Computational Astrophysics 2023/2024

Physics of Data

Part-3: *Atmospheres*

Submission deadline: 23/12/2024

Assignment 3: A Spectral Journey

"Only in the darkness can you see the stars"

Martin Luther King, Jr.

Learning aims: By solving these exercises, you will generate your transmission spectrum using TauREx (forward model) and retrieve atmospheric parameters from an input spectrum (inverse model).

Tasks:

A. **A Spectral resemblance:** Generate a transmission spectrum with TauREx. Use the planet you choose in assignment 2 – Task A for the planetary and stellar parameters. Put H2O, CH4, CO2 and CO in the atmosphere; their abundances should be randomised within [10^{-8}, 10^{-2}]. Submit the transmission spectrum in a file called [planet_name]_assignment3_taskA_spectrum.dat with three columns (wavelength in micron, (rp/rs)^2, sqrt((rp/rs)^2)), plot it in a file called [planet_name]_assignment3_taskA_spectrum.png and report the forward model parameters in a file called [planet_name]_assignment3_taskA_parameters.txt *(In the submission, report the date and hashcode of the commit associated with the creation of the last file of the taskA.)*

B. **The Real Ghost:** Choose a real known planet from https://exoplanetarchive.ipac.caltech.edu/cgi-bin/atmospheres/nph-firefly?atmospheres. Ideally, use the planet you picked up in assignment 2 (check if the following criteria are valid). Otherwise, use one of the planets in the archive, choosing the following criteria:

1) Select a transmission spectrum;

2) It should have a JWST observation;
3) Select a planet with a published article.

Write the transmission spectrum in a file called [planet_name]_spectrum_assignment3_taskB.dat with three columns (wavelength in micrometers, (rp/rs)^2, and error). Plot the spectrum and store it in a file called [planet_name]_spectrum_assignment3.png. Report the physical parameters of the system (star + planet) and the reported chemistry of the atmosphere in the related paper in a file [planet_name]_[article_name]_report_assignment3_TaskB.txt
(In the submission, report the date and hashcode of the commit associated with the creation of the last file for the taskB)

C. **Mocking the Universe:** Perform an atmospheric retrieval of the synthetic spectrum of point A. Retrieve the molecular abundances for all the molecules in point A, together with the temperature and the radius of the planet (if it is computationally intense, use the virtual machine in CloudVeneto, or fix the parameters and try to retrieve at least H2O, the radius and the temperature of the planet). Plot the posterior distribution of the retrieved parameters and compare the input parameters with the retrieved spectrum. Write a submission file called assignment3_taskC.txt where you put all the input parameters of the planet, the retrieved parameters and the error bars. Plot them visually in a scatter point called assignment3_taskC.png (and label each point). *(In the submission, report the date and hashcode of the commit associated with the creation of the file assignment3_taskC.txt.)*

D. **My final research:** Perform an atmospheric retrieval of the real spectrum of point B. Retrieve the molecular abundances of all the molecules in point A, together with the temperature and the radius of the planet (if it is computationally intense, use the virtual machine in CloudVeneto, or fix the parameters and try to retrieve at least H2O, the radius and the temperature of the planet). Plot the posterior

distribution of the retrieved parameters and compare the input parameters with the retrieved spectrum (if applicable). Write a submission file called assignment3_taskD.txt, where you distinguish all the fixed and retrieved parameters with their error bars. *(In the submission, report the date and hashcode of the commit associated with the creation of the file assignment3_taskD.txt.)*

Challenges (not mandatory):

E. **daneel knows the atmospheres:** Define in the daneel.atmosphere folder a class to create a forward model according to some input parameters. Follow the taurex tutorial for some suggestion. The parameters should be expressed within the a parameters file. The daneel.atmosphere module should be called from the command line as: daneel -i path_to_the_parameters.yaml -a model

With the '-a' flag (for atmosphere).

You should be able to save the forward model in the two columns (wavelength in micron, (rp/rs)^2 and sqrt((rp/rs)^2). The saved spectrum file name should be defined within the parameters.yaml file.

F. **Let's Retrieve it!** Define in the daneel.atmosphere folder a class to retrieve an input spectrum. As before Follow the Taurex tutorial for some suggestions on the retrieval modules. The fitting parameters should be expressed within the parameters file. The daneel.atmosphere module should be called from the command line as: daneel -i path_to_the_parameters.yaml -a retrieve

With the '-a' flag (for atmosphere).

You should be able to save the retrieved spectrum. The saved spectrum file name should be defined within the parameters.yaml file.

For each of these commits, report the commit hash and the task of the assignments.