

# The **AtMoCiad** database

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## Introduction

### 0.0.1 History of the project

This database is the result of several decades of research in aeronomy, most of them happening before I even was born. As we will see in this little section, some of the sources and their authors have been lost in the past compilations of data, and we wish to aknowledge them here.

The objective of this project was to gather all the available cross-sections of interest for Aeronomy of the Earth and Planet, and to have a “clean” database, with the most possible sources, and the most possible information on the uncertainties. This latest part became a huge motivation for the project, as the uncertainties are often neglected in the databases, and are the most important parameter for the comparison of the different sources, and for the understanding of the differences between the models. I came to that realization during my PhD, in Grenoble, France, when I was working on creating a code for computing the airglow and ionization in the atmosphere of Venus under the direction of J. Lilenstein. I was using the Trans\* model, intitially Transsolo for the Earth, then Transmars/Titan for Mars and Titan; all of these models were developped for a specific planet and had their very specific cross-sections. The code was working well, but as long as we were adding planets, we were adding cross-sections, and the code was becoming more and more difficult to maintain. When I finished my PhD, I did my post-doc at NASA Langley Research center, in Hampton, Virginia. As a fresh French person coming into the us, the paperwork to let me go on-site took months, and I had to work off-site, with fewer resources for the initial project I was hired for. This is when I decided to create the Aeroplanets model, to have a single code for all the planets, and to have a single database for all the cross-sections. This is how the AtMoCiad project was born.

The code was developped fast enough, in 2009 and 2010, and led to several papers in 2011 and 2012. The database was at a good level, but took more than a decade to come to the current level due to funding, time, etc. In the meantime, work was done on other papers [20], other processes (such as cosmic rays, proton precipitations, etc) and led to incremental improvements of the databse.

The full philosophy and approach is explained in the paper accompanying this database; however, the history of the project is not. This is why I wanted to write this introduction, to aknowledge the people who helped me in this project, and to explain the history of the project.

In the following pages, you will see the word BDD appear. This is the French acronym for Database, and is used when I refer to the cross-sections

I found in the Trans\* models but for which I never figured out exactly where they came from. My understanding is that several of these cross-sections were compiled by Lummerzheim for his PhD [44], but I never found the original sources. Some must have been compiled for the original Transsolo/Transcar paper [46]. These papers likely cover all the cross-sections for N<sub>2</sub>, O<sub>2</sub>, O, and Ar. Additional work on N<sub>2</sub> and CH<sub>4</sub> was done for Titan [42] and Mars [74, 75]. Work on doubly ionized cross-sections was also done for Earth by [61]. It is likely that other cross-sections computations were used in the creation of what we have here, maybe the work of Phelps [52] was used somewhere, but I have no way to prove it. One of the reasons for that is the modifications done on cross-sections in the original compilation, due to the way the code was working, especially for the electrons. The cross-sections for the excitation was correctly handled, with a threshold, the energies and values. However, for the ionizations, a main cross-section was used and then a branching ratio was given for all the sub-species, with maybe a threshold for their productions. The code was not able to handle Auger electrons and it created some issues when trying to compute the average energy per ion-pair production. This is why the Aeroplanet model was so crucial and led to the [63] paper. In addition, the work on understanding the uncertainties was on its way, and led to the 2012 papers [21, 22]. I was able to get a small amount of funding for the database around 2014, at a time when money was scarce for NASA projects, and I had to spend too much time writing other grants to fully publish the results. After that, I was able to get more funding for aeronomy projects, which enabled me to hire a colleague - Bradley Hegyi- part-time to clean the database and to add more cross-sections, and to publish a first version of the project.

Now, additional work has been made to correctly add the H/p cross-sections, even if they are not filled with the same level of details as the other cross-sections. The database is now ready for the community, and I hope it will be useful for the aeronomy and chemistry communities. I wish to thank all my co-authors and colleagues who helped me in this project. It would never have happened without them. The errors, omissions, and mistakes in this database are all my fault, and I hope the community will help me correct them in the future.

G.Gronoff, September 2024, Hampton, Virginia, USA

### 0.0.2 Presentation of the database

Ionization, excitation, dissociations are terms of the utmost importance when dealing with the physics of upper atmospheres.

Several physical processes are at the origin of the creation of an ionosphere

for the planets. The same are also at the origin of the heating, and the formation of different kinds of airglow and aurorae in the thermospheres.

To model these upper atmosphere, of either Earth, planets, or comets, along as other kinds of plasma, some parameters are needed. Among them, the cross sections for ionization, excitation, dissociation...

Up to now, no centralized database was available for these processes, leading to several problems:

- Each team has its own database, with its own history. Therefore, some processes are up to date, some very old...
- It is impossible to compare two team databases, because of their standards. It is also impossible to compare two codes by different teams, since the high dependence on cross sections does not allow to discriminate whether the differences come from the implementation of the physical processes or from the inputs.
- Each time a cross section is measured, it takes a very long time to diffuse in the community, highlighting the precedent issues.
- The chemists and experimentalists, and especially the people measuring and/or computing the cross sections, hardly communicate with the aeronomy community. Therefore, they do not know the needs for specific cross section improvements, and have to perform a very important bibliographic work to compare their measurements with previous work. Unfortunately, such efforts are likely to be only partly published, leading to the same efforts for the following teams.
- On the contrary, aeronomists can detect problems in dataset when they compare models and experiments. It is also possible for them to improve estimation of absolute values, and extrapolation of existing datasets. These results, independently of their quality, never reaches the chemistry community.

Among these problems, one parameter was always neglected in the previous models and databases: **the uncertainty of the cross sections**.

This term is one of the most important for the comparison of the different sources, but also to understand the different outputs of the models.

When we compare the sources, the claimed uncertainty the most important parameter for extracting the recommended cross section. The other cross sections can sometimes be used to refine the absolute value (correction of the discrepancy).

For the models, the cross sections are the main sources of uncertainties. Therefore, the uncertainty of the model can be computed to a good extent through the variations of the cross sections. A fast technique is the use of a Monte Carlo technique (it will be used in the following to estimate the quality of the electron cross sections dataset).

All these problems leads to the creation of a centralized database for cross sections, which makes a link between notably the aeronomy and chemistry communities. And has to include the uncertainties, the extrapolations and the most possible number of different sources for each processes, in order to select the recommended uncertainty.

This database, described in the document, is named **AtMoCiad**, which stands for **A**tomic and **M**olecular **C**ross section for **i**onization and **a**irglow<sup>1</sup> **D**atabase<sup>2</sup>.

The physics associated with these cross sections, and how to use them correctly, is described in the paper accompanying the database (Gronoff et al. 2024). It is also described in the *Aeroplanets* model papers [21, 22] which is used to check the dataset; but which is also the first aeronomy model using **AtMoCiad**.

In a first chapter (1), we will present the data for the ionization, excitation and dissociation by the photons.

In a second chapter (2), we will present the electron impact cross sections.

In a third chapter (4), we will explain the future improvements of the database (proton impact cross sections and hydrogen impact cross-sections...).

In the appendixes (5), we will describe the technical storage, plotting and web interfacing of the database.

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<sup>1</sup>or aurora

<sup>2</sup>For the connoisseurs, it is also a recursive acronym: **AtMoC** is another Database

# **Chapter 1**

## **Photoionization**

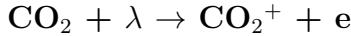
### **Introduction**

## 1.1 Cross section of ph impact with CO<sub>2</sub>

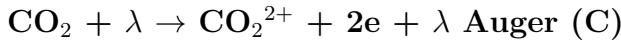
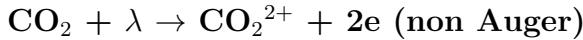
### 1.1.1 Total Cross Section

### 1.1.2 Inelastic Cross Sections

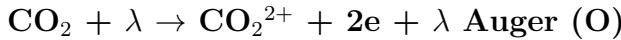
#### Ionization Cross Sections



**CO<sub>2</sub><sup>+</sup> + e (PHIDRATES)** Photoionization of CO<sub>2</sub> yielding CO<sub>2</sub><sup>+</sup> + e from the review of PHIDRATES. [24] The uncertainty, not claimed by the review, is estimated at 30%. The data, in nm, have been directly adapted in eV.



**CO<sub>2</sub><sup>2+</sup> Auger (C) K-Shell (Avakyan 1998)** K-shell photoionization of CO<sub>2</sub>, with excitation of the C, from the review work [3]. Claimed uncertainty of 20%. The rate for the double ionization (including the following dissociation, not studied) is 74%, letting 26% of Auger fluorescence. The energy of the Auger electron (ejected in the double ionization cases) is 223 eV. The reported values in [3] were in nm, following several boxes, including lines, and were adapted in eV for the database.



**CO<sub>2</sub><sup>2+</sup> Auger (O) K-Shell (Avakyan 1998)** K-shell photoionization of CO<sub>2</sub>, with excitation of the C, from the review work [3]. Claimed uncertainty of 20%. The rate for the double ionization (including the following dissociation, not studied) is 99.31%, letting .69% of Auger fluorescence. The energy of the Auger electron (ejected in the double ionization cases) is 467 eV. The reported values in [3] were in nm, following several boxes, including lines, and were adapted in eV for the database.

Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi PHIDRATES	0	5.45:12400	???	U	Fig. 1.29 1.30
Revi [75] BDD	0	7.2:532	???	U	Fig. 1.29 1.30
Revi [3]	0	12:8260	20%		Fig. 1.29 1.30
Adap PHIDRATES+Avakyan	0	5.45:8260	20%	RU	Fig. 1.29 1.30

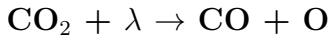
Table 1.1: Total cross section for  $\lambda$  impact on CO<sub>2</sub>

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$\text{CO}_2 + \lambda \rightarrow \text{CO}_2^+ + e^-$	Revi PHIDRATES	13.733	13.79:12400	??%	U	Fig. 1.5 1.6
	Revi [75]	13.733	13.733:-1	??%	U	Fig. 1.5 1.6
	Revi [3]	13.773	13.773:-1	20%	RUE	Fig. 1.5 1.6
$\text{CO}_2 + \lambda \rightarrow \text{O}^+ + \text{CO} + e^-$	Adap PHIDRATES+Awakyan	13.733	13.733:-1	20%	RUE	Fig. 1.5 1.6
	Revi PHIDRATES	19.070	19.070:-1	30%	RUE	Fig. 1.11 1.12
	Revi BDD + [75]	19.070	19.070:-1	??%	U	Fig. 1.11 1.12
$\text{CO}_2 + \lambda \rightarrow \text{CO}^+ + \text{O}^+ + 2e^-$	Revi BDD + [75]	39.200	39.200:-1	??%	U	Fig. 1.11 1.12
	Revi BDD + [75]	39.200	39.200:-1	??%	U	Fig. 1.23 1.24
	Revi PHIDRATES	23	23:-1	30%	RUE	Fig. 1.15 1.16
$\text{CO}_2 + \lambda \rightarrow \text{C}^+ + \text{O}_2 + e^-$	Revi BDD + [75]	27.9	27.9:-1	??%	U	Fig. 1.15 1.16
	Revi [3]	37.6	37.6:-1	20%	RUE	Fig. 1.19 1.20
	Adap [41]	37.600	37.600:-1	50%	U	Fig. 1.19 1.20
$\text{CO}_2 + \lambda \rightarrow \text{CO}_2^{2+} + 2e^- + \lambda$ Auger (C)	Revi [3]	282	340:830	20%		Fig. 1.21 1.22
	Revi [3]	53.9	830:610	20%		Fig. 1.21 1.22
$\text{CO}_2 + \lambda \rightarrow \text{CO}^+ + \text{O} + e^-$	Revi PHIDRATES	19.446	19.446:-1	30%	RUE	Fig. 1.23 1.24
	Revi [75] BDD	19.446	19.446:-1	??%	U	Fig. 1.23 1.24

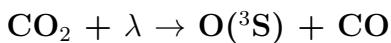
Table 1.2: Ionization Cross section for  $\lambda$  impact on  $\text{CO}_2$



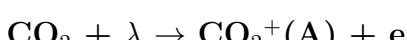
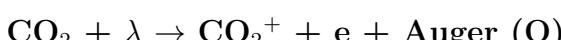
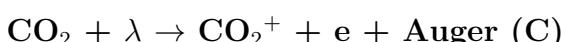
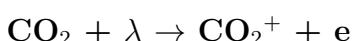
#### Dissociation Cross Sections



#### Excitation Cross Sections



#### 1.1.3 Recommended data set



#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$\text{CO}_2 + \lambda \rightarrow \text{CO} + \text{O}$	Revi PHDRATES	16.440	16.440:-1	?%?%	U	Fig. 1.9 1.10
	Revi BDD + [75]	16.440	16.440:-1	?%?%	U	Fig. 1.9 1.10

Table 1.3: Dissociation Cross section for  $\lambda$  impact on  $\text{CO}_2$

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$CO_2 + \lambda \rightarrow CO_2^+(B) + e$	Revi [3] Meas [72]	18.076 18.076	18.076:-1 18.076:-1	20% 15%		Fig. 1.1 1.2 Fig. 1.1 1.2
$CO_2 + \lambda \rightarrow CO(A^{1\Pi}) + O$	Meas [16] Meas [16]	13.390 13.390	13.390:-1 13.390:-1	50% 50%	E RE	Fig. 1.3 1.4 Fig. 1.3 1.4
$CO_2 + \lambda \rightarrow CO_2^+(C) + e$	Revi [3]	19.395	19.395:-1	20%		Fig. 1.7 1.8
$CO_2 + \lambda \rightarrow O(^1D) + CO$	Revi PHDRATES Adap [65]	7 7	7:-1 7:-1	???:% 20%	U	Fig. 1.13 1.14 Fig. 1.13 1.14
$CO_2 + \lambda \rightarrow CO(a^3\Pi) + O$	Adap [65] + PHDRATES Revi AMOP Meas [37] Meas [37]	11.420 11.420 11.420	11.420:-1 11.420:-1 11.420:-1	???:% 50% 50%	RUE	Fig. 1.13 1.14 Fig. 1.17 1.18 U Fig. 1.17 1.18 RUE
$CO_2 + \lambda \rightarrow O(^1S) + CO$	Meas [37] Meas [37] Meas [37] + PHDRATES	9 9 9	9:-1 9:-1 9:-1	20% 20% 20%	UE RUE	Fig. 1.17 1.18 Fig. 1.25 1.26 Fig. 1.25 1.26
$CO_2 + \lambda \rightarrow O(^3S) + CO$	Meas [76]	16.44	16.44:-1	30%	RUE	Fig. 1.27 1.28
$CO_2 + \lambda \rightarrow CO_2^+(A) + e$	Revi [3] Meas [72]	17.316 17.316	17.316:-1 17.316:-1	20% 15%		Fig. 1.31 1.32 Fig. 1.31 1.32

Table 1.4: Excitation Cross section for  $\lambda$  impact on  $CO_2$

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$\text{CO}_2 + \lambda \rightarrow \text{CO}(\text{A}'\text{II}) + \text{O}$	Meas [15]	13.390	13.390:-1	50%	RE	Fig. 1.33 1.34 1.35 1.36
$\text{CO}_2 + \lambda \rightarrow \text{CO}(\alpha^3\text{II}) + \text{O}$	Meas [37]	11.420	11.420:-1	50%	RUE	Fig. 1.33 1.34 1.35 1.36
$\text{CO}_2 + \lambda \rightarrow \text{O}(^3\text{S}) + \text{CO}$	Meas [76]	16.44	16.44:-1	30%	RUE	Fig. 1.33 1.34 1.35 1.36
$\text{CO}_2 + \lambda \rightarrow \text{O}(\text{I}^{\text{D}}) + \text{CO}$	Adap [65] + PHDRATES	7	7:-1	20%	RUE	Fig. 1.33 1.34 1.35 1.36
$\text{CO}_2 + \lambda \rightarrow \text{O}(\text{S}) + \text{CO}$	Meas [37] + PHDRATES	9	9:-1	20%	RUE	Fig. 1.33 1.34 1.35 1.36
$\text{CO}_2 + \lambda \rightarrow \text{CO}_2^+ + \text{e}$	Adap PHDRATES + [2]	13.733	13.733:-1	20%	RUE	Fig. 1.33 1.34 1.35 1.36
$\text{CO}_2 + \lambda \rightarrow \text{CO}_2^+ + \text{e} + \text{Auger (C)}$	Revi [2]	282	282:-1	20%		Fig. 1.33 1.34 1.35 1.36
$\text{CO}_2 + \lambda \rightarrow \text{CO}_2^+ + \text{e} + \text{Auger (O)}$	Revi [2]	539	539:-1	20%		Fig. 1.33 1.34 1.35 1.36
$\text{CO}_2 + \lambda \rightarrow \text{CO}_2^+ + \text{O} + \text{e}$	Revi PHDRATES	19.446	19.446:-1	30%	RUE	Fig. 1.33 1.34 1.35 1.36
$\text{CO}_2 + \lambda \rightarrow \text{O}^+ + \text{CO} + \text{e}$	Revi PHDRATES	19.070	19.070:-1	30%	RUE	Fig. 1.33 1.34 1.35 1.36
$\text{CO}_2 + \lambda \rightarrow \text{C}^+ + \text{O}_2 + \text{e}$	Revi PHDRATES	23	23:-1	30%	RUE	Fig. 1.33 1.34 1.35 1.36
$\text{CO}_2 + \lambda \rightarrow \text{CO}_2^+(\text{A}) + \text{e}$	Meas [72]	17.316	17.316:-1	15%		Fig. 1.33 1.34 1.35 1.36
$\text{CO}_2 + \lambda \rightarrow \text{CO}_2^+(\text{B}) + \text{e}$	Meas [72]	18.076	18.076:-1	15%		Fig. 1.33 1.34 1.35 1.36
$\text{CO}_2 + \lambda \rightarrow \text{CO}_2^+(\text{C}) + \text{e}$	Revi [2]	19.395	19.395:-1	20%		Fig. 1.33 1.34 1.35 1.36
$\text{CO}_2 + \lambda \rightarrow \text{CO}_2^{++}$	Revi [3]	37.6	37.6:-1	20%		Fig. 1.33 1.34 1.35 1.36
$\text{CO}_2 + \lambda \rightarrow \text{CO}_2^{2+} + 2\text{e}$	Revi [49] + [41]	37.600	37.600:-1	50%	U	Fig. 1.33 1.34 1.35 1.36
$\text{CO}_2 + \lambda \rightarrow \text{Total}$	Adap PHDRATES + [2]	0	0:-1	20%	RU	Fig. 1.33 1.34 1.35 1.36

Table 1.5: Recommended Cross section for  $\lambda$  impact on  $\text{CO}_2$

the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

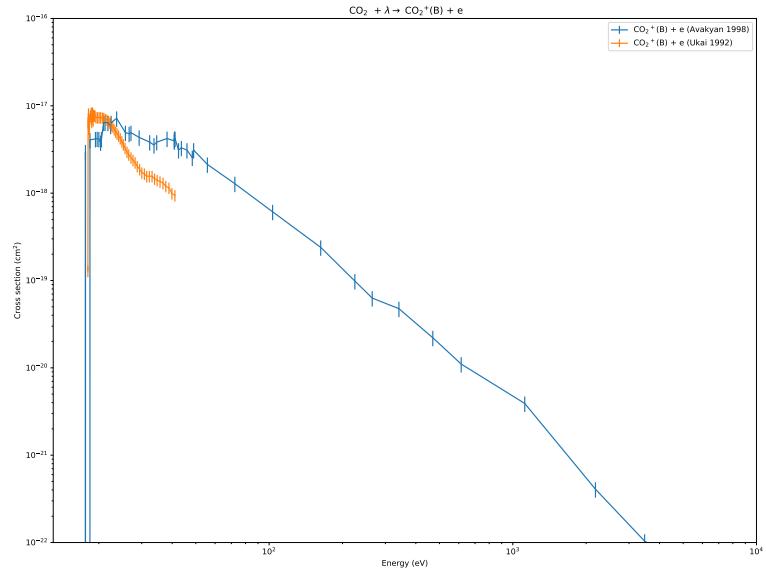


Figure 1.1: Cross sections for  $\text{CO}_2 + \lambda \rightarrow \text{CO}_2^+(\text{B}) + e$

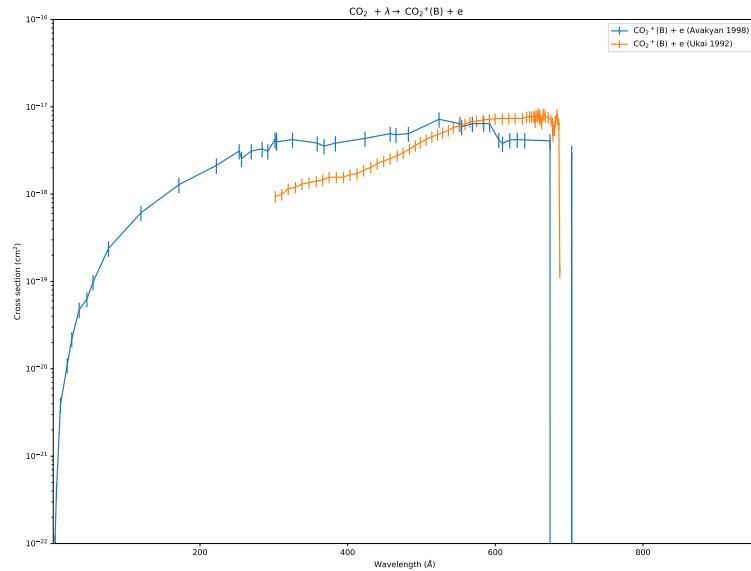
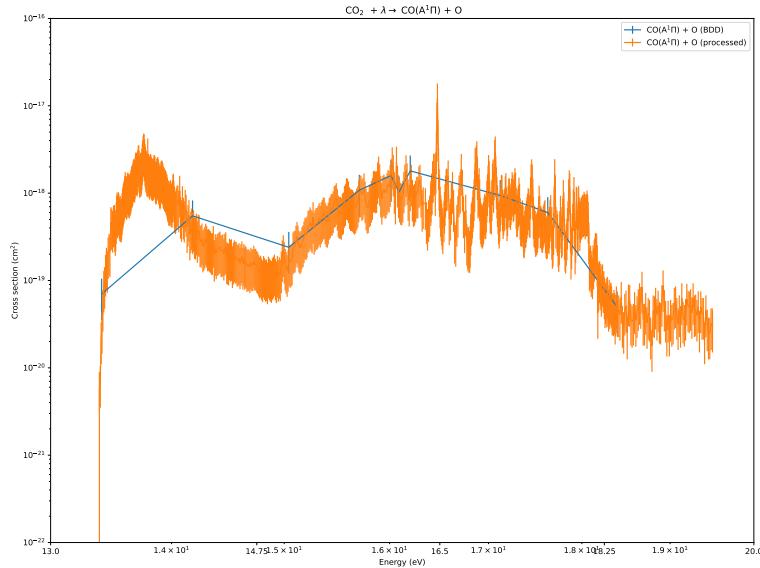
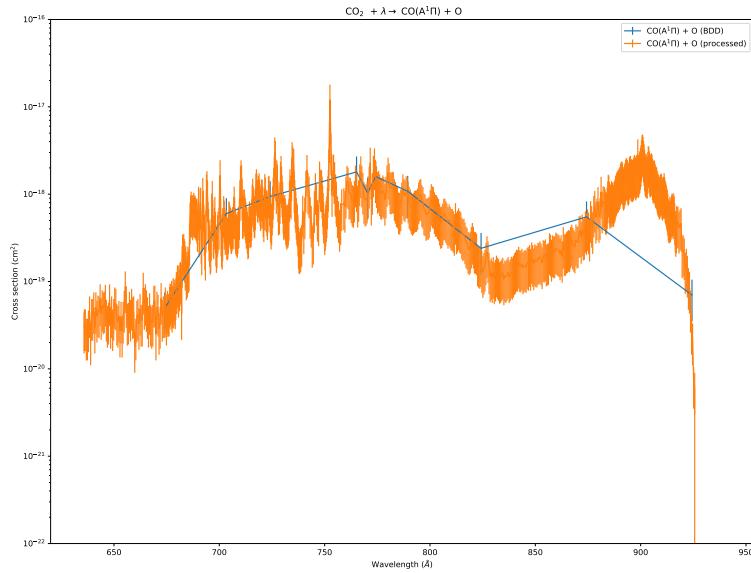


Figure 1.2: Cross sections for  $\text{CO}_2 + \lambda \rightarrow \text{CO}_2^+(\text{B}) + e$  (wavelength version)

Figure 1.3: Cross sections for  $CO_2 + \lambda \rightarrow CO(A^1\Pi) + O$ Figure 1.4: Cross sections for  $CO_2 + \lambda \rightarrow CO(A^1\Pi) + O$  (wavelength version)

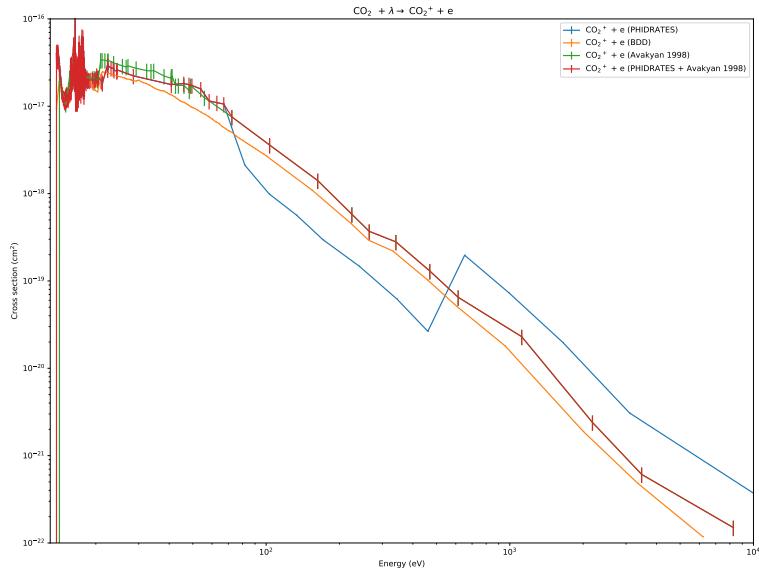


Figure 1.5: Cross sections for  $\text{CO}_2 + \lambda \rightarrow \text{CO}_2^+ + e^-$

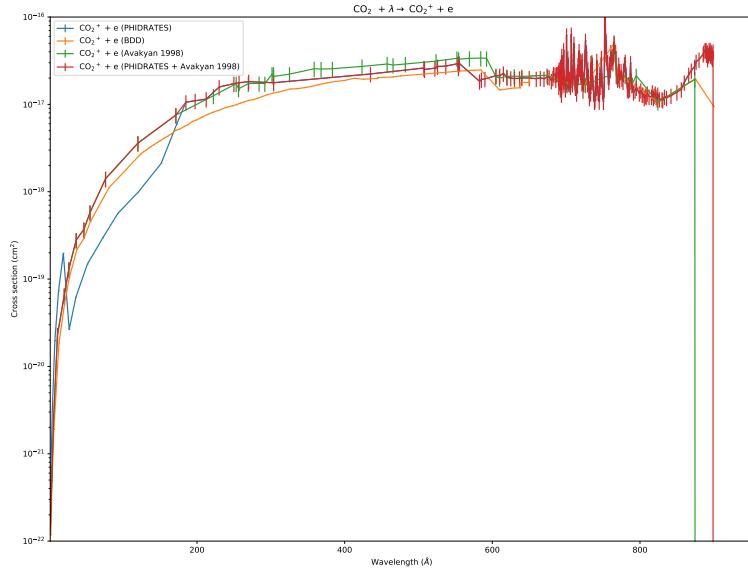
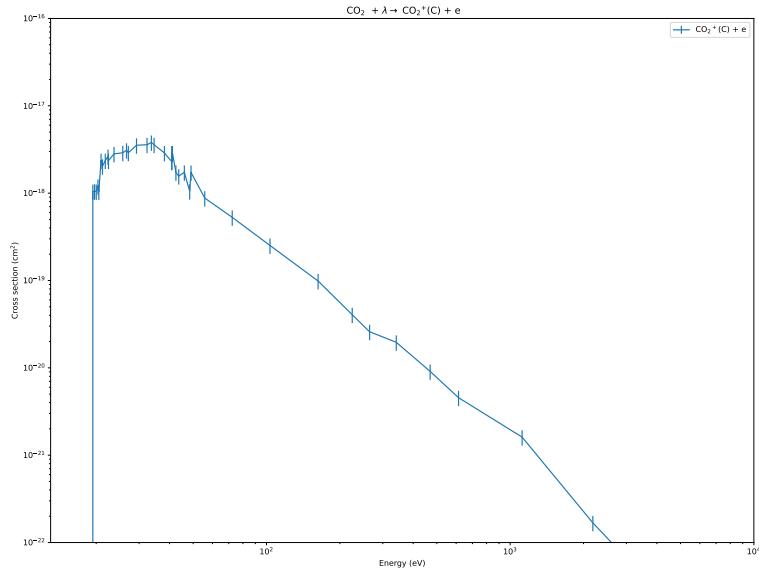
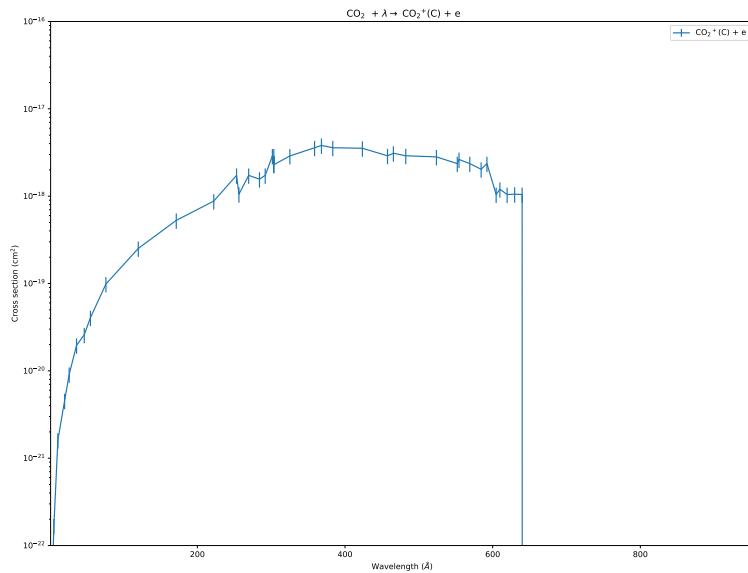


Figure 1.6: Cross sections for  $\text{CO}_2 + \lambda \rightarrow \text{CO}_2^+ + e^-$  (wavelength version)

Figure 1.7: Cross sections for  $CO_2 + \lambda \rightarrow CO_2^+(C) + e$ Figure 1.8: Cross sections for  $CO_2 + \lambda \rightarrow CO_2^+(C) + e$  (wavelength version)

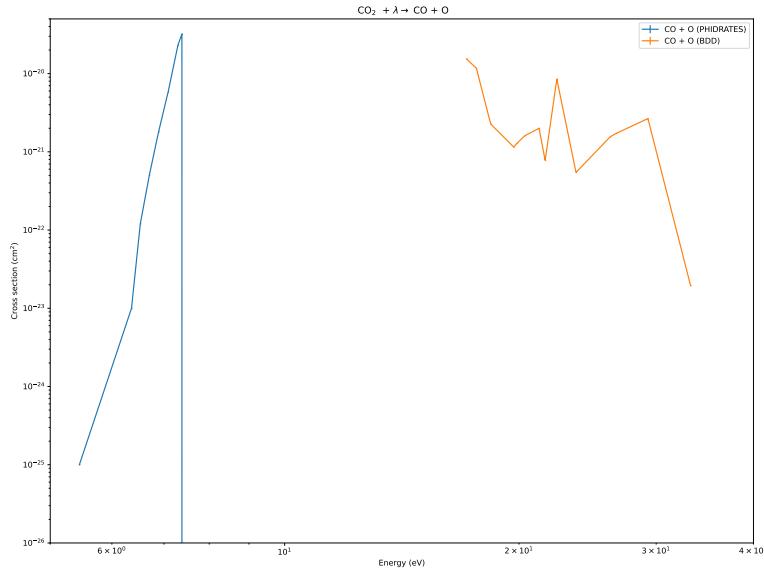


Figure 1.9: Cross sections for  $\text{CO}_2 + \lambda \rightarrow \text{CO} + \text{O}$

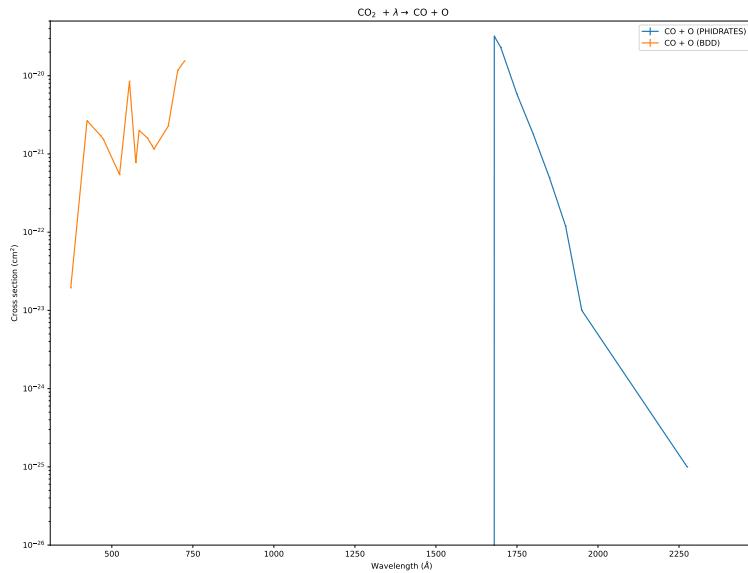
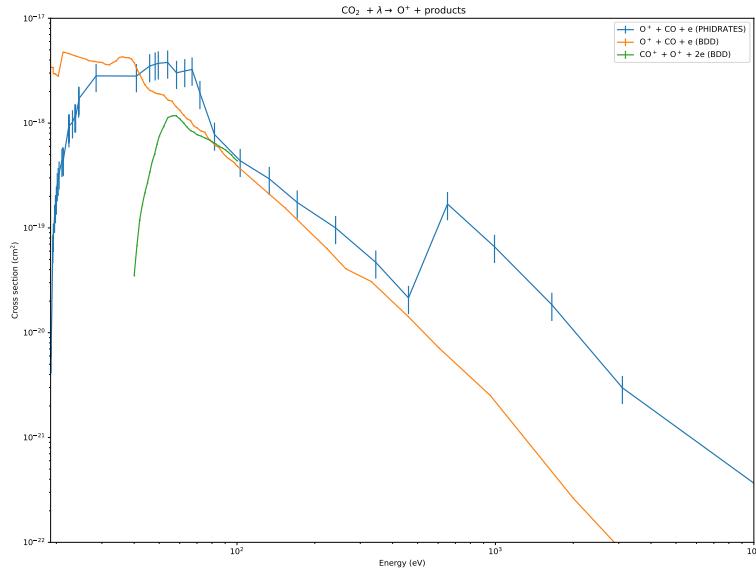
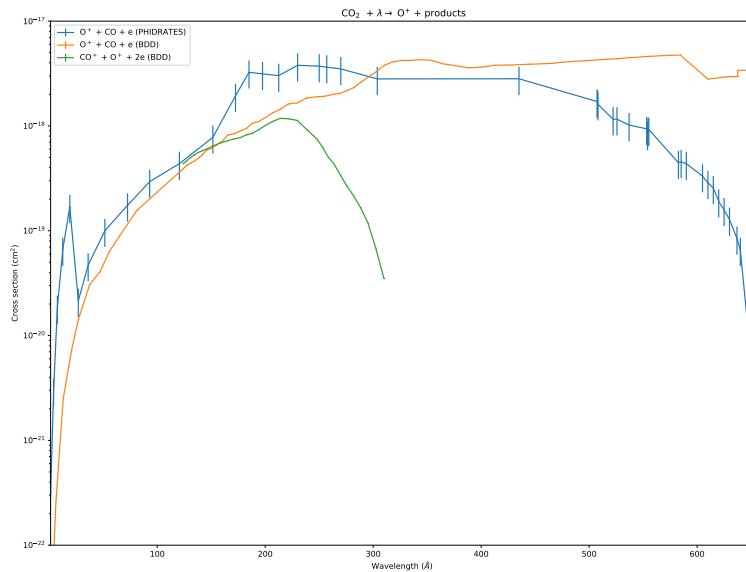


Figure 1.10: Cross sections for  $\text{CO}_2 + \lambda \rightarrow \text{CO} + \text{O}$  (wavelength version)

Figure 1.11: Cross sections for  $\text{CO}_2 + \lambda \rightarrow \text{O}^+ + \text{products}$ Figure 1.12: Cross sections for  $\text{CO}_2 + \lambda \rightarrow \text{O}^+ + \text{products}$  (wavelength version)

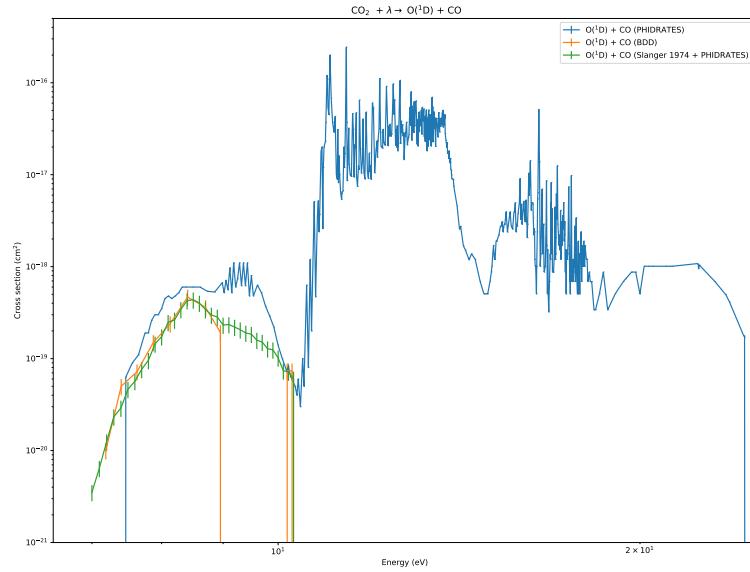


Figure 1.13: Cross sections for  $\text{CO}_2 + \lambda \rightarrow \text{O}({}^1\text{D}) + \text{CO}$

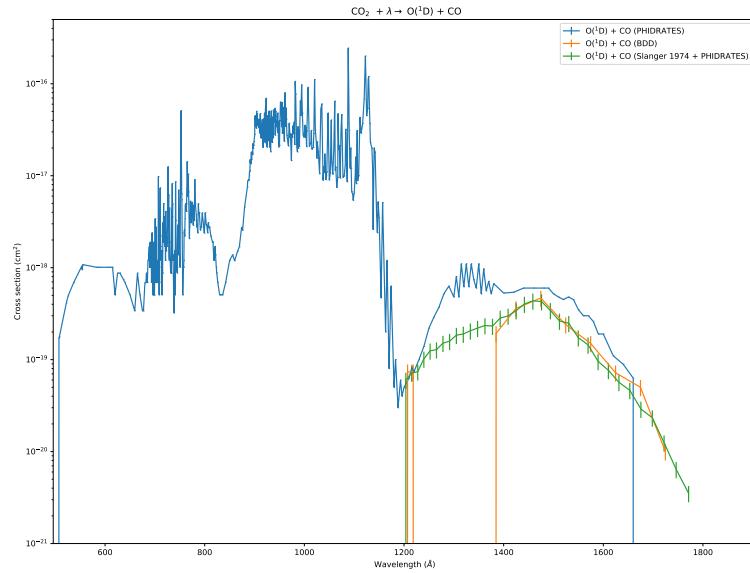
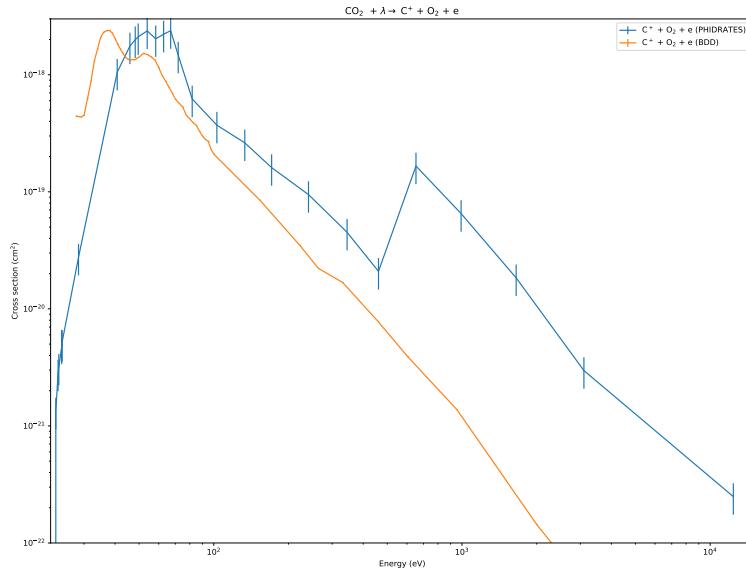
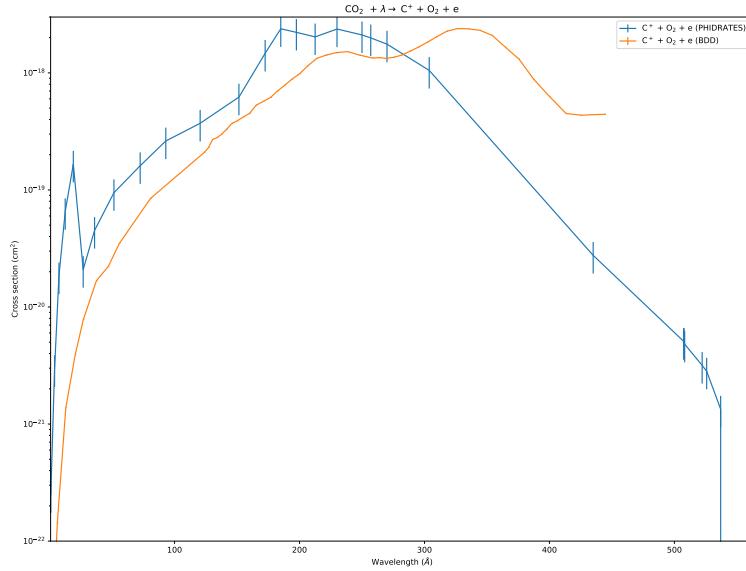


Figure 1.14: Cross sections for  $\text{CO}_2 + \lambda \rightarrow \text{O}({}^1\text{D}) + \text{CO}$  (wavelength version)

Figure 1.15: Cross sections for  $\text{CO}_2 + \lambda \rightarrow \text{C}^+ + \text{O}_2 + \text{e}$ Figure 1.16: Cross sections for  $\text{CO}_2 + \lambda \rightarrow \text{C}^+ + \text{O}_2 + \text{e}$  (wavelength version)

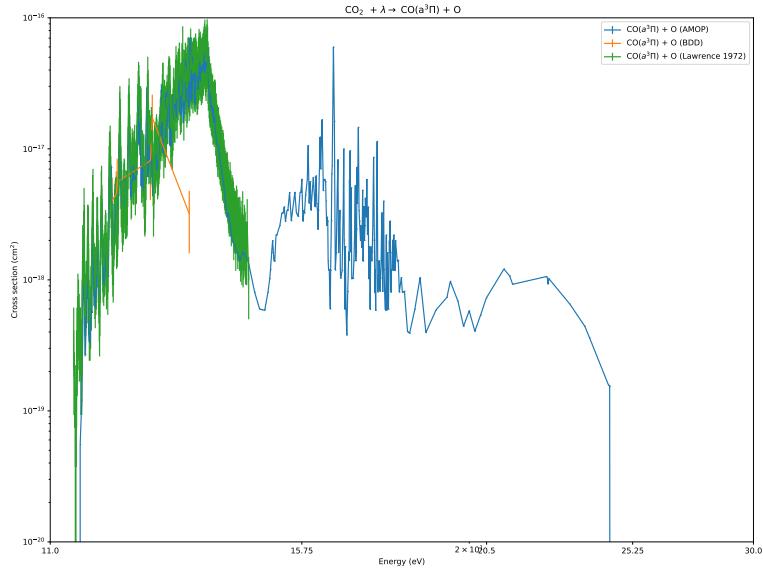


Figure 1.17: Cross sections for  $\text{CO}_2 + \lambda \rightarrow \text{CO}(\text{a}^3\Pi) + \text{O}$

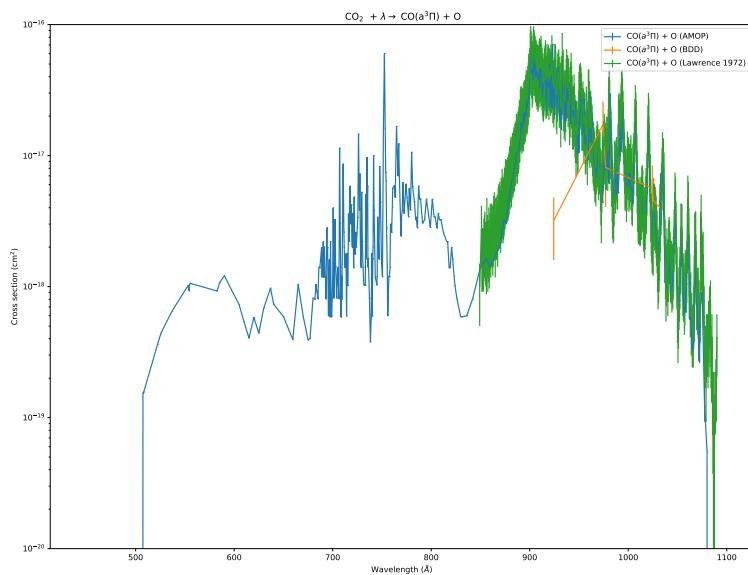
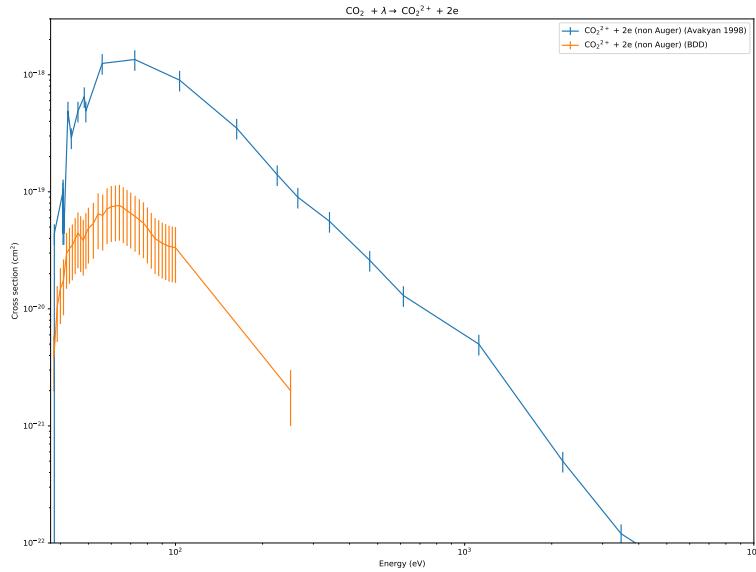
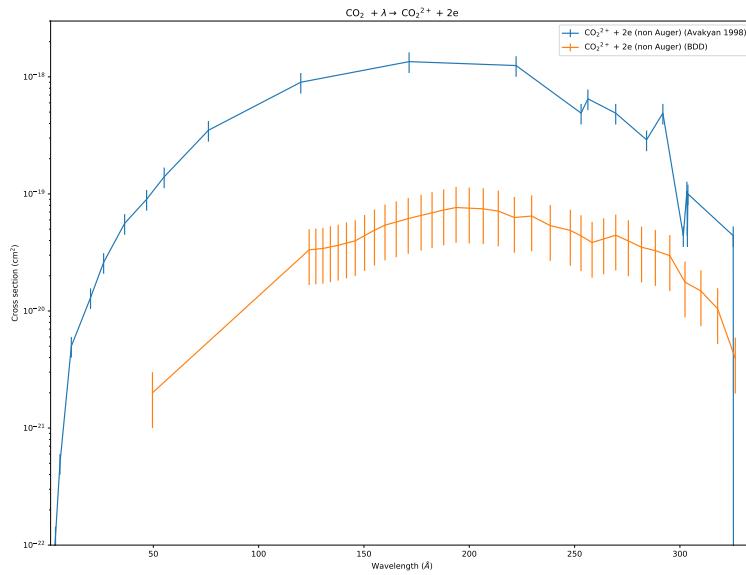


Figure 1.18: Cross sections for  $\text{CO}_2 + \lambda \rightarrow \text{CO}(\text{a}^3\Pi) + \text{O}$  (wavelength version)

Figure 1.19: Cross sections for  $\text{CO}_2 + \lambda \rightarrow \text{CO}_2^{2+} + 2\text{e}$ Figure 1.20: Cross sections for  $\text{CO}_2 + \lambda \rightarrow \text{CO}_2^{2+} + 2\text{e}$  (wavelength version)

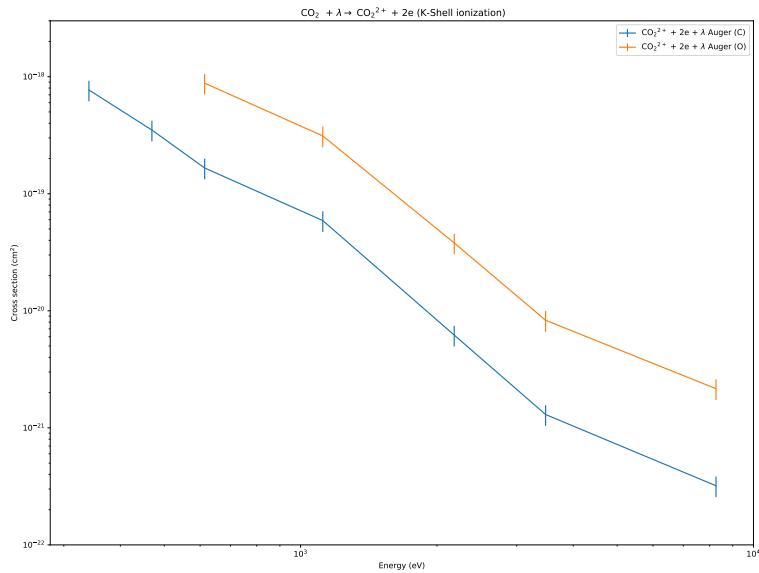


Figure 1.21: Cross sections for  $\text{CO}_2 + \lambda \rightarrow \text{CO}_2^{2+} + 2e$  (K-Shell ionization)

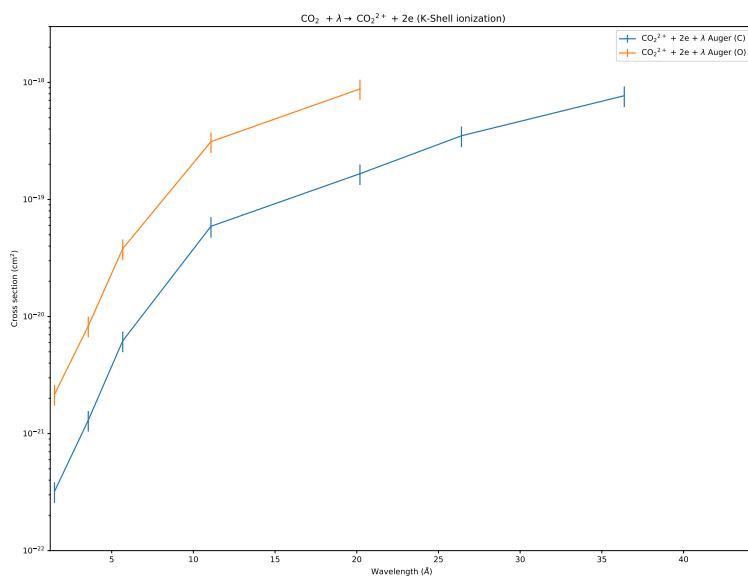
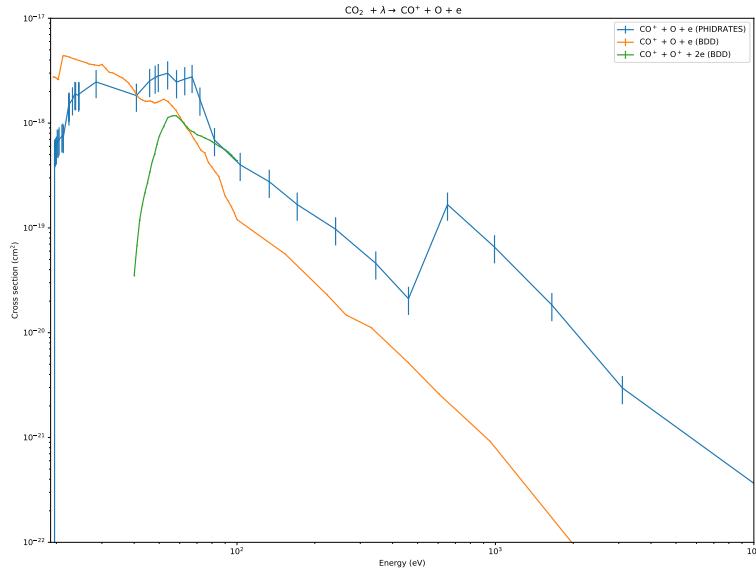
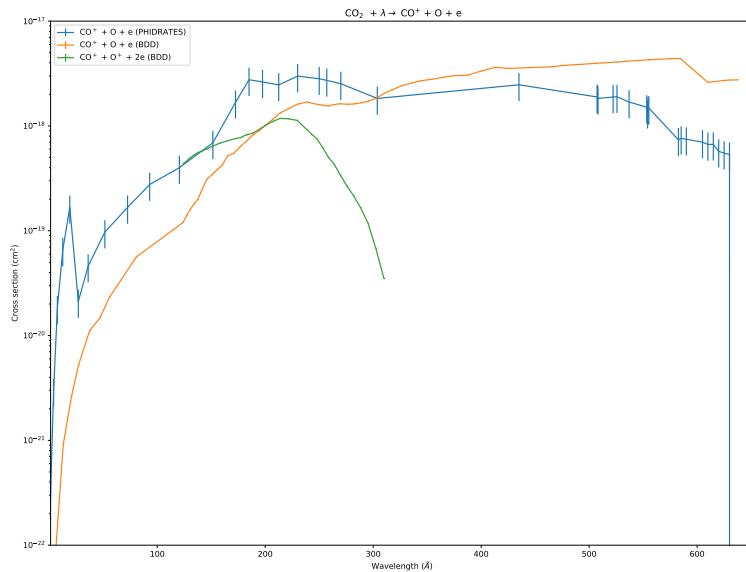


Figure 1.22: Cross sections for  $\text{CO}_2 + \lambda \rightarrow \text{CO}_2^{2+} + 2e$  (K-Shell ionization) (wavelength version)

Figure 1.23: Cross sections for  $\text{CO}_2 + \lambda \rightarrow \text{CO}^+ + \text{O} + \text{e}$ Figure 1.24: Cross sections for  $\text{CO}_2 + \lambda \rightarrow \text{CO}^+ + \text{O} + \text{e}$  (wavelength version)

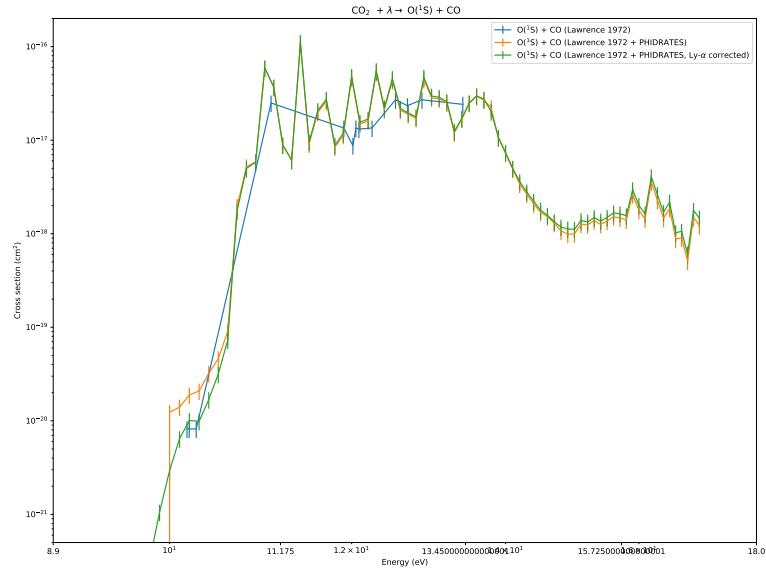


Figure 1.25: Cross sections for  $\text{CO}_2 + \lambda \rightarrow \text{O}({}^1\text{S}) + \text{CO}$

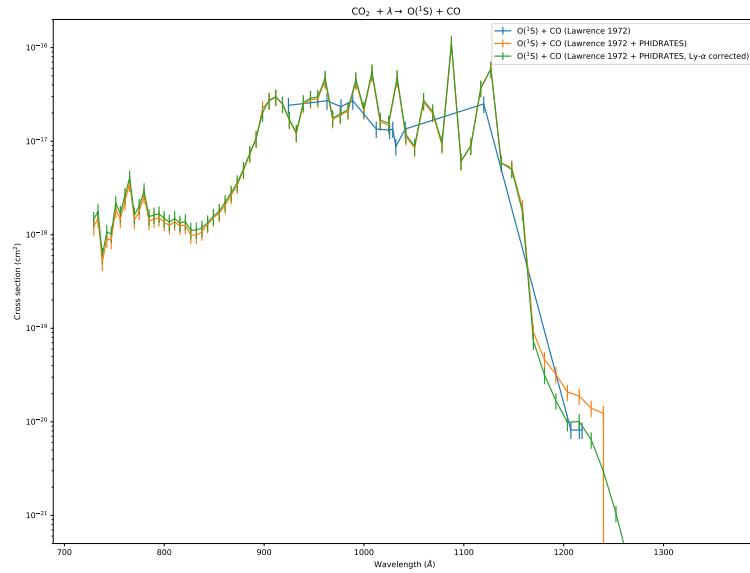
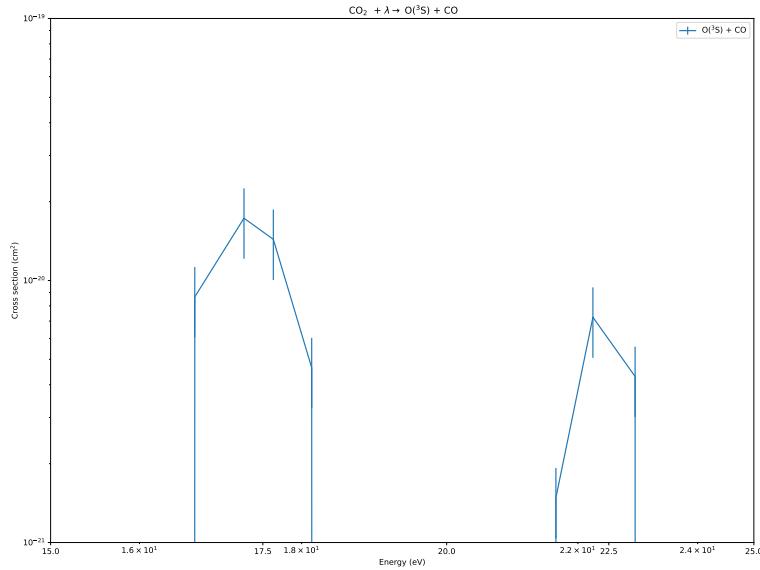
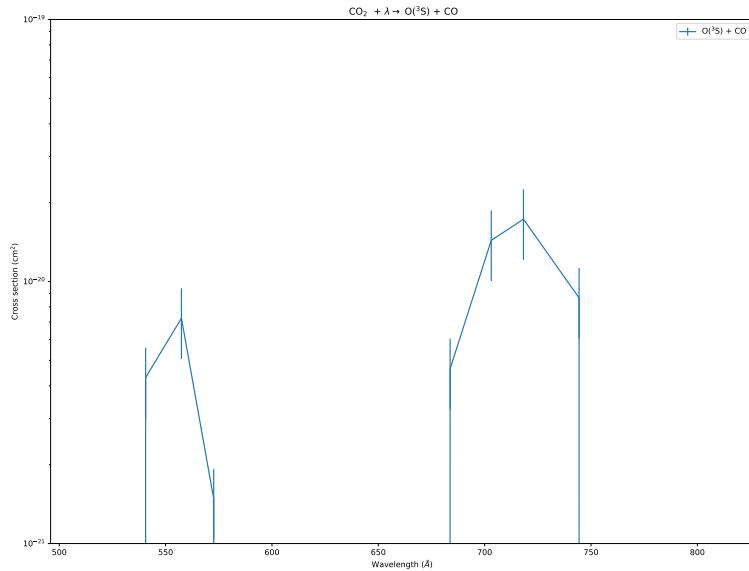


Figure 1.26: Cross sections for  $\text{CO}_2 + \lambda \rightarrow \text{O}({}^1\text{S}) + \text{CO}$  (wavelength version)

Figure 1.27: Cross sections for  $CO_2 + \lambda \rightarrow O(^3S) + CO$ Figure 1.28: Cross sections for  $CO_2 + \lambda \rightarrow O(^3S) + CO$  (wavelength version)

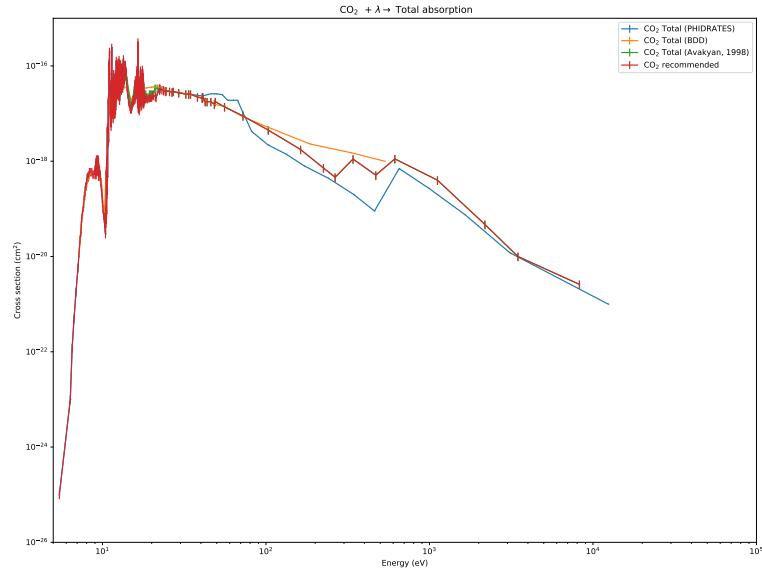


Figure 1.29: Cross sections for  $\text{CO}_2 + \lambda \rightarrow \text{Total absorption}$

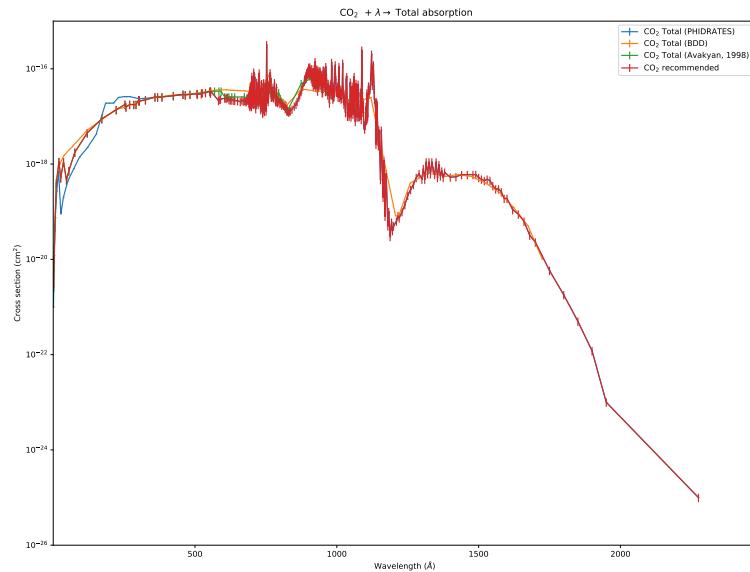
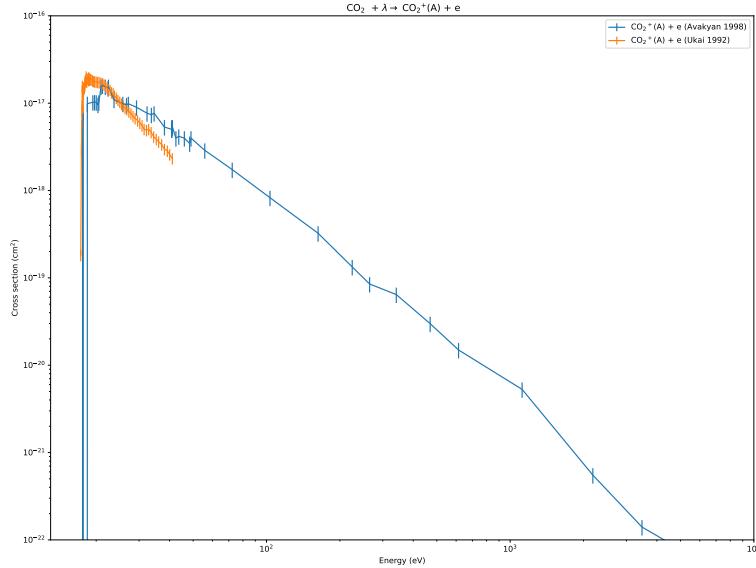
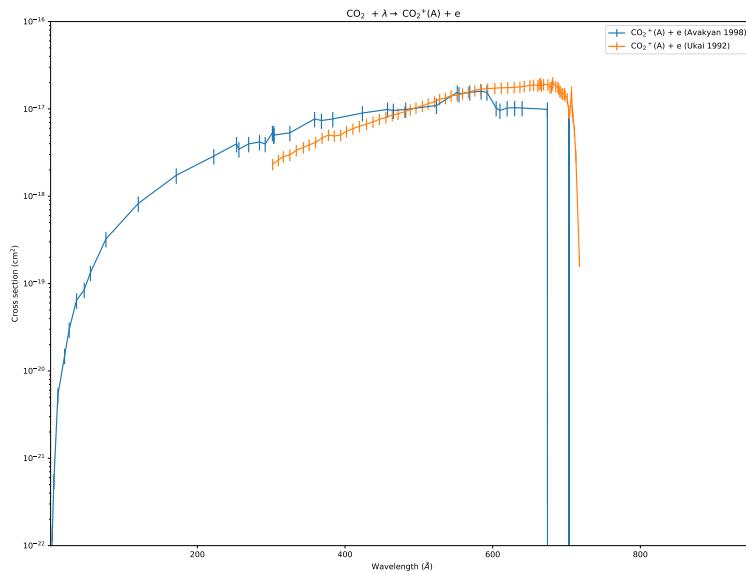
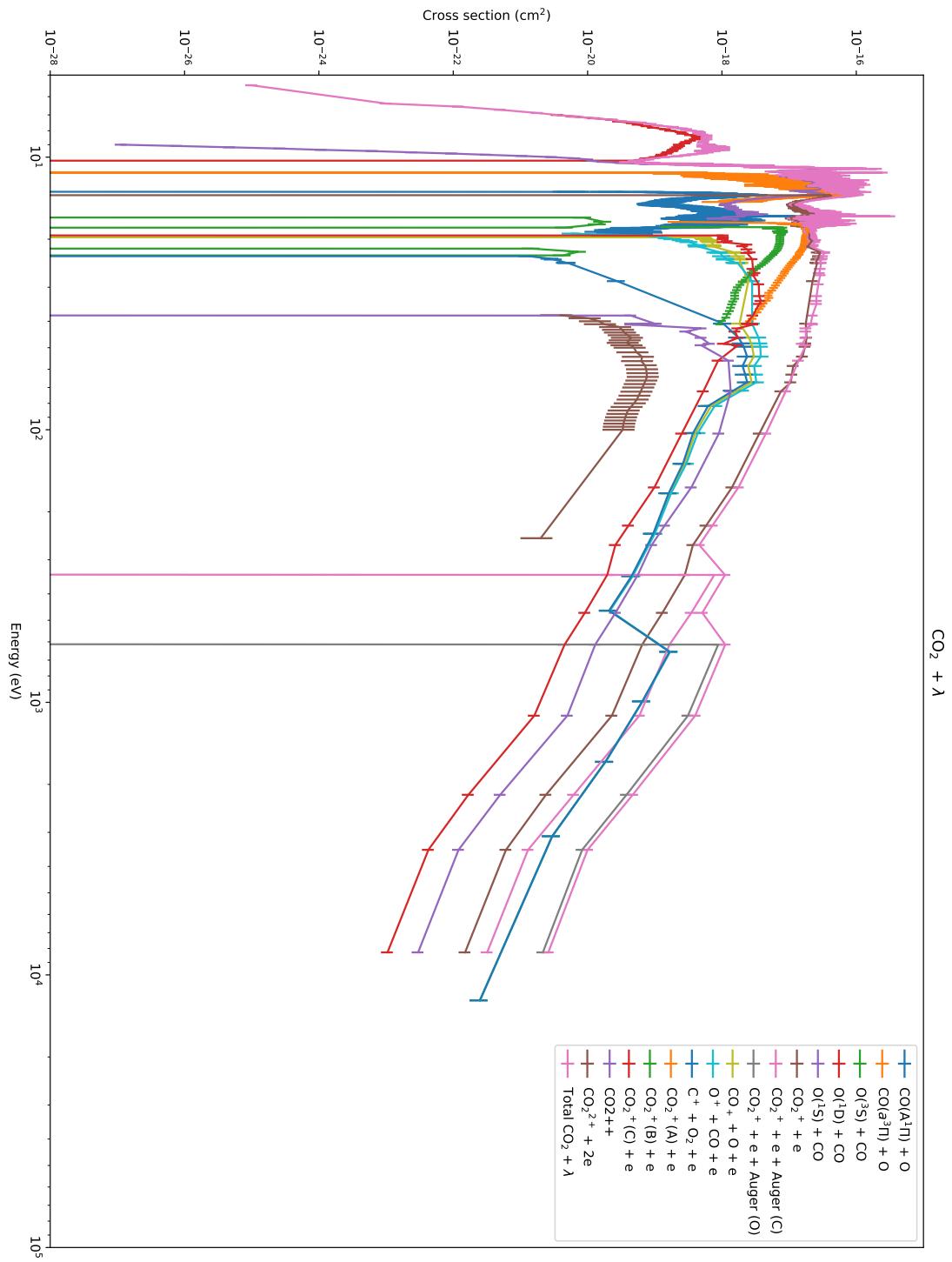
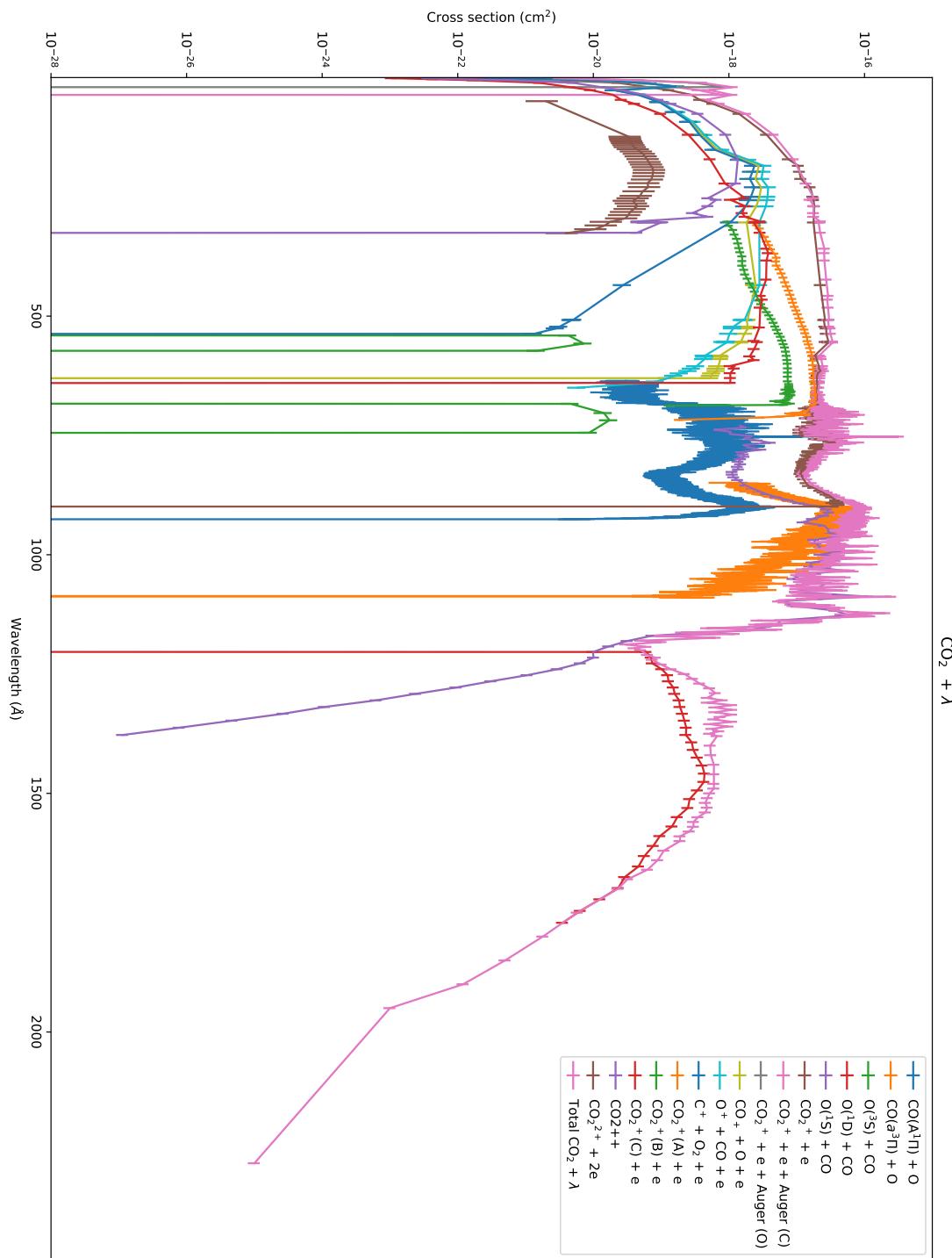


Figure 1.30: Cross sections for  $\text{CO}_2 + \lambda \rightarrow \text{Total absorption}$  (wavelength version)

Figure 1.31: Cross sections for  $CO_2 + \lambda \rightarrow CO_2^+(A) + e$ Figure 1.32: Cross sections for  $CO_2 + \lambda \rightarrow CO_2^+(A) + e$  (wavelength version)

Figure 1.33: Cross sections for CO<sub>2</sub> + λ

Figure 1.34: Cross sections for  $\text{CO}_2 + \lambda$  (wavelength version)

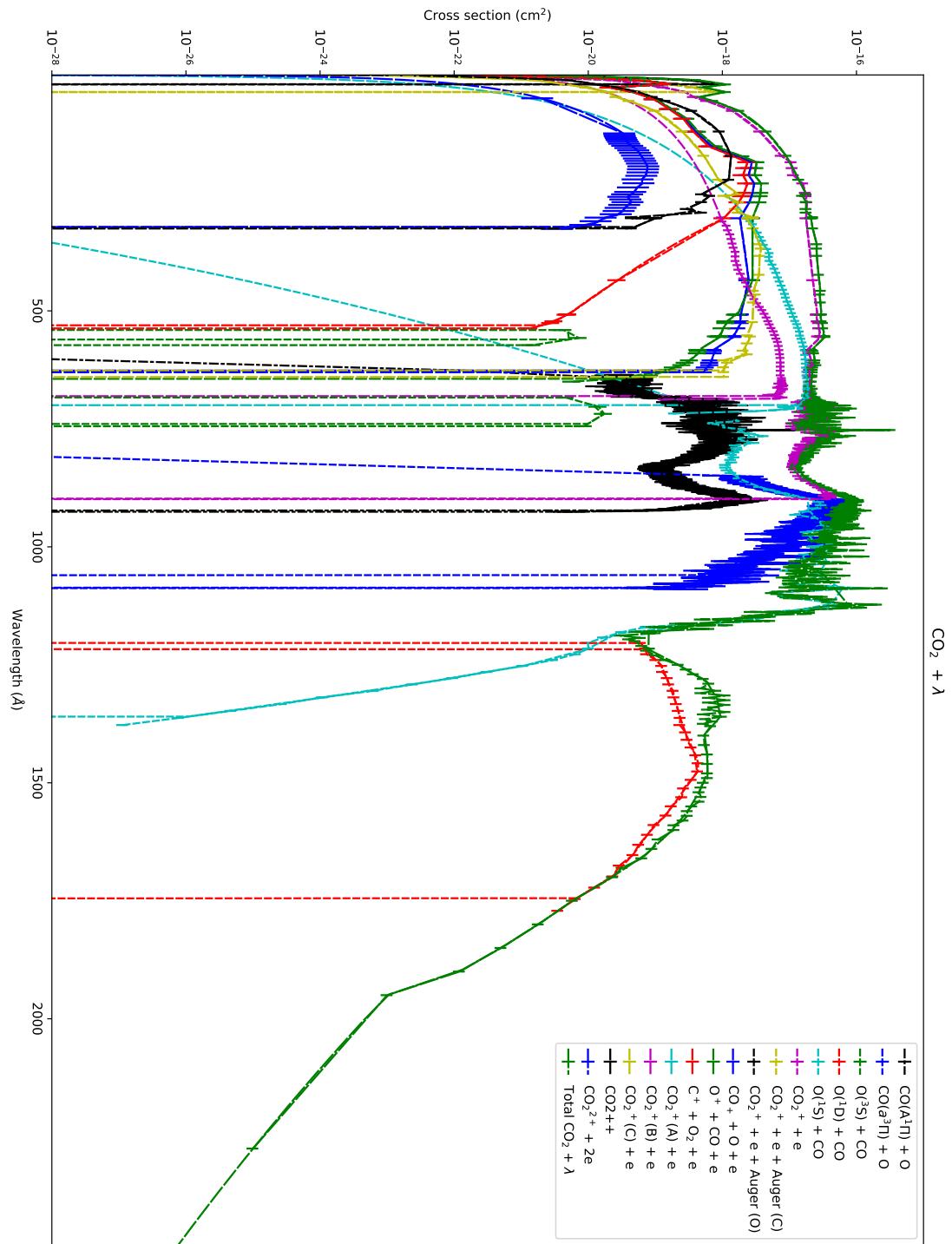


Figure 1.35: Cross sections for CO<sub>2</sub> + λ (with extrapolation version)

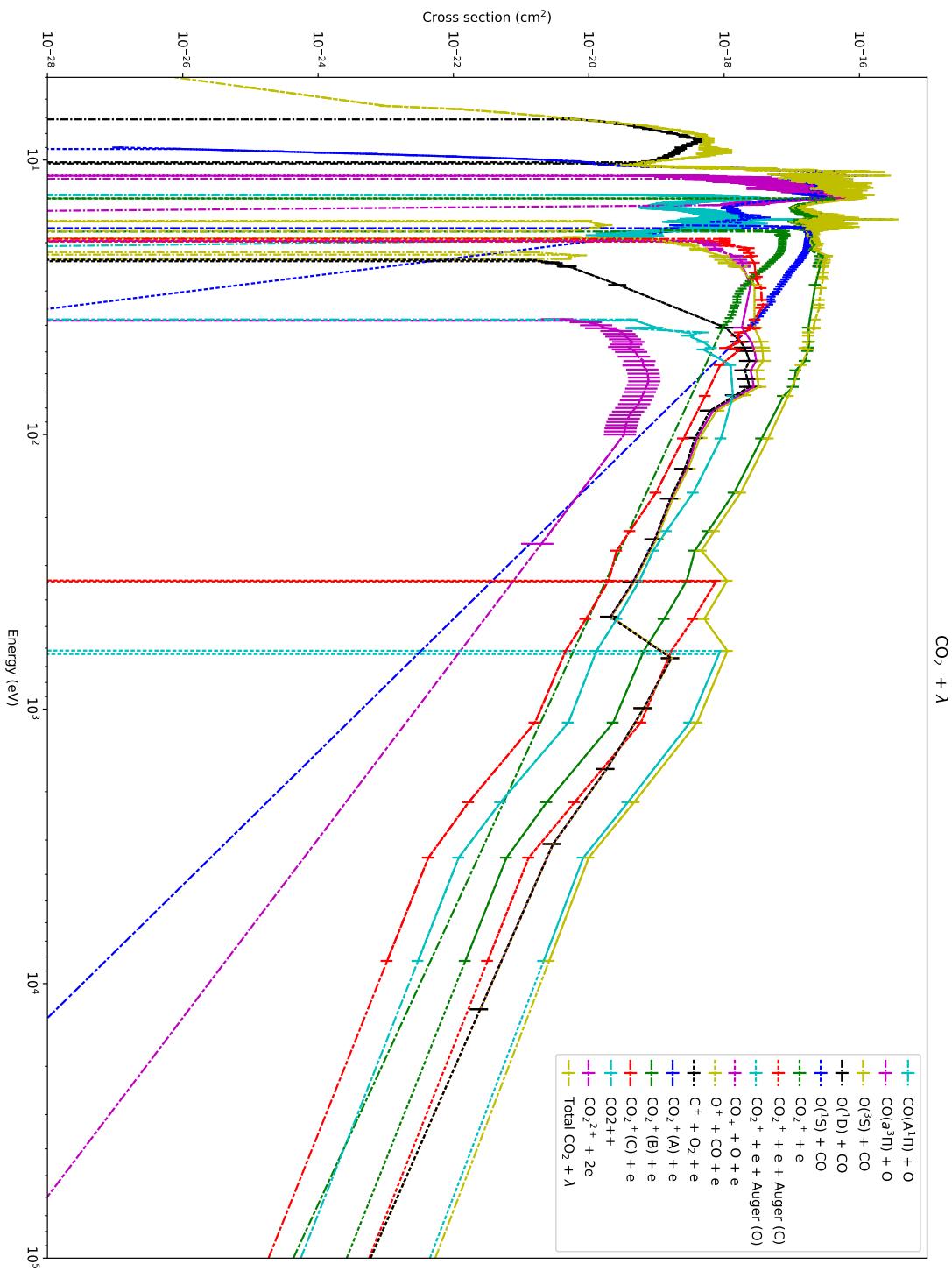


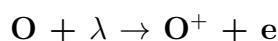
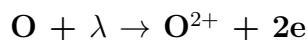
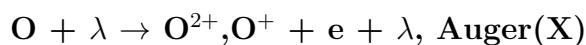
Figure 1.36: Cross sections for CO<sub>2</sub> + λ (wavelength with extrapolation version)

## 1.2 Cross section of ph impact with O

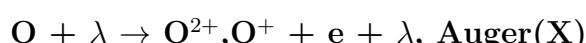
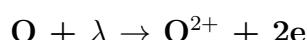
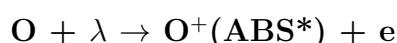
### 1.2.1 Total Cross Section

### 1.2.2 Inelastic Cross Sections

#### Ionization Cross Sections



### 1.2.3 Recommended data set



#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi [3]	0	0:-1	20%		Fig. 1.43 1.44
Revi [46]	0	0:-1	????%	U	Fig. 1.43 1.44
Revi PHIDRATES	0	0:-1	????%	U	Fig. 1.43 1.44

Table 1.6: Total cross section for  $\lambda$  impact on O

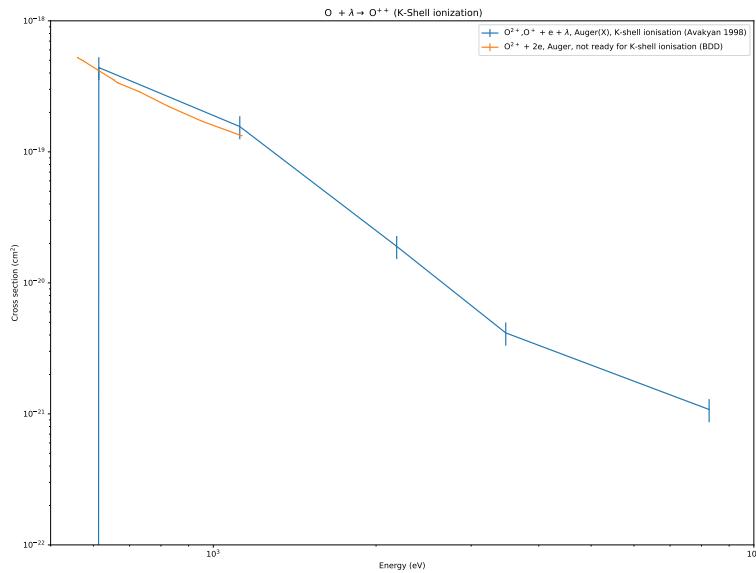
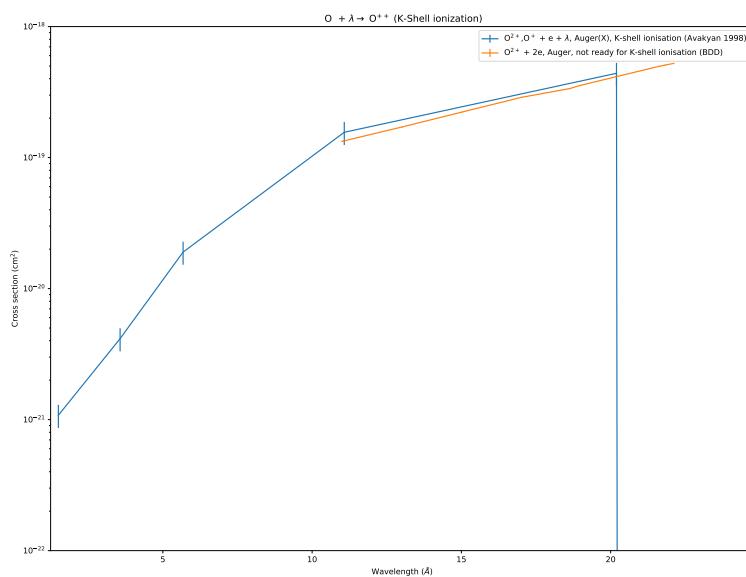
Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$O + \lambda \rightarrow O^{2+}, O^+ + e + \lambda$ , Auger(X)	Revi [3]	539	539:-1	20%	R	Fig. 1.37 1.38
$O + \lambda \rightarrow O^{2+} + 2e$	Revi [45] Revi [2] Revi [45]	532 48.74 48.74	532:-1 48.74:-1 48.74:-1	?%? 20% ?%?	U R U	Fig. 1.37 1.38 Fig. 1.39 1.40 Fig. 1.39 1.40
$O + \lambda \rightarrow O^+ + e$	Revi [2] Revi [45]	13.618 13.61	13.618:-1 13.61:-1	20% ?%?	R U	Fig. 1.41 1.42 Fig. 1.41 1.42

Table 1.7: Ionization Cross section for  $\lambda$  impact on O

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
O + $\lambda \rightarrow O^+(^4S) + e$	Revi [2]	13.618	13.618:-1	20%		Fig. 1.45 1.46 1.47 1.48
O + $\lambda \rightarrow O^+(^2D) + e$	Revi [2]	16.941	16.941:-1	20%		Fig. 1.45 1.46 1.47 1.48
O + $\lambda \rightarrow O^+(^2P) + e$	Revi [2]	18.635	18.635:-1	20%		Fig. 1.45 1.46 1.47 1.48
O + $\lambda \rightarrow O^+(^4P^*) + e$	Revi [2]	28.48	28.48:-1	20%		Fig. 1.45 1.46 1.47 1.48
O + $\lambda \rightarrow O^+(^2P^*) + e$	Revi [2]	39.98	39.98:-1	20%		Fig. 1.45 1.46 1.47 1.48
O + $\lambda \rightarrow O^+(ABS^*) + e$	Revi [2]	13.618	13.618:-1	20%		Fig. 1.45 1.46 1.47 1.48
O + $\lambda \rightarrow O^{2+} + 2e$	Revi [2]	48.74	48.74:-1	20%		Fig. 1.45 1.46 1.47 1.48
O + $\lambda \rightarrow O^{2+}, O^+ + e + \lambda, Auger(X)$	Revi [2]	539	539:-1	20%	R	Fig. 1.45 1.46 1.47 1.48
O + $\lambda \rightarrow$ Total	Revi [2]	0	0:-1	20%		Fig. 1.45 1.46 1.47 1.48

Table 1.8: Recommended Cross section for  $\lambda$  impact on O

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Figure 1.37: Cross sections for  $O + \lambda \rightarrow O^{++}$  (K-Shell ionization)Figure 1.38: Cross sections for  $O + \lambda \rightarrow O^{++}$  (K-Shell ionization) (wavelength version)

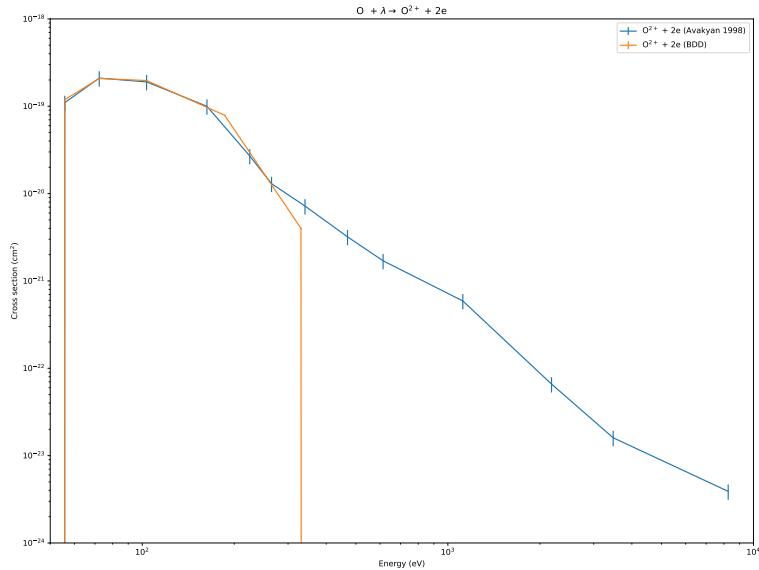


Figure 1.39: Cross sections for  $O + \lambda \rightarrow O^{2+} + 2e$

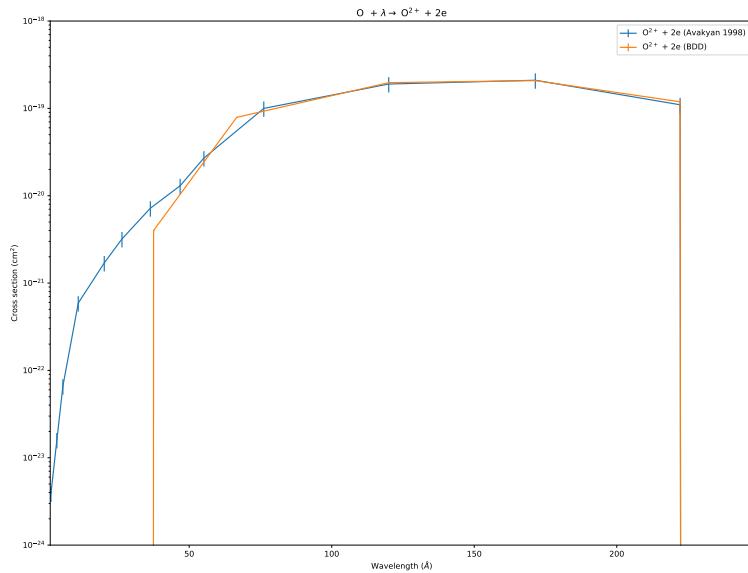
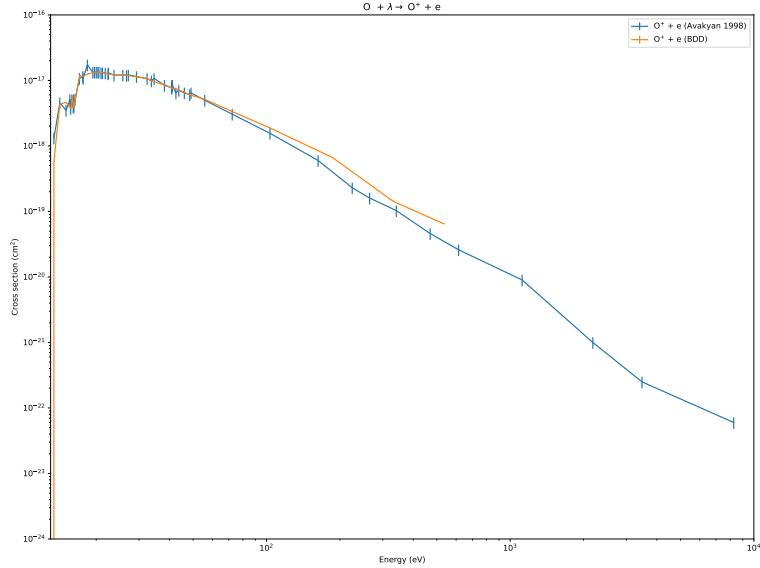
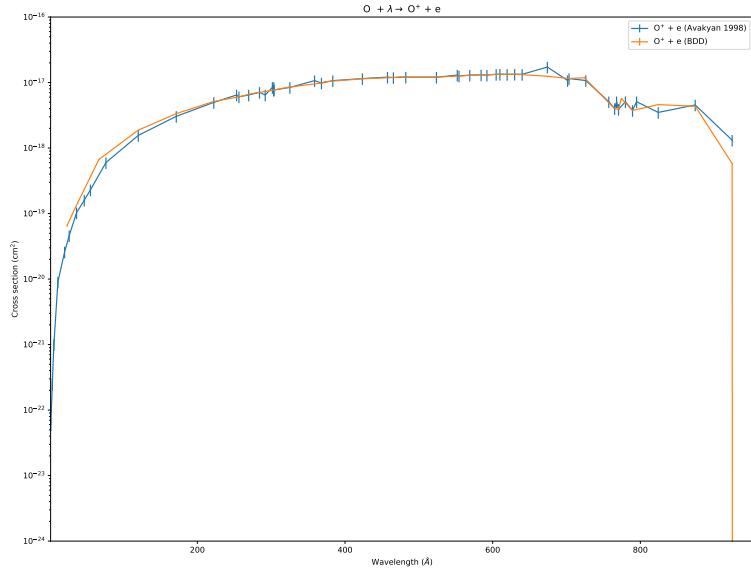


Figure 1.40: Cross sections for  $O + \lambda \rightarrow O^{2+} + 2e$  (wavelength version)

Figure 1.41: Cross sections for  $O + \lambda \rightarrow O^+ + e$ Figure 1.42: Cross sections for  $O + \lambda \rightarrow O^+ + e$  (wavelength version)

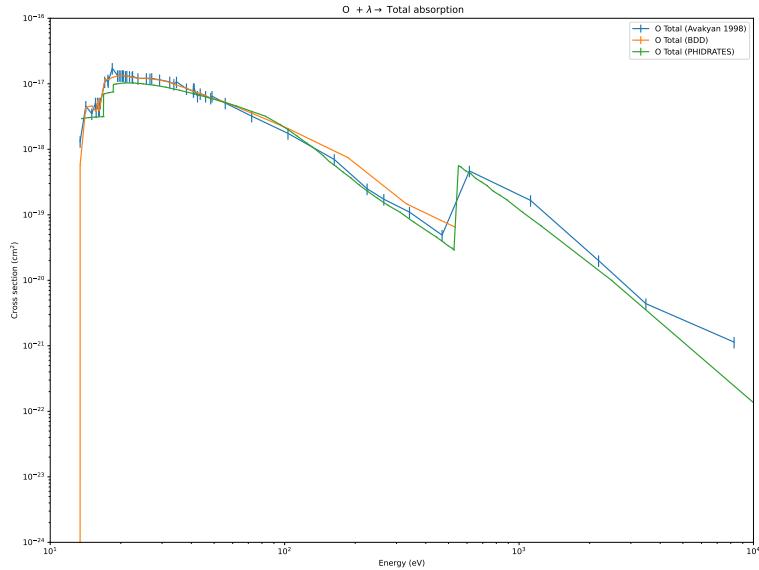


Figure 1.43: Cross sections for  $O + \lambda \rightarrow$  Total absorption

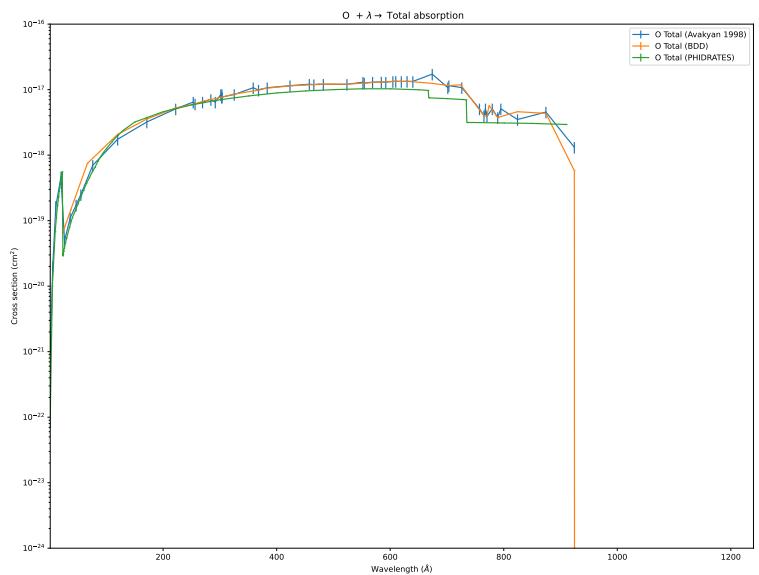
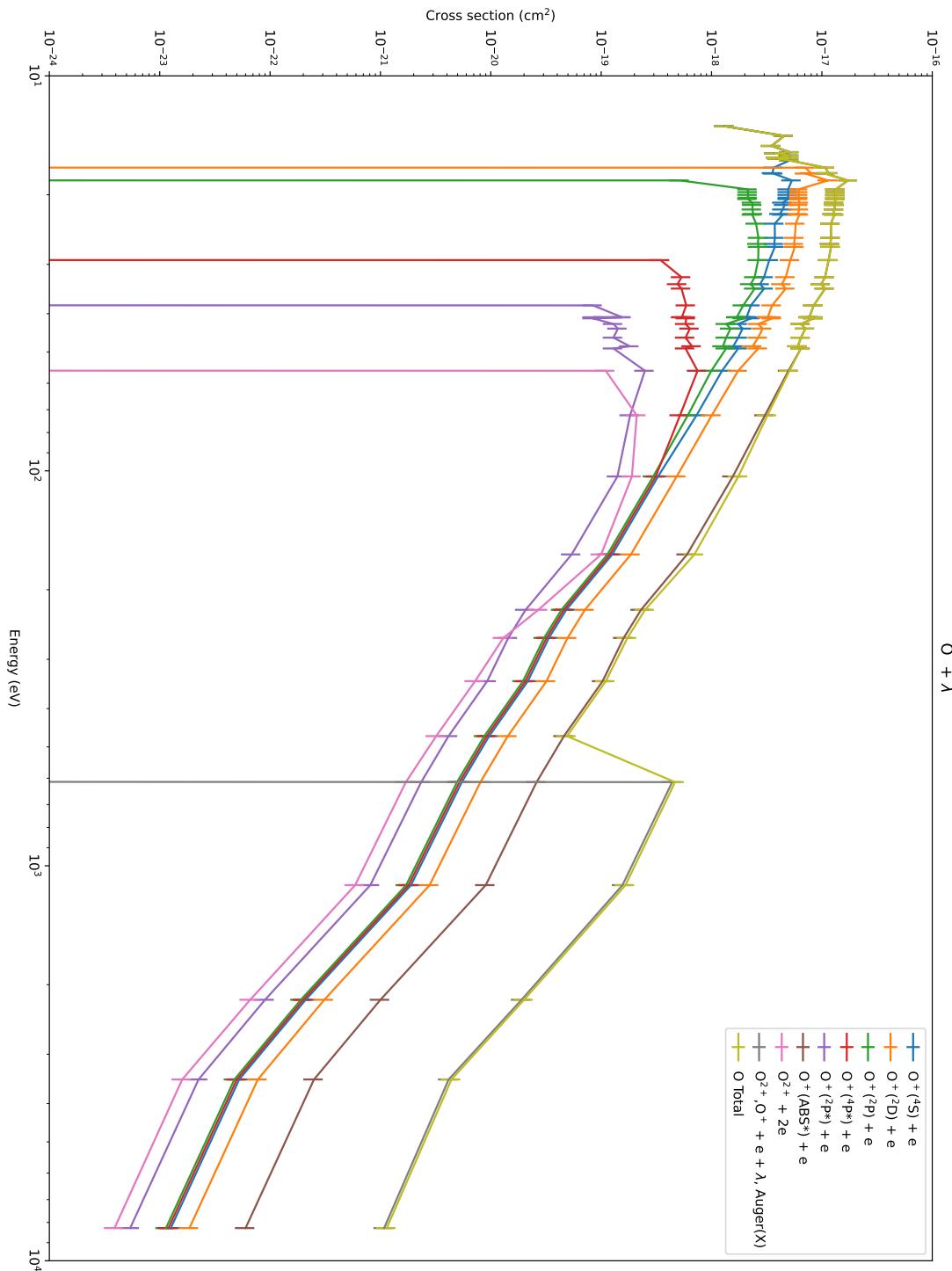
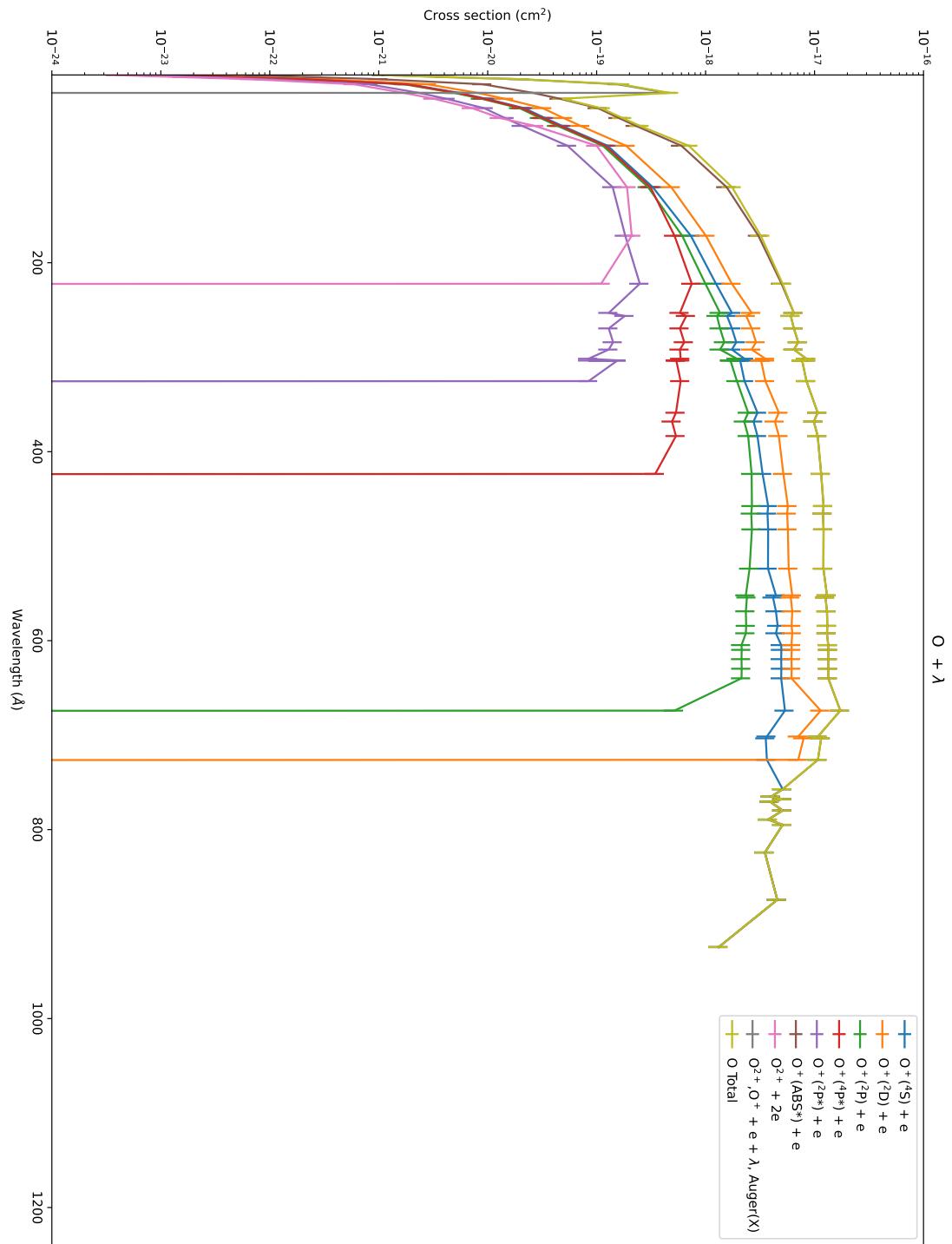
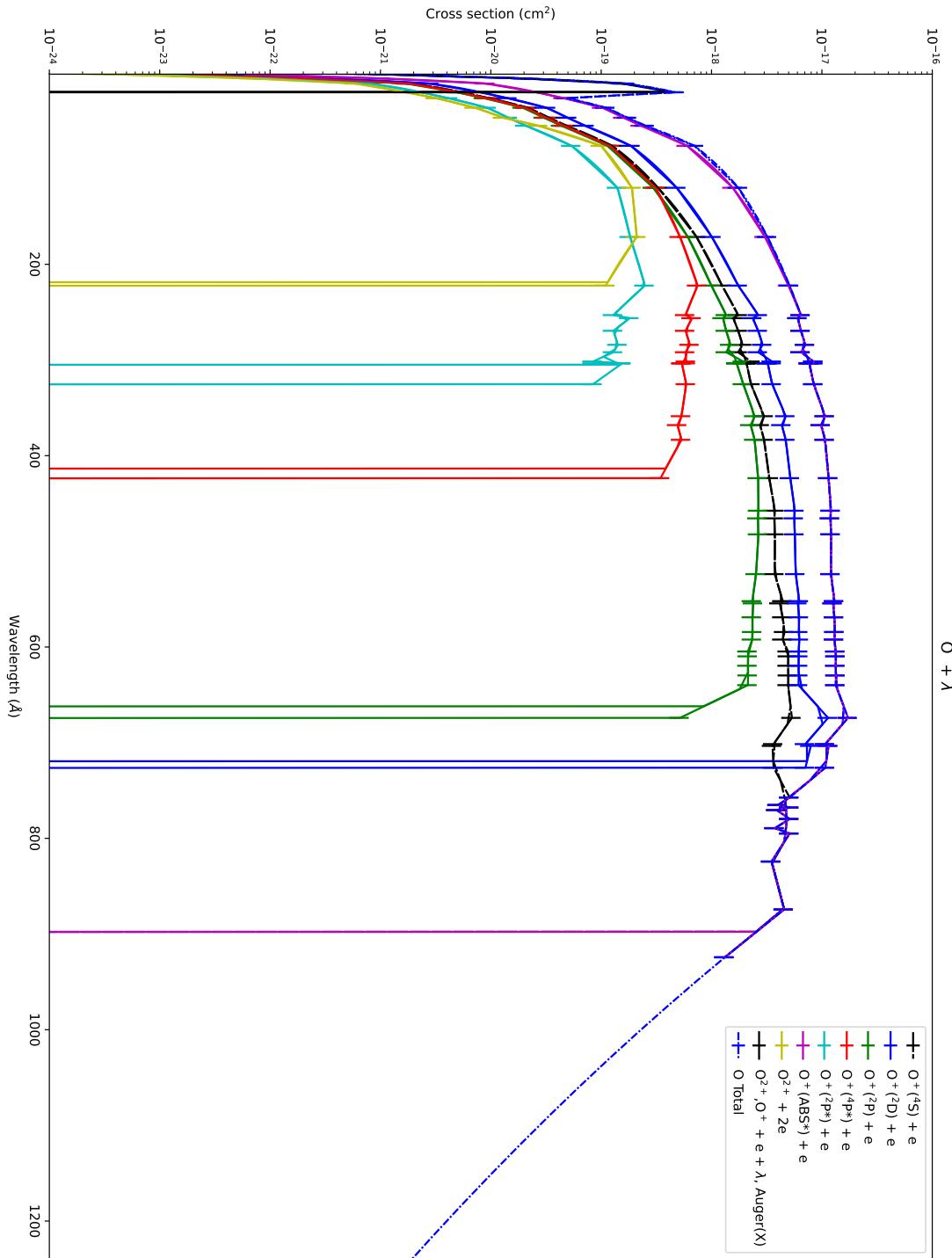


Figure 1.44: Cross sections for  $O + \lambda \rightarrow$  Total absorption (wavelength version)

Figure 1.45: Cross sections for  $O + \lambda$

Figure 1.46: Cross sections for  $O + \lambda$  (wavelength version)

Figure 1.47: Cross sections for  $O + \lambda$  (with extrapolation version)

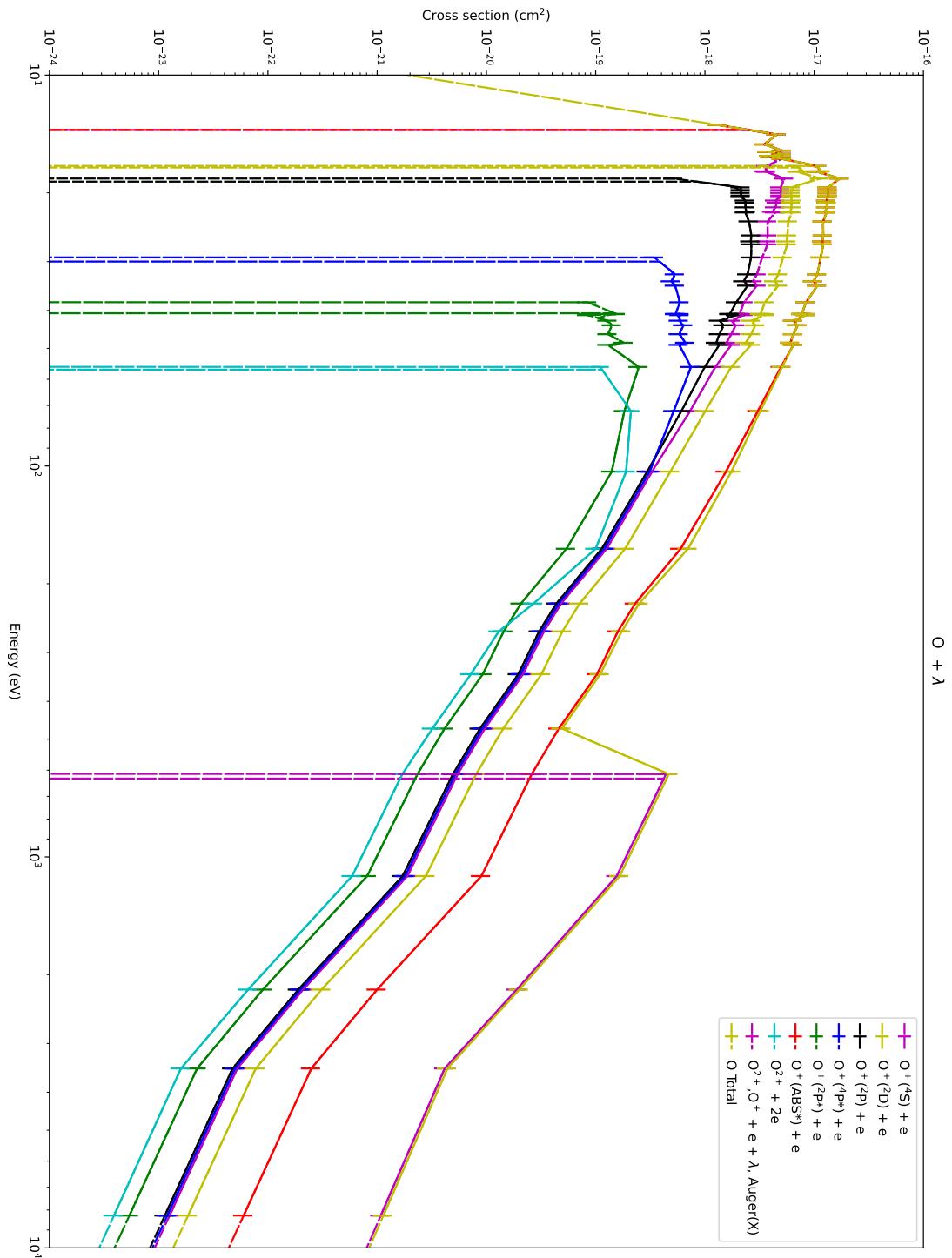


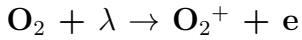
Figure 1.48: Cross sections for O +  $\lambda$  (wavelength with extrapolation version)

## 1.3 Cross section of ph impact with $O_2$

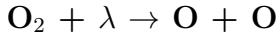
### 1.3.1 Total Cross Section

### 1.3.2 Inelastic Cross Sections

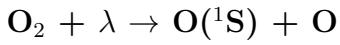
#### Ionization Cross Sections



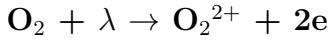
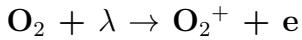
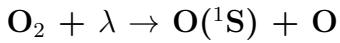
#### Dissociation Cross Sections



#### Excitation Cross Sections



### 1.3.3 Recommended data set



**$O_2^{2+}$  BDD** Adapted nm - $\lambda$  eV, from old database: hence the high uncertainty. The ionization was adapted from the ionization cross-section for N2. The work of [55] for the ratio of double photoionization to single ionization was used for the estimate as explained in [19]

Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi [2]	0	0:-1	20%		Fig. 1.59 1.60
Revi BDD + [46]	0	0:-1	??%	U	Fig. 1.59 1.60
Revi PHDRATES	0	0:-1	??%	U	Fig. 1.59 1.60
Adap PHDRATES + [2]	0	0:-1	20%	RU	Fig. 1.59 1.60

Table 1.9: Total cross section for  $\lambda$  impact on O<sub>2</sub>

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$O_2 + \lambda \rightarrow O^+ + O + e$	Revi BDD + [46] Revi PHDRATES	18.73 18.73	18.73:-1 18.73:-1	??% 20%	U RU	Fig. 1.49 1.50 Fig. 1.49 1.50
$O_2 + \lambda \rightarrow O_2^+ + e$	Revi [2] Revi BDD + [46] Revi AMOP Adap AMOP + BDD + [2] Revi PHDRATES	12.071 12.8 12.8 12.8 12.8	12.071:-1 12.8:-1 12.8:-1 12.8:-1 12.8:-1	20% ??% ??% 20% ??%	U U U U U	Fig. 1.55 1.56 Fig. 1.55 1.56 Fig. 1.55 1.56 Fig. 1.55 1.56 Fig. 1.55 1.56

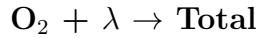
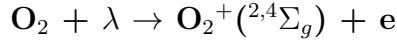
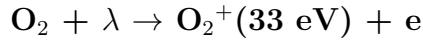
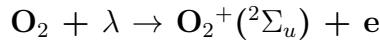
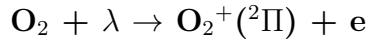
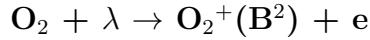
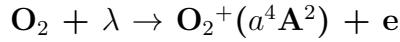
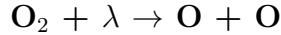
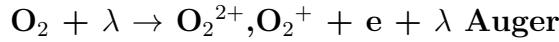
Table 1.10: Ionization Cross section for  $\lambda$  impact on  $O_2$

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$O_2 + \lambda \rightarrow O + O$	Revi PHIDRATES	5	5-1	??%	RU	Fig. 1.53 1.54

Table 1.11: Dissociation Cross section for  $\lambda$  impact on  $O_2$

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$O_2 + \lambda \rightarrow O(^1D) + O$	Adap [46] Revi PHDRATES	7 7	7:-1 7:-1	20% ????%	U	Fig. 1.51 1.52 Fig. 1.51 1.52
$O_2 + \lambda \rightarrow O(^1S) + O$	Adap BDD + [46] Revi PHDRATES	11 11	11:-1 11:-1	20% ????%	U	Fig. 1.57 1.58 Fig. 1.57 1.58

Table 1.12: Excitation Cross section for  $\lambda$  impact on  $O_2$



### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$O_2 + \lambda \rightarrow O(^1D) + O$	Adap BDD	7	7:-1	20%		Fig. 1.61 1.62 1.63 1.64
$O_2 + \lambda \rightarrow O(^1S) + O$	Adap ? BDD	11	11:-1	20%		Fig. 1.61 1.62 1.63 1.64
$O_2 + \lambda \rightarrow O_2^+ + e$	Adap AMOP + BDD + [2]	12.8	12.8:-1	20%		Fig. 1.61 1.62 1.63 1.64
$O_2 + \lambda \rightarrow O^+ + O + e$	Revi AMOP	18.73	18.73:-1	<b>20%</b>	RU	Fig. 1.61 1.62 1.63 1.64
$O_2 + \lambda \rightarrow O_2^{2+} + 2e$	Revi BDD, [45] + [19]	36.13	36.13:-1	<b>50%</b>	RU	Fig. 1.61 1.62 1.63 1.64
$O_2 + \lambda \rightarrow O_2^{2+}, O_2^+ + e + \lambda$ Auger	Revi [3]	539	539:-1	20%	R	Fig. 1.61 1.62 1.63 1.64
$O_2 + \lambda \rightarrow O + O$	Revi PHDRATES	5	5:-1	<b>?;?%;</b>	RU	Fig. 1.61 1.62 1.63 1.64
$O_2 + \lambda \rightarrow O_2^+(a^4A^2) + e$	Revi [3]	16.10	16.10:-1	20%		Fig. 1.61 1.62 1.63 1.64
$O_2 + \lambda \rightarrow O_2^+(b^4) + e$	Revi [3]	18.171	18.171:-1	20%		Fig. 1.61 1.62 1.63 1.64
$O_2 + \lambda \rightarrow O_2^+(\mathbf{B}^2) + e$	Revi [3]	20.296	20.296:-1	20%		Fig. 1.61 1.62 1.63 1.64
$O_2 + \lambda \rightarrow O_2^+(^2\Pi) + e$	Revi [3]	22.8	22.8:-1	20%		Fig. 1.61 1.62 1.63 1.64
$O_2 + \lambda \rightarrow O_2^+(c^4\Sigma) + e$	Revi [3]	24.6	24.6:-1	20%		Fig. 1.61 1.62 1.63 1.64
$O_2 + \lambda \rightarrow O_2^+(^2\Sigma_u) + e$	Revi [3]	28	28:-1	20%		Fig. 1.61 1.62 1.63 1.64
$O_2 + \lambda \rightarrow O_2^+(33 \text{ eV}) + e$	Revi [2]	33	33:-1	20%		Fig. 1.61 1.62 1.63 1.64
$O_2 + \lambda \rightarrow O_2^+(^2\Sigma_g) + e$	Revi [3]	40	40:-1	20%		Fig. 1.61 1.62 1.63 1.64
$O_2 + \lambda \rightarrow \text{Total}$	Adap AMOP + [2]	0	0:-1	<b>20%</b>	RU	Fig. 1.61 1.62 1.63 1.64

Table 1.13: Recommended Cross section for  $\lambda$  impact on  $O_2$

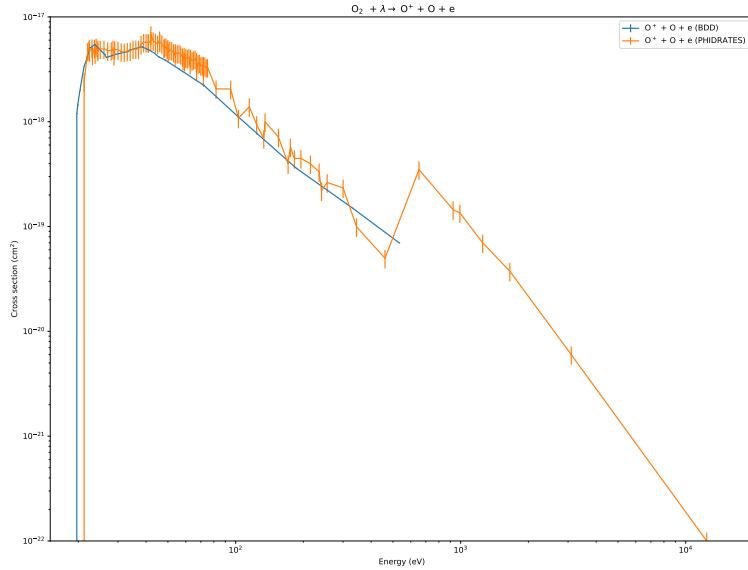


Figure 1.49: Cross sections for  $O_2 + \lambda \rightarrow O^+ + O + e$

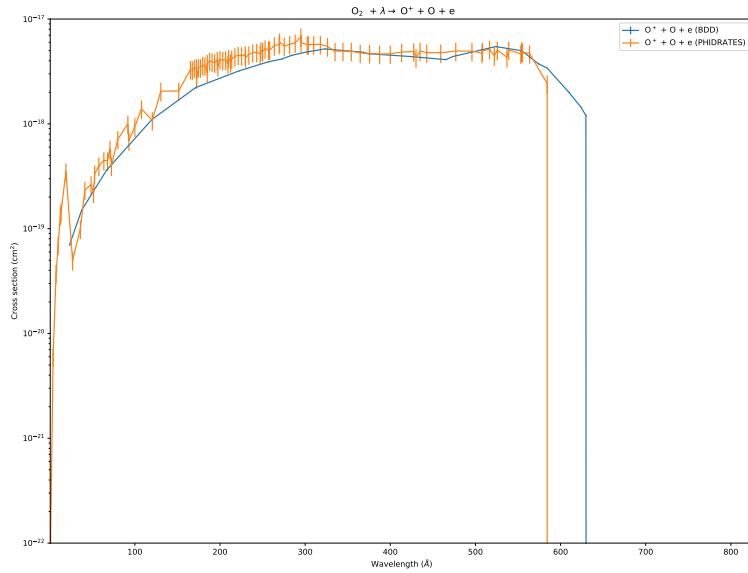
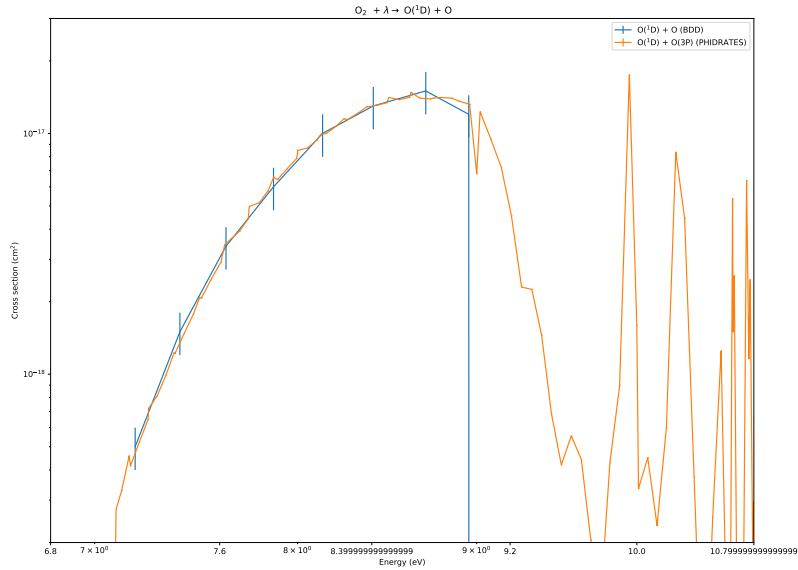
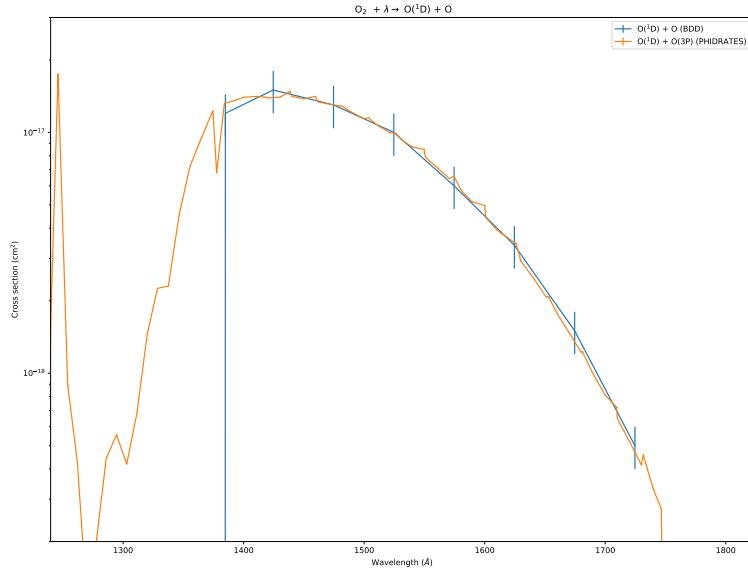


Figure 1.50: Cross sections for  $O_2 + \lambda \rightarrow O^+ + O + e$  (wavelength version)

Figure 1.51: Cross sections for  $O_2 + \lambda \rightarrow O(^1D) + O$ Figure 1.52: Cross sections for  $O_2 + \lambda \rightarrow O(^1D) + O$  (wavelength version)

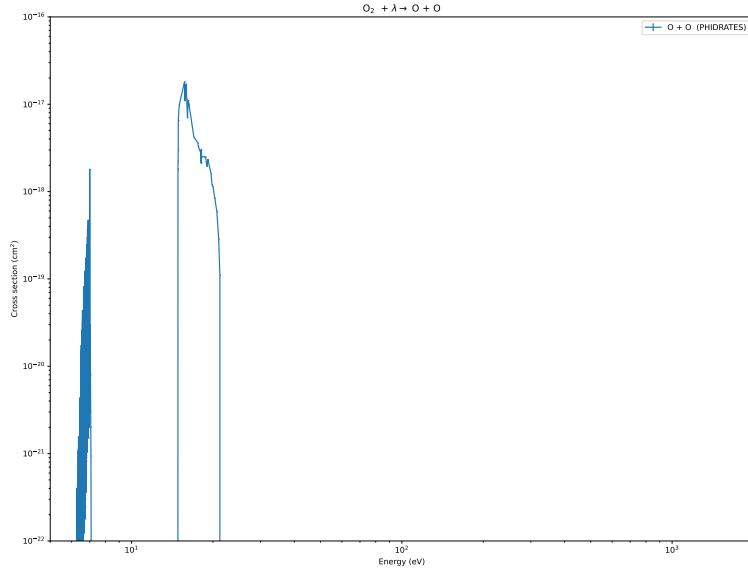


Figure 1.53: Cross sections for  $O_2 + \lambda \rightarrow O + O$

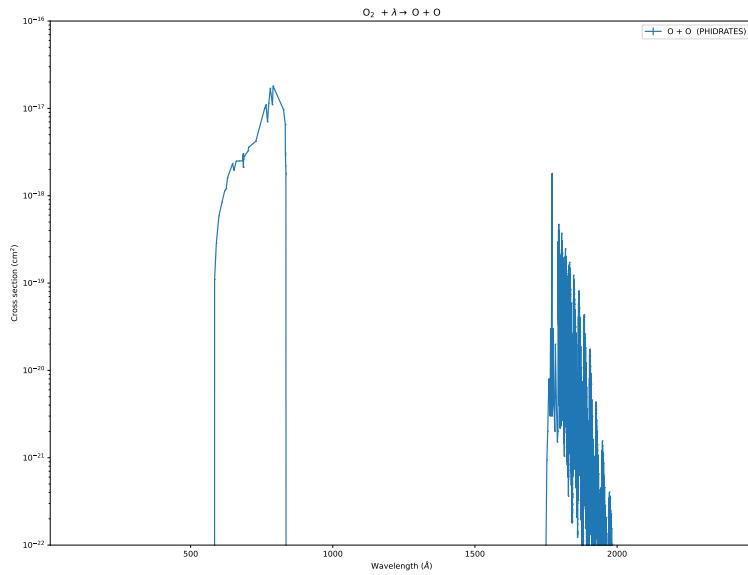
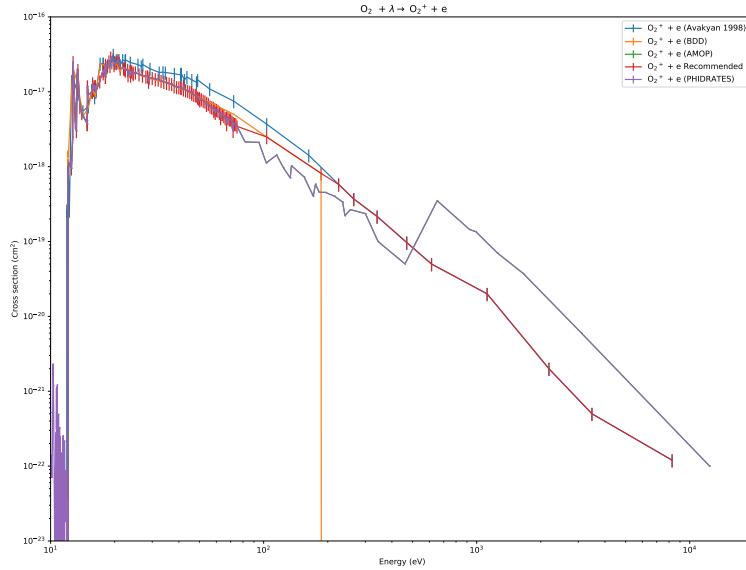
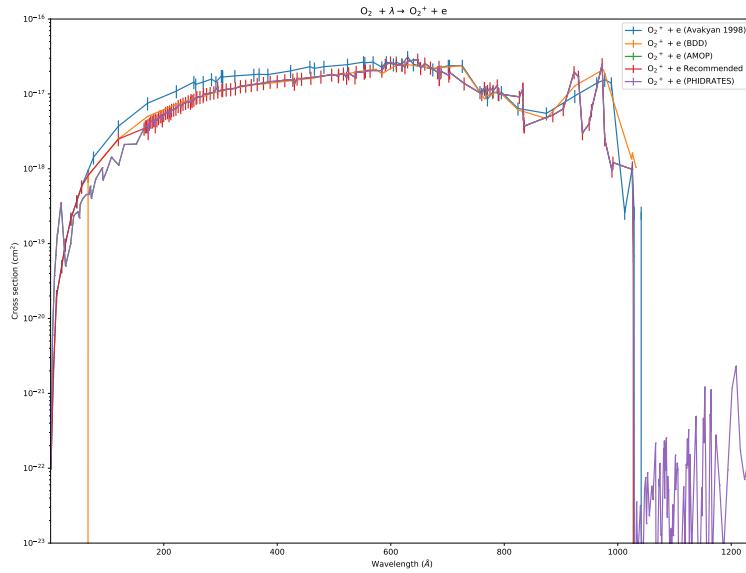


Figure 1.54: Cross sections for  $O_2 + \lambda \rightarrow O + O$  (wavelength version)

Figure 1.55: Cross sections for  $O_2 + \lambda \rightarrow O_2^+ + e$ Figure 1.56: Cross sections for  $O_2 + \lambda \rightarrow O_2^+ + e$  (wavelength version)

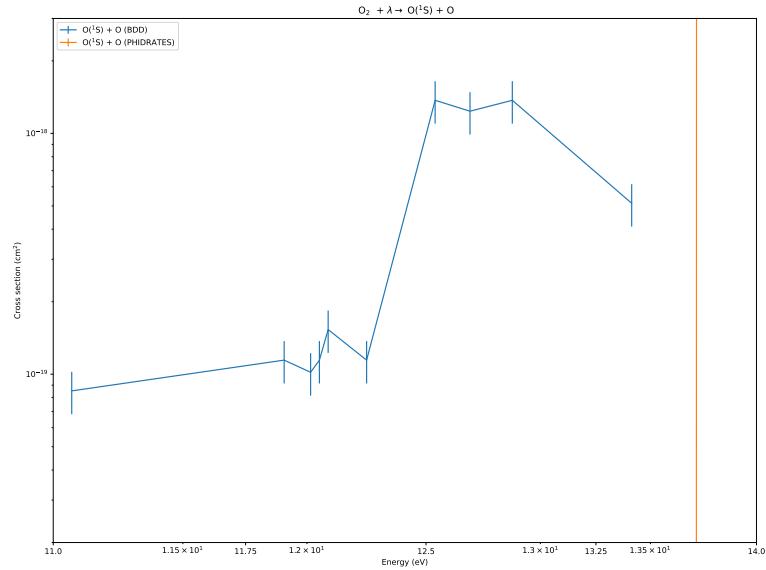


Figure 1.57: Cross sections for  $O_2 + \lambda \rightarrow O(^1S) + O$

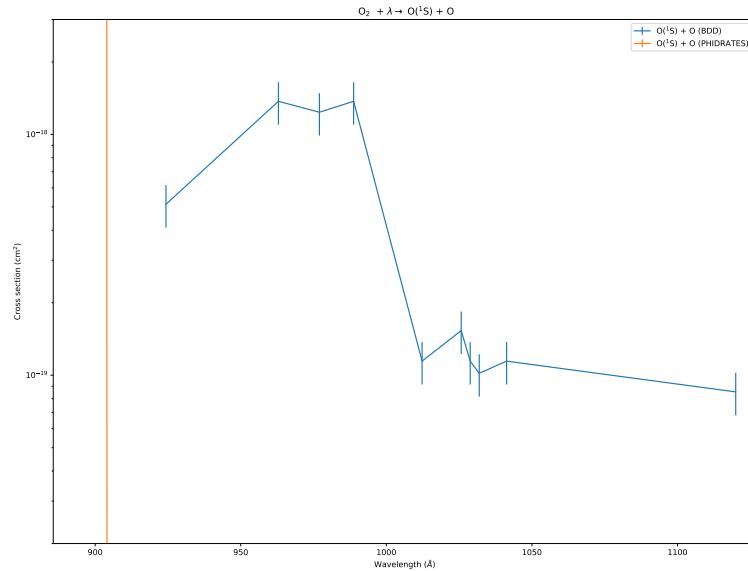
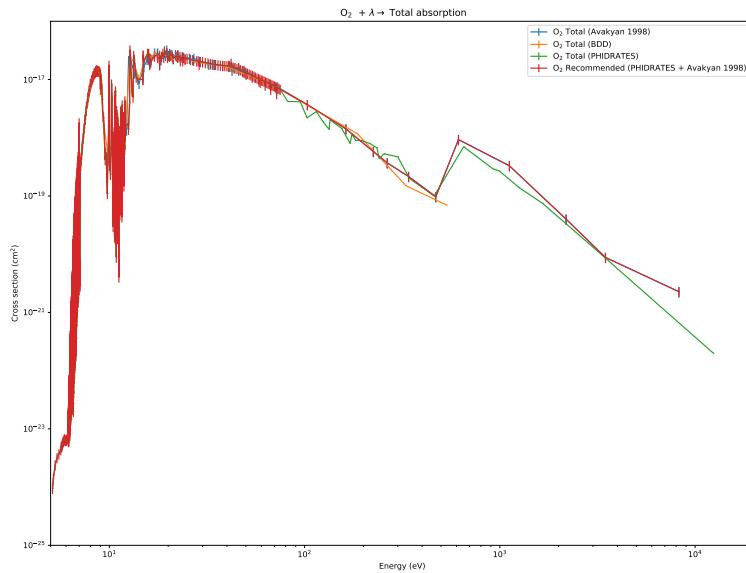
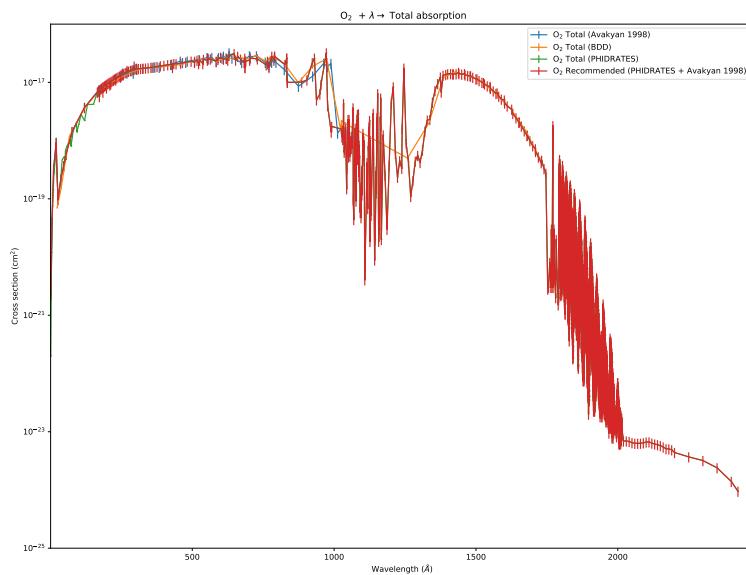
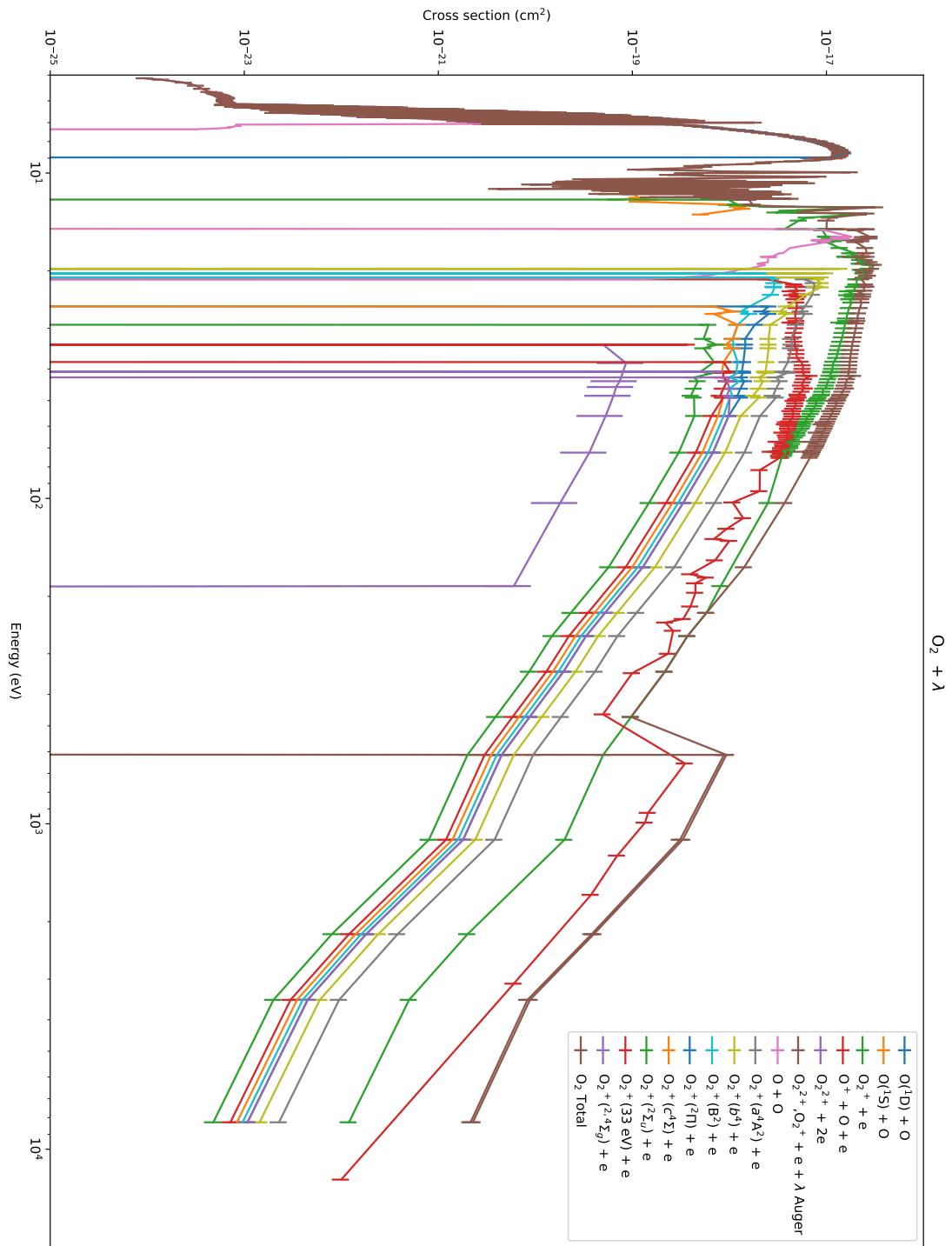
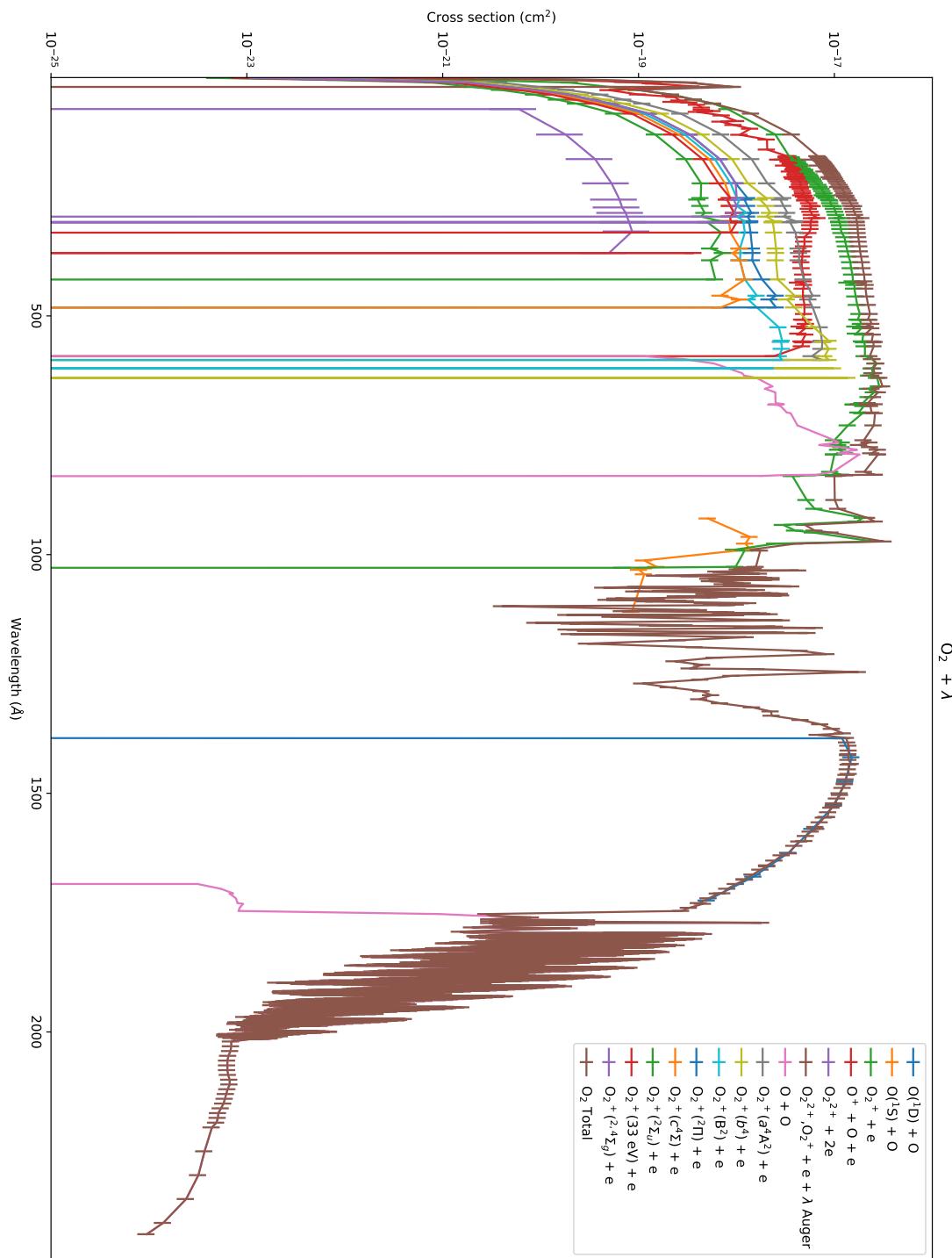


Figure 1.58: Cross sections for  $O_2 + \lambda \rightarrow O(^1S) + O$  (wavelength version)

Figure 1.59: Cross sections for  $O_2 + \lambda \rightarrow$  Total absorptionFigure 1.60: Cross sections for  $O_2 + \lambda \rightarrow$  Total absorption (wavelength version)

Figure 1.61: Cross sections for  $O_2 + \lambda$

Figure 1.62: Cross sections for  $O_2 + \lambda$  (wavelength version)

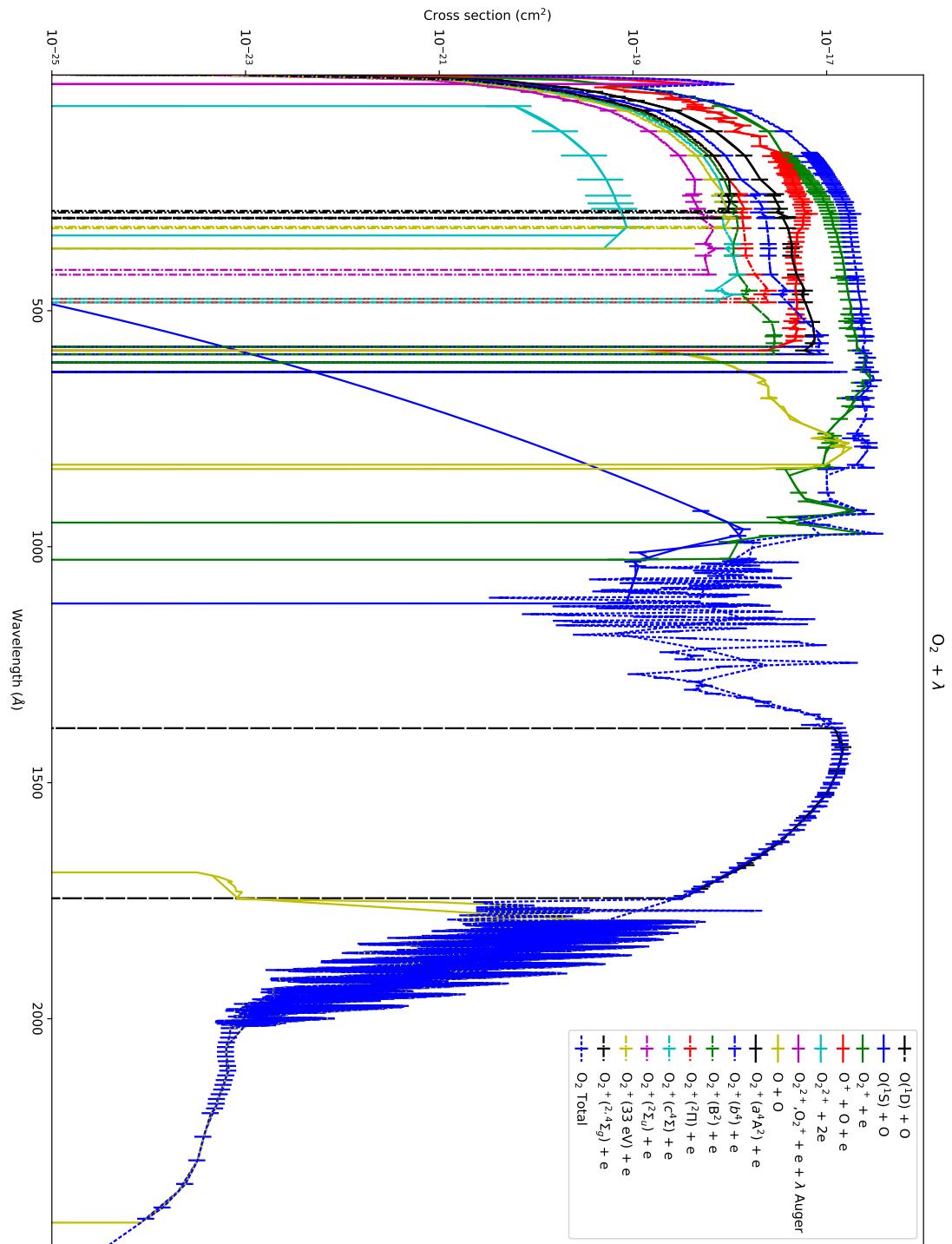


Figure 1.63: Cross sections for  $O_2 + \lambda$  (with extrapolation version)

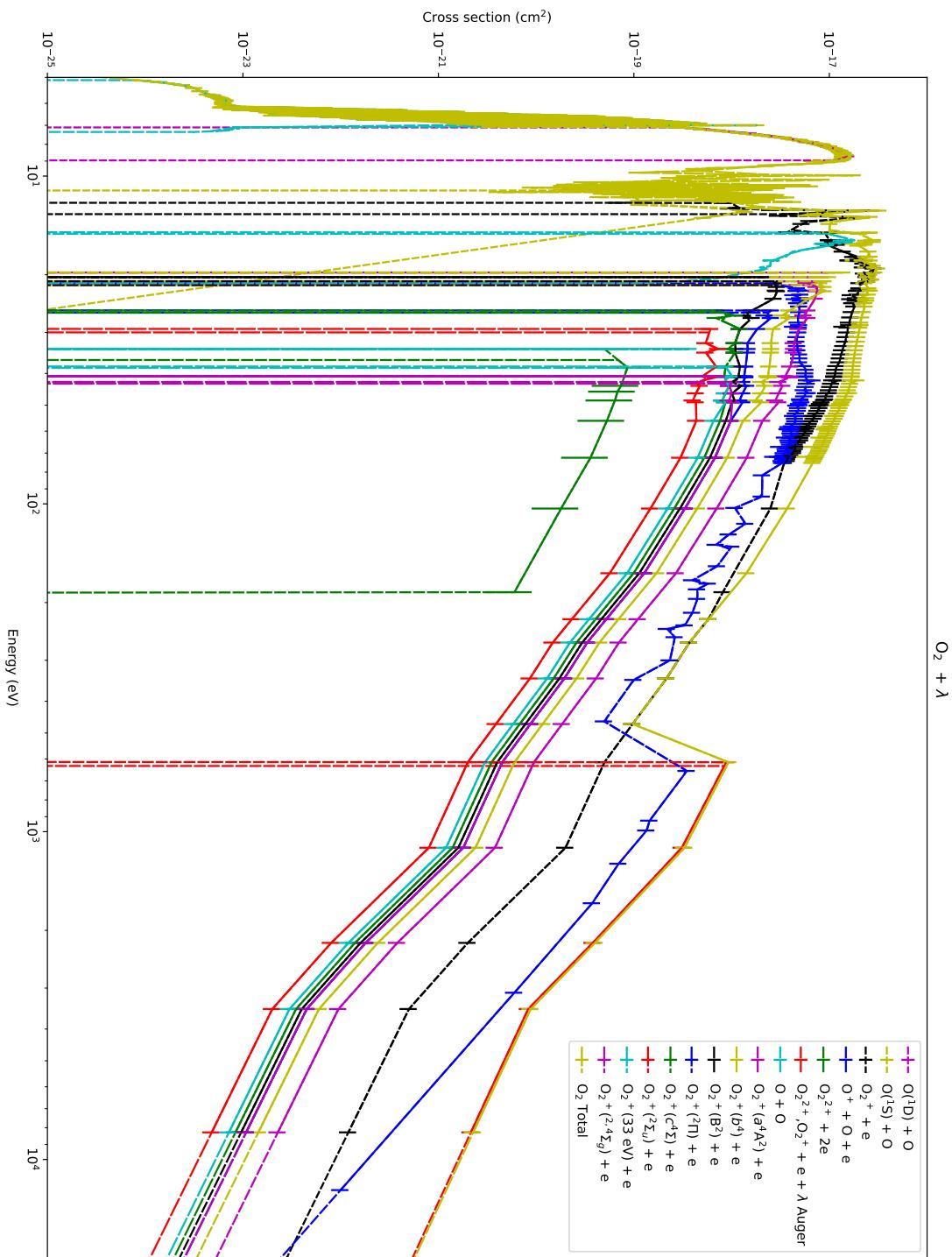


Figure 1.64: Cross sections for  $O_2 + \lambda$  (wavelength with extrapolation version)



Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi [2]	0	0:-1	20%		Fig. 1.77 1.78
Revi BDD + [74]	0	0:-1	???	U	Fig. 1.77 1.78
Revi PHIDRATES	0	0:-1	???	U	Fig. 1.77 1.78
Aclap PHIDRATES + [2]	0	0:-1	20%	RU	Fig. 1.77 1.78

Table 1.14: Total cross section for  $\lambda$  impact on CO

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$\text{CO} + \lambda \rightarrow \text{CO}^{2+} + 2\text{e}$	Revi [2]	41.294	41.294:-1	20%		Fig. 1.65 1.66
$\text{CO} + \lambda \rightarrow \text{O}^+ + \text{C} + \text{e}$	Revi BDD + [74]	24.71	24.71:-1	???	U	Fig. 1.67 1.68
$\text{CO} + \lambda \rightarrow \text{O}^+$	Revi PHIDRATES	24.71	24.71:-1	20%	RU	Fig. 1.67 1.68
$\text{CO} + \lambda \rightarrow \text{C}^+ + \text{O} + \text{e}$	Revi BDD + [74]	22.37	22.37:-1	???	U	Fig. 1.71 1.72
$\text{CO} + \lambda \rightarrow \text{CO}^+$	Revi PHIDRATES	22.37	22.37:-1	20%	RU	Fig. 1.71 1.72
$\text{CO} + \lambda \rightarrow \text{CO}^+ + \text{e}$	Revi [2] Revi PHIDRATES	14.014 14.01	14.014:-1 14.01:-1	20% ???	U	Fig. 1.73 1.74 Fig. 1.73 1.74
	Revi BDD + [74] Revi PHIDRATES + [2] + [48]	14.01 14.01	14.01:-1 14.01:-1	??? 20%	U RU	Fig. 1.73 1.74 Fig. 1.73 1.74

Table 1.15: Ionization Cross section for  $\lambda$  impact on CO

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$\text{CO} + \lambda \rightarrow \text{O}(\text{I}\text{D}) + \text{C}(\text{I}\text{D})$	Adap PHIDRATES + McElroy	14.36	14.36:-1	50%	UE	Fig. 1.69 1.70
$\text{CO} + \lambda \rightarrow \text{O}(\text{I}^3\text{S}) + \text{C}$	Revi BDD + [74] Meas [76] Adap [76]	18.4 18.4 18.4	18.4:-1 18.4:-1 18.4:-1	30% 30% 30%	RUE	Fig. 1.75 1.76 Fig. 1.75 1.76 Fig. 1.75 1.76

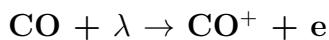
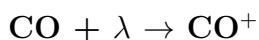
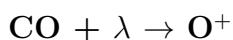
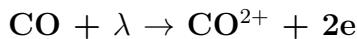
Table 1.16: Excitation Cross section for  $\lambda$  impact on CO

## 1.4 Cross section of ph impact with CO

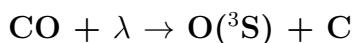
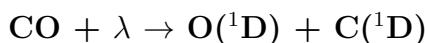
### 1.4.1 Total Cross Section

### 1.4.2 Inelastic Cross Sections

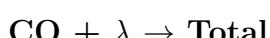
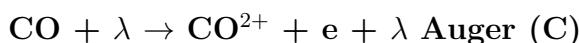
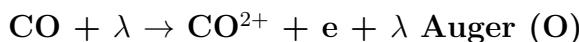
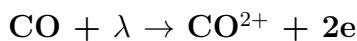
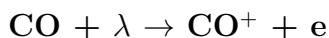
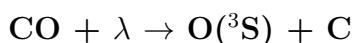
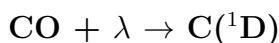
#### Ionization Cross Sections



#### Excitation Cross Sections



### 1.4.3 Recommended data set



#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of

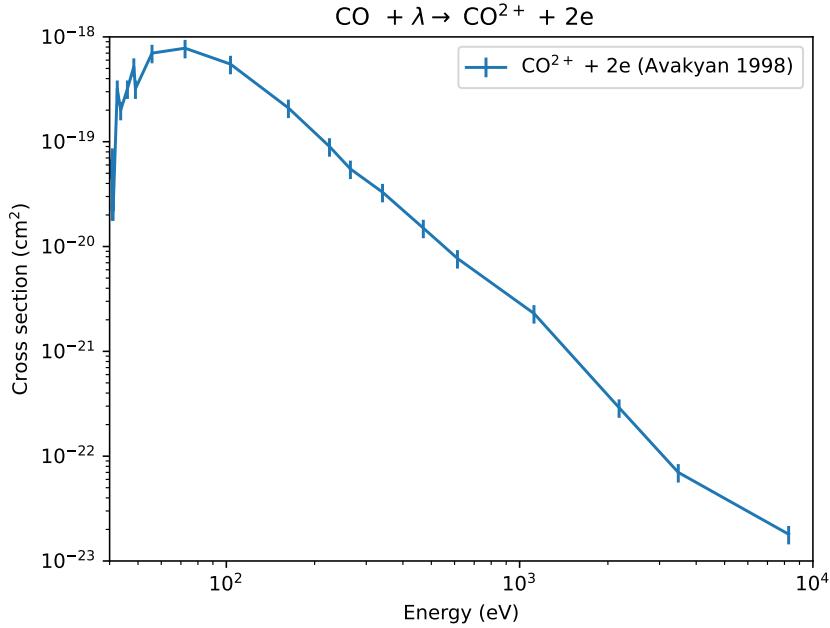
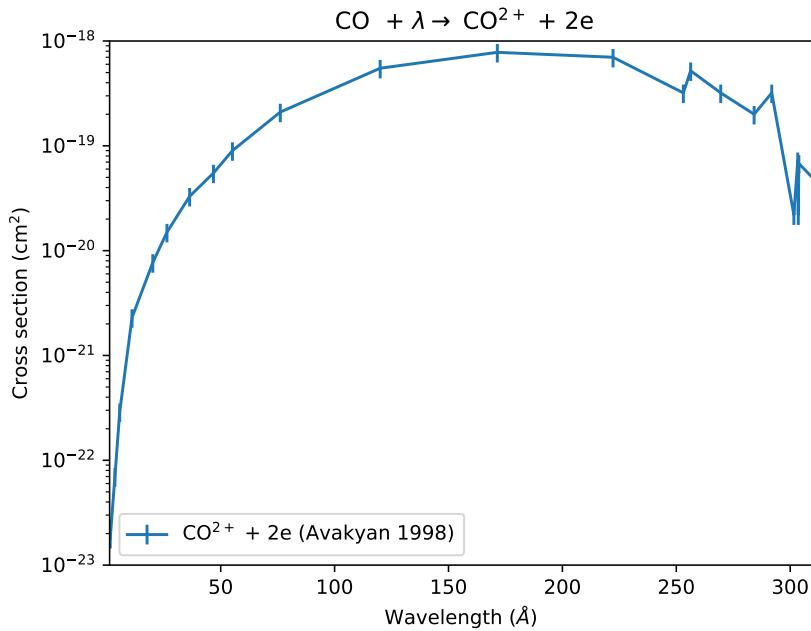
Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$\text{CO} + \lambda \rightarrow \text{C}^1(\text{D})$	Adap PHIDRATES	14.36	14.36:-1	<b>50%</b>	UE	Fig. 1.79 1.80 1.81 1.82
$\text{CO} + \lambda \rightarrow \text{O}(^3\text{S}) + \text{C}$	Adap [76]	18.4	18.4:-1	<b>30%</b>	RUE	Fig. 1.79 1.80 1.81 1.82
$\text{CO} + \lambda \rightarrow \text{C}^+ + \text{O} + \text{e}$	Revi PHIDRATES	22.37	22.37:-1	<b>20%</b>	RU	Fig. 1.79 1.80 1.81 1.82
$\text{CO} + \lambda \rightarrow \text{O}^+ + \text{C} + \text{e}$	Revi PHIDRATES	24.71	24.71:-1	<b>20%</b>	RU	Fig. 1.79 1.80 1.81 1.82
$\text{CO} + \lambda \rightarrow \text{CO}^+ + \text{e}$	Adap PHIDRATES + [2] + [48]	14.01	14.01:-1	<b>20%</b>	RU	Fig. 1.79 1.80 1.81 1.82
$\text{CO} + \lambda \rightarrow \text{CO}^{2+} + 2\text{e}$	Revi [2]	41.294	41.294:-1	<b>20%</b>		Fig. 1.79 1.80 1.81 1.82
$\text{CO} + \lambda \rightarrow \text{CO}^{2+} + \text{e} + \lambda \text{ Auger } (\text{O})$	Revi [2]	539	539:-1	<b>20%</b>	R	Fig. 1.79 1.80 1.81 1.82
$\text{CO} + \lambda \rightarrow \text{CO}^{2+} + \text{e} + \lambda \text{ Auger } (\text{C})$	Revi [2]	282	282:-1	<b>20%</b>	R	Fig. 1.79 1.80 1.81 1.82
$\text{CO} + \lambda \rightarrow \text{CO}^+(\text{A}) + \text{e}$	Revi [2]	16.5	16.5:-1	<b>20%</b>		Fig. 1.79 1.80 1.81 1.82
$\text{CO} + \lambda \rightarrow \text{CO}^+(\text{B}) + \text{e}$	Revi [2]	19.7	19.7:-1	<b>20%</b>		Fig. 1.79 1.80 1.81 1.82
$\text{CO} + \lambda \rightarrow \text{CO}^+(\text{C}) + \text{e}$	Revi [2]	13.5	13.5:-1	<b>20%</b>		Fig. 1.79 1.80 1.81 1.82
$\text{CO} + \lambda \rightarrow \text{CO}^+(\text{W}) + \text{e}$	Revi [2]	32	32:-1	<b>20%</b>		Fig. 1.79 1.80 1.81 1.82
$\text{CO} + \lambda \rightarrow \text{CO}^+(\text{?S}) + \text{e}$	Revi [2]	40	40:-1	<b>20%</b>		Fig. 1.79 1.80 1.81 1.82
$\text{CO} + \lambda \rightarrow \text{Total}$	Adap PHIDRATES + [2]	0	0:-1	<b>20%</b>	RU	Fig. 1.79 1.80 1.81 1.82

Table 1.17: Recommended Cross section for  $\lambda$  impact on CO

the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Figure 1.65: Cross sections for  $\text{CO} + \lambda \rightarrow \text{CO}^{2+} + 2\text{e}$ Figure 1.66: Cross sections for  $\text{CO} + \lambda \rightarrow \text{CO}^{2+} + 2\text{e}$  (wavelength version)

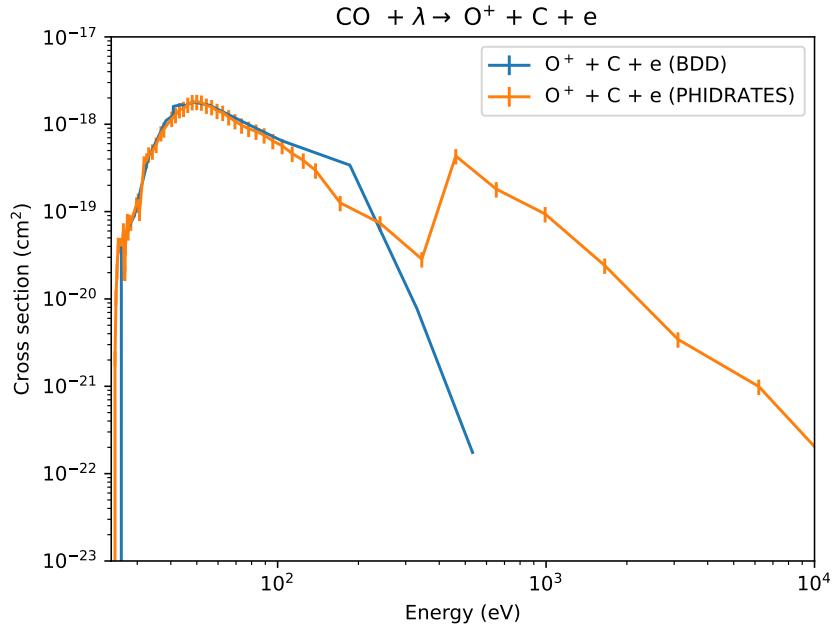


Figure 1.67: Cross sections for  $\text{CO} + \lambda \rightarrow \text{O}^+ + \text{C} + \text{e}$

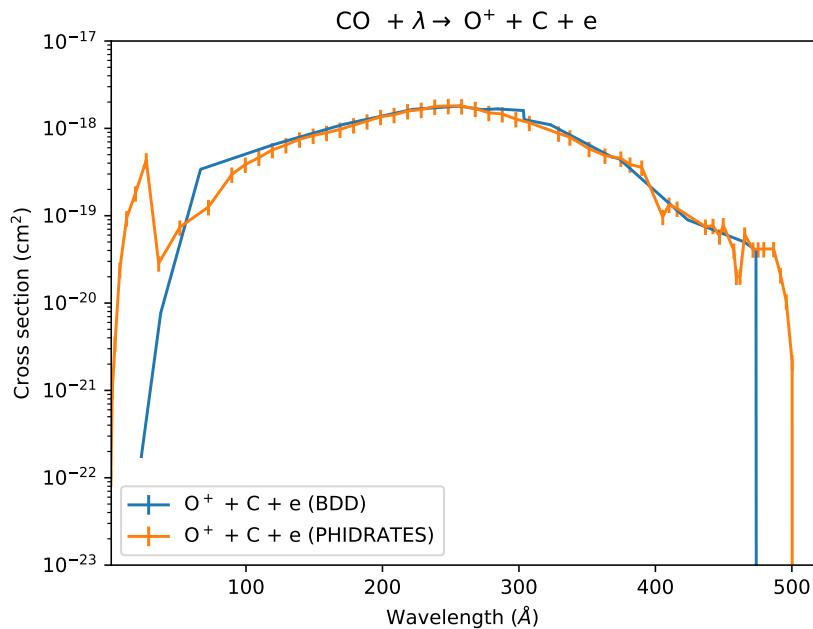
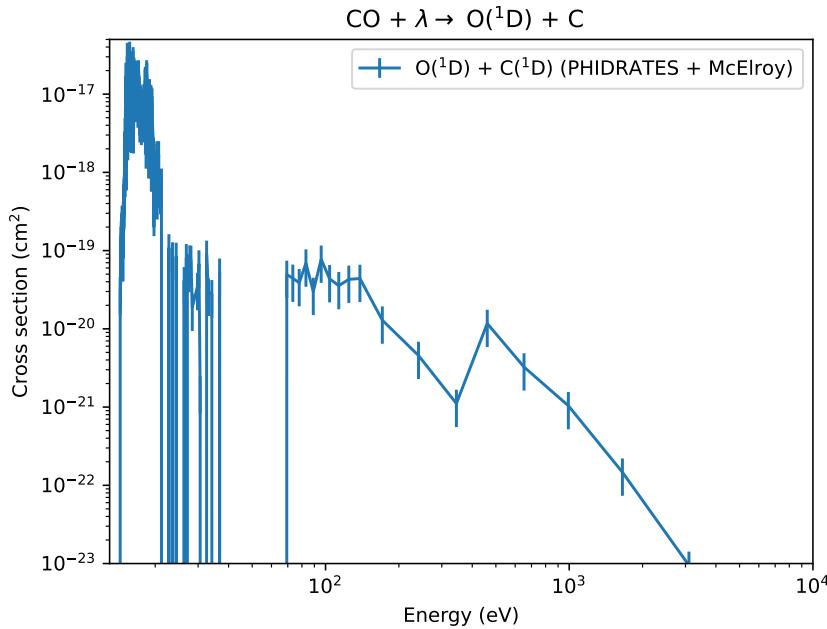
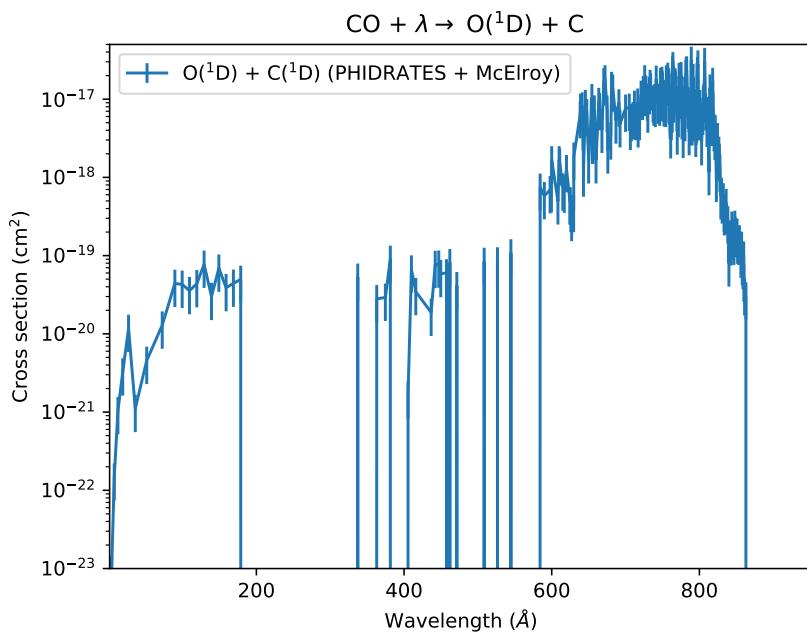


Figure 1.68: Cross sections for  $\text{CO} + \lambda \rightarrow \text{O}^+ + \text{C} + \text{e}$  (wavelength version)

Figure 1.69: Cross sections for  $\text{CO} + \lambda \rightarrow \text{O}({}^1\text{D}) + \text{C}$ Figure 1.70: Cross sections for  $\text{CO} + \lambda \rightarrow \text{O}({}^1\text{D}) + \text{C}$  (wavelength version)

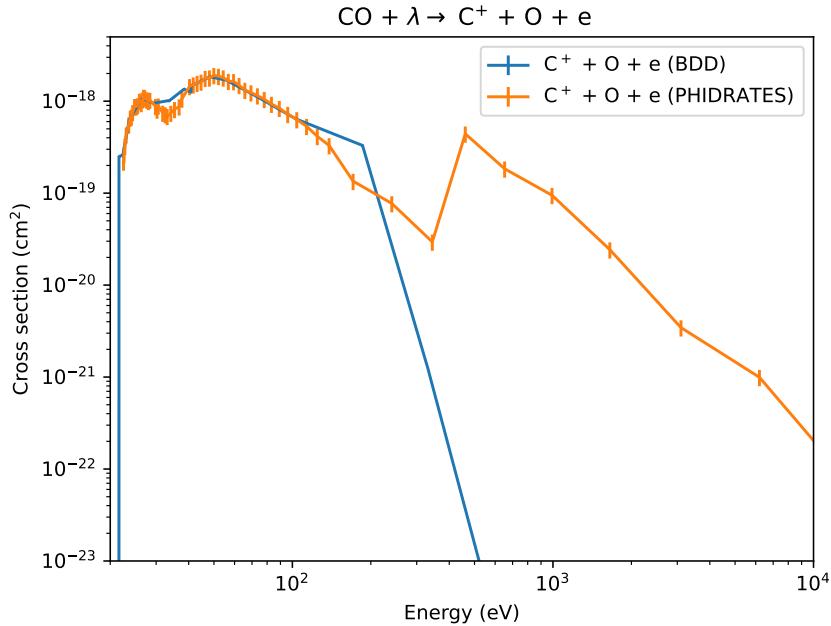


Figure 1.71: Cross sections for  $\text{CO} + \lambda \rightarrow \text{C}^+ + \text{O} + \text{e}$

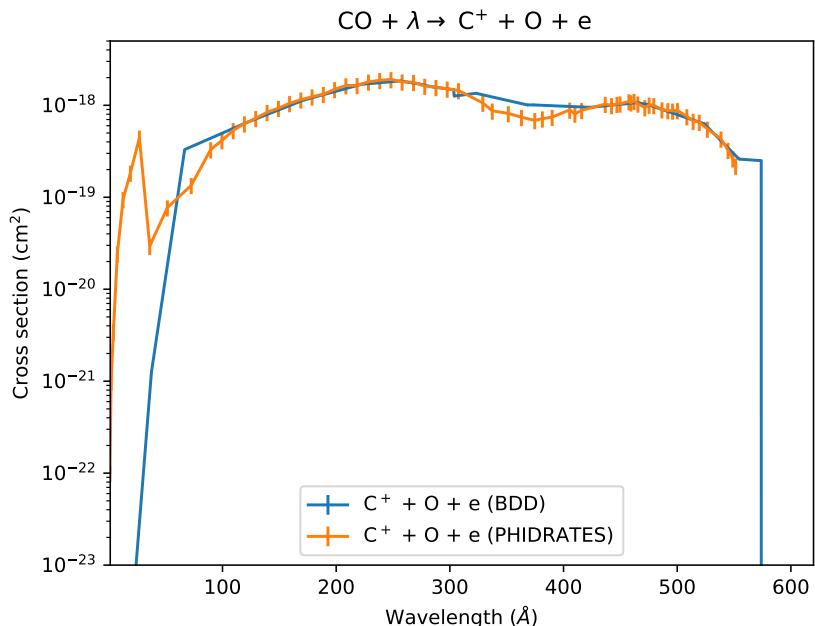


Figure 1.72: Cross sections for  $\text{CO} + \lambda \rightarrow \text{C}^+ + \text{O} + \text{e}$  (wavelength version)

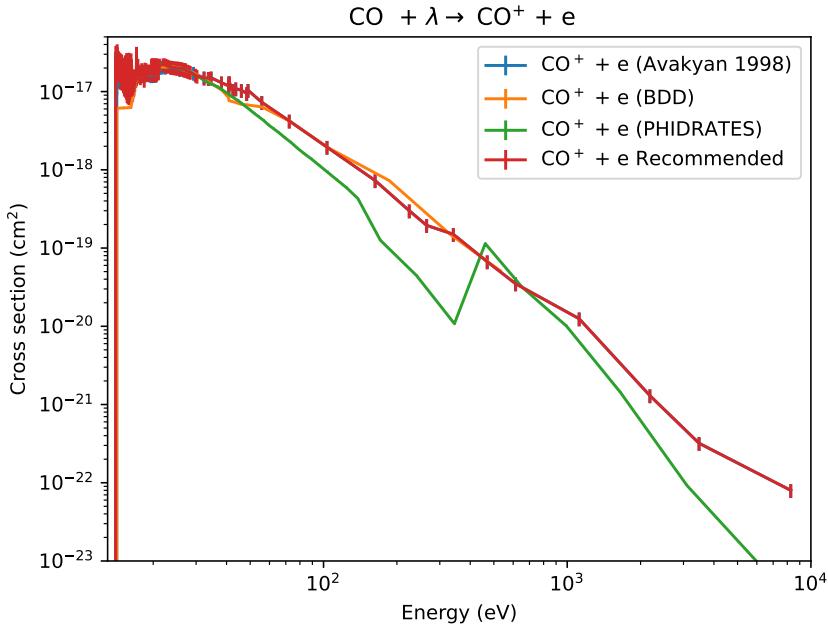


Figure 1.73: Cross sections for  $\text{CO} + \lambda \rightarrow \text{CO}^+ + e$

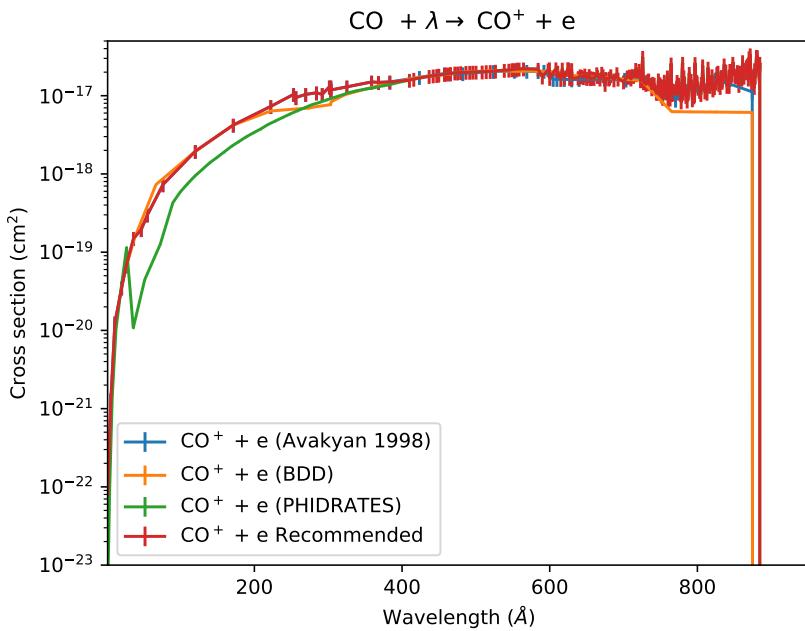


Figure 1.74: Cross sections for  $\text{CO} + \lambda \rightarrow \text{CO}^+ + e$  (wavelength version)

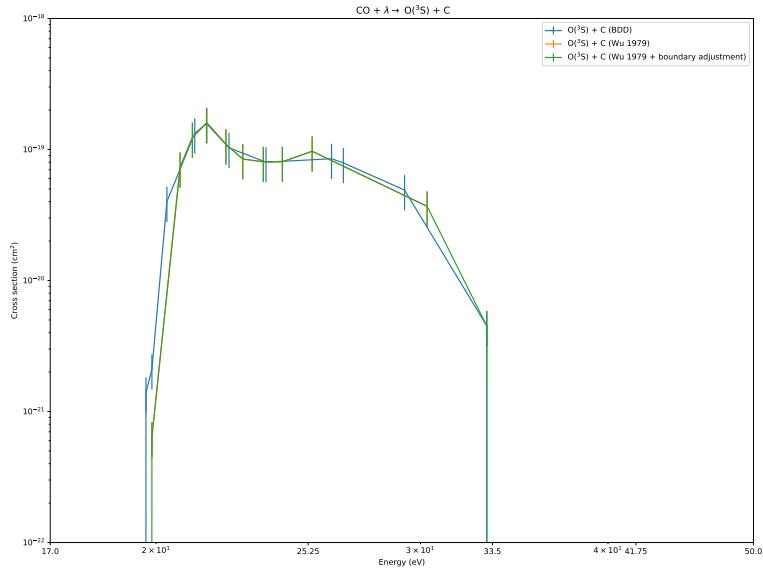


Figure 1.75: Cross sections for  $\text{CO} + \lambda \rightarrow \text{O}({}^3\text{S}) + \text{C}$

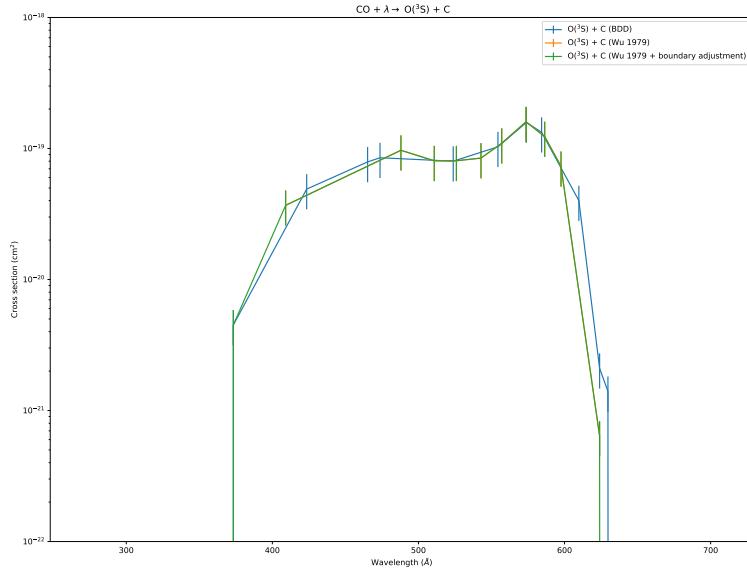


Figure 1.76: Cross sections for  $\text{CO} + \lambda \rightarrow \text{O}({}^3\text{S}) + \text{C}$  (wavelength version)

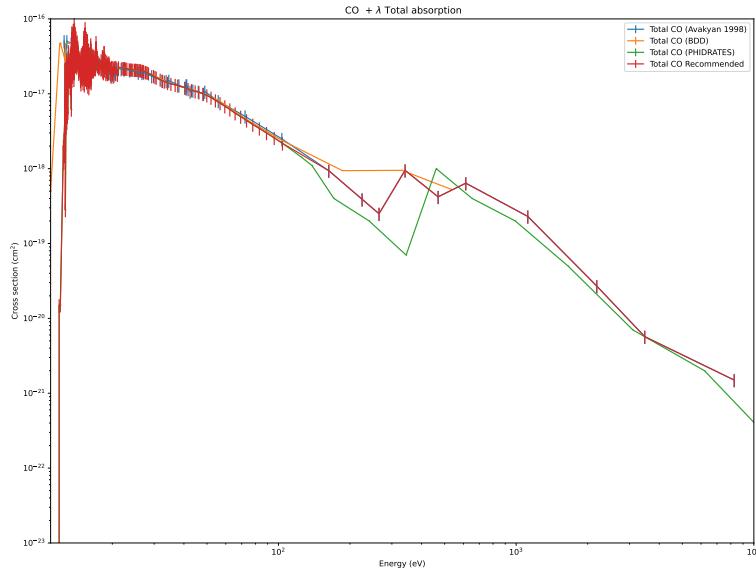


Figure 1.77: Cross sections for  $\text{CO} + \lambda$  Total absorption

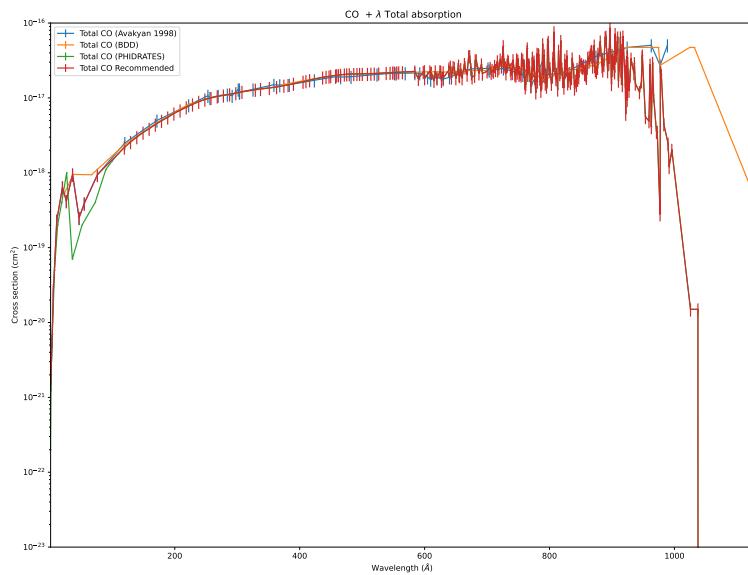
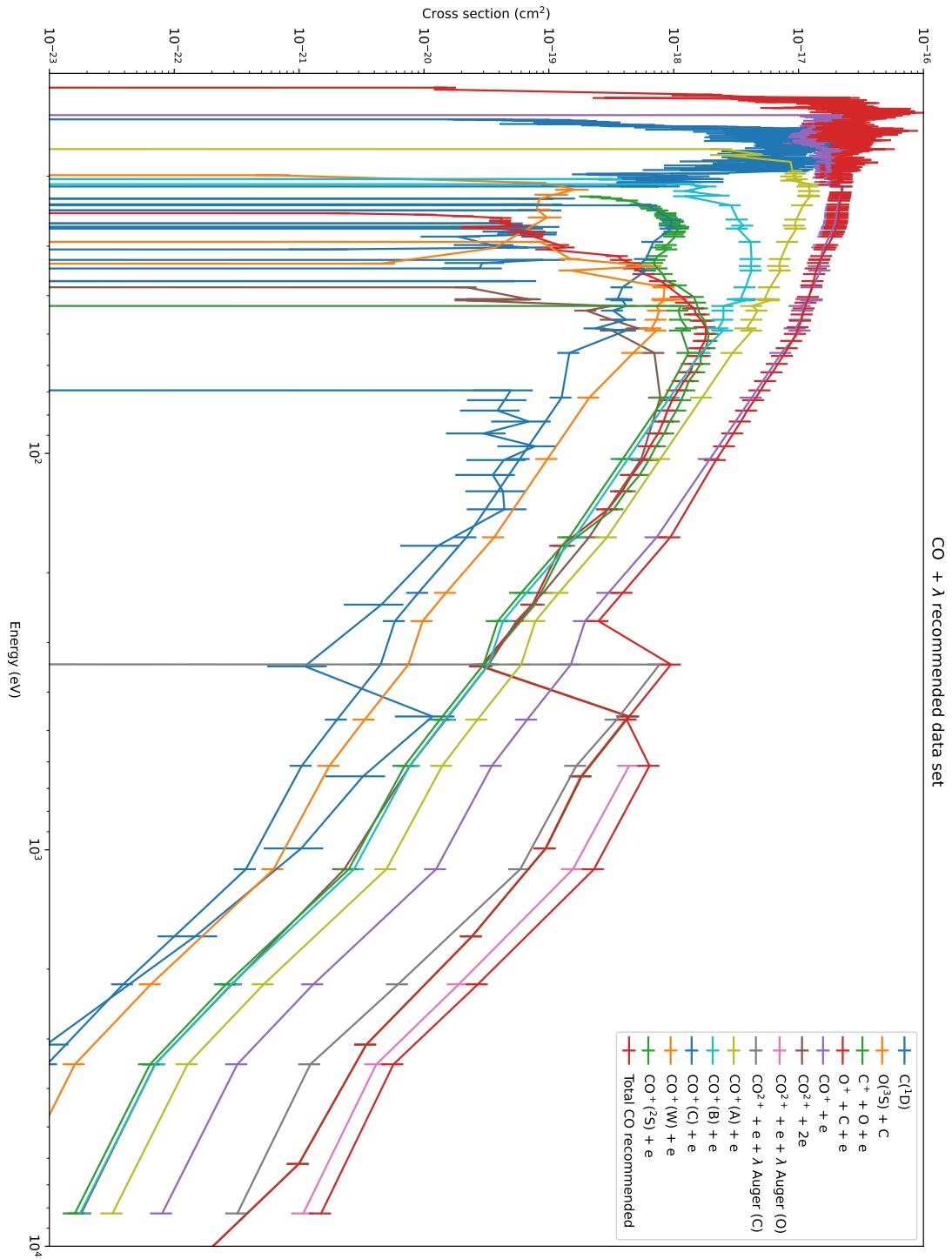


Figure 1.78: Cross sections for  $\text{CO} + \lambda$  Total absorption (wavelength version)

Figure 1.79: Cross sections for  $\text{CO} + \lambda$  recommended data set

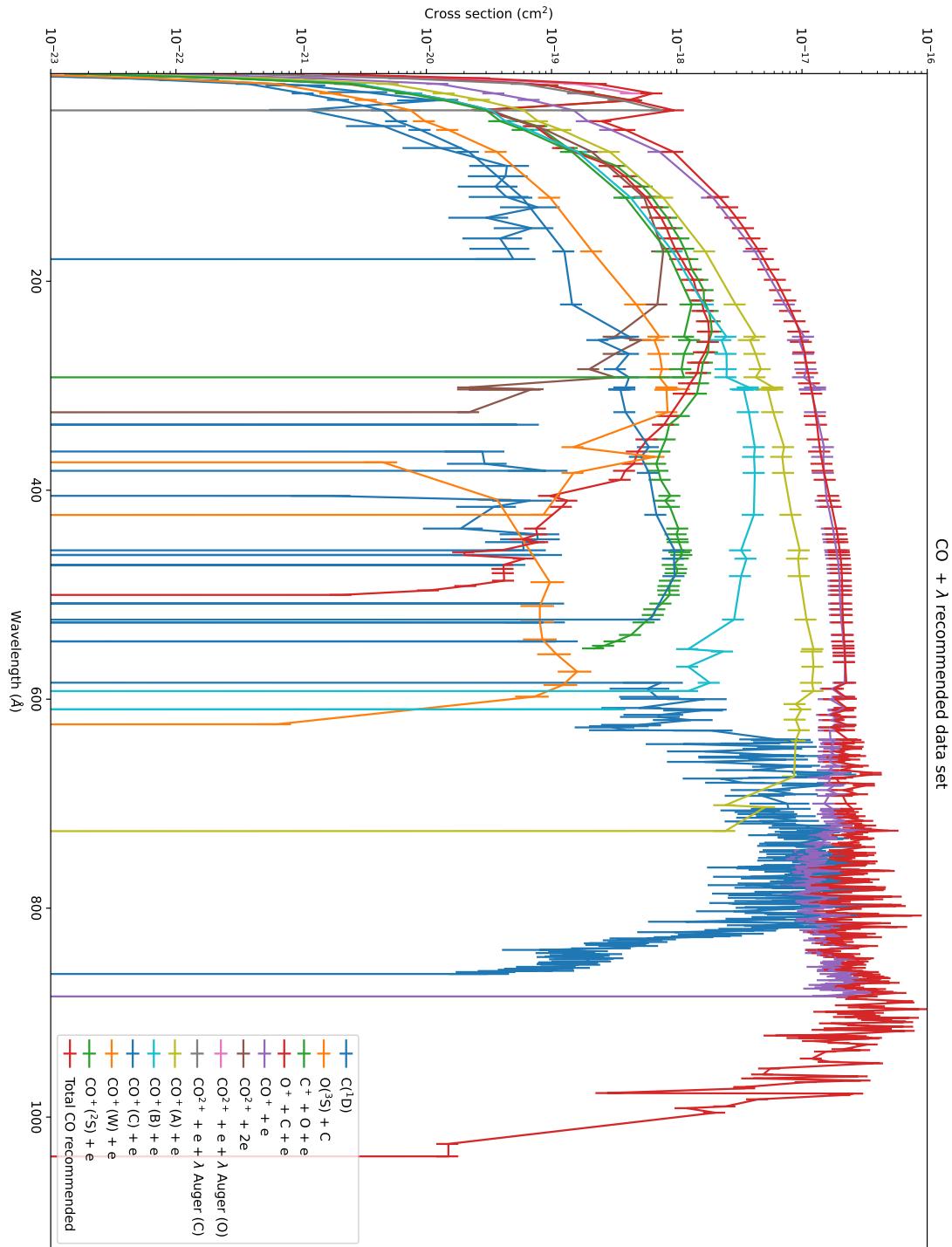


Figure 1.80: Cross sections for  $\text{CO} + \lambda$  recommended data set (wavelength version)

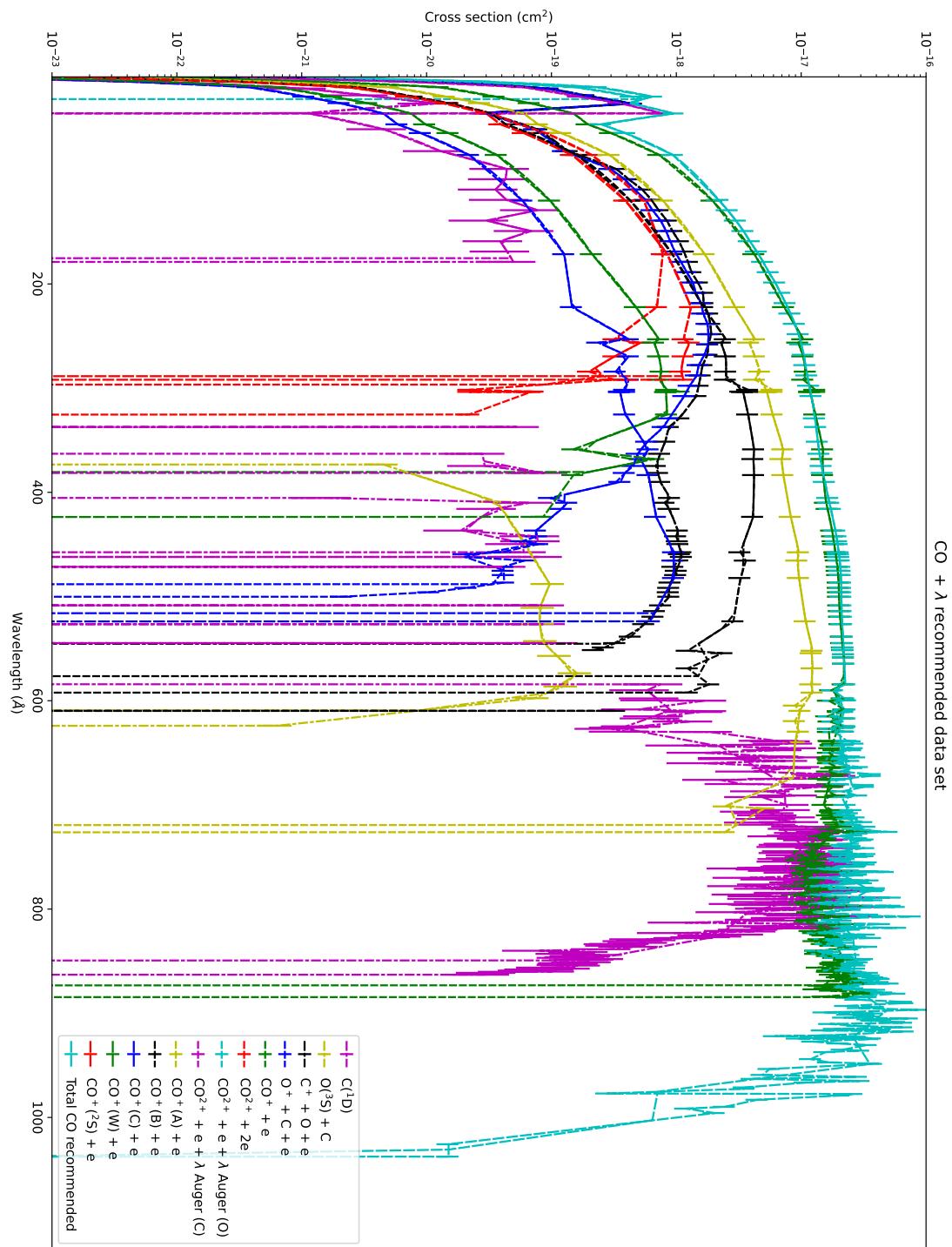


Figure 1.81: Cross sections for  $\text{CO} + \lambda$  recommended data set (with extrapolation version)

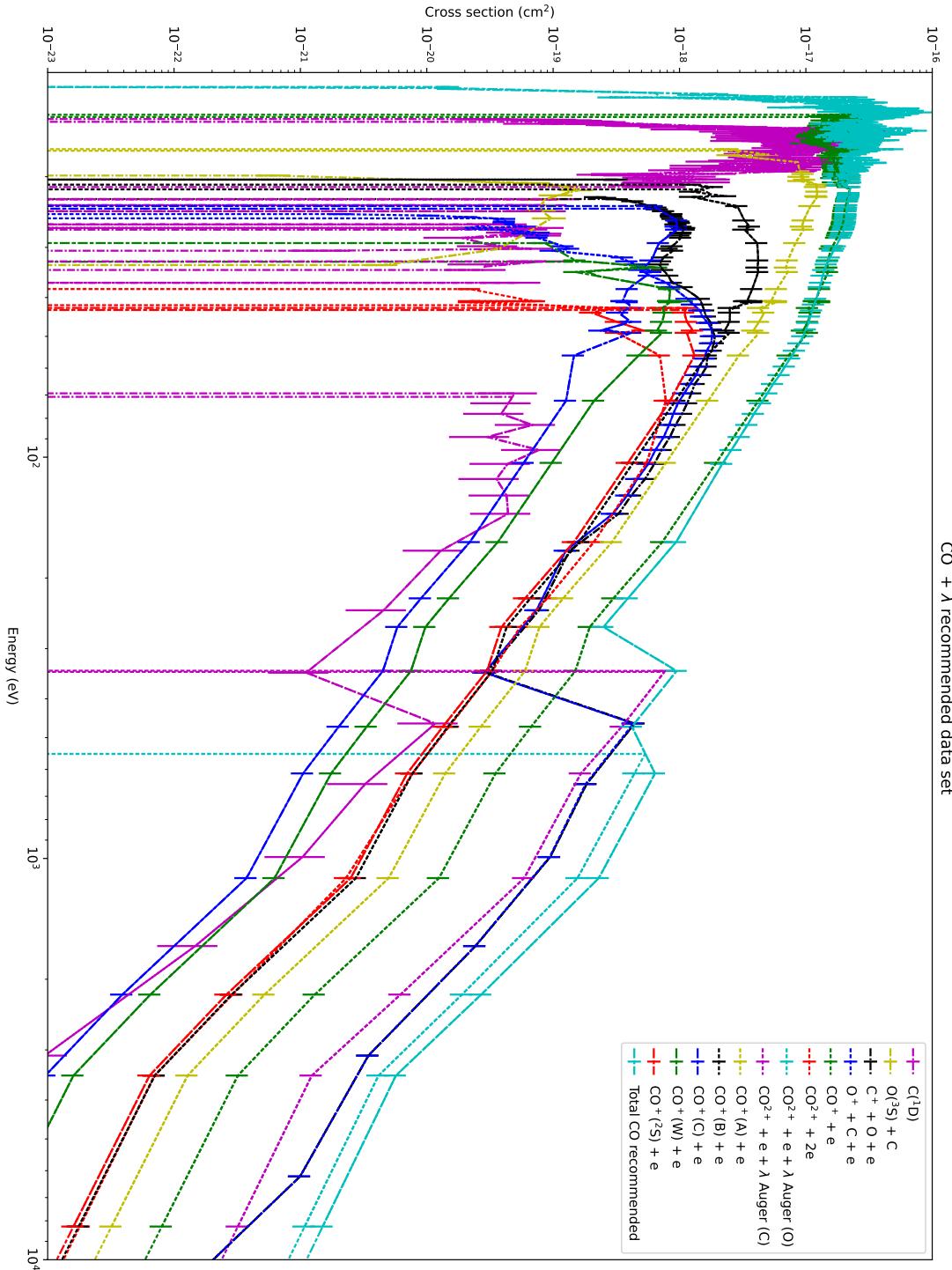


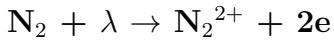
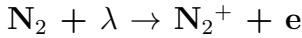
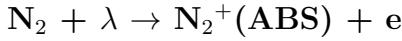
Figure 1.82: Cross sections for  $\text{CO} + \lambda$  recommended data set (wavelength with extrapolation version)

## 1.5 Cross section of ph impact with N<sub>2</sub>

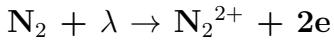
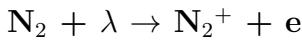
### 1.5.1 Total Cross Section

### 1.5.2 Inelastic Cross Sections

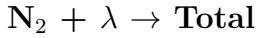
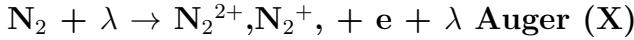
#### Ionization Cross Sections



### 1.5.3 Recommended data set



**N<sub>2</sub><sup>2+</sup> BDD** The ionization was adapted from the ionization cross-section for N<sub>2</sub>. The work of [55] for the ratio of double photoionization to single ionization was used for the estimate as explained in [19]



#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi [3]	0	0:-1	20%		Fig. 1.89 1.90
Revi BDD	0	0:-1	????%	U	Fig. 1.89 1.90
Revi PHDRATES	0	0:-1	????%	U	Fig. 1.89 1.90
Adap PHDRATES + [3]	0	0:-1	20%	RU	Fig. 1.89 1.90

Table 1.18: Total cross section for  $\lambda$  impact on  $N_2$

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$N_2 + \lambda \rightarrow N_2^+(ABS) + e^-$	Revi [3] [3]	15.581	15.581:-1	20%	U	Fig. 1.83 1.84
$N_2 + \lambda \rightarrow N_2^+ + e^-$	Revi BDD Revi PHDRATES [24] Adap PHDRATES+Avakyan [24, 3]	15.6 15.6 15.6	15.6:-1 15.6:-1 15.6:-1	??% ??% 20%	U U U	Fig. 1.83 1.84 Fig. 1.83 1.84 Fig. 1.83 1.84
$N_2 + \lambda \rightarrow N^+ + N + e^-$	Revi BDD Revi PHDRATES [24]	24.3 24.3	24.3:-1 24.3:-1	??% 20%	U RU	Fig. 1.85 1.86 Fig. 1.85 1.86
$N_2 + \lambda \rightarrow N_2^{2+} + 2e^-$	Revi [19]	43.6	43.6:-1	50%	U	Fig. 1.87 1.88

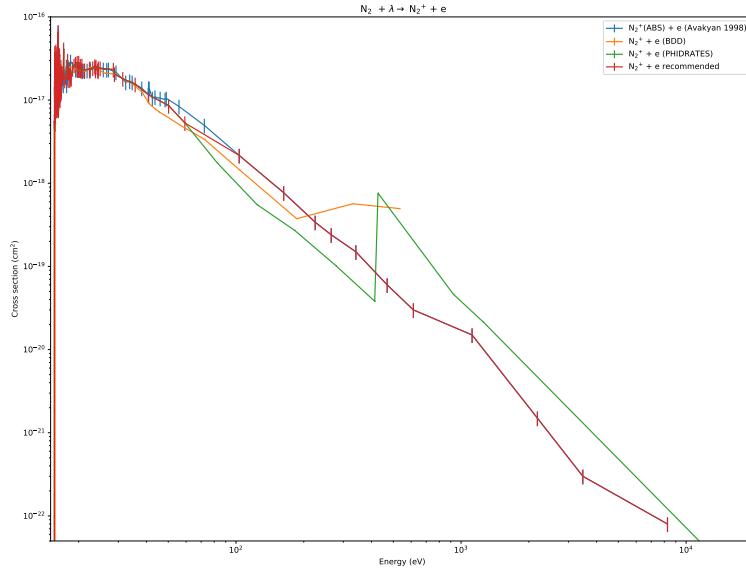
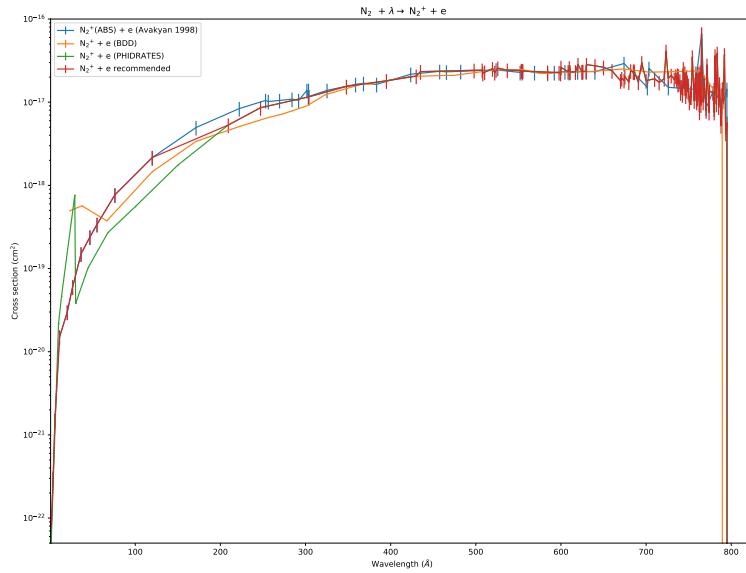
Table 1.19: Ionization Cross section for  $\lambda$  impact on  $N_2$

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plot(s)
$N_2 + \lambda \rightarrow N_2^+ + e$	Adap PHIDRATES + [2]	15.6	15.6:-1	<b>20%</b>	U	Fig. 1.91 1.92 1.93 1.94
$N_2 + \lambda \rightarrow N^+ + N + e$	Revi PHIDRATES	24.3	24.3:-1	<b>20%</b>	RU	Fig. 1.91 1.92 1.93 1.94
$N_2 + \lambda \rightarrow N_2^{2+} + 2e$	Revi [19]	43.6	43.6:-1	<b>50%</b>	U	Fig. 1.91 1.92 1.93 1.94
$N_2 + \lambda \rightarrow N_2^{2+}, N_2^+, + e + \lambda$ Auger (X)	Revi [3]	400	400:-1	20%	R	Fig. 1.91 1.92 1.93 1.94
$N_2 + \lambda \rightarrow N_2^+(A) + e$	Revi [2]	16.7	16.7:-1	20%		Fig. 1.91 1.92 1.93 1.94
$N_2 + \lambda \rightarrow N_2^+(B) + e$	Revi [2]	18.75	18.75:-1	20%		Fig. 1.91 1.92 1.93 1.94
$N_2 + \lambda \rightarrow N_2^+(F) + e$	Revi [2]	27	27:-1	20%		Fig. 1.91 1.92 1.93 1.94
$N_2 + \lambda \rightarrow N_2^+(G) + e$	Revi [2]	31	31:-1	20%		Fig. 1.91 1.92 1.93 1.94
$N_2 + \lambda \rightarrow N_2^+(2\Sigma_g) + e$	Revi [2]	35	35:-1	20%		Fig. 1.91 1.92 1.93 1.94
$N_2 + \lambda \rightarrow \text{Total}$	Adap PHIDRATES + [2]	0	0:-1	<b>20%</b>	RU	Fig. 1.91 1.92 1.93 1.94

Table 1.20: Recommended Cross section for  $\lambda$  impact on  $N_2$

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Figure 1.83: Cross sections for  $N_2 + \lambda \rightarrow N_2^+ + e$ Figure 1.84: Cross sections for  $N_2 + \lambda \rightarrow N_2^+ + e$  (wavelength version)

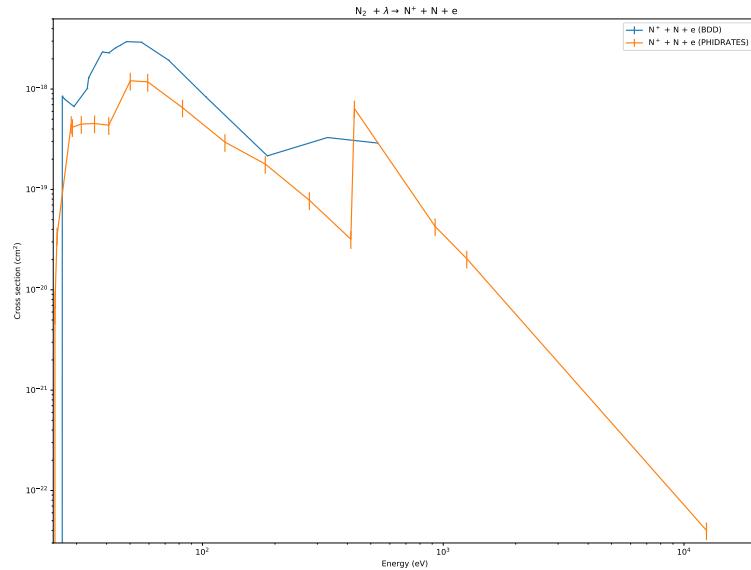


Figure 1.85: Cross sections for  $N_2 + \lambda \rightarrow N^+ + N + e$

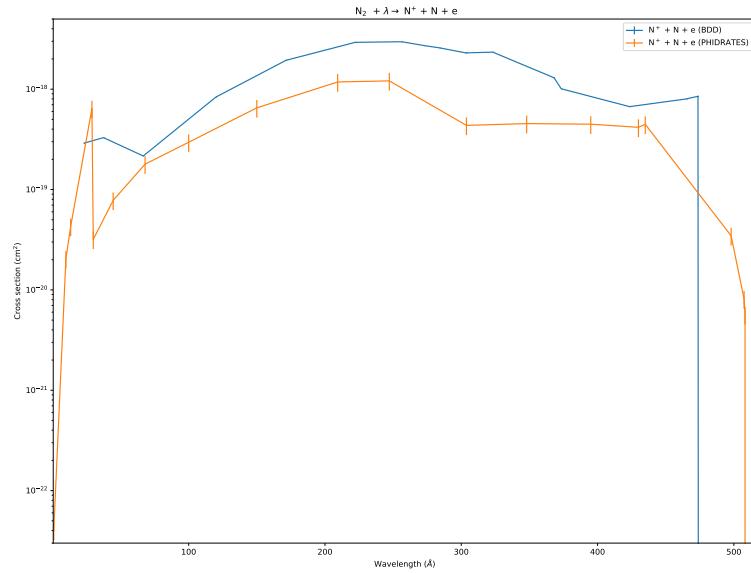
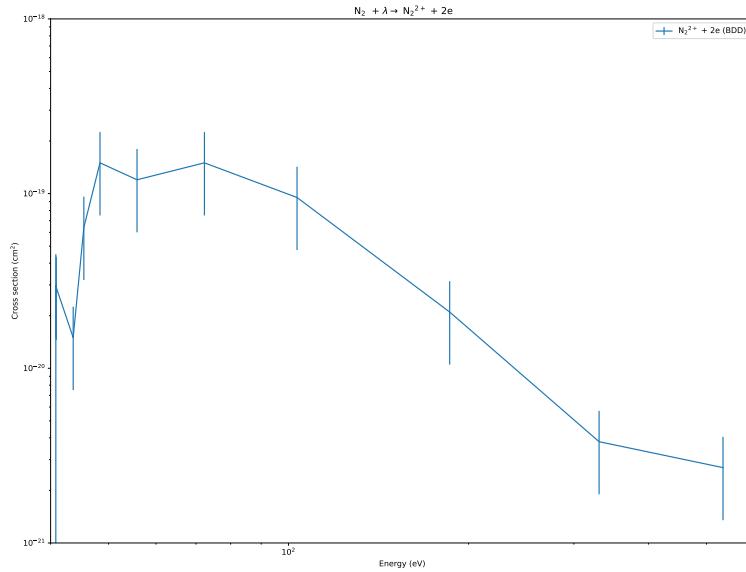
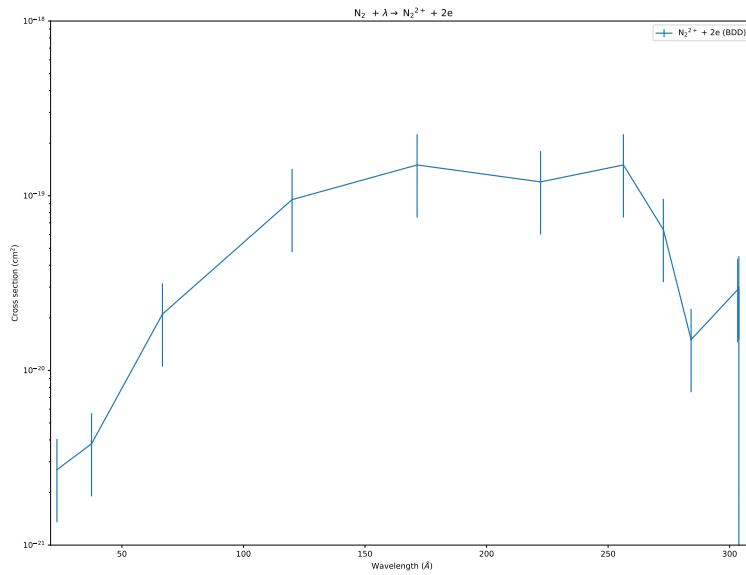


Figure 1.86: Cross sections for  $N_2 + \lambda \rightarrow N^+ + N + e$  (wavelength version)

Figure 1.87: Cross sections for  $\text{N}_2 + \lambda \rightarrow \text{N}_2^{2+} + 2\text{e}$ Figure 1.88: Cross sections for  $\text{N}_2 + \lambda \rightarrow \text{N}_2^{2+} + 2\text{e}$  (wavelength version)

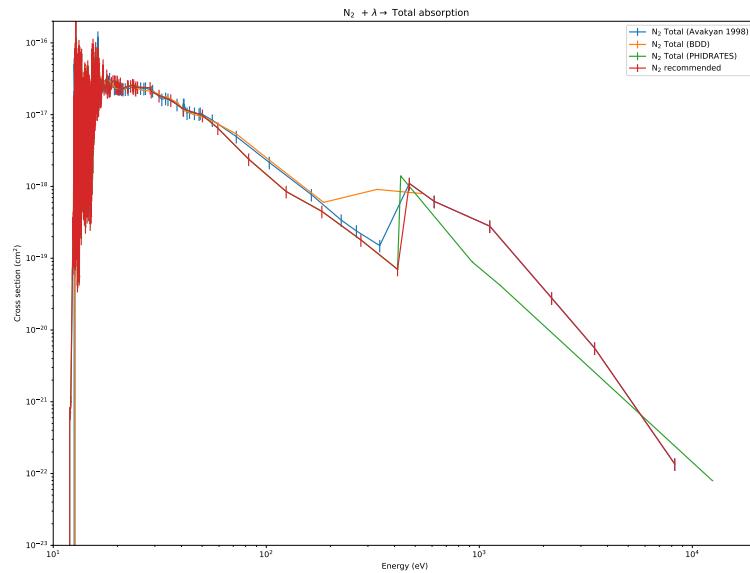


Figure 1.89: Cross sections for  $\text{N}_2 + \lambda \rightarrow \text{Total absorption}$

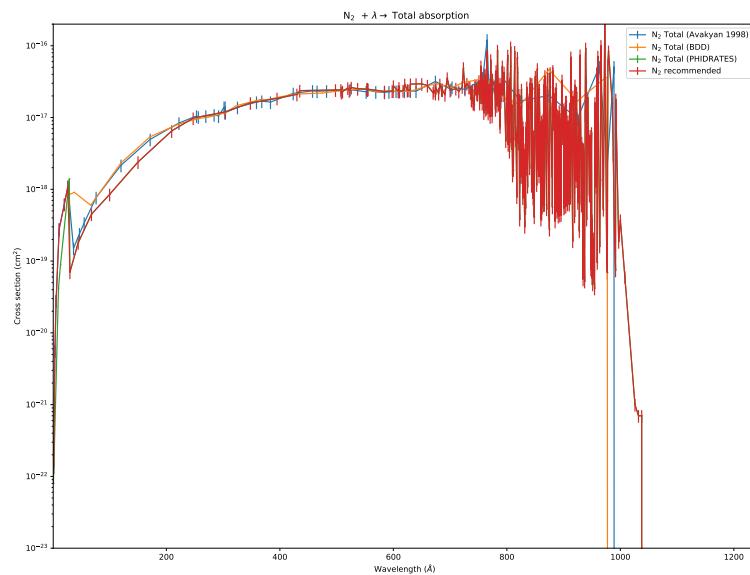
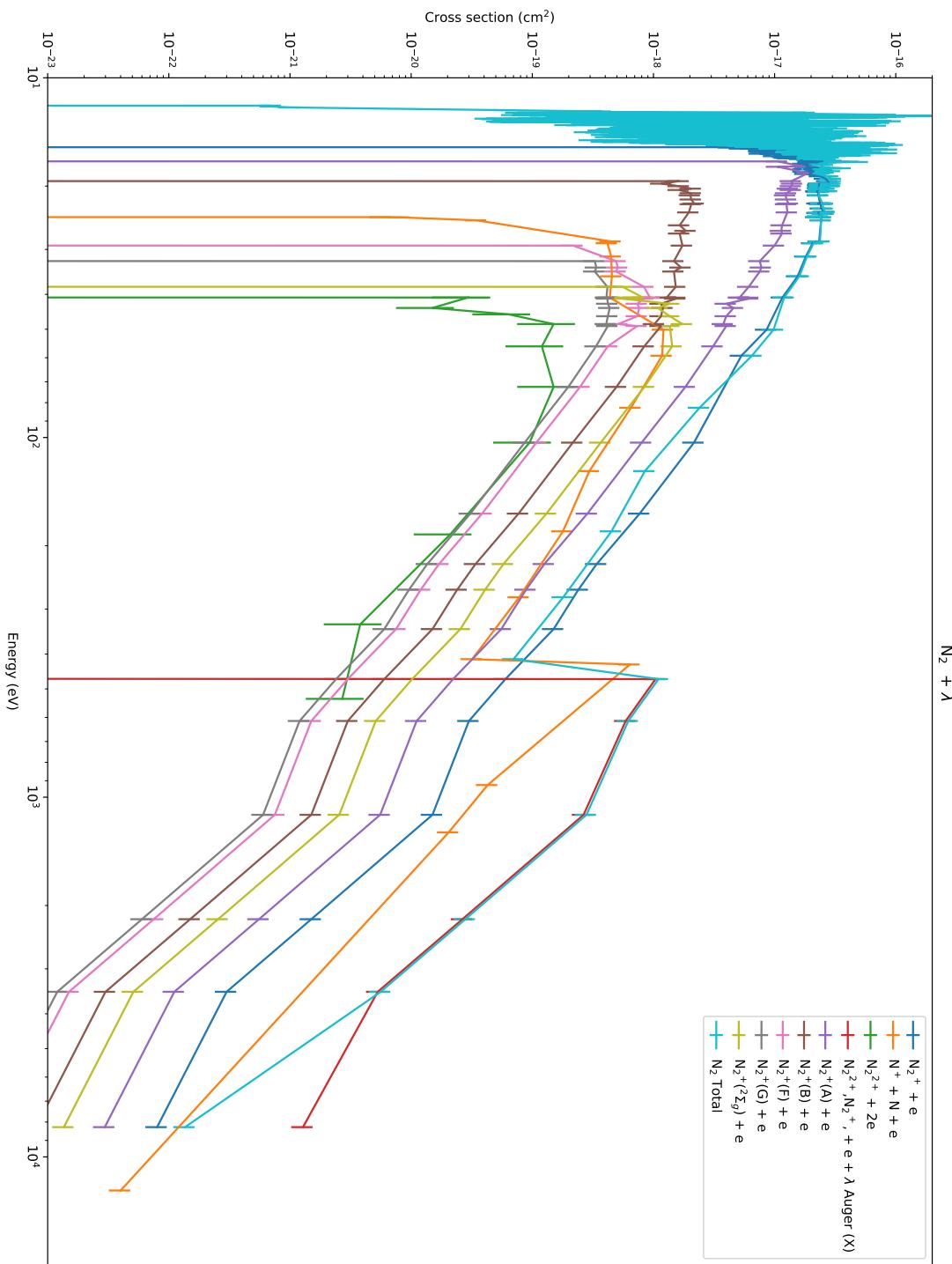
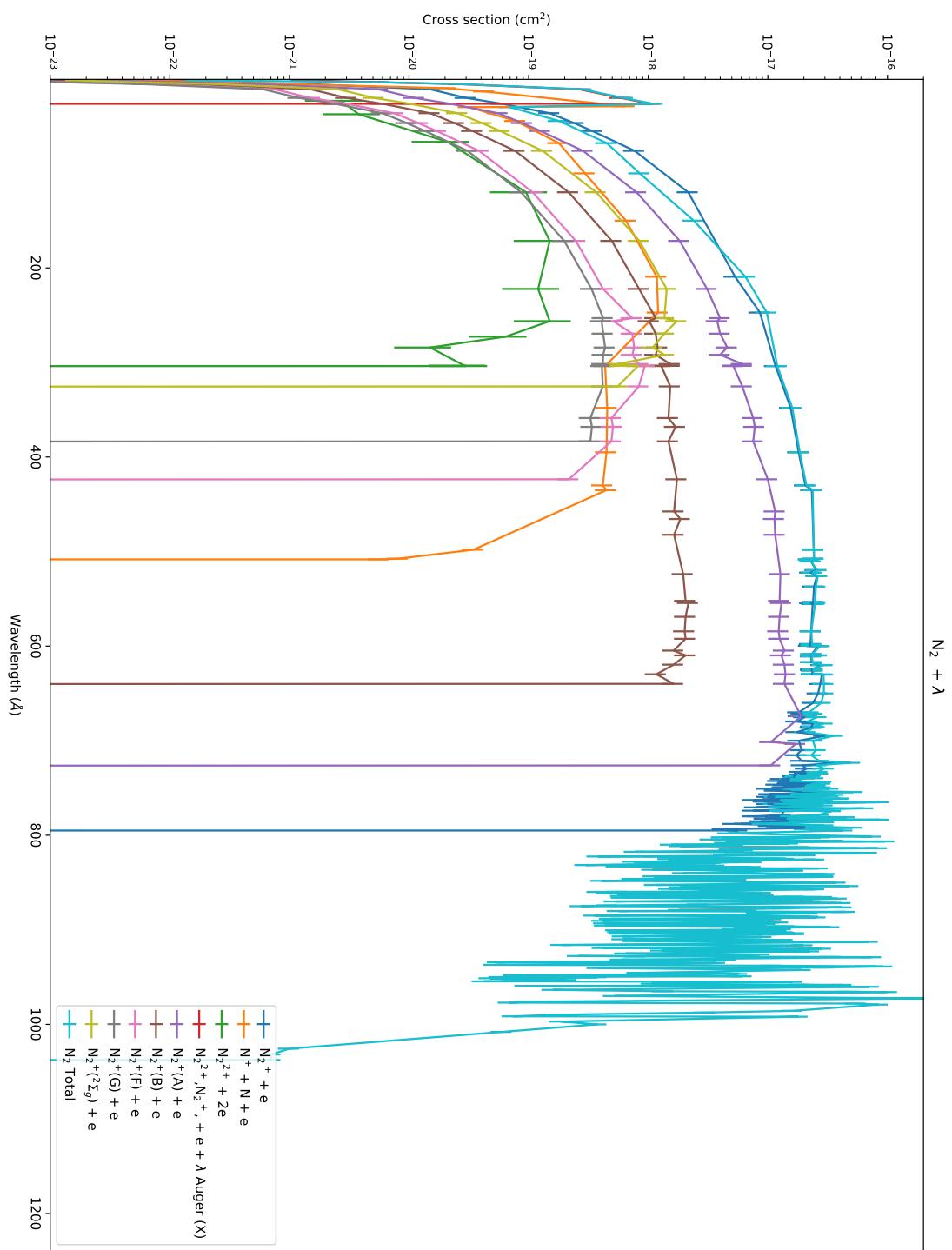
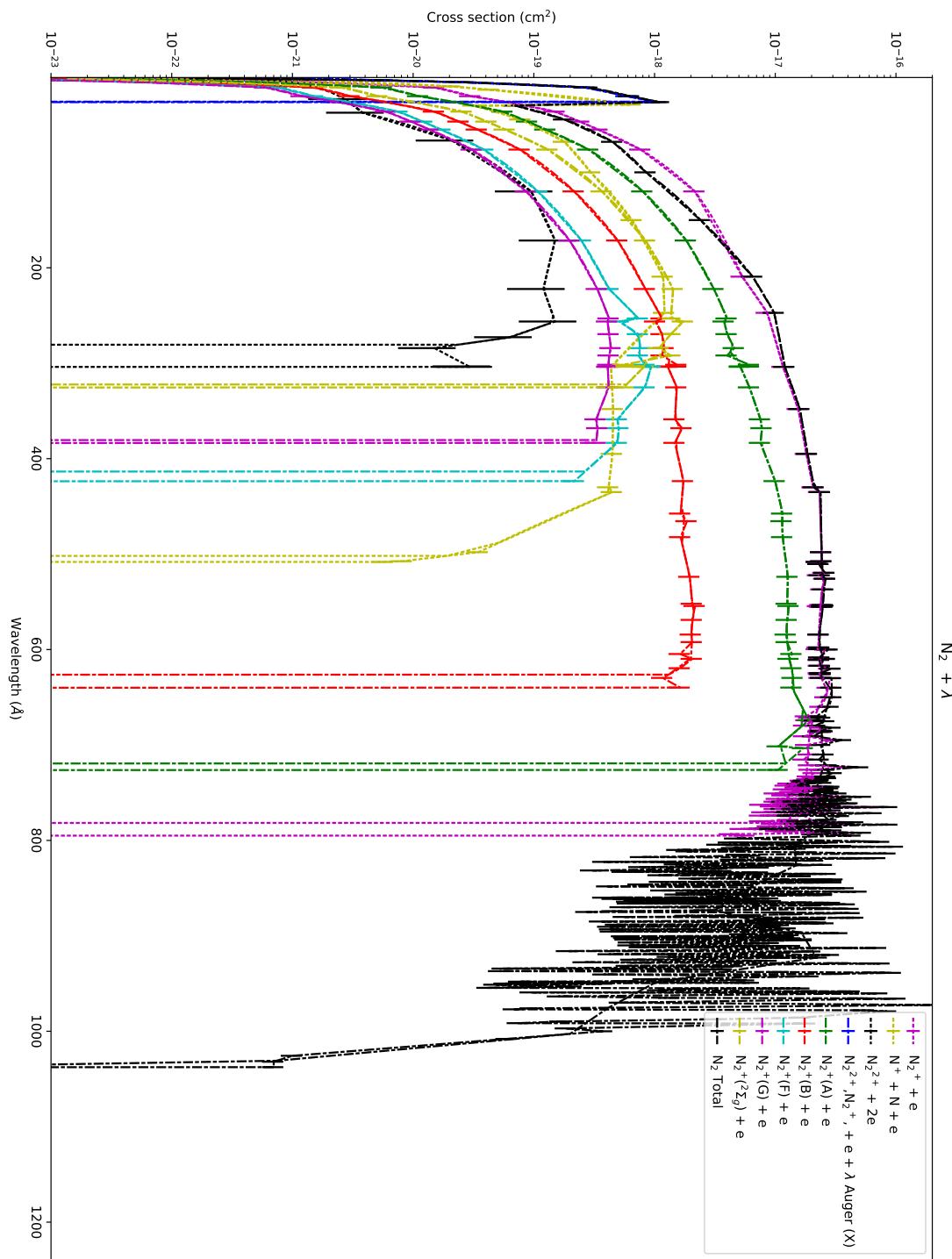


Figure 1.90: Cross sections for  $\text{N}_2 + \lambda \rightarrow \text{Total absorption}$  (wavelength version)

Figure 1.91: Cross sections for N<sub>2</sub> + λ

Figure 1.92: Cross sections for  $\text{N}_2 + \lambda$  (wavelength version)

Figure 1.93: Cross sections for  $N_2 + \lambda$  (with extrapolation version)

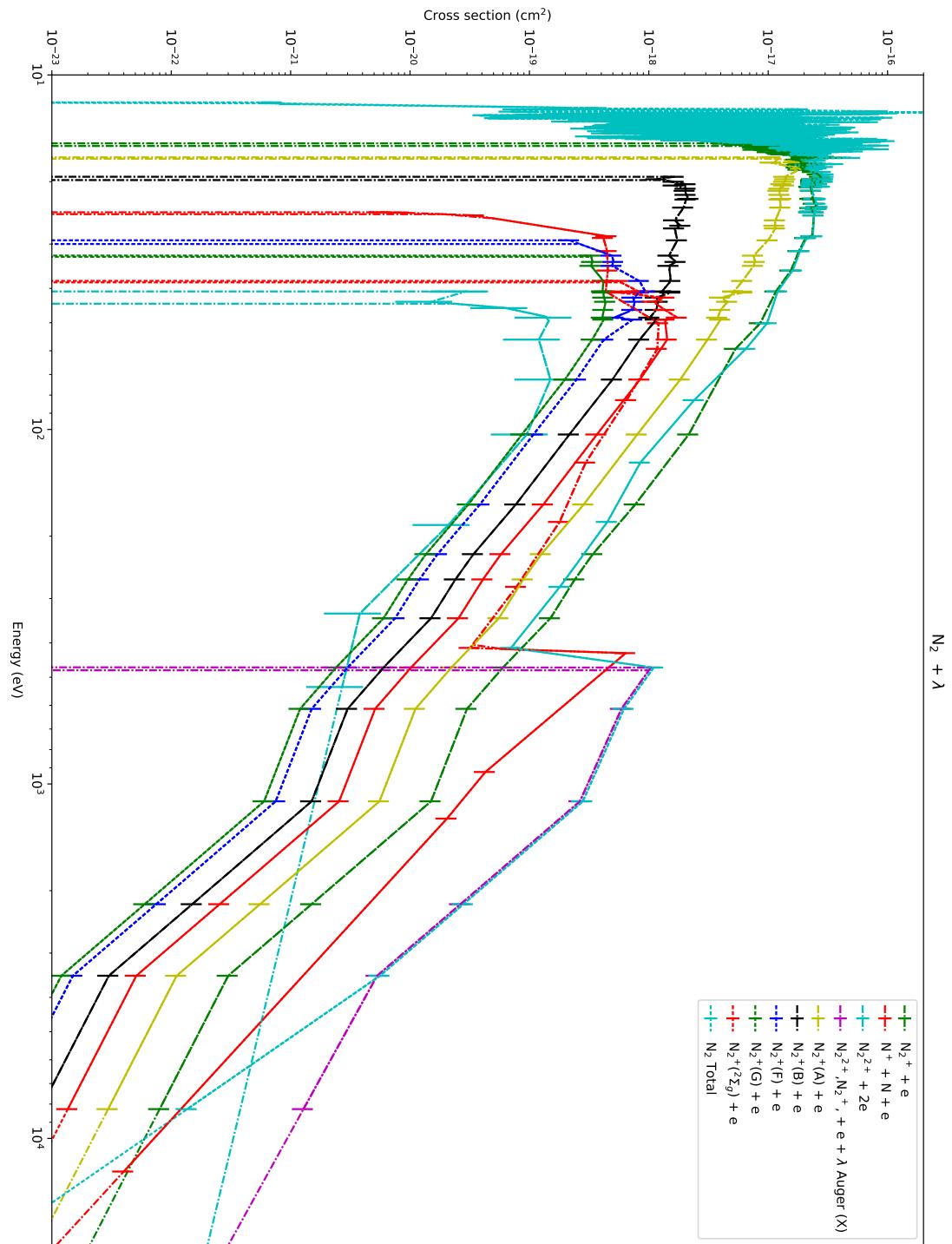


Figure 1.94: Cross sections for  $N_2 + \lambda$  (wavelength with extrapolation version)

## 1.6 Cross section of ph impact with CH<sub>4</sub>

### 1.6.1 Total Cross Section

### 1.6.2 Inelastic Cross Sections

#### Ionization Cross Sections

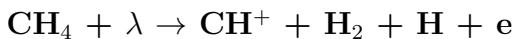


**CH<sub>3</sub><sup>+</sup> (BDD)** Original source unknown. In the BDD review in [40]. It is probable a branching ratio from the simple ionization. The data, in nm, have been adapted in eV from the Torr boxes.

**CH<sub>3</sub><sup>+</sup> (PHIDRATES)** Photoionization of CH<sub>4</sub> yielding CH<sub>3</sub><sup>+</sup> + H + e from the review of PHIDRATES [24]. The uncertainty, not claimed by the review, is estimated at 30%. The data, in nm, have been directly adapted in eV.



**CH<sub>2</sub><sup>+</sup> PHIDRATES** Photoionization of CH<sub>4</sub> yielding CH<sub>2</sub><sup>+</sup> + H<sub>2</sub> + e from the review of PHIDRATES [24]. The uncertainty, not claimed by the review, is estimated at 30%. The data, in nm, have been directly adapted in eV.



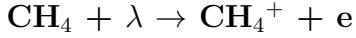
**CH<sup>+</sup> (PHIDRATES)** Photoionization of CH<sub>4</sub> yielding CH<sup>+</sup> + H<sub>2</sub> + H + e from the review of PHIDRATES [24]. The uncertainty, not claimed by the review, is estimated at 30%. The data, in nm, have been directly adapted in eV.



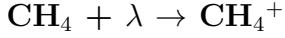
**CH<sub>4</sub><sup>2+</sup> Auger, (Avakyan 1998)** K-shell photoionization of CH<sub>4</sub> from the review work of Avakyan et al. [3]. Claimed uncertainty of 20%. The rate for the double ionization (including the following dissociation, not studied) is 99.74%, letting 0.26% of Auger fluorescence. The energy of the Auger electron (ejected in the double ionization cases) is 229 eV. The reported values in Avakyan et al. [3] were in nm, averaged over several boxes, which corresponds to ranges of wavelength, and were adapted in eV for the database.

Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi [3]	0	13.8260	20%		Fig. 1.111 1.112
Revi [40]	0	12.535	??% ??%	U	Fig. 1.111 1.112
Revi PHDRATES	0	4.47:12400	20%	RUE	Fig. 1.111 1.112

Table 1.21: Total cross section for  $\lambda$  impact on  $\text{CH}_4$

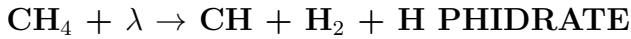


**CH<sub>4</sub><sup>+</sup> (Avakyan 1998)** Photoionization of CH<sub>4</sub> yielding CH<sub>4</sub><sup>+</sup> (every states) + e from the review work of [3]. Claimed uncertainty of 20%. The reported values in [3] were in nm, following the Torr boxes, and were adapted in eV for the database.

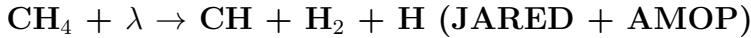


**CH<sub>4</sub><sup>+</sup> (BDD)** CH<sub>4</sub><sup>+</sup> photoproduction from the BDD [40]. Original work and uncertainty unknown.

### Dissociation Cross Sections



**CH + H<sub>2</sub> + H** Photoionization of CH<sub>4</sub> yielding CH + H<sub>2</sub> + H from the review of PHIDRATES. The uncertainty, not claimed by the review, is estimated at 30%. The data, in nm, have been directly adapted in eV.



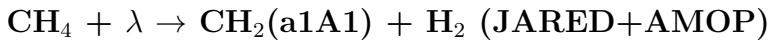
**CH + H<sub>2</sub> + H JARED + AMOP** Photoionization of CH<sub>4</sub> yielding CH + H<sub>2</sub> + H. The total cross section comes from AMOP The yields comes from Jared Bell/TIEGCM.



**CH<sub>3</sub> JARED + AMOP** Photoionization of CH<sub>4</sub> yielding CH<sub>3</sub> + H. The total cross section comes from AMOP The yields comes from Jared Bell/TIEGCM.



**CH<sub>2</sub> + 2 H AMOP+JARED** Photoionization of CH<sub>4</sub> yielding CH<sub>2</sub> + 2 H. The total cross section comes from AMOP The yields comes from Jared Bell/TIEGCM.



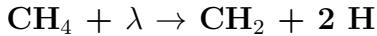
**CH<sub>2</sub>(a) + H<sub>2</sub> Jared** Photoionization of CH<sub>4</sub> yielding CH<sub>2</sub>(a) + H<sub>2</sub>. The total cross section comes from AMOP The yields comes from Jared Bell/TIEGCM.

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$\text{CH}_4 + \lambda \rightarrow \text{CH}_3^+ + \text{H} + e^-$	Revi [40] PHIDRATES	14. 14.	15.532 14.4;12400	?% 30%	U RU	Fig. 1.95 1.96 Fig. 1.95 1.96
$\text{CH}_4 + \lambda \rightarrow \text{CH}_2^+ + \text{H}_2 + e^-$	Revi PHIDRATES	15	15.4;12400	30%	RU	Fig. 1.97 1.98
$\text{CH}_4 + \lambda \rightarrow \text{H}^+ + \text{CH}_3 + e^-$	Revi PHIDRATES	18	18;-1	30%	U	Fig. 1.101 1.102
$\text{CH}_4 + \lambda \rightarrow \text{CH}^+ + \text{H}_2 + \text{H} + e^-$	Revi PHIDRATES	20	20.11;12400	30%	RU	Fig. 1.105 1.106
$\text{CH}_4 + \lambda \rightarrow \text{CH}_4^{2+}, \text{CH}_4^+ + e + \lambda$ Auger (C)	Revi [3]	282	340;8260	20%	R	Fig. 1.107 1.108
$\text{CH}_4 + \lambda \rightarrow \text{CH}_4^+ + e^-$	Revi [3]	12.98	13.4;8265	20%		Fig. 1.109 1.110
$\text{CH}_4 + \lambda \rightarrow \text{CH}_4^+$	Revi [40]B DD PHIDRATES Adap PHIDRATES+[3]	12.1 12.1 12.1	12.69;533 13.3;12400 13.3;12400	?% ?% 30%	U U RU	Fig. 1.109 1.110 Fig. 1.109 1.110 Fig. 1.109 1.110

Table 1.22: Ionization Cross section for  $\lambda$  impact on  $\text{CH}_4$



**CH<sub>2</sub>(a<sup>1</sup>A<sub>1</sub>) + H<sub>2</sub>** Photoionization of CH<sub>4</sub> yielding CH<sub>2</sub> excited + H<sub>2</sub> from the review of [24]. The uncertainty, not claimed by the review, is estimated at 30%. The data, in nm, have been directly adapted in eV.

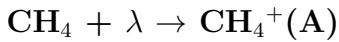


**CH<sub>2</sub> + 2 H** Photoionization of CH<sub>4</sub> yielding CH<sub>2</sub> + 2 H from the review of [24]. The uncertainty, not claimed by the review, is estimated at 30%. The data, in nm, have been directly adapted in eV.



**CH<sub>3</sub>** Photoionization of CH<sub>4</sub> yielding CH<sub>3</sub> + H from the review of PHIDRATES [24]. The uncertainty, not claimed by the review, is estimated at 30%. The data, in nm, have been directly adapted in eV.

### 1.6.3 Emission Cross Sections

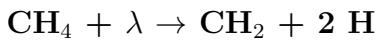


**CH<sub>4</sub><sup>+</sup>(A), [2]** Photoionization of CH<sub>4</sub> yielding CH<sub>4</sub><sup>+</sup>(A) + e from the review work of [3]. Claimed uncertainty of 20%. The reported values in [3] were in nm, following the Torr boxes, and were adapted in eV for the database. Because this is not the total ionization of CH<sub>4</sub>, this cross section has a - NOTOT kind of state, and it does not count for the creation of an electron. This is the **recommended** cross section for that state.

### 1.6.4 Recommended data set



**CH<sub>2</sub>(a<sup>1</sup>A<sub>1</sub>) + H<sub>2</sub>** Photoionization of CH<sub>4</sub> yielding CH<sub>2</sub> excited + H<sub>2</sub> from the review of [24]. The uncertainty, not claimed by the review, is estimated at 30%. The data, in nm, have been directly adapted in eV.



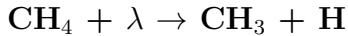
**CH<sub>2</sub> + 2 H** Photoionization of CH<sub>4</sub> yielding CH<sub>2</sub> + 2 H from the review of [24]. The uncertainty, not claimed by the review, is estimated at 30%. The data, in nm, have been directly adapted in eV.

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$\text{CH}_4 + \lambda \rightarrow \text{CH} + \text{H}_2 + \text{H}$ PHIDRATE	Revi PHIDRATES	9	9:-1	30%	RU	Fig. 1.99 1.100
$\text{CH}_4 + \lambda \rightarrow \text{CH} + \text{H}_2 + \text{H}$ (JARED + AMOP)	Revi JARED + AMOP	9	9:-1	30%	U	Fig. 1.99 1.100
$\text{CH}_4 + \lambda \rightarrow \text{CH}_3 + \text{H}$ (JARED + AMOP)	Revi JARED + AMOP	4	4:-1	30%	U	Fig. 1.99 1.100
$\text{CH}_4 + \lambda \rightarrow \text{CH}_2 + 2 \text{ H}$ (JARED+AMOP)	Revi AMOP + JARED	9.4	9.4:-1	30%	U	Fig. 1.99 1.100
$\text{CH}_4 + \lambda \rightarrow \text{CH}_2(\text{a}1\text{A}^1) + \text{H}_2$ (JARED+AMOP)	Revi Jared + AMOP	5.5	5.5:-1	30%	U	Fig. 1.99 1.100
$\text{CH}_4 + \lambda \rightarrow \text{CH}_2(\text{a}''\text{A}^1) + \text{H}_2$	Revi PHIDRATES	5.5	5.5:-1	30%	RU	Fig. 1.99 1.100
$\text{CH}_4 + \lambda \rightarrow \text{CH}_2 + 2 \text{ H}$	Revi PHIDRATES	9.4	9.4:-1	30%	RU	Fig. 1.99 1.100
$\text{CH}_4 + \lambda \rightarrow \text{CH}_3 + \text{H}$	Revi PHIDRATES	4	4:-1	30%	RU	Fig. 1.99 1.100

Table 1.23: Dissociation Cross section for  $\lambda$  impact on  $\text{CH}_4$

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Picts
$CH_4 + \lambda \rightarrow CH_4^+ (A)$	Revi [3]	24	23.7:8260	20%	R	Fig. 1.103 1.104

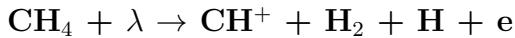
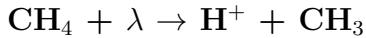
Table 1.24: Emission Cross section for  $\lambda$  impact on  $CH_4$



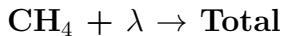
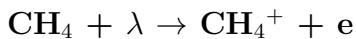
**CH<sub>3</sub>** Photoionization of CH<sub>4</sub> yielding CH<sub>3</sub> + H from the review of PHIDRATES [24]. The uncertainty, not claimed by the review, is estimated at 30%. The data, in nm, have been directly adapted in eV.



**CH + H<sub>2</sub> + H** Photoionization of CH<sub>4</sub> yielding CH + H<sub>2</sub> + H from the review of PHIDRATES. The uncertainty, not claimed by the review, is estimated at 30%. The data, in nm, have been directly adapted in eV.



**CH<sub>4</sub> Auger,[3](1998)** K-shell photoionization of CH<sub>4</sub> from [3]. Claimed uncertainty of 20%. The rate for the double ionization (including the following dissociation, not studied) is 99.74%, letting 0.26% of Auger fluorescence. The energy of the Auger electron (ejected in the double ionization cases) is 229 eV. The reported values in [3] were in nm, following the Torr boxes, and were adapted in eV for the database.



#### Legend for the properties

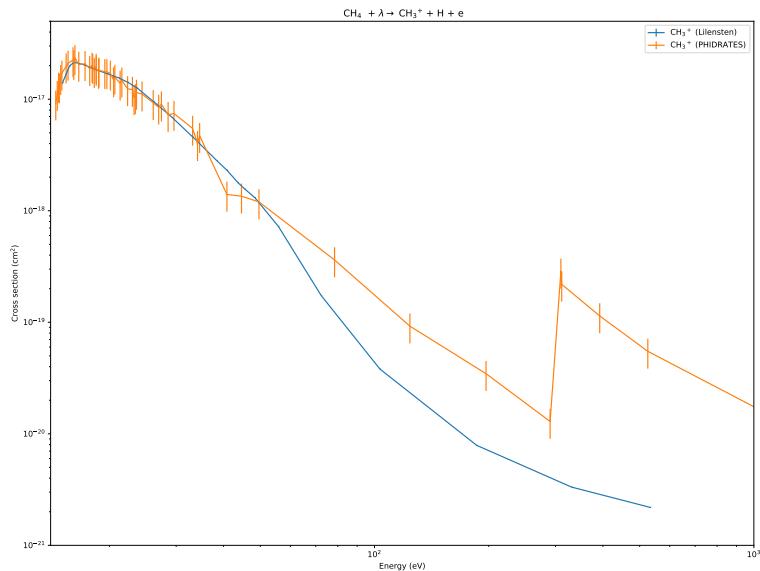
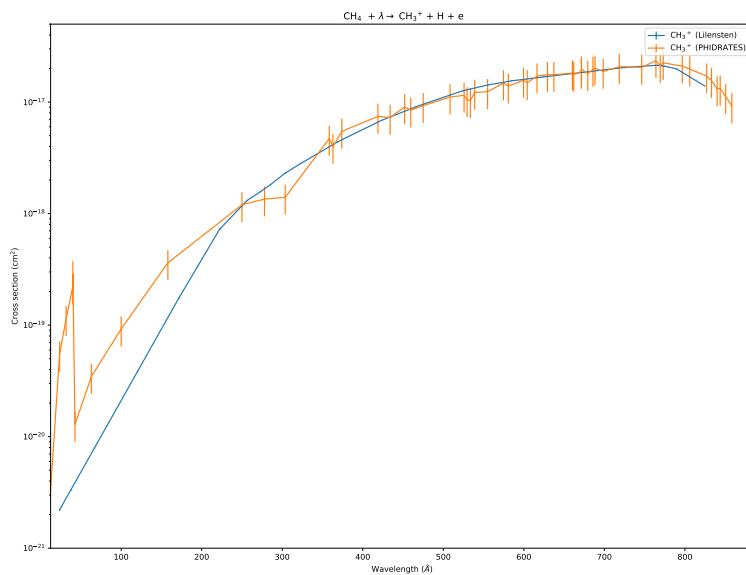
**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$CH_4 + \lambda \rightarrow CH_2(a' A^1) + H_2$	Revi PHDRATES	5.5	5.5:-1	30%	RU	Fig. 1.113 1.114 1.115 1.116
$CH_4 + \lambda \rightarrow CH_2 + 2 H$	Revi PHDRATES	9.4	9.4:-1	30%	RU	Fig. 1.113 1.114 1.115 1.116
$CH_4 + \lambda \rightarrow CH_3 + H$	Revi PHDRATES	4	4:-1	30%	RU	Fig. 1.113 1.114 1.115 1.116
$CH_4 + \lambda \rightarrow CH + H_2 + H$	Revi PHDRATES	9	9:-1	30%	RU	Fig. 1.113 1.114 1.115 1.116
$CH_4 + \lambda \rightarrow H^+ + CH_3$	Revi PHDRATES	18	18:-1	30%	U	Fig. 1.113 1.114 1.115 1.116
$CH_4 + \lambda \rightarrow CH^+ + H_2 + H + e$	Revi PHDRATES	20	20:-1	30%	U	Fig. 1.113 1.114 1.115 1.116
$CH_4 + \lambda \rightarrow CH_2^+ + H_2 + e$	Revi PHDRATES	15	15:-1	30%	U	Fig. 1.113 1.114 1.115 1.116
$CH_4 + \lambda \rightarrow CH_3^+ + H + e$	Revi PHDRATES	19.	19:-1	30%	U	Fig. 1.113 1.114 1.115 1.116
$CH_4 + \lambda \rightarrow CH_4^{2+}, CH_4^+ + e + \lambda Anger (C)$	Revi [3]	282	340:3260	20%	R	Fig. 1.113 1.114 1.115 1.116
$CH_4 + \lambda \rightarrow CH_4^+ + e$	Adap PHDRATES+Avakyan	12.1	12.1:-1	30%	RU	Fig. 1.113 1.114 1.115 1.116
$CH_4 + \lambda \rightarrow CH_4^+(A) + e$	Revi [3]	24	24:-1	20%	R	Fig. 1.113 1.114 1.115 1.116
$CH_4 + \lambda \rightarrow Total$	Revi PHDRATES	0	0:-1	20%	RUE	Fig. 1.113 1.114 1.115 1.116

Table 1.25: Recommended Cross section for  $\lambda$  impact on  $CH_4$

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Figure 1.95: Cross sections for  $CH_4 + \lambda \rightarrow CH_3^+ + H + e$ Figure 1.96: Cross sections for  $CH_4 + \lambda \rightarrow CH_3^+ + H + e$  (wavelength version)

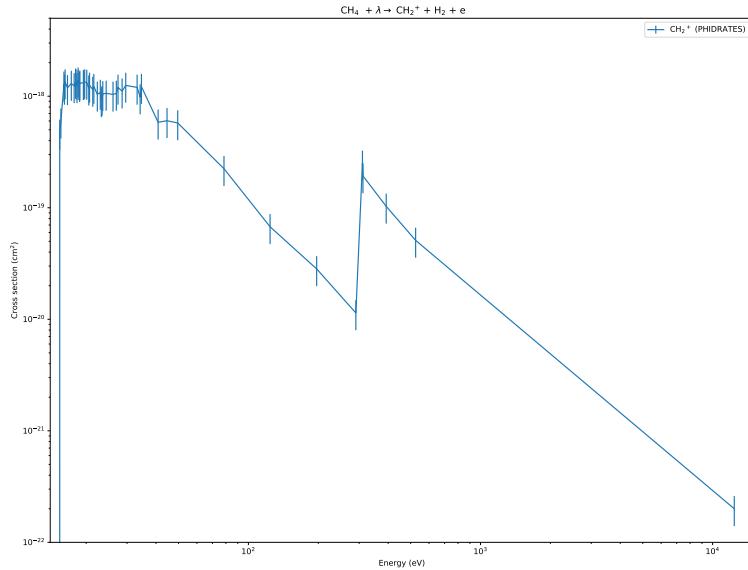


Figure 1.97: Cross sections for  $\text{CH}_4 + \lambda \rightarrow \text{CH}_2^+ + \text{H}_2 + \text{e}$

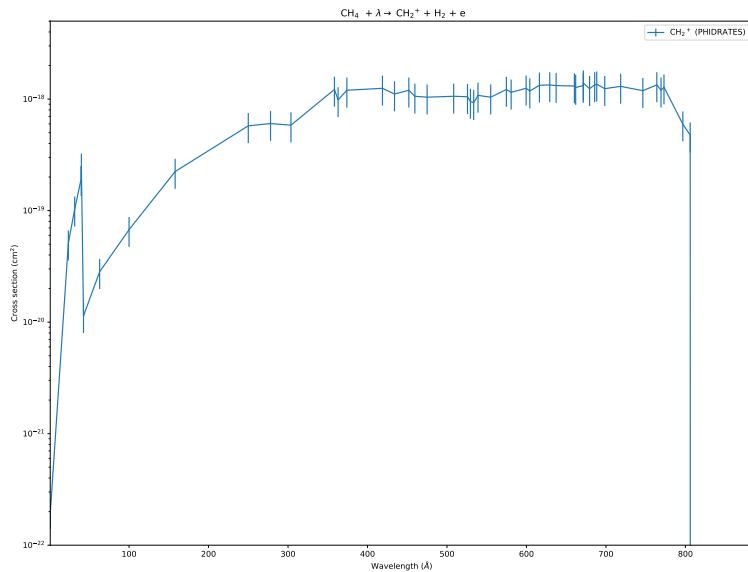
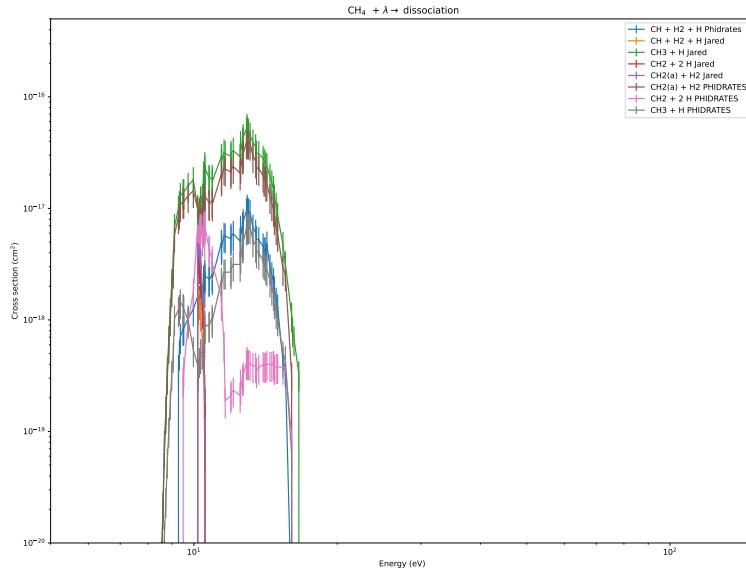
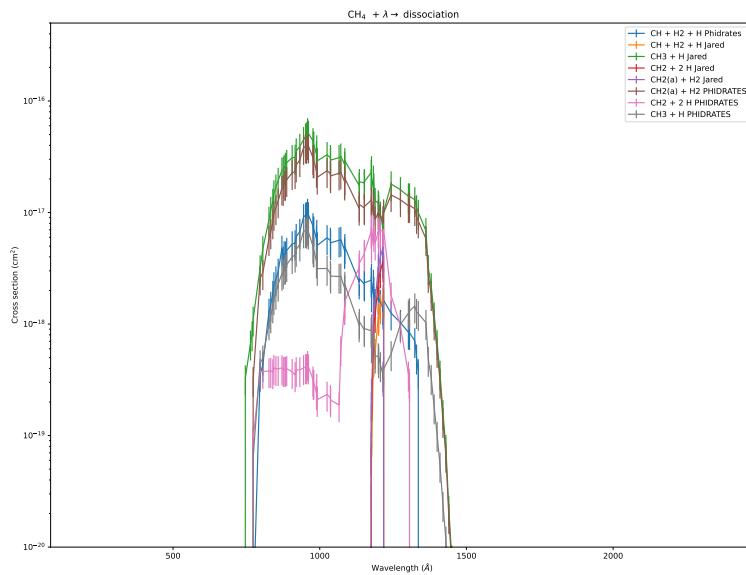


Figure 1.98: Cross sections for  $\text{CH}_4 + \lambda \rightarrow \text{CH}_2^+ + \text{H}_2 + \text{e}$  (wavelength version)

Figure 1.99: Cross sections for  $CH_4 + \lambda \rightarrow$  dissociationFigure 1.100: Cross sections for  $CH_4 + \lambda \rightarrow$  dissociation (wavelength version)

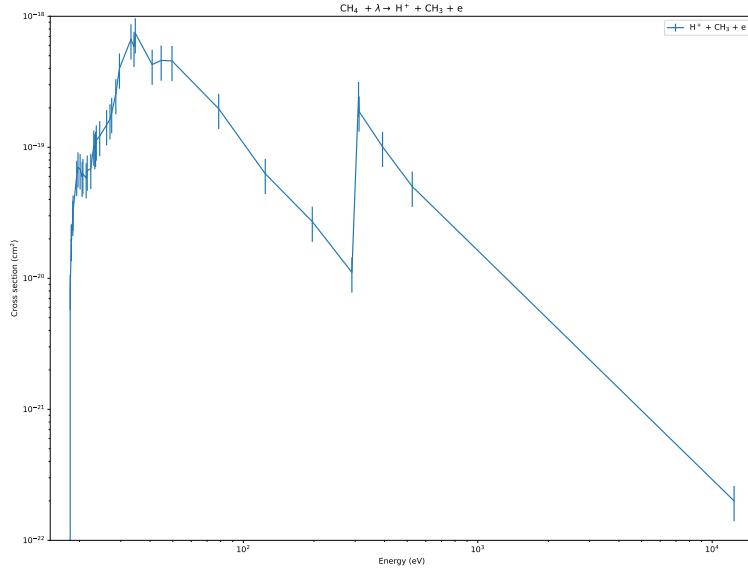


Figure 1.101: Cross sections for  $\text{CH}_4 + \lambda \rightarrow \text{H}^+ + \text{CH}_3 + \text{e}$

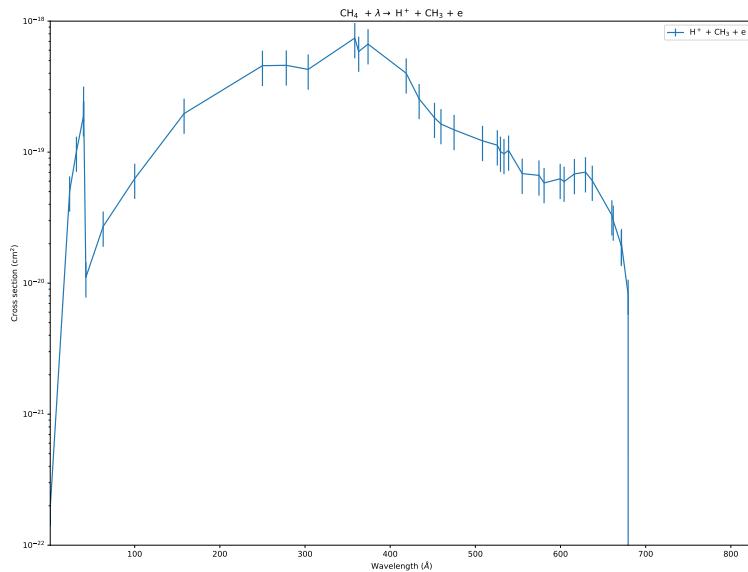


Figure 1.102: Cross sections for  $\text{CH}_4 + \lambda \rightarrow \text{H}^+ + \text{CH}_3 + \text{e}$  (wavelength version)

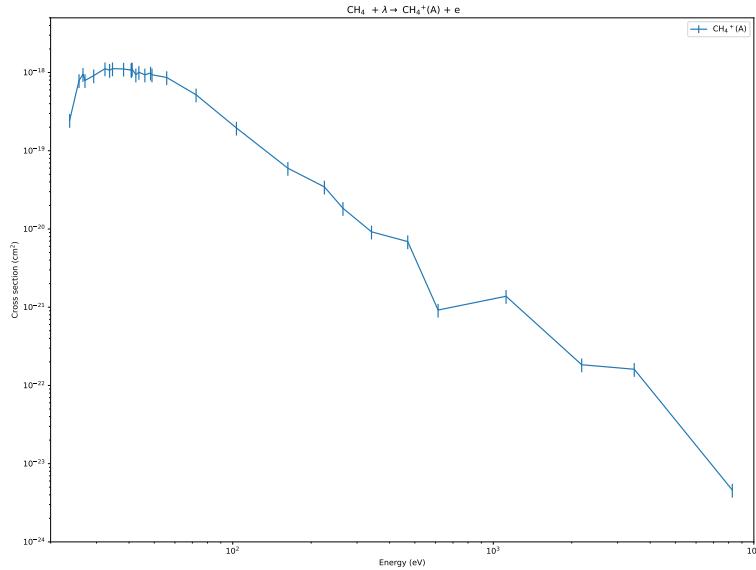


Figure 1.103: Cross sections for  $CH_4 + \lambda \rightarrow CH_4^+(A) + e$

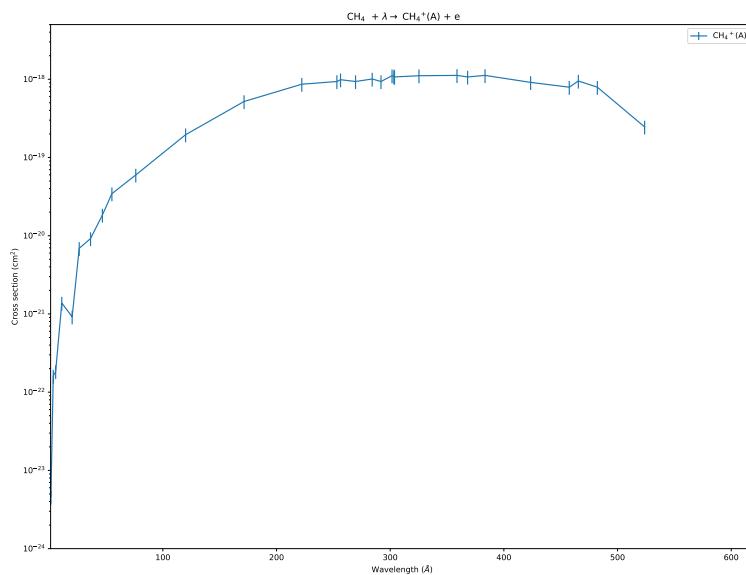


Figure 1.104: Cross sections for  $CH_4 + \lambda \rightarrow CH_4^+(A) + e$  (wavelength version)

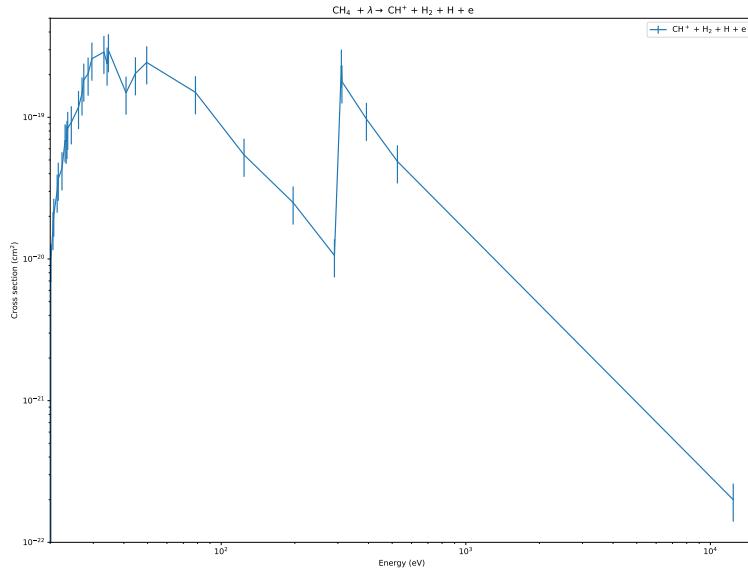


Figure 1.105: Cross sections for  $\text{CH}_4 + \lambda \rightarrow \text{CH}^+ + \text{H}_2 + \text{H} + \text{e}$

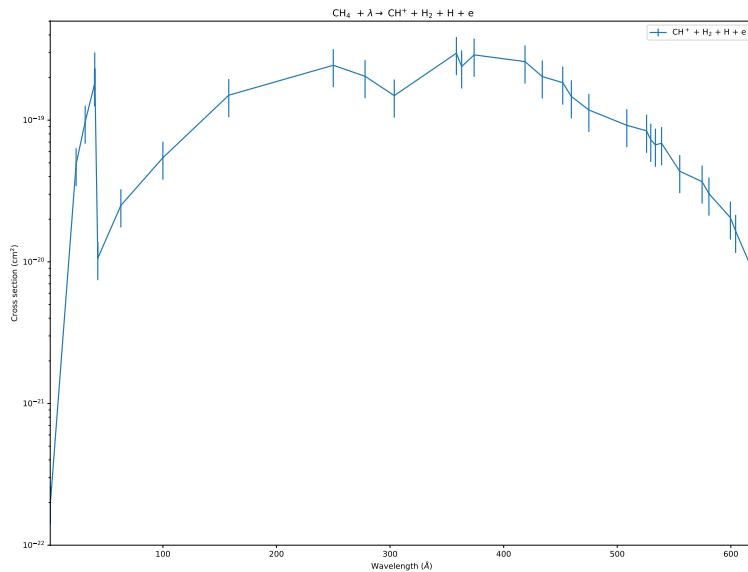


Figure 1.106: Cross sections for  $\text{CH}_4 + \lambda \rightarrow \text{CH}^+ + \text{H}_2 + \text{H} + \text{e}$  (wavelength version)

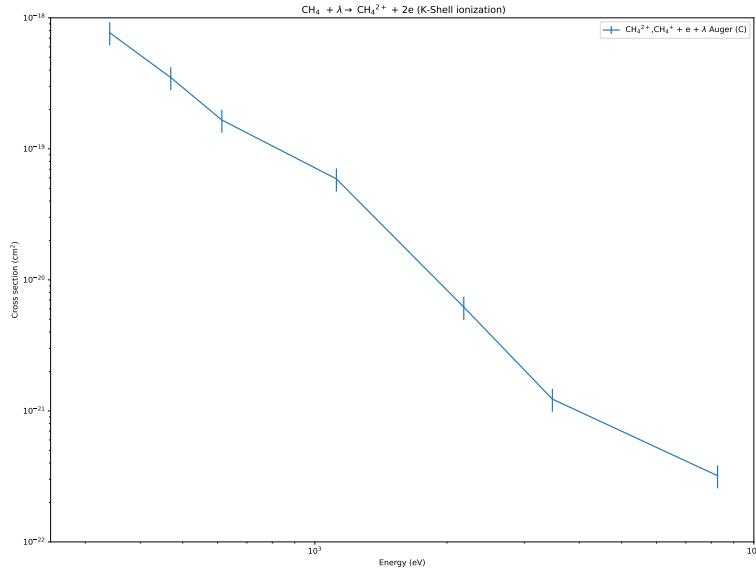


Figure 1.107: Cross sections for  $CH_4 + \lambda \rightarrow CH_4^{2+} + 2e$  (K-Shell ionization)

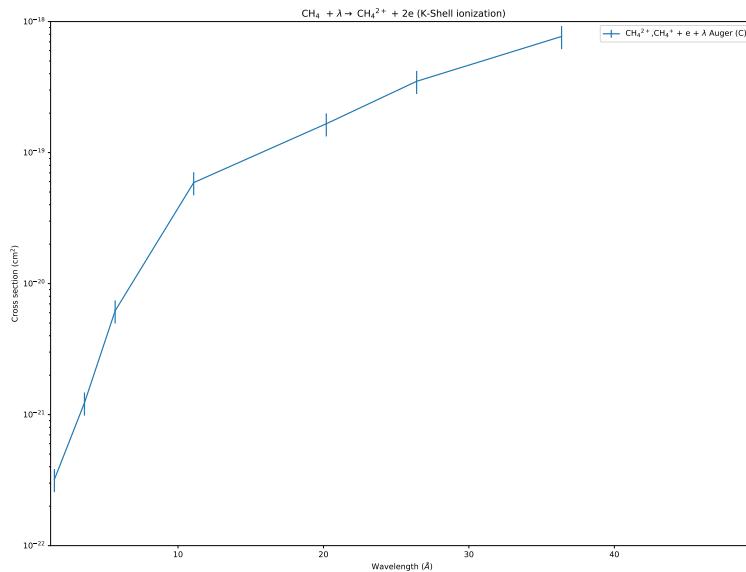


Figure 1.108: Cross sections for  $CH_4 + \lambda \rightarrow CH_4^{2+} + 2e$  (K-Shell ionization) (wavelength version)

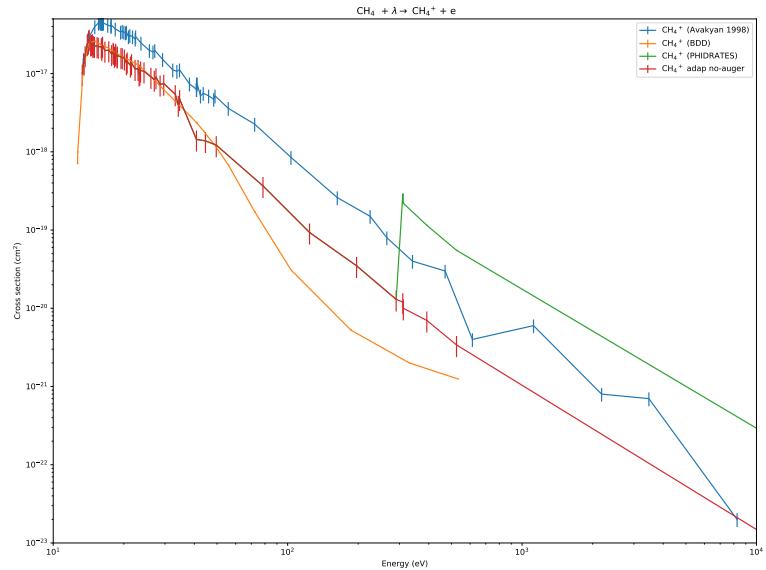


Figure 1.109: Cross sections for CH<sub>4</sub> + λ → CH<sub>4</sub><sup>+</sup> + e

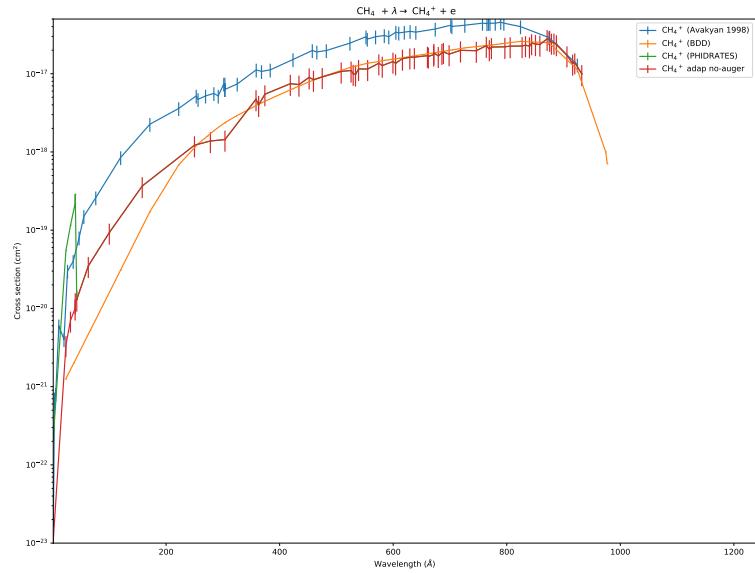


Figure 1.110: Cross sections for CH<sub>4</sub> + λ → CH<sub>4</sub><sup>+</sup> + e (wavelength version)

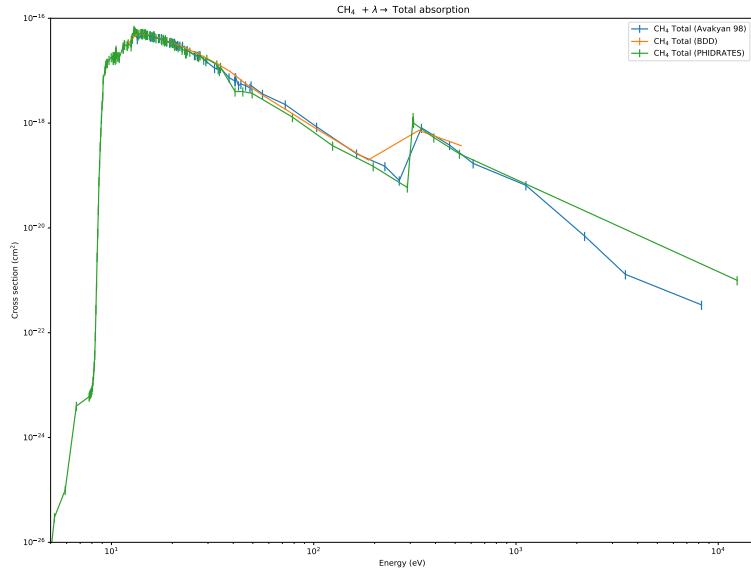


Figure 1.111: Cross sections for  $CH_4 + \lambda \rightarrow$  Total absorption

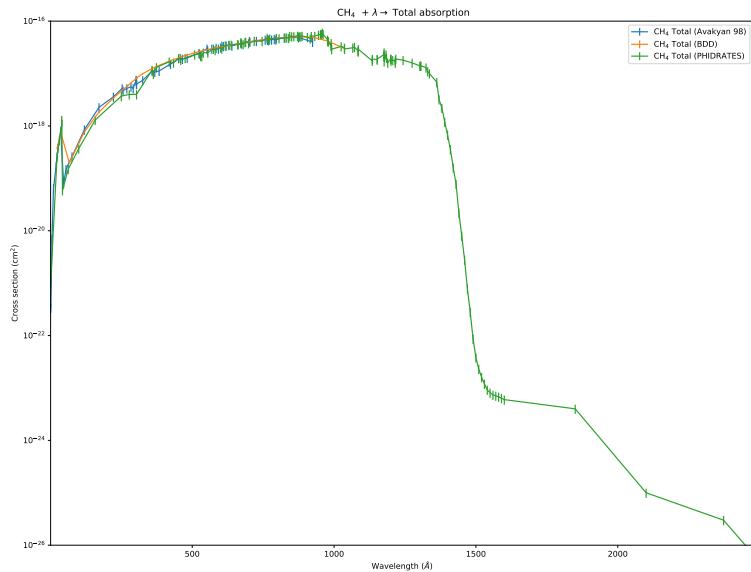
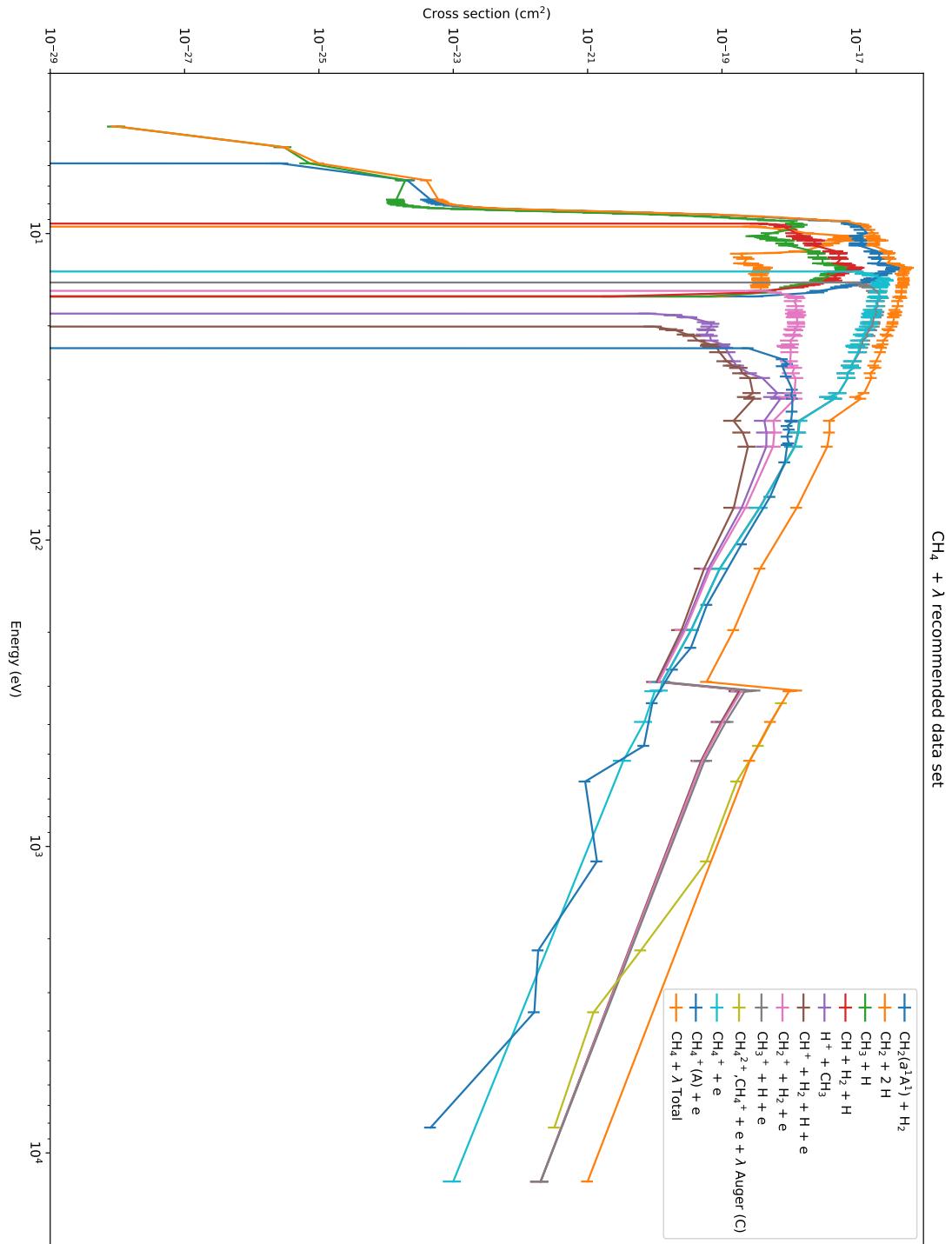


Figure 1.112: Cross sections for  $CH_4 + \lambda \rightarrow$  Total absorption (wavelength version)

Figure 1.113: Cross sections for  $\text{CH}_4 + \lambda$  recommended data set

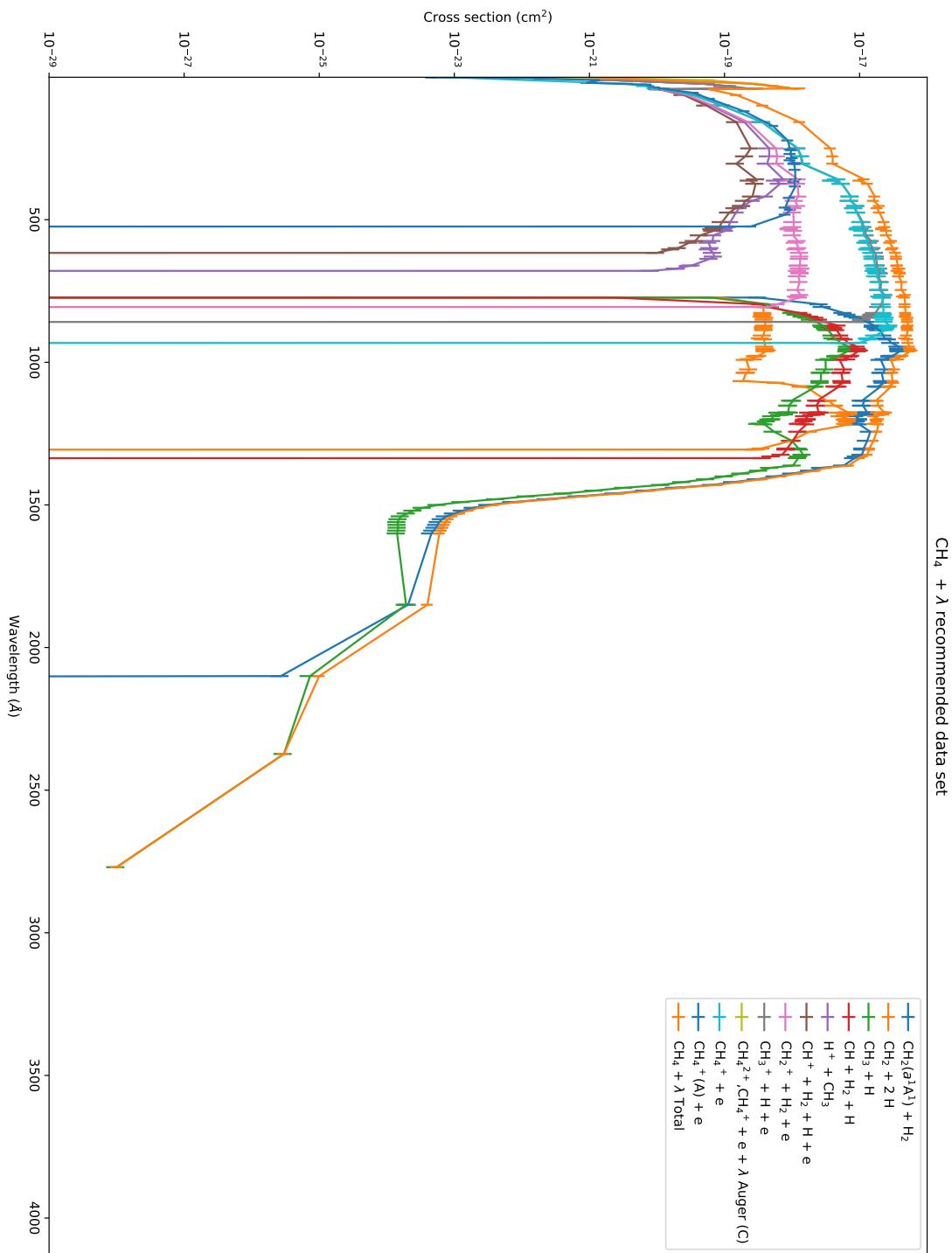


Figure 1.114: Cross sections for  $CH_4 + \lambda$  recommended data set (wavelength version)

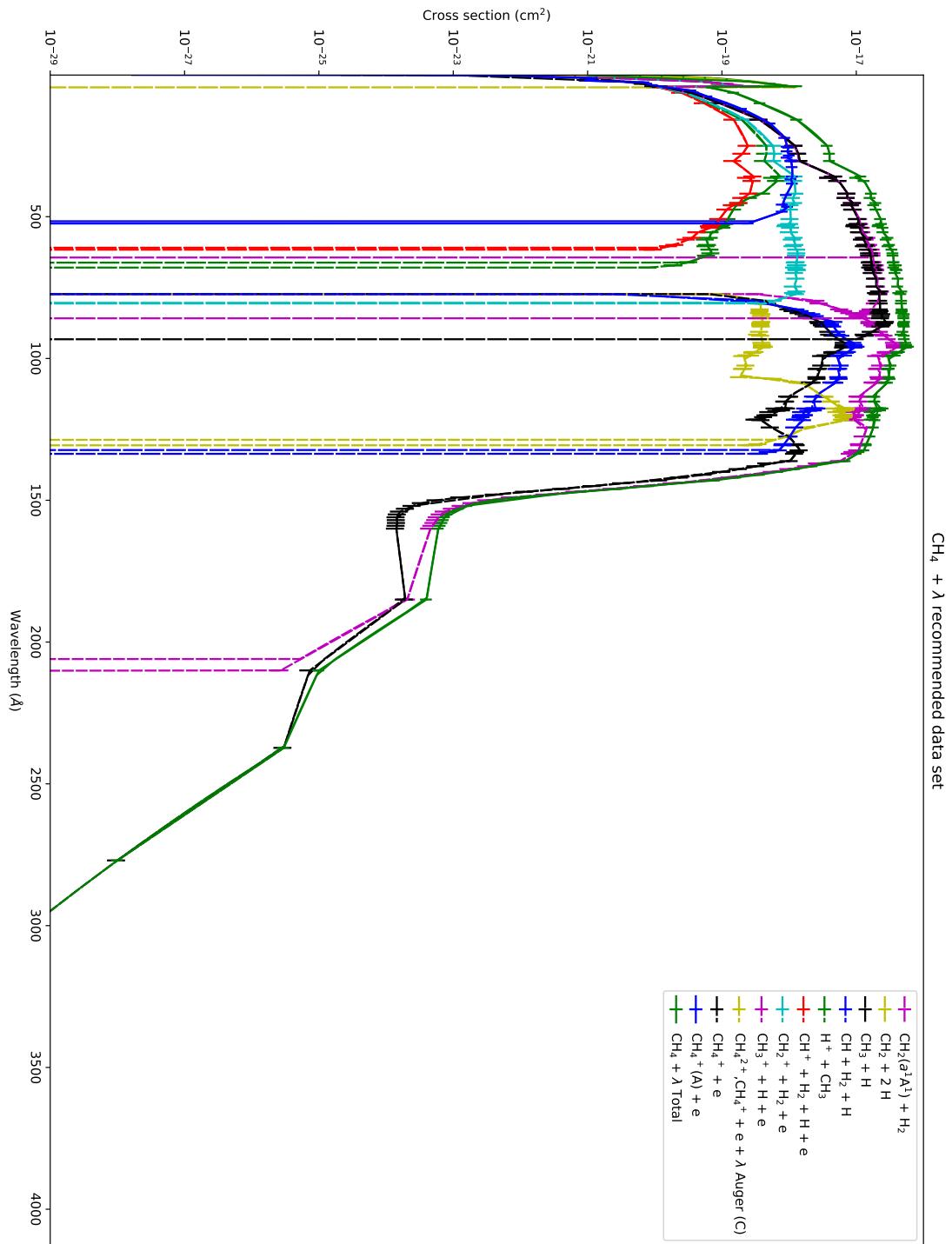


Figure 1.115: Cross sections for  $\text{CH}_4 + \lambda$  recommended data set (with extrapolation version)

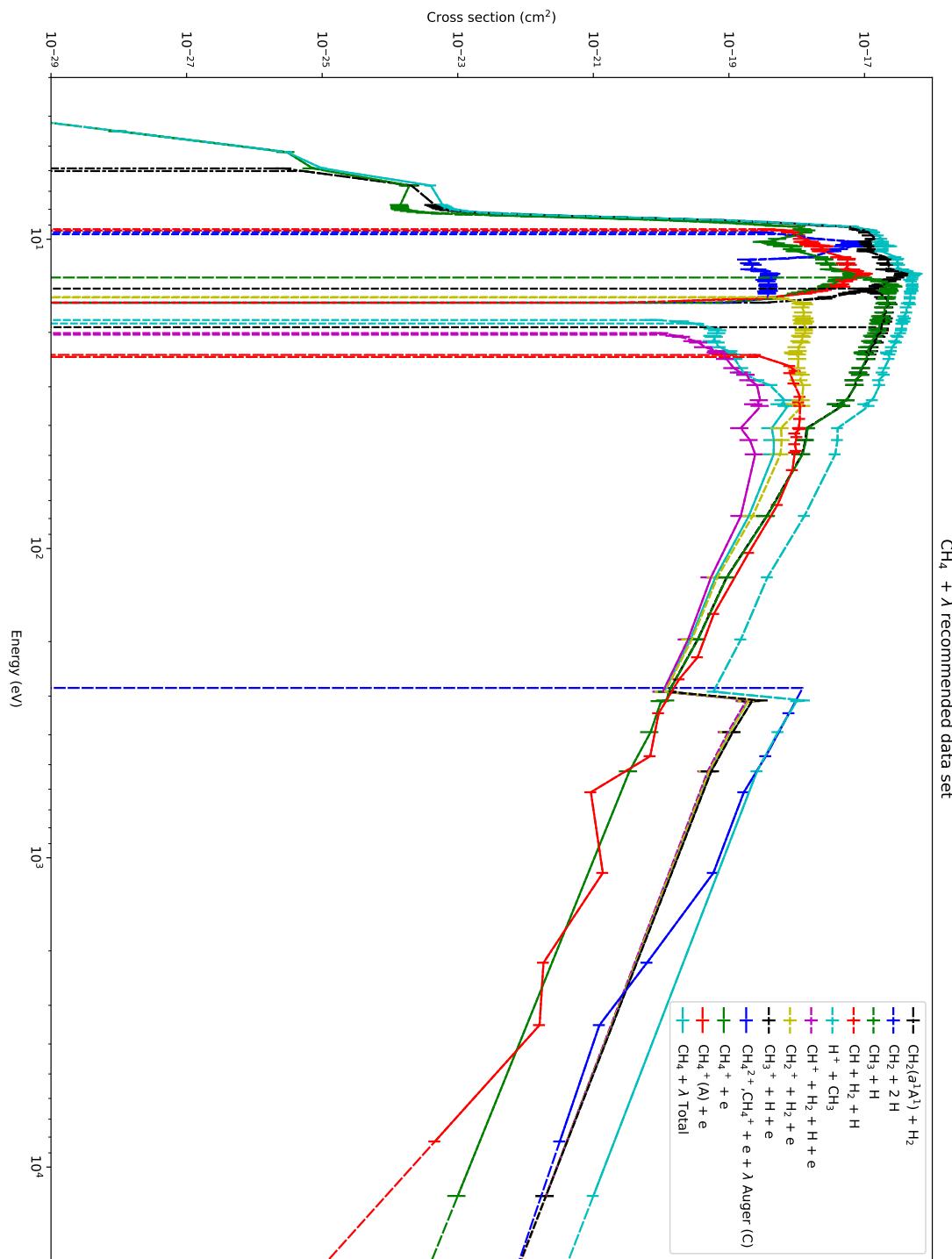


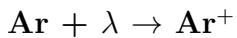
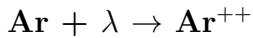
Figure 1.116: Cross sections for  $\text{CH}_4 + \lambda$  recommended data set (wavelength with extrapolation version)

## 1.7 Cross section of ph impact with Ar

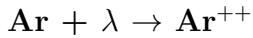
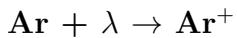
### 1.7.1 Total Cross Section

### 1.7.2 Inelastic Cross Sections

#### Ionization Cross Sections



### 1.7.3 Recommended data set



#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi PHIDRATES	0	15.:12400	??% ??%	U	Fig. 1.119 1.120
Revi [45] BDD	0	7.2:532	??% ??%	U	Fig. 1.119 1.120

Table 1.26: Total cross section for  $\lambda$  impact on Ar

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$\text{Ar} + \lambda \rightarrow \text{Ar}^{++}$	Revi [45] BDD	24.6	24.6:-1	??%	U	Fig. 1.117 1.118
$\text{Ar} + \lambda \rightarrow \text{Ar}^+$	Revi PHDRATES Revi [45] BDD	13.6 13.6	13.6:-1 13.6:-1	20% ??%	RU U	Fig. 1.121 1.122 Fig. 1.121 1.122

Table 1.27: Ionization Cross section for  $\lambda$  impact on Ar

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
Ar + $\lambda$ → Ar <sup>+</sup>	Revi PHDRATES	13.6	13.6:-1	20%	RU	Fig. 1.123
Ar + $\lambda$ → Ar <sup>++</sup>	Revi [45] BDD	24.6	24.6:-1	??%	U	Fig. 1.123
Ar + $\lambda$ → Total	Revi PHDRATES	0	15:-12400	10%	U	Fig. 1.123

Table 1.28: Recommended Cross section for  $\lambda$  impact on Ar

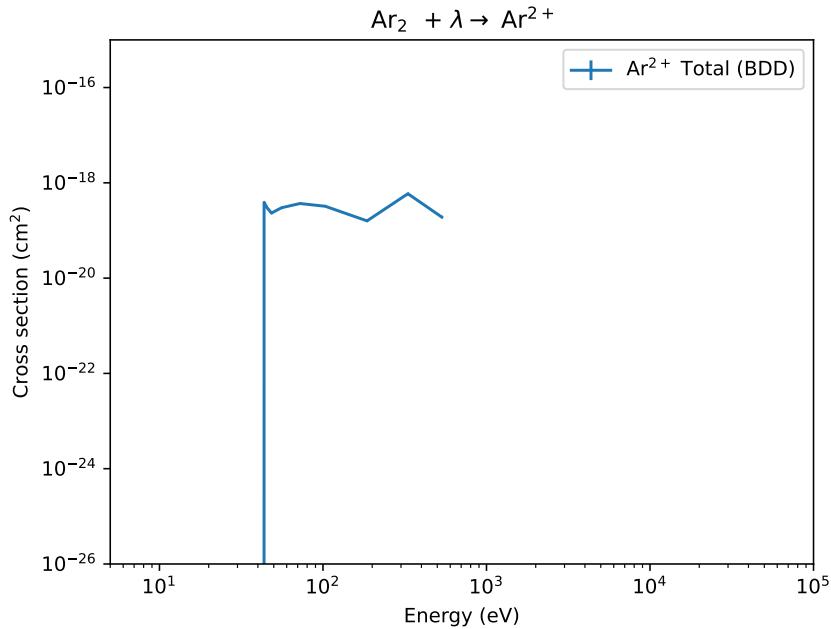


Figure 1.117: Cross sections for  $\text{Ar}_2 + \lambda \rightarrow \text{Ar}^{2+}$

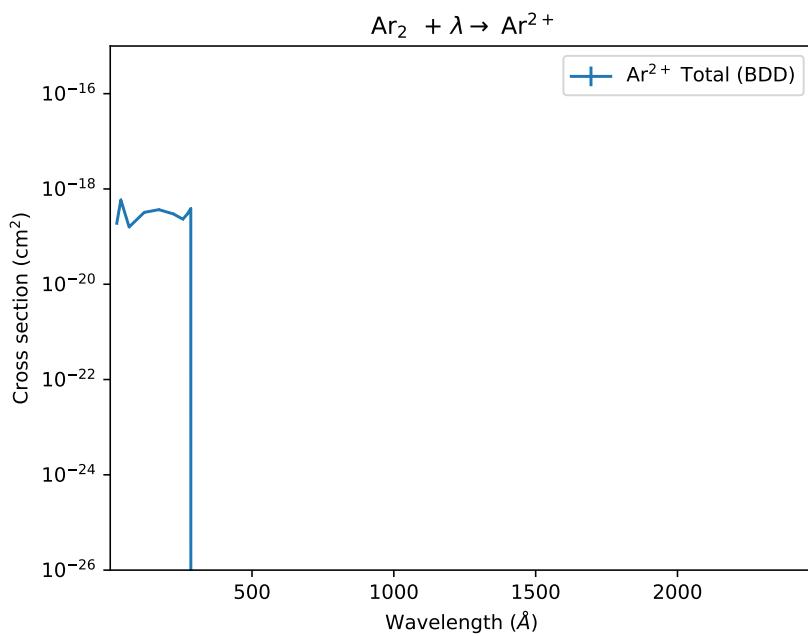
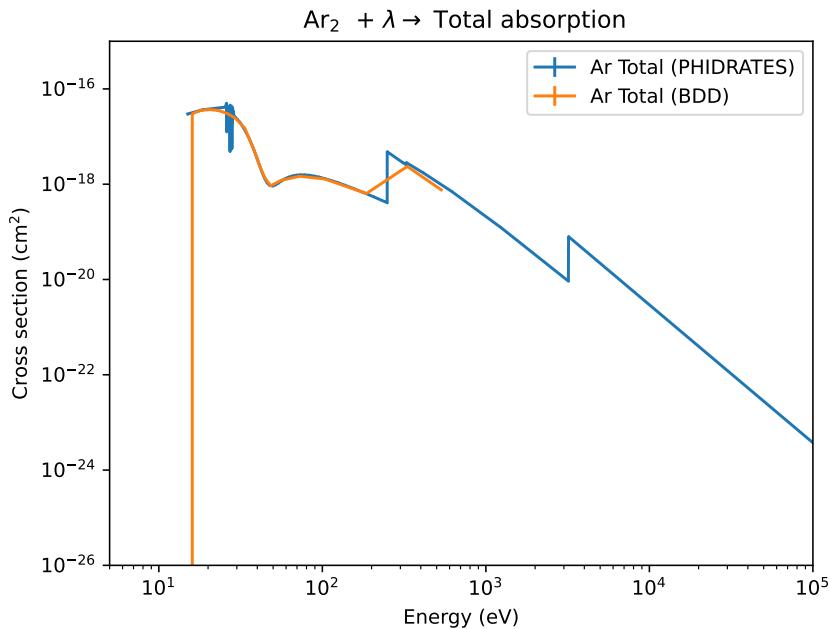
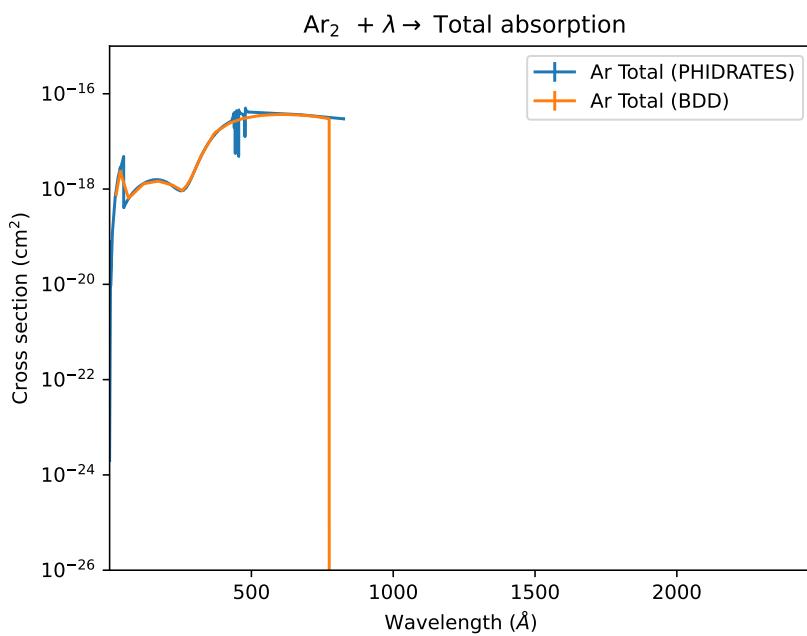
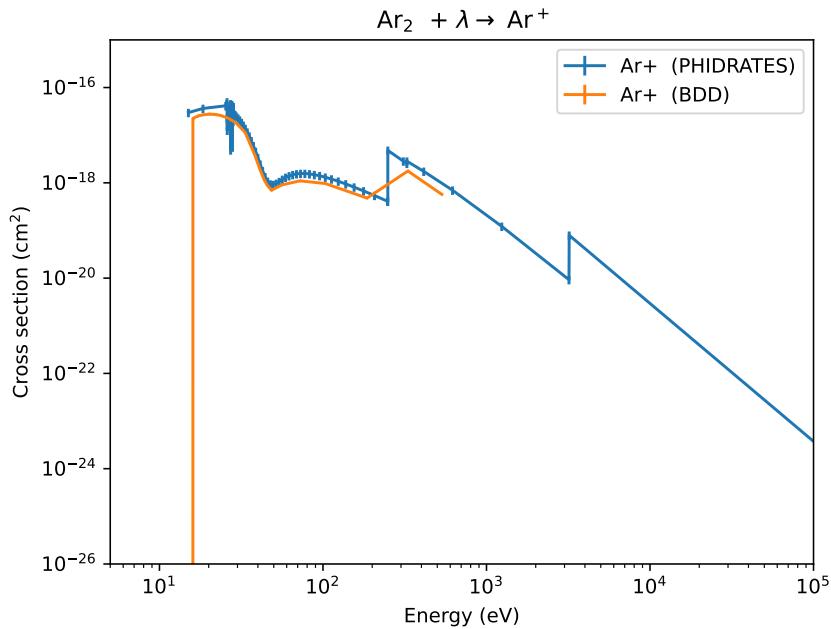
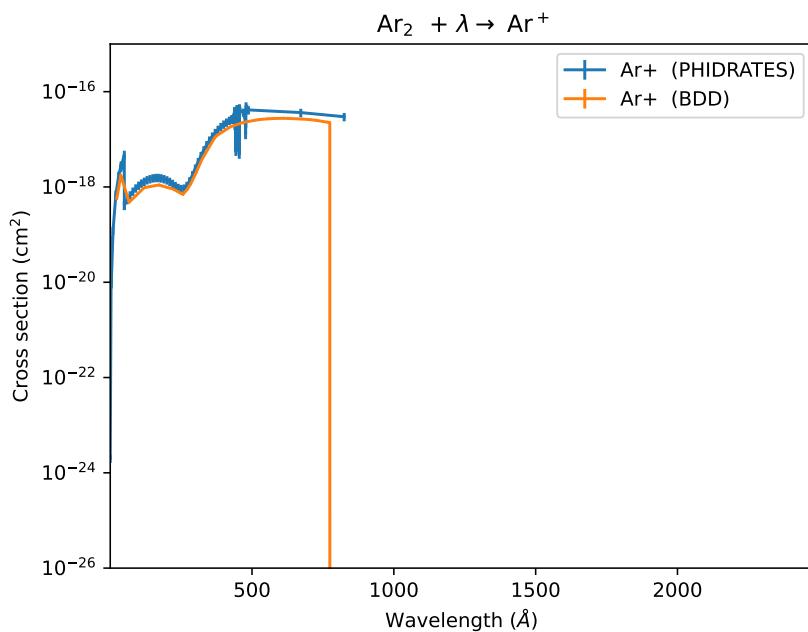
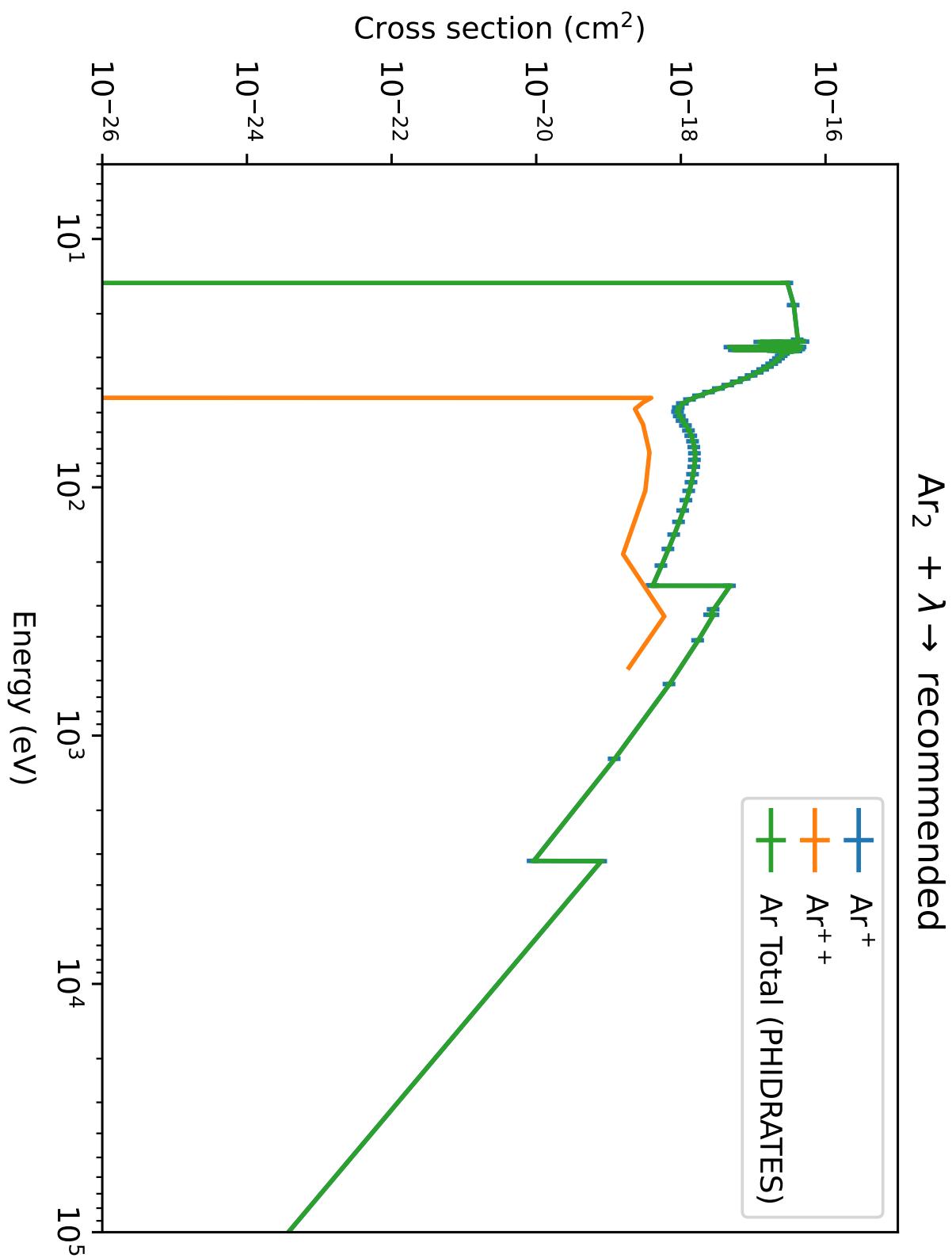


Figure 1.118: Cross sections for  $\text{Ar}_2 + \lambda \rightarrow \text{Ar}^{2+}$  (wavelength version)

Figure 1.119: Cross sections for  $\text{Ar}_2 + \lambda \rightarrow \text{Total absorption}$ Figure 1.120: Cross sections for  $\text{Ar}_2 + \lambda \rightarrow \text{Total absorption}$  (wavelength version)

Figure 1.121: Cross sections for  $\text{Ar}_2 + \lambda \rightarrow \text{Ar}^+$ Figure 1.122: Cross sections for  $\text{Ar}_2 + \lambda \rightarrow \text{Ar}^+$  (wavelength version)

Figure 1.123: Cross sections for  $\text{Ar}_2 + \lambda \rightarrow \text{recommended}$

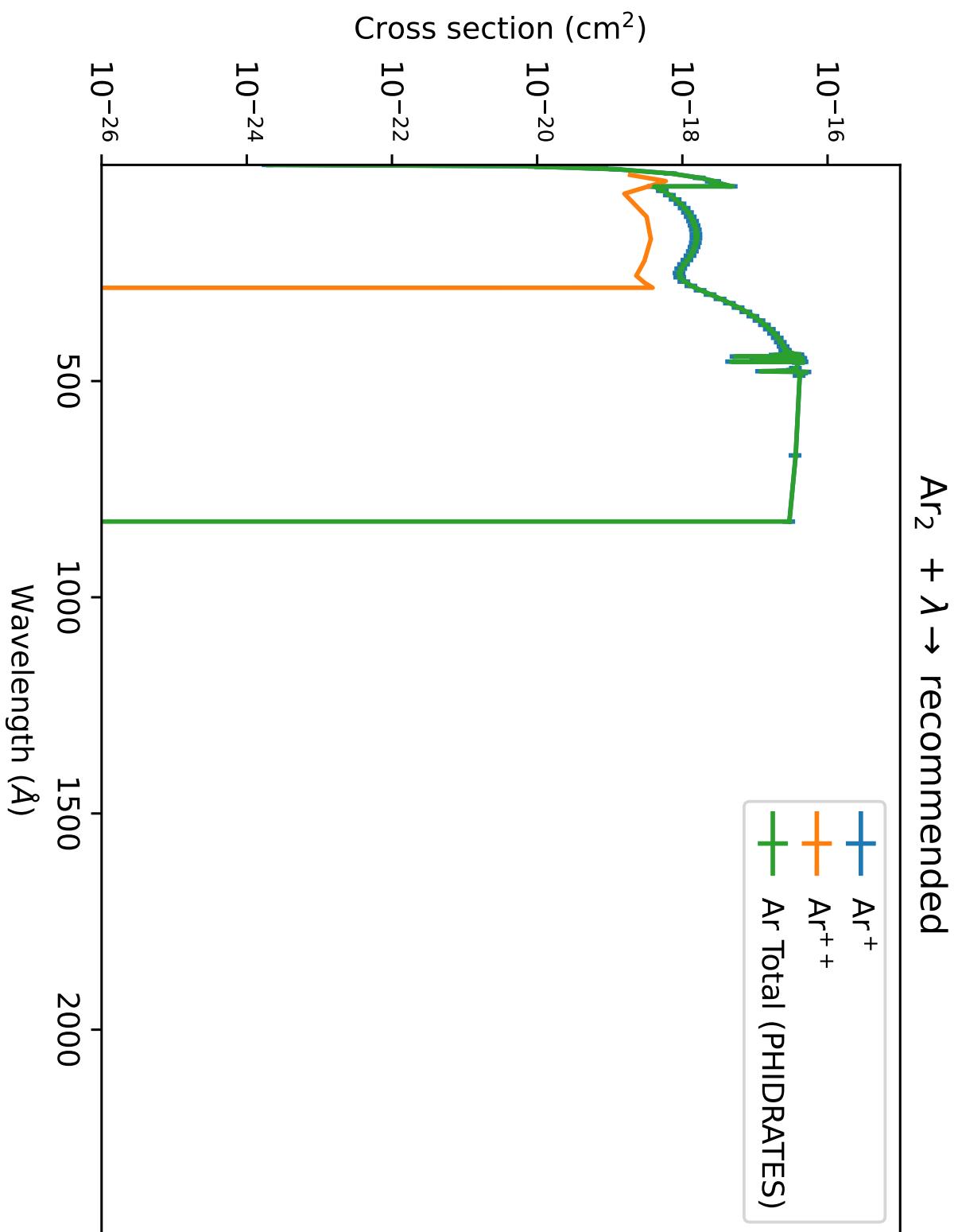


Figure 1.124: Cross sections for  $\text{Ar}_2 + \lambda \rightarrow \text{recommended}$  (wavelength version)

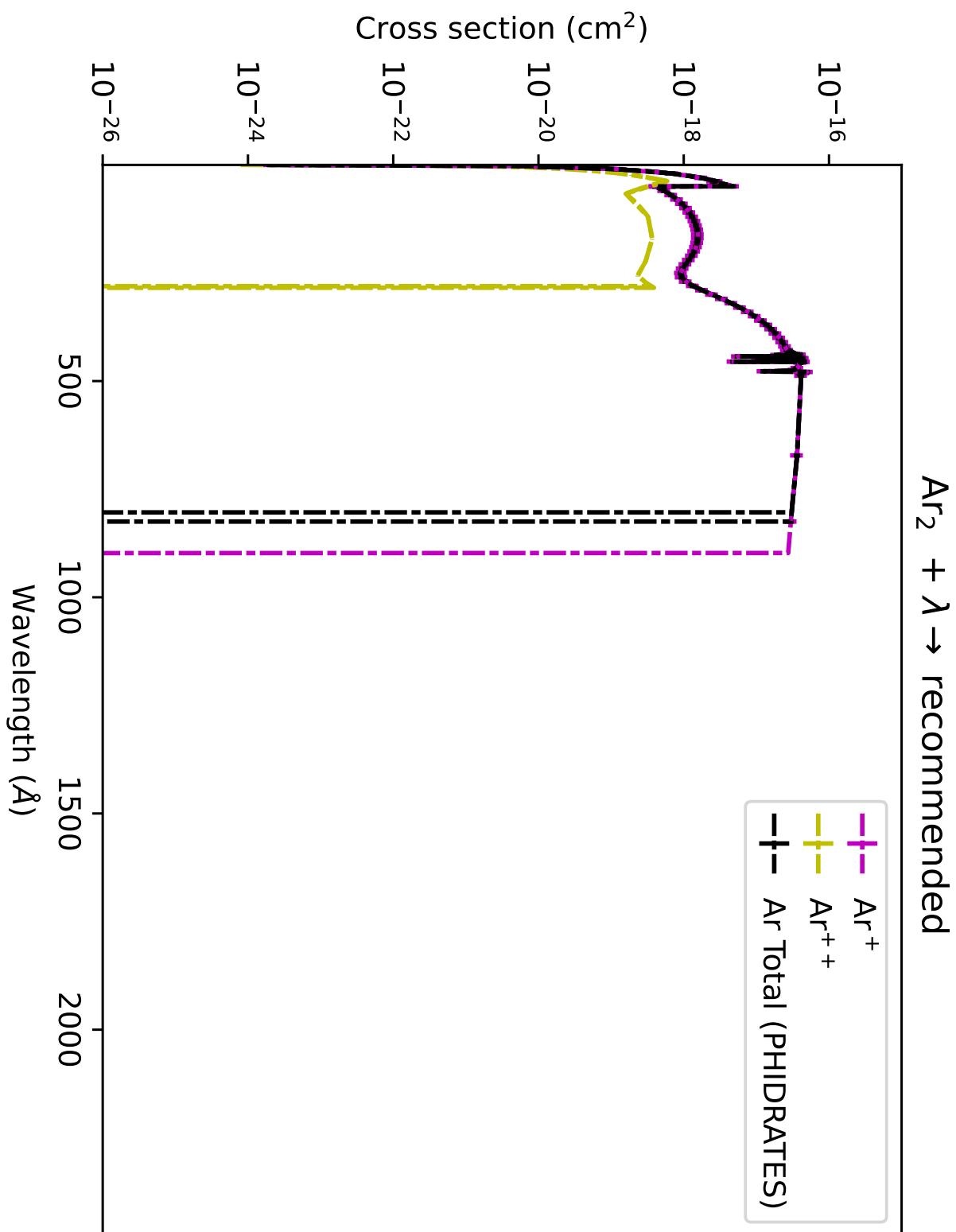


Figure 1.125: Cross sections for  $\text{Ar}_2 + \lambda \rightarrow \text{recommended}$  (with extrapolation version)

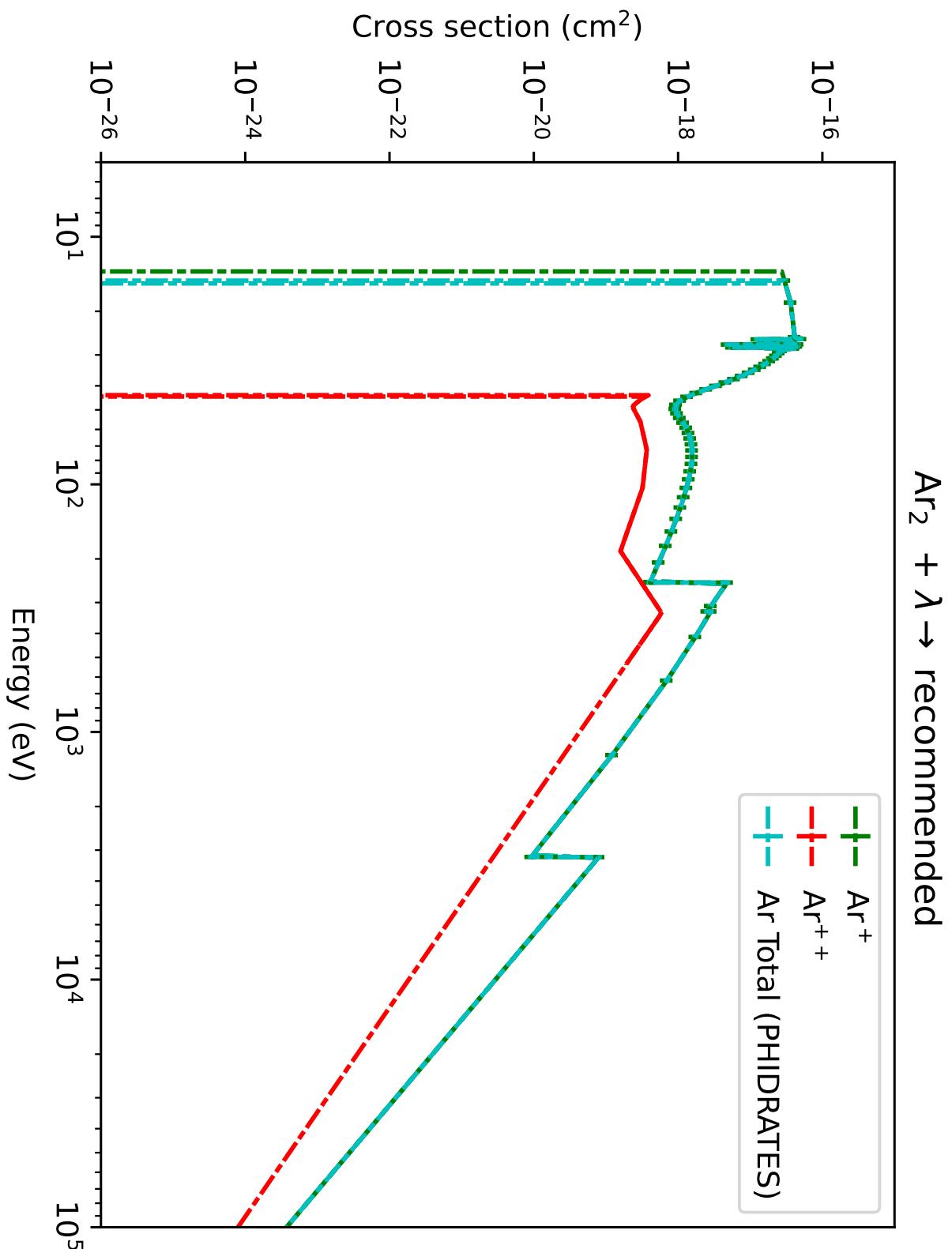


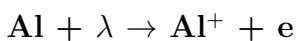
Figure 1.126: Cross sections for  $\text{Ar}_2 + \lambda \rightarrow \text{recommended}$  (wavelength with extrapolation version)

## 1.8 Cross section of ph impact with Al

### 1.8.1 Total Cross Section

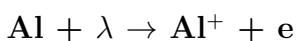
### 1.8.2 Inelastic Cross Sections

#### Ionization Cross Sections



**Al ionization (PHIDRATES)** Total photoionization of Al from the review of PHIDRATES [24]. The uncertainty, not claimed by the review, is estimated at 20%. The data, in nm, have been directly adapted in eV.

### 1.8.3 Recommended data set



**Al total absorption (PHIDRATES)** Total photoionization of Al from the review of PHIDRATES [24]. The uncertainty, not claimed by the review, is estimated at 20%. The data, in nm, have been directly adapted in eV.



**Al total absorption (PHIDRATES)** Total photoabsorption of Al from the review of PHIDRATES [24]: the total ionization was considered being the total cross section. The uncertainty, not claimed by the review, is estimated at 5%. The data, in nm, have been directly adapted in eV.

#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi PHDRATES	0	5.834551:124000	5%		Fig. 1.129 1.130

Table 1.29: Total cross section for  $\lambda$  impact on Al

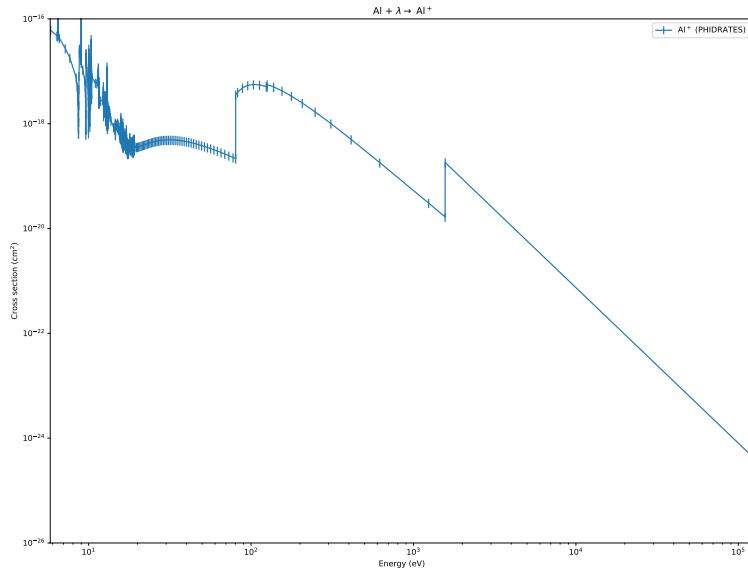
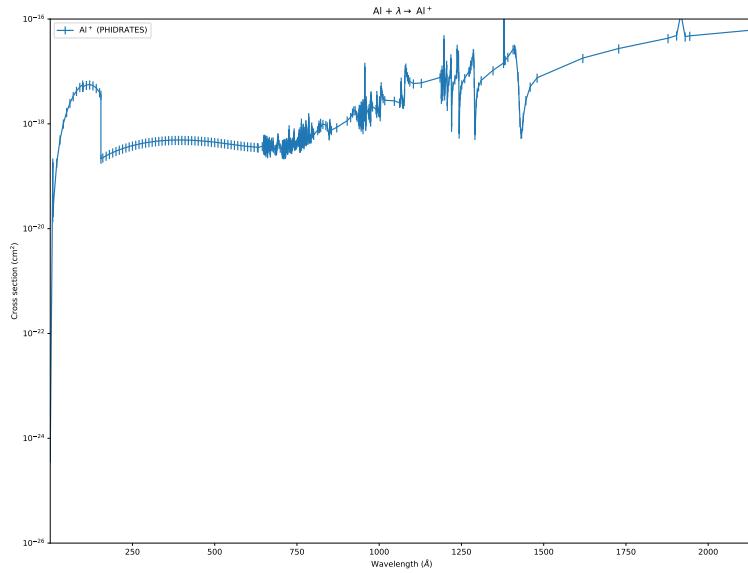
Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
Al + $\lambda \rightarrow Al^+ + e^-$	Revi PHIDRATES	5.834551	5.834551:124000	20%		Fig. 1.127 1.128

Table 1.30: Ionization Cross section for  $\lambda$  impact on Al

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
Al + $\lambda \rightarrow \text{Al}^+ + e^-$	Revi PHIDRATES	5.834551	5.834551:124000	20%	Fig. 1.131 1.132 1.133 1.134	
Al + $\lambda \rightarrow$ Total	Revi PHIDRATES	0	5.834551:124000	5%	Fig. 1.131 1.132 1.133 1.134	

Table 1.31: Recommended Cross section for  $\lambda$  impact on Al

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Figure 1.127: Cross sections for  $\text{Al} + \lambda \rightarrow \text{Al}^+$ Figure 1.128: Cross sections for  $\text{Al} + \lambda \rightarrow \text{Al}^+$  (wavelength version)

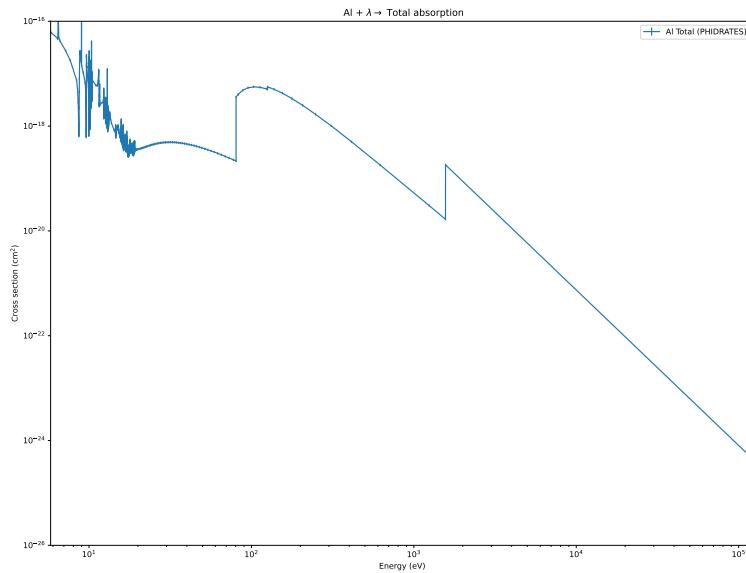


Figure 1.129: Cross sections for  $\text{Al} + \lambda \rightarrow \text{Total absorption}$

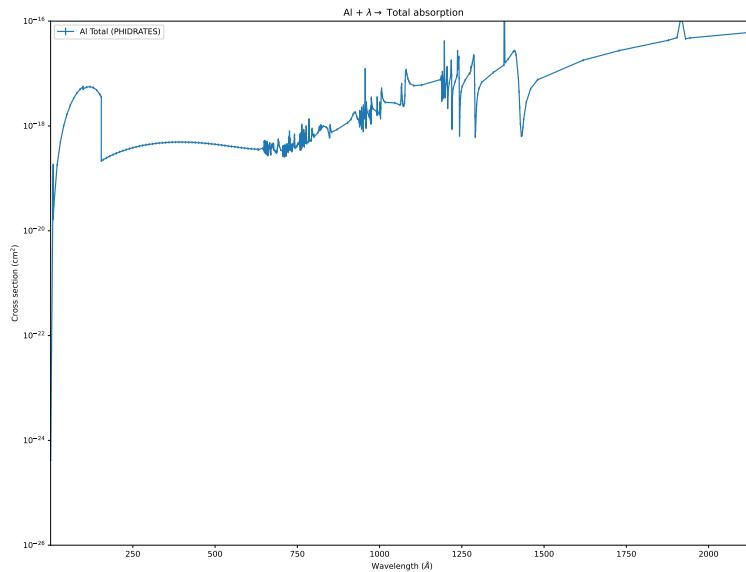
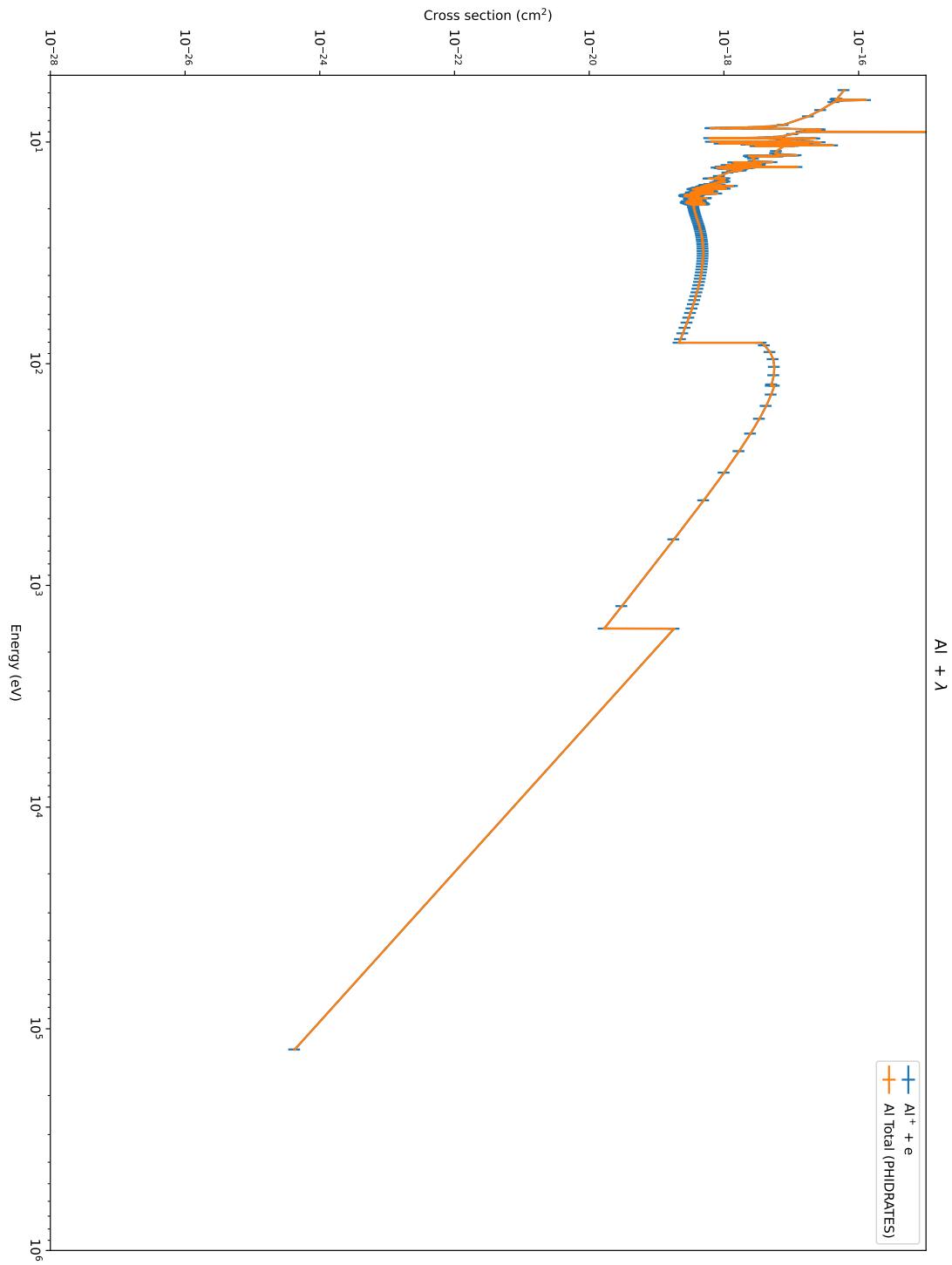
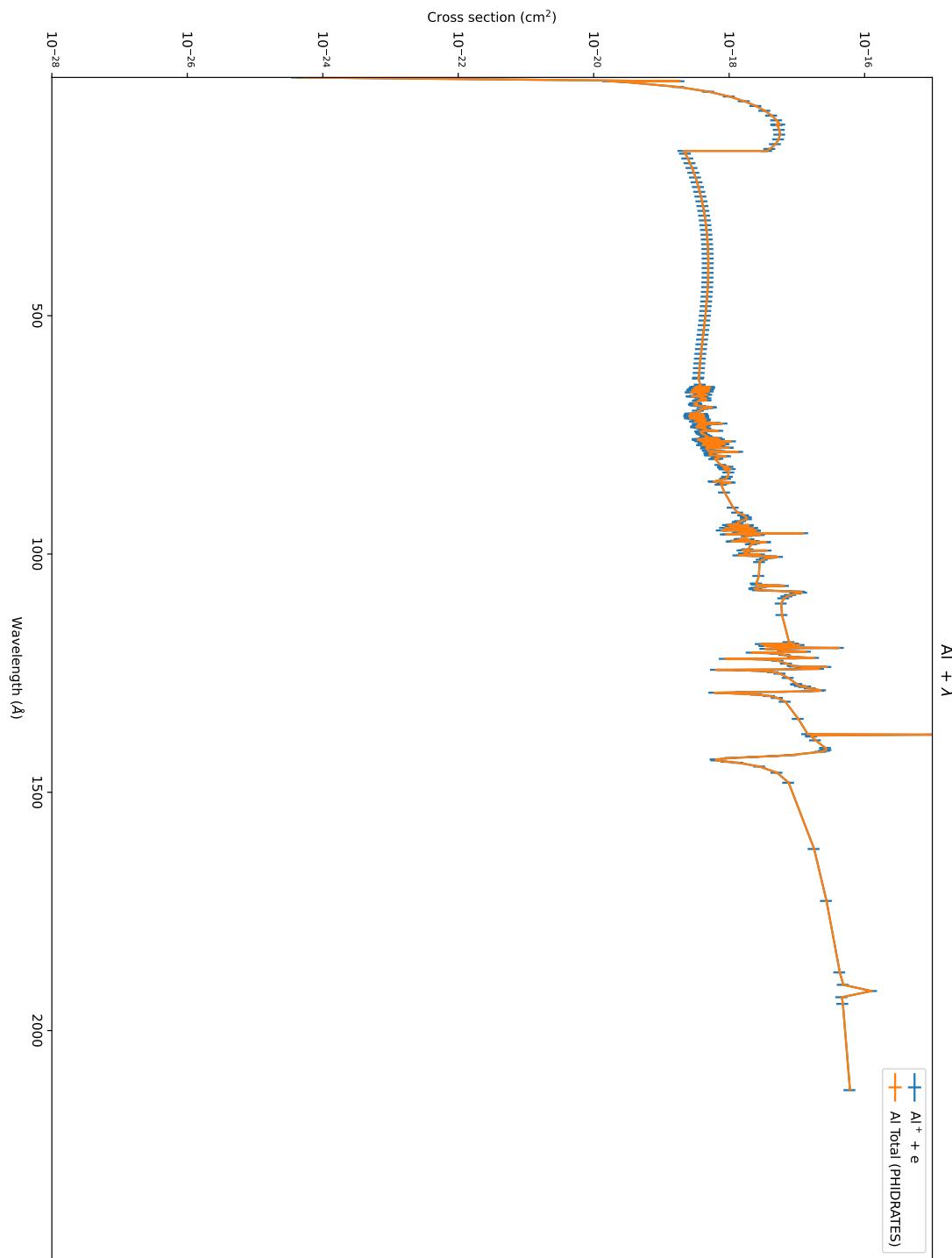


Figure 1.130: Cross sections for  $\text{Al} + \lambda \rightarrow \text{Total absorption}$  (wavelength version)

Figure 1.131: Cross sections for  $\text{Al} + \lambda$

Figure 1.132: Cross sections for  $\text{Al} + \lambda$  (wavelength version)

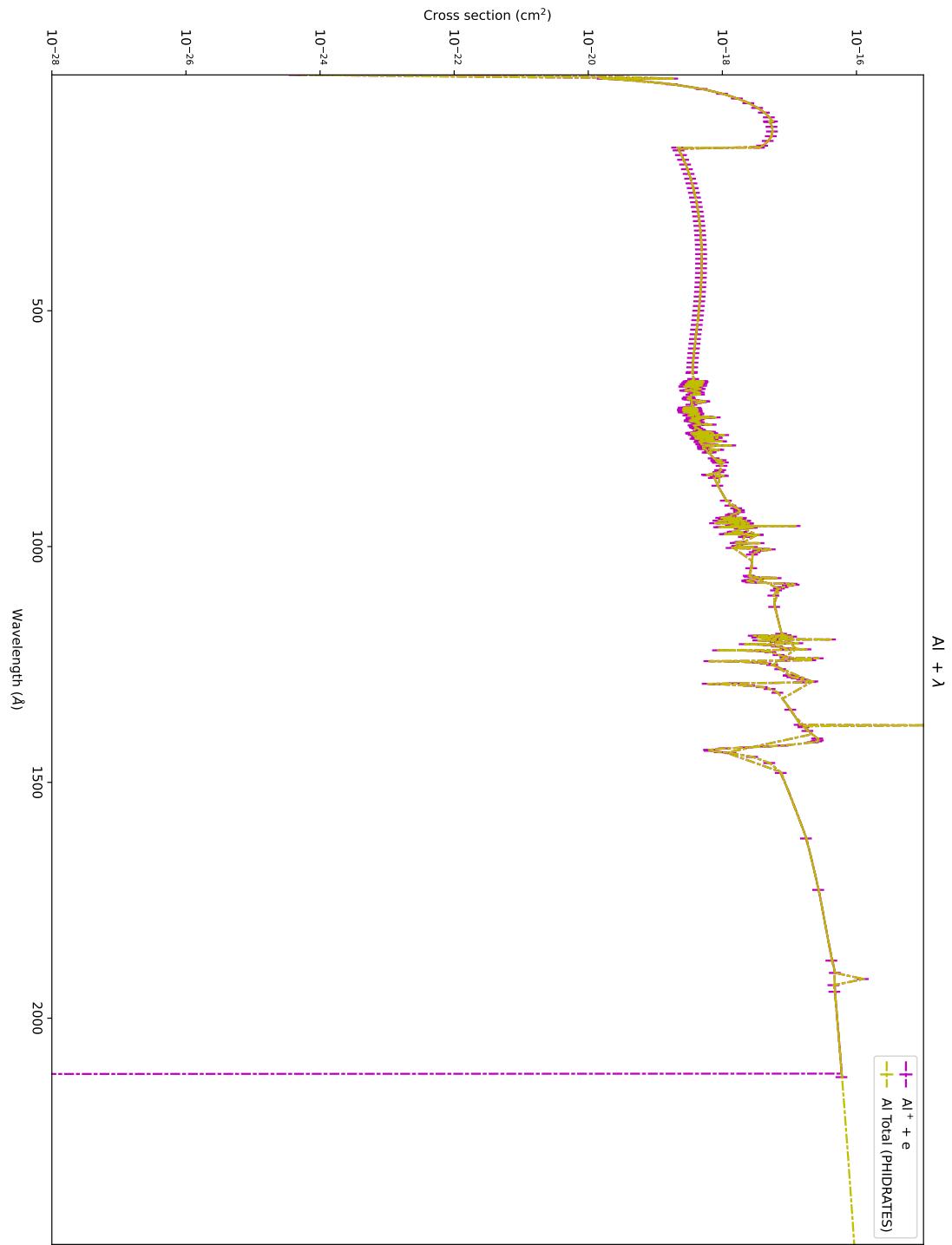


Figure 1.133: Cross sections for  $\text{Al} + \lambda$  (with extrapolation version)

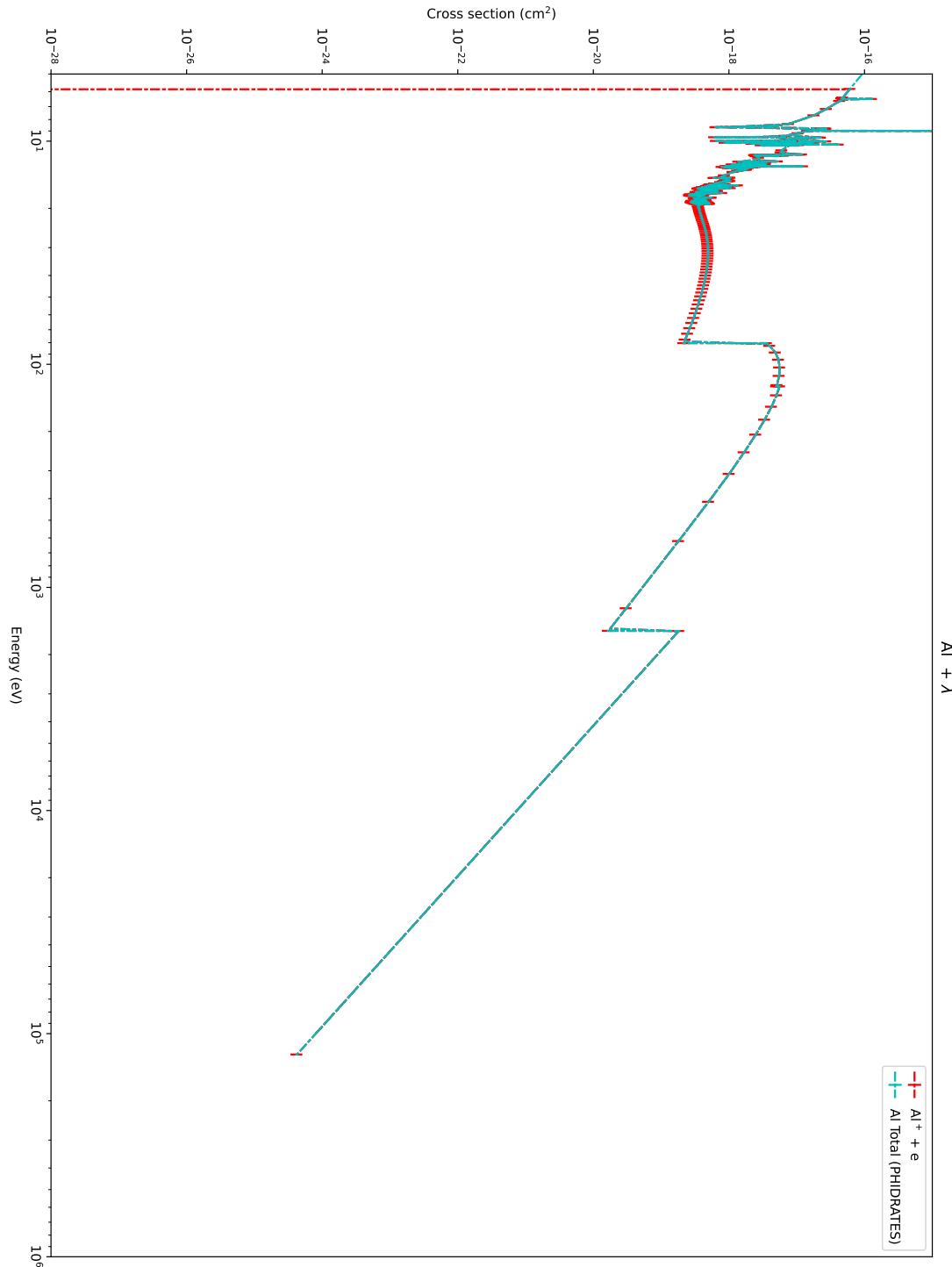


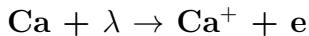
Figure 1.134: Cross sections for  $\text{Al} + \lambda$  (wavelength with extrapolation version)

## 1.9 Cross section of ph impact with Ca

### 1.9.1 Total Cross Section

### 1.9.2 Inelastic Cross Sections

#### **Ionization Cross Sections**



**Ca<sup>+</sup> + e (PHIDRATES)** Photoionization of Ca yielding Ca<sup>+</sup> + e from the review of AMOP. The uncertainty, not claimed by the review, is estimated at 20%. The data, in nm, have been directly adapted in eV.

**Ca<sup>+</sup> + e (PHIDRATES)** Photoionization of Ca yielding Ca<sup>+</sup> + e from the review of Phidrates [24]. . The uncertainty, not claimed by the review, is estimated at 20%. The data, in nm, have been directly adapted in eV.

#### **Legend for the properties**

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

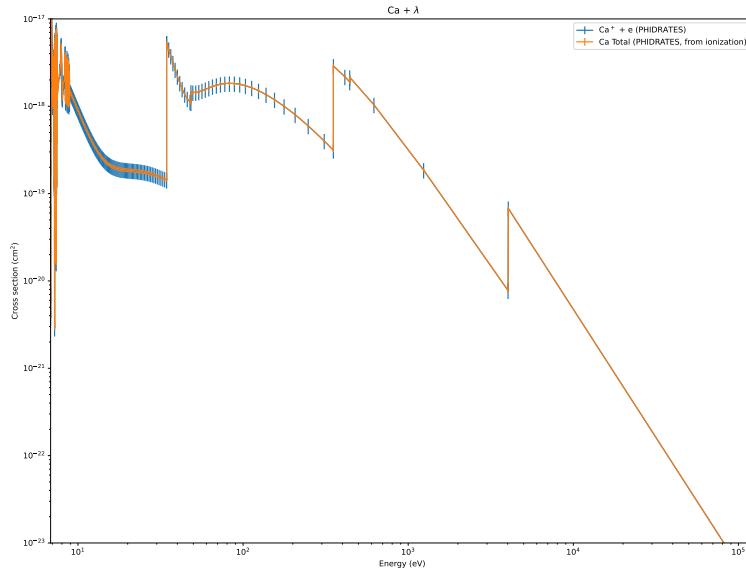
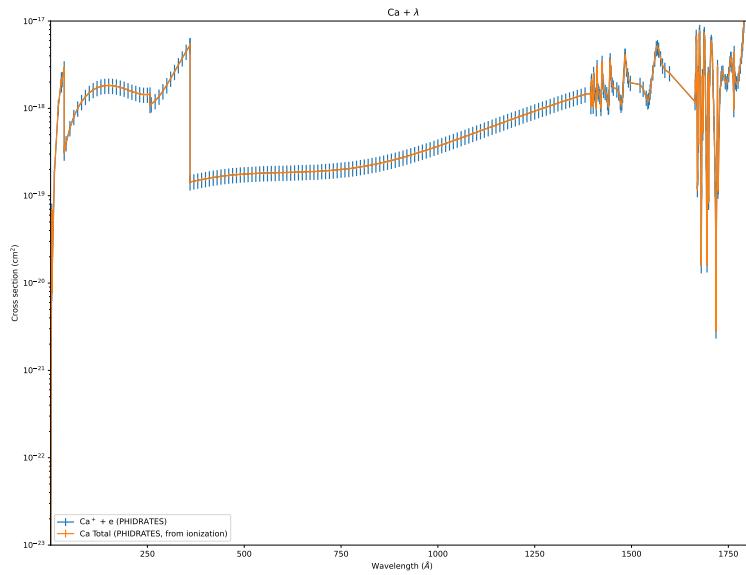
**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi PHDRATES	0	5.753327:124000	5%	Fig. 1.135	1.136
Revi PHDRATES	0	5.753327:124000	20%	Fig. 1.141	1.142

Table 1.32: Total cross section for  $\lambda$  impact on Ca

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$\text{Ca} + \lambda \rightarrow \text{Ca}^+ + e^-$	Revi PHIDRATES	5.753327	5.753327:124000	20%		Fig. 1.135 1.136 1.137 1.138
	Revi PHIDRATES	5.753327	5.753327:124000	20%		Fig. 1.139 1.140

Table 1.33: Ionization Cross section for  $\lambda$  impact on Ca

Figure 1.135: Cross sections for  $\text{Ca} + \lambda$ Figure 1.136: Cross sections for  $\text{Ca} + \lambda$  (wavelength version)

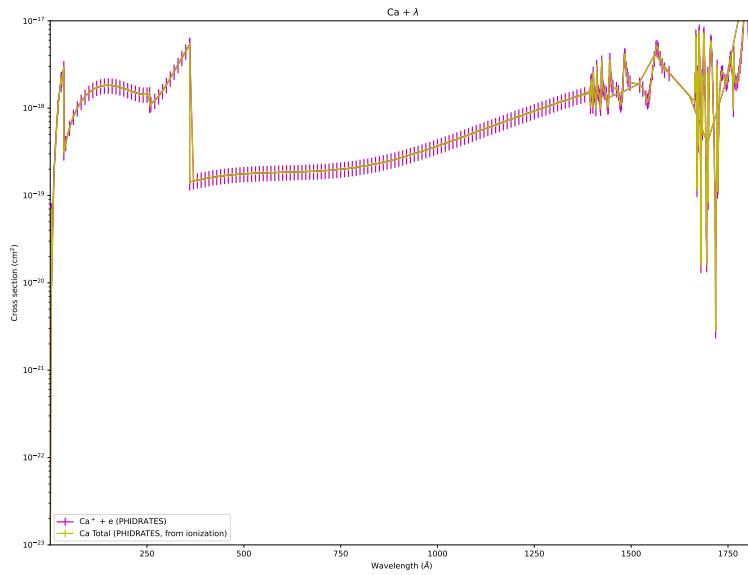


Figure 1.137: Cross sections for  $\text{Ca} + \lambda$  (with extrapolation version)

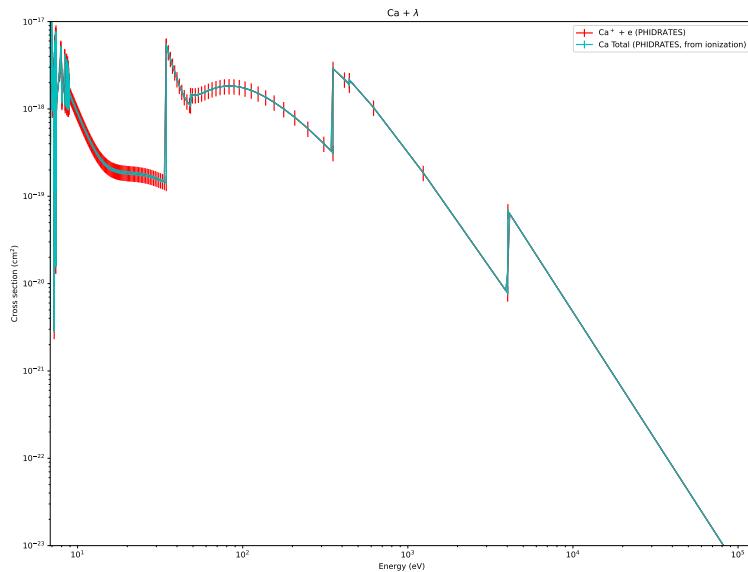
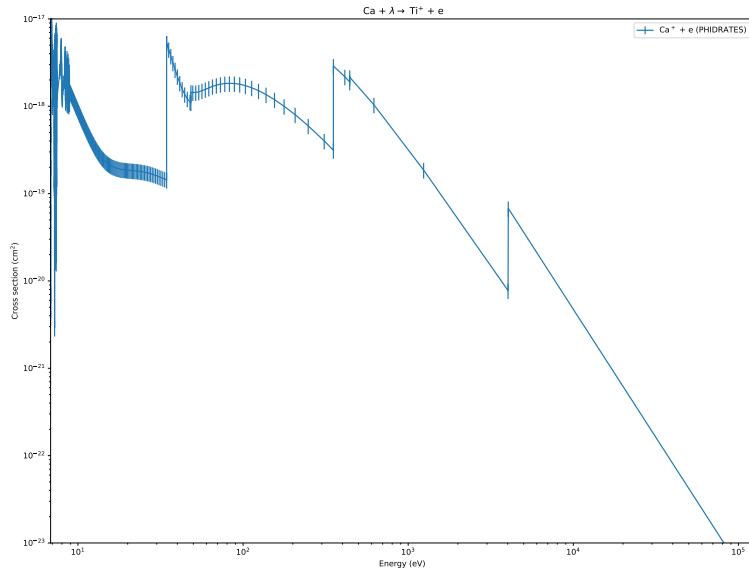
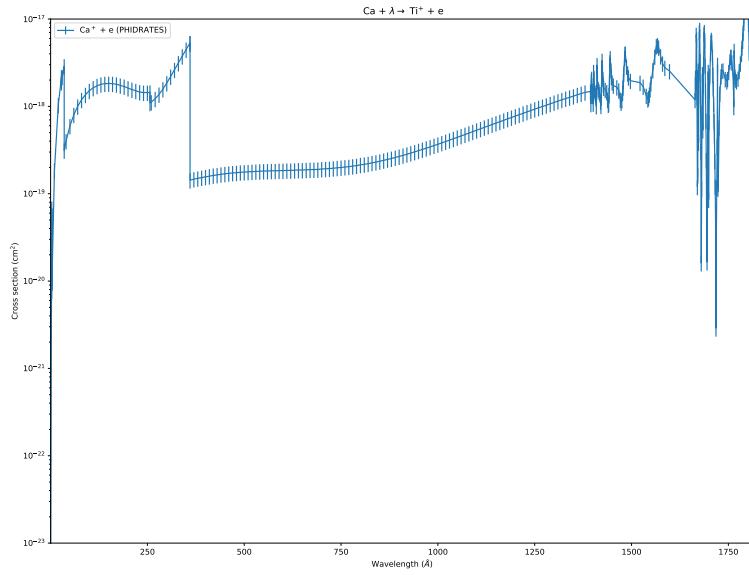


Figure 1.138: Cross sections for  $\text{Ca} + \lambda$  (wavelength with extrapolation version)

Figure 1.139: Cross sections for  $\text{Ca} + \lambda \rightarrow \text{Ti}^+ + e$ Figure 1.140: Cross sections for  $\text{Ca} + \lambda \rightarrow \text{Ti}^+ + e$  (wavelength version)

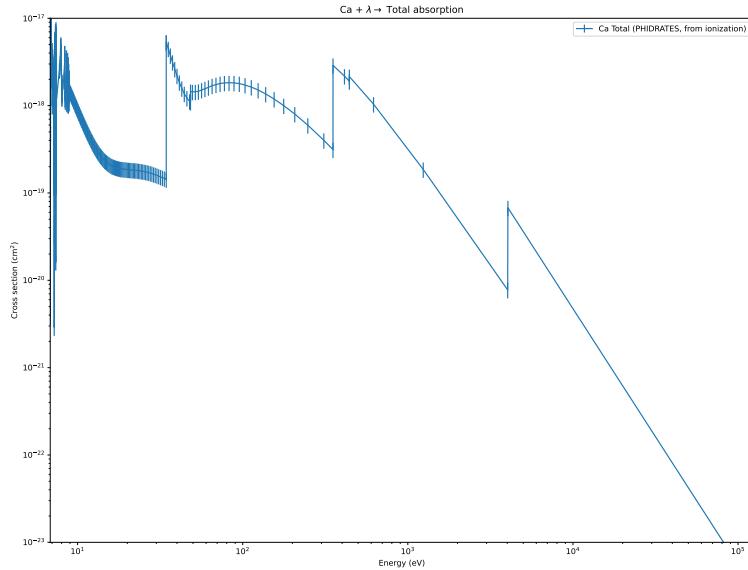


Figure 1.141: Cross sections for  $\text{Ca} + \lambda \rightarrow \text{Total absorption}$

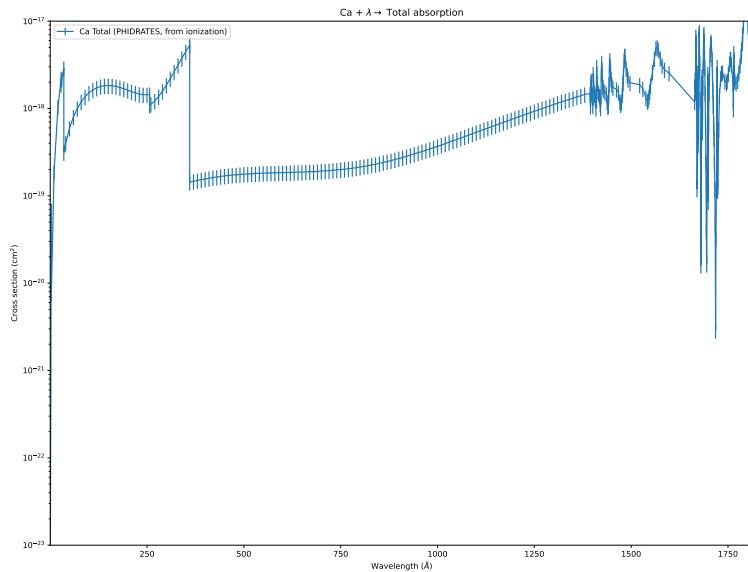


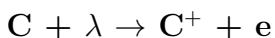
Figure 1.142: Cross sections for  $\text{Ca} + \lambda \rightarrow \text{Total absorption}$  (wavelength version)

## 1.10 Cross section of ph impact with C

### 1.10.1 Total Cross Section

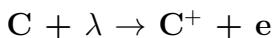
### 1.10.2 Inelastic Cross Sections

#### Ionization Cross Sections

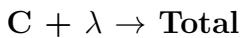


**C ionization (PHIDRATES)** Total photoionization of C from the review of PHIDRATES [24]. The uncertainty, not claimed by the review, is estimated at 20%. The data, in nm, have been directly adapted in eV.

### 1.10.3 Recommended data set



**C ionization (PHIDRATES)** Total photoionization of C from the review of PHIDRATES [24]. The uncertainty, not claimed by the review, is estimated at 20%. The data, in nm, have been directly adapted in eV.



**Al total absorption (PHIDRATES)** Total photoabsorption of C from the review of PHIDRATES [24]: the total ionization was considered being the total cross section. The uncertainty, not claimed by the review, is estimated at 5%. The data, in nm, have been directly adapted in eV. We added a value in the beginning to prevent poor interpolation

#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi PHIDRATES	0	11.44:124000	5%		Fig. 1.145 1.146

Table 1.34: Total cross section for  $\lambda$  impact on C

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$C + \lambda \rightarrow C^+ + e$	Revi PHIDRATES	11.448	11.448218:124000	20%		Fig. 1.143 1.144

Table 1.35: Ionization Cross section for  $\lambda$  impact on C

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$C + \lambda \rightarrow C^+ + e$	Revi PHIDRATES	11.448	11.448:18.124000	20%	Fig. 1.147 1.148 1.149 1.150	
$C + \lambda \rightarrow \text{Total}$	Revi PHIDRATES	0	11.44:124000	5%		Fig. 1.147 1.148 1.149 1.150

Table 1.36: Recommended Cross section for  $\lambda$  impact on C

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

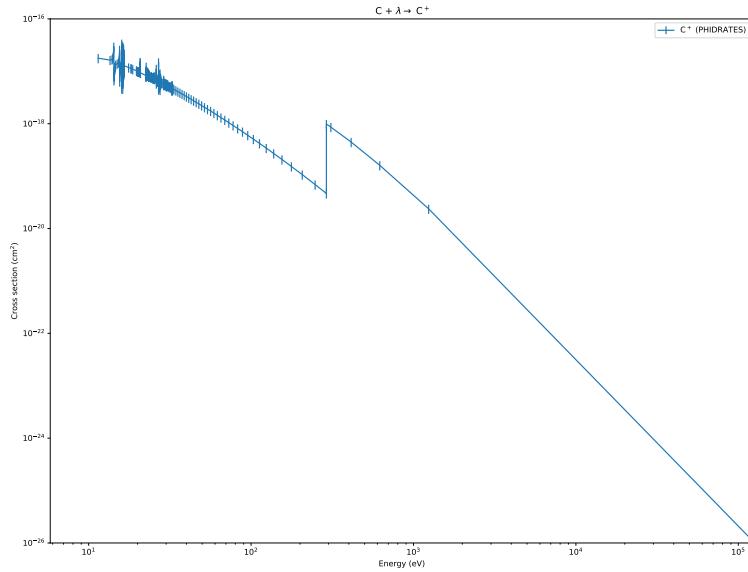


Figure 1.143: Cross sections for  $\text{C} + \lambda \rightarrow \text{C}^+$

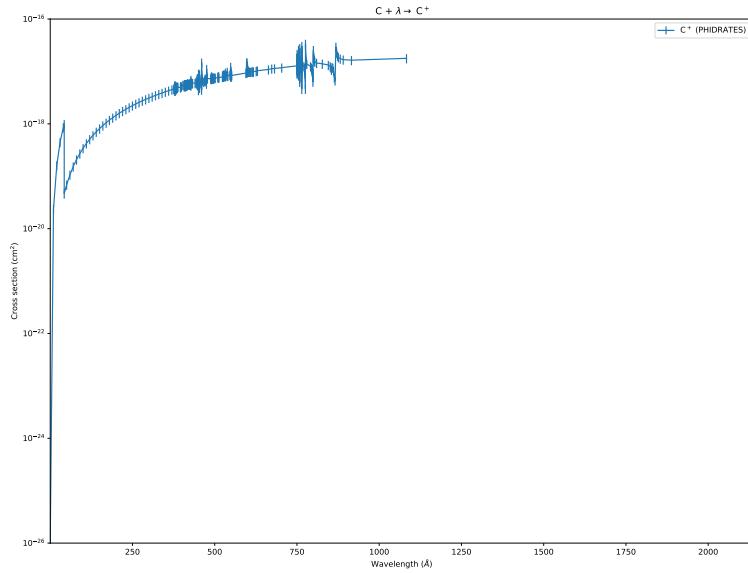


Figure 1.144: Cross sections for  $\text{C} + \lambda \rightarrow \text{C}^+$  (wavelength version)

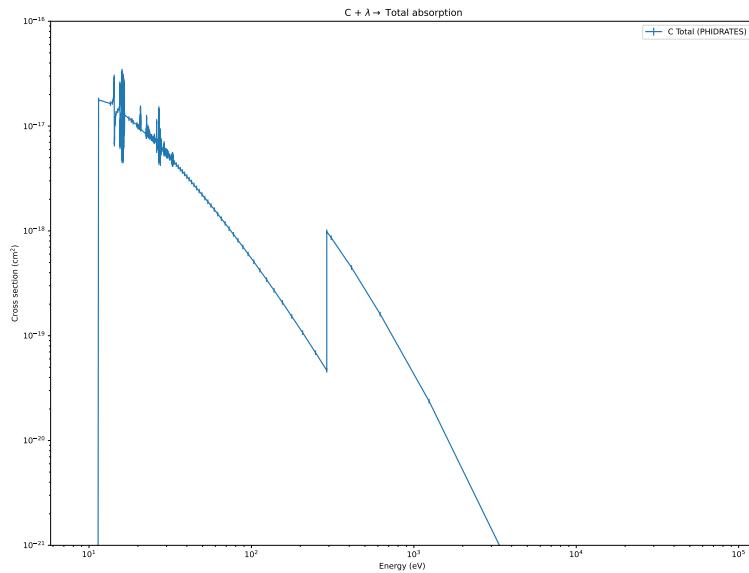


Figure 1.145: Cross sections for  $C + \lambda \rightarrow$  Total absorption

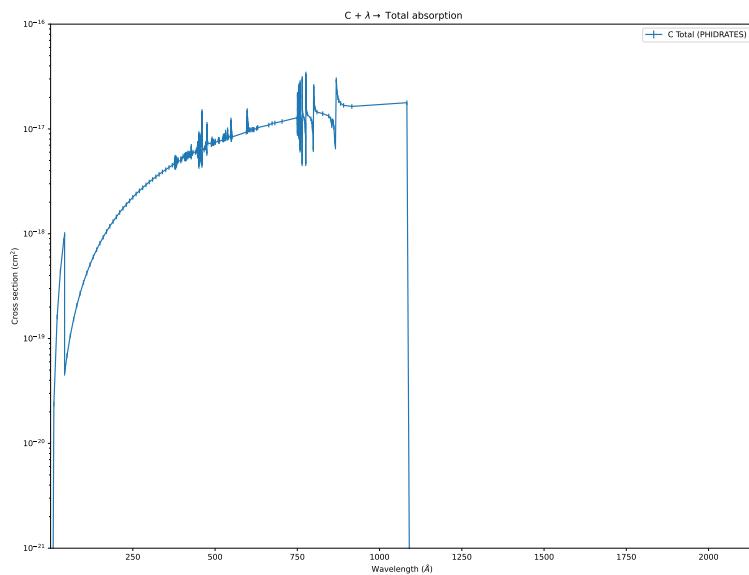
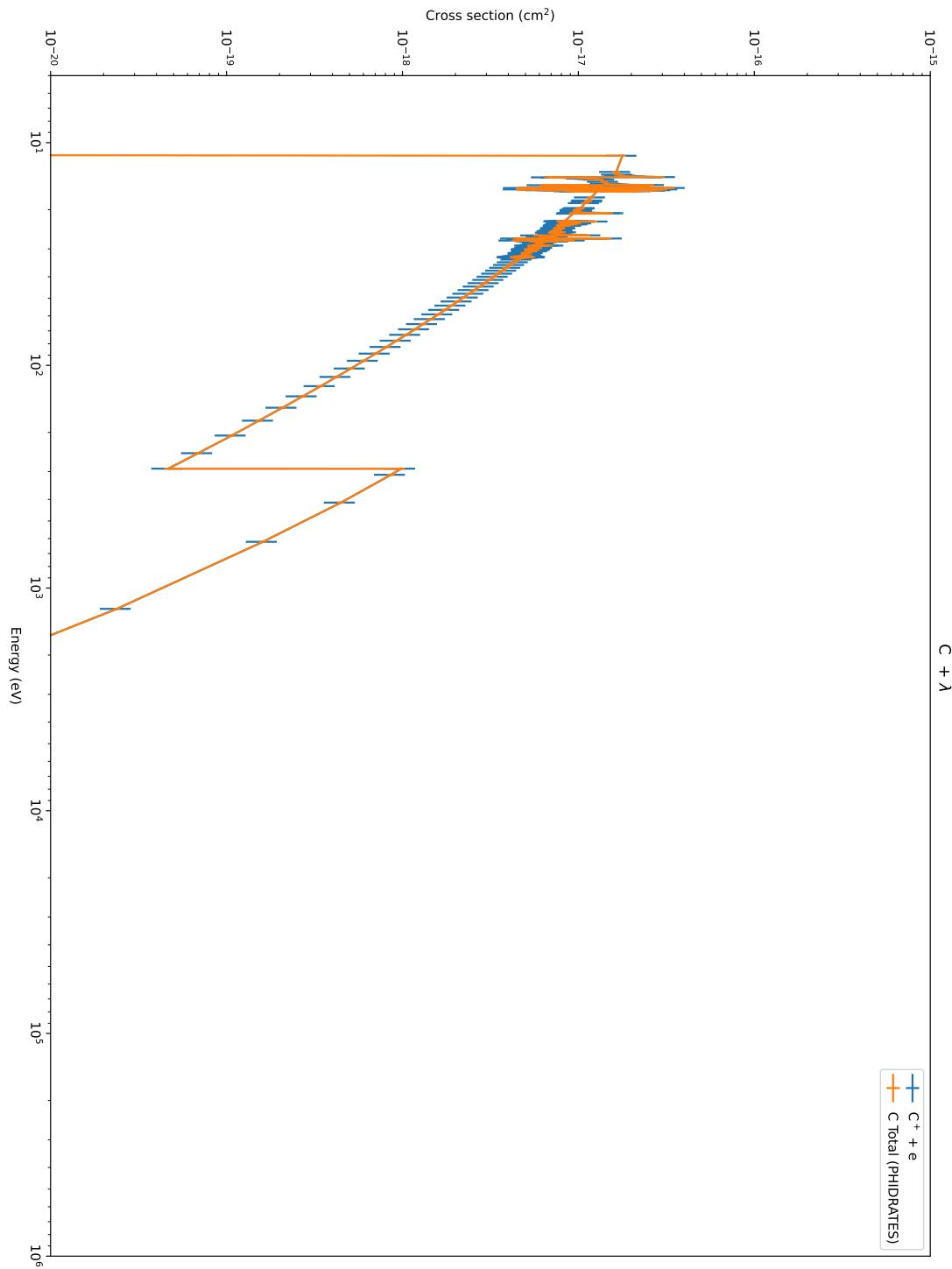
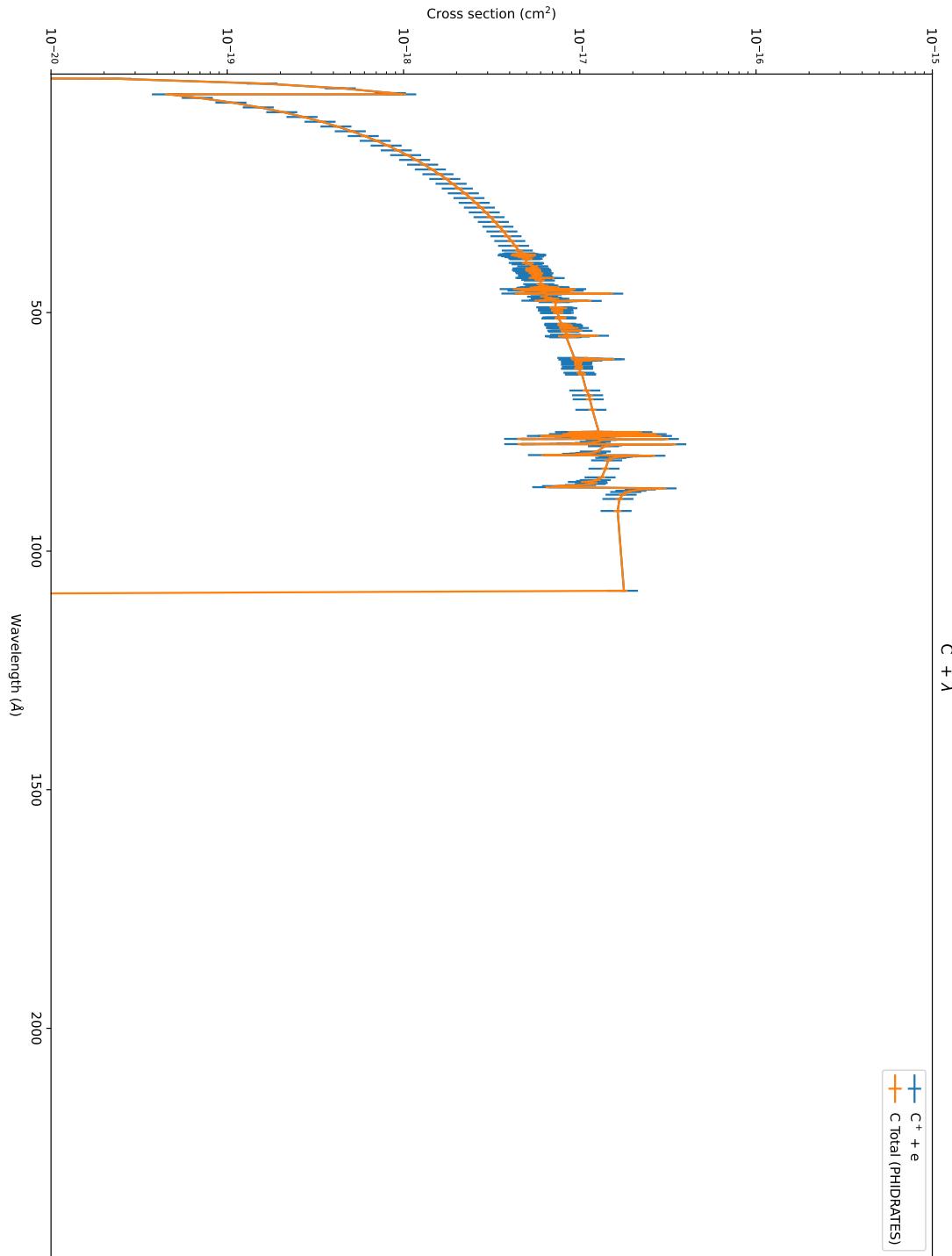
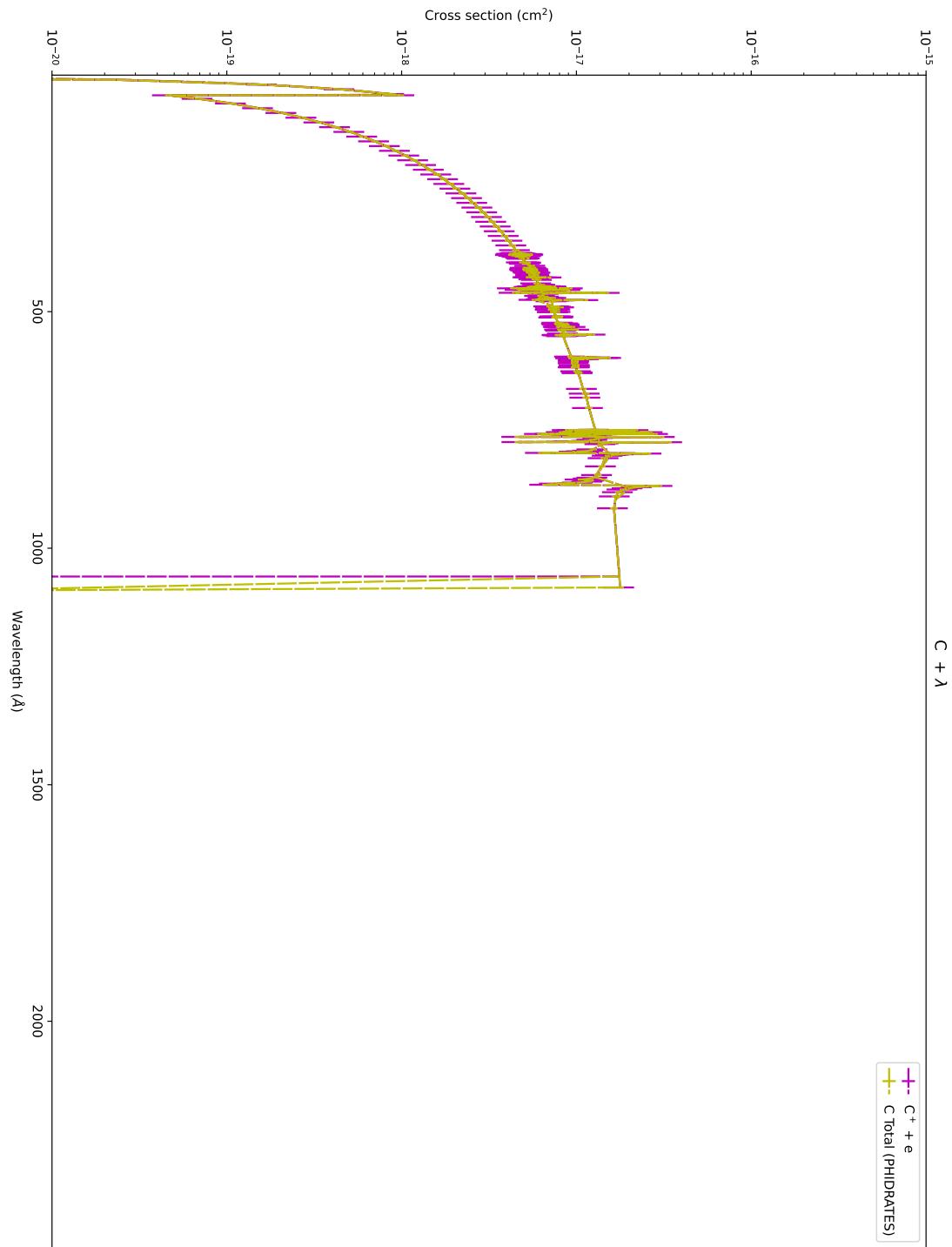


Figure 1.146: Cross sections for  $C + \lambda \rightarrow$  Total absorption (wavelength version)

Figure 1.147: Cross sections for  $\text{C} + \lambda$

Figure 1.148: Cross sections for  $C + \lambda$  (wavelength version)

Figure 1.149: Cross sections for  $\text{C} + \lambda$  (with extrapolation version)

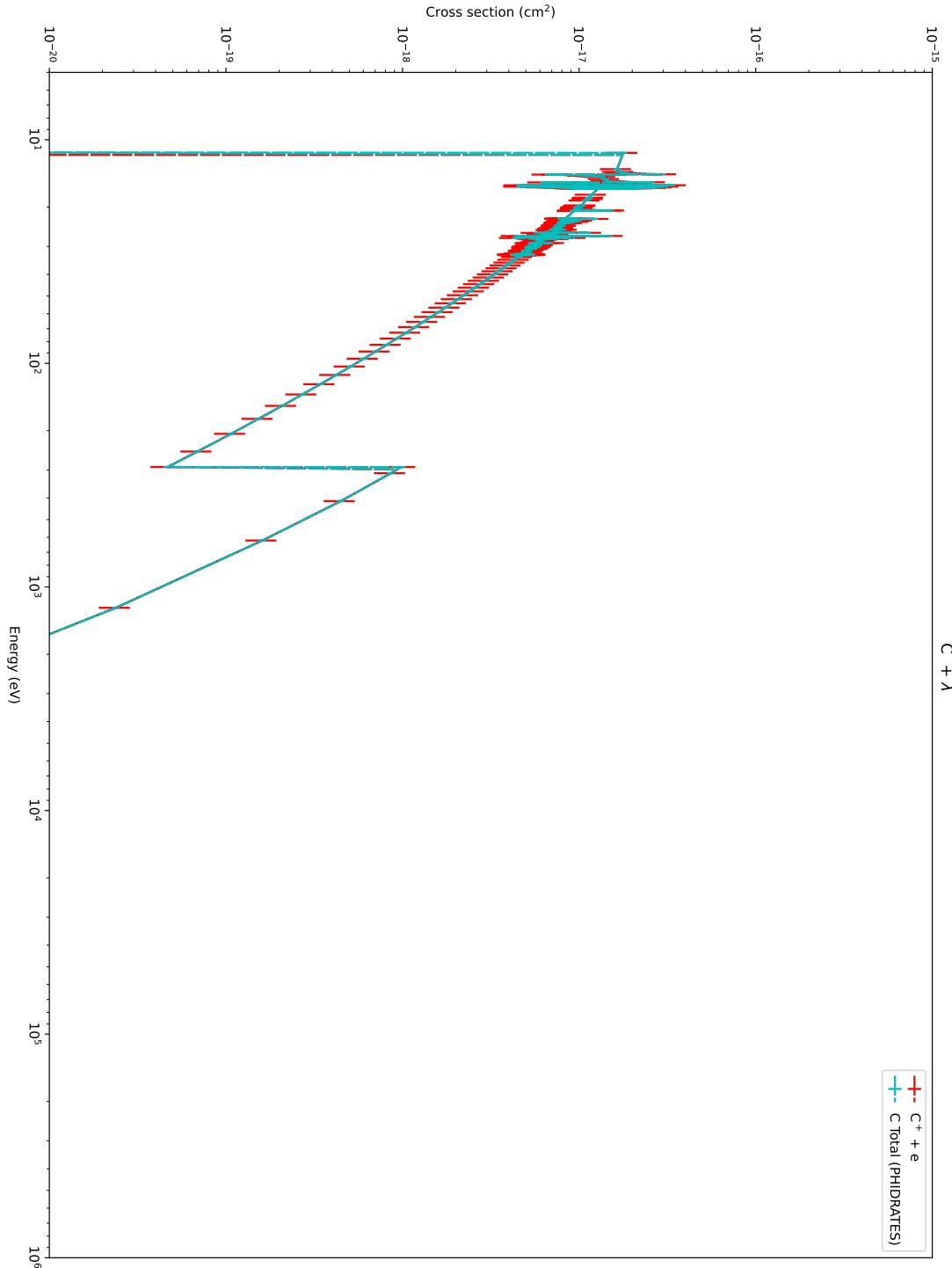


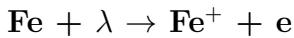
Figure 1.150: Cross sections for  $\text{C} + \lambda$  (wavelength with extrapolation version)

## 1.11 Cross section of ph impact with Fe

### 1.11.1 Total Cross Section

### 1.11.2 Inelastic Cross Sections

#### Ionization Cross Sections



**Fe<sup>+</sup> + e (PHIDRATES)** Photoionization of Fe yielding Fe<sup>+</sup> + e from the review of PHIDRATES.[24] The uncertainty, not claimed by the review, is estimated at 20%. The data, in nm, have been directly adapted in eV.

**Fe<sup>+</sup> + e (PHIDRATES)** Photoionization of Fe yielding Fe<sup>+</sup> + e from the review of PHIDRATES.[24] The uncertainty, not claimed by the review, is estimated at 20%. The data, in nm, have been directly adapted in eV.

#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

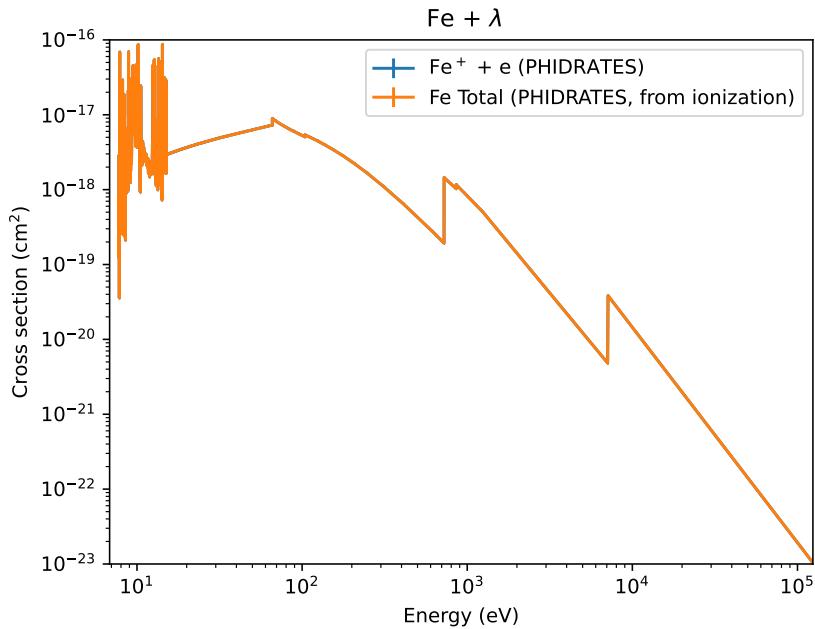
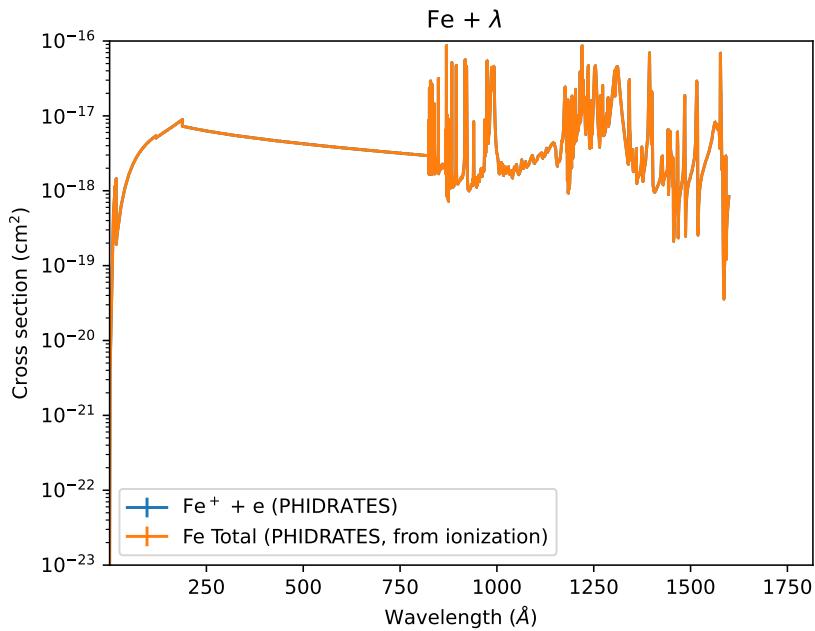
**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

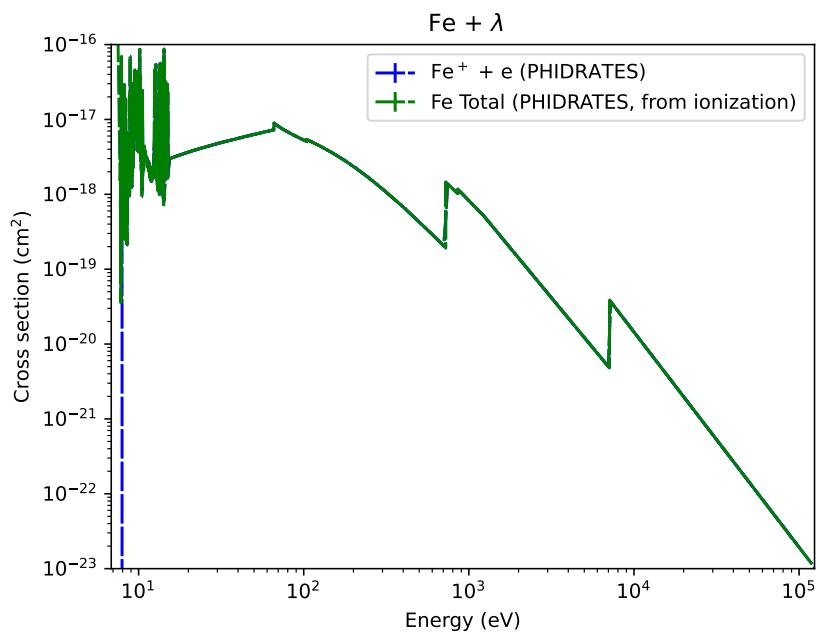
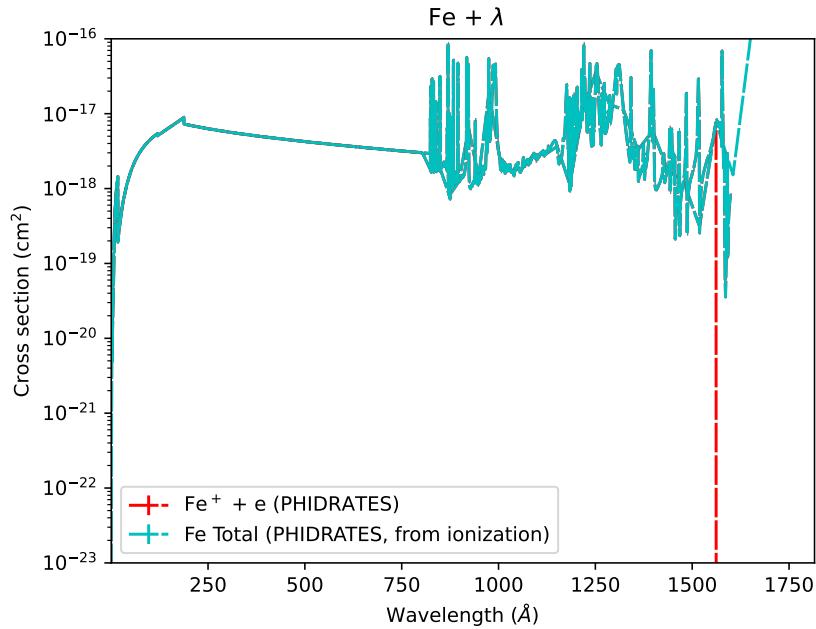
Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi PHDRATES	0	7.753859:124000	??:%	U	Fig. 1.151 1.152 1.153 1.154
Revi PHDRATES	0	7.753859:124000	??:%	U	Fig. 1.157 1.158

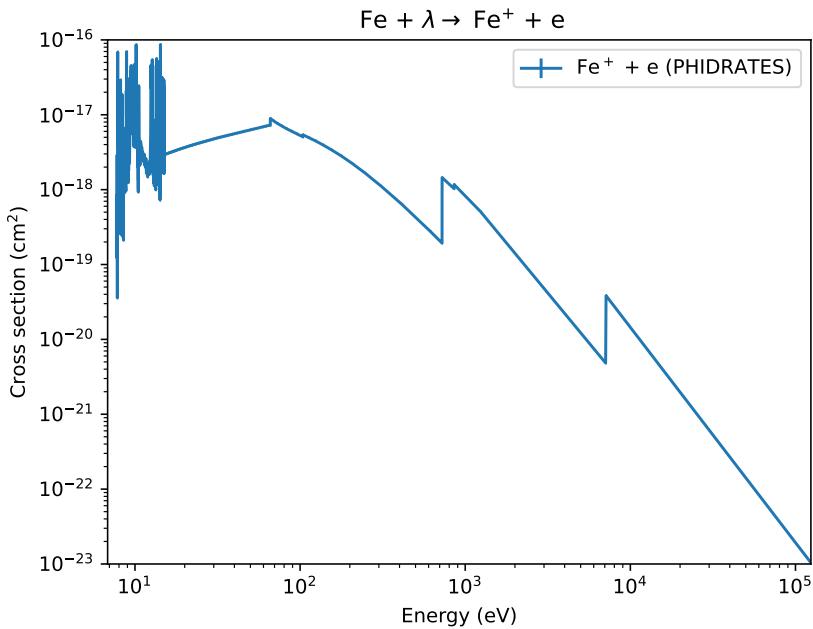
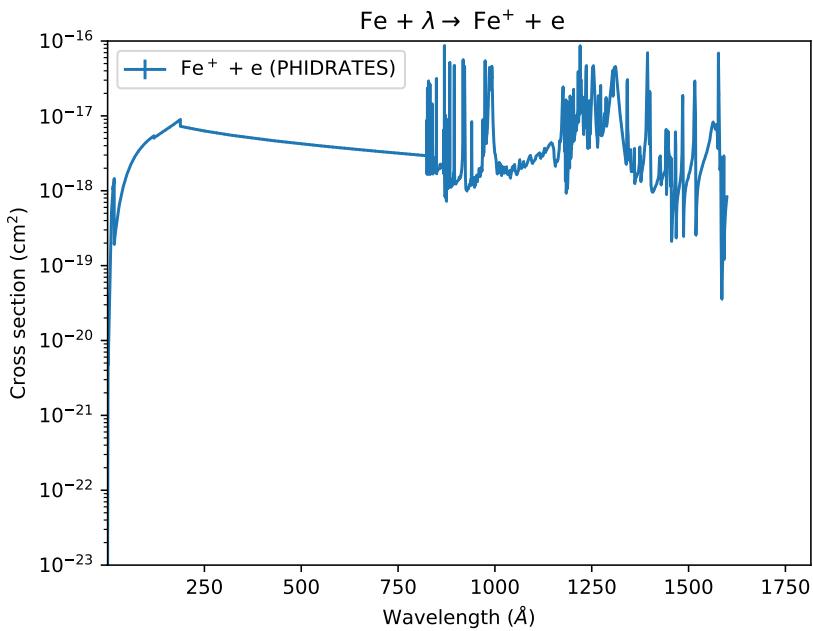
Table 1.37: Total cross section for  $\lambda$  impact on Fe

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$\text{Fe} + \lambda \rightarrow \text{Fe}^+ + e^-$	Revi PHDRATES	7.753859	7.753859:1.24000	?%?	U	Fig. 1.151 1.152 1.153 1.154
	Revi PHDRATES	7.753859	7.753859:1.24000	?%?	U	Fig. 1.155 1.156

Table 1.38: Ionization Cross section for  $\lambda$  impact on Fe

Figure 1.151: Cross sections for  $\text{Fe} + \lambda$ Figure 1.152: Cross sections for  $\text{Fe} + \lambda$  (wavelength version)



Figure 1.155: Cross sections for  $\text{Fe} + \lambda \rightarrow \text{Fe}^+ + e$ Figure 1.156: Cross sections for  $\text{Fe} + \lambda \rightarrow \text{Fe}^+ + e$  (wavelength version)

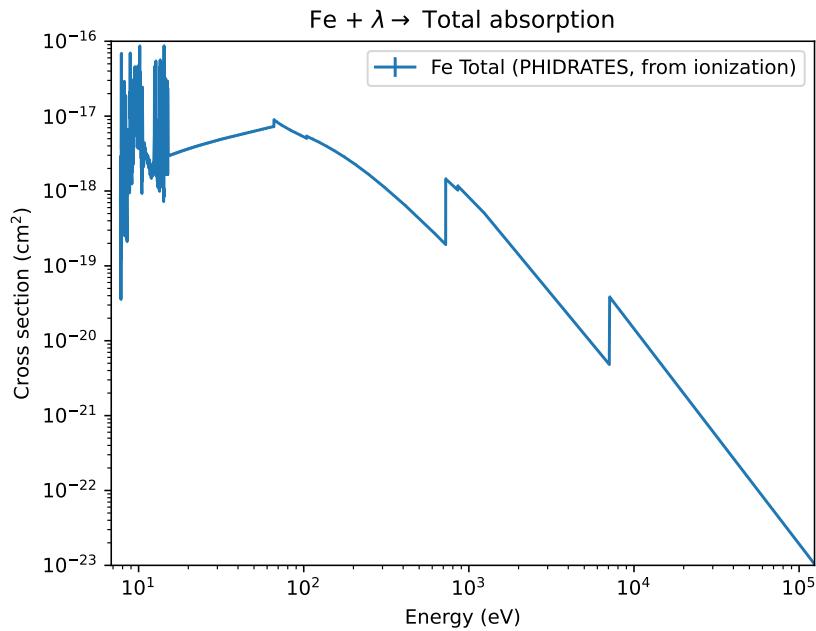


Figure 1.157: Cross sections for  $\text{Fe} + \lambda \rightarrow \text{Total absorption}$

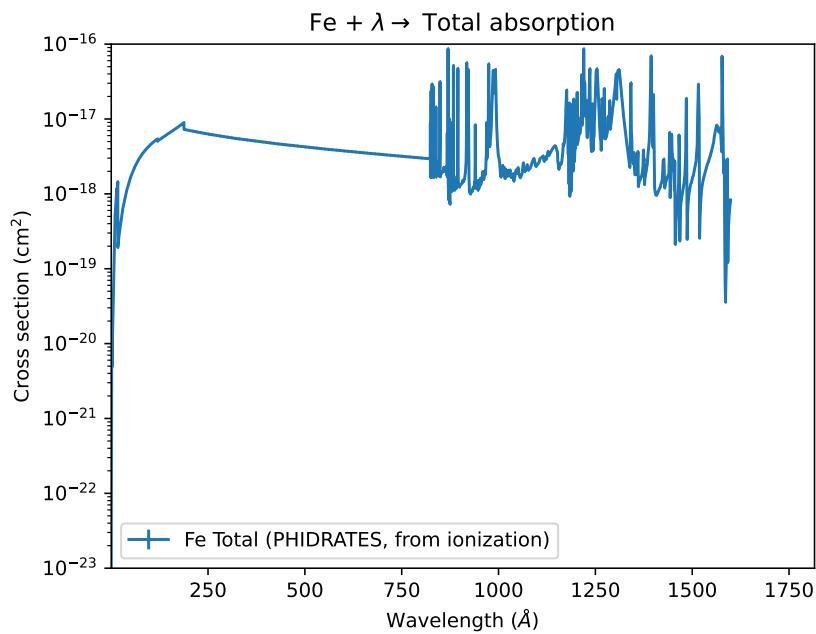


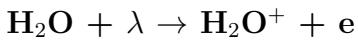
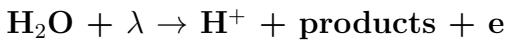
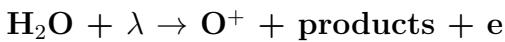
Figure 1.158: Cross sections for  $\text{Fe} + \lambda \rightarrow \text{Total absorption}$  (wavelength version)

## 1.12 Cross section of ph impact with H<sub>2</sub>O

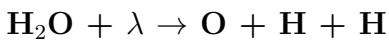
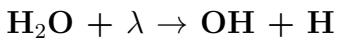
### 1.12.1 Total Cross Section

### 1.12.2 Inelastic Cross Sections

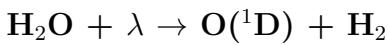
#### Ionization Cross Sections



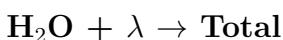
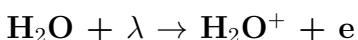
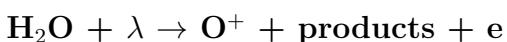
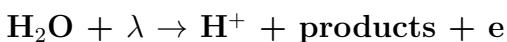
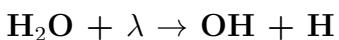
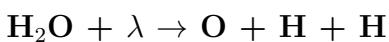
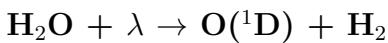
#### Dissociation Cross Sections



#### Excitation Cross Sections



### 1.12.3 Recommended data set



#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi [3]	0	0:-1	20%		Fig. 1.171 1.172
Meas [77]	0	0:-1	???	U	Fig. 1.171 1.172
Revi PHIDRATES	0	0:-1	???	U	Fig. 1.171 1.172
Meas CFAMOL	0	0:-1	???	U	Fig. 1.171 1.172
Adap [3] + PHIDRATES + CFAMOL	0	0:-1	???	RUE	Fig. 1.171 1.172

Table 1.39: Total cross section for  $\lambda$  impact on H<sub>2</sub>O

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$H_2O + \lambda \rightarrow O^+ + \text{products} + e^-$	Revi AMOP	18.7	18.7:-1	20%	R	Fig. 1.159 1.160
$H_2O + \lambda \rightarrow H^+ + \text{products} + e^-$	Revi PHIDRATES	18.7	18.7:-1	20%	R	Fig. 1.161 1.162
$H_2O + \lambda \rightarrow H_2O^+ + e^-$	Revi [3] Revi PHIDRATES [24]	12.593 12.593	12.593:-1 12.593:-1	20% <span style="color:red">??%</span>	U	Fig. 1.169 1.170 Fig. 1.169 1.170

Table 1.40: Ionization Cross section for  $\lambda$  impact on  $H_2O$

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$\text{H}_2\text{O} + \lambda \rightarrow \text{OH} + \text{H}$	Revi PHDRATES	6.665	6.665:-1	??% ??%	U	Fig. 1.165 1.166
$\text{H}_2\text{O} + \lambda \rightarrow \text{O} + \text{H} + \text{H}$	Revi PHDRATES	9.50	9.50:-1	??% ??%	RU	Fig. 1.167 1.168

Table 1.41: Dissociation Cross section for  $\lambda$  impact on  $\text{H}_2\text{O}$

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
H <sub>2</sub> O + λ → O( <sup>1</sup> D) + H <sub>2</sub>	Revi PHIDRATES	8.6	8.6:-1	??% ??%	RU	Fig. 1.163 1.164

Table 1.42: Excitation Cross section for λ impact on H<sub>2</sub>O

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$\text{H}_2\text{O} + \lambda \rightarrow \text{O}({}^1\text{D}) + \text{H}_2$	Revi PHIDRATES	8.6	8.6:-1	20%	R	Fig. 1.173 1.174 1.175 1.176
$\text{H}_2\text{O} + \lambda \rightarrow \text{O} + \text{H} + \text{H}$	Revi PHIDRATES	9.50	9.50:-1	20%	R	Fig. 1.173 1.174 1.175 1.176
$\text{H}_2\text{O} + \lambda \rightarrow \text{OH} + \text{H}$	Revi PHIDRATES	6.665	6.665:-1	20%		Fig. 1.173 1.174 1.175 1.176
$\text{H}_2\text{O} + \lambda \rightarrow \text{H}^+ + \text{products} + \text{e}$	Revi PHIDRATES	18.7	18.7:-1	20%	R	Fig. 1.173 1.174 1.175 1.176
$\text{H}_2\text{O} + \lambda \rightarrow \text{O}^+ + \text{products} + \text{e}$	Revi PHIDRATES	18.7	18.7:-1	20%	R	Fig. 1.173 1.174 1.175 1.176
$\text{H}_2\text{O} + \lambda \rightarrow \text{H}_2\text{O}^+ + \text{e}$	Revi PHIDRATES	12.593	12.593:-1	20%		Fig. 1.173 1.174 1.175 1.176
$\text{H}_2\text{O} + \lambda \rightarrow \text{Total}$	Adap [3] + PHIDRATES + CFAMOL	0	0:-1	15%	RUE	Fig. 1.173 1.174 1.175 1.176

Table 1.43: Recommended Cross section for  $\lambda$  impact on  $\text{H}_2\text{O}$

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

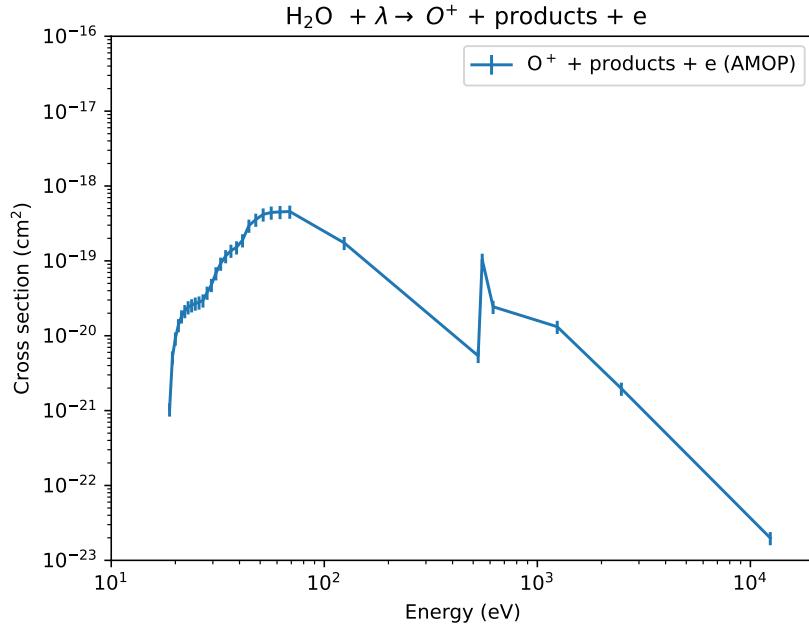


Figure 1.159: Cross sections for  $\text{H}_2\text{O} + \lambda \rightarrow \text{O}^+ + \text{products} + \text{e}$

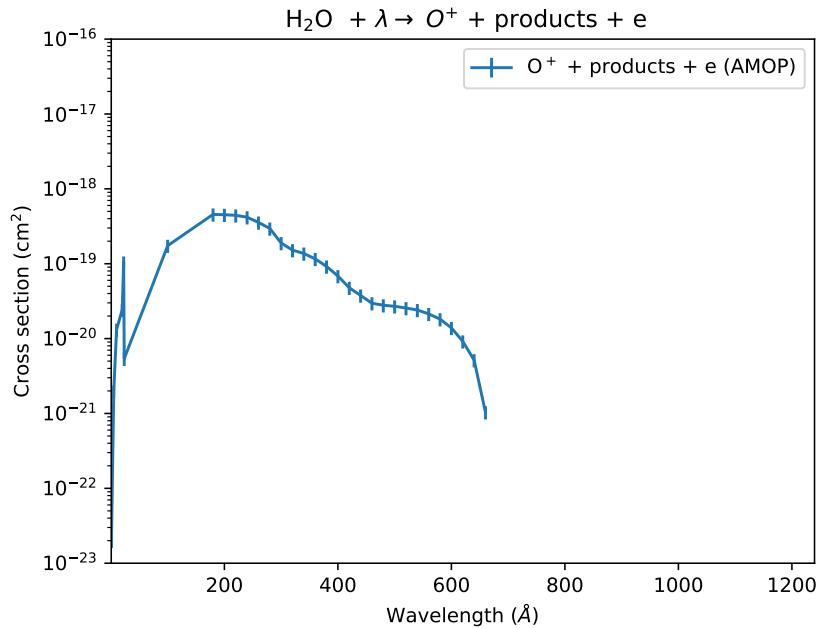


Figure 1.160: Cross sections for  $\text{H}_2\text{O} + \lambda \rightarrow \text{O}^+ + \text{products} + \text{e}$  (wavelength version)

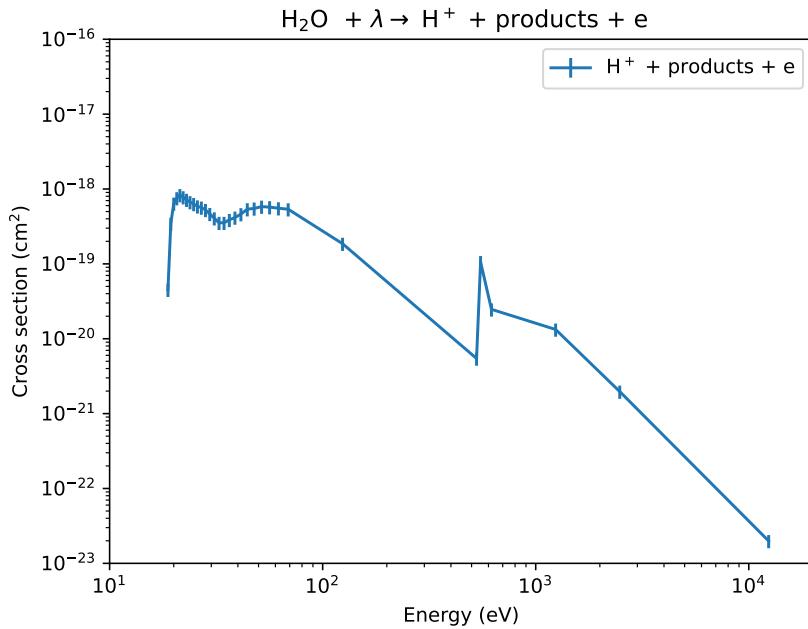


Figure 1.161: Cross sections for  $H_2O + \lambda \rightarrow H^+ + \text{products} + e$

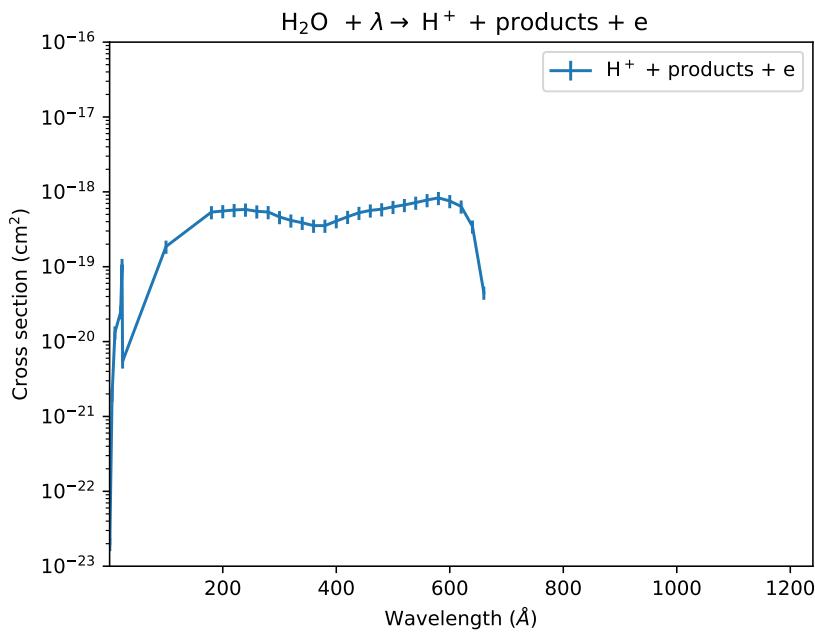


Figure 1.162: Cross sections for  $H_2O + \lambda \rightarrow H^+ + \text{products} + e$  (wavelength version)

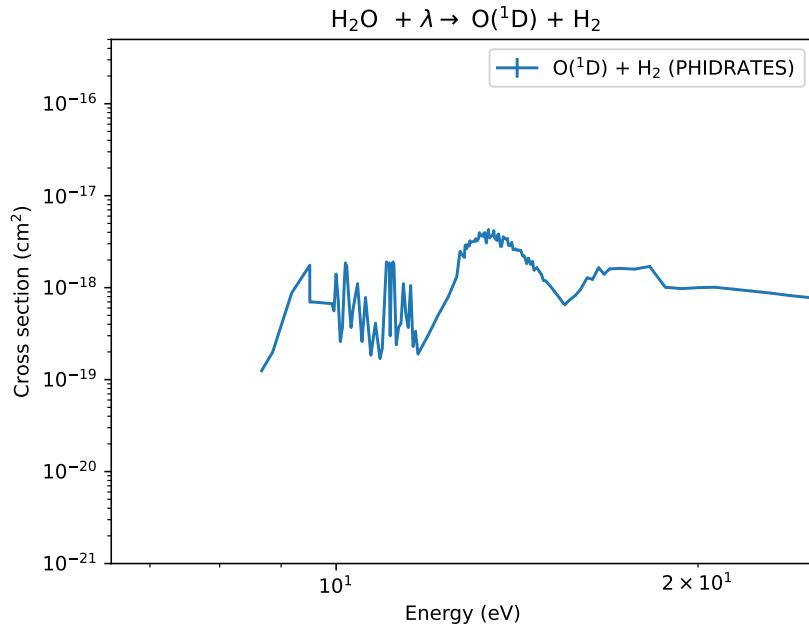


Figure 1.163: Cross sections for  $\text{H}_2\text{O} + \lambda \rightarrow \text{O}^{(1\text{D})} + \text{H}_2$

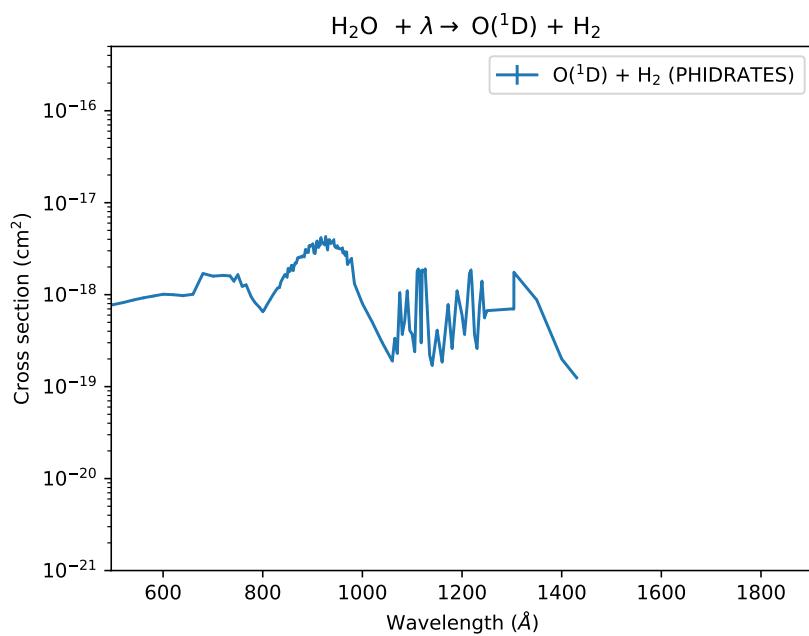
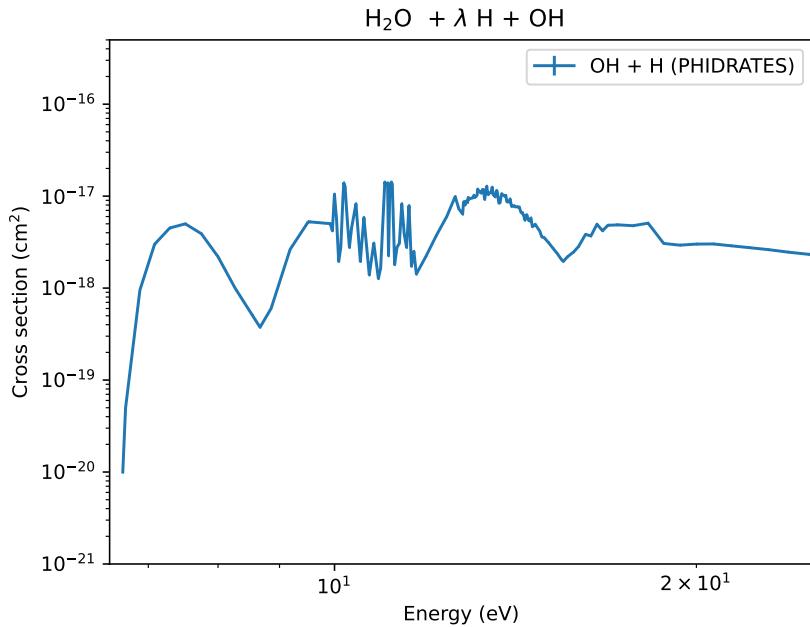
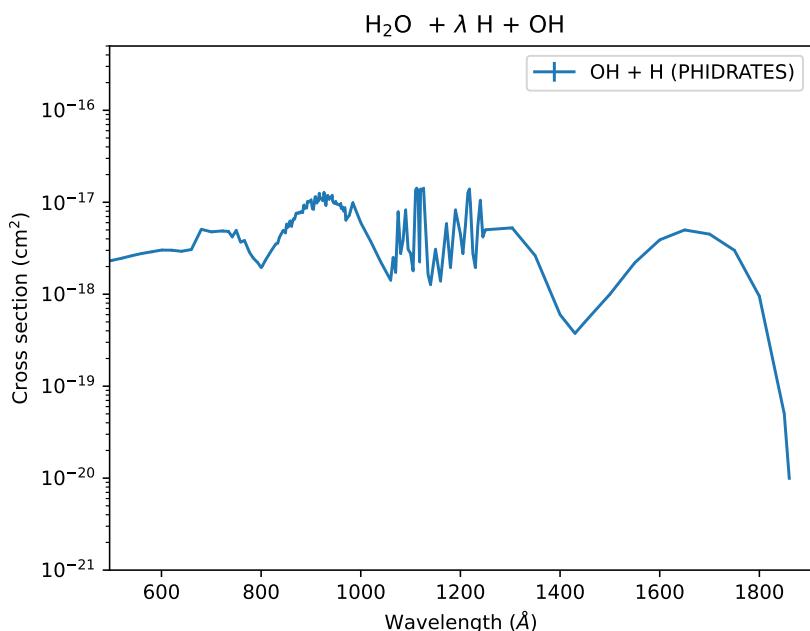


Figure 1.164: Cross sections for  $\text{H}_2\text{O} + \lambda \rightarrow \text{O}^{(1\text{D})} + \text{H}_2$  (wavelength version)

Figure 1.165: Cross sections for  $H_2O + \lambda H + OH$ Figure 1.166: Cross sections for  $H_2O + \lambda H + OH$  (wavelength version)

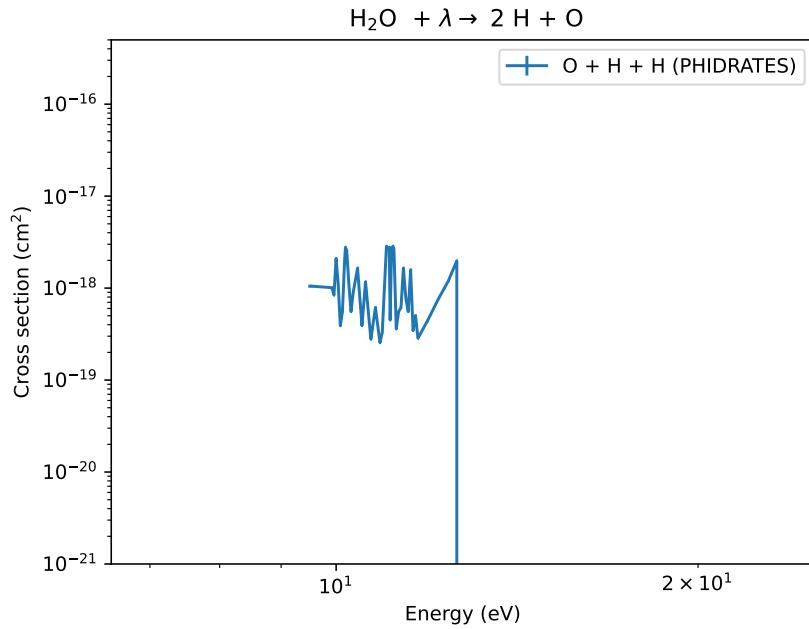


Figure 1.167: Cross sections for  $\text{H}_2\text{O} + \lambda \rightarrow 2 \text{ H} + \text{O}$

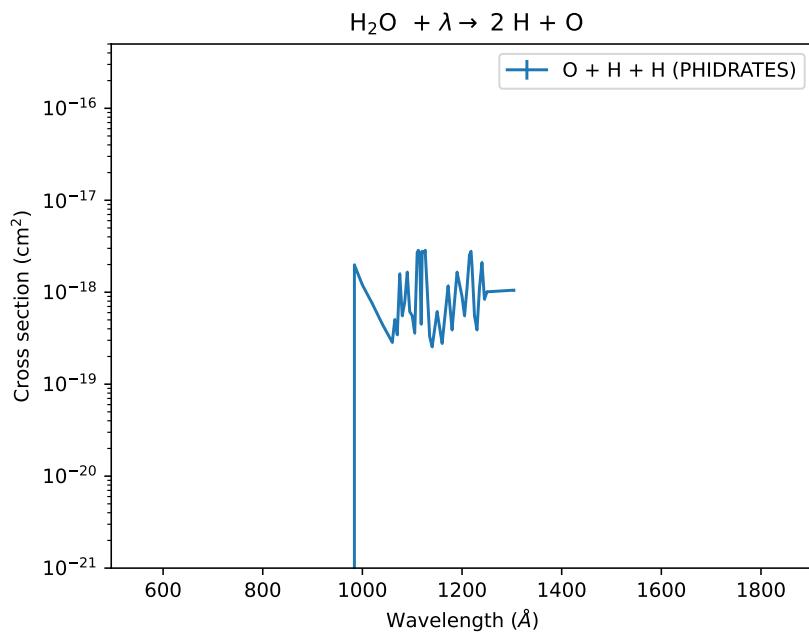
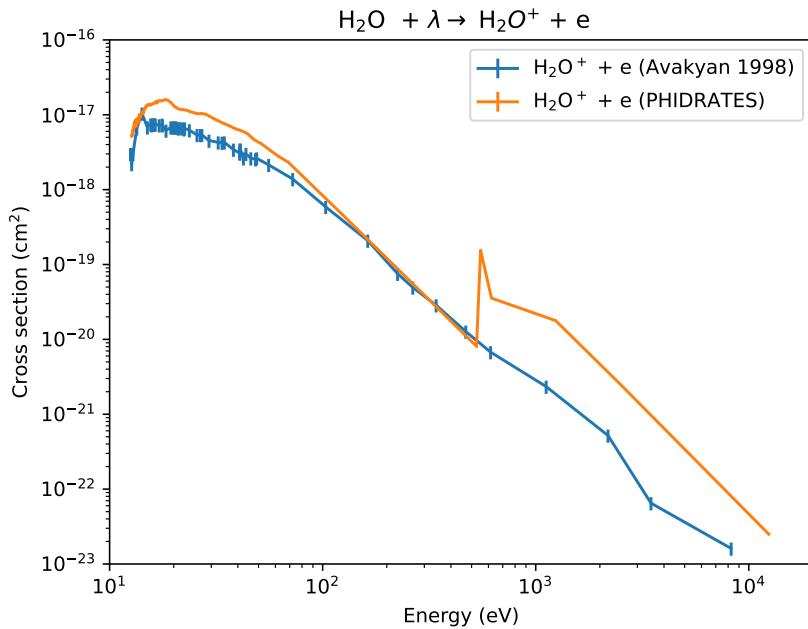
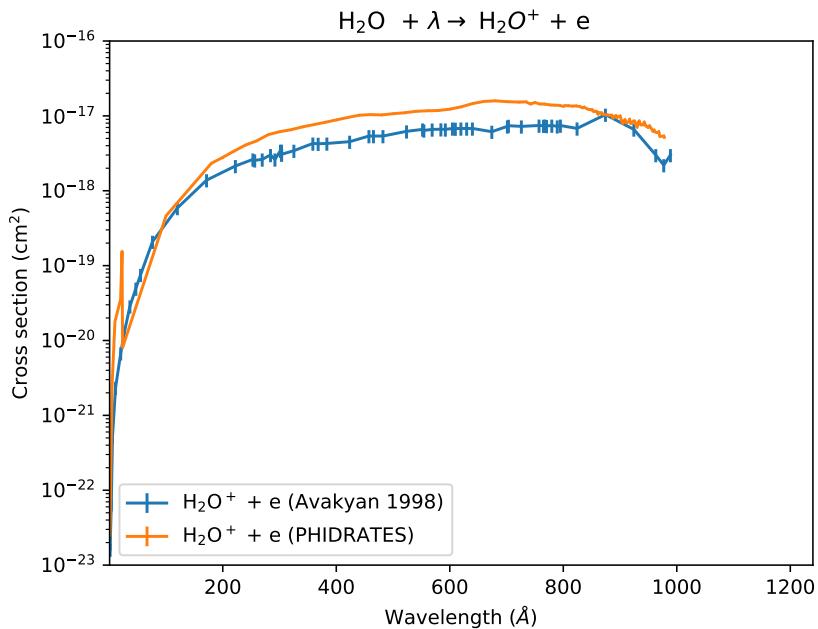


Figure 1.168: Cross sections for  $\text{H}_2\text{O} + \lambda \rightarrow 2 \text{ H} + \text{O}$  (wavelength version)

Figure 1.169: Cross sections for  $H_2O + \lambda \rightarrow H_2O^+ + e$ Figure 1.170: Cross sections for  $H_2O + \lambda \rightarrow H_2O^+ + e$  (wavelength version)

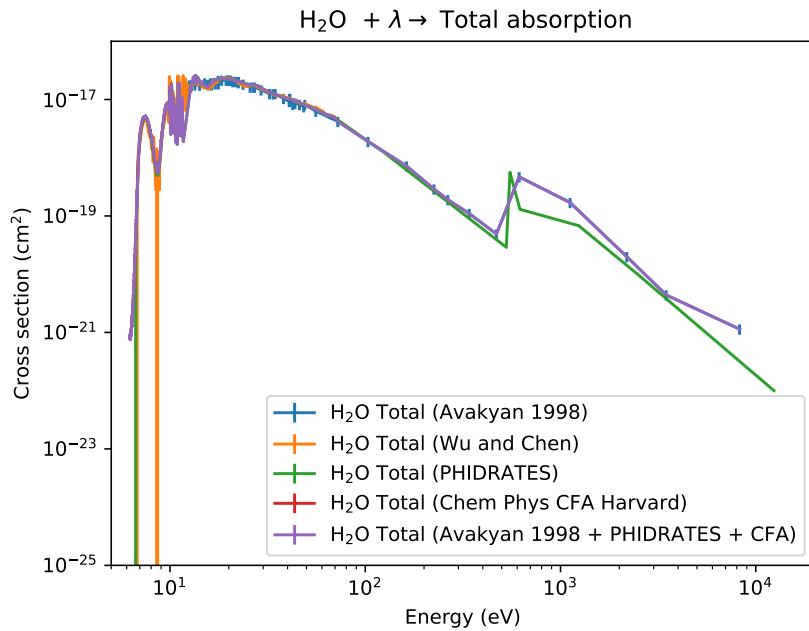


Figure 1.171: Cross sections for  $\text{H}_2\text{O} + \lambda \rightarrow \text{Total absorption}$

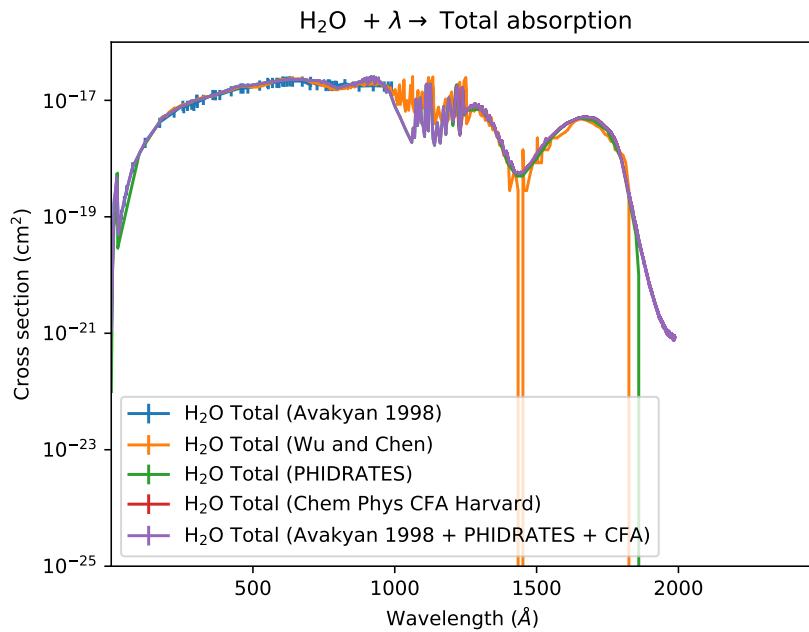
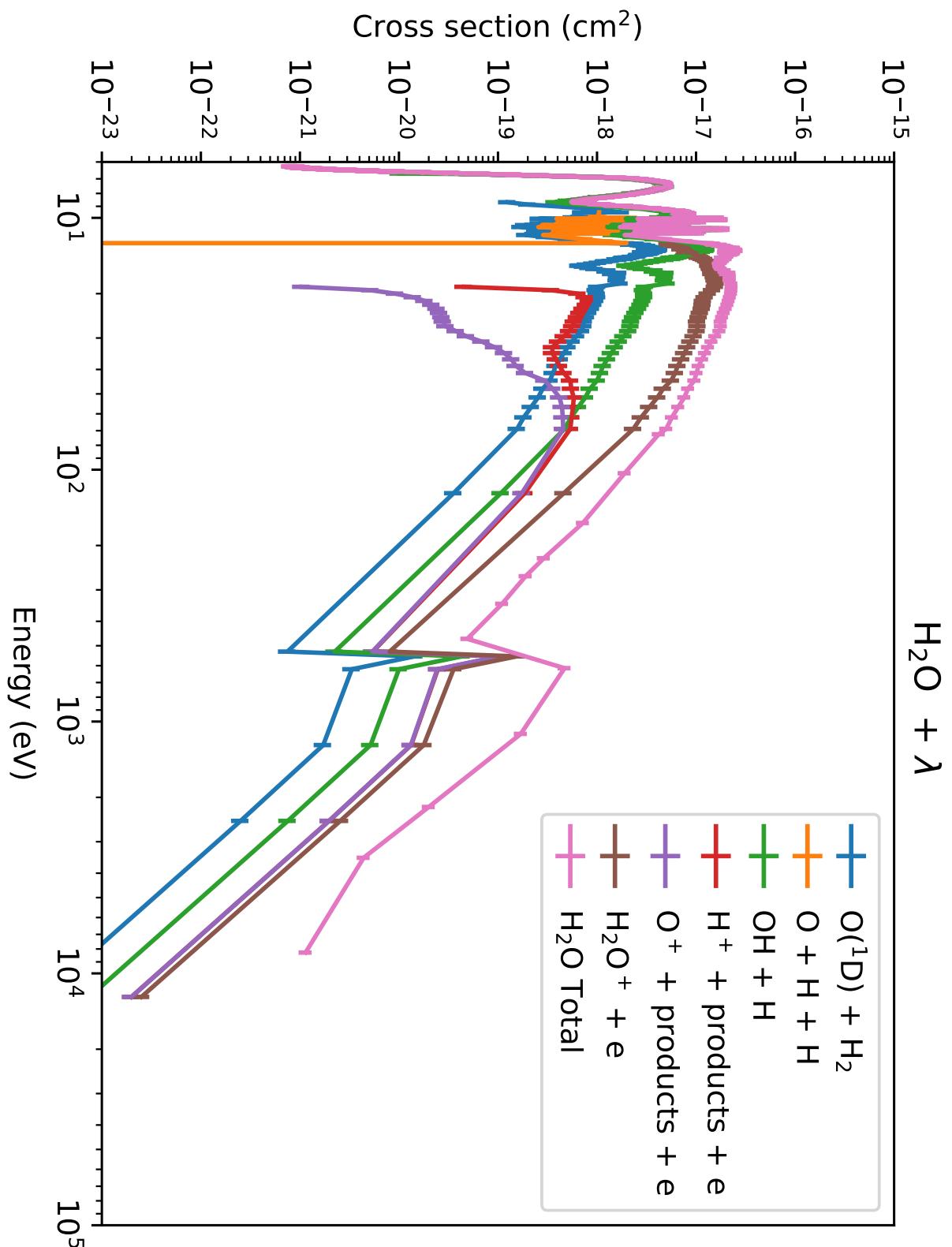
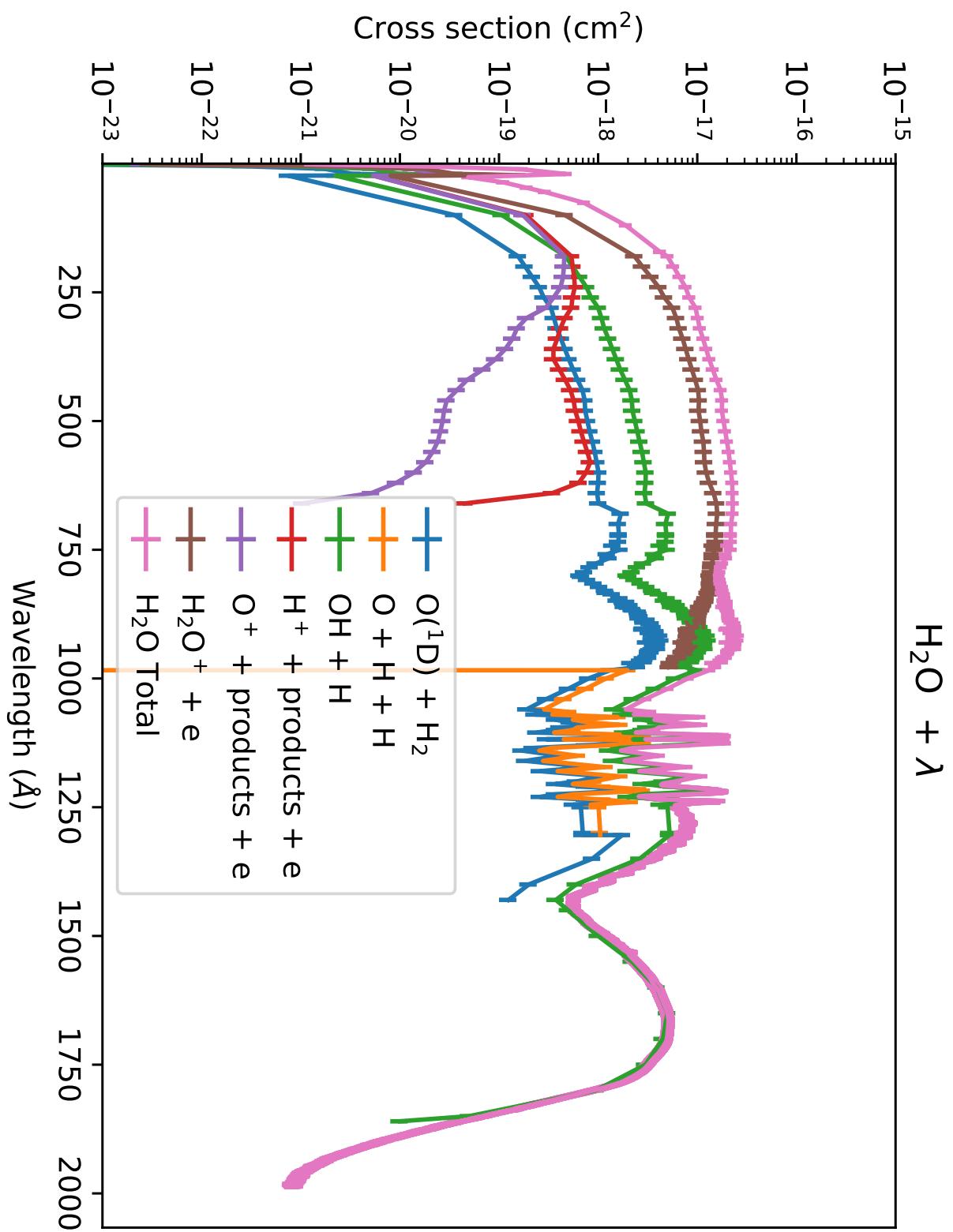
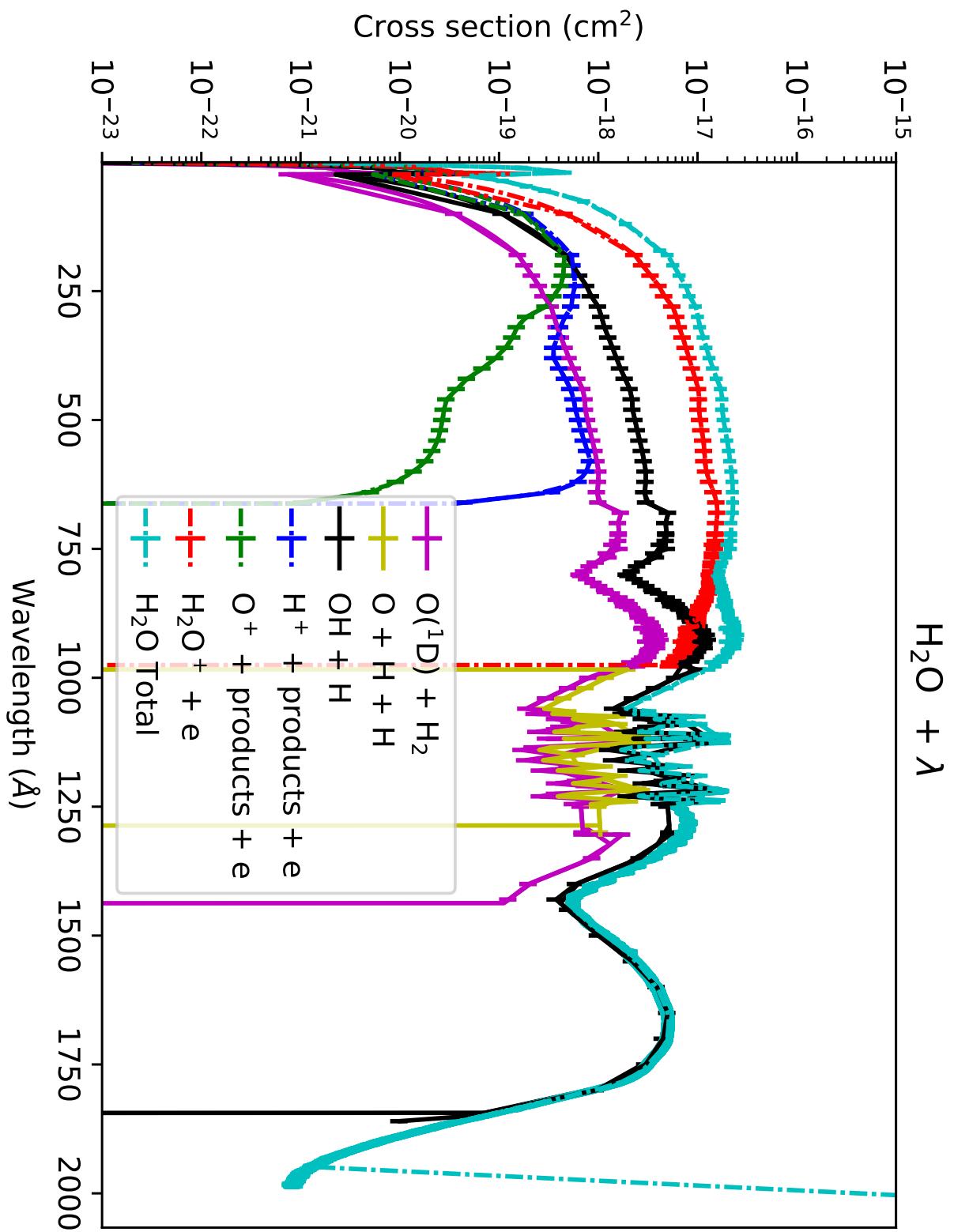


Figure 1.172: Cross sections for  $\text{H}_2\text{O} + \lambda \rightarrow \text{Total absorption}$  (wavelength version)

Figure 1.173: Cross sections for  $\text{H}_2\text{O} + \lambda$

Figure 1.174: Cross sections for  $\text{H}_2\text{O} + \lambda$  (wavelength version)

Figure 1.175: Cross sections for H<sub>2</sub>O + λ (with extrapolation version)

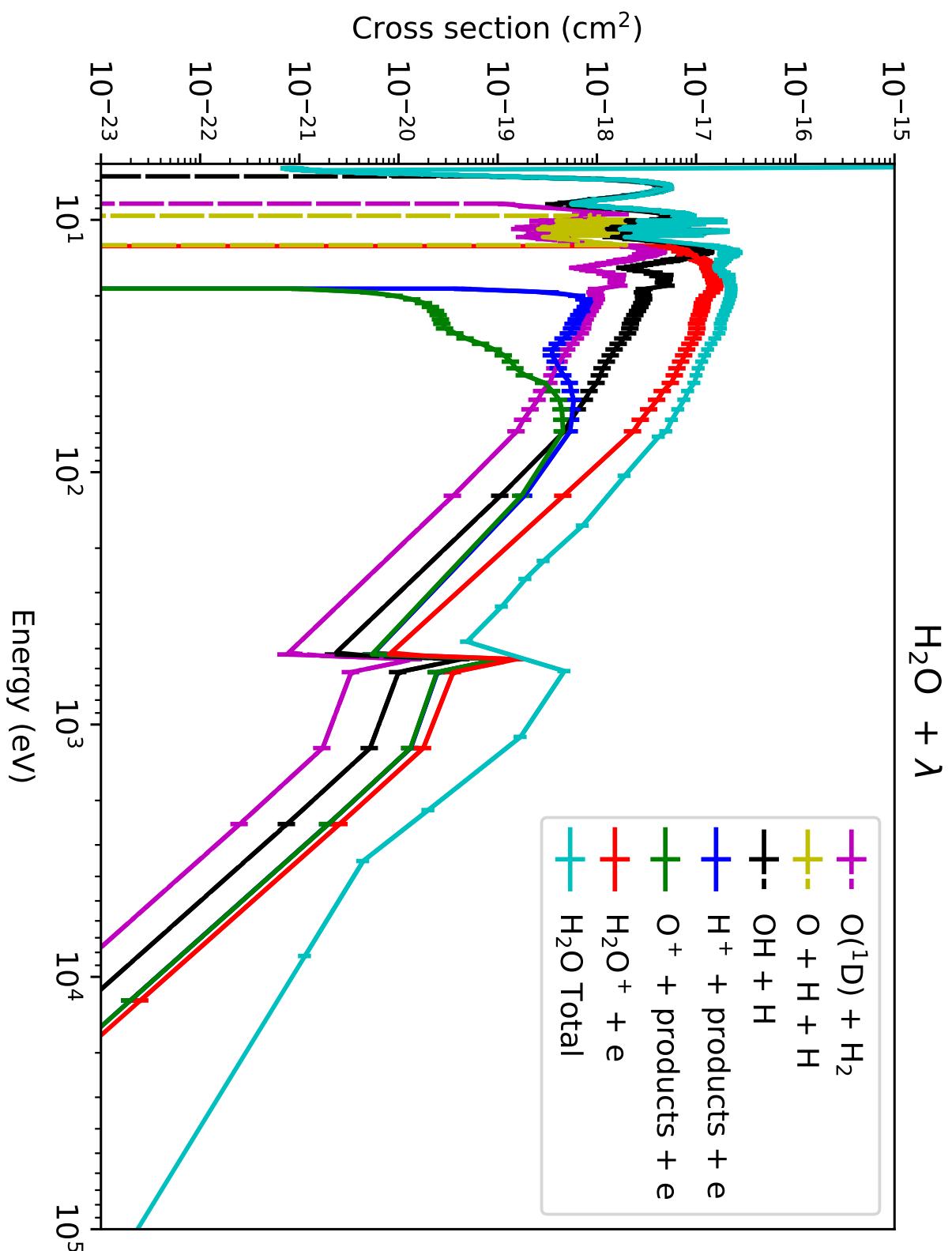


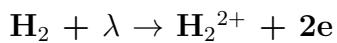
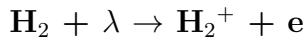
Figure 1.176: Cross sections for  $\text{H}_2\text{O} + \lambda$  (wavelength with extrapolation version)

## 1.13 Cross section of ph impact with H<sub>2</sub>

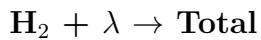
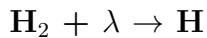
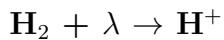
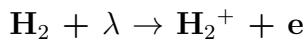
### 1.13.1 Total Cross Section

### 1.13.2 Inelastic Cross Sections

#### Ionization Cross Sections



### 1.13.3 Recommended data set



#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi [3]	0	0:-1	20%	RU	Fig. 1.183 1.184
Revi [78, 79]	0	0:-1	???	U	Fig. 1.183 1.184

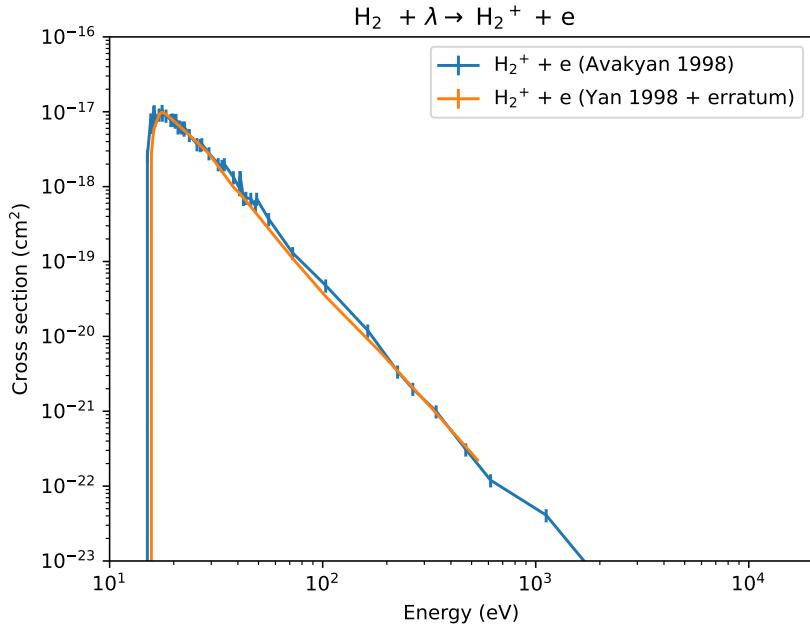
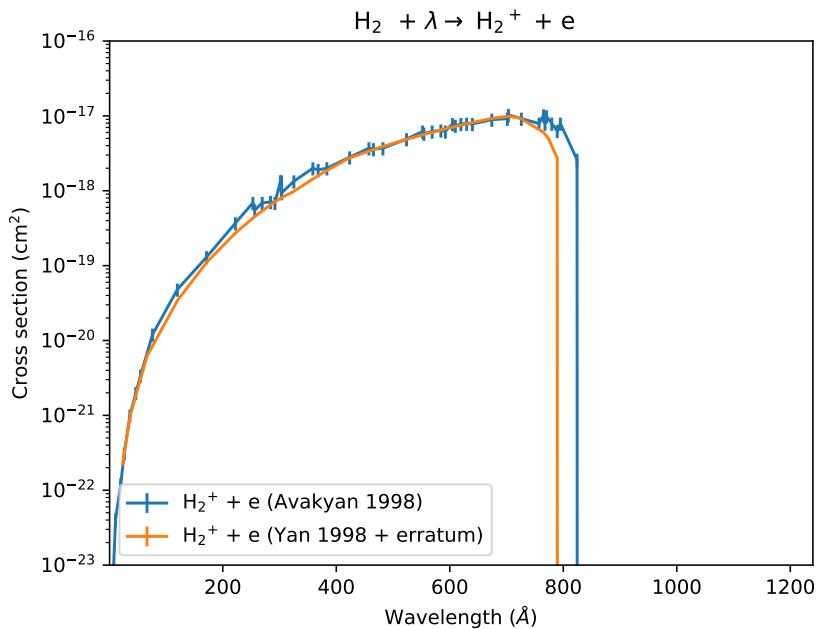
Table 1.44: Total cross section for  $\lambda$  impact on  $\text{H}_2$

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$H_2 + \lambda \rightarrow H_2^+ + e$	Revi [3]	15.42589	15.42589-1	20%	RU	Fig. 1.177 1.178
$H_2 + \lambda \rightarrow H^+ + H + e$	Revi Yan 98+erratum [78, 79]	15.4	15.4:-1	??%	U	Fig. 1.177 1.178
$H_2 + \lambda \rightarrow H_2^{2+} + 2e$	Revi [7]	18.1	18.1:-1	20%	RU	Fig. 1.179 1.180
	Revi [3]	47.5	47.5:-1	20%		Fig. 1.181 1.182

Table 1.45: Ionization Cross section for  $\lambda$  impact on  $H_2$

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$H_2 + \lambda \rightarrow H_2^+ + e^-$	Revi [3]	15.42589	15.42589:-1	20%	RU	Fig. 1.185 1.186 1.187 1.188
$H_2 + \lambda \rightarrow H^+$	Revi [7]	18.1	18.1:-1	20%	RU	Fig. 1.185 1.186 1.187 1.188
$H_2 + \lambda \rightarrow H$	Revi [17]	20	20:-1	??%	RU	Fig. 1.185 1.186 1.187 1.188
$H_2 + \lambda \rightarrow \text{Total}$	Revi [3]	0	0:-1	20%	RU	Fig. 1.185 1.186 1.187 1.188

Table 1.46: Recommended Cross section for  $\lambda$  impact on  $H_2$

Figure 1.177: Cross sections for  $H_2 + \lambda \rightarrow H_2^+ + e$ Figure 1.178: Cross sections for  $H_2 + \lambda \rightarrow H_2^+ + e$  (wavelength version)

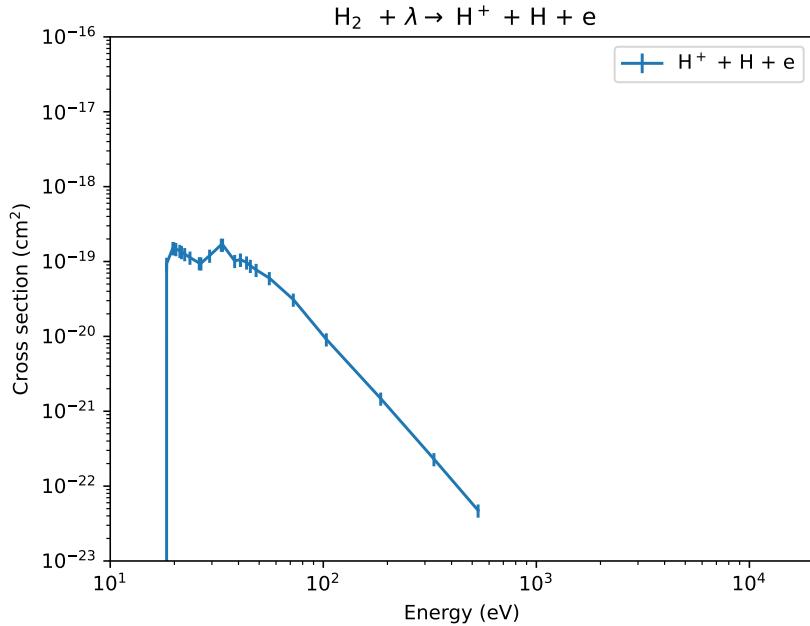


Figure 1.179: Cross sections for  $\text{H}_2 + \lambda \rightarrow \text{H}^+ + \text{H} + \text{e}$

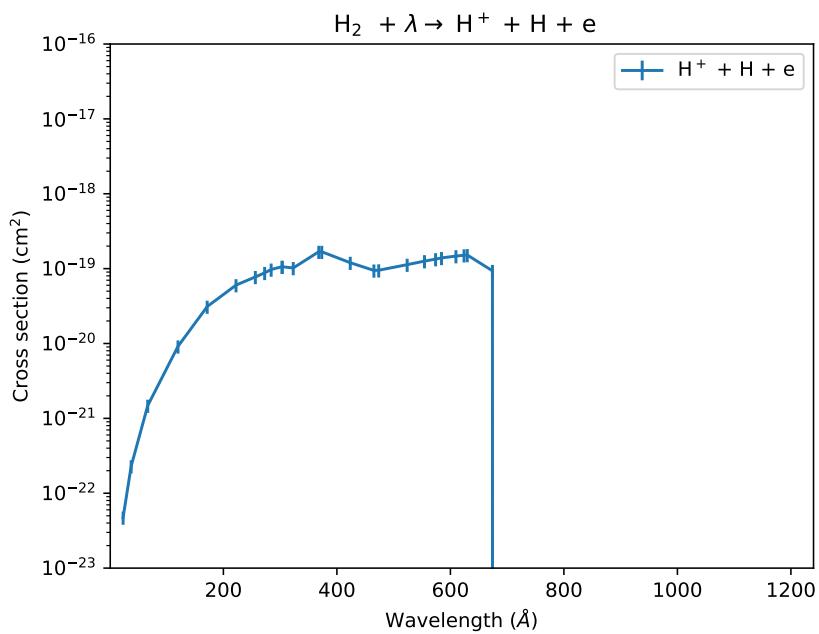
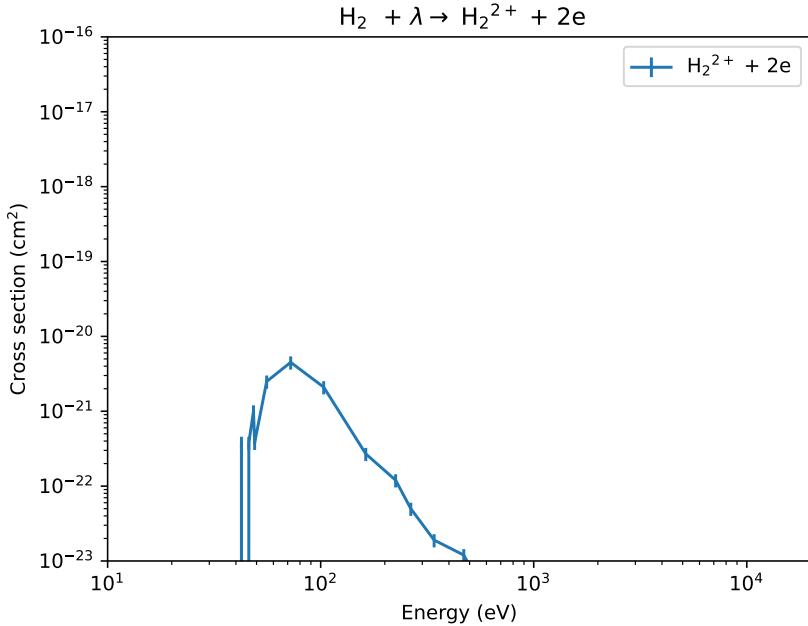
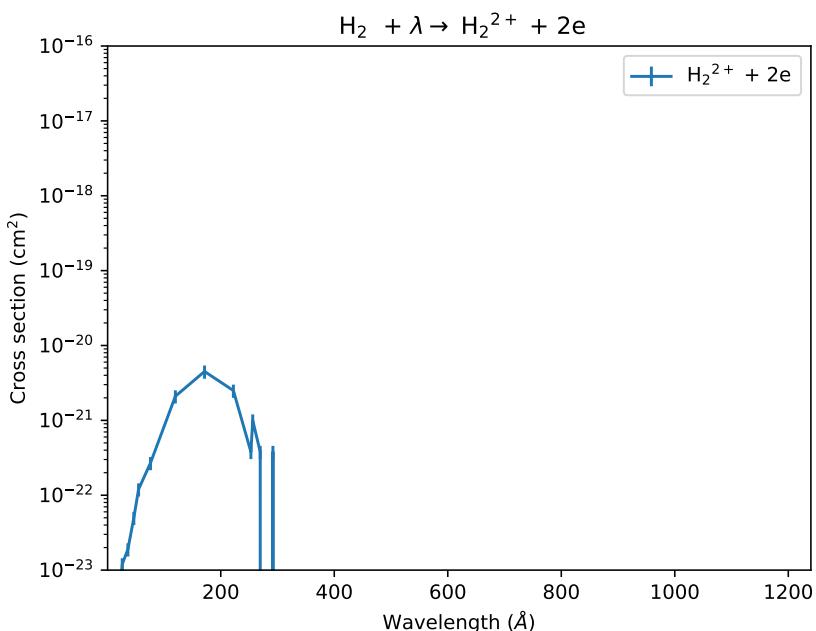


Figure 1.180: Cross sections for  $\text{H}_2 + \lambda \rightarrow \text{H}^+ + \text{H} + \text{e}$  (wavelength version)

Figure 1.181: Cross sections for  $H_2 + \lambda \rightarrow H_2^{2+} + 2e$ Figure 1.182: Cross sections for  $H_2 + \lambda \rightarrow H_2^{2+} + 2e$  (wavelength version)

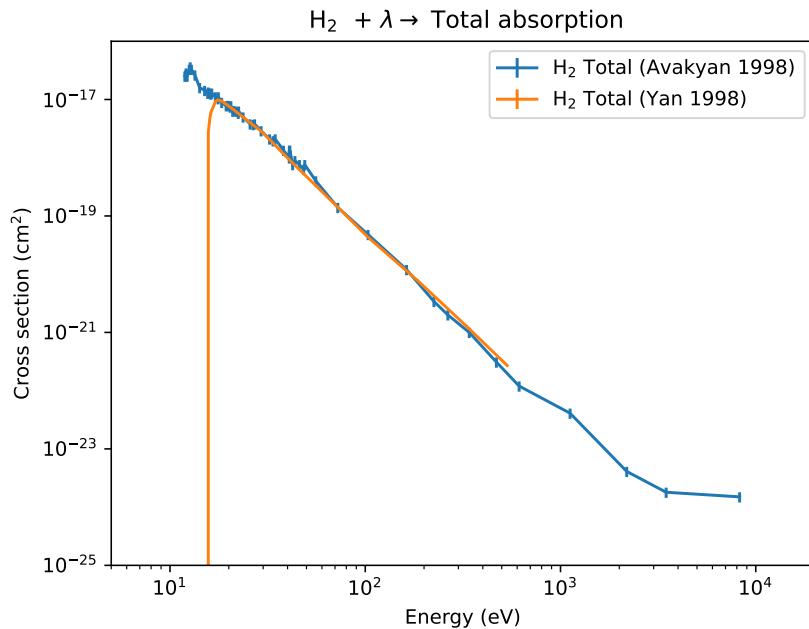


Figure 1.183: Cross sections for  $\text{H}_2 + \lambda \rightarrow \text{Total absorption}$

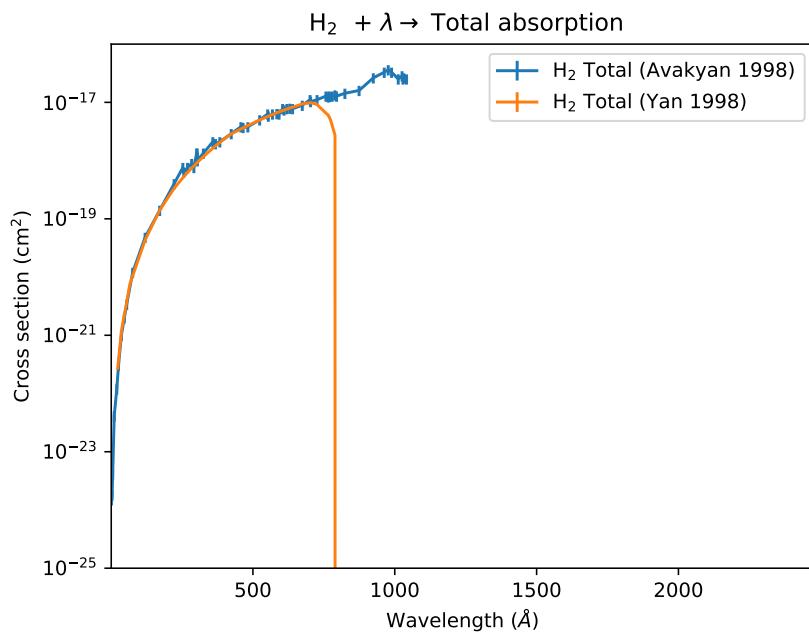
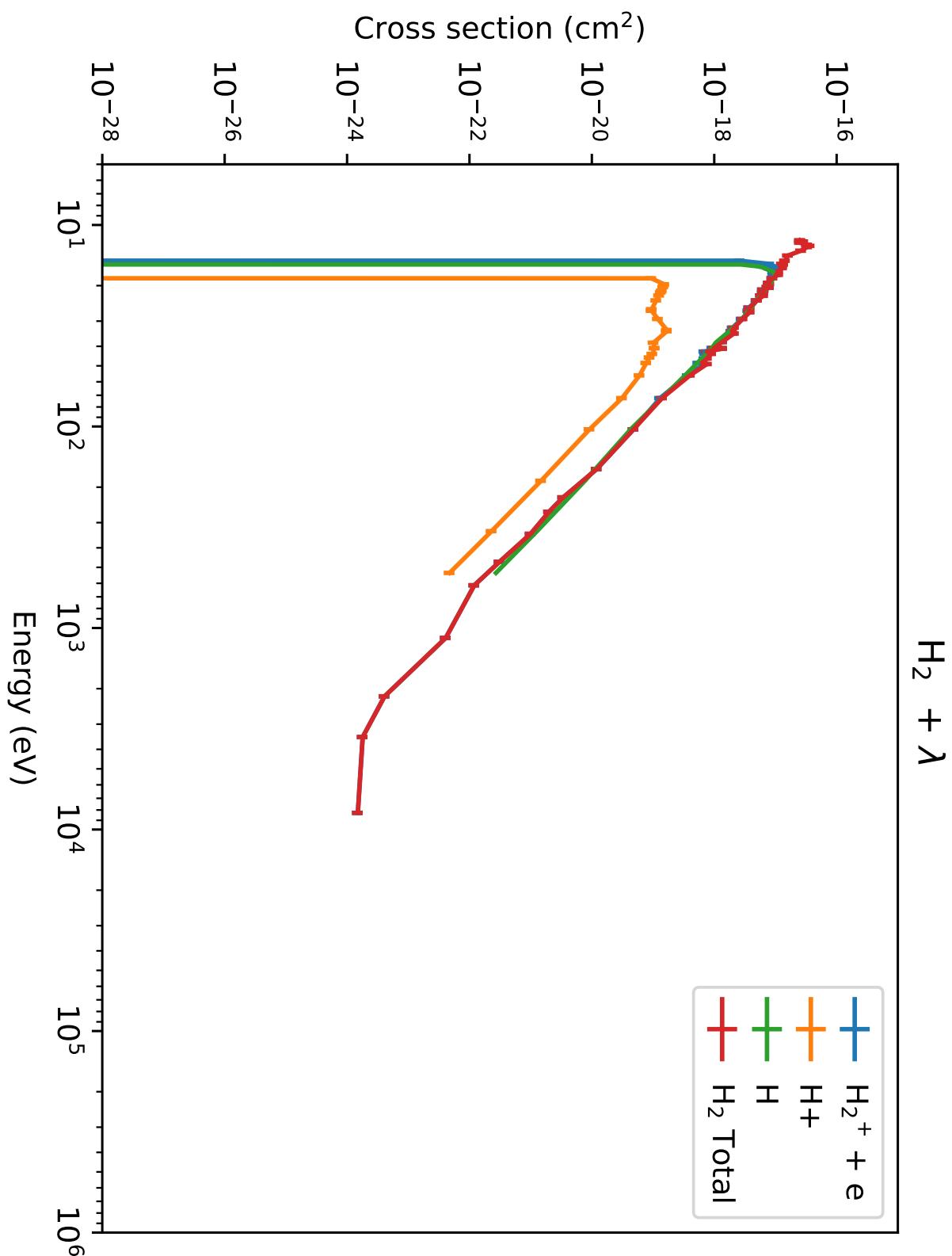
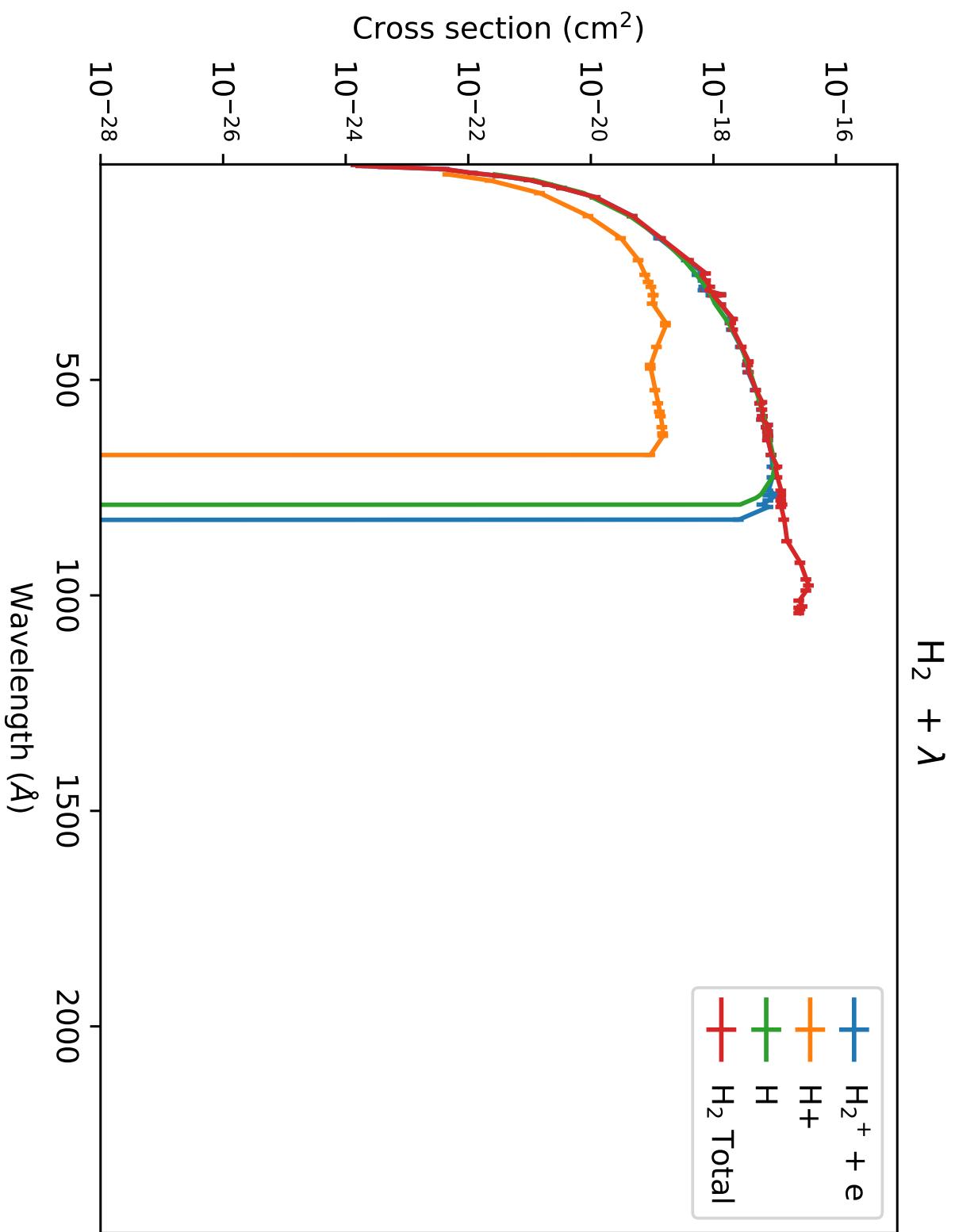
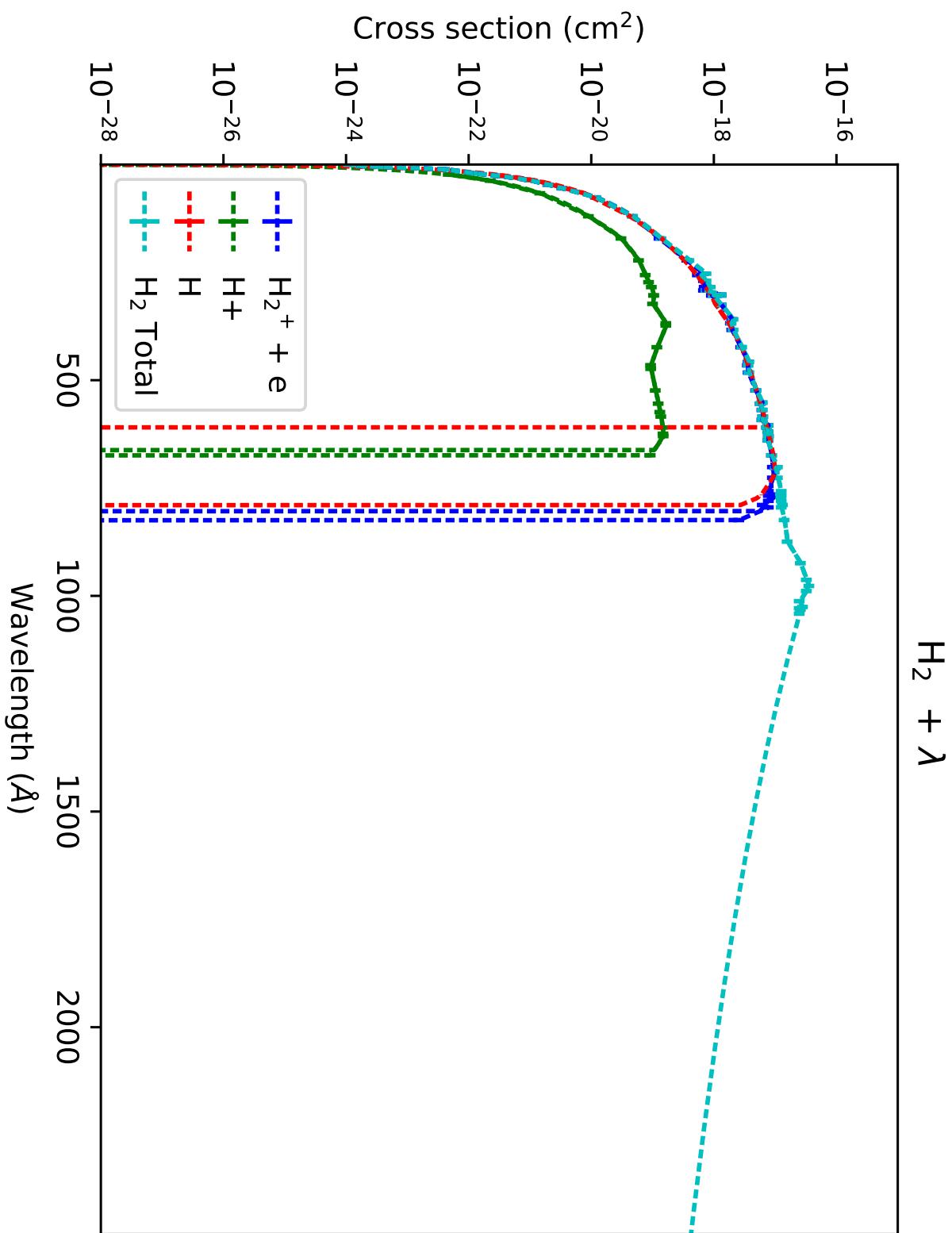


Figure 1.184: Cross sections for  $\text{H}_2 + \lambda \rightarrow \text{Total absorption}$  (wavelength version)

Figure 1.185: Cross sections for  $H_2 + \lambda$

Figure 1.186: Cross sections for  $\text{H}_2 + \lambda$  (wavelength version)

Figure 1.187: Cross sections for  $H_2 + \lambda$  (with extrapolation version)

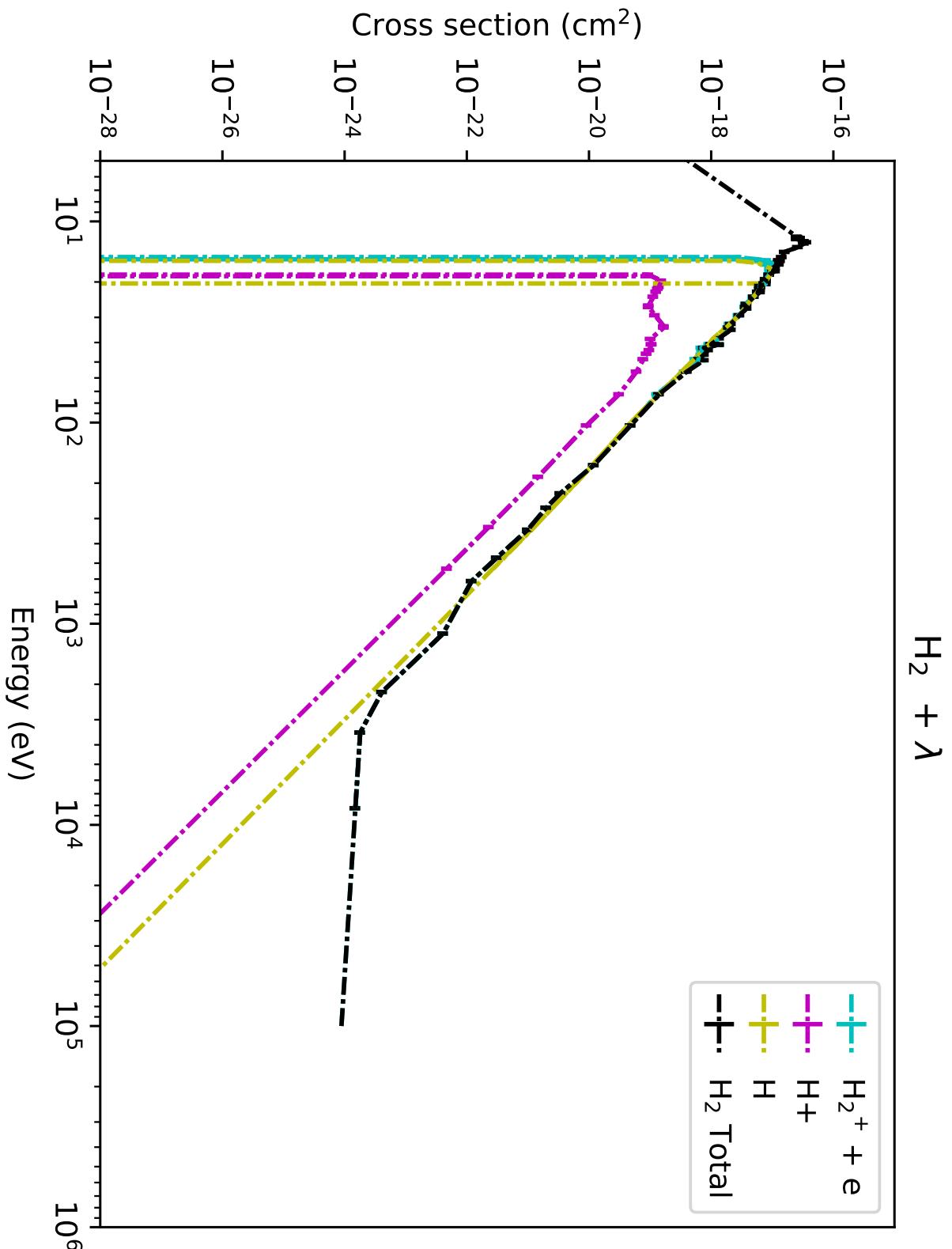


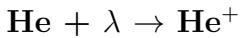
Figure 1.188: Cross sections for  $\text{H}_2 + \lambda$  (wavelength with extrapolation version)

## 1.14 Cross section of ph impact with He

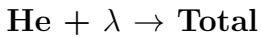
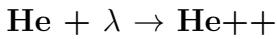
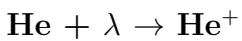
### 1.14.1 Total Cross Section

### 1.14.2 Inelastic Cross Sections

#### Ionization Cross Sections



### 1.14.3 Recommended data set



#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi PHIDRATES	0	0:-1	??%	U	Fig. 1.189 1.190
Revi BDD [45]	0	0:-1	??%	U	Fig. 1.189 1.190
Revi BDD v2 [45]	0	0:-1	??%	U	Fig. 1.189 1.190

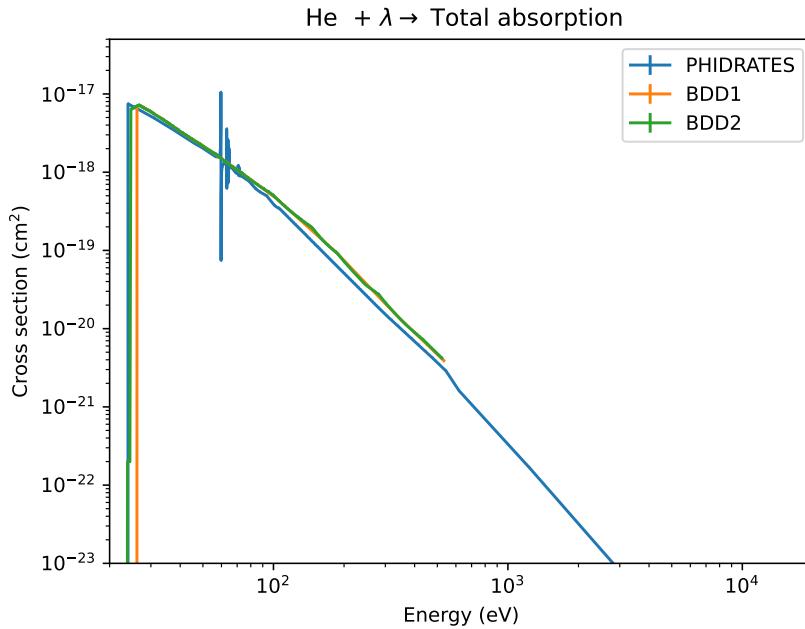
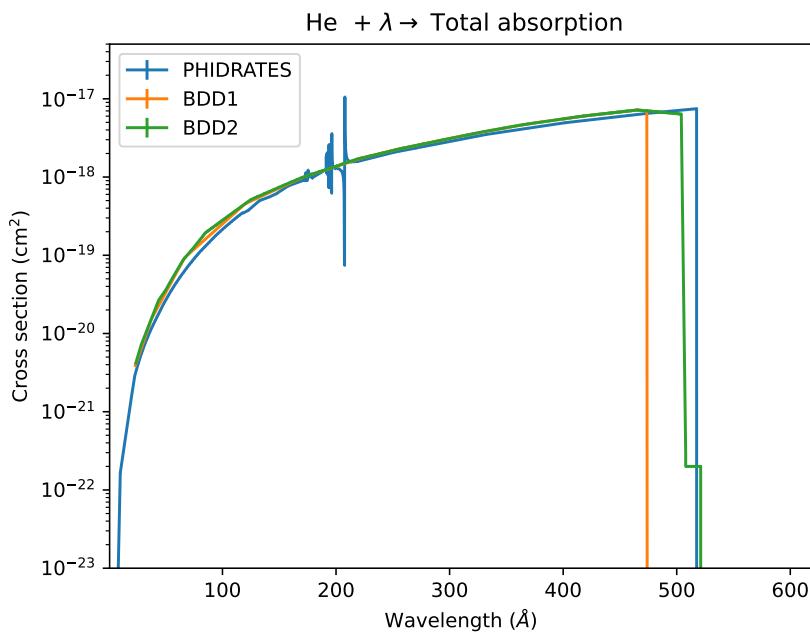
Table 1.47: Total cross section for  $\lambda$  impact on He

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
He + $\lambda \rightarrow \text{He}^+$	Revi PHIDRATES (old)	24.5	24.5-1	??%	U	Fig. 1.191 1.192
	Revi PHIDRATES	24.5	24.5-1	??%	RU	Fig. 1.191 1.192
	Meas [78]	24.5	24.5-1	??%	U	Fig. 1.191 1.192
	Meas [56]	24.5	24.5-1	??%	U	Fig. 1.191 1.192
	Meas [5]	24.5	24.5-1	??%	U	Fig. 1.191 1.192
	Revi BDD [45]	24.5	24.5-1	??%	U	Fig. 1.191 1.192
	Revi BDD v2	24.5	24.5-1	??%	U	Fig. 1.191 1.192

Table 1.48: Ionization Cross section for  $\lambda$  impact on He

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$\text{He} + \lambda \rightarrow \text{He}^+$	Revi PHIDRATES	24.5	24.5:-1	??%	RU	Fig. 1.193 1.194 1.195 1.196
$\text{He} + \lambda \rightarrow \text{He}^{++}$	Revi [57]	79.	79.:-1	??%	U	Fig. 1.193 1.194 1.195 1.196
$\text{He} + \lambda \rightarrow \text{Total}$	Revi PHIDRATES	0	0:-1	??%	RU	Fig. 1.193 1.194 1.195 1.196

Table 1.49: Recommended Cross section for  $\lambda$  impact on He

Figure 1.189: Cross sections for  $\text{He} + \lambda \rightarrow$  Total absorptionFigure 1.190: Cross sections for  $\text{He} + \lambda \rightarrow$  Total absorption (wavelength version)

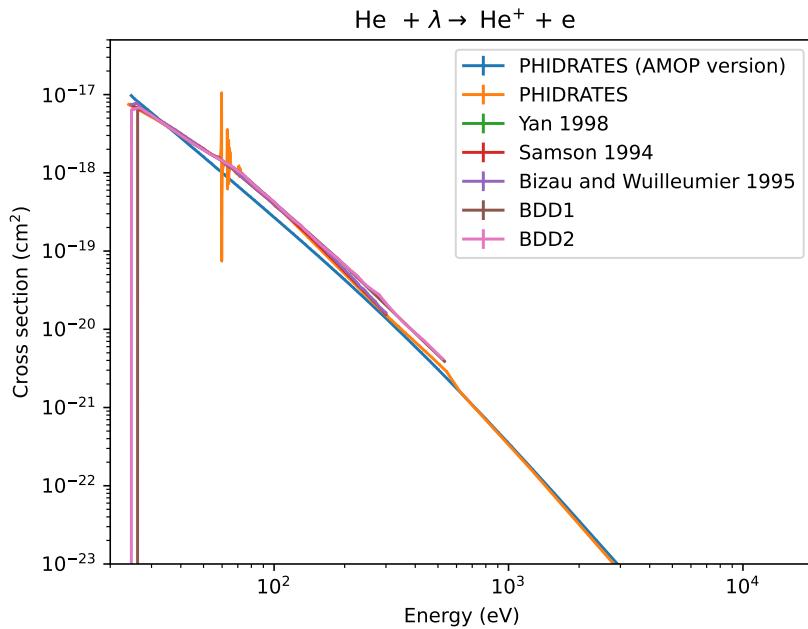


Figure 1.191: Cross sections for  $\text{He} + \lambda \rightarrow \text{He}^+ + e^-$

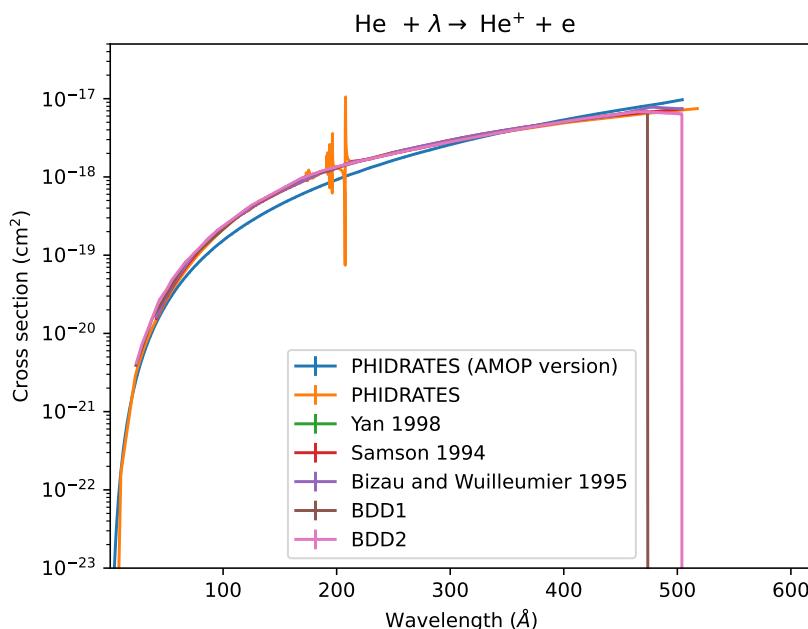
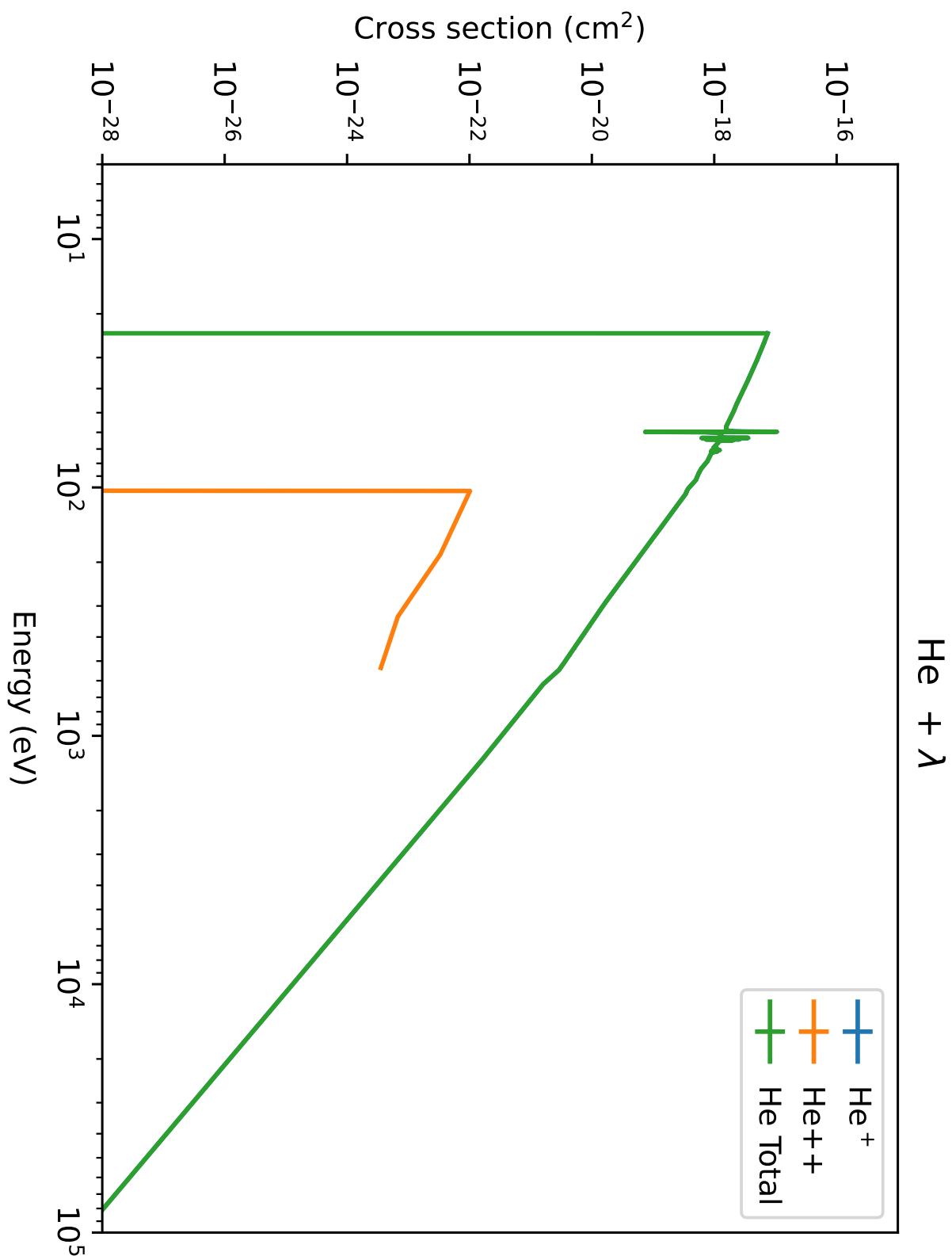
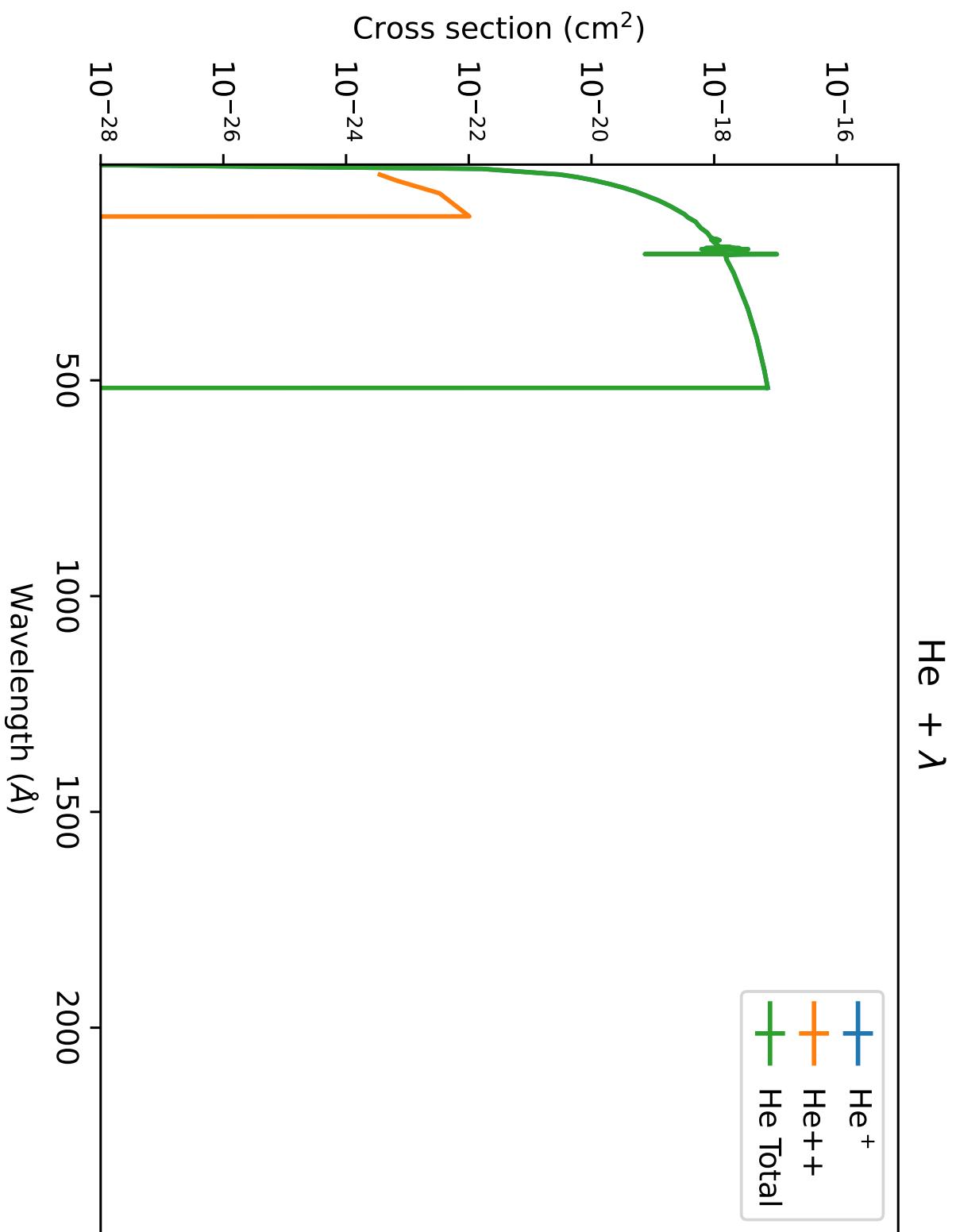
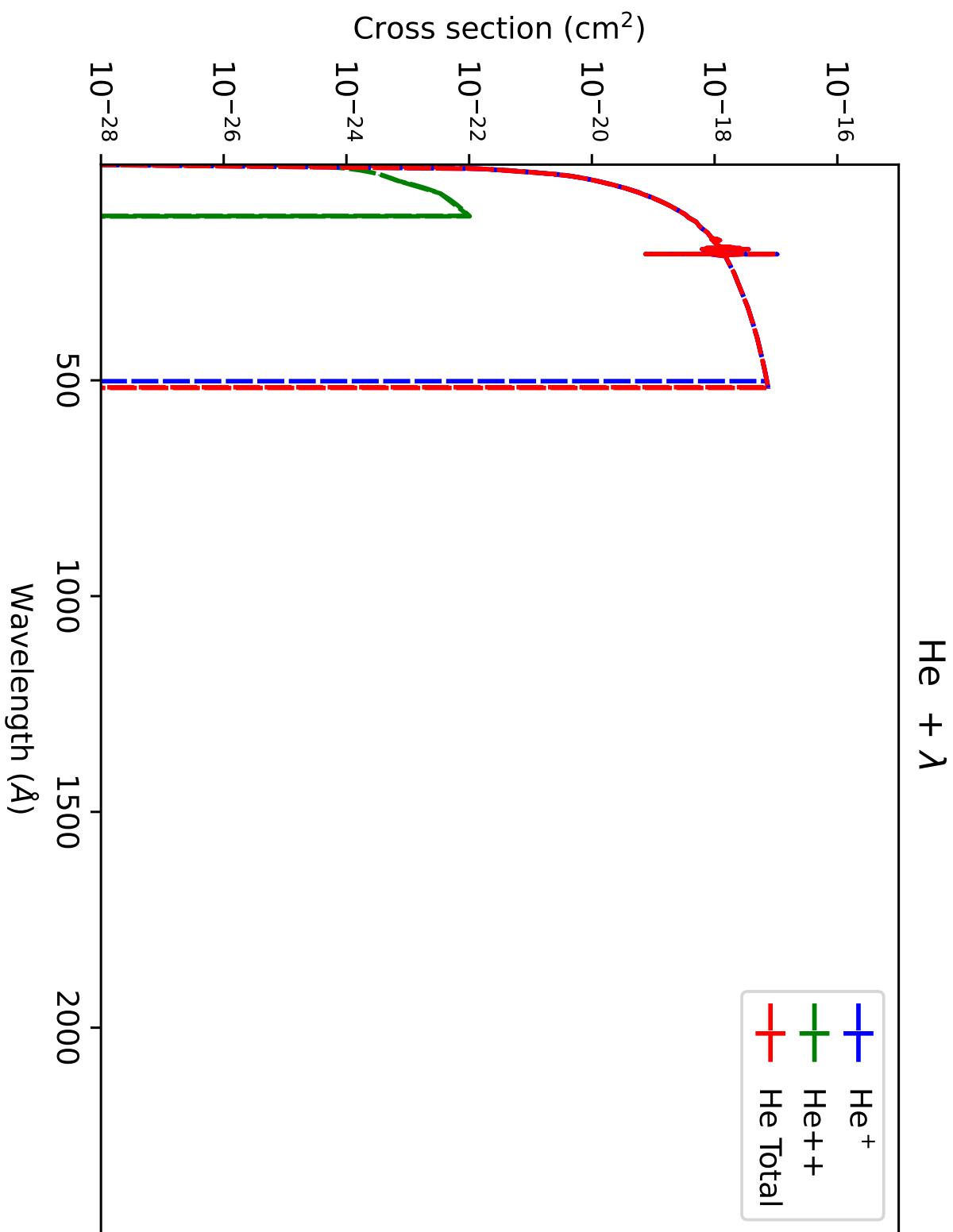


Figure 1.192: Cross sections for  $\text{He} + \lambda \rightarrow \text{He}^+ + e^-$  (wavelength version)

Figure 1.193: Cross sections for  $\text{He} + \lambda$

Figure 1.194: Cross sections for  $\text{He} + \lambda$  (wavelength version)

Figure 1.195: Cross sections for  $\text{He} + \lambda$  (with extrapolation version)

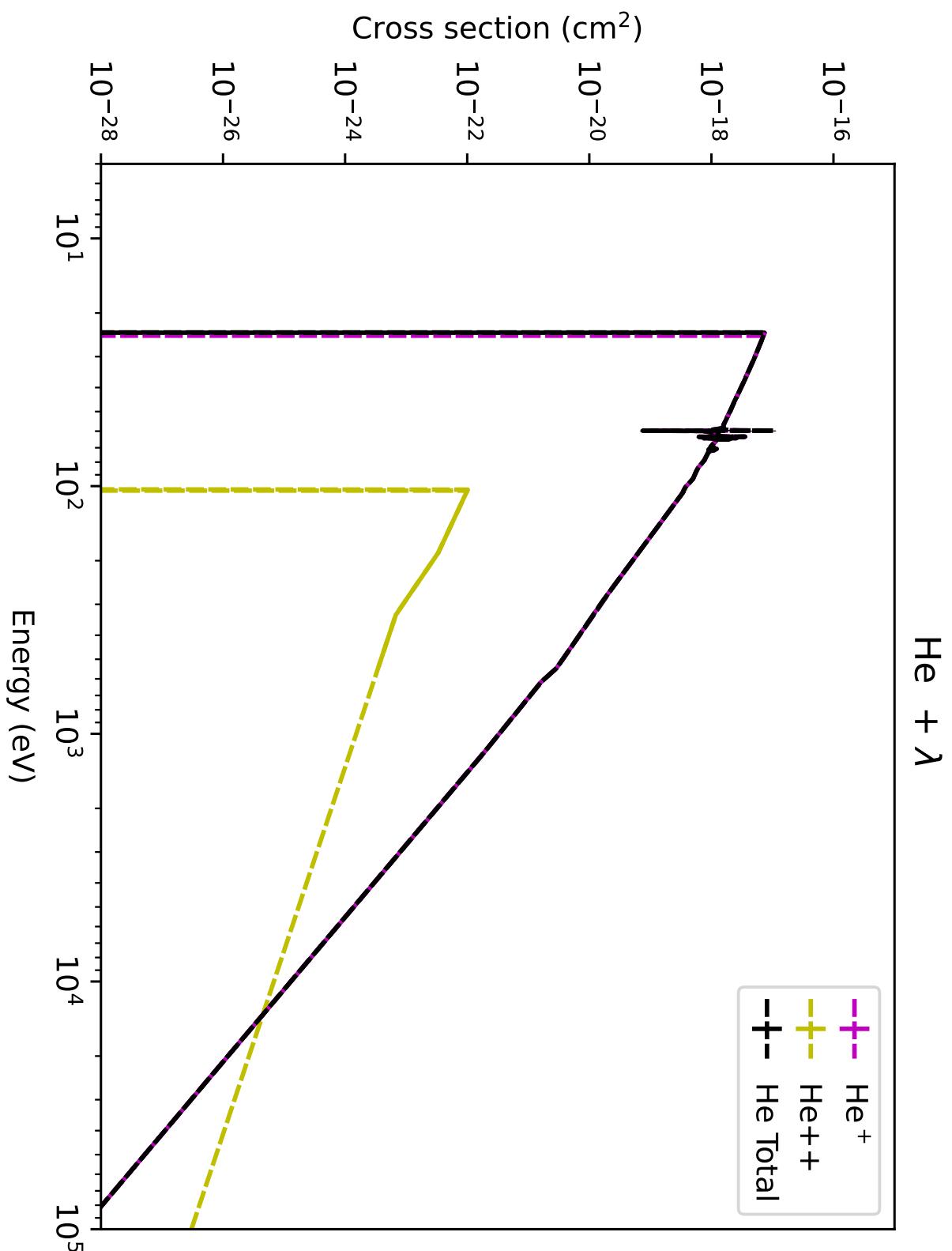


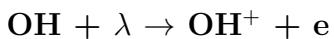
Figure 1.196: Cross sections for  $\text{He} + \lambda$  (wavelength with extrapolation version)

## 1.15 Cross section of ph impact with OH

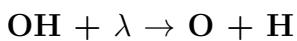
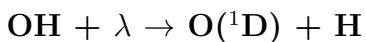
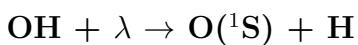
### 1.15.1 Total Cross Section

### 1.15.2 Inelastic Cross Sections

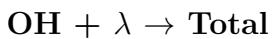
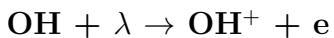
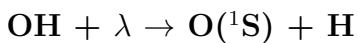
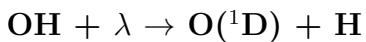
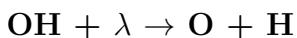
#### Ionization Cross Sections



#### Dissociation Cross Sections



### 1.15.3 Recommended data set



#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi PHIDRATES	0	0:-1	??% ??%	RU	Fig. 1.205 1.206

Table 1.50: Total cross section for  $\lambda$  impact on OH

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$\text{OH} + \lambda \rightarrow \text{OH}^+ + e^-$	Revi PHDRATES	18.7	18.7:-1	??% ??%	RU	Fig. 1.197 1.198

Table 1.51: Ionization Cross section for  $\lambda$  impact on OH

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$\text{OH} + \lambda \rightarrow \text{O}({}^1\text{S}) + \text{H}$	Revi PHDRATES	9	9:-1	??% ??%	U	Fig. 1.199 1.200
$\text{OH} + \lambda \rightarrow \text{O}({}^1\text{D}) + \text{H}$	Revi PHDRATES	2.5	2.5:-1	??% ??%	U	Fig. 1.201 1.202
$\text{OH} + \lambda \rightarrow \text{O} + \text{H}$	Revi PHDRATES	4.5	4.5:-1	??% ??%	U	Fig. 1.203 1.204

Table 1.52: Dissociation Cross section for  $\lambda$  impact on OH

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$\text{OH} + \lambda \rightarrow \text{O} + \text{H}$	Revi PHIDRATES	4.5	4.5:-1	?%?	U	Fig. 1.207 1.208 1.209 1.210
$\text{OH} + \lambda \rightarrow \text{O}({}^1\text{D}) + \text{H}$	Revi PHIDRATES	2.5	2.5:-1	?%?	U	Fig. 1.207 1.208 1.209 1.210
$\text{OH} + \lambda \rightarrow \text{O}({}^1\text{S}) + \text{H}$	Revi PHIDRATES	9	9:-1	?%?	U	Fig. 1.207 1.208 1.209 1.210
$\text{OH} + \lambda \rightarrow \text{OH}^+ + \text{e}$	Revi PHIDRATES	18.7	18.7:-1	?%?	RU	Fig. 1.207 1.208 1.209 1.210
$\text{OH} + \lambda \rightarrow \text{Total}$	Revi PHIDRATES	0	0:-1	?%?	RU	Fig. 1.207 1.208 1.209 1.210

Table 1.53: Recommended Cross section for  $\lambda$  impact on OH

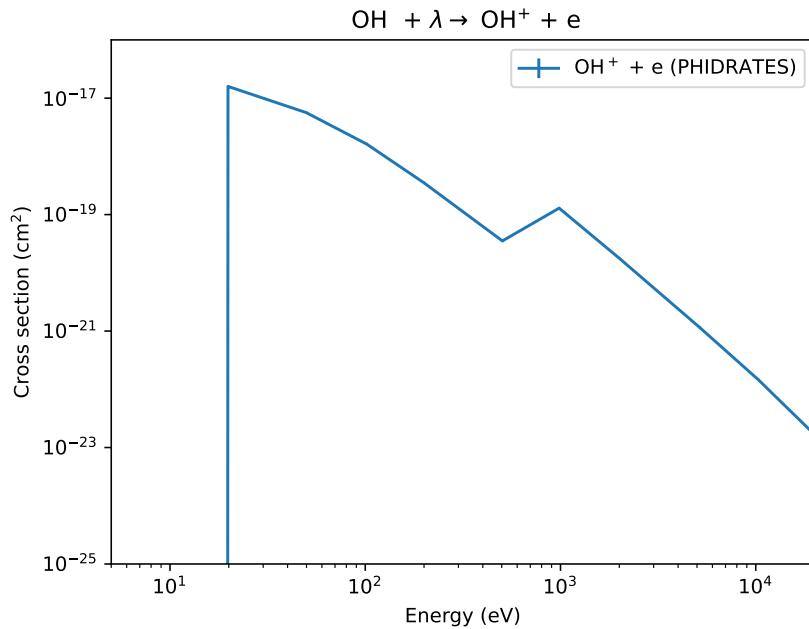


Figure 1.197: Cross sections for  $\text{OH} + \lambda \rightarrow \text{OH}^+ + e$

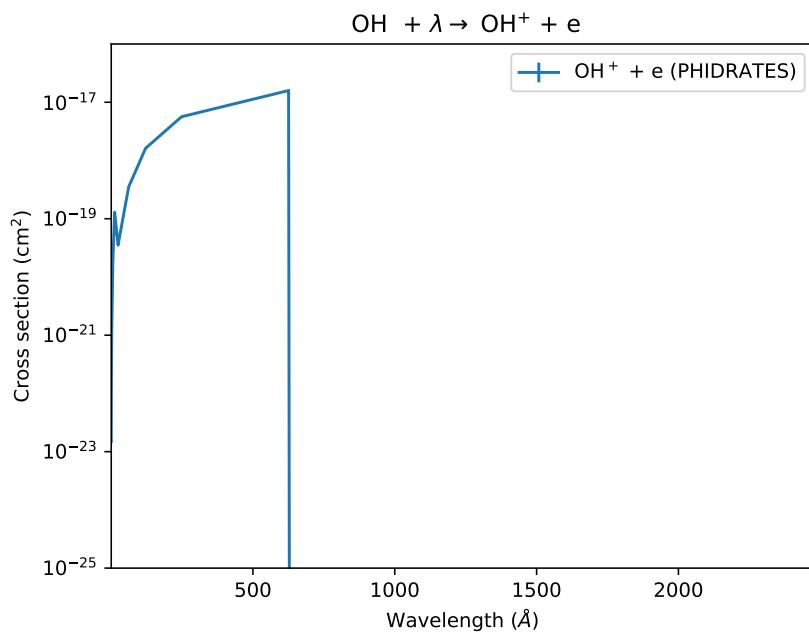
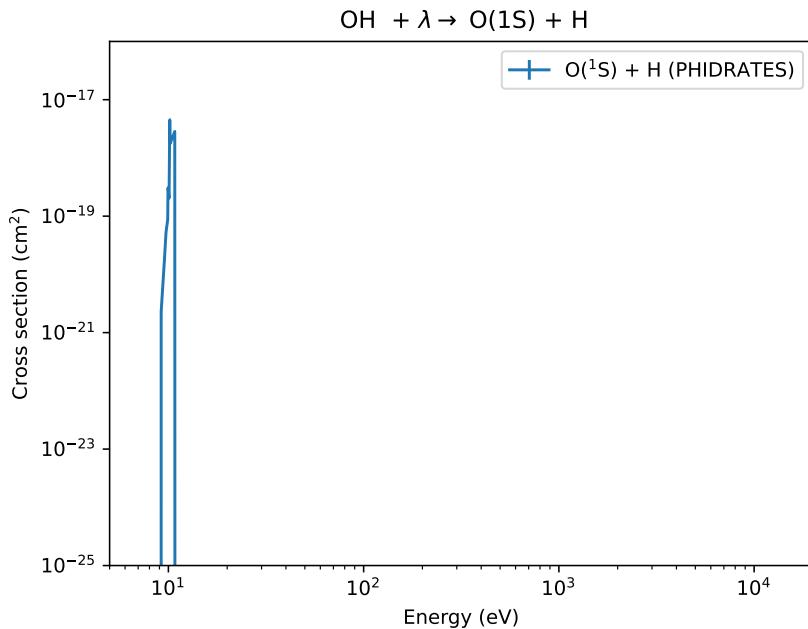
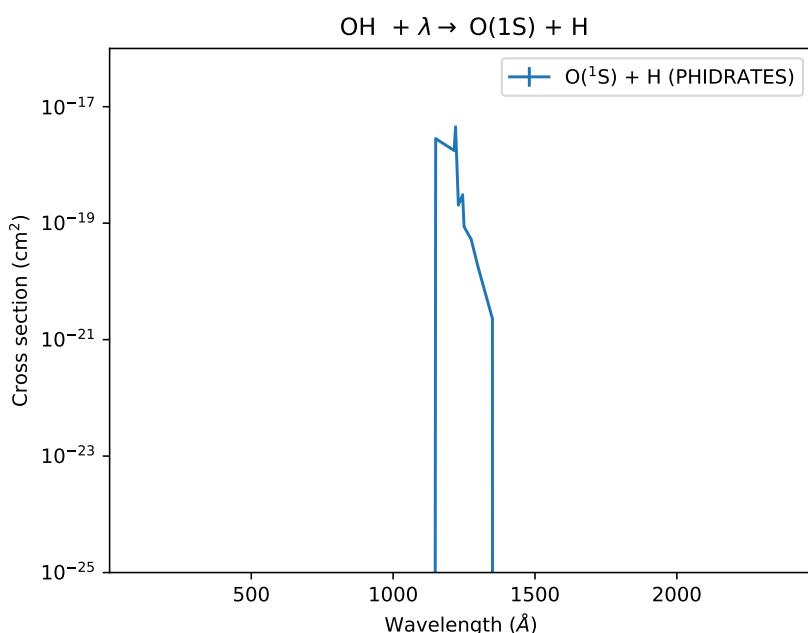


Figure 1.198: Cross sections for  $\text{OH} + \lambda \rightarrow \text{OH}^+ + e$  (wavelength version)

Figure 1.199: Cross sections for  $\text{OH} + \lambda \rightarrow \text{O}(1\text{S}) + \text{H}$ Figure 1.200: Cross sections for  $\text{OH} + \lambda \rightarrow \text{O}(1\text{S}) + \text{H}$  (wavelength version)

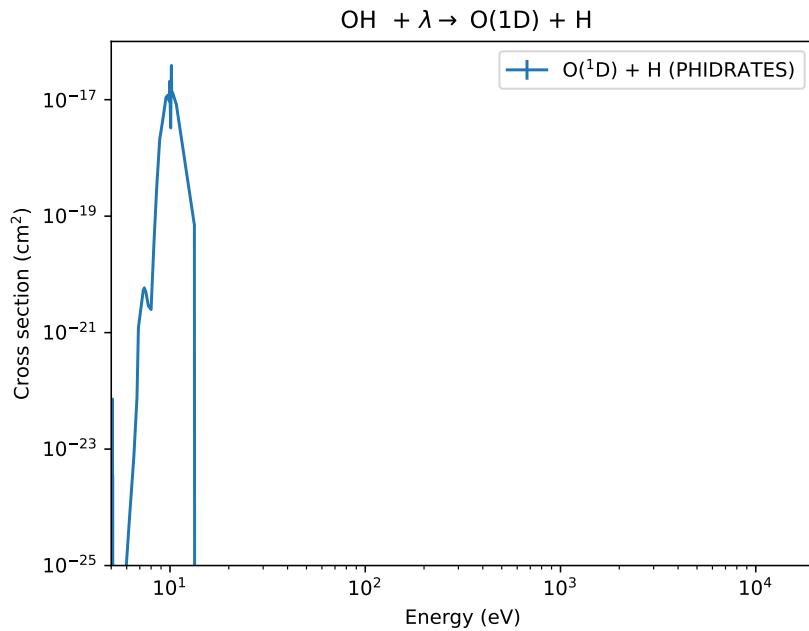


Figure 1.201: Cross sections for  $\text{OH} + \lambda \rightarrow \text{O(1D)} + \text{H}$

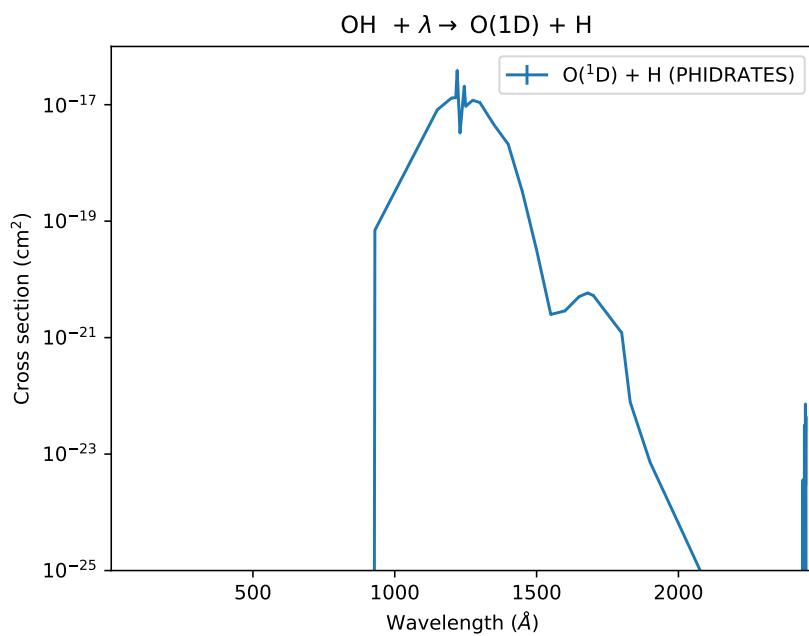
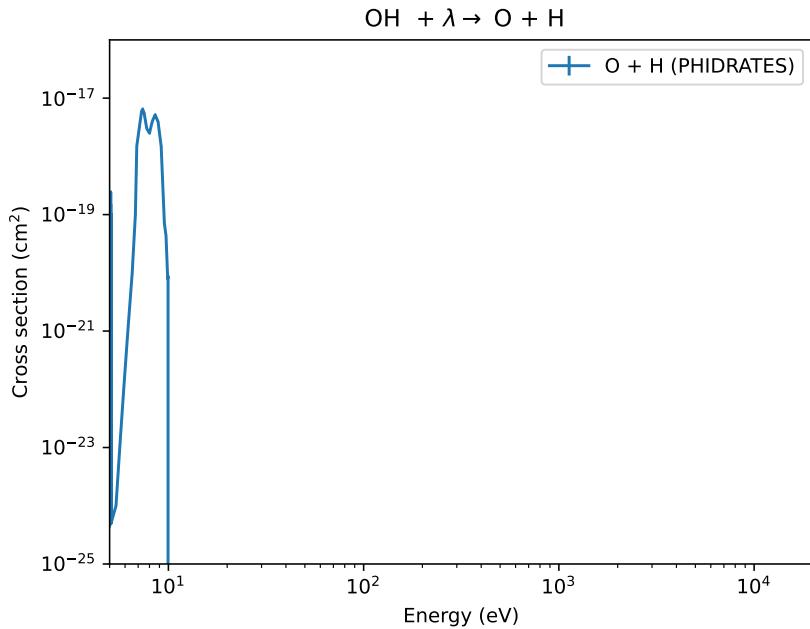
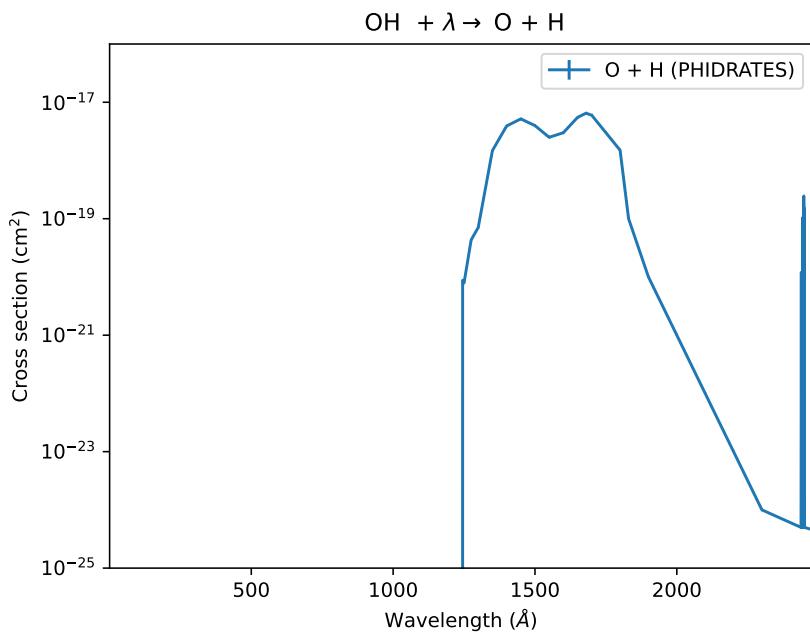


Figure 1.202: Cross sections for  $\text{OH} + \lambda \rightarrow \text{O(1D)} + \text{H}$  (wavelength version)

Figure 1.203: Cross sections for  $\text{OH} + \lambda \rightarrow \text{O} + \text{H}$ Figure 1.204: Cross sections for  $\text{OH} + \lambda \rightarrow \text{O} + \text{H}$  (wavelength version)

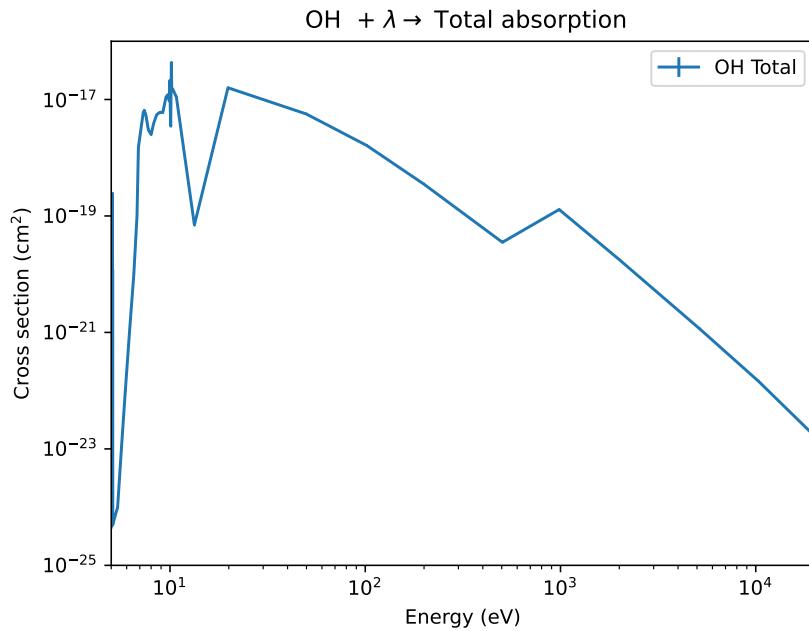


Figure 1.205: Cross sections for  $\text{OH} + \lambda \rightarrow$  Total absorption

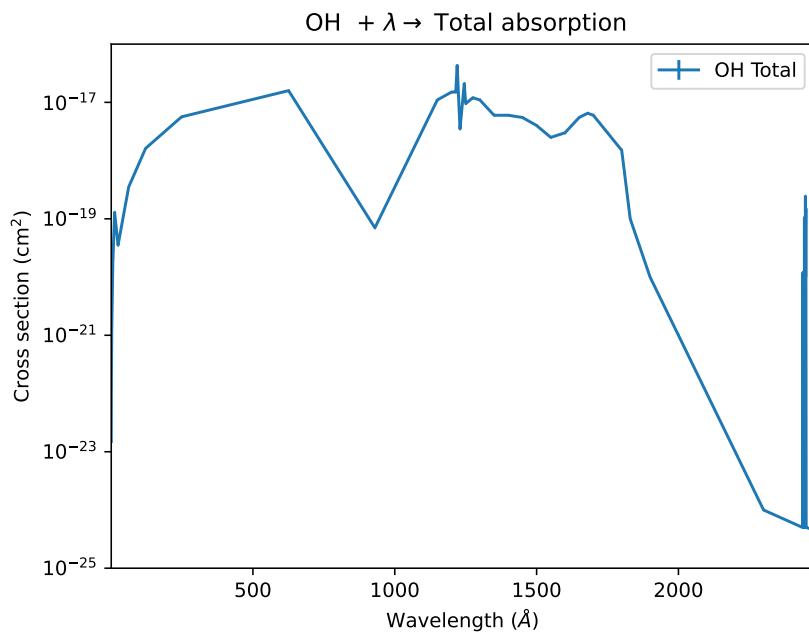
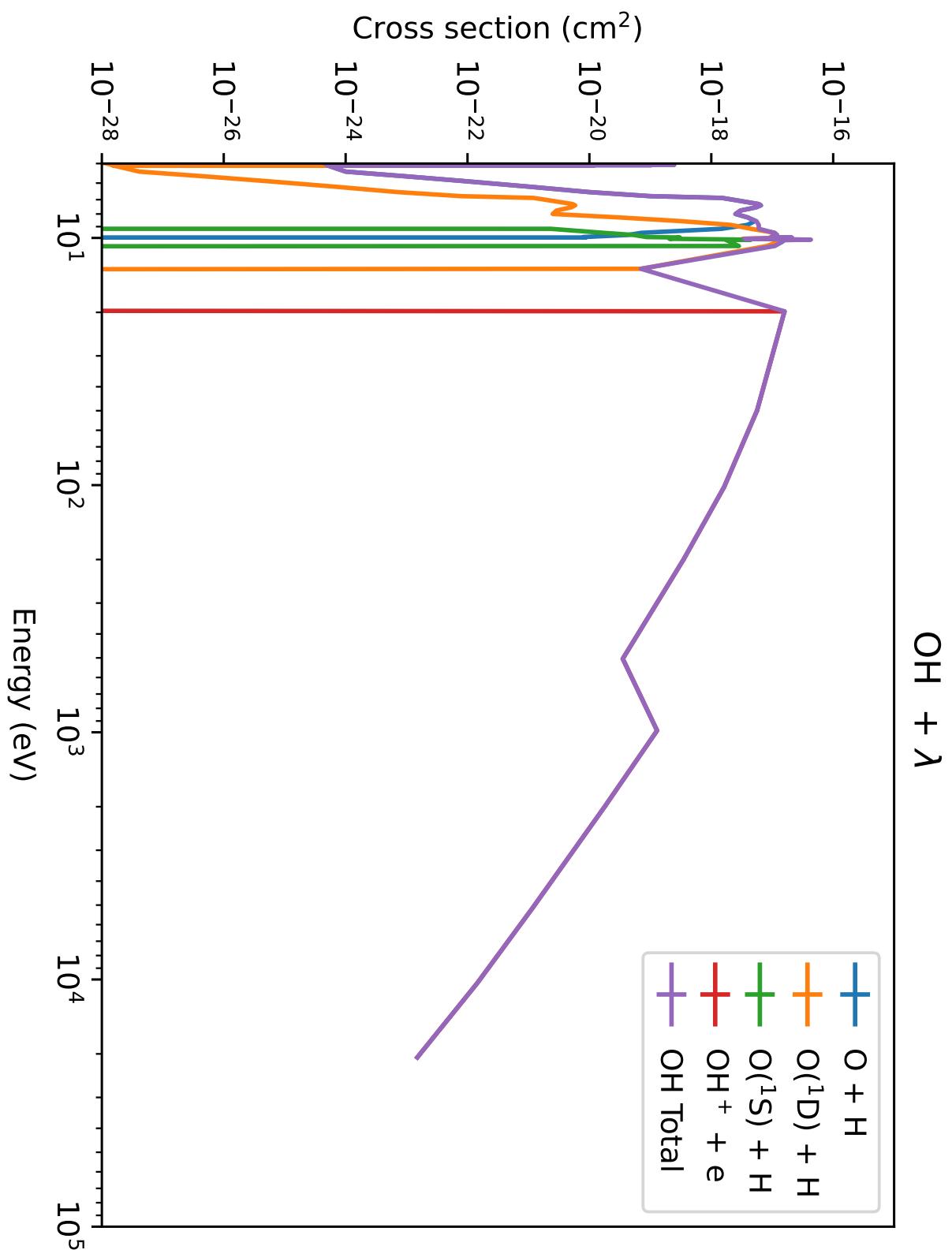
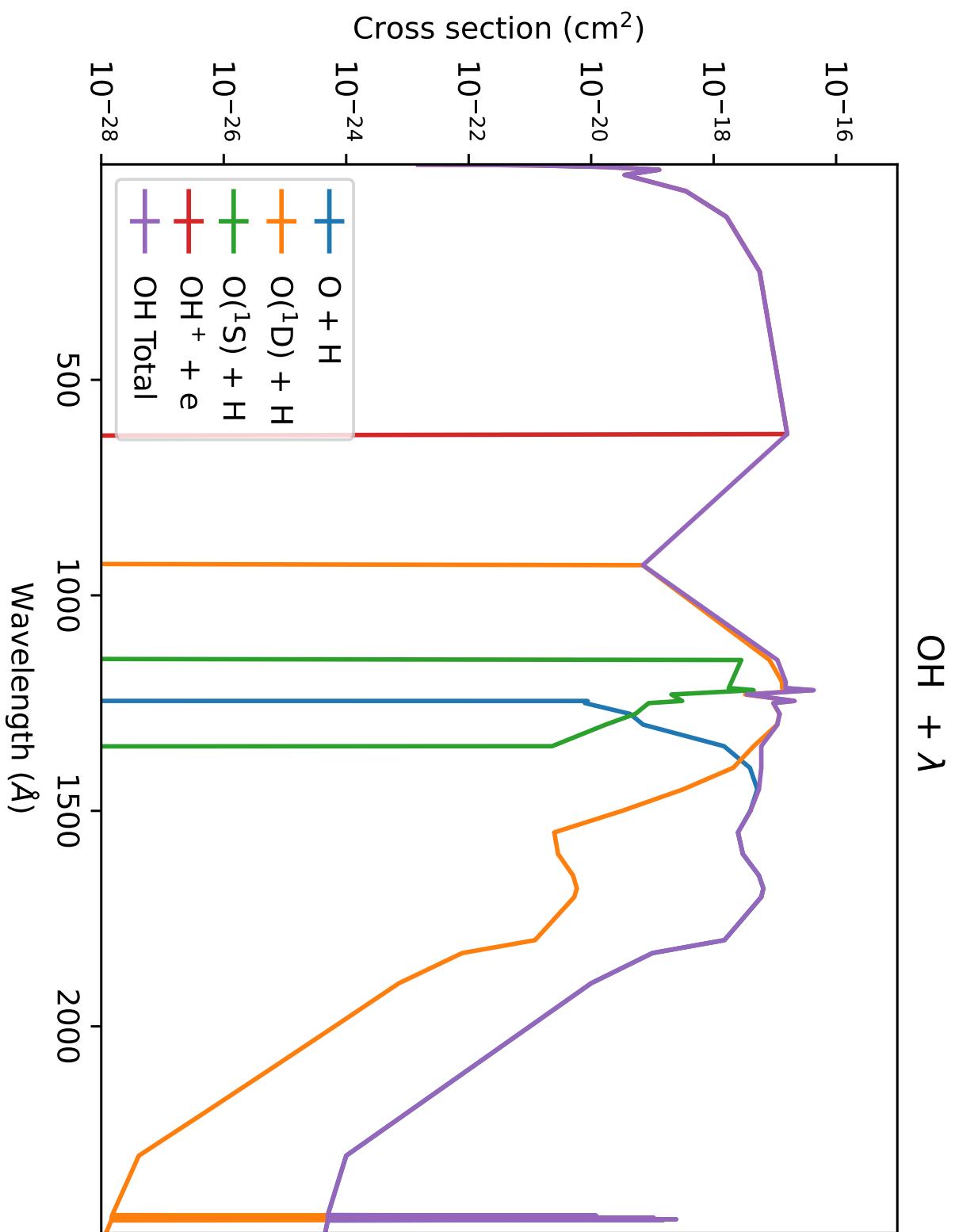
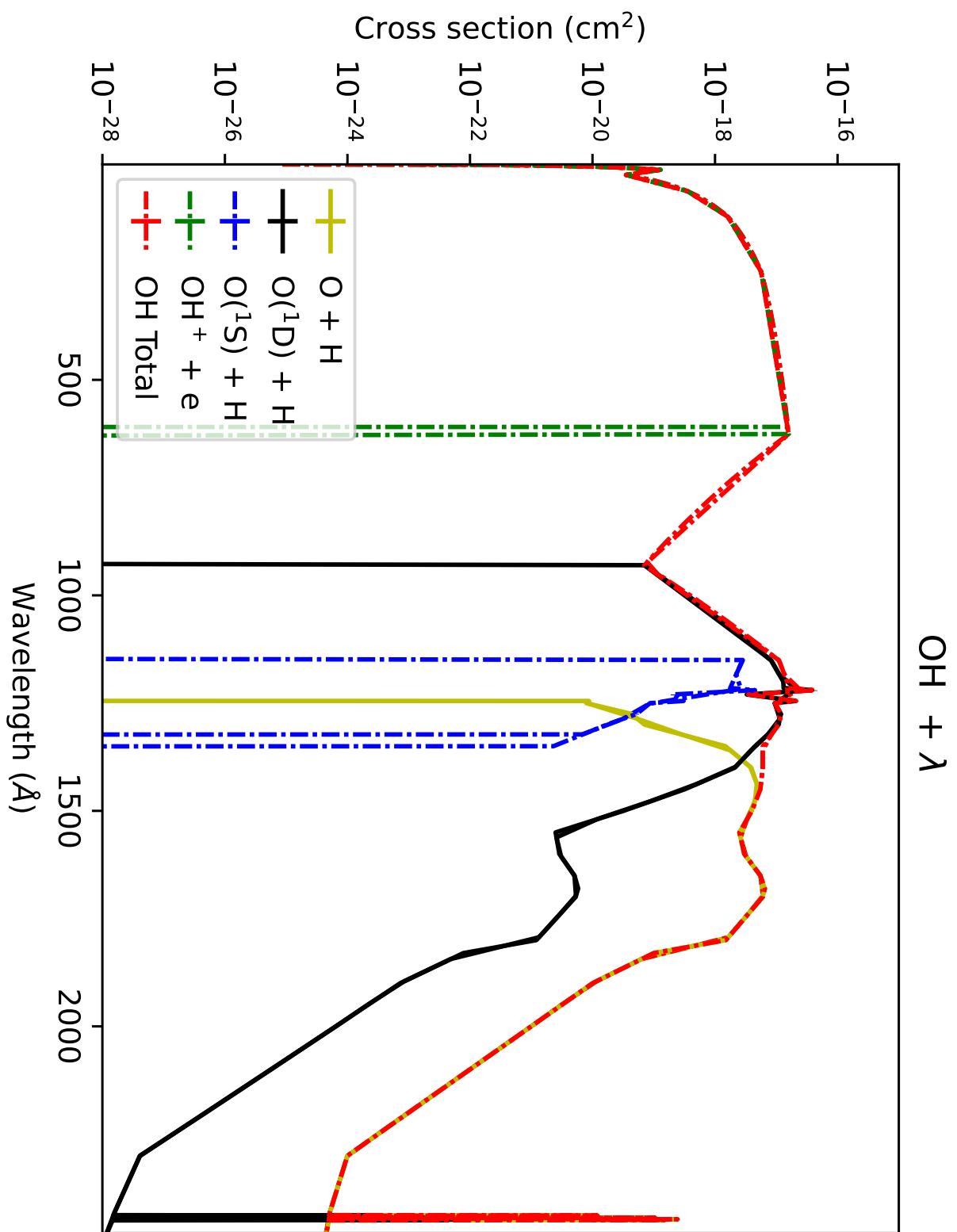


Figure 1.206: Cross sections for  $\text{OH} + \lambda \rightarrow$  Total absorption (wavelength version)

Figure 1.207: Cross sections for OH +  $\lambda$

Figure 1.208: Cross sections for  $\text{OH} + \lambda$  (wavelength version)

Figure 1.209: Cross sections for  $\text{OH} + \lambda$  (with extrapolation version)

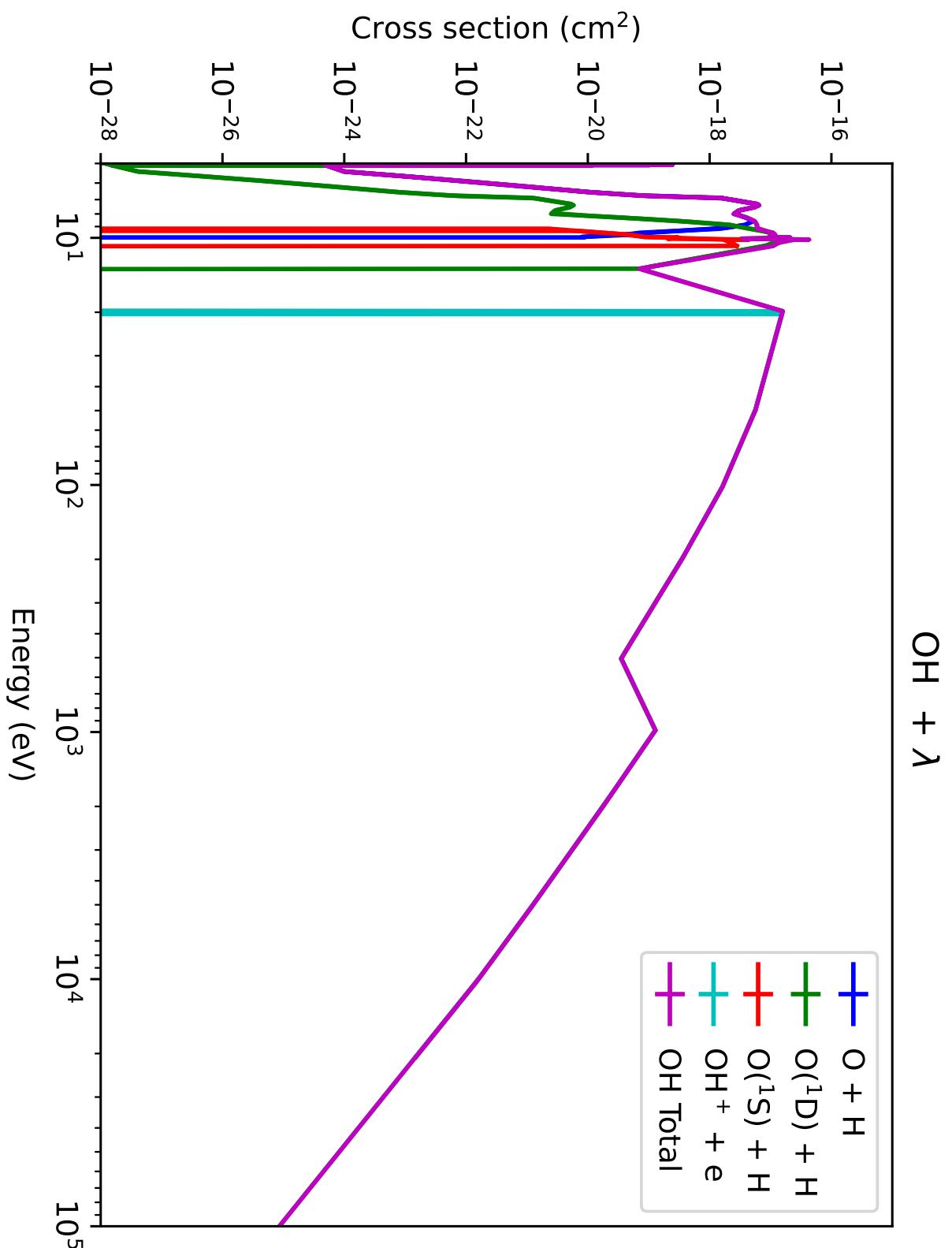


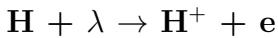
Figure 1.210: Cross sections for  $\text{OH} + \lambda$  (wavelength with extrapolation version)

## 1.16 Cross section of ph impact with H

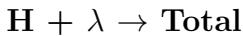
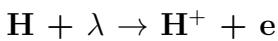
### 1.16.1 Total Cross Section

### 1.16.2 Inelastic Cross Sections

#### Ionization Cross Sections



### 1.16.3 Recommended data set



#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi Rees	0	0:-1	??%	U	Fig. 1.213 1.214
Revi AMOP	0	0:-1	15%	U	Fig. 1.213 1.214

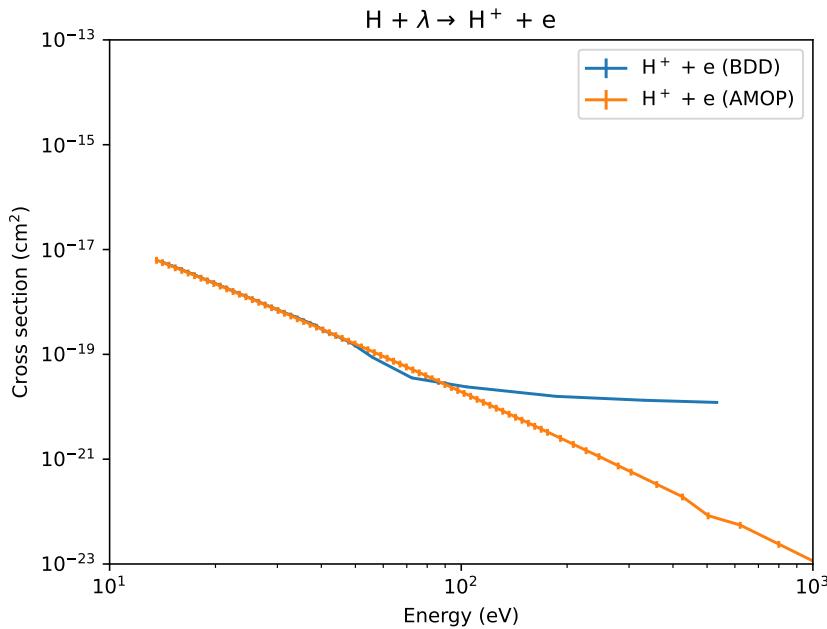
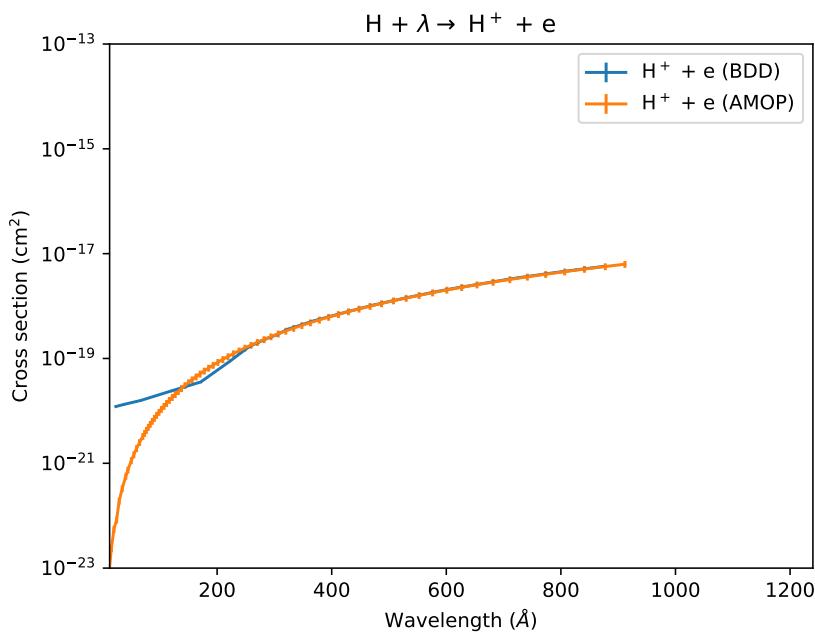
Table 1.54: Total cross section for  $\lambda$  impact on H

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$H + \lambda \rightarrow H^+ + e$	Revi Rees	13.5	13.5:-1	??% 15%	U	Fig. 1.211 1.212
	Revi AMOP	13.5	13.5:-1			Fig. 1.211 1.212

Table 1.55: Ionization Cross section for  $\lambda$  impact on H

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$H + \lambda \rightarrow H^+ + e^-$	Revi AMOP	13.5	13.5:-1	15%		Fig. 1.215 1.216 1.217 1.218
$H + \lambda \rightarrow \text{Total}$	Revi AMOP	0	0:-1	15%		Fig. 1.215 1.216 1.217 1.218

Table 1.56: Recommended Cross section for  $\lambda$  impact on H

Figure 1.211: Cross sections for  $\text{H} + \lambda \rightarrow \text{H}^+ + \text{e}$ Figure 1.212: Cross sections for  $\text{H} + \lambda \rightarrow \text{H}^+ + \text{e}$  (wavelength version)

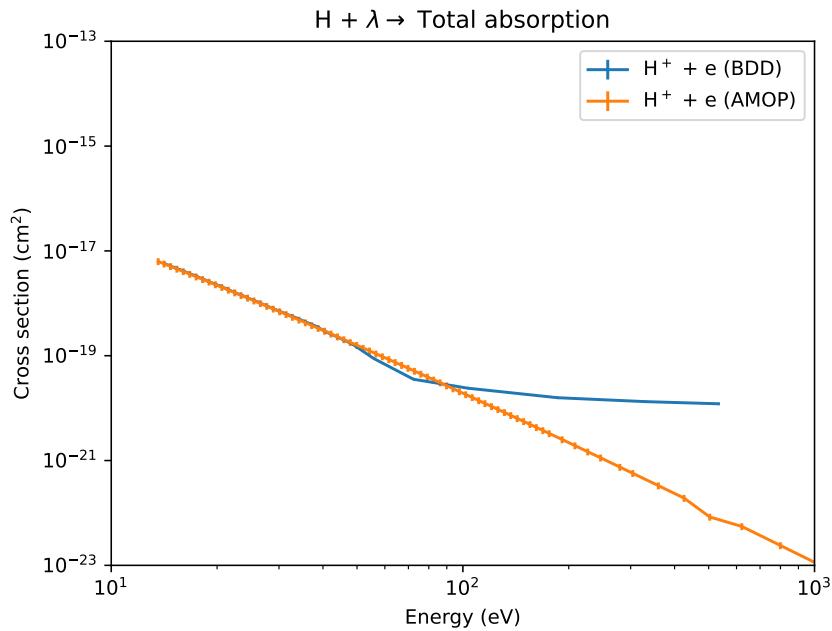


Figure 1.213: Cross sections for  $H + \lambda \rightarrow$  Total absorption

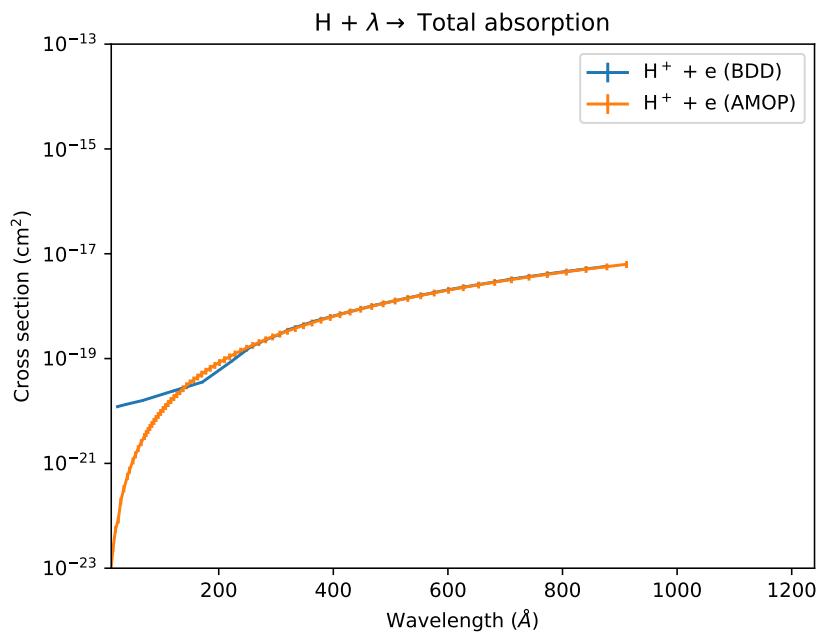
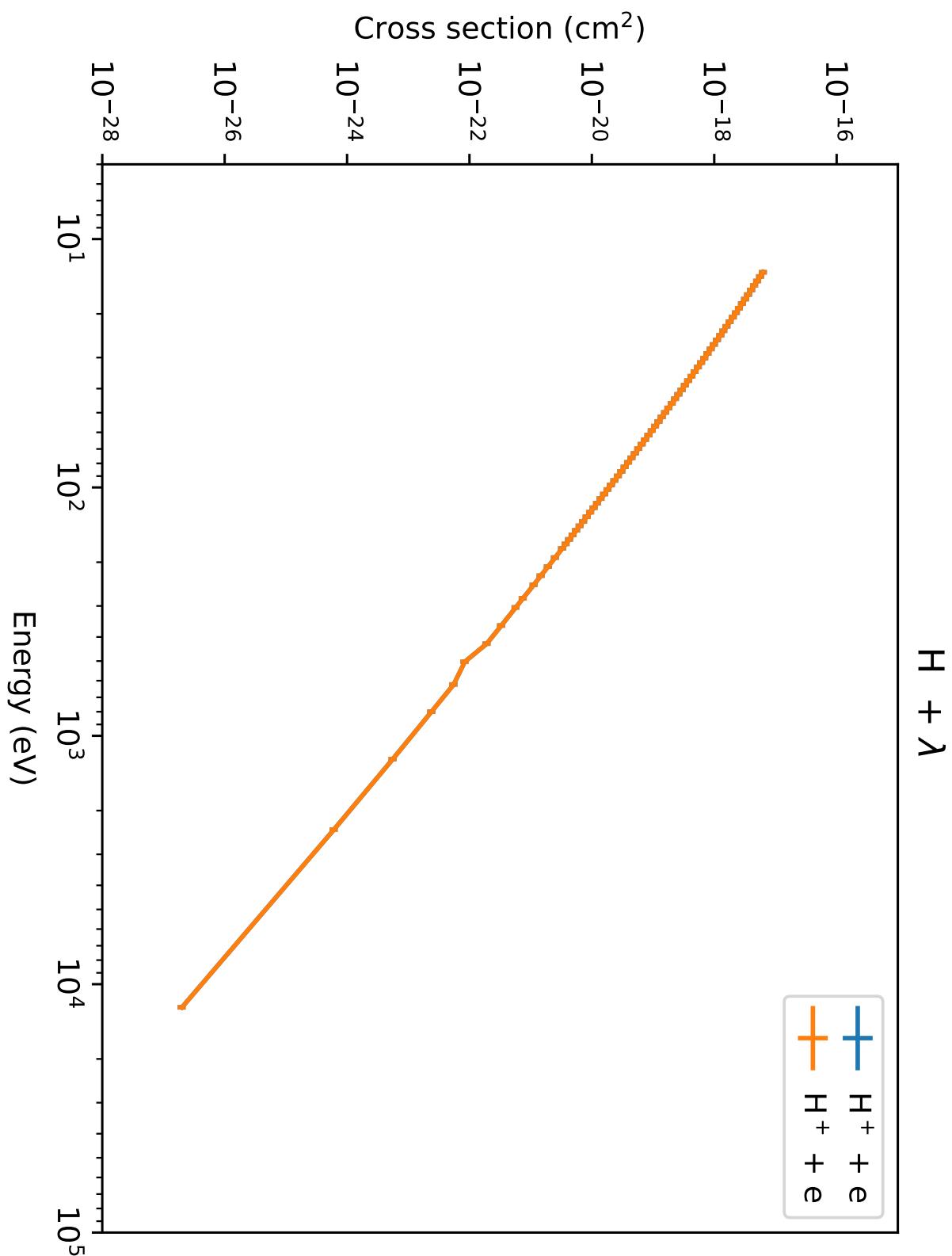


Figure 1.214: Cross sections for  $H + \lambda \rightarrow$  Total absorption (wavelength version)

Figure 1.215: Cross sections for  $\text{H} + \lambda$

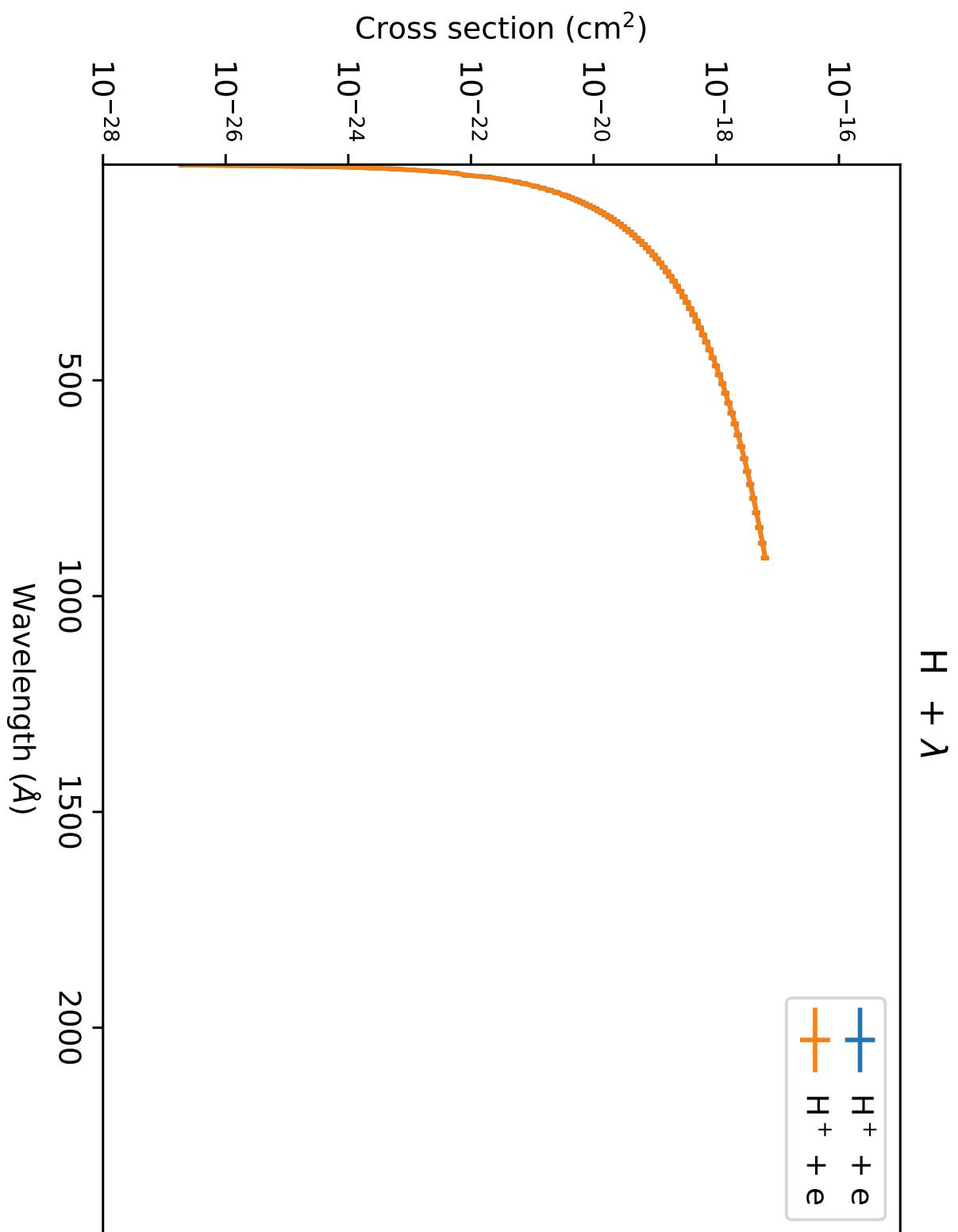
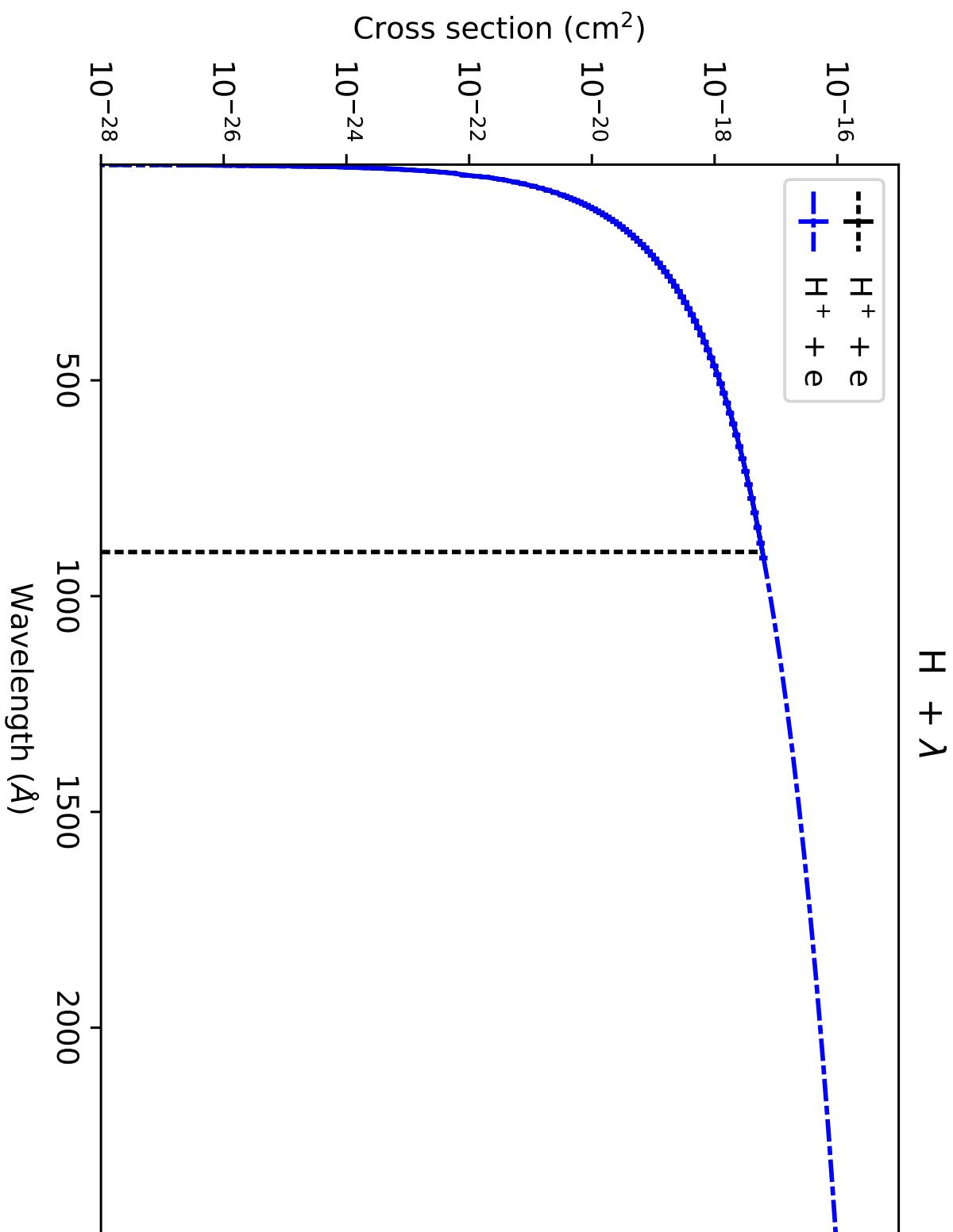


Figure 1.216: Cross sections for  $H + \lambda$  (wavelength version)

Figure 1.217: Cross sections for  $\text{H} + \lambda$  (with extrapolation version)

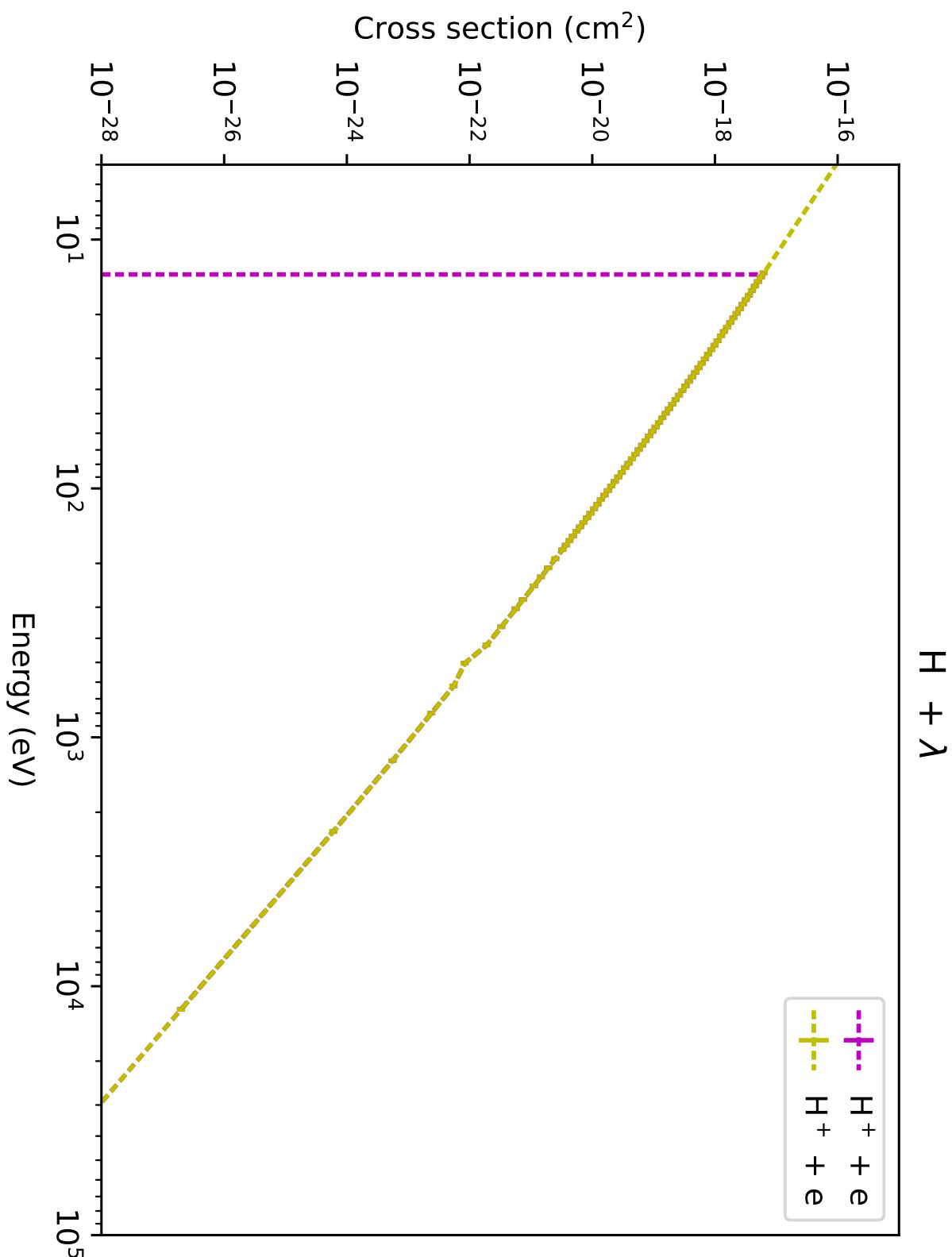


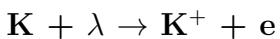
Figure 1.218: Cross sections for  $\text{H} + \lambda$  (wavelength with extrapolation version)

## 1.17 Cross section of ph impact with K

### 1.17.1 Total Cross Section

### 1.17.2 Inelastic Cross Sections

#### Ionization Cross Sections



**K<sup>+</sup> + e (PHIDRATES)** Photoionization of K yielding K<sup>+</sup> + e from the review of PHIDRATES. The uncertainty, not claimed by the review, is estimated at 20%. The data, in nm, have been directly adapted in eV.

**K<sup>+</sup> + e (PHIDRATES)** Photoionization of K yielding K<sup>+</sup> + e from the review of PHIDRATES [24] The uncertainty, not claimed by the review, is estimated at 20%. The data, in nm, have been directly adapted in eV.

#### Legend for the properties

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**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

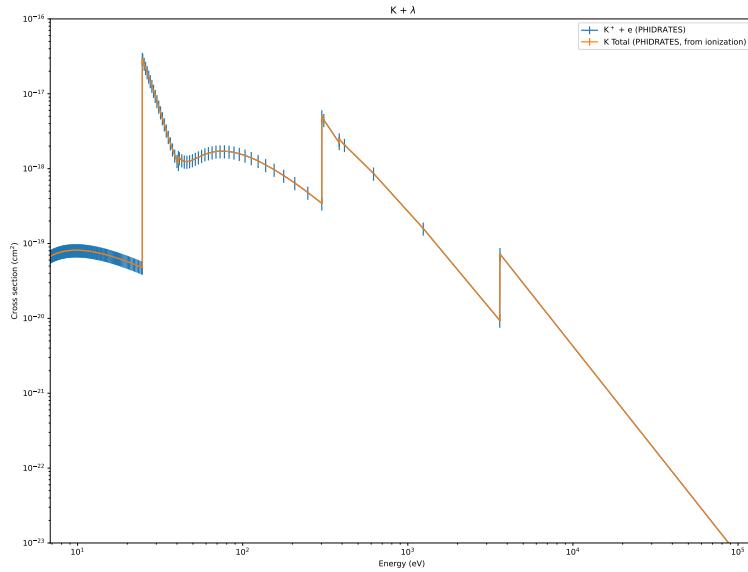
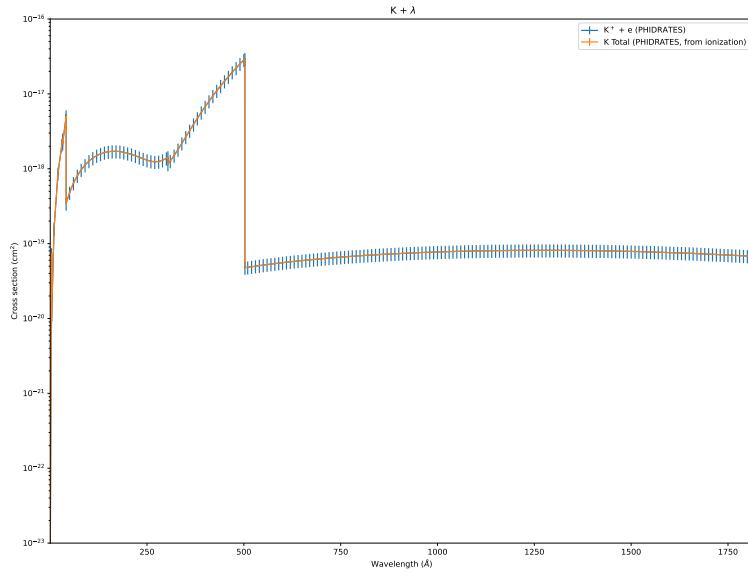
**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

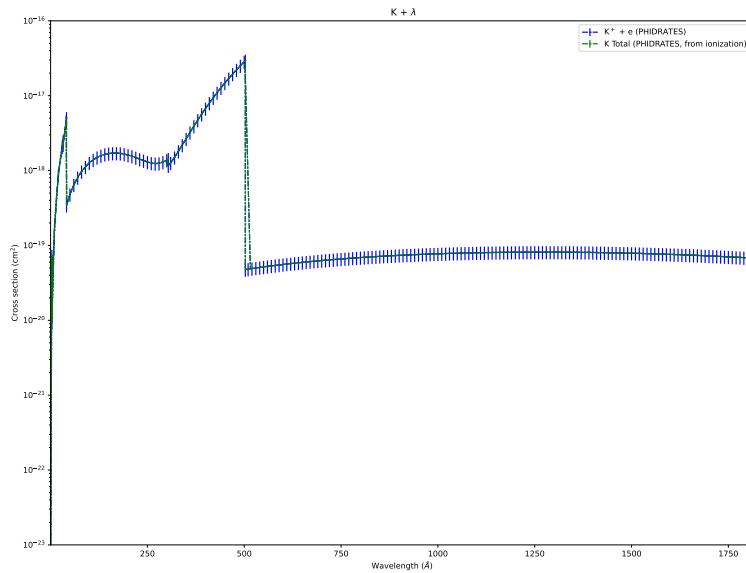
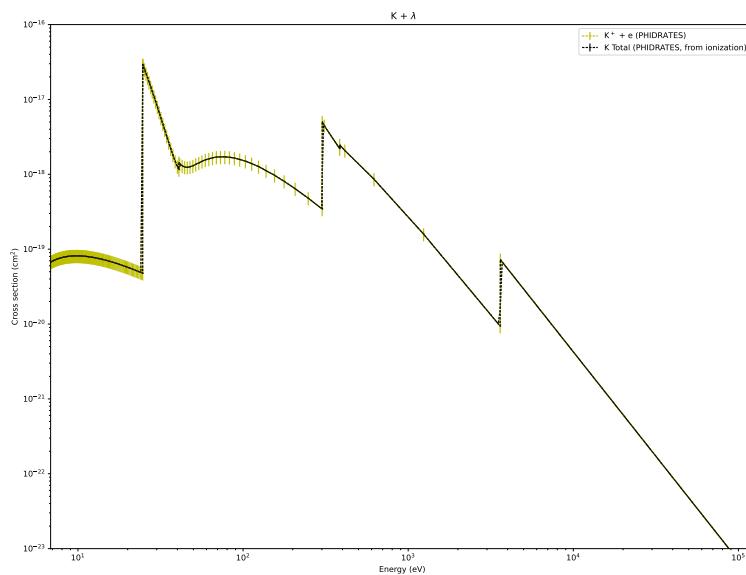
Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi PHDRATES	0	4.340667:124000	?%?	U	Fig. 1.219 1.220 1.221 1.222
Revi PHDRATES	0	4.340667:124000	?%?	U	Fig. 1.225 1.226

Table 1.57: Total cross section for  $\lambda$  impact on K

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$K + \lambda \rightarrow K^+ + e$	Revi PHDRATES	4.340667	4.340667:124000	20%	U	Fig. 1.219 Fig. 1.220
	Revi PHDRATES	4.340667	4.340667:124000	??%	U	Fig. 1.221 Fig. 1.223

Table 1.58: Ionization Cross section for  $\lambda$  impact on K

Figure 1.219: Cross sections for  $K + \lambda$ Figure 1.220: Cross sections for  $K + \lambda$  (wavelength version)

Figure 1.221: Cross sections for  $K + \lambda$  (with extrapolation version)Figure 1.222: Cross sections for  $K + \lambda$  (wavelength with extrapolation version)

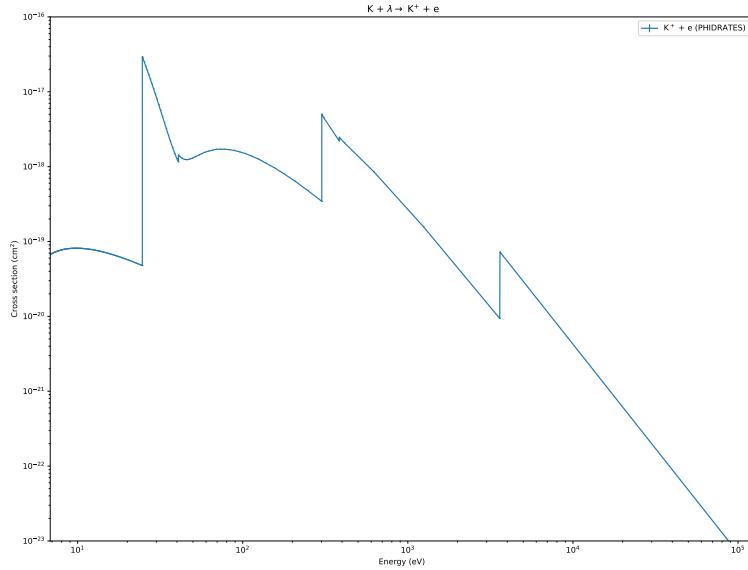


Figure 1.223: Cross sections for  $K + \lambda \rightarrow K^+ + e$

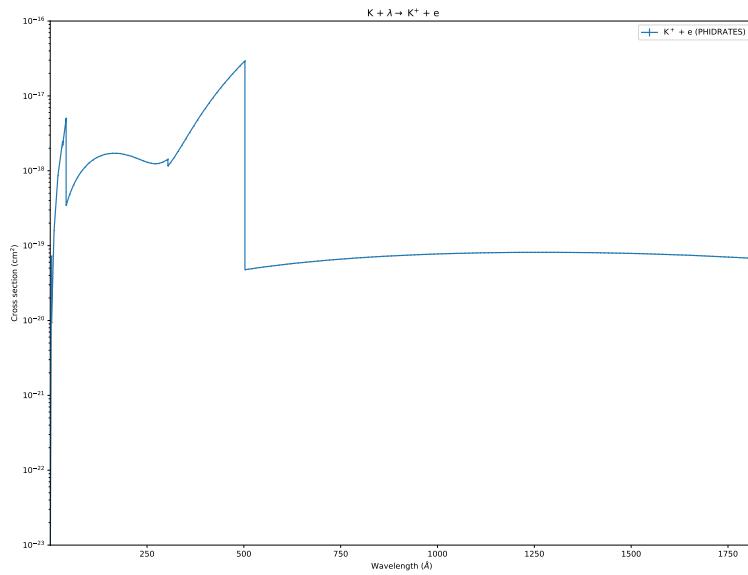
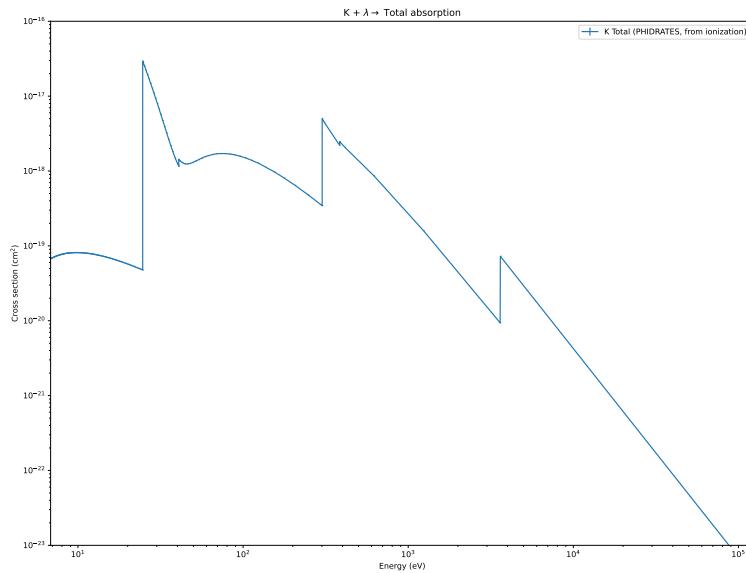
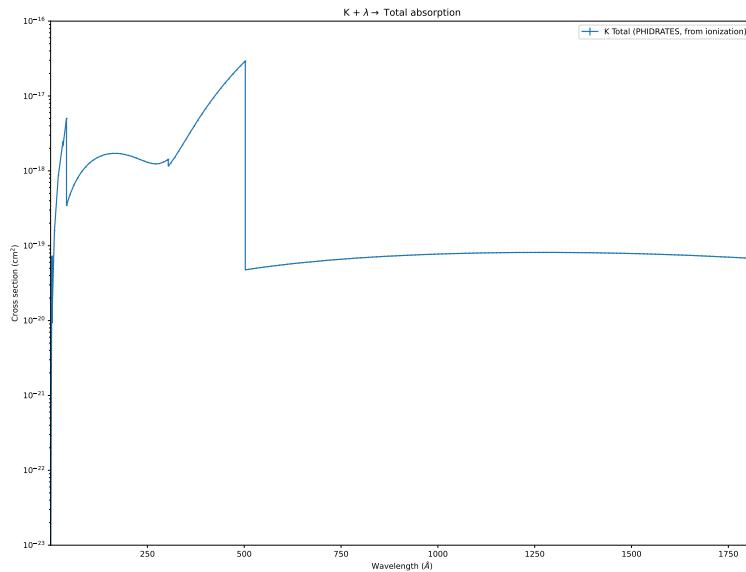


Figure 1.224: Cross sections for  $K + \lambda \rightarrow K^+ + e$  (wavelength version)

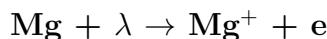
Figure 1.225: Cross sections for  $K + \lambda \rightarrow$  Total absorptionFigure 1.226: Cross sections for  $K + \lambda \rightarrow$  Total absorption (wavelength version)

## 1.18 Cross section of ph impact with Mg

### 1.18.1 Total Cross Section

### 1.18.2 Inelastic Cross Sections

#### Ionization Cross Sections



**Mg<sup>+</sup> + e (PHIDRATES)** Photoionization of Mg yielding Mg<sup>+</sup> + e from the review of PHIDRATES. The uncertainty, not claimed by the review, is estimated at 20%. The data, in nm, have been directly adapted in eV.

**Mg<sup>+</sup> + e (PHIDRATES)** Photoionization of Mg yielding Mg<sup>+</sup> + e from the review of PHIDRATES. [24] The uncertainty, not claimed by the review, is estimated at 20%. The data, in nm, have been directly adapted in eV.

#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

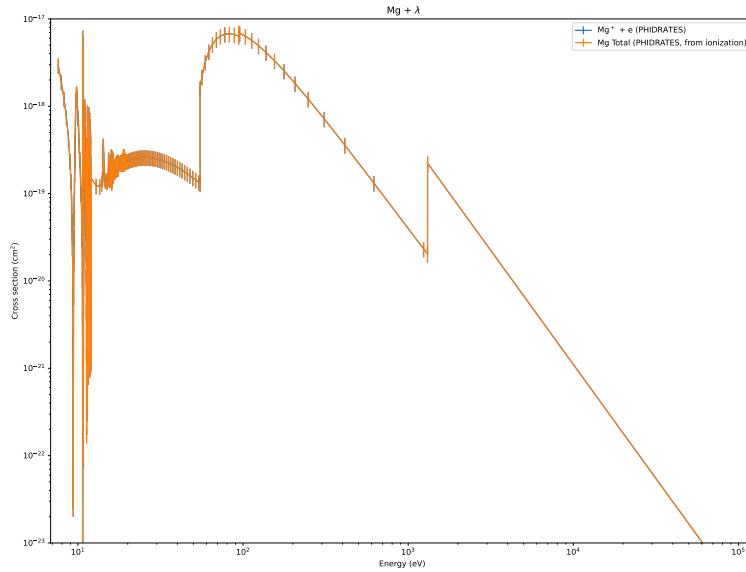
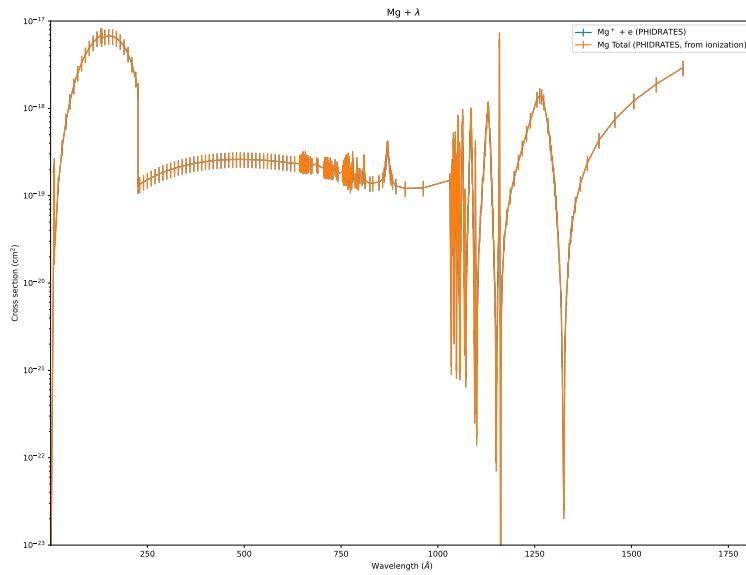
**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi PHDRATES	0	7.592419:124000	20%		Fig. 1.227 1.228 1.229 1.230
Revi PHDRATES	0	7.592419:124000	20%		Fig. 1.233 1.234

Table 1.59: Total cross section for  $\lambda$  impact on Mg

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$Mg + \lambda \rightarrow Mg^+ + e^-$	Revi PHIDRATES	7.592419	7.592419:124000	20%		Fig. 1.227 1.228 1.229 1.230
	Revi PHIDRATES	7.592419	7.592419:124000	20%		Fig. 1.231 1.232

Table 1.60: Ionization Cross section for  $\lambda$  impact on Mg

Figure 1.227: Cross sections for Mg +  $\lambda$ Figure 1.228: Cross sections for Mg +  $\lambda$  (wavelength version)

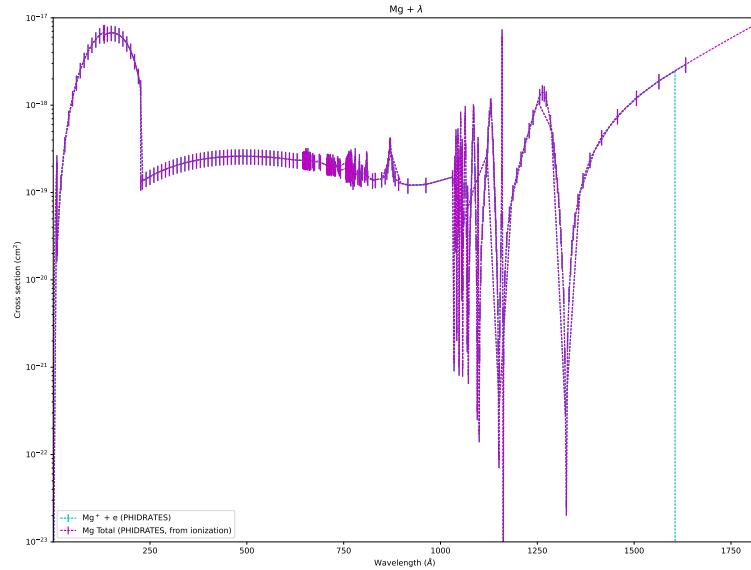


Figure 1.229: Cross sections for  $\text{Mg} + \lambda$  (with extrapolation version)

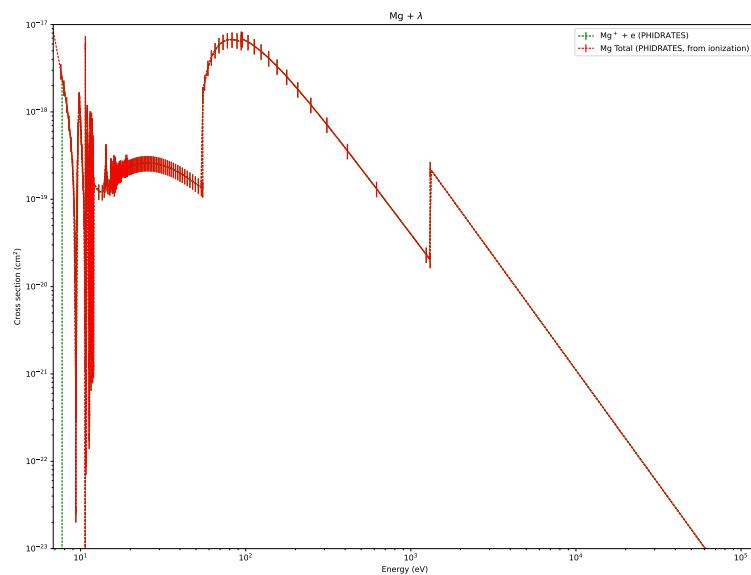
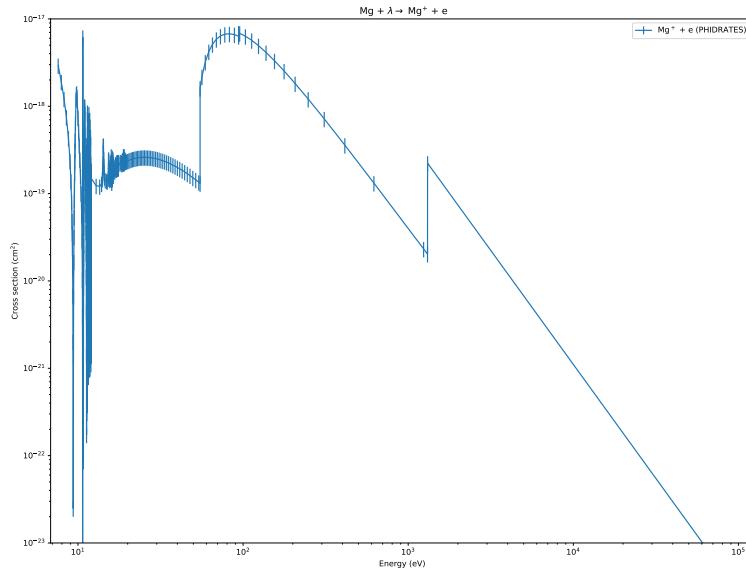
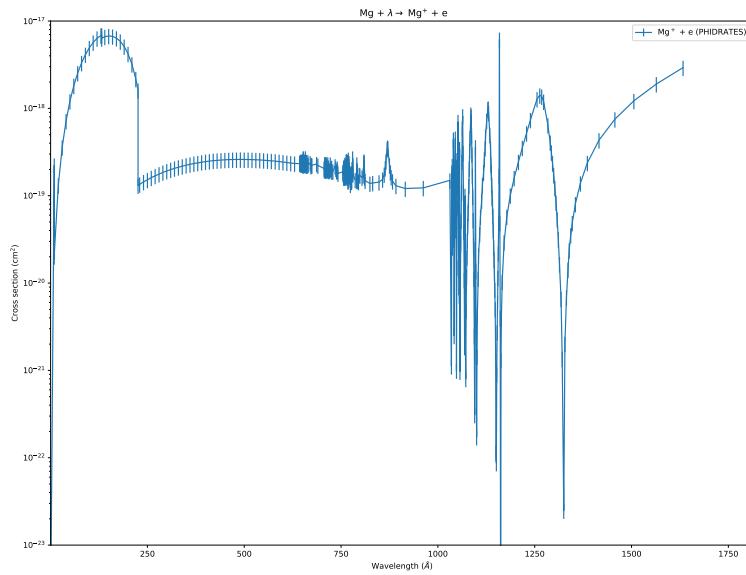


Figure 1.230: Cross sections for  $\text{Mg} + \lambda$  (wavelength with extrapolation version)

Figure 1.231: Cross sections for  $\text{Mg} + \lambda \rightarrow \text{Mg}^+ + e$ Figure 1.232: Cross sections for  $\text{Mg} + \lambda \rightarrow \text{Mg}^+ + e$  (wavelength version)

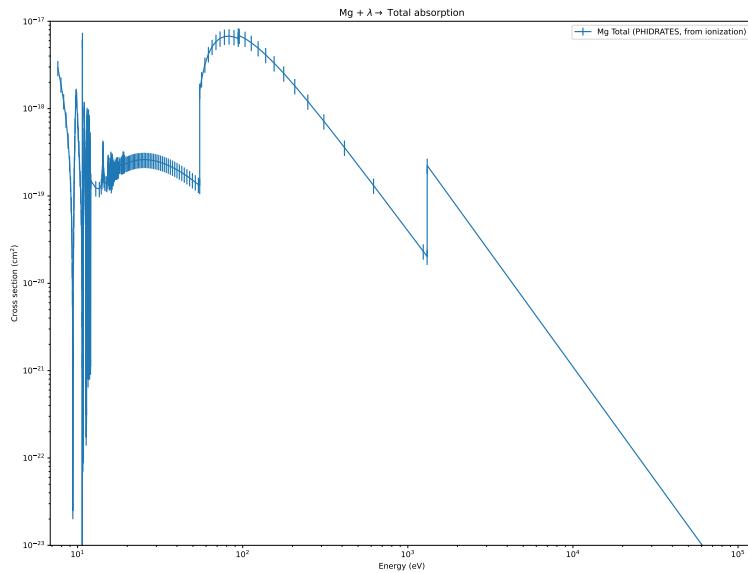


Figure 1.233: Cross sections for  $\text{Mg} + \lambda \rightarrow$  Total absorption

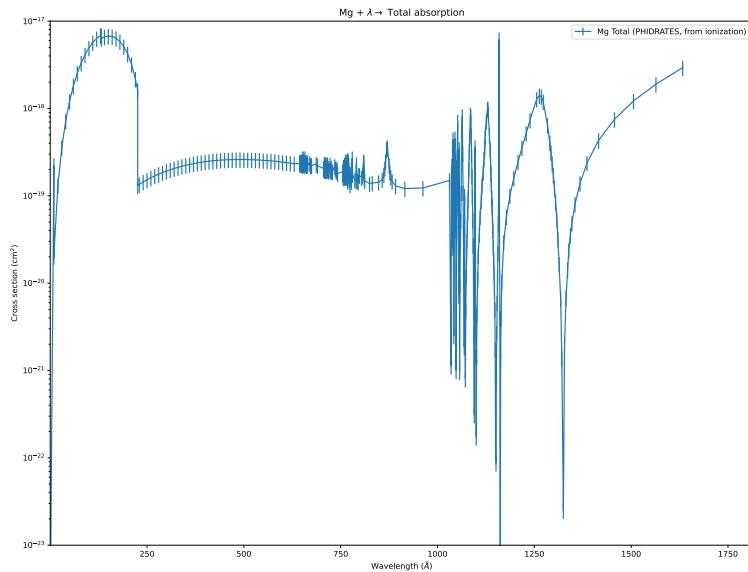


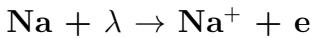
Figure 1.234: Cross sections for  $\text{Mg} + \lambda \rightarrow$  Total absorption (wavelength version)

## 1.19 Cross section of ph impact with Na

### 1.19.1 Total Cross Section

### 1.19.2 Inelastic Cross Sections

#### Ionization Cross Sections



**Na<sup>+</sup> + e (PHIDRATES)** Photoionization of Na yielding Na<sup>+</sup> + e from the review of PHIDRATES. The uncertainty, not claimed by the review, is estimated at 20%. The data, in nm, have been directly adapted in eV.

**Na<sup>+</sup> + e (PHIDRATES)** Photoionization of Na yielding Na<sup>+</sup> + e from the review of PHIDRATES.[24] The uncertainty, not claimed by the review, is estimated at 20%. The data, in nm, have been directly adapted in eV.

#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

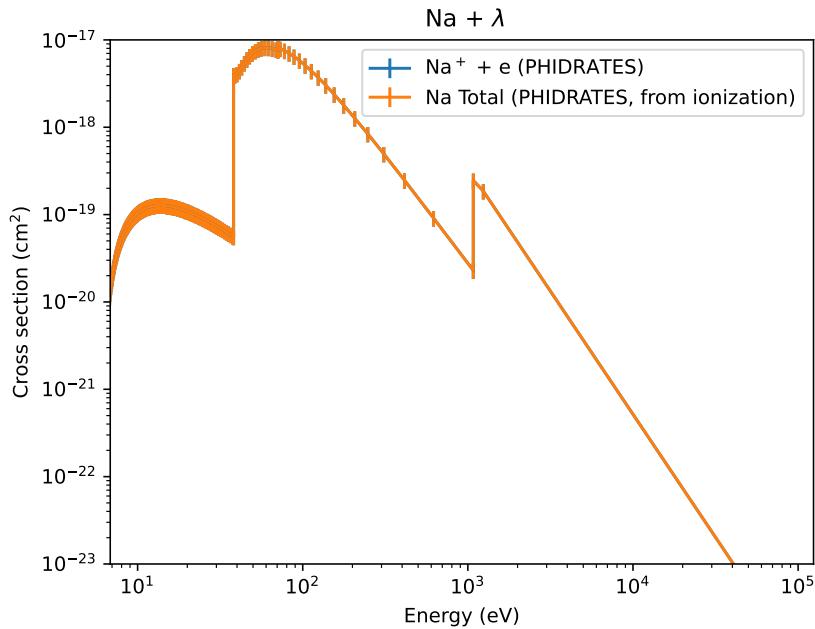
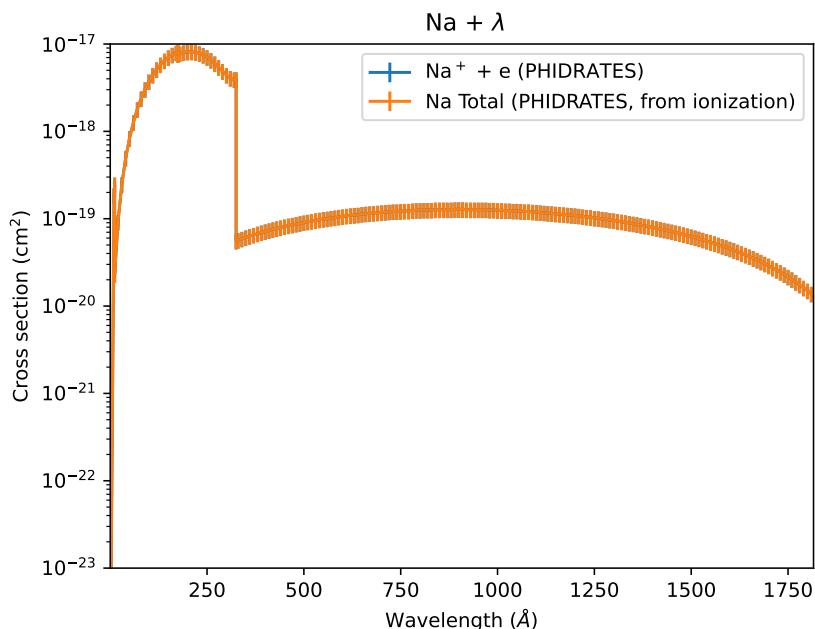
**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

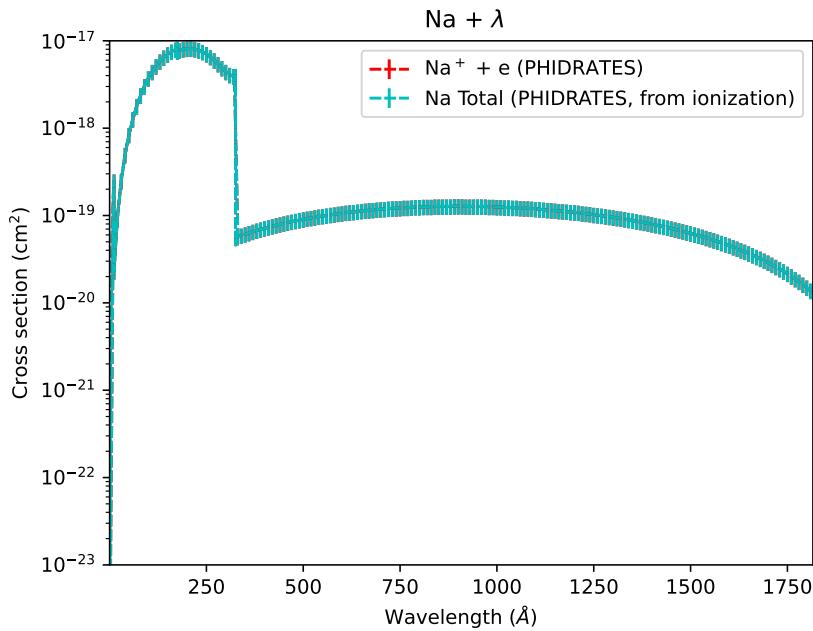
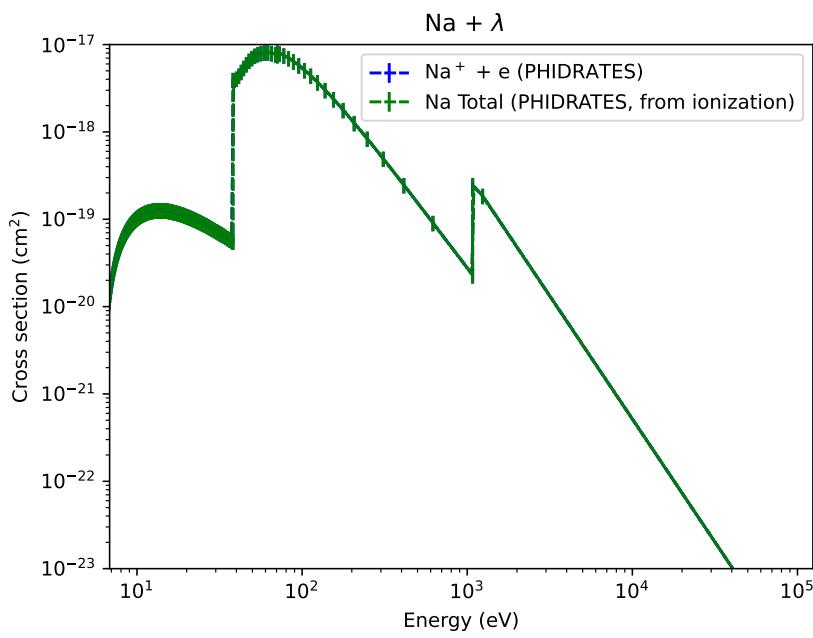
Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi PHDRATES	0	5.139071:124000	20%		Fig. 1.235 1.236 1.237 1.238
Revi PHDRATES	0	5.139071:124000	20%		Fig. 1.241 1.242

Table 1.61: Total cross section for  $\lambda$  impact on Na

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
Na + $\lambda$ → Na <sup>+</sup> + e	Revi PHIDRATES	5.139071	5.139071:124000	20%		Fig. 1.235 Fig. 1.236
	Revi PHIDRATES	5.139071	5.139071:124000	20%		Fig. 1.237 Fig. 1.239

Table 1.62: Ionization Cross section for  $\lambda$  impact on Na

Figure 1.235: Cross sections for  $\text{Na} + \lambda$ Figure 1.236: Cross sections for  $\text{Na} + \lambda$  (wavelength version)

Figure 1.237: Cross sections for  $\text{Na} + \lambda$  (with extrapolation version)Figure 1.238: Cross sections for  $\text{Na} + \lambda$  (wavelength with extrapolation version)

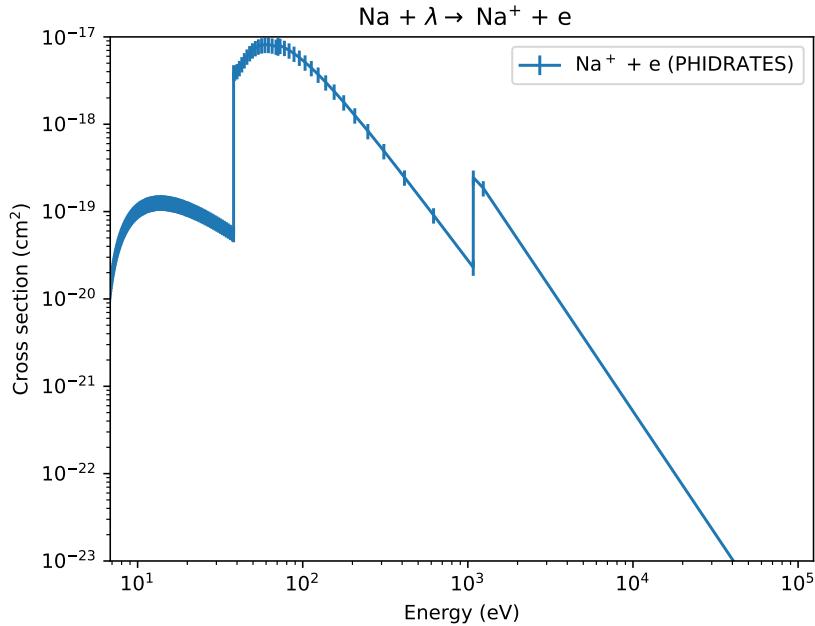


Figure 1.239: Cross sections for  $\text{Na} + \lambda \rightarrow \text{Na}^+ + \text{e}$

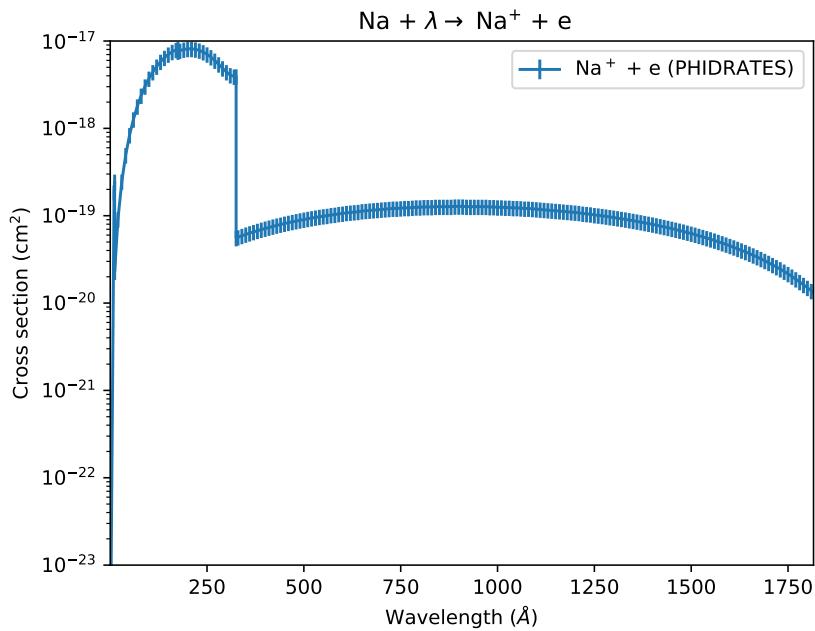


Figure 1.240: Cross sections for  $\text{Na} + \lambda \rightarrow \text{Na}^+ + \text{e}$  (wavelength version)

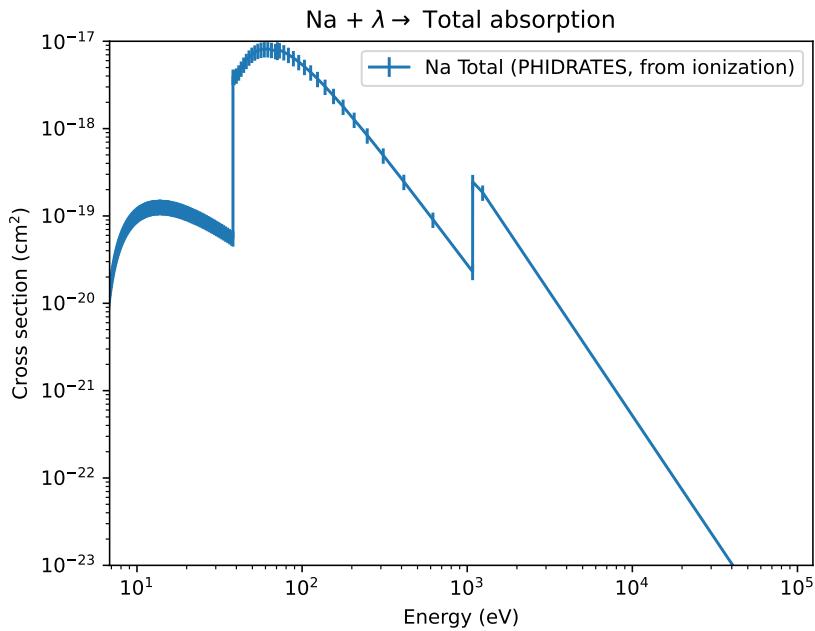


Figure 1.241: Cross sections for  $\text{Na} + \lambda \rightarrow$  Total absorption

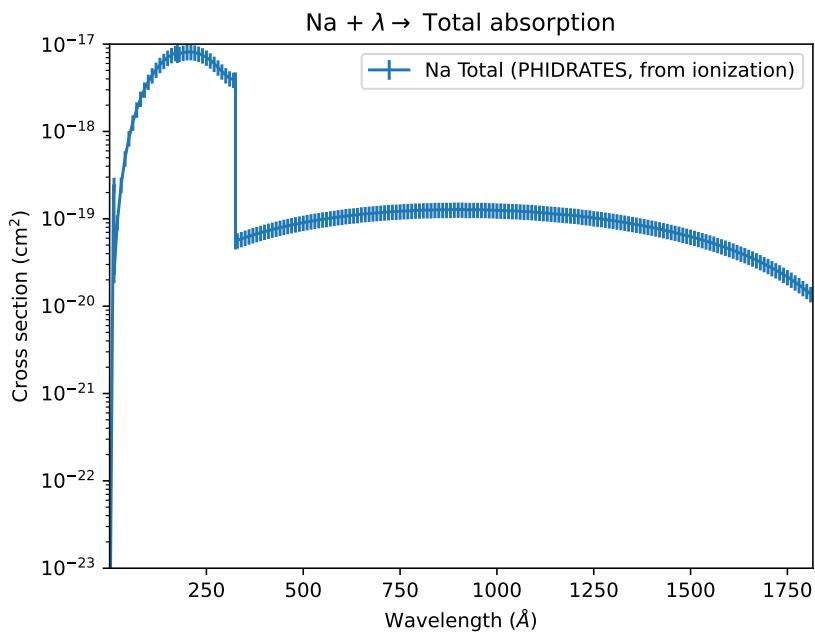


Figure 1.242: Cross sections for  $\text{Na} + \lambda \rightarrow$  Total absorption (wavelength version)

## 1.20 Cross section of impact with

### 1.20.1 Inelastic Cross Sections

#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

## 1.21 Cross section of impact with

### 1.21.1 Inelastic Cross Sections

#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections = Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

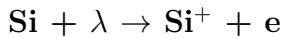
**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

## 1.22 Cross section of ph impact with Si

### 1.22.1 Total Cross Section

### 1.22.2 Inelastic Cross Sections

#### Ionization Cross Sections



**Si<sup>+</sup> + e (PHIDRATES)** Photoionization of Si yielding Si<sup>+</sup> + e from the review of PHIDRATES. The uncertainty, not claimed by the review, is estimated at 20%. The data, in nm, have been directly adapted in eV.

**Si<sup>+</sup> + e (PHIDRATES)** Photoionization of Si yielding Si<sup>+</sup> + e from the review of PHIDRATES.[24] The uncertainty, not claimed by the review, is estimated at 20%. The data, in nm, have been directly adapted in eV.

#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

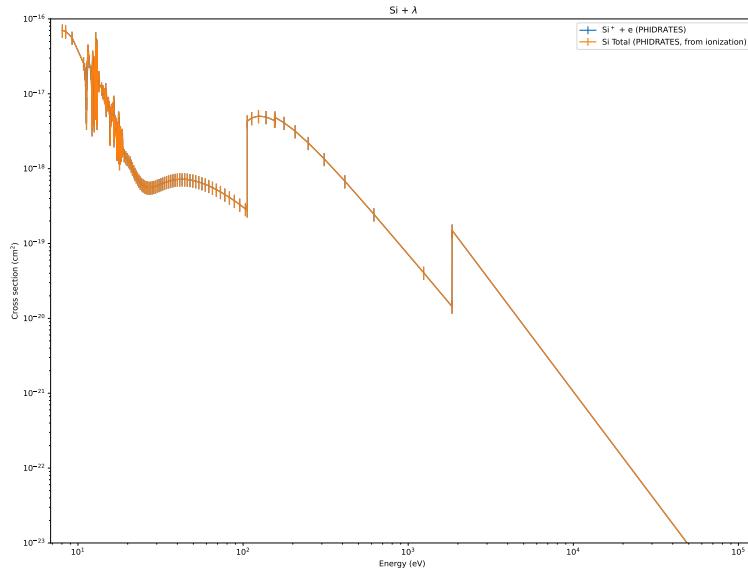
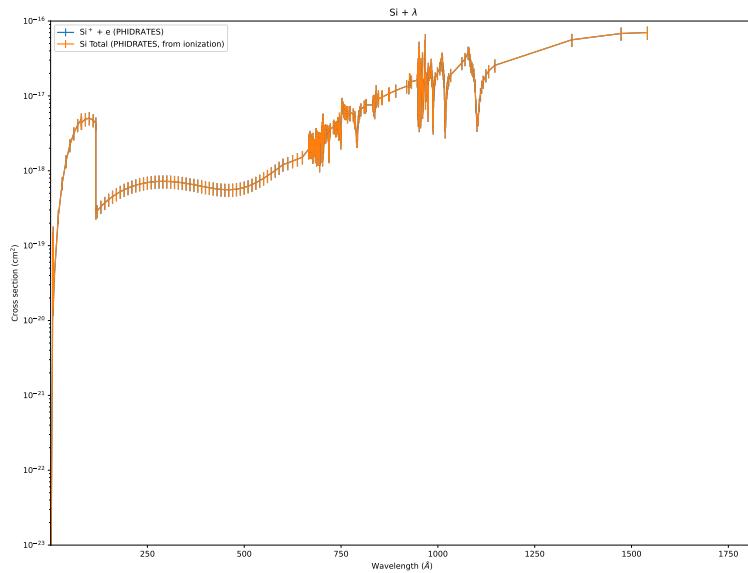
**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi PHDRATES	0	8.045698:124000	20%	Fig. 1.243	1.244
Revi PHDRATES	0	8.045698:124000	20%	Fig. 1.249	1.250

Table 1.63: Total cross section for  $\lambda$  impact on Si

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$\text{Si} + \lambda \rightarrow \text{Si}^+ + e^-$	Revi PHDRATES	6.828113	6.828113:124000	20%	Fig. 1.243 1.244 1.245 1.246	Fig. 1.247 1.248
	Revi PHDRATES	6.828113	6.828113:124000	20%		

Table 1.64: Ionization Cross section for  $\lambda$  impact on Si

Figure 1.243: Cross sections for  $\text{Si} + \lambda$ Figure 1.244: Cross sections for  $\text{Si} + \lambda$  (wavelength version)

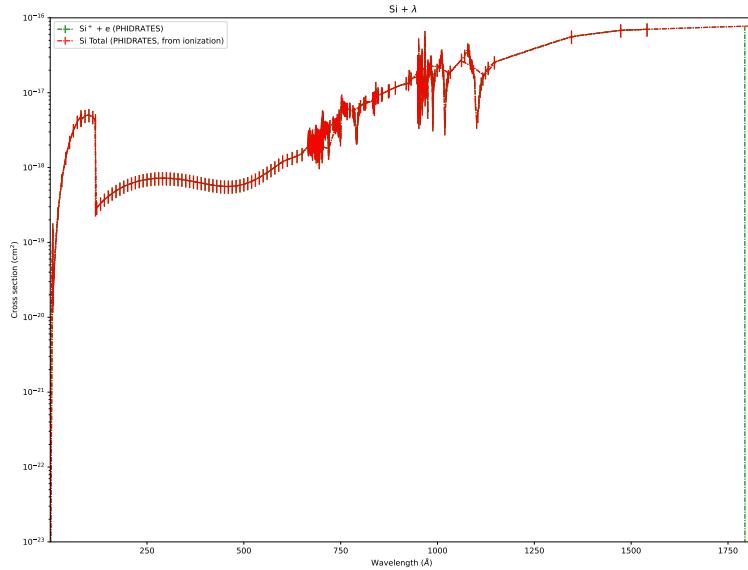


Figure 1.245: Cross sections for  $\text{Si} + \lambda$  (with extrapolation version)

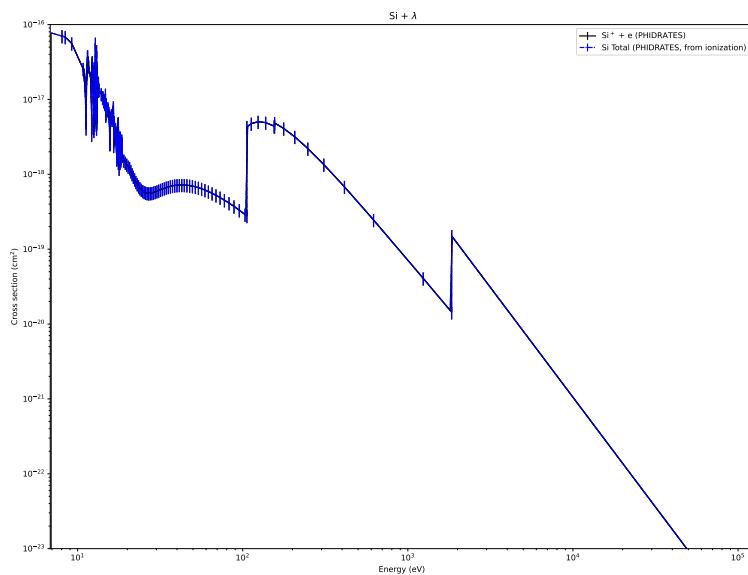
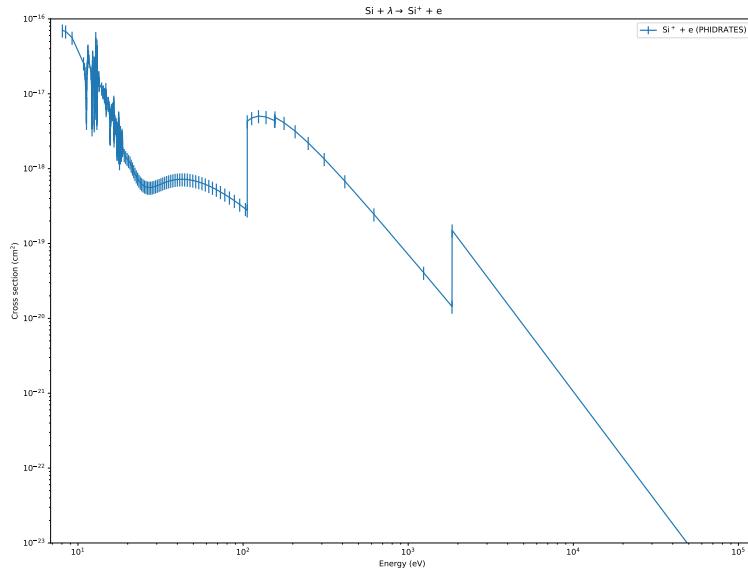
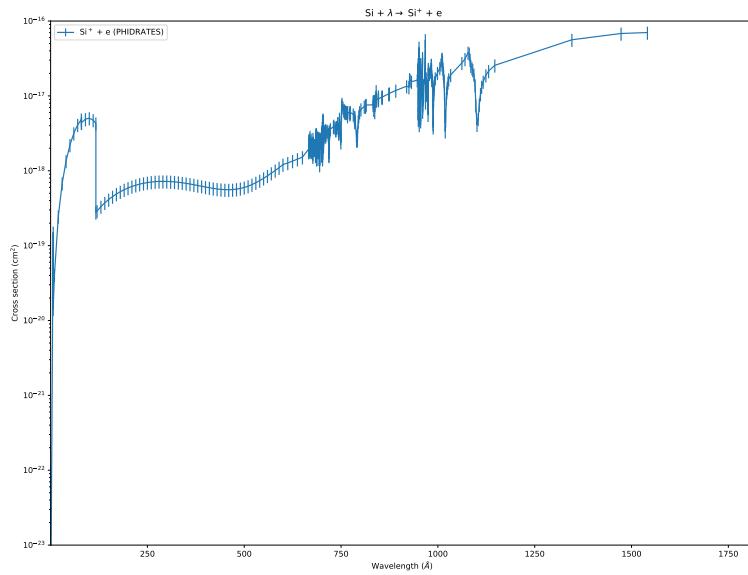


Figure 1.246: Cross sections for  $\text{Si} + \lambda$  (wavelength with extrapolation version)

Figure 1.247: Cross sections for  $\text{Si} + \lambda \rightarrow \text{Si}^+ + \text{e}$ Figure 1.248: Cross sections for  $\text{Si} + \lambda \rightarrow \text{Si}^+ + \text{e}$  (wavelength version)

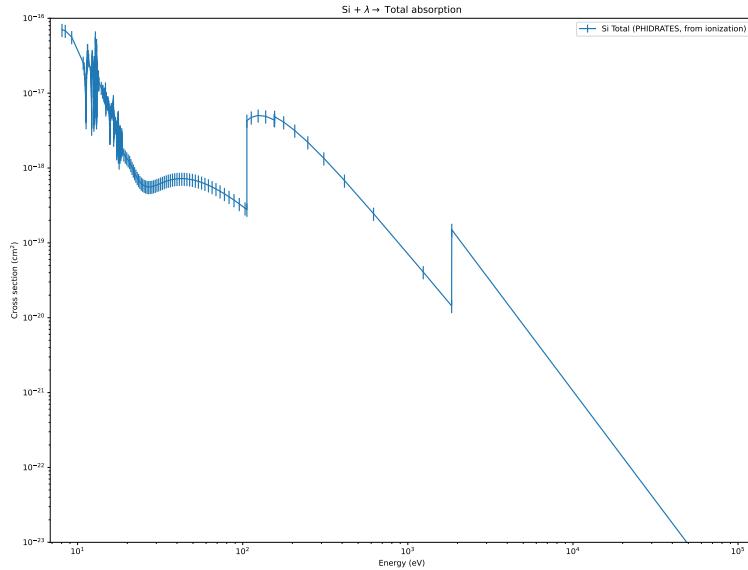


Figure 1.249: Cross sections for  $\text{Si} + \lambda \rightarrow \text{Total absorption}$

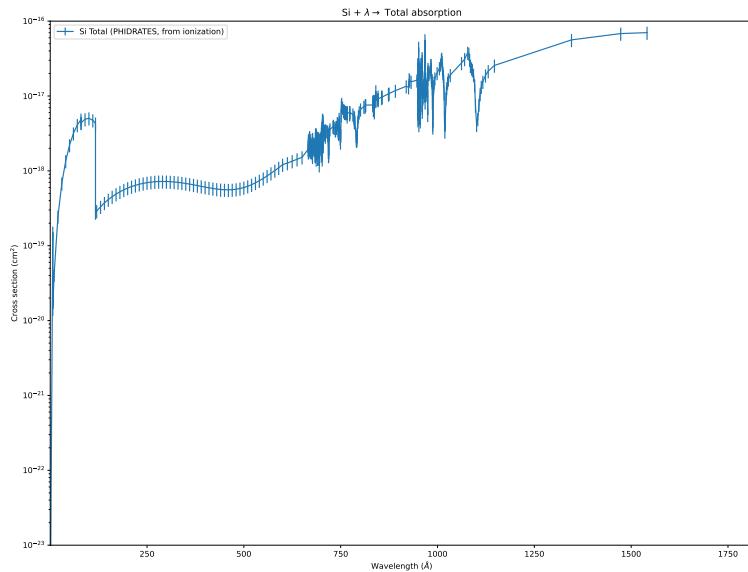


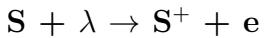
Figure 1.250: Cross sections for  $\text{Si} + \lambda \rightarrow \text{Total absorption}$  (wavelength version)

## 1.23 Cross section of ph impact with S

### 1.23.1 Total Cross Section

### 1.23.2 Inelastic Cross Sections

#### Ionization Cross Sections



**S<sup>+</sup> + e (PHIDRATES)** Photoionization of S yielding S<sup>+</sup> + e from the review of PHIDRATES. The uncertainty, not claimed by the review, is estimated at 20%. The data, in nm, have been directly adapted in eV.

**S<sup>+</sup> + e (PHIDRATES)** Photoionization of S yielding S<sup>+</sup> + e from the review of PHIDRATES.[24] The uncertainty, not claimed by the review, is estimated at 20%. The data, in nm, have been directly adapted in eV.

#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

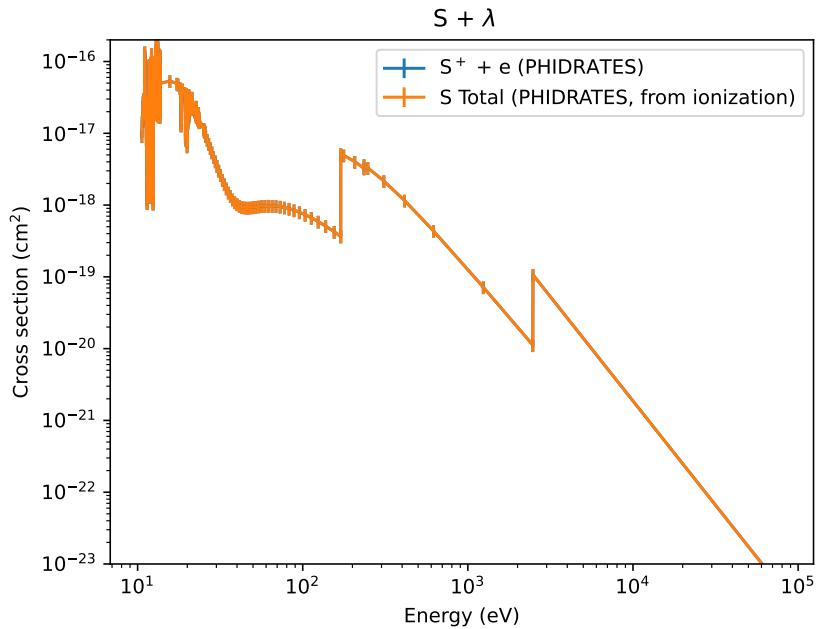
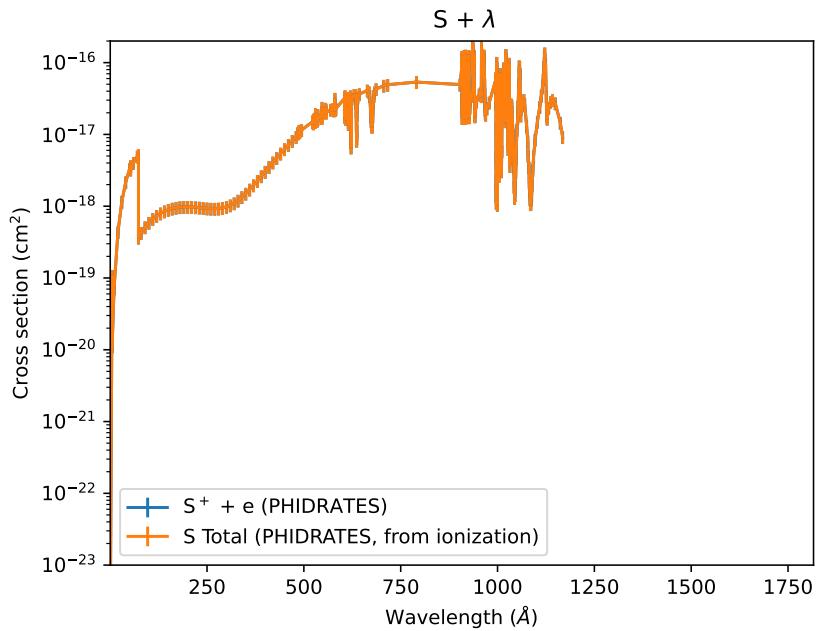
**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

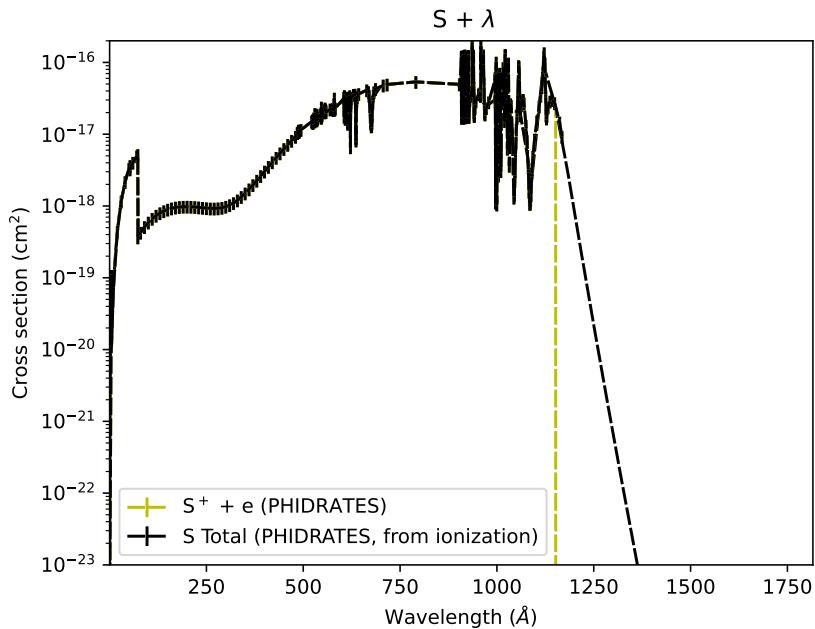
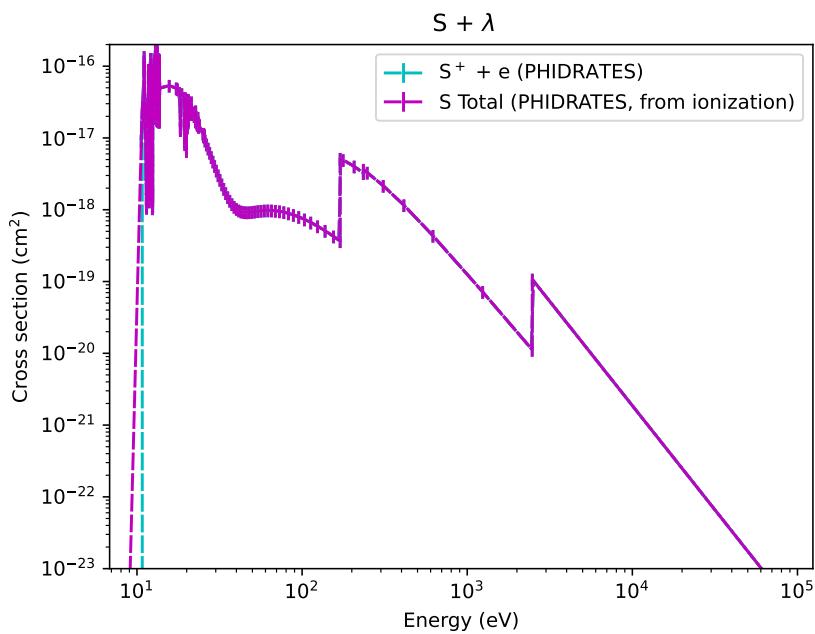
Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi PHDRATES	0	10.615086:124000	20%		Fig. 1.251 1.252 1.253 1.254
Revi PHDRATES	0	10.615086:124000	20%		Fig. 1.257 1.258

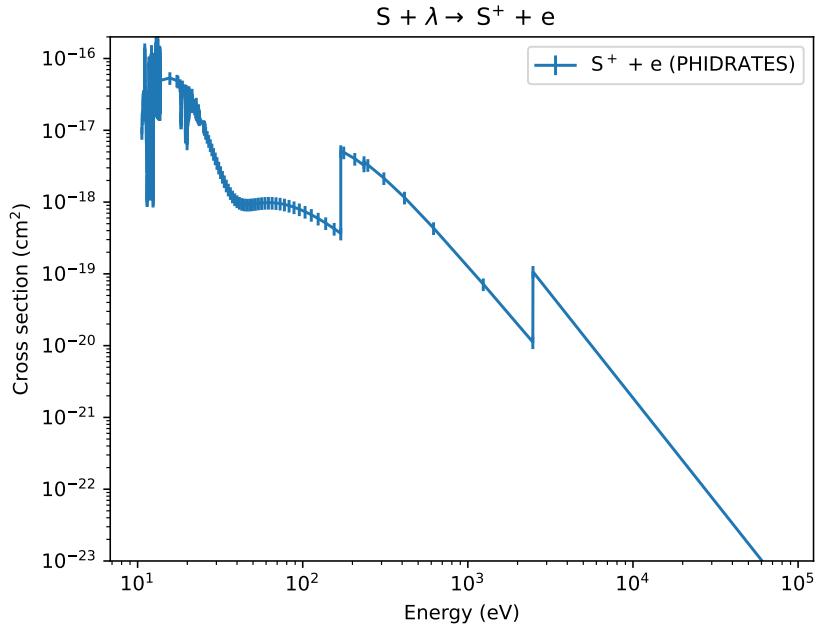
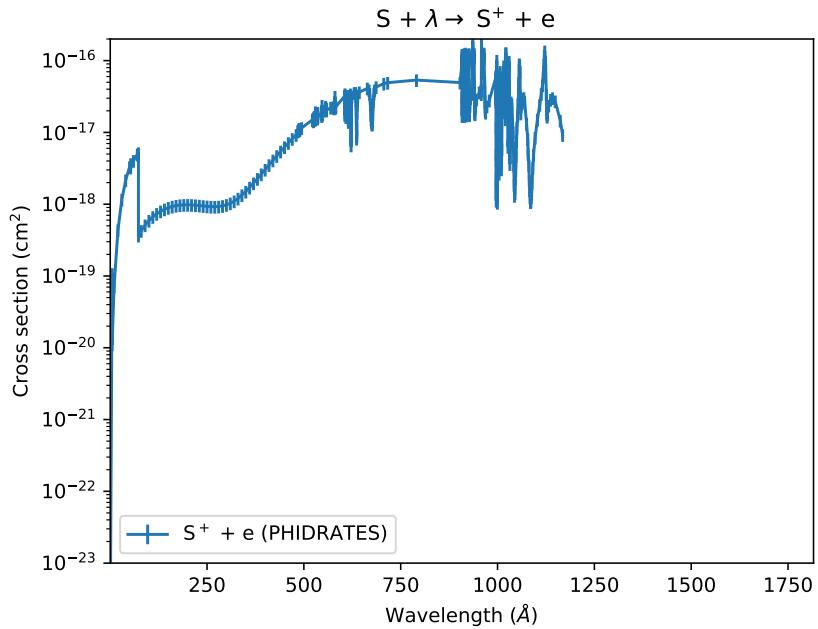
Table 1.65: Total cross section for  $\lambda$  impact on S

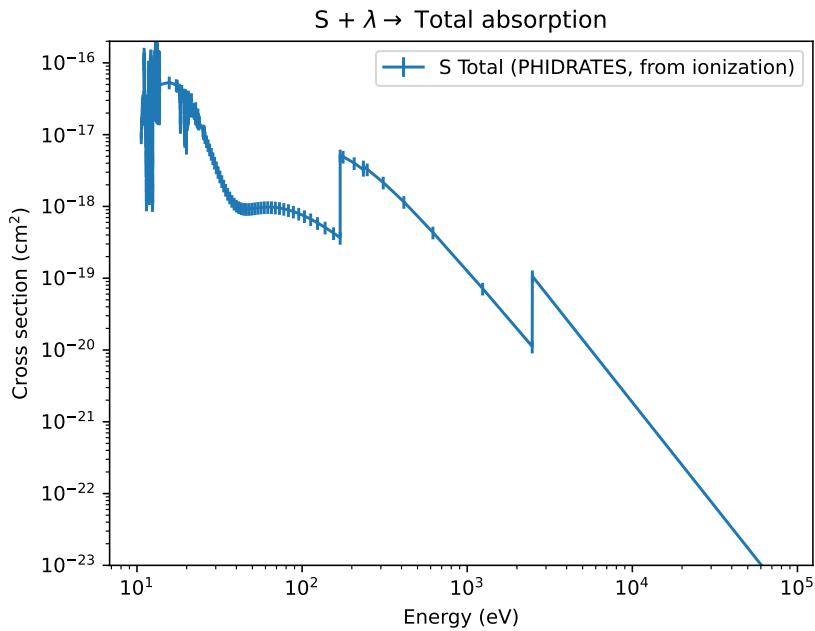
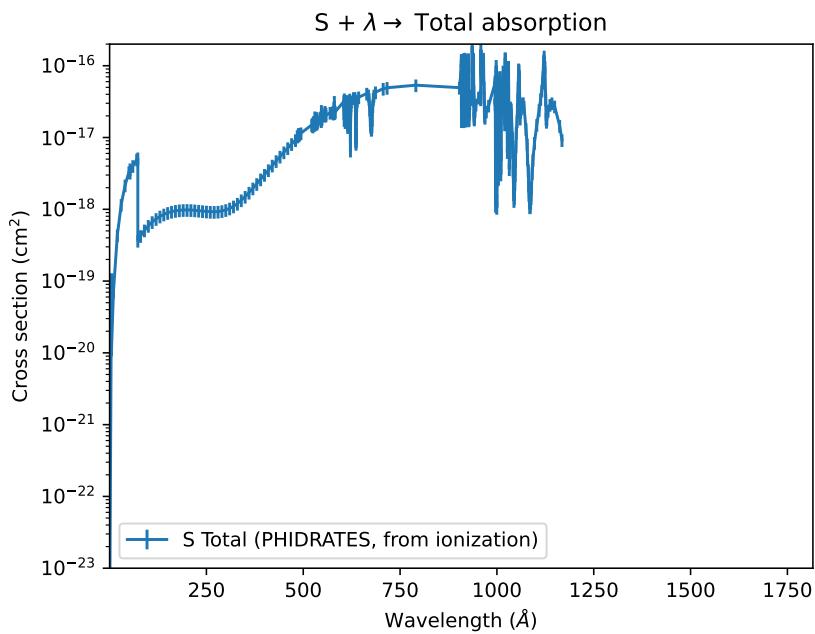
Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
S + $\lambda \rightarrow S^+ + e^-$	Revi PHDRATES	10.615086	10.615086:124000	20%		Fig. 1.251 Fig. 1.252
	Revi PHDRATES	10.615086	10.615086:124000	20%		Fig. 1.253 Fig. 1.255 Fig. 1.256

Table 1.66: Ionization Cross section for  $\lambda$  impact on S

Figure 1.251: Cross sections for  $S + \lambda$ Figure 1.252: Cross sections for  $S + \lambda$  (wavelength version)

Figure 1.253: Cross sections for  $S + \lambda$  (with extrapolation version)Figure 1.254: Cross sections for  $S + \lambda$  (wavelength with extrapolation version)

Figure 1.255: Cross sections for  $S + \lambda \rightarrow S^+ + e$ Figure 1.256: Cross sections for  $S + \lambda \rightarrow S^+ + e$  (wavelength version)

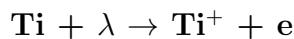
Figure 1.257: Cross sections for  $S + \lambda \rightarrow$  Total absorptionFigure 1.258: Cross sections for  $S + \lambda \rightarrow$  Total absorption (wavelength version)

## 1.24 Cross section of ph impact with Ti

### 1.24.1 Total Cross Section

### 1.24.2 Inelastic Cross Sections

#### Ionization Cross Sections



**Ti<sup>+</sup> + e (PHIDRATES)** Photoionization of Ti yielding Ti<sup>+</sup> + e from the review of PHIDRATES.[24] The uncertainty, not claimed by the review, is estimated at 15%. The data, in nm, have been directly adapted in eV.

**Ti<sup>+</sup> + e (PHIDRATES)** Photoionization of Ti yielding Ti<sup>+</sup> + e from the review of PHIDRATES.[24] The uncertainty, not claimed by the review, is estimated at 15%. The data, in nm, have been directly adapted in eV.

#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

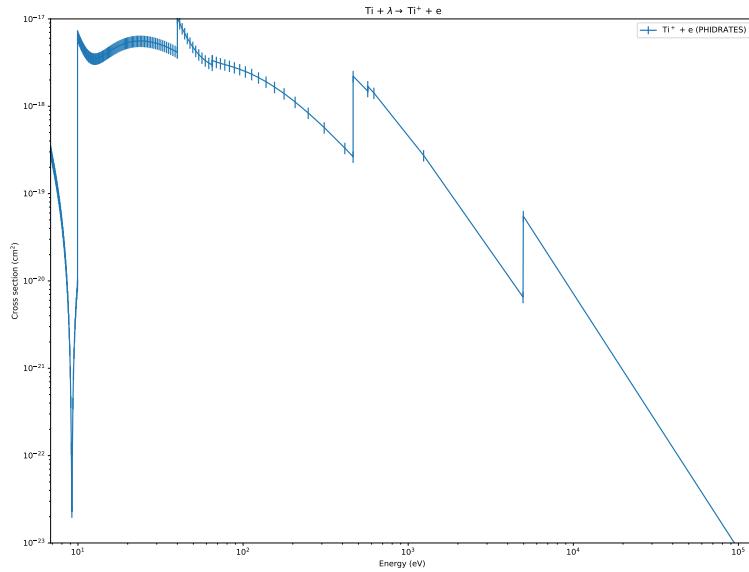
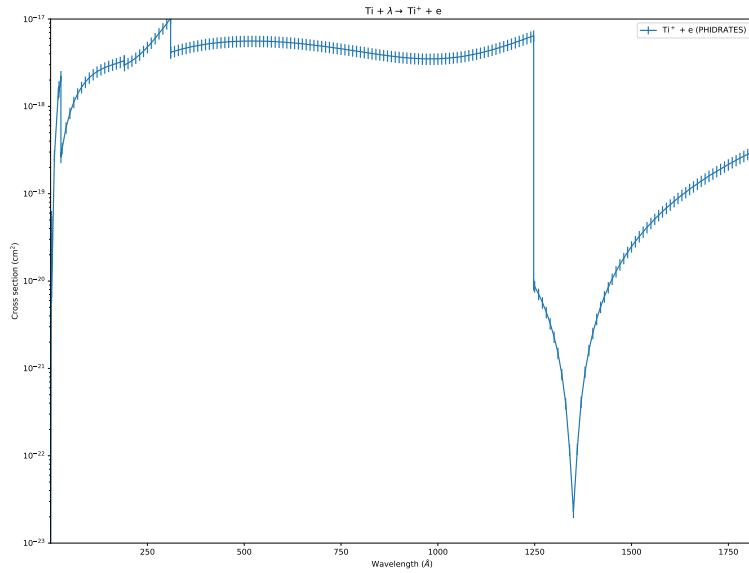
**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

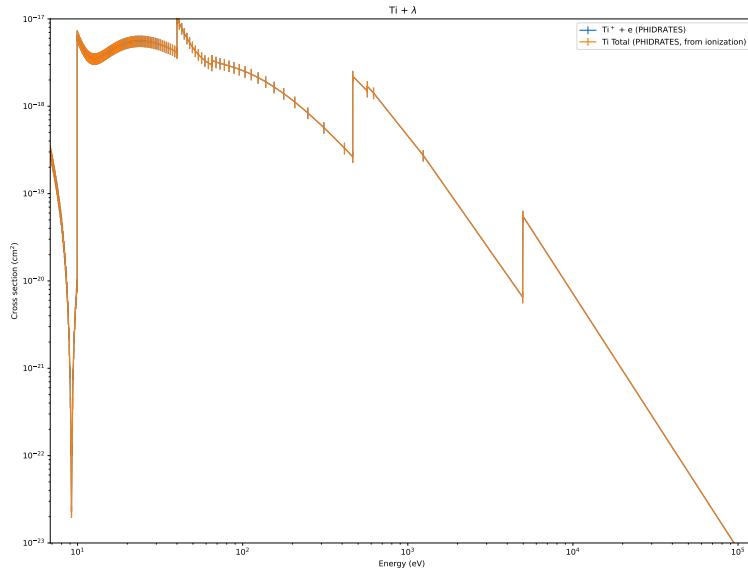
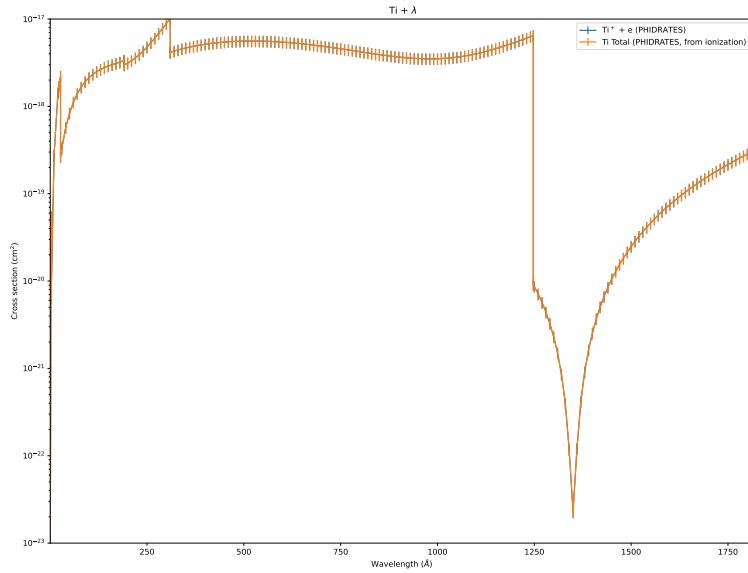
Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi PHDRATES	0	6.828113:124000	15%		Fig. 1.261 1.262 1.263 1.264
Revi PHDRATES	0	6.828113:124000	15%		Fig. 1.265 1.266

Table 1.67: Total cross section for  $\lambda$  impact on Ti

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$Ti + \lambda \rightarrow Ti^+ + e^-$	Revi PHIDRATES	6.828113	6.828113:124000	15%		Fig. 1.259 1.260
	Revi PHIDRATES	6.828113	6.828113:124000	15%		Fig. 1.261 1.262 1.263 1.264

Table 1.68: Ionization Cross section for  $\lambda$  impact on Ti

Figure 1.259: Cross sections for  $\text{Ti} + \lambda \rightarrow \text{Ti}^+ + e$ Figure 1.260: Cross sections for  $\text{Ti} + \lambda \rightarrow \text{Ti}^+ + e$  (wavelength version)

Figure 1.261: Cross sections for  $\text{Ti} + \lambda$ Figure 1.262: Cross sections for  $\text{Ti} + \lambda$  (wavelength version)

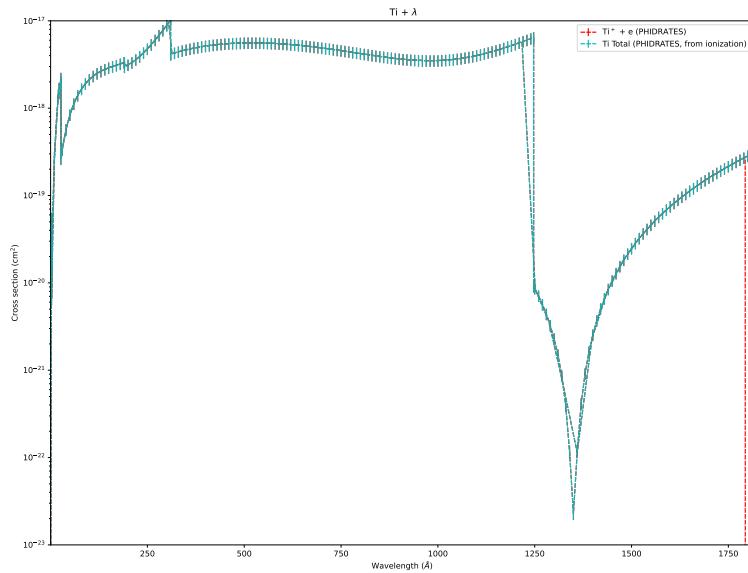


Figure 1.263: Cross sections for  $\text{Ti} + \lambda$  (with extrapolation version)

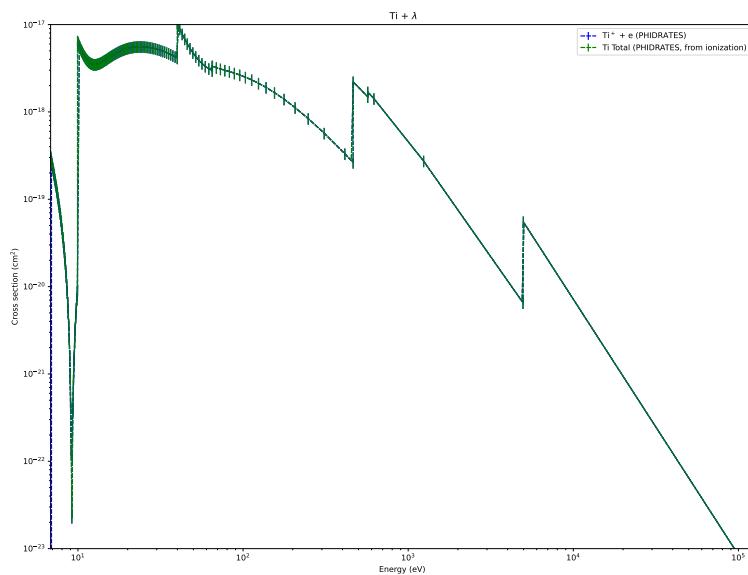


Figure 1.264: Cross sections for  $\text{Ti} + \lambda$  (wavelength with extrapolation version)

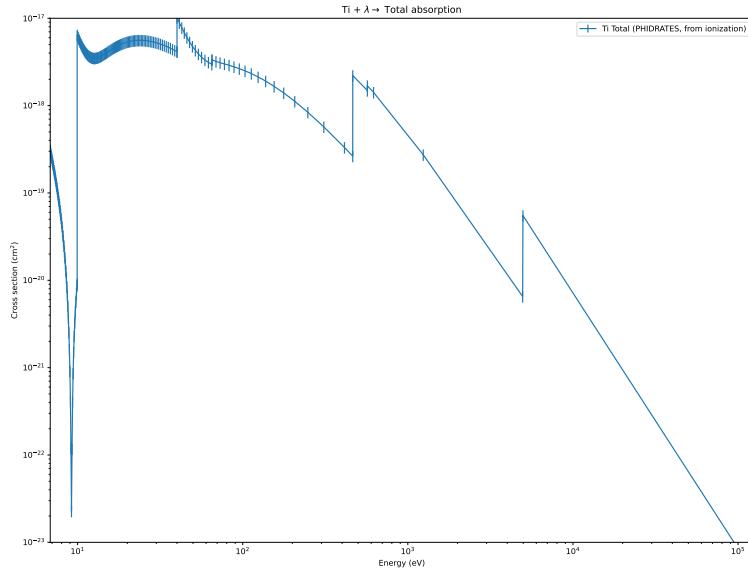


Figure 1.265: Cross sections for  $\text{Ti} + \lambda \rightarrow \text{Total absorption}$

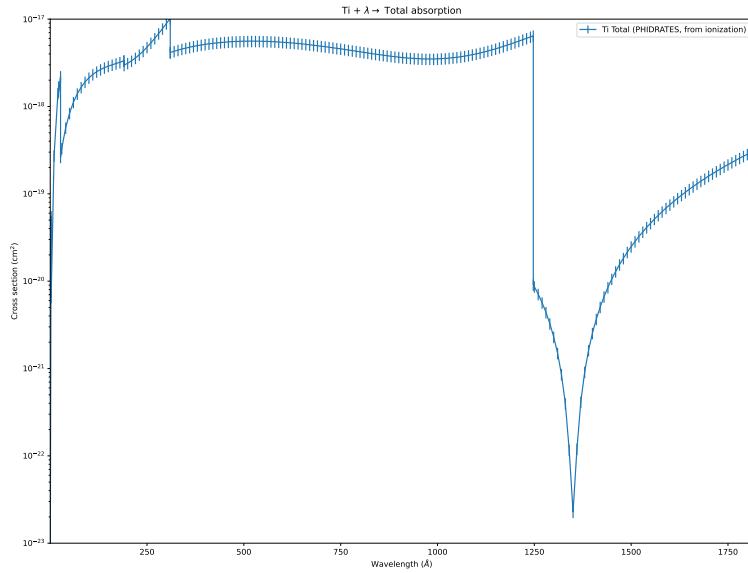


Figure 1.266: Cross sections for  $\text{Ti} + \lambda \rightarrow \text{Total absorption}$  (wavelength version)

# **Chapter 2**

## **Electron impact**

### **Introduction**



Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
Ar + e → Ar+	Revi [6]	15.755	15.755:-1	10%	U	Fig. 2.1
Ar + e → Ar++	Revi [6]	43.40	43.40:-1	20%	U	Fig. 2.1
	Adap [64]+ Lilensten	43.40	43.40:-1	30%	U	Fig. 2.1
Ar + e → Ar+(4P)	Revi [6]	35.40	35.40:-1	20%	U	Fig. 2.1
	Revi [64]+ Lilensten	35.40	35.40:-1	30%	U	Fig. 2.1
Ar + e → M Shell	Revi [64]	15.76	15.76:-1	30%	U	Fig. 2.1
Ar + e → M Shellv2	Revi [64]	15.76	15.76:-1	30%	U	Fig. 2.1
Ar + e → Ar++(Auger)	Revi [64]	250.0	250.0:-1	30%	U	Fig. 2.1

Table 2.1: Ionization Cross section for e impact on Ar

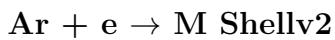
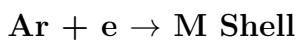
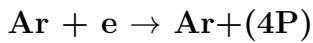
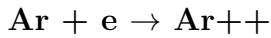
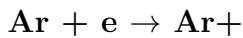
Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
Ar + e → Ar(4s3/2) 3P1	Revi [64]	11.6	11.6:-1	30%	U	Fig. 2.2
Ar + e → Ar(1S) — Is it 1P1	Revi [6]	11.548	11.548:-1	???	U	Fig. 2.2
Ar + e → Ar(4s1/2) 1P1	Revi [64]	11.8	11.8:-1	30%	U	Fig. 2.2
Ar + e → Ar(2P)	Revi [6]	12.906	12.906:-1	???	U	Fig. 2.2

Table 2.2: Excitation Cross section for e impact on Ar

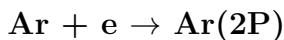
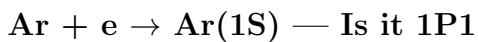
## 2.1 Cross section of e impact with Ar

### 2.1.1 Inelastic Cross Sections

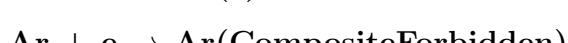
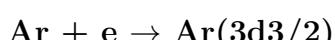
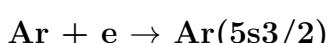
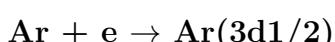
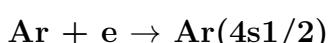
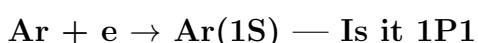
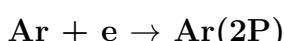
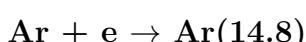
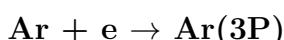
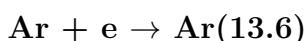
#### Ionization Cross Sections



#### Excitation Cross Sections



### 2.1.2 Recommended data set



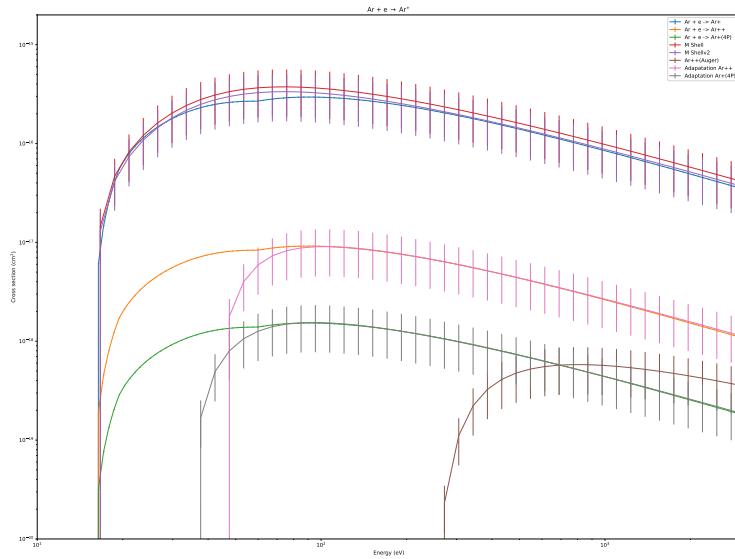
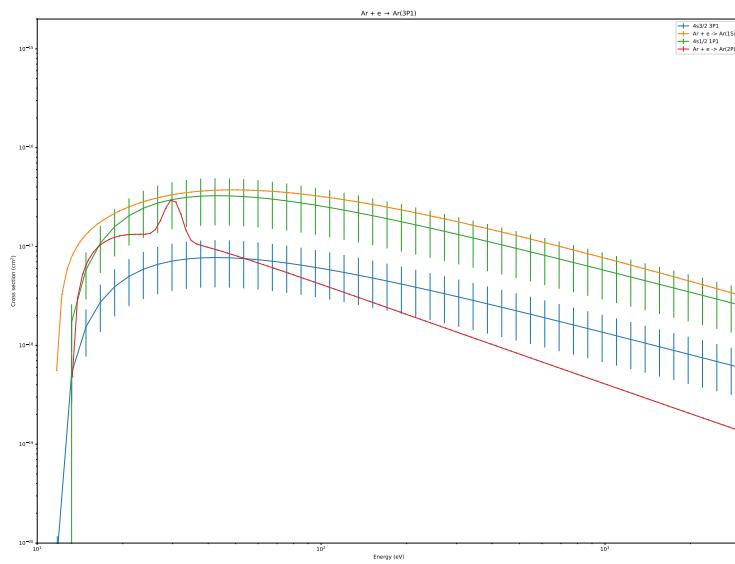
Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
Ar + e → Ar(1S)	Revi [6]	13.844	13.844:-1	??%	U	Fig. 2.3.2.4
Ar + e → Ar(3P)	Revi [6]	14.461	14.461:-1	??%	U	Fig. 2.3.2.4
Ar + e → Ar(14.8)	Revi [6]	14.805	14.805:-1	??%	U	Fig. 2.3.2.4
Ar + e → Ar(2P)	Revi [6]	12.906	12.906:-1	??%	U	Fig. 2.3.2.4
Ar + e → Ar(1S) — Is it 1P1	Revi [6]	11.548	11.548:-1	??%	U	Fig. 2.3.2.4
Ar + e → Ar(4s1/2)	Revi [64]	11.8	11.8:-1	30%	U	Fig. 2.3.2.4
Ar + e → Ar(3d1/2)	Revi [64]	13.9	13.9:-1	30%	U	Fig. 2.3.2.4
Ar + e → Ar(5s3/2)	Revi [64]	14.1	14.1:-1	30%	U	Fig. 2.3.2.4
Ar + e → Ar(3d3/2)	Revi [64]	14.1	14.1:-1	30%	U	Fig. 2.3.2.4
Ar + e → Ar(5sprime1/2)	Revi [64]	14.3	14.3:-1	30%	U	Fig. 2.3.2.4
Ar + e → Ar(3dprime3/2)	Revi [64]	14.3	14.3:-1	30%	U	Fig. 2.3.2.4
Ar + e → Ar(a)	Revi [64]	14.9	14.9:-1	30%	U	Fig. 2.3.2.4
Ar + e → Ar(b)	Revi [64]	15.05	15.05:-1	30%	U	Fig. 2.3.2.4
Ar + e → Ar(c)	Revi [64]	15.2	15.2:-1	30%	U	Fig. 2.3.2.4
Ar + e → Ar(d)	Revi [64]	15.4	15.4:-1	30%	U	Fig. 2.3.2.4
Ar + e → Ar(e)	Revi [64]	15.5	15.5:-1	30%	U	Fig. 2.3.2.4
Ar + e → Ar(CompositeForbidden)	Revi [64]	13.0	13.0:-1	30%	U	Fig. 2.3.2.4
Ar + e → M Shell	Revi [64]+ Lilensten	15.76	15.76:-1	30%	U	Fig. 2.3.2.4
Ar + e → Ar++(Auger)	Revi [64]	250.0	250.0:-1	5%	U	Fig. 2.3.2.4
Ar + e → Ar++	Adap [64]+ Lilensten	43.40	43.40:-1	30%	U	Fig. 2.3.2.4
Ar + e → Ar+(4P)	Revi [64]+ Lilensten	35.40	35.40:-1	30%	U	Fig. 2.3.2.4
Ar + e → Elastic	Revi [6]	0	0:-1	30%	U	Fig. 2.3.2.4

Table 2.3: Recommended Cross section for e impact on Ar

the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Figure 2.1: Cross sections for  $\text{Ar} + \text{e} \rightarrow \text{Ar}^+$ Figure 2.2: Cross sections for  $\text{Ar} + \text{e} \rightarrow \text{Ar}(3\text{P}1)$

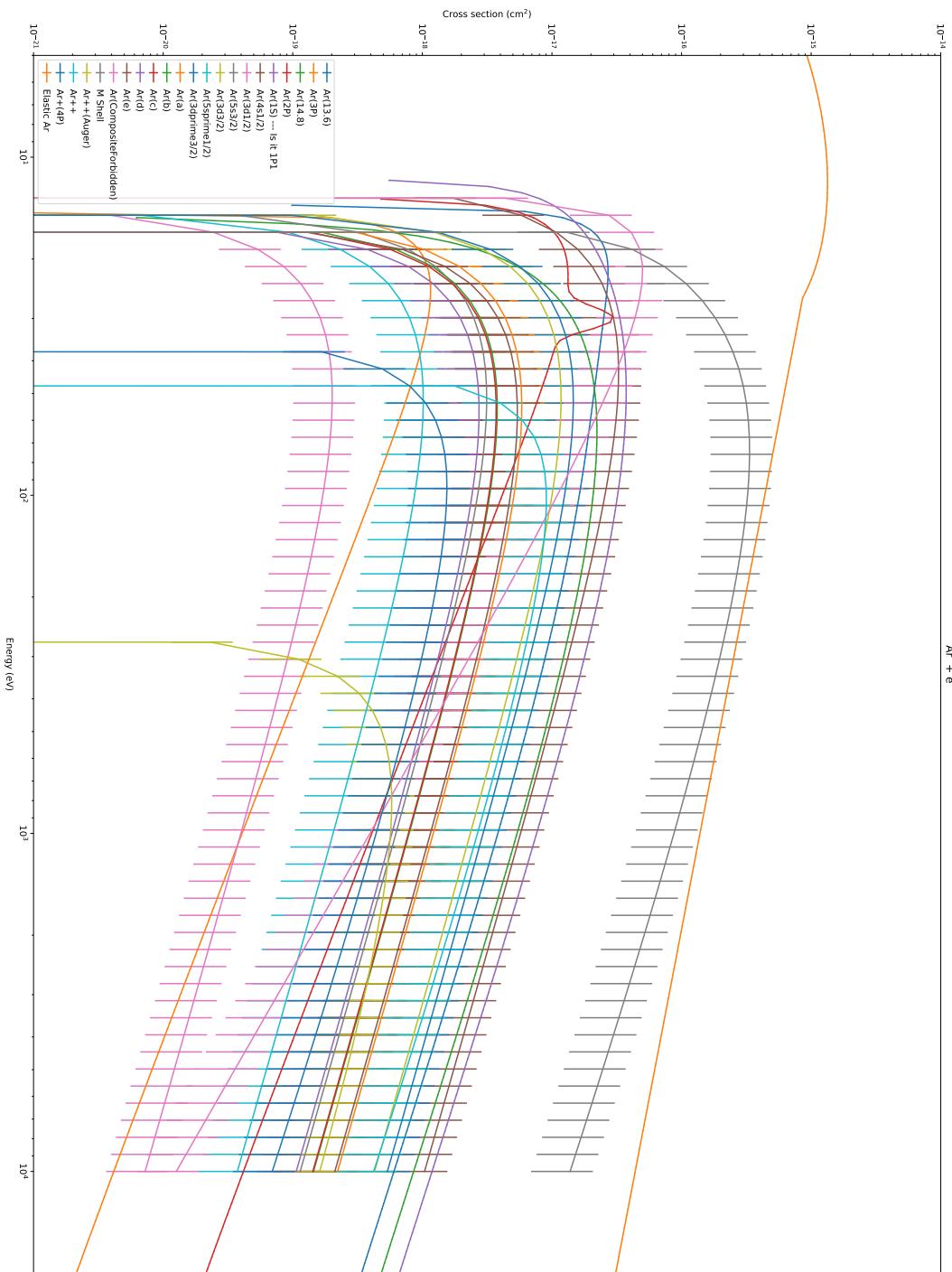


Figure 2.3: Cross sections for Ar + e

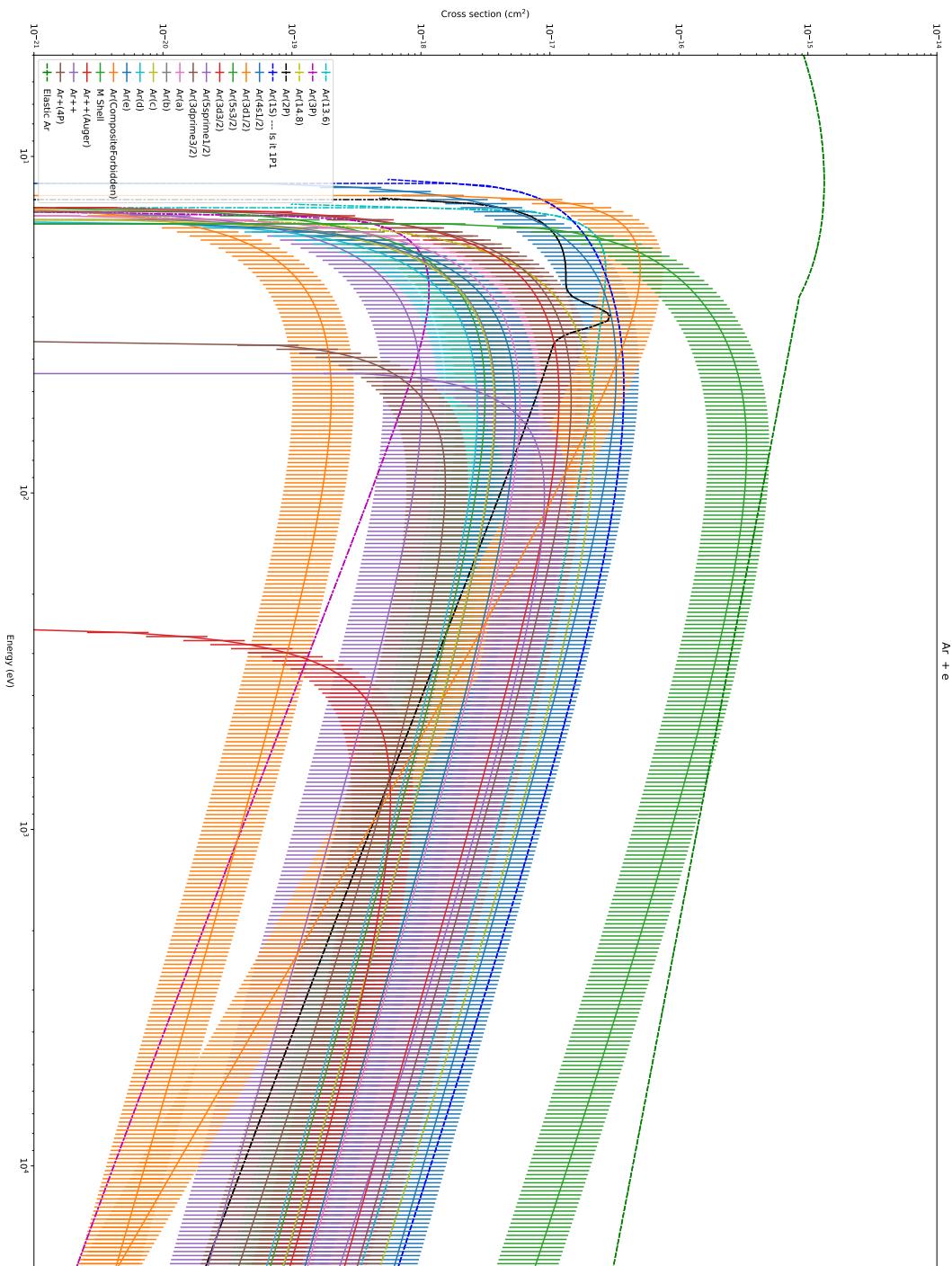


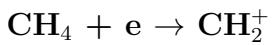
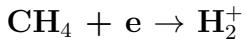
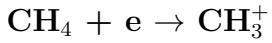
Figure 2.4: Cross sections for  $\text{Ar} + \text{e}$  (wavelength with extrapolation version)

## 2.2 Cross section of e impact with CH<sub>4</sub>

### 2.2.1 Elastic Cross Section

### 2.2.2 Inelastic Cross Sections

#### Ionization Cross Sections



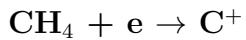
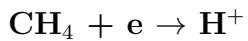
**Notes for CH<sub>4</sub><sup>++</sup> K-Shell ionization, Frémont 2006 + [60] + [8]** The K-Shell ionization of CH<sub>4</sub> by electron impact has been studied in [13]. The ratio K-shell/simple ionization has been taken in that paper. The total cross section has been computed by multiplying this ratio by the recommended ionization cross section, coming from an adaptation of the work of [8] with the analytic cross sections in [60].

Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi BDD [40]	0	0:-1	???	U	Fig. 2.8
Revi [34]	0	0:-1	???	U	Fig. 2.8
Revi [60]	0	0.2 : 1000.0	20%	RE	Fig. 2.8

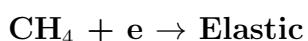
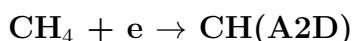
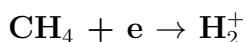
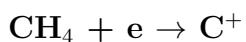
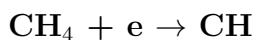
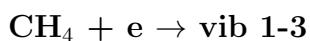
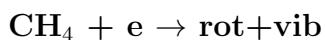
Table 2.4: Elastic cross section for e impact on CH<sub>4</sub>

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$CH_4 + e \rightarrow CH_3^+$	Revi BDD [40]	14.30	14.30:-1	??% 5%	U	Fig. 2.5
	Meas [8]	14.24	15.0 : 1000.0	5%		Fig. 2.5
	Revi [60]	14.24	15.0 : 1000.0	7%	E	Fig. 2.5
	Adap [8] + [60]	14.24	14.24:-1	5%	RUE	Fig. 2.5
$CH_4 + e \rightarrow H_2^+$	Meas [8]	20.230000	15.0 : 1000.0	7.5%		Fig. 2.6
	Revi [60]	20.230000	25.0 : 1000.0	20%	E	Fig. 2.6
	Adap [8] + [60]	20.230000	20.230000:-1	7.5%	RUE	Fig. 2.6
$CH_4 + e \rightarrow CH_2^+$	Meas [8]	15.200000	15.0 : 1000.0	6.5%		Fig. 2.7
	Revi [60]	15.200000	17.5 : 1000.0	10%	E	Fig. 2.7
	Adap [8] + [60]	15.200000	15.200000:-1	6.5%	RUE	Fig. 2.7
$CH_4 + e \rightarrow CH_4^+ + (Auger)$	Adap [13] + [60] + [8]	282	282:-1	50%		Fig. 2.9
$CH_4 + e \rightarrow H^+$	Meas [8]	18.00	15.0 : 1000.0	5.5%		Fig. 2.10
	Revi [60]	18.00	25.0 : 1000.0	7%	E	Fig. 2.10
	Adap [8] + [60]	18.00	18.00:-1	5.5%	RUE	Fig. 2.10
$CH_4 + e \rightarrow C^+$	Meas [8]	28.200000	15.0 : 1000.0	8.5%		Fig. 2.11
	Revi [60]	28.200000	30.0 : 1000.0	8.5%	E	Fig. 2.11
	Adap [8] + [60]	28.200000	28.200000:-1	8.5%	RUE	Fig. 2.11
$CH_4 + e \rightarrow CH_4^+$	?? ? Rees + Liljensten	12.10	12.10:-1	??% 5%	U	Fig. 2.12
	Meas [8]	12.10	15.0 : 1000.0	5%		Fig. 2.12
	Revi [60]	12.99	15.0 : 1000.0	5%	E	Fig. 2.12
	Adap [8] + [60]	12.99	12.99:-1	5%	RUE	Fig. 2.12
$CH_4 + e \rightarrow CH^+$	Meas [8]	24.14	15.0 : 1000.0	6.5%		Fig. 2.13
	Revi [60]	24.140000	25.0 : 1000.0	10%	E	Fig. 2.13
	Adap [8] + [60]	24.140000	24.140000:-1	6.5%	RUE	Fig. 2.13

Table 2.5: Ionization Cross section for e impact on  $CH_4$



### 2.2.3 Recommended data set



#### Legend for the properties

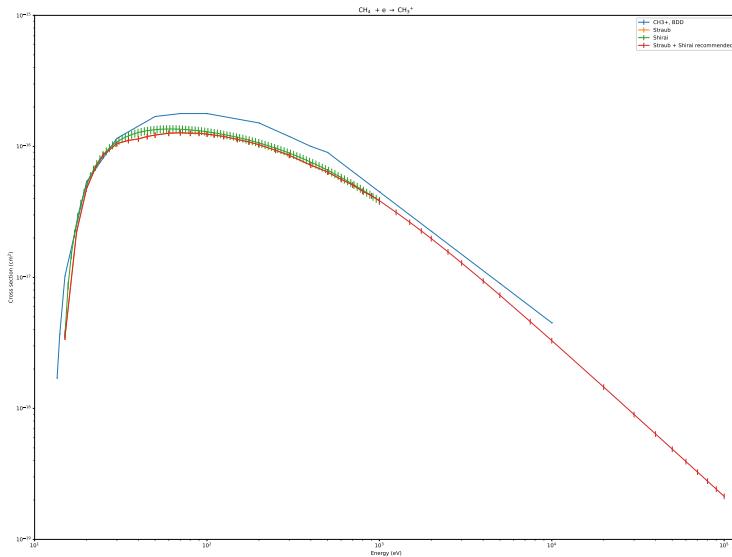
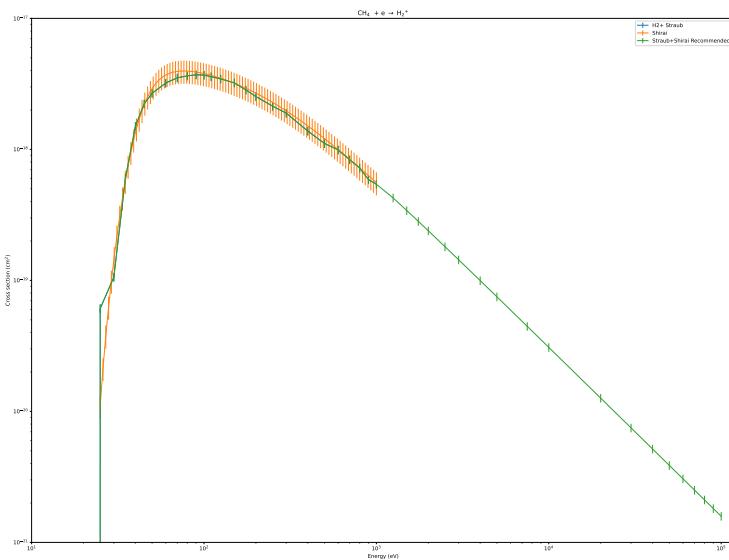
**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

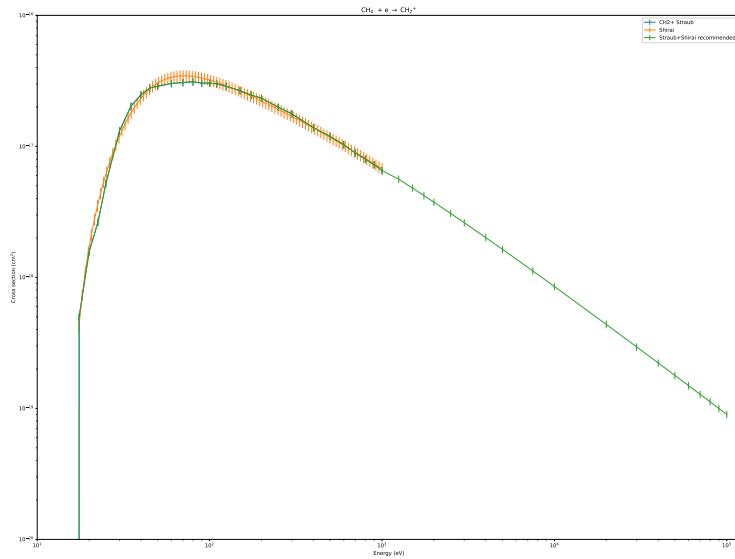
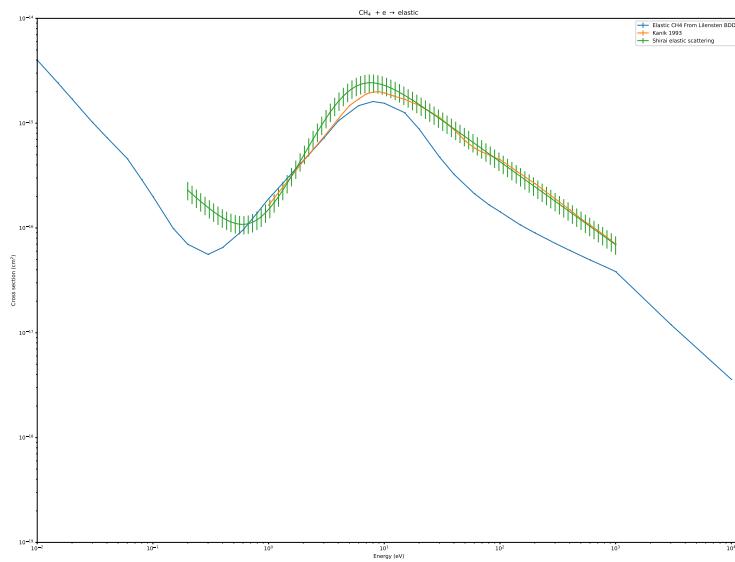
Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
CH <sub>4</sub> + e → rot+vib	Theo [10]	0.162	0.162:-1	???:%	U	Fig. 2.14 2.15
CH <sub>4</sub> + e → vib 1-3	Theo [10]	0.361	0.361:-1	???:%	U	Fig. 2.14 2.15
CH <sub>4</sub> + e → CH <sub>3</sub>	Adap [12]	14.	14.:-1	20%	RUE	Fig. 2.14 2.15
CH <sub>4</sub> + e → CH <sub>2</sub>	Adap [12]	15.	15.:-1	20%	RUE	Fig. 2.14 2.15
CH <sub>4</sub> + e → CH	Adap [12]	25.	25.:-1	20%	RUE	Fig. 2.14 2.15
CH <sub>4</sub> + e → CH <sub>4</sub> <sup>+</sup>	Adap [8] + [60]	12.99	12.99:-1	5%	RUE	Fig. 2.14 2.15
CH <sub>4</sub> + e → CH <sub>3</sub> <sup>+</sup>	Adap [8] + [60]	14.24	14.24:-1	5%	RUE	Fig. 2.14 2.15
CH <sub>4</sub> + e → CH <sub>2</sub> <sup>+</sup>	Adap [8] + [60]	15.200000	15.200000:-1	6.5%	RUE	Fig. 2.14 2.15
CH <sub>4</sub> + e → CH <sup>+</sup>	Adap [8] + [60]	24.140000	24.140000:-1	6.5%	RUE	Fig. 2.14 2.15
CH <sub>4</sub> + e → C <sup>+</sup>	Adap [8] + [60]	28.200000	28.200000:-1	8.5%	RUE	Fig. 2.14 2.15
CH <sub>4</sub> + e → H <sub>2</sub> <sup>+</sup>	Adap [8] + [60]	20.230000	20.230000:-1	7.5%	RUE	Fig. 2.14 2.15
CH <sub>4</sub> + e → H <sup>+</sup>	Adap [8] + [60]	18.00	18.00:-1	5.5%	RUE	Fig. 2.14 2.15
CH <sub>4</sub> + e → CH <sub>4</sub> <sup>+</sup> (Auger)	Adap [13] + [60] + [8]	282	282:-1	50%	RUE	Fig. 2.14 2.15
CH <sub>4</sub> + e → CH(A2D)	Revi [60]	12.200000	14.6 : 5000.0	30%	UE	Fig. 2.14 2.15
CH <sub>4</sub> + e → Elastic	Revi [60]	0	0.2 : 1000.0	20%	RE	Fig. 2.14 2.15

Table 2.6: Recommended Cross section for e impact on CH<sub>4</sub>

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Figure 2.5: Cross sections for  $\text{CH}_4 + \text{e} \rightarrow \text{CH}_3^+$ Figure 2.6: Cross sections for  $\text{CH}_4 + \text{e} \rightarrow \text{H}_2^+$

Figure 2.7: Cross sections for CH<sub>4</sub> + e → CH<sub>2</sub><sup>+</sup>Figure 2.8: Cross sections for CH<sub>4</sub> + e → elastic

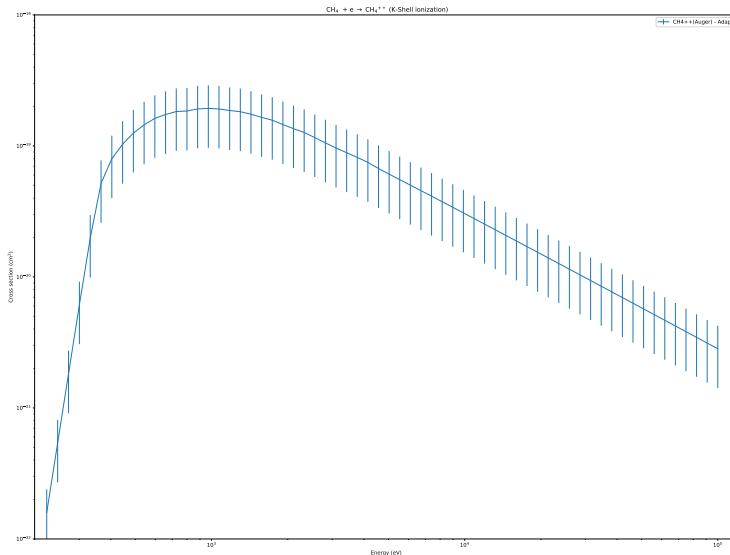


Figure 2.9: Cross sections for  $CH_4 + e \rightarrow CH_4^{++}$  (K-Shell ionization)

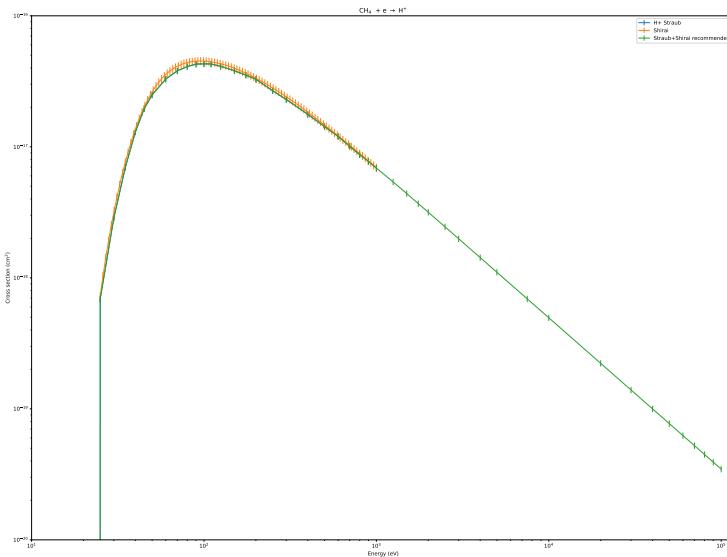
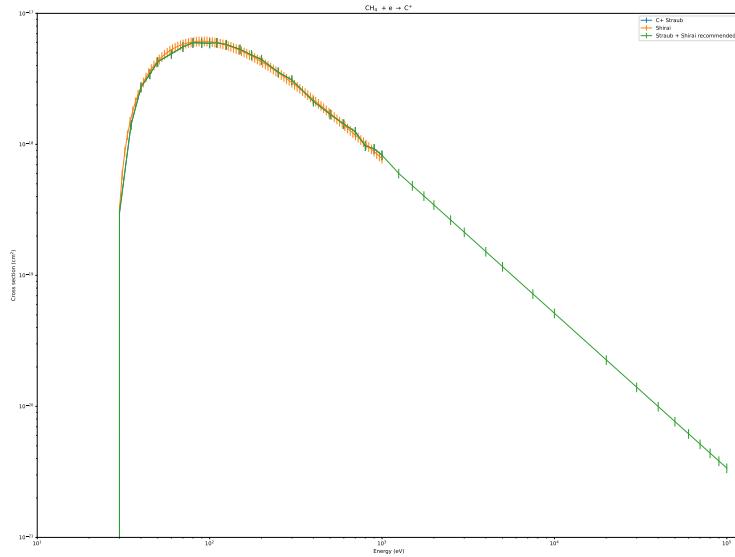
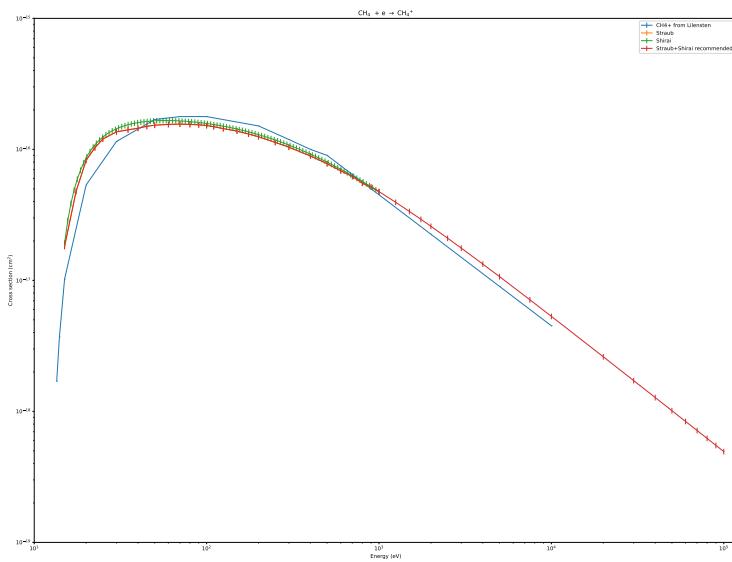
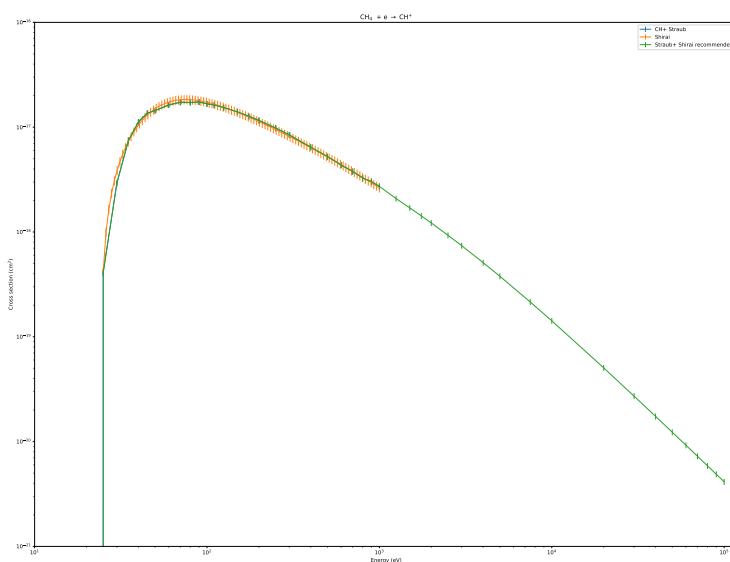
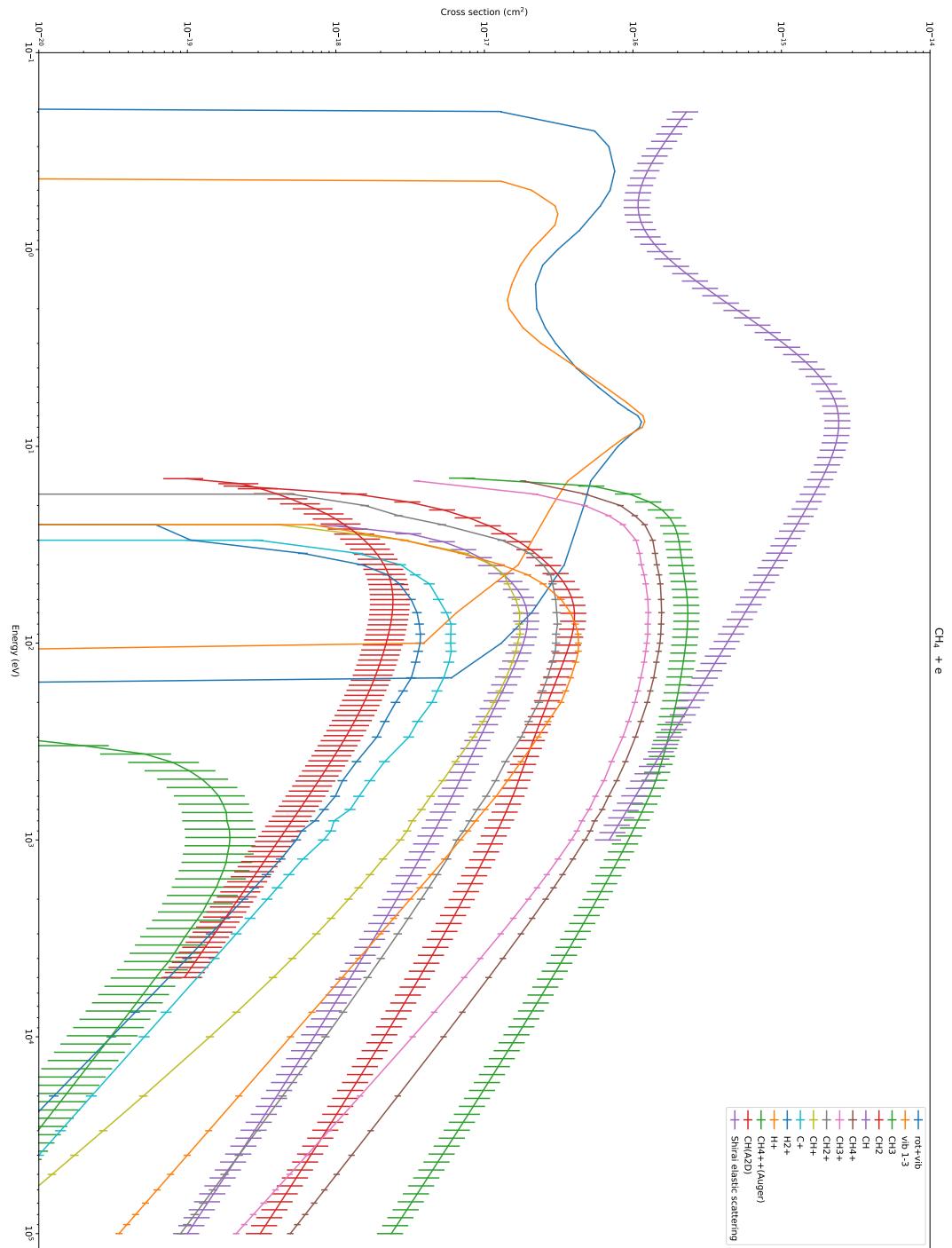


Figure 2.10: Cross sections for  $CH_4 + e \rightarrow H^+$

Figure 2.11: Cross sections for  $\text{CH}_4 + \text{e} \rightarrow \text{C}^+$ Figure 2.12: Cross sections for  $\text{CH}_4 + \text{e} \rightarrow \text{CH}_4^+$

Figure 2.13: Cross sections for  $CH_4 + e \rightarrow CH^+$

Figure 2.14: Cross sections for CH<sub>4</sub> + e

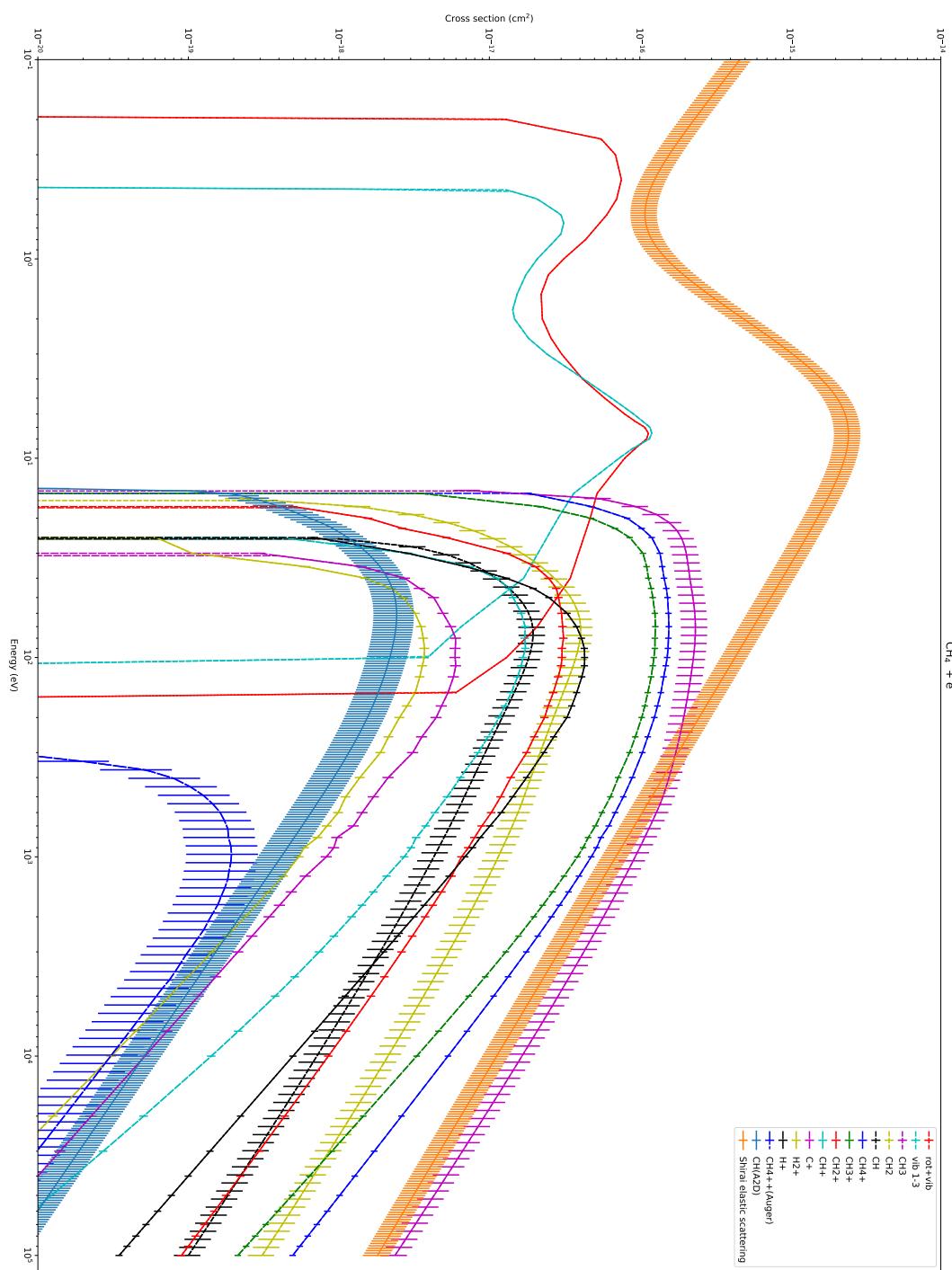


Figure 2.15: Cross sections for  $\text{CH}_4 + \text{e}$  (wavelength with extrapolation version)

## 2.3 Cross section of e impact with CO<sub>2</sub>

### 2.3.1 Total Cross Section

### 2.3.2 Elastic Cross Section

### 2.3.3 Inelastic Cross Sections

#### Ionization Cross Sections



**Notes for CO<sub>2</sub><sup>++</sup> K-Shell ionization, Frémont 2006 + [8] + [59]** The K-Shell ionization of CO<sub>2</sub> by electron impact has not been studied in [13], but we assumed that the K-Shell/single ionization ratio is close to the CH<sub>4</sub> one which is used here. The total cross section has been computed by multiplying this ratio by the recommended ionization cross section, coming from [8] and [59]. The Auger electrons are coming from [2]. We consider that we have an equal chance to excite the Auger in any of the atoms of the molecules. I.e. we have twice more chance in an O than in a C

Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi [59]	0	0.5 : 5000.0	7%	E	Fig. 2.23
Revi [25]	0	0.1 : 1000.0	5%		Fig. 2.23
Revi [74] BDD	0	0:-1	???:%	U	Fig. 2.23
Adap [25] + [59] + [8] + ...	0	0:-1	20%	U	Fig. 2.23

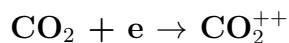
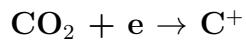
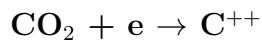
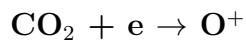
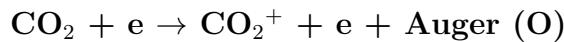
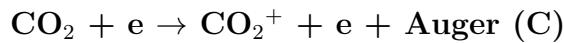
Table 2.7: Total cross section for e impact on CO<sub>2</sub>

Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi [59]	0	1.0 : 1000.0	28%	E	Fig. 2.24
Revi [70]	0	.1 : 5000.0	50%		Fig. 2.24
Revi [25]	0	3.5 : 1000.0	18%		Fig. 2.24
Adap [25] + [59]	0	3.5 : 1000.0	18%	RUE	Fig. 2.24

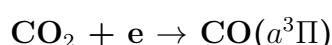
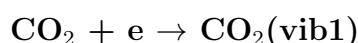
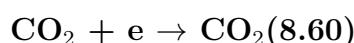
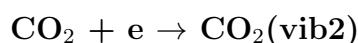
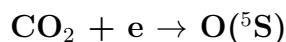
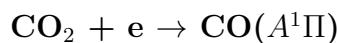
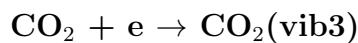
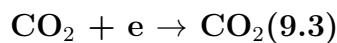
Table 2.8: Elastic cross section for e impact on CO<sub>2</sub>

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
CO <sub>2</sub> + e → O <sup>++</sup>	Revi [59] Meas [8] Revi [25] Revi [74] Adap [8] + [59]	54.20 54.20 54.20 54.20 54.20	80.0 : 1000.0 54.20:-1 54.20:-1 54.20:-1 54.20:-1	20% 11% 11% <b>??%</b> <b>11%</b>	E U RUE	Fig. 2.19 Fig. 2.19 Fig. 2.19 Fig. 2.19 Fig. 2.19
CO <sub>2</sub> + e → CO <sub>2</sub> <sup>++</sup> (Auger)	Adap [13] + [59]+Straub 2004	539	539:-1	<b>50%</b>	UE	Fig. 2.25 2.26
CO <sub>2</sub> + e → CO <sub>2</sub> <sup>+</sup> + e + Auger (C)	Revi [2] Revi [2]	282	282:-1	20%	R	Fig. 2.25 2.26
CO <sub>2</sub> + e → CO <sub>2</sub> <sup>+</sup> + e + Auger (O)	Revi [2] Revi [59] Meas [8] Revi [25] Revi BDD Adap [8] + [59]	539 19.000000 19.0 19 19 19.0	25.0 : 1000.0 19.0:-1 19:-1 19:-1 19.0:-1	7% 5% 5% <b>??%</b> <b>5%</b>	E U RUE	Fig. 2.25 2.26 Fig. 2.25 2.26 Fig. 2.25 2.26
CO <sub>2</sub> + e → O <sup>+</sup>	Revi [59] Meas [8] Revi [25] Revi BDD Adap [8] + [59]	52.20 52.20 52.20 51.2 52.20	80.0 : 1000.0 52.20:-1 52.20:-1 51.2:-1 52.20:-1	15% 11% 11% <b>??%</b> <b>11%</b>	E U RUE	Fig. 2.28 Fig. 2.28 Fig. 2.28 Fig. 2.28 Fig. 2.28
CO <sub>2</sub> + e → C <sup>++</sup>	Revi [59] Meas [8] Revi [25] Revi BDD Adap [8] + [59]	27.800000 27.8 27.8 27.8 27.8	30.0 : 1000.0 27.8:-1 27.8:-1 27.8:-1 27.8:-1	9% 5% 5% <b>??%</b> <b>5%</b>	E U RUE	Fig. 2.30 Fig. 2.30 Fig. 2.30 Fig. 2.30 Fig. 2.30
CO <sub>2</sub> + e → C <sup>+</sup>	Revi [59] Meas [8] Revi [25] Revi BDD Adap [8] + [59]	37.2 37.4 37.4 37.4	45.0 : 1000.0 37.4:-1 37.4:-1 37.4:-1	12% 6% 6% <b>6%</b>	E U RUE	Fig. 2.32 Fig. 2.32 Fig. 2.32 Fig. 2.32
CO <sub>2</sub> + e → CO <sub>2</sub> <sup>++</sup>	Revi [59] Meas [8] Revi [25] Adap [8] + [59]	13.800000 13.80000 13.80000 13.80000	15.0 : 1000.0 13.8000:-1 13.80000:-1 13.80000:-1	12% 5% 5% <b>5%</b>	E RUE	Fig. 2.33 Fig. 2.33 Fig. 2.33 Fig. 2.33
CO <sub>2</sub> + e → CO <sub>2</sub> <sup>+</sup>	Revi [59] Meas [8] Revi [25] Adap [8] + [59]	19.500000 19.5000 19.5 19.5000	25.0 : 1000.0 19.5000:-1 19.5:-1 19.5000:-1	9% 5% 5% <b>5%</b>	E U RUE	Fig. 2.36 Fig. 2.36 Fig. 2.36 Fig. 2.36
CO <sub>2</sub> + e → CO <sup>+</sup>	Revi [59] Meas [8] Revi [25] Revi BDD Adap [8] + [59]	19.5000 19.5 19.5 19.5000	25.0 : 1000.0 19.5000:-1 19.5:-1 19.5000:-1	9% 5% <b>??%</b> <b>5%</b>	E U RUE	Fig. 2.37 Fig. 2.37 Fig. 2.37 Fig. 2.37

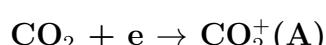
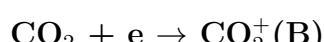
Table 2.9: Ionization Cross section for e impact on CO<sub>2</sub>



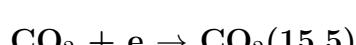
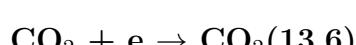
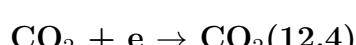
#### Excitation Cross Sections



#### 2.3.4 Emission Cross Sections



#### 2.3.5 Recommended data set



Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$CO_2 + e \rightarrow CO_2(9,3)$	Revi [74]	9.30	9.30:-1	??% ??%	U	Fig. 2.17
$CO_2 + e \rightarrow CO_2(vib3)$	Revi [25] Revi [74]	0.29100 0.291	1.5:-30 0.291:-1	30% ??% ??%	U	Fig. 2.18 Fig. 2.18
$CO_2 + e \rightarrow CO(A^1\Pi)$	Adap [1] + Simon2008 Revi [59]	13.48 13.60	13.48:-1 15.0 : 350.0	50% 20%	RU E	Fig. 2.20 2.21 Fig. 2.20 2.21
$CO_2 + e \rightarrow O(^3S)$	Meas [1] Meas [1] + Ajello 2019	25 25	25:-1 25:-1	30% 30%		Fig. 2.22 Fig. 2.22
$CO_2 + e \rightarrow CO_2(vib2)$	Revi [25] Revi BDD Adap [25]+BDD+extrapolation	0.16700000 0.167 0.167	0.16700000:-1 0.167:-1 0.167:-1	30% ??% ??%	U RUE	Fig. 2.27 Fig. 2.27
$CO_2 + e \rightarrow CO_2(8,60)$	Revi BDD	8.60	8.60:-1	??% ??%	U	Fig. 2.29
$CO_2 + e \rightarrow CO_2(vib1)$	Revi [25] Revi BDD	0.08300000 0.083	0.08300000:-1 0.083:-1	30% ??% ??%	U	Fig. 2.31 Fig. 2.31
$CO_2 + e \rightarrow CO(a^3\Pi)$	Adap [2] + [62] Adap [3] + [21] Meas Lee 2021	11.46 11.46 11.46	11.46:-1 11.46:-1 11.46:-1	75% 25% 25%	U RU RU	Fig. 2.34 2.35 Fig. 2.34 2.35 Fig. 2.34 2.35
$CO_2 + e \rightarrow O(^1S)$	Meas [38] Adap [38] + [59] Revi [59]	9.64 9.64 11.000000	9.64:-1 9.64:-1 12.0 : 1000.0	12% 12% 15%	RUE E	Fig. 2.38 Fig. 2.38 Fig. 2.38
$CO_2 + e \rightarrow O(^3S)$	Meas [1] Adap [1] + modification for extrapolation	20 20	20:-1 20:-1	30% 30%		Fig. 2.39 Fig. 2.39

Table 2.10: Excitation Cross section for e impact on  $CO_2$

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$\text{CO}_2 + e \rightarrow \text{CO}_2^+(B)$	Revi [59]	18.10000	20.0 : 2000.0	25%	RE	Fig. 2.16
	Revi [25]	18.80000	18.80000:-1	25%		Fig. 2.16
	Revi BDD	18.8	18.8:-1	25%		Fig. 2.16
$\text{CO}_2 + e \rightarrow \text{CO}_2^+(A)$	Revi [59]	17.30000	20.0 : 2000.0	25%	RE	Fig. 2.40
	Revi [25]	17.30000	17.30000:-1	25%		Fig. 2.40
	Revi BDD	17.32	17.32:-1	25%		Fig. 2.40

Table 2.11: Emission Cross section for e impact on  $\text{CO}_2$

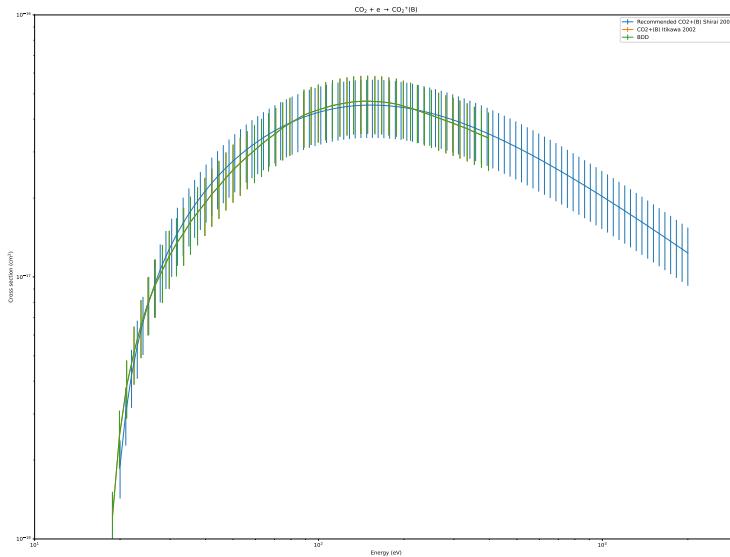
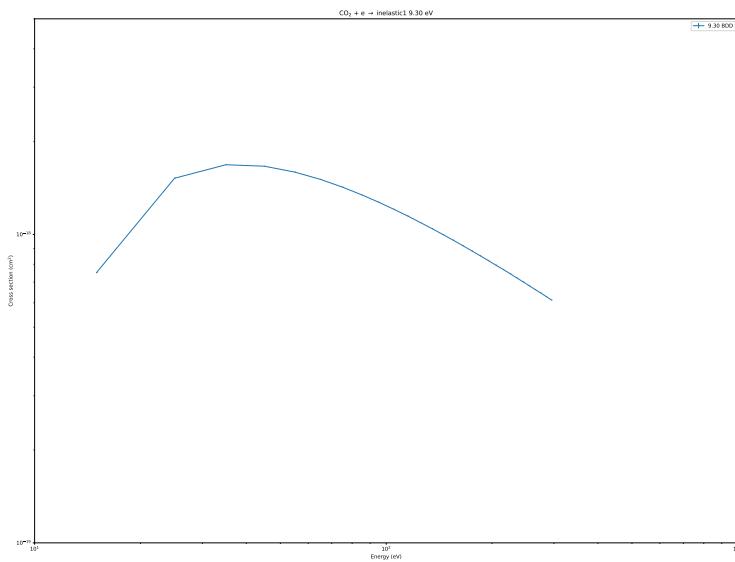
Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
CO <sub>2</sub> + e → CO <sub>2</sub> (Vib010)	Revi [64]	0.08	0.08:-1	30%	U	Fig. 2.41 2.42
CO <sub>2</sub> + e → CO <sub>2</sub> (Vib100)	Revi [64]	0.18	0.18:-1	30%	U	Fig. 2.41 2.42
CO <sub>2</sub> + e → CO <sub>2</sub> (Vib001)	Revi [64]	0.3	0.3:-1	30%	U	Fig. 2.41 2.42
CO <sub>2</sub> + e → CO <sub>2</sub> (8.6)	Revi [64]	8.6	8.6:-1	30%	U	Fig. 2.41 2.42
CO <sub>2</sub> + e → CO <sub>2</sub> (9.3)	Revi [64]	9.3	9.3:-1	30%	U	Fig. 2.41 2.42
CO <sub>2</sub> + e → CO <sub>2</sub> (11.1)	Revi [64]	7.76	7.76:-1	30%	U	Fig. 2.41 2.42
CO <sub>2</sub> + e → CO <sub>2</sub> (12.4)	Revi [64]	9.61	9.61:-1	30%	U	Fig. 2.41 2.42
CO <sub>2</sub> + e → CO <sub>2</sub> (13.6)	Revi [64]	10.5	10.5:-1	30%	U	Fig. 2.41 2.42
CO <sub>2</sub> + e → CO <sub>2</sub> (15.5)	Revi [64]	15.5	15.5:-1	30%	U	Fig. 2.41 2.42
CO <sub>2</sub> + e → CO <sub>2</sub> (16.3)	Revi [64]	12.3	12.3:-1	30%	U	Fig. 2.41 2.42
CO <sub>2</sub> + e → CO <sub>2</sub> (17.0)	Revi [64]	13	13:-1	30%	U	Fig. 2.41 2.42
CO <sub>2</sub> + e → CO <sub>2</sub> (17.8)	Revi [64]	14.7	14.7:-1	30%	U	Fig. 2.41 2.42
CO <sub>2</sub> + e → CO <sub>2</sub> (CI(1279))	Revi [64]	15.7	15.7:-1	30%	U	Fig. 2.41 2.42
CO <sub>2</sub> + e → CO <sub>2</sub> (CI(1329))	Revi [64]	21.8	21.8:-1	30%	U	Fig. 2.41 2.42
CO <sub>2</sub> + e → CO <sub>2</sub> (CI(1561))	Revi [64]	22.4	22.4:-1	30%	U	Fig. 2.41 2.42
CO <sub>2</sub> + e → CO <sub>2</sub> (CI(1657))	Revi [64]	21.1	21.1:-1	30%	U	Fig. 2.41 2.42
CO <sub>2</sub> + e → CO( <sup>3</sup> Π)	Adap [21]	11.46	11.46:-1	25%	RUE	Fig. 2.41 2.42
CO <sub>2</sub> + e → CO(A <sup>1</sup> Π)	Adap [1] + [62]	13.48	13.48:-1	50%	RUE	Fig. 2.41 2.42
CO <sub>2</sub> + e → O( <sup>3</sup> S)	Adap [1] + modification for extrapolation	20	20:-1	30%	R	Fig. 2.41 2.42
CO <sub>2</sub> + e → O( <sup>3</sup> S)	Meas [1]	25	25:-1	30%	RUE	Fig. 2.41 2.42
CO <sub>2</sub> + e → O( <sup>1</sup> S)	Adap [38] + [59]	9.64	9.64:-1	12%	RUE	Fig. 2.41 2.42
CO <sub>2</sub> + e → CO <sup>+</sup>	Adap [8] + [59]	19.5	19.5:-1	5%	RUE	Fig. 2.41 2.42
CO <sub>2</sub> + e → O <sup>+</sup>	Adap [8] + [59]	19.1	19.1:-1	5%	RUE	Fig. 2.41 2.42
CO <sub>2</sub> + e → C <sup>+</sup>	Adap [8] + [59]	27.8	27.8:-1	5%	RUE	Fig. 2.41 2.42
CO <sub>2</sub> + e → O <sup>++</sup>	Adap [8] + [59]	54.2	54.2:-1	11%	RUE	Fig. 2.41 2.42
CO <sub>2</sub> + e → C <sup>++</sup>	Adap [8] + [59]	51.2	51.2:-1	11%	RUE	Fig. 2.41 2.42
CO <sub>2</sub> + e → CO <sub>2</sub> <sup>+</sup>	Adap [8] + [59]	37.4	37.4:-1	6%	RUE	Fig. 2.41 2.42
CO <sub>2</sub> + e → CO <sub>2</sub> <sup>+(A)</sup>	Revi [59]	17.32	20.0 : 2000.0	25%	RE	Fig. 2.41 2.42
CO <sub>2</sub> + e → CO <sub>2</sub> <sup>+(B)</sup>	Revi [59]	18.8	20.0 : 2000.0	25%	RE	Fig. 2.41 2.42
CO <sub>2</sub> + e → CO <sub>2</sub> <sup>+</sup>	Adap [8] + [59]	13.770	13.770:-1	5%	RUE	Fig. 2.41 2.42
CO <sub>2</sub> + e → CO <sub>2</sub> <sup>++(Auger)</sup>	Adap [13] + [59]+Straub 2004	539	539:-1	50%	RUE	Fig. 2.41 2.42
CO <sub>2</sub> + e → Elastic	Adap [25] + [59]	0	3.5 : 1000.0	18%	RUE	Fig. 2.41 2.42

Table 2.12: Recommended Cross section for e impact on CO<sub>2</sub>

the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Figure 2.16: Cross sections for  $\text{CO}_2 + e \rightarrow \text{CO}_2^+(\text{B})$ Figure 2.17: Cross sections for  $\text{CO}_2 + e \rightarrow \text{inelastic1 } 9.30 \text{ eV}$

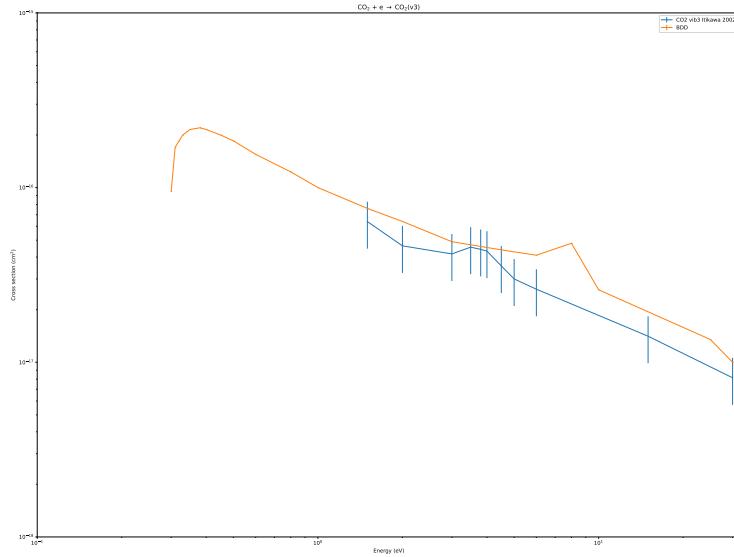


Figure 2.18: Cross sections for  $\text{CO}_2 + \text{e} \rightarrow \text{CO}_2(\text{v3})$

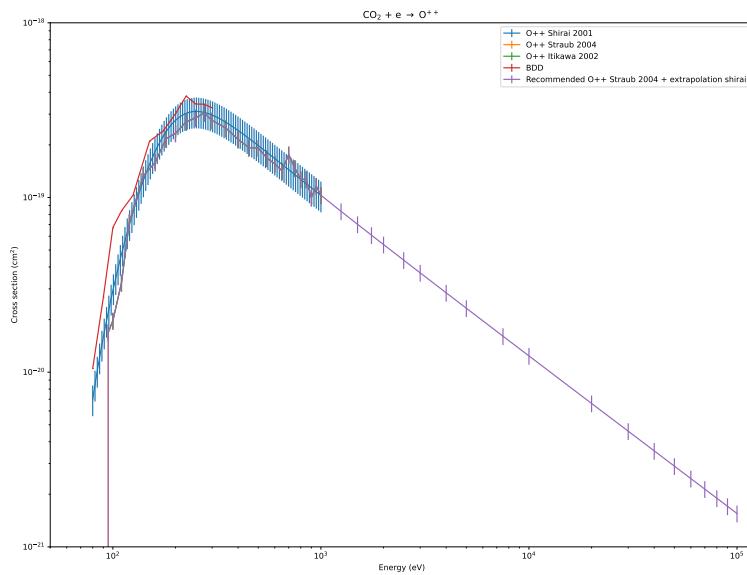


Figure 2.19: Cross sections for  $\text{CO}_2 + \text{e} \rightarrow \text{O}^{++}$

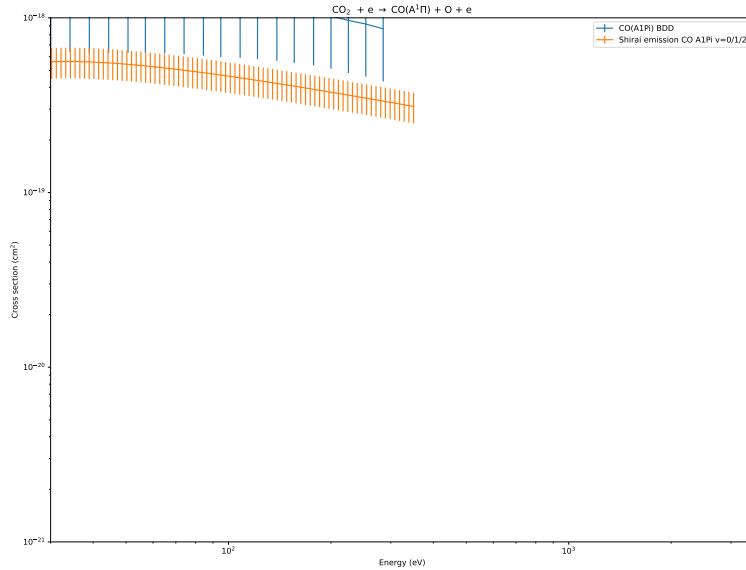


Figure 2.20: Cross sections for  $\text{CO}_2 + \text{e} \rightarrow \text{CO}(\text{A}^1\Pi) + \text{O} + \text{e}$

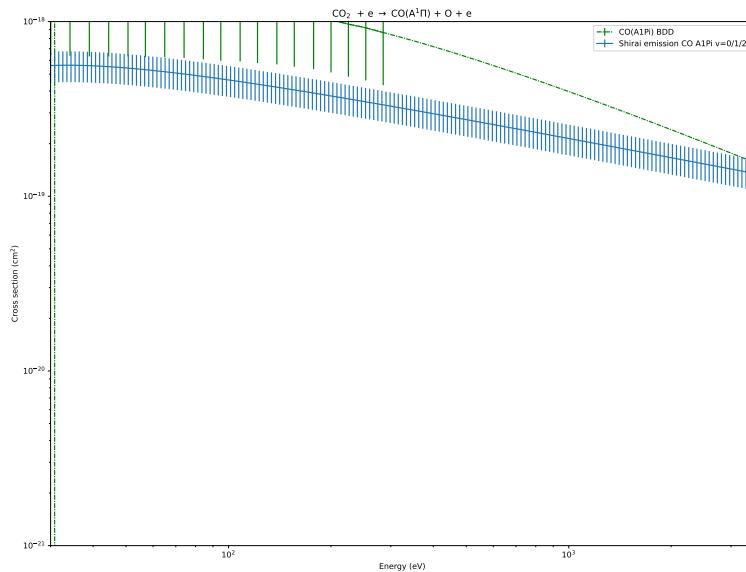


Figure 2.21: Cross sections for  $\text{CO}_2 + \text{e} \rightarrow \text{CO}(\text{A}^1\Pi) + \text{O} + \text{e}$  (wavelength with extrapolation version)

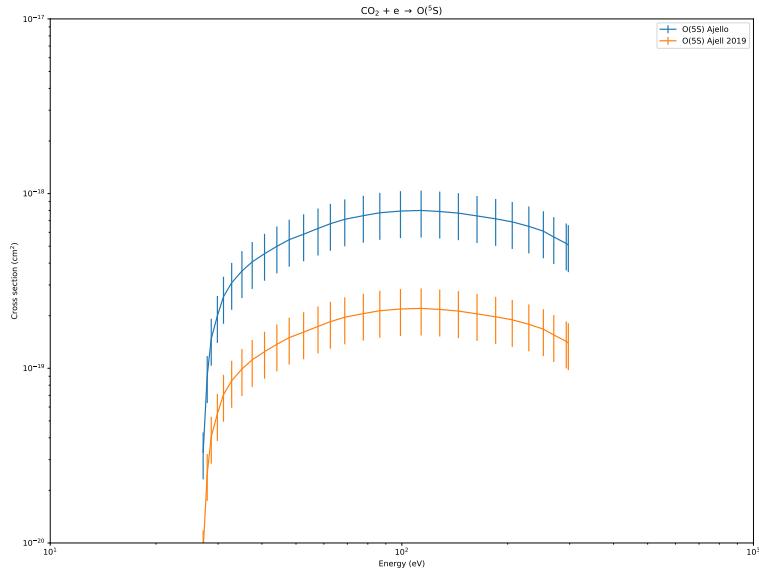


Figure 2.22: Cross sections for  $\text{CO}_2 + e \rightarrow \text{O}({}^5\text{S})$

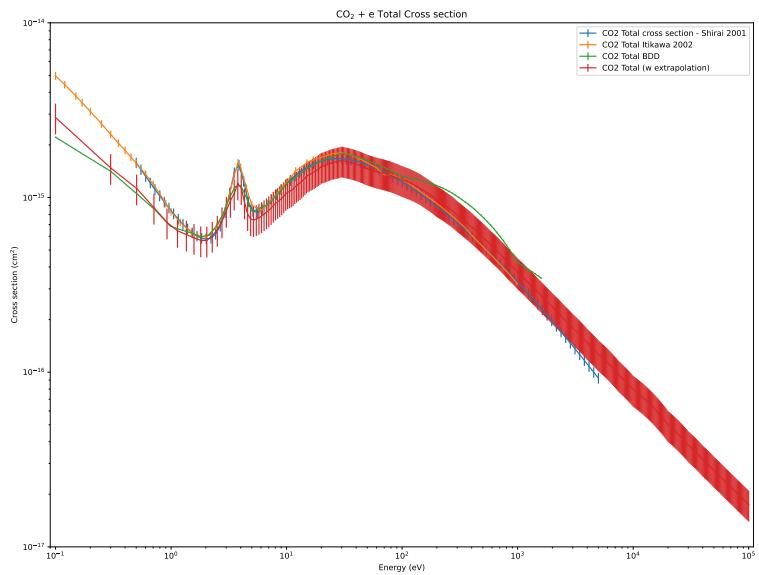
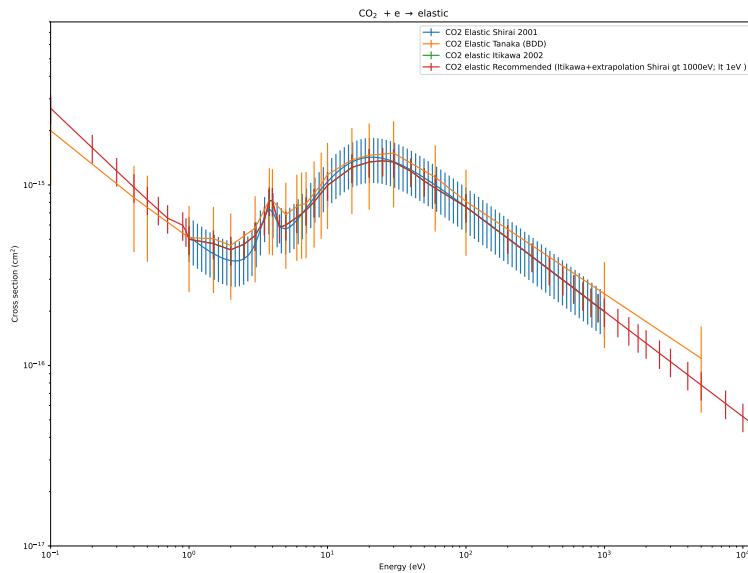
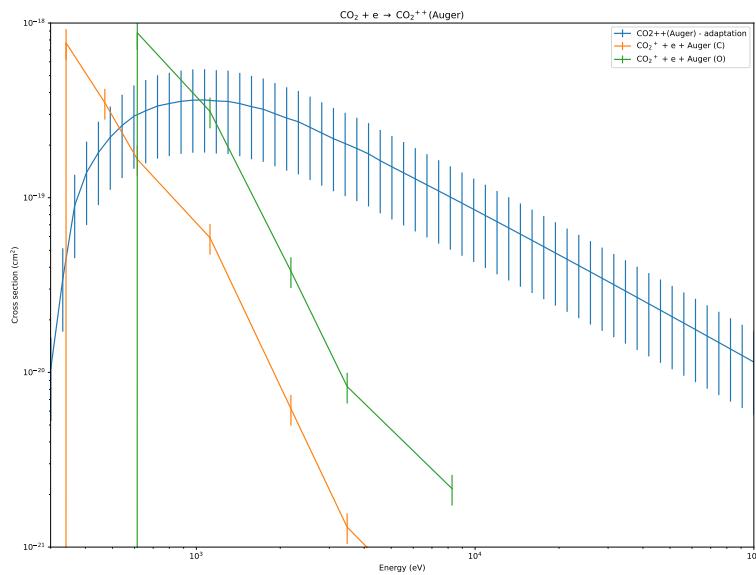


Figure 2.23: Cross sections for  $\text{CO}_2 + e$  Total Cross section

Figure 2.24: Cross sections for CO<sub>2</sub> + e → elasticFigure 2.25: Cross sections for CO<sub>2</sub> + e → CO<sub>2</sub><sup>++</sup>(Auger)

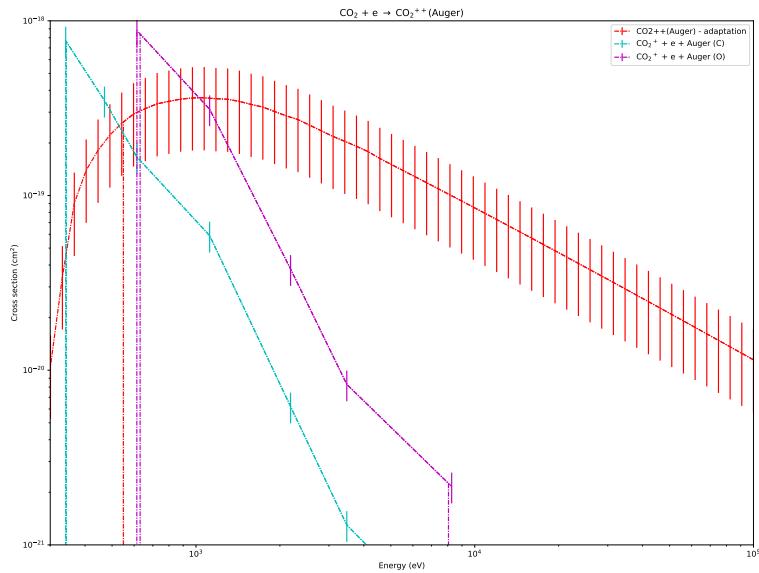


Figure 2.26: Cross sections for  $\text{CO}_2 + \text{e} \rightarrow \text{CO}_2^{++}$ (Auger) (wavelength with extrapolation version)

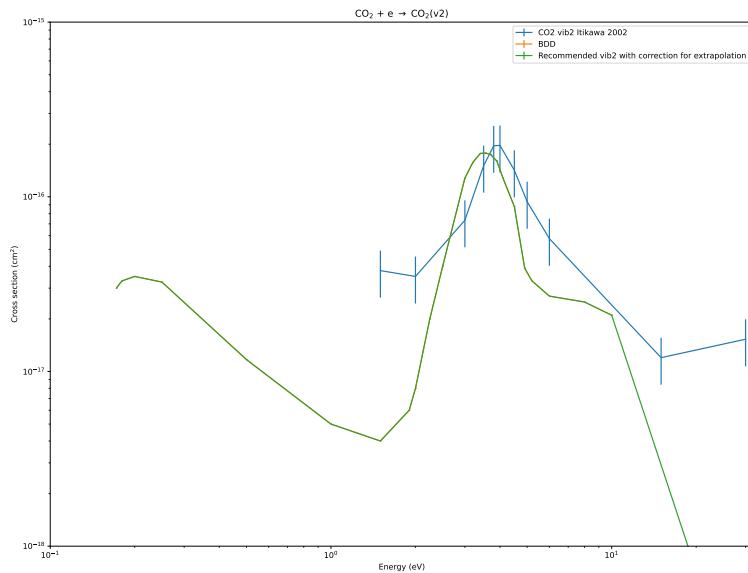
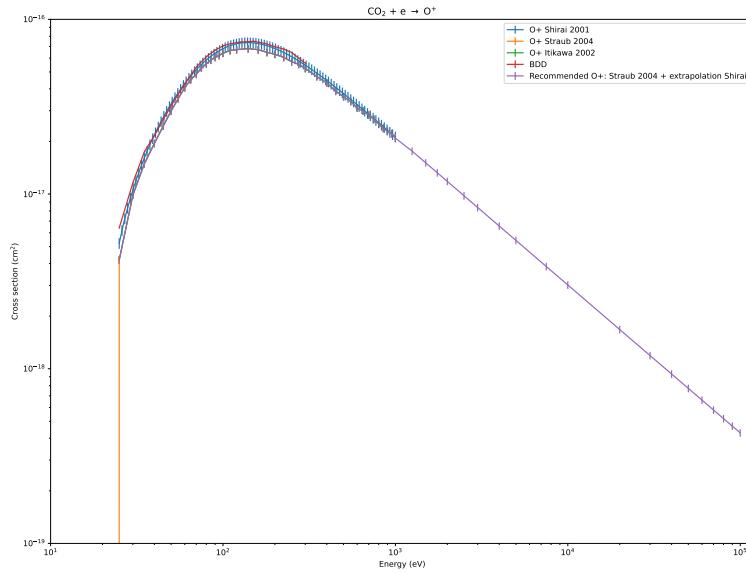
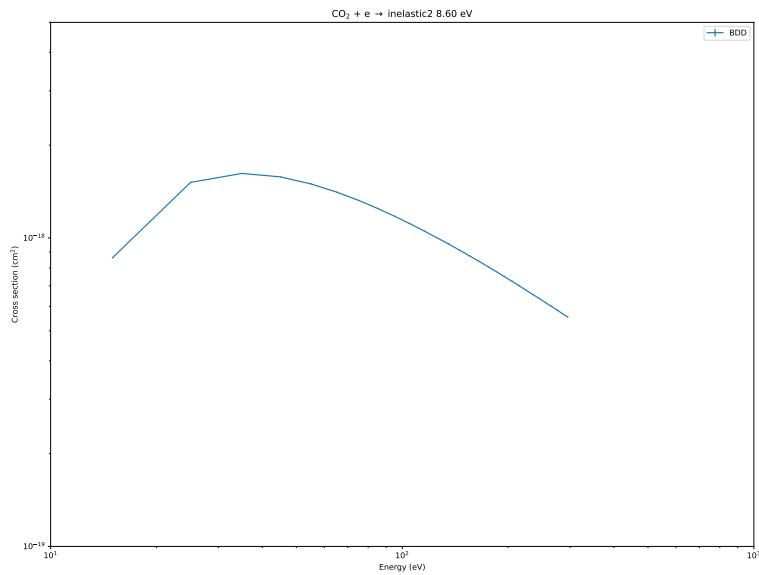


Figure 2.27: Cross sections for  $\text{CO}_2 + \text{e} \rightarrow \text{CO}_2(\text{v2})$

Figure 2.28: Cross sections for  $\text{CO}_2 + \text{e} \rightarrow \text{O}^+$ Figure 2.29: Cross sections for  $\text{CO}_2 + \text{e} \rightarrow \text{inelastic2 } 8.60 \text{ eV}$

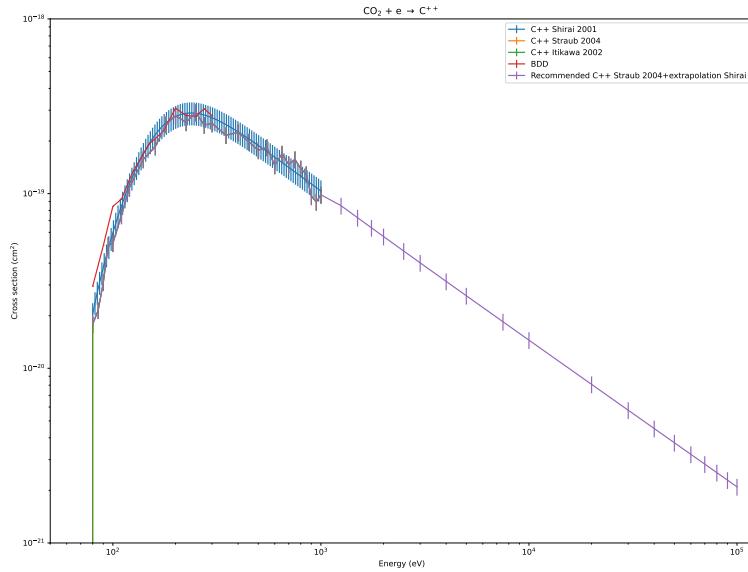


Figure 2.30: Cross sections for CO<sub>2</sub> + e → C<sup>++</sup>

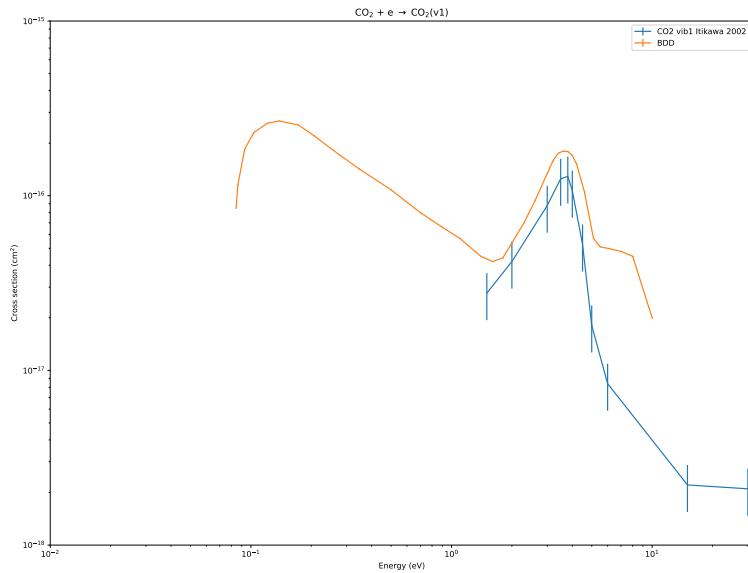
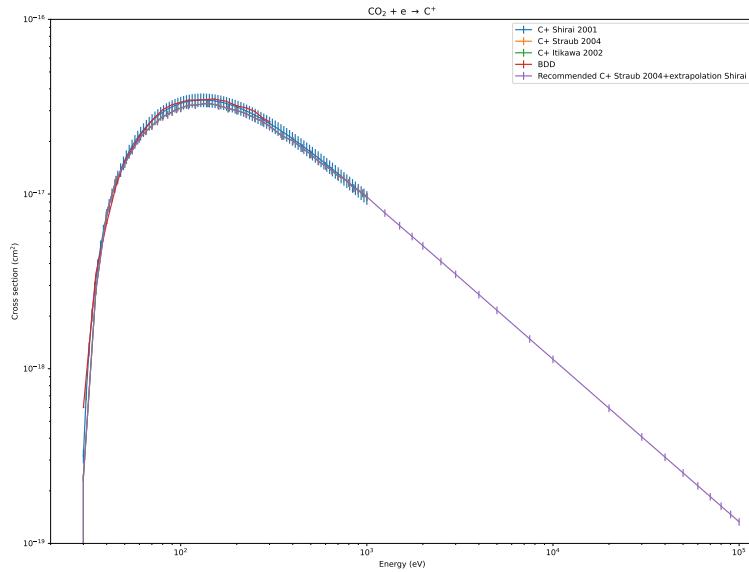
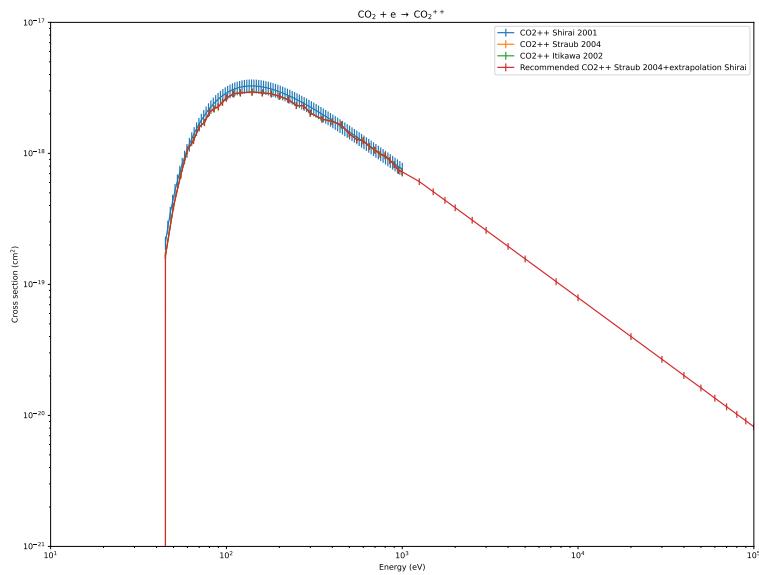


Figure 2.31: Cross sections for CO<sub>2</sub> + e → CO<sub>2</sub>(v1)

Figure 2.32: Cross sections for CO<sub>2</sub> + e → C<sup>+</sup>Figure 2.33: Cross sections for CO<sub>2</sub> + e → CO<sub>2</sub><sup>++</sup>

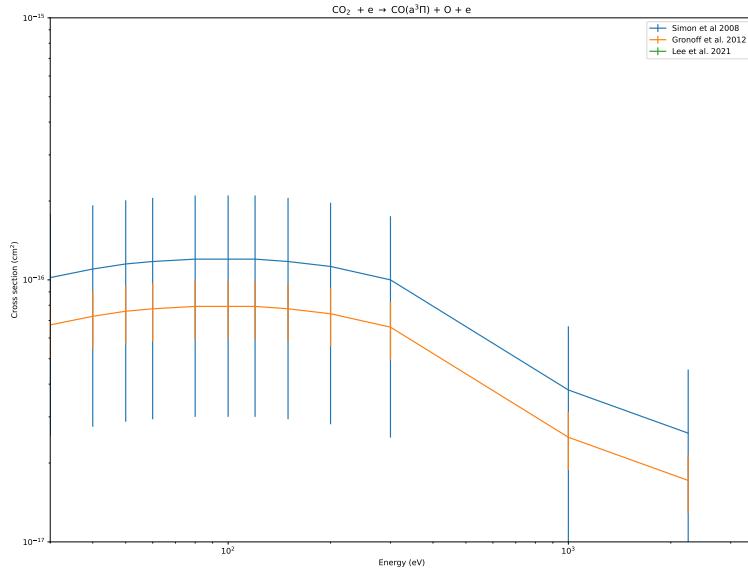


Figure 2.34: Cross sections for  $\text{CO}_2 + \text{e} \rightarrow \text{CO}(\text{a}^3\Pi) + \text{O} + \text{e}$

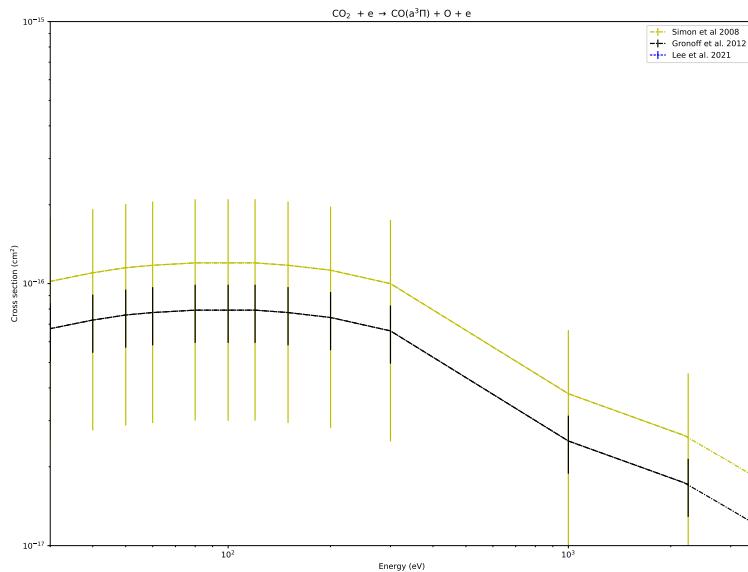
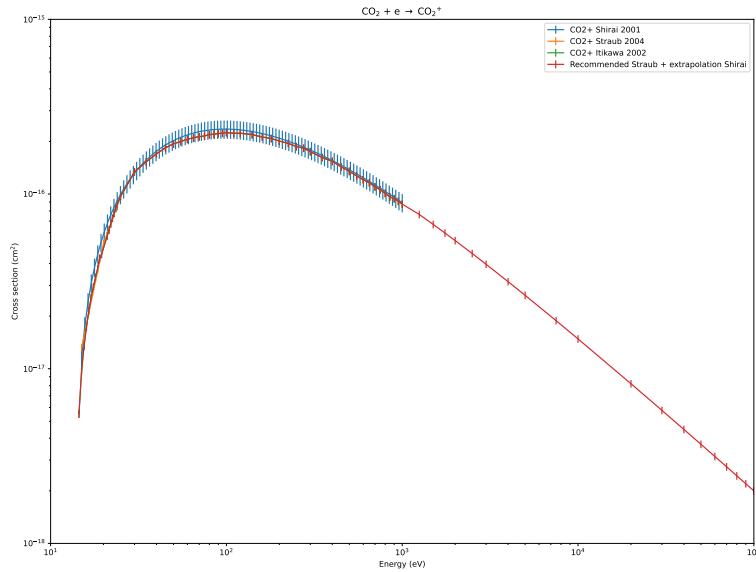
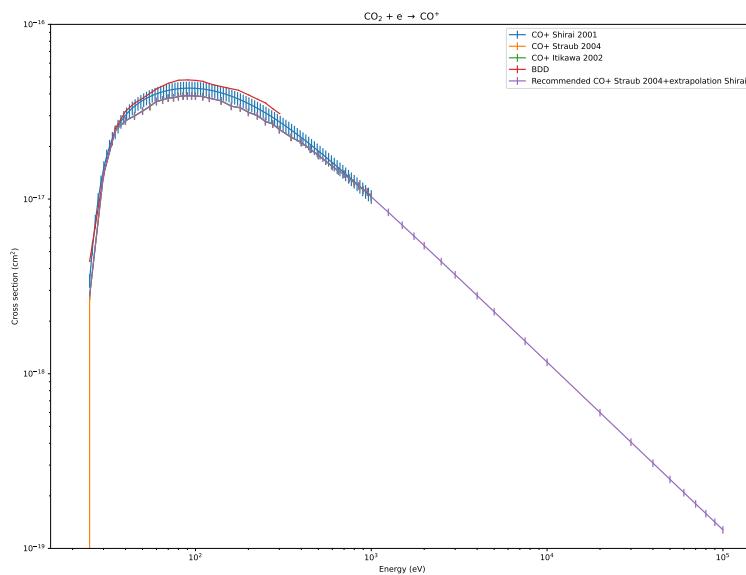


Figure 2.35: Cross sections for  $\text{CO}_2 + \text{e} \rightarrow \text{CO}(\text{a}^3\Pi) + \text{O} + \text{e}$  (wavelength with extrapolation version)

Figure 2.36: Cross sections for CO<sub>2</sub> + e → CO<sub>2</sub><sup>+</sup>Figure 2.37: Cross sections for CO<sub>2</sub> + e → CO<sup>+</sup>

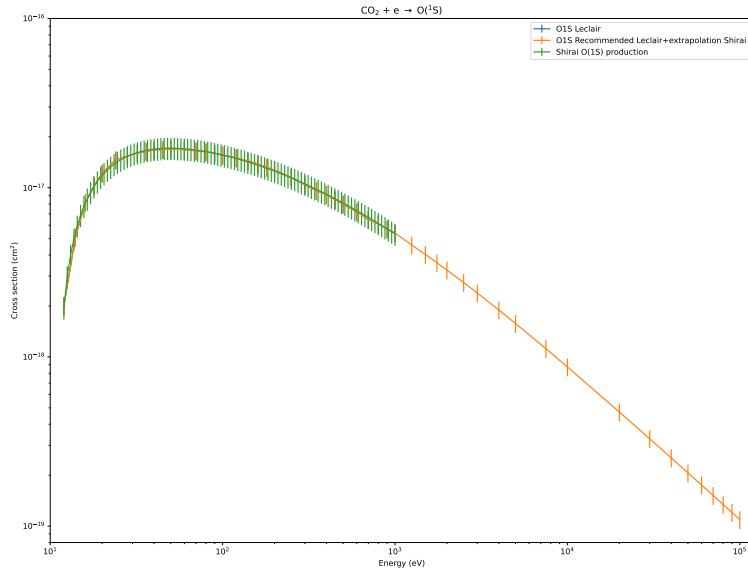


Figure 2.38: Cross sections for  $\text{CO}_2 + \text{e} \rightarrow \text{O}(^1\text{S})$

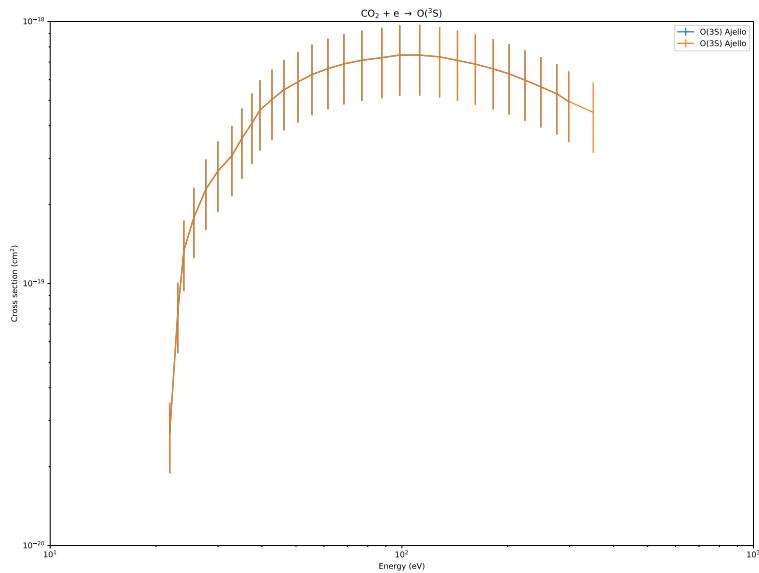
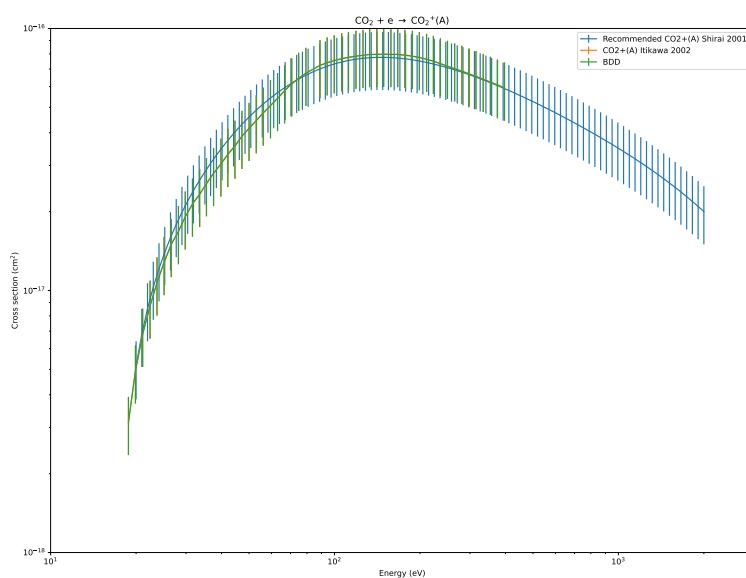
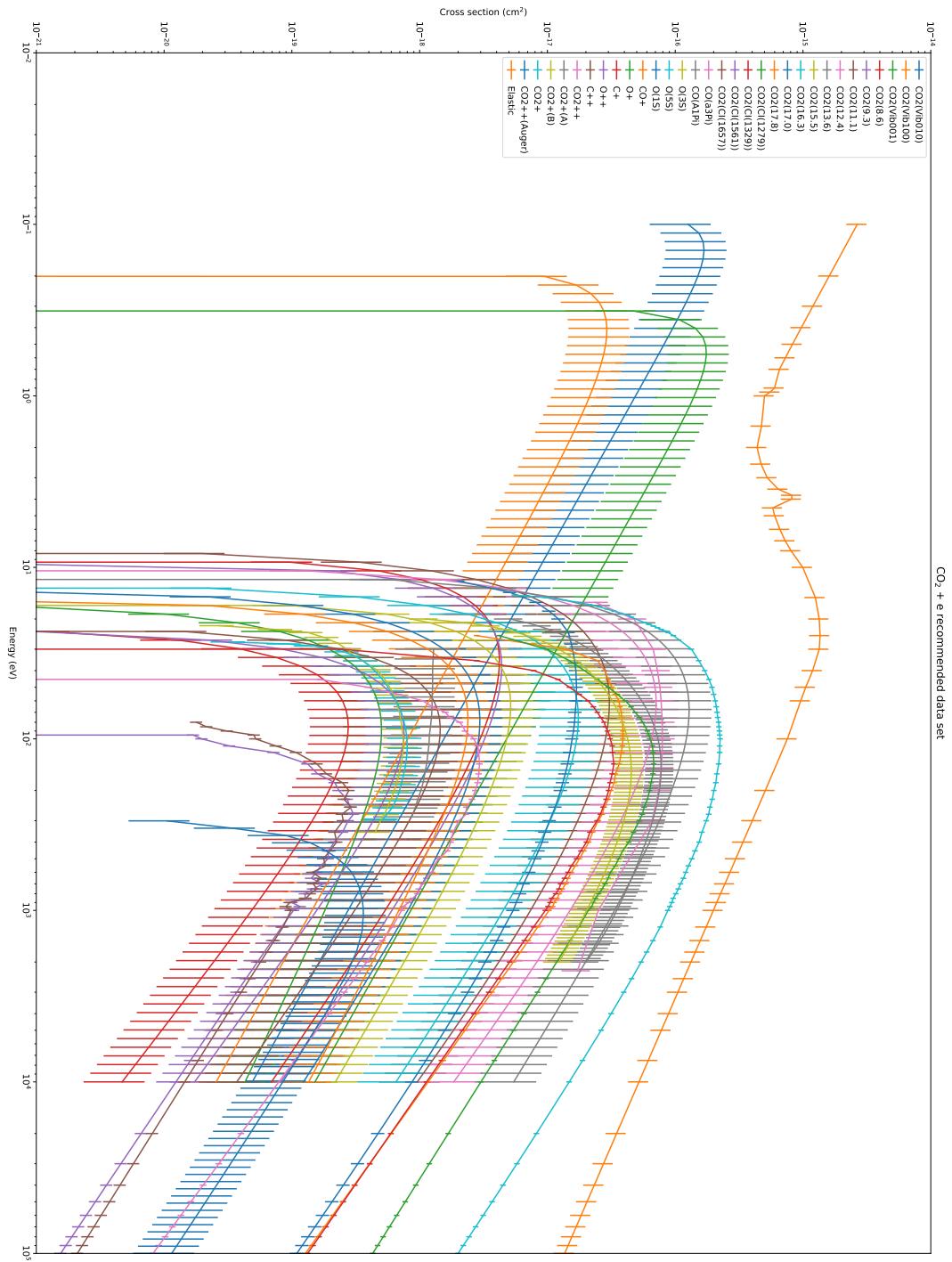


Figure 2.39: Cross sections for  $\text{CO}_2 + \text{e} \rightarrow \text{O}(^3\text{S})$

Figure 2.40: Cross sections for CO<sub>2</sub> + e → CO<sub>2</sub><sup>+</sup>(A)

Figure 2.41: Cross sections for CO<sub>2</sub> + e recommended data set

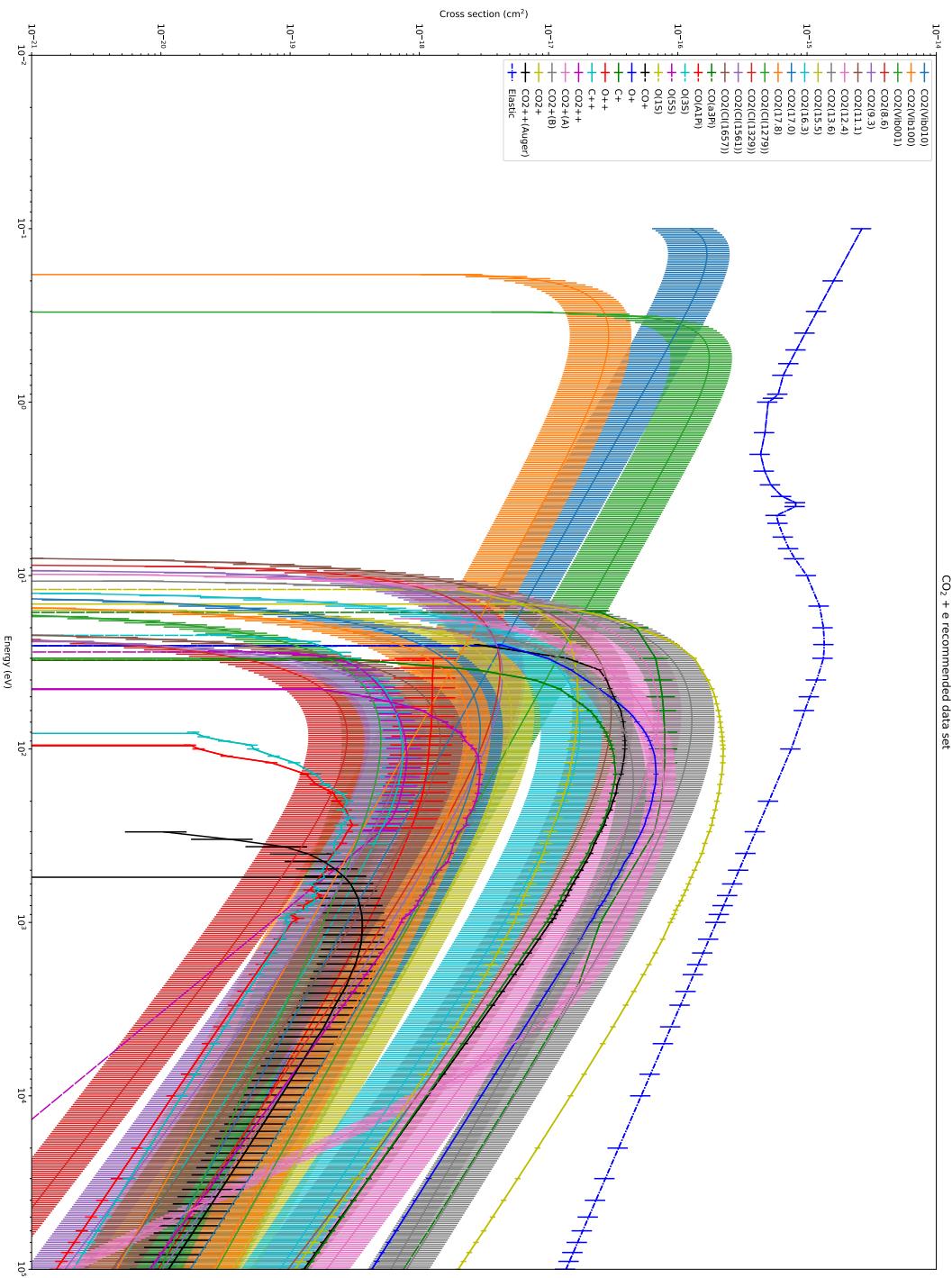


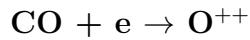
Figure 2.42: Cross sections for  $\text{CO}_2 + \text{e}$  recommended data set (wavelength with extrapolation version)

## 2.4 Cross section of e impact with CO

### 2.4.1 Elastic Cross Section

### 2.4.2 Inelastic Cross Sections

#### Ionization Cross Sections



**Notes for CO<sup>++</sup> K-Shell ionization, Frémont 2006 + Straub2004**  
The K-Shell ionization of CO by electron impact has not been studied in [13], but we assumed that the K-Shell/single ionization ratio is close to the CH<sub>4</sub> one which is used here. The total cross section has been computed by multiplying this ratio by the recommended ionization cross section, coming from [8].

**Notes for CO<sup>++</sup> K-Shell ionization, Frémont 2006 + Shirai2002**  
The K-Shell ionization of CO by electron impact has not been studied in [13], but we assumed that the K-Shell/single ionization ratio is close to the CH<sub>4</sub> one which is used here. The total cross section has been computed by multiplying this ratio by the ionization cross section, coming from [60].

Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi [34]	0	0:-1	<b>15%</b>	RU	Fig. 2.44
Revi [60]	0	1.0 : 1000.0	15%	E	Fig. 2.44

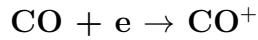
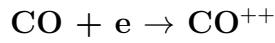
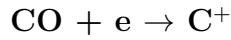
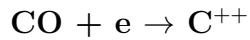
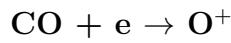
Table 2.13: Elastic cross section for e impact on CO

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$\text{CO} + \text{e} \rightarrow \text{O}^{++}$	Revi [60]	59.800000	80.0 : 600.0	20%	RE	Fig. 2.43
$\text{CO} + \text{e} \rightarrow \text{CO}^{++}$ (Auger)	Adap [13] + [8] Adap [13] + [60]	410 410 410	410:-1 410:-1 410:-1	50% 50%	RUE UE	Fig. 2.45 Fig. 2.45
$\text{CO} + \text{e} \rightarrow \text{O}^+$	Revi [60] <b>???? Straub 2004 adapted for extrapolation</b> Meas [8]	24.700000 24.7 24.7	30.0 : 600.0 15.0 : 1000.0 15.0 : 1000.0	12% 6% 6%	E RE RE	Fig. 2.46 Fig. 2.46 Fig. 2.46
$\text{CO} + \text{e} \rightarrow \text{C}^{++}$	Revi [60]	46.800000	60.0 : 600.0	20%	RE	Fig. 2.47
$\text{CO} + \text{e} \rightarrow \text{C}^+$	Revi [60] Meas [8]	22.400000 22.400000	25.0 : 600.0 15.0 : 1000.0	12% 6%	E RE	Fig. 2.48 Fig. 2.48
$\text{CO} + \text{e} \rightarrow \text{CO}^{+}$	Meas [8] Revi [59] Adap [8] + [59]	41.8 41.8 41.8	15.0 : 1000.0 50.0 : 600.0 41.8:-1	30% 20% 30%	E E RUE	Fig. 2.49 Fig. 2.49 Fig. 2.49
$\text{CO} + \text{e} \rightarrow \text{CO}^+$	Revi [60] Revi BDD Meas [8]	14.000000 14.01 14.01	17.5 : 600.0 14.01:-1 14.01:-1	12% 5% 5%	E U RE	Fig. 2.50 Fig. 2.50 Fig. 2.50

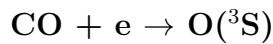
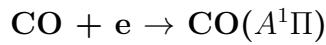
Table 2.14: Ionization Cross section for e impact on CO

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
CO + e → CO( $a^3\Pi$ )	Meas Furlong and Newell 1996 [14]	6.14	6.14:-1	5%	RE	Fig. 2.51
CO + e → CO( $A^1\Pi$ )	Meas [4]	7.	7.:-1	25%	R	Fig. 2.52
CO + e → O( $^3S$ )	Meas [1]	20	20:-1	30%	R	Fig. 2.53

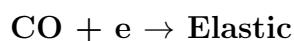
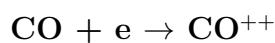
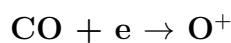
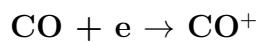
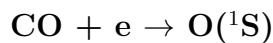
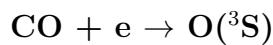
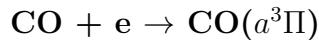
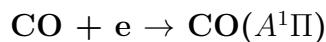
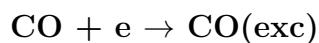
Table 2.15: Excitation Cross section for e impact on CO



### Excitation Cross Sections



### 2.4.3 Recommended data set



### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of

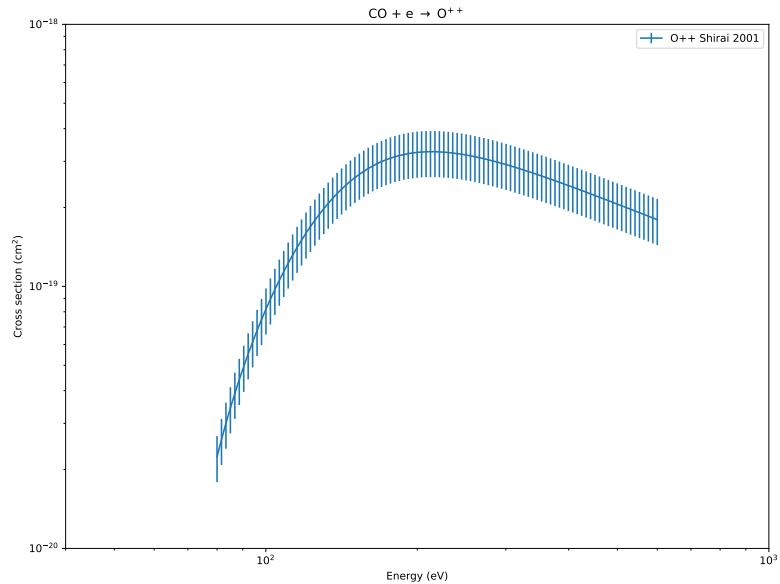
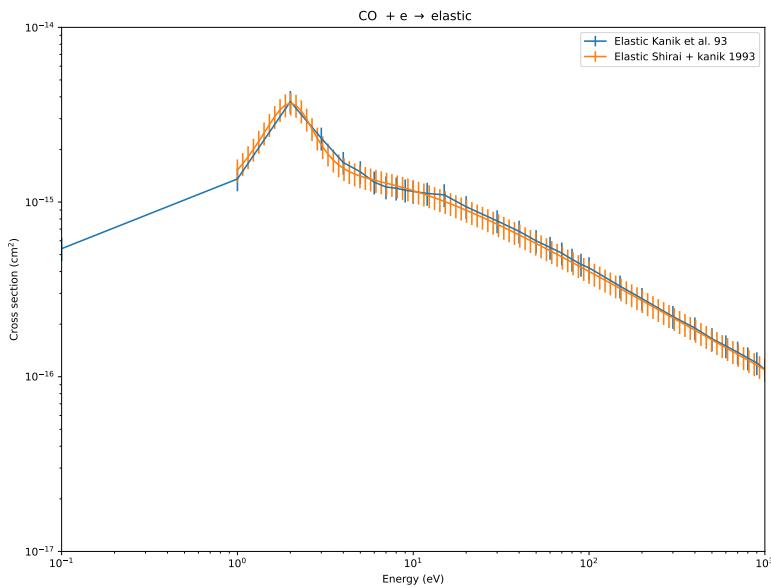
Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
CO + e → CO(rot+vib)	Revi BDD	0.64	0.64:-1	??% ??%	U	Fig. 2.54 2.55
CO + e → CO(exc)	Revi BDD	6.	6.:-1	??% ??%	U	Fig. 2.54 2.55
CO + e → CO( $A^1\Pi$ )	Meas [4]	7.	7.:-1	25%	R	Fig. 2.54 2.55
CO + e → CO( $a^3\Pi$ )	Meas Furlong and Newell 1996 [14]	6.14	6.14:-1	5%	RE	Fig. 2.54 2.55
CO + e → O( $^3S$ )	Meas [1]	20	20:-1	30%	R	Fig. 2.54 2.55
CO + e → O( $^1S$ )	Revi [60]	15.300000	18.0 : 300.0	36%	RE	Fig. 2.54 2.55
CO + e → CO <sup>+</sup>	Meas [8]	14.01	15.0 : 1000.0	5%	RE	Fig. 2.54 2.55
CO + e → O <sup>+</sup>	Adap [8] + extrapolation	24.7	15.0 : 1000.0	6%	RE	Fig. 2.54 2.55
CO + e → C <sup>+</sup>	Meas [8]	22.400000	15.0 : 1000.0	6%	RE	Fig. 2.54 2.55
CO + e → CO <sup>++</sup>	Adap [8] + [59]	41.8	41.8:-1	30%	RUE	Fig. 2.54 2.55
CO + e → C <sup>++</sup>	Revi [60]	46.800000	60.0 : 600.0	20%	RE	Fig. 2.54 2.55
CO + e → O <sup>++</sup>	Revi [60]	59.800000	80.0 : 600.0	20%	RE	Fig. 2.54 2.55
CO + e → CO <sup>++</sup> (Auger)	Adap [13] + [8]	410	410:-1	50%	RUE	Fig. 2.54 2.55
CO + e → Elastic	Revi [34]	0	0:-1	15%	RU	Fig. 2.54 2.55

Table 2.16: Recommended Cross section for e impact on CO

the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Figure 2.43: Cross sections for  $\text{CO} + \text{e} \rightarrow \text{O}^{++}$ Figure 2.44: Cross sections for  $\text{CO} + \text{e} \rightarrow \text{elastic}$

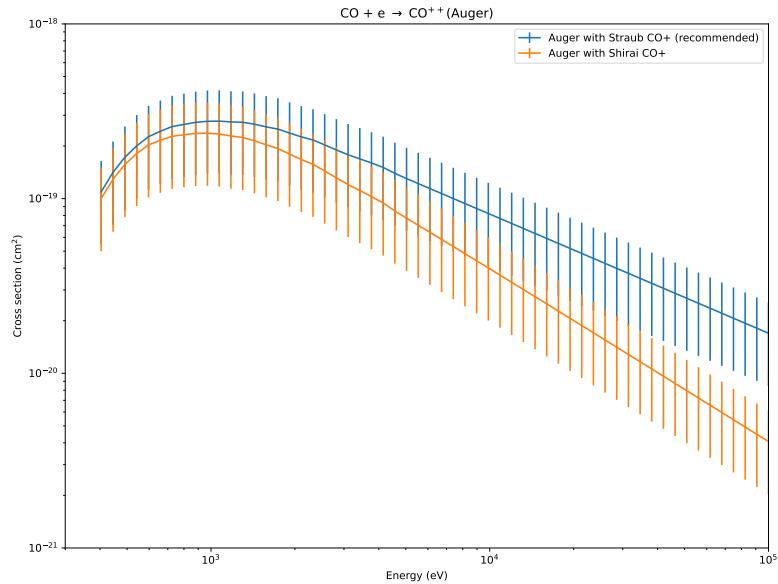


Figure 2.45: Cross sections for  $\text{CO} + \text{e} \rightarrow \text{CO}^{++}$ (Auger)

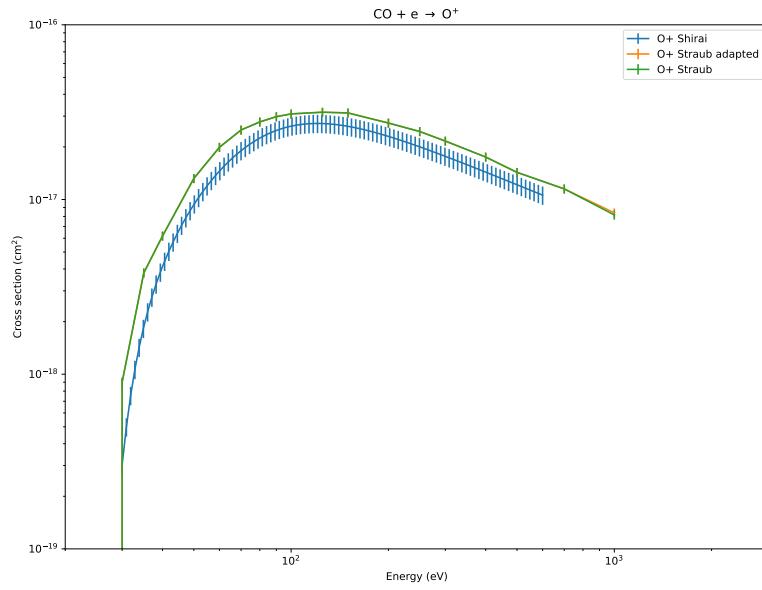
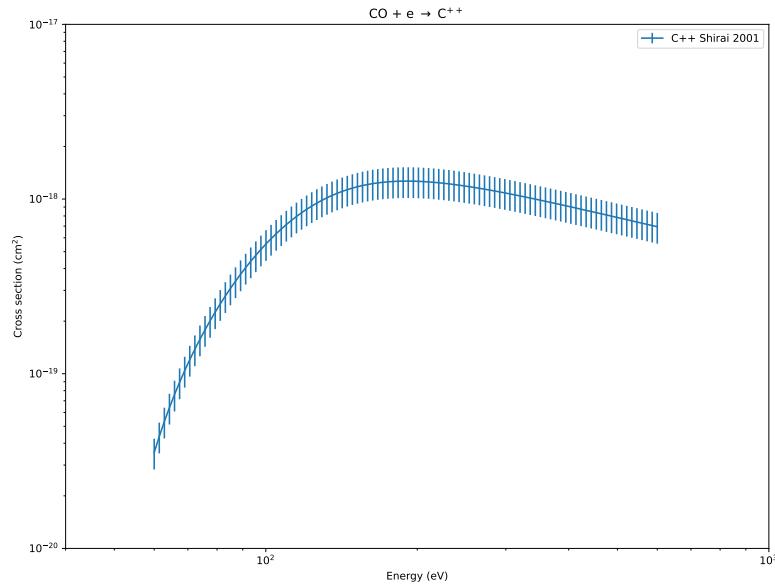
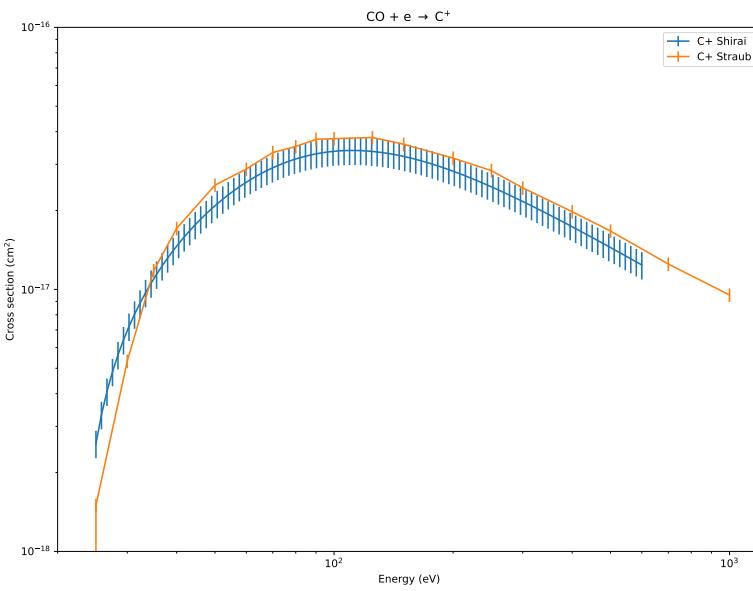
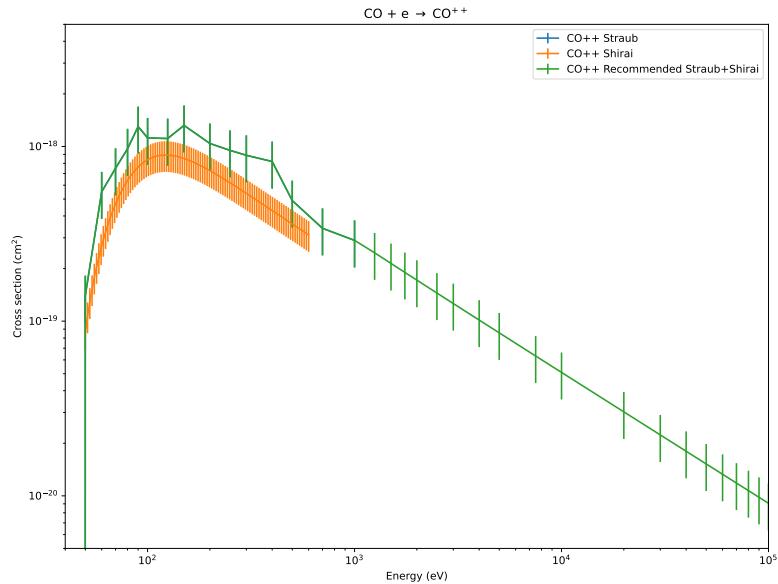
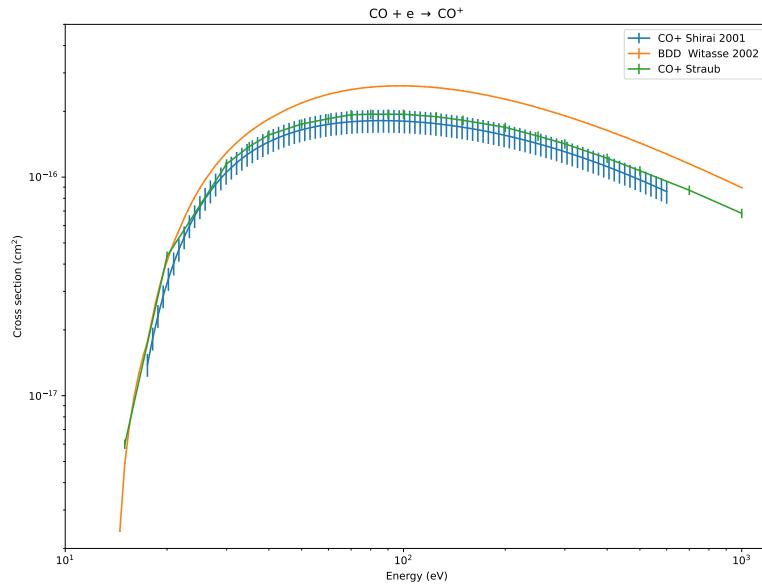
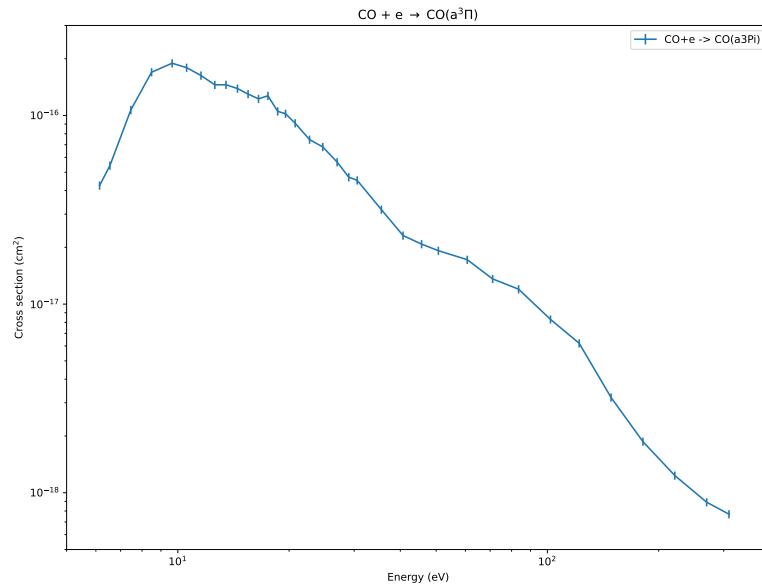
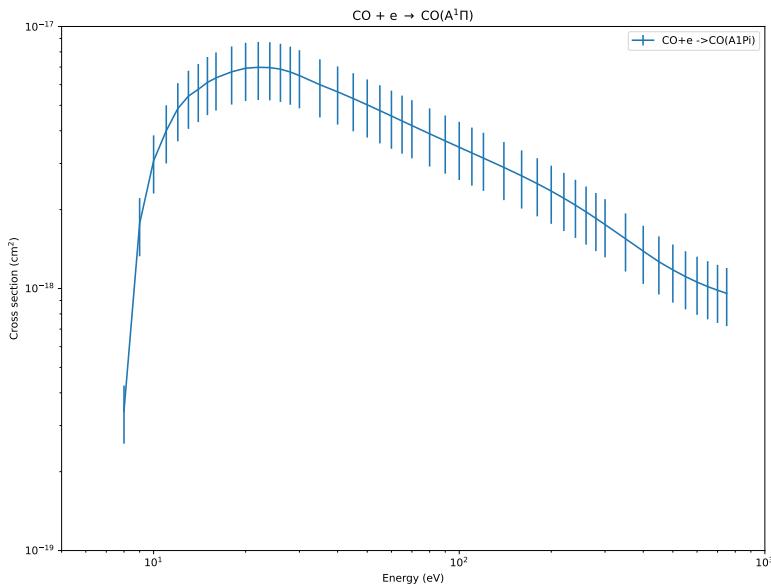


Figure 2.46: Cross sections for  $\text{CO} + \text{e} \rightarrow \text{O}^+$

Figure 2.47: Cross sections for  $\text{CO} + \text{e} \rightarrow \text{C}^{++}$ Figure 2.48: Cross sections for  $\text{CO} + \text{e} \rightarrow \text{C}^+$

Figure 2.49: Cross sections for  $\text{CO} + \text{e} \rightarrow \text{CO}^{++}$ Figure 2.50: Cross sections for  $\text{CO} + \text{e} \rightarrow \text{CO}^+$

Figure 2.51: Cross sections for  $\text{CO} + \text{e} \rightarrow \text{CO}(\text{a}^3\Pi)$ Figure 2.52: Cross sections for  $\text{CO} + \text{e} \rightarrow \text{CO}(\text{A}^1\Pi)$

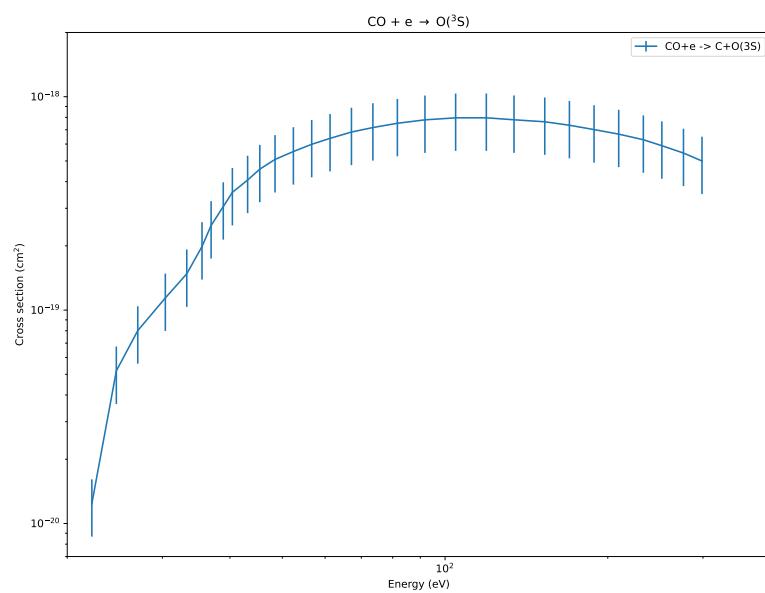
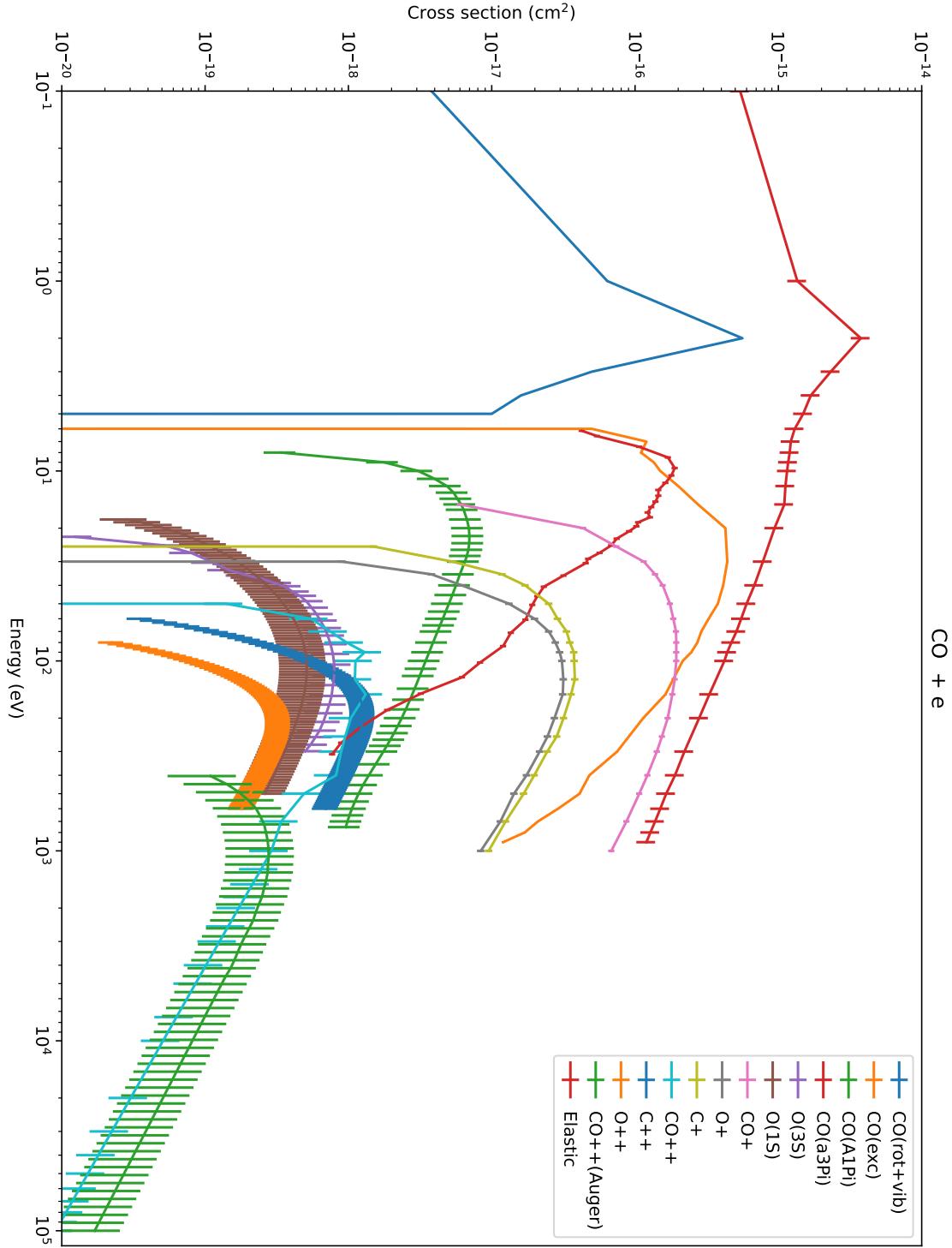


Figure 2.53: Cross sections for  $\text{CO} + \text{e} \rightarrow \text{O}({}^3\text{S})$

Figure 2.54: Cross sections for  $\text{CO} + \text{e}$

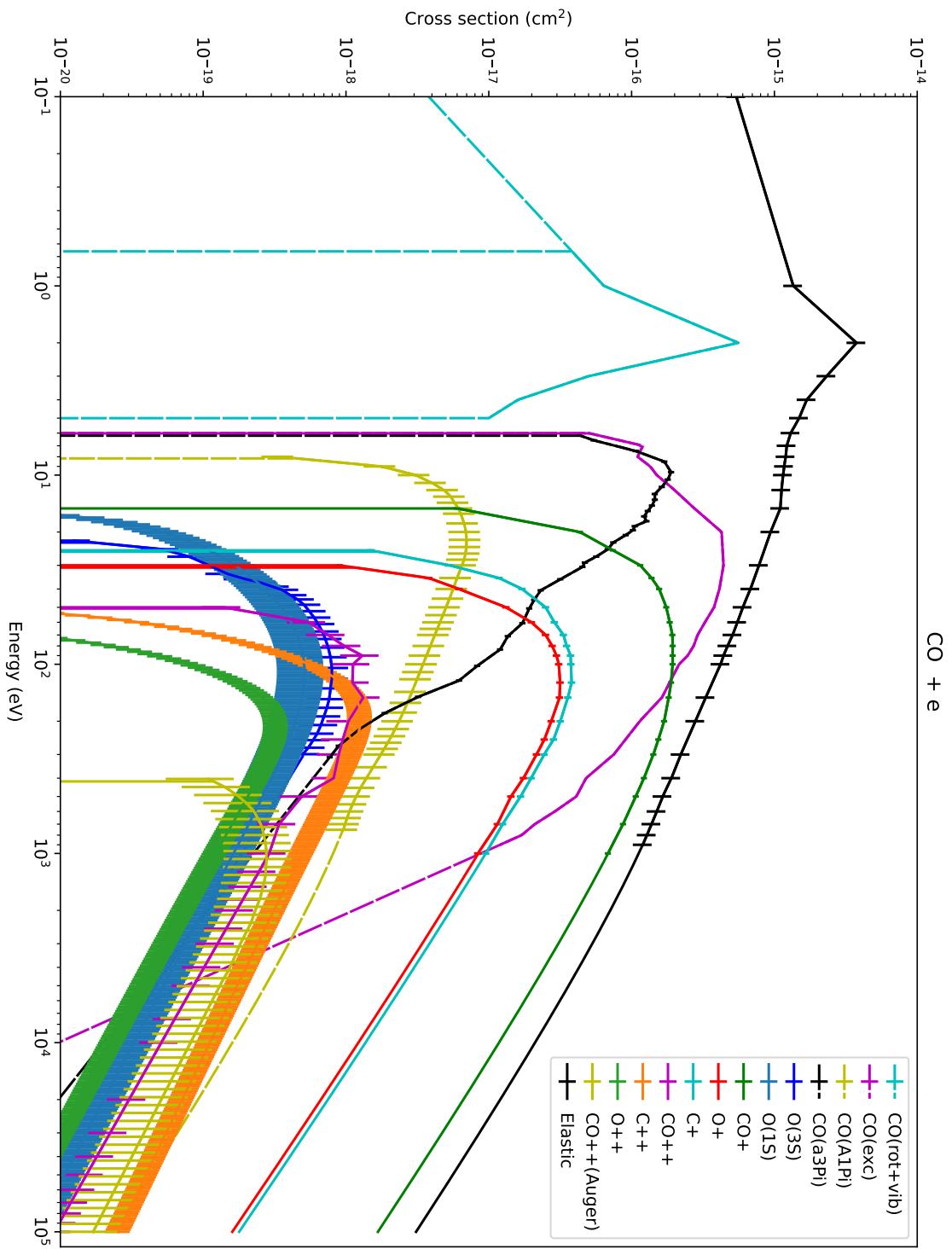


Figure 2.55: Cross sections for  $\text{CO} + \text{e}$  (wavelength with extrapolation version)



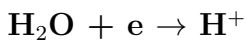
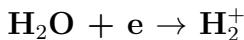
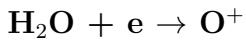
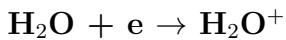
Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}^+$	Adap Itikawa Revi [64]	13.5 12.620	13.5:-1 12.620:-1	10% <b>30%</b>	R U	Fig. 2.56 2.57 Fig. 2.56 2.57
$\text{H}_2\text{O} + \text{e} \rightarrow \text{OH}^+$	Adap Itikawa Revi [64] Adap Itikawa Revi [64]	17.5 20.000 17.5 20.000	17.5:-1 20.000:-1 17.5:-1 20.000:-1	10% <b>30%</b> 10% <b>30%</b>	R U R U	Fig. 2.56 2.57 Fig. 2.56 2.57 Fig. 2.60 2.61 Fig. 2.60 2.61
$\text{H}_2\text{O} + \text{e} \rightarrow \text{O}^+$	Adap Itikawa Revi [64]	25 20.000	25:-1 20.000:-1	10% <b>30%</b>	R U	Fig. 2.56 2.57 Fig. 2.56 2.57
$\text{H}_2\text{O} + \text{e} \rightarrow \text{O}^{++}$	Adap Itikawa Revi [64]	90 60.000	90:-1 60.000:-1	10% <b>30%</b>	R U	Fig. 2.56 2.57 Fig. 2.56 2.57
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2^+$	Adap Itikawa Revi [64]	30 23.000	30:-1 23.000:-1	10% <b>30%</b>	R U	Fig. 2.56 2.57 Fig. 2.56 2.57
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}^+$	Adap Itikawa Revi [64] Adap Itikawa Revi [64]	20 20 20.000	20:-1 20:-1 20.000:-1	10% <b>30%</b> 10% <b>30%</b>	R U R U	Fig. 2.56 2.57 Fig. 2.60 2.61 Fig. 2.60 2.61 Fig. 2.60 2.61

Table 2.17: Ionization Cross section for e impact on  $\text{H}_2\text{O}$

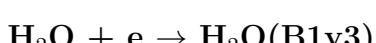
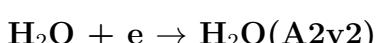
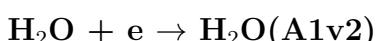
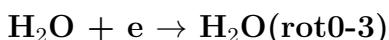
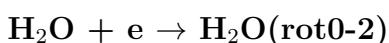
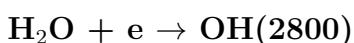
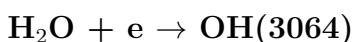
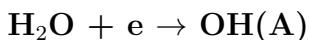
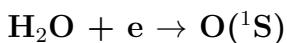
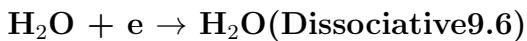
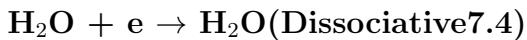
## 2.5 Cross section of e impact with H<sub>2</sub>O

### 2.5.1 Inelastic Cross Sections

#### Ionization Cross Sections



#### Excitation Cross Sections



Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{Triplet}12.5)$	Revi [64]	12.500	12.500:-1	30%	U	Fig. 2.58 2.59
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{Dissociative}7.4)$	Revi [64]	7.400	7.400:-1	30%	U	Fig. 2.58 2.59
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{Dissociative}9.6)$	Revi [64]	9.670	9.670:-1	30%	U	Fig. 2.58 2.59
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{Diffuse})$	Revi [64]	13.320	13.320:-1	30%	U	Fig. 2.58 2.59
$\text{H}_2\text{O} + \text{e} \rightarrow \text{O}^1\text{S}$	Adap Itikawa	18.5	18.5:-1	10%	R	Fig. 2.58 2.59
$\text{H}_2\text{O} + \text{e} \rightarrow \text{OH(A)}$	Adap Itikawa	10	10:-1	10%	R	Fig. 2.58 2.59
$\text{H}_2\text{O} + \text{e} \rightarrow \text{OH(3064)}$	Revi [64]	13.320	13.320:-1	30%	U	Fig. 2.58 2.59
$\text{H}_2\text{O} + \text{e} \rightarrow \text{OH(2800)}$	Revi [64]	16.40	16.40:-1	30%	U	Fig. 2.58 2.59
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{rot}0-1)$	Revi [26]	0.005	0.005:-1	30%	RE	Fig. 2.62 2.63
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{rot}0-2)$	Revi [26]	0.009	0.009:-1	30%	RE	Fig. 2.62 2.63
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{rot}0-3)$	Revi [26]	0.02	0.02:-1	30%	RE	Fig. 2.62 2.63
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{rot}0-0)$	Revi [26]	0.01	0.01:-1	30%	RE	Fig. 2.62 2.63
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2(\text{vib 100 001})$	Revi [26]	0.453	0.453:-1	30%	RE	Fig. 2.62 2.63
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{vib 010})$	Revi [26]	0.198	0.198:-1	30%	RE	Fig. 2.62 2.63
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{A}1\text{v}2)$	Revi [64]	0.198	0.198:-1	30%	U	Fig. 2.62 2.63
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{A}2\text{v}2)$	Revi [64]	0.391	0.391:-1	30%	U	Fig. 2.62 2.63
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{A}4\text{v}2)$	Revi [64]	0.453	0.453:-1	30%	U	Fig. 2.62 2.63
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{B}1\text{v}3)$	Revi [64]	0.466	0.466:-1	30%	U	Fig. 2.62 2.63
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{B}2\text{v}1+\text{v}3)$	Revi [64]	0.661	0.661:-1	30%	U	Fig. 2.62 2.63
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{B}1\text{v}1+\text{v}3)$	Revi [64]	0.899	0.899:-1	30%	U	Fig. 2.62 2.63
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{B}1\text{v}1+\text{v}3)$	Revi [64]	1.092	1.092:-1	30%	U	Fig. 2.62 2.63
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{B}2\text{v}1+\text{v}3)$	Revi [64]	1.316	1.316:-1	30%	U	Fig. 2.62 2.63

Table 2.18: Excitation Cross section for e impact on  $\text{H}_2\text{O}$

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$H_2O + e \rightarrow O(^3S)$	Adap Itikawa	25	25:-1	10%	R	Fig. 2.58 2.59
$H_2O + e \rightarrow H(^1Ly\alpha)$	Adap Itikawa	25	25:-1	10%	R	Fig. 2.58 2.59
$H_2O + e \rightarrow H(^1\beta)$	Adap Itikawa	20	20:-1	10%	R	Fig. 2.58 2.59
$H_2O + e \rightarrow O(^3p^3P)$	Adap Itikawa	20	20:-1	10%	R	Fig. 2.58 2.59
$H_2O + e \rightarrow O(^5P)$	Adap Itikawa	20	20:-1	10%	R	Fig. 2.58 2.59

Table 2.19: Emission Cross section for e impact on  $H_2O$

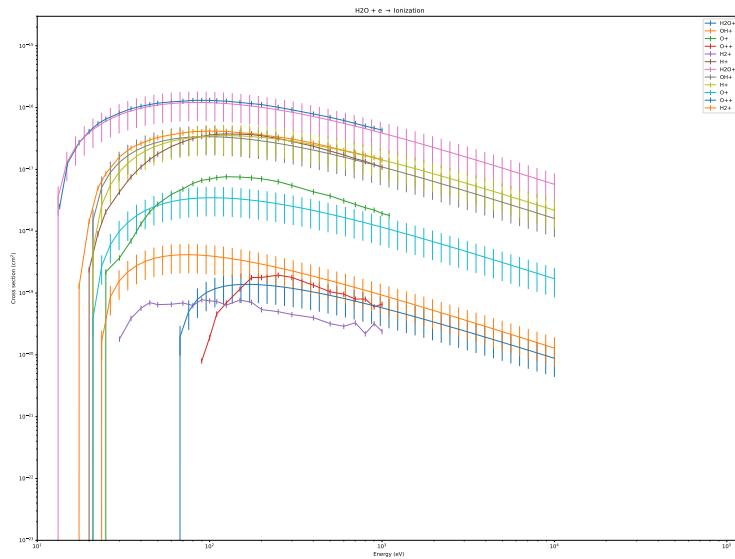
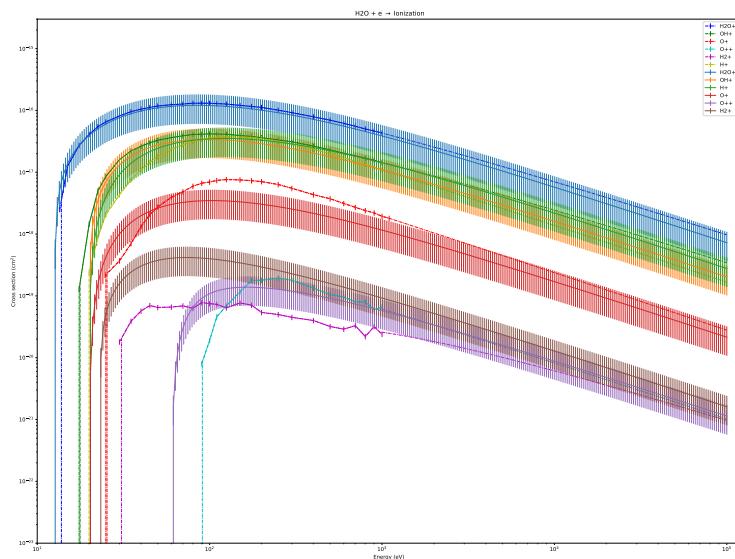
Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{rot-0})$	Revi [26]	0.005	0.005:-1	30%	RE	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{rot-0-2})$	Revi [26]	0.009	0.009:-1	30%	RE	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{rot-0-3})$	Revi [26]	0.02	0.02:-1	30%	RE	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{rot-0-0})$	Revi [26]	0.01	0.01:-1	30%	RE	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2(\text{vib 100 001})$	Revi [26]	0.453	0.453:-1	30%	RE	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{vib 010})$	Revi [26]	0.198	0.198:-1	30%	RE	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{Triplet12.5})$	Revi [64]	12.500	12.500:-1	30%	U	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{Dissociative7.4})$	Revi [64]	7.400	7.400:-1	30%	U	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{Dissociative9.6})$	Revi [64]	9.670	9.670:-1	30%	U	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{Diffuse})$	Revi [64]	13.320	13.320:-1	30%	U	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{OH(A)}$	Adap Itikawa	10	10:-1	10%	R	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H(3d)}$	Adap Itikawa	20	20:-1	10%	R	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{OH}$	Adap Itikawa	10	10:-1	10%	R	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{O(^1S)}$	Adap Itikawa	18.5	18.5:-1	10%	R	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{O(^3S)}$	Adap Itikawa	25	25:-1	10%	R	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H(Ly alpha)}$	Adap Itikawa	25	25:-1	10%	R	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H(beta)}$	Adap Itikawa	20	20:-1	10%	R	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{O(3p3P)}$	Adap Itikawa	20	20:-1	10%	R	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{O(5P)}$	Adap Itikawa	20	20:-1	10%	R	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{RydbergA})$	Revi [64]	12.620	12.620:-1	30%	U	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{RydbergB})$	Revi [64]	12.620	12.620:-1	30%	U	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{RydbergC})$	Revi [64]	12.620	12.620:-1	30%	U	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}(\text{RydbergD})$	Revi [64]	12.620	12.620:-1	30%	U	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2\text{O}^+$	Revi [64]	12.620	12.620:-1	30%	U	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{OH}^+$	Revi [64]	20.000	20.000:-1	30%	U	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}^+$	Revi [64]	20.000	20.000:-1	30%	U	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{O}^+$	Adap Itikawa	25	25:-1	10%	R	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{O}^{++}$	Revi [64]	60.000	60.000:-1	30%	U	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{H}_2^+$	Revi [64]	23.000	23.000:-1	30%	U	Fig. 2.64 2.65
$\text{H}_2\text{O} + \text{e} \rightarrow \text{Elastic}$	Revi [26]	0	0:-1	30%	RUE	Fig. 2.64 2.65

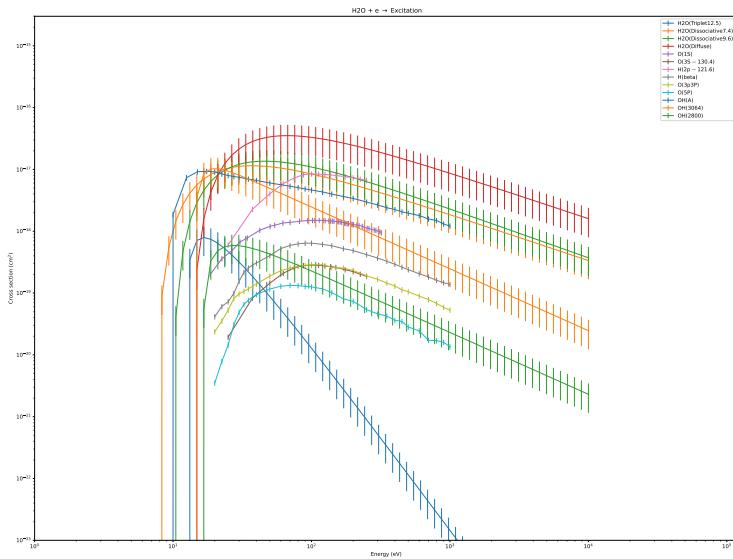
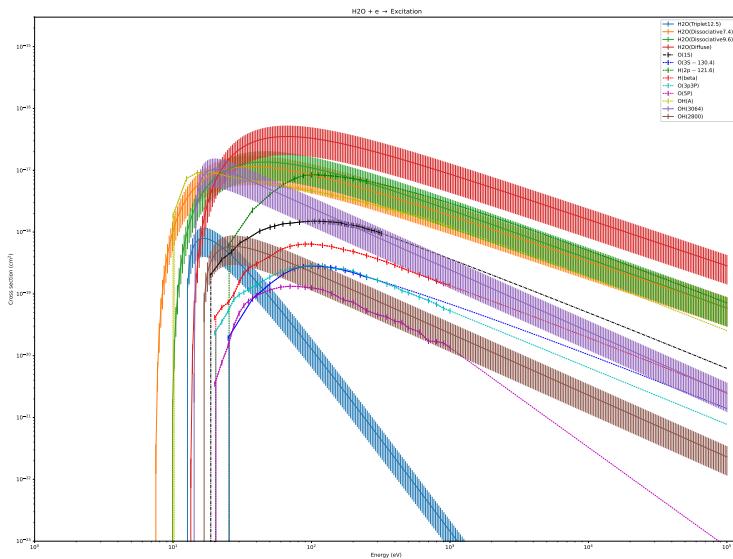
Table 2.20: Recommended Cross section for e impact on  $\text{H}_2\text{O}$

the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Figure 2.56: Cross sections for  $\text{H}_2\text{O} + \text{e} \rightarrow \text{Ionization}$ Figure 2.57: Cross sections for  $\text{H}_2\text{O} + \text{e} \rightarrow \text{Ionization}$  (wavelength with extrapolation version)

Figure 2.58: Cross sections for  $H_2O + e \rightarrow$  ExcitationFigure 2.59: Cross sections for  $H_2O + e \rightarrow$  Excitation (wavelength with extrapolation version)

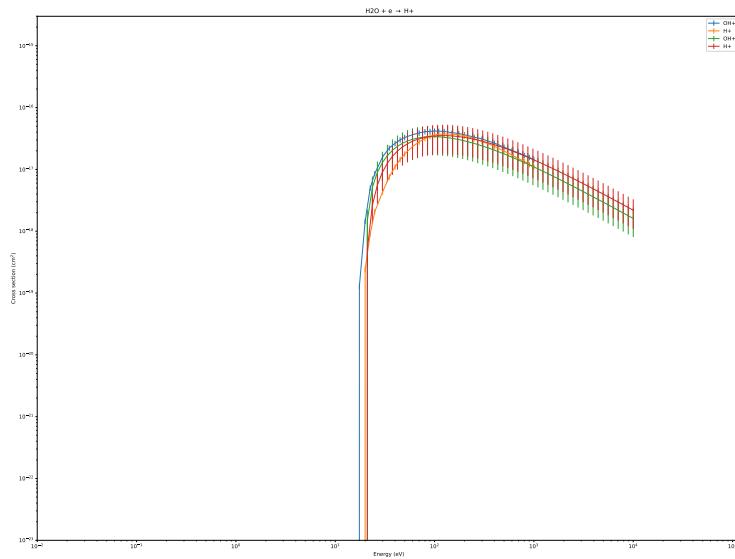


Figure 2.60: Cross sections for  $\text{H}_2\text{O} + \text{e} \rightarrow \text{H}^+$

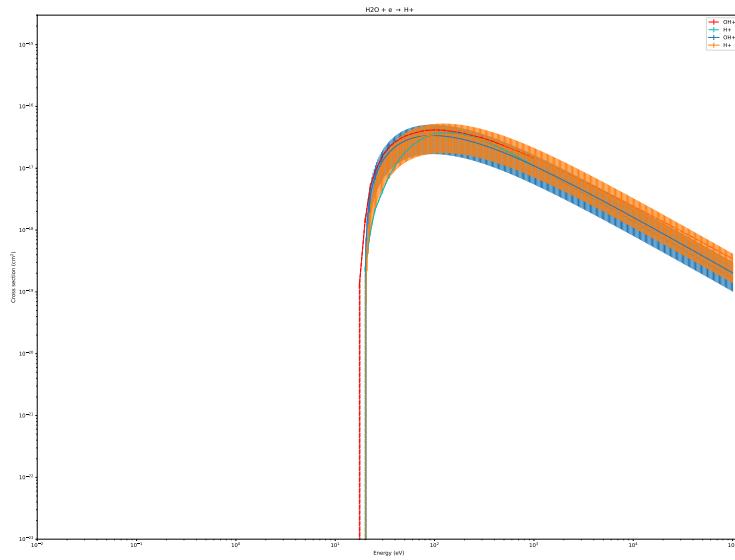
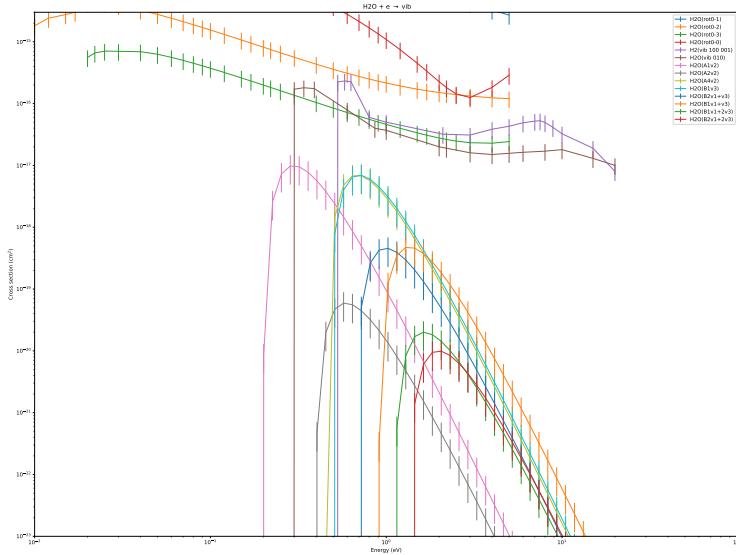
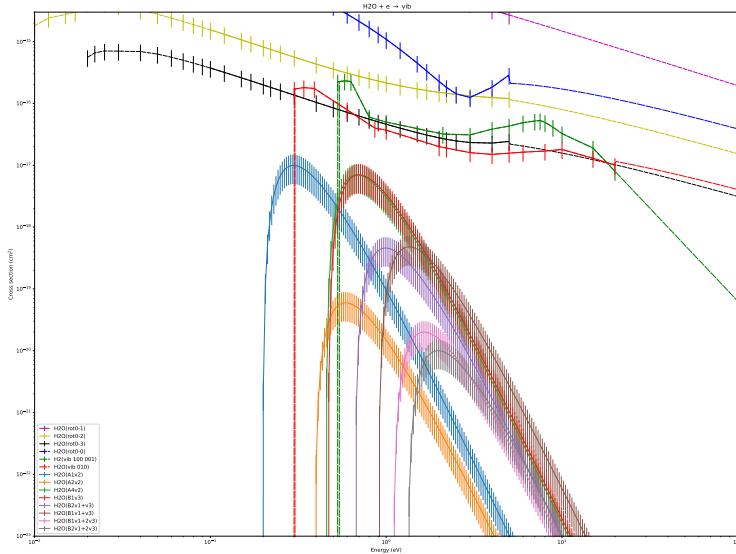
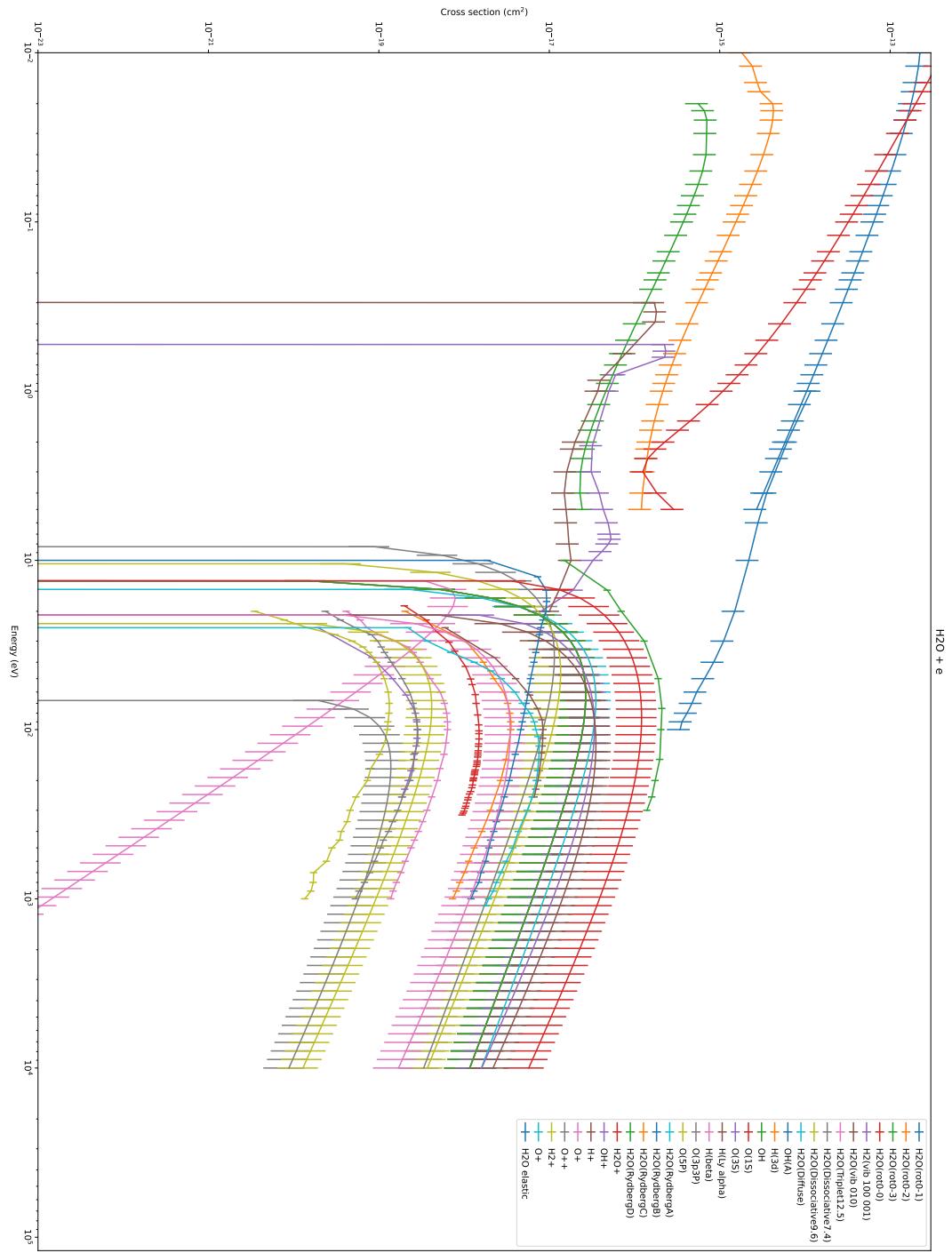
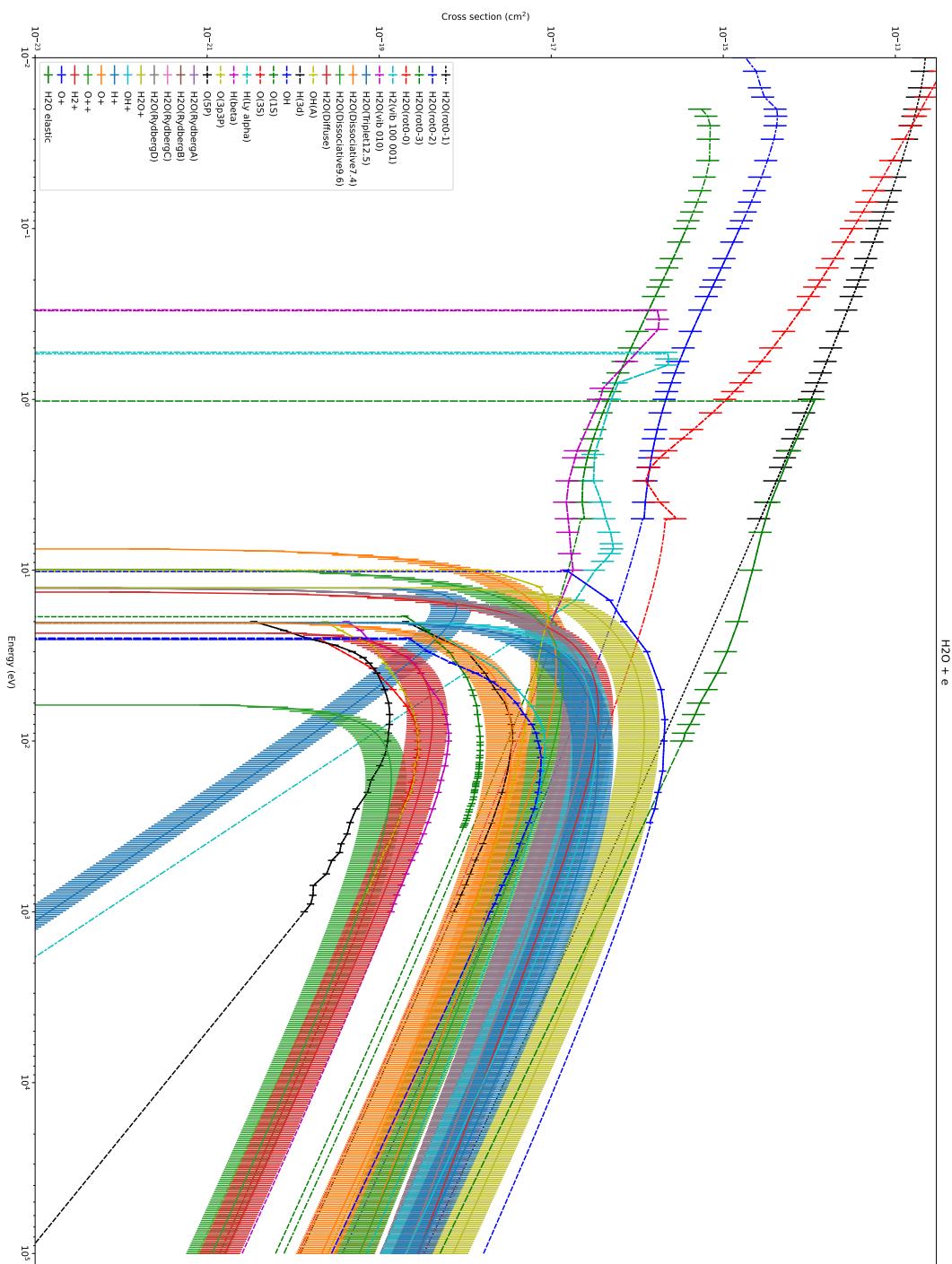


Figure 2.61: Cross sections for  $\text{H}_2\text{O} + \text{e} \rightarrow \text{H}^+$  (wavelength with extrapolation version)

Figure 2.62: Cross sections for  $H_2O + e \rightarrow \text{vib}$ Figure 2.63: Cross sections for  $H_2O + e \rightarrow \text{vib}$  (wavelength with extrapolation version)

Figure 2.64: Cross sections for  $\text{H}_2\text{O} + \text{e}$





Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi [50]	0	0:-1	30%	RUE	Fig. 2.69

Table 2.21: Elastic cross section for e impact on  $H_2$

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$H_2 + e \rightarrow H_2^+$	Revi [80]	15.426	15.426:-1	7%	U RE	Fig. 2.67
	Revi [2]	15.426	15.426:-1	15%		Fig. 2.67
	Meas [66]	15.426	15.426:-1	5%		Fig. 2.67
	Revi Phelps [51]	15.426	15.426:-1	20%		Fig. 2.67
	Revi [64]	16.000	16.000:-1	30%		Fig. 2.67
	Adap [43]	15.4	15.4:-1	30%		Fig. 2.67
$H_2 + e \rightarrow H^+$	Meas [66]	18.1	18.1:-1	5%	Fig. 2.70	Fig. 2.70
	Revi [80]	18.1	18.1:-1	7%		Fig. 2.70
	Revi [2]	18.1	18.1:-1	15%		Fig. 2.70

Table 2.22: Ionization Cross section for e impact on  $H_2$

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$H_2 + e \rightarrow H_2(\text{Rydberg})$	Adap [9]	15.5	15.5:-1	30%	RE	Fig. 2.66
$H_2 + e \rightarrow H_2(I,y\text{Series})$	Revi [64]	16	16:-1	30%	U	Fig. 2.66
$H_2 + e \rightarrow H_2(W\text{eSeries})$	Revi [64]	16	16:-1	30%	U	Fig. 2.66
$H_2 + e \rightarrow H_2(B1\text{Su})$	Adap $H_2(B\ 1S+u\ (2pS))$ [9]	11.37	11.37:-1	30%	RE	Fig. 2.68
	Revi [64]	13.013	13.013:-1	30%	U	Fig. 2.68
$H_2 + e \rightarrow H_2(C1\text{Pu})$	Adap [9]	11.7	11.7:-1	30%	RE	Fig. 2.68
	Revi [64]	12.465	12.465:-1	30%	U	Fig. 2.68
$H_2 + e \rightarrow H_2(\text{rot})$	Adap [9]	0.001	0.001:-1	30%	RE	Fig. 2.71
$H_2 + e \rightarrow H_2(c3piu)$	Revi [64]	11.870	11.870:-1	30%	U	Fig. 2.72
$H_2 + e \rightarrow H_2(b3sigma+u)$	Revi [64]	10.000	10.000:-1	30%	U	Fig. 2.72
$H_2 + e \rightarrow H_2(a3sigma+g)$	Revi [64]	11.890	11.890:-1	30%	U	Fig. 2.72
$H_2 + e \rightarrow H_2(abc)$	Adap [30]	10	10:-1	30%	RE	Fig. 2.72

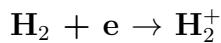
Table 2.23: Excitation Cross section for e impact on  $H_2$

## 2.6 Cross section of e impact with H<sub>2</sub>

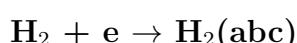
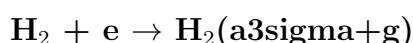
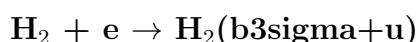
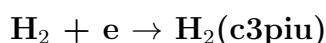
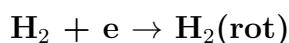
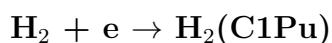
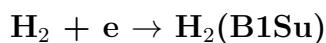
### 2.6.1 Elastic Cross Section

### 2.6.2 Inelastic Cross Sections

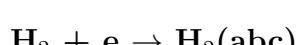
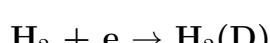
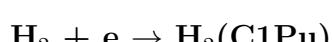
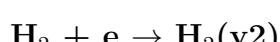
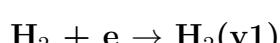
#### Ionization Cross Sections



#### Excitation Cross Sections



### 2.6.3 Recommended data set



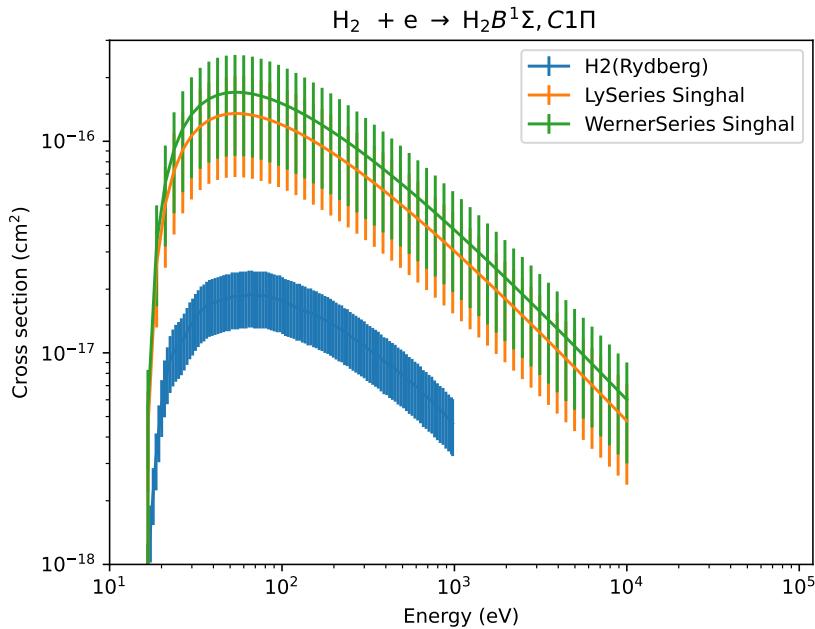
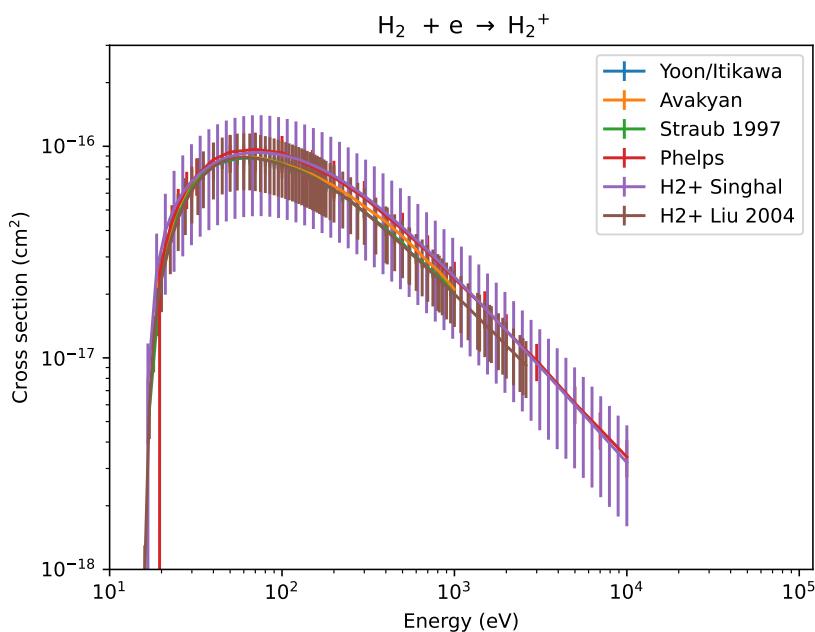
Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$H_2 + e \rightarrow H_2(\text{rot})$	Adap [9]	0.001	0.001:-1	30%	RE	Fig. 2.73 2.74
$H_2 + e \rightarrow H_2(v1)$	Adap [30]	.5	.5:-1	30%	RE	Fig. 2.73 2.74
$H_2 + e \rightarrow H_2(v2)$	Adap [30]	1	1:-1	30%	RE	Fig. 2.73 2.74
$H_2 + e \rightarrow H_2(B1Su)$	Adap $H_2(B\ 1S+u\ (2pS))$ [9]	11.37	11.37:-1	30%	RE	Fig. 2.73 2.74
$H_2 + e \rightarrow H_2(B\text{prime})$	Adap [9]	19.5	19.5:-1	30%	RE	Fig. 2.73 2.74
$H_2 + e \rightarrow H_2(B\text{seconde})$	Adap [9]	14.2	14.2:-1	30%	RE	Fig. 2.73 2.74
$H_2 + e \rightarrow H_2(C1Pu)$	Adap [9]	11.7	11.7:-1	30%	RE	Fig. 2.73 2.74
$H_2 + e \rightarrow H_2(D)$	Adap [9]	13.6	13.6:-1	30%	RE	Fig. 2.73 2.74
$H_2 + e \rightarrow H_2(D\text{prime})$	Adap [9]	14.3	14.3:-1	30%	RE	Fig. 2.73 2.74
$H_2 + e \rightarrow H_2(EP)$	Adap [9]	12.2	12.2:-1	30%	RE	Fig. 2.73 2.74
$H_2 + e \rightarrow H_2(abc)$	Adap [30]	10	10:-1	30%	RE	Fig. 2.73 2.74
$H_2 + e \rightarrow H_2(\text{Rydberg})$	Adap [9]	15.5	15.5:-1	30%	RE	Fig. 2.73 2.74
$H_2 + e \rightarrow H_2^+$	Adap [43]	15.4	15.4:-1	30%	RE	Fig. 2.73 2.74
$H_2 + e \rightarrow H^+$	Adap [30] + [80]	18	18:-1	30%	RE	Fig. 2.73 2.74
$H_2 + e \rightarrow H(2p)$	Adap Ajello 91 APJ, 371, 422-431	14.67	14.67:-1	10%	RE	Fig. 2.73 2.74
$H_2 + e \rightarrow \text{Elastic}$	Revi [50]	0	0:-1	30%	RUE	Fig. 2.73 2.74

Table 2.24: Recommended Cross section for e impact on  $H_2$

the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Figure 2.66: Cross sections for  $H_2 + e \rightarrow H_2B^1\Sigma, C1\Pi$ Figure 2.67: Cross sections for  $H_2 + e \rightarrow H_2^+$

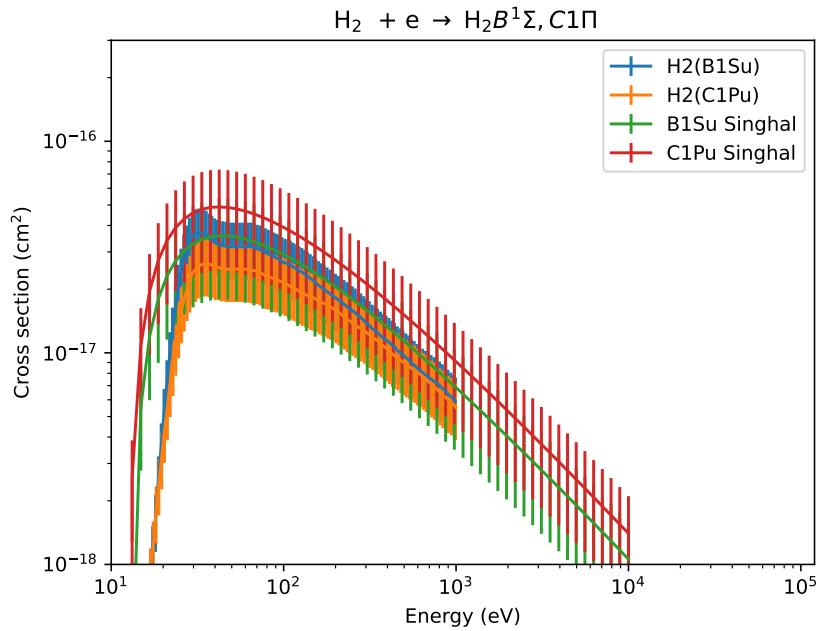


Figure 2.68: Cross sections for  $\text{H}_2 + \text{e} \rightarrow \text{H}_2B^1\Sigma, C1\Pi$

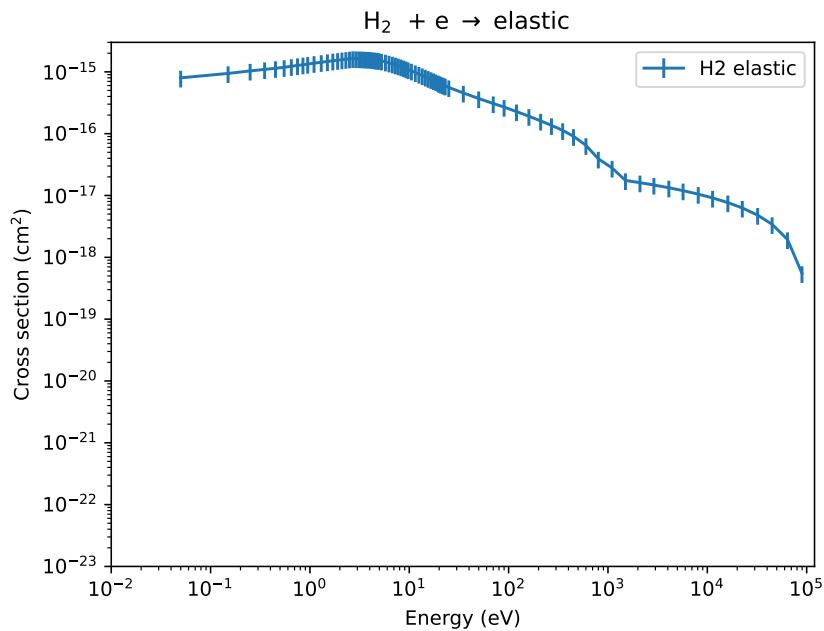
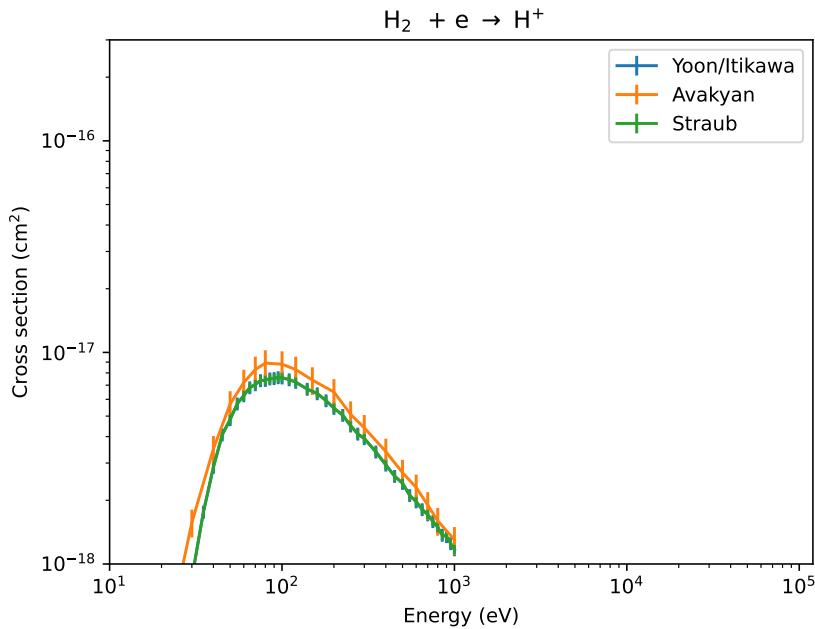
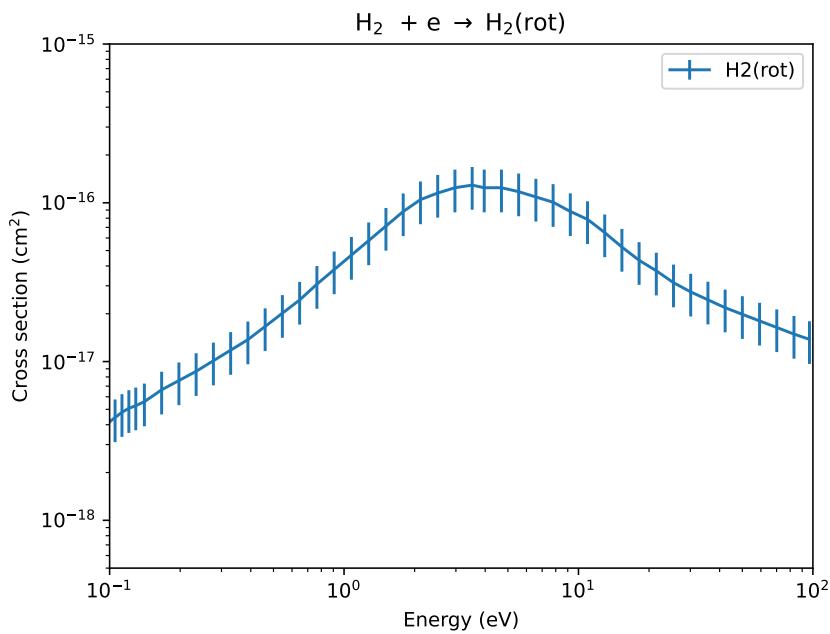


Figure 2.69: Cross sections for  $\text{H}_2 + \text{e} \rightarrow \text{elastic}$

Figure 2.70: Cross sections for  $H_2 + e \rightarrow H^+$ Figure 2.71: Cross sections for  $H_2 + e \rightarrow H_2(\text{rot})$

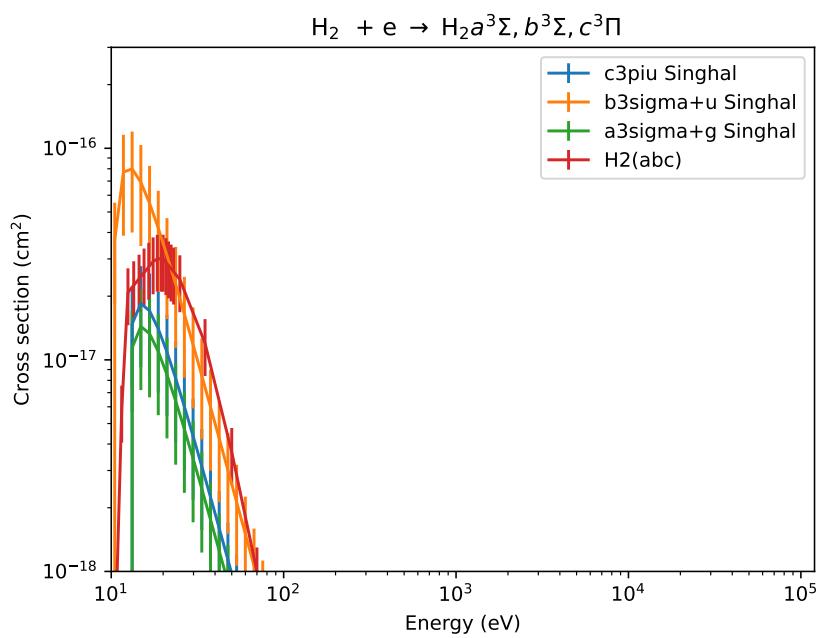
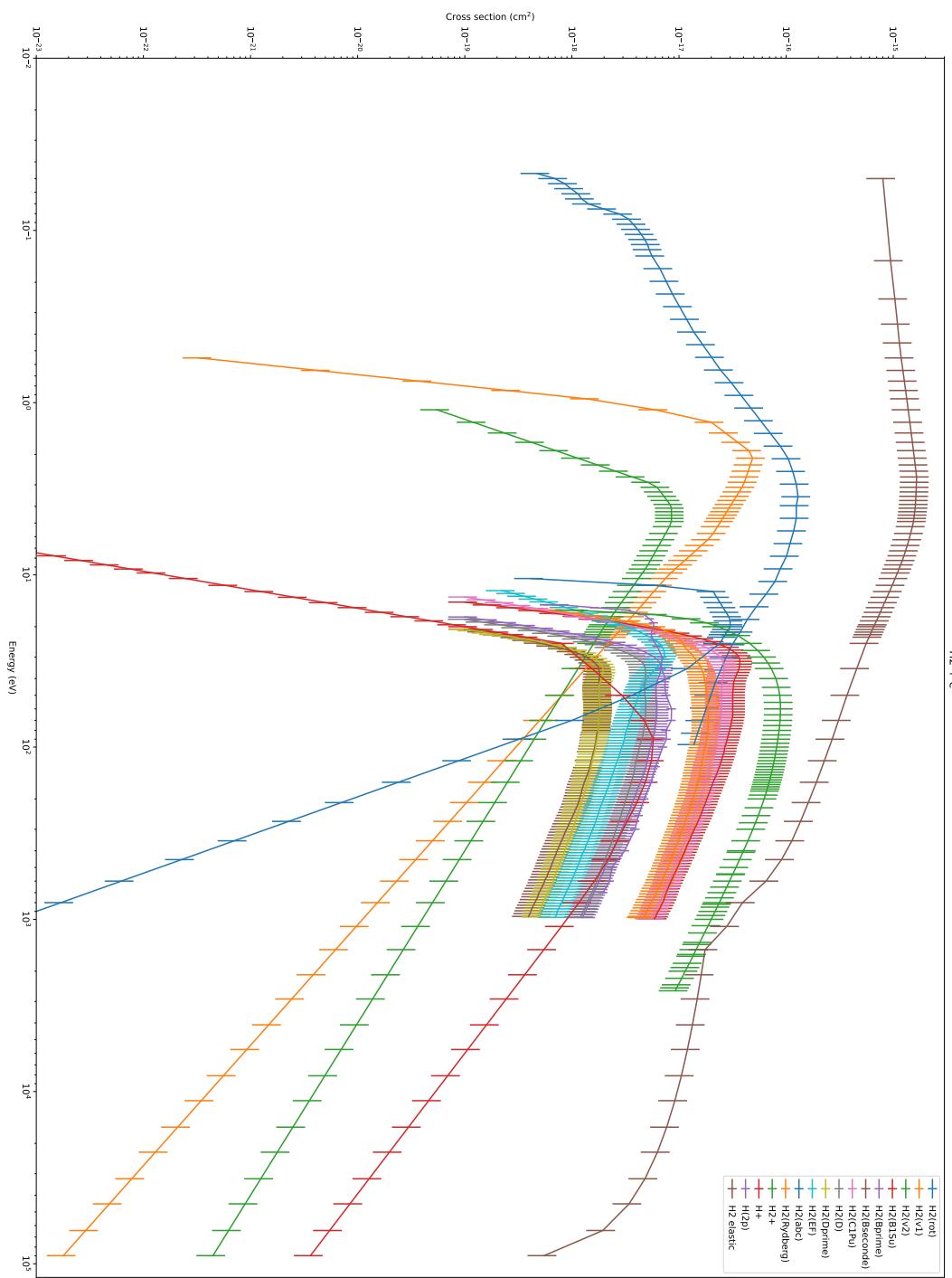


Figure 2.72: Cross sections for  $\text{H}_2 + \text{e} \rightarrow \text{H}_2a^3\Sigma, b^3\Sigma, c^3\Pi$

Figure 2.73: Cross sections for  $H_2 + e$

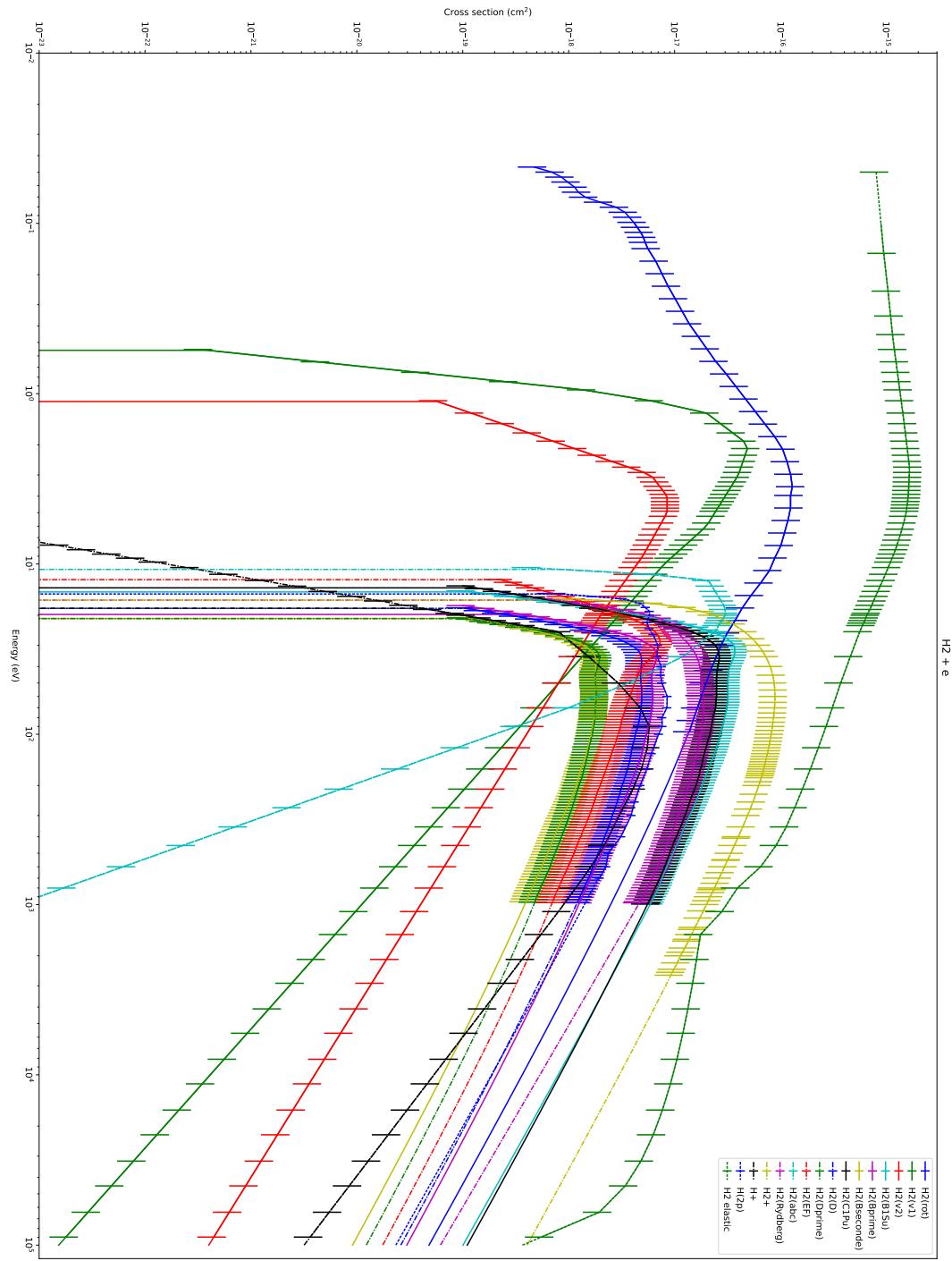


Figure 2.74: Cross sections for H<sub>2</sub> + e (wavelength with extrapolation version)



Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$\text{He} + \text{e} \rightarrow \text{He}(2\text{S}\frac{1}{2})$	Adap [54]	19.847	19.847:-1	15%	RE	Fig. 2.75 2.76
$\text{He} + \text{e} \rightarrow \text{He}(2\text{S}\frac{1}{2})$	Adap [54]	20.63	20.63:-1	15%	RE	Fig. 2.75 2.76
$\text{He} + \text{e} \rightarrow \text{He}(2\text{P}\frac{1}{2})$	Adap [54]	20.993	20.993:-1	15%	RE	Fig. 2.75 2.76
$\text{He} + \text{e} \rightarrow \text{He}(2\text{P}\frac{3}{2})$	Adap [54]	21.247	21.247:-1	15%	RE	Fig. 2.75 2.76
$\text{He} + \text{e} \rightarrow \text{He}(3\text{S}\frac{1}{2})$	Adap [54]	22.749	22.749:-1	15%	RE	Fig. 2.75 2.76
$\text{He} + \text{e} \rightarrow \text{He}(3\text{S}\frac{1}{2})$	Adap [54]	22.951	22.951:-1	15%	RE	Fig. 2.75 2.76
$\text{He} + \text{e} \rightarrow \text{He}(3\text{P}\frac{1}{2})$	Adap [54]	23.038	23.038:-1	15%	RE	Fig. 2.75 2.76
$\text{He} + \text{e} \rightarrow \text{He}(3\text{D}\frac{5}{2})$	Adap [54]	23.105	23.105:-1	15%	RE	Fig. 2.75 2.76
$\text{He} + \text{e} \rightarrow \text{He}(3\text{D}\frac{3}{2})$	Adap [54]	23.105	23.105:-1	15%	RE	Fig. 2.75 2.76
$\text{He} + \text{e} \rightarrow \text{He}(3\text{P}\frac{3}{2})$	Adap [54]	23.118	23.118:-1	15%	RE	Fig. 2.75 2.76
$\text{He} + \text{e} \rightarrow \text{He}(4\text{S}\frac{1}{2})$	Adap [54]	23.626	23.626:-1	15%	RE	Fig. 2.75 2.76
$\text{He} + \text{e} \rightarrow \text{He}(4\text{S}\frac{1}{2})$	Adap [54]	23.706	23.706:-1	15%	RE	Fig. 2.75 2.76
$\text{He} + \text{e} \rightarrow \text{He}(4\text{P}\frac{1}{2})$	Adap [54]	23.74	23.74:-1	15%	RE	Fig. 2.75 2.76
$\text{He} + \text{e} \rightarrow \text{He}(4\text{D}\frac{5}{2})$	Adap [54]	23.77	23.77:-1	15%	RE	Fig. 2.75 2.76
$\text{He} + \text{e} \rightarrow \text{He}(4\text{D}\frac{3}{2})$	Adap [54]	23.77	23.77:-1	15%	RE	Fig. 2.75 2.76
$\text{He} + \text{e} \rightarrow \text{He}(4\text{F}\frac{5}{2})$	Adap [54]	23.77	23.77:-1	15%	RE	Fig. 2.75 2.76
$\text{He} + \text{e} \rightarrow \text{He}(4\text{F}\frac{3}{2})$	Adap [54]	23.77	23.77:-1	15%	RE	Fig. 2.75 2.76
$\text{He} + \text{e} \rightarrow \text{He}(4\text{P}\frac{3}{2})$	Adap [54]	23.77	23.77:-1	15%	RE	Fig. 2.75 2.76
$\text{He} + \text{e} \rightarrow \text{He}^{+}$	Adap [54]	24.6	24.6:-1	15%	RE	Fig. 2.75 2.76
$\text{He} + \text{e} \rightarrow \text{He}^{++}$	Adap [53]	79	79:-1	40%	RE	Fig. 2.75 2.76
$\text{He} + \text{e} \rightarrow \text{Elastic}$	Revi [67]	0	0:-1	30%	RUE	Fig. 2.75 2.76

Table 2.25: Recommended Cross section for e impact on He

## 2.7 Cross section of e impact with He

### 2.7.1 Inelastic Cross Sections

#### 2.7.2 Recommended data set

$\text{He} + \text{e} \rightarrow \text{He}(2\text{St})$

$\text{He} + \text{e} \rightarrow \text{He}(2\text{Ss})$

$\text{He} + \text{e} \rightarrow \text{He}(2\text{Pt})$

$\text{He} + \text{e} \rightarrow \text{He}(2\text{Ps})$

$\text{He} + \text{e} \rightarrow \text{He}(3\text{St})$

$\text{He} + \text{e} \rightarrow \text{He}(3\text{Ss})$

$\text{He} + \text{e} \rightarrow \text{He}(3\text{Pt})$

$\text{He} + \text{e} \rightarrow \text{He}(3\text{Dt})$

$\text{He} + \text{e} \rightarrow \text{He}(3\text{Ds})$

$\text{He} + \text{e} \rightarrow \text{He}(3\text{Ps})$

$\text{He} + \text{e} \rightarrow \text{He}(4\text{St})$

$\text{He} + \text{e} \rightarrow \text{He}(4\text{Ss})$

$\text{He} + \text{e} \rightarrow \text{He}(4\text{Pt})$

$\text{He} + \text{e} \rightarrow \text{He}(4\text{Dt})$

$\text{He} + \text{e} \rightarrow \text{He}(4\text{Ds})$

$\text{He} + \text{e} \rightarrow \text{He}(4\text{Ft})$

$\text{He} + \text{e} \rightarrow \text{He}(4\text{Fs})$

$\text{He} + \text{e} \rightarrow \text{He}(4\text{Ps})$

$\text{He} + \text{e} \rightarrow \text{He}+$

$\text{He} + \text{e} \rightarrow \text{He}++$

$\text{He} + \text{e} \rightarrow \text{Elastic}$

#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of

the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

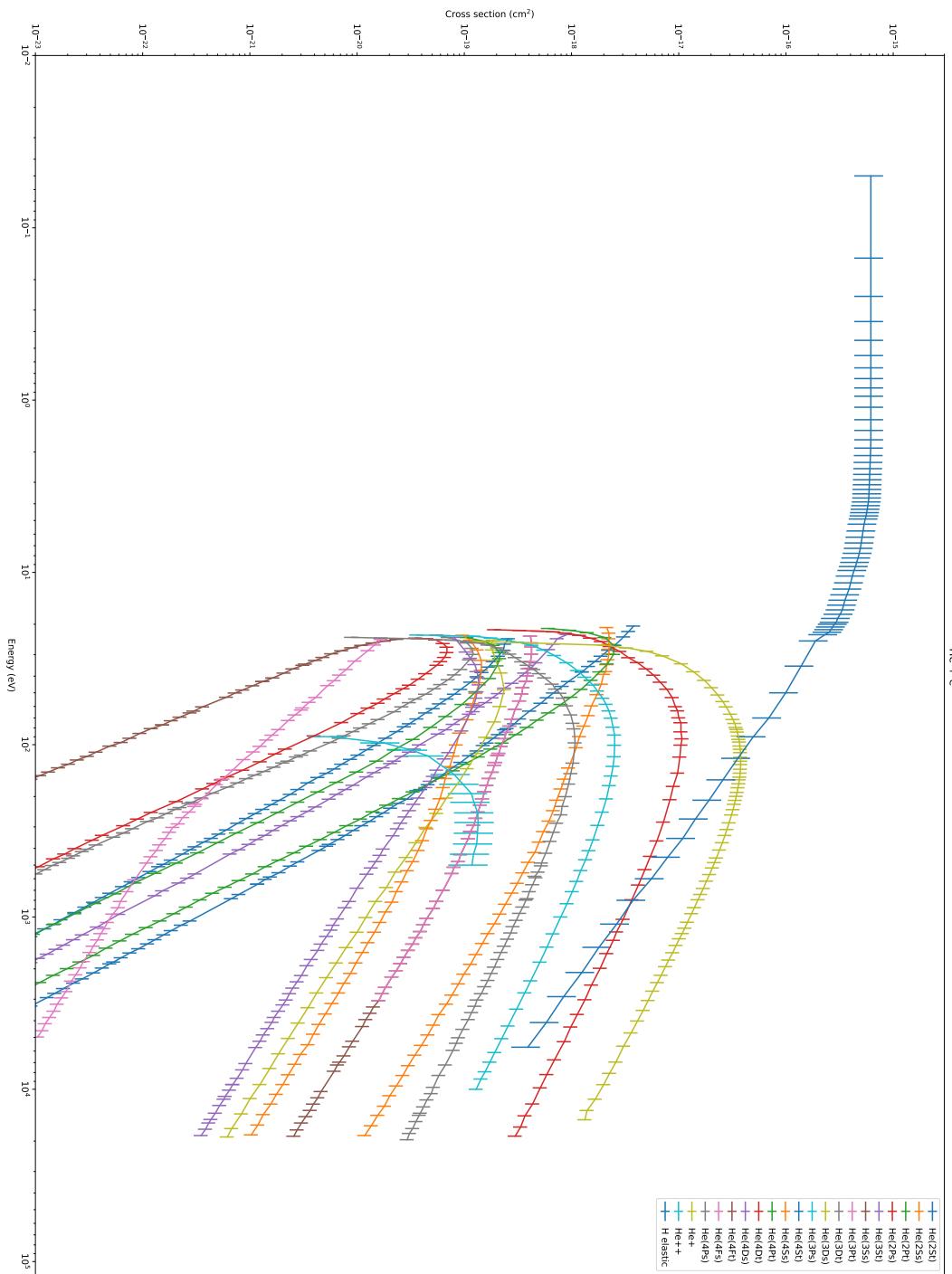


Figure 2.75: Cross sections for He + e

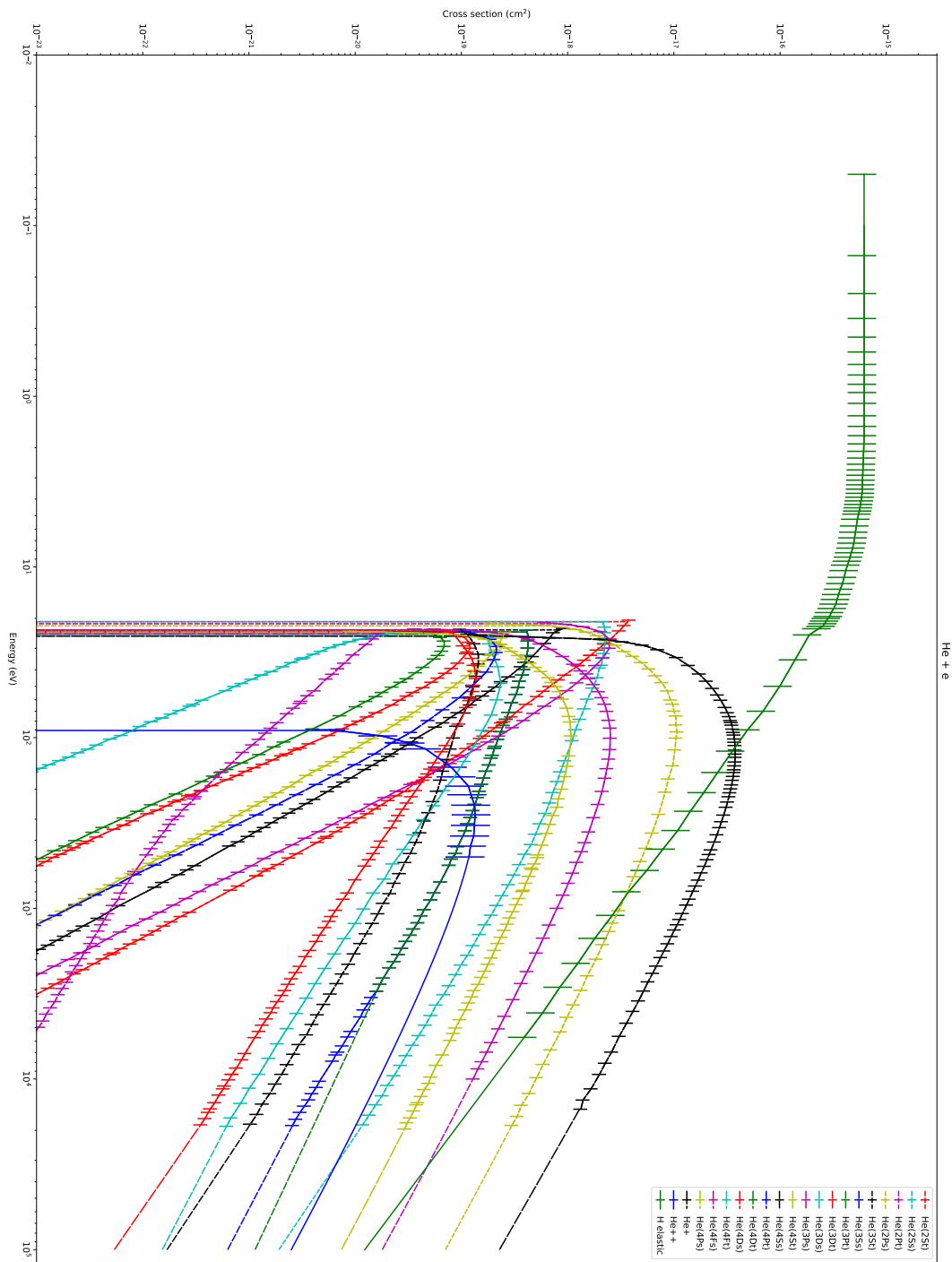
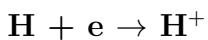


Figure 2.76: Cross sections for He + e (wavelength with extrapolation version)

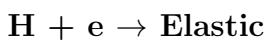
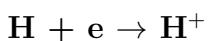
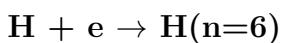
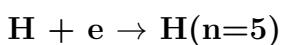
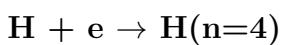
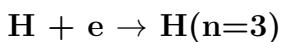
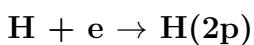
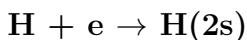
## 2.8 Cross section of e impact with H

### 2.8.1 Inelastic Cross Sections

#### Ionization Cross Sections



### 2.8.2 Recommended data set



#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$H + e \rightarrow H^+$	Revi [2] Meas [58]	13.6 13.6	13.6:-1 13.6:-1	15% 15%	RE E	Fig. 2.77 Fig. 2.77

Table 2.26: Ionization Cross section for e impact on H

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
H + e → H(2s)	Adap [30]	10.1988	10.1988:-1	50%	RE	Fig. 2.78 2.79
H + e → H(2p)	Meas James 1997	10.1988	10.1988:-1	10%	RE	Fig. 2.78 2.79
H + e → H(n=3)	Adap [30]	12.0875	12.0875:-1	50%	RE	Fig. 2.78 2.79
H + e → H(n=4)	Adap [30]	12.7485	12.7485:-1	50%	RE	Fig. 2.78 2.79
H + e → H(n=5)	Adap [30]	13.0545	13.0545:-1	50%	RE	Fig. 2.78 2.79
H + e → H(n=6)	Adap [30]	13.2207	13.2207:-1	50%	RE	Fig. 2.78 2.79
H + e → H <sup>+</sup>	Revi [2]	13.6	13.6:-1	15%	RE	Fig. 2.78 2.79
H + e → Elastic	Revi [67]	0	0:-1	<b>30%</b>	RUE	Fig. 2.78 2.79

Table 2.27: Recommended Cross section for e impact on H

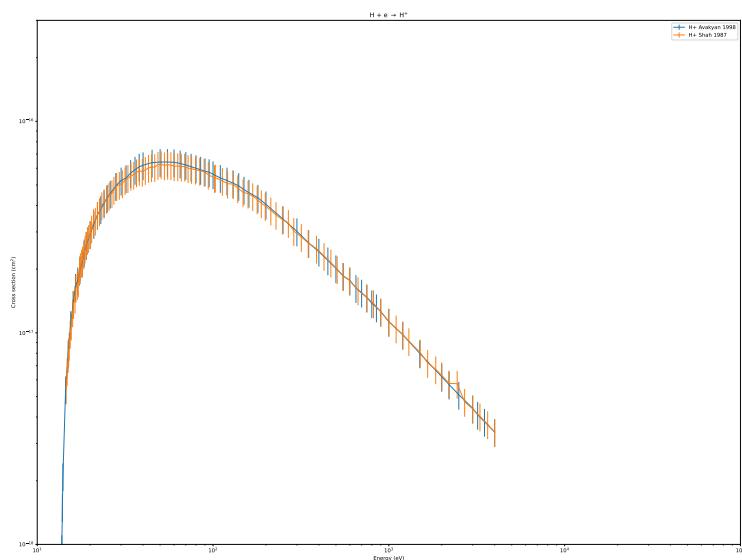
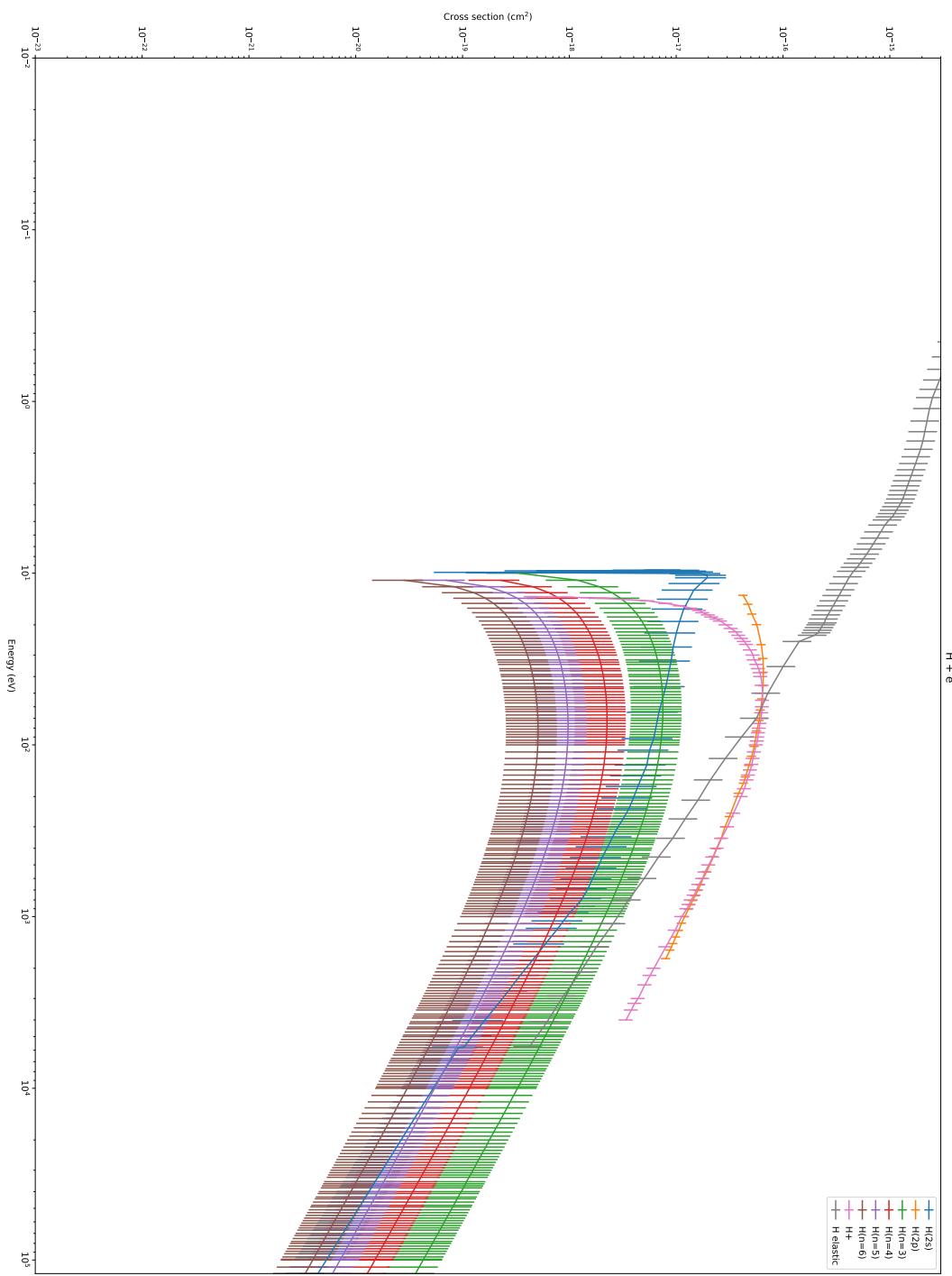


Figure 2.77: Cross sections for  $H + e \rightarrow H^+$

Figure 2.78: Cross sections for  $H + e$

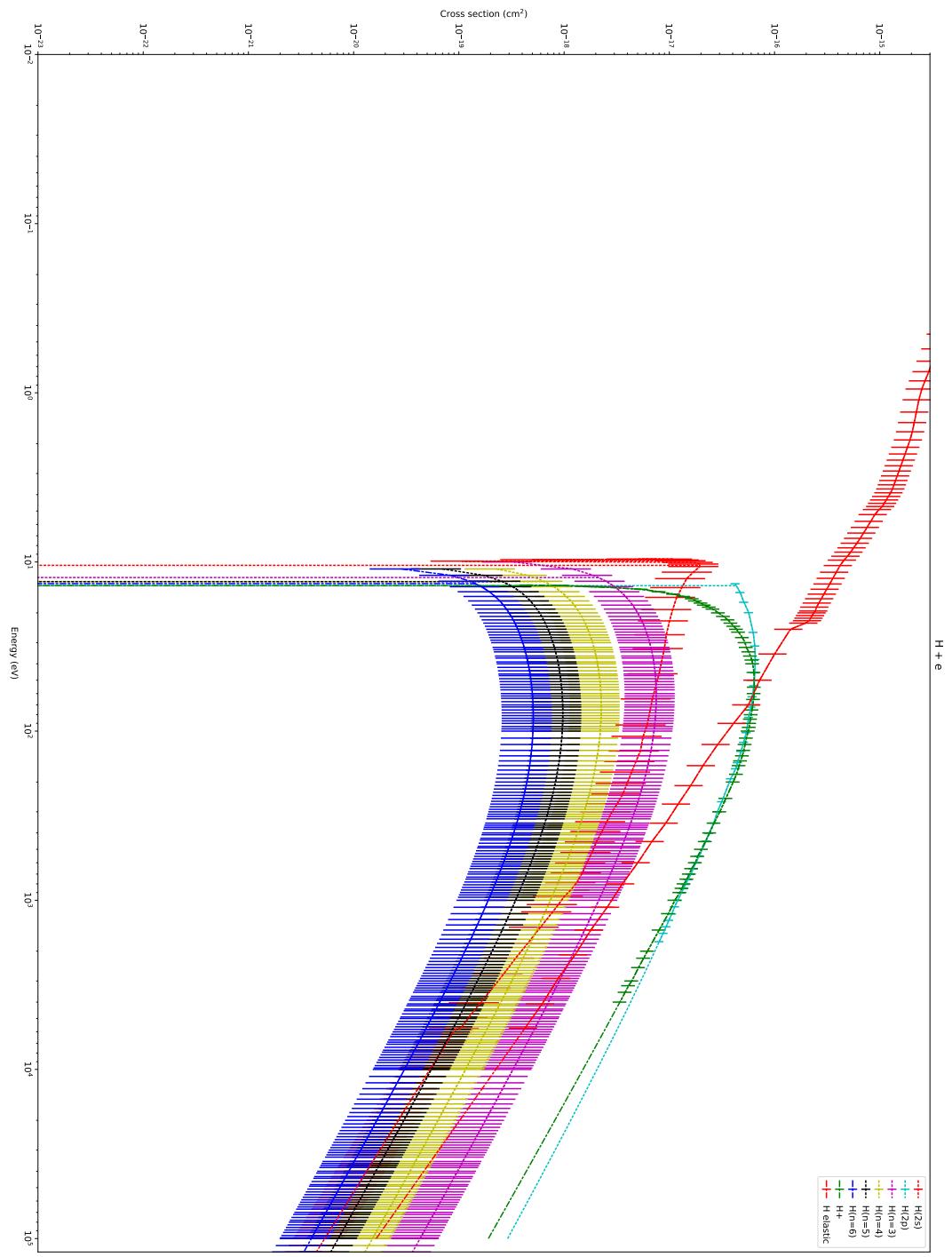


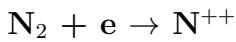
Figure 2.79: Cross sections for  $H + e$  (wavelength with extrapolation version)

## 2.9 Cross section of e impact with N<sub>2</sub>

### 2.9.1 Elastic Cross Section

### 2.9.2 Inelastic Cross Sections

#### Ionization Cross Sections



**Notes for N<sub>2</sub><sup>++</sup> K-Shell ionization, Frémont + [68]** The K-Shell ionization of N<sub>2</sub> by electron impact has been studied in [13]. The ratio K-shell/simple ionization has been taken in that paper. The total cross section has been computed by multiplying this ratio by the recommended ionization cross section, coming from [68].

Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi BDD	0	0:-1	??%	U	Fig. 2.81
Revi [29]	0	0:-1	20%		Fig. 2.81
Revi [68] + [69]	0	0.0514 : 5220.0	20%	E	Fig. 2.81
Adap [28]+[68]	0	0:-1	20%	RUE	Fig. 2.81

Table 2.28: Elastic cross section for e impact on N<sub>2</sub>

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
N <sub>2</sub> + e → N++	Revi [29] Meas [8] Revi [68] Adap [8] + [68]	70 70 53.900000 70	70:-1 70:-1 70.0 : 1000.0 70:-1	6% 6% 10% <b>6%</b>	E RUE	Fig. 2.80 Fig. 2.80 Fig. 2.80 Fig. 2.80
N <sub>2</sub> + e → N <sub>2</sub> ++(Auger)	Adap [13] + [68]	400	400:-1	<b>50%</b>	RUE	Fig. 2.82
N <sub>2</sub> + e → N <sup>+</sup>	Revi [29] Meas [8] Revi [68] Adap [8] + [68]	30 30 24.300000 30	30:-1 30:-1 30.0 : 1000.0 30:-1	5% 5% 8% <b>5%</b>	E RUE	Fig. 2.84 Fig. 2.84 Fig. 2.84 Fig. 2.84
N <sub>2</sub> + e → N <sub>2</sub> ++	Revi BDD Adap [8]	43.0 43	43.0:-1 43:-1	?%?% <b>50%</b>	U RUE	Fig. 2.85 Fig. 2.85
N <sub>2</sub> + e → N <sub>2</sub> <sup>+</sup>	Revi [68] + [69] Revi [29] Revi BDD Meas [8] Adap [8] + [68]	15.600000 15.580 15.58 15.58 15.58	17.0 : 1000.0 15.580:-1 15.58:-1 15.58:-1 15.58:-1	7% 5% ????% 5% <b>5%</b>	E U RUE	Fig. 2.86 Fig. 2.86 Fig. 2.86 Fig. 2.86 Fig. 2.86

Table 2.29: Ionization Cross section for e impact on N<sub>2</sub>

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$N_2 + e \rightarrow 2*N$	Revi [68]	9.760000	12.0 : 200.0	25%	E	Fig. 2.88
	Revi [68]	9.760000	12.0 : 200.0	25%	E	Fig. 2.89
	Revi [29]	12	12:-1	25%		Fig. 2.89
	Adap [28]+[68]	12	12:-1	25%	RUE	Fig. 2.89
$N_2 + e \rightarrow vib$	Revi [68]	9.760000	12.0 : 200.0	25%	E	Fig. 2.88

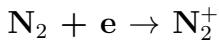
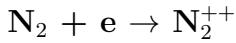
Table 2.30: Dissociation Cross section for e impact on  $N_2$

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
N <sub>2</sub> + e → N <sub>2</sub> (a'1S <sub>u</sub> -)	Revi [68]	8.400000	11.0 : 1000.0	50%	E	Fig. 2.83
	Revi [29]	8.399	8.399:-1	33%		Fig. 2.83
	Adap [28]+ [68]	8.399	8.399:-1	33% 33%	RUE	Fig. 2.83
N <sub>2</sub> + e → N <sub>2</sub> (vib)	Revi [29]	0.5	0.5:-1	???%	U	Fig. 2.88
N <sub>2</sub> + e → N <sub>2</sub> (vib) shirai	Revi [68]	.290000	1.05 : 48.5	25%	E	Fig. 2.88

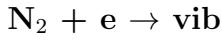
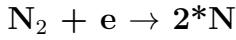
Table 2.31: Excitation Cross section for e impact on N<sub>2</sub>

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$N_2 + e \rightarrow N_2(391.4)$	Revi [28] Revi [69]	18 18.800000	18:-1 19.0 : 10000.0	15% <b>20%</b>	U	Fig. 2.87 Fig. 2.87
$N_2 + e \rightarrow N_2(427.8)$	Revi [69]	18.800000	20.5 : 399.0	<b>20%</b>	U	Fig. 2.87
$N_2 + e \rightarrow N_2(470.9)$	Revi [69]	18.800000	20.5 : 399.0	<b>20%</b>	U	Fig. 2.87
$N_2 + e \rightarrow N_2(358.2)$	Revi [69]	19.000000	29.2 : 400.0	<b>20%</b>	U	Fig. 2.87

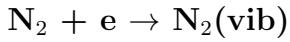
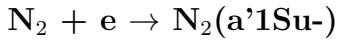
Table 2.32: Emission Cross section for e impact on  $N_2$



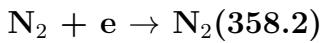
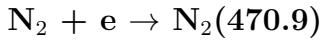
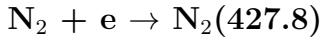
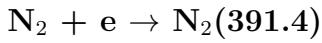
### Dissociation Cross Sections



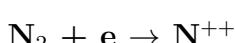
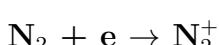
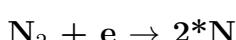
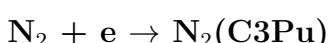
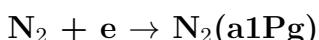
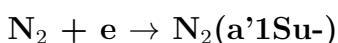
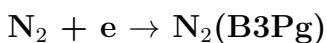
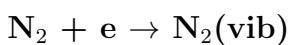
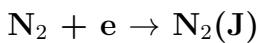
### Excitation Cross Sections



### 2.9.3 Emission Cross Sections



### 2.9.4 Recommended data set



## CHAPTER 2. ELECTRON IMPACT

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$N_2 + e \rightarrow N_2(J)$	Revi [29]	0.0015	0.0015:-1	20%		Fig. 2.90 2.91
$N_2 + e \rightarrow N_2(vib)$	Adap [29] + correction for extrapolation	0.5	0.5:-1	??%	U	Fig. 2.90 2.91
$N_2 + e \rightarrow N_2(A3Su+)$	Revi [29]	6.169	6.169:-1	35%		Fig. 2.90 2.91
$N_2 + e \rightarrow N_2(B3Pg)$	Revi [29]	7.353	7.353:-1	35%		Fig. 2.90 2.91
$N_2 + e \rightarrow N_2(W3Di)$	Revi [29]	7.362	7.362:-1	40%		Fig. 2.90 2.91
$N_2 + e \rightarrow N_2(B'3St)$	Revi [29]	8.165	8.165:-1	30%		Fig. 2.90 2.91
$N_2 + e \rightarrow N_2(a'1Su)$	Adap [28]+ [68]	8.399	8.399:-1	33%	RUE	Fig. 2.90 2.91
$N_2 + e \rightarrow N_2(a1Pg)$	Revi [29]	8.549	8.549:-1	25%		Fig. 2.90 2.91
$N_2 + e \rightarrow N_2(W1Di)$	Revi [29]	8.890	8.890:-1	33%		Fig. 2.90 2.91
$N_2 + e \rightarrow N_2(C3Pu)$	Revi [29]	11.032	11.032:-1	33%		Fig. 2.90 2.91
$N_2 + e \rightarrow N_2(E3Sg+)$	Revi [29]	11.875	11.875:-1	40%		Fig. 2.90 2.91
$N_2 + e \rightarrow N_2(a'1Sg+)$	Revi [29]	12.255	12.255:-1	33%		Fig. 2.90 2.91
$N_2 + e \rightarrow 2^*N$	Adap [28]+ [68]	12	12:-1	25%	RUE	Fig. 2.90 2.91
$N_2 + e \rightarrow N_2^+$	Adap [8] + [68]	15.58	15.58:-1	5%	RUE	Fig. 2.90 2.91
$N_2 + e \rightarrow N^+$	Adap [8] + [68]	30	30:-1	5%	RUE	Fig. 2.90 2.91
$N_2 + e \rightarrow N^{++}$	Adap [8] + [68]	70	70:-1	6%	RUE	Fig. 2.90 2.91
$N_2 + e \rightarrow N_2^{++}$	Revi BDD	43.0	43.0:-1	50%		Fig. 2.90 2.91
$N_2 + e \rightarrow N_2^{++}(Auger)$	Adap [13] + [68]	400	400:-1	50%	RUE	Fig. 2.90 2.91
$N_2 + e \rightarrow N_2(3914)$	Revi [29] Revi [69]	18 18.800000	18:-1 19.0 : 10000.0	??% 20%	U U	Fig. 2.90 2.91 Fig. 2.90 2.91
$N_2 + e \rightarrow N_2(427.8)$	Revi [69]	18.800000	20.5 : 399.0	20%	U	Fig. 2.90 2.91
$N_2 + e \rightarrow N_2(\alpha-X)$	Revi [29]	10	10:-1	??%	U	Fig. 2.90 2.91
$N_2 + e \rightarrow N_2(C-B)$	Revi [29]	10	10:-1	??%	U	Fig. 2.90 2.91
$N_2 + e \rightarrow N_2(c'4-X)$	Adap [29] + corrected for extrapolation	10	10:-1	??%	U	Fig. 2.90 2.91
$N_2 + e \rightarrow N_2(113.4)$	Revi [29]	60	60:-1	??%	U	Fig. 2.90 2.91
$N_2 + e \rightarrow N(120nm)$	Revi [29]	50	50:-1	??%	U	Fig. 2.90 2.91
$N_2 + e \rightarrow N(124.3)$	Adap [29] + correction for extrapolation	50	50:-1	??%	U	Fig. 2.90 2.91
$N_2 + e \rightarrow N(149.4)$	Revi [29]	50	50:-1	??%	U	Fig. 2.90 2.91
$N_2 + e \rightarrow N(108.4)$	Adap [29] + correction for extrapolation	50	50:-1	??%	U	Fig. 2.90 2.91
$N_2 + e \rightarrow \text{Elastic}$	Adap [28]+ [68]	0	0:-1	20%	RUE	Fig. 2.90 2.91

Table 2.33: Recommended Cross section for e impact on  $N_2$

the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

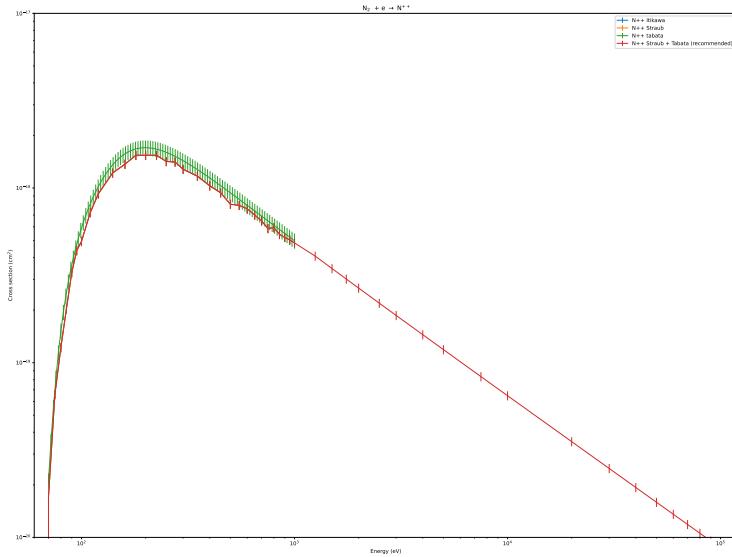


Figure 2.80: Cross sections for  $N_2 + e \rightarrow N^{++}$

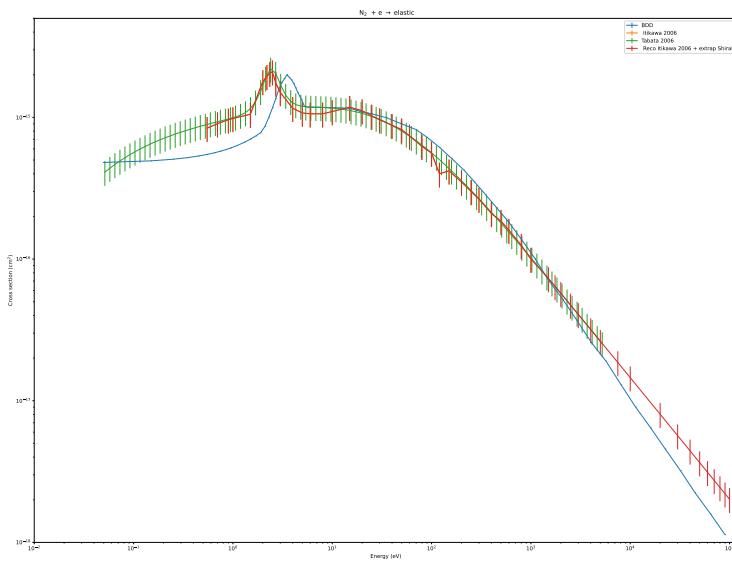
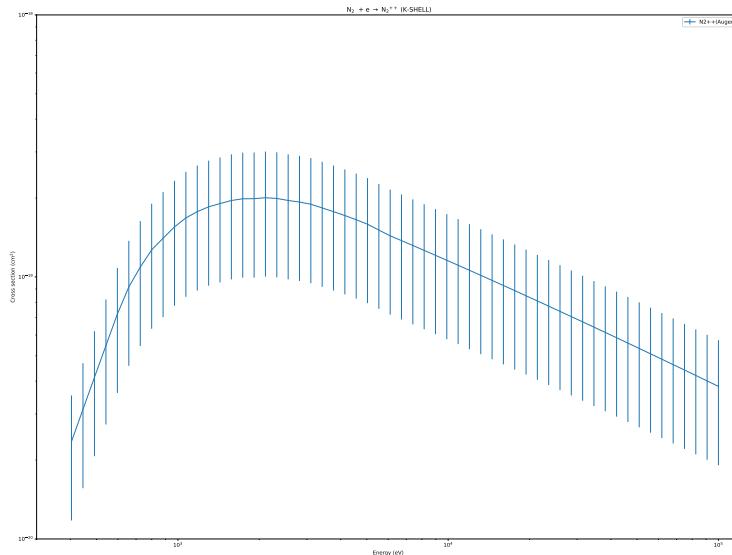
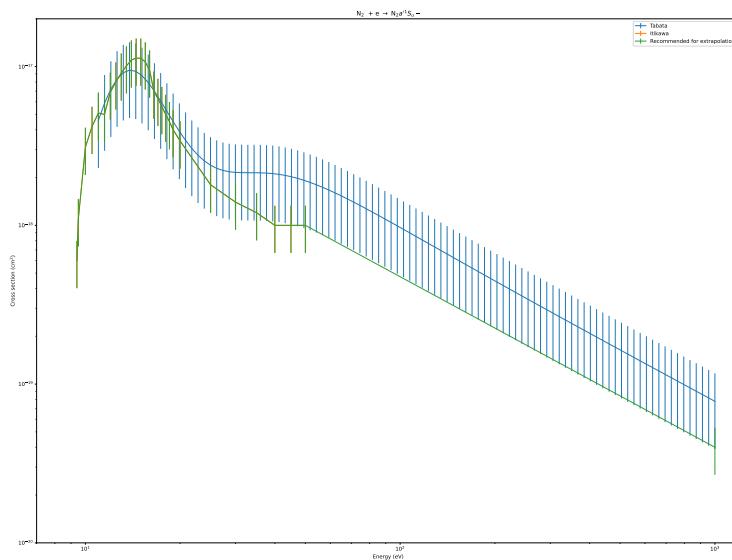


Figure 2.81: Cross sections for  $N_2 + e \rightarrow \text{elastic}$

Figure 2.82: Cross sections for  $N_2 + e \rightarrow N_2^{++}$  (K-SHELL)Figure 2.83: Cross sections for  $N_2 + e \rightarrow N_2 a' ^1 S_u -$

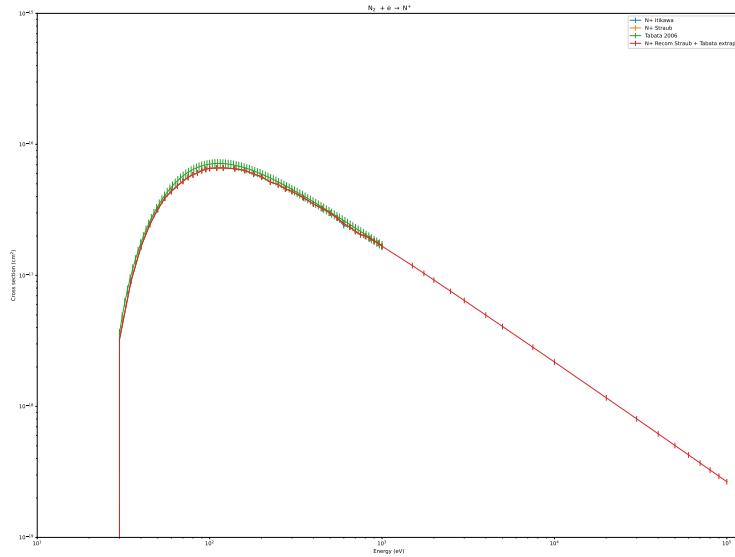


Figure 2.84: Cross sections for  $N_2 + e \rightarrow N^+$

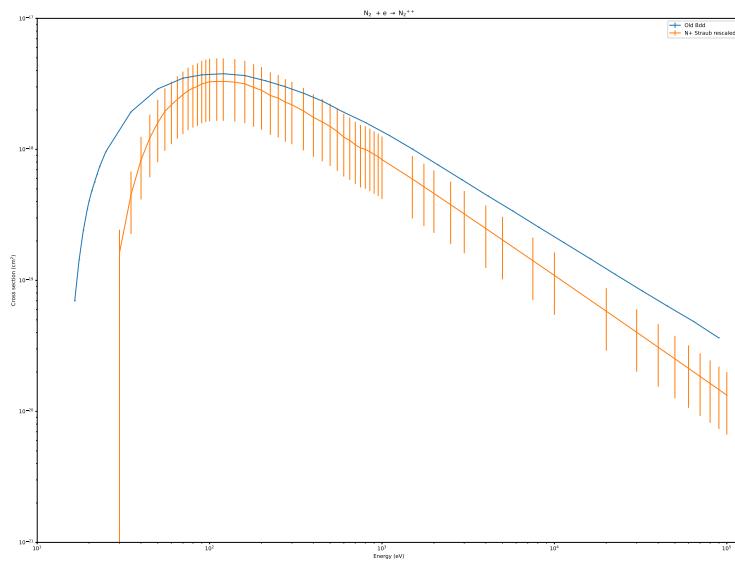
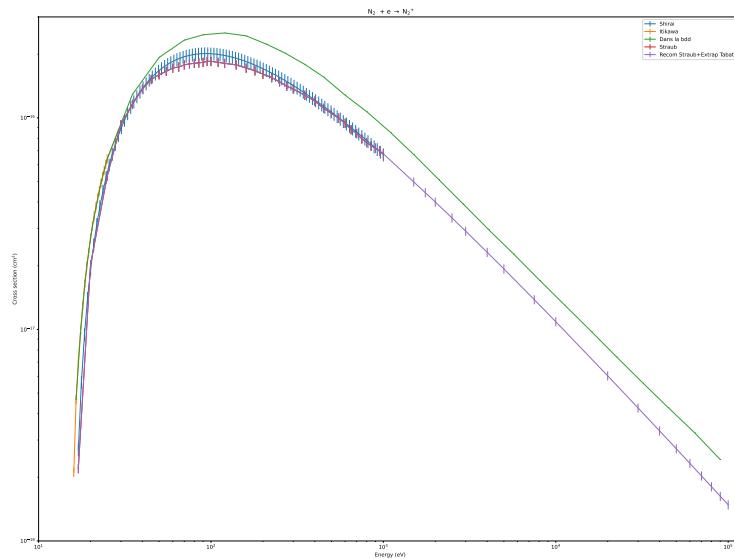
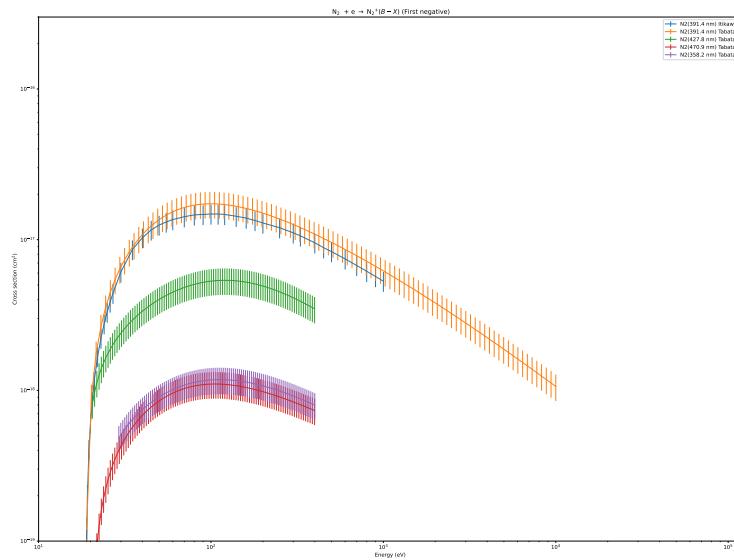


Figure 2.85: Cross sections for  $N_2 + e \rightarrow N_2^{++}$

Figure 2.86: Cross sections for  $N_2 + e \rightarrow N_2^+$ Figure 2.87: Cross sections for  $N_2 + e \rightarrow N_2^+(B-X)$  (First negative)

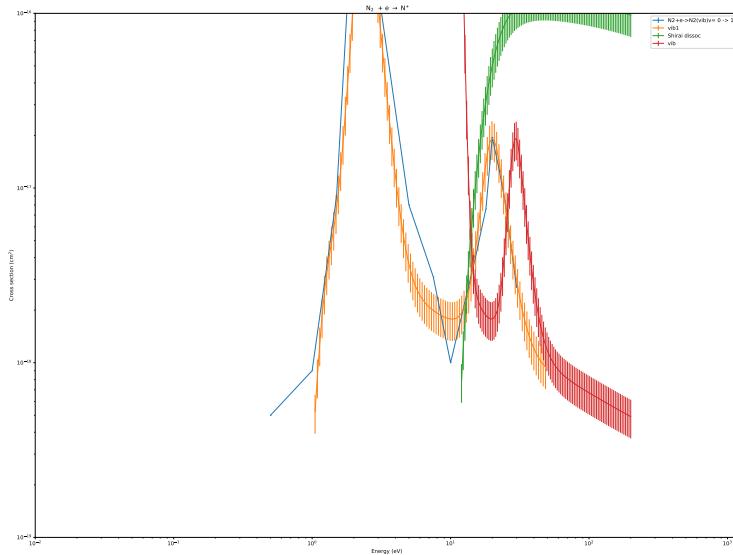


Figure 2.88: Cross sections for  $\text{N}_2 + \text{e} \rightarrow \text{N}^+$

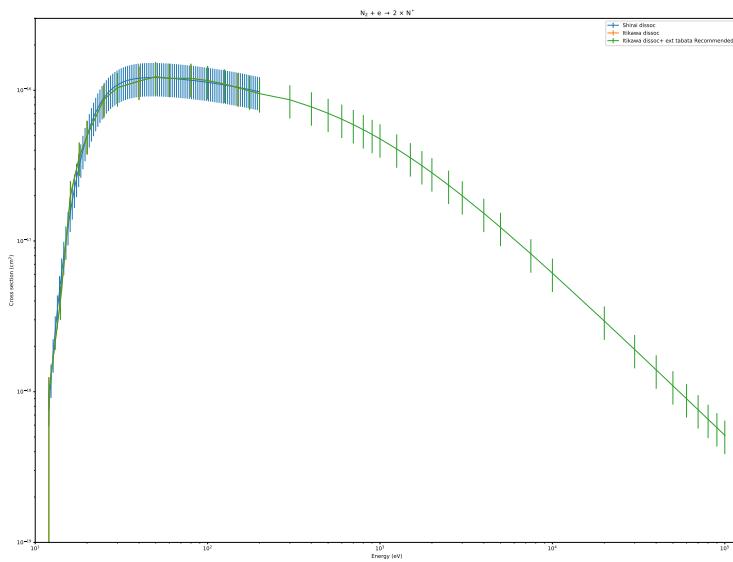


Figure 2.89: Cross sections for  $\text{N}_2 + \text{e} \rightarrow 2 \times \text{N}^*$

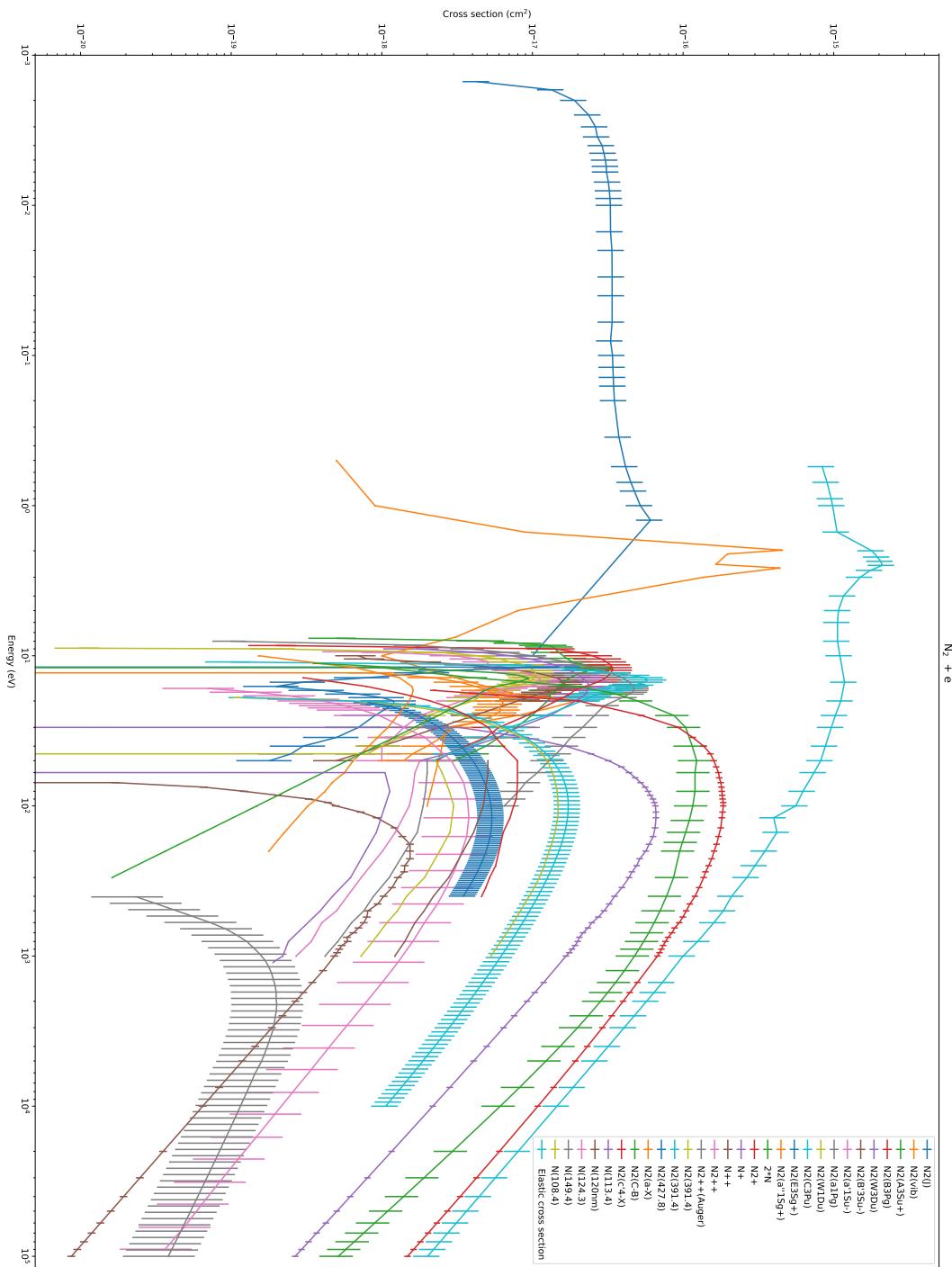


Figure 2.90: Cross sections for  $\text{N}_2 + \text{e}$

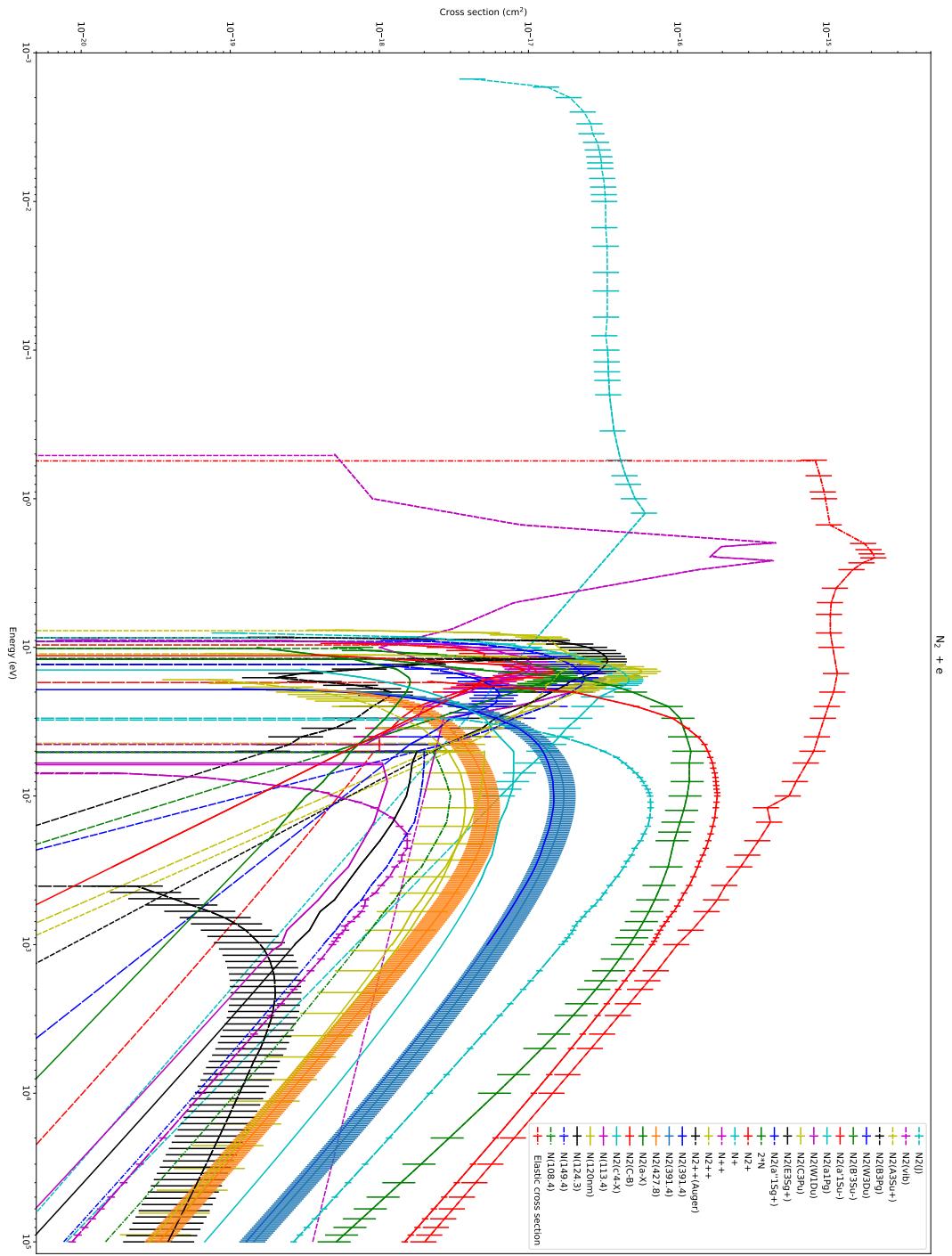


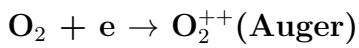
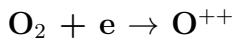
Figure 2.91: Cross sections for  $\text{N}_2 + \text{e}$  (wavelength with extrapolation version)

## 2.10 Cross section of e impact with O<sub>2</sub>

### 2.10.1 Elastic Cross Section

### 2.10.2 Inelastic Cross Sections

#### Ionization Cross Sections



**Notes for O<sub>2</sub><sup>++</sup> K-Shell ionization, Frémont 2006 + Straub2004** The K-Shell ionization of O by electron impact has not been studied in [13], but we assumed that the K-Shell/single ionization ratio is close to the O<sub>2</sub> one which is used here. The total cross section has been computed by multiplying this ratio by the recommended ionization cross section, coming from [8].

Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi [29]	0	0:-1	20%	R	Fig. 2.97
Revi BDD	0	0:-1	???	U	Fig. 2.97

Table 2.34: Elastic cross section for e impact on O<sub>2</sub>

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$O_2 + e \rightarrow O^{++}$	Meas [8]	73.	73.:-1	6%	RU	Fig. 2.96
	Revi [29]	73.	73.:-1	6%		Fig. 2.96
	Adap [8]	73.	73.:-1	6%		Fig. 2.96
$O_2 + e \rightarrow O_2^{++} (\text{Auger})$	Adap [13] + [8]	539	539:-1	20%	RUE	Fig. 2.98
	Meas [8]	23.	23.:-1	5%		Fig. 2.99
	Adap [8]	23.	23.:-1	5%		Fig. 2.99
	Revi [29]	23.	23.:-1	5%		Fig. 2.99
$O_2 + e \rightarrow O^+$	Revi BDD	23.	23.:-1	???%	U	Fig. 2.99
	Revi BDD	36.13	36.13:-1	???%		Fig. 2.100
	Adap [8]	36.13	36.13:-1	40%		Fig. 2.100
	Adap [8]	36.13	36.13:-1	40%		Fig. 2.100
$O_2 + e \rightarrow O_2^+$	Revi [29]	12.8	12.8:-1	5%	R	Fig. 2.101
	Meas [8]	12.8	12.8:-1	5%		Fig. 2.101
	Revi BDD	12.8	12.8:-1	???%		Fig. 2.101

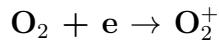
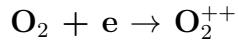
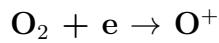
Table 2.35: Ionization Cross section for e impact on  $O_2$

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$O_2 + e \rightarrow 2 O(^*)$	Revi [29]	13	13:-1	34%		Fig. 2.92

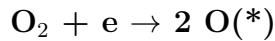
Table 2.36: Dissociation Cross section for e impact on  $O_2$

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$O_2 + e \rightarrow B3Su$	Revi [29] Revi [29]	6.120 6.120	6.120:-1 6.120:-1	20% 20%		Fig. 2.94 Fig. 2.94
$O_2 + e \rightarrow B3Su - LB$	Revi [29] Revi [29]	6.120 6.120	6.120:-1 6.120:-1	20% 20%		Fig. 2.94 Fig. 2.94
$O_2 + e \rightarrow B3Su - 2B$	Revi [29] Revi [29]	6.120 6.120	6.120:-1 6.120:-1	23% 23%		Fig. 2.94 Fig. 2.94
$O_2 + e \rightarrow O_2(B3Su)$	Revi [64]	8.4	8.4:-1	30% %	U	Fig. 2.94
$O_2 + e \rightarrow O_2(9.9)$	Revi [64]	9.9	9.9:-1	30% %	U	Fig. 2.94
$O_2 + e \rightarrow v1$	Revi [29]	0.3	0.3:-1	????%	U	Fig. 2.102
$O_2 + e \rightarrow v2$	Revi [29]	0.3	0.3:-1	????%	U	Fig. 2.102
$O_2 + e \rightarrow v3$	Revi [29]	6	6:-1	????%	U	Fig. 2.102
$O_2 + e \rightarrow O_2(vib0-3)$	Revi BDD	0.3	0.3:-1	????%	U	Fig. 2.102
$O_2 + e \rightarrow O_2(vib3-4)$	Revi ? BDD	.630	.630:-1	????%	U	Fig. 2.102

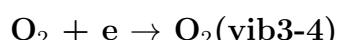
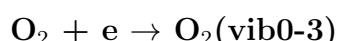
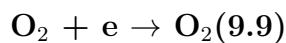
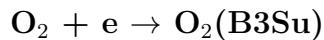
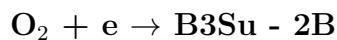
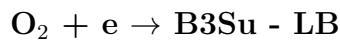
Table 2.37: Excitation Cross section for e impact on  $O_2$



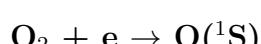
### Dissociation Cross Sections



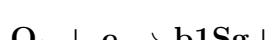
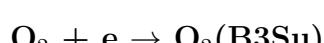
### Excitation Cross Sections



### 2.10.3 Emission Cross Sections



### 2.10.4 Recommended data set



Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$O_2 + e \rightarrow O_2^+$	Revi [29]	19	19:-1	24%	RE	Fig. 2.93
	Revi [29]	18	18:-1	24%		Fig. 2.95
$O_2 + e \rightarrow O(^1S)$	Meas [39]	16.	16.:-1	18%	Fig. 2.103	
$O_2 + e \rightarrow 777.4\text{nm}$	Meas [11]	19	19:-1	15%	Fig. 2.104	

Table 2.38: Emission Cross section for e impact on  $O_2$

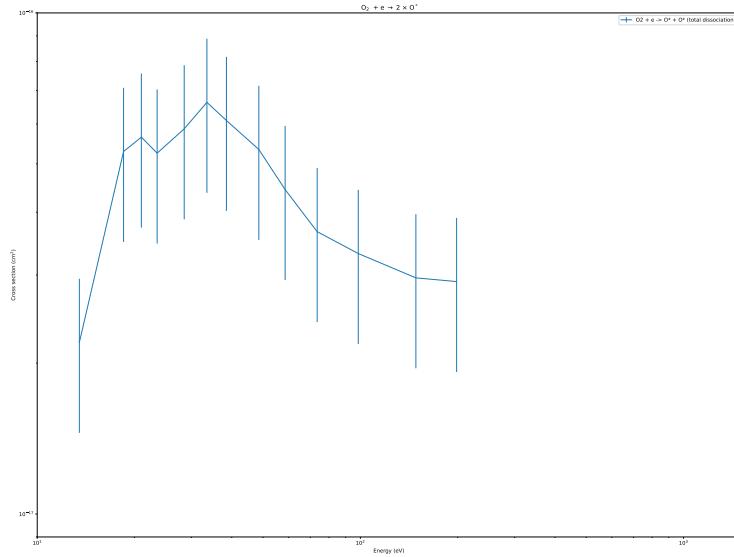
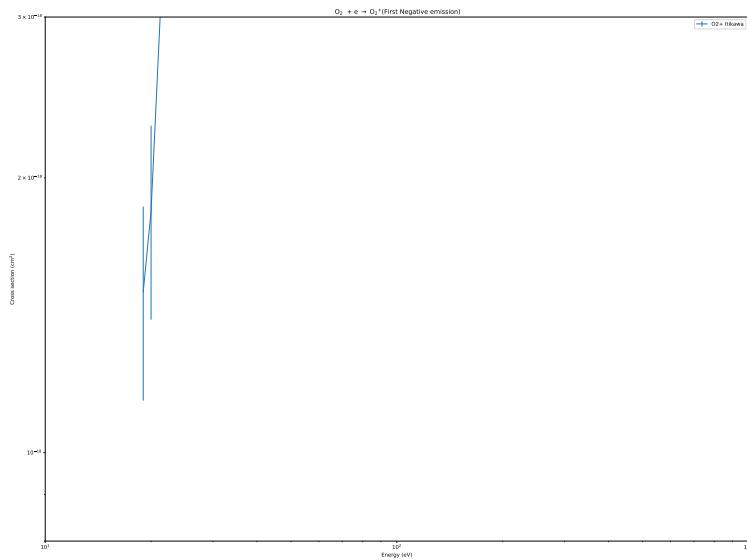
Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$O_2 + e \rightarrow v1$	Revi [29]	0.3	0.3:-1	??%	U	Fig. 2.105 2.106
$O_2 + e \rightarrow O_2^-(B3Su)$	Revi [64]	8.4	8.4:-1	30%	U	Fig. 2.105 2.106
$O_2 + e \rightarrow O_2(9.9)$	Revi [64]	9.9	9.9:-1	30%	U	Fig. 2.105 2.106
$O_2 + e \rightarrow v2$	Revi [29]	0.3	0.3:-1	??%	U	Fig. 2.105 2.106
$O_2 + e \rightarrow v3$	Revi [29]	6	6:-1	??%	U	Fig. 2.105 2.106
$O_2 + e \rightarrow A1D_g$	Revi [29]	0.977	0.977:-1	16%	U	Fig. 2.105 2.106
$O_2 + e \rightarrow b1S_g^+$	Revi [29] + addition for extrapolation	1.627	1.627:-1	18%	Fig. 2.105 2.106	Fig. 2.105 2.106
$O_2 + e \rightarrow A3Su$ A '3Du c1Su	Revi [29]	4.2	4.2:-1	50%	Fig. 2.105 2.106	Fig. 2.105 2.106
$O_2 + e \rightarrow B3Su$	Revi [29]	6.120	6.120:-1	20%	Fig. 2.105 2.106	Fig. 2.105 2.106
$O_2 + e \rightarrow B3Su - LB$	Revi [29]	6.120	6.120:-1	20%	Fig. 2.105 2.106	Fig. 2.105 2.106
$O_2 + e \rightarrow B3Su - 2B$	Revi [29]	6.120	6.120:-1	23%	Fig. 2.105 2.106	Fig. 2.105 2.106
$O_2 + e \rightarrow 2 O(^*)$	Revi [29]	13	13:-1	34%	Fig. 2.105 2.106	Fig. 2.105 2.106
$O_2 + e \rightarrow O_2^+$	Meas [8]	12.8	12.8:-1	5%	R	Fig. 2.105 2.106
$O_2 + e \rightarrow O_2^+$	Adap [8]	23.	23:-1	5%	RU	Fig. 2.105 2.106
$O_2 + e \rightarrow O^{++}$	Adap [8]	73.	73:-1	6%	RU	Fig. 2.105 2.106
$O_2 + e \rightarrow O_2^{++}$	Adap [8]	36.13	36.13:-1	40%	Fig. 2.105 2.106	Fig. 2.105 2.106
$O_2 + e \rightarrow O_2^{++}$ (Ainger)	Adap [13] + [8]	539	539:-1	20%	RUE	Fig. 2.105 2.106
$O_2 + e \rightarrow O_2^+(B4Sg)$	Revi [29]	18	18:-1	24%	Fig. 2.105 2.106	Fig. 2.105 2.106
$O_2 + e \rightarrow O_2^+(A2Pu)$	Revi [29]	18	18:-1	24%	Fig. 2.105 2.106	Fig. 2.105 2.106
$O_2 + e \rightarrow O_2^1S$	Meas [39]	16.	16:-1	18%	RE	Fig. 2.105 2.106
$O_2 + e \rightarrow 777.4nm$	Meas [11]	19	19:-1	15%	Fig. 2.105 2.106	Fig. 2.105 2.106
$O_2 + e \rightarrow$ Elastic	Revi [29]	0	0:-1	20%	R	Fig. 2.105 2.106

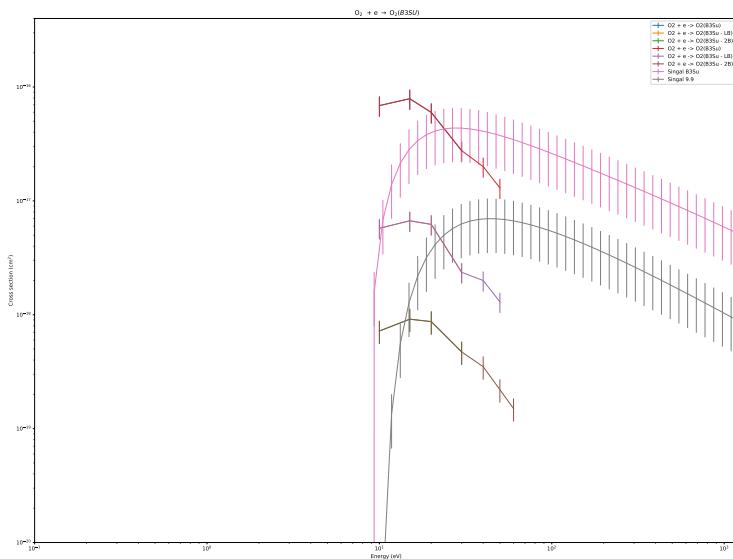
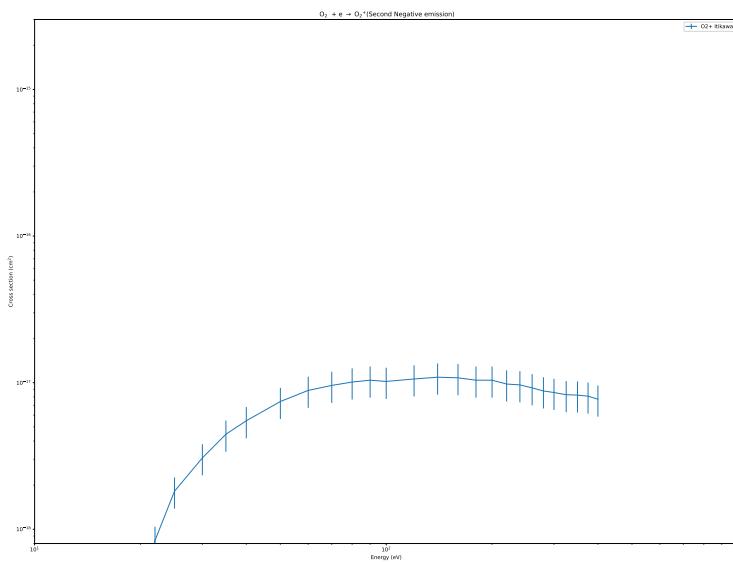
Table 2.39: Recommended Cross section for e impact on  $O_2$

the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections – Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Figure 2.92: Cross sections for  $O_2 + e \rightarrow 2 \times O^*$ Figure 2.93: Cross sections for  $O_2 + e \rightarrow O_2^+$  (First Negative emission)

Figure 2.94: Cross sections for  $O_2 + e \rightarrow O_2(B3SU)$ Figure 2.95: Cross sections for  $O_2 + e \rightarrow O_2^+(Second Negative emission)$

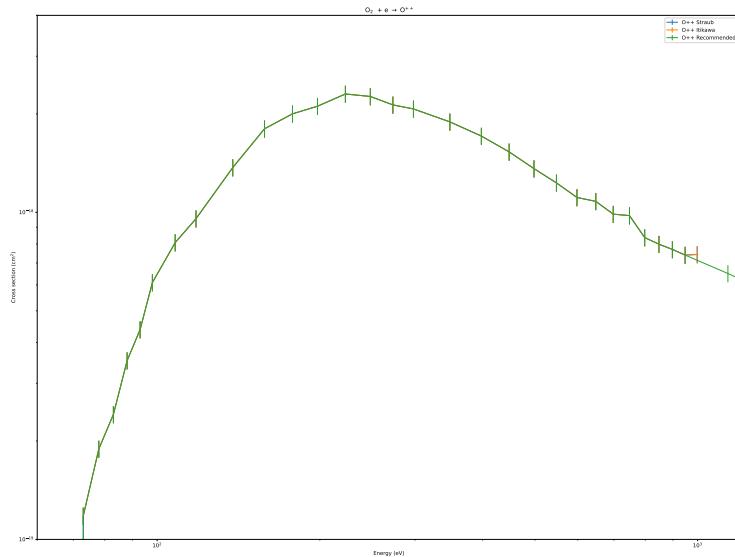


Figure 2.96: Cross sections for  $O_2 + e \rightarrow O^{++}$

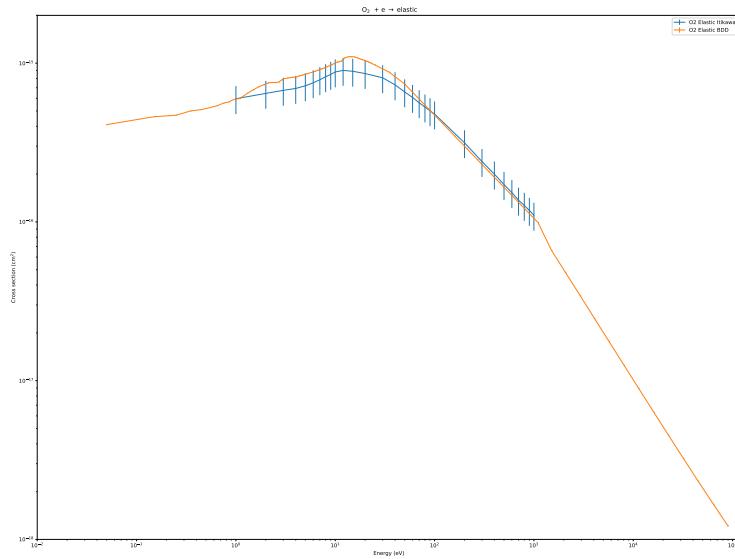
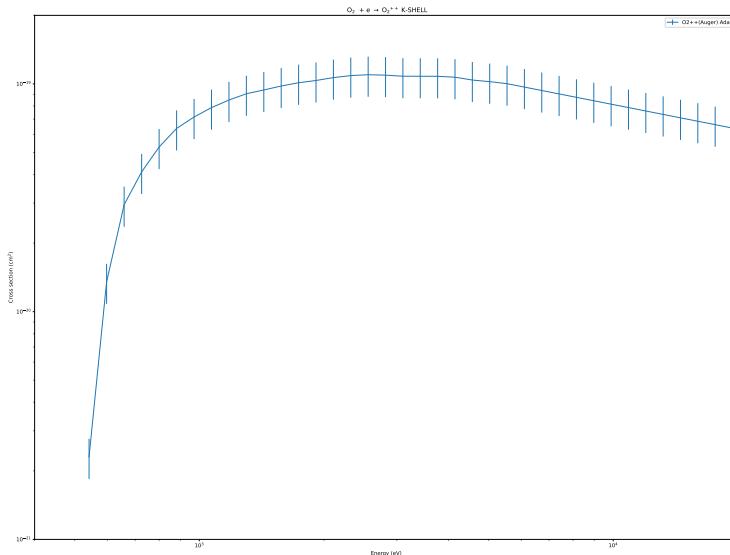
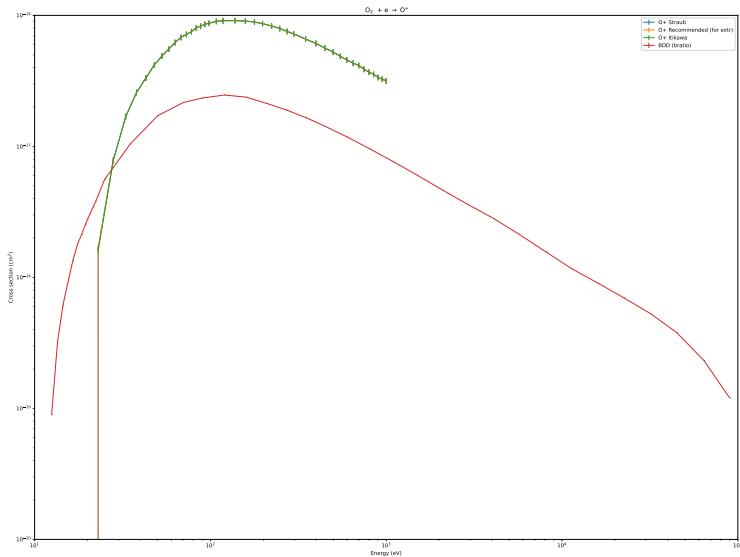


Figure 2.97: Cross sections for  $O_2 + e \rightarrow$  elastic

Figure 2.98: Cross sections for  $O_2 + e \rightarrow O_2^{++}$  K-SHELLFigure 2.99: Cross sections for  $O_2 + e \rightarrow O^+$

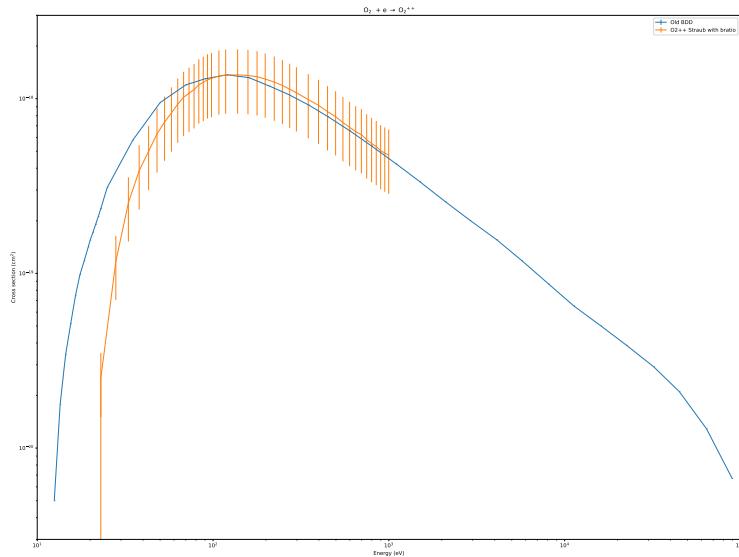


Figure 2.100: Cross sections for  $O_2 + e \rightarrow O_2^{++}$

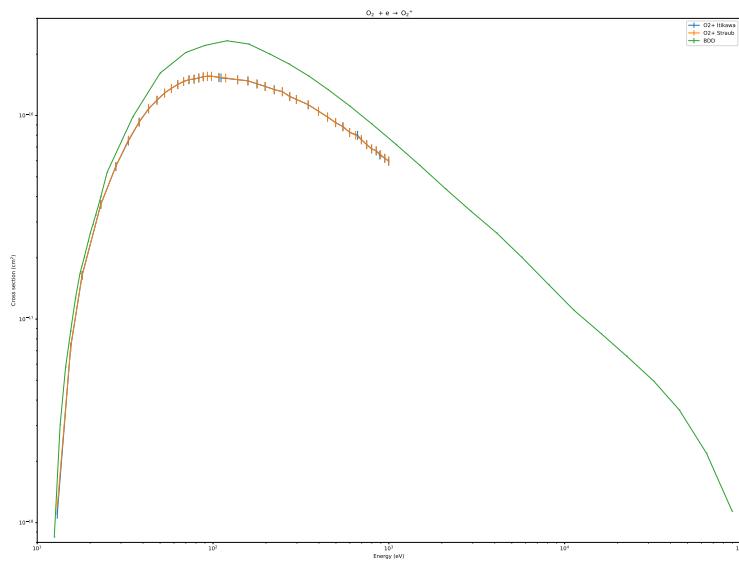
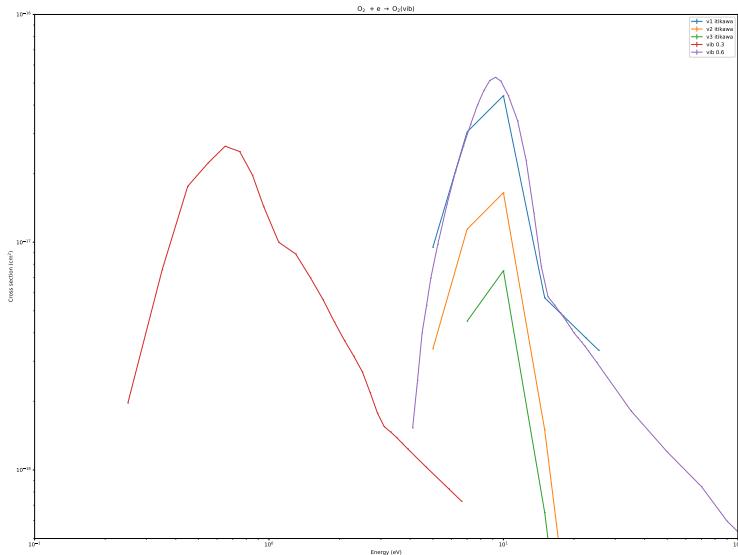
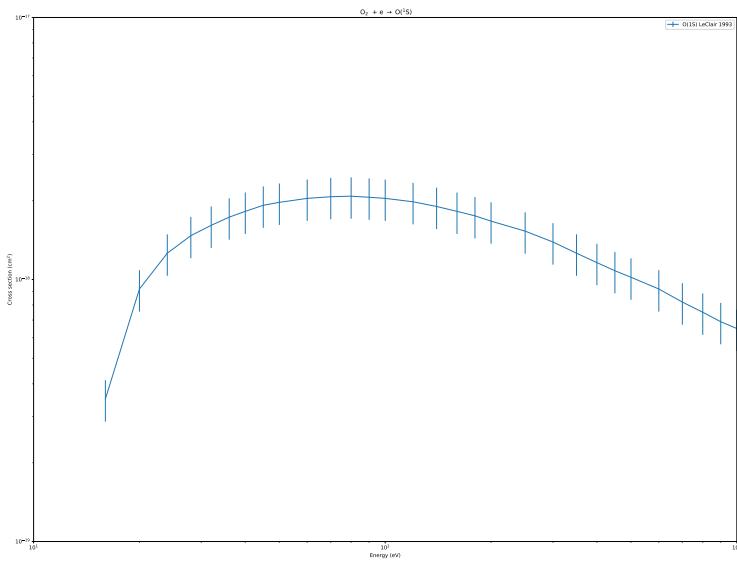


Figure 2.101: Cross sections for  $O_2 + e \rightarrow O_2^+$

Figure 2.102: Cross sections for  $O_2 + e \rightarrow O_2(\text{vib})$ Figure 2.103: Cross sections for  $O_2 + e \rightarrow O(^1S)$

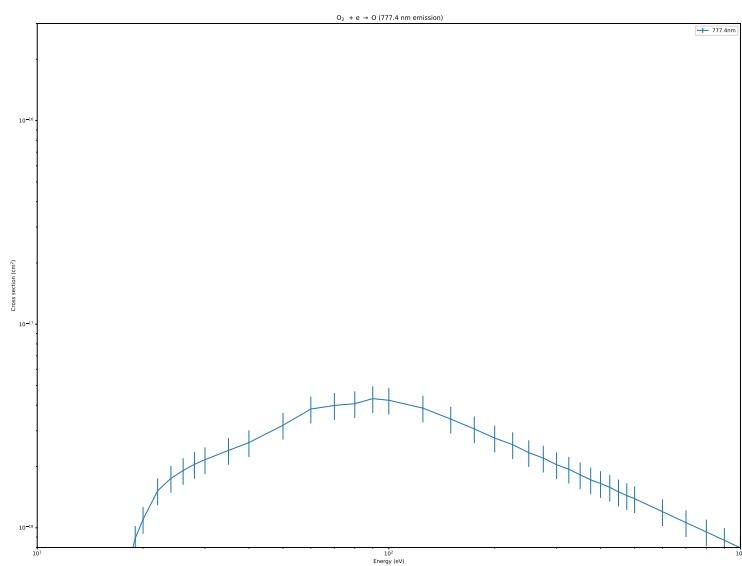
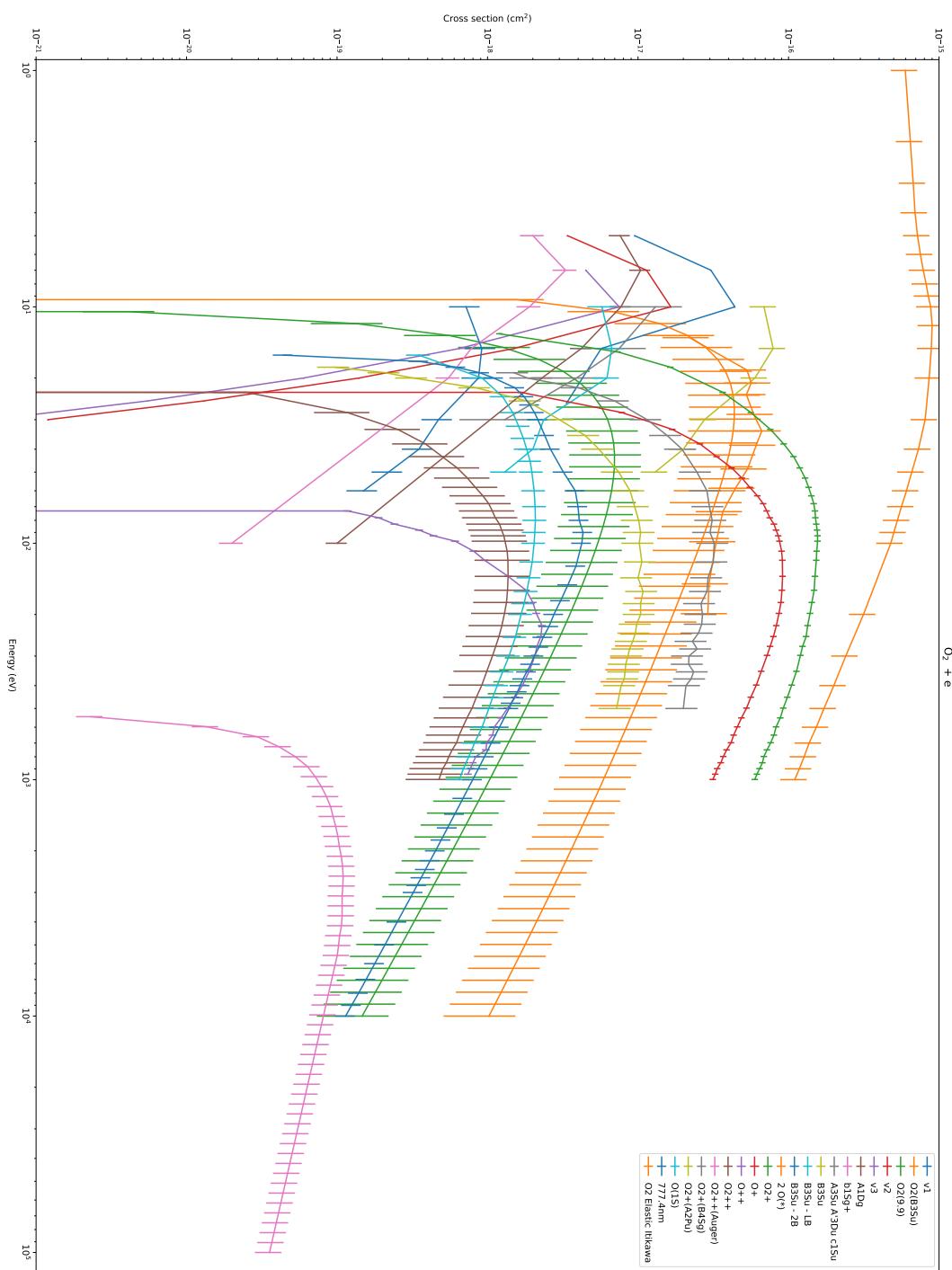


Figure 2.104: Cross sections for  $O_2 + e \rightarrow O$  (777.4 nm emission)

Figure 2.105: Cross sections for  $O_2 + e$

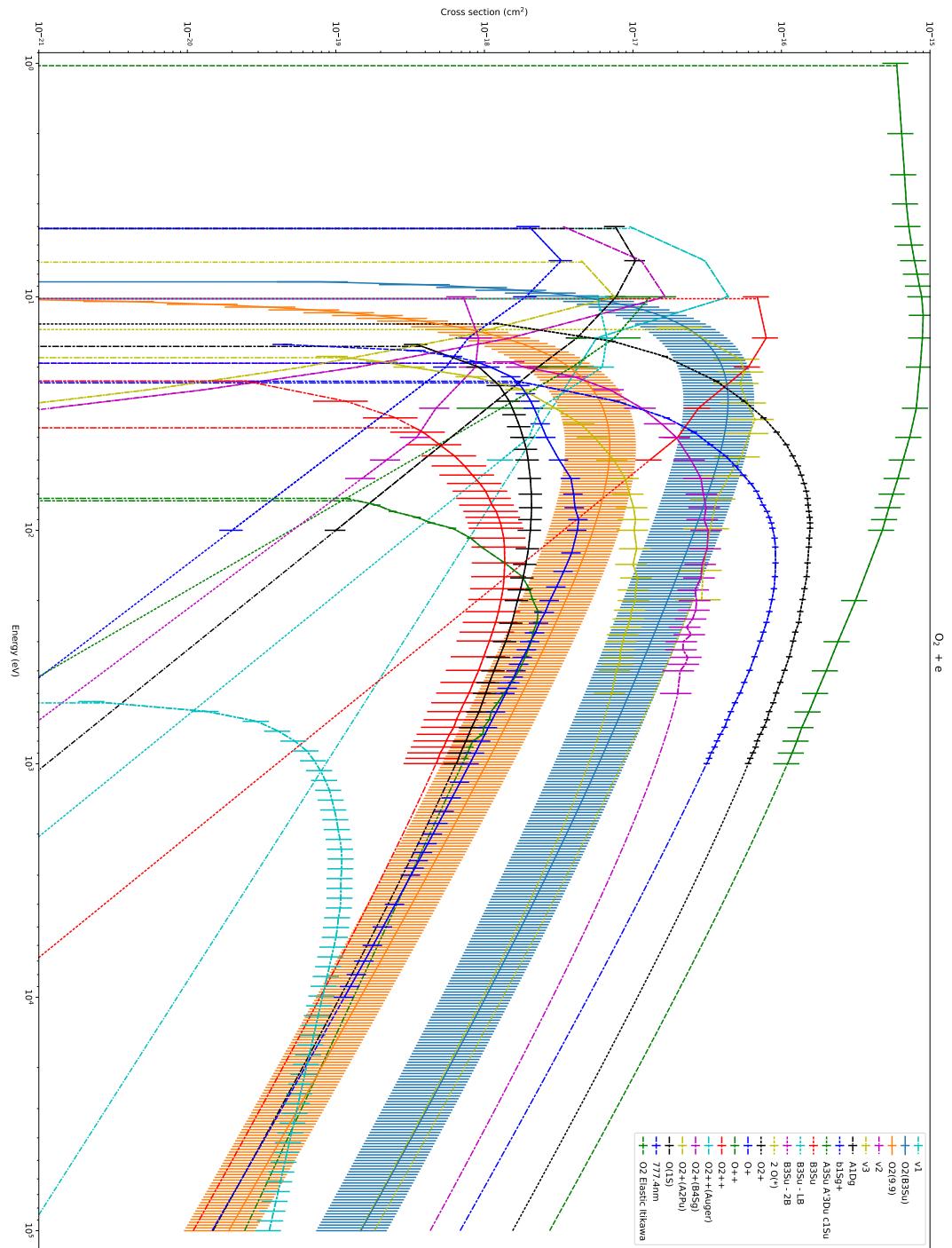


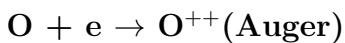
Figure 2.106: Cross sections for  $O_2 + e$  (wavelength with extrapolation version)

## 2.11 Cross section of e impact with O

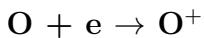
### 2.11.1 Elastic Cross Section

### 2.11.2 Inelastic Cross Sections

#### Ionization Cross Sections



**Notes for O<sup>++</sup> K-Shell ionization, [18]** The K-Shell ionization of O by electron impact has been studied in [18]. It has been extrapolated here. [2] and Hubbell et al. 1994 are used for the Auger energy and percentage

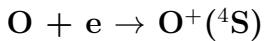


**Notes for O<sup>+</sup> BDD** That ionization source comes from the old database (BDD), probable from Rees. It is adapted for extrapolation, but the uncertainty is unknown.

**Notes for O<sup>+</sup> [71]** That ionization source comes from the measurements of [71]. These measurements are the latest, and have been taken in consideration in other sources (like[3]). The claimed uncertainty is 10%.

**Notes for O<sup>+</sup> [2]** The cross section, from [2], comes from the measurements of [71], smoothed, and adapted for extrapolation. The claimed uncertainty is 10%. This was the previously recommended cross section for that process before the adaptation with states

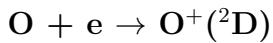
**Notes for O<sup>+</sup> Laher 1995** The cross section, was adapted from the disponible bibliography at that time. The claimed uncertainty was close to 10%, but probably more important.



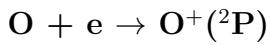
**Notes for O<sup>+</sup> [2]** The cross section, from [2], comes from the measurements of [71], smoothed, and adapted for extrapolation. The claimed uncertainty is 10%. This cross section was adapted with the branching ratio of [35]

Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Fig
Revi BDD	0	0:-1	30%		Fig. 2.112
Revi [27]	0	0:-1	30%	U	Fig. 2.112
Adap [27] + [73]	0	0:-1	30%	UE	Fig. 2.112
Adap [27] + [73] + High E estimation	0	0:-1	30%	RUE	Fig. 2.112

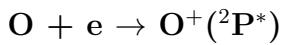
Table 2.40: Elastic cross section for e impact on O



**Notes for  $\mathbf{O}^+$  [2]** The cross section, from [2], comes from the measurements of [71], smoothed, and adapted for extrapolation. The claimed uncertainty is 10%. This cross section was adapted with the branching ratio of [35]



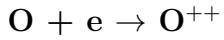
**Notes for  $\mathbf{O}^+$  [2]** The cross section, from [2], comes from the measurements of [71], smoothed, and adapted for extrapolation. The claimed uncertainty is 10%. This cross section was adapted with the branching ratio of [35]



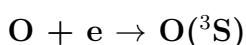
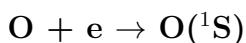
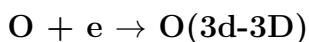
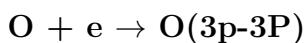
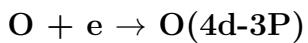
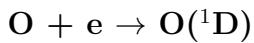
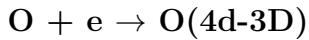
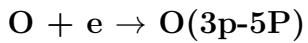
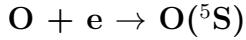
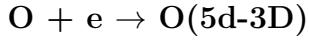
**Notes for  $\mathbf{O}^+$  [2]** The cross section, from [2], comes from the measurements of [71], smoothed, and adapted for extrapolation. The claimed uncertainty is 10%. This cross section was adapted with the branching ratio of [35]

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$O + e \rightarrow O^{++}(\text{Auger})$	Meas Glupe Mehlhorn 1967	539	539:-1	15%	RE	Fig. 2.113
$O + e \rightarrow O^+$	Revi BDD	13.61	13.61:-1	??%	U	Fig. 2.122
	Meas [71]	13.61	13.61:-1	10%	Fig. 2.122	
	Revi [2]	13.61	13.61:-1	10%	Fig. 2.122	
	Revi [35]	13.61	13.61:-1	10%	Fig. 2.122	
$O + e \rightarrow O^+(4S)$	Revi [2] + [35]	13.618	13.618:-1	10%	RE	Fig. 2.122
$O + e \rightarrow O^+(\text{2D})$	Revi [2] + [35] $O^+(\text{2D})$	16.941	16.941:-1	10%	RE	Fig. 2.122
$O + e \rightarrow O^+(\text{2P})$	Revi [2] + [35]	18.635	18.635:-1	10%	RE	Fig. 2.122
$O + e \rightarrow O^+(\text{2P}^*)$	Revi [2] + [35]	28.48	28.48:-1	10%	RE	Fig. 2.122
$O + e \rightarrow O^{++}$	Revi BDD	48.74	48.74:-1	??%	U	Fig. 2.125
	Meas [71]	48.74	48.74:-1	15%	Fig. 2.125	
	Adap [71]+extrapolation	48.74	48.74:-1	15%	RUE	Fig. 2.125

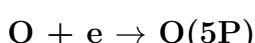
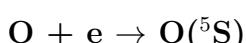
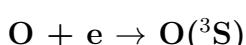
Table 2.41: Ionization Cross section for e impact on O



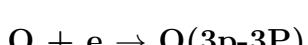
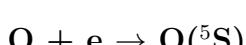
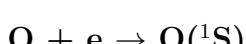
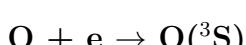
#### Excitation Cross Sections



#### 2.11.3 Emission Cross Sections



#### 2.11.4 Recommended data set



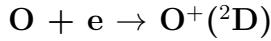
Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
$O + e \rightarrow O(5d-3D)$	Revi Majeed 95	13.	13:-1	??%	U	Fig. 2.107
$O + e \rightarrow O(3s^*-3P)$	Revi Majeed 95	14.	14:-1	??%	U	Fig. 2.108
$O + e \rightarrow O(^5S)$	Revi BDD Revi Laher 90 Revi Majeed 95 Meas Doering and Gulcicec Meas [3]	10 9.14 9.14 9.14 9.14	10:-1 9.14:-1 9.14:-1 9.14:-1 9.14:-1	50% ??% 40% 50% 50%	R U U Fig. 2.109 Fig. 2.109	Fig. 2.109 Fig. 2.109 Fig. 2.109 Fig. 2.109 Fig. 2.109
$O + e \rightarrow O((3S)3D)$	Revi BDD Revi Majeed 95 Revi Majeed 95 + extrapolation Revi Laher 90	15. 12.53 12.53 15.	15.:-1 12.53:-1 12.53:-1 15.:-1	??% ??% ??% ??%	U RU RU U	Fig. 2.111 Fig. 2.111 Fig. 2.111 Fig. 2.111
$O + e \rightarrow O(2p5-3P)$	Revi Majeed 95 Revi Laher 90	15.65 15.65	15.65:-1 15.65:-1	25% 25%	R R	Fig. 2.114 Fig. 2.114
$O + e \rightarrow O(\text{Rydberg})$	Revi Majeed 95	11	11:-1	50%	U	Fig. 2.116
$O + e \rightarrow O(3p-5P)$	Revi Laher 90 Revi Majeed 95	10.73 10.73	10.73:-1 10.73:-1	50% 50%	R U	Fig. 2.117 Fig. 2.117
$O + e \rightarrow O(4d-3D)$	Revi Majeed 95	12.8	12.8:-1	??%	U	Fig. 2.118
$O + e \rightarrow O(^1D)$	Adap Itikawa 90 Revi Laher 90 Revi Majeed 95	2.1 1.96 1.96	2.1:-1 1.96:-1 1.96:-1	50% 50% 50%	RE Fig. 2.119 Fig. 2.119	Fig. 2.119 Fig. 2.119 Fig. 2.119
$O + e \rightarrow O((3S)1D)$	Revi BDD Revi Laher 90	14.5 12.53	14.5:-1 12.53:-1	??% ??%	U U	Fig. 2.120 Fig. 2.120
$O + e \rightarrow O(4d-3P)$	Revi Majeed 95	13.	13:-1	??%	U	Fig. 2.121
$O + e \rightarrow O(3p-3P)$	Meas [23] Revi Laher 90 Revi Majeed 95	10.99 10.98 10.98	10.99:-1 10.98:-1 10.98:-1	50% 50% 50%	Fig. 2.123 Fig. 2.123 R	Fig. 2.123 Fig. 2.123 Fig. 2.123
$O + e \rightarrow O(3d-3D)$	Revi Majeed 95	12.1	12.1:-1	??%	U	Fig. 2.124
$O + e \rightarrow O(^1S)$	Revi ? BDD Revi Laher 90 Revi Majeed 95	4. 4.18 4.18	4.:-1 4.18:-1 4.18:-1	54% 54% 54%	R R R	Fig. 2.126 Fig. 2.126 Fig. 2.126
$O + e \rightarrow O(^3S)$	Revi Johnson 05 Revi Laher 90 Revi Majeed 95	10. 10. 10.	10.:-1 10.:-1 10.:-1	20% 50% 50%	U R R	Fig. 2.127 Fig. 2.126 Fig. 2.127
$O + e \rightarrow O(\text{finestr})$	Revi BDD Revi [27] Revi [27]	0.0178 0.0178 0.0178	0.0178:-1 0.0178:-1 0.0178:-1	??% 50% 50%	U RU RU	Fig. 2.128 Fig. 2.128 Fig. 2.128

Table 2.42: Excitation Cross section for e impact on O

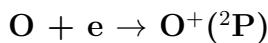
Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
O + e → O( <sup>3</sup> S)	Revi BDD Revi Johnson 05	10. 10.	10.:-1 10.:-1	?%?% 20%	U	Fig. 2.110 Fig. 2.110
	Revi [31] Adap [31] + [32]	10. 10.	10.:-1 10.:-1	24% 24%	R	Fig. 2.110 Fig. 2.110
O + e → O( <sup>3</sup> S)3D)	Meas [81]	15.	15.:-1	?%?% ?%?%	U	Fig. 2.111
O + e → O( <sup>3</sup> S)	???? Zipf 1985	10.	10.:-1	50%	U	Fig. 2.115
O + e → O(5P)	Adap Johnson 05 and [33] and [36]	10.	10.:-1	20%	R	Fig. 2.117

Table 2.43: Emission Cross section for e impact on O

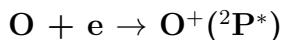
tainty is 10%. This cross section was adapted with the branching ratio of [35]



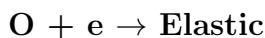
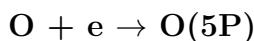
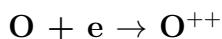
**Notes for  $\mathbf{O}^+$  [2]** The cross section, from [2], comes from the measurements of [71], smoothed, and adapted for extrapolation. The claimed uncertainty is 10%. This cross section was adapted with the branching ratio of Laher 90



**Notes for  $\mathbf{O}^+$  [2]** The cross section, from [2], comes from the measurements of [71], smoothed, and adapted for extrapolation. The claimed uncertainty is 10%. This cross section was adapted with the branching ratio of [35]



**Notes for  $\mathbf{O}^+$  [2]** The cross section, from [2], comes from the measurements of [71], smoothed, and adapted for extrapolation. The claimed uncertainty is 10%. This cross section was adapted with the branching ratio of [35]



### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

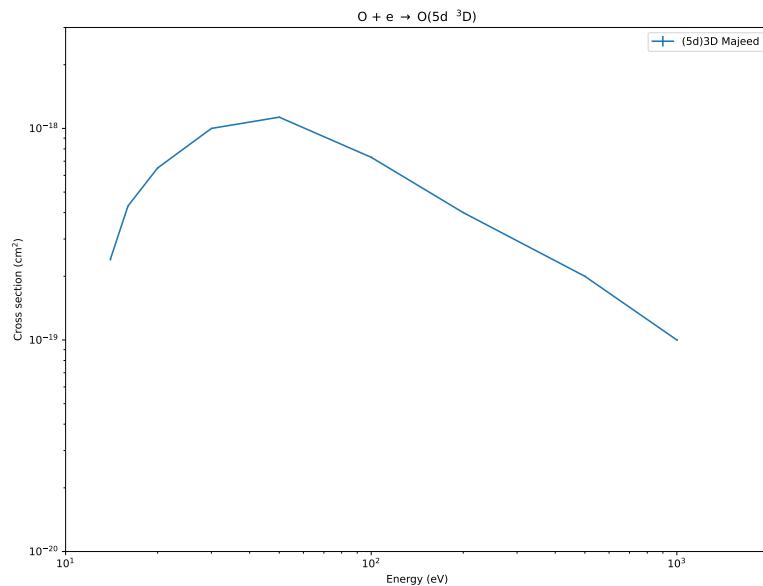
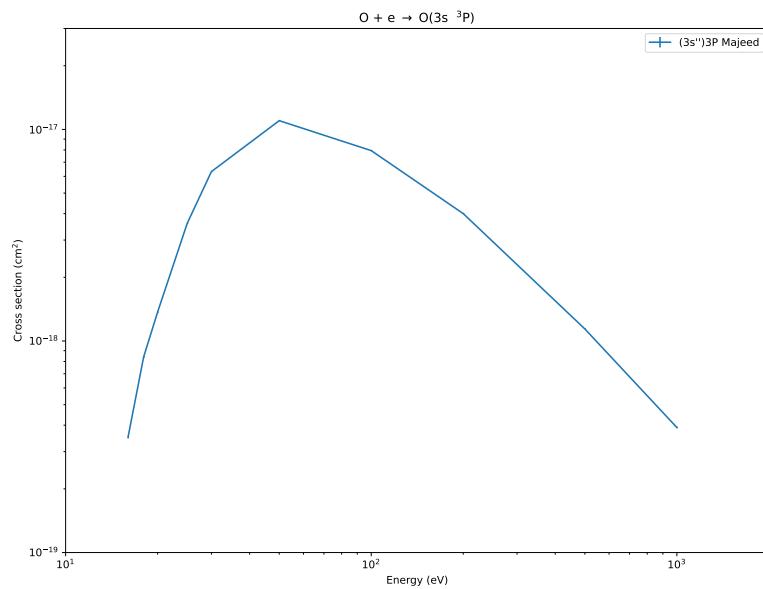
**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the

Process	Reference	Threshold (eV)	Range of energy (eV)	Uncertainty	Properties	Plots
O + e → O(finestr)	Revi [27]	0.0178	0.0178:-1	50%	RU	Fig. 2.129 2.130
	Revi [27]	0.0178	0.0178:-1	50%	RU	Fig. 2.129 2.130
O + e → O( <sup>3</sup> S)	Adap [31] + [32]	10.	10.:-1	24%	R	Fig. 2.129 2.130
O + e → O( <sup>1</sup> D)	Adap [27]	1.96	1.96:-1	50%	RE	Fig. 2.129 2.130
O + e → O( <sup>1</sup> S)	Revi [35]	4.18	4.18:-1	54%	R	Fig. 2.129 2.130
O + e → O( <sup>3</sup> S)	Revi [35]	9.14	9.14:-1	50%	R	Fig. 2.129 2.130
O + e → O(3p-3P)	Revi [47]	10.98	10.98:-1	50%	R	Fig. 2.129 2.130
O + e → O(3p-5P)	Revi [35]	10.73	10.73:-1	50%	R	Fig. 2.129 2.130
O + e → O(2p5-3P)	Revi [35]	15.65	15.65:-1	25%	R	Fig. 2.129 2.130
O + e → O(Rydberg)	Revi [47]	11	11:-1	50%	U	Fig. 2.129 2.130
O + e → O((3S)3D)	Revi [47]	12.53	12.53:-1	???	RU	Fig. 2.129 2.130
O + e → O(3d-3D)	Adap [47]	12.1	12.1:-1	???	U	Fig. 2.129 2.130
O + e → O(5d-3D)	Revi [47]	13.	13.:-1	???	U	Fig. 2.129 2.130
O + e → O(4d-3D)	Revi [47]	12.8	12.8:-1	???	U	Fig. 2.129 2.130
O + e → O(3s"-3P)	Revi [47]	14.	14.:-1	???	U	Fig. 2.129 2.130
O + e → O(4d-3P)	Revi [47]	13.	13.:-1	???	U	Fig. 2.129 2.130
O + e → O <sup>+</sup> ( <sup>4</sup> S)	Revi [2] + [35]	13.61	13.618:-1	10%	RE	Fig. 2.129 2.130
O + e → O <sup>+</sup> ( <sup>2</sup> D)	Revi [2] + Laher 90 O <sup>+</sup> ( <sup>2</sup> D)	16.94	16.941:-1	10%	RE	Fig. 2.129 2.130
O + e → O <sup>+</sup> ( <sup>2</sup> P)	Revi [2] + [35]	18.63	18.635:-1	10%	RE	Fig. 2.129 2.130
O + e → O <sup>+</sup> ( <sup>2</sup> P*)	Revi [2] + [35]	28.48	28.48:-1	10%	RE	Fig. 2.129 2.130
O + e → O <sup>++</sup>	Adap [71] + extrapolation	48.74	48.74:-1	15%	RUE	Fig. 2.129 2.130
O + e → O <sup>++</sup> (Auger)	Meas [18]	539	539:-1	15%	RE	Fig. 2.129 2.130
O + e → O(5P)	Adap [32] and [33] and [36]	10.	10.:-1	20%	R	Fig. 2.129 2.130
O + e → Elastic	Adap [27] + [73] + High E estimation	0	0:-1	30%	RUE	Fig. 2.129 2.130

Table 2.44: Recommended Cross section for e impact on O

uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Figure 2.107: Cross sections for  $O + e \rightarrow O(5d\ ^3D)$ Figure 2.108: Cross sections for  $O + e \rightarrow O(3s\ ^3P)$

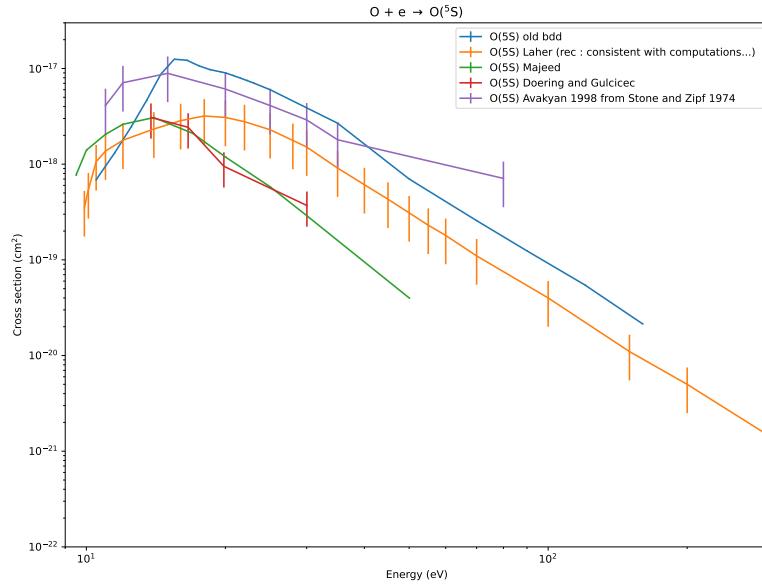


Figure 2.109: Cross sections for  $O + e \rightarrow O(^5S)$

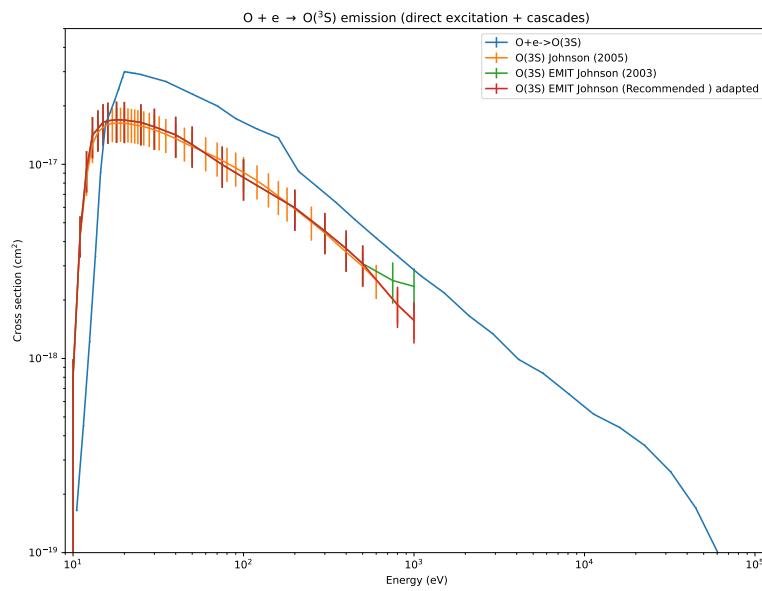
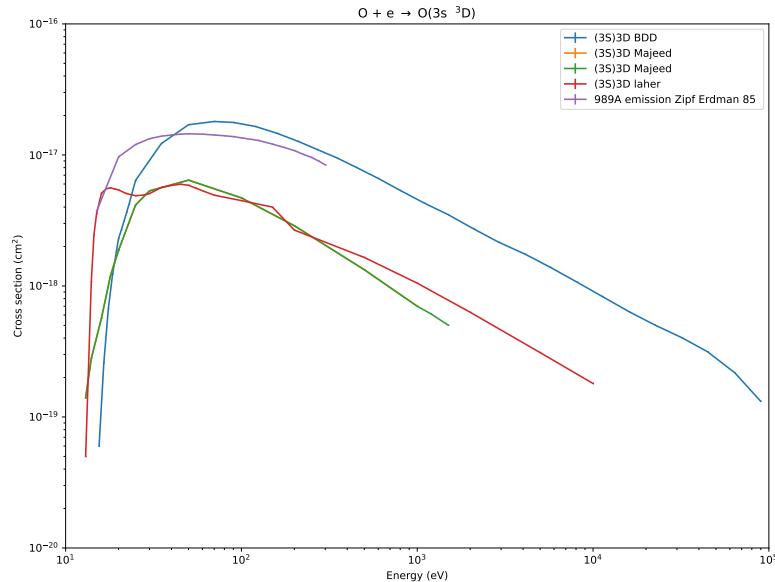
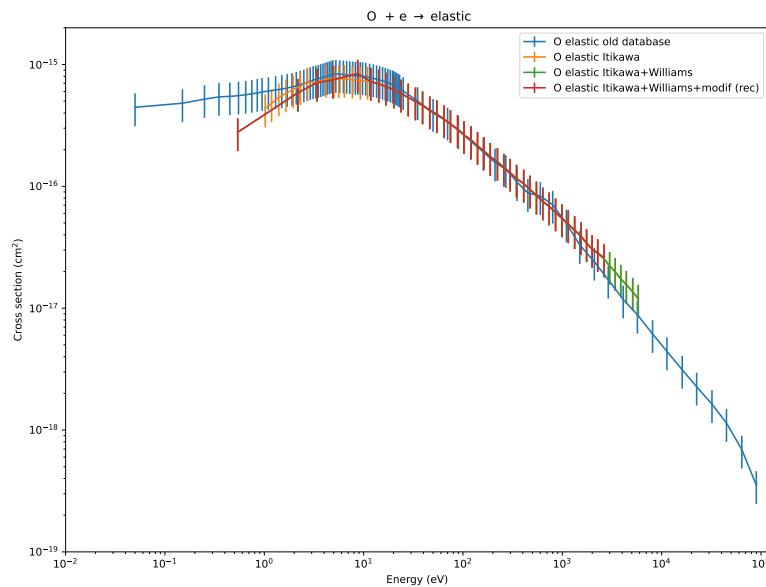


Figure 2.110: Cross sections for  $O + e \rightarrow O(^3S)$  emission (direct excitation + cascades)

Figure 2.111: Cross sections for  $O + e \rightarrow O(3s\ ^3D)$ Figure 2.112: Cross sections for  $O + e \rightarrow \text{elastic}$

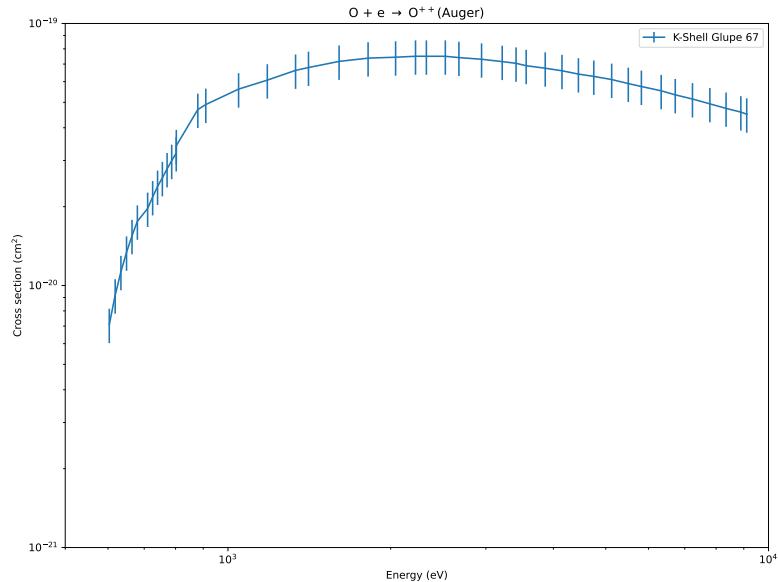


Figure 2.113: Cross sections for  $O + e \rightarrow O^{++}$  (Auger)

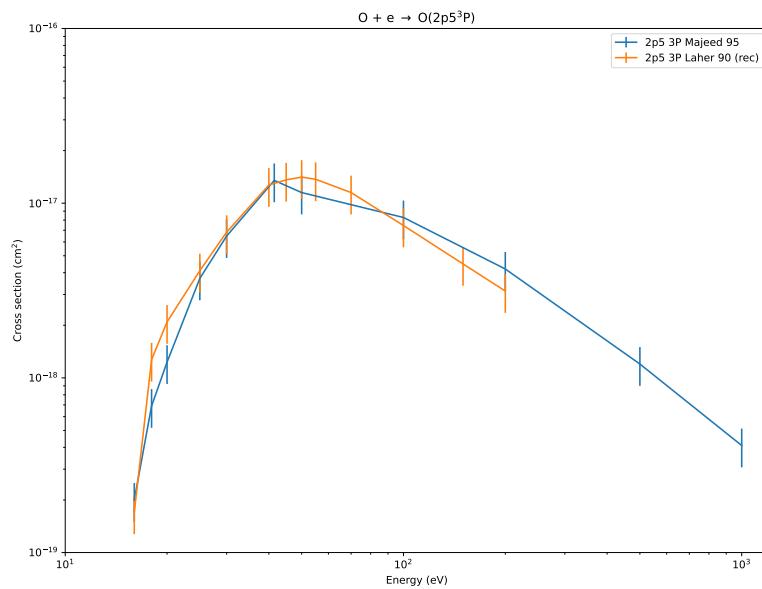


Figure 2.114: Cross sections for  $O + e \rightarrow O(2p5^3P)$

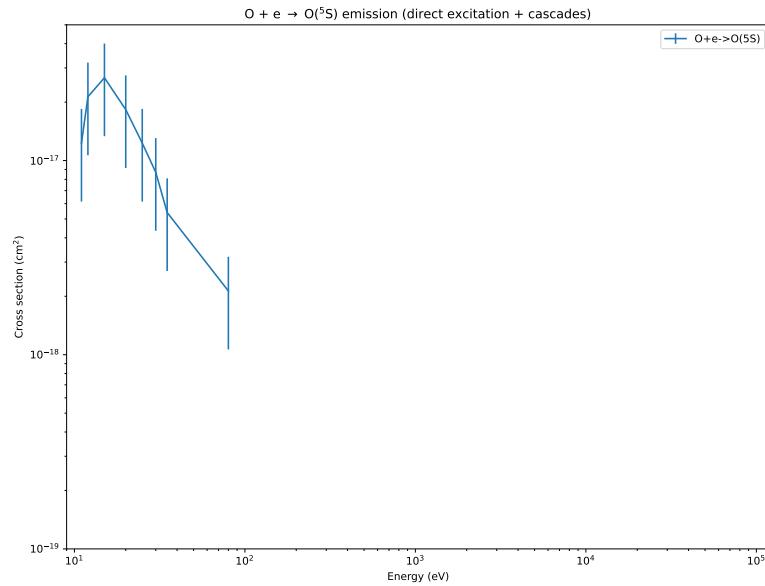


Figure 2.115: Cross sections for  $\text{O} + \text{e} \rightarrow \text{O}({}^5\text{S})$  emission (direct excitation + cascades)

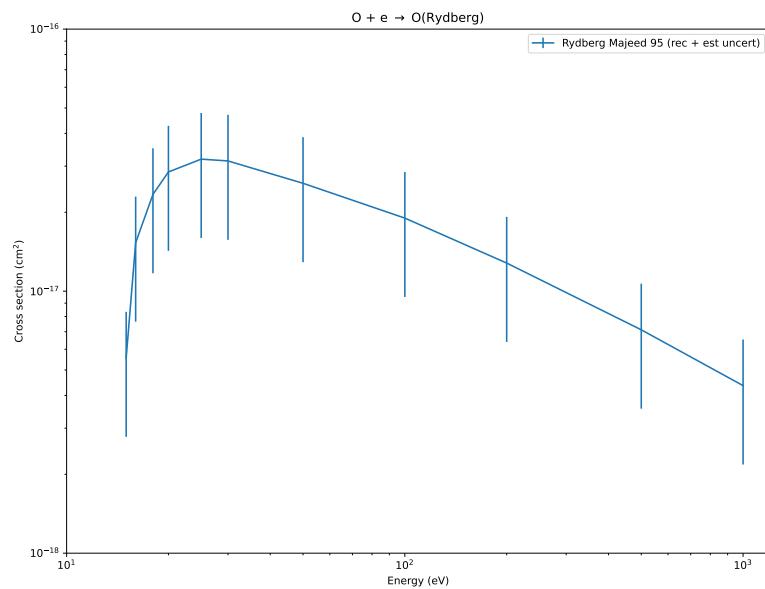


Figure 2.116: Cross sections for  $\text{O} + \text{e} \rightarrow \text{O}(\text{Rydberg})$

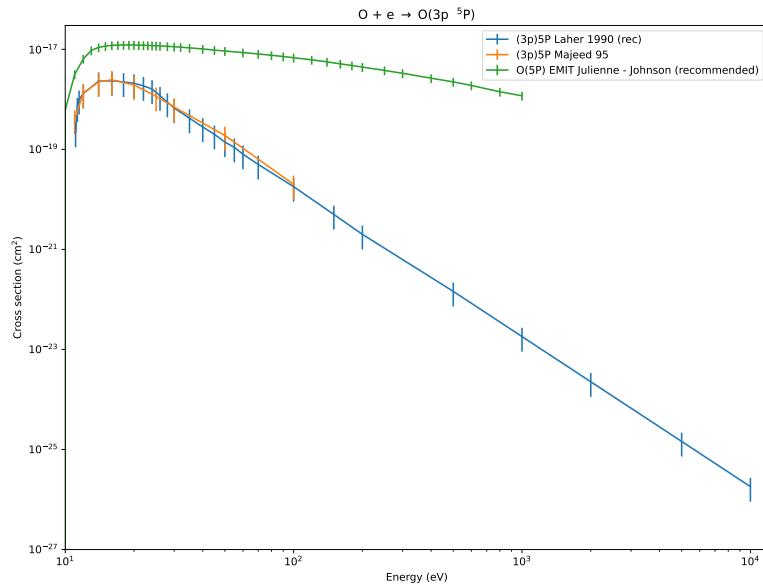


Figure 2.117: Cross sections for  $O + e \rightarrow O(3p\ ^5P)$

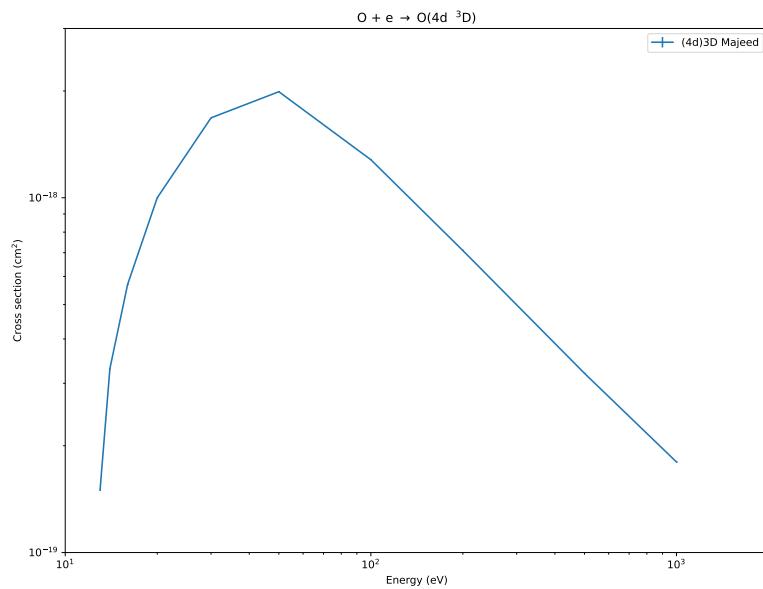
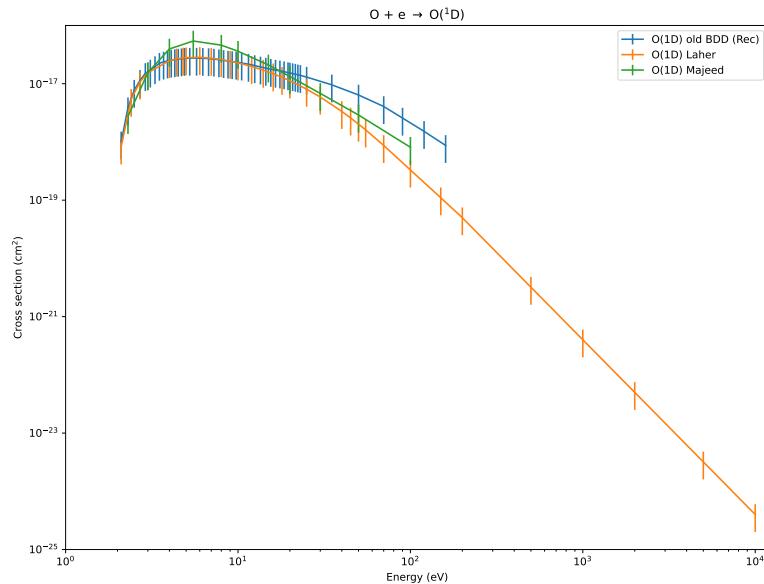
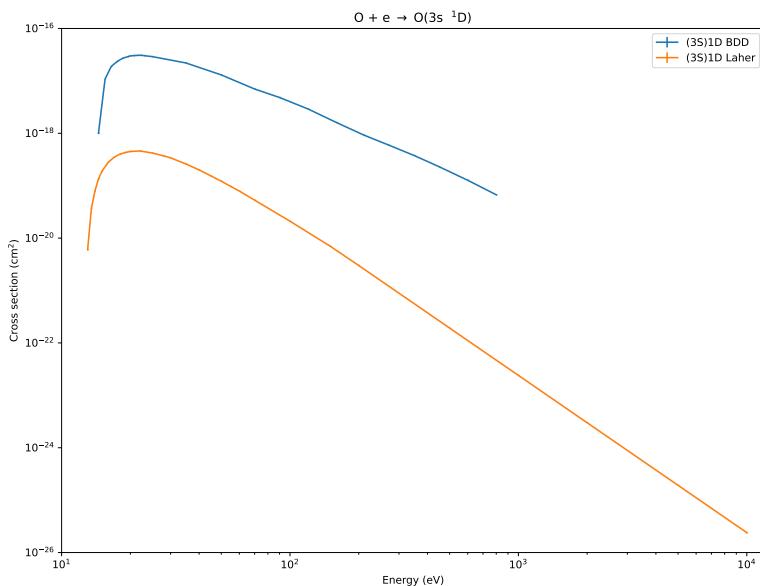
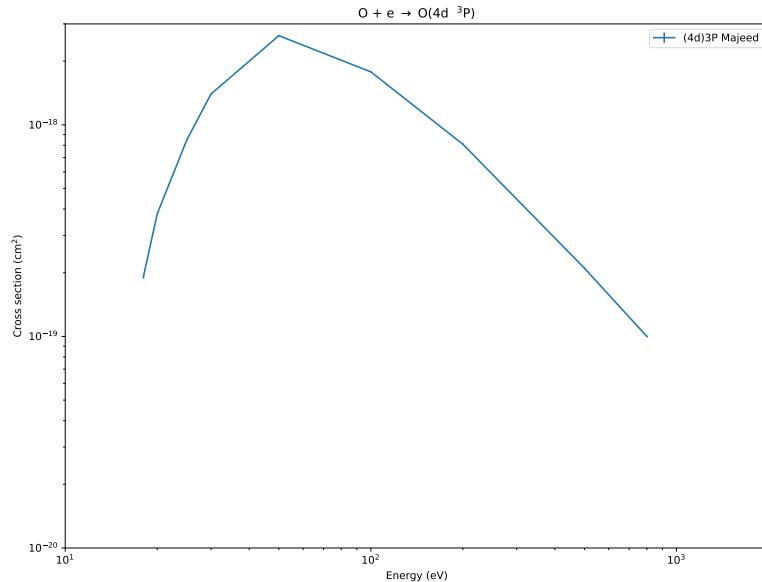
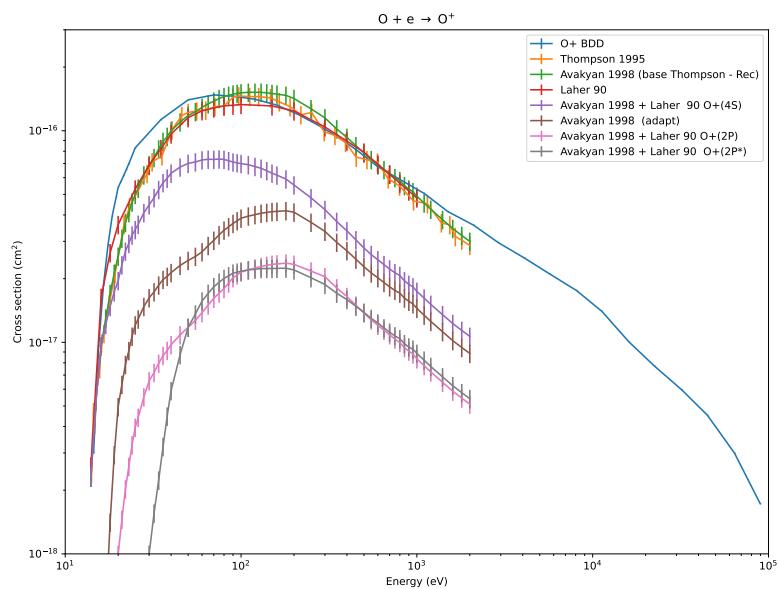
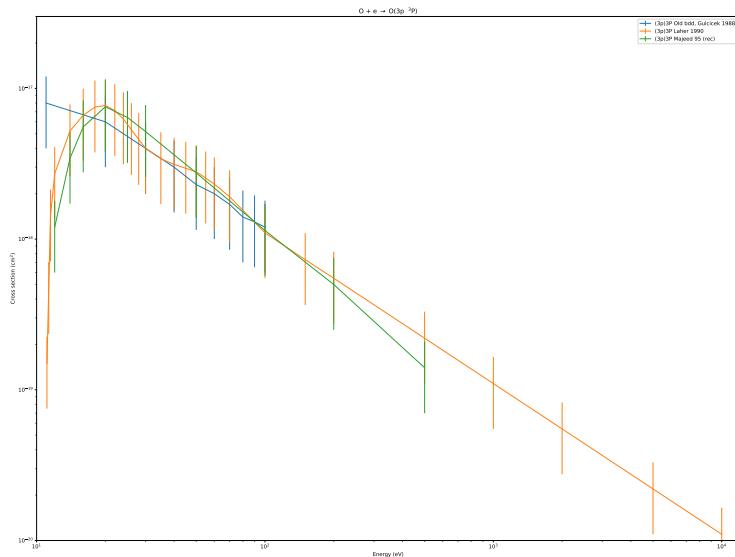
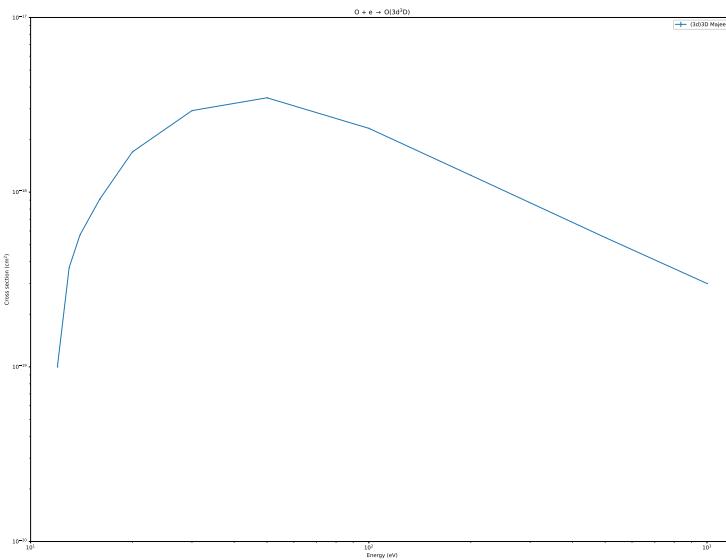
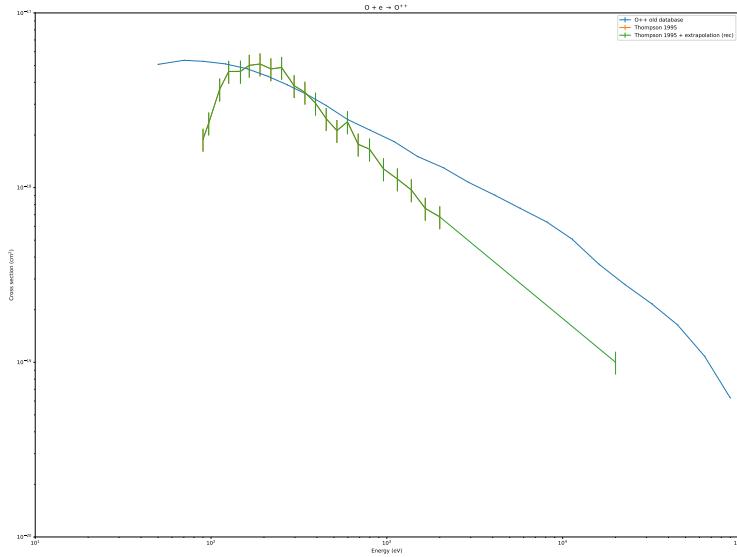
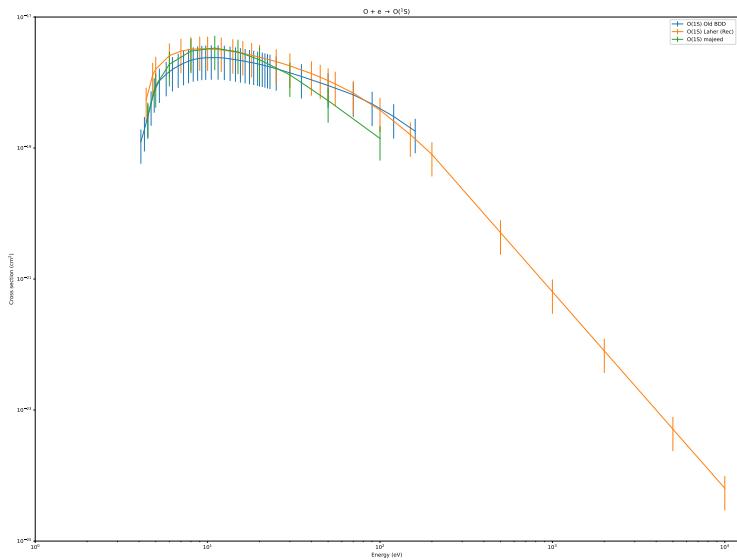


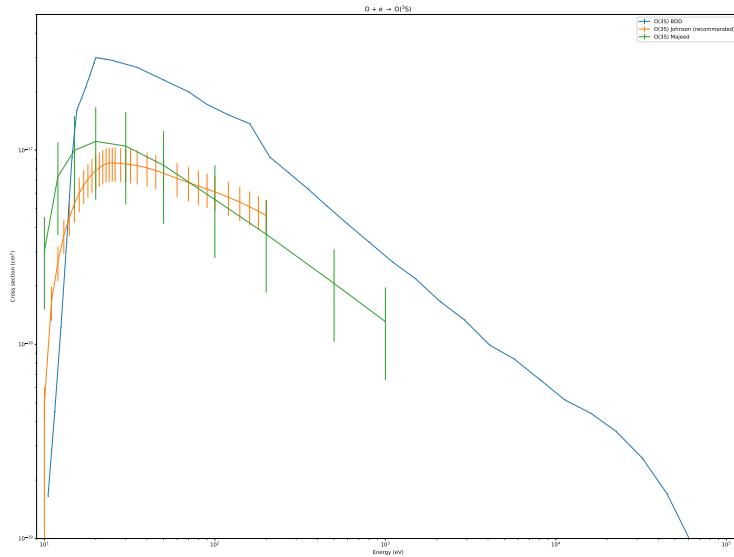
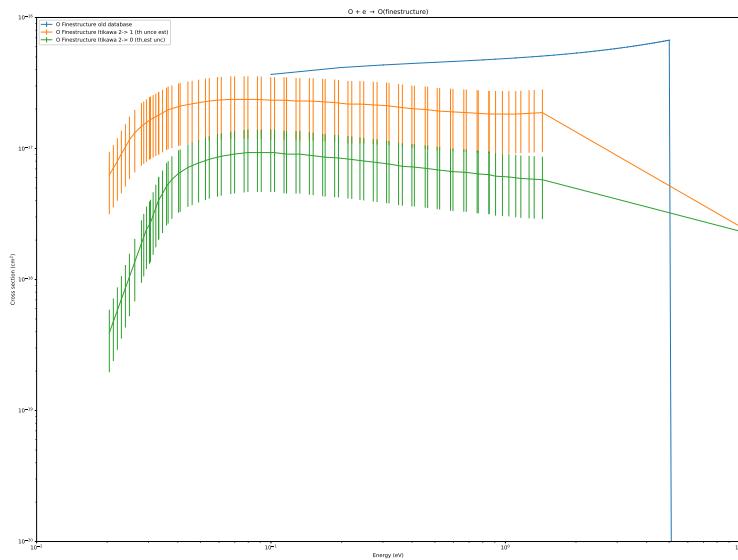
Figure 2.118: Cross sections for  $O + e \rightarrow O(4d\ ^3D)$

Figure 2.119: Cross sections for  $O + e \rightarrow O(^1D)$ Figure 2.120: Cross sections for  $O + e \rightarrow O(3s ^1D)$

Figure 2.121: Cross sections for  $O + e \rightarrow O(4d\ ^3P)$ Figure 2.122: Cross sections for  $O + e \rightarrow O^+$

Figure 2.123: Cross sections for  $O + e \rightarrow O(3p\ ^3P)$ Figure 2.124: Cross sections for  $O + e \rightarrow O(3d\ ^3D)$

Figure 2.125: Cross sections for  $O + e \rightarrow O^{++}$ Figure 2.126: Cross sections for  $O + e \rightarrow O(^1S)$

Figure 2.127: Cross sections for  $O + e \rightarrow O(^3S)$ Figure 2.128: Cross sections for  $O + e \rightarrow O(\text{finestructure})$

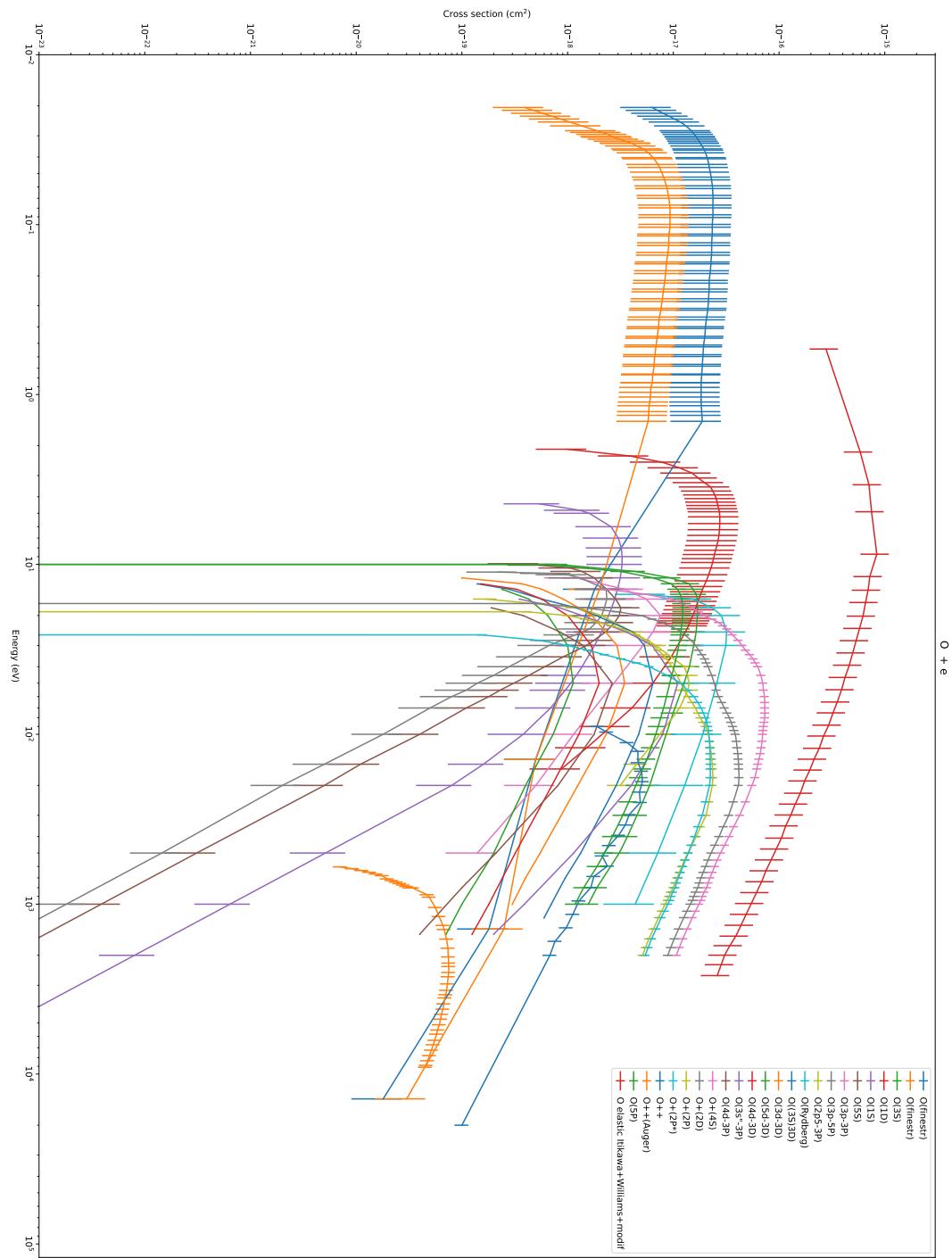


Figure 2.129: Cross sections for O + e

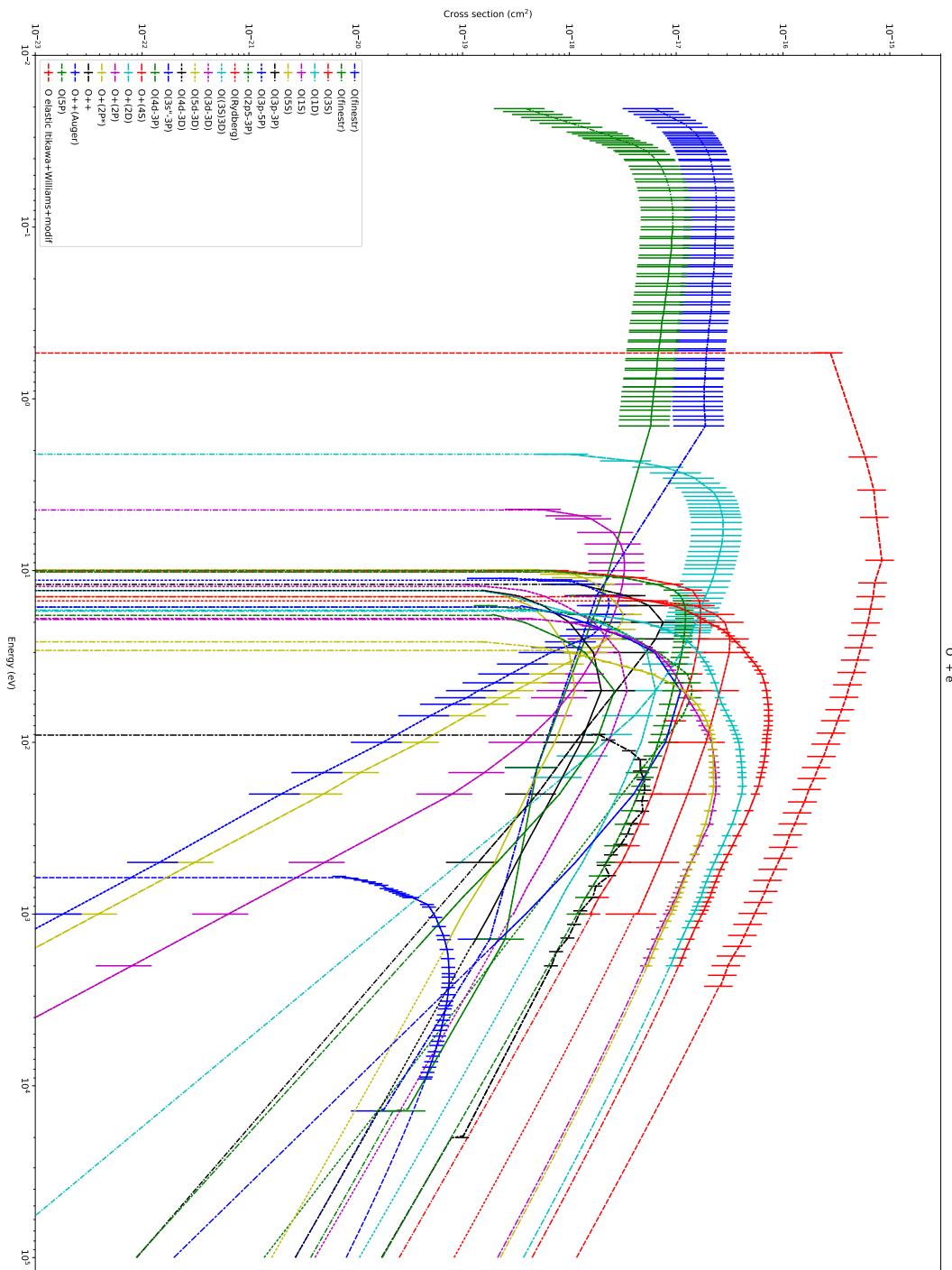


Figure 2.130: Cross sections for O + e (wavelength with extrapolation version)

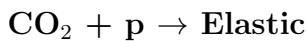
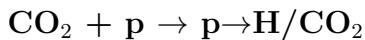
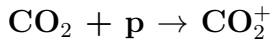
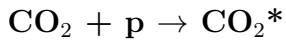
## **2.12 Cross section of impact with Protons**

### **2.12.1 Inelastic Cross Sections**

## 2.13 Cross section of p impact with CO<sub>2</sub>

### 2.13.1 Inelastic Cross Sections

#### 2.13.2 Recommended data set



#### Legend for the properties

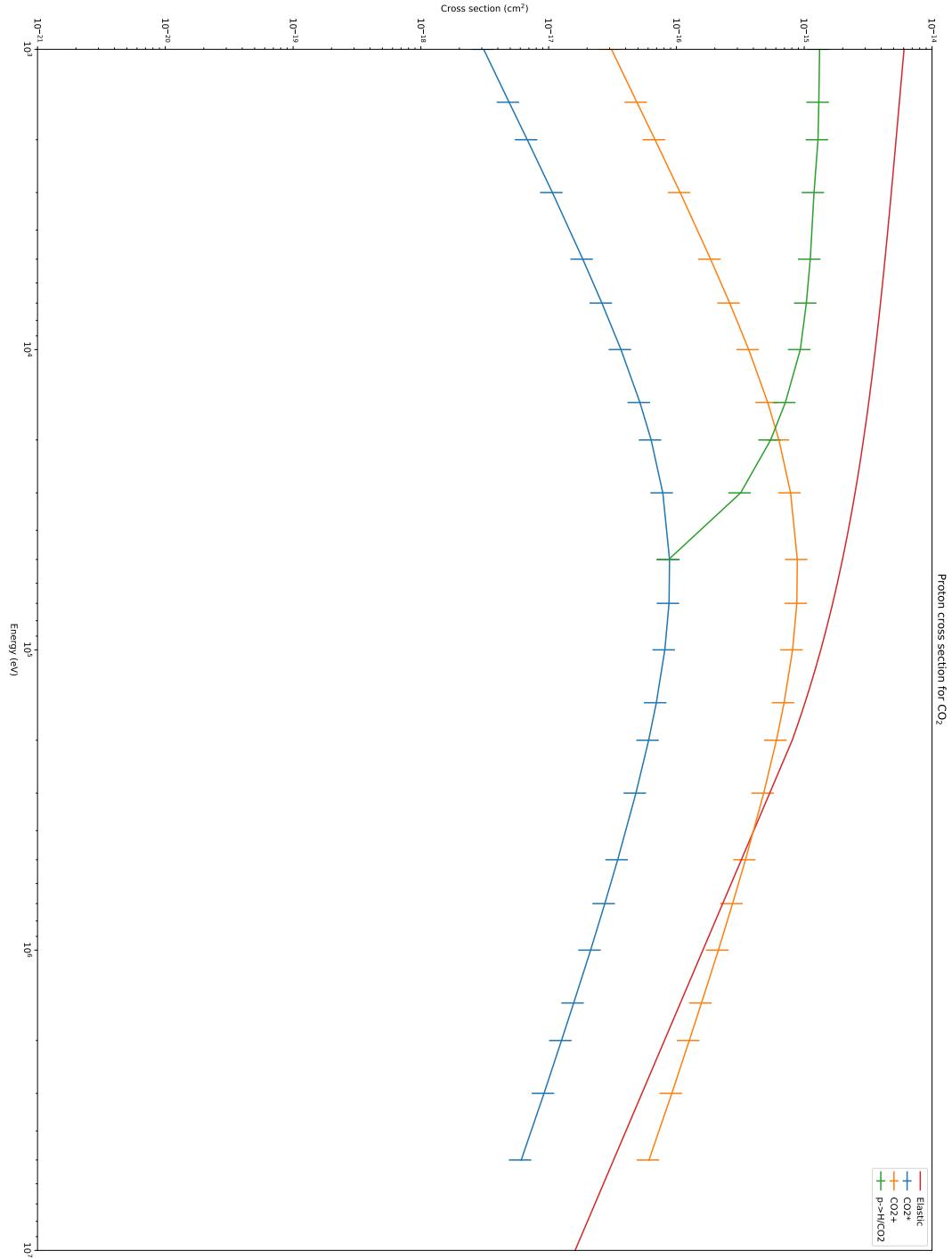
**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Process	Reference	Threshold	Range of energy	Uncertainty	Properties	Plots
$\text{CO}_2 + \text{p} \rightarrow \text{CO}_2^*$	Adap [2] Gronoff Basu 1987	10	10:-1	20%		Fig. 2.131 2.132
$\text{CO}_2 + \text{p} \rightarrow \text{CO}_2^+$	Revi basu 1987	17	17:-1	20%		Fig. 2.131 2.132
$\text{CO}_2 + \text{p} \rightarrow \text{p} \rightarrow \text{H/CO}_2$	Revi [2]	13.6	13.6:-1	20%		Fig. 2.131 2.132
$\text{CO}_2 + \text{p} \rightarrow \text{Elastic}$	Adap Gronoff + Kozelov and Ivanov 1992	0	0:-1	???:%	U	Fig. 2.131 2.132

Table 2.45: Recommended Cross section for p impact on CO<sub>2</sub>

Figure 2.131: Cross sections for Proton cross section for CO<sub>2</sub>

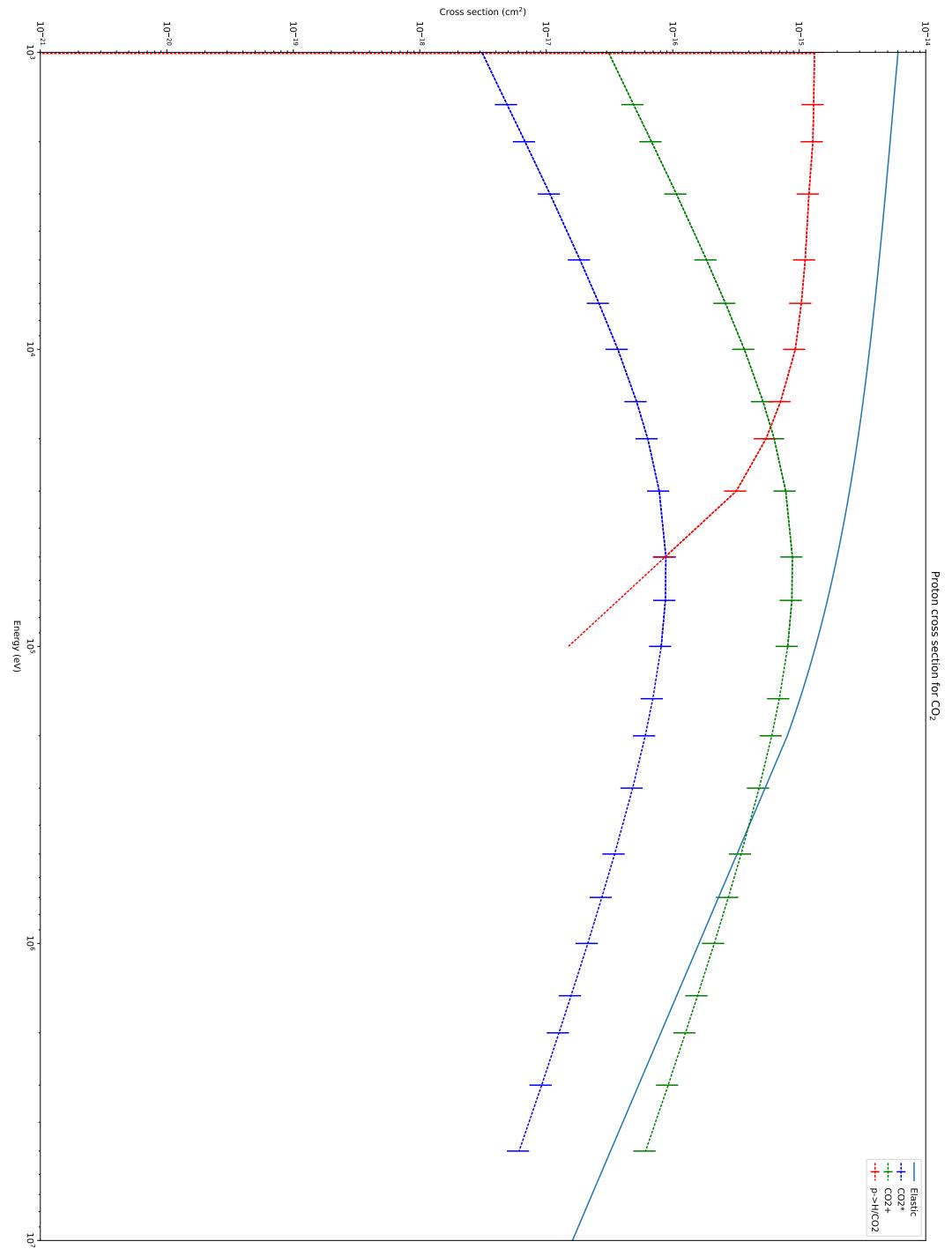


Figure 2.132: Cross sections for Proton cross section for CO<sub>2</sub> (wavelength with extrapolation version)

## 2.14 Cross section of impact with

### 2.14.1 Inelastic Cross Sections

#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections = Total cross section)

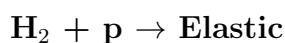
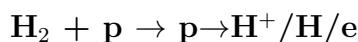
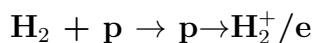
**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

## 2.15 Cross section of p impact with H<sub>2</sub>

### 2.15.1 Inelastic Cross Sections

#### 2.15.2 Recommended data set



#### Legend for the properties

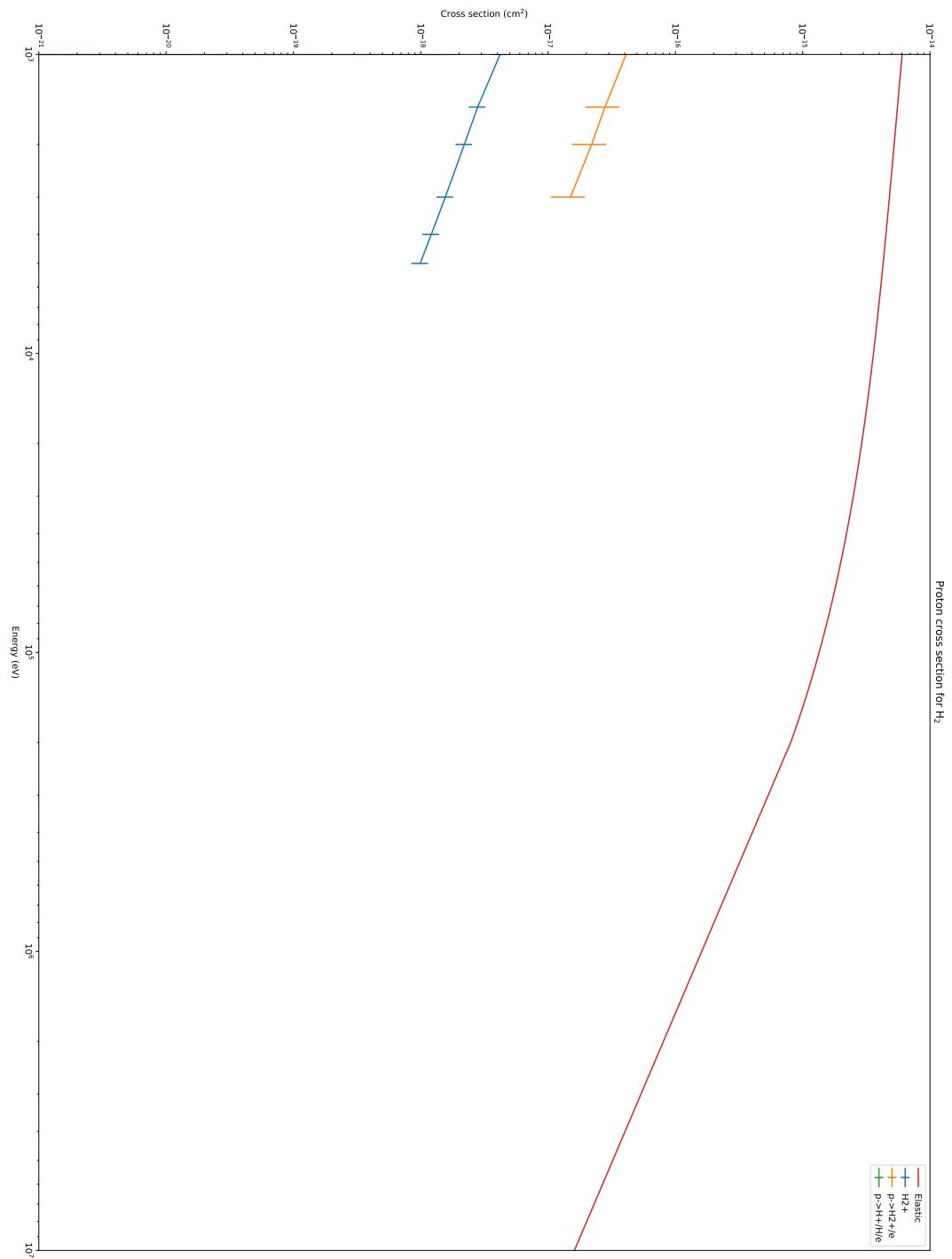
**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Process	Reference	Threshold	Range of energy	Uncertainty	Properties	Plots
$H_2 + p \rightarrow H_2^+$	Revi [2]	15.4	15.4:-1	15%	U	Fig. 2.133 2.134
$H_2 + p \rightarrow p \rightarrow H_2^+ / e$	Revi [3]	15.4	15.4:-1	30%	U	Fig. 2.133 2.134
$H_2 + p \rightarrow p \rightarrow H^+ / H/e$	Revi [3]	15.4	15.4:-1	30%	U	Fig. 2.133 2.134
$H_2 + p \rightarrow$ Elastic	Adap Gronoff + Kozelov and Ivanov 1992	0	0:-1	?%?	U	Fig. 2.133 2.134

Table 2.46: Recommended Cross section for p impact on  $H_2$

Figure 2.133: Cross sections for Proton cross section for H<sub>2</sub>

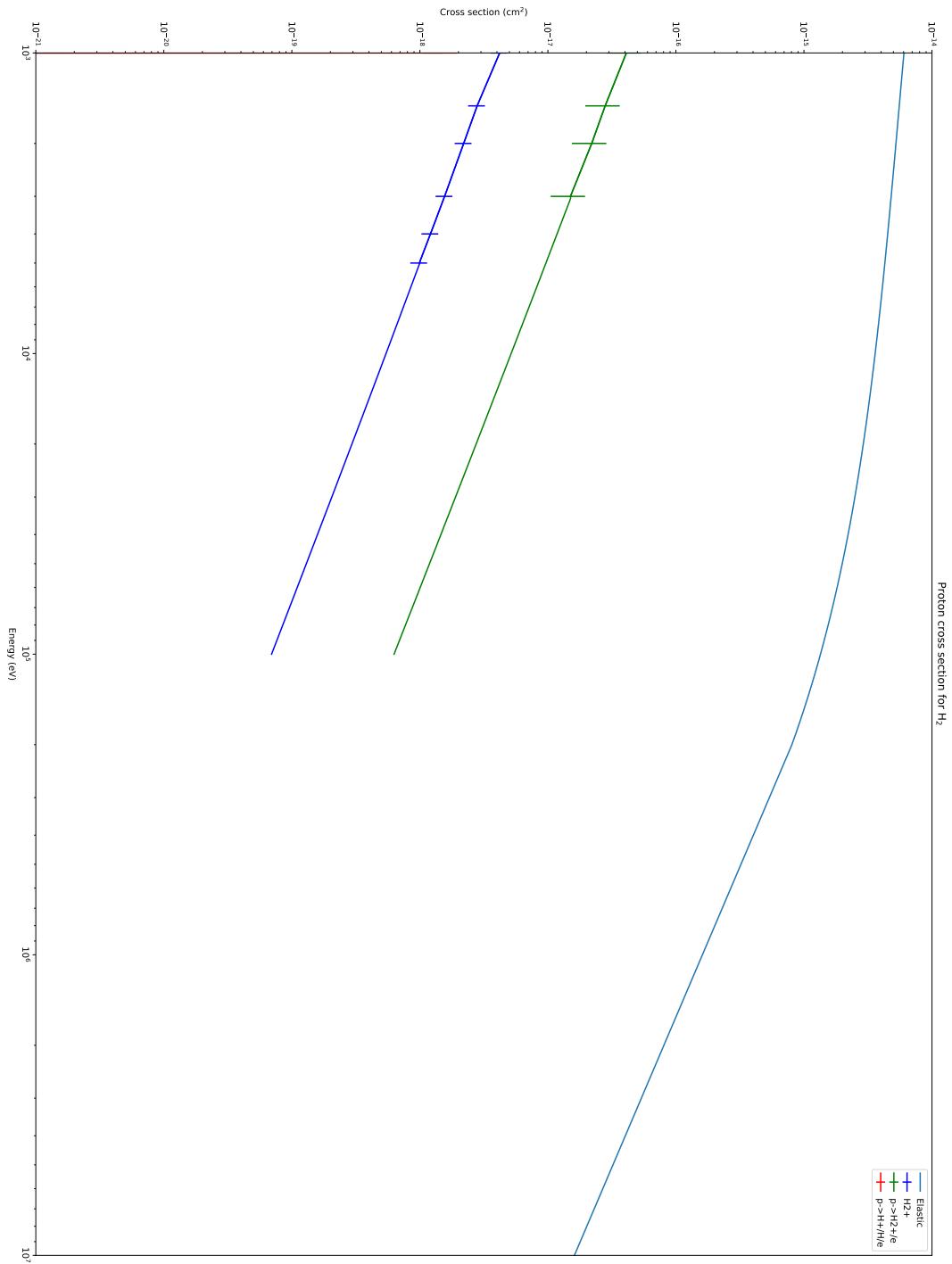
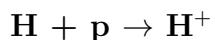


Figure 2.134: Cross sections for Proton cross section for H<sub>2</sub> (wavelength with extrapolation version)

## 2.16 Cross section of p impact with H

### 2.16.1 Inelastic Cross Sections

### 2.16.2 Recommended data set



#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Process	Reference	Threshold	Range of energy	Uncertainty	Properties	Plots
$H + p \rightarrow H^+$	Revi [3]	13.6	13.6:-1	15%	U	Fig. 2.135 2.136
$H + p \rightarrow$ Elastic	Adap Gronoff + Kozelov and Ivanov 1992	0	0:-1	??%	U	Fig. 2.135 2.136

Table 2.47: Recommended Cross section for p impact on H

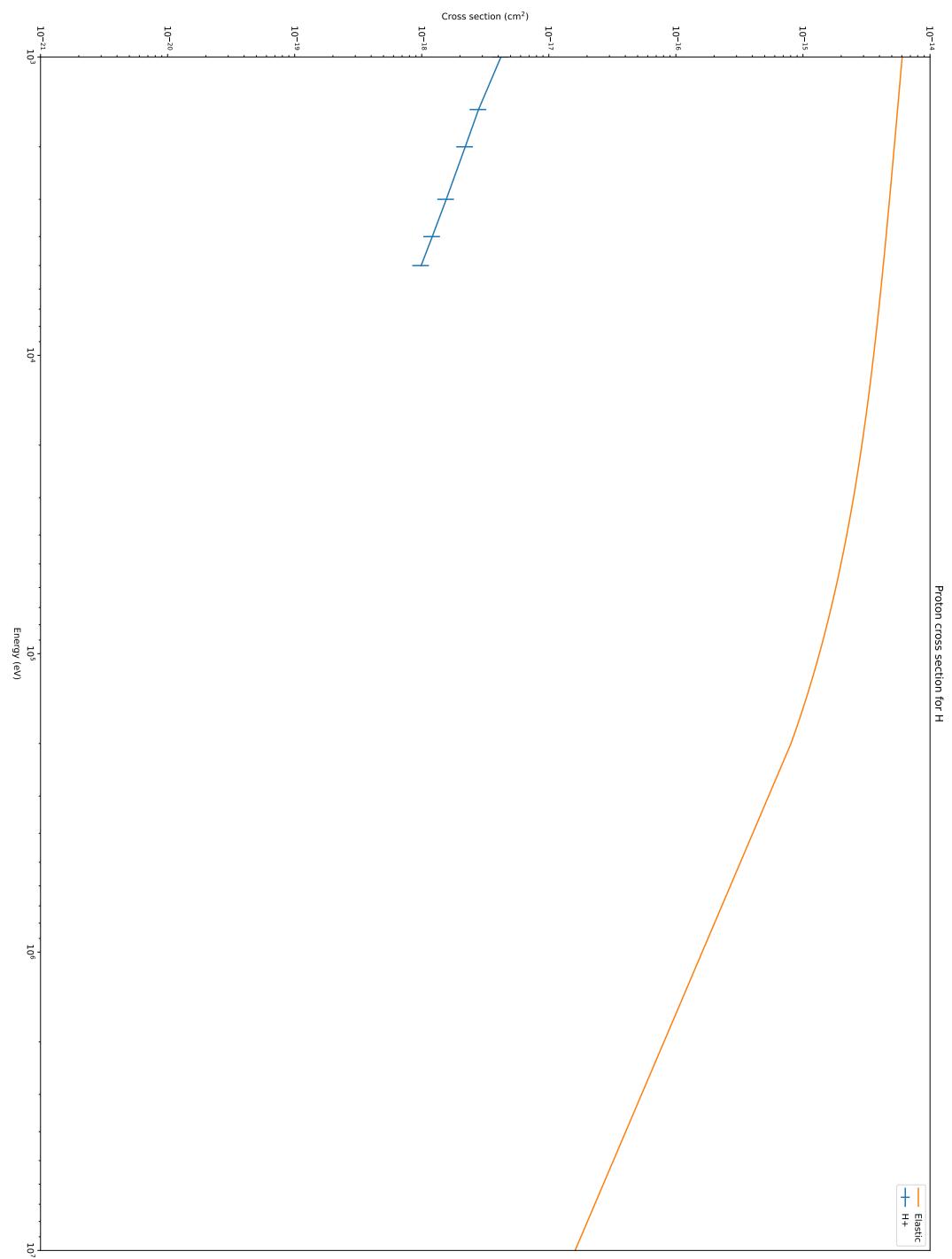


Figure 2.135: Cross sections for Proton cross section for H

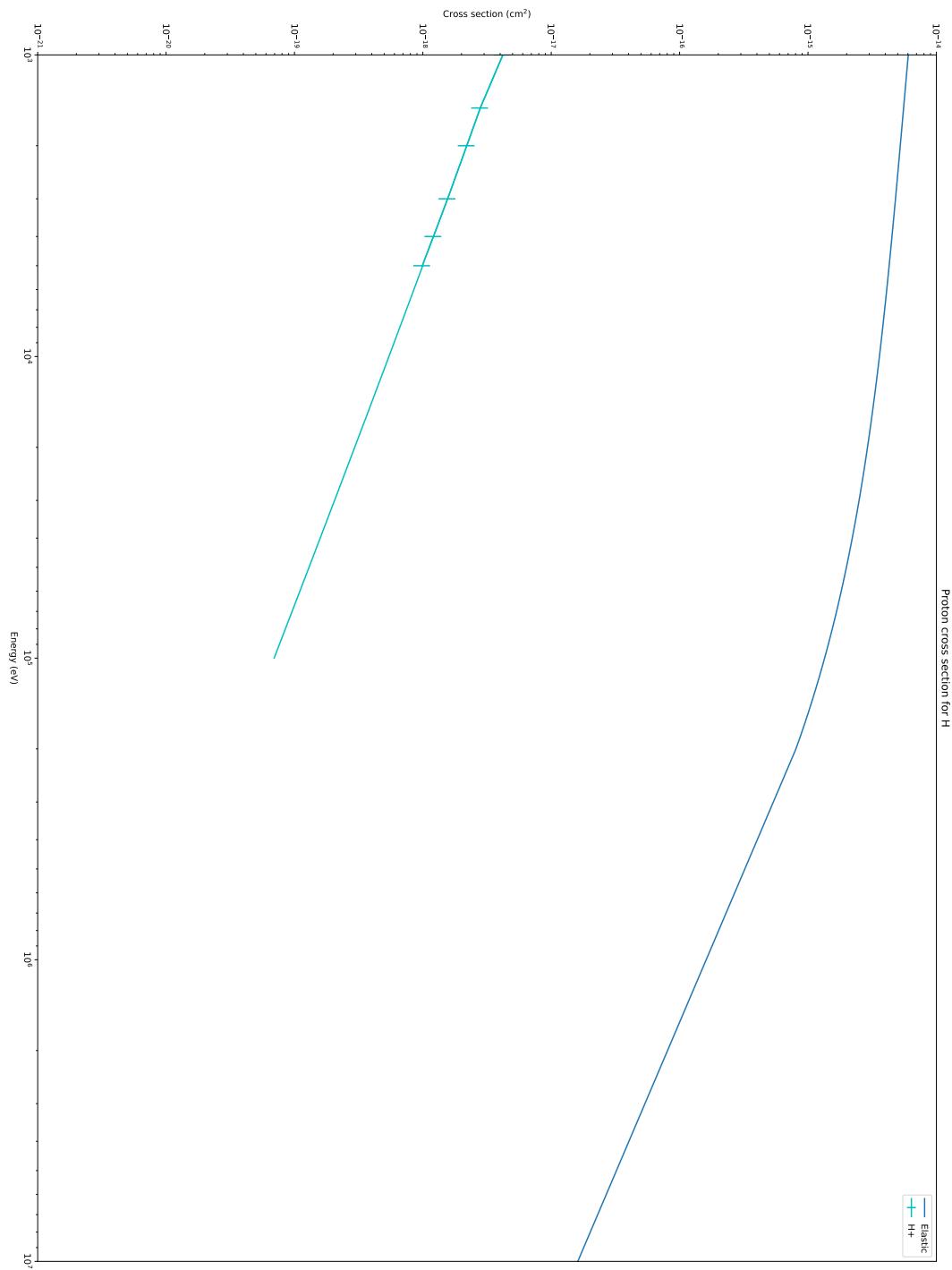
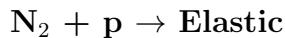
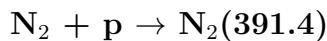
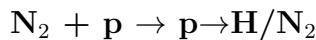
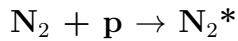


Figure 2.136: Cross sections for Proton cross section for H (wavelength with extrapolation version)

## 2.17 Cross section of p impact with N<sub>2</sub>

### 2.17.1 Inelastic Cross Sections

#### 2.17.2 Recommended data set



#### Legend for the properties

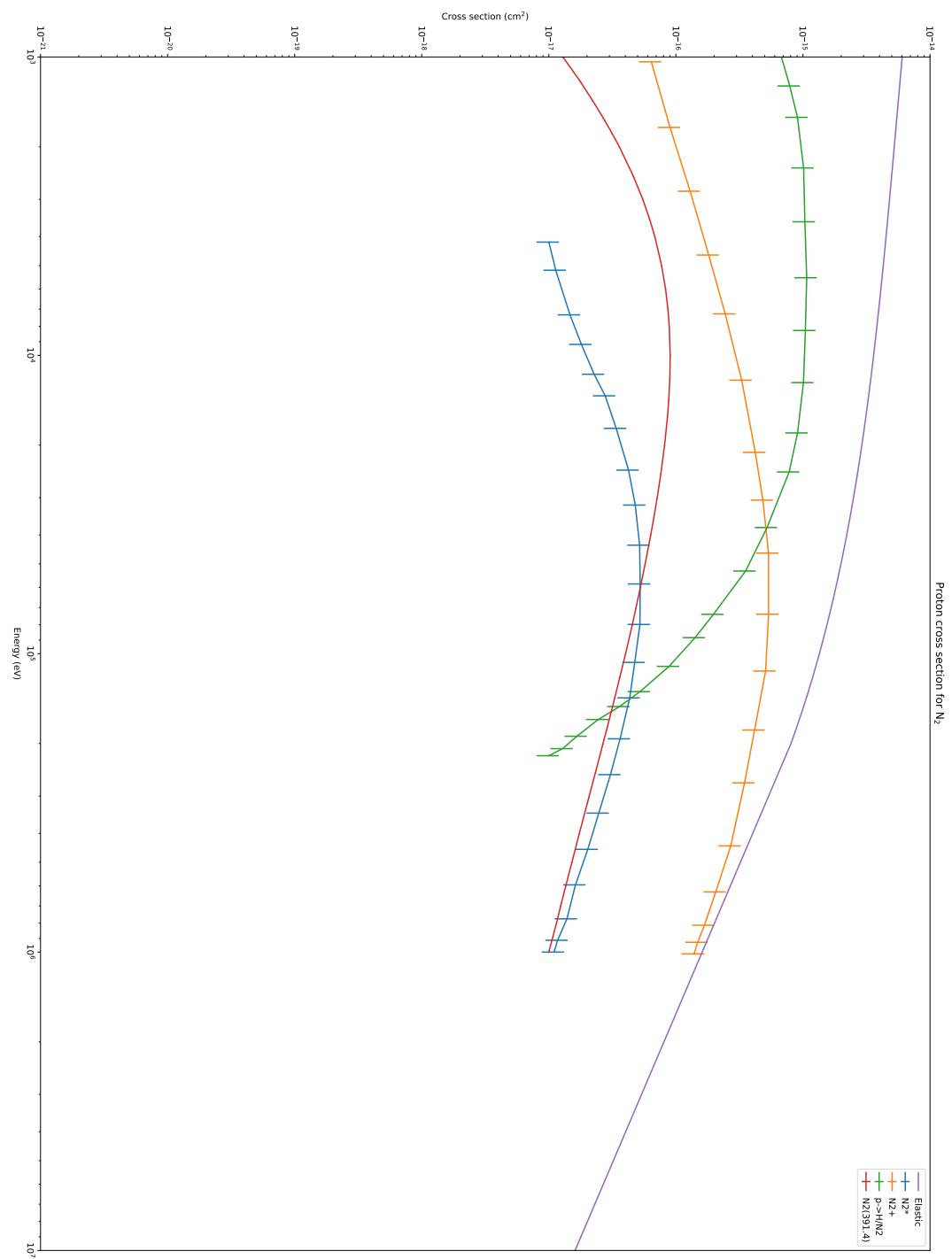
**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Process	Reference	Threshold	Range of energy	Uncertainty	Properties	Plots
$N_2 + p \rightarrow N_2^*$	???? Basu 87 - crsprot.dat	10	10:-1	20%		Fig. 2.137 2.138
$N_2 + p \rightarrow N_2^+$	???? Basu 87 - crsprot.dat	17	17:-1	20%		Fig. 2.137 2.138
$N_2 + p \rightarrow p \rightarrow H/N_2$	???? Green and Peterson 68 - crsprot.dat	13.6	13.6:-1	20%		Fig. 2.137 2.138
$N_2 + p \rightarrow N_2(391.4)$	Revi [3]	18	18:-1	????%	U	Fig. 2.137 2.138
$N_2 + p \rightarrow$ Elastic	Adap Gronoff +Kozelov and Ivanov 1992	0	0:-1	????%	U	Fig. 2.137 2.138

Table 2.48: Recommended Cross section for p impact on  $N_2$

Figure 2.137: Cross sections for Proton cross section for N<sub>2</sub>

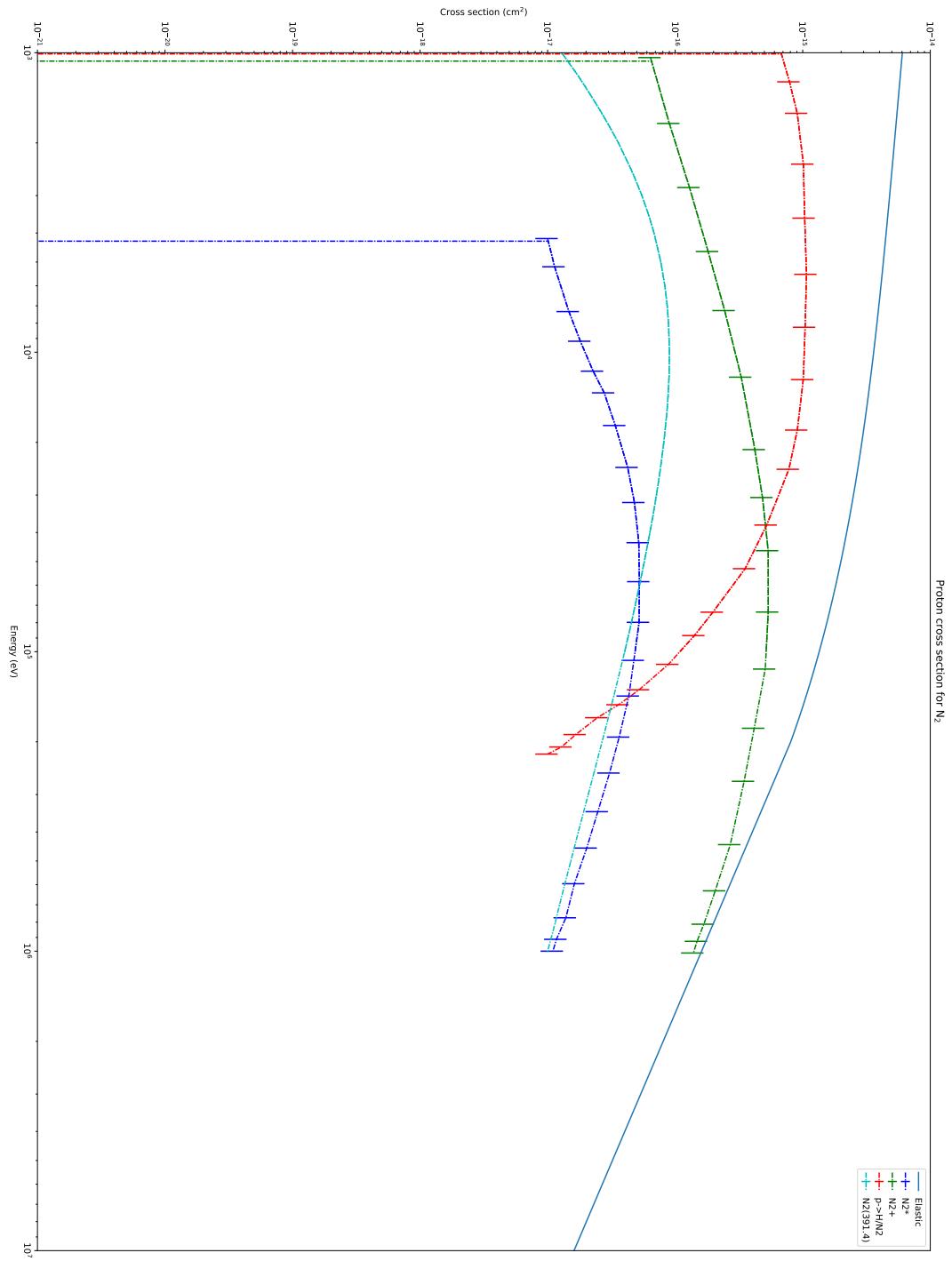
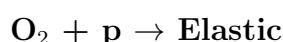
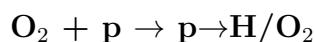
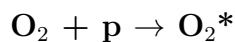


Figure 2.138: Cross sections for Proton cross section for N<sub>2</sub> (wavelength with extrapolation version)

## 2.18 Cross section of p impact with O<sub>2</sub>

### 2.18.1 Inelastic Cross Sections

#### 2.18.2 Recommended data set



#### Legend for the properties

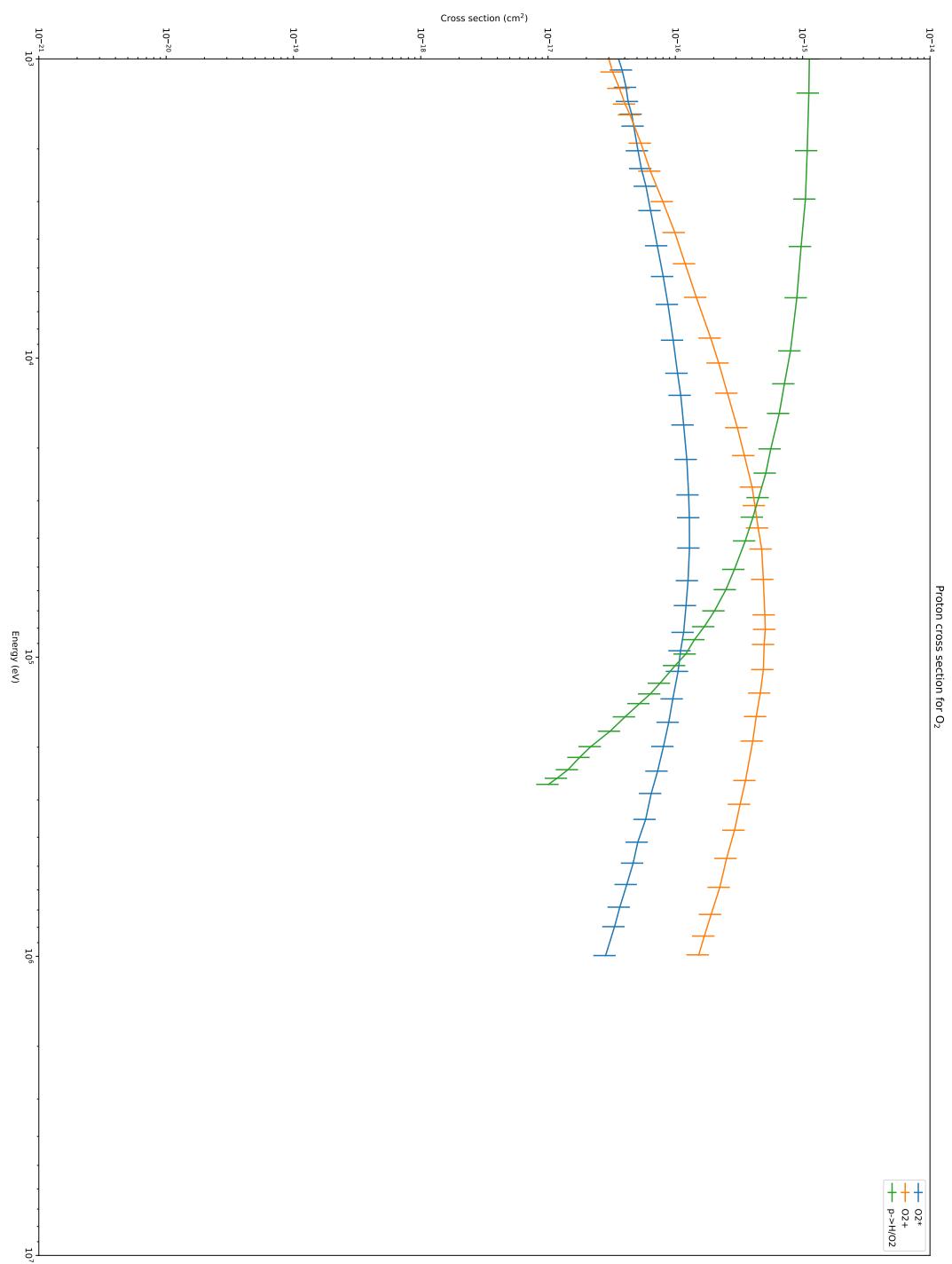
**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Process	Reference	Threshold	Range of energy	Uncertainty	Properties	Plots
$O_2 + p \rightarrow O_2^*$	???? Basu 1987	8	8:-1	20%		Fig. 2.139 2.140
$O_2 + p \rightarrow O_2^\pm$	???? Basu 87 - crsprot.dat	15	15:-1	20%		Fig. 2.139 2.140
$O_2 + p \rightarrow p \rightarrow H/O_2$	???? Green and Peterson 68 - crsprot.dat	13.6	13.6:-1	20%		Fig. 2.139 2.140
$O_2 + p \rightarrow$ Elastic	Adap Gronoff +Kozelov and Ivanov 1992	0	0:-1	????%	U	Fig. 2.139 2.140

Table 2.49: Recommended Cross section for p impact on  $O_2$

Figure 2.139: Cross sections for Proton cross section for O<sub>2</sub>

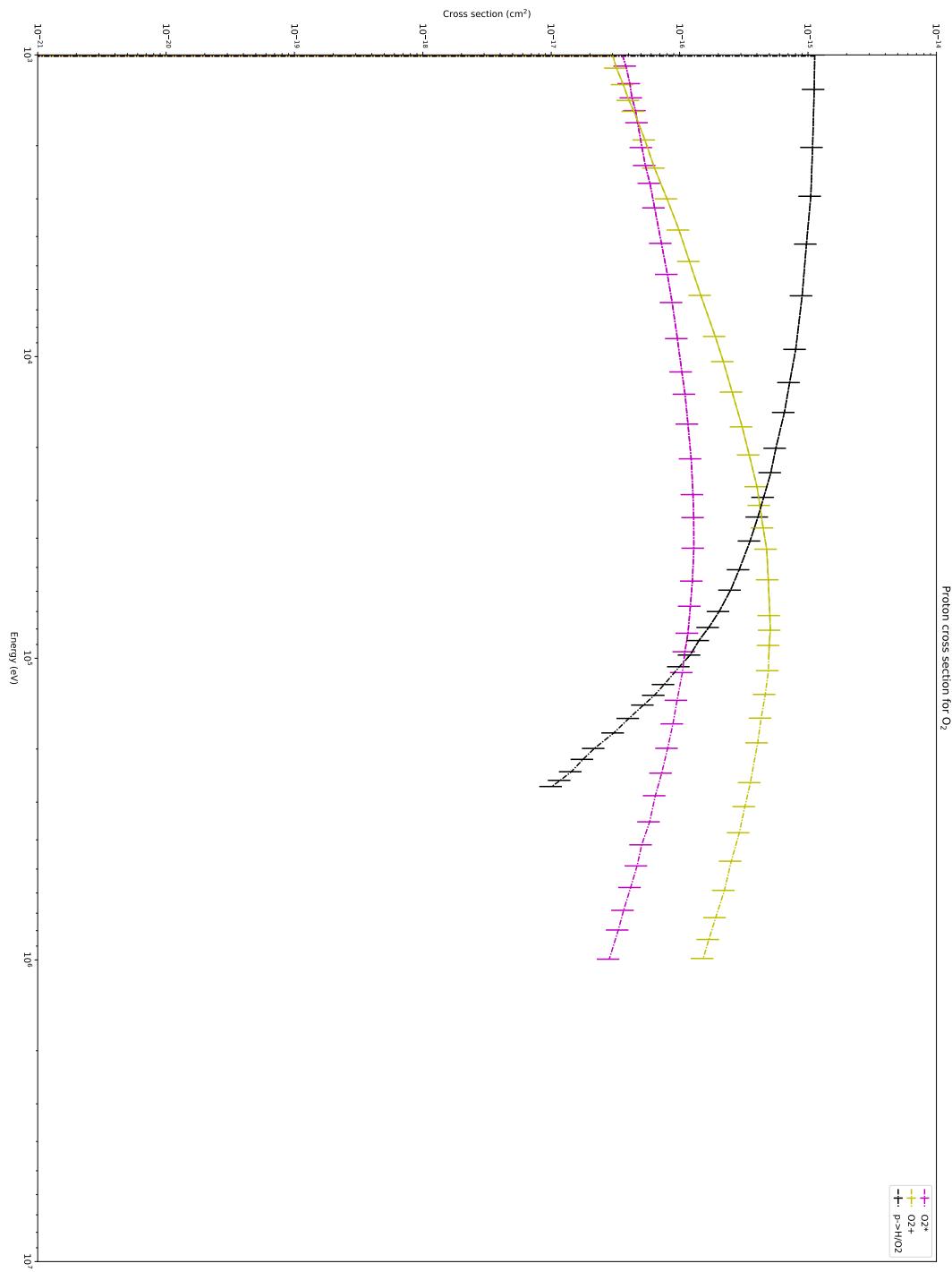
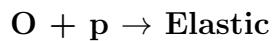
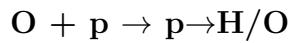
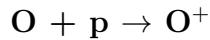
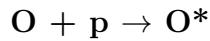


Figure 2.140: Cross sections for Proton cross section for O<sub>2</sub> (wavelength with extrapolation version)

## 2.19 Cross section of p impact with O

### 2.19.1 Inelastic Cross Sections

#### 2.19.2 Recommended data set



#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Process	Reference	Threshold	Range of energy	Uncertainty	Properties	Plots
O + p → O*	???? Basu 87 - crsprot.dat	13	13:-1	20%		Fig. 2.141 2.142
O + p → O <sup>+</sup>	???? Basu 87 - crsprot.dat	16	16:-1	20%		Fig. 2.141 2.142
O + p → p→H/O	????? Green and Peterson 68 - crsprot.dat	13.6	13.6:-1	20%		Fig. 2.141 2.142
O + p → Elastic	???? The work has to be done for this one	0	0:-1	????%	U	Fig. 2.141 2.142

Table 2.50: Recommended Cross section for p impact on O

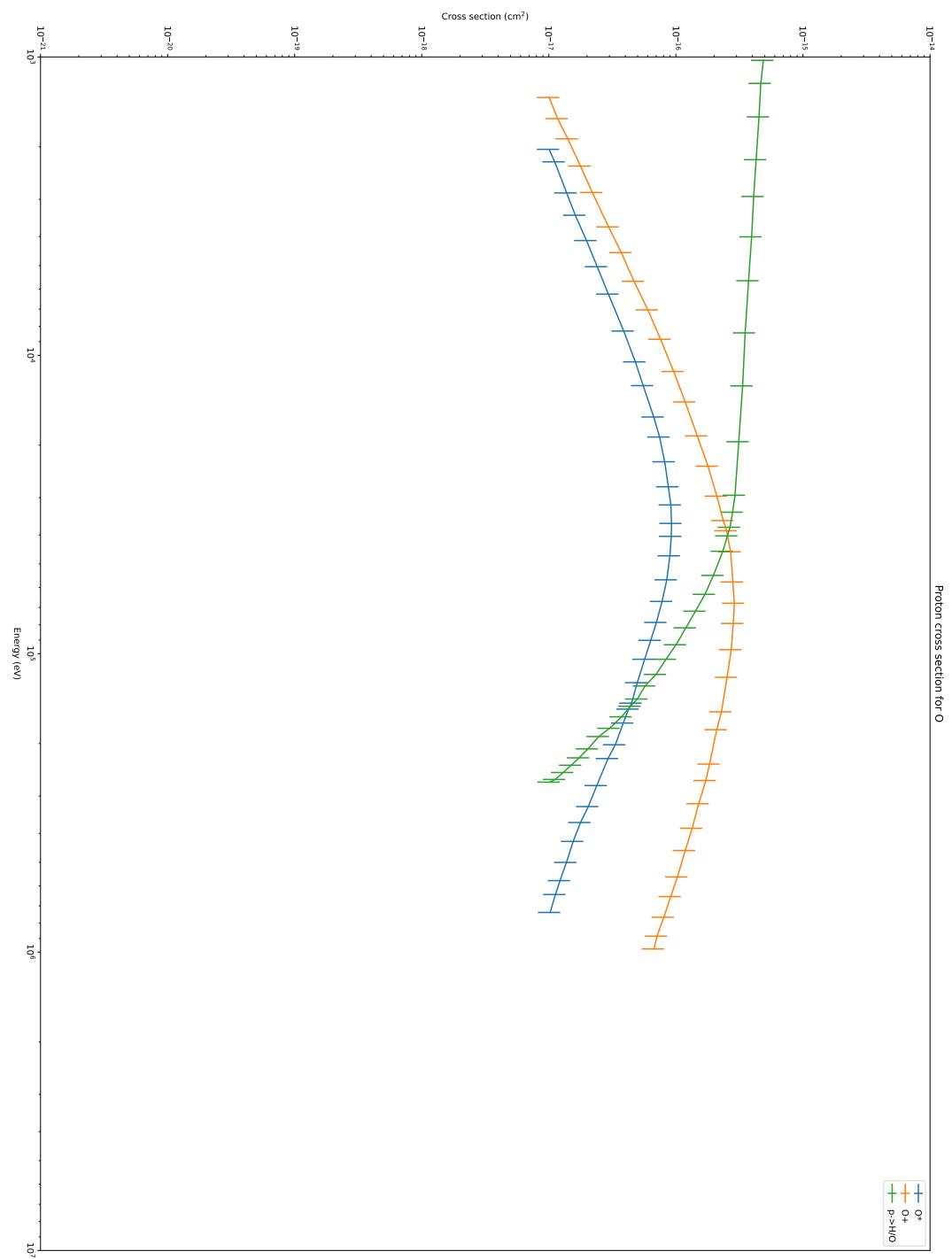


Figure 2.141: Cross sections for Proton cross section for O

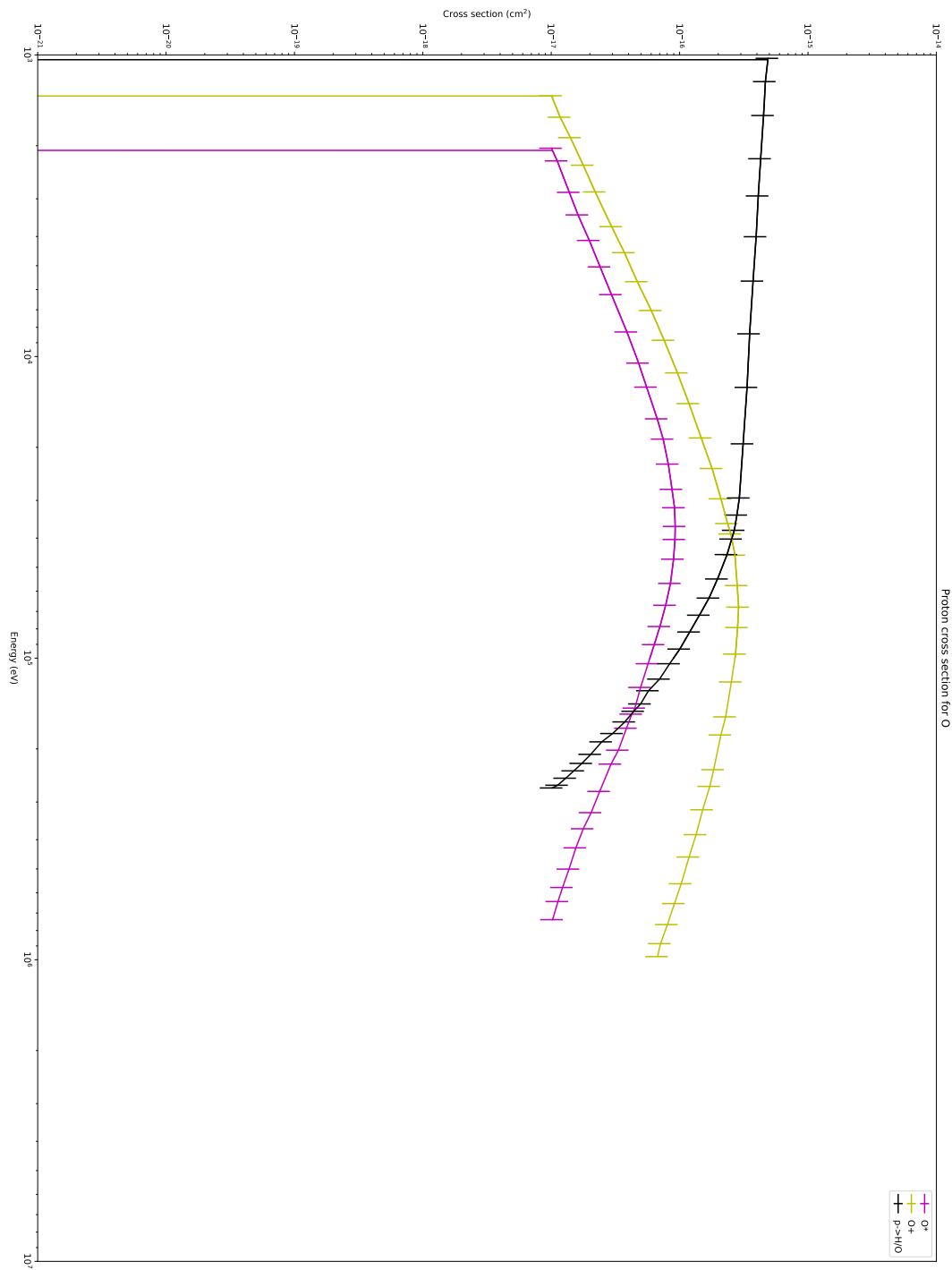


Figure 2.142: Cross sections for Proton cross section for O (wavelength with extrapolation version)

**2.20 Cross section of impact with Hydrogen**

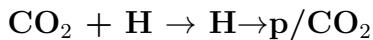
## 2.21 Cross section of H impact with CO<sub>2</sub>

### 2.21.1 Inelastic Cross Sections

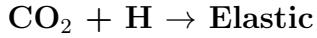
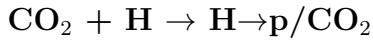
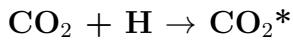
#### Ionization Cross Sections



#### 2.21.2 Emission Cross Sections



#### 2.21.3 Recommended data set



#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Process	Reference	Threshold	Range of energy	Uncertainty	Properties	Plots
$\text{CO}_2 + \text{H} \rightarrow \text{CO}_2^+$	Revi [2] ???? Basu 1987 -[3]- Gronoff Revi Haider 2002	17 17 17	17:-1 17:-1 17:-1	20% 20% 20%		Fig. 2.143 2.144 Fig. 2.143 2.144 Fig. 2.143 2.144

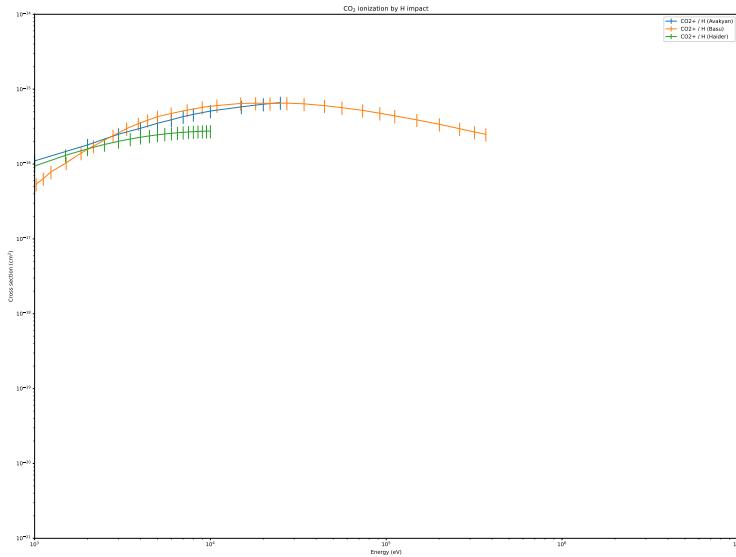
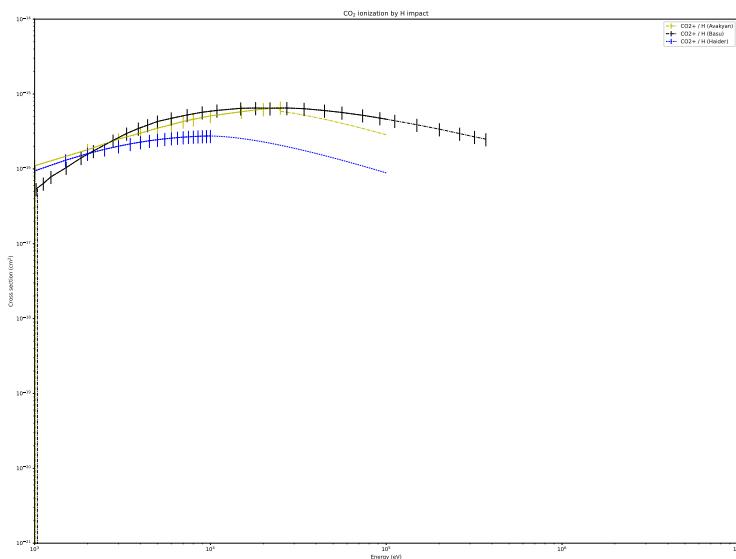
Table 2.51: Ionization Cross section for H impact on  $\text{CO}_2$

Process	Reference	Threshold	Range of energy	Uncertainty	Properties	Plots
CO <sub>2</sub> + H → H → p/CO <sub>2</sub>	Revi [2]	17	17:-1	20%		Fig. 2.145 2.146
	Adap Green 1968 -[3]- Gronoff	3.4	3.4:-1	20%		Fig. 2.145 2.146
	Adap Haider et al. 2002	3.4	3.4:-1	20%		Fig. 2.145 2.146

Table 2.52: Emission Cross section for H impact on CO<sub>2</sub>

Process	Reference	Threshold	Range of energy	Uncertainty	Properties	Plots
$\text{CO}_2 + \text{H} \rightarrow \text{CO}_2^*$	Adap Basu 87 - Gronoff	10	10:-1	20%		Fig. 2.147 2.148
$\text{CO}_2 + \text{H} \rightarrow \text{CO}_2^+$	Adap Basu 87-[3]- Gronoff	17	17:-1	20%		Fig. 2.147 2.148
$\text{CO}_2 + \text{H} \rightarrow \text{H-}\!\!\rightarrow\!\! \text{p}/\text{CO}_2$	Adap Green and Peterson 68 -[3]- Gronoff	3.4	3.4:-1	20%		Fig. 2.147 2.148
$\text{CO}_2 + \text{H} \rightarrow \text{Elastic}$	Adap Gronoff +Kozelov and Ivanov 1992	0	0:-1	?%?	U	Fig. 2.147 2.148

Table 2.53: Recommended Cross section for H impact on CO<sub>2</sub>

Figure 2.143: Cross sections for CO<sub>2</sub> ionization by H impactFigure 2.144: Cross sections for CO<sub>2</sub> ionization by H impact (wavelength with extrapolation version)

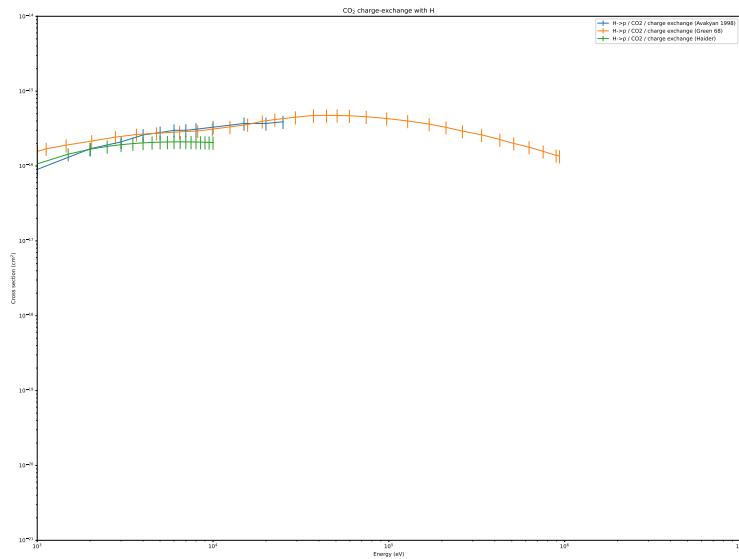


Figure 2.145: Cross sections for CO<sub>2</sub> charge-exchange with H

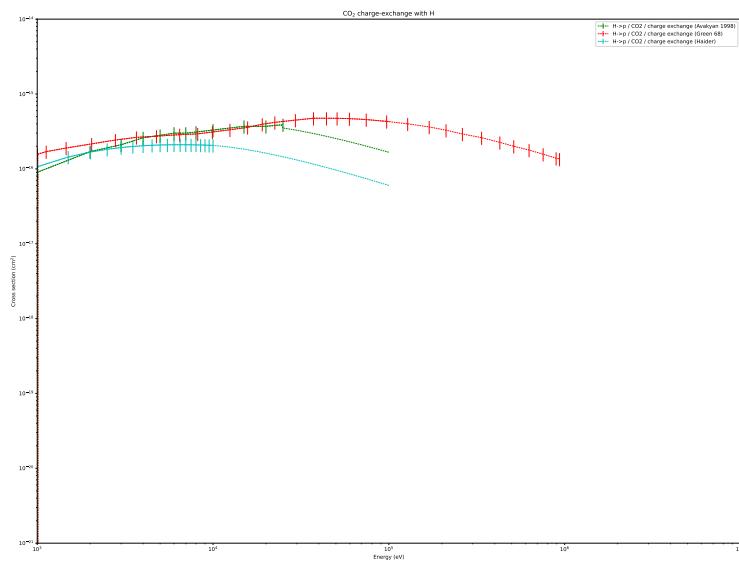
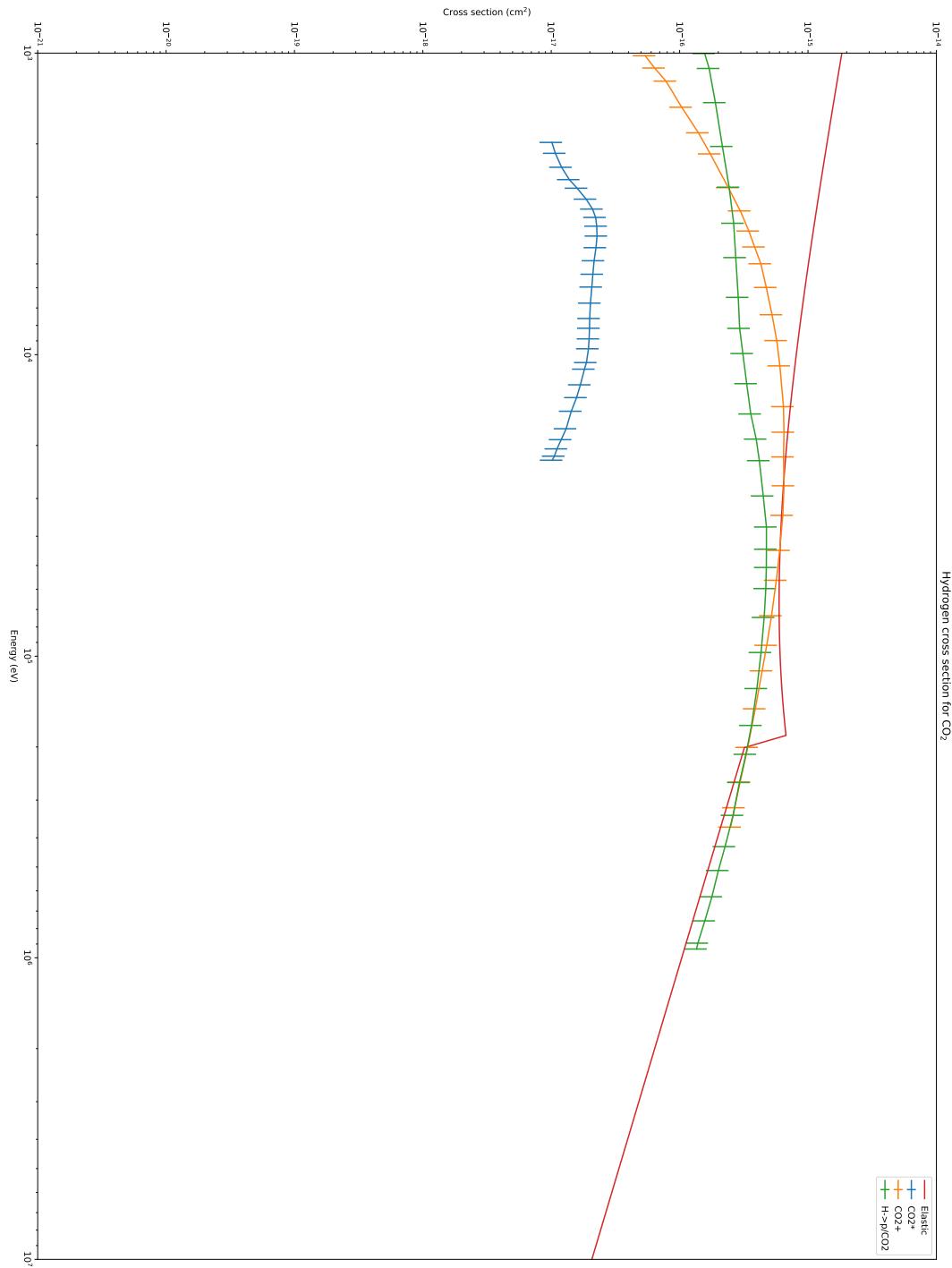


Figure 2.146: Cross sections for CO<sub>2</sub> charge-exchange with H (wavelength with extrapolation version)

Figure 2.147: Cross sections for Hydrogen cross section for CO<sub>2</sub>

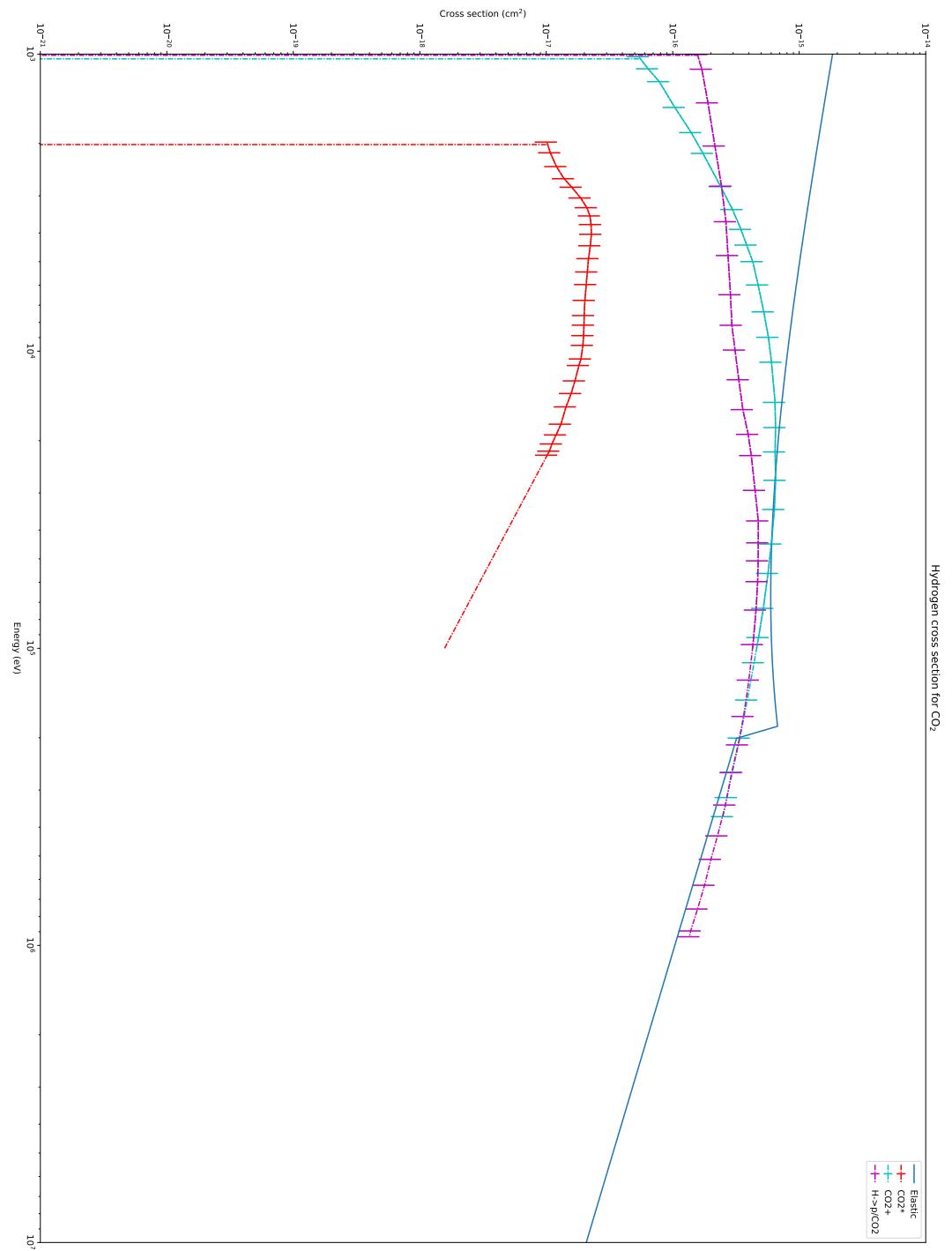
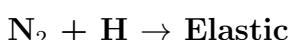
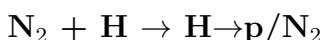


Figure 2.148: Cross sections for Hydrogen cross section for CO<sub>2</sub> (wavelength with extrapolation version)

## 2.22 Cross section of H impact with N<sub>2</sub>

### 2.22.1 Inelastic Cross Sections

#### 2.22.2 Recommended data set



#### Legend for the properties

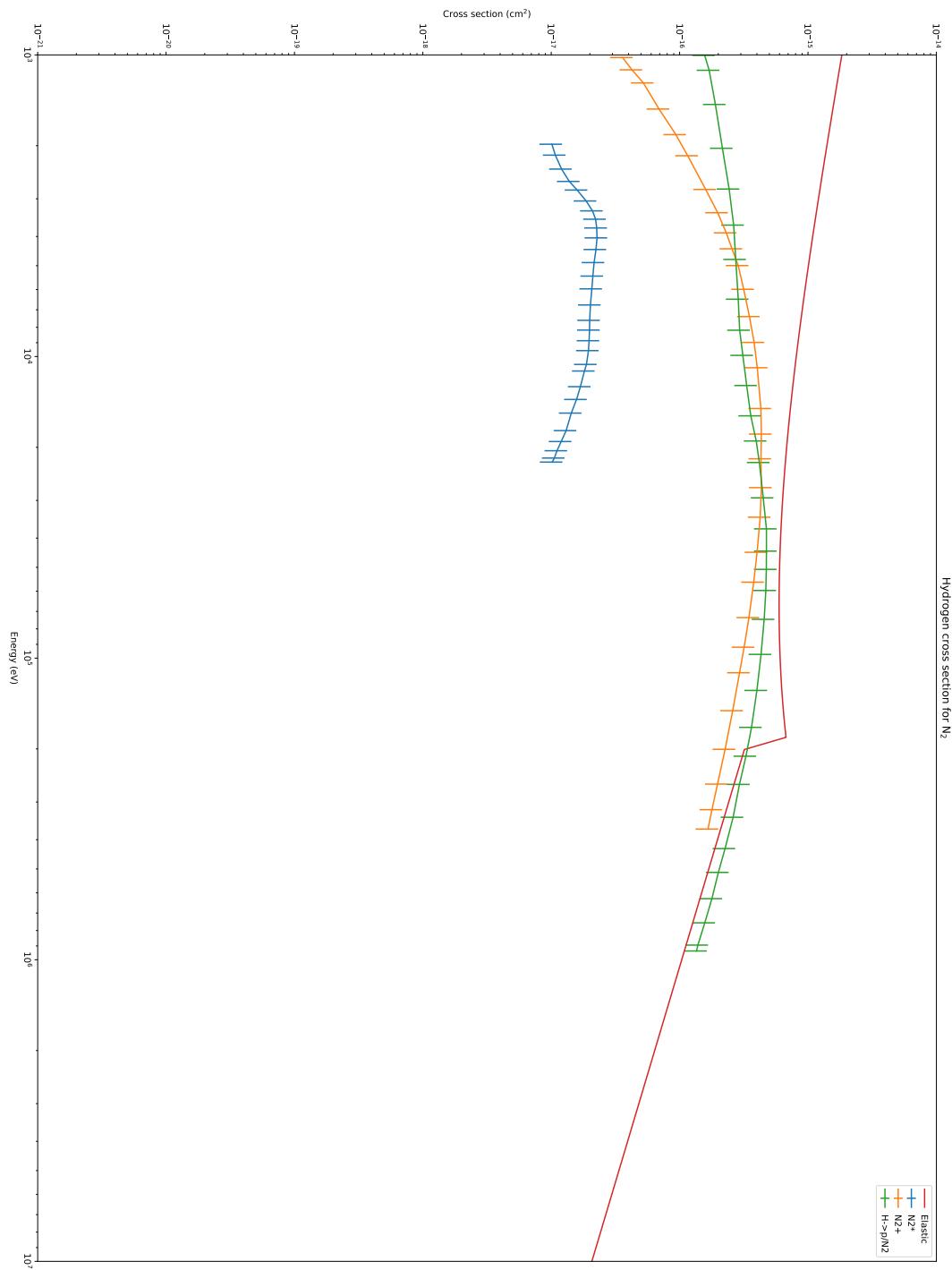
**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Process	Reference	Threshold	Range of energy	Uncertainty	Properties	Plots
$N_2 + H \rightarrow N_2^*$	Revi Basu 1987	10	10:-1	20%		Fig. 2.149 2.150
$N_2 + H \rightarrow N_2^+$	Revi Basu 87	17	17:-1	20%		Fig. 2.149 2.150
$N_2 + H \rightarrow H \rightarrow p/N_2$	Revi Green and Peterson 1968	3.4	3.4:-1	20%		Fig. 2.149 2.150
$N_2 + H \rightarrow$ Elastic	Revi Kozelov and Ivanov 1992	0	0:-1	??%	U	Fig. 2.149 2.150

Table 2.54: Recommended Cross section for H impact on  $N_2$

Figure 2.149: Cross sections for Hydrogen cross section for N<sub>2</sub>

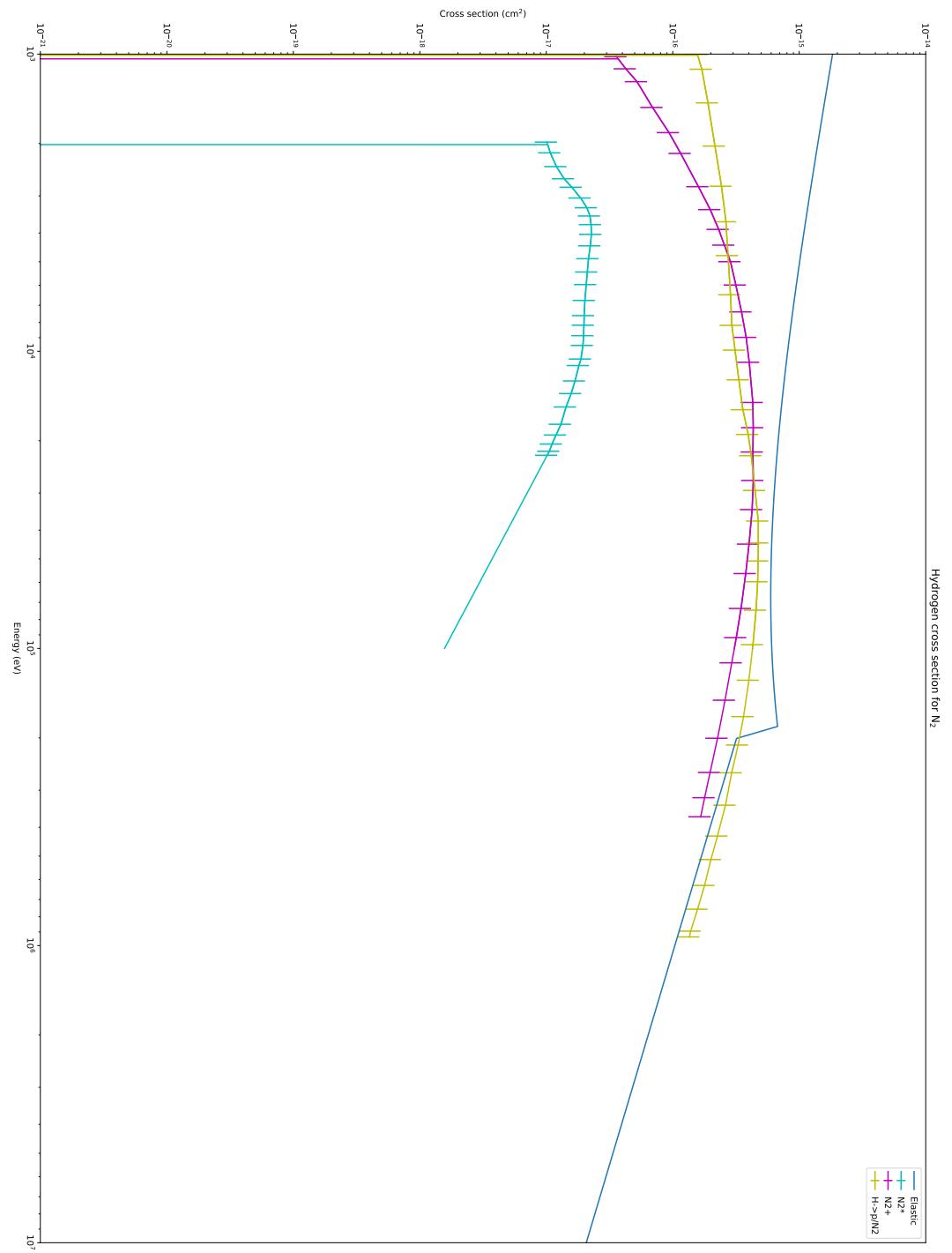
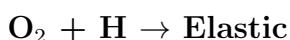
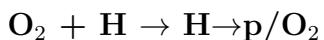
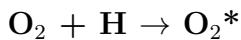


Figure 2.150: Cross sections for Hydrogen cross section for  $\text{N}_2$  (wavelength with extrapolation version)

## 2.23 Cross section of H impact with O<sub>2</sub>

### 2.23.1 Inelastic Cross Sections

#### 2.23.2 Recommended data set



#### Legend for the properties

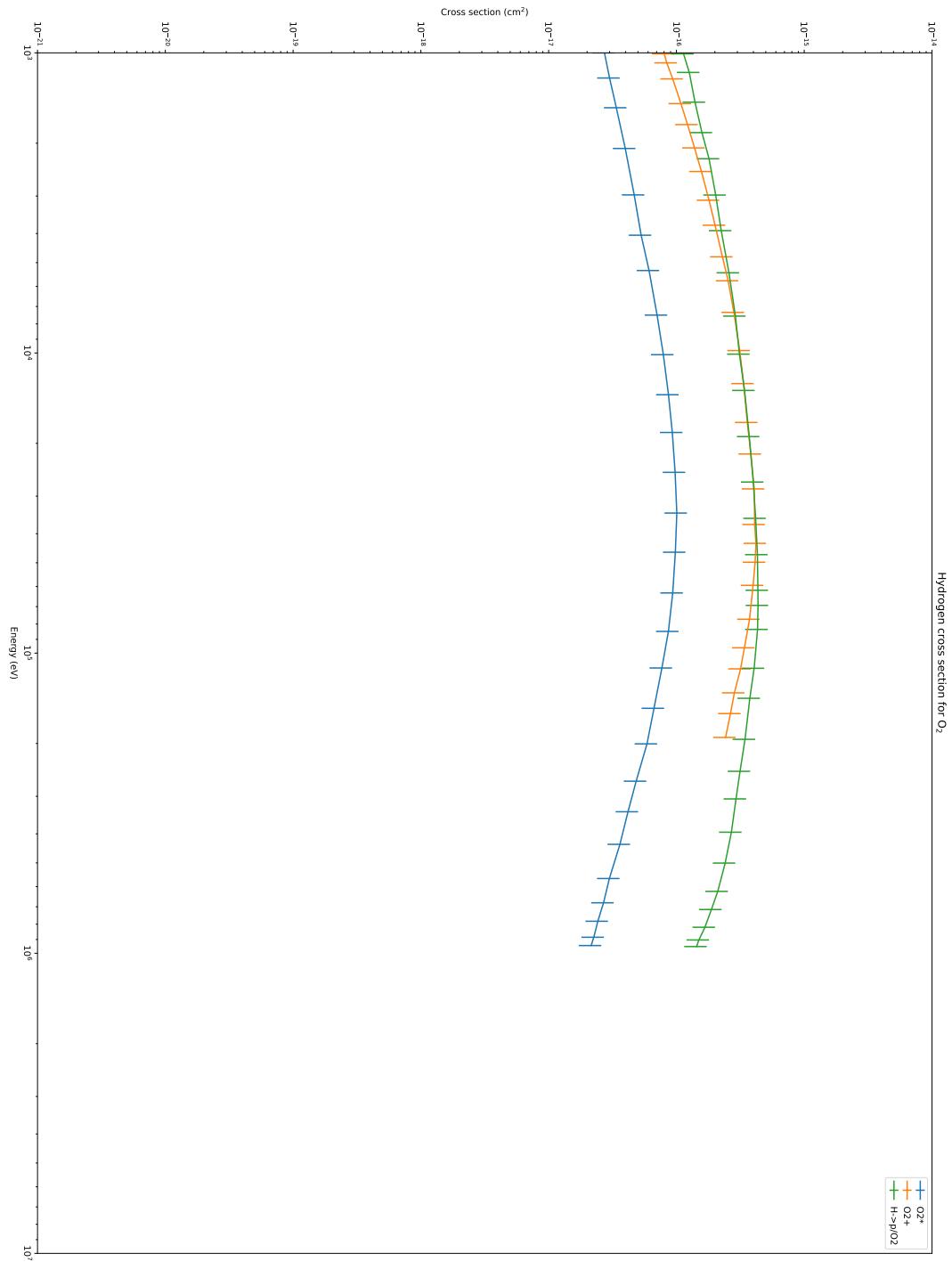
**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Process	Reference	Threshold	Range of energy	Uncertainty	Properties	Plots
$O_2 + H \rightarrow O_2^*$	Revi Basu 1987	8	8:-1	20%		Fig. 2.151 2.152
$O_2 + H \rightarrow O_2^+$	Revi Basu 1987	15	15:-1	20%		Fig. 2.151 2.152
$O_2 + H \rightarrow H \rightarrow p/O_2$	Revi Green and Peterson 1968	1.4	1.4:-1	20%		Fig. 2.151 2.152
$O_2 + H \rightarrow$ Elastic	???? The work has to be done for this one	0	0:-1	??% ??%	U	Fig. 2.151 2.152

Table 2.55: Recommended Cross section for H impact on  $O_2$

Figure 2.151: Cross sections for Hydrogen cross section for O<sub>2</sub>

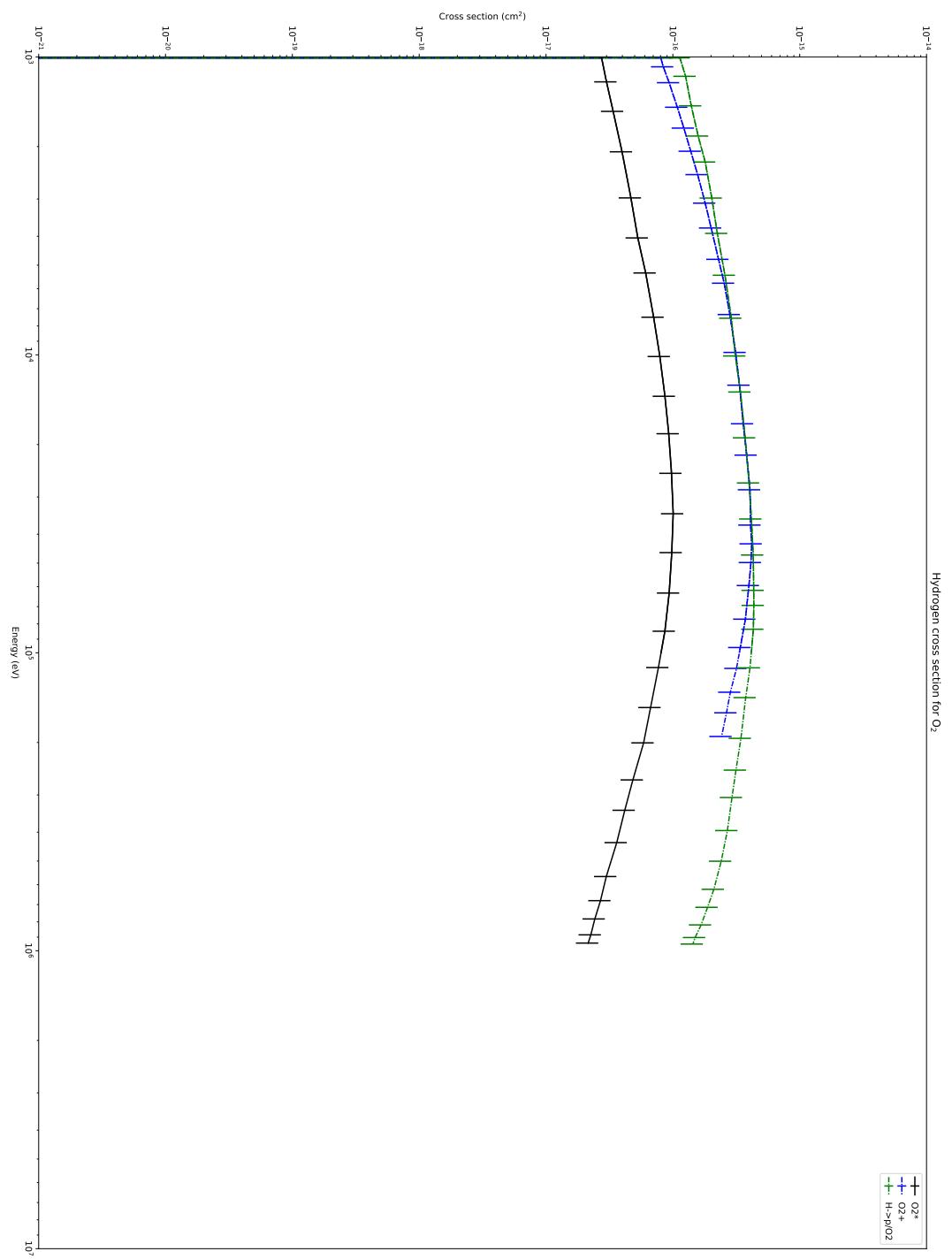
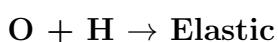
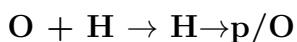


Figure 2.152: Cross sections for Hydrogen cross section for O<sub>2</sub> (wavelength with extrapolation version)

## 2.24 Cross section of H impact with O

### 2.24.1 Inelastic Cross Sections

#### 2.24.2 Recommended data set



#### Legend for the properties

**R** : Recommended cross section for the processus. It is used in the main file. The selection of the recommended cross section is based on the quality of the data (e.g. errorbars, comparison with other experiments), the possibility of extrapolation, and the origin of the work, coupled with the consistency (sum of recommended cross sections / Total cross section)

**U** : Estimated uncertainty: sometimes, the uncertainty is not given, because of theoretical work... The authors of the database have to estimate the uncertainty, but the quality of that estimation can be questionable. Moreover, when data from different sources have been adapted (e.g. for extrapolation), the uncertainty can be modified...

**E** : Validated for extrapolation: the extrapolation of these cross sections is plausible. For example, when an analytic function has been applied...

Process	Reference	Threshold	Range of energy	Uncertainty	Properties	Plots
O + H → O*	Revi Basu 1987	13	13:-1	20%		Fig. 2.153 2.154
O + H → O <sup>+</sup>	Revi Basu 1987	16	16:-1	20%		Fig. 2.153 2.154
O + H → H→p/O	Revi Green and Peterson 1968	2.4	2.4:-1	20%		Fig. 2.153 2.154
O + H → Elastic	???? The work has to be done for this one	0	0:-1	????%	U	Fig. 2.153 2.154

Table 2.56: Recommended Cross section for H impact on O

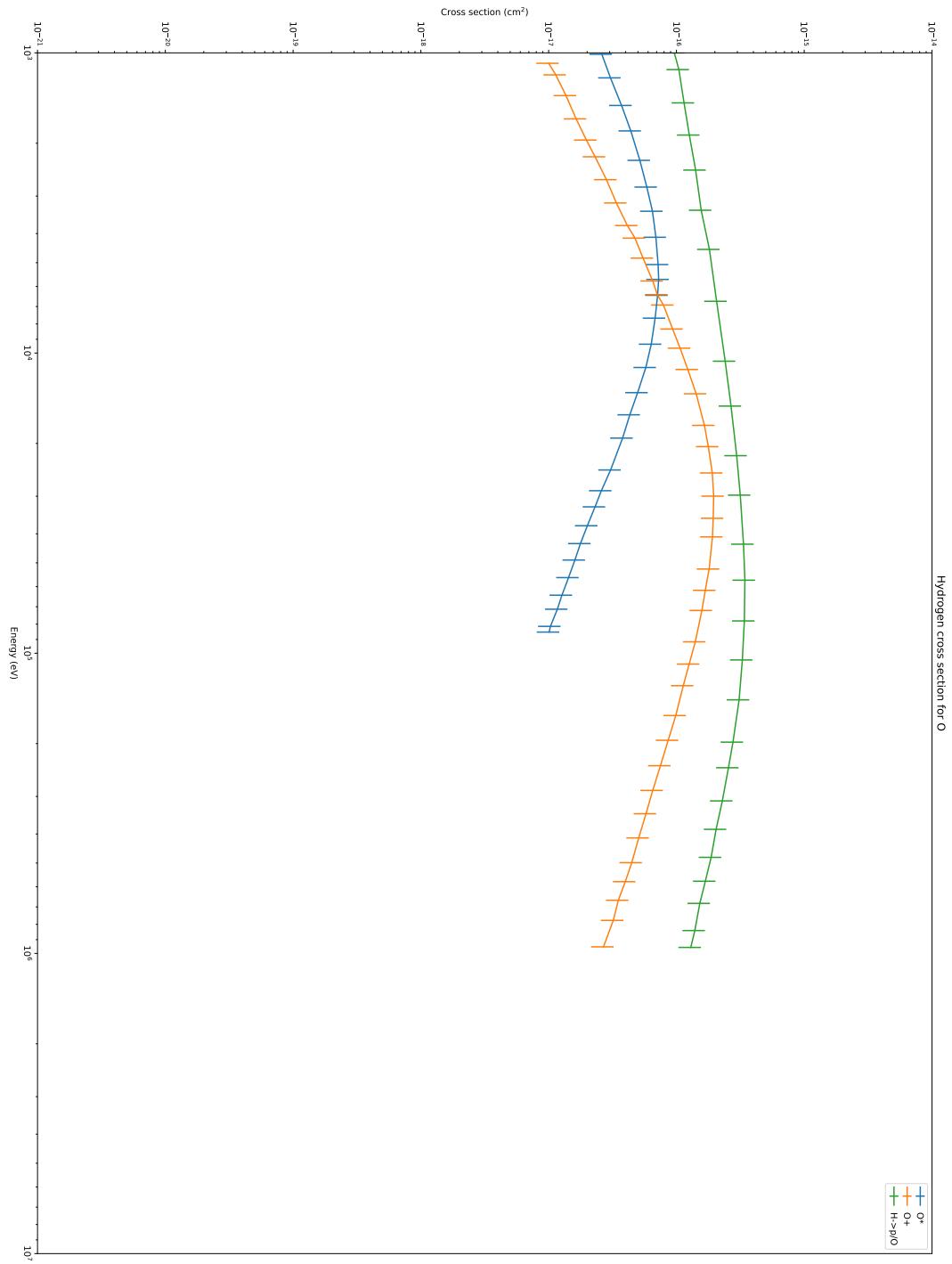


Figure 2.153: Cross sections for Hydrogen cross section for O

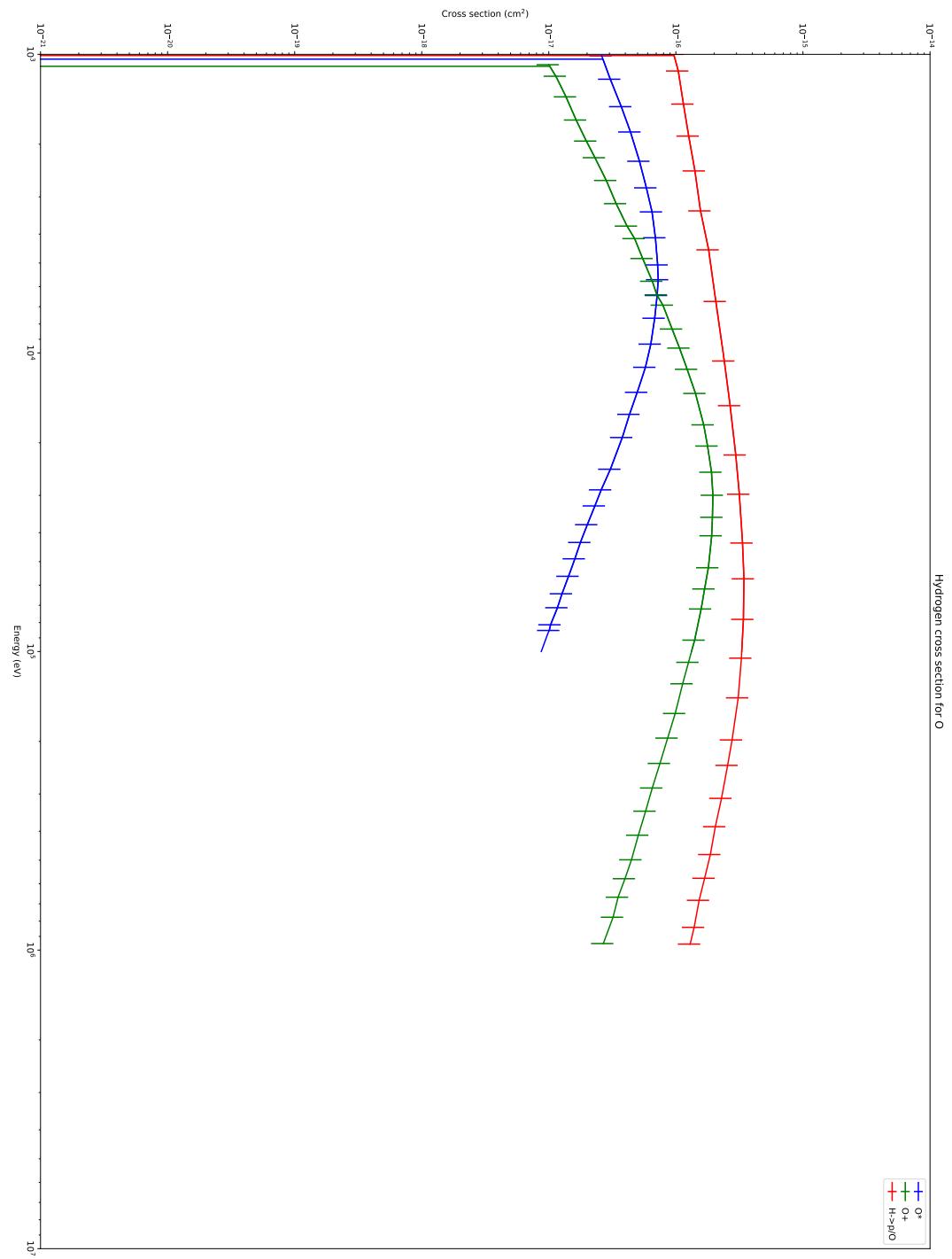


Figure 2.154: Cross sections for Hydrogen cross section for O (wavelength with extrapolation version)

# Chapter 3

## Sources for specific state or ions

### 3.1 Automatic computation of the list

The list can be automatically generated from the different files, or the recommended cross section file.

For consistency reasons, the following list was generated from the recommended set of data. The main reason lies in the non-recommended files: sometimes, the authors cannot discriminate between two species with their experiment, and then, gives the production for the two species (example:  $O_2^{++}$  and  $O^+$  cannot be discriminated in standard ion mass spectrometer). It is stated in the specie list for that cross section in the non-recommended set, while in the recommended one, we tried to extract the species produced).



# Chapter 4

## Evolution of the database

We have a basic set of cross-sections for the impact of Hydrogen and Protons, however, this part of the database is quite sparse and should be further improved.

Other evolution for the database include taking into account the temperature dependence of the cross-sections, notably for the photodissociation of molecules at cross-sections in the 200-300 nm range. This would require a more detailed study of the temperature dependence of the cross-sections, and the implementation of a temperature-dependent database. This is particularly important for the deeper parts of the atmospheres, such as the O<sub>3</sub> layer, where the temperature-dependence of the cross-sections can be significant.

Another potential source of evolution is for the ionization of ions and multiple-ionization cross-sections.



# Chapter 5

## Conclusion

The **AtMoCiad** database, presented here, will soon be released on internet, with free access. Contrarily to older databases, the design, presented in the appendixes, was developed for frequent modification and updates. Moreover, it is intended to be extended and completed for the scientific community, by the scientific community.

More than an useful tool for each user, **AtMoCiad** is also the basis for comparing the different codes developed by the modelers, along with a reference for the experimental community, and especially the laboratory that measure these cross sections.



# Appendix A

## The XML files

### A.1 Working with XML files

XML is a kind of standardized ASCII file. It looks like HTML, but strict (markup should be closed, no bracing like `< a >< b >< /a >< /b >` but `< a >< b >< /b >< /a >`). It is well suited for defining configuration, especially for communication between different softwares. Unfortunately for scientific purpose, it does not explicitly defines the notion of array (some specific files format, like hdf, are more suited when dealing with very large data files): list of numbers are used as array for the following.

Several advantages can be found in XML files:

1. Flexibility: you can make a lot of commentaries: reading XML files does not depend on the position of your data (contrary to the typical interface file in Fortran, for which the number of value to read has to be stated).
2. Size of data: you don't have to declare the size of your arrays, it is computed automatically.
3. Position of your information: you can put the information wherever you want! For example AeroPlanets uses a XPath wrapper to read the file: it depends on the hierarchy and the name of the markup.
4. Possibility to duplicate markup. Typically the output of selected species production! You can select different species...
5. Mixing strings and numbers! This allows REALLY flexible softwares. Typically in this case, you define the species, and its cross section.

Therefore, the addition of a new species can be straightforward<sup>1</sup>.

## 6. Widely used formating system. It is easy to write

Of course, when implementing a full support of XML files, you have to take into account several points:

- XML is not a real user-computer interface. But editors exists, and it is the best format if you plan to add a web-based interface.
- XML is not dedicated to large dataset. When dealing with very big files, you should consider using HDF (binary, but without endianness problems).
- For the present database, the need for flexibility (frequent modifications), for interfacing (plot, python, C++), and for ease of integration into a system dedicated for several planets, oriented us toward the direct use of XML files<sup>2</sup>

As you can see, the authors of this documents highly encourage the use of the XML (and HDF) file format.

Anyway, to have a comprehensive XML file, i.e. really flexible and usable in your model, several concepts needs to be understood.

### A.1.1 Hierarchy

The hierarchy of the markup is very important. Hierarchy means dependence. It is well suited for large set of options. Example, to define the mass and the ground state of CO<sub>2</sub>, the XML way could be:

```
<!-- The XML comment are inside this king of strange brackets! -->
<CO2>
<!-- Mass in amu -->
<mass>44.00995</mass>

<!-- List of possible states, beginning with the ground state -->
<states>
X
```

---

<sup>1</sup>It is especially true in AeroPlanets , you can define a new species in your database, then add its atmospheric model in the configuration file! In other terms, you can add a specie in a planet model without modifying the source code and so without recompilation.

<sup>2</sup>For people considering using other file format, the best solution is to use python-elementtree to create a conversion software.

```
</states>
<!-- ... -->
</CO2>
```

Here, state and mass are hierarchically inferior to CO2. (Note the way we write commentaries `<!-- -->`). Such writing allows to define several species, with the same template<sup>3</sup>.

**In the following, the hierarchy for the options will be written in a XPATH-style.**

It means that the “mass” option in the precedent example will be presented as `/CO2/mass`.

## A.1.2 Markup keys

Sometimes<sup>4</sup>, we can use a key inside the markup `<truc key='42'>bla</truc>`. We use this option to add simple statements, like model type:

```
<!-- altitude grid -->
<alt_grid>
<!--
use_model type:
0 : standard grid
1 : data
-->
<use_model type="0"/>
<!--
If we use a standard grid, the options are:
type 0 : exp decrease
type 1 : power law decrease
type 2 : constant width
-->
<st_grid type="0">
<altmin>120</altmin>
<altmax>300</altmax>
<number>50</number>
</st_grid>

<alldata></alldata>
```

---

<sup>3</sup>Note to developers: XPath defines nodes to work with such templates.

<sup>4</sup>Strictly speaking, use of keys can be avoided in XML: it could be replaced by the use of a hierarchically inferior markup. Anyway, we sometimes prefer not to write the closing markup: understandable names are sometimes very long... .

```
</alt_grid>
```

This facility is really powerful when we work with uncertainties:

```
<Cross unit="cm2" uncertainty="30%">
...

```

We can define the uncertainty for an array really easily.

### A.1.3 Numerical values

Two key are very important for the database, the “fact” and “uncertainty” keys.

These are used a lot in the definition, and bad interpretation of the database could come from the misuse of these keys.

#### The “fact” key

The numerical values can be modified thanks to the “fact” key. For example:

```
<a fact='12'>1</a>
```

will give a result of 12 if it is treated as a numerical value.

#### The “uncertainty” key

As explained before, this key is used to define the uncertainty of the dataset. If used with a % sign, it is perceived as a percentage. If not, it should be taken as the  $1-\sigma$  difference.

## A.2 The cross section files

The cross section XML files are the core of the database. They can easily be modified, transformed into other kind of files, or automatically plotted with the specific tools.

These standardized files also contains information to automatically create the web and pdf interfaces to the database. The photoionization cross sections files are the simplest, because more information are needed for the electron files. Therefore, we will describe the photon files before the improvements in the electron files.

The recommended cross section files are the dataset that should be used in the different softwares. In AeroPlanets , these XML files are directly used as inputs.

### A.2.1 The heading of the cross section files

To ensure the validity of the documents, it starts and ends with the “<crs>/</crs>” markup. The cross sections, should be put in the valid format inside a SPECIE markup. For example, for a file with CO<sub>2</sub> and O<sup>+</sup> cross sections, the file should look like:

```
<crs>
...
<CO2>
...
</CO2>
...

<O_PLUS>
...
</O_PLUS>
</crs>
```

Because the ‘+’ character is not allowed inside the XML markup name, it has to be transformed into \_PLUS in the database.

Strictly speaking, the cross section files are meant to describe only one species, and only one kind of interaction.

This allows an automatic plot and some other automatic interactions, by putting some markup specific to that file.

For example, if one file contains the cross sections for one process, from different sources. We could define a specific title, limits for an automatic plot, plotname...

**/crs/Name :** The name of the species that reacts. (\*)<sup>5</sup>

**/crs/Collider :** The name of the particle that impacts with the species (ph for photons, e for electrons, and soon p for protons). (\*)

**/crs/RecommendedFile :** If the RecommendedFile markup is present, the system knows that it is likely to be the whole set for the different cross sections. It is notably used inside the plotting system to plot the name of the process for each cross section, and not the extended legend.

---

<sup>5</sup>(\*) stands for mandatory options.

**/crs/title :** Title of the cross section file, typically written in latex: the pylab library is able to transform formulae for the title of the plots. (\*)

**/crs/Emin :** For plotting: lower energy boundary. (\*)

**/crs/Emax :** For plotting: upper energy boundary. (\*)

**/crs/Cmin :** For plotting: lower cross section boundary. (\*)

**/crs/Cmax :** For plotting: upper cross section boundary. (\*)

**/crs/plotname :** The name of the standard plot (no extrapolation, abscissa unit is energy in eV). (\*)

**/crs/lambplotname :** If present, creates a plot against wavelength (no extrapolation, abscissa unit is in angstrom).

**/crs/explotname :** If present, extrapolates the standard plot (extrapolation, abscissa unit is energy in eV)

**/crs/exlambplotname :** If present, extrapolates the wavelength plot (extrapolation, abscissa unit is in angstrom).

**Example: the header for the recommended CO<sub>2</sub> + λ cross section file**

```
<crs>
<Name>CO2</Name>
<Collider>ph</Collider>
<RecommendedFile/>
<title> CO$._2$ + $\\lambda$</title>
<Emin>5</Emin>
<Emax>1E5</Emax>
<Cmax>1E-15</Cmax>
<Cmin>1E-28</Cmin>
<plotname>seff_CO2_ph_recommended.pdf</plotname>
<lambplotname>seff_CO2_ph_recommended_lambda.pdf</lambplotname>
<explotname>seff_CO2_ph_recommendedex.pdf</explotname>
<exlambplotname>seff_CO2_ph_recommended_lambdaex.pdf</exlambplotname>
<CO2>
```

```
...
</C02>
</crs>
```

### A.2.2 The photoionization cross section file (cross section basic file)

The cross sections works like the species file concerning the name (except that the highest markup<sup>6</sup> is “crs”).

**/crs/species** The species markup. Highest markup for the real definition.

**/crs/species/TotalCrs** This markup allows to define the total cross section. Very useful when we know it: it is really more precise than sum up ionization cross section.

The typical use of this markup is :

```
<TotalCrs>
<Egrid unit="eV">
</Egrid>
<Cross unit="cm2">
</Cross>
</TotalCrs>
```

Typically, the unit can have the uncertainty key:

```
<Cross unit="cm2" uncertainty="30%">
<Cross unit="cm2" uncertainty="0.1">
```

You can define an  $1\sigma$  uncertainty in percentage: very useful when your cross section varies on a huge range of parameters! But you can also give a relative uncertainty, in the example, 0.1 stands for  $\pm 0.1$ .

In both sub-markup, a “unit” key is defined. It is not used in AeroPlanets now<sup>7</sup>, but:

- It is better when you check your data.
- It allows to be used of the standard units for the code.
- It can really be useful when used with other sources.

---

<sup>6</sup>All the files will have an highest markup now: it allows to look at the XML file with firefox, and therefore to allows firefox to detect the XML errors!

<sup>7</sup>Boost has a unit module...

Now, the only accepted units are “eV” for the energy grid and “cm<sup>2</sup>” for the cross sections.

Of course, you could use the “fact” option to modify the global value, this is the best way to transform Barn into cm<sup>2</sup>...

**/crs/species/TotalCrsIsTheSum** As stated in the main document, for photoionization, it is better to have a total absorption cross section, instead of adding the other cross sections, because the uncertainty of the flux would be decoupled from the uncertainties of each processes which can be variable. Anyway, if you do not have a total cross section, just add

```
<TotalCrsIsTheSum/>
```

it allows to define that the total cross section is the sum of the other.

**/crs/species/Process** keys: name of the process, number of electrons, and threshold. It is also possible to add ions, very useful when double ionization. Note that the number of ions of electrons are floating point values<sup>8</sup>!

The number of electrons could be 0 even if there is an ionization. This is a technique used to take into account one excited state of an ion while the total ionization is computed through a more precise cross section.

```
<Process name="" electrons="" threshold="">
<!-- also possible:
<Process name="" electrons="" threshold="" ions="">
-->
<Species>
<Specie name="" state="" />
<Specie name="" state="" number="" />
</Species>
<Egrid unit="eV">
</Egrid>
<Cross unit="cm2">
</Cross>
</Process>
```

**/crs/species/Process/Species** The Species defines a list of species created through the process.

---

<sup>8</sup>Useful when the produced species are determined with a branching ratio.

**/crs/species/Process/Species/Specie** One of the created species (you can have several species, or 0! -but it is not really useful unless this is necessary for total crs sum- ). The key for the species is its name and its state. The state can be X. It allows to compute the production of excited states! One of the very important point for the species state is the possibility to add “-NOTOT” at the end of the state. It defines that the state created for the species has already been counted in the total species production.

For example, the electron production for  $\text{CO}_2^+$  can be computed without taking into account the different states. But if we need the A state, we have to add the Itikawa 2002 cross section. If we need both total production (accurate) and A state production, we just need to add -NOTOT at the end of the state name like in this example.

If we do not have the precision for the state computed, typically for an ion, the best way is to define the excited state as “Total”.

```
<!-- Itikawa 2002 for CO2+(A)-->
<Process name="CO2+e -> CO2+(A) " electrons="0" threshold="17.32">
<Species>
<Specie name="CO2+" state="A-NOTOT"/>
</Species>
<!-- The ionization is not taken
into account, because
it is a subproduct of the total ionization
-->
...
</Process>
```

On the contrary, some processes defines the production of the X, A, B,...states. But not the total production. In that case, we do not add the -NOTOT at the end, and, by detecting that fact, we know that we must add each processes to get the total production.

The addition of -NOTOT is therefore specific to the recommended file, and depends on the whole set of cross sections.

### Concerning the electron production

The electron production is computed by adding the electron production of all processes, thanks to the number of electrons parameters. If you want to define a subprocess, you must let the number of electron produced at 0!

### Shirai cross sections

The electron cross sections from Shirai et al. [59, 60], Tabata et al. [68] can also be included (if one day, this kind of parametrisation of cross section is done for photoionisation, it could be adapted too).

**/crs/species/Process/Shirai** To define that we are using the Shirai/Tabata cross sections. An example of the interface for these cross sections files could be seen in the section A.3.

**/crs/species/Process/Emin** The minimum energy where it is defined (For non-Shirai system, it is the energy of the first non-zero data point. It can be automatically determined there.)

**/crs/species/Process/Emax** The maximum energy where it is defined (For non-Shirai system, it is the energy of the last non-zero data point. When the system is extrapolated, it could be a point defined for having a good shape, or the point where the extrapolation is expected to be valid It can be automatically determined there.). .

**/crs/species/Process/Equation** Gives the type of the equation, and the article id (and the number in the article, but not used). Since the equations are dependent upon the species and the number, we are not reproducing them here. However, the example codes for plotting the cross-sections show an implementation of the equations.

**/crs/species/Process/params** Gives the parameters for the cross section.

```
<Process name="C02+e -> O + C" electrons="0" threshold="11.100000">
<Shirai/><!--Shirai et al 2001 analytic cross section -->
<Species>
<Specie name="C" state="X"/>
<Specie name="O" state="X" number="2"/>
</Species>
<Emin> 13.5 </Emin>
<Emax> 199.0 </Emax>
<Equation type="1" article_id="C02" article_number="36"/>
<params>
7.040000e-01    1.084000e+00    2.680000e-02    5.700000e-01
</params>
```

</Process>

The equation types for the Shirai cross sections are:

### Singhal cross sections

The electron cross sections from Singhal [64] can also be included. The interface is the same as the Shirai cross sections, but the markup is different.

**/crs/species/Process/Singhal** To define that we are using the Singhal cross sections.

**/crs/species/Process/params** Gives the parameters for the cross section.

**/crs/species/Process/AF** Gives the autoionization factor for the process.

**/crs/species/Process/Omega** Set up if the equation for this cross section is of Omega type

**/crs/species/Process/Ctype** Set up if the equation for this cross section is of C type

**Implementation of the cross-sections** There are 3 types of cross-sections for Shirai: first the ionization cross-sections type, then the excitation cross-sections types C and Omega. Once you get the parameters from the database, from parray[0] to parray[n], and the energy E for the computation, you can go as follows:

parray[0] is the threshold, so any E lower than parray[0] will return 0.0. We define

$$q0 = 6.513E - 14 \quad (\text{A.1})$$

This allows to return a cross-section in cm<sup>2</sup>.

For a Omega type cross-section, the cross-section is computed as:

$$\text{ratio} = \frac{\text{parray}[0]}{E} \quad (\text{A.2})$$

$$\text{Term1} = \frac{q0 \times \text{parray}[5]}{\text{parray}[0]^2} \quad (\text{A.3})$$

$$\text{Term2} = (1 - (\text{ratio}^{\text{parray}[1]}))^{\text{parray}[2]} \quad (\text{A.4})$$

$$Term3 = ratio^{parray[4]} \quad (A.5)$$

$$CrossSection = Term1 \times Term2 \times Term3 \quad (A.6)$$

For a C type cross-section, the cross-section is computed as (log is the natural logarithm):

$$ratio = \frac{parray[0]}{E} \quad (A.7)$$

$$Term1 = \frac{q0 \times parray[5]}{E \times parray[0]} \quad (A.8)$$

$$Term2 = (1 - (ratio^{parray[1]}))^{parray[2]} \quad (A.9)$$

$$Term3 = \log(e + 4 * parray[4]/ratio) \quad (A.10)$$

$$CrossSection = Term1 \times Term2 \times Term3 \quad (A.11)$$

For the ionization cross-section, the cross-section is computed as:

$$\sigma_0 = 1E - 16 \quad (A.12)$$

$$A_E = \frac{parray[1]}{E + parray[2]} \times \log \left( \frac{E}{parray[3]} + parray[4] + \frac{parray[5]}{E} \right) \quad (A.13)$$

$$\Gamma = \frac{parray[6] \times E}{E + parray[7]} \quad (A.14)$$

$$T_0 = parray[8] - \frac{parray[9]}{E + parray[10]} \quad (A.15)$$

$$T_m = 0.5 \times (E - parray[0]) \quad (A.16)$$

$$Term1 = A_E \quad (A.17)$$

$$Term2 = \Gamma \quad (A.18)$$

$$Term3 = \arctan \left( \frac{T_m - T_0}{\Gamma} \right) + \arctan \left( \frac{T_0}{\Gamma} \right) \quad (A.19)$$

$$CrossSection = \sigma_0 \times Term1 \times Term2 \times Term3 \quad (A.20)$$

### Example of implementation in the database

```
<Process electrons="0" name="H2O+e -> H2O(A2v2)" threshold="0.391">
  <Species>
    <Specie name="H2O" state="A2v2"/>
  </Species>
  <Legend>H2O(A2v2)</Legend>
  <Proc>H2O(A2v2)</Proc>
  <Section>excitation</Section>
  <Source type="review">Singhal</Source>
```

```

<Notes>from the book Elements of Space Physics</Notes>
<uncertainty>30%</uncertainty>
<EstimatedUncertainty/>
<Excitation/>
<Singhal/>
<params>0.391 1.000 3.000 0.391 6.000 0.000043 0.0</params>
<AF>0.0</AF>
<Omega/>
</Process>

<Process electrons="0" name="H2+e -> C1Pu" threshold="12.465">
<Species>
<Specie name="H2" state="C1Pu"/>
</Species>
<Legend>C1Pu</Legend>
<Proc>H2(C1Pu)</Proc>
<Section>excitation</Section>
<Source type="review">Singhal</Source>
<Notes>from the book Elements of Space Physics</Notes>
<uncertainty>30%</uncertainty>
<EstimatedUncertainty/>
<Excitation/>
<Singhal/>
<params>12.465 0.85 1.464 12.465 0.300 0.392300</params>
<AF>0</AF>
<Ctype/>
</Process>

```

### A.2.3 The Electron cross section file (extends the standard cross section!)

The electron cross section is basically the same file as the photoionization cross section<sup>9</sup>. The main difference is that the total cross section is not used. So, we generally define it as TotalCrsIsTheSum.

The total cross section is replaced by elastic, ionization and excitation cross sections (ionization and excitation are the inelastic cross sections, these cross sections have technically almost no differences, except being computed separately).

---

<sup>9</sup>Heritage in C++! A fantastic concept!

**/crs/species/ElasticCrs** Elastic cross section, defined like every other cross sections.

**/crs/species/ExcitationCrs, /crs/species/IonizationCrs** Allows to define total excitation and ionization cross sections. These options are NOT RECOMMENDED. Because energy conservation for electron impact is computed by using thresholds: energy conservation is not computed in that case!

We recommend to use Excitation and Ionization!

**/crs/species/Process/Excitation** Allows to specify that this is an excitation process that should be used to compute the total excitation cross section.

**/crs/species/Process/Ionization** Allows to specify that this is an ionization process that should be used to compute the total excitation cross section.

### Concerning the total electron production

The total electron production is computed by adding the ionization process results (computed by the number of electrons). Therefore, if you use a subprocess (of a previously defined process), you should consider that its ionization is already taken into account. If you define that this sub-process creates also an electron, if the first process creates an electron, the result will be a double-ionization (probably not what you want in that case).

When more than one electron are created in the process, the electrons production is correctly stored, but for the electron flux, all the energy is put inside one electron.

When there is an Auger process, the Auger electron is correctly put in the flux.

### Auger electron computation

The Auger electron process is taken into account in AeroPlanets . The principle is simple: a suborbit is ionized (creates one electrons) and one electron of an upper orbits falls to that orbit, creating a photon that is absorbed by the species itself; therefore, creating another ionization. This leads to a double ionization, with a second electron very specific: it has the energy of the transition; it is an auger electron.

In the **photoionization** and **electron impact** cross section, you can add the Auger process simply by defining a cross section, and adding the Auger markup:

**/crs/species/Process/Auger** Allows to define the Auger process, and the Auger electron energy:

```
<Auger energy="500"/>
```

Several Auger electrons can be created in one process, with different efficiency, you can simply do:

```
<Auger energy="500" fact="0.5"/>
<Auger energy="800" fact="0.5"/>
```

If no efficiency is defined, it is considered to be one.

#### A.2.4 The recommended data set cross section

The recommended data set cross section works technically like the other files. The main difference is the “/crs/RecommendedFile” in its heading. This markup could be used for discriminating against the other types, for example by displaying the process and not the sources when plotting.

The recommended data set is not automatically created from the other files right now. This may become true in the future, and, in that case, people writing the database should not care about the consistency between the other files and the recommended data set.

### A.3 The plotting tools

A set of plotting tools for the database can be found in the directories names “codepy3”. These tools are coded in python, and use the matplotlib library for plotting. The tools are designed to be used with the database, and are able to plot the cross sections. A more detailed description of the tools, their use, and their implementation can be found in the README file in the codepy3 directory as well as the documentation file “Atmociad\_doc\_v2.pdf”.

The vast majority of the images in the present document are automatically generated using these tools.

## A.4 The ASCII files

Files in ASCII, as computed by Aeroplanets, are located in the directory ASCII. These are compiled from the recommended data, on regular basis (but the database in XML is likely more up-to-date).

# Nomenclature

AeroPlanets Software developed by G. Gronoff on the basis of the Trans\* codes. It is an upper atmosphere of the earth and planet model, for computing ionization, dissociation and excitation. It has several modules for computing the emissions, for retrieval... It is the first model using the **AtMoCiad** database, and its development was useful for determining the necessary parameters of the database xml files.

AMOP Photoionization cross sections database compiled by the AMOP group. The name has now changed into PHIDRATES and is located at <http://phidrates.space.swri.edu/>.

AtMoCiad The Atomic and Molecular Cross sections for ionization and air-glow database. The database described in the present document.

BDD Old database. The database used in the very old versions of the Trans\* codes. Typically used as a reference when actual references are lost.

XML eXtensible Markup Language: document format based on Markup. To simplify, it is a text (ASCII/UTF8....) document containing markups to define its structure, and the relations between the several parts of the text.

XPath Set of techniques to easily navigate in a XML document. The basic concept is to follow the 'roots' to the 'leaves' of the document, by giving all the nodes. An example can be found in A.1.1. Thanks to the wide use of XML, notably in web-based technology, XPath techniques are implemented in several programming languages. For example, python has the ElementTree module, extensively used in the plotting and transforming examples.



# Bibliography

- [1] J. Ajello. Emission cross section of *CO* by electron impact in the interval 1260 – 5000 Å. *J. Chem. Phys.*, 55:3169, 1971.
- [2] S. V. et al. Avakyan, editor. *Collision processes and excitation of UV emission from planetary atmospheric gases : a handbook of cross sections*, 1998.
- [3] S.V. Avakyan, R.N. Ilin, V.M. Lavrov, and G.N Ogurtsov. *Collision processes and excitation of ultraviolet emission from planetary atmospheric gases: A Handbook of cross sections*. Gordon and Breach Publishing Group, London, 1998.
- [4] L. W. Beegle, J. M. Ajello, G. K. James, D. Dziczek, and M. Alvarez. High resolution emission spectroscopy of the  $A^1\Pi - X^1\Sigma^+$  fourth positive band system of *CO* excited by electron impact. *A&A*, 347:375–390, jul 1999.
- [5] J.M. Bizau and F.J. Wuilleumier. Redetermination of absolute partial photoionization cross sections of he and ne atoms between 20 and 300 ev photon energy. *Journal of Electron Spectroscopy and Related Phenomena*, 71(3):205–224, 1995. ISSN 0368-2048. doi: [https://doi.org/10.1016/0368-2048\(94\)02268-2](https://doi.org/10.1016/0368-2048(94)02268-2). URL <https://www.sciencedirect.com/science/article/pii/0368204894022682>.
- [6] J. Bretagne, G. Callede, M. Legentil, and V. Puech. Relativistic electron-beam-produced plasmas. I. Collision cross sections and loss function in argon. *Journal of Physics D Applied Physics*, 19(5):761–777, May 1986. doi: 10.1088/0022-3727/19/5/010.
- [7] YM Chung, E-M Lee, T Masuoka, and James AR Samson. Dissociative photoionization of h<sub>2</sub> from 18 to 124 ev. *The Journal of chemical physics*, 99(2):885–889, 1993.

- [8] Atomic and Molecular collision group. Atomic and Molecular Collisions Group, 2004. URL <http://www.ruf.rice.edu/~atmol/index.html>.
- [9] A. Dalgarno, Min Yan, and Weihong Liu. Electron Energy Deposition in a Gas Mixture of Atomic and Molecular Hydrogen and Helium. *The Astrophysical Journal Supplement Series*, 125:237–256, November 1999. URL <http://adsabs.harvard.edu/abs/1999ApJS..125..237D>.
- [10] D. K. Davies, L. E. Kline, and W. E. Bies. Measurements of swarm parameters and derived electron collision cross sections in methane. *Journal of Applied Physics*, 65(9):3311, 1989. ISSN 00218979. doi: 10.1063/1.342642. URL <http://link.aip.org/link/JAPIAU/v65/i9/p3311/s1&Agg=doi>.
- [11] P. W. Erdman and E. C. Zipf. Excitation of the OI ( $3s\ 5S_0$ – $3p\ 5P$ ;  $\lambda$  7774 Å) multiplet by electron impact on O<sub>2</sub>. *The Journal of Chemical Physics*, 87(8):4540–4545, October 1987. ISSN 00219606. doi: doi:10.1063/1.453696. URL [http://jcp.aip.org/resource/1/jcpa6/v87/i8/p4540\\_s1](http://jcp.aip.org/resource/1/jcpa6/v87/i8/p4540_s1).
- [12] Daniel A. Erwin and Joseph A. Kunc. Electron-impact dissociation of the methane molecule into neutral fragments. *Physical Review A*, 72(5):052719, November 2005. doi: 10.1103/PhysRevA.72.052719. URL <http://link.aps.org/doi/10.1103/PhysRevA.72.052719>.
- [13] F. Frémont, A. Hajaji, and J. Y. Chesnel. K -shell and total ionization cross sections following electron-molecule collisions: An empirical scaling law. *Phys. Rev. A*, 74(5):052707, November 2006. doi: 10.1103/PhysRevA.74.052707.
- [14] J. M. Furlong and W. R. Newell. Total cross section measurement for the metastable ? state in CO. *Journal of Physics B Atomic Molecular Physics*, 29(2):331–338, January 1996. doi: 10.1088/0953-4075/29/2/020.
- [15] E. P. Gentieu and J. E. Mentall. Cross sections for production of the CO( $A^1\Pi$  –  $X^1\Sigma$ ) fourth positive band system and O( ${}^3S$ ) by photodissociation of CO<sub>2</sub>. *J. Chem. Phys.*, 58:4803, 1972.
- [16] E. P. Gentieu and J. E. Mentall. Cross sections for production of the CO(A  ${}^1\Pi$ -X  ${}^1\Sigma$ ) Fourth Positive band system and O( ${}^3S$ ) by photodissociation of CO<sub>2</sub>. *J. Chem. Phys.*, 58(11):4803–4815, June 1973. doi: 10.1063/1.1679063.

- [17] M Glass-Maujean and H Schmoranzer. Dissociation dynamics of doubly excited states of molecular hydrogen. *Journal of Physics B: Atomic, Molecular and Optical Physics*, 38(8):1093, 2005.
- [18] G. Glupe and W. Mehlhorn. A new method for measuring electron impact ionization cross sections of inner shells. *Physics Letters A*, 25: 274–275, aug 1967. doi: 10.1016/0375-9601(67)90901-2.
- [19] G. Gronoff, J. Lilenstein, C. Simon, O. Witasse, R. Thissen, O. Dutuit, and C. Alcaraz. Modelling dications in the diurnal ionosphere of Venus. *A&A*, 465(2):641–645, 2007. doi: 10.1051/0004-6361:20065991.
- [20] G. Gronoff, P. Arras, S. Baraka, J. M. Bell, G. Cessateur, O. Cohen, S. M. Curry, J. J. Drake, M. Elrod, J. Erwin, K. Garcia-Sage, C. Garraffo, A. Glocer, N. G. Heavens, K. Lovato, R. Maggiolo, C. D. Parkinson, C. Simon Wedlund, D. R. Weimer, and W. B. Moore. Atmospheric Escape Processes and Planetary Atmospheric Evolution. *Journal of Geophysical Research: Space Physics*, 125(8):e2019JA027639, 2020. ISSN 2169-9402. doi: 10.1029/2019JA027639. URL <https://onlinelibrary.wiley.com/doi/abs/10.1029/2019JA027639>. eprint: <https://onlinelibrary.wiley.com/doi/pdf/10.1029/2019JA027639>.
- [21] Guillaume Gronoff, Cyril Simon Wedlund, Christopher J. Mertens, Mathieu Barthélemy, Robert J. Lillis, and Olivier Witasse. Computing uncertainties in ionosphere-airglow models: II. The Martian airglow. *Journal of Geophysical Research*, 117:17 PP., May 2012. doi: 201210.1029/2011JA017308. URL <http://www.agu.org/pubs/crossref/2012/2011JA017308.shtml>.
- [22] Guillaume Gronoff, Cyril Simon Wedlund, Christopher J. Mertens, and Robert J. Lillis. Computing uncertainties in ionosphere-airglow models:I. Electron flux and species production uncertainties for Mars. *Journal of Geophysical Research*, 117:18 PP., April 2012. doi: 201210.1029/2011JA016930. URL <http://www.agu.org/journals/ja/ja1204/2011JA016930/>.
- [23] E. E. Gulcicek, J. P. Doering, and S. O. Vaughan. Absolute differential and integral electron excitation cross sections for atomic oxygen. VI - The 3P - 3P and 3P - 5P transitions from 13.87 to 100 eV. *J. Geophys. Res.*, 93:5885–5889, jun 1988.
- [24] W.F. Huebner and J. Mukherjee. Photoionization and photodissociation rates in solar and blackbody radiation fields. *Planetary and Space Science*, 106:11–45, 2015. ISSN 0032-0633. doi: <https://doi.org/10.1016/>

- j.pss.2014.11.022. URL <https://www.sciencedirect.com/science/article/pii/S003206331400381X>.
- [25] Y. Itikawa. Cross Sections for Electron Collisions With Carbon Dioxide. *Journal of Physical and Chemical Reference Data*, 31:749, sep 2002. doi: 10.1063/1.1481879.
  - [26] Y. Itikawa. Cross sections for electron collisions with water molecules. *Journal of Physical and Chemical Reference Data*, 34:1, 2005. doi: 10.1063/1.1799251.
  - [27] Y. Itikawa and A. Ichimura. Cross Sections for Collisions of Electrons and Photons with Atomic Oxygen. *Journal of Physical and Chemical Reference Data*, 19(3):637–651, May 1990. ISSN 00472689. doi: doi: 10.1063/1.555857. URL [http://jpcrd.aip.org/resource/1/jpcrbu/v19/i3/p637\\_s1?isAuthorized=no](http://jpcrd.aip.org/resource/1/jpcrbu/v19/i3/p637_s1?isAuthorized=no).
  - [28] Yukikazu Itikawa. Cross sections for electron collisions with nitrogen molecules. *Journal of Physical and Chemical Reference Data*, vol. 35, issue 1, p. 31, 35, 2006. doi: 10.1063/1.1937426.
  - [29] Yukikazu Itikawa. Cross sections for electron collisions with oxygen molecules. *Journal of Physical and Chemical Reference Data*, 38(1):1, 2009. doi: 10.1063/1.3025886.
  - [30] Ratko K. Janev, William D. Langer, and E. Douglass Jr. Elementary processes in hydrogen-helium plasmas: cross sections and reaction rate coefficients. 2012. URL [https://books.google.com/books?hl=en&lr=&id=9\\_PuCAAAQBAJ&oi=fnd&pg=PA3&dq=janev+1987&ots=cDE10\\_cn6M&sig=02mcd-d2mL9pRQWWGwIXM6B-PfY](https://books.google.com/books?hl=en&lr=&id=9_PuCAAAQBAJ&oi=fnd&pg=PA3&dq=janev+1987&ots=cDE10_cn6M&sig=02mcd-d2mL9pRQWWGwIXM6B-PfY). Publisher: Springer Science & Business Media.
  - [31] P. V. Johnson, I. Kanik, D. E. Shemansky, and X. Liu. Electron-impact cross sections of atomic oxygen. *Journal of Physics B Atomic Molecular Physics*, 36:3203–3218, aug 2003. doi: 10.1088/0953-4075/36/15/303.
  - [32] P. V. Johnson, I. Kanik, J. W. McConkey, and S. S. Tayal. Collisions of electrons with atomic oxygen: current status. *Canadian Journal of Physics*, Vol. 83, p. 589-616, 83, 2005. doi: 10.1139/P05-034.
  - [33] P. S. Julienne and J. Davis. Cascade and radiation trapping effects on atmospheric atomic oxygen emission excited by electron impact. *Journal of Geophysical Research*, 81(7):1397, 1976. ISSN 0148-0227. doi:

- 10.1029/JA081i007p01397. URL <http://www.agu.org/journals/ja/v081/i007/JA081i007p01397/>.
- [34] I. Kanik, S. Trajmar, and J. C. Nickel. Total electron scattering and electronic state excitations cross sections for o2, co, and ch4. *J. Geophys. Res.*, 98:7447–7460, apr 1993. doi: 10.1029/92JE02811.
  - [35] R. R. Laher and F. R. Gilmore. Updated excitation and ionization cross sections for electron impact on atomic oxygen. *Journal of Physical and Chemical Reference Data*, 19:277–305, jan 1990.
  - [36] B. S. Lanchester, M. Ashrafi, and N. Ivchenko. Simultaneous imaging of aurora on small scale in OI (777.4 nm) and N21P to estimate energy and flux of precipitation. *Ann. Geophys.*, 27(7):2881–2891, July 2009. ISSN 1432-0576. doi: 10.5194/angeo-27-2881-2009. URL <http://www.ann-geophys.net/27/2881/2009/>.
  - [37] G. M. Lawrence. Photodissociation of  $CO_2$  to produce  $CO(a^3\Pi)$ . *J. Chem. Phys.*, 56:3435, 1972.
  - [38] L. R. Leclair, M. D. Brown, and J. W. McConkey. Selective detection of O(1 S) and CO(a 3 Pi) following electron impact on CO using solid xenon. *J. Chem. Phys.*, 189:769–777, dec 1994.
  - [39] Lance R. Leclair and J. W. McConkey. Selective detection of O( ${}^1S_0$ ) following electron impact dissociation of O<sub>2</sub> and N<sub>2</sub>O using a XeO\* conversion technique. *J. Chem. Phys.*, 99(6):4566–4577, September 1993. doi: 10.1063/1.466056.
  - [40] J. Lilensten, O. Witasse, C. Simon, H. Soldi-Lose, O. Dutuit, R. Thissen, and C. Alcaraz. Prediction of a  $N_2^{++}$  layer in the upper atmosphere of Titan. *Geophys. Res. Lett.*, 32(3), 2005. doi: 10.1029/2004GL021432.
  - [41] J. Lilensten, C. Simon Wedlund, M. Barthélémy, R. Thissen, D. Ehrenreich, G. Gronoff, and O. Witasse. Dications and thermal ions in planetary atmospheric escape. *Icarus*, 222(1):169–187, 2013.
  - [42] Jean Lilensten, Cyril Simon, Olivier Witasse, Odile Dutuit, Roland Thissen, and Christian Alcaraz. A fast computation of the diurnal secondary ion production in the ionosphere of Titan. *Icarus*, 174(1): 285–288, 2005. doi: 10.1016/j.icarus.2004.12.002.
  - [43] Xianming Liu and Donald E. Shemansky. Ionization of Molecular Hydrogen. *The Astrophysical Journal*, 614(2):1132–1142, October 2004.

- ISSN 0004-637X. doi: 10.1086/423890. URL <http://iopscience.iop.org/0004-637X/614/2/1132/>.
- [44] Lummerzheim. *Electron transport and optical emissions in the aurora*. PhD thesis, University of Alaska, December 1987.
  - [45] D. Lummerzheim and J. Lilensten. Electron transport and energy degradation in the ionosphere: evaluation of the numerical solution, comparison with laboratory experiments and auroral observations. *Annales Geophysicae*, 12(10/11):1039–1051, 1994. ISSN 0992-7689. URL <http://www.ann-geophys.net/12/1039/1994/>.
  - [46] D. Lummerzheim and J. Lilensten. Electron transport and energy degradation in the ionosphere: evaluation of the numerical solution, comparison with laboratory experiments and auroral observations. *Annales Geophysicae*, 12(10/11):1039–1051, 1994. ISSN 0992-7689. URL <http://www.ann-geophys.net/12/1039/1994/>.
  - [47] T. Majeed and D. J. Strickland. New survey of electron impact cross sections for photoelectron and auroral electron energy loss calculations. *Journal of Physical and Chemical Reference Data*, 26:335–349, mar 1997.
  - [48] T. Masuoka. Single- and double-photoionization cross sections of nitric oxide ( $NO$ ) and ionic fragmentation of  $NO^+$  and  $NO^{2+}$ . *Phys. Rev. A*, 48:1955–1963, sep 1993. doi: 10.1103/PhysRevA.48.1955.
  - [49] T. Masuoka. Single- and double-photoionization cross sections of carbon dioxide ( $CO_2$ ) and ionic fragmentation of  $CO_2^+$  and  $CO_2^{2+}$ . *Phys. Rev. A*, 50:3886–3894, nov 1994. doi: 10.1103/PhysRevA.50.3886.
  - [50] J. C. Nickel, I. Kanik, S. Trajmar, and K. Imre. Total cross section measurements for electron scattering on H<sub>2</sub> and N<sub>2</sub> from 4 to 300 eV. *Journal of Physics B Atomic Molecular Physics*, 25:2427–2431, May 1992. ISSN 0953-4075. doi: 10.1088/0953-4075/25/10/020. URL <https://ui.adsabs.harvard.edu/abs/1992JPhB...25.2427N>. Publisher: IOP ADS Bibcode: 1992JPhB...25.2427N.
  - [51] A. V. Phelps. Collision cross sections for electrons with atmospheric species. Technical report, Joint Inst. for Lab. Astrophysics, Boulder, CO, 1972. URL <https://www.osti.gov/biblio/4528832>.
  - [52] A. V. Phelps. Collision cross sections for electrons with atmospheric species. Technical report, Joint Inst. for Lab. Astrophysics, Boulder, CO, 1972. URL <https://www.osti.gov/biblio/4528832>.

- [53] M. S. Pindzola, F. Robicheaux, and J. Colgan. Double ionization of helium by fast bare ion collisions. *Journal of Physics B: Atomic, Molecular and Optical Physics*, 40(10):1695, April 2007. ISSN 0953-4075. doi: 10.1088/0953-4075/40/10/004. URL <https://dx.doi.org/10.1088/0953-4075/40/10/004>.
- [54] Yu. Ralchenko, R.K. Janev, T. Kato, D.V. Fursa, I. Bray, and F.J. de Heer. Electron-impact excitation and ionization cross sections for ground state and excited helium atoms. *Atomic Data and Nuclear Data Tables*, 94(4):603–622, July 2008. ISSN 0092-640X. doi: 10.1016/j.adt.2007.11.003. URL <http://www.sciencedirect.com/science/article/B6WBB-4S62CDX-1/2/c0af31841e71427c64dfab43c07c3163>.
- [55] J. A. R. Samson. Proportionality of electron-impact ionization to double photoionization. *Phys. Rev. Lett.*, 65:2861–2864, dec 1990. doi: 10.1103/PhysRevLett.65.2861.
- [56] James A. R. Samson and G. N. Haddad. Total photoabsorption cross sections of H<sub>2</sub> from 18 to 113 eV. *Journal of the Optical Society of America B*, 11(2):277–279, February 1994. doi: 10.1364/JOSAB.11.000277. URL <http://josab.osa.org/abstract.cfm?URI=josab-11-2-277>.
- [57] James AR Samson, RJ Bartlett, and ZX He. Probability for double photoionization of he and ne. *Physical Review A*, 46(11):7277, 1992.
- [58] M. B Shah, D. S Elliott, and H. B Gilbody. Pulsed crossed-beam study of the ionisation of atomic hydrogen by electron impact. *Journal of Physics B Atomic Molecular Physics*, 20:3501–3514, July 1987. doi: 10.1088/0022-3700/20/14/022.
- [59] Toshizo Shirai, Tatsuo Tabata, and Hiroyuki Tawara. Analytic cross sections for electron collisions with co, co<sub>2</sub>, and h<sub>2</sub>o relevant to edge plasma impurities. *Atomic Data and Nuclear Data Tables, Volume 79, Issue 1, p. 143-184.*, 79, 2001. doi: 10.1006/adnd.2001.0866.
- [60] Toshizo Shirai, Tatsuo Tabata, Hiroyuki Tawara, and Yukikazu Itikawa. Analytic cross sections for electron collisions with hydrocarbons: Ch<sub>4</sub>, c<sub>2</sub>h<sub>6</sub>, c<sub>2</sub>h<sub>4</sub>, c<sub>2</sub>h<sub>2</sub>, c<sub>3</sub>h<sub>8</sub>, and c<sub>3</sub>h<sub>6</sub>. *Atomic Data and Nuclear Data Tables, Volume 80, Issue 2, p. 147-204.*, 80, 2002. doi: 10.1006/adnd.2001.0878.
- [61] C. Simon, J. Lilenstein, O. Dutuit, R. Thissen, O. Witasse, C. Alcaraz, and H. Soldi-Lose. Prediction and modelling of doubly-charged ions in the Earth’s upper atmosphere. *Annales Geophysicae*, 23:781–797, mar

2005. URL [http://adsabs.harvard.edu/cgi-bin/nph-bib\\_query?bibcode=2005AnGeo..23..781S&db\\_key=AST](http://adsabs.harvard.edu/cgi-bin/nph-bib_query?bibcode=2005AnGeo..23..781S&db_key=AST).
- [62] C. Simon, O. Witasse, F. Leblanc, G. Gronoff, and J.-L. Bertaux. Day-glow on Mars: Kinetic modelling with SPICAM UV limb data. *Planetary and Space Science*, 2008. doi: 10.1016/j.pss.2008.08.012.
- [63] C. Simon Wedlund, G. Gronoff, J. Lilensten, H. Ménager, and M. Barthélemy. Comprehensive calculation of the energy per ion pair or  $\langle I \rangle W \langle /I \rangle$  values for five major planetary upper atmospheres. *Annales Geophysicae*, 29(1):187–195, January 2011. ISSN 0992-7689. doi: 10.5194/angeo-29-187-2011. URL <https://angeo.copernicus.org/articles/29/187/2011/>. Publisher: Copernicus GmbH.
- [64] RP Singhal. *Elements of Space Physics*. PHI Learning Pvt. Ltd., 2009.
- [65] T. G. Slanger, R. L. Sharpless, G. Black, and S. V. Filseth. Photodissociation quantum yields of  $CO_2$  between 1200 and 1500 Å. *J. Chem. Phys.*, 61:5022–5027, dec 1974.
- [66] H. C. Straub, D. Lin, B. G. Lindsay, K. A. Smith, and R. F. Stebbings. Absolute partial cross sections for electron-impact ionization of  $CH_4$  from threshold to 1000 eV. *J. Chem. Phys.*, 106:4430–4435, mar 1997. doi: 10.1063/1.473468.
- [67] D. J. Strickland, R. R. Meier, J. H. Hecht, and A. B. Christensen. Deducing composition and incident electron spectra from ground-based auroral optical measurements. I - Theory and model results. II - A study of auroral red line processes. III - Variations in oxygen density. *Journal of Geophysical Research*, 94:13527–13539, October 1989. URL <http://adsabs.harvard.edu/abs/1989JGR....9413527S>.
- [68] Tatsuo Tabata, Toshizo Shirai, Masao Satake, and Hirotaka Kubo. Analytic cross sections for electron impact collisions with nitrogen molecules. *Atomic Data and Nuclear Data Tables*, 92:375–406, May 2006. URL <http://adsabs.harvard.edu/abs/2006ADNDT..92..375T>.
- [69] Tatsuo Tabata, Toshizo Shirai, Masao Satake, and Hirotaka Kubo. Erratum to “Analytic cross sections for electron impact collisions with nitrogen molecules” [At. Data Nucl. Data Tables 92 (2006) 375–406]. *Atomic Data and Nuclear Data Tables*, 98(1):74, January 2012. ISSN 0092-640X. doi: 10.1016/j.adt.2011.06.002. URL <https://www.sciencedirect.com/science/article/pii/S0092640X11000489>.

- [70] H. Tanaka, T. Ishikawa, T. Masai, T. Sagara, L. Boesten, M. Takekawa, Y. Itikawa, and M. Kimura. Elastic collisions of low- to intermediate-energy electrons from carbon dioxide: Experimental and theoretical differential cross sections. *Phys. Rev. A*, 57(3):1798–1808, March 1998. doi: 10.1103/PhysRevA.57.1798.
- [71] W. R. Thompson, M. B. Shah, and H. B. Gilbody. Single and double ionization of atomic oxygen by electron impact. *Journal of Physics B Atomic Molecular Physics*, 28:1321–1330, apr 1995. doi: 10.1088/0953-4075/28/7/023.
- [72] Masatoshi Ukai, Kosei Kameta, Noriyuki Kouchi, Kazunori Nagano, Yoshihiko Hatano, and Kenichiro Tanaka. Autoionizing-resonance enhanced preferential photodissociation of CO<sub>2</sub> in superexcited states. *The Journal of Chemical Physics*, 97(5):2835–2842, 09 1992. ISSN 0021-9606. doi: 10.1063/1.463026. URL <https://doi.org/10.1063/1.463026>.
- [73] J. F. Williams and L. J. Allen. Low-energy elastic scattering of electrons from atomic oxygen. *Journal of Physics B: Atomic, Molecular and Optical Physics*, 22(21):3529, November 1989. ISSN 0953-4075. doi: 10.1088/0953-4075/22/21/015. URL <https://dx.doi.org/10.1088/0953-4075/22/21/015>.
- [74] O. Witasse, O. Dutuit, J. Lilenstein, R. Thissen, J. Zabka, C. Alcaraz, P. L. Blelly, S. W. Bouger, S. Engel, L. H. Andersen, and K. Seiersen. Prediction of a CO<sub>2</sub><sup>2+</sup> layer in the atmosphere of Mars. *Geophys. Res. Lett.*, 29:104–1, apr 2002. URL [http://adsabs.harvard.edu/cgi-bin/nph-bib\\_query?bibcode=2002GeoRL..29h.104W&db\\_key=AST](http://adsabs.harvard.edu/cgi-bin/nph-bib_query?bibcode=2002GeoRL..29h.104W&db_key=AST).
- [75] O. Witasse, O. Dutuit, J. Lilenstein, R. Thissen, J. Zabka, C. Alcaraz, P.-L. Blelly, S. W. Bouger, S. Engel, L. H. Andersen, and K. Seiersen. Correction to “Prediction of a CO<sub>2</sub><sup>2+</sup> layer in the atmosphere of Mars”. *Geophys. Res. Lett.*, 30(7):12–1, 2003. doi: 10.1029/2003GL017007.
- [76] C. Y. R. Wu and D. L. Judge. The atomic oxygen 1304 Å emission produced through photodissociation of CO and CO<sub>2</sub>. *Chemical Physics Letters*, 68:495–498, January 1979. doi: 10.1016/0009-2614(79)87245-0.
- [77] C. Y. Robert Wu and F. Z. Chen. Velocity distributions of hydrogen atoms and hydroxyl radicals produced through solar photodissociation of water. *Journal of Geophysical Research: Planets*, 98(E4):7415–7435, 1993. doi: <https://doi.org/10.1029/92JE03016>. URL <https://agupubs.onlinelibrary.wiley.com/doi/abs/10.1029/92JE03016>.

- [78] M. Yan, H. R. Sadeghpour, and A. Dalgarno. Photoionization Cross Sections of He and H<sub>2</sub>. *The Astrophysical Journal*, 496(2):1044, April 1998. ISSN 0004-637X. doi: 10.1086/305420. URL <https://dx.doi.org/10.1086/305420>.
- [79] M. Yan, H. R. Sadeghpour, and A. Dalgarno. Erratum: Photoionization Cross Sections of He and H<sub>2</sub>. *The Astrophysical Journal*, 559:1194–1194, October 2001. ISSN 0004-637X. doi: 10.1086/322775. URL <https://ui.adsabs.harvard.edu/abs/2001ApJ...559.1194Y>. ADS Bibcode: 2001ApJ...559.1194Y.
- [80] Jung-Sik Yoon, Mi-Young Song, Jeong-Min Han, Sung Ha Hwang, Won-Seok Chang, Bongju Lee, and Yukikazu Itikawa. Cross Sections for Electron Collisions with Hydrogen Molecules. *Journal of Physical and Chemical Reference Data*, 37:913–931, June 2008. URL <http://adsabs.harvard.edu/abs/2008JPCRD..37..913Y>.
- [81] E. C. Zipf and P. W. Erdman. Electron impact excitation of atomic oxygen: Revised cross sections. *Journal of Geophysical Research: Space Physics*, 90(A11):11087–11090, 1985. ISSN 2156-2202. doi: 10.1029/JA090iA11p11087. URL <https://onlinelibrary.wiley.com/doi/abs/10.1029/JA090iA11p11087>. eprint: <https://onlinelibrary.wiley.com/doi/pdf/10.1029/JA090iA11p11087>.