Multi-Wavelength Analysis of the Most Luminous Young Stellar Object in the Large Magellanic Cloud

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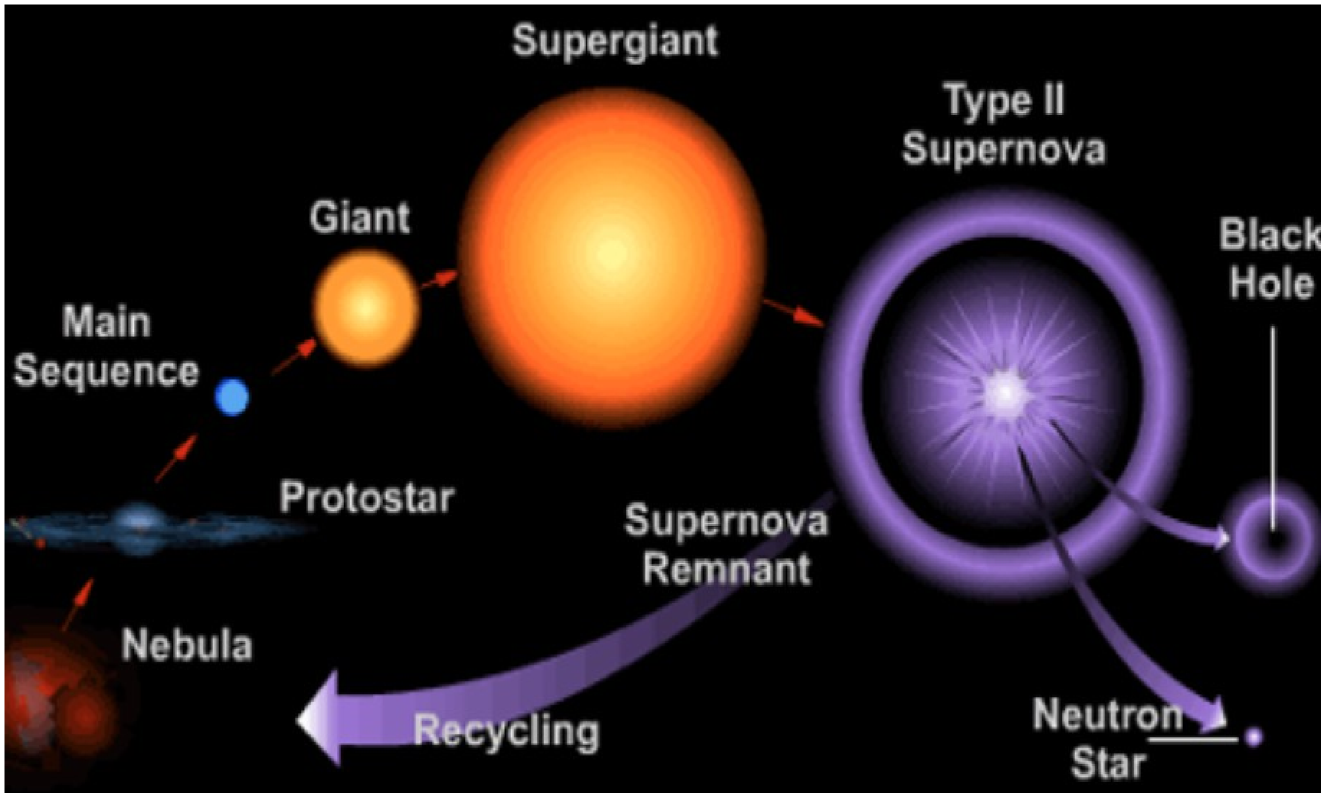
- Can we see observational signature of outflows from massive YSOs?

Studying High Mass Star Formation is Difficult

The formation of massive stars (greater than 8 solar masses) has a profound impact on galaxies.



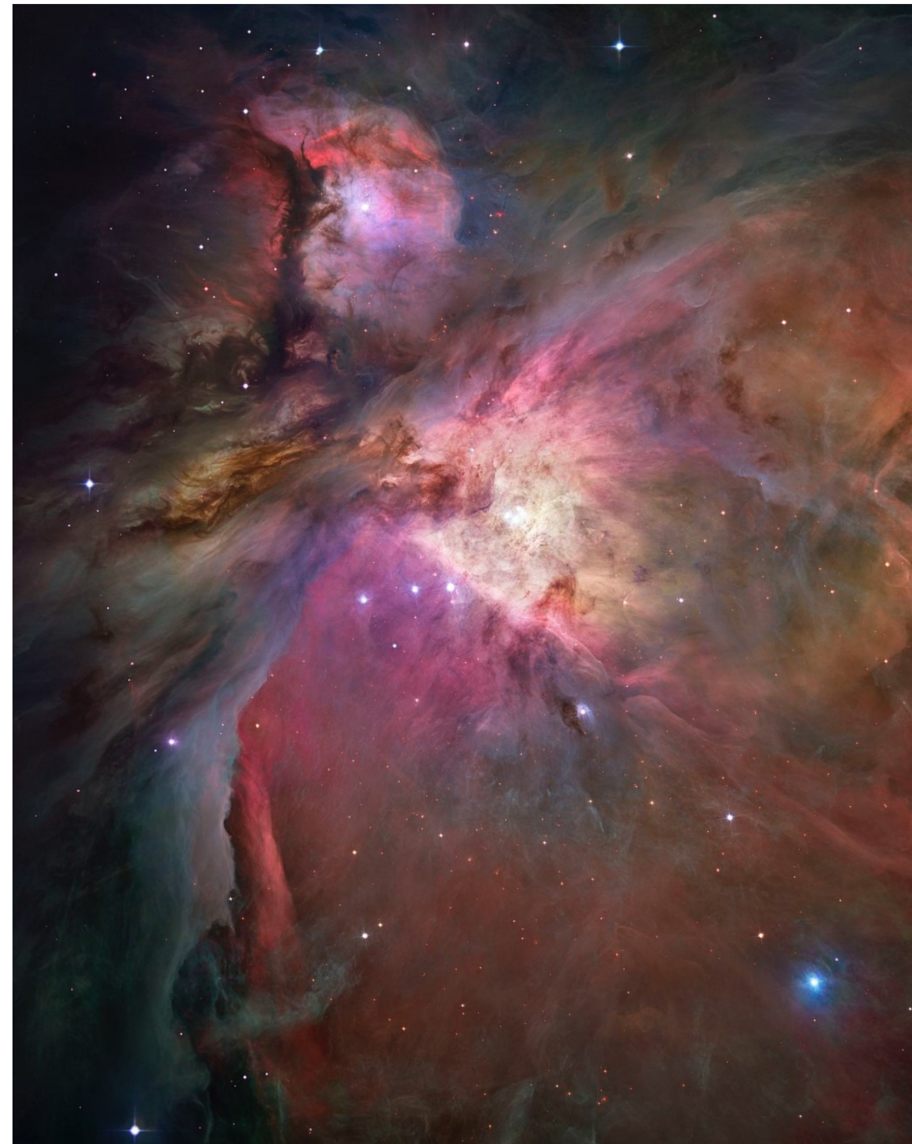
Massive star formation is difficult to observe.

- High mass stars are rare.
- High mass stars evolve very quickly.
- Most likely obscured by dust or found in dense clusters.

Massive Star Formation: Not Just Scaled Up Version of Low Mass Star Formation

- Radiative forces play little effect on low mass star formation.
- Gravitational interactions play a much more important role.
- Massive stars are still accreting once they reach the main sequence.
- Massive stars can trigger star formation in nearby region.

Nebula in Serpens
Photo Credit: ESO

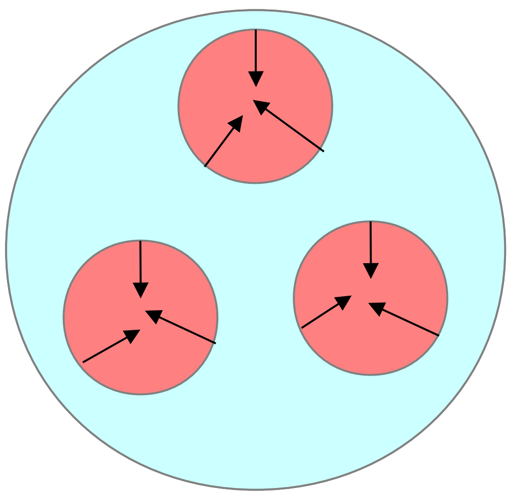


Orion Nebula
Photo Credit: NASA

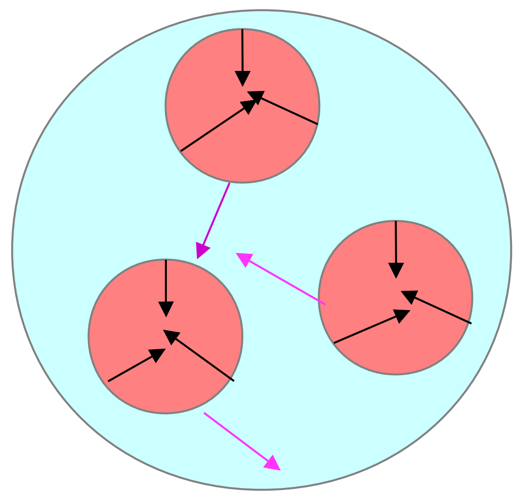
How do Massive Stars Form?

- There are currently three different theories on how massive stars form.

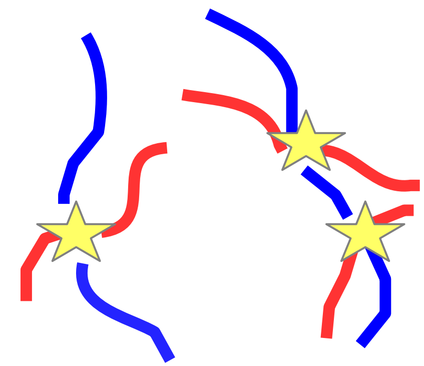
Monolithic Collapse



Competitive Accretion



Filamentary Collision



- Definitions
  - Filaments: >10 pc long and <1 pc wide
  - Clump: 2-5 pc in size
  - Cores: <1 pc in size
- Massive star formation exclusive takes place in high density regions

The Large Magellanic Cloud

Distance: 50 kpc (Schaefer et al. 2008)

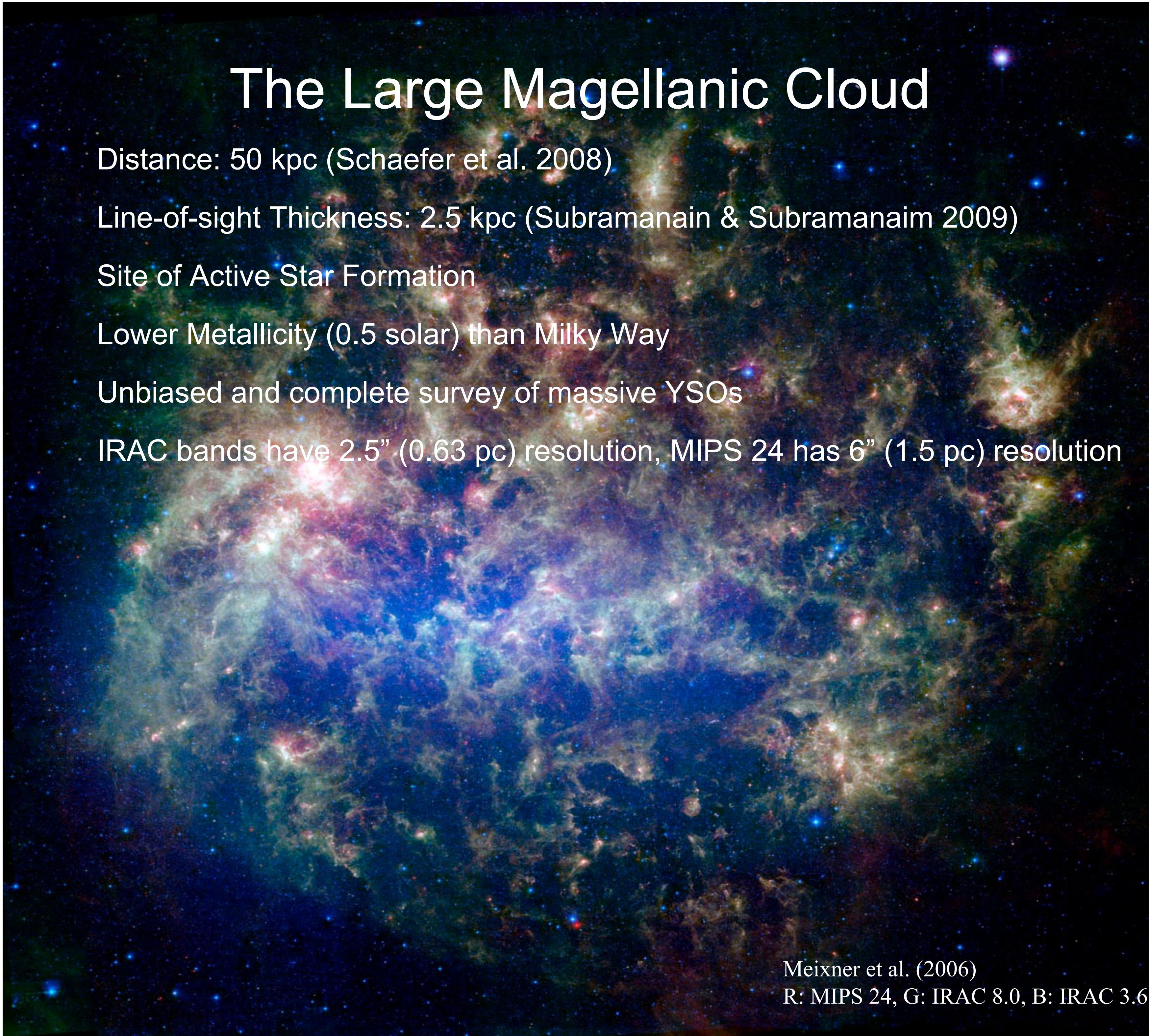
Line-of-sight Thickness: 2.5 kpc (Subramanain & Subramanaim 2009)

Site of Active Star Formation

Lower Metallicity (0.5 solar) than Milky Way

Unbiased and complete survey of massive YSOs

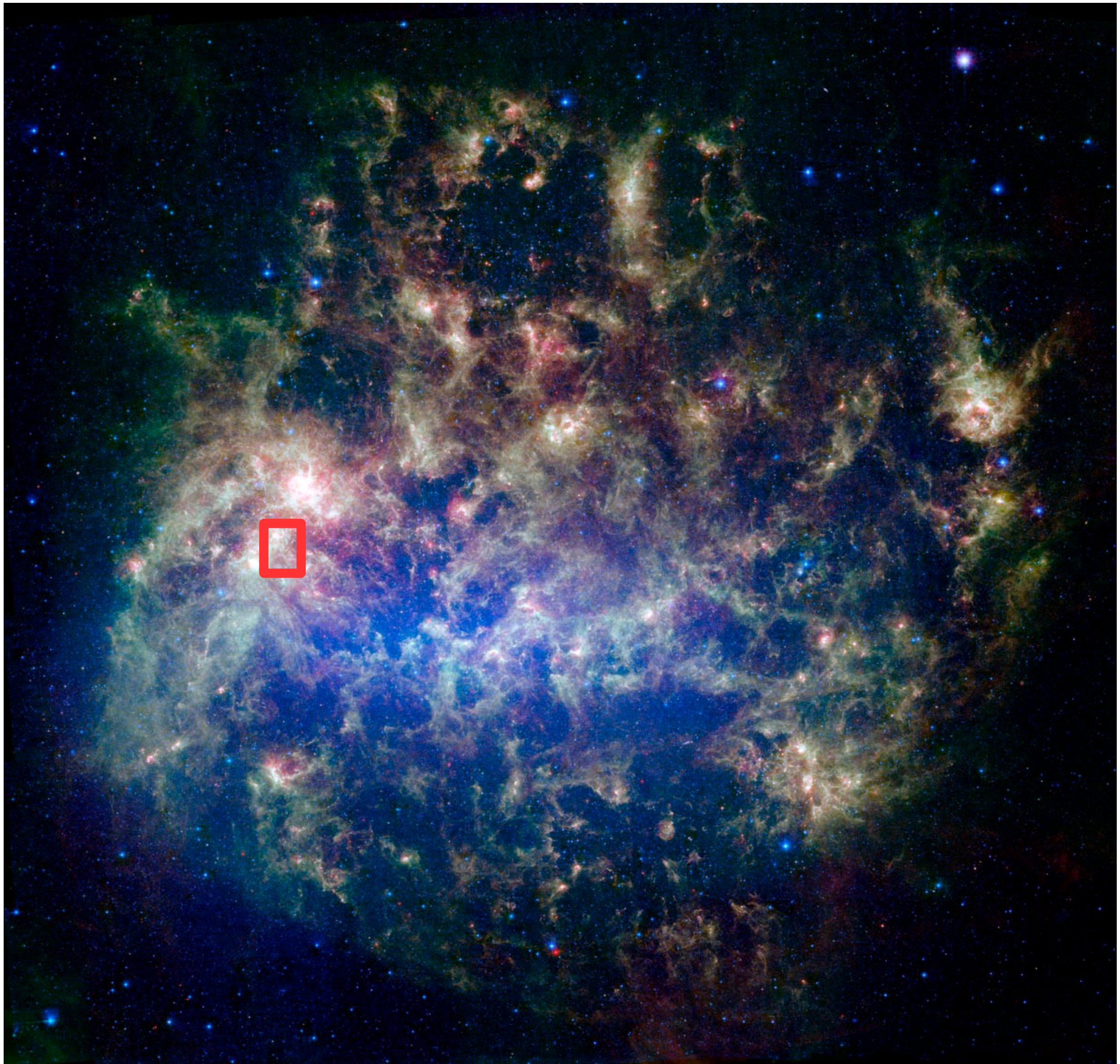
IRAC bands have 2.5” (0.63 pc) resolution, MIPS 24 has 6” (1.5 pc) resolution



Meixner et al. (2006)
R: MIPS 24, G: IRAC 8.0, B: IRAC 3.6

Where is the Most Luminous YSO Located? 30 Doradus?

Where is the Most Luminous YSO Located? N159?

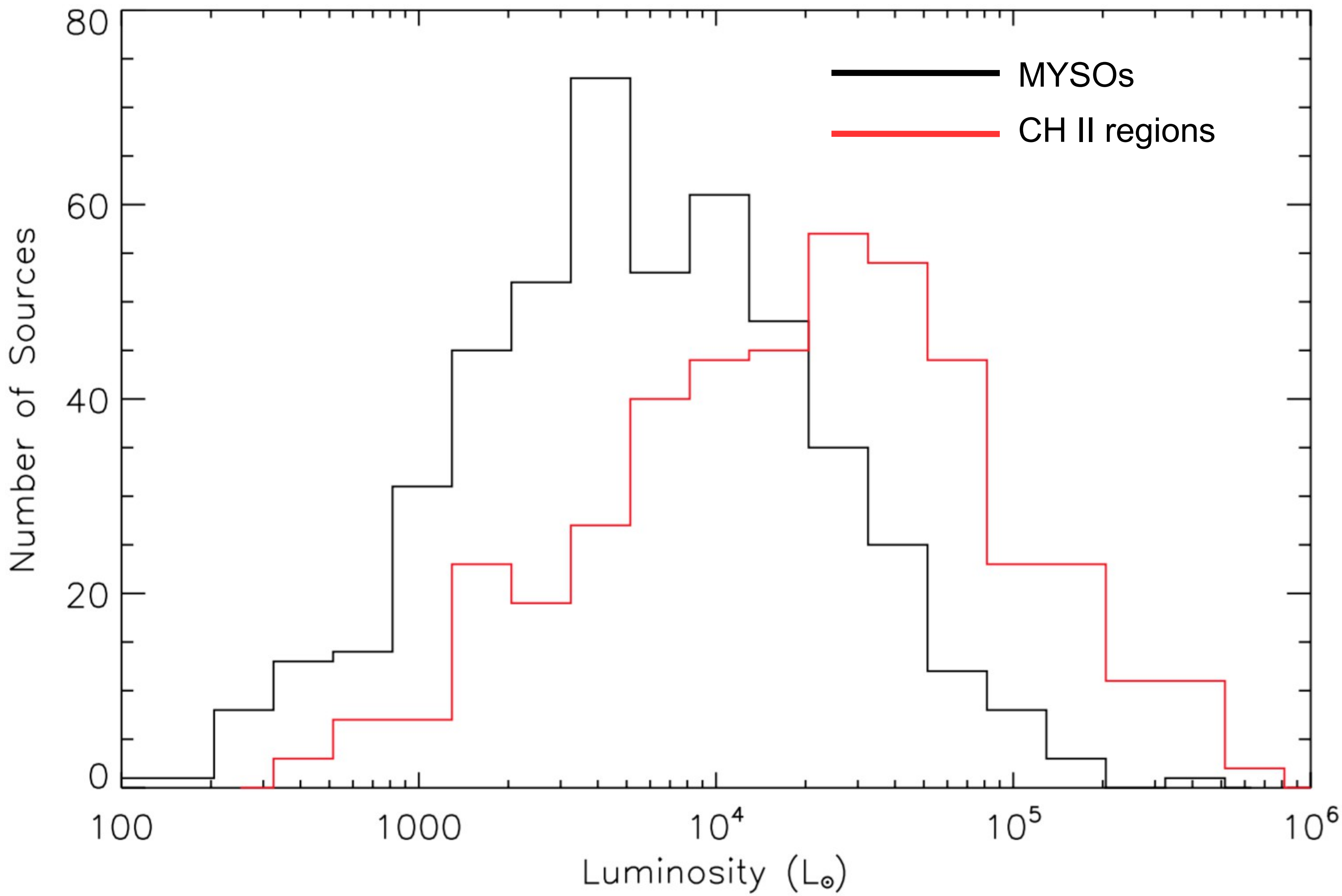


Where is the Most Luminous YSO Located? N11?

Where is the Most Luminous YSO Located? N113?

It is N79!

How Luminous is the MYSO in N79?



Mottram et al. (2011)

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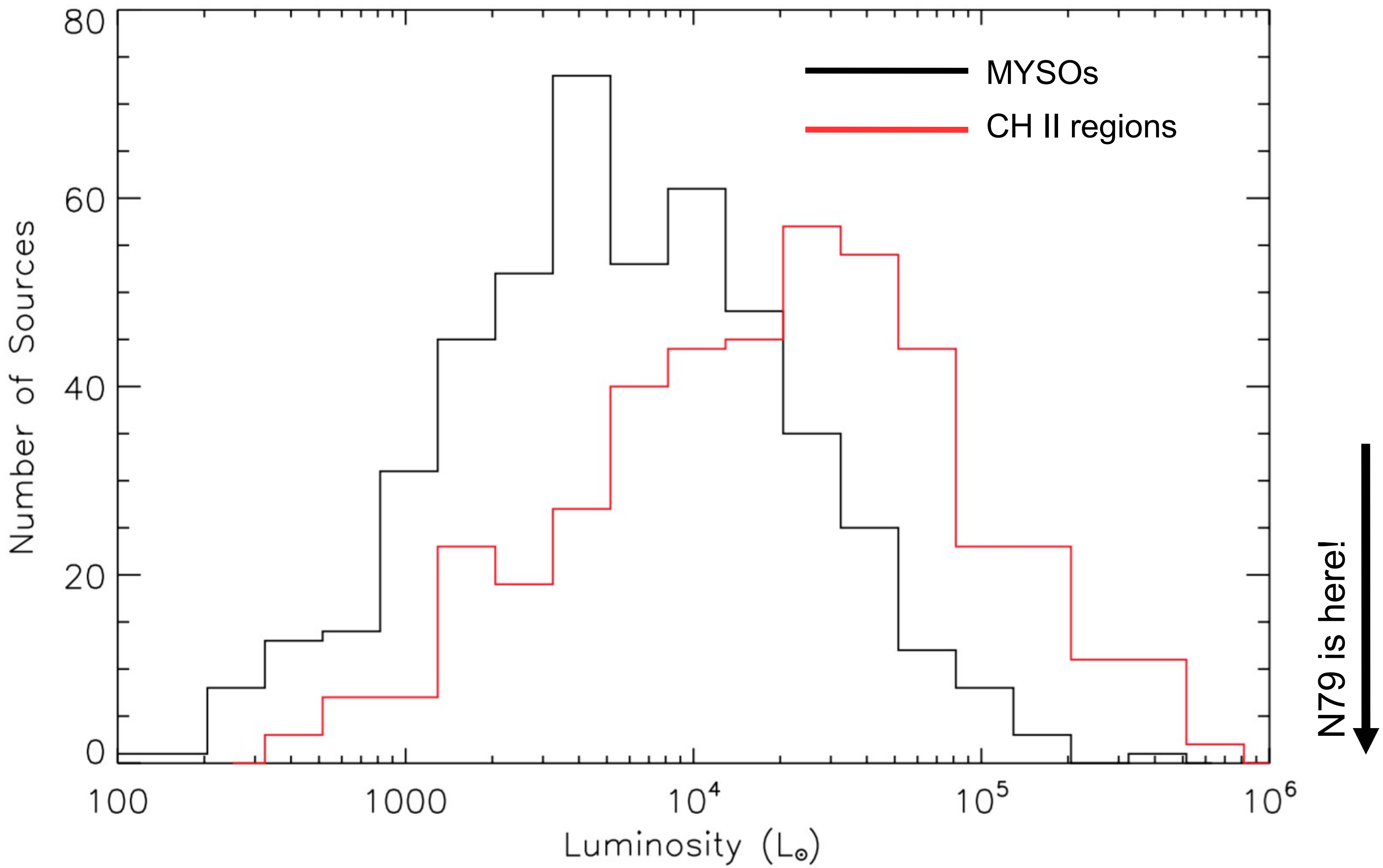


Mottram et al. (2011)

Cartoon of High Mass Star Formation

HII Region | Outer PDR Region | Inner PDR Region | Cold CO Clump | Embedded Protostar

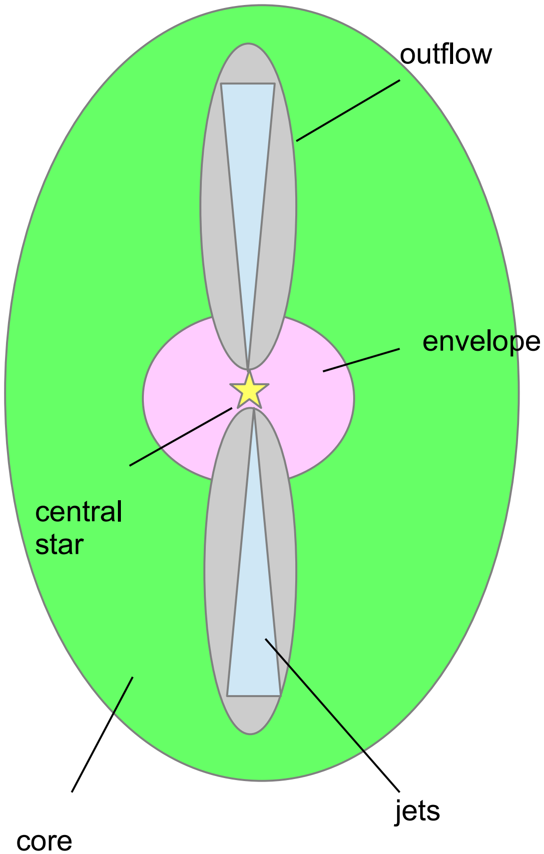
UV Flux →

H^+

H, C^+, O

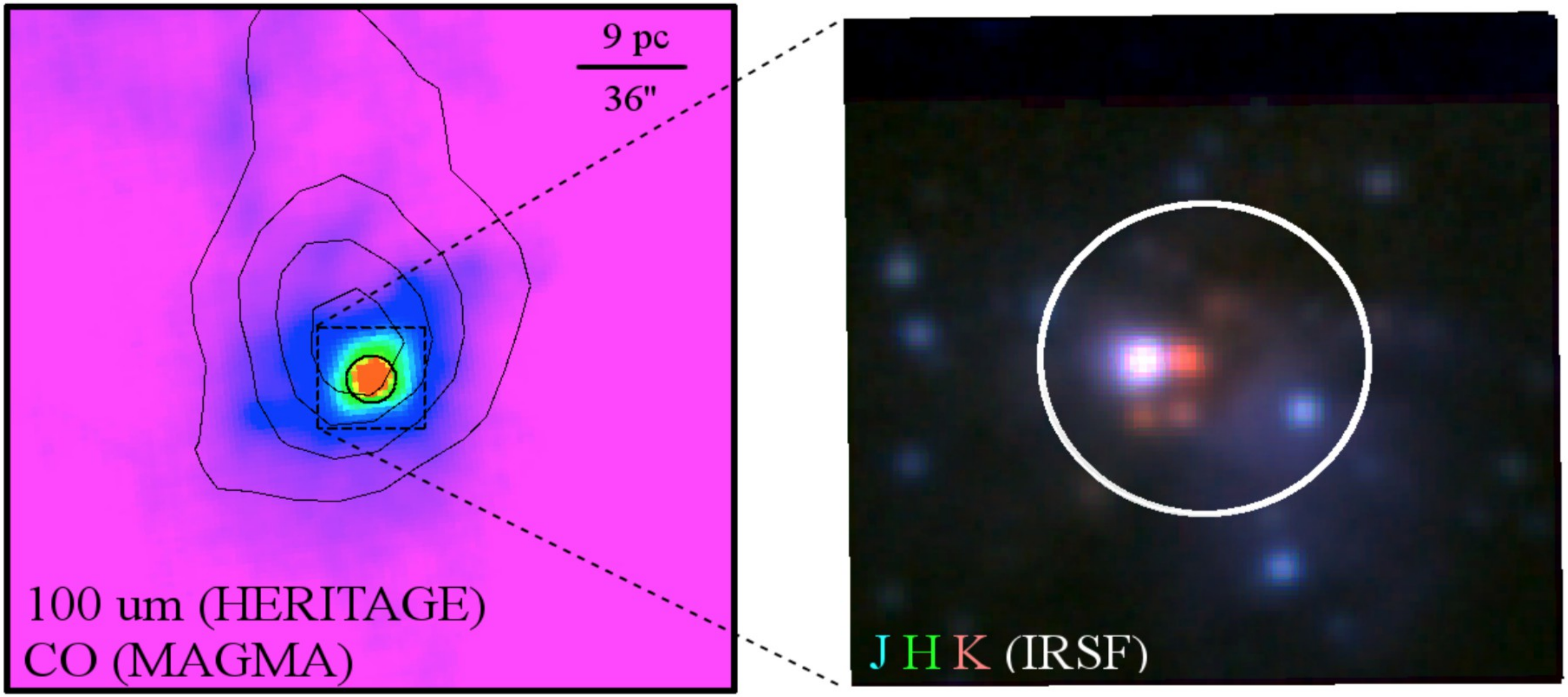
H_2 , CO, O_2

CO, H_2



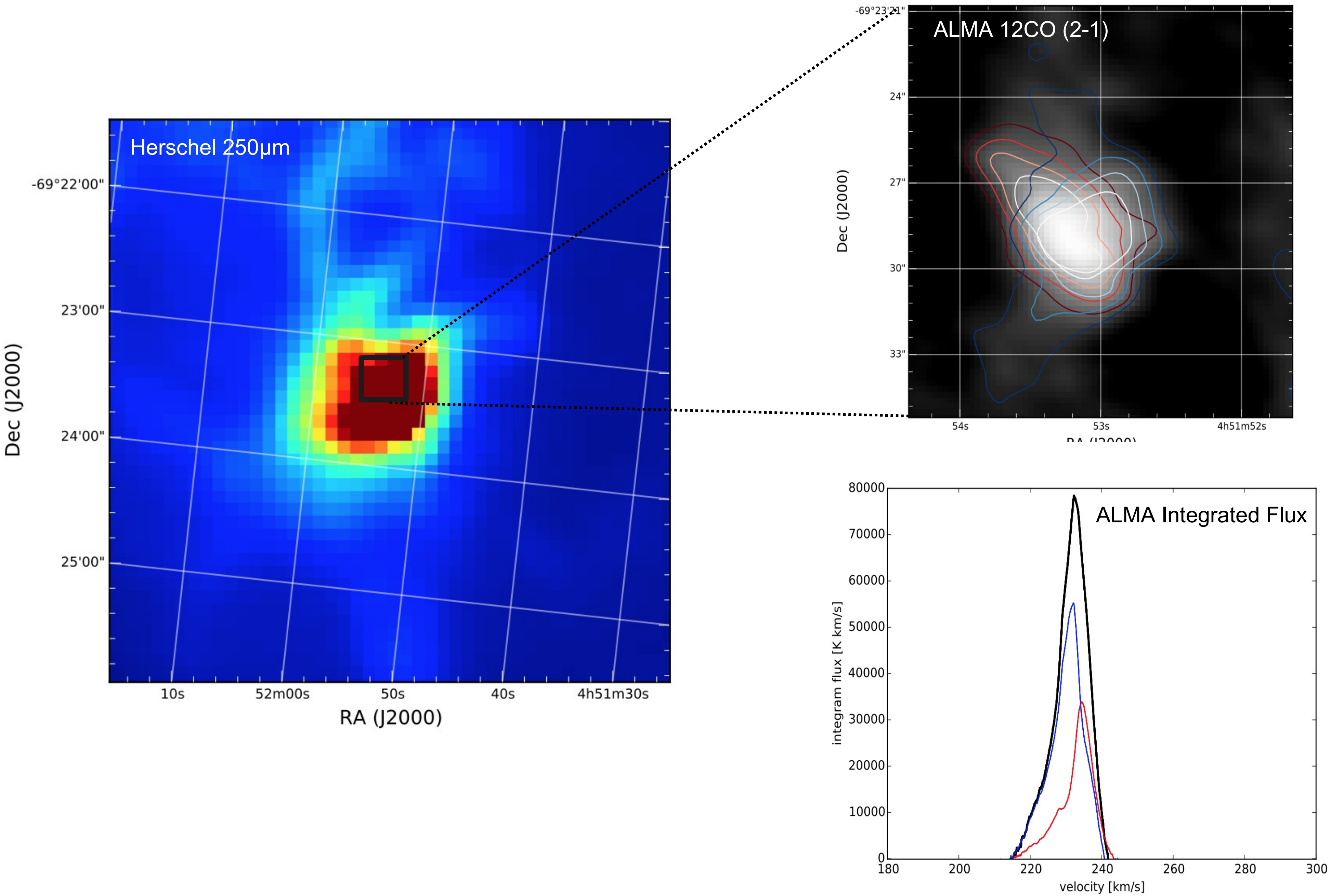
This is the Most Luminous YSO!

- Indebetouw et al. (2004) classify the central source as an O5V star.
- The most luminous YSO has a bolometric luminosity of 1.5 x 10^{6} solar luminosity.
- The most massive protostar is surrounded by five other protostars.

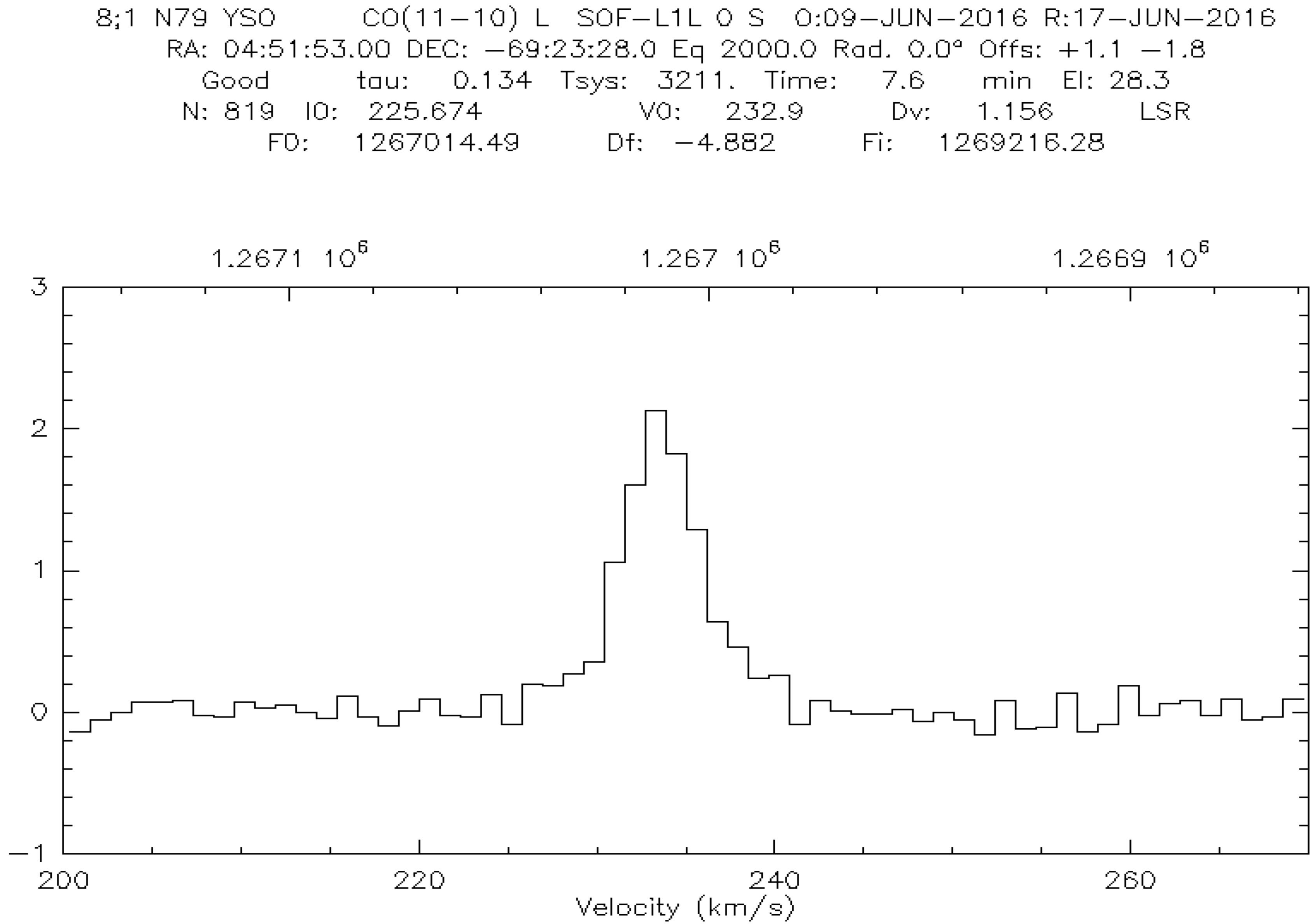


Left: 100μm image from Herschel HERITAGE (color, Meixer et al. 2013) with CO (contours, Wong et al. 2011) from MAGMA. Resolution of Herschel PACS 100μm is 8” (2pc). Resolution of MAGMA is 45” (11pc). Right: A 3-color, near-IR image zoomed in on the target.

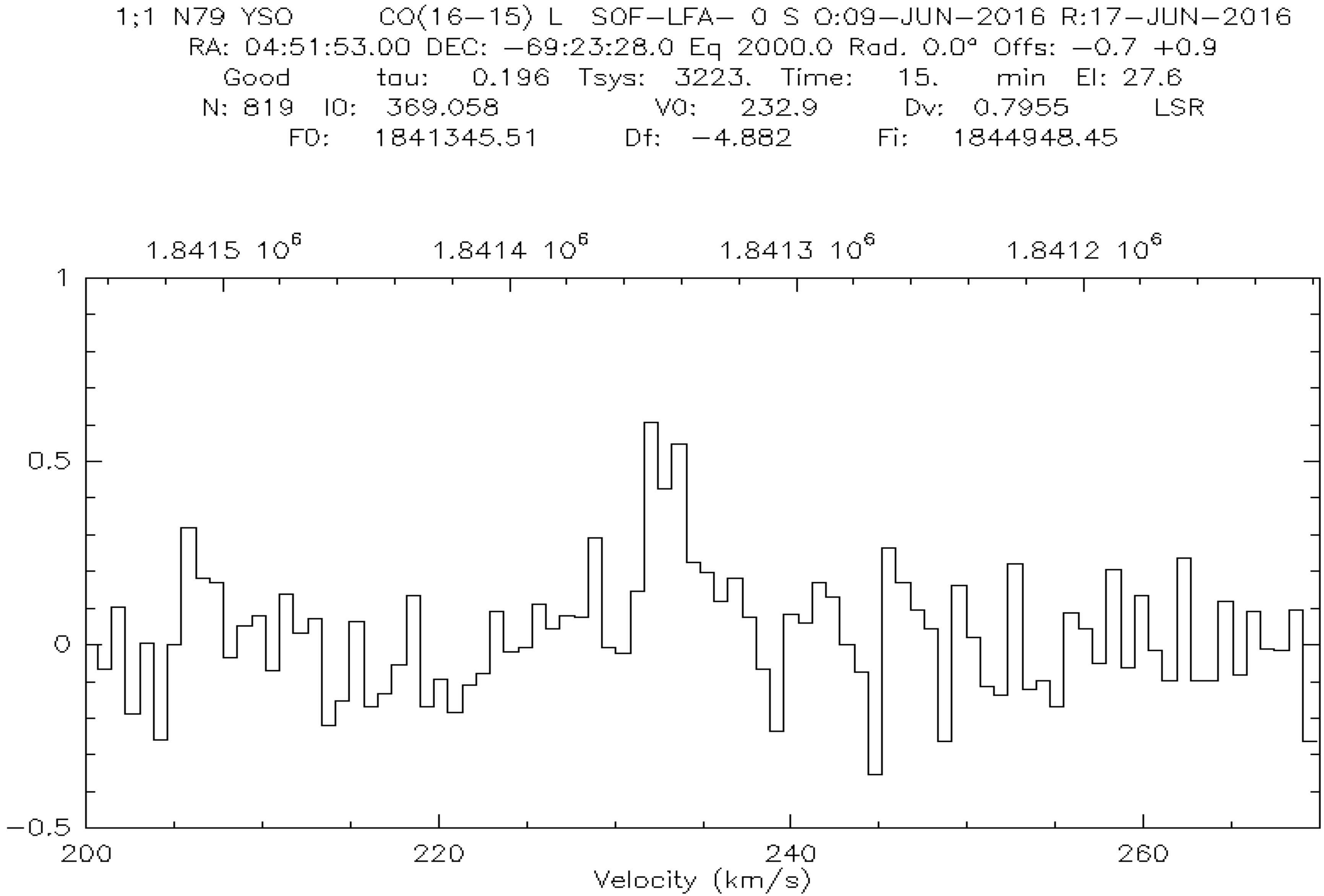
Herschel 250μm Map + ALMA CO Map



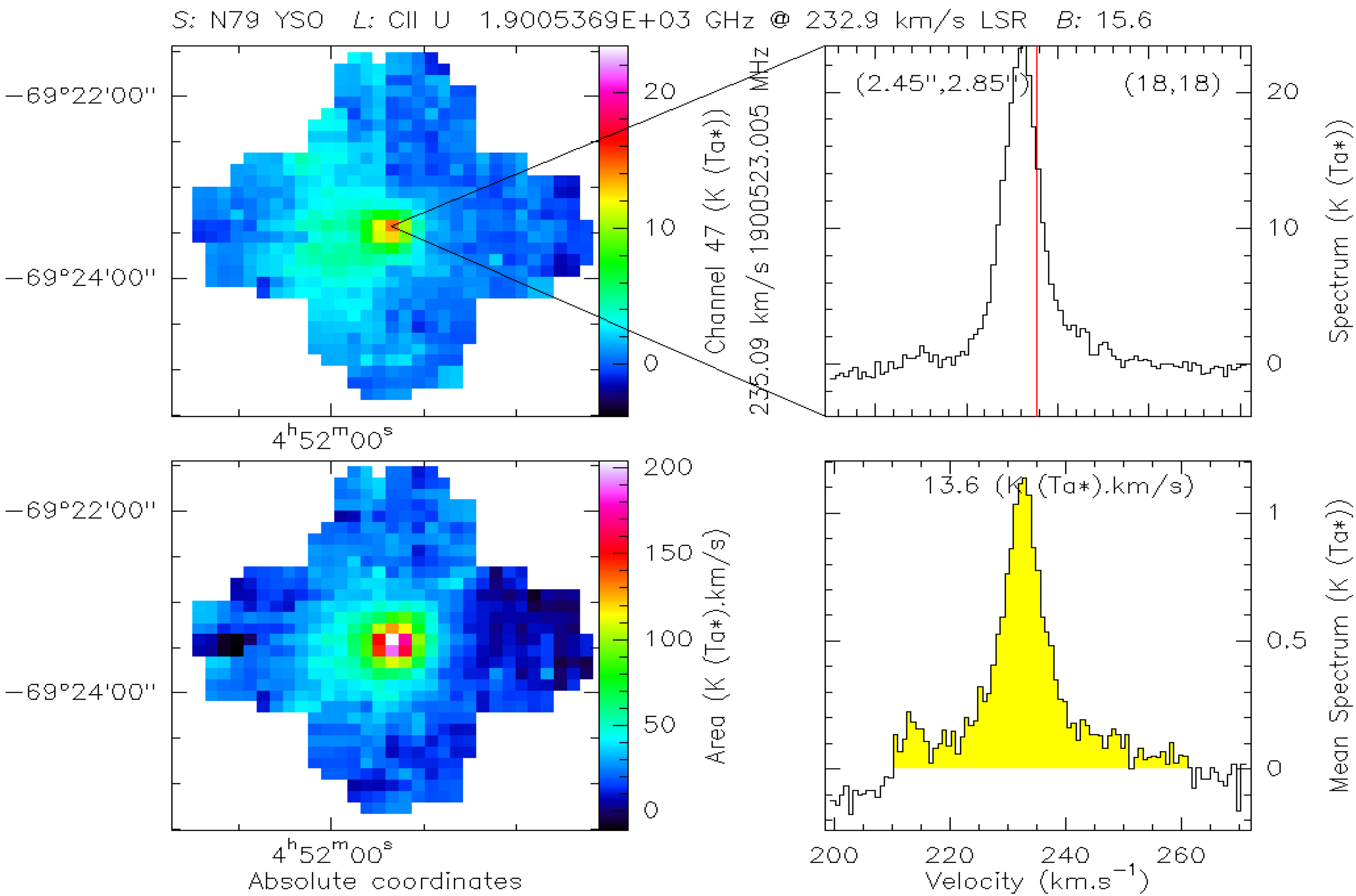
SOFIA GREAT CO (11-10)



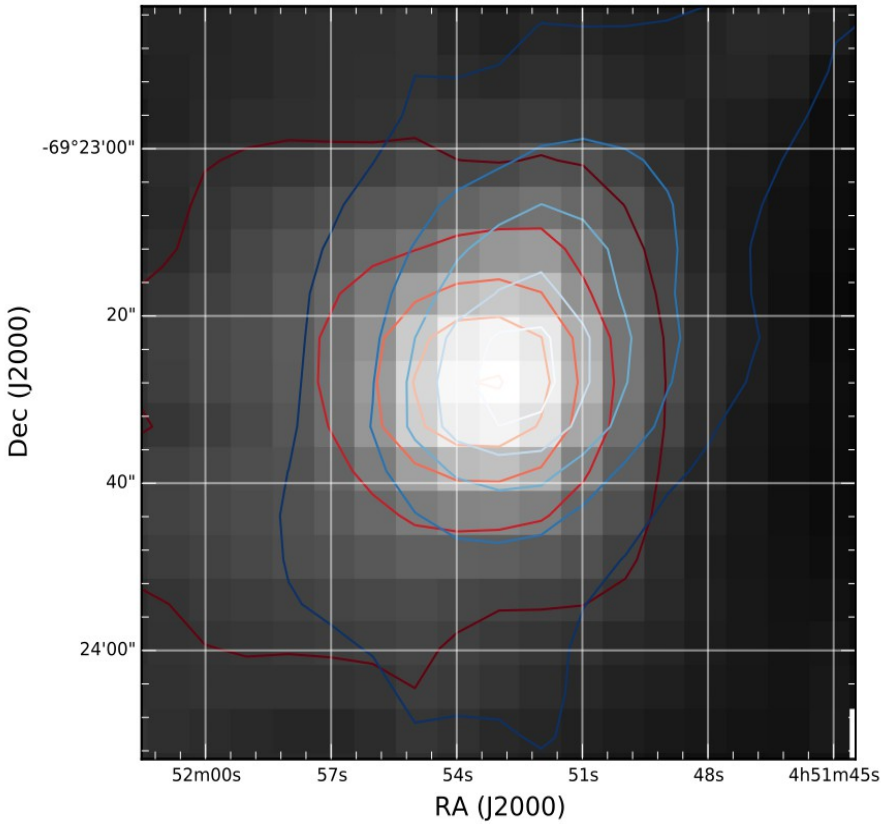
SOFIA GREAT CO (16-15)

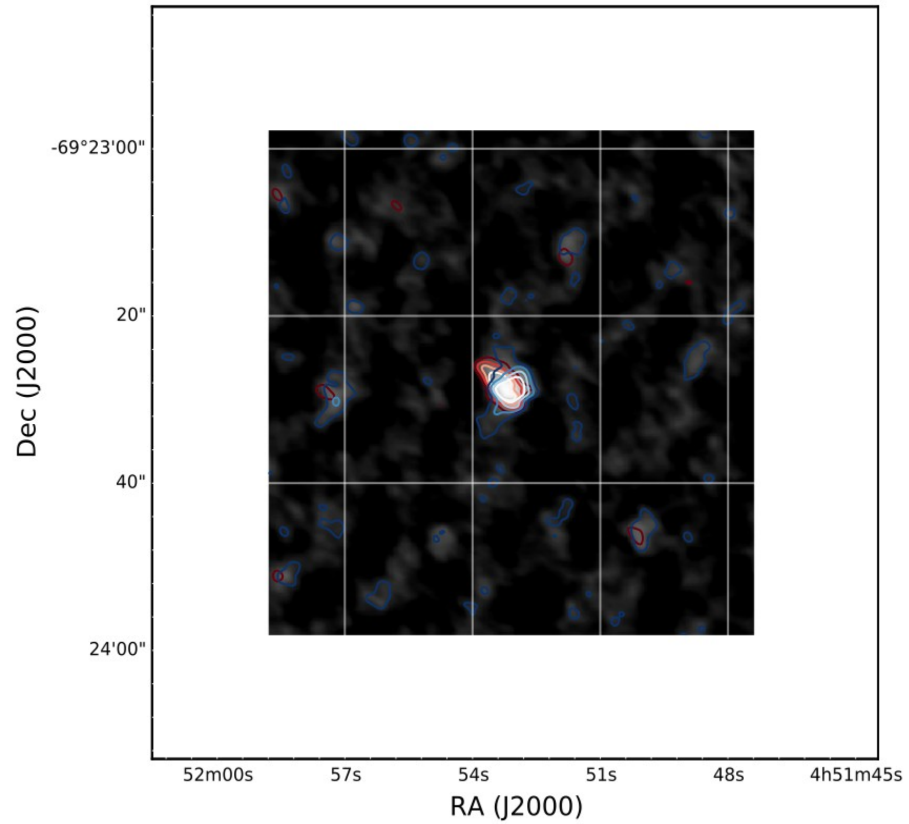


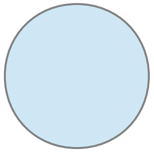
SOFIA [CII] Map



SOFIA [CII] Map + ALMA CO Map



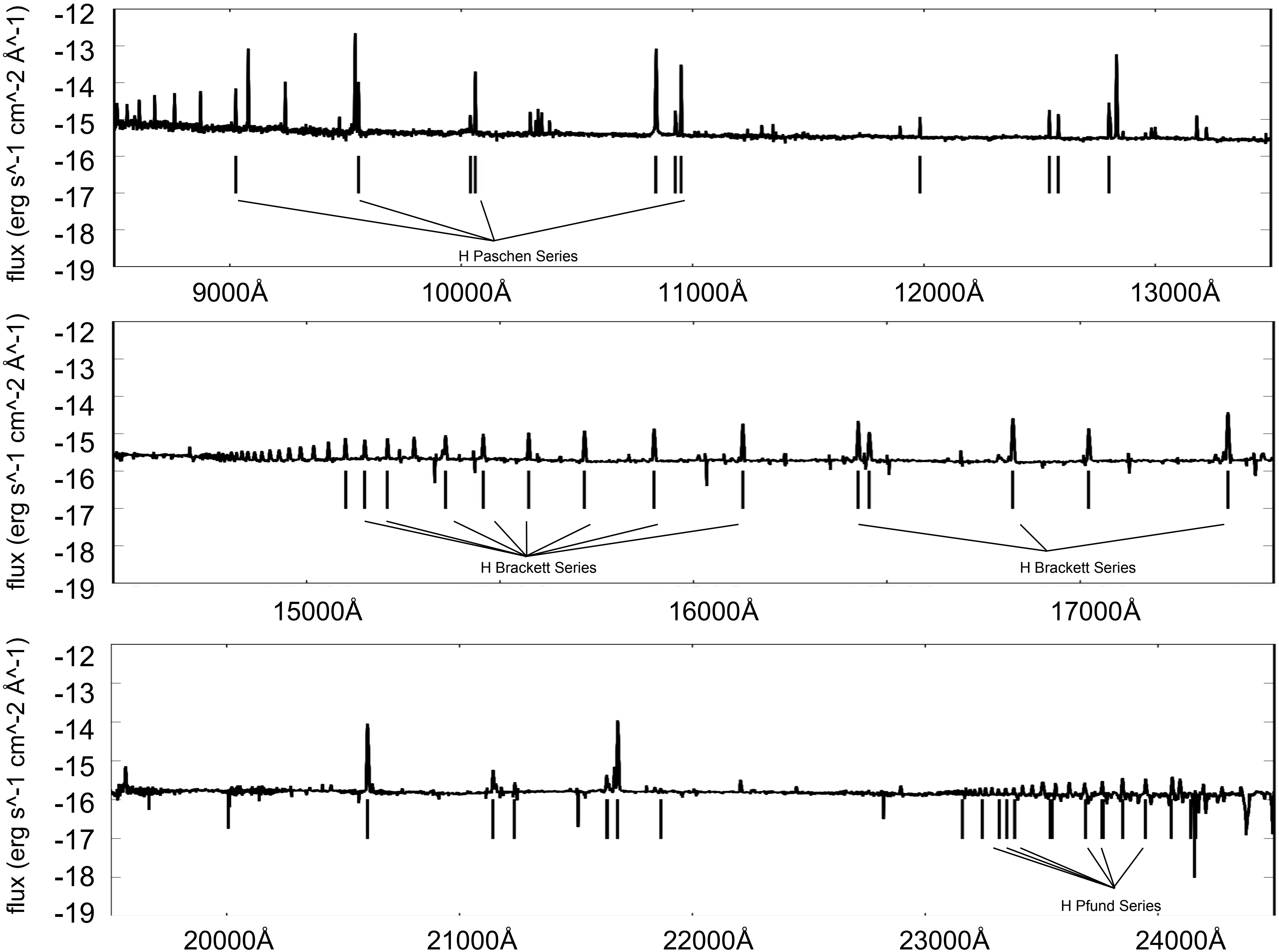




GREAT beam

ALMA beam

Magellan FIRE Spectrum of YSO in N79



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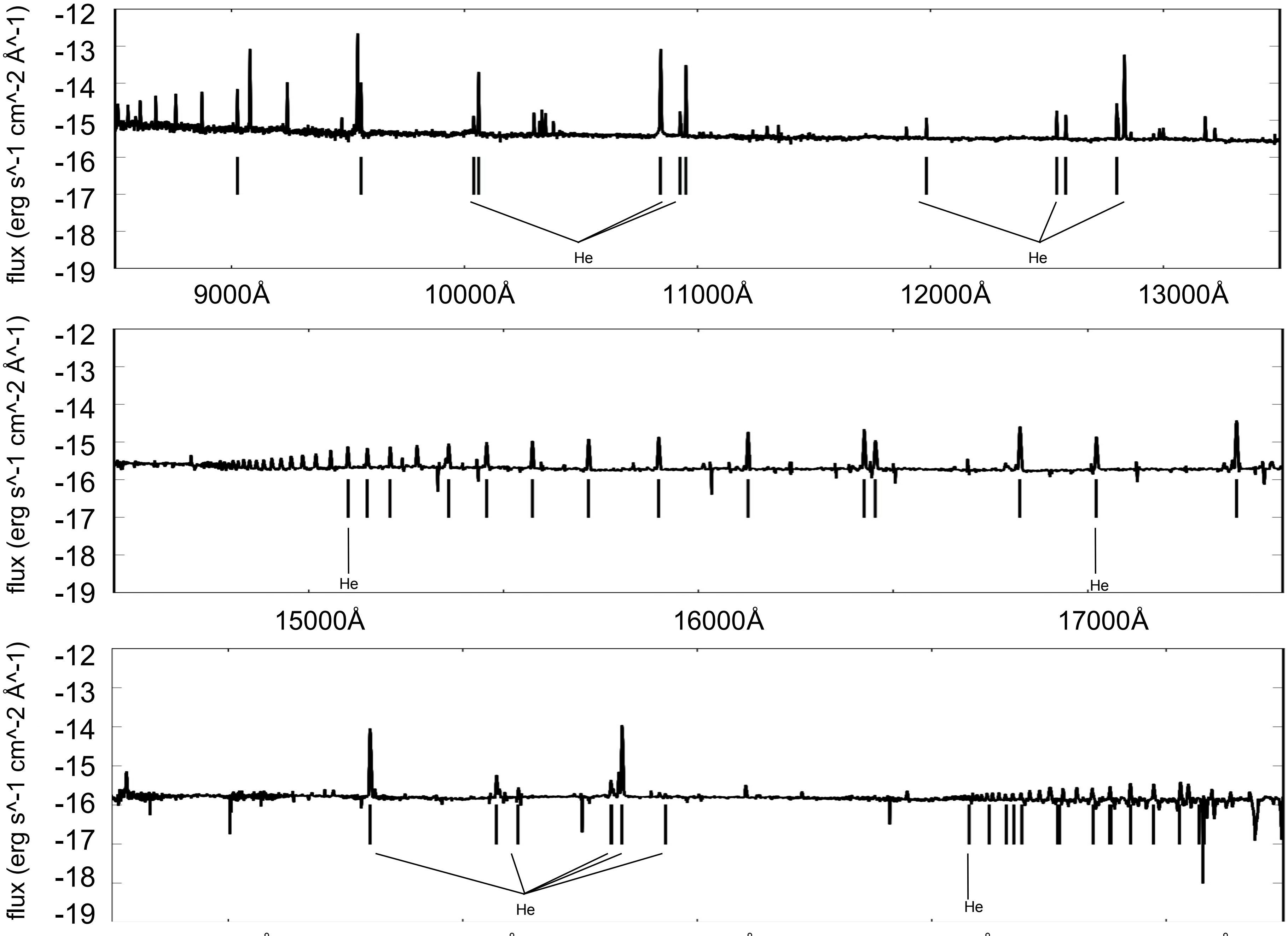

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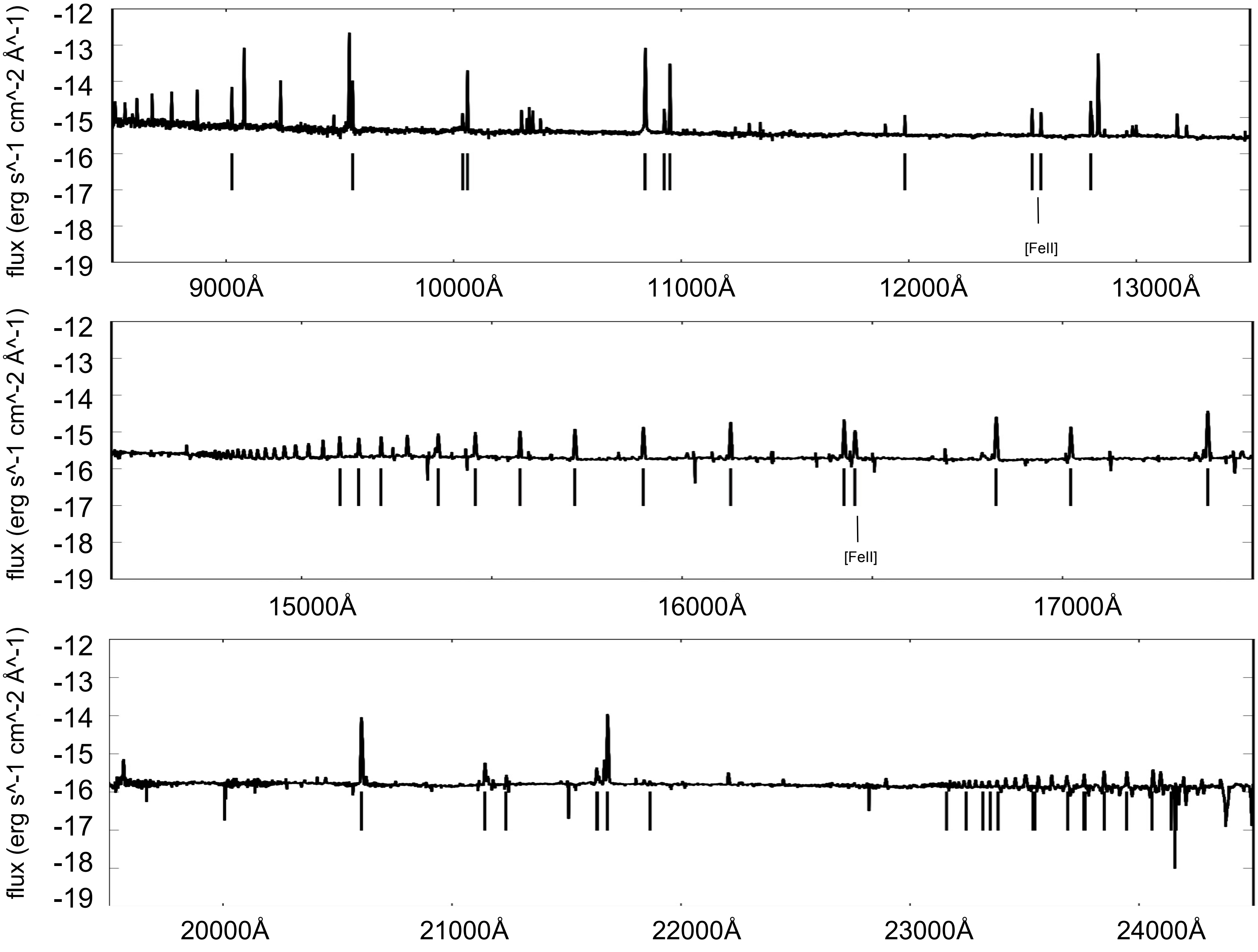

Magellan FIRE Spectrum of YSO in N79

- [FeII] line ratios can give us extinction to the source:

$$A_V = \left[2.5/\left(\frac{A_{\lambda_2} - A_{\lambda_1}}{A_V}\right)\right] \times \left(\log\frac{F_{\lambda_1}}{F_{\lambda_2}} - \log\frac{I_{\lambda_1}}{I_{\lambda_2}}\right)$$

- $2.5/((A_{\lambda 1} - A_{\lambda 2})/A_V)$ is dependent on which extinction law you use.
- $I_{\lambda 1}/I_{\lambda 2}$ is equal to the ratio of the spontaneous emission coefficients.
- In N79 $A_V = 3$.

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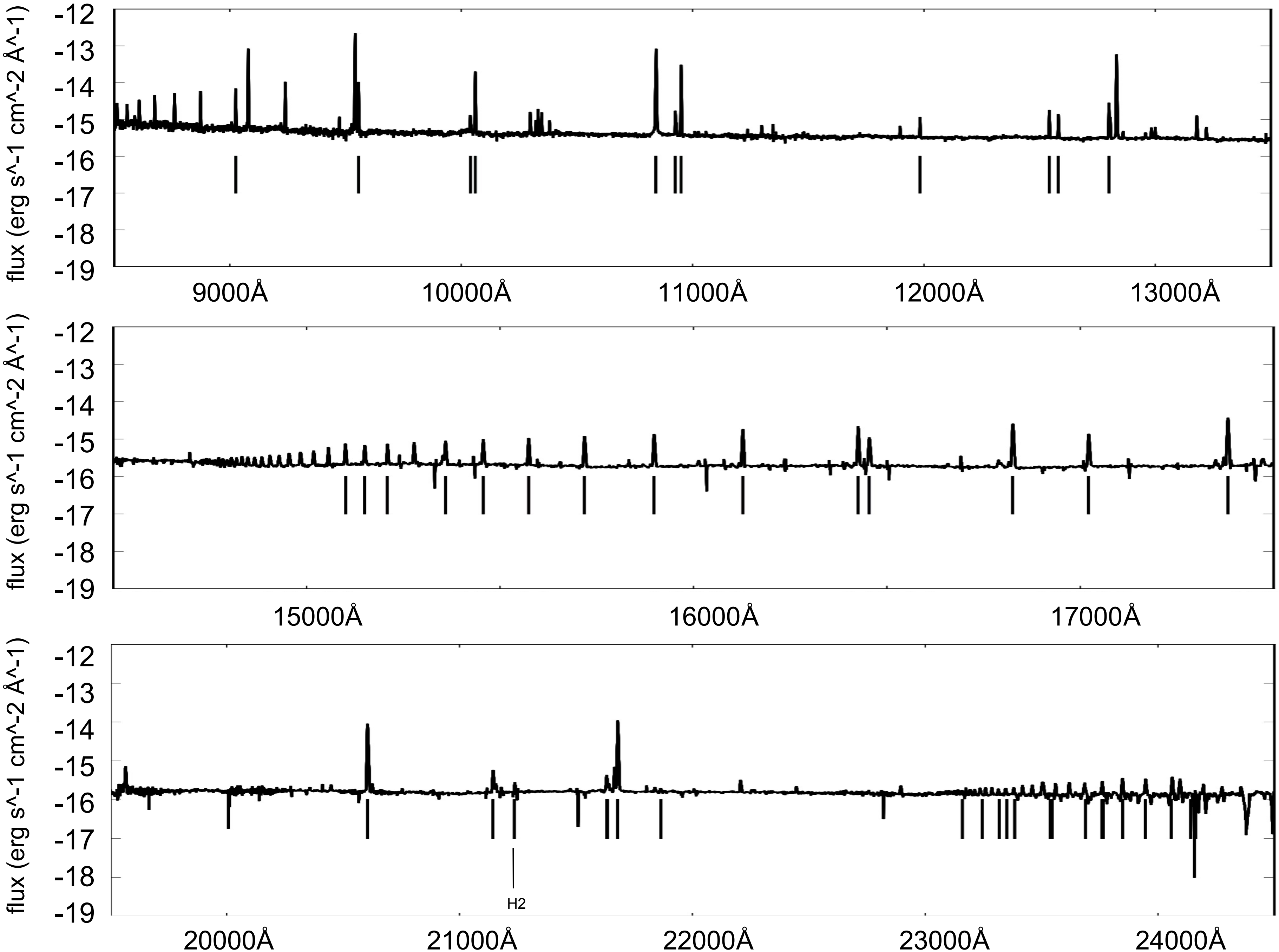

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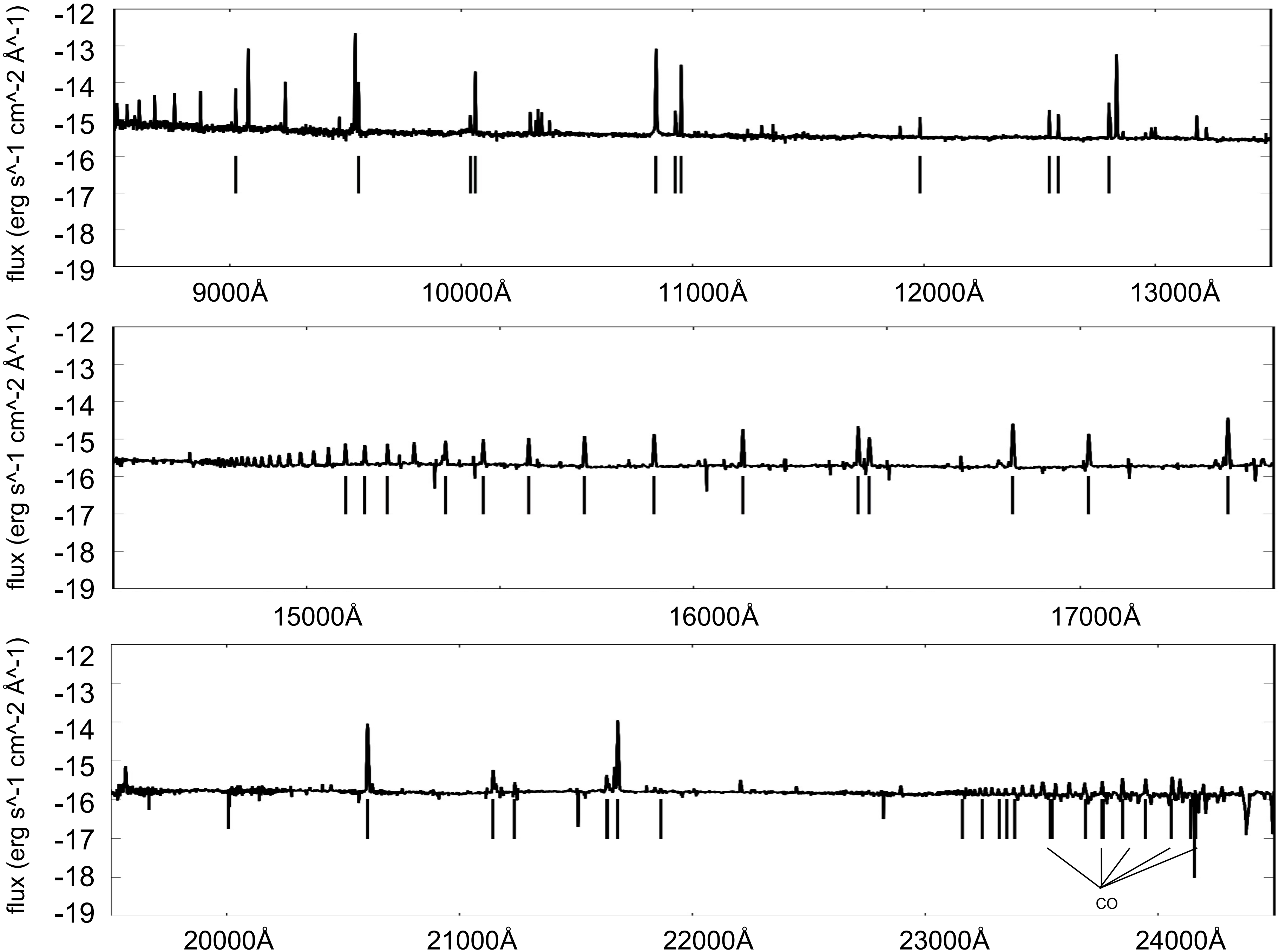
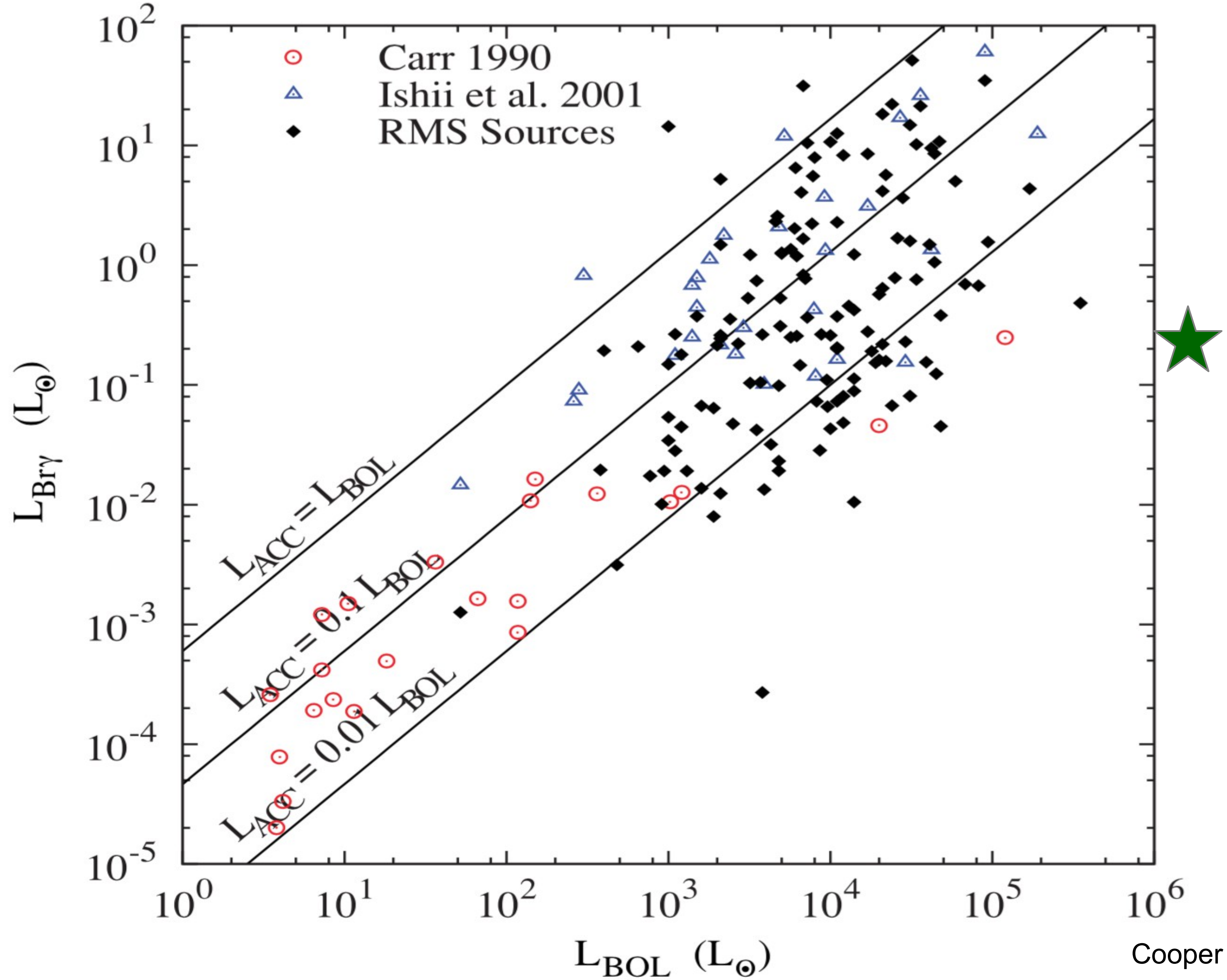


How do Emission Lines of the Massive YSO in N79 Compare to Milky Way YSOs?

Brγ Traces Accretion



Cooper et al. (2013)

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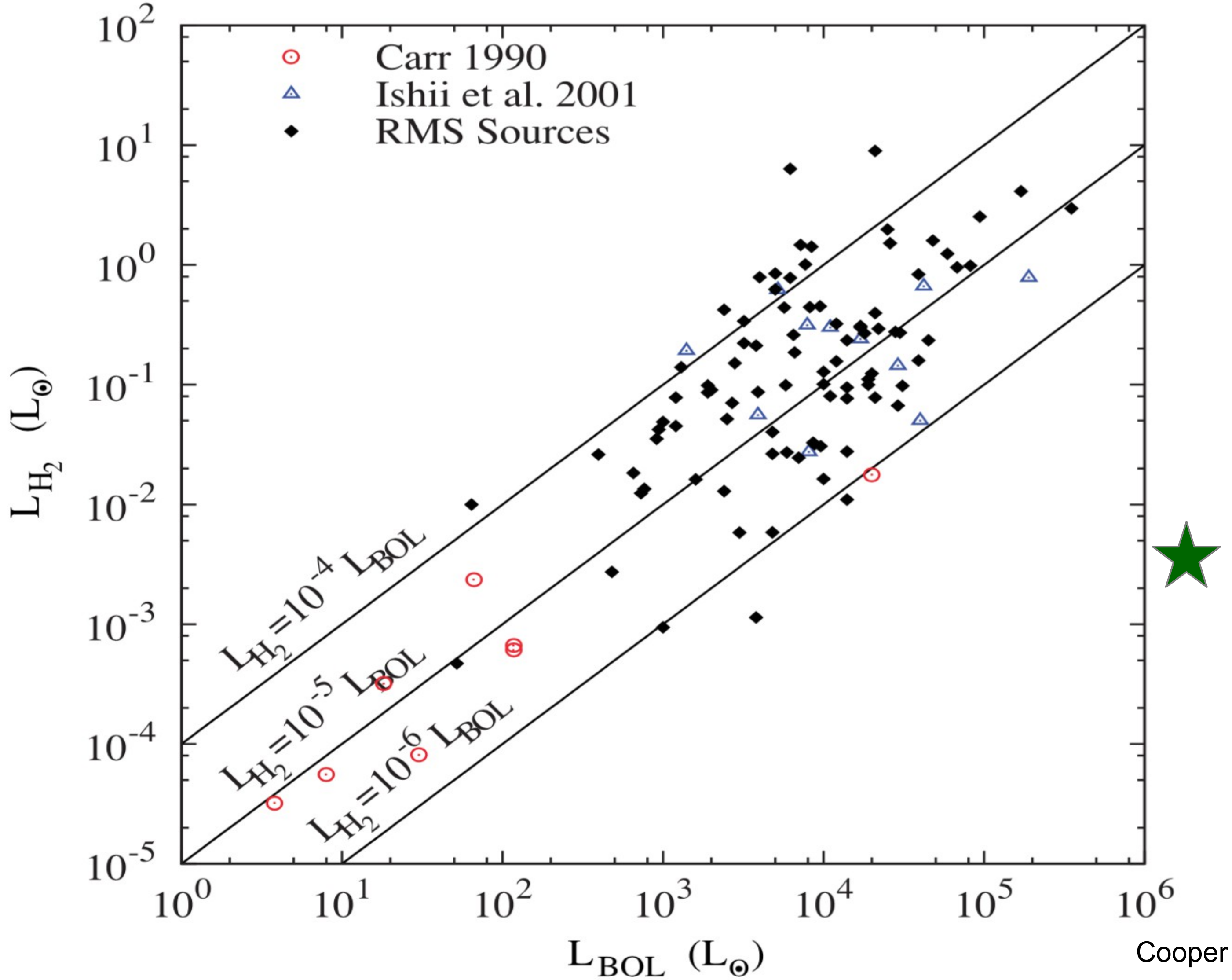
H_2 Emission Means there are Shocks



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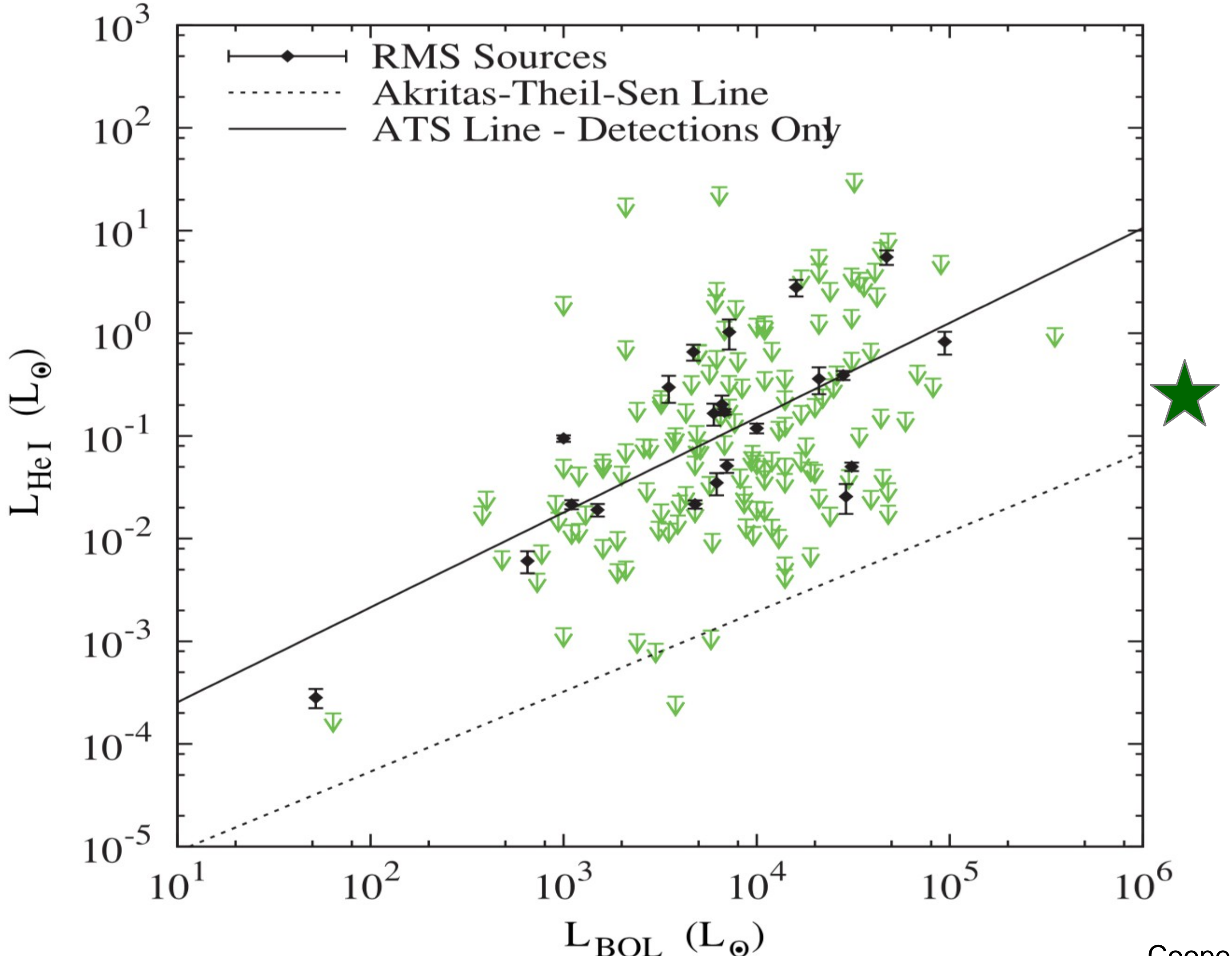
MYSO in N79 is Hot Enough to Ionize He



Cooper et al. (2013)

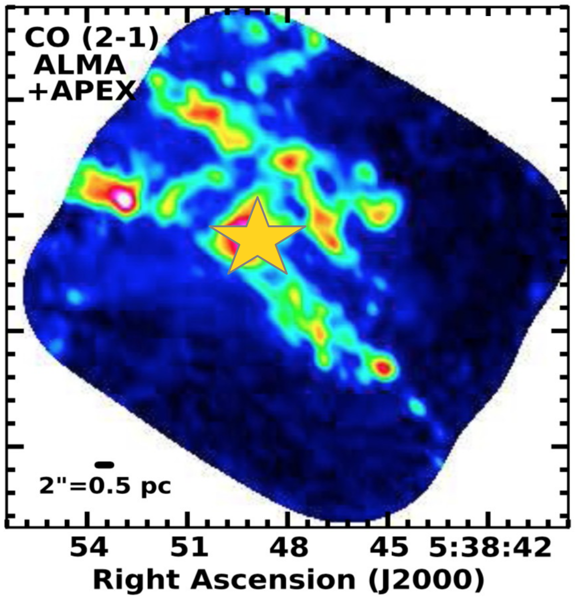
Conclusion I – Most Luminous YSO is Weird

- Most luminous YSO is not located where we would expect.
- Most luminous YSO is not accreting as much, producing as strong shocks, and not ionizing as much Helium as massive YSOs in the Milky Way.

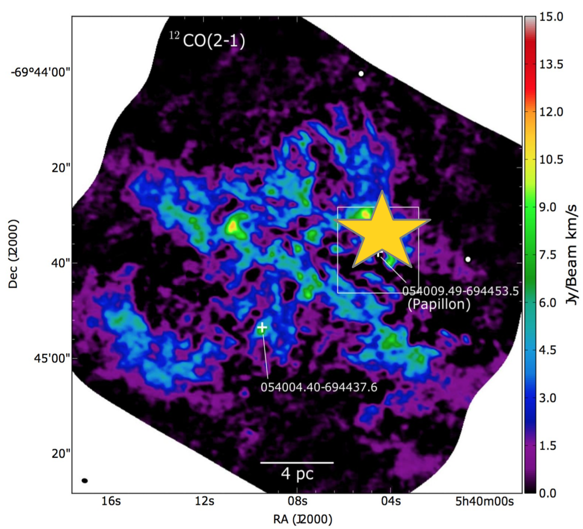
Conclusion II – We Have Lots of Data

- ALMA
  - 12CO, 13CO, C18O, HCO+
  - We can study the molecular gas structure and dynamics.
- SOFIA
  - CO (11-10) spectrum, CO (16-15) spectrum, [CII] map
  - We can determine the structure of the PDR.
  - We can compare the high-J CO spectra to the molecular gas spectra from ALMA to get a better understanding of the gas dynamics.
- Magellan FIRE Spectrograph
  - We can analyze the properties of the central protostar and how the protostar affects the surrounding gas.

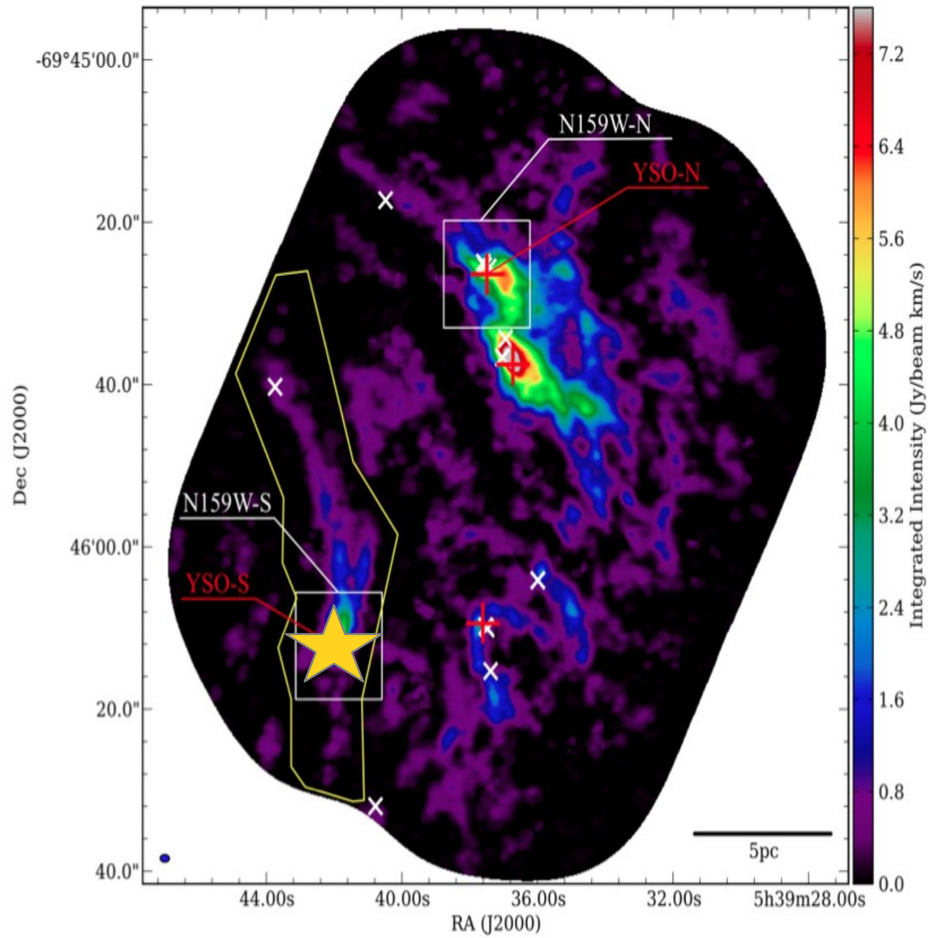
Conclusion III – Future Work



ALMA CO - 30 Doradus
Indebetouw et al. (2013)



ALMA CO - N159E
Saigo et al. (2016)



ALMA CO - N159W
Fukui et al. (2015)

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