highly complex, each cell-surface molecule that is involved in guiding axons to their appropriate targets probably serves multiple such functions in different circuits, depending on the cellular and developmental context. It will be crucial to account for each molecule's context-dependent roles during the assembly of diverse neuronal circuits.

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Astronomy

Great Dimming of Betelgeuse explained

Emily M. Levesque

Observations suggest that an unexpected dimming of the massive star Betelgeuse resulted from dust forming over a cold patch in the star's southern hemisphere. This finding improves our understanding of such massive stars. **See p.365**

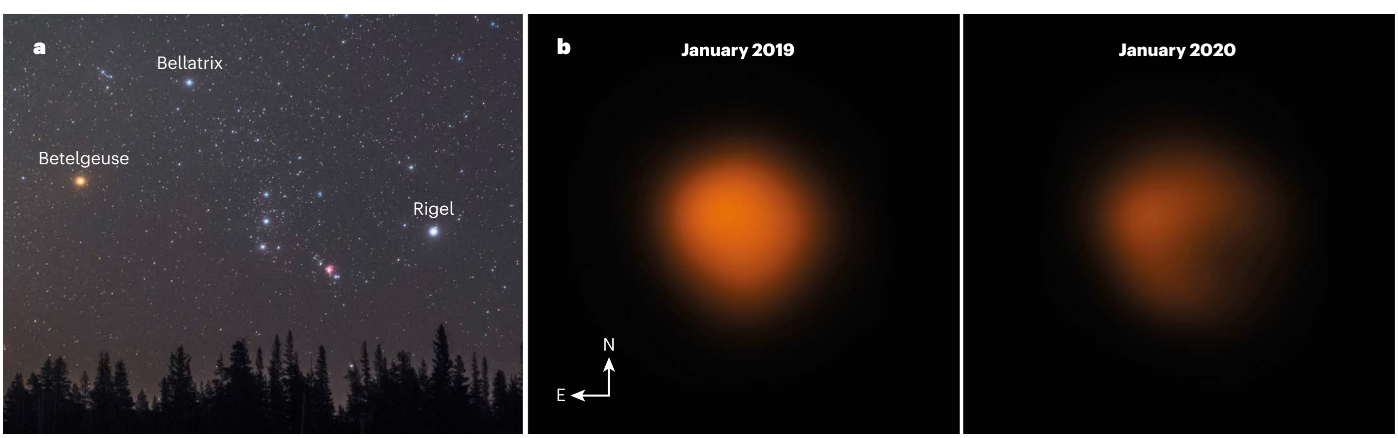
In December 2019, astronomers reported[1] a surprising change in the appearance of Betelgeuse. The bright red star in the shoulder of the Orion constellation had begun dimming dramatically during the preceding two months. In the following weeks, Betelgeuse's rapid and unprecedented dimming continued. By mid-February 2020, the star had plummeted to about 35% of its typical brightness[2] before swiftly recovering over the next few months. The event captivated professional and amateur stargazers alike because such rapid and visible changes in the night sky are rare. Now, a year after Betelgeuse's recovery from what has become known as its Great Dimming, Montargès *et al.*[3] (page 365) present a detailed picture of and compelling explanation for this strange behaviour.

Betelgeuse was born with about 20 times the mass of the Sun[4]. Such massive stars evolve much faster than their lower-mass counterparts, with lifetimes of mere millions rather than billions of years. Betelgeuse is a red supergiant — a stage in the evolution of massive stars that begins when these stars transition from fusing hydrogen in their cores to fusing helium; this leads to the cooling and expansion of their outer layers. The cores then spend several million years fusing progressively heavier elements before collapsing. These dying stars produce the spectacular fireworks show of a supernova, leaving behind neutron stars or black holes, and enriching their surroundings as they hurl the elements made in their interiors into interstellar space.

Red supergiants represent an extreme stage of stellar evolution. They are the largest stars in the Universe — for instance, Betelgeuse has a radius 900 times that of the Sun[4], and if it were placed at the centre of the Solar System, it would swallow all 4 inner planets and nearly reach the orbit of Jupiter. The huge cold outer layers of red supergiants pulsate, and host a handful of enormous convective cells (volumes of material that move as a result of convection). Furthermore, these outer layers shed mass that can eventually form dust in the star's surrounding environment.

Modelling the outer layers of red supergiants is extremely challenging, because the mechanisms driving mass loss and dust production are complex, and the effects of these various quirks on the star's brightness, evolution and eventual death are far from clear. Nevertheless, efforts to better understand red supergiants are worth the trouble because these stars are key players in the cycle of stellar birth and death and in the chemical evolution of the cosmos.

Betelgeuse's Great Dimming was evident with the naked eye, but the observations presented by Montargès *et al.* reveal the full details of the star's sudden change in appearance. Betelgeuse's large size and close proximity to Earth (about 220 parsecs, or 724 light years[5]) make it one of only a few stars that can be seen as a spatially resolved disk rather



A. BABAK TAFRESHI/SPL

Figure 1 | Location and observations of Betelgeuse. a, Normally, Betelgeuse is the brightest star in the Orion constellation; Rigel is the second brightest and Bellatrix the third brightest. **b**, Montargès *et al.*[3] observed Betelgeuse before (January 2019) and during (January 2020) a period known as the Great Dimming, in which the star was comparable in brightness to Bellatrix. The observations show that the light loss was concentrated in Betelgeuse's southern hemisphere. A detailed analysis by the authors suggests that a southern dust cloud temporarily blocked much of the star's light.

than a single point. Using instruments on the European Southern Observatory's Very Large Telescope in Chile, Montargès and colleagues captured pictures of Betelgeuse both before and during the Great Dimming. A comparison of these images shows that the star hadn't simply shrunk or dimmed uniformly. Instead, the light loss was concentrated in the star's southern hemisphere (Fig. 1).

Could the dimming be explained by a short-lived cold patch on Betelgeuse's southern surface, produced by the churn of enormous convective cells? Or might a clump of dust be blocking our view of the star, making it temporarily seem dimmer? Some early observations concluded that the dimming was probably caused by dust, and that this dust had been made by Betelgeuse itself[6,7]. However, other work presented evidence of temperature changes in the star's atmosphere, and suggested that cooling might also have played a part in the dimming[8,9]. Montargès *et al.* addressed this uncertainty by modelling both scenarios and comparing the models with their images. They conclude that, although dust was the ultimate culprit, the two scenarios are not at odds but are linked.

Observations show evidence of a mass-loss episode that began nearly a year before the Great Dimming[7,10], releasing a clump of gas. Montargès and colleagues suggest that, in late 2019, a combination of normal pulsation behaviour and a convection-driven cold patch in the star's southern hemisphere began to cool the local environment. The drop in temperature allowed the recently shed gas in that region to rapidly form dust. This process generated a dense southern dust cloud that temporarily blocked much of Betelgeuse's light, giving us what we saw as the Great Dimming.

What does this mean for Betelgeuse? Its behaviour in late 2019 made headlines, in part because of the tantalizing prospect that the dimming might be a sign of the star's imminent demise. Betelgeuse is an irresistible target on which to pin hopes of seeing a supernova happen in our own Galaxy. Such events are incredibly rare, with the most recent observation of a Milky Way supernova pre-dating the invention of the telescope. However, Montargès *et al.* make clear that the Great Dimming does not indicate any sign of an impending supernova. Importantly, they also note that Betelgeuse might not give us much warning – astronomers currently cannot predict, at least on any realistic human timescale, when a star will die.

The lack of an explosive conclusion might seem disappointing, but Montargès and colleagues' results go beyond explaining one brief wink of a nearby star. Could other red supergiants show signs of their own Great Dimmings? Next-generation facilities focused on monitoring stellar brightness over time, or on studying the signatures of dust in the infrared spectra of stars, could prove invaluable for expanding the lessons learnt here. This exquisitely detailed study of Betelgeuse's unexpected behaviour lays the groundwork for unravelling the properties of an entire population of stars.

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