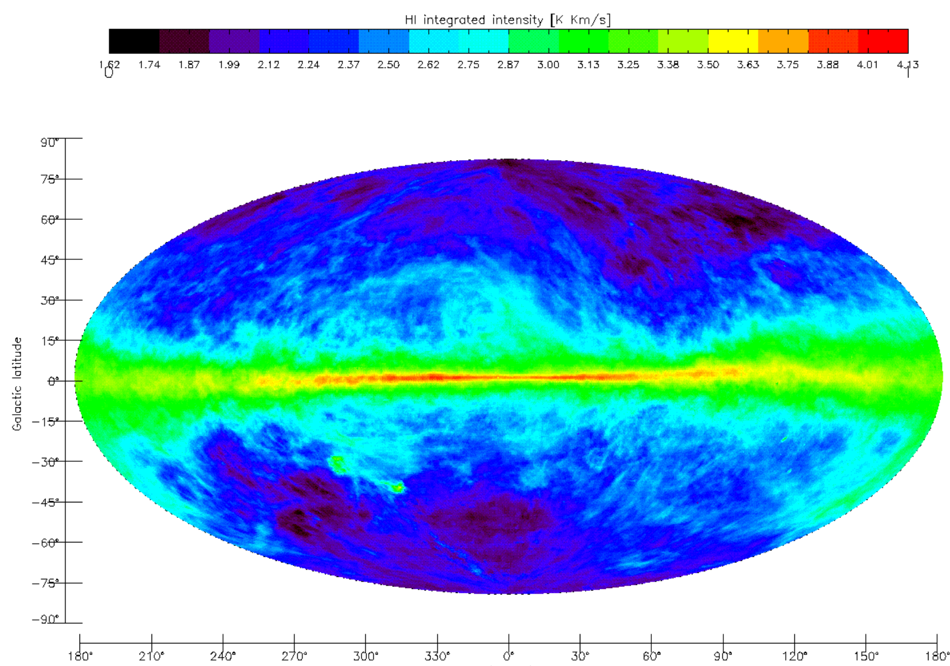
Warm Neutral Medium,HI 21 cm surveys and Cold Neutral Medium

Distribution of HI in the Galaxy

- HI is distributed essentially across the mid-plane of the Galaxy. It is spread across the mid-plane with scale height that increases as we move away from the center of the disk in the plane of the galaxy. This is called flaring. As we move away from the center the volume density and surface density falls off rapidly. There is a tight correlation between surface density, mid-plane volume density, and scale height for R¡35 kpc. HI disk is well defined to a distance of R=35kpc. At larger radial distances the Milky Way is surrounded by a faint, patchy, and highly turbulent HI distribution that has been traced out to R=60 kpc (Kalberla Dedes 2008).
- HI gas has two phases that exist together, Warm neutral medium (WNM) and Cold neutral medium (CNM). Both the phase exist in pressure equilibrium with stable phase temperatures T< 300K (CNM), and T> 5000K (WNM).
- All sky surveys from various sources map the distribution of HI region across the Galaxy. HI regions are spread as far as three times as their stellar companions. The scale height of HI column increases exponentially with distance from galactic center.This spread is called Flaring.



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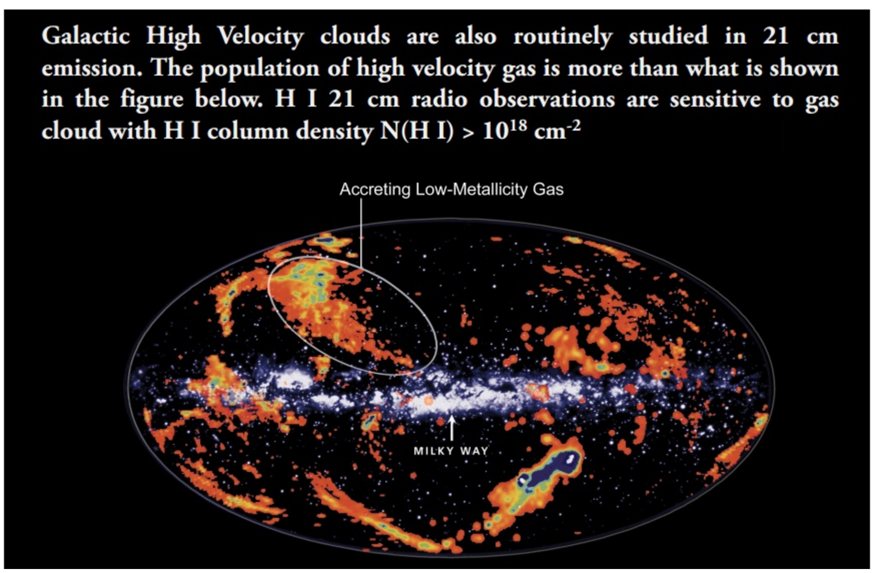
Map for integrated intensity for neutral hydrogen in galactic coordinates obtained from LAB survey (Kalberla et al. 2005)

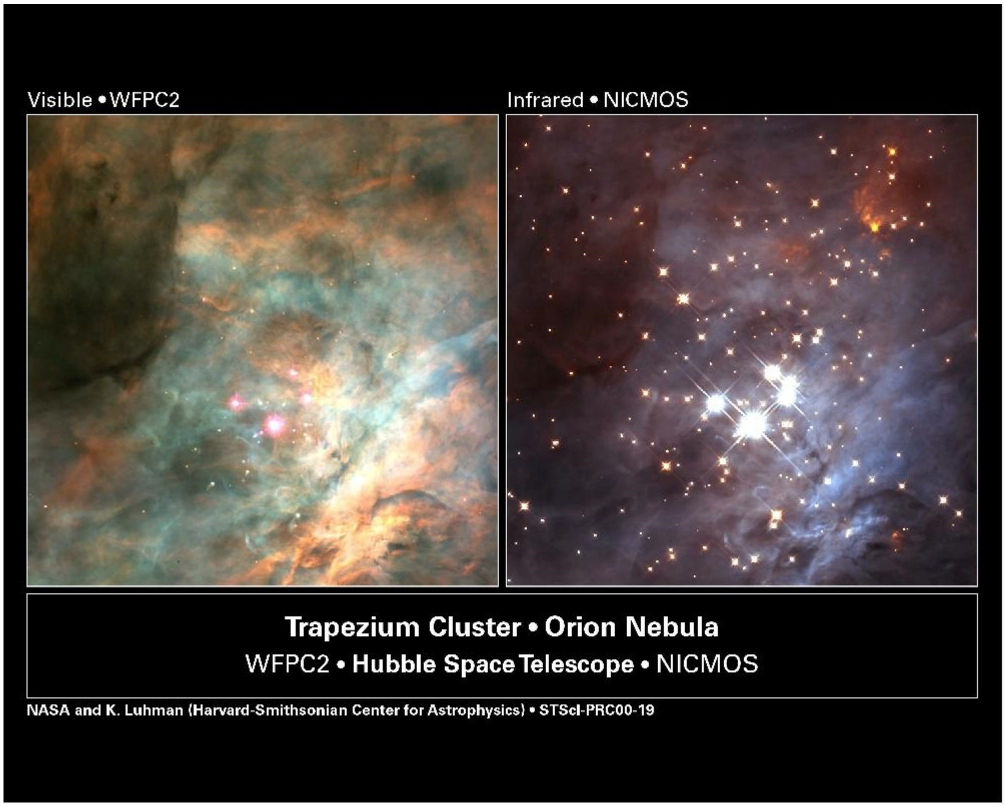
- High Velocity Clouds: These are gas clouds in extended galactic halo. When looking at the distribution of HI clouds for various rotational speeds, one doesn't expect to see anything for velocity range >70 kmps towards $l = 180^o$. Instead gas nearby b= $+70^o$ is approaching at >70 kmps. The HVCs of HI rain down on the disk even faster, at over 100 kmps. There are various theories on the origin of these clouds.The fountain theory says that some of it may be disk material which is thrown up by supernova or winds from massive stars and now it is falling back. Others, like the gas in the Magenallic Stream is being ripped off through tidal interaction with Milky way. Another theory called Gas Infall theory suggest that the formation of Milky Way is still in process and these gas clouds are the fuels to form new stars. Intergalactic replenishment theory says that the Milky Way and Andromeda galaxies may be embedded in a massive sea of hot intergalactic gas (blue). Out of this gas, cold clumps may condense and get captured by the galaxiesforming new high-velocity clouds that eventually fall in. This model is still uncertain.

- Mapping of HI regions is a strong function of column density of neutral hydrogen in the region. For a column density less than 10^8 cm^{-3} HI region is transparent. This means there maybe clouds with $N_{HI} < 10^8 cm^{-3)}$. UV surveys shows that there may be as much as 80 percent of HI region in the halo of the Galaxy.

[H] 

Cold Neutral Medium

- Molecular clouds are the densest and coldest phase of ISM. Molecular clouds are comprised of $H_2, CO, OH, NH_3, HCN, H_2O$,aromatic hydrocarbons and many other organic molecules. Star formation occurs in molecular clouds.



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Hierarchical Sub-structure in a molecular cloud

Terminology for Cloud Complexes and Their Components

Categories	Size (pc)	n_H (cm^{-3})	Mass ($M_\odot$)	Linewidth ($km\,s^{-1}$)	A_V (mag)	Examples
GMC Complex	$25-200$	$50-300$	$10^5-10^{6.8}$	$4-17$	$3-10$	M17, W3, W51
Dark Cloud Complex	$4-25$	10^2-10^3	$10^3-10^{4.5}$	$1.5-5$	$4-12$	Taurus, Sco-Oph
GMC	$2-20$	10^3-10^4	$10^3-10^{5.3}$	$2-9$	$9-25$	Orion A, Orion B
Dark Cloud	$0.3-6$	10^2-10^4	$5-500$	$0.4-2$	$3-15$	B5, B227
Star-forming Clump	$0.2-2$	10^4-10^5	$10-10^3$	$0.5-3$	$4-90$	OMC-1, 2, 3, 4
Core	$0.02-0.4$	10^4-10^6	$0.3-10^2$	$0.3-2$	$30-200$	B335, L1535

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Substructure of molecular clouds

- Abundance of molecules in ISM can be inferred from the spectrum of the cloud.

  Astronomical spectra comes from three types of transitions:

  i). Rotational Transition: Atoms within molecule undergoes rotation about the center of mass which emits in long wavelength ranging from radio for heavy polyatomic molecules, and microwave (mm) for lighter molecules.

  ii). Vibrational transition: Vibrational transitions are also quantized within a molecule. The vibrational level of common small molecules such as CO, CS, and HCN are separated by energies corresponding to emission at a few microns.

iii). Electronic Transition: Emissions due to electronic transition corresponds similar wavelengths to the allowed transitions of neutral atoms: the visible and ultraviolet.

- The symmetric H_2 has no dipole moment, so its rotational transitions are 137^2 times slower. The least transition of H_2 corresponds to emission at 20 microns, so cold H_2 hardly radiates at all; only shocked gas with T>1000 K gives strong emission. The next most abundant molecule in the dense gas is carbon monoxide, with roughly one CO molecule per 10^4 of H_2. Thus CO is used as a proxy for detection of H_2.
- CO lowest rotational transitions are at excitation energy E/k=5.5K, which is within the temperature of molecular cloud.
- H_2 abundance in ISM (i.e., molecular gas in the ISM) is estimated by converting the CO abundance into an H_2 abundance.