ASTRONOMY

More than an eclipse

The collapse of stellar winds extends the cyclical blackout of the Eta Carinae star

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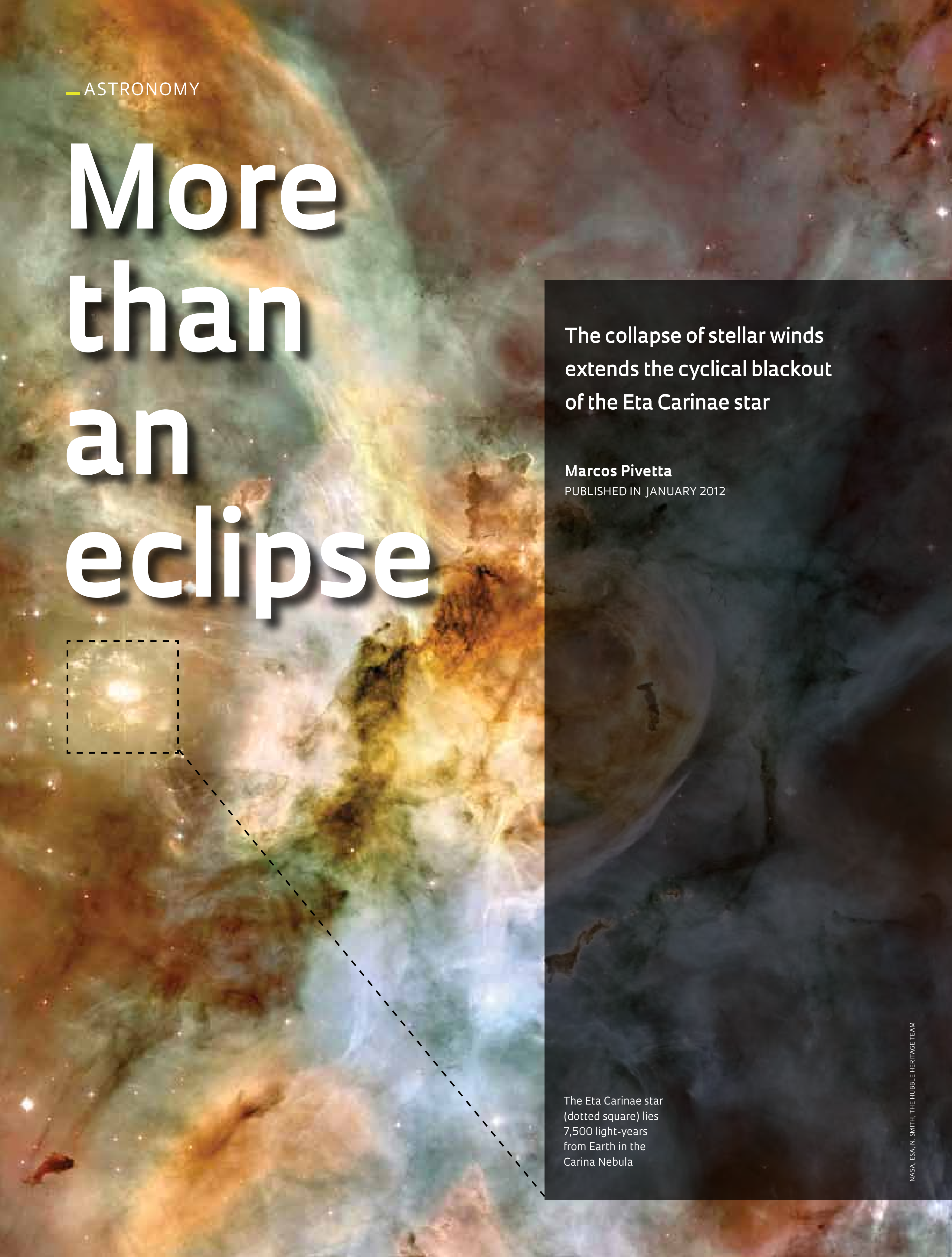


The Eta Carinae star (dotted square) lies 7,500 light-years from Earth in the Carina Nebula

NASA, ESA, N. SMITH, THE HUBBLE HERITAGE TEAM

The brutal nature of the loss of brightness that affects the enigmatic giant star Eta Carinae from time to time may finally have been explained by an international team of astrophysicists led by Brazilians. Every five and a half years, Eta Carinae stops shining for approximately 90 consecutive days in certain bands, particularly the X-ray band, of the electromagnetic spectrum. The researcher Augusto Damineli and the post-PhD researcher Mairan Teodoro, both from the University of São Paulo (USP), analyzed the data recorded by five land-based telescopes in South America during the star's latest blackout, from January to March 2009, and collected evidence that this literally obscure event conceals two different but interwoven phenomena rather than just one, as most astrophysicists had believed up until now.

First, there is a sort of eclipse of the X-ray emissions of this binary system comprising two very large stars: Eta Carinae A, the main and largest star, with approximately 90 times the mass of the Sun, and Eta Carinae B, a star two-thirds smaller and ten times less brilliant than Eta Carinae A. The blocking of the emissions is caused by the passage of the larger star in front of the field of vision of observers on Earth. This phenomenon is fairly well-known and studied, and it lasts no longer than one month. However, how can one explain the other 60 blackout days? The answer, according to Damineli and Teodoro, concerns a second mechanism that extends the loss of the X-ray brightness of the Eta Carinae system.

As soon as the eclipse ends, the two stars are on their way to their periastron, the point when they come closest to each other (a distance of 230 million kilometers). The stellar winds of Eta Carinae A, consisting of a jet of particles that permanently escape from its surface, begin dominating the binary system, confining the stellar winds of the smaller star and pushing them back onto the surface of Eta Carinae B. What happens is something that astrophysicists call a collapse of the collision zone of the winds of the two stars, which, until then, were in a balanced state.

In terms of the emission of light, the collapse of the winds (a theoretical proposition never actually observed until now) has two consequences: extending the duration, sometimes for more than two months, of the lower level of brightness in the X-ray band and giving rise to ultraviolet emissions, which is the primary novel finding of this work. In other words, in the midst of the X-ray blackout, there is a flash of hitherto unreported ultraviolet light. "The two phenomena are entangled and give rise to a complex situation," explains Damineli, who has been studying Eta Carinae for more than two decades. "If they were to occur separately, it would be easier to see them."

The new work of the Brazilians provides a more detailed explanation of the dynamics of the mechanisms that underlie the cyclical, temporary reduction in brightness of Eta Carinae, the most heavily studied Milky Way star after the Sun and one of the largest and most luminous stars known. The first month of the habitual 90-day X-ray blackout can be attributed to the eclipse, and the following two months can be attributed to the stellar wind collapse mechanism. However, although the evidence points to this, explaining the blackout is not quite so simple.

Although the blackout has a starting date, it does not seem to have a particular end date. For example, the last blackout began on January 11, 2009, as expected, but only lasted for 60 days, one month less than expected. "Two blackouts are not necessarily alike," states Teodoro. "The eclipse seems to last for approximately 30 days, but the stellar wind collapse process seems to last for a variable amount of time." It seems that the stellar wind collapse process can last from 30 to 60 days.

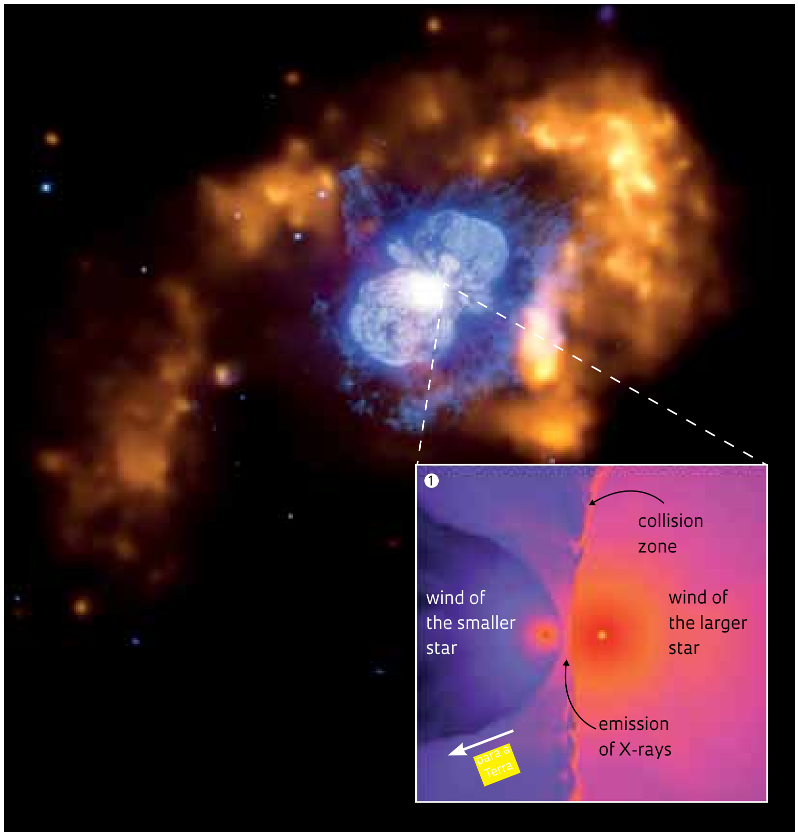
This complex set of circumstances was described in detail in an article accepted for publication by the *Astrophysical Journal* (*ApJ*). Aside from Damineli and Teodoro, who are the study's main authors, there are 24 other researchers from Brazil, South America, Europe, the United States and Australia who were part of the study. Data from the Soar astrophysics research observatory in Cerro Pachon in the Chilean Andes (which is an initiative in which Brazil has a stake and which contains one of the most powerful telescopes employed in this study) were fundamental for obtaining clues of the phenomena involved in the Eta Carinae blackouts. Damineli is the coordinator of a thematic FAPESP project involving the installation of a high-resolution spectrograph, Steles, in Soar.

DYING, EXPLOSIVE AND MARRIED

Eta Carinae, one of the Milky Way's most fascinating celestial bodies, lies 7,500 light-years from Earth in the southern constellation of Carina, to the right of the Southern Cross. According to the classification by astrophysicists, it is ranked as a supergiant star of an extremely rare class of blue luminous variable stars, which currently has only a few tens of members but which must have been common in the early days of the Universe. It is a colossal and distant object that cannot be seen with the naked eye, although a trained observer equipped with good binoculars can find it on winter or autumn nights. The diameter of the system's main star is equal to the distance between the Earth and the Sun. Its brightness is even more impressive and is approximately 5 million times greater than that of the Sun. When it goes through its cyclical blackout every five and a half years, Eta Carinae stops emitting energy equivalent to 20 thousand Suns in the X-ray, ultraviolet and radio spectra.

Eta Carinae has other uncommon features that make it even more unique. At only 2.5 million years old, or approximately 1,800 times younger than our Sun, it is already a dying and potentially explosive celestial body. It should literally blow up, turning into a hypernova, at any time between now and a few thousand years in the future. "Its death should produce an explosion of gamma rays, the most energy-rich type of event in the Universe," states Damineli. A mere 170 years ago, the megastar apparently entered a terminal and turbulent stage at the peak of its decadence. Since 1840, it has been undergoing major eruptions in which it loses matter in amounts of the order of tens of solar masses, while its brightness temporarily increases. In 1843, Eta Carinae became visible to the naked eye during the day for months and was almost as bright as Sirius, which is the brightest star in the night sky and is at most 30 light-years from Earth.

At that time, as a result of the eruption, the megastar acquired a trait that further complicates its observation. The star became surrounded by a dense cloud of gas and dust, which was named Homunculus, in the shape of two lobules. "Eta Carinae is a particularly



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90 SUNS are required to equal the mass of Eta Carinae

3 MONTHS is the maximum time of the star's reduced brilliance

difficult object to study," comments astrophysicist Ross Parkin, who is from the Australian National University and is a specialist in the creation of computer models that attempt to reproduce the interaction of the stellar winds of binary systems. He is also a coauthor of the article published in *ApJ* (one of his simulations was employed in the work of the Brazilians). "It's complicated to see it, because it is immersed in this massive envelope of dust."

Damineli's name is tied to the story of this mysterious celestial object. Going against the opinion of many people, he was the first to advocate almost 20 years ago that Eta Carinae was a two-star system rather than a single star and that this duo underwent occasional blackouts. "Eta Carinae was not only fat, it was also married," says the professor from IAG, USP's Institute of Astronomy, Geophysics and Atmospheric Science, who has a talent for coining statements that are as funny as they are informative. "I fully credit these discoveries to Damineli, who was the first person to realize this," says the veteran researcher Theodore Gull from NASA's Goddard Space Flight Center.

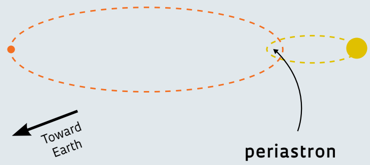
The unexpected ultraviolet brightness in the midst of the blackout of X-rays in 2009 was indirectly identified by the Brazilians by means of the recording of a weak emission on a spectral line of ionized helium gas, HeII4686 A.

The dynamics of the blackout

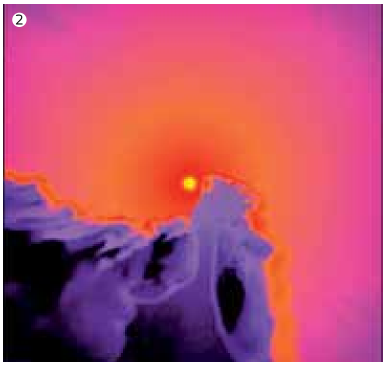
Eta Carinae is a two-star system within a gas and dust cloud (left). The stellar wind collision zone produces X-ray emissions (fig. 1). Every 5.5 years, when the stars reach the closest point of their orbits (periastron), the emissions cease to be visible (fig. 2). The larger star passes in front of the field of vision of observers on Earth, causing an eclipse. The proximity of the two stars causes the wind of Eta Carinae A to engulf and push back the wind of the smaller star (fig. 3). This phenomenon prolongs the X-ray blackout and causes ultraviolet emission.

The orbit of the star duo

The largest star, Eta Carinae A, has a mass equal to that of ninety Suns, whereas the mass of the smallest star, Eta Carinae B, equals thirty Suns.



SOURCE MAIRAN TEODORO



IMAGES: 1, 2 AND 3: ROSS PARKIN

Positive values on this line are a form of a spectral signature indicating that there is a source of ultraviolet rays in the observed location. "The sign of ionized helium that we saw during the 2009 blackout is only 20% greater than the limit of what telescopes can measure," says Damineli, "but it is equivalent to the brightness of ten thousand suns in the ultraviolet extreme." Capturing the signal was also made easier by the Eta Carinae "siege" that Teodoro coordinated two years ago, when five telescopes observed the star at different points in time. All of these data explain this explains why the scientific community, which also monitored the three preceding blackouts (in 1992, 1997 and 2003), did not report emissions in this spectral line.

The best explanation as to why there is an ultraviolet burst during X-ray blackouts is that there is a decrease in the stellar winds of Eta Carinae that fall back onto its smaller sister. "I think that there is very good evidence to indicate that this occurs for a short time during the periastron," states the American astrophysicist Michael Corcoran, one of the co-authors of the work, from the Goddard Space Flight Center. His colleague, Nathan Smith, from the University of Arizona and another researcher who studies this star, has a similar opinion. "The authors of the study did very careful work and measured the line of emission of ionized helium consistently," says Smith, who was not involved in the *ApJ* article. "Their analysis really does seem to support the conclusion that the zone of the collision of the winds falls temporarily onto the secondary star."

Understanding the interactions between the stellar winds of the two Eta Carinae stars seems to be essential to unravel the phenomenon involved in the blackout. It is an uneven tug-of-war between two rather different contenders. Also emitted from the Sun, the stellar wind is a mechanism whereby mass is lost through a jet of particles that generally have an electrical charge, such as the protons and electrons released by an ionized gas. Through this mechanism, the larger Eta Carinae star releases in just one day an amount of mass equivalent to that of Earth. Its wind is quite dense and travels at 600 kilometers a second in space. "It is five times slower than the wind of the secondary star, which is more rarified," explains Teodoro.

Most of the time, the winds of the two Eta Carinae stars are balanced. They meet at a point between the two stars, and this collision produces shock waves that result in the emission of X-rays. These are the emissions that cannot be detected from Earth during the blackouts. When the two stars get too close to each other, the power play between them clearly favors the larger star. The wind of Eta Carinae A, which behaves like a wall against the particle jet of the smaller star, causes the wind of Eta Carinae B to be reflected back to the smaller star. This is the so-called collapse of the stellar wind collision region, the phenomenon that leads to a fleeting emission of ultraviolet radiation in the midst of an X-ray blackout.

According to data from the German astrophysicist Andrea Mehner, from ESO (European Southern Observatory) in Chile, the star's wind has become more rarified in the last 10 years, and its density has decreased by one-third. However, Damineli's observations do not corroborate this interpretation. According to him, the density of the wind of the main Eta Carinae star has not fluctuated much in the last decade. A good opportunity to gather further information regarding this polemic issue will occur during the upcoming blackout of the star, which should begin in July 2014, when many telescopes will turn their mirrors toward this giant celestial body. ■

THE PROJECT

Steles: high-resolution spectrograph for Soar - nº 2007/02933-3

MODALITY
Thematic Project

COORDINATOR
Augusto Damineli – IAG/USP

INVESTMENT
R$ 1,373,456.33 (FAPESP)

Scientific article

TEODORO, M. *et al.* He II 4686 in Eta Carinae: collapse of the wind-wind collision region during periastron passage. ***The Astrophysical Journal.*** Forthcoming.