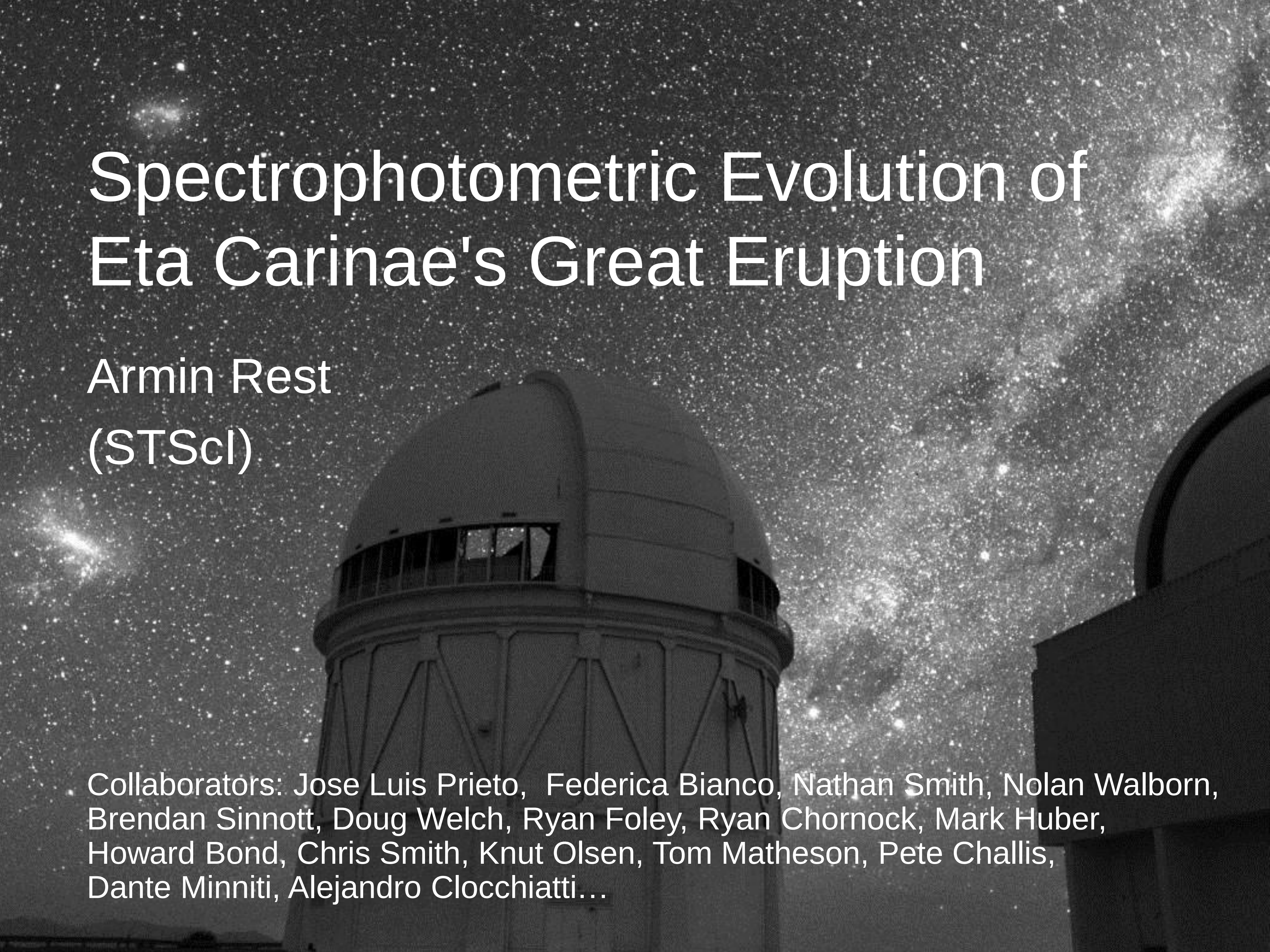


Spectrophotometric Evolution of Eta Carinae's Great Eruption

Armin Rest

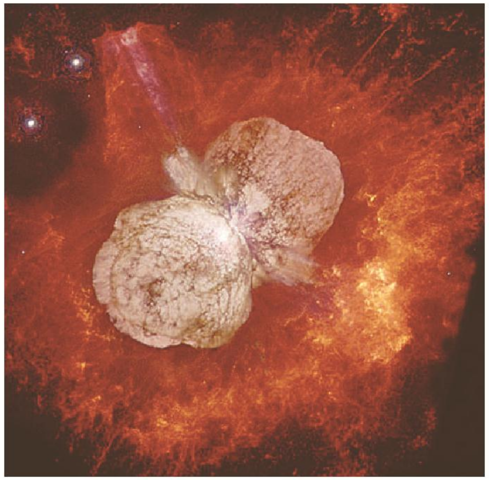
(STScI)

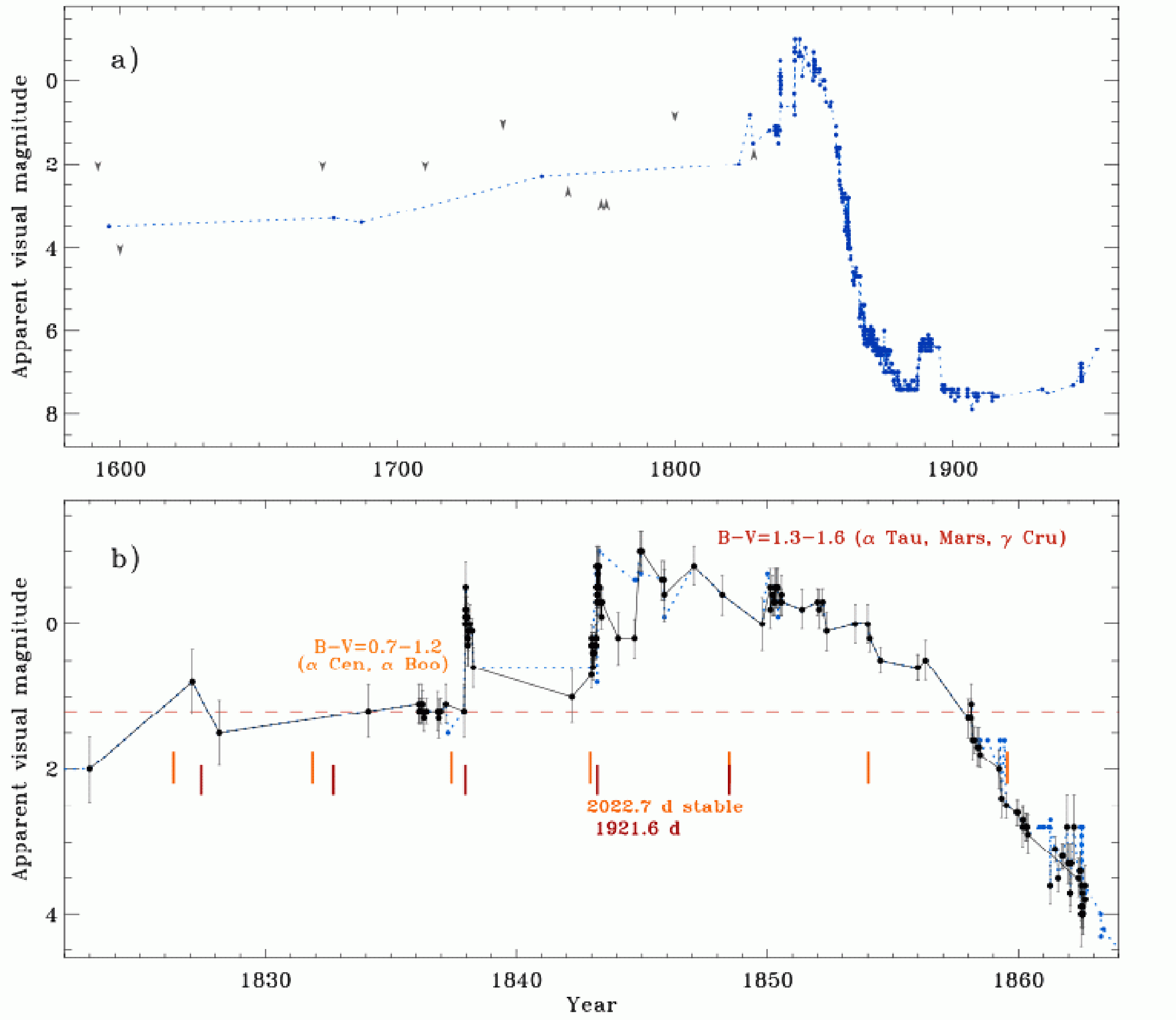
Collaborators: Jose Luis Prieto, Federica Bianco, Nathan Smith, Nolan Walborn, Brendan Sinnott, Doug Welch, Ryan Foley, Ryan Chornock, Mark Huber, Howard Bond, Chris Smith, Knut Olsen, Tom Matheson, Pete Challis, Dante Minniti, Alejandro Clocchiatti…

η Car historical light curve

Smith & Frew 2011

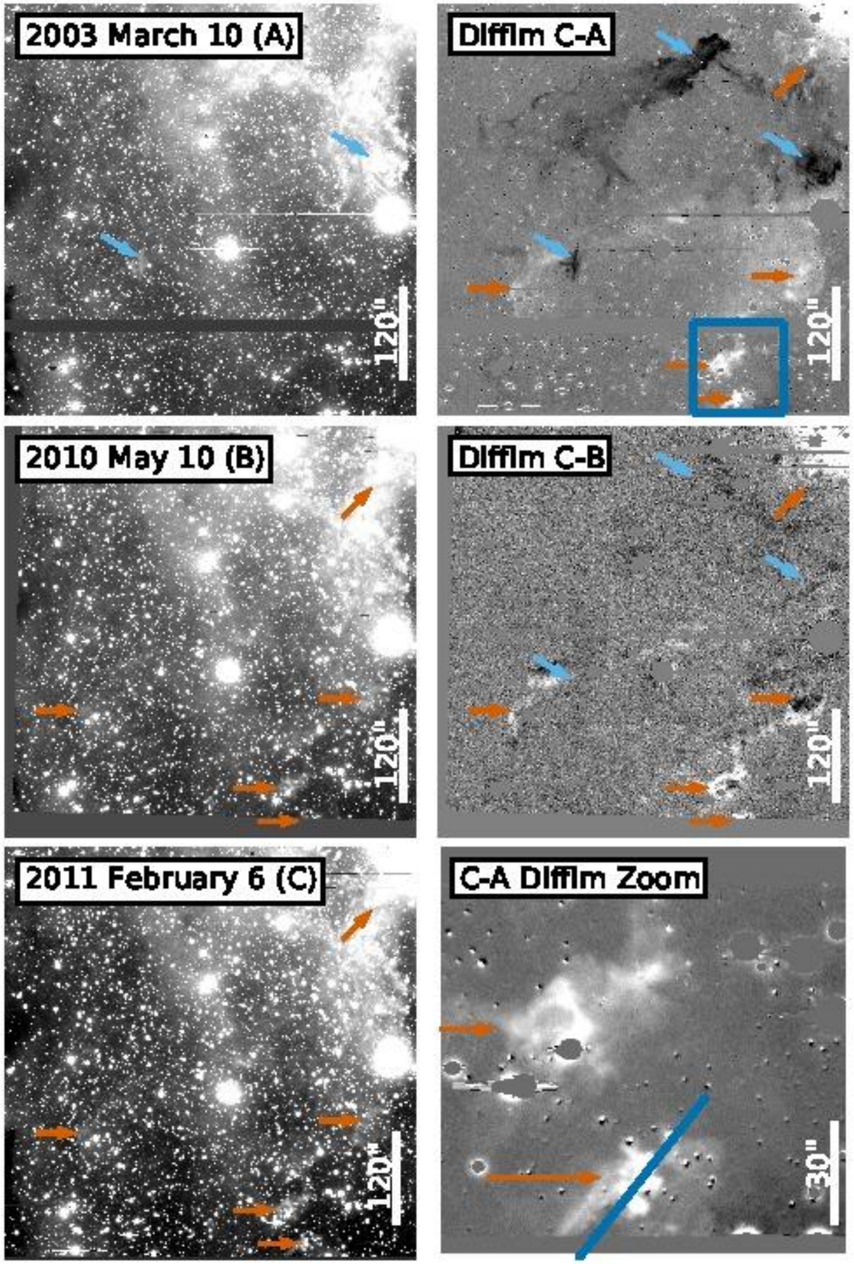
- Great Eruption from 1838-1858 (Mass loss >10 M_{solar})
- Peaks in 1837, 1843, 1845



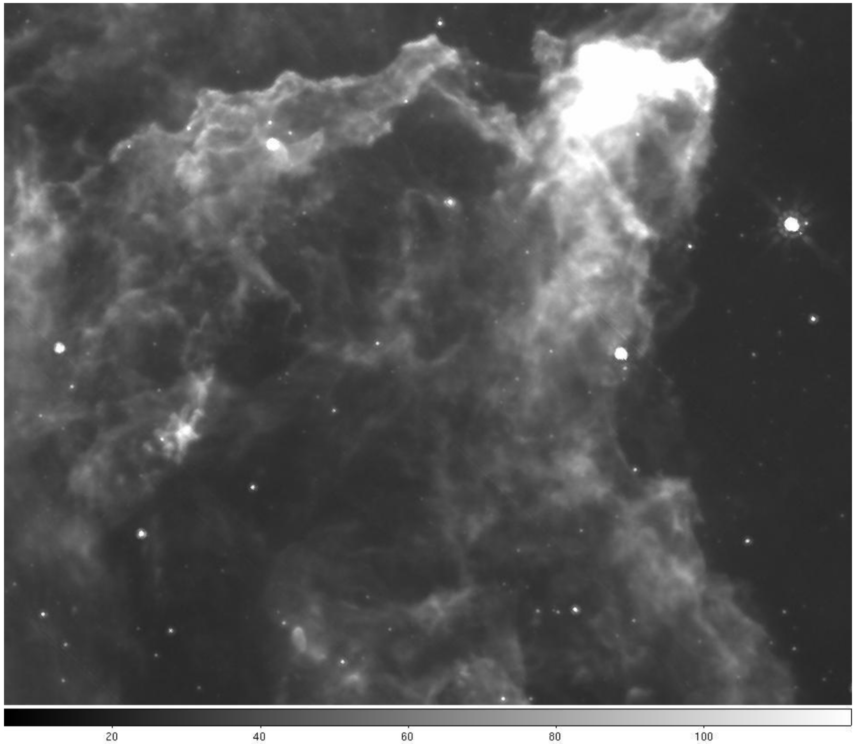


Light Echoes!

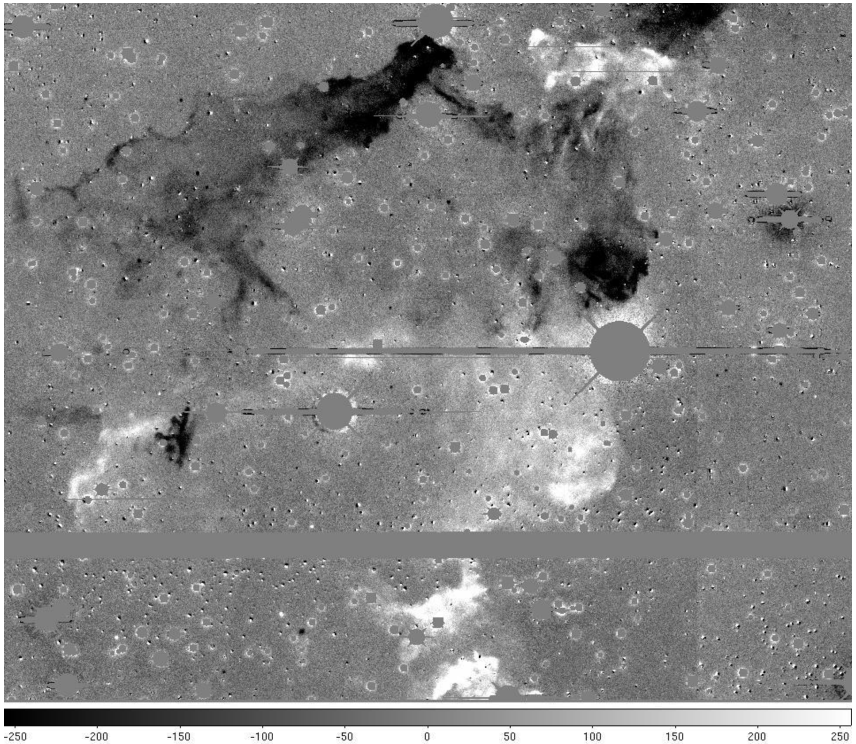
Rest et al. 2012, Nature



Scattering Dust



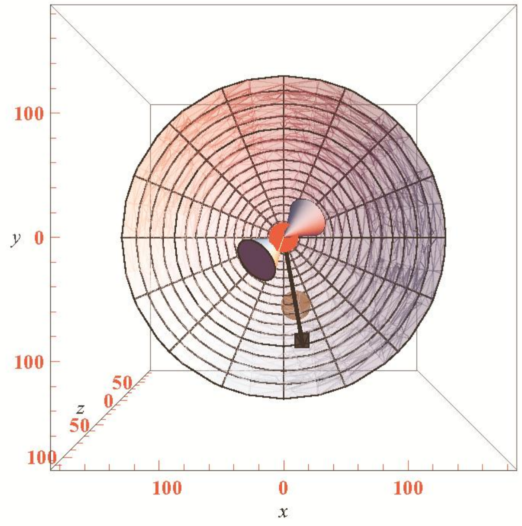
Spitzer Image (8 microns)

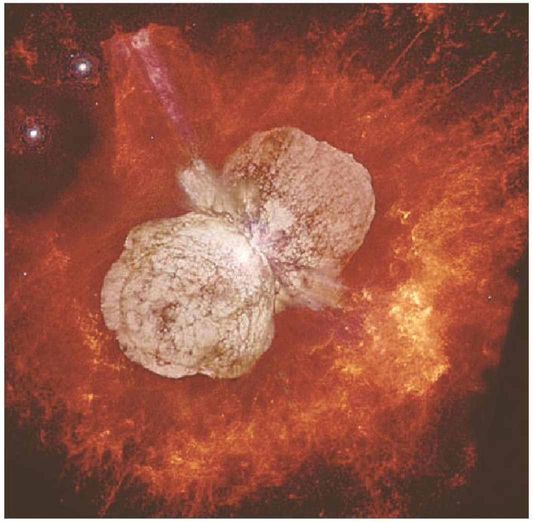


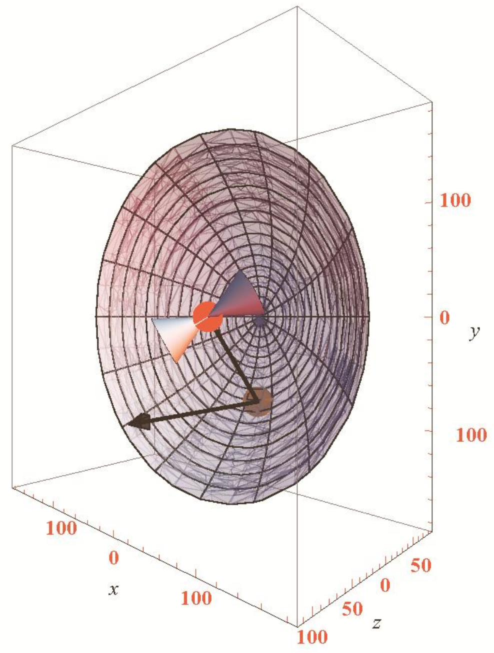
Difference Image
black: light echo in 2003
white: light echo in 2011

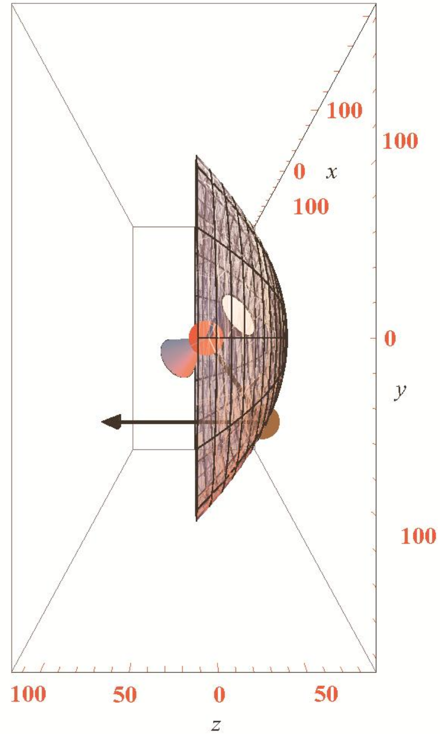
3D view

- η Car light echo roughly perpendicular to equator of Homunculus Nebula



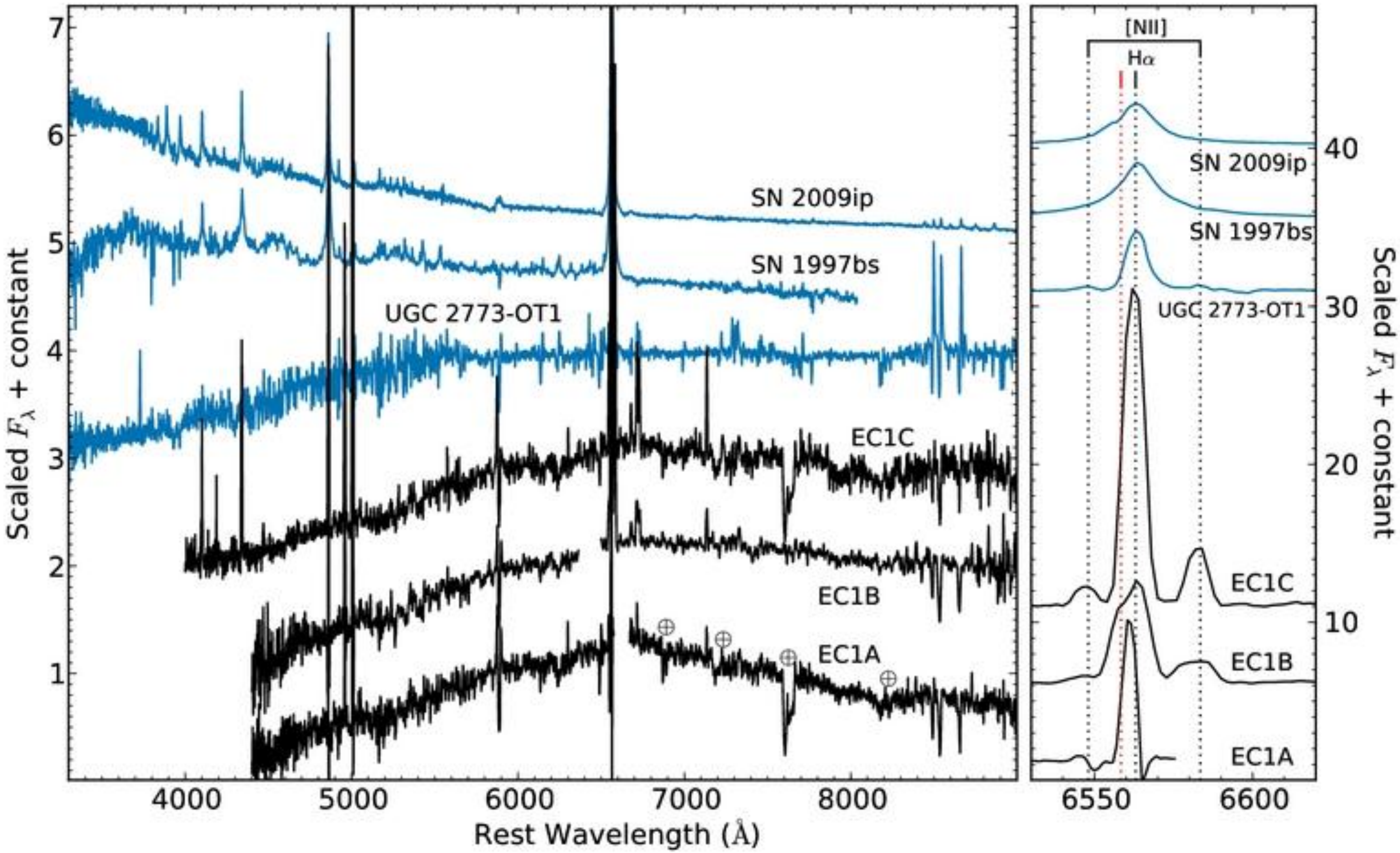






Light Echo Spectrum of η Car Great Eruption

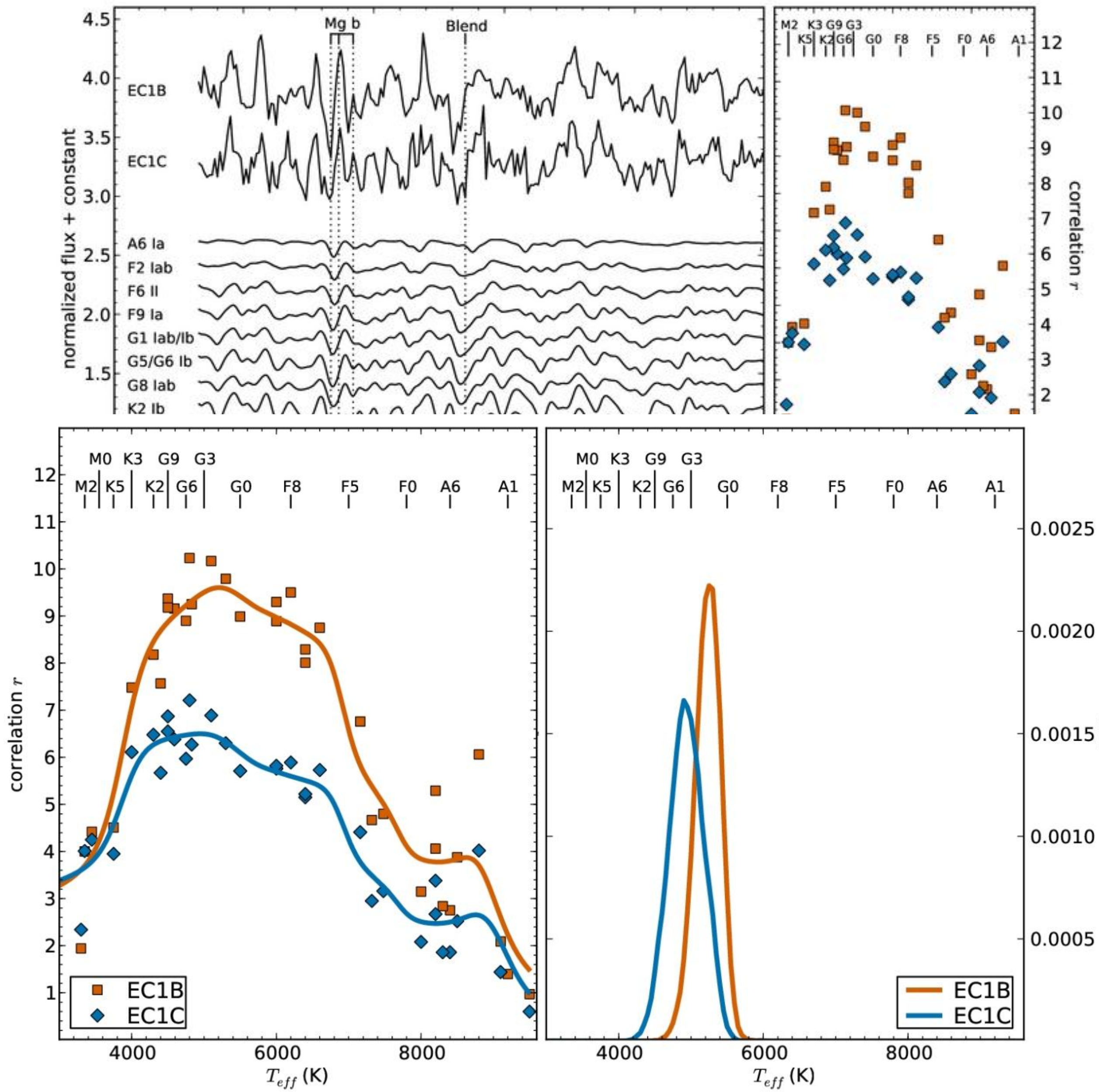
Rest et al. 2012



GE spectrum

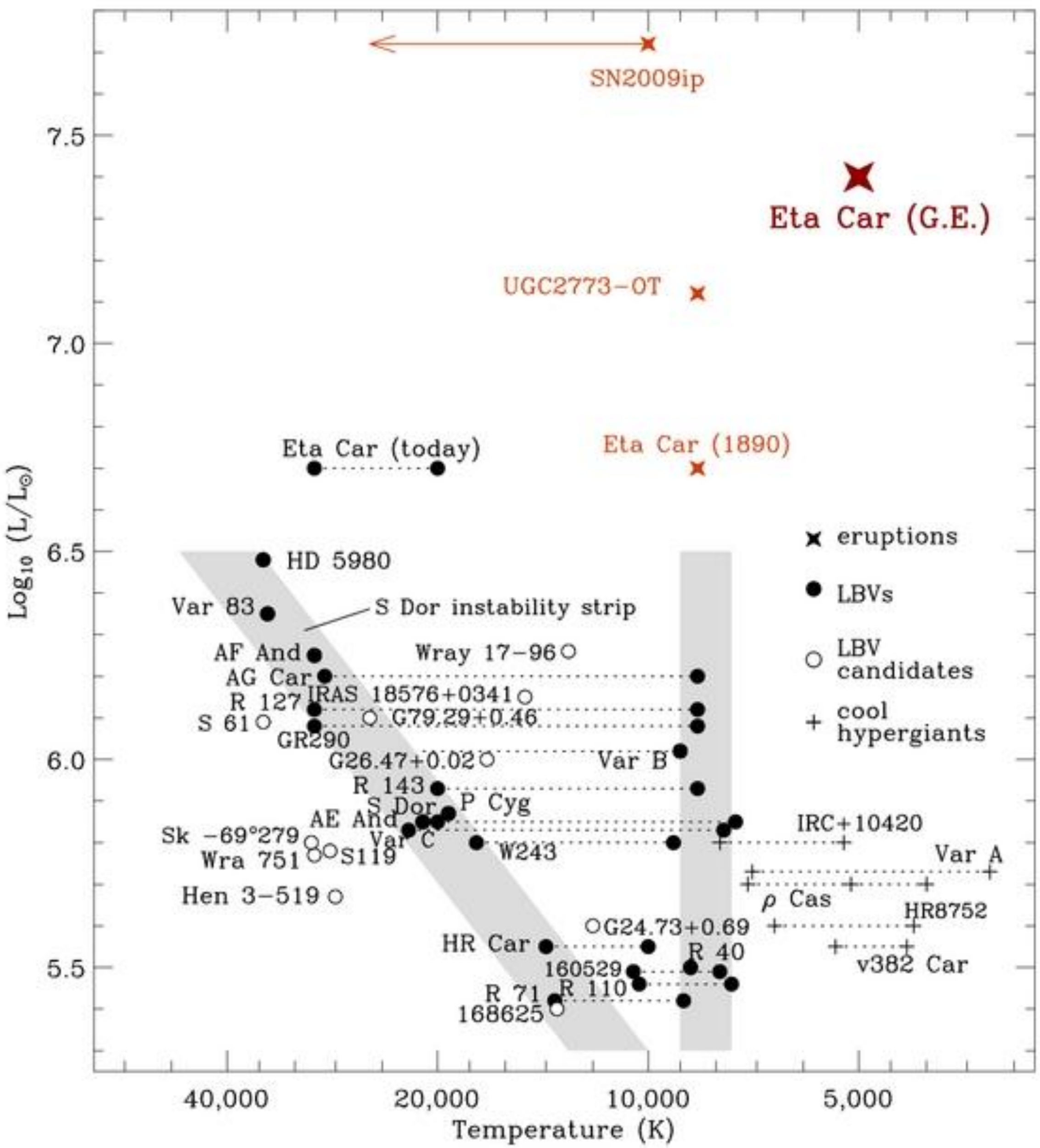
- Best correlation to supergiant spectra: G2-G5 (~5000 K)
- Ca NIR triplet: blueshift ~200 km/s, asymmetric shape
- Supergiant templates: UVES (Bagnulo+) and Ca IR triplet (Cennaro+)

Rest et al., in press



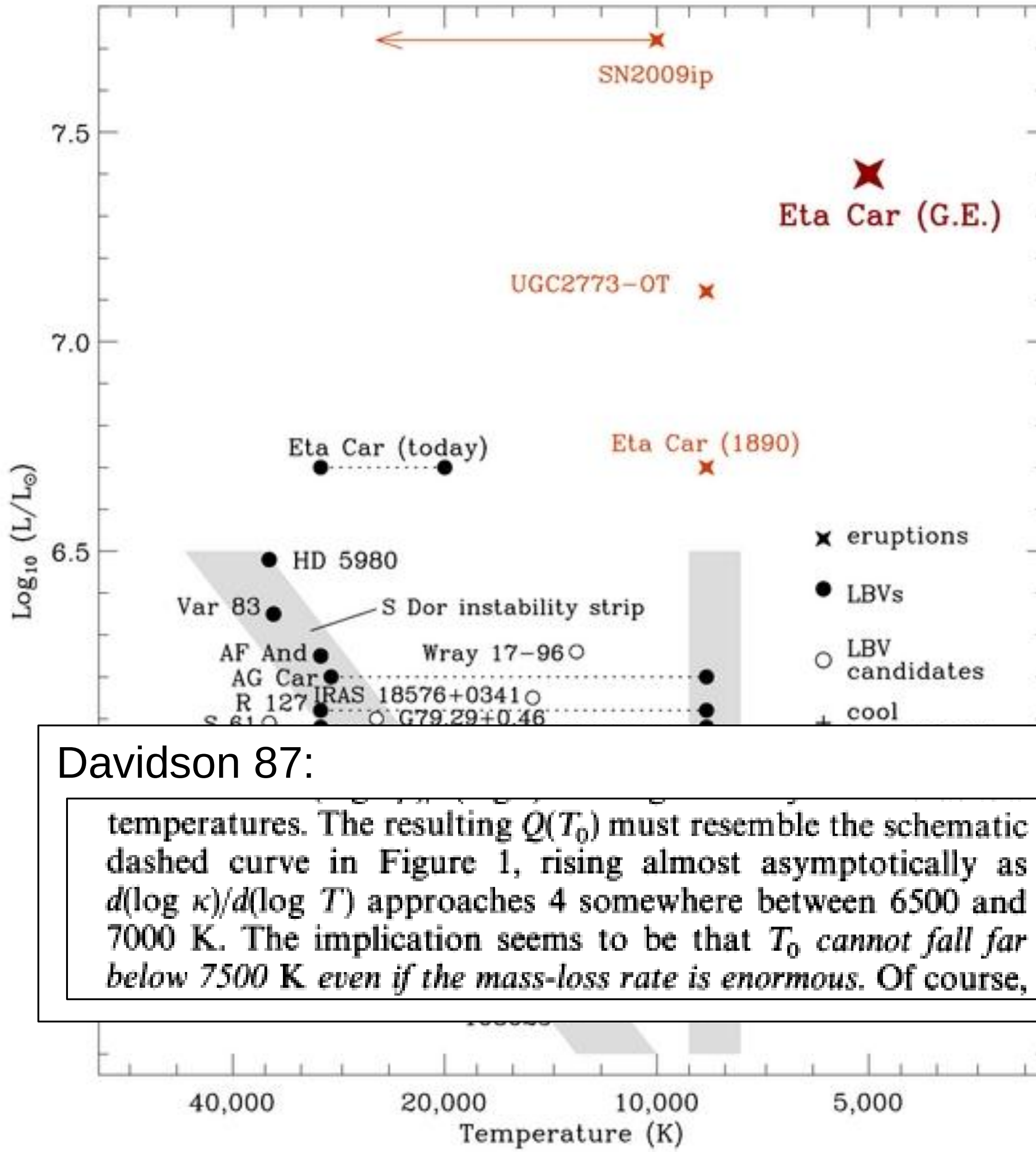
LBVs & η Car

- G type is later than common for LBV outbursts
- Exceeds theoretical limits of opaque wind model by Davidson 1987



LBVs & η Car

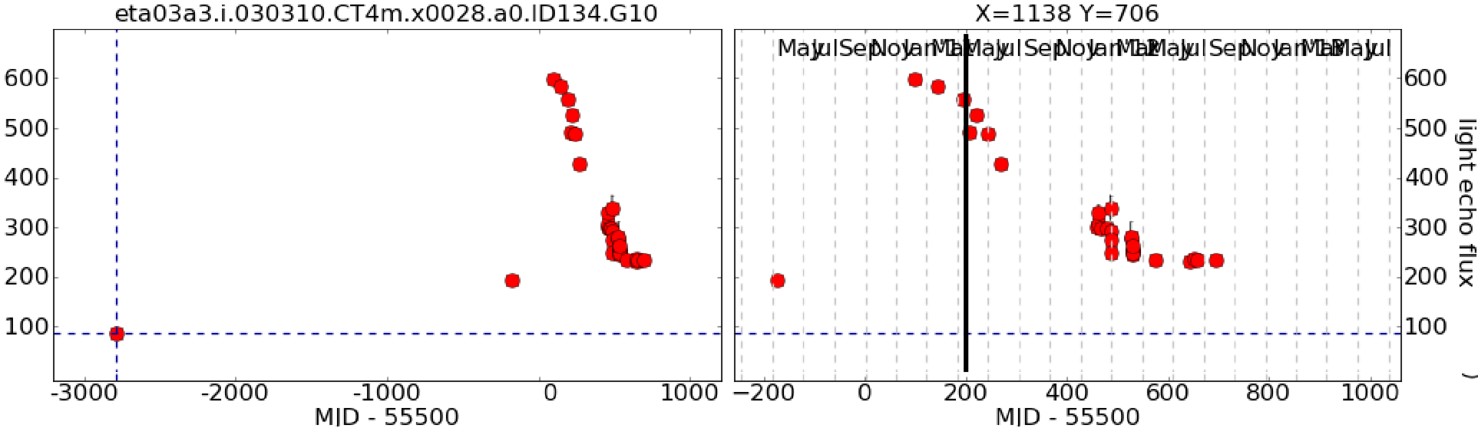
- G type is later than common for LBV outbursts
- Exceeds theoretical limits of opaque wind model by Davidson 1987
- Davidson & Humphreys 2012: claim that Davidson 1987 opaque wind model always predicted T=5400-6500K, even if text said 7000K



Davidson 87:

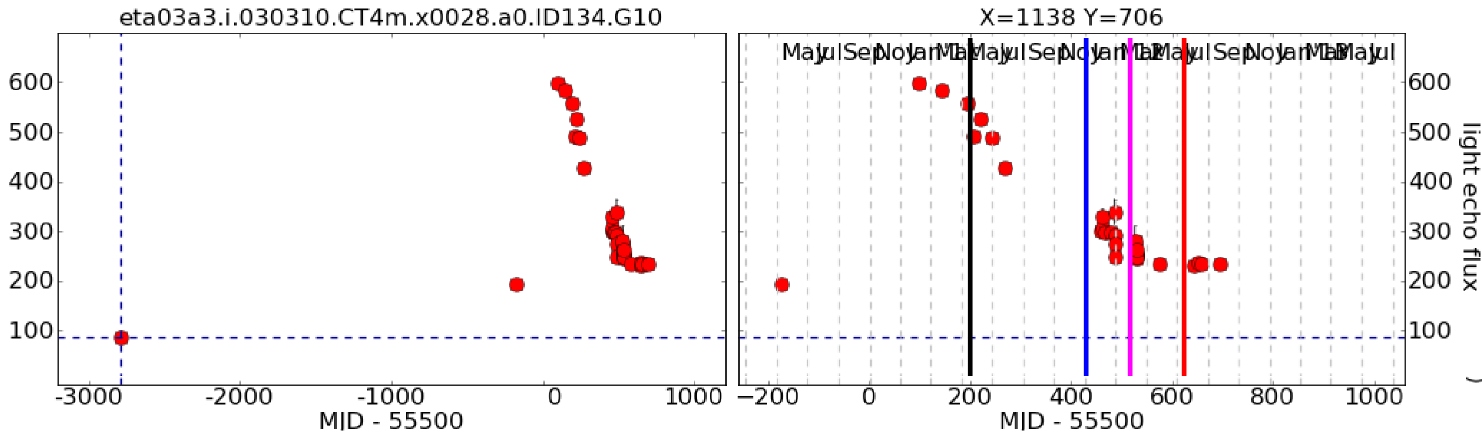
> temperatures. The resulting $Q(T_0)$ must resemble the schematic dashed curve in Figure 1, rising almost asymptotically as $d(\log \kappa)/d(\log T)$ approaches 4 somewhere between 6500 and 7000 K. The implication seems to be that T_0 *cannot fall far below 7500* K *even if the mass-loss rate is enormous*. Of course,

1843 peak

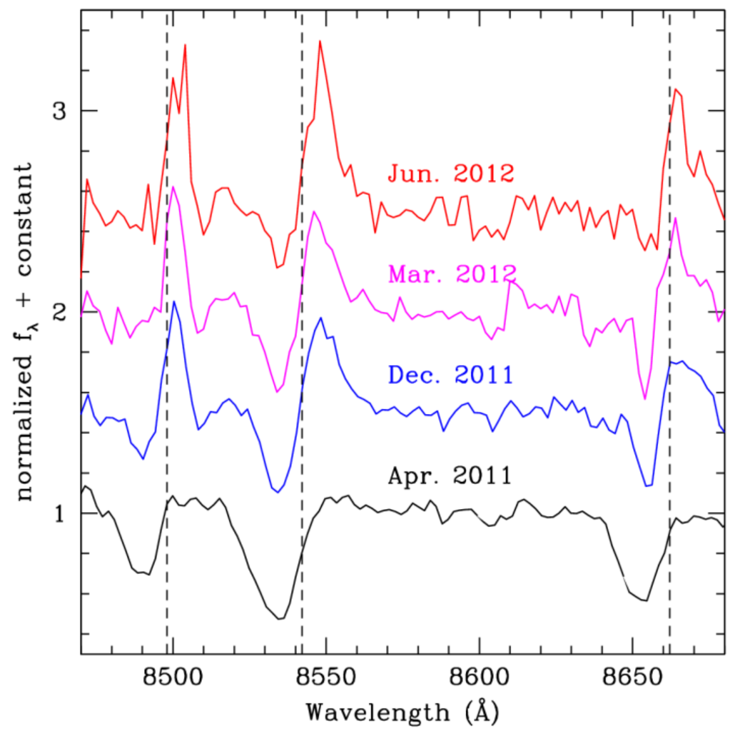


eta03a3.i.030310.CT4m.x0028.a0.ID134.G10
X=1138 Y=706
MJD - 55500
MJD - 55500
light echo flux

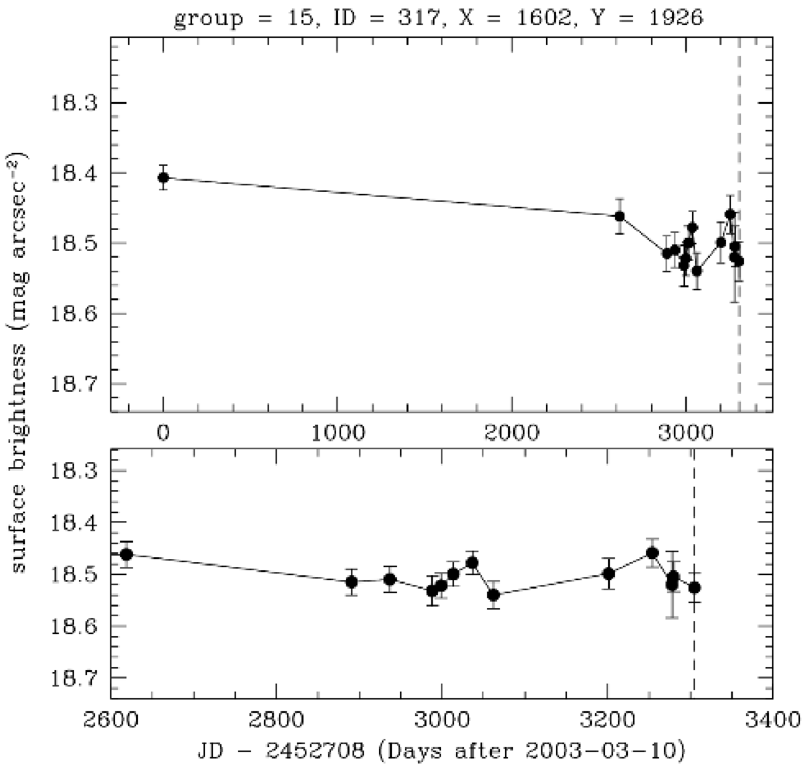
1843 peak

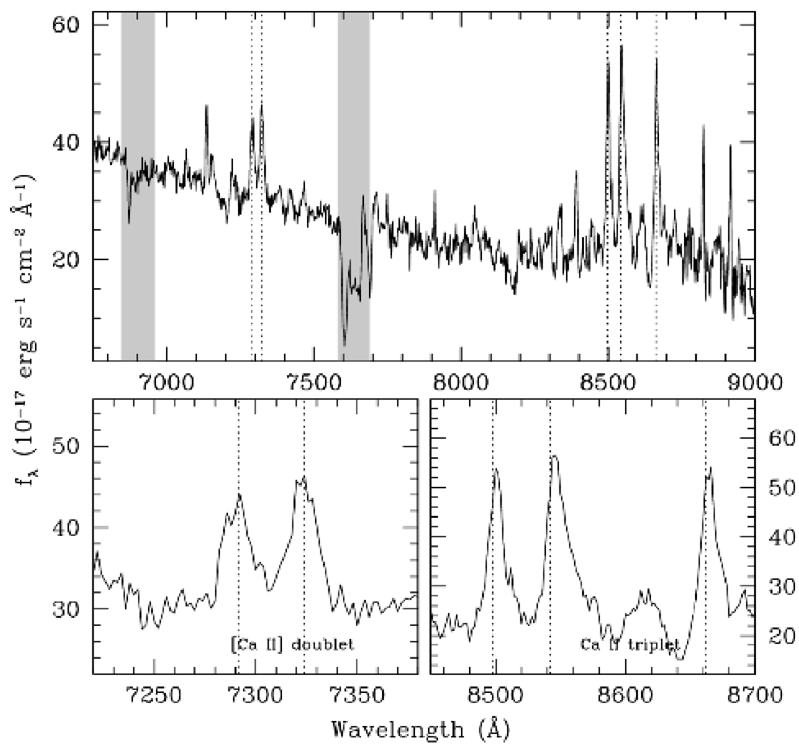


- At early times (~1843) absorption spectrum
- Evolves to P-Cygni profile 6 months later
- Nearly pure emission lines 14 month later

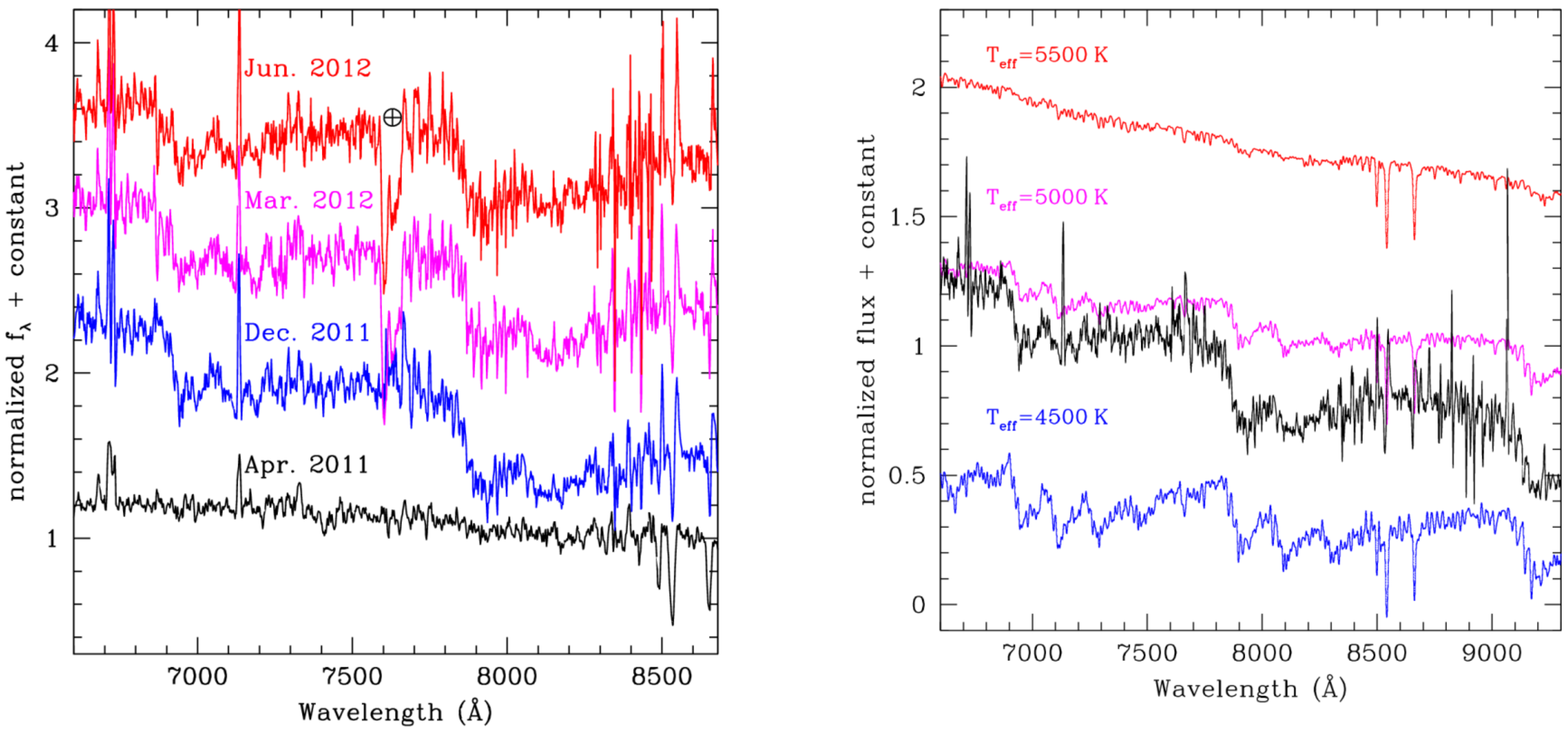


1850+ spectrum

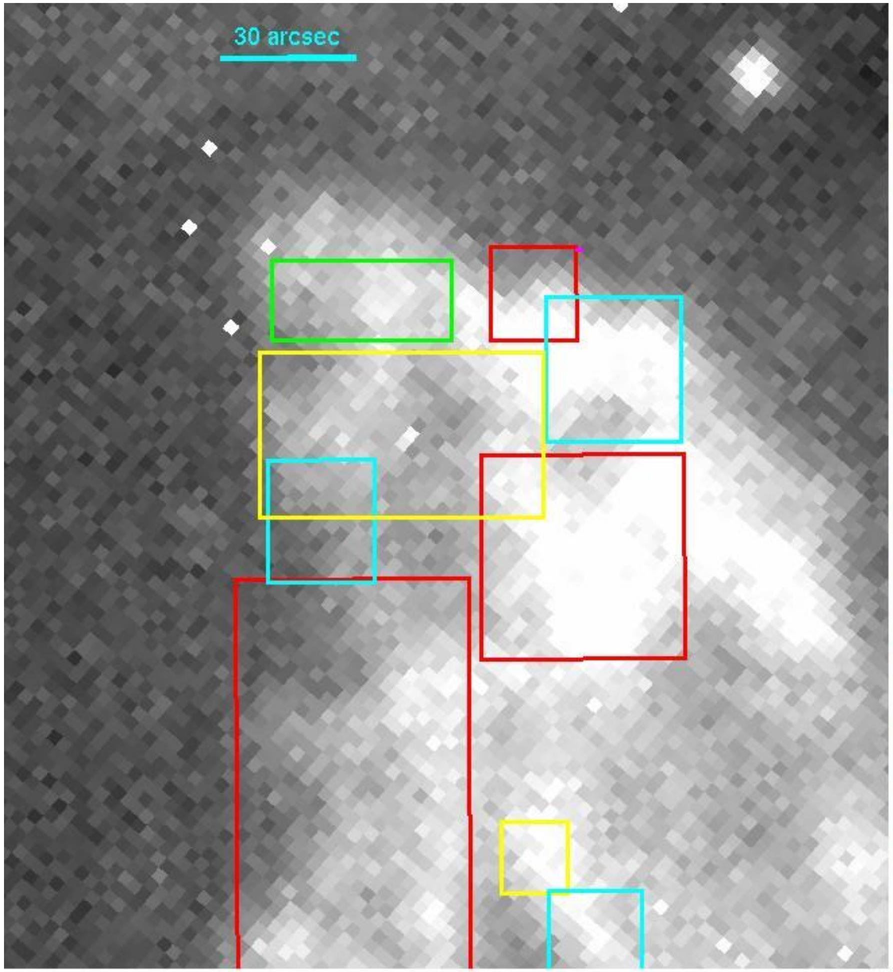




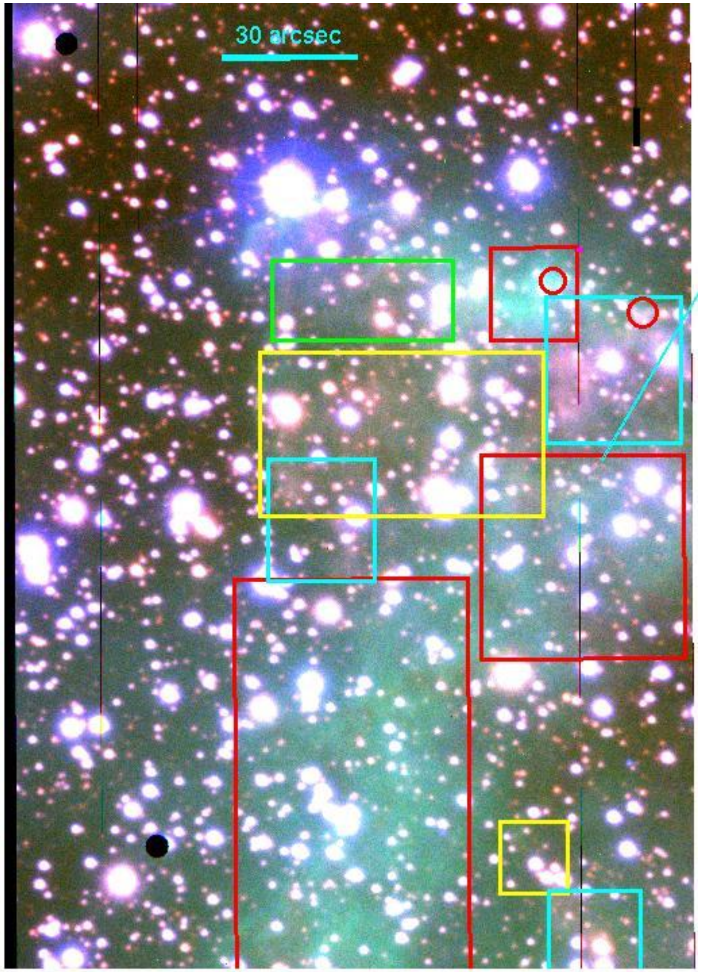
CN bands in post-1843 peak



Pre-1837 spectrum

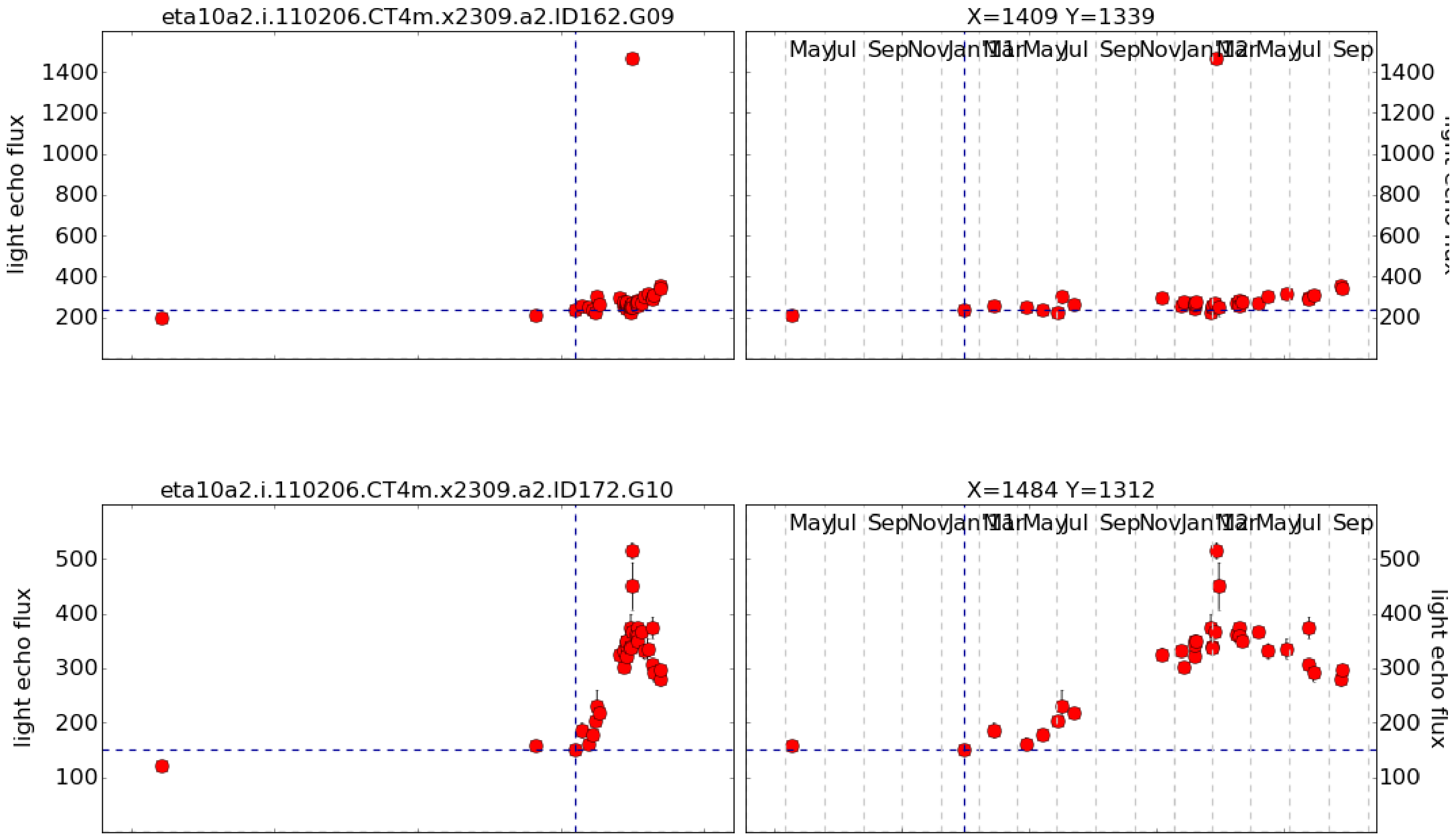


Wise 8 micron

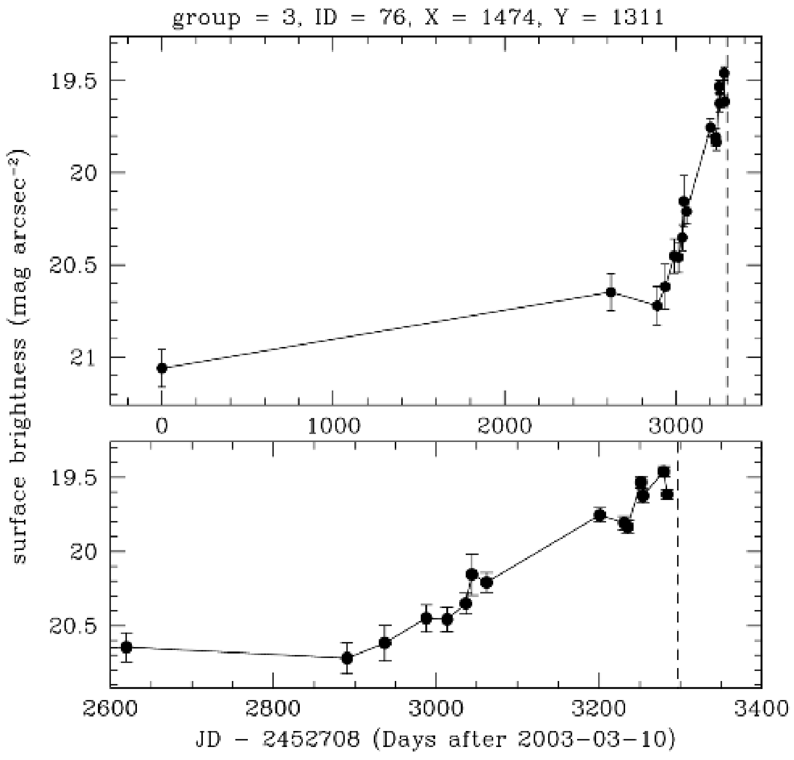


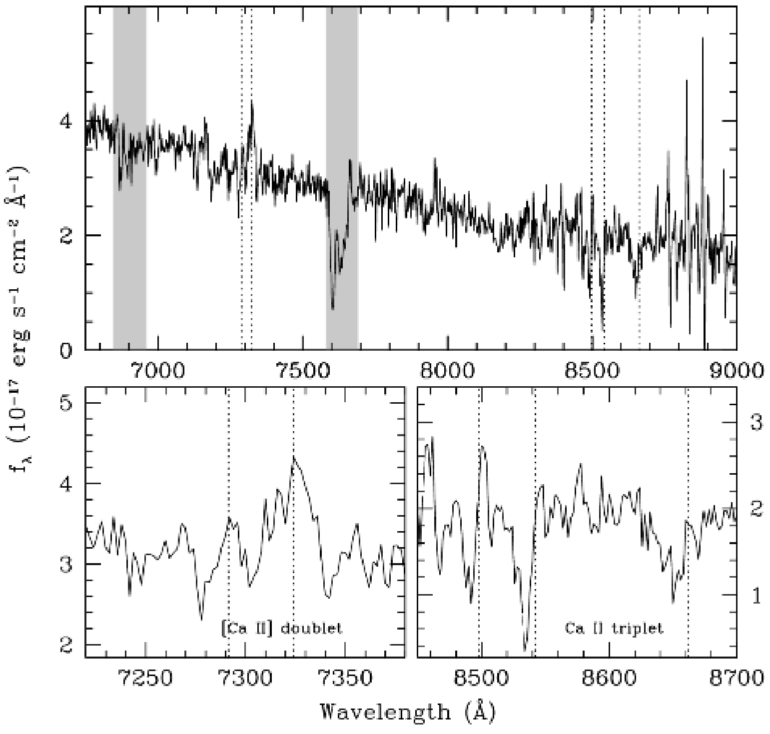
gri SOAR image

Light curves pre-1837 and 1837



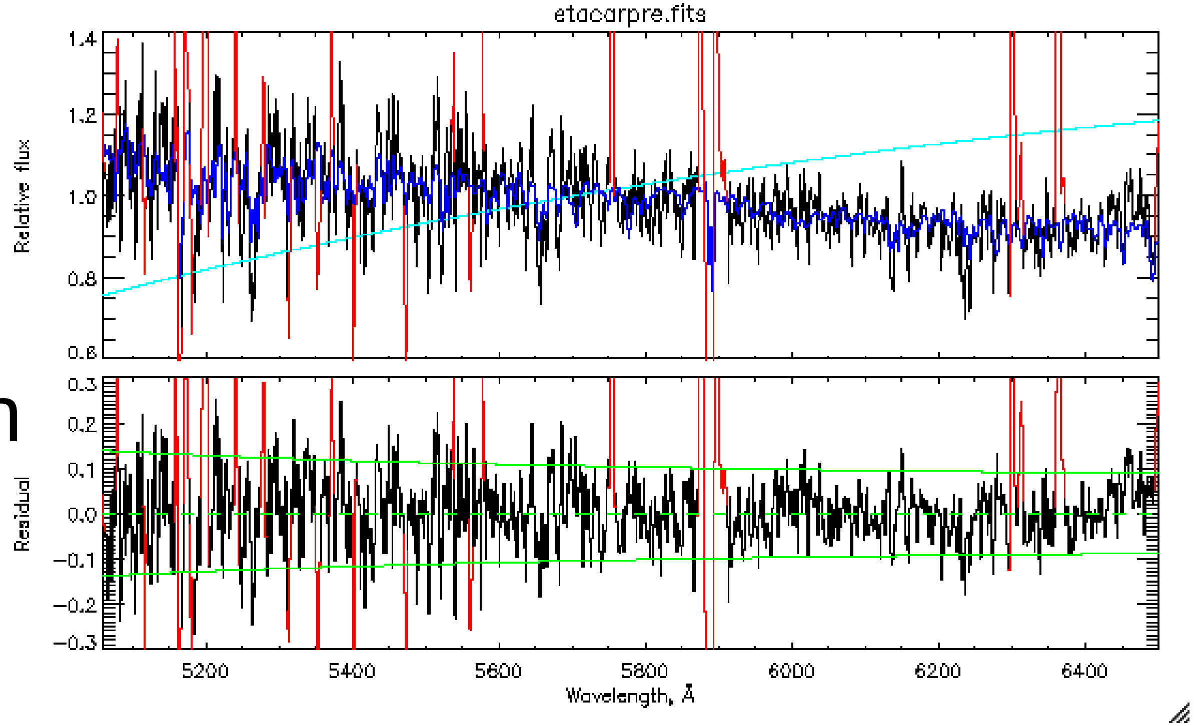
1837 peak


group = 3, ID = 76, X = 1474, Y = 1311
surface brightness (mag arcsec⁻²)
19.5
20
20.5
21
0
1000
2000
3000
2600
2800
3000
3200
3400
JD − 2452708 (Days after 2003-03-10)


f_λ (10^{-17} erg s⁻¹ cm⁻² Å⁻¹)
7000
7500
8000
8500
9000
[Ca II] doublet
Ca II triplet
7250
7300
7350
8500
8600
8700
Wavelength (Å)

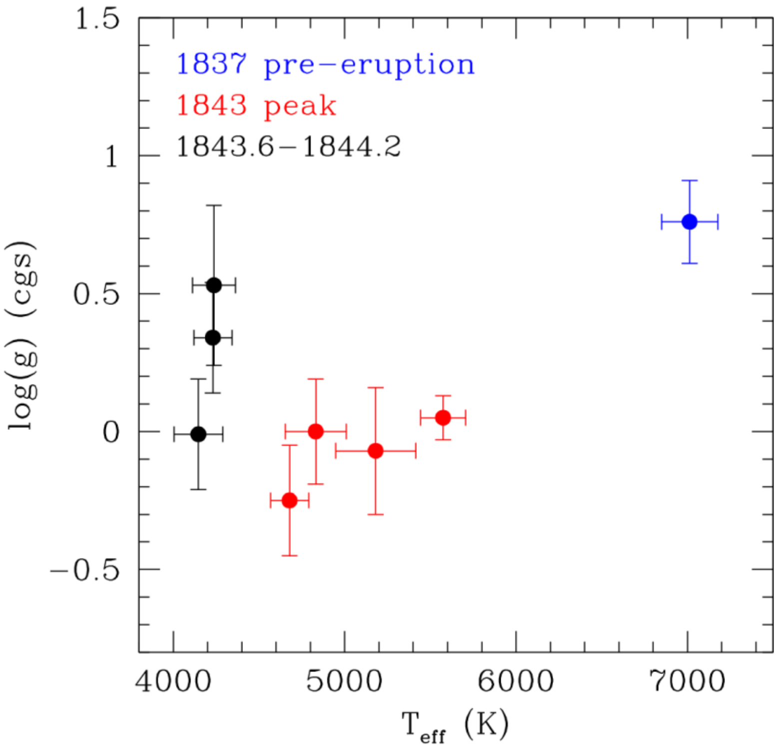
Pre-1837 peak

- Ulyss IDL package
- Elodie spectral stellar library
- Very good fit with 7000K spectrum
- 200 km/s blueshift

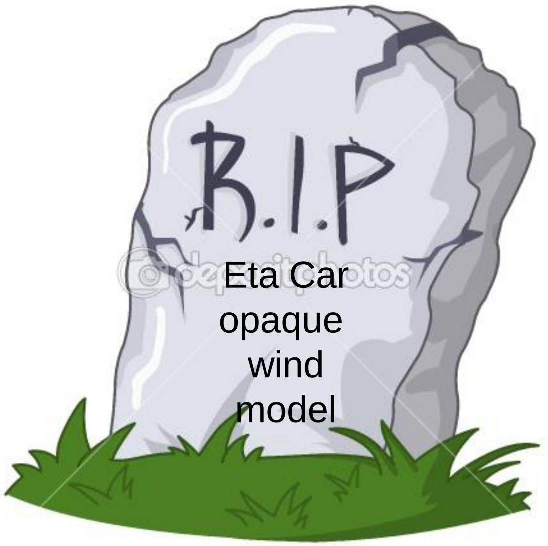


Temperature and surface gravity

- Ulyss IDL package
- Elodie spectral stellar library
- Pre-1837: Very good fit with 7000K spectrum
- Post 1843 minimum: P-Cygni profile, thus T could be biased



Summary



- η Car light echo spectrum of 1943 peak:
  - Similar to G2-G5 supergiant, ~5000 K
  - No emission lines!
  - Blueshifted Ca NIR triplet by ~200 km/s,
  - Asymmetric shape of Ca NIR triplet: blue tail up to -850 km/s
- η Car light echo spectra post-1943 peak, at minimum
  - Changes from absorption to emission line spectrum with time
  - Temperature stays the same at 5000K if not getting cooler
  - Strong CN bands
- Pre-eruption spectrum
  - Best fit with 7000K SG spectrum
  - Higher surface gravity
- In a few years: **The Great Eruption in 4D!**

Davidson 87

least for our purposes.

The $Q(T_0)$ curve becomes very steep at the left side of Figure 1 because opacity declines quickly with decreasing temperature below 7000 K; this effect will occur with any reasonable set of opacities. In fact, the effect is probably more dramatic than a simple constant-n curve indicates. Imagine, for example, a wind whose speed $v(r)$ is proportional to r, so that $\rho(r)$ is proportional to r^{-3}. For high values of T_0, where the opacity κ is nearly uniform, the wind is well represented by the $n = 3$ curve in Figure 1. However, for temperatures below 7500 K the opacity becomes strongly temperature-dependent; and since $T(r)$ decreases outward, then so does $\kappa(r)$. Consequently, the model index $n = -d(\log \kappa\rho)/d(\log r)$ rises significantly above 3 at low temperatures. The resulting $Q(T_0)$ must resemble the schematic dashed curve in Figure 1, rising almost asymptotically as $d(\log \kappa)/d(\log T)$ approaches 4 somewhere between 6500 and 7000 K. The implication seems to be that T_0 *cannot fall far below 7500* K *even if the mass-loss rate is enormous.* Of course, at low temperatures radiative acceleration becomes more difficult because the opacity is low; this consideration will be mentioned again later. Gradients in $\alpha(r)$ are less crucial than those in $\kappa(r)$ and typically have the effect of changing n by amounts of the order of ± 0.5.

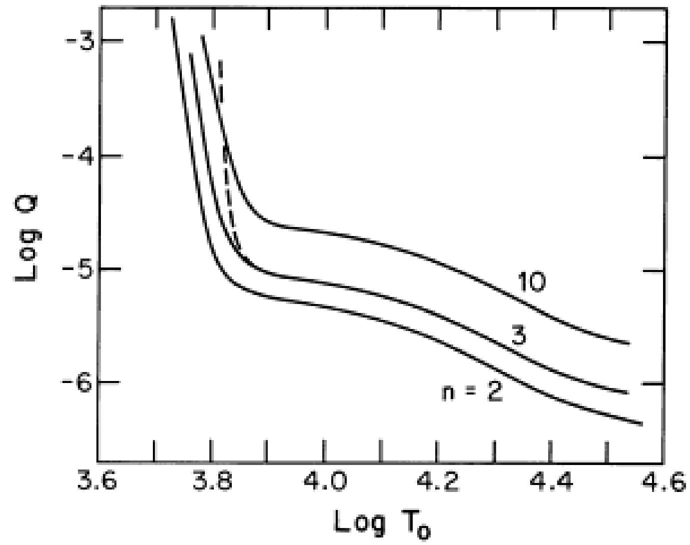
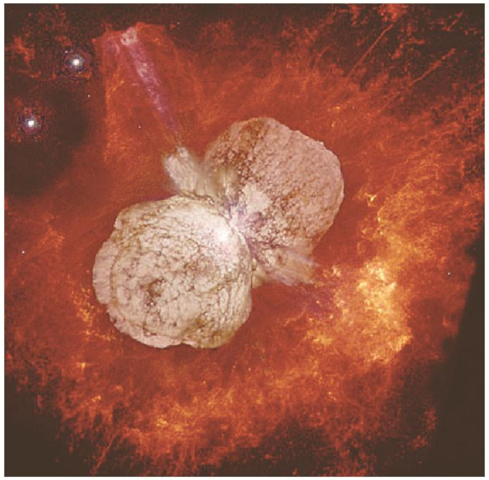
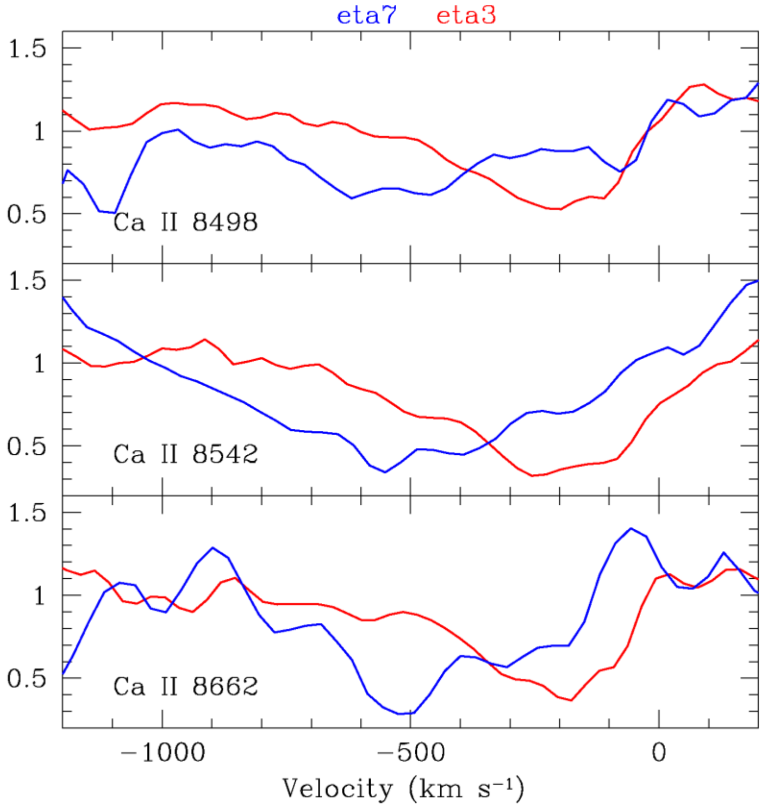


FIG. 1.—The quantity Q, proportional to $\dot{M}v_0^{-1}L^{-0.7}$, as a function of characteristic radiation temperature T_0 for simplified wind models in the range $10^{5.6}\ L_\odot \lesssim L \lesssim 10^7\ L_\odot$. See eq. (4). If the assumed opacities are revised as suggested at the end of § III, then each plotted value of Q should be decreased by a factor of ~ 2. Dashed curve is a schematic indication of how Q probably behaves for a given flow structure rather than a given model index n (*see* § III).

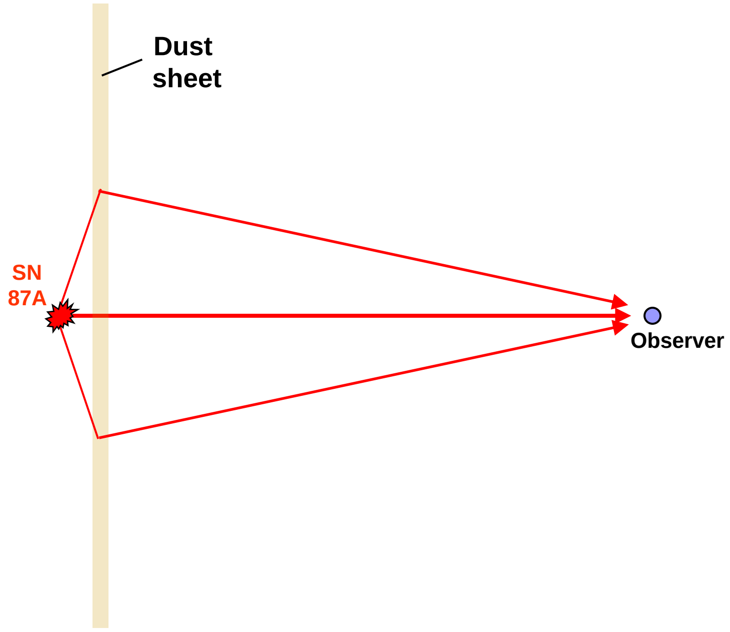
3D Spectroscopy

- Red: looking at equator. Blueshift ~200 km/s
- Blue: looking into lobe. Blueshift ~500-600 km/s (not the highest S/N…)



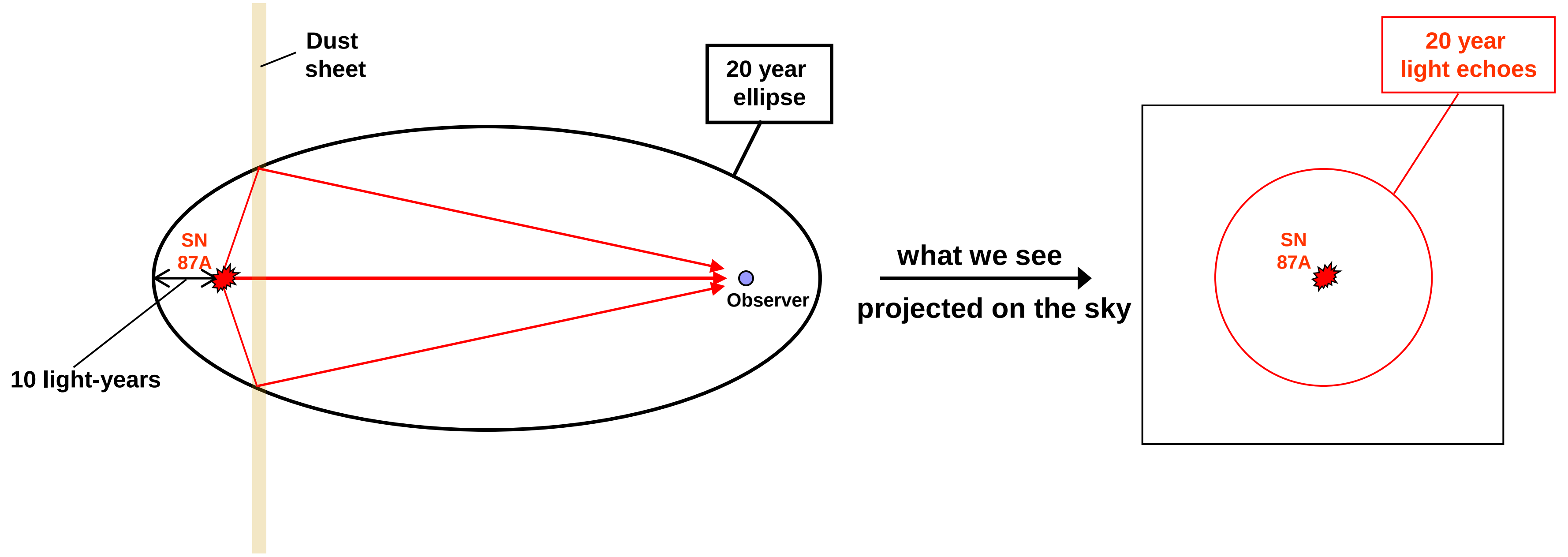


Geometry of Light Echoes



Geometry of Light Echoes

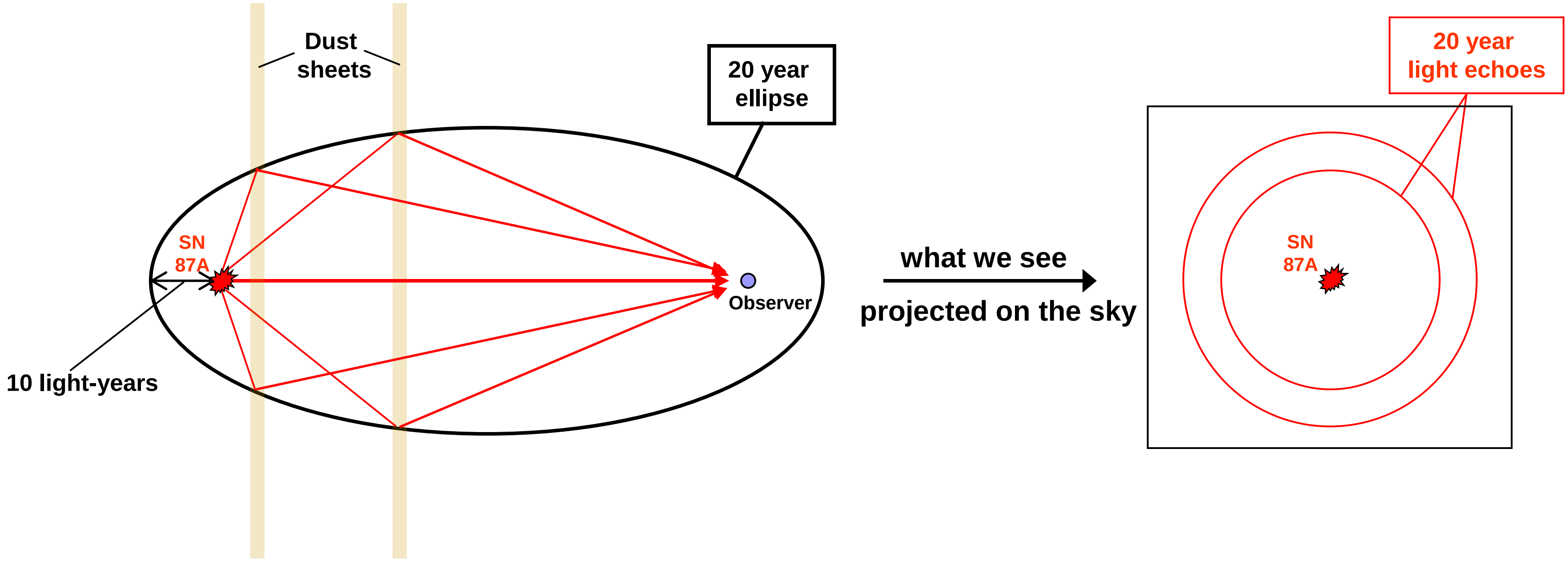
Ellipsoids trace out surfaces of constant arrival time



Extra path: 2 x 10 light years ⇨ Light echo after 20 years

Geometry of Light Echoes

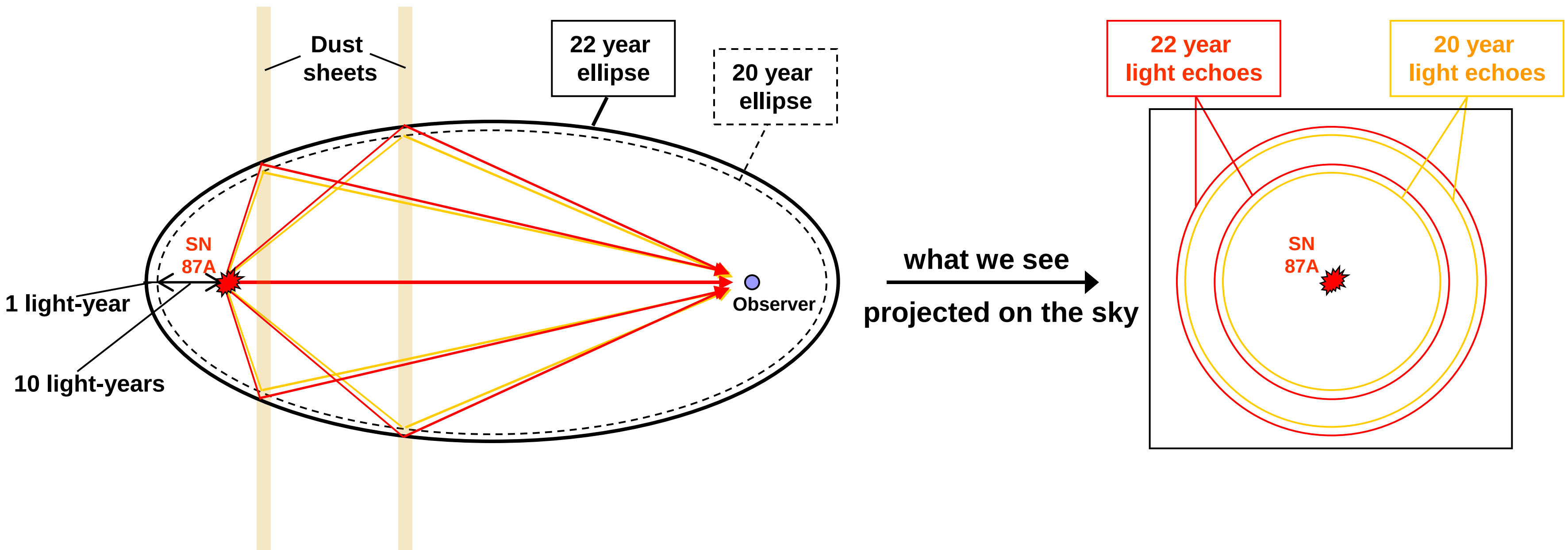
Ellipsoids trace out surfaces of constant arrival time



Extra path: 2 x 10 light years ⇨ Light echo after 20 years

Geometry of Light Echoes

Ellipsoids trace out surfaces of constant arrival time



Extra path: 2 x 10 light years ⇨ Light echo after 20 years
Extra path: 2 x 11 light years ⇨ Light echo after 22 years

Geometry of Light Echoes

SN 87A difference image, 2003-2001