Interstellar Medium --- Syllabus

Graduate Institute of Astronomy Fall 2011

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The course consists of two main parts: (1) the morphological and physical characteristics of various material components found in the interstellar space, from extremely cold molecular clouds, to diffuse atomic hydrogen nebulae, to hot ionized gases around luminous stars; (2) our current understanding of star-forming processes, as well as interactions between stars and their environments, will be reviewed. We will discuss what has been observed, and the theories to interpret these results.

* *Textbook*: ***Physics of the Interstellar and Intergalactic Medium***, by Bruce T. Draine (2011, Princeton) 新竹華通書坊 03-572-0317

* ***Subjects:*** gaseous nebulae and dust clouds; photoionization; Strömgren spheres; stellar winds; circumstellar disks and star formation; galactic magnetic fields: Zeeman effects; polarization

Primary reference: *Interstellar Processes* by D.J. Hollenbach & H. A. Thronson, Jr. (Reidel) --- A close look at our Milky Way Galaxy, including its morphology, stellar content, stellar population, kinematics and dynamics.

* ***Subjects:*** 21-cm line observations; giant molecular clouds; stellar population; initial mass function; galactic kinematics and dynamics; the Galactic center

Primary reference: <u>*Galactic Astronomy*</u> by D. Mihalas and J. Binney (Freeman)

There will be midterm and final exams. Expect homework sets. In addition to "standard" textbook problems, there will be questions for which I do not know the answers myself. For these you will need to read research papers in the literature. The following references are found useful:

- ✓ *Astrophysics II* by Bowers and Deeming
- ✓ *Physics of the Interstellar Medium* by Dyson & Williams
- ✓ *The Milky Way as a Galaxy* by Gilmore, King, & van der Kruit
- ✓ *Astrophysics of Gaseous Nebulae and Active Galactic Nuclei* by Osterbrock
- ✓ *The Galactic Interstellar Medium* by Pfenniger & Bartholdi
- ✓ *Physics of the Galaxy and Interstellar Matter* by Scheffler & Elsässer
- ✓ *Physical Processes in the Interstellar Medium* by Lyman Spitzer

The following are some useful background references:

- ✓ *Stars, Nebulae, and the Interstellar Medium* by Kitchin
- ✓ *Atoms, Stars, and Nebulae* by Aller
- ✓ *The New Cosmos* by Unsöld & Baschek

Book by Bruce Draine

- An overall good book, to read or to reference
- A total of 42 chapters; first 6 on basic physics; later chapters on astrophysical applications
- With extensive (and up-to-date) appendices
- In cgs and standard astronomical units
- Wavelength in Ångstroms in vacuo, i.e., shifted by 1Å , e.g., [OIII] doublet at 4960, 5008, rather than at 4959 and 5007 in air.
- Author's web http://www.princeton.edu/~draine/book/ has an updated errata document, problem sets, etc.

Interstellar Medium (ISM)

- 1811 William Herschel "*holes in the starry sky*"
- 1904 J. Hartmann "*stationary*" calcium lines in the spectroscopic binary δ Orionis → of IS origin
- 1919 Barnard catalog of dark nebulae
- Photography → emission and reflection nebulae; dark clouds
- 1930 Struve: absorption ↑ as distance ↑

→beginning of ISM as a new branch of astronomy
➔results usually tentative

Star Shadows Remote Observatory

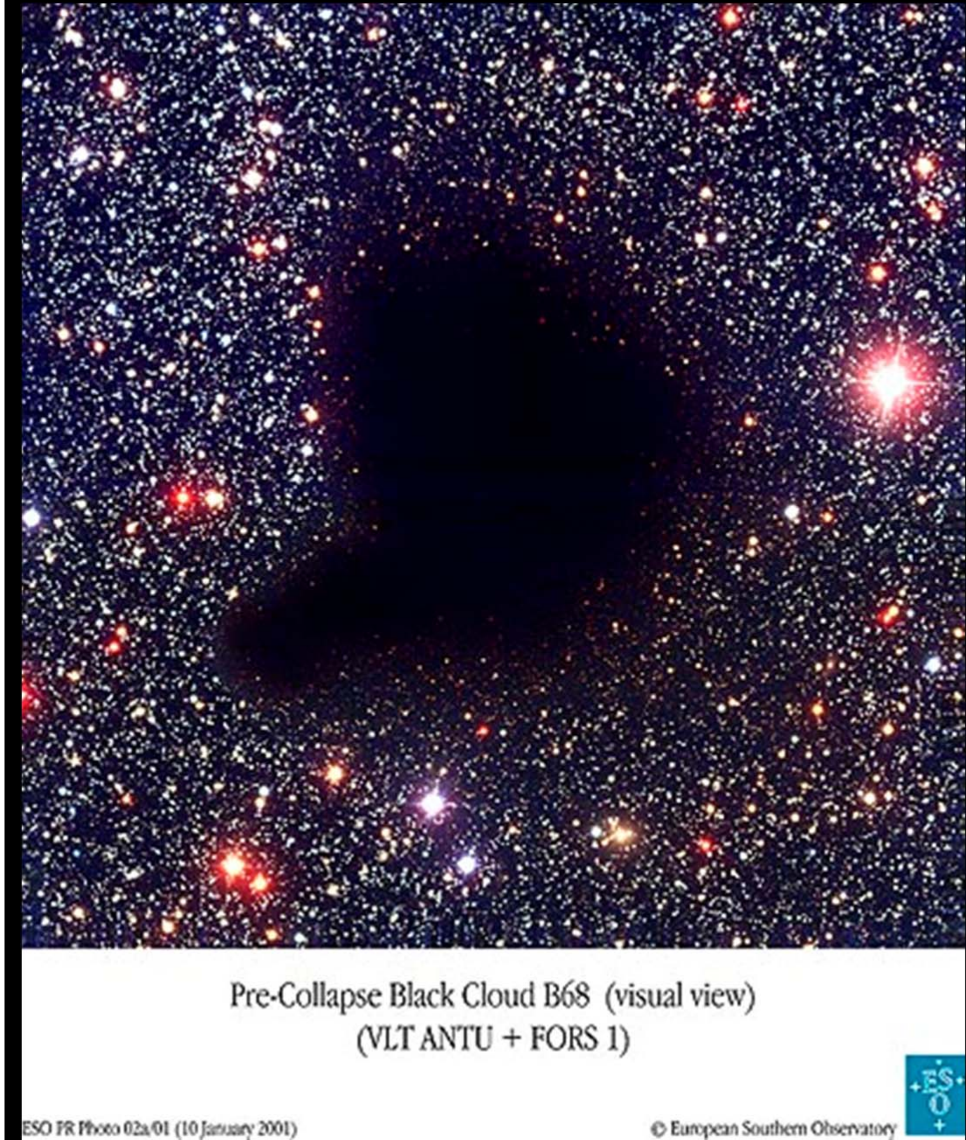
Horsehead Nebula

Hubble Heritage

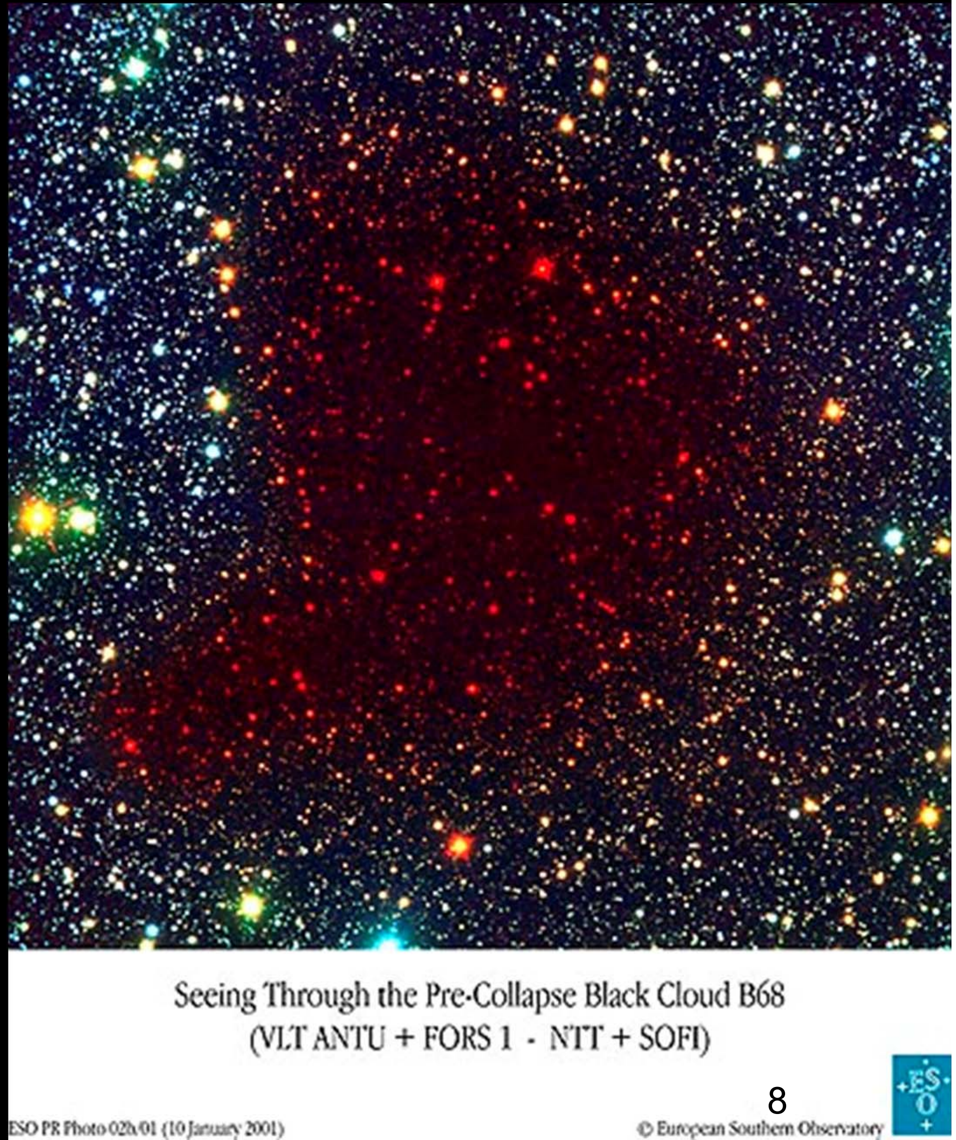
NASA, ESA, and The Hubble Heritage Team (STScI/AURA) • Hubble Space Telescope WFPC2 • STScI-PRC01-12

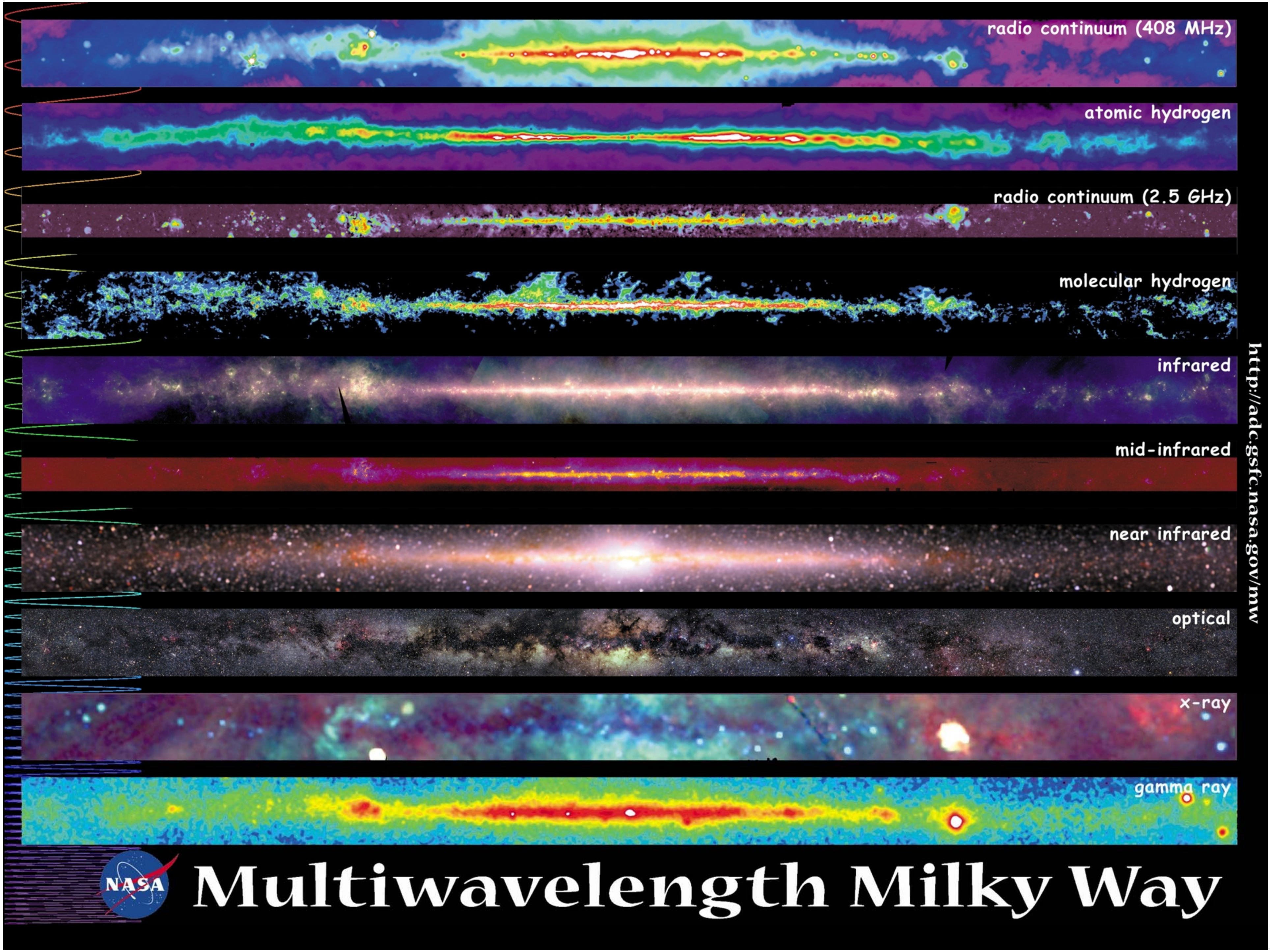
© Anglo-Australian Observatory Photograph by David Malin

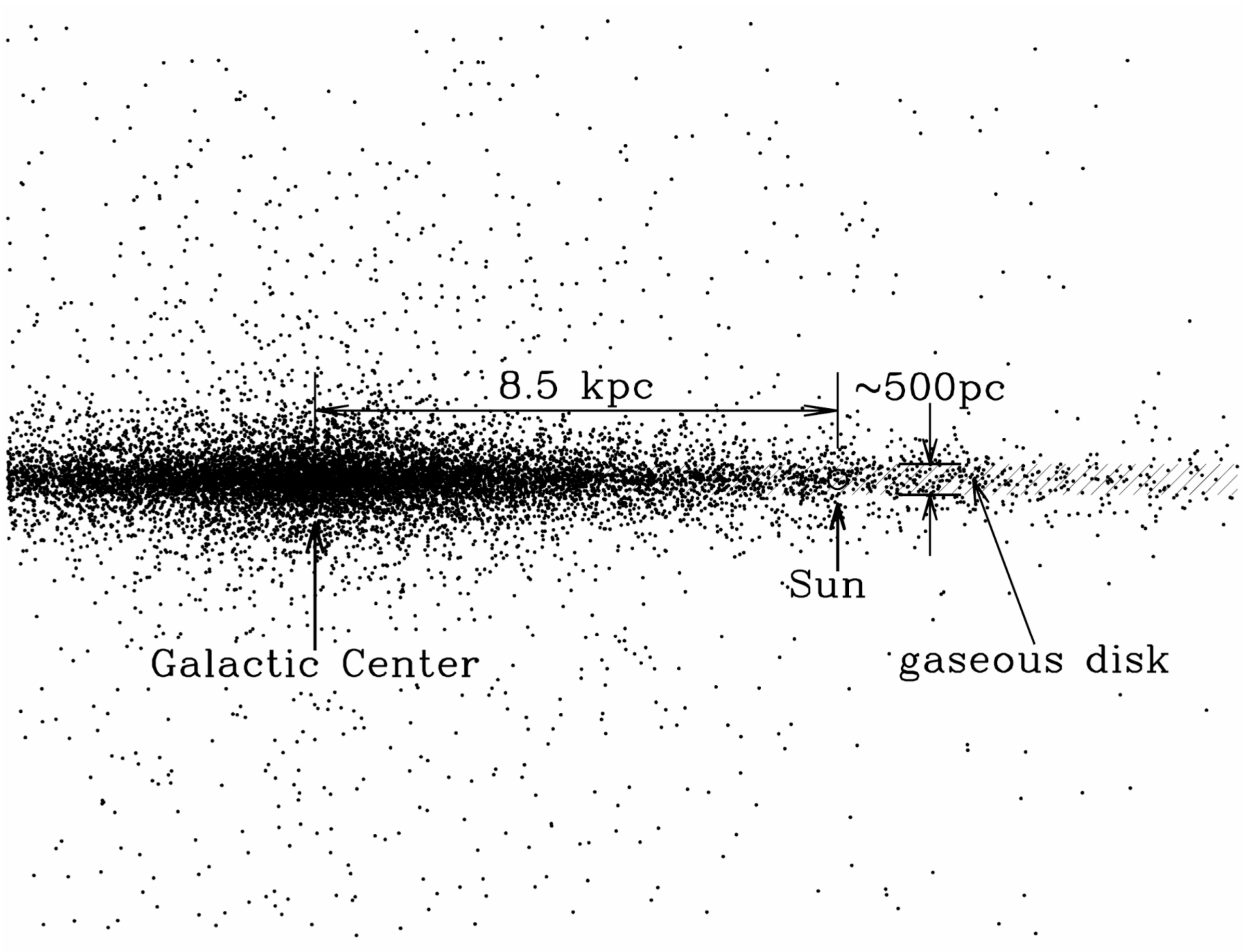
可見光影像



加上紅外線影像




radio continuum (408 MHz)
atomic hydrogen
radio continuum (2.5 GHz)
molecular hydrogen
infrared
mid-infrared
near infrared
optical
x-ray
gamma ray
http://adc.gsfc.nasa.gov/mw
NASA
Multiwavelength Milky Way


8.5 kpc
~500pc
Sun
Galactic Center
gaseous disk

Interstellar Medium (ISM)

- ISM is very sparse ---

  [star-star distance] / [stellar diameter]
  ~ 1 pc/10^{11} cm ~ 3 x 10^{7} :1
  in terms of volume (space) ~ 10^{22}

  ➔ Stars truly tiny compared with the space between them

- Mass: [gas + dust] / total ~ 10%
  but density very low

Interstellar Medium (ISM)

- Gas, dust, radiation, magnetic fields, cosmic rays (i.e., charged particles)
- ISM mass = 15% of the total visible matter of the Milky Way galaxy
- ISM: 99% mass in gas, 1% in dust
- Of the gas, 90%, H; 10% He
- Hydrogen: mainly H I (atomic), H II (ionized), and H_2 (molecular)
- Studies of ISM ---
  - Beginning of evolution of baryonic matter "recombination"
  - Stars form out of ISM
  - Important ingredient of a galaxy

Material Constituents of the ISM

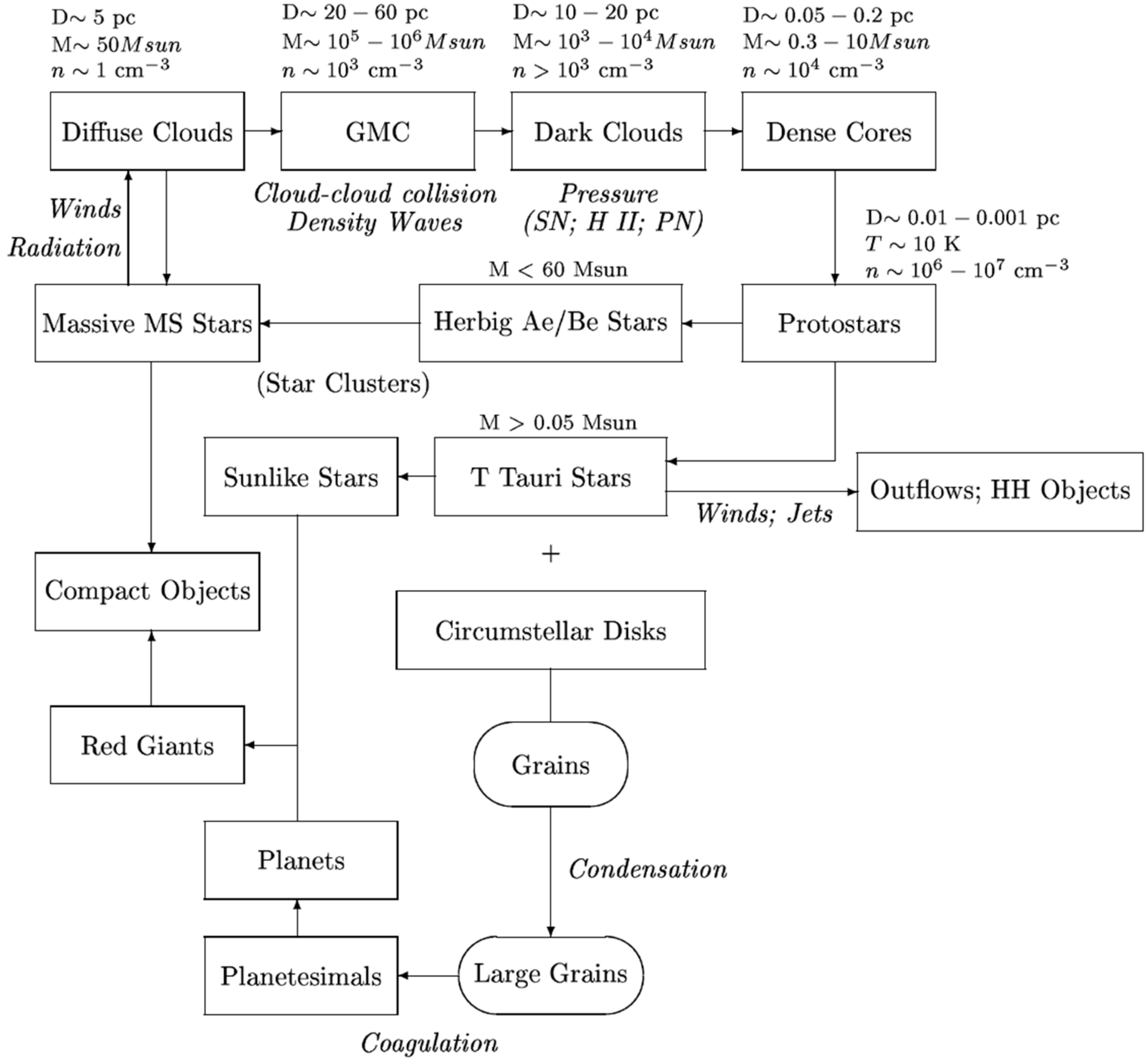
Name	T (K)	n (cm^{-3})	Properties
Hot, intercloud and coronal gas	10^6	10^{-4}	
Warm intercloud gas	10^4	0.1	
Diffuse cloud (H I)	10^2	0.1	Mostly H I; $n_e/n_0=10^{-4}$
H II regions	10^4	>10	
Dark Molecular Clouds	10	> 10^3	Mostly H_2 mol. and dust
Supernova Remnants	10^4~10^7	>1	
Planetary Nebulae			

Energy Density in the Local ISM

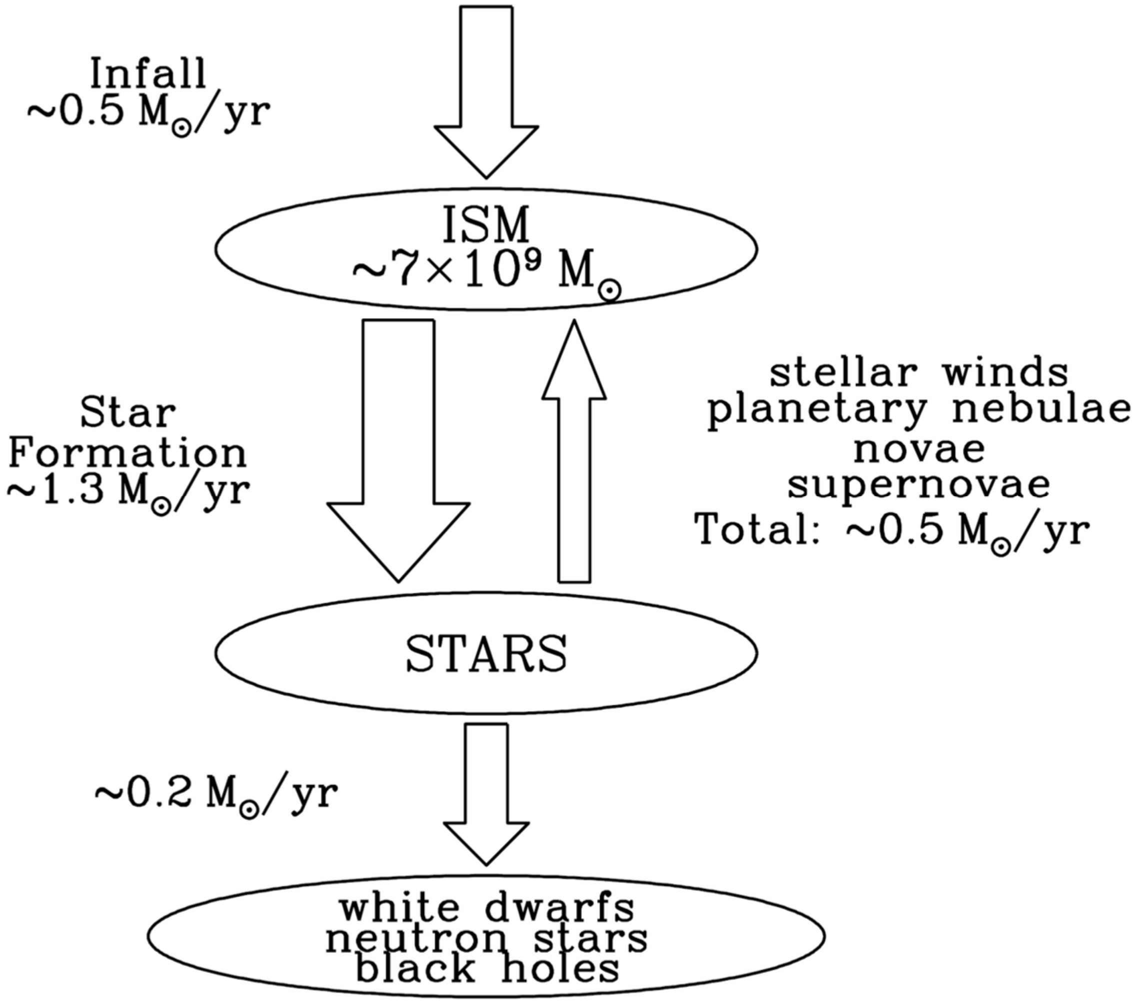
Component	u (eV/cm^{-3})	Properties
Cosmic microwave background	0.265	
FIR radiation from dust	0.31	
Starlight	0.54	
Thermal kinetic energy	0.49	
Turbulent kinetic energy	0.22	
Magnetic field	0.89	
Cosmic rays	1.39	

There seems to be equi-partition between these energies.
Why? Read Draine's book, page 10

In this course, we will discuss mainly the diffuse clouds, H II regions and dark clouds, whereas the warm and hot intercloud gas will be briefly reviewed.



Galactic Ecology



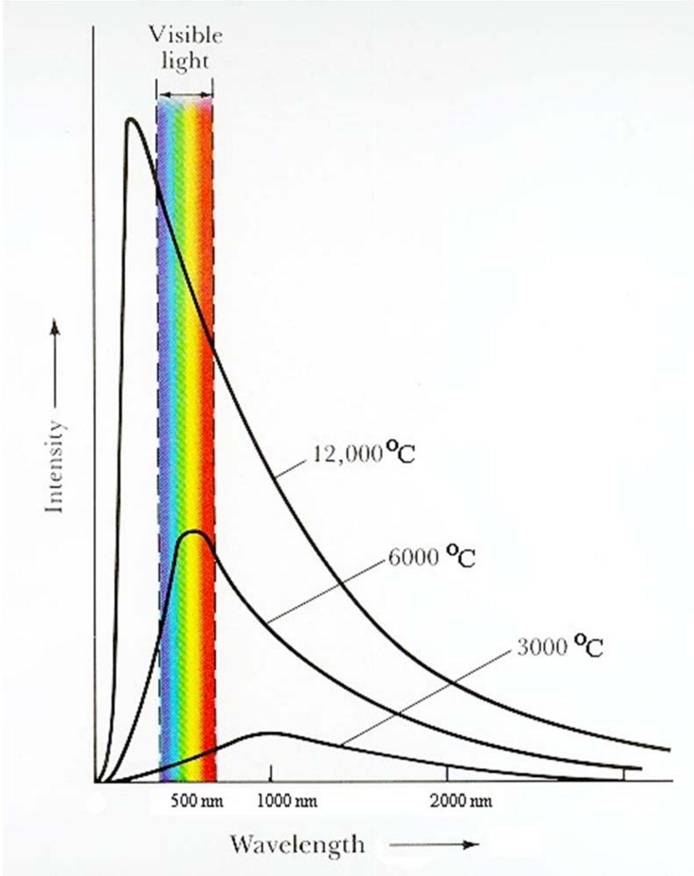
Flow of baryons in the Milky Way

Observations of ISM

- Difficult: typical temperature of gas either too **low** or too **high**, so observable only outside of visible wavelengths

$$\lambda_{\max} T \sim 2900\ [\mu\mathrm{m}\ \cdot \mathrm{K}]$$

Not possible until the second half of the 20th century (instruments, from space, etc.)



Observations of ISM/Stars/Galaxies

- Electromagnetic (EM) radiation (from gamma rays to radio waves) + Cosmic rays + neutrinos + gravitational waves
- EM radiation (by photometry, spectroscopy, or polarization)
  - line (absorption, emission) in a narrow range of frequency
    e.g., $h\nu + H(^1S) \rightarrow H(^2P)$ ($h\nu$=10.2 ev or λ=121.6 nm
  - continuum (absorption, emission) over a wide range of frequency
    e.g., $h\nu + H(^1S) \rightarrow H^+ + e^-$ ($h\nu \geqq 13.6$ ev or $\lambda \leqq 91.2$ nm

- **Line** emission --- atom/ion/molecule already excited (by collisions or absorption of a photon, stellar or else)
- **Line** absorption --- atom initially in a lower state and absorbs a background photon
- Transition between 2 quantum levels (electronic, rotational, vibrational, stretching…)
- Collision $u \rightarrow l$ or $l \rightarrow u$ (upwards or downwards)
  spontaneous emission $u \rightarrow l$ (only downwards)
  absorption $l \rightarrow u$ (only upwards)
- Diagnosis: line strength, central wavelength, shape (profile), …

- **Continuum**

  Absorption --- bound-free (ionization)

  free-free

  Emission --- (thermal) bremsstrahlung

  (non-thermal) synchrotron
- Matter ←→ energy ➔ what we observe
- Thermodynamics (ISM cooling, heating, chemical reactions …)

Frisch et al. 2011, ARAA

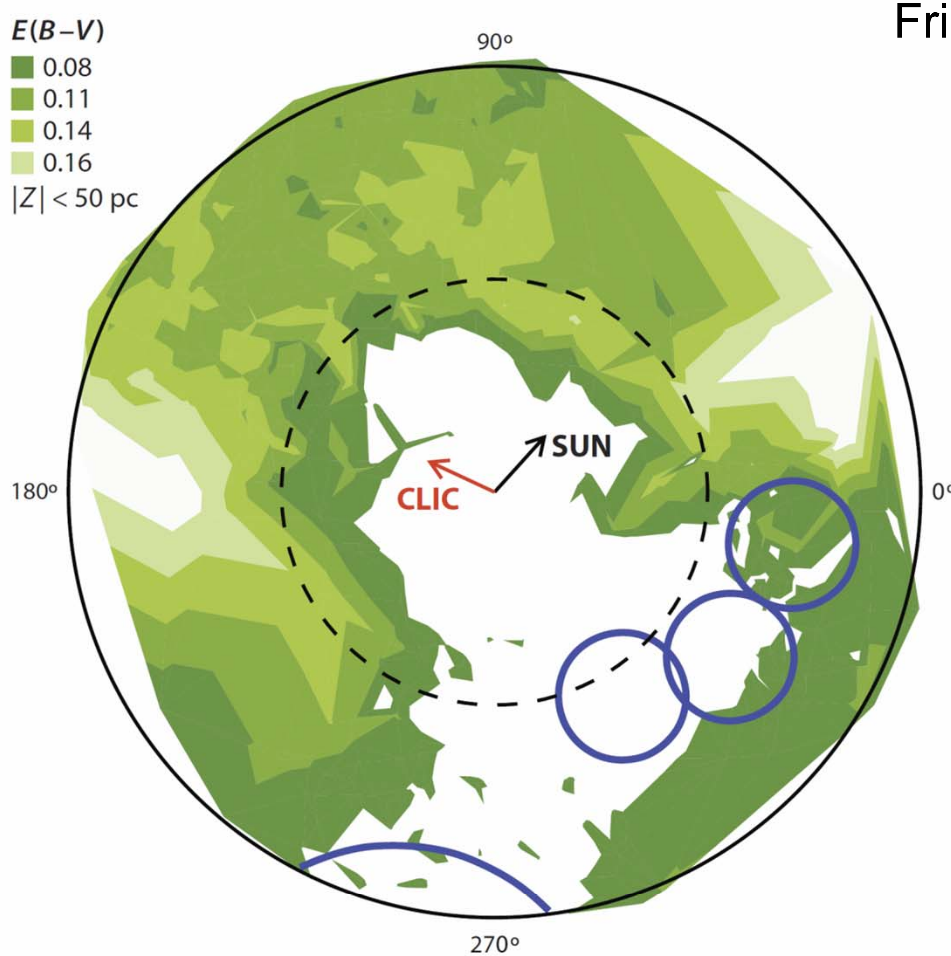


Figure 1

The Local Bubble, as defined by interstellar dust, is shown based on color excess $E(B-V)$ data in the Hipparcos catalog (Perryman 1997). Projected extinctions are shown for stars within 50 pc of the Galactic plane. The local standard of rest (LSR) vector motions of the cluster of local interstellar clouds (CLIC; *red arrow*) and the Sun (*black arrow*) are nearly perpendicular. The best-fitting local interstellar magnetic field (Section 7) overlaps the solar motion in this projection. $E(B-V)$ contour levels of 0.08, 0.11, 0.14, and 0.16 mag correspond to log $N(\text{H I} + H_2)$ column densities of 20.65, 20.82, 20.90, and 20.96, respectively, for $N(\text{H I} + H_2)/E(B-V) = 5.8 \times 10^{21}$ atoms cm^{-2} mag (Bohlin, Savage & Drake 1978). The locations of the three subgroups of the Sco-Cen Association (*large blue circles*) and Gum Nebula (*arc* centered near $\ell \sim 260°$) are given.