CRETIN

Session 8

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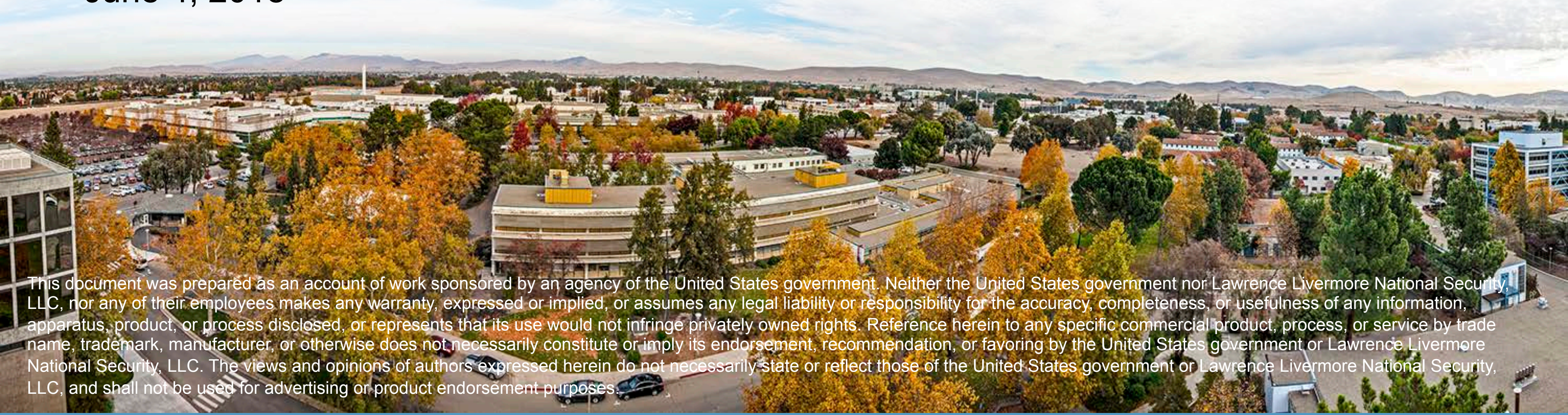

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Session topics

Line radiation transport

- Physics considerations
  - what is important / different about lines?
  - material coupling and convergence
  - important physical effects
- Code options
  - setting up frequency meshes
  - options for including physical effects
  - methods for achieving convergence
  - lineshapes

Specifying lines and options

Line specifications include a transition, frequency mesh, and physics options:

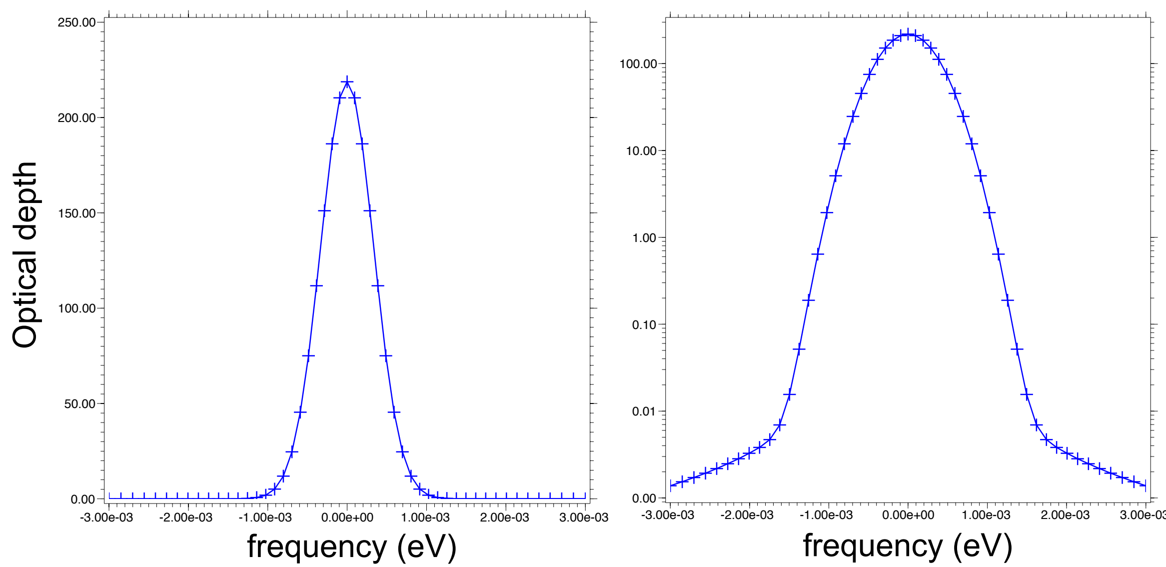
line *iline iz iso i1 iso i2*
lbins *nbins dE ratio [nbins2 dE2 ratio2] …*
linetype *options*

iline : line index
iz iso i1 iso i2 : transition
nbins dE : # bins in [$h\nu_0$, $h\nu_0 \pm$ dE]

- Line bins should resolve the line profile and extend into the wings
- The code analytically extends profiles beyond *dE* assuming a Lorentzian shape

Example:
Hydrogen Ly-α
T_e = 1 eV, $N_H = 10^{16}$

line 1 1 1 1 1 2
lbins 25 0.003 1.02



Physics options

Line options which can be set by **linetype** specify:

- treatment (transport w/ or w/o consistency, escape factor)
- discretization (choice available only in 1D)
- convergence method (choice available only in 1D)
- line profile (Voigt, Doppler, Lorentzian, Stark, Stark w/ B-field)
- redistribution option (CRD, PRD w/ r2a or r2)

Options set with the **linedefault** command apply to all lines defined later

Main controls

- **switch 37**: turn line transfer on if ≠ 0
- **switch 38**: treat continuum as constant or varying w/ frequency
  (constant → lines may remain symmetric)
- **switch 62**: include electron scattering as a loss term

"linetype" / "linedefault" options

Transport treatment / discretization:

none	no transport (i.e. ignore this line)
formal / formald	transport w/o consistency (w/ or w/o Doppler)
complin / complind	complete linearization (w/ or w/o Doppler)
rybicki / feautrier	solution method for linearized operator
approximate	approximate operator treatment
doppler / nodoppler	include Doppler shifts (or not)
escape	use escape factors (i.e. no line transport)

Line profile:

voigt, lorentzian, gaussian	
total, totalb	Stark lineshape, w/ B-field

Redistribution:

crd	complete redistribution
prd, r2a, r2, r5a	partial redistribution: angle-averaged (r2a, r5a) angle-dependent (r2)

Interacting lines

Lines can interact directly through overlapping profiles

resonant *iline1 iline2 iline3 …*

resonance *iline1 iline2 de*

de: difference in line center energies

- This can apply to lines from different elements
- The code constructs a <u>single</u> frequency grid for all specified lines
- All line profiles are treated as asymmetric

Line from the same element can interact indirectly through kinetics, e.g. sharing the same upper (or lower) level

joinline *iline1 iline2 iline3 ...*

- This matters when both lines are optically thick
- The code transports these lines together while accounting for kinetics interactions

Convergence options / controls

Overall convergence requires iteration of kinetics + transport:

switch 44: max. # of iterations per timestep

param 56: max. change in charge state populations

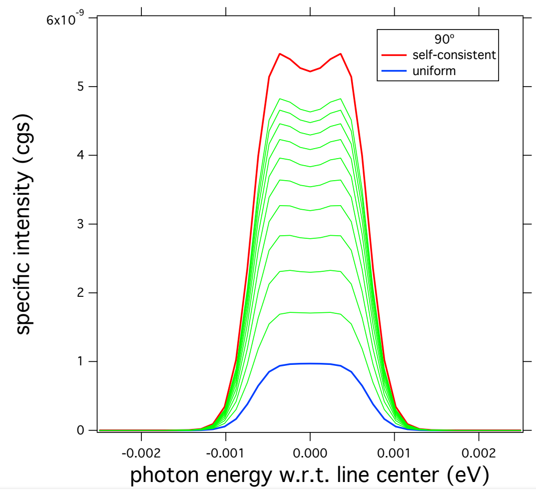
param 57: max. change in line "strength" $\bar{J}$

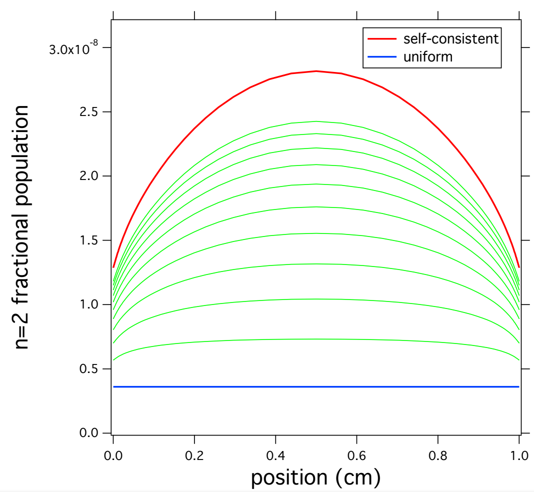
Convergence method uses linearization (i.e. Newton-Raphson) in $\bar{J}$

- full operator in 1D, approximate operator in 2D / 3D
- 2-level system converges in 1 iteration, full system converges quickly

switch 40, 41: controls on convergence of approximate operator

Hydrogen Ly-α





Line edits

- Edit specifications include the line index as the first edit index
- Intensity edits refer to the distribution function f_γ in units of photons/mode
- Edit quantities with ‘cgs’ in the name are in cgs units
- Line frequencies **evline** are measured w.r.t. line center
- (Almost) All edits are in the laboratory frame
- Edits for quantities which are affected by Doppler shifts are available with or without a direction (i.e. **editray** index)
  - w/o direction → fluid frame **lkap**(*iline,ir,ifr*)
  - w/ direction → lab frame **lkap+**(*iline,ir,ifr,idir*)

  Note: the same directional dependence applies to spectral edits

Line edit examples

Plot
xvar evline *iline*
yvar lkap+ *iline ir* 0 *idir*
yvar lkaptot+ *iline ir* 0 *idir*

Absorption coefficient profile for line *iline* at node *ir* in laboratory frame direction *idir*
lkap+ : component produced by line transition
lkaptot+ : total absorption coefficient

absorption: **lkap, lkap±, lkaptot, lkaptot±** (iline, ir, ifr, [idir])
emission: **lemis, lemis±, lemistot, lemistot±** (iline, ir, ifr, [idir])
specific intensity: **iline±** (iline, ir, ifr, idir)

optical depth: **tauline, tauline±** (iline, [±ir], ifr, [idir])
ir = 0 : over entire ray
ir > 0 : from *ir* to (upper) boundary
ir < 0 : from (1D lower boundary) to *ir*

<u>Integrated over angle</u>
intensity: **jline, jline0, jlinecgs, jline0cgs** (iline, ir, ifr)
flux: **lflux±** (iline, ir, ifr)

<u>Integrated over line profile</u>
energy density: **eline** (iline, ir)
kinetics: **jbar, jbarcgs** (iline, ir)

Argon sphere – identifying transitions

- T_e = 1 keV, N_i = 6 x 10^{22} cm^{-3}, R = 0.005 cm
- Atomic model: dca_18k
- Line transfer on H-α and He-α

enot	1	h-like	4426.270			
elev	1	1	1s_______2		2.	0.000000
elev	1	2	2p_______2		2.	3318.223
elev	1	3	2s_______2		2.	3318.376
elev	1	4	2p_______4		4.	3323.039

N=1

N=2

enot	2	he-like	4118.595		
elev	2	1	1s_______1	1.	0.000000
elev	2	2	1s2s_____3	3.	3103.705
elev	2	3	1s2p_____1	1.	3123.268
elev	2	4	1s2p_____3	3.	3123.910
elev	2	5	1s2s_____1	1.	3123.925
elev	2	6	1s2p_____5	5.	3126.622
elev	2	7	1s2p_____3	3.	3140.205

H-α transitions:

data	phxs					
d	1	1	1	2	1.37957E-01	3.73646E+00
d	1	1	1	3	1.90219E-08	3.73629E+00
d	1	1	1	4	2.73463E-01	3.73105E+00

He-α transitions:

d	2	1	2	2	3.23842E-08	3.99472E+00
d	2	1	2	4	1.22059E-02	3.96888E+00
d	2	1	2	6	3.66479E-06	3.96544E+00
d	2	1	2	7	7.59492E-01	3.94828E+00

Argon sphere – H-α components

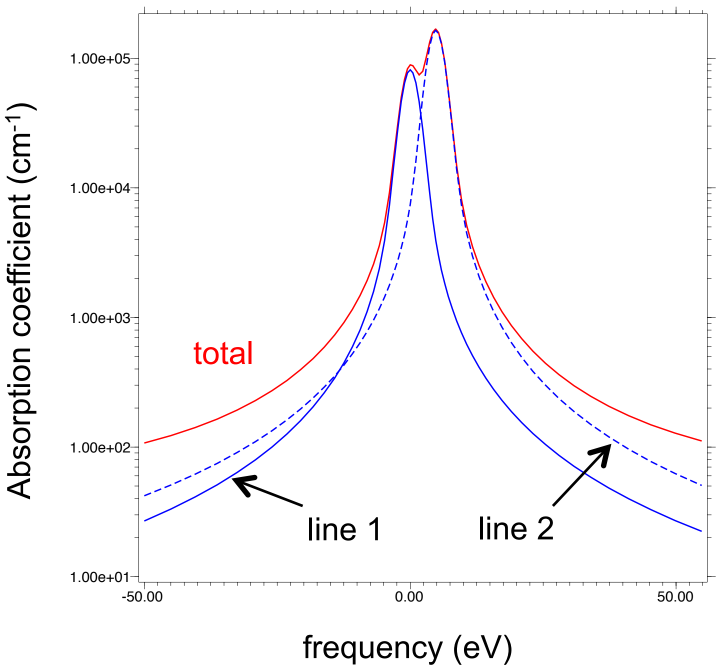
line 1 1 1 1 1 2
  lbins 25 50.0 1.1

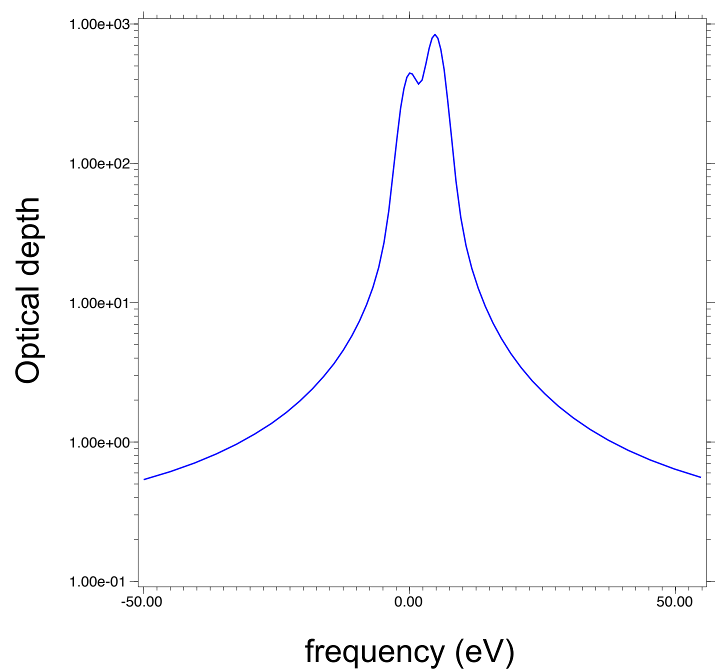
line 2 1 1 1 1 4
  lbins 25 50.0 1.1

resonant 1 2

H-α

- Lines share a frequency mesh
- Total quantities include continuum contributions
- Individual components are only available for local quantities



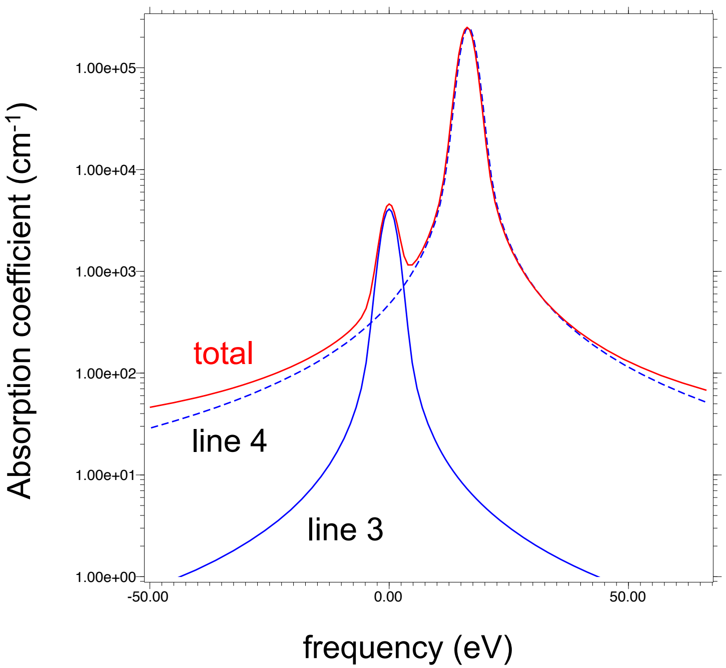


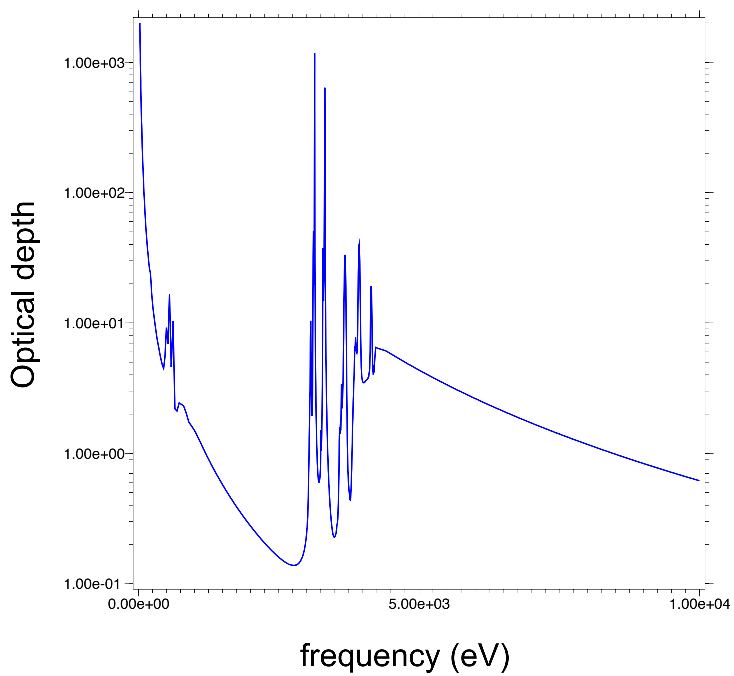
Argon sphere – He-α components

```
line 3 1 2 1 2 4
  lbins 25 50.0 1.1

line 4 1 2 1 2 7
  lbins 25 50.0 1.1

resonant 3 4
```

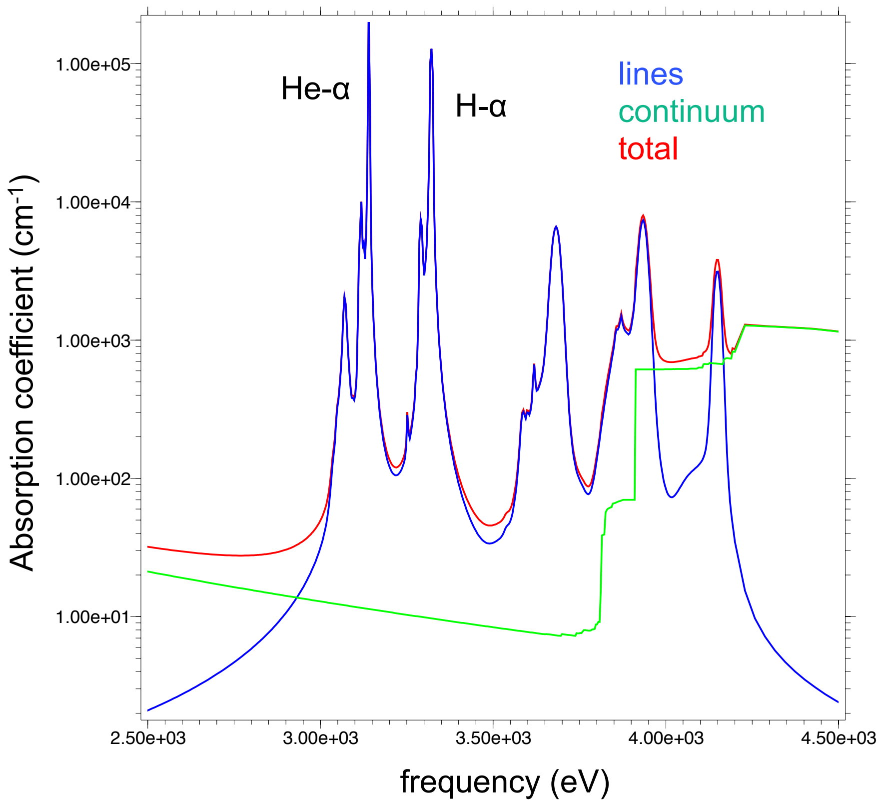
He-α

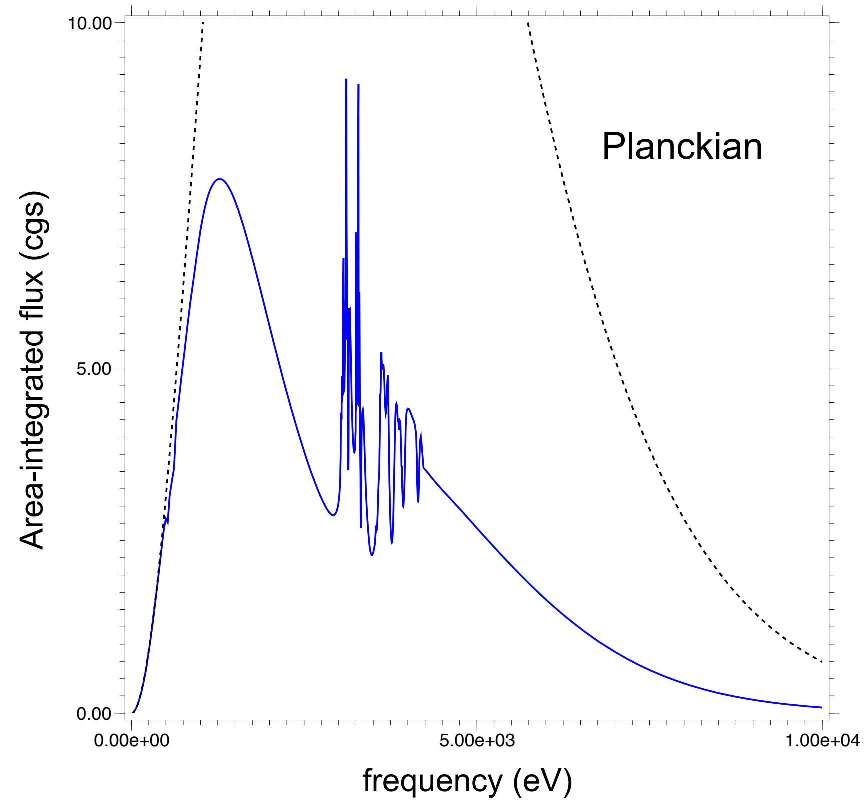
- Minor component is visible, but unimportant
- Major component is shifted significantly on minor component frequency mesh





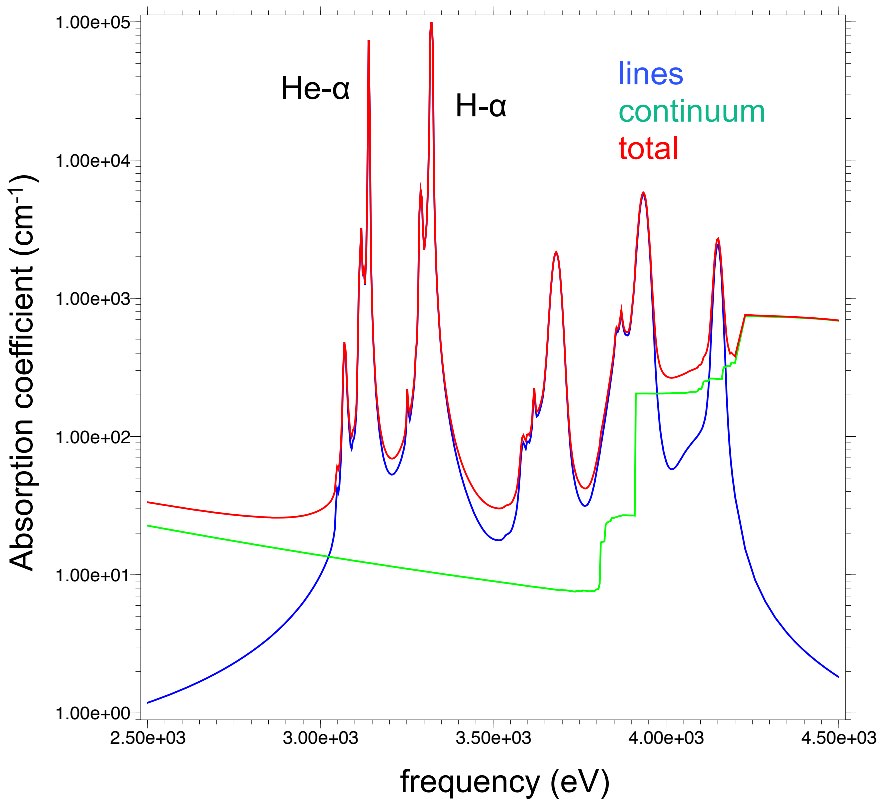
Argon sphere – full spectrum (w/o continuum transfer)

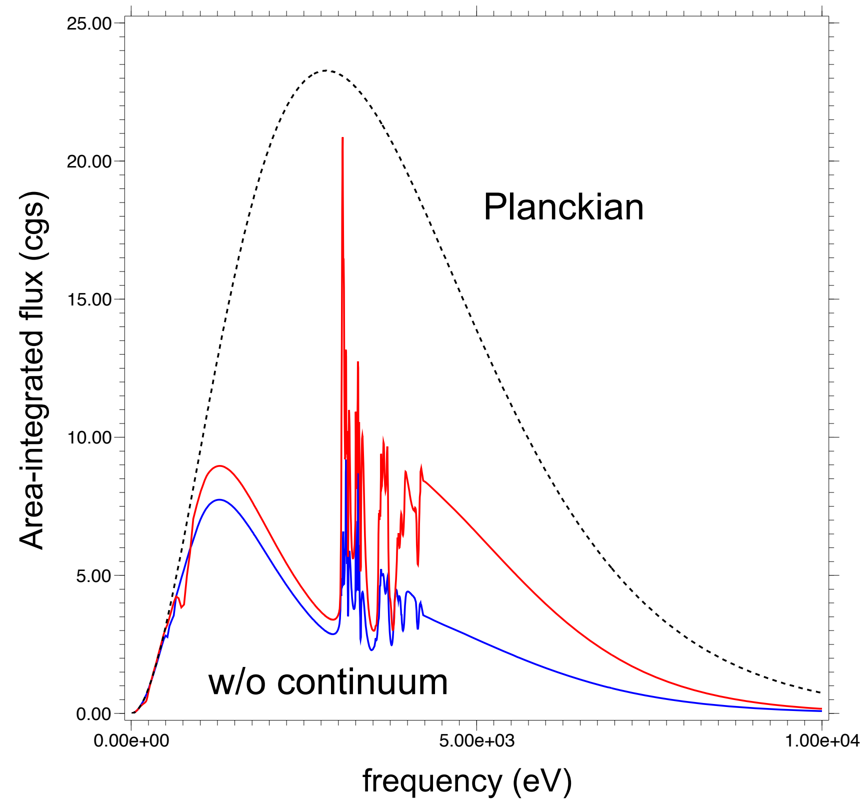




Line profiles are <u>almost</u> resolved in these figures

Argon sphere – full spectrum (w/ continuum transfer)





Line profiles are <u>almost</u> resolved in these figures

Incorporating line transfer into a simulation

1. Identify strong transitions with large optical depths
2. Estimate line widths to set frequency bins
3. Check line profiles – **tauline**, **jline** – for resolution and coverage
4. Check for convergence with # of angles

(Almost) all results can be obtained with increased <u>continuum</u> resolution

Benefits of adding line transfer

- efficient resolution
- faster convergence for self-consistency
- line profiles (redistribution)