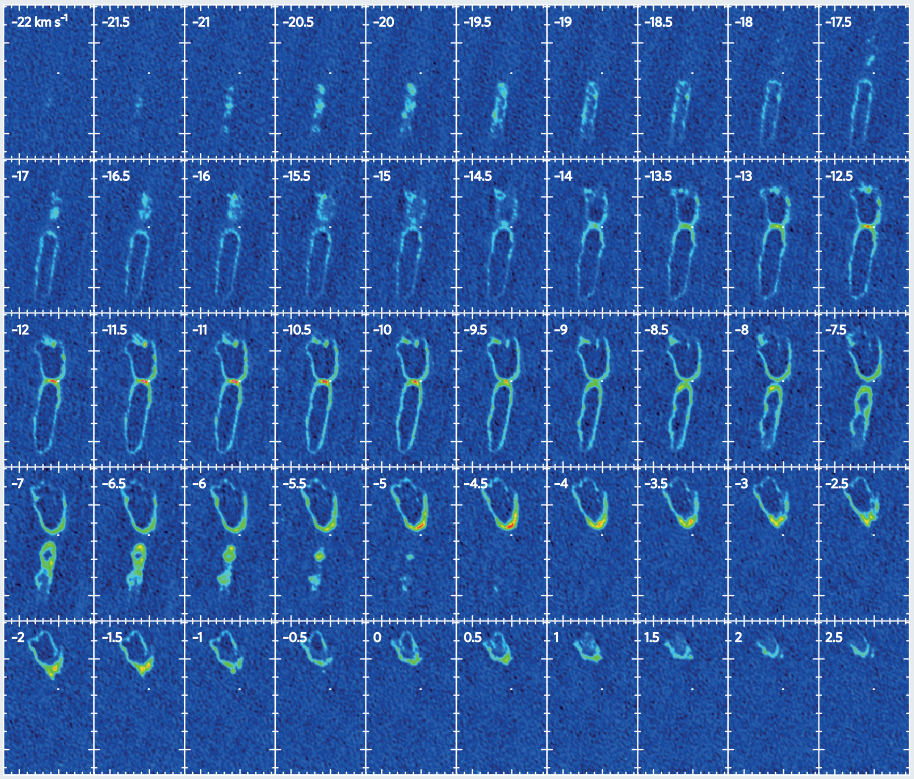
EVOLVED STARS

Carving out the Boomerang

The Boomerang is an intriguing protoplanetary nebula: not only does it boast a prodigiously high mass-loss rate and low luminosity, it also has bipolar lobes which are seen in absorption against the cosmic microwave background. Developing their extensive investigation into the Boomerang, Raghvendra Sahai and collaborators (*Astrophys. J.*, in the press; preprint at https://arxiv.org/abs/1703.06929) have observed CO rotational lines using the Atacama Compact Array. Visible in the CO (J = 3–2) rotational level channel map (pictured) are the two lobes of the nebula; the emission traces the walls of the lobes with 0.3 arcsecond resolution.

The southern lobe is more elongated than the northern, which has a more complex geometrical structure: it contains several bubble-like features. The lobes are not colinear, but offset, depending on the velocity channel. The blueshifted emission (with velocities in the –17.5 to –14.5 km s^{-1} range) shows a slight misalignment, but the redshifted emission (redwards of –14.5 km s^{-1}) has a difference in axis alignment of up to ~30°. The lobes are the result of several mass-loss episodes; using measured extents and expansion velocities, it is possible to piece together a rough evolutionary history. Some 3,500 years ago, this object ejected an outflow (the ultra-cold outflow seen in absorption against the cosmic microwave background). This was followed by the formation of the toroidal waist (~2,000 years ago) that helped constrain a fast bipolar outflow, which has a kinetic age of less than ~1,000 years, at least from the southern lobe. The northern lobe is significantly smaller, but its complex geometry means that any age determination is difficult (although it is likely to be contemporary or younger). The present geometry (shown in the image) is a result of the interaction of these different ejections.



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The dense waist that separates the lobes has an extent of 1,740 × 275 au, and is expanding much more slowly than the lobes. An S-shaped structure can be seen in the Hubble Space Telescope polarization images also presented in the article, possibly produced by binary interaction. Sahai *et al.* hypothesize that the secondary has now merged with the primary's core, leading to the ejection of the primary's envelope, which developed into the bipolar outflow.

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