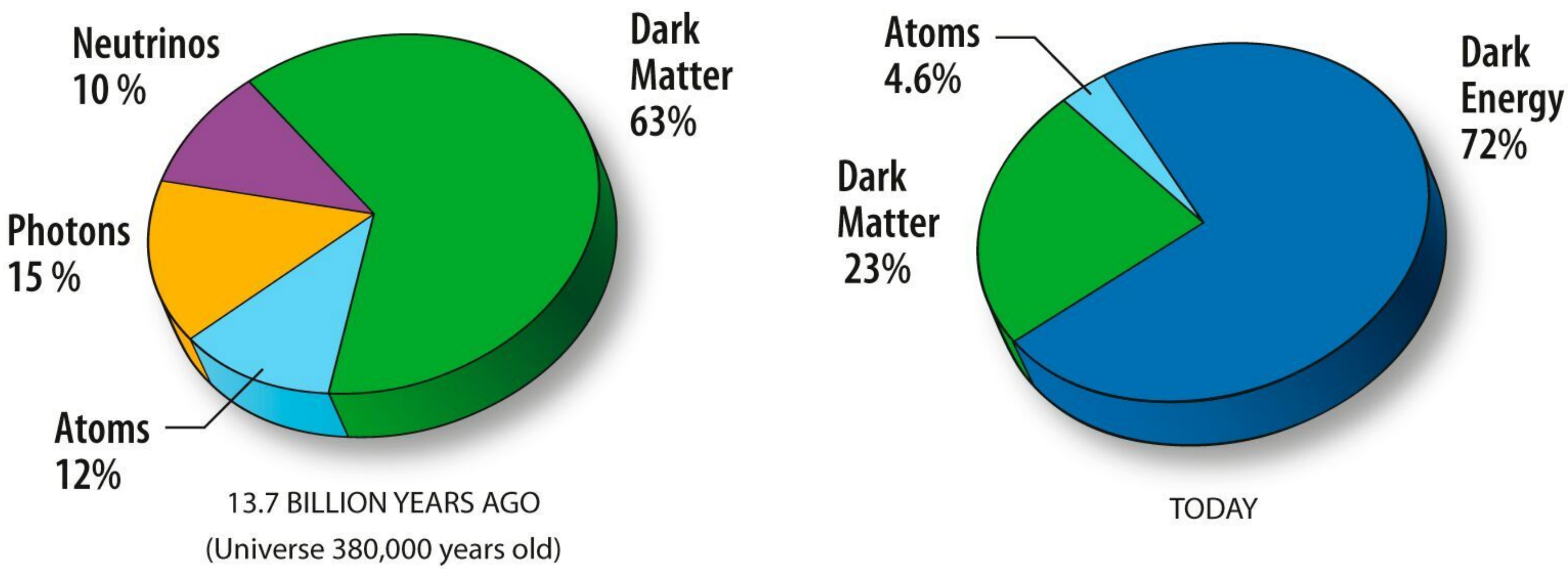
Insterstellar Medium (Introduction)

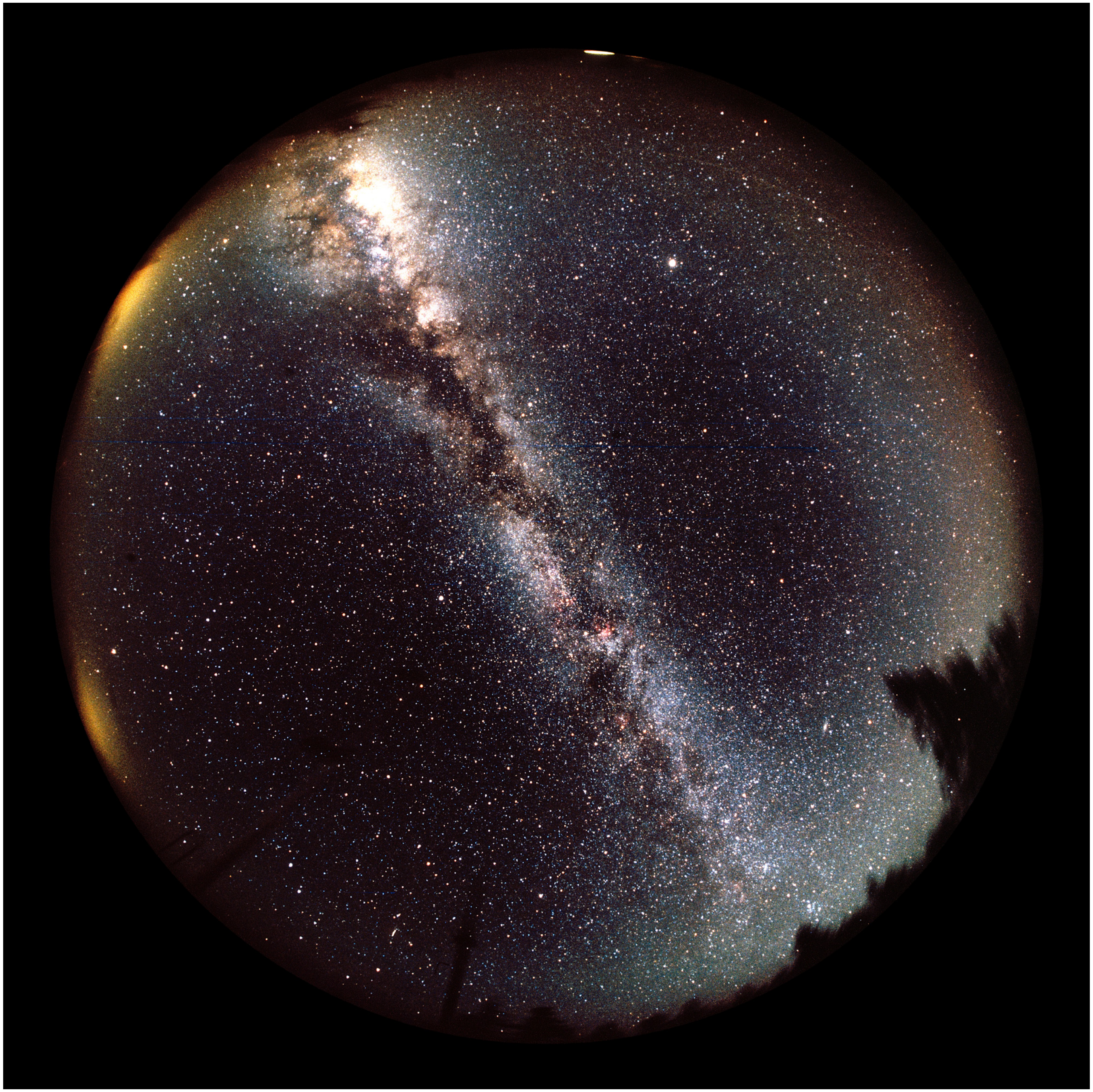
(Adapted from presentation by Lynne Hillenbrand)

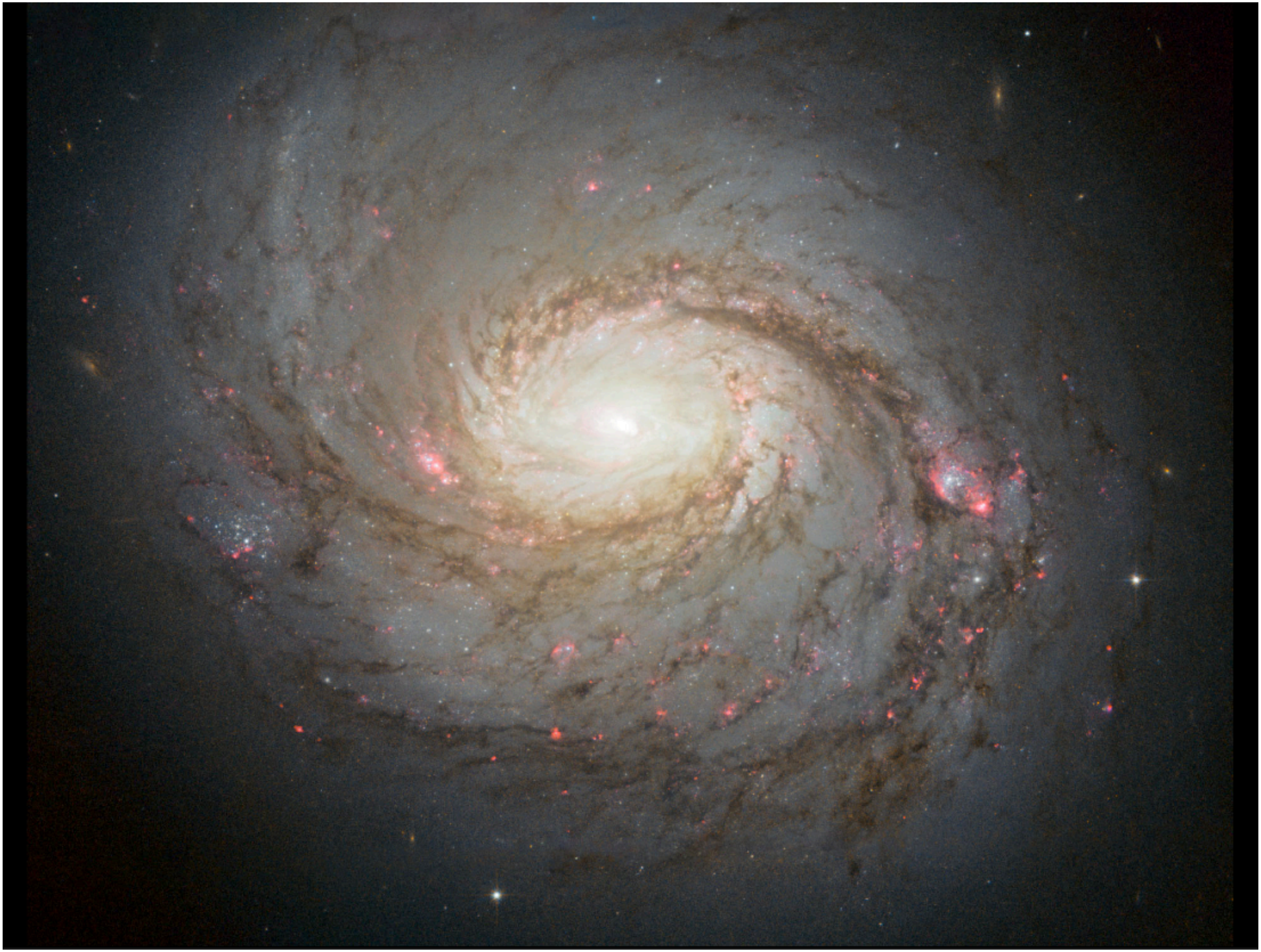
Evolution over cosmic time in the composition of the universe



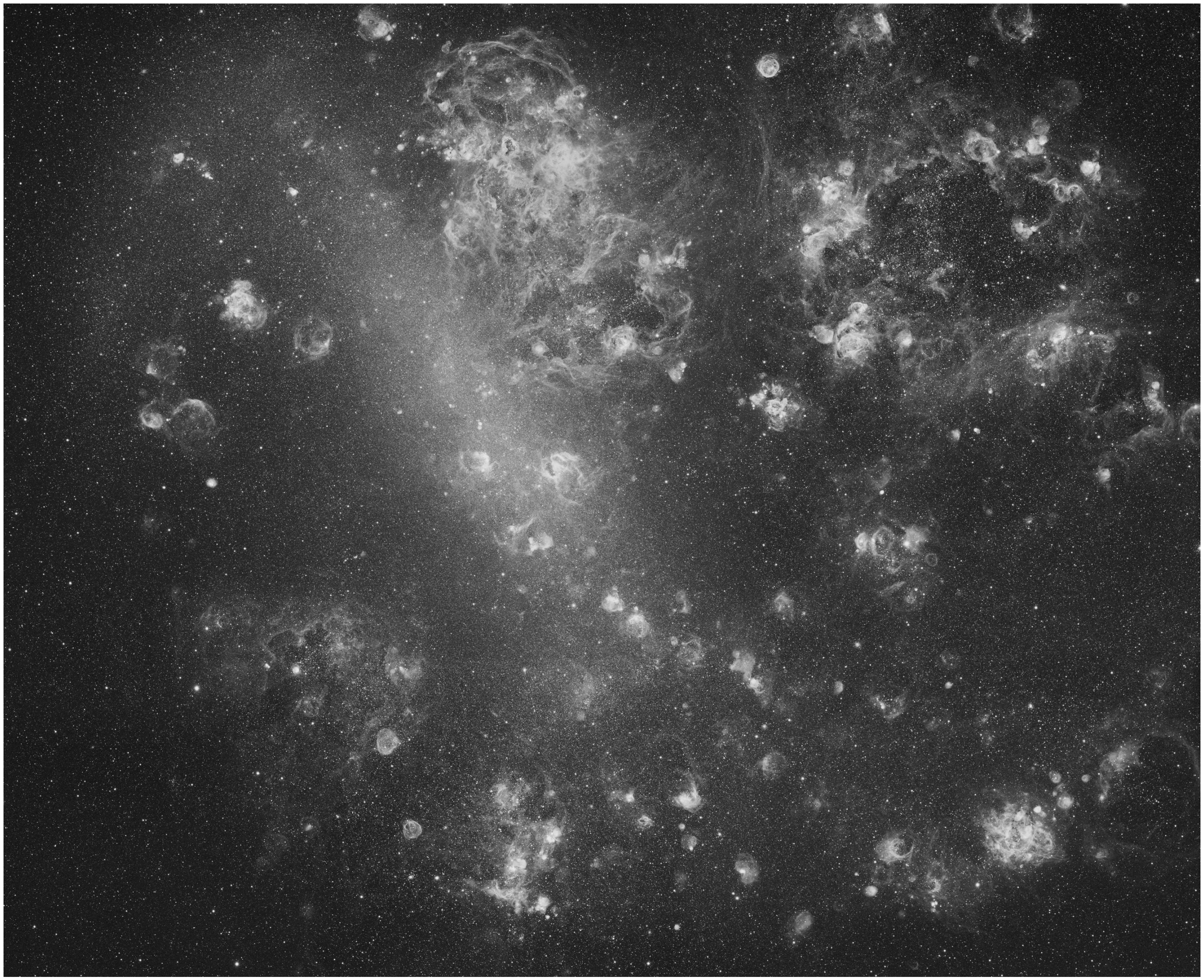
"atoms" = H, He, and traces of Li, Be, B

"atoms" = the entire periodic table and the rich chemistry that it enables

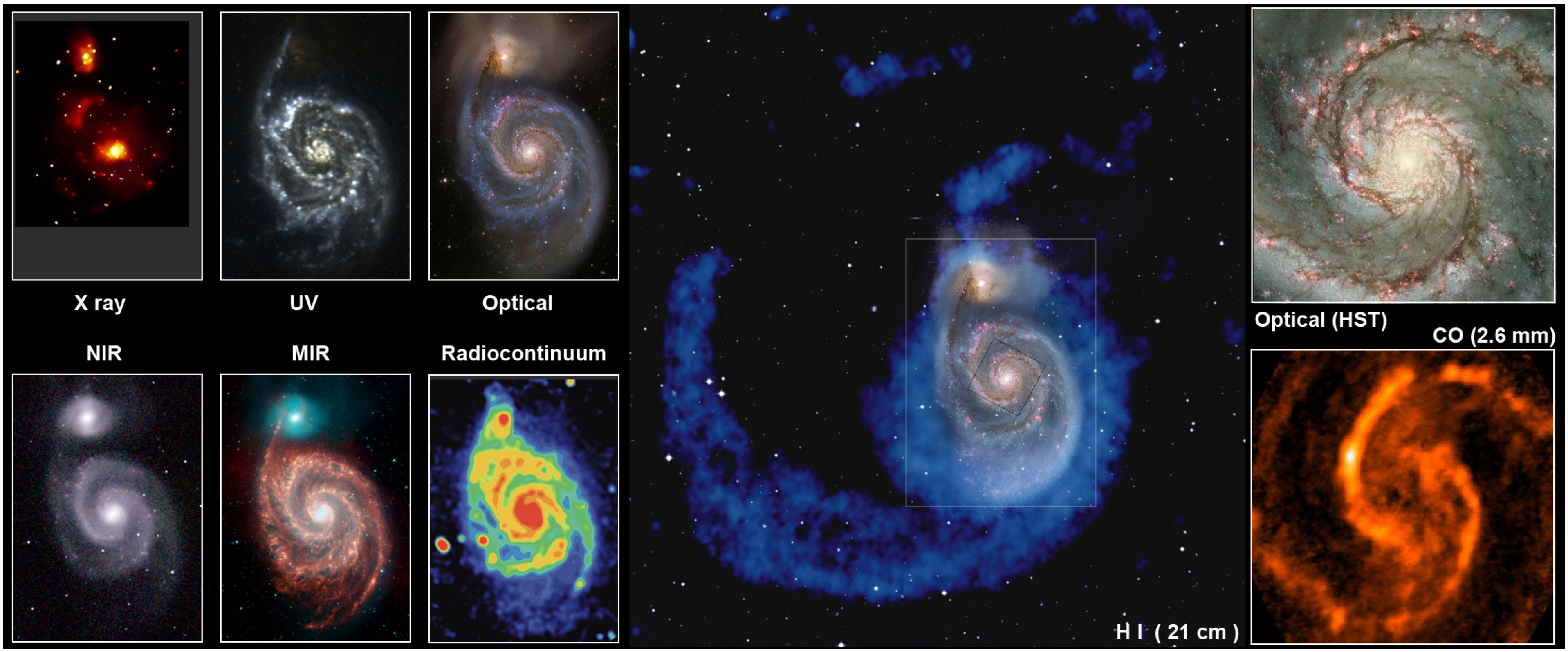




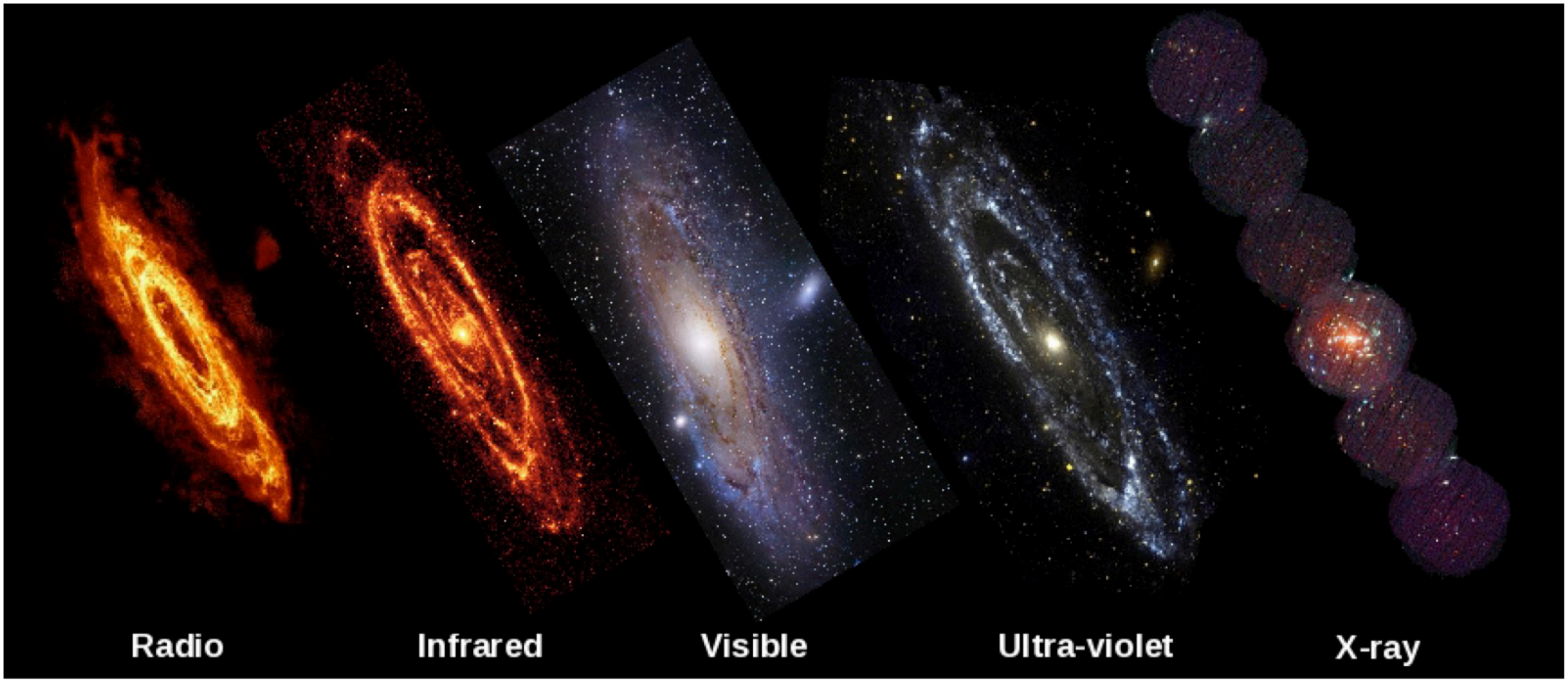
LMC in H-alpha emission



M51 (Whirlpool Galaxy)



M31 (Andromeda)



A multiwavelength view of M31 and two of its satellite galaxies, NGC 205 and M32. Understanding galaxy evolution requires deciphering star-formation history as traced by stellar populations of different ages and the interplay between stars, gas, dust, dark matter, and the galactic environment. *[Radio: WSRT, R. Braun; IR; NASA, Spitzer, K. Gordon; Visible: Robert Gendler; UV: NASA, GALEX; X-ray: ESA, XMM, W. Pietsch]*

A rough accounting of the mass budget:

- MW: star formation more-or-less steady for past ~8 Gyr (Rocha-Pinto et al. 2000):
  $M > 1M_\odot$ stars are dying at ~same rates as being formed.
- $M_{\rm ISM} \approx 5 \times 10^9 M_\odot$ in MW
- Sources and Sinks:

$$
\begin{array}{rll}
\dot{M}_{\rm ISM} \approx & +1M_\odot/\,{\rm yr} & : \text{Infall} \\
 & -3M_\odot/\,{\rm yr} & : \text{Star Formation} \\
 & +1M_\odot/\,{\rm yr} & : \text{Stellar Outflows} \\
\hline
\text{Net} & : -1M_\odot/\,{\rm yr} &
\end{array}
$$

- ISM declining on timescale $M_{\rm ISM}/|\dot{M}_{\rm ISM}| \approx 5\,{\rm Gyr}$
- Atom (or grain) in ISM incorporated in a star on timescale

$$\frac{M_{\rm ISM}}{\rm SFR} \approx \frac{5 \times 10^9 M_\odot}{3M_\odot/\,{\rm yr}} \approx 1.5\,{\rm Gyr}$$

B. Draine

Interstellar Medium

note contrast to stars (ay101) which are in the opposite regime

- low density
- collisions between particles infrequent
- interactions between radiation and matter rare
- thermal equilibrium <u>not</u> valid – in fact ISM conditions far from equilib.

- heating
  - stellar photons (uv)
  - high energy photons (x-rays) and particles (cosmic rays)
  - shocks (from supernovae, novae, young star jets, winds)
  - gas/grain interaction

- cooling
  - for gas, collisional excitation followed by <u>radiative</u> de-excitation
  - atoms and molecules
  - for dust, thermal ``blackbody" emission
  - optically thin path for photons to escape surrounding gas/dust

1. Stars inject   momentum, kinetic energy, photons, magnetic field into the ISM
2. Towards the end stars injenct new elements
3. Explosive endings inject cosmic rays and newly synthesized elements
4. Need to trace birth to death of stars

Energy Densities in the Local ISM

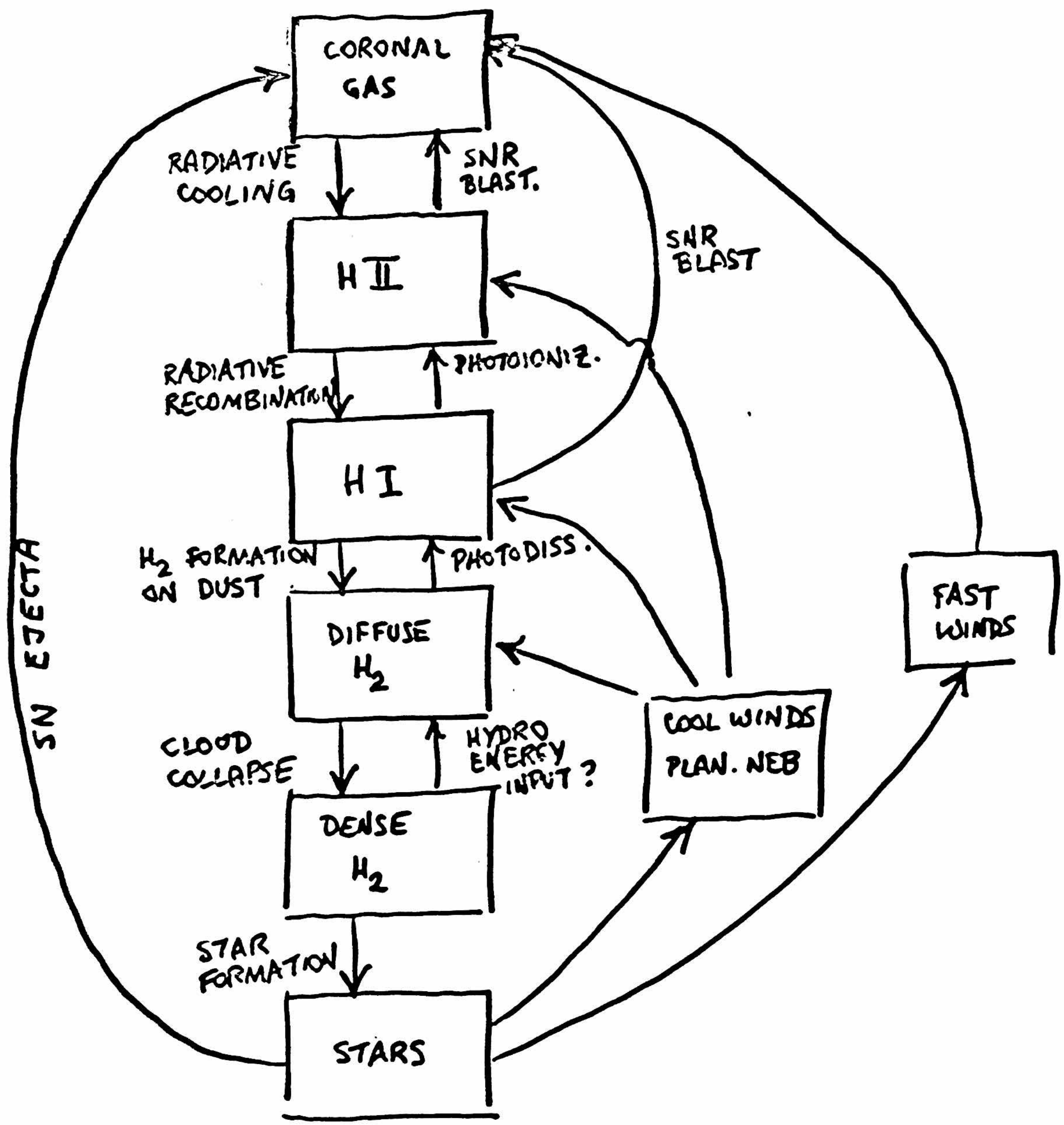
- u is energy density in erg / cm^3 or eV / cm^3
- many contributors, and all but CMB are coupled:

		eV / cm^3
$u_{thermal}$	3/2 P	0.4
u_{hydro}	$\frac{1}{2} \rho v^2$	0.18
$u_{magnetic}$	$B^2 / 8\pi$	0.22
$u_{star\ light}$	sum of planck functions	0.5
$u_{cosmic\ rays}$	empirical (from voyager)	1.8
$u_{CMB\ radiation}$	2.7 K planck function	0.25

NOTE: these numbers are all within same order of magnitude!

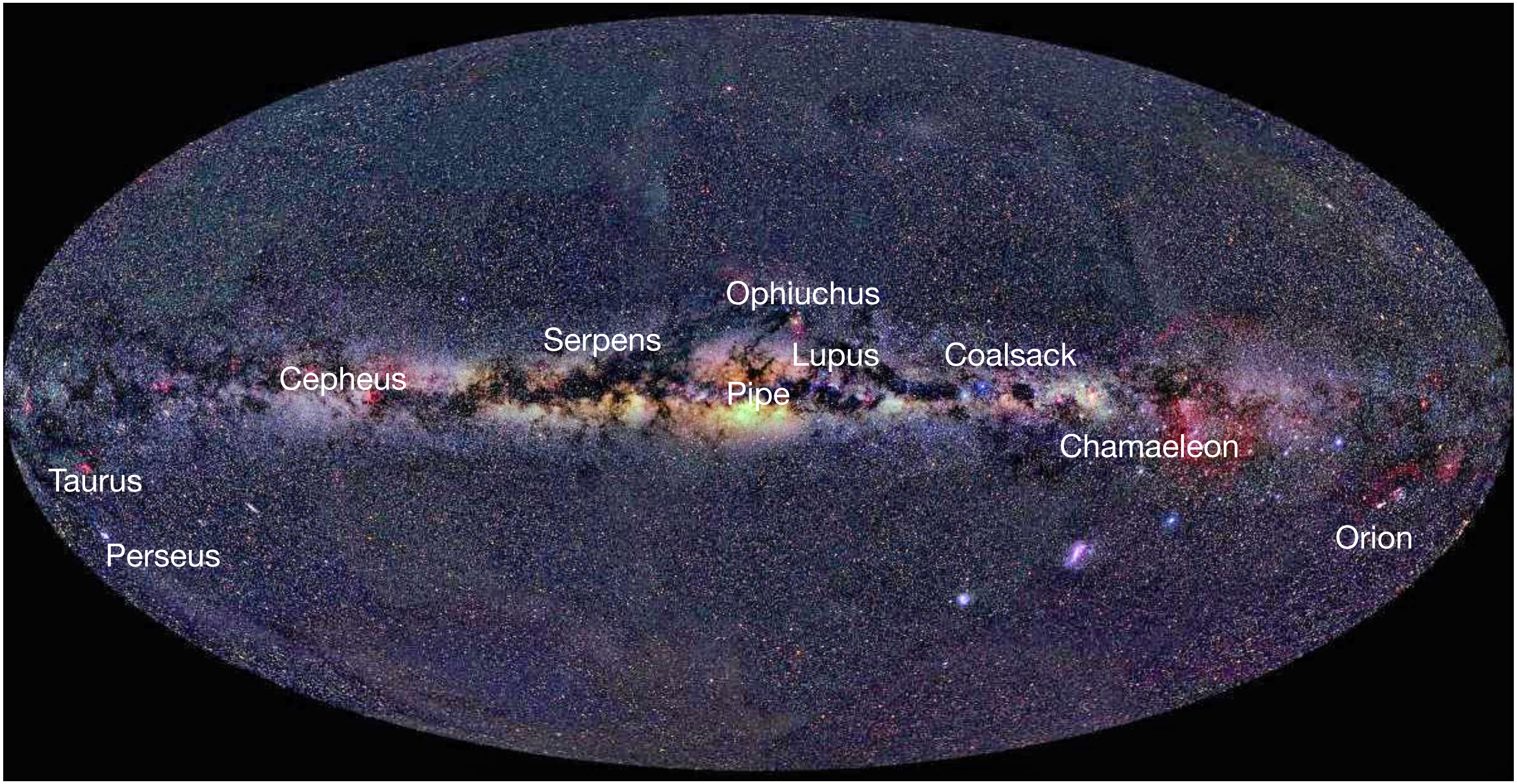
Conditions can be very different in other ISM environments.

MASS FLOW AMONG PHASES OF ISM



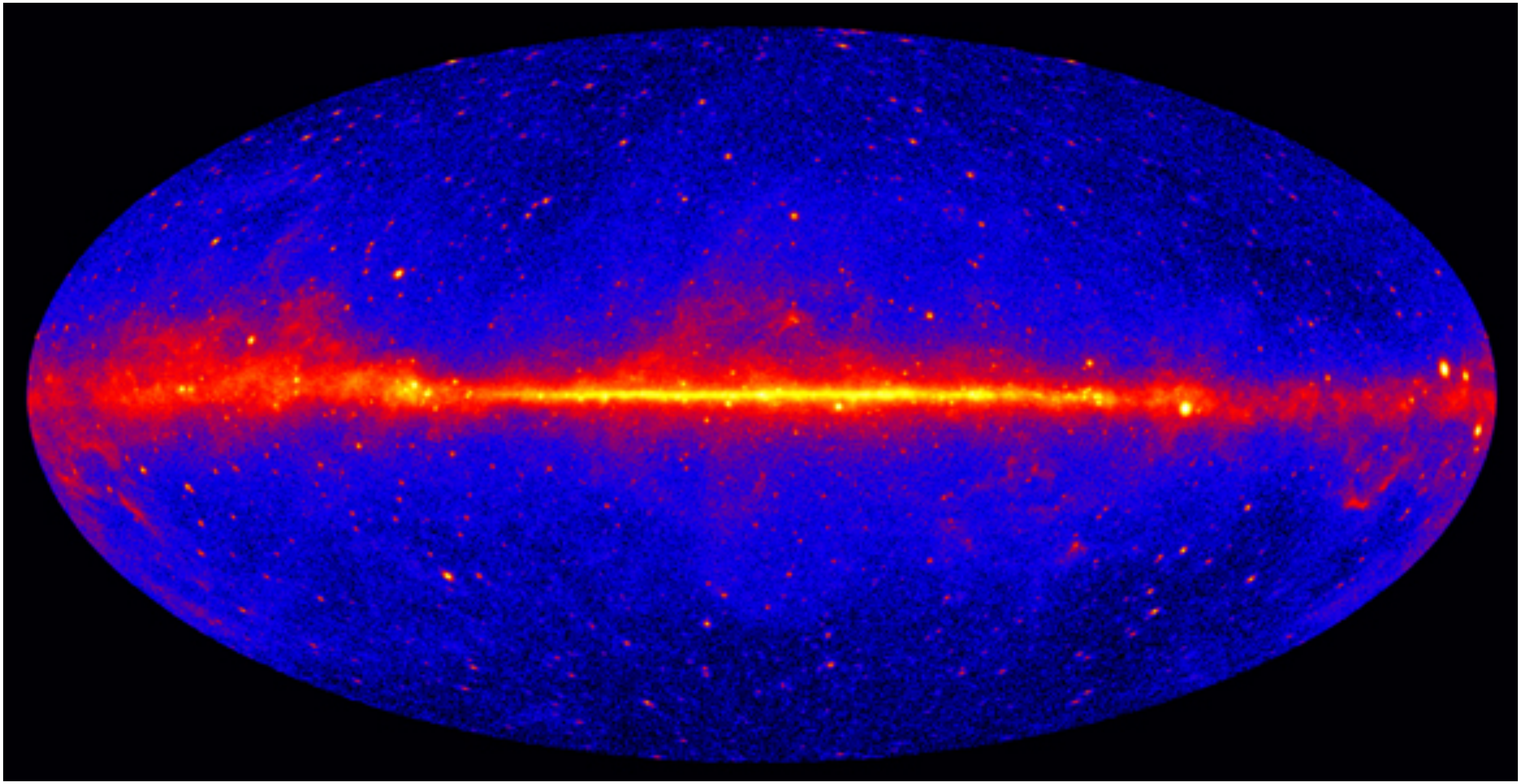
B. Draine

Halpha emission

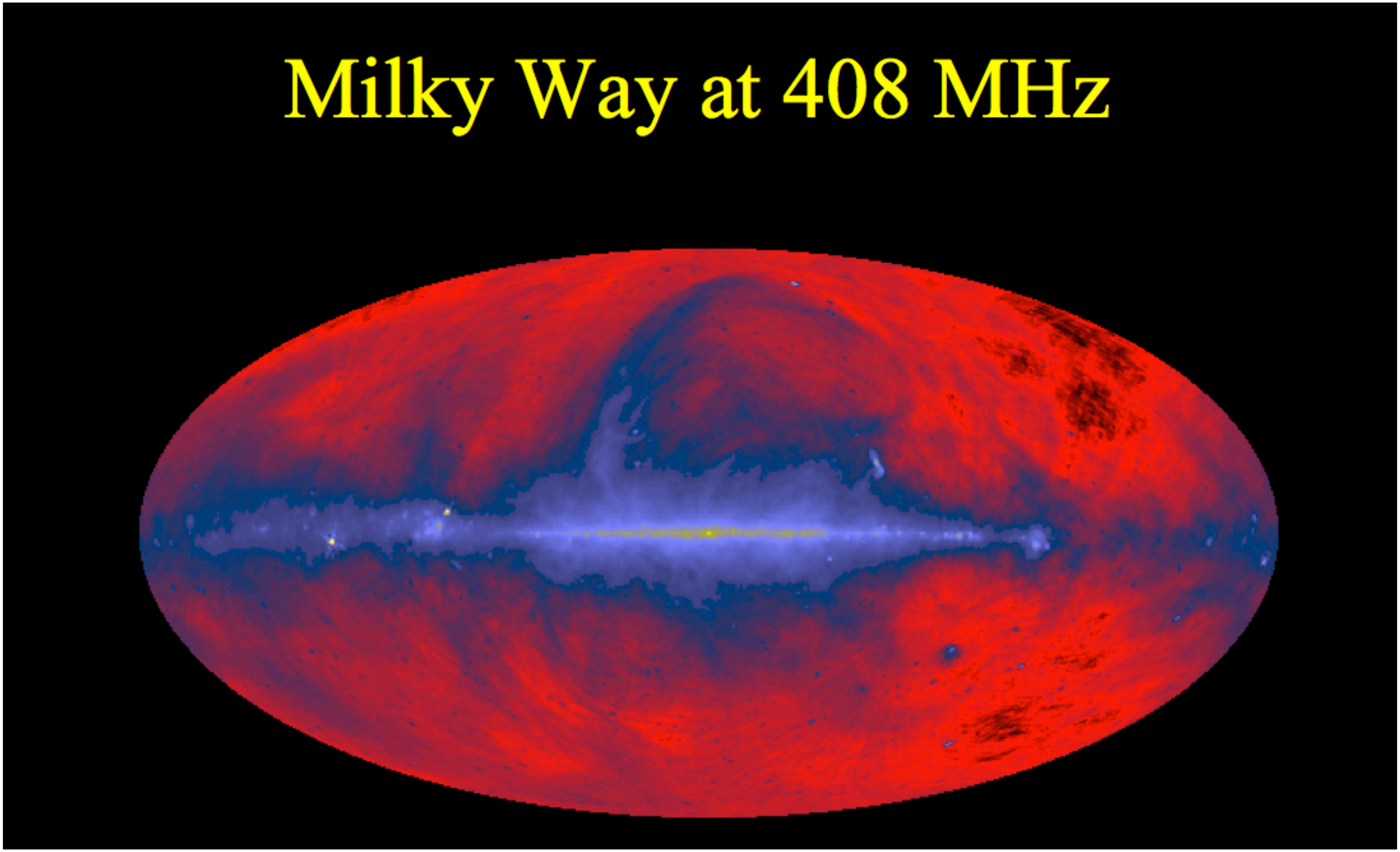


A. Mellinger / APOD

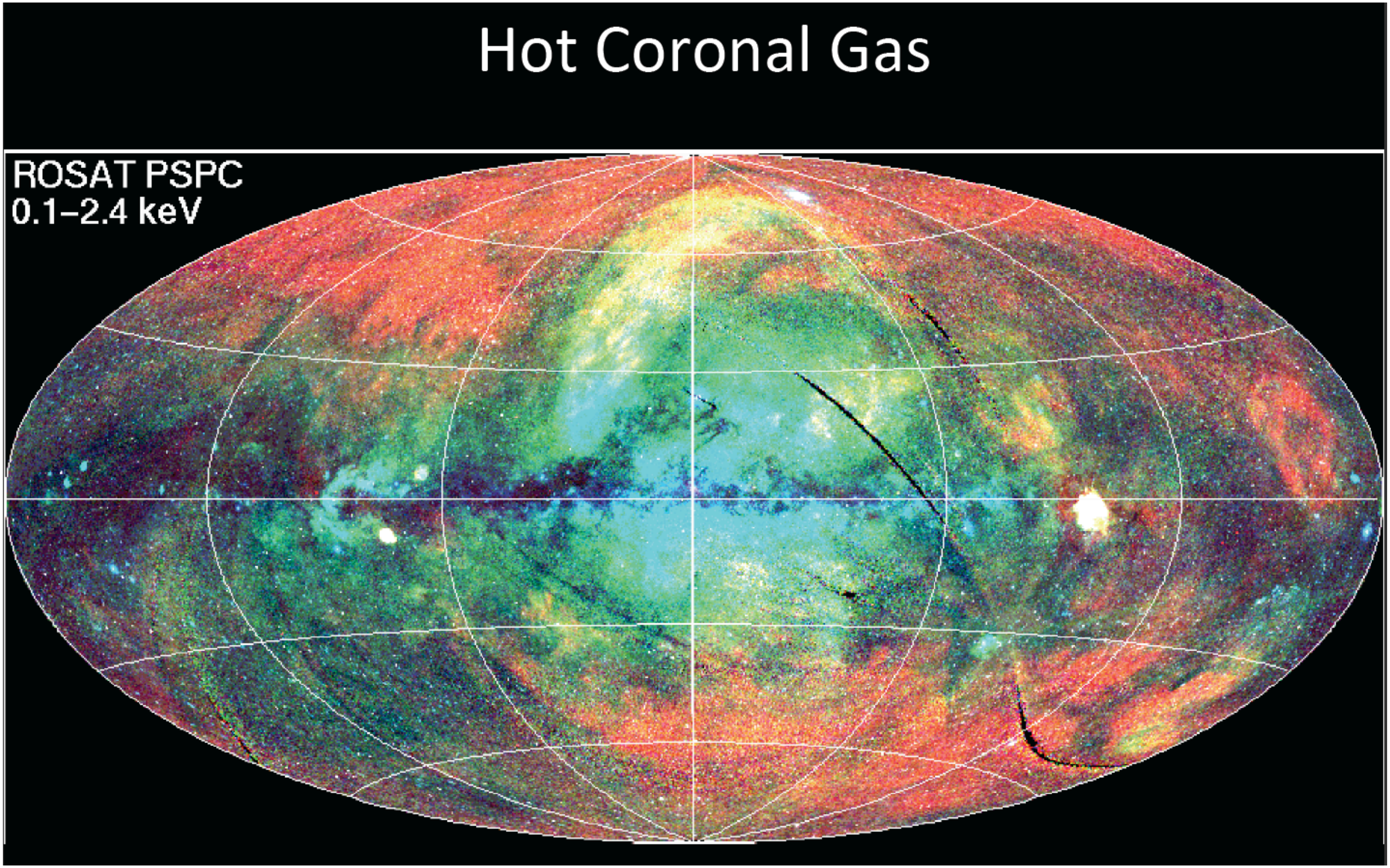
Fermi (gamma ray) All-Sky Image



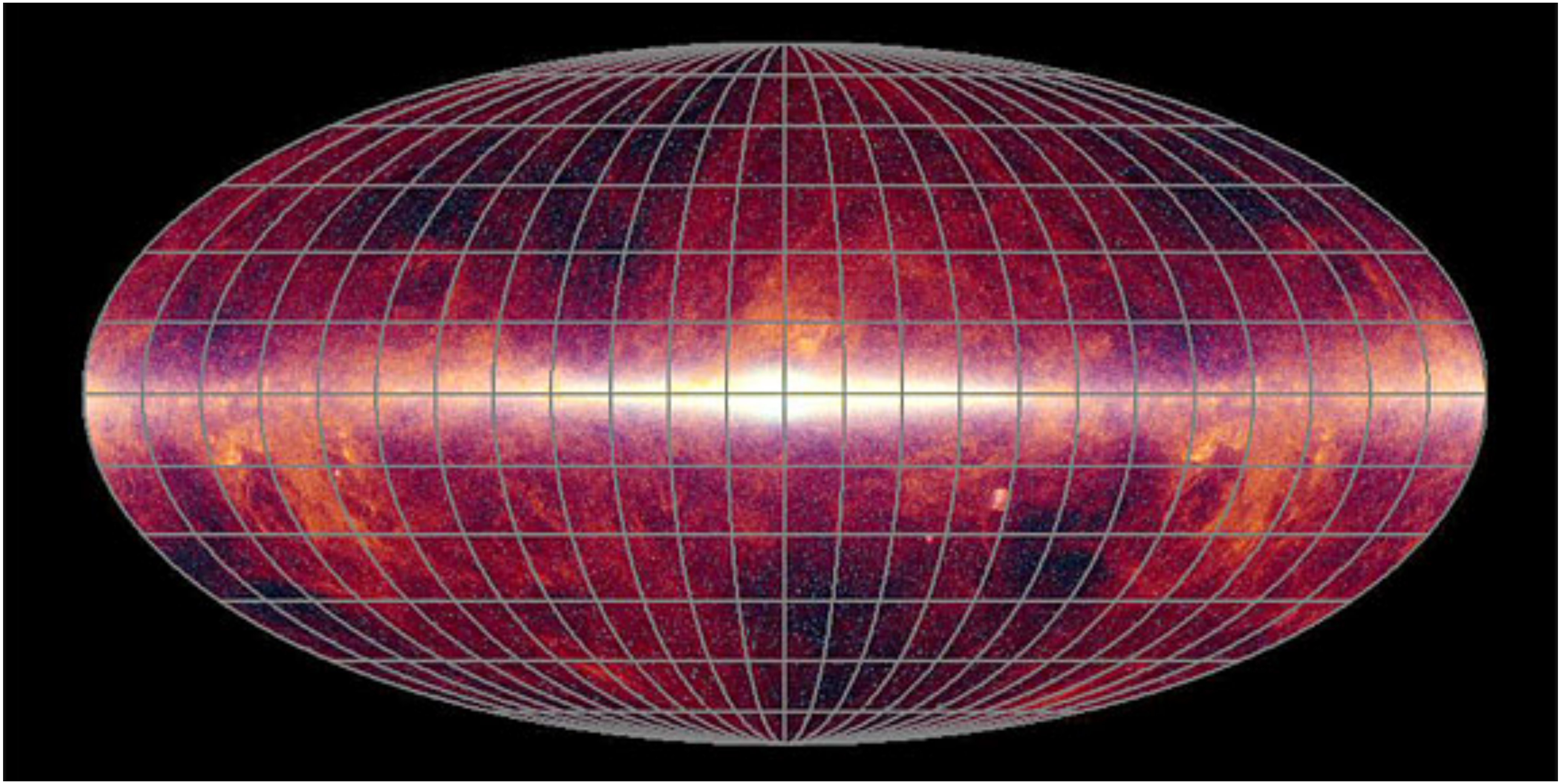
Non-thermal emission at 0.7 m (radio)



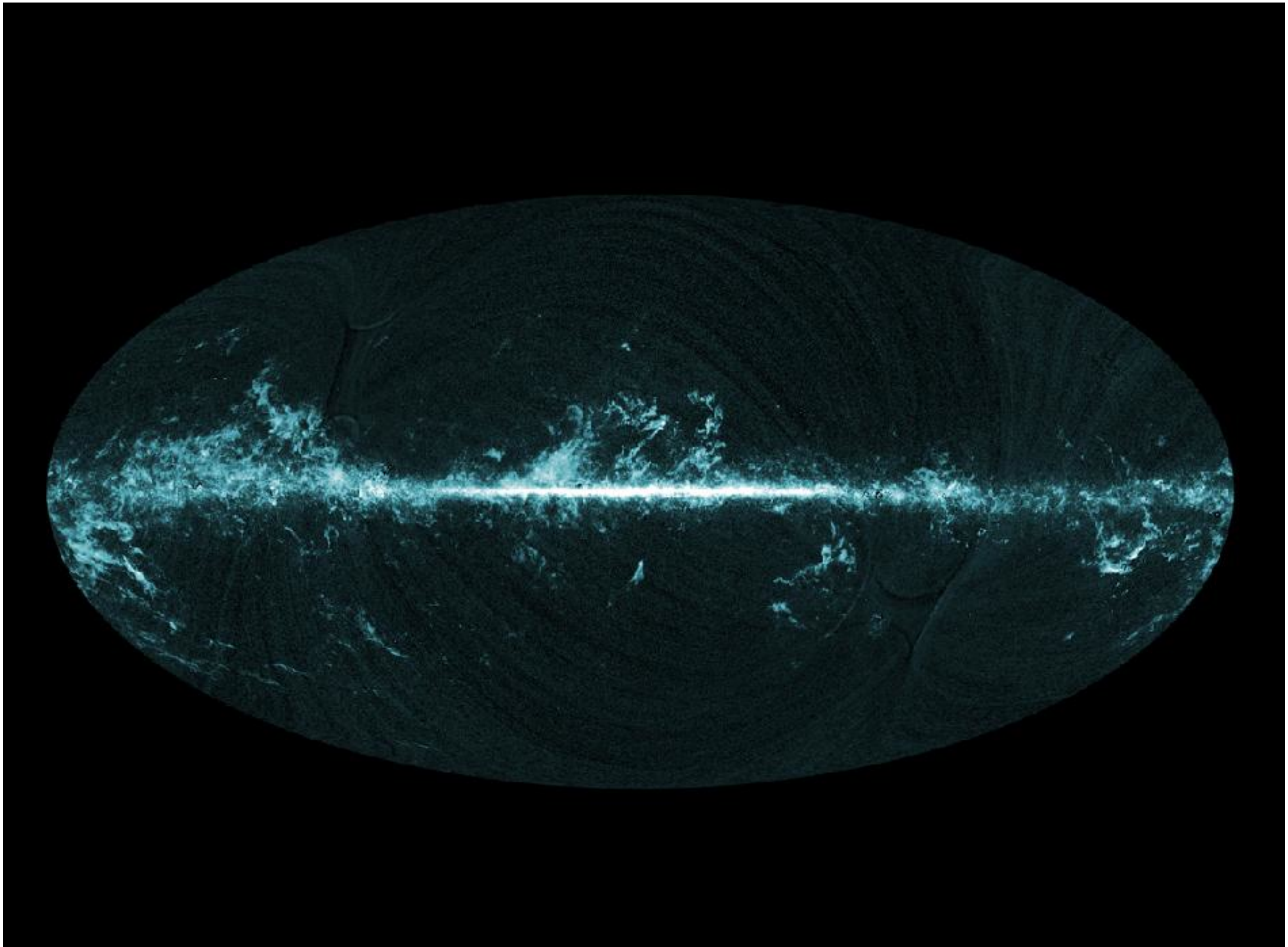
ROSAT (x-ray) All-Sky Image



WISE (mid-infrared) All-Sky Image



Planck's "CO map" at 3mm

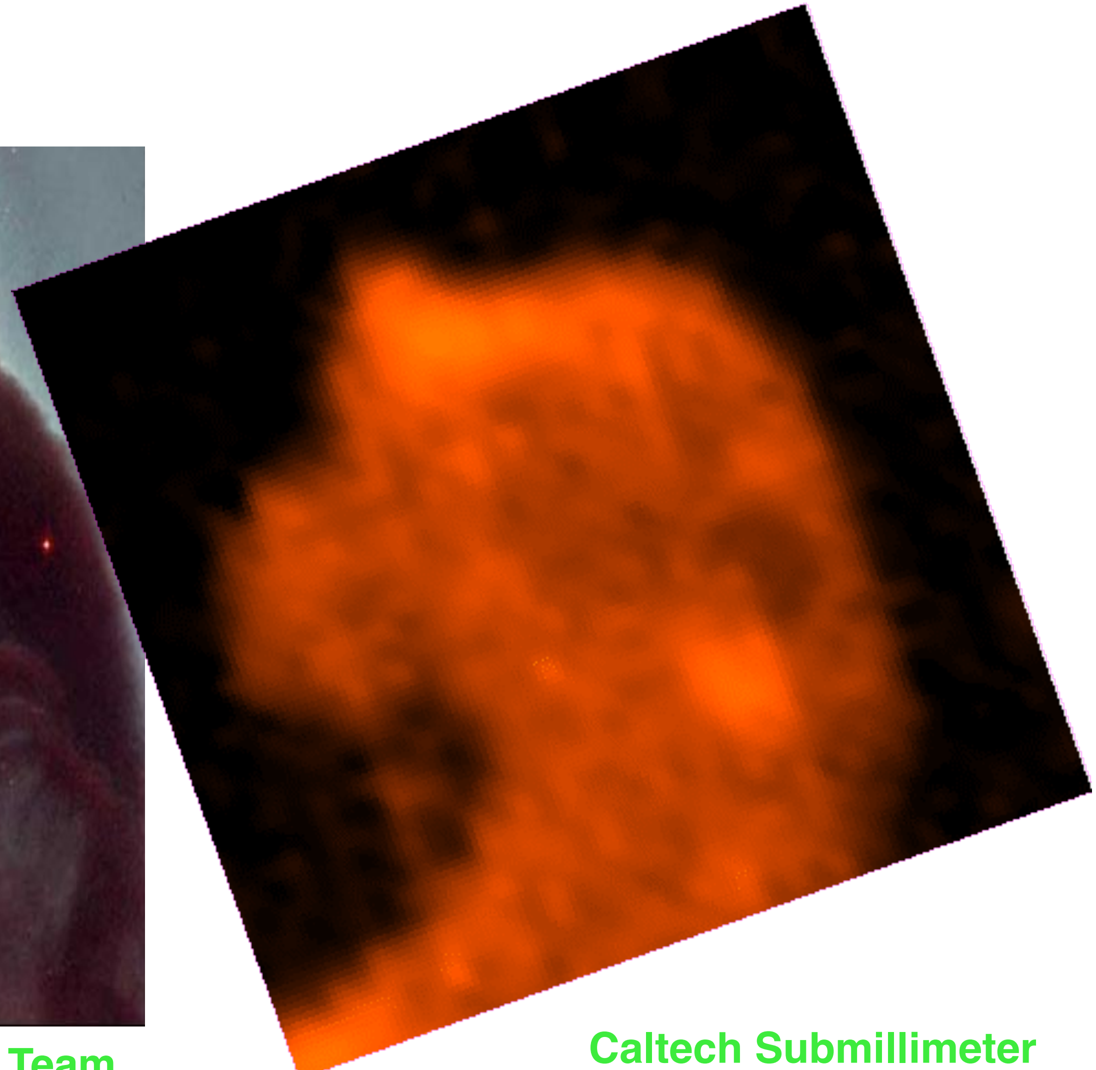


Birth to Death

Molecular gas (CO J=3-2) image

Optical image

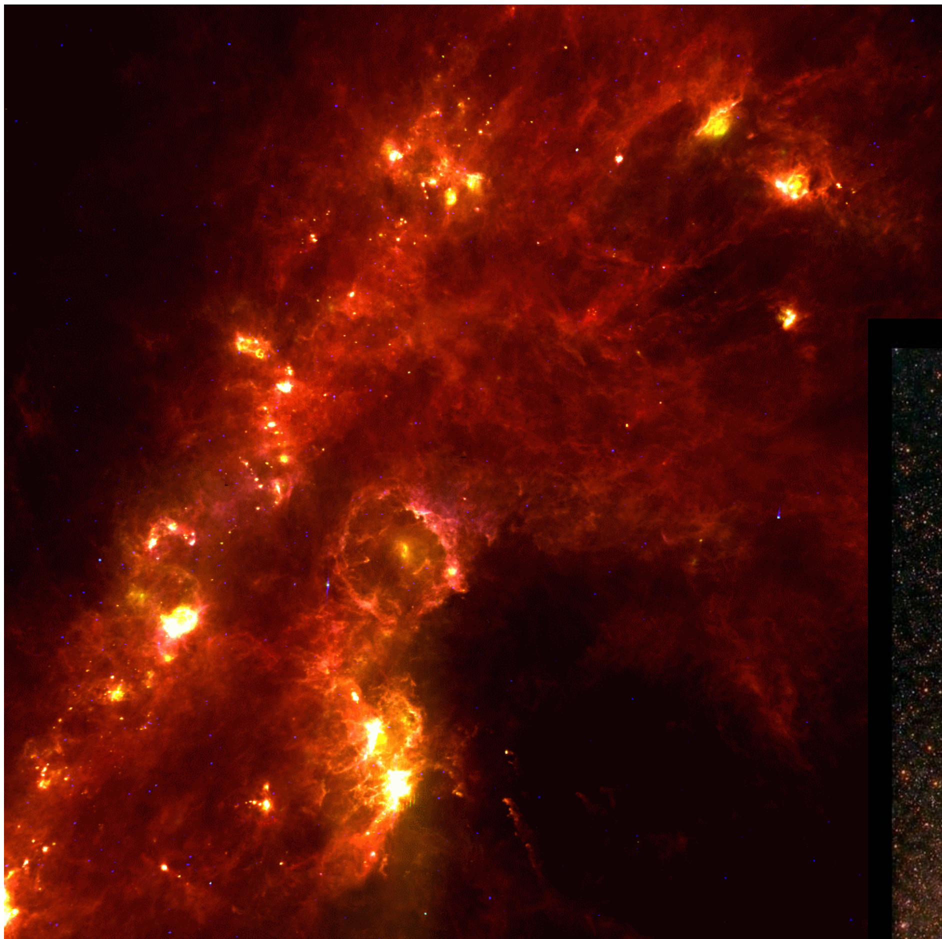
NASA, Hubble Heritage Team



Caltech Submillimeter Observatory

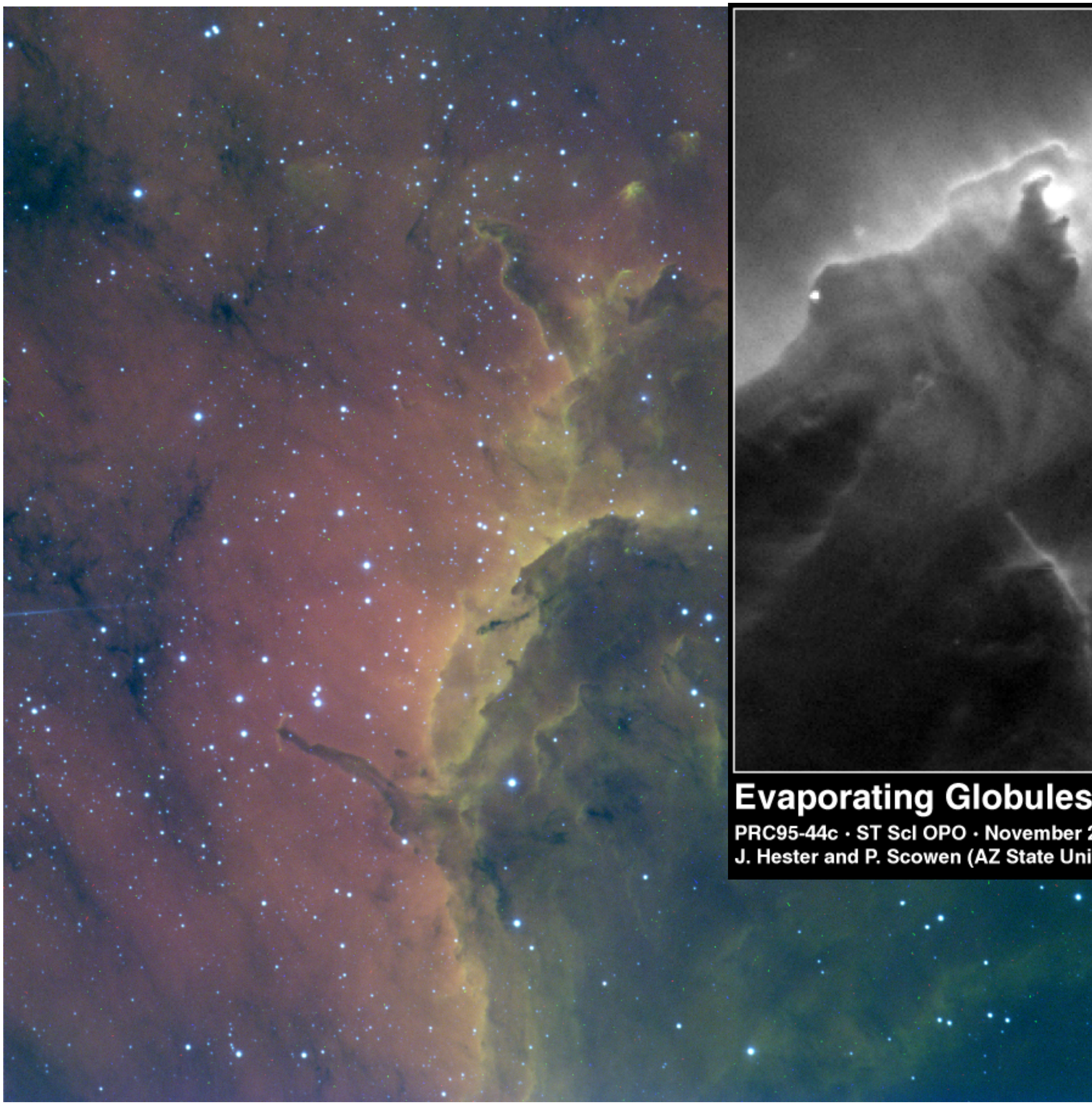
A dark nebula

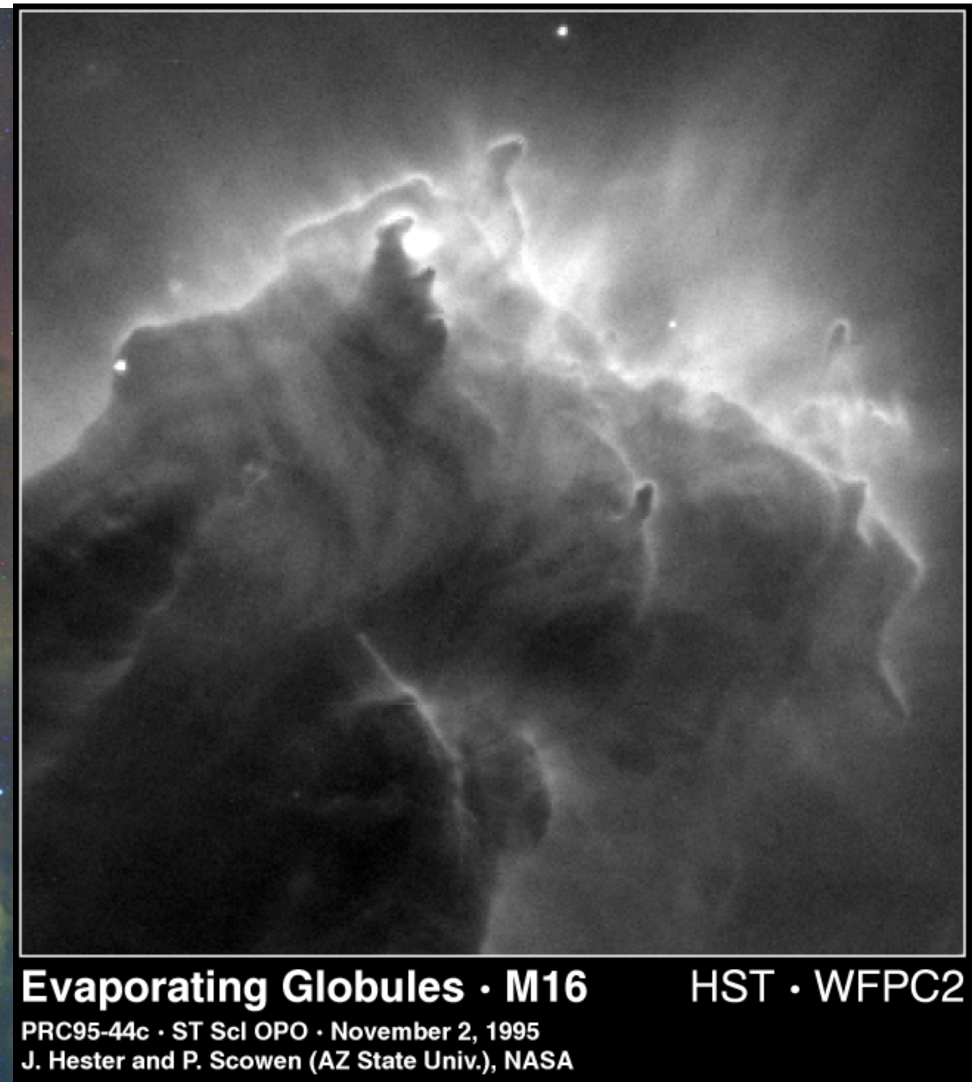
Perseus-Taurus-Orion Region



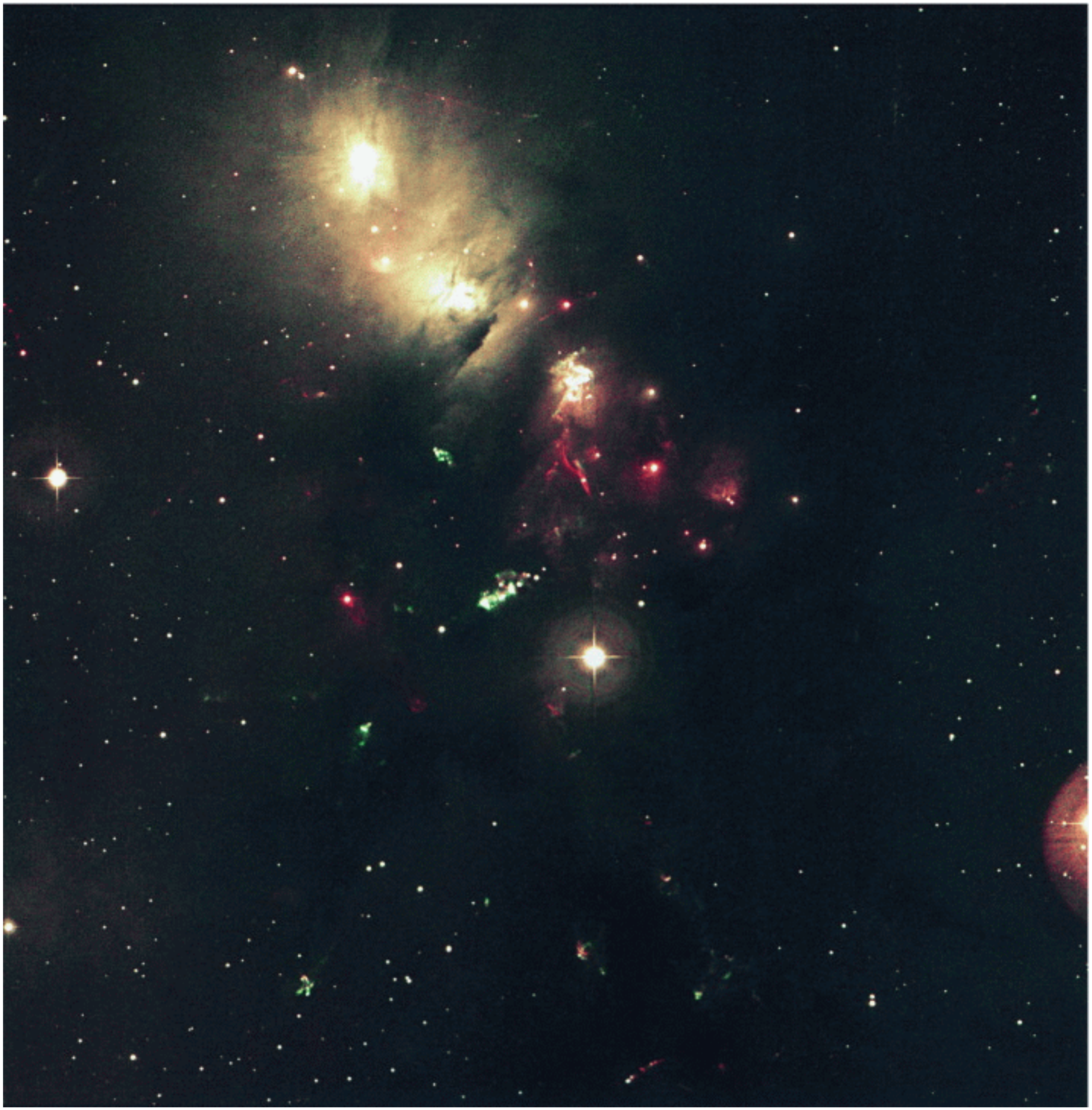
mid-infrared: dust emission

optical: - stars
- dust absorption
- gas (H-alpha emission)





A photon-dominated region (PDR)

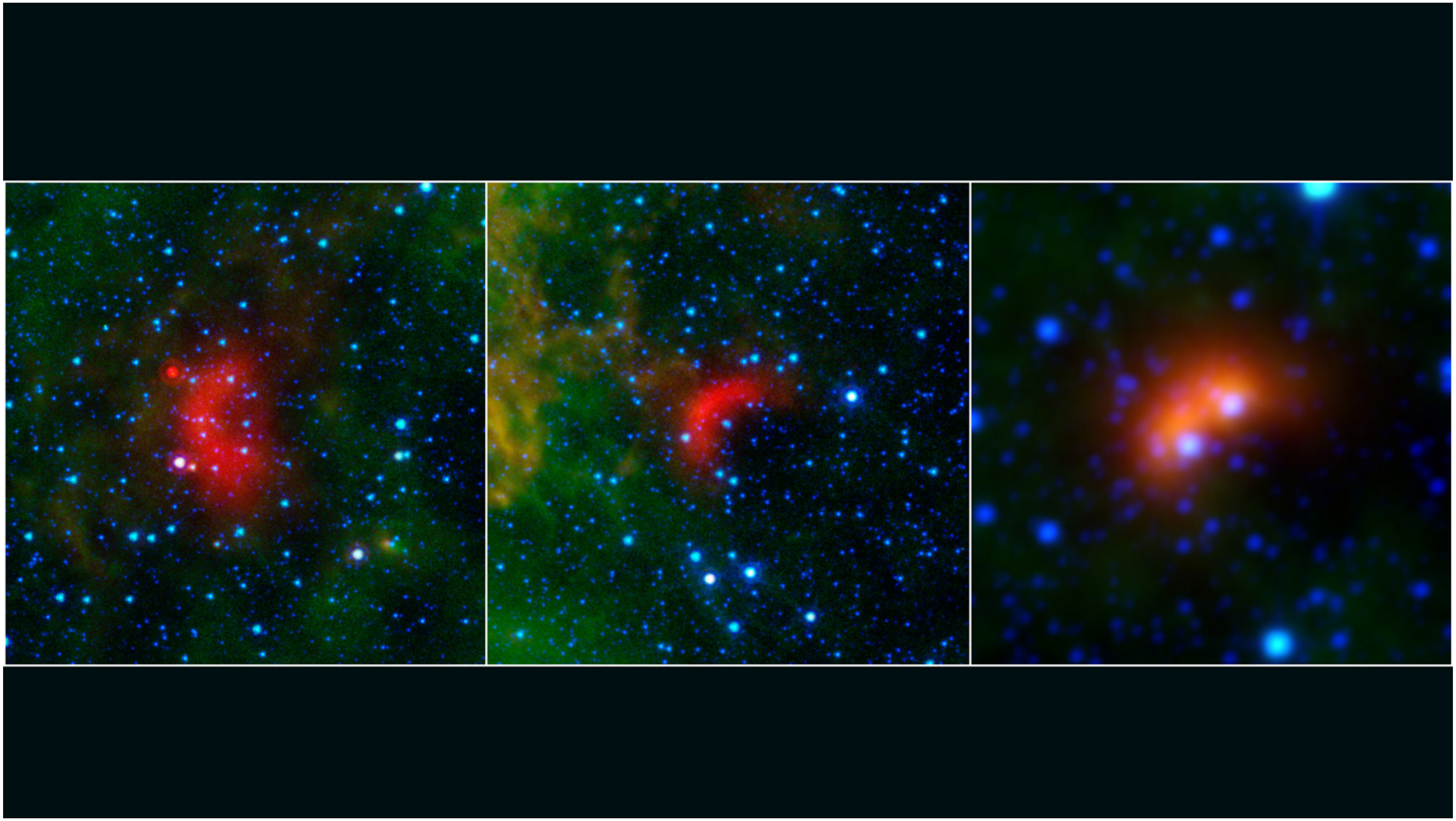


Jets from young stars shock the ambient ISM

An ionized or "HII" region associated with the formation of massive stars.

Pleiades Star Cluster

A reflection nebula



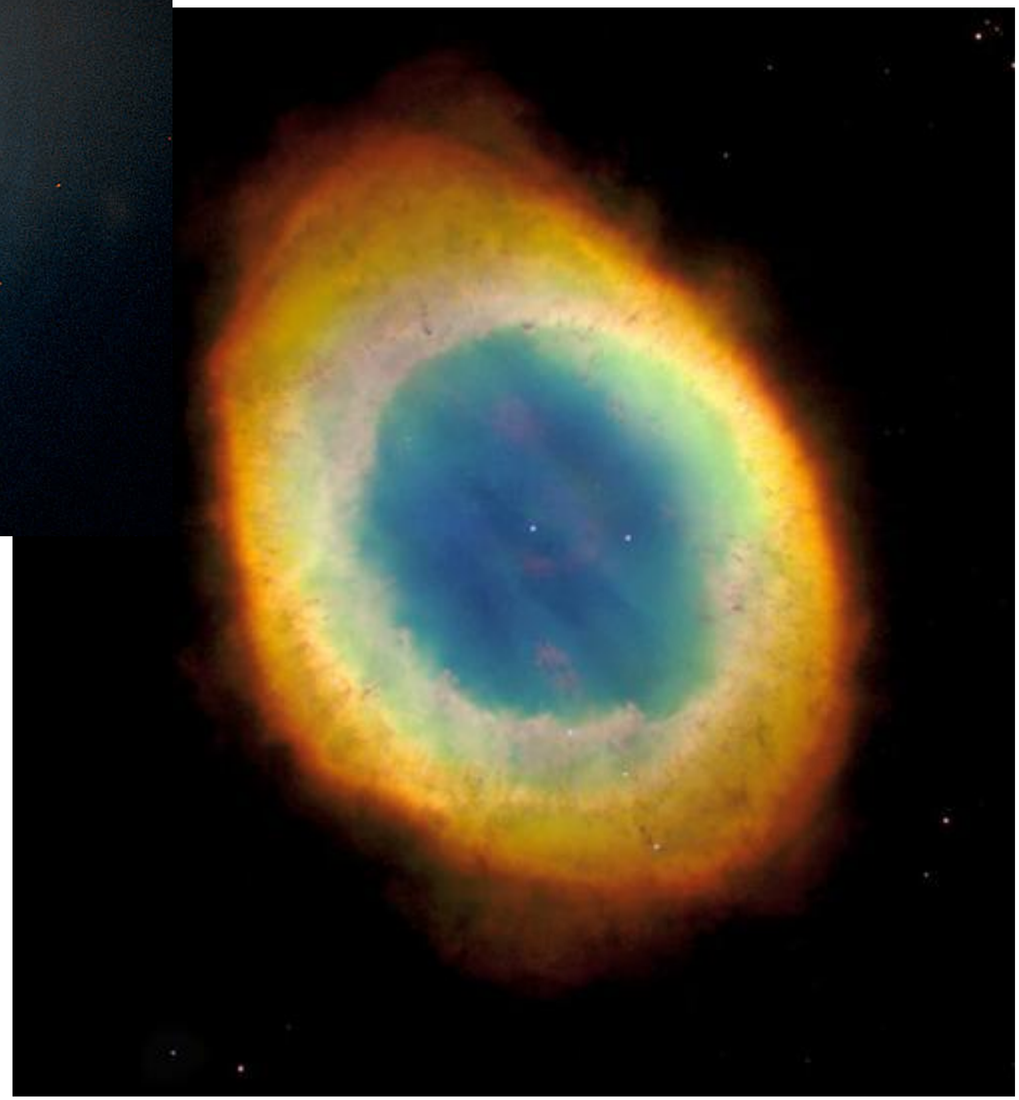
Bow shocks thought to mark the paths of massive, speeding stars are highlighted in these images from NASA's Spitzer Space Telescope and Wide-field Infrared Survey Explorer, or WISE.Cosmic bow shocks occur when massive stars zip through space, pushing material ahead of them in the same way that water piles up in front of a race boat. The stars also produce high-speed winds that smack into this compressed material. The end result is pile-up of heated material that glows in infrared light. In these images, infrared light has been assigned the colored red.Green shows wispy dust in the region and blue shows stars .The two images at left are from Spitzer, and the one on the right is from WISE. The speeding stars thought to be creating the bow shocks can be seen at the center of each arc-shaped feature. The image at right actually consists of two bow shocks and two speeding stars. All the speeding stars are massive, ranging from about 8 to 30 times the mass of our sun.

Wind bubbles

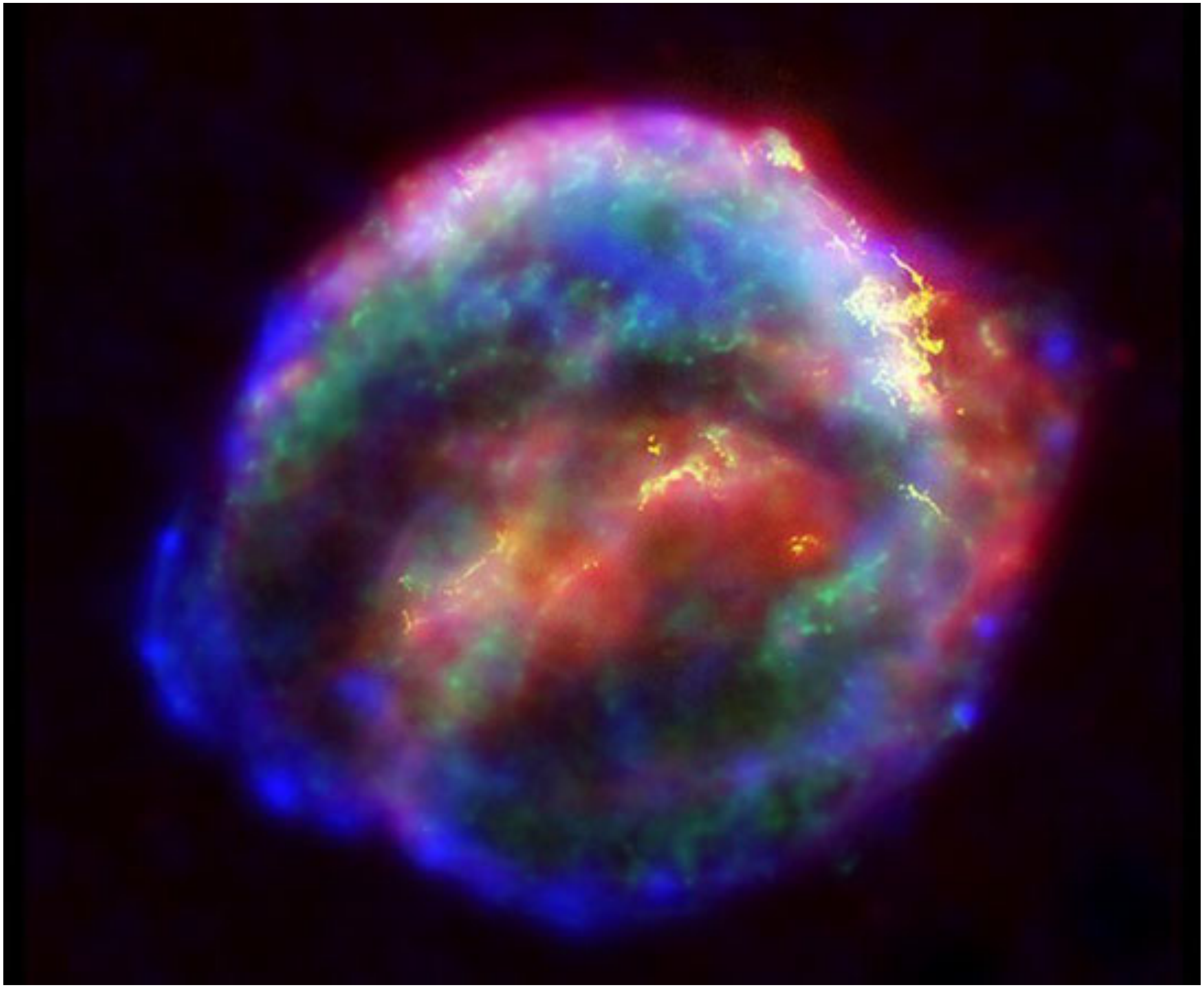
Sharpless 308, diameter = 3x full moon, central Wolf-Rayet star, M = 45 Msun, d = 3 pc

NGC 7635 “bubble nebular”, Casiopeia, central O-star, d = 4 kpc

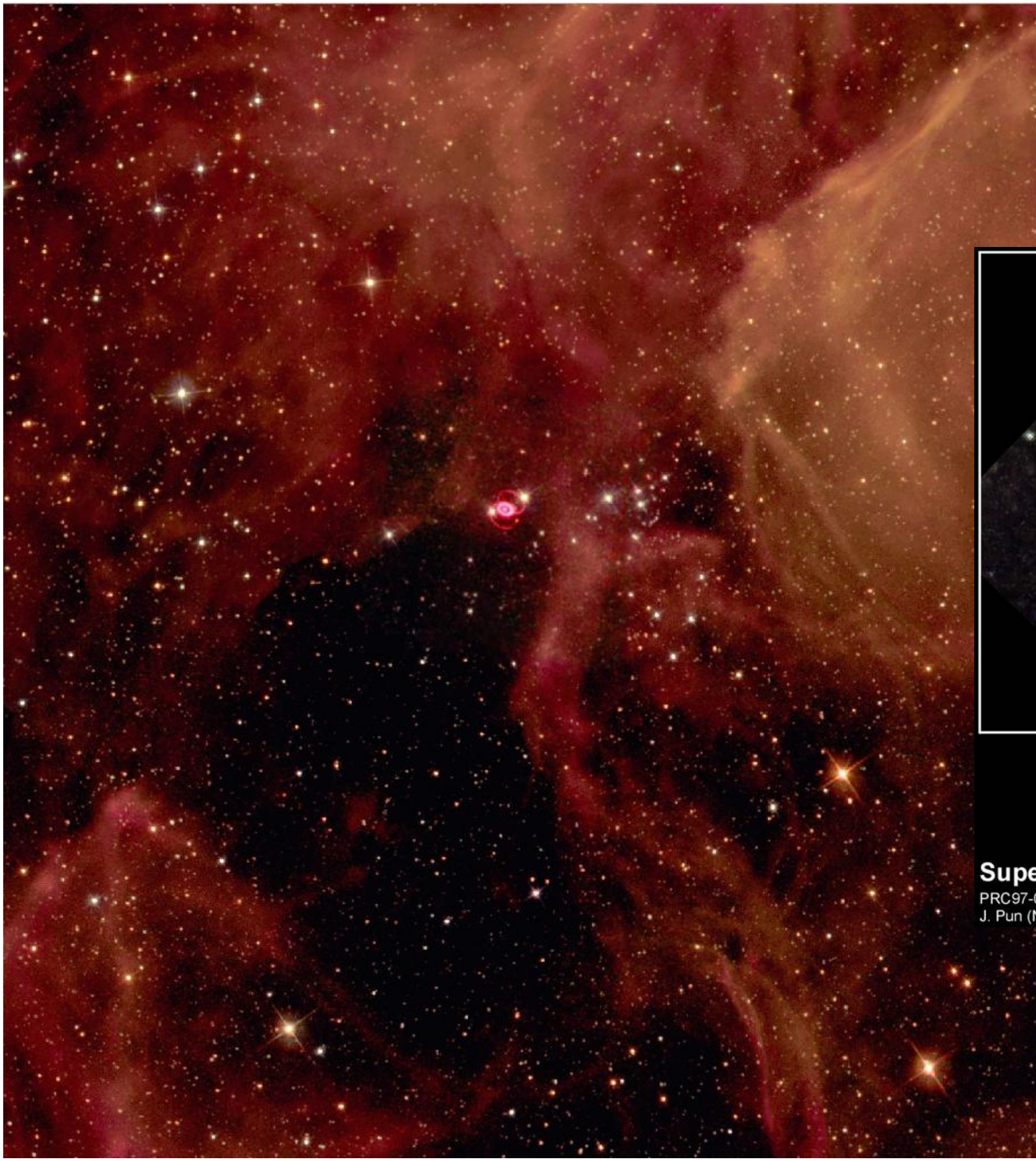
Crescent Nebula, surrounding the Wolf-Rayet star WR136

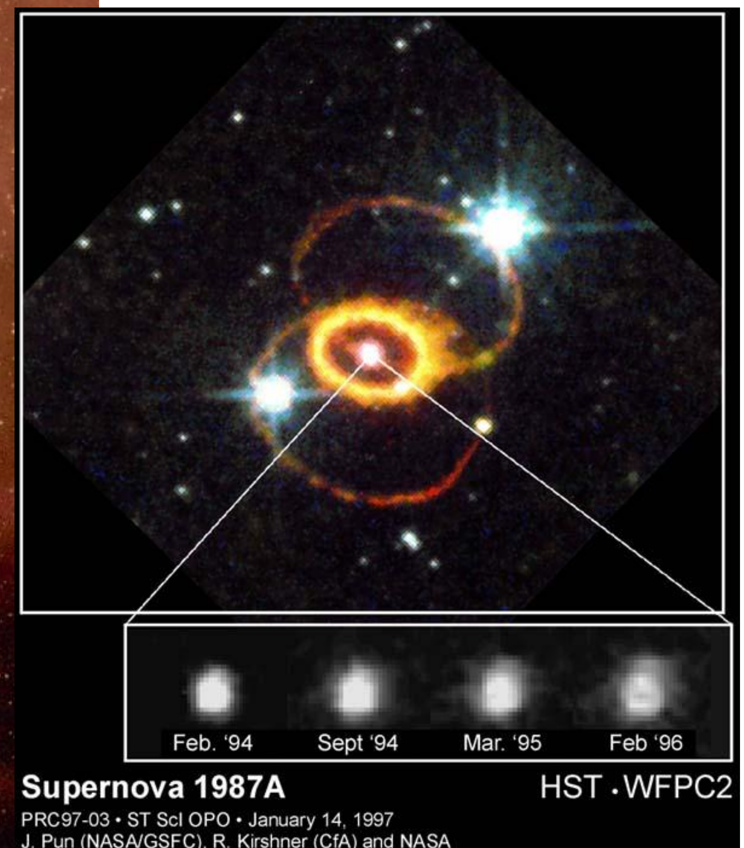


Ejecta from evolved stars

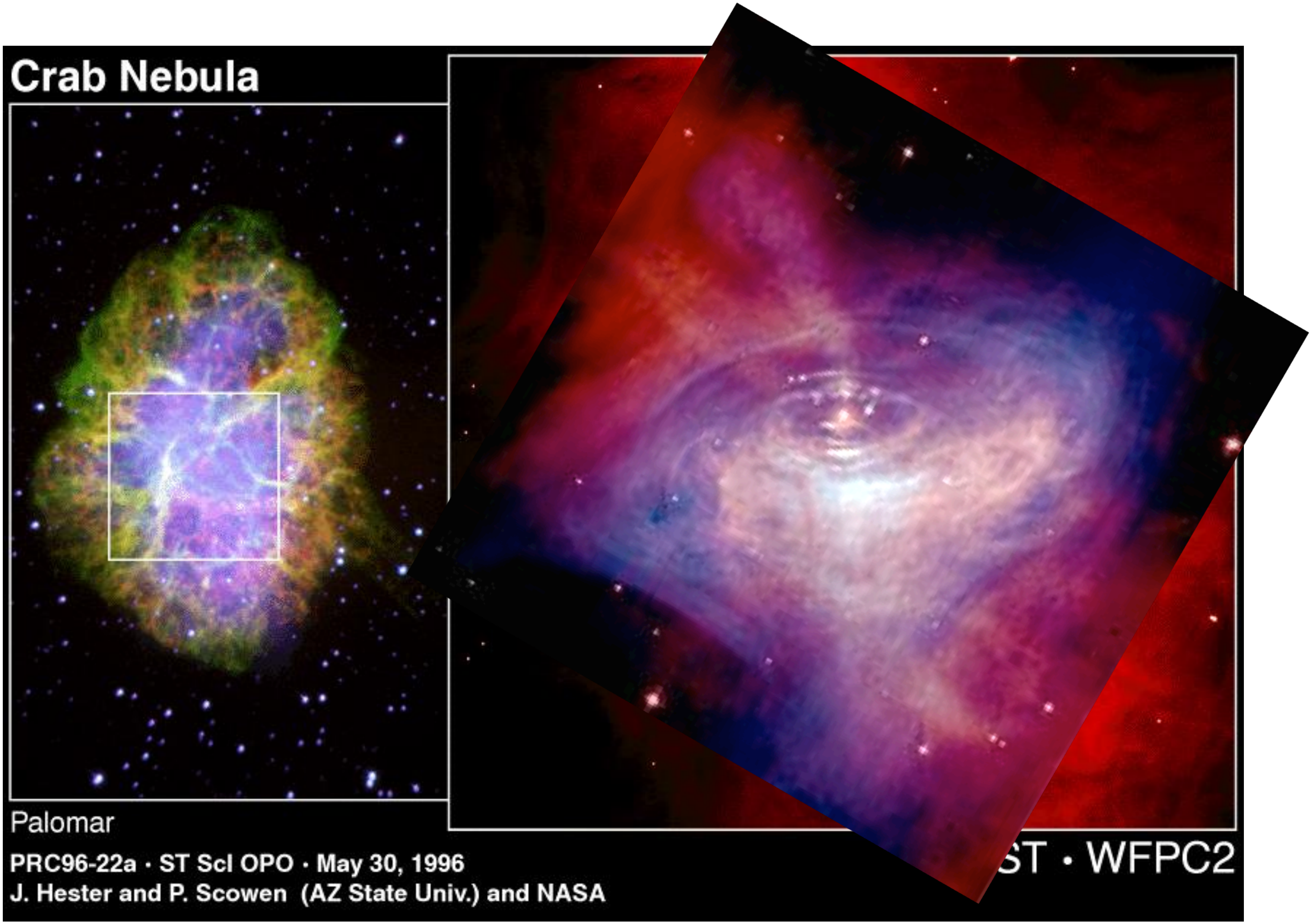


An image of the Kepler supernova remnant (seen by Kepler in 1604), taken in three wavelengths: visible (yellow; Hubble), infrared (red; Spitzer), and X-ray (blue; Chandra). New analyses of the X-ray images allow scientists to determine the most probable distance to the object: about twenty-one thousand light-years. Credit: NASA Chandra/Spitzer/Hubble





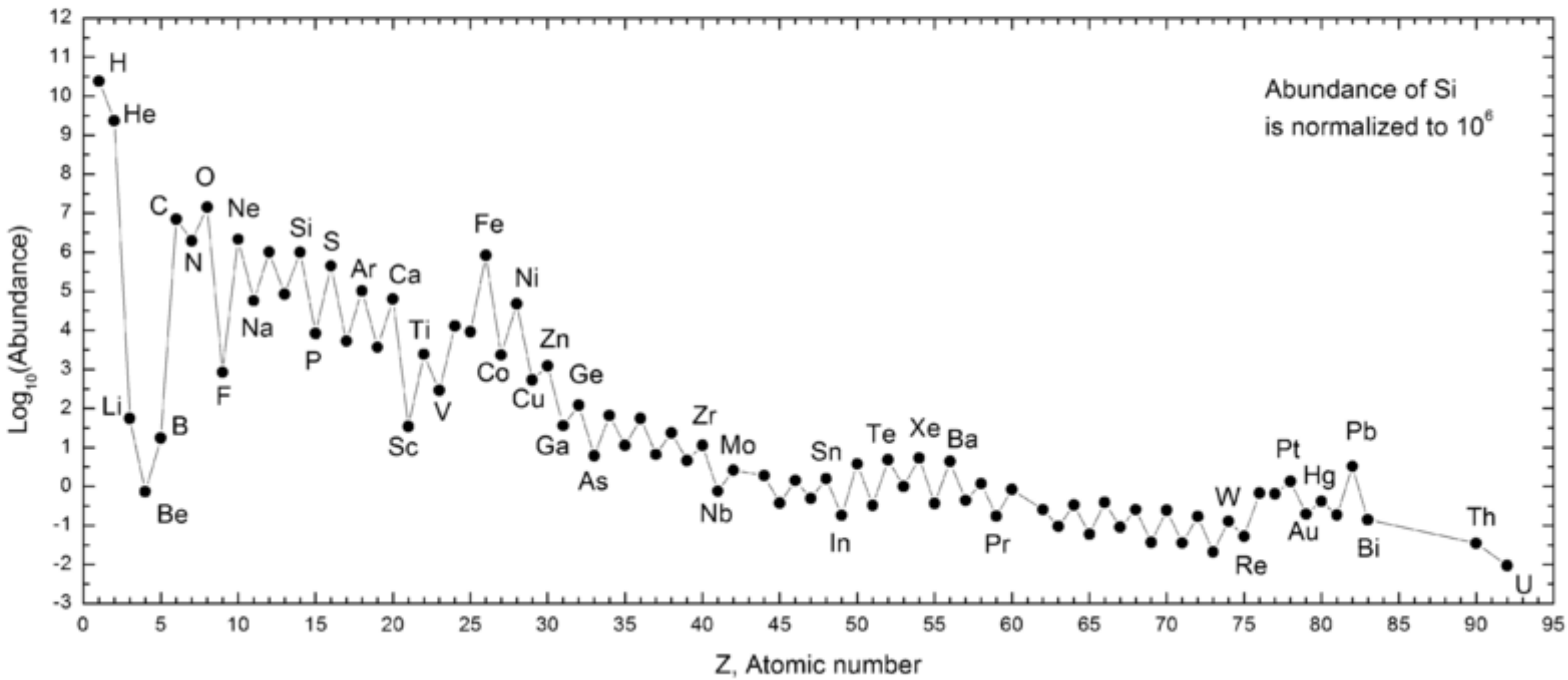
Supernova blast wave



Supernova recorded by Chinese astronomers in 1054 – we know the age!
Contains Crab Pulsar at 30 msec - movie

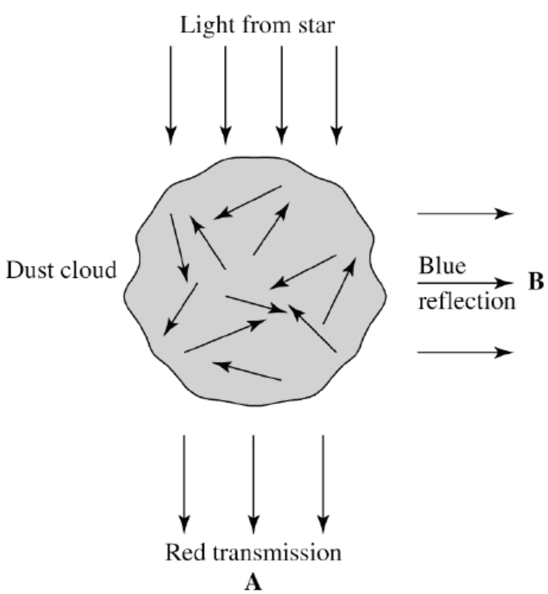
Other than H (& He)
"Metals" & Dust

Detailed abundance pattern of the baryonic matter matters!



Dust

- only 1% of the ISM, but high impact
- vehicle for formation of molecules
- role in heating/cooling of ISM
- extinction = absorption and scattering of starlight (wavelength dependent – more at smaller λ)



extinction:

$$I_\lambda = I_{\lambda 0} e^{-\tau_\lambda}$$

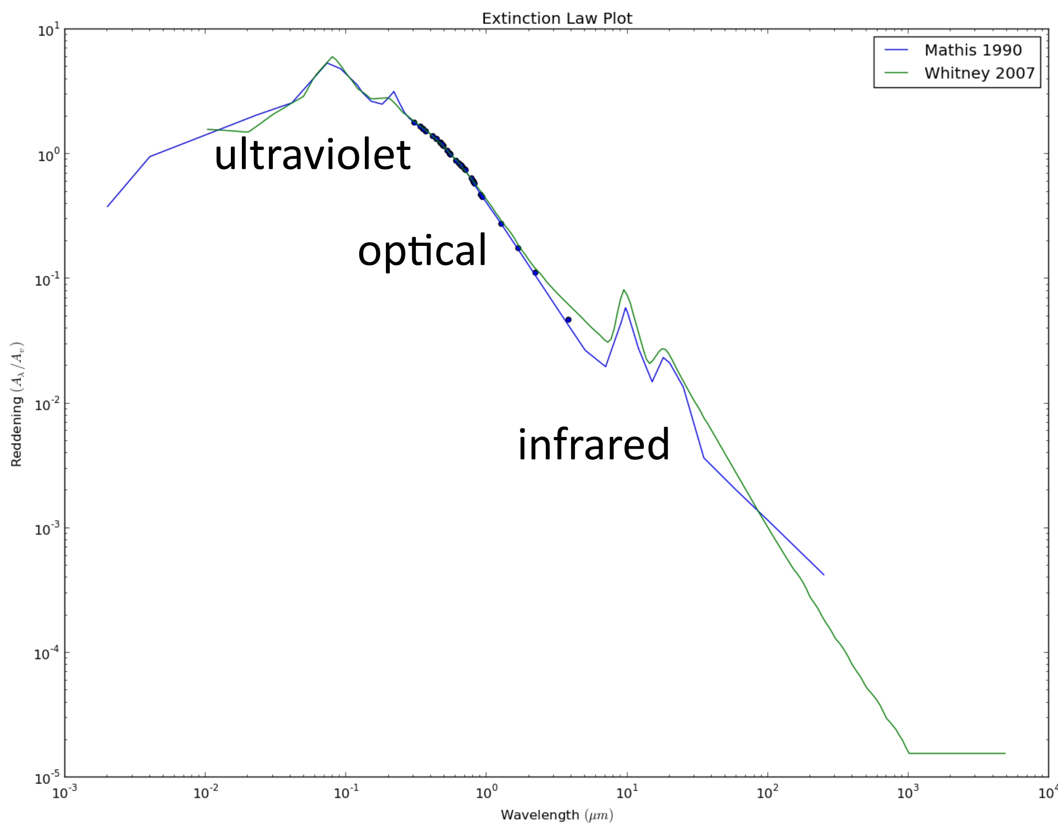
I_λ: intensity at λ

τ_λ: optical depth at λ

Extinction Law

$$m = M + 5 \log d - 5 + A$$

apparent magnitude; absolute magnitude; distance in pc; extinction



- Dust absorbs, heats up, and then re-radiates photons, and it also scatters them out of the line of sight.
- There is a general relationship between extinction and wavelength but exact form depends on grain size distribution and composition.
- Usually quote in terms of A_V or "extinction" at optical wavelengths. But depending on how determined, may be reported as e.g. A_J or A_K.