(Astro)Physics 343 Lecture # 6: Lab # 3; the Interstellar Medium

This week's schedule

Monday, 2/28 at 12:00pm in Serin 401:

Dr. Dušan Kereš (Berkeley): "Universe in a Box"

Lab sections will meet at regular times this week.

Sections A, B, C, D, E = R. Lindner

Special note: no office hours this afternoon (5:00–6:20pm).

Lab # 3: spectral line observations!

So far all of our observations with the SRT have been with receiver mode 1, and we've simply averaged over (most) channels since we've only been interested in continuum emission from the Sun.

For line observations, we care about individual channels!

mode 1 = 500 kHz bandwidth ← all data so far

mode 2 = 250 kHz bandwidth

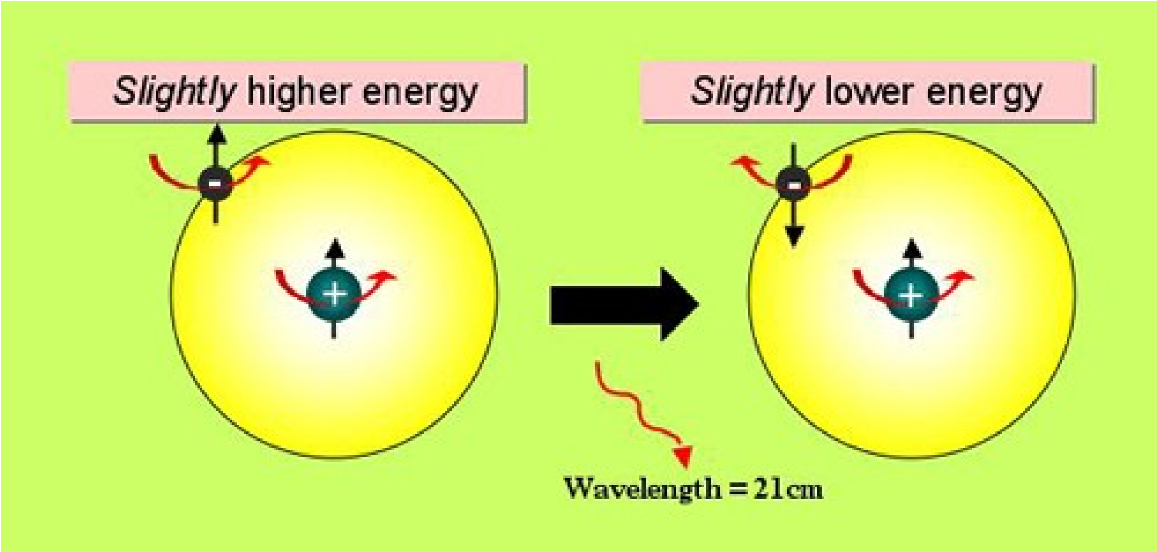
mode 3 = 125 kHz bandwidth

mode 4 = 3 x 500 kHz bandwidth (with overlaps: 1218.75 kHz bandwidth with 156 channels)

The key "spin flip" transition: 21cm H line

In a H atom, when the electron and the proton switch from having parallel spins to having antiparallel spins, a photon is emitted at

λ = 21cm $\leftrightarrow$ ν = 1420.4 MHz.



Doesn't trace ionized or molecular gas – just neutral atomic gas!

Courtesy of Swinburne University.

Velocities in astronomy

Observed frequency and wavelength are related to rest (emitted) frequency and wavelength by a velocity (or redshift).

Exact relation = Doppler shift:

$\nu_0/\nu = \lambda/\lambda_0 = 1 + z = \gamma\,(1+ v/c)$ **for** $\gamma = (1-v^2/c^2)^{-1/2}$

and for relative velocities, $\Delta\nu/\nu = \Delta\lambda/\lambda = \Delta z/(1 + z) = \Delta v/c$.

However, astronomers also make different approximations...

radio: $\nu \simeq \nu_0\,(1- v_{rad}/c)$

optical: $\lambda \simeq \lambda_0\,(1+ v_{opt}/c)$

Distances in astronomy

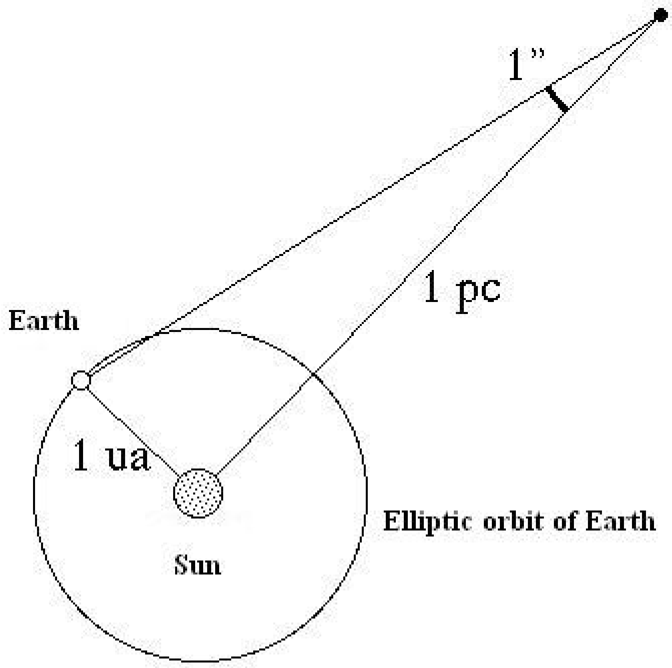
Nearest stars can have distances measured by parallax:

the apparent shift in position relative to the background pattern of more distant stars caused by the earth's motion around the Sun.

1 parsec = 1 pc:

3.089×10^{18} cm

~ 3.3 light years



Distances inside galaxies ~ kpc.

Distance between galaxies ~ Mpc.

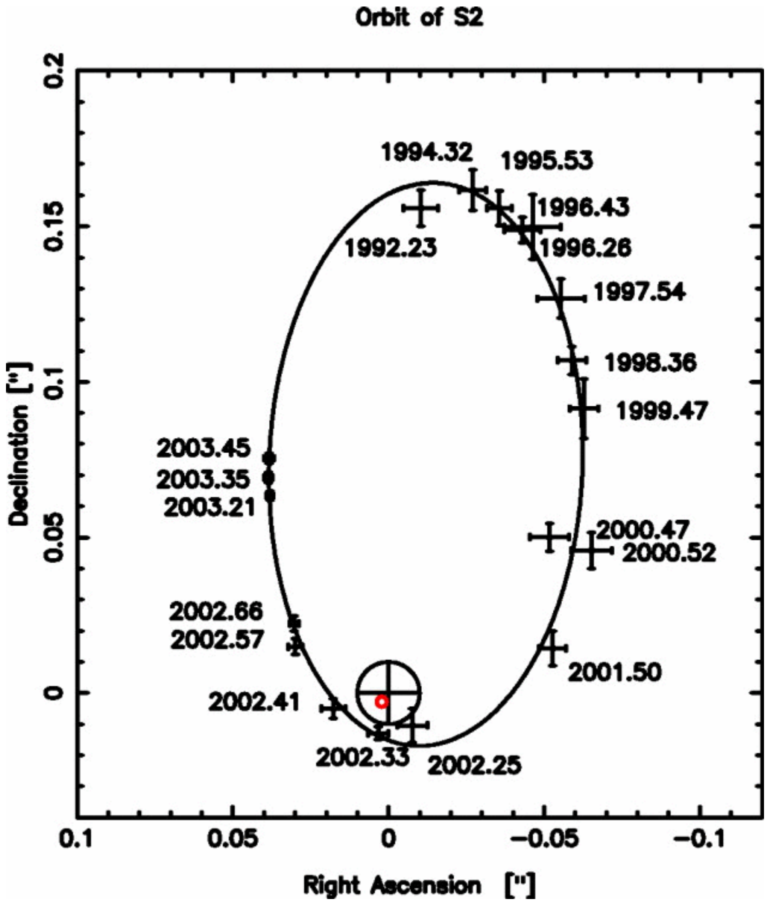
Stellar components of spiral galaxies

Spiral galaxies have two principal components: disk and bulge.

Where is the Sun within the Galaxy?

Note on terminology: Milky Way = "the Galaxy"; other "galaxies" are not capitalized.

Sun and solar system lie at a distance of 7.94 kpc from the Galactic Center, where a supermassive black hole lies.



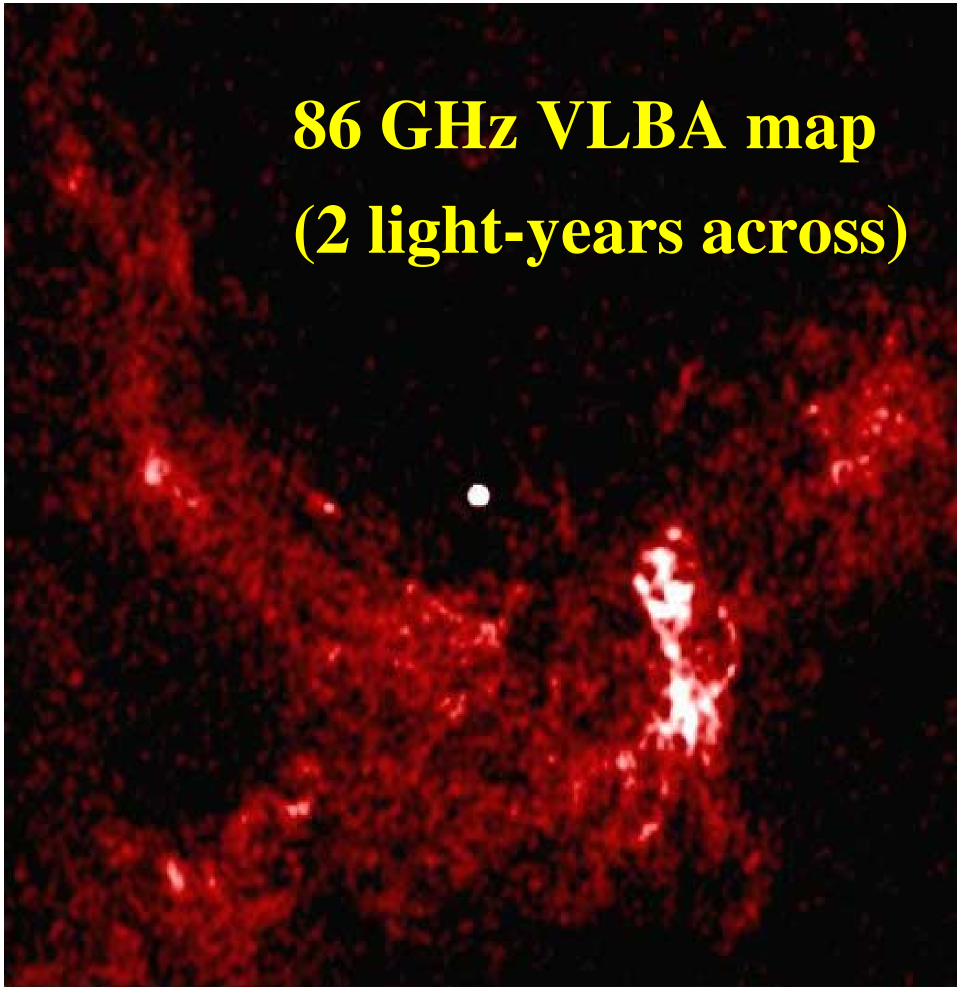
Eisenhauer et al. (2003)

Central black hole is a radio source!

Motions of stars imply a large central mass – but from low proper motion of Sgr A* ("Sagittarius A–star"), we know that *it* must be massive.

Observations with the Very Long Baseline Array reveal a proper motion only due to the Sun's motion around the Galaxy.

Shen et al. (2005)

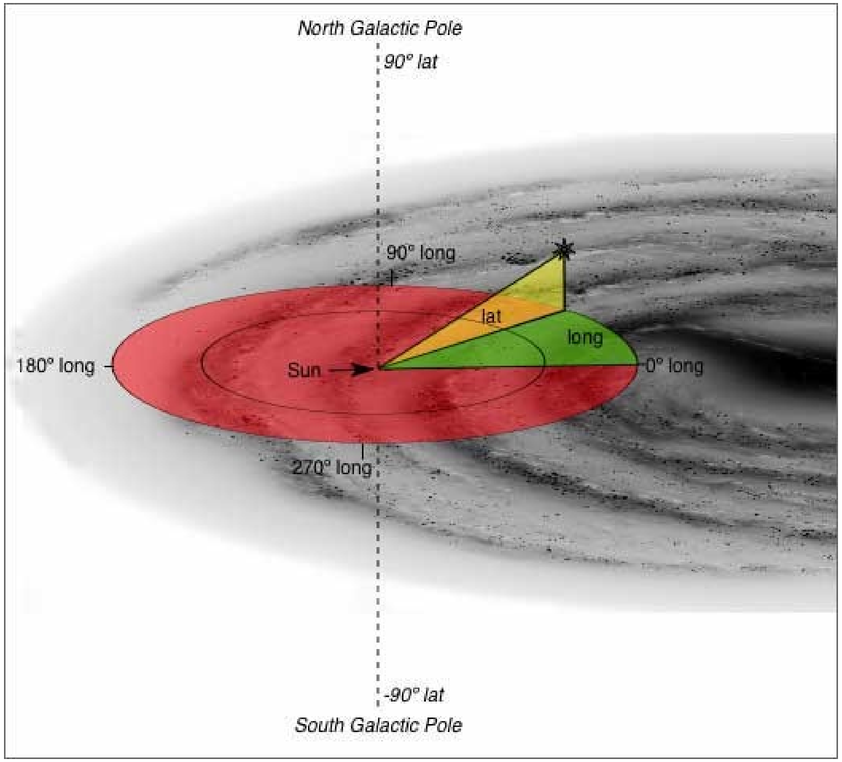


Galactic coordinates

The Sun is also located within the disk.

b = Galactic latitude (above/below plane)

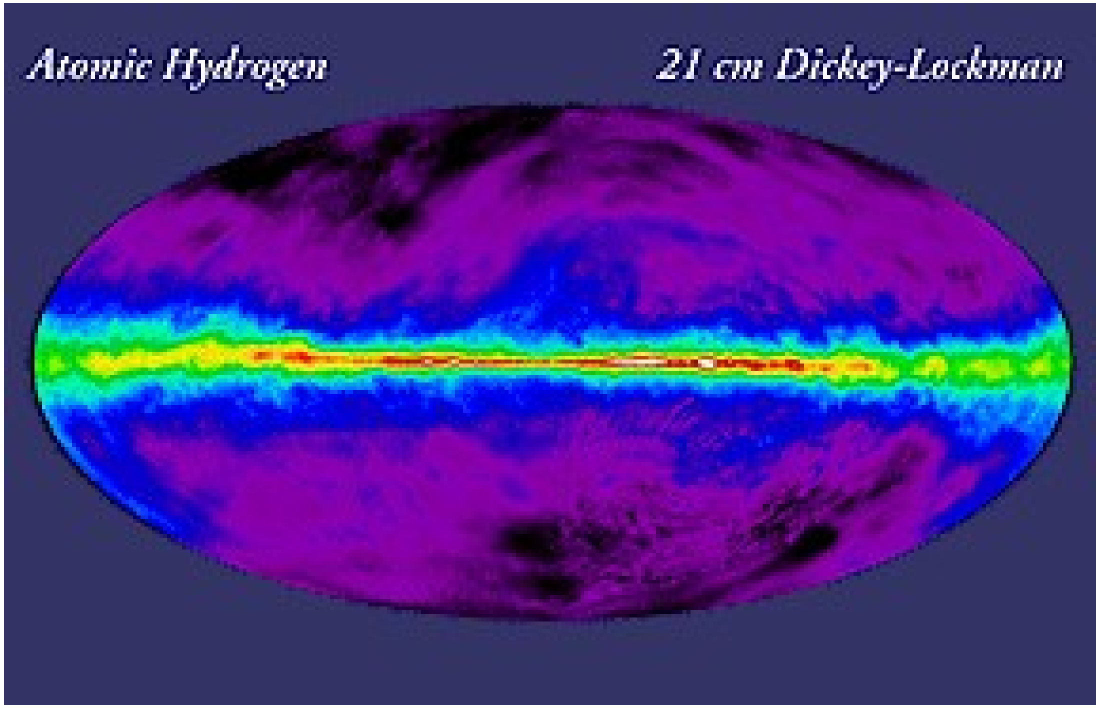
l = Galactic longitude (0 towards Galactic Center)



HI in the Milky Way

Nearly all the HI (neutral H) in the Galaxy is located in the disk.

Observed velocities governed by (a) rotation (b) random motions.



(plotted in Galactic coordinates)

Quiz

The interstellar medium and its variants

ISM = interstellar medium = whatever gas and dust exists in the space between a galaxy's stars.

ICM = intracluster medium = hot gas filling the volume between galaxies in a group or cluster

IGM = intergalactic medium = material that has been ejected from galaxies or never made it into a galaxy in the first place

Why should we care about the ISM?

Tongue in cheek answer: every astronomy talk can be followed by one of three (ISM-related) questions:

(1) What about dust?

(2) What about magnetic fields?

(3) What about the initial mass function (i.e., relative numbers of newborn stars of different masses that result when a large gas cloud turns into stars all at once)?

Why should we care about the ISM?

Serious answer: the ISM serves as the raw material for star formation and the dumping ground for the products of stellar nucleosynthesis (notably, all elements heavier than helium).

Moreover, the ISM affects nearly all observations we make by absorbing, scattering, or swamping the radiation from other sources of interest.

(for dust, absorption + scattering = extinction)

Key property of the ISM: composition

Gas mass fractions *X* (hydrogen) + *Y* (helium) + *Z* ("metals") = 1:

Shortly after the Big Bang: no stars yet

$X = 0.75$

$Y = 0.25$

$Z = 0.00$

In the Sun (and surrounding ISM):

$X = 0.739$

$Y = 0.248$

$Z = 0.012$ (of which oxygen contributes 0.005)

Key property of the ISM: phase

Two parcels of gas with the same composition can have very different physical states. We characterize the phase of interstellar gas with our answers to two questions:

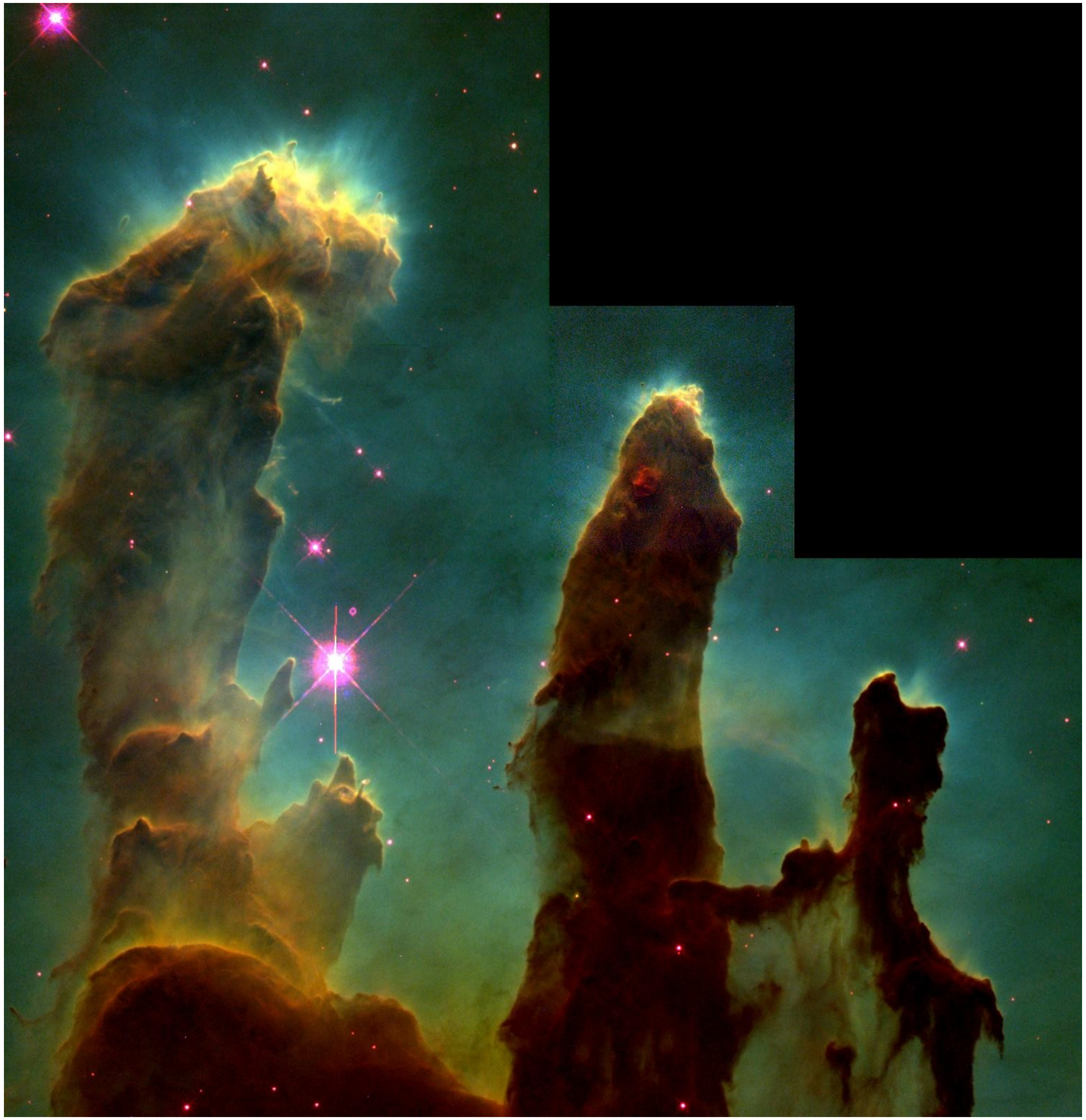
(1) In what form is the hydrogen predominantly found (ionized HII, neutral HI, and/or molecular H_2)?

(2) What are the temperature and density of the gas?

Observed phases of the ISM

Phase	n (cm^{-3})	T (K)	nT (K cm^{-3})	% V	% M
hot ionized	0.003	10^6	3000	50	4
warm ionized	0.1	8000	800	25	14
warm neutral	0.5	8000	4000	30	38
cold neutral	50	80	4000	1	30
molecular clouds	> 2000	10	> 20000	0.5	13

Molecular gas: birthplace of stars



Eagle Nebula, imaged with the *Hubble Space Telescope*:

young stars that have emerged from their dusty birth clouds

+ still younger stars that are still enshrouded

Star-forming regions

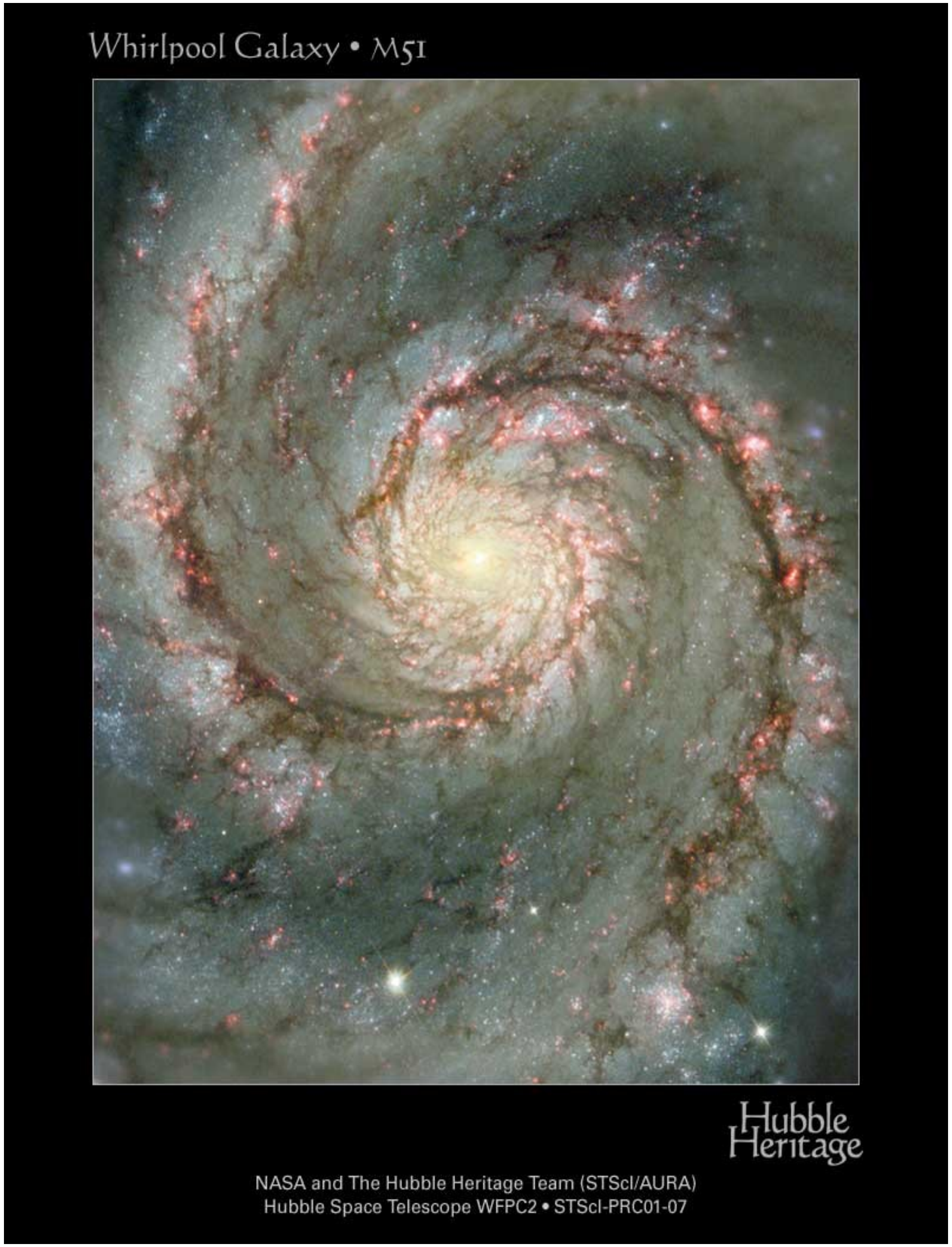
Carina Nebula imaged with the *Hubble Space Telescope*:

A mixture of still-forming and young stars, some so massive that they are on the verge of exploding (e.g., η Car).

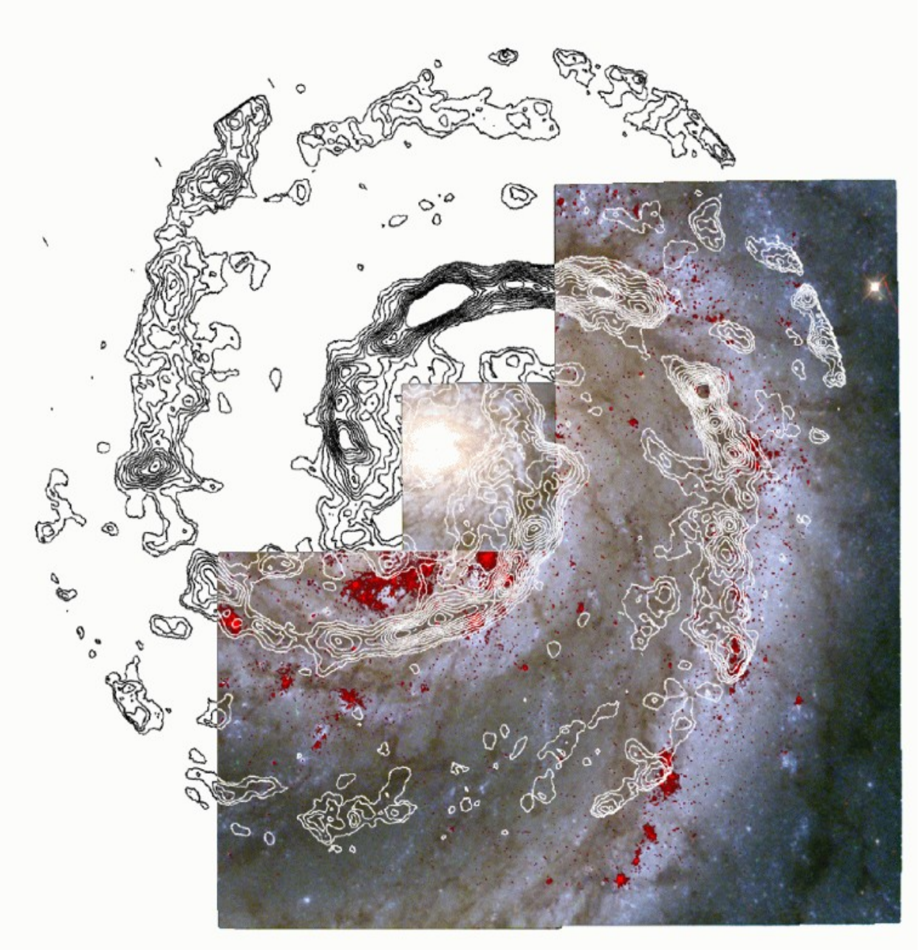
Don't mess with the interstellar medium!

The "defiant finger" in the Carina Nebula (NASA/*HST*).

Molecular gas: birthplace of stars

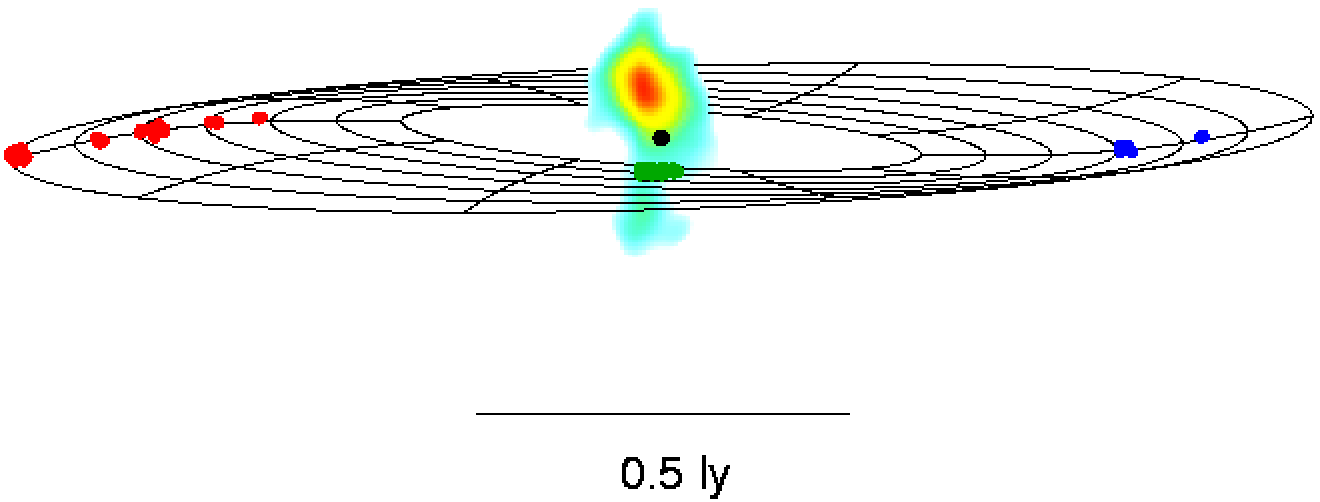


M51: CO contours overlaid on Pa α emission + optical light



Molecular gas: fuel for black holes

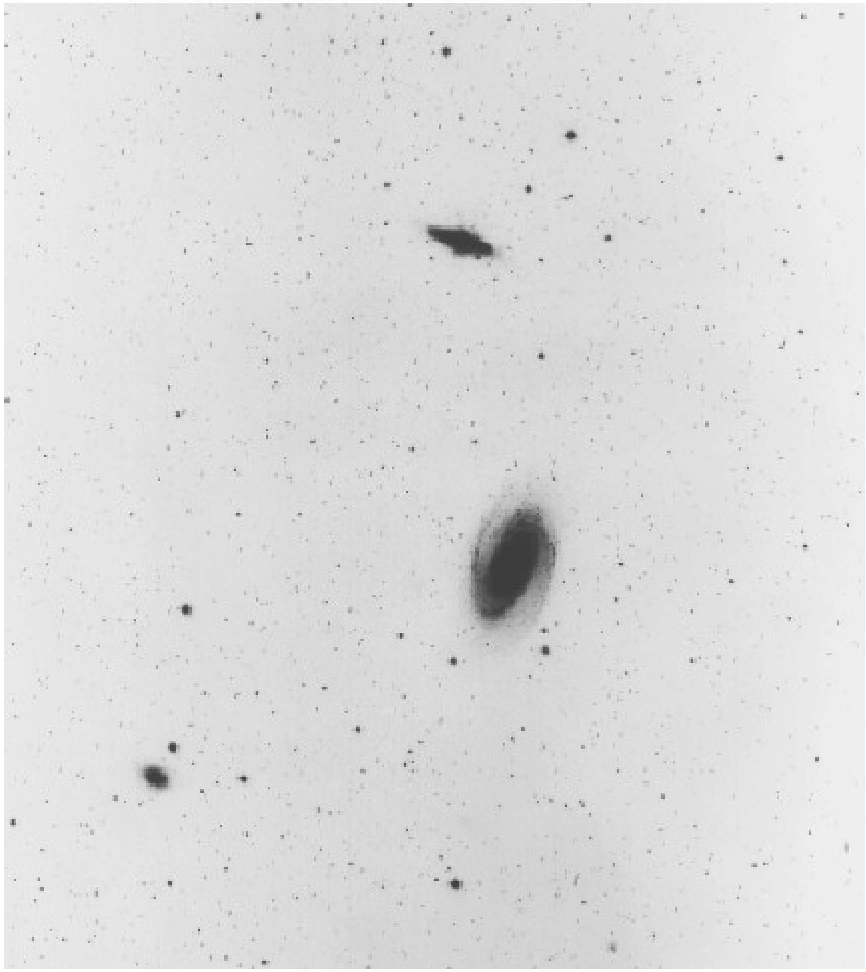
NGC4258: H_2O maser emission from dense, warm gas in clumps that are moving towards us, away from us, and in the plane of the sky (Herrnstein et al. 1997).

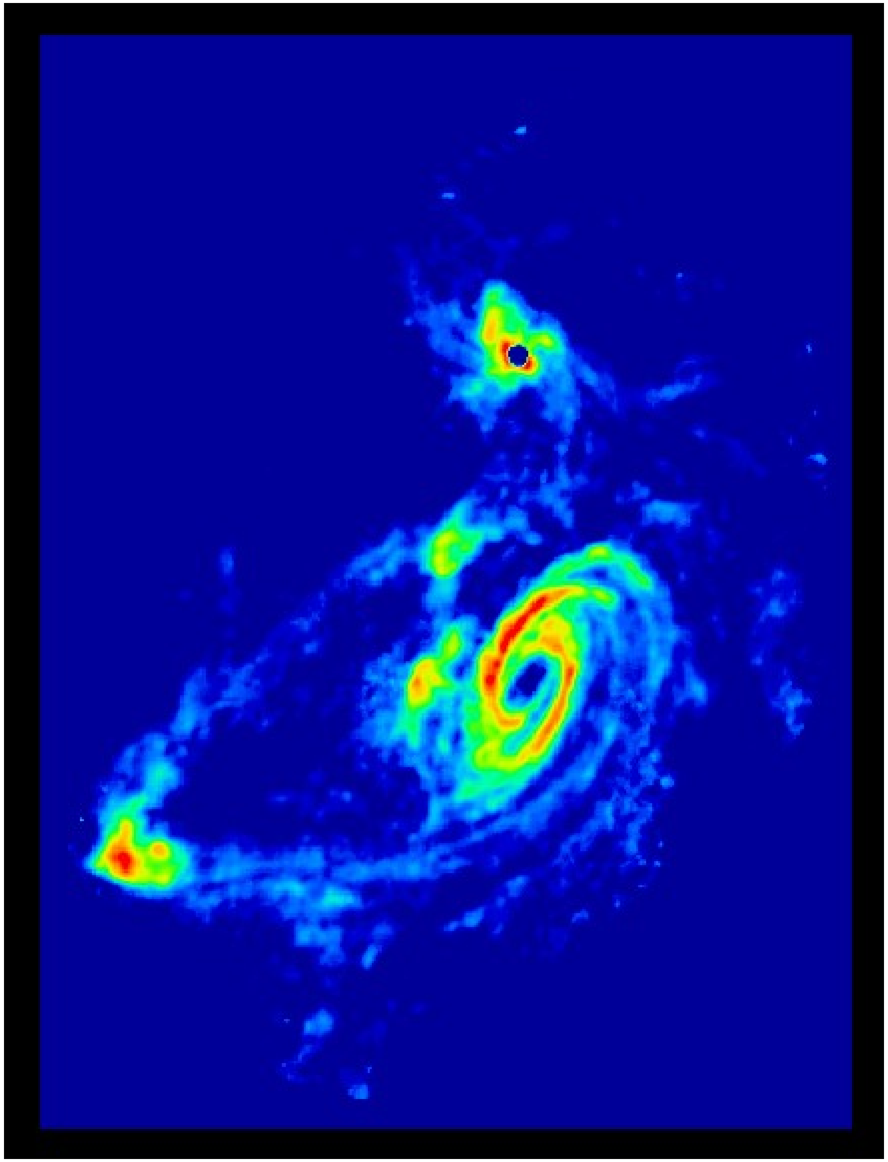


This gas fuels the black hole, which drives a jet perpendicular to the disk.

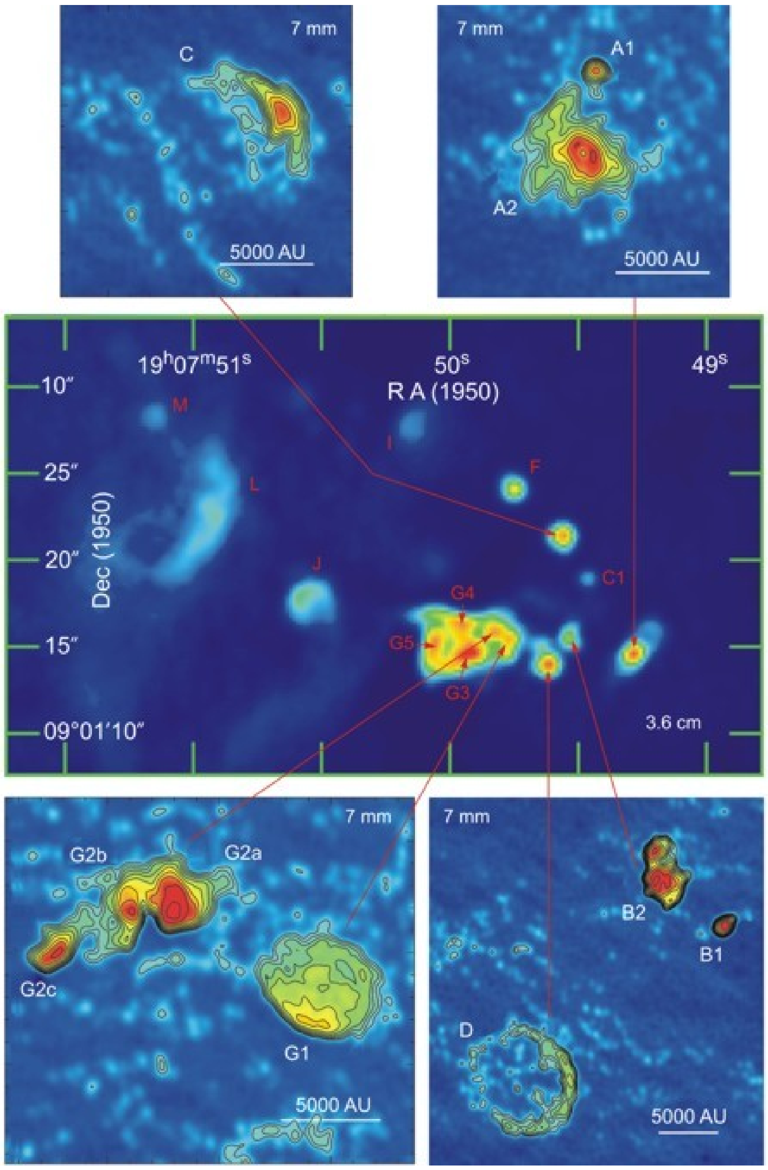
Atomic gas: a major gas reservoir

M81 group: optical starlight (left) + VLA HI (right)





Ionized gas: HII regions...



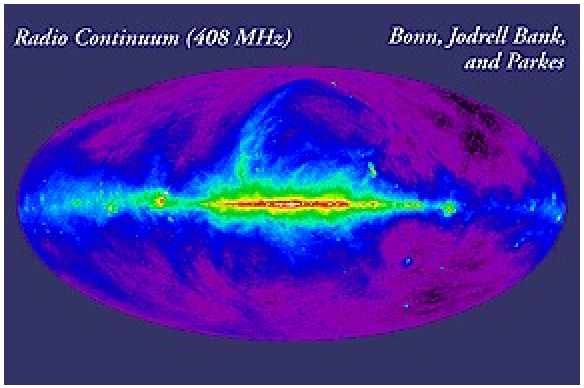
Free-free emission from young, “ultracompact” (high-n_e) HII regions in Milky Way: middle = 3.6cm, insets = 7mm

C. DePree, M. Goss, J. Welch, & D. Wilner

...and superwinds

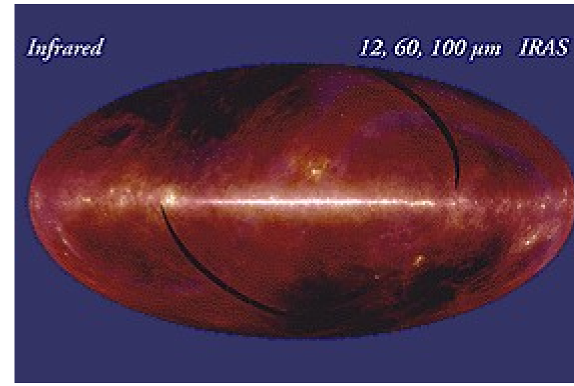
Starburst galaxy M82: X-ray emitting hot gas and Hα emission from ionized gas trace ejection of material along minor axis

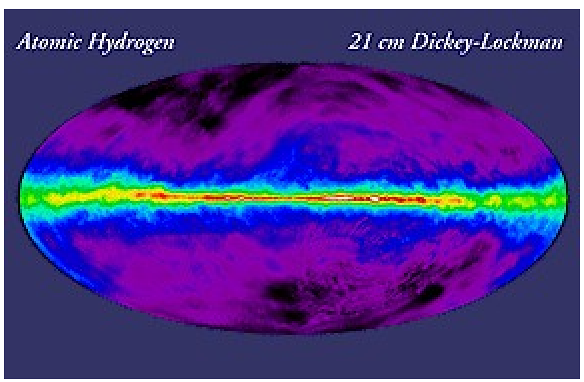
A multiwavelength view of the Milky Way



radio continuum

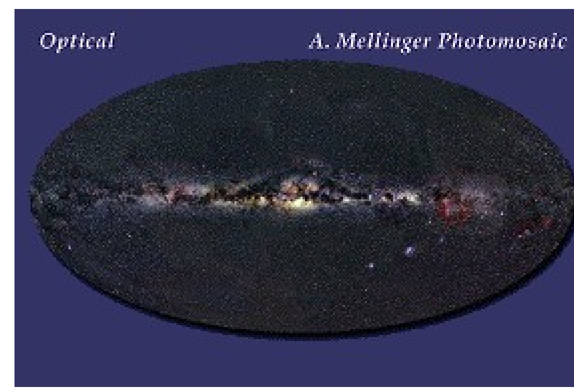
infrared (dust)

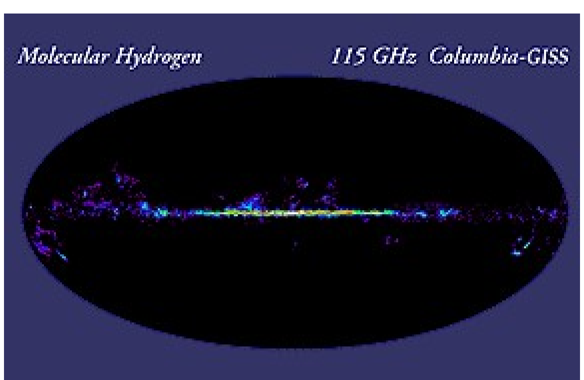




HI

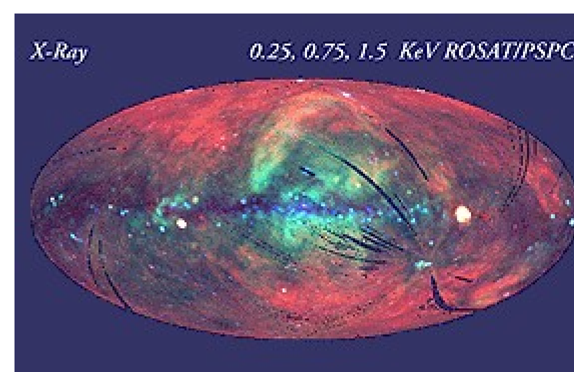
optical





CO (H_2)

X-ray



Pressure equilibrium

Phase	nT (K cm^{-3})
hot ionized	3000
warm ionized	800
warm neutral	4000
cold neutral	4000
molecular clouds	> 20000

Several phases of the ISM have the same thermal pressure as each other (nkT). This makes sense: a hot, dense bubble of gas will tend to expand until it reaches pressure equilibrium with its surroundings.

Molecular clouds do not follow this pattern: they are bound by self-gravity!