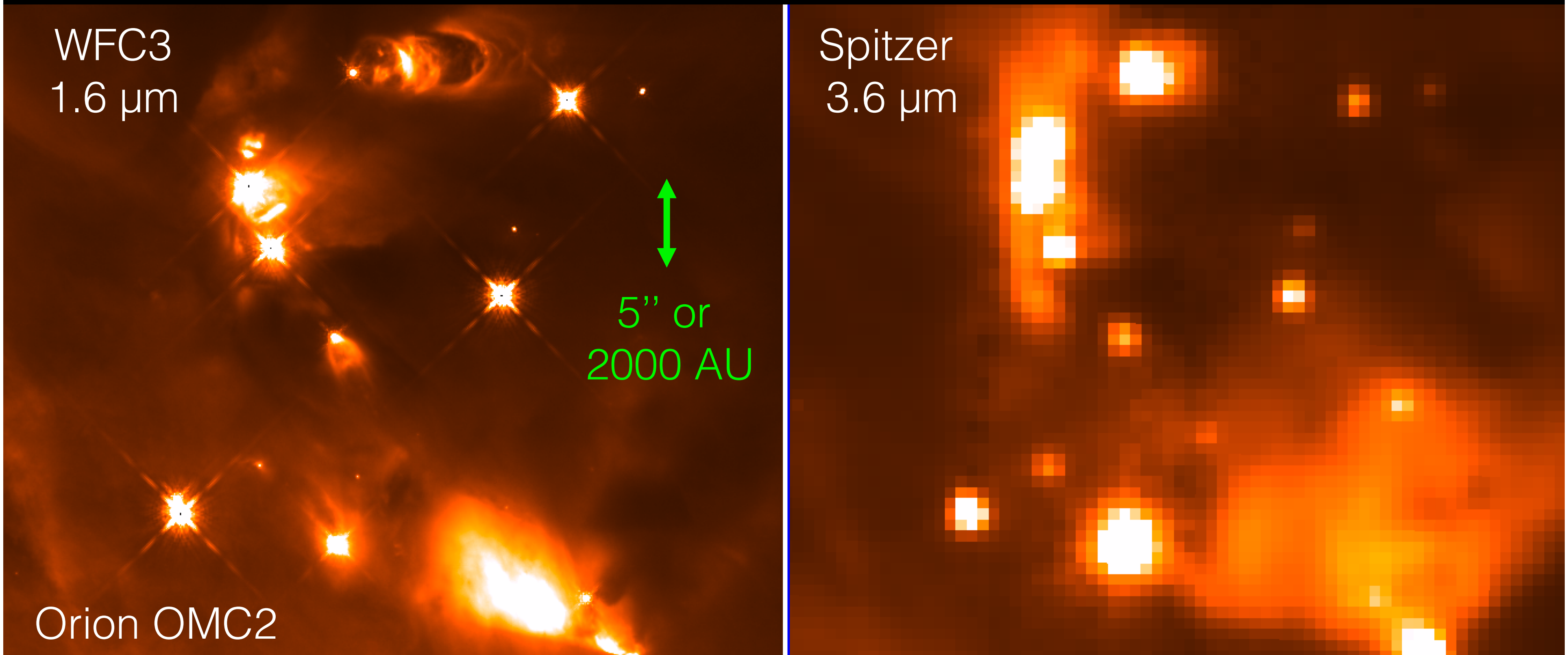
HST/WFC3 Surveys of Nearby Molecular Clouds: A Pathfinder for WFIRST Observations of Star Formation in the Nearest 2 kpc



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Rob Gutermuth (U. Mass)
Will Fischer (GSFC)
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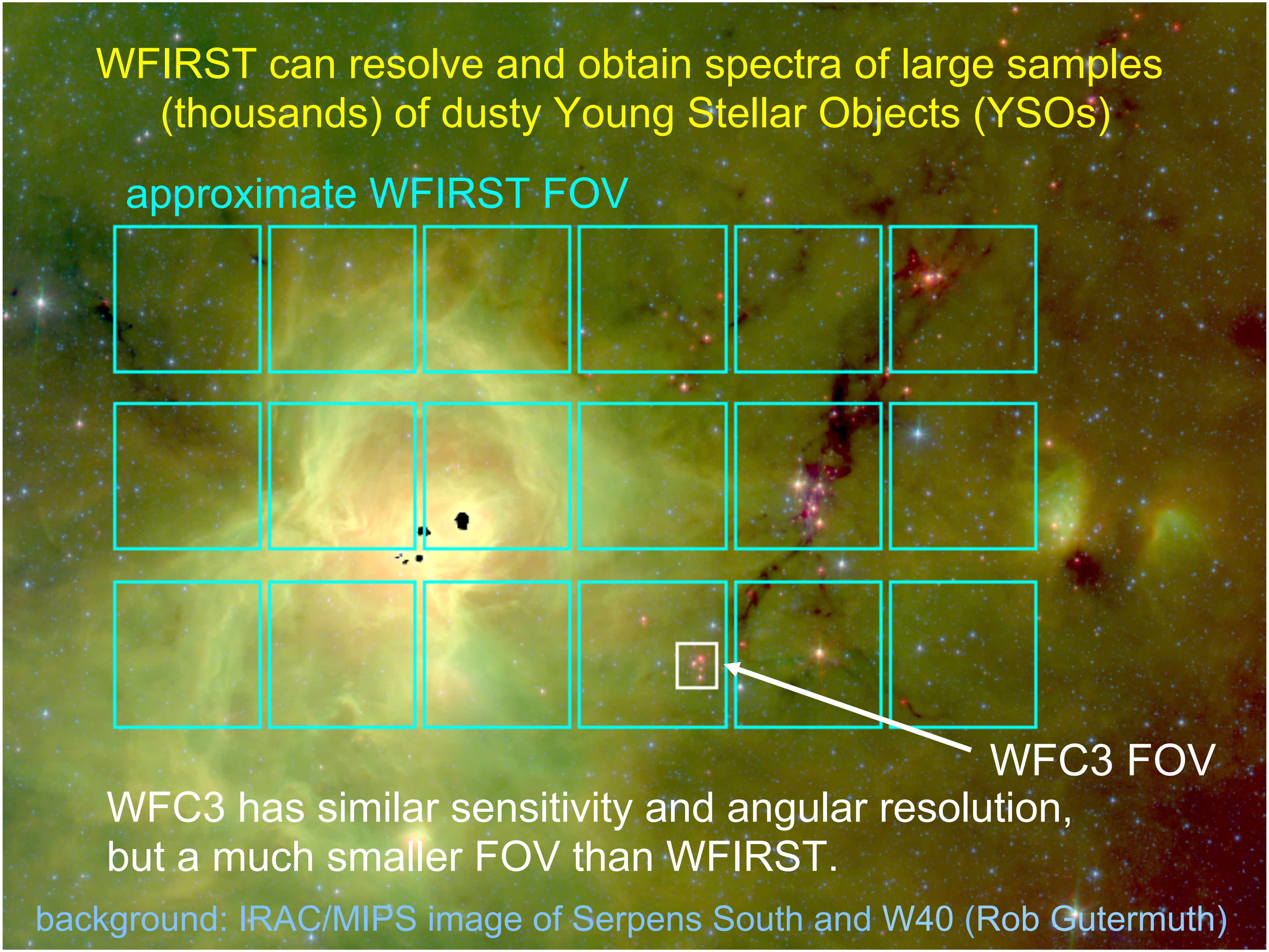
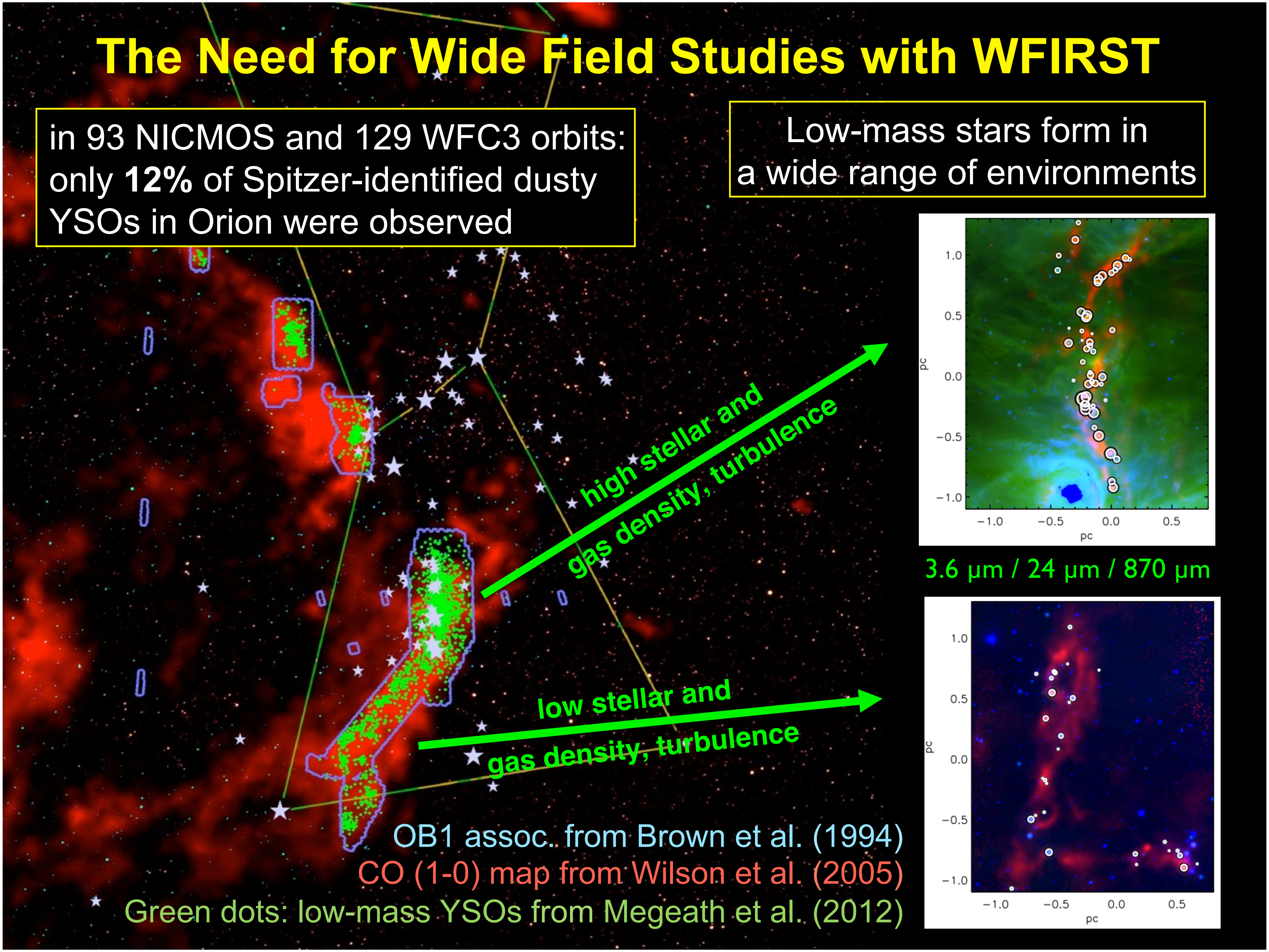
J. J. Booker (U. of Toledo)
Brian Mazur (U. of Toledo)
Zsofia Nagy (U. of Toledo)
Marina Kounkel (U. Michigan)

HERSCHEL ORION PROTOSTAR SURVEY


WFIRST can resolve and obtain spectra of large samples (thousands) of dusty Young Stellar Objects (YSOs)
approximate WFIRST FOV
WFC3 FOV
WFC3 has similar sensitivity and angular resolution, but a much smaller FOV than WFIRST.
background: IRAC/MIPS image of Serpens South and W40 (Rob Gutermuth)


The Need for Wide Field Studies with WFIRST
in 93 NICMOS and 129 WFC3 orbits: only 12% of Spitzer-identified dusty YSOs in Orion were observed
Low-mass stars form in a wide range of environments
high stellar and gas density, turbulence
low stellar and gas density, turbulence
3.6 µm / 24 µm / 870 µm
pc
OB1 assoc. from Brown et al. (1994)
CO (1-0) map from Wilson et al. (2005)
Green dots: low-mass YSOs from Megeath et al. (2012)

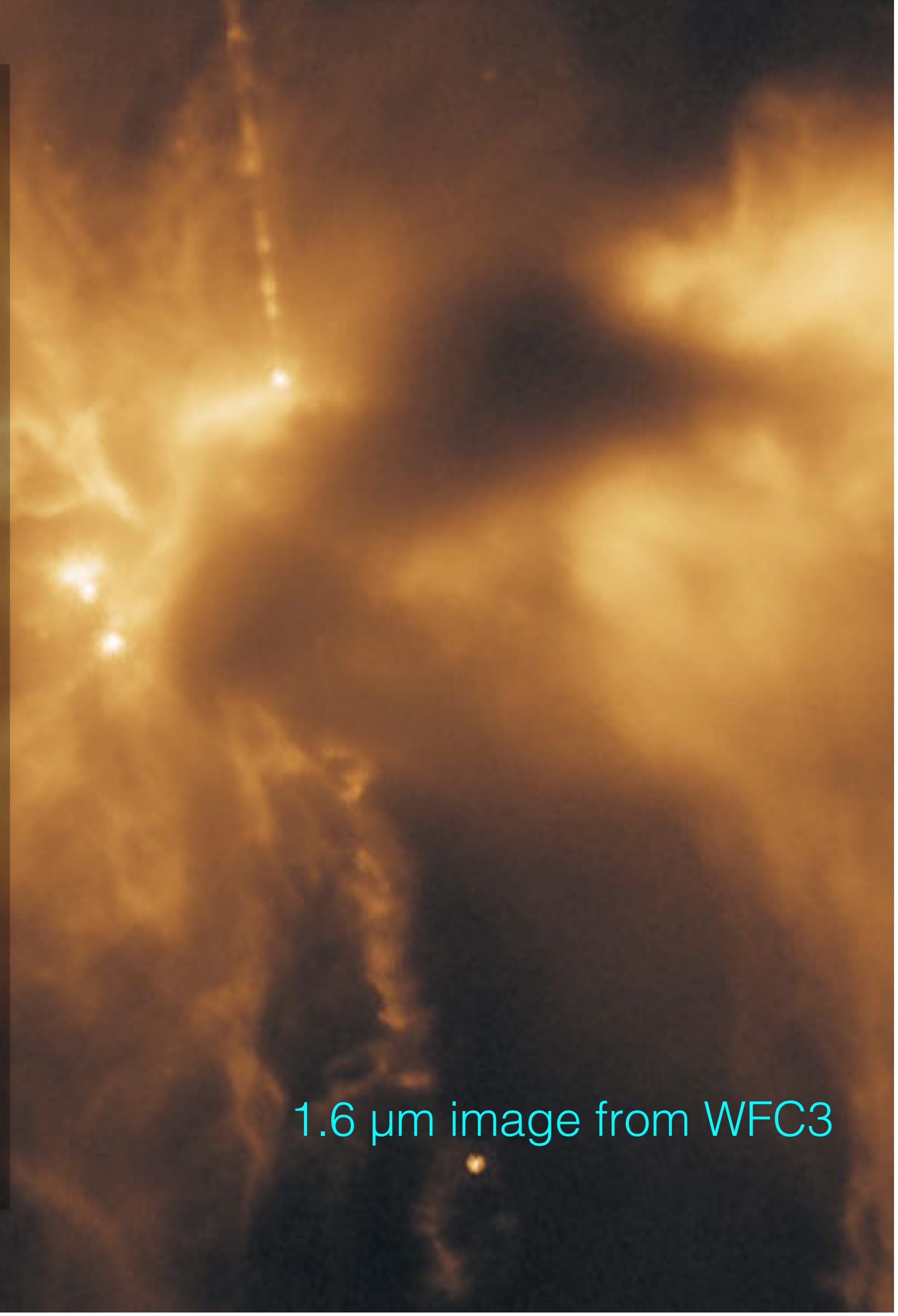
The Importance of Low-Mass Star Formation

Dominant form of star formation: low-mass stars dominate mass and numbers. (The Universe is an M-star factory!)

The formation of potentially habitable planets is a by-product of low-mass star formation.

Processes that control the assembly of mass, multiplicity, and the properties of disks are poorly understood.

These processes can only be studied in nearby (< 2 kpc) star-forming regions.



1.6 μm image from WFC3

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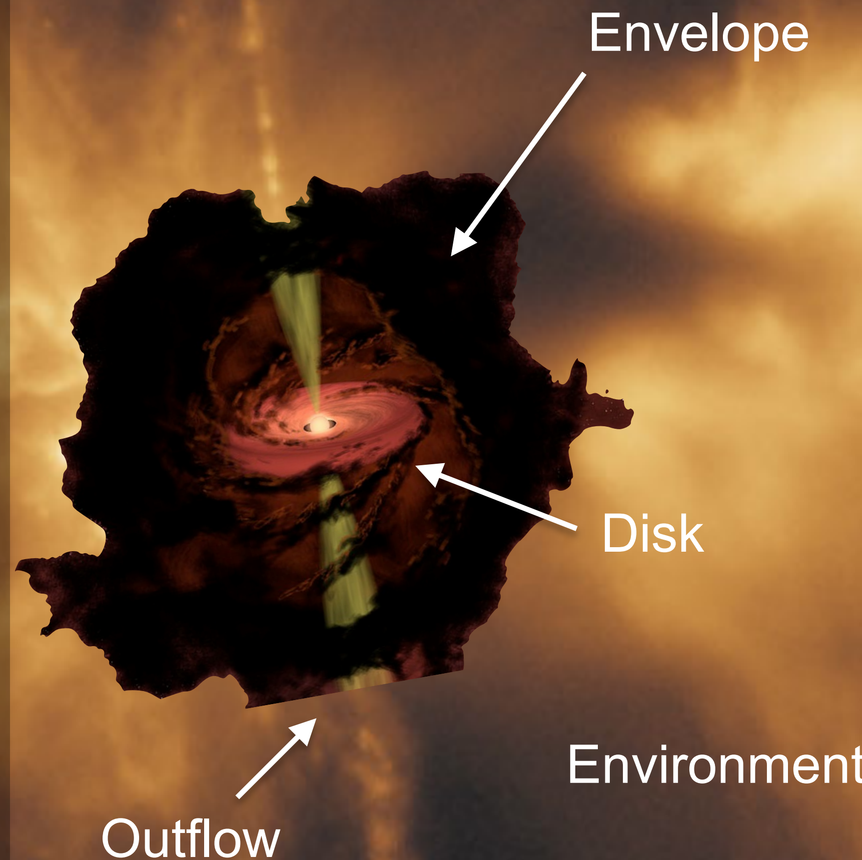
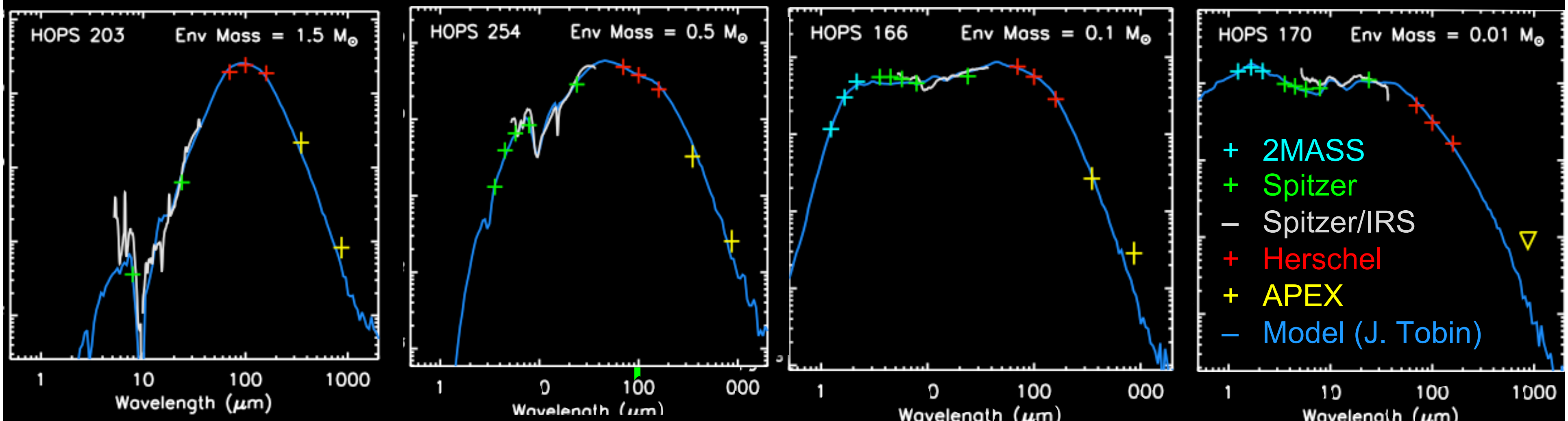


1.6 μm image from WFC3

Artist conception by Robert Hurt

Protostellar Evolution in SEDs & Images

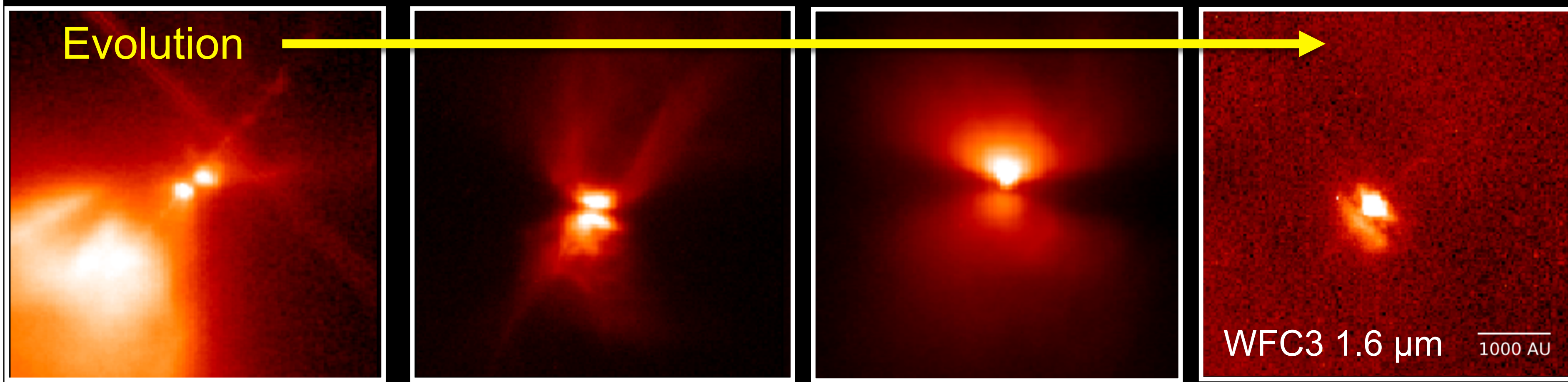


Class 0 Protostar

Class I Protostar

Flat-spectrum Protostar

Pre-main-sequence star with disk



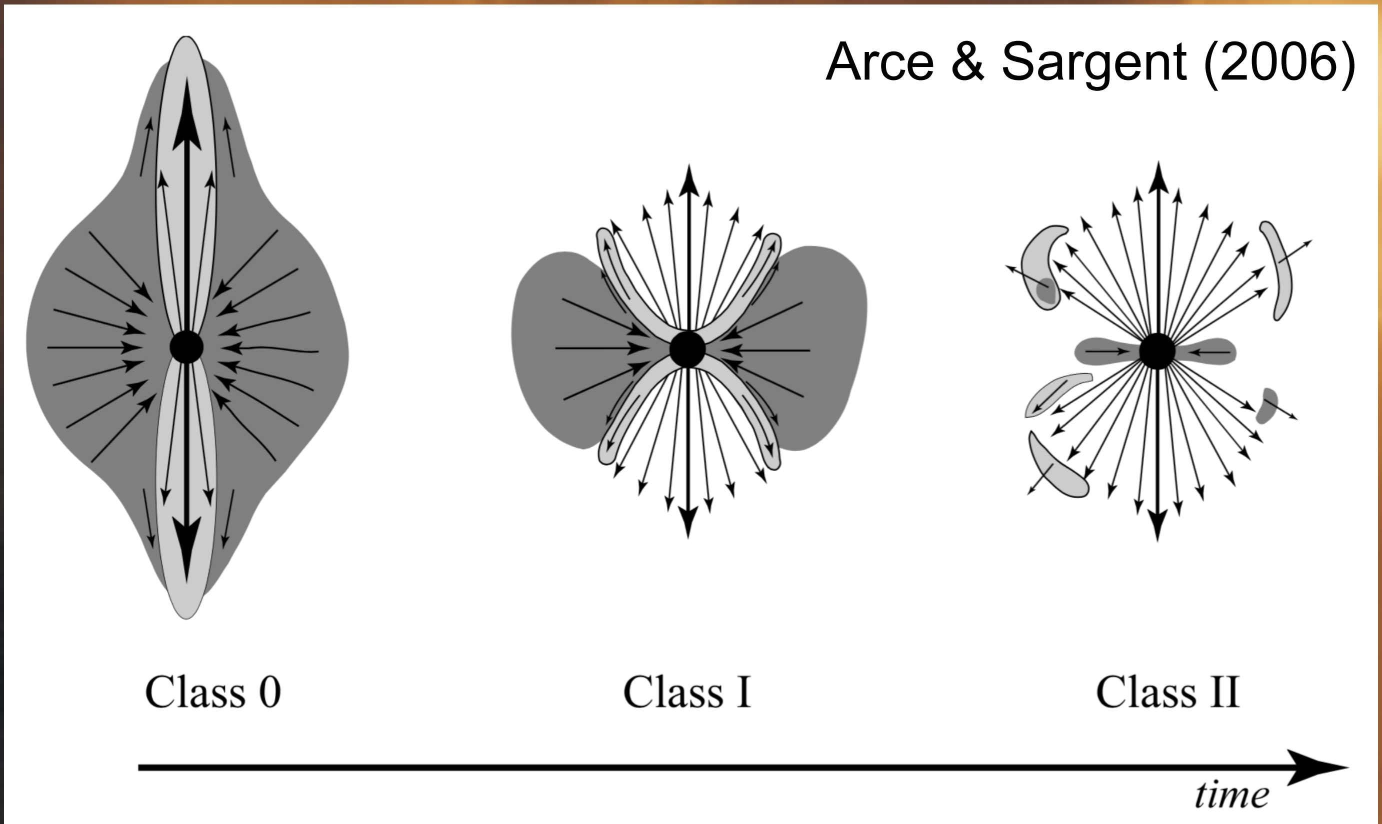
HERSCHEL ORION PROTOSTAR SURVEY

Manoj et al. (2013)
Stutz et al. (2013)

Fischer et al. (2014)
Furlan et al. (2016)

Kounkel et al. (2016)
Booker et al. in prep.

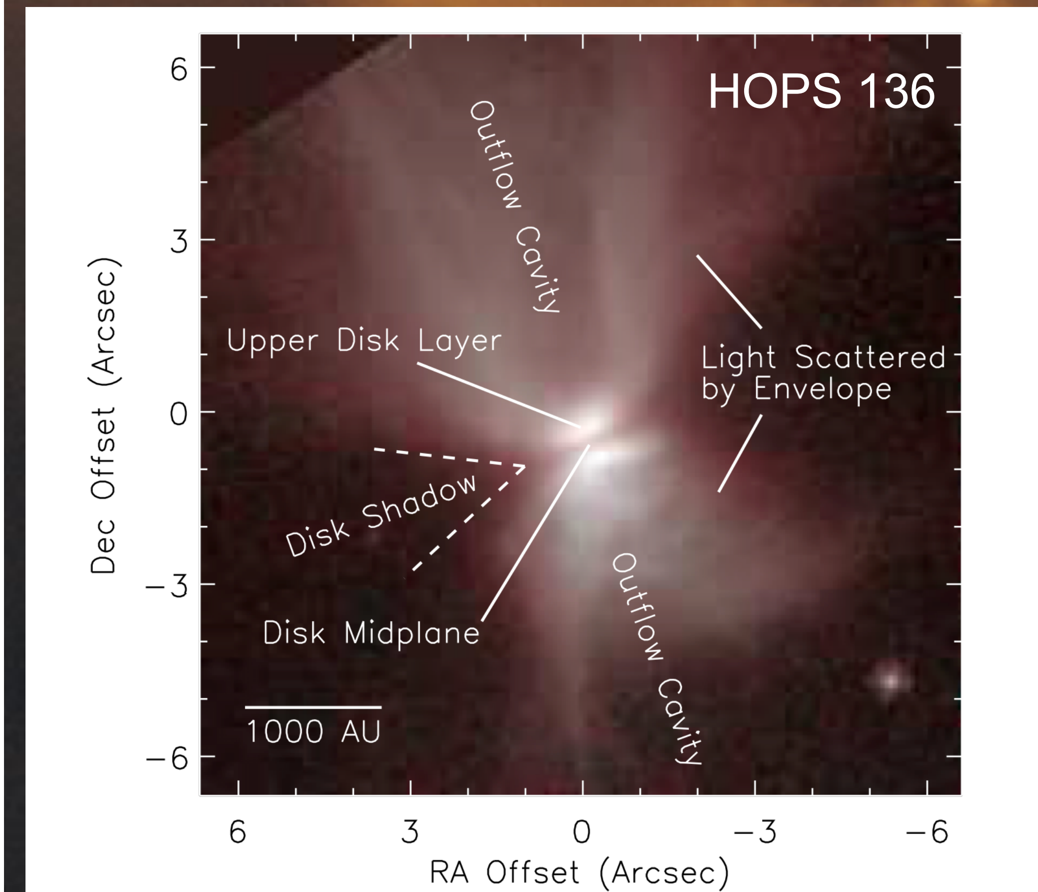
Why is star formation so inefficient?
What halts the infall of gas onto protostars?

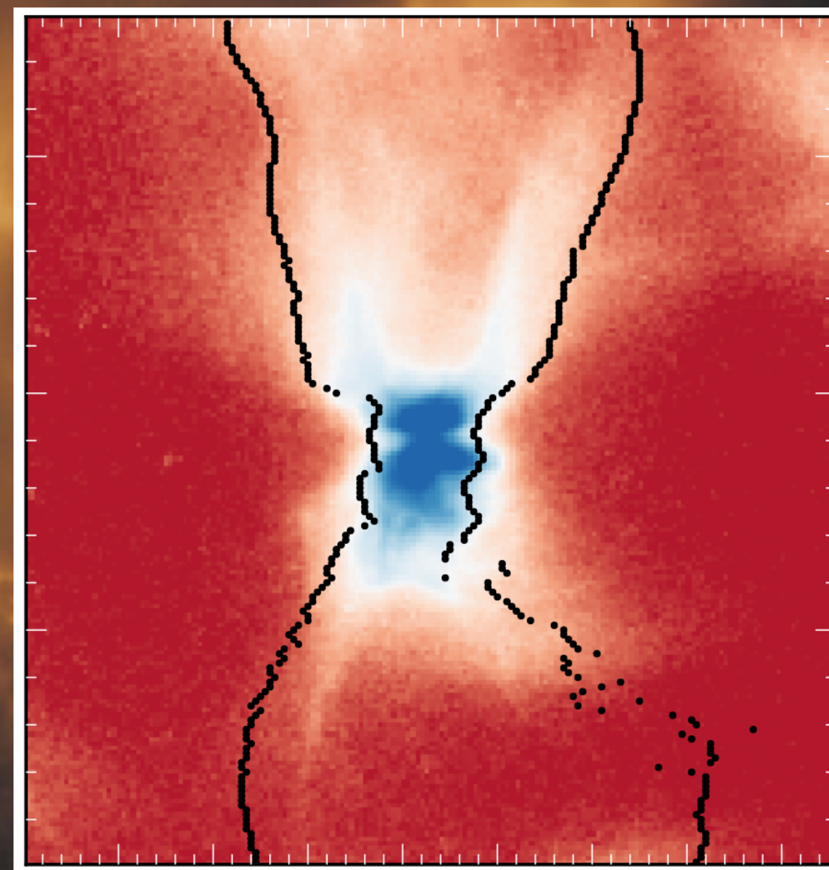


Current picture: clearing by outflows stops infall/accretion and contributes to inefficiency.

Scattered Light Cavities as a Measure of Envelope Clearing by Outflows

NICMOS 1.6 and 2.05 μm





Fischer et al. (2014)

Booker et al. in prep.

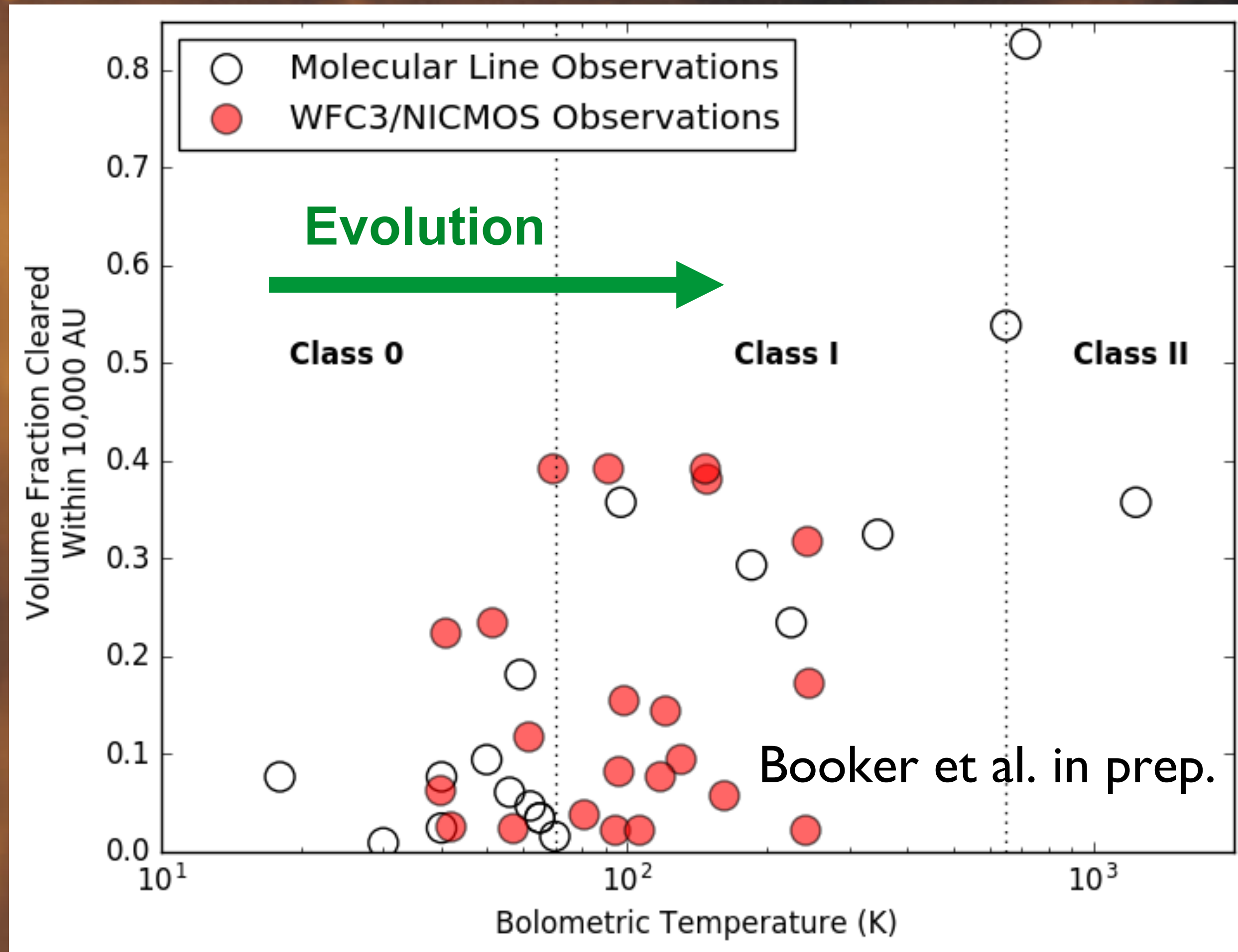
Use 1.6 μm images to measure outflow cavities

Do Outflows Clear Envelopes?

No evidence of progressive clearing

Protostars with evolved envelopes can have narrow cavities.

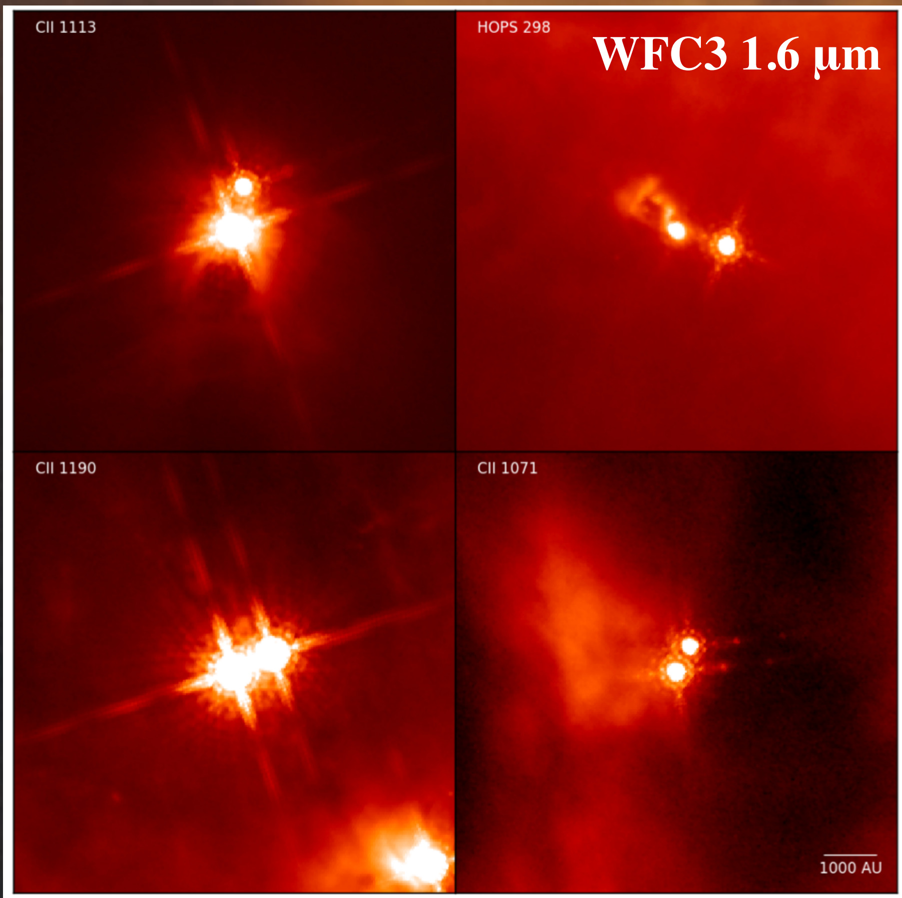
HST answer: *probably not*



Cavities can be mapped around 10% of protostars with favorable inclinations and envelope densities.
Need larger samples spanning larger range of luminosities.

Evidence that Multiplicity Depends on Formation Environment

Companion fraction between 100 and 1000 AU



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

+/- 1-2% uncertainty (due to line-of-sight contaminant subtraction)

Kounkel et al. (2016)

Evidence of enhanced formation of companions in dense environments. Large samples needed to rule out random fluctuations with high significance.

How Do Companions Form?

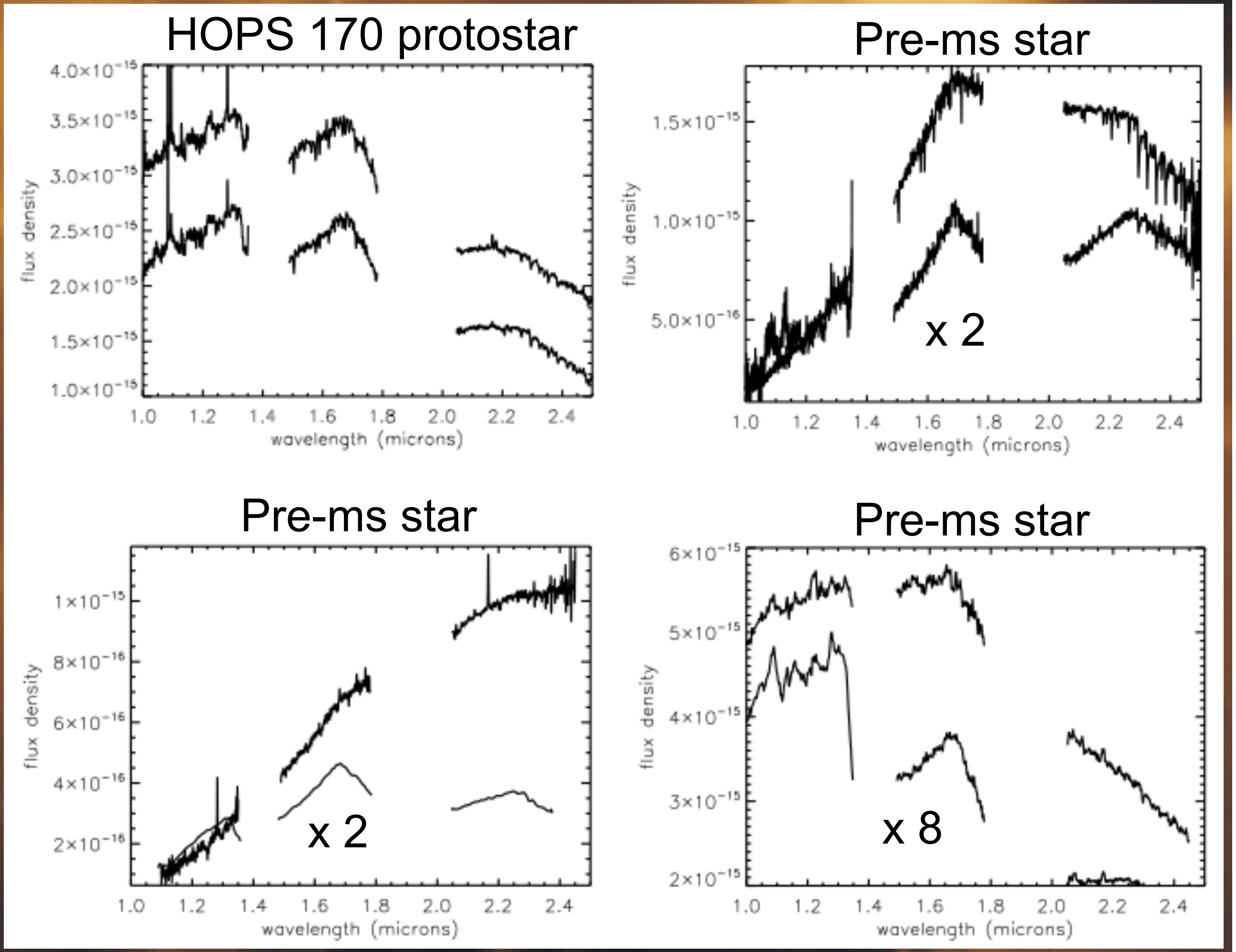
Do they form in disks, by envelope fragmentation, or both?

Mass function of companions is constraint on mechanism.

Spectral types can be determined from low-resolution spectra.

WFC3 and WFIRST can detect companions and isolated objects down to 5 M_{Jup} at an age of 1 Myr.

WFIRST spectroscopy over large areas can find rare, very low-mass objects.



IRTF SpeX spectra

B. Mazur

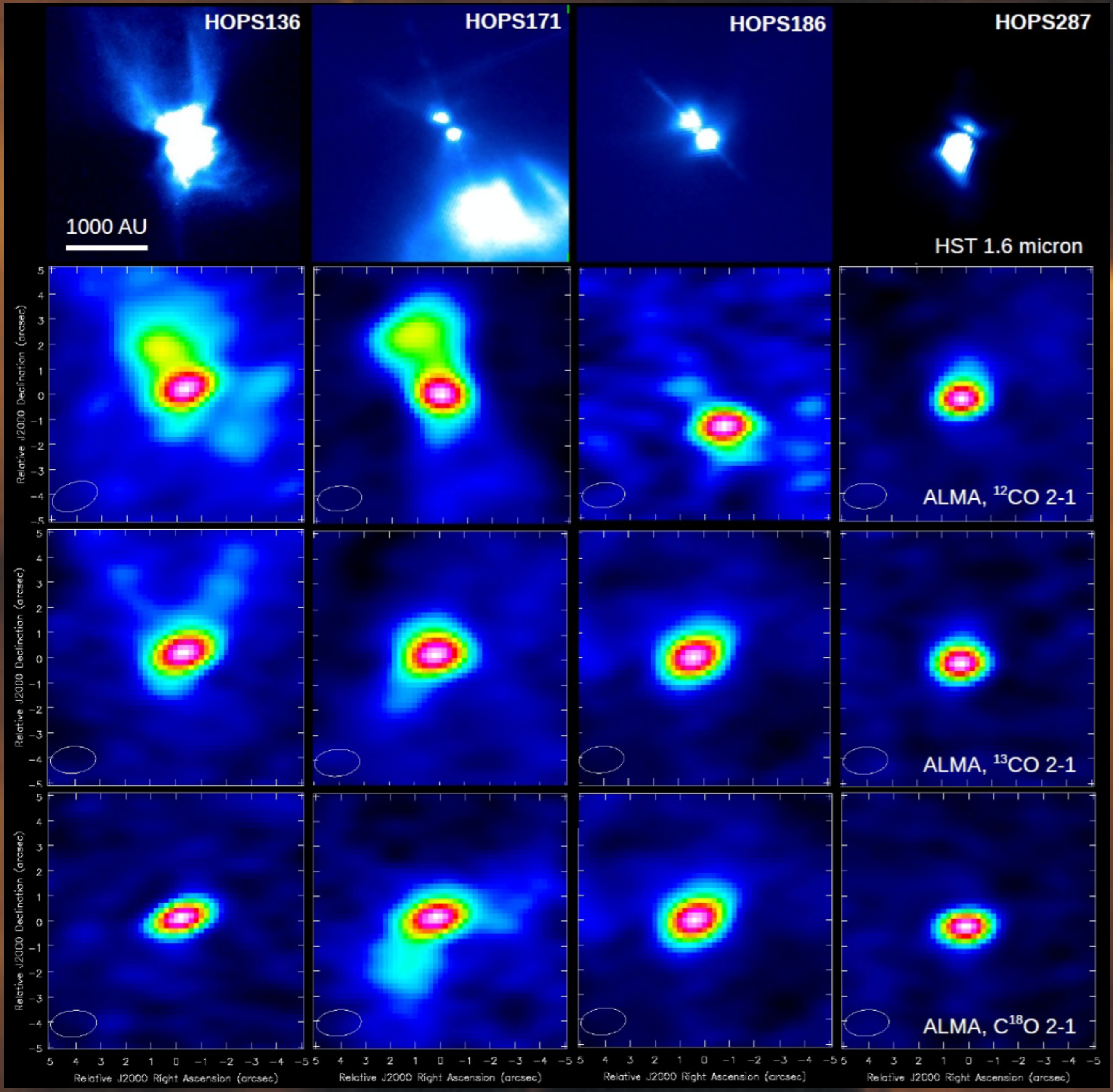
ALMA and WFIRST resolve complementary structures

WFC3-selected edge-on protostars observed with ALMA in lines and continuum.

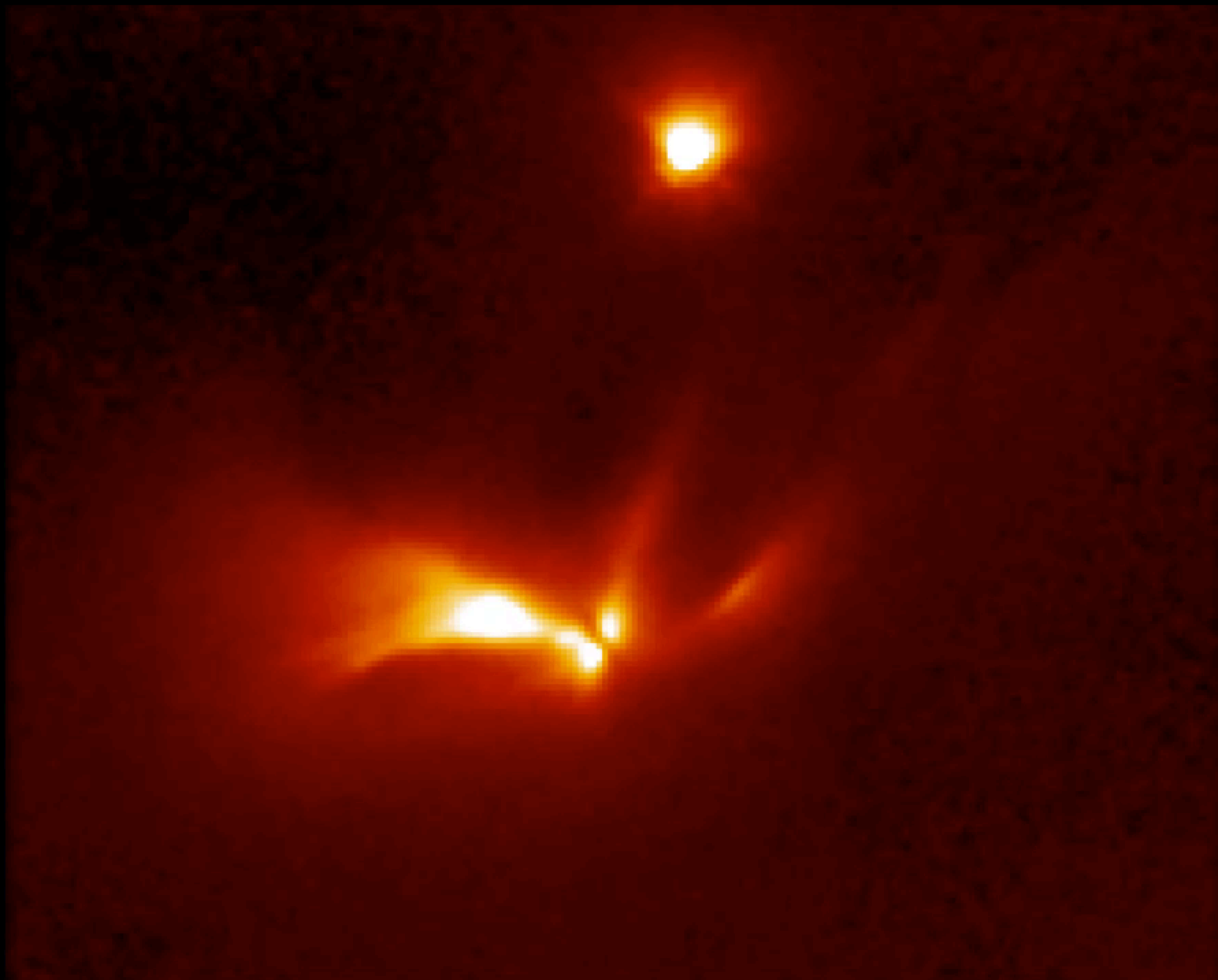
WFC3 detects disks in absorption, ALMA sees disks in emission.

Figure: Z. Nagy

HST: Booker et al. in prep.
ALMA: Nagy et al. in prep.

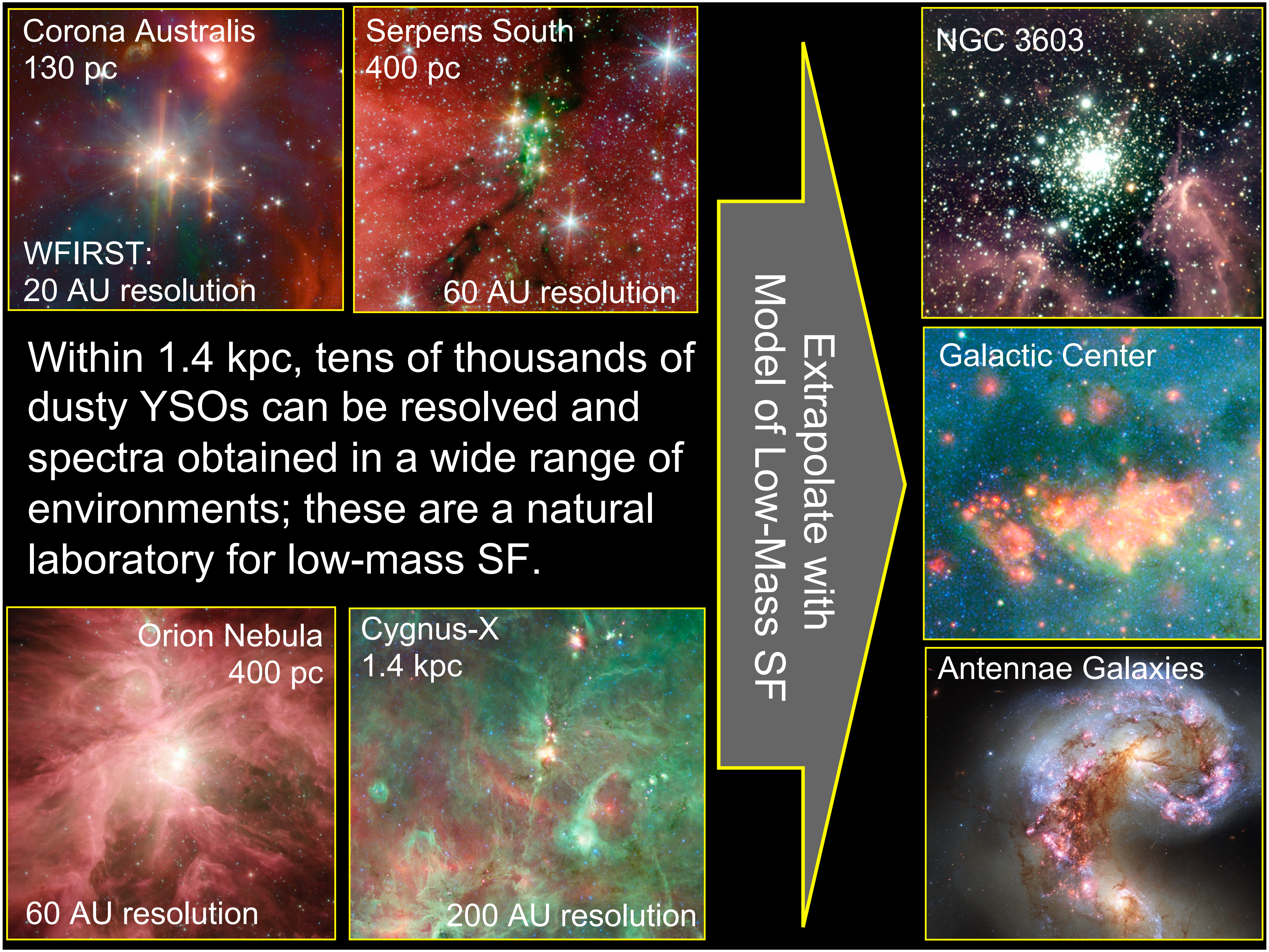


Spatially Resolved Variability with WFC3



Burst created by disk accretion modulated by 25.3 day period binary, illuminating outflow cavities.

Muzerolle, Furlan et al. (2013)


Corona Australis
130 pc
WFIRST:
20 AU resolution
Serpens South
400 pc
60 AU resolution
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.
Orion Nebula
400 pc
60 AU resolution
Cygnus-X
1.4 kpc
200 AU resolution
Extrapolate with
Model of Low-Mass SF
NGC 3603
Galactic Center
Antennae Galaxies