A Comparison of Protostellar Luminosity Functions Across Diverse Star Forming Environments

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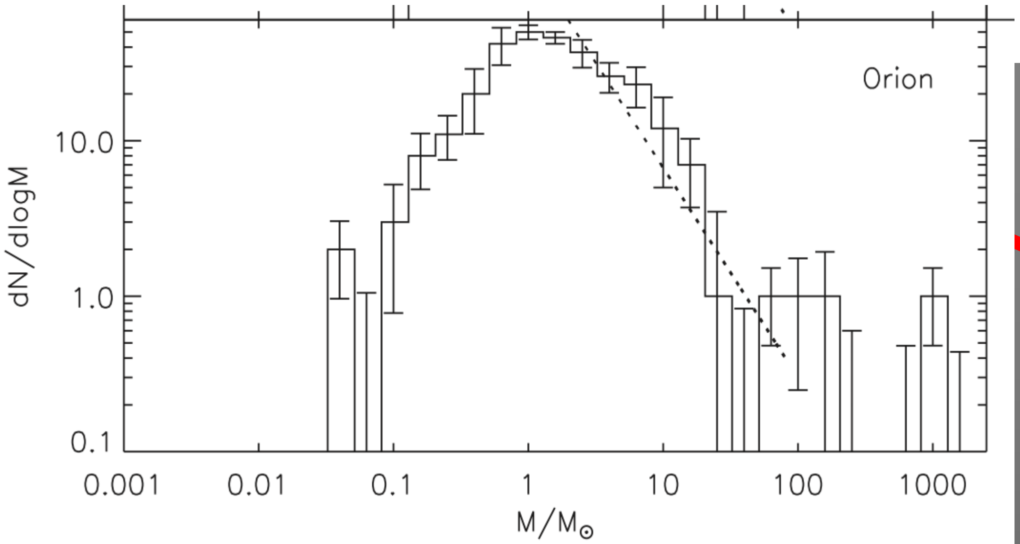
Fundamental Question:

How does environment affect star formation and the properties of nascent stars?

Protostars are still located in their natal environment, allowing us to connect the star formation process to its environment.



Sadavoy et al. 2010

Core mass function

Protostellar luminosity function

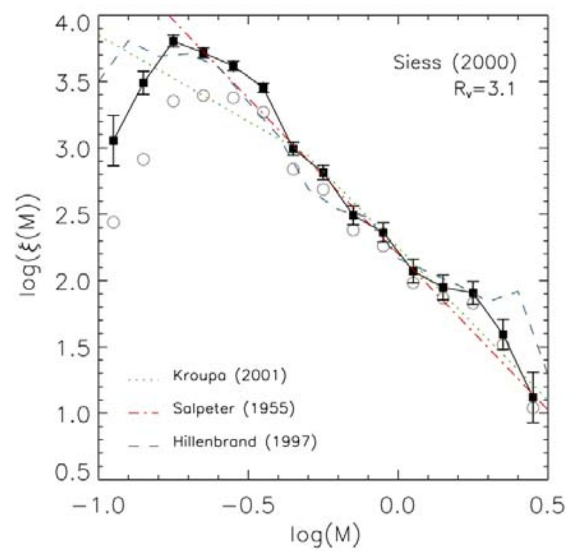
Protostellar luminosity:

$$L = L_* + L_{acc} = L_* + \frac{GM\dot{M}}{r}$$

Protostellar luminosity is in part a measure of mass accretion rate.

<u>"Luminosity Problem":</u>

Protostars have luminosities less than would be expected for the accretion rate determined from the anticipated IMF and observed star formation rate (Kenyon & Hartmann 1990, Dunham et al. 2010).



Initial mass function

Da Rio et al. 2010

Orion

Perseus

Spitzer surveys have provided an unprecedented sample of protostars in clouds at distances < 1 kpc with diverse properties:

Clouds with distributed, low-mass star formation (SF):
  Taurus, Lupus, Chamaeleon (34 protostar candidates)

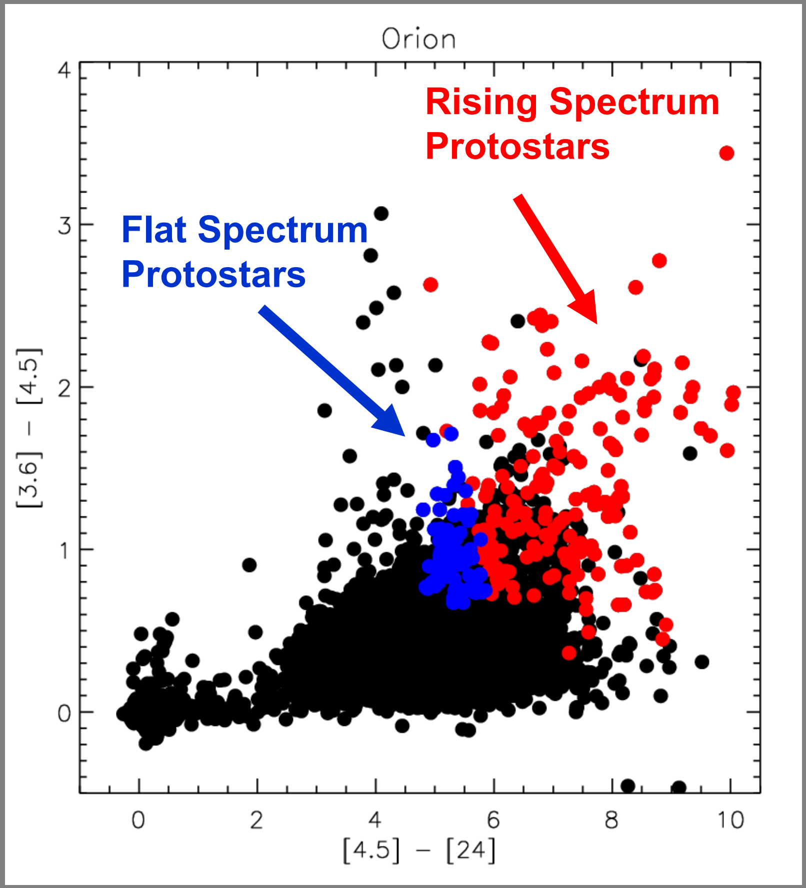
Clouds with clustered, low-mass SF:
  Serpens (40), Perseus (58), Ophiuchus (24)

Clouds with high- and low-mass SF:
  Orion (274), Cep OB3 (97), Mon R2 (89)

To compare star formation in these clouds spanning a range of diverse environments, we have constructed protostellar luminosity functions for each of these kinds of clouds.

Serpens

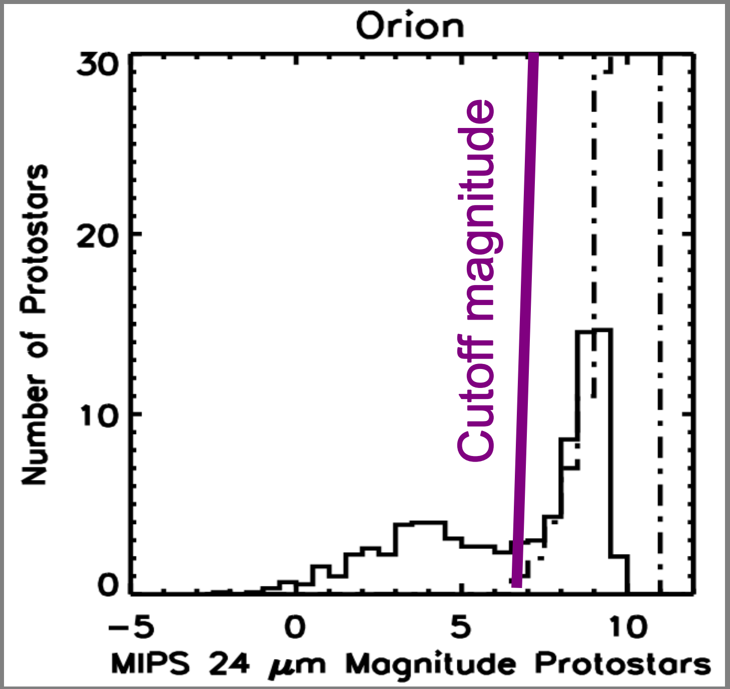
Infrared Protostar Candidate Selection



Select protostars by their mid-IR colors (Megeath et al. 2009).

The protostar sample includes sources with both flat and rising SEDs.

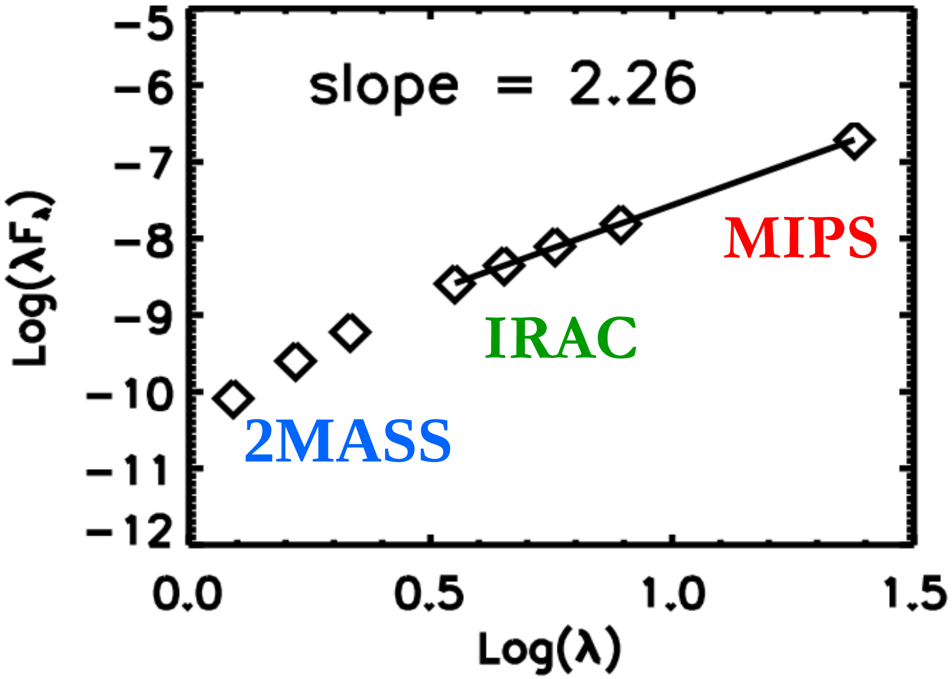
Our sample will not contain very deeply embedded Class 0 sources with faint [24] emission.

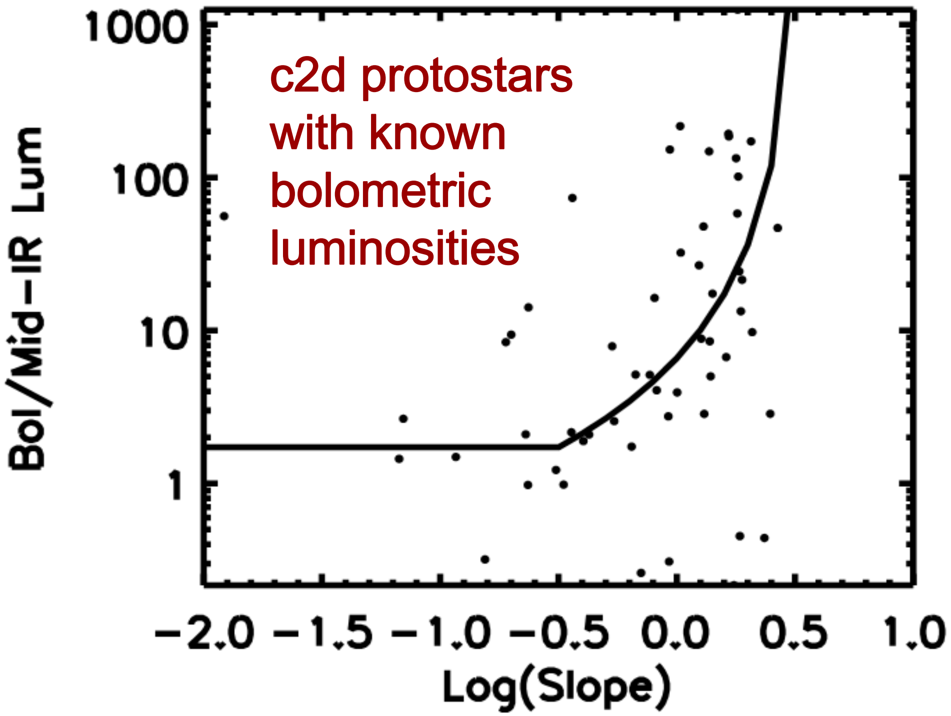


Minimize contamination due to galaxies by comparing [24] with a set of galaxies from the SWIRE sample and setting the [24] cutoff magnitude.

We require protostars to have [24] detections and Av > 3.

Luminosity-Slope Relationship





1. **Calculate 3-24 micron SED slope from IRAC and MIPS data.**
2. Integrate over 1-24 micron bands to calculate mid-IR luminosity.
3. **Convert mid-IR to bolometric luminosities using an empirically derived relationship.**

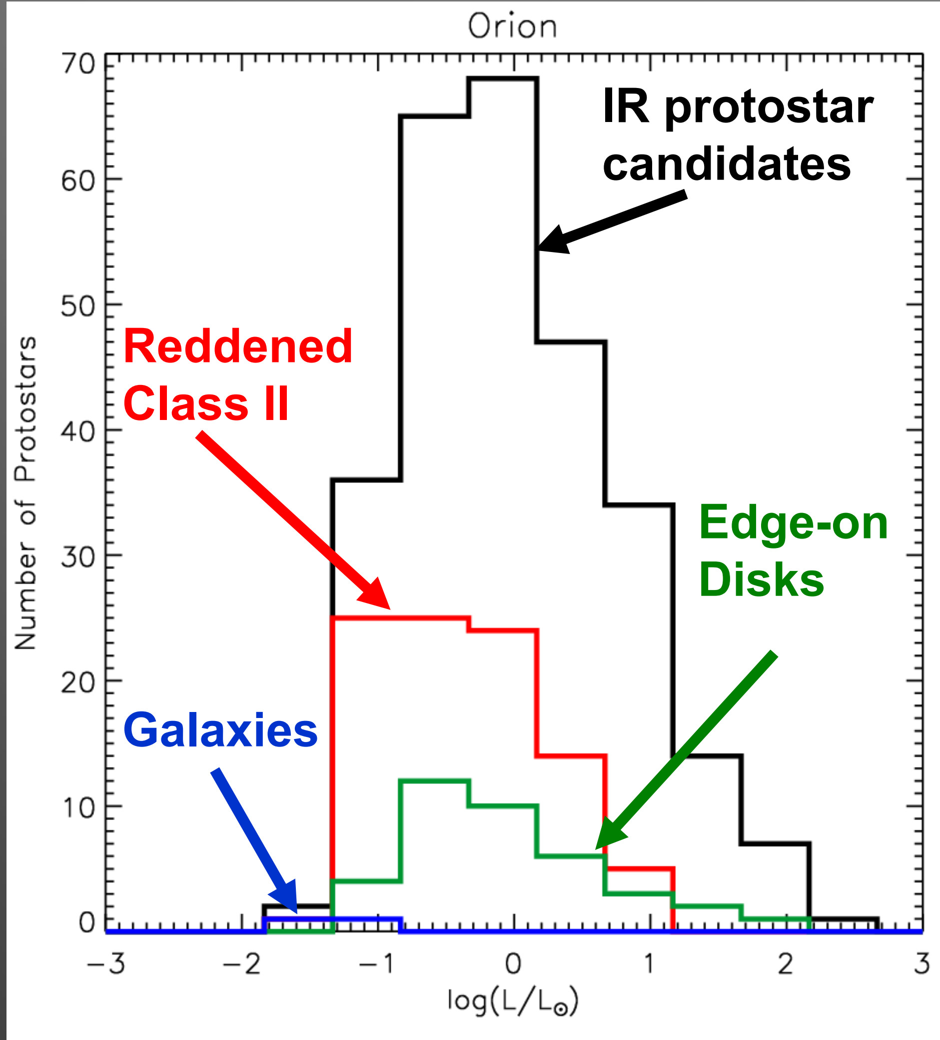
Contamination Removal

Possible sources of contamination:

1. **Reddened Class II** Estimated with a Monte Carlo simulation that uses a representative sample of Orion Class II sources and extinction maps for each cloud to predict the number of reddened disks misidentified as protostars.

2. **Edge-on Disk** Estimated using technique from Gutermuth et al. 2009 and a low-Av sample of YSOs from Cep OB3b.

3. **Background Galaxy** Estimated using the SWIRE sample.



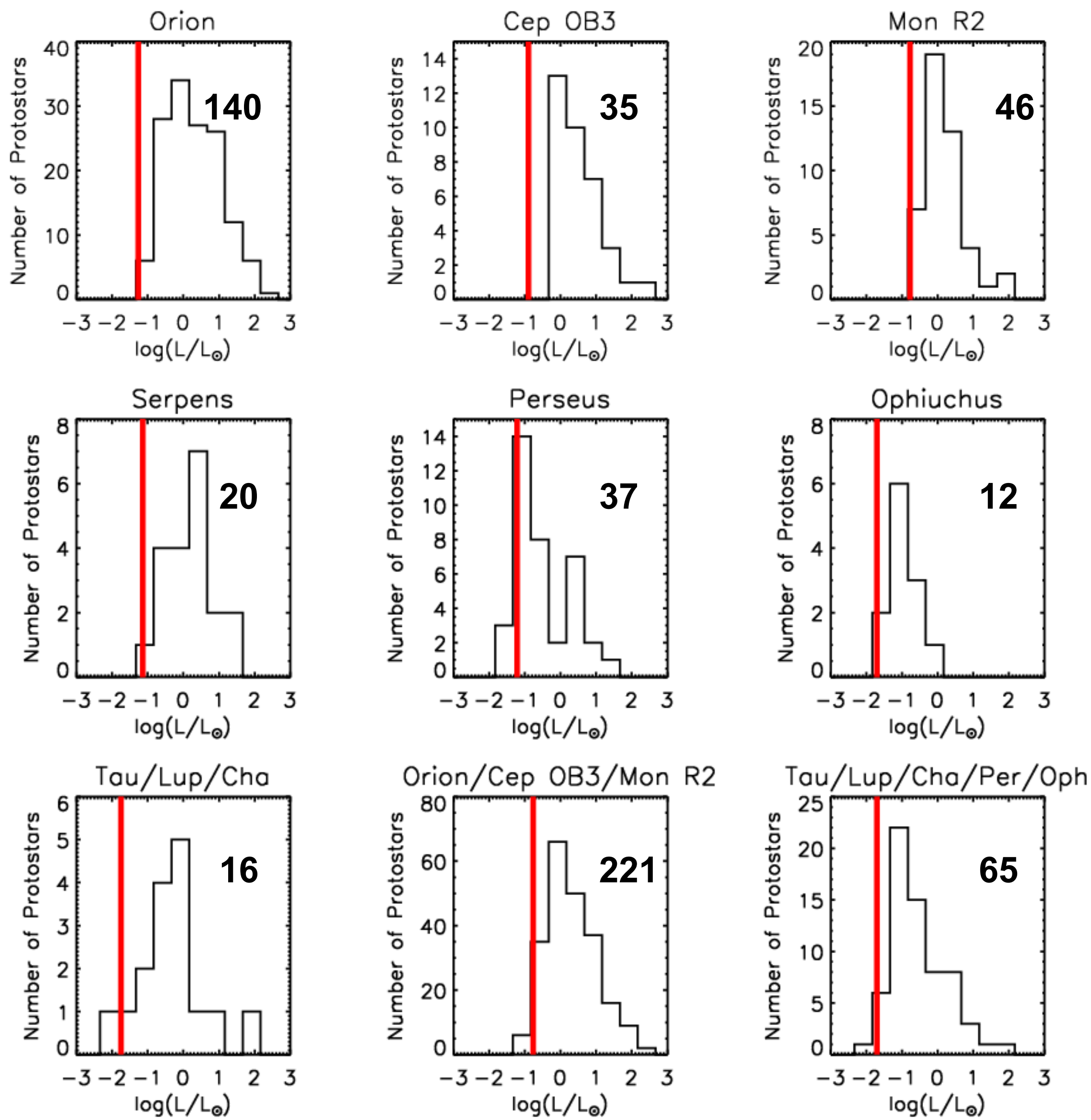
Luminosity Functions for Contamination Subtracted Protostars

Luminosity functions peak near 1 L_{sun} for clouds which form high mass stars, and at 0.1 L_{sun} for Perseus and Ophiuchus.

Orion, Cep OB3, and Mon R2 show tails extending to luminosities > 100 L_{sun}.

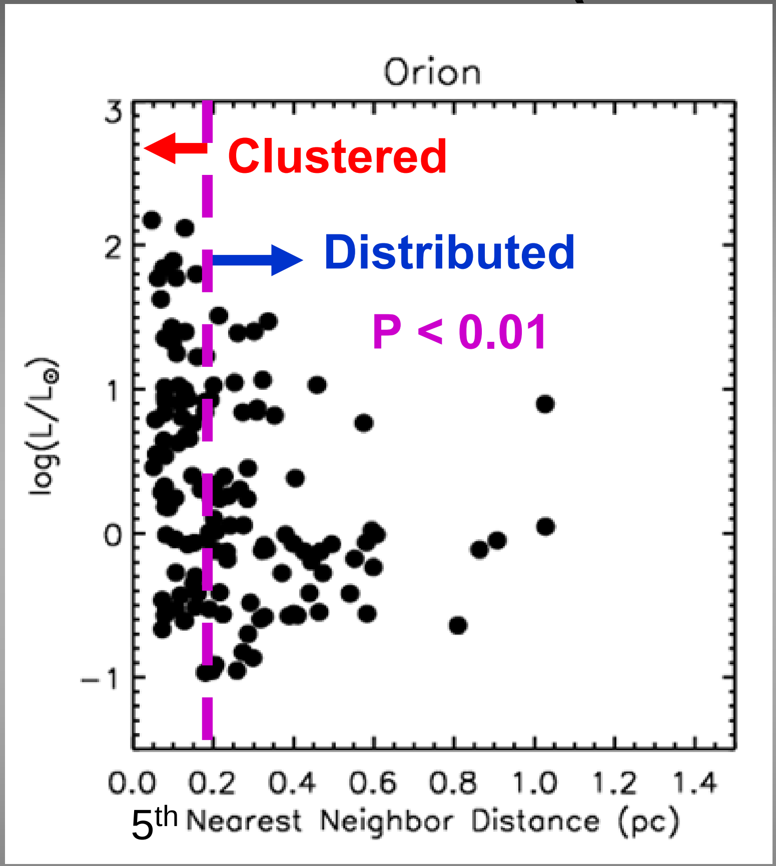
Combined luminosity functions differ between high mass SF clouds and low mass SF clouds, with a KS test probability P = 0.02.

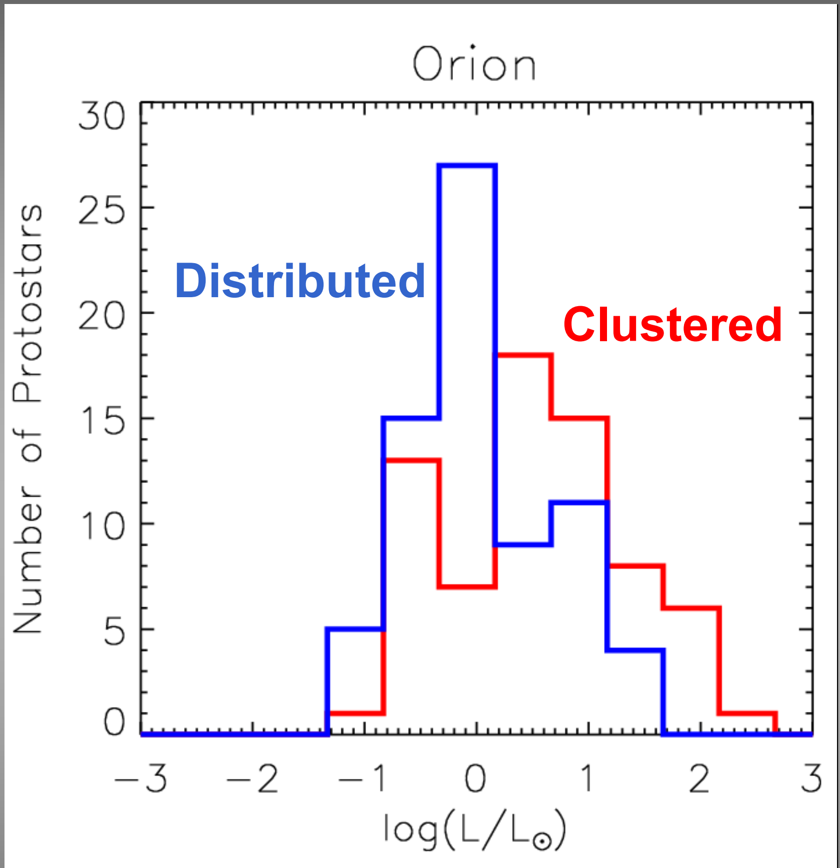
Luminosities less than expected for continuous accretion over 5 x 10^5 years (L_{acc} ~ 5 L_{sun}), particularly for low mass regions → luminosity problem not solved.



Sensitivity limit based on [24] cutoff

Luminosity vs. Clustering: Nearest Neighbor (nn = 5) Distances





Clustering cutoff length to 5th nearest neighbor YSO selected so that there are equal numbers of clustered and distributed protostars.

Orion clustered protostars extend to higher luminosities, difference in clustered and distributed luminosity functions are statistically different.

More crowded regions will be more incomplete to faint protostars; however, drop off at faint luminosities appears to be determined primarily by subtraction of reddened stars with disks.

Protostars link the CMF and the IMF.

We construct protostellar luminosity functions from Spitzer mid-IR data.

Contamination due to edge-on or reddened Class II YSOs eliminates a nearly half of all IR protostar candidates, but does not solve the "luminosity problem".

Luminosity functions peak near 1 L_{sun} for clouds which form high mass stars, and peak at 0.1 L_{sun} for Perseus and Ophiuchus.

The luminosity function for clouds which form high mass stars are statistically different from those of clouds which do not.

Orion clustered protostars extend to higher luminosities than do Orion distributed protostars, and there is a significant difference between luminosity functions of clustered and distributed populations.

Protostellar luminosity functions appear to change with environment (between clouds with and without high mass star formation, and between clustered and distributed regions).

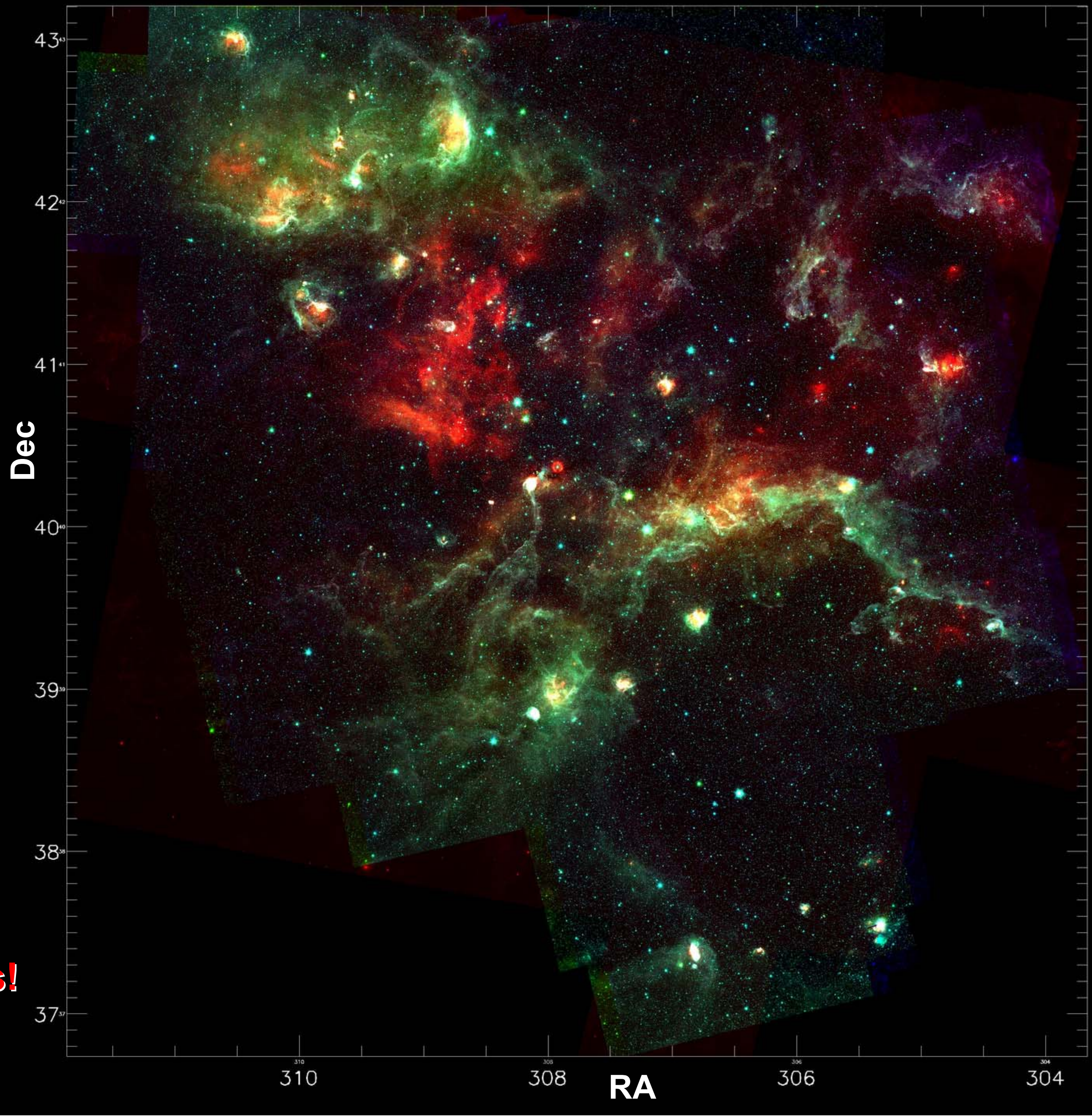
Given correlation between stellar density and gas density (Gutermuth et al. in prep), is this due to higher gas column densitites in regions with clusters and nascent high mass stars?

Next Step: Cygnus-X (1.7 kpc)

Cygnus-X legacy survey: Hora et al. in prep.

3.6 μm blue
4.5 μm green
24 μm red

Caution: Work in Progress!



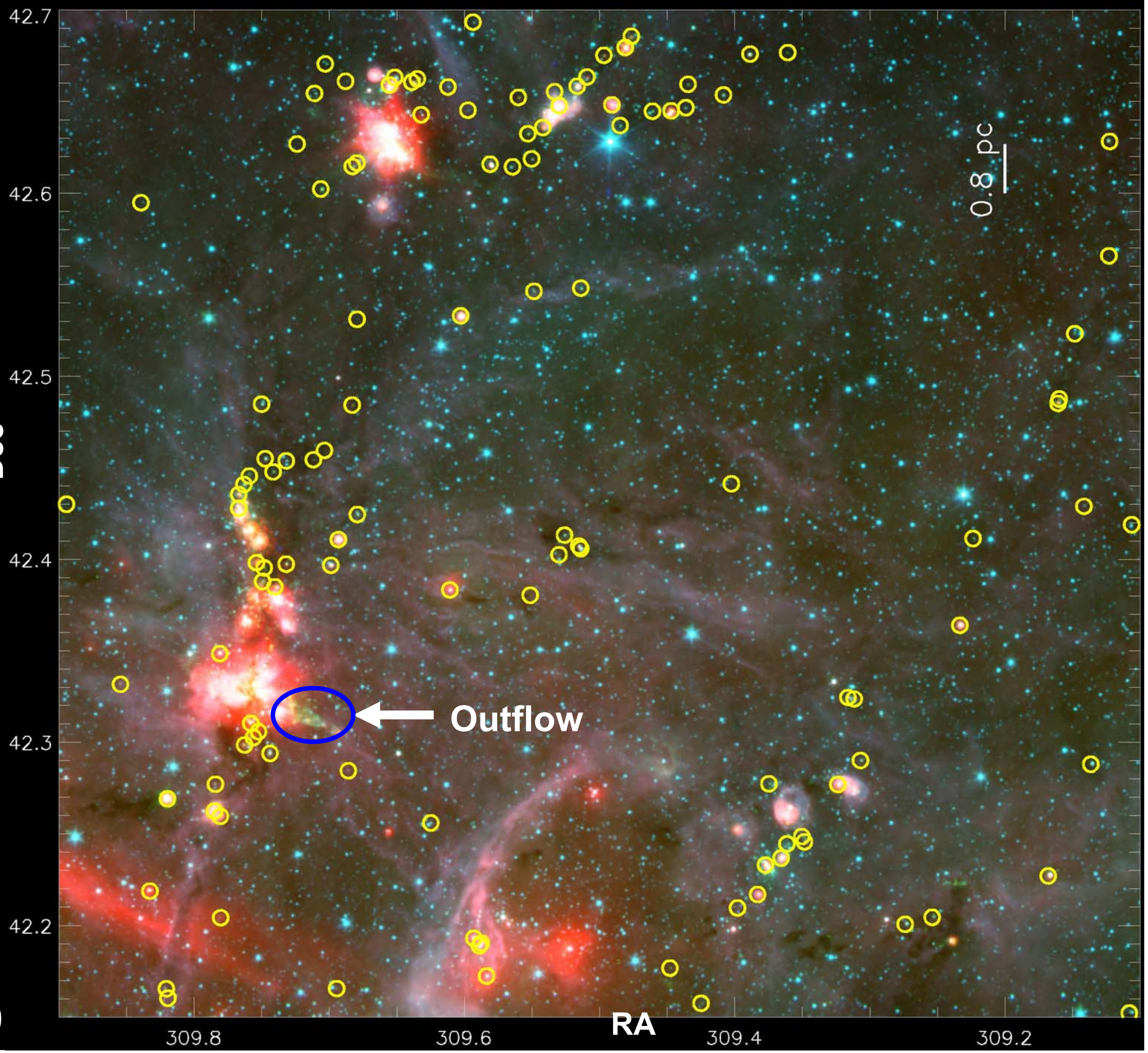
Protostars in DR21 and surroundings

Brightest sources may be affected by saturation/confusion.

Class II not shown

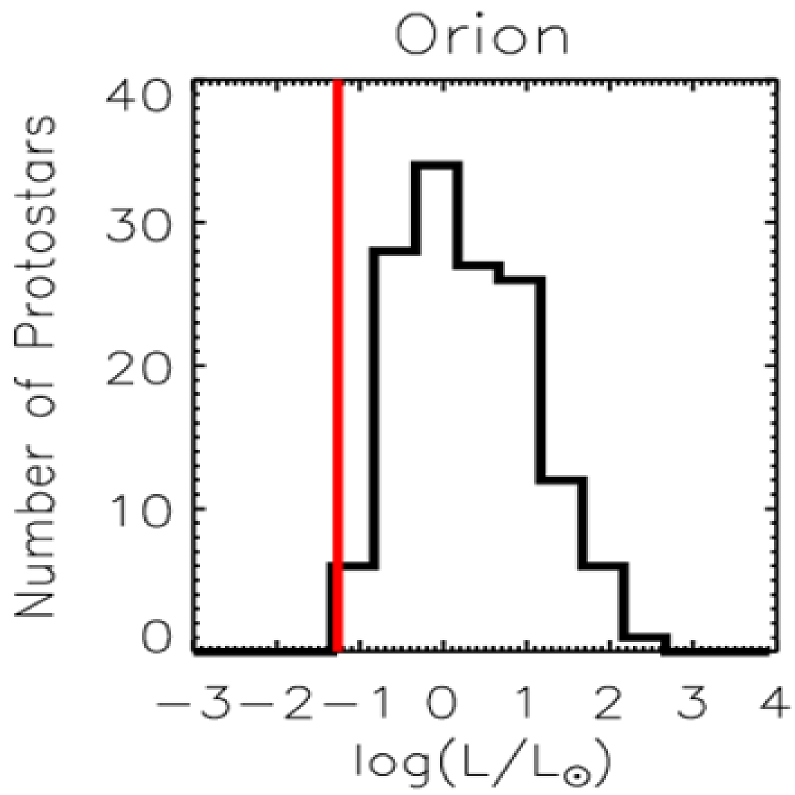
Yellow circles protostars

3.6 μm blue
4.5 μm green
24 μm red



Beerer et al. 2010

Cygnus-X Luminosity Function



Sensitivity limit based on [24] cutoff

Many more protostars in Cygnus-X (770) than Orion (140)

Need to better establish the completeness at both faint and bright luminosities

Cygnus-X Luminosity vs. NN Distance (nn = 5)

Clustering cutoff length at 0.52 pc (Orion at 0.19 pc)

Preliminary results indicate that there is a similar dependence of protostellar luminosity on stellar density in Cygnus-X as in Orion.