The Interstellar Medium

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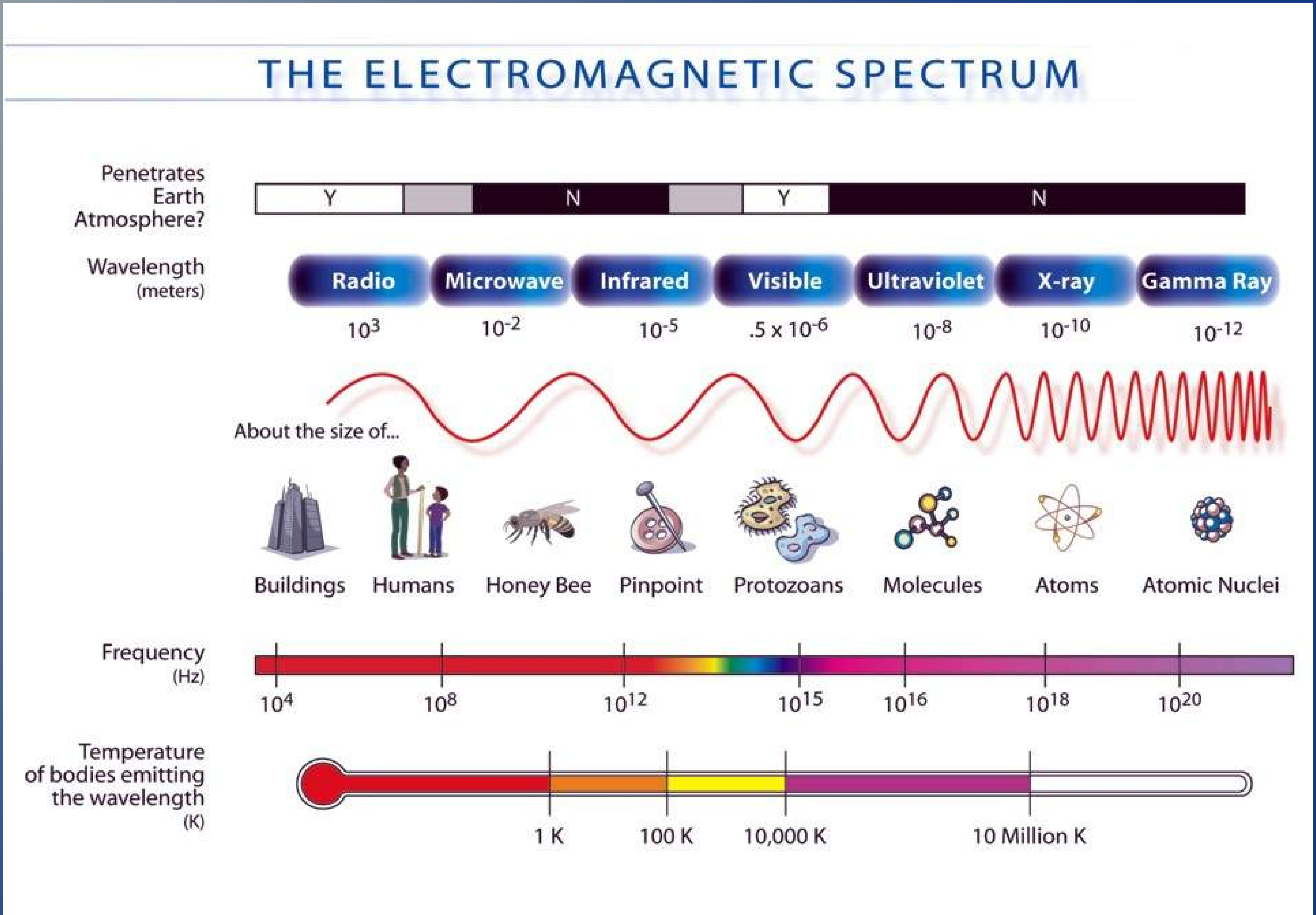
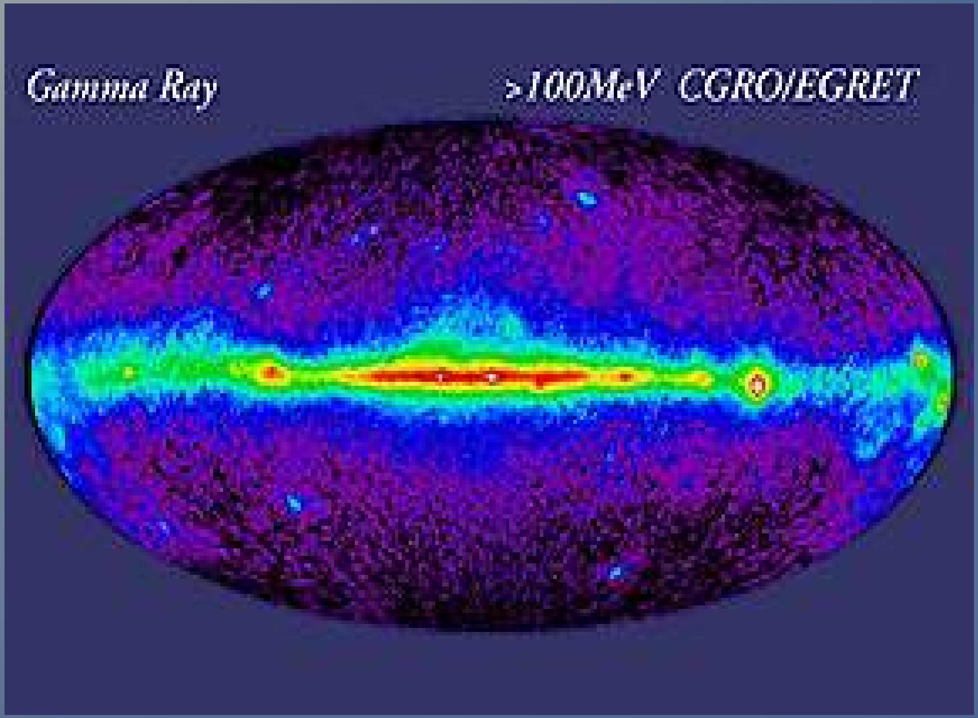
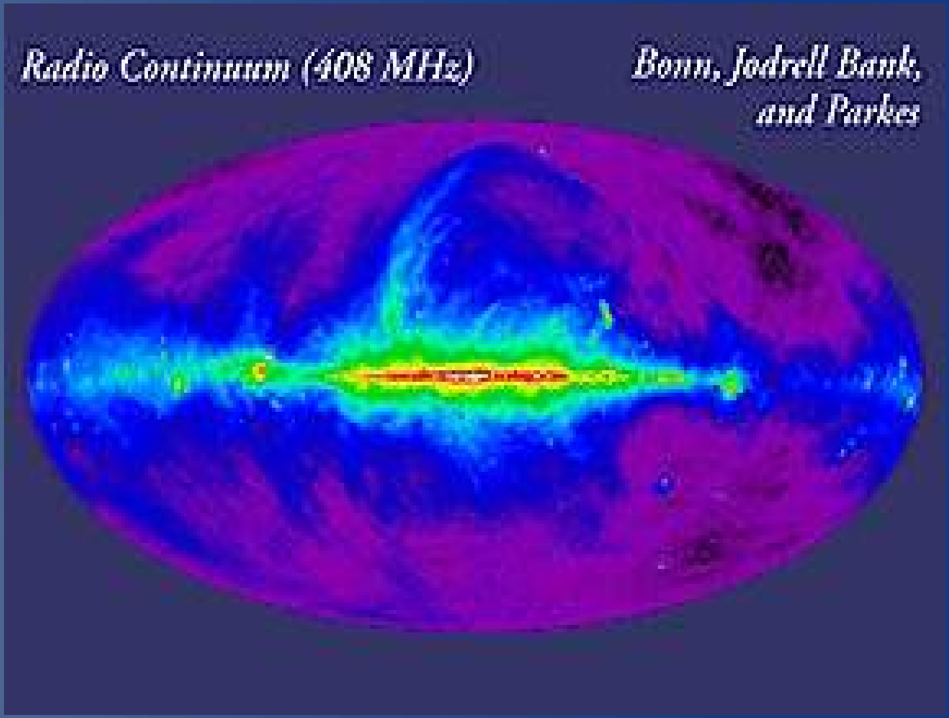
What is ISM?

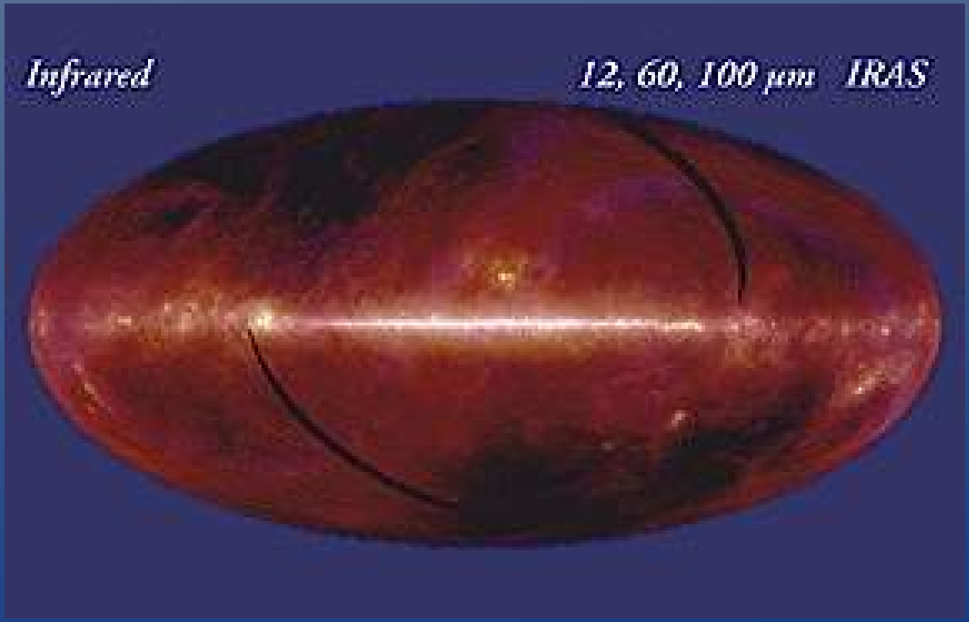
- Medium between stars – similar to our atmosphere – elements like H, O, N, S...; molecules like CO, CS, NH_3, H_2O,.....; dust....
- Also objects like supernova remnants, planetary nebula, star forming regions, reflection nebulae....are ISM.
- Too faint for eyes to detect emission from ISM.
- Telescopes operating at wavebands ranging from gamma-ray to radio can detect emission from ISM.
- Multiwavelength all sky surveys of the Milky Way and other galaxies help us understand the composition, distribution, morphology and physical conditions in these amazing systems.

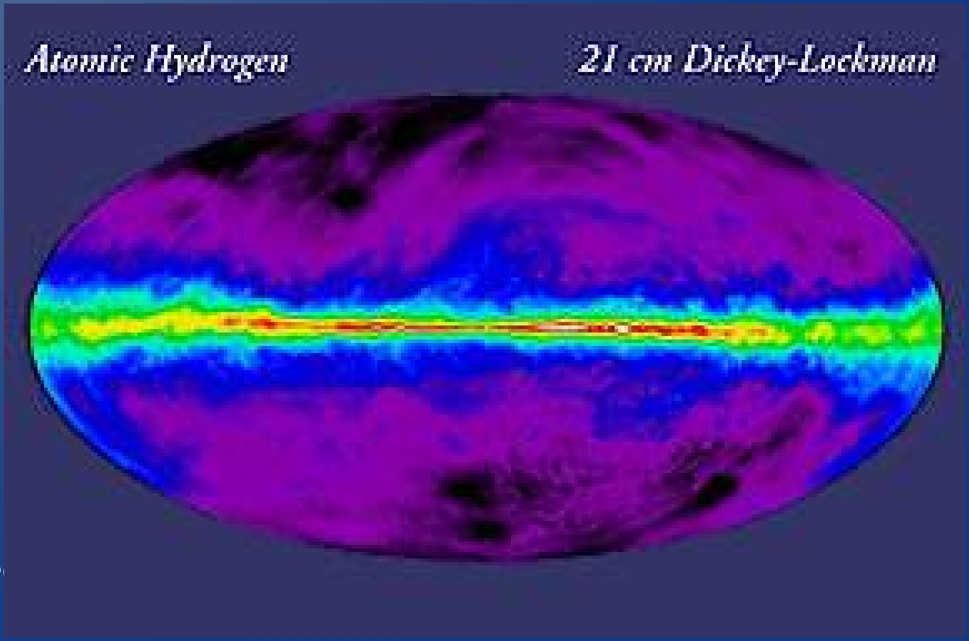

THE ELECTROMAGNETIC SPECTRUM
Penetrates Earth Atmosphere?
Y
N
Y
N
Wavelength (meters)
Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma Ray
10^3
10^-2
10^-5
.5 x 10^-6
10^-8
10^-10
10^-12
About the size of...
Buildings
Humans
Honey Bee
Pinpoint
Protozoans
Molecules
Atoms
Atomic Nuclei
Frequency (Hz)
10^4
10^8
10^12
10^15
10^16
10^18
10^20
Temperature of bodies emitting the wavelength (K)
1 K
100 K
10,000 K
10 Million K

Multiwavelength Milky Way









Diagnostics

Gamma rays:

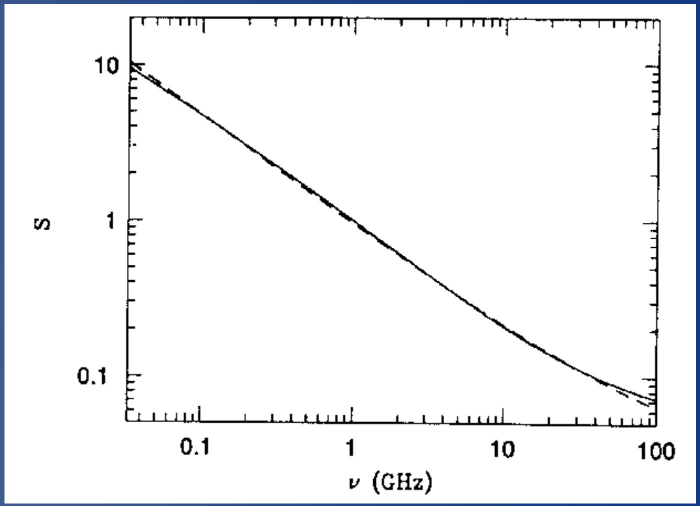
Photons > 100 MeV – collisions of cosmic rays with nuclei in IS clouds + compact sources such pulsars; other sources are AGN, GRB...

Mid and Far infrared emission:

Emission from hot dust heated by star forming regions in the galaxy.

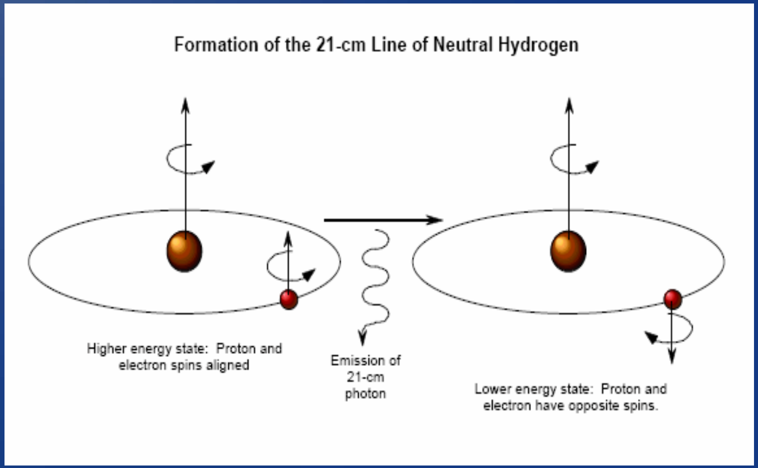
408 MHz radio continuum:

Synchrotron emission: relativistic particles spiral in magnetic field giving rise to emission over wide frequency range

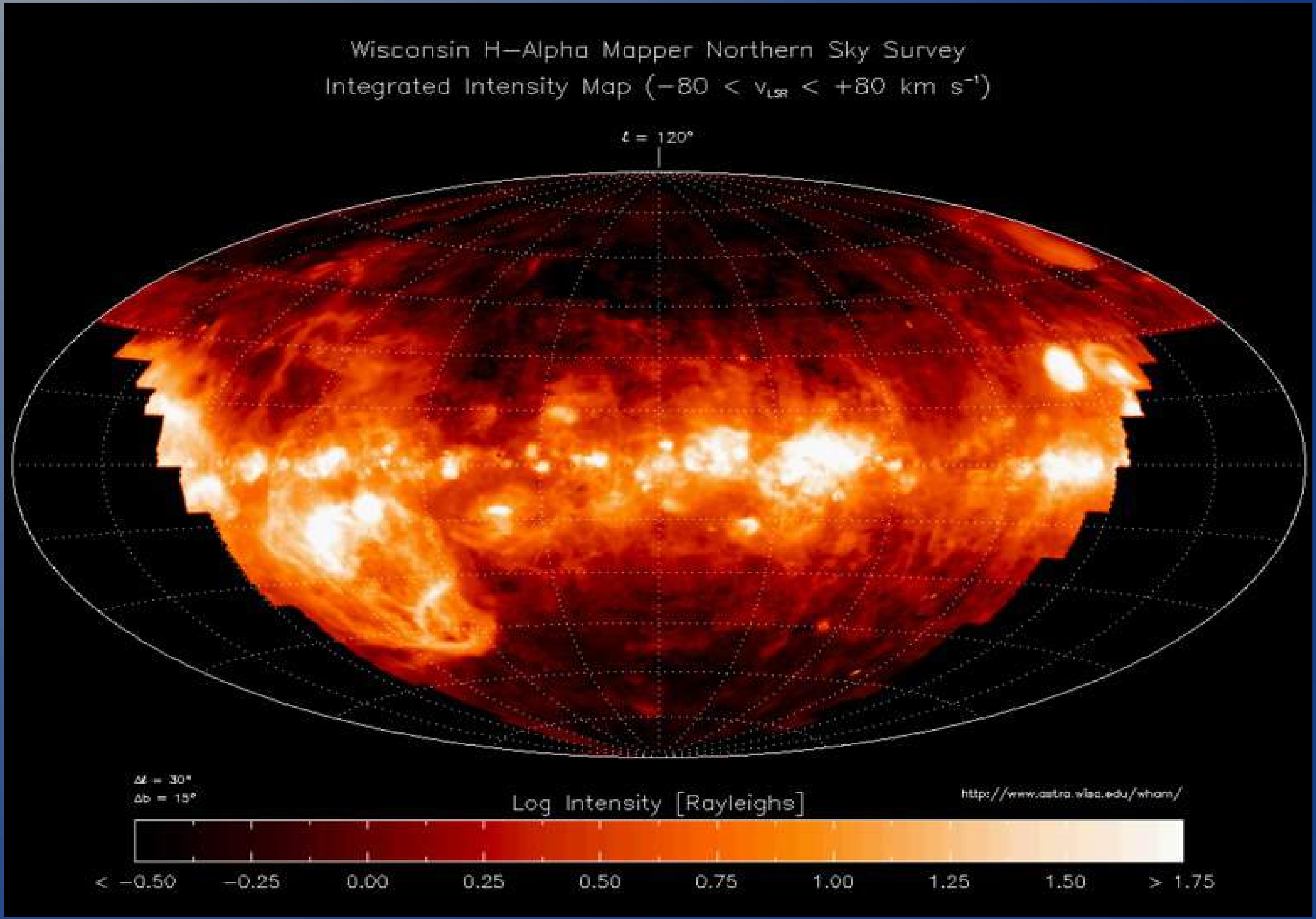


21cm narrow band emission:

Long-lived hyperfine structure bound-bound transition in atomic hydrogen.



Distribution of ionized gas



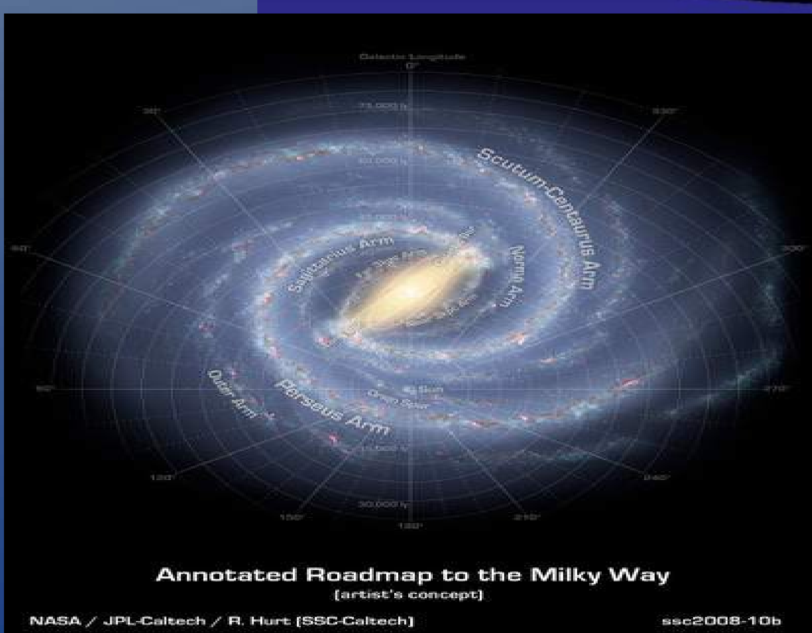
Milky Way in the near infrared

Disk and Bulge

Disk galaxies

Spiral arms not seen

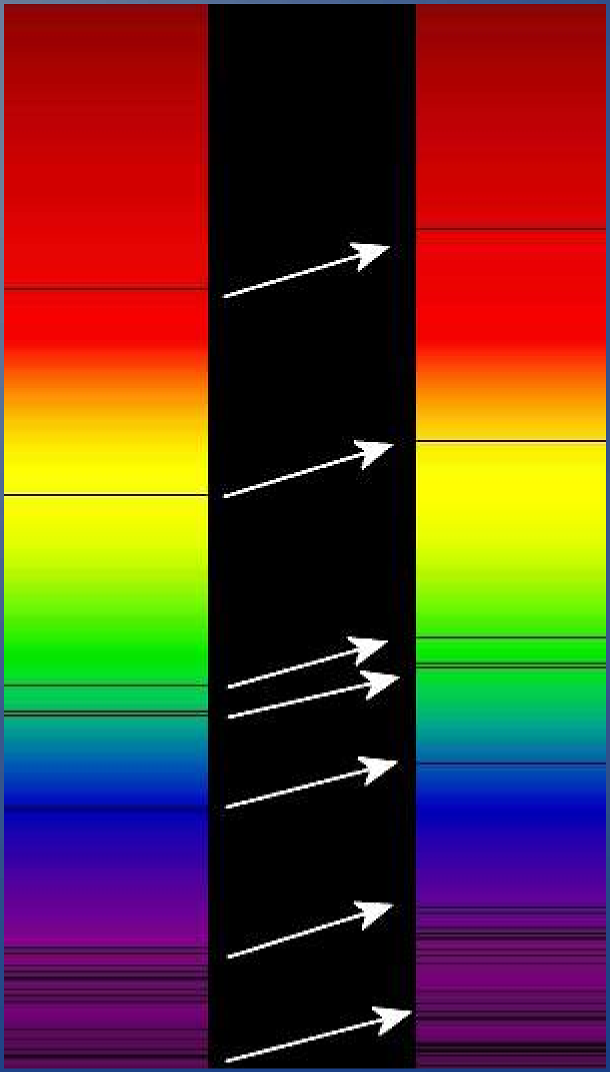
NIR – stars

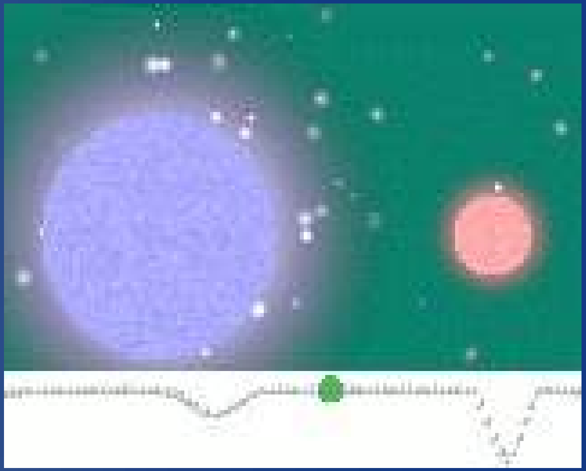


Artist's impression of the top view of our galaxy

Discovery of ISM

- 1904 – Johannes Hartmann
- Stationary CaII lines (3934 Angstroms) in the absorption spectrum of a spectroscopic binary stellar system, Delta Orionis
- Rest of the lines Doppler shift with orbital motion.
- Change in freq = vel / c * rest freq





Discovery of dust:

- Dust cloud in the Galaxy – light from background stars is obscured giving rise to 'holes in the sky' effect.
- Barnard 68 →
- Observed in 18th , 19th century

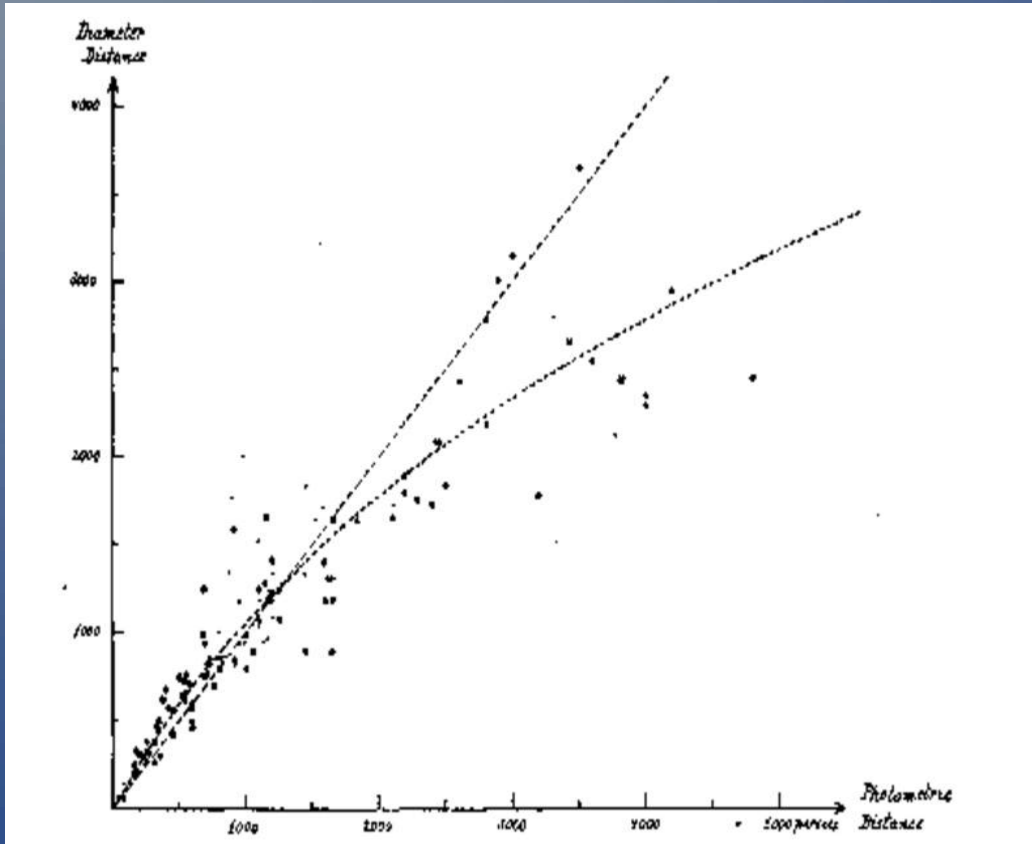
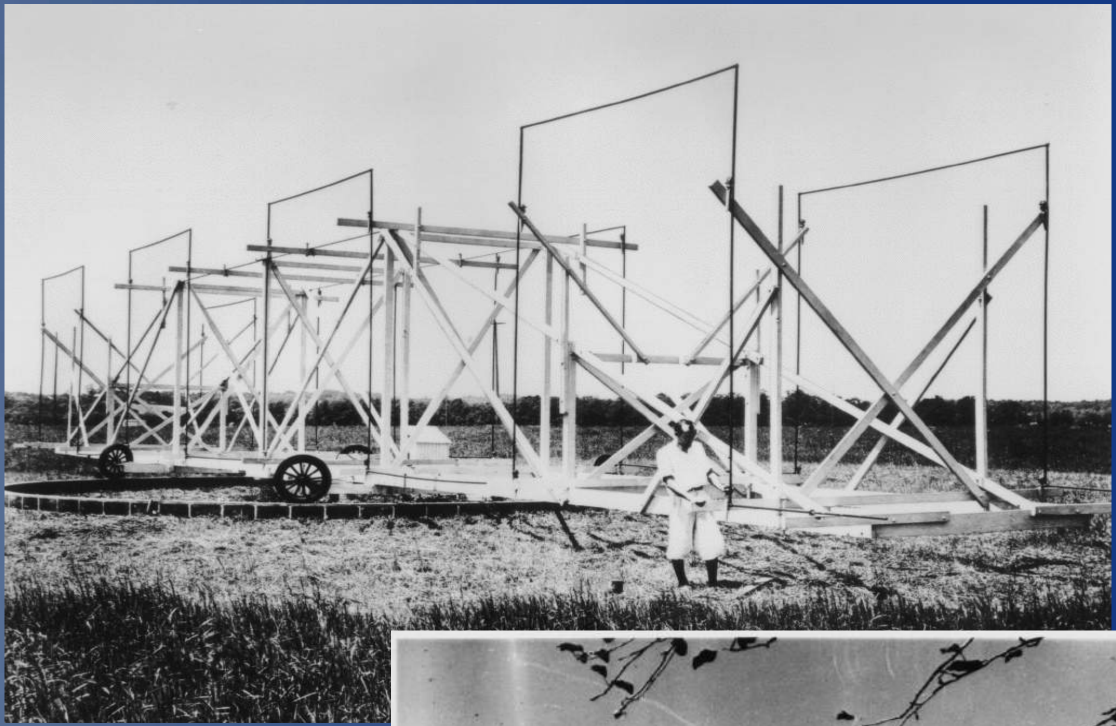


FIG. 1.—Comparison of the distances of 100 open star clusters determined from apparent magnitudes and spectral types (abscissae) with those determined from angular diameters (ordinates). The large dots

- 1930 – Trumpler gave definitive explanation from his study of distance to star clusters
- Angular diameter distance versus apparent magnitude distance – different → modification of radiation by intervening medium

Discovery of Extraterrestrial Radio waves

- 1932 – Karl Jansky detects extraterrestrial radio signal at 20.5 Mhz -> the periodicity of the signal was 23h56m instead of 24h.
- 1930s,1940s – Grote Reber builds first parabolic radio telescope 31.4ft diameter and maps radio sky at 160 MHz



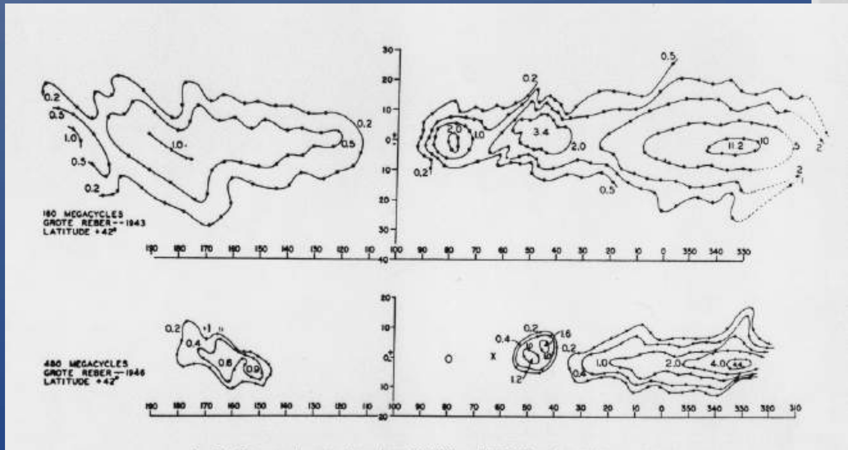
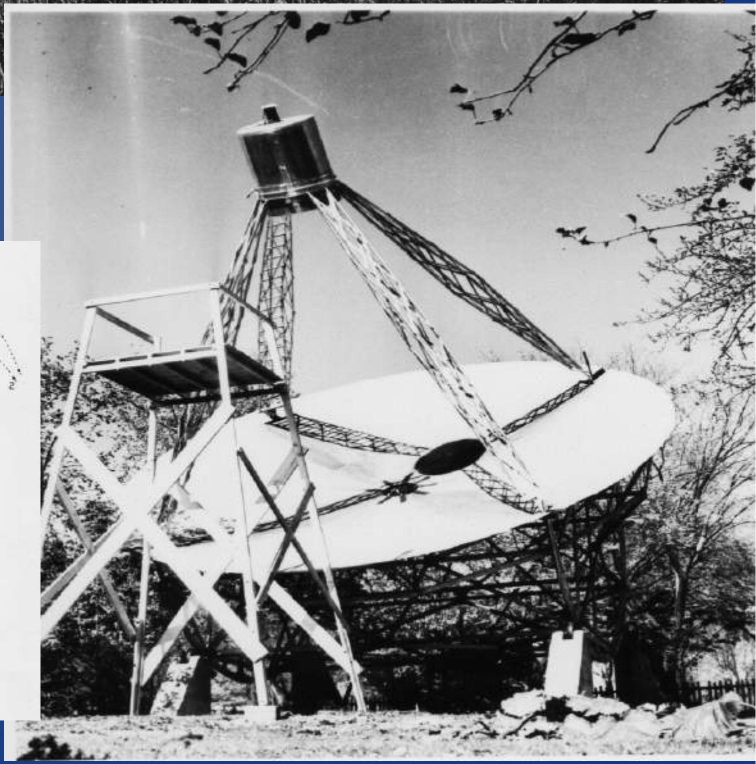
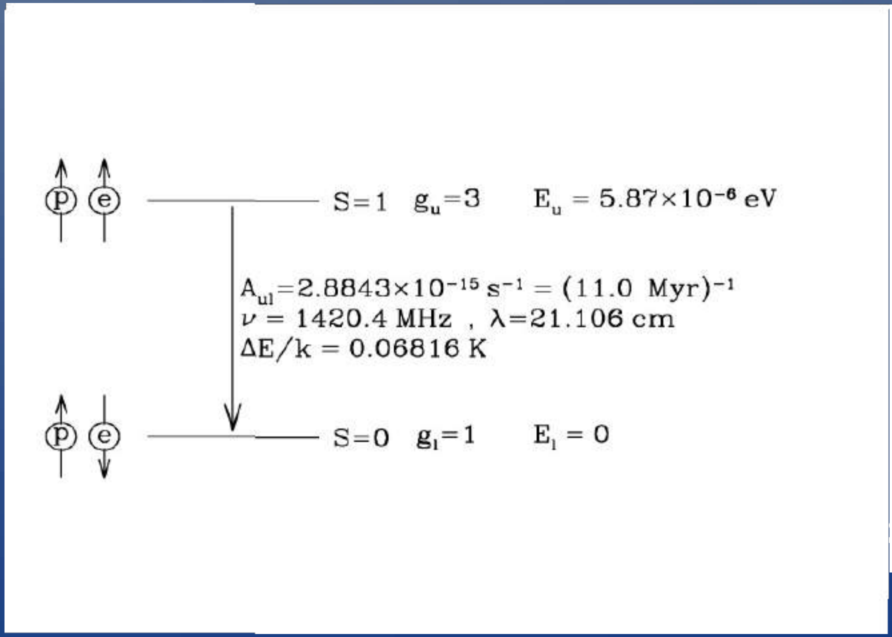


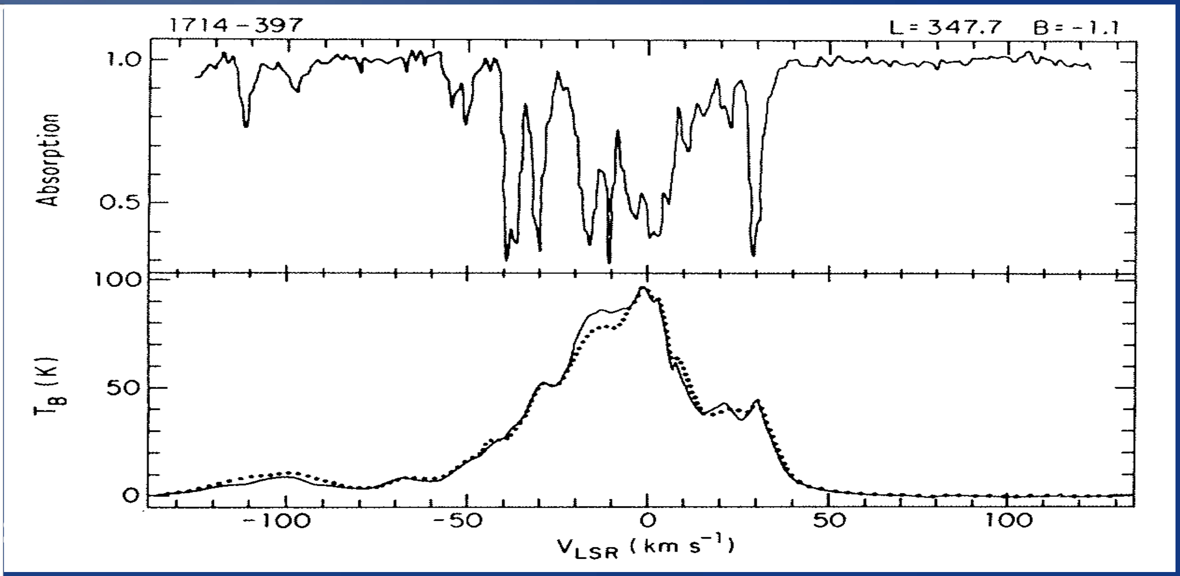
Fig. 7—Contours of constant intensity at 160 MHz and 480 MHz, taken at Wheaton, Illinois.



Discovery of spectral line of Hydrogen atom at 21cm from ISM

- 1945 – Hendrik van der Hulst predicts that the 21 cm hyperfine transition in the H atom with rest frequency:1420.405751 Mhz should be detectable from ISM inspite of very low transition probability – spin flip transition
- 1951 – Ewen & Purcell, Muller & Oort detect the 21cm line of HI from the Galaxy.



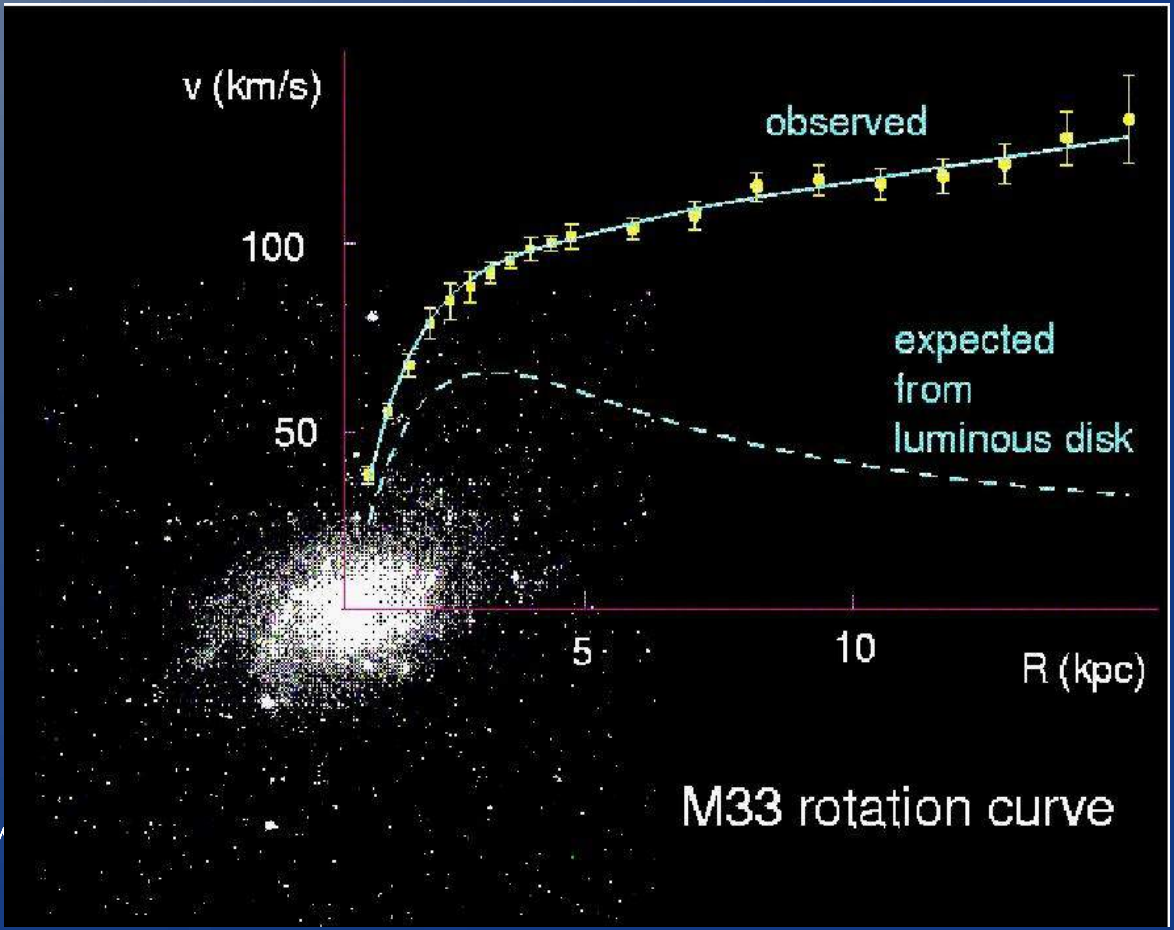


Rotation curve of galaxy

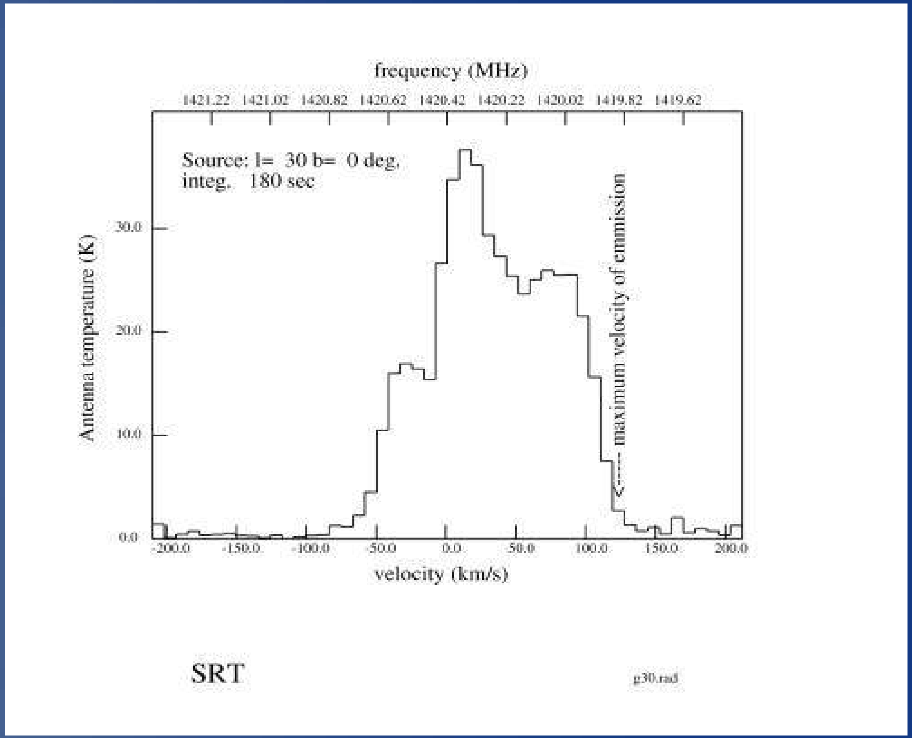
- Stars and HI 21cm line used to find this.
- Jan Oort – 1930s first found evidence of dark matter

•1960s,1970s – Vera Rubin and group find that stellar velocities are not Keplerian beyond solar circle. Finds the rotation curves of several spiral galaxies using the 21cm HI line which flatten at large R. All this gave strong evidence for dark matter....

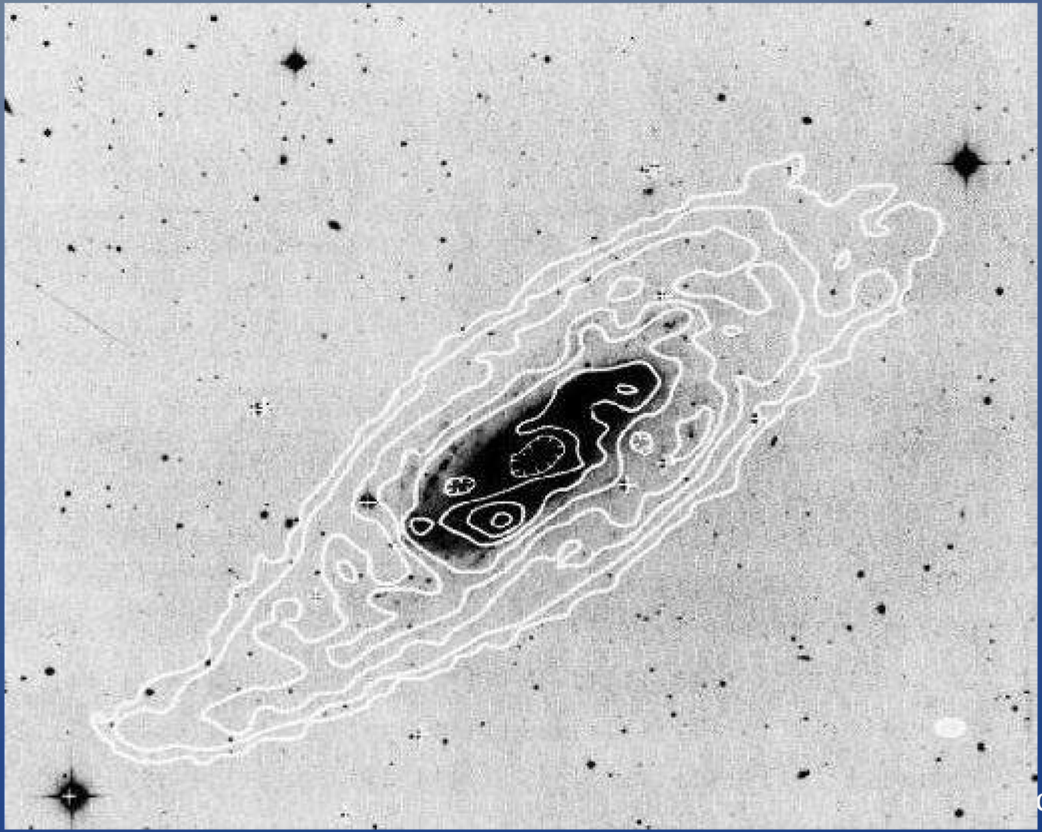
V^2=GM/r



http://www.hep.shef.ac.uk/research/dm/images/rotationCurve.jpg http://www.haystack.mit.edu/edu/undergrad/srt/SRT%20Projects/sample_grotSpec.jpg



NGC 3198 – stellar disk; HI disk; rotation curve; dark matter halo



http://bustard.phys.nd.edu/Phys171/lectures/darkhalo_lg.jpg

Composition of ISM

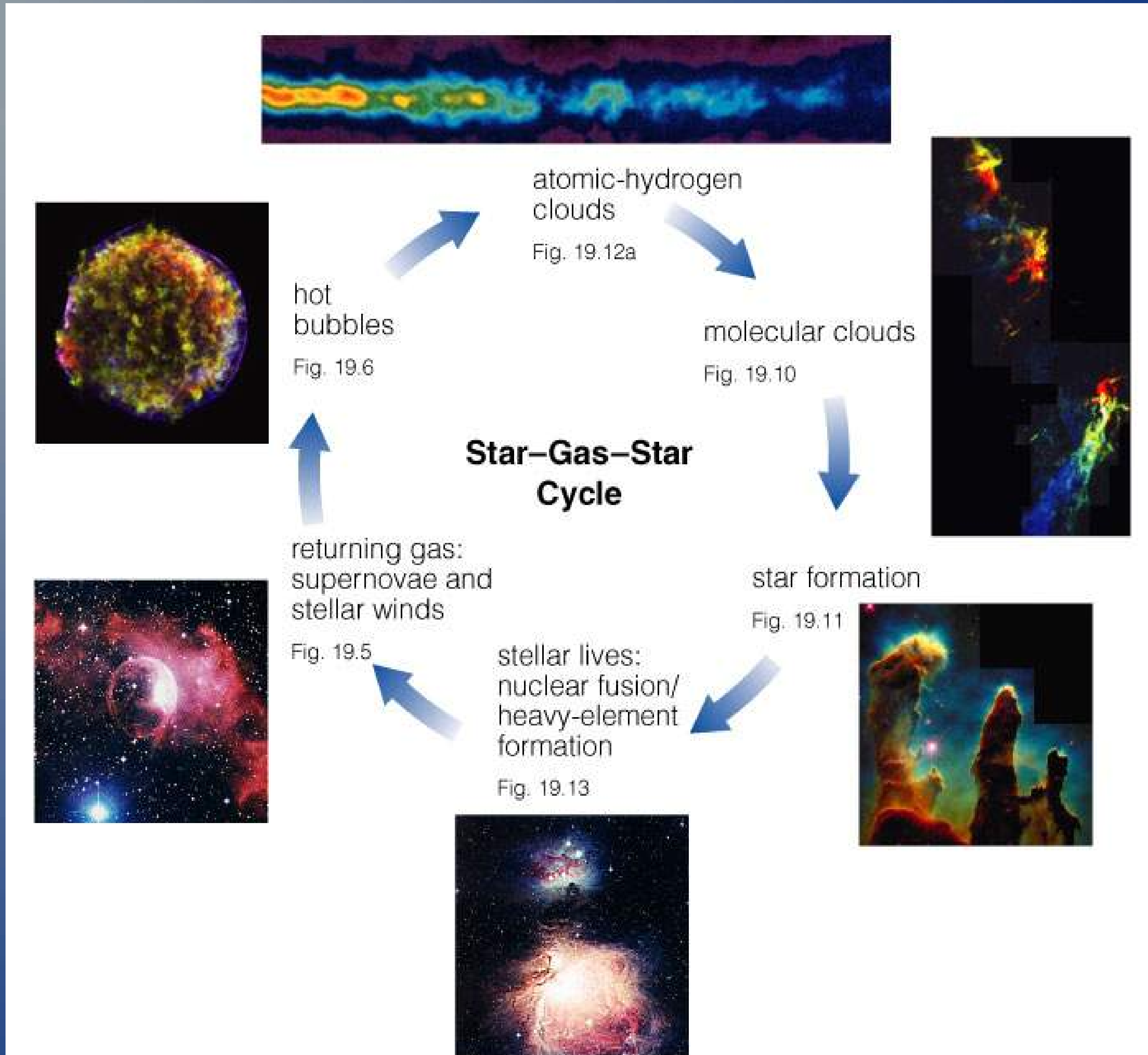
- Hydrogen – most abundant
- 'Metals' - elements heavier than H
- Dust – silica, graphite
- Large number of molecules
- Polycyclic Aromatic Hydrocarbon – cyclic molecules
- Objects like star forming clouds, supernova remnants, planetary nebulae....

Physical conditions in ISM - H

- WNM T=8000 K; n = 0.5 /cc
- WIM   T=8000K; n = 0.1 /cc
- CNM   T=80K; n = 50 /cc
- HIM   T=10^6 K; n = 0.003 /cc
- H_2 clouds T=10K; n = > 200 /cc
- HII regions T=10^4 K; n = 1-10^5 /cc
- Rough Pressure equilibrium constant ~ n T

ISM

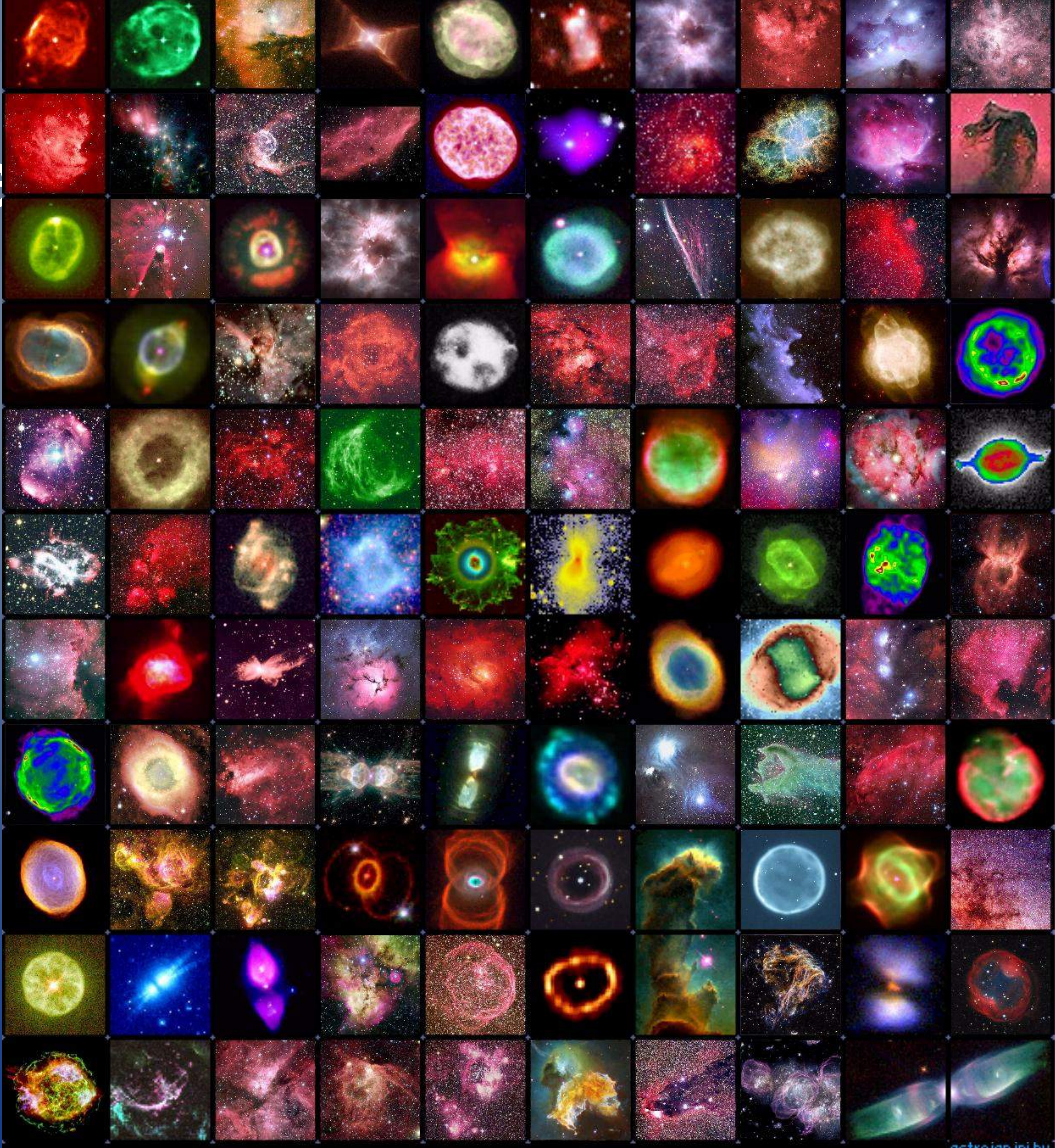
- gas → mainly H, He in different chemical states: HI, HII, H_2; ~90% H; ~ 8% He; rest heavier elements referred to as metals and dust – trace elements important.
- Stars ~ 10^11 solar mass
- gas → ~ 7 x 10^9 solar mass – mostly H, He - 60% HI, 23% HII, 17% H2
- Disk half thickness ~ 250 pc near sun → thin disk compared to diametre of disk: 15 kpc.


atomic-hydrogen clouds
Fig. 19.12a
molecular clouds
Fig. 19.10
star formation
Fig. 19.11
stellar lives: nuclear fusion/ heavy-element formation
Fig. 19.13
returning gas: supernovae and stellar winds
Fig. 19.5
hot bubbles
Fig. 19.6
Star–Gas–Star Cycle

Messier Catalogue

- Galactic nebulae/clusters
- External galaxies
- Charles Messier in 1770s catalogued visible objects - M <n>
- e.g. M1....M101

http://scienceblogs.com/startswithabang/files/2012/08/NebulaMosaic.jpeg

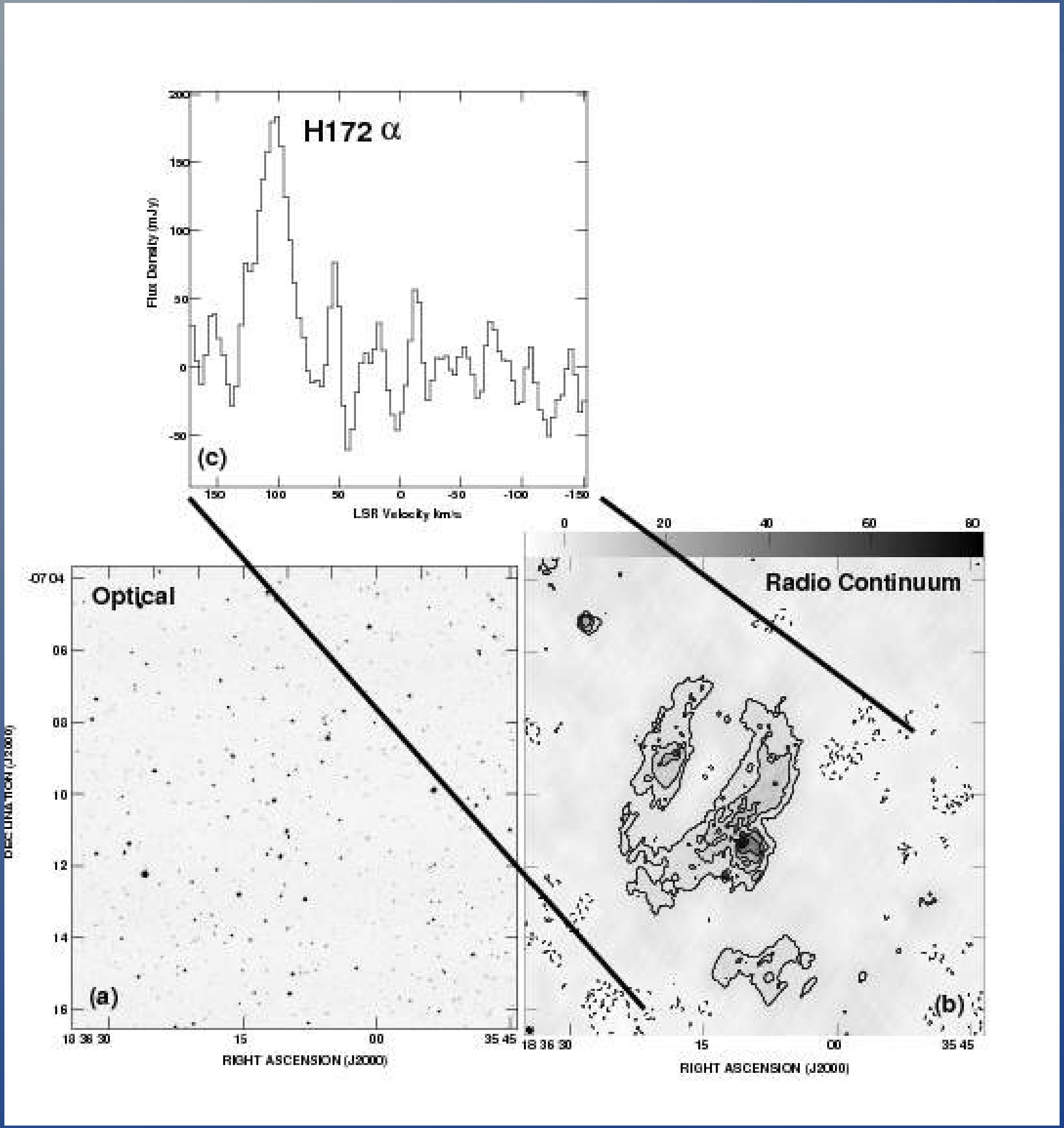


Star forming regions - H+

- Red – Halpha
- Blue – Oxygen
- 200 pc across
- 500000+ hot stars
- 30 Doradus

http://www.nasa.gov/mission_pages/hubble/science/30doradus.html

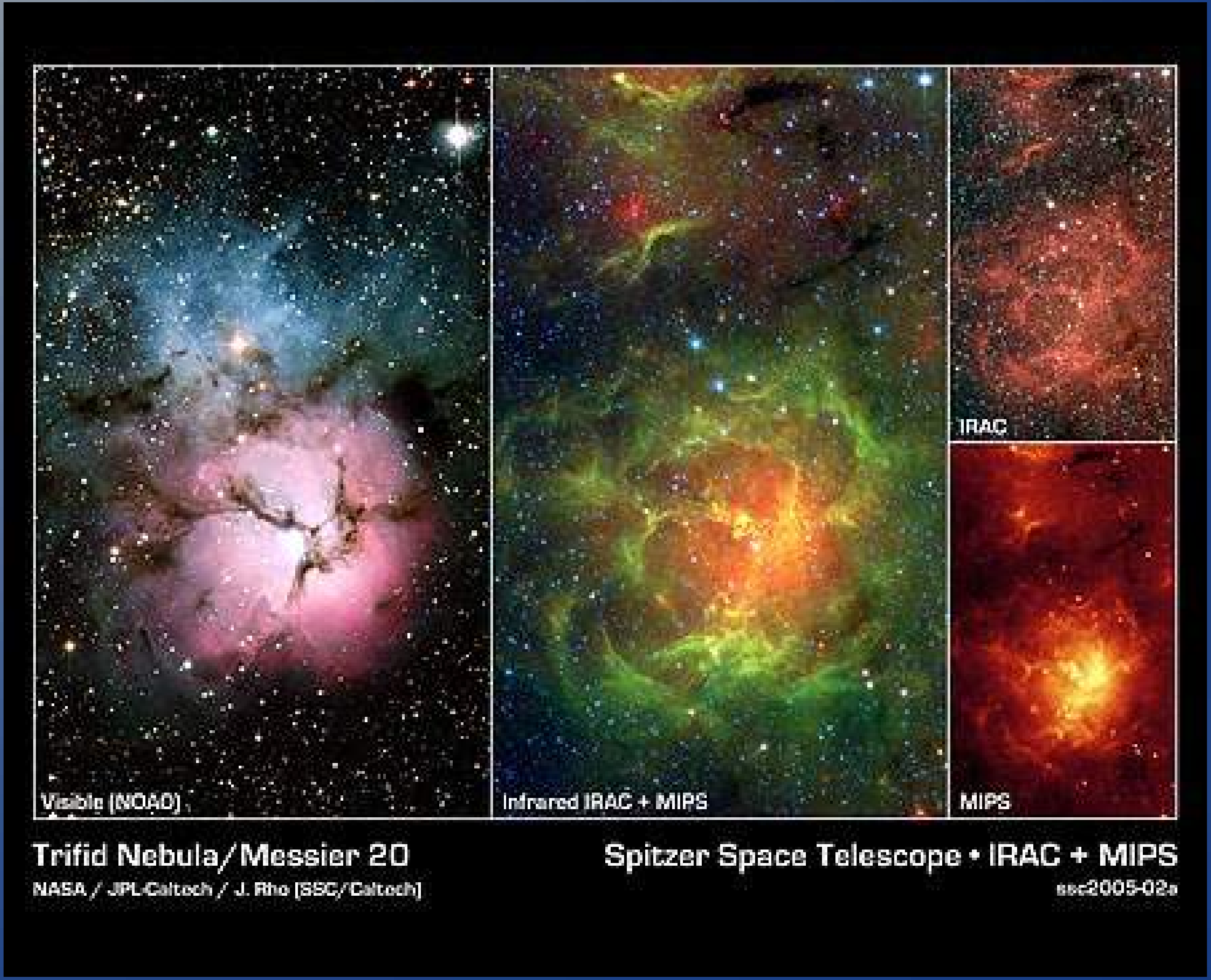
Radio and optical.....dust!



Horsehead nebula, NGC 2023, NGC 2024 in Orion

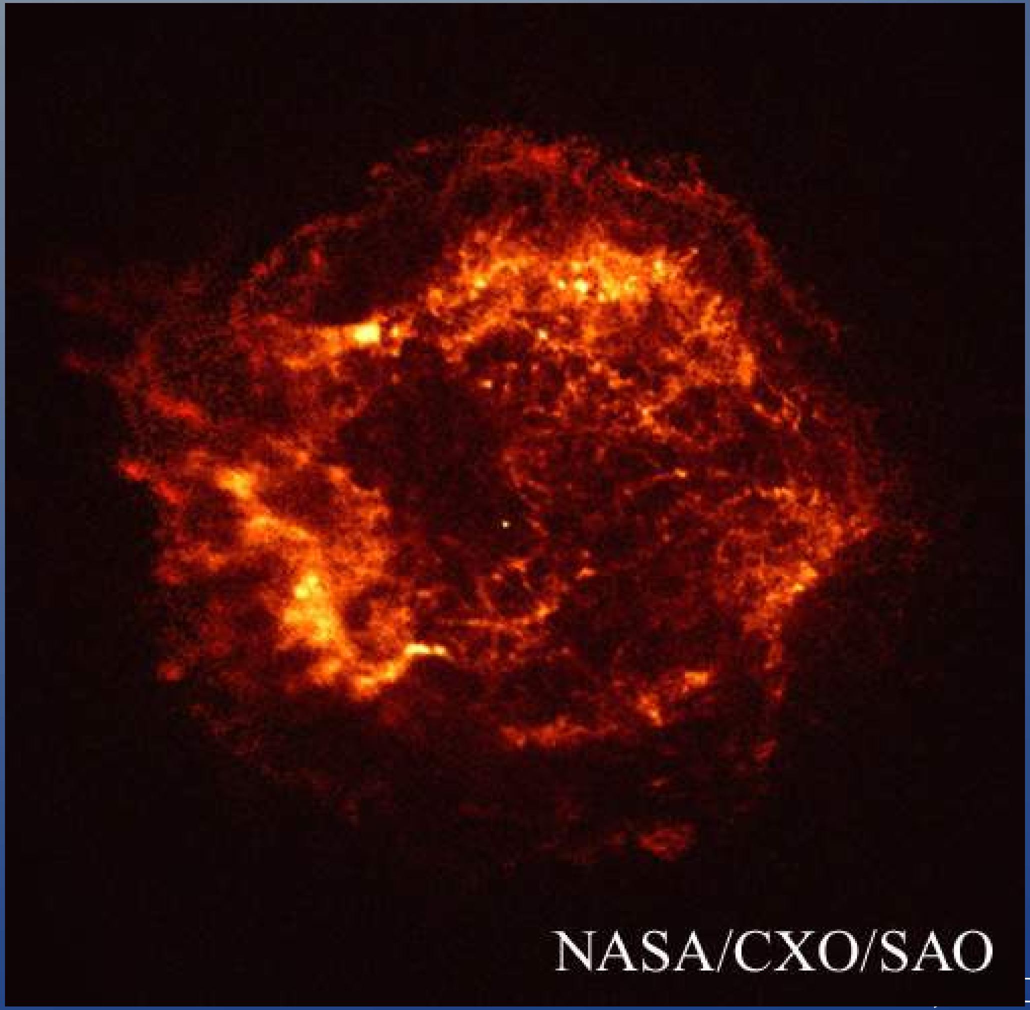
http://apod.nasa.gov/apod/image/0503/horsehead_steinberg_big.jpg

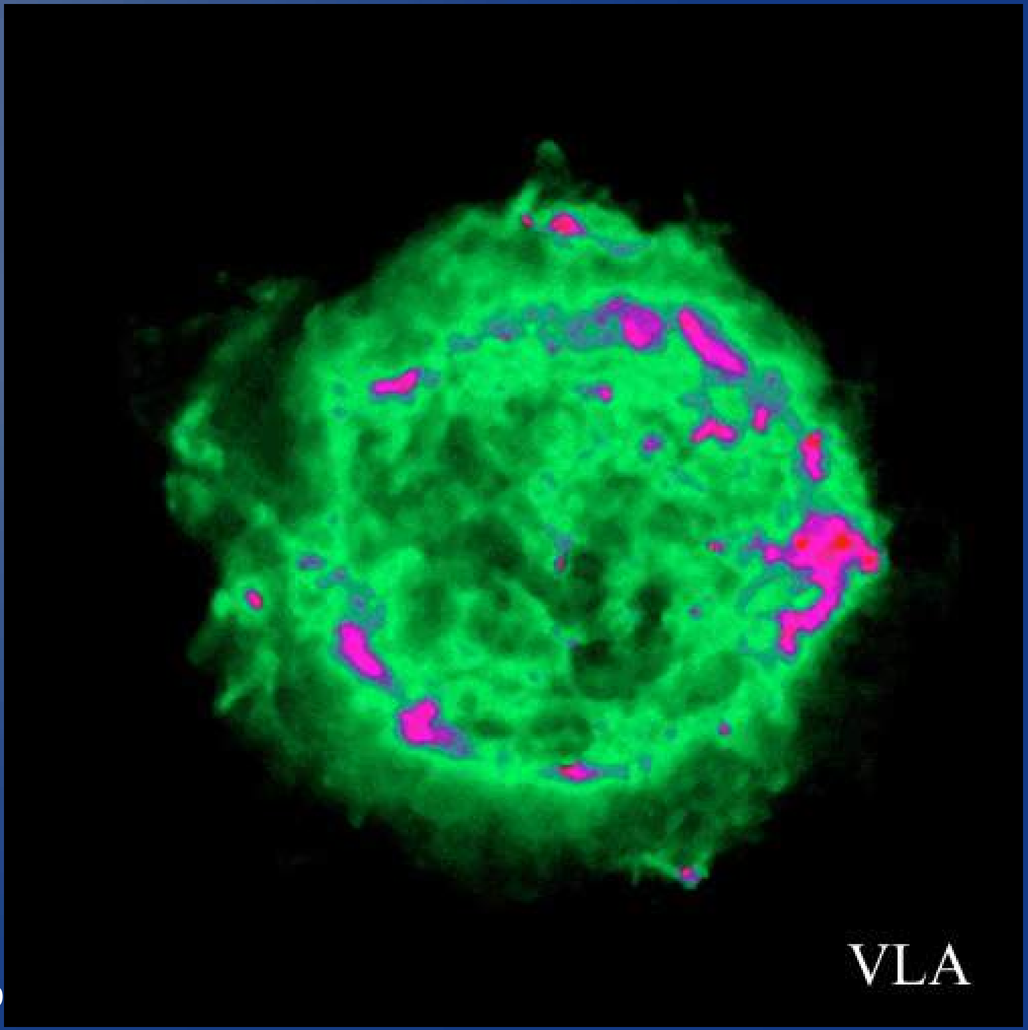
Multiwavelength HII



ISM population -SNR....

- Cassieopia A – most intense SNR in radio; size ~ 3 pc





Reflection nebula -NGC 2023

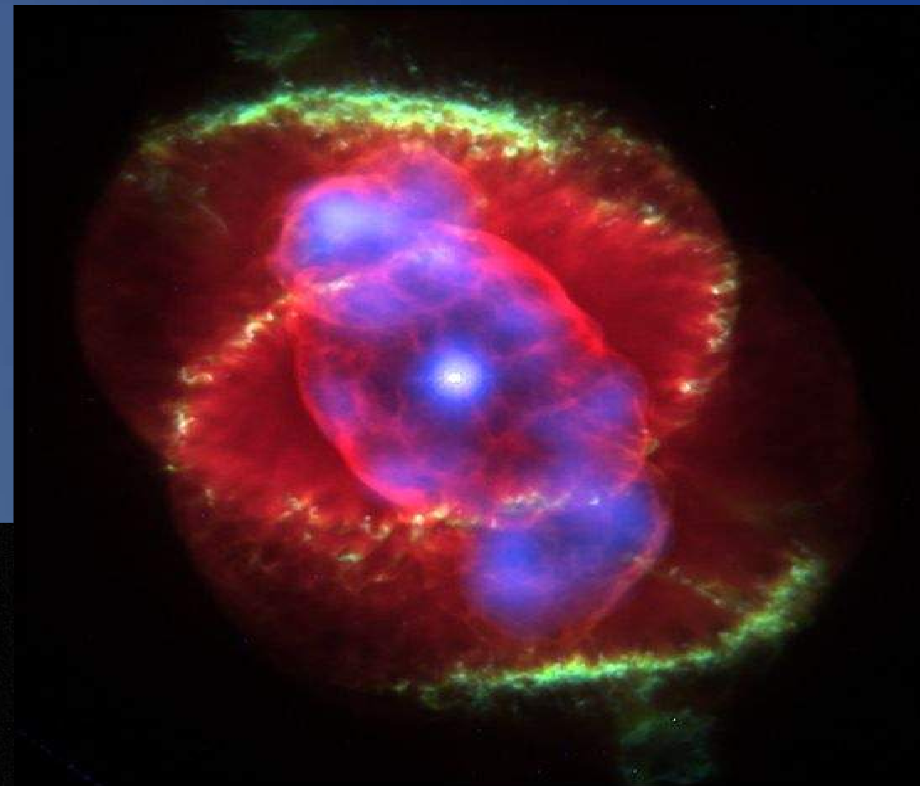
Blue light of a B-type star is reflected by dust cloud forming a reflection nebula

http://www.rc-astro.com/img/b33_ngc2023_2005-01-10_web.jpg

Planetary nebulae

NGC 7293

NGC 6326

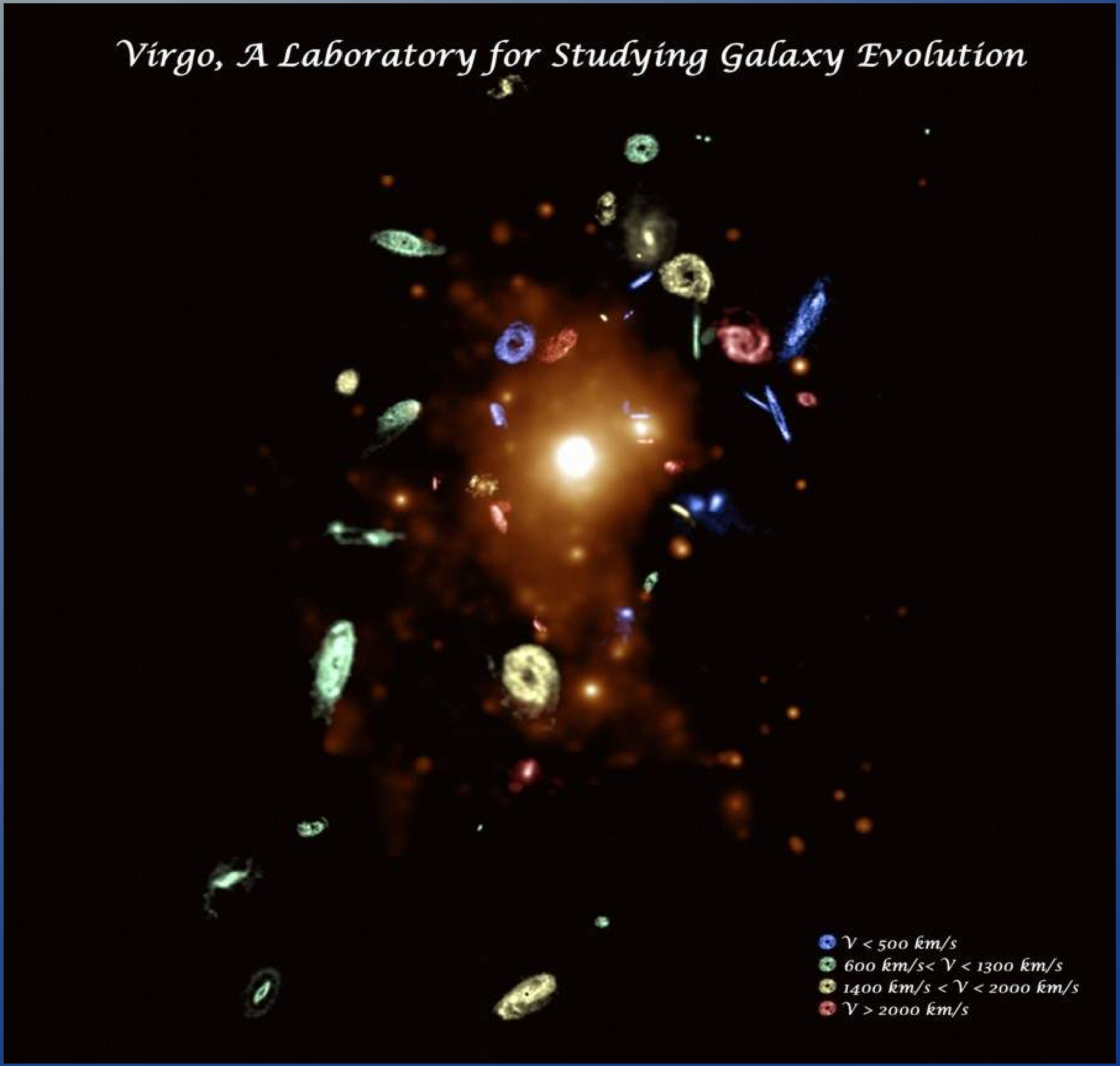


Cat's Eye nebula

- Emission nebulae – metal input

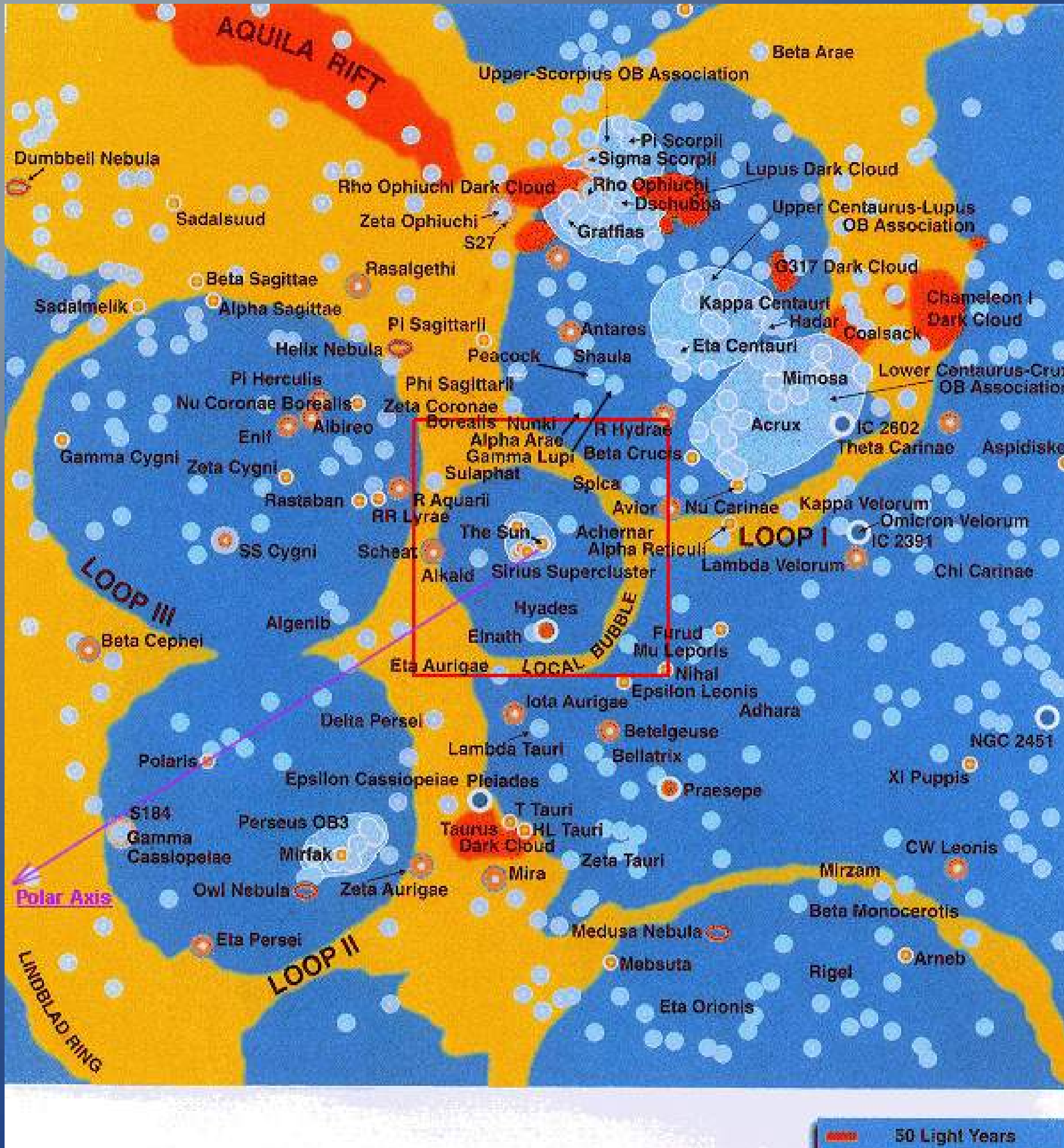
http://upload.wikimedia.org/wikipedia/commons/thumb/b/b1/NGC7293_(2004).jpg/220px-NGC7293_(2004).jpg

Extragalactic ISM



Hot gas ICM in Virgo cluster of galaxies

- ICM Mass ~ mass in galaxies



ISM in solar neighbourhood – LISM

- Bubbles of hot gas caused by SN explosions

Final Comments

- ISM rich in composition
- ISM rich in physical conditions – cold, hot, very hot....energetic phenomenon...crucial in star formation
- Multiwavelength studies bring out the variety
- Radio powerful – no dust obscuration can probe the entire ISM
- Dynamically very important

Final Comments

Since 1901 – our understanding has increased - 20th century saw several outstanding discoveries in/due to ISM:

- ISM itself
- Dust
- Relativistic particles accelerated in magnetic field
- HI spectral line, molecules
- Dark matter
- Extragalactic objects/gas – cosmology
- Also driven technology for powerful radio telescopes