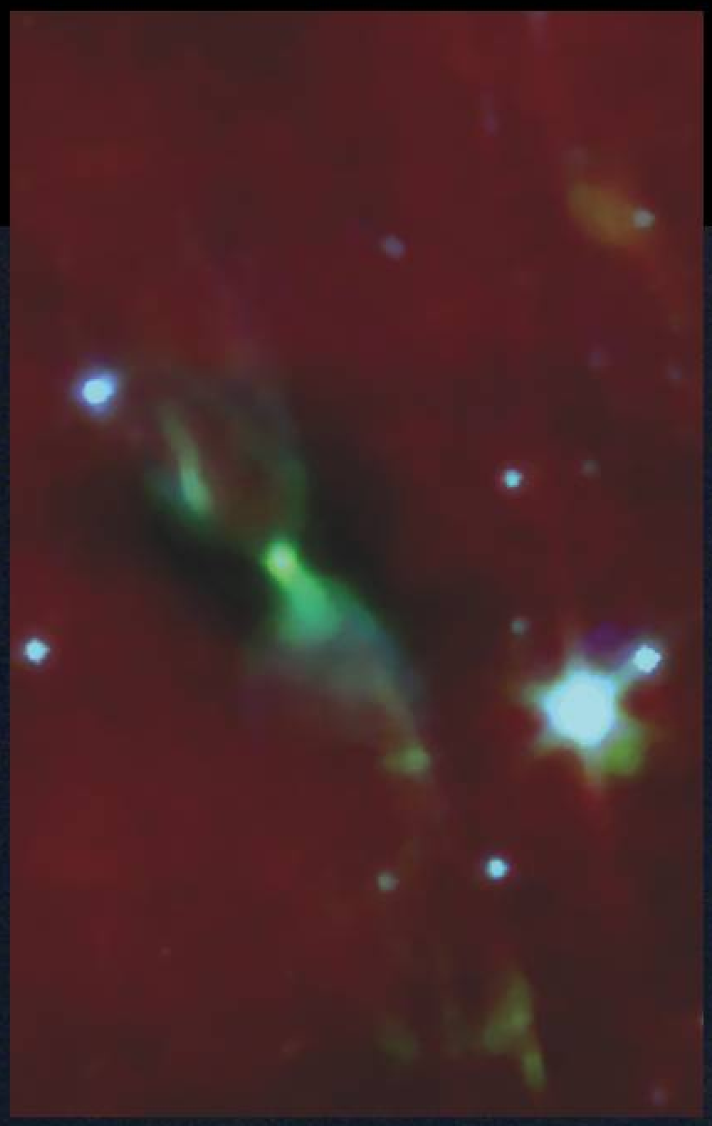
Inferring B-field Strength in a Proto-Brown Dwarf Driven Outflow

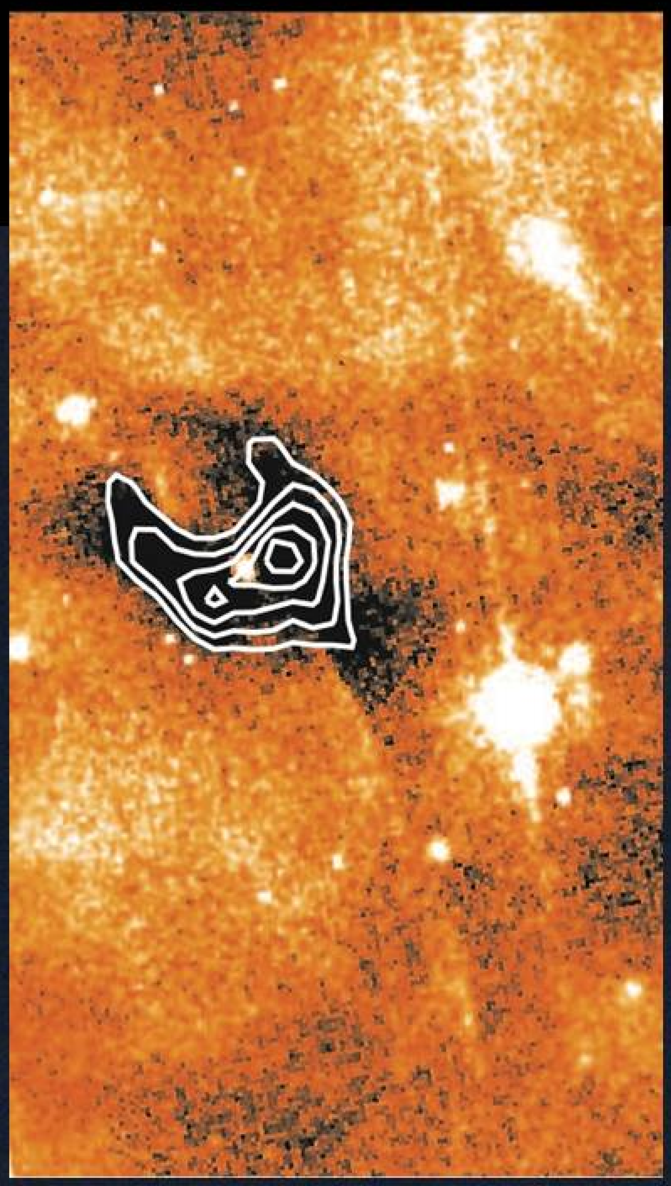
Mary Barsony (SSI), Grace Wolf-Chase (Adler & U. Chicago), Jennifer Wiseman (NASA/GSFC), & Raghvendra Sahai (JPL)

IRAS 16253-2429, located in the nearby (d=125 pc) ρ Ophiuchi cloud, is the powering source of the Wasp-Waist Nebula [1]. It is one of 50 bona fide VeLLOs (Very Low Luminosity Objects) identified in the Spitzer c2d survey [2].



The Wasp-Waist Nebula's dramatic bipolar shape is evident in this *Spitzer* IRAC image [1].

The infall envelope of the proto-brown dwarf is seen both in absorption against the bright PAH background of the cloud in the 8.0 mm *Spitzer* image below and in NH3(1,1) emission (contours) mapped with the VLA.

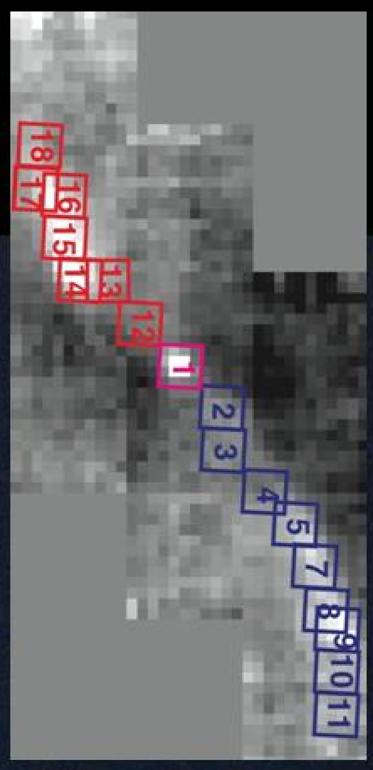


Infall Envelope Mass

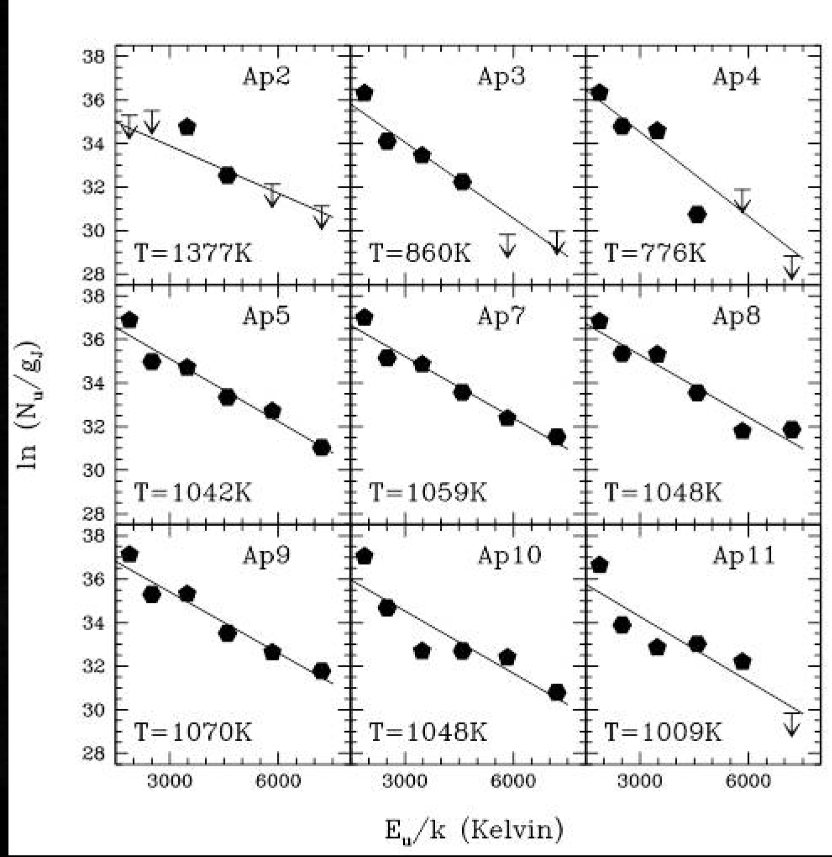
The inferred mass of the infall envelope is just 0.15 $M_\odot$—0.2 $M_\odot$. Since only a small fraction of the infall envelope eventually lands on the central object, IRAS 16253-2429 is very likely to be a proto-brown dwarf. Its infall envelope mass is the smallest of any VeLLO. The mass estimates agree from three independent methods: 8.0 μm absorption, 1.1mm emission, and NH3 emission.

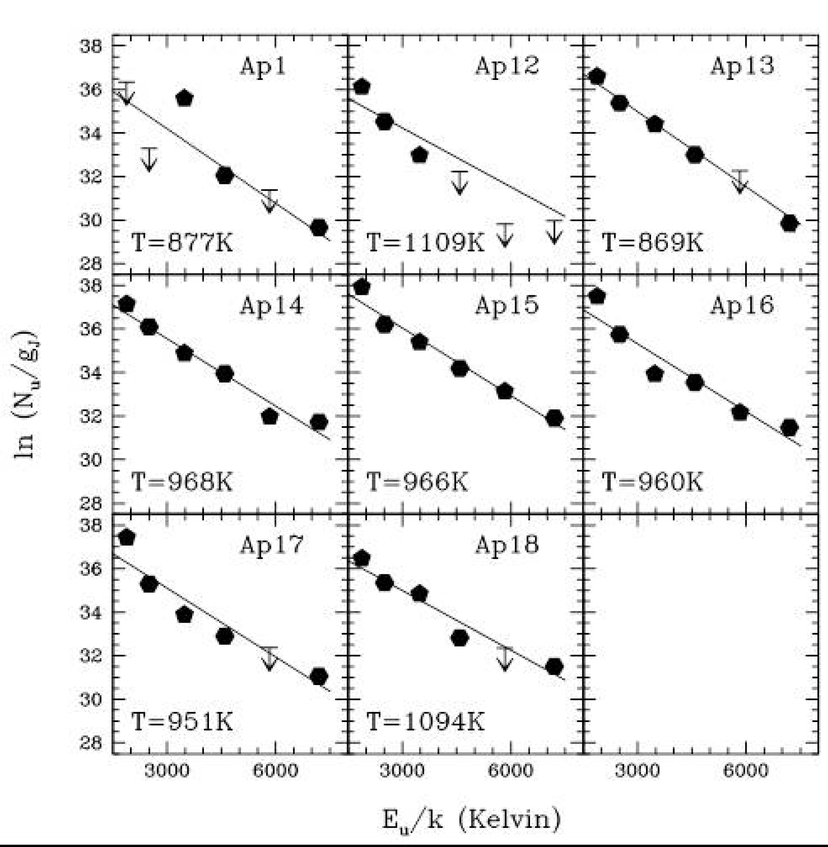
Spitzer IRS (Infrared Spectrometer) scan-mapping of the central 2.25′ x 1′ of the Wasp-Waist Nebula reveals the S-shaped outflow in the lowest rotational transitions of the H2 molecule [1], as distinct from the bipolar cavity, best seen in the leftmost IRAC image.

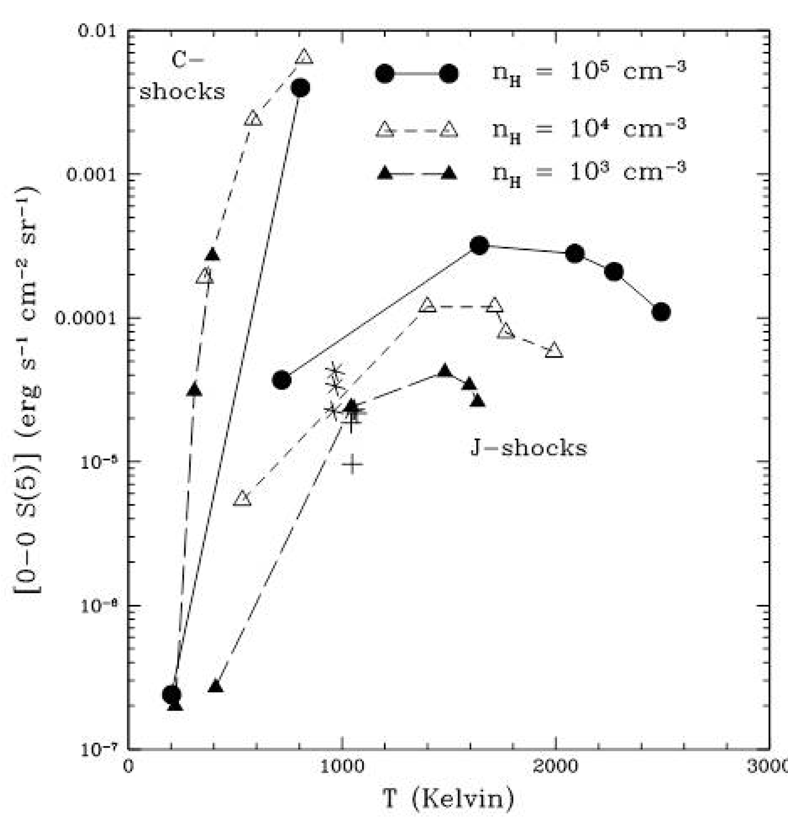
NH3 (1,1) contours are overlaid, and show how the envelope gas cradles the outflow cavities.



Apertures used for studying physical parameters associated with the flow: blue=blue-shifted lobe; red=red-shifted lobe; magenta = central object







Inferred B-field Strengths

Measurement of B-field strengths in cold, dense cloud cores is notoriously difficult, relying on Zeeman splitting measurements of appropriate radio spectral lines or from the dispersion of dust polarization vectors. An alternative is to compare pure rotational H_2 emission line maps of shocks in outflow lobes with detailed shock models [4]. By so doing, we find slow, J-type shocks throughout the flow lobes, consistent with initial (transverse to the shock) B-field strengths of just ~3 μG in the blue-shifted lobe, and 10-32 μG in the red-shifted lobe.

Constant Temperature

Excitation diagrams as a function of aperture in the blue-shifted outflow lobe (top left) and in the red-shifted lobe (top right) deduced from six pure rotational H_2 transitions mapped with *Spitzer*'s IRS instrument [1]. Excitation temperatures derived from best-fit lines for each aperture are indicated, and are remarkably constant at T~960K in the red-shifted lobe and T~1050K in the blue-shifted lobe.

Shock Models

Data (integrated 6.9 μm line intensity) from apertures in the red-shifted lobe (stars) and the blue-shifted lobe (crosses) near T~1000K are plotted along with selected shock models [3]. Both C-shock and J-shock models are plotted. Each model point corresponds to a specific shock velocity. From lower left to upper right: v_s=20 km s^{-1}, 30 km s^{-1}, and 40 km s^{-1} for the C-shock models; v_s=5 km s^{-1} to 25 km s^{-1} in 5 km s^{-1} steps for the J-shock models. Symbol shapes indicate relevant pre-shock densities.

References

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[2] Dunham, M.M., Crapsi, A., Evans, N.J. II, Bourke, T.L., Huard, T.L., Myers, P.C., & Kauffmann, J. 2008, "Identifying the Low-Luminosity Populations of Embedded Protostars in the c2d Observations of Clouds and Cores," ApJS 179 249

[3] Wilgenbus, D., Cabrit, S., Pineau des Forets, G., & D.R. Flower 2000, "The *ortho:para* H_2 Ratio in C- and J-type Shocks," A&A, 356, 1010

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Background Image: Moonrise at the VLA during the NH3 observations

Credit: J. Wiseman