

# JWST Photometry and Spectra Reveal Dust and Ice in the Magellanic Clouds

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PID: 1227, 1235

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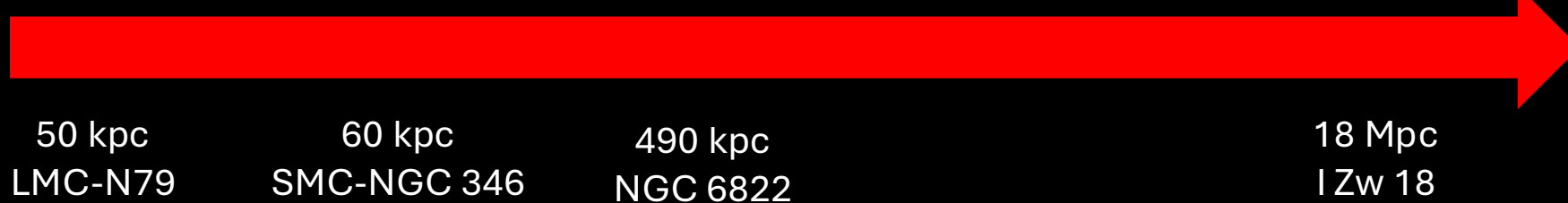
Photo Credit: NASA, ESA, CSA, O. Nayak, M. Meixner

# Why Study Extra-Galactic Star Formation at Low Metallicity?

Metallicities similar to that of Universe's peak Star Formation Epoch



Known Distance → Known Luminosities



Maximize Statistics: 100s to 1000s of sources in one image

JWST Synergy with ALMA & HST enables Milky Way like studies for first time

10 kpc

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## Why Study Super Star Clusters?

**SSCs are rare but were the predominant method star formation took place 6-7 billion years ago**

Meixner et al. (2006)

Red: MIPS 24, Green: IRAC 8.0, Blue: IRAC 3.6

10 kpc

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10 kpc

R136 SSC in  
30 Doradus



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**MW has Westerlund 1 (age ~ 3 Myr) and LMC has R136 in 30 Doradus region (age ~ 25 Myr)**

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SSC H72.97-  
69.39 in N79



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**JWST NIRCам observations reveal LMC to have another SSC in the N79 region less than 100,000 years old**

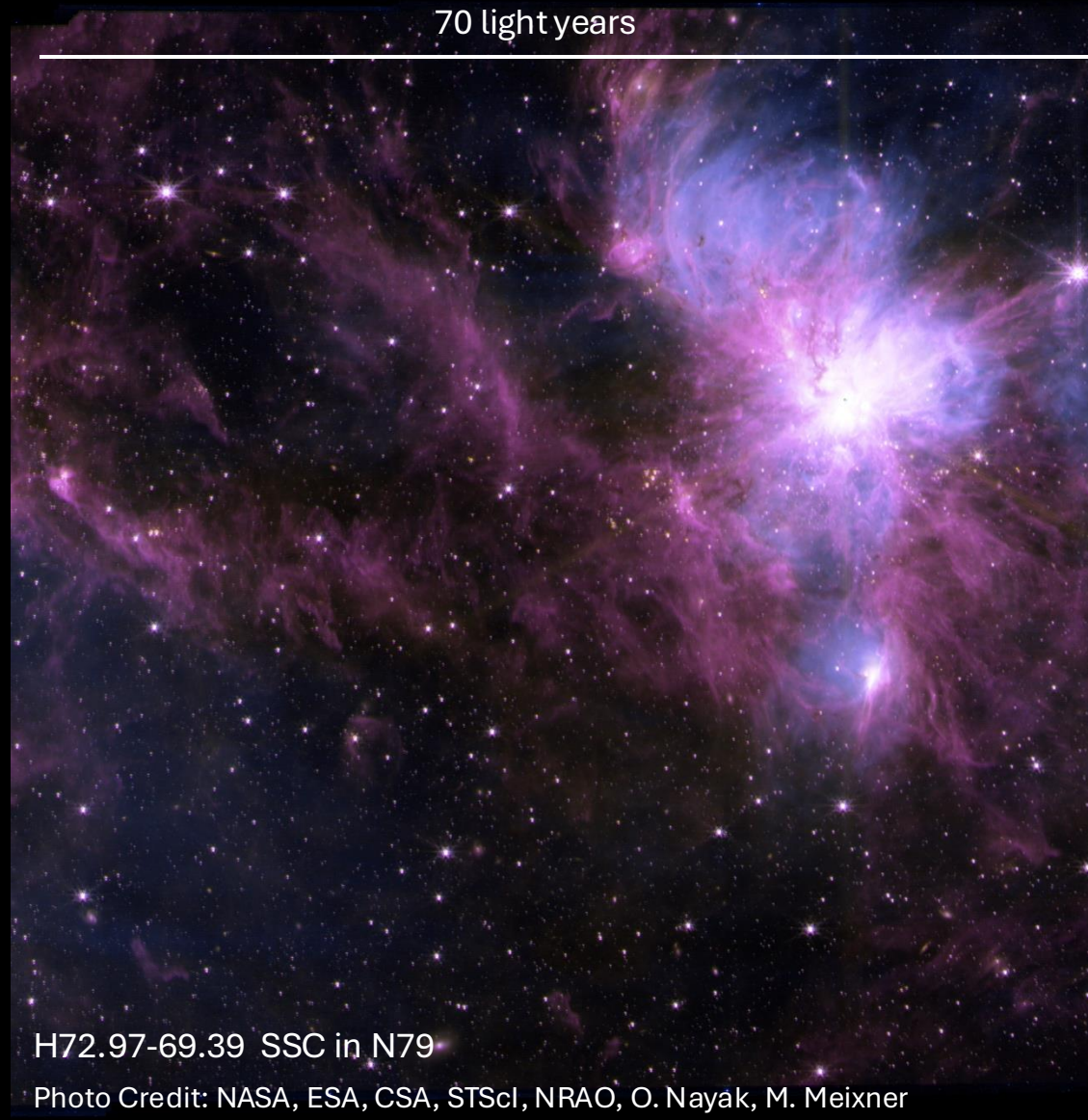
170 light years



R136 SSC in 30 Doradus


Photo Credit: NASA, ESA, CSA, STScI, Webb ERO Production Team

70 light years



H72.97-69.39 SSC in N79

Photo Credit: NASA, ESA, CSA, STScI, NRAO, O. Nayak, M. Meixner



JWST NIRCам observations  
reveal over 1500 protostars  
are forming within this SSC

The most massive stars are  
forming in the central region  
with the brightest emission

The lower mass stars are  
mostly further away and along  
the wispy structure

JWST NIRCам F187N  
JWST NIRCам F335M  
JWST NIRCам F444W

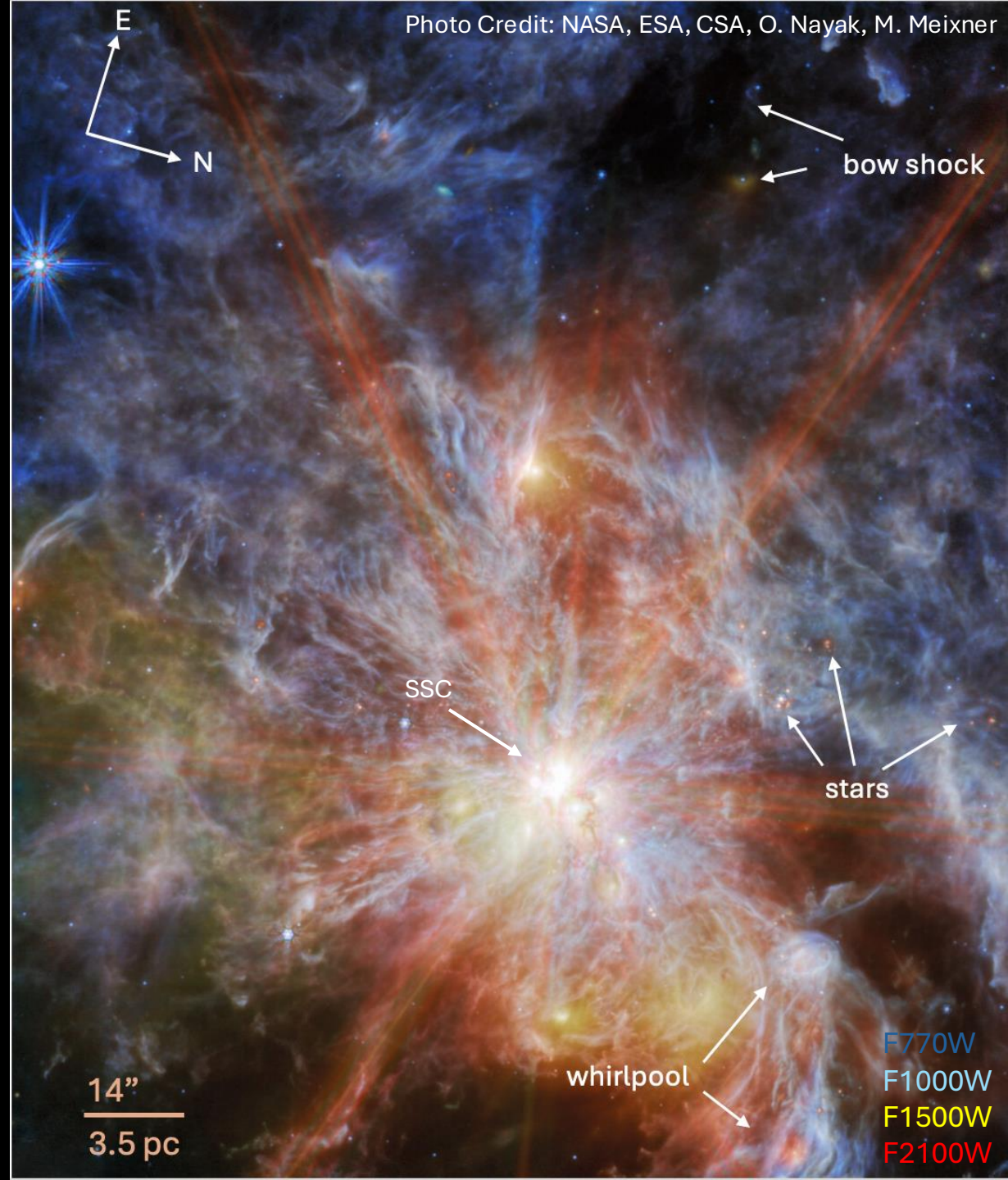
NIRCam observations represents early- and late-stage star formation



JWST NIRCam F187N  
JWST NIRCam F335M  
JWST NIRCam F444W

# JWST MIRI and NIRCам Reveals Over a Thousand Protostars Forming Near SSC H72.97-69.39

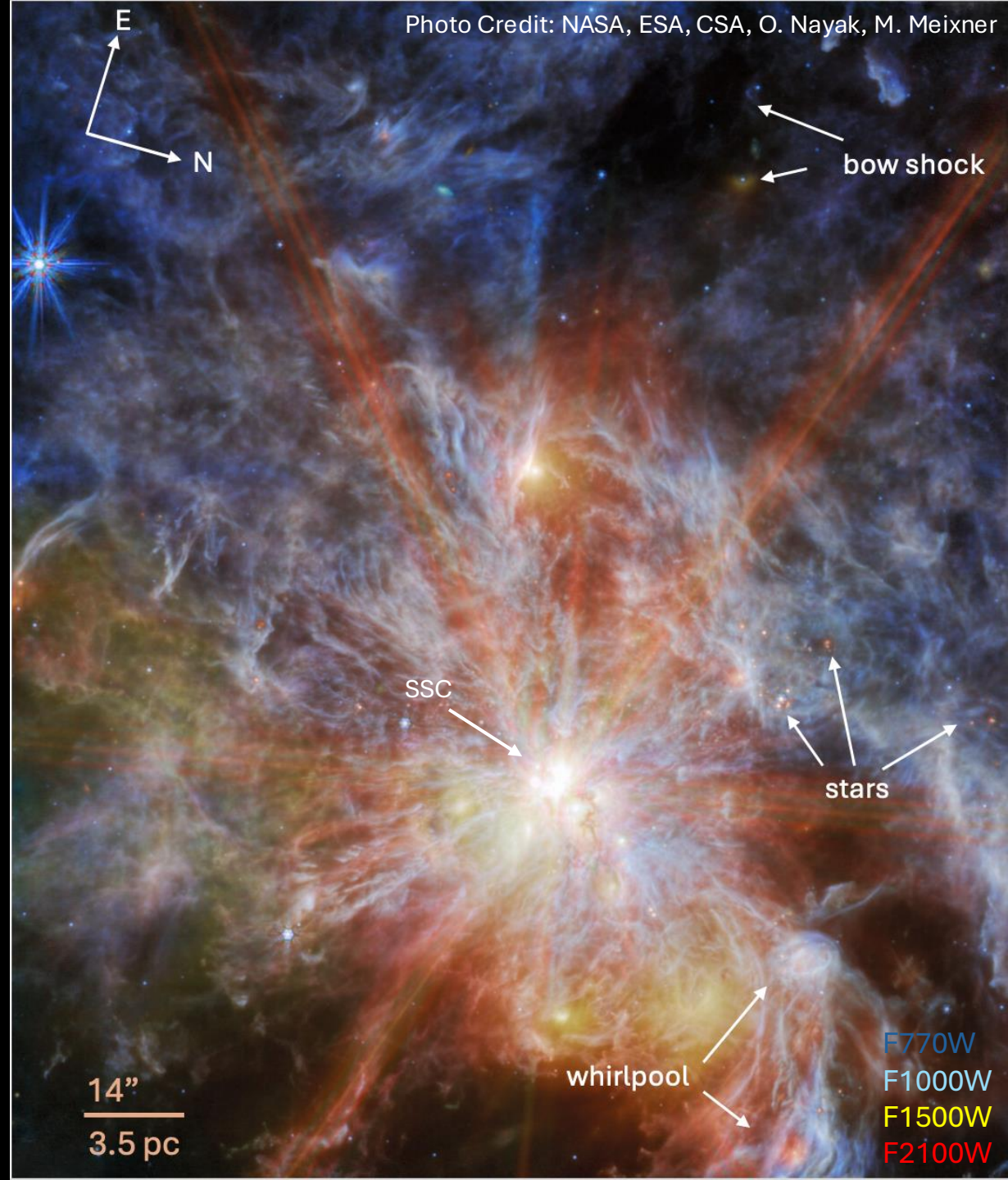
This MIRI image shows the protostars, bow shocks, and whirlpool-like structure in the emission



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There are 102 YSOs identified with MIRI imaging and MIRI spectroscopic imaging

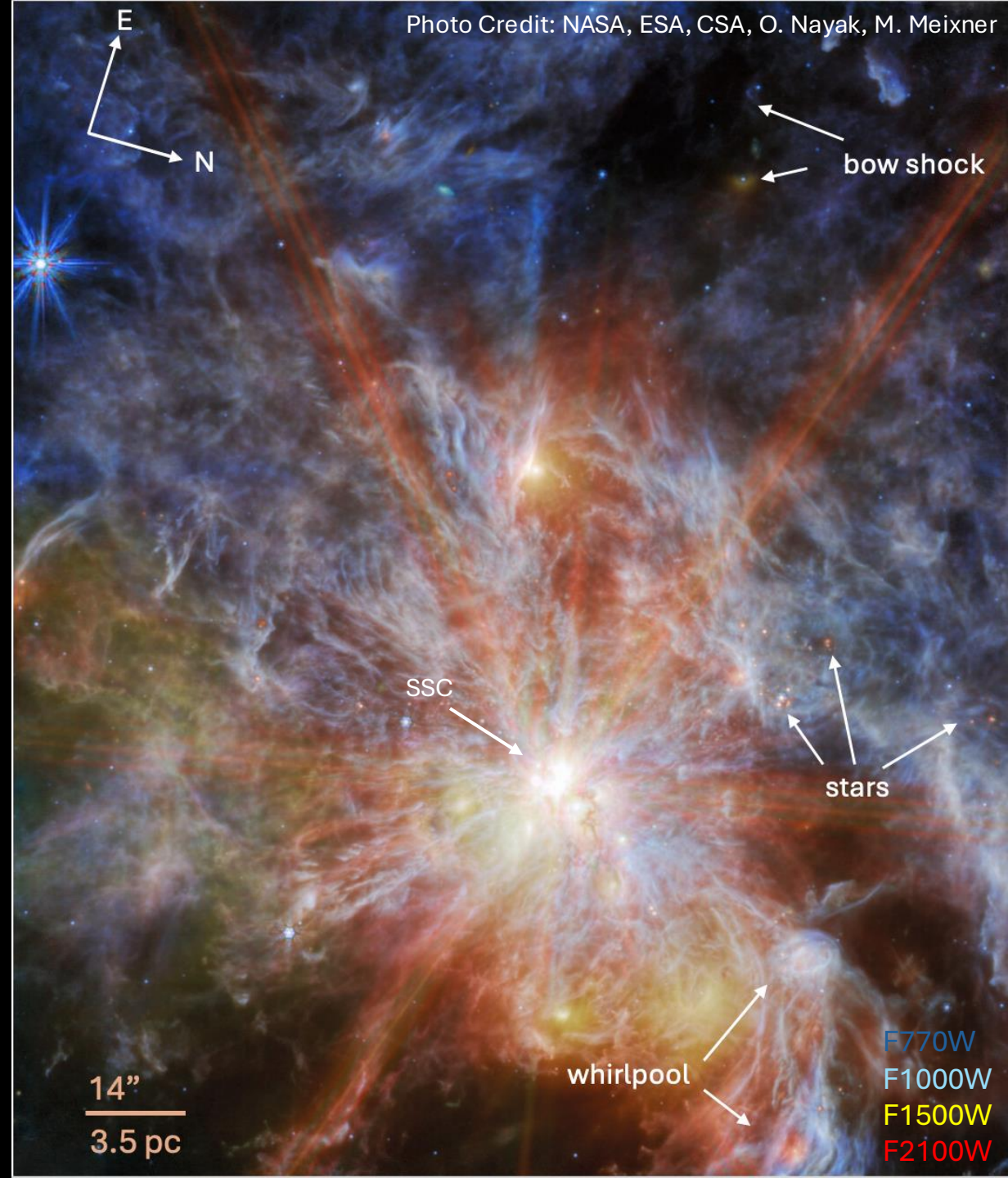


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This MIRI image shows the protostars, bow shocks, and whirlpool-like structure in the emission

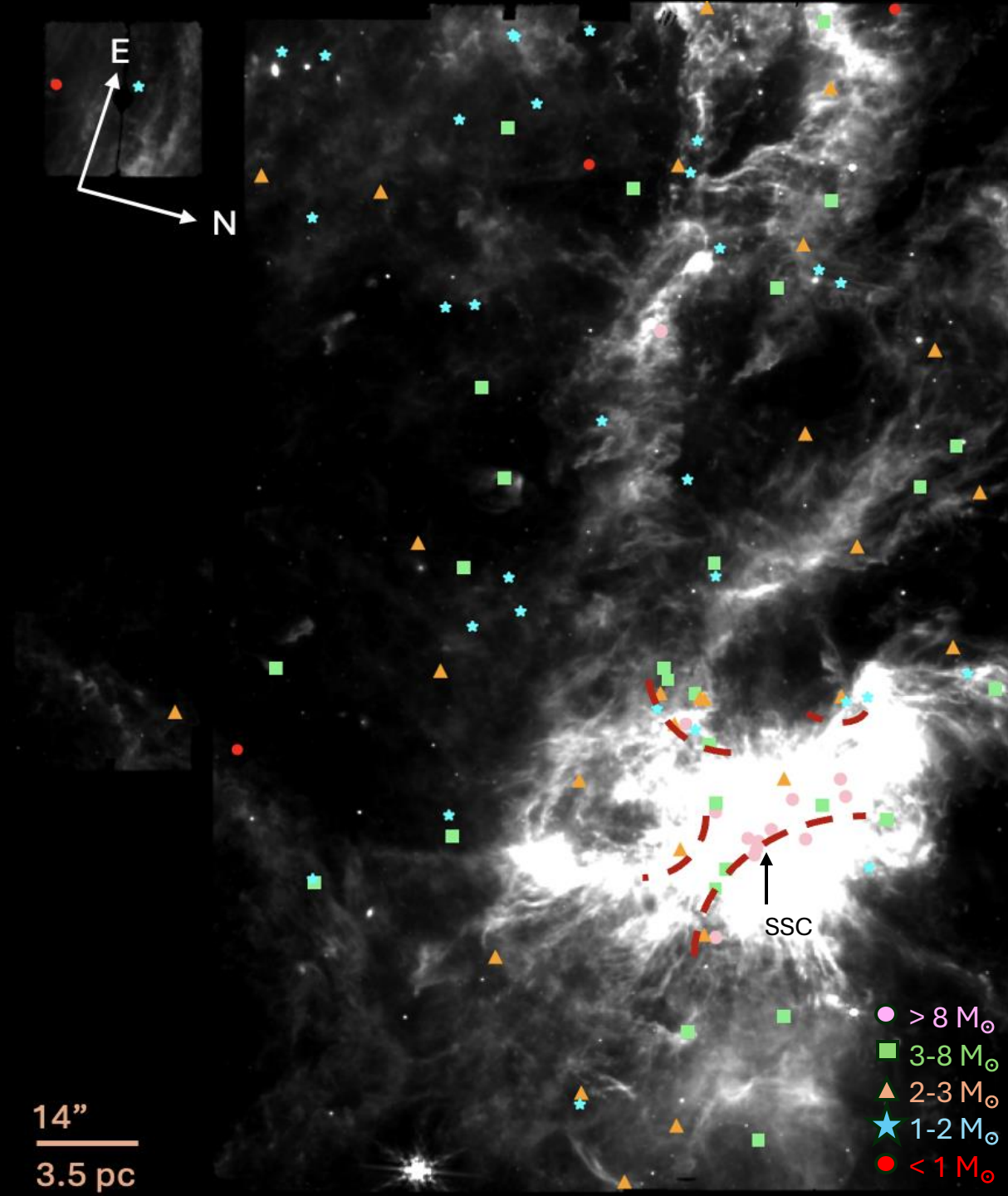
There are 102 YSOs identified with MIRI imaging and MIRI spectroscopic imaging

NIRCam data shows over 1500 protostars forming in a footprint slightly larger than the MIRI footprint and prove unambiguously that H72.97-69.93 is an SSC



# MIRI Observed YSOs Between $0.7 - 38 M_{\odot}$

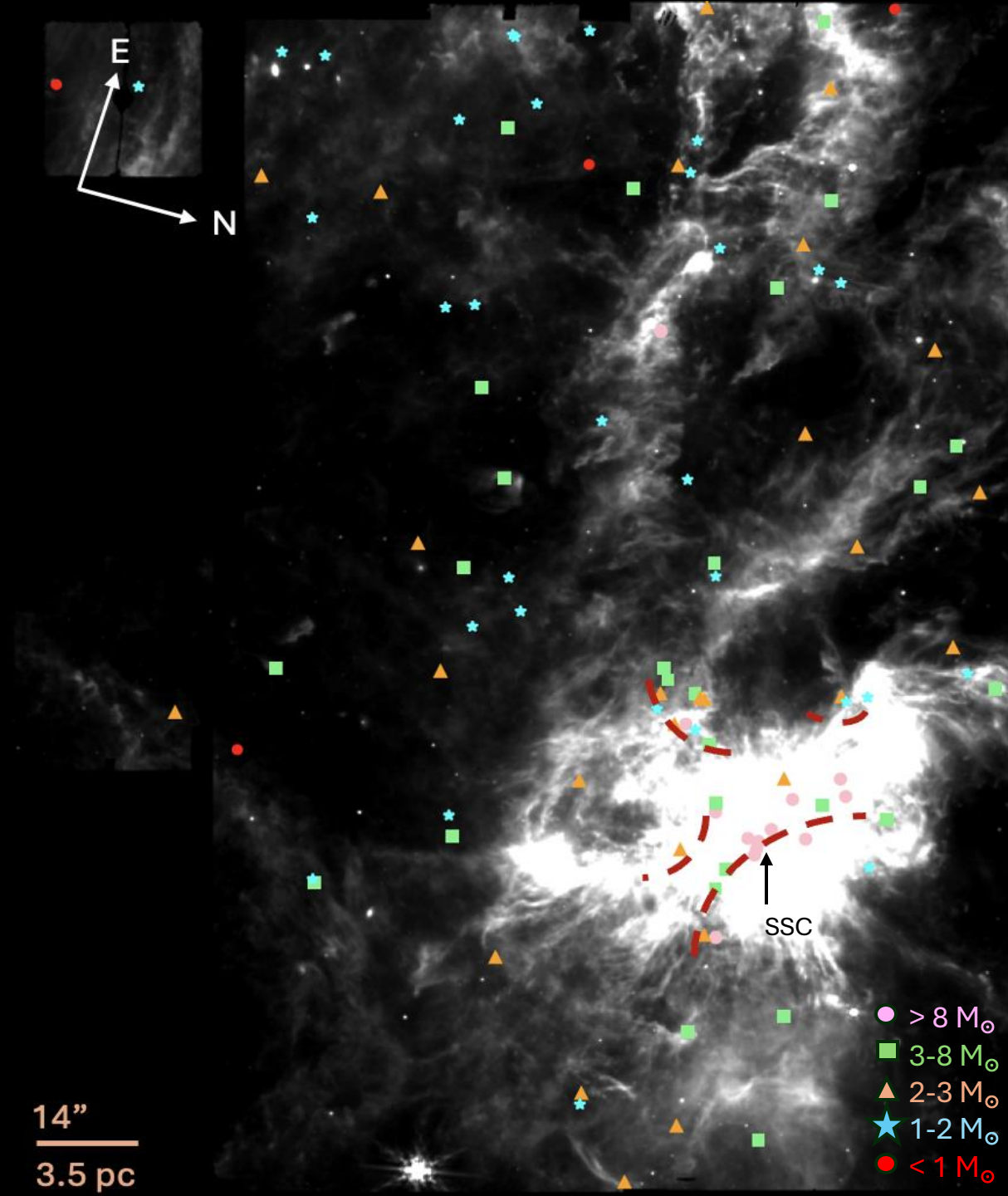
There are 13 YSOs greater than  $8 M_{\odot}$  shown in  
this F1000W MIRI image



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12/13 YSOs greater than  $8 M_{\odot}$  are located at or near the SSC H72.97-69.39

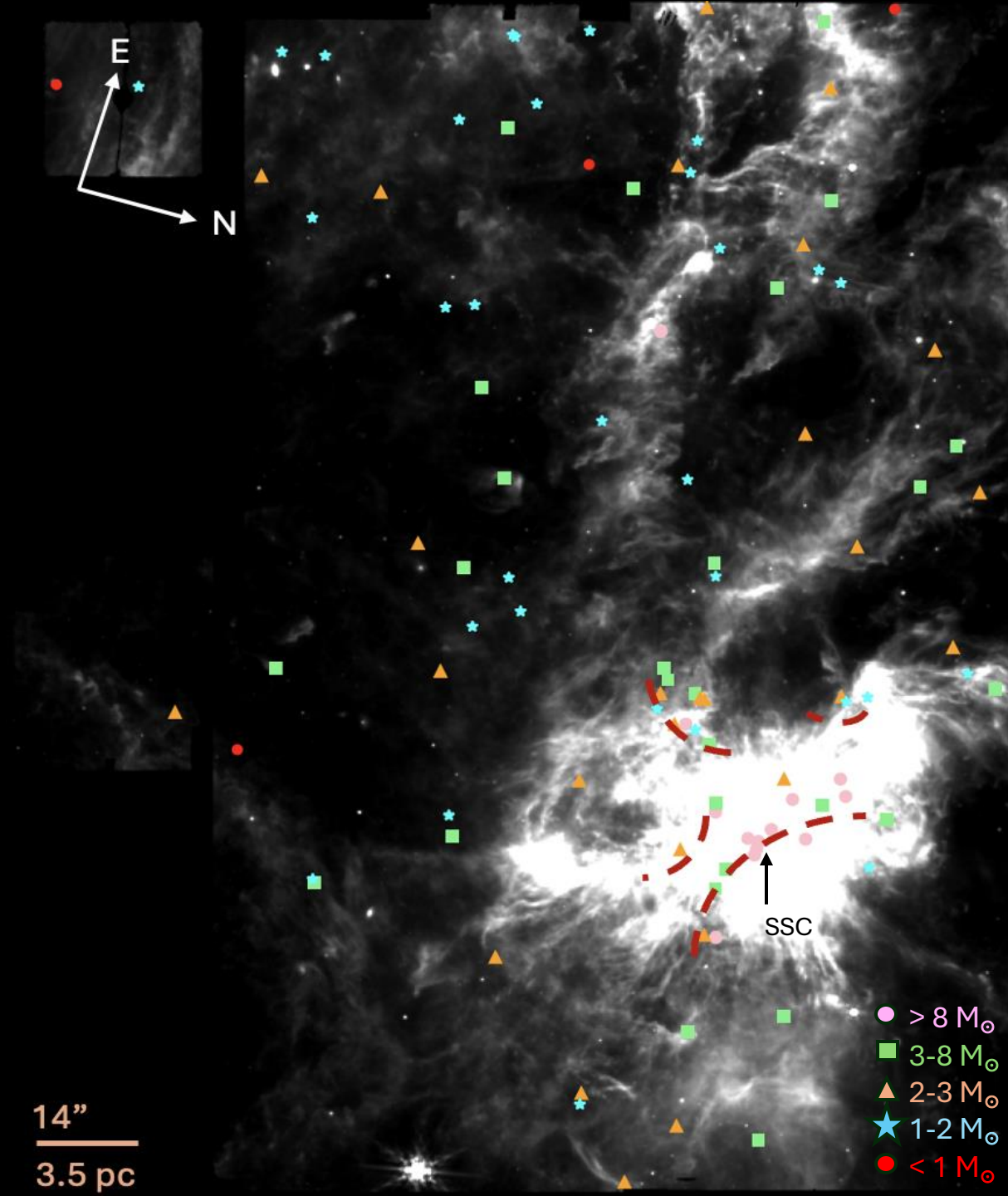


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12/13 YSOs greater than  $8 M_{\odot}$  are located at or near the SSC H72.97-69.39

More massive YSOs seem to be forming along shell-like arcs closer to the gravitational center of the cluster, and less massive YSOs form further away and in pillar-like structures



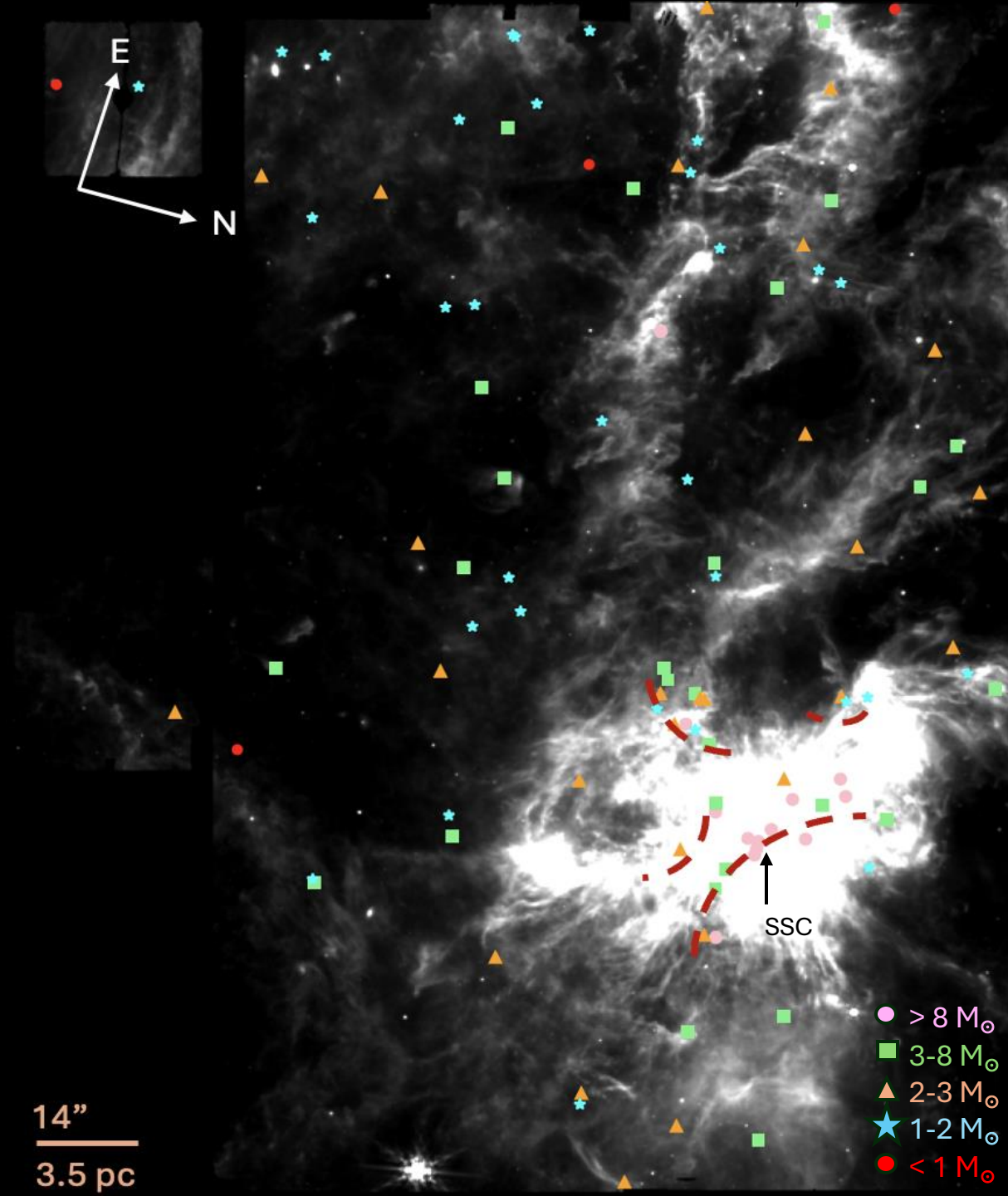
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The mass segregation observed with MIRI is similar to observations of RCW120 (Figueira et al. 2017) and modeling done by Walch et al. (2013)



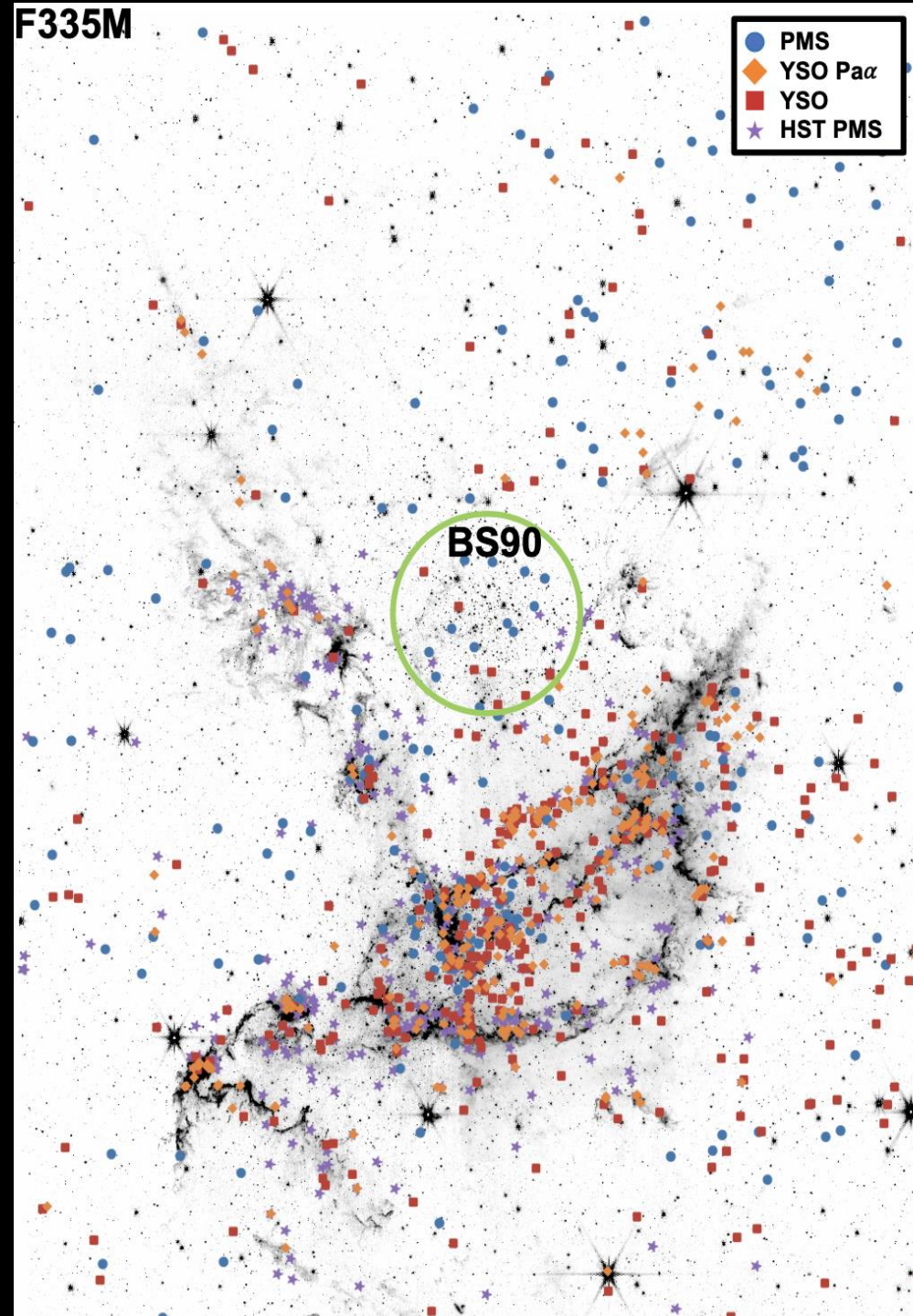
- PMS
- ◆ YSO Pa $\alpha$
- YSO
- ★ HST PMS

# Small Magellanic Cloud (0.3 $Z_{\odot}$ )

NIRCam discovered thousands of lower mass (less than 5  $M_{\odot}$ ) YSOs



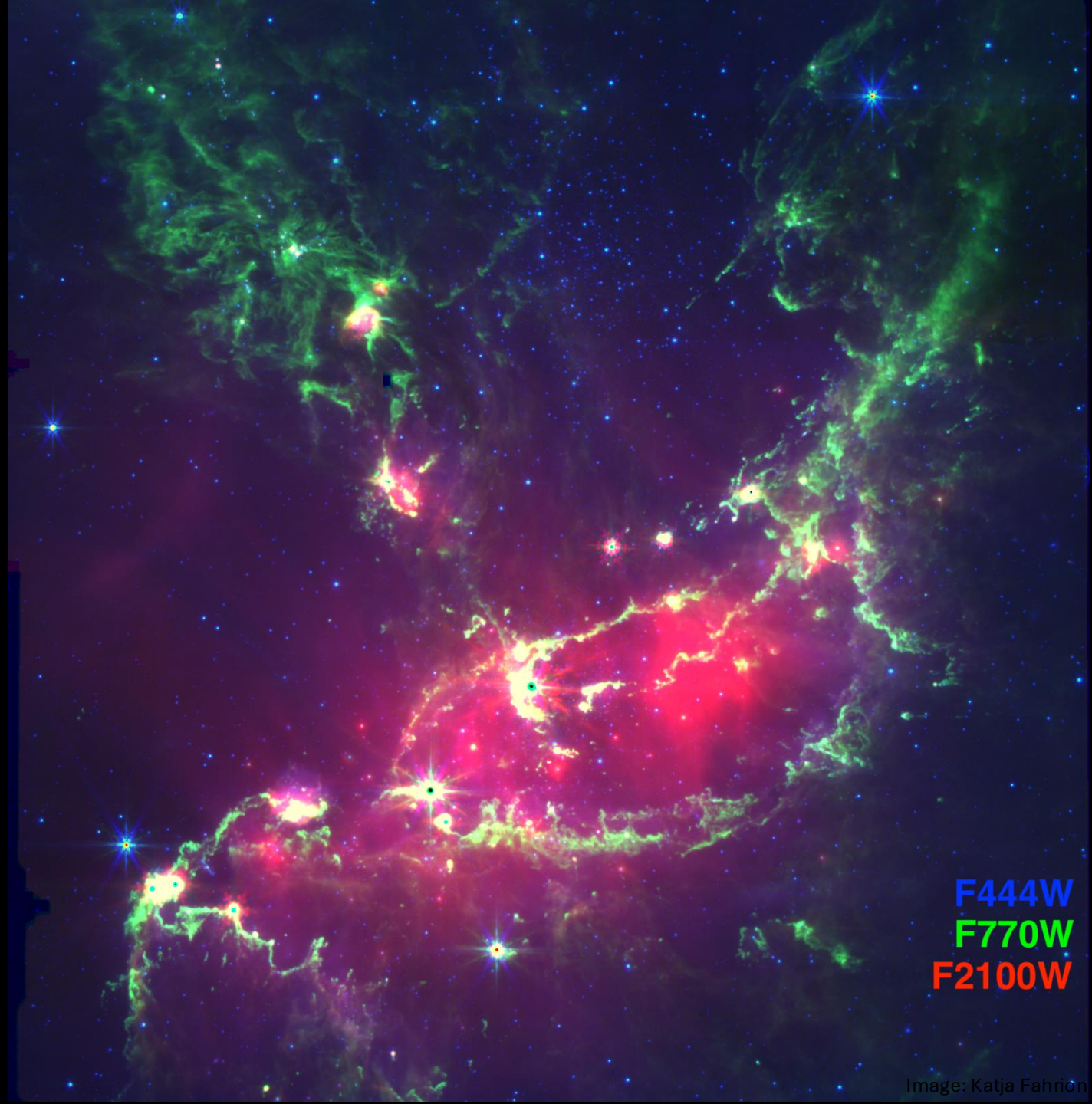
NIRCam Filters | F200W F277W F335M F444W



# NGC 346

## WHAT MIRI REVEALS

MIRI traces the structure of  
diffuse emission from  
cooler gas and dust.  
Deeply embedded YSOs  
shine brightly



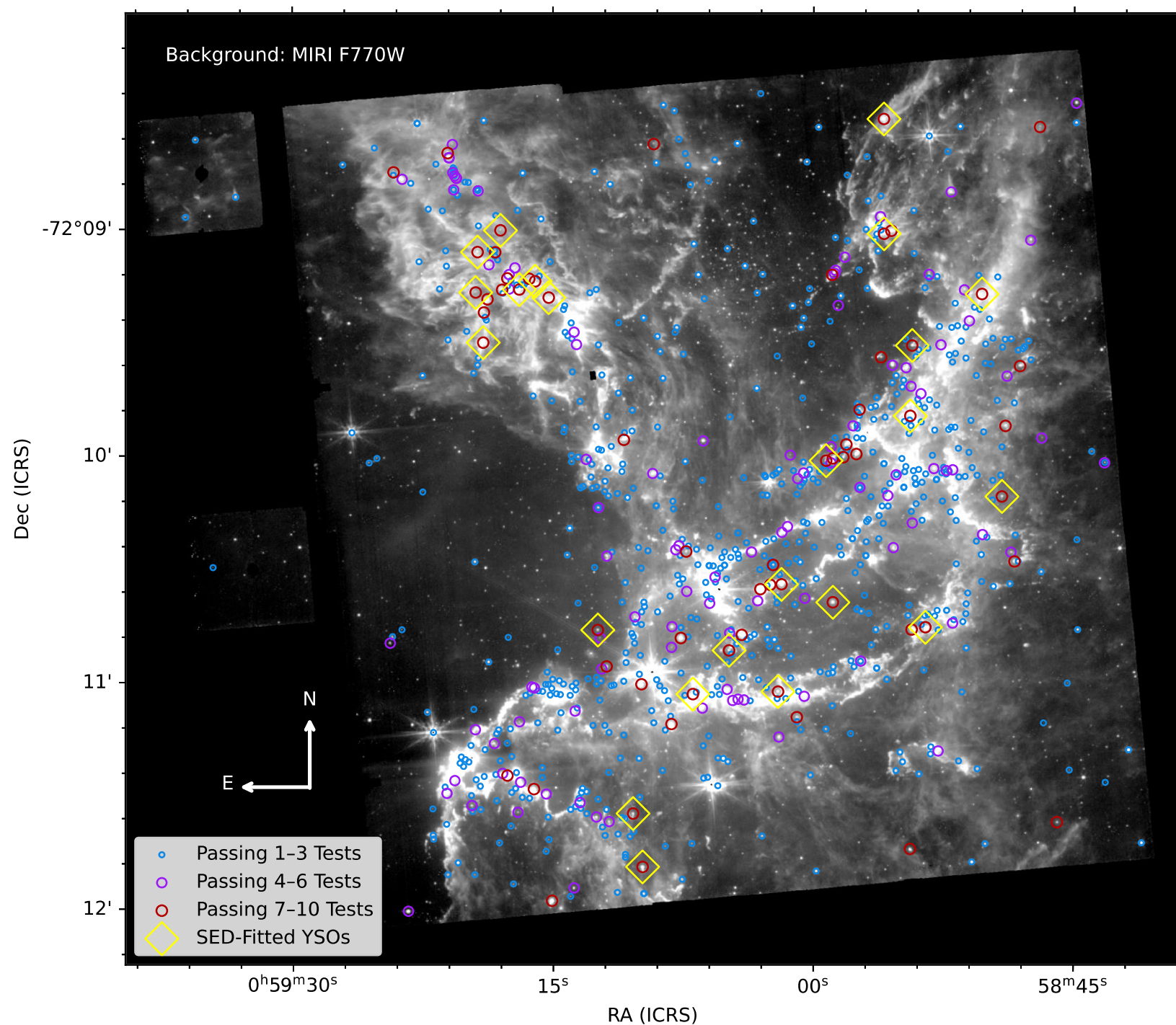
F444W  
F770W  
F2100W

NGC 346

MIRI finds **833**

candidate YSOs, many  
also having been  
flagged as YSOs with  
NIRCam

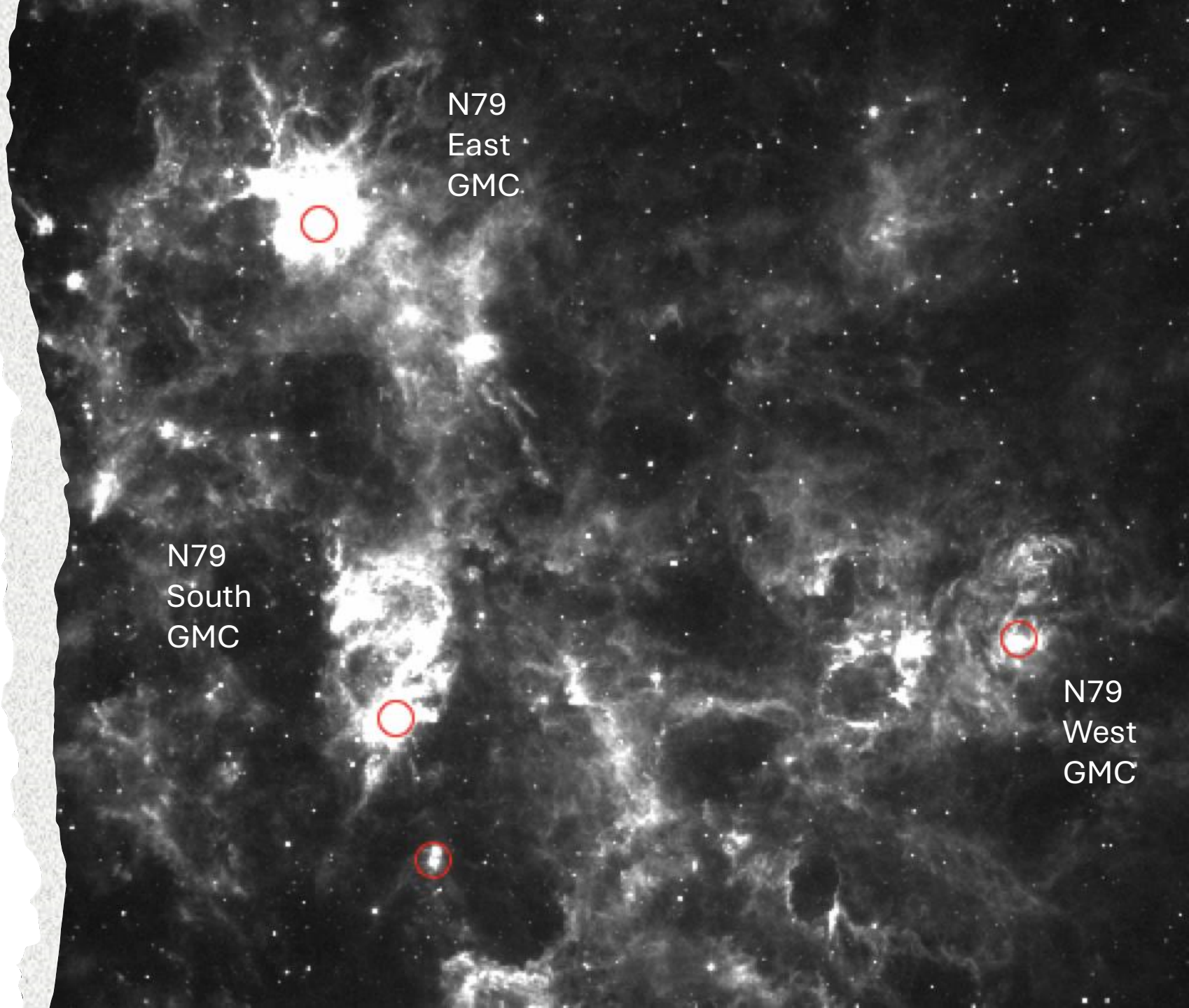
Redder, more deeply-  
embedded sources lie  
along filaments of gas  
and dust



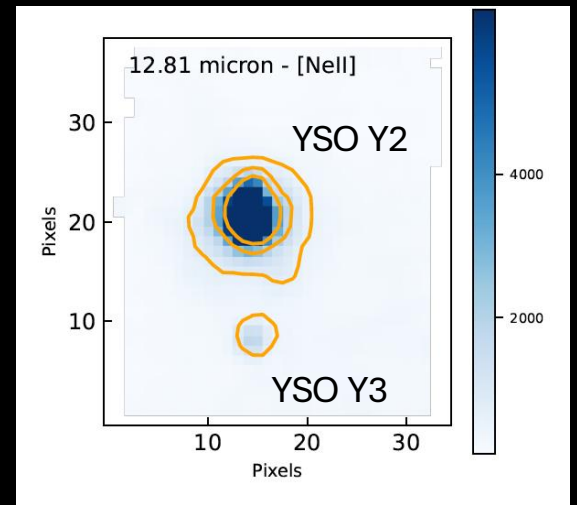
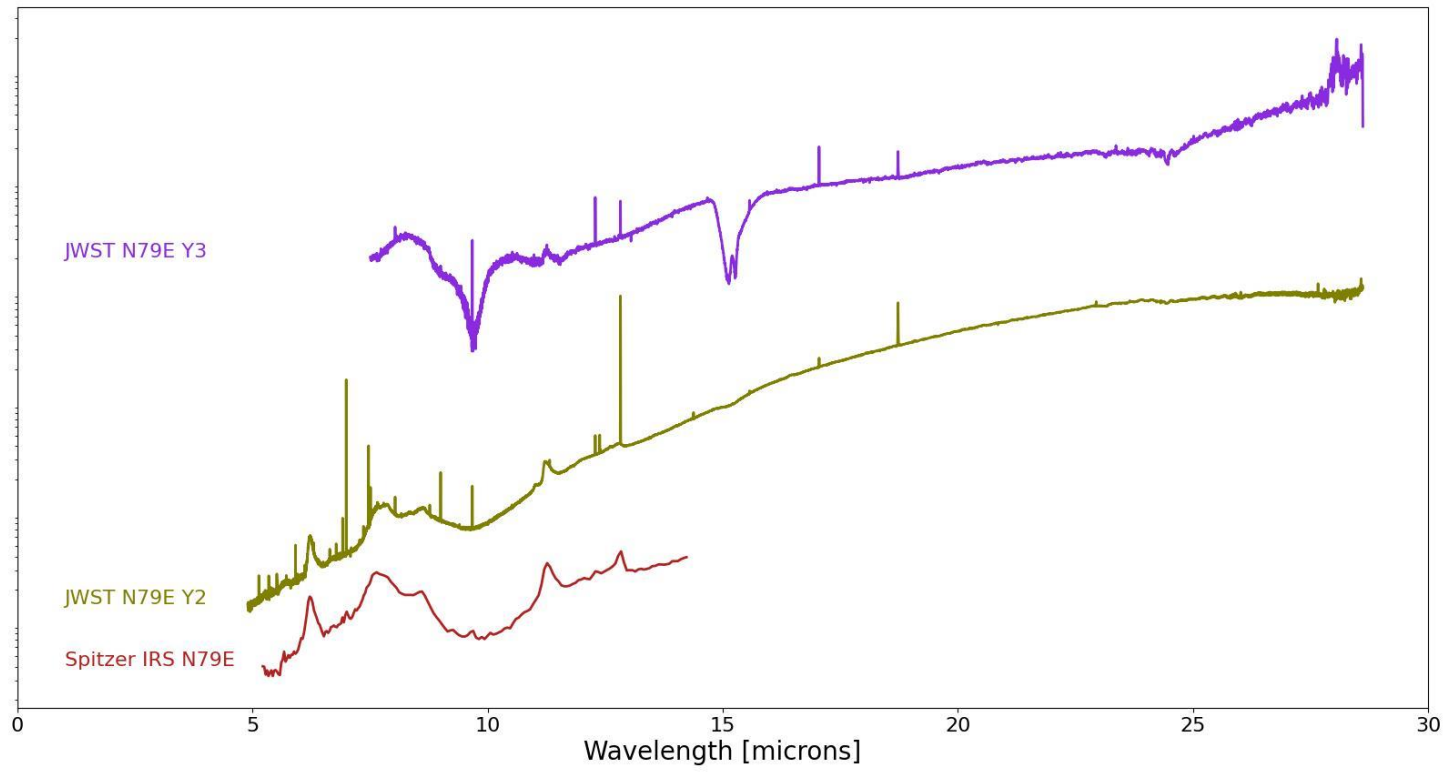
We have MIRI MRS Spectra of 11 YSOs in the N79 region with four pointings (shown in the figure)

An additional 9 YSOs were observed in the NGC 346 region with four pointings

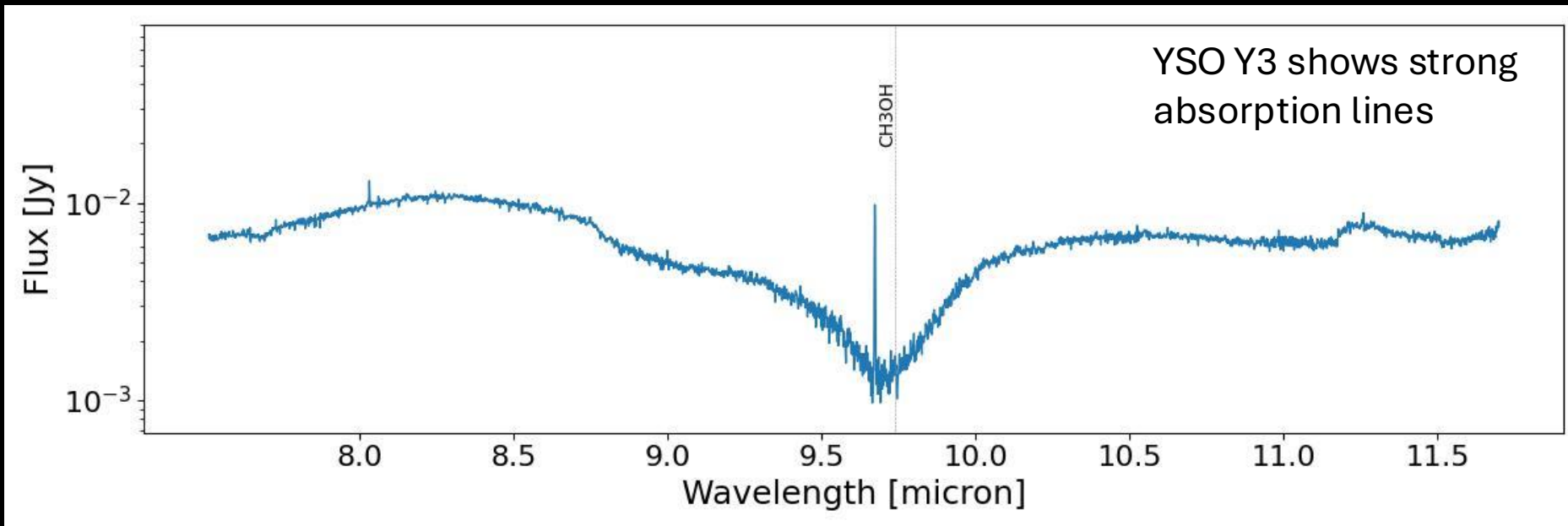
We determined where to point MIRI MRS based on previous Spitzer, Herschel, and ALMA observations



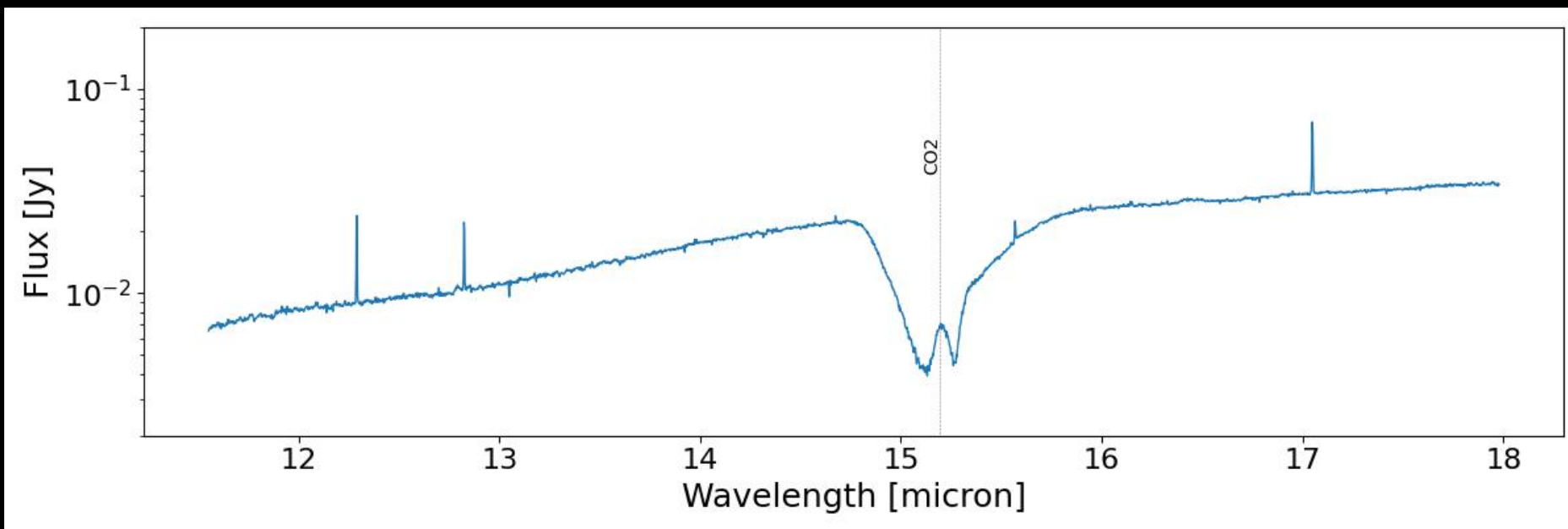
# N79 East has the Youngest YSO in All the MIRI MRS Observations



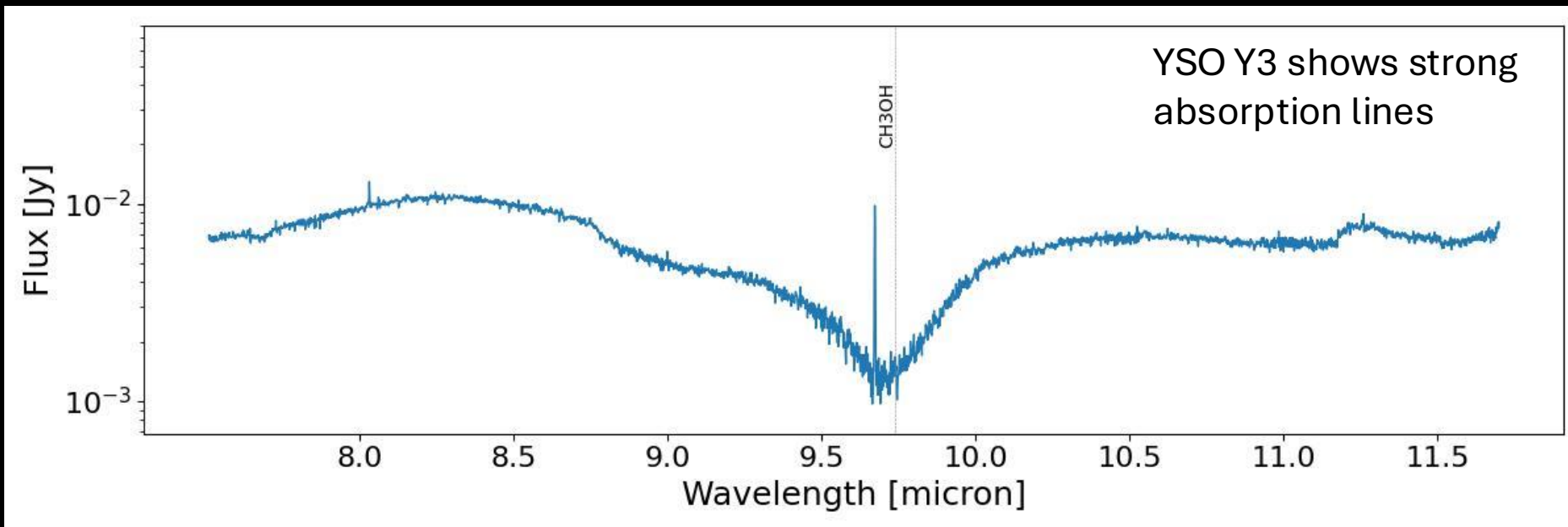
Channel 2



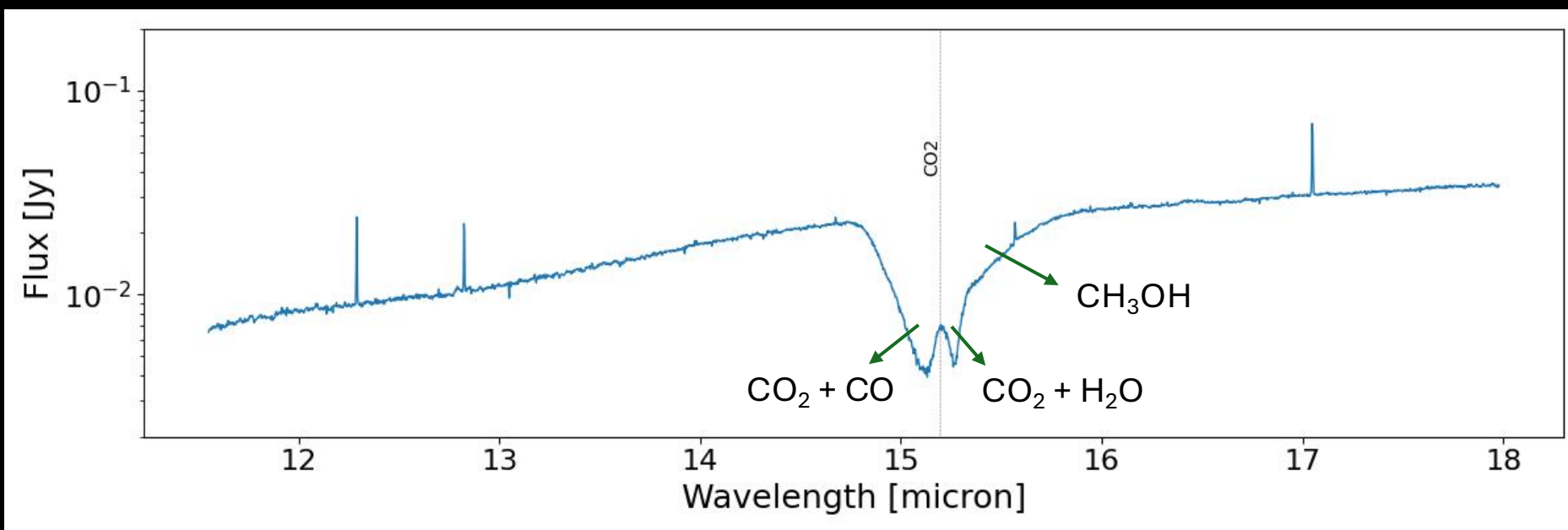
Channel 3



Channel 2



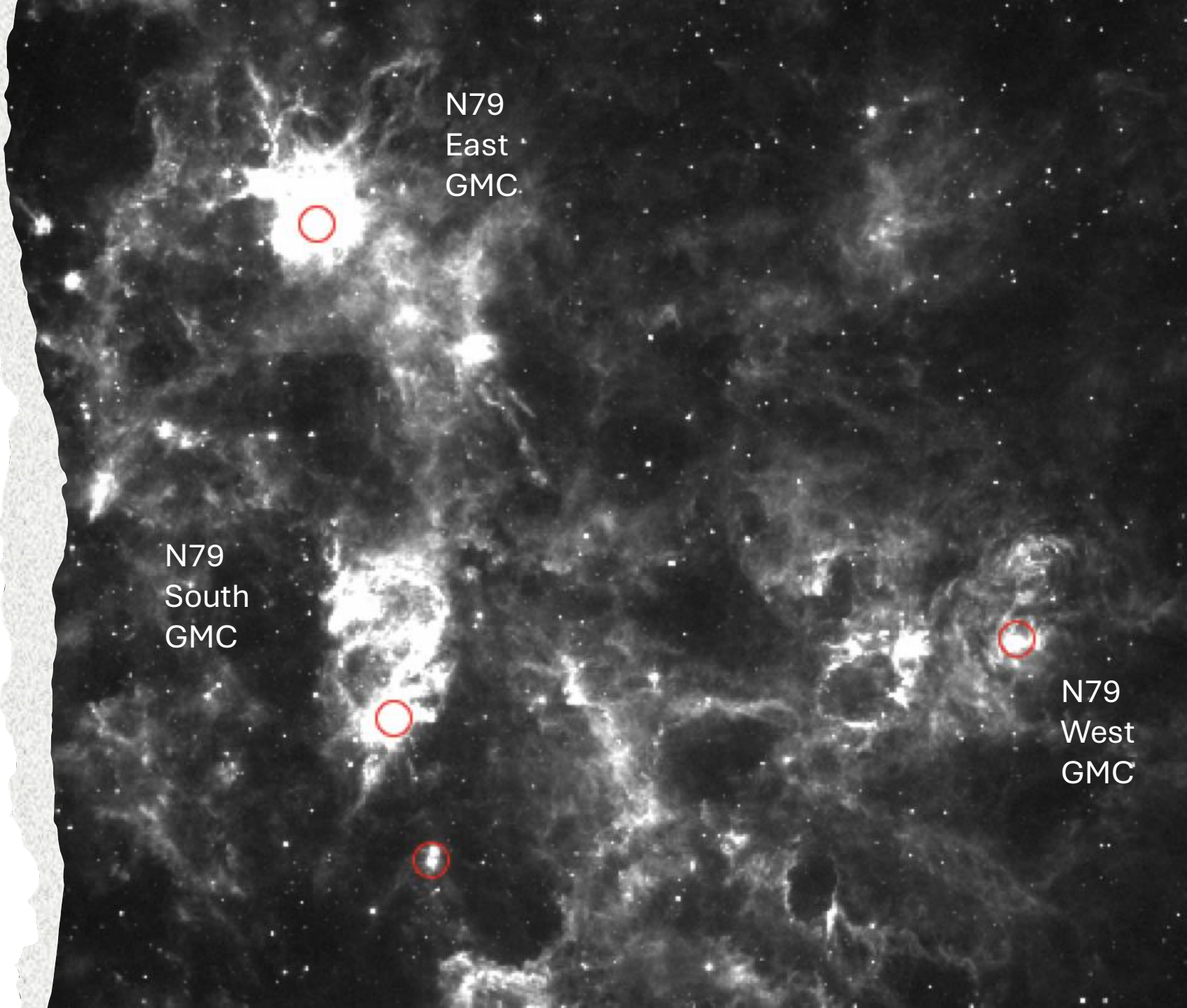
Channel 3



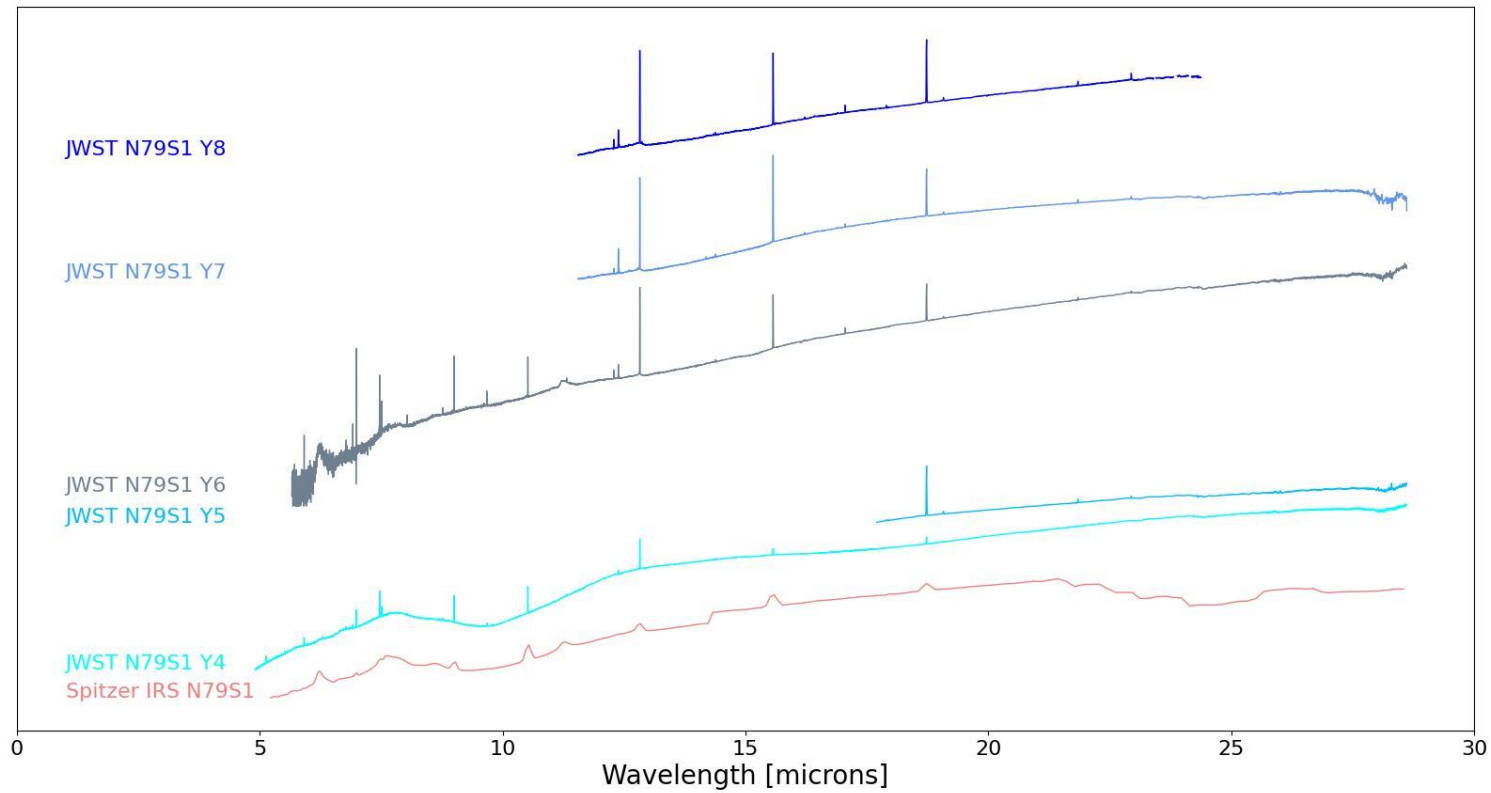
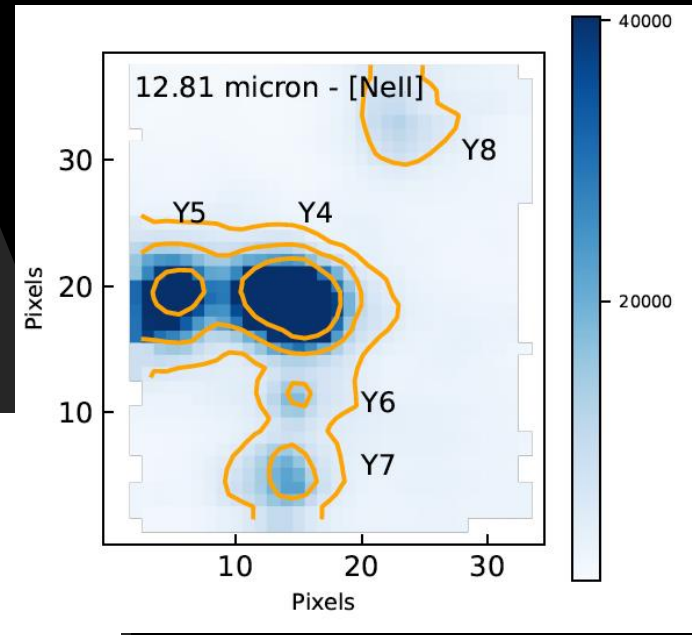
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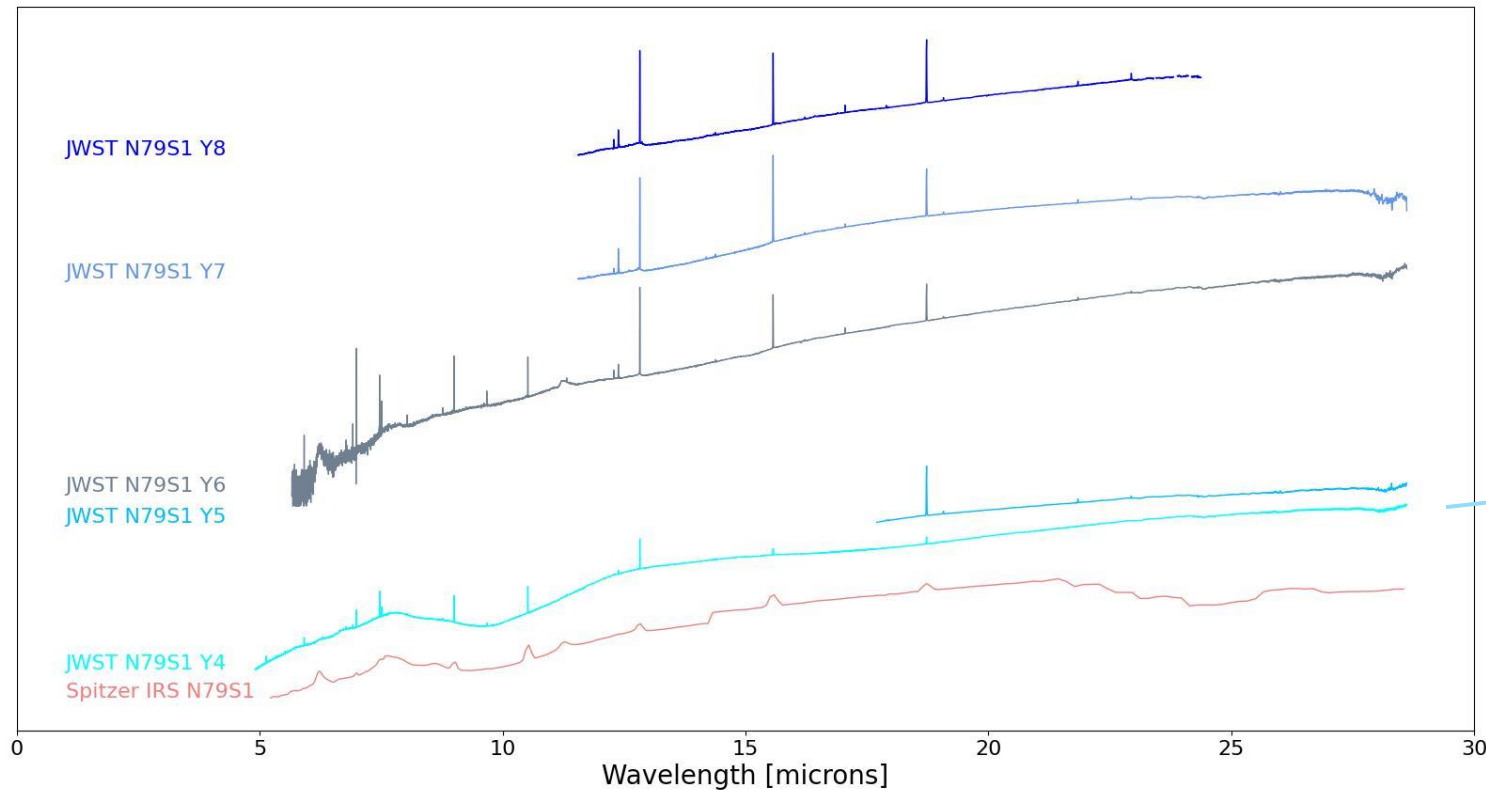
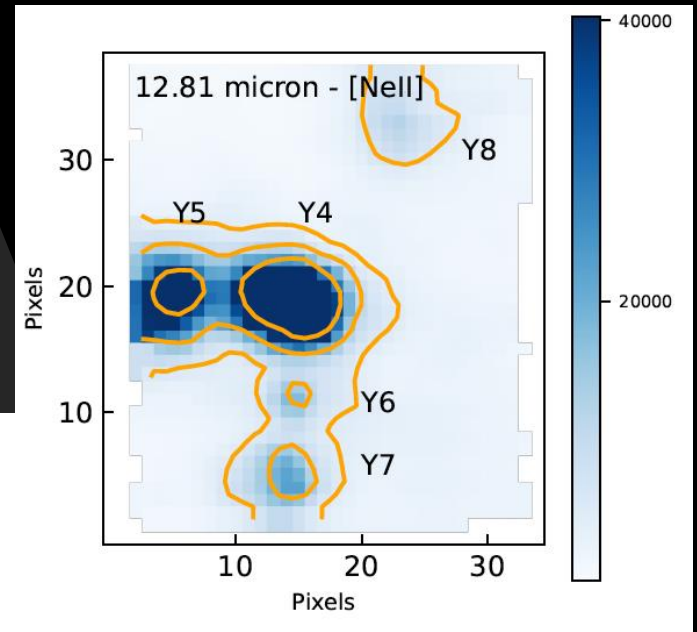
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# There are two dominant YSOs at the center of SSC H72.97-69.39

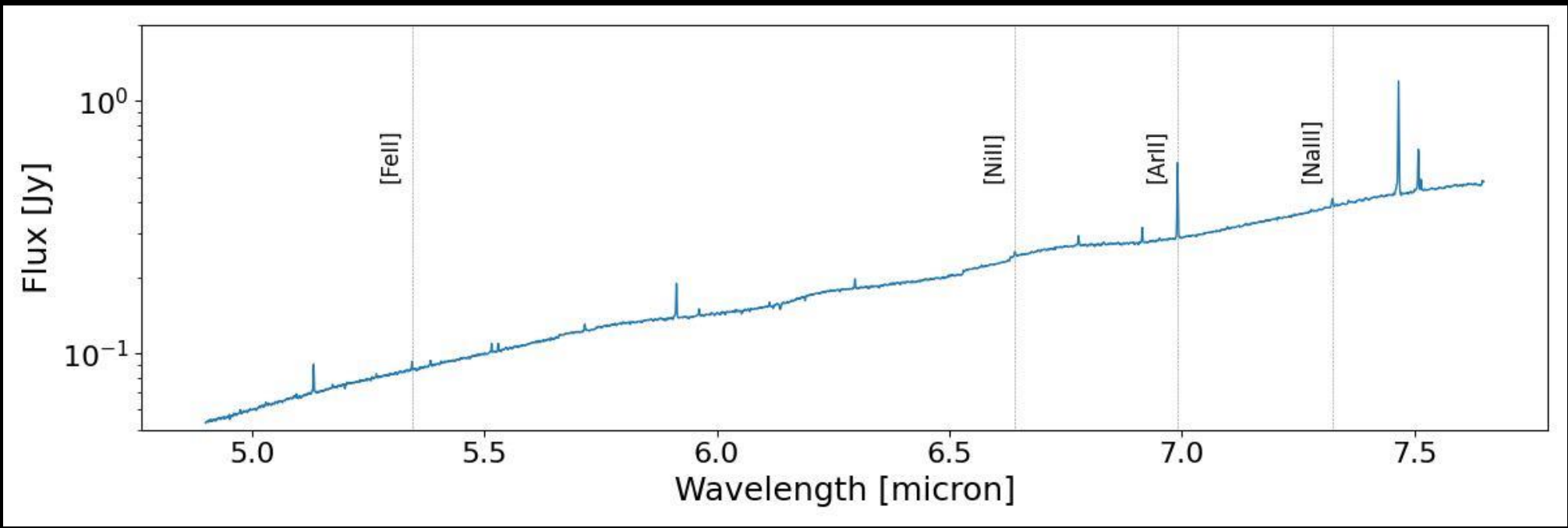


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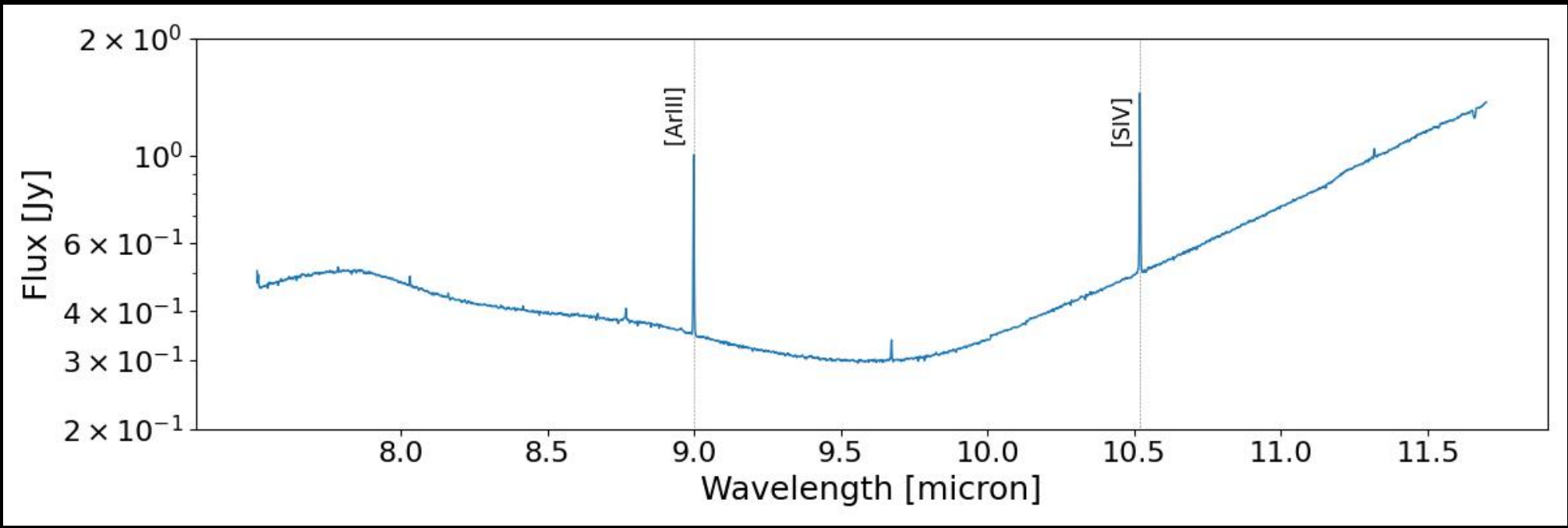


Y4 is  $40 M_{\odot}$   
and over  
 $500,000 L_{\odot}$

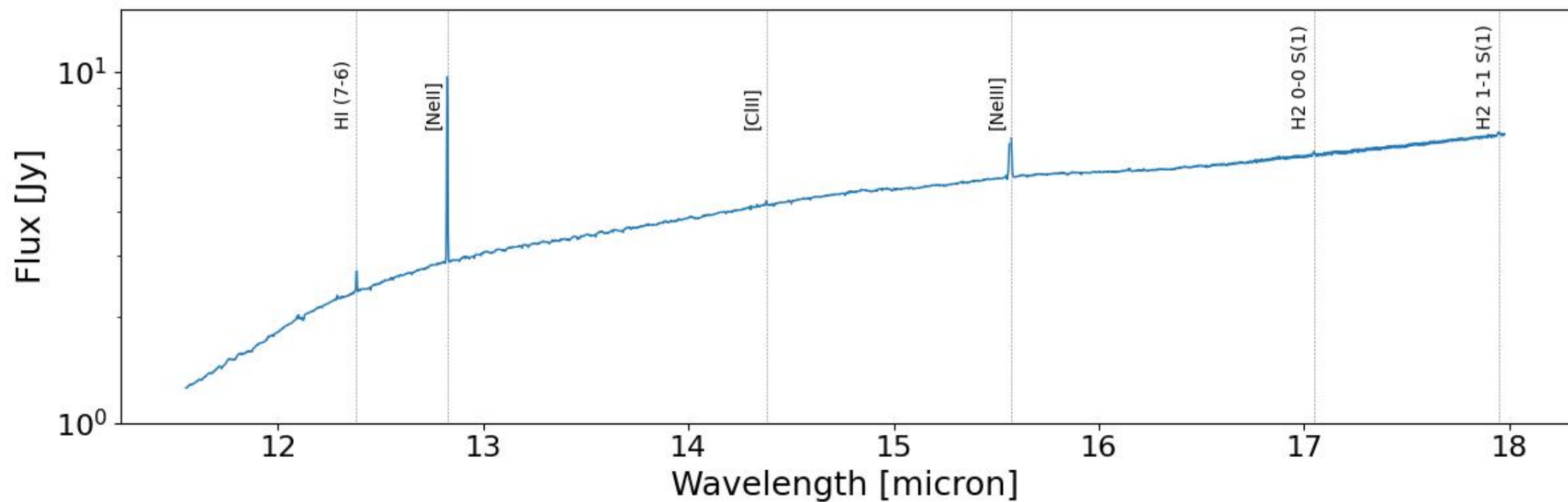
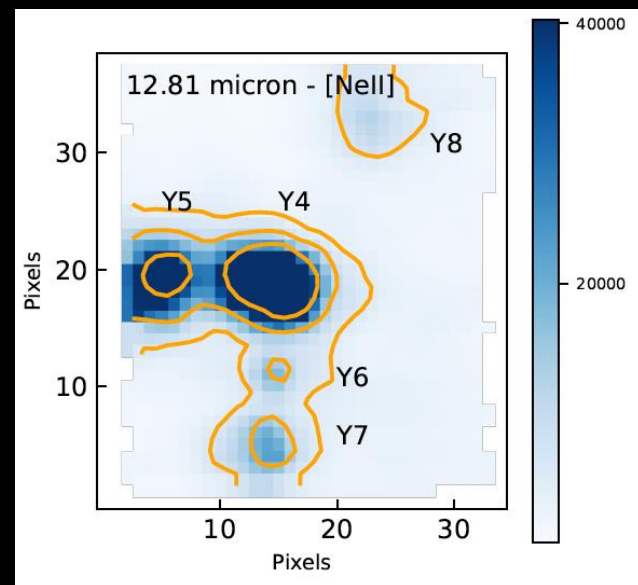
Channel 1  
Fine-Structure  
Emission



Channel 2  
Fine-Structure  
Emission

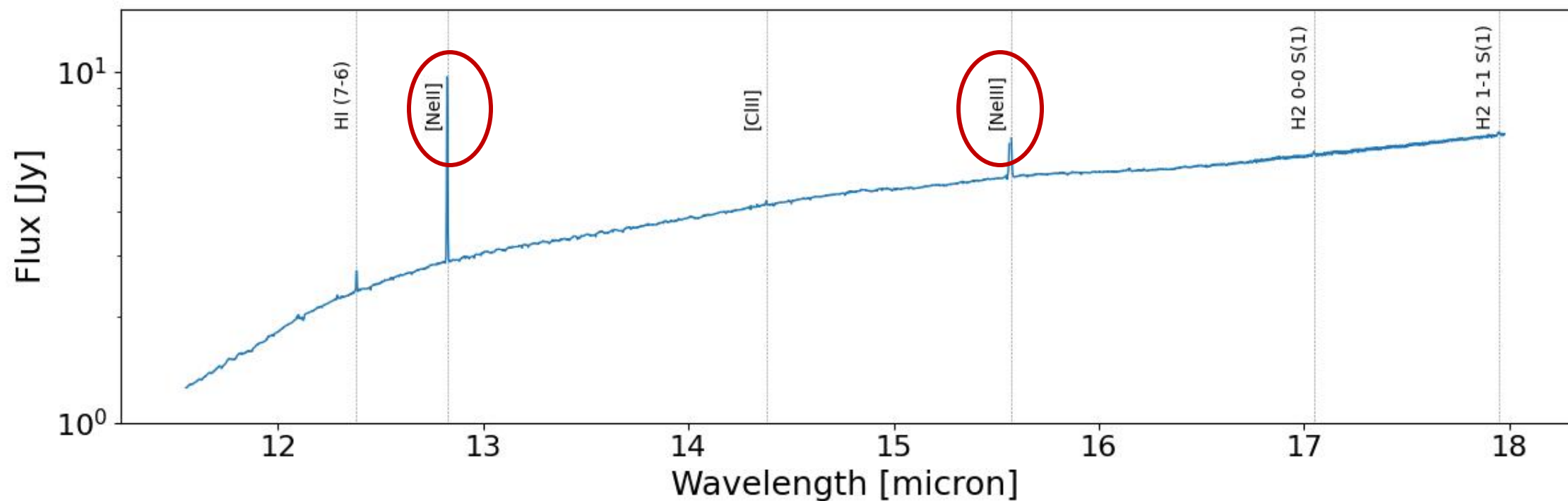
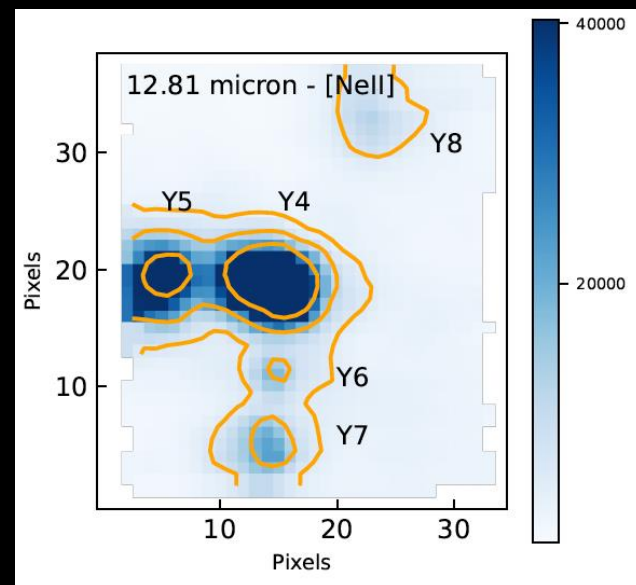


# Channel 3 Spectrum of YSO Y4



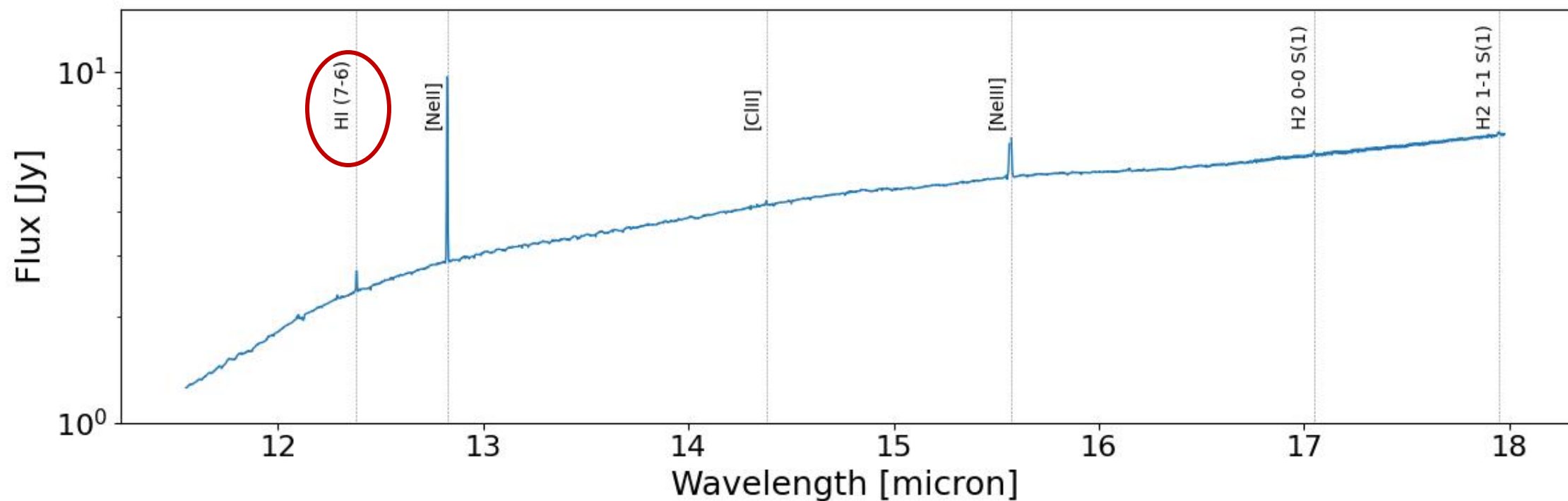
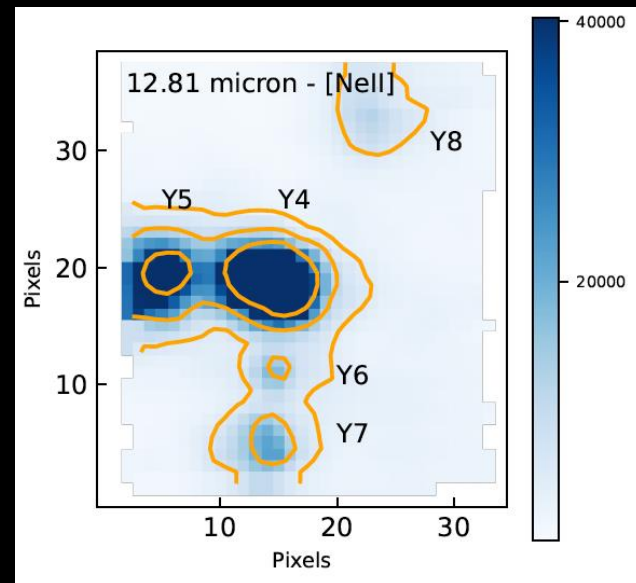
# Channel 3 Spectrum of YSO Y4

The presence of [Ne II] and [Ne III] requires ionization energy greater than 41 eV which means there are high energy UV photons from the central star or from high-velocity shocks



# Channel 3 Spectrum of YSO Y4

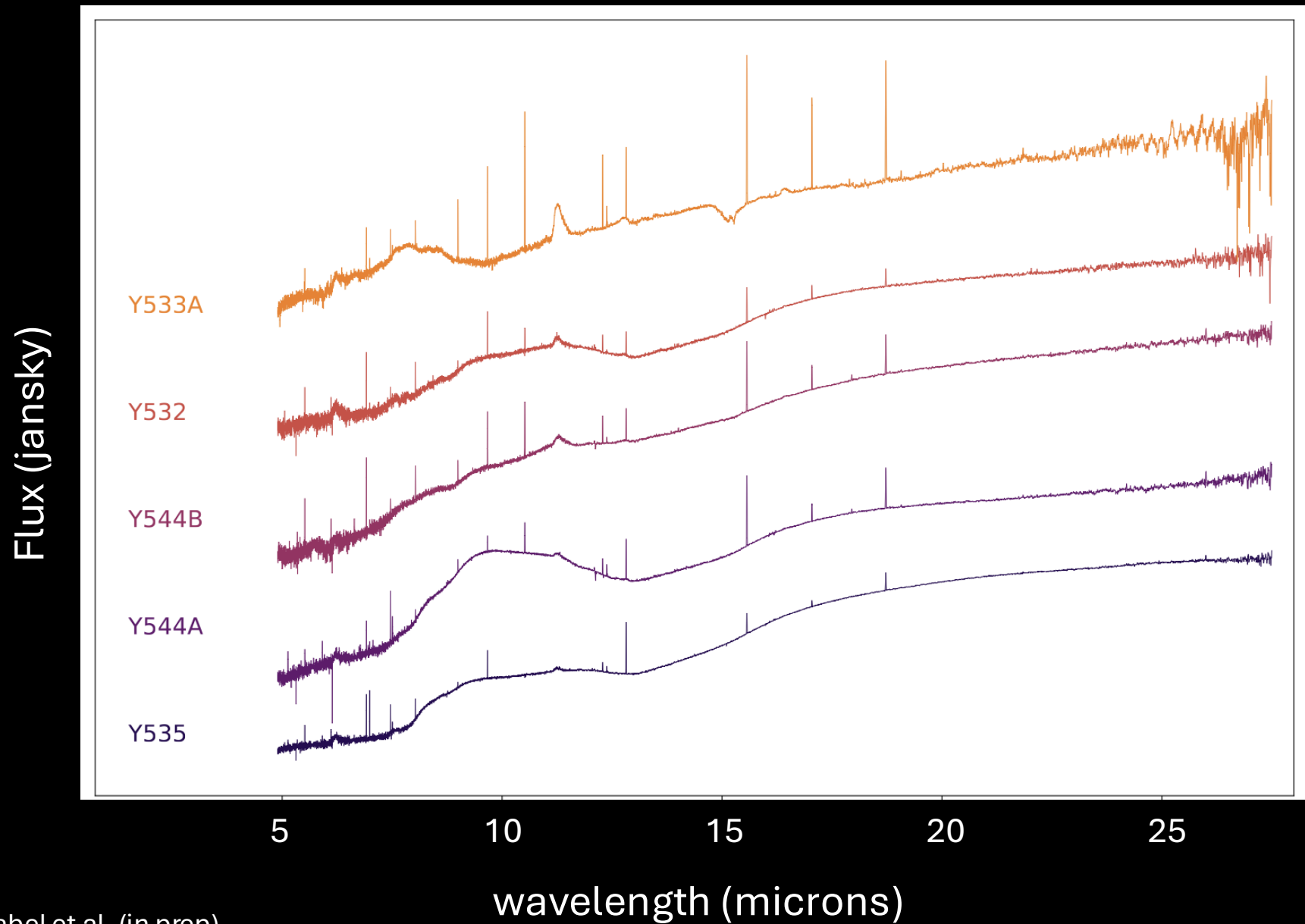
Mass accretion rate inferred from the HI (7-6) Humphreys line is  $0.02 M_{\odot} \text{ yr}^{-1}$  which means every 50 years this single protostar is accreting an amount of mass equivalent to the Sun



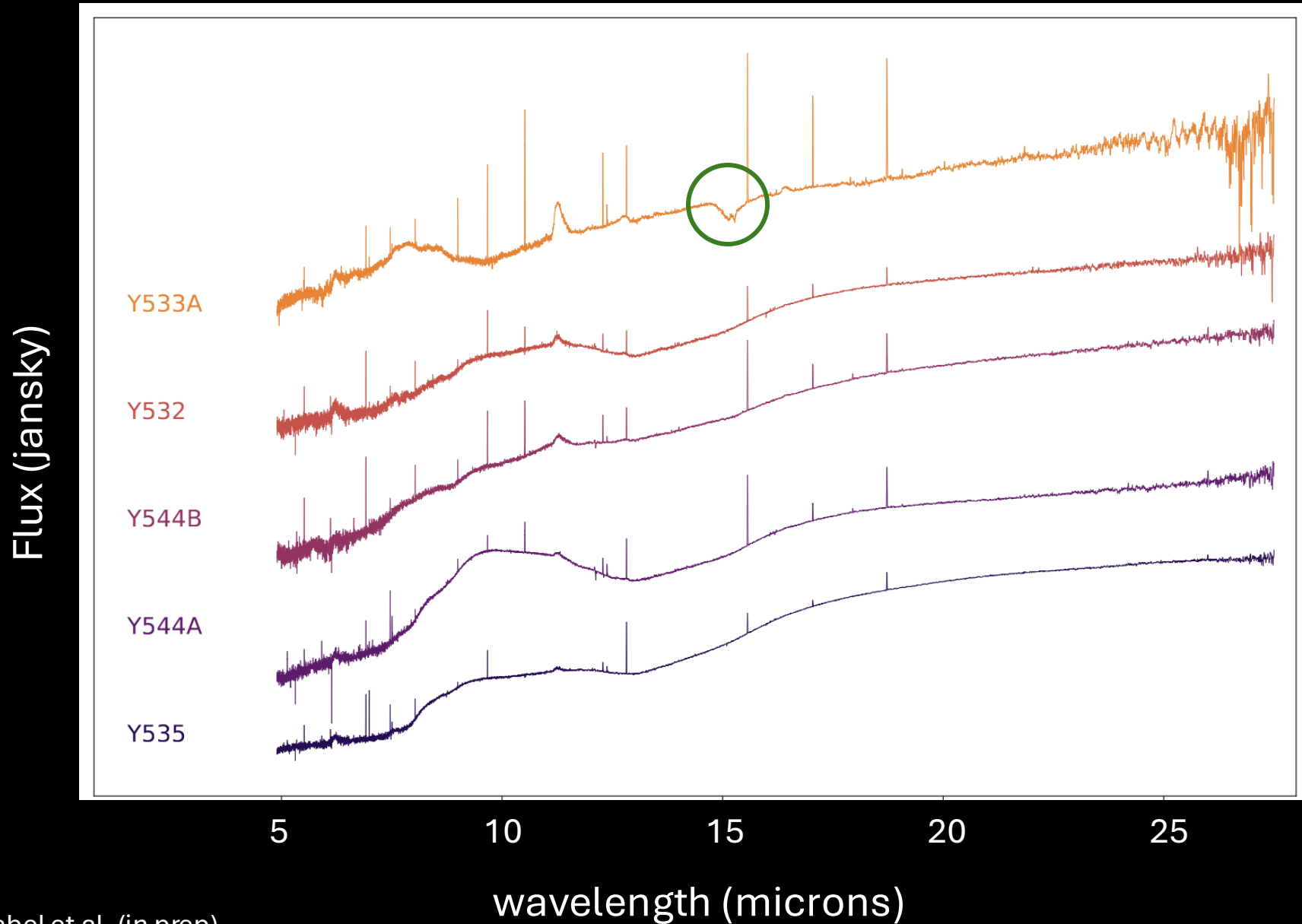
# Four MRS Pointings Towards NGC 346



# Spectra of YSOs in NGC 346



# Spectra of YSOs in NGC 346



Absorption feature at 15.2 microns in F553A is not as deep as the same absorption feature in YSO Y3 in N79 East

Could be because this YSO is not as embedded, or because Y553A is less massive than YSO Y3 ( $7M_{\odot}$  vs.  $18M_{\odot}$ )

# Summary

- JWST NIRCam and MIRI images reach up to 7 magnitudes deeper than prior surveys of LMC-N79 and SMC-NGC 346
- N79: 106 YSOs identified masses 0.7-40  $M_{\odot}$ ; the most massive concentrated at H72.97-69.39; MIRI MRS spectroscopy reveal gas, dust, and ice
- NGC 346: First time embedded low-mass young stellar objects in extra-galactic environment; NIRCam reveals 1000+ YSOs within observed footprint; MRS spectroscopy show similar emission lines to YSOs in N79

Backup Slides

10 kpc

R136 SSC in  
30 Doradus



SSC H72.97-  
69.39 in N79



## Using the LMC as a Laboratory

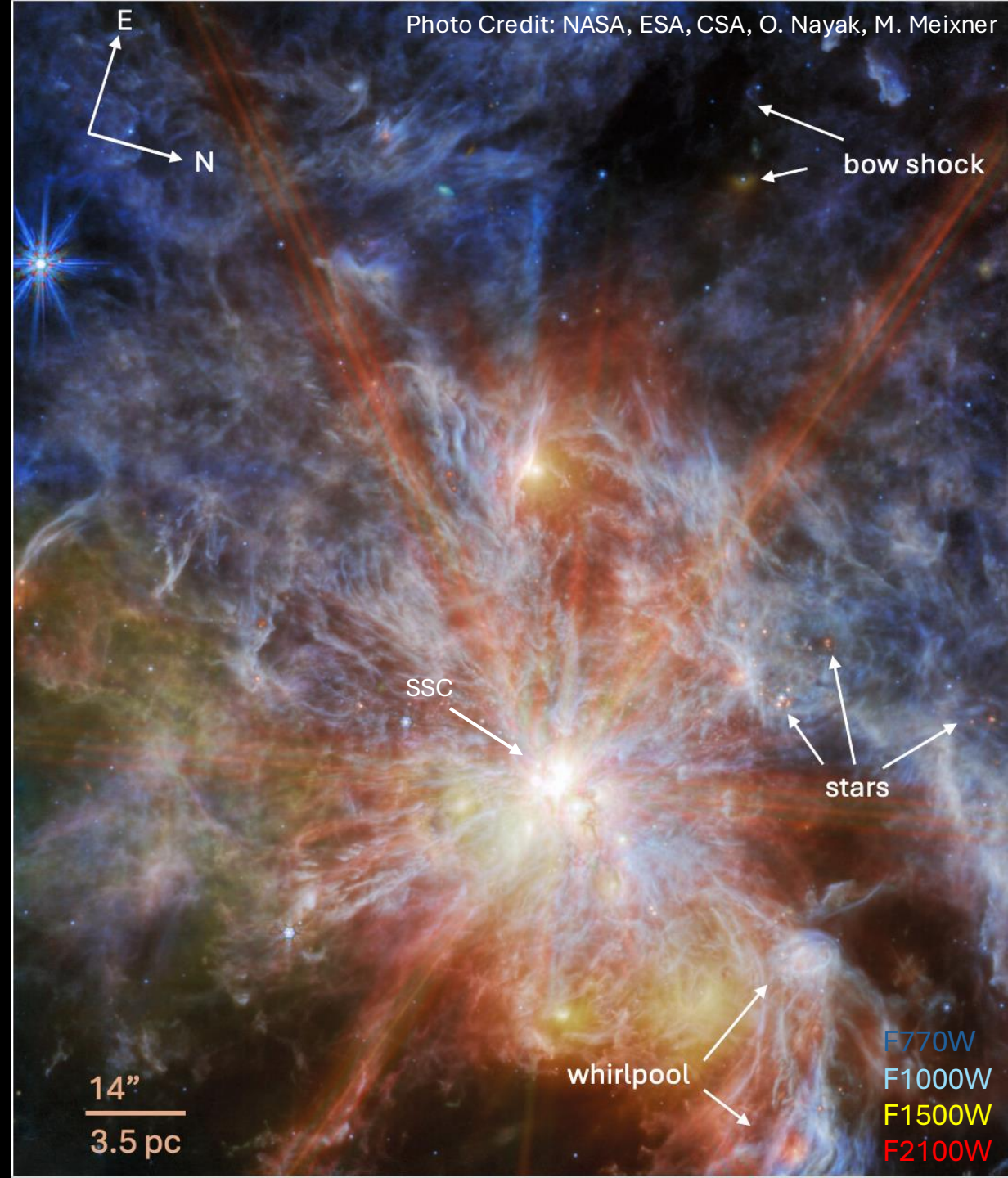
**Only 160,000 light years away**

**Proximity and face-on orientation make the Large Magellanic Cloud an ideal laboratory to study star formation**

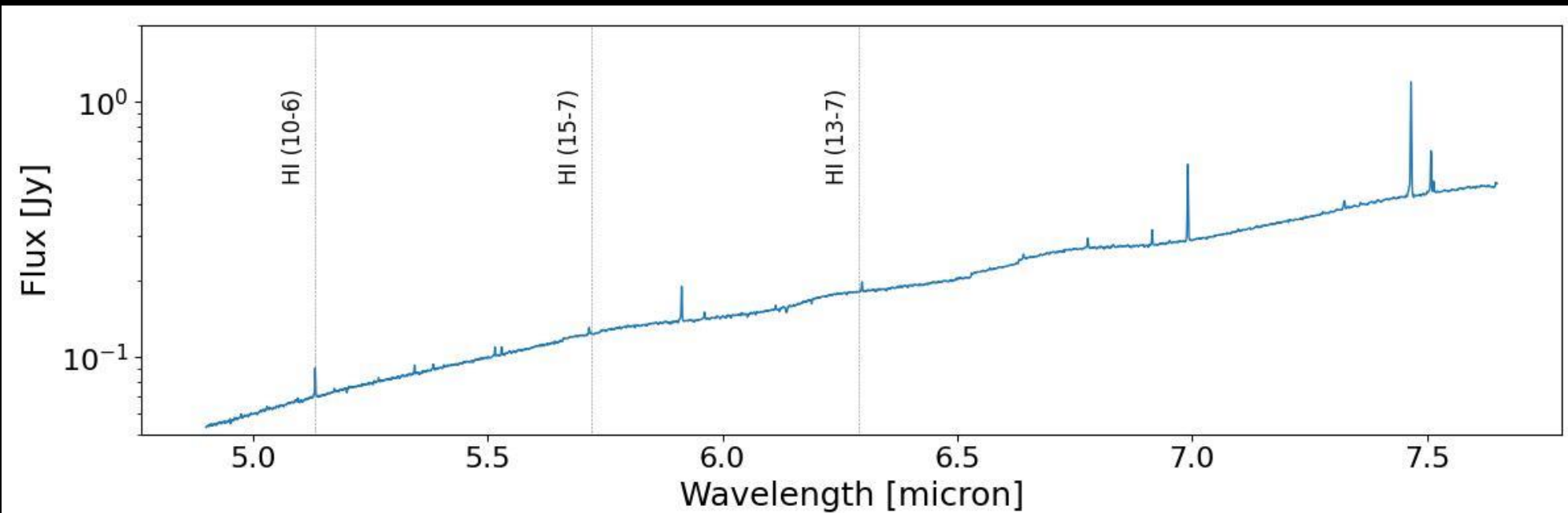
**30 Doradus is host to a super star cluster 25-30 million years old**

**JWST confirms N79 is host to another super star cluster less than 100,000 years old**

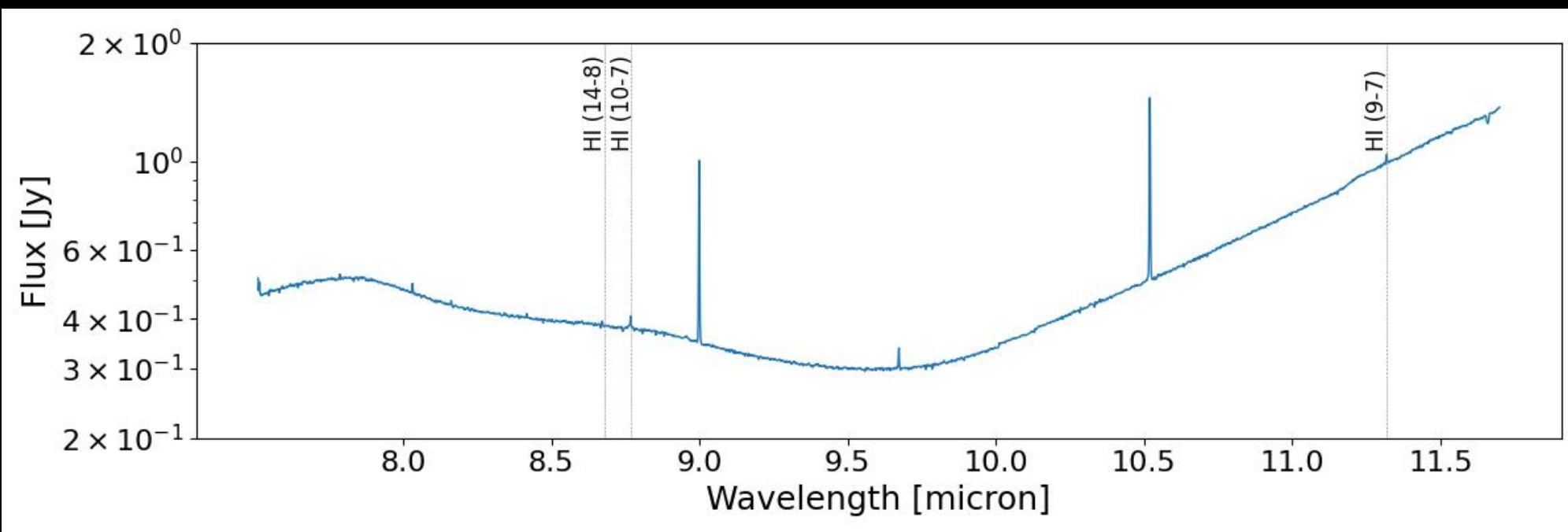
Fitting IMF to NIRCam observations of 1500+ protostars indicates the SFR is between  $0.5 - 3 M_{\odot} \text{ yr}^{-1}$



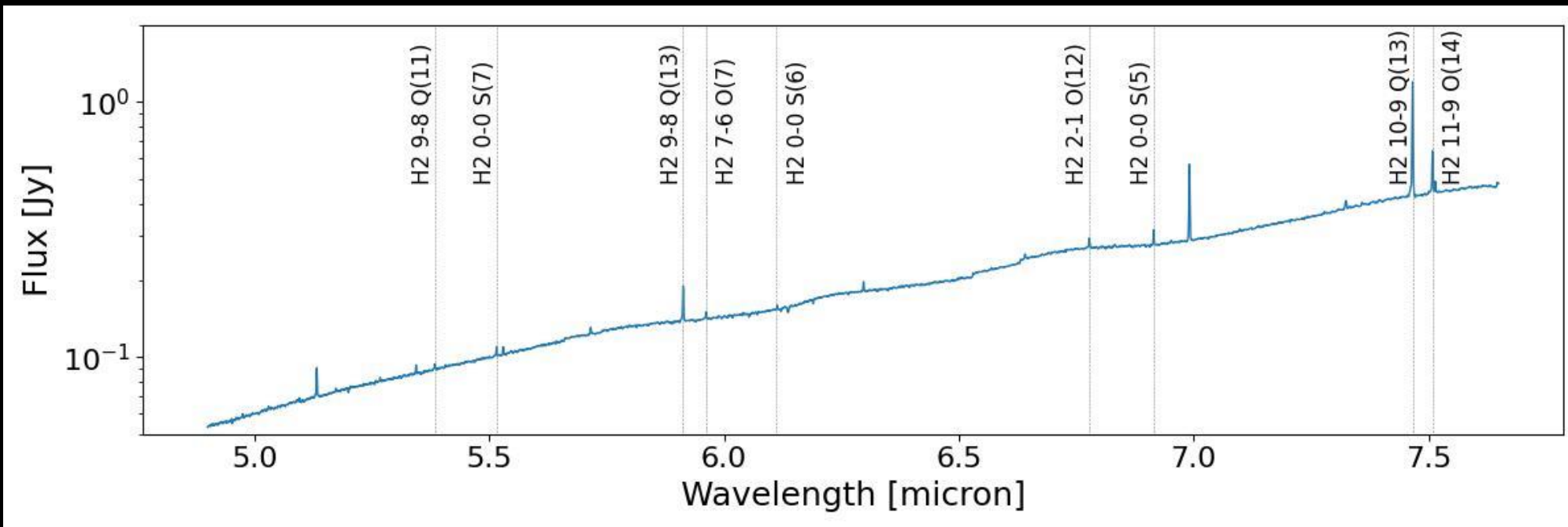
YSO Y4Channel 1  
HI Emission



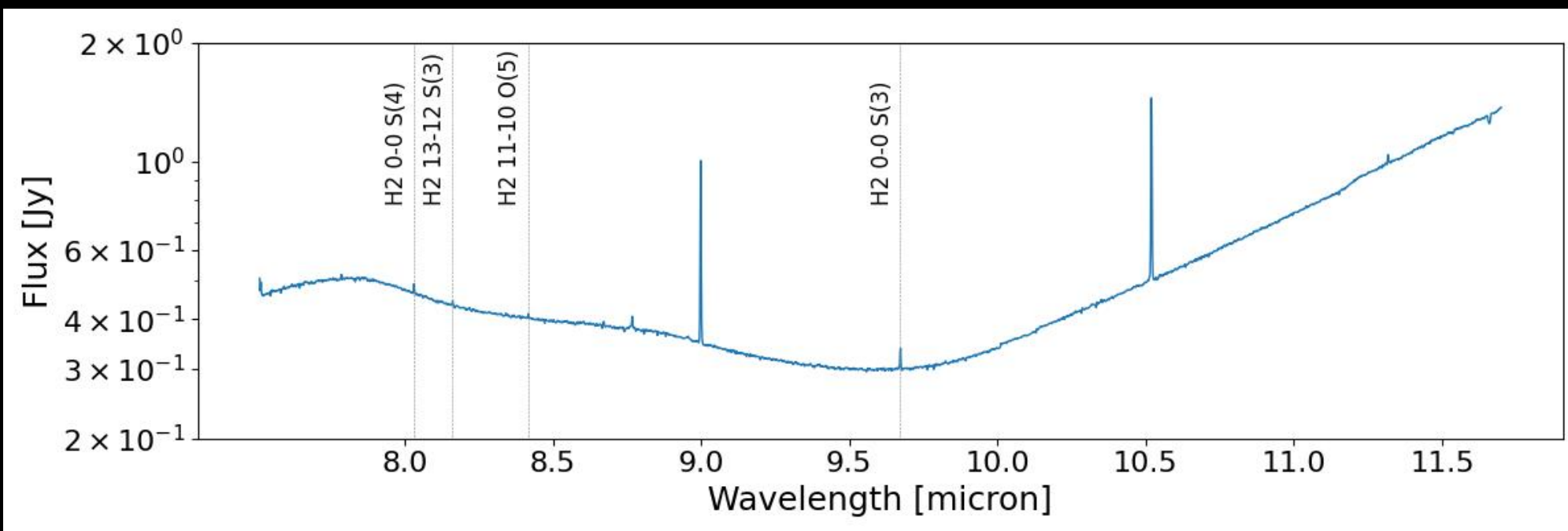
YSO Y4Channel 2  
HI Emission



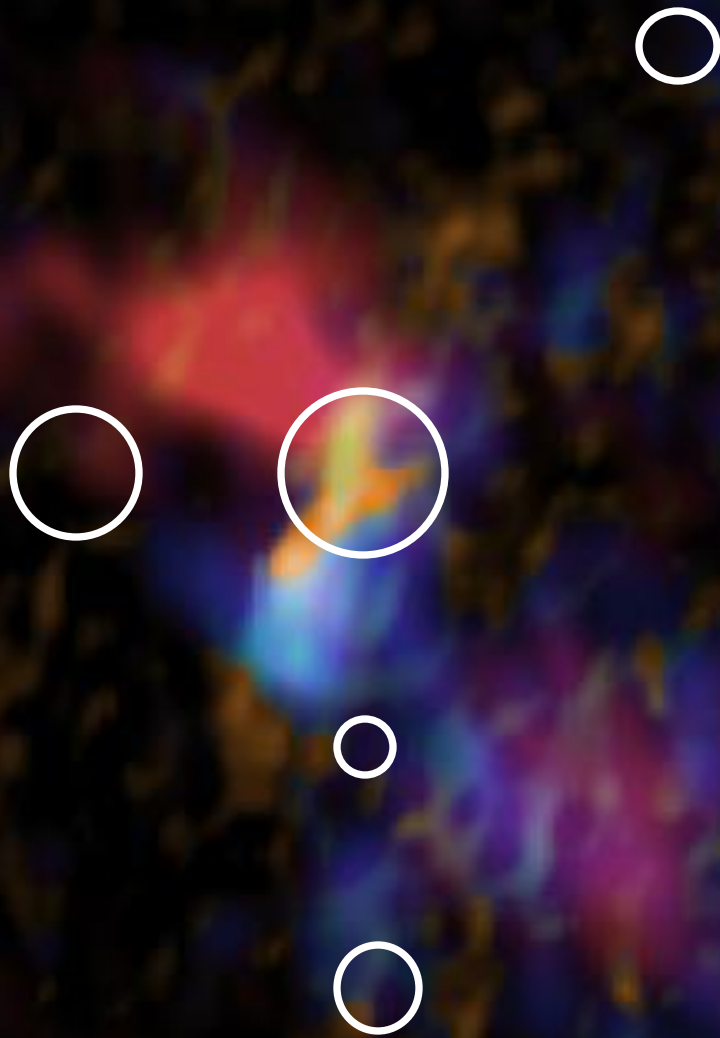
YSO Y4 Channel 1  
H<sub>2</sub> Emission



YSO Y4 Channel 2  
H<sub>2</sub> Emission



ALMA sulfur monoxide  
ALMA blue-shift outflow  
ALMA red-shift outflow



## ALMA + JWST

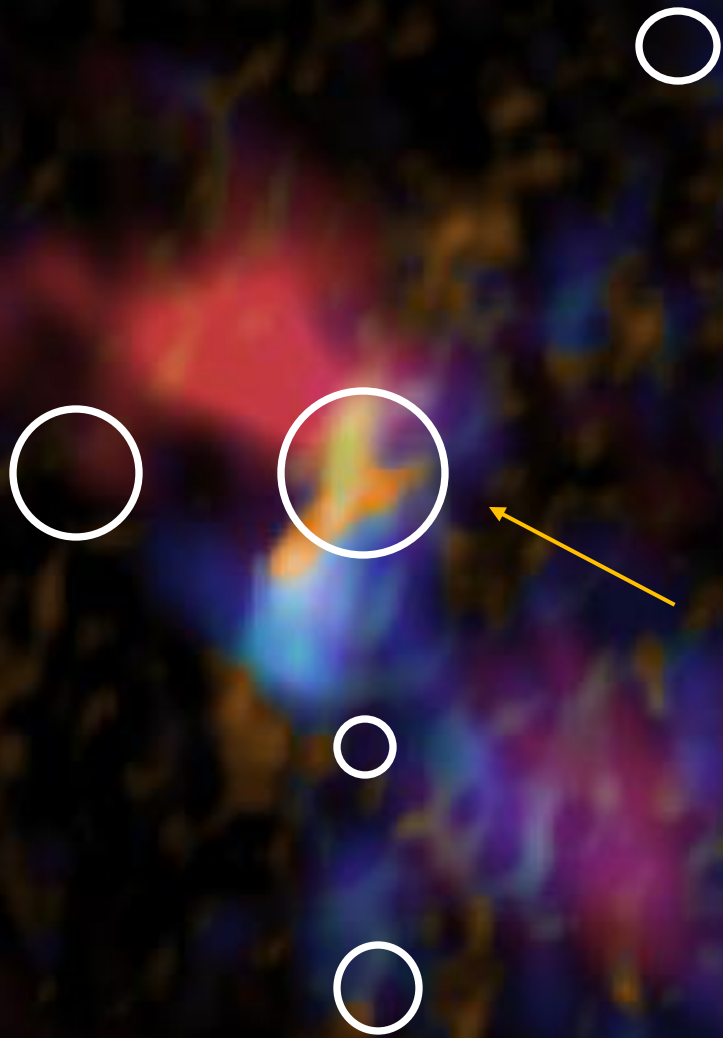
ALMA reveals light receding away from us in red and light coming towards us in blue.

Size of the red- and blue-shifted outflows reveal the age to be less than 100,000 years old.

There are five massive protostars at the center of the super star cluster and have a total mass of 150 times that of the Sun as revealed by JWST.

5 lightyear

ALMA sulfur monoxide  
ALMA blue-shift outflow  
ALMA red-shift outflow



Sulfur monoxide is 2000 more dense than carbon monoxide (red and blue) and only associated with the central protostar possibly tracing accretion onto the protostar

5 lightyear