Credit: ALMA (ESO/NAOJ/NRAO)/T. Wong/S. Dagnello

Applications of Interferometry: Protostars and Disks

Sarah Sadavoy (Queen's University)
sarah.sadavoy@queensu.ca

CRASIES Summer School

May 27, 2026

Credit: ESO/ B Trafreshi

About Me and My Journey

Credit: ALMA (ESO/NAOJ/NRAO)/T. Wong/S. Dagnello

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Orion constellation - DSS optical image (wikisky)

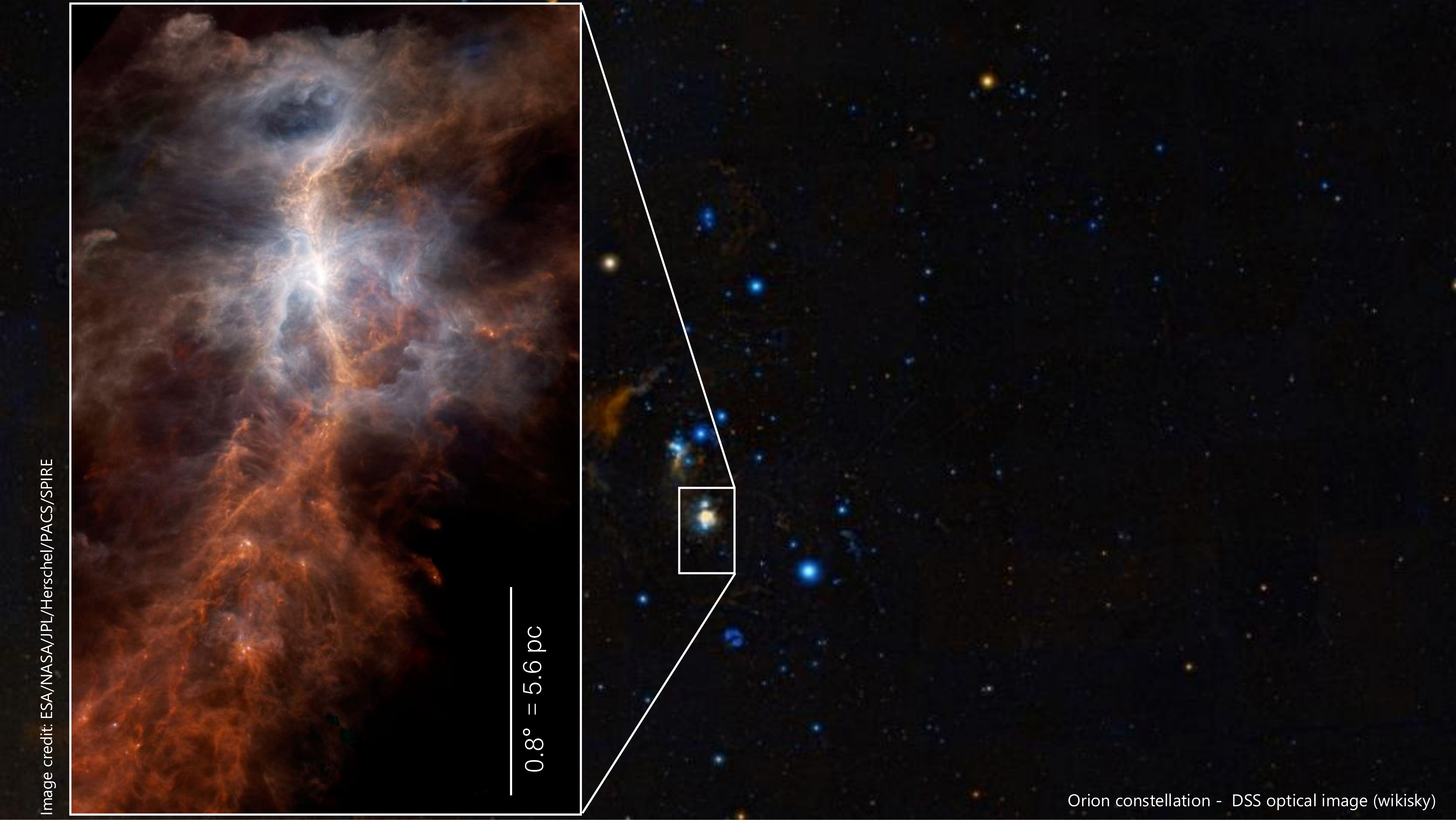

Image credit: ESA/NASA/JPL/Herschel/PACS/SPIRE

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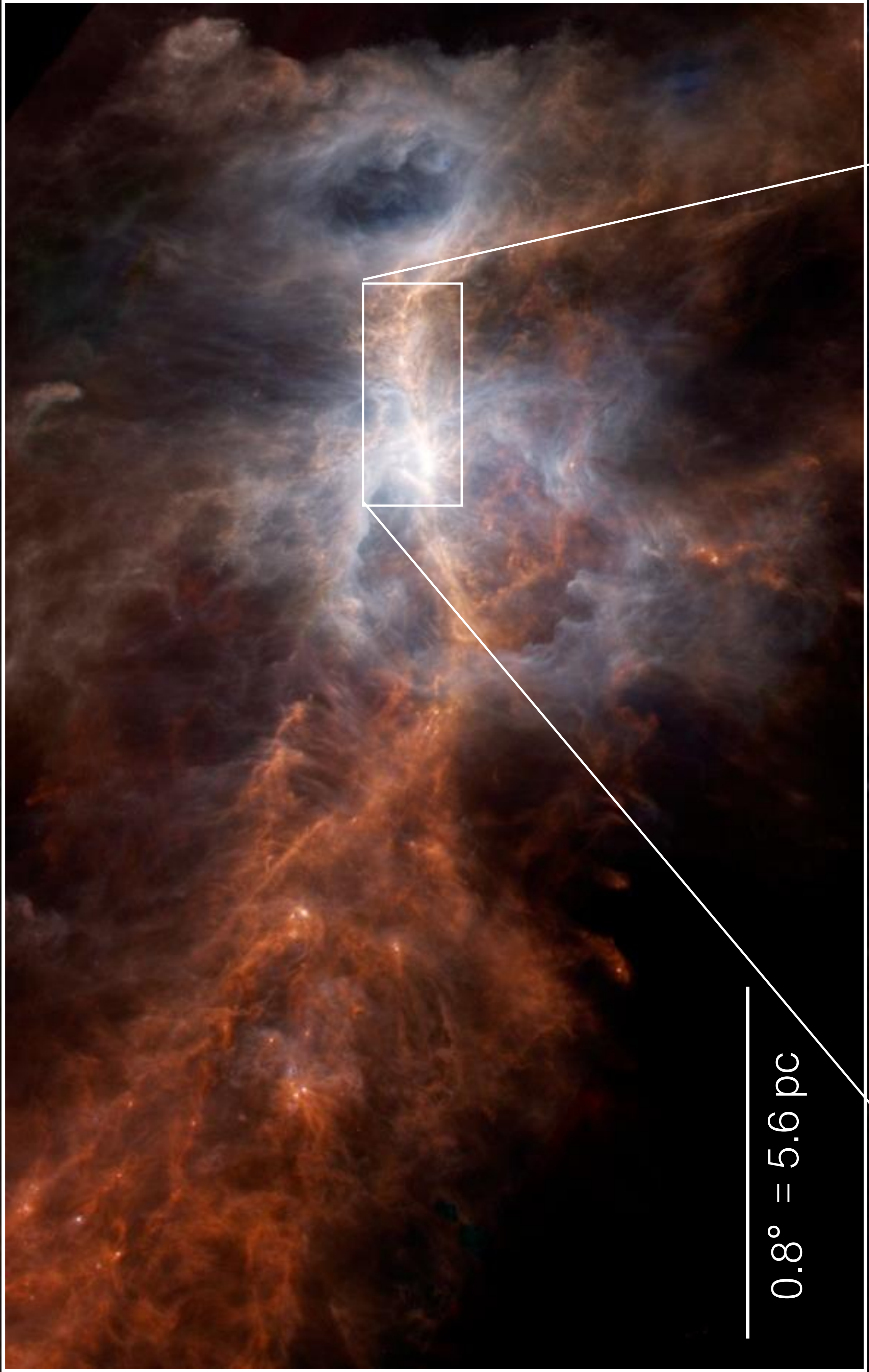

Image credit: ESA/NASA/JPL/Herschel/PACS/SPIRE

Image credit: N. Billot/R. Hurt/ESA/
PACS/NASA/JPL-Caltech/IRAM

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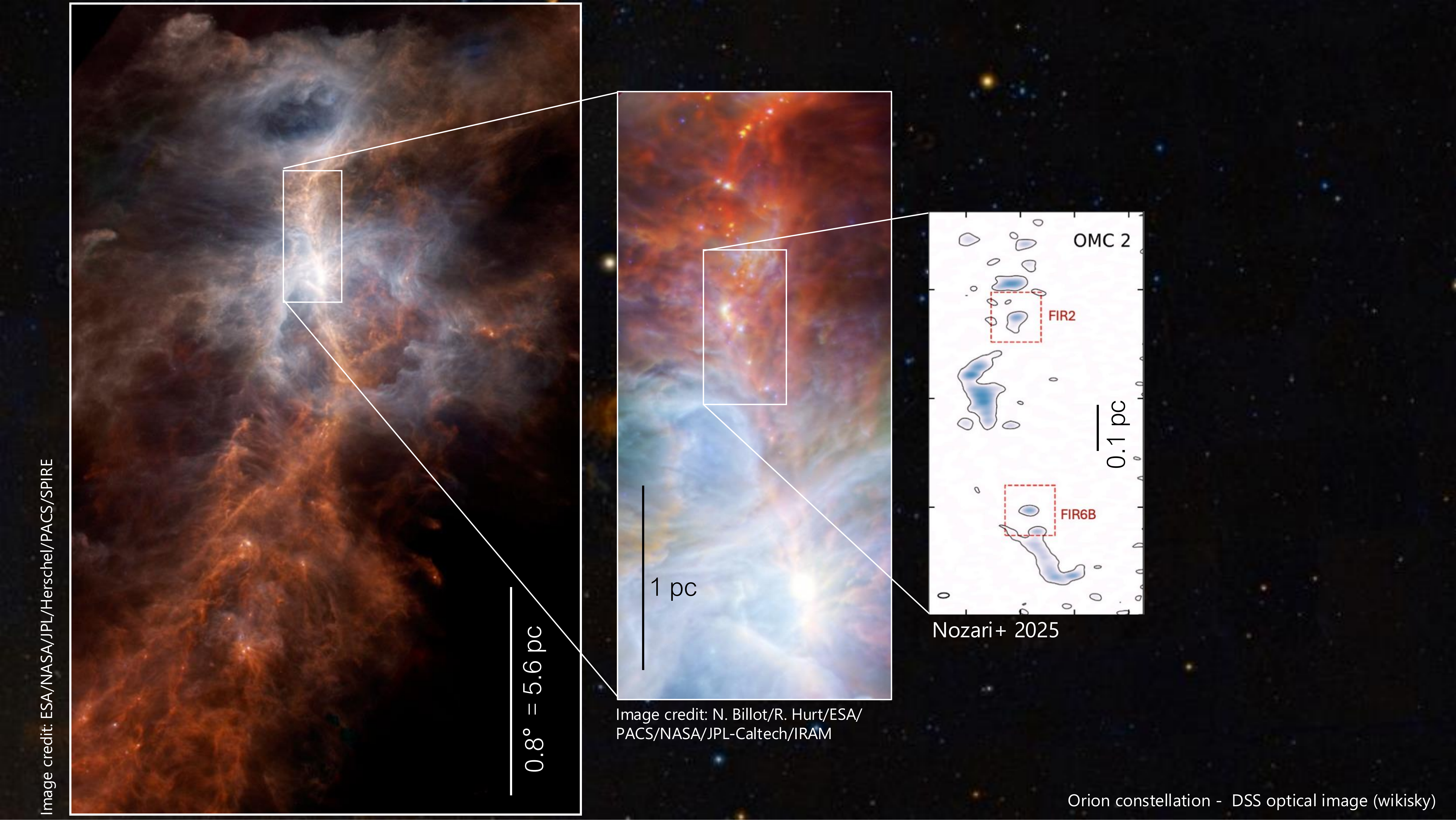
Image credit: ESA/NASA/JPL/Herschel/PACS/SPIRE
0.8° = 5.6 pc
1 pc
Image credit: N. Billot/R. Hurt/ESA/
PACS/NASA/JPL-Caltech/IRAM
OMC 2
FIR2
0.1 pc
FIR6B
Nozari+ 2025
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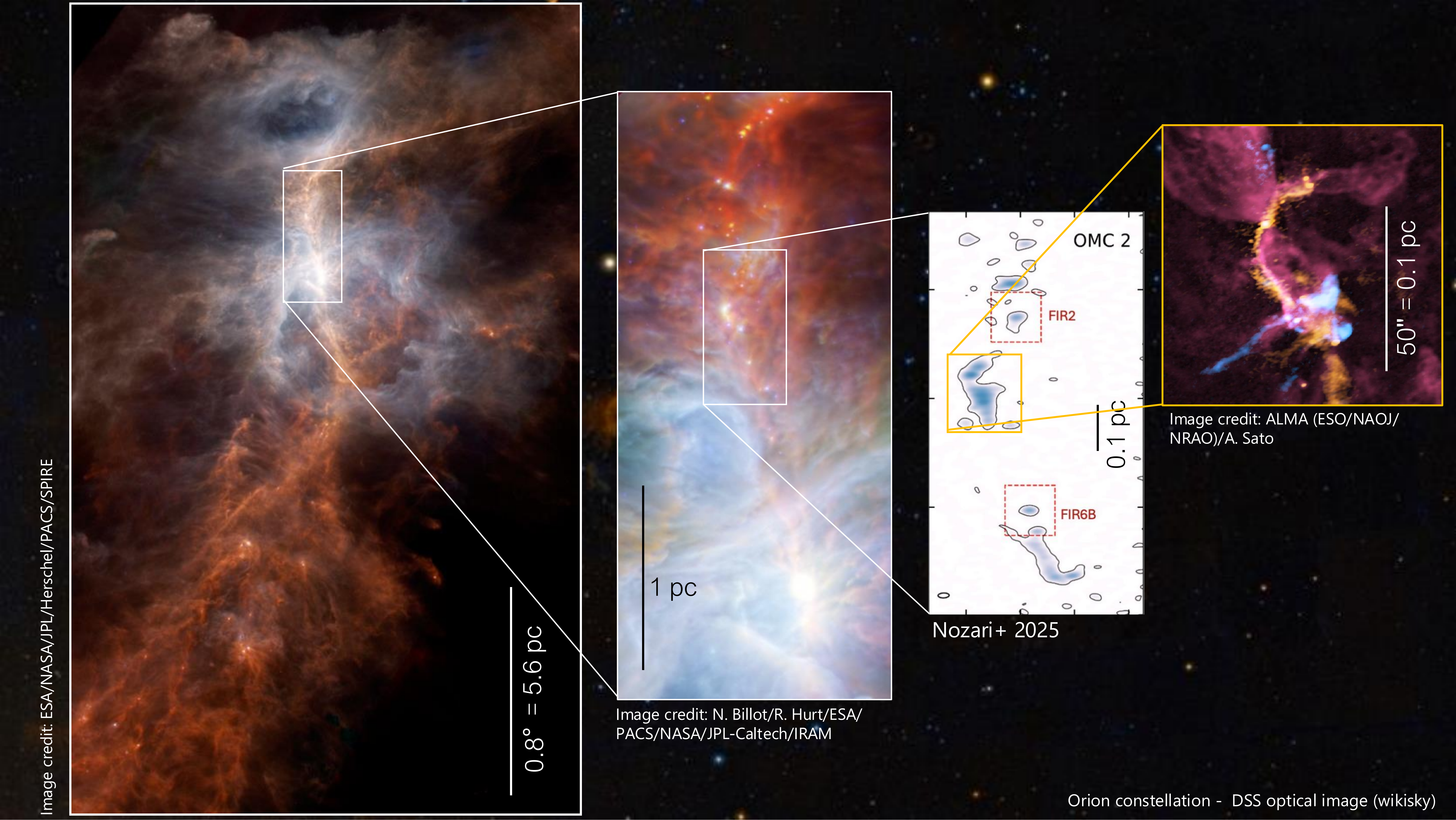

Image credit: ESA/NASA/JPL/Herschel/PACS/SPIRE
0.8° = 5.6 pc
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50" = 0.1 pc
Image credit: ALMA (ESO/NAOJ/
NRAO)/A. Sato
Orion constellation - DSS optical image (wikisky)

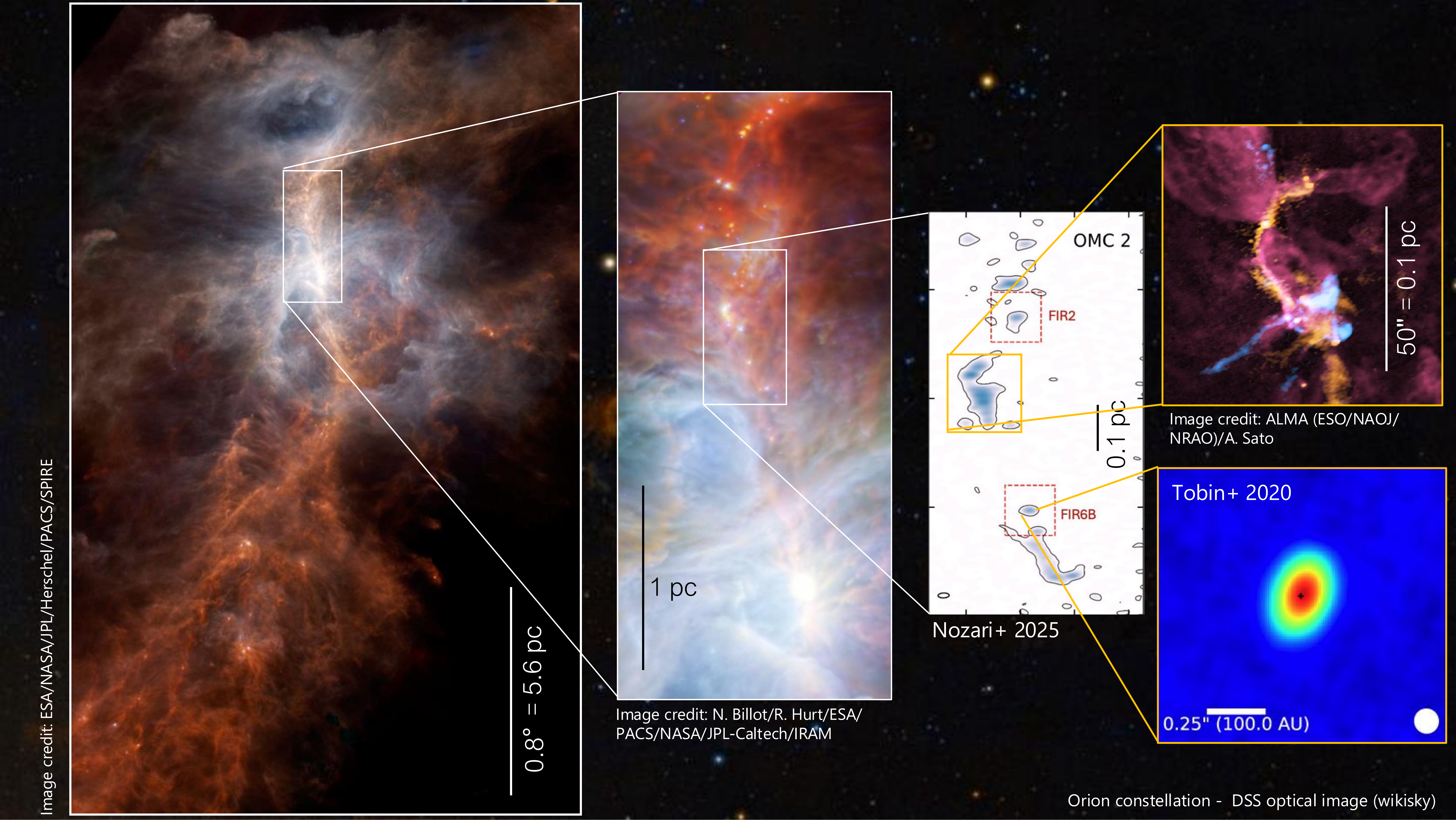

Image credit: ESA/NASA/JPL/Herschel/PACS/SPIRE
0.8° = 5.6 pc
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OMC 2
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50" = 0.1 pc
Image credit: ALMA (ESO/NAOJ/NRAO)/A. Sato
Tobin+ 2020
0.25" (100.0 AU)
Orion constellation - DSS optical image (wikisky)

Protostellar Environments and Disks

→ Interferometry filters out large-scale emission, capturing the conditions around young stars

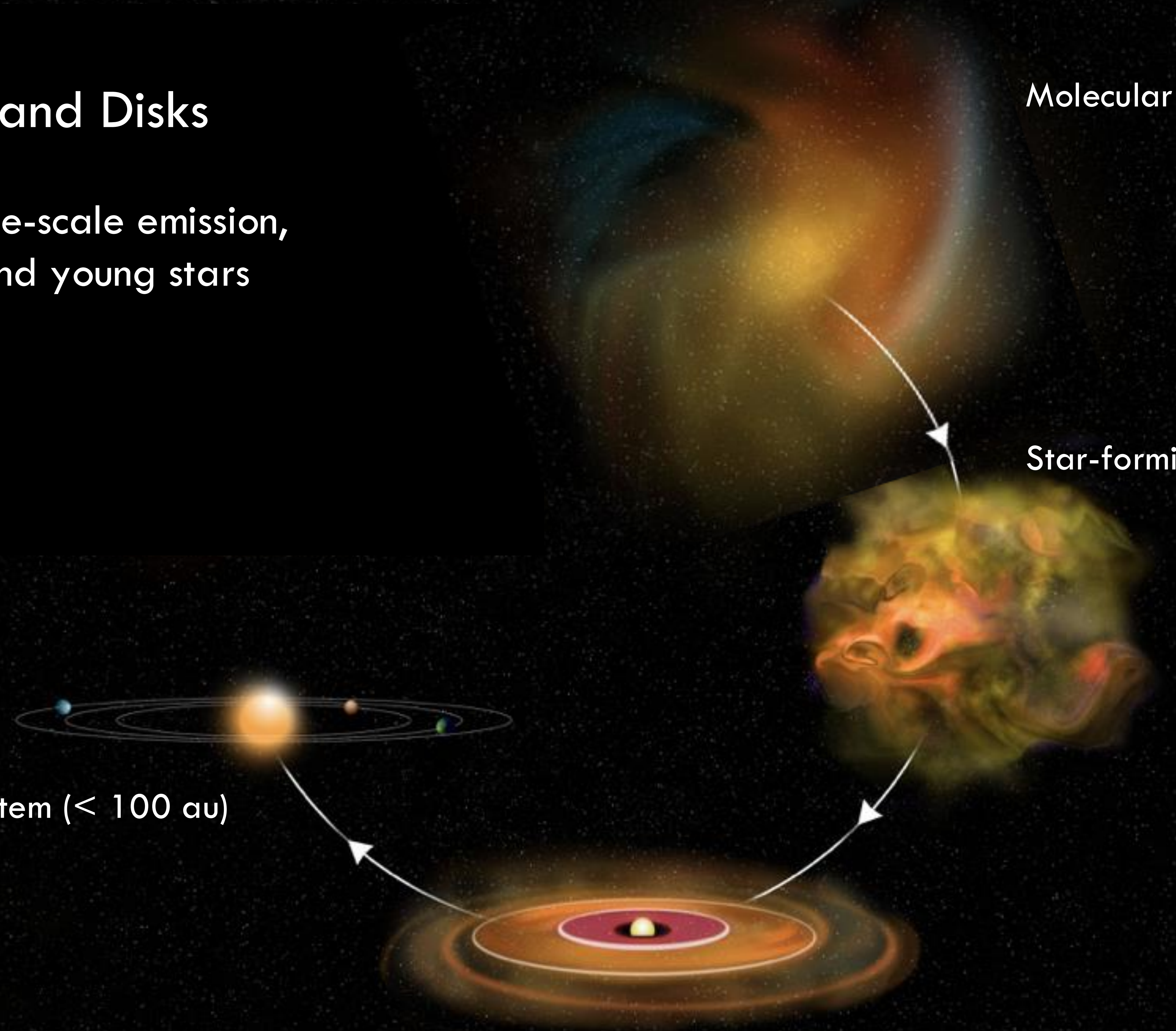


Image credit: B. Saxton / NRAO / AUI / NSF

Protostellar Environments and Disks

→ Interferometry filters out large-scale emission, capturing the conditions around young stars

→ Star formation is complex and dynamic, so multiple probes (dust, gas, polarization) needed

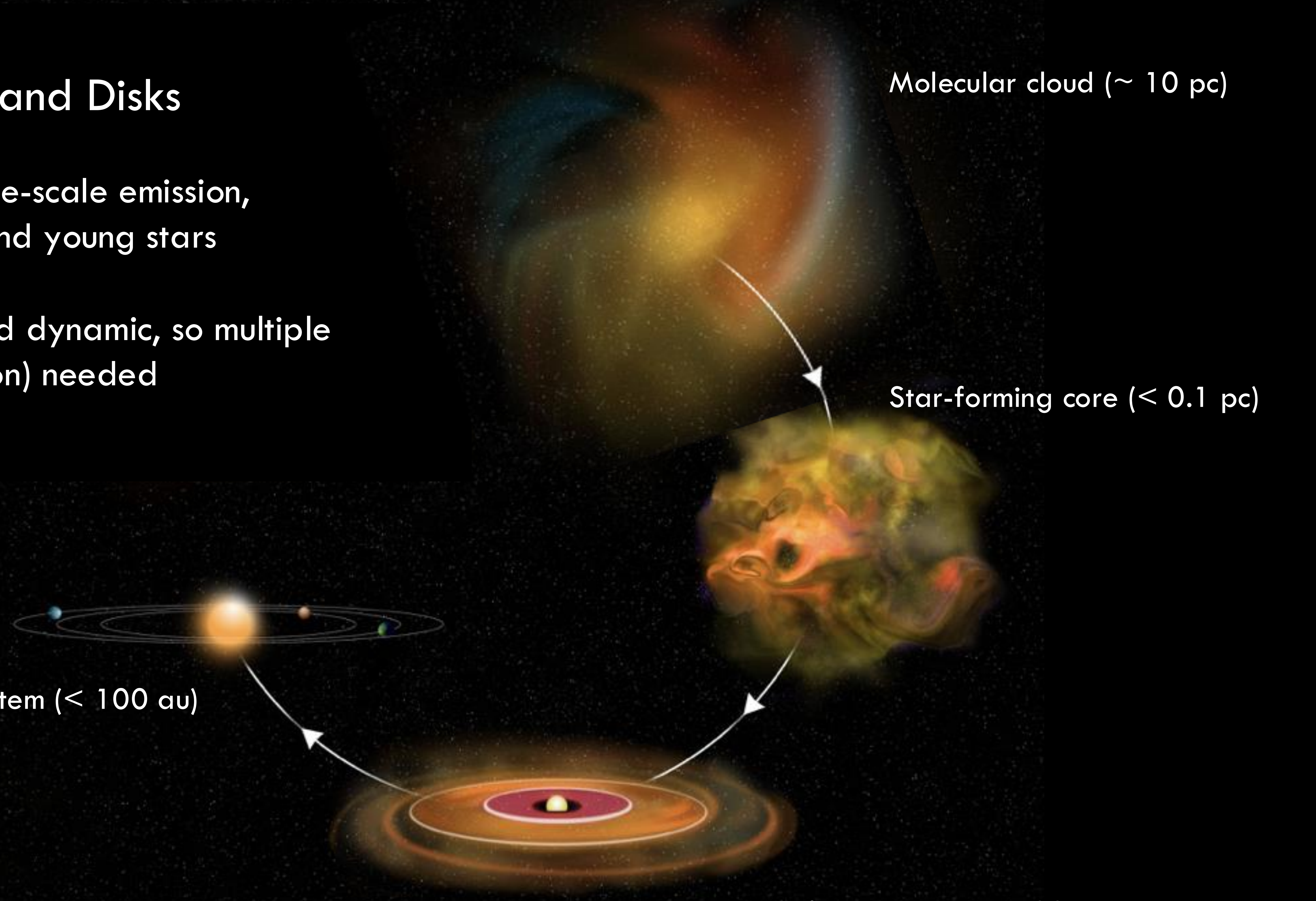
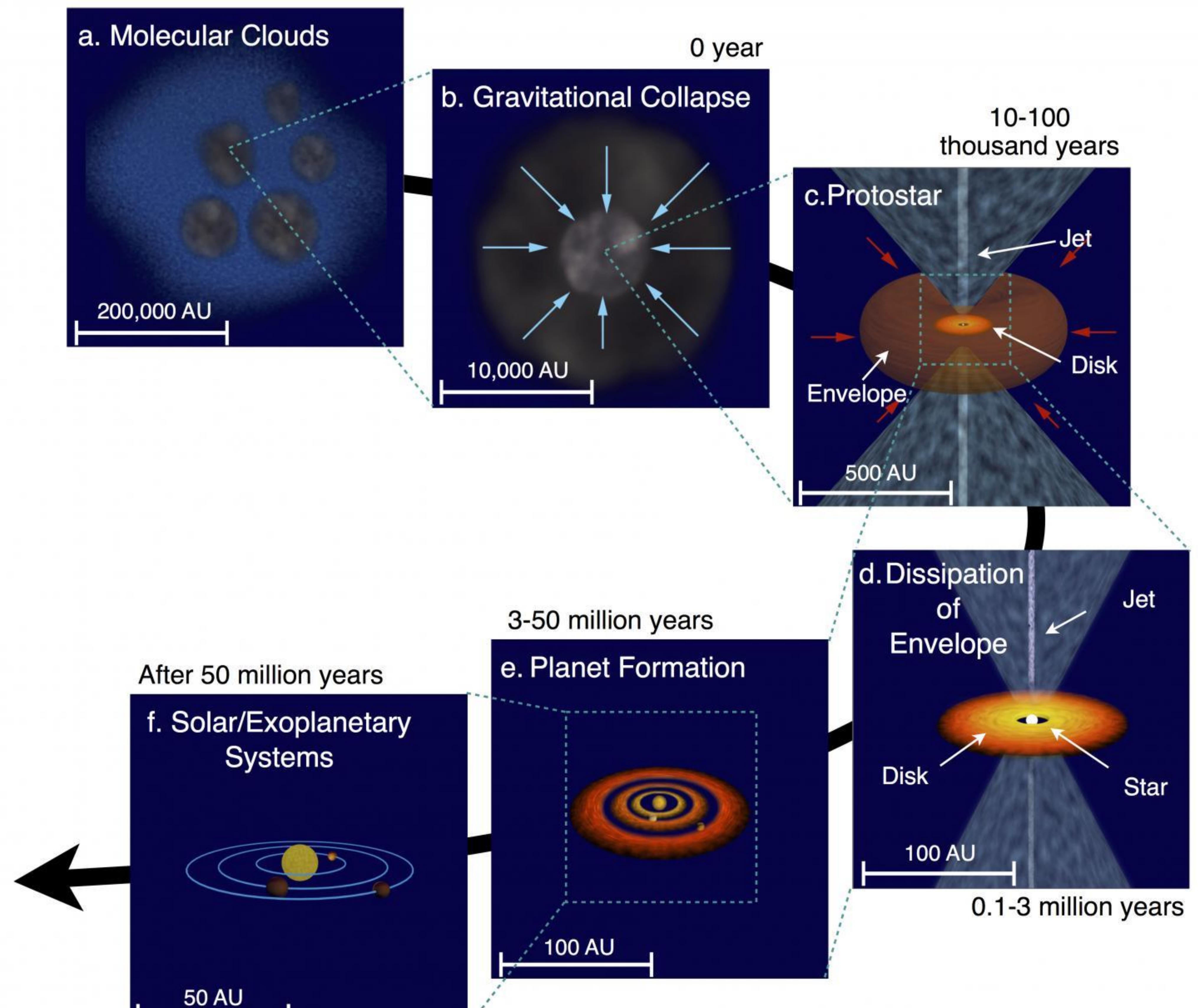


Image credit: B. Saxton / NRAO / AUI / NSF

The Dynamic Environment of Star Formation



Credit: ASIAA

Young stellar objects have:

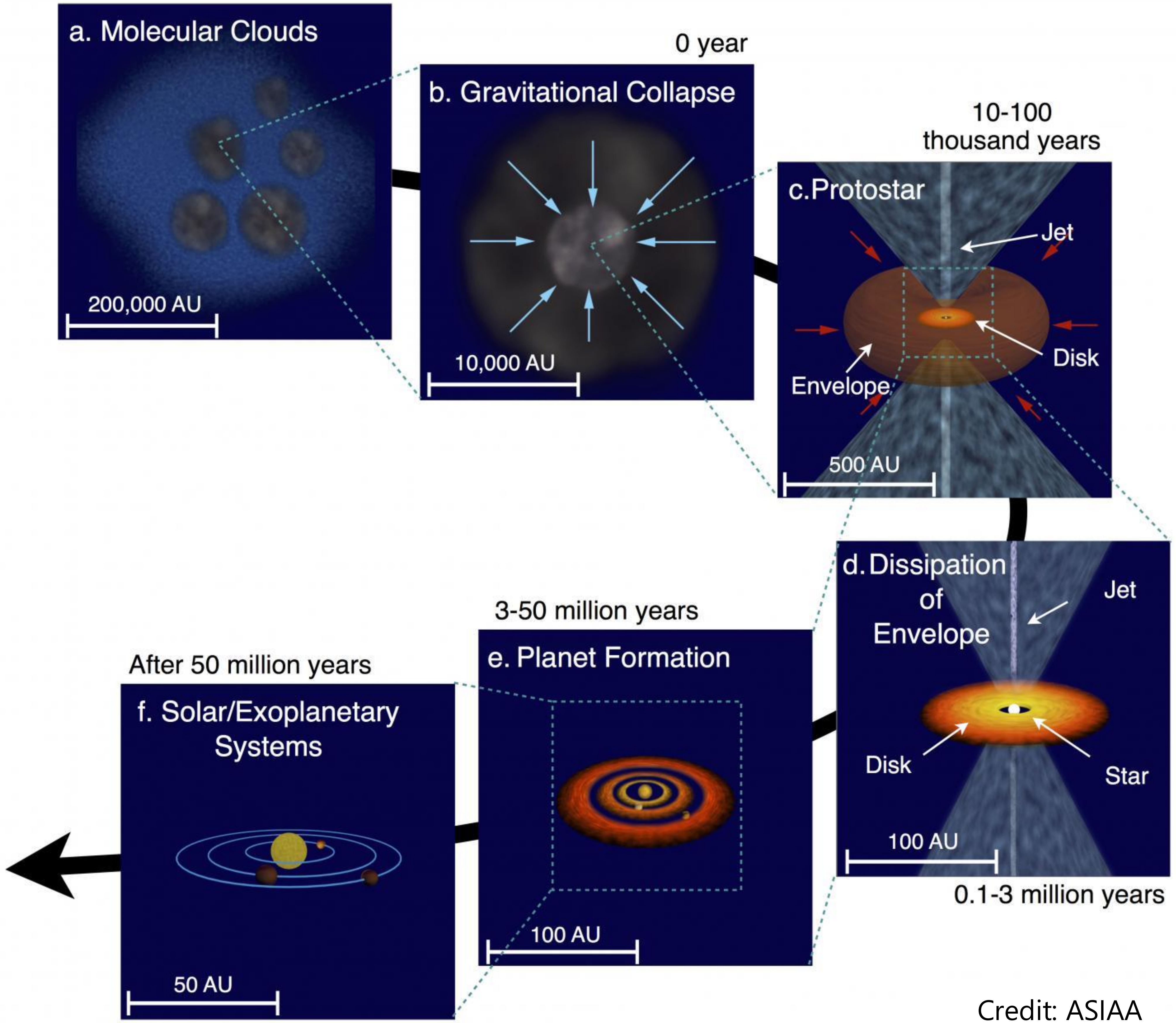
Outflows and jets

Accretion / infall from envelopes

Rotating disks

Temperature/density gradients

The Dynamic Environment of Star Formation



Credit: ASIAA

Young stellar objects have:

Outflows and jets

Accretion / infall from envelopes

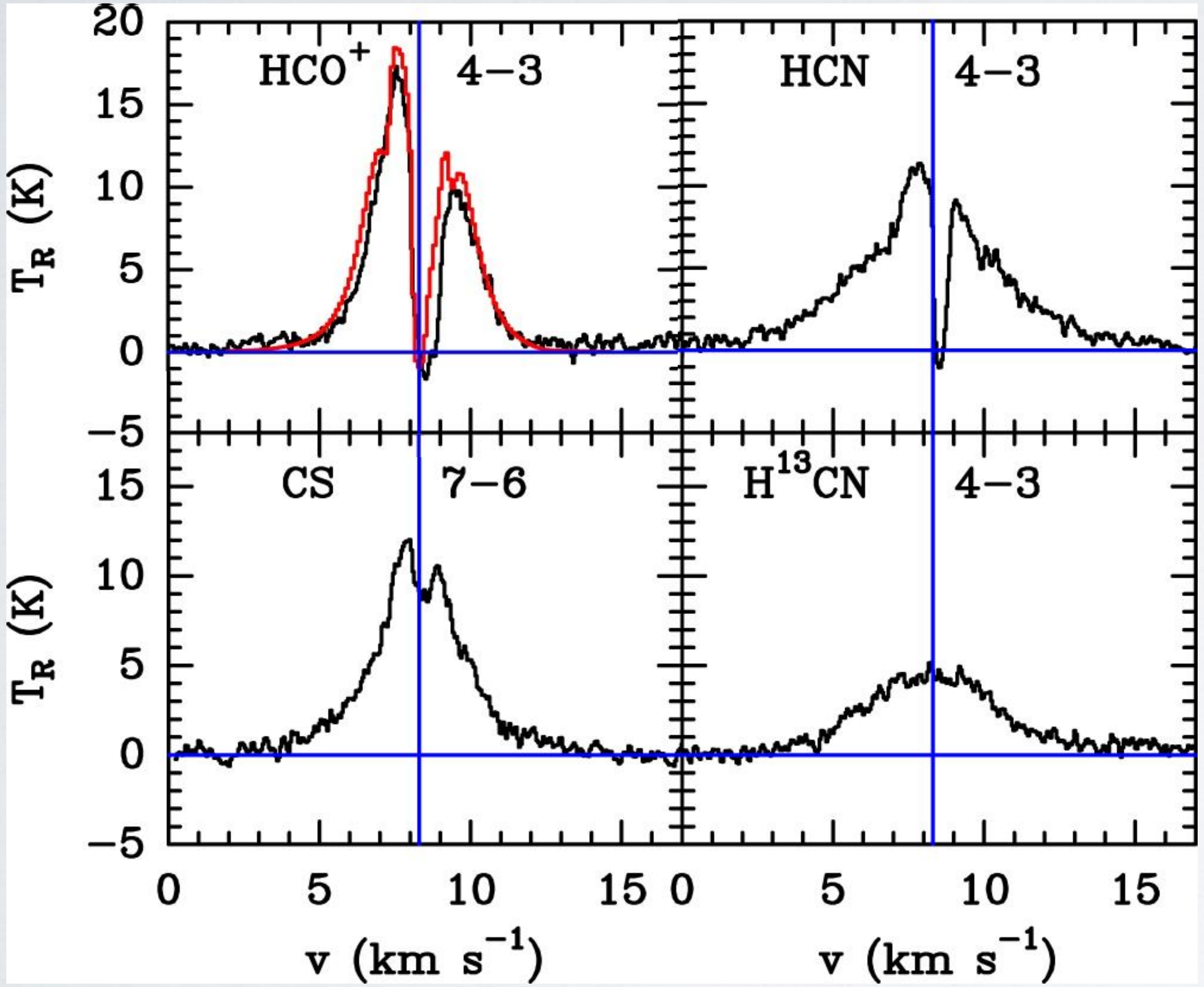
Rotating disks

Temperature/density gradients

→ touch on different probes with interferometers (mostly ALMA)

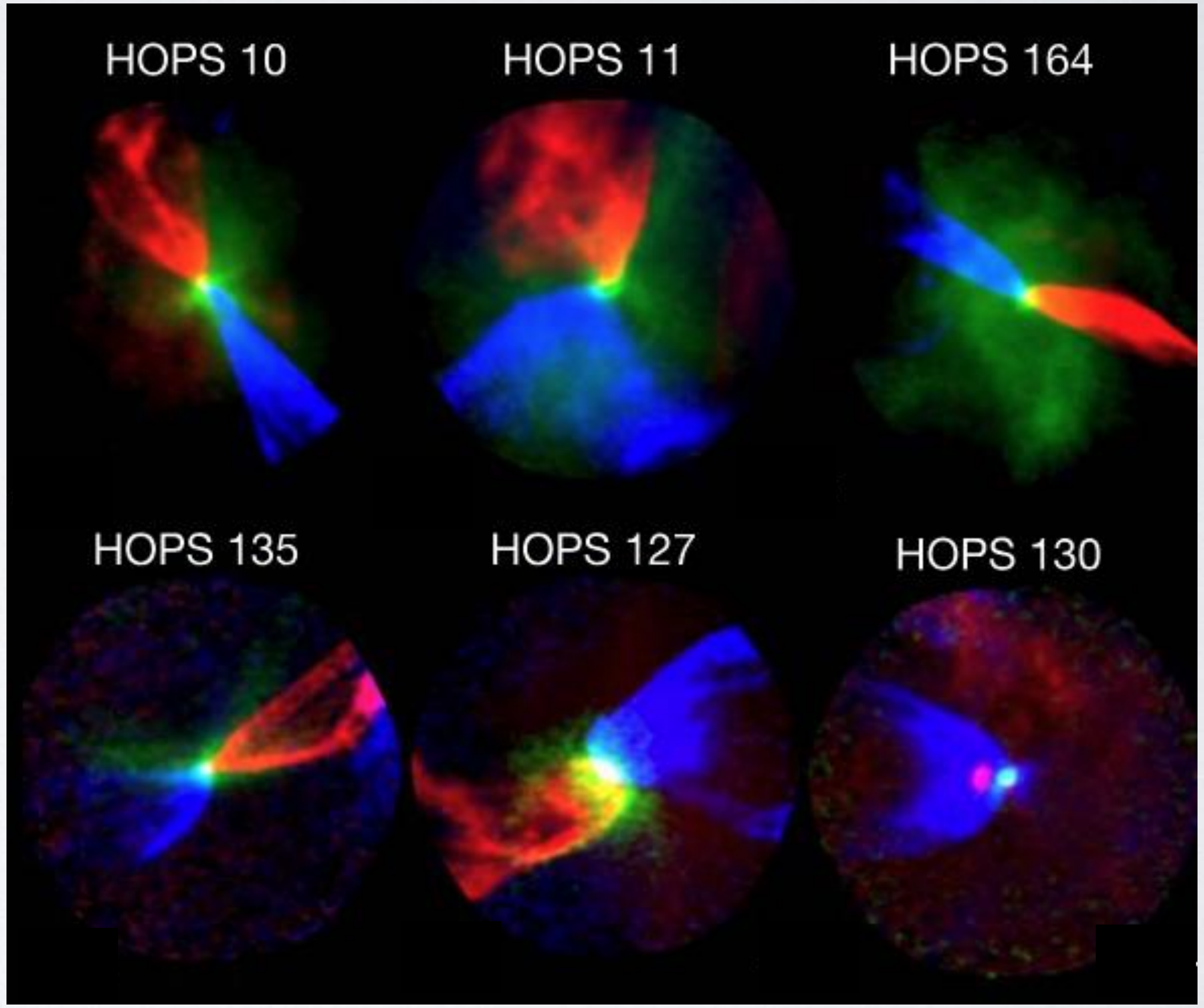
Spectral Line Data: Infall and Outflow

Gas infalling onto stars and disks



Evans+ 2015

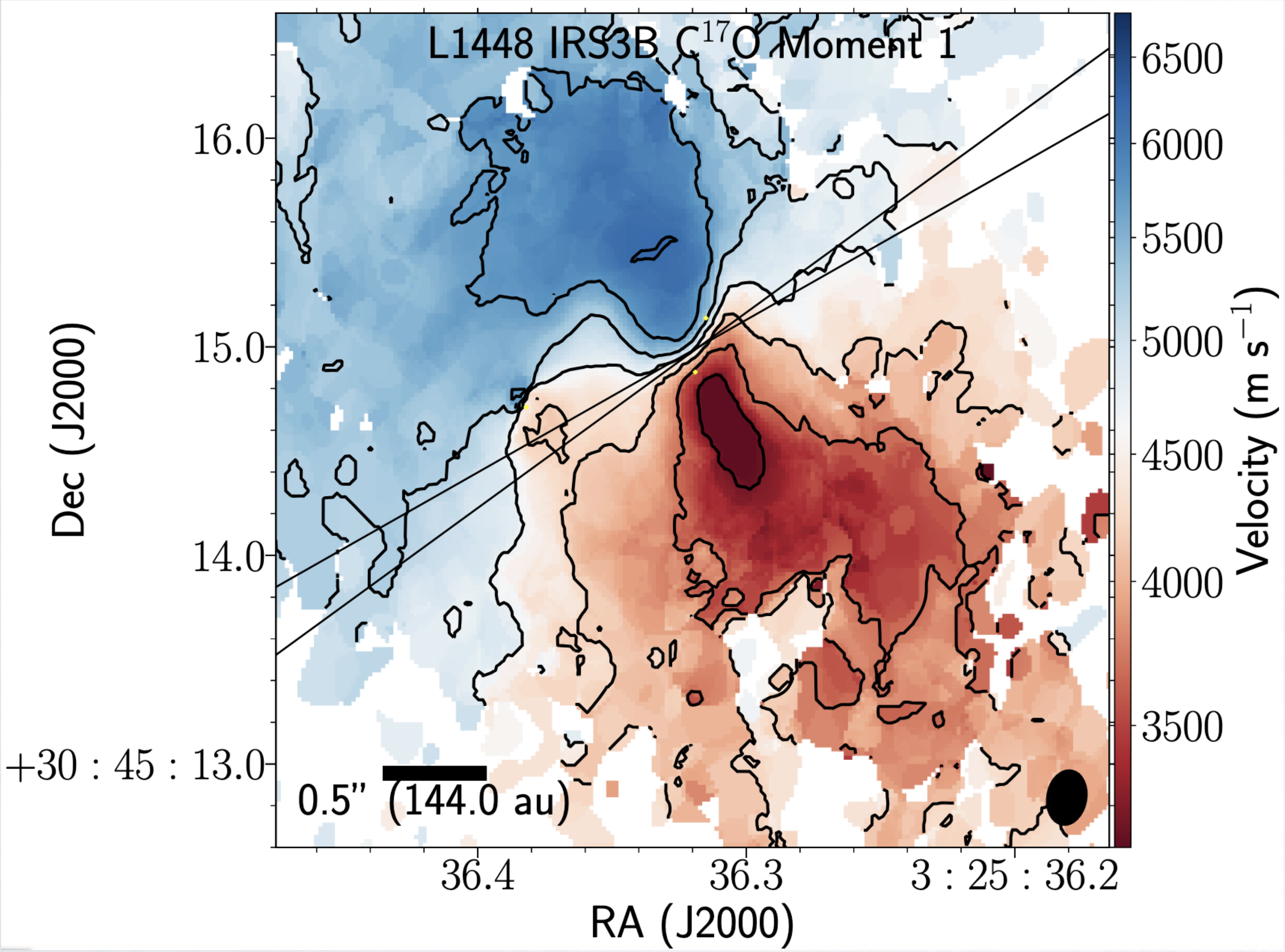
Gas outflowing from young stars

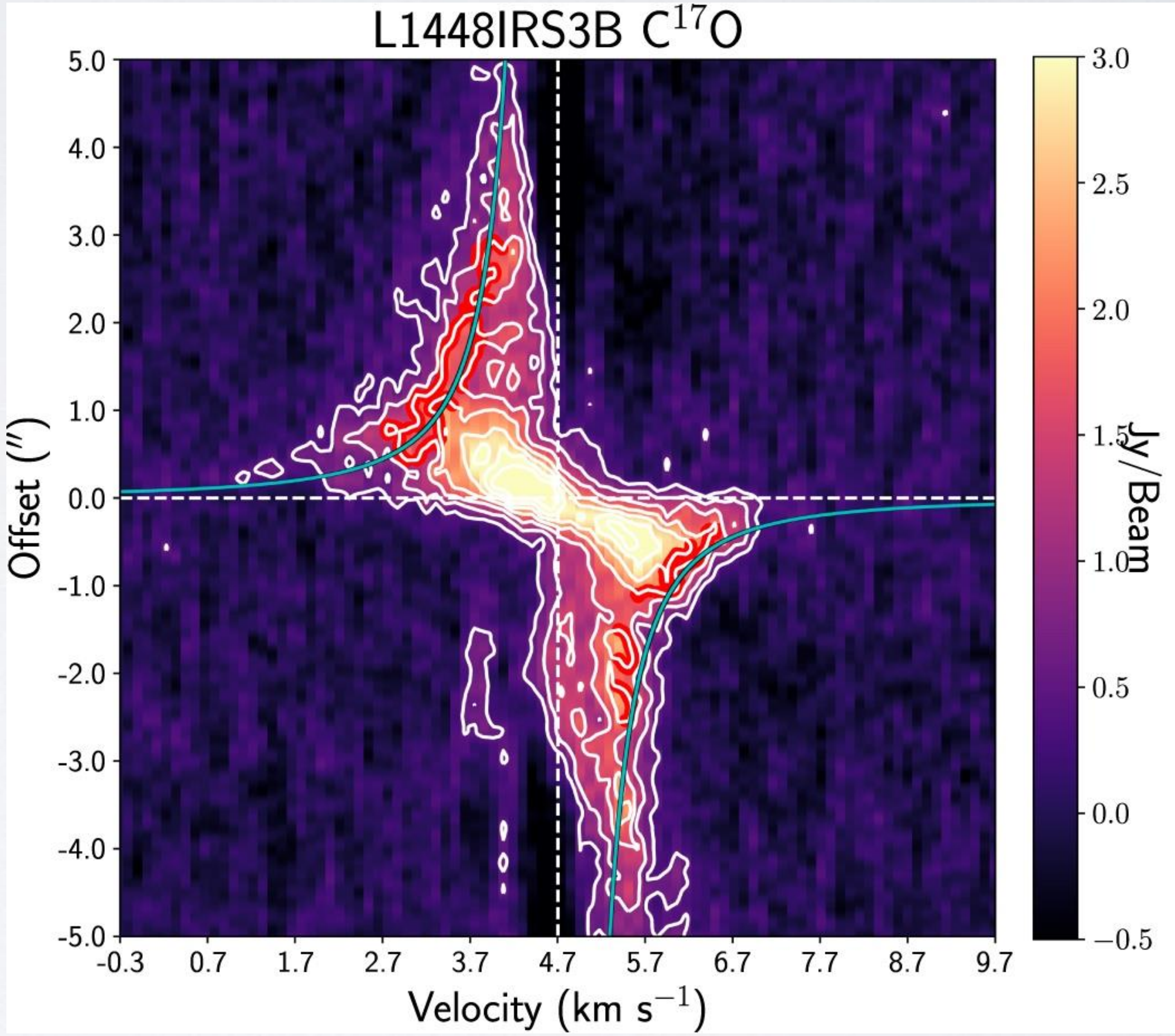


Hsieh+ 2023

Spectral Line Data: Keplerian Rotation

Using velocity gradients to model the disk rotation and get stellar masses
→ often the only method to get masses of protostars!

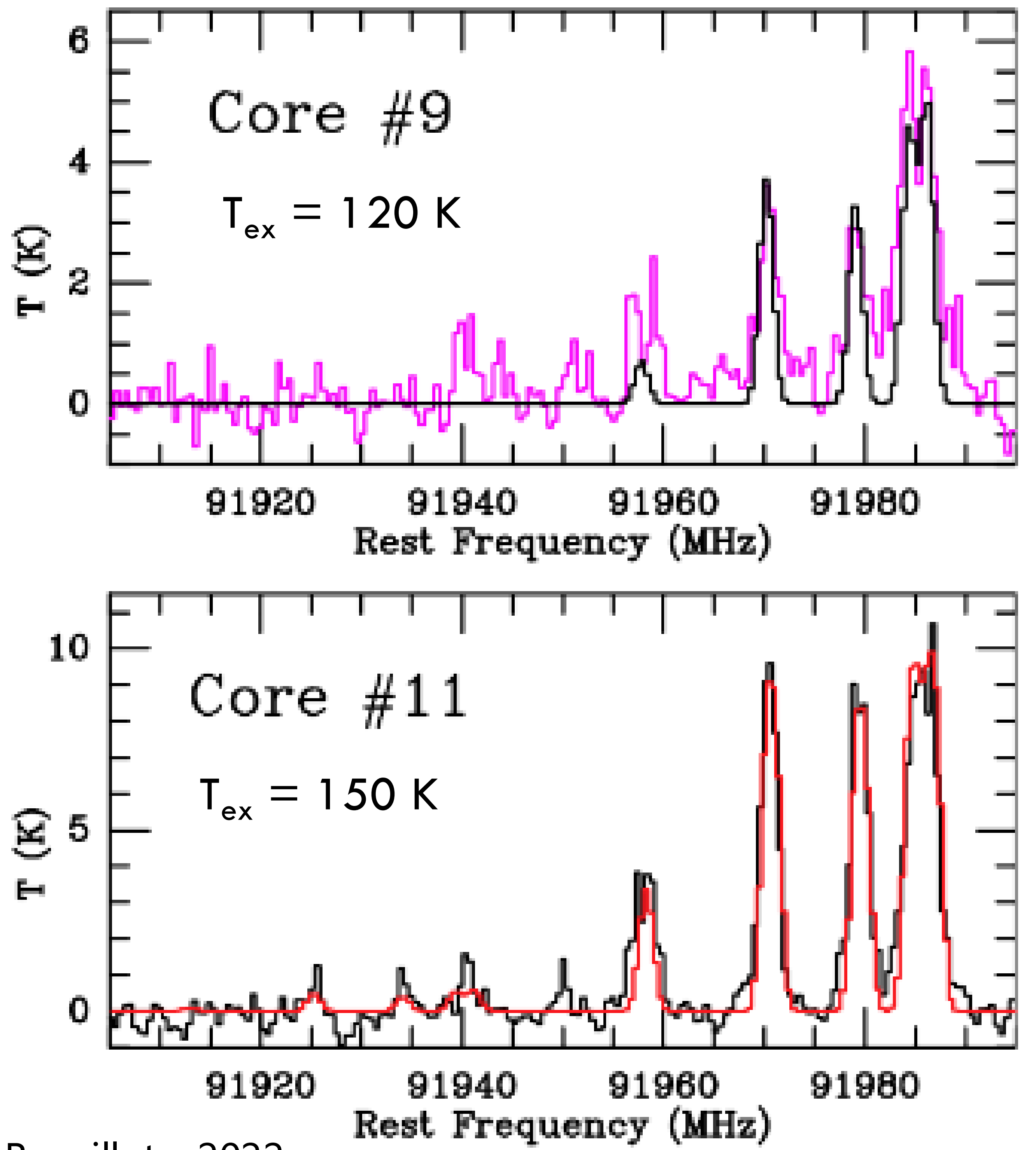




Reynolds+ 2021

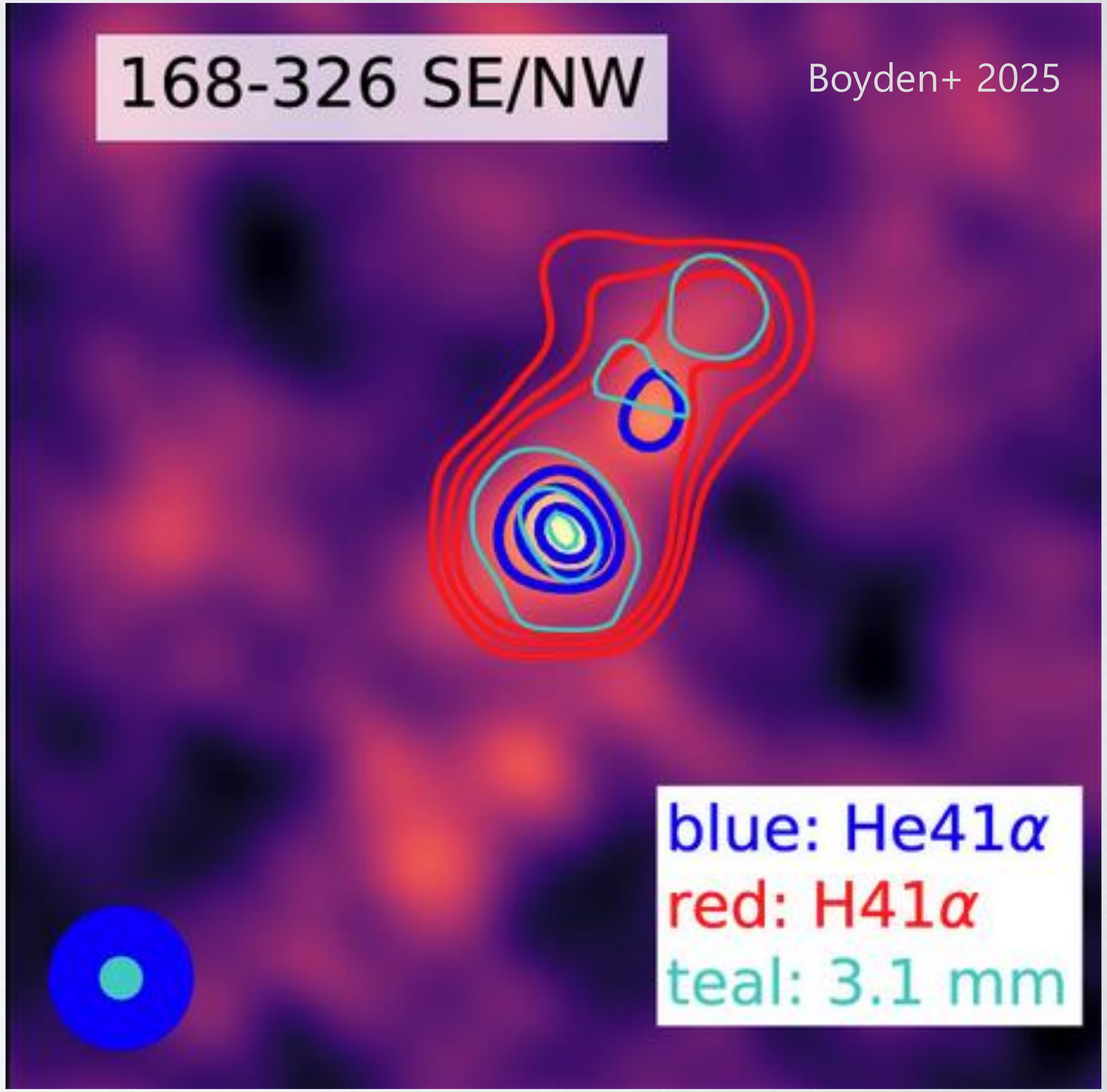
Spectral Line Data: Physical Conditions

Measuring gas temperature with CH_3CN



Brouillet+ 2022

Ionized gas with radio recombination lines



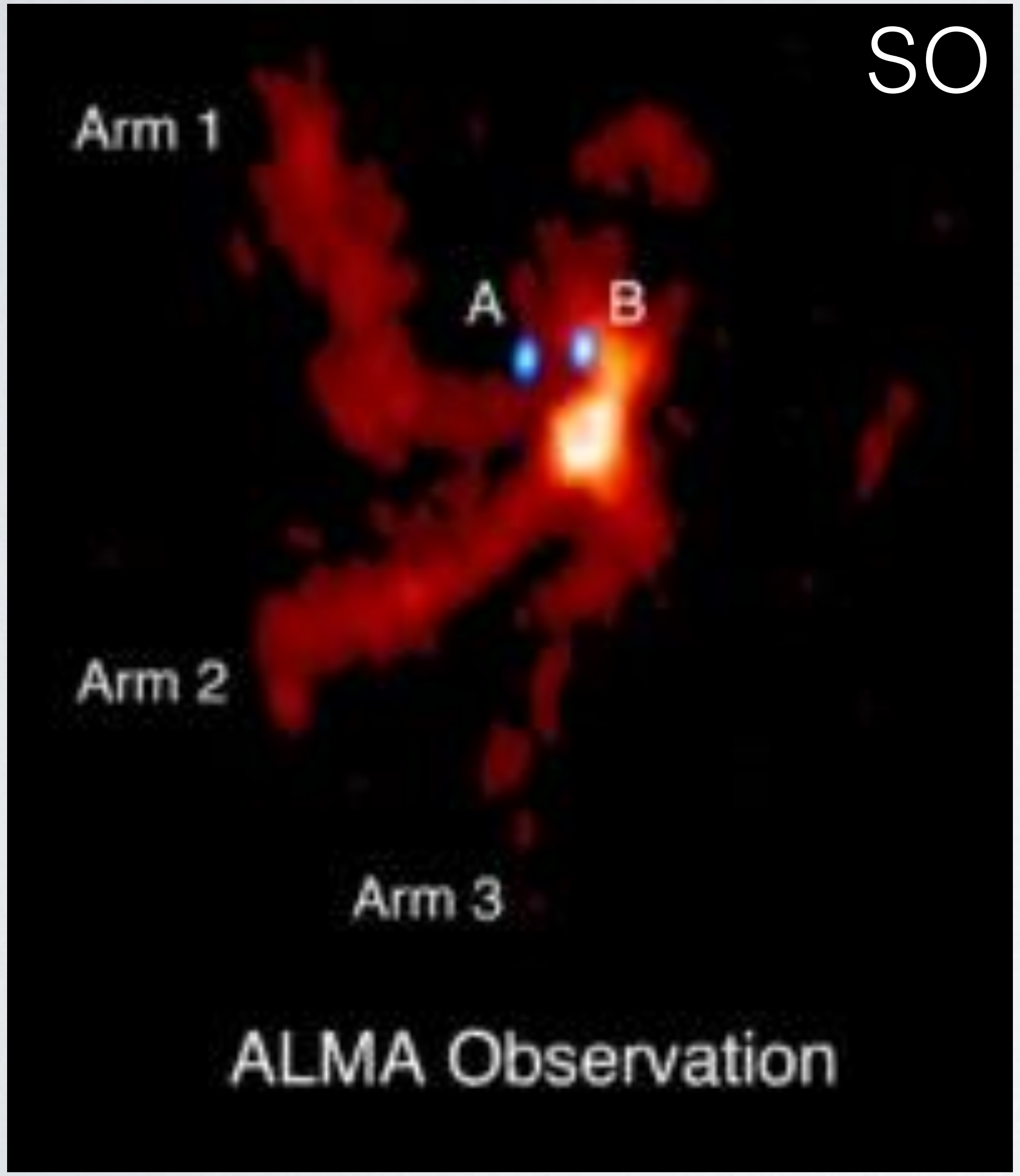
Open Key Question:

How do stars get their mass?

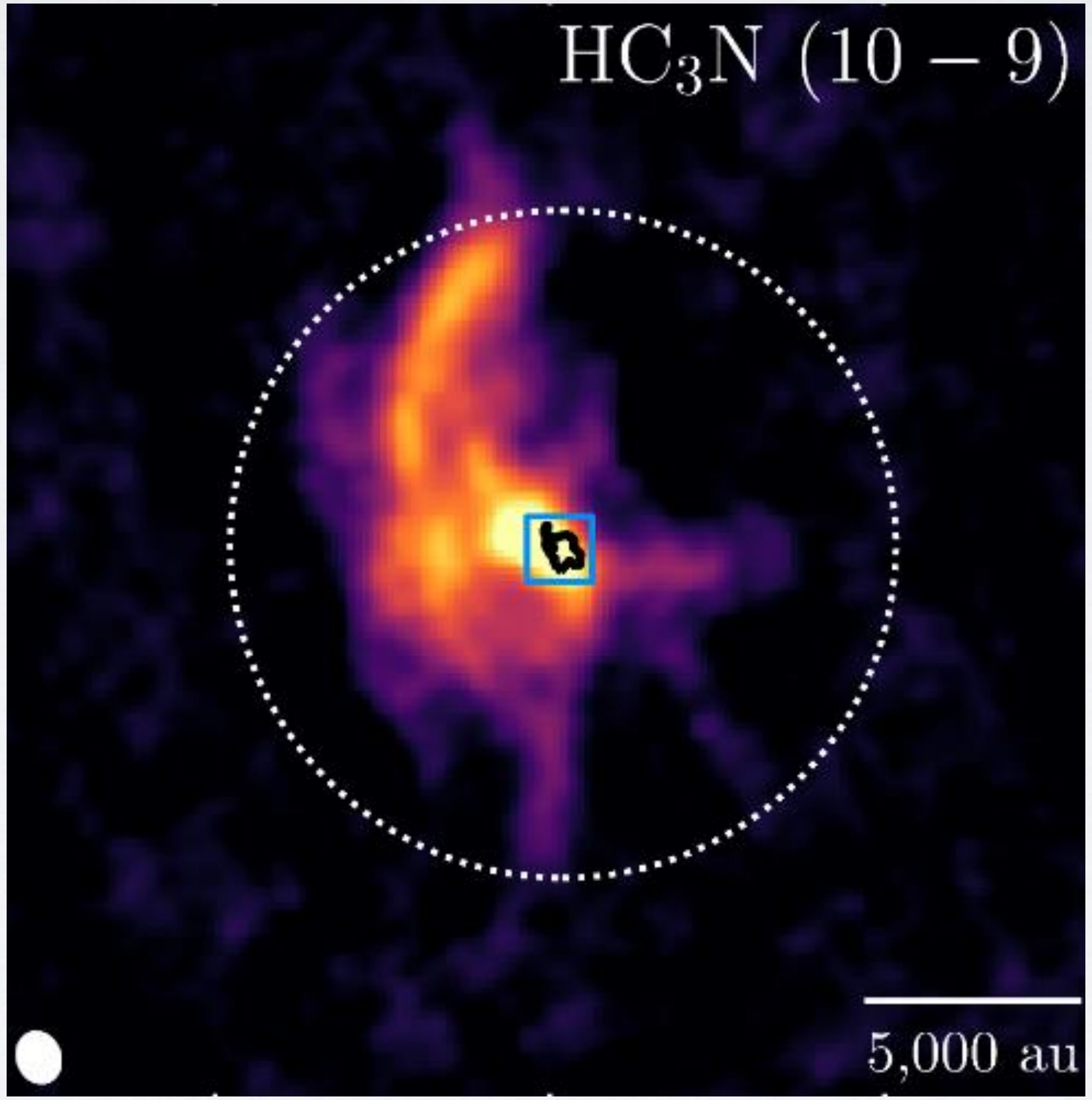
Velocity Streamers

Elongated gas features connected to protostars

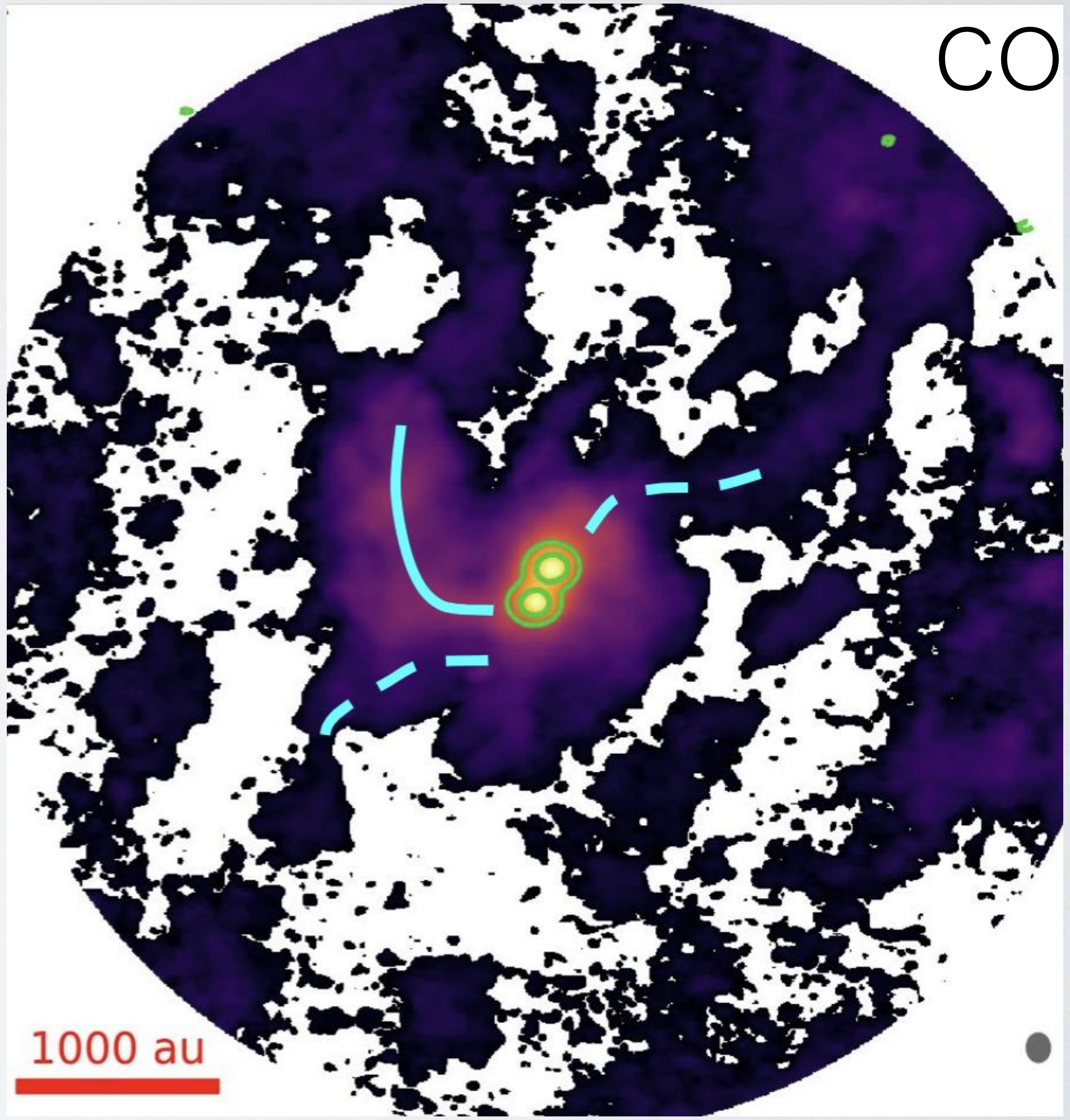
First detection of these features in last ~ 5 years with ALMA (mostly in gas)



ALMA (ESO/NAOJ/NRAO), J.-E. Lee et al. 2023



Pineda+ 2020



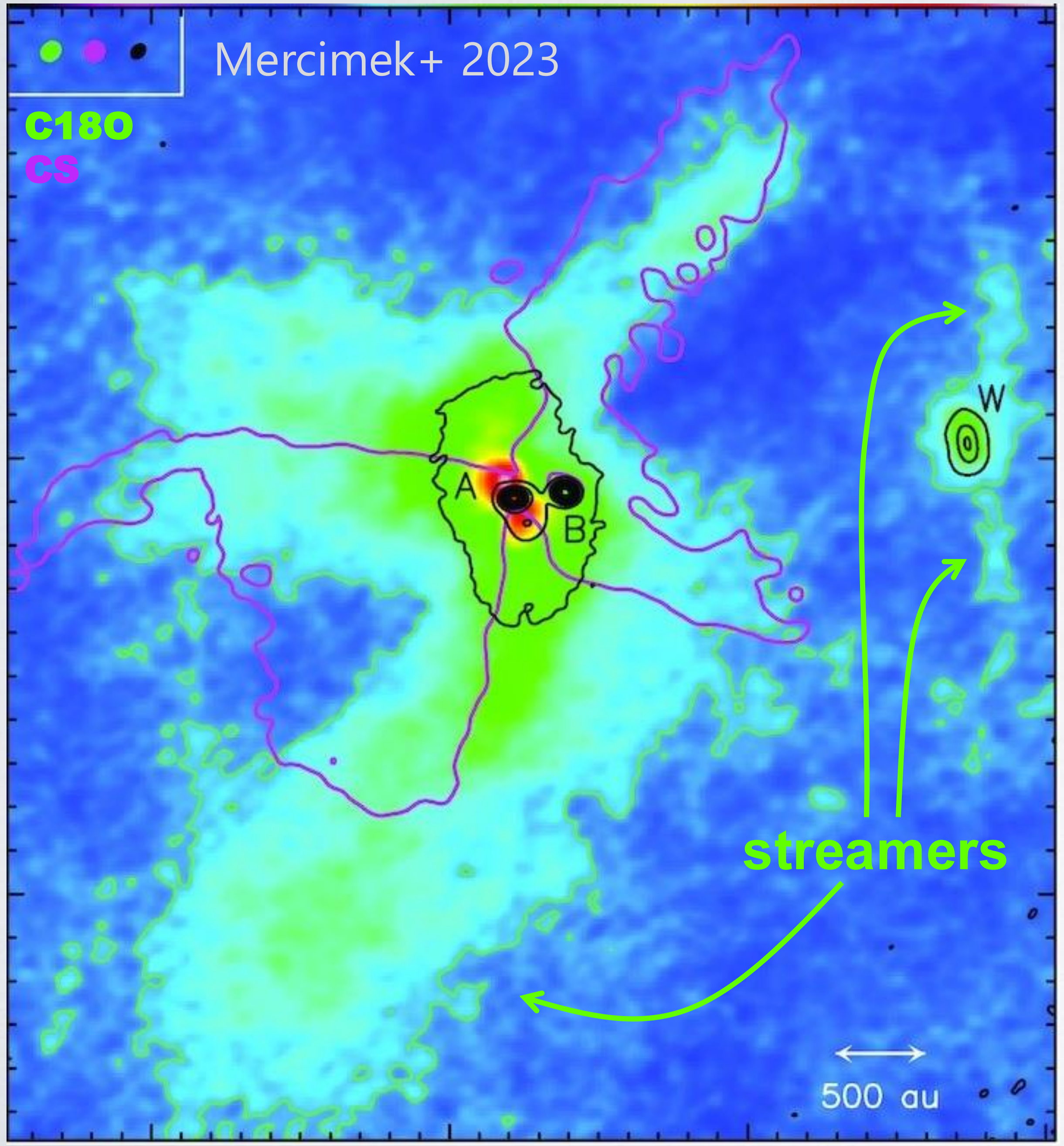
Gupta+ 2023

see also, Takakuwa+ 2017; Dong+ 2022; Valdivia-Mena+ 2022, 2024; Cacciapuoti+ 2023; Sadavoy+ 2024; Codella+ 2024; Kido+ 2025

Velocity Streamers

Elongated gas features connected to protostars

Could be dynamical interactions between stars



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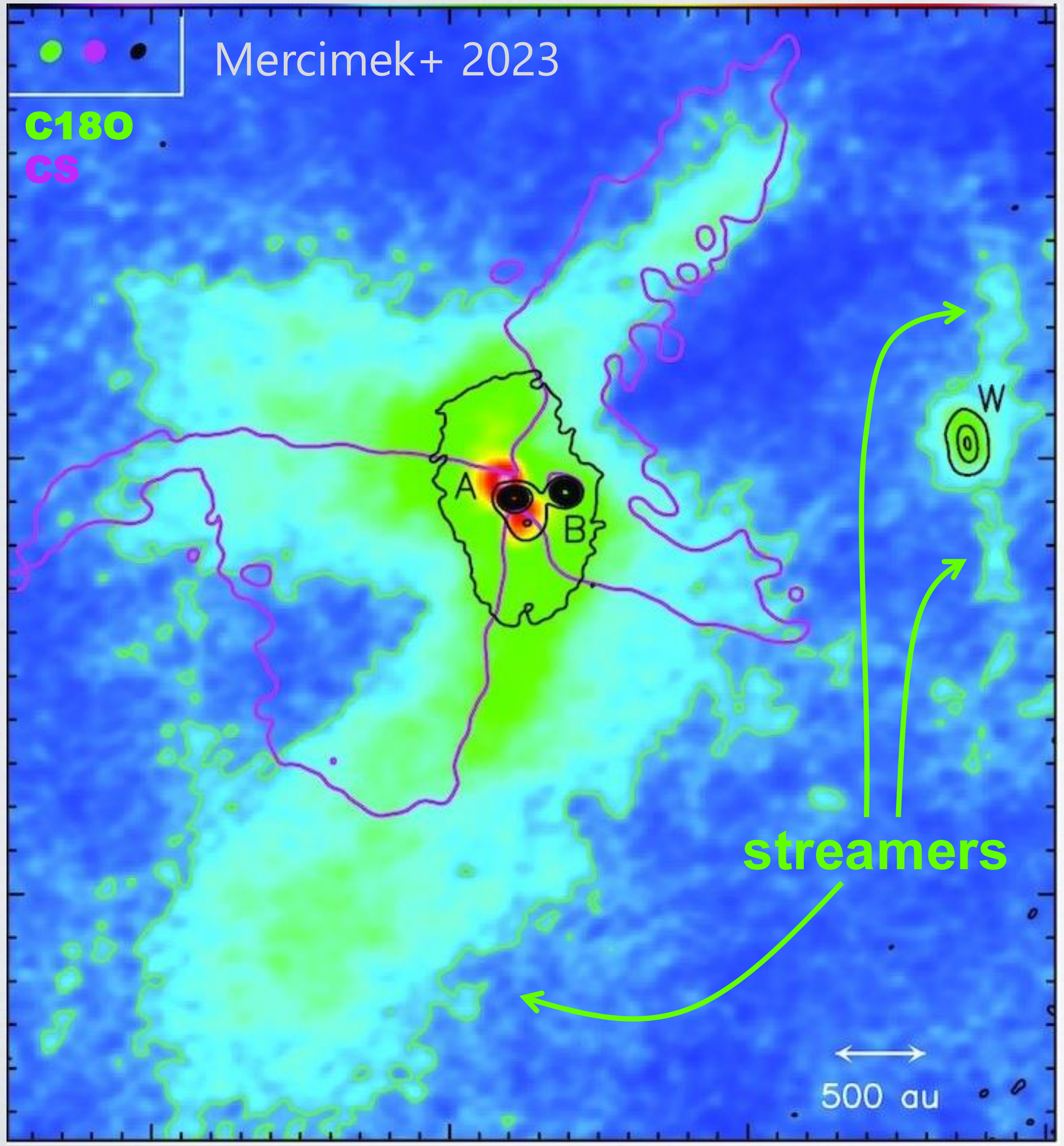
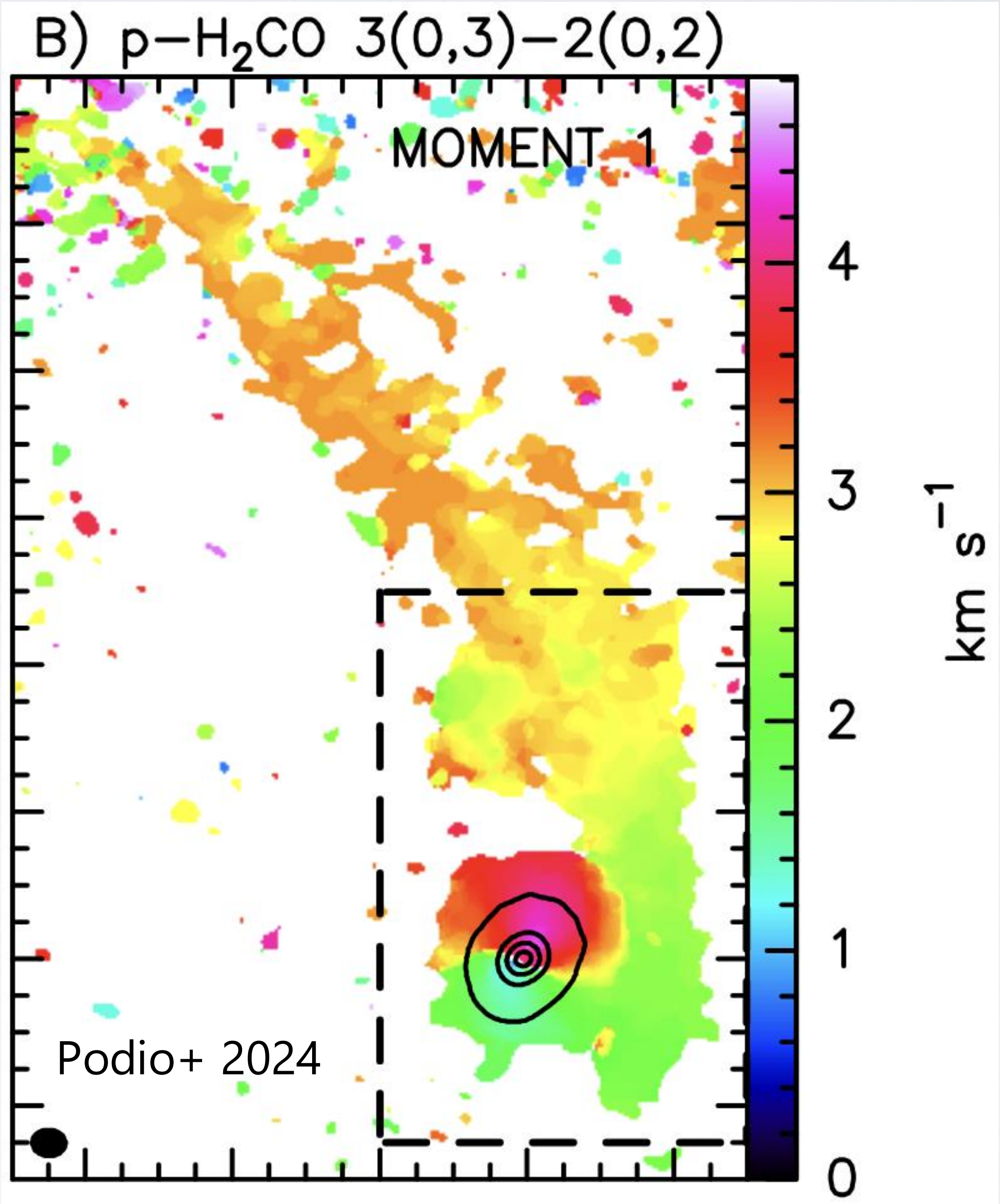


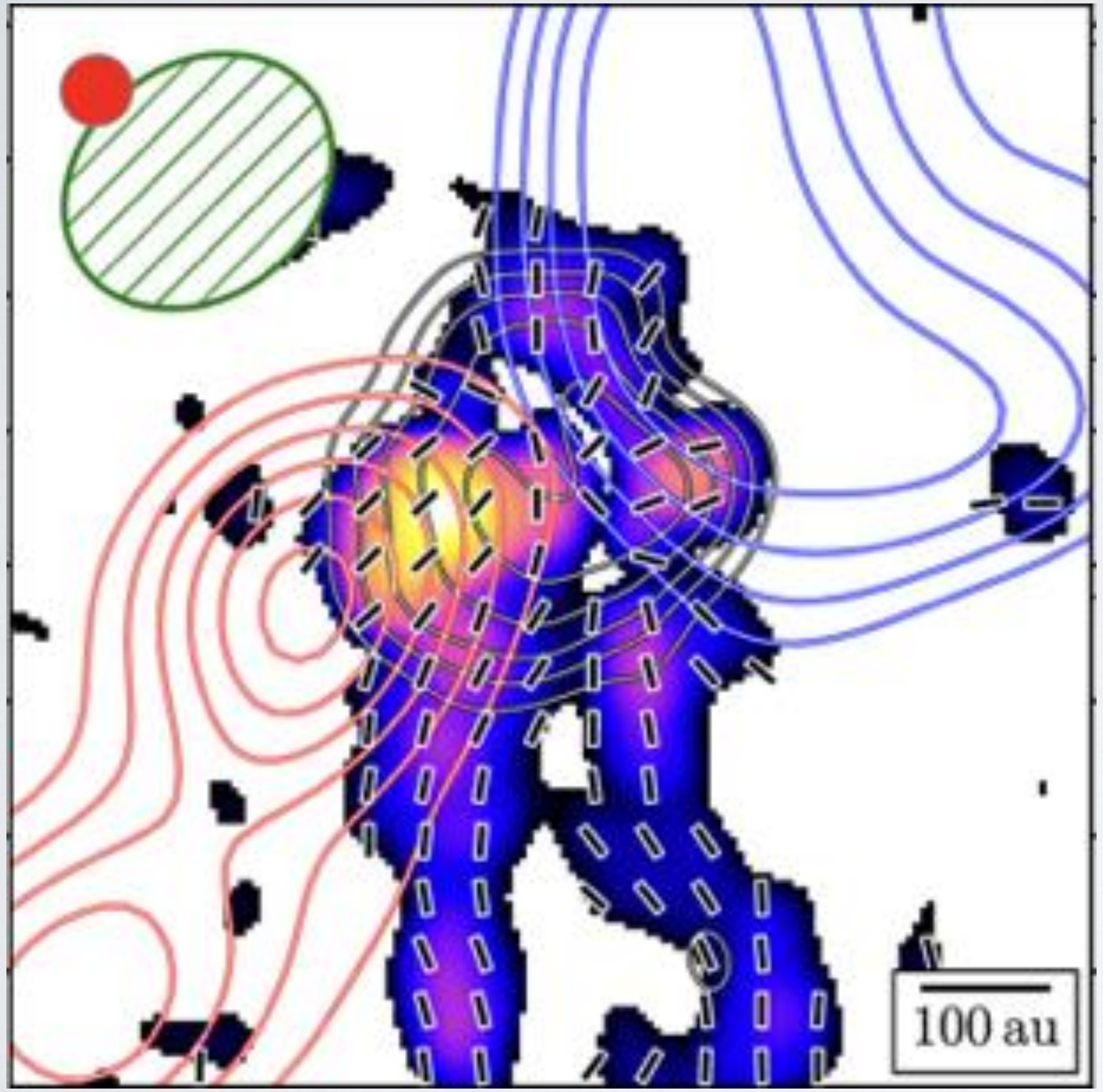
Could be accretion streamers onto young stars



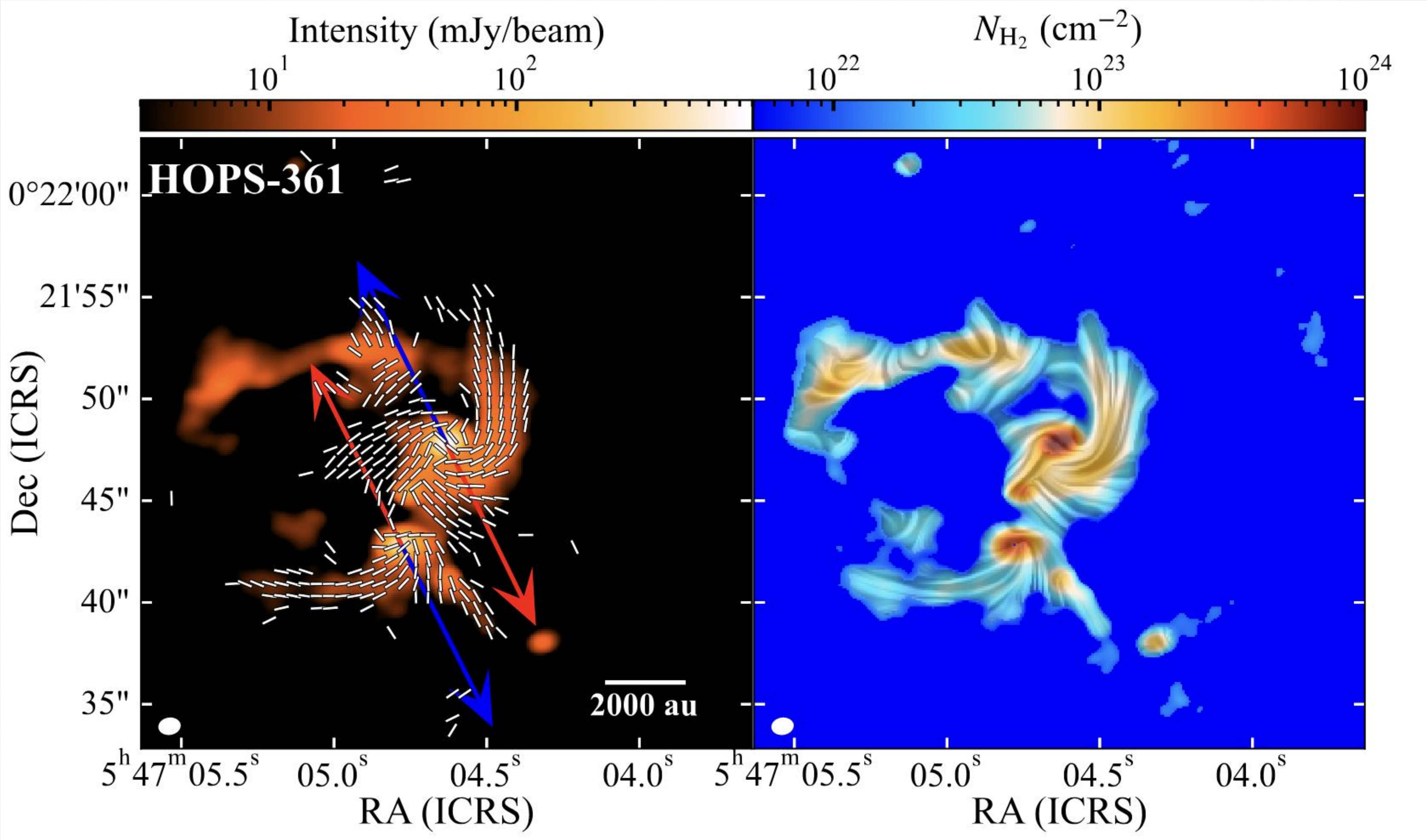
see also, Takakuwa+ 2017; Dong+ 2022; Valdivia-Mena+ 2022, 2024; Cacciapuoti+ 2023; Sadavoy+ 2024; Codella+ 2024; Kido+ 2025

Velocity Streamers

Magnetic fields aligned with velocity streamers → channel for gas to flow



Le Gouellec+ 2019



Cai+ 2026

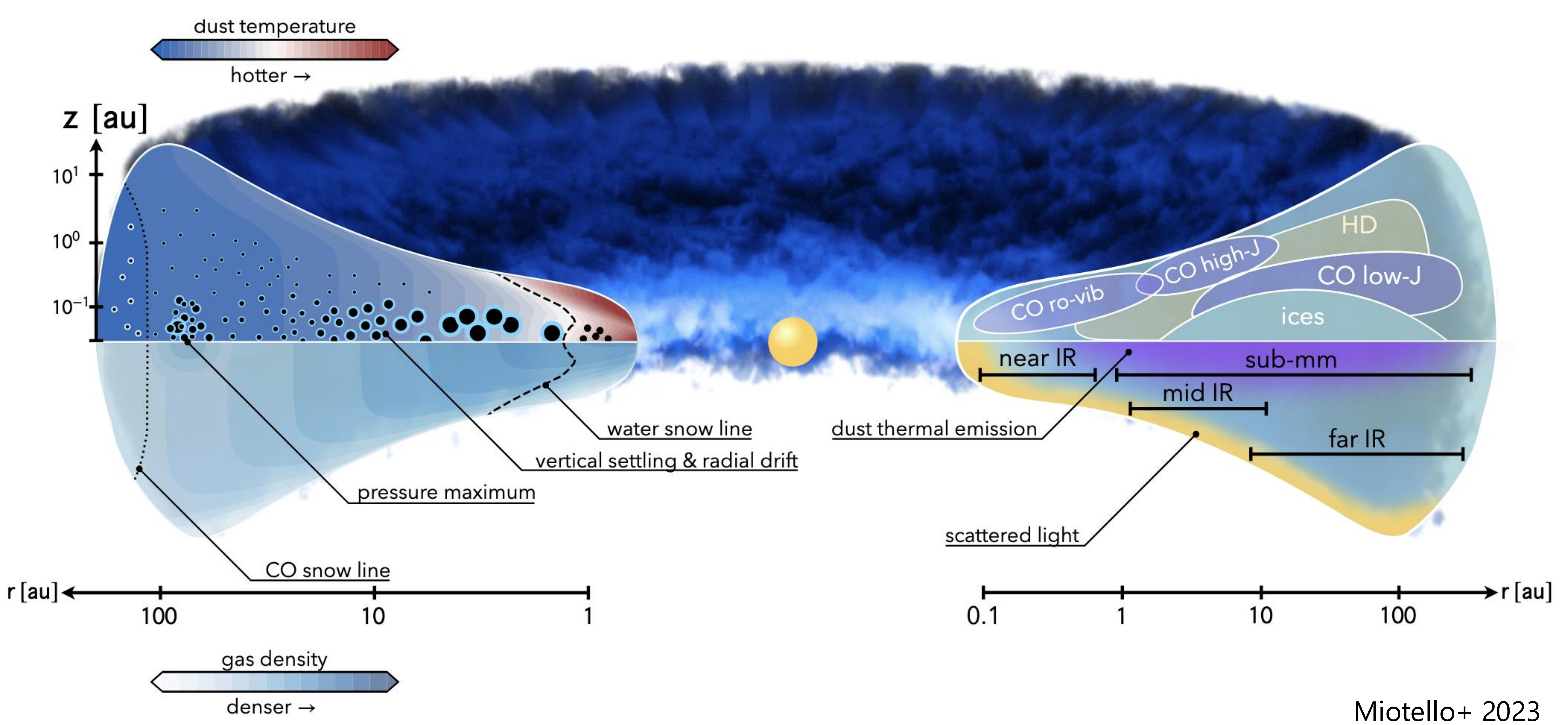
see also, Gómez+ 2018; Sadavoy+ 2018; Takahashi+ 2019; Huang+ 2025; Cortes+ 2025

The Physical Properties of Dynamics of Disks

The Physical Properties of Dynamics of Disks

Disks are complex: rotating, evolving 3D structures with density and temperature gradients

→ different tracers will probe different layers or different radii



Miotello+ 2023

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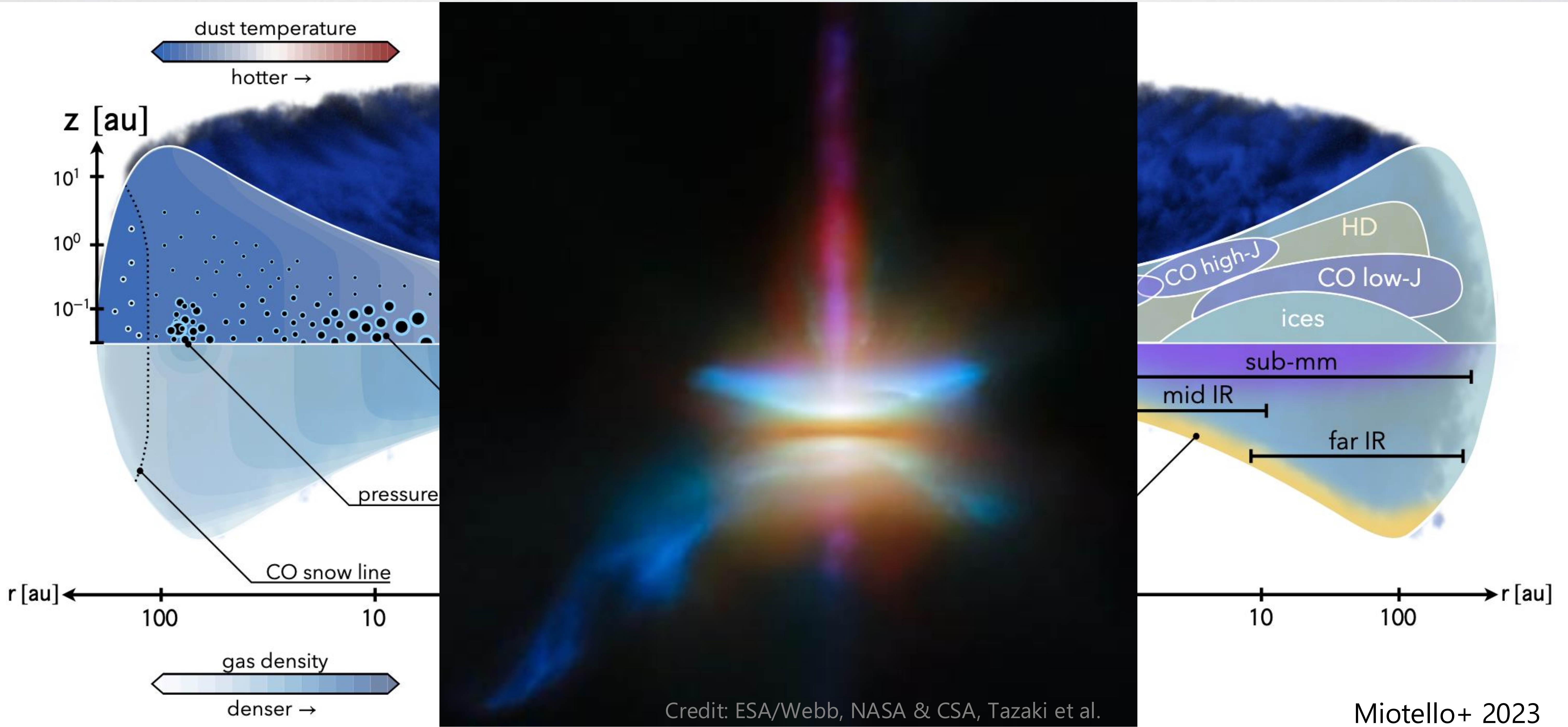
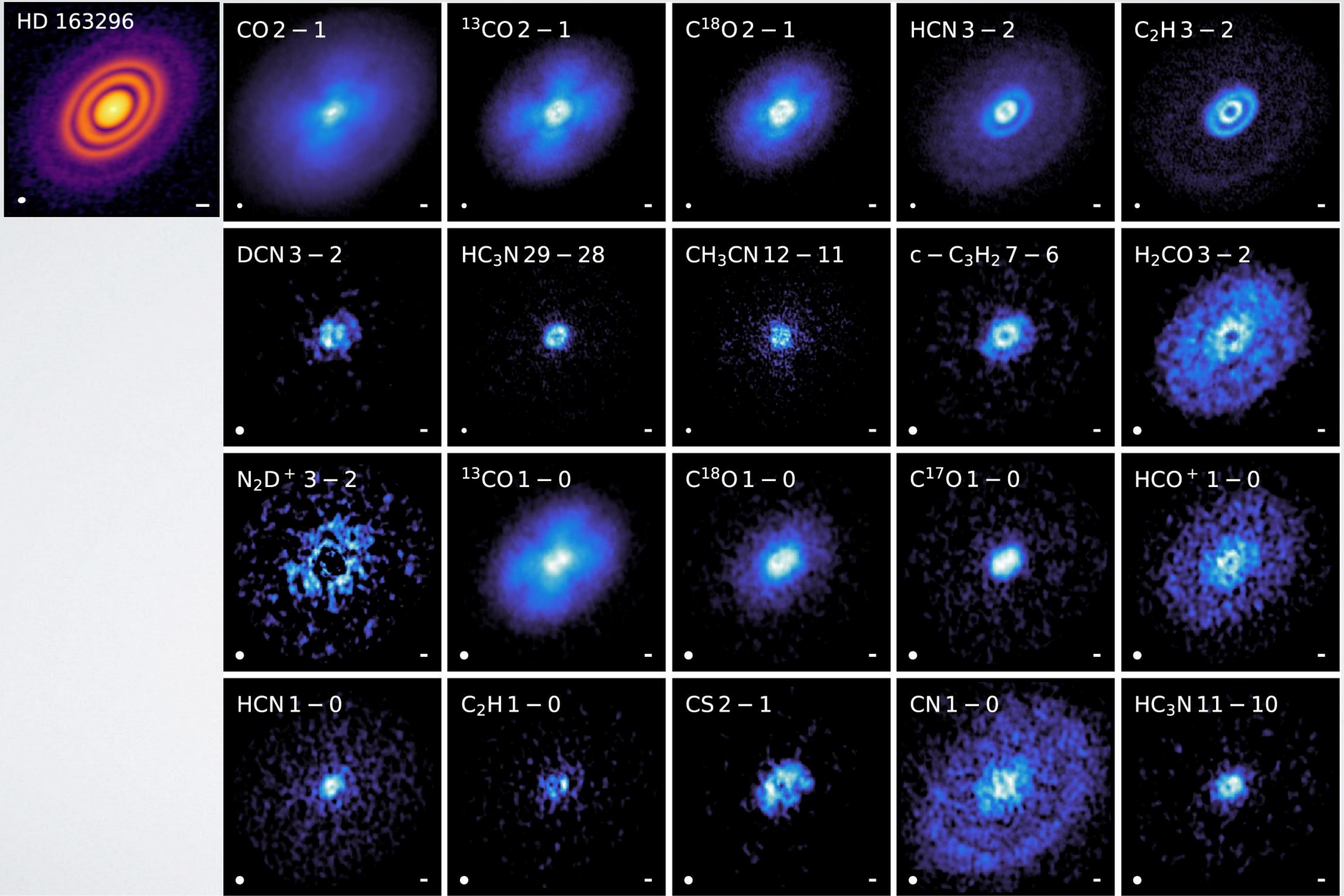


Credit: ESA/Webb, NASA & CSA, Tazaki et al.

Miotello+ 2023

The Physical Properties of Dynamics of Disks

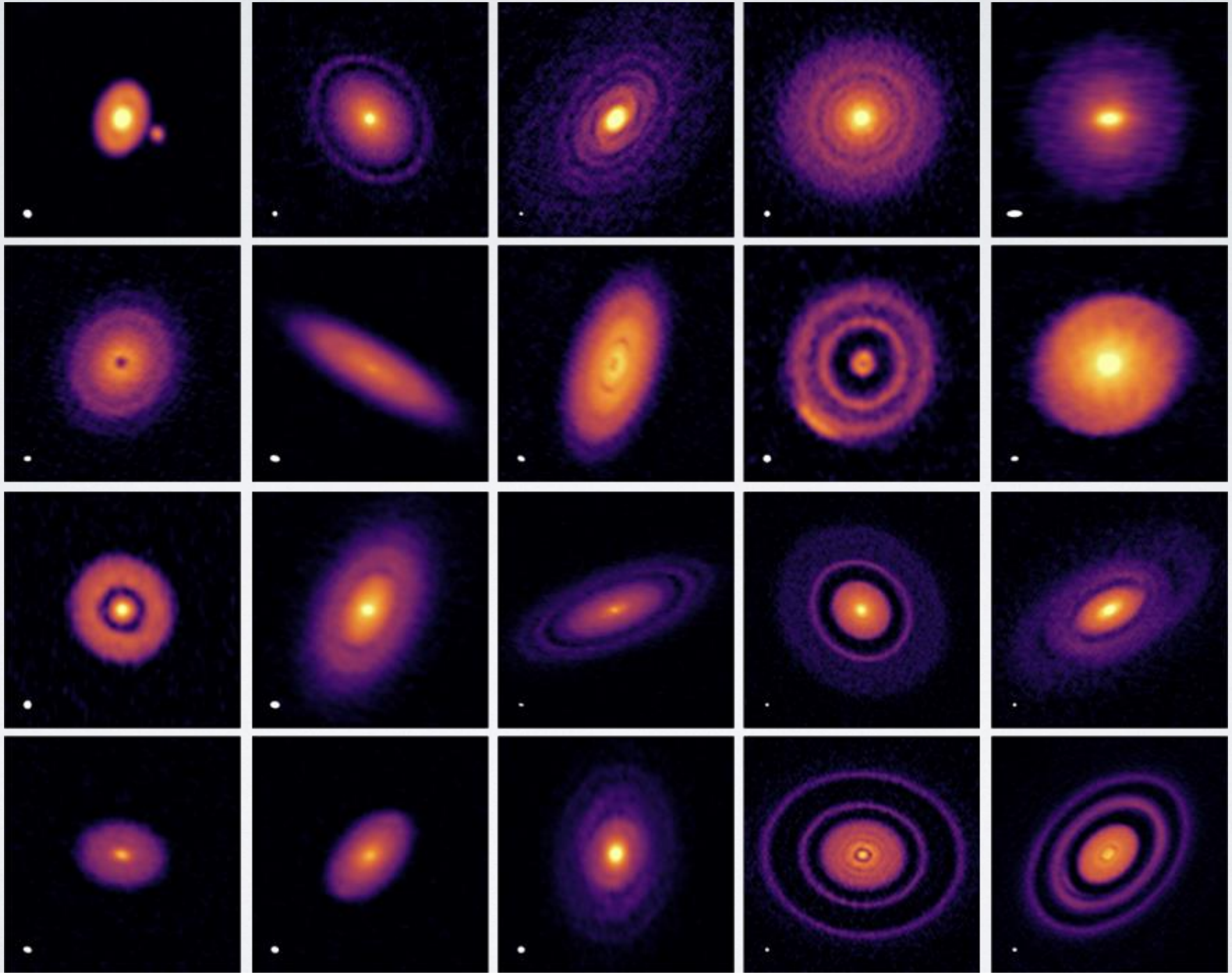


Öberg+ 2021

Open Key Question:

How and when do planets form?

Disk Structure and Planet Formation: Are they connected?

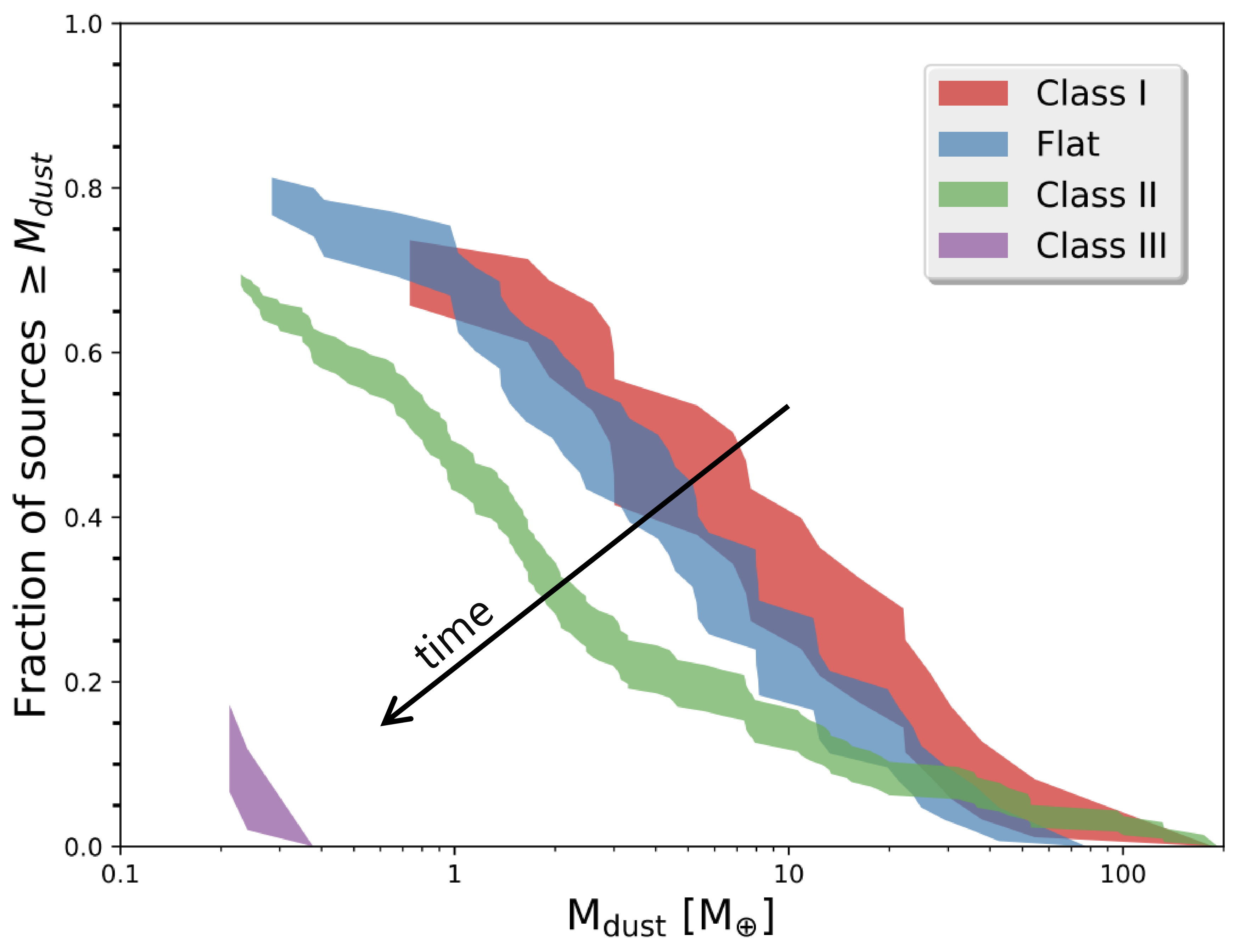


Credit: ALMA/ S. Andrews/ N. Lira / DSHARP team

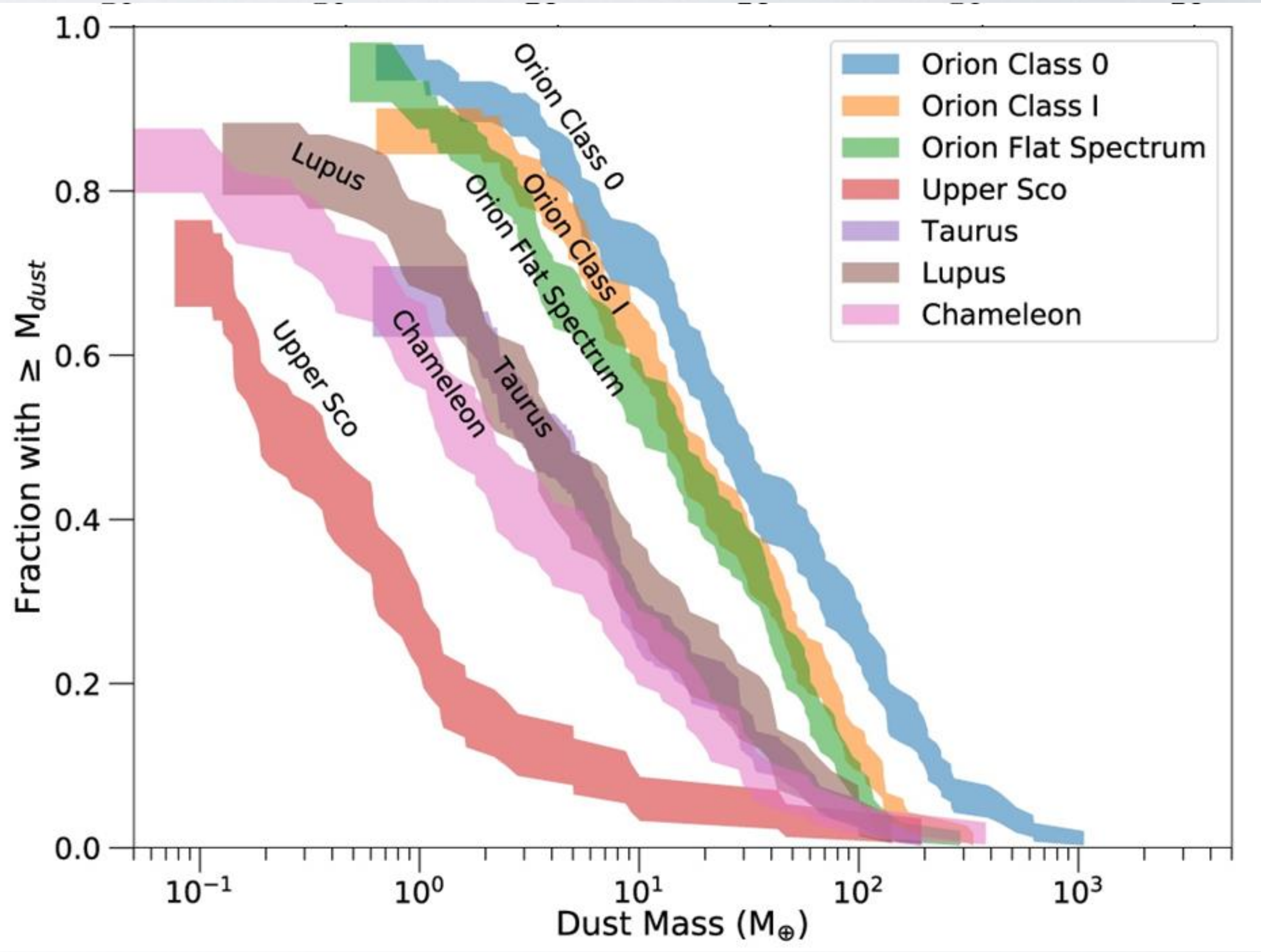
Planet-forming Disks: Disk Mass

Disk masses tend to decrease with time (younger disks have more mass than older disks)

→ when planets form has impact on what masses they can have



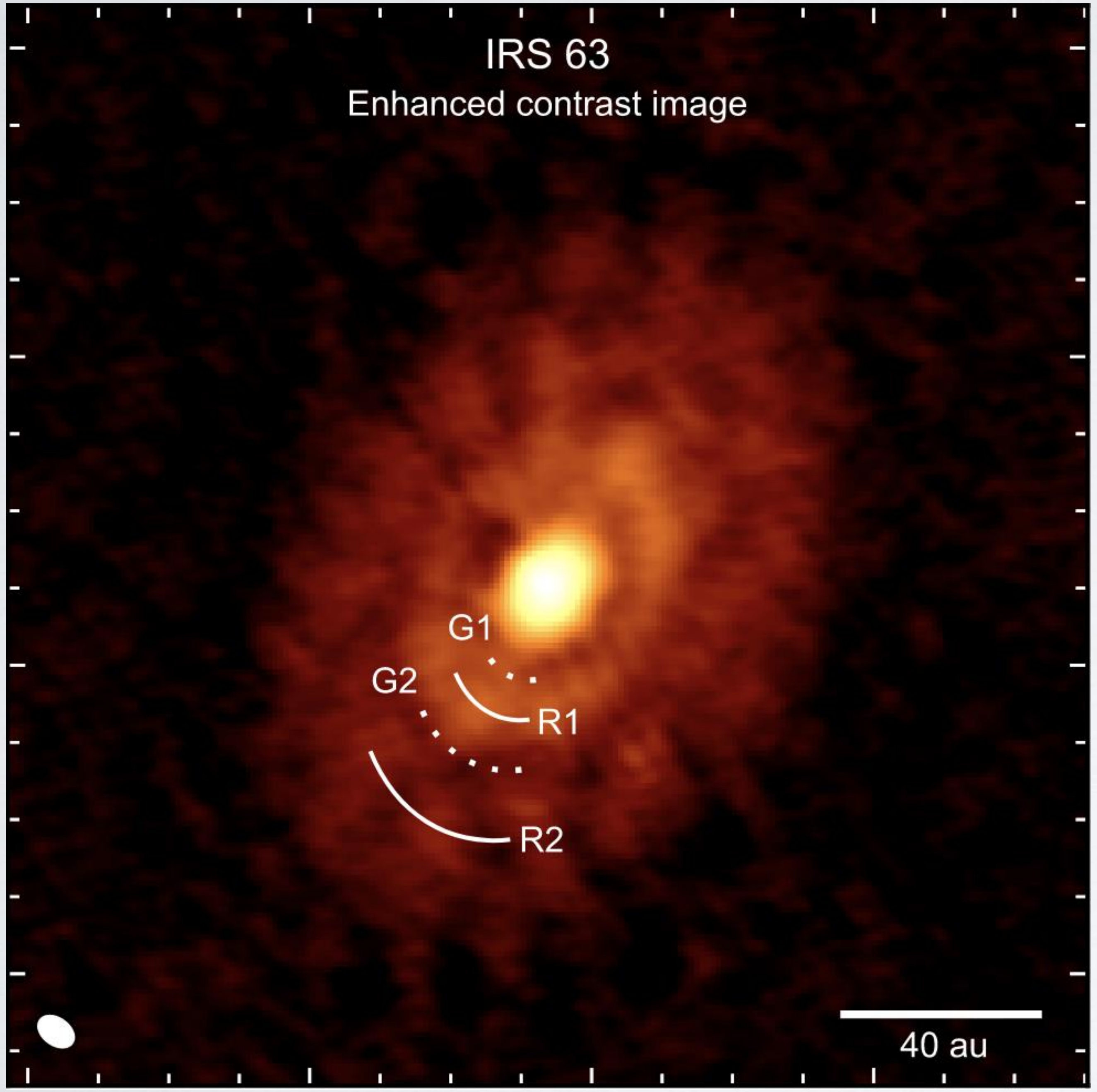
Williams+ 2019



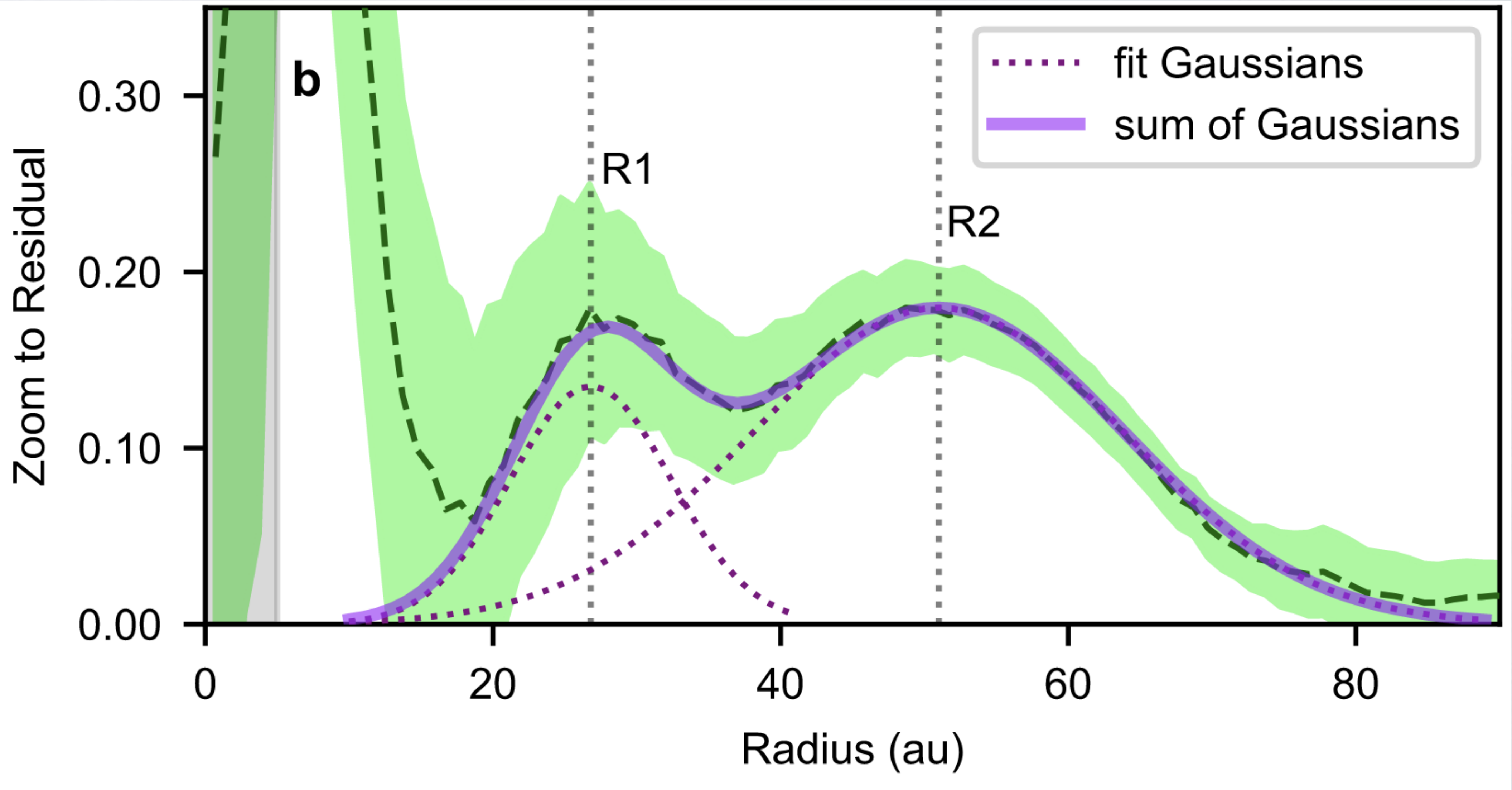
Tobin+ 2020

Gaps in Young Disks

Structure detections in younger, more massive protostellar disks → onset of planet formation?



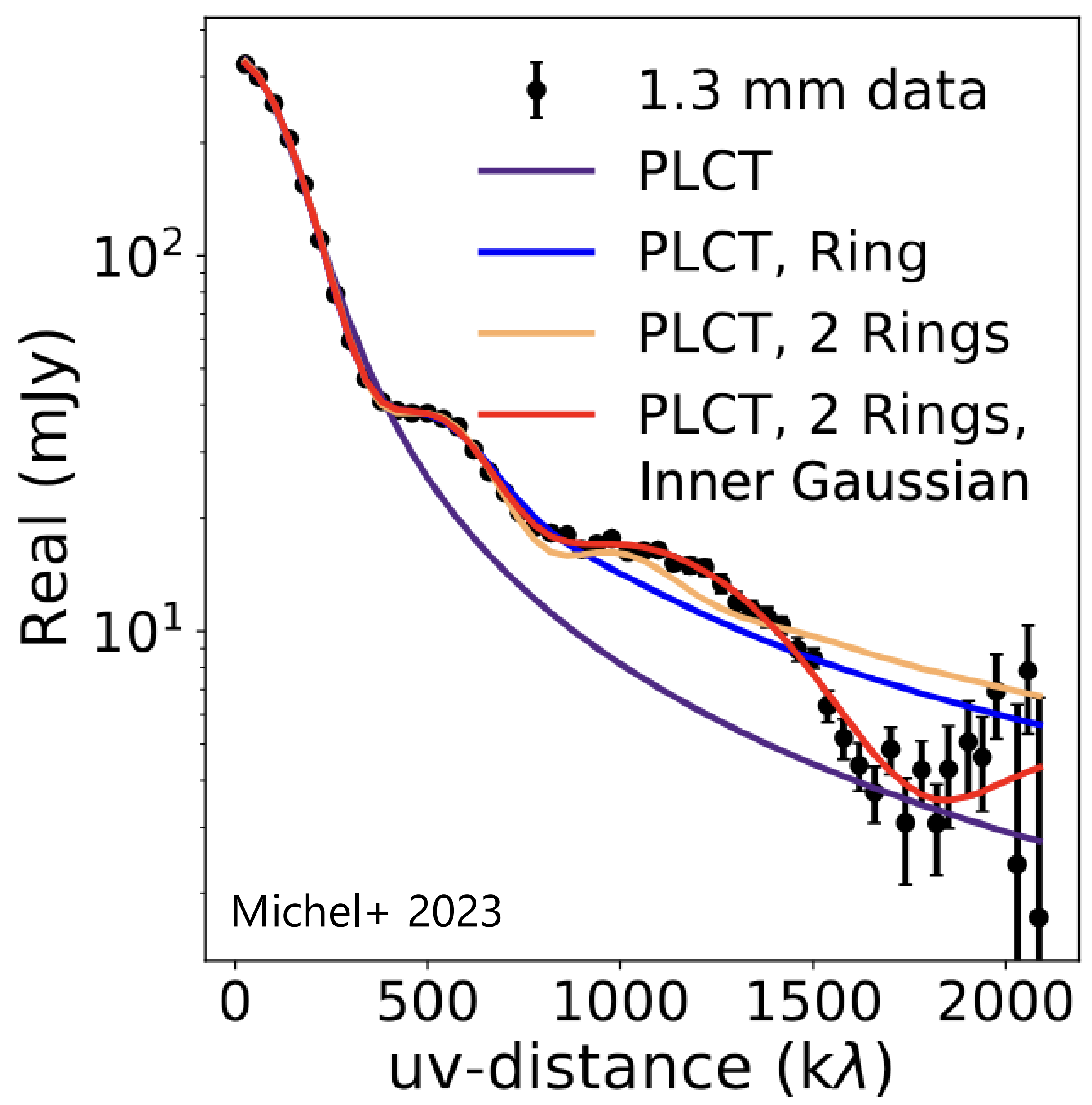
Segura-Cox+ 2020

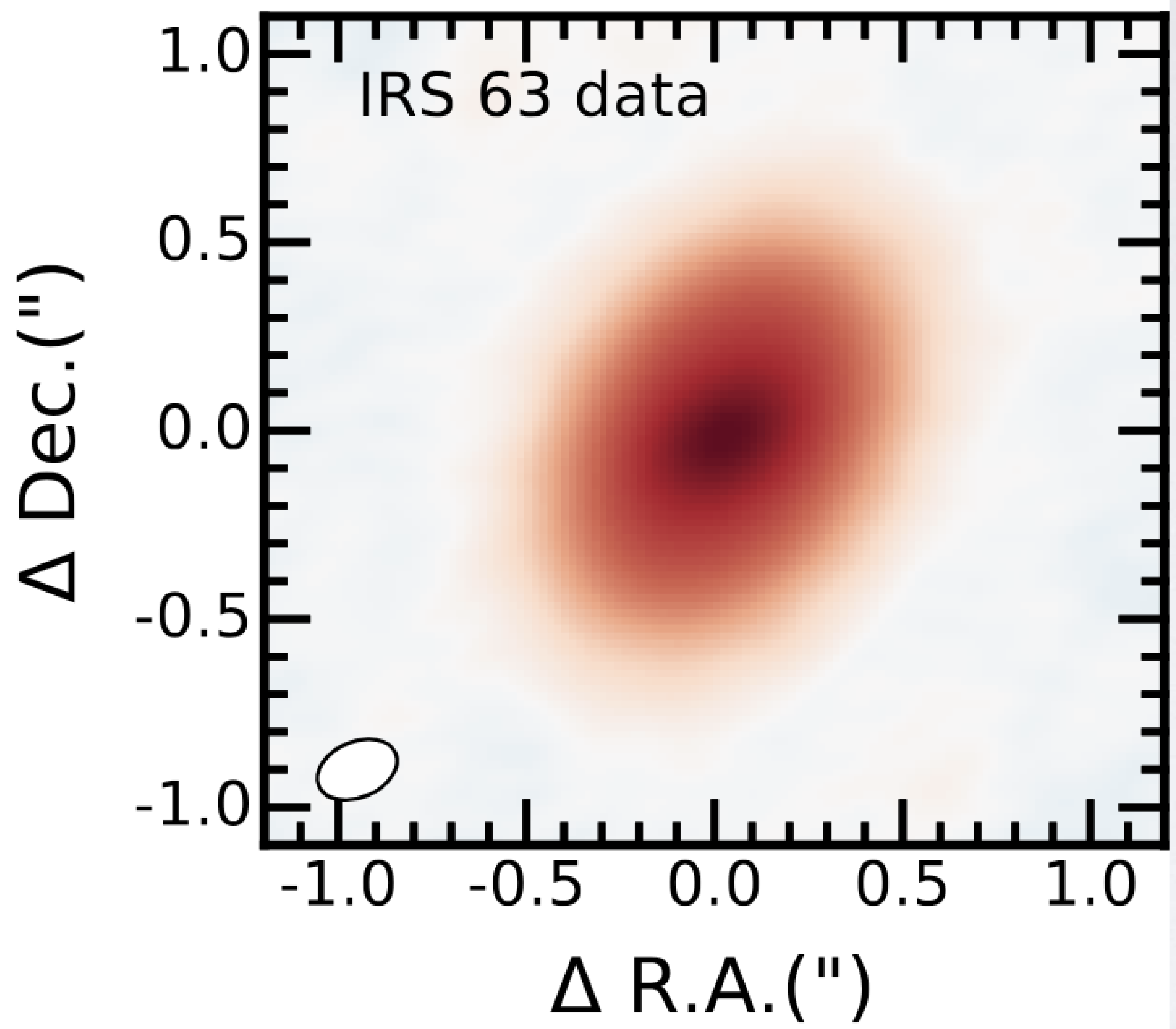


see also, Sheehan+ 20222; Michel+ 2023; Sai+ 2023; Ohashi+ 2023; Hsieh+ 2025; Vioque+ 2025

Gaps in Young Disks

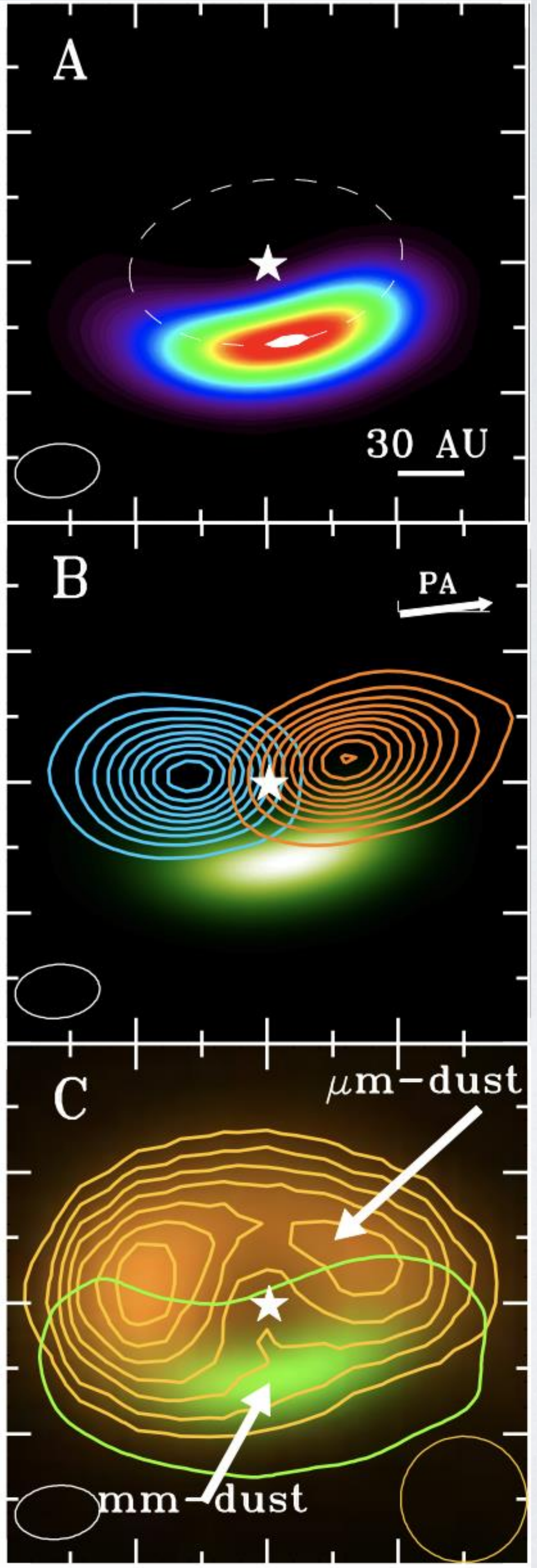
With interferometry, we can use visibilities rather than images to detect structure!





see also, Segura-Cox+ 2020; Sheehan+ 2022; Sai+ 2023; Ohashi+ 2023; Hsieh+ 2025; Vioque+ 2025

To Make Planets, Dust Grains Must Grow



van der Marel+ 2013

Multi-wavelength observations show pressure traps where dust can grow

→ gaps can also serve as pressure traps

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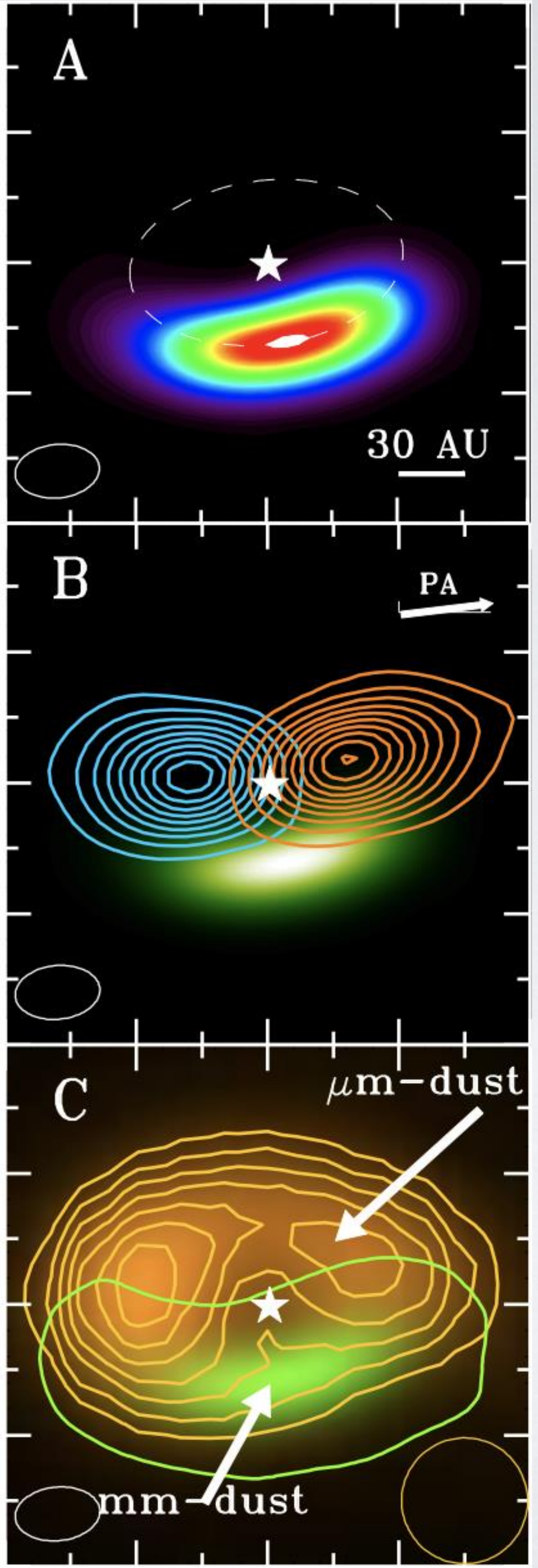

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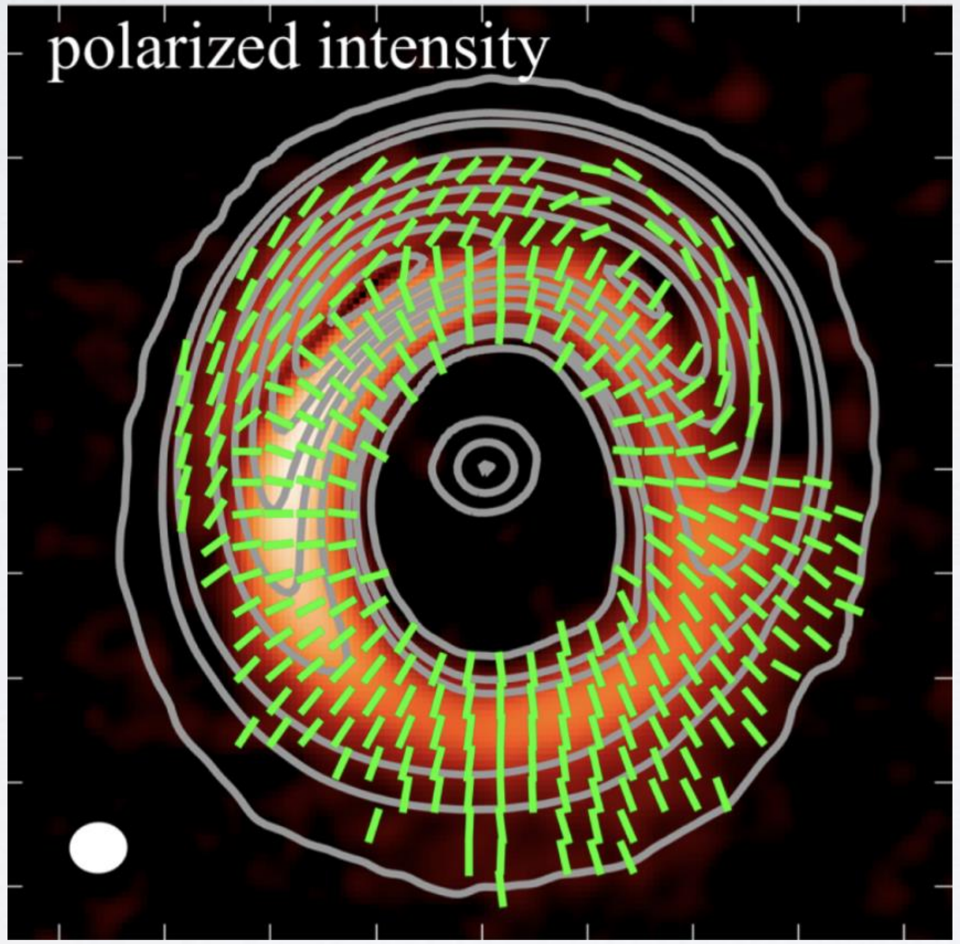
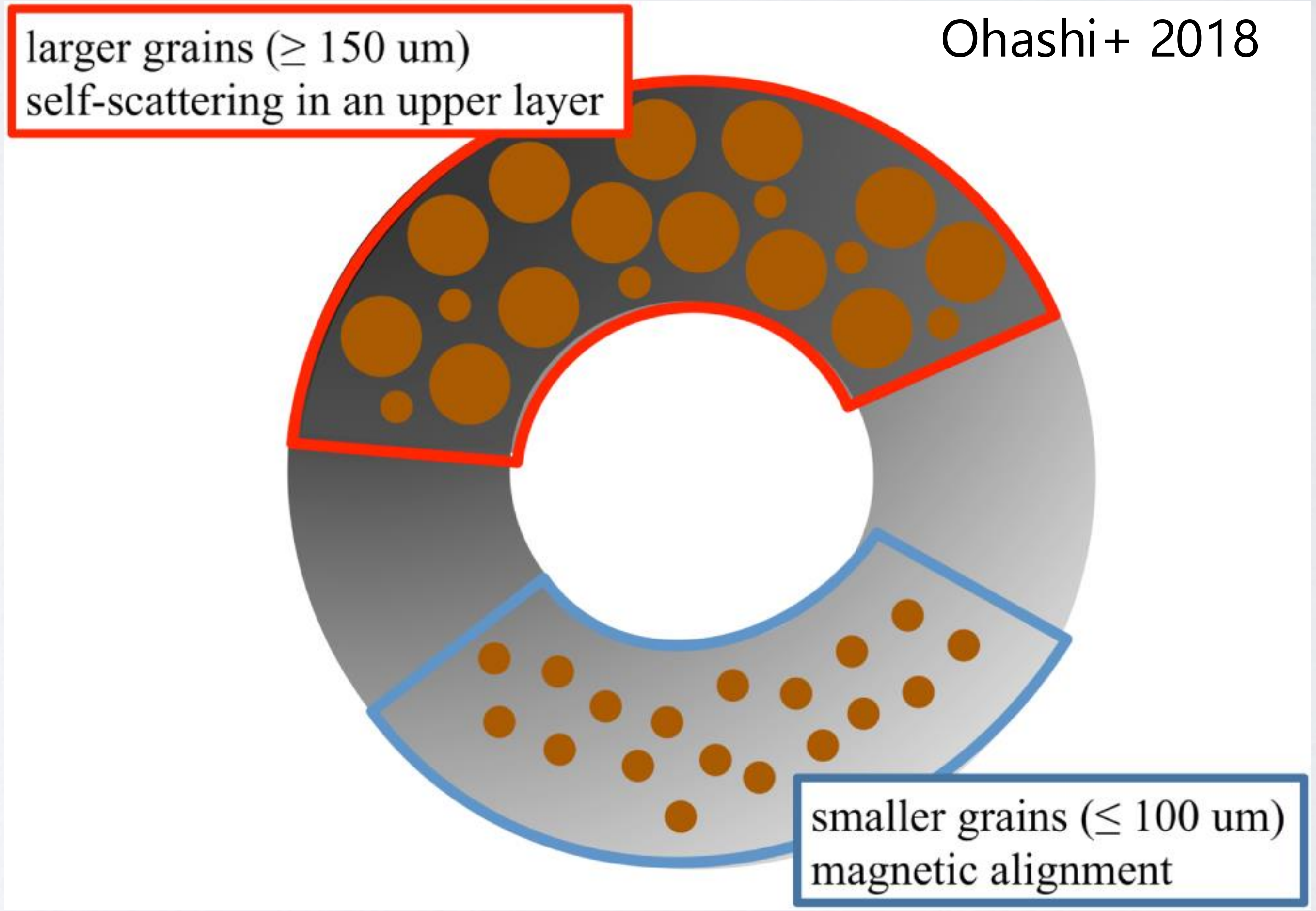




Ohashi+ 2018

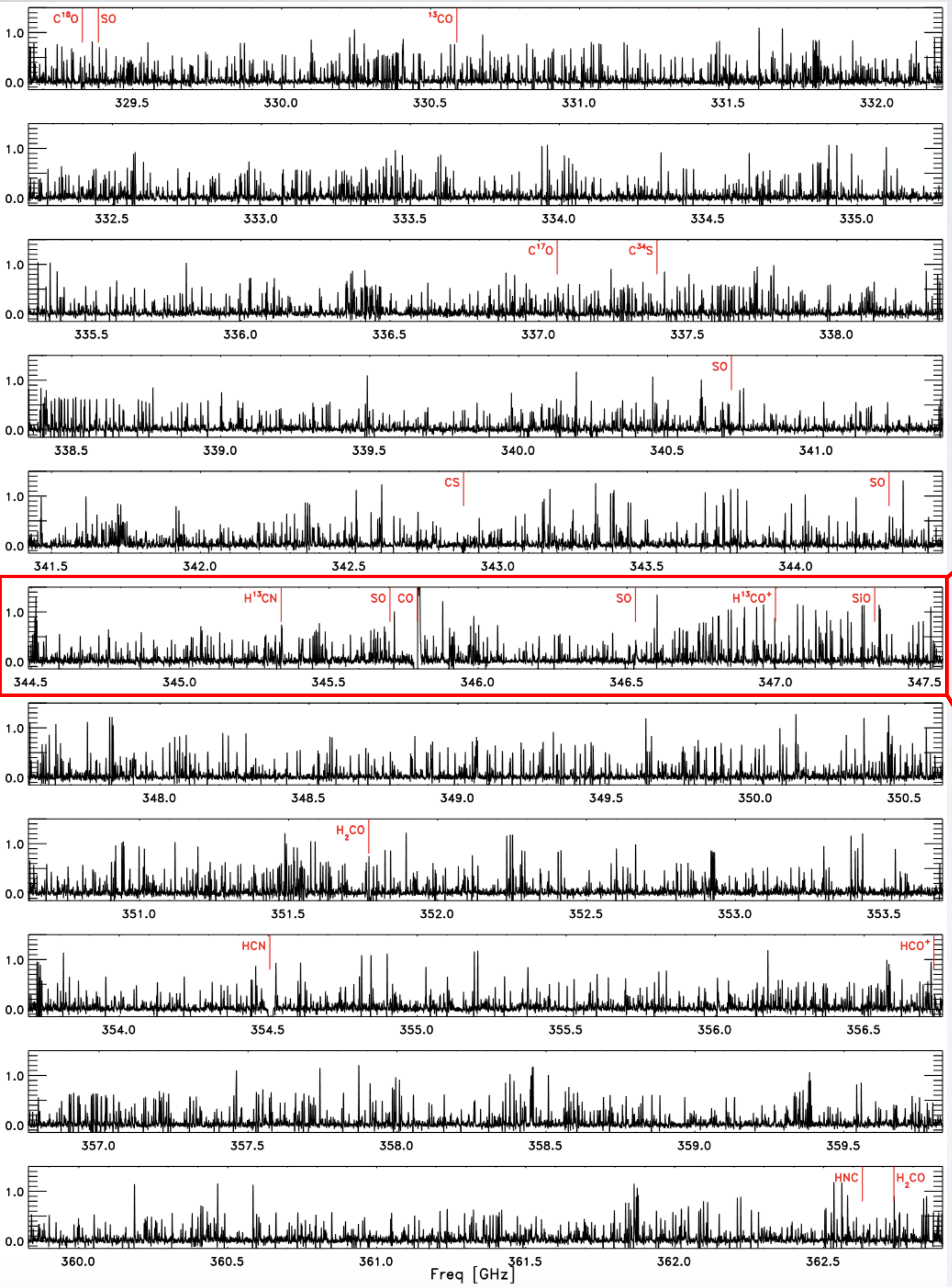
Dust polarization is a relatively new method to constrain dust grain sizes

see also, Kataoka+ 2015, 2016; Yang+ 2017; Stephens+ 2017; Lin+ 2021, 2024; Zhang+ 2023

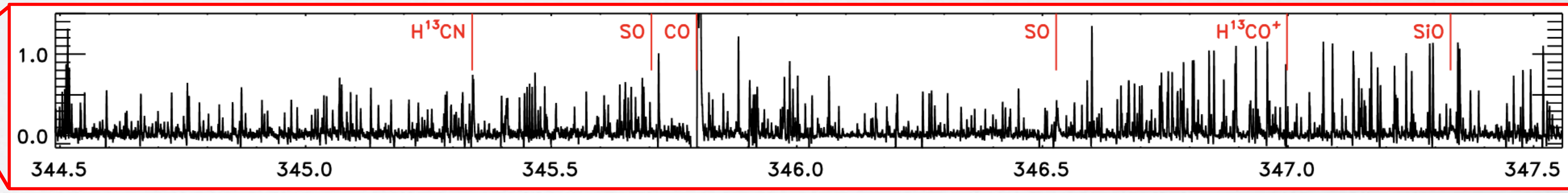
Some Future Prospects…

Astrochemistry

Studying the chemical make-up of protostars and pathways to life



Current capabilities have limited spectral bandpass

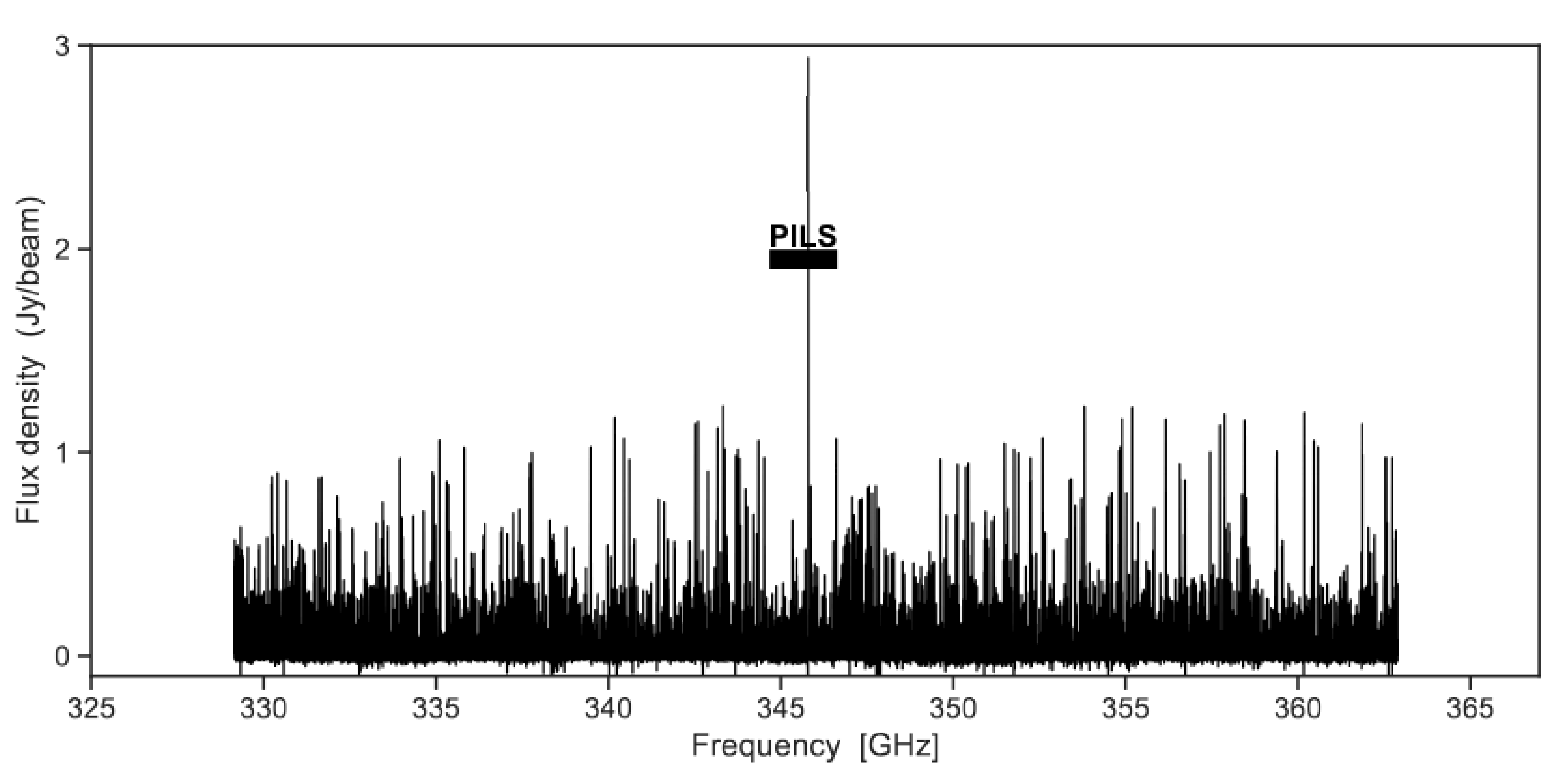


Jørgensen et al. 2016

ALMA: Wide-band Upgrades

Efficient unbiased surveys and more serendipitous line detections

Current Band 7 coverage with ALMA: required 18 settings

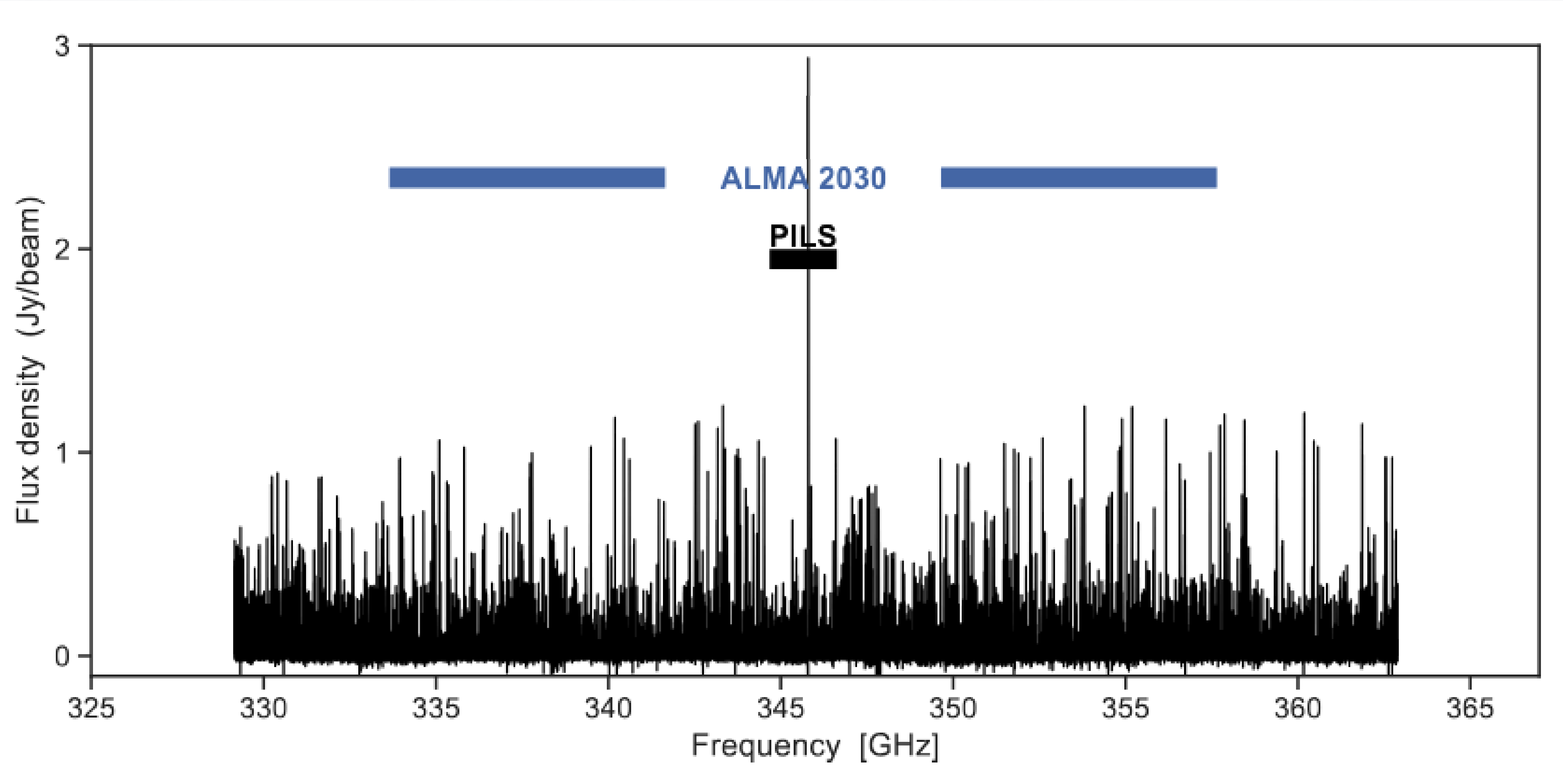


Carpenter et al. 2022 (ALMA Memo 621)

ALMA: Wide-band Upgrades

Efficient unbiased surveys and more serendipitous line detections

Future upgrades would cover 16 GHz in only a few settings



Carpenter et al. 2022 (ALMA Memo 621)

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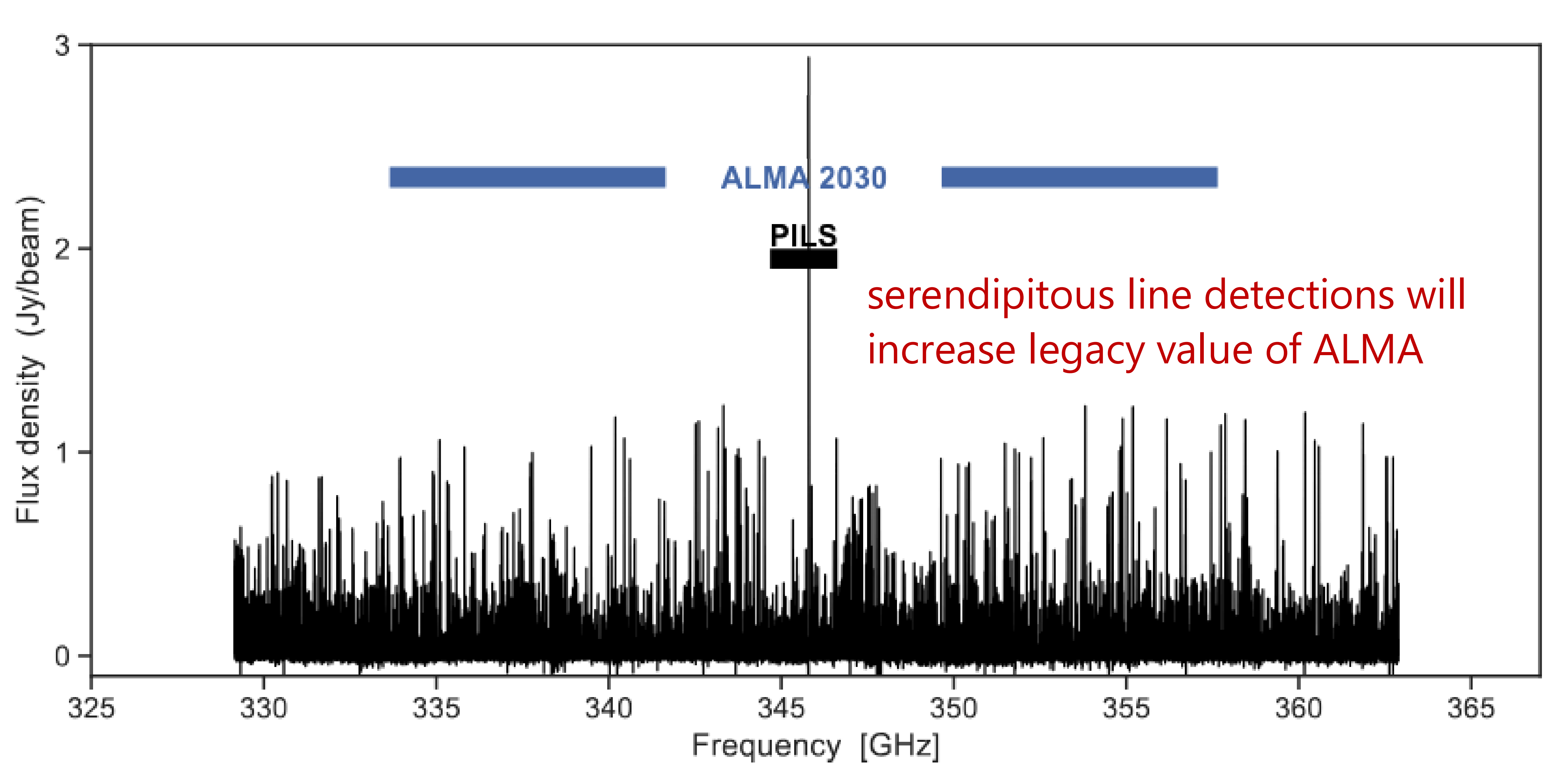
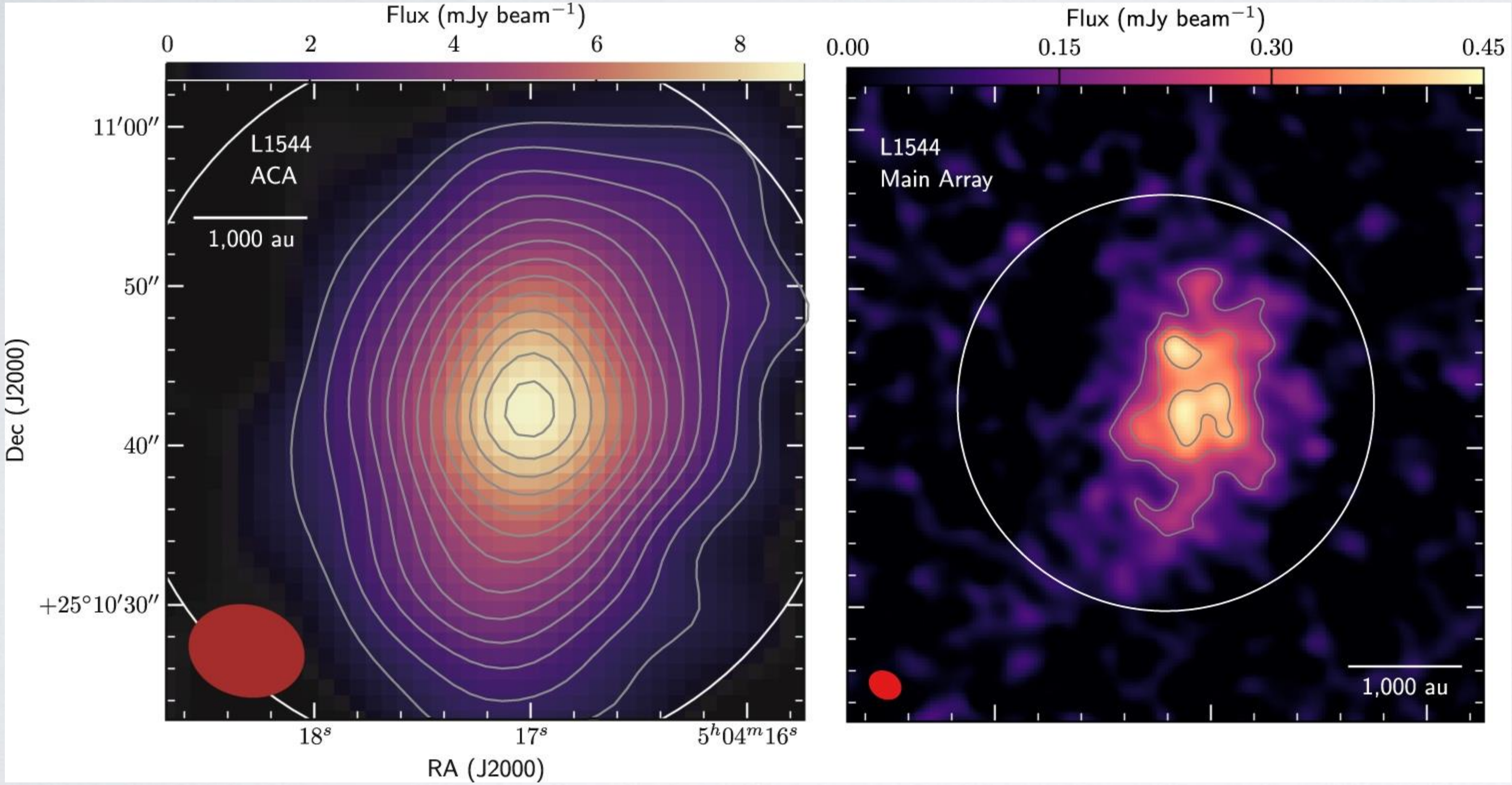


Carpenter et al. 2022 (ALMA Memo 621)

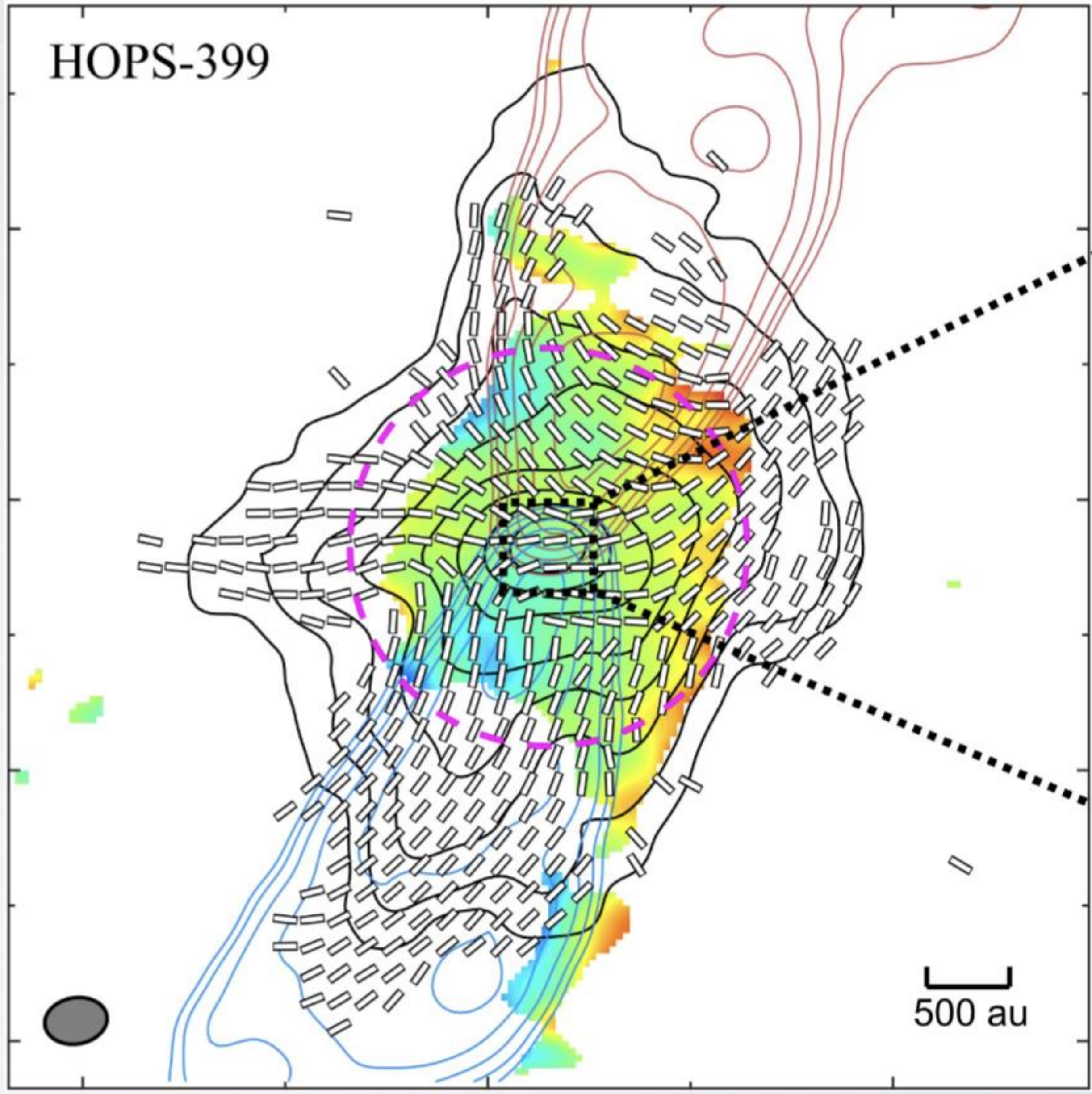
ALMA: Wide-band Upgrades

Higher continuum sensitivity to detect fainter dust emission

Higher continuum sensitivities to detect fainter mass structures and polarization

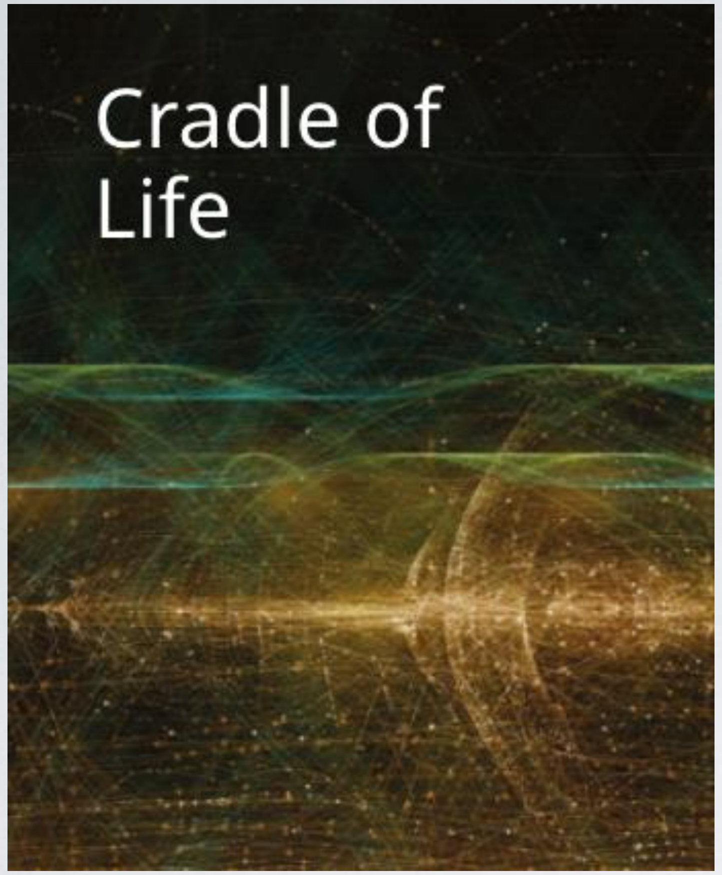


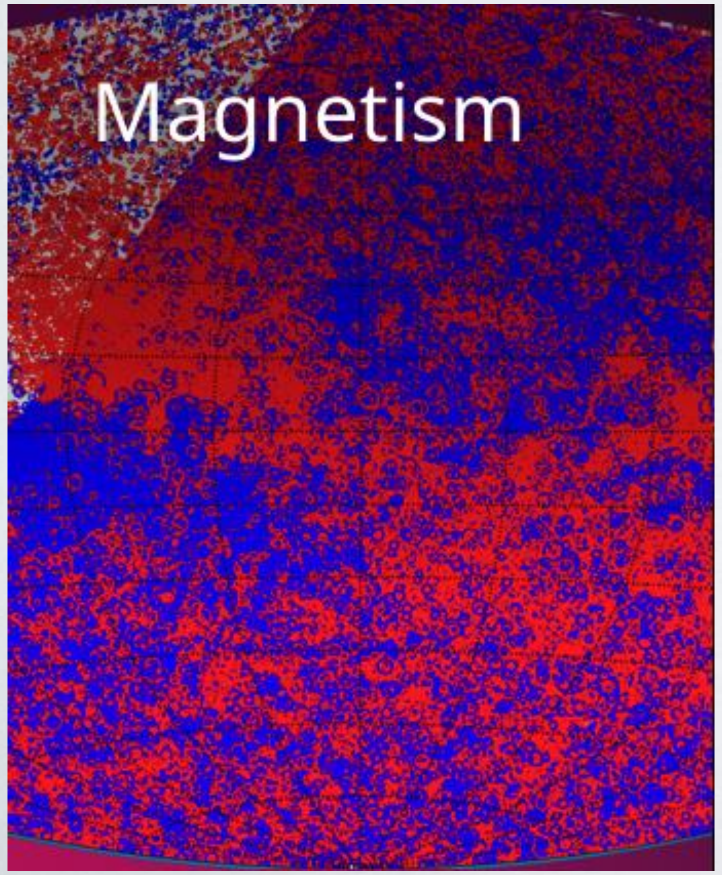
Caselli+ 2019



Huang+ 2025

Longer Wavelengths: SKA / ngVLA





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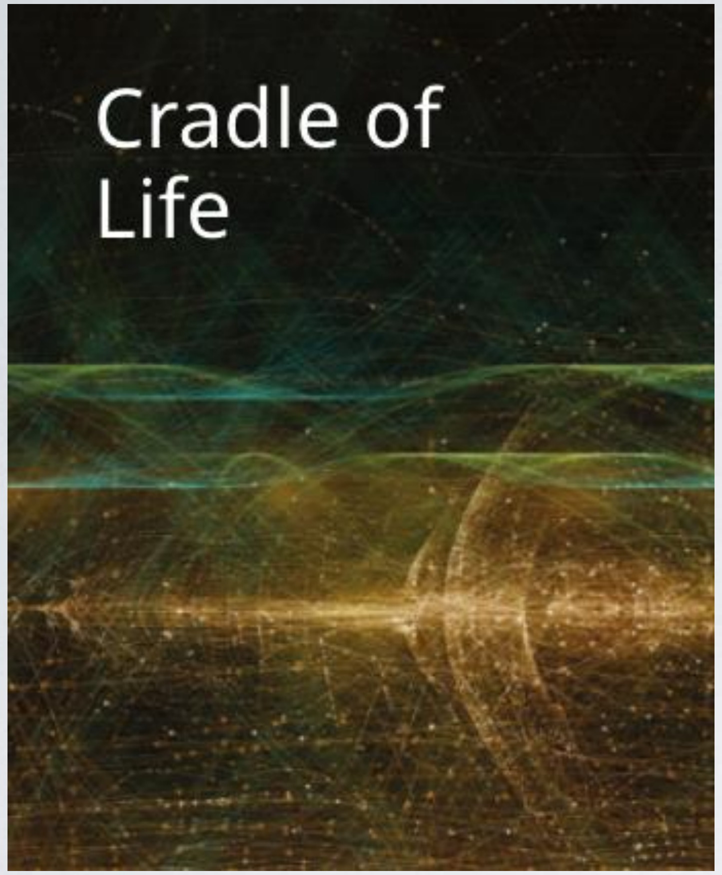
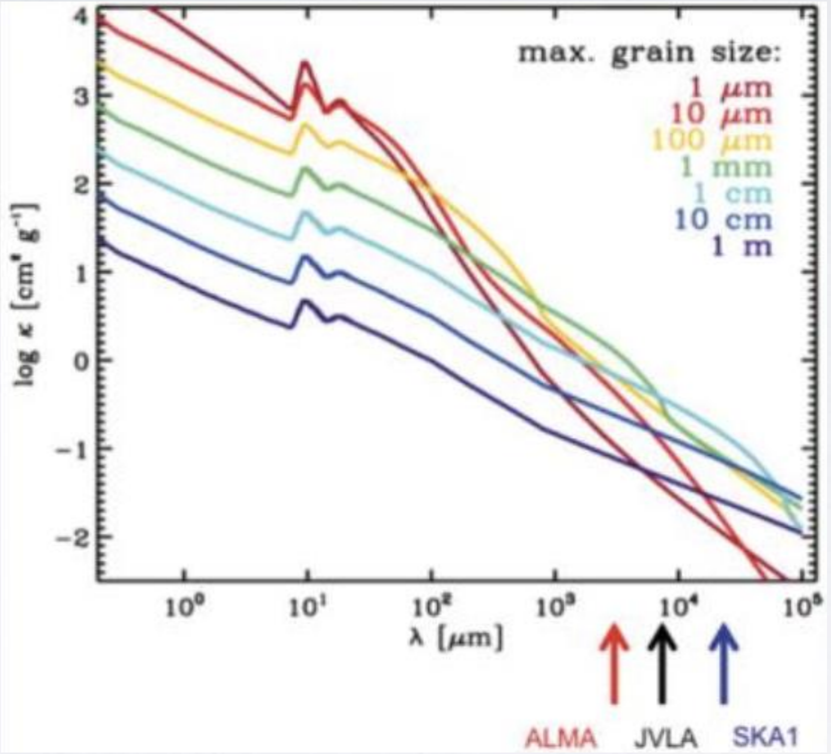
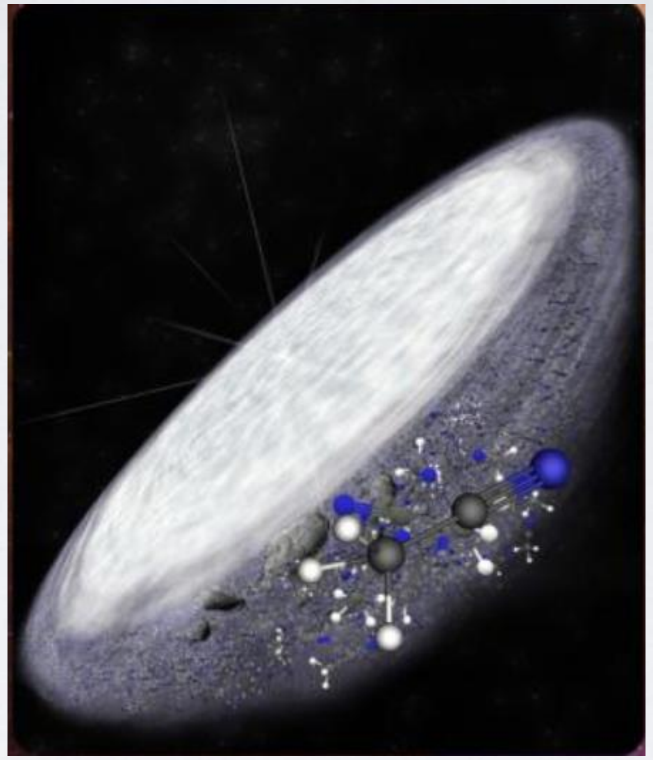


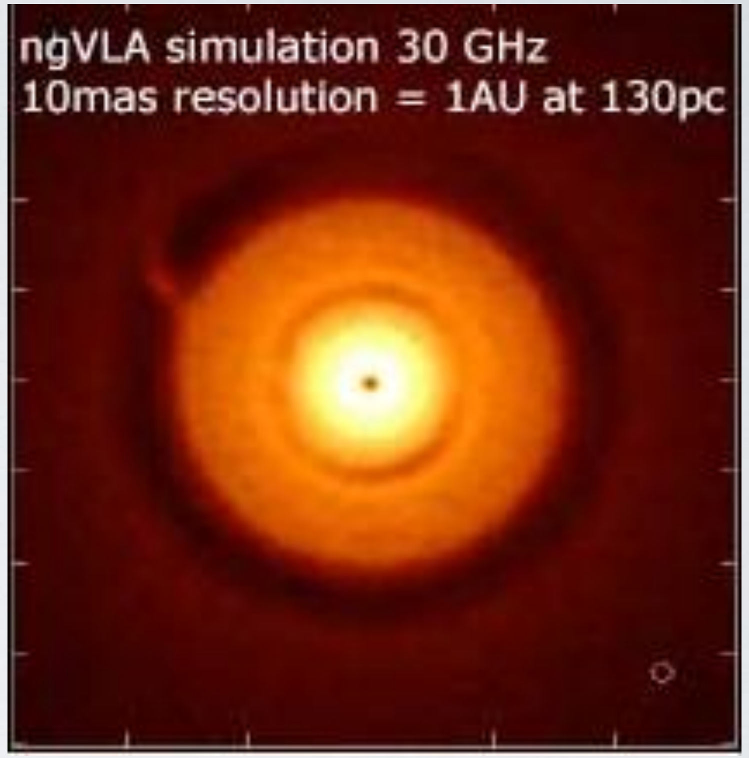
Dust grain properties

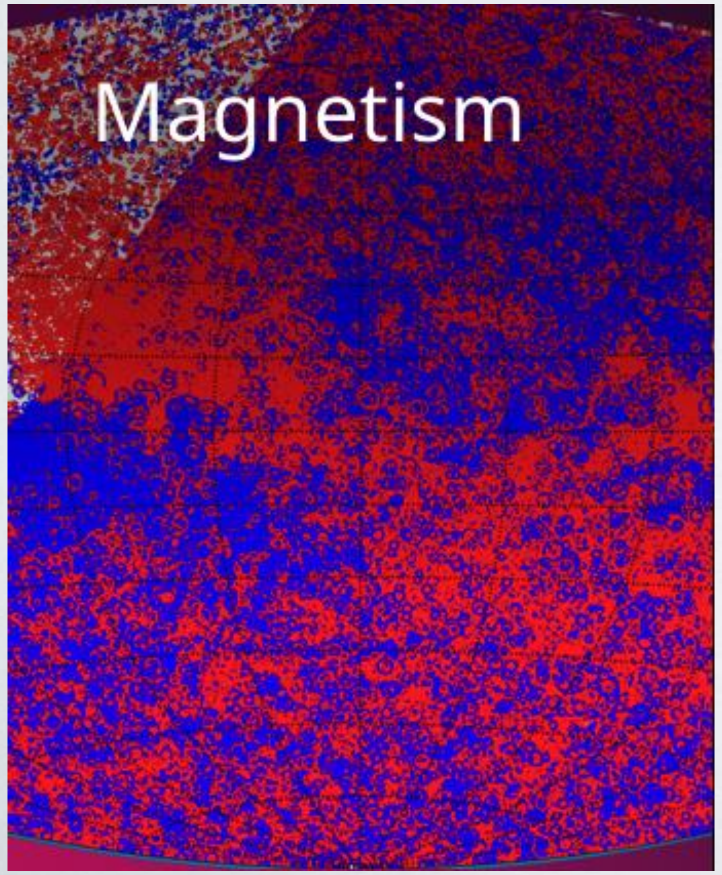


Pre-biotic molecules



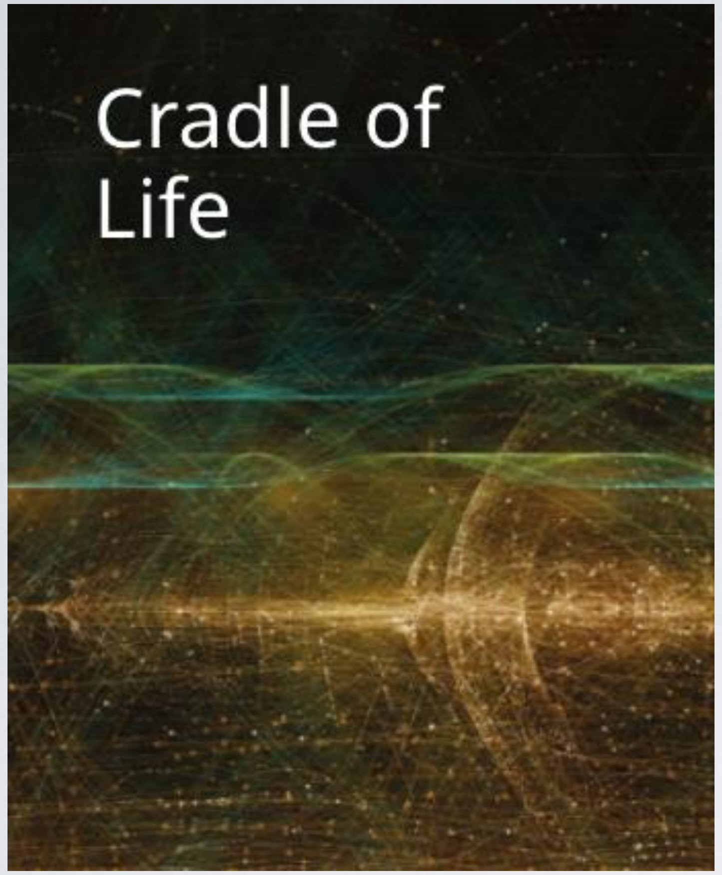
Protoplanets / planet formation





Images from SKA/NRAO science cases

Longer Wavelengths: SKA / ngVLA



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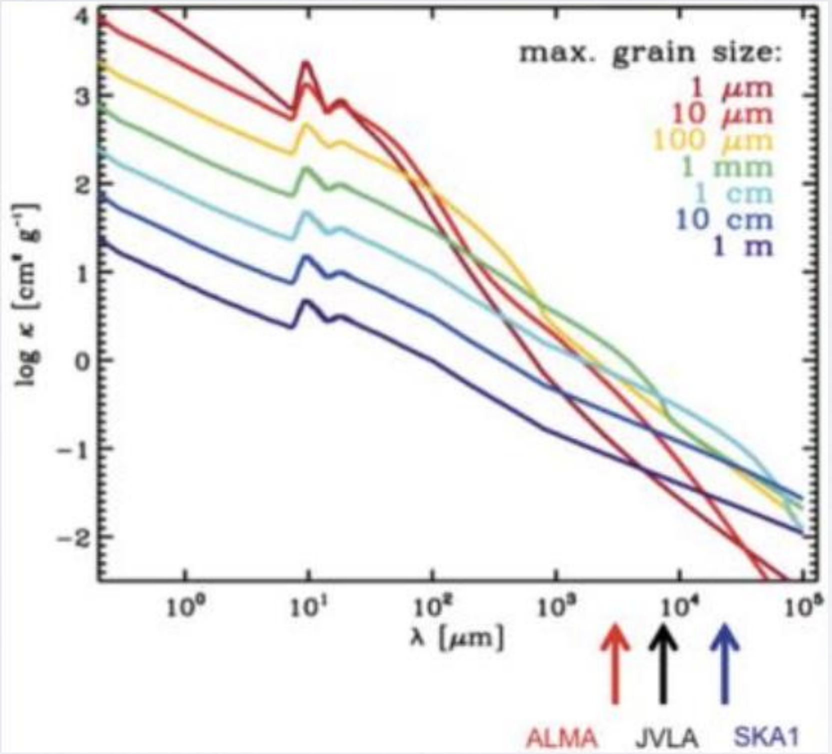

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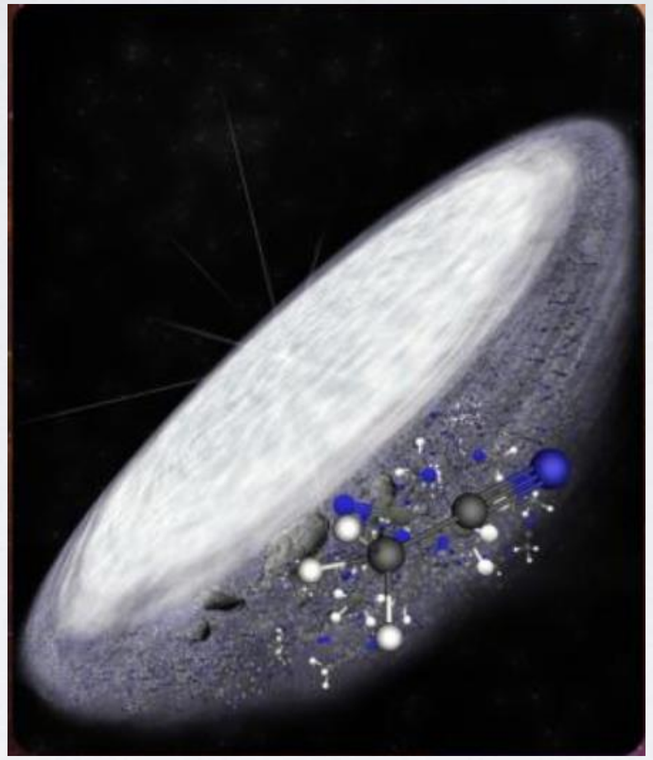
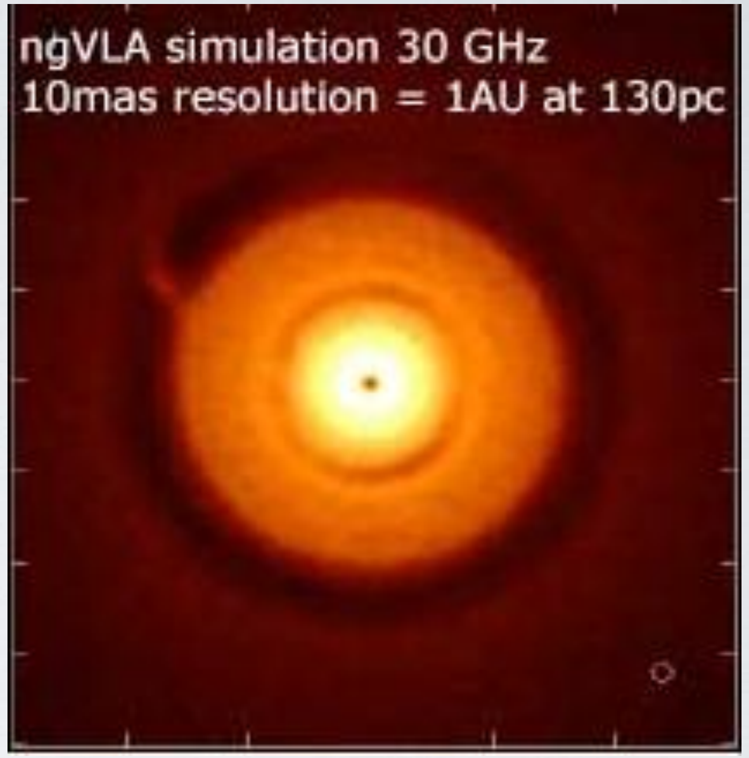
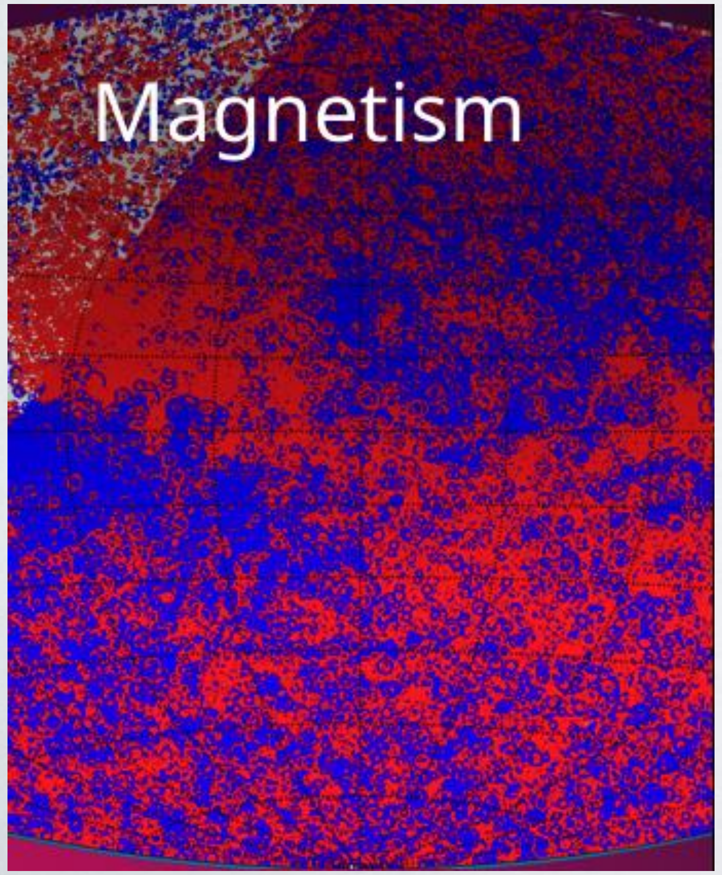
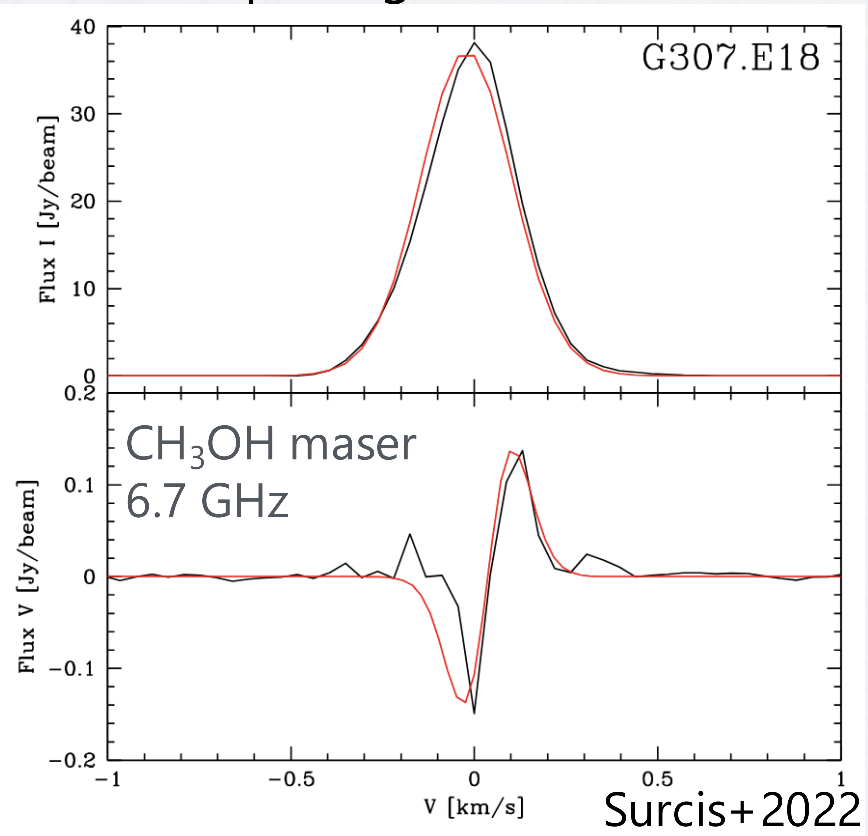


Protoplanets / planet formation



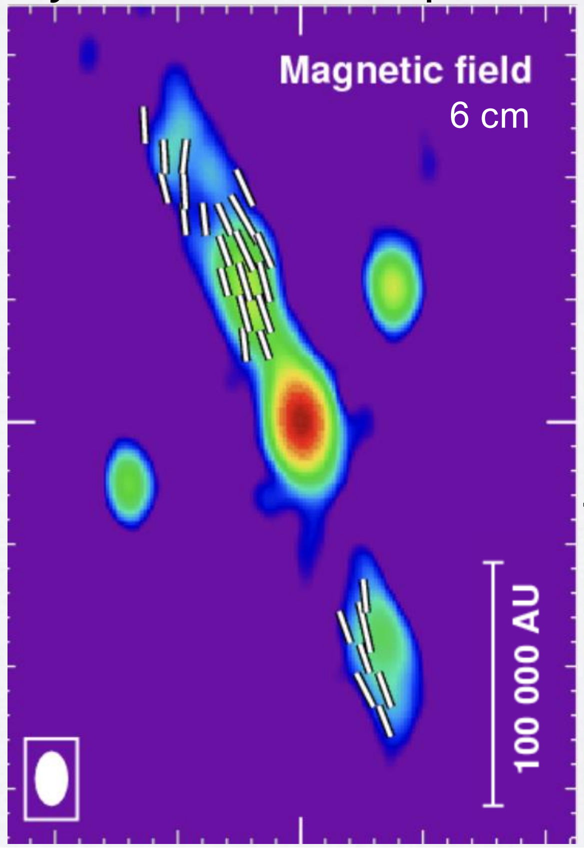


Zeeman splitting



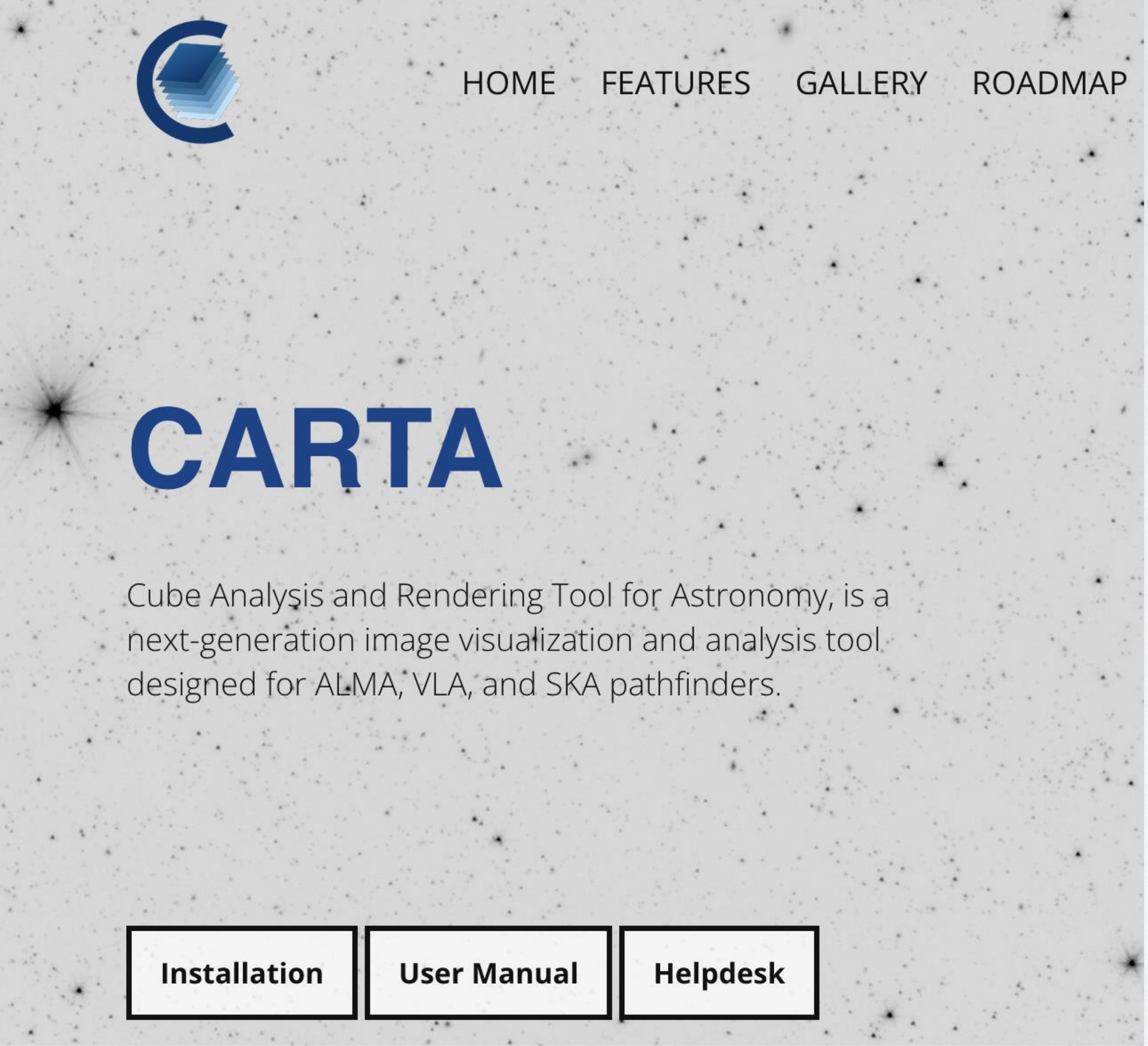
Surcis+2022

Synchrotron in a protostellar jet



Carrasco-González+2010

Images from SKA/NRAO science cases



CARTA Activity

Activity to play with protostellar and disk data using the ALMA archive and the online version of CARTA

You can download CARTA later (additional features)