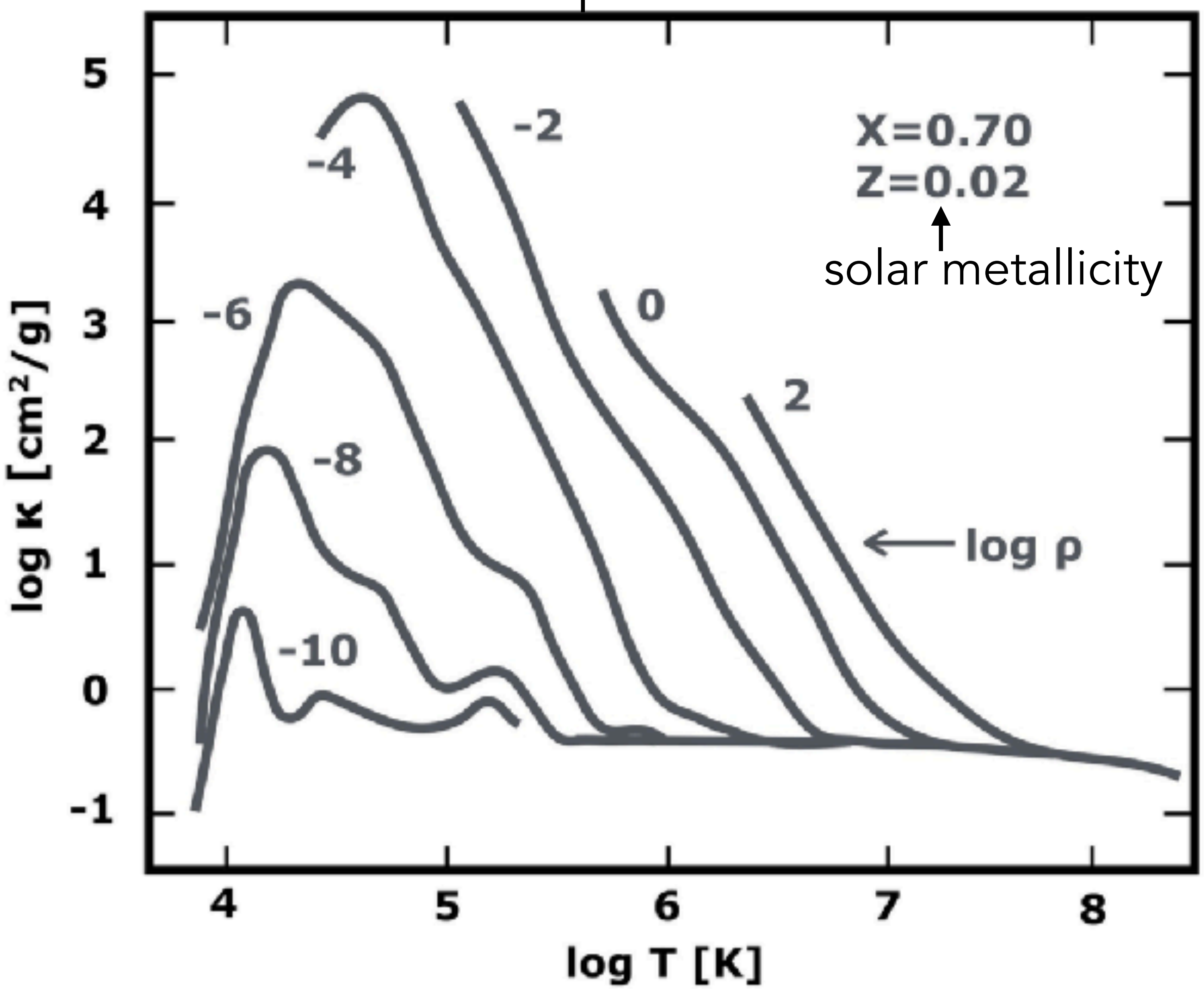
Physics 239
Radiative Processes in Astrophysics

Lecture #5: Rosseland Mean Opacity

Rosseland Mean Opacity

Lamers & Levesque

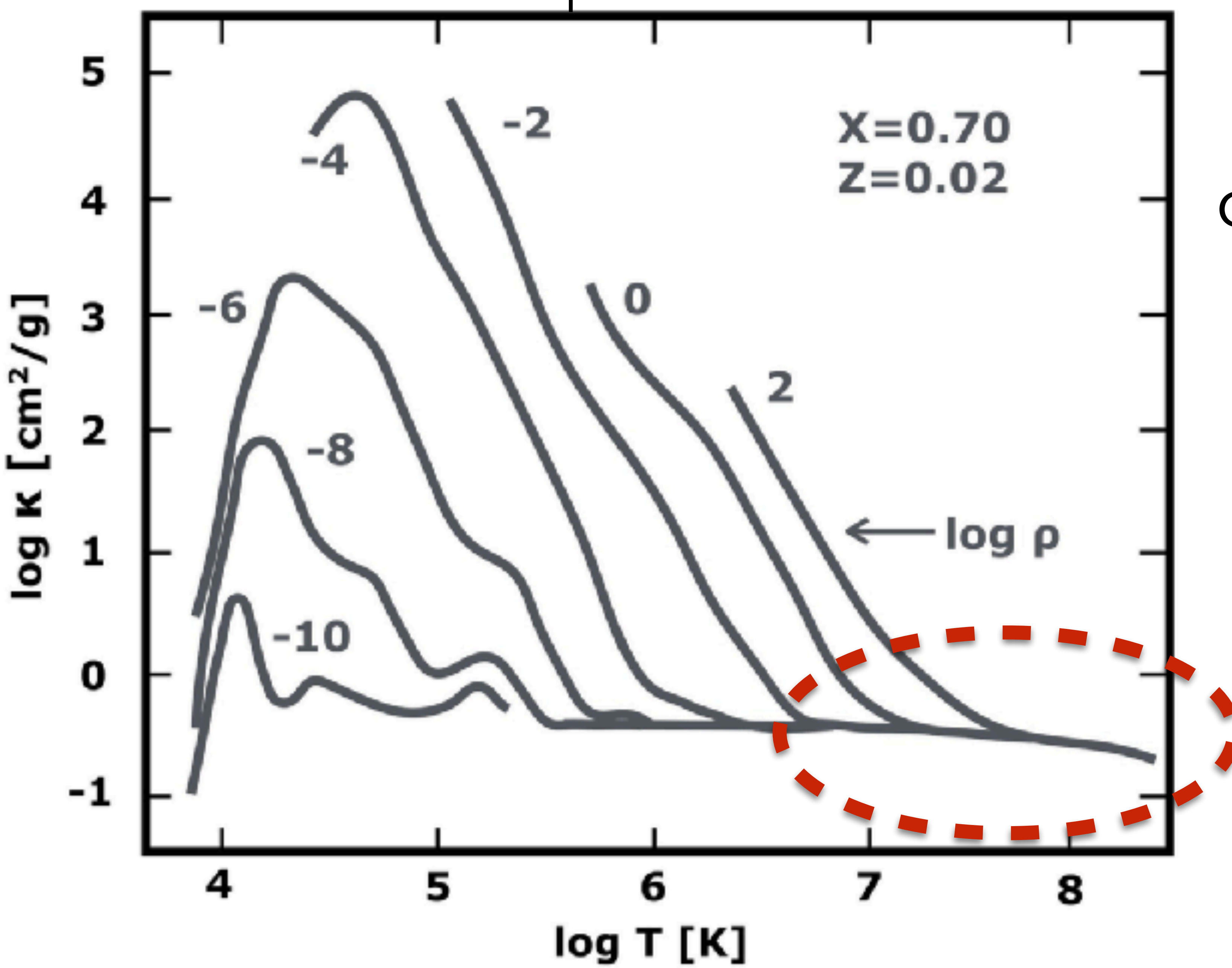


Very useful in stellar structure and evolution calculations!

https://opalopacity.llnl.gov/opal.html

Rosseland Mean Opacity

Lamers & Levesque



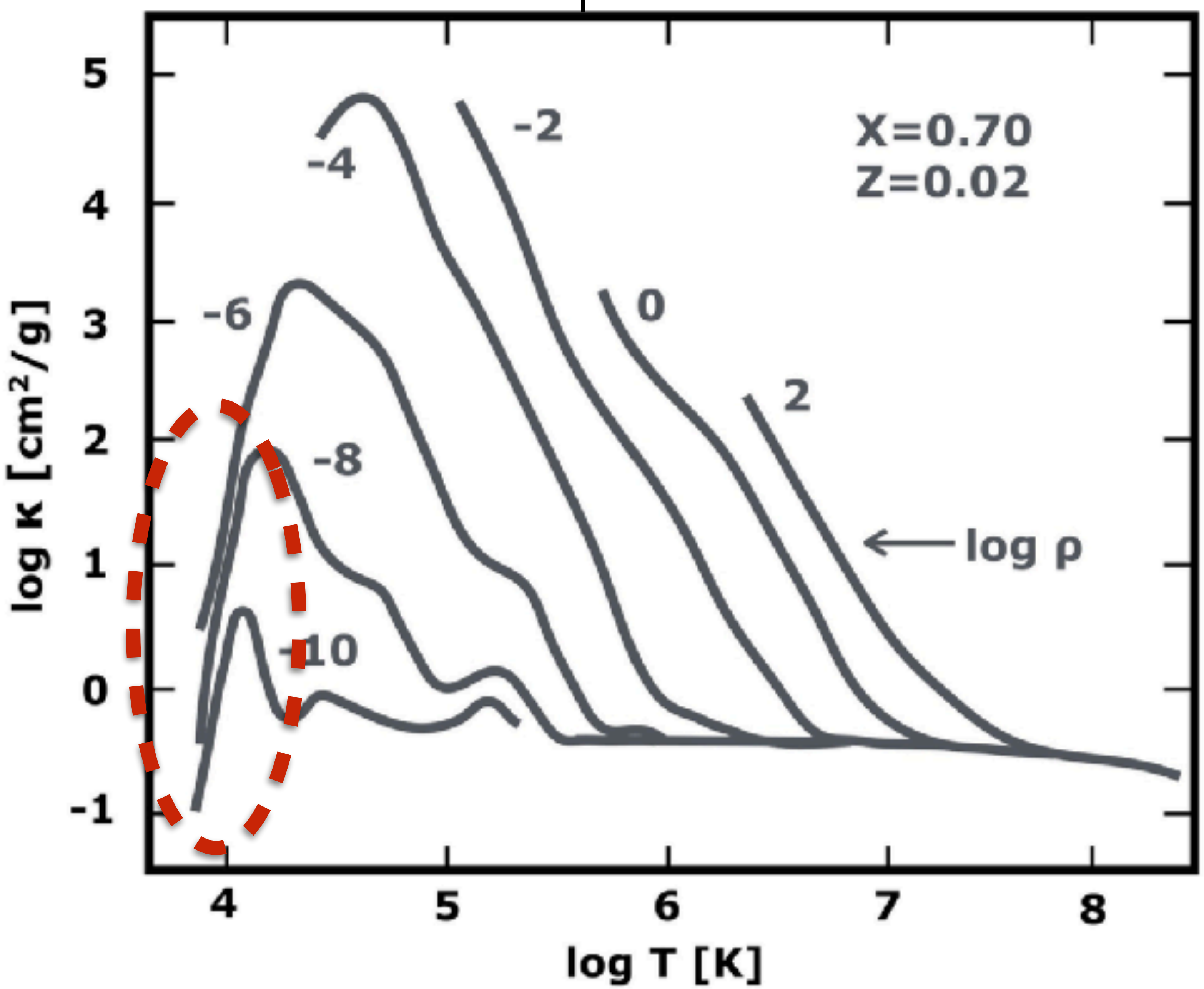
What provides most opacity at very high T?

Everything is ionized, opacity is primarily scattering off e- (Thompson scattering). Cross section doesn't change with T, ρ

Also true for lower T, lower ρ

Rosseland Mean Opacity

Lamers & Levesque

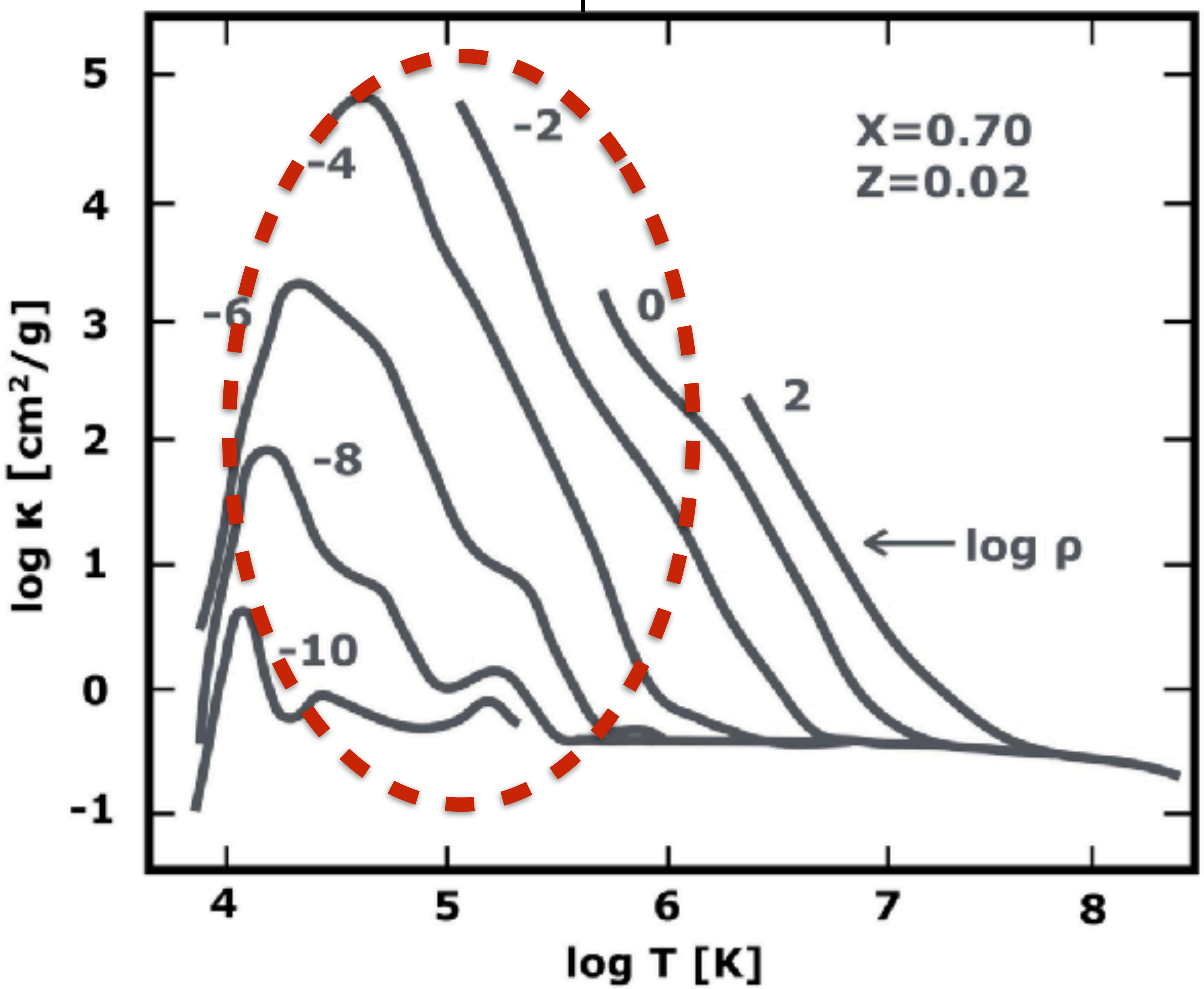


Steepness of the opacity increase at low T is due to H-

Why: need opacity in visible when T~6000 K, for H need atoms with electron in n=2 level, H- can be ionized by optical photons, big cross section.

Rosseland Mean Opacity

Lamers & Levesque



Opacity for a given density, peaks between $T \sim 10^4$-10^6 K

Plasma here is partially ionized, *many* possible bound-bound, bound-free transitions within atoms.

Solving the General Radiative Transfer Problem: What we have done so far

- looked at an approximation of scattering as a random walk
- used that to understand limit and qualitative behavior of scattering + absorption in eq. of radiative transfer
- worked out a useful case where $D >> l_*$ and things are thermalized leading to radiative diffusion and the Rosseland mean opacity

Solving the Radiative Transfer Equation

- Monte Carlo methods
- Discrete ordinate methods
- Lambda-iteration
- Moment methods

Monte Carlo Radiative Transfer

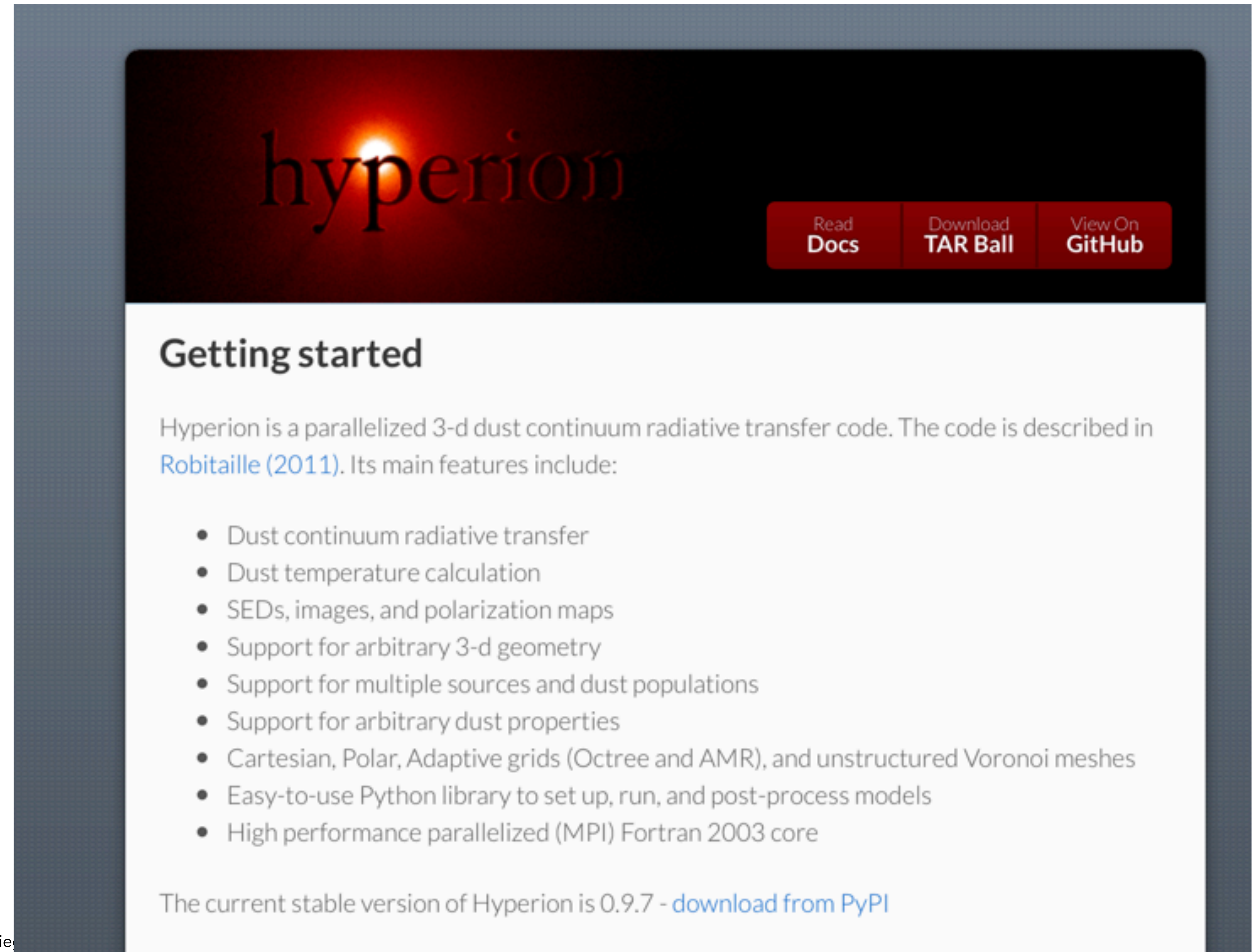
Statistically follow the path of photon "packets"

Use random number generation to decide direction of next step after an interaction of photons & matter.

Main issue: limited statistics & noise.

Often only continuum processes, no line abs/emission.

Monte Carlo Radiative Transfer



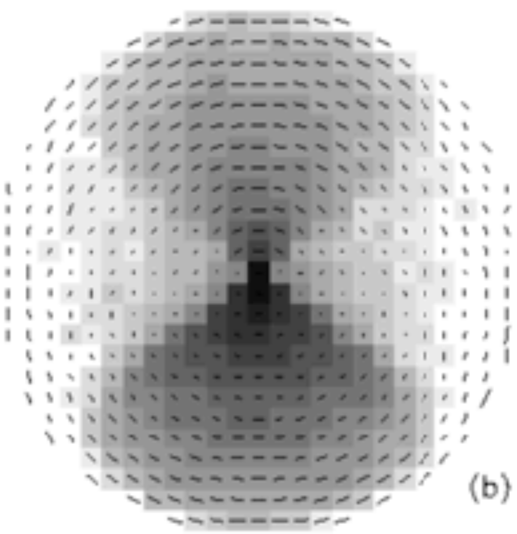
Getting started

Hyperion is a parallelized 3-d dust continuum radiative transfer code. The code is described in Robitaille (2011). Its main features include:

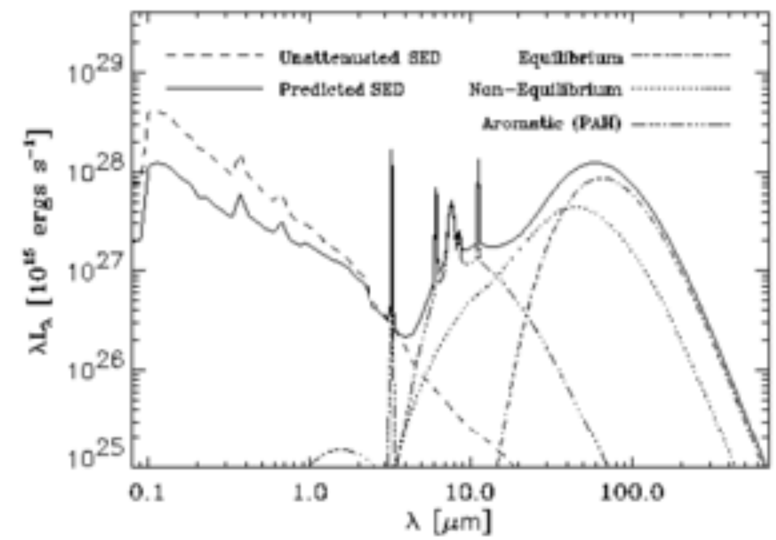
- Dust continuum radiative transfer
- Dust temperature calculation
- SEDs, images, and polarization maps
- Support for arbitrary 3-d geometry
- Support for multiple sources and dust populations
- Support for arbitrary dust properties
- Cartesian, Polar, Adaptive grids (Octree and AMR), and unstructured Voronoi meshes
- Easy-to-use Python library to set up, run, and post-process models
- High performance parallelized (MPI) Fortran 2003 core

The current stable version of Hyperion is 0.9.7 - download from PyPI

Monte Carlo Radiative Transfer



The DustI Radiative Transfer, Yeah!
Model
aka
The DIRTY Model



- The DIRTY model is a code for computing the radiative transfer of photons through dust including the reemission of the energy absorbed by the dust.
- The radiative transfer is done using Monte Carlo techniques allowing for arbitrary distributions of photon emitters (stars, gas, accretion disks, dust) and arbitratry distributions of the dust (scatterers and absorbers).
- The dust reemission is calculated using analytic techniques including equilibrium thermal emission (large particles), non-equilibrium thermal emission (small particles), and aromatic feature emission (PAH molecules?). The dust reemission is done self-consistantly with the radiative transfer which allows for self absorption by the dust.

The DIRTY model is fully described in:

- The DIRTY Model. I. Monte Carlo Radiative Transfer Through Dust
  K. D. Gordon, K. A. Misselt, A. N. Witt, & G. C. Clayton 2001, ApJ, 551, 269
- The DIRTY Model. II. Self-Consistent Treatment of Dust Heating and Emission in a 3-D Radiative Transfer Code
  K. A. Misselt, K. D. Gordon, G. C. Clayton, & M. J. Wolff 2001, ApJ, 551, 277

Discrete Ordinate Methods

Divide all coordinates (also angles and frequencies) into discrete grid cells.

Main issue: limited resolution.

Lambda Iteration

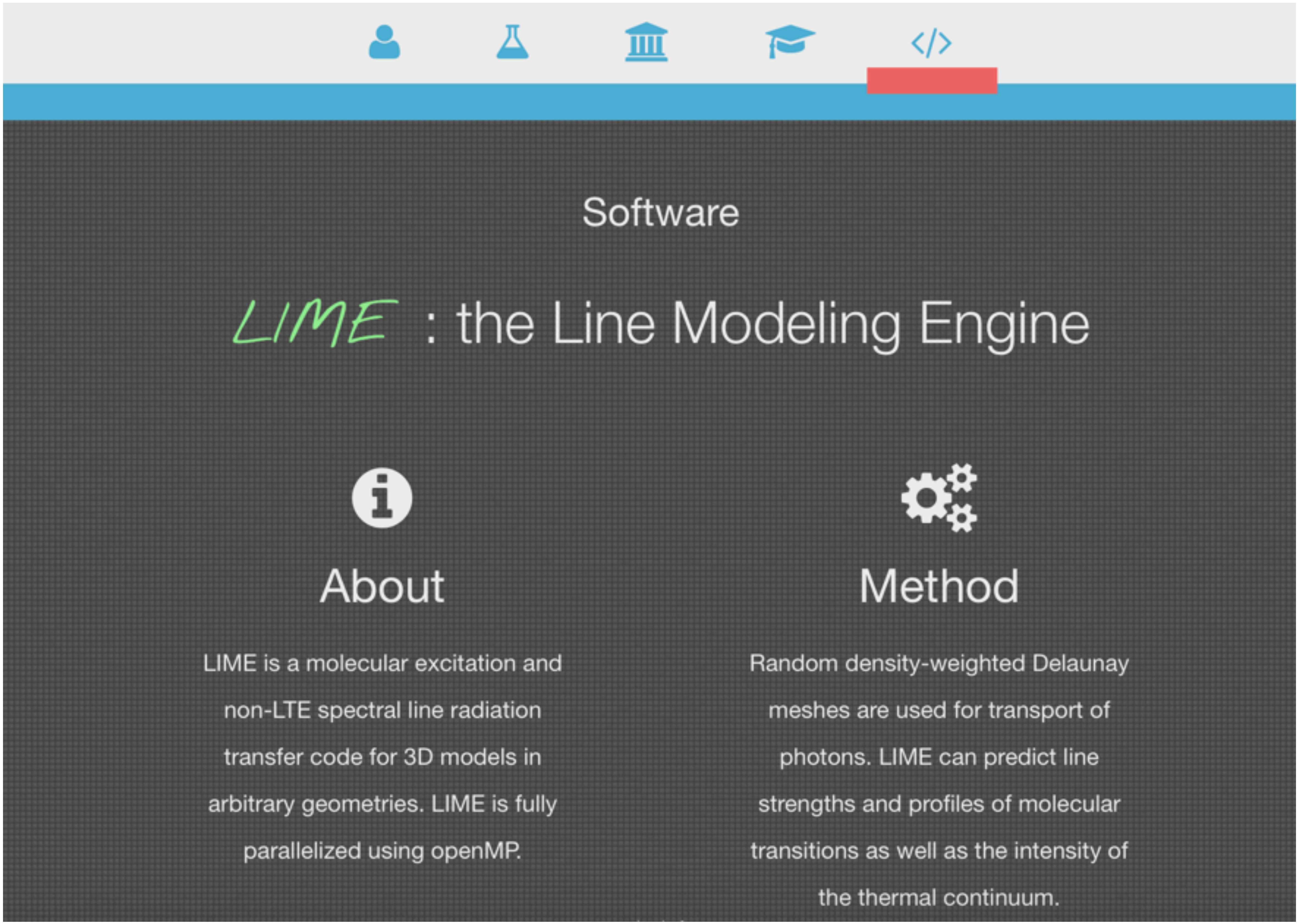
1. make initial guess for J_ν
2. integrate transfer eq along many rays
3. compute J_ν at all locations, thereby computing scattering emissivity j_ν
4. go back to 2 and loop till J_ν converges

Global (transfer eq) ⟶ Local (emissivity) ⟶ Global (transfer eq)

first iteration: "single scattering"

Main issue: for $\tau \gg 1$, $N_{sca} \sim \tau^2$, need *many* iterations

Combo of Monte Carlo & Lambda Iteration



Moment-based Methods

Take moments of the radiation field to reduce the scope of the problem and then find a “closure relation”.

what does this mean…