Multi-Phase Interstellar Medium

Picture of the Diffuse Interstellar Medium

→ 1956 Spitzer, Ap J, 124, 20
"On a Possible Interstellar Galactic Corona"

* pressure equilibrium $n_e = n_p = \frac{5 \times 10^2}{T}$
  every component is in pressure equilibrium with the normal HI clouds with $n_H = 10\ cm^{-3}$ and $T = 100K$.
* hydrostatic equilibrium ⊥ the galactic plane

$$\frac{d \log n(z)}{dz} = - \frac{m K(z)}{kT}$$

where $K(z)$ is the gravitational acceleration in the z direction ⊥ to the galactic plane.

$Z_c \equiv$ "coronal height" = z at which n drops to $\frac{1}{e}$ times the value at $z=0$

T (°K)	3×10^4	10^5	3×10^5	10^6	3×10^6
Z_c (pc)	520	1,400	3,200	7,500	27,000
$n_e Z_c$ (cm^{-2})	2.7×10^{19}	2.2×10^{19}	1.6×10^{19}	1.2×10^{19}	1.4×10^{19}

For a corona with $T \sim 10^6 K$, the mean free path is ~ 4 pc, but the gyroradius is much smaller. (so that hydromagnetic shocks can still occur.)

→ 1969 Field, Goldsmith, Habing, ApJ, 155, L149
"Cosmic Ray Heating of the Interstellar Gas"

The Two-Phase model of the diffuse ISM.

* Considers only the cosmic ray heating.

* cooling Λ , heating Γ

  net cooling rate coefficient $\mathcal{L}$

  $$\mathcal{L} = \Lambda - \Gamma/n$$

thermal instability $\left(\frac{\partial \mathcal{L}}{\partial T}\right)_p < 0 \Rightarrow K_\Lambda - 1 < K_\Gamma$

where $K_\Lambda \equiv \left(\frac{\partial \ln \Lambda}{\partial \ln T}\right)_p$ & $K_\Gamma \equiv \left(\frac{\partial \ln \Gamma}{\partial \ln T}\right)_p$

Γ is independent of temperature, $K_\Gamma = 0$

* At pressure equilibrium, any component with $K_\Lambda < 1$ would be thermally unstable.

* Look at Dalgarno & McCray's cooling function. At $T > 10^{5.5}$, $\left(\frac{\partial \ln \Lambda}{\partial \ln T}\right)_p \lesssim 1$, so a galactic corona or any hot gas component is thermally unstable.

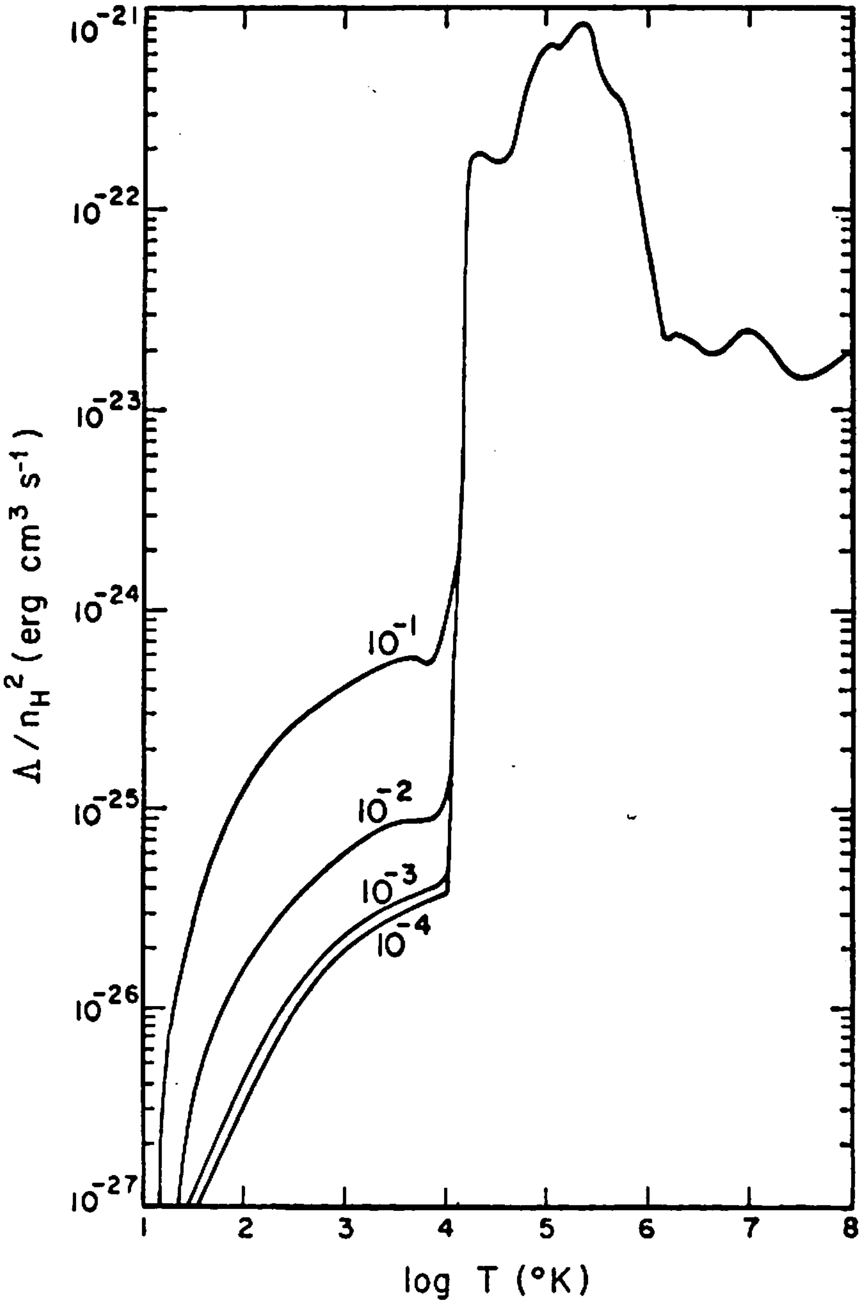

Figure 6.2 Cooling function for interstellar gas [6]. Values of $\Lambda(T)/n_{\rm H}^2$ are shown as functions of the temperature T. For $T < 10{,}000$°K, the different curves represent different values of $x \equiv n_e/n_{\rm H}$, while for $T > 10{,}000$°K, collisional ionization is assumed for all elements. Depletion and the possible presence of dust grains [7] or of H_2 are ignored.

→ 1974. Cox and Smith, ApJ, 189, L105
"Large-Scale Effects of SNRs on the Galaxy: Generation and Maintenance of A Hot Network of Tunnels"

Each SN generates ~10^{51} ergs in the initial energy of its SNR. The SNR has its central cavity filled with hot gas.
If the SN rate is high enough, the ISM will be filled by connected SNRs, forming hot tunnels.

→ 1976 Shapiro, P.R., Field, G.B. ApJ, 205, 762.
"Consequences of a New Hot Component of the ISM"

* Inspired by soft x-ray background observations and Copernicus OVI absorption line observations.

* Assume a steady-state model of the hot component, the soft x-ray background and the OVI absorption require a pressure 10 times higher.
* Conclude a time-dependent model,
  hot gas rises about 1 kpc above the disk before cooling and condensing to form clouds and falling to the plane at ~100 km/s.
* "Galactic Fountain"

→ 1977 McKee and Ostriker 1977, ApJ, 218, 148

"A Theory of the ISM: Three Components Regulated by SN Explosions in an Inhomogeneous Substrate"

Three-Phase Model of the ISM

* Energy inputs — SNe
* Cloudlets survive the SNR shock, evaporate in the SNR interior, increase the density and radiative loss.
* mass balance: cloud evaporation rate = dense shell formation rate

  energy balance: SNR shock input = radiation loss
* Pressure equilibrium
* Filling factor of the HIM is at least 50%

$$T \simeq 5\times10^{5}\left(\frac{S_{SN}}{10^{-13}\,pc^{-3}\,yr^{-1}}\right)^{2/7}\ K$$

* $nT = \frac{P}{k} = $ a few 10^{3}

McKee & Ostriker 1977, ApJ, 218, 148 (5)

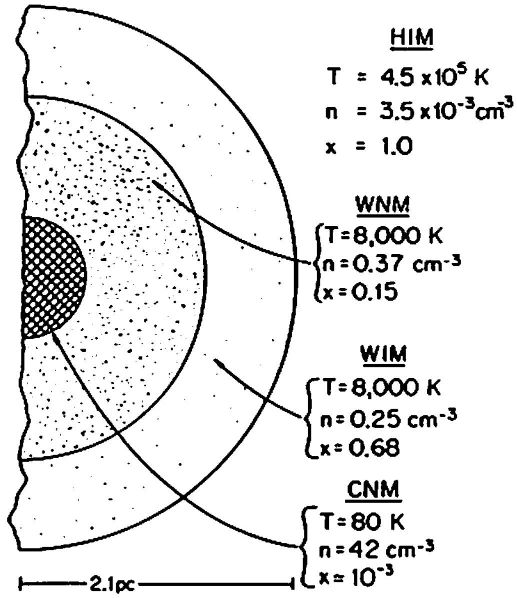

FIG. 1

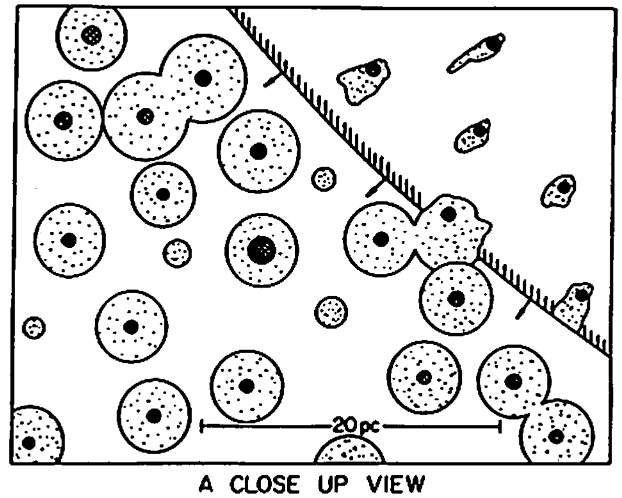

FIG. 2

FIG. 1.—Cross section of a characteristic small cloud. The crosshatched region shows the cold core, which gives the usual optical absorption lines. Next is the warm neutral medium (WNM) with ionization produced by soft X-ray background. The outer layer (WIM) is gas largely ionized by stellar UV background. Typical values of hydrogen density n, temperature T, and ionization $x = n_e/n$ are shown for each component, except that a higher than average value of the soft X-ray flux has been assumed in order to produce a significant amount of WNM at this pressure.

FIG. 2.—Small-scale structure of the interstellar medium. A cross section of a representative region 30 pc × 40 pc in extent is shown, with the area of the features being approximately proportional to their filling factors. A supernova blast wave is expanding into the region from the upper right. The radius of the neutral cores of the clouds (represented by crosshatching) ranges from about 0.4 to 1 pc in this small region; all the clouds with cores have warm envelopes (*dotted regions*) of radius $a_w \sim 2.1$ pc. A few clouds are too small to have cores. The envelopes of clouds inside the SNR are compressed and distorted.

compensate for it in the previous work in this paper by simply decreasing the assumed supernova energy E_{51} by ~30%, a change which would have negligible effect on any of the calculated quantities.

b) Warm Neutral Medium

We estimate from Chevalier's (1974) calculations that soft X-ray photons in the energy range 40–120 eV ($h\bar{\nu}$ = 60 eV) are produced in amount $\epsilon_x = 1.1 \times 10^{-16} S_{-13} E_{51}$ photons cm^{-3} s^{-1}. These will penetrate through the

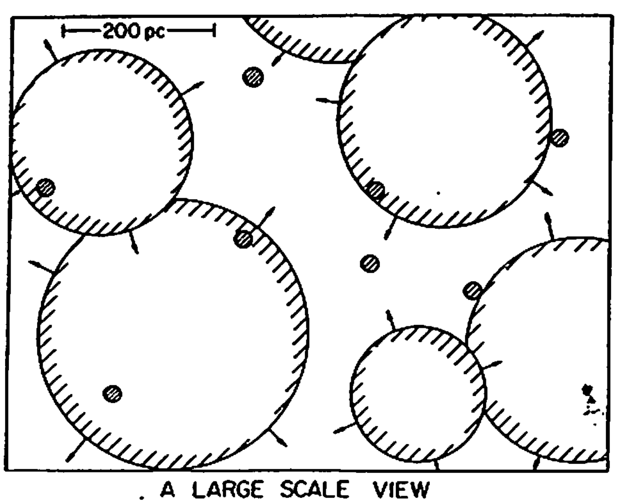

FIG. 3.—Large-scale structure of the interstellar medium. The scale here is 20 times greater than in Fig. 1: the region is 600 × 800 pc. Only SNRs with $R < R_c = 180$ pc and clouds with $a_0 > 7$ pc are shown. Altogether about 9000 clouds, most with $a_w \sim 2.1$ pc, would occur in a region this size.

(6)

Observationally, four phases of the diffuse ISM have been defined:

- CNM
  - cold neutral medium; $T \sim 80\,K$
  - usually distributed in dense, largely neutral HI clouds
  - not seen in every direction
  - velocity widths smaller
  - cloud-cloud velocity dispersion ~ 6.9 km/s
- WNM
  - warm neutral medium; $T \sim 8000\,K$
  - wide-spread, seen in all directions
  - the z-scale height of $5 < \sigma < 17$ km/s component is larger than that of the $\sigma < 5$ km/s component. (σ: linewidth)
  - the thermal velocity dispersion gives an upper limit of $T_k = 9600\,K$, but there is a long tail.
- WIM
  - warm ionized medium; $T \sim 8000\,K$
  - $H\alpha$ emission, widely spread
- HIM
  - hot ionized medium; $T \sim 10^6\,K$
  - seen in soft X-rays and OVI absorption.
  - can't see far, don't know how pervasive it is.