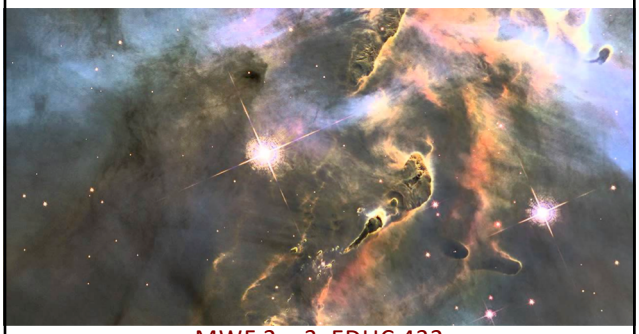
AST 300B
Radiation & Matter



MWF 2 – 3 EDUC 432

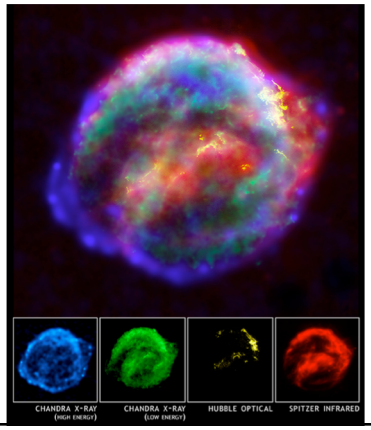
ISM is ***Dynamic***

- ISM is far from thermodynamic equilibrium
- Non-equilibrium state maintain by input of "free energy"
  - UV radiation from stars
  - kinetic energy injection from Supernovae
- ISM exists in "Phases"

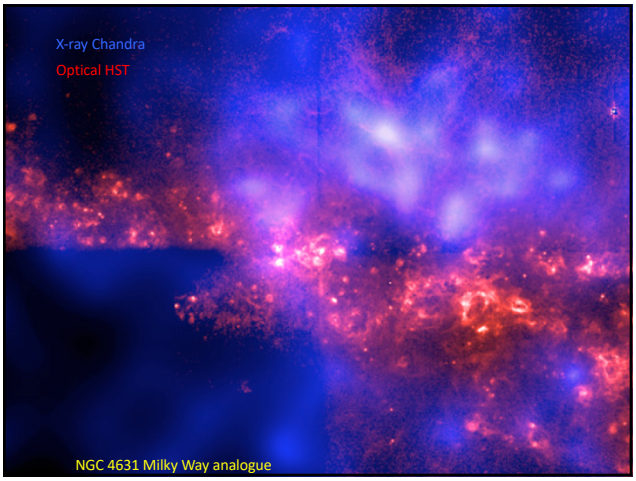
HIM: Hot Ionized Medium

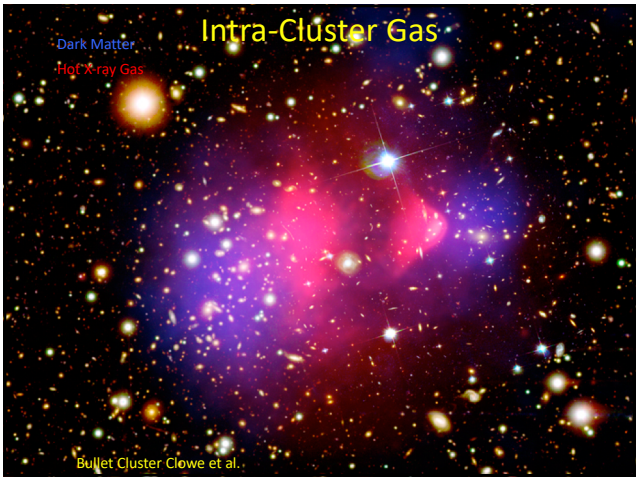
- $T > 10^{5.5}$ K $n_H \sim 0.004$ cm^{-3} $f_V \sim 0.5$?
- Shock heated & Collisionally ionized
- Cooling via:
  - Adiabatic expansion
  - X-ray emission
- Observed by:
  - UV and X-ray emission
  - Radio synchrotron

HIM: Hot Ionized Medium



Example : NGC 4631



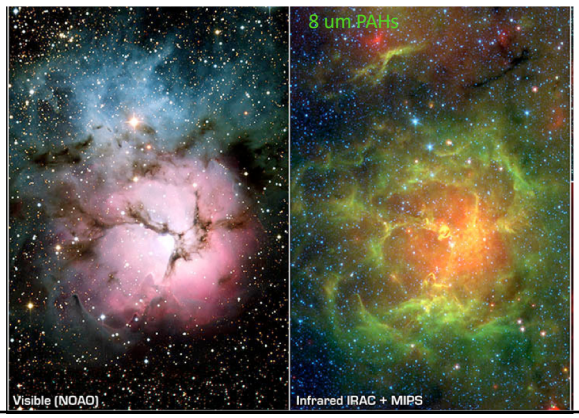


WIM : Warm Ionized Medium

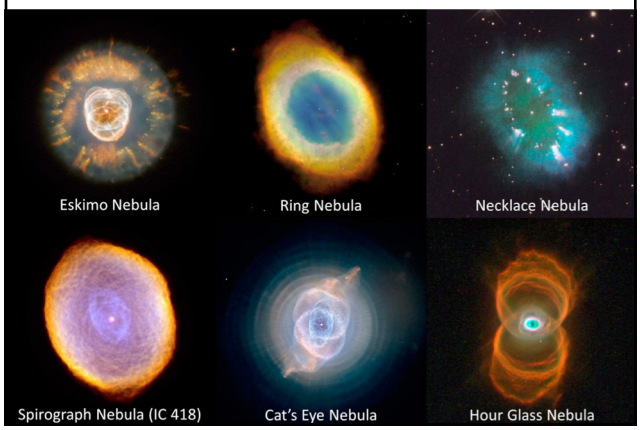
- $T > 10^4$ K $n_H \sim 0.3 - 10^4$ cm^{-3} $f_V \sim 0.1$
- Photoelectric heating (H,He) and photoionized
- Cooling via:
  - Optical line emission
  - Free-free emission
  - Fine structure line emission
- Observed by:
  - Optical line emission
  - Thermal radio continuum

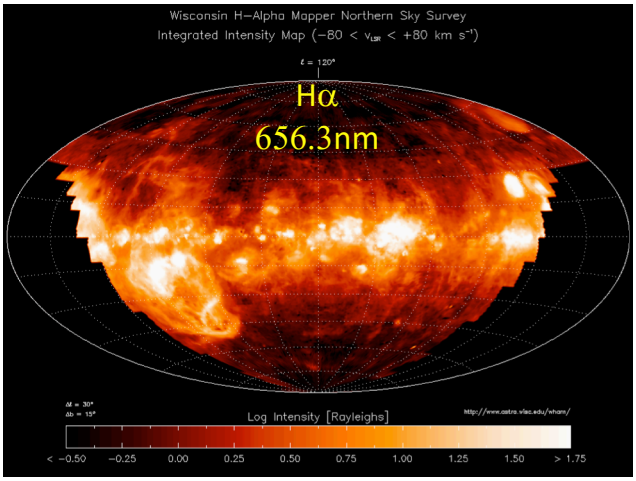
Warm Ionized Medium: HII Regions

Warm Ionized Medium: HII Regions



Warm Ionized Medium: PN





HI is 2 Phase Medium – WNM/CNM

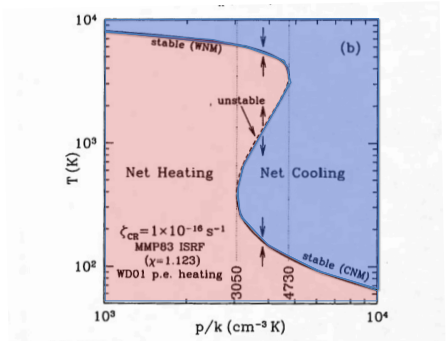


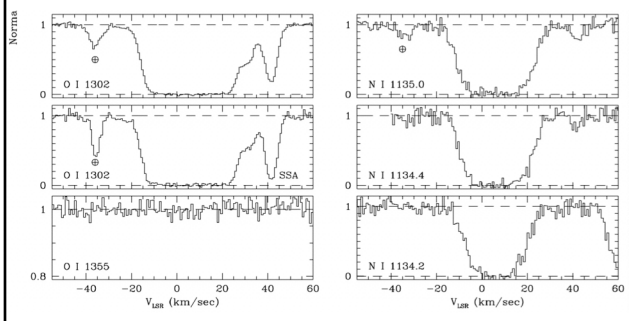
Figure 30.2 (a) Steady state temperature T as a function of density n_H, for gas heated by cosmic rays and photoelectric heating by dust grains. Two lines of constant $n_H T$ are shown. (b) Steady state temperature T as a function of thermal pressure p. For $3200 \lesssim p/k \lesssim 4400\,\mathrm{cm^{-3}\,K}$ there are three possible equilibria – a high-T WNM solution, a low-T CNM solution, and an intermediate temperature equilibrium that is thermally unstable.

Draine Physics of the ISM and IGM

WNM: Warm Neutral Medium

- T ~ 5000 K n_H ~ 0.6 cm^{-3} f_V ~ 0.4
- Photoelectric heating (dust) and ionized by starlight & cosmic rays
- Cooling via:
  - Optical line emission
  - Fine structure line emission
- Observed by:
  - HI 21 cm emission & absorption
  - Optical, UV absorption lines

WNM: Warm Neutral Medium

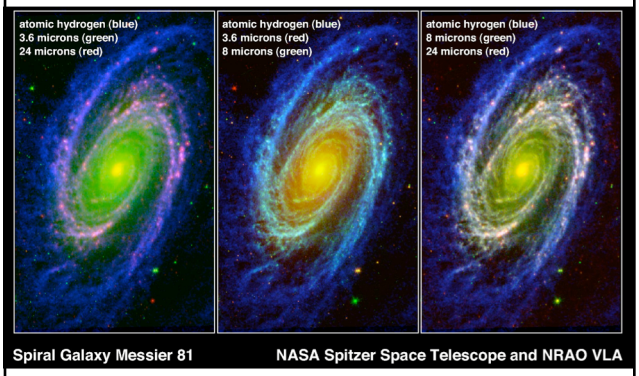


Howk et al. 1999 ApJ, 525, 253

CNM: Cold Neutral Medium – Cool HI

- T ~ 100 K n_H ~ 30 cm^{-3} f_V ~ 0.01
- Photoelectric heating (dust) and ionized by starlight & cosmic rays
- Cooling via:
  - Fine structure line emission
- Observed by:
  - HI 21 cm emission & absorption
  - Optical, UV absorption lines

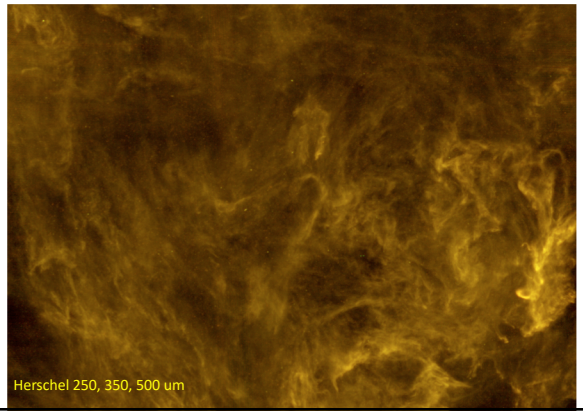
CNM: Cold Neutral Medium – Cool HI



CNM: Cold Neutral Medium – Diffuse H_2

- T ~ 50 K n_H ~ 100 cm^{-3} f_V ~ 0.001
- Photoelectric heating (dust) and ionized by starlight & cosmic rays
- Cooling via:
  - Fine structure line emission
- Observed by:
  - HI 21 cm emission & absorption
  - CO emission
  - Optical, UV absorption lines

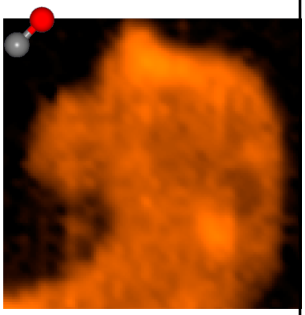
Polaris Flare (Diffuse Cloud Complex)



Carbon Monoxide Traces Molecular Clouds

Optical

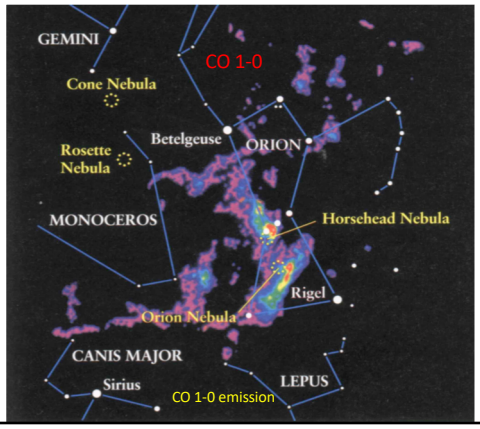
CO J=3-2 345 GHz



CNM: Cold Neutral Medium – Dense H_2

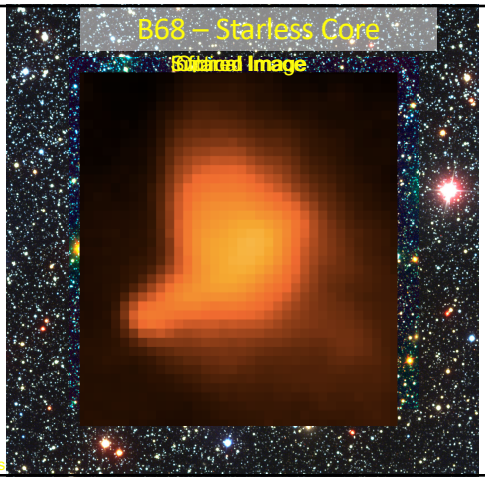
- T ~ 10-50 K n_H ~ 10^3 - 10^6 cm^{-3} f_V ~ 10^{-4}
- Photoelectric heating (dust) and ionized and heated by cosmic rays
- Cooling via:
  - CO line emission
  - CI fine structure line emission
- Observed by:
  - CO emission
  - Dust thermal infrared emission

Orion ~ 440 pc – Nearest High Mass SFR



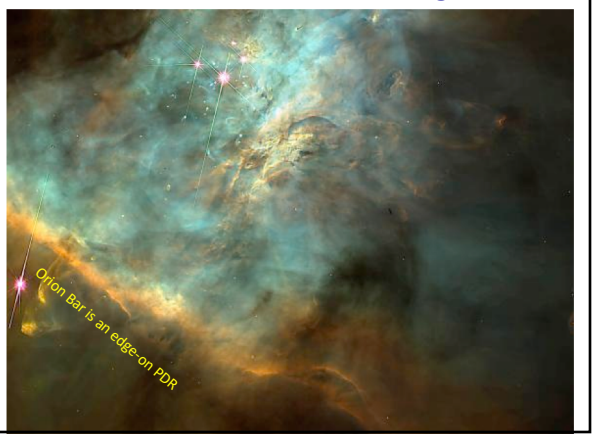
CNM: Cold Neutral Medium – Dense H_2

B68 – Starless Core

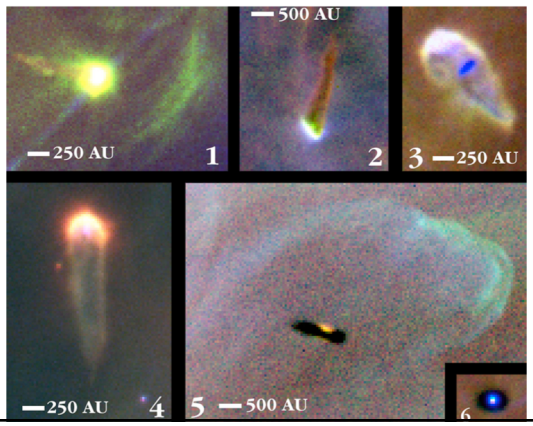


CNM meet WIM

PDR: PhotoDissociation Region



CNM meet WIM – Orion Proplyds (Disks)



Milky Way

Milky Way

- Total mass within 15 kpc 10^{11} M_{sun}
  - 5 x 10^{10} M_{sun} Stars
  - 5 x 10^{10} M_{sun} Dark Matter
  - 7 x 10^{9} M_{sun} ISM Gas
  - Hydrogen In form:
    - 60% H atoms
    - 20% H_2 molecules
    - 20% ionized

Draine Physics of the ISM and IGM

ISM Energy Densities

Table 1.5 Energy Densities in the Local ISM

Component	$u(\mathrm{eV\,cm^{-3}})$	Note
Cosmic microwave background ($T_{\rm CMB} = 2.725\,\mathrm{K}$)	0.265	*a*
Far-infrared radiation from dust	0.31	*b*
Starlight ($h\nu < 13.6\,\mathrm{eV}$)	0.54	*c*
Thermal kinetic energy $(3/2)nkT$	0.49	*d*
Turbulent kinetic energy $(1/2)\rho v^2$	0.22	*e*
Magnetic energy $B^2/8\pi$	0.89	*f*
Cosmic rays	1.39	*g*

a Fixsen & Mather (2002).
b Chapter 12.
c Chapter 12.
d For $nT = 3800\,\mathrm{cm^{-3}\,K}$ (see §17.7).
e For $n_{\rm H} = 30\,\mathrm{cm^{-3}}$, $v = 1\,\mathrm{km\,s^{-1}}$, or $\langle n_{\rm H}\rangle = 1\,\mathrm{cm^{-3}}$, $\langle v^2\rangle^{1/2} = 5.5\,\mathrm{km\,s^{-1}}$.
f For median $B_{\rm tot} \approx 6.0\,\mu\mathrm{G}$ (Heiles & Crutcher 2005).
g For cosmic ray spectrum X3 in Fig. 13.5.

Draine Physics of the ISM and IGM