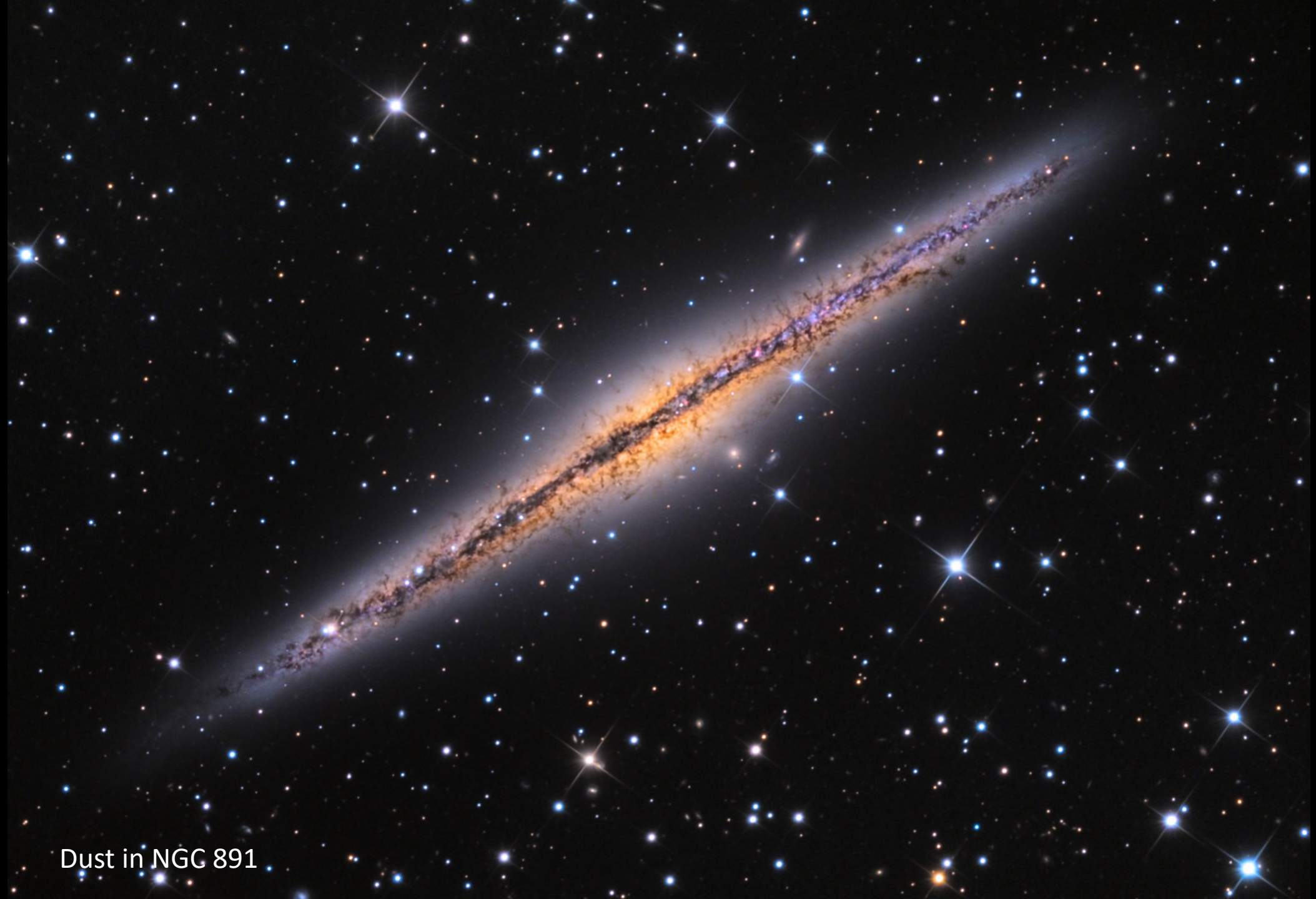
Dust in the Milky Way



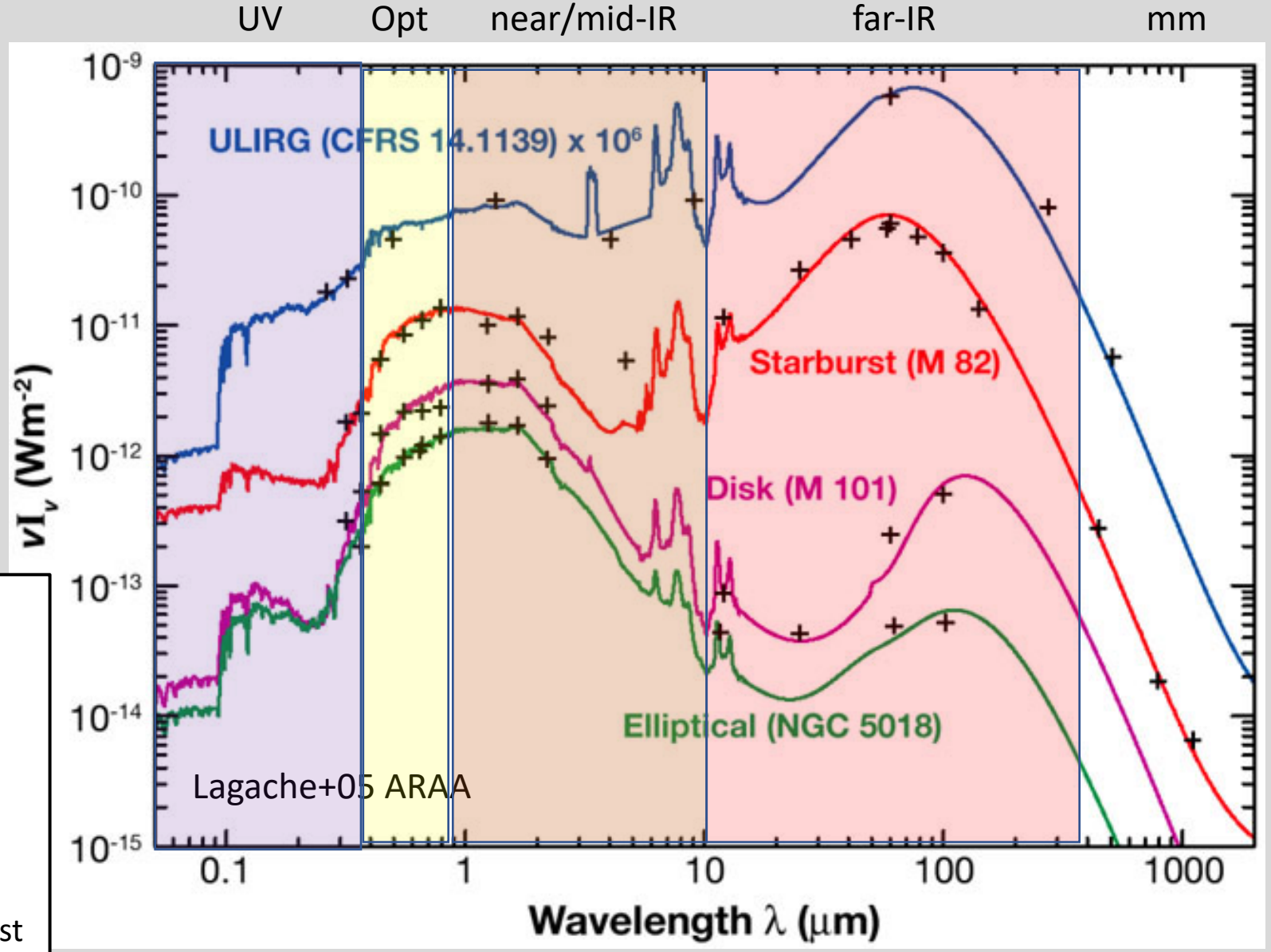
Dust in NGC 891

Dust in NGC 891

Thermal emission from dust

Dust absorbs radiation from stars and AGN, heats up, reradiates **blackbody emission** in the far infrared.

Far-IR emission traces starburst/AGN activity



Example spectra ⇒

- **Elliptical:** very little dust /star formation
- **M101:** normal spiral galaxy
- **Starburst:** High star formation rates
- **ULIRG** (ultra-luminous infrared galaxy): dust heated by intense starburst and/or AGN.

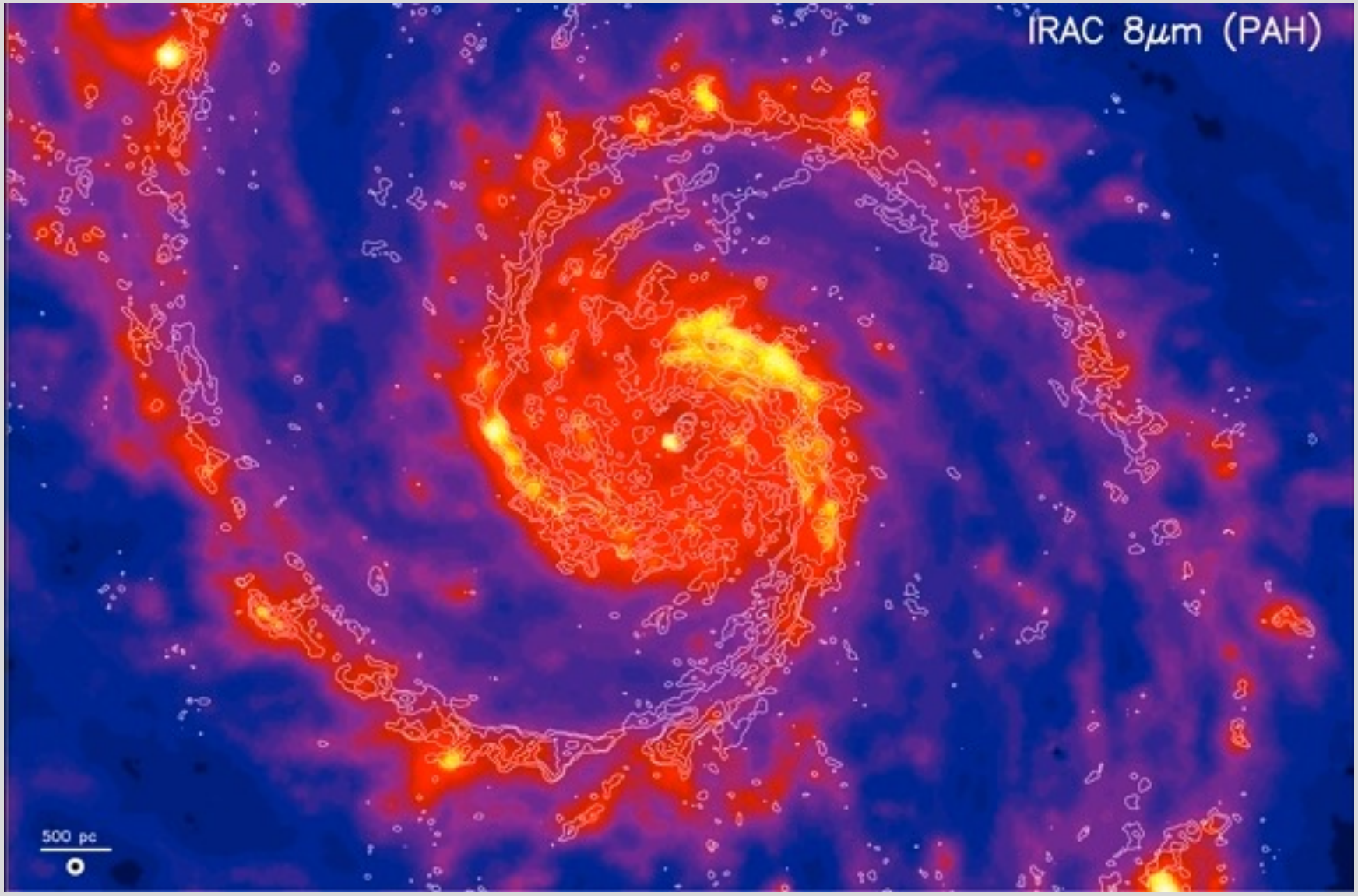
Thermal emission from dust

Dust grains also produce broad **emission lines** in the mid-IR.

PAH emission: “Polycyclic Aromatic Hydrocarbons”

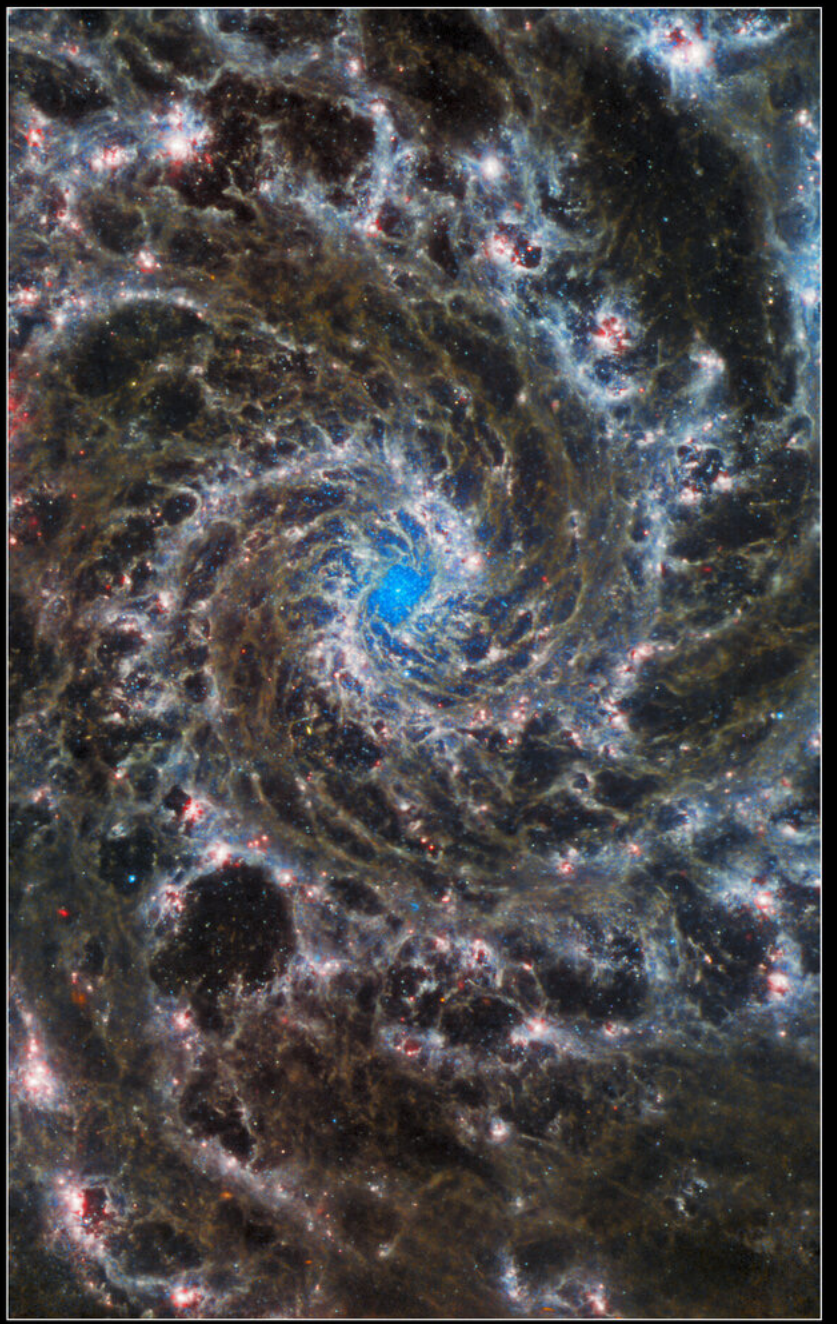
This emission traces warm dust in the spiral arms and nucleus.

PAH emission in M51



Hubble / Optical

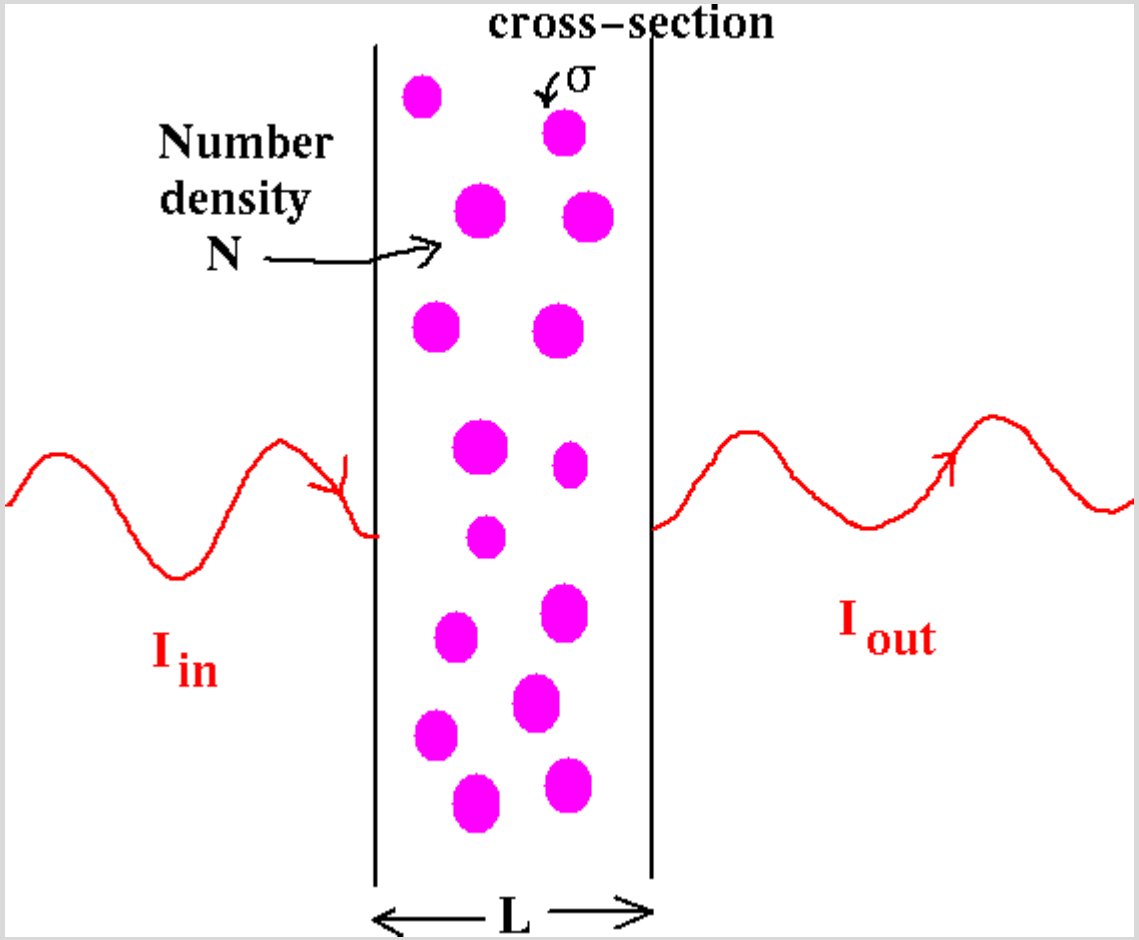
Hubble & Webb



Webb / Infrared

Dust Extinction

Imagine light going through a slab of dust particles



Define optical depth: $\tau = N\sigma L$

then $I_{out} = I_{in}e^{-\tau}$

Working out the extinction in magnitudes

The light is extincted by a factor

$$I_{out}/I_{in} = e^{-\tau}$$

Converting this to magnitudes:

$$\begin{aligned} m_{out} - m_{in} &= -2.5\log(e^{-\tau}) \\ &= -2.5(-\tau)\log e \\ &= 1.086\tau \end{aligned}$$

We define the extinction term in magnitudes as

$$A = 1.086\tau$$

so $m_{out} - m_{in} = A$

In other words, the true apparent magnitude (if there had been no dust) is related to the observed apparent magnitude by

$$m_{true} = m_{obs} - A$$

Reddening and Extinction

Dust extincts more at bluer wavelengths, so it also reddens the light. Define redding as:

$$\underbrace{E(B-V)}_{\text{reddening}} = \underbrace{(B-V)}_{\text{observed color}} - \underbrace{(B-V)_0}_{\text{true color}}$$

More reddening, more extinction $A = R \times E(B-V)$

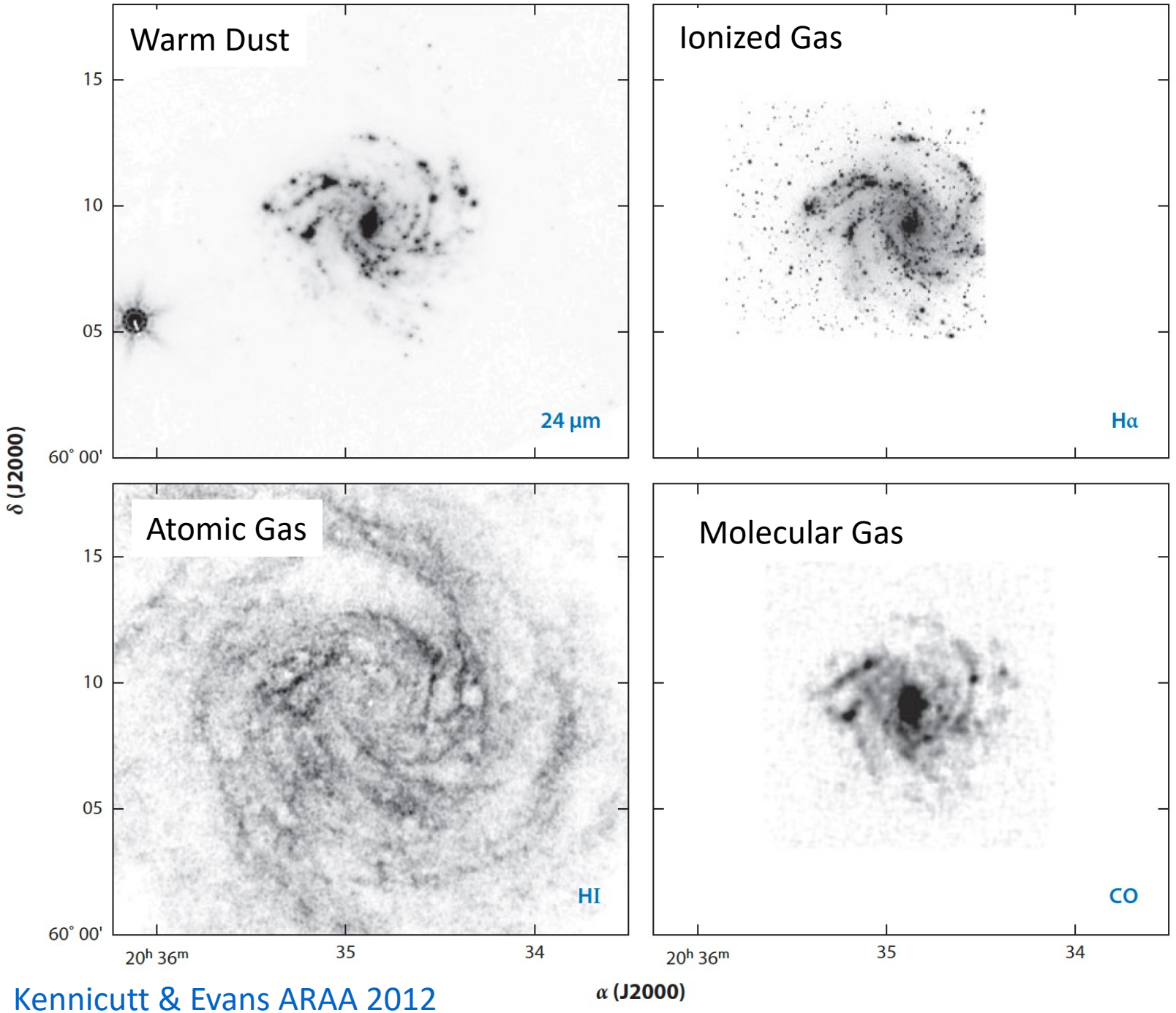
Spatial Distribution of ISM in Spiral Galaxies

Atomic gas (HI) is generally quite extended, outer regions are HI gas-rich.

Molecular gas more centrally concentrated.

Ionized gas (i.e., star formation) follows molecular gas.

Warm dust follows star formation.



Kennicutt & Evans ARAA 2012

Hot gas: X-rays

Gas heated to 10^5 – 10^6 K by supernovae, stellar winds, shocks.

Highly ionized, so no emission lines in the optical/UV. Largely radiates via **Bremstrahhlung** or **free-free** radiation from charged particles (e^-).

Connect thermal energy and photon energy: kT ≈ hv, gives emission in X-ray.

Some line emission from highly ionized atoms (typically Fe).

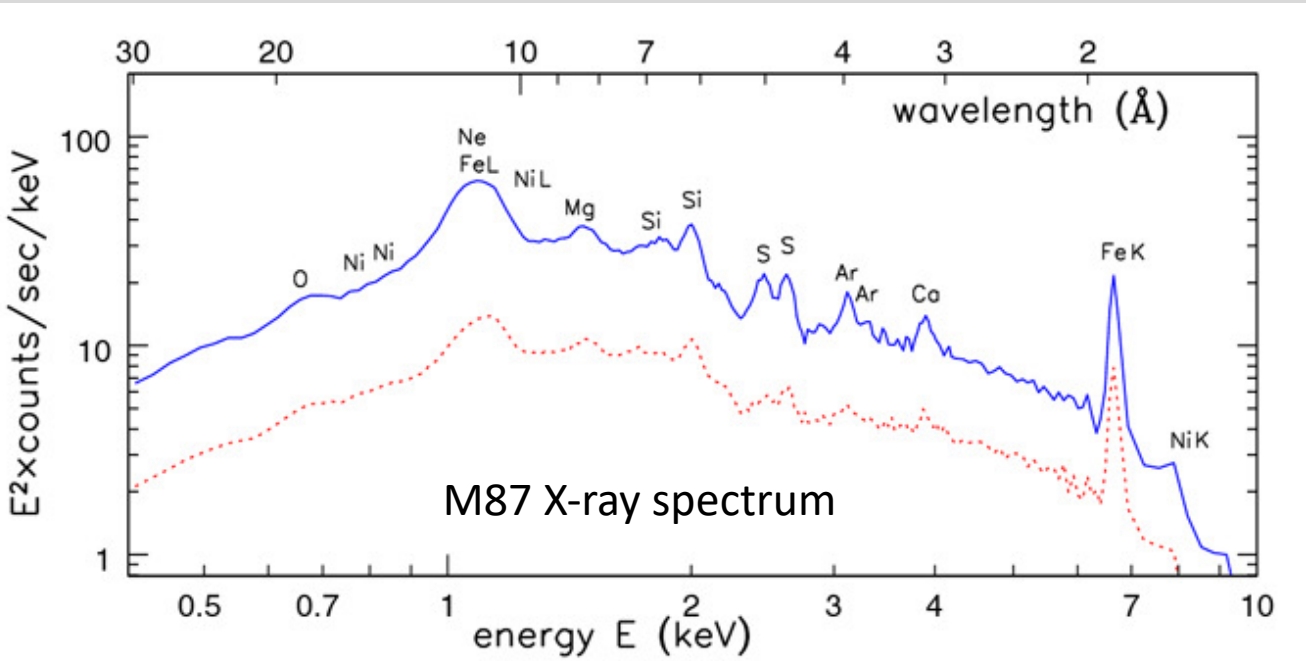
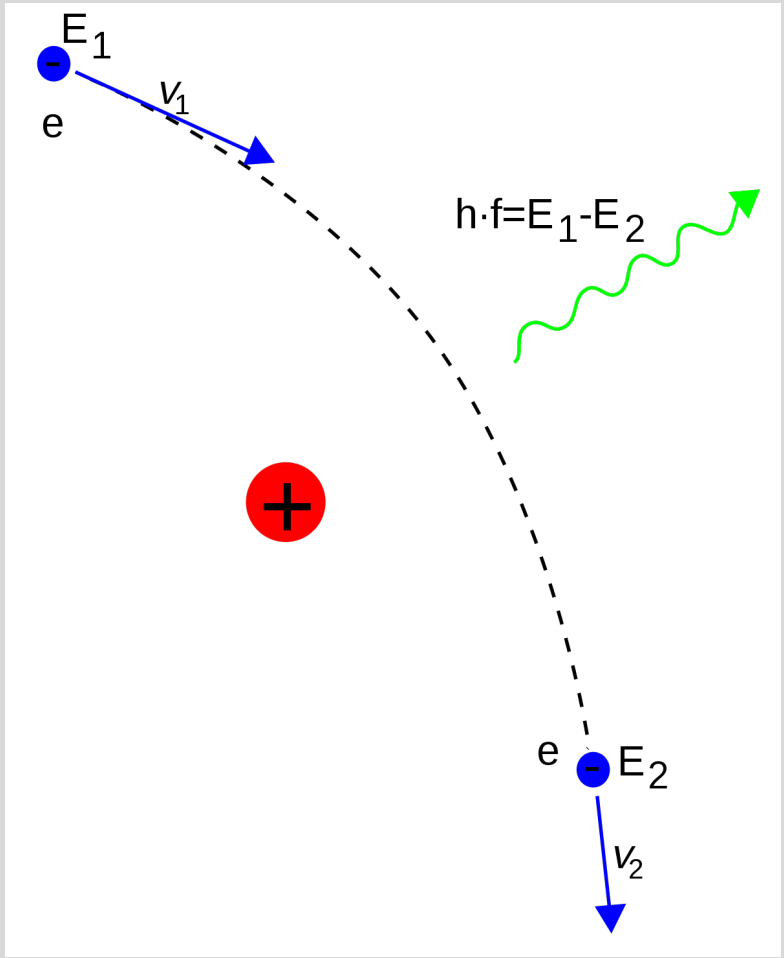


Fig 6.21 (K. Matsushita) 'Galaxies in the Universe' Sparke/Gallagher CUP 2007

Bremstrahhlug / free-free emission

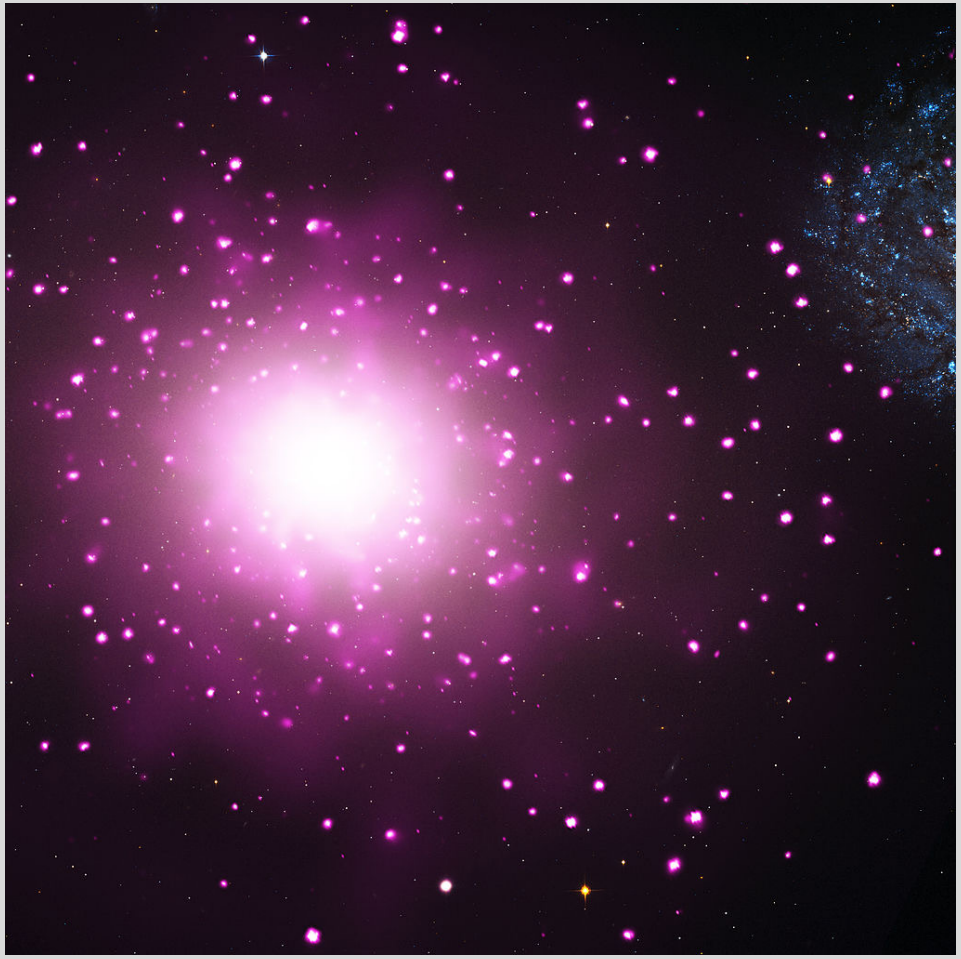


Hot gas in elliptical galaxies (NGC 4649, Strader+)

Optical Starlight

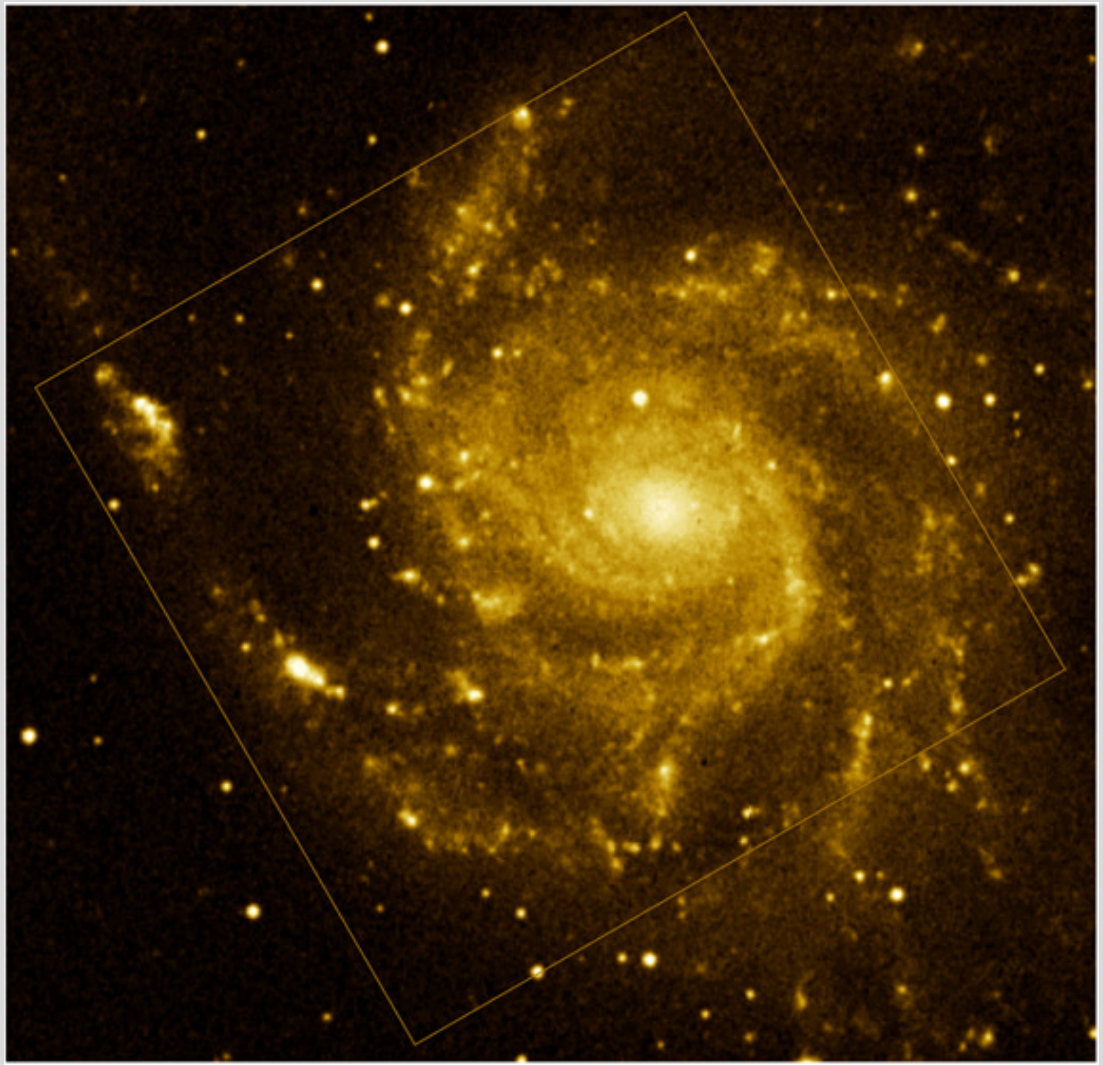
X-ray Emission

Smooth diffuse emission: free-free emission from hot gas
Point sources: accreting neutron star or black hole (not free-free emission!)



Hot gas in spiral galaxies (M101)

Optical Starlight



X-ray Emission

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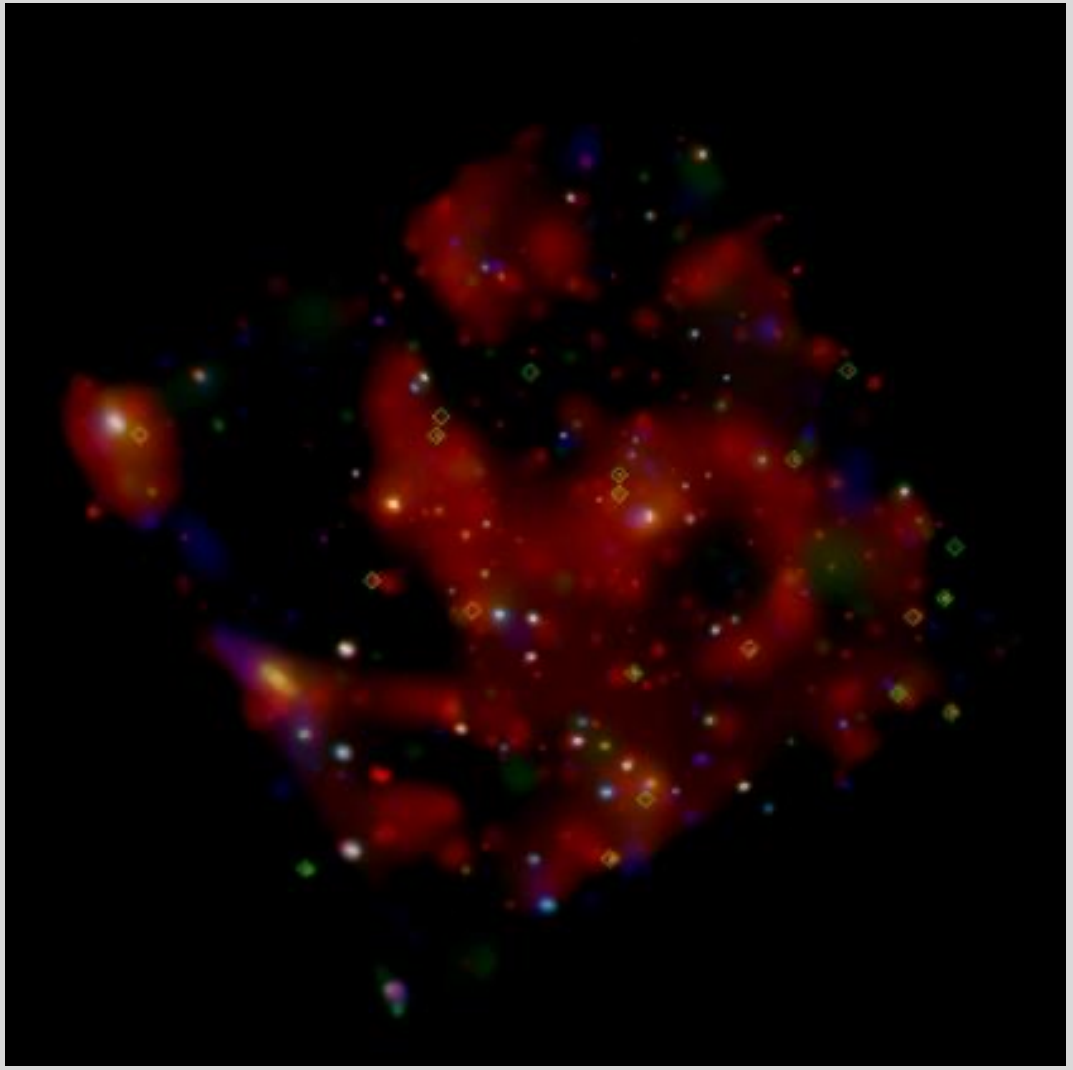
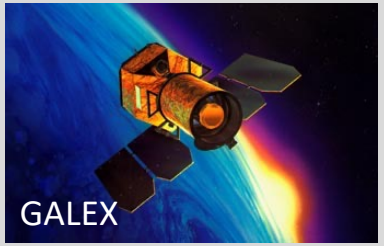
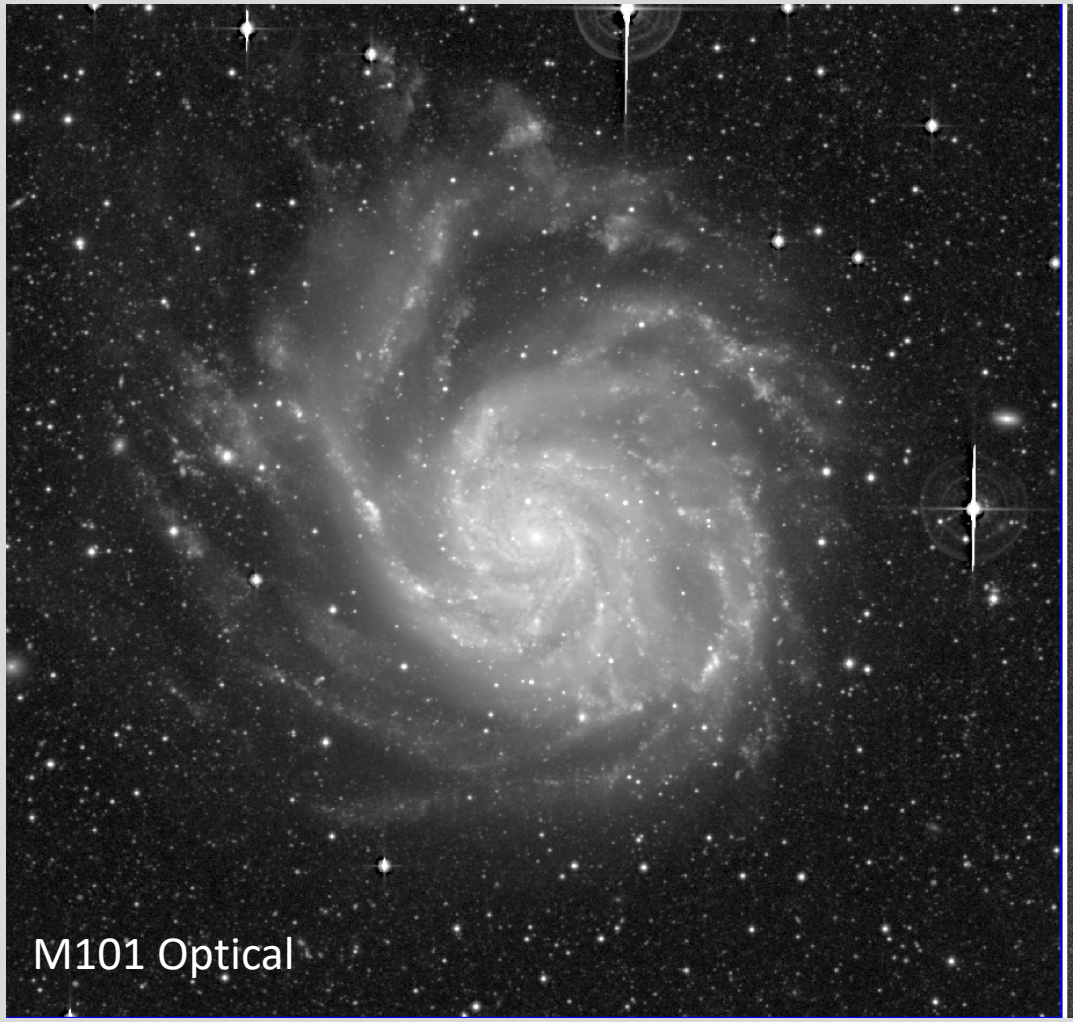
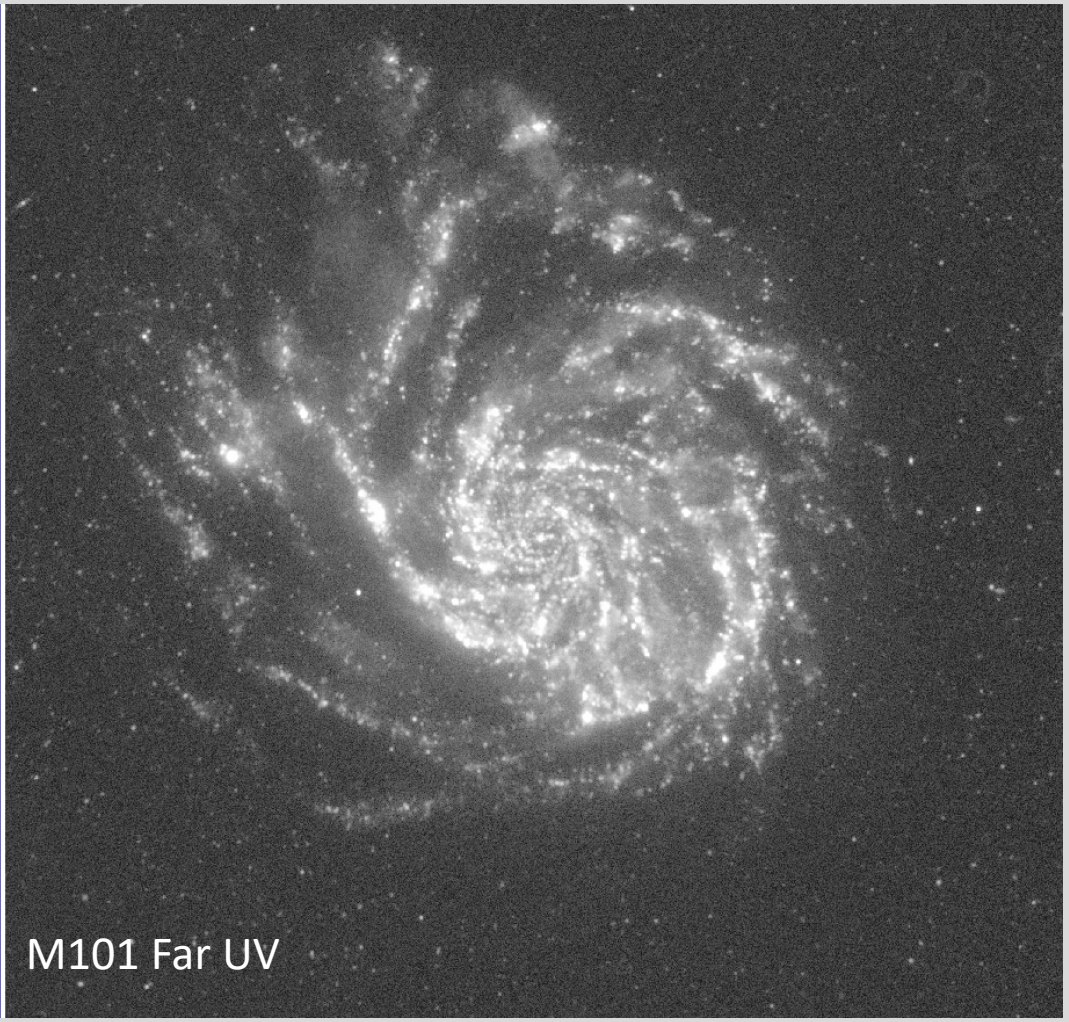


Tracing Star Formation in Galaxies



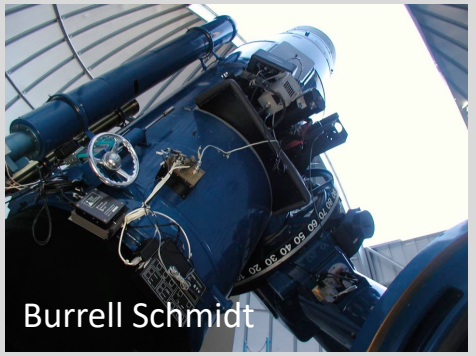
Far ultraviolet (≈1500Å) traces emission from massive young stars with ages $\lesssim$ 100 Myr.
Total FUV luminosity ⇒ Star Formation Rate on this timescale.
But ultraviolet light is very sensitive to dust extinction.

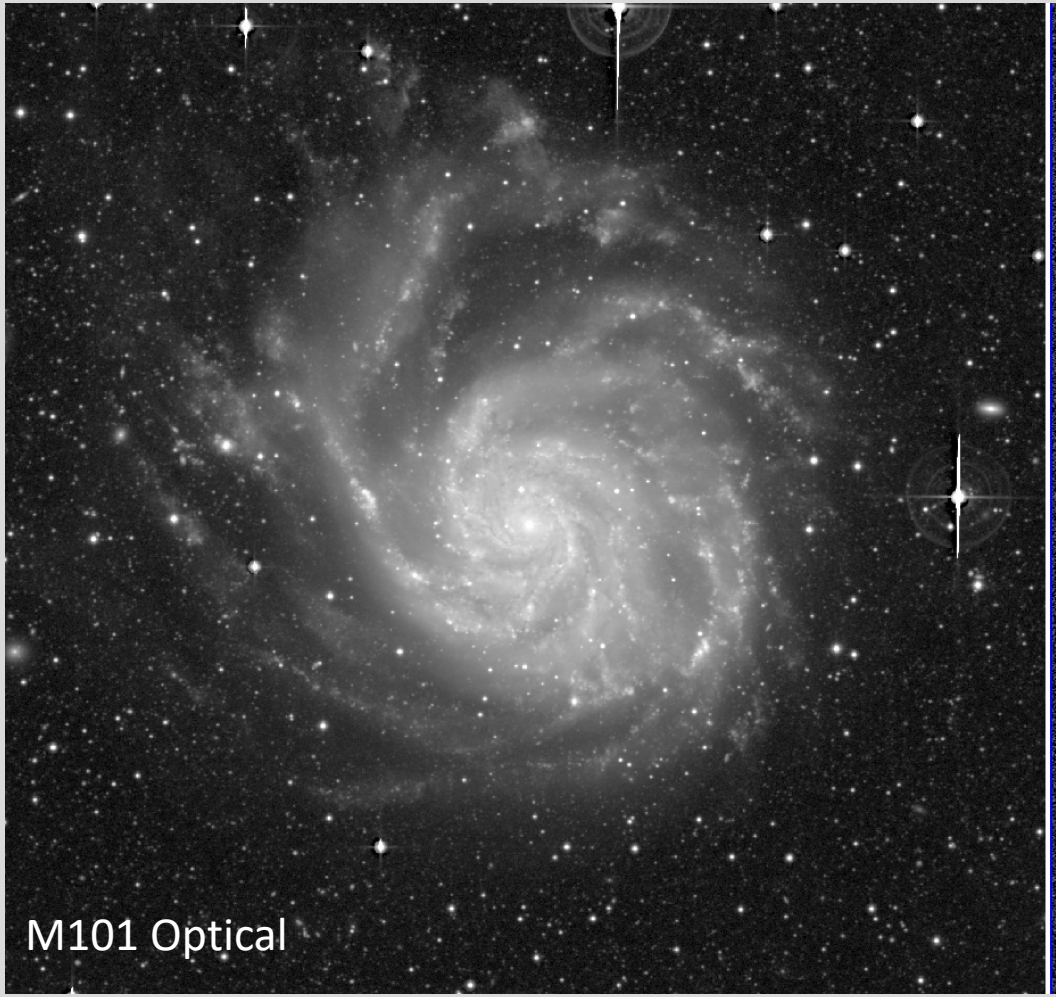


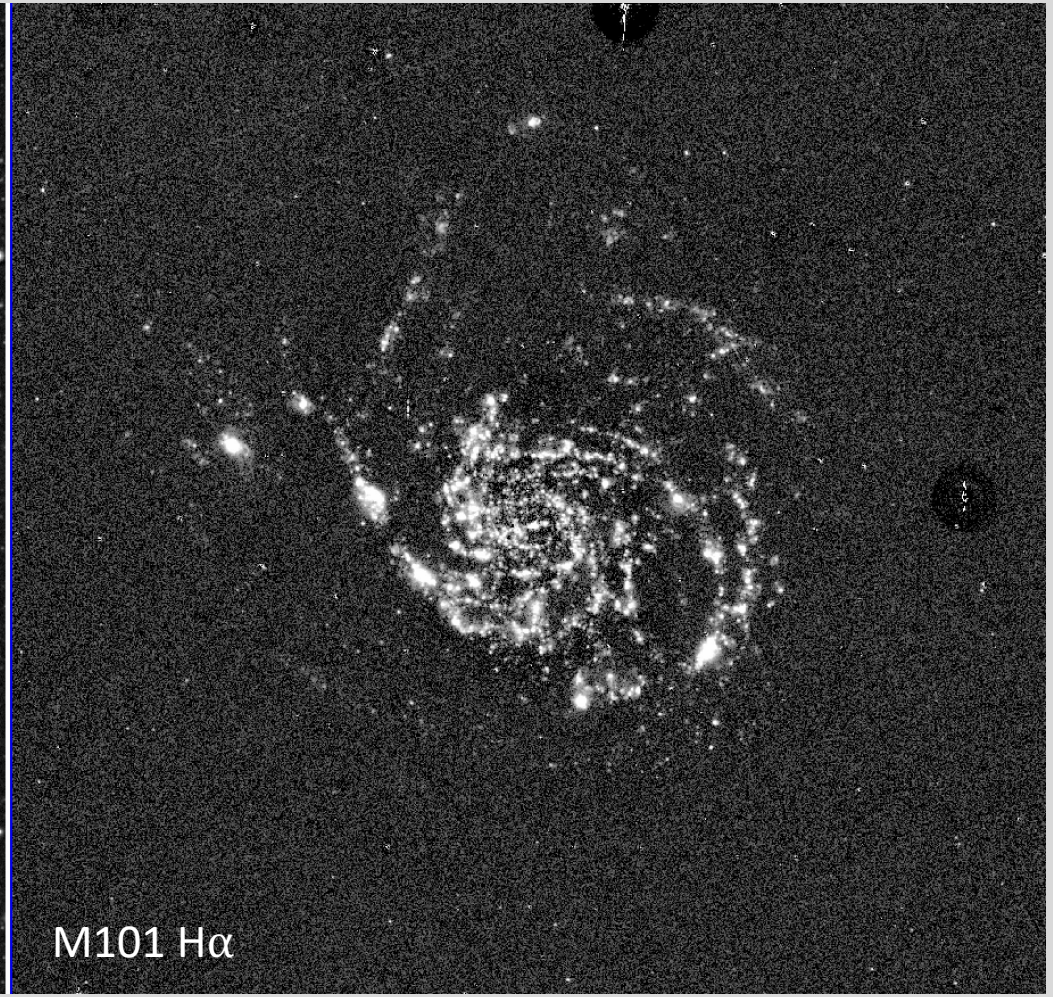


Tracing Star Formation in Galaxies

Hα luminosity traces emission from massive young stars with ages $\lesssim$ 10 Myr (hot enough to ionize H).
UV light ($\lambda < 912$ Å) ionizes hydrogen gas; when it recombines it emits Hα.
Total Hα luminosity ⇒ Star Formation Rate on this timescale.
Less sensitive to dust extinction (redder wavelength).


Burrell Schmidt


M101 Optical

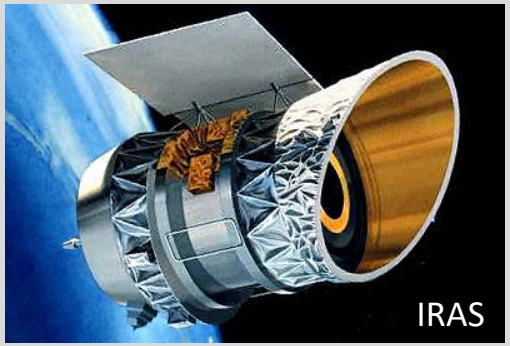

M101 Hα

Tracing Star Formation in Galaxies

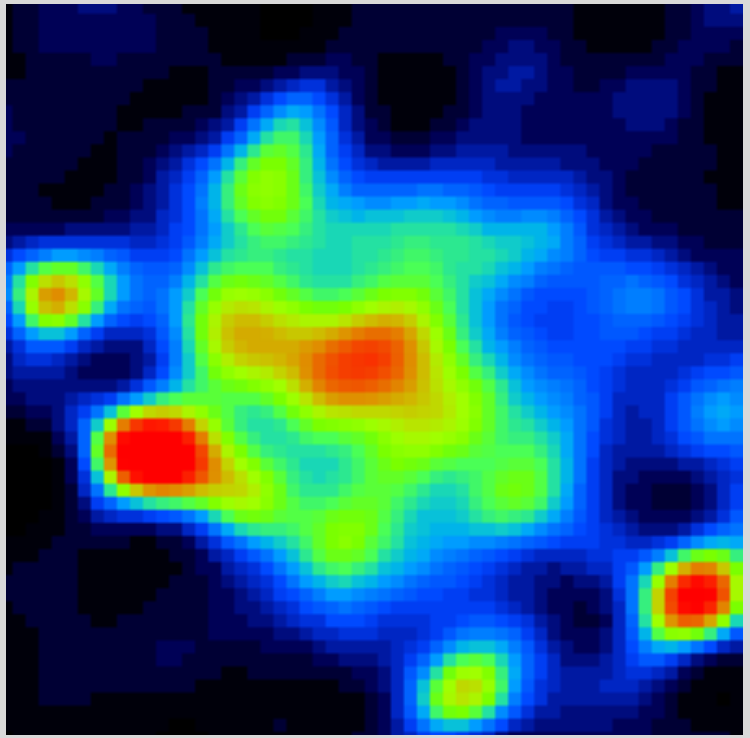
Mid Infrared luminosity traces *line emission* from warm dust heated by young stars.
Total MIR luminosity ⇒ Star Formation Rate.
No dust extinction at these wavelengths

multi-λ image
red = 24 μm
warm dust

Tracing Star Formation in Galaxies



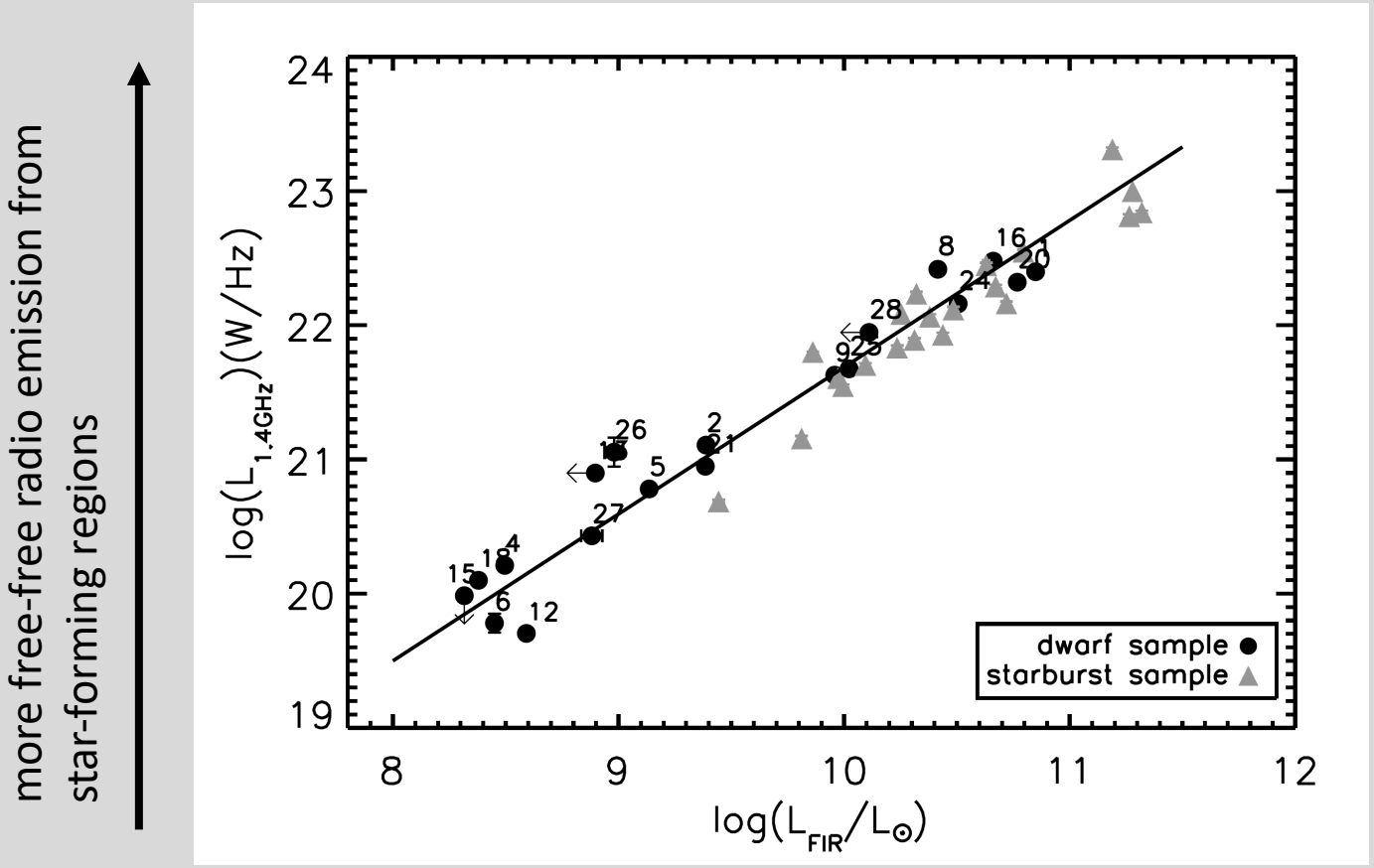
Far infrared luminosity traces *blackbody (continuum) emission* from dust heated by young stars.
Total FIR luminosity ⇒ Star Formation Rate.
No dust extinction at these wavelengths.



100 µm image
red = bright

Tracing Star Formation in Galaxies

Radio continuum, traces free-free emission from electrons in ionized HII regions
Total 1.4 Ghz luminosity ⇒ Star Formation Rate.
No extinction, but other sources can contribute to radio continuum.



Wu+08