The curious case of Betelgeuse

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Betelgeuse is the nearest red supergiant, one of the brightest stars in our sky, and statistically speaking it would be expected to be “typical”. Yet it exhibits many features that seem “curious”, to say the least. For instance it has a high proper motion. It rotates fast. It has little dust. It dimmed unexpectedly. Is any of these, and other, phenomena atypical, and taken together does it make Betelgeuse atypical? This is important to know, because we need to know whether Betelgeuse might be a prototype of red supergiants in general, or certain subclasses of red supergiants, since we can study it in such great detail. It is also important to know as it may be a link to understanding other, apparently atypical cases such as supernova 1987A, and maybe even such exotica as Thorne-Zytkov objects. Studying this question in itself helps us understand how we deal with rarity and coincidence in understanding the Universe we live in.

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1. Prologue

Not far in the sky from the most famous supernova remnant, the Crab Nebula, the most famous red supergiant, Betelgeuse, has been a familiar sight for peoples in either hemisphere. Distinctively orange, and one of the brightest lights on the nightly celestial firmament, its prominent position in the corner of arguably the most iconic constellation, Orion, Betelgeuse commands our attention and this in itself makes it special. This perspective aims to challenge the uniqueness and surprising behaviour of many a favourite star, and what it tells us about us. It could be seen as a more philosophical sequel to the Paris 2012 workshop on Betelgeuse.

2. Is Betelgeuse typical?

It’s got to be, right? Surely, as the nearest example of a red supergiant, Betelgeuse must be ordinary? This is because the chances are favourable for a draw of one from among many to be drawn from the most common.

While this may often be true, and hence unremarkable and thus unnoticed, it is not always the case, as is expected when considering many draws from samples that do include rare examples. (The basis for many false associations, let alone causal relationships.) For instance, the first supernova witnessed by naked eye for three centuries, and the best studied, supernova 1987A wasn’t! It had been expected to have been a star like Betelgeuse to have exploded, and yet it was all but. (Though
they may have much more in common than at first sight.)

We are not placed in a typical red supergiant environment. While within a Bubble created by multiple supernovæ, we are not currently situated in a spiral arm. So perhaps Betelgeuse is typical for this particular environment, but not necessarily for red supergiants that are largely found in the denser, more actively star-forming regions of a spiral galaxy such as the spectacular H II regions in the prominent spiral arms several times more distant, or the even more distant massive clusters near the Galactic Centre.

But all things considered, Betelgeuse does not stand out in either luminosity, temperature, mass-loss rate or dust content – in fact it looks like a fairly commonly identified SN II-P progenitor! (But this may partly be a selection bias of the progenitor identification strategies.)

3. Is Betelgeuse atypical?

Just like most people look similar – four limbs, a head with a pair of eyes and ears and a nose upfront – when inspected more closely individual traits set us apart. This doesn’t make each specimen a species, and in the end, we have much more in common than differentiates us, both in terms of the way we look and the way we behave.

Among Betelgeuse’s perplexities count its location at some distance from sites of recent star formation, its large space motion, and a picture-perfect bow shock. Upon close inspection, it spins at a baffling rate and also is super-nitrogenous.

And then came the ‘Great Dimming’. (Which may have nothing or all to do with the above.) A drop in brightness by half relegated Betelgeuse to the realm of much more inconspicuous stars, but sent alarm bells ringing with fears – or excitement – for its imminent luminous demise.

But none have been scrutinised as much as Betelgeuse. Brief late phases of under-represented stars at birth, red supergiants themselves are rare, so few are seen up as close as Betelgeuse. It is not how well we know Betelgeuse, but how poorly we know the other red supergiants that defines its curiousness.

4. Our one-sided view of Betelgeuse

Because of the attention it has recently received, we shall first unpick how rare is Betelgeuse’s Great Dimming, before we return to its full portfolio of properties.

By our very own nature as observers and thinking minds, and our position in the Universe, we suffer from anthropocentric bias: just because we didn’t see it before, or elsewhere, doesn’t make it rare per se. The 20th-century artist Pablo Picasso exposed this imperfect picture by recovering what is hidden from view in a form referred to as “cubism”. But how do we do that in reality? Do we know it? Do we infer it? Or do we ignore it? If you look out into a field and see what looks like a black lamb, what do you conclude? That:
• lambs are black?
• lambs exist that are black?
• lambs exist of which at least one side is black?
• apparitions exist that look like lambs of which at least one side is black?

Despite well-known examples of non-isotropy in astronomy (cf. exoplanet transits, γ-ray bursts, pulsars) it is too often overlooked.

Betelgeuse forms dust clouds episodically, as convection cells cause dark spots that induce cooler circumstellar conditions where dust can form, likely in an already cooler parcel of lifted gas. In the case of Betelgeuse this is exacerbated because Betelgeuse is on the cusp between a warm chromosphere and dusty wind. Counting the number of dust clouds and considering their projected distances from Betelgeuse, a dust cloud forms about once every five years!

Imagine Betelgeuse were cubic and we only faced one side at a time (compare a standard die), then we’d only see one in every six events randomly happening on one of its sides. (In reality the polar and equatorial regions may display different behaviour especially in the case of a rapidly spinning Betelgeuse.) This means we may have had a Great Dimming on our side once every few decades (cf. the visual lightcurve), but we certainly missed Great Dimmings happening on another side!

It is tempting to expect a dust cloud to form at every minimum in the ~2000 day cycle. But that depends on whether this periodicity represents radial pulsation (in which case it is true) or convectional modulation – in which case the five-yearly cloud would always be in front, though other clouds would be forming more frequently throughout, above cool convection cells not seen by us, hence being in tension with observational evidence. It is more likely that a dust cloud forms at a pulsational minimum but only above a cool convection cell (the latter causing the ~400-day cycle, but again that’s our biased perspective, there could be a cool convection cell somewhere on the surface at all times). In fact, forming at some height above the surface, such dust cloud is less likely to be seen directly in front of the star than the convection cell is – at one stellar radius above the surface this chance is already diminished by a factor four. (Note that even the cloud purported to have caused the Great Dimming did not cover the entire face of Betelgeuse.) The Great Dimming might have been our treat, but bread and butter for Betelgeuse.

Previous dimmings have been disputed, but it is not outrageous if of a few expected chance occurrences (as opposed to predicted events) just one has materialised. A century is not a very long time span in the life of a star, even that of a red supergiant (one pro mille!), and Betelgeuse may have exhibited many more dimmings, and may exhibit many more to come. Our Sun has arguably been more dramatic, as we know it so well: the sunspot cycle is a fairly regular rhythm of activity, but we are still astounded by the Maunder Minimum of the late-17th and early-18th centuries – what if the telescope had only been invented a century later? (We would never have known.)
5. How common are anomalies?

If Betelgeuse ought to be common for being the nearest red supergiant, then so should be Antares for being only the second-nearest red supergiant. But as we argued, this is not a given. It would be much less likely, though, if both Betelgeuse and Antares were special. This then begs the question: is Betelgeuse different from Antares?

Antares has similar luminosity, temperature, convection\textsuperscript{13}, mass loss, (low) dust content and lightcurve (with similar dimmings). Like Betelgeuse, it produces discrete dust clouds\textsuperscript{14,15}. But Antares is a slow rotator and is accompanied by a hot star (on a sufficiently wide orbit not to be directly affected by it). How different does that make them?

Imagine stars are characterised by five features, that each have a 1:10 chance of being anomalous (imagine a ten-sided die). Then 1:2 stars are expected to be anomalous. Every other star. So a star is just as likely to be common as it is to be anomalous, despite the majority of stars to be common in any given feature. It should not come as a surprise if both Betelgeuse and Antares had some properties that are rare among the general population of red supergiants. This is what makes individual people distinctive.

Imagine another scenario, where a penguin among other penguins in a colony is distinguished by:

• the colour of its coat: blue (as opposed to brown).
• the texture of its coat: smooth (as opposed to fluffy).
• the colour of its cheeks: yellow.
• the colour of the underbill: orange.

Does that make this individual penguin anomalous in four ways? Most definitely not! It is anomalous in just one way: being an adult (surrounded by infants)!

Fig. 1. Betelgeuse has various characteristics which have been treated as peculiarities. Irrespective of whether these are indeed oddities at all, they can be reduced to fewer characteristics – possibly just one – for which there may well be a totally reasonable – if not banal – explanation.
Returning to the curious case of Betelgeuse, its isolated location, high speed and bow shock are all related, and so may be its fast rotation and nitrogen enrichment – both can be reconciled into one: binary interaction (Fig. 1). And a common one at that: 10–40 per cent of massive stars will be affected by a companion.

Then which is more special: Betelgeuse or Antares? Neither – both cases are expected equally: the result of binary interaction (Betelgeuse) and multiple but unaffected (Antares). The nearby Universe thus seems to be living up to expectations remarkably well!

6. How to find out how common is Betelgeuse?

Moving onwards, if we want to find out what red supergiants typically look like, how they generally evolve, and how and why some may deviate from the norm, we will not succeed in this by studying Betelgeuse harder and longer, but by statistical studies of samples of other red supergiants, such as:

- lightcurve studies based on sparse and/or time-limited data but for large samples in nearby galaxies (‘Great Dimmings’ may be seen in other galaxies, too),
- nitrogen abundance measurements and their link with rotation,
- radial velocity monitoring and spectral energy distributions, to determine binary fractions,
- three-dimensional space motion studies in conjunction with rejuvenation scenarios, to determine past binary interactions,
- interferometric size measurements in relation to the location on the Hertzsprung–Russell Diagram, and mass (loss) measurements from seismology.

Fig. 2. What draws your eye? The white canvas that occupies most of what you’re looking at? Or the black dot offset from the centre, which only covers a tiny fraction of your view? We are drawn to the exceptional, not the norm.
7. Epilogue

The take-away message from this discussion is that when making inferences we need to account for biases. We tend to look for the distinctive, not the common. For instance, when we look at a white panel with a black dot (Fig. 2) our attention is drawn to the dot even though it occupies much less space than the rest of the canvass. Just as we occupy ourselves with the few per cent of baryonic Universe, preferentially in its condensed forms, leaving the vastness of space largely neglected. If we saw less of the canvass, we might have missed the black dot altogether, but if we saw more we might find out black dots to be rather common!

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