3D ISM-Shock Spectral Emission Models

Thermal Cooling in Inhomogeneous ISM Simulations

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Cooling in the ISM

- Astrophysical plasmas cool in a highly non-linear fashion.
- In general, the cooling may be dynamically unimportant, or a significant part of the energy budget.
- Calculation of the ISM plasma cooling is performed in a range of degrees of complexity and accuracy depending on the purpose of the calculations.

Cooling in the ISM

- Geometry and Radiative Transfer may strongly affect the outcome.
- The Interstellar Medium is *NOT* uniform, in density or velocity.
- When dynamical and thermal timescales are coupled, and turbulent structres are important, then time dependent 3D inhomogeneous models are necessary.

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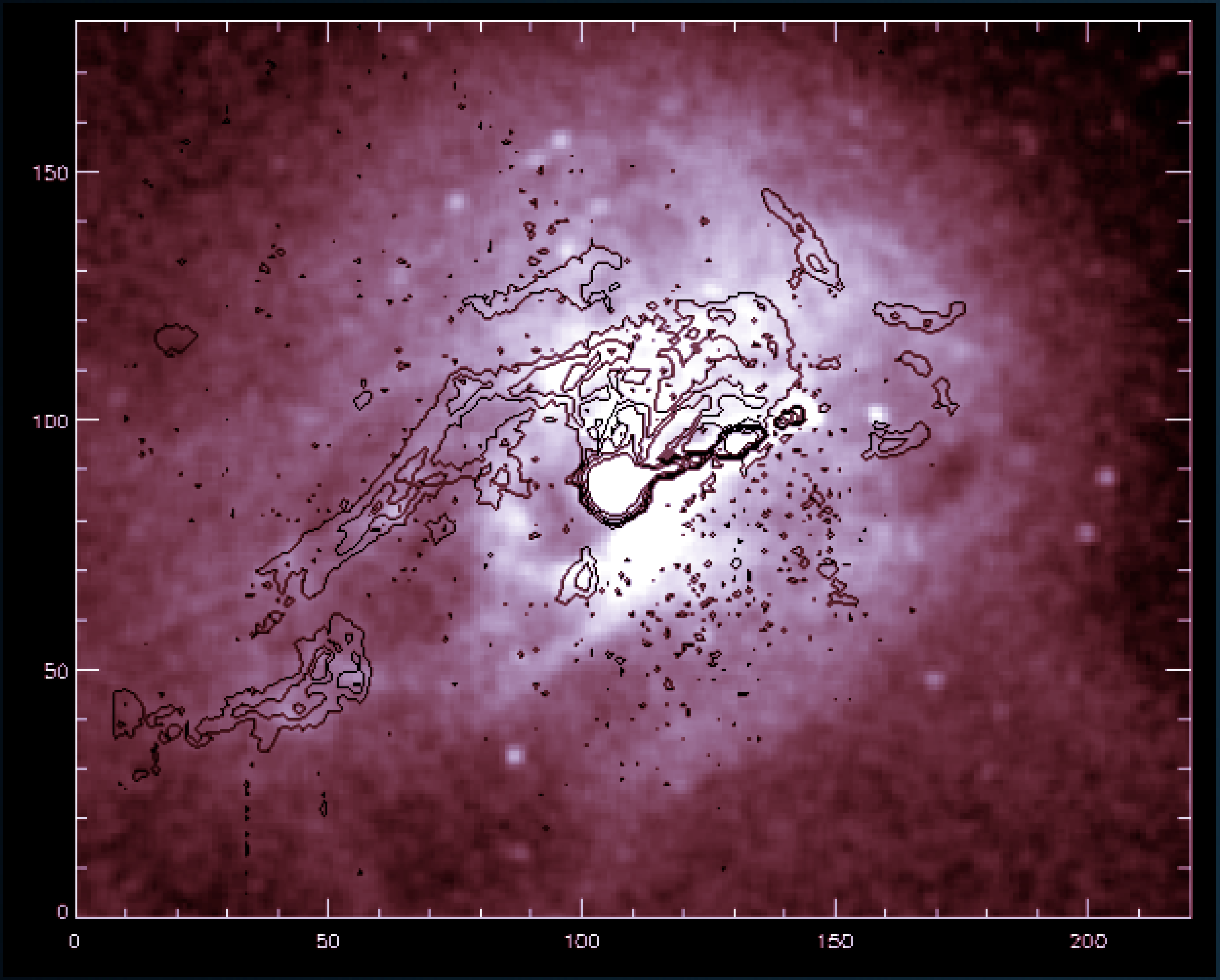
Example: Nearby RGs with Resolved Hosts – M87



Sparkes et al 2004 astro-ph/0402204

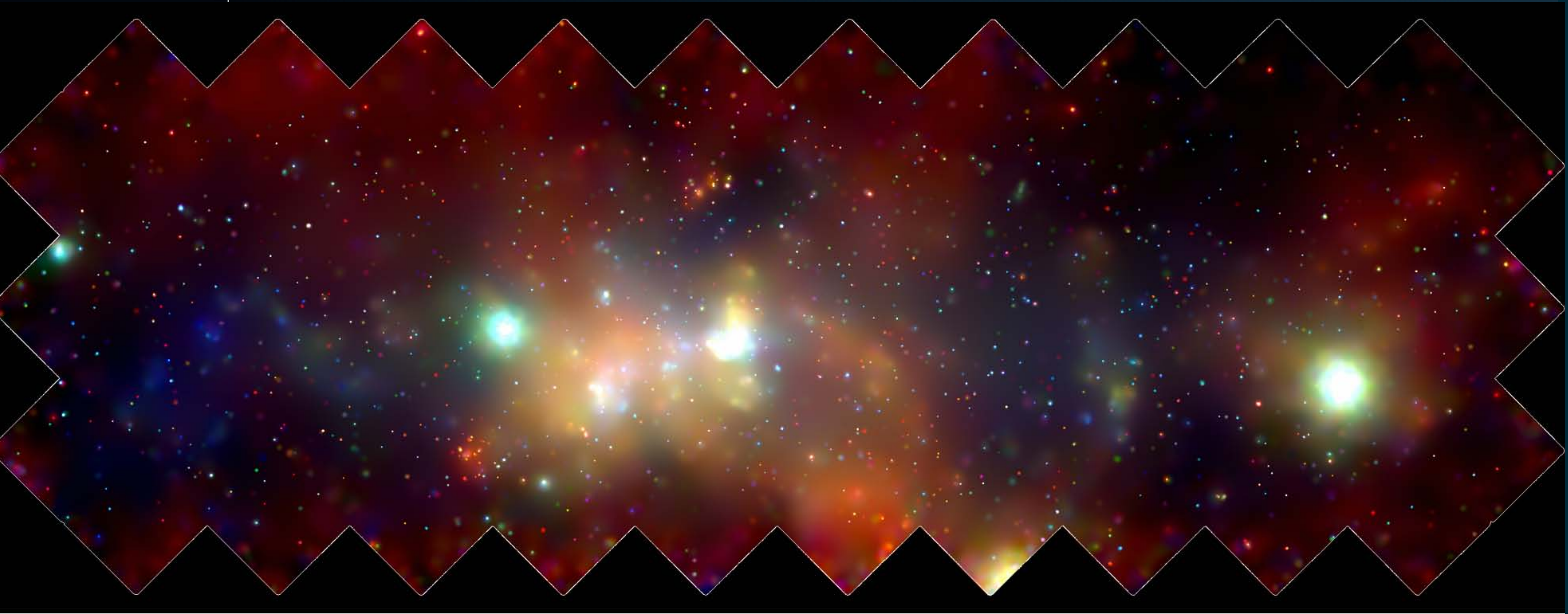
Example: Active Galaxies: Cen A

NASA / JPL-Caltech / J. Keene (SSC/Caltech)

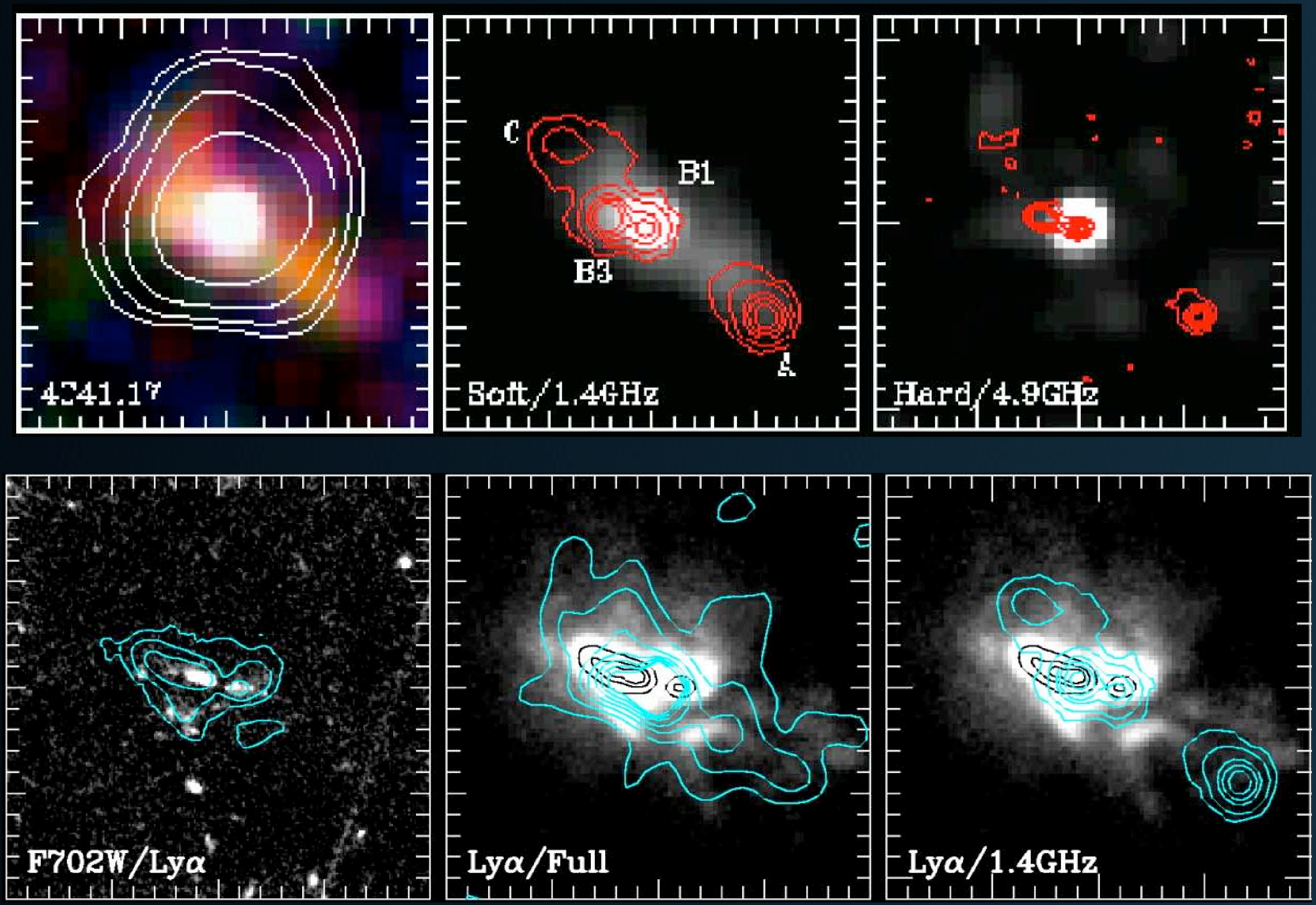
Example: Equilibrium Heating and Cooling: HII regions

Example: Galactic ISM

Example: Galactic ISM

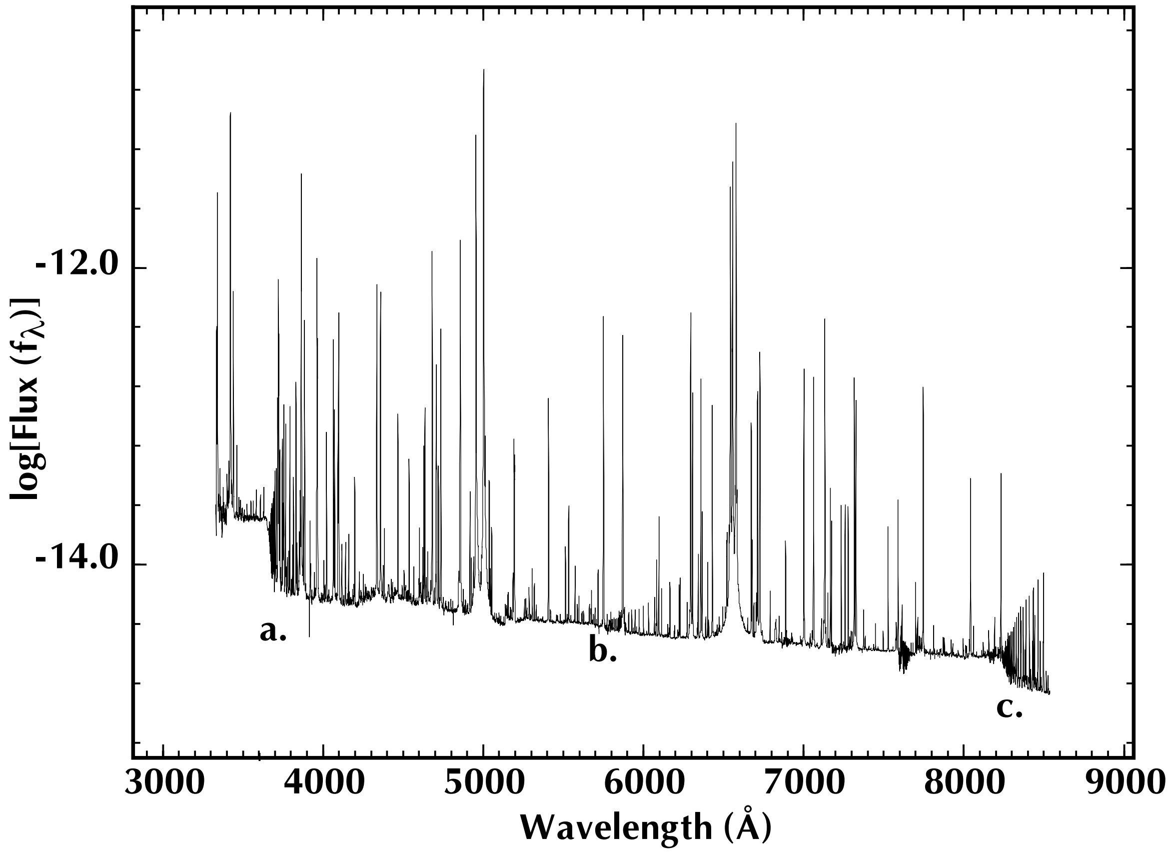


Example: z= 3.8 galaxy 4C41.7

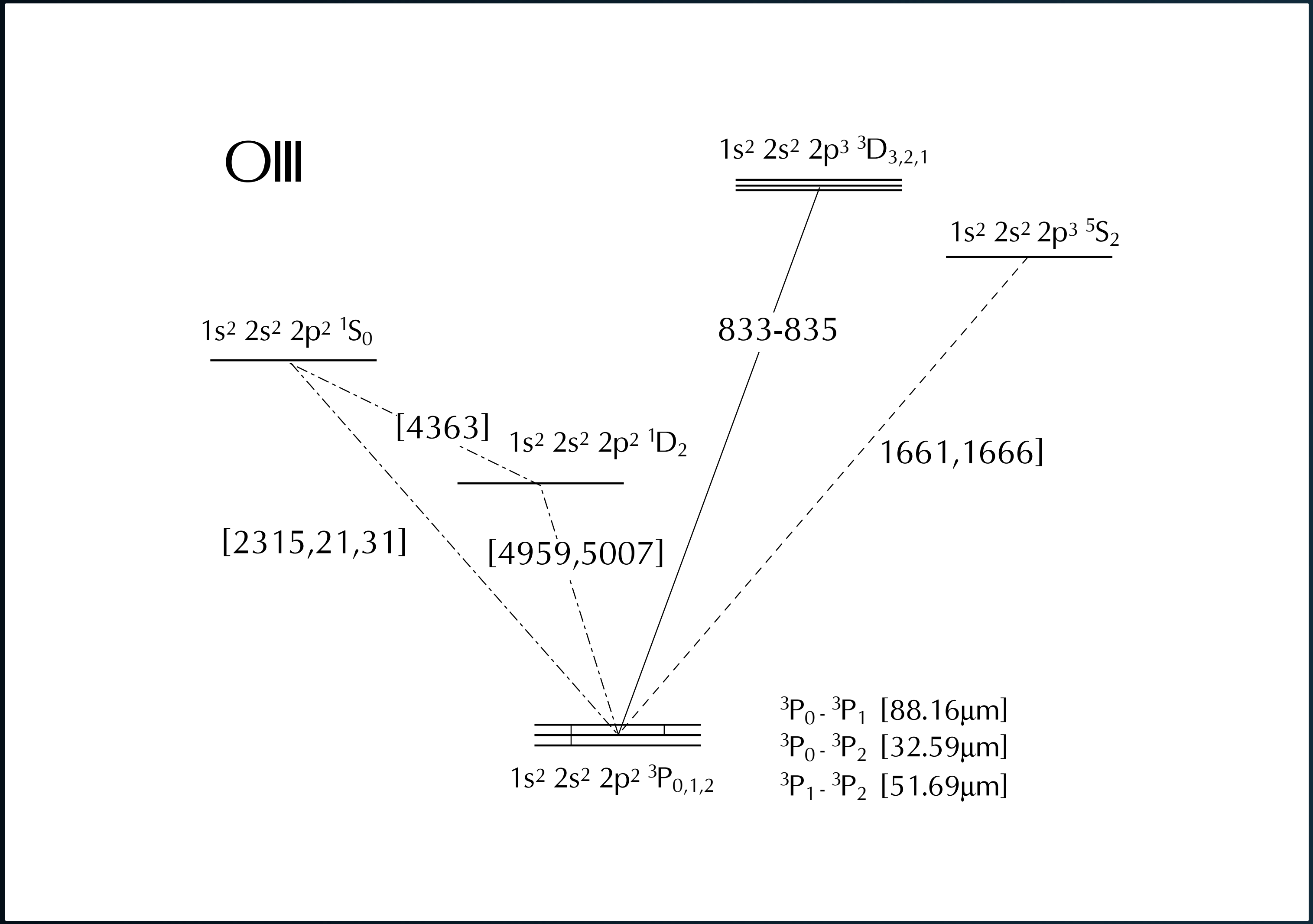


4C41.17 Scharf et al 2003

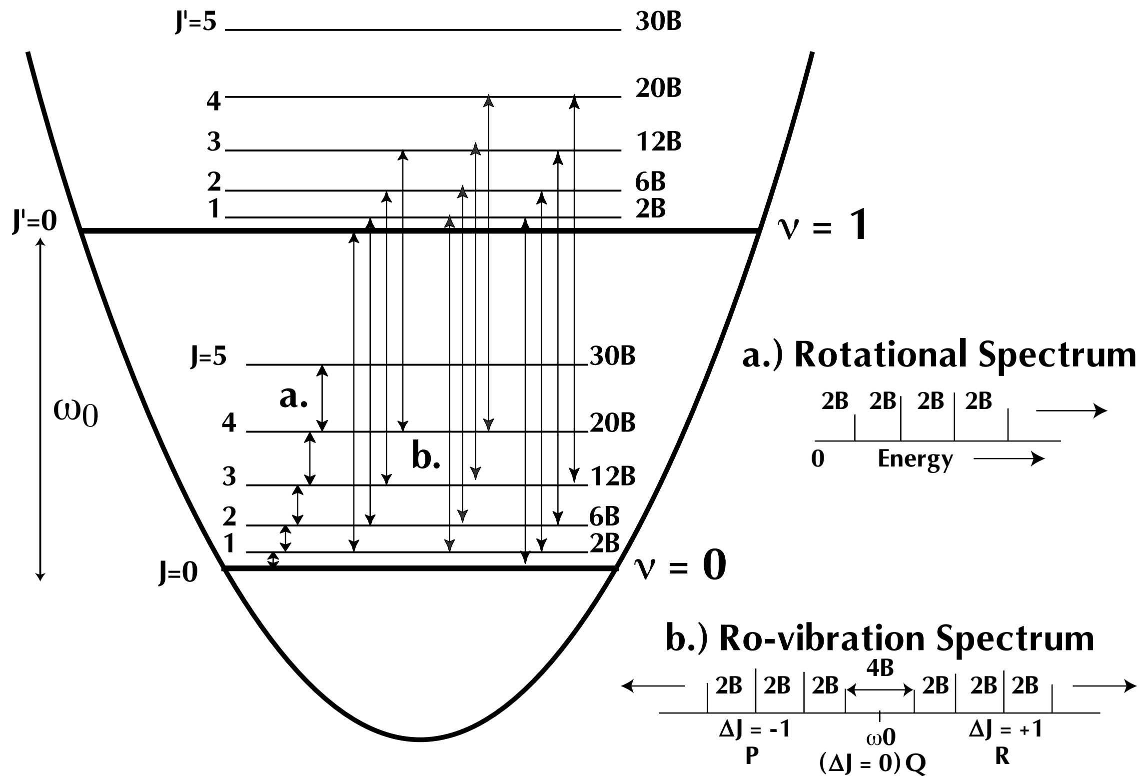
Theoretical Approach: ISM thermal emission



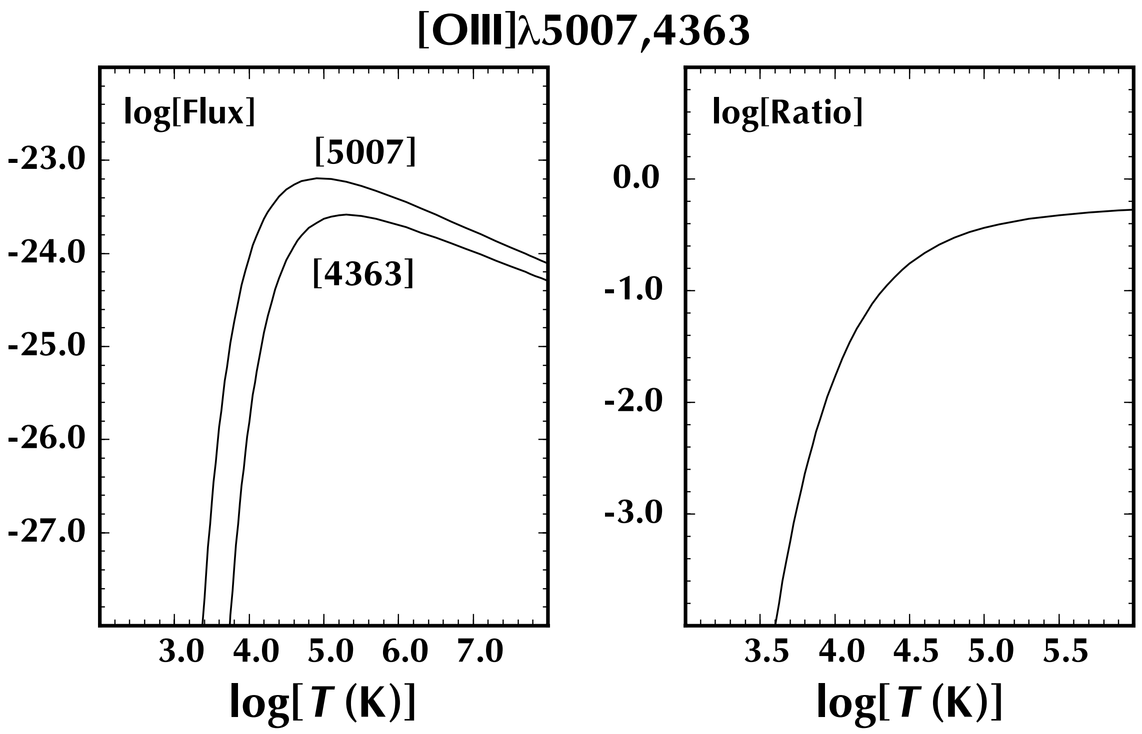
Detailed Cooling



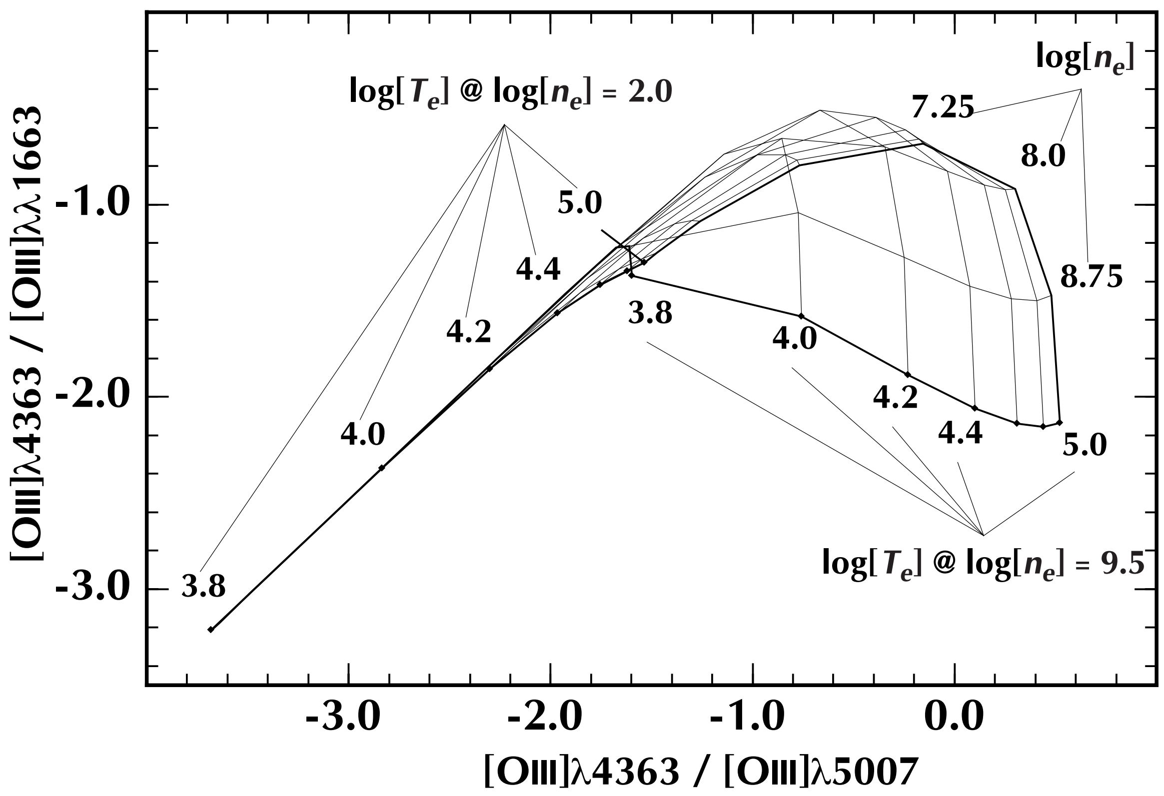
Detailed Cooling



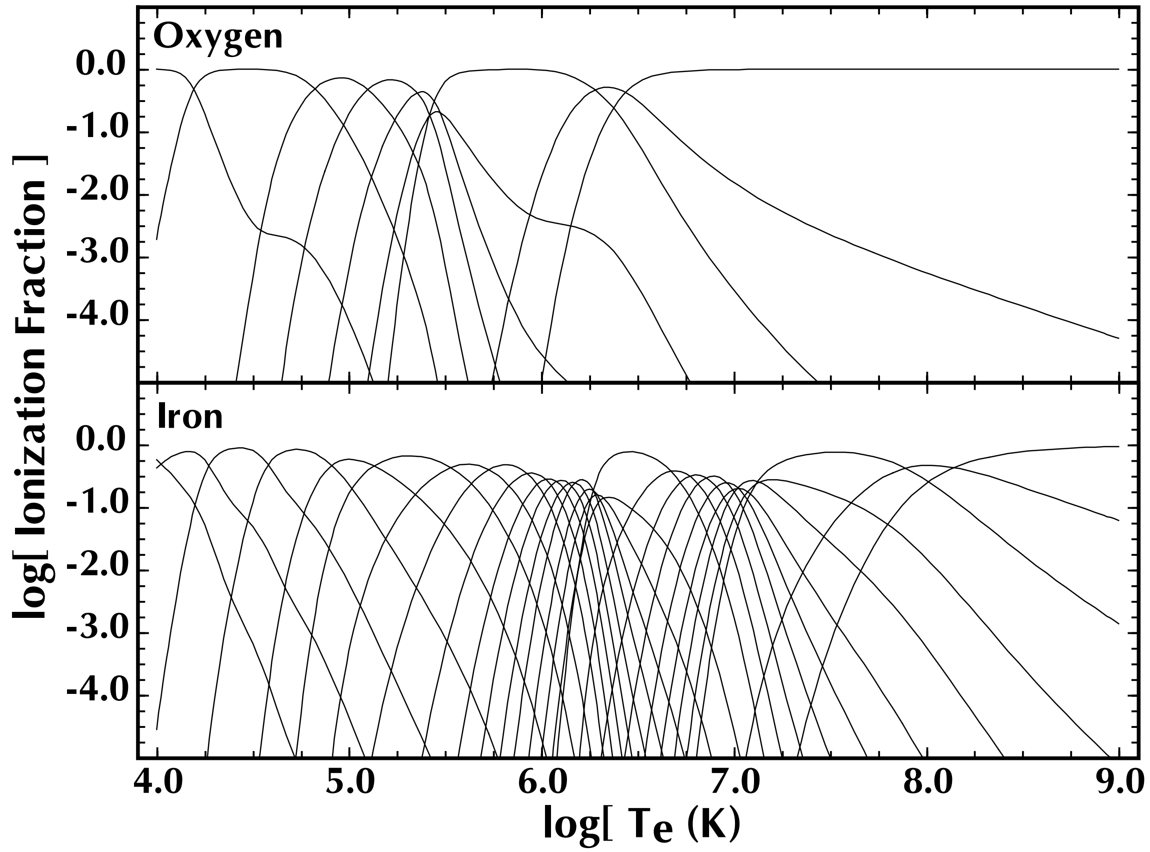
Detailed Cooling



Detailed Cooling



Cooling in the ISM



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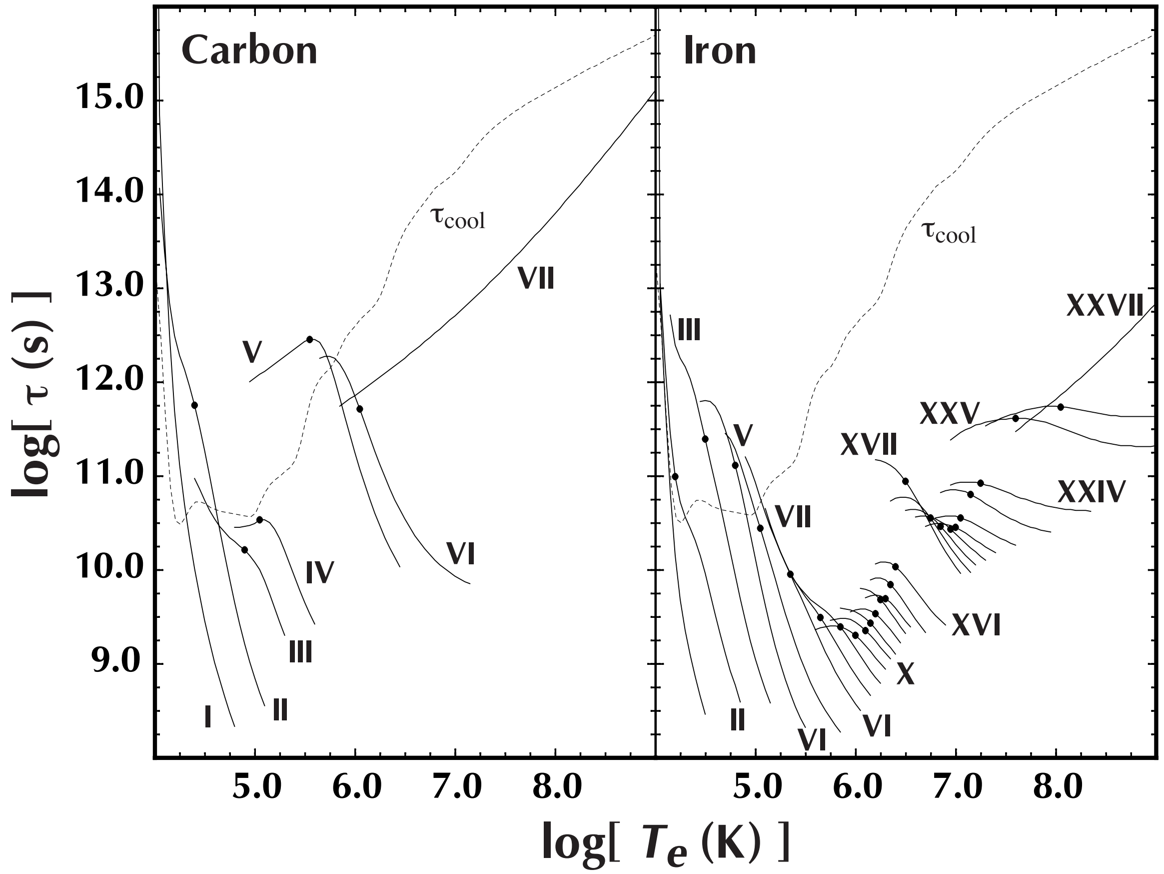

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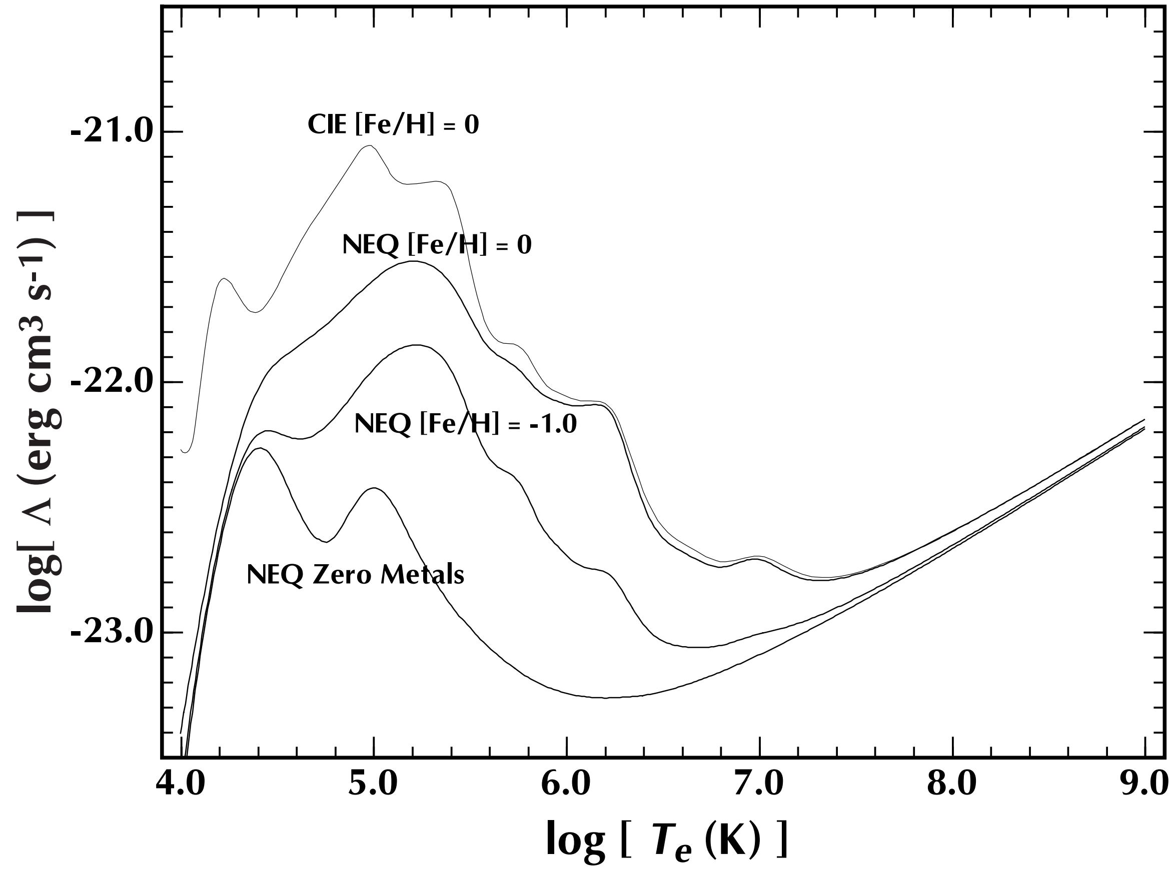
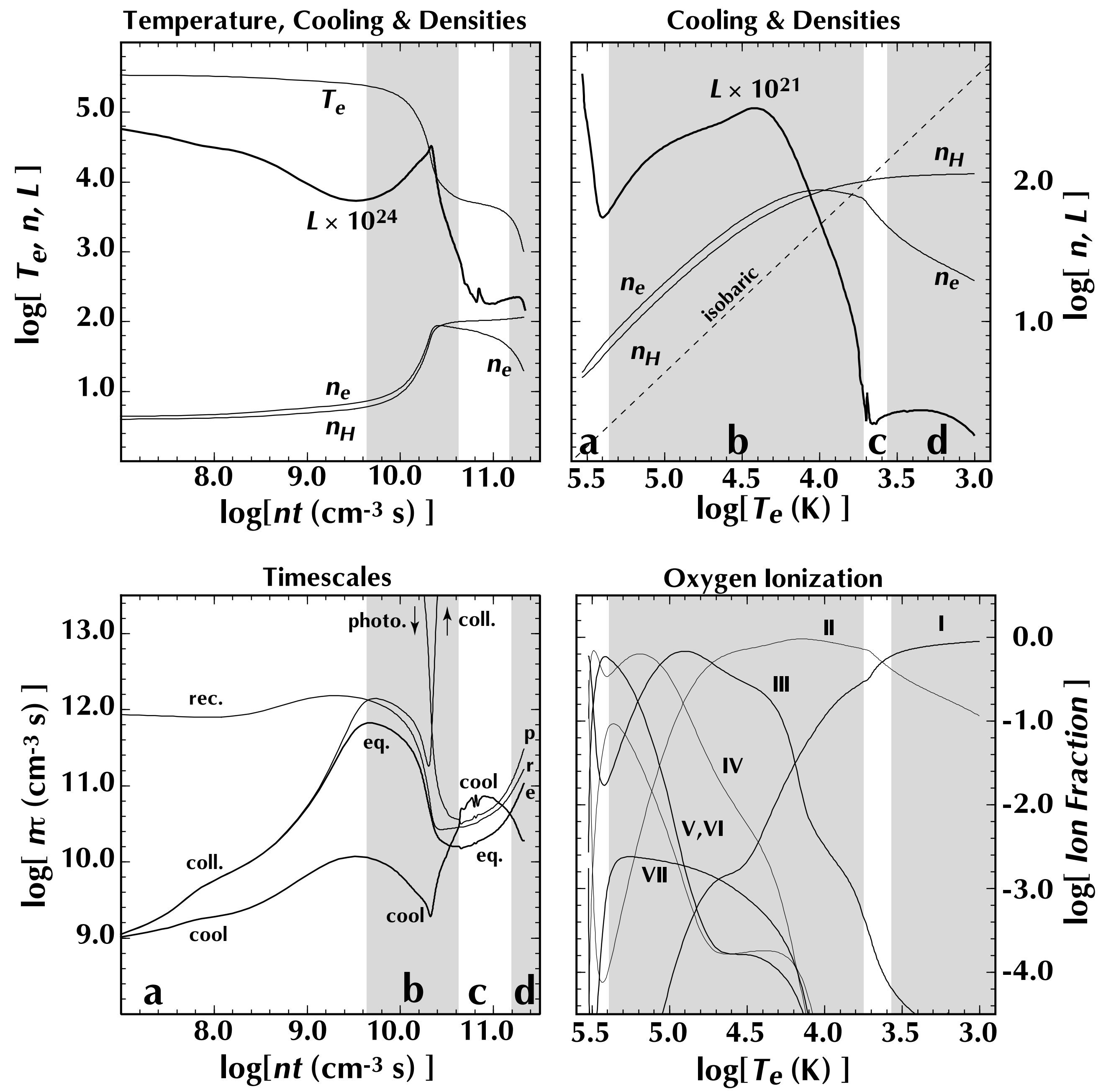
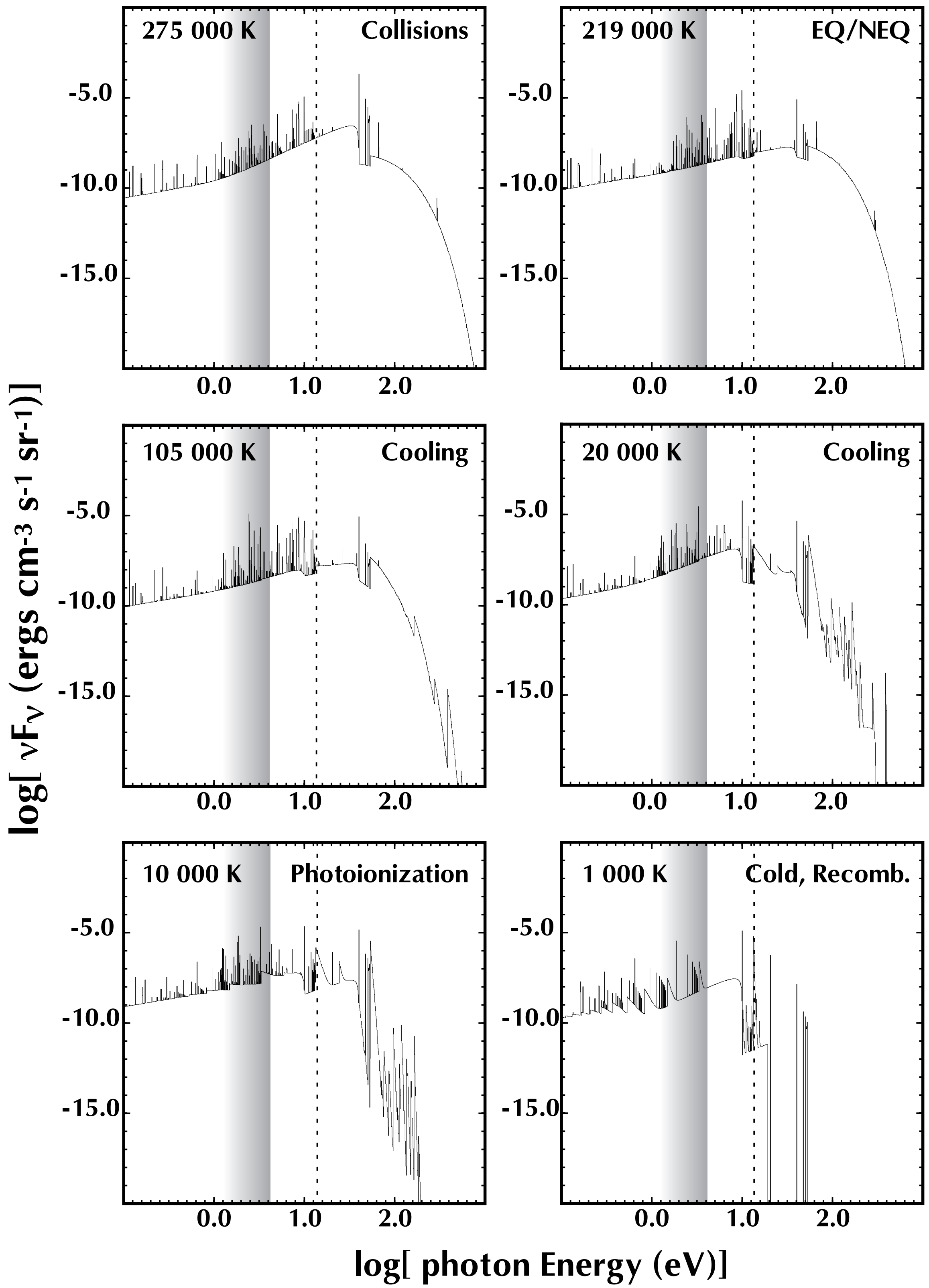


Cooling in the ISM





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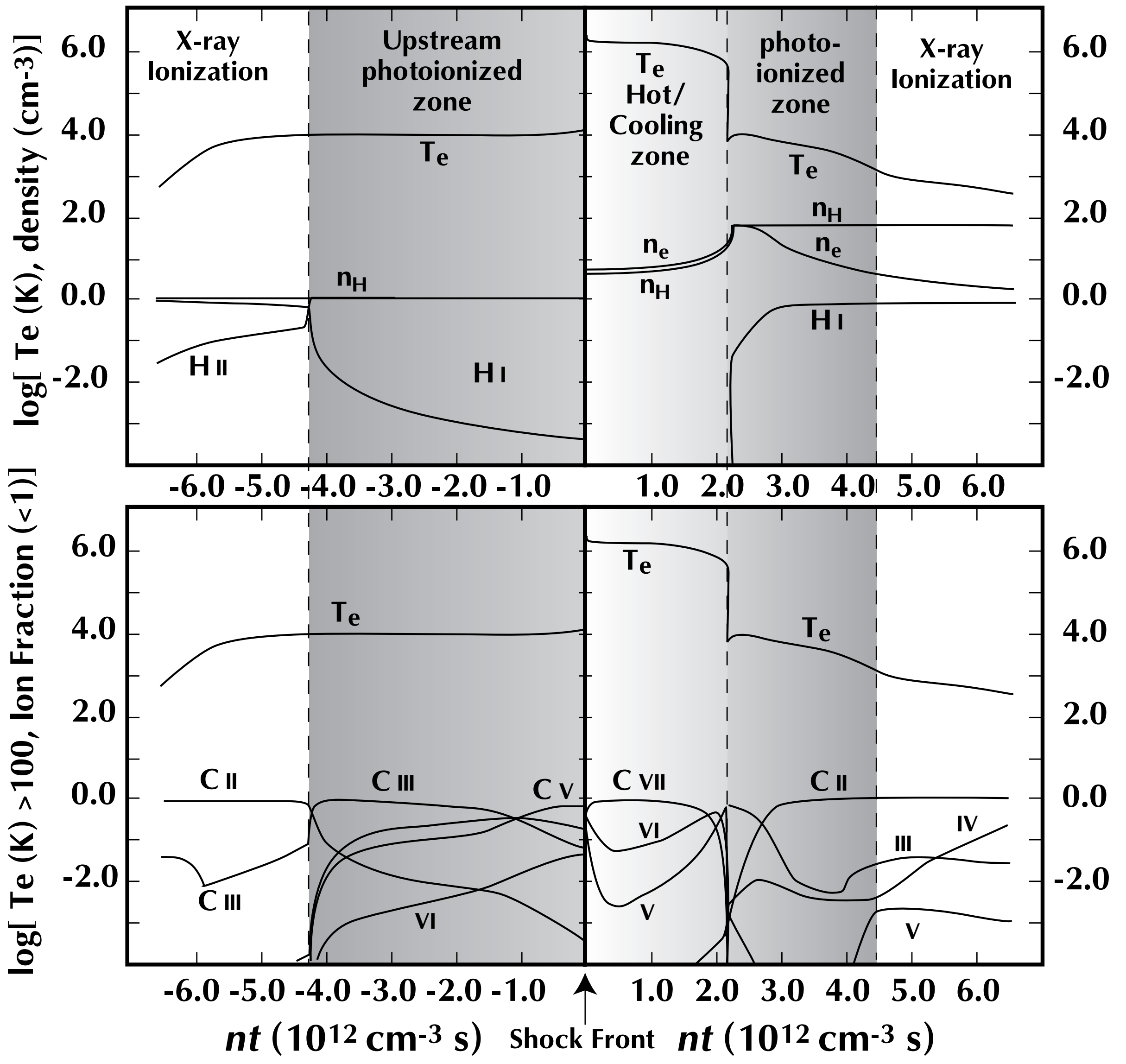
Cooling in the ISM



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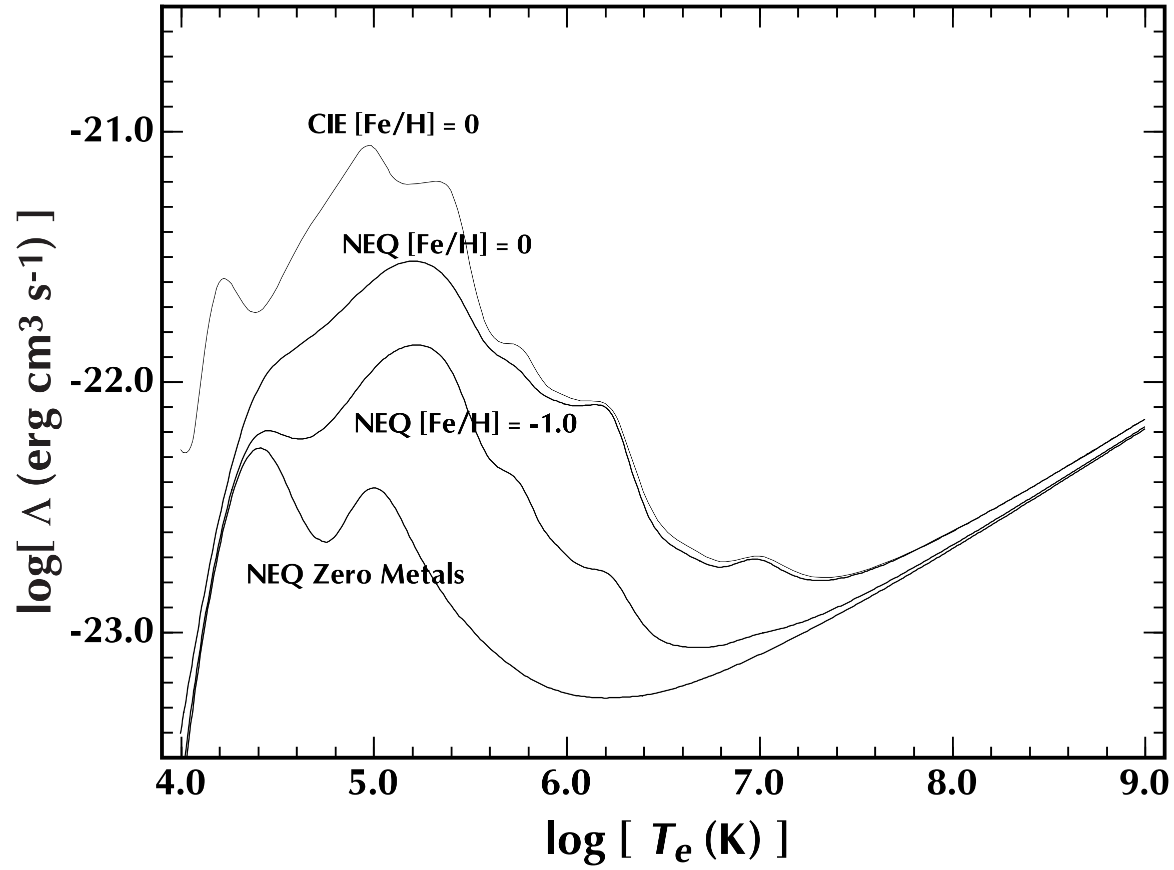


Theoretical Approach: ISM Thermal Emission

- The behaviour and properties of the observed ISM plasma tells us about the underlying processes:
  - Input of Energy and Momentum: winds, jets
  - Distribution of Energy Sources: starbursts, clusters
  - Composition: enrichment histories

Theoretical Approach: ISM thermal emission

- Require detailed a ISM model

  - Microphysics- ionisation,excitation, molecular chemistry, dust physics, radiative transfer
  - Excitation Mechanisms: shocks, photoionisation
  - Phase structure and distributions
  - Dynamical Radiative properties

Initial Conditions

It would be useful to have a simple parameterisation that captures more of the ISM properties, beyond smooth distributions

Simulations must change from a simple locally uniform geometric initial conditions, $\langle \rho \rangle$, $\langle P \rangle$ and **v** – to a description of a skewed density/velocity distribution, with a fractal turbulent spatial distribution.

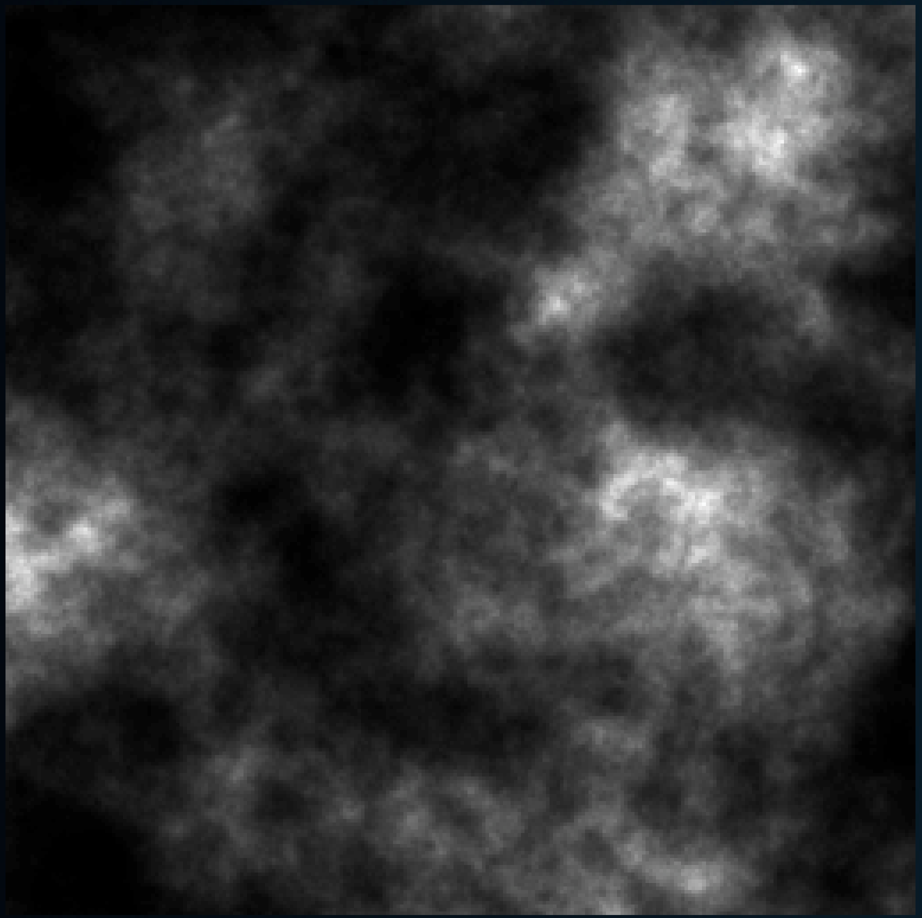
Single Point and Two Point statistics of a Fractal turbulent ISM

- Preferably Analytical Approximations!
  - Log-Normal distributions
    - ‘Long Tail’, Intermittant distributions
    - Observed in many fully developed 3D turbulent fields
    - Refers to the single point local statitics, or the histogram of the varables.
    - Skewed, so that the mean, the median and mode are not equal, or even similar
    - Well characterised functions, See Notes
  - Kolmogarov Turbulence
    - Describes the essential fractal nature of a self-similar structure, via staructure functuions or Isotropic scalar powerspectra.
    - Kolmogarov Turbulence characterised the two-point statistics with a single powerlaw index, derived from a dimensional analysis of a turbulent cascade, in 1941. Observed to hold over many orders of scales of magnitude in real world fractals.
    - Under certain conditions, the power spectrum index and the second order structure function indices are related, and either may be used in analysis of structures, See Notes

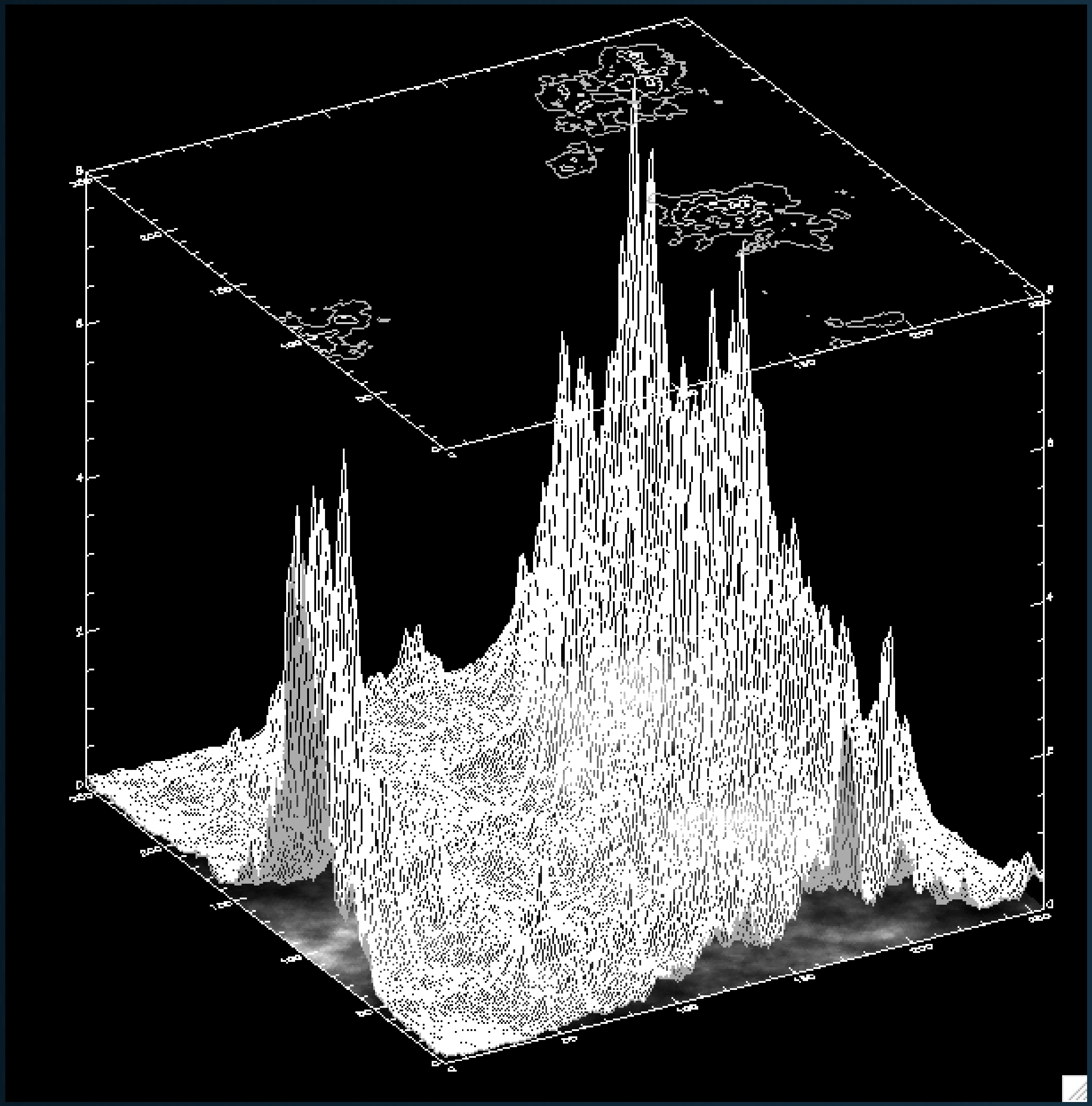
Initial Conditions

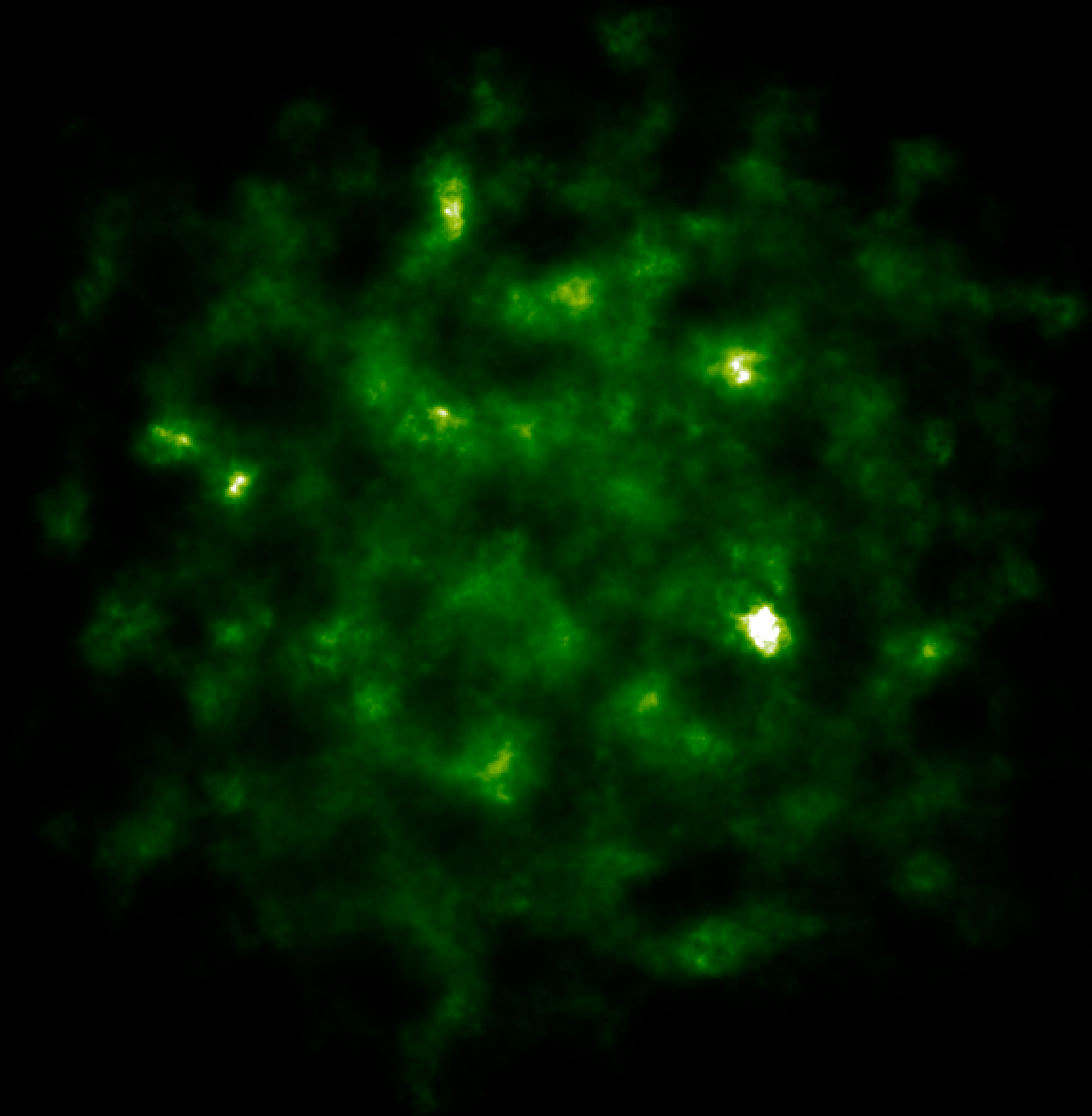
- Log-Normal Distribution - a skewed, local, distribution characterised by the mean, μ, and the variance, σ^2
- For $\mu = 1$, $\sigma^2 = 5$, 0.5 of the mass resides in 0.25 of the volume. The mode is ~1/20 of the mean.
- Mean $\neq$ Median $\neq$ Mode

Dynamic Galaxy X-ray SED: Host ISM



Kolmogarov Spectrum
Density, $\sigma^2 = 5$



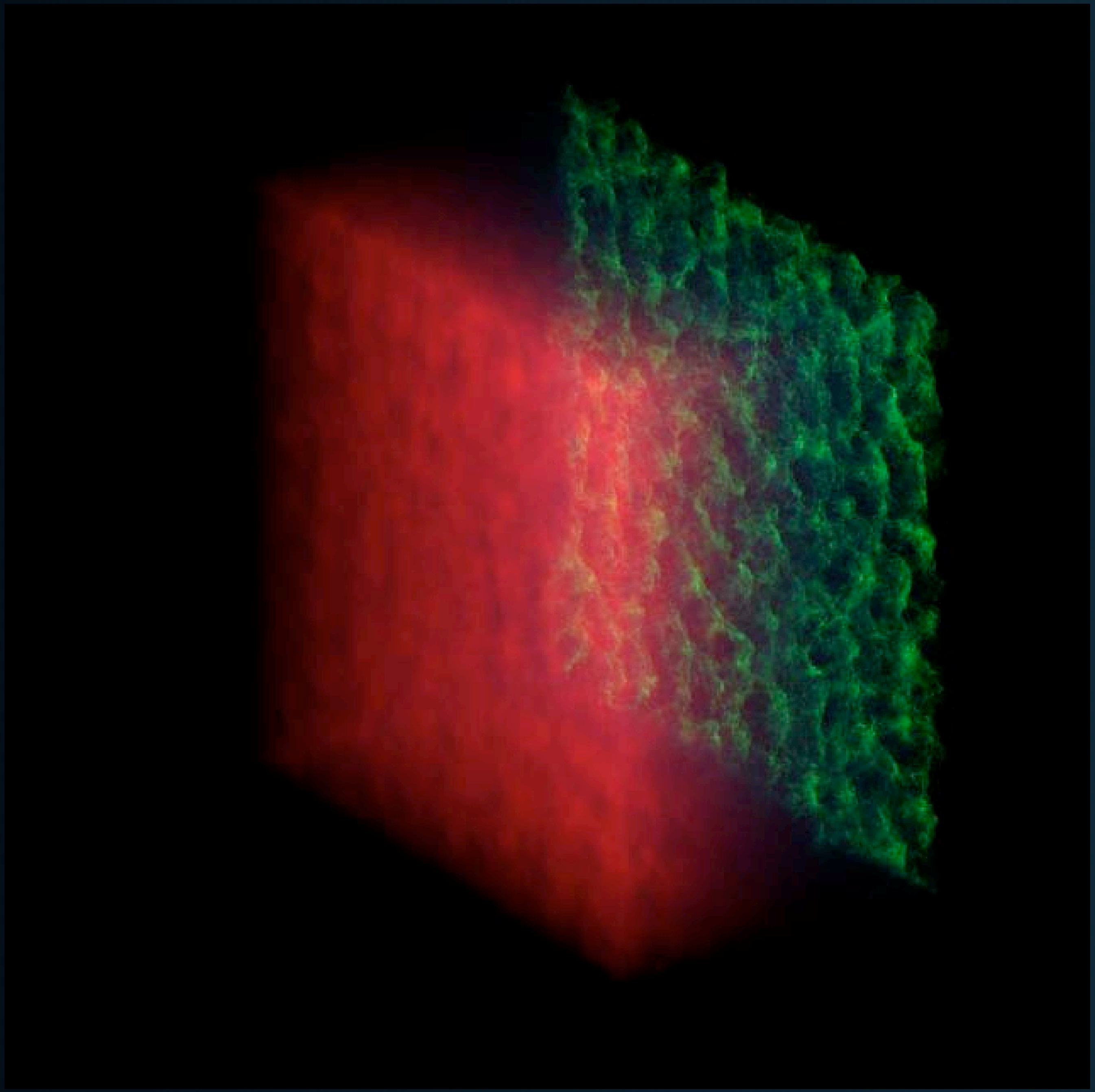


New 3D X-ray Spectral Synthesis Shock Models

Hypersonic Shockwaves

- Shocks are a ubiquitous and fairly generic means of transforming kinetic energy into hot thermal plasmas and emission.
- They are Dynamical ‘initial value’ problems, which may be integrated over time to produce ensemble averages.
- With tools developed to compute time dependent 3D shocks in detail, other more general problems become possible.

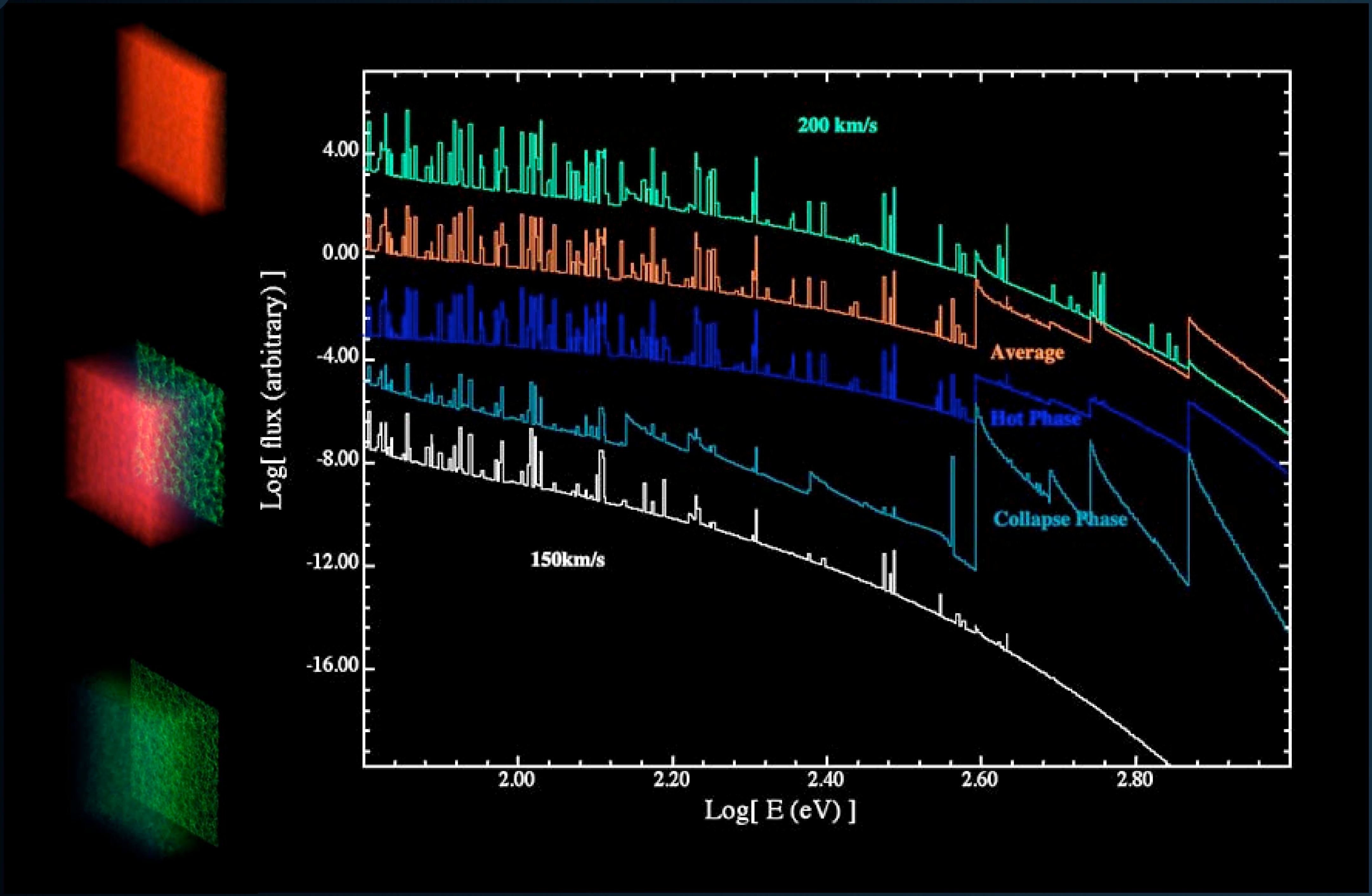
3D X-ray Wall Shock Model X-ray Rendering



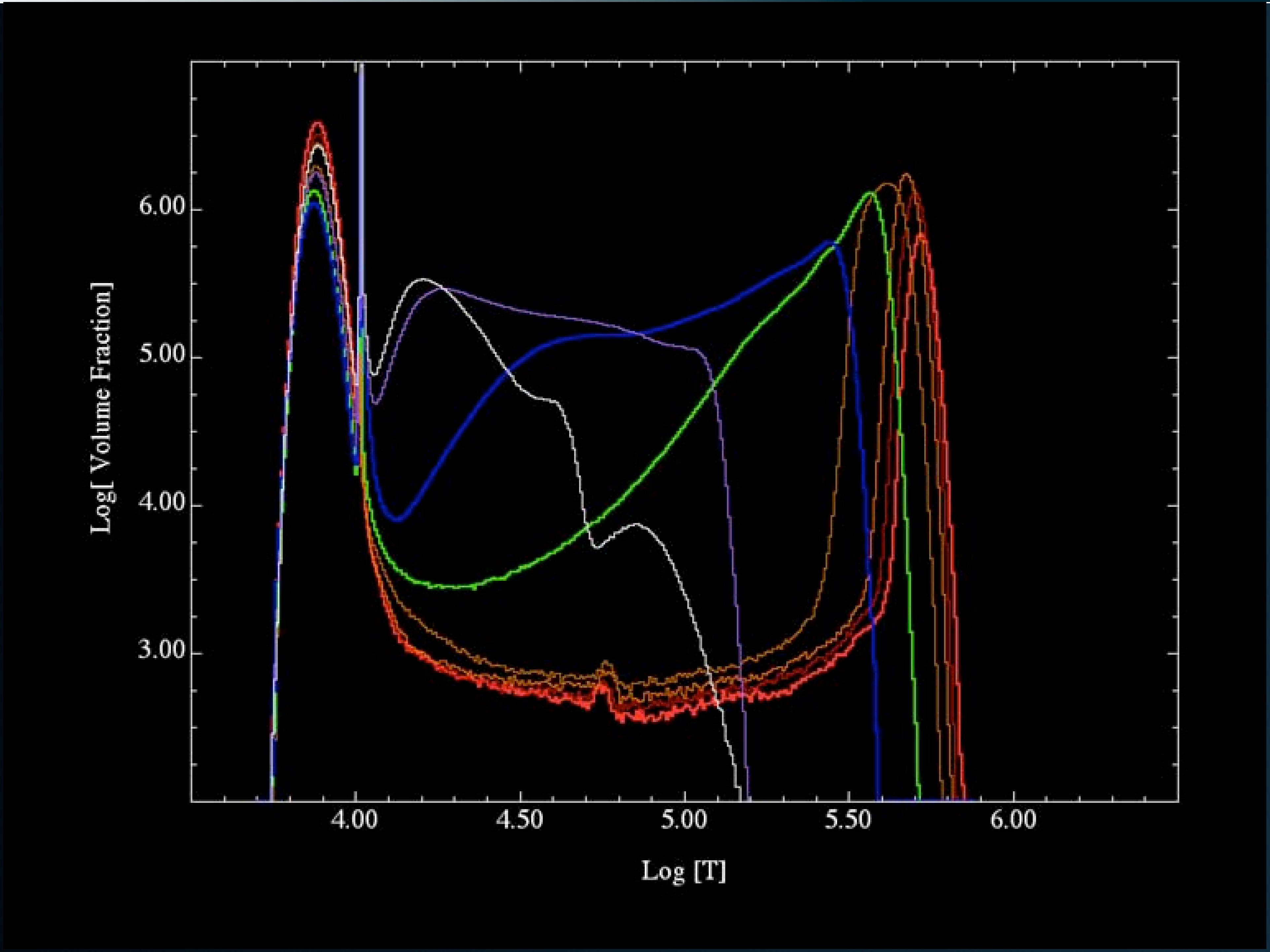
Soft X-ray Emission

R = 0.2-0.3 keV
G= 0.3-0.4 keV
B = 0.4-0.5 keV

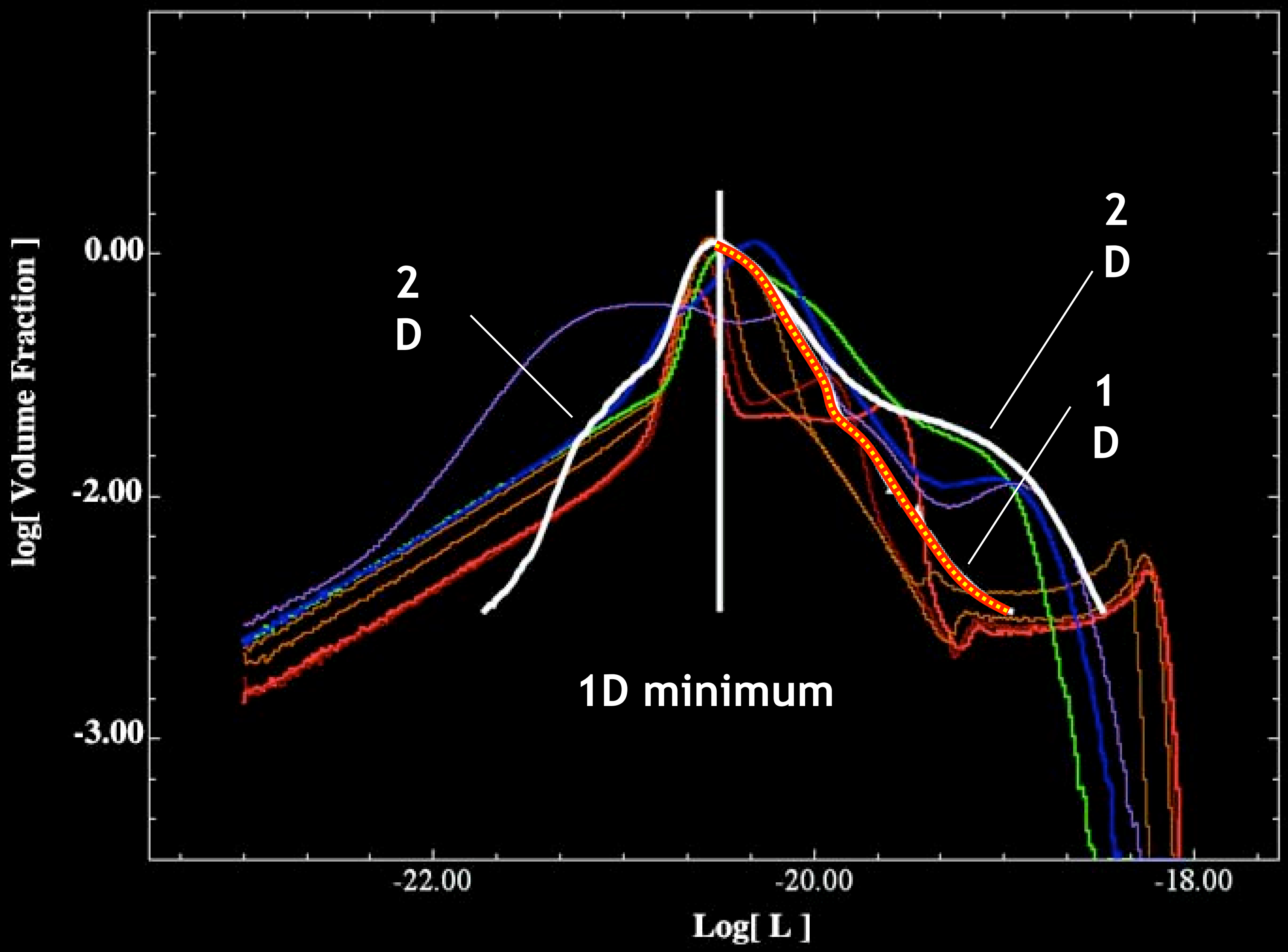
3D X-ray Wall Shock Model Spectra



3D X-ray Wall Shock Model
Thermal Distribution



3D X-ray Wall Shock Model Cooling Distribution



3D X-ray Spectral Synthesis Shock Models Summary

- 3D dynamical models are essential, as the turbulence and thermal instability generated structures are affected by the dimensionality of the simulations.

- By influencing the distribution of density and temperatures over time, the resulting spectrum is also dependent on the model dimensionality.

- Only steady shocks can be computed accurately in 1D or 2D.

- These 3D models will give new spectra for the ionising field produced by shockwaves in the ISM

3D X–ray Spectral Synthesis Shock Models Summary

Limitations of new models presented here:

- Avoiding, for now, the difficult 3D radiative transfer problem, restricting to optically thin X-ray models and radio emission
- They are a compromise between complete self-consistency and speed of execution
- These 3D models remain limited in resolution, new methods will be required to solve higher velocity shocks. Normal adaptive mesh methods will not be sufficient.

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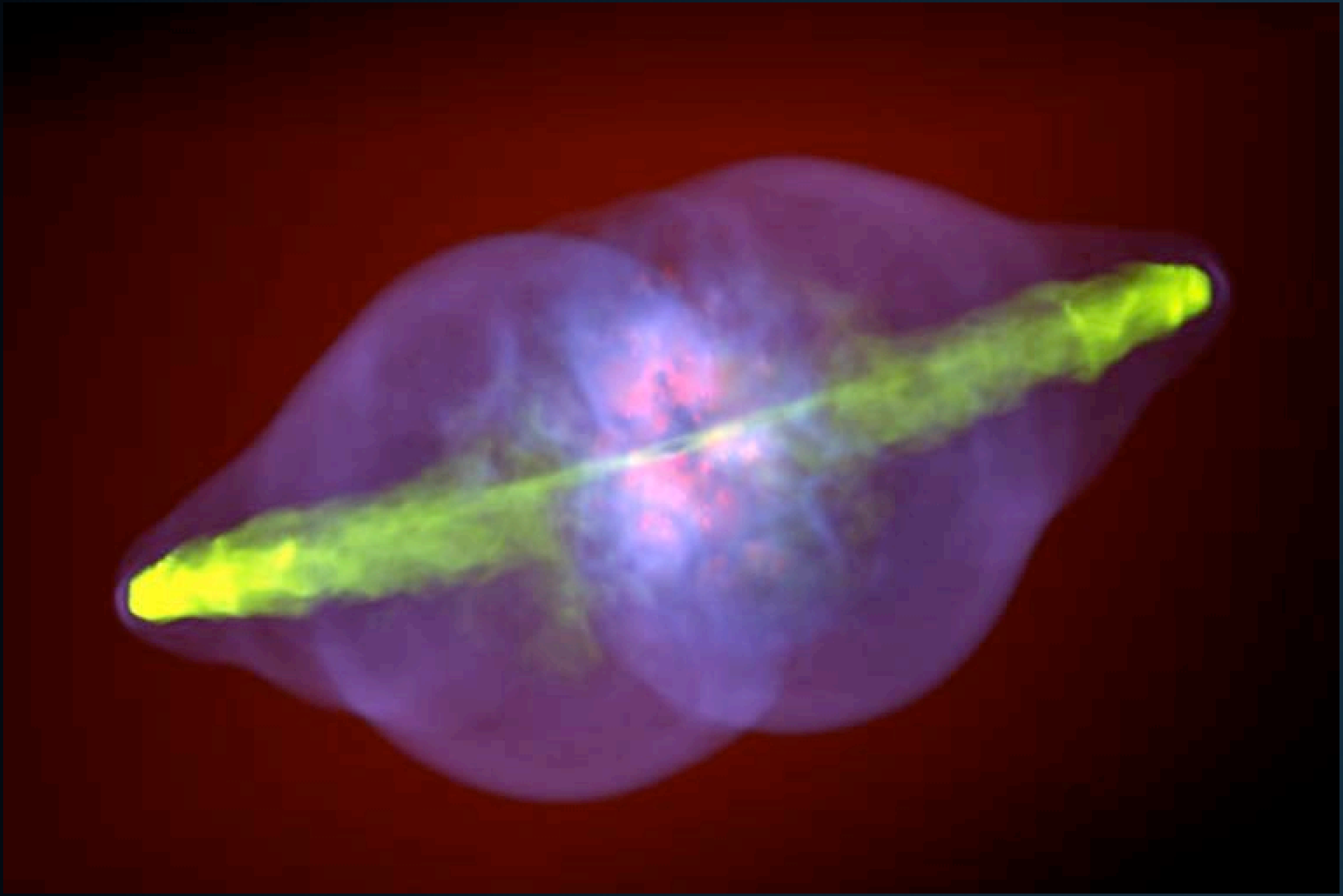
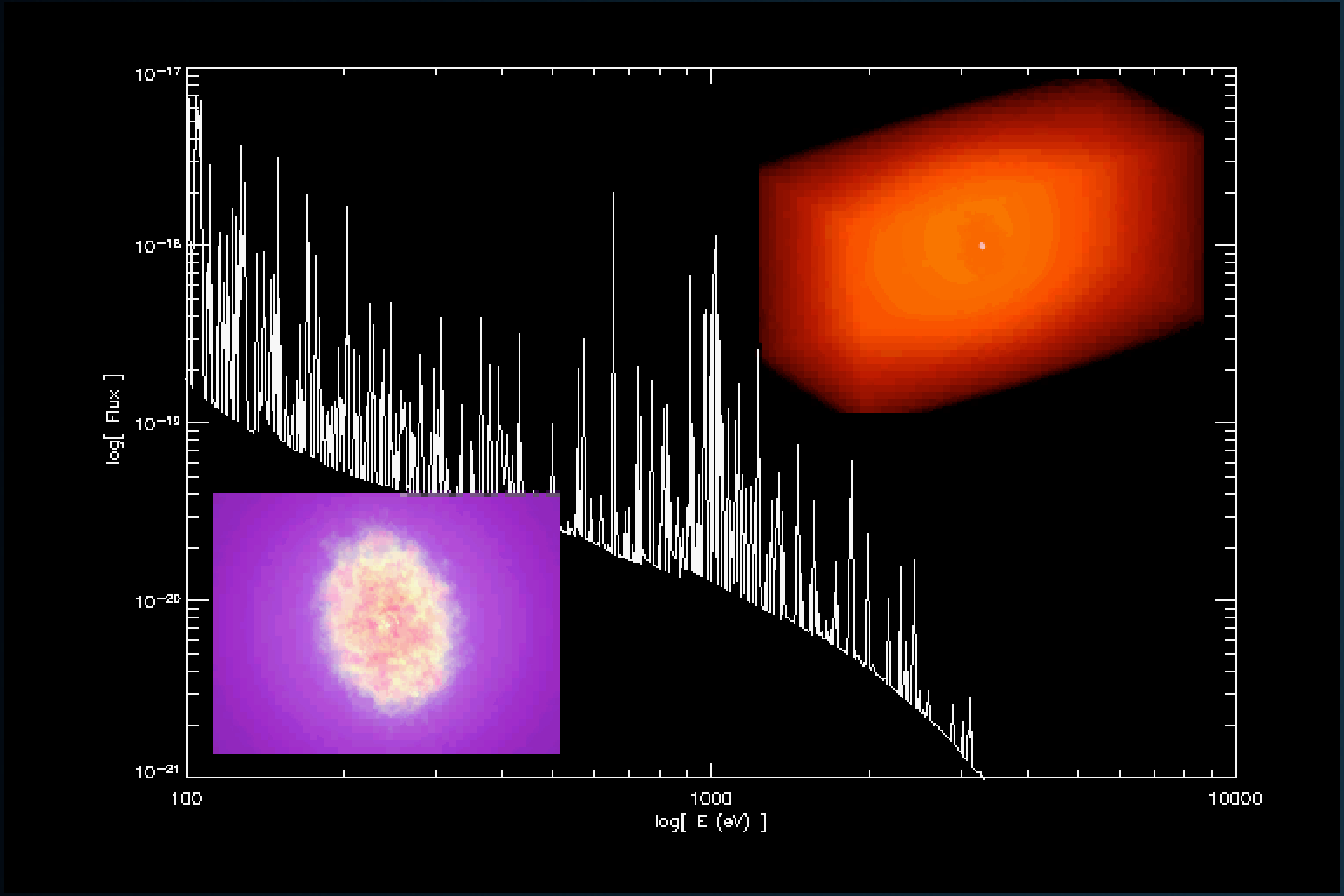
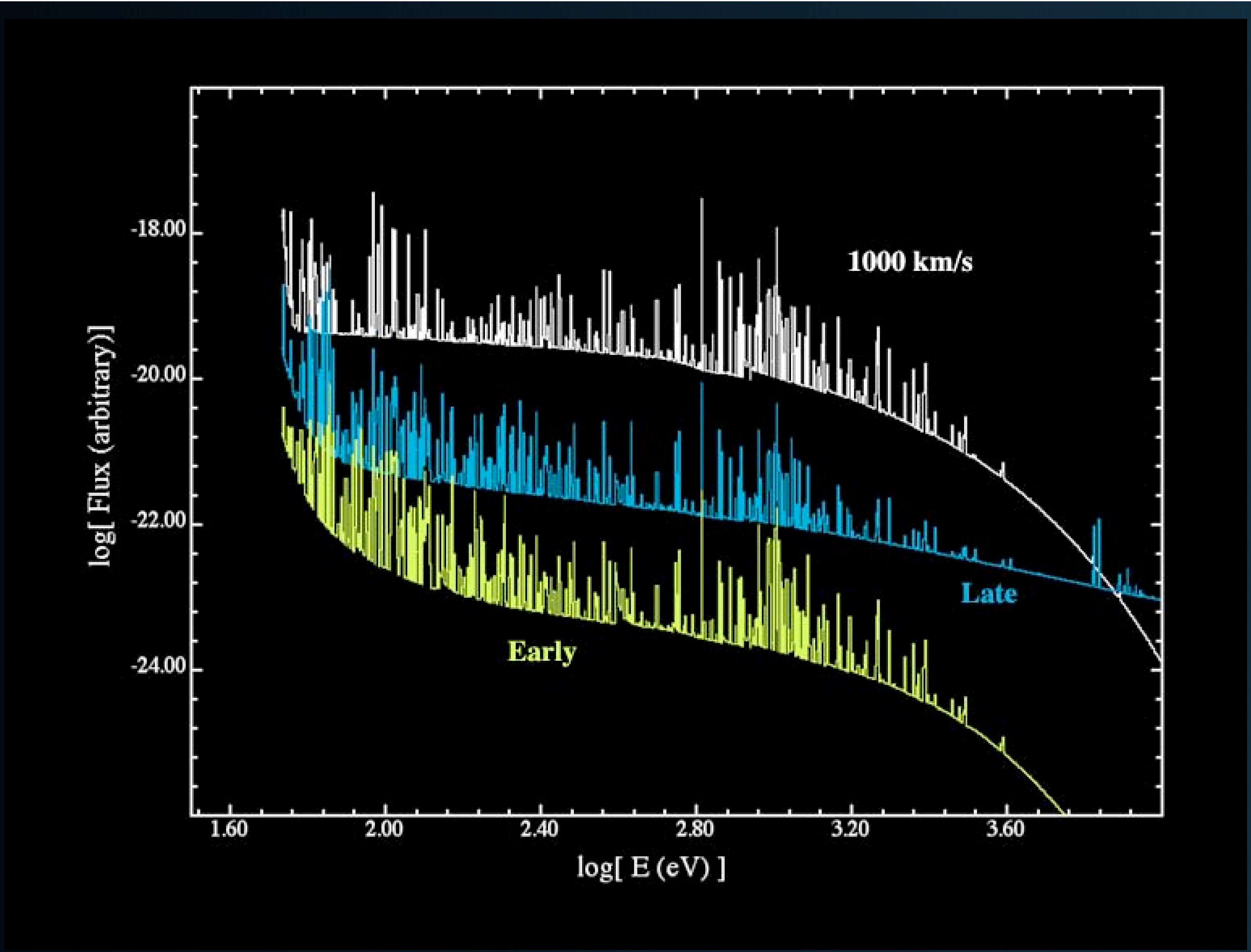
Dynamic Galaxy X-ray SED: Radio Jet — X-ray overlay

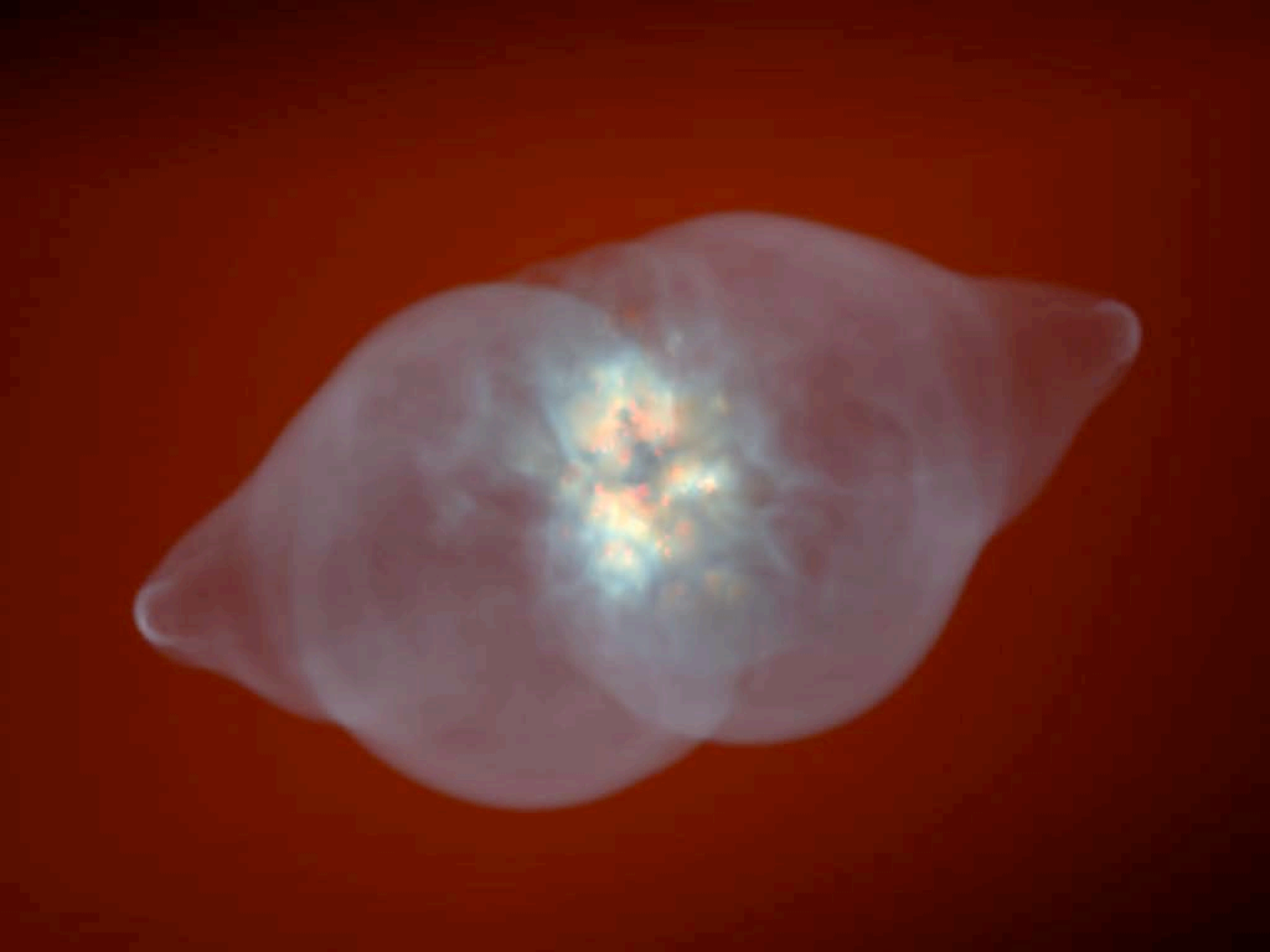


Dynamic Galaxy X-ray SED: Spectra



Dynamic Galaxy X-ray SED: Spectra





Future Directions – Hot Bubbles and Entrainment

M87 jet bubble
Sparks et al 2004.

Hot - Cool Medium Interface Regions

Model