Three ISM Components Regulated By Supernova Explosions

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Outline

Introduction of ISM

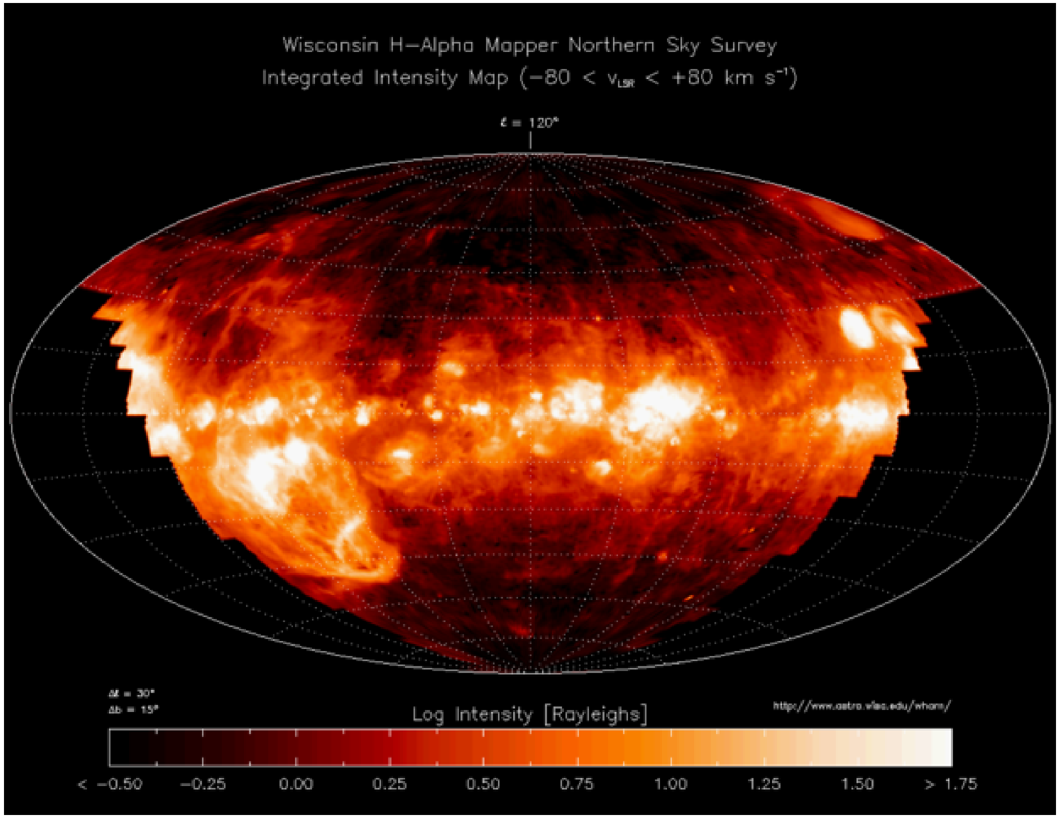
Thermostat problem and McKee & Ostriker’s model

Comparison with observation

Present knowledge of the Galactic ISM

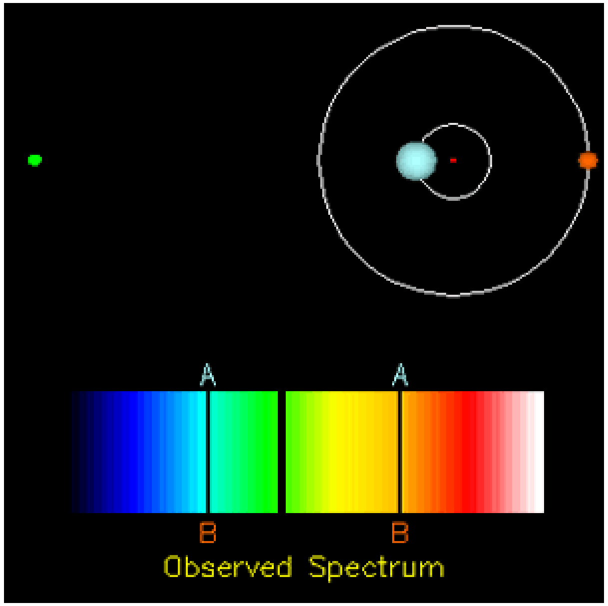
Introduction of ISM

The interstellar medium (ISM) is the matter and radiation that exists in the space between the star systems in a galaxy.



Introduction of ISM

The first detection of cold diffuse ISM was made by Johannes Hartmann in 1904. He discovered stationary absorption lines of Ca II in the spectrum of the binary δ Orionis.



Introduction of ISM

After decades of efforts, different effects(extinction, reddening, polarization, etc.) were uncovered by observation.

People also realized that the ISM is filled with cosmic rays and magnetic field too.

Thermostat problem and McKee & Ostriker's model

Background:

• Two-phase ISM(Field, Goldsmith, and Habing ,1969)
Cold dense clouds
Warm intercloud medium
• the total energy of a supernova remnant (SNR)

$$E \sim 10^{51} E_{51} \text{ ergs}$$

• hot SNRs occur locally at a rate

$$S \sim 10^{-13.0} \text{ pc}^{-3} \text{ yr}^{-1}$$

Thermostat problem and McKee & Ostriker's model

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the average supernova power density is

$$6.15 \times 10^{-26} \text{ erg cm}^{-3} \text{ s}^{-1}.$$

the emissivity of gas at temperature T and pressure p is

$$\varepsilon = \text{L}n^2 = 2.7 \times 10^{-27} \text{ erg cm}^{-3} \text{ s}^{-1}[\text{p}/(1.5 \times 10^{-12} \text{ dyn cm}^{-2})]^2/\text{T}_6^{5/2}$$

Thermostat problem and McKee & Ostriker's model

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the ratio of the above quantities is

$$[p/(1.5 \times 10^{-12}\ \mathrm{dyn\ cm^{-2}})]^2\ (0.29/T_6)^{5/2}$$

at typical value,

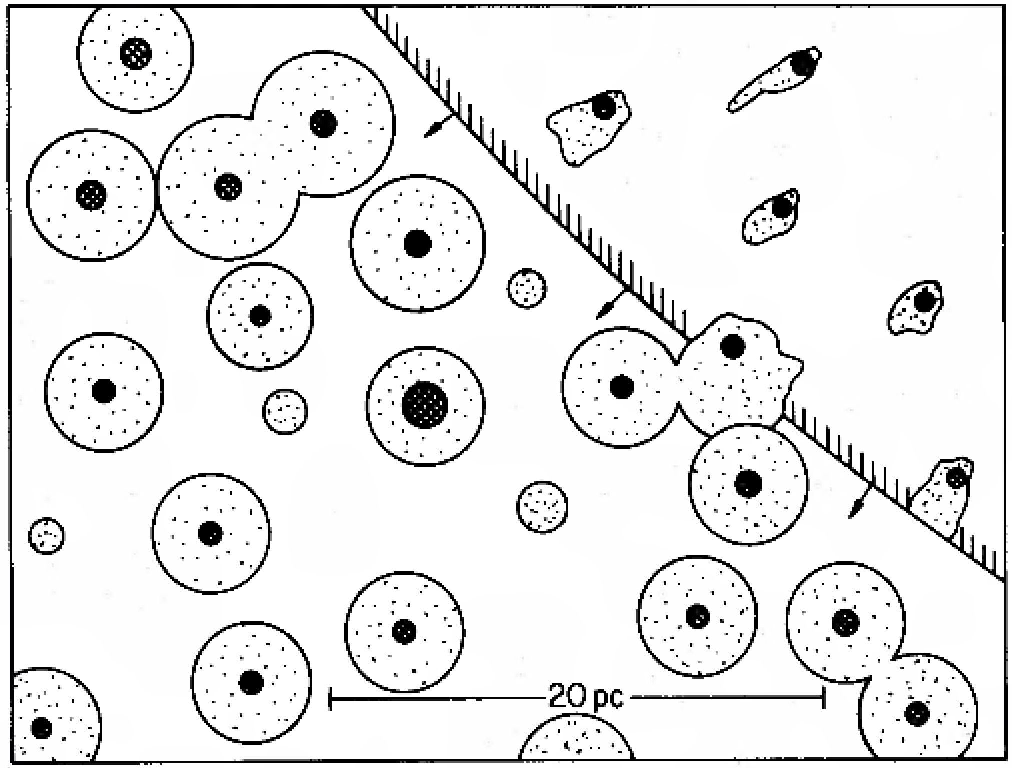
$$p/k = 11{,}000\ \mathrm{cm^{-3}\ K}$$

$$T \sim 3 \times 10^5\ \mathrm{K}$$

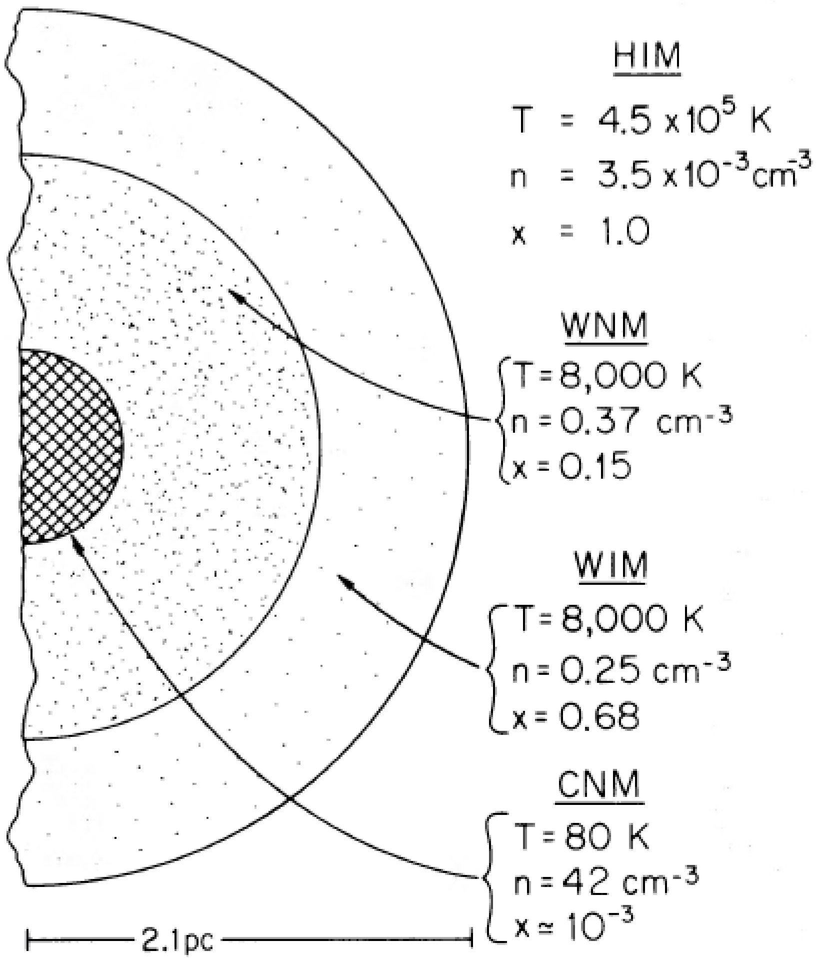
much lower n → Thermal runaway

Thermostat problem and McKee & Ostriker's model

In the ISM model of McKee & Ostriker(1977), the disaster was averted by having thermal evaporation of clouds within remnants



Thermostat problem and McKee & Ostriker's model



HIM: hot ionized low density medium

WNM: warm neutral medium

WIM: warm ionized medium

CNM: cold neutral medium

x: ionization

Thermostat problem and McKee & Ostriker's model

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For SNR evolution, basic interaction is thermal conduction. Energy and mass conservation give

$$E_{\mathrm{th}} = 1.5 \rho_h c_h{}^2 V$$

$$\frac{dM}{dt} = 4\pi R^2 \rho_0 v_b + N_{\mathrm{cl}} \dot{M}_{\mathrm{ev}} V$$

Thermostat problem and McKee & Ostriker's model

Cooling point: half the SNR energy has been radiated and a dense shell forms

$$R_c = 10^{2.21} {E_{51}}^{0.04} \alpha^{0.19} \beta^{0.04} (Q_c/S_{-13})^{0.23} = 10^{2.26}\ \mathrm{pc}\,,$$

$$t_c = 10^{6.18} {E_{51}}^{-0.11} \alpha^{-0.20} \beta^{-0.11} (Q_c/S_{-13})^{0.31} = 10^{5.90}\ \mathrm{yr}\,,$$

$$v_{bc} = 10^{1.80} {E_{51}}^{0.15} \alpha^{0.39} \beta^{0.15} (Q_c/S_{-13})^{-0.08} = 10^{2.13}\ \mathrm{km\ s^{-1}}\,,$$

$$n_{hc} = 10^{-2.04} {E_{51}}^{0.59} \alpha^{-0.14} \beta^{-0.41} (Q_c/S_{-13})^{-0.54} = 10^{-2.34}\ \mathrm{cm^{-3}}\,,$$

$$\tilde{P}_{hc} = 10^{3.80} {E_{51}}^{0.89} \alpha^{-0.58} \beta^{-0.11} (Q_c/S_{-13})^{-0.69} = 10^{3.67}\ \mathrm{K\ cm^{-3}}\,,$$

$$T_{hc} = 10^{5.47} {E_{51}}^{0.30} \alpha^{-0.45} \beta^{+0.30} (Q_c/S_{-13})^{-0.15} = 10^{5.64}\ \mathrm{K}\,,$$

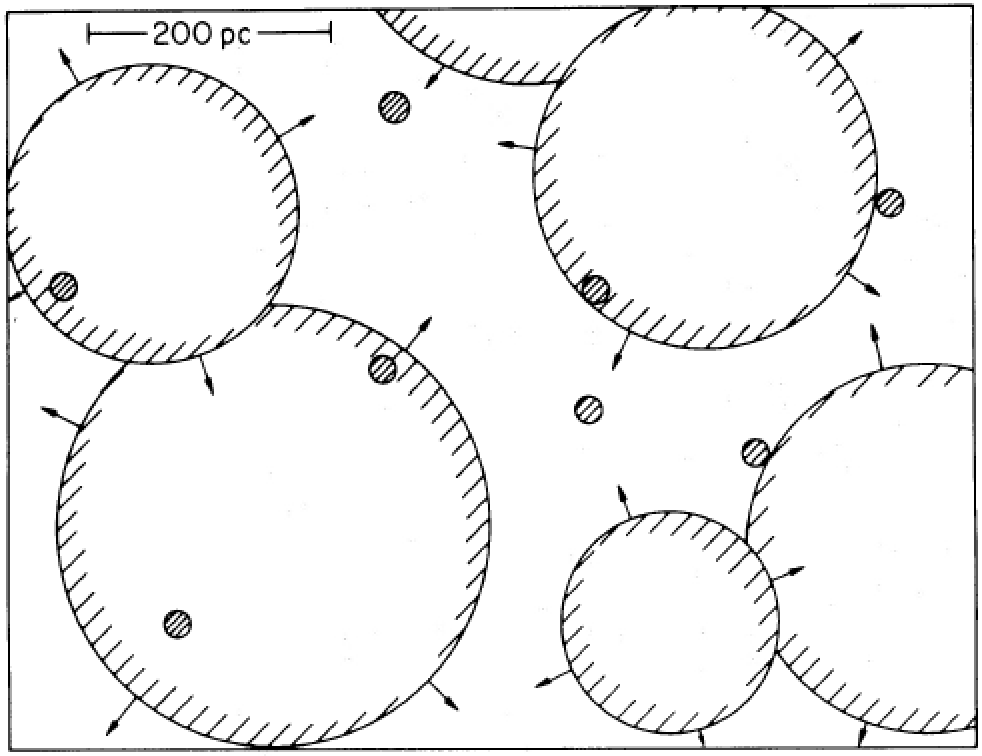
Thermostat problem and McKee & Ostriker's model

For HIM, there are three balance relation

(1) Pressure balance

(2) Mass balance

(3) Energy balance



SNRs with $R < R_c = 180$ pc and clouds with $a_0 > 7$ pc are shown.

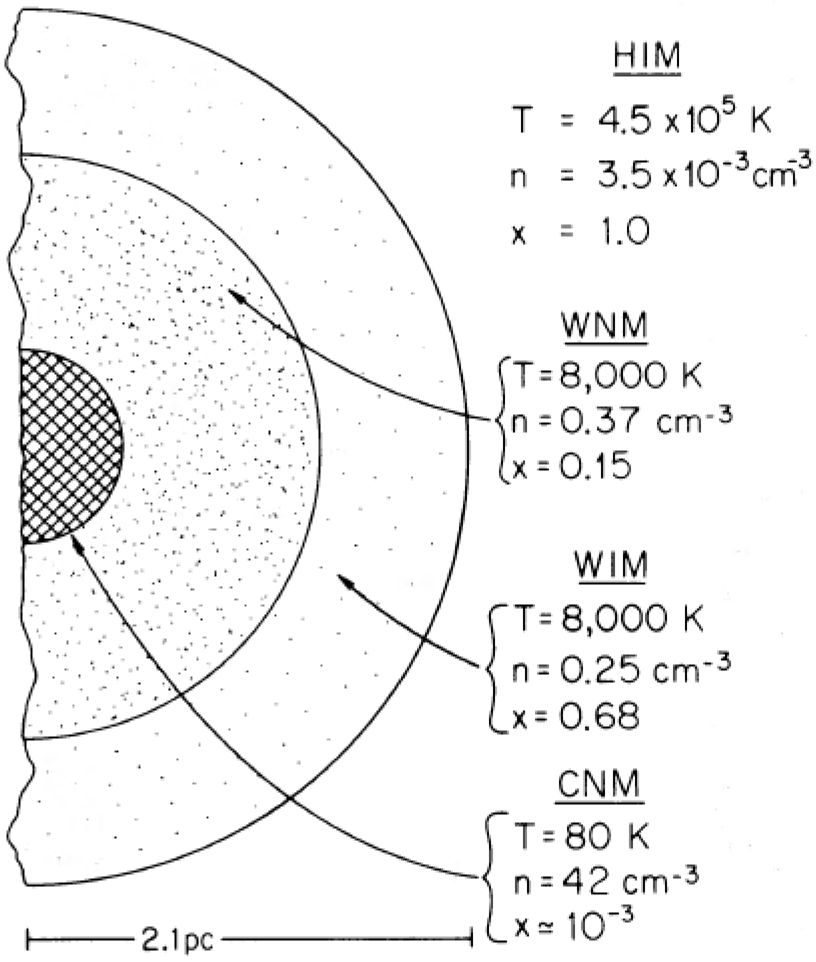
Thermostat problem and McKee & Ostriker's model

Average hot medium: $\langle n_h \rangle = 10^{0.19} n_{hc} Q_c{}^{0.63} = 10^{-2.31} Q_c{}^{0.09} = 4.6 \times 10^{-3}\ \mathrm{cm}^{-3}$,

$$\langle \tilde{P}_h \rangle = 10^{0.45} \tilde{P}_{hc} Q_c{}^{0.84} = 10^{3.94} Q_c{}^{0.15} = 7.9 \times 10^{3}\ \mathrm{K\ cm}^{-3} ,$$

$$\langle T_h \rangle = 10^{0.15} T_{hc} Q_c{}^{0.40} = 10^{5.74} Q_c{}^{0.25} = 4.6 \times 10^{5}\ \mathrm{K} .$$

Thermostat problem and McKee & Ostriker's model



HIM: hot ionized low density medium

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Comparison with observation

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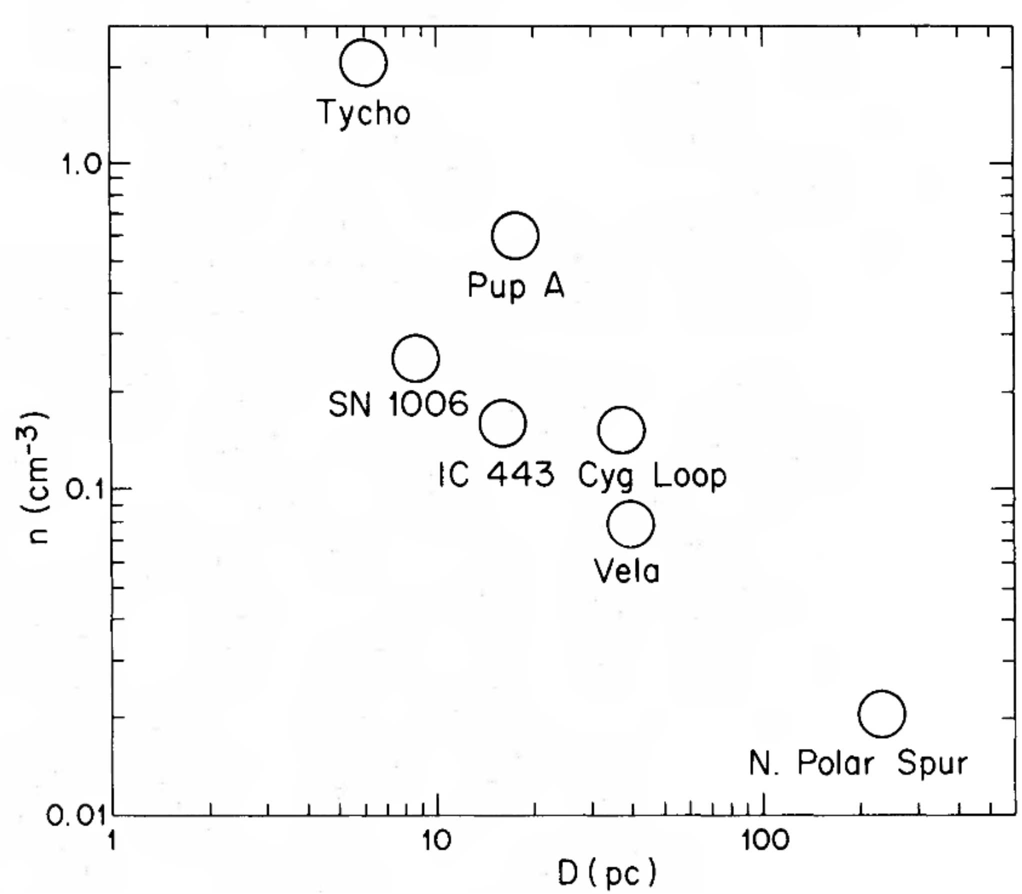
$n \propto R^{-5/3}$

vs $n \sim const.$



Mean density within galactic SNRs plotted versus diameter of remnant

Comparison with observation

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For OVI line (a good ISM tracer around $10^{5.5}$K), this is the first theoretical work which derived n(OVI) for hot ISM ($9 \times 10^{-8}\,\mathrm{cm}^{-3}$

For soft X-ray intensity, the prediction is in agreement with observation in some bands.

Clouds velocity, etc.

Present knowledge of the Galactic ISM （Ferriere, 2001)

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Far beyond 3 phases...

Component	T (K)	n (cm^{-3})	$\Sigma_\odot$ ($M_\odot$ pc^{-2})
Molecular	$10-20$	10^2-10^6	~ 2.5
Cold atomic	$50-100$	$20-50$	~ 3.5
Warm atomic	$6000-10000$	$0.2-0.5$	~ 3.5
Warm ionized	~ 8000	$0.2-0.5$	~ 1.4
Hot ionized	$\sim 10^6$	~ 0.0065	

Descriptive parameters of the different components of the interstellar gas, $\Sigma_\odot$ include 70.4 % of hydrogen, 28.1 % of helium, and 1.5 % of heavier elements.

Reference

McKee, C. F., Ostriker, J. P. 1977, *ApJ*, 218, 148
Ferriere, K. M. 2001, *Reviews of Modern Physics*, 73, 1031
Cox, D. P. 2005, *ARAA*, 43, 337

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