Non-Equilibrium Chemistry & Cooling in Diffuse Interstellar Gas

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We are interested in the transition from the warm ISM (10^4 K) to the cold ISM (100 K).

The thermal instability between these phases leads to short cooling times. Chemical non-equilibrium could potentially be important.
Introduction: Cooling Processes

➢ H excitation
  - Difficult to excite ground-state H\text{I} below \sim 8000 \text{ K}. 
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➢ **Metal line cooling**
  - Fine structure energy levels are close together.
  - Easy to excite even at low temperatures.
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➢ Molecular hydrogen
  - Excitation of ro-vibrational energy levels
Introduction: Heating Processes

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➢ Photoelectric dust heating
  - UV photons eject electrons from dust grains.
  - Important at very low temperatures (10’s K).
Introduction:
Chemical Network

H, He, N, C, O, Ne, Mg, Si, S, Fe:

➢ Photoionisation (incl Auger ionisation)
➢ Collisional ionisation
➢ Recombination
➢ Charge transfer
➢ Cosmic ray ionisation
Introduction: Chemical Network

Molecules (H₂, CO & intermediate species):

- H₂ formation on dust grains
- H₂ formation via H⁻
- Photodissociation
- CO chemistry: Glover et al. (2010)
Equilibrium Cooling

Haardt & Madau (2001) extragalactic UVB; $n_H = 1 \text{ cm}^{-3}$
Implementation in GADGET

➢ An SPH simulation using Gadget 3 (Springel 2005) with the EAGLE subgrid physics models, plus our chemical model.

➢ $M_{\text{tot}} = 2 \times 10^9 \, h^{-1} \, M_\odot$.

➢ $m_{\text{gas}} = 658 \, h^{-1} \, M_\odot$. 
Implementation in GADGET
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We track gas cooling rates in non-equilibrium.

- Important coolants include CII, Fell, Sill, OI & H2.
- Recombination lags can enhance the cooling rate in interstellar gas.

We have implemented this chemical model in the SPH code GADGET.
Non-Equilibrium Cooling

\[ n_H(10^4 \ K) = 1 \ cm^{-3} \]