HST Images of Protostellar Disks and Envelopes in Orion

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Introduction

We present near-infrared HST NICMOS+WFC3 images of 244 protostars, tracing with better than 70 AU spatial resolution the scattered light from the protostellar envelopes and in some cases, the absorption and shadowing by protostellar disks. Orion is home to half the young stellar objects in the nearest 500 pc and is a largely unexplored ground for scattered-light studies of protostellar envelopes and disks. This region is the focus of HOPS, the Herschel Orion Protostar Survey, a multi-observatory study of protostars using Herschel, Spitzer, Hubble, and APEX. Scattered light images allow us to break degeneracies in fitting the 1–870 micron spectral energy distributions (see posters by E. Furlan and W. Fischer), in particular by constraining the inclination of the source and the opening angle of the envelope cavity.

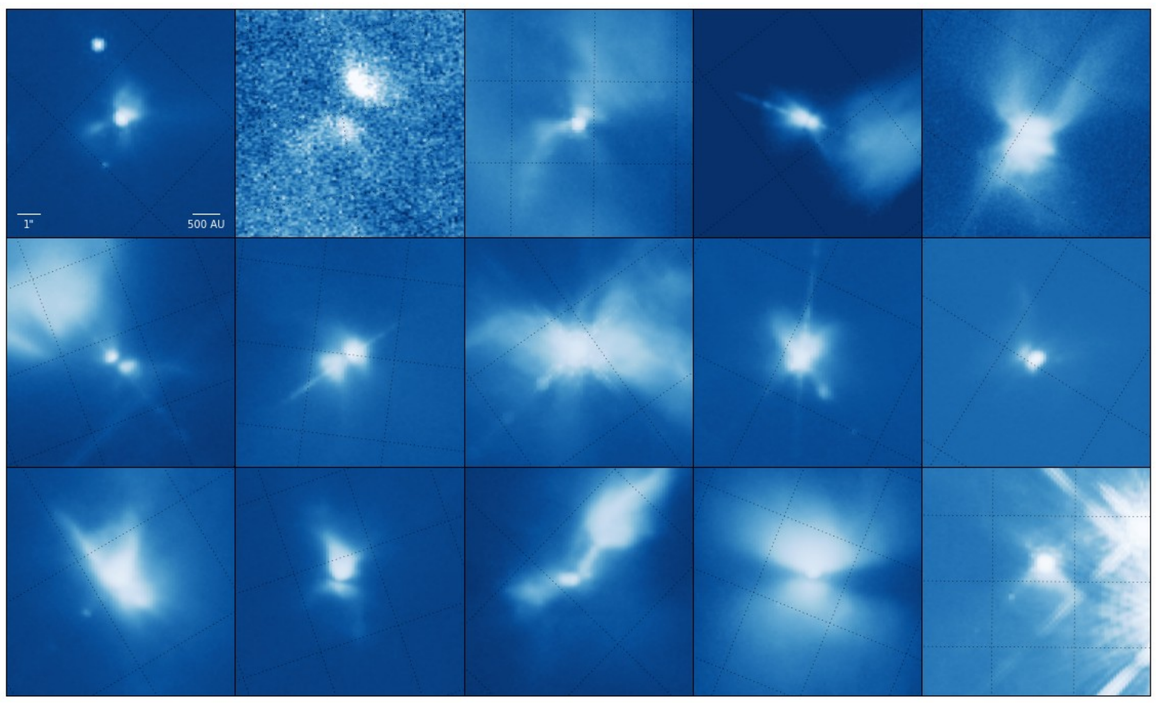
We also present a grid of 2900 models of the scattered light images to show how the nebulosity depends on cavity shape and inclination. For edge-on protostars, the comparison of the HST images to models allows us to determine the properties of protostellar disks by their shape in absorption against the scattered light and by the shadows they cast in the envelope.

Here we show a subsample of 15 edge-on sources We then present a detailed analysis of HOPS 136 (Fischer et al. in prep.), where we have used the NICMOS data to provide strong constraints on the disk radius, mass, and structure.

Sample

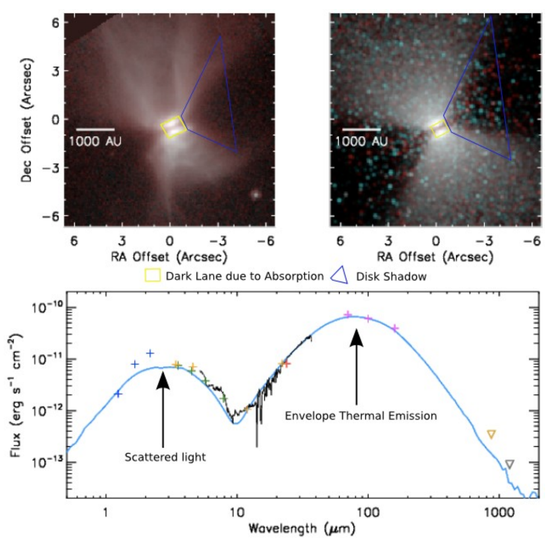
- The Orion Molecular Clouds contain the largest sample of protostars within 500 pc
- 488 protostellar candidates were identified by Megeath et al (2012) using Spitzer 3-24 μm
- 330 were observed in far-infared in the Herschel Orion Protostellar Survey (HOPS)
- Imaging and photometry from 1.6-870 μm was obtained for constructing SEDs.
- NICMOS imaging at 1.6 and 2.05 μm was obtained for 89 sources.
- After the failure of NICMOS, 197 more sources were imaged with WFC3 at 1.6 μm

A Sample of 15 Edge-on Protostars found in Orion



HST NICMOS or WFC3 images at 1.6 μm of fifteen sources. Each image is 10” on a side, hence showing a 4200 x 4200 AU region. HOPS 136 is in the upper right. The resolved scattered light nebulae show evidence of absorption by a disk and/or shadow cast into the surrounding envelope by the disk. Several objects also show clear examples of emission from jets.

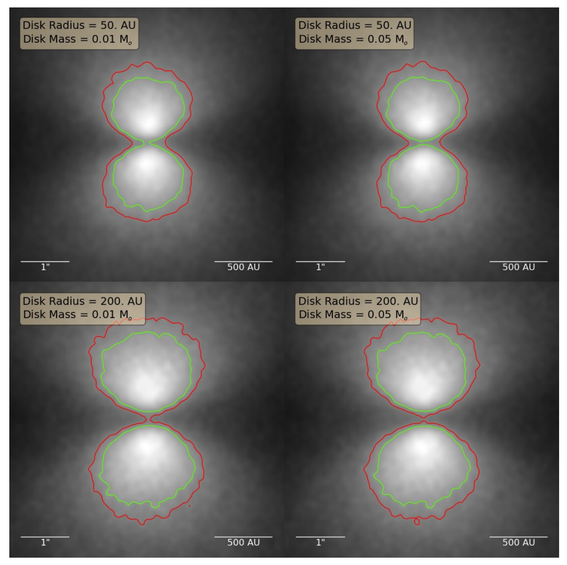
HOPS 136: Determining the Properties of an Edge-On Protostellar Disk



Top left: NICMOS image of HOPS 136. Cyan represents 1.6 μm while red represents 2.05 μm emission. *Top right*: Model image with same color scheme. *Bottom*: SED containing data from 2MASS (blue); WISE (orange); Spitzer IRAC (green), IRS (black), and MIPS (red); Herschel/PACS (magenta); APEX/LABOCA (gold); IRAM/MAMBO (gray); and the modeled SED (light blue).

- Edge-on protostar in southern end of L1641
- Bolometric temperature of 180 K, matching with a Class I source (Chen et al. 1995)
- Light scattered in the envelope is apparent in NICMOS F160W and F205W images.
- The following disk properties are constrained by fits to radiative transfer models (Fischer et al. In prep):
  - Disk radius: 450 ± 20 AU
  - Mass of disk: 0.003 ± 0.001 $M_\odot$
  - Disk scale height at 100 AU: 22 ± 2 AU
  - Radial density exponent: 2.20 ± 0.05
  - Disk flaring exponent: 1.20 ± 0.05
- We have an ALMA observation in a high priority queue for cycle 1 to observe the angular momentum distribution of this and 3 other edge-on sources

Model Grid



The grid above compares disk radii and masses in edge-on protostars. Contours show 50% and 58% of the maximum emission. The sources with 50 AU disks are just resolvable with HST.

Monochromatic Models

- Model grid generated with the monochromatic Monte Carlo code HO-CHUNK.ttsscat from Barbara Whitney (see Whitney & Hartmann 1992 and 1993 for methodology)
- Varied infall rates, cavity angles, disk sizes/masses, and inclination for 2560 models, with other models exploring density distributions
- Infall rate is best constrained by the SED, giving us a reduced subspace in the model grid to consider
- The models show that the width of the dust lane is mainly dependent on the disk radius
- The concavity of the dark lane and the concentration of brightness towards the center reveal disk and radial flaring exponents, which are narrowly probed in the models
- Disk mass has a slight effect on the width of the shadow, as well as affecting the contrast of the structures with the dark lane.

Acknowledgments

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References

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