News & views

Astronomy

Interstellar shocks unveil material around new stars

Joel Green

Astronomers have obtained spectacular images of an interstellar jet launched from a newly forming star. Careful comparison with archival data offers a fresh take on the chemistry of the environment that surrounds it. **See p.48**

The birth of stars can give rise to the most beautiful space images. And with unprecedented resolution and sensitivity, the James Webb Space Telescope (JWST) produces infrared images of these events unlike any seen before. Far from being just pretty pictures, these images can reveal information about the material that is expelled from a protostar in more minute detail than images from other instruments can. On page 48, Ray *et al.*[1] demonstrate how they trained the telescope on one such sight – a large and powerful interstellar jet known as Herbig-Haro 211, which is ejected at high speed from a spinning protostar in the Perseus cloud complex, a giant collection of molecular gas and dust just 321 parsecs from Earth[2].

By studying jets such as Herbig-Haro 211, astronomers hope to understand how cold, diffuse gas and dust is transformed into new stars. Understanding this process for stars in the Milky Way could potentially inform us about star formation in other galaxies. One approach to investigating these jets involves examining the way they alter their surroundings as they blaze a trail through the Universe.

Ray and colleagues' data suggest that Herbig-Haro 211 has already travelled a considerable distance through the Perseus cloud, at least hundreds of times farther than the breadth of our own planetary system. This means that the jet has already crashed into a lot of material along the way, leaving interstellar shocks in its wake (Fig. 1). But the gases that the authors observed in the jet indicate that it is travelling at the relatively slow speed of tens of kilometres per second, so the shocks don't actually destroy the surrounding material on a molecular scale. Instead, these shocks shape the molecular cloud and the star-forming medium – and JWST is the ideal instrument to measure these effects.

But before this telescope revolutionized research in astronomy, there was another instrument capable of astrophotography just as beautiful as that produced by JWST. NASA's infrared Spitzer Space Telescope operated from 2003 to 2020, and was, in many ways, JWST's predecessor (see go.nature.com/3cmzkaa). During its lifetime, Spitzer provided the highest spatial resolution of any space telescope at infrared wavelengths (or colours). However, its colour palette put limits on the information (and astrophotography) that the telescope could acquire.

To convey the images of star-forming regions captured by Spitzer, astronomers recoloured infrared wavelengths as blue, green and red, assigned in order of wavelength. The shortest wavelength observed by Spitzer was 3.6 micrometres, which mainly captured non-dusty objects, such as stars, so these were generally coloured blue. Dusty material was coloured red because it was detected with the longest-wavelength channels of 8.0 μm and 24 μm. Most hot gas was coloured green, coming in at 4.5 μm.

The relatively limited blending between the channels created striking scenes, but made it difficult to attribute a colour to a specific molecule or crystalline feature. Resolution is not only important in the spatial pixels of

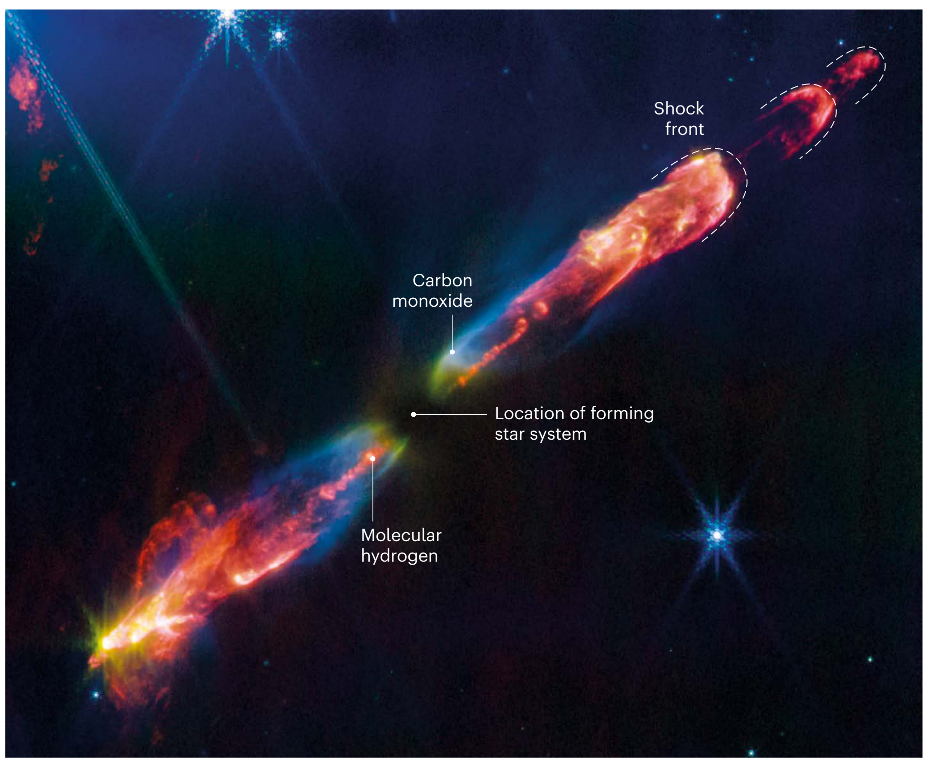

Figure 1 | An interstellar jet from a young star. Ray *et al.*[1] used one of the James Webb Space Telescope's infrared instruments to study gases surrounding a jet known as Herbig-Haro 211, which is ejected from a newly forming star. Different infrared wavelengths of light reveal information about specific types of molecule and dust particle, and these allowed the authors to determine the regions of Herbig-Haro 211 from which carbon monoxide (blue) and molecular hydrogen (red) emanate. This information, in turn, reveals the details of shocks that the jet generates as it crashes into interstellar material, bettering our understanding of how stars form. (Adapted from Fig. 1 of ref. 1.)

an image, but also in distinguishing different frequencies, which requires a richer infrared colour palette than the seven broad channels that Spitzer was able to offer.

JWST has solved this problem by offering high-resolution, multi-channel imaging, the power of which is on full display in Ray and colleagues' work. The authors used two channels with narrow and medium bandwidths that partially overlap, and attempted to isolate the source of light that Spitzer had previously observed at 4.5 µm. The nebulous appearance of the Spitzer signals in this range earned them the name of the green fuzzies. On the basis of their frequency, the signals were assumed to be closely identified with outflows from young stars[3], which were expected to contain either molecular hydrogen (H_2), carbon monoxide (CO) or both gases — showing up at roughly these wavelengths.

Ray *et al*. found emission associated with both carbon monoxide and molecular hydrogen in the 4.5–5 µm wavelength range — a close match to the green fuzzies captured by Spitzer. The researchers then compared the spatial distribution of the calibrated JWST data with that of the Spitzer data and found a striking similarity between the two. This provides a compelling argument that the green fuzzies do indeed correspond to CO and H_2 emission, and one that required only the information provided by JWST's infrared images, rather than any complicated modelling.

Astronomers often attribute the green emission to molecular hydrogen[4], scattered light or both[5], and this assumption has even been used to calibrate models (see, for example, ref. 3). But Ray *et al*. 'subtracted' H_2 from their CO data, and in doing so, produced an image that is particularly intriguing, because it offers a glimpse into the differences between jet and outflow emission. CO and H_2 are produced under different conditions, and separating the two is a crucial diagnostic in the modelling of interstellar shocks.

The JWST image (Fig. 1) suggests that CO emanates mostly from the inner regions of Herbig-Haro 211 and the very edges of the shock fronts, whereas the H_2 comes from the central column and the full breadth of nearly all the arcs that form the backbone of the outflow. It is therefore clear that H_2 can survive some shocks that destroy CO molecules. But the fact that CO can still be seen on the edges of the shocks implies that both gases contribute to the green fuzzies, challenging the assumption that the Spitzer signals are dominated by H_2 emission[3]. Alternatively, it could turn out that there is something special about the particular region around Herbig-Haro 211, or about the local area around outflows in general. Indeed, shocks that can destroy molecules have been seen in other protostellar outflow systems[6–8].

Other sources must be checked in a similar fashion to establish a rule of thumb. Ray and colleagues' results are certainly striking, but they are not without controversy. Careful modelling and analysis will be required before their conclusions can be applied more broadly to other young stars in our Galaxy. Once the true ratio of the two molecules is known, it can be used to calibrate the entire Spitzer data set, which is currently much larger than that of the young JWST.

Fundamentally, the great value of this comparison between JWST and Spitzer data results from the legacy of the earlier telescope; if such an interpretation can be applied broadly, then it enhances the analysis of all green fuzzies in the Spitzer archives. The value of legacy data cannot be understated. Spitzer's archival data set is not the only archival data set that can be used for comparison with a next-generation observatory. Many of the early discoveries from JWST have or will come about through comparison with other infrared space telescopes, such as NASA's Hubble Space Telescope, as well as ground-based facilities.

Indeed, when Ray and colleagues compared one of their images with one taken in 2002 by the European Southern Observatory's Very Large Telescope[9], the researchers found that the shock fronts had shifted significantly outward, travelling at speeds of around 100 km per second. Their interpretation is that the shocked regions are not actually moving this fast, but that successive portions of the cloud are lighting up as the jet passes underneath, like a string of festive light bulbs illuminating in rapid sequence. If the shocked regions themselves were moving at such incredible speeds, their molecules would be ripped apart, but this not consistent with the authors' observations.

Such revelations demonstrate the power of comparison over long timescales — as well as the fact that astrophotography need not be merely beautiful. Archival images will continue to have a key role in revealing the secrets of star formation while instruments become ever more advanced, as Ray and colleagues' intriguing study shows.

Joel Green is at the Space Telescope Science Institute, Baltimore, Maryland 21218, USA.
e-mail: jgreen@stsci.edu

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Archaeology

Hominins built with wood 476,000 years ago

Annemieke Milks

Understanding the timeline of technological developments sheds light on early societies. A remarkable finding in Africa of a structure made from shaped wood provides clues about our hominin relatives. **See p.107**

The archaeological record is biased against the preservation of organic materials. For no period is this more true than for the Pleistocene epoch, spanning roughly 2.6 million to 11,600 ago. This period provides only isolated examples of early evidence of hominin ancestors using wood or other plant materials. On page 107, Barham *et al*.[1] present their discoveries of modified wood from Kalambo Falls in Zambia. These include the earliest-known example of a hominin-crafted wooden structure, as well as a collection of wooden tools.

Archaeologists' understanding of the use of wood as a raw material during the course of hominin evolution is limited to samples from archaeological sites that have exceptional preservation — usually through either extremely arid conditions or waterlogged sites that lack oxygen. From the Middle Pleistocene (around 774,000 to 129,000 years ago), wooden tools, such as complete spears, have been found at Eurasian sites, including at Clacton-on-Sea, UK, from around 400,000 years ago[2] and at Schöningen in Germany from around 300,000 years ago[3]. Evidence of wood use from this period in Africa is more limited. The other subject of this research is one for which scientists have even less information: to what extent did Mid-Pleistocene hominins structure their environments, if they did at all.

Kalambo Falls, a Middle Pleistocene site, was