High-Resolution Modelling of the ISM with Time Dependent Ionisation Structure

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Outline

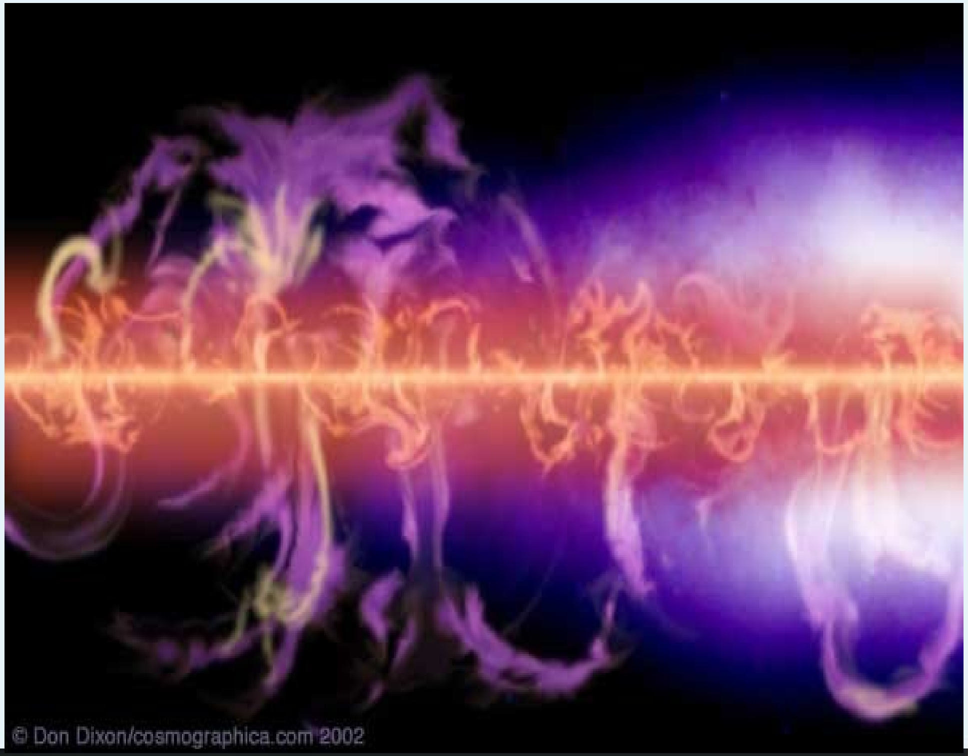
1. Motivation – Modelling ISM (+ Disk-Halo + HVCs + DIGs)

2. CIE vs NEI

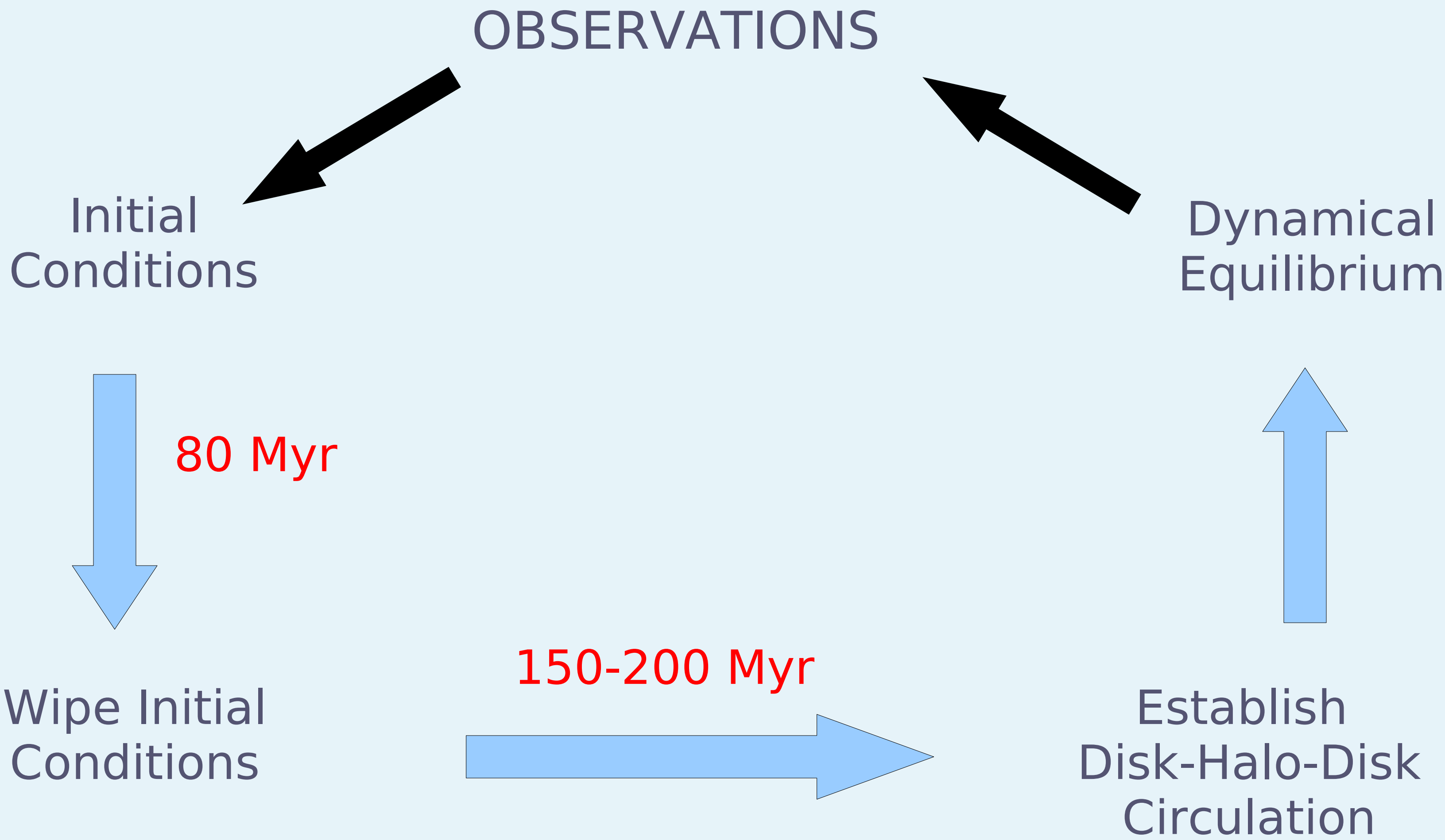
3. MHD + Thermodynamical code algorithm

4. Modelling the ISM and Tests

5. Final remarks



Simulation time...



Model Setup

Large grid: 1 kpc × 1kpc × ± 10 kpc (highest res. Δx=0.5 pc)

Star Formation based on local n and T: n >10 cm^{-3}/T<100 K

IMF (Stothers 1972 or Fuchs et al. 2006)

Formation and motion of OB associations (v_{rms} ~ 5 km/s)

Type Ia,b/II SNe: random + clustered (~60%)

Background heating due to diffuse UV photon field

Galactic gravitational field by stars

Local self-gravity

Collisional Ionization or Non-equilibrium ionization calculations

Asplund et al 2005 abundances

ISM Modelling

- Bottom up approximation (i.e., include physical processes at a step by step approach ---> identify the role of each process): e.g.,

CIE ⇒ HD Self-Grav Heat Cond ⇒ NIE

- Form stars in a self-consistent way (use IMF and efficiencies)
- Use a turbulent ISM, driven by SNe and stellar winds
- Use a grid covering at least 10 kpc
- Use a computational domain larger than 10x L_d

$L_d \sim$ 75 pc (Avillez & Breitschwerdt 2007)

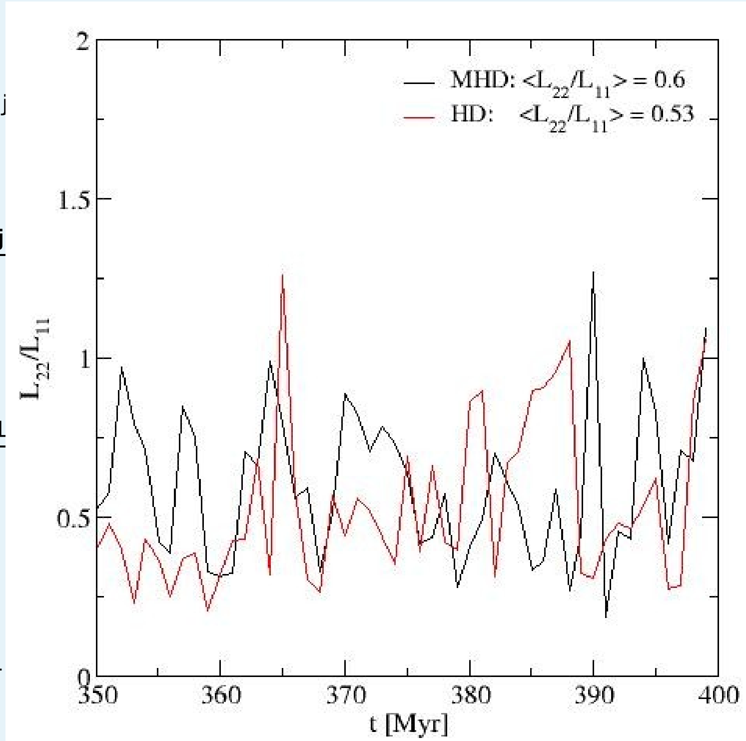
Injection Scales and Homogeneity...

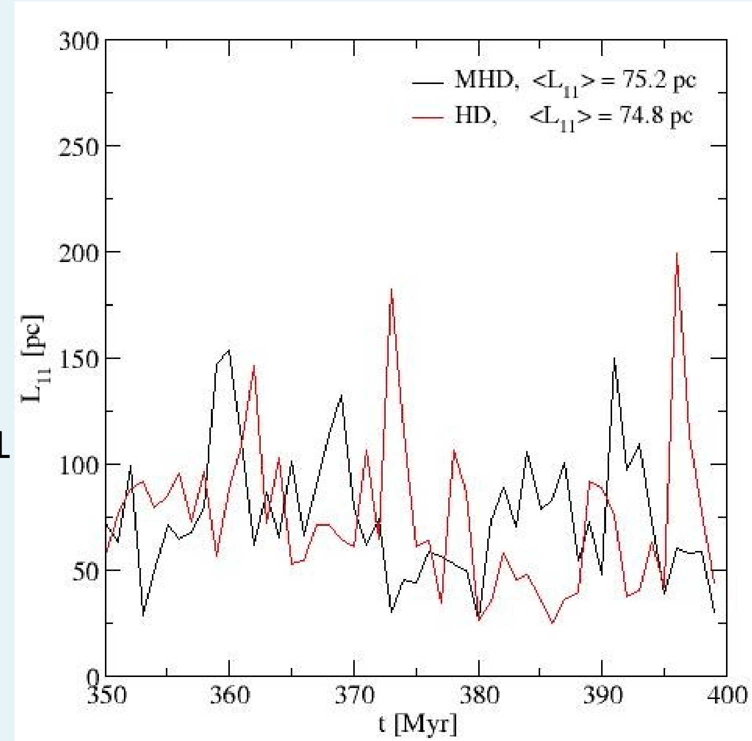
R_{ij} ... ion

R_{ij} ... l_j ... $|^2$

$\frac{R_{11}}{u^2}$ ... $\simeq 1$ ... 1

L_{11}



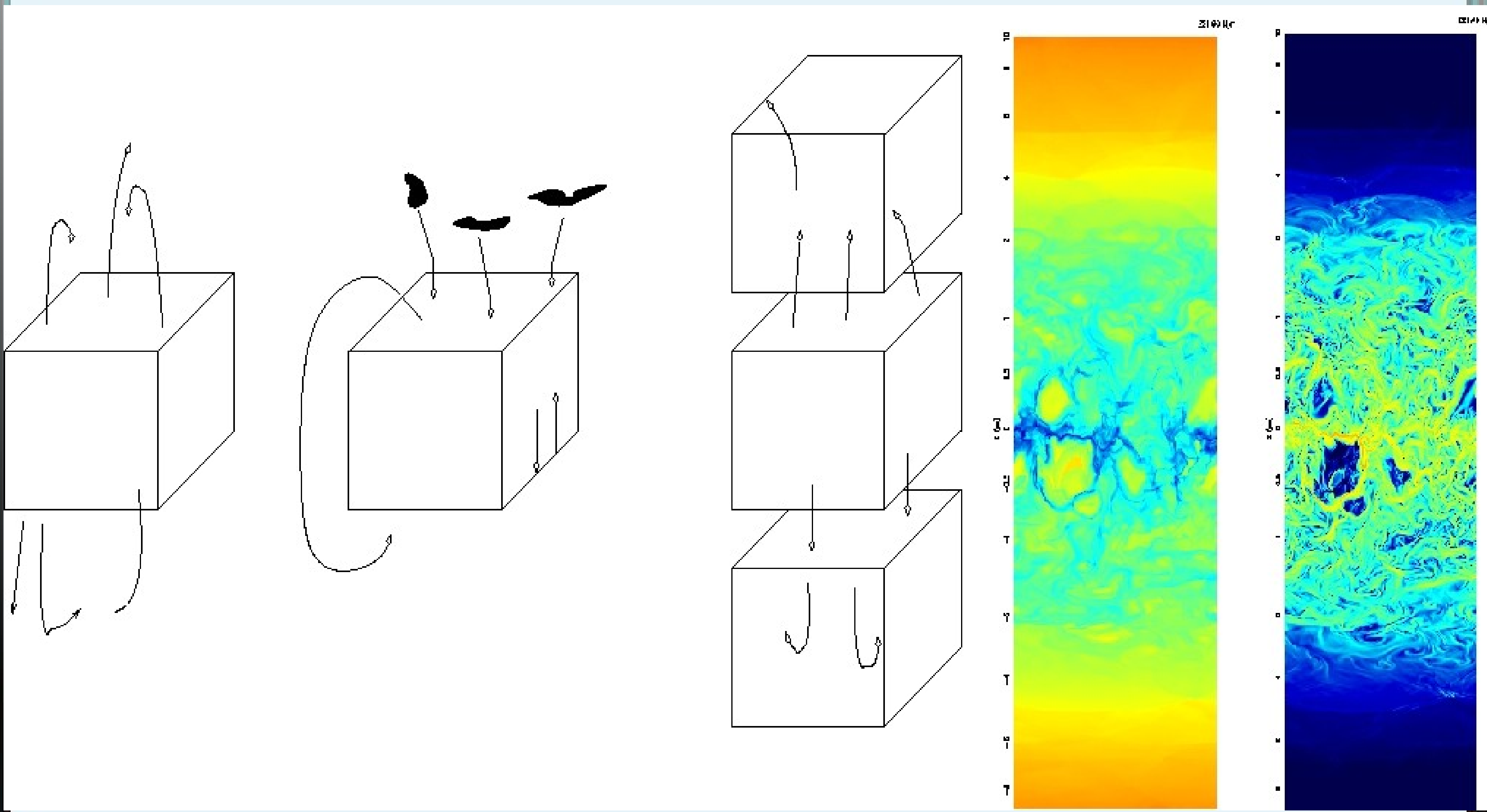


Avillez & Breitschwerdt (2007, APJL)

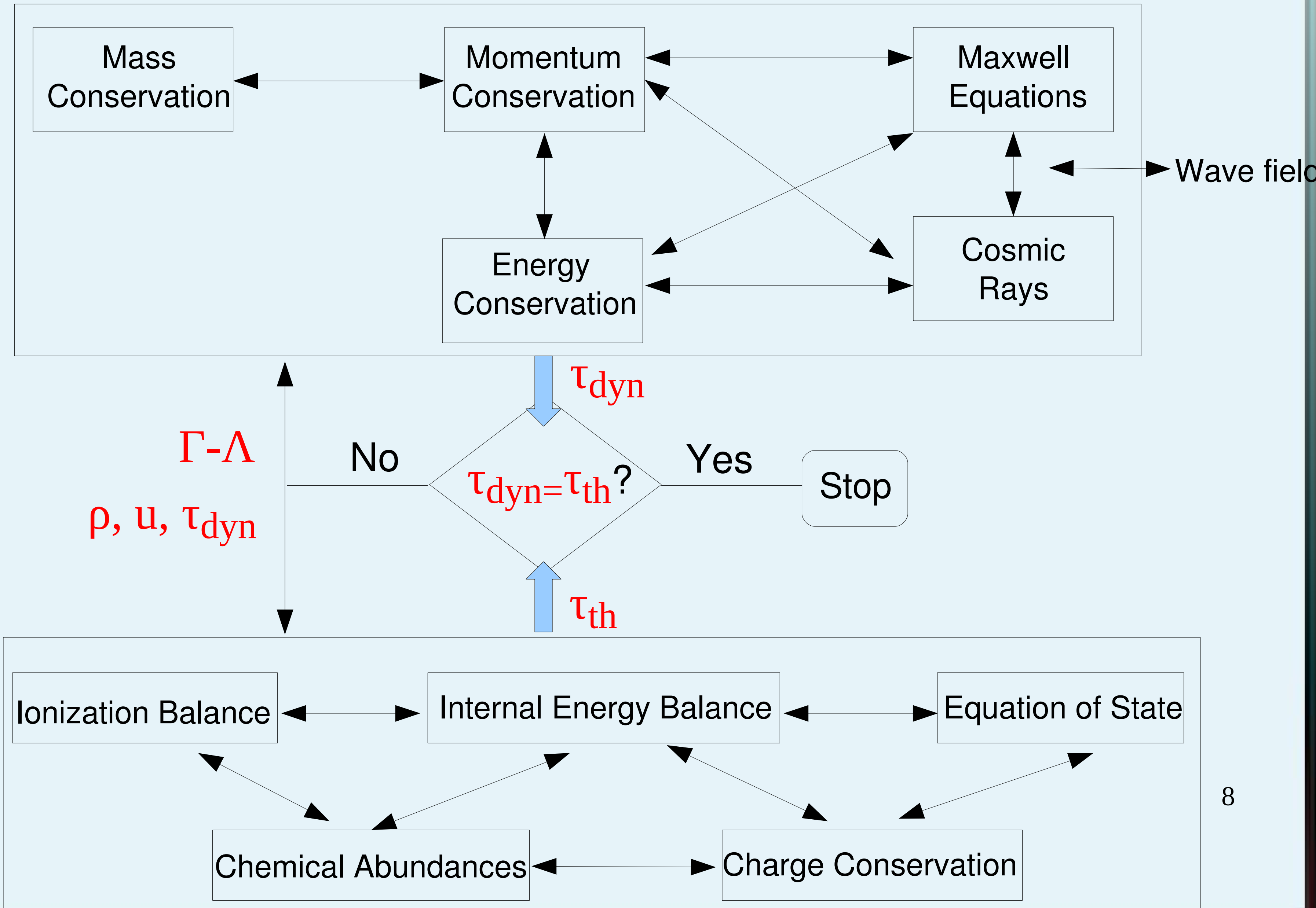
$$L_{22} = \int_0^{+\infty} g(l,t)\,dl = 0.5\,L_{11}$$

$$\tau_d = \frac{e}{\dot{e}} \simeq (9.8\,\mathrm{Myr})\left(\frac{L_d}{100\,\mathrm{pc}}\right)\left(\frac{v_{rms}}{10\,\mathrm{km\,s^{-1}}}\right) = (7.35\,\mathrm{Myr})\left(\frac{v_{rms}}{10\,\mathrm{km\,s^{-1}}}\right)$$

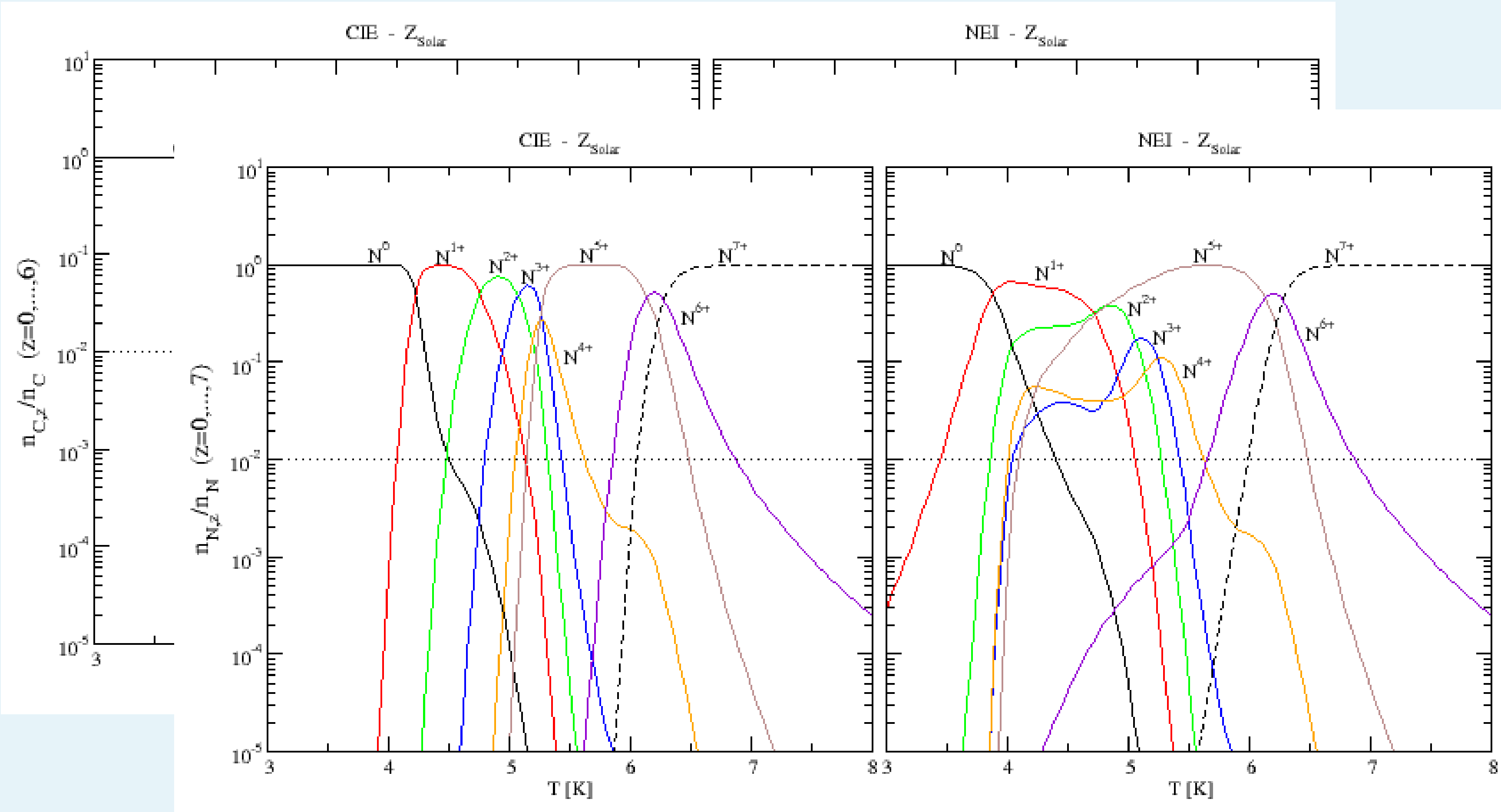
Computational Domain



Dynamics + Thermodynamics Algorithm (EVAF-PAMR Code)



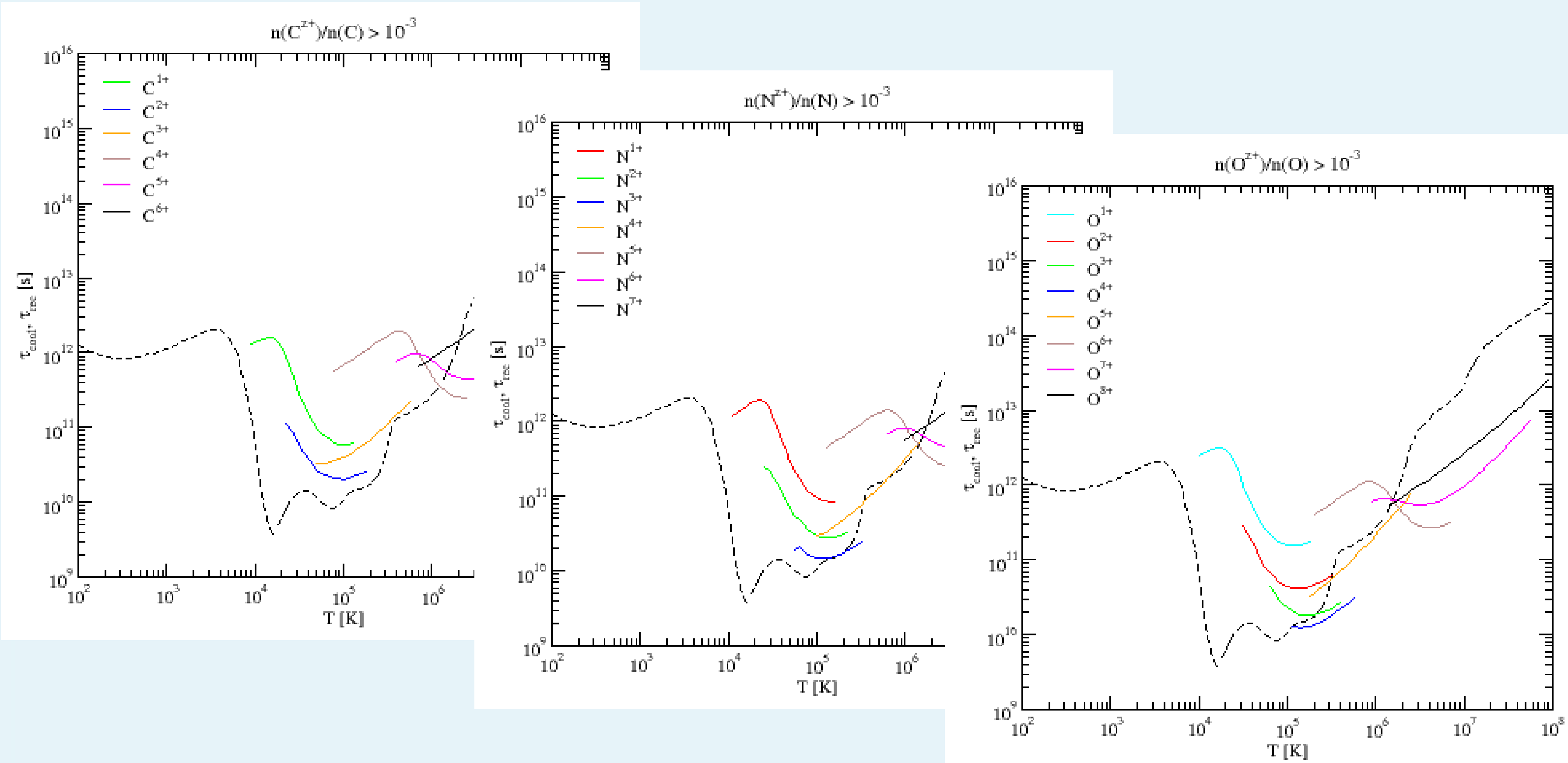
CIE vs NEI – Ionization Structure of C and N



CIE: Ionization fractions depend only on T–sharply peaked!

NEI: Ionization fractions depend on the dynamical and thermal history!

Cooling vs recombination time scales



- CIE is good approximation providing $t_{rec} < t_{cool}$
- However, for $T < 10^{6.2}$ K → $t_{rec} > t_{cool}$

CIE Description of the ISM has a Problem!

➔ We need self-consistent NEI modeling

- Outflow changes ρ, T
- Modifies ioniz. Structure
- Modifies Λ(ρ, T)
- Changes outflow

Physical processes in optically thin plasmas – EAF code

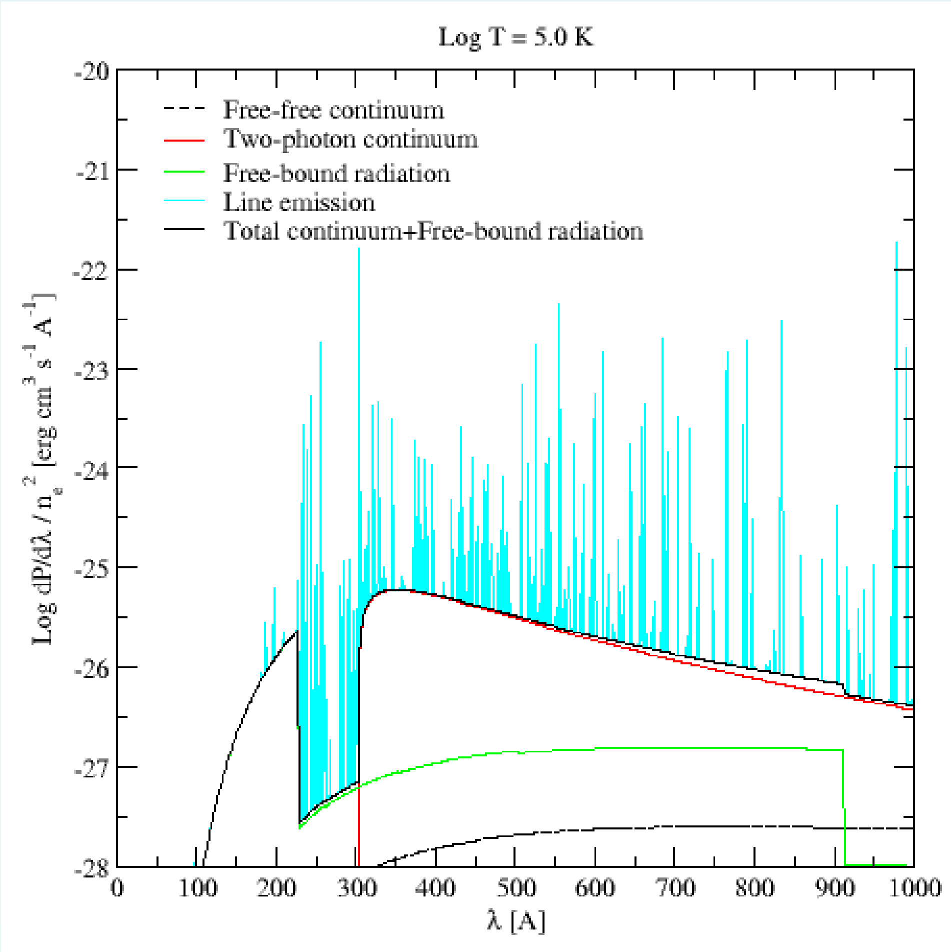
- Ionization and Recombination
  - Collisional ionization by thermal electrons
  - Excitation-Autoionization + Auger effect
  - Charge exchange reactions
  - Radiative + dielectronic recombination
  - Photoionization
  - Comptonization
  - Ionization of H and He by photo- and Auger electrons

Be carefull about

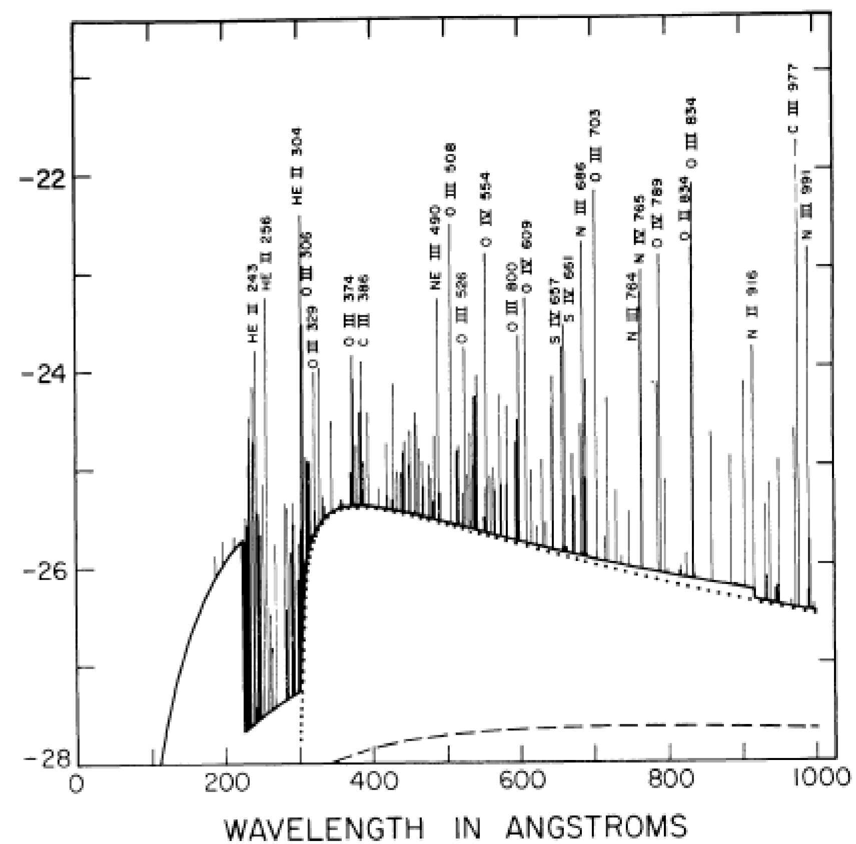
3-body recombination!

- Heating and Cooling Processes
  - Heating by photo- and Compton ionization
  - Cooling by bremsstrahlung
  - Cooling by recombination and collisional ionization
  - Cooling by collisional excitation

Testing the code – CIE: Continuum + Line Emission



Stern et al. 1978



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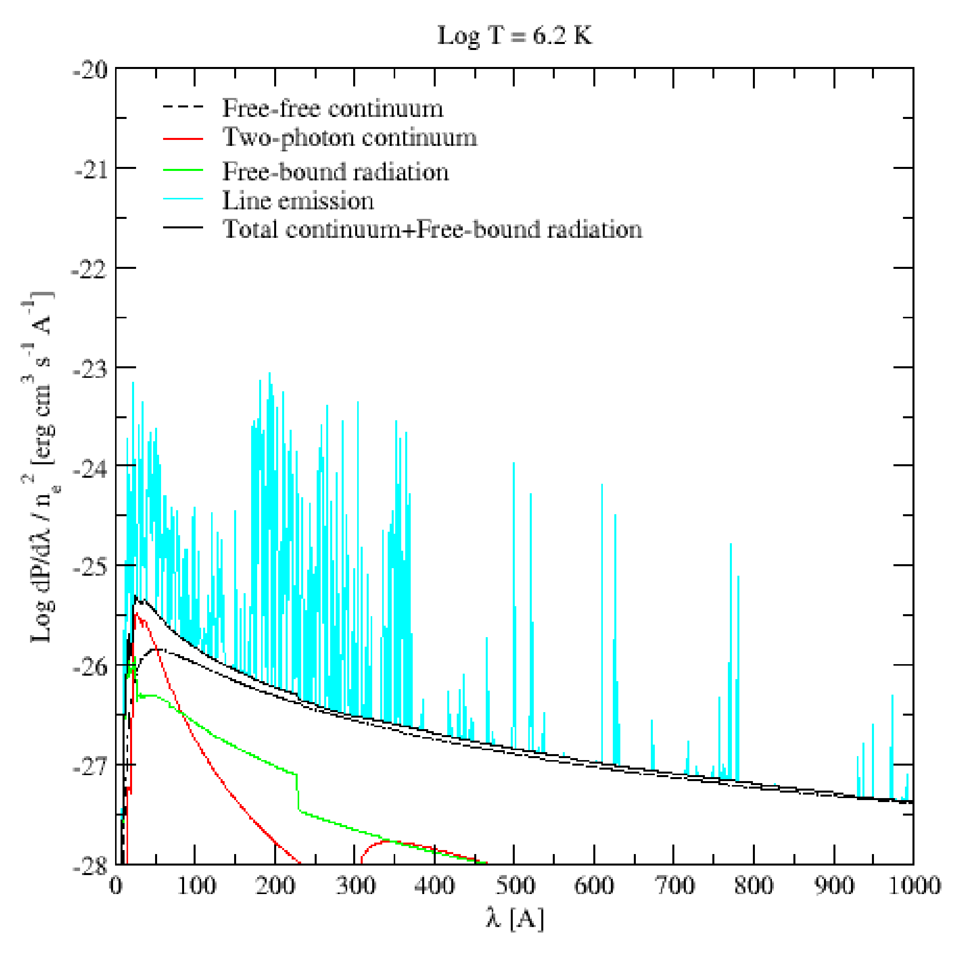

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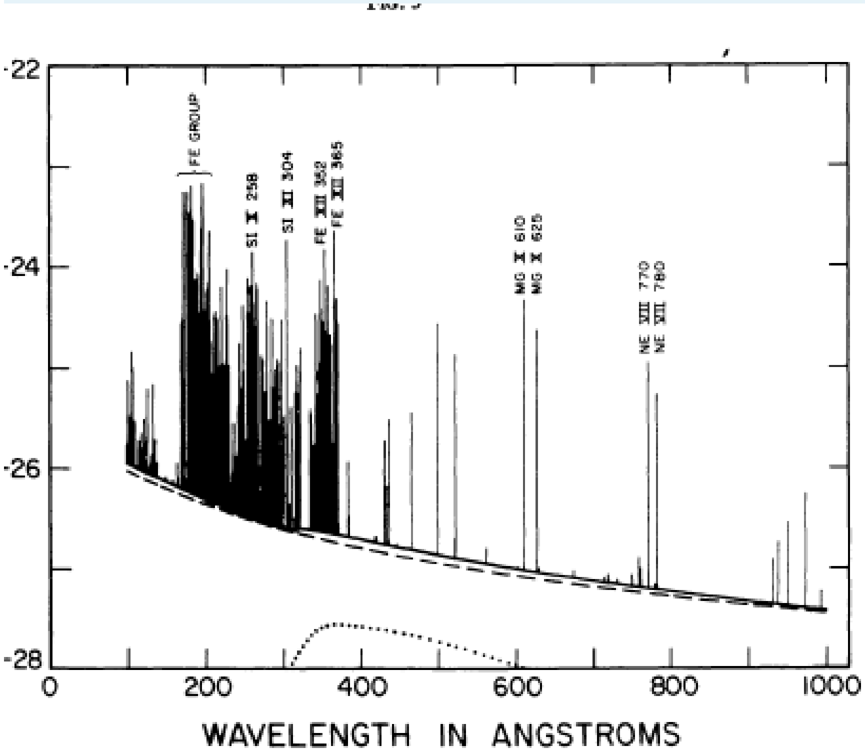

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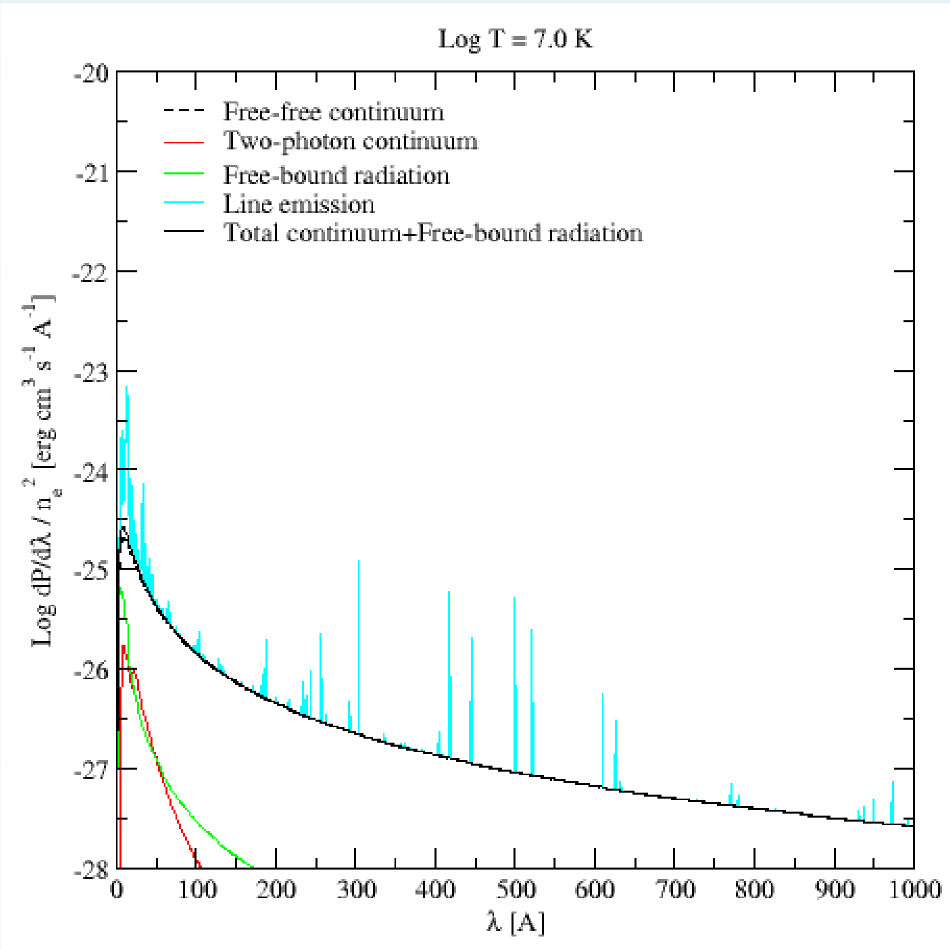

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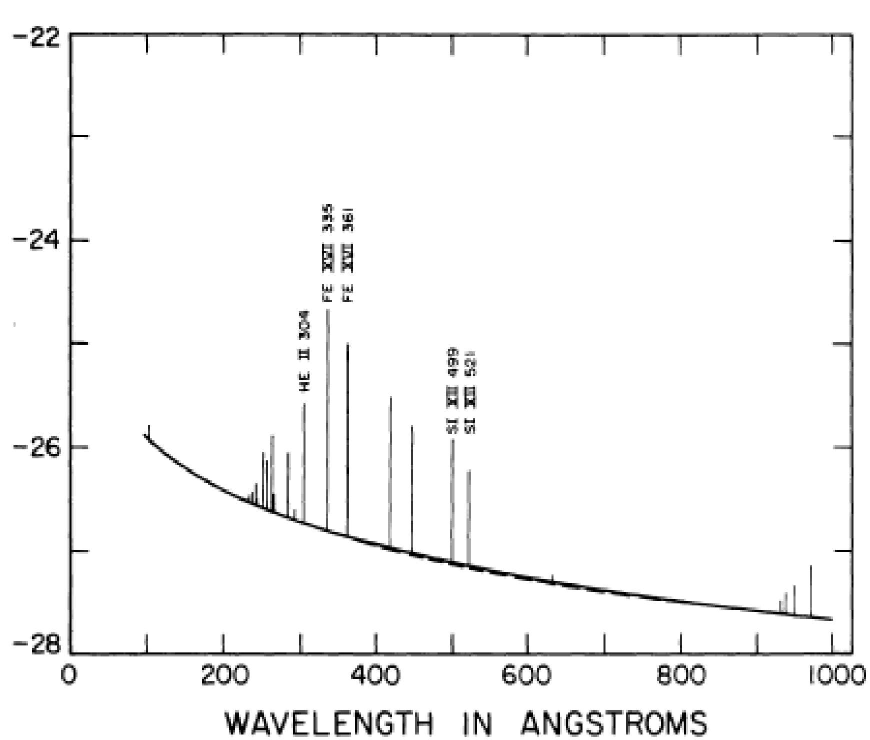
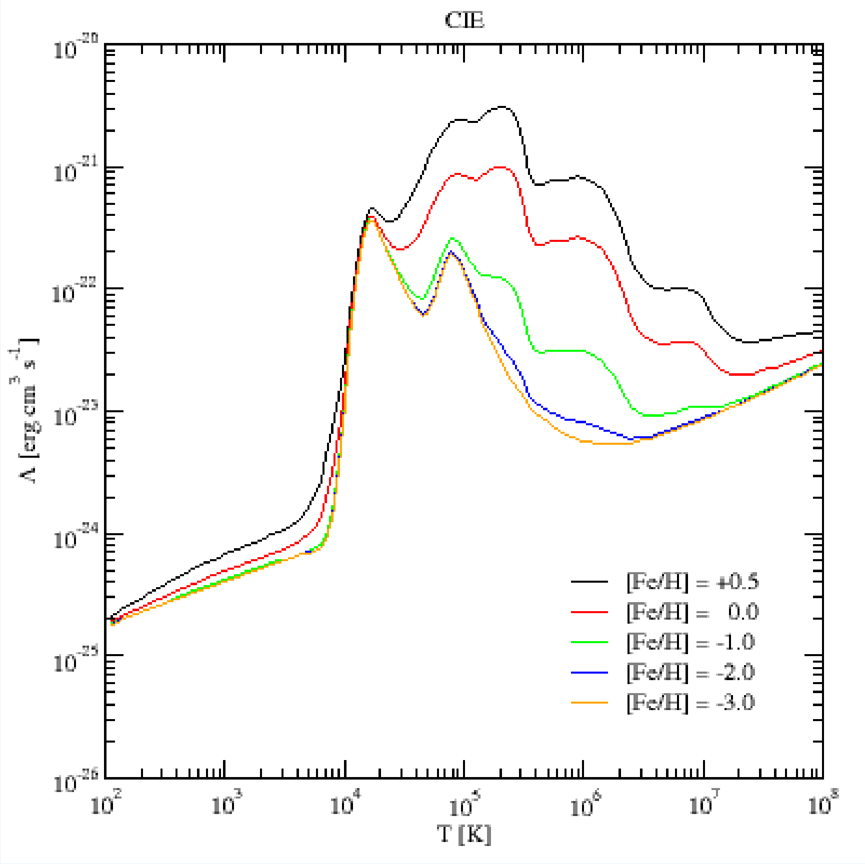
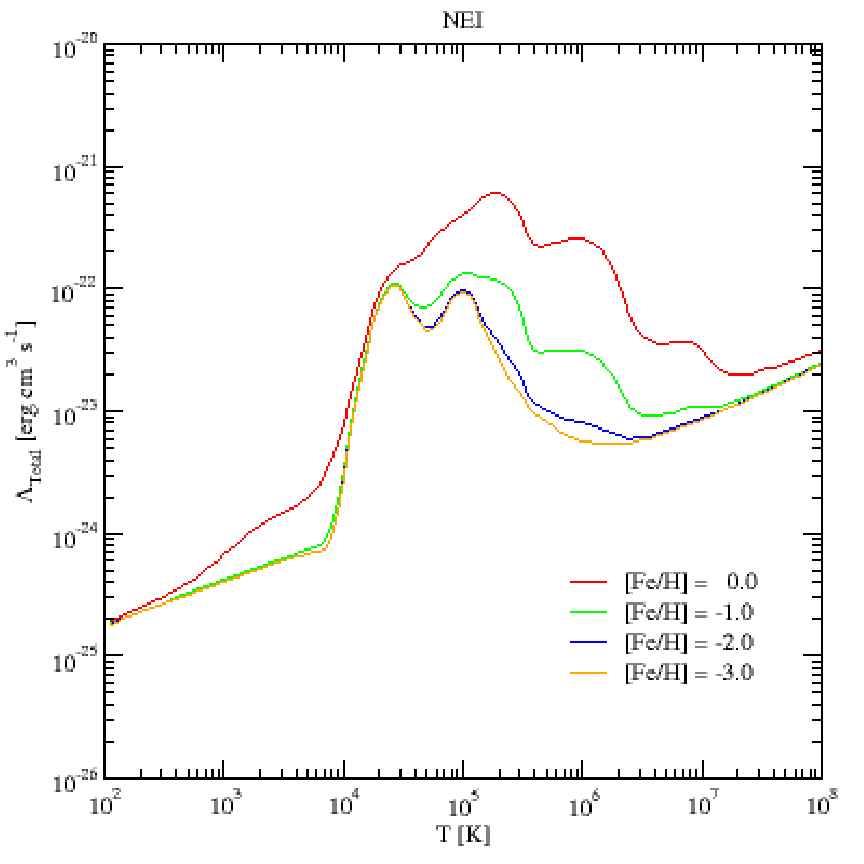
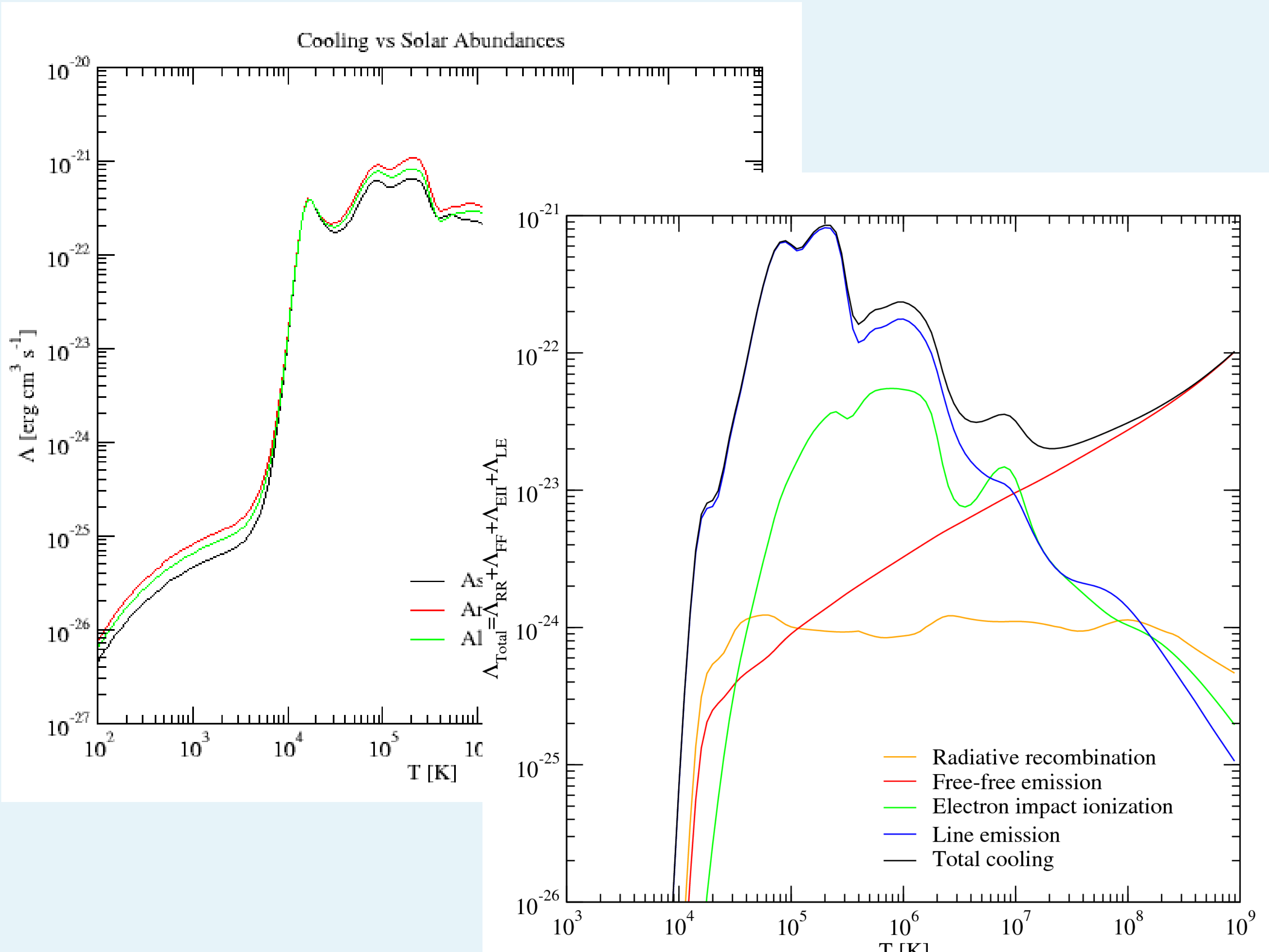


CIE & NEI Cooling Functions vs. [Fe/H]

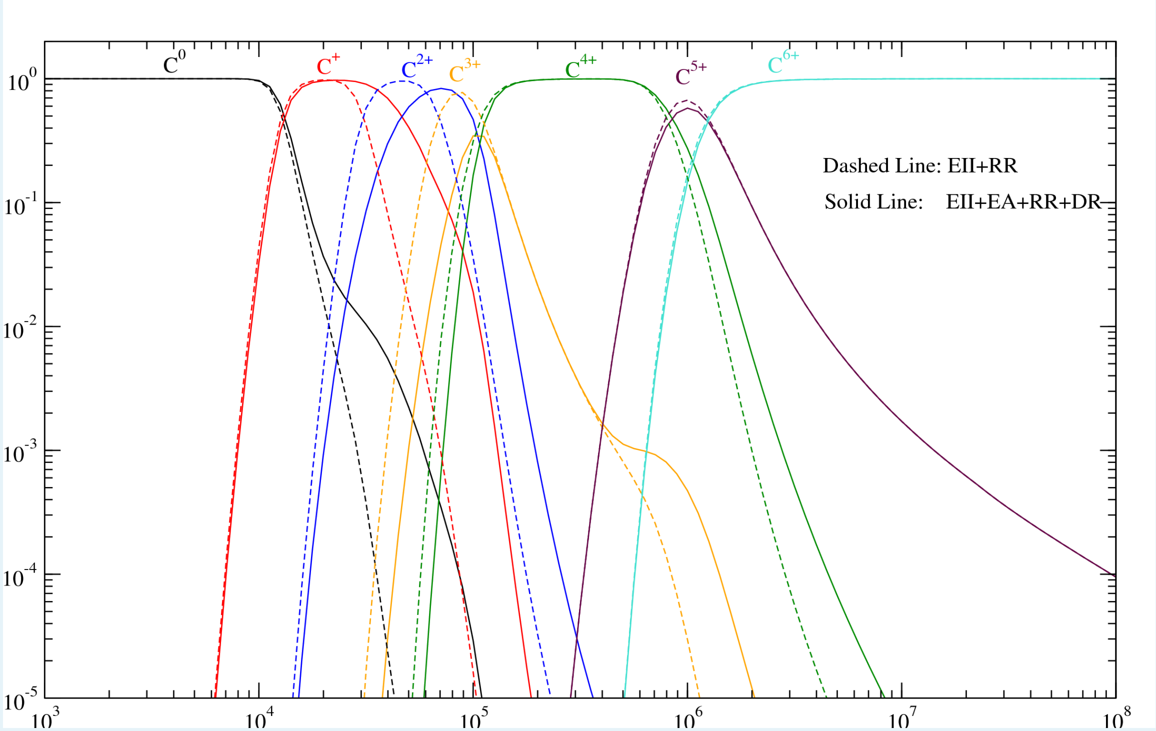




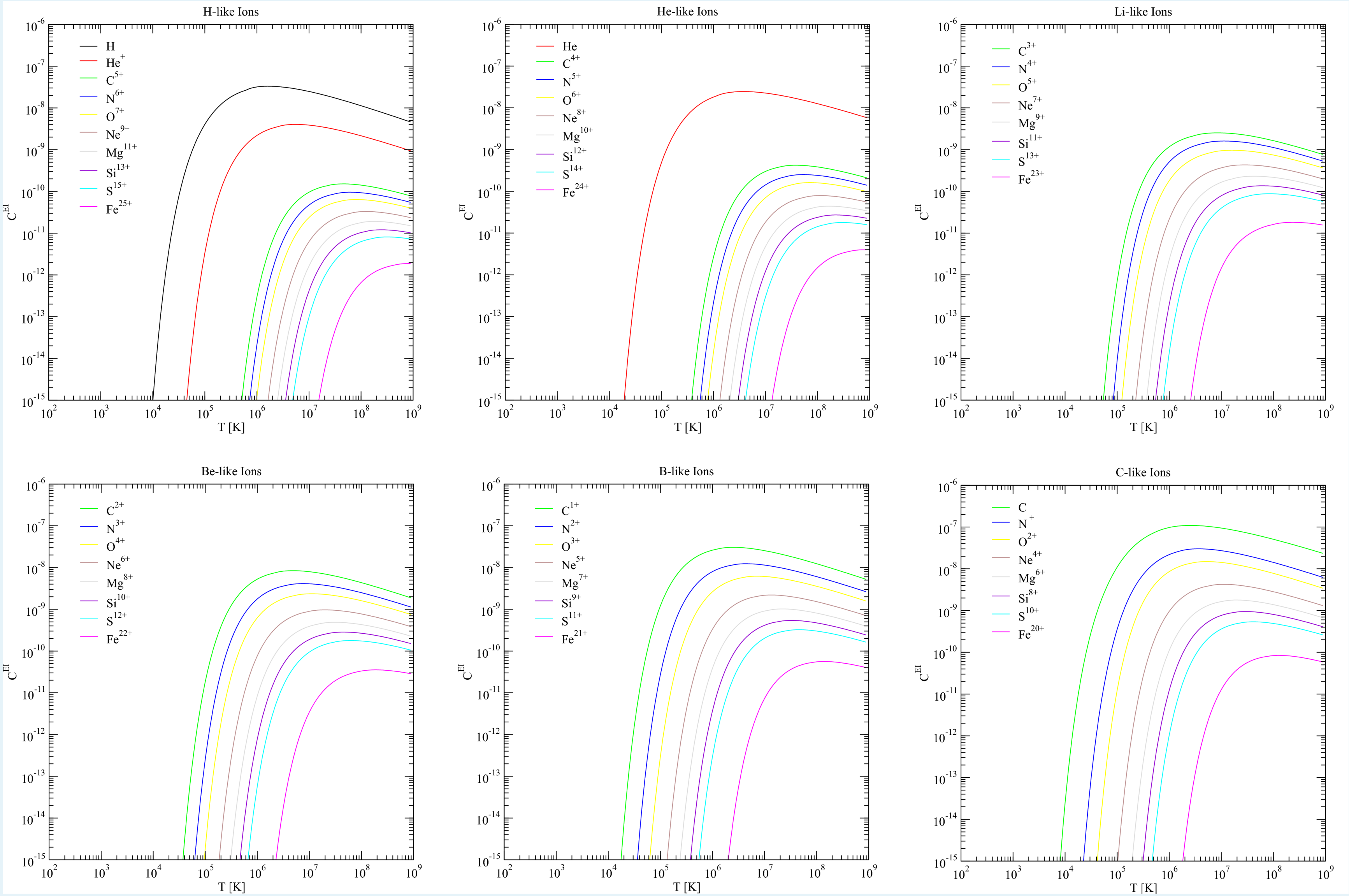
Cooling function vs. Processes



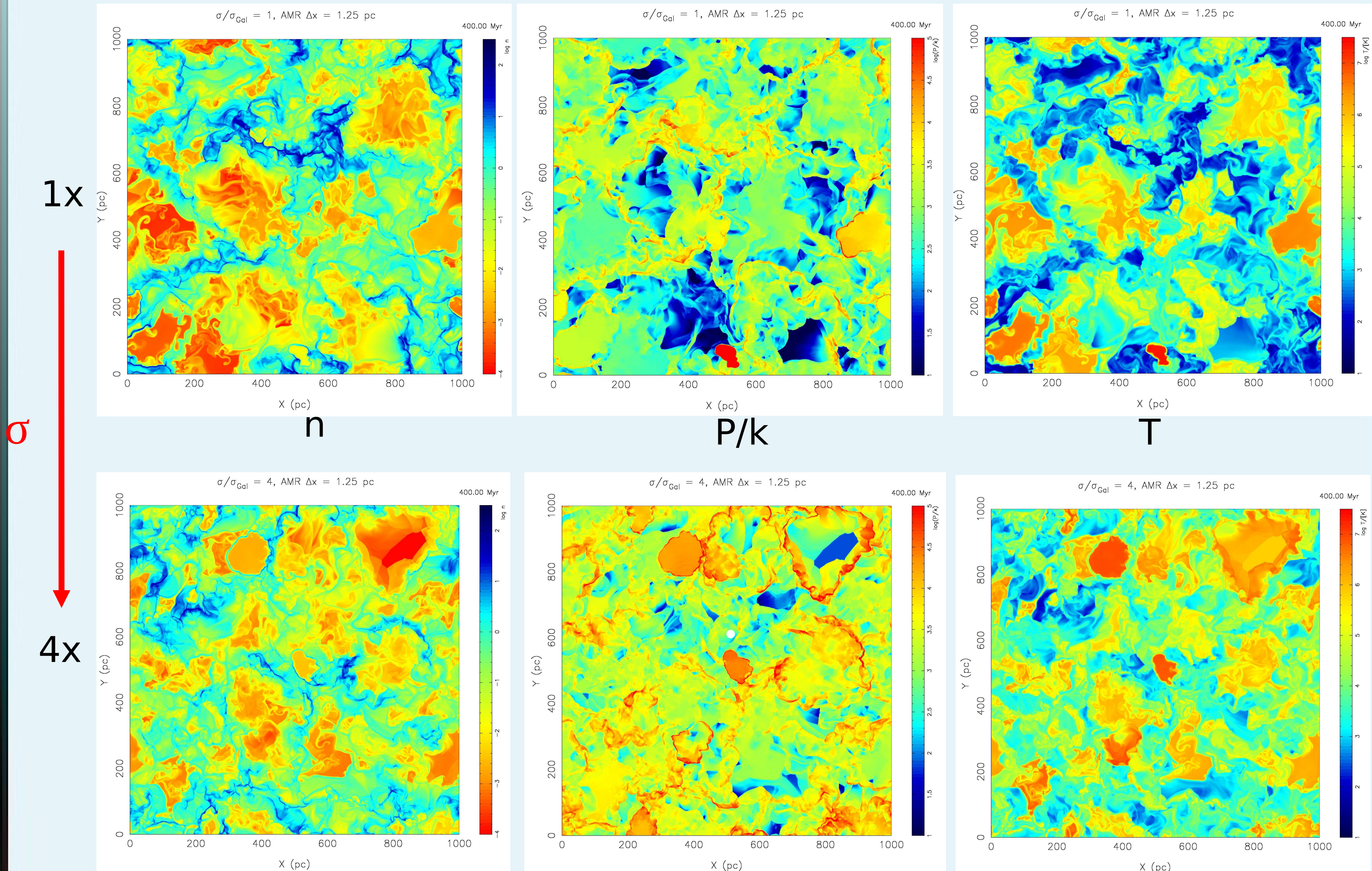
Dielectronic, Radiative Recombination Effects - Carbon



Electron Impact Ionization

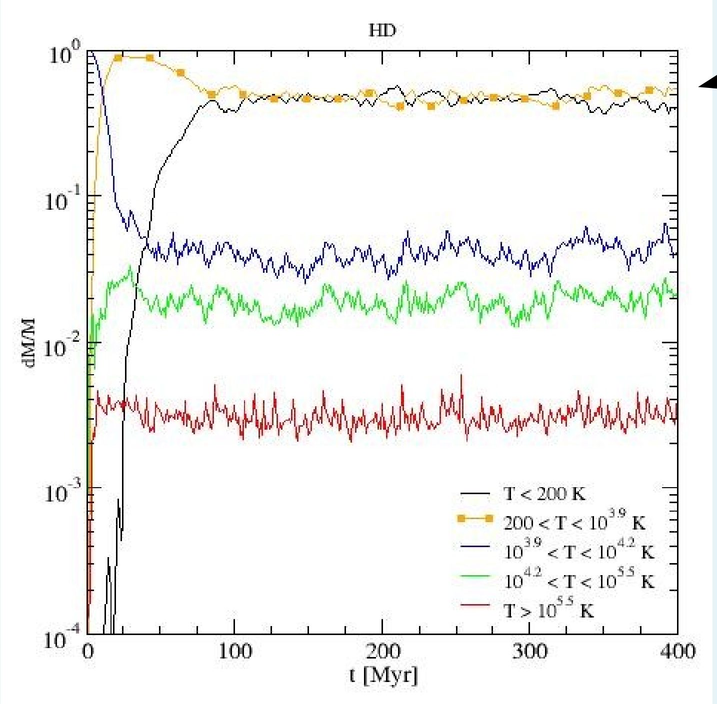


In the Galactic Midplane



AMR, HD 3D simulations with SN driving, and cooling + heating.

...and in the large scale ISM simulations we get...



Up to 50% of the ISM mass is in the thermally unstable regime

de Avillez & Breitschwerdt 2005

- Consistent with observations: Dickey et al. 1979; Fitzpatrick & Spitzer 1993; Heiles 2001; Kanekar et al. 2003; Heiles & Troland 2003
- Gazol & Scalo 2000; Norman & Wada 2001.

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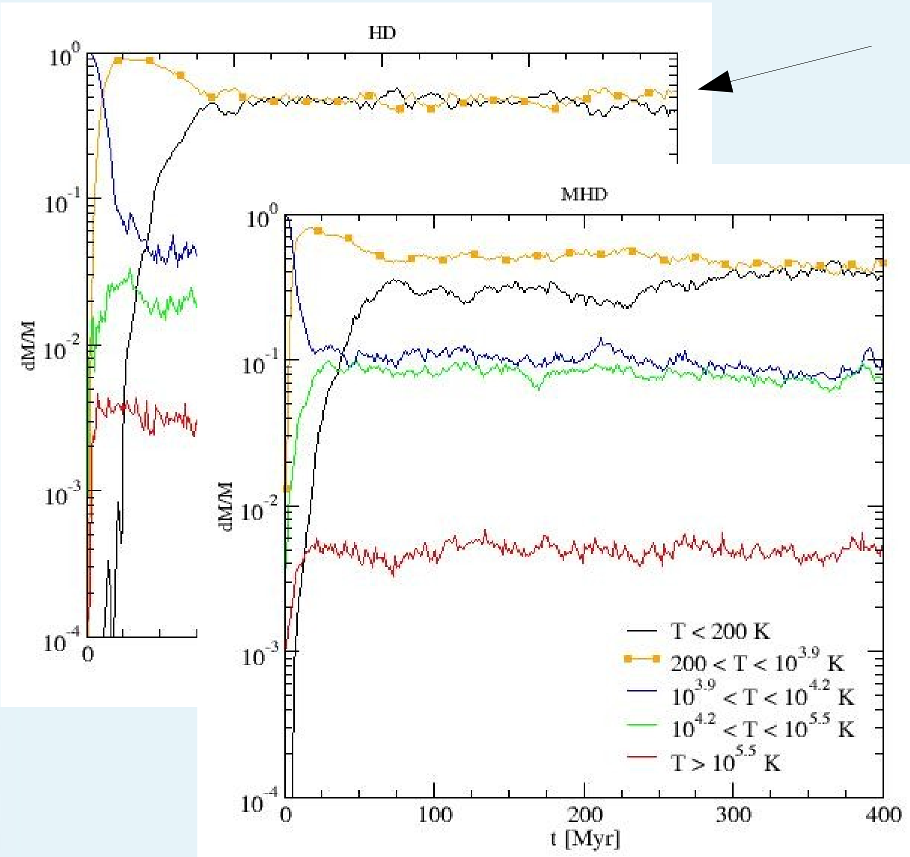

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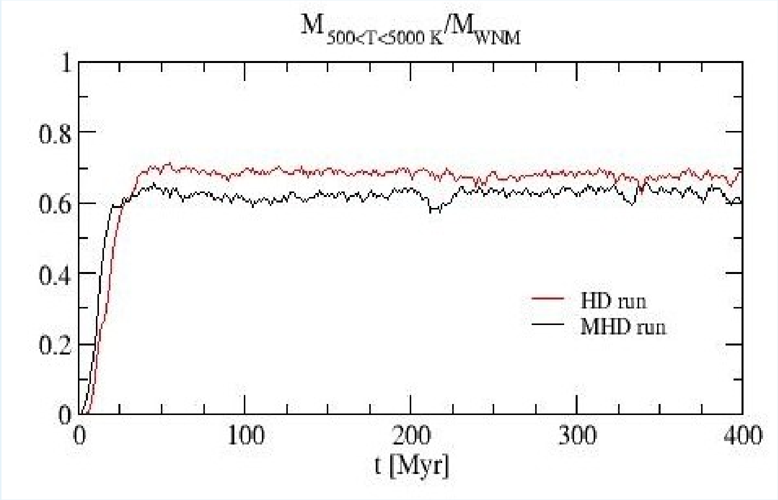

60-70% of the WNM mass is in the TU regime

- Consistent with observations: Dickey et al. 1979; Fitzpatrick & Spitzer 1993; Heiles 2001; Kanekar et al. 2003; Heiles & Troland 2003; Gazol & Scalo 2000; Norman & Wada 2001.

Summary

- CIE Description of the ISM is not correct for log T< 6.2 K.
- Cooling time < Recombination time of ions
- Plasma keeps a record of its history
- Ionization structure modifies the cooling feeding back into plasma.

- New 3D ISM Modelling tracking down for the ionization structure
- Tested the new code against observations
- We use GPUs to calculate the ionization structure


"That's all Folks!"