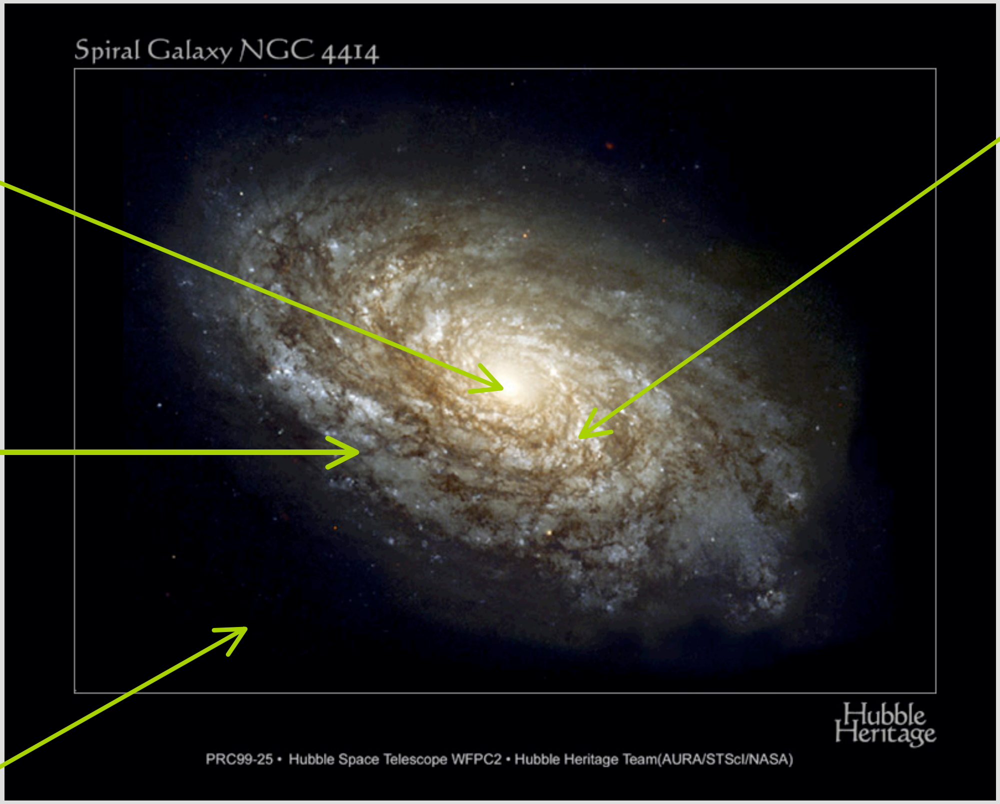
Components of the Milky Way

Sun and Solar System lie in a spiral galaxy - most common type in relatively isolated parts of the Universe.

Bulge + supermassive black hole

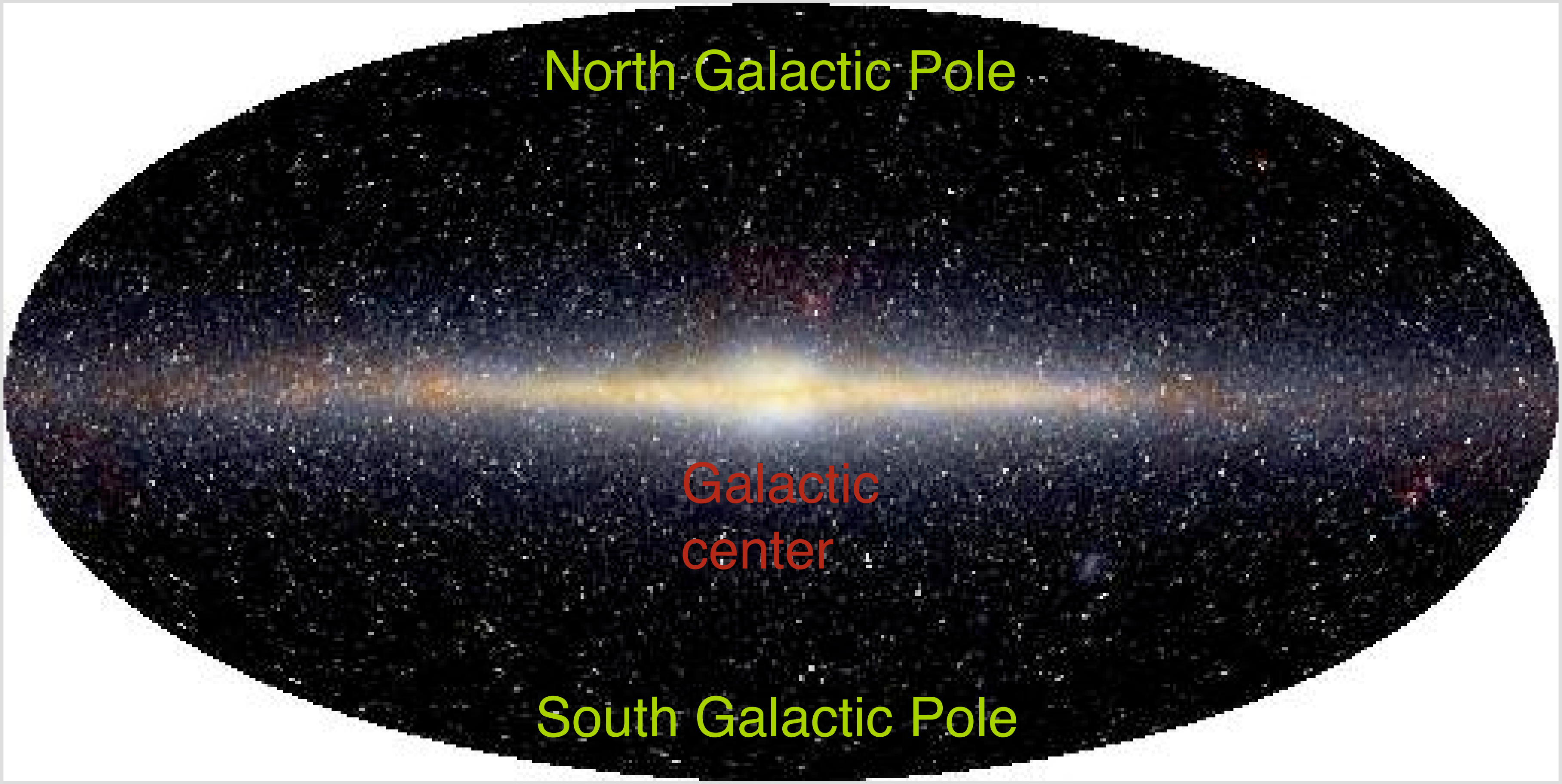


Spiral arms where stars are formed

Disk of gas and stars

Halo - not visible here, containing stars but dominated by dark matter. Extends out beyond the optical extent of the galaxy.

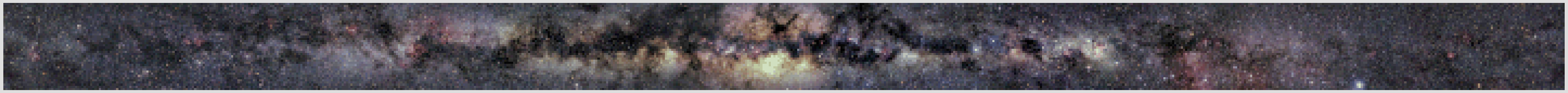
From our vantage - out in the disk, easiest to see the structure in the Milky Way in the infra-red.



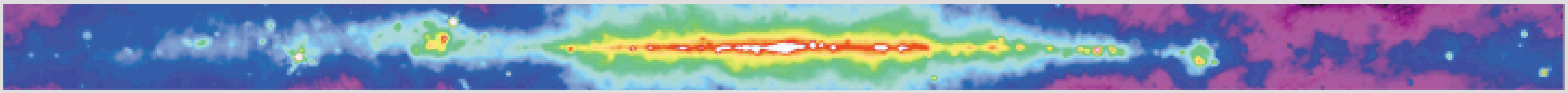
Map in Galactic co-ordinates. Infra-red radiation is not strongly absorbed by dust, so looking here at cool stars throughout the Milky Way.

Milky Way in different wavebands

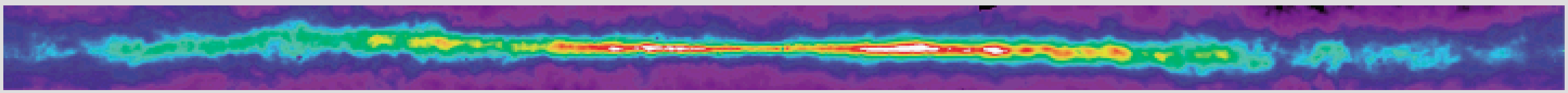
Optical



Radio at 408 MHz

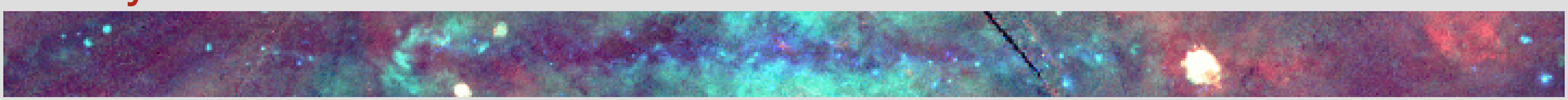


Radio at 21cm (atomic hydrogen)

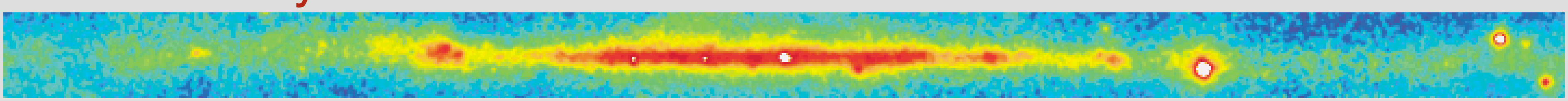


Infra-red

X-rays



Gamma-rays



Star Formation

Gas in the Milky Way exists in different phases:

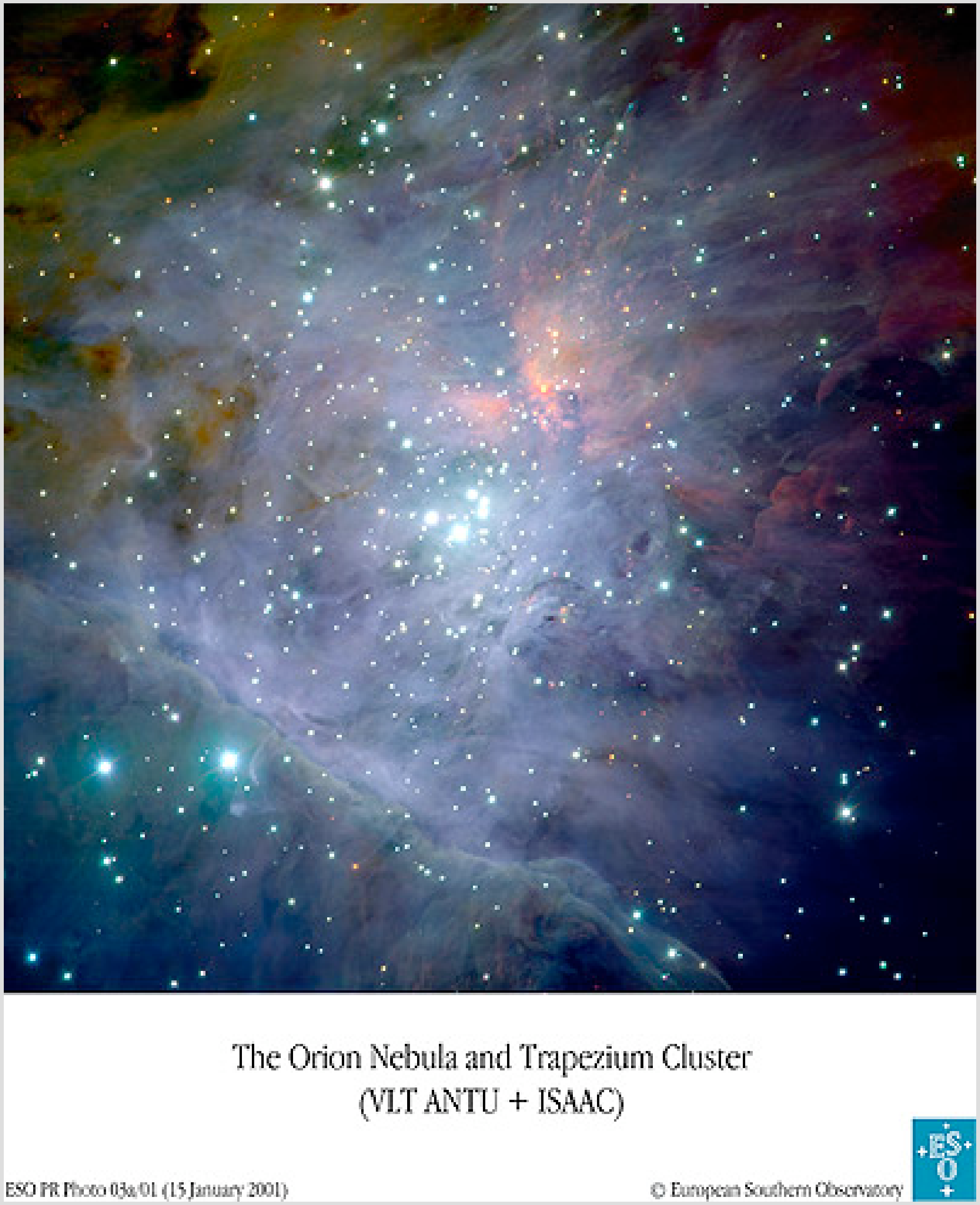
- **Molecular gas** (T = 10 - 100 K)
- **Atomic hydrogen** (neutral gas, called H I)
- **Ionized gas** (called H II)

Most of the gas is in atomic form, but stars form out of the molecular material:

- **Giant molecular cloud** forms a whole cluster of stars, may have mass of 10^6 M_{sun}, size ~10 pc = 3 x 10^{19} cm
- **Molecular cloud core** of a few Solar masses, perhaps 0.1 pc in size, forms one or (normally) a few stars.

Estimate the characteristic time scales for these structures.

Molecular clouds



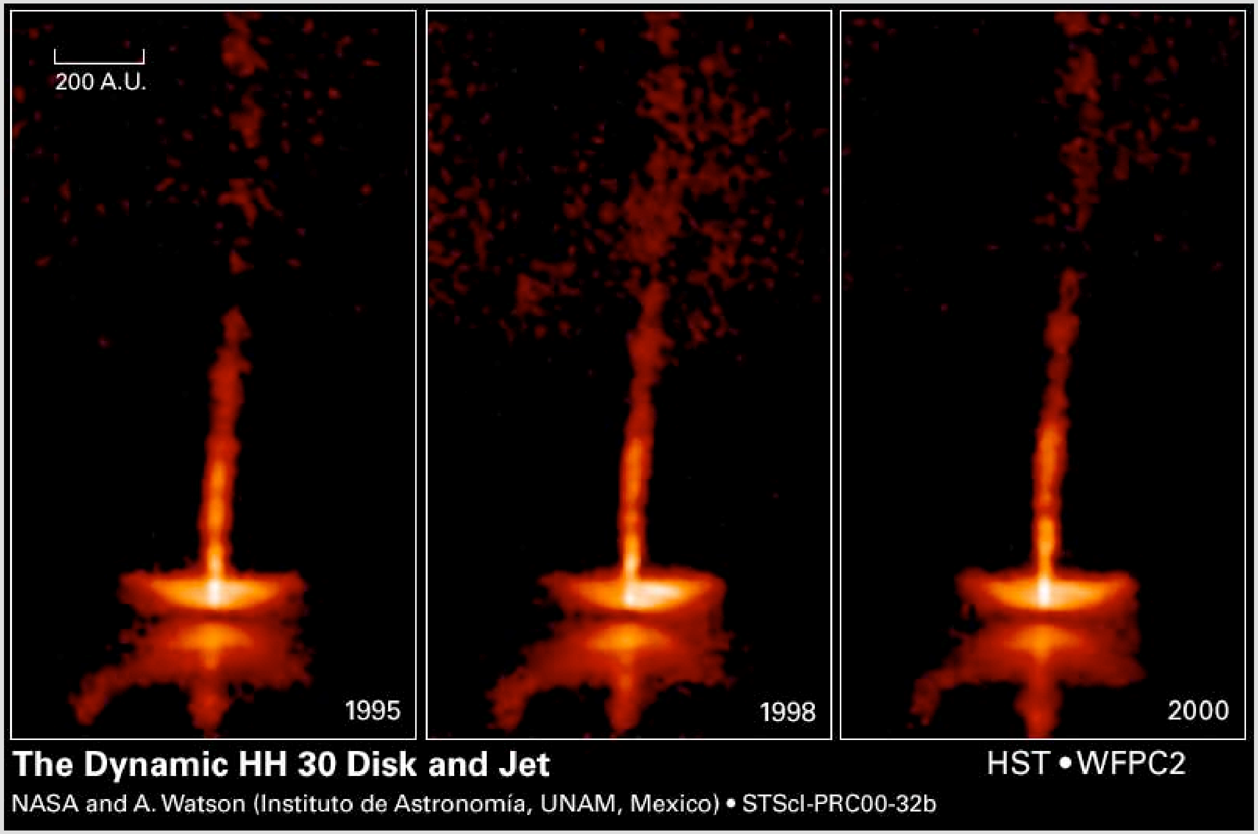
Nearby regions of star formation:

- TW Hydrae - small region
- Taurus - no massive stars
- Orion - nearest region with massive as well as low-mass stars

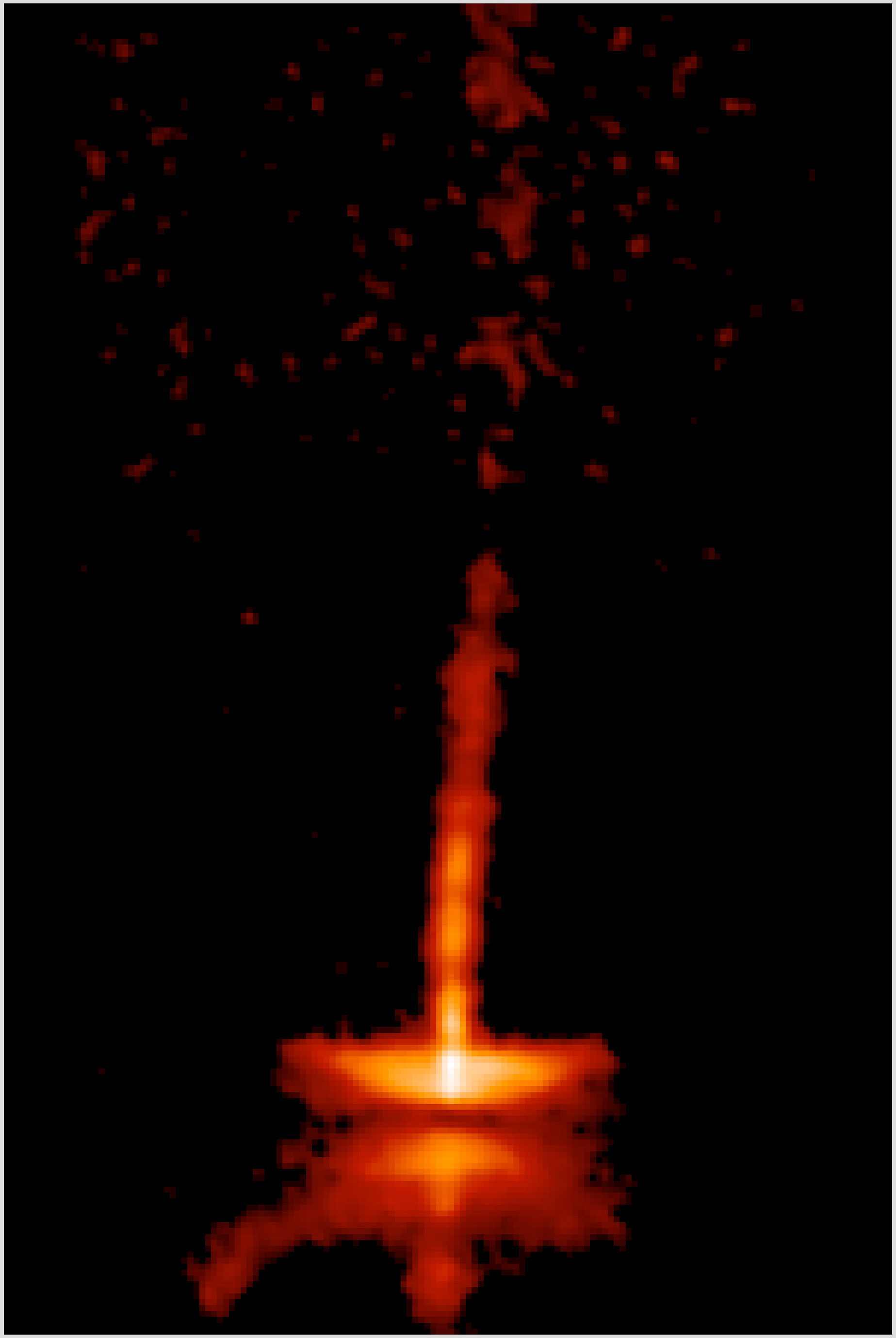
The `**Angular Momentum** Problem' of Star Formation

If angular momentum is conserved during collapse, cores of molecular clouds have far more angular momentum than a single star - even rotating at breakup:

→ **Binary formation** is probable
Disk formation is inevitable



HST image of a protoplanetary disk and jet around a young star



Jet velocities are a few hundred km/s from protostars.

c.f. escape velocity:

$$v_{esc} = \sqrt{\frac{2GM_*}{R_*}}$$

$$\approx 440 \left(\frac{M_*}{M_{sun}} \right)^{1/2} \left(\frac{R_*}{2R_{sun}} \right)^{-1/2} \text{ km/s}$$

Jets are probably launched from close to the star - most likely from the inner regions of the disk.

How fast are jets from black holes?

Stars on the Main Sequence

Gravitational binding energy of a star of mass M, radius R is ~ GM^2 / R. Energy is liberated as protostars (and brown dwarfs and giant planets) contract.

Eventually, central temperature becomes high enough for fusion of H -> He. Contraction ceases - **main sequence phase**.

Estimate the main-sequence lifetime:

- Fusion of H to He yields □= 6 x 10^{18} erg / g
- Solar mass is $M_{sun} = 2 \times 10^{33}$ g
- Solar luminosity is $L_{sun} = 3.9 \times 10^{33}$ erg / s
- Mass fraction of hydrogen in the Sun X = 0.7
- Stars leave the main sequence **before** all the hydrogen is exhausted - fraction consumed □ = 0.1.

Main sequence lifetime is estimated to be:

$$t_{ms} \approx \frac{\square\square X M_{sun}}{L_{sun}} = 7 \times 10^{9} \left(\frac{\square}{0.1} \right) \text{yr}$$

Empirically, more massive stars are more luminous. Very roughly:

$$L \propto M^{3.5}$$

$$\Rightarrow \quad t_{ms} \propto M^{-2.5}$$

Conclude: massive stars are short lived, but for most stars hydrogen burning lifetime is long compared to formation time scale.

Masses of stars span ~ 3 orders of magnitude:

$M < 13\ M_{Jupiter} \sim 10^{-2}\ M_{sun}$: no significant nuclear fusion at all
`Planetary mass objects'

$13\ M_J < M < 0.08\ M_{sun}$: deuterium fusion but no fusion of
ordinary hydrogen - brown dwarfs

$M \sim 100\ M_{sun}$: very rough upper limit set by radiation pressure

On main sequence, mass largely sets the luminosity, radius and surface temperature. Stars form one-parameter family - c.f. the **Hertzprung-Russell** diagram.

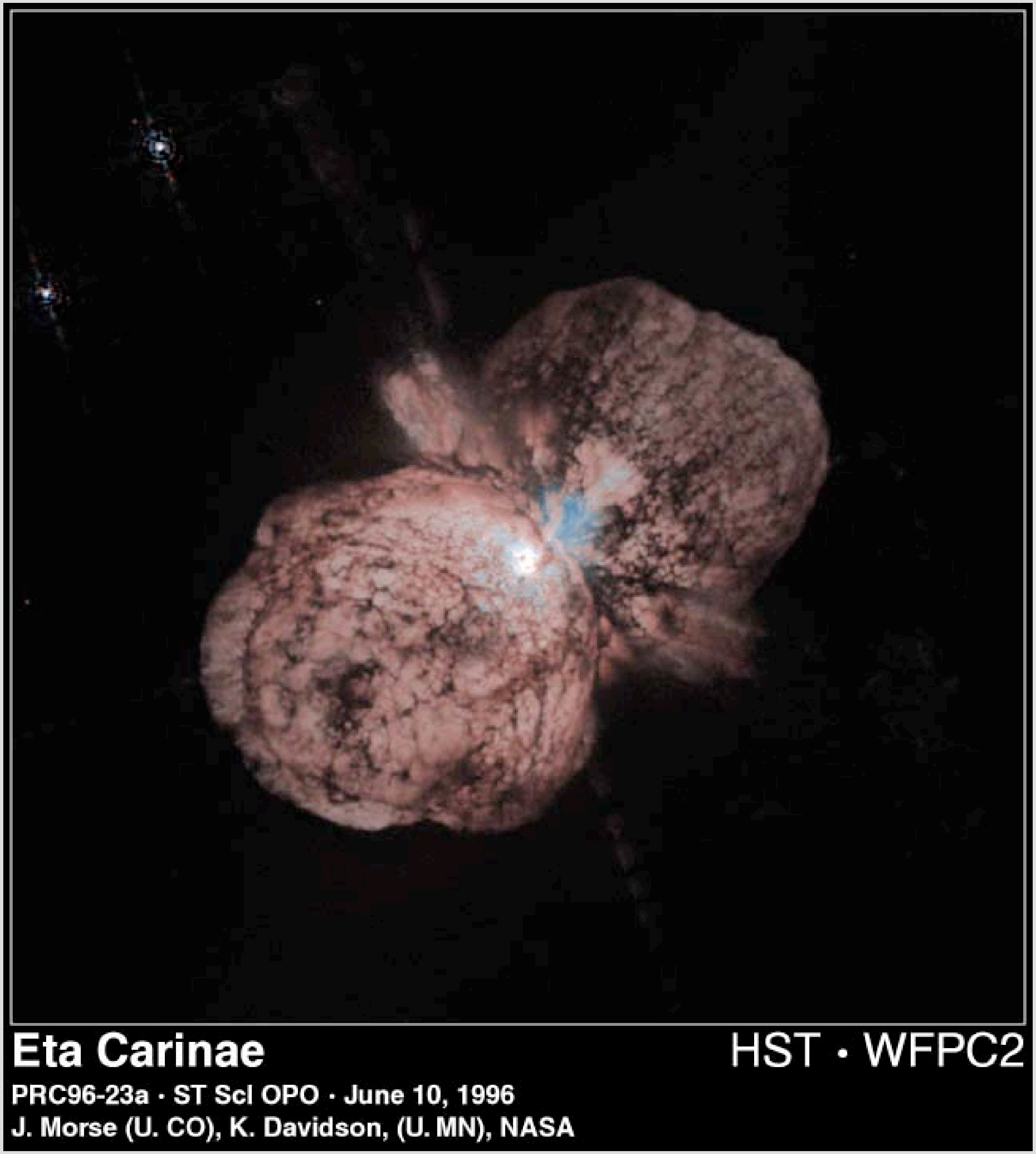
Post-main-sequence evolution

Once hydrogen burning has finished, evolution speeds up because further nuclear reactions yield much less energy:

- H -> He: yields 6×10^{18} erg / g (of pure hydrogen)
- He -> C: yields 6×10^{17} erg / g (of pure helium)

Complicated evolution gives:

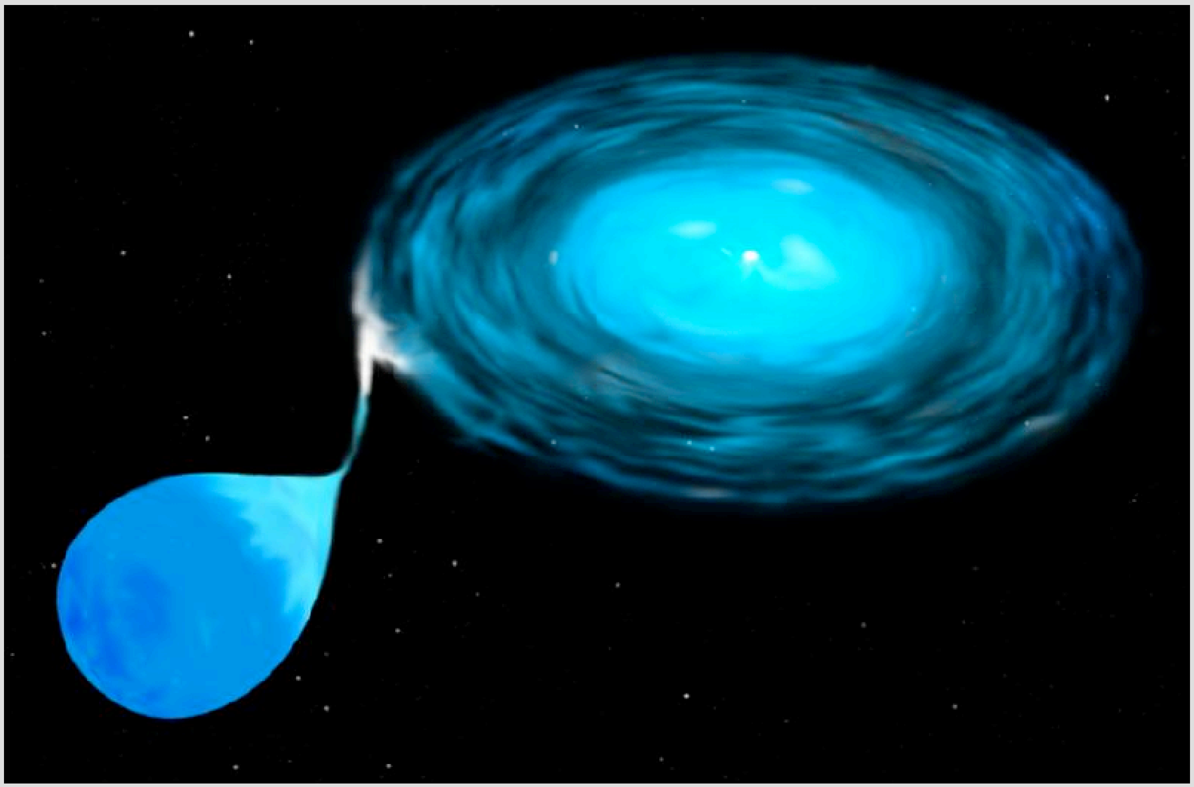
Low-mass stars	**Intermediate-mass**	**High-mass**
↓	↓	↓
Red giants	Giant phases	Giant phases
↓	↓	↓
Planetary nebulae	Type II supernovae	Type II supernovae
↓	↓	↓
White dwarfs	Neutron stars	Black holes



Outflows from a massive star nearing end of its lifetime

Stellar remnants are normally dim and hard to observe - know of only a handful of isolated neutron stars and ~zero isolated stellar mass black holes, though Galactic population 10^8 - 10^9.

Exception: compact objects in mass transfer binaries:



Powered by mass accretion:

$$L = \eta \dot{M} c^2$$

η ~ 0.1 possible for neutron stars and black holes - large luminosity, strong X-ray sources.