Eta Carinae

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Eta Carinae is a supermassive star visible from Earth from the southern hemisphere. It is notable for its variability. Starting around 1837, the star underwent an event known as the "Great Eruption" that lasted 20 years. During the Great Eruption, the star's apparent magnitude increased to approximately -1, making it the second brightest extrasolar object for a brief period in 1843. A lesser eruption occurred in the 1890s, again increasing Eta's brightness. Eta is typically at magnitude 6-8. There is evidence of another massive eruption having occurred thousands of years ago in a larger nebula spread around the Homonculus nebula that is the result of the Great Eruption.

Eta Carinae is located in the Carina Nebula in the Carina spiral arm of the Milky Way about 7000 light years from Earth. The Carina Nebula is a dense star formation region (Figure 1) containing many massive stars. Eta is a member of the cluster Trumpler 16, which with nearby Trumpler 14 contains 6 of 17 known O3 stars in the galaxy. Eta is probably 2300±200 kpc away, the distance being very uncertain because of anomalous extinction (i.e. absorption due to the interstellar medium) in the Carina nebula. The Carina Nebula is part of a giant molecular cloud 130-pc across with mass around $10^{5.7}\mathcal{M}_{\odot}$.

Such a large star is also very luminous. Davidson and Humphreys give luminosity $\mathcal{L} = 1.9 \times 10^{40}$ erg s^{-1} $\approx 10^{6.7}\mathcal{L}_{\odot}$. In order to avoid violating the Eddington limit, the mass must be greater than $90\mathcal{M}_{\odot}$ and is thought to be around $120\mathcal{M}_{\odot}$. The Eddington Limit is the natural limit to the luminosity that can be radiated by a spherically symmetric accretion onto a compact object. In the Great Eruption, the luminosity increased to $10^{7.3}\mathcal{L}_{\odot}$, exceeding the Eddington limit by a factor of 4. The star's "photosphere" was therefore somewhere around the orbit of Saturn. The Great Eruption lasted 20 years and during it Eta radiated energy on the order of $10^{49.5}$ ergs. It ejected at least $1\mathcal{M}_{\odot}$ at hundreds of kilometers per second. The kinetic energy of the ejected mass was on the order of $10^{48.8}$ ergs.

The Great Eruption was a very uncommon event among stars. Although there was a lesser eruption in Eta decades later, the Great Eruption was an extended event involving a massive increase in the energy output of the star. Other stars do not achieve the same energy output over extended periods, rather such bursts only occur during star death when supernovae occur. However, some LBV stars will similarly eject large portions of their mass in less spectacular events. It appears that in Eta Carinae large mass expulsion events have occurred before. There is a larger, fainter nebula outside of the Homonculus that would correspond to a mass-expulsion event thousands of years ago (Figure 3). There are no predictions for further events of the same magnitude, but it is expected that Eta will continue to be volatile and will experience a short life, particularly because it's powerful solar wind will probably lead it to blow off its hydrogen and become a Wolf-Rayet star eventually.

Eta is classed as a Luminous Blue Variable star. LBVs are in the upper portion of the Hertzsprung-Russell diagram and are characterized by a $\mathcal{L}/\mathcal{M}$ ratio near the Eddington limit for radiation from a spherical accretion. LBVs eject mass when the Eddington limit is exceeded and move back towards the left on the H-R diagram. LBVs will experience eruptions and some will blow off their outer layer of hydrogen to become Wolf-Rayet stars.

The Homonculus nebula is the mass ejected during the Great Eruption. It is the two-lobed object visible in pictures of Eta Carinae (Figure 2). Its polar axis is tilted 52° from our line of sight. The outward velocity from the pole of each lobe is about 650 km/s. In visual wavelengths, the Homonculus is mostly a reflection nebula rather than an emission nebula, though there are some strong emission lines closer to the star. Most of Eta's luminosity emerges from the Homonculus as thermal infrared emission from dust grains heated by the star's UV light. The lobes have diameters around .1 pc $\approx 10^{17.5}$ cm. To a first approximation, we know they are hollow because they exhibit limb brightening in infrared images (similar to the shell problem from our homework).

The star itself is a less known but nonetheless significant object of interest. Information on the star is difficult to detect because most of its light is obscured by the Homonculus. Most of Eta's luminosity is in the UV range. The continuum energy of the star is around 30000K and most of the Lyman continuum photons with $\lambda < 912\AA$ are absorbed by the solar wind. The photospheric radius is probably on the order of $100R_{\odot} \approx 0.4$AU, although the star itself may be smaller if its wind is opaque.

The mass loss of the star is much greater than that caused by the star's radiative loss. The total luminosity of the star is approximately $1.9 \times 10^{40}\frac{erg}{s} \approx$

$10^{6.7}L_{\odot}$.

$$\frac{dm}{dt} = \frac{\mathcal{L}}{c^2} = \frac{1.9 \times 10^{40}\frac{erg}{s}}{(3.00 \times 10^{10}\frac{cm}{s})^2} = 2.1 \times 10^{19}\frac{g}{s} = 3.3 \times 10^{-7}\frac{\mathcal{M}_{\odot}}{yr}$$

In principle, this would mean that the star would lose approximately 1 solar mass during its expected lifetime of 3 million years from radiative loss. During the Great Eruption the luminosity rose to $10^{7.3}\mathcal{L}_{\odot} = 7.6 \times 10^{40}\frac{ergs}{s}$, which meant that over a period of 20 years of emission the total energy radiated was 4.8×10^{49}ergs, which by the same calculation used above meant a mass loss of $2.7 \times 10^{-5}\mathcal{M}_{\odot}$. The total mass loss was around $1\mathcal{M}_{\odot}$, which indicates that most of the loss was not from radiation but from ejection, as can be witnessed in the Homonculus nebula. The true estimate of mass loss per year under relatively normal conditions as interpreted from solar wind observations is approximately $10^{-3.3}\frac{\mathcal{M}_{\odot}}{yr}$, several orders of magnitude larger than the radiative mass loss.

One of the most important problems related to Eta Carinae has been determining the cause of its periodic fluctuations. It was only recently observed that during the past 150 years there have been regular changes in brightness every 5.52 years. There are strong reasons to believe that this fluctuation is the result of another star in the system, even though it means the orbiting star would have an average orbital radius of 15 AU with eccentricity at least .8 (its closest approach would be about 3 AU). A suggested mechanism for the energy transfer to the Homonculus nebula in this case was ejected mass from the central star accreting onto the smaller orbiting star and being ejected at high energies from it. This can account for 8×10^{49}ergs, and therefore can account for the Homonculus's energy estimated at $10^{49.6} - 10^{50}$ergs. Another reason to believe that the system is binary is the angular momentum loss from the Great Eruption. As a single star, Eta could not have maintained a fast rotation after ejecting massive amounts of matter and increasing its moment of inertia. A fast rotation is required by most single-star models of Eta Carinae.

The binary star's effects were witnessed in 2003. Hubble's Advanced Camera for Surveys (ACS) observed a significant decrease in ultraviolet light. The decrease in the binary model results from the smaller star's light being obscured by the thick solar wind near the large star. Normally the smaller star's light would excite portions of the Homonculus nebula to emit light in the UV range, but during its closest approach of approximately 3 AU that does not happen. (Figures 4,5)

Although the binary star is likely to be responsible for the 5.5 year fluctuations observed by Hubble, there are other fluctuations that should be attributed to the LBV star. There is an 85 day periodic fluctuation over 1-2 KeV x-ray emissions that is probably a periodicity in the star that fits an LBV envelope model. There is also thought to be a longer term periodicity in the star's massive eruptions that explains the Great and Lesser eruptions, though since there is less data on this sort of periodicity it is less understood.

Figure 1: The Carina Nebula

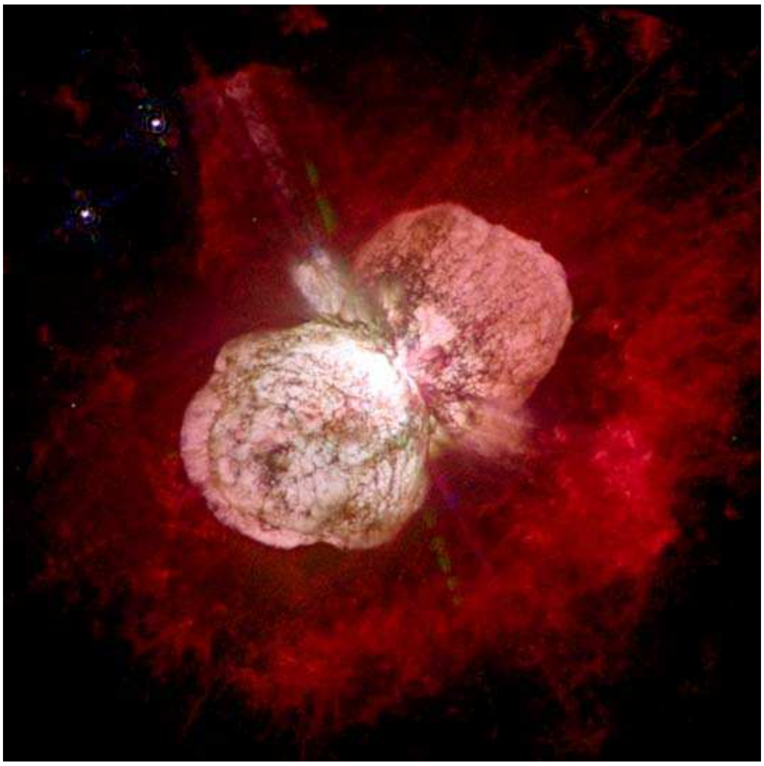

Figure 2: η Carinae and the Homonculus Nebula

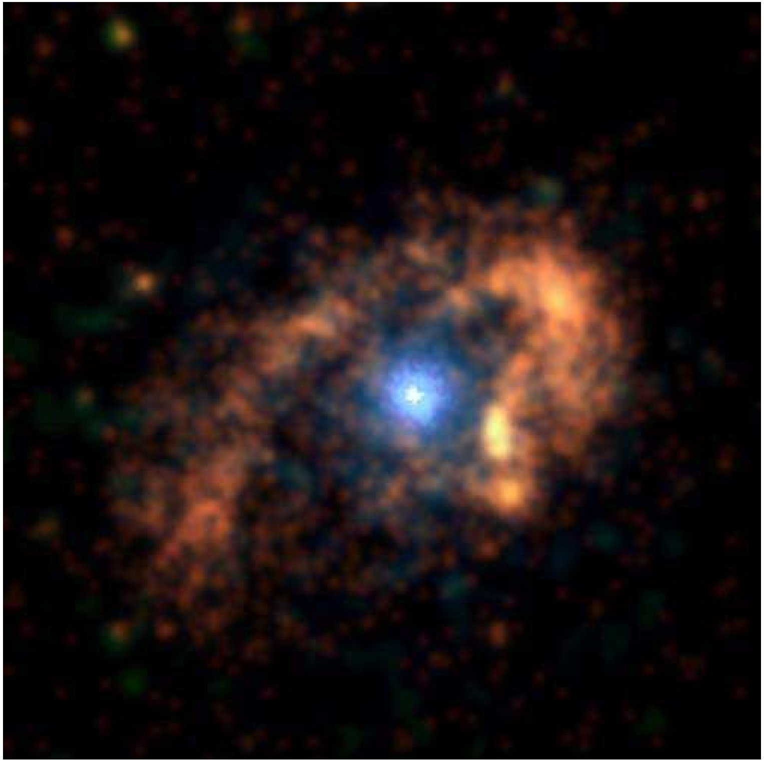

Figure 3: η Carinae, the Homonculus Nebula, and beyond. The outer horseshoe shape is 2 light years across and the central object is Eta and the Homonculus. This false-color picture is an x-ray photo.

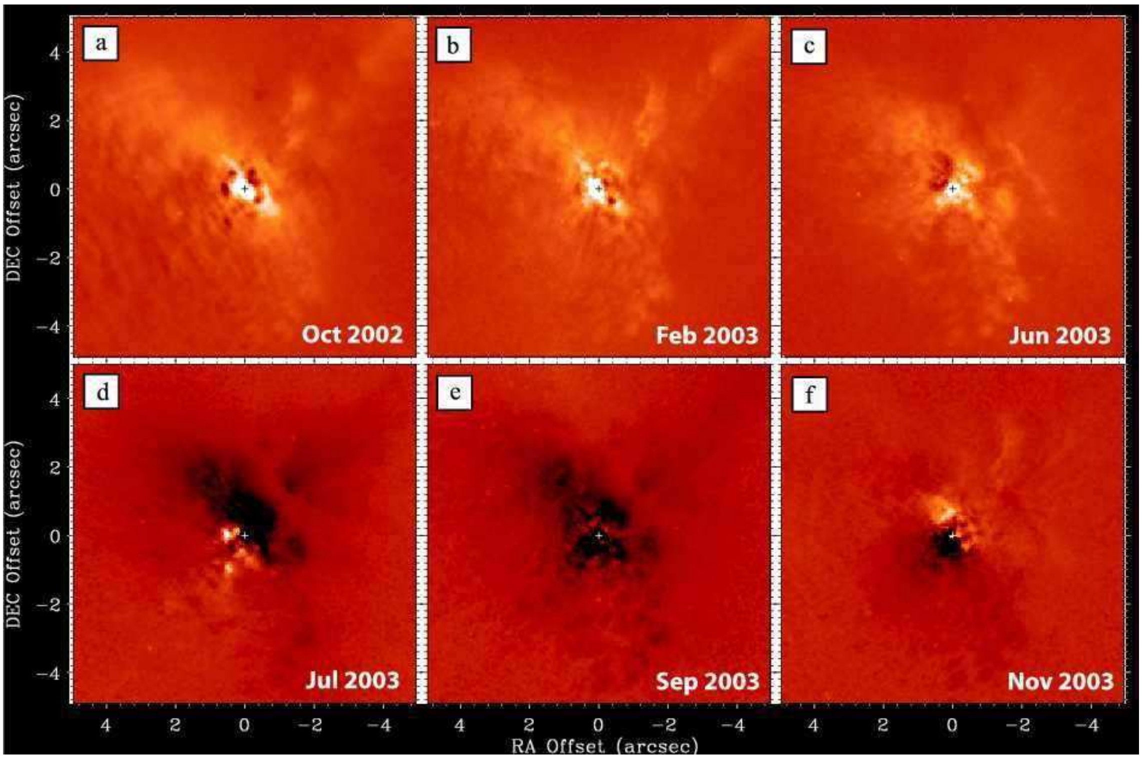

Figure 4: UV imaging of η Carinae during the 2003.5 UV event, which was predicted based on past periodic occurrences every 5.52 years. The relative dimness of UV light in the dark regions is thought to be a result of thick solar wind blocking out a small, hot companion star's UV emission

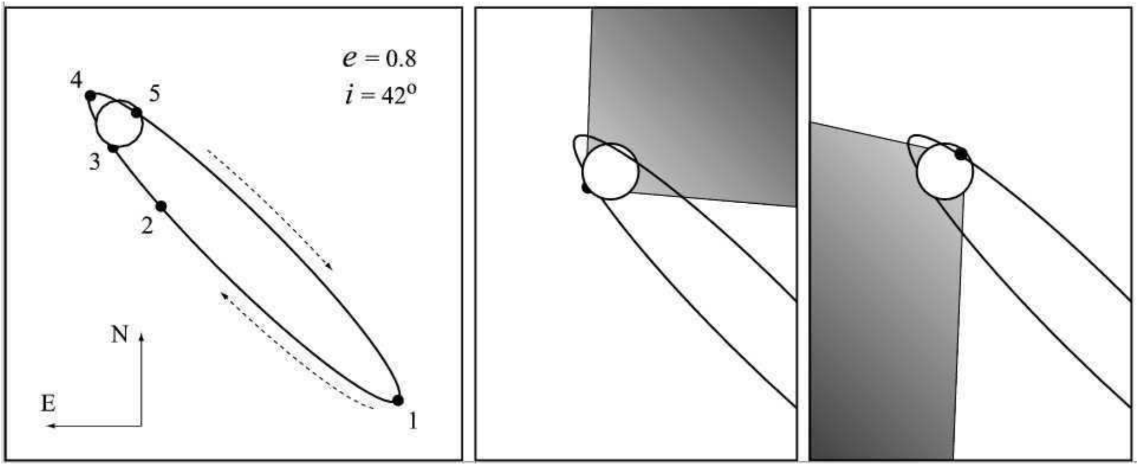

Figure 5: The expected orbit of a companion star. It would be approximately 30 $\mathcal{M}_{\odot}$ and follow a very eccentric orbit The grey areas show where the star's light would be blocked by Eta's wind. In this diagram, North is up and East to the left.

References

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