CRETIN

Session 6

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April 30, 2018

LLNL-PRES-751314

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

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Session topics

Radiation transport

- ”Flavors”: continuum, lines, spectral
- Goals: energetics, kinetics / populations / spectra
- Main commonalities
  - considerations for meshes in space, angle and frequency
  - edit specifications
- Major differences
  - setting up frequency meshes
  - options for including physical effects
  - methods for achieving convergence

Radiation transport "flavors"

Continuum, lines and spectra are treated separately for efficiency

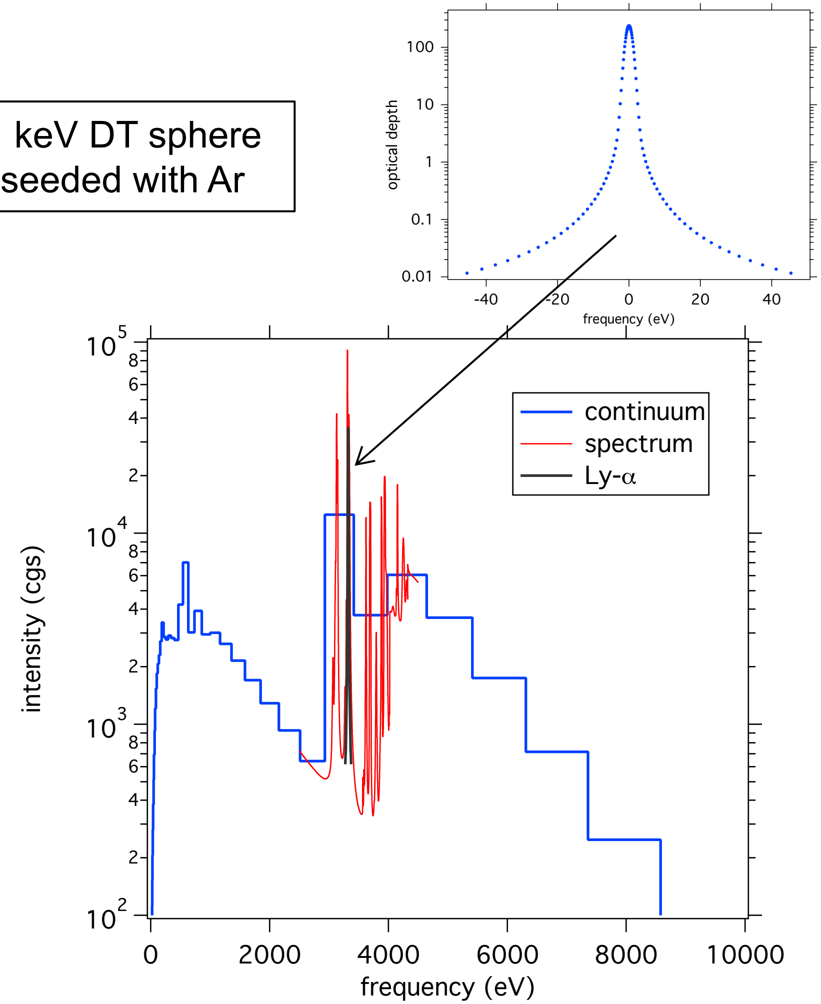
Iterated to consistency with atomic kinetics (and other processes):

- <u>continuum radiation</u> coarsely-binned over full energy range for evaluating photo rates
- <u>line radiation</u> finely-binned for resolving individual line profiles

Evaluated after convergence:

- <u>spectral radiation</u> at arbitrary energies to resolve features of interest

1 keV DT sphere seeded with Ar



Spatial meshes

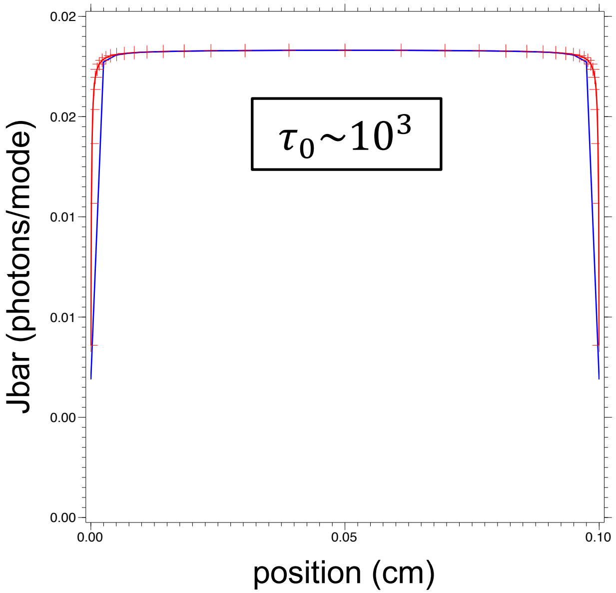
- All types of radiation transport in a Cretin run use the same spatial mesh
  - mixing centerings (for rad-hydro runs) is possible but discouraged
- The main consideration is resolving boundary layers
  a) Boundaries produce non-uniformities in the radiation field within $\tau_\nu \sim 1$
  b) The radiation field produces non-uniformities in the material properties
  c) Escaping radiation may originate primarily in the boundary layer
- This can be an issue for quantities sensitive to the boundary layer

Example:

Optically thick (multiple) line transfer

Two mesh specifications:

1) rlin 1 41 0.0 1.0
2) rgeom 1 21 0.0 0.5 1.e-4 +1
   rgeom 21 41 0.5 1.0 1.e-4 -1



Symmetries (reflective boundary conditions)

- Symmetries are specified with **switch(34)** (or by boundary conditions)
  - 1D: switch(34) > 0 ⇒ symmetric about *ir*=1
  - 2D/ 3D: each digit specifies symmetries on a logical boundary
    digit -   <u>2D</u> k: 10's, l: 1's   <u>3D</u> k: 100's, l:10's, m: 1's
    value - 0: none, 1 or 3: lower boundary, 2 or 3: upper boundary

  e.g. switch(34) = 13 in <u>2D</u> or 133 in <u>3D</u> gives one open boundary at k=kmax

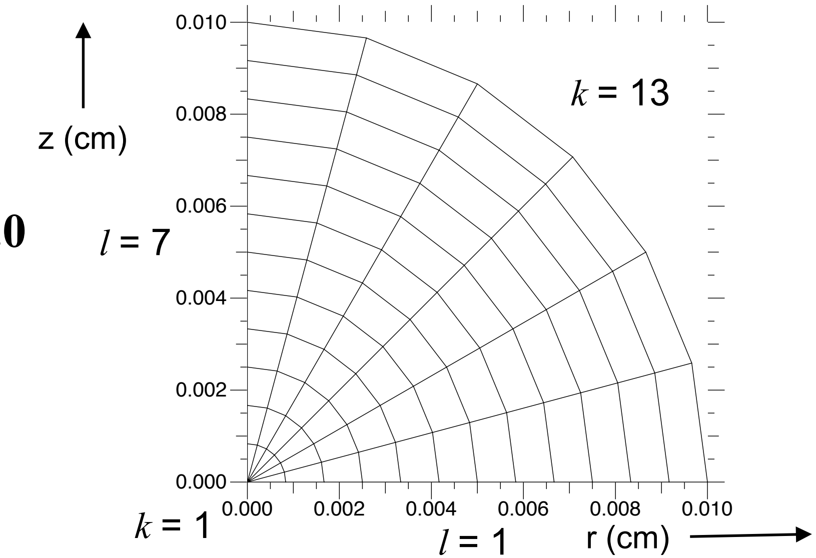
Example: sphere in RZ geometry

geometry rz
wedge 1 13 1 7   0. 0.01 90.0 0.0   1.0 1.0
switch 34 13

Symmetry point @ origin: k=l=1

Symmetry line @ z-axis: l=7

Symmetry plane @ z=0: l=1



Symmetries are only valid along coordinate axes / planes

Boundary conditions and sources

Boundary conditions require position, direction, magnitude and frequency

- Position and direction come from **xfilebc** or **boundary** commands
- Intensity distribution can come from a simple formula or tabulated data

- **xfilebc** *ix mu phi multiplier isotropy* **kl** *kmin kmax lmin lmax mmin mmax*
  xfilebc *ix mu phi multiplier isotropy* **xy** *xmin xmax ymin ymax zmin zmax*
  ix: index of xfile containing boundary data
  isotropy ≠ 0: boundary condition is treated as isotropic external field
- **boundary** *package type k1 [k2 l1 l2 m1 m2]* **{history | xfile | source}** *id* [*multiplier*]
  package: **radiation** or **all** (other options apply to other physics)
  type: **reflecting**, **isotropic**, **streaming** “
- **source jbndry** *ix* **black-body** *trad [multiplier]*
  source jbndry *ix emin emax* {**black-body | power-law** *a b*} **{history | xfile | profile | constant}**
  {value | rate | integral | initial} {id | value} [*multiplier*] *[ireg | k1 k2 l1 l2 m1 m2]*
- **source jnu …** ← provides internal radiation sources

Source specifications sum to give the final spectrum
Sources apply to continuum and spectral radiation

Angular meshes

All types of radiation transport in Cretin use discrete ordinates (S_N) methods with the same angular mesh

— exception: spectral transport may not need an angular mesh

The number of angles in the angular mesh depends on geometry

- 1D planar / spherical : 1 angle $\mu = \cos(\theta)$
- 1D cylindrical, 2D, 3D : 2 angles $(\mu\, ,\phi)$

The angular mesh

1. Provides a basis for doing solid-angle integrals:

$$\int I_\nu \, d\Omega = \int_0^{2\pi} d\phi \int_{-1}^{1} d\mu \, I_\nu(\mu,\phi) \rightarrow \sum_j \Delta\phi_j \sum_i \Delta\mu_i I_\nu(\mu_i,\phi_j)$$

2. Resolves angular variations in the radiation field

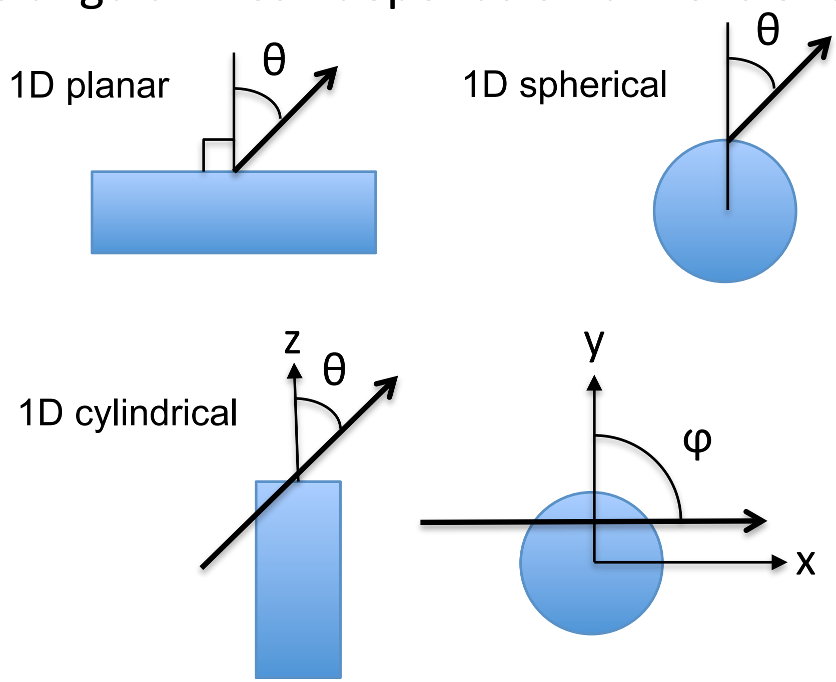
Warning: resolving angular scales in 2D / 3D may be very difficult – see John Castor's book "Radiation Hydrodynamics"

Angle specifications – 1D

- The number(s) of angles are specified by

  angles *nmu (nphi)*

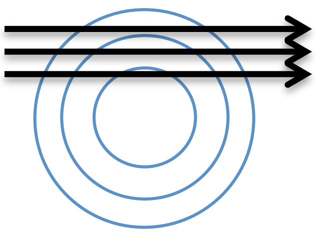
- The angular mesh depends on dimensionality and geometry:



Planar / cylindrical:
nmu = # angles in 90º

Spherical (*nmu*) / cylindrical (*nphi*):
<u>mininum</u> # used for integrations

"long characteristics"



In non-planar geometry, the total # of "rays" increases with the # of zones

Angle specifications – 1D

- Gaussian integration is used to integrate over *mu* in planar / cylindrical geometry $\Longrightarrow$ values of *mu* correspond to zeroes of Legendre polynomials

  switch 8 = 0 : Gaussian integration over [-1,1]
  ≠ 0 : double-Gaussian integration over [0,1]

$$\int_{-1}^{1} I_\nu(\mu)\,d\mu \quad \text{vs} \quad 2\int_{0}^{1}\left[I_\nu(\mu)+I_\nu(-\mu)\right]d\mu$$

A few general comments:

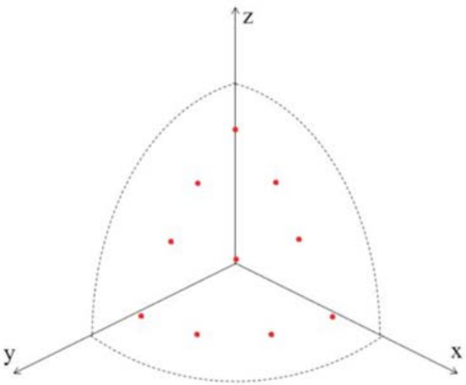
- All transport is 3-dimensional, with symmetries used to decrease the work
- Correspondence with S_N designation: N = 2 x *nmu*

Angle specifications – 2D, 3D

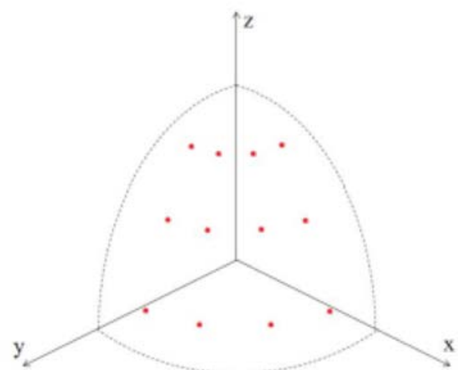
- The number(s) of directions in a quadrant / octant are specified by angles *nmu* *(nphi)*

- Angle sets are determined by **switch 8** :
  0: Carlson set A
  1: Carlson set B (equivalent to double-Gaussian)
  2: product set with Gaussian *mu*
  3: product set with double-Gaussian *mu*
  4: level symmetric set (valid for *nmu* up to 10 ⇔ S_{20})

- Total number of directions per quadrant / octant:
  0, 1, 4: *½ x nmu x (nmu+/-1)*
  2, 3: *nmu x nphi*



level symmetric – *nmu* = 4



product set – *nmu,nphi* = 3,4

Angle sets A, B are described in: B. Carlson, "The Numerical Theory of Neutron Transport", Methods in Comp. Physics, Vol. 1, 1963

Edit specifications

- Edits for transport types have very similar names
  e.g. *inu+, isp+, iline+* for specific intensity
  cflux+, spflux+, iflux+ for flux
  jnu, jsp, jline for angle-averaged intensity
- Continuum / spectral transport are done in cgs units (*jnu*: erg/cm^2/s/Hz/ster)
  Line transport uses the photon distribution function (*jline*: photons/mode)
  conversion factor $2h\nu^3/c^2$ is available as: jmode iline
- Directions are specified by the 4th edit index and must be defined:
  editray *idir mu phi type* *type* = 0: use the closest existing direction
  ≠ 0: add this exact direction

  edit

  xvar *energy* | *sp_energy* | *evline iline*
  yvar *inu+ 0 ir 0 idir* | *isp+ 0 ir 0 idir* | *iline+ iline 0 ir 0 idir*
- In 1D geometries, +(-) specifies direction of increasing (decreasing) node index
  In 2D/3D, +(-) designations are identical and (*mu,phi*) give direction of photons

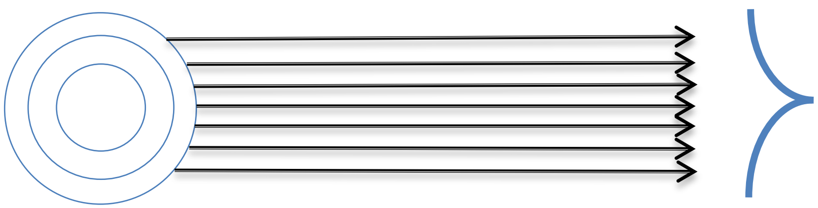
Other useful transport edits

Spectral frequency sub-mesh specification:

spectrum nspec E0 E1 ratio [“wavelength”]
spectral-group *is* ES0 ES1 [“wavelength”]

Area-integrated edits – *jnuarea, jsparea, lnuarea* – 1D spherical / cylindrical

xvar *sp_energy* *is* ← *is* = 0 means full spectral range
yvar *jsparea* *is* *ir* ← area-integrated out to radius *ir*



2D/3D equivalent: detector edits – *cdetect, spdetect, idetect*

detector *idtct* x y [z] mu phi dΩ ← specifies position and orientation of detector
detector *idtct* x y [z] mu phi dΩ **extent** dr + spatial extent

Directions for detectors are specified from photons leaving the detector

Frequency meshes

- Continuum radiation uses the same frequency mesh as the atomic kinetics
  ebins *nbins emin emax [ratio]* ← or **fbins**, **wbins**
  energy *e0 e1 e2 e3 …* ← or **frequency**, **wavelength**
  – or –
  pbins |**rbins** *i0 i1 e0 e1* ← in units of keV
  pbinlin | **rbin_lin** *i0 i1 e0 e1*

- Spectral radiation
  spectrum *nbins emin emax [ratio]*

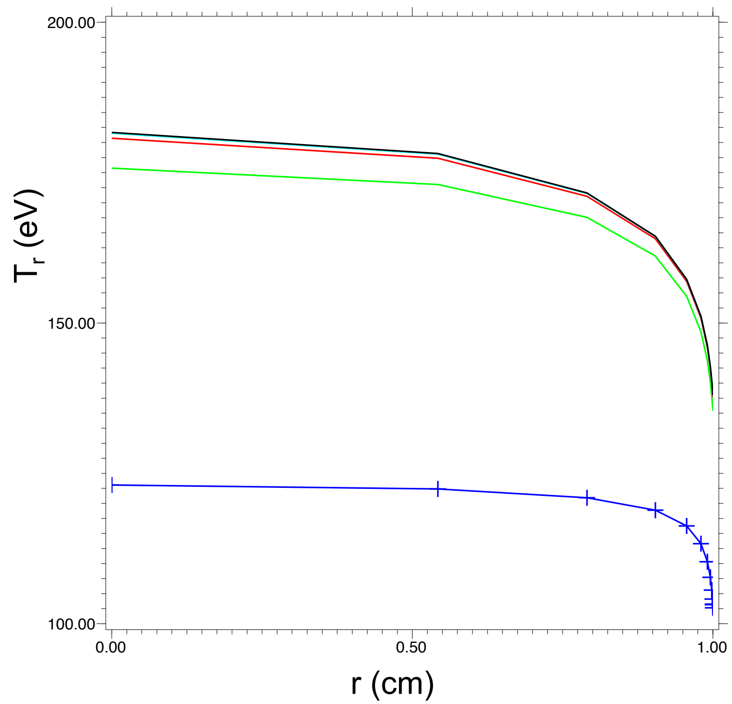
  Default behavior is to evaluate spectral absorption / emission coefficients at the exact spectral bin energies, which may miss narrow lines or peaks
  switch 125 ≠ 0 : integrate over (constructed) spectral bin intervals

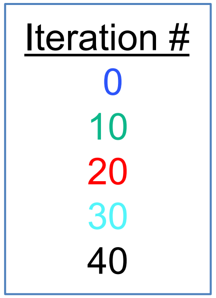
  When starting from a restart or spectral dump, specifying a new frequency mesh in the (optional) generator replaces the original frequency mesh

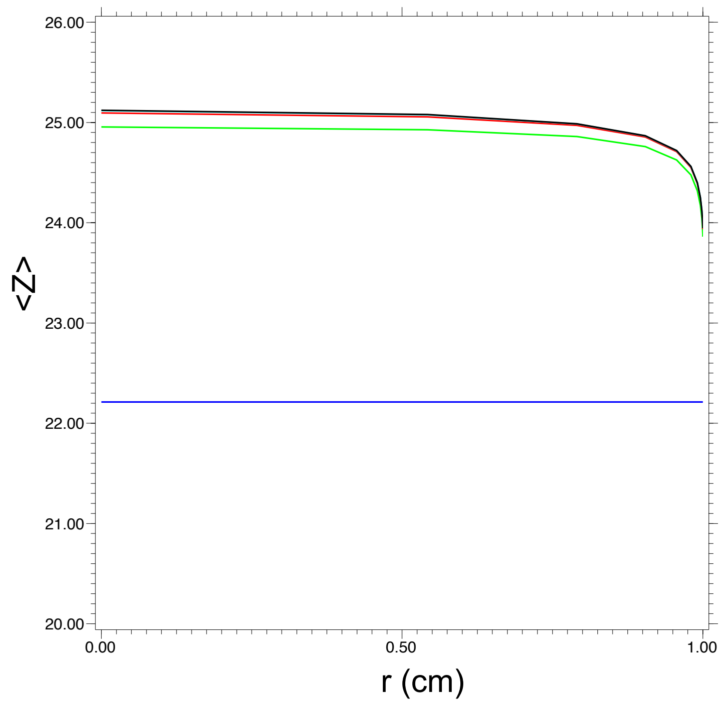
Multiple ebins, etc. or spectrum commands may be used
Frequencies do not need to be specified in consecutive order

Example: Kr sphere

- Uniform material conditions: T_e = 200 eV, ρ = 0.01 g/cm^3
- Continuum transfer w/ vacuum boundary condition
- Initial conditions: T_r = 0
- Spatial mesh: **rgeom 1 13 0. 1. 1.e-3 -1**
- Frequency mesh: **ebins 1 161 1.e0 1.e4**
- Iterated to 10^{-3} in all charge states → 40 iterations







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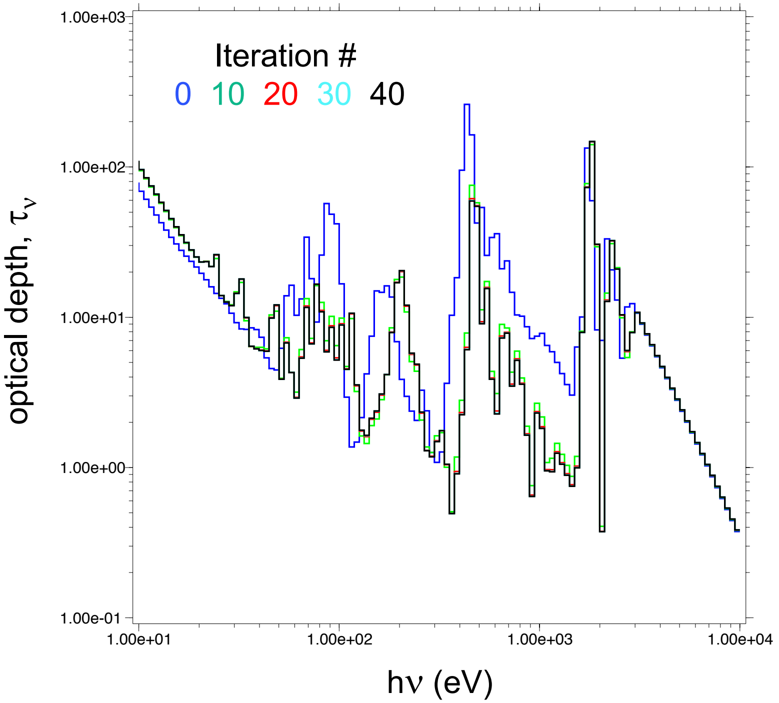
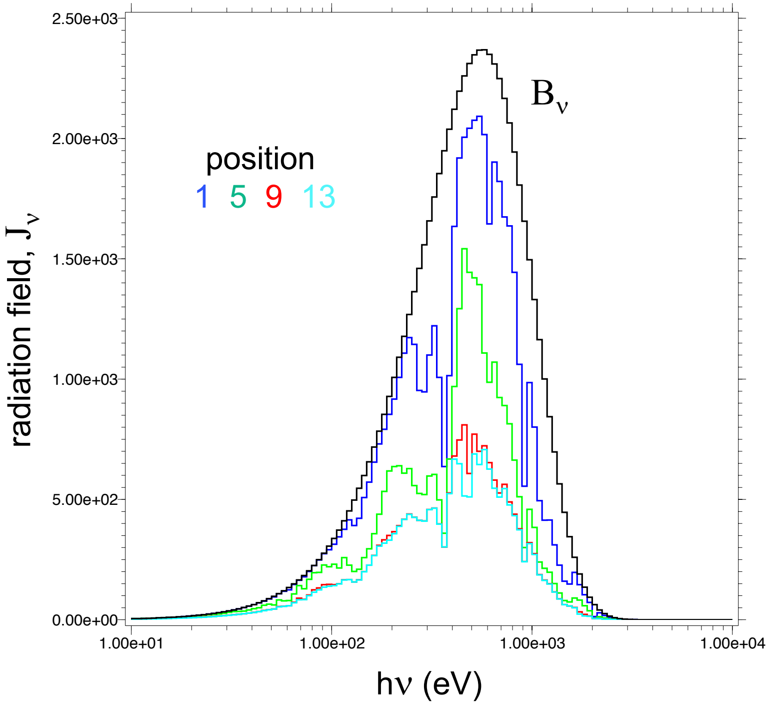
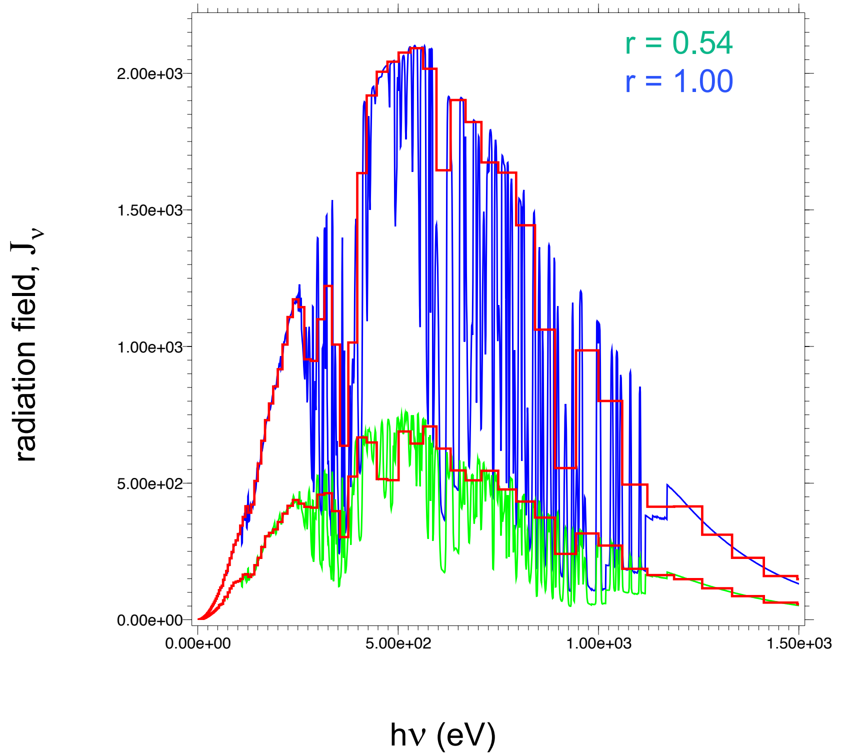
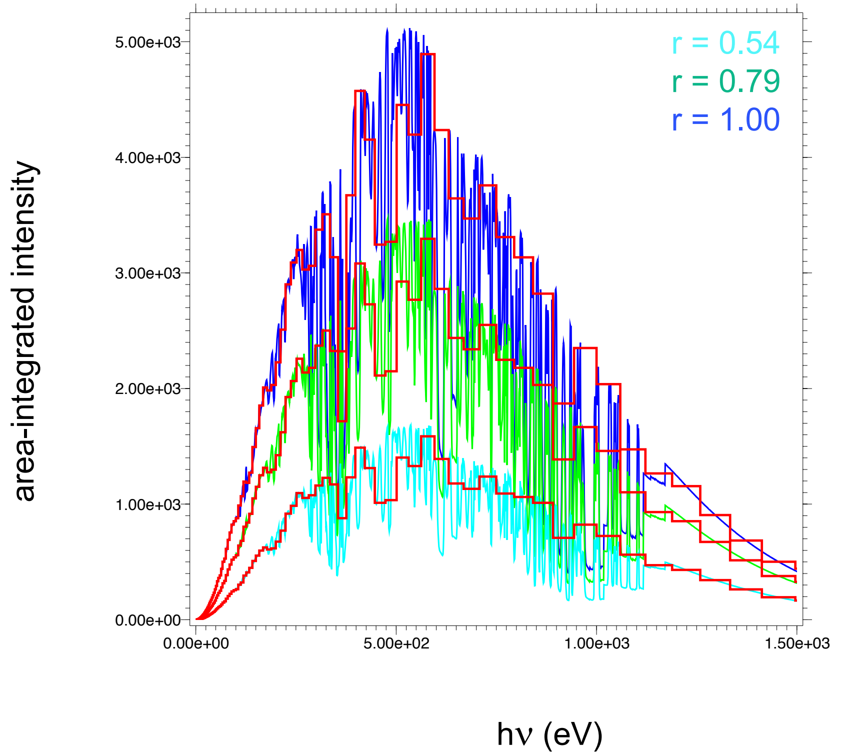




Example: Kr sphere

- Frequency mesh: **ebins 1 161 1.e0 1.e4**
- Spectral frequency mesh: **spectrum 2000 1. 2000.**
- Area-integrated edits (jsparea / jnuarea)





Example: Kr sphere – 2D

- Spatial mesh: **geometry rz**
  wedge 1 13 1 7 0. 0.01 90.0 0.0 1.0 1.0 **[1 13 1 91]**
  switch 34 13
- Edit direction: **editray 1 1. 0. 1** (parallel to +z axis)
- Boundary condition: **xfilebc 1 1. 0. 1. 1 kl 13 13 4 5** **[xy .0045 .005 .008 .01]**
  source jbndry 1 2.0e3 3.0e3 black-body constant value 1.e3 1.e-2