



1: An unusually large number of massive stars lie in the Carina nebula, the brightest part of the Milky Way with the unaided eye. The brightest star in the nebula is Eta Carinae. Field of view about 45 arcmin across. (Wolfgang Duschl, ITA, U. Heidelberg and Kerstin Weis, MPIfR Bonn.)

# Enigmatic Eta Carinae

The next stage in the evolution of Eta Carinae – famed for its explosive eruption in the 19th century – should be observed around the world in the summer. **Julian Pittard** reviews the story so far.

**M**assive stars, although rare, exert a disproportionate influence on their surroundings. In normal galaxies they are the main sources of ionizing radiation, and their powerful stellar winds and especially their dramatic deaths as supernovae have a huge effect on the surrounding interstellar medium (ISM), enriching it with nuclear processed material, and controlling its dynamics. Massive stars commonly form in groups or associations, and the collective energy input from these can produce shells, blowouts and galactic winds, which influence the evolution of their host galaxies. However, despite their importance, there is much unknown about massive stars: How do they form (through accretion on to a single object or via stellar mergers)? How do they live (e.g. is the LBV phase common or not)? How do they evolve? Do they form stellar-mass black holes? How often do they undergo large-scale mass-loss episodes? And because these stars are so rare, we need to study each one in detail.

As well as being perhaps the most massive star in our galaxy, Eta Carinae is also one of the least stable. It is best known as the survivor of the greatest non-terminal stellar explosion ever recorded. In 1843 it briefly became the second brightest visual object outside the solar system, with a peak luminosity rivaling that of 30 million Suns. The beautiful bipolar nebula which surrounds Eta Car, shown on the cover, has its origin in this colossal outburst, termed the “Great Eruption”, and estimates suggest that it contains many solar masses of material. Another powerful outburst, known as the Little

## Abstract

Eta Carinae is perhaps the most massive and luminous star in our galaxy, and is also one of the most enigmatic. Despite over a century and a half of study since an enormous eruption which expelled several solar masses of material into interstellar space, and which guaranteed its infamy, astronomers have struggled to understand its true nature. With a key event in the cycle of this star expected during the summer of 2003, an unprecedented programme of observations has been organized by astronomers around the world. Eta Carinae may at last be about to reveal some of its most fundamental secrets.

Eruption, occurred in the 1890s, and it remains extremely variable to this day.

If the central star(s) in Eta Car could be seen directly, many of its mysterious properties would probably have been understood long ago. However, the underlying star or stellar system is obscured from view by the dense ejecta and an optically thick circumstellar shell or wind, to the extent that even today this object is poorly understood. Astronomers continue to hold differing views about its nature, with most discussion focused on whether it is single, binary, or a compact multiple grouping of stars; the cause of the two large outbursts; the underlying mechanism for its current variability; and the process responsible for shaping its explosion

debris. All these topics remain controversial.

This article introduces the most important characteristics of Eta Car. It is an extreme showcase of the effects of variability on evolution in the upper Hertzsprung-Russell (H-R) diagram; it is surrounded by an incredibly rich assortment of mass flows over a wide range of physical scales which challenge numerous gas dynamical models; its observed emission serves as an excellent testbed for many atomic processes; it pollutes and alters the chemistry of the surrounding medium with nuclear processed material. This article also reports on a fundamental advance in recent years – the discovery of an apparent periodicity in observational data – and discusses its implications alongside the conjecture that the central object is a binary system of two massive stars. It finishes with some details of the extraordinary campaign of observations planned over the next year. In writing this article I have drawn on many sources in the existing literature, including an excellent, comprehensive review by Davidson and Humphreys (1997).

## Eta Car as a Luminous Blue Variable

Our knowledge of Eta Car dates back about 400 years. From about 1600 until the early 1830s it was observed to undergo changes in brightness of roughly a factor of 6, being reported between second and fourth magnitudes. It may have become unusually active from about 1820, but in 1837 it brightened still further, fluctuating between first and zero magnitude for almost 20 years, in an event that we call the Great Eruption. In 1843 it briefly

reached a magnitude of about  $-1$ . After 1856 it faded, stabilizing at seventh or eighth magnitude around 1870. A Little Eruption occurred between 1887 and 1895, but it has since been more stable than in the centuries preceding the Great Eruption. A nebula around the star became visible after 1900 and, since 1940, the central object has gradually brightened. It is now between fifth and sixth magnitude. IR observations in the late 1960s and early 70s revealed that Eta Car continues to maintain an incredibly high luminosity, and this can be used to estimate a lower limit for its mass by assuming that it radiates at the Eddington limit – this is where the upward force on free electrons due to Thompson scattering (which is the smallest possible opacity for ionized matter) is equal to the downward gravitational force. For abundances appropriate for an evolved star, the current luminosity implies a minimum mass of  $100 M_{\odot}$ , although this would be reduced slightly if it turns out that Eta is not a single star.

The presently accepted view is that the central object consists of at least one extreme member of the class of stars known as Luminous Blue Variables (LBVs; Humphreys and Davidson 1994). These are evolved massive stars subject to violent instabilities and periods of large mass loss. Very massive stars ( $M > 60 M_{\odot}$ ) are thought to evolve from an O-type main sequence star, through an LBV phase to a Wolf-Rayet (WR) star, before ending their lives in a supernova (or even hypernova) explosion. These stages represent the transition from core-H burning to shell-H burning to core-He burning. There remains much uncertainty, however, as to whether such stars also pass through a red supergiant (RSG) phase, and whether some WR stars are actually core-H burning and therefore are actually pre-LBV. As no red or yellow supergiants are known that are brighter than  $\log(L/L_{\odot}) \sim 5.8$  (Humphreys and Davidson 1979, de Jager 1998), it seems likely that the most luminous stars of all evolve in a different way to their lower luminosity cousins, though this is a subject that is still debated intensely. Also, while we know that Eta Car is evolved, it is not clear how representative it is of the most massive stars.

LBVs are known to oscillate between states of quiescence, in which the star is fainter and hotter, and eruptive phases, where the star is cooler and brighter, over timescales between years and tens of years (Humphreys and Davidson 1994). The removal of the stellar envelope to reveal the hot core underneath is the defining process of this evolutionary period, although because of the rarity and complex nature of these stars there is still no definitive theory for mass-loss during the LBV stage, which has a typical lifetime of  $\sim 10^4$  yr.

This is unfortunate because mass loss signifi-

cantly affects the evolution of massive stars, and alters the tracks that they take across the H-R diagram. A star with an initial mass of  $60 M_{\odot}$  may explode as a supernova with a mass below  $\sim 10 M_{\odot}$  (Meynet and Maeder 2000), the remainder having been ejected into the interstellar medium throughout its short life (compare with stars like the Sun, which retain almost all of their mass during their lives). The LBV phase is notable for the highest mass-loss rates of all, where the star may lose of order  $1 M_{\odot}$  every 1000 years through a dense stellar wind. Episodic eruptions remove even more mass.

Over the last few decades, our understanding of the upper H-R diagram has benefitted immensely from theoretical calculations of stellar evolution. However, as we are currently unable to explain fully the mass-loss process during the LBV stage, our knowledge of the physics and evolution of the most massive stars lacks completeness. All theoretical models of evolutionary tracks in the upper H-R diagram are subject to assumptions concerning mass loss, and while we cannot yet self-consistently model such tracks, the models and observational work on the distribution of stars in the upper H-R diagram together allow us to broadly sketch the evolution of such stars.

Roughly speaking, as a star with an initial mass greater than  $60 M_{\odot}$  leaves the main sequence, its radius expands while it maintains constant luminosity, moving towards the right in the H-R diagram. Since its  $L/M$  ratio is of the same order of magnitude as the Eddington limit, it is potentially unstable, and the constant mass loss that it experiences drives it ever closer to this point. When it reaches some critical radius or surface temperature, the star suddenly loses mass in one or more LBV eruptions, whose causes are not yet understood. Under such drastic mass loss, the star shrinks and moves back to the left in the H-R diagram. The position of the instability limit in the H-R diagram chases the star since its  $L/M$  ratio has increased, making it fundamentally less stable. At this point the star is an LBV.

Eta Car fits this qualitative description well. It is located in the expected region of the H-R diagram, it is evolved, and its pre-1830 variability looks like LBV eruptions. The Great Eruption was more dramatic than any other well-studied LBV event, but this is acceptable given that Eta Car is more luminous than any other known LBV in our galaxy.

The majority of proposed mechanisms to drive LBV instabilities, the onset of higher mass-loss rates and the underlying eruptions, are concerned with the importance of radiation pressure and high opacities within the outer envelope of the LBV. One conjecture is that the observed behaviour arises from dynamical instabilities deep in the outer envelope of the star, where an iron opacity peak leads to a

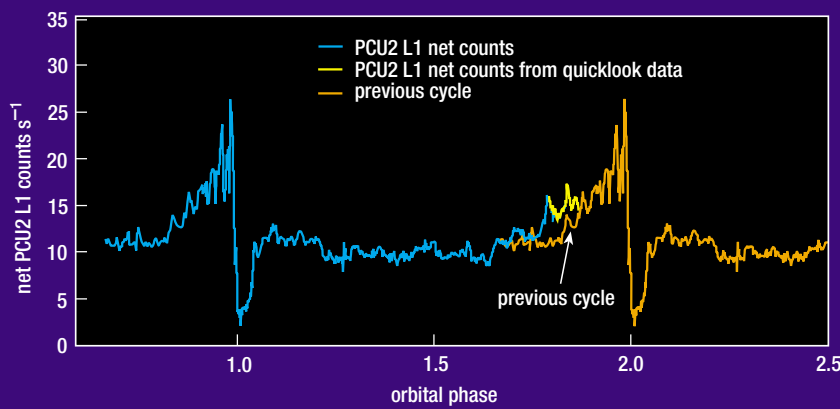
potentially large region of turbulent convection. If a turbulent fluctuation in this zone were to temporarily increase the mass-loss rate, a runaway process may then eject the entire convective envelope until the base of the perturbed region penetrates down into the underlying stable radiative layers. Theoretical models (Stothers 2000) predict that this runaway mass loss should repeat cyclically with a period of  $\sim 4$  yr for Eta Car (essentially the thermal relaxation timescale of the outer envelope), which agrees well with the observed cycle time (described below). More powerful outbursts (such as the Great Eruption) can be associated with larger perturbations. A “modified Eddington limit”, stellar rotation (e.g. Langer *et al.* 1994, Zethson *et al.* 1999), and binarity (Gallagher 1989) have also been considered as causes of the cyclical outbursts.

To summarize, it appears that Eta Car is an extreme example of the LBV class, though many fundamental questions remain unanswered (Davidson and Humphreys 1997): Is Eta Car a single or binary star? Which instability mechanism is responsible for its cyclical variability? Was the Great Eruption caused by the same mechanism? If Eta Car is a binary, did this influence the Great Eruption? Why did the Great Eruption end? Why did an isolated Lesser Eruption occur? Was this caused by the same process? Identifying whether or not Eta Car is a binary is central to many of these questions because it has implications for the Great Eruption, modelling of the stellar spectrum, the creation of the bipolar nebula, and the observed variability, as I discuss later.

## The nebula

It is possible to deduce a great deal of information about the central object in Eta Car from studying its surroundings, in particular its dusty bipolar nebula known as the “Homunculus” (“the little man” – see cover). Modern IR observations show that the emission is limb-brightened and has the characteristics of two hollow, thin-walled, clumpy spheres. The polar diameter of the nebula is approximately 0.7 ly (the angular diameter is approximately 19 arcsec). The expansion velocity at the poles is around  $650 \text{ km s}^{-1}$ , while slower velocities are seen towards the equator. The mass of dust in the nebula is approximately  $0.04 M_{\odot}$  – a thousand times the combined mass of the nine planets in our solar system. With a standard value for the gas-to-dust mass ratio, the nebula contains of order 2–4  $M_{\odot}$  of material. This is consistent with estimates based on visual wavelength scattering, but the assumptions behind both determinations are uncertain enough that the actual value could be as high as  $10 M_{\odot}$ .

The clumpy appearance of the lobes is most likely to be a result of gas-dynamic instabilities,



2: The X-ray flux from Eta Carinae as monitored by RXTE. The flux is relatively constant over the majority of the 5.5 yr period, but experiences large variations over one fifth of the cycle. Of particular note is the precipitous fall into minimum, the asymmetry of the ingress and egress, and the presence of quasi-periodic flares. The latter were first noticed during the rise to maximum (Corcoran *et al.* 1997), and an 85-day period was cautiously assigned. They are not detected during minimum, but there is a tentative hint of one or two flares after the X-ray flux recovers. It is possible that the period of the flaring may help to discriminate between models, though since the flares probe smaller scale structure in the wind their interpretation will probably be non-trivial. (Michael Corcoran, Goddard Space Flight Center.)

and several scenarios for their formation are possible. Perhaps they result from the action of a continuous stellar wind inside each massive ejecta shell. Alternatively, they may be the imprints of clump destruction, in which case the peak luminosity observed during the Great Eruption may have been augmented by this process. They could be related to the instabilities that form in homogeneous atmospheres close to the Eddington limit (Shaviv 2000). Or they could be the result of radiation pressure acting on dust.

The ragged nature of an equatorial debris-disk in the midplane of the lobes was recognized about 10 years ago (Duschl *et al.* 1995). The ejecta appears much more fragmented and irregular, and the observed morphology consists largely of long radial “streaks”, “spokes”, “rays” or “fans”. Mass estimates are far more uncertain than for the lobes – a tentative value is  $0.5 M_{\odot}$ . Within the central core region ( $r < 0.3$  arcsec) there are numerous circumstellar blobs (e.g. the “Weigelt objects”) whose emission contaminates most ground-based observations of the central object.

Proper motion studies from HST images taken several years apart (Morse *et al.* 2001) have revealed that the gas in the nebula is ballistic: that is, the gas furthest from the centre of the nebula is receding the fastest, and vice versa, in a type of miniature “Hubble-flow”. A movie of the nebula expansion run backwards in time shows that all of the gas in the bipolar lobes converges on the centre at the same instant, around the year 1843, and was thus created in a single explosive event. The age of the equatorial ejecta, on the other hand, is more controversial and there is reason to suspect a mixture of material from multiple events.

From estimates of the nebula mass and

expansion velocity, it is possible to derive the kinetic energies of the mass ejections. An impression of the nature of the eruptions can then be obtained by evaluating the ratio of the luminous energy during the eruption to the kinetic energy of the ejecta,  $\sigma$ ; lower values are generally more “explosive”. We find that  $\sigma \sim 11$  for the bipolar lobes and  $\sigma \sim 2$  for the equatorial ejecta (for comparison,  $\sigma \sim 0.03$  for supernovae,  $\sigma \sim 1$  for novae, and for massive star winds  $\sigma \sim 10^2$ – $10^4$ ). The variation in the  $\sigma$  values, together with their different morphology, may imply that a different physical mechanism created the lobes and the equatorial skirt.

There are two main theories for why the Homunculus is bipolar: either the surrounding medium shaped a spherical ejection of mass (e.g. if the surrounding medium was much denser near equatorial latitudes, the nebula would preferentially expand along the poles), or the ejection itself was intrinsically aspherical (rotating stars with line-driven winds can produce bipolar outflows that are both denser and faster at the poles). Shaping by magnetic fields is also a possibility, but current models indicate that this method doesn’t easily produce bipolars. Distinguishing between the two more likely scenarios may require kinematic information from inside the nebula. Related work has recently uncovered evidence for a smaller bipolar nebula with the Homunculus, called the “Little Homunculus” (Ishibashi 2003) which may have been formed by the Little Eruption.

Extended structures surrounding Eta Car are also visible with the use of highly sensitive imaging and long-slit spectroscopy. Just outside the Homunculus there appears to be a spherical-like structure (termed the “Ghost Shell”, Currie *et al.* 2002), which may also be related to the Great Eruption. Surrounding this is a still larger

structure (approximately 4 by 1.5 lyr) which appears to be bipolar, yet is rotated almost  $90^\circ$  with respect to the Homunculus (Bohigas *et al.* 2000). Estimates of its mass are uncertain, but it is likely that it contains approximately 5–10  $M_{\odot}$  of material, and it appears to be of order 13 000 yr old. It is puzzling why these structures have different shapes and orientations. Unfortunately, direct evidence of even older evolutionary features will almost certainly have been washed out by a combination of aging, the complexity of the Carina nebula (figure 1), and the additional stirring that the other massive stars in the Trumpler 14 and 16 clusters produce. It is clear, however, that there were many large outbursts before the Great Eruption, and Eta Car has undoubtedly had a huge effect on the energy budget and shaping of its environment.

The nebula and its near surroundings have now been studied for half a century, yet new discoveries continue to be made. A recent addition to the wealth of features associated with Eta Car are the remarkable high-speed filaments protruding radially from the Homunculus, of which five are spatially resolved (Morse *et al.* 1998). These features – “spikes”, “whiskers” or “strings” – are typically 0.2–0.5 lyr long, and are highly collimated (length-to-width ratio between 30 and 100). They point directly back to Eta Car, but are not perfectly straight, showing localized kinks and brightness knots. Their velocity structure appears almost linear with distance (Weis *et al.* 1999) and they have high-speed knots of emission just beyond their tips (Currie *et al.* 2000).

While there are many possible explanations for this phenomenon, the most plausible model yet involves the passage of ballistic “bullets” of material through the dense circumstellar environment (Redman *et al.* 2002). The filaments are then associated with ablated material, and the separation between the high-speed knots and the filament tips indicates that the time required for shocked material to cool and become optically visible is  $\sim 10$  yr. This in turn suggests that the material surrounding the Homunculus is itself expanding at velocities of order  $500 \text{ km s}^{-1}$ , and is consistent with the idea that the Homunculus is expanding directly into a slow wind from a previous evolutionary phase of the central object, or the interpretation that hot gas surrounds the nebula. The latter may also be favoured by the fact that the filaments are so highly collimated, since this may require that the bullets are moving subsonically through hot surroundings (Dyson *et al.* 1993).

### Recent observational developments and support for a 5.5 yr periodicity

Major advances in our knowledge of Eta Car have occurred since the discovery of a 5.5 yr periodicity in an IR emission line: the He I

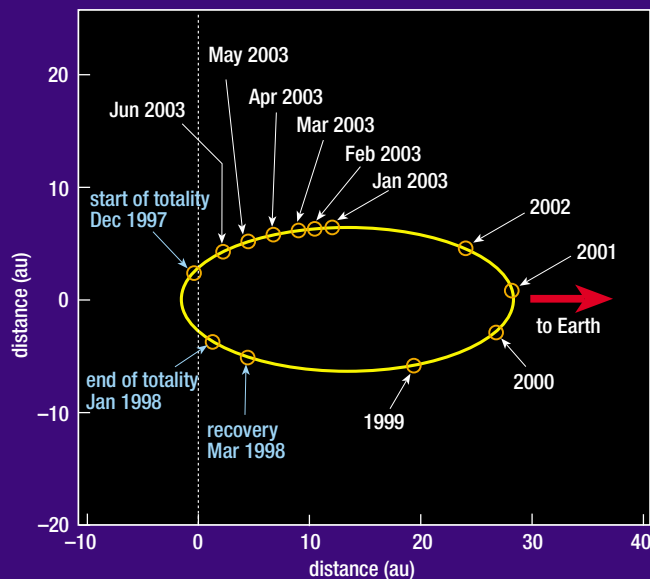
10830 Å line disappears (Damineli 1996). Suspected periodicities for Eta Car had been noted many times before this, yet all were subsequently revealed to be spurious. However, the 5.5 yr periodicity is remarkable for the fact that predictions based on it occurred as expected, and it is now supported by observations in the radio, optical and X-ray bands, and also by historical data (Feast *et al.* 2001). Since this discovery reveals the timescale of a fundamental process in Eta Car, it immediately provides great insight.

The disappearance of the He I 10830 Å flux is known as an “event”, and the next one is predicted to occur around June–July 2003. It is associated with an X-ray minimum, and (with slight delays) radio minima. In the K-band IR, there is a peak followed by a sharp minimum, followed by a recovery. In figure 2, we show the X-ray variability that has been monitored in gorgeous detail by RXTE since 1995. Although RXTE has only recently started observing a second complete period, the X-ray flux from the latest cycle matches very well that of the previous cycle if we impose a 5.5 yr phasing. X-ray observations enjoy a distinct advantage over those made at other wavelengths: hard (i.e. high energy) X-rays easily penetrate the obscuring nebula, and thereby reveal information directly from the central source.

The unusual stability of the 5.5 yr periodicity in the IR led Damineli (1996) to conjecture that it could be related to an orbital period, and in subsequent work the observed low excitation event was associated with periastron passage of a highly eccentric orbit (Damineli *et al.* 1997 – see also figure 3). There it was postulated that Eta Car should show strong wind–wind interaction effects. This violent phenomenon is a central feature of massive star binaries, and occurs when two stellar winds supersonically collide (e.g. Stevens *et al.* 1992 – see also figure 4). A large region of high temperature ( $T$  of order  $10^8$  K) plasma is created at the wind–wind interface and radiates predominantly at X-ray energies. This emission can be analysed to determine the underlying properties of the stellar winds (e.g. their velocities, the mass-loss rates of the stars, etc).

While it is fair to say that at the time of writing the 5.5 yr periodicity is supported by the majority of the astronomical community, the binary hypothesis remains highly controversial. There remains great uncertainty about the orbital and stellar parameters, and not all observations have confirmed this emerging picture (Davidson *et al.* 2000). It remains plausible that the observed variability could be explained by a highly unstable single star. In the following, therefore, the merits and pitfalls of the single and binary models are discussed, as their ability to explain the observational data, particularly the X-ray emission, is examined.

**3: Proposed orbit of the binary system. The position of the companion star relative to the LBV primary is shown. The closest approach of the stars is known as periastron, and they are most widely separated at apastron. Earth is shown to the right, but there is some controversy over the orientation of the system with respect to Earth. (Michael Corcoran, Goddard Space Flight Center.)**



### One star or two?

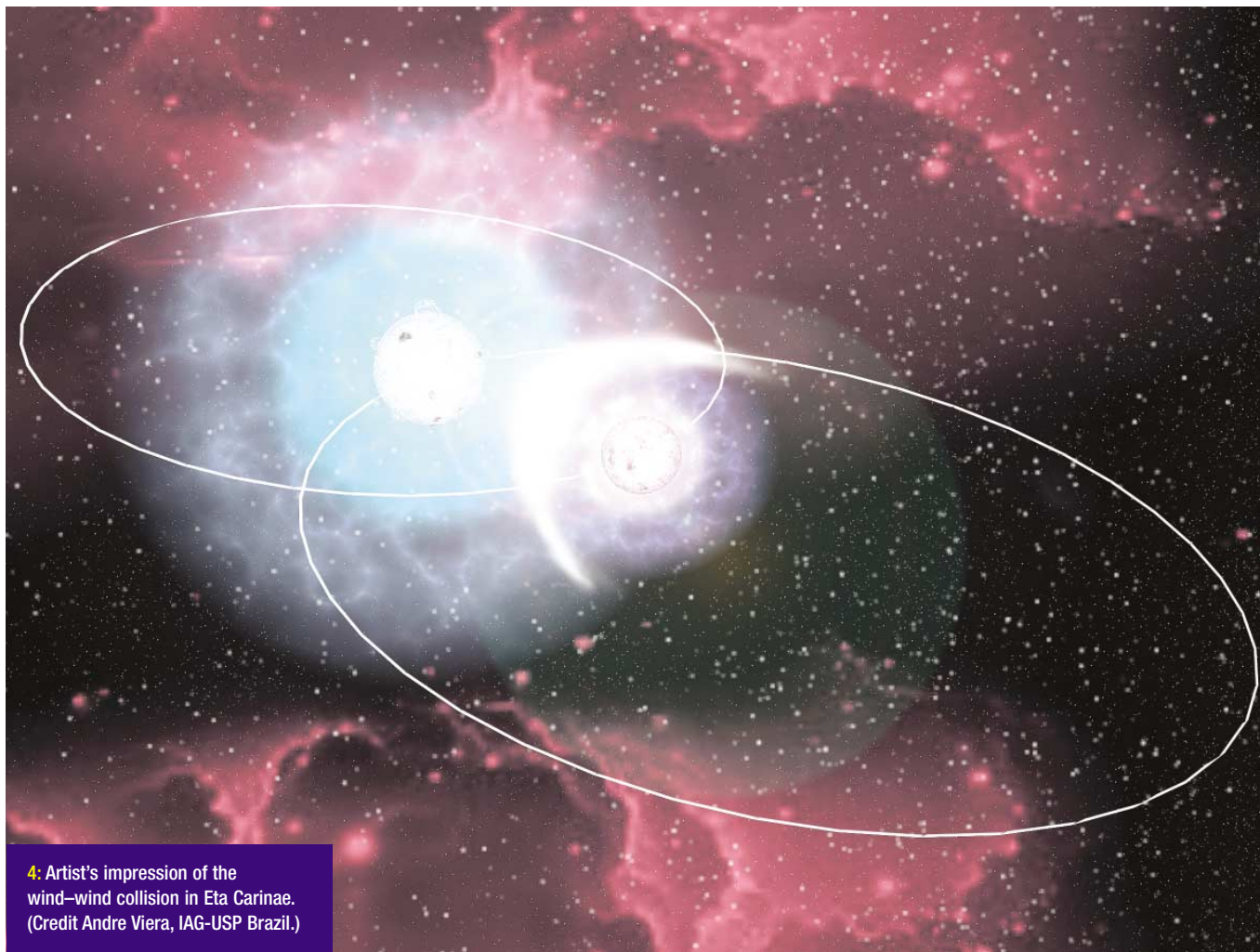
The high-excitation lines and the 3 cm radio emission is believed to arise from equatorial gas surrounding the central object, and in both the single and binary models the observed periodicity is attributed to variation in the ionizing hard-UV flux at this position. In the single-star model it is supposed that this is caused by changes in the intrinsic UV flux as the star varies in both size and temperature (Smith *et al.* 2000). In the binary model it is conjectured that the UV radiation from a hotter companion star is only able to ionise a small, nearby volume when the stars are close together. In contrast, at apastron, the UV ionises a much larger volume (Duncan and White, 2003).

Now consider the observed X-ray emission. In the binary model, the shape of the X-ray lightcurve is explained as follows. If the two stars are in a highly eccentric orbit, they spend most of their time with a wide, and roughly constant, separation, which is reflected by a fairly constant X-ray flux from the wind–wind collision zone. As the stars begin to approach one another, theory predicts that the flux should rise. A steep-sided minimum will occur at the correct phase if the system is viewed such that our line of sight passes through the dense wind of the primary star around the time of the stars’ closest approach (periastron passage). As the stars start to separate, the companion star will once again move in front, the strong absorption will disappear and the flux will recover to its quiescent level. This is a good qualitative description of the data (figure 2), and was predicted ahead of observations (Pittard *et al.* 1998). Quantitative modelling of the lightcurve remains somewhat poorer (e.g. the asymmetry of the minimum), but is expected to improve as more sophisticated models eliminate prior assumptions. In further support of the binary model, the orientation of

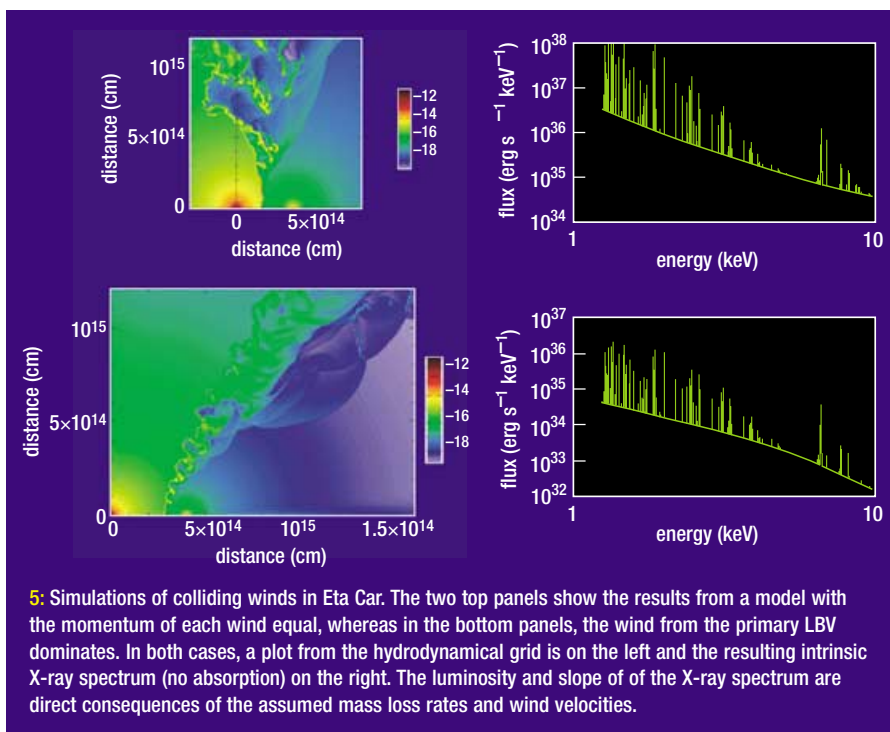
the orbit implied from the X-ray data is in good agreement with most determinations based on line spectroscopy, and X-ray spectra appear to be indicative of colliding winds emission.

Single massive stars are also well known as X-ray sources. In these, it is generally thought that the X-ray emission arises from shocks generated by the unstable nature of their wind acceleration. However, the X-ray emission from Eta Car is observed to be both harder and more luminous than is typical for single stars, and this proves to be highly problematic for the single-star interpretation. One is forced to adopt some process that can generate much higher luminosities and shock temperatures than normally observed, and that can also account for large variations of the X-ray flux. One proposition is that the X-ray emission forms at an unstable boundary layer between a fast polar outflow and a slower equatorial wind, with the variation caused by large-scale changes in the wind structure. While not beyond possibility, a single-star model faces substantially greater difficulties than the binary model in explaining the observed X-ray emission.

To explain the quasi-periodic flaring superimposed on the X-ray lightcurve, both the single and binary models assume that shells of enhanced density form in the wind of the LBV star. In the single-star model it is conjectured that the shells directly produce X-ray variability. In contrast, in some binary models the enhanced X-ray emission is thought to occur when the disturbances encounter the wind–wind collision. Crucially, the flare period is predicted to lengthen after periastron passage due to a “Doppler effect”, whereas in the single-star model the periodicity should remain roughly constant. Unfortunately, interpretation of current data is complicated by variation in the underlying X-ray emission, and it has proved difficult to distinguish between these two



4: Artist's impression of the wind-wind collision in Eta Carinae. (Credit Andre Viera, IAG-USP Brazil.)



5: Simulations of colliding winds in Eta Car. The two top panels show the results from a model with the momentum of each wind equal, whereas in the bottom panels, the wind from the primary LBV dominates. In both cases, a plot from the hydrodynamical grid is on the left and the resulting intrinsic X-ray spectrum (no absorption) on the right. The luminosity and slope of the X-ray spectrum are direct consequences of the assumed mass loss rates and wind velocities.

scenarios. Alternative explanations are also possible – maybe the disturbances are generated in the companion star's wind, or are caused by a stochastic process. Lack of a Doppler effect is, however, neither evidence against the binary

model nor for the single-star model because the flaring process could occur well before the disturbance encounters the wind collision zone.

In conclusion, the current arguments for the binary scenario are more compelling than those

for the single-star interpretation, though not yet conclusive.

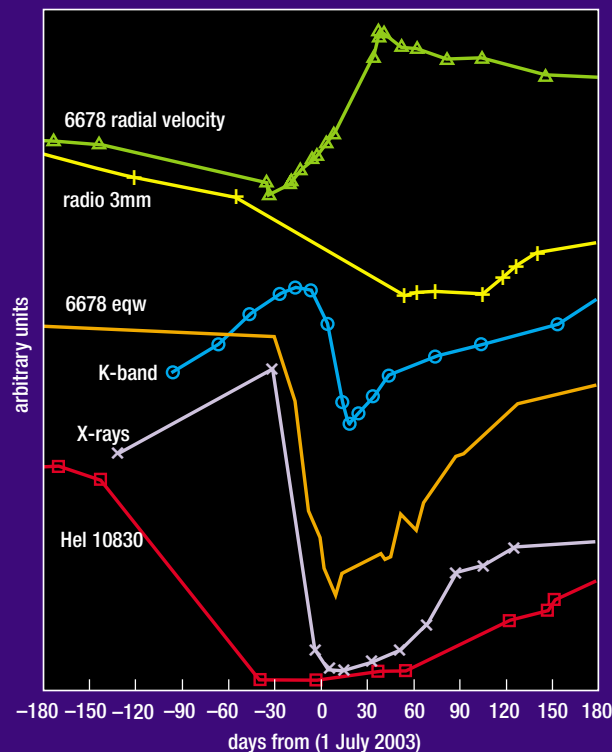
### Measurements of the mass-loss rate

The single star/binary distinction for Eta Car has strong implications for any attempted determination of the rate of mass loss through stellar wind(s). Because this is a crucial parameter for the evolution of massive stars, an appropriate measurement for Eta Car would provide a unique calibration point in the upper H-R diagram.

Analysis of radio and millimetre observations has found  $\dot{M} \sim 10^{-3.5} - 10^{-2.6} M_{\odot} \text{ yr}^{-1}$ . Though based on a single-star model, corrections for binarity are expected to be small. By ordinary stellar standards, these are huge (though trivial compared to the Great Eruption). An alternative method is to compare the strength of emission and absorption features in the IR-UV against theoretical fluxes from a stellar atmosphere and wind model. A recent analysis of an HST spectrum using this technique determined  $\dot{M} \sim 10^{-3} M_{\odot} \text{ yr}^{-1}$  (Hillier *et al.* 2001), in good agreement with the central value inferred from radio/mm observations, though the quality of the fit in certain parts of the spectrum was unsatisfactory.

Two determinations of the mass-loss rate in

**6:** Expected variability during the next event which is predicted to occur in the summer of 2003. From top to bottom, the lines show the radial velocity of the He I 6678 Å line, the 3mm radio flux, the K-band IR flux, the equivalent width of the 6678 Å line, the 2–10 keV X-ray flux and the equivalent width of the He I 10870 Å line. (Augusto Damineli, IAG-USP, Brazil.)



Eta Car have been specifically based on a binary model. In the first such estimate, the X-ray lightcurve was matched against results from analytical expressions of the emission from the wind–wind collision. In a more recent determination, a high resolution X-ray spectrum was compared against theoretical expectations of the emission as calculated from hydrodynamical models of the wind–wind collision (Pittard and Corcoran 2002 – see also figure 5). Both investigations yielded a value of  $\dot{M} \sim 2.5 \times 10^{-4} M_{\odot} \text{yr}^{-1}$  for the LBV star over the majority of the orbit (it is not yet clear whether there is an enhancement in  $\dot{M}$  during periastron passage, although this has been used to explain the changes in the radio lightcurve from period to period and the characteristics of the X-ray emission at minimum). While resolving some problems with the fit to the HST data, these values – four times smaller than typically inferred – may be too low to prevent the nebula becoming fully ionized. They also imply that the companion star will itself have an extremely powerful stellar wind, and a luminosity high enough to be detected in optical spectra.

It is clear that we are currently unable to determine the mass-loss rate to within a factor of approximately 3 either side of a central value of  $\sim 10^{-3} M_{\odot} \text{yr}^{-1}$ . A range of this magnitude is highly significant to the evolution of massive stars during the LBV stage, since it affects the amount of mass lost during “quiescence” as opposed to during large scale eruptions. It will also bear on the interaction of the star with its surroundings. Given the importance of Eta Car as a unique astrophysical laboratory, it is

crucial that its mass-loss rate be more tightly constrained.

## Conclusions

Our understanding of Eta Car has progressed markedly over the last decade and, with new observational discoveries and theoretical developments occurring all the time, its underlying nature is gradually being teased out. We continue to gain a fuller appreciation of the nebula, its possible formation mechanisms, and how these relate to the central star(s). Structure both inside and outside the nebula is slowly being revealed. Our analysis of the central object, while difficult, has also improved substantially. High spatial resolution HST observations have allowed us to peer much deeper into the core of the nebula, and to obtain, for the first time, spectra of the central star(s) largely uncontaminated by the nebula. Recent X-ray data has been just as important in determining the fundamental processes occurring within the heart of Eta Car. It has revealed signatures against which competing models can be tested, and has also proved invaluable in aiding the interpretation of data taken at other wavelengths.

The next “event” is expected during June–July 2003, and will be one of the most anticipated astronomical occurrences. Our current capacity to observe this in just about every important region of the electromagnetic spectrum means that we can probe the nature of this event in a way unprecedented before. A multiwavelength observing campaign has been meticulously planned and includes large ground-based optical, IR and radio programmes, and 72 orbits of

HST time as part of an HST “Treasury” project. In the X-ray waveband Eta Car will be probed by an approved Chandra “Large Project”, six snapshot observations with XMM and, hopefully, daily monitoring with RXTE. At even higher energies, INTEGRAL will attempt to obtain the first gamma-ray detection. In figure 6 we show the variability that we expect to see based on observations from the last event. While these observations will build upon the impressive background of work that currently exists and will provide an excellent opportunity to determine the most fundamental property of this system – whether or not the central object is a single star – it is also clear how transient all of this is. Eventually the Homunculus will dissipate. The periodicity may be fundamental or instead just a strange characteristic of the current evolutionary state. And our ability to obtain UV spectra, and X-ray data with high spatial and temporal resolution is also likely to be short lived. Observations of the next event are therefore urgently awaited. Perhaps we will ultimately find that both camps are to some extent correct: that the observations are best explained by the combination of a violently unstable LBV star around which orbits an almost equally extreme companion. In the meantime there is an exciting voyage of discovery to be made. ●

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