# Surveying Star Forming Regions in the Near-IR with <100 AU Resolution: Lessons from HST Surveys of Nearby Molecular Clouds

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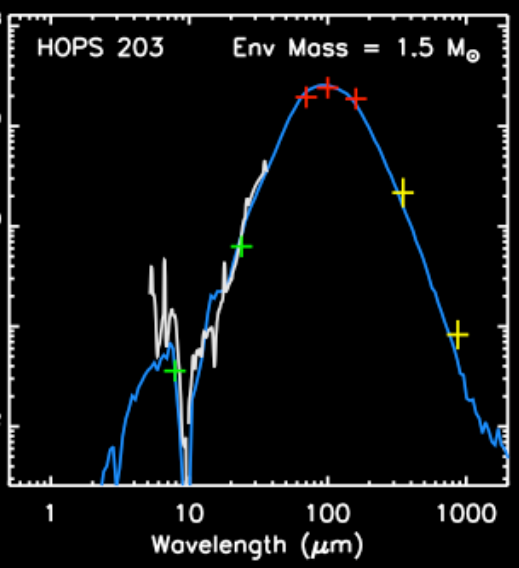
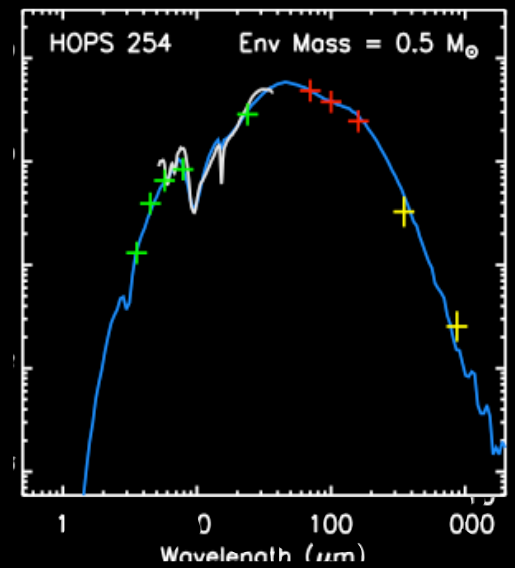
WFC3 F160W

Cepheus

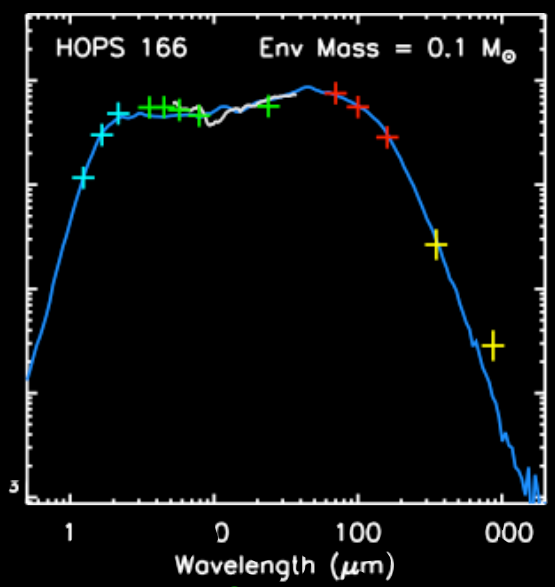
# Evolution of SEDs and YSO Morphology



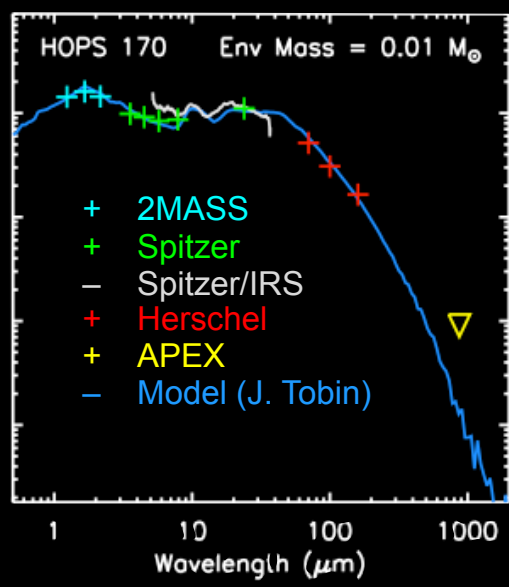

Class 0 Protostar



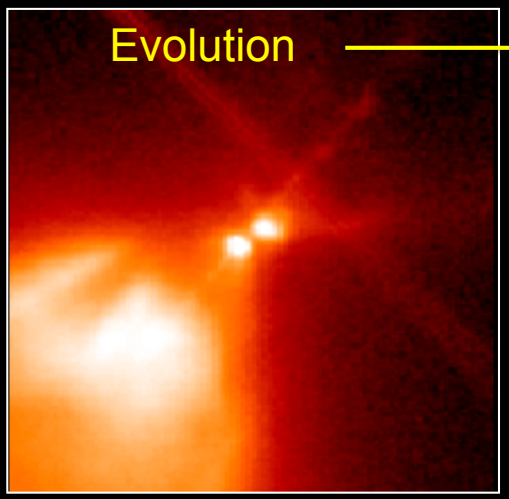

Class I Protostar

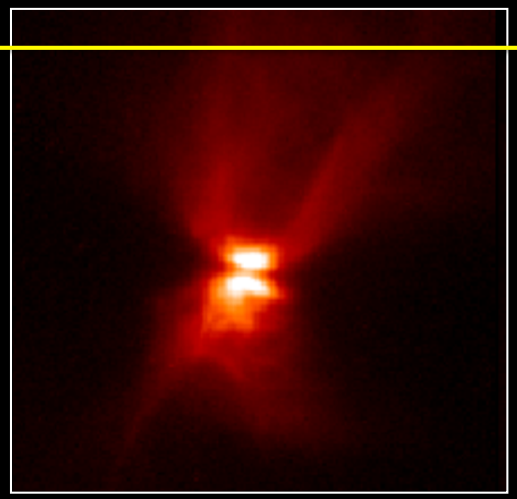


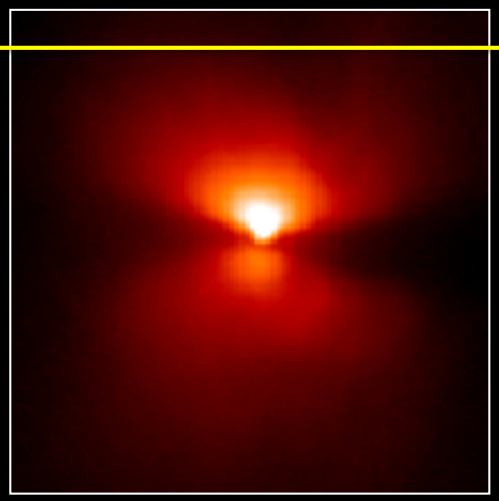

Flat Spectrum Protostar

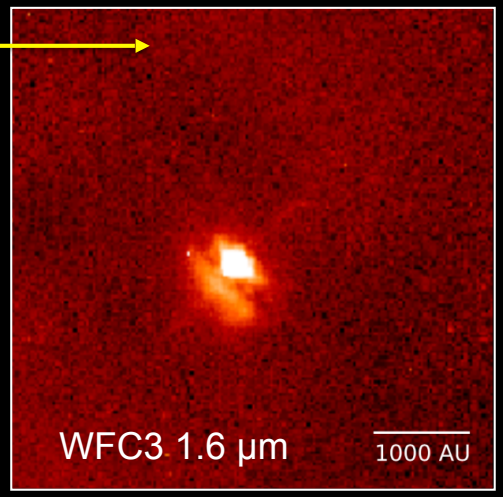



Pre-ms star with disk








HERSCHEL ORION PROTOSTAR SURVEY

Manoj et al. 2013
Stutz et al. 2013

Fischer et al. 2014
Furlan et al 2016

Kounkel et al. 2016
Habel et al. in prep.

http://irsa.ipac.caltech.edu/data/Herschel/HOPS/overview.html

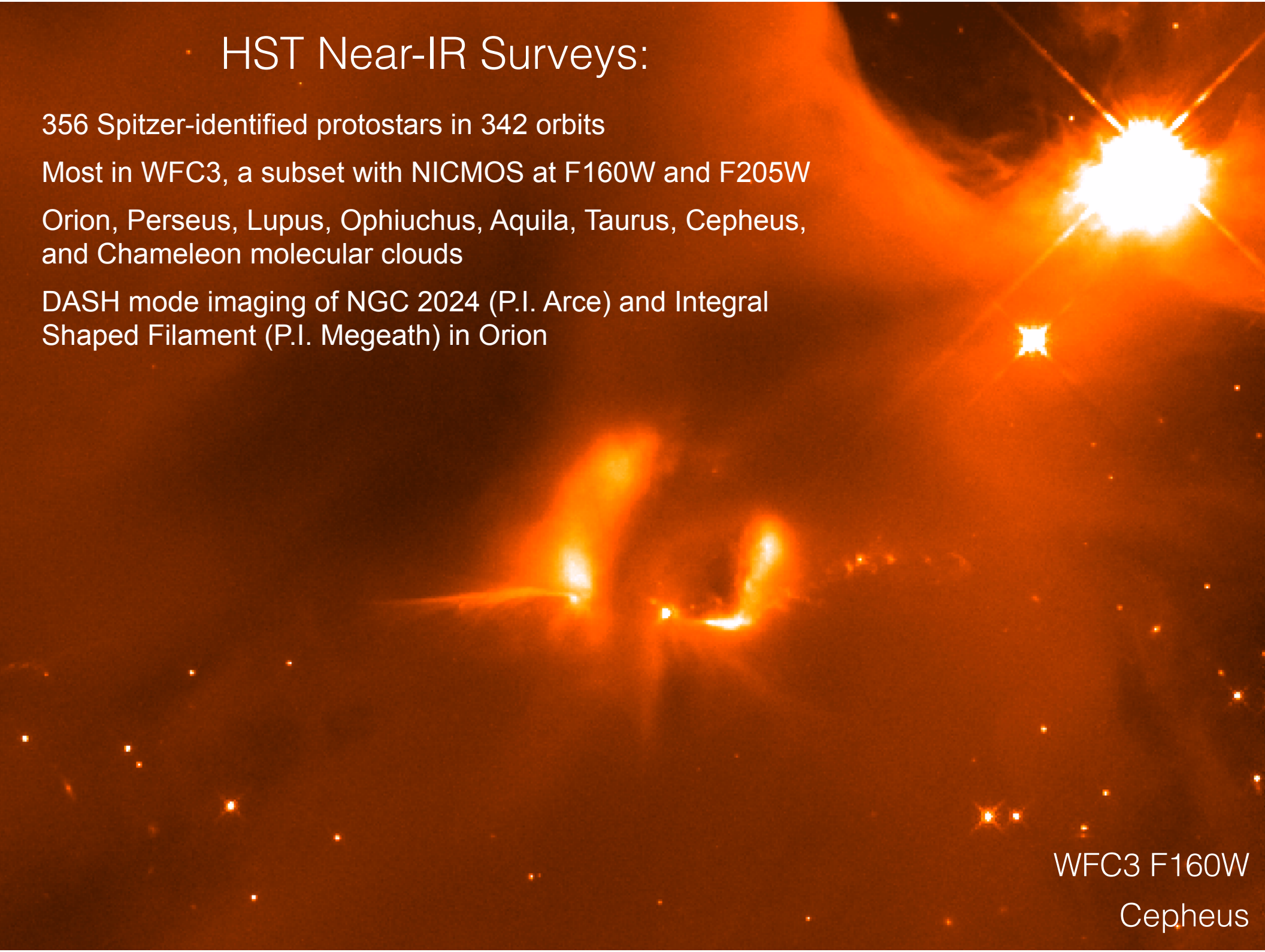
# HST Near-IR Surveys:

356 Spitzer-identified protostars in 342 orbits

Most in WFC3, a subset with NICMOS at F160W and F205W

Orion, Perseus, Lupus, Ophiuchus, Aquila, Taurus, Cepheus, and Chameleon molecular clouds

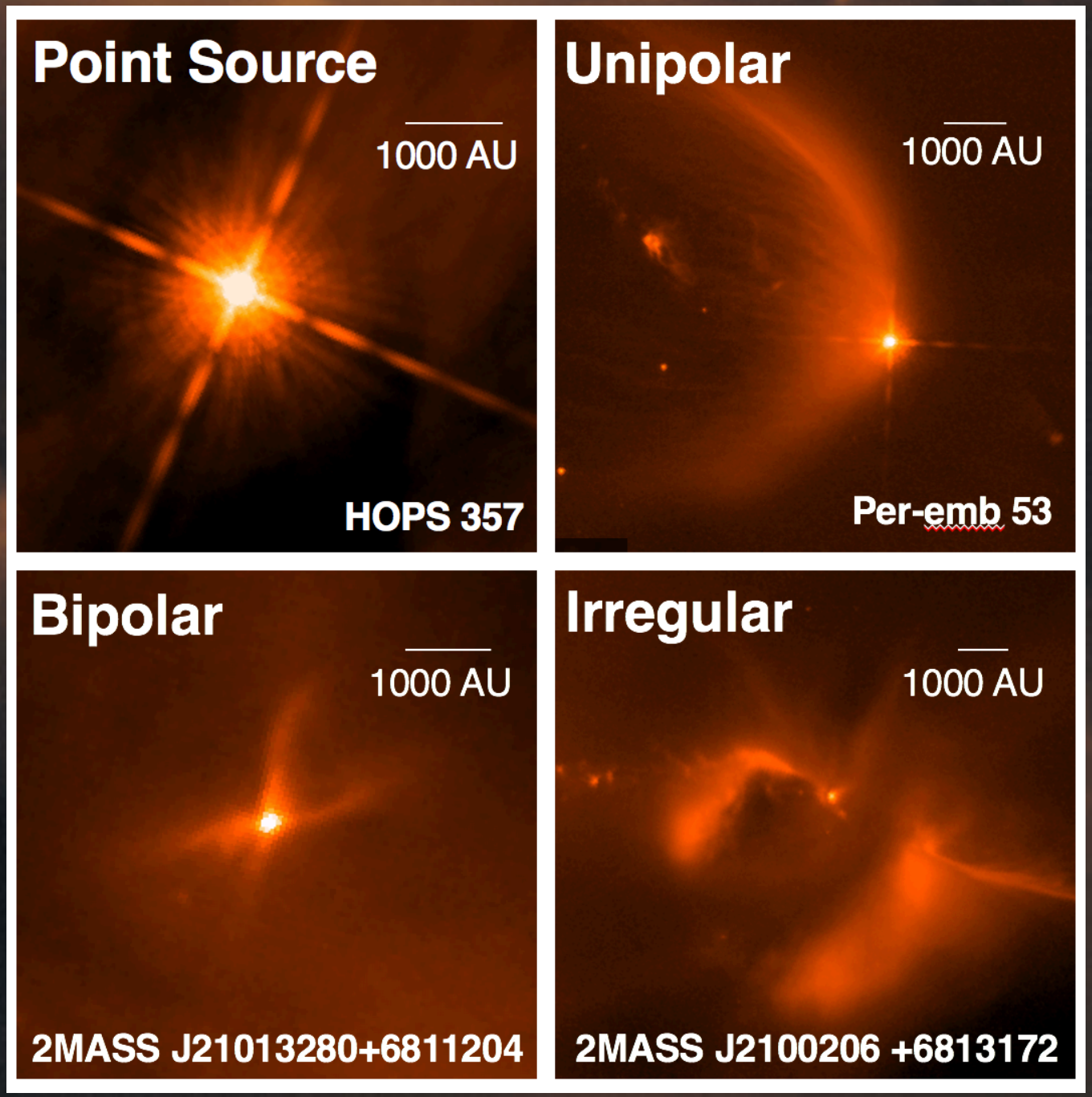
DASH mode imaging of NGC 2024 (P.I. Arce) and Integral Shaped Filament (P.I. Megeath) in Orion



WFC3 F160W

Cepheus

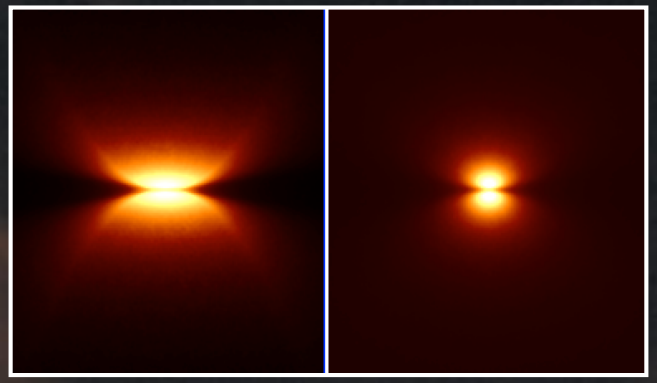
# 1.6 μm Morphologies: Depend on Multiple Parameters




## Primary Factors:

- Inclination
- Envelope Density
- Cavity Size
- Dust properties

RT models



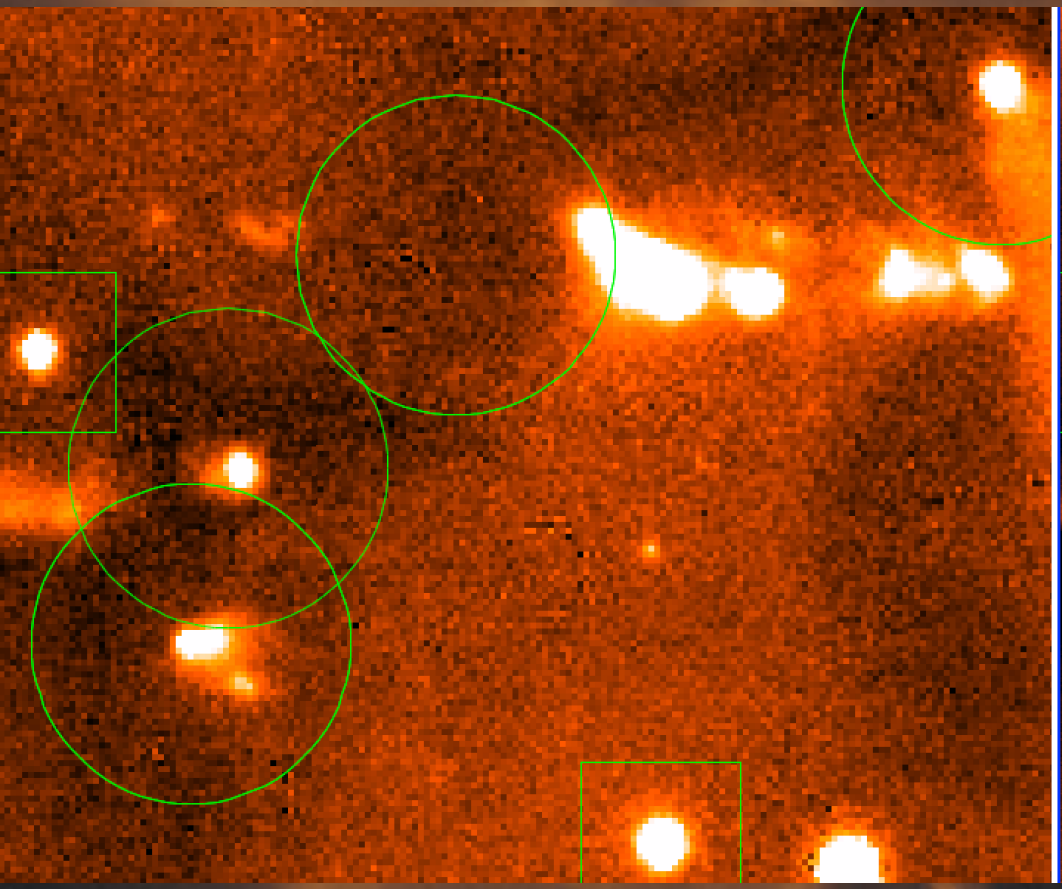
Bigger Grains

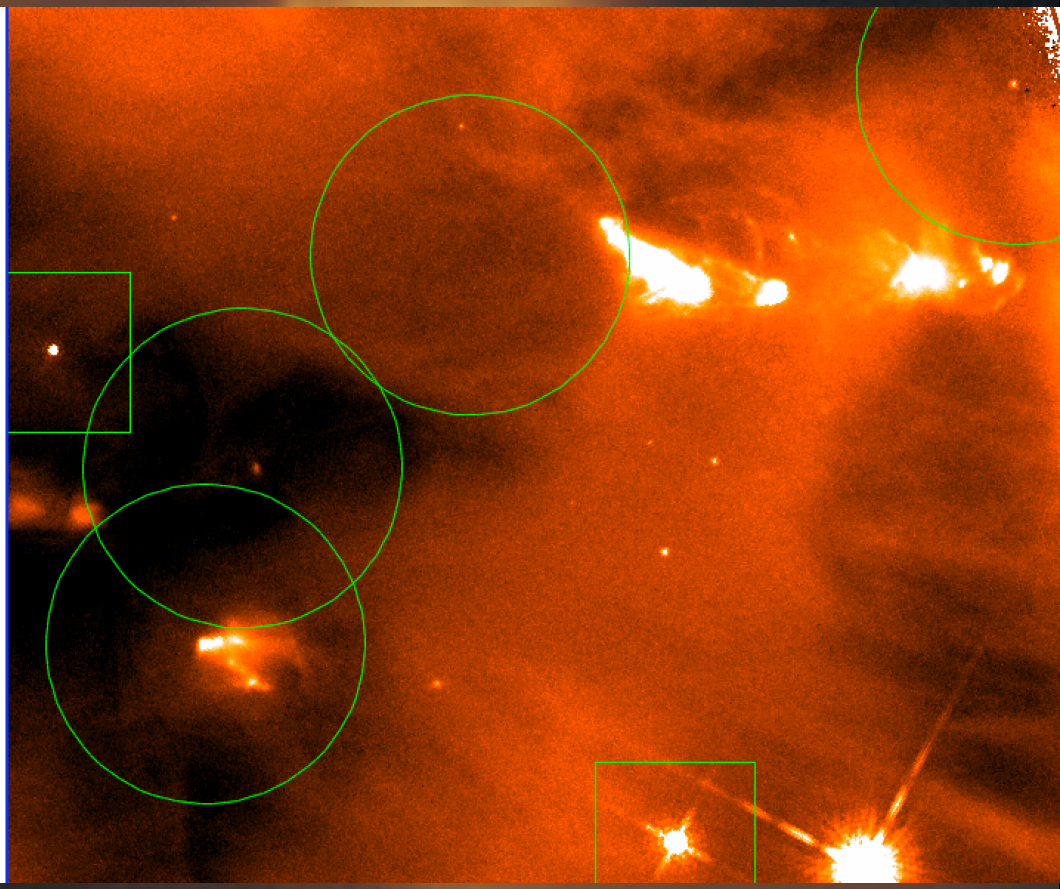
Background: HOPS 386:
1.6 μm image, J. Schmidt

# Comparing F160W and K-band

KPNO 4M @ Ks

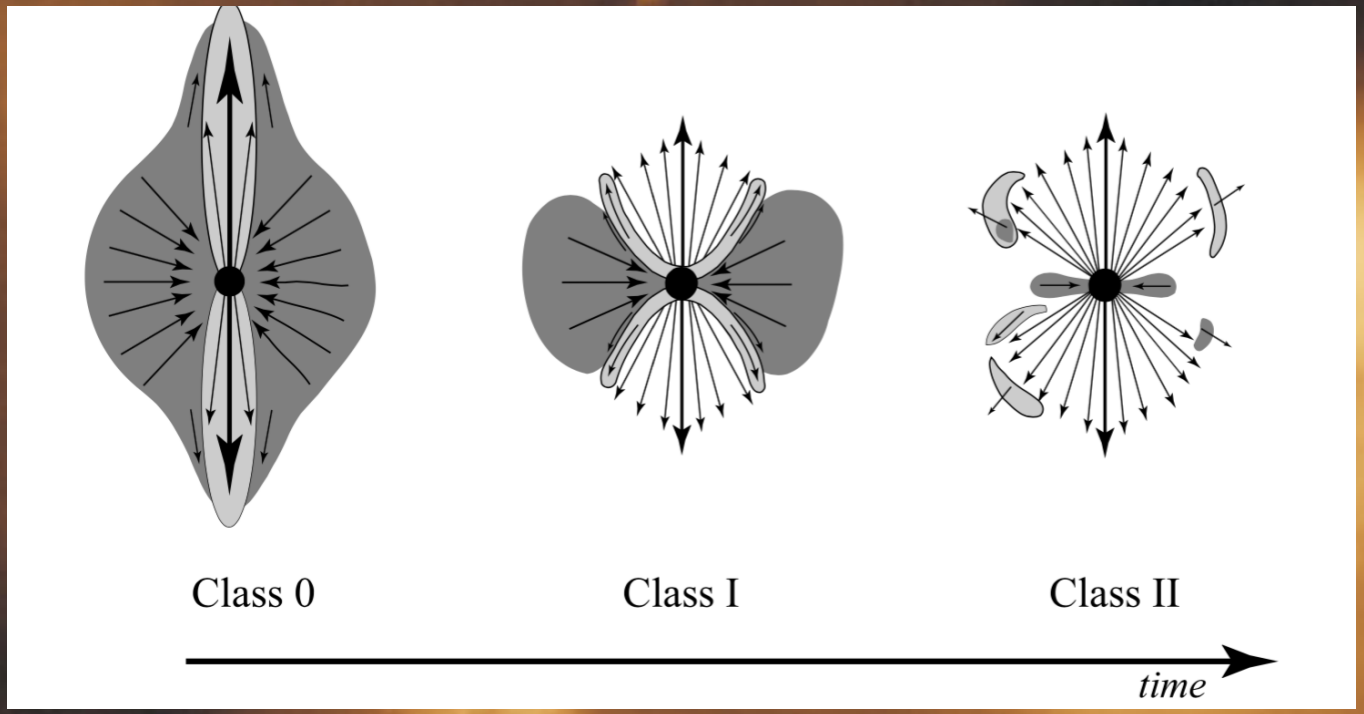
HST/WFC3 @ F160W



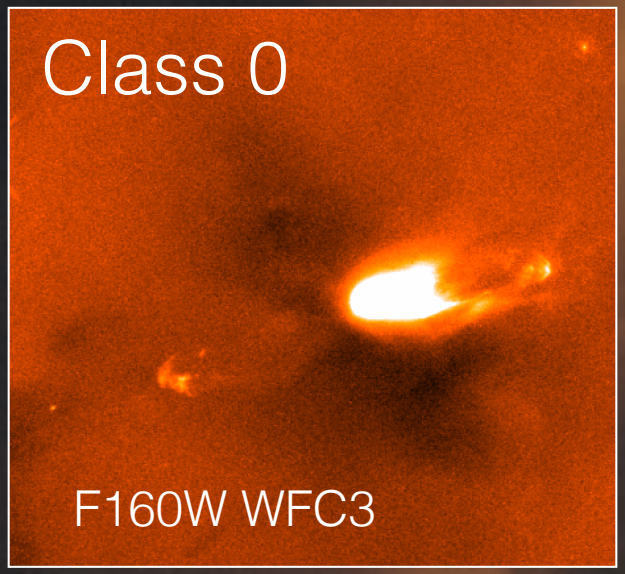


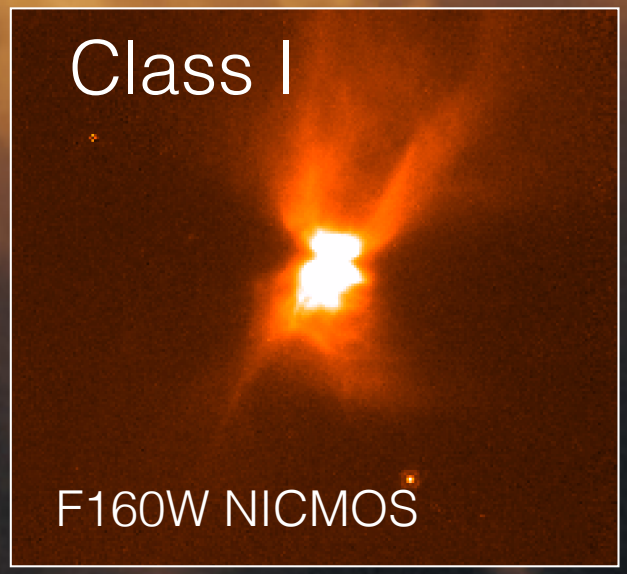
Circles are HOPS protostars (Furlan et al. 2016)
Square pre-ms stars with disks (Megeath et al. 2012)

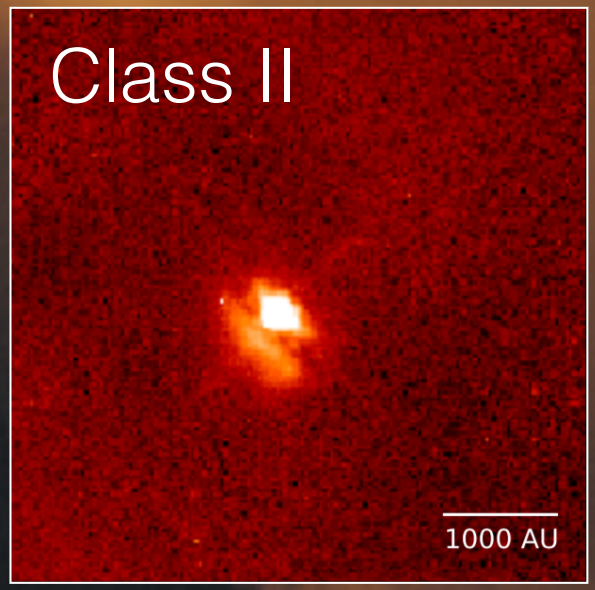
# Do outflows clear envelopes and set stellar masses?



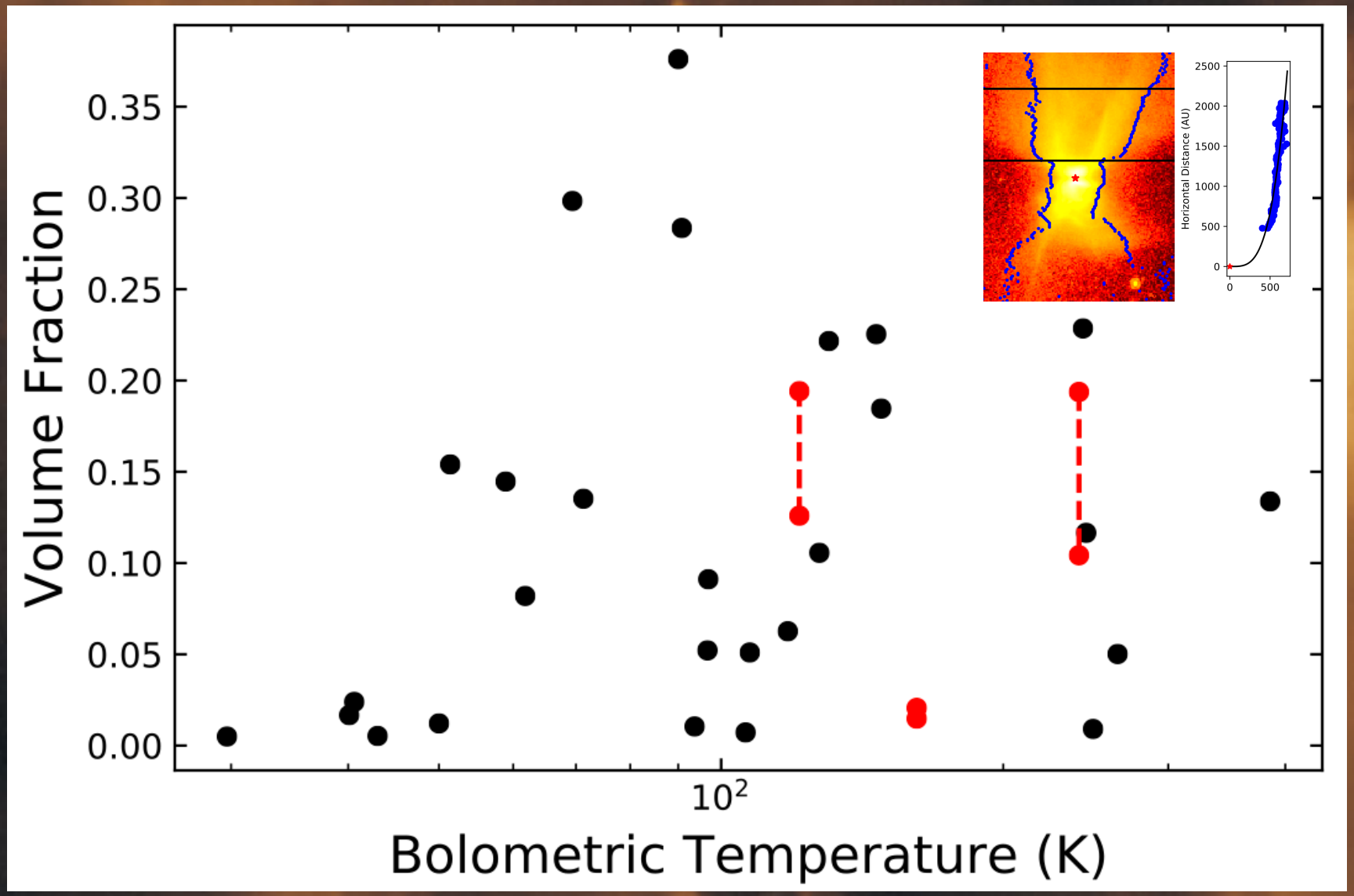

Arce & Sargent (2006)



# Do outflows clear envelopes and set stellar masses?




Evolution

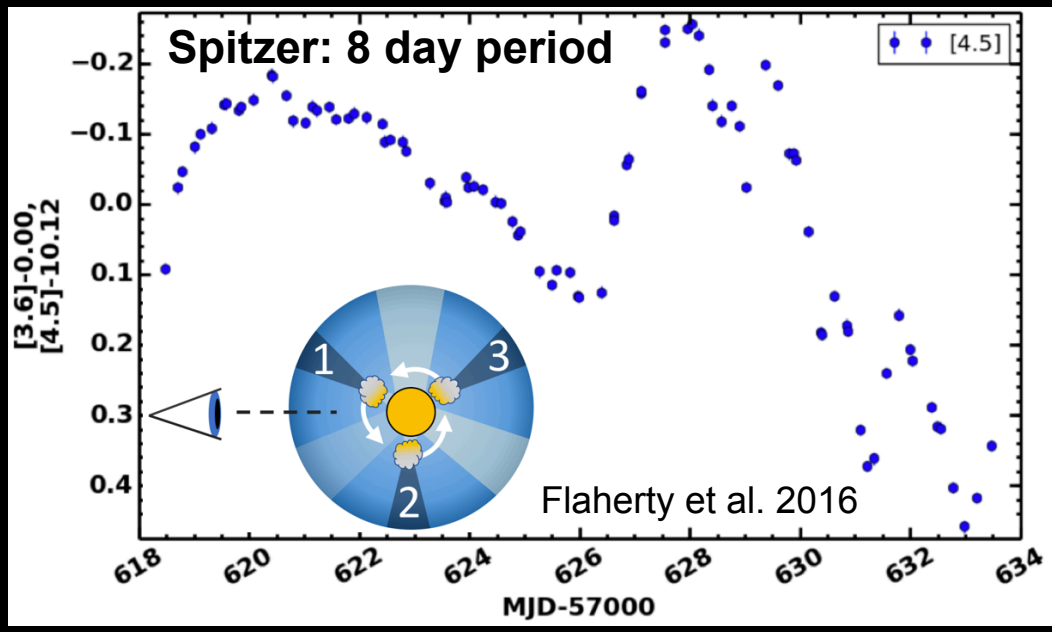
Habel et al. in prep

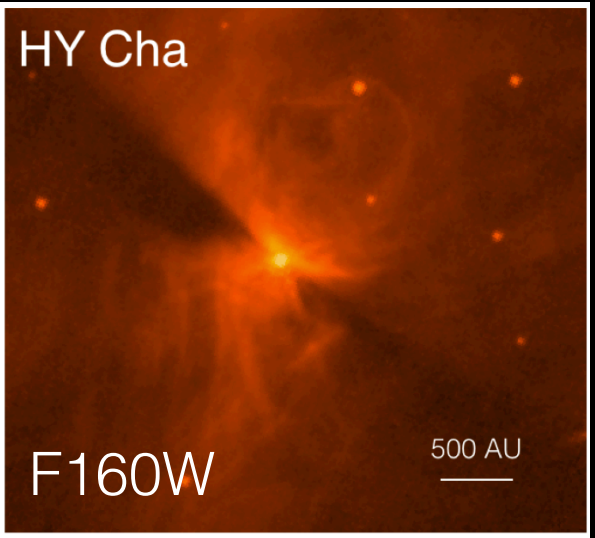
# Morphological Variability

25.4 day period, F160W

L54361

Muzerolle, Furlan, Flaherty, Balog, Gutermuth (2013)

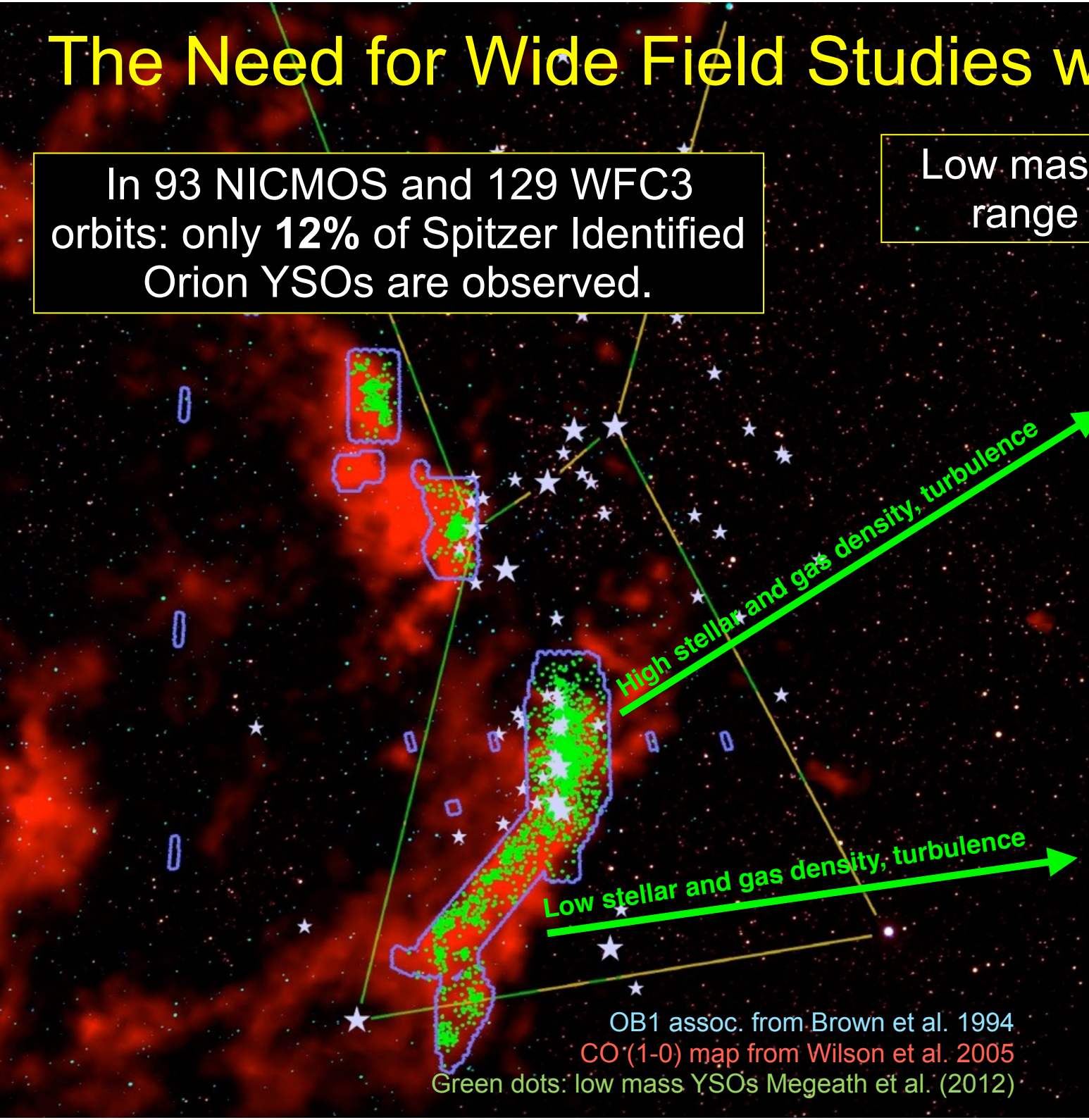


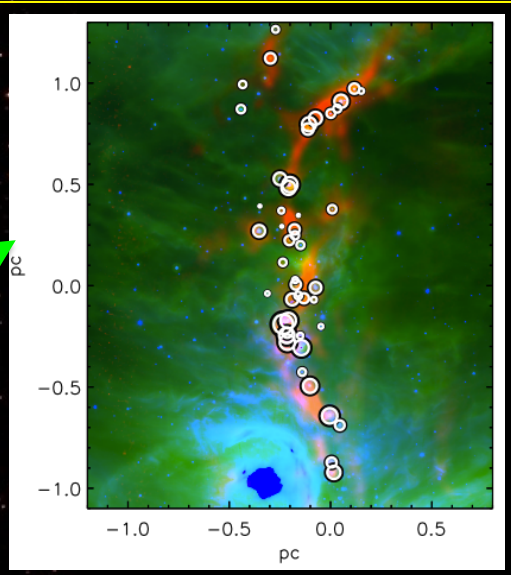



# The Need for Wide Field Studies with WFIRST

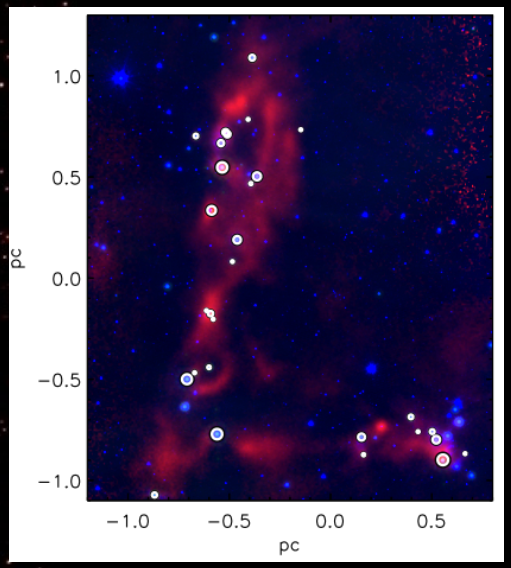
In 93 NICMOS and 129 WFC3 orbits: only **12%** of Spitzer Identified Orion YSOs are observed.

Low mass stars form in wide range of environments.



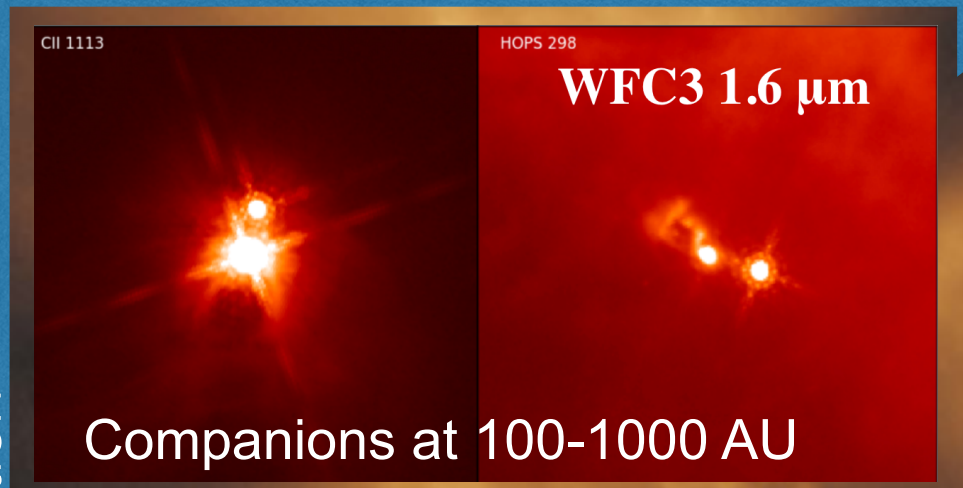

3.6 μm / 24 μm / 870 μm



# Higher Incidence of Multiples in Dense Regions

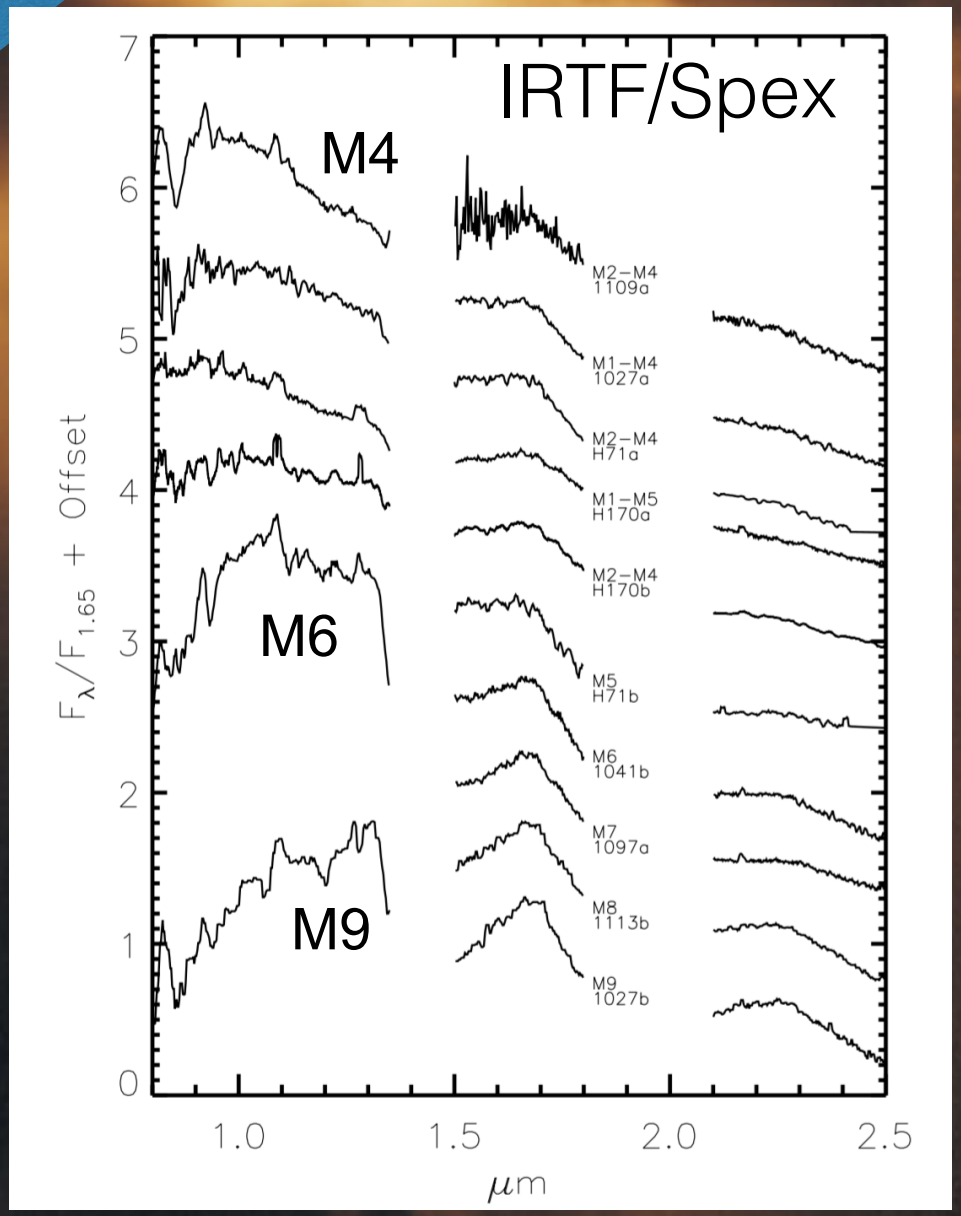
Environment

Evolution



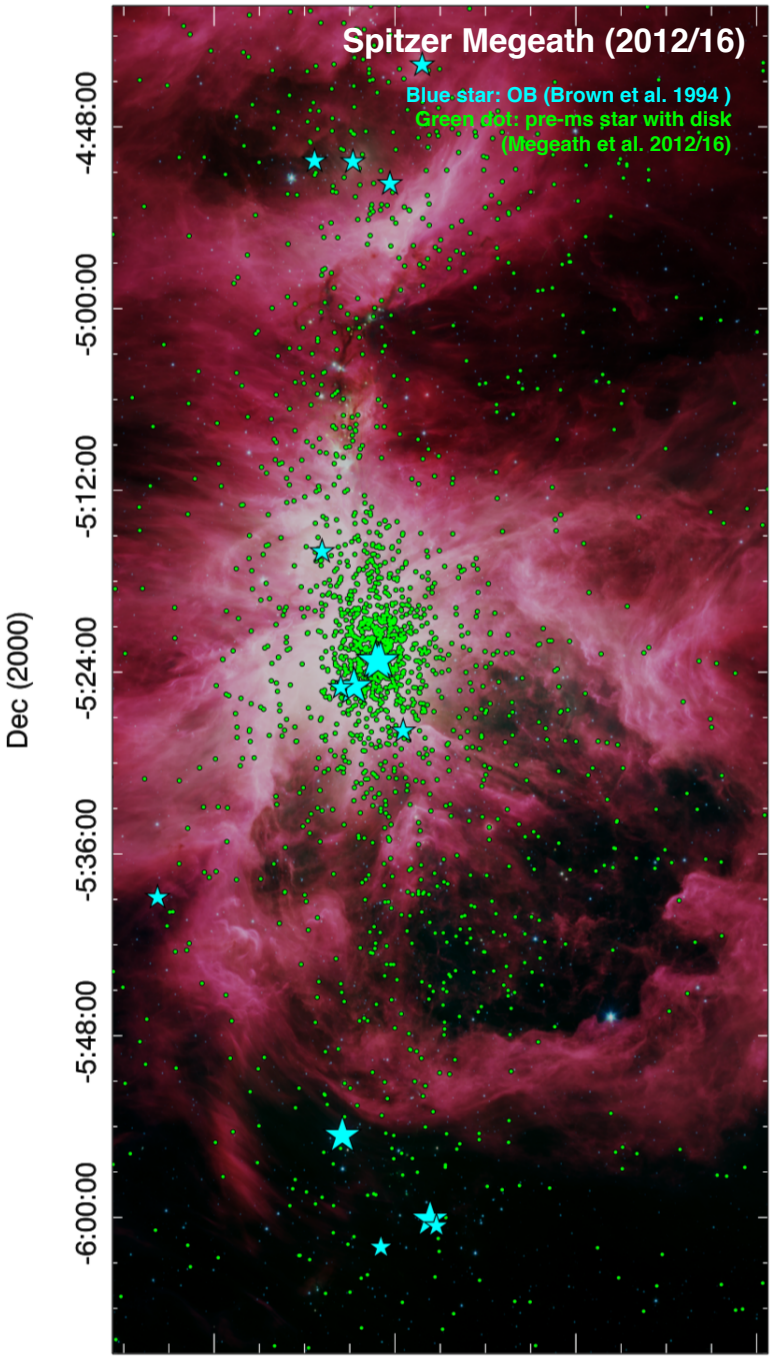

| | >45 pc$^{-2}$ (high) | < 45 pc$^{-2}$ (low) |
|---|---|---|
| Envir. Density | | |
| Proto stars | 19.2% | 10.8% |
| Pre-ms stars | 13.9% | 10.2% |
| Merged YSOs | 15.6% | 10.5% |

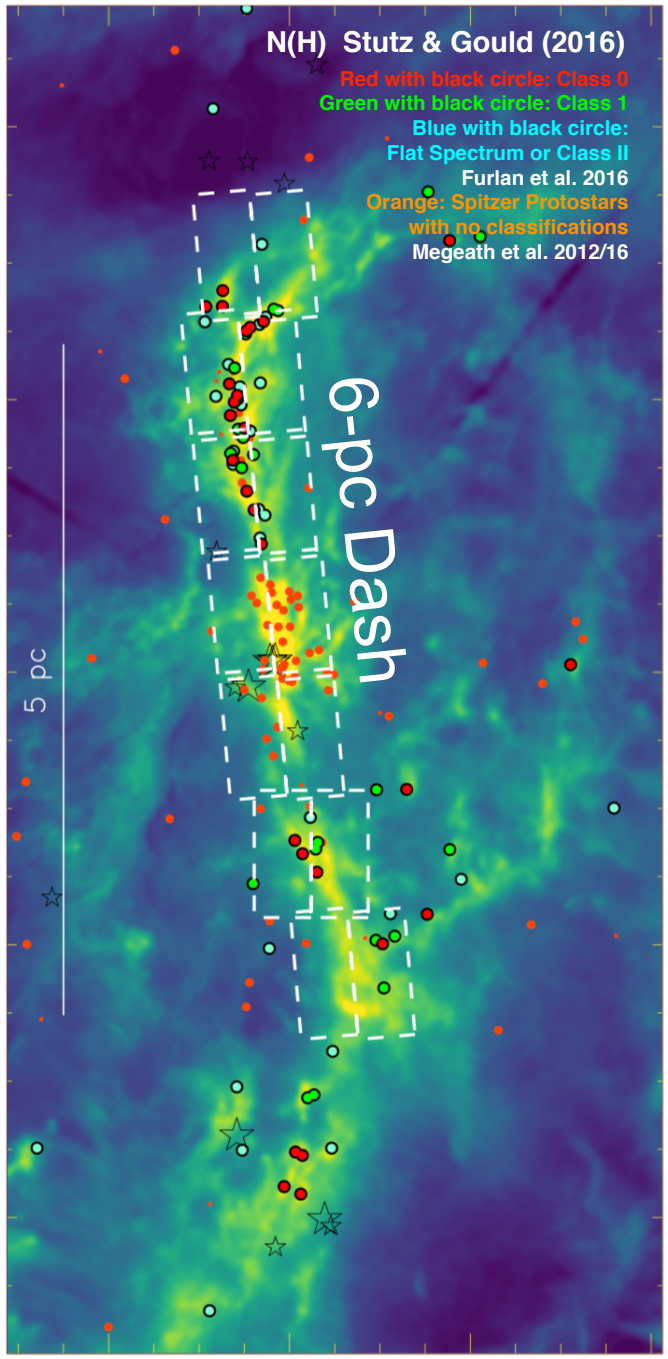
Kounkel et al. 2016



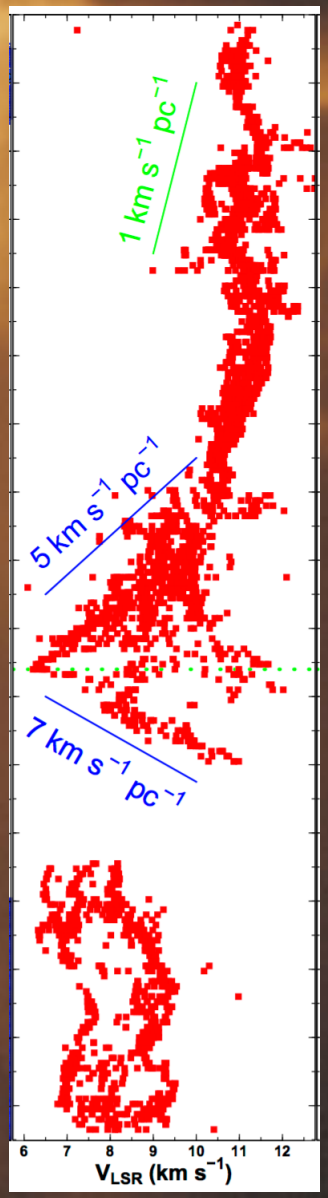

Mazur et al. in prep.

# Infall into the Orion Nebula Cluster?



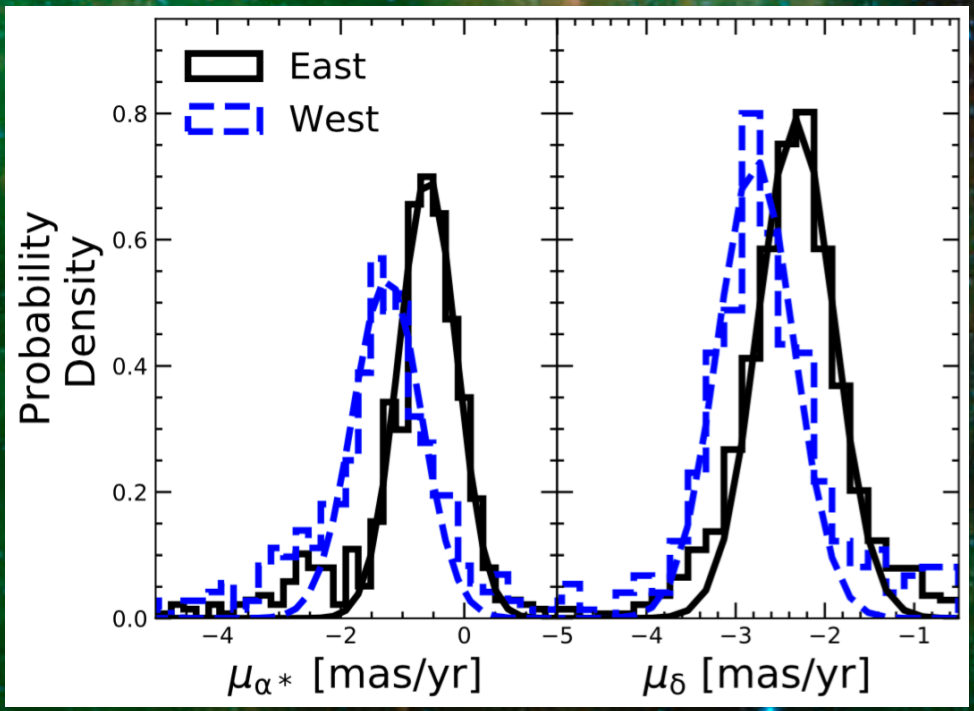

1 km s$^{-1}$ ~ 5 mas over 10 years



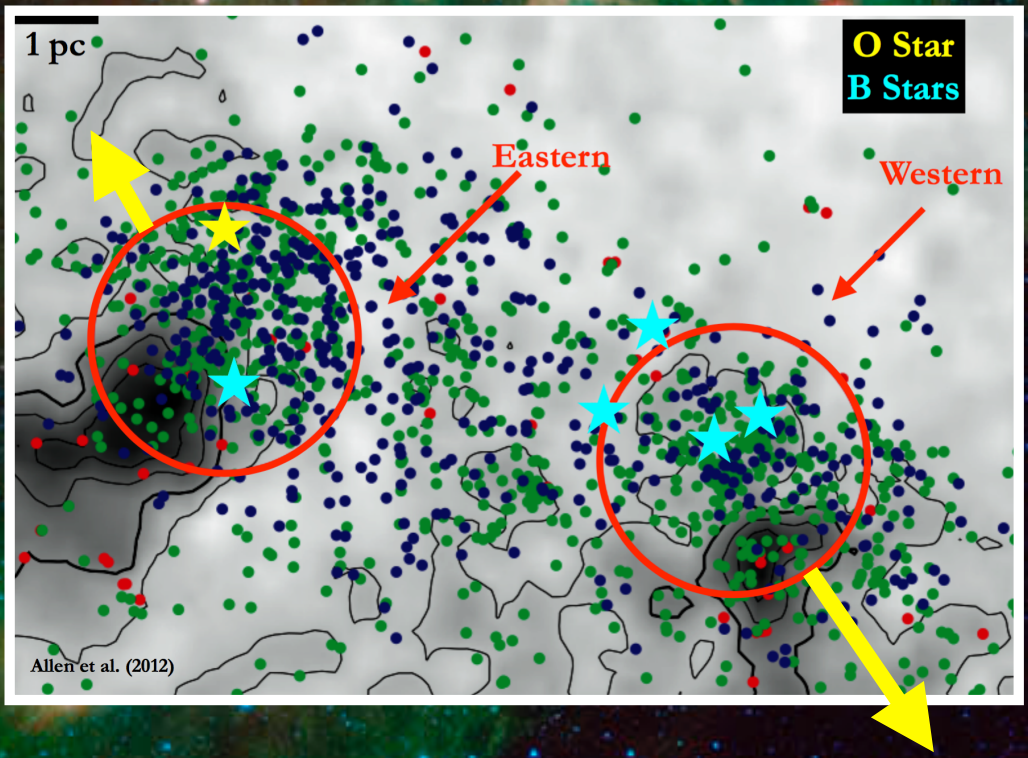

Hacar et al. 2017

# Gaia DR2 Parallaxes of Sub-Clusters in Cep OB3b

Gaia DR2: moving apart at 2 km $s^{-1}$

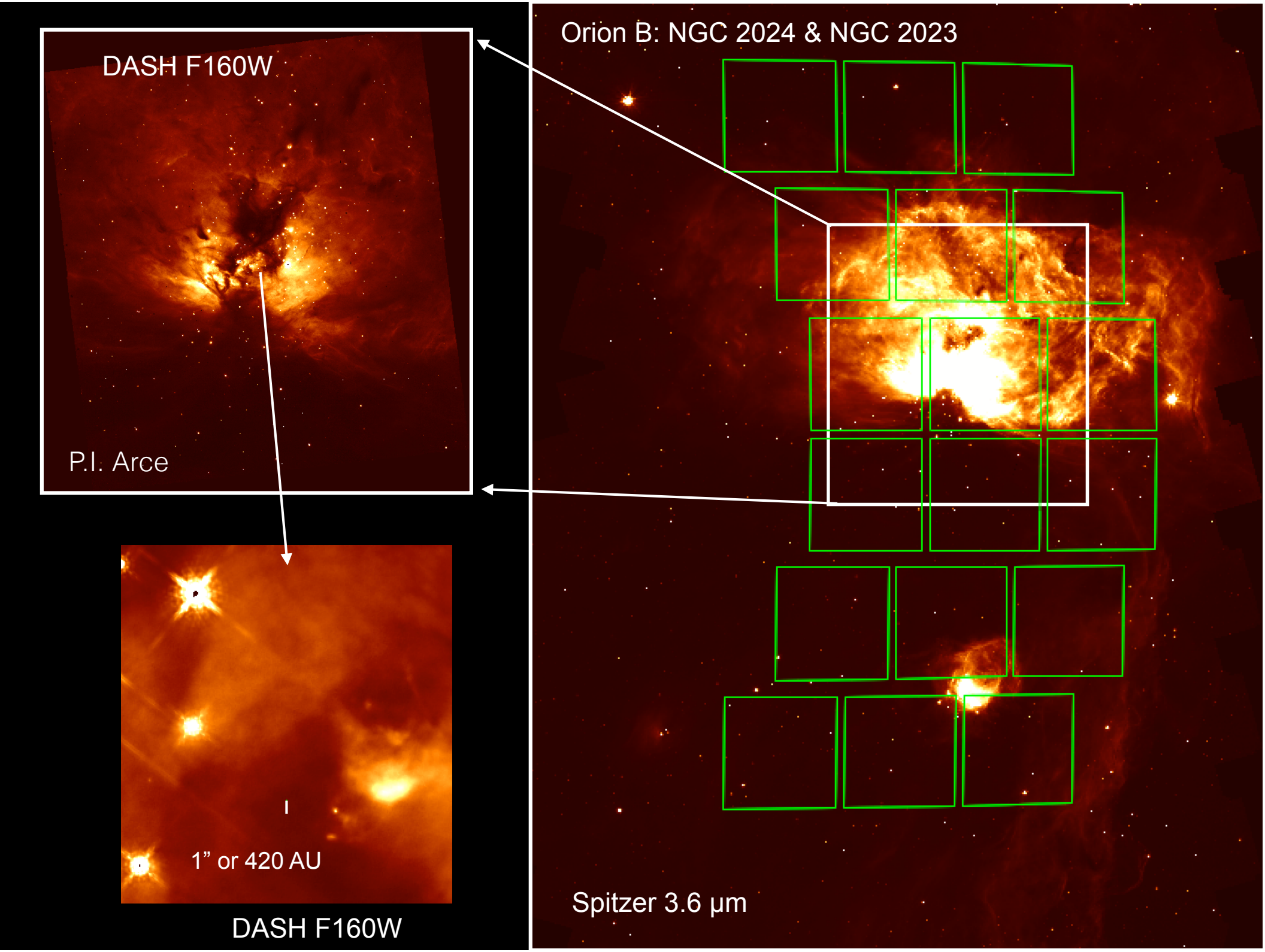



Spitzer+Chandra+2MASS

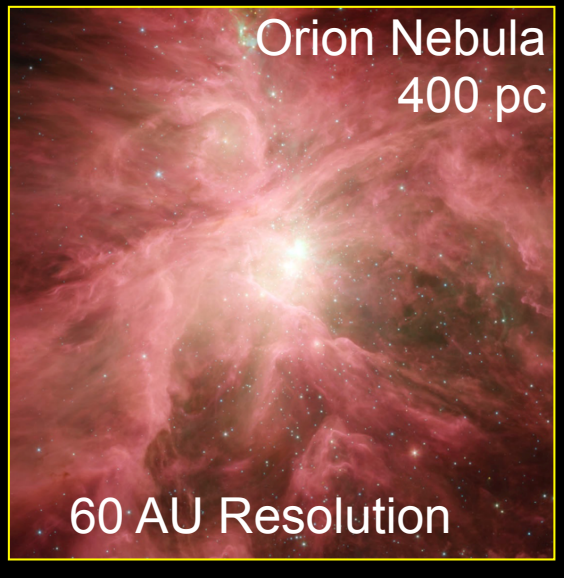


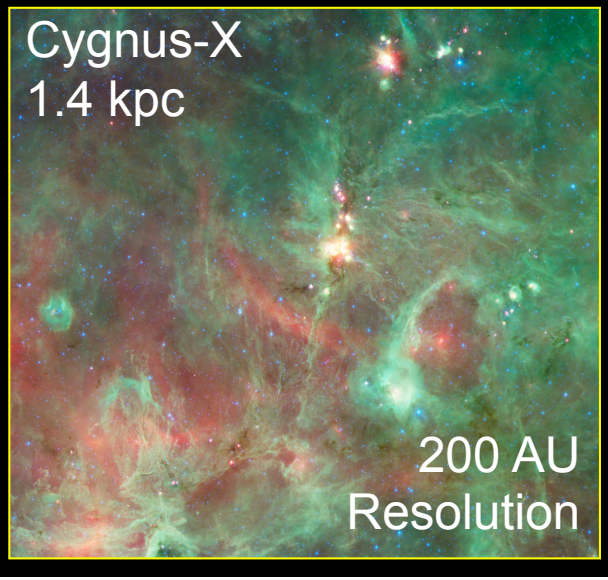

Spitzer MIPS/IRAC image

Karnath et al. 2019, Allen et al. 2012


Orion B: NGC 2024 & NGC 2023
DASH F160W
P.I. Arce
1" or 420 AU
DASH F160W
Spitzer 3.6 μm

Within 1.4 kpc, tens of thousands of dusty YSOs can be resolved and spectra obtained in a wide range of environments, these are a natural laboratory for low mass SF.

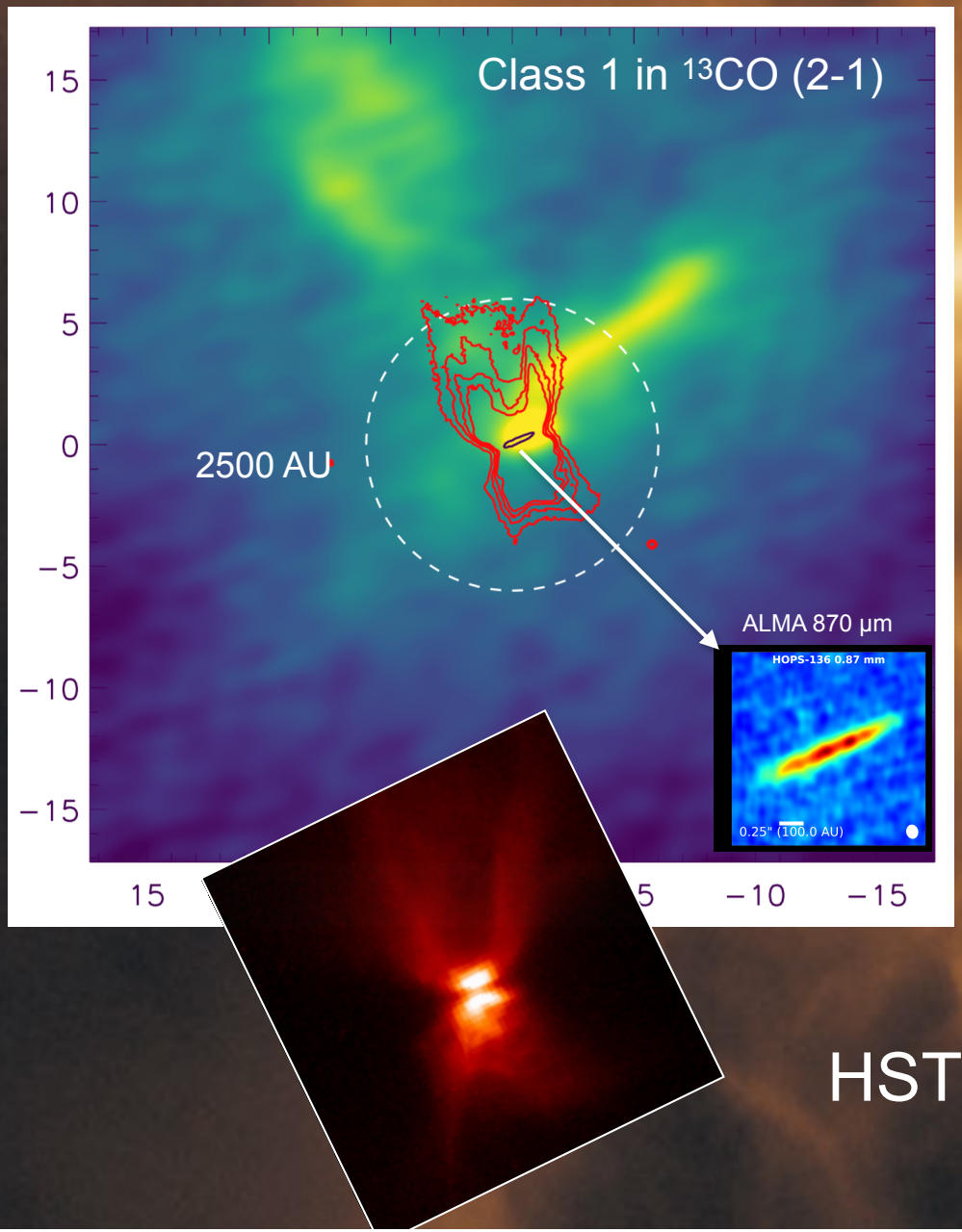


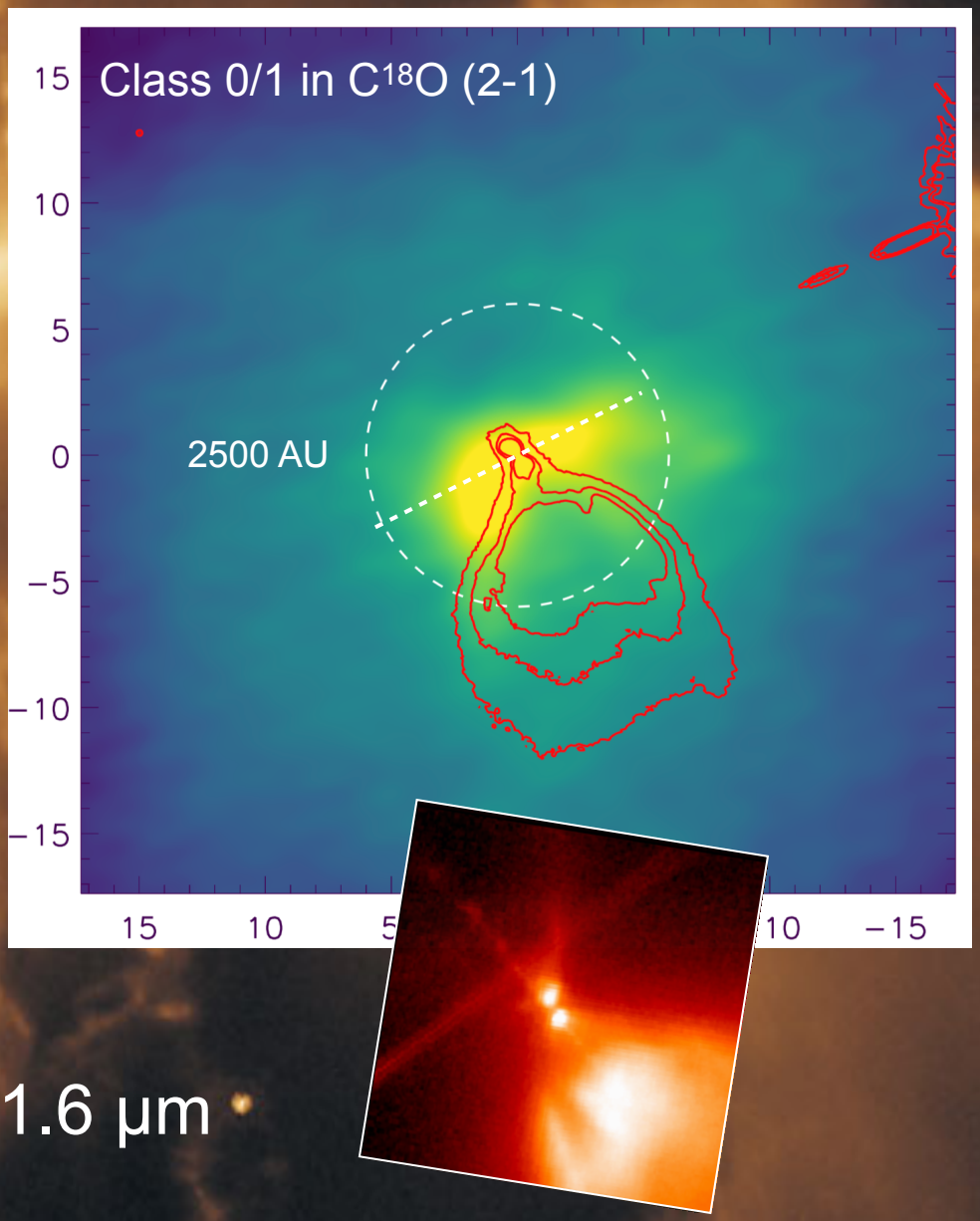

Extrapolate with
Model of Low Mass SF

# ALMA $^{13}CO$ and $C^{18}O$ Mapping of Isolated Orion Edge-on Protostars (12 m + ACA + TP)

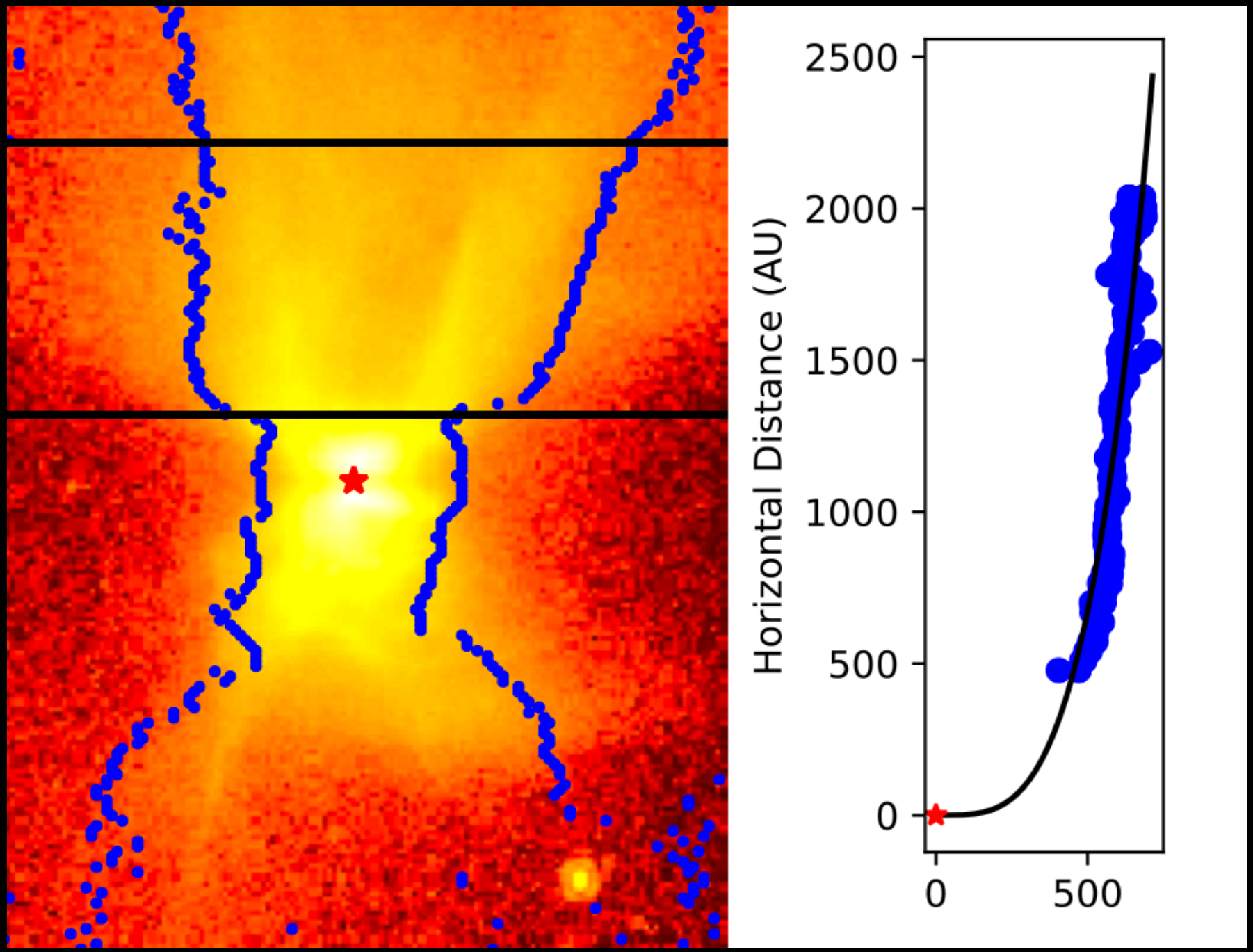
HOPS 136: Z. Nagy in prep.

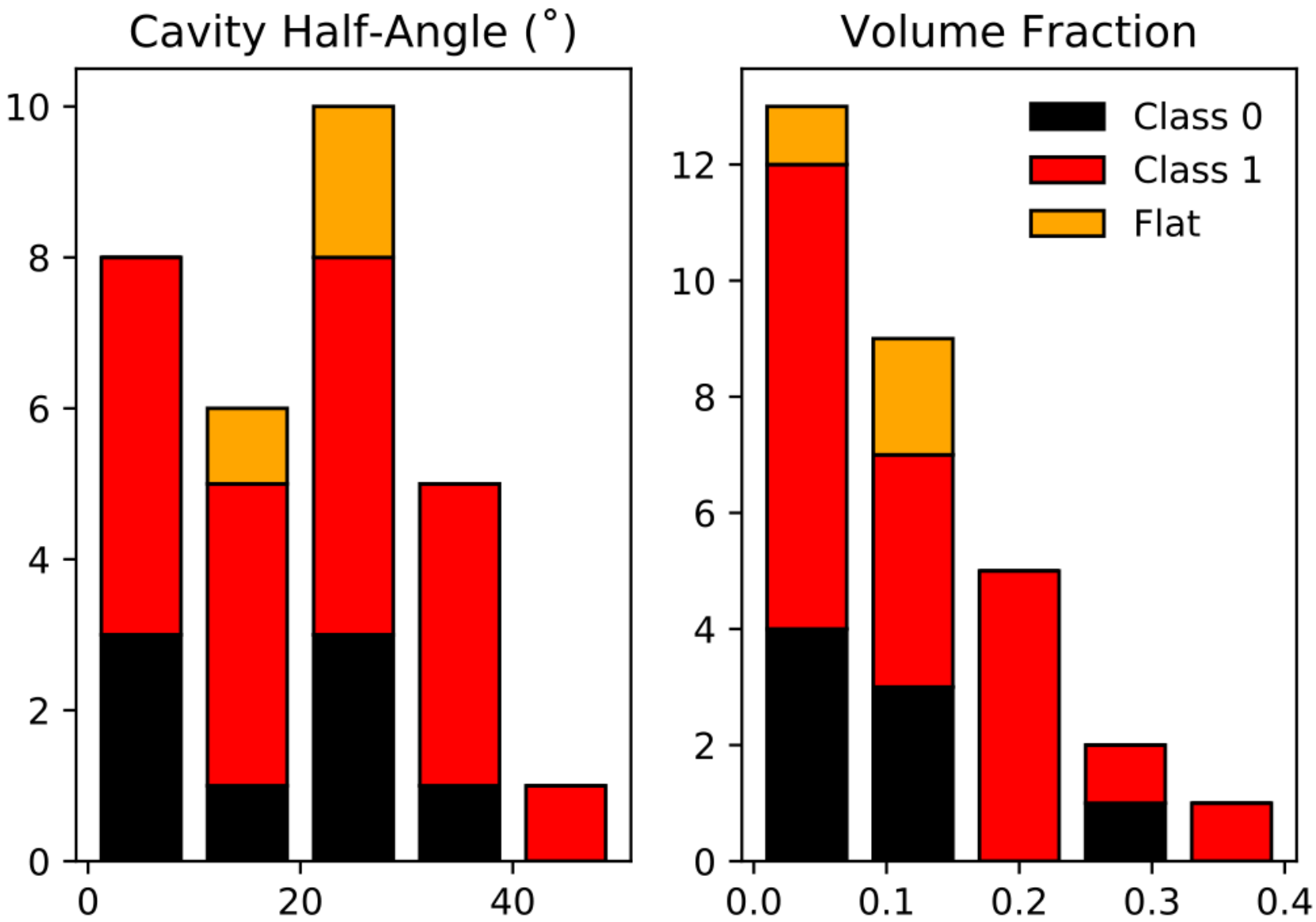


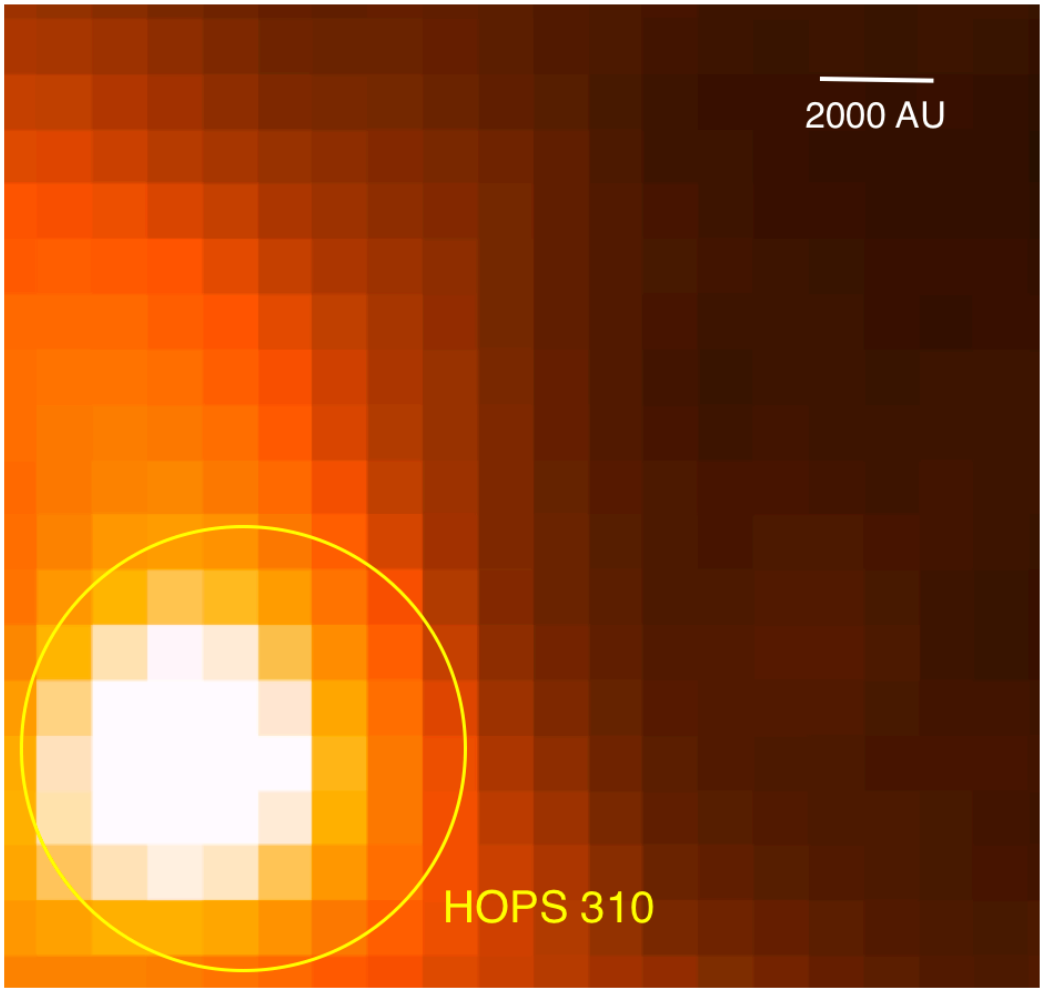

HOPS 171: J. Booker & Z. Nagy in prep.

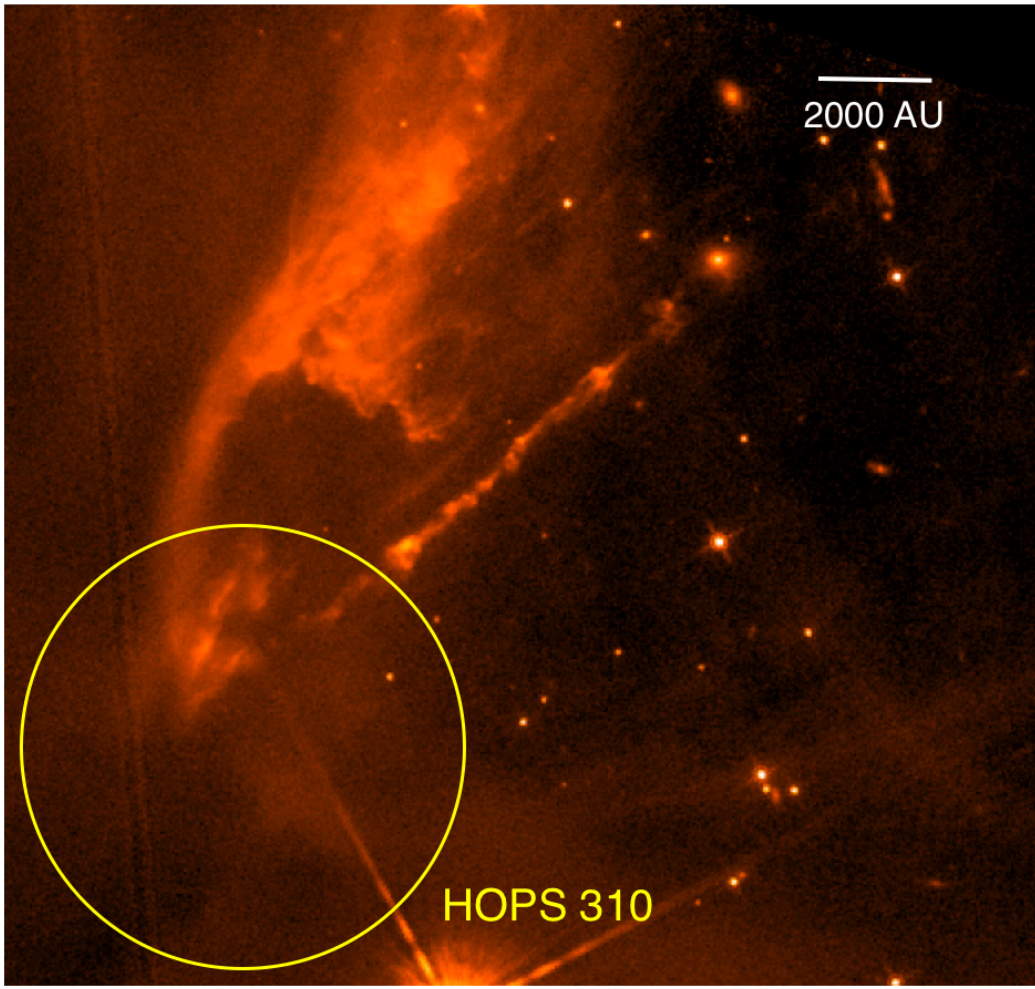


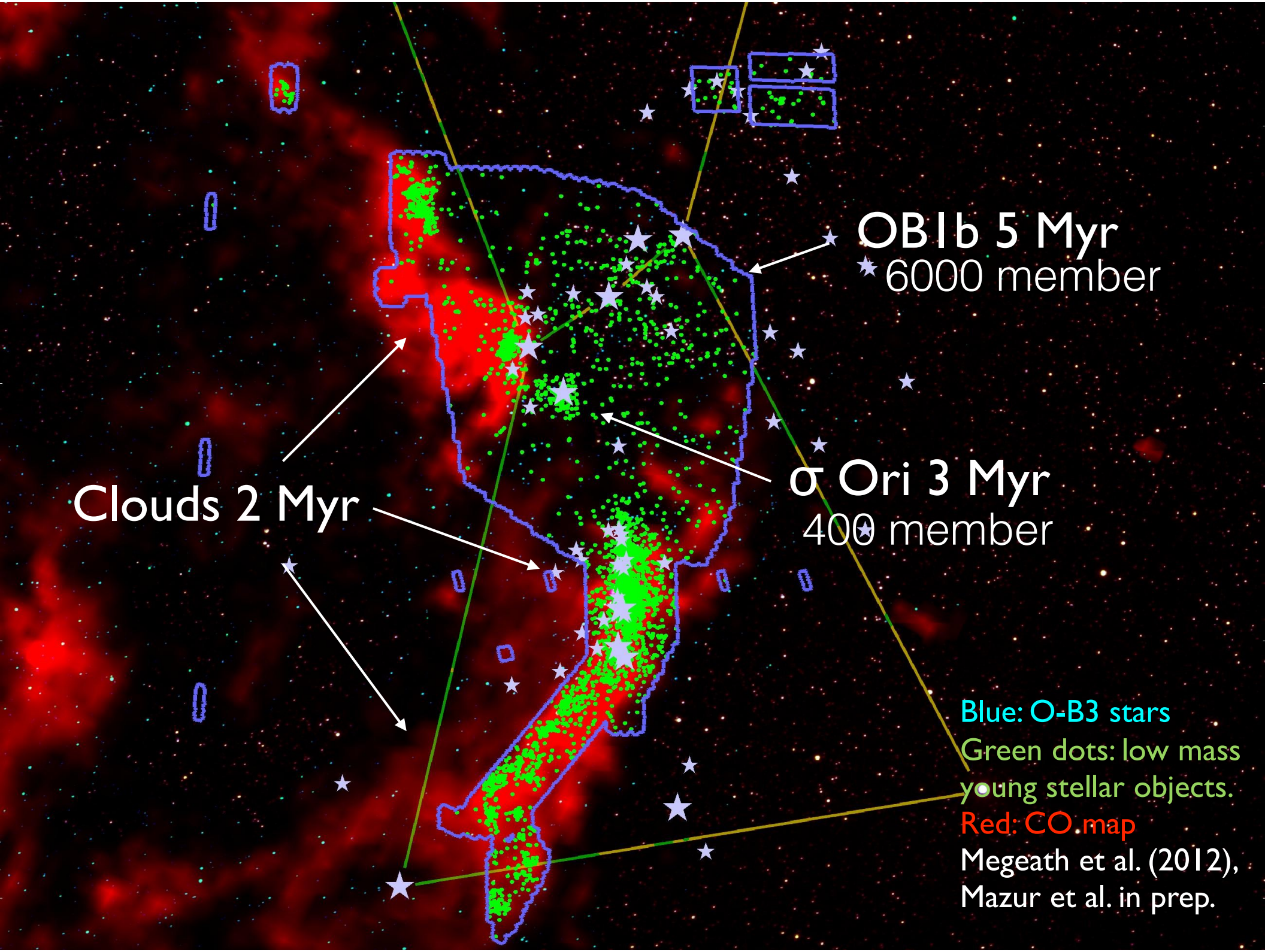
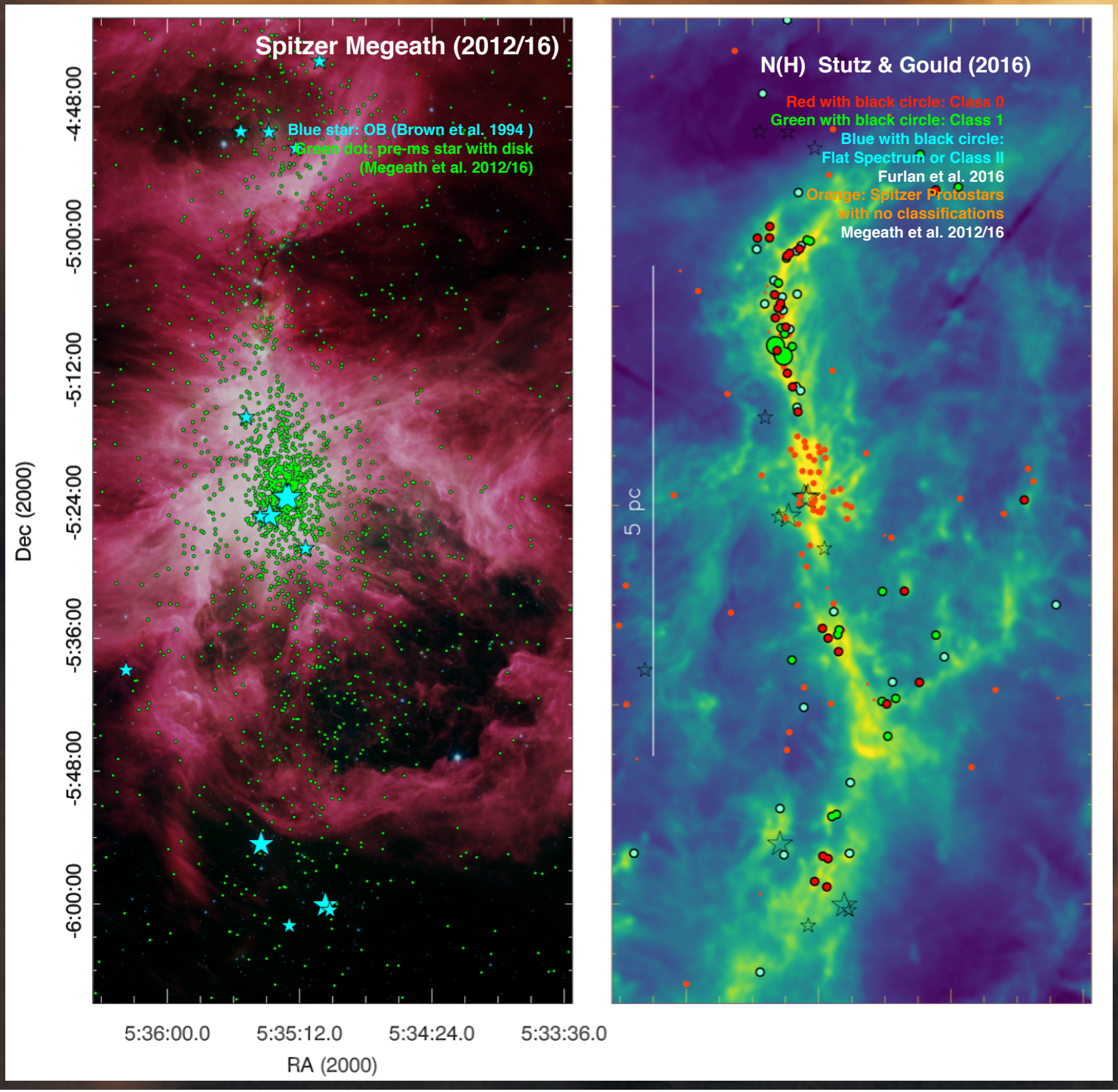
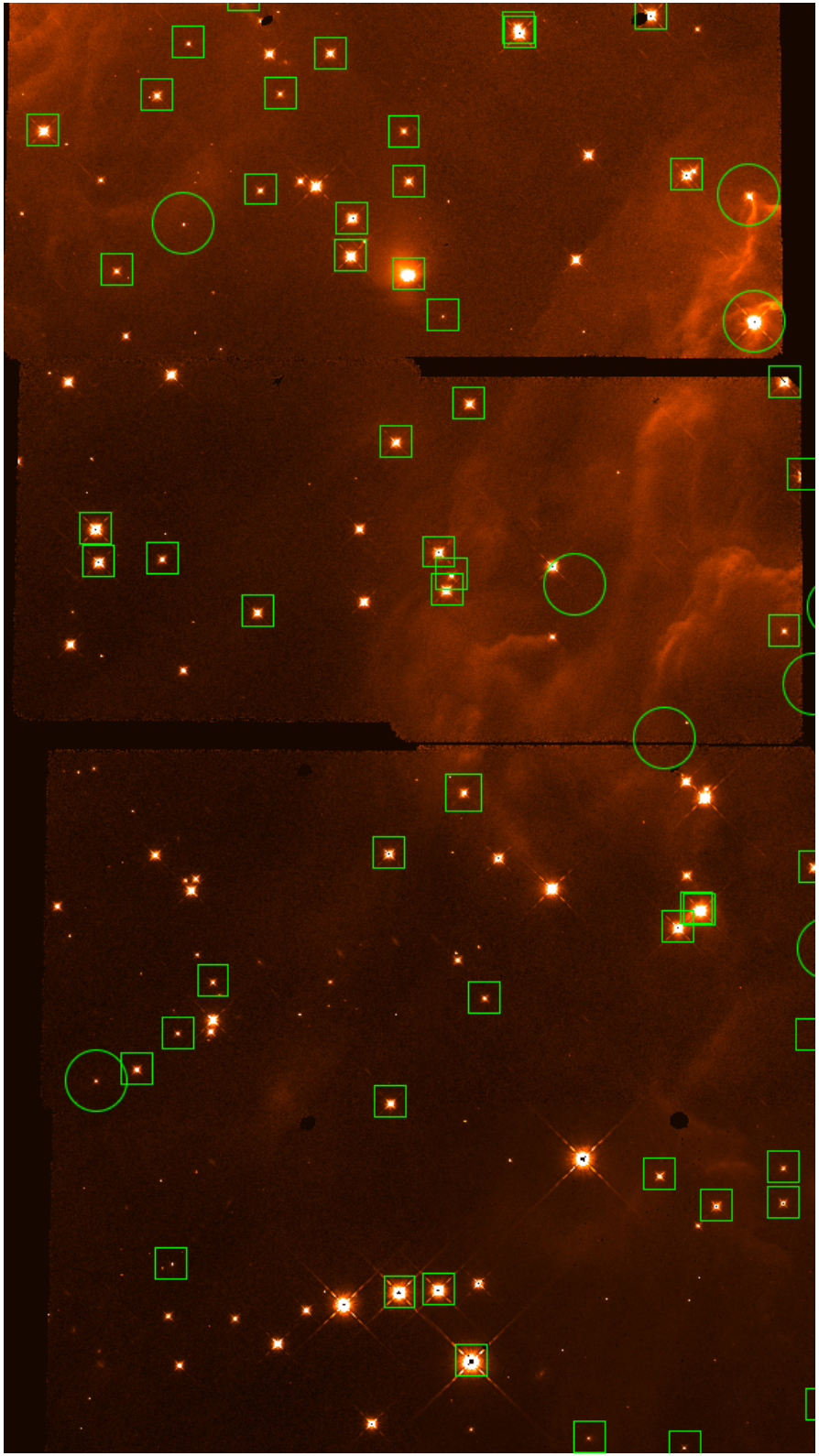
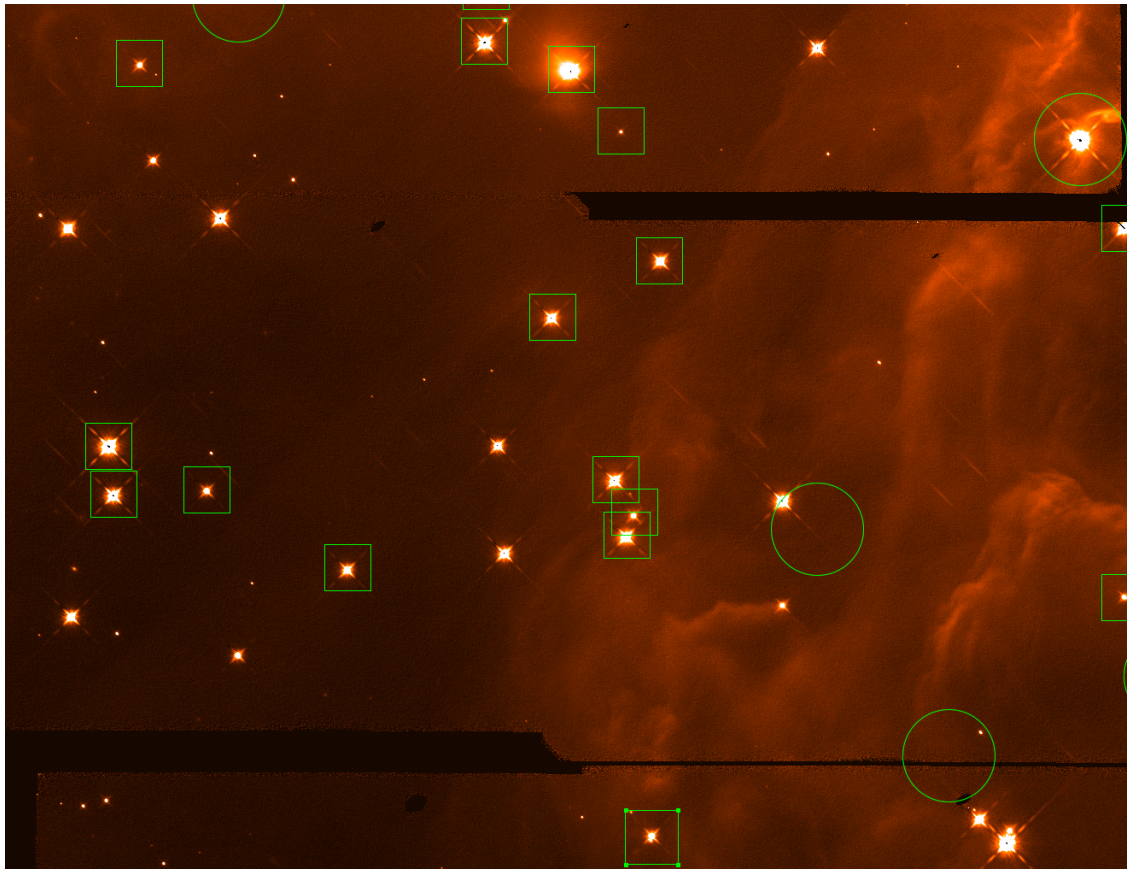
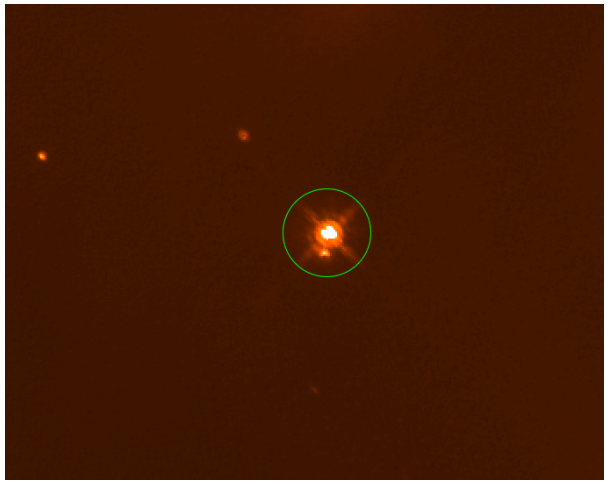

HST 1.6 μm


2500
2000
1500
1000
500
0
Horizontal Distance (AU)
0
500


Cavity Half-Angle (°)
Volume Fraction
Class 0
Class 1
Flat
0
2
4
6
8
10
12
0
20
40
0.0
0.1
0.2
0.3
0.4


2000 AU
HOPS 310


2000 AU
HOPS 310


OB1b 5 Myr
6000 member
σ Ori 3 Myr
400 member
Clouds 2 Myr
Blue: O-B3 stars
Green dots: low mass young stellar objects.
Red: CO map
Megeath et al. (2012), Mazur et al. in prep.

# The Importance of Extended Fields