Sculpting a Bipolar Preplanetary Nebula with Highly-Collimated Fast Jets

Raghvendra Sahai

*Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, USA*

M. Claussen, M. Morris, C. Sanchez Contreras

Pre-planetary nebulae (PPNe), transition objects between the AGB and Planetary Nebulae (PN) phases, hold the key to understanding how the slowly expanding, largely spherical, circumstellar envelopes (CSEs) of AGB stars transform into highly-aspherical PNs with elongated lobes expanding at high speeds. In 1998, Sahai & Trauger proposed that, as stars evolve off the AGB, they drive collimated fast winds that sweep up and shock the AGB CSE, producing the observed dramatic change in circumstellar geometry and kinematics. The PPN, IRAS 22036+5306 (I22036) offers exciting support for this hypothesis. Its highly structured morphology in HST images, and CO $J = 3 - 2$ interferometric mapping, show that fast (~200 km/s), collimated jet-like outflows are actively sculpting the CSE into a bipolar PPN. I22036 is thus a key object in clarifying the physics of the transition to bipolarity at the beginning of post-AGB evolution.

We present the results of a multiwavelength study of I22036. New HST H$\alpha$ and [O i] emission-line images clearly delineate the active shocks, and deep broad-band images reveal point-symmetric ansae beyond the tips of the main bipolar lobes, an extended round halo representing the remnant AGB CSE, and the central star. Optical long-slit (echelle) spectroscopy with the Keck/ESI shows the detailed kinematical structure of the shocked regions. Near-IR (1.1–2.4 µm) spectroscopy of I22036 using the Palomar 200-inch/TripleSpec spectrograph shows strong H$\alpha$ ($\delta V = 1$) emission from shocked molecular gas in a bipolar outflow. Prominent CO ($\delta V = 2$) bandheads are seen in emission towards the center, indicating very hot (>few × 1000 K) gas in a disk or outflow.
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Raghvendra Sahai (JPL/Caltech), M. Claussen (NRAO), M. R. Morris (UCLA), C. Sánchez Contreras (CSIC, Spain)

1. Introduction

Preplanetary nebula (PPN), short-lived transition objects between T Tauri and Herbig Ae/Be, feature jets and shocks in the outer envelopes of star-forming regions, thought to be collimated by surrounding, highly structured magnetic fields. A notable example is the Herbig-Haro region HH 1, with a jet visible in optical images. Jet activity is essential to our understanding of the transition from protostars to the more mature AGB stars.

2. Observational Results

2.1. ABE Imaging

(a) Image of HH 1 (red: F814W, green: F606W, blue: F438W) shows a jet-like feature extending away from the star. The jet is unresolved, suggesting it is a collimated jet.

(b) Image of HH 2 (red: F814W, green: F606W, blue: F438W) shows a similar jet-like feature extending away from the star. The jet is also unresolved, suggesting it is a collimated jet.

2.2. Spectroscopy

(a) NIR (1-2 μm) spectroscopy shows a strong CO emission line at 4.7 μm, indicating the presence of hot gas near the jet. The line is broadened, suggesting the gas is moving at high velocities.

(b) Hα emission line is strong in the jet region, indicating the presence of ionized gas. The line is broadened, suggesting the gas is moving at high velocities.

3. Discussion

Jet activity is essential to our understanding of the transition from protostars to the more mature AGB stars. Jets can be collimated by surrounding magnetic fields, which can lead to the formation of bipolar nebulae. The presence of jets in preplanetary nebulae is a key indicator of the transition to bipolarity.

4. Future Work

We are carrying out multi-wavelength continuum observations with the VLA to probe large-grain dust in the dust-free regions of the nebula. We have a scheduled Cycle 17 STIS program to map the Hα emission at high spatial resolution and adequate spectral resolution using the new slitless spectroscopy mode. We plan to use integral field spectroscopy to map the nebula and determine the nature of the observed jet activity.

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