Tracing Protostellar Envelope Evolution in Orion with Herschel

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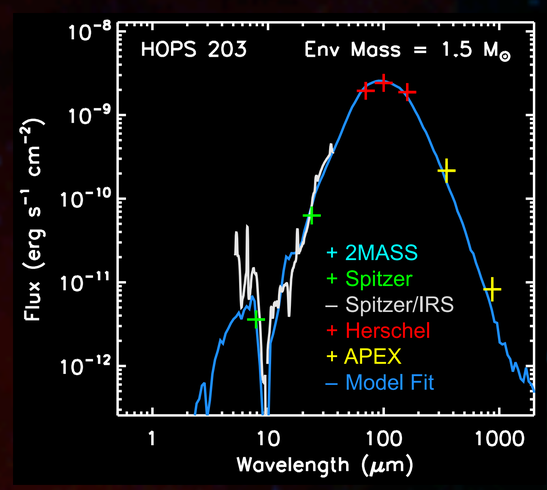
HOPS: Herschel Orion Protostar Survey

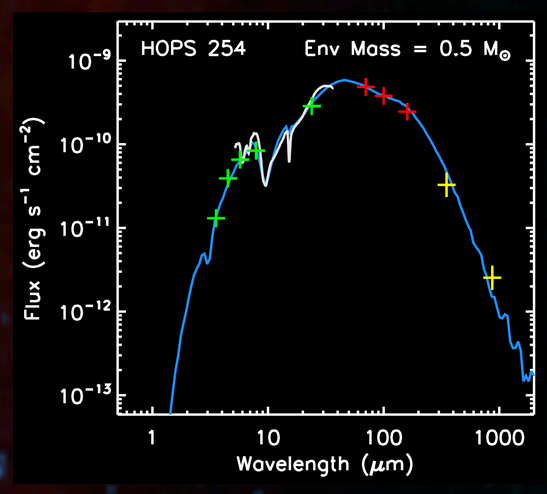
- 200 hour Open-Time Key Program
- Observe the Spitzer-identified Orion protostars with PACS
  - Imaging at 70 and 160 μm of > 300 protostars
  - Spectroscopy from 55 to 200 μm of 33 protostars
- Extensive additional data: HST imaging, Spitzer imaging and spectroscopy, APEX sub-millimeter imaging, IRTF near-infrared spectroscopy, other ground-based imaging and spectroscopy
- A complete study of protostars in a single cloud complex

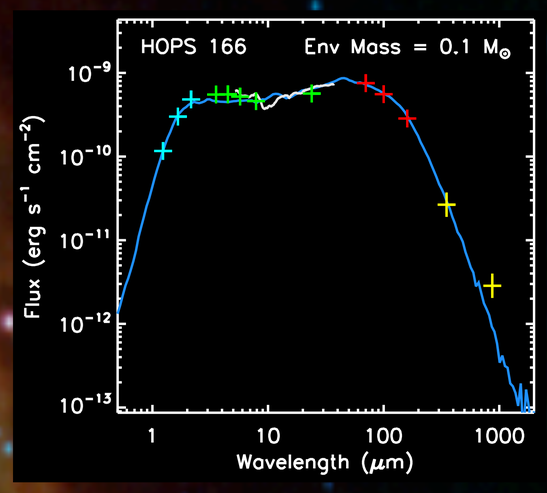
SED and Image Analysis

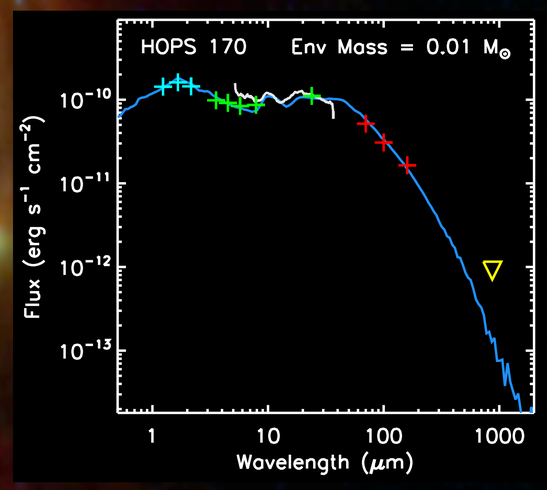
- SEDs from 2MASS, Spitzer, Herschel, APEX; sample to the right demonstrates dependence of SED on envelope mass (inside 5000 AU)
- Crucially, Herschel data fill in the peak of the SED
- Fit with a grid of 3040 models at 10 inclinations (Furlan et al., in prep.)
- Additional constraints on inclination, cavity angle, disk properties, envelope density from HST images (Booker et al., in prep.)

Sample SEDs

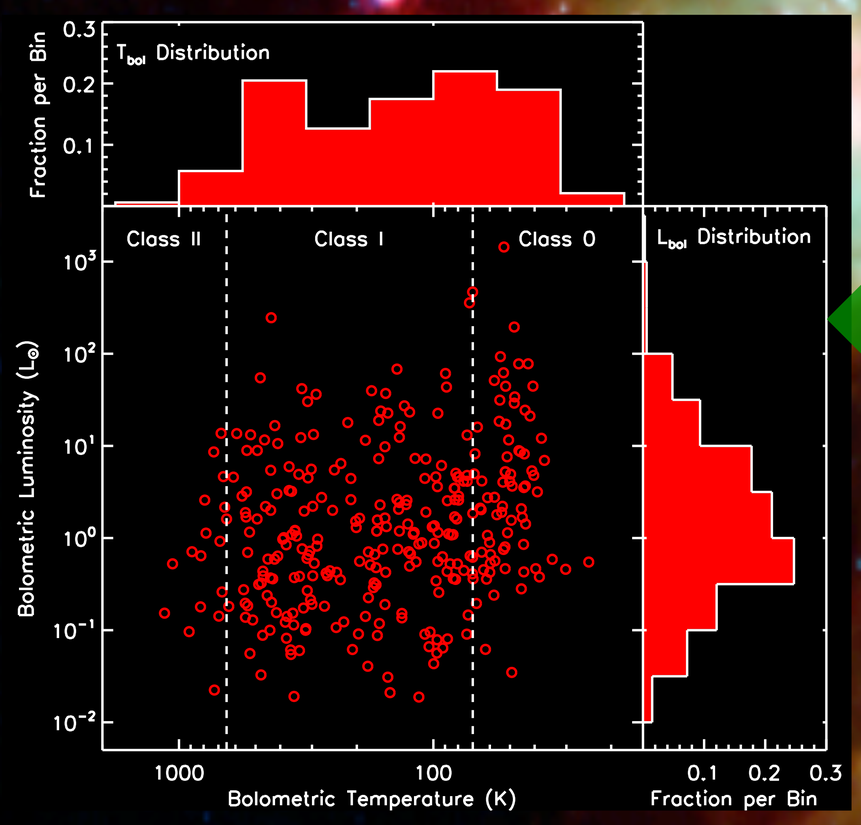








Evolutionary Diagrams of the HOPS Sample



Observed Distribution (BLT)

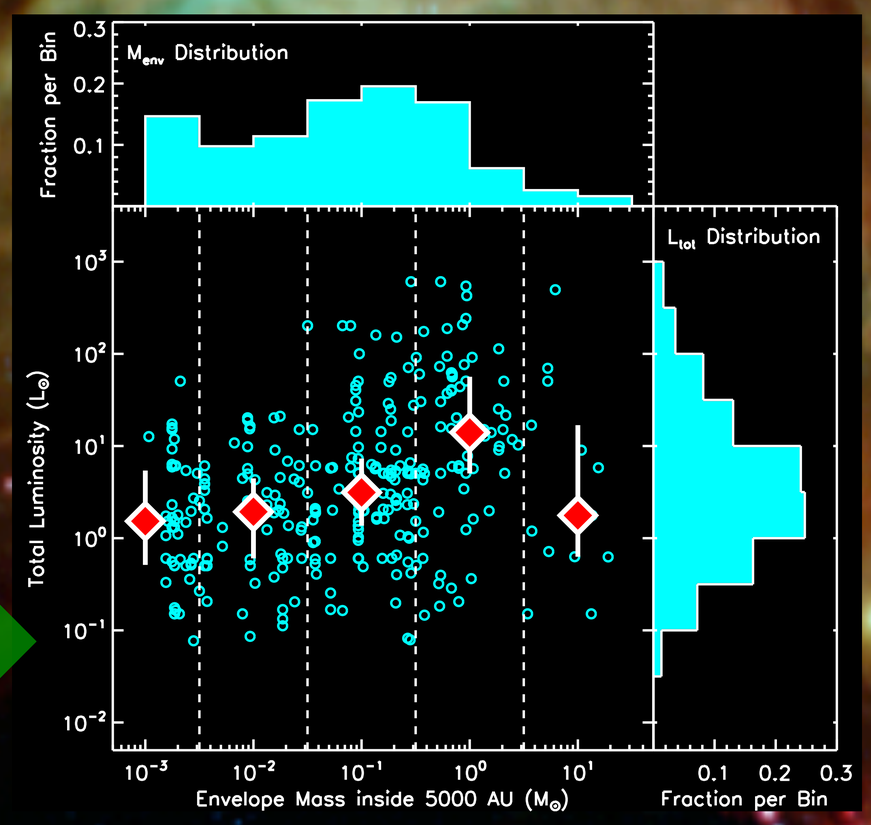
- Integrate under SEDs
- L_{bol}: Bolometric luminosity
- T_{bol}: Bolometric temperature, the T_{eff} of a blackbody with the same mean frequency as the SED
- Use standard division into Classes by T_{bol}
  Class 0: $T_{bol} < 70$ K
  Class I: 70 K < T_{bol} < 650 K

	Number	Fraction	Lifetime*	Median Lum.
Class 0	93	0.30	0.15 Myr	3.5 $L_\odot$
Class I	222	0.70	0.35 Myr	1.0 $L_\odot$

*Assumes 0.5 Myr protostellar lifetime (Spitzer c2d)

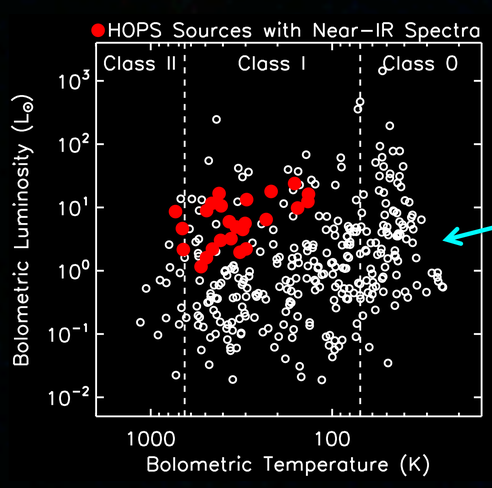
Modeled Distribution (TLM)

- Apply SED modeling to get envelope properties
- L_{tot}: Luminosity corrected for inclination & foreground extinction
- M_{env}: Envelope mass inside 5000 AU, the region probed by IR observations
- Median luminosities (red diamonds) peak at M_{env} ~ 1 $M_\odot$
- Possible explanations for this peak:
  1) Protostars with ~ 1 $M_\odot$ envelopes are forming more massive stars
  2) Low-mass protostars have higher mass infall rates early in their evolution
- The L1641 region of Orion, unlikely to be forming massive stars, shows a similar trend, supporting (2)



Conclusions

- SED and image fitting yield luminosities and envelope masses for >300 Orion protostars, more than half the total in the nearest 500 pc
- Class 0 lifetime is 0.15 Myr if protostellar lifetime is 0.5 Myr
- Median luminosity decreases as T_{bol} increases and envelope mass decreases, with substantial scatter
- Accretion luminosities for late Class I objects are typically a small fraction of their total luminosities



Direct Brγ Probe of Accretion Luminosity

- IRTF/SpeX data (0.8–2.5 μm, R=2000) obtained for bright Class I HOPS targets
- Convert Brγ line luminosity to accretion luminosity
- Total luminosity >> accretion luminosity for most late Class I sources