HERSCHEL ORION PROTOSTAR SURVEY (HOPS) @10 years

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HOPS: 200 h Open-Time Key Program with Herschel

With Herschel, we imaged the Spitzeridentified Orion protostars in the far IR, where they are brightest.

Why Orion?

- Orion Molecular Cloud contains the largest sample of protostars in the nearest 420 pc.
- Orion protostars have a wide range of luminosities, different evolutionary stages, and they are forming in diverse environments

PACS imaging at 70, 160 μ m of >300 protostars

PACS spectroscopy (55-200µm) of 33 protostars

Red dots = HOPS targets Gray scale = extinction





Some HOPS results:

- Clarification of the nature of NGC 1999: Dark Cloud or Hole in the Sky?
- Building of well-sampled SEDs (HOPS + SOFIA, Spitzer, APEX) and detailed modeling of 330 Orion protostars.
- Discovery of PBRS: Extremely young Orion protostars.
- Identification of four outbursting Orion protostars.
- Established correlation between bolometric luminosity and the luminosity of the far-IR CO lines generated by outflow shocks.
- Imaging of a far-IR protostellar jet with strong shocks in an intermediate luminosity protostar of the sample.
- Signs of triggered star-formation by outflow (HOPS + VLA).

Is NGC 1999 (V380 Ori) nebula a Dark Cloud?



The cloud remains dark in the far-IR, suggesting a high extinction. A strong submm emission is expected.

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No submm emission of the cloud is detected. This is not a dark cloud but a genuine *hole in the nebula* -- Carved by outflows? (Stanke+2010)

f APEX 350 μm APEX 850 μm d y ()

SED fitting of 300 protostars in Orion

SED constructed with 2MASS, Spitzer, Herschel, and APEX data





Modeling of the SED as dust thermal emission + scattered light from a circumstellar envelope and a disk (Furlan +2016) Far-IR Herschel data enable accurate measurement of luminosity, and bolometric temperature of the protostars, and help to constrain the





Class I (125 in Orion)



Class II (11 in Orion)



Env Mass = $0.01 M_{\odot}$

 ∇

1000





HOPS 170

Furlan+2016





Outbursting HOPS protostars:



Outbursting HOPS protostars:



Four protostars have burst since the 2004-05 Spitzer maps of Orion * HOPS 383 was the first Class 0 outburst discovered * Four outbursts in 319 protostars in 13 years suggests that each protostar bursts every ~1000 yrs on average. Also see Fischer+2019

CO Emission from Accretion-Driven Outflows

(Manoj et al. 2013; DIGIT data provided by J. Green & N. Evans)



T_{rot} curve for CO is independent of source luminosity and envelope density; most likely explanation is that emission is from shock-heated material in outflow.

More luminous sources have more CO luminosity; suggests momentum and mass flow rates of the outflows correlate with bolometric luminosity: sources with high L_{bol} have higher accretion and outflow rates

The most luminous protostars in the OMC 2 region



The formation of a HOPS protostar triggered by the impact of the jet of another protostar?



SOFIA GREAT [OI] spectrum (Megeath et al in prep).



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