Near-Infrared Observations of Massive Star Formation in the Outflowing Region AFGL 5180

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Pictured: JWST-NIRCam view of LDN 1527
Credit: NASA, ESA, CSA, and STScI, J. DePasquale (STScI)

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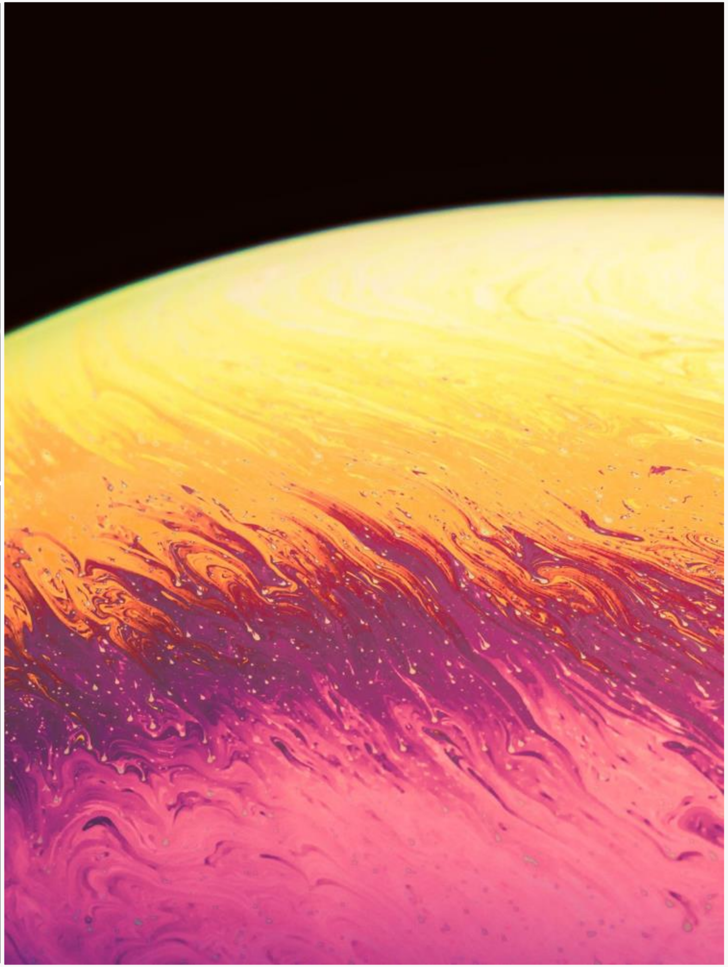
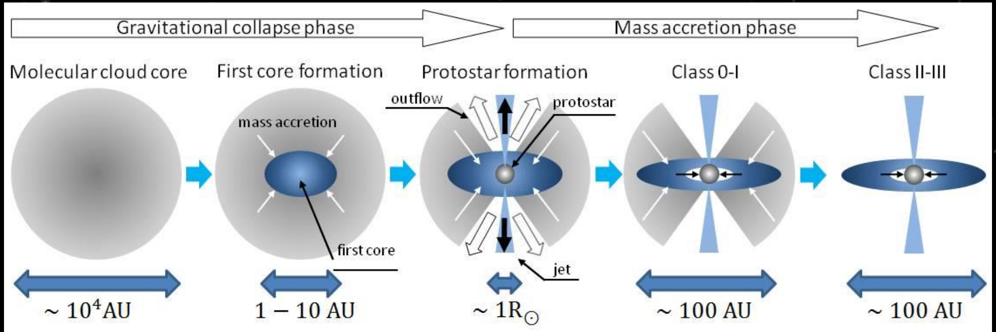
Introduction

Massive star formation, jets, and the near-infrared



Despite its importance, the process of massive star formation is poorly understood



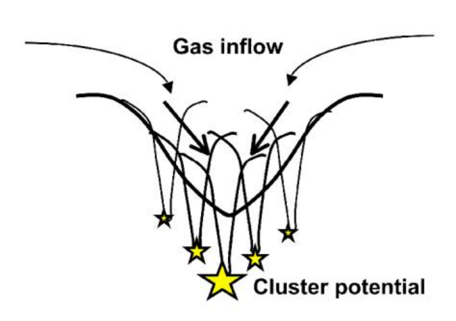
Credit: Y. Tsukamoto

Core accretion theories state that massive star formation occurs in a mostly scaled-up version as low-mass stars

Observational prediction: **isolated massive star formation is possible**

Competitive Accretion theories predict that massive star formation occurs via accretion of gas widely distributed throughout the cloud, and in constant proximity to low-mass protostars

Observational prediction: **isolated massive star formation is impossible; massive star formation is highly clustered**



Credit: Bonnell et al. (2007)

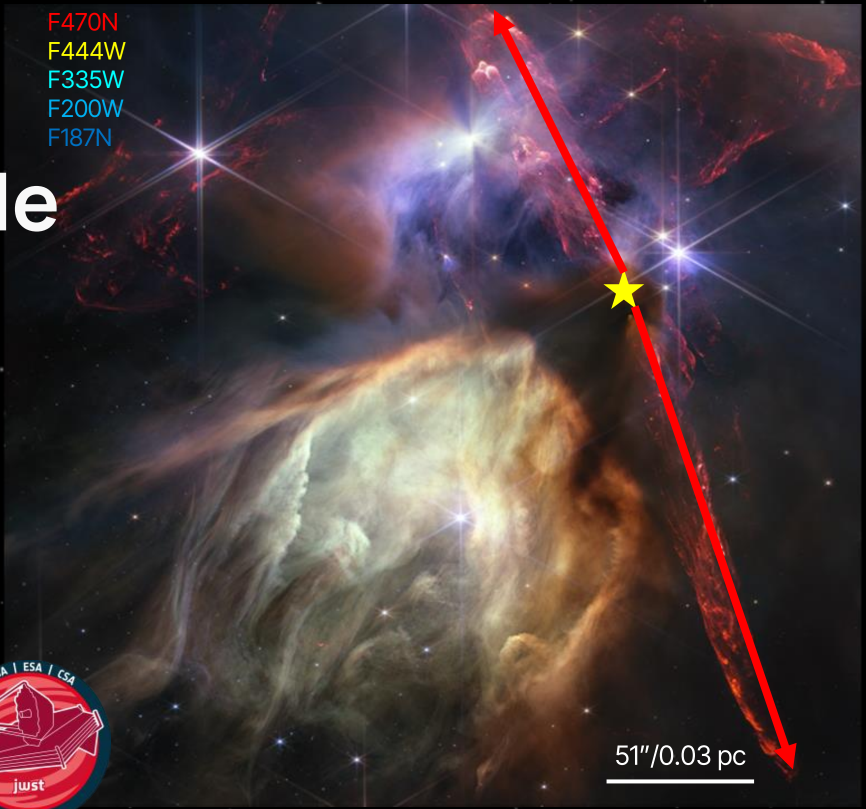
For a recent review on massive star formation, see Tan et al. (2014) and references therein

Near-Infrared (NIR) observations of protostellar jets provide key diagnostics of star formation

Protostars are often **heavily obscured** and **small-scale** (~au), unlike their jets, which are **bright** and **large-scale** (~pc)

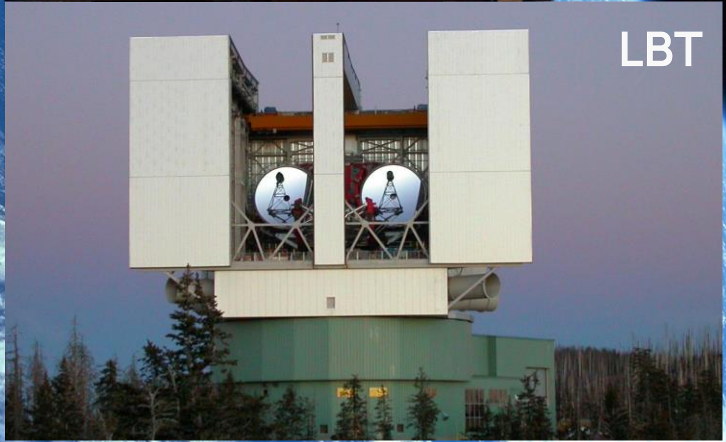
NIR wavelengths allow a **transparent, high angular resolution view** into star-forming regions and **contain many jet tracers** (HI, [FeII], shocked H_2 emission)

…Hence, SOMA-NIR



Pictured: NIRCam image of Rho-Ophiuchi star-forming region
Credit: NASA, ESA, CSA, STScI, Klaus Pontoppidan, Alyssa Pagan
Red = F470N; tracing shocked H_2 emission from outflows

The SOMA-NIR Survey



~50 high-mass star-forming regions observed with SOFIA

>30 have been observed with HST/LBT/VLT/JWST

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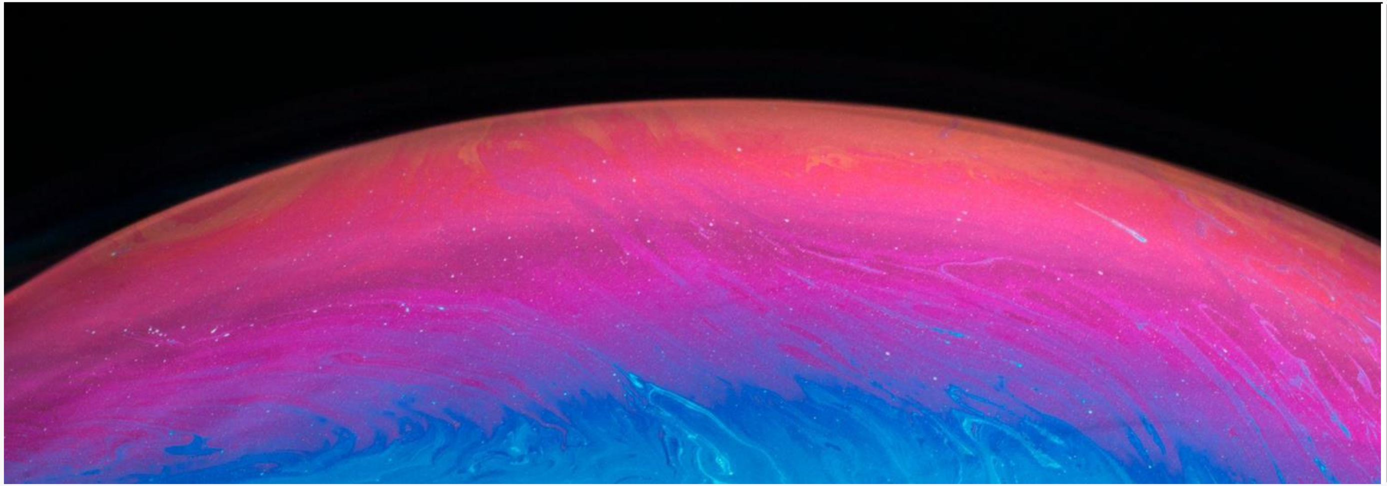
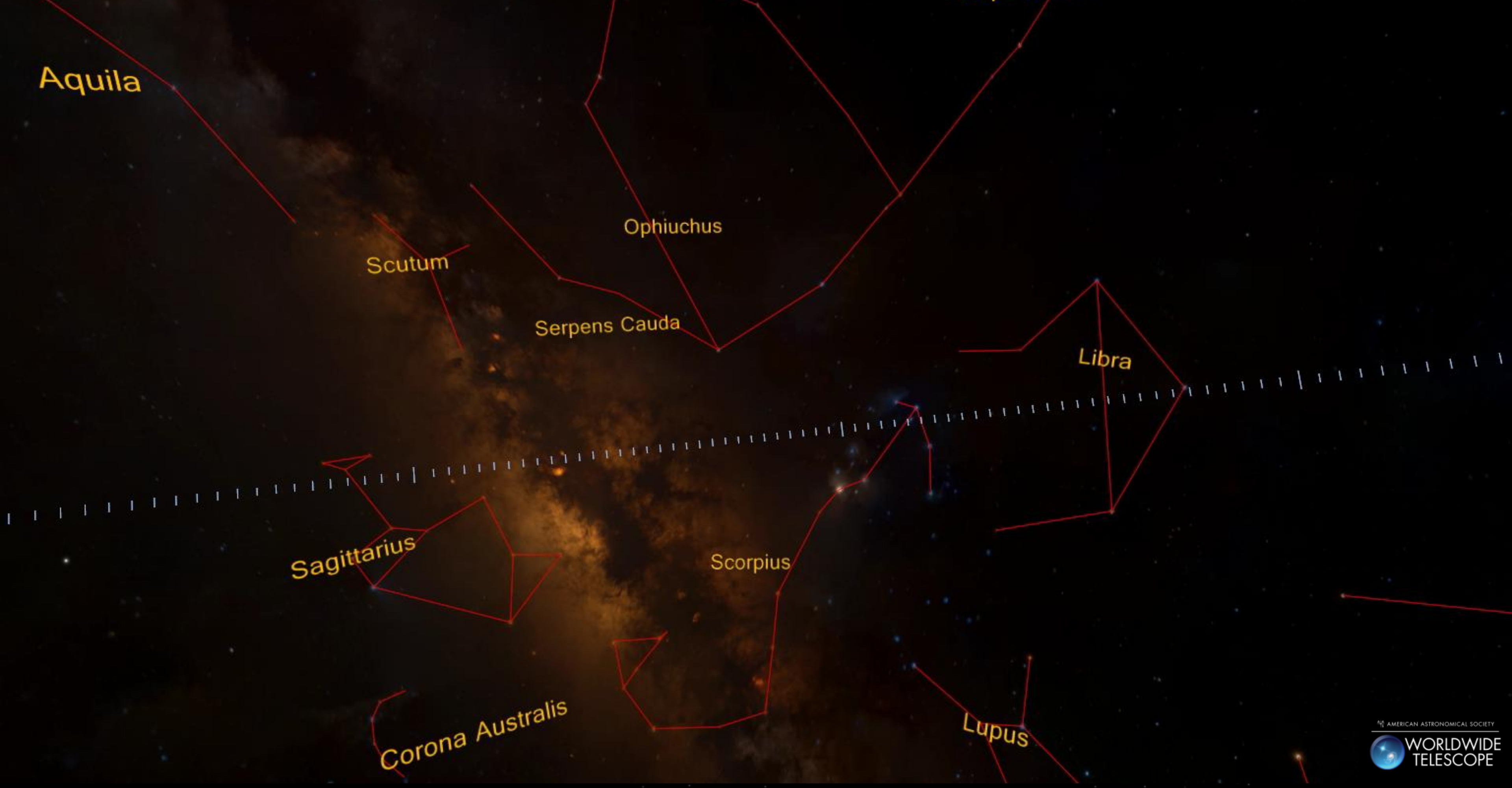
AFGL 5180

Location, characteristics, past and present data



Digitized Sky Survey RGB (Visible)



Characteristics of AFGL 5180

At a distance of ~2 kpc[1]

Part of the Gemini OB1 star-forming complex[1,2]

Source of a bright Class II 6.7 GHz methanol maser emission[3], strongly associated with massive star formation[4]

Source of multiple sites of water maser emission[5]

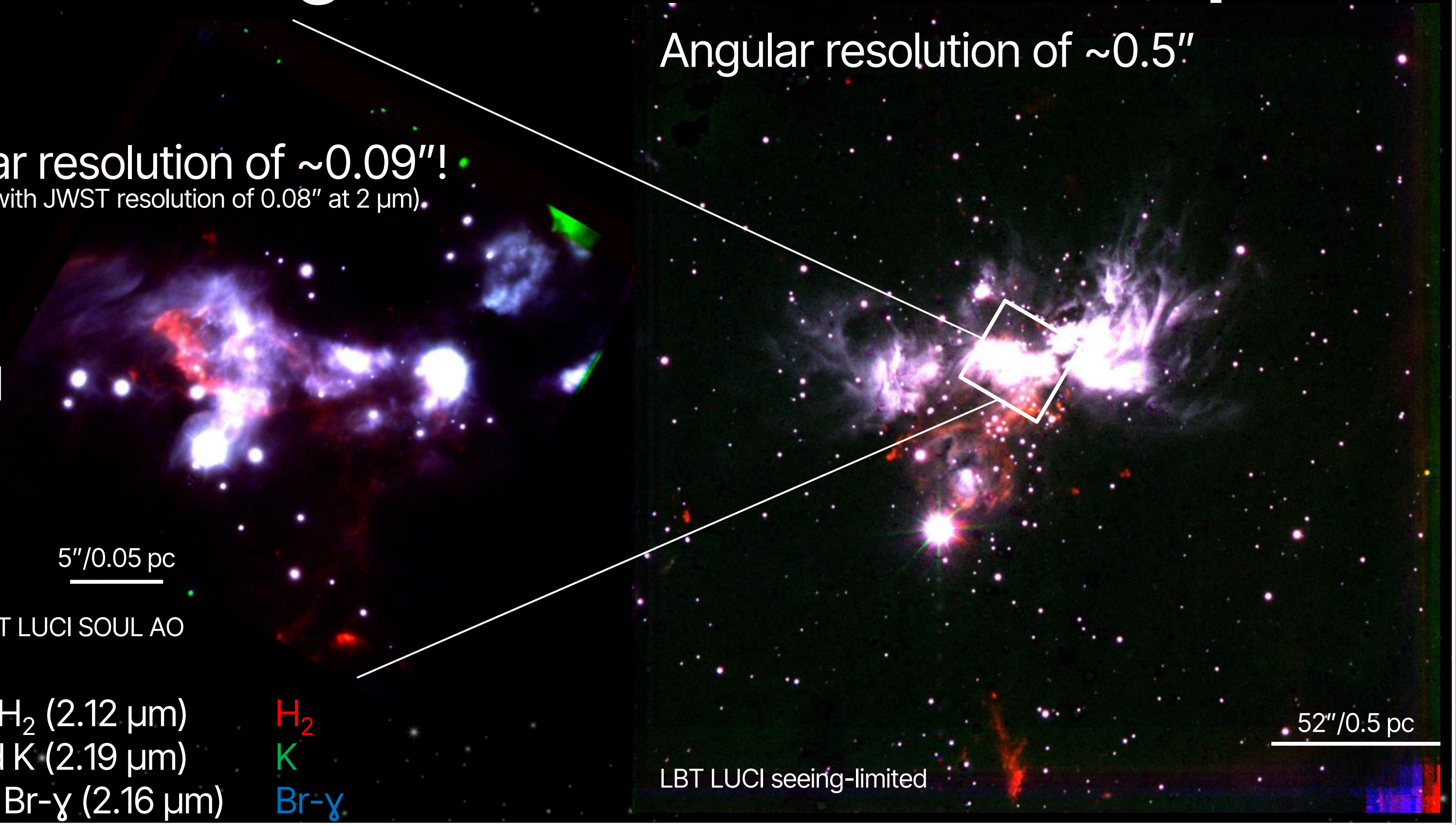
Previous studies suggest the presence of **multiple outflows** driven by **multiple sources**[6,7]

Pictured: 3-color HST image of AFGL 5180 (from ESA/Hubble Picture of the Day)
Credit: ESA/Hubble & NASA, J. C. Tan, R. Fedriani, J. Schmidt

[1]Zucker et al. (2020) [2]Carpenter et al. (1995b) [3]Mutie et al. (2021) [4]Breen et al. (2013) [5]Tofani et al.(1995) [6]Yao et al. (2000) [7]Longmore et al. (2006)

Our Data: Large Binocular Telescope (LBT)

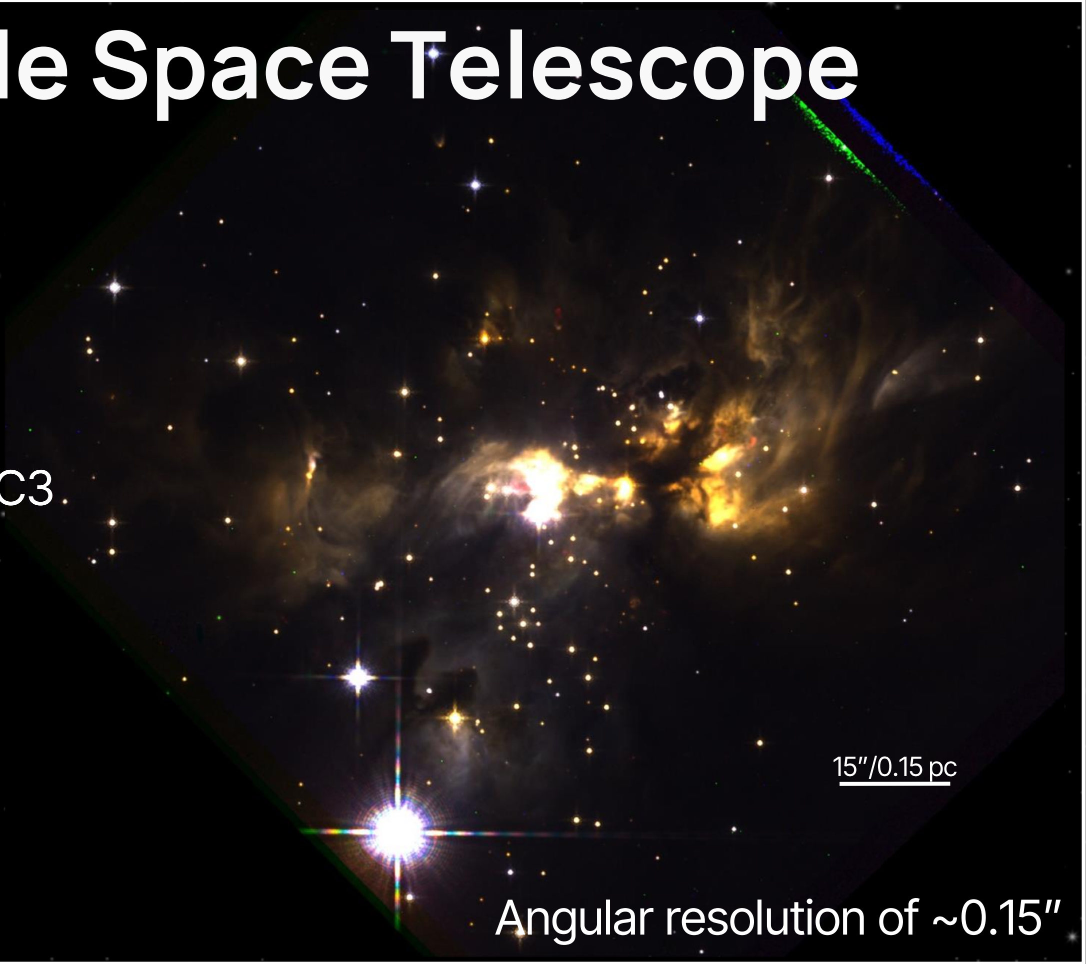
We utilize NIR seeing-limited and AO data from LUCI



Red: narrow-band H_2 (2.12 μm) — H_2
Green: broad-band K (2.19 μm) — K
Blue: narrow-band Br-ɣ (2.16 μm) — Br-ɣ

Our Data: Hubble Space Telescope (HST)

We utilize NIR data from HST WFC3



Red: narrow-band [FeII] (1.64 μm) F164N
Green: broad-band H (1.60 μm) F160W
Cyan: narrow-band Paβ (1.28 μm) F128N
Blue: broad-band J (1.10 μm) F110W

Angular resolution of ~0.15″

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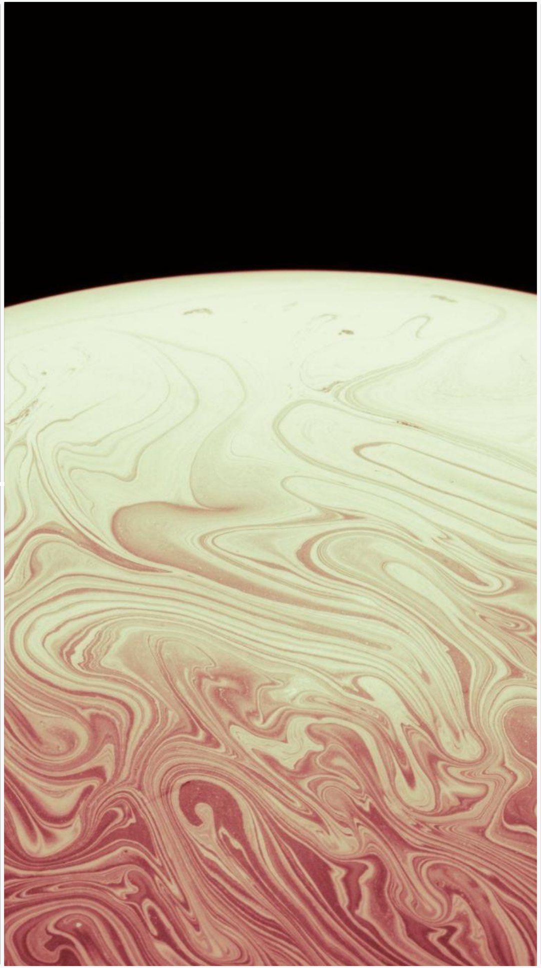
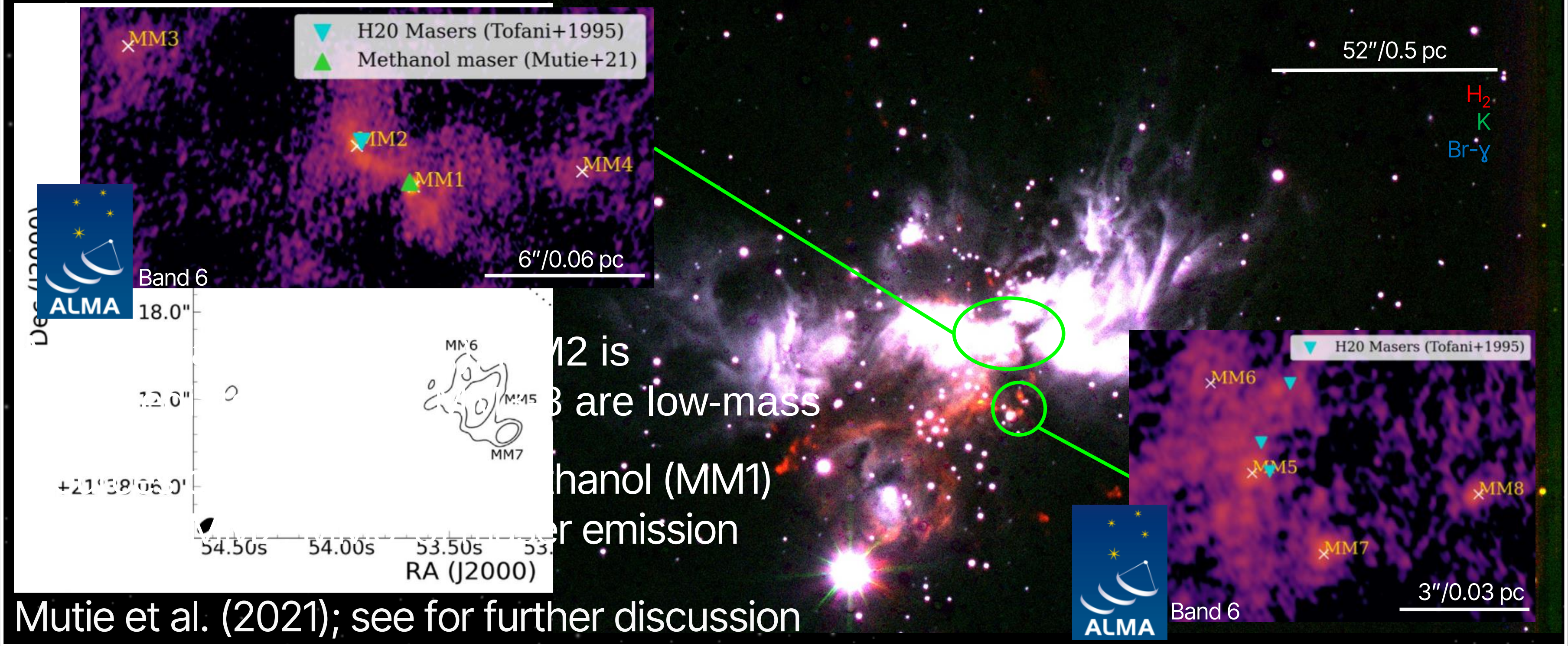
Results

Identifying sources, knots, and outflows

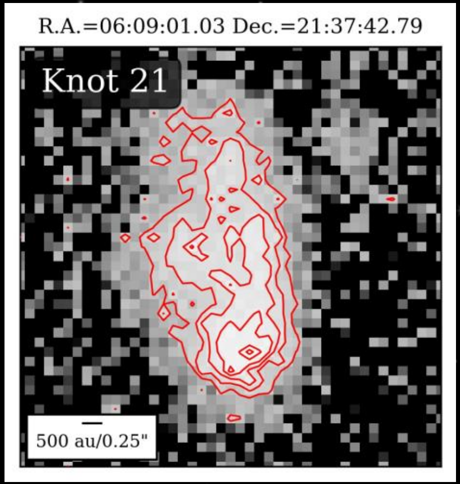


Previous work on ALMA data identifies 8+ YSO candidates in AFGL 5180

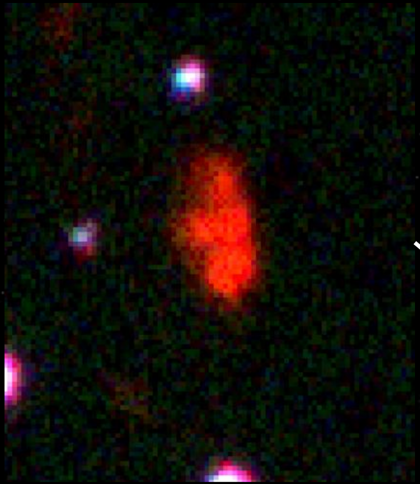


Mutie et al. (2021); see for further discussion

~40 jet features were identified in the LBT H_2 and HST [FeII] data

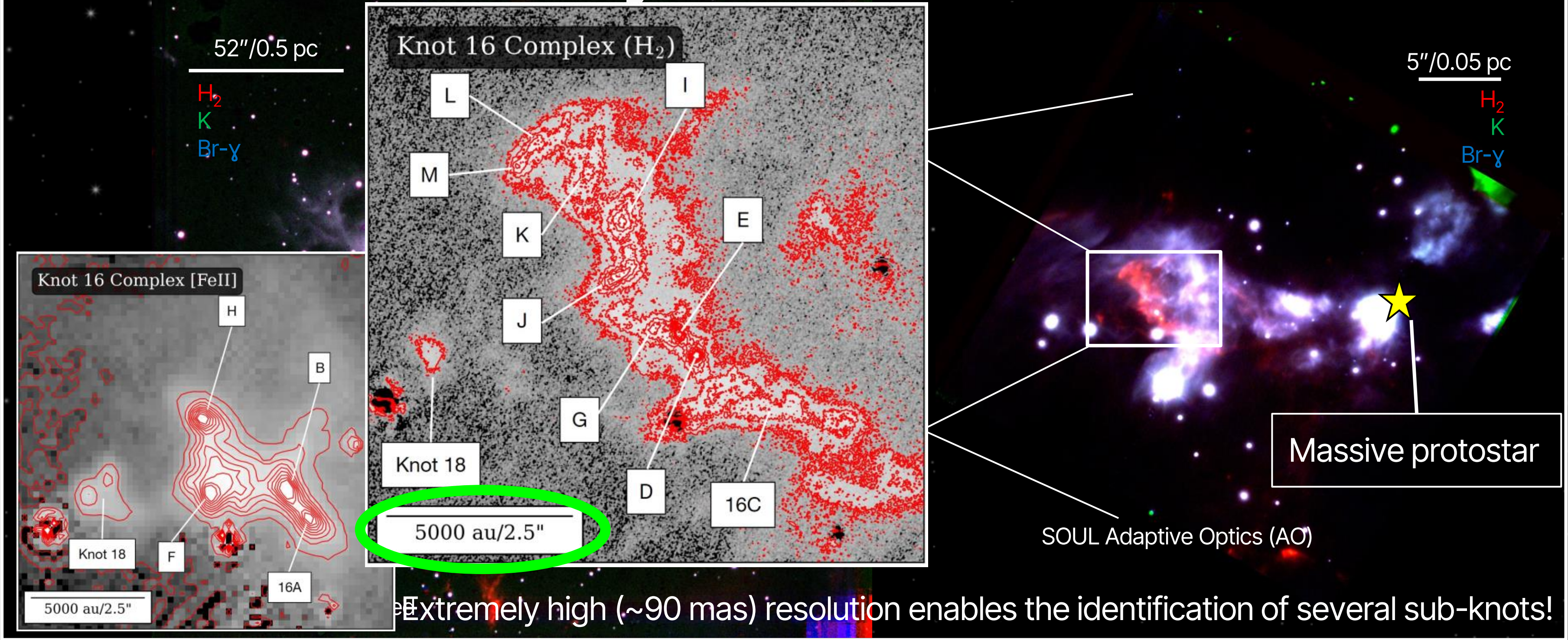


Contours: 3, 5, 7, 9, 11, 13, 15σ above the local background



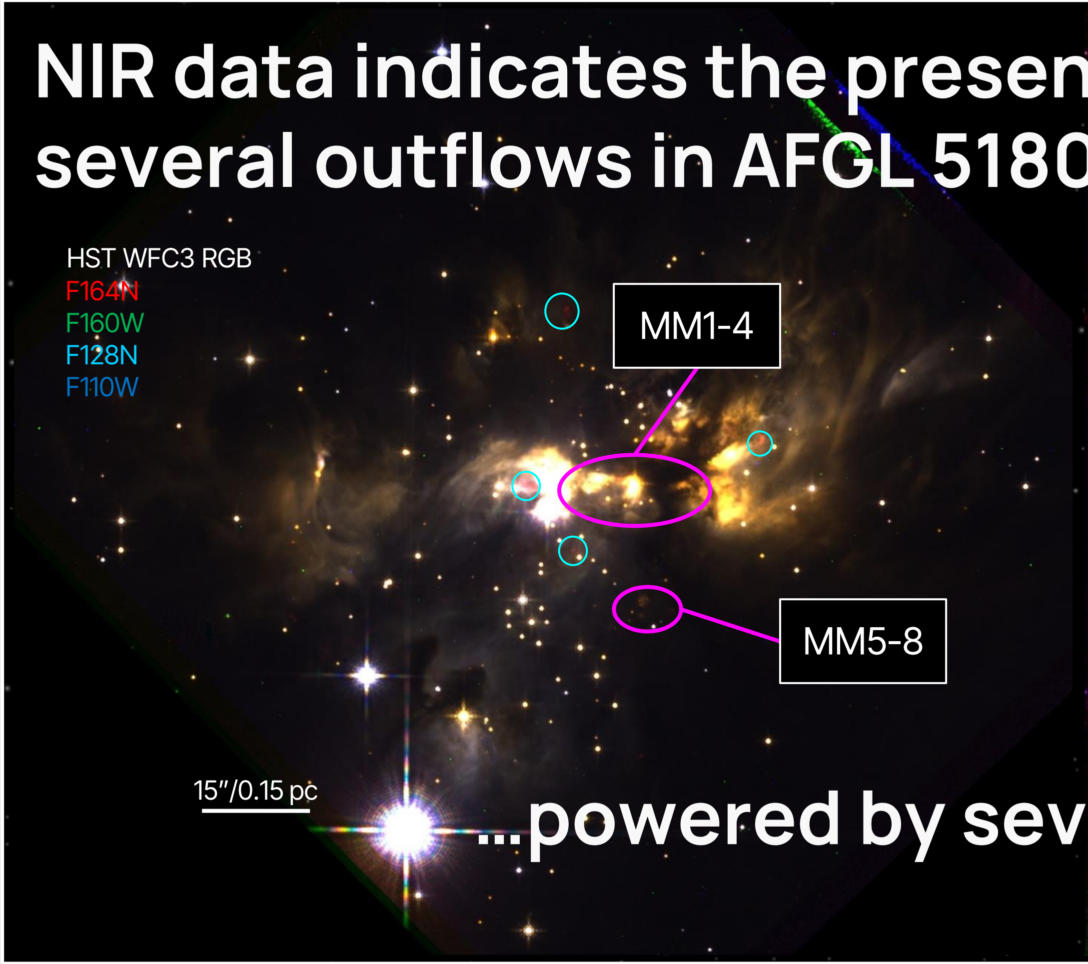
Knots are identified by **sampling the local σ** and **generating significance maps** in continuum-subtracted images

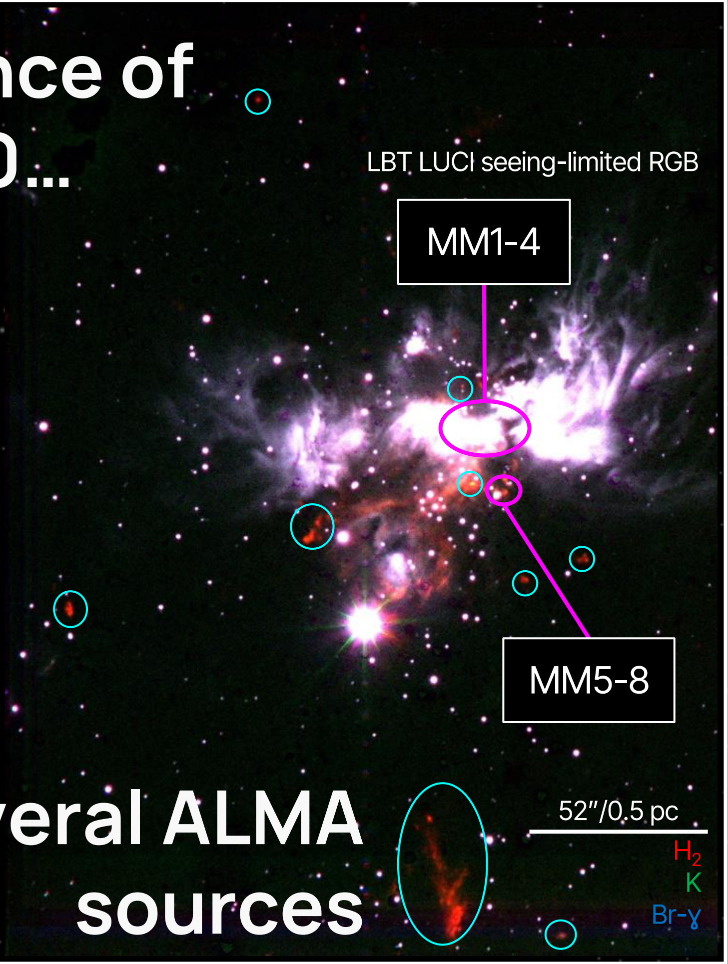
Revealing intricate substructure in a massive stellar jet with LBT SOUL AO



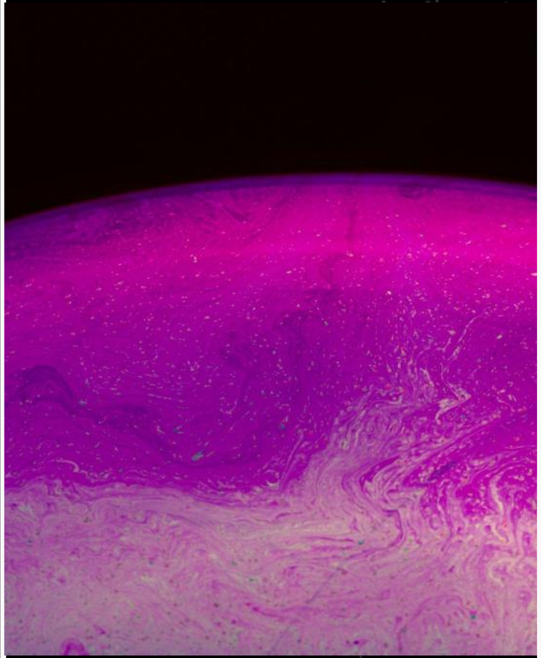
Extremely high (~90 mas) resolution enables the identification of several sub-knots!

NIR data indicates the presence of several outflows in AFGL 5180…





…powered by several ALMA sources



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Discussion

Interpretation of the results, implications on massive star formation, and EGOs

What is happening in AFGL 5180?

Could we be seeing an explosive outflow?

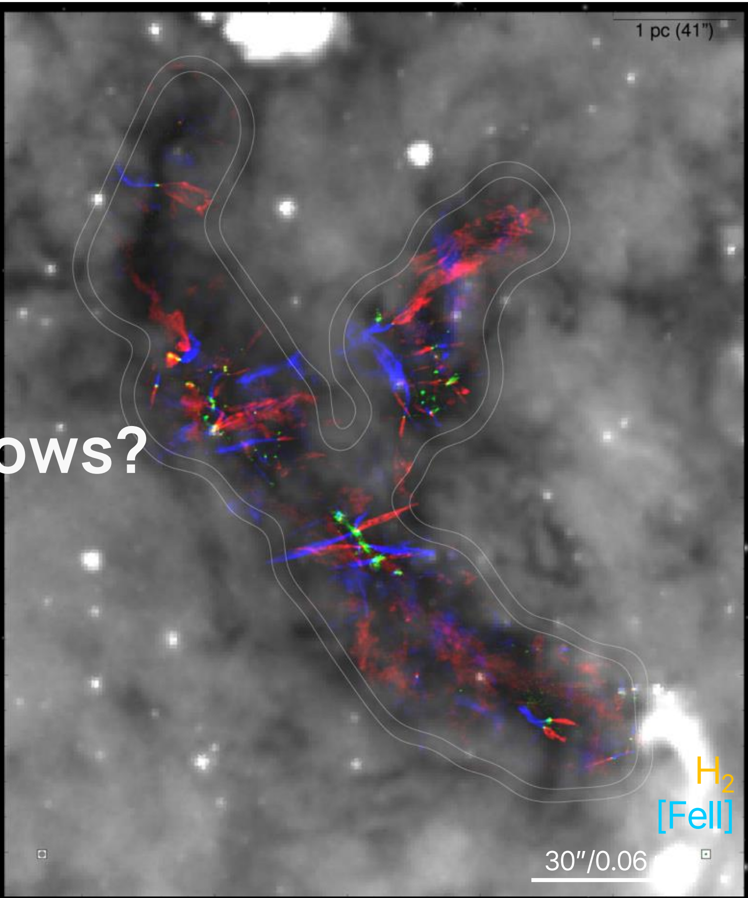
We favor the interpretation of **multiple outflows** being driven by **multiple sources**

Which sources drive which outflows?

Uncertainty in attributing knots to **specific sources**– too crowded!

↓

Proper motions are needed to better constrain the outflowing sources (Fedriani et al. in prep.)



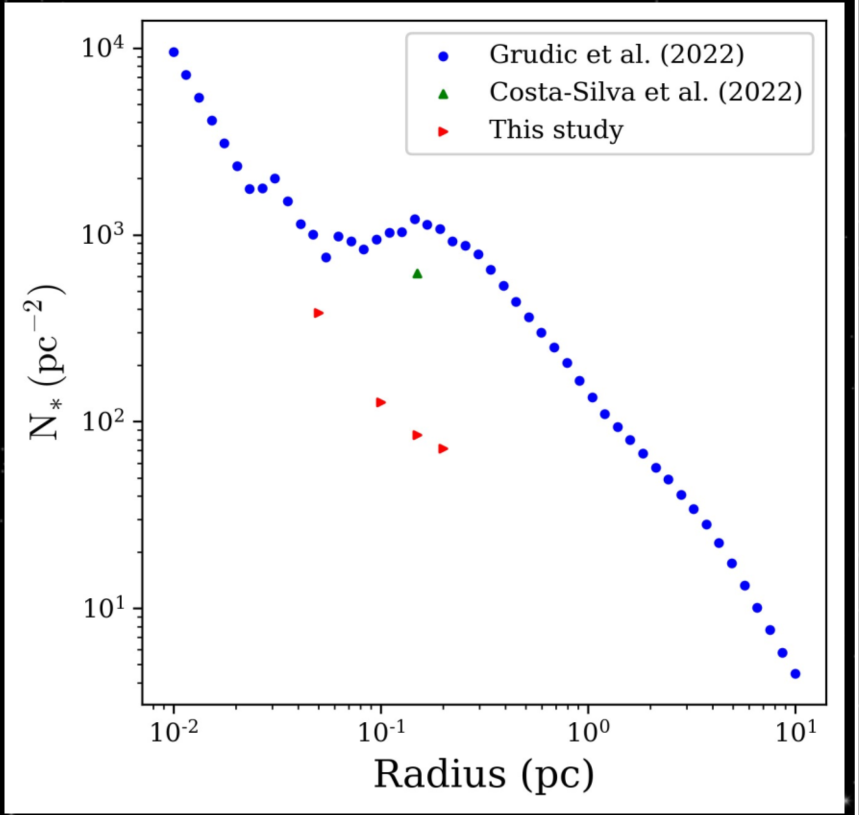
Picture: Massive explosive protostellar outflows in G28.37+0.07
Credit: Kong et al. (2019)

Picture: ALMA 1.3mm CO(2-1) observation of Orion KL
Credit: Bally et al. (2015)

The implications of AFGL 5180 on MSF

Stellar densities observed in AFGL 5180 fall far below those of simulations that align with competitive accretion models

The degree of clustering observed in AFGL 5180 around the central massive protostar MM1 suggests a **Core Accretion** model and **isolated massive star formation**

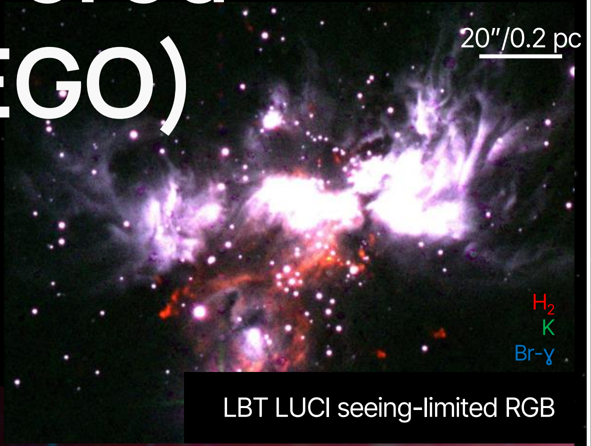


AFGL 5180: a newly discovered Extended Green Object (EGO)

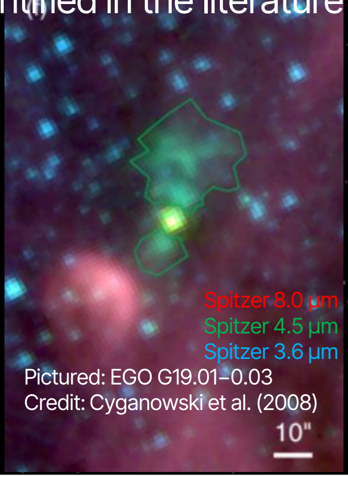
Extended 'green' emission in Spitzer 4.5 μm corresponds with the outflow seen in LBT/HST

AFGL 5180 appears to be a very prominent **Extended Green Object** (EGO), EGO G188.95+0.92, never before identified in the literature[1,2]!

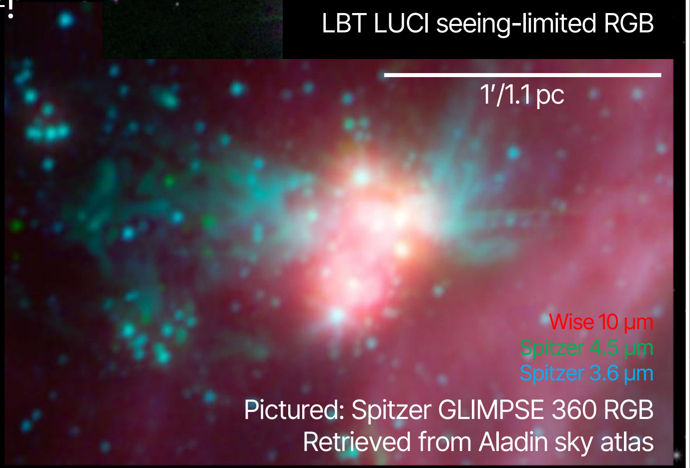
Class of objects associated with excess emission at Spitzer 4.5 μm due to **shocked molecular hydrogen emission lines** tracing **outflows** and correlated with **methanol masers** and **massive star formation**[1]– all characteristics of AFGL 5180



LBT LUCI seeing-limited RGB



Pictured: EGO G19.01–0.03
Credit: Cyganowski et al. (2008)



Pictured: Spitzer GLIMPSE 360 RGB
Retrieved from Aladin sky atlas

[1]For an original catalog of EGOs from GLIMPSE as well as general characteristics, see Cyganowski et al. (2008) [2]Chen et al. (2013)


Credit: NASA, ESA, CSA, STScl, K. Pontoppidan, A. Pagan

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Conclusions

Future outlook, closing thoughts, and summary

Future work with AFGL 5180

Credit: Andy Anderson

Spectra!

Yes, we have them

Long-slit LBT & IFU VLT

- Kinematic and dynamic analysis
- Analysis of shock tracers (HI, [FeII], H_2)
- Constraints on outflow direction, speed, mass, temperature, etc.

Stay tuned for the paper!

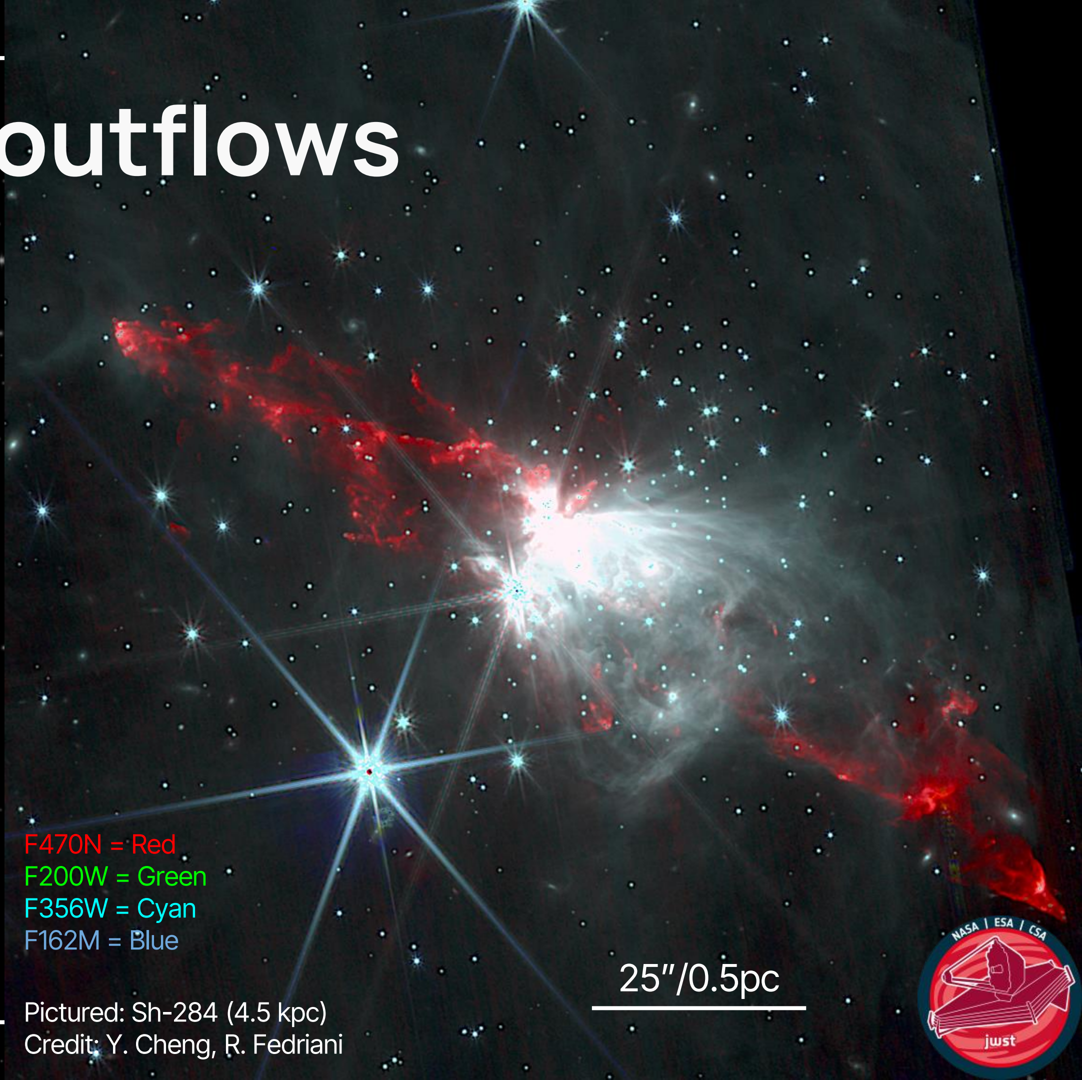
Future outlook: outflows with JWST

What happens when you point JWST-NIRCam at a massive star-forming region?

Cycle 1 program 2317: Sh-284 (PI: Y. Cheng)

Cycle 2 program 3907: IRAS07299, G339.88-1.26 (PI: Y. Zhang)

Cycle 2 program 4147: G359.44−0.102 in Sagittarius C (PI: S. Crowe)

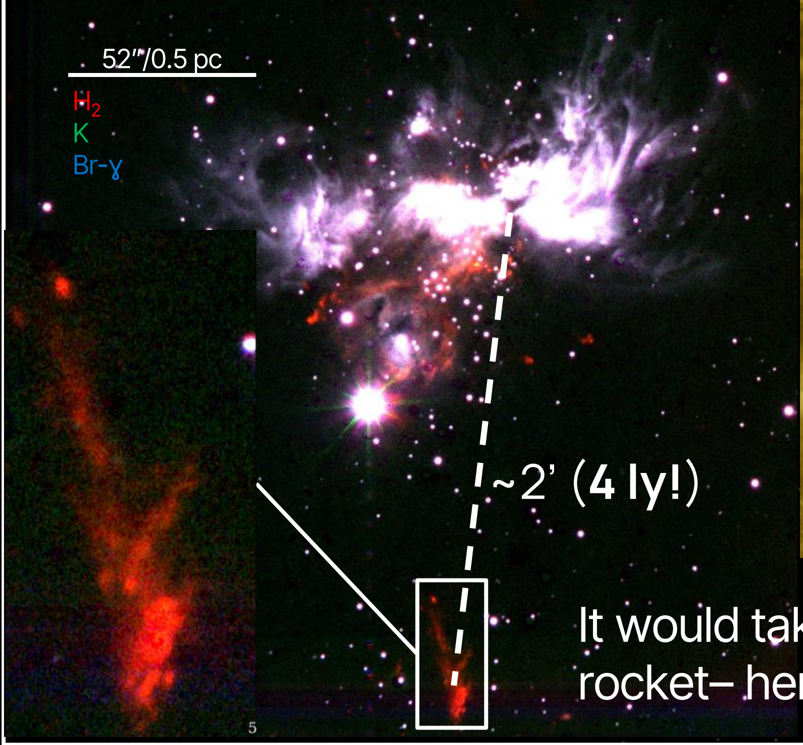


Summary

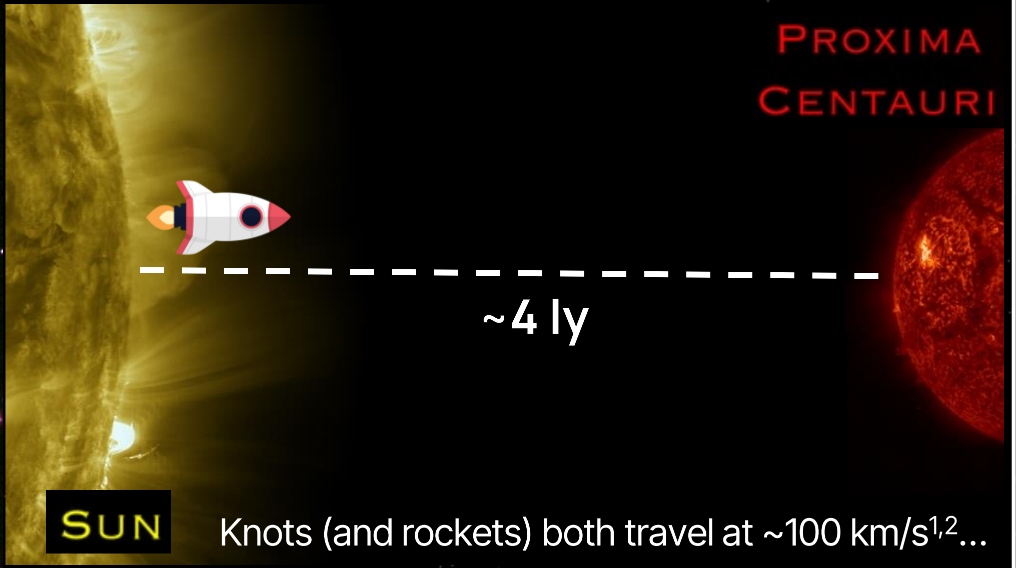
- Massive star formation theory is split between Core & Competitive Accretion
- Observations attempt to produce a resolution: SOMA and SOMA-NIR
- Protostellar jets are key diagnostics of star formation– and best seen in the NIR
- Cutting-edge NIR data from LBT and HST reveal dozens of jet features, along with several sources from ALMA, in the massive star-forming region AFGL 5180
- ~90 mas LBT SOUL Adaptive Optics data reveals fine detail in a massive jet
- Clustering of MSF in AFGL 5180 supports Core Accretion models
- Spitzer GLIMPSE data reveals that AFGL 5180 is an Extended Green Object (EGO), corroborating the presence of energetic outflows and MSF

Bottom line:
NIR observations of protostellar jets are key to addressing observational constraints and characterizing star-forming regions in intricate detail.

A sense of physical scale– the Southern Bow Shock



Credit: NASA Scientific Visualization Studio



Knots (and rockets) both travel at ~100 km/s[1,2]...

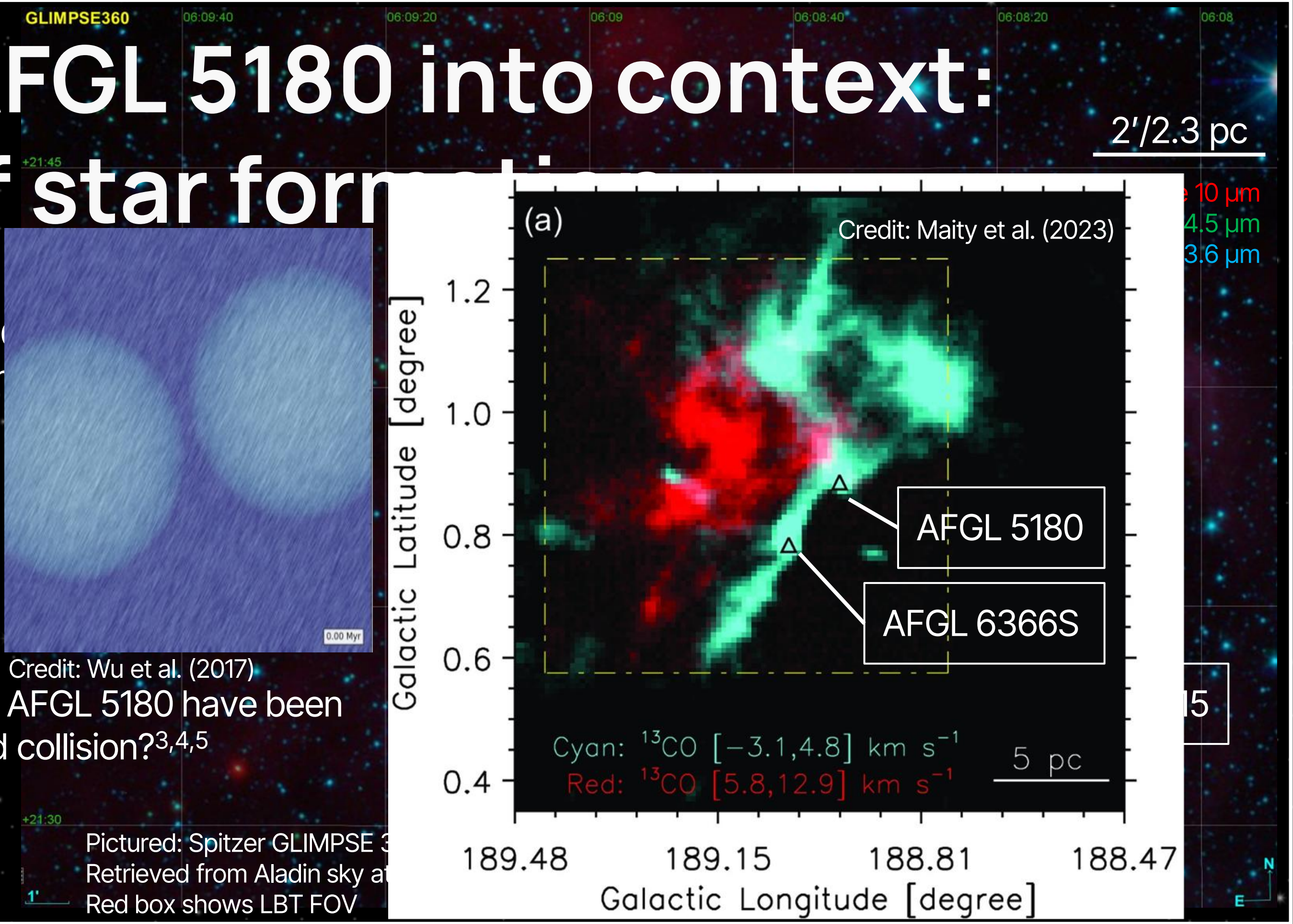
It would take ~10,000 yr to reach Proxima Centauri by rocket– hence the kinematic age of our bow shock!

[1]See Fedriani et al. (2018) and references therein [2]Within an order of magnitude

Placing AFGL 5180 into context: origins of star formation

Could star formation in AF[...] triggered by feedback fro[...]

Or, could star formation in AFGL 5180 have been triggered by a cloud-cloud collision?[3,4,5]



Credit: Wu et al. (2017)

Pictured: Spitzer GLIMPSE 3[...]
Retrieved from Aladin sky at[...]
Red box shows LBT FOV

[1]Carpenter et al. (1995a) [2]Carpenter et al. (1995b) [3]Vasyunina et al. (2010) [4]Shimoikura et al. (2013) [5]Maity et al. (2023)