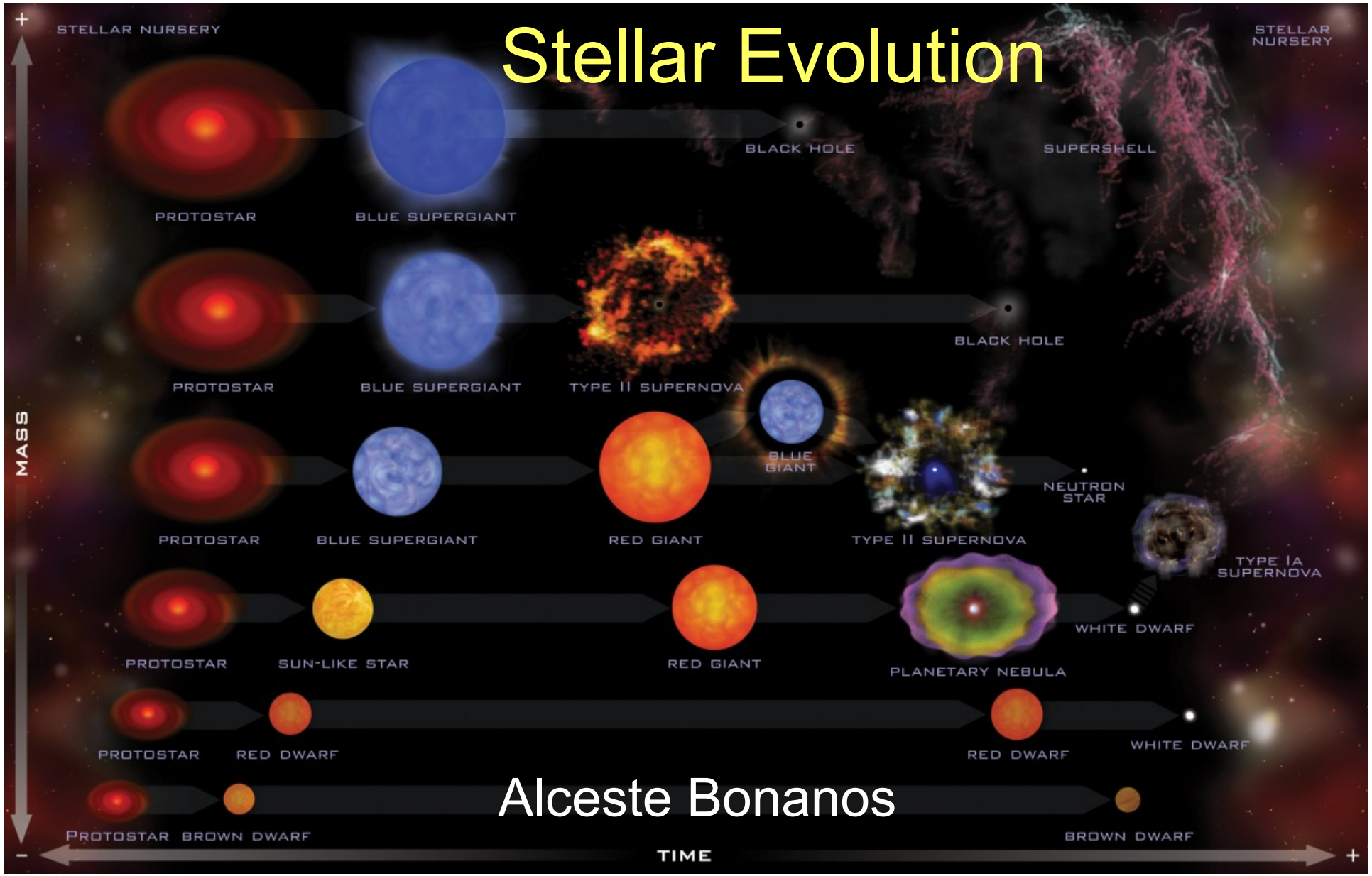
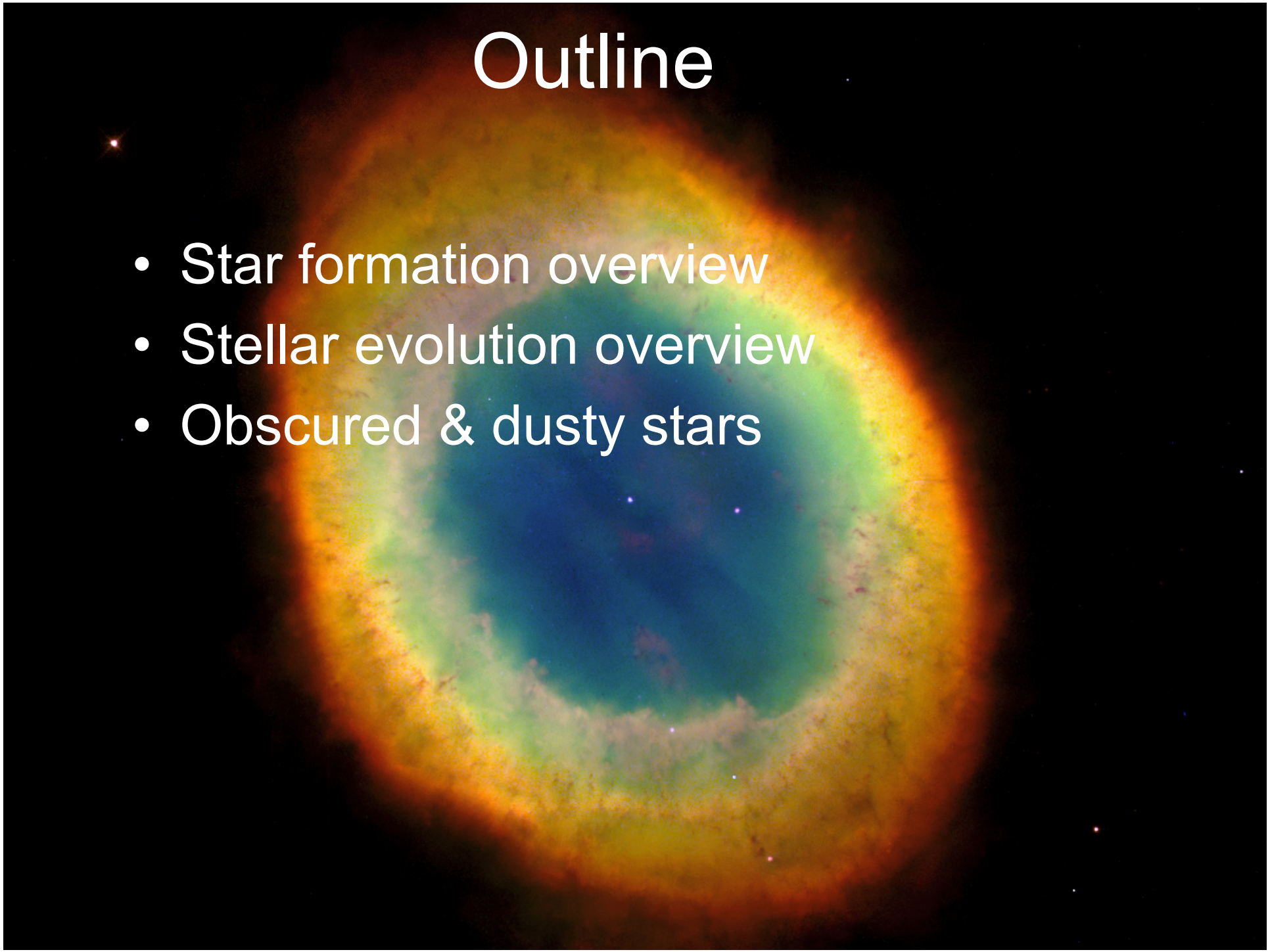


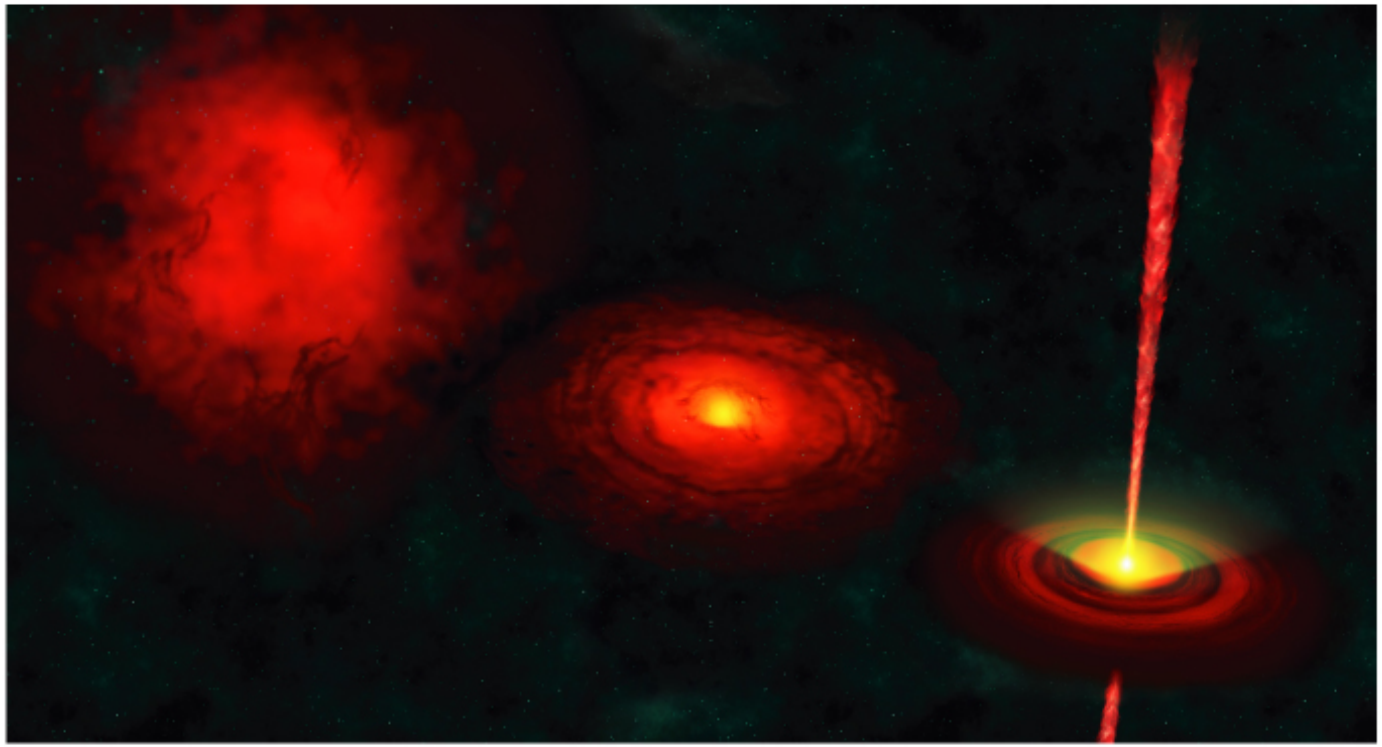
Institute of Astronomy & Astrophysics
National Observatory of Athens

Outline



- Star formation overview
- Stellar evolution overview
- Obscured & dusty stars

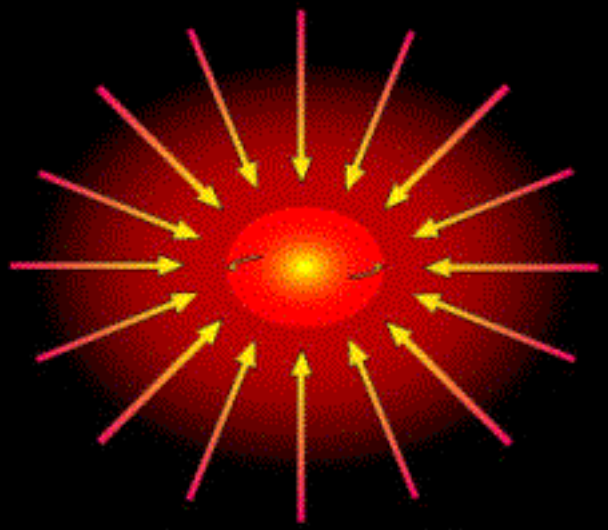
Collapse of a molecular cloud

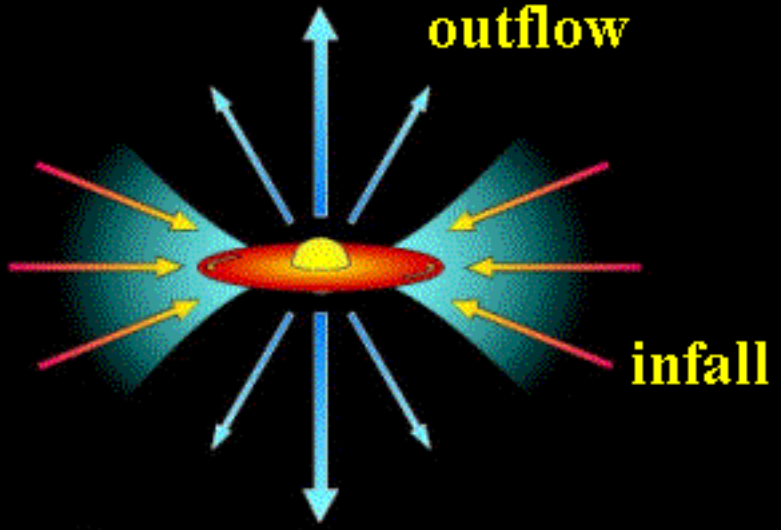


$$M_J = \left(\frac{5kT}{Gm}\right)^{3/2}\left(\frac{3}{4\pi\rho}\right)^{1/2}$$

$$\text{if } M_{\text{cloud}} > M_J \rightarrow \text{collapse!}$$

How are single stars born?



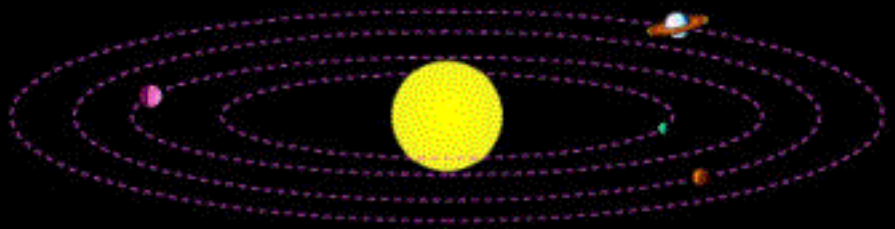


Cloud collapse

10^4 yrs; 10-10^4 AU; 10-300K

Rotating disk

10^{5-6} yrs; 1-10^3 AU; 100-3000K



Planet formation

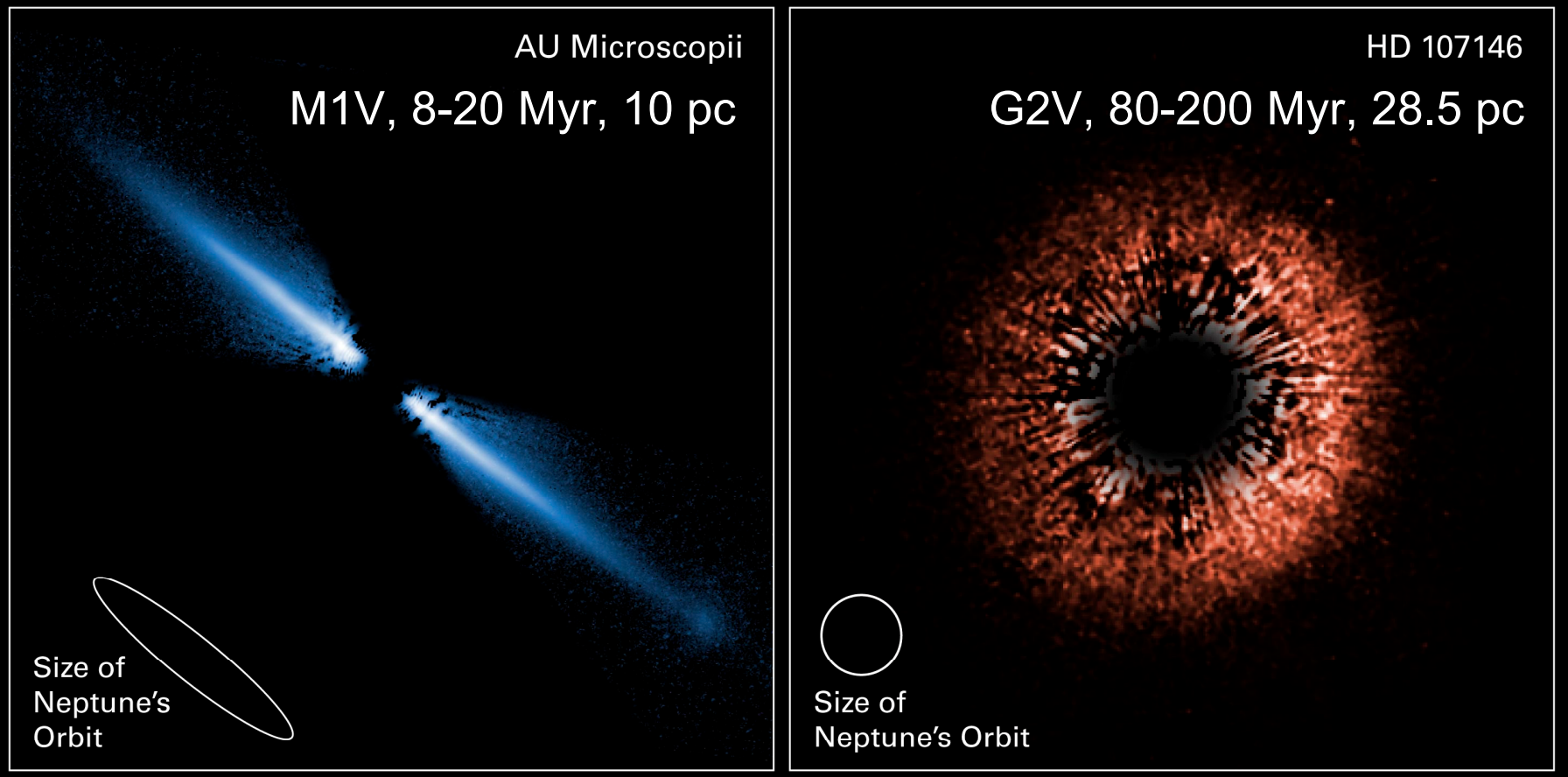
10^{6-7} yrs; 1-100 AU; 100-3000K

Mature solar system

10^{7-9} yrs; 1-100 AU; 200-3000K

Scenario largely from indirect tracers.

Fig. by McCaughrean



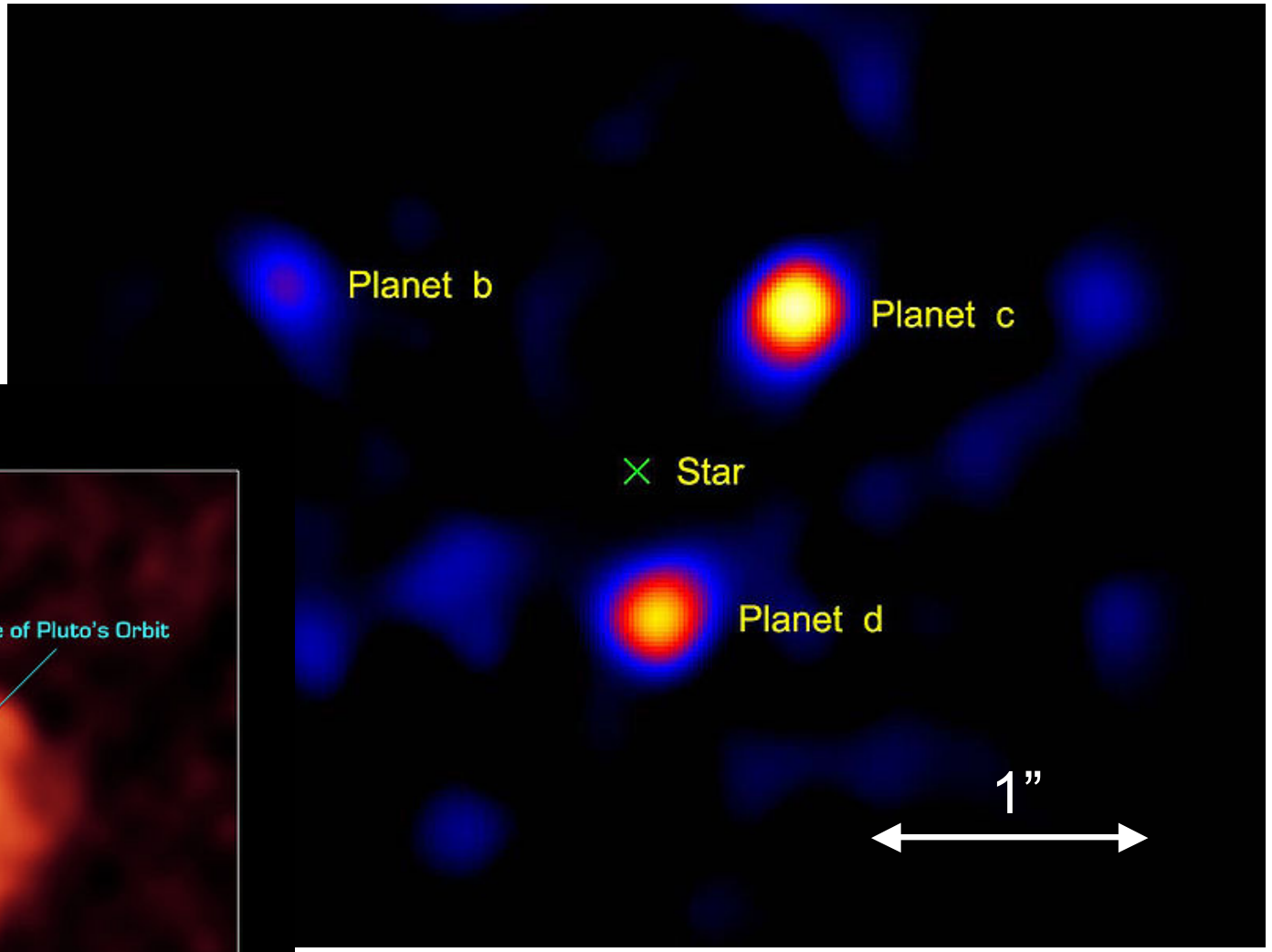
Circumstellar Debris Disks
Hubble Space Telescope • ACS HRC

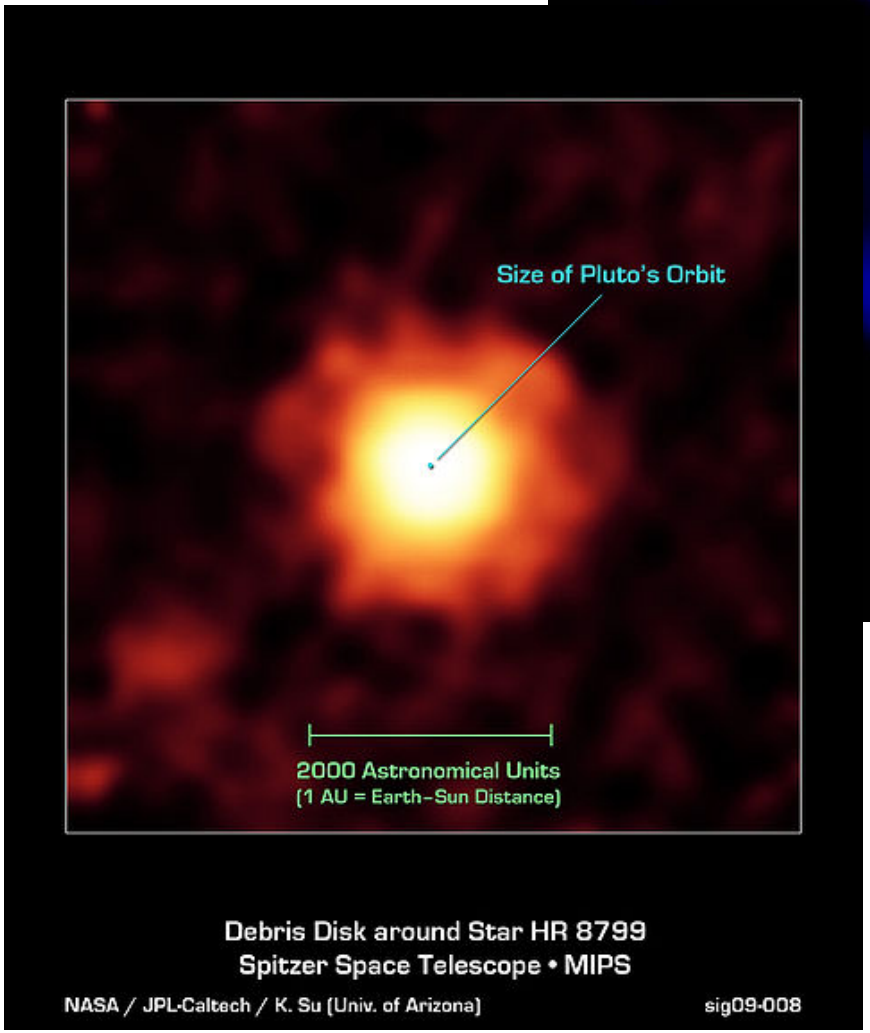
NASA, ESA, J. Krist (STScI/JPL), D.R. Ardila (JHU), D.A. Golimowski (JHU), M. Clampin (NASA/Goddard), H. Ford (JHU), G. Hartig (STScI), G. Illingworth (UCO-Lick) and the ACS Science Team

STScI-PRC04-33a

HR 8799

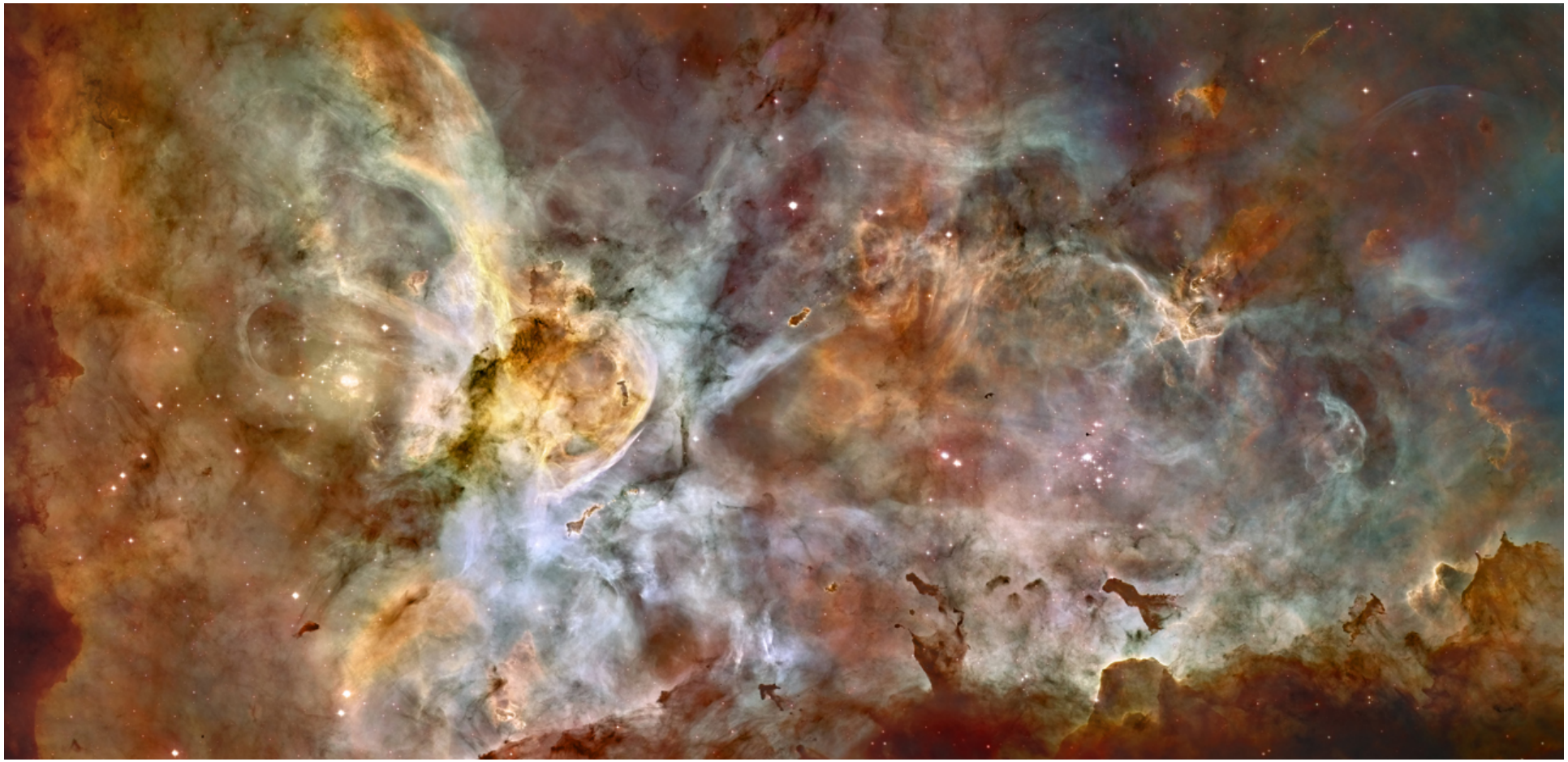
(A5V, 60 Myr, 39pc)





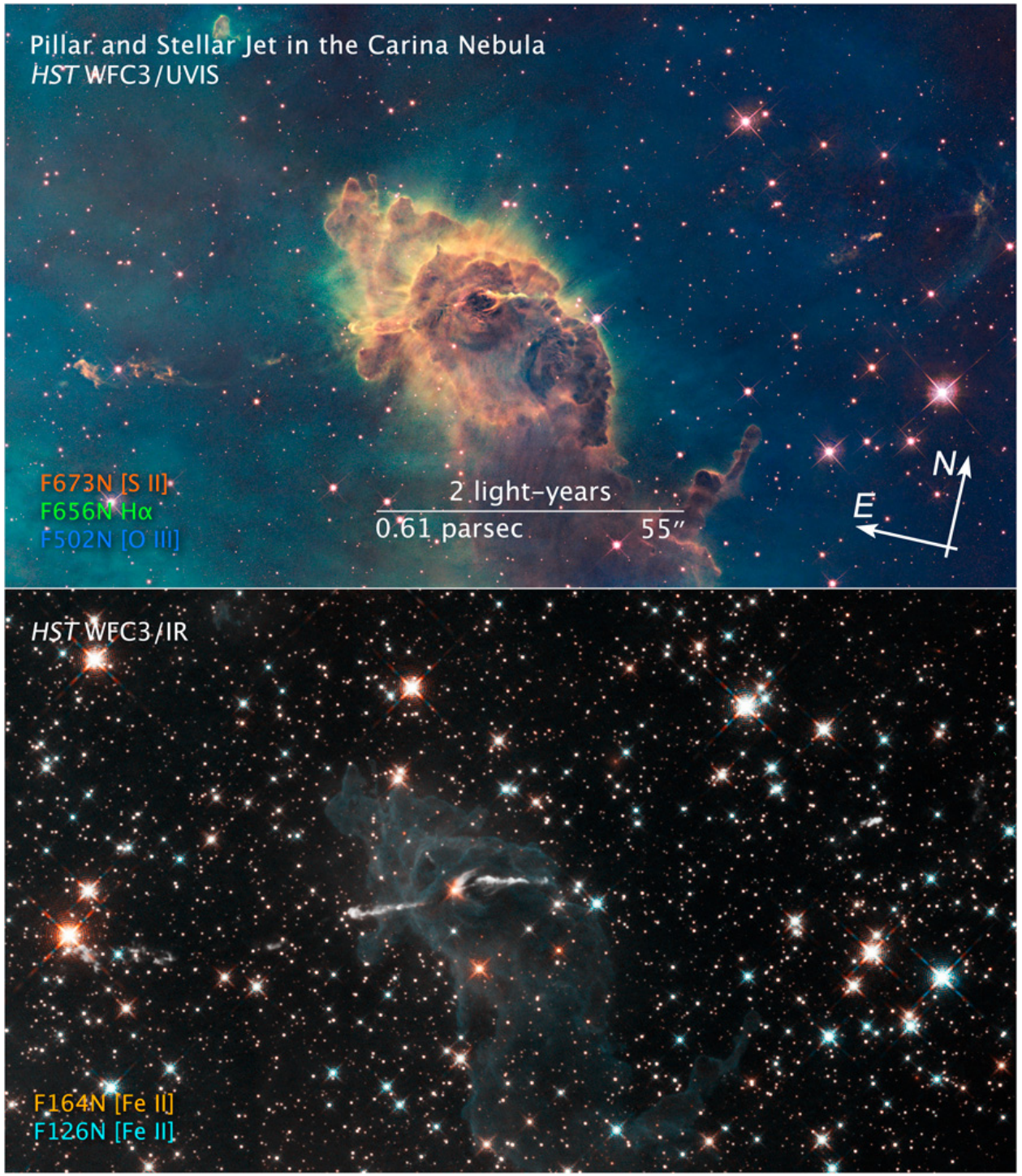
Serabyn et al. 2010, *Nature*, 464, 1018
(high contrast, vortex coronograph)

Carina nebula

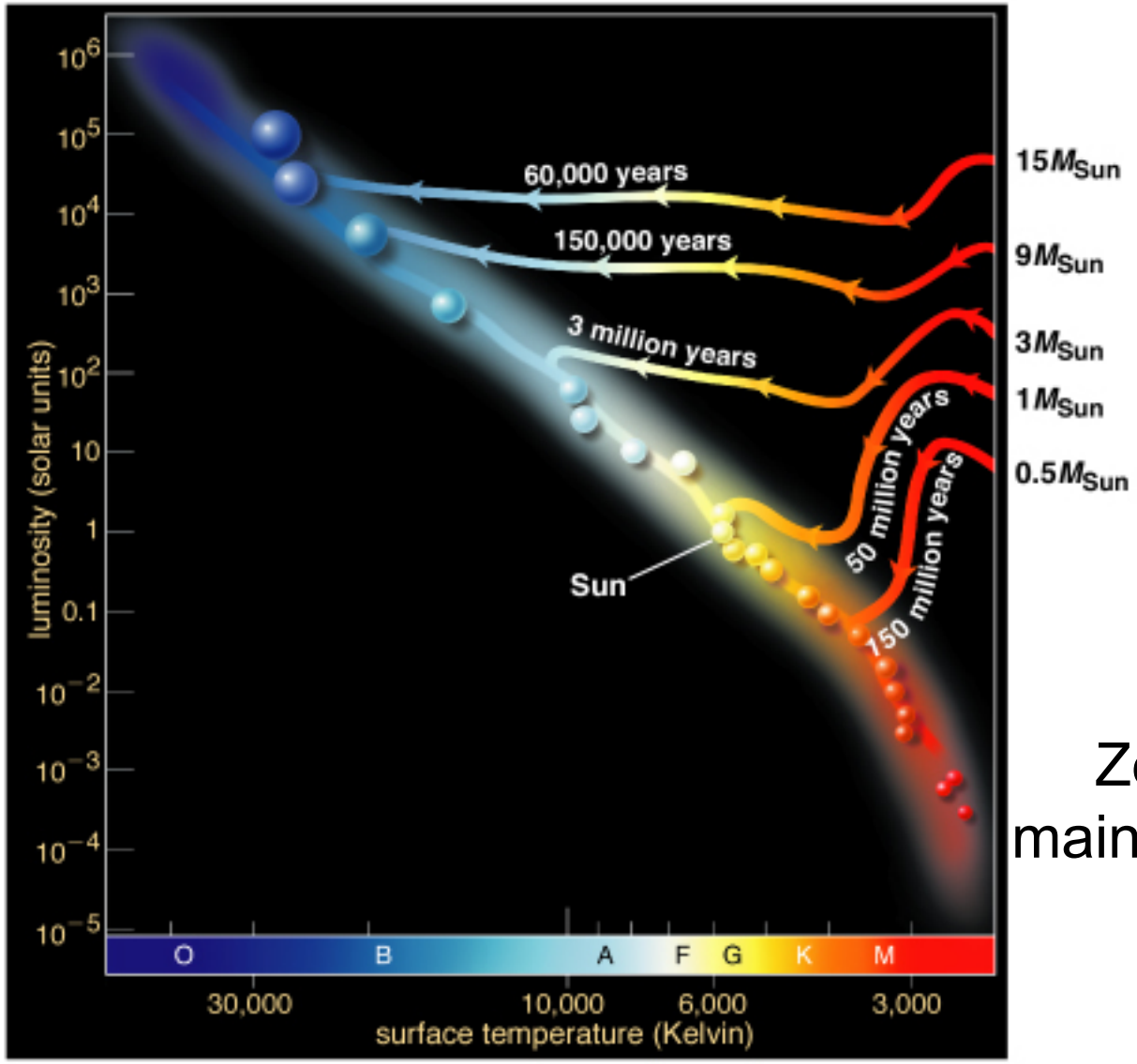


NASA, ESA, N. Smith (University of California, Berkeley), and the Hubble Heritage Team (STScI/AURA)

50 light years

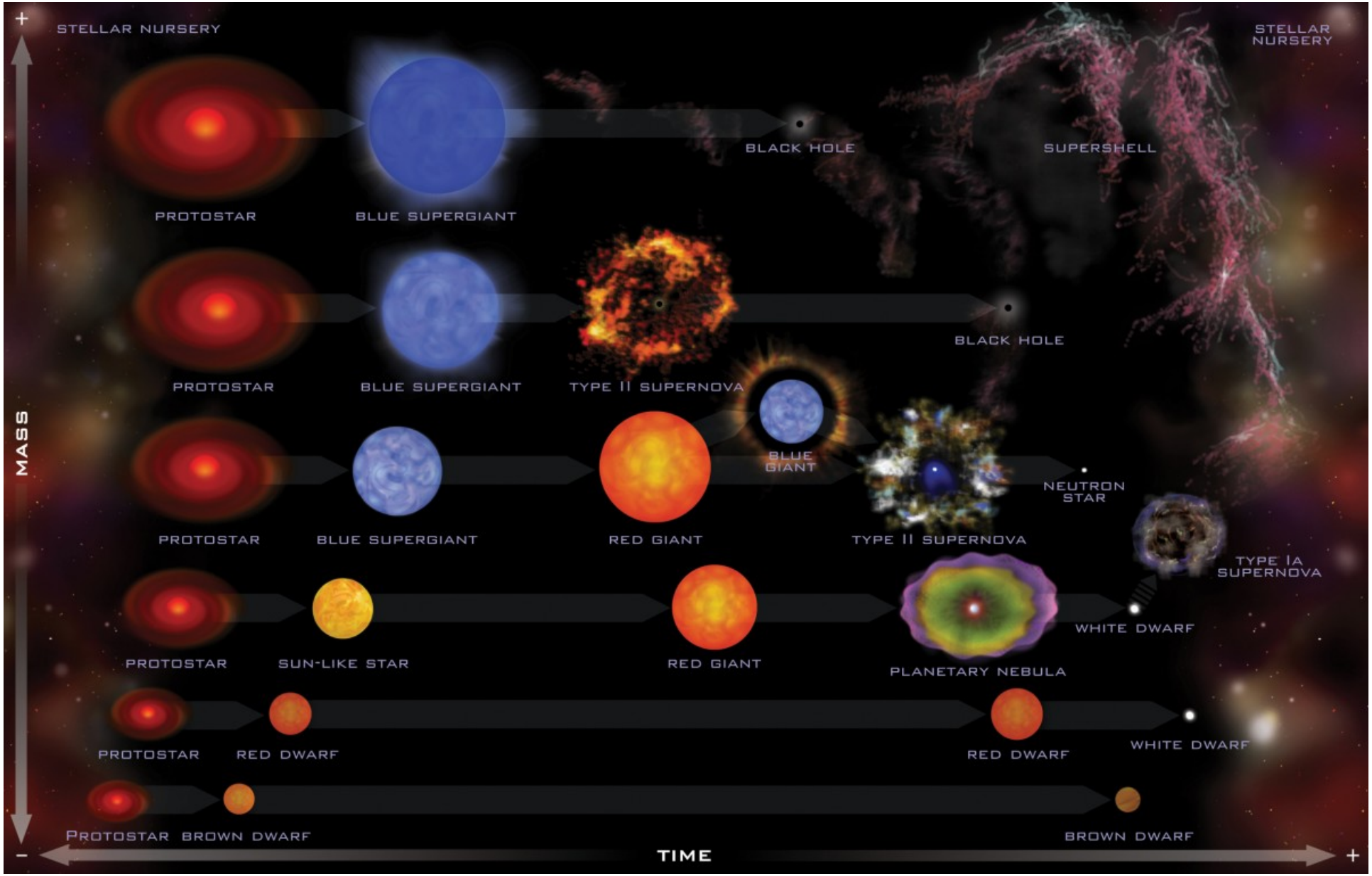

Pillar and Stellar Jet in the Carina Nebula
HST WFC3/UVIS
F673N [S II]
F656N Hα
F502N [O III]
2 light-years
0.61 parsec
55″
N
E
HST WFC3/IR
F164N [Fe II]
F126N [Fe II]

Hertzsprung-Russell diagram



Zero age
main sequence

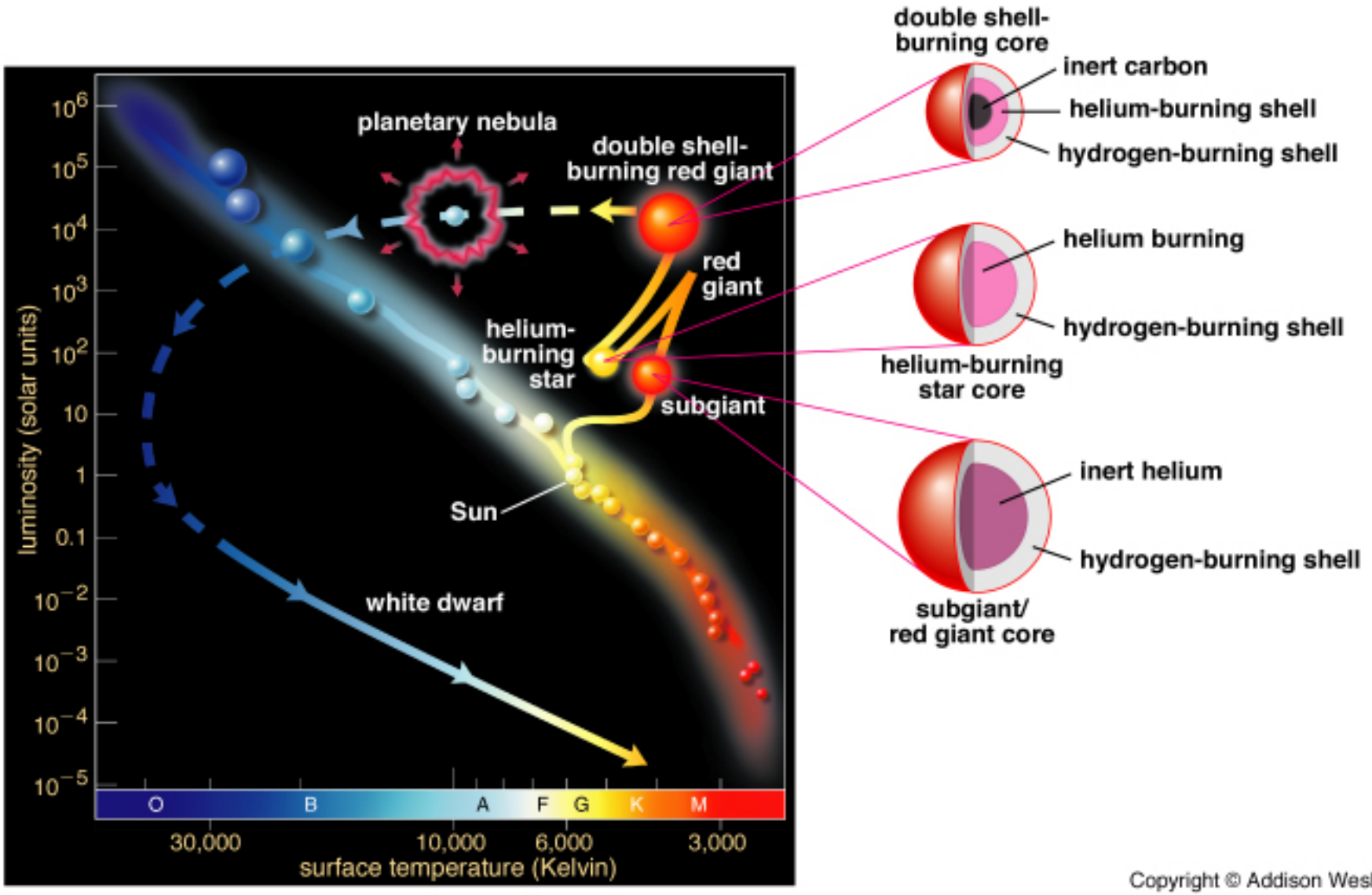
Stellar evolution

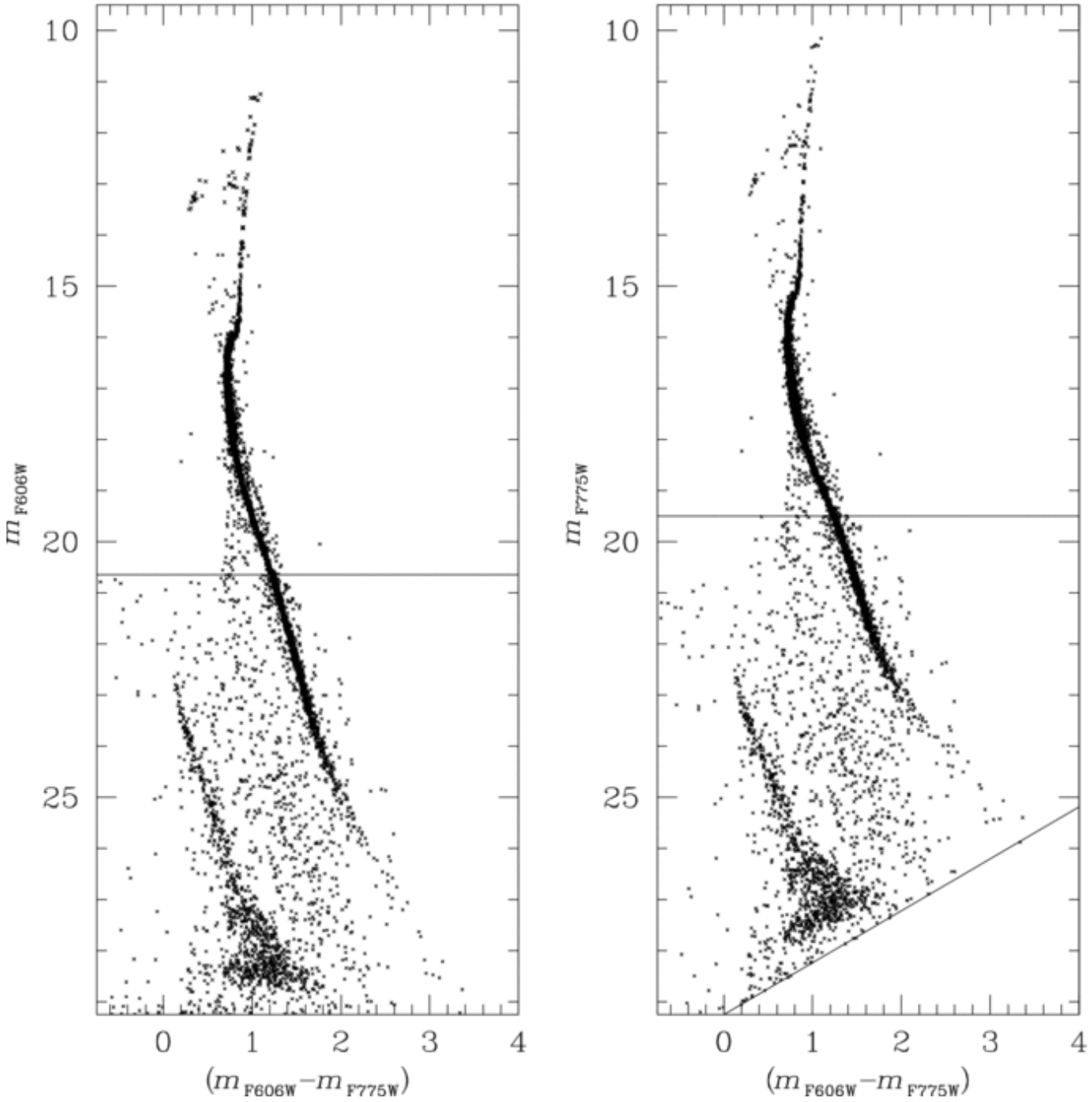


Stellar evolution

- The initial stellar mass determines its fate
- Gravity ⟷ gas pressure
- High mass stars live short (<10^7 years), spectacular lives
- Low mass stars live long (~10^{10} years), lives

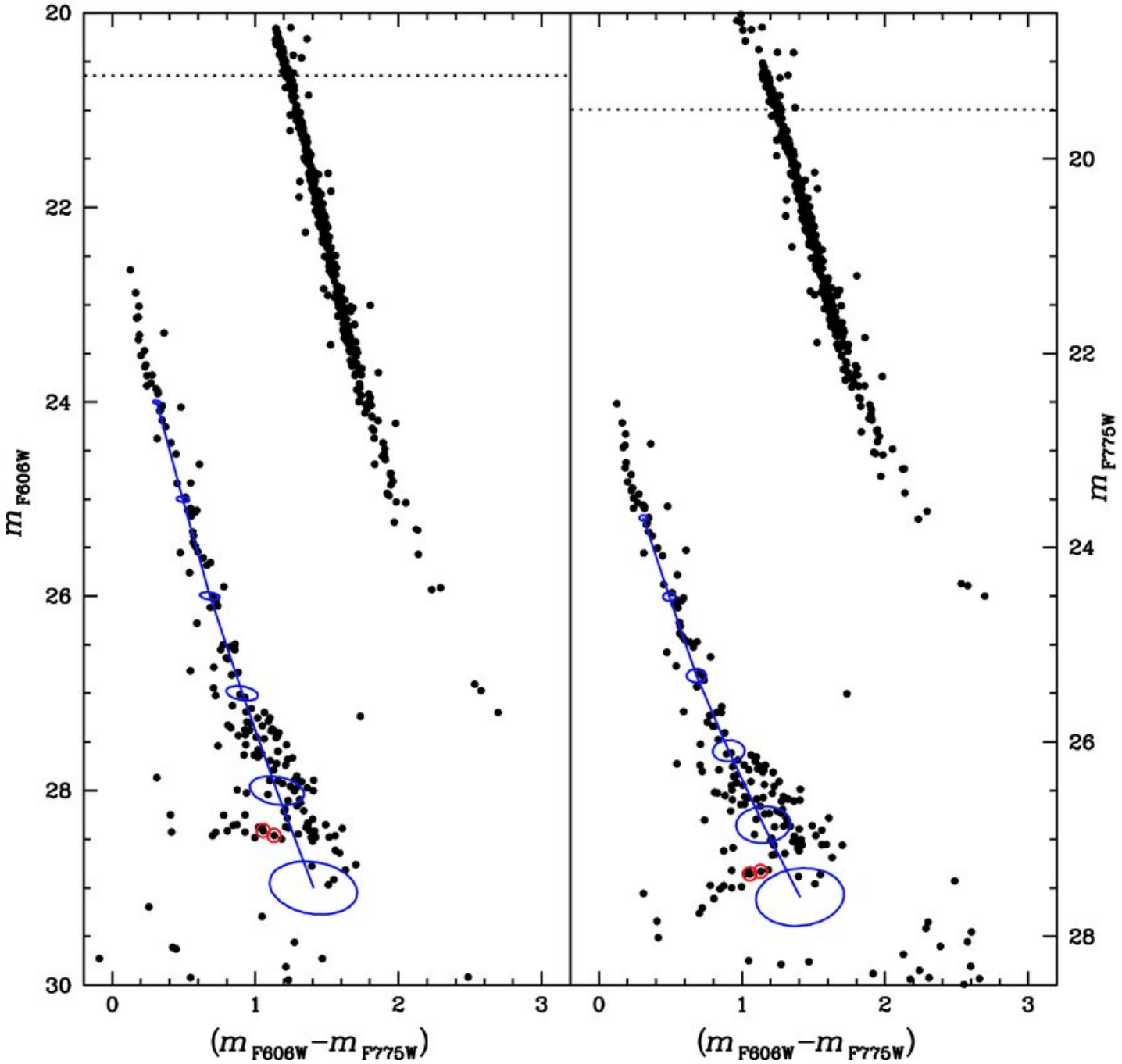
Evolution of low mass (< 8 M_o) stars





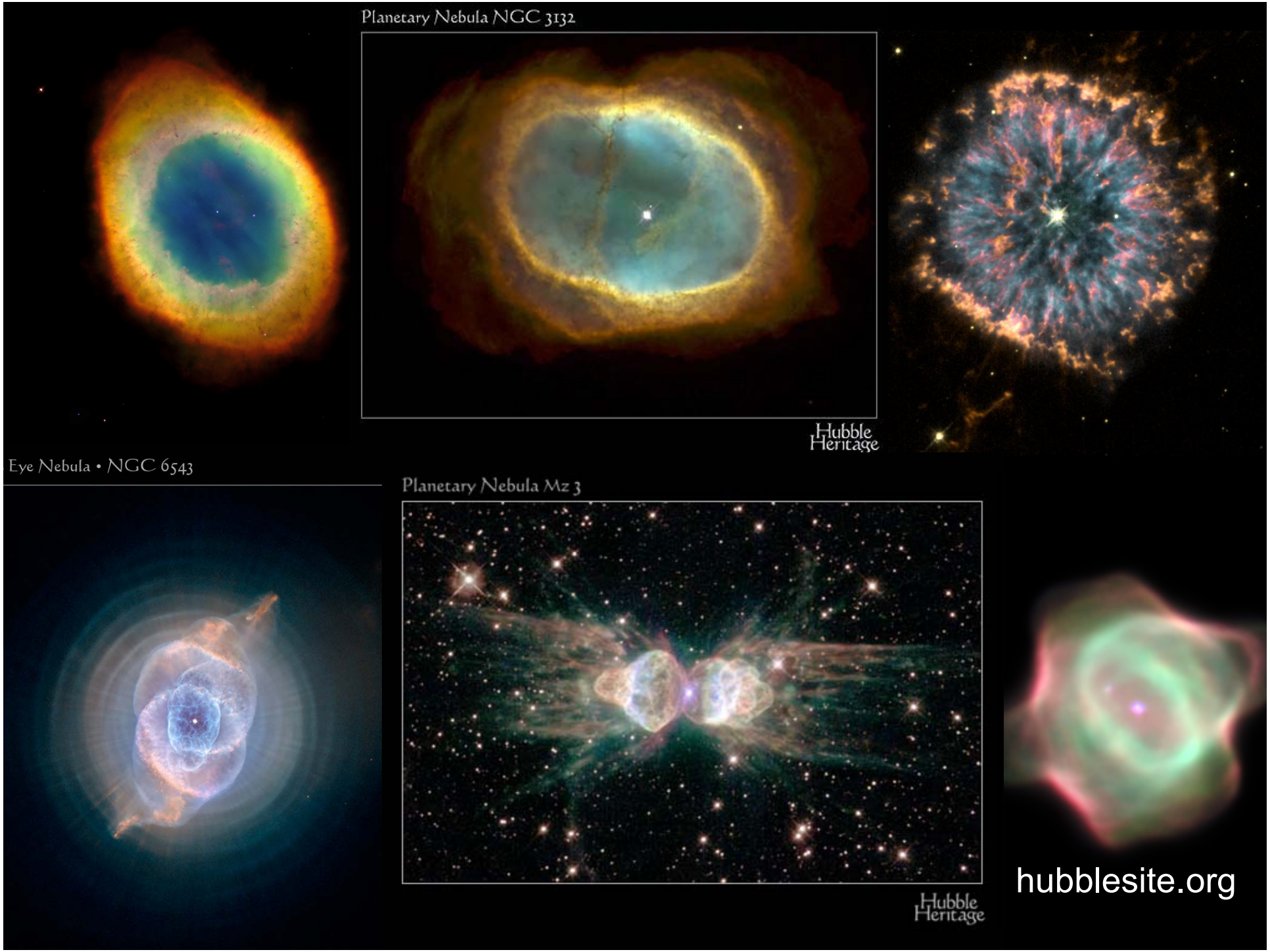
Globular cluster M4

Bedin et al. (2009) with ACS/HST

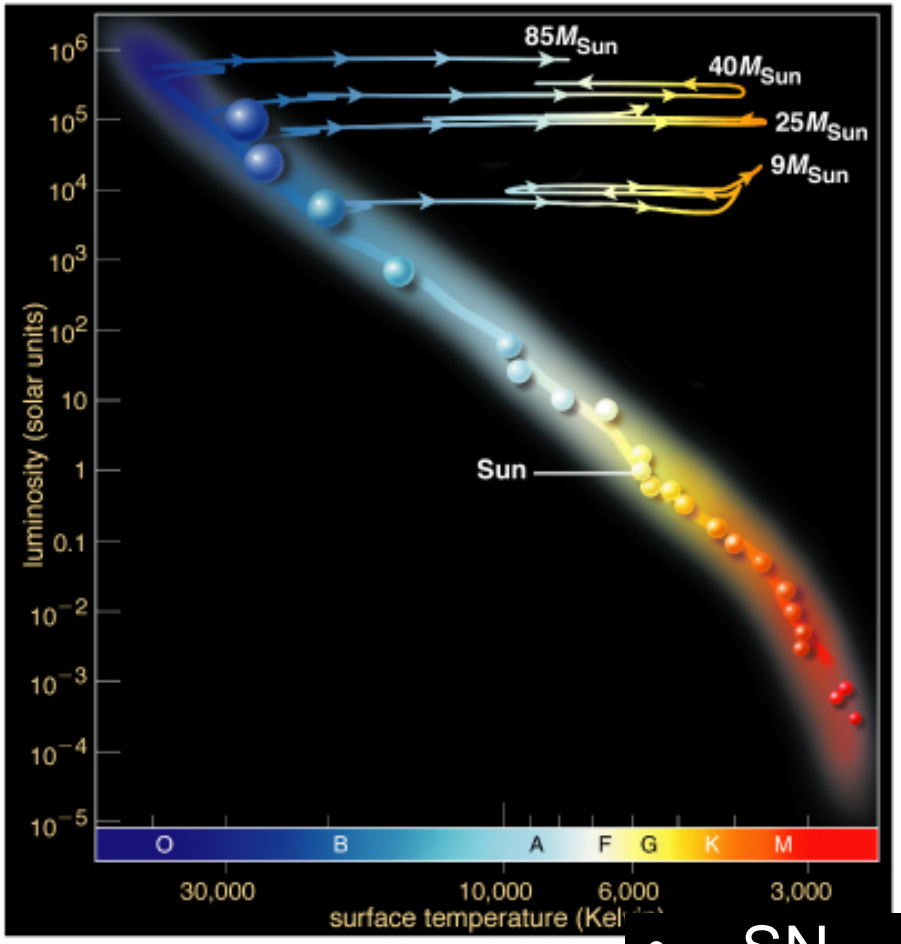


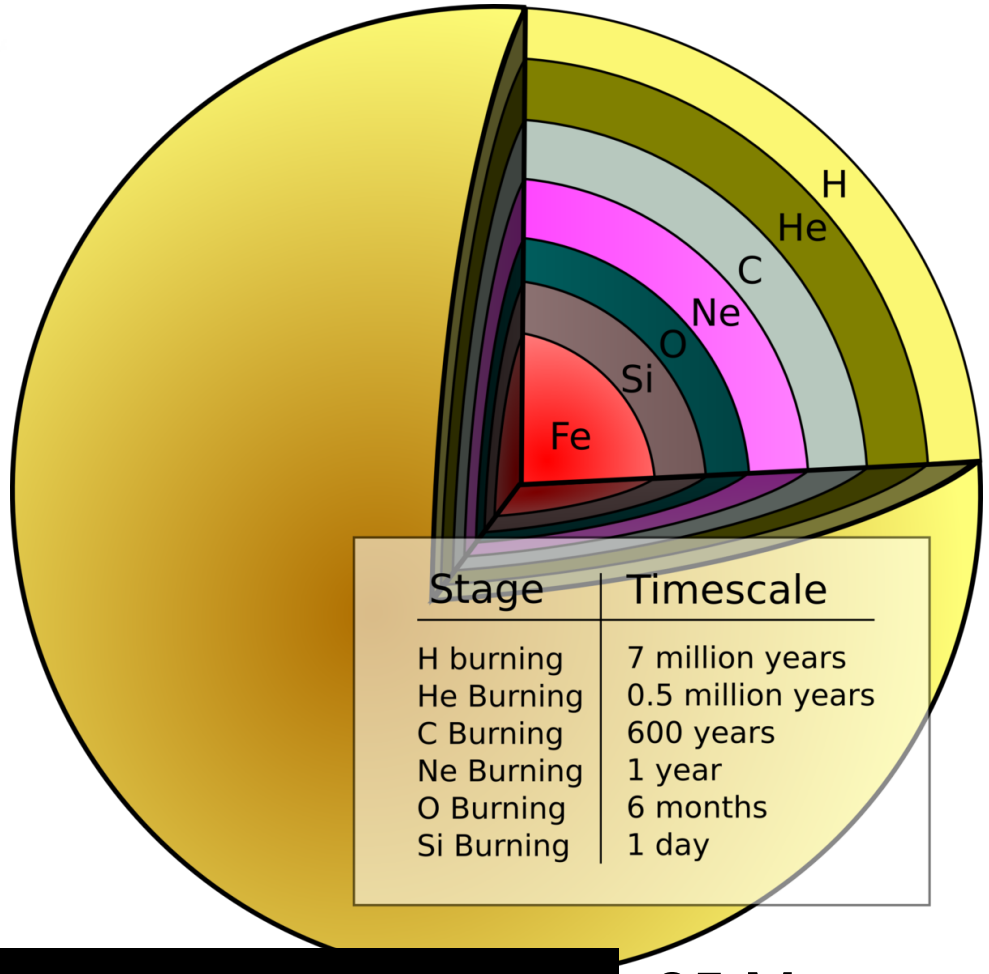
Globular cluster M4

Bedin et al. (2009)


Planetary Nebula NGC 3132
Hubble Heritage
Eye Nebula • NGC 6543
Planetary Nebula Mz 3
Hubble Heritage
hubblesite.org

Evolution of high mass (> 8 M_o) stars

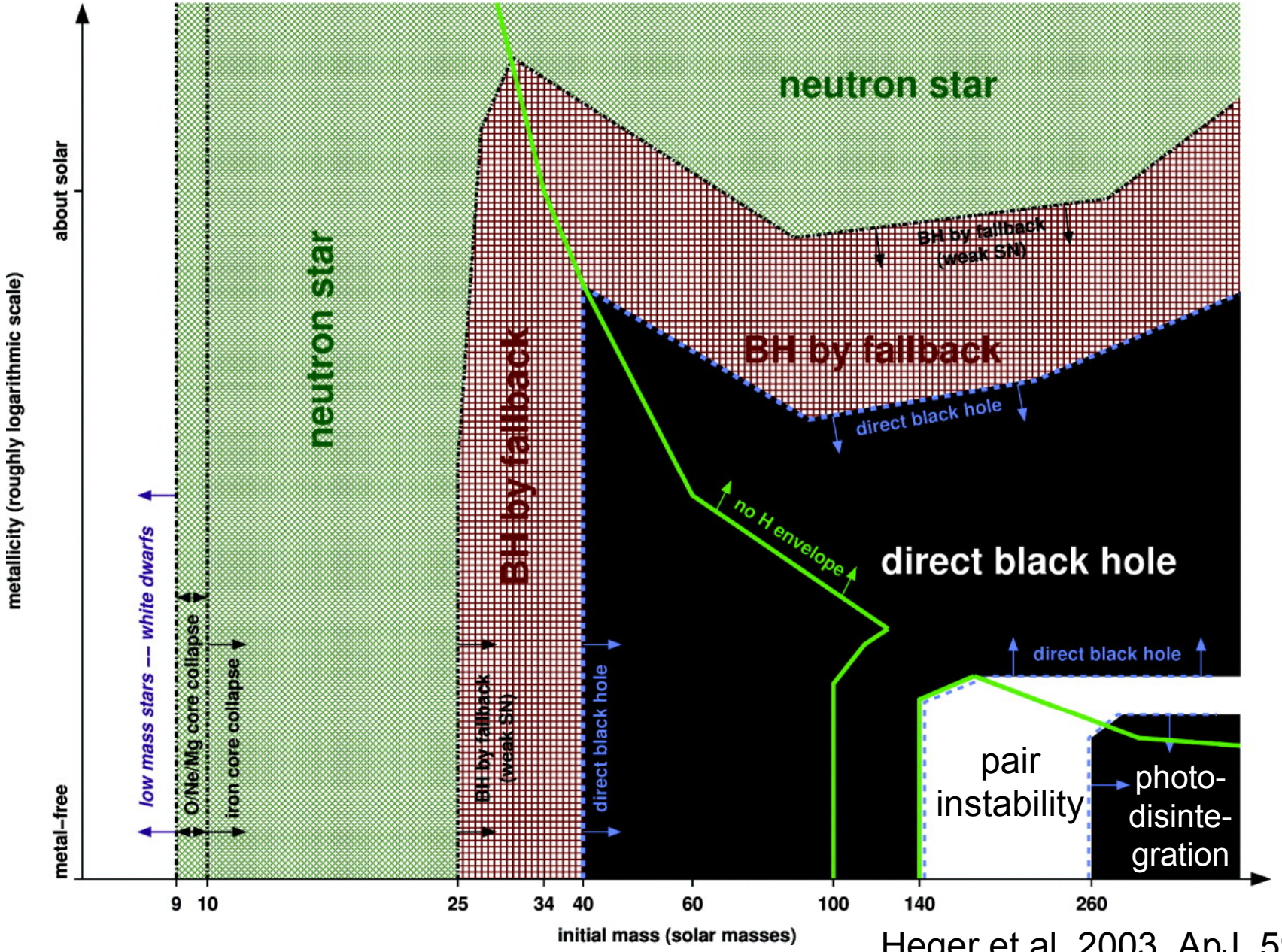




25 M_o

- SN
- SN+GRB
- Nothing? (Kochanek et al. 2008)

Massive star remnants



Heger et al. 2003, ApJ, 591, 288

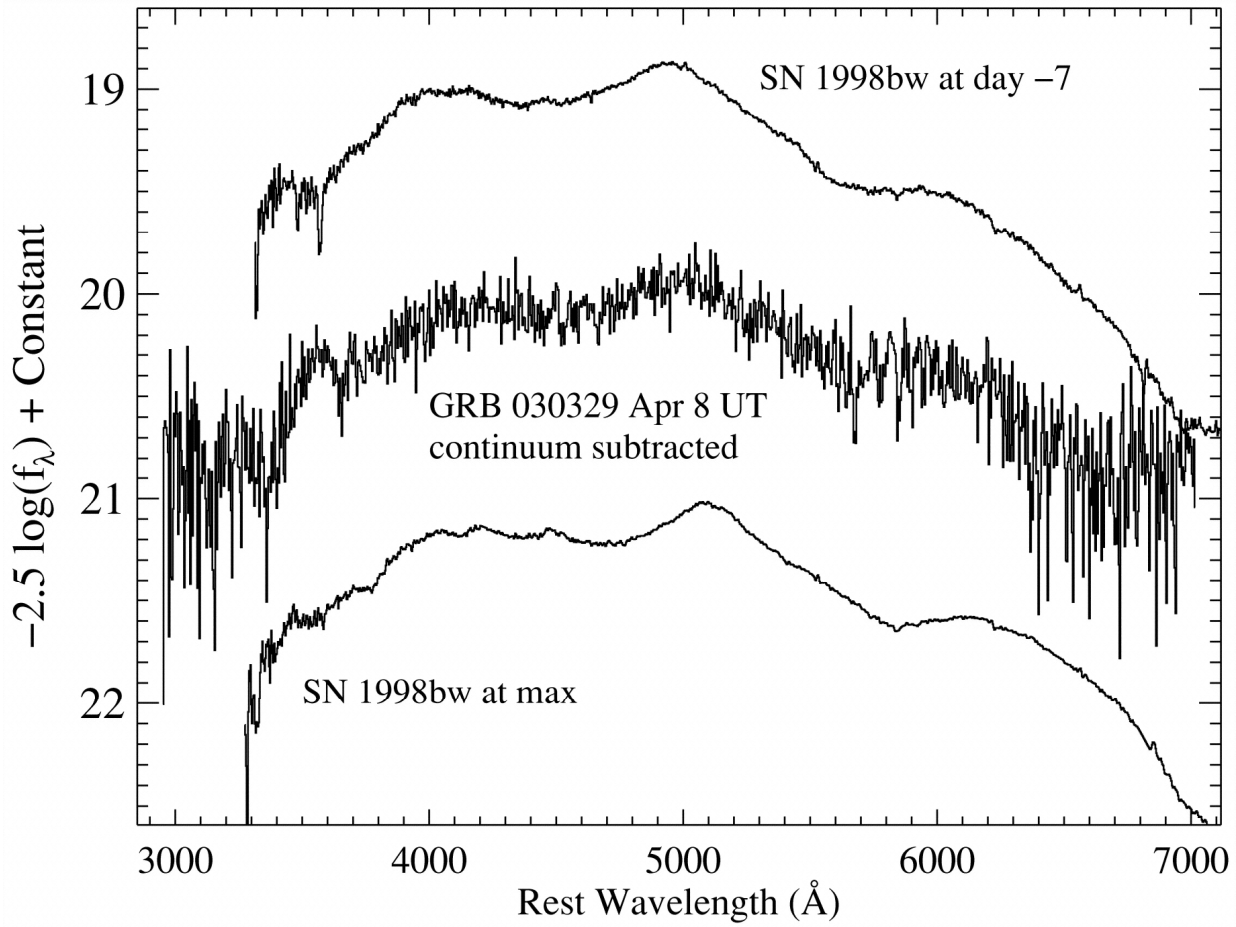
Credit: X-ray: NASA / CXC, Nathan Smith, Weidong Li (UC Berkeley) et al.;
IR: Lick/UC Berkeley/J.Bloom, C.Hansen

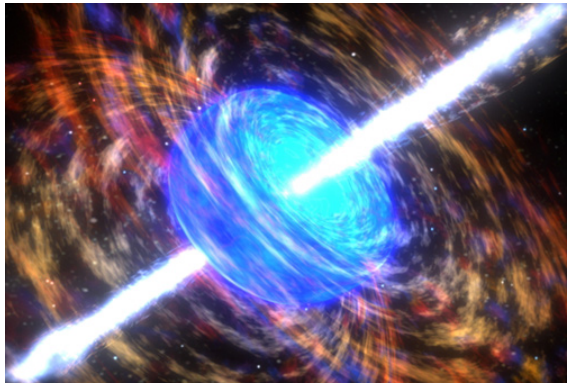
Supernova SN 2006gy

Pair instability SN?

Smith et al. 2007,
ApJ, 666, 1116

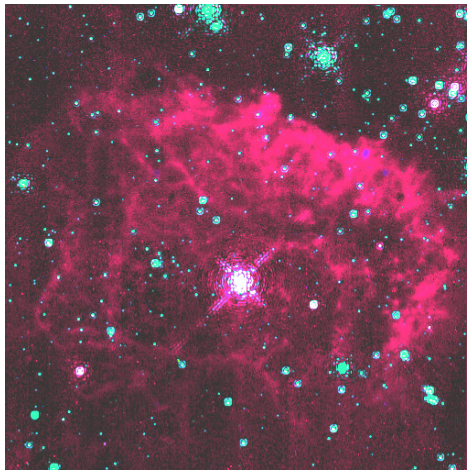
Gamma-ray bursts



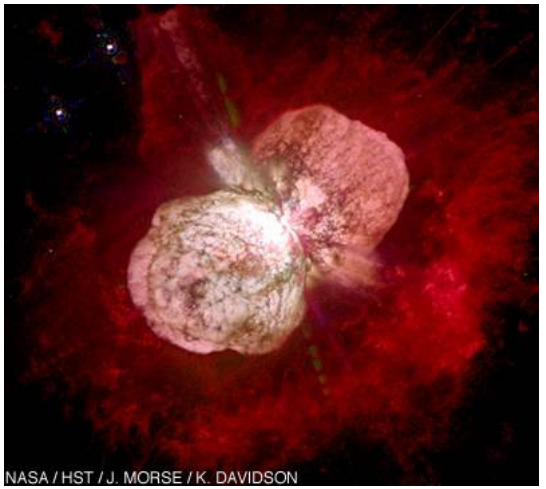


GRB030329+SN2003dh: the *first* confirmation of a GRB-SNIc connection!

Stanek et al. 2003, ApJL, 591, 17

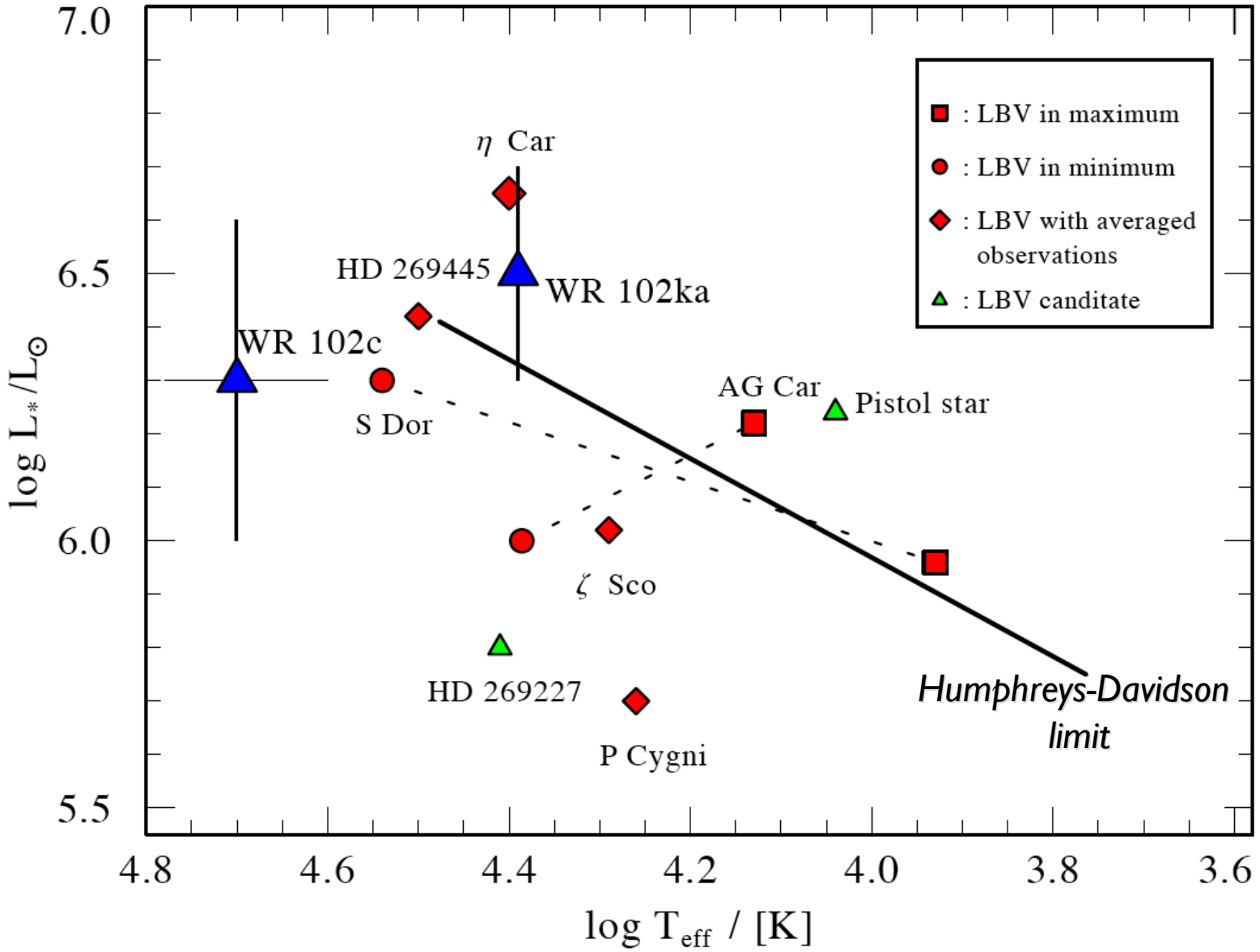


Obscured & dusty stars



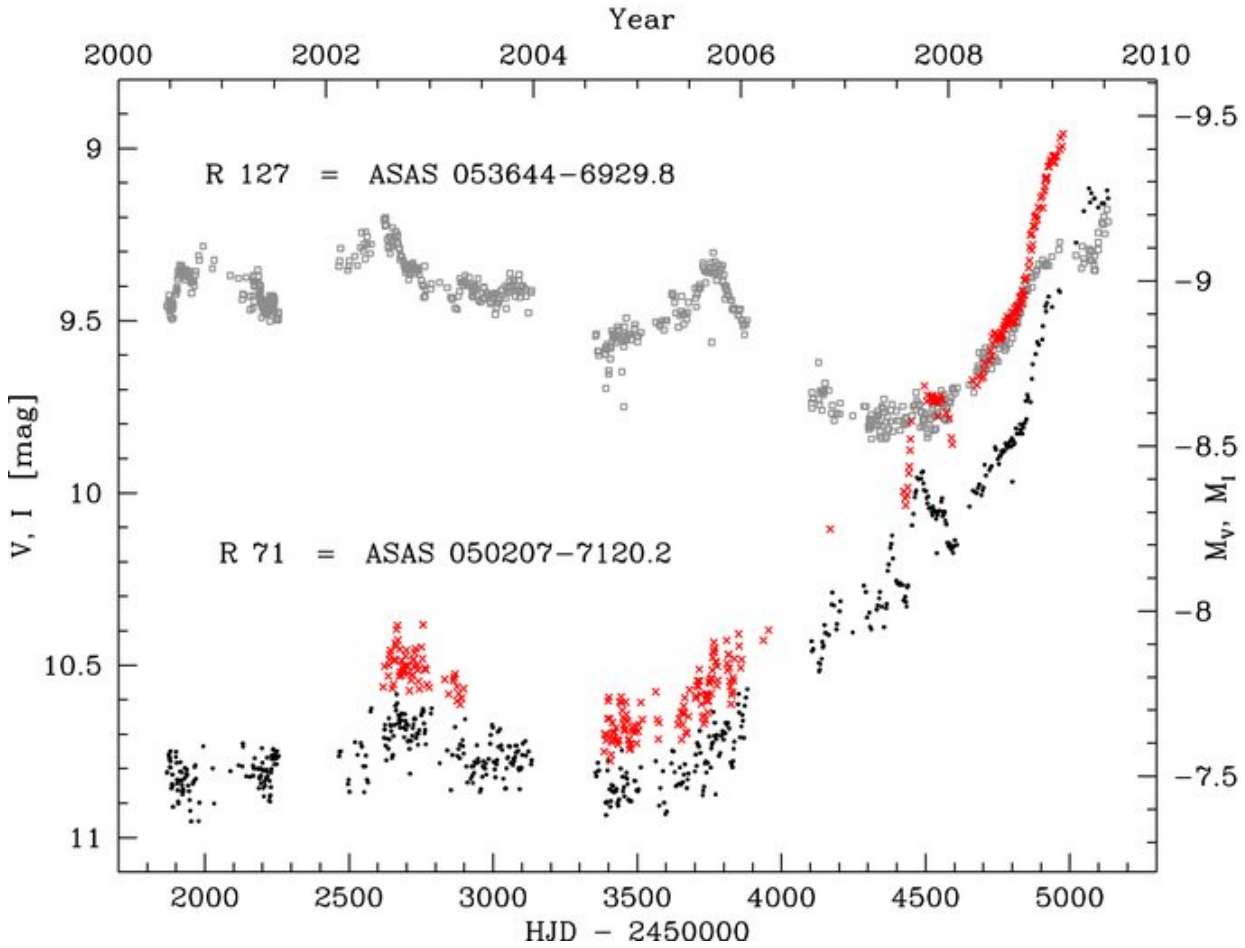
- Asymptotic giant branch stars
- Red supergiants
- Luminous blue variables
- Supergiant B[e] stars
- “Pinwheel” nebulae
- Dusty transient progenitors
- Galactic Center

Luminous blue variables

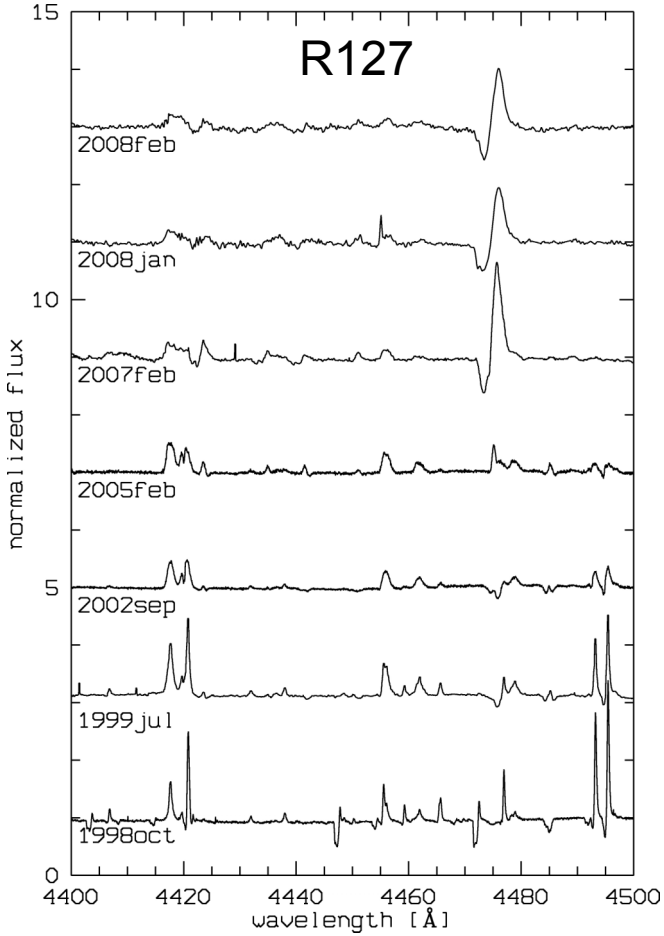


Barniske et al. (2008)

LBV light curves & spectra

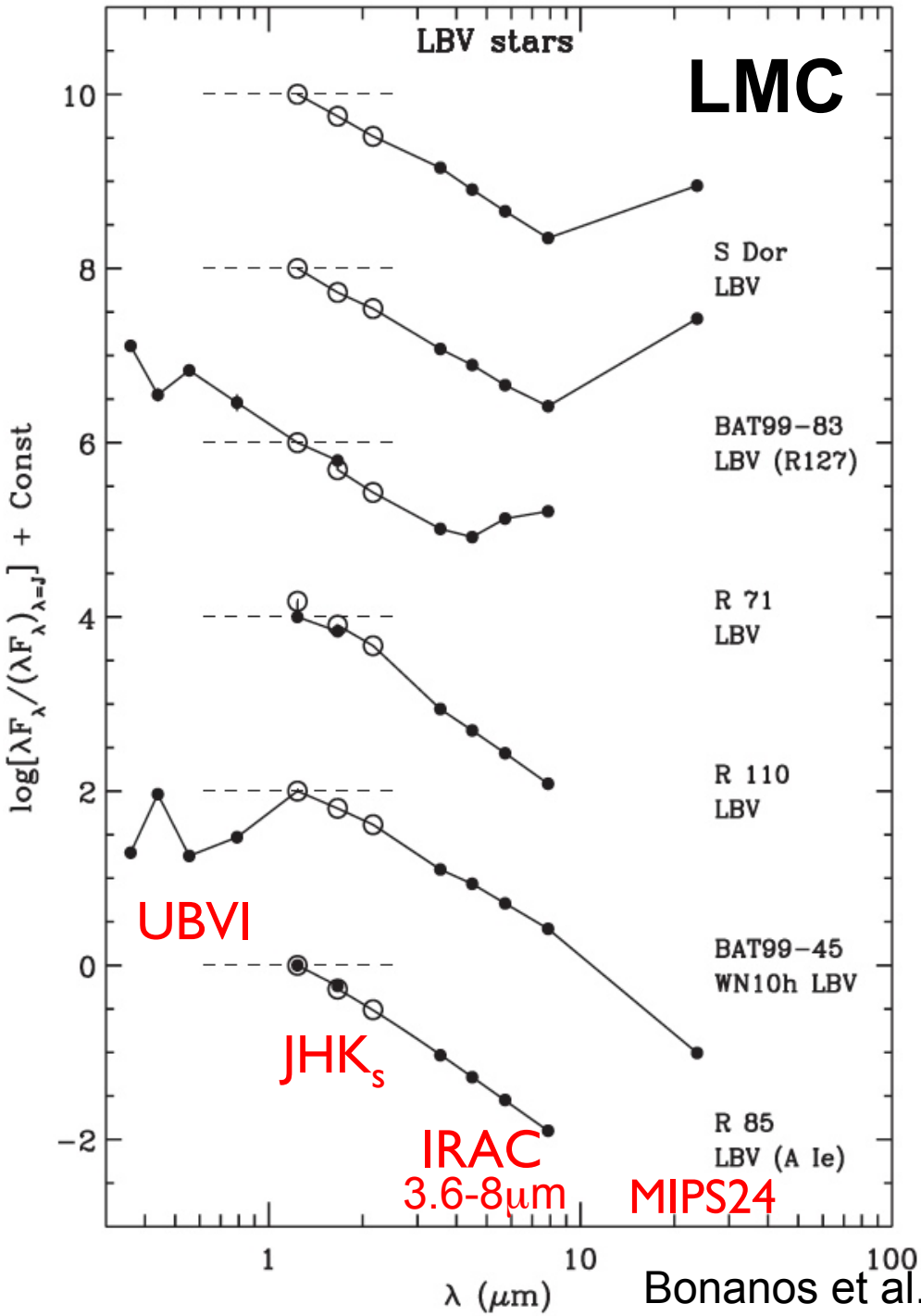


Szczygiel et al. (2010)

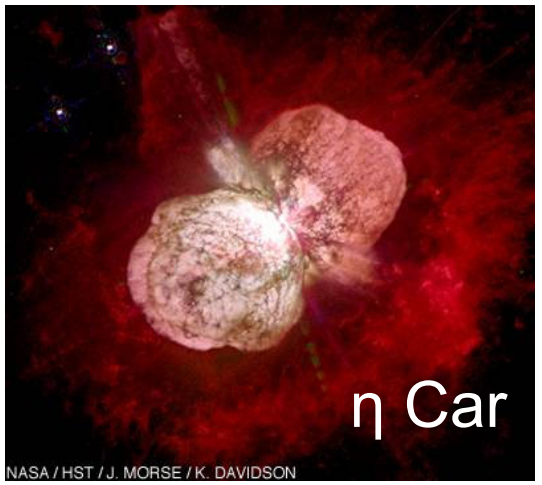


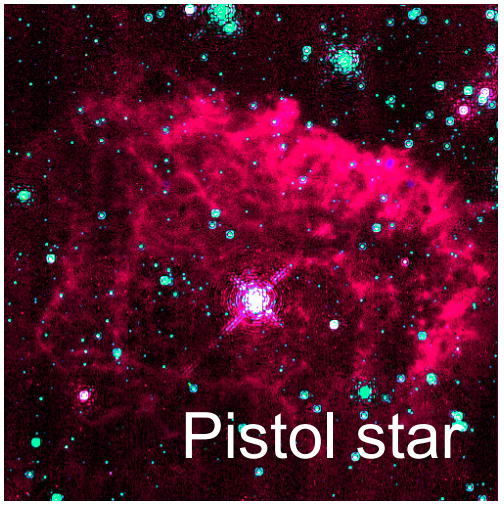
Walborn et al. (2008)

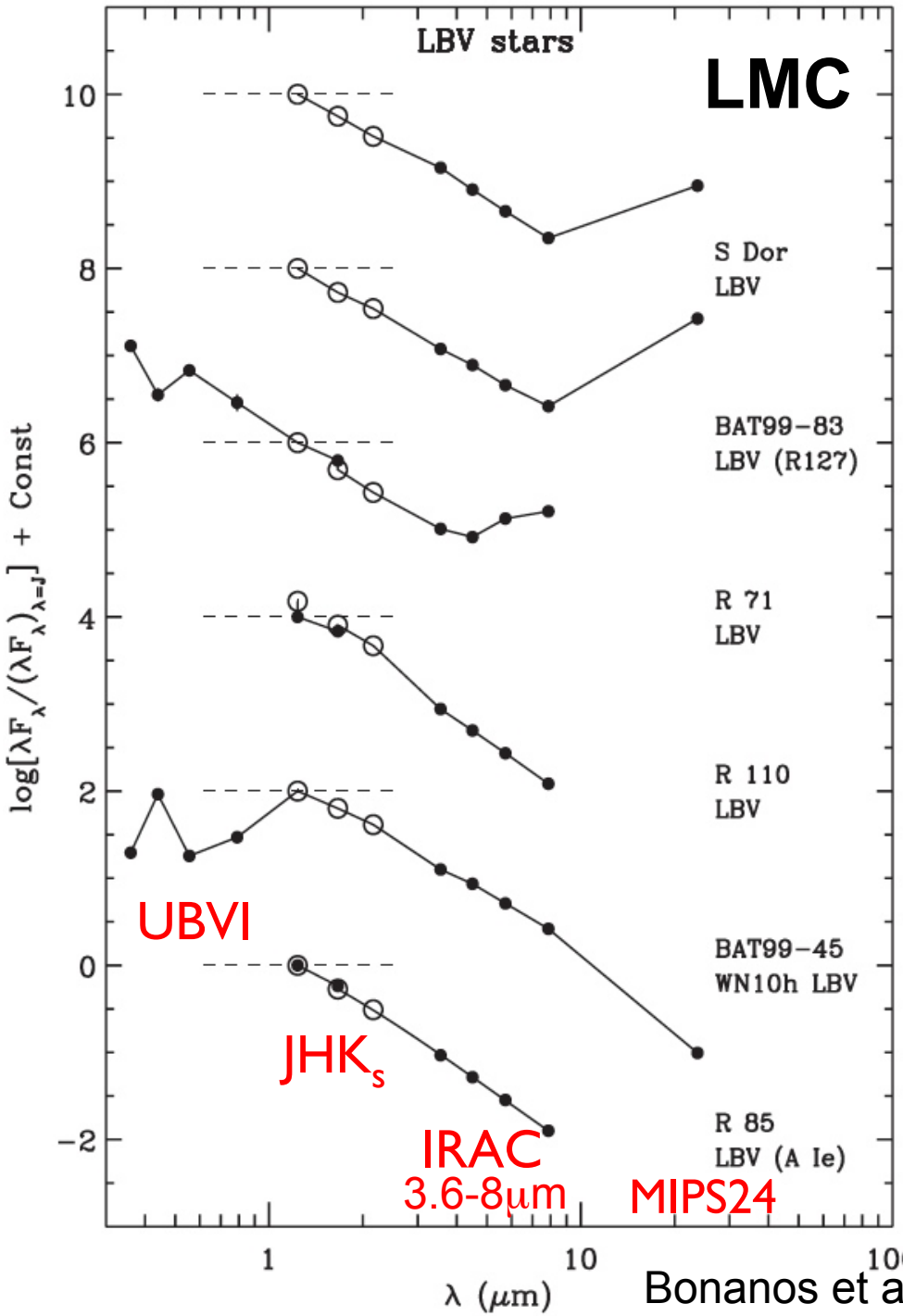
Luminous blue variables



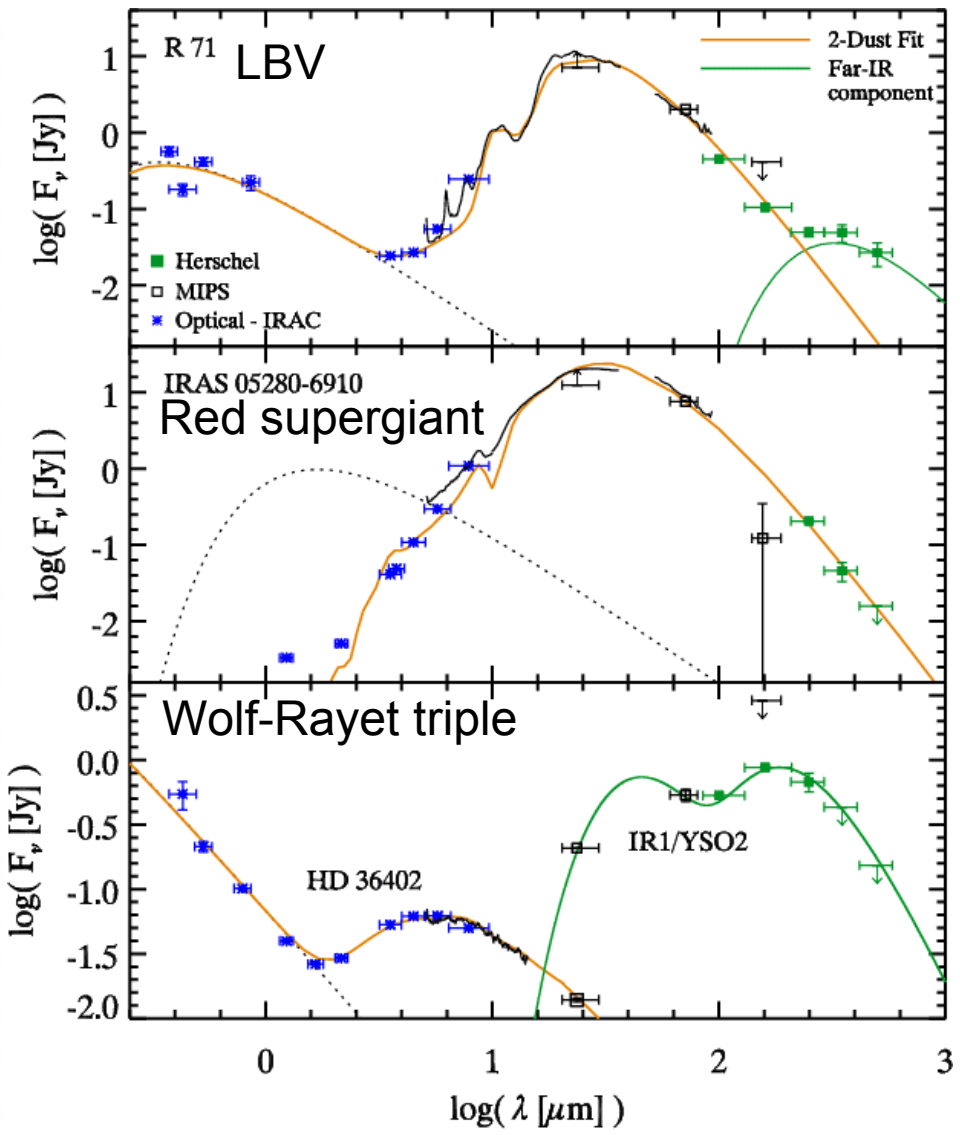
Bonanos et al. (2009)







Bonanos et al. (2009)



Boyer et al. (2010)

Supergiant B[e] stars

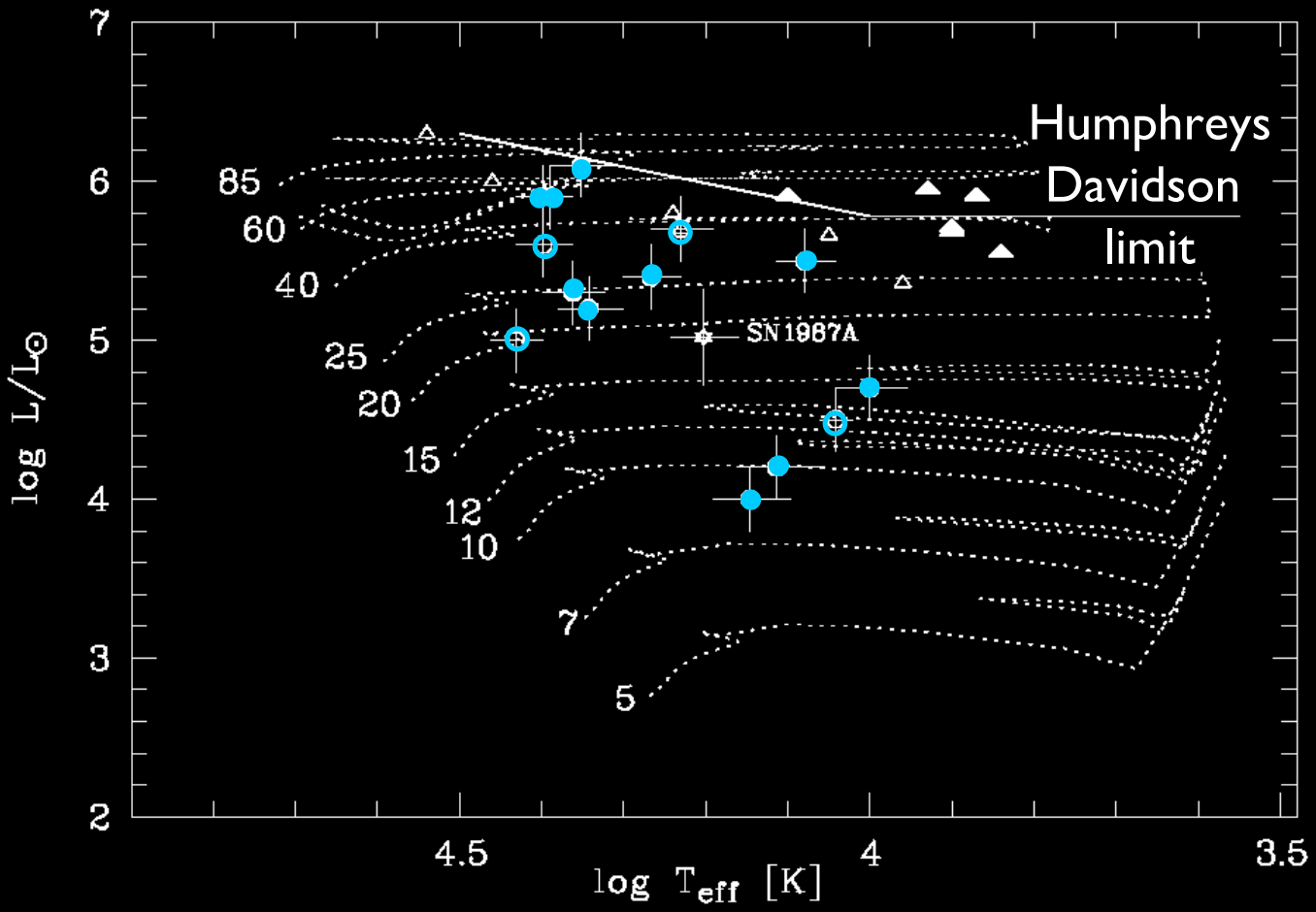
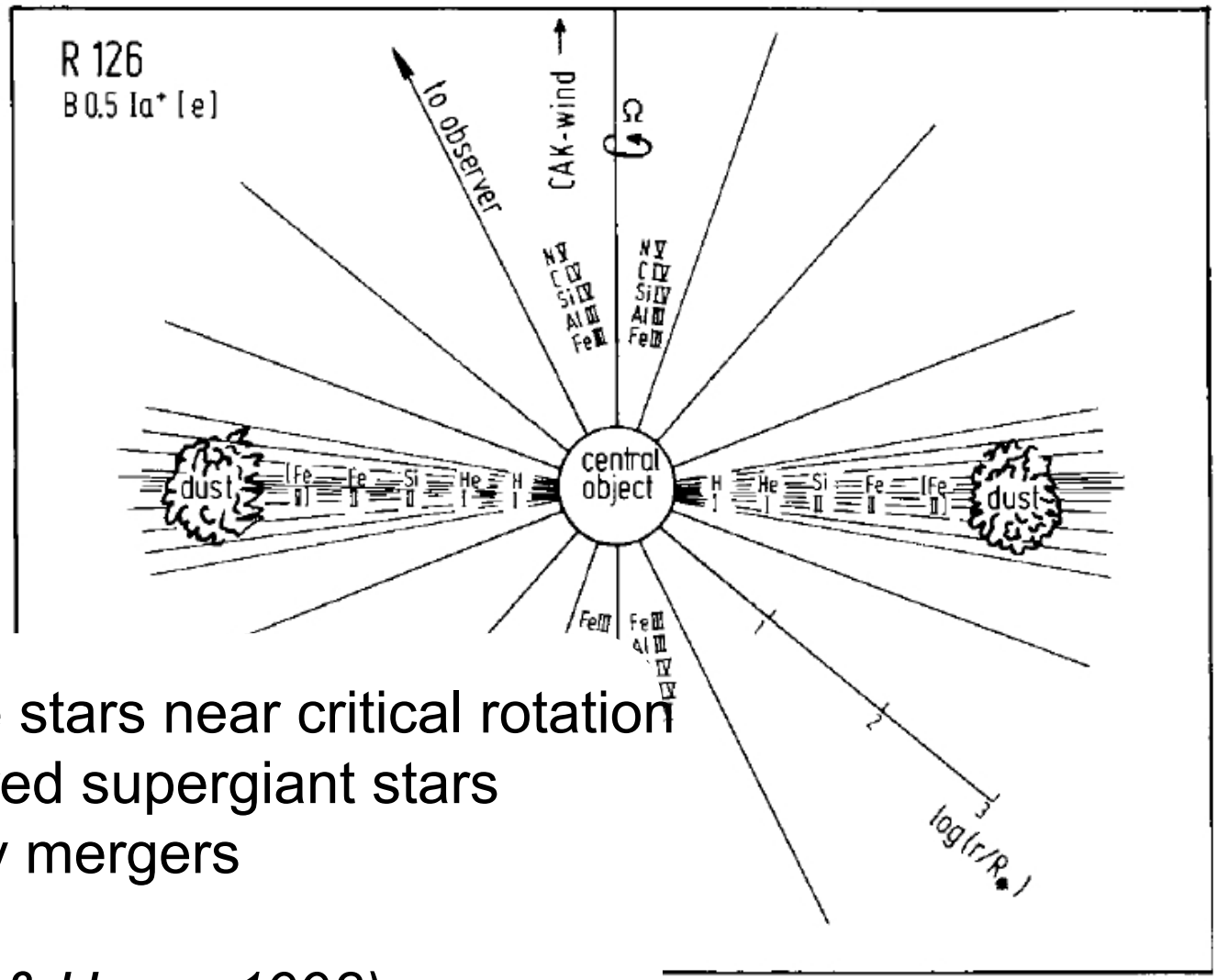


Figure 1. H-R diagram showing the location of the B[e] supergiants in the LMC (filled circles) and the SMC (open circles). Also shown are the 6 LBVs in the MCs (open triangles: minimum phase, filled triangles: maximum phase). The position of the precursor of SN 1987A is indicated. The solid line denotes the Humphreys-Davidson limit. Evolutionary tracks are from Schaller et al. (1992) for $Z = 0.008$.

Zickgraf (2006)

Supergiant B[e] stars

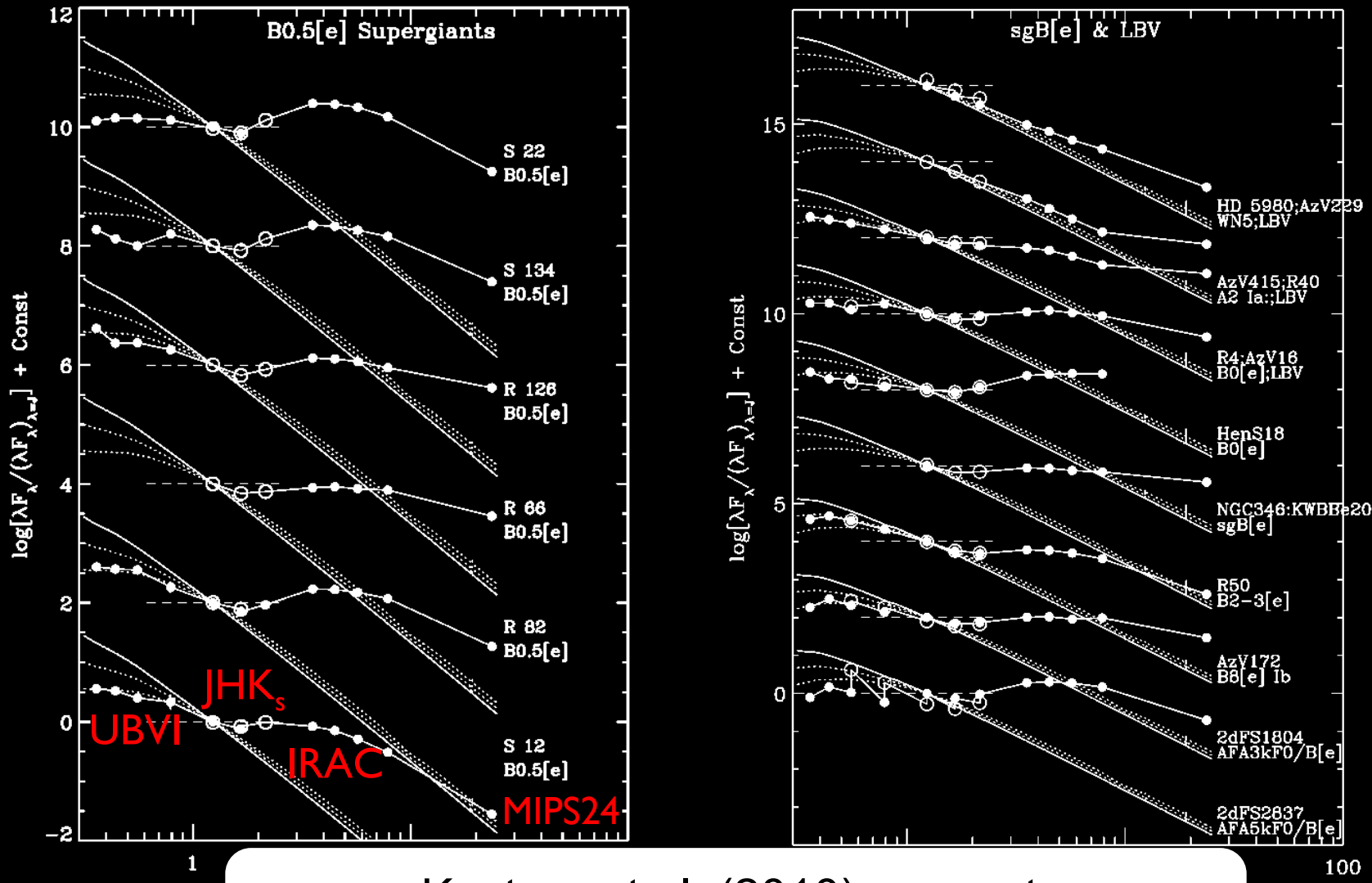


1) single stars near critical rotation
2) post-red supergiant stars
3) binary mergers

(Langer & Heger 1998)

Zickgraf (2006)

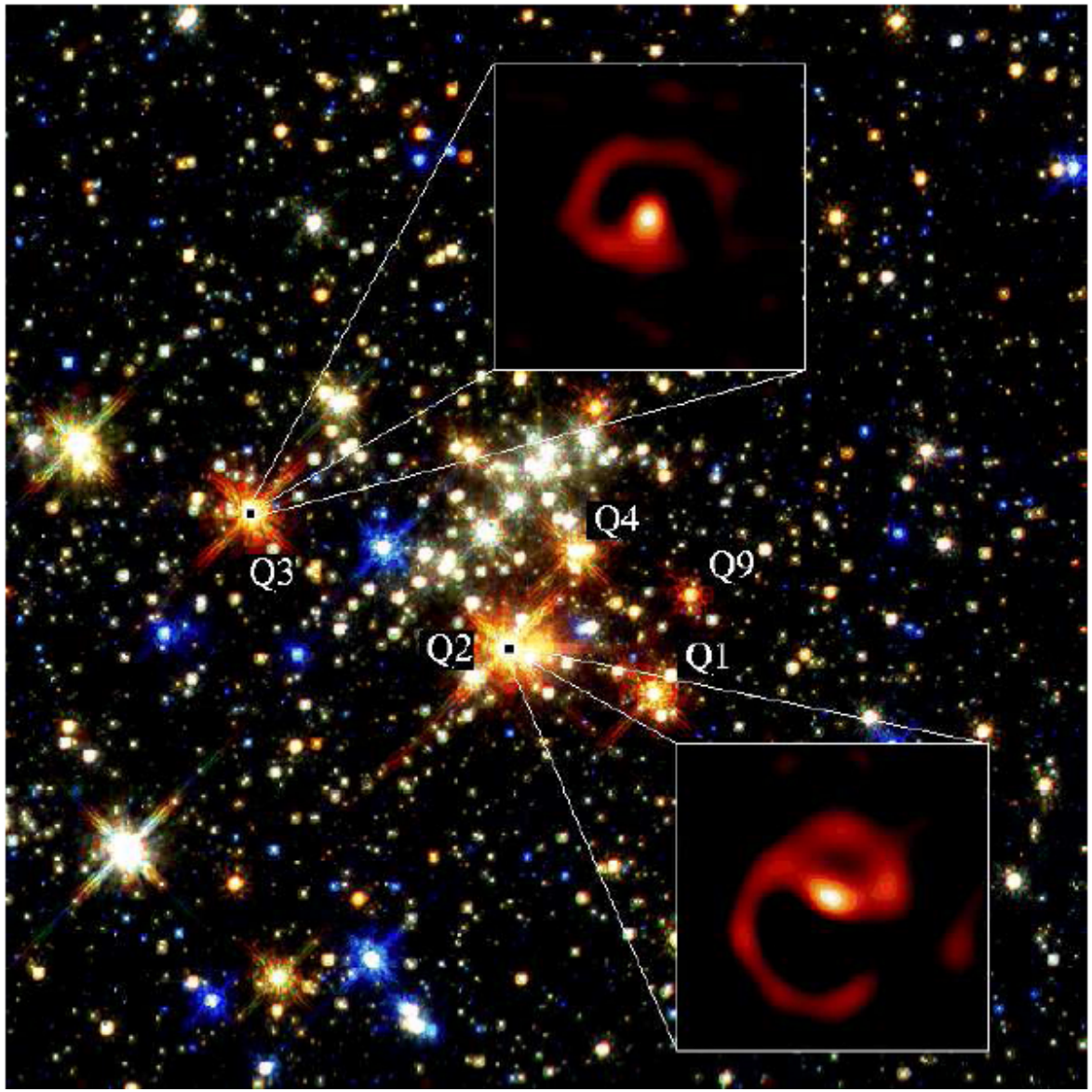
Supergiant B[e] stars



Kastner et al. (2010) suggest:
post-RSG in binaries with circumbinary disks

“Pinwheel” nebulae

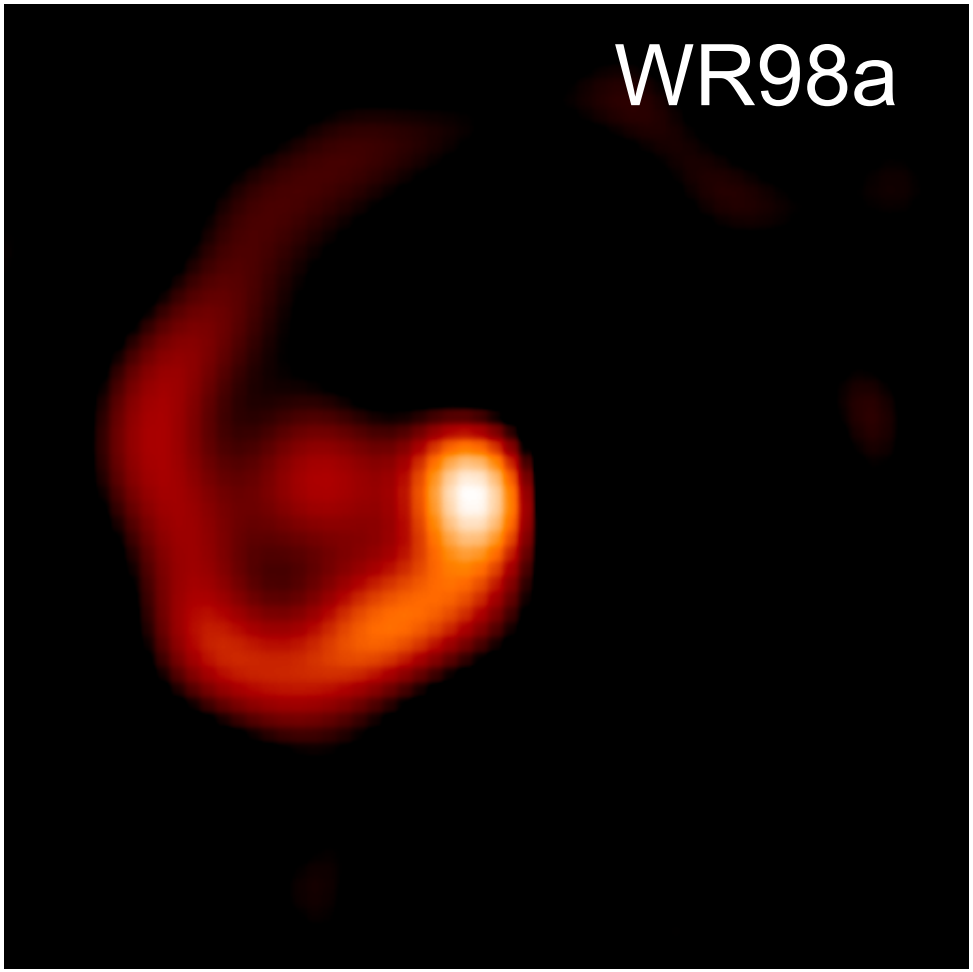
Colliding wind (or Wolf-Rayet) binaries



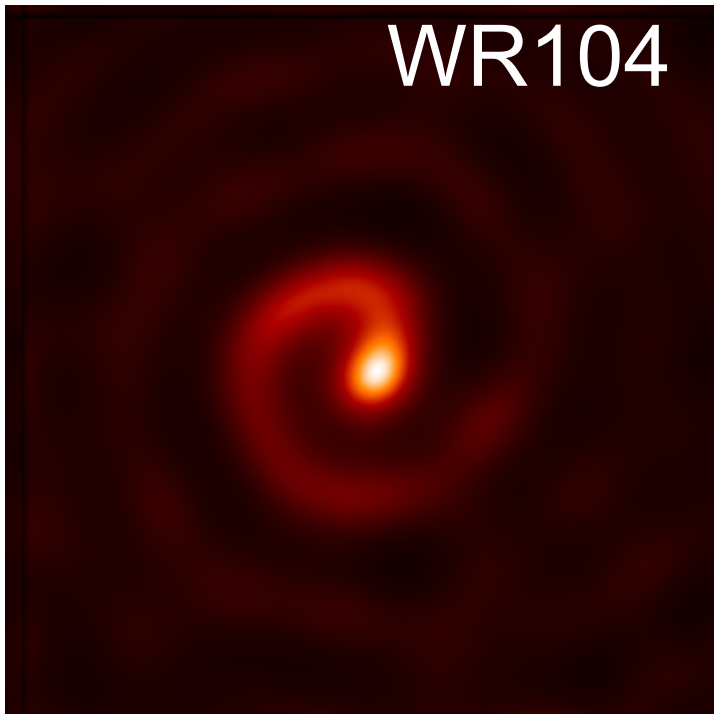
Keck diffraction limited images

Tuthill et al. 2006, *Science*, 313, 5789

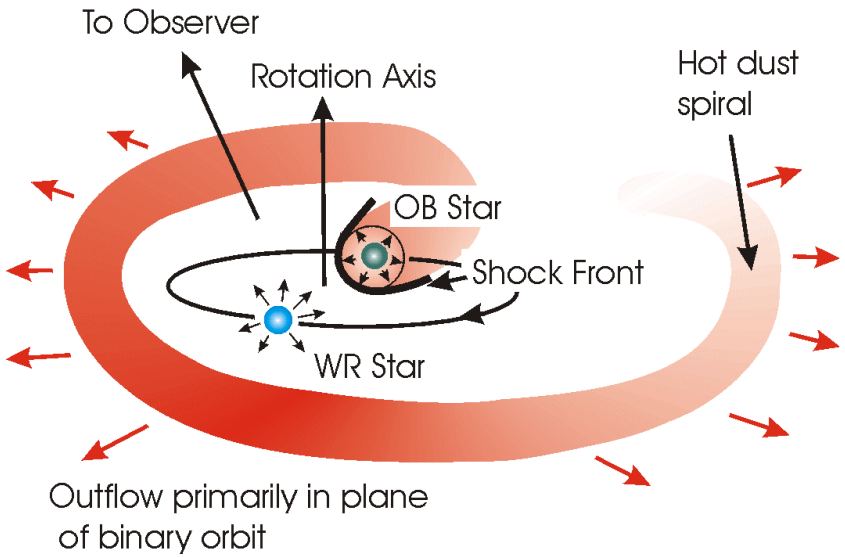
“Pinwheel” nebulae



P=565+/-50 days, Monnier et al. (1999)

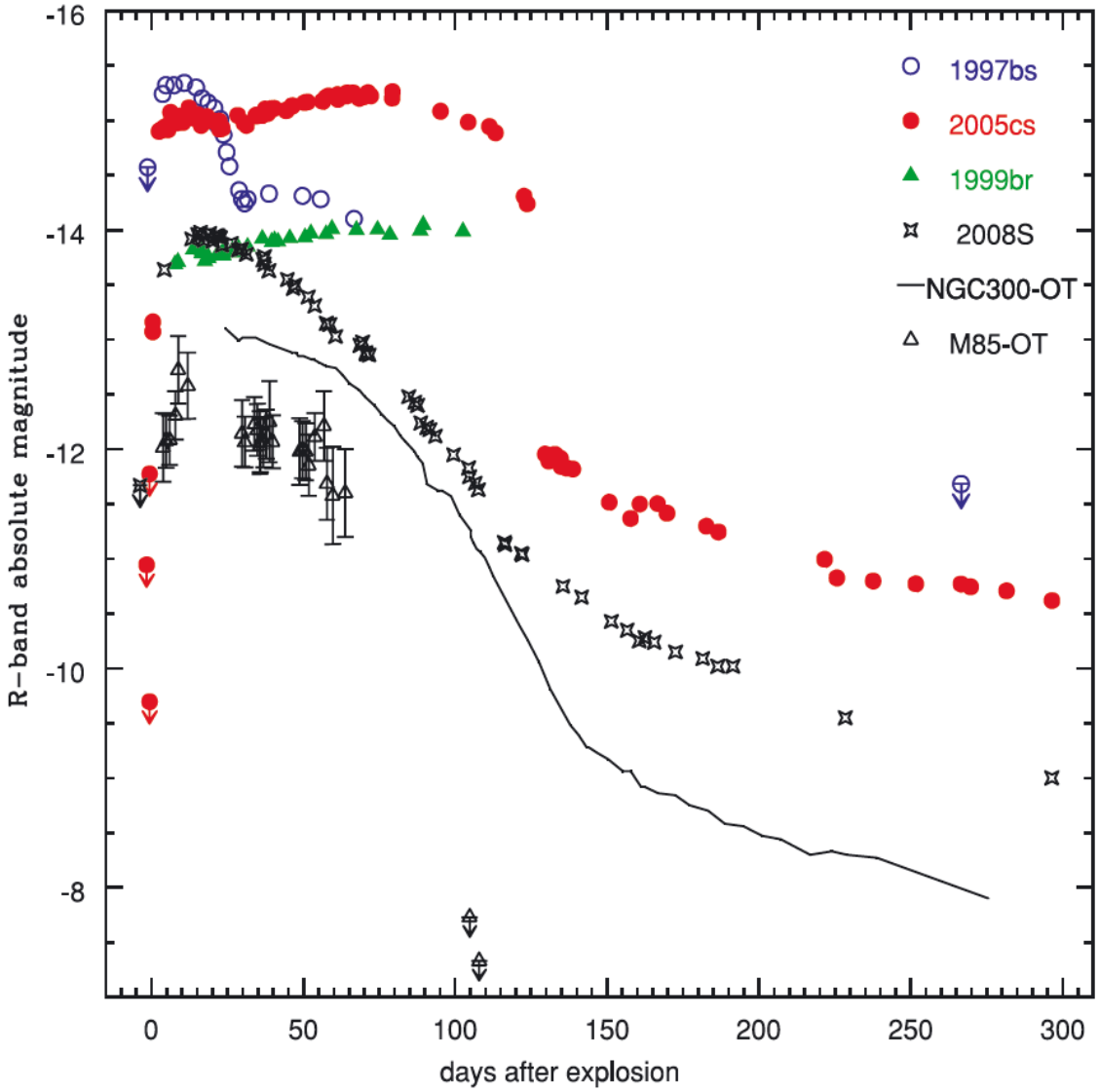


P=241.5+/-0.5 days, Tuthill et al. (2008)



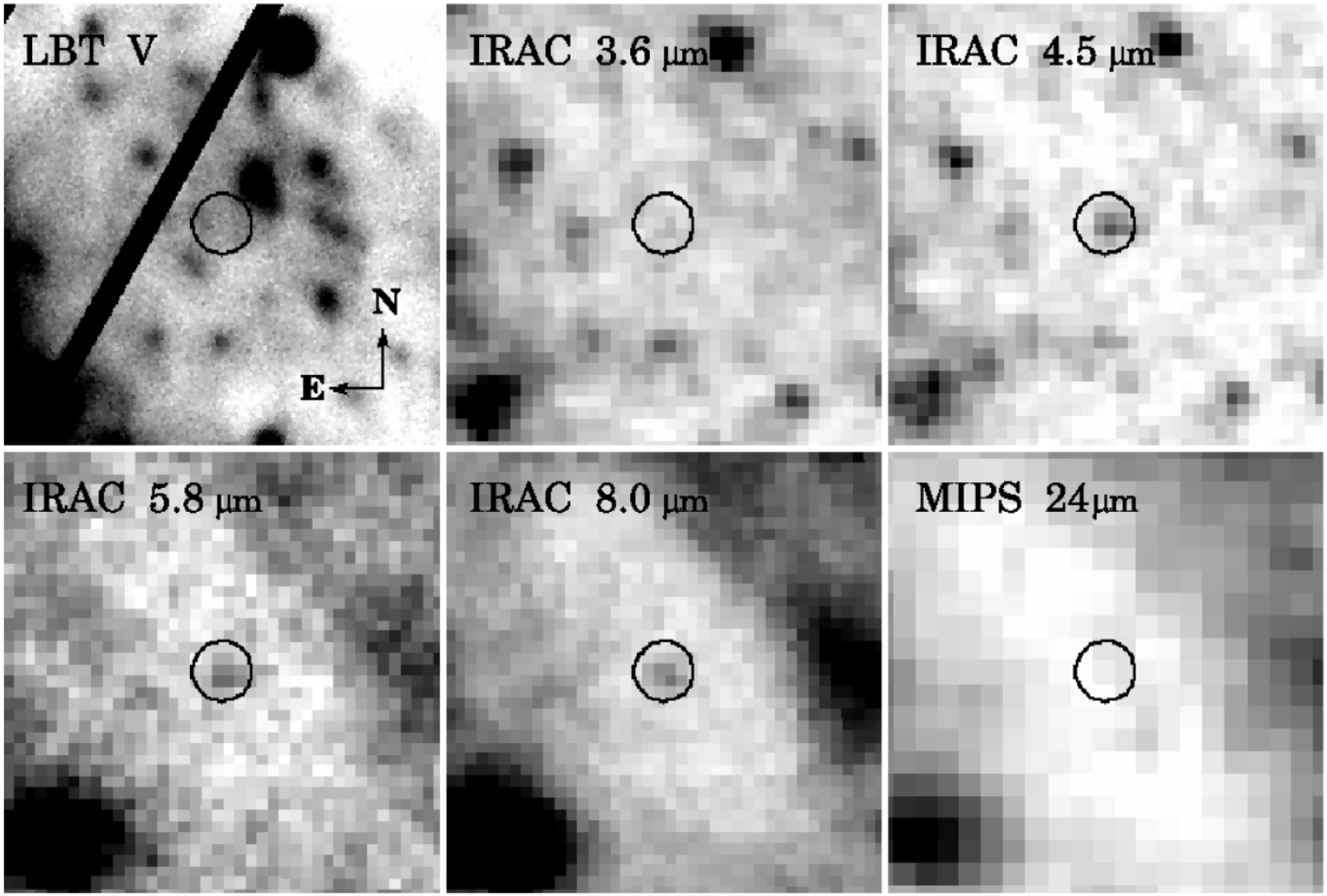
K-band aperture masking interferometry with Keck

New transients:
SN 2008S, NGC 300-OT, SN 2010da



Botticella et al. (2009)

Obscured progenitor of SN 2008S

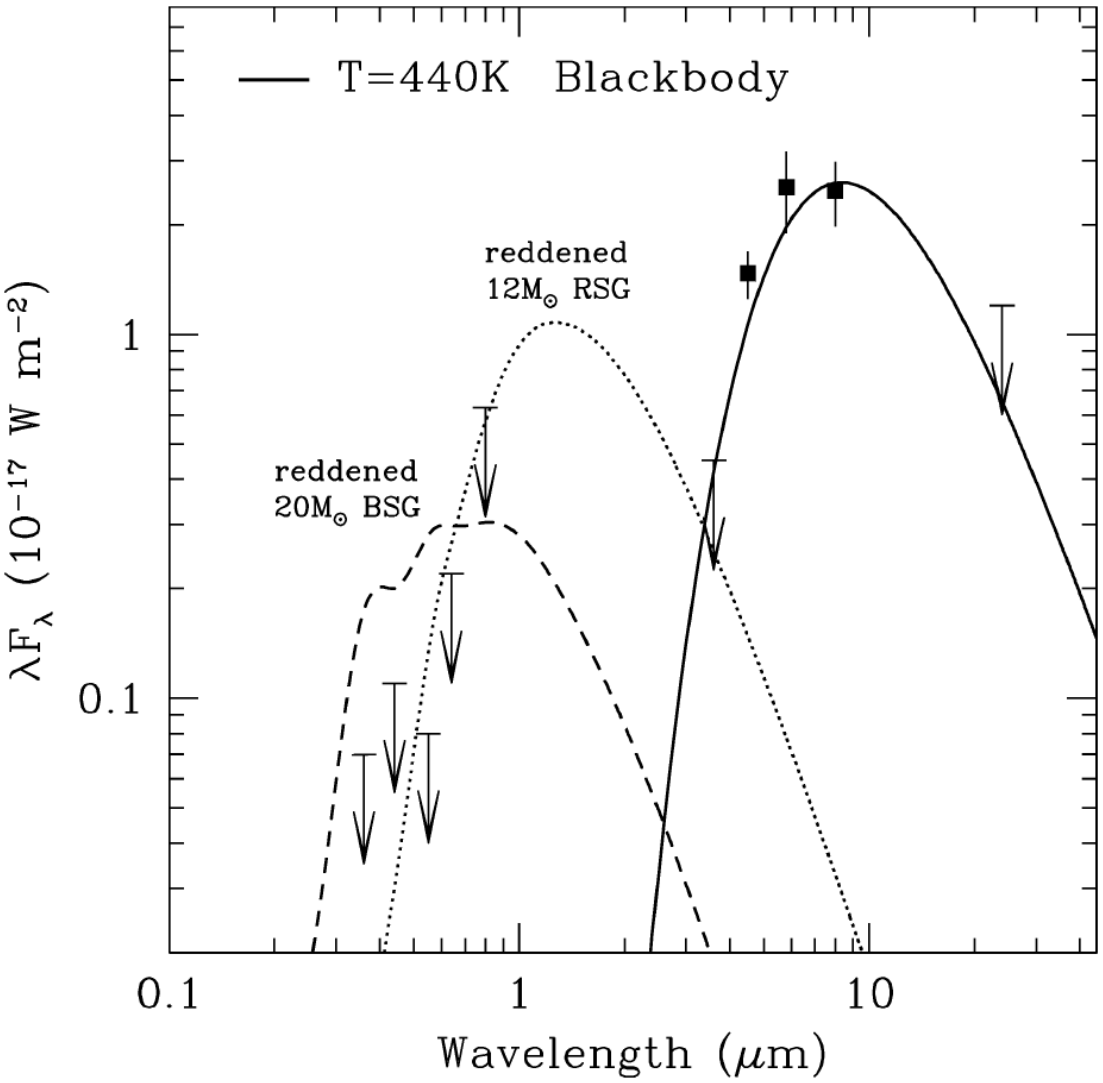


$L \sim 3.5 \times 10^4 L_o$

$M \sim 10 M_o$

Prieto et al. (2008)

SN 2008S

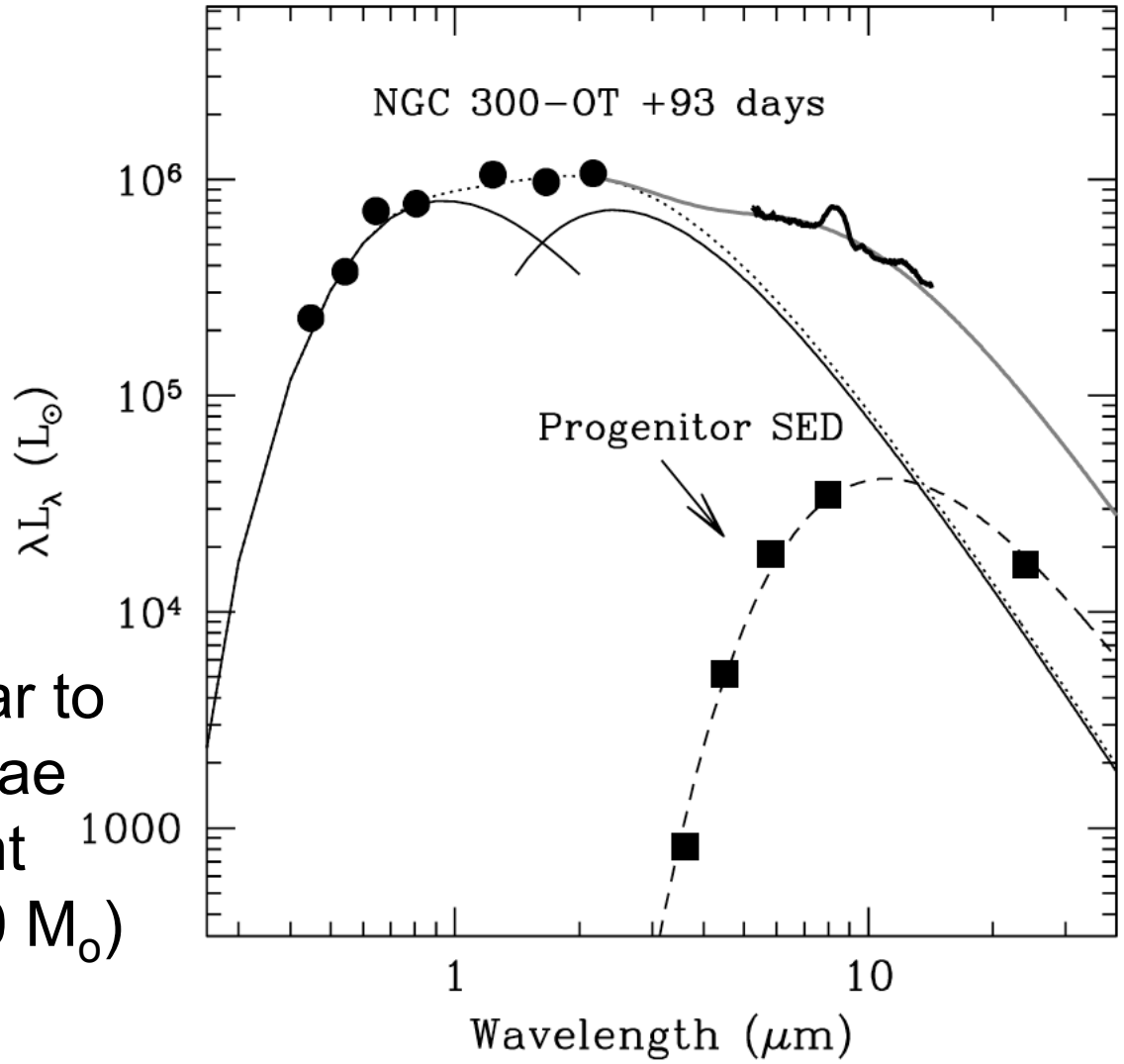


Possible mechanisms:

- Massive white dwarf birth (M_{ZAMS}~6-8 M_o)
- Electron-capture supernova (M_{ZAMS}~9 M_o)
- Low-L iron core-collapse supernova (M_{ZAMS}~10-12 M_o)
- Massive star outburst (M_{ZAMS}~10-15 M_o)

Prieto et al. (2008)

NGC 300-OT

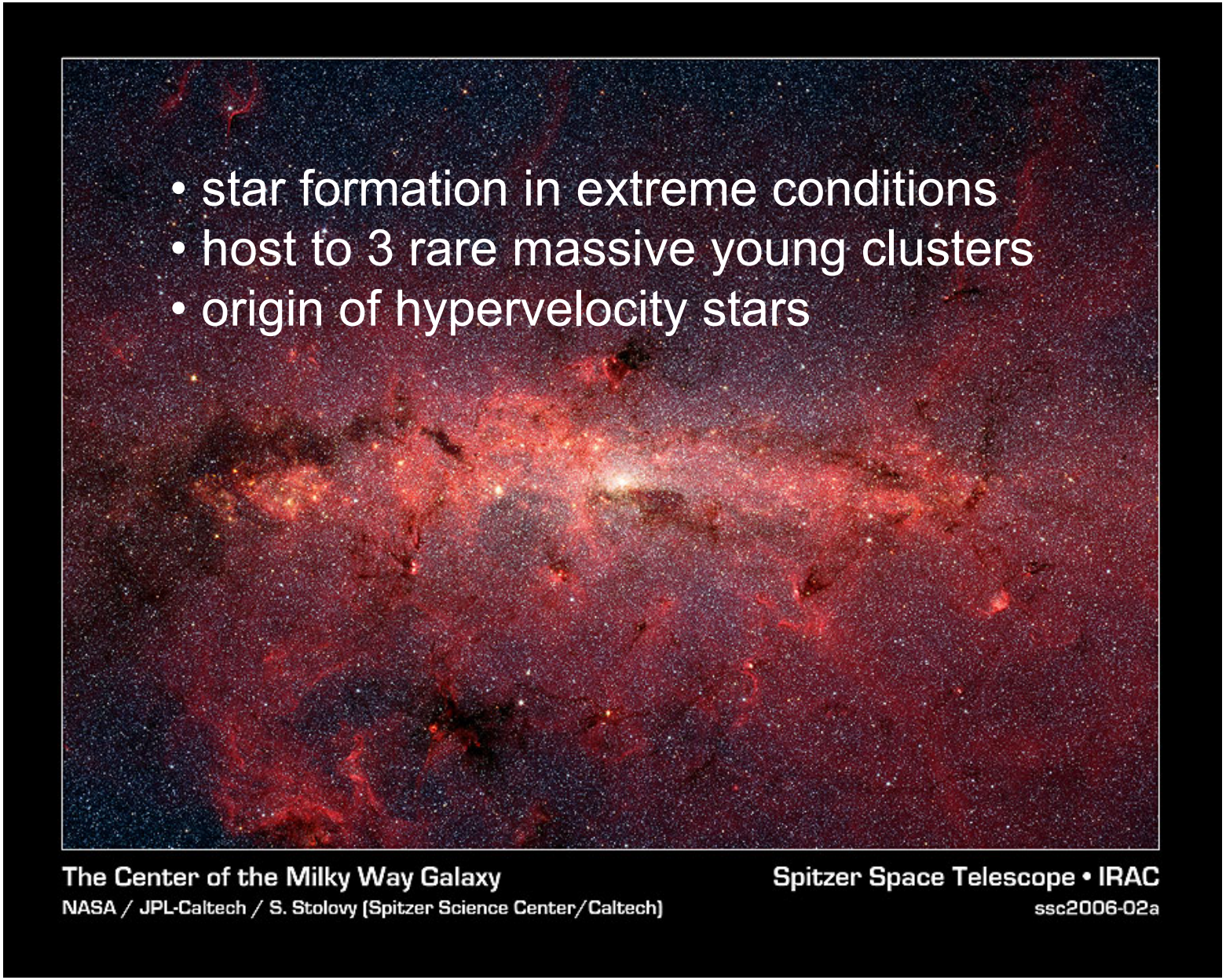


Spitzer spectrum similar to proto-planetary nebulae
→an explosive event
on a massive (M ~ 6-10 M_o) AGB star?

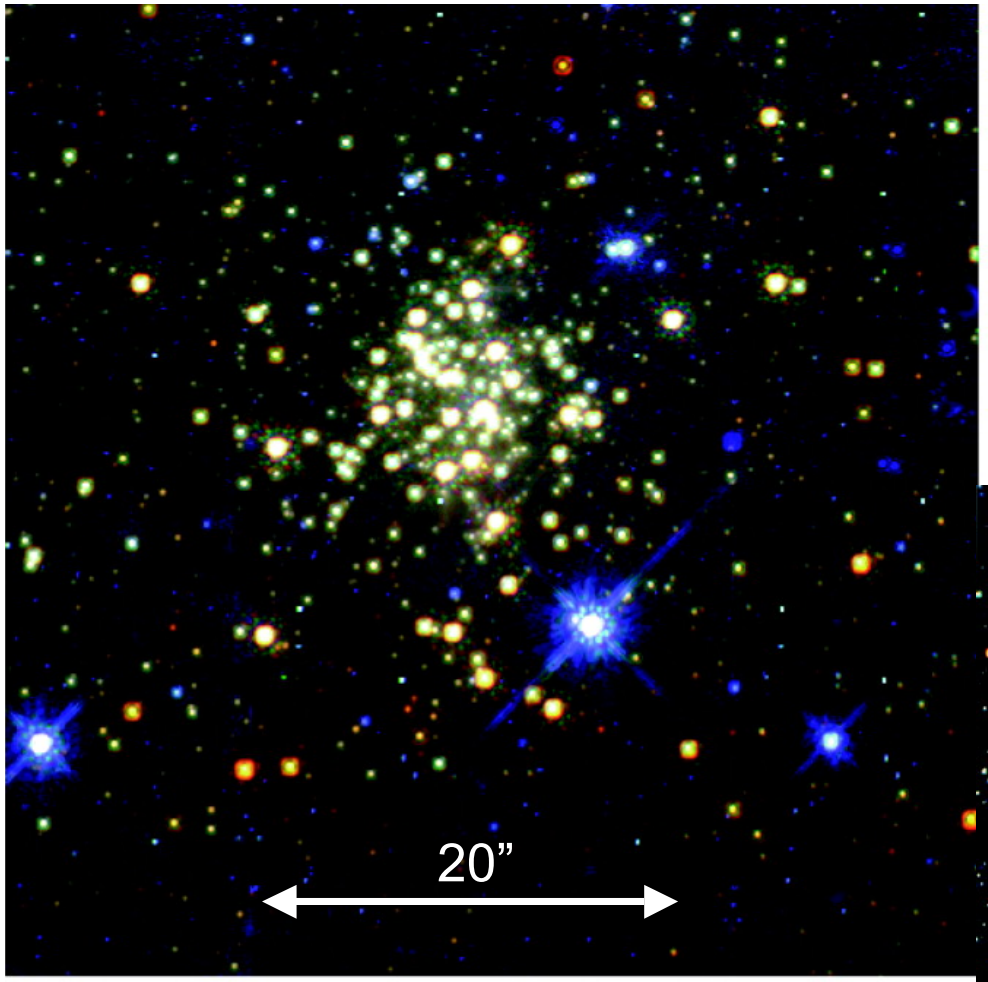
"these transients are very important for our understanding of the evolution of stars at the dividing line between "high" and "low" mass"

Prieto et al. (2009)

Obscured Galactic Center

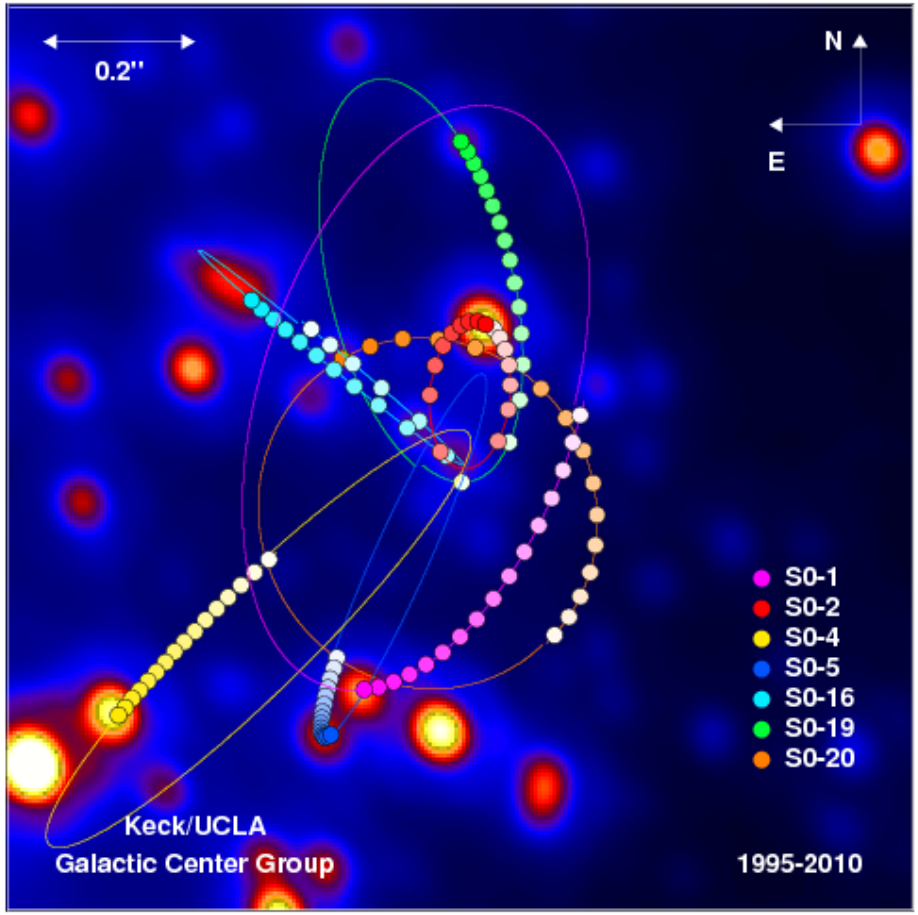


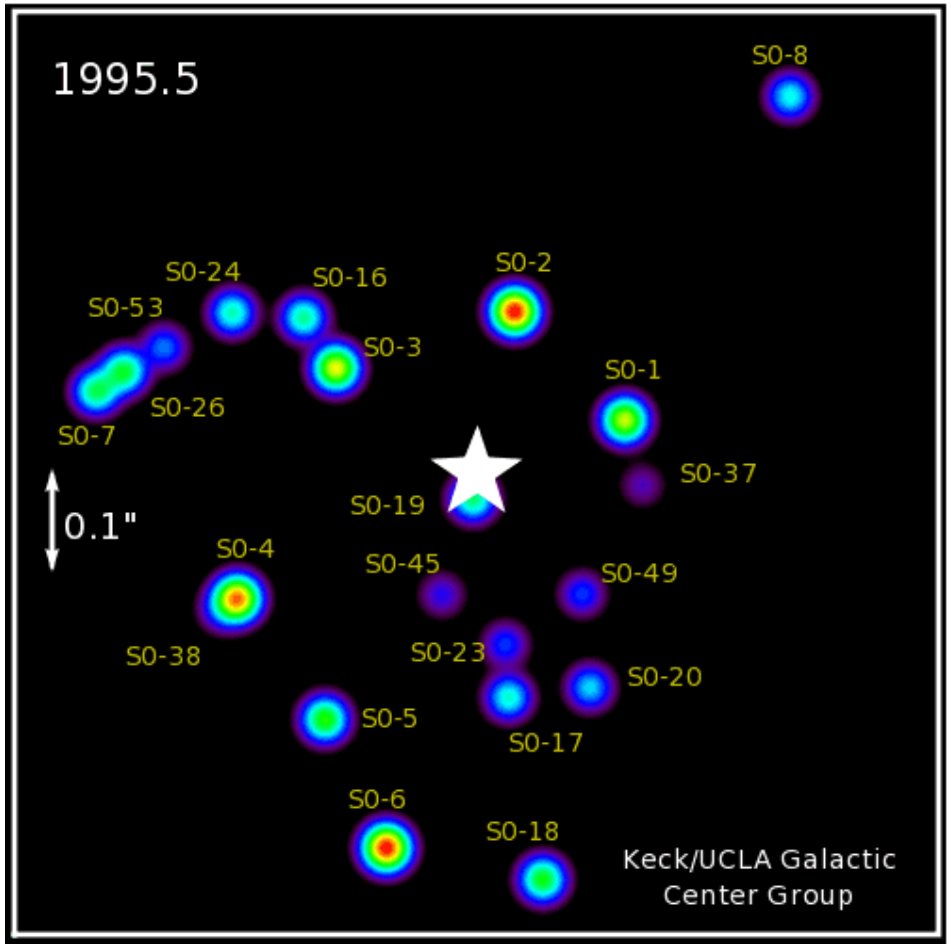
Arches & Quintuplet clusters



HST/NICMOS
Figer et al. (1999)

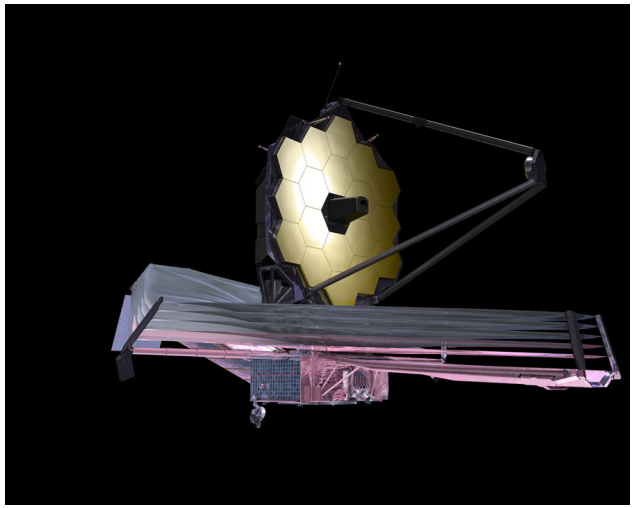
Stellar orbits in the Central Parsec



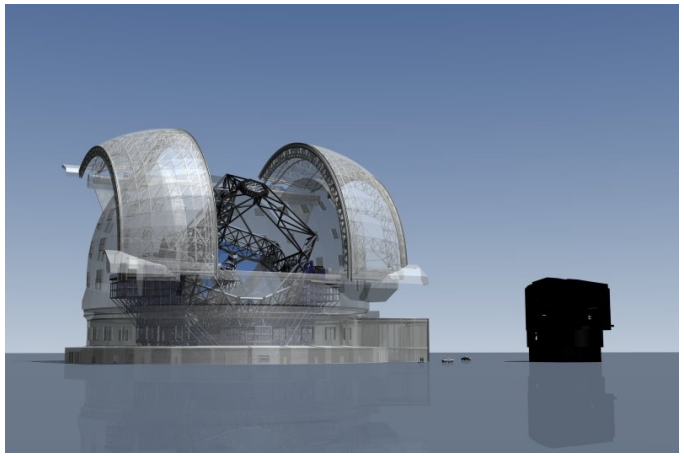


Conclusions

- Certain dusty phases of stellar evolution are not well understood (LBVs, supergiant B[e], new transients)
- Infrared detectors & space telescopes are revealing new classes of obscured stars
- New transient phenomena are being discovered



Future Telescopes



- **Space telescopes** in the optical (*HST*), infrared (*JWST*-2014, *Spitzer*, *Herschel*), X-rays (*Chandra*) allow for a complete view of stars & enable extragalactic stellar astrophysics
- **Next generation of telescopes:** *European-Extremely Large Telescope* (E-ELT, 42m), *Thirty Meter Telescope* (TMT, 30m), *Giant Magellan Telescope* (GMT, 24.5m)
- **Variable sky:** *PanStarrs* & *Large Synoptic Survey Telescope* (LSST, 2015)