Spectrophotometric Evolution of Eta Carinae's Great Eruption

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η Car historical light curve

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

Smith & Frew 2011
Light Echoes!

Rest et al. 2012, Nature

Eta Carinae

2003 March 10 (A)

2010 May 10 (B)

2011 February 6 (C)

C-A Diffim Zoom
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 $\eta$ Car Great Eruption

Rest et al. 2012
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+)
LBVs & η Car

- G type is later than common for LBV outbursts
- Exceeds theoretical limits of opaque wind model by Davidson 1987
LBVs & \( \eta \) 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 \( T = 5400-6500 \)K, even if text said 7000K

Davidson 87:

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

Armin Rest, 03/12/08, Wunch
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

[Graphs and spectra]
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!
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 $\kappa$ 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 $n = -d(\log \kappa)/d(\log r)$ 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 $\pm 0.5$.

How strongly in $Q(T)$ affected by uncertainty in $\xi$ is...
3D Spectroscopy

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

[Graph showing three lines labeled 'eta7', 'eta3', 'Ca II 8498', 'Ca II 8542', 'Ca II 8662']
Geometry of Light Echoes

Dust sheet

SN 87A

Observer
Geometry of Light Echoes

Ellipsoids trace out surfaces of constant arrival time

Extra path: $2 \times 10$ light years → Light echo after 20 years
Geometry of Light Echoes

Ellipsoids trace out surfaces of constant arrival time

Extra path: $2 \times 10$ light years $\rightarrow$ 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

22 year light echoes

20 year light echoes