Accretion Onto a Companion

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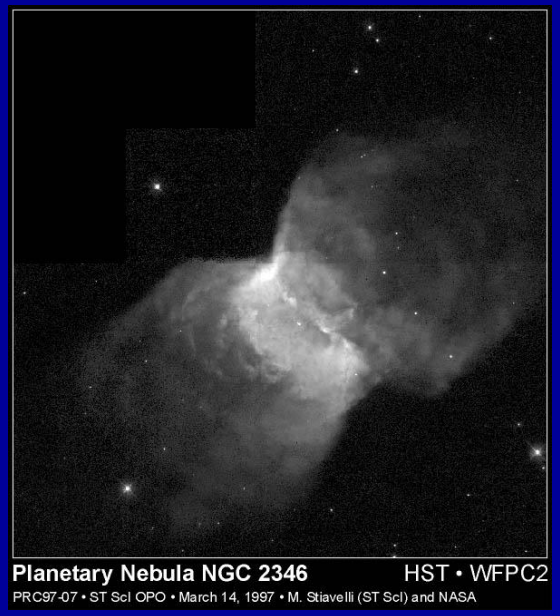
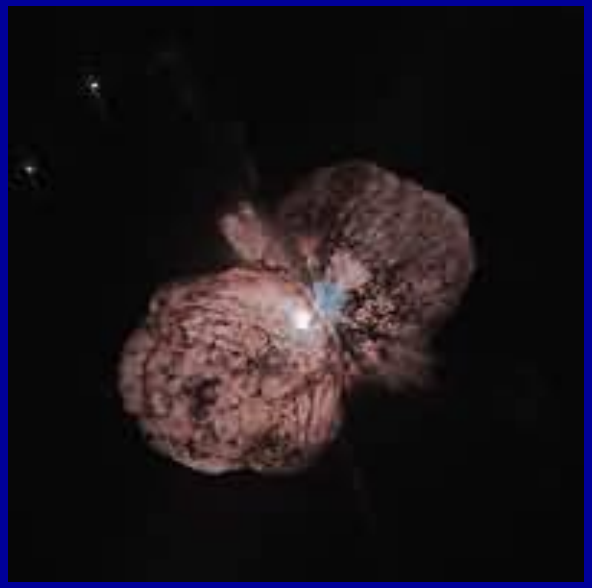
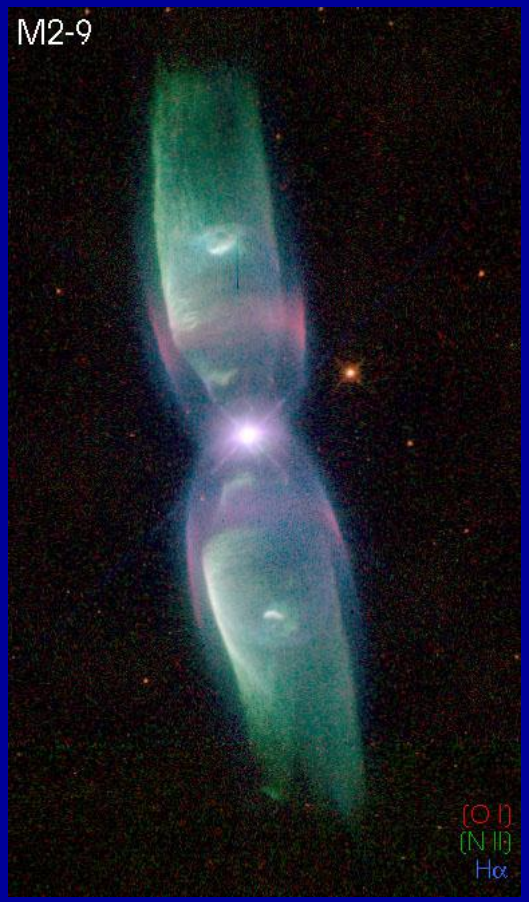
Most people working on circumstellar **bipolar nebulae** accept the view that strong binary interactions are behind the bipolar structures.



NGC 2346: Bipolar planetary nebula with a central binary: P = 16 days



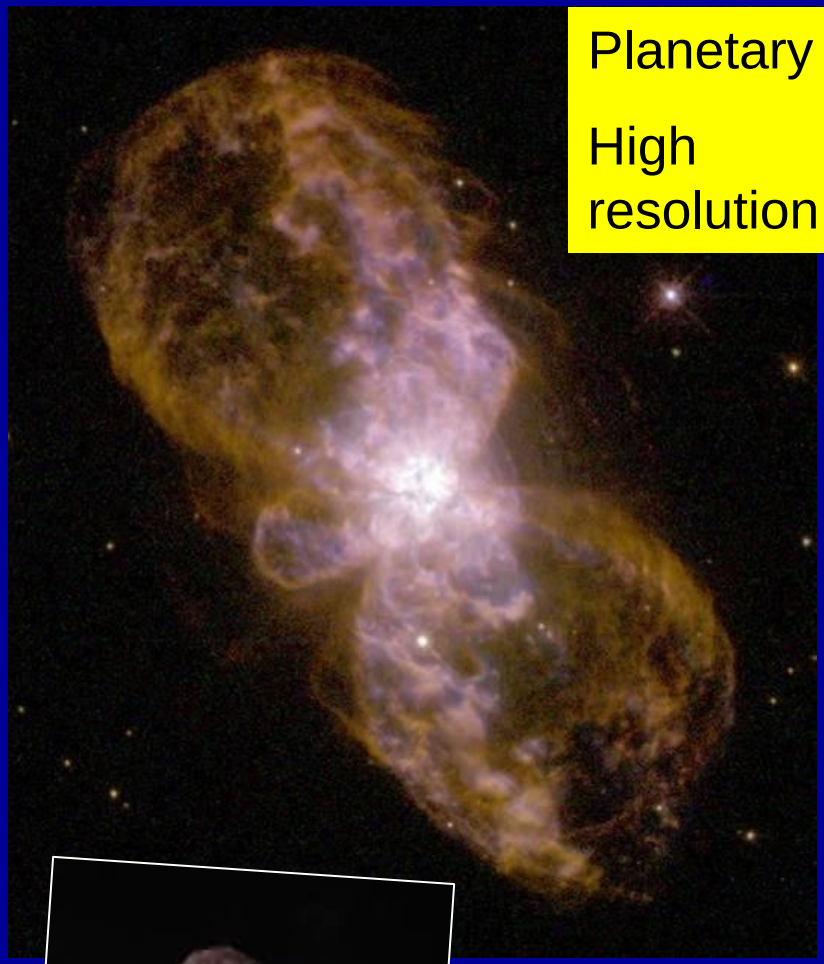


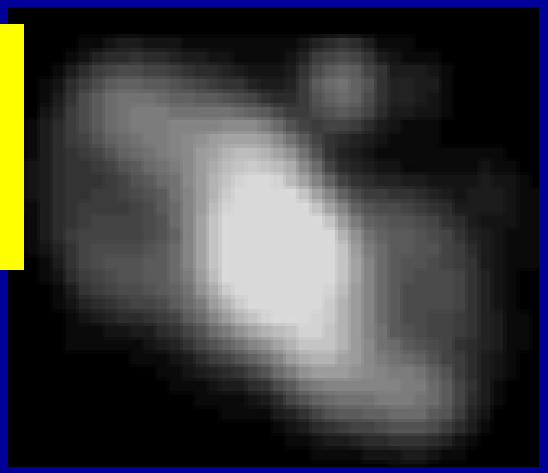
M2-9: Bipolar planetary nebula with 120 years shift period

Planetary Nebula Hb 5:

High resolution

Low resolution



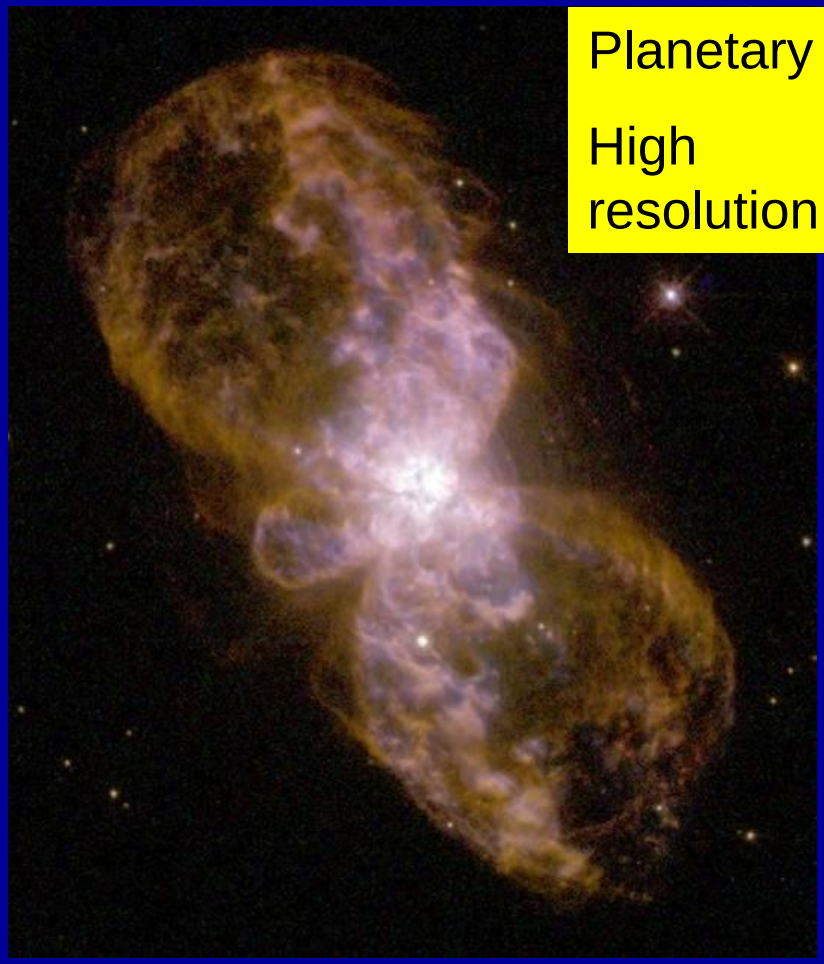


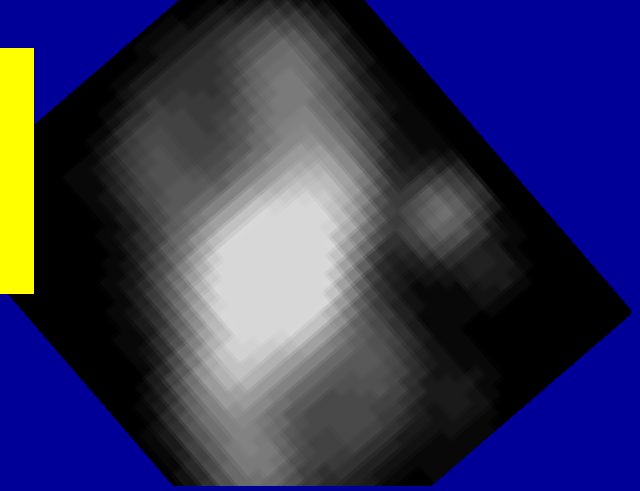
Eta Carinae

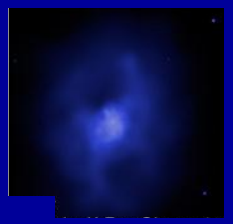
Planetary Nebula Hb 5:

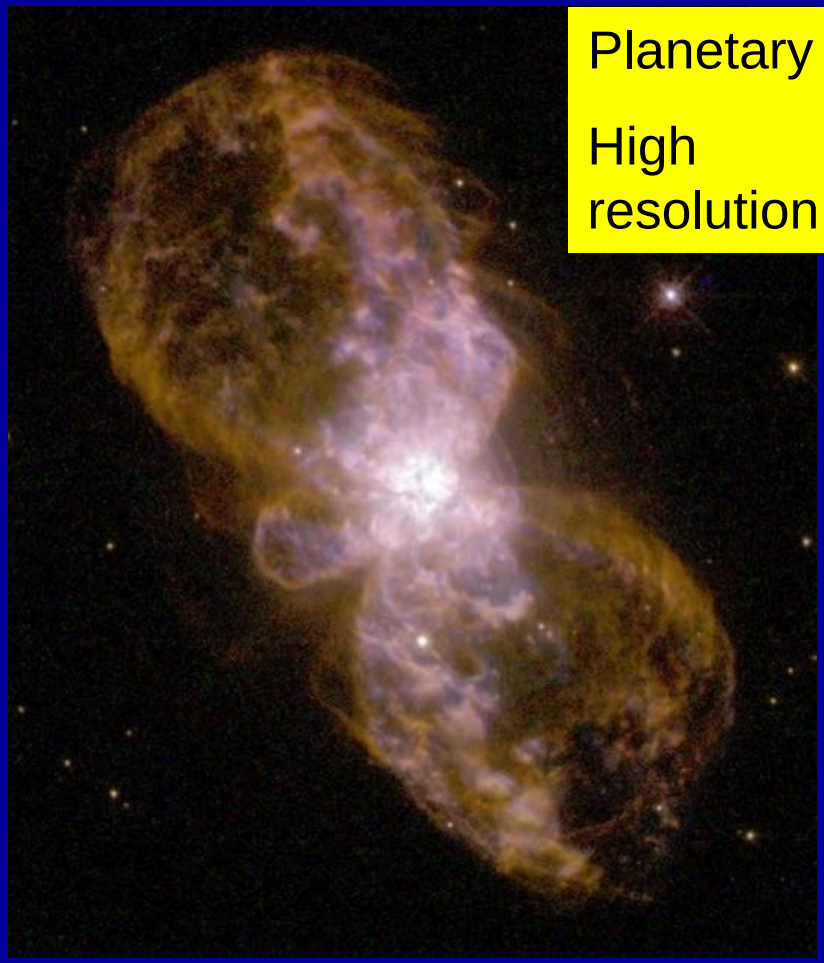
High resolution

Low resolution





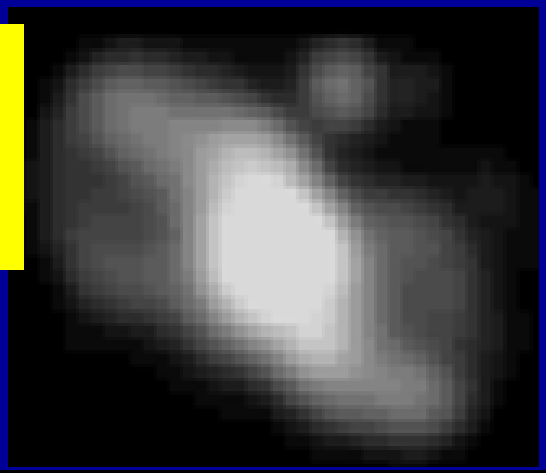


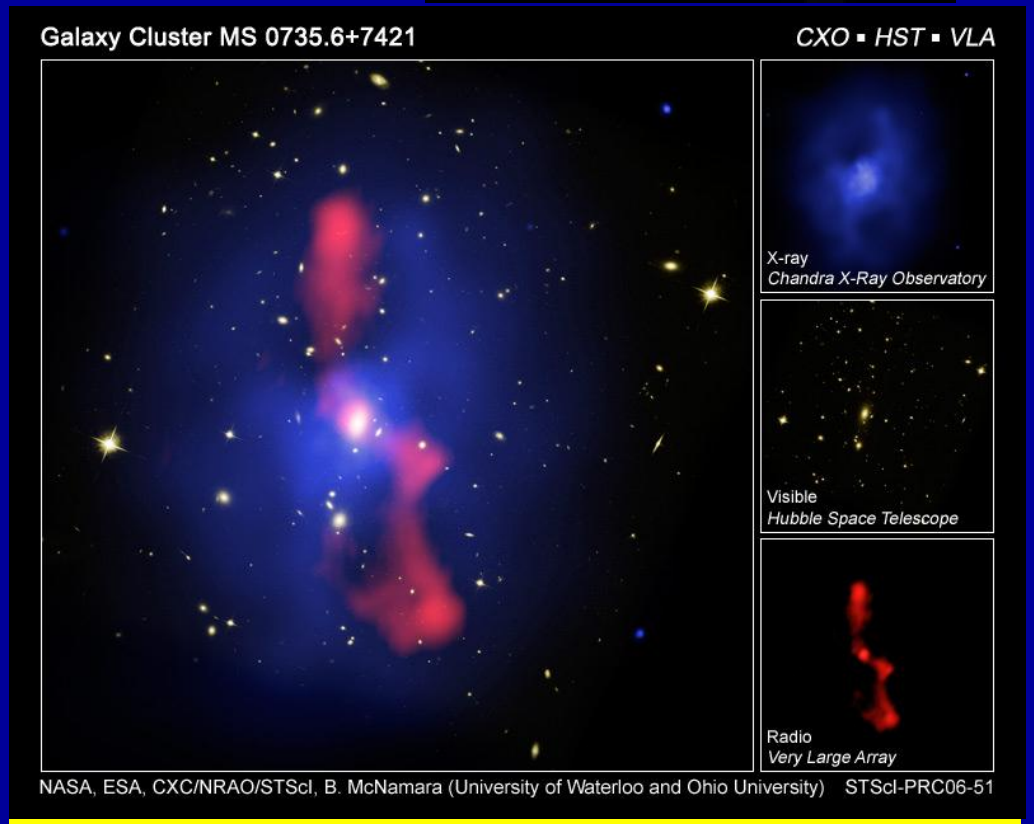


Planetary Nebula Hb 5:

High resolution

Low resolution





MS 0735.6+7421 A cluster of galaxies

Shaping by jets

The model:

A companion accretes mass, forms and accretion disk, and launches two opposite jets.

High accretion luminosity

Fitting the light curve of the

Lesser Eruption

with the binary of Eta Carinae.

Kashi & Soker 2010

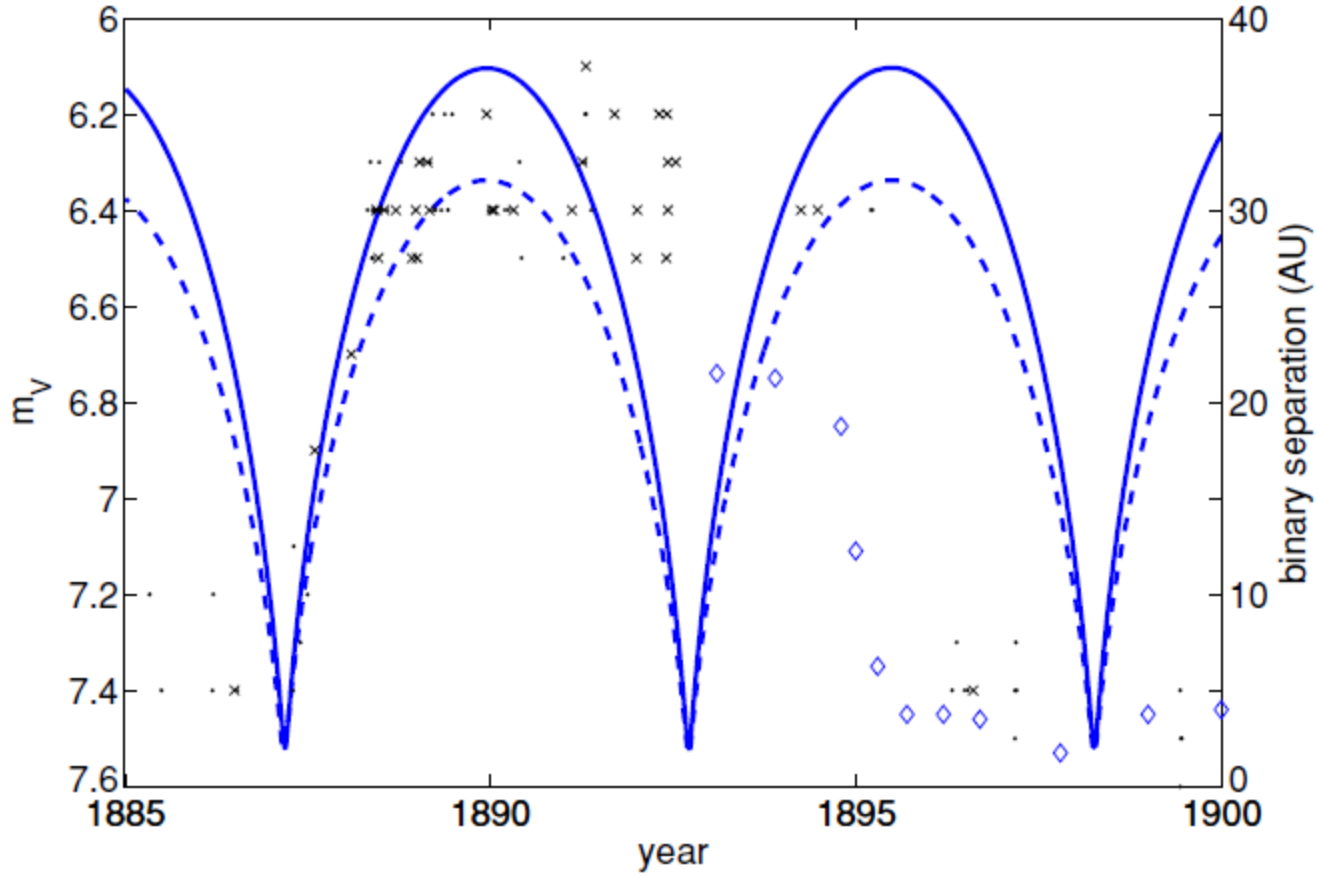


Figure 2. Binary separation (blue lines) and the V-magnitude light curve (Frew 2004, marked by black symbols, see legend in Figure 1; Humphreys et al. 1999 and E. Fernandez-Lajus 2009, private communication, marked by diamonds) during the Lesser Eruption (LE) of η Car (1887.3–1895.3). Dashed blue line: counting periastron passages back in time, not taking into account any mass loss or mass transfer. We used the common parameters $P_0 = 5.539$ yr, $a_0 = 16.64$ AU, $e_0 = 0.9$, $M_1 = 120\,M_\odot$, and $M_2 = 30\,M_\odot$ to draw the binary

Fitting the light curve of the

Great Eruption

with the binary of Eta Carinae.

Kashi & Soker 2010

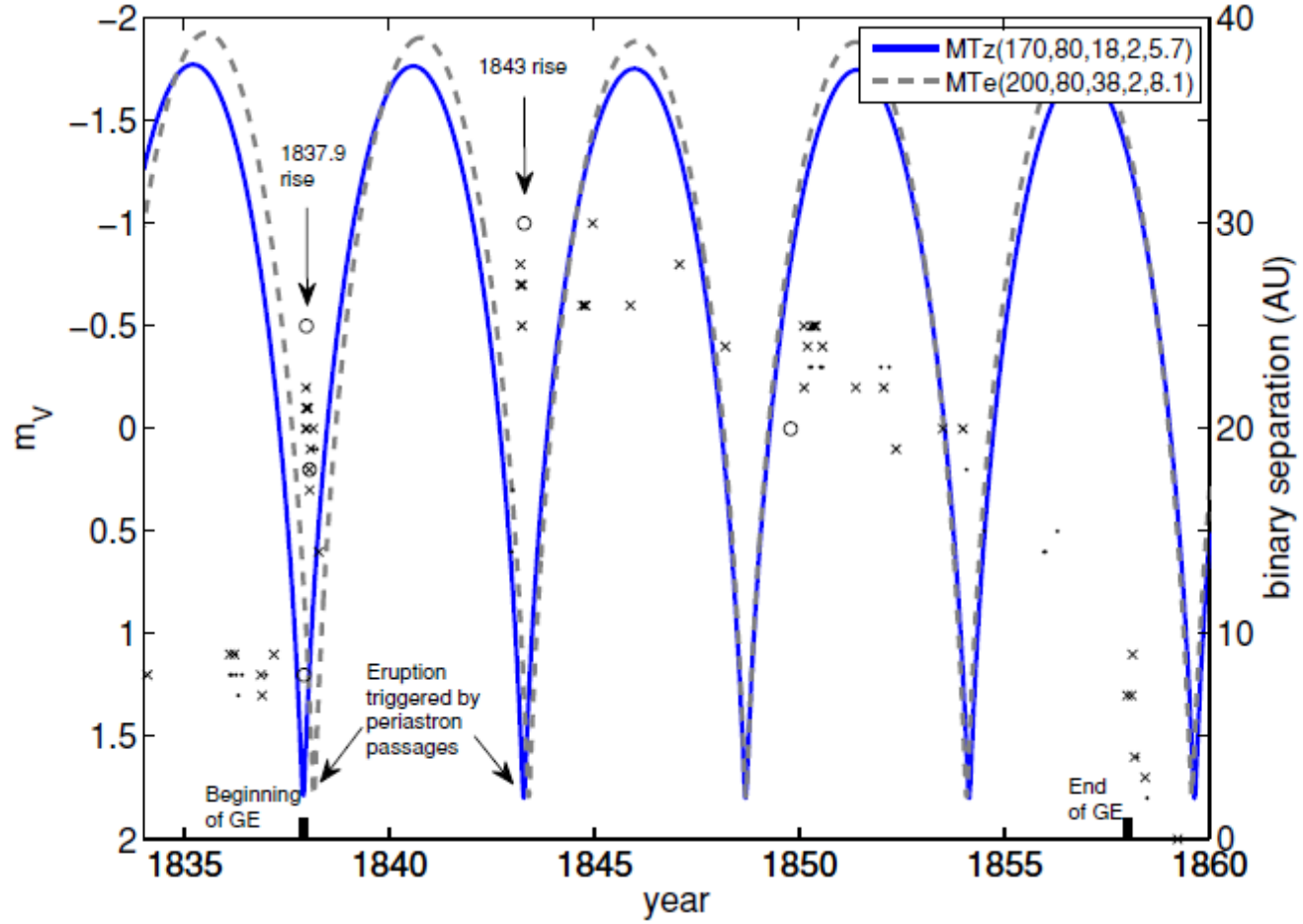


Figure 7. Binary separation (right axis: for two models) and V magnitude light curve (left axis: data from Frew 2004, see legend in Figure 1) during the GE of η Car for the mass transfer ZAMS model (MTz; solid blue line), and the "MTe" model (dashed gray line). The parameters are given in the legend in the order (M_1, M_2, M_{l1}, M_{l2}, M_t); see Table 1 for definitions of symbols. "MTe" is our preferred model, taking into account that the two stars already evolved from the ZAMS. For our preferred model, as well as the "MTz model," two periastron passages nicely fit the rapid rises in the V magnitude in 1837.9 and 1843.

Fitting the light curve of the

P Cygni

with a binary system

From Kashi (2010) who predicts the presence of a binary system in P Cygni with P ~ 7 years

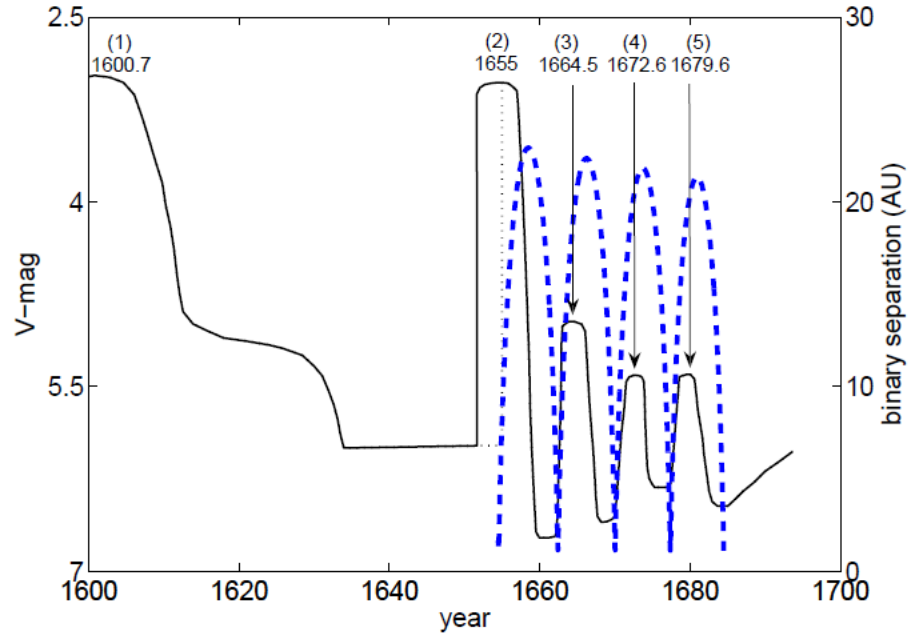
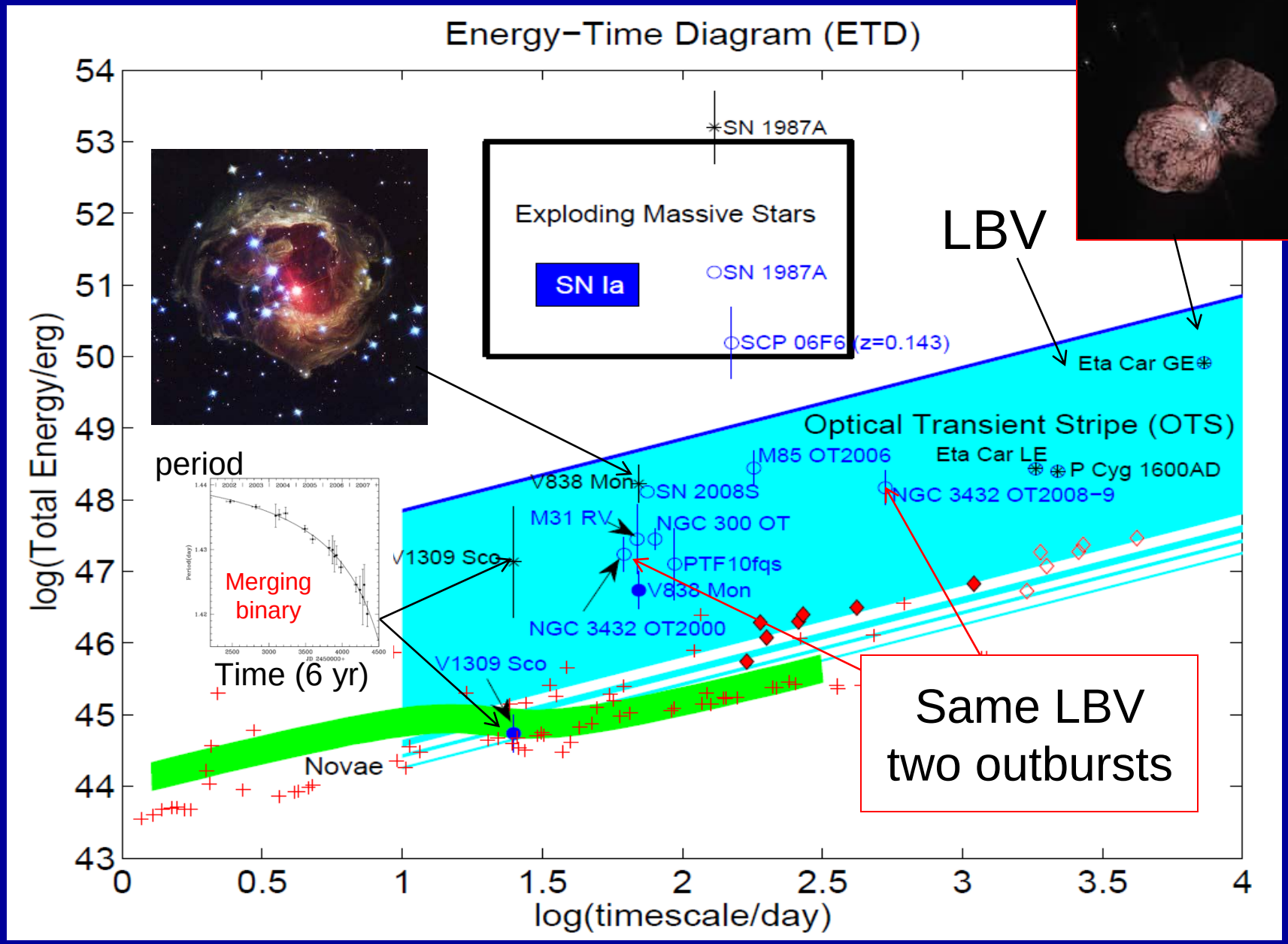
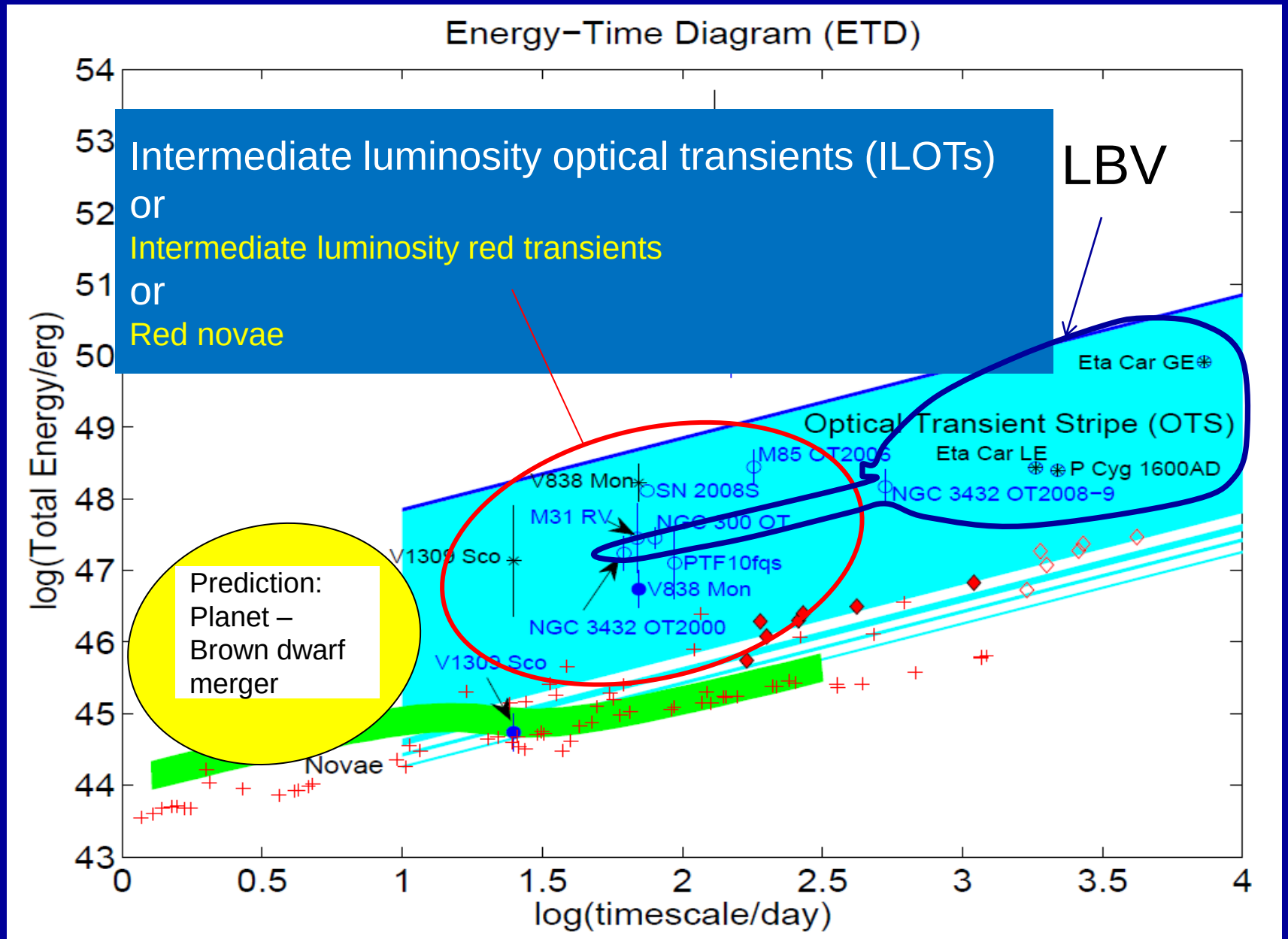


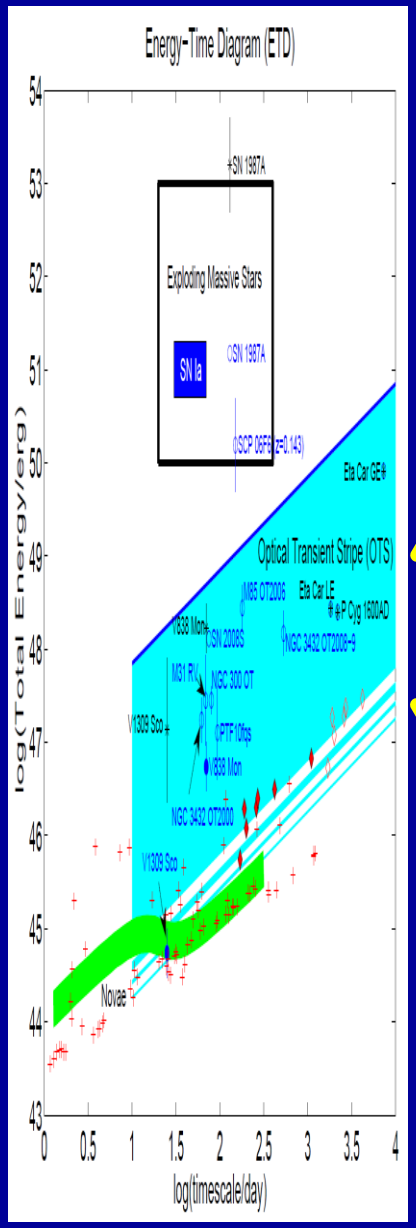
Fig. 2.— Solid black line (left axis): the visual light curve during the 17th century eruption of P Cygni (de Groot 1988). The peaks in luminosity are numbered. The time interval between the observed peaks is decreeing with time. Though the light curve shows an increase in 1653.5, there are evidences that this increase actually occurred in 1655 (dotted vertical line; Lamers & de Groot 1992). Note that the straight horizontal line between 1634 and 1652 is in fact lack of observations, as the star was too faint during that period. Dashed blue line (right axis): the binary separation r during the eruption of P Cygni between 1654.5 and 1684.5 (same as the third panel in Fig. 1). It is assumed that orbital period of the companion when the eruption is terminated was $P_f = 7$ yrs. The calculation involves mass transfer of $M_{\rm acc} = 0.08$ M$_\odot$ from the $M_1 = 25$ M$_\odot$ LBV to the $M_2 = 3$ M$_\odot$ MS companion (see equation (9)), and mass loss of $M_{\rm ej} = 0.05$ M$_\odot$ to the nebula. The perias-

Energy versus eruption time



Energy versus eruption time





Our (Kashi & Soker 2010) model:
High mass accretion rate onto a main sequence star:

Hydrogen ignition requires

$$T_{virial} \approx 10^7 \text{K} \quad \Rightarrow$$

$$\left(\frac{GM_*}{R_*}\right)_{MS} \approx \frac{\left(10^7 \text{K}\right)k}{\mu m_H} = 4 \times 10^{48} \text{erg} \, M_{\odot}^{-1}$$

From this we get the binding energy of a main sequence star $\approx 4 \times 10^{48\pm1}$erg.

The GE (according to Kashi & Soker 2010)

Mass transferred from primary to secondary during the Great Eruption.

Mass launched from the accretion disk around the secondary during the Great Eruption.

$$M_{\rm acc} = M_t - M_{l2}$$
$$= 3.7 \left(\frac{E_{\rm GE}}{8 \times 10^{49}\,{\rm erg}}\right)\left(\frac{R_2}{14.3\,R_\odot}\right)\left(\frac{M_2}{80\,M_\odot}\right)^{-1} M_\odot. \quad (9)$$

Similar to Soker (2007), who assumed that ~2/3 of the material transferred is accreted onto the secondary, we assume that $M_{\rm acc} \simeq 0.65 M_t$, and take $M_t = 5.7\,M_\odot$ and $M_{l2} = 2\,M_\odot$.

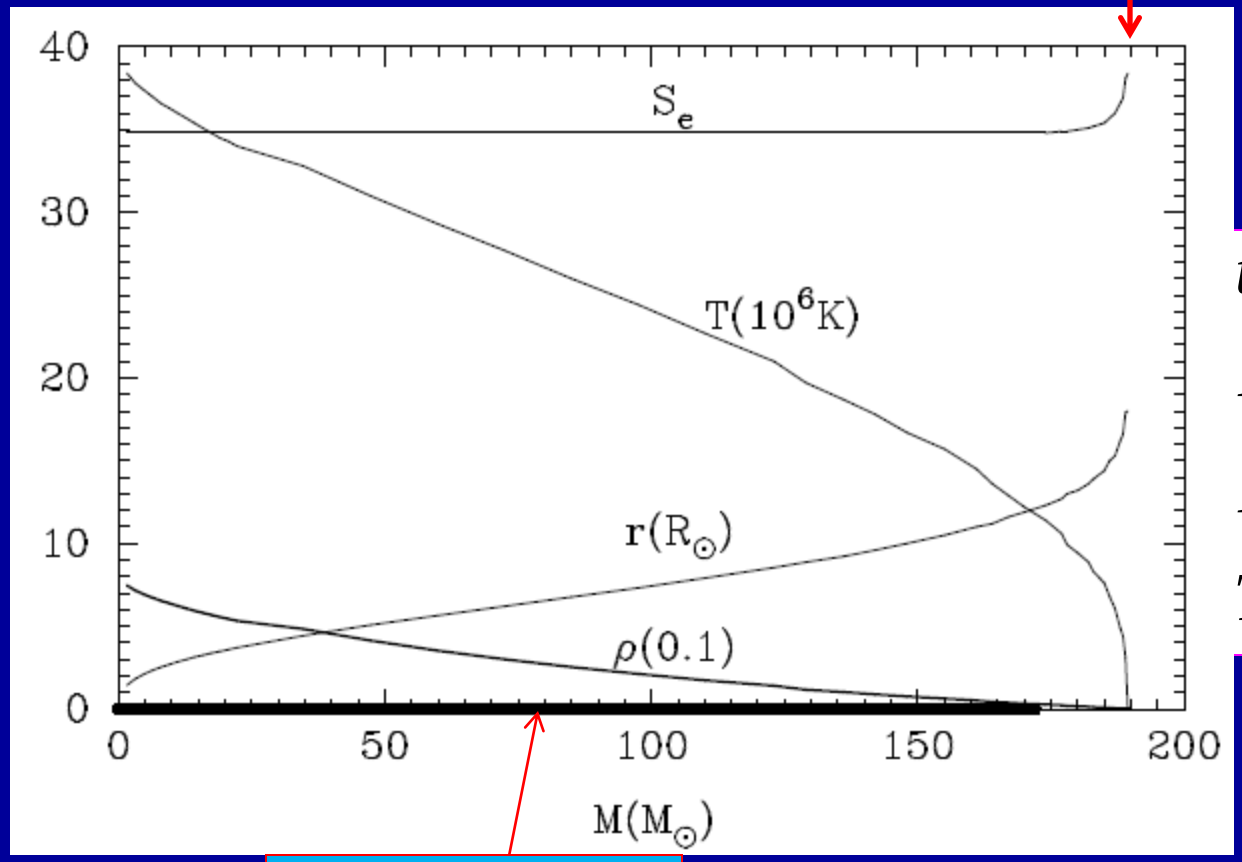
<u>Conclusion</u>: The high luminosity of LBV major outbursts is due to accretion.
The LBV instability is of high mass loss, not extreme luminosity.

Next 4 pages:
The magnetic instability model

LBV major eruption triggered by magnetic fields

(from Harpaz & Soker 2009)

Young massive star: Note! Only outer radiative region



$t = 0$

$M_0 = 190 M_\odot$

$L = 3 \times 10^6 L_\odot$

$T_{\rm eff} = 57,000 \rm K$

convection

$t = 2.55\,\mathrm{Myr}$

$M_0 = 139 M_\odot$

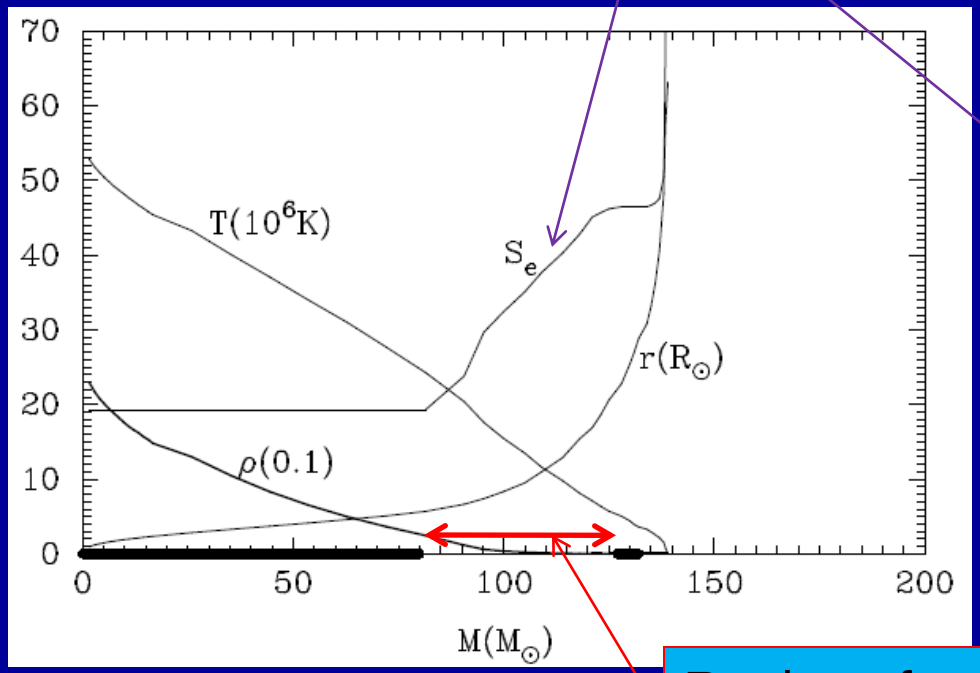
$L = 3\times10^6 L_\odot$

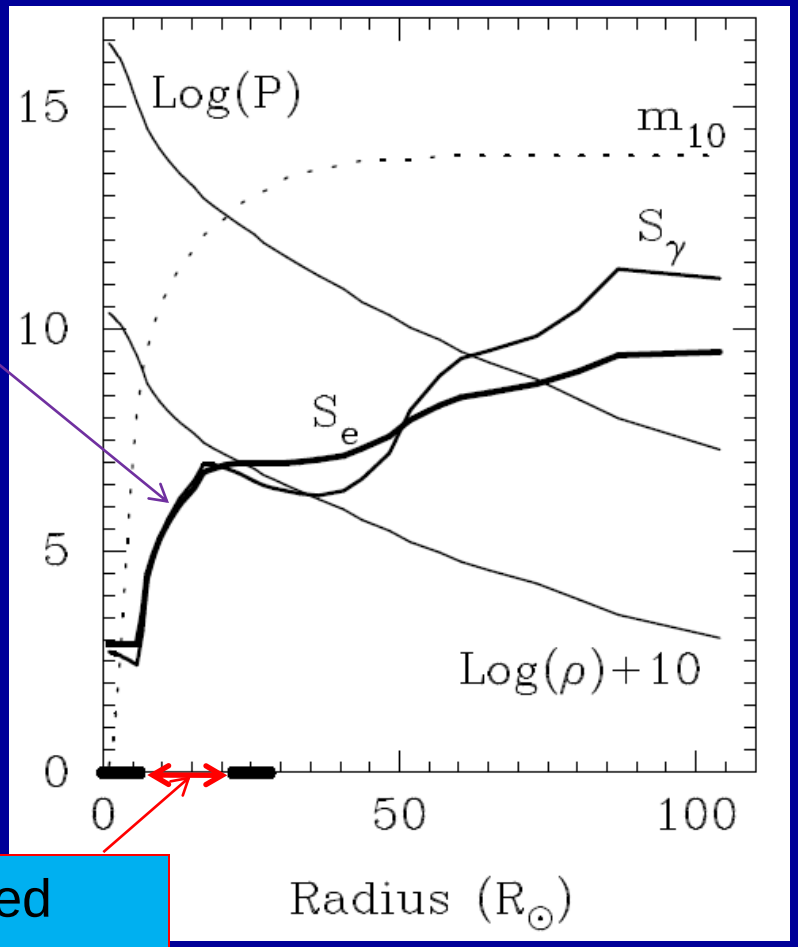
$T_{\mathrm{eff}} = 16{,}000\,\mathrm{K}$

Evolved LBV Model

Note! 2 radiative regions

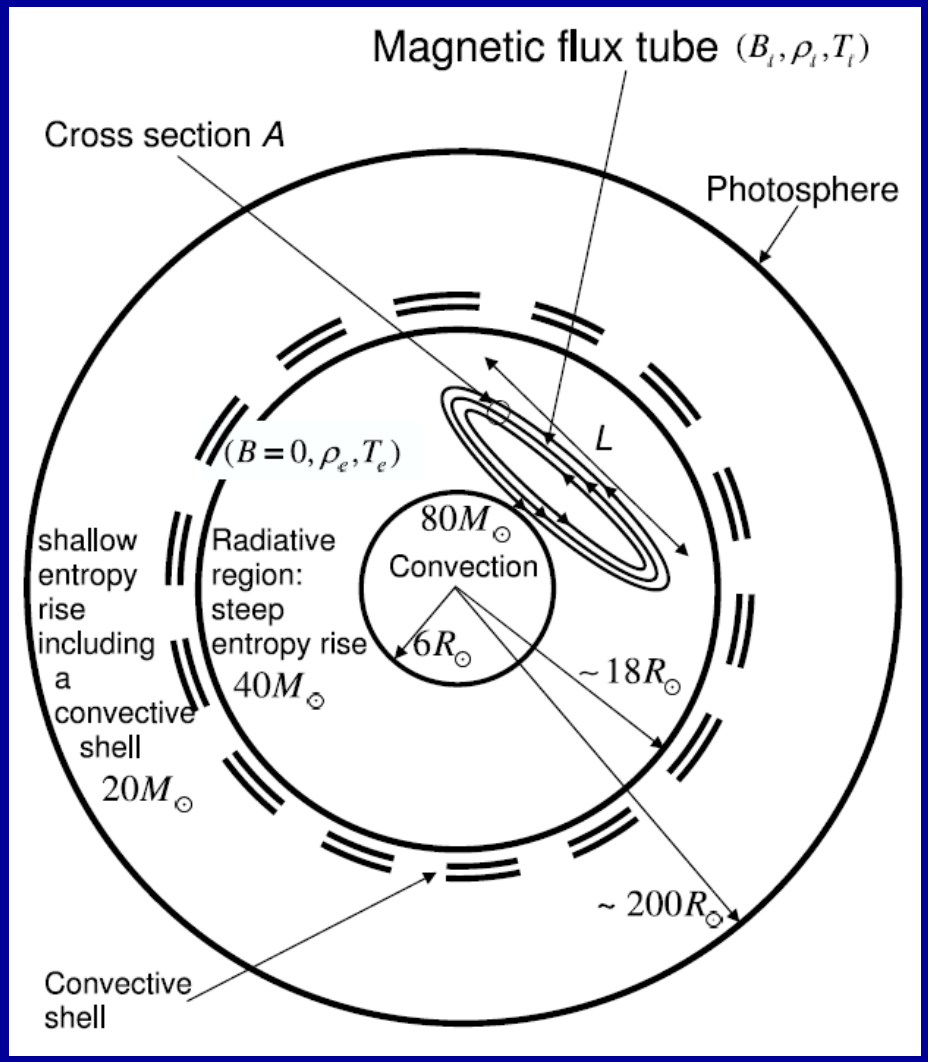
Steep entropy gradient





Region of stored Magnetic energy

Schematic drawing of the stellar model just before the eruption, with a flux loop embedded in the radiative envelope.

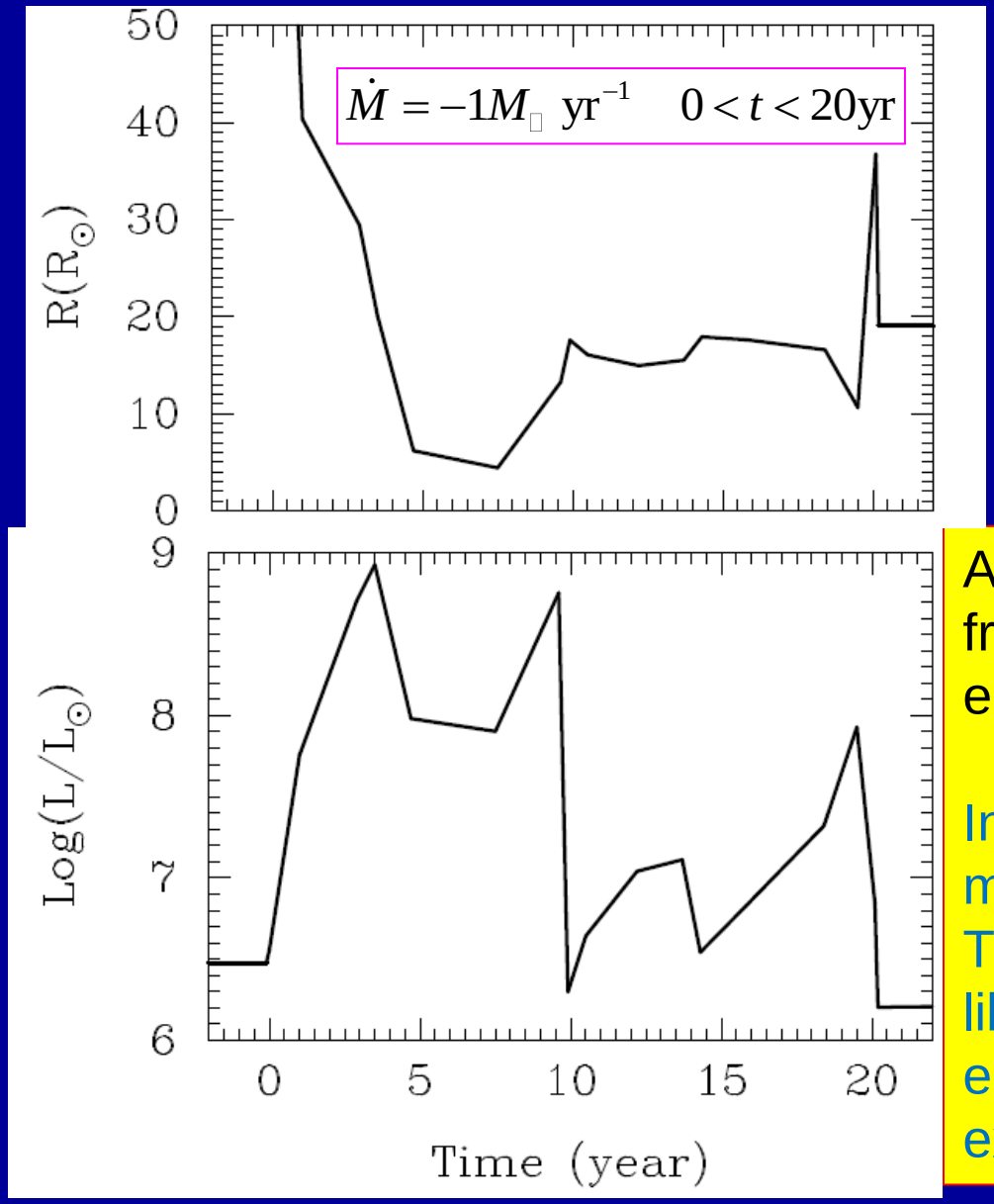


$t = 2.55\,\mathrm{Myr}$

$M_0 = 139 M_\odot$

$L = 3\times 10^6 L_\odot$

$T_{\mathrm{eff}} = 16{,}000\,\mathrm{K}$



Pre-outburst:

$M_0 = 139 M_\odot$

$L = 3 \times 10^6 L_\odot$

$T_{\mathrm{eff}} = 16{,}000\mathrm{K}$

$\mathrm{R} \sim 200\,\mathrm{R}_\odot$

At t=0 we start to remove mass from the outer part of the envelope at a rate of 1Mo/year.

Initial mass removal by magnetic activity.
Then the star contracts and liberates energy that uplifts the envelope and causes an extreme mass loss episode.