



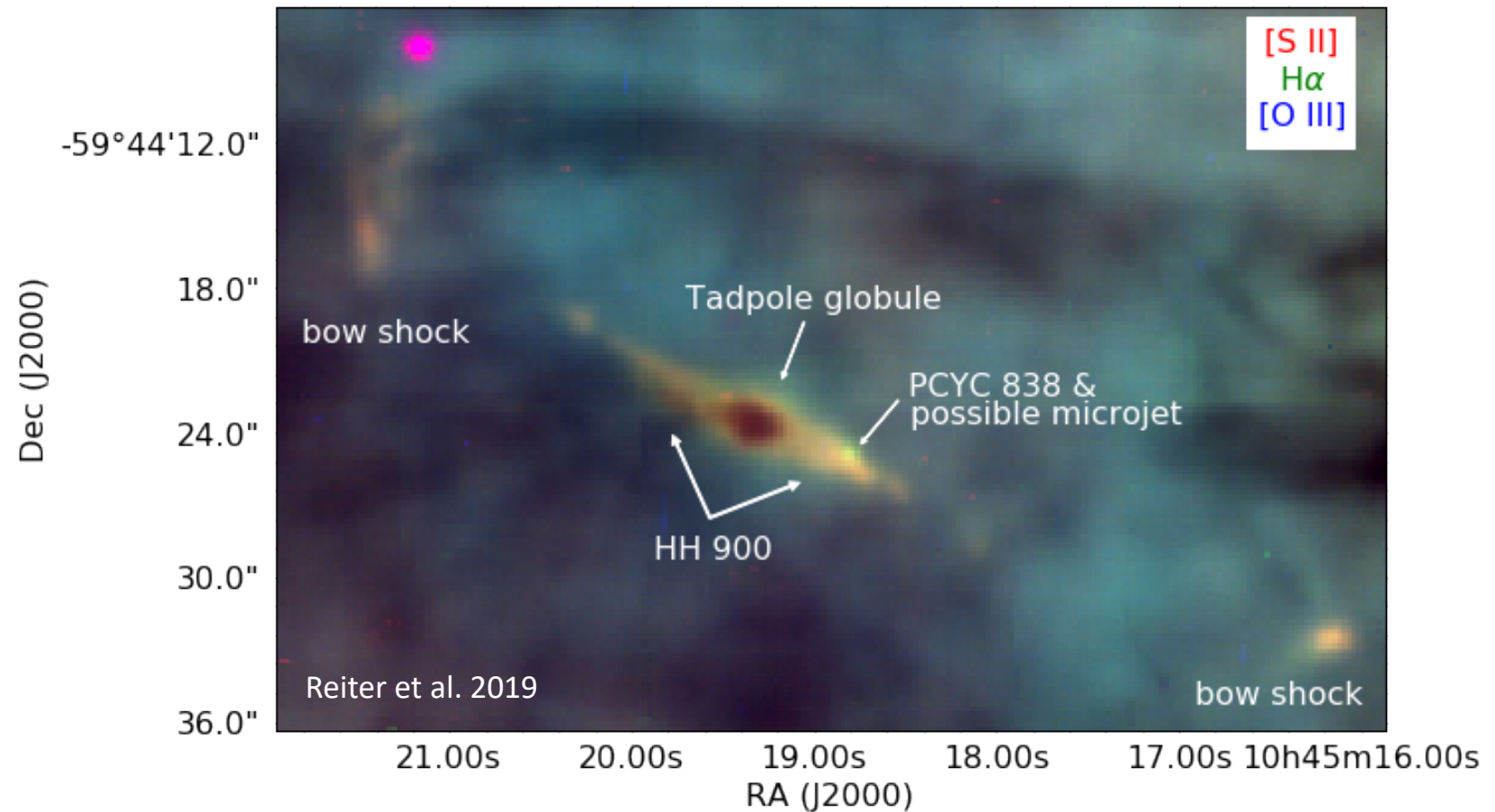
Resolving the role of environment with IFU spectroscopy in typical star and planet forming regions

Megan Reiter

Assistant Professor

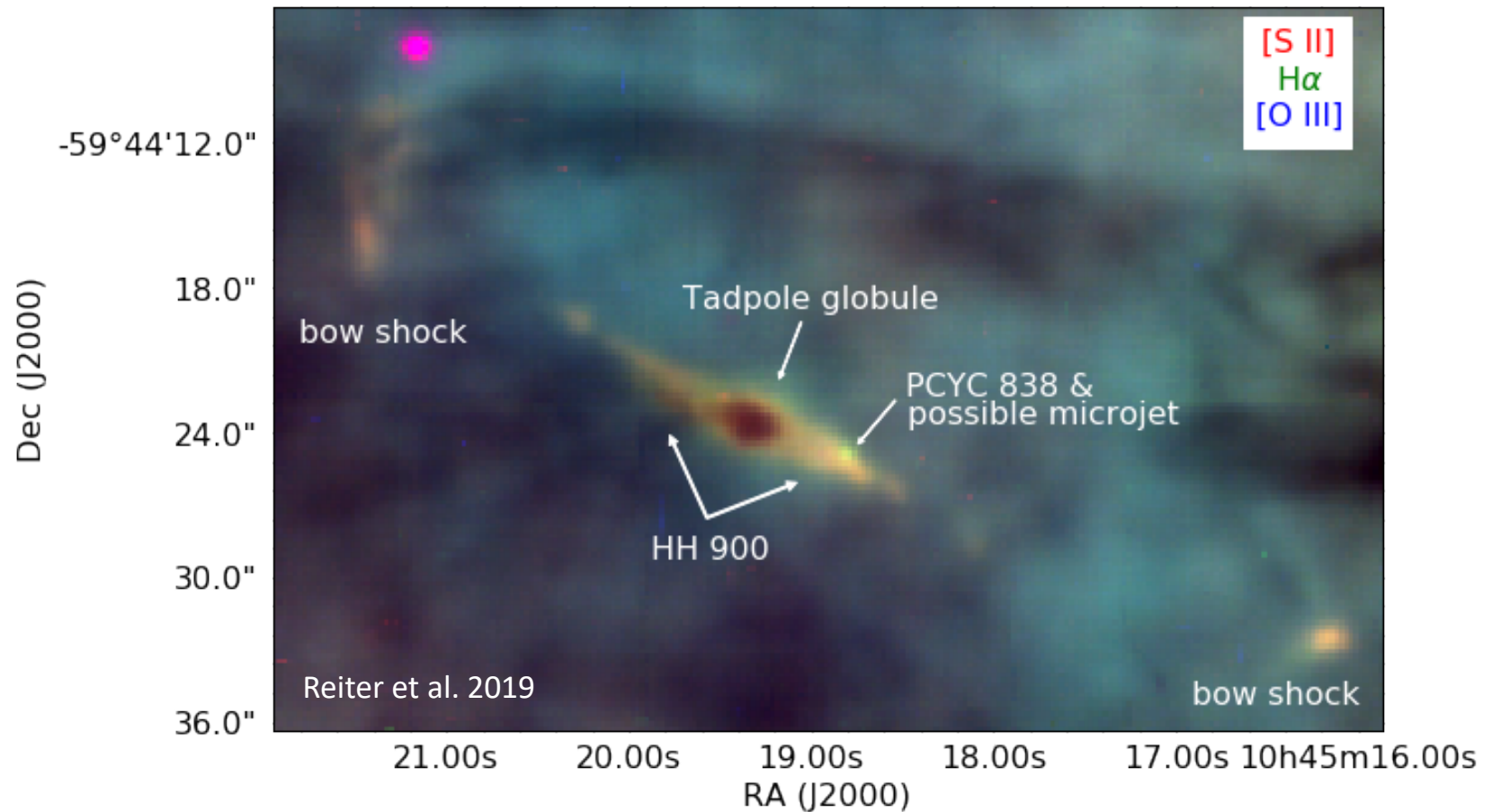
Rice University

MUSE is excellent for studying star formation, including outflows – one of the original science goals for MUSE.



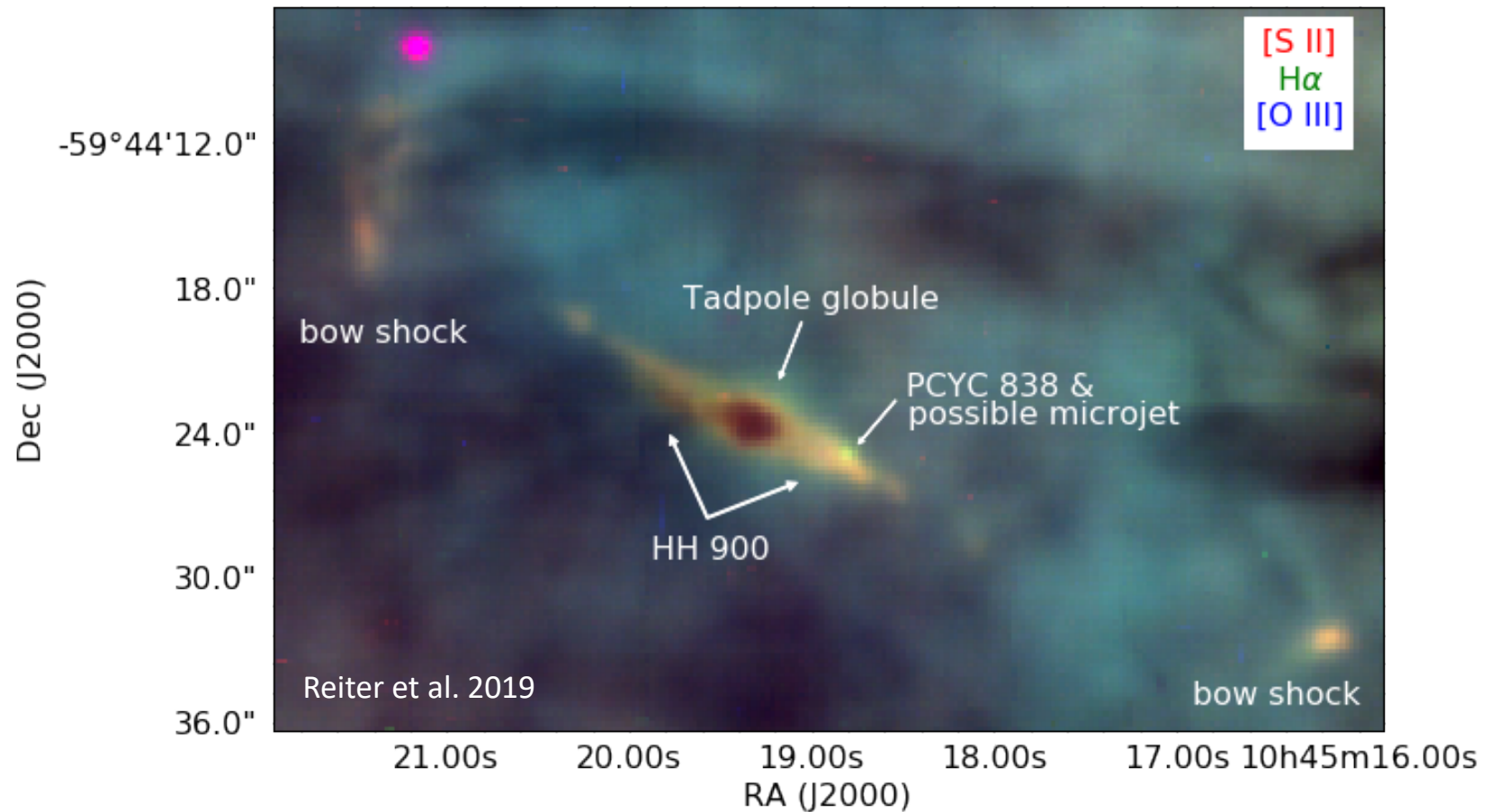
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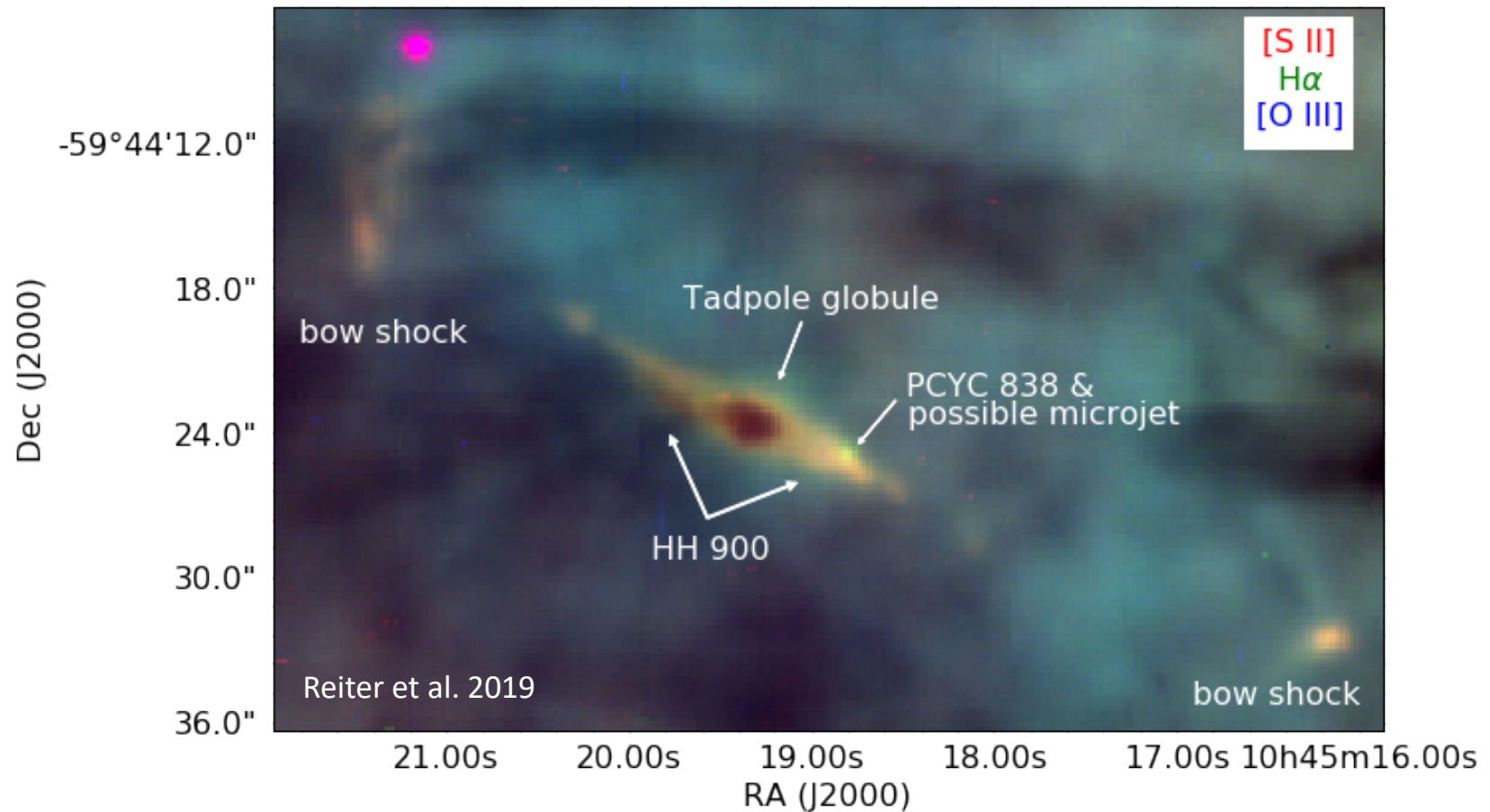
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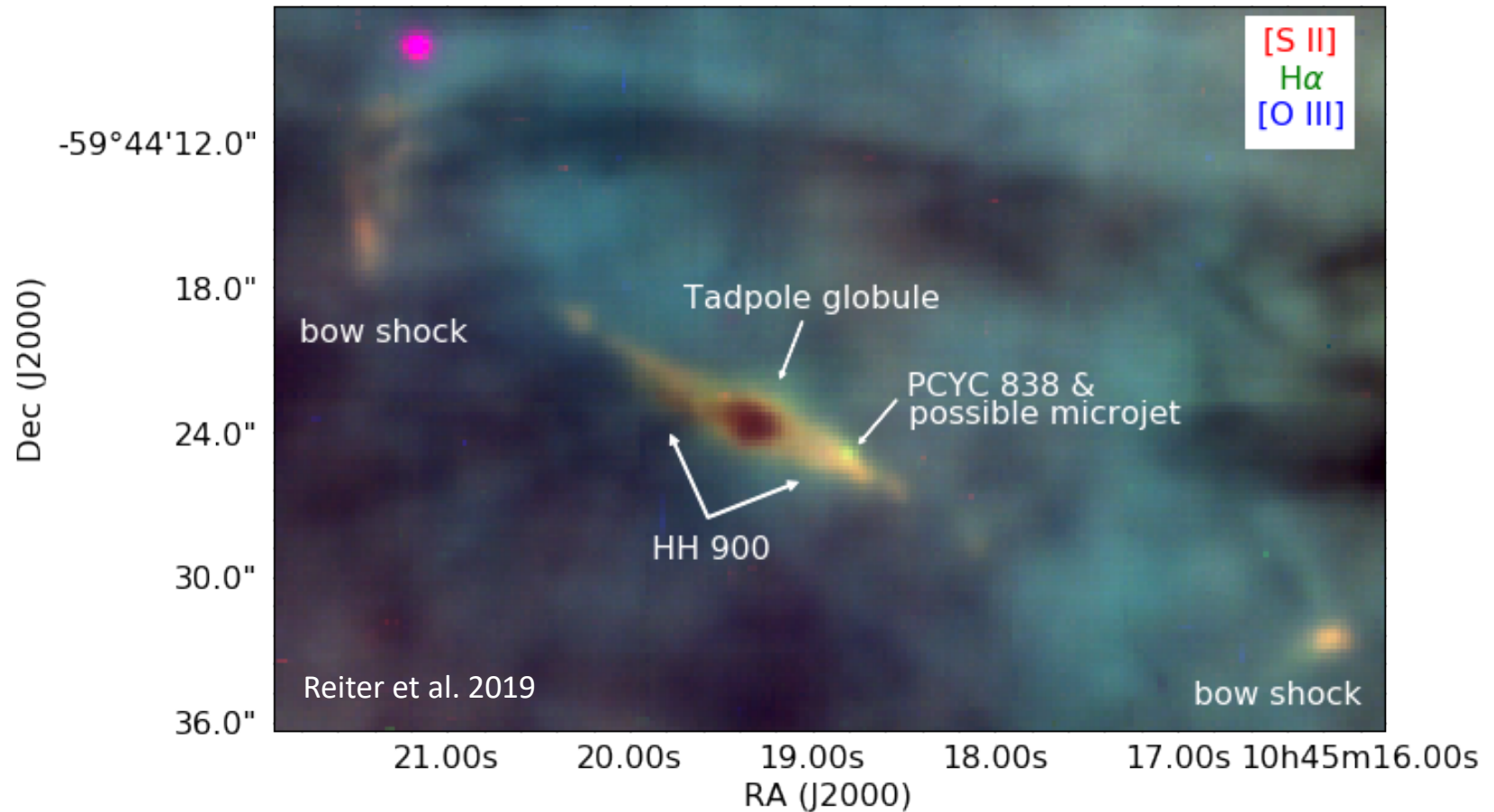
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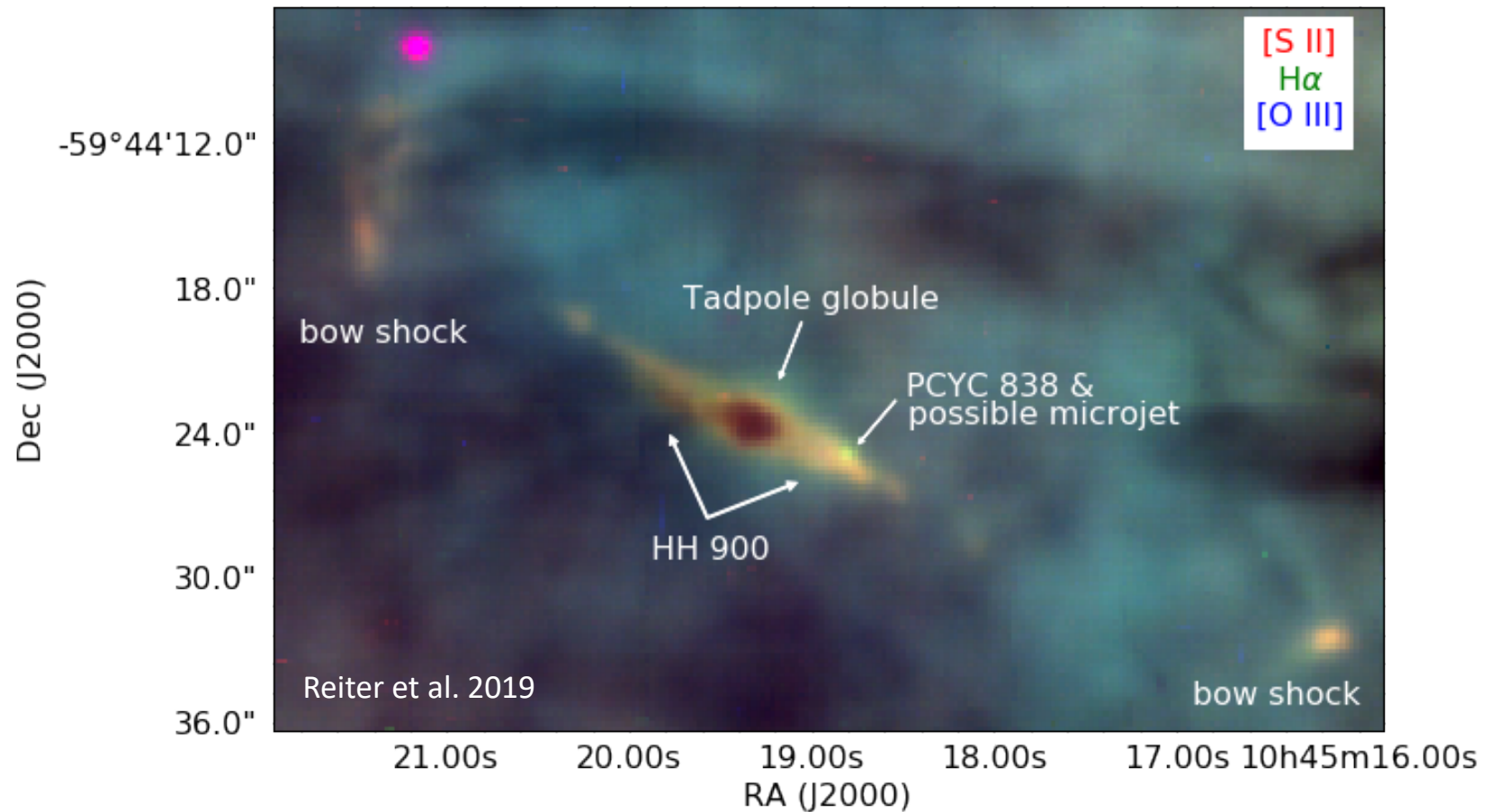
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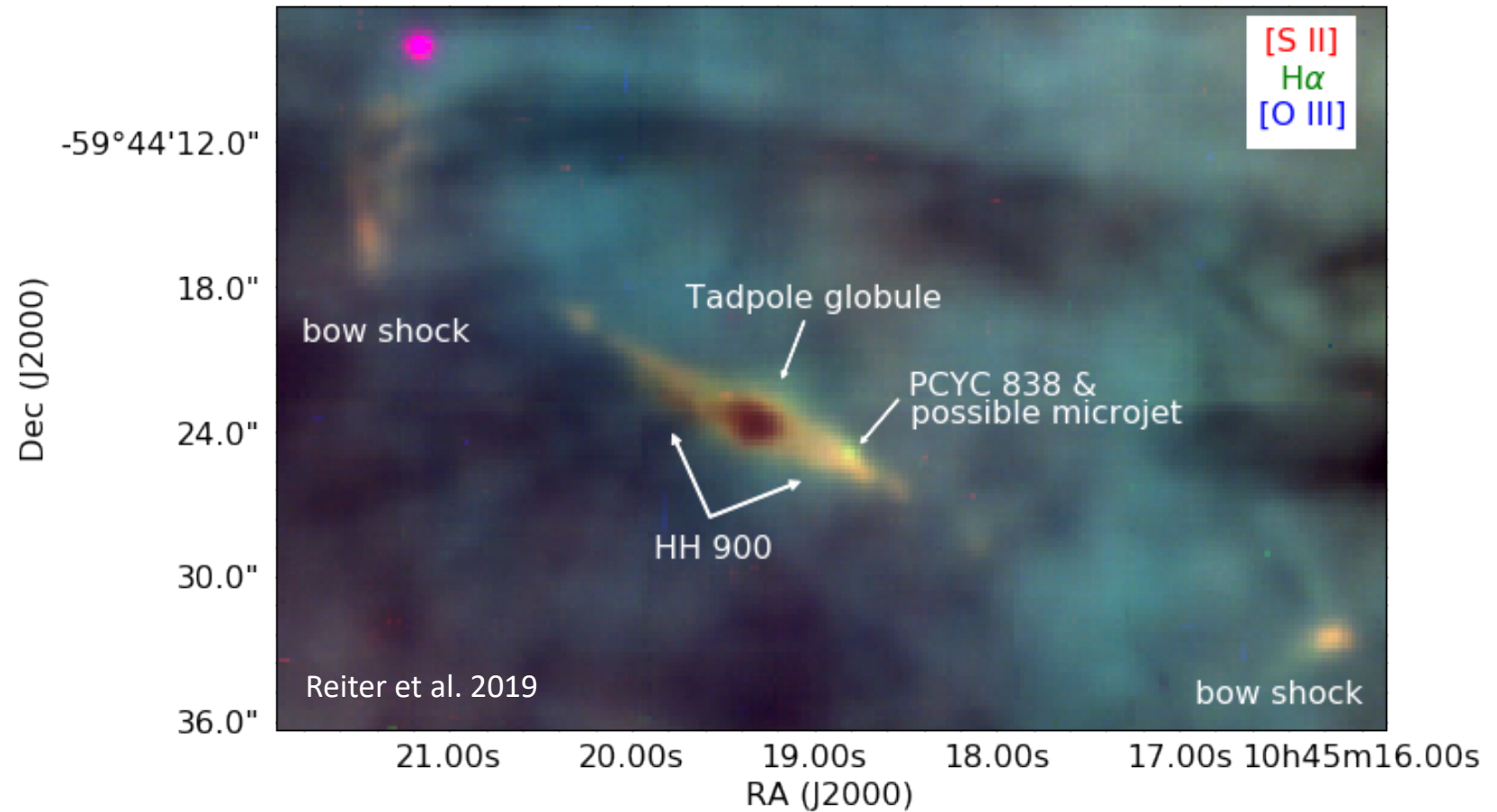


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- Discovery potential: what's that line (telling us)

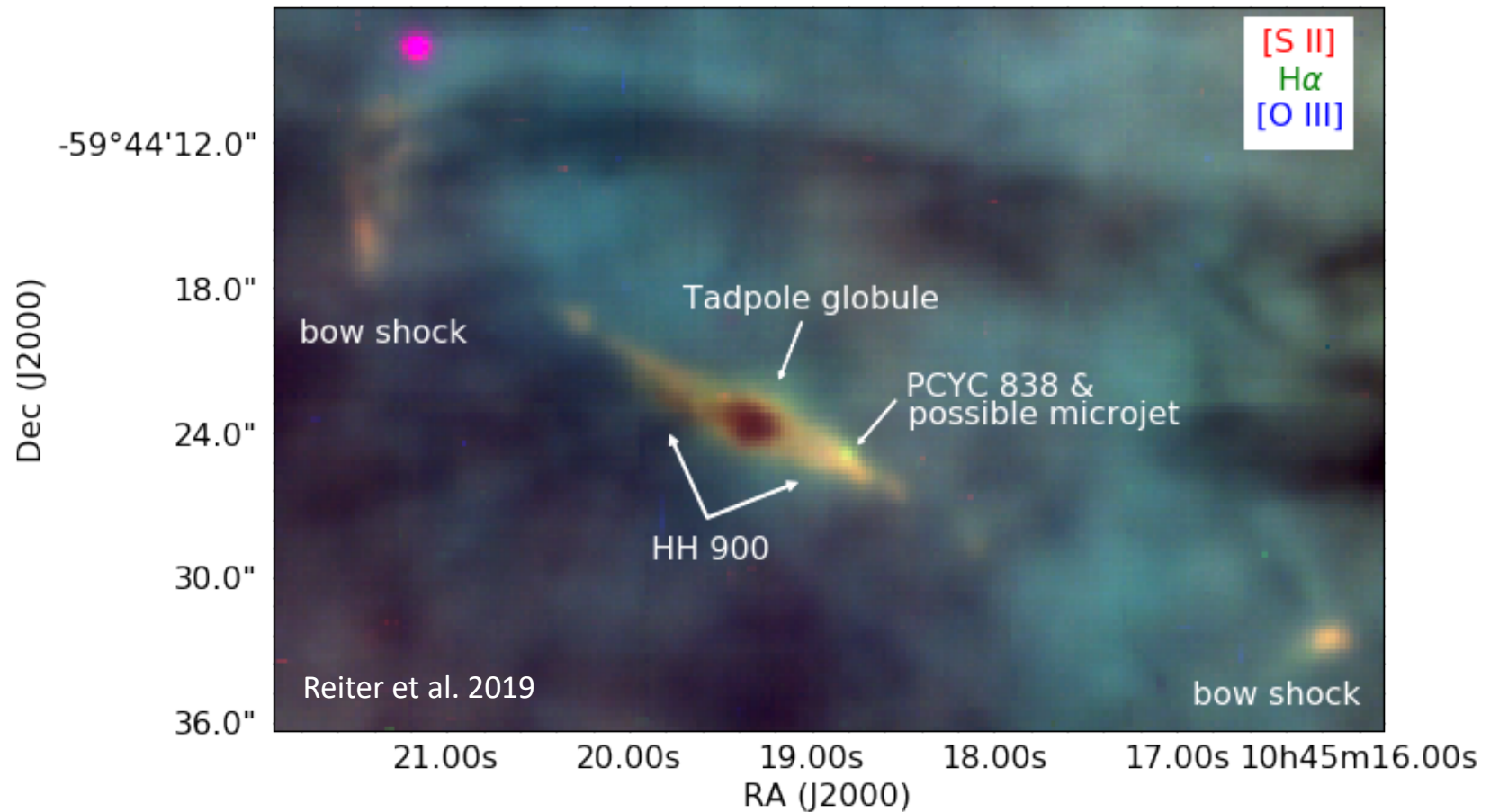


Outflows are excellent for studying star/planet formation, especially when observed with MUSE+ERIS+ALMA.



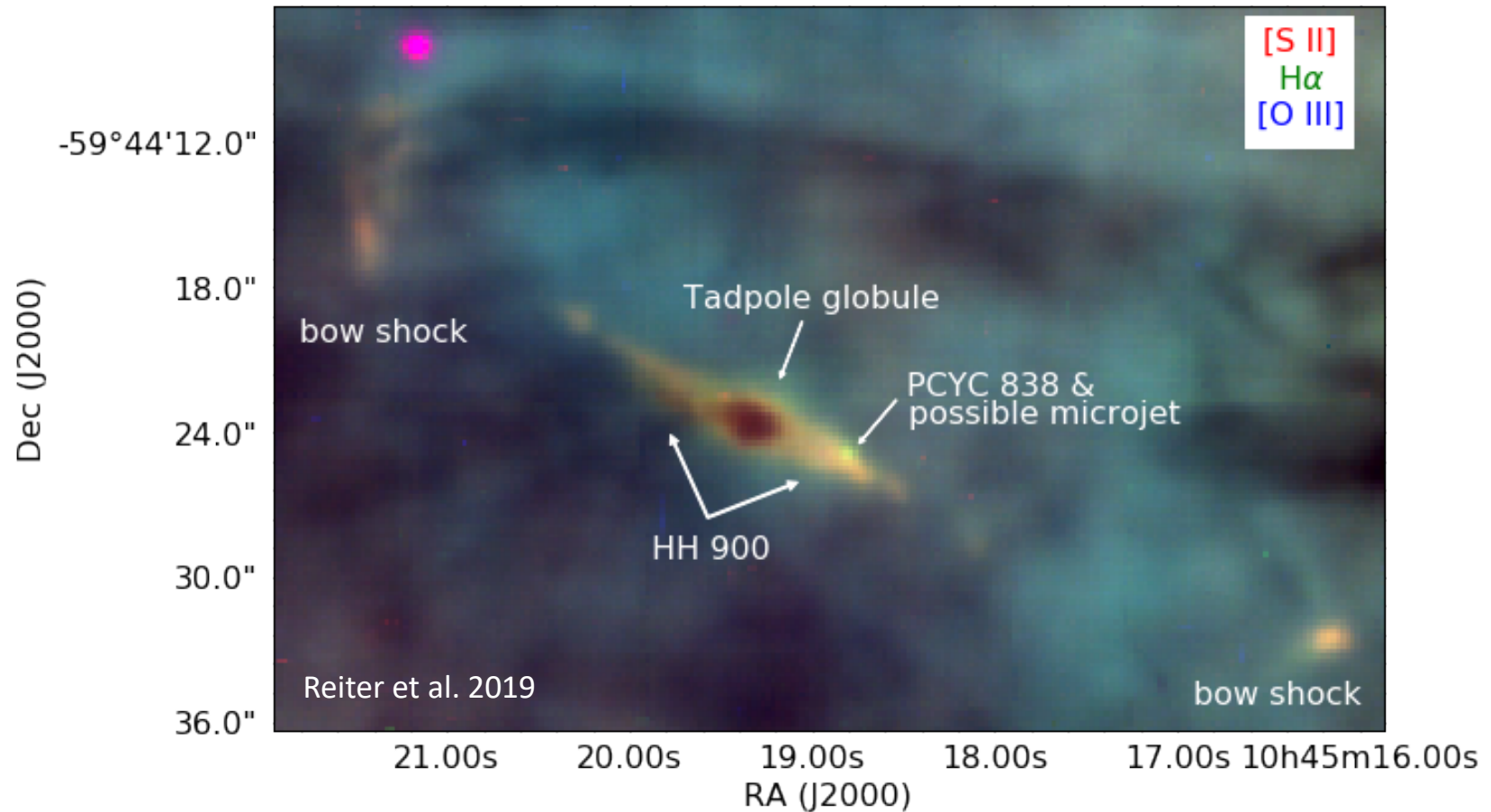
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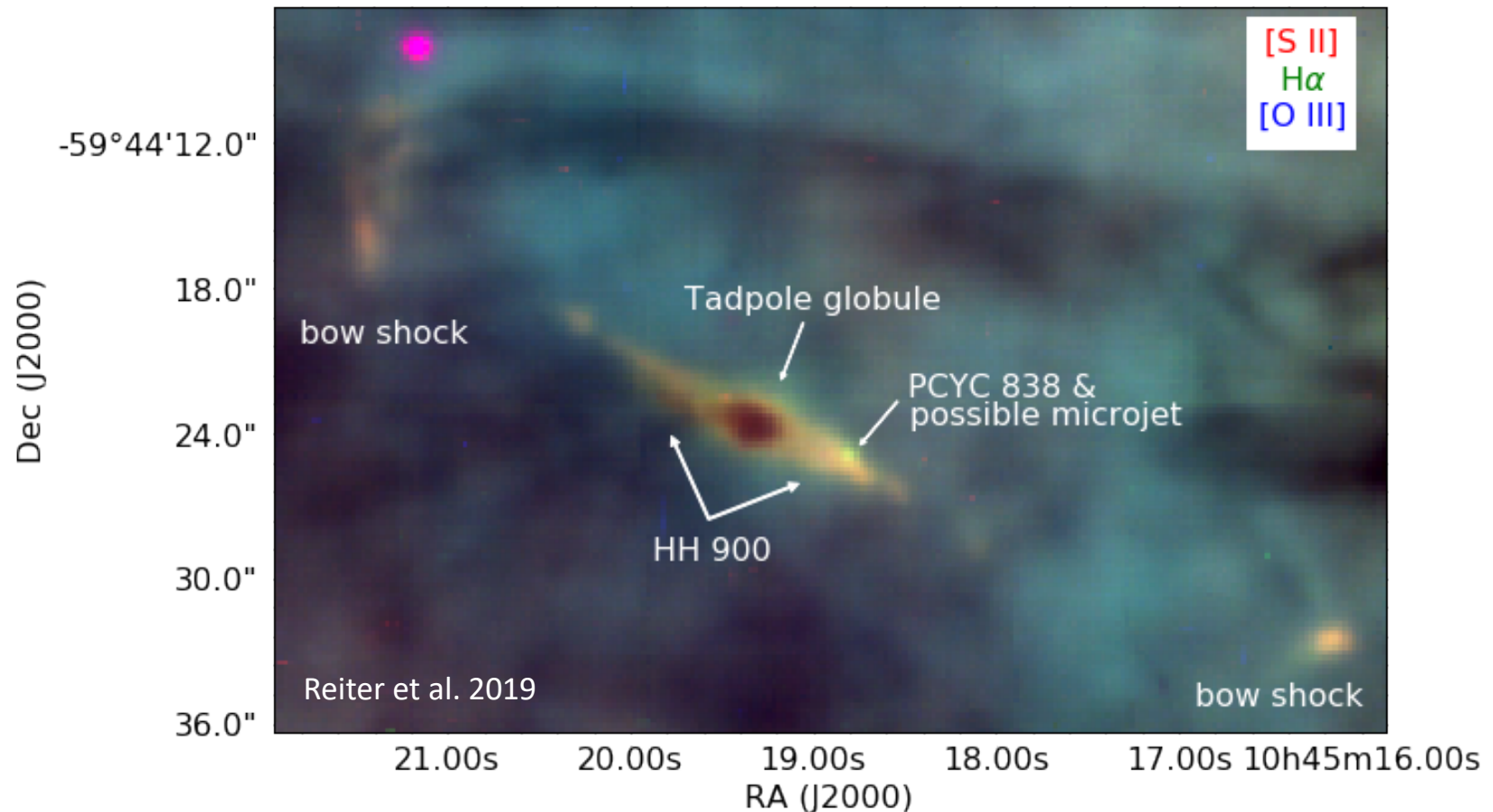
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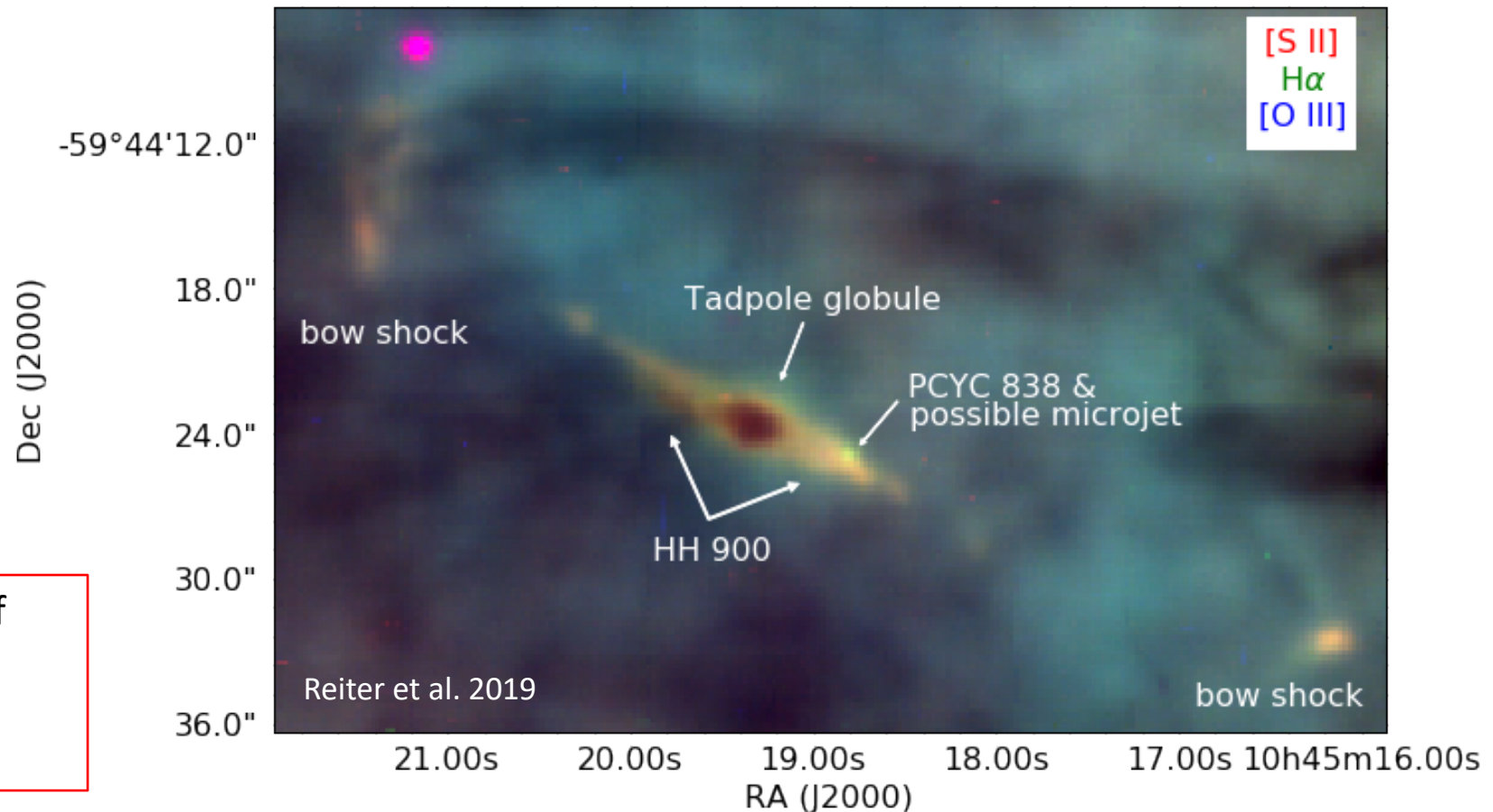
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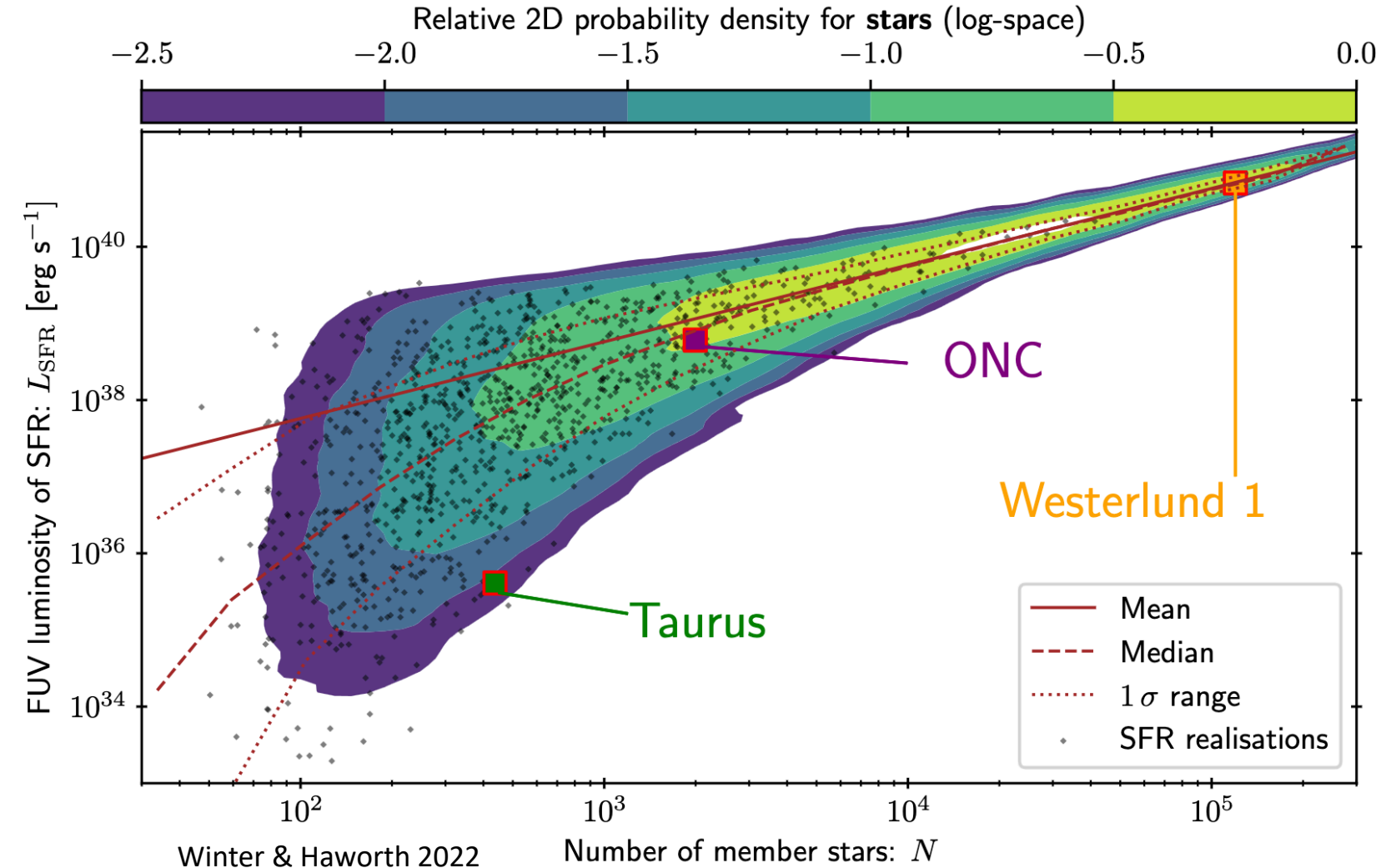
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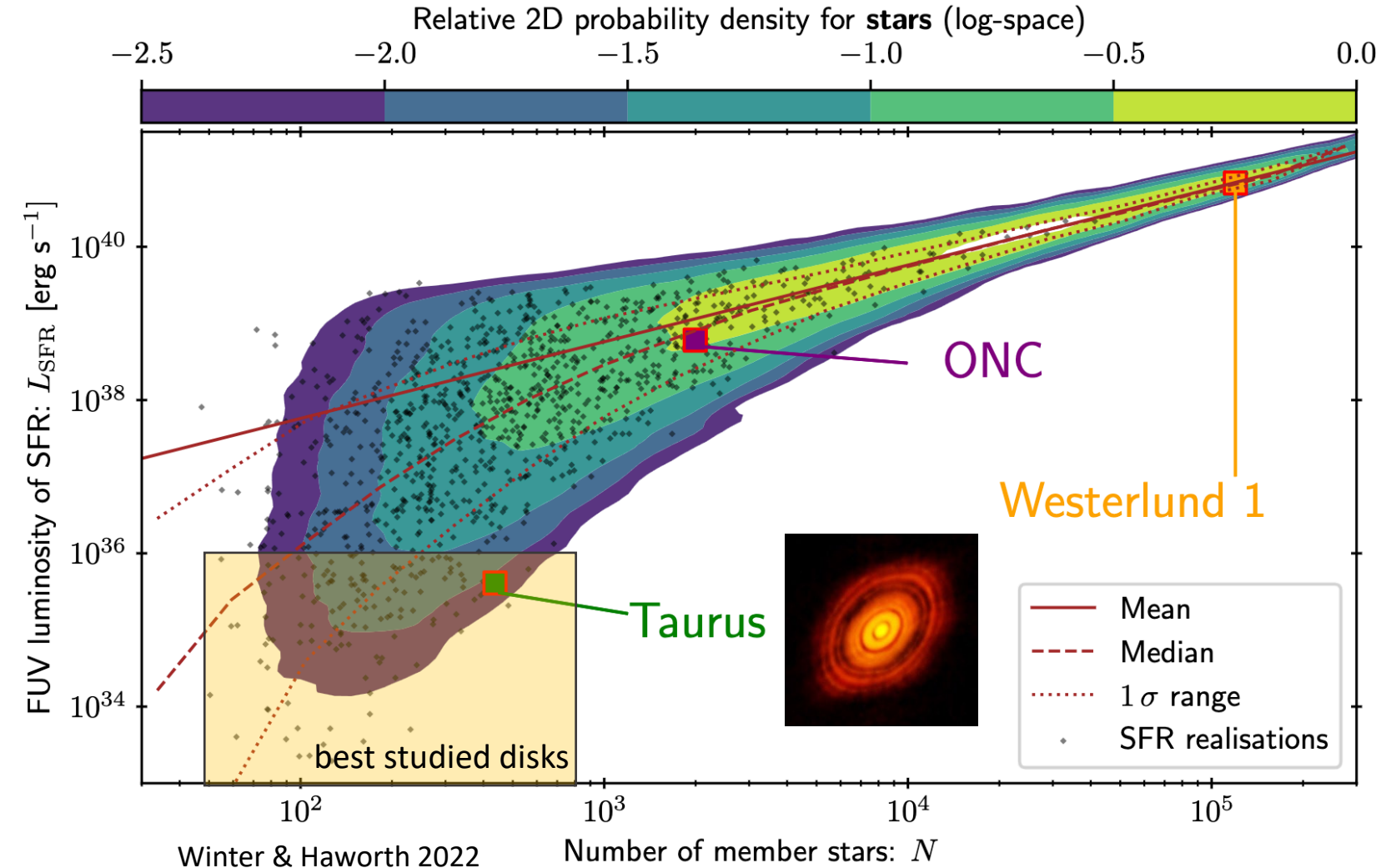
\rightarrow only ALMA observations of planet-forming disks at 2 kpc around jet-driving protostars (Cortes-Rangel 2020, 2023)



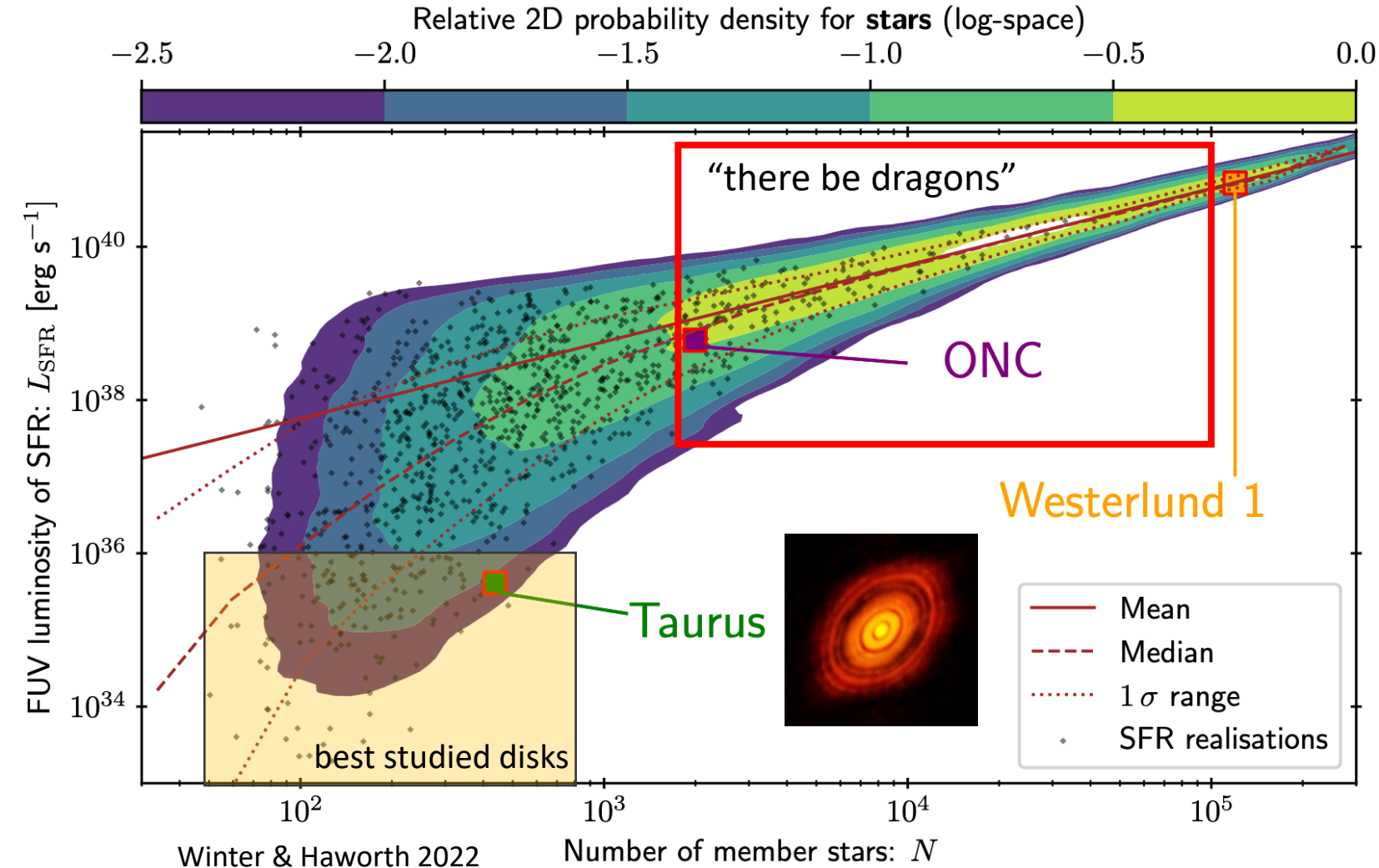
Most stars form near high-mass stars that will illuminate and evaporate the planet-forming disks around nearby low-mass stars.



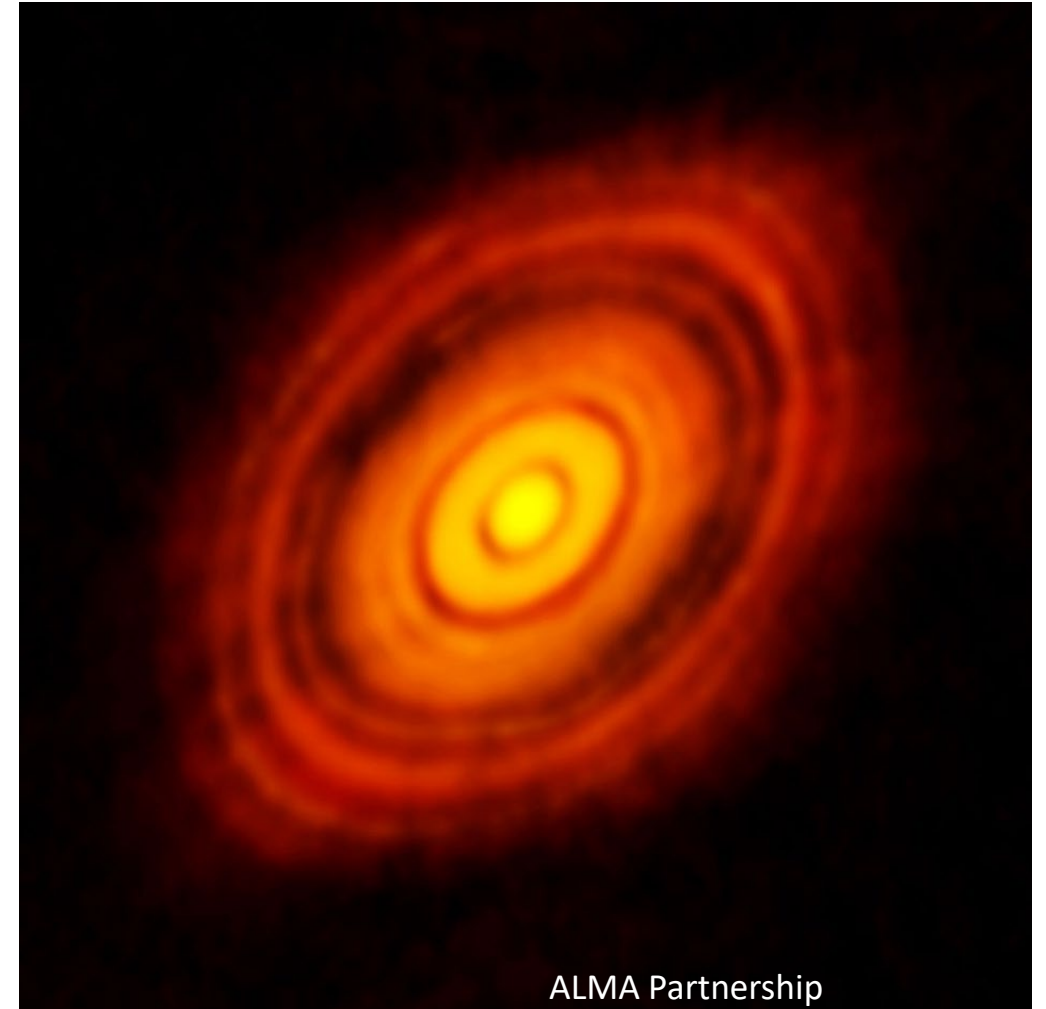
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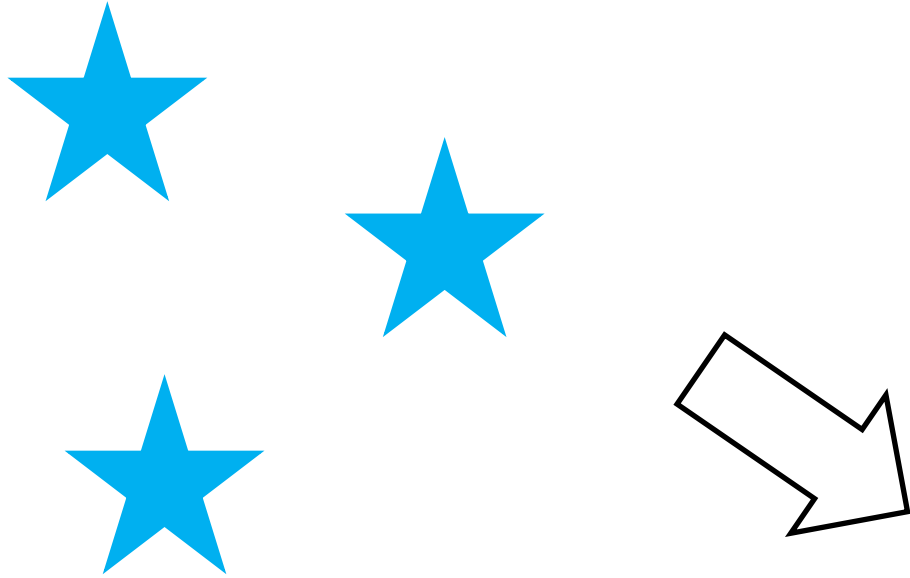
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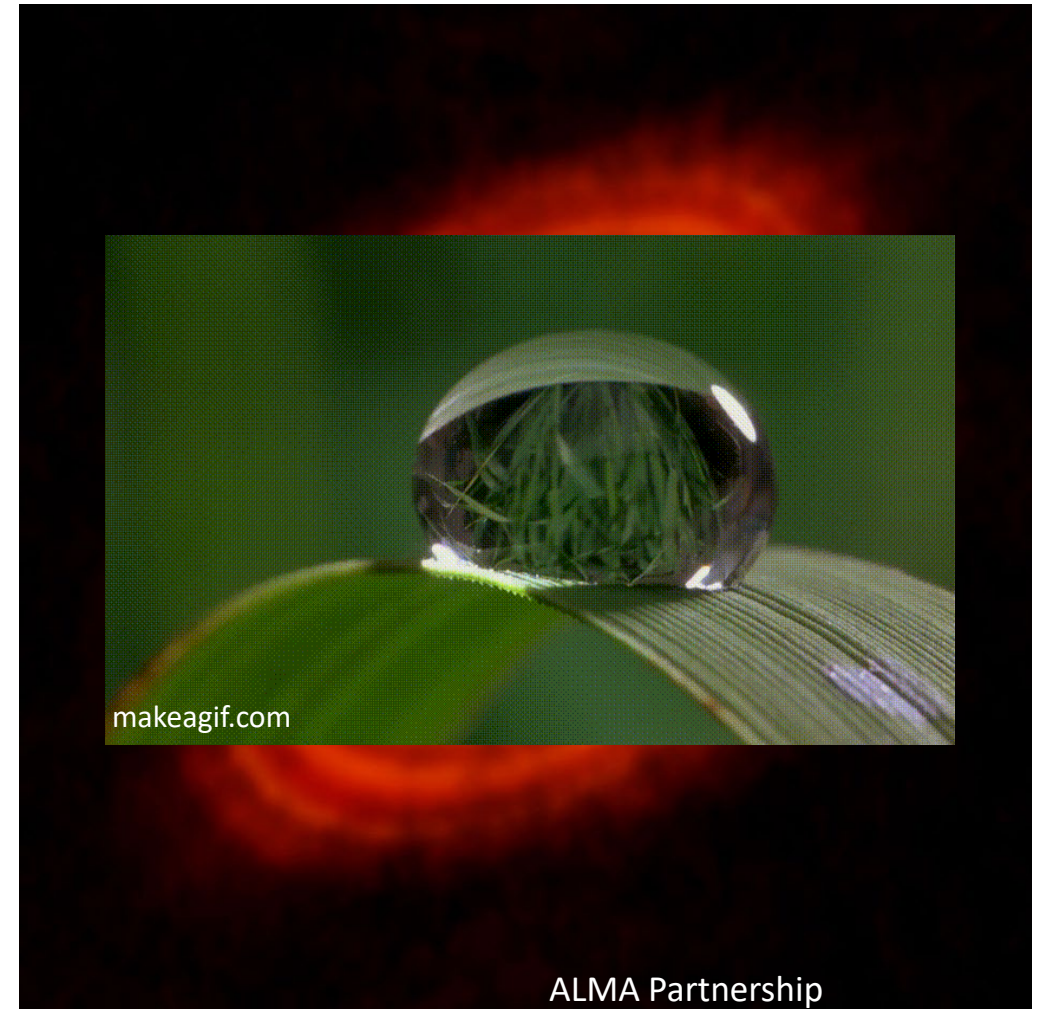
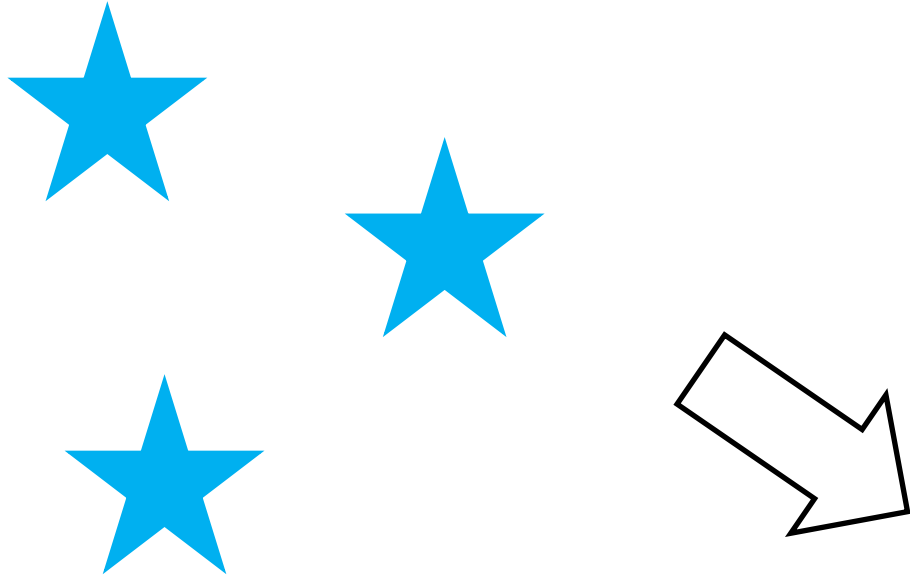
Feedback (esp. radiation) from massive stars affects planet-forming disks by heating and photoevaporating them.



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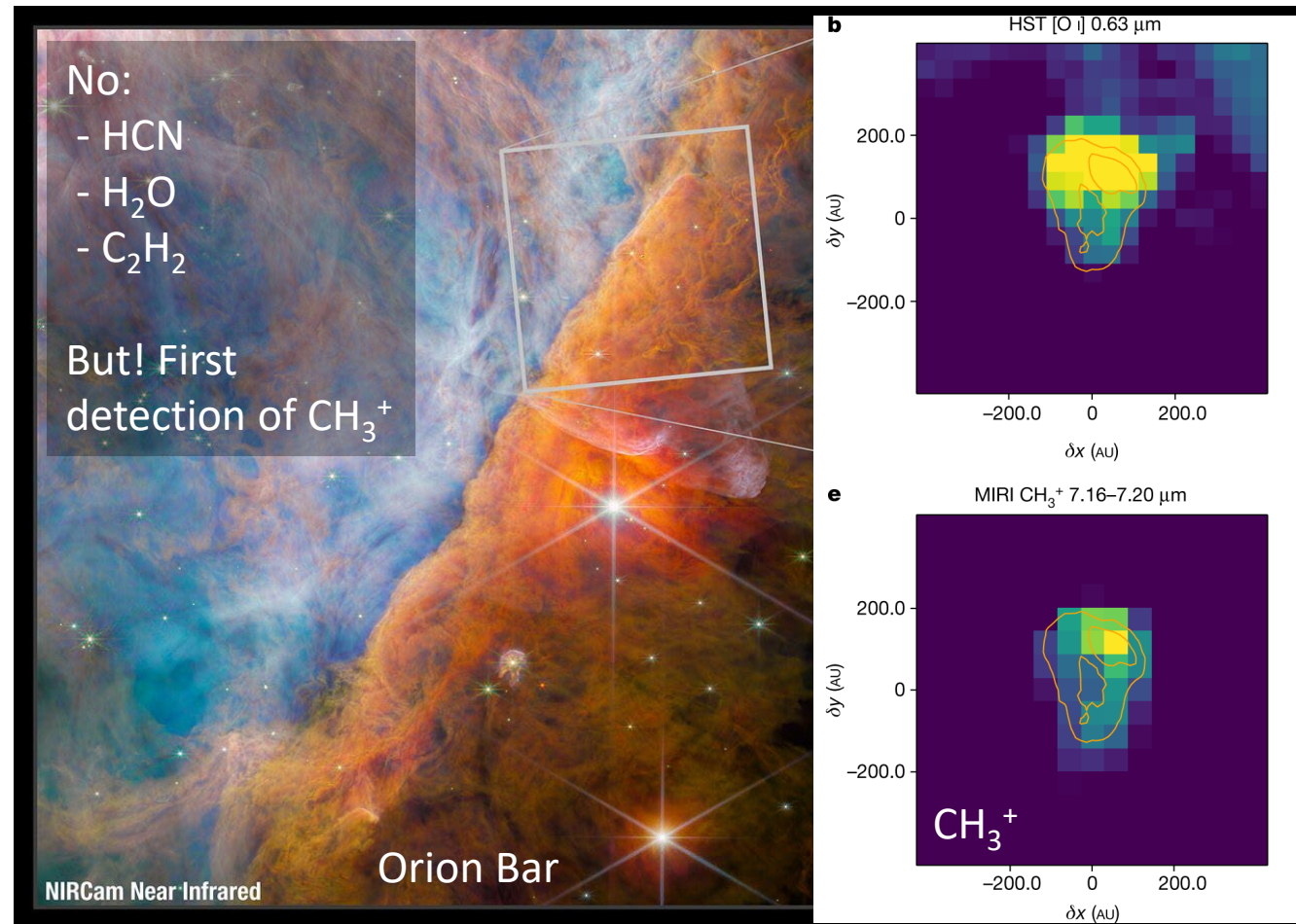
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Berné et al. 2023

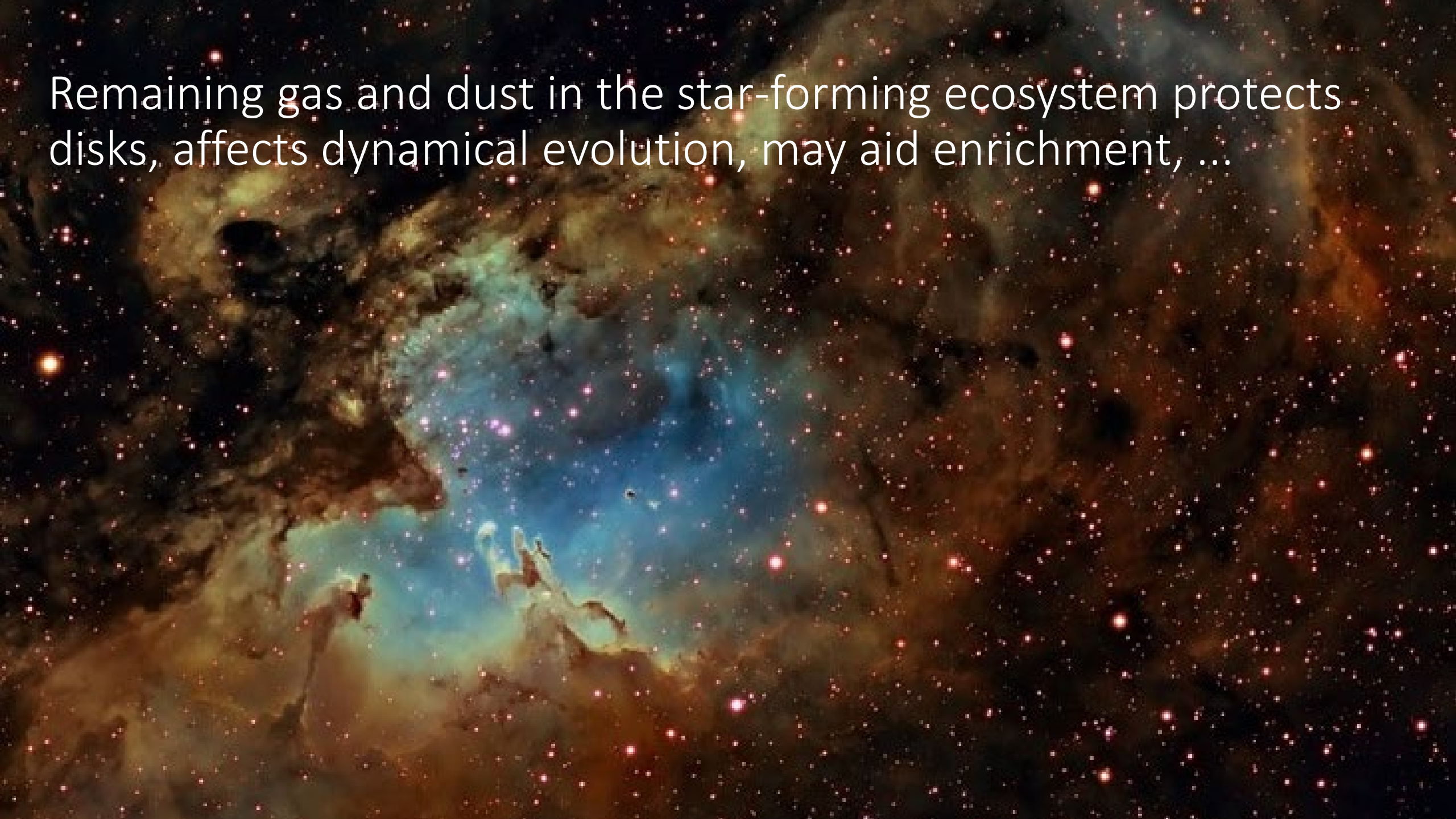
→ see also Ramirez-Tannus et al. 2023

Feedback (esp. radiation) from massive stars affects planet-forming disks by heating and photoevaporating them.

1. the **timescale** for planet formation
2. the **ingredients** for terrestrial planets
3. how the ecosystem evolves, thus regulating exoplanet **demographics**



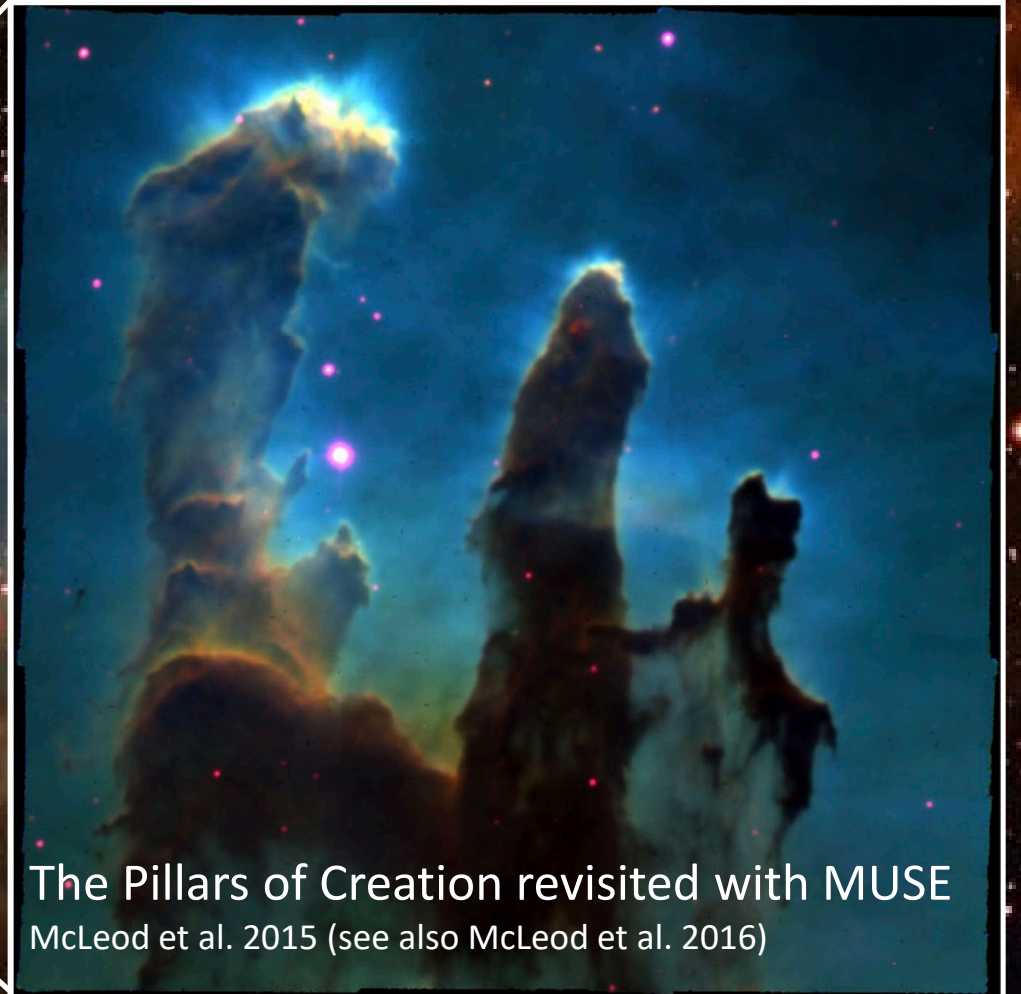
Remaining gas and dust in the star-forming ecosystem protects disks, affects dynamical evolution, may aid enrichment, ...



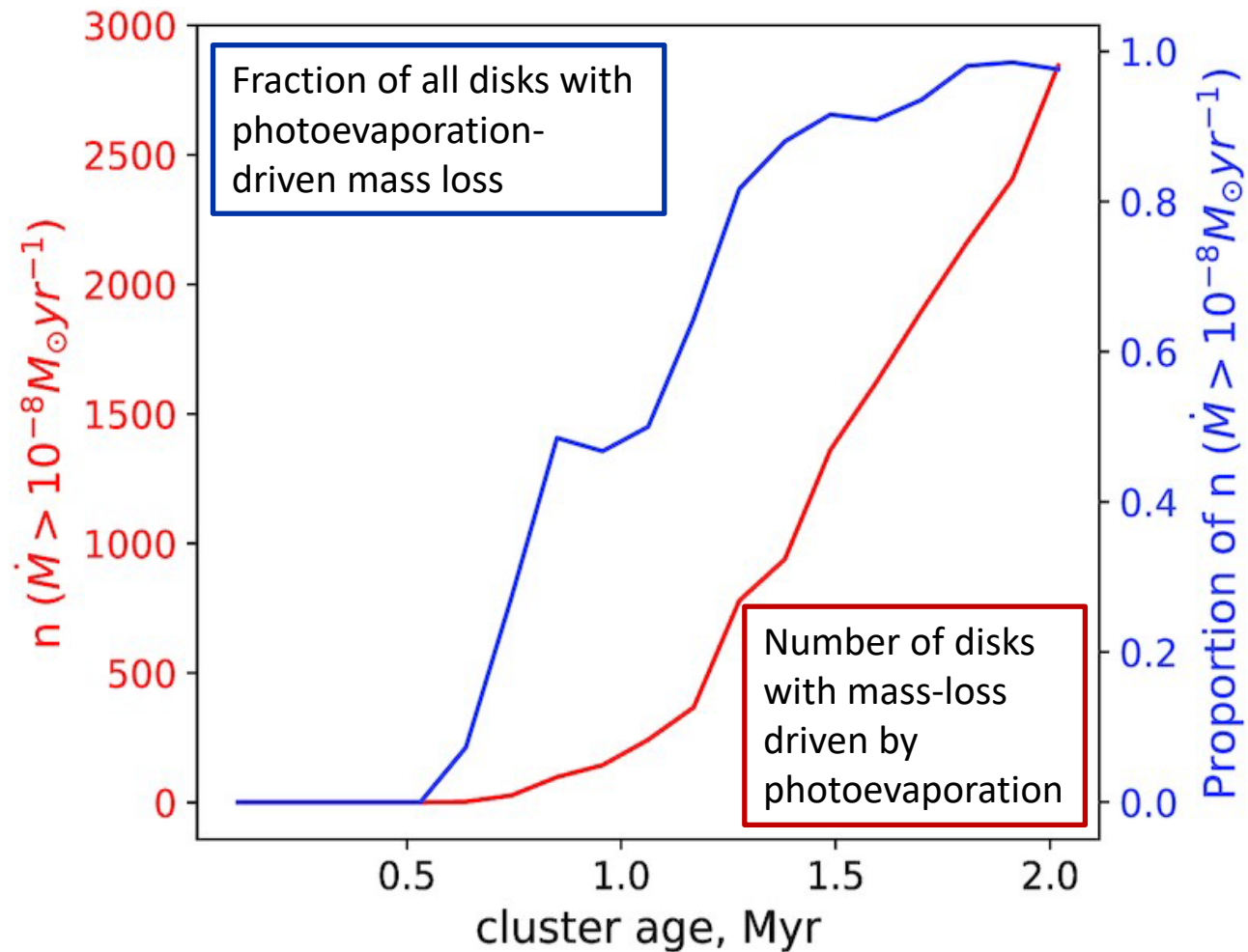
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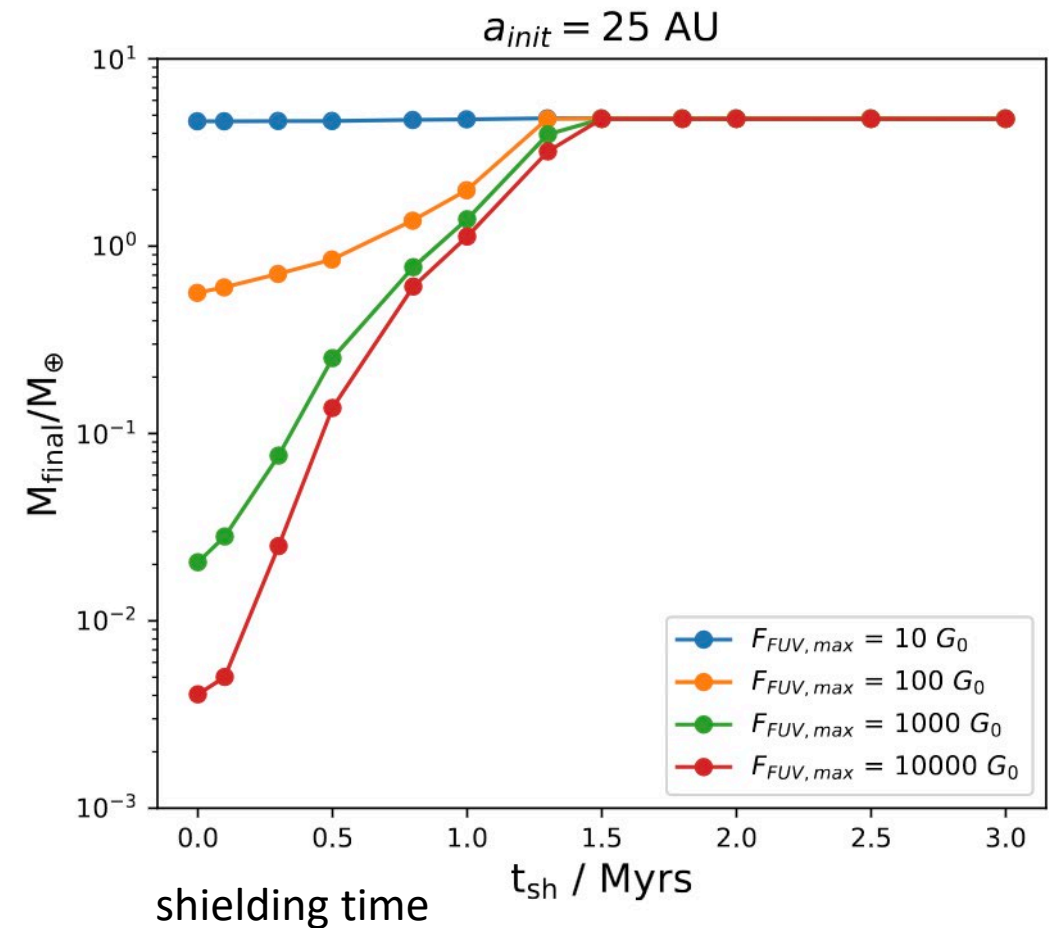
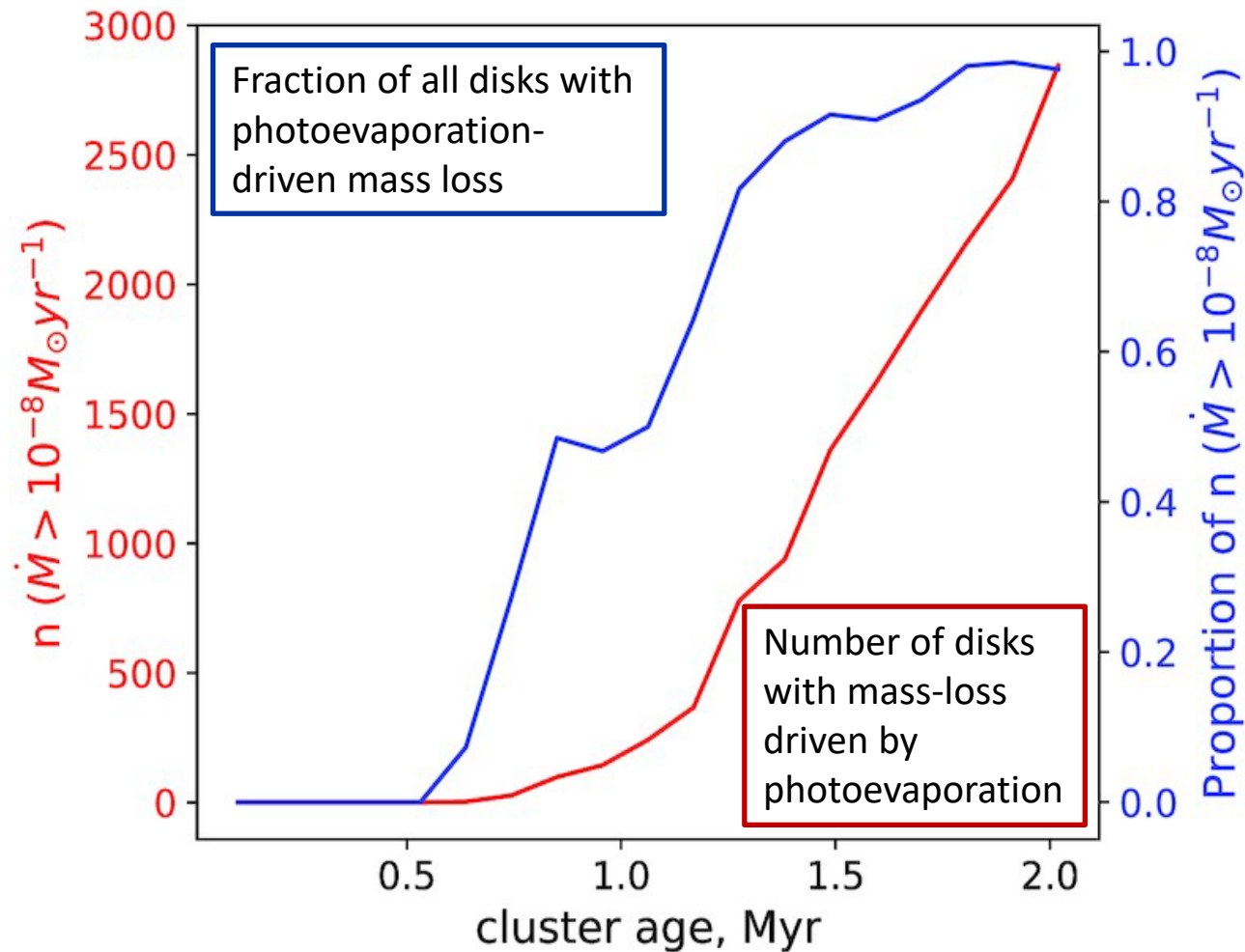
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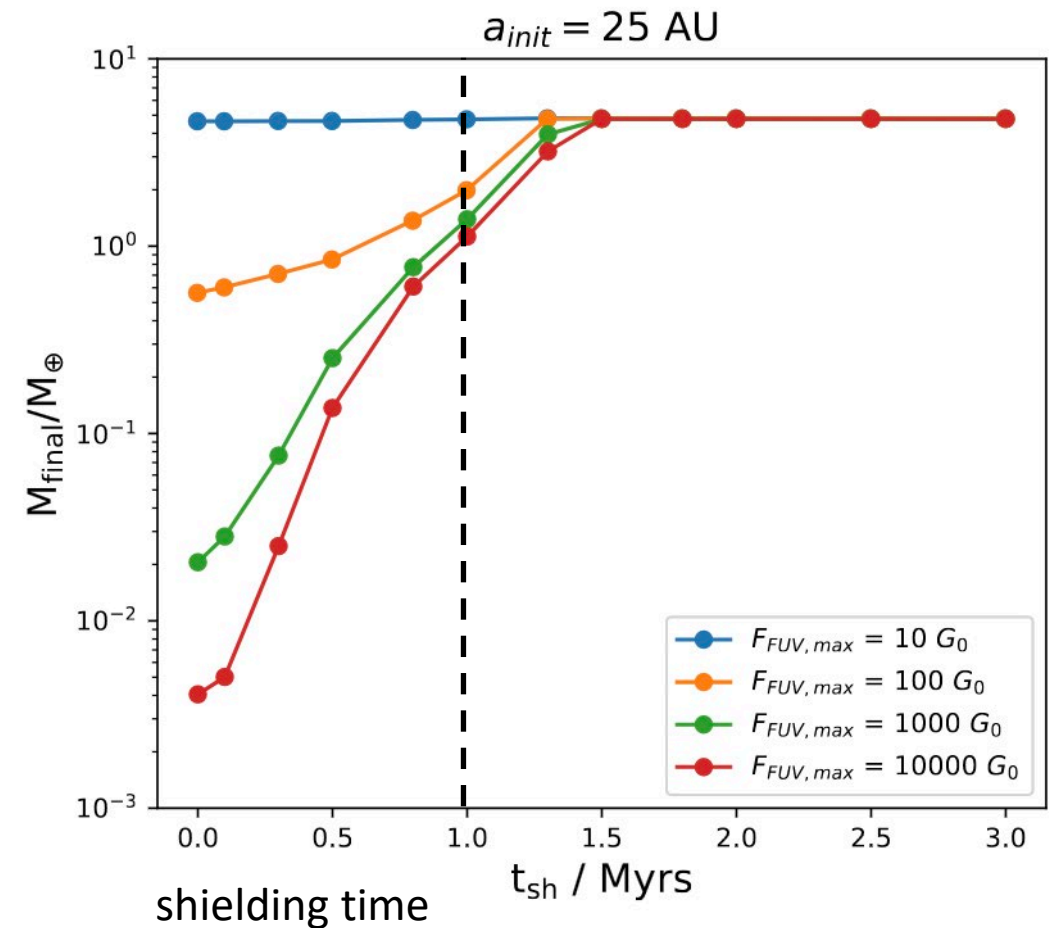
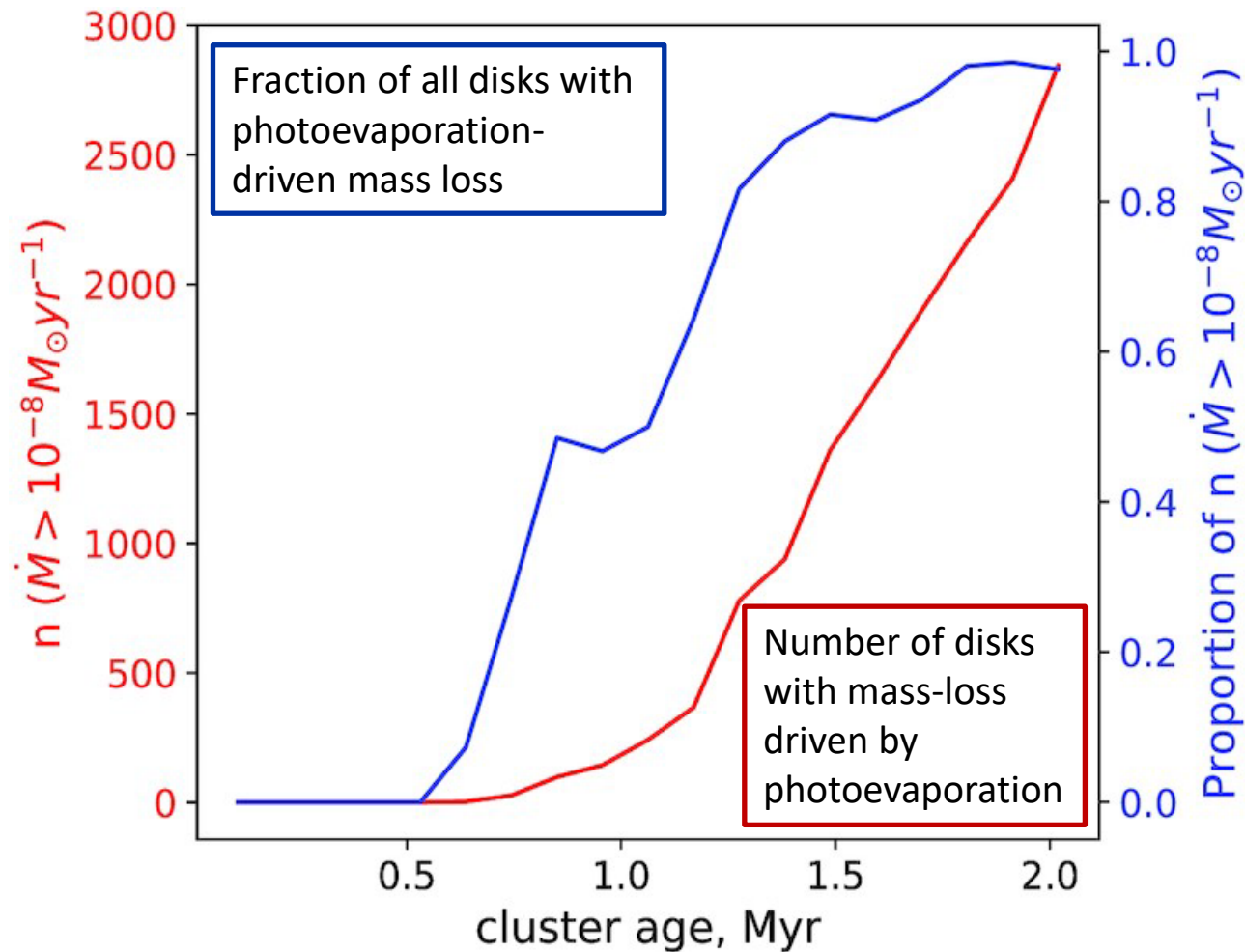
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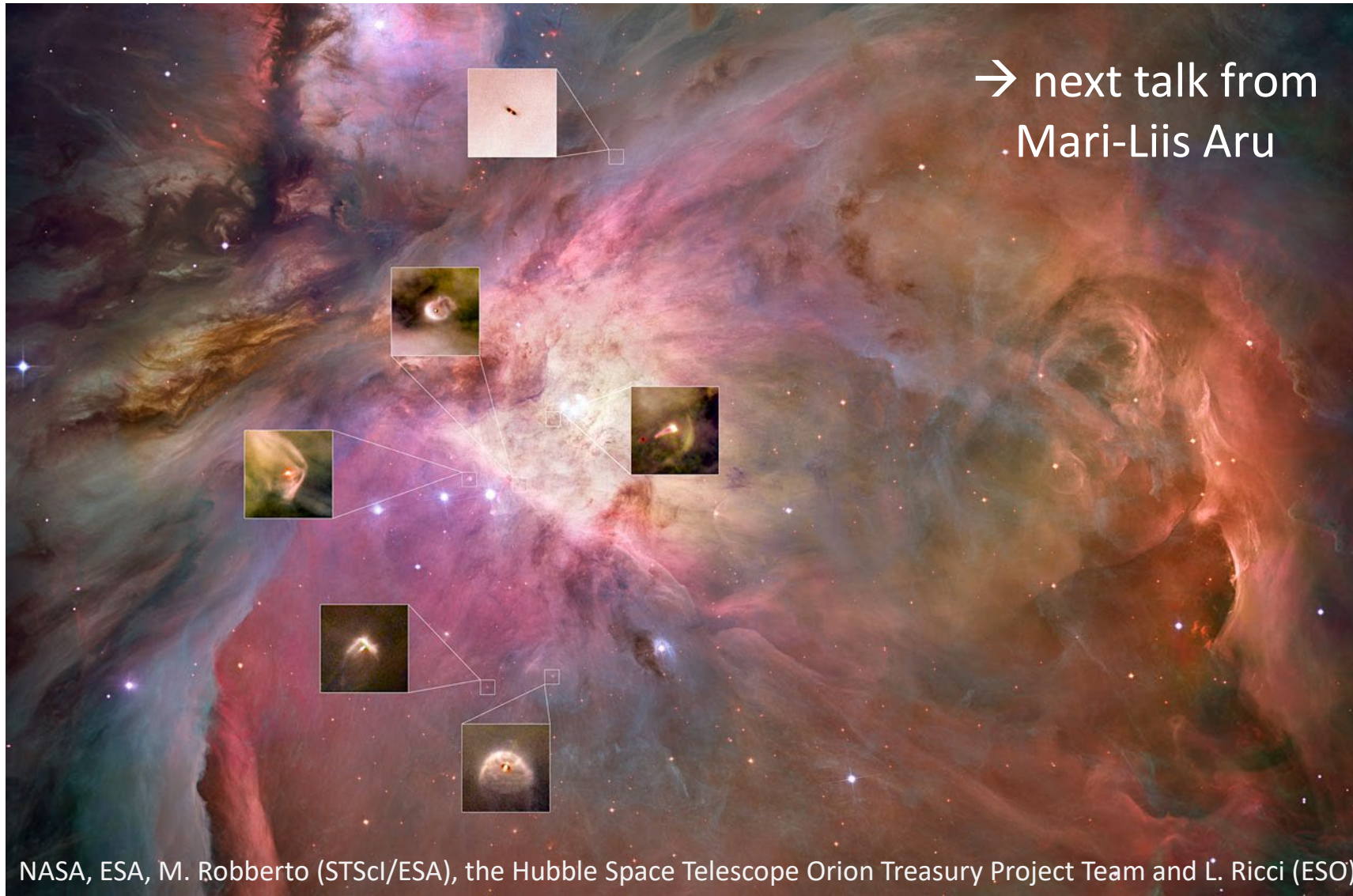
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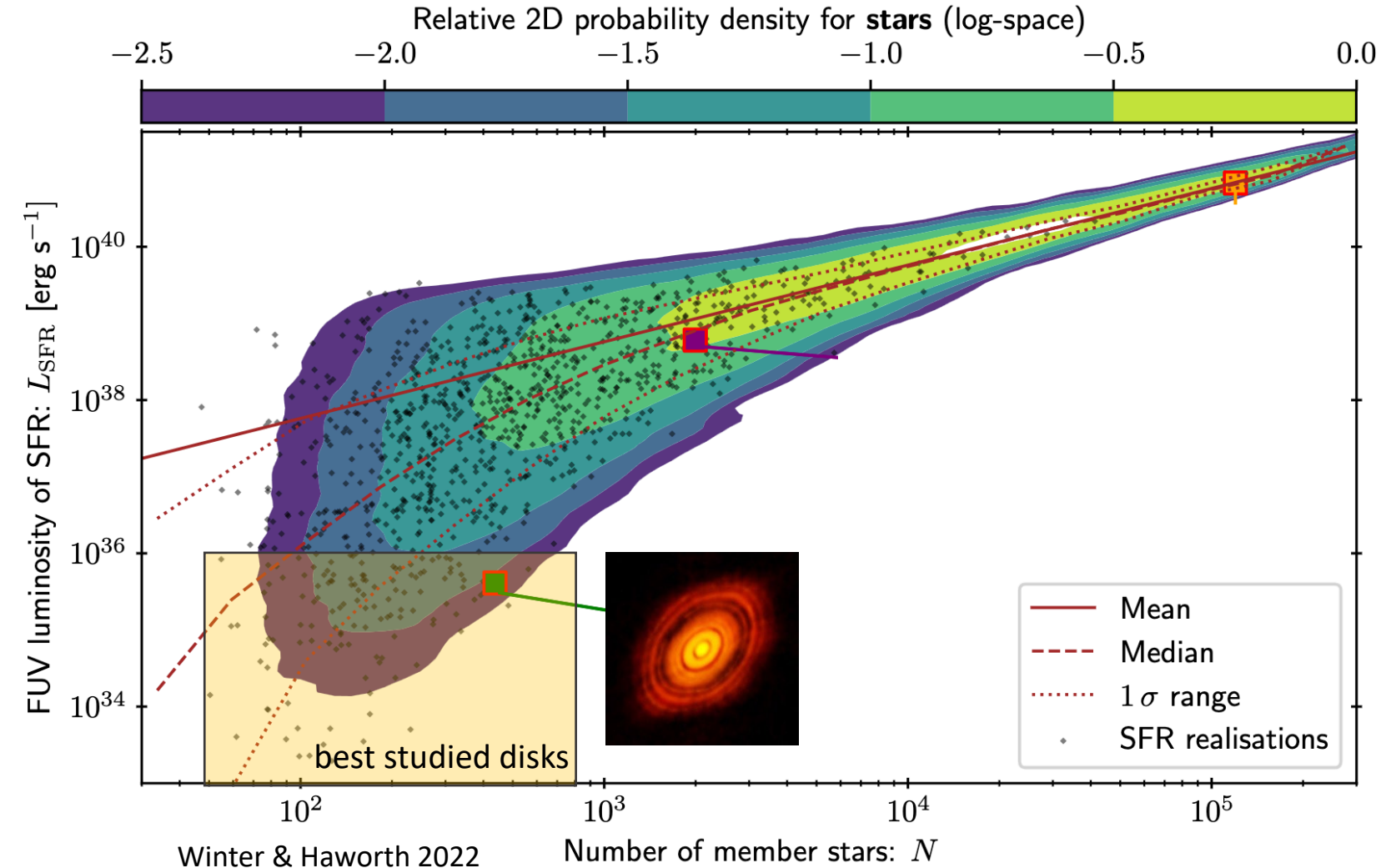
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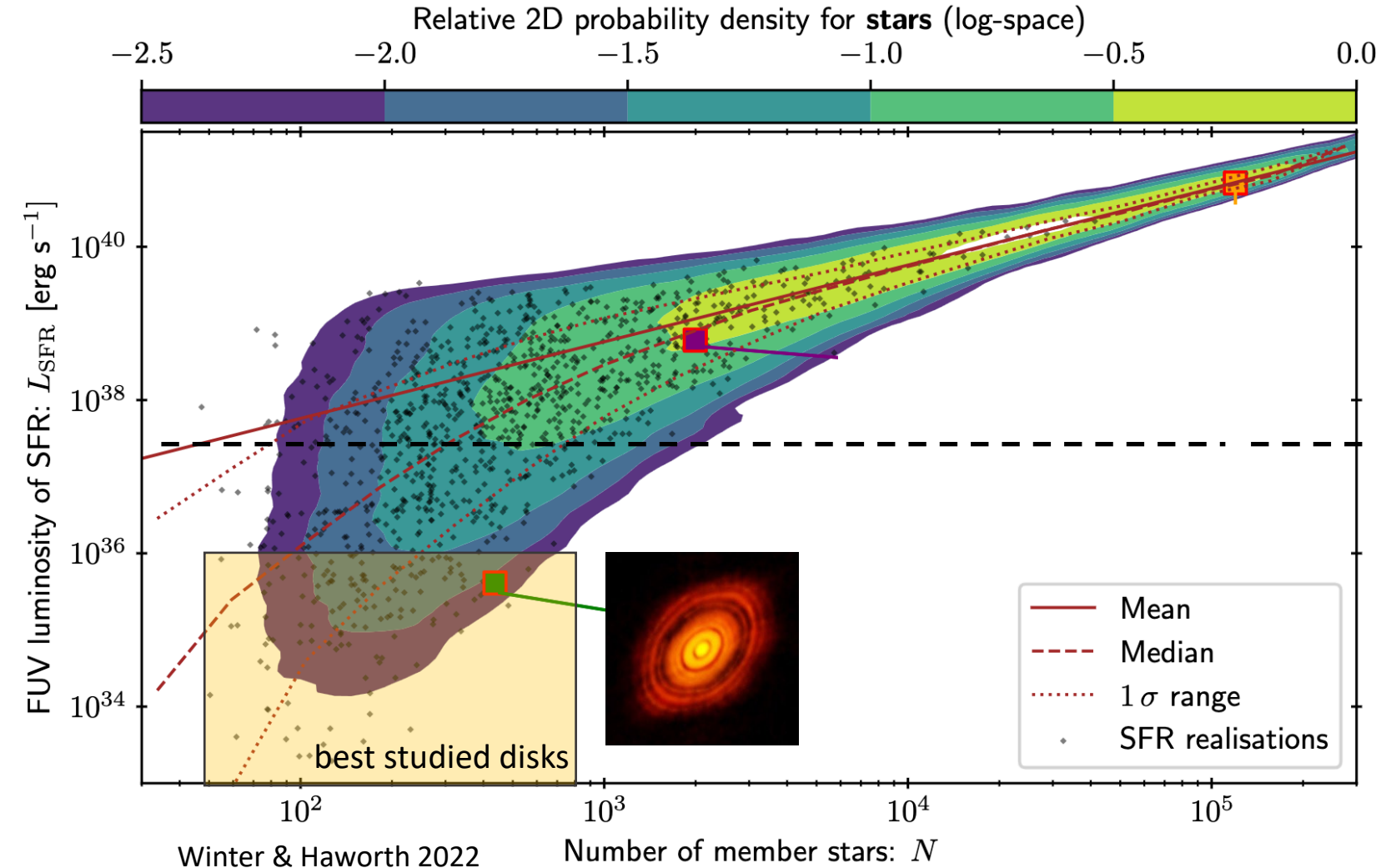
Photoevaporating protoplanetary disks (proplyds) are direct evidence of external photoevaporation of disks.



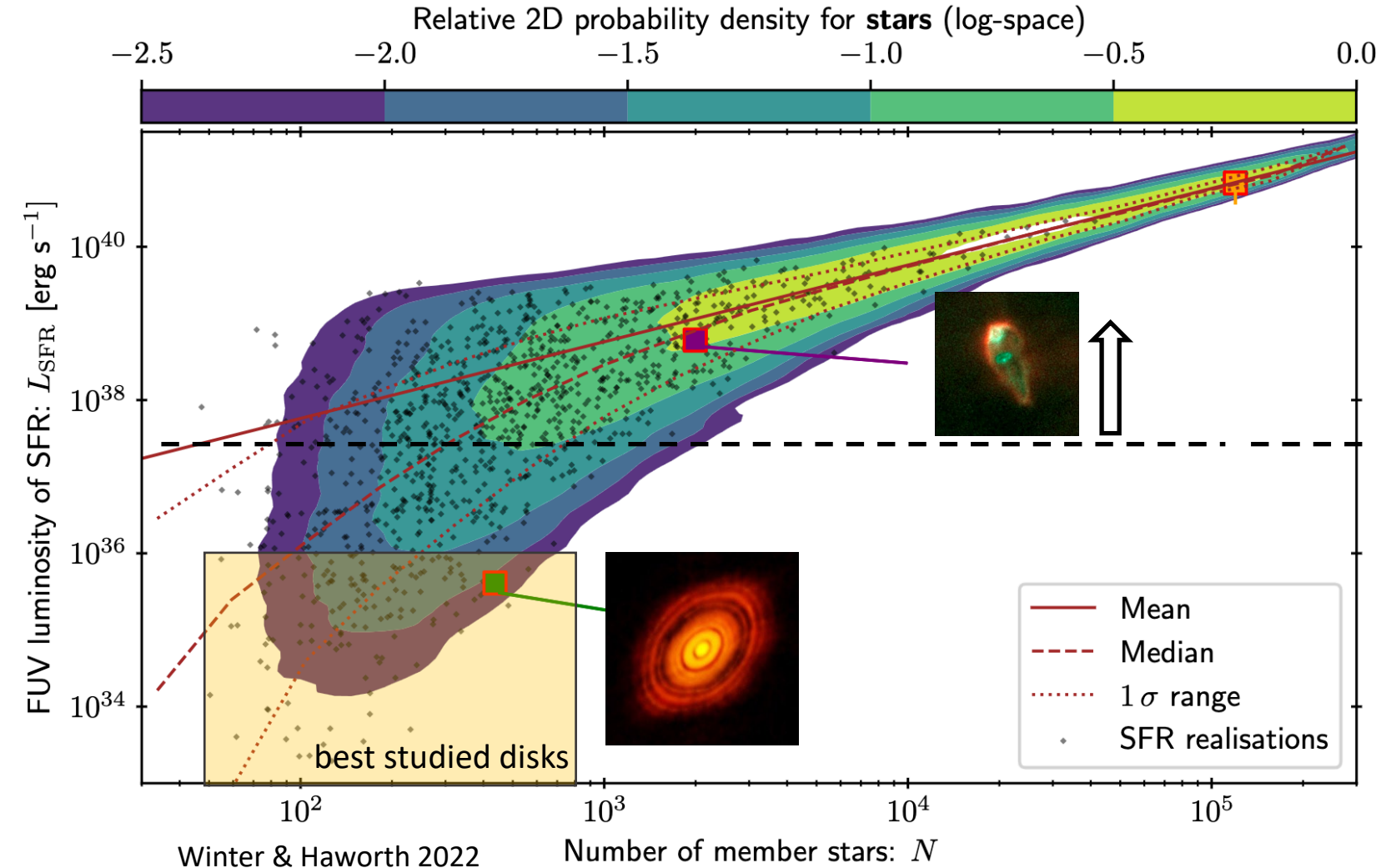
Most planet-forming disks will be affected by UV from nearby high-mass stars.



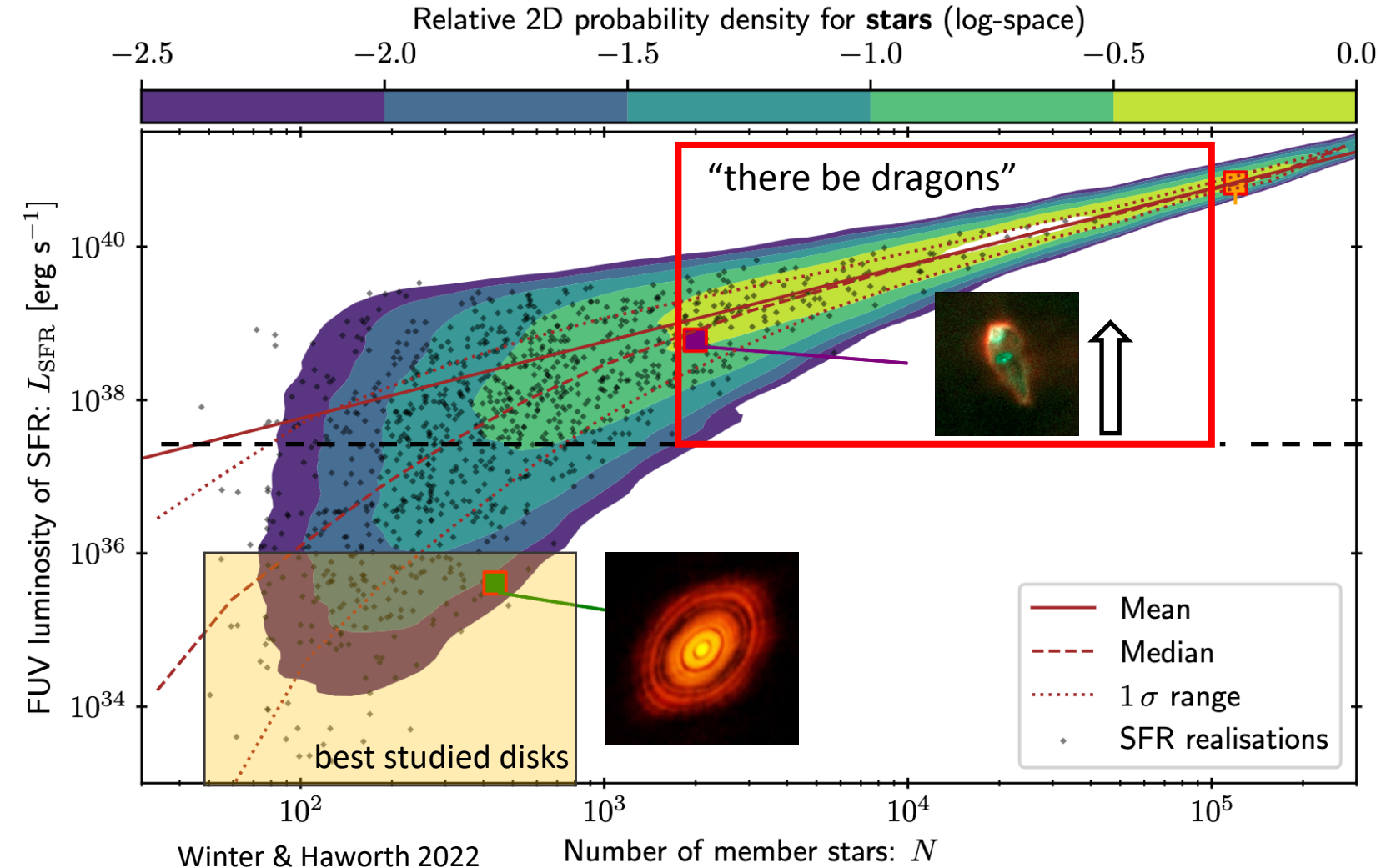
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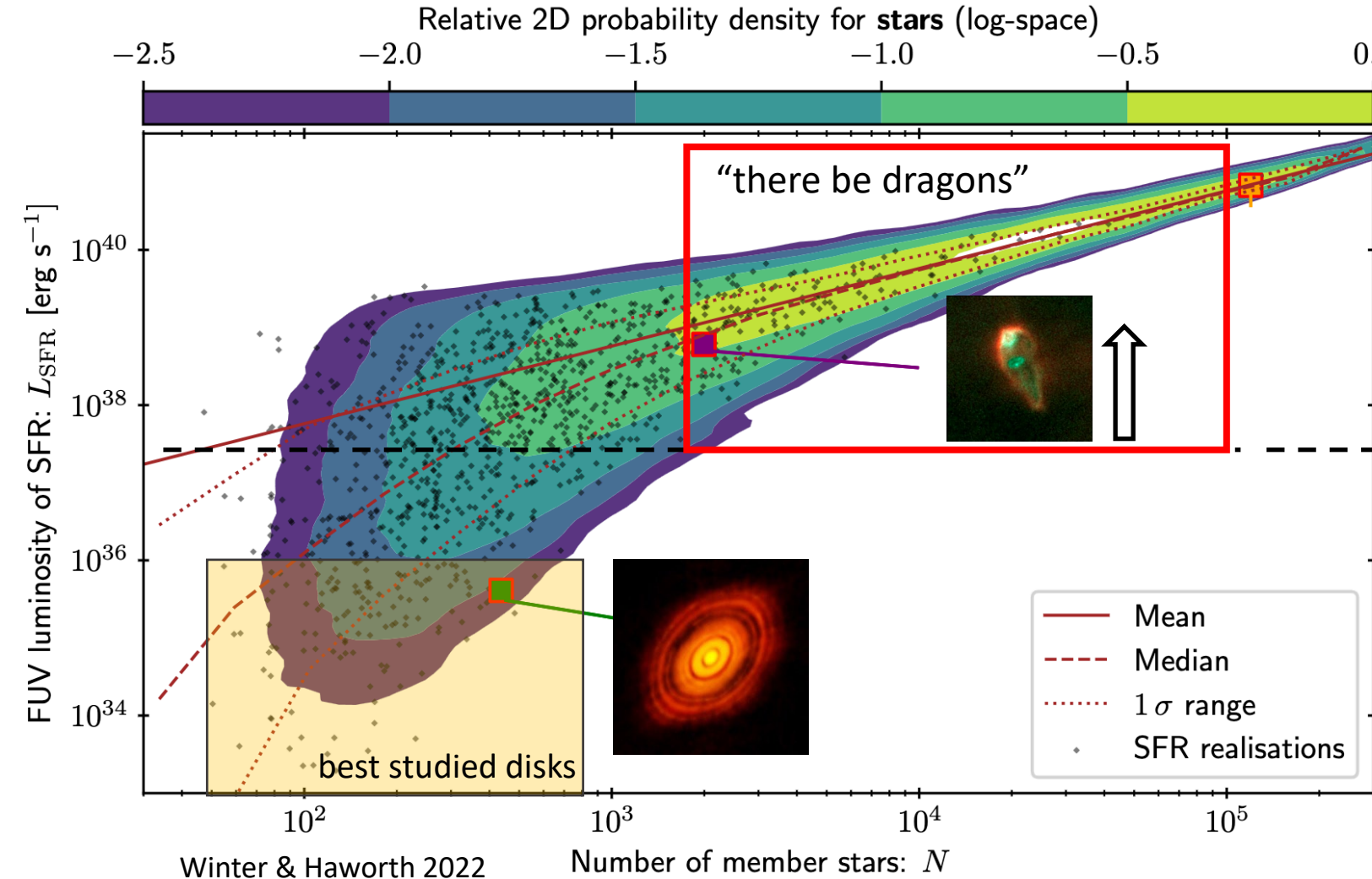
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Timescale: external UV destroys disks, reducing time & mass for planet formation

→ Need surveys of different high-mass regions – **MUSE!**



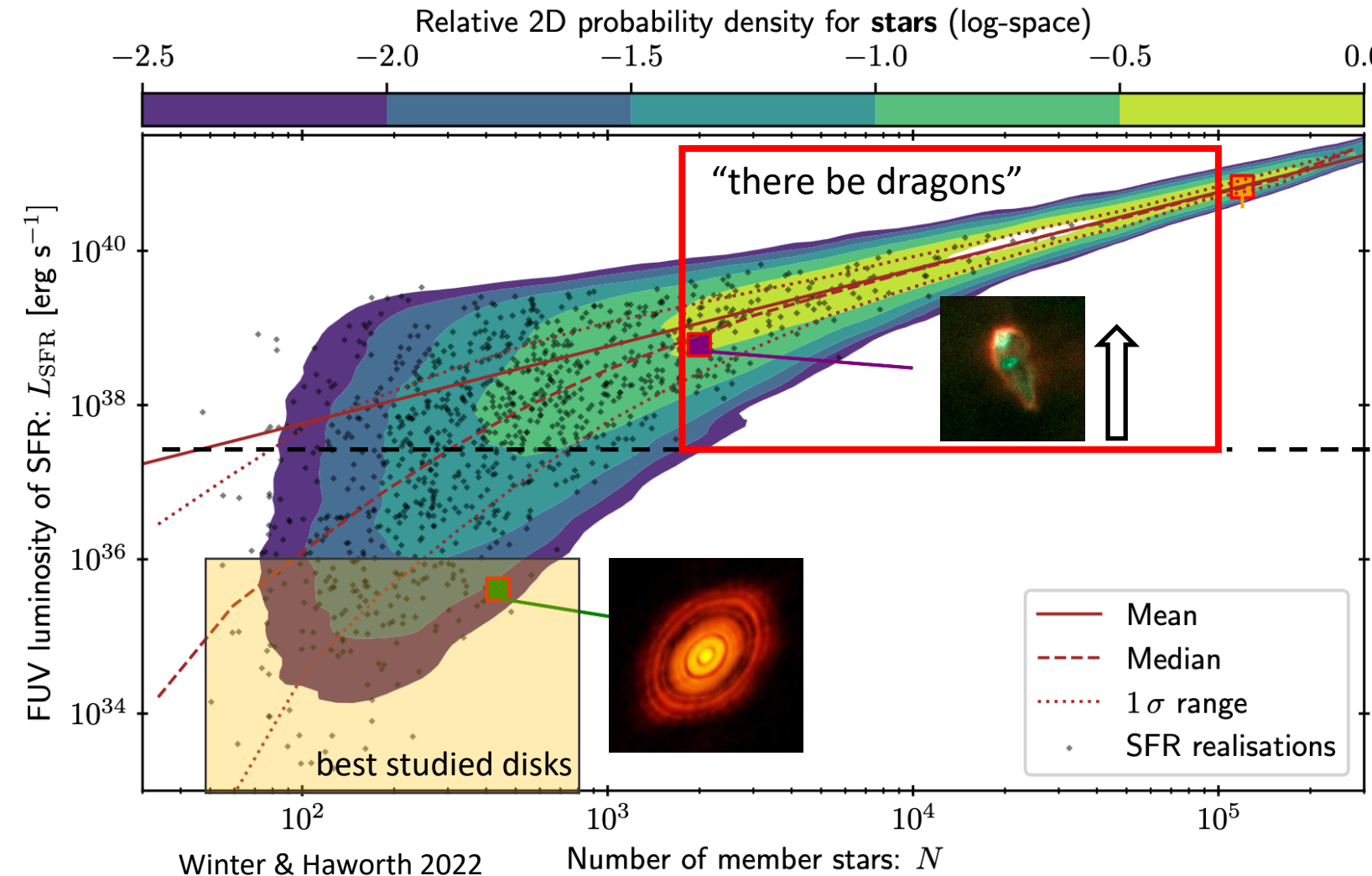
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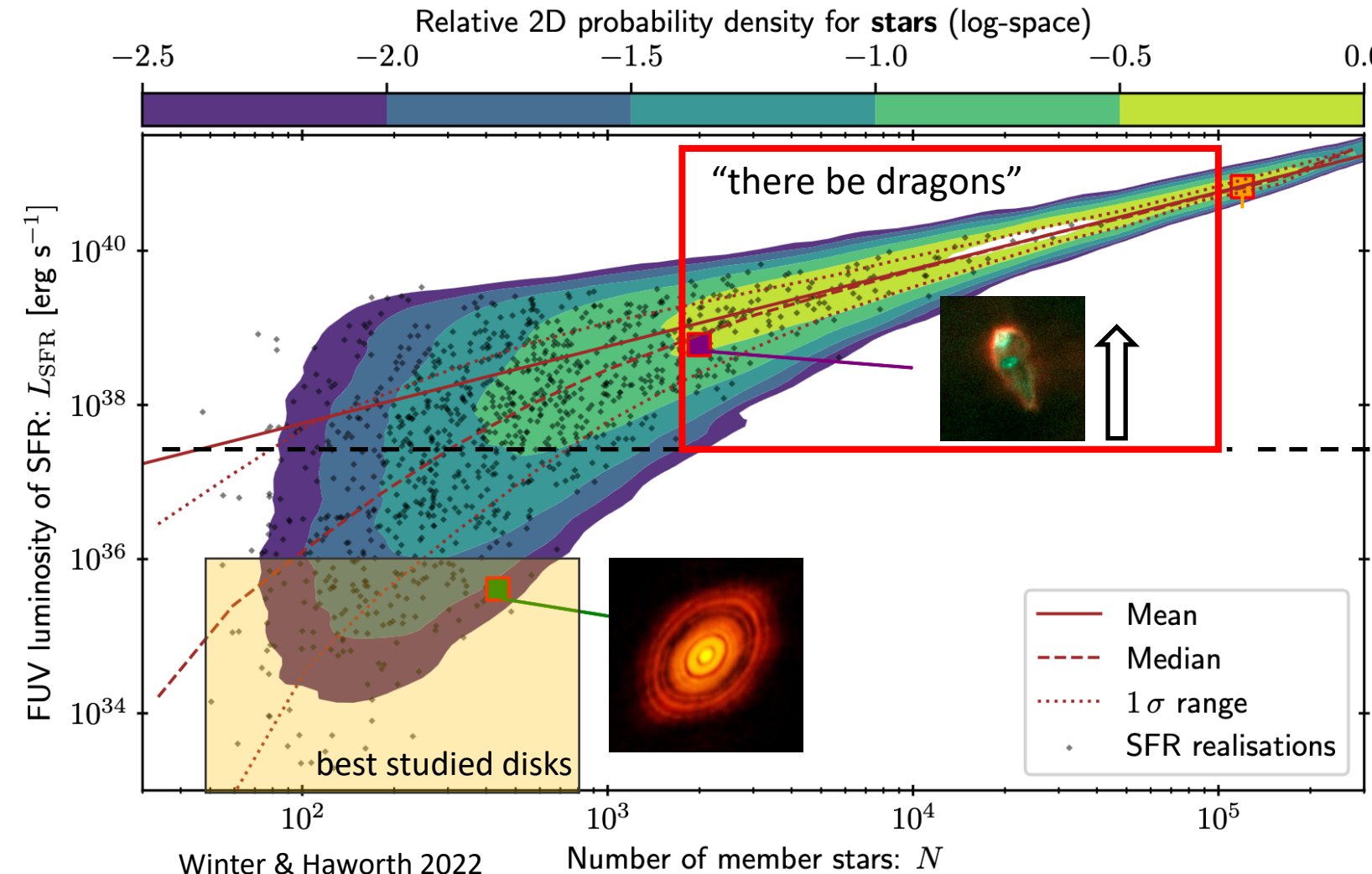
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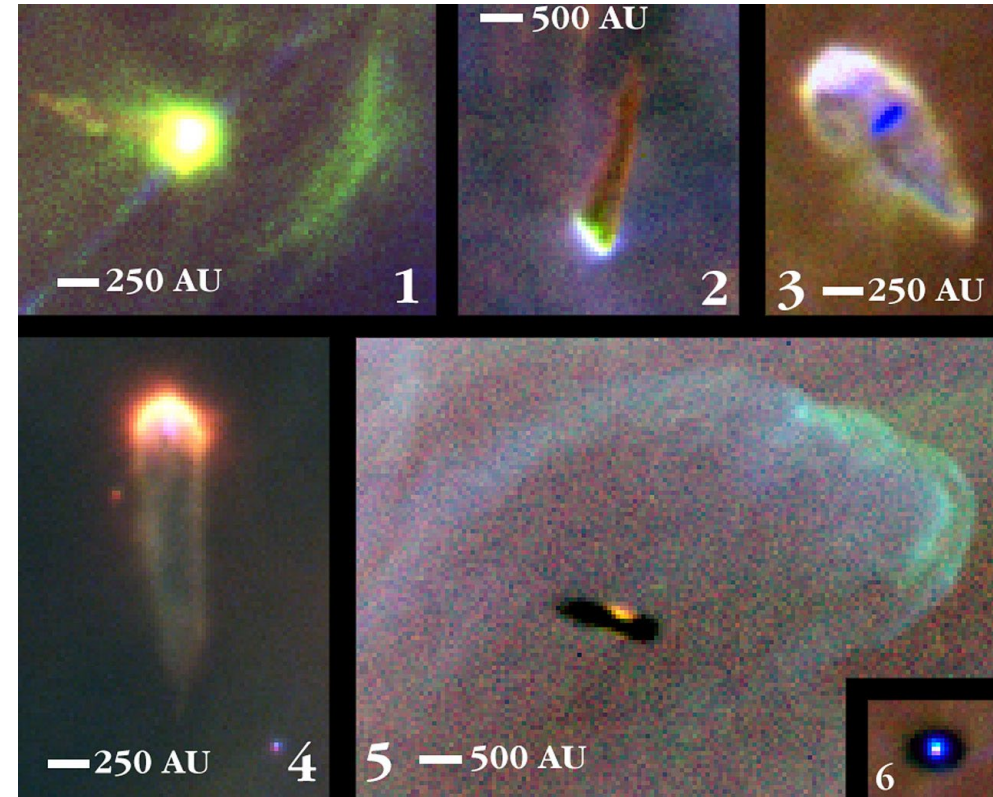
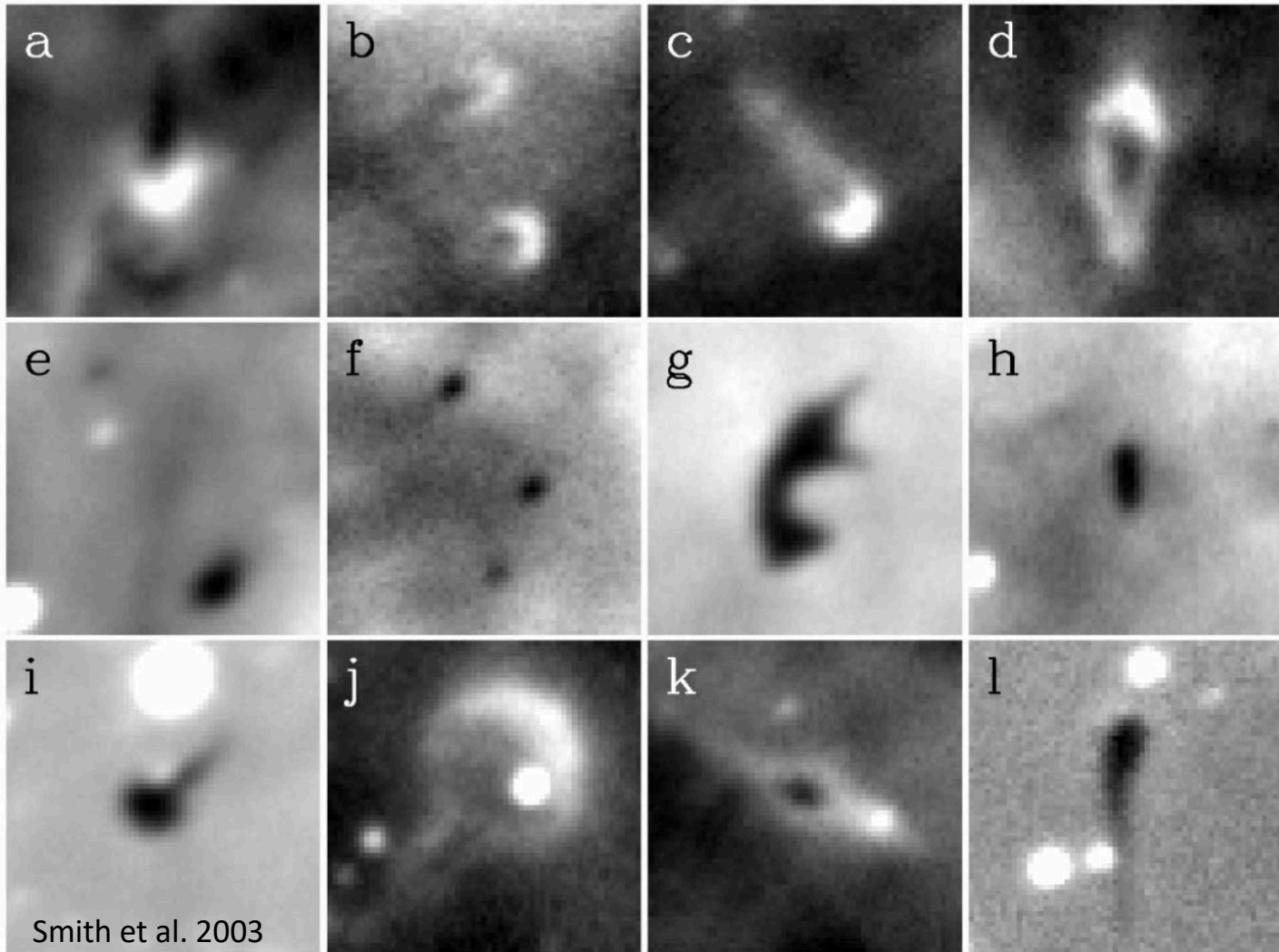
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Environment: evolution may be crucial to understand the demographics of exoplanets

→ Need to measure the local gas/dust environment – **MUSE!**

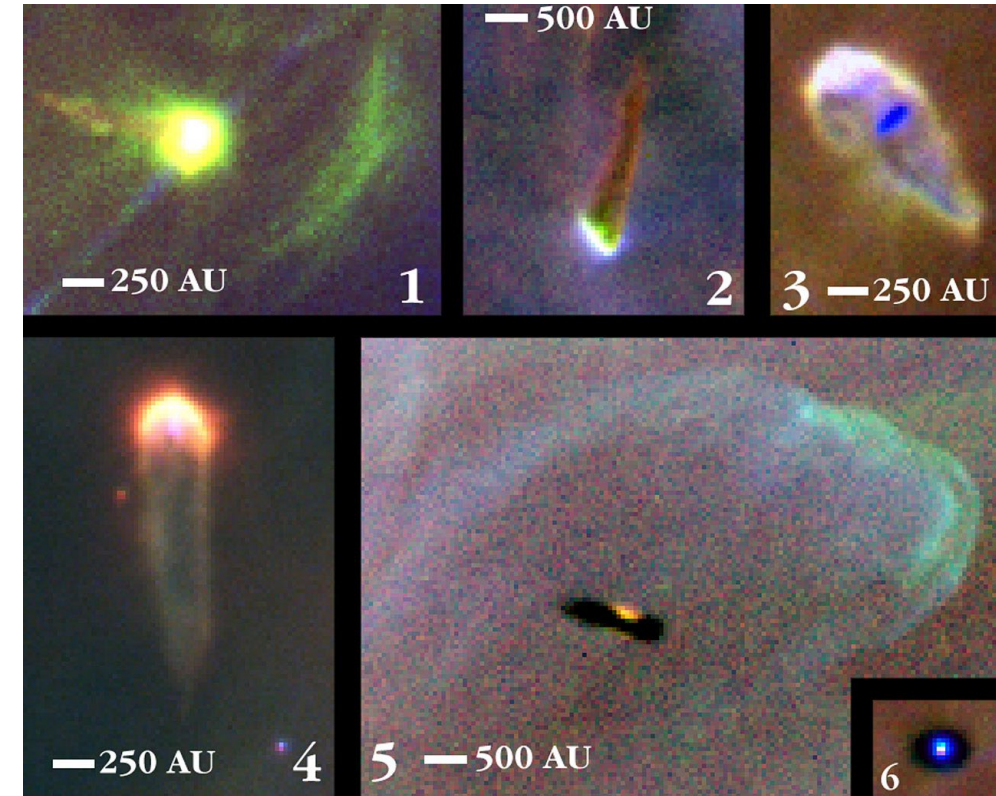
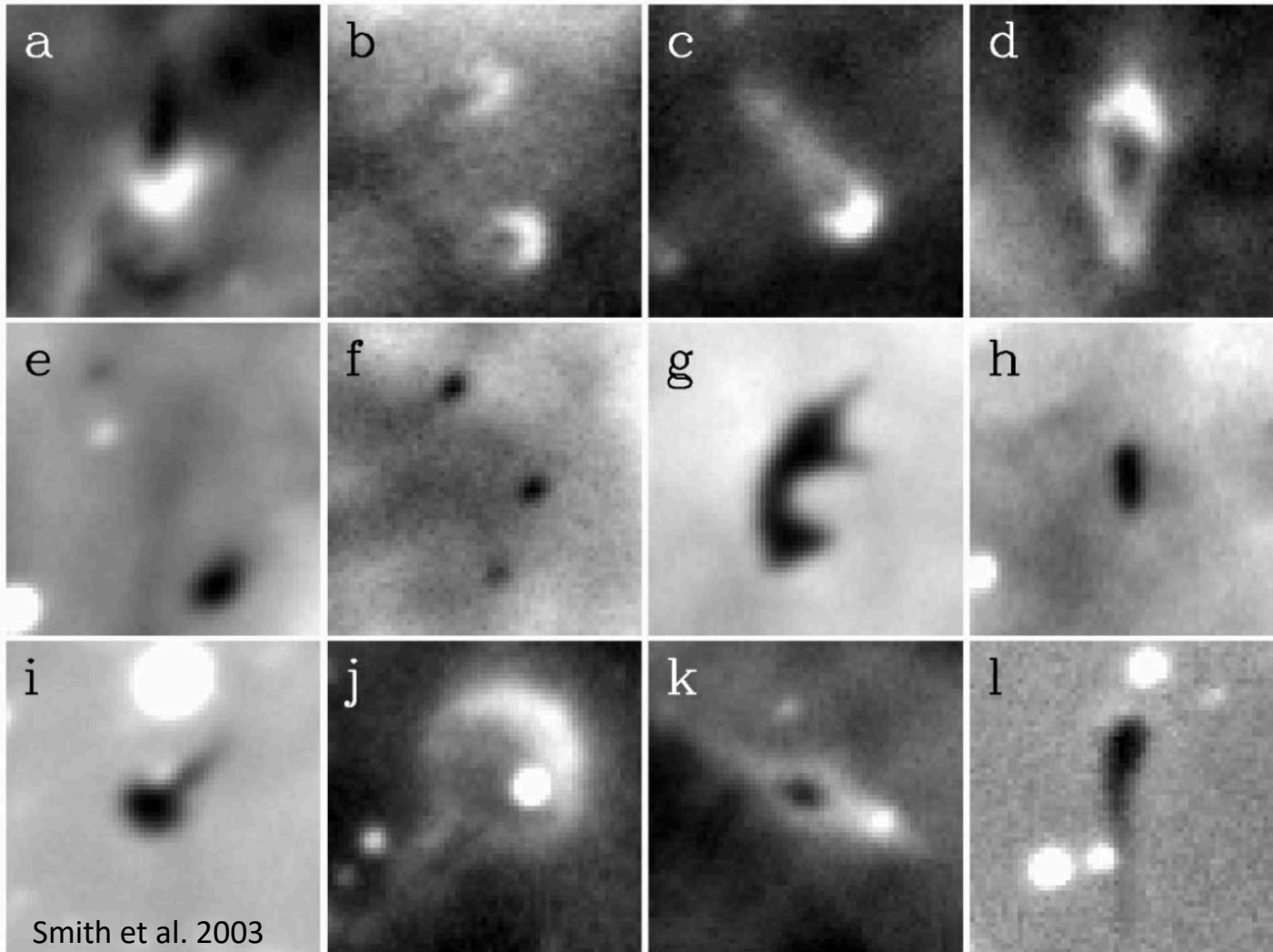


True proplyds are small, $\sim 250\text{-}500$ AU, not well-resolved for $d \geq 2$ kpc even with MUSE NFM.



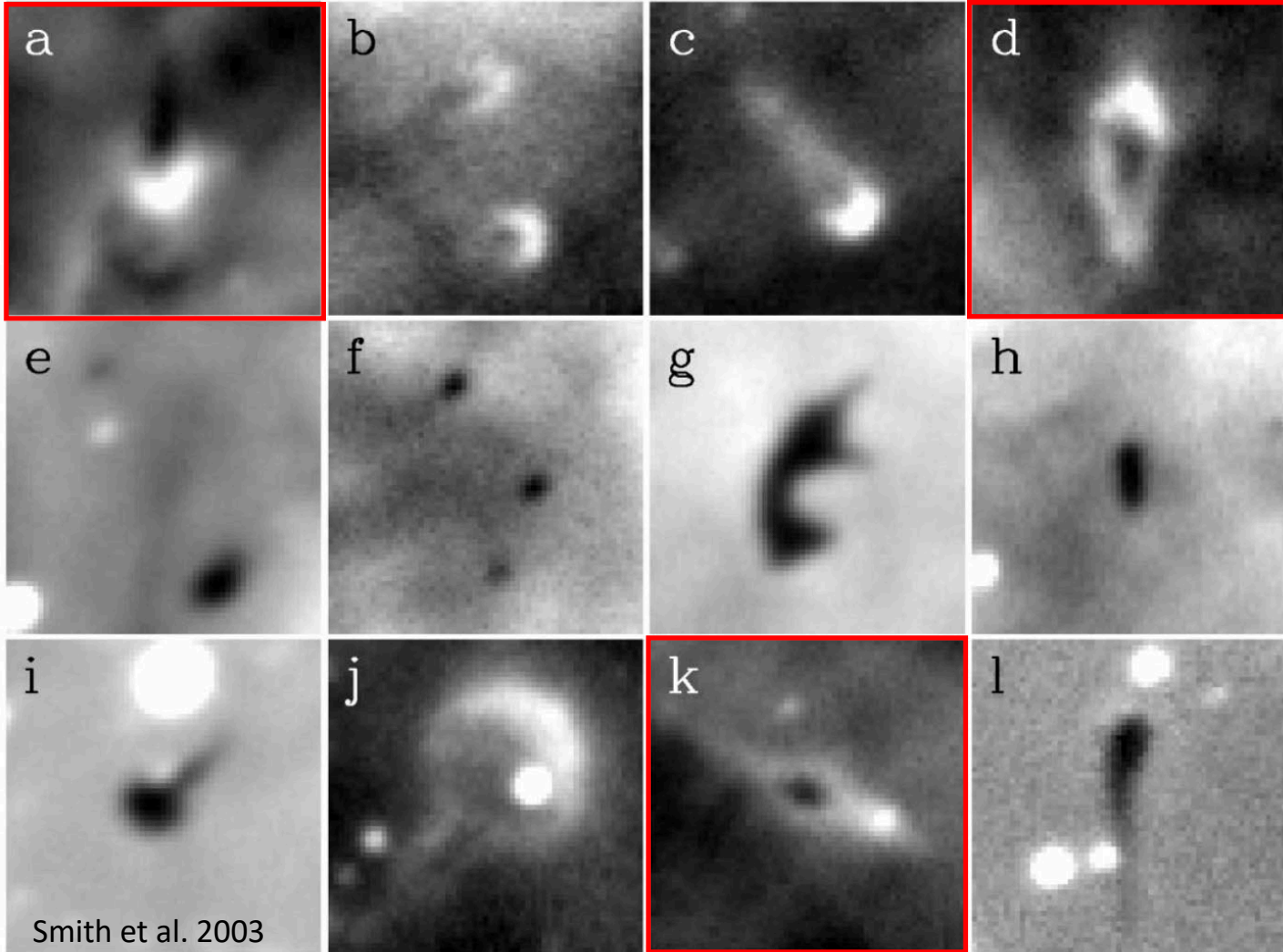
ESA/Hubble

Most published candidates are evaporating gaseous globules; need ELT to resolve proplyds in $d \geq 2$ kpc regions.

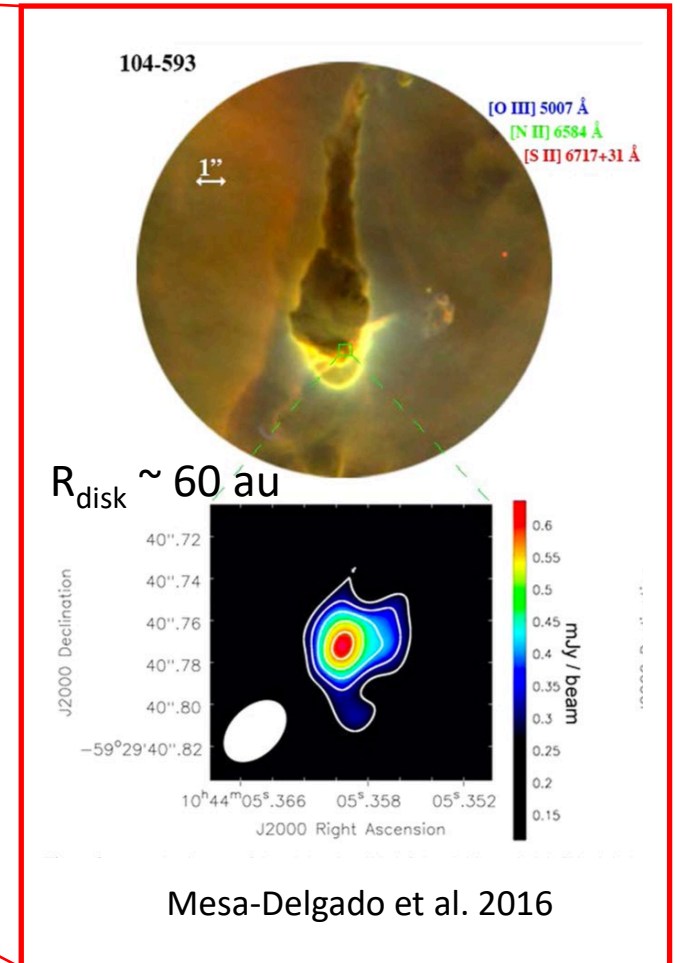
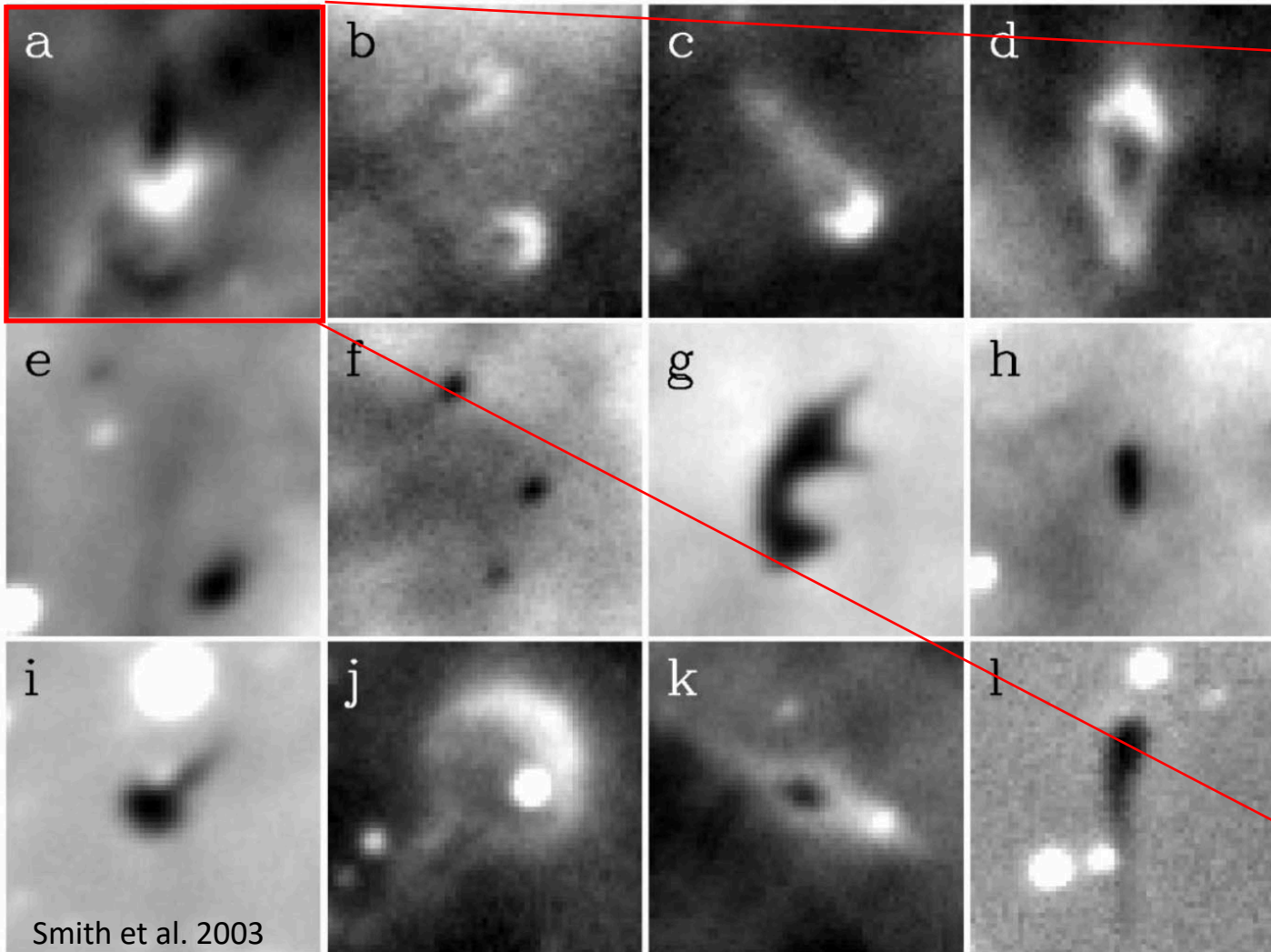


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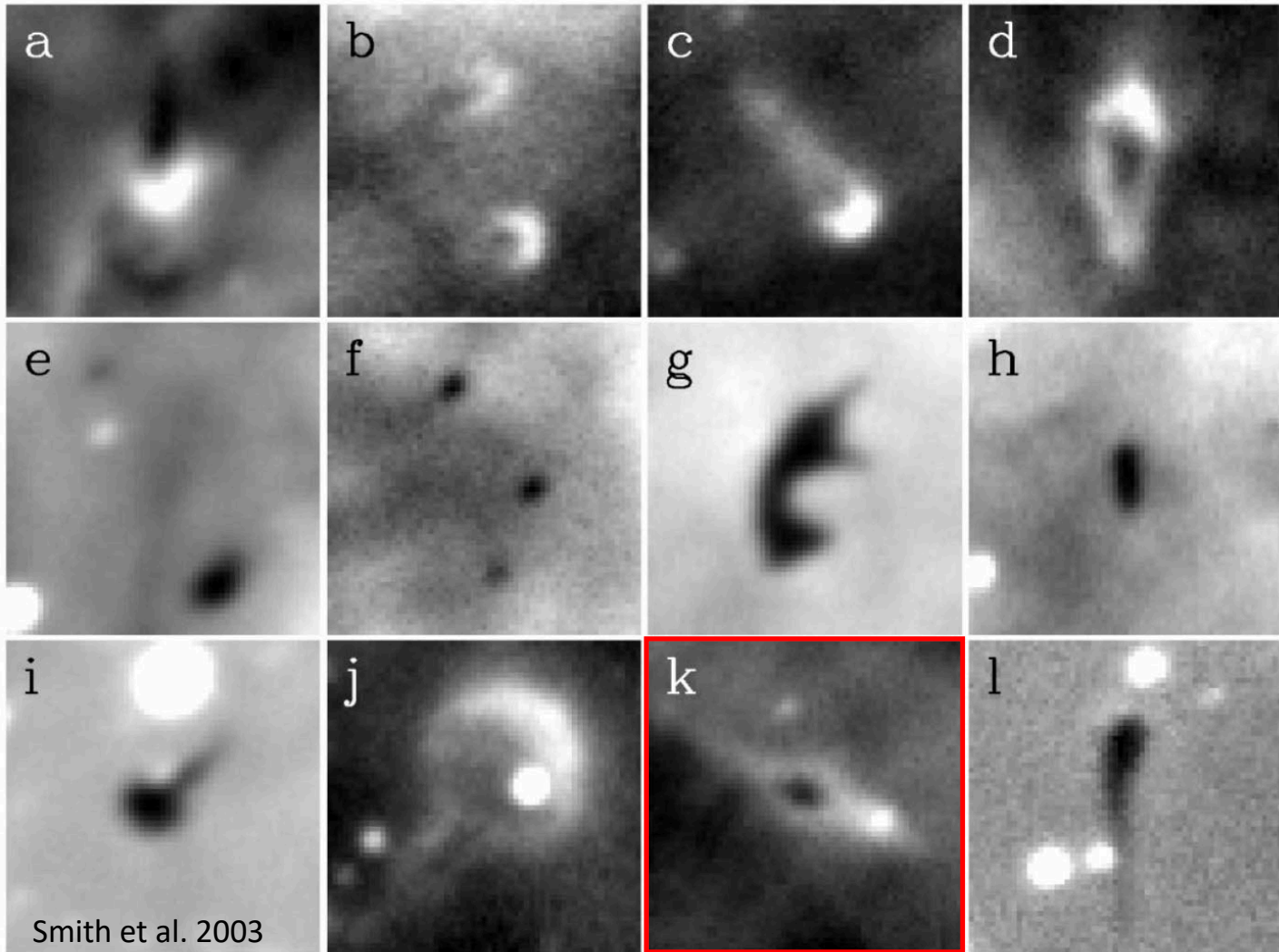


Protostellar jets have enabled the first and so far only ALMA observations of disks in $d \geq 2$ kpc regions.

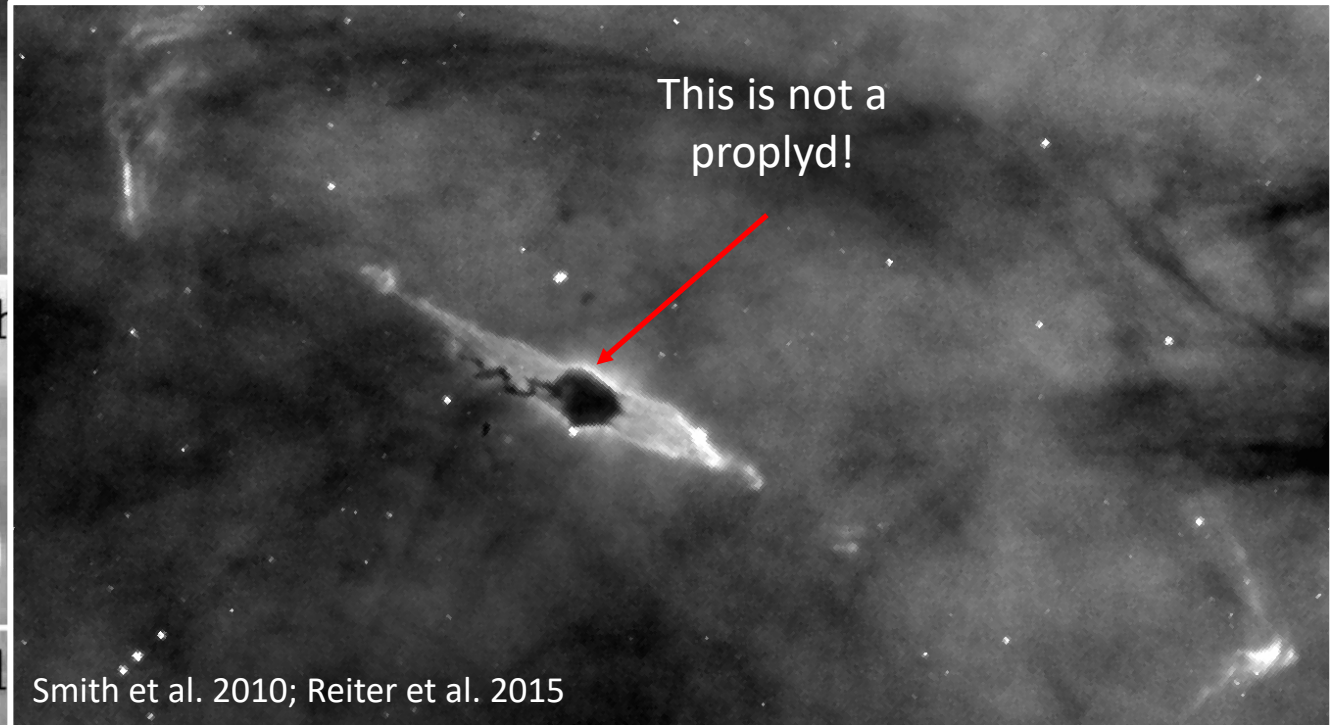
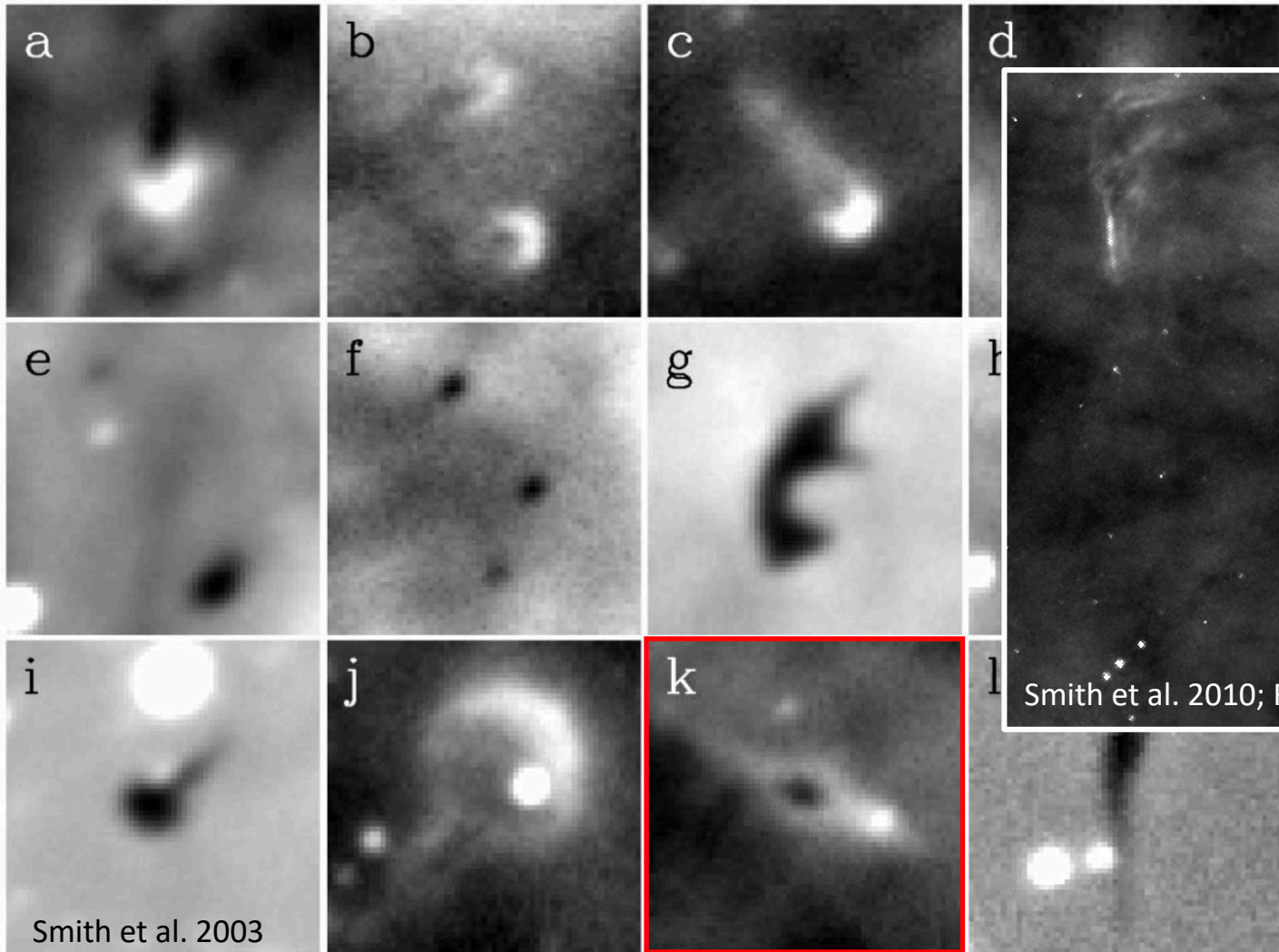


→ see also Cortes-Rangel et al. 2020, 2023, Reiter et al. 2020

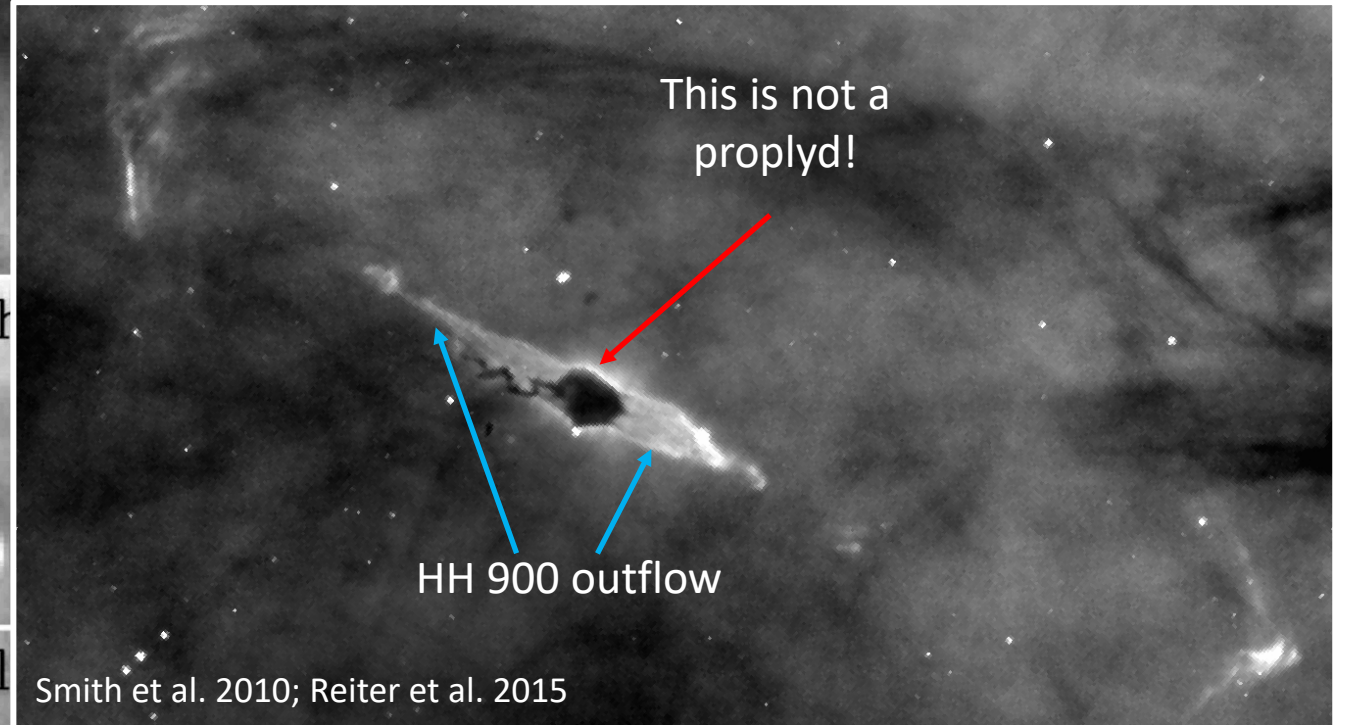
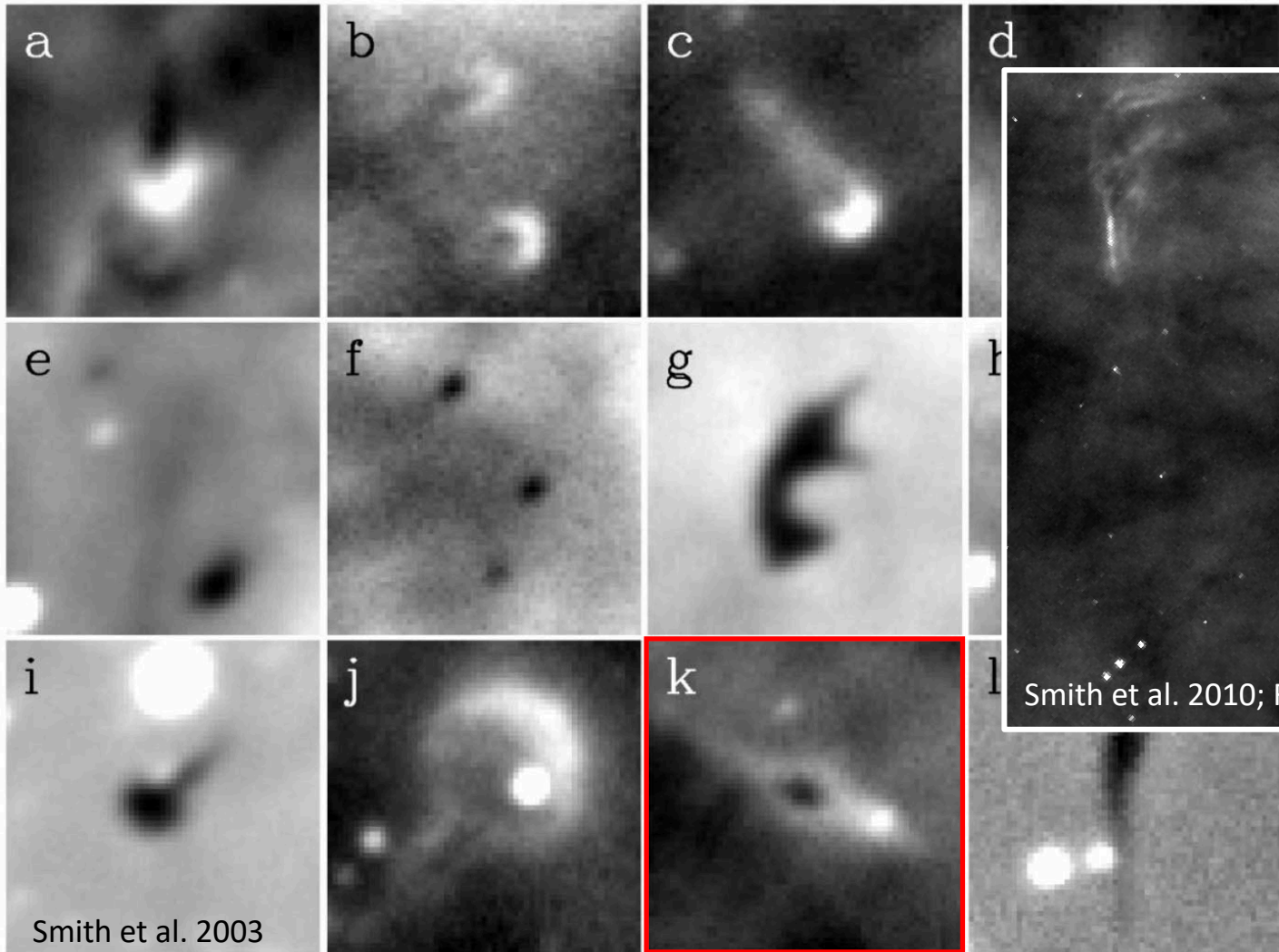
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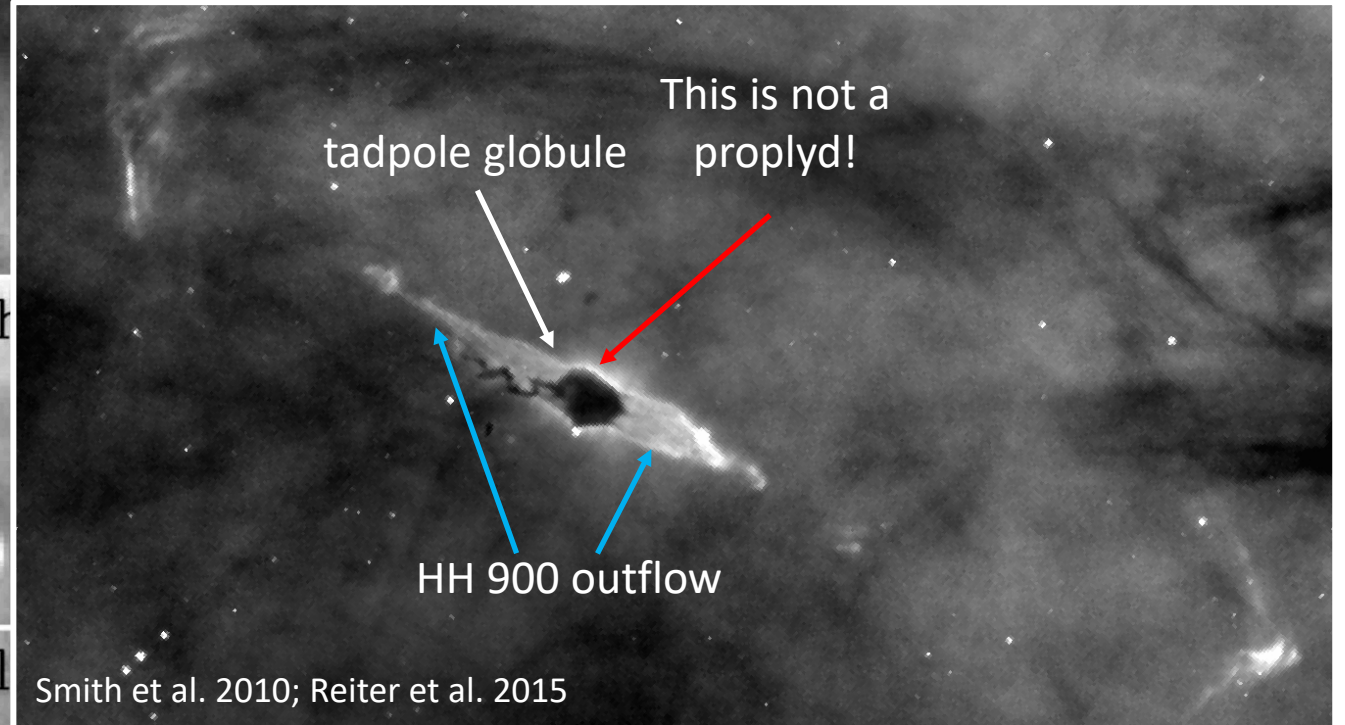
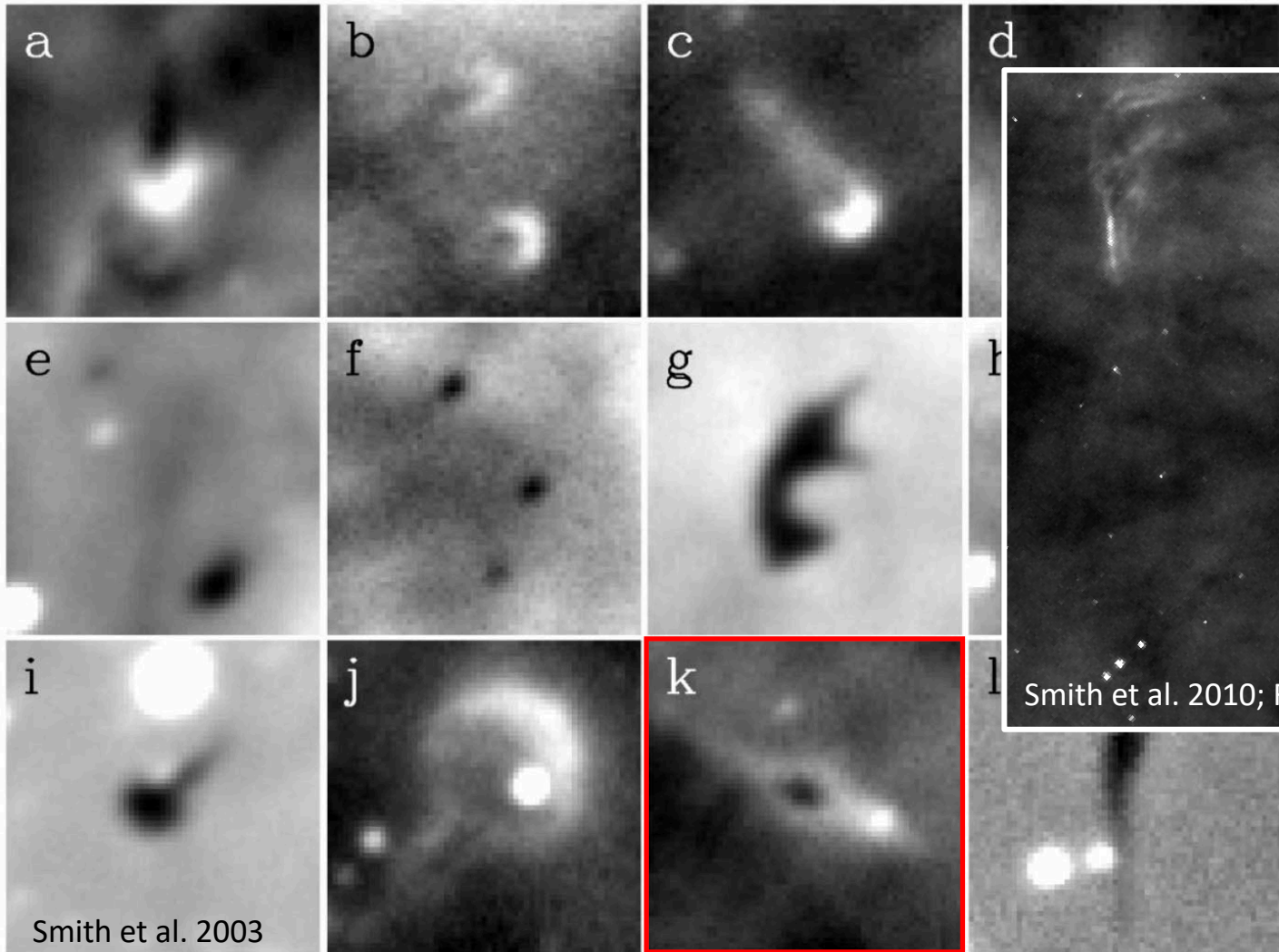
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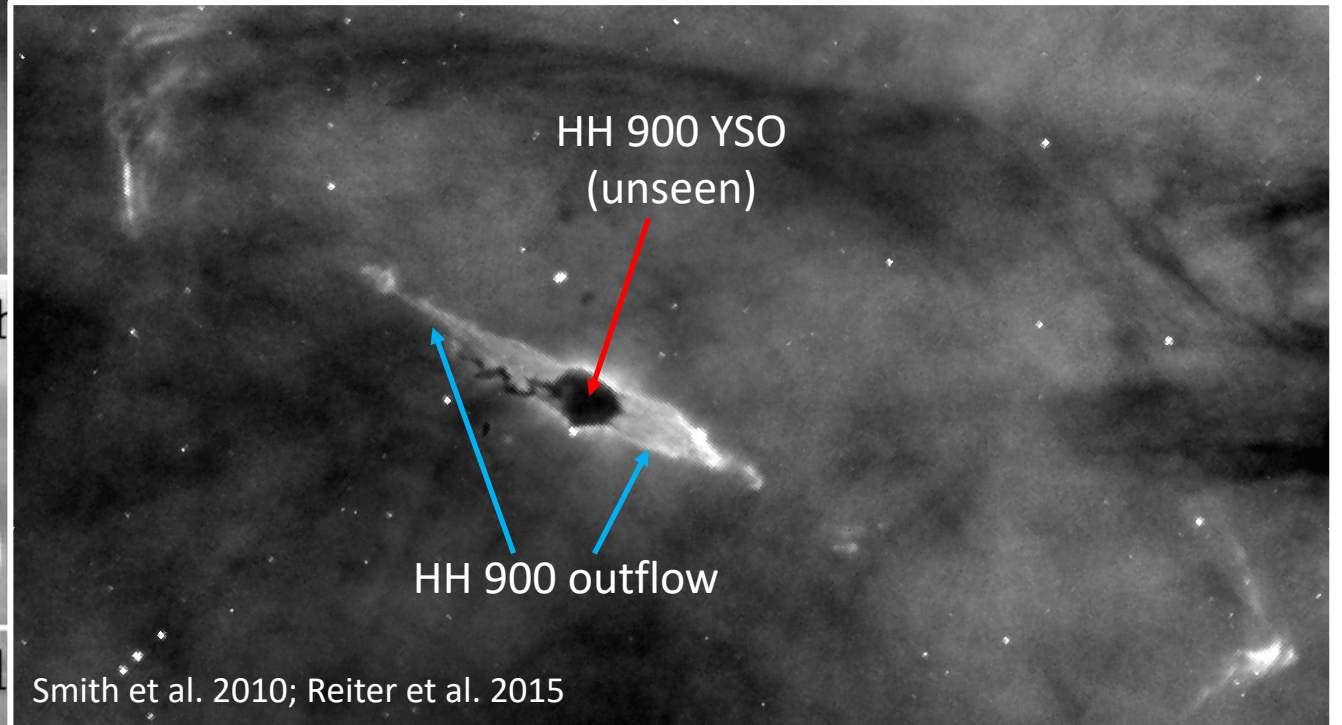
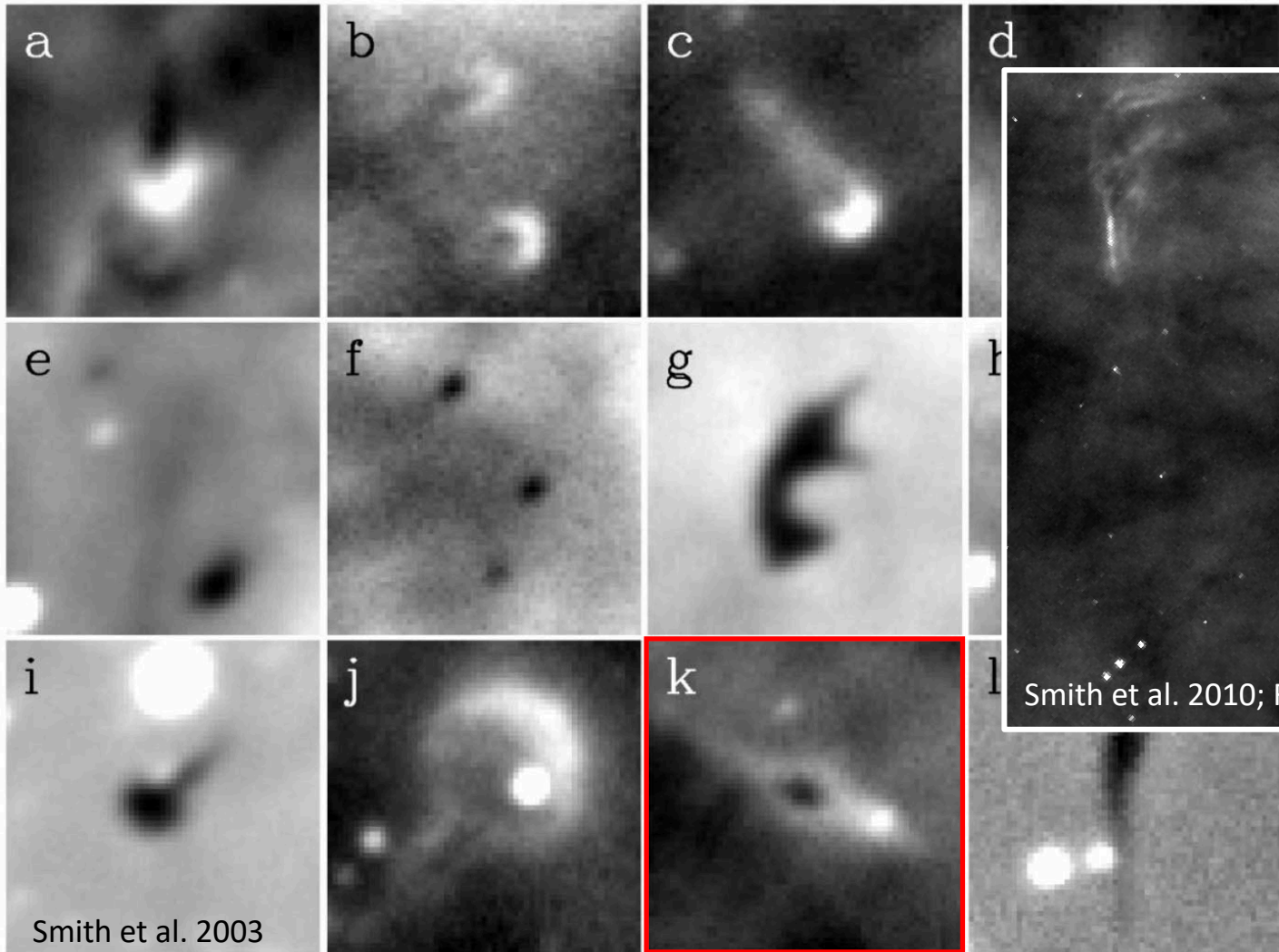
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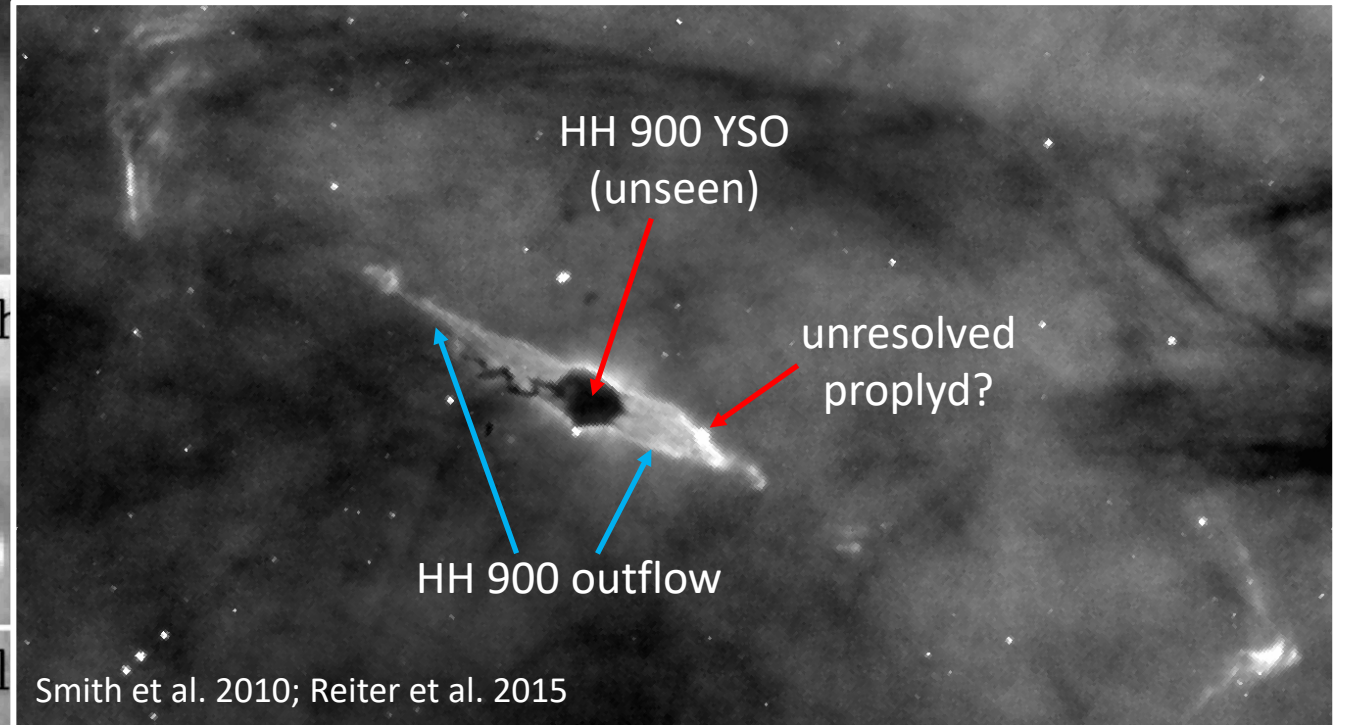
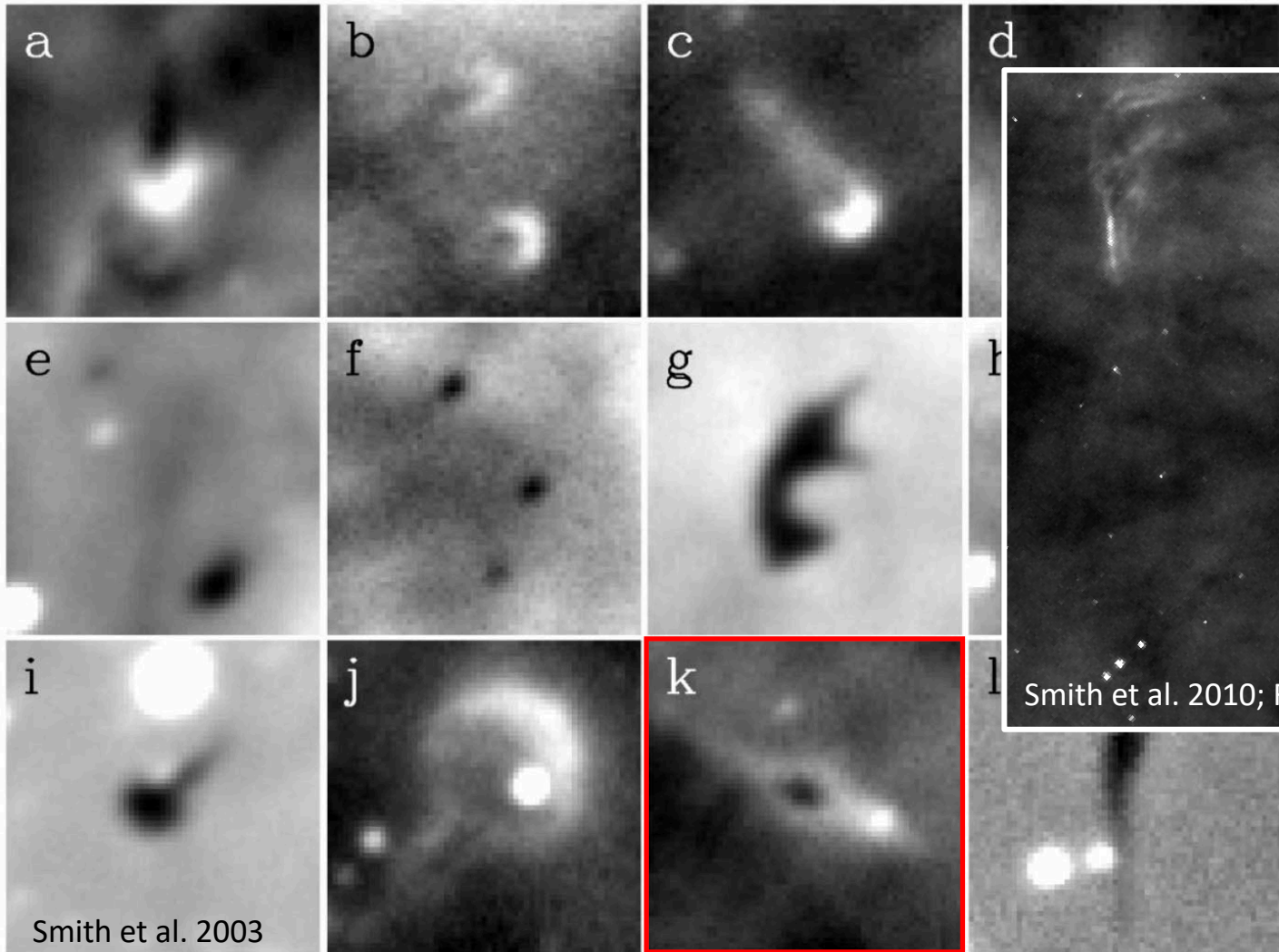
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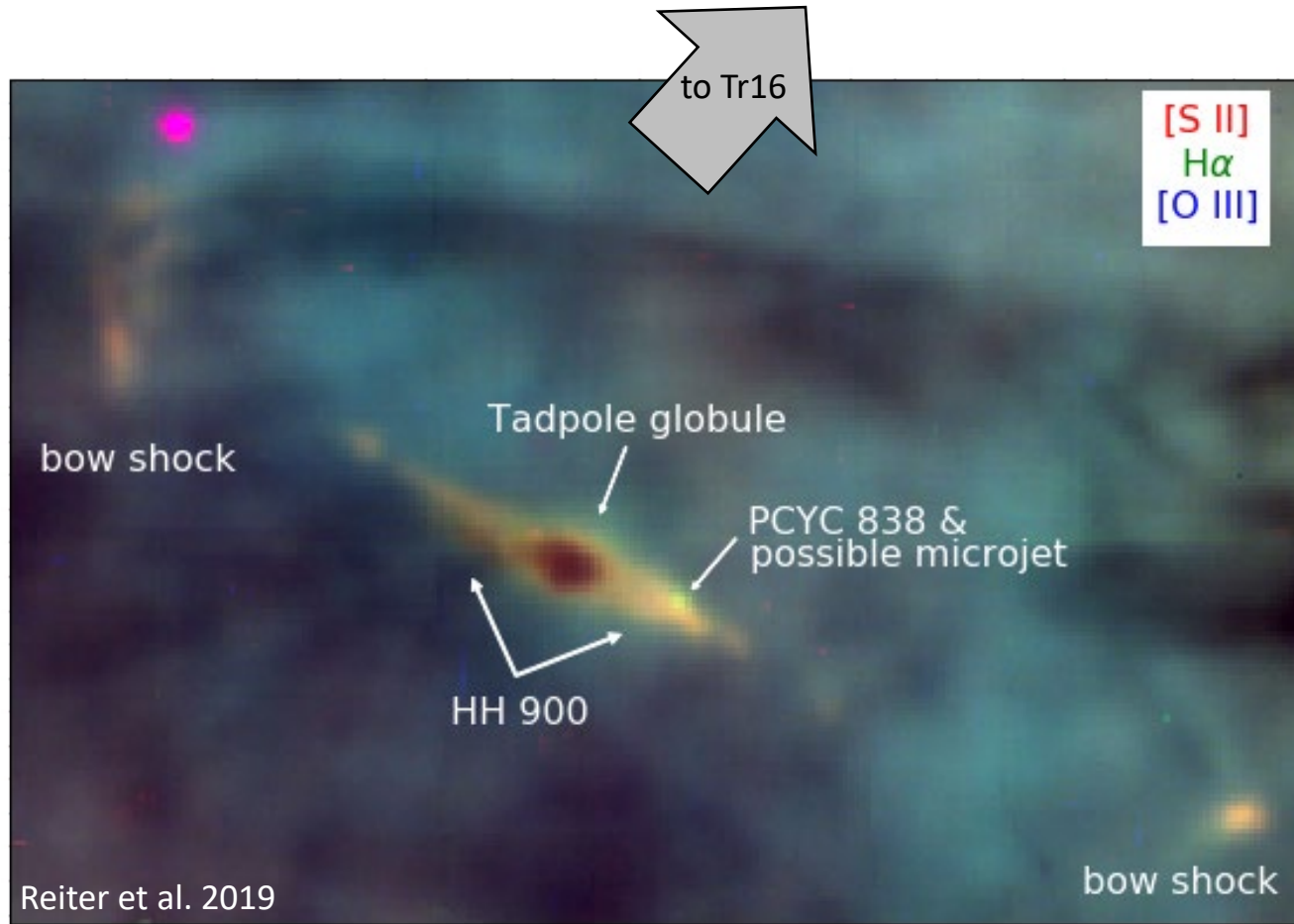
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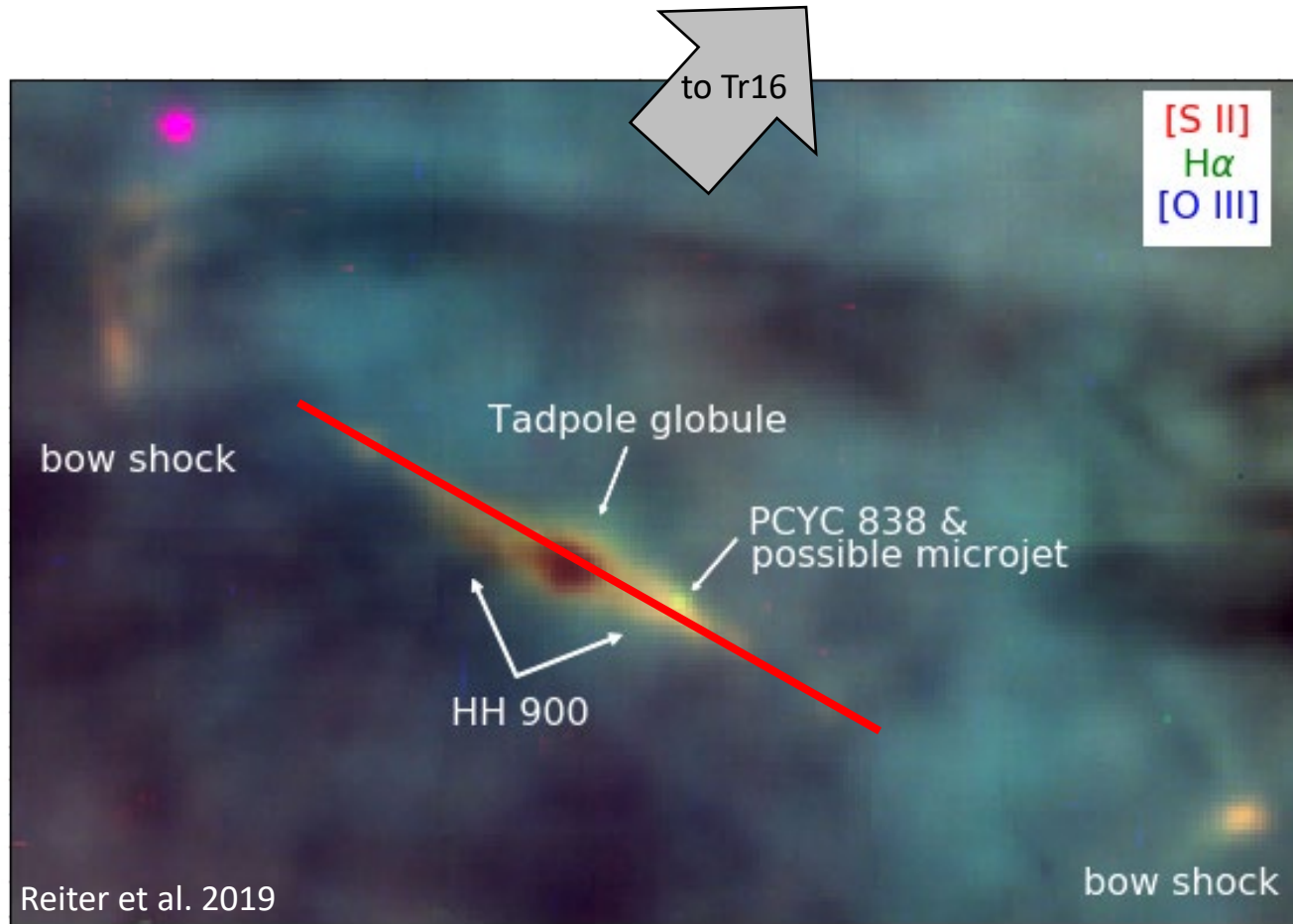
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Using MUSE to put star/planet-forming disks in context:
ionization front properties of the globule and outflow.

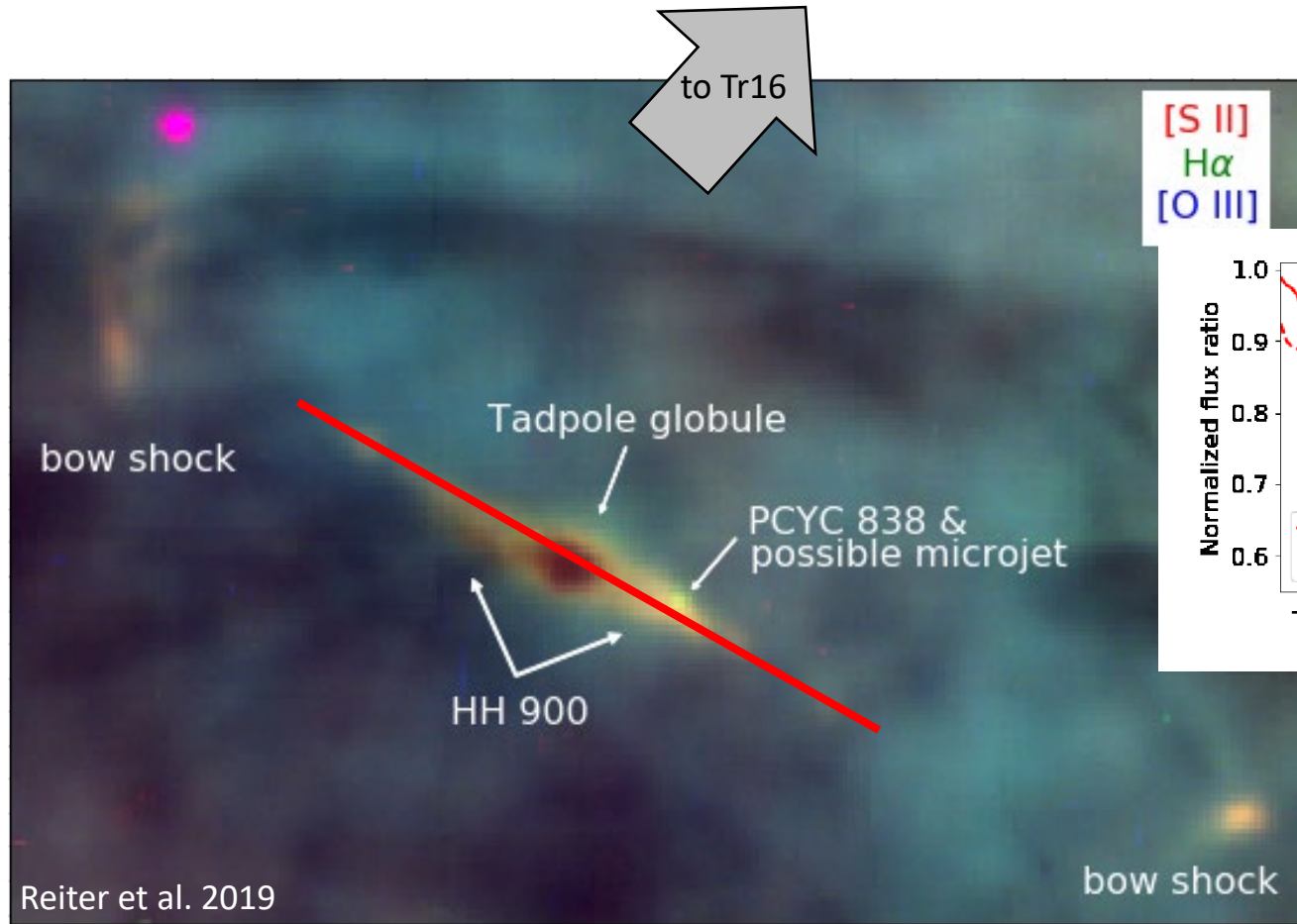


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Externally illuminated by nearby OB stars?

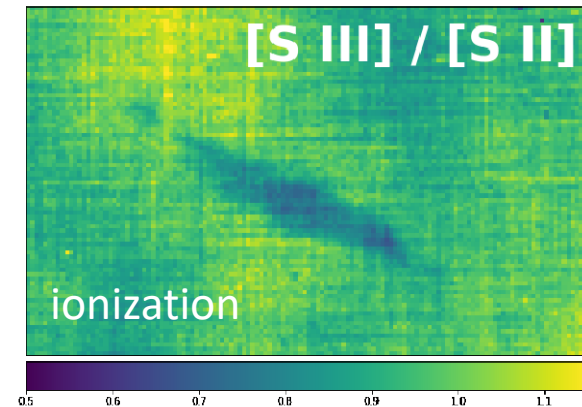
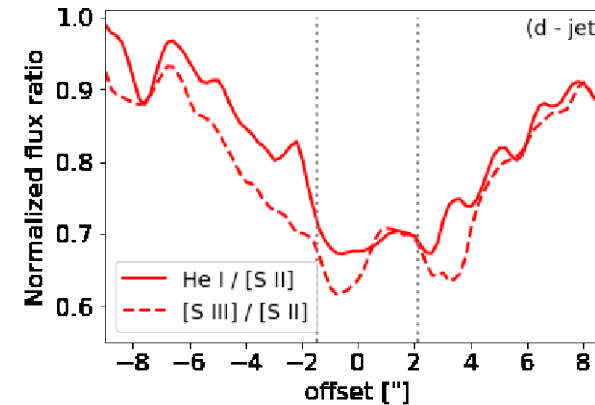
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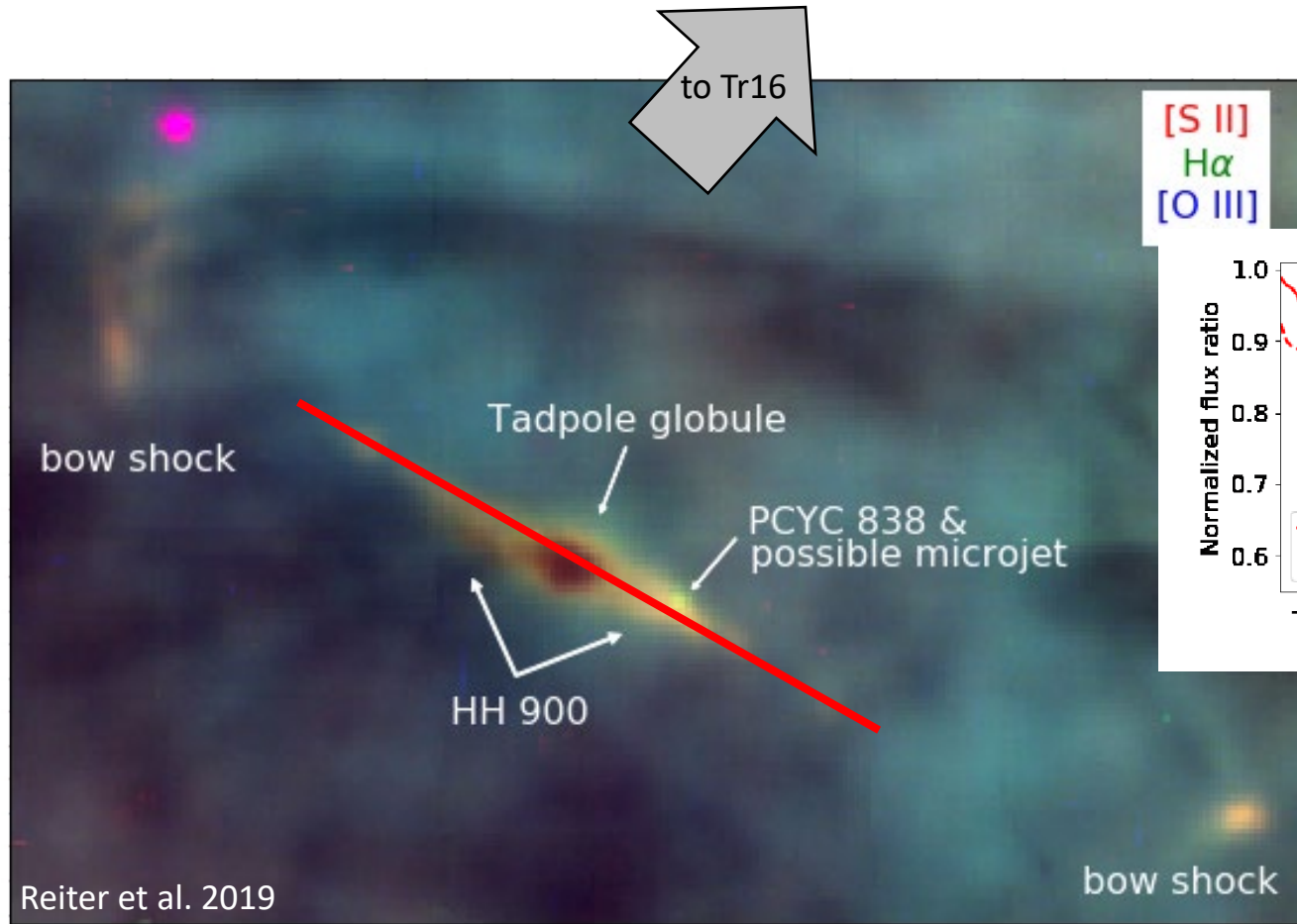
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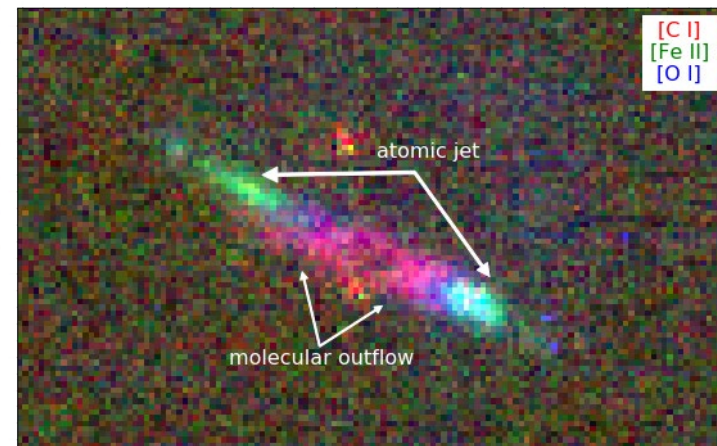
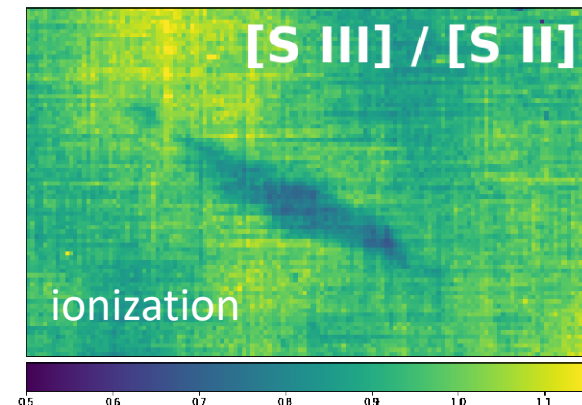
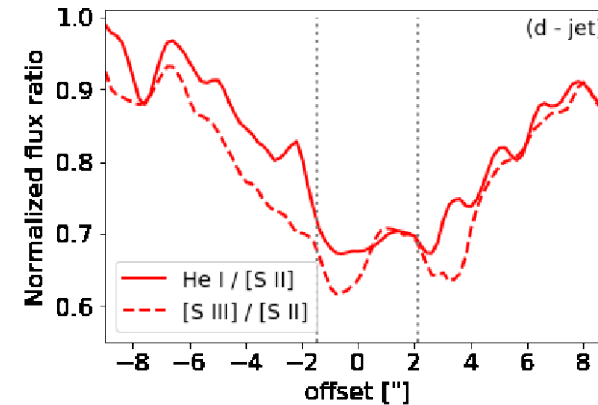
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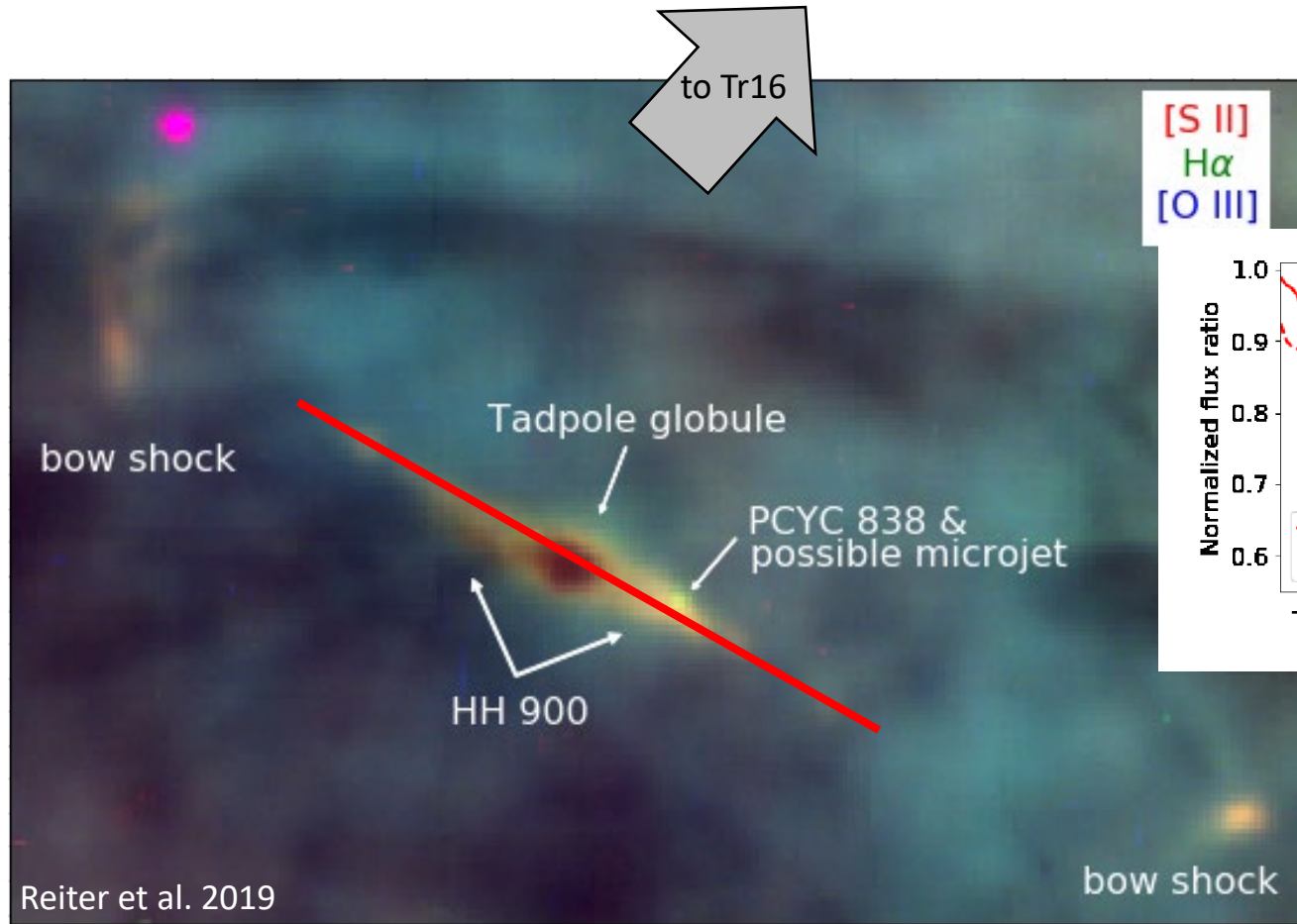
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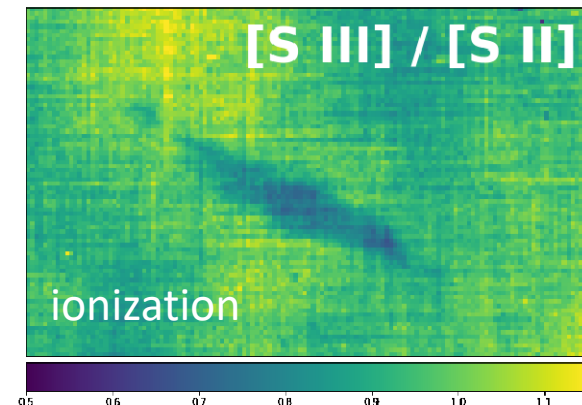
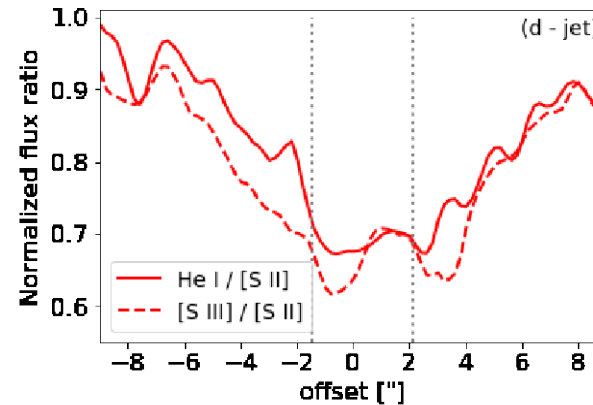
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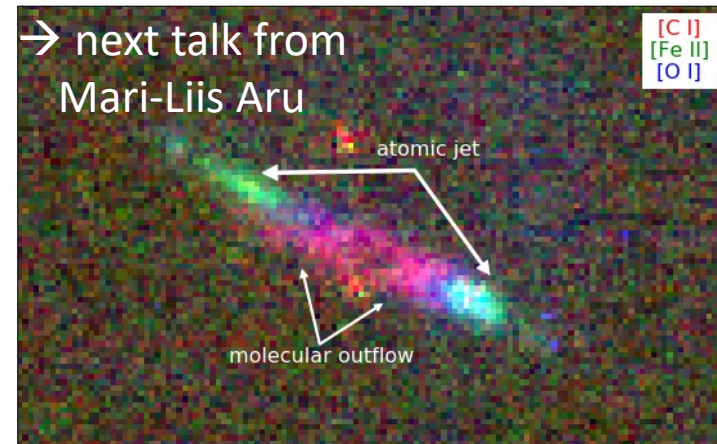
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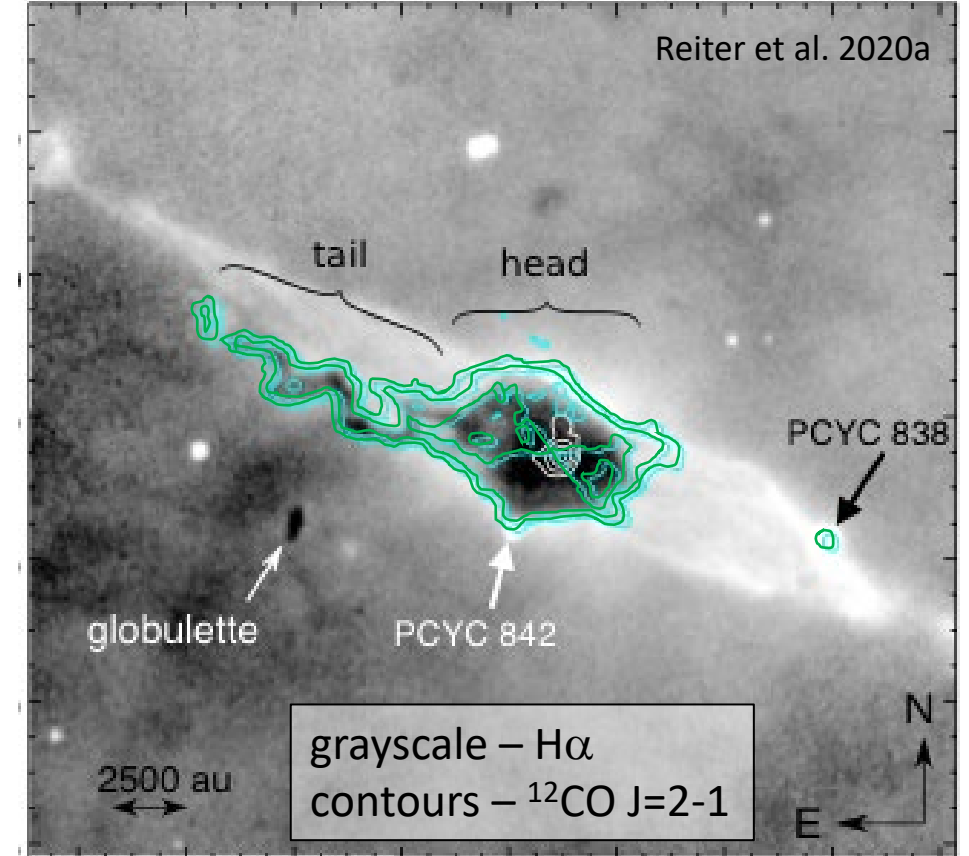
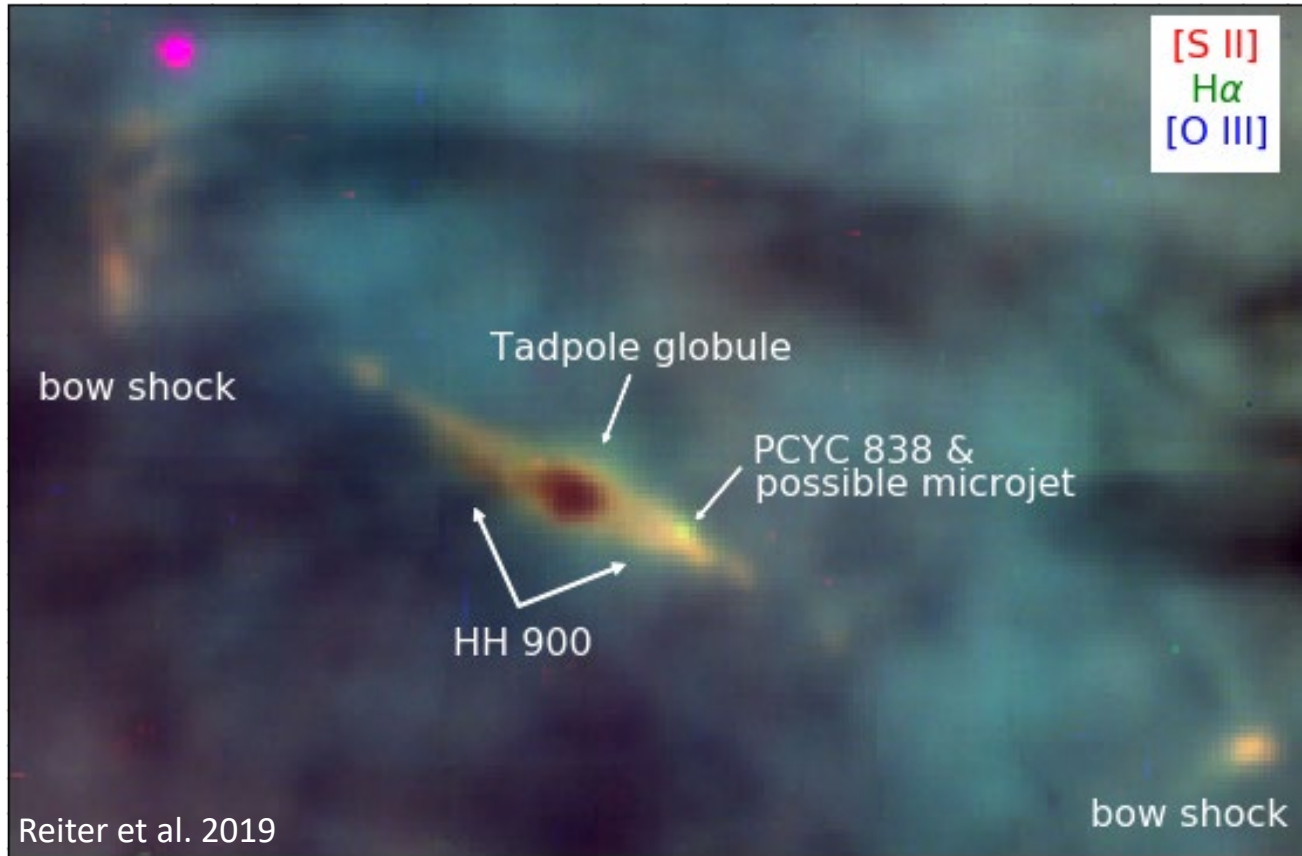


→ next talk from
Mari-Liis Aru

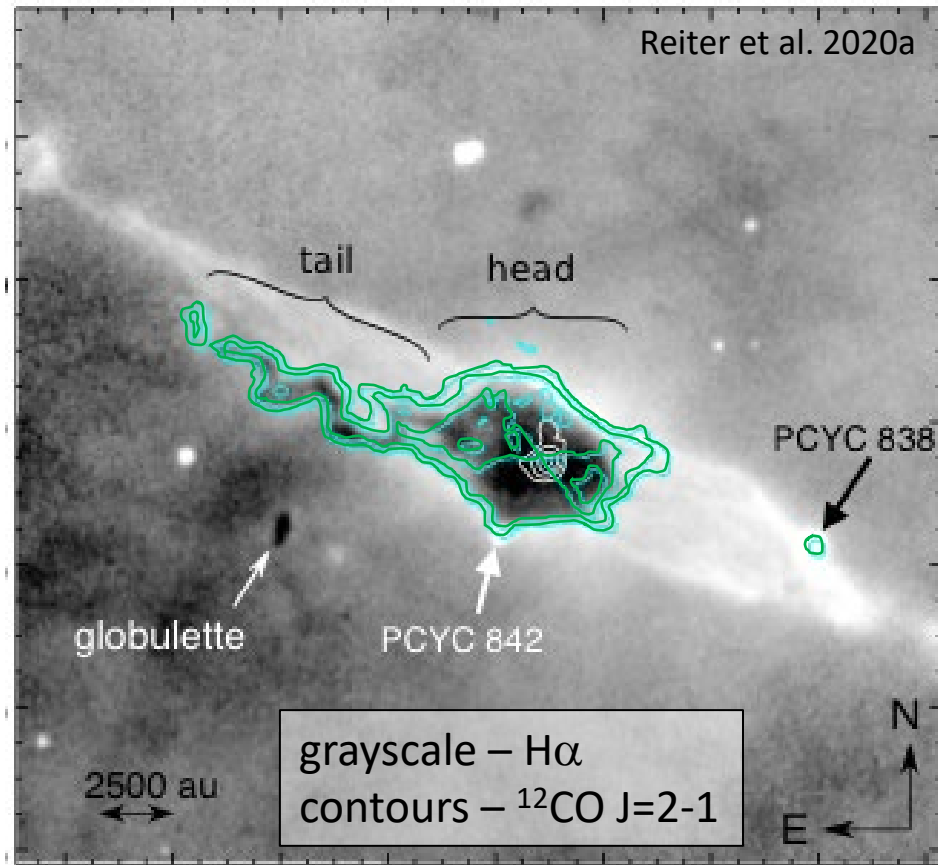


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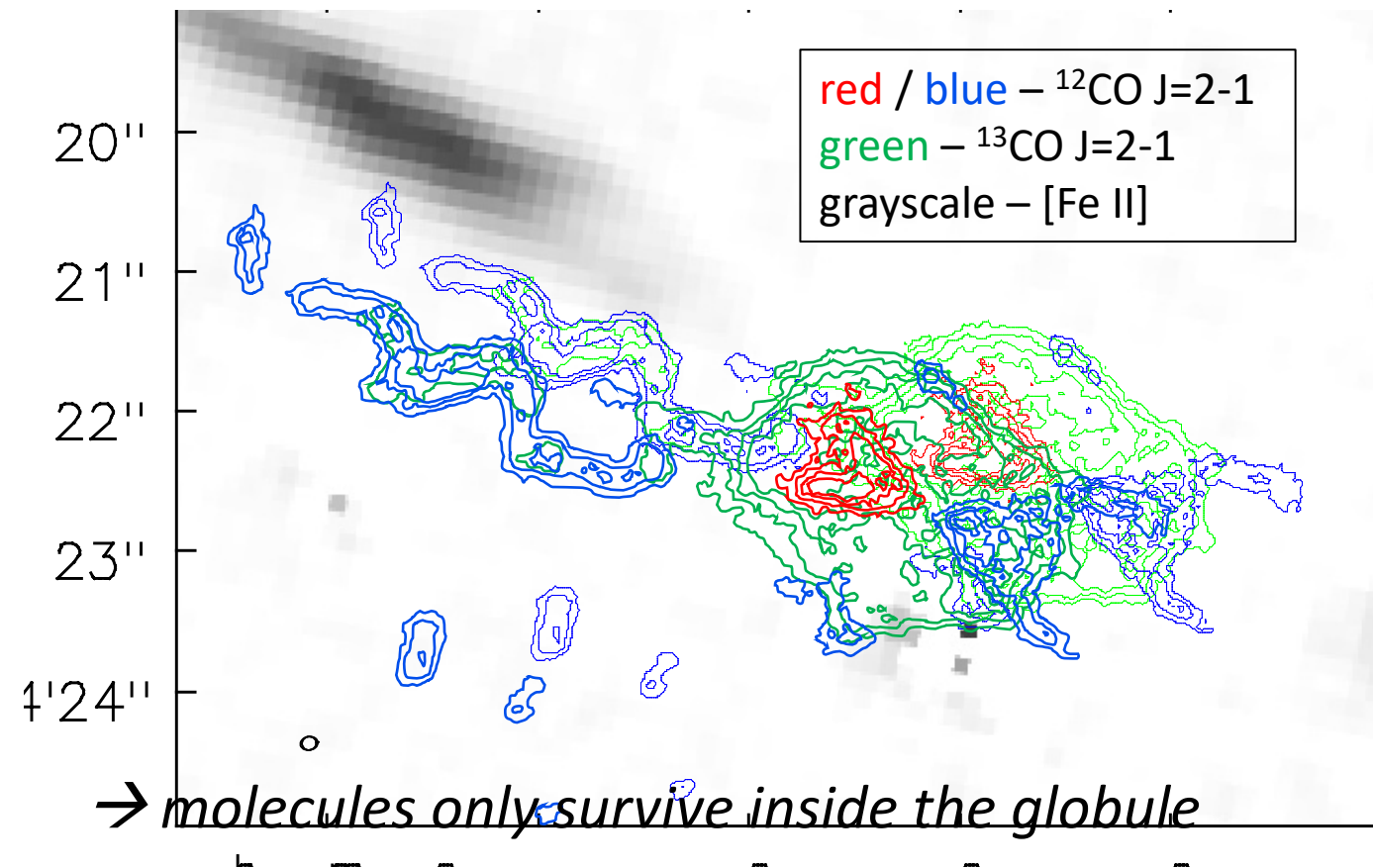
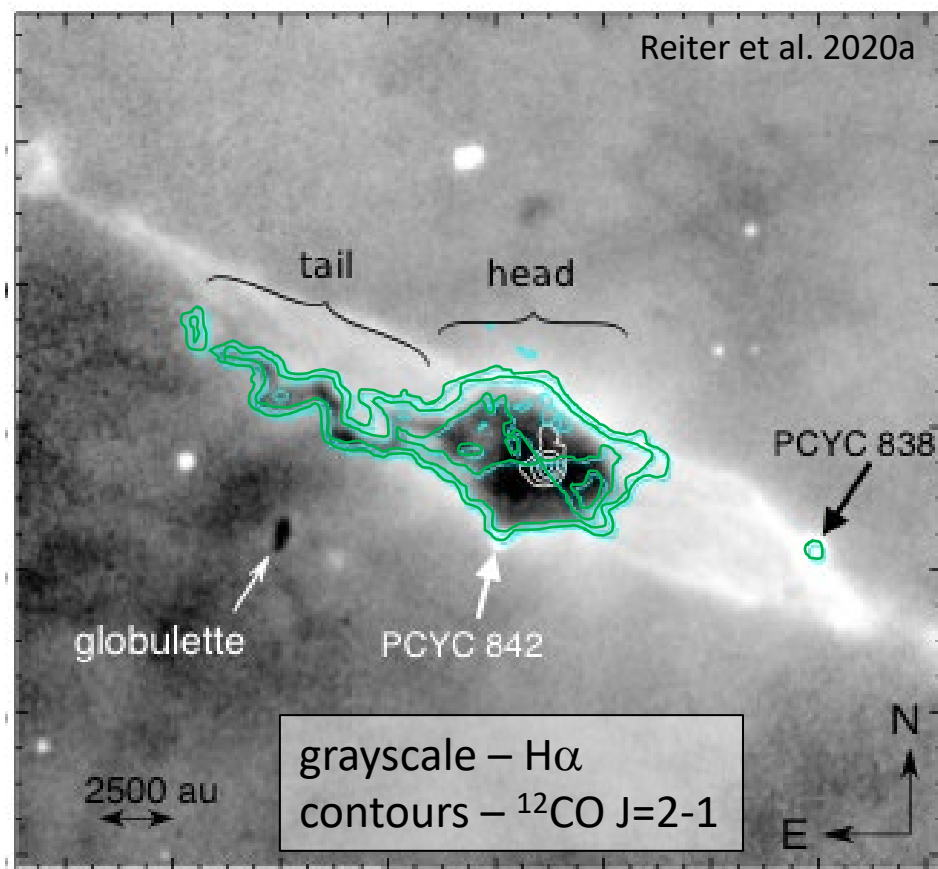
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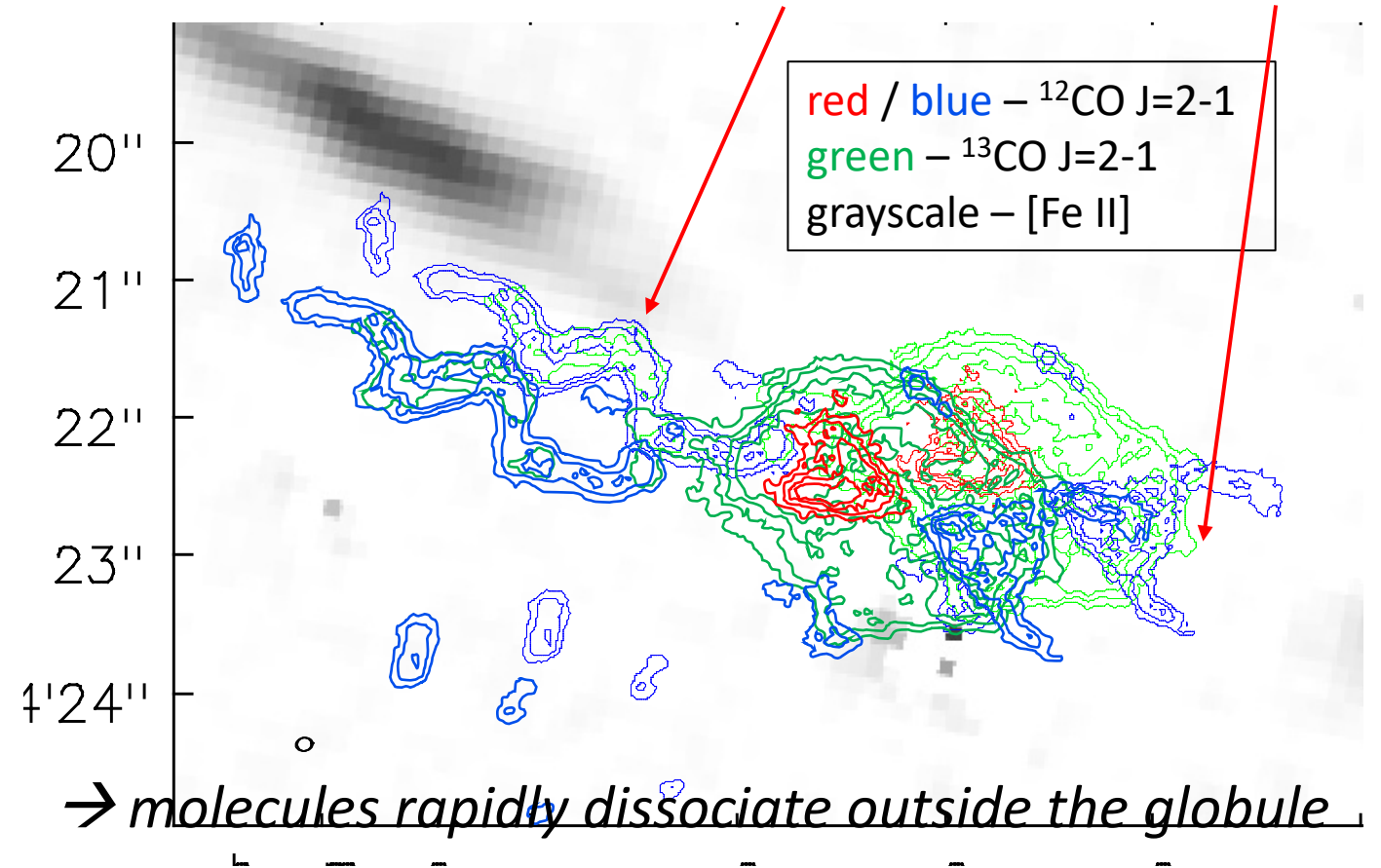
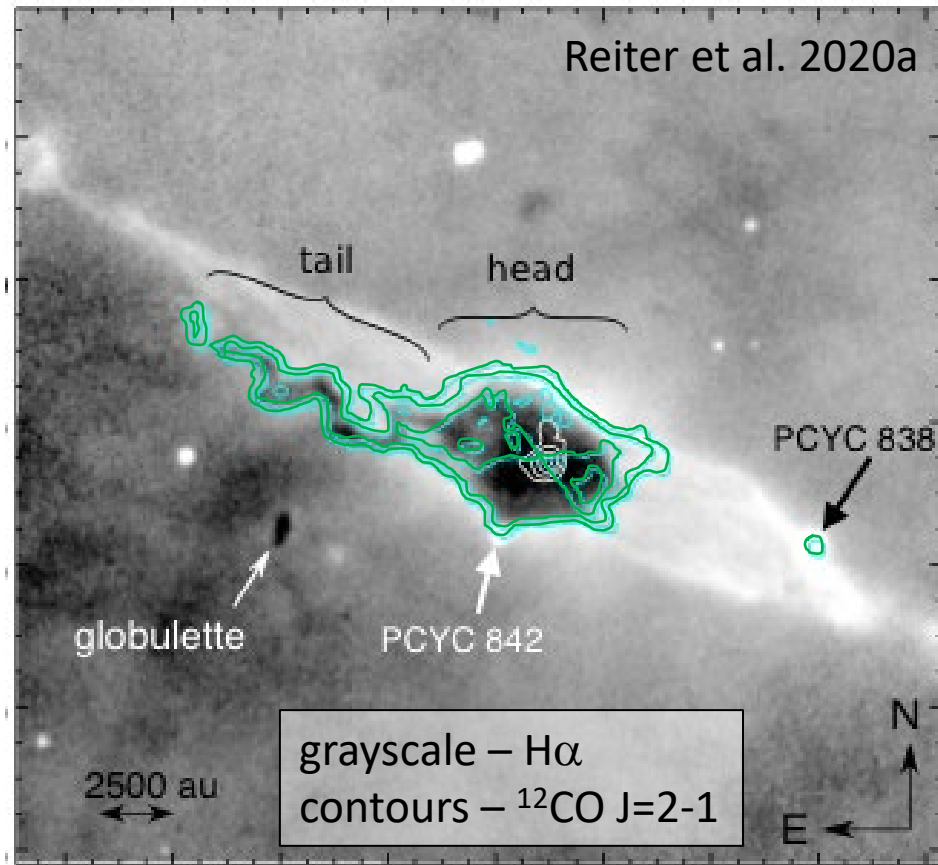
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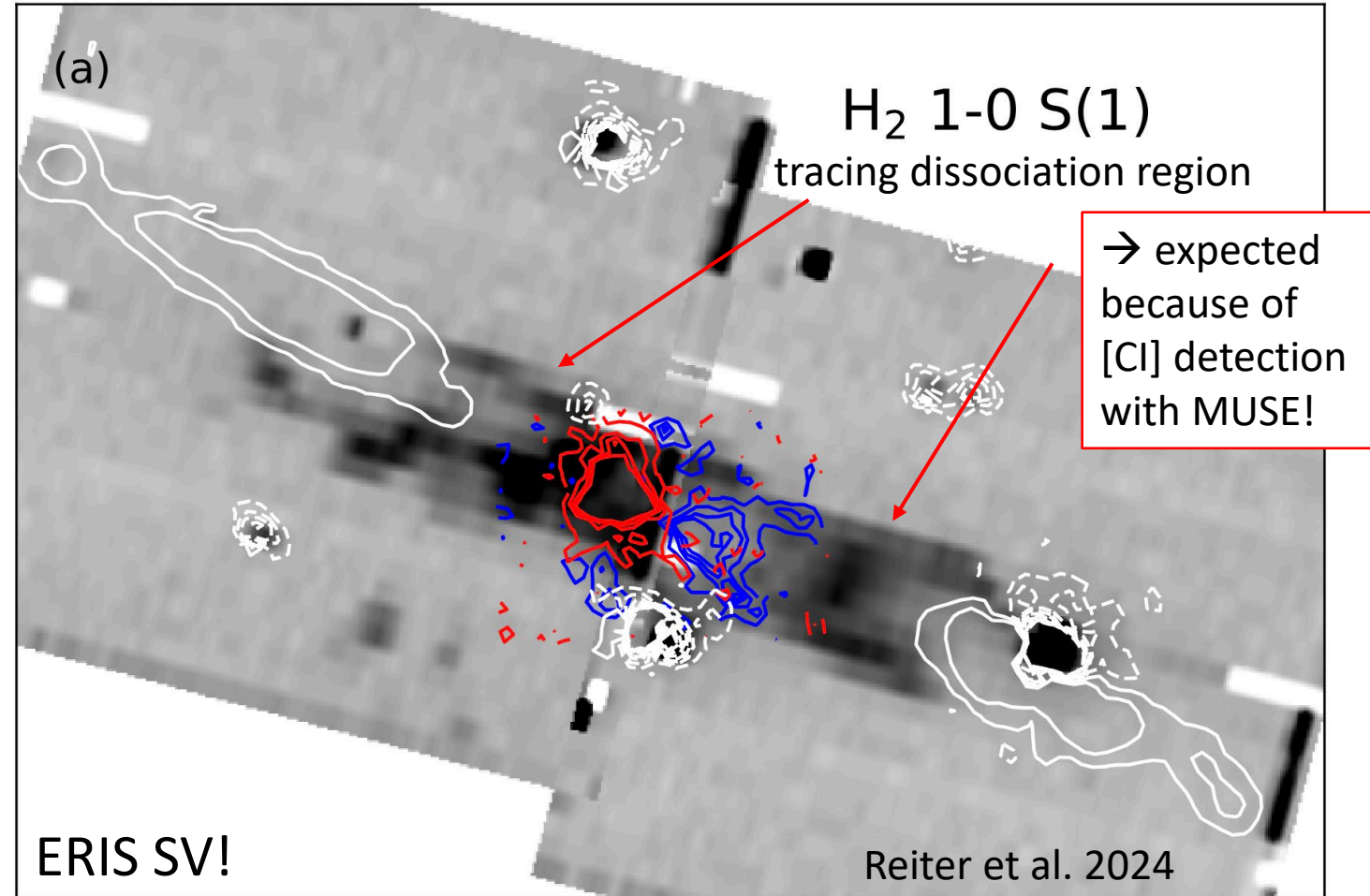
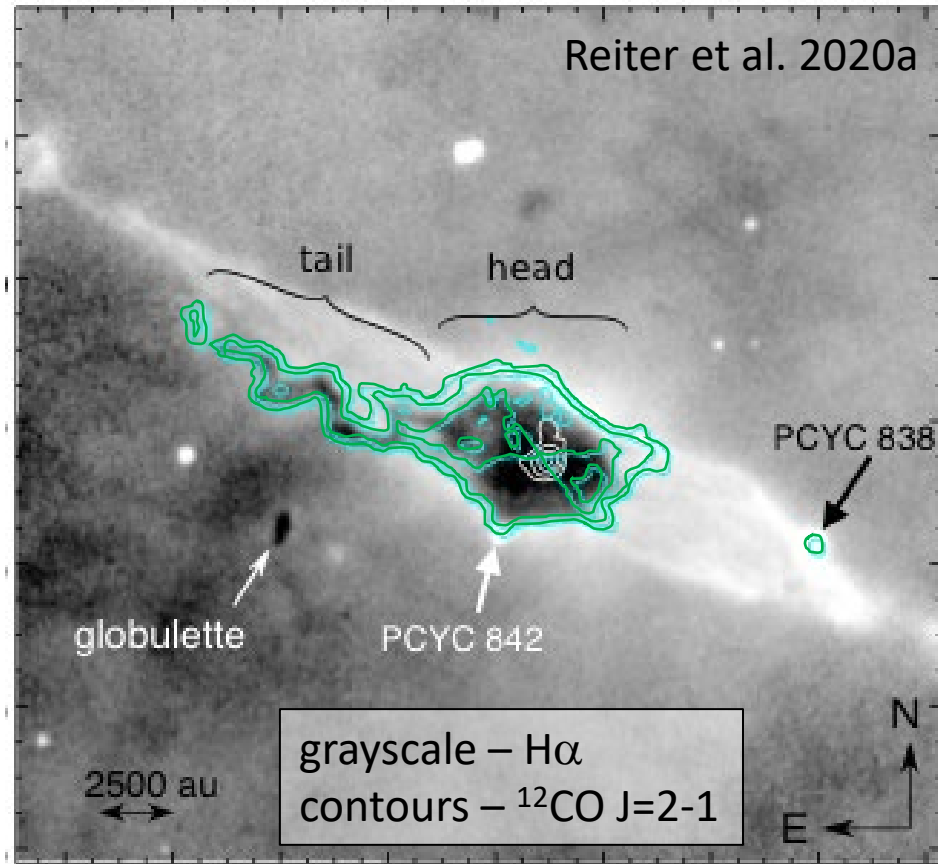
MUSE+ALMA connects the ionized outflow (in the H II region) and the molecular outflow (in the globule).



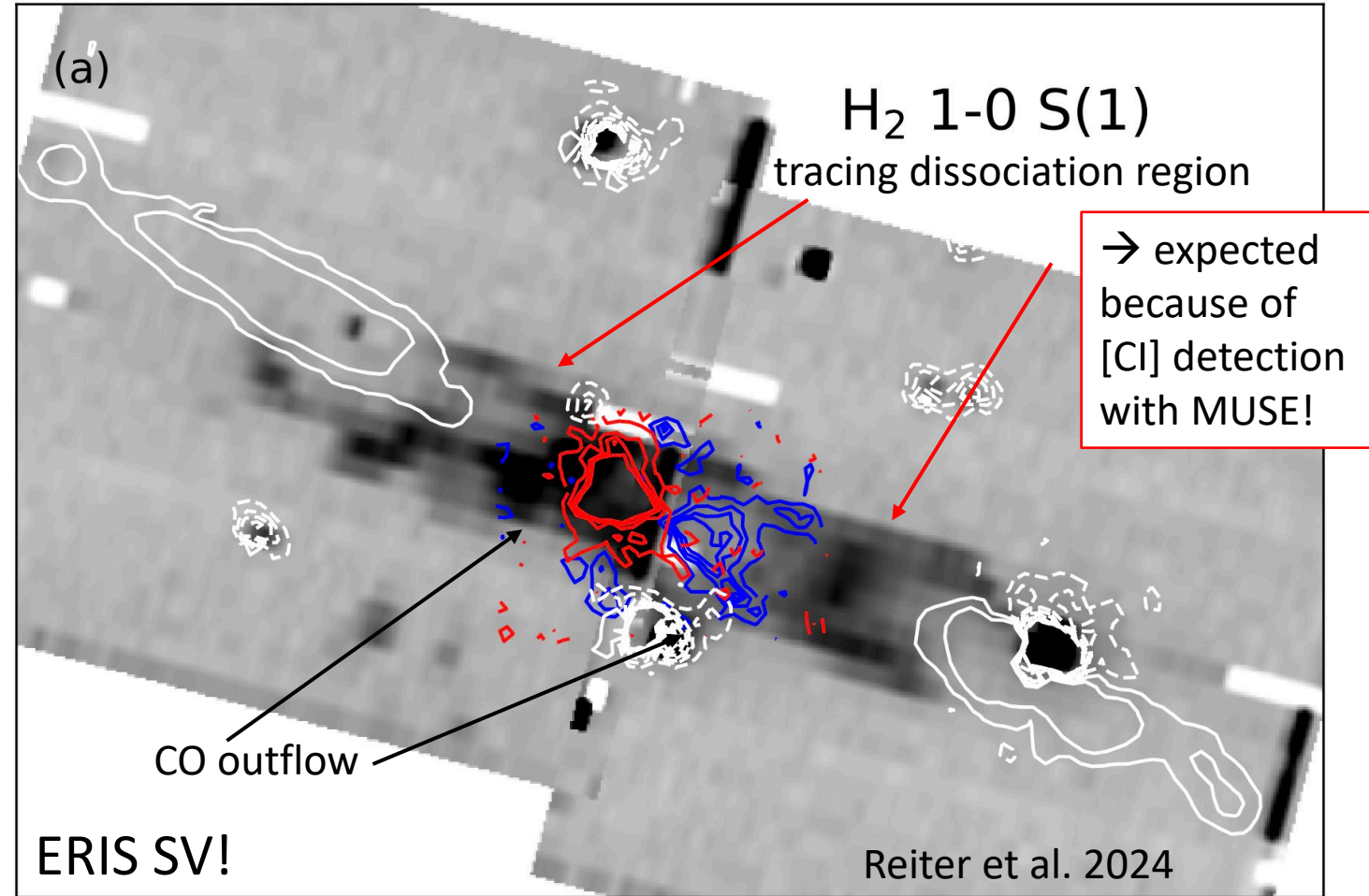
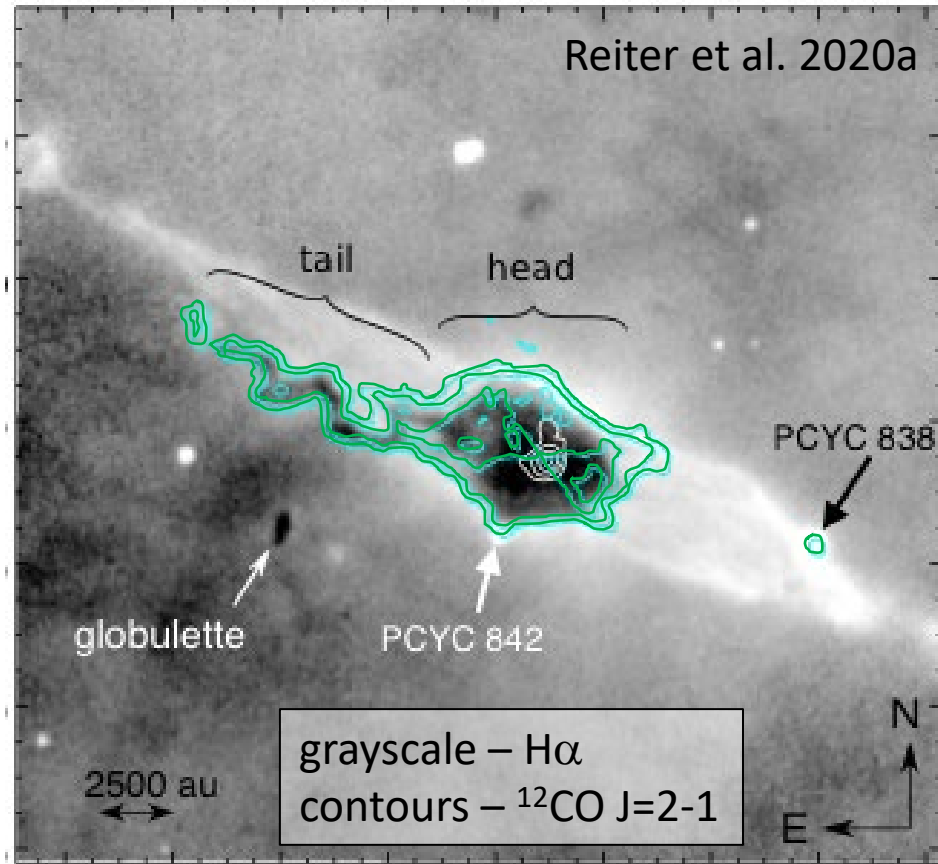
Molecules are rapidly dissociated once the outflow enters the H II region – no cold CO, only hot H₂.



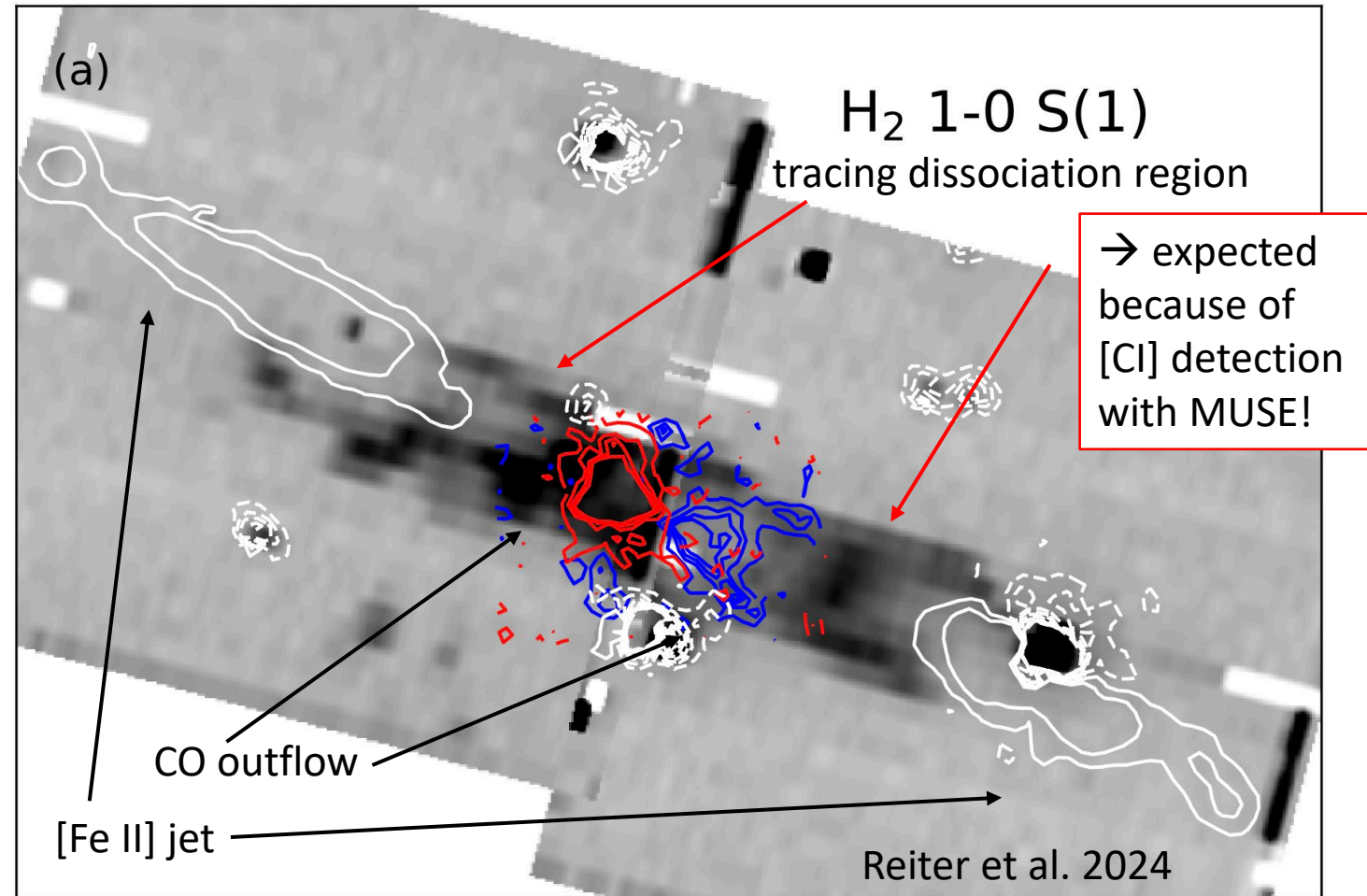
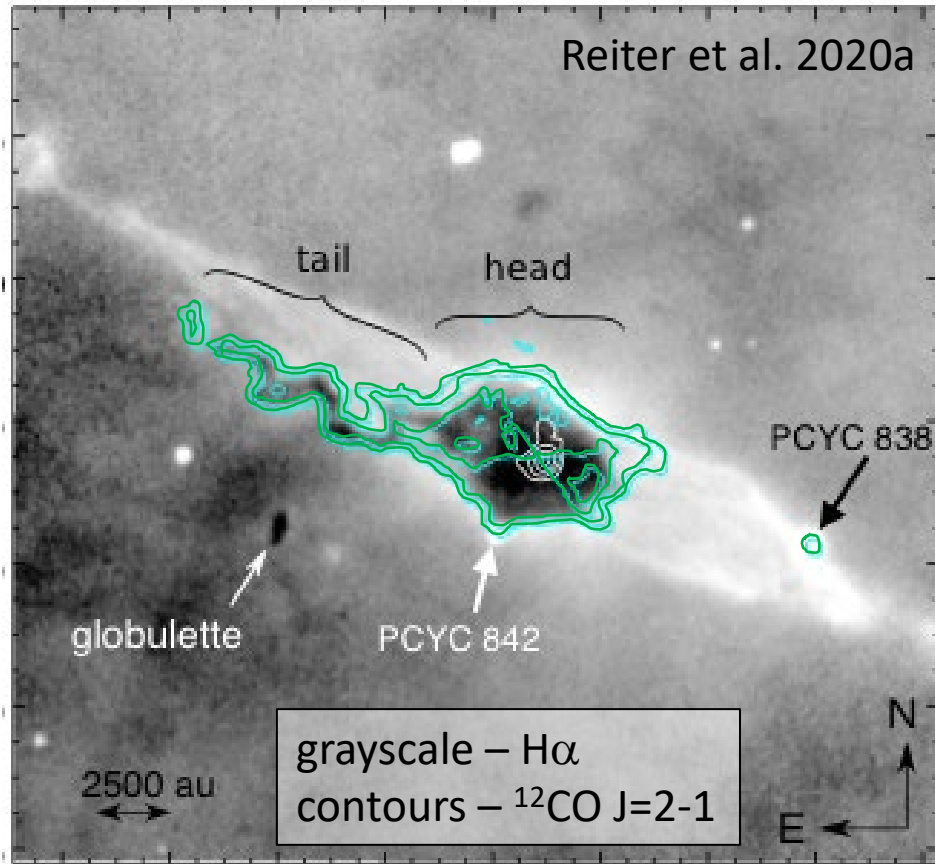
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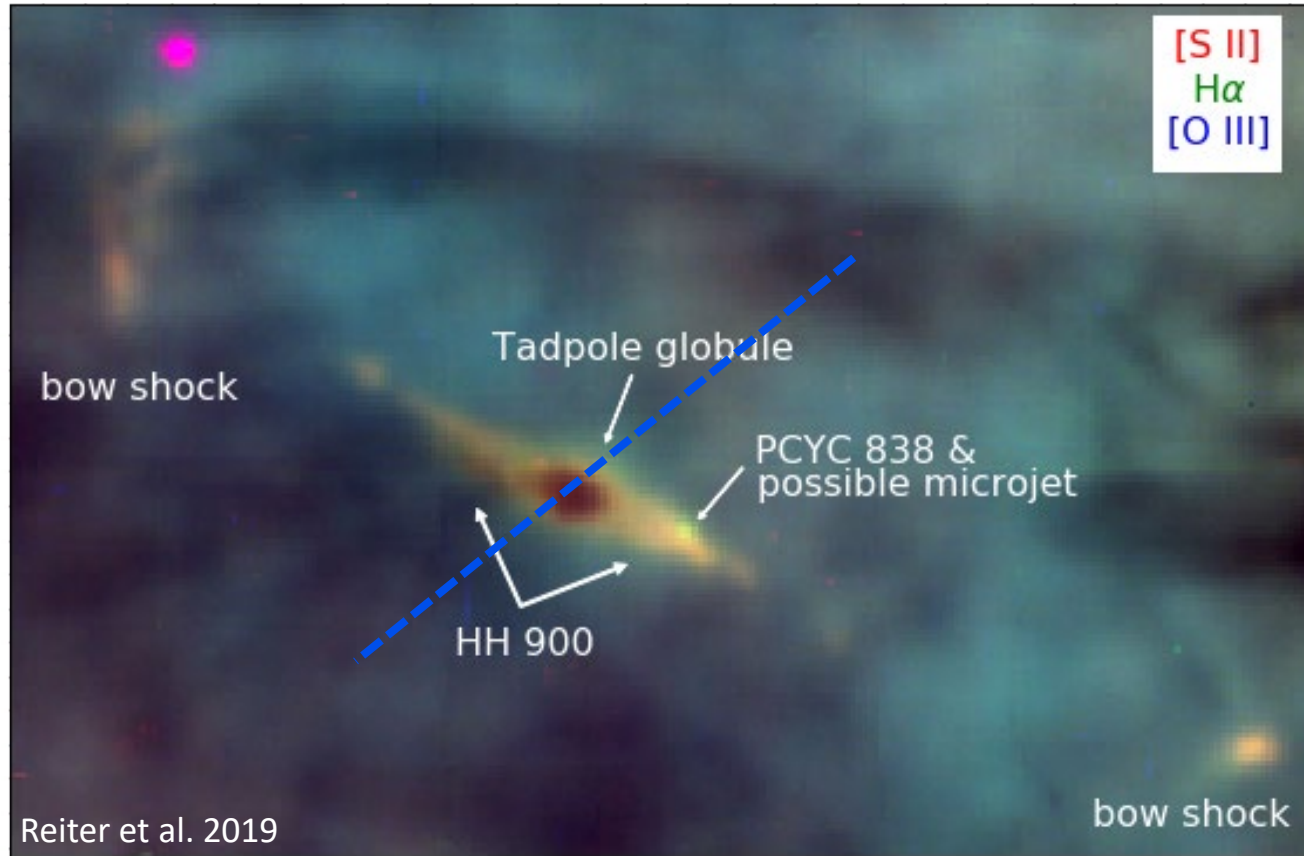
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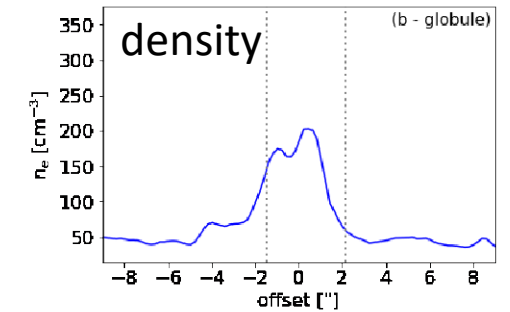
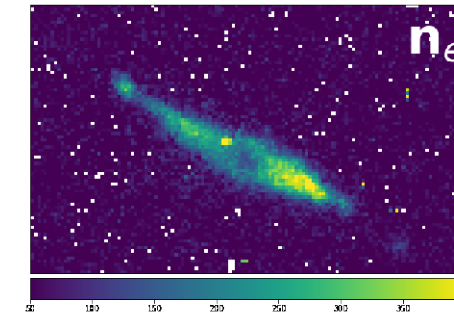
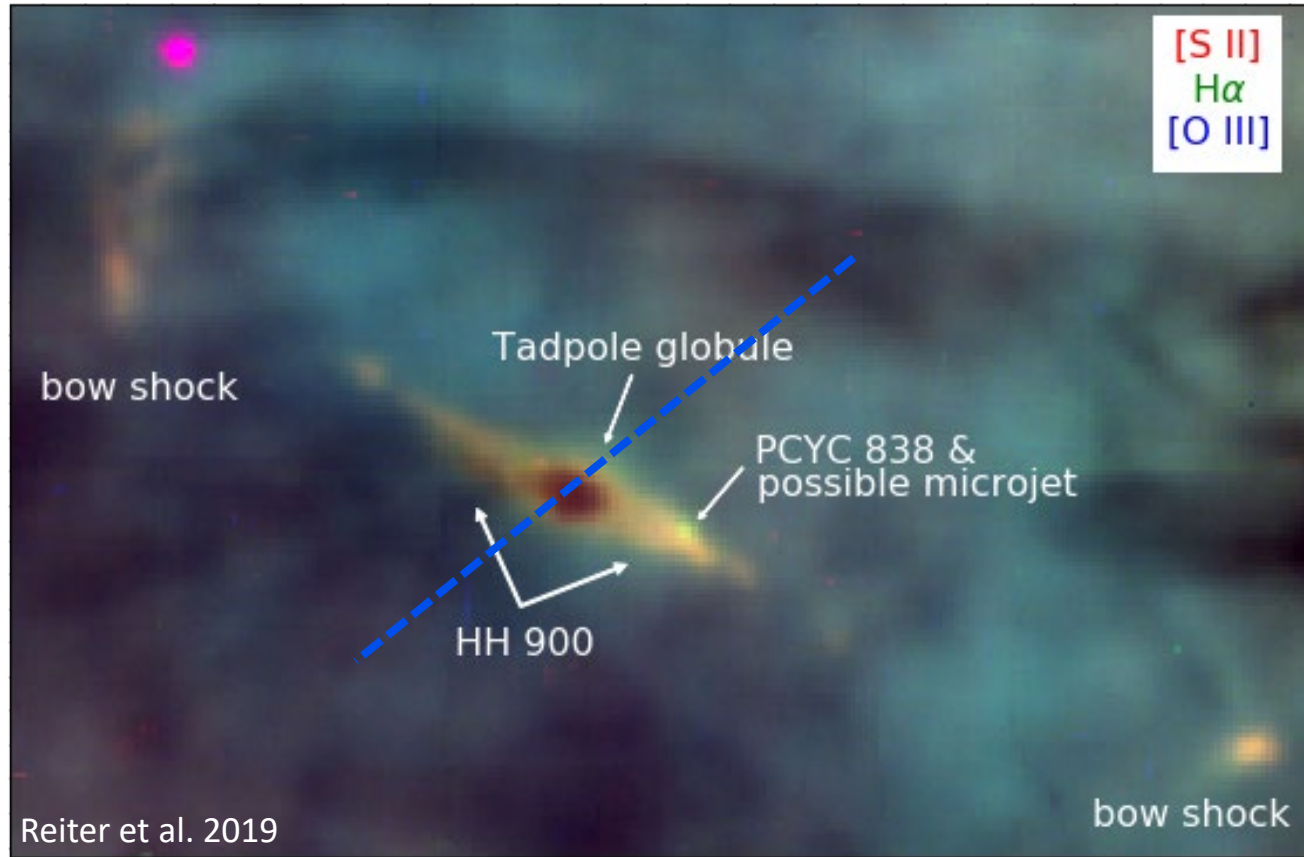
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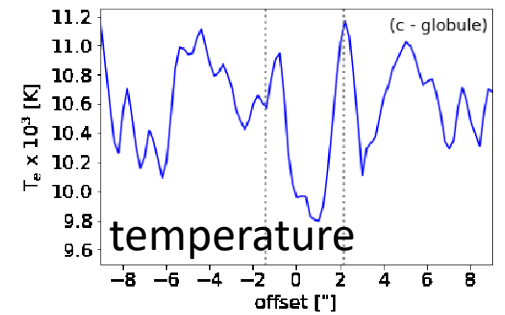
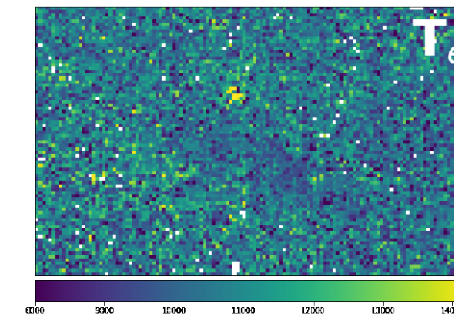
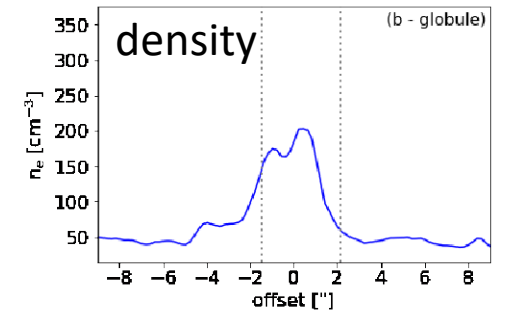
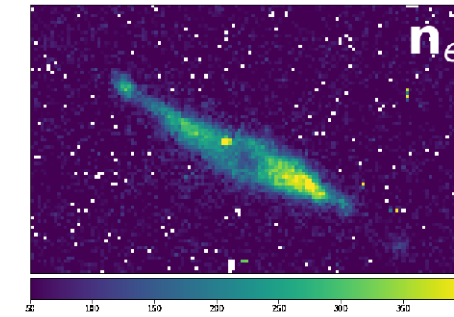
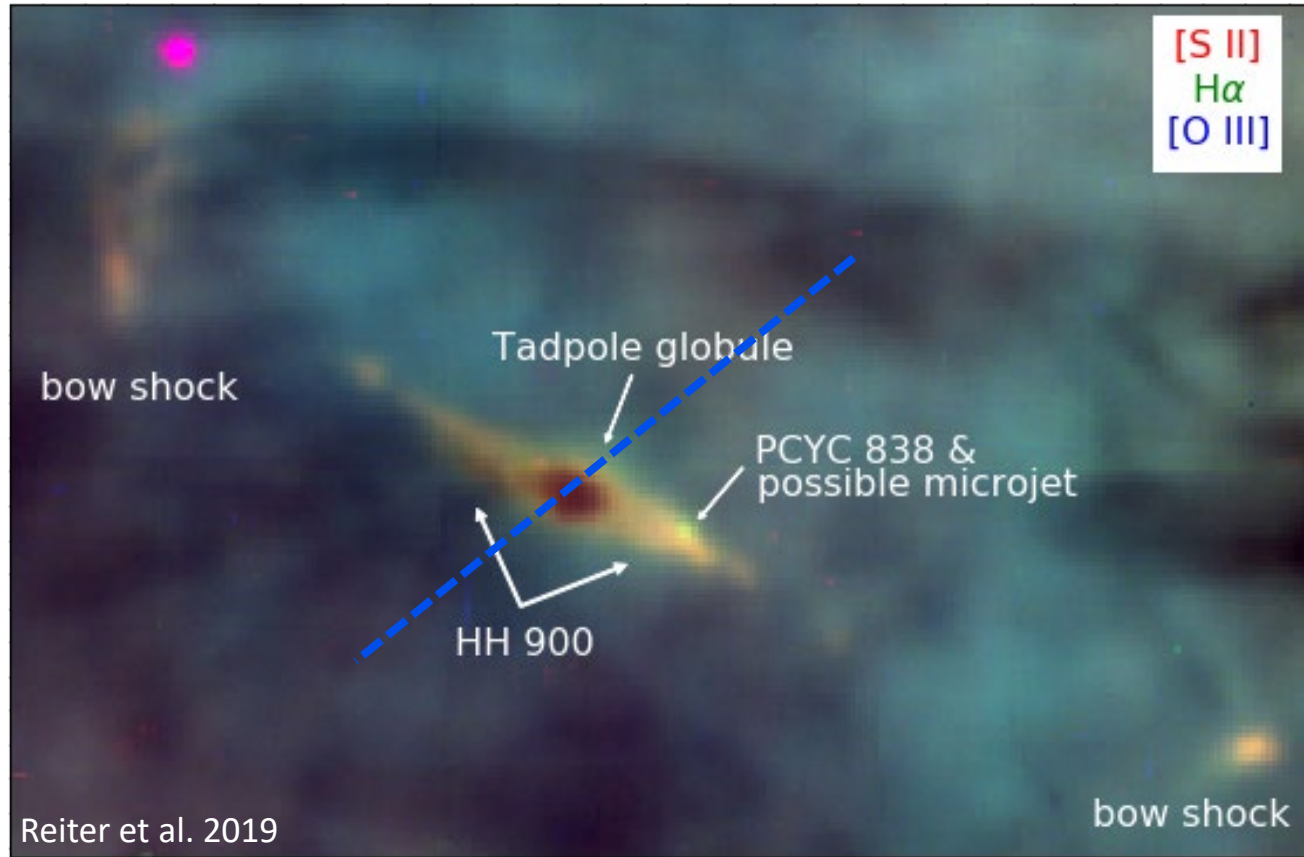
Using MUSE to put star/planet-forming disks in context:
photoevaporation rate and lifetime of the globule.



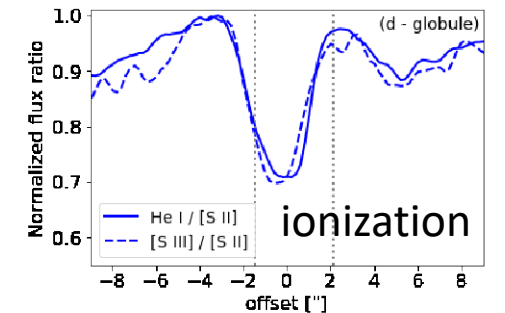
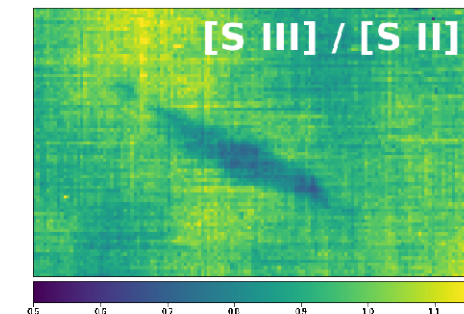
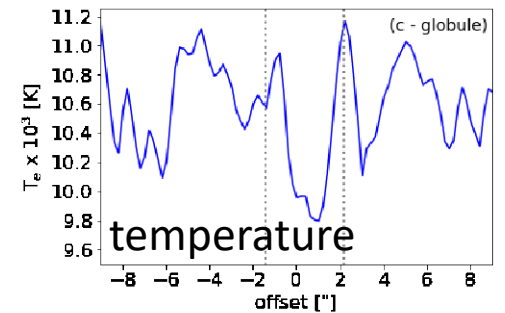
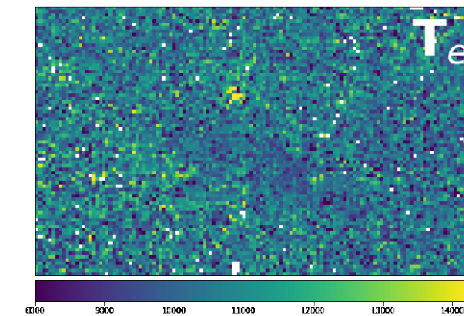
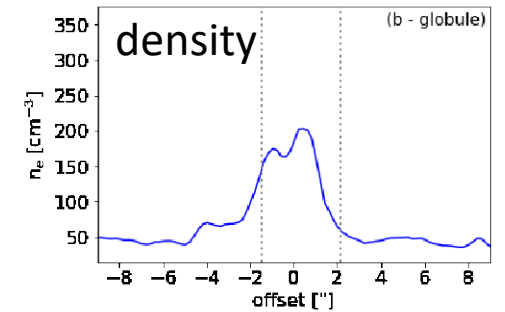
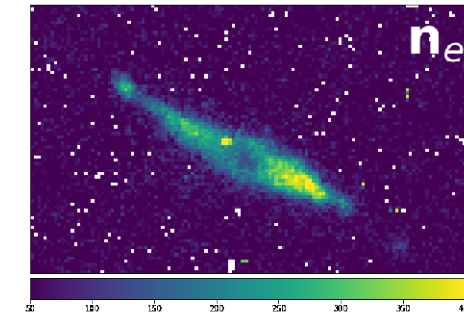
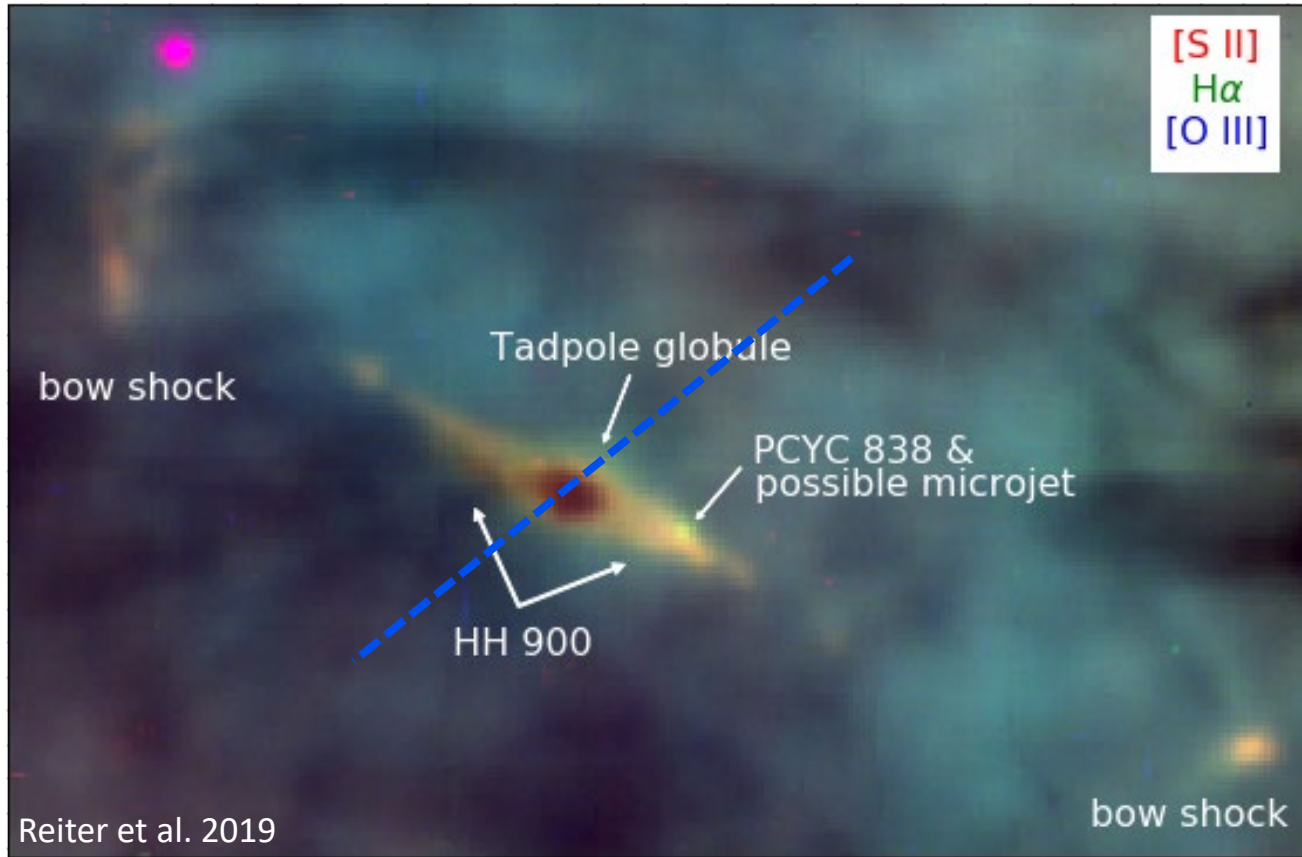
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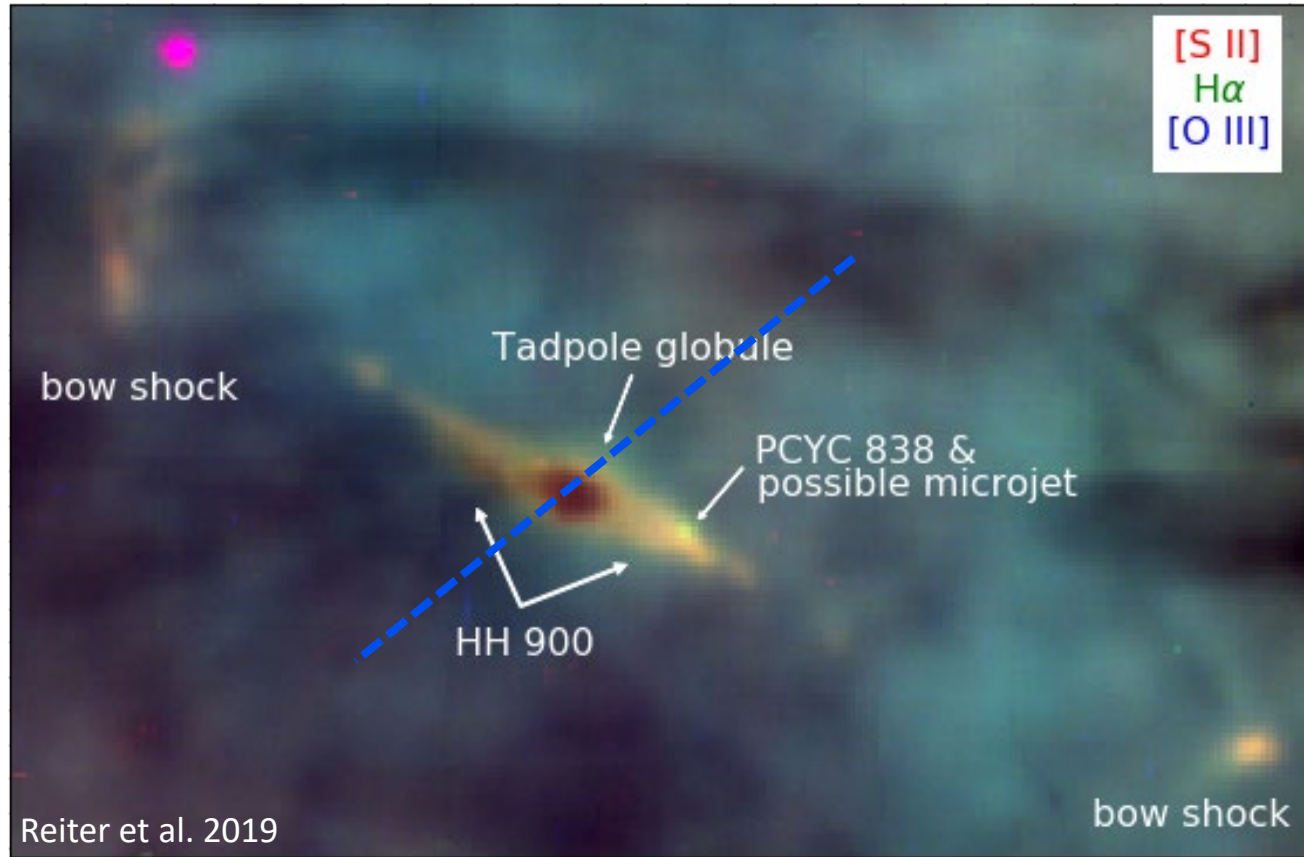
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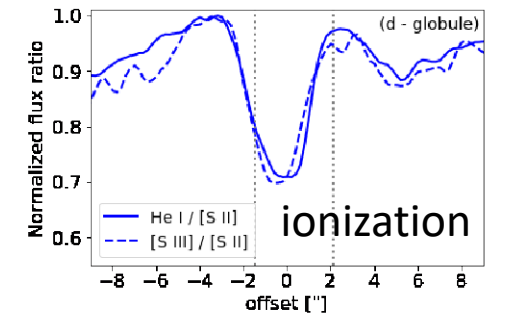
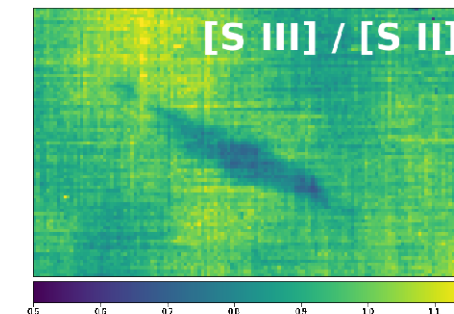
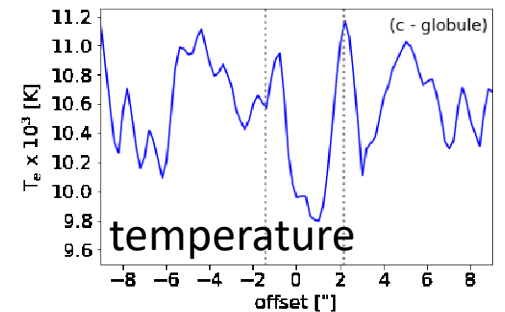
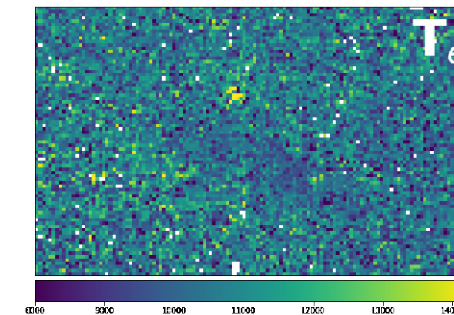
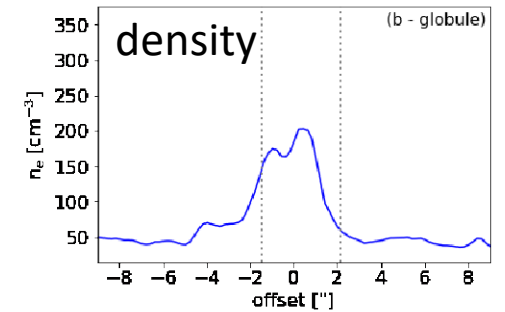
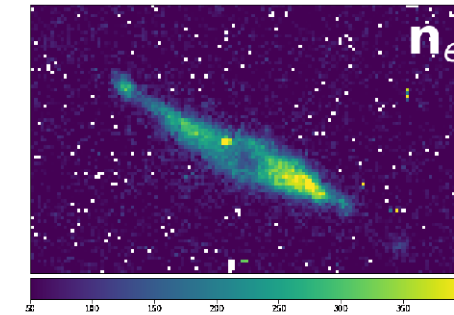
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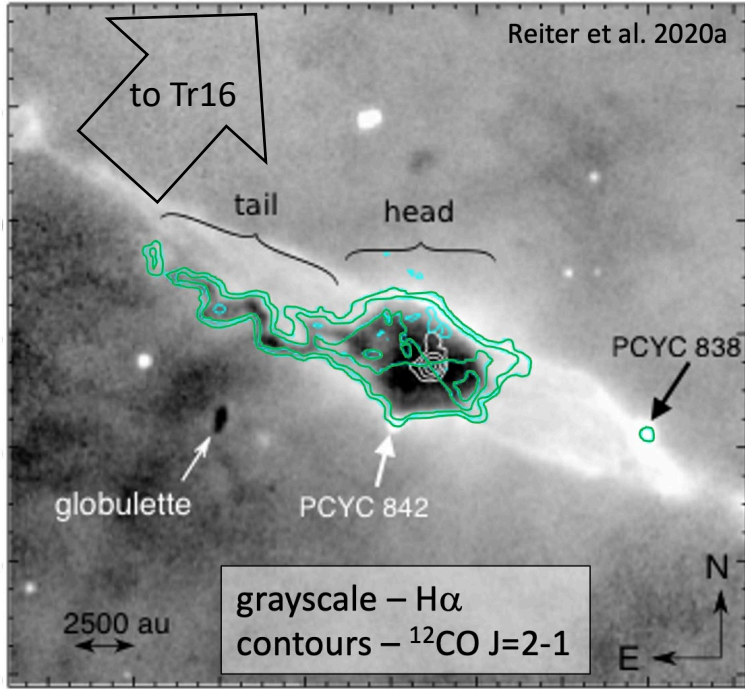
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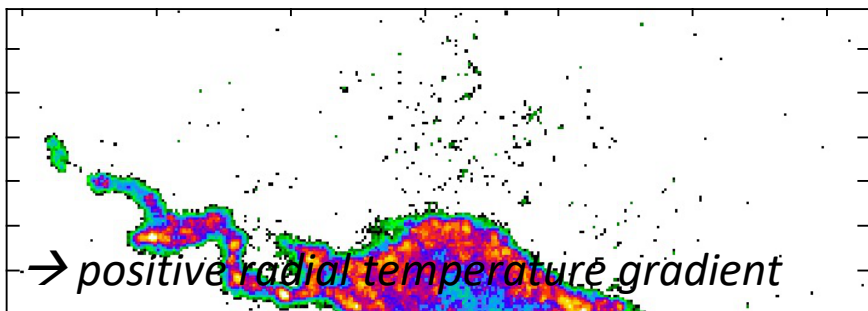
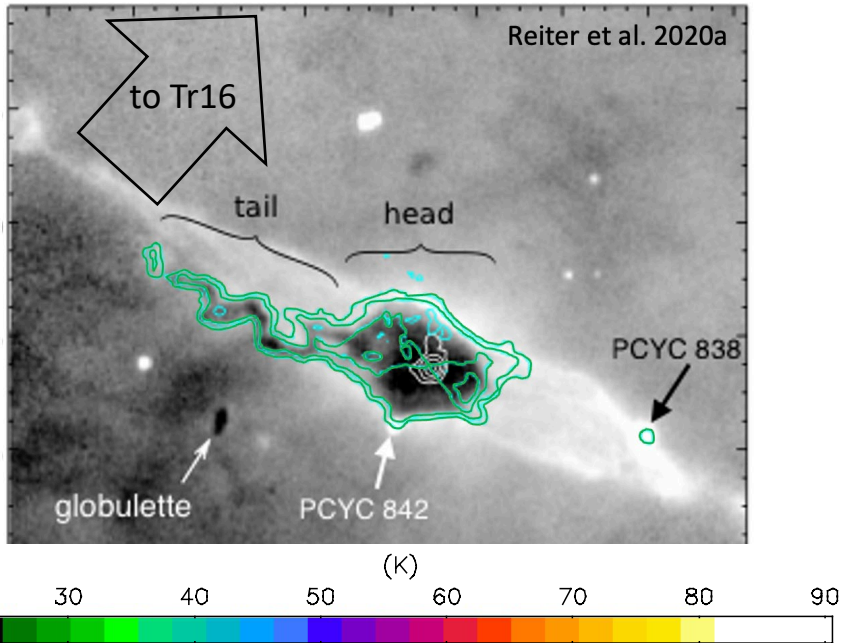
→ globule will be completely ablated in ~ 4 Myr



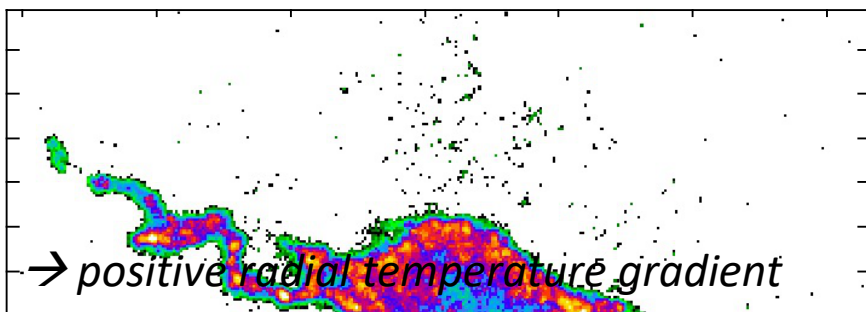
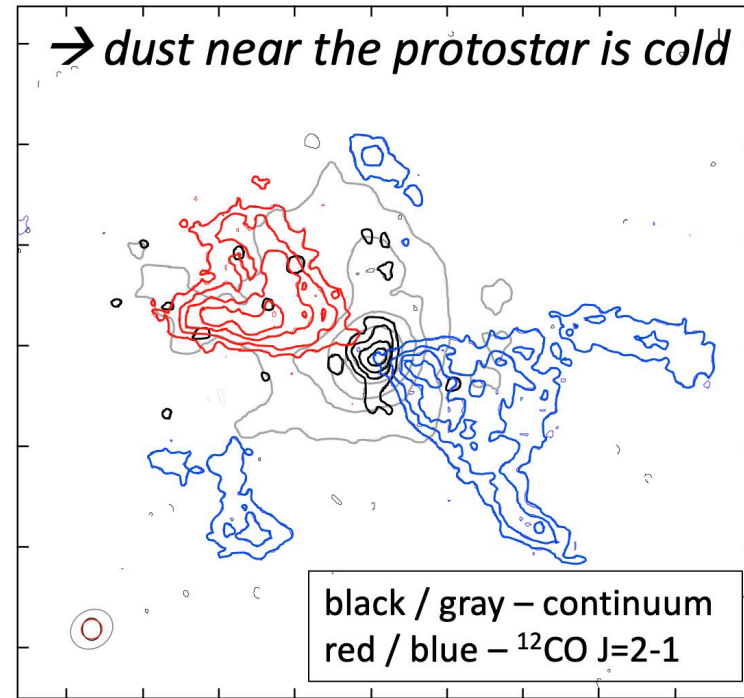
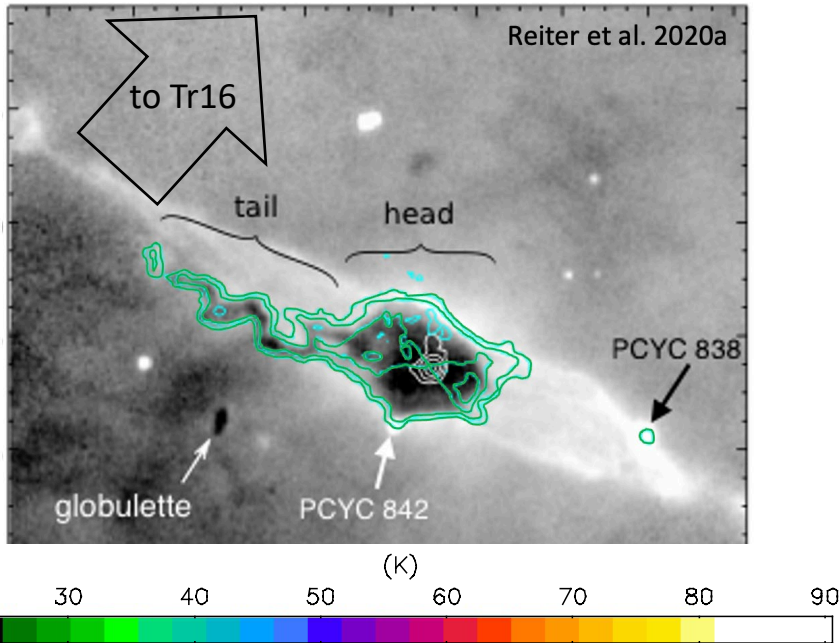
Quantify the impact of external heating on the chemistry and kinematics of the star-/planet-forming system.



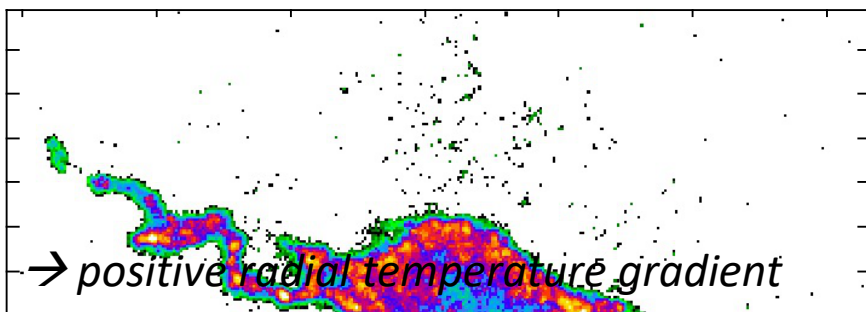
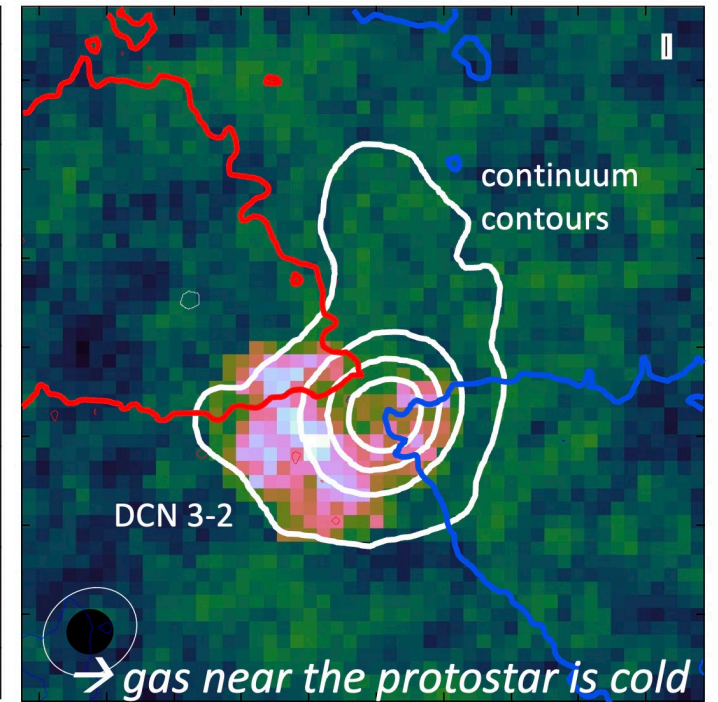
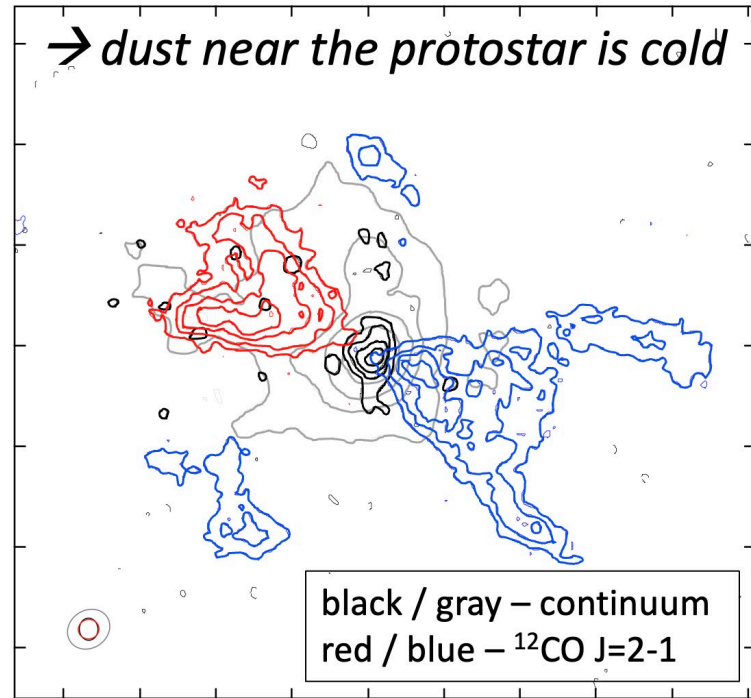
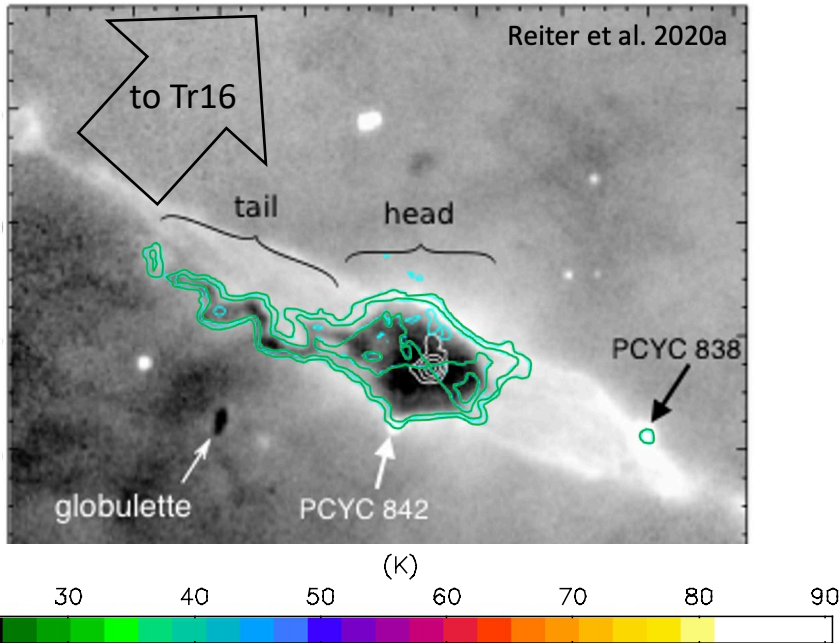
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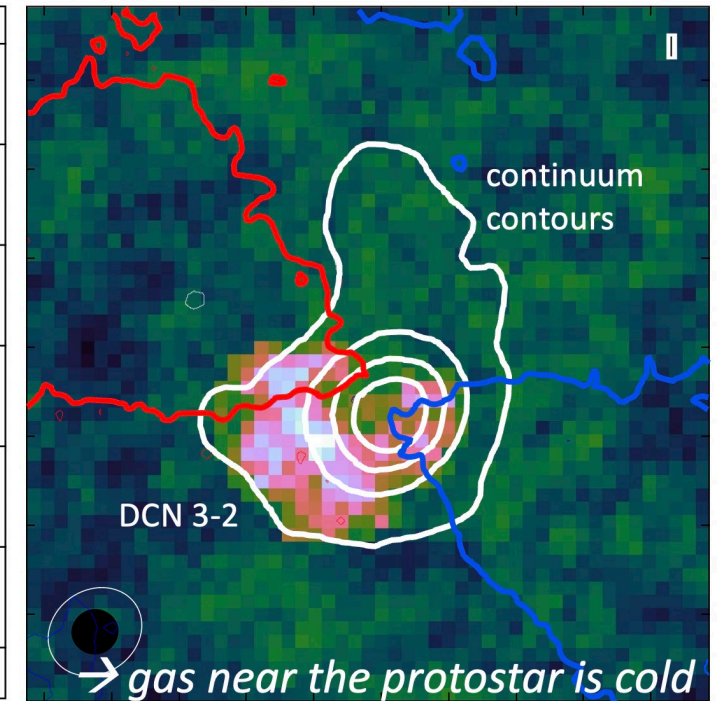
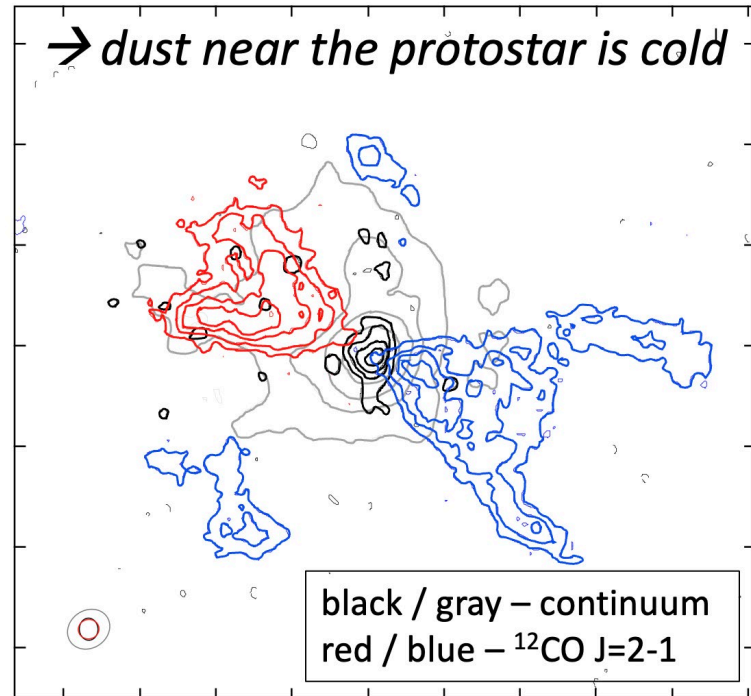
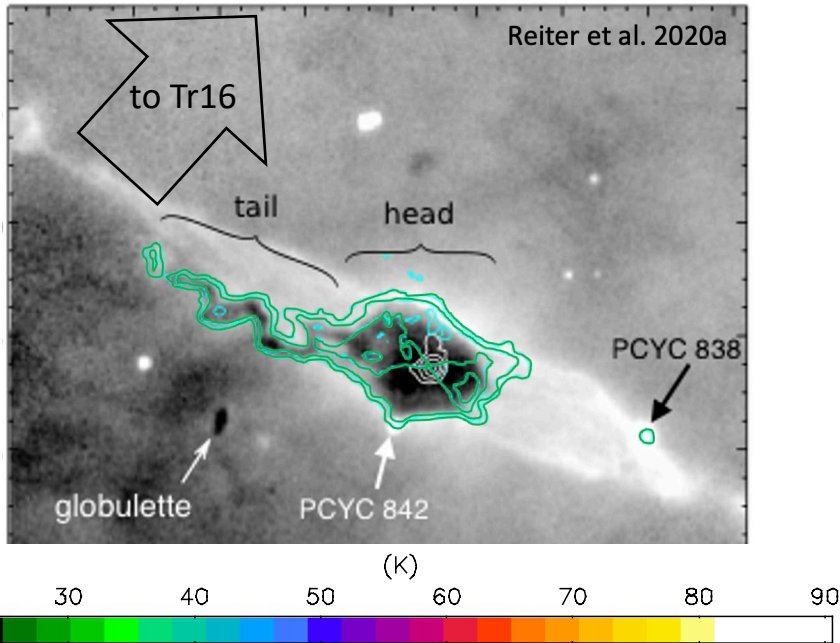
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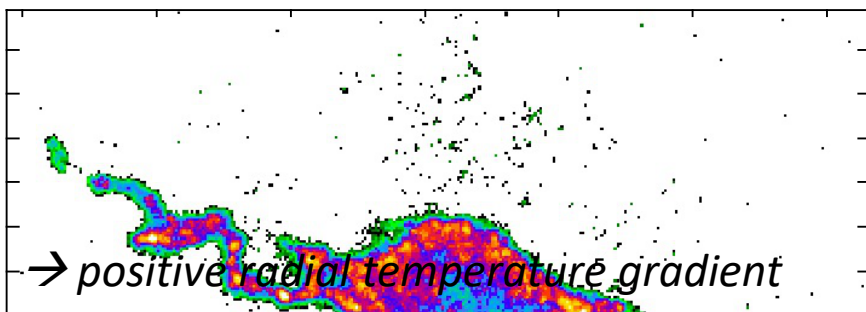
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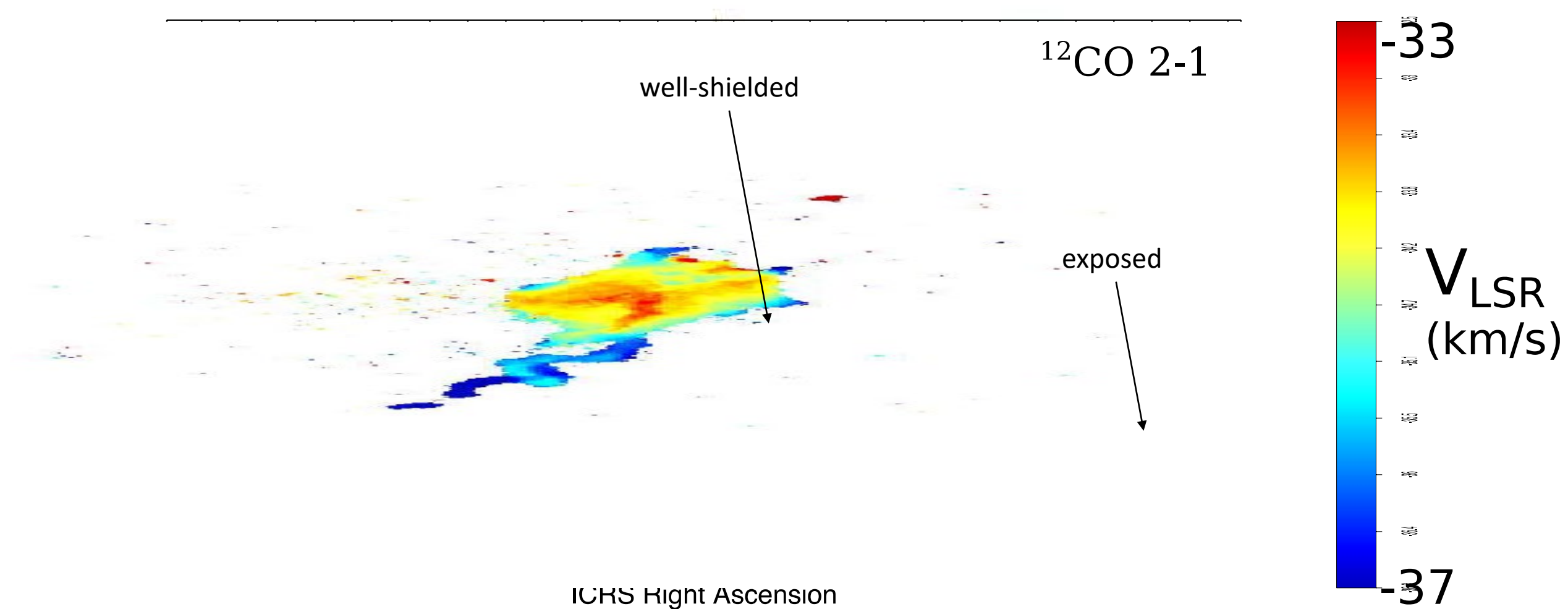
Quantify the impact of external heating on the chemistry and kinematics of the star-/planet-forming system.



→ globule will be completely ablated in ~ 4 Myr



Protostars embedded in dense cocoons may not notice their environment; exposed YSOs absolutely will.



Most planet-forming disks will be affected by UV from nearby high-mass stars.

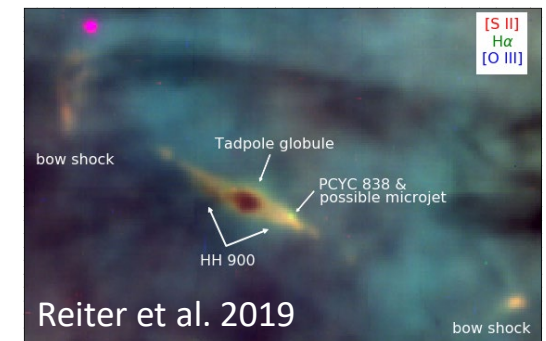
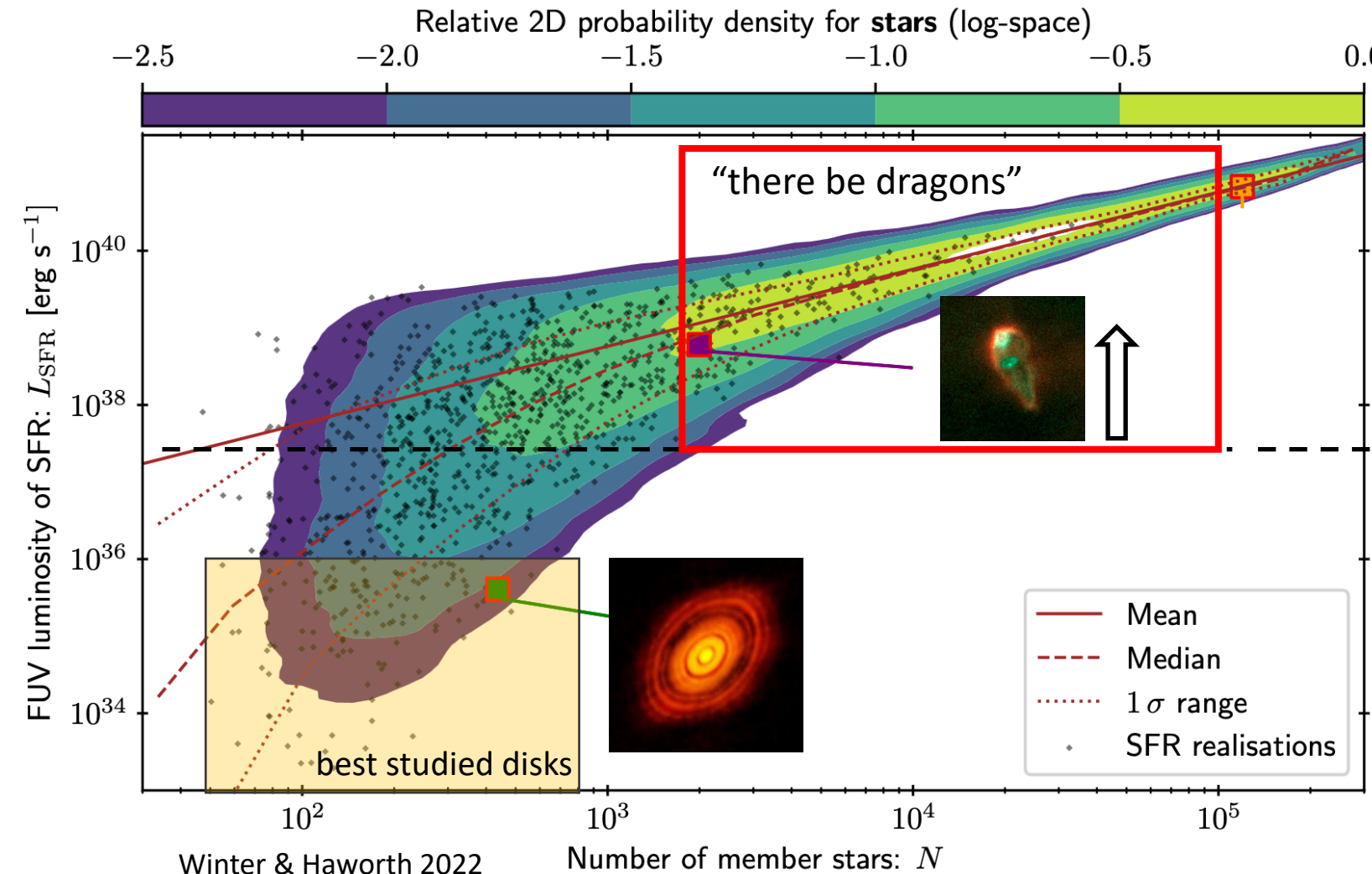
Timescale: external UV destroys disks, reducing time & mass for planet formation

→ Need surveys of different high-mass regions – **MUSE!**

Ingredients: UV may leave organics intact and/or enable organic chemistry – need more representative samples

→ Need sample of low-mass sources in different UV environments – **MUSE!**

Environment: evolution may be crucial to understand the demographics of exoplanets



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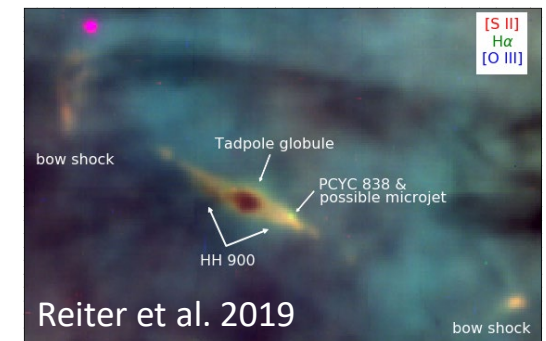
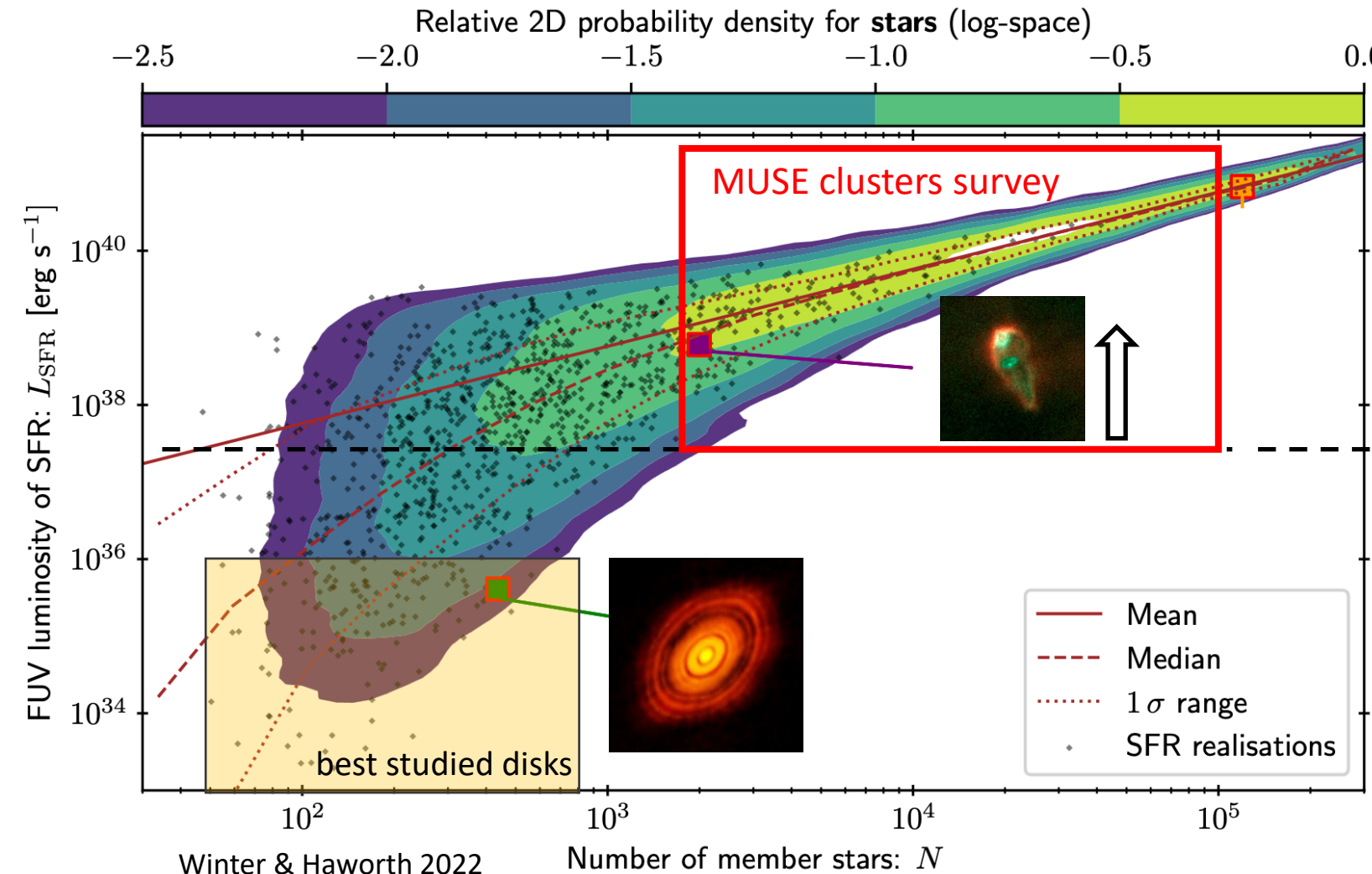
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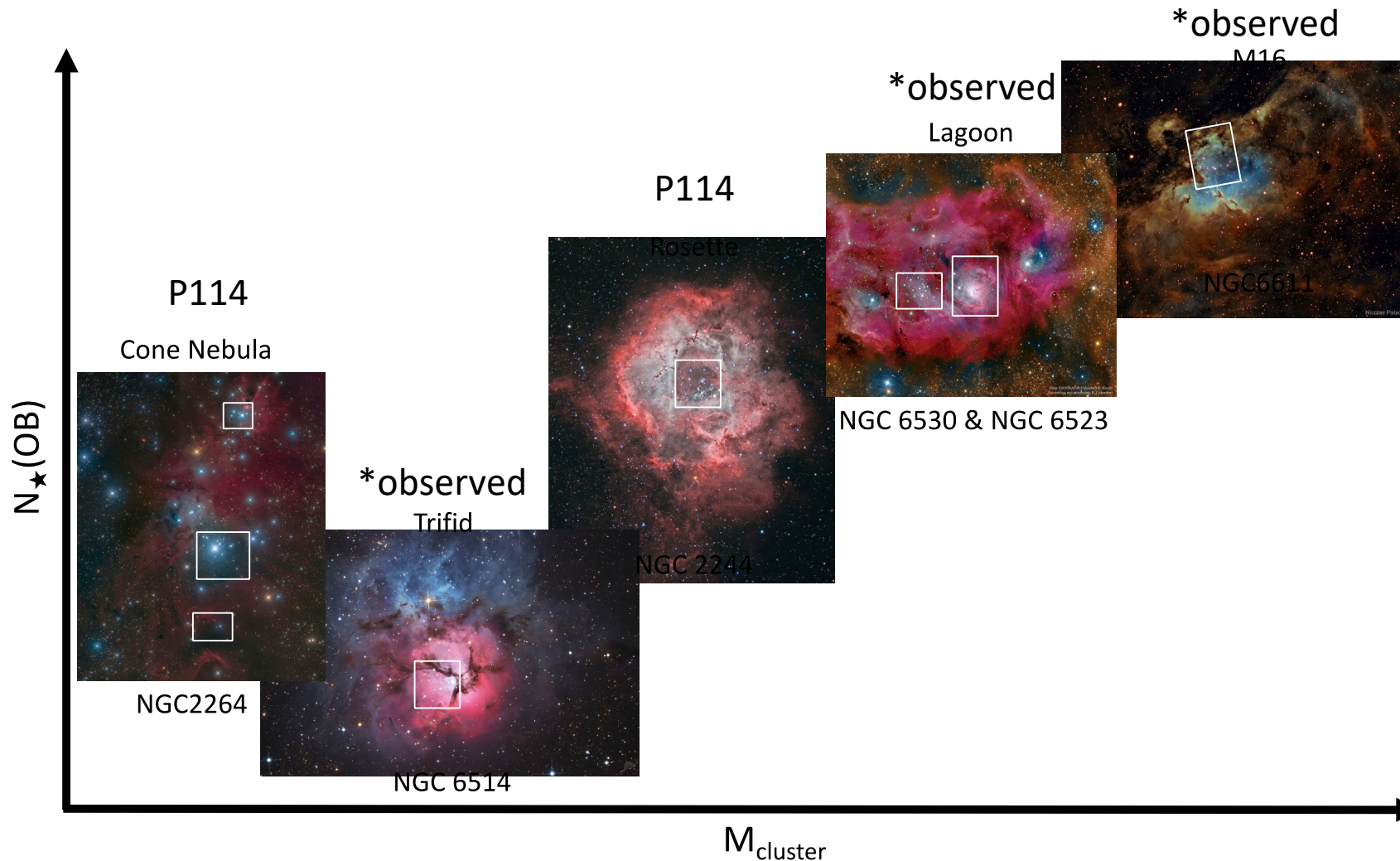
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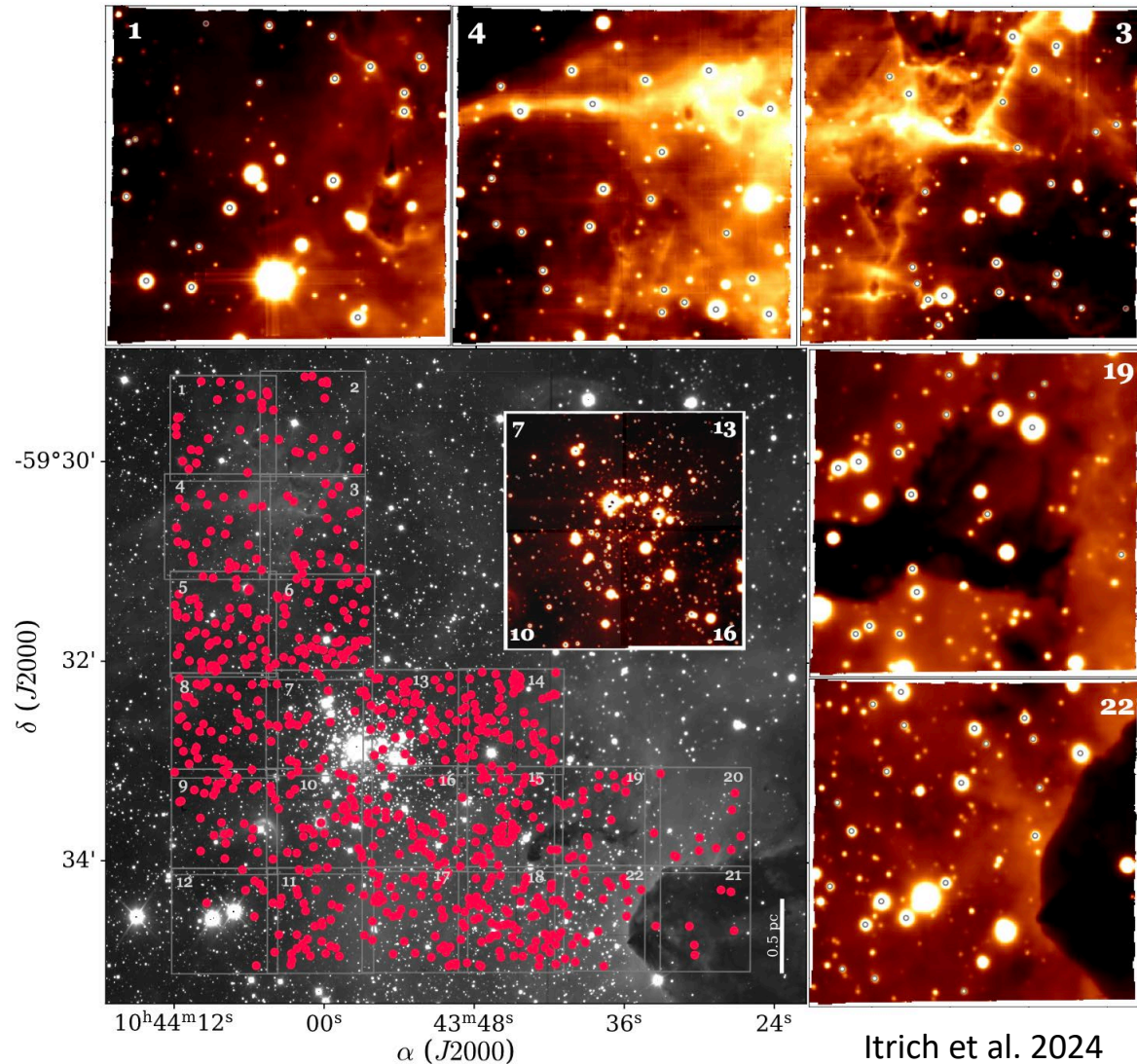


Quantifying the impact of external photoevaporation on planet-forming disks requires a survey of typical conditions.

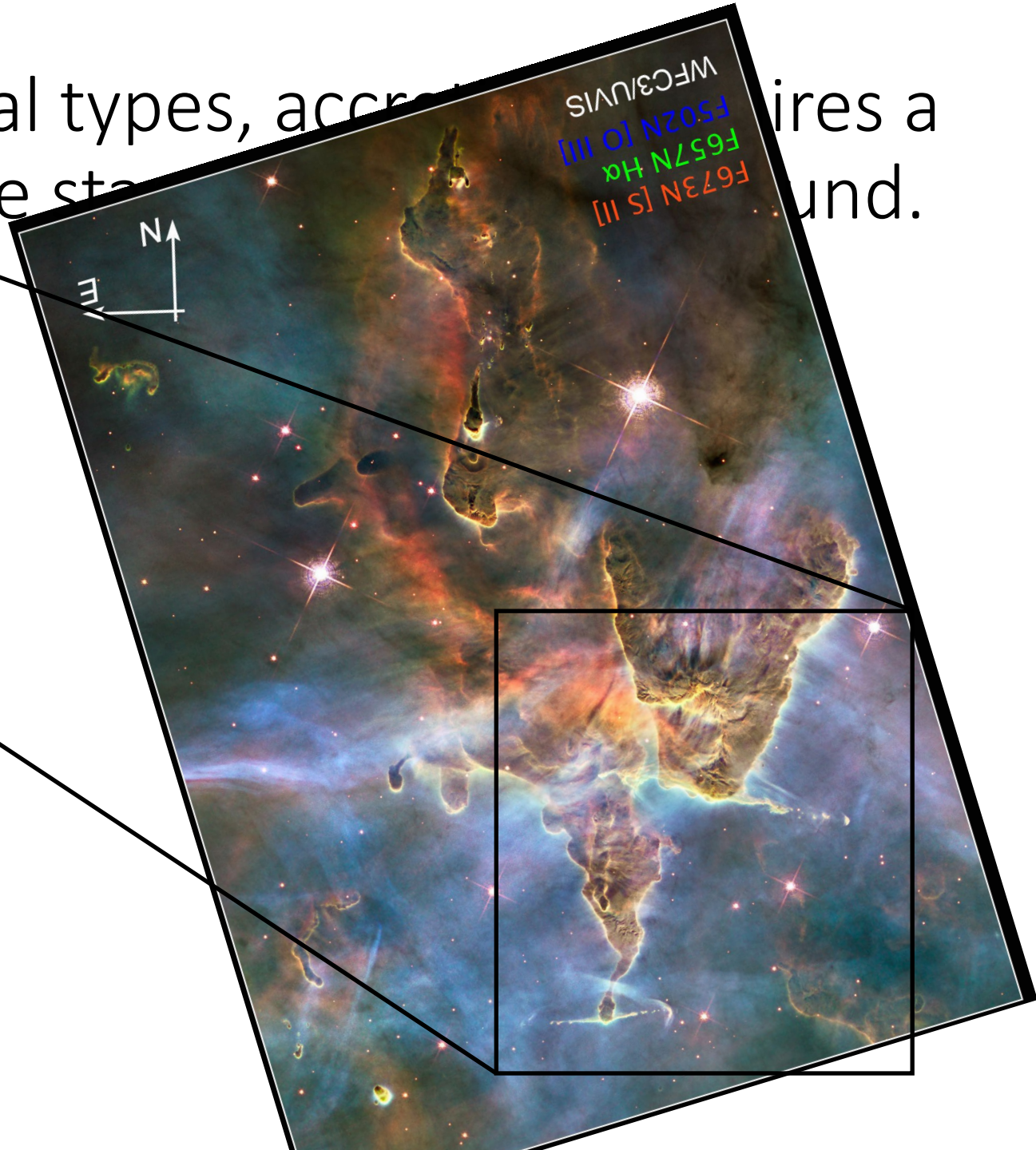
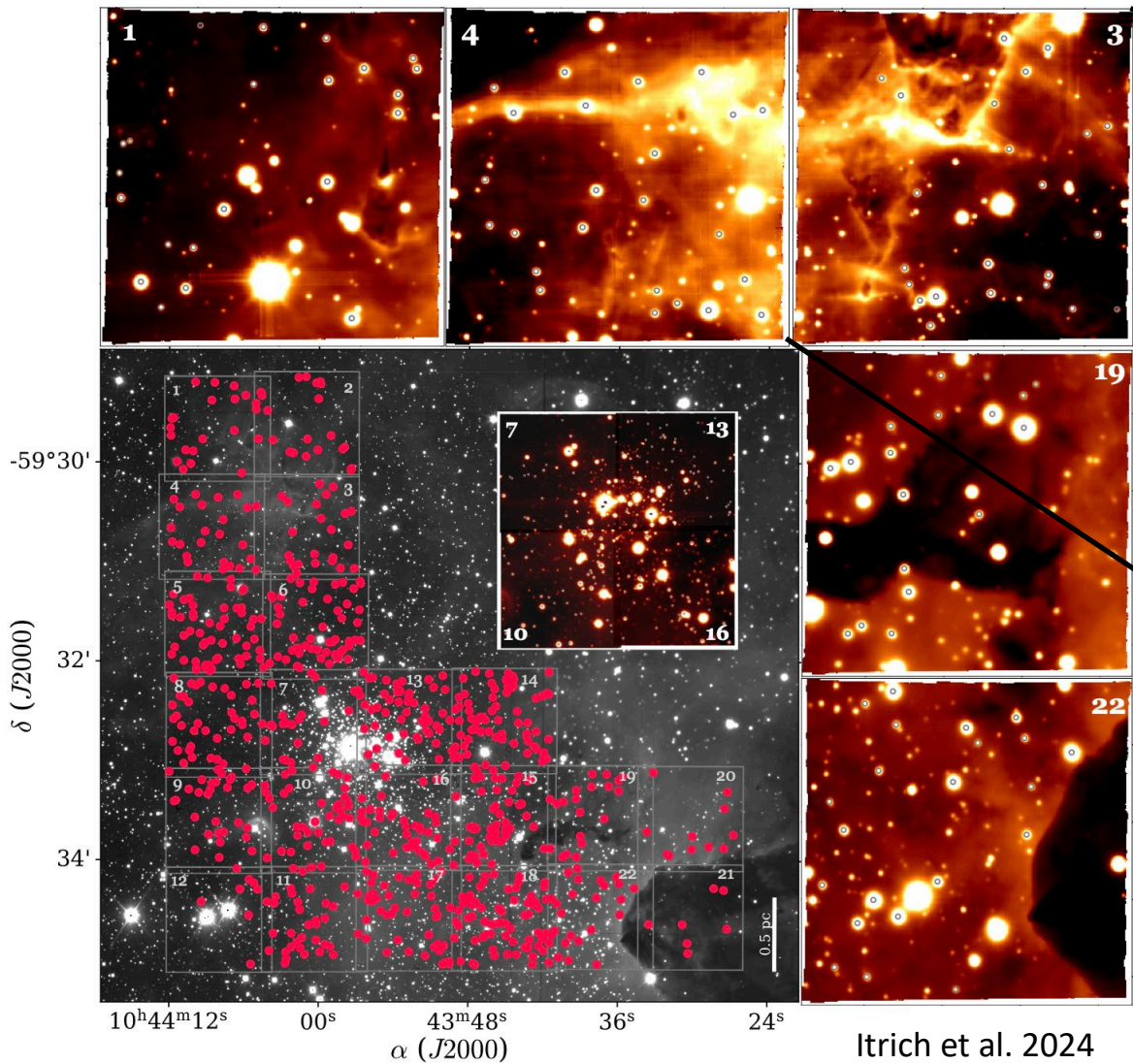


MUSE VLT: 112 hours awarded
67 hours observed
PI: M. Reiter
NSF CAREER grant 2339164
***hiring a postdoc soon!**

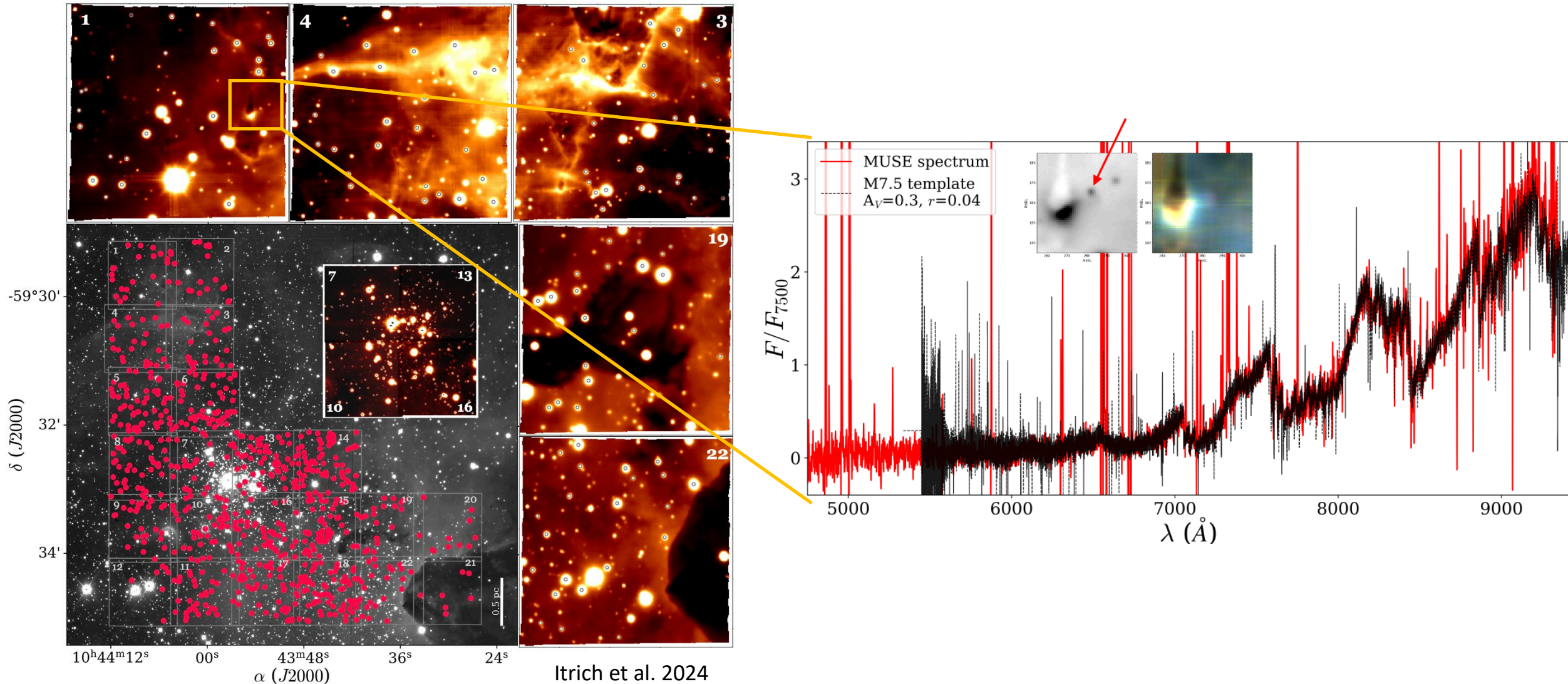
With MUSE, measure spectral types, accretion (requires a disk!), outflows, *and* separate stars from the background.



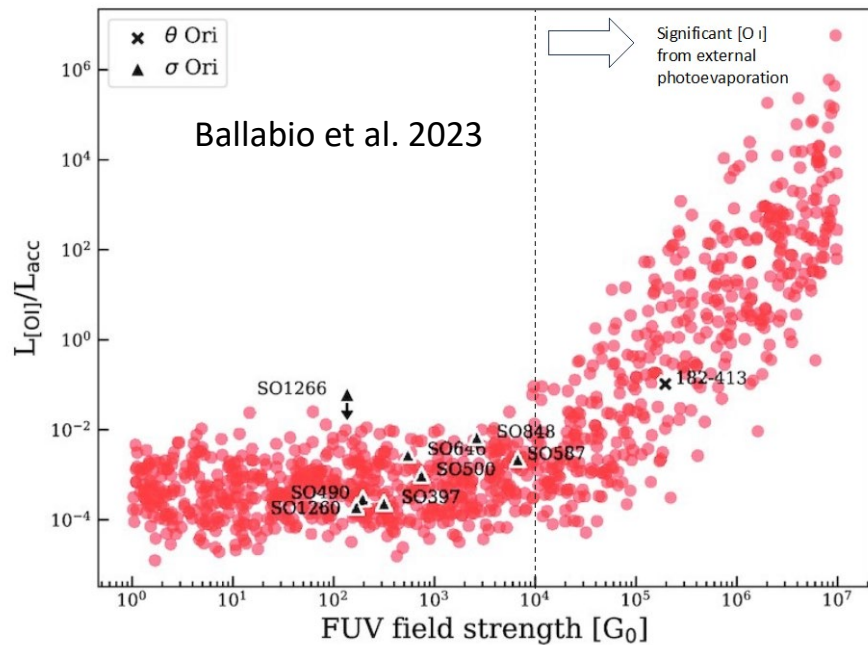
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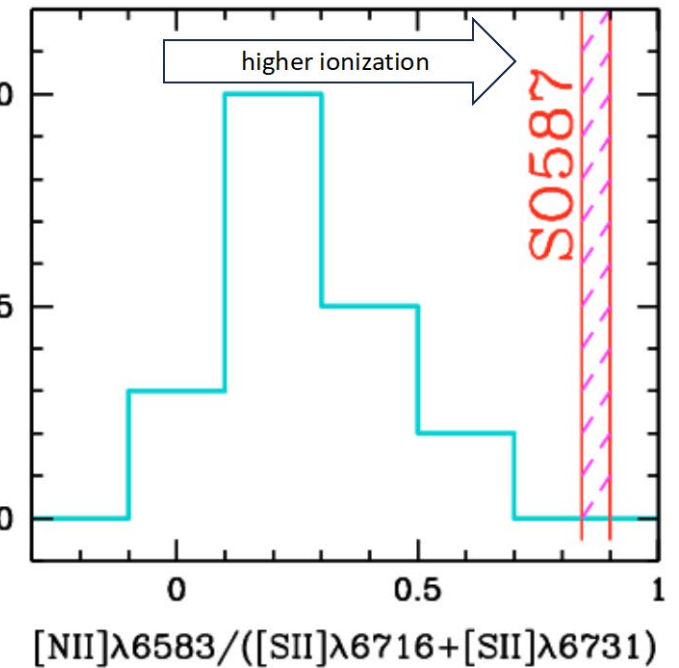
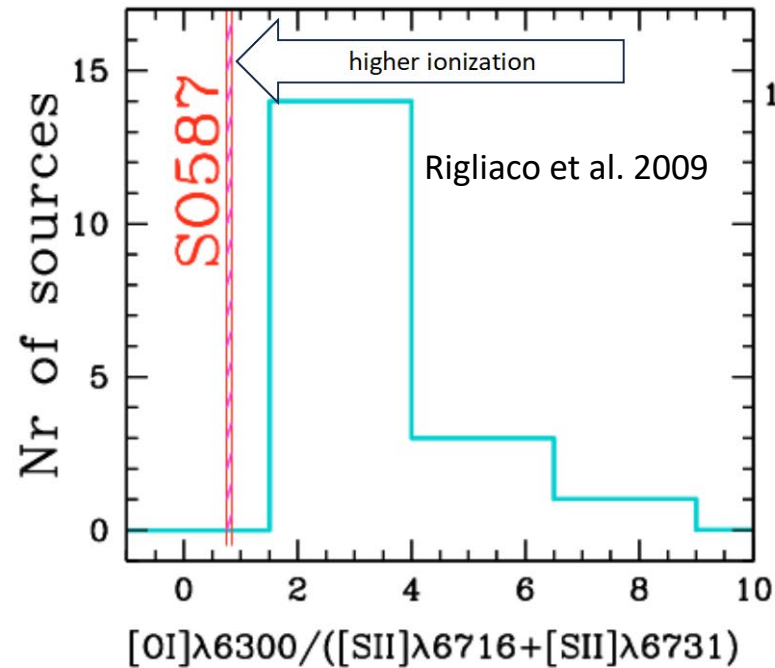
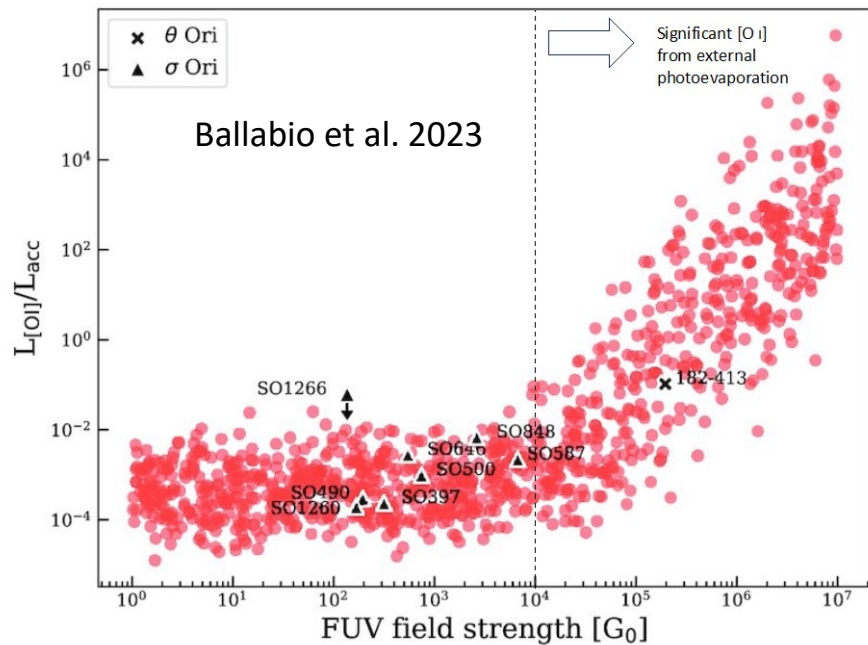
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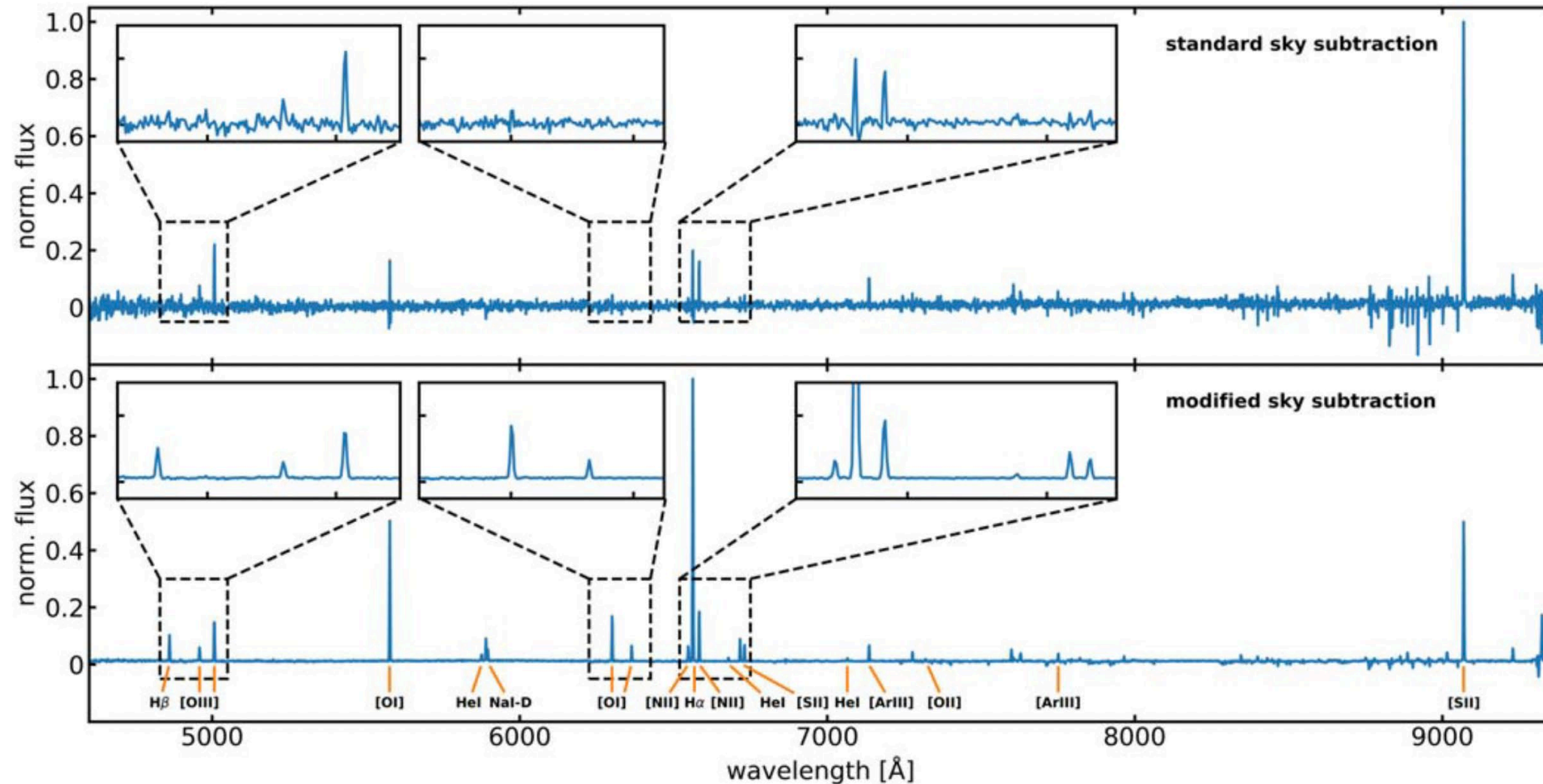
Search for diagnostics of external photoevaporation that are not spatially resolved – confirm with ELT.



Search for diagnostics of external photoevaporation that are not spatially resolved – confirm with ELT.

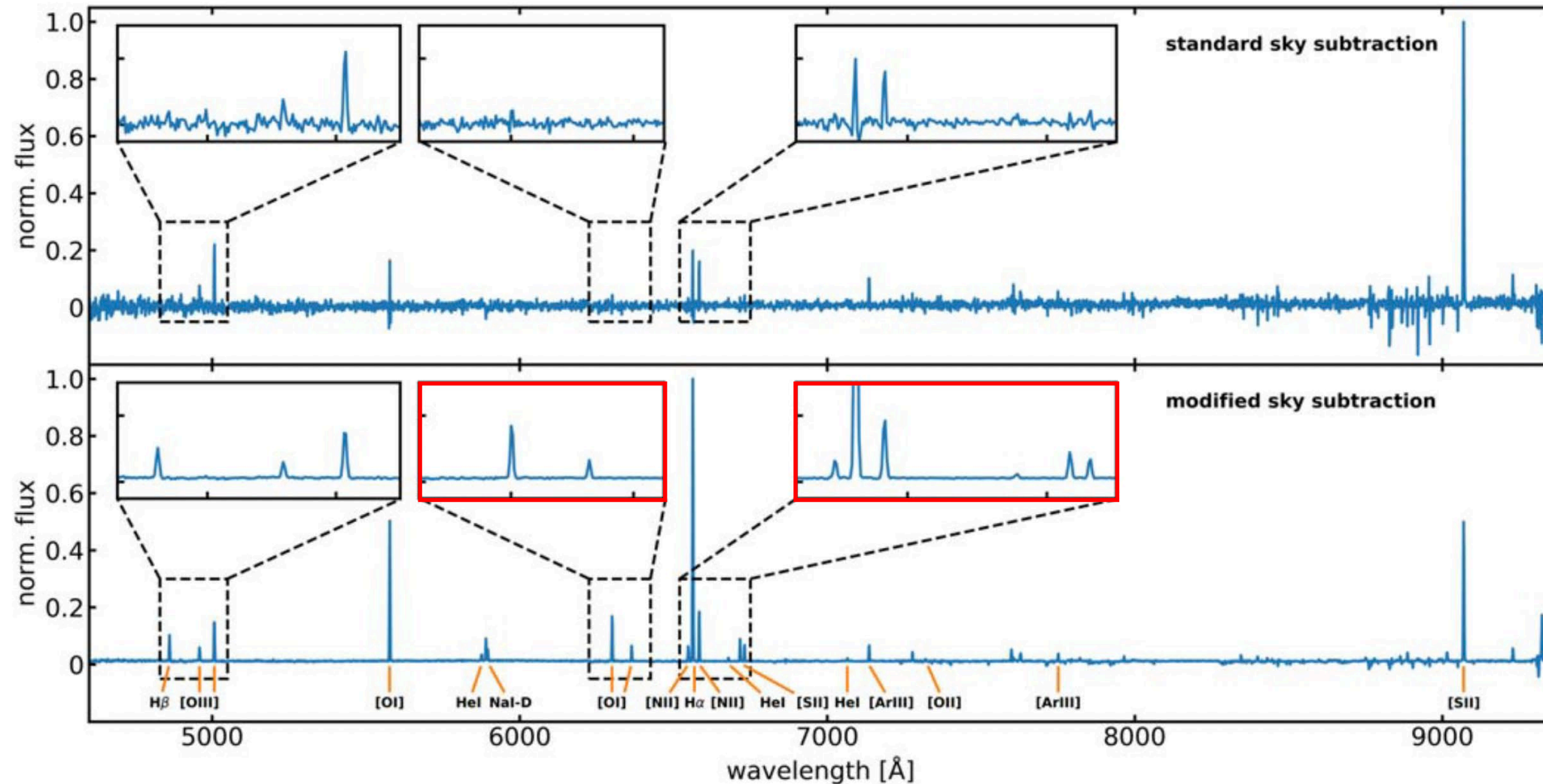


Challenge: subtracting sky lines without affecting the fluxes or shapes of key emission lines.



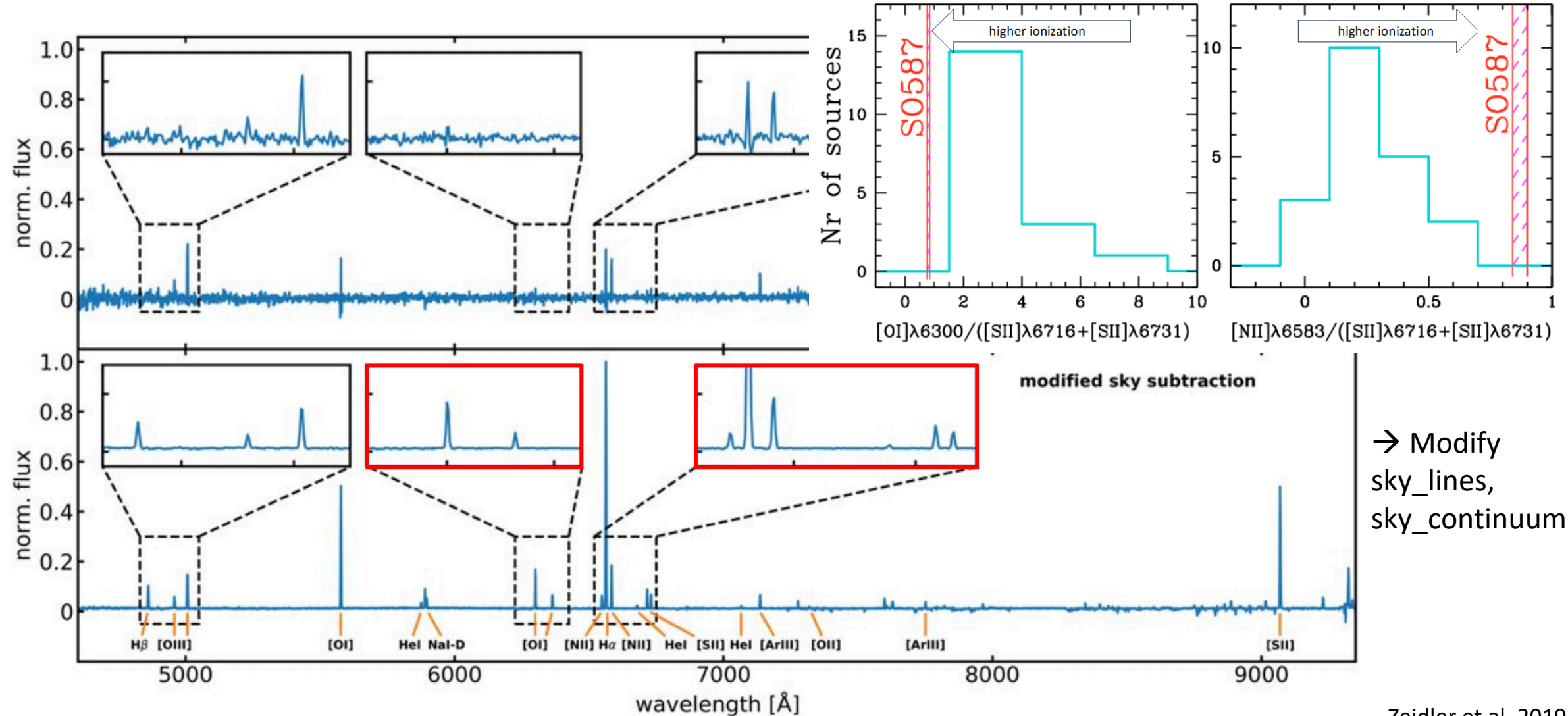
→ Modify
sky_lines,
sky_continuum

Challenge: subtracting sky lines without affecting the fluxes or shapes of key emission lines.

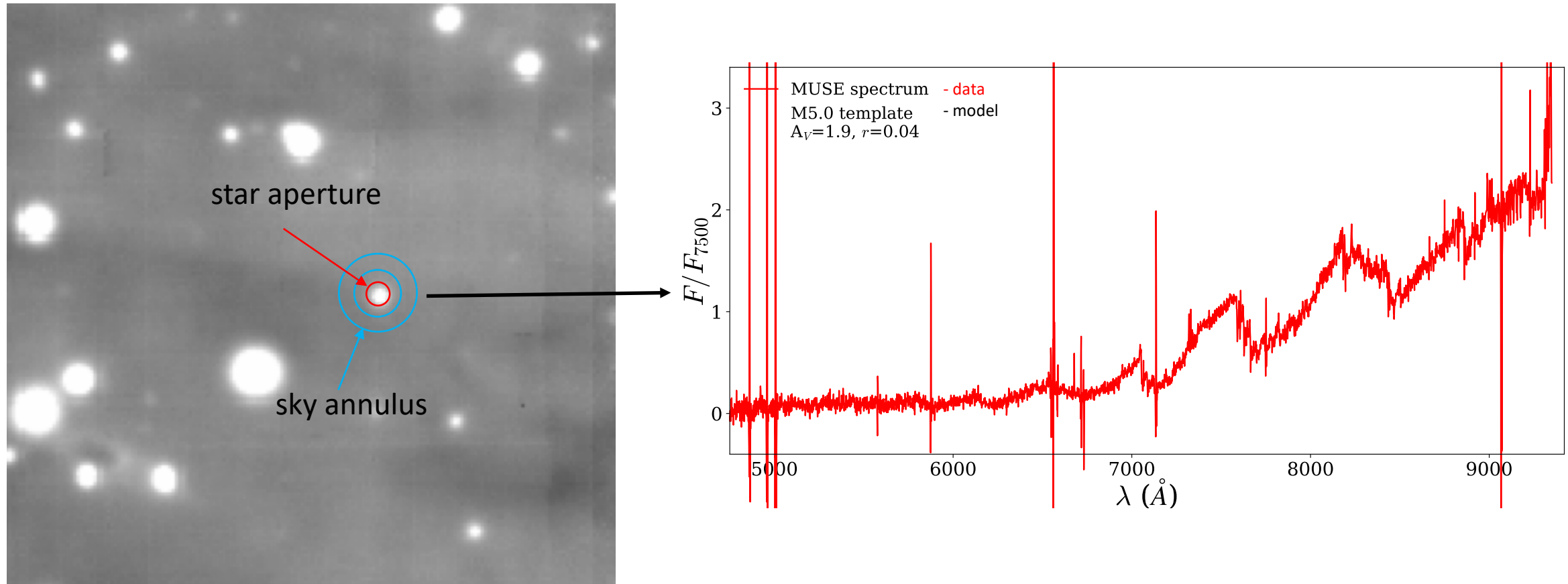


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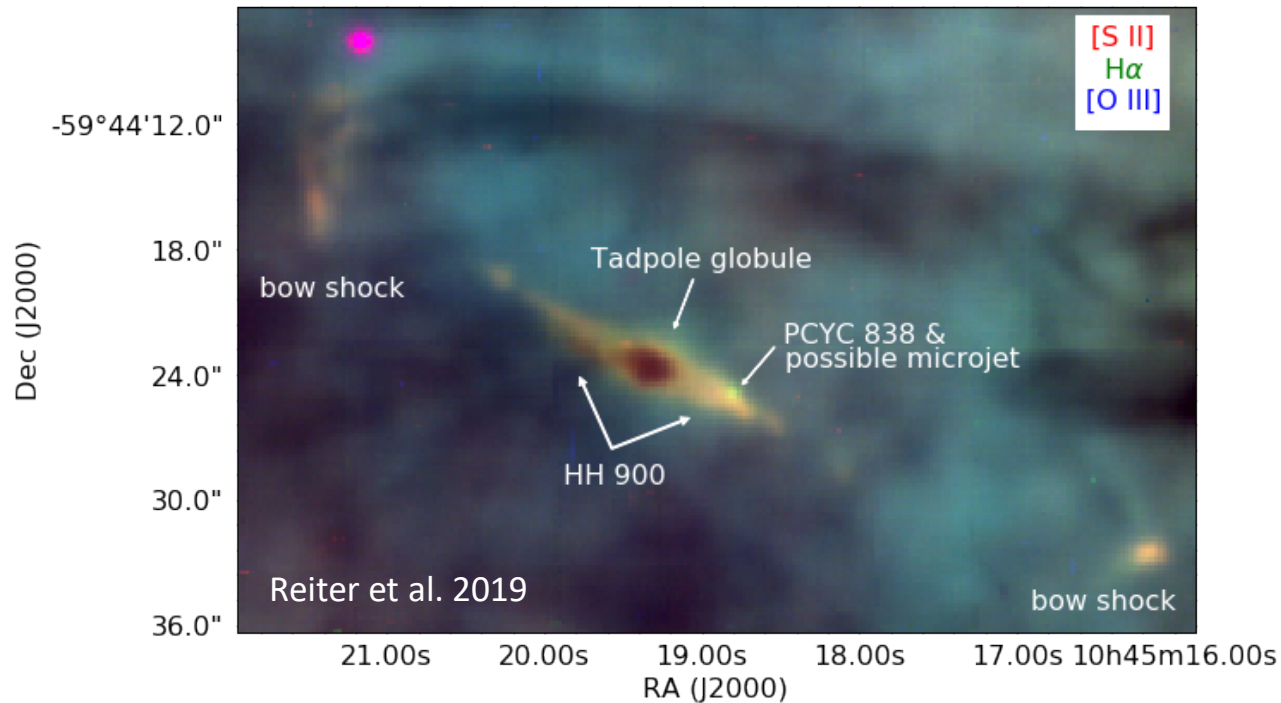
Challenge: subtracting sky lines without affecting the fluxes or shapes of key emission lines.



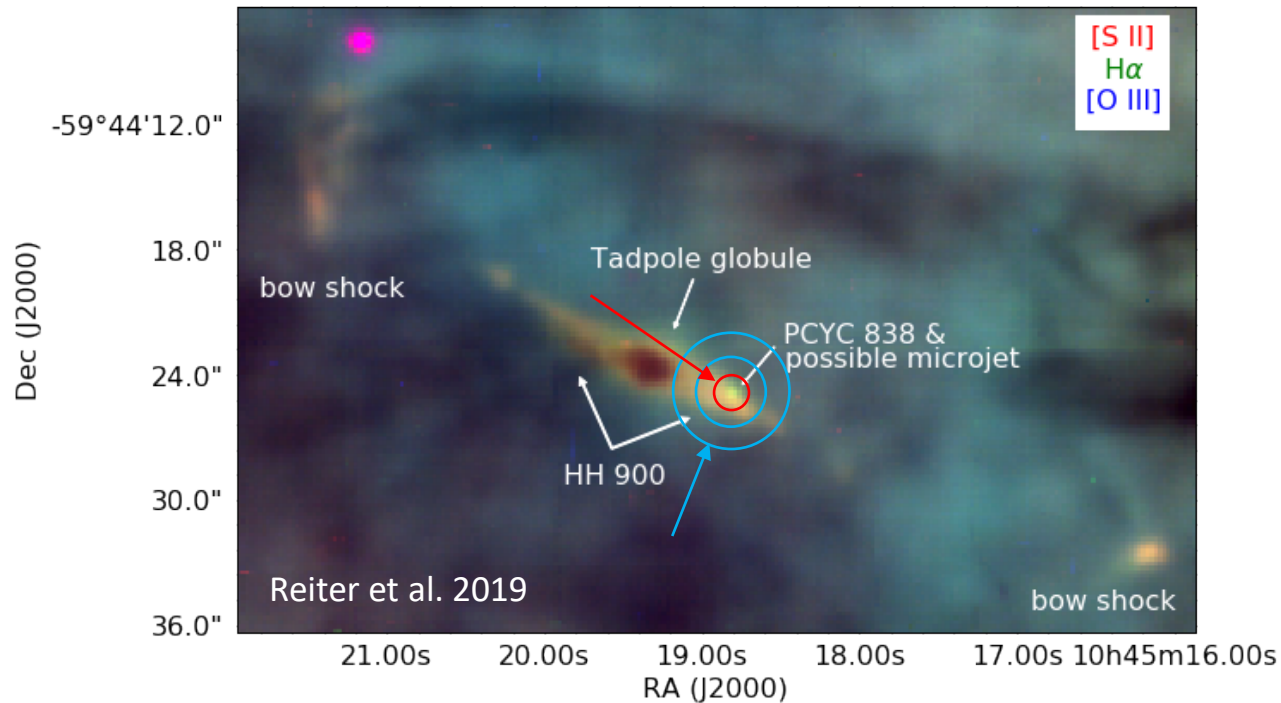
Challenge: subtracting the “sky” without affecting the fluxes or shapes of key emission lines.



Challenge: everything is evaporating – clouds, jets, disks, and the HII region are all bright in key lines.

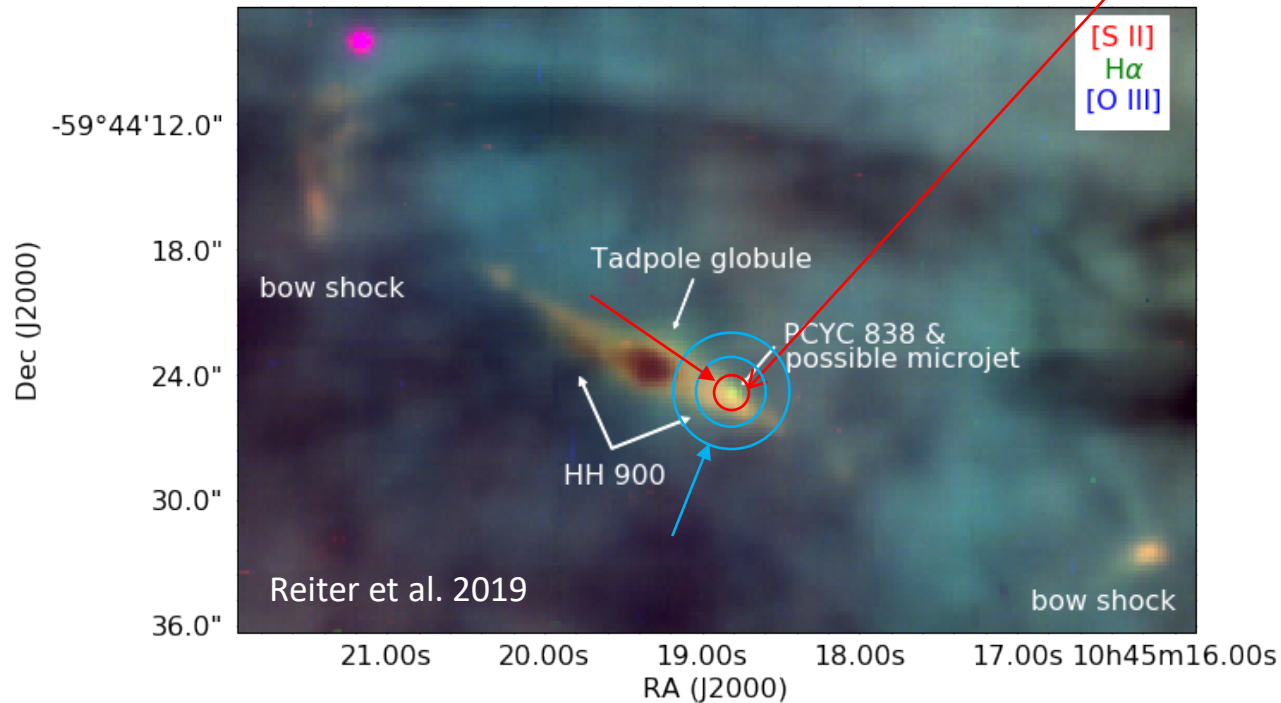


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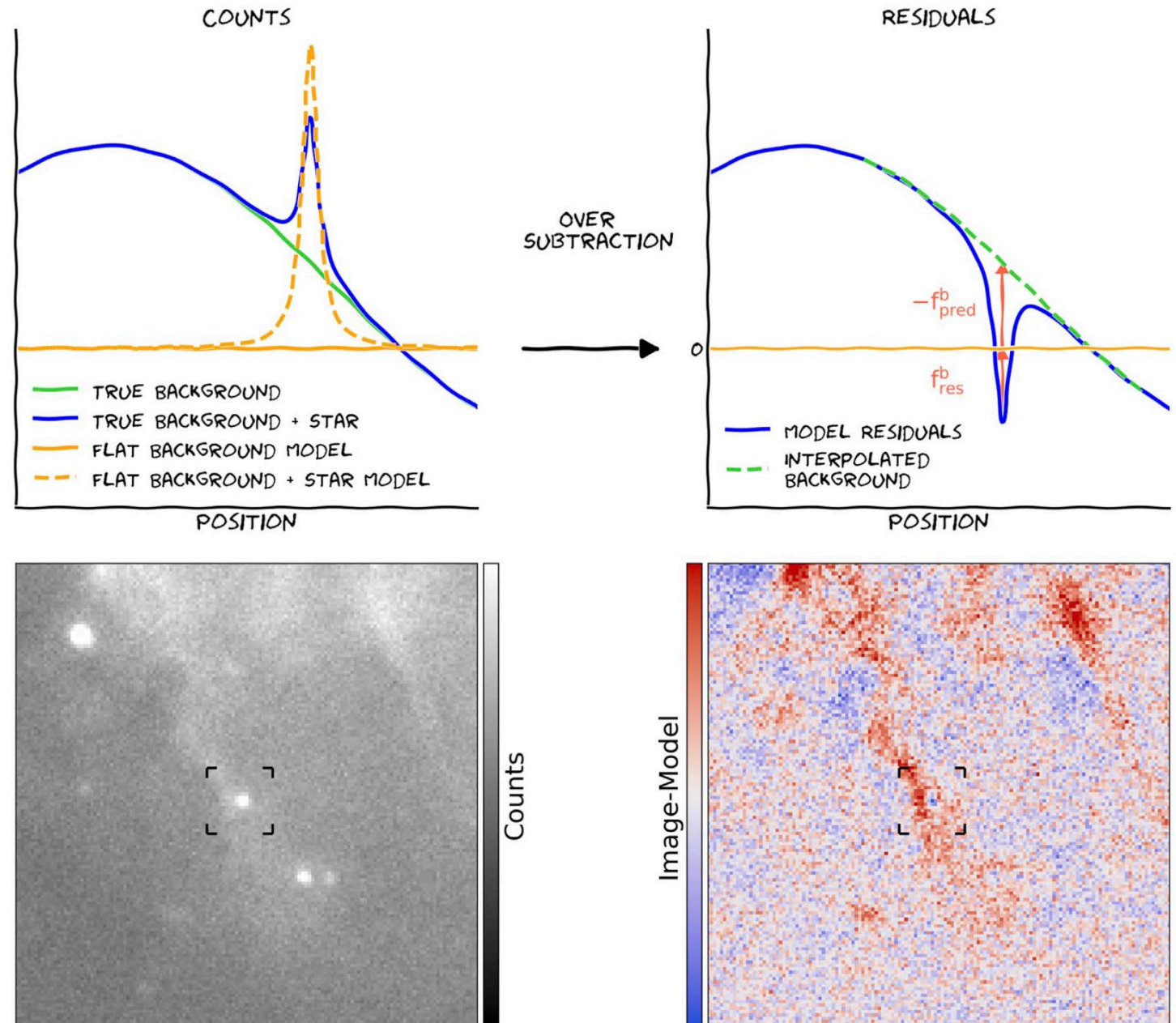
Challenge: everything is evaporating – clouds, jets, disks, and the HII region are all bright in key lines.

1mm continuum
CO J=2-1
near-IR excess
→ evaporation signatures?



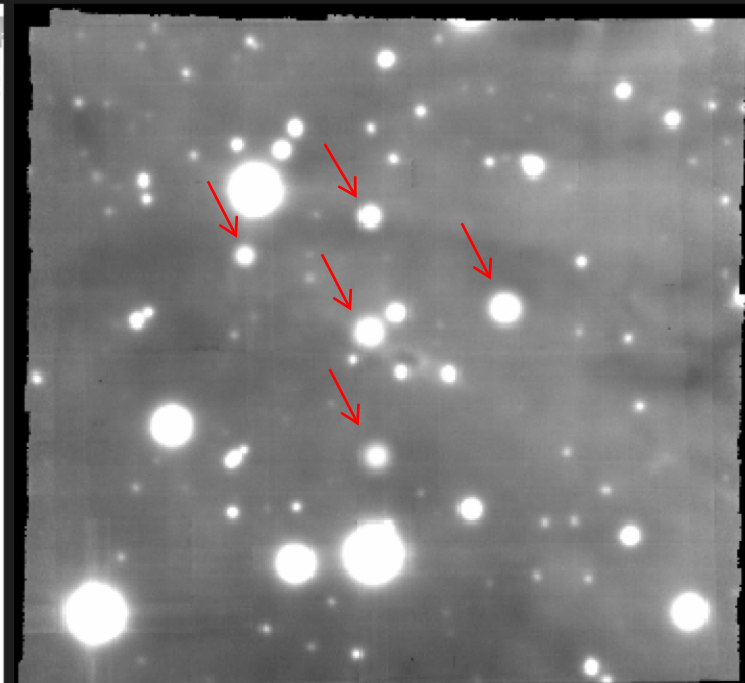
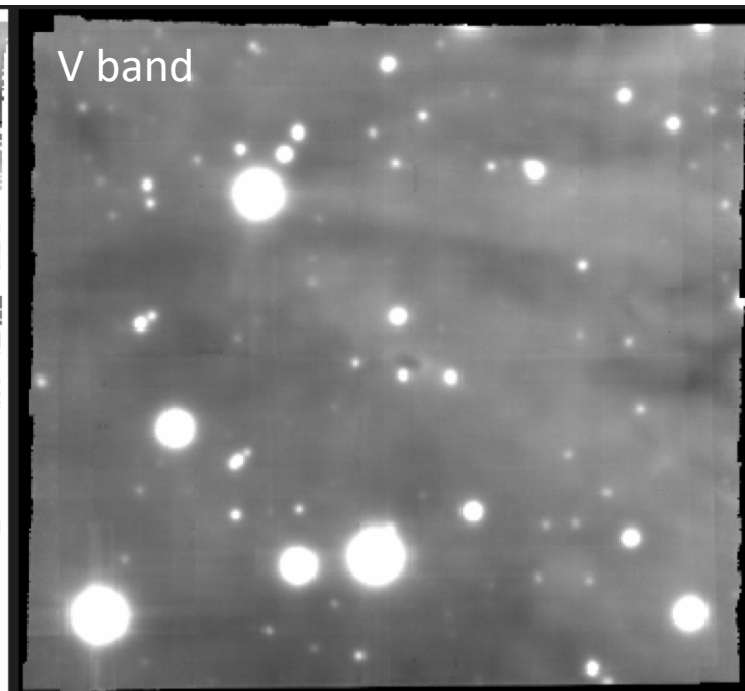
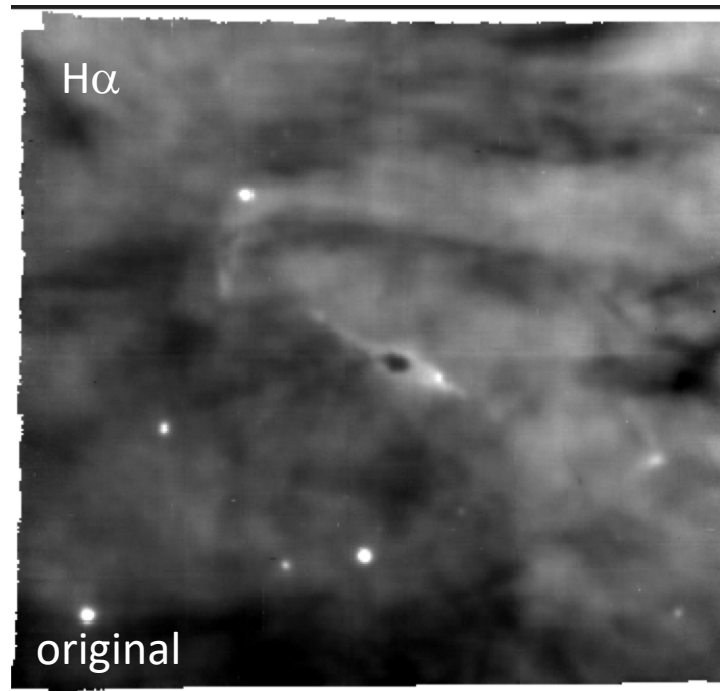
Developing Gaussian process techniques to model and remove structured backgrounds.

(Or I get by with a little help from my friends in Statistics).

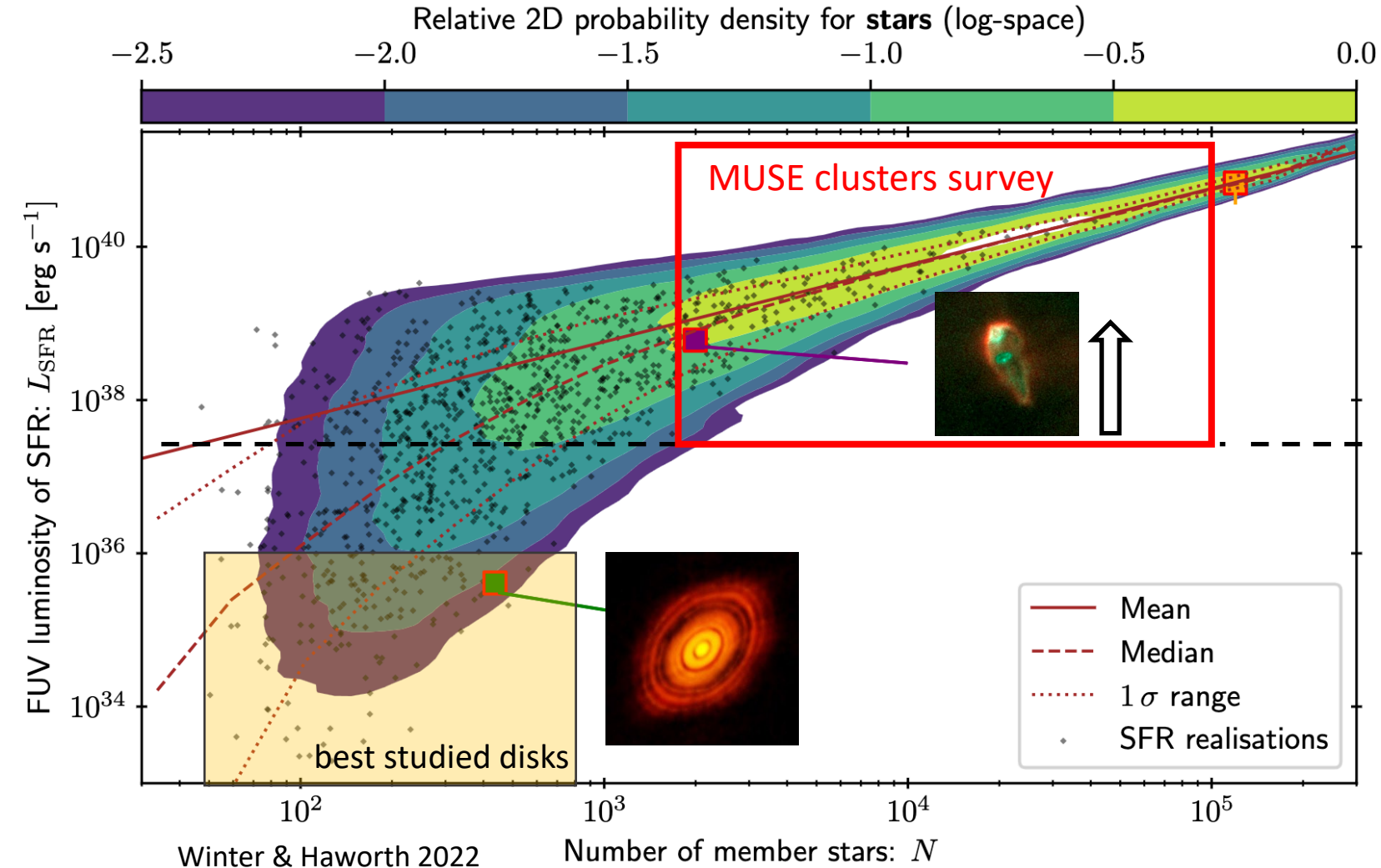


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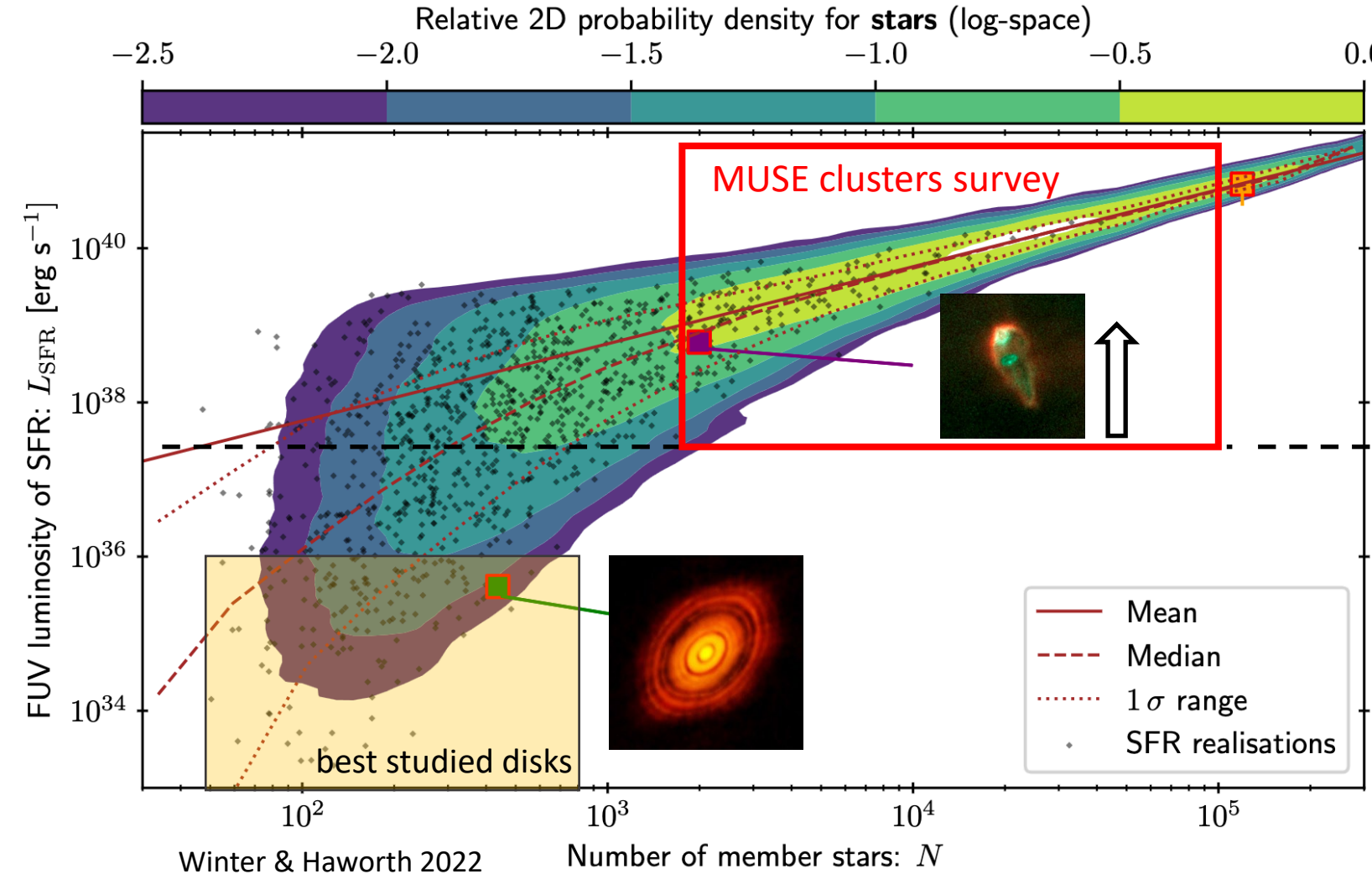
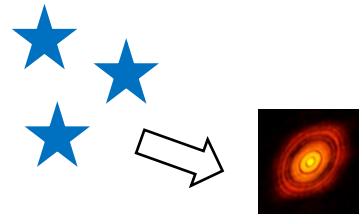


Most planet-forming disks will be affected by UV from nearby high-mass stars.



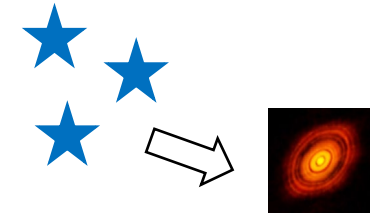
Most planet-forming disks will be affected by UV from nearby high-mass stars.

Timescale: external UV destroys disks, reducing time & mass for planet formation

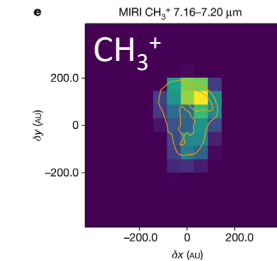


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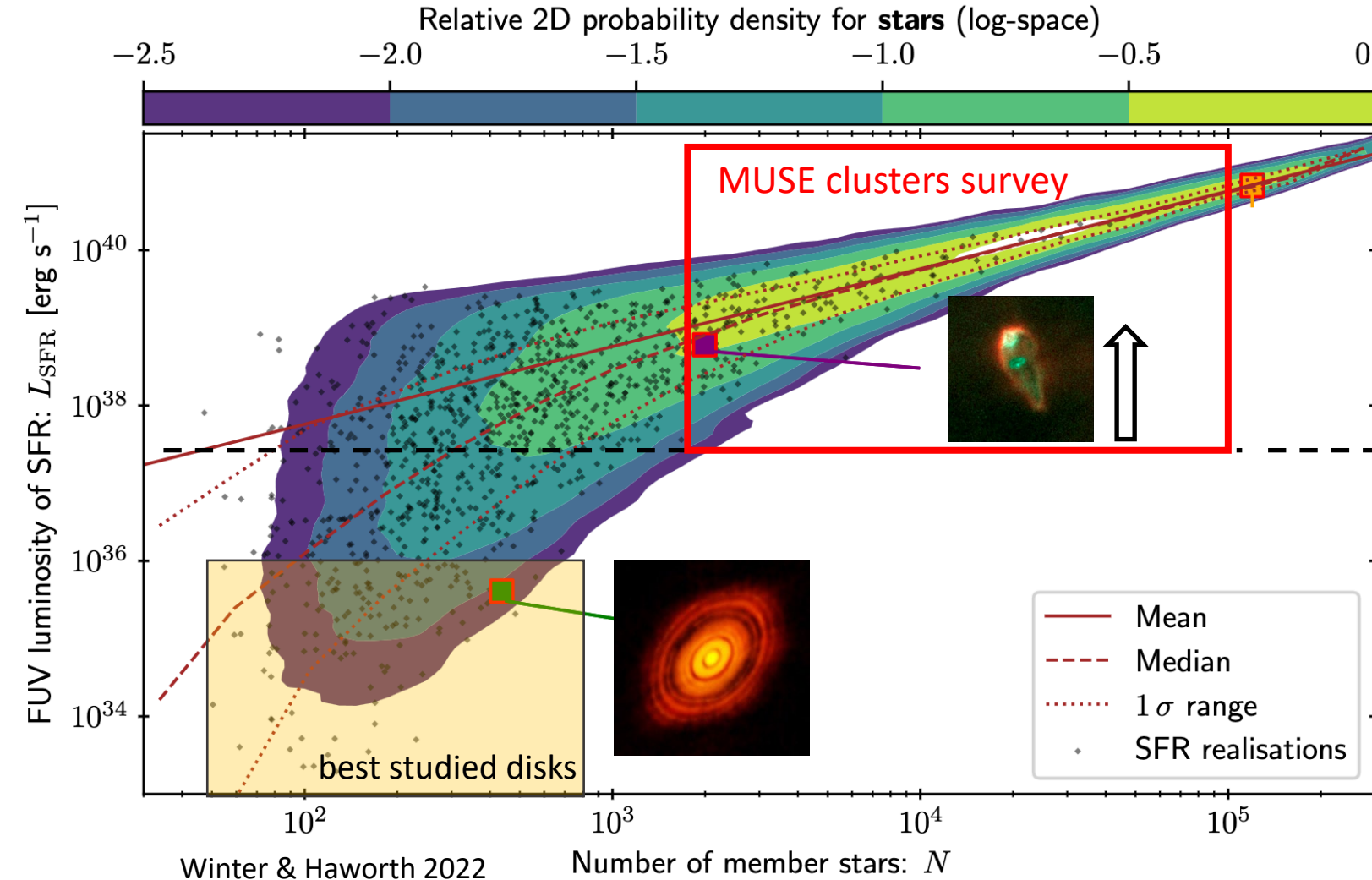
Timescale: external UV destroys disks, reducing time & mass for planet formation



Ingredients: UV may leave organics intact and/or enable organic chemistry – need more representative samples



Berné et al. 2023

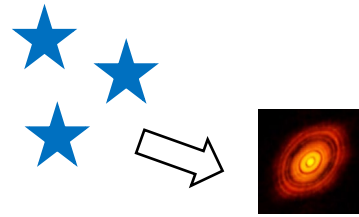


Winter & Haworth 2022

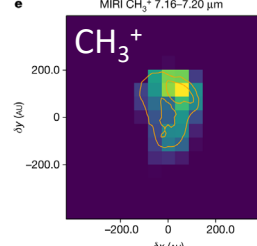
Number of member stars: N

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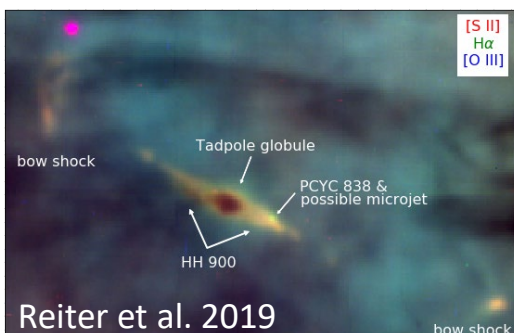


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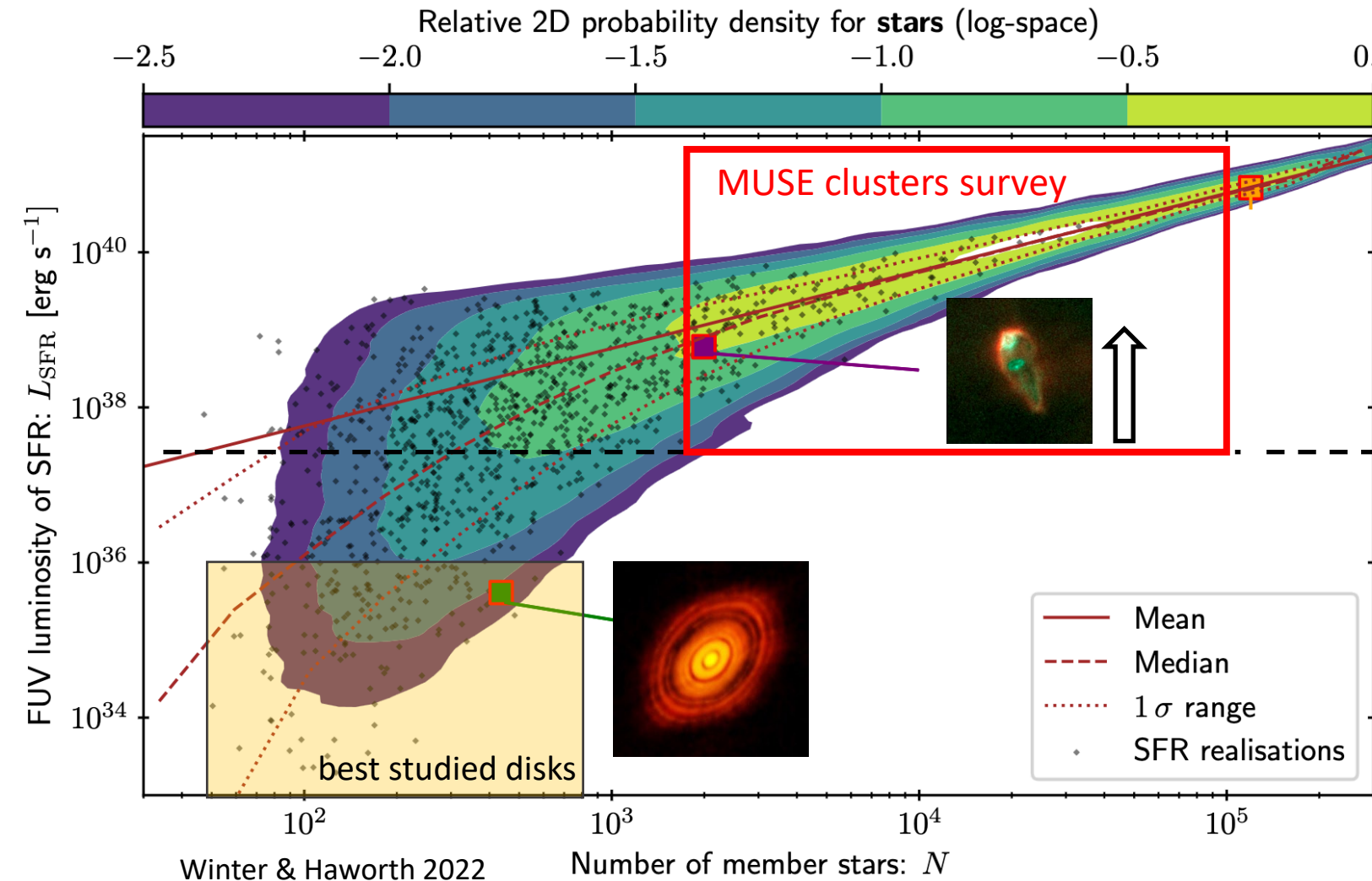


Berné et al. 2023

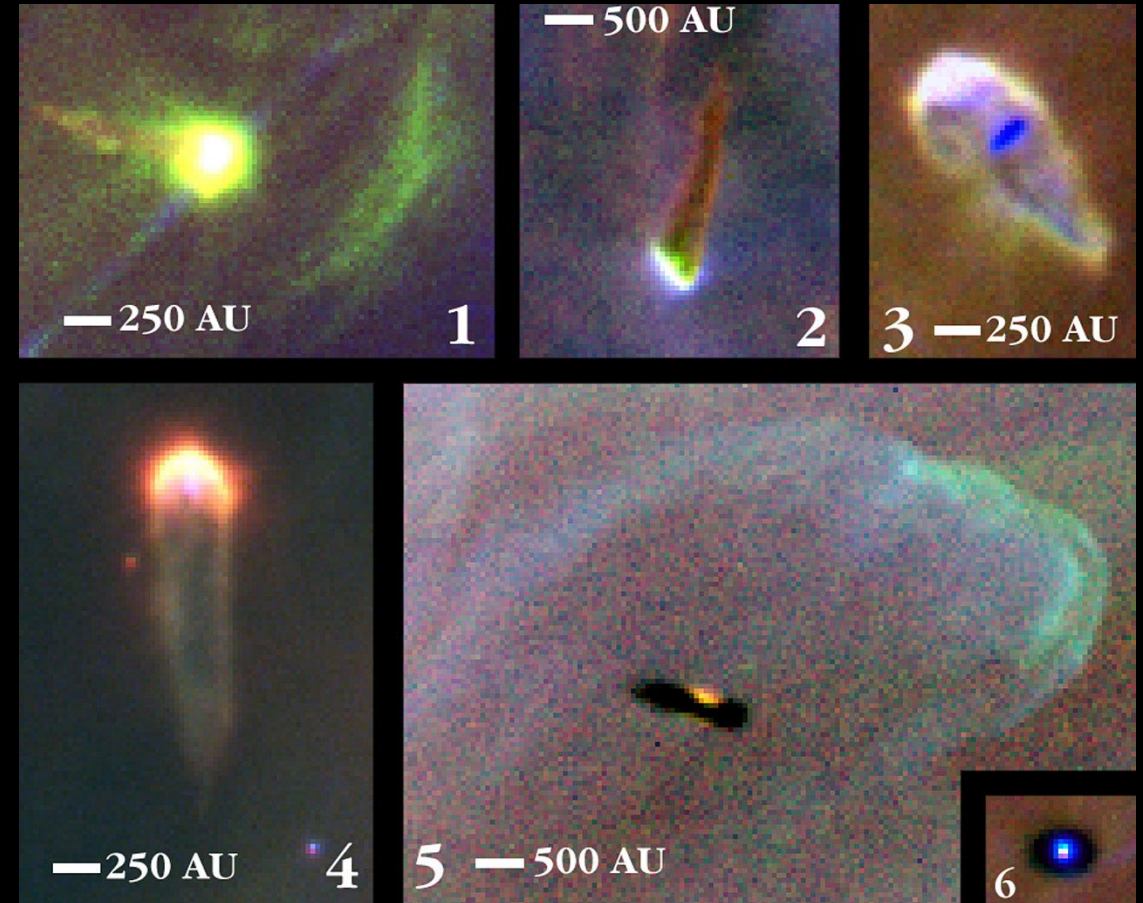
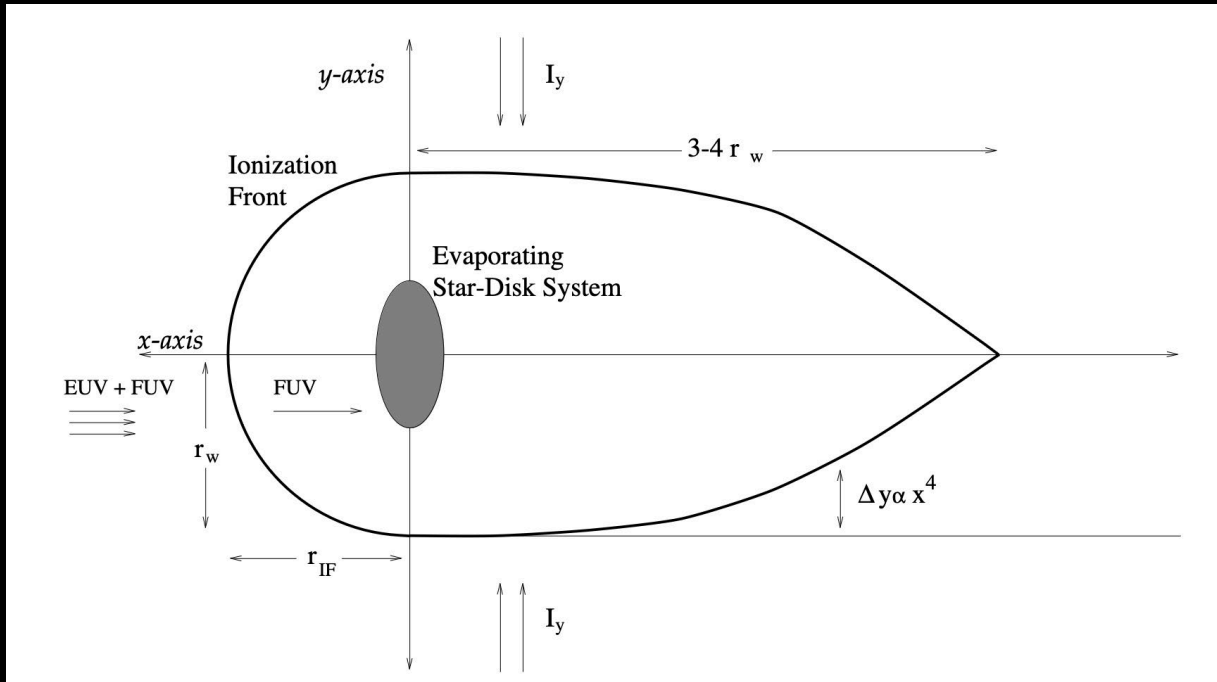
Environment: evolution may be crucial to understand the demographics of exoplanets



Reiter et al. 2019



Anatomy of a proplyd

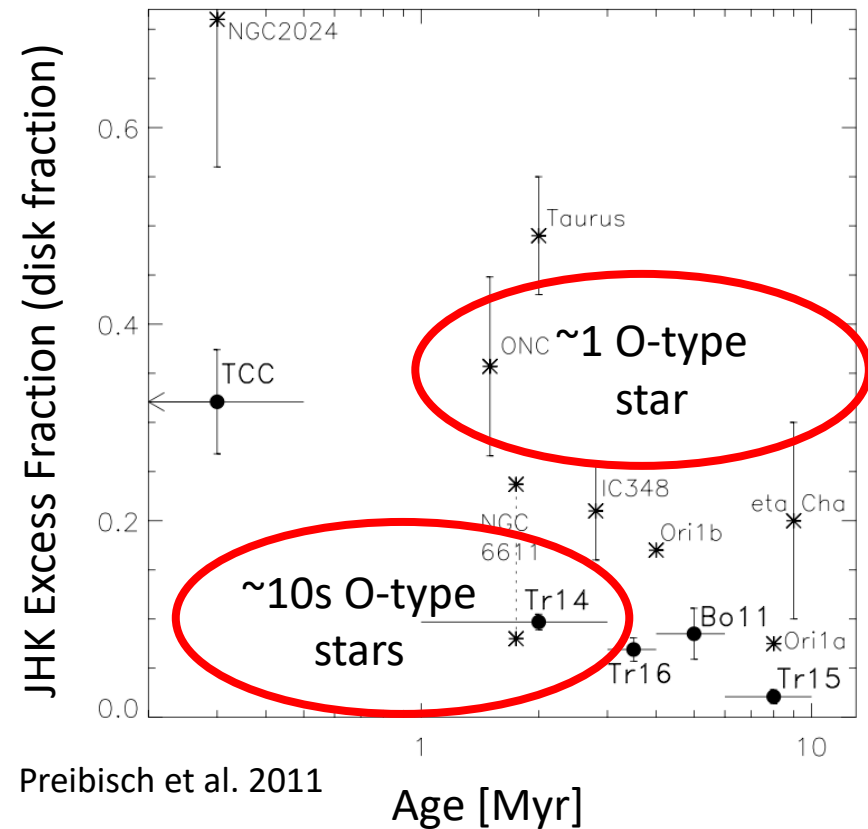


ESA/Hubble

Johnstone et al. (1998)

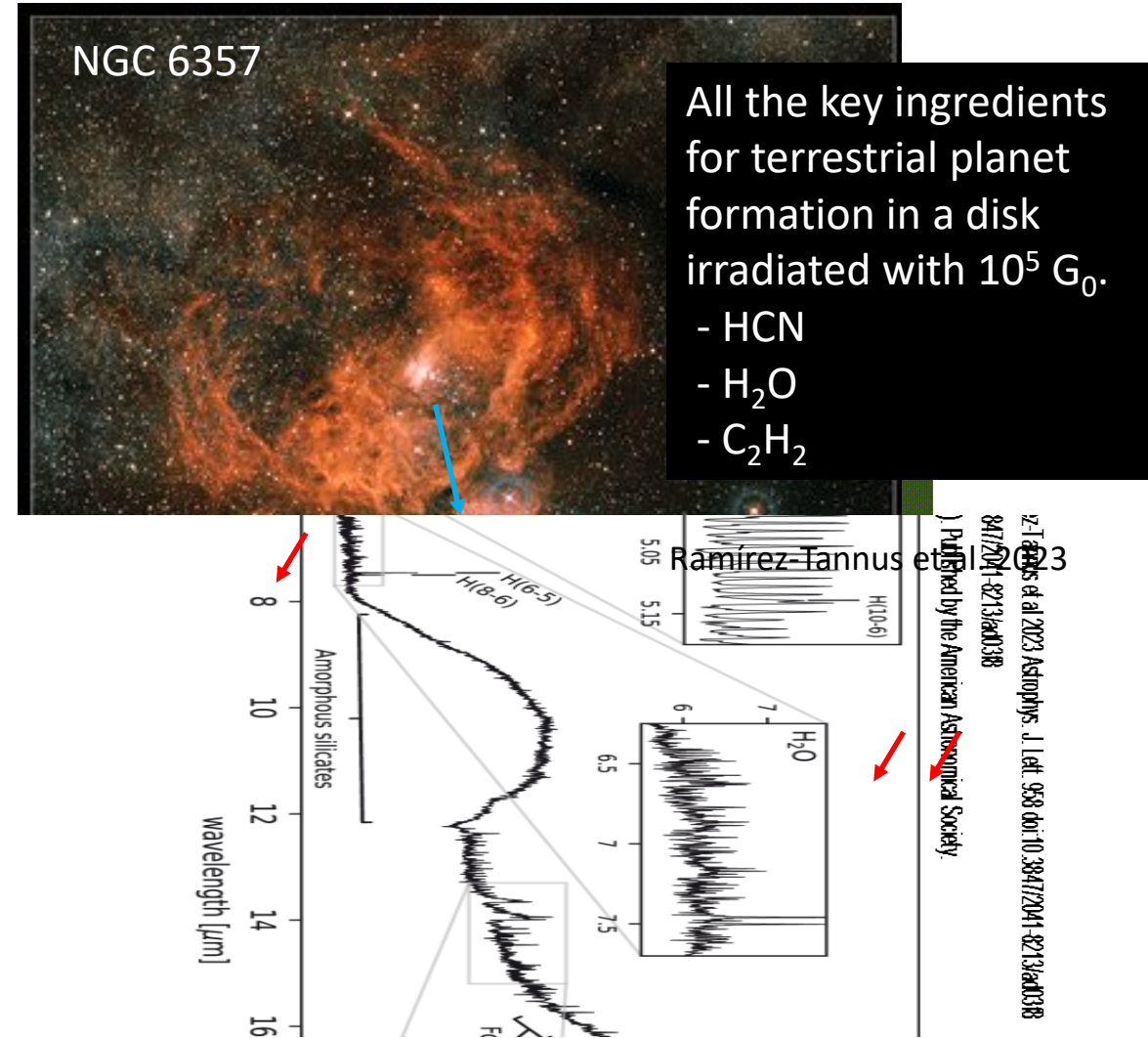
Feedback (esp. radiation) from massive stars affects planet-forming disks by heating and photoevaporating them.

1. the **timescale** for planet formation



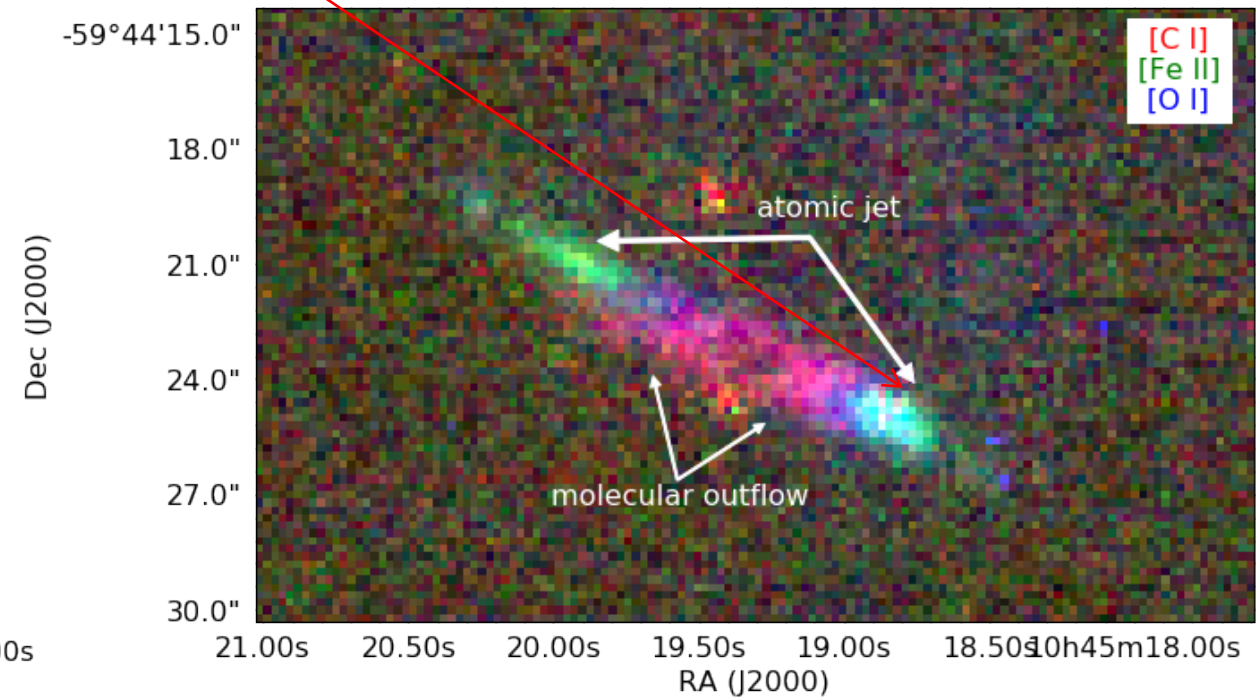
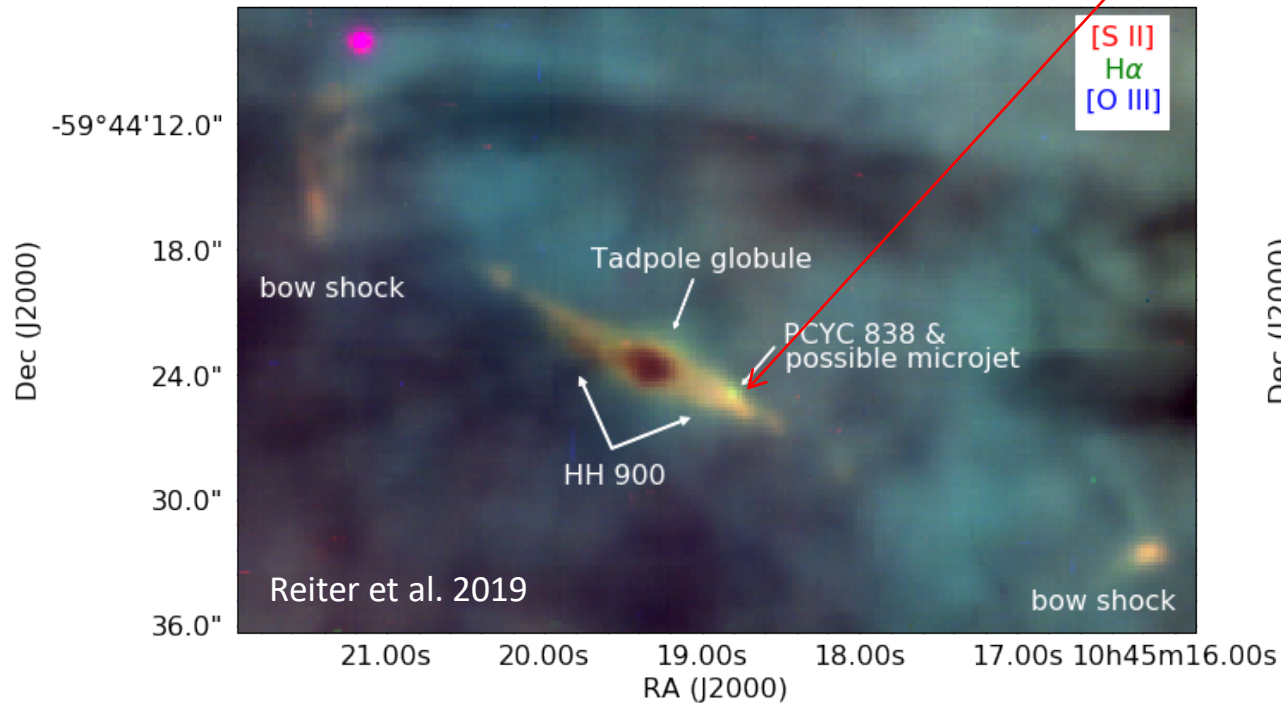
Feedback (esp. radiation) from massive stars affects planet-forming disks by heating and photoevaporating them.

1. the **timescale** for planet formation
2. the **ingredients** for terrestrial planets

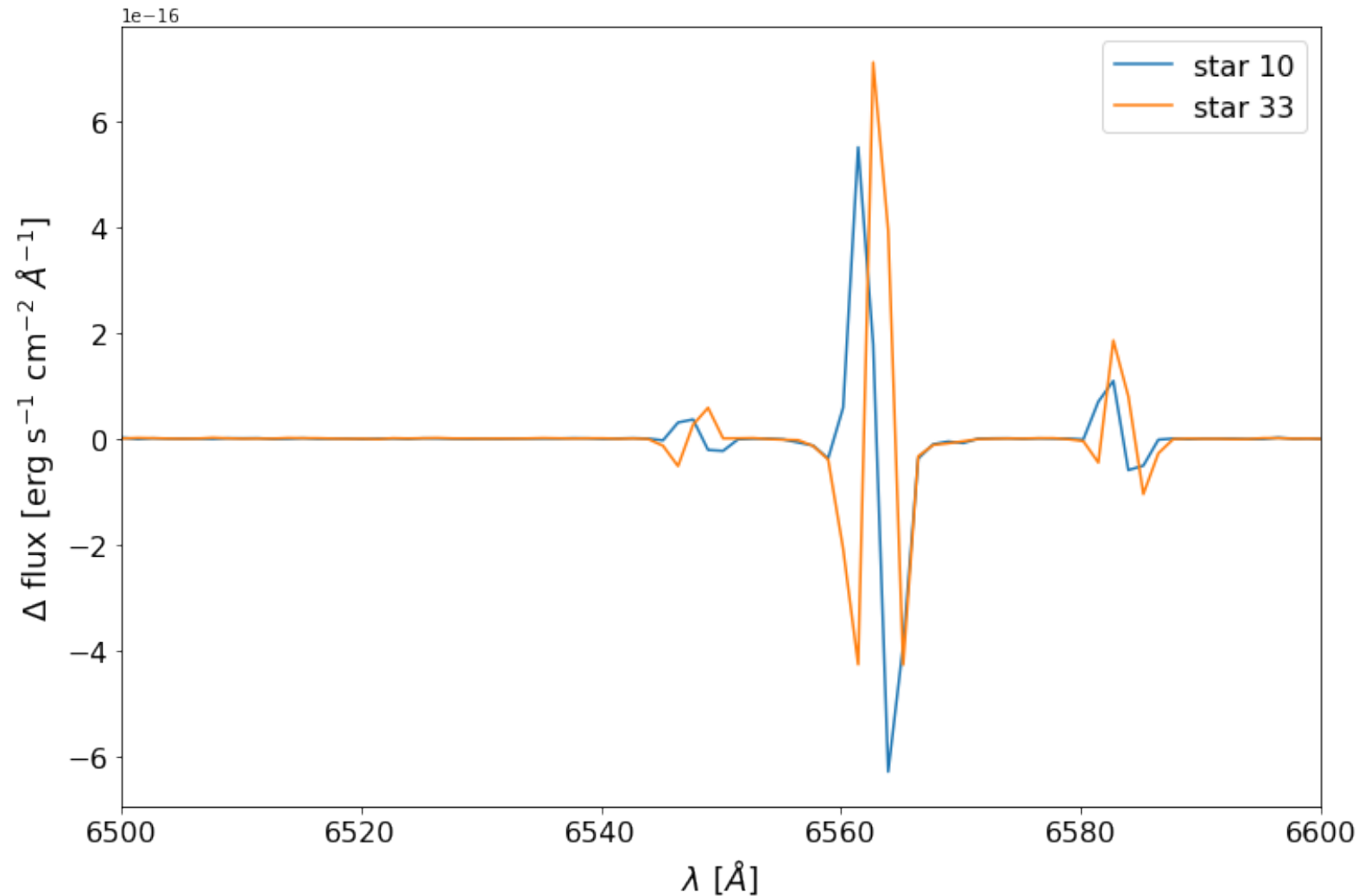


Challenge: everything is evaporating – clouds, jets, disks, and the HII region are all bright in key lines.

1mm continuum
CO J=2-1
near-IR excess
→ evaporation signatures?

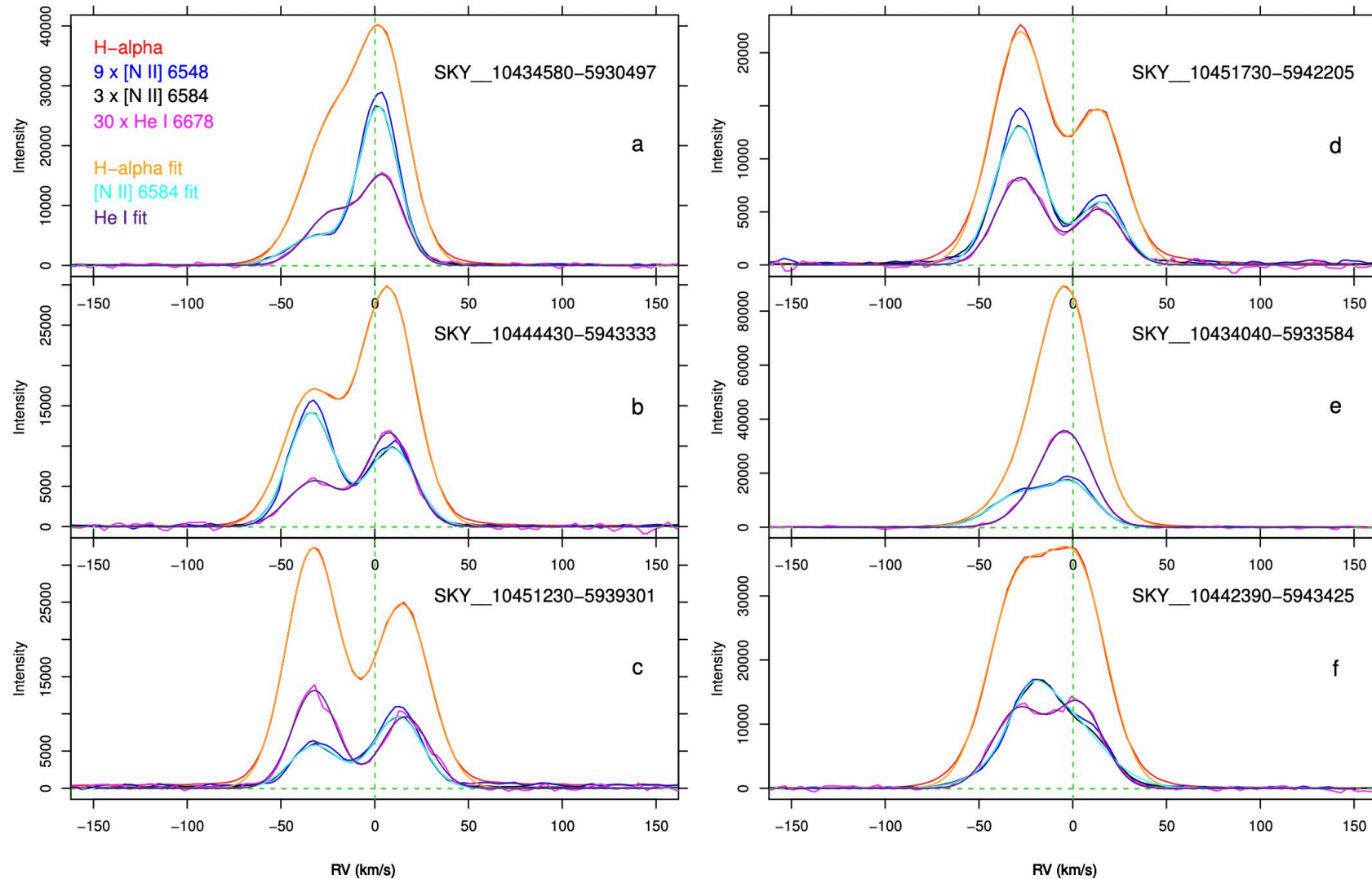


Difference between sky subtraction types shows that nebular emission affects flux and shape of key lines.

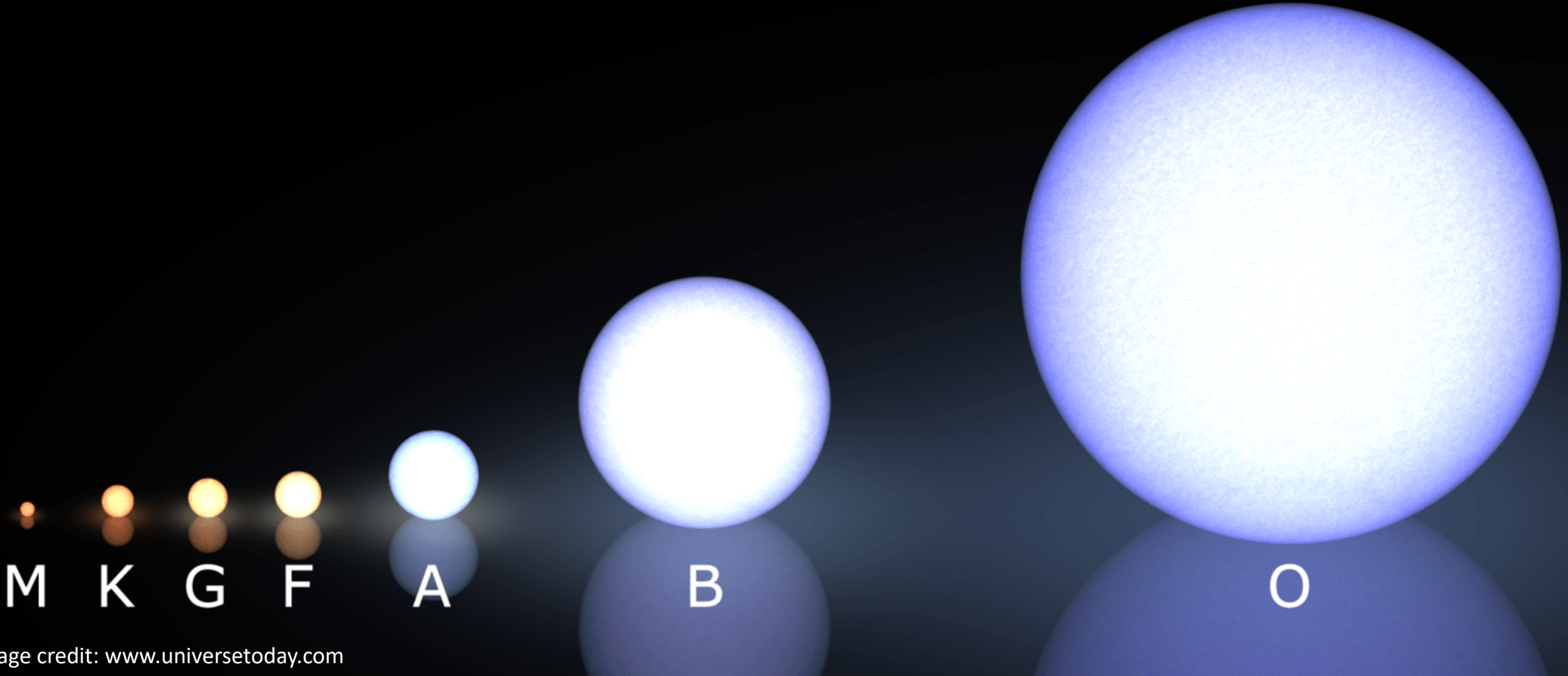


→ thanks to Domi for extracting spectra from multiple reductions

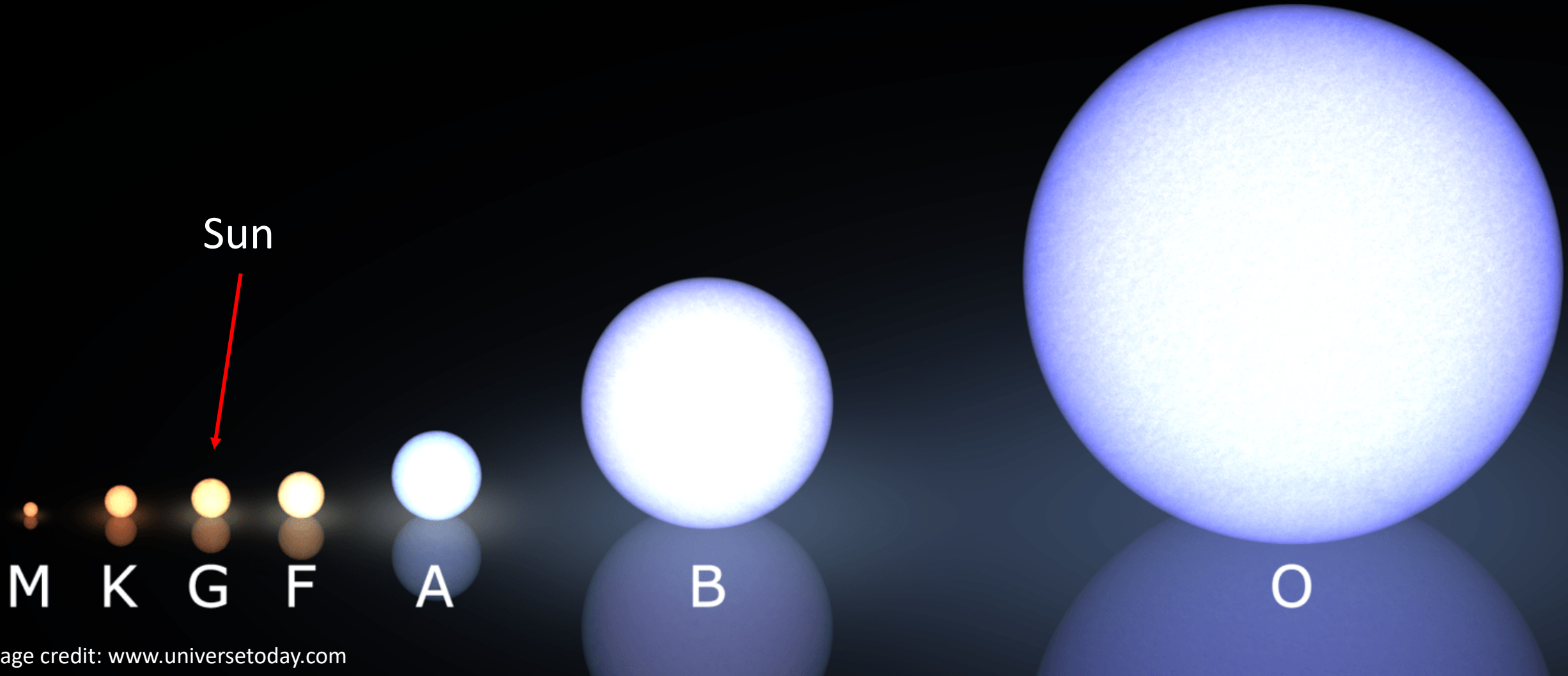
Not just the flux – nebular lines have complex shape that varies over the nebula.



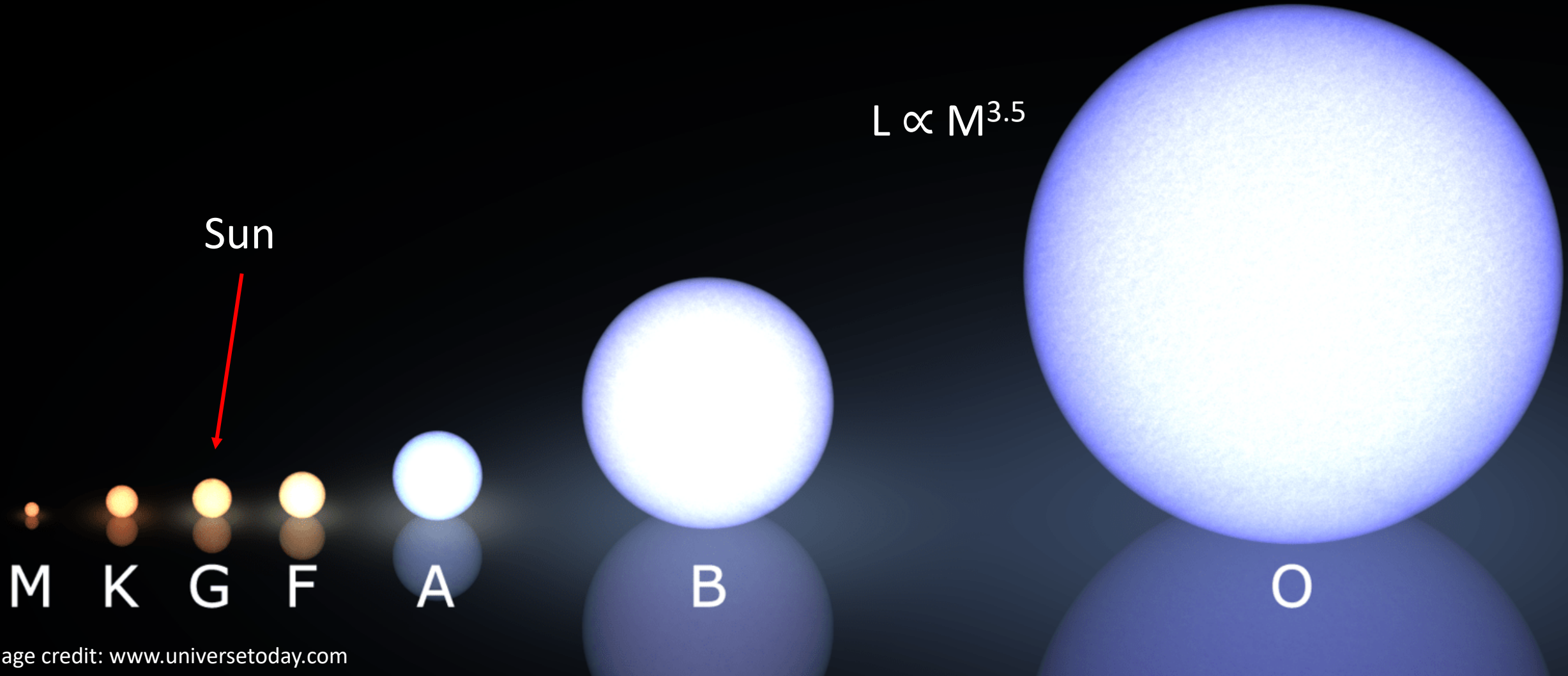
Low-mass stars are most likely to host Earth-like planets;
high-mass stars have strongest influence on environment.



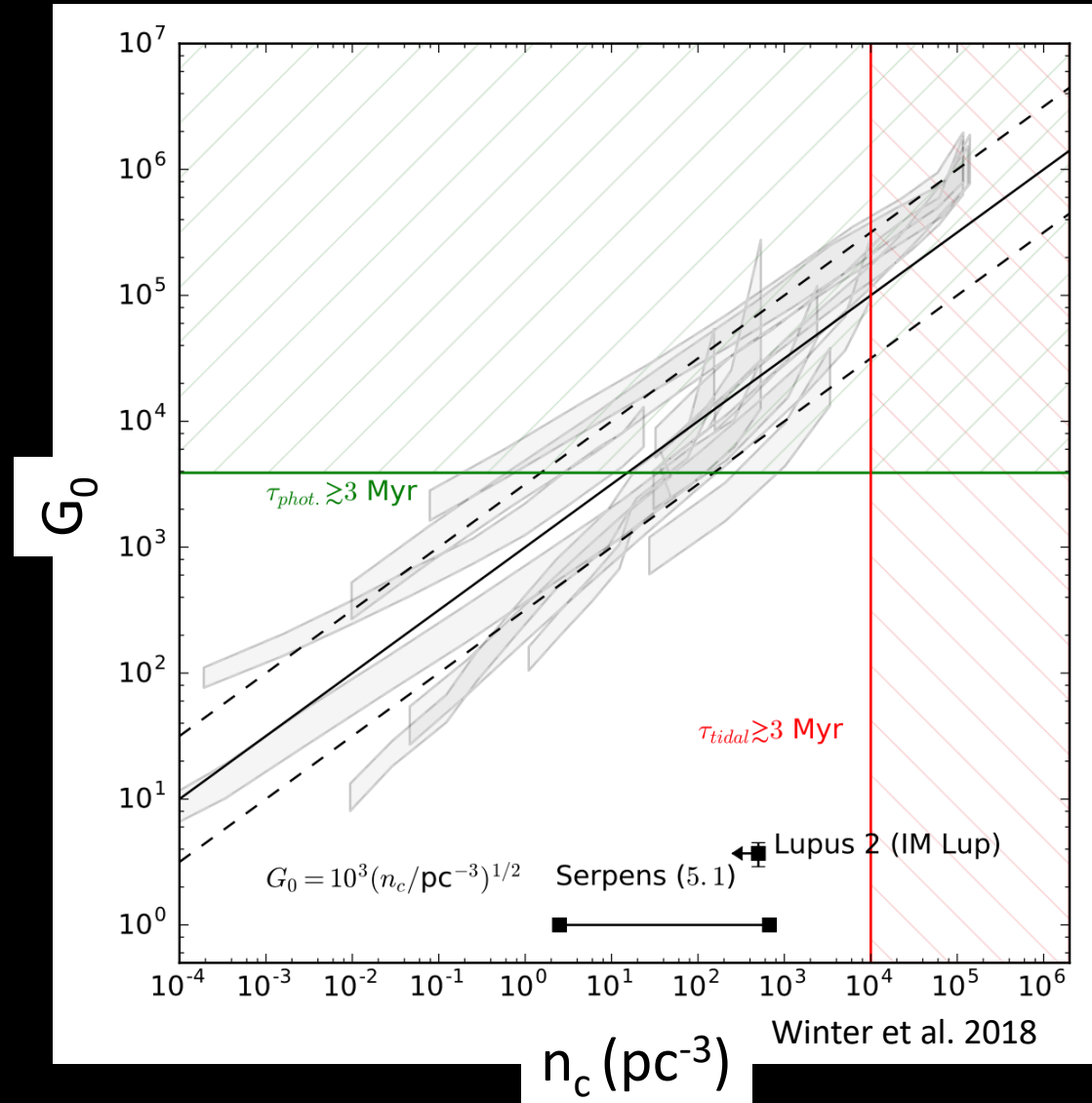
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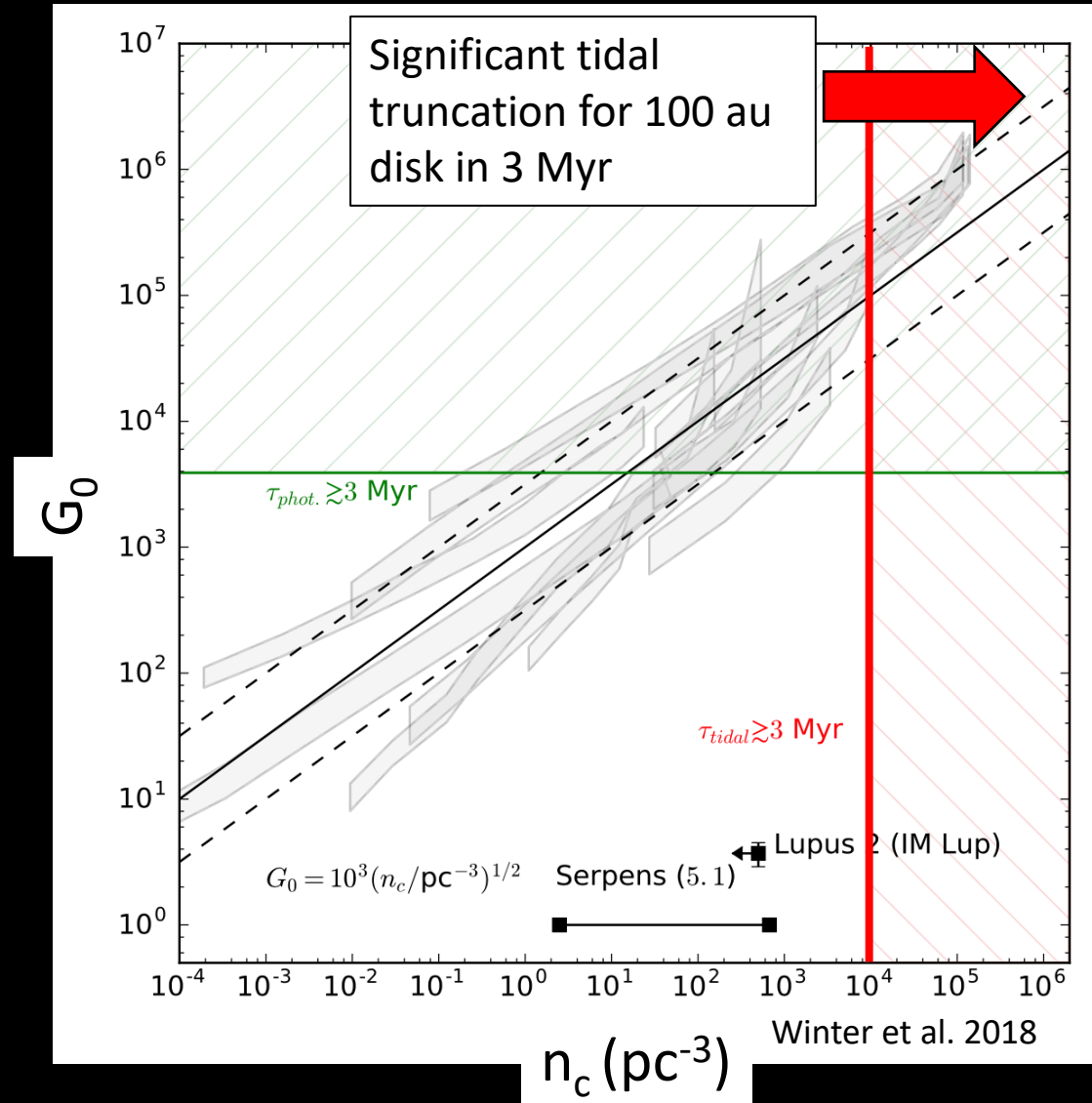
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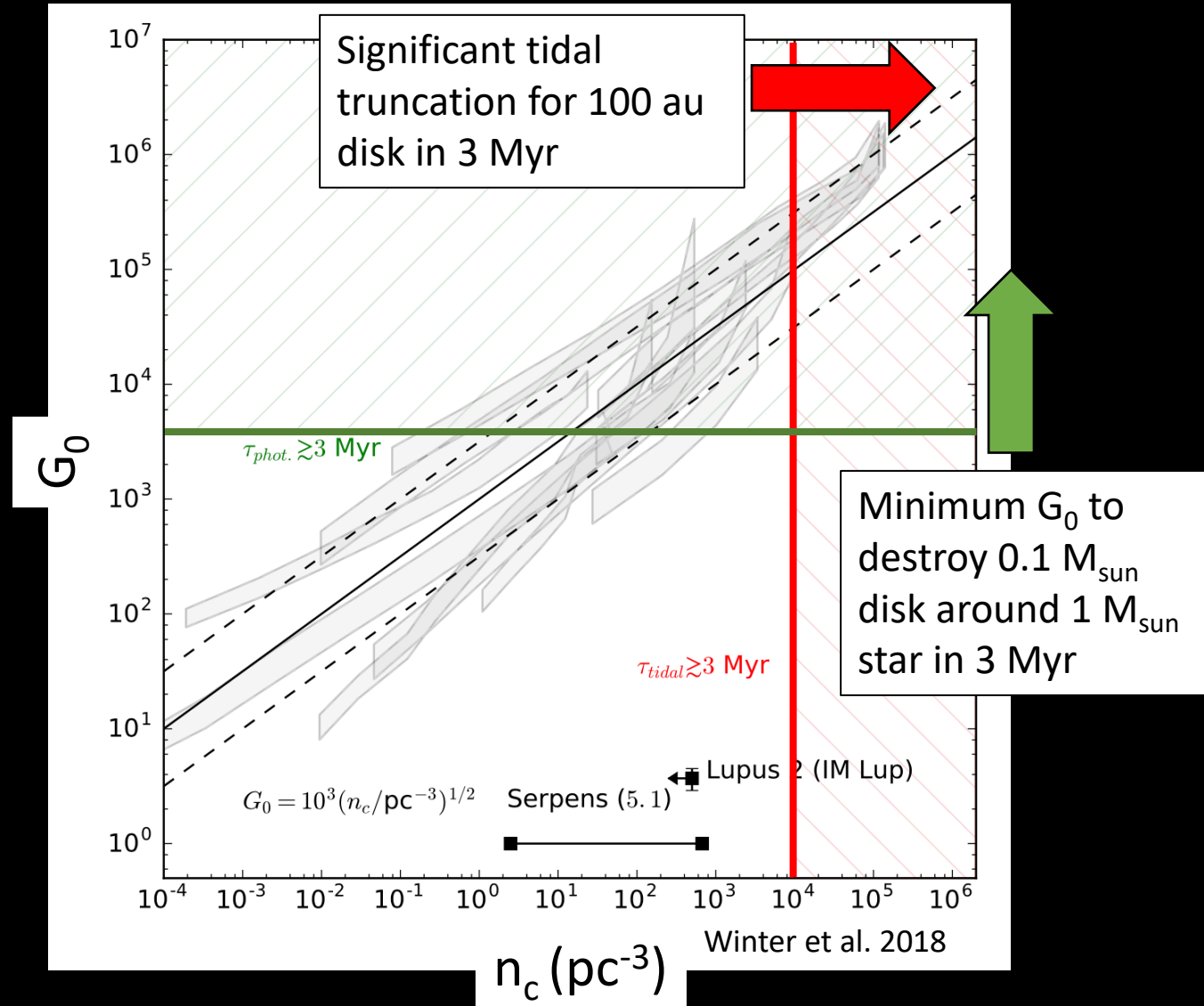
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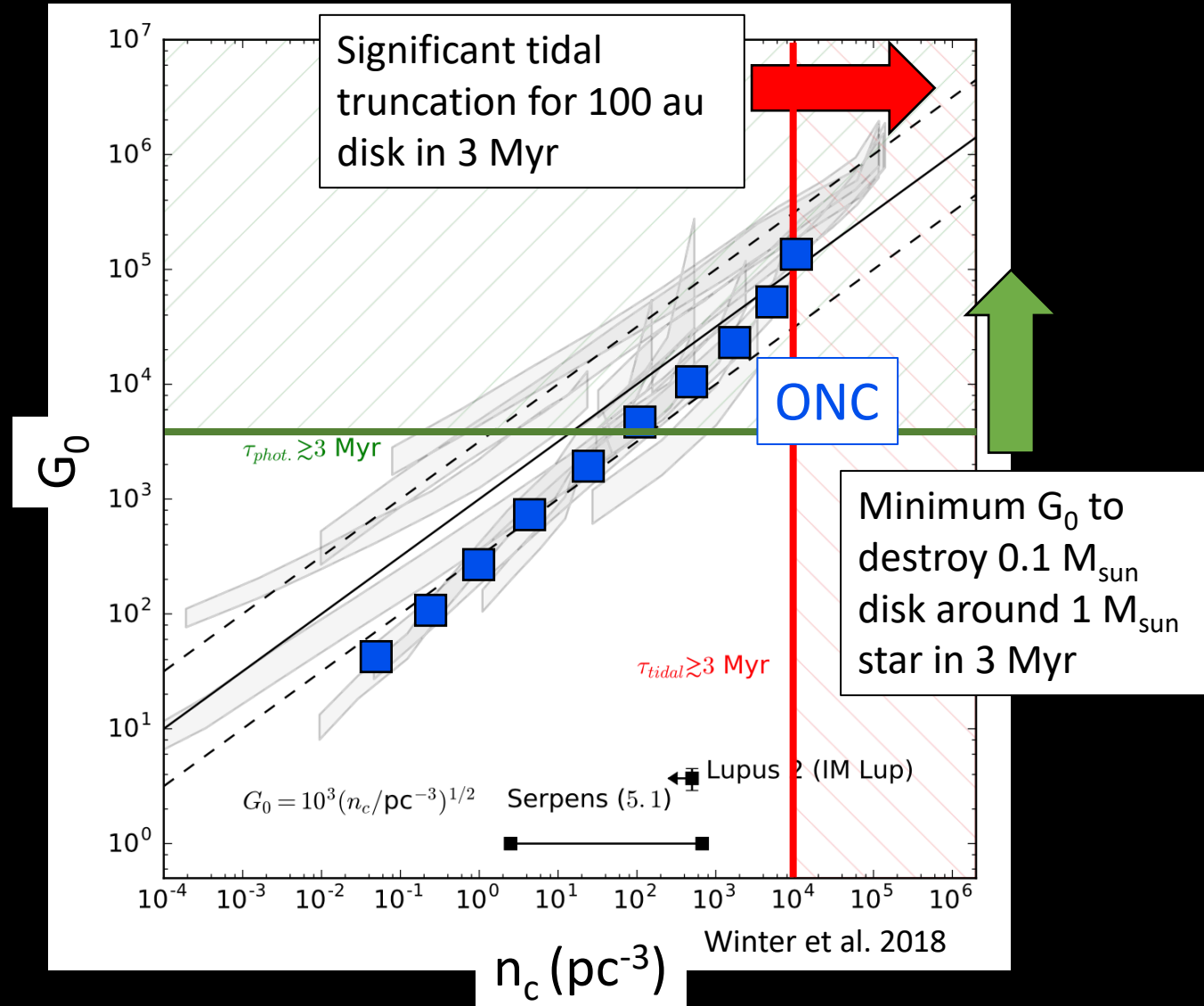
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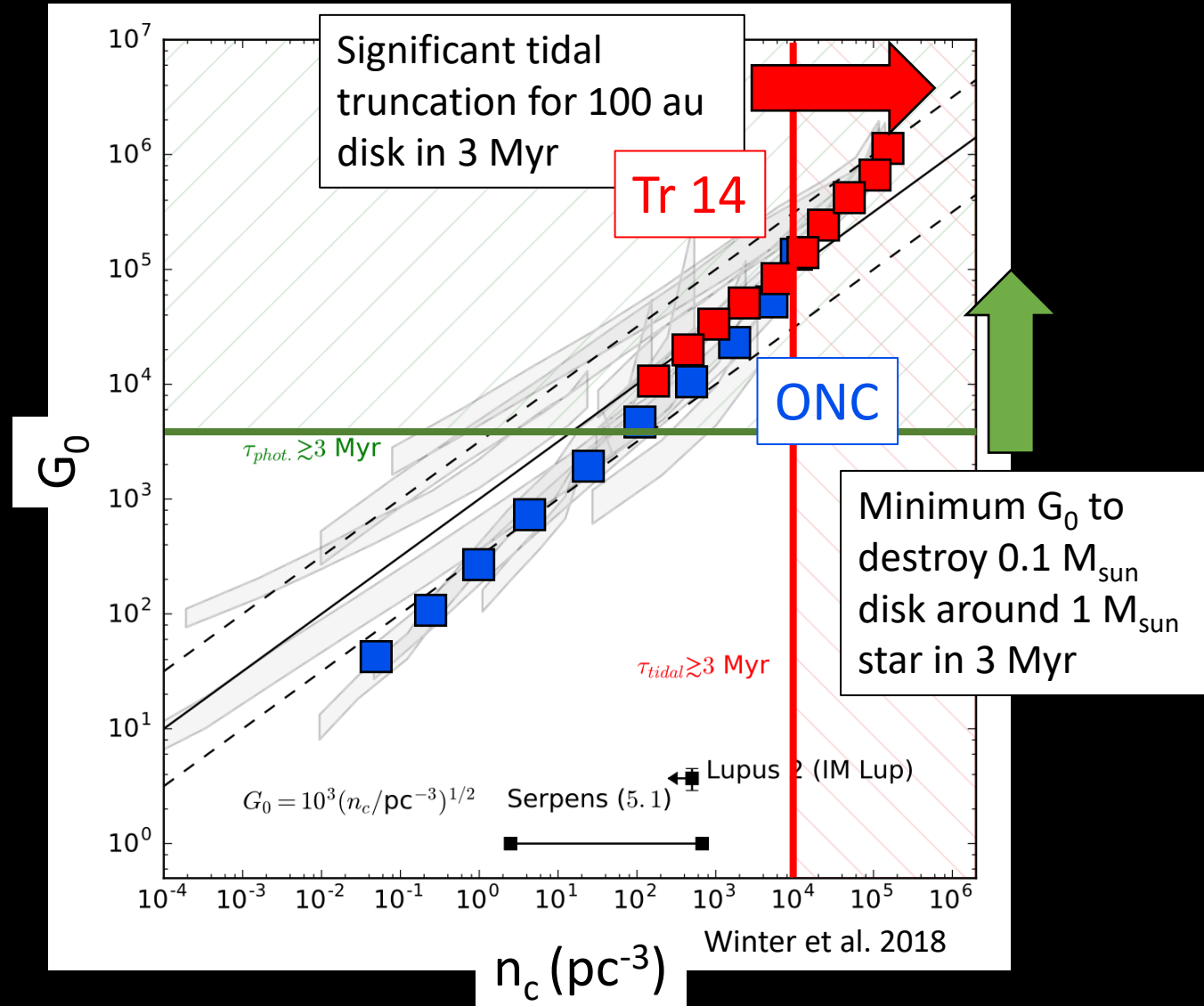
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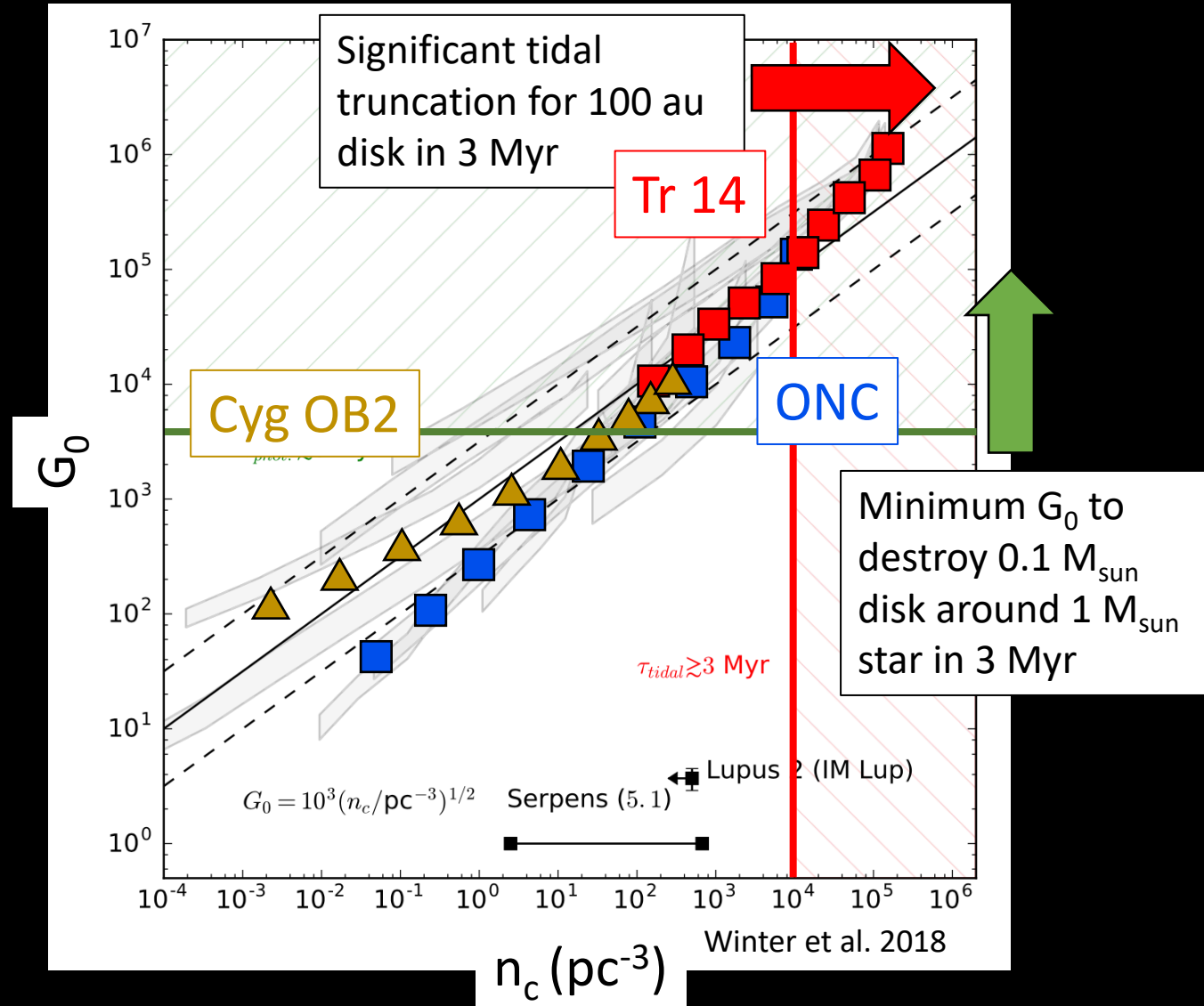
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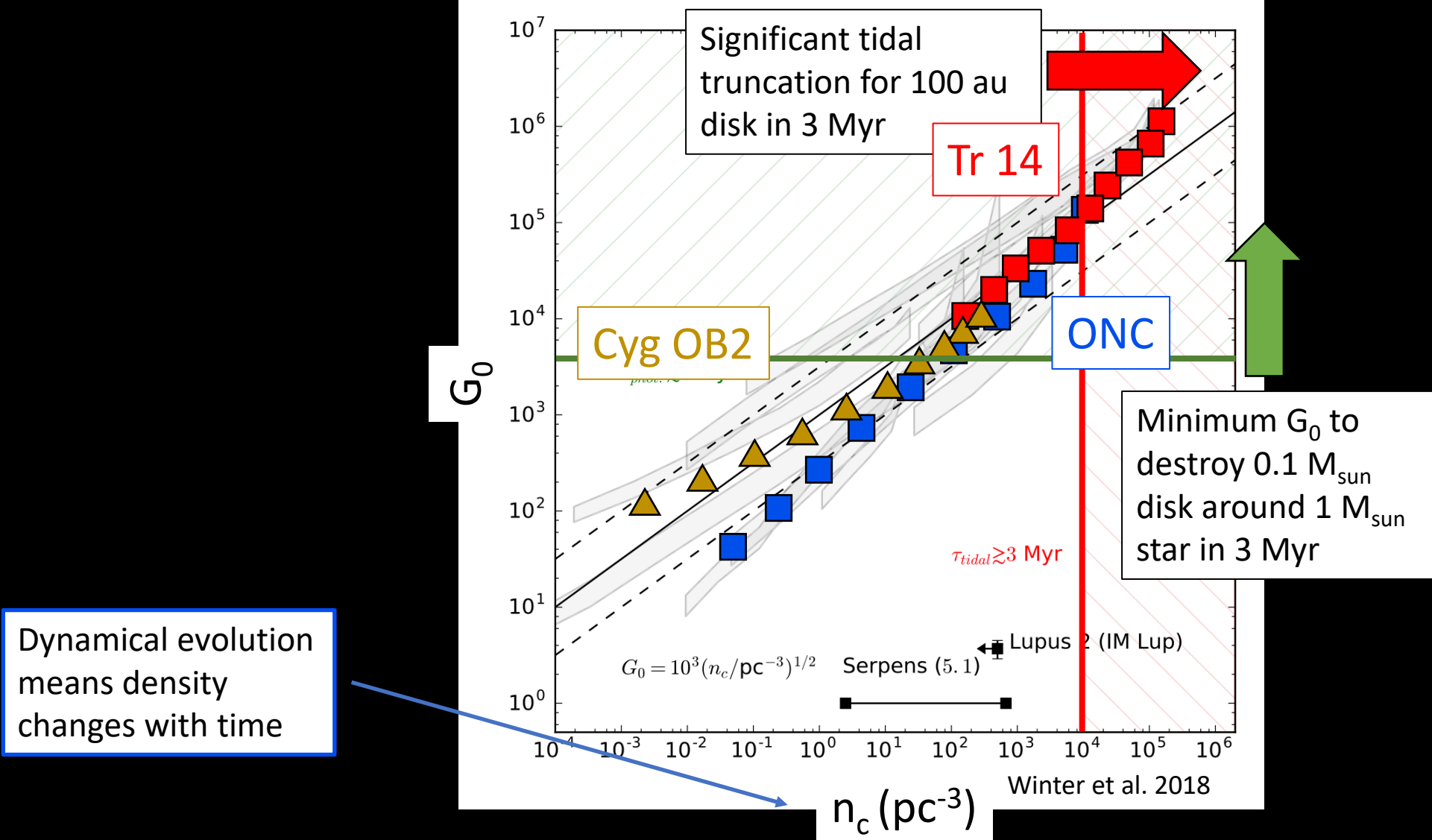
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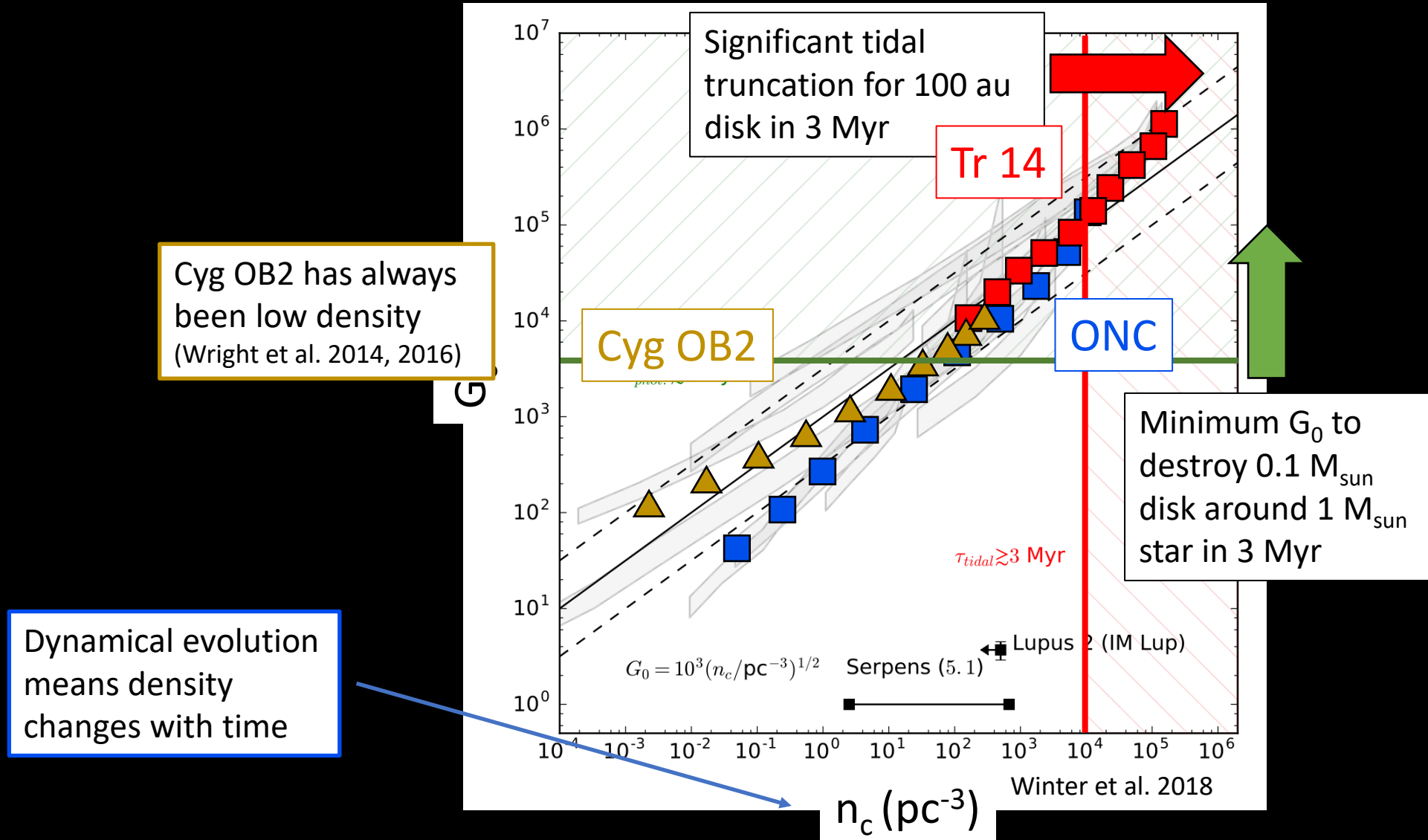
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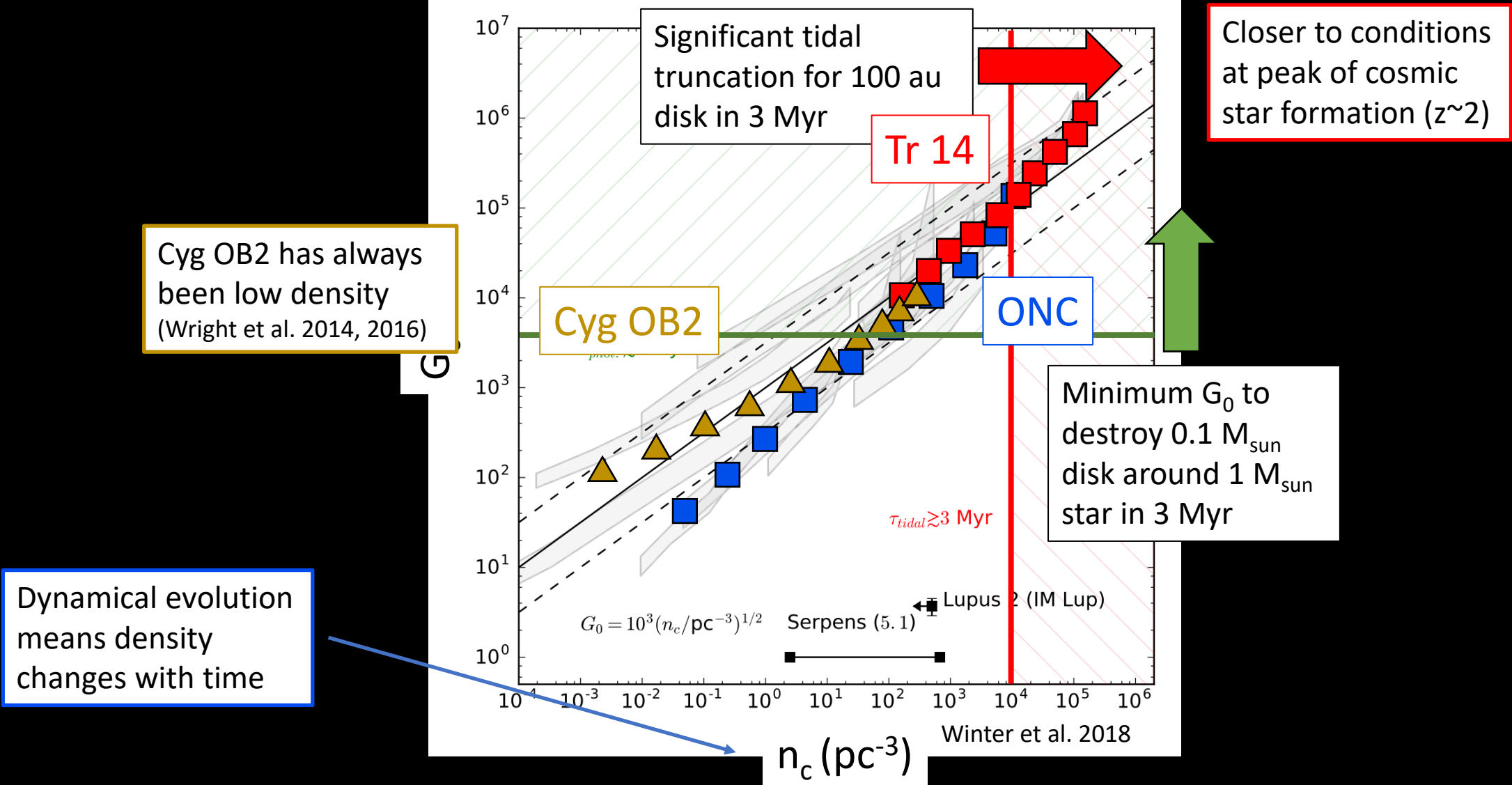
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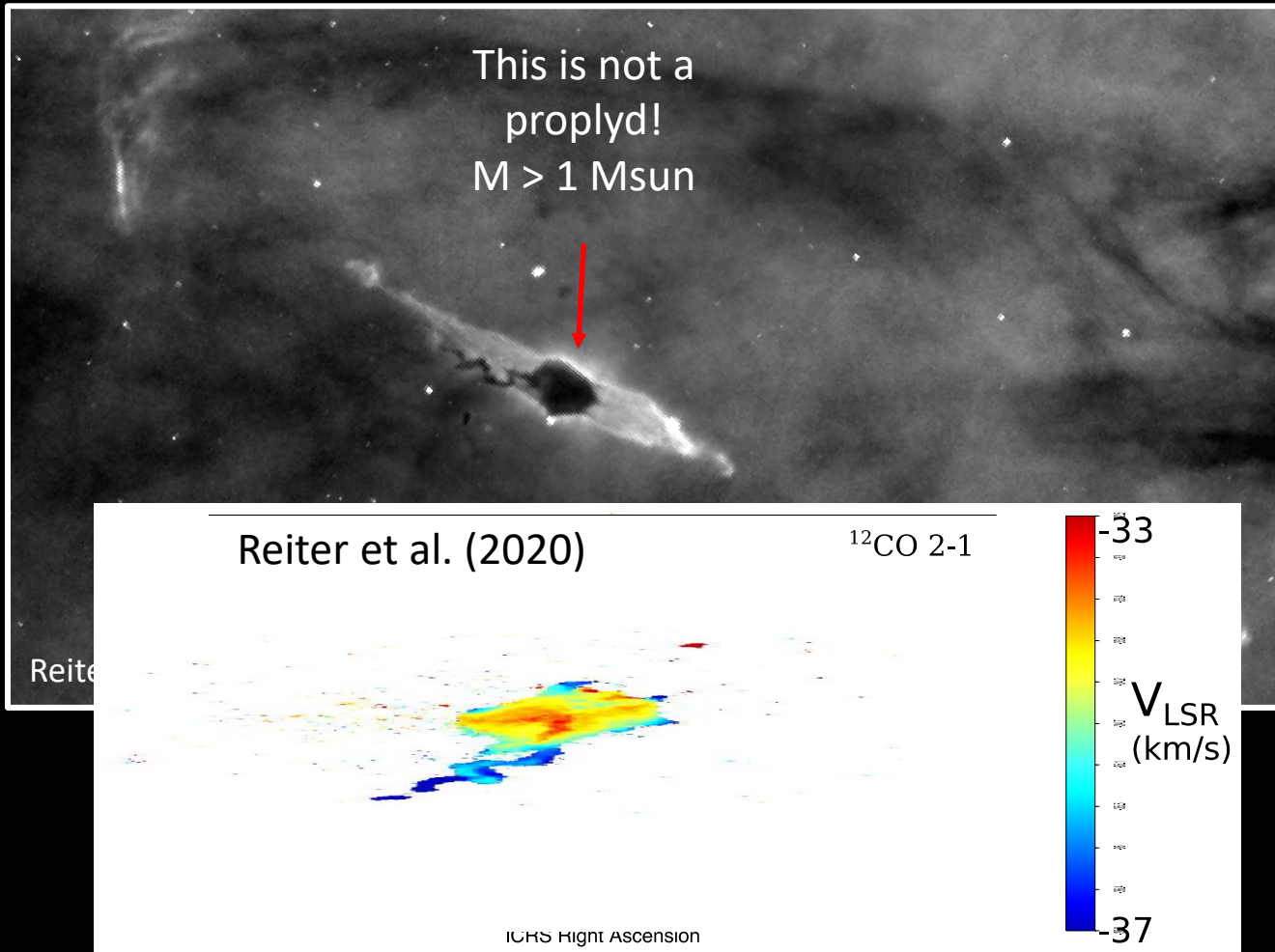
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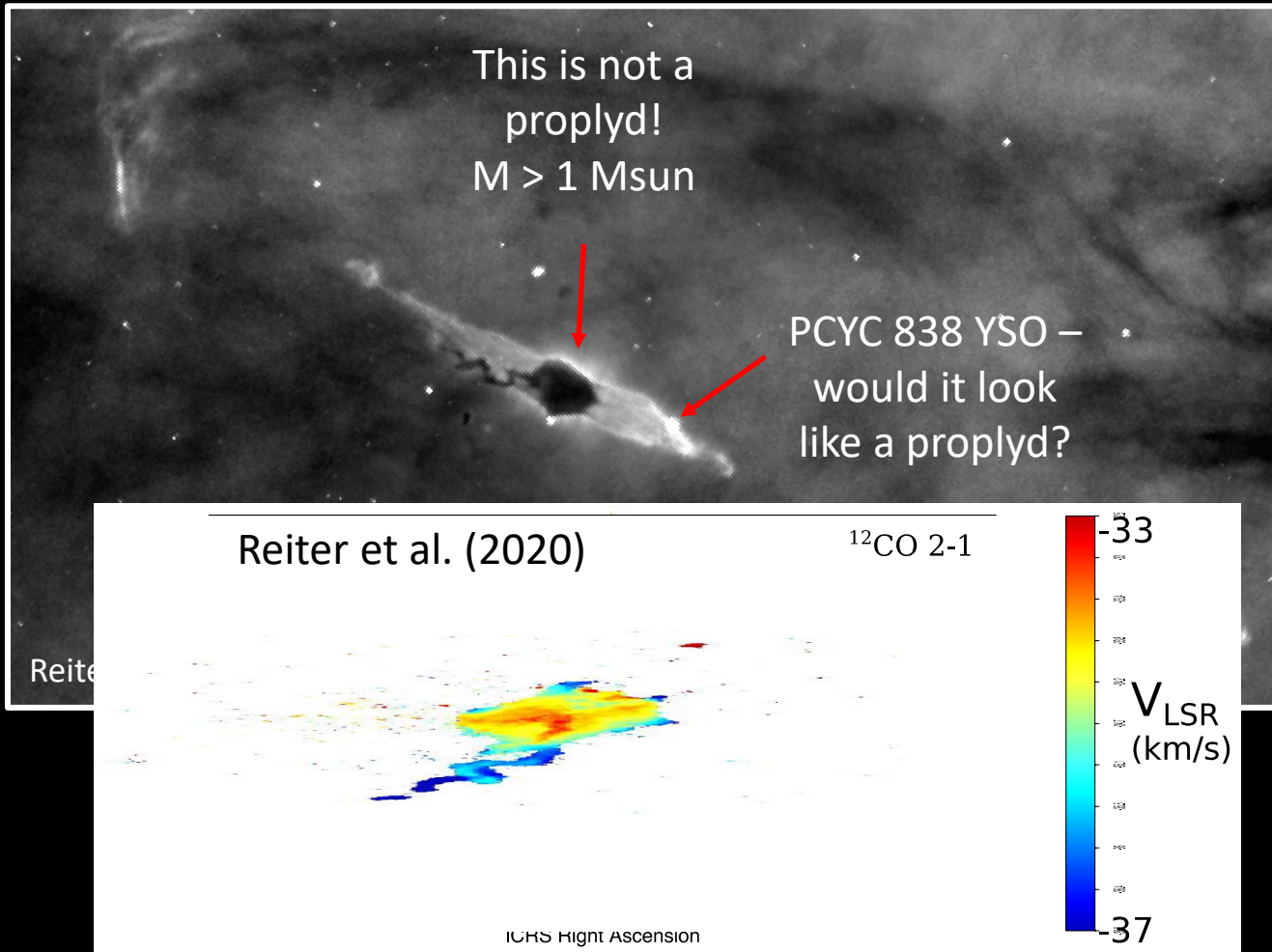
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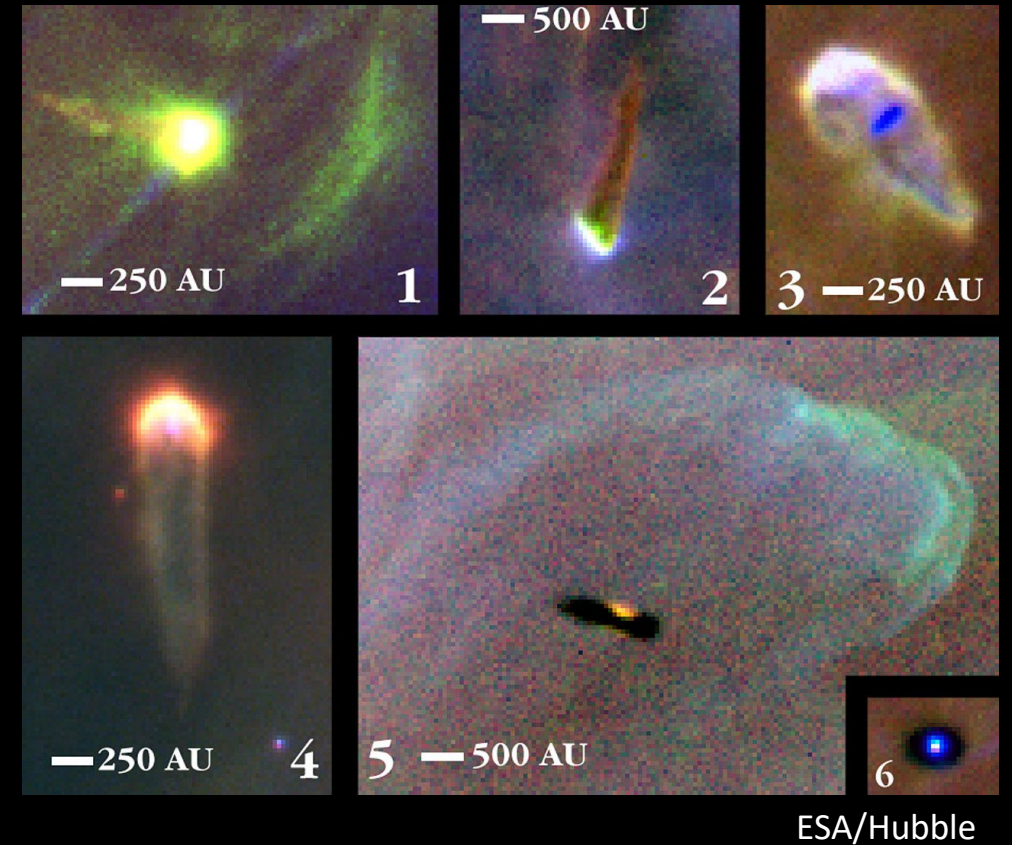
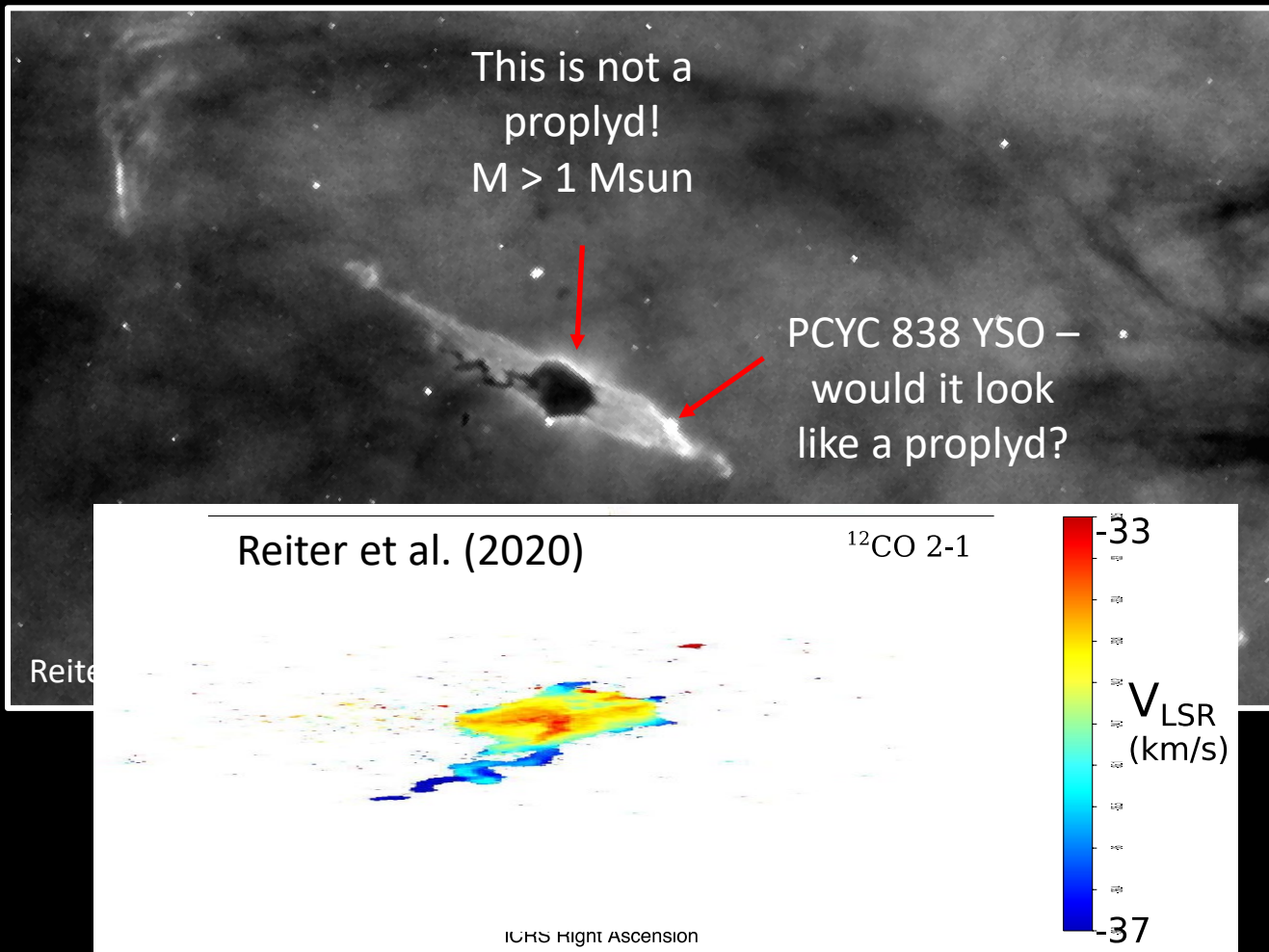
In a region with $d \geq 2$ kpc, a proplyd that is ~ 250 -500 AU large will be ~ 1 -2 pixels in a MUSE NFM image.



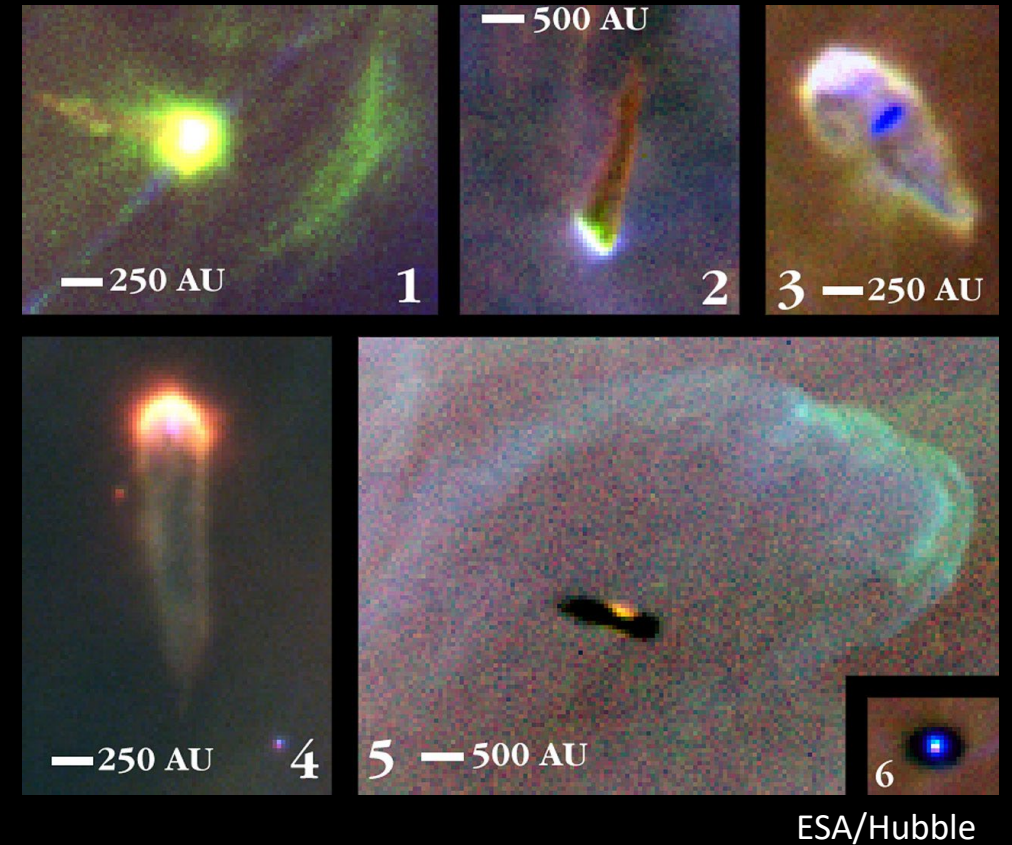
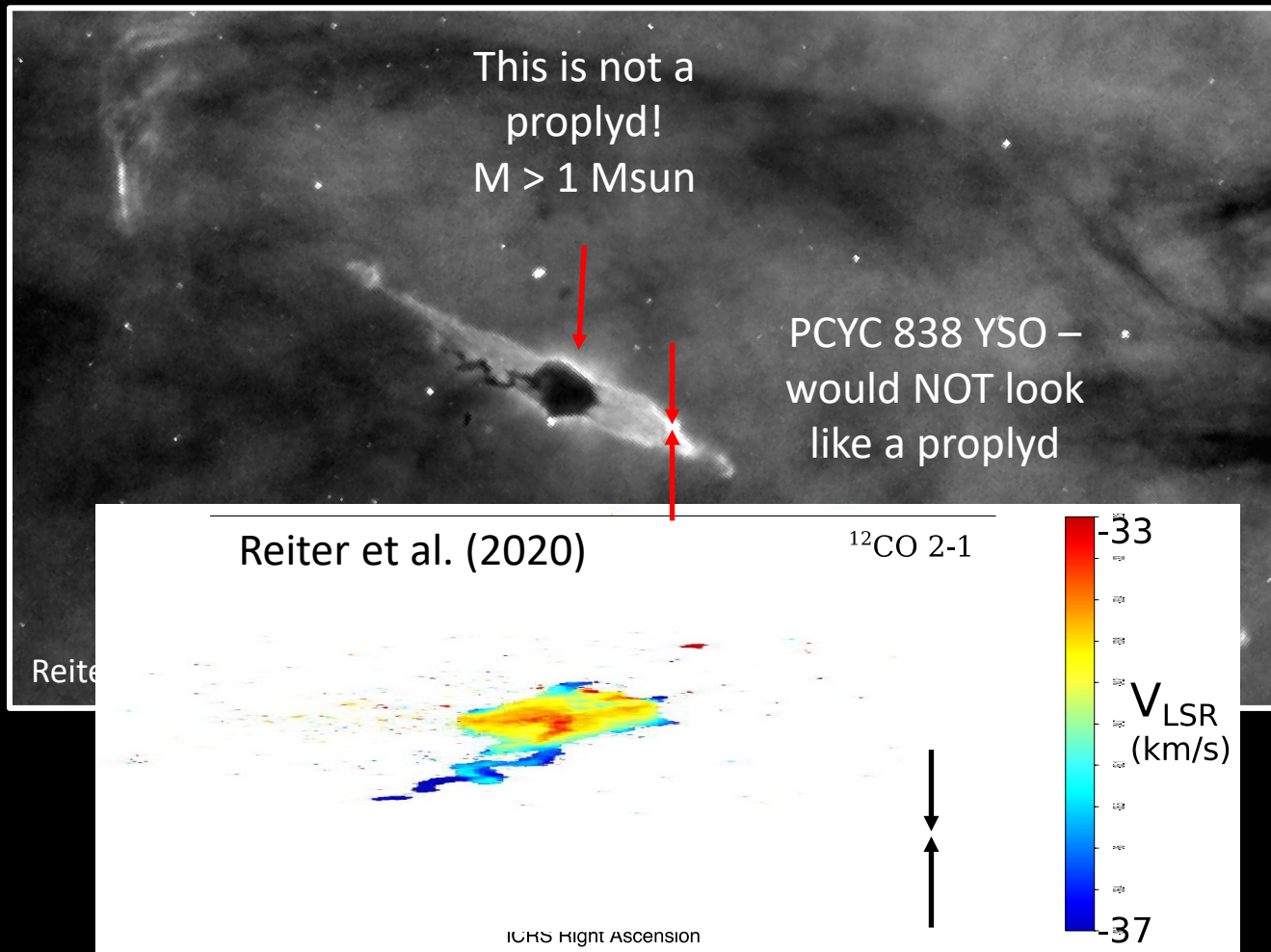
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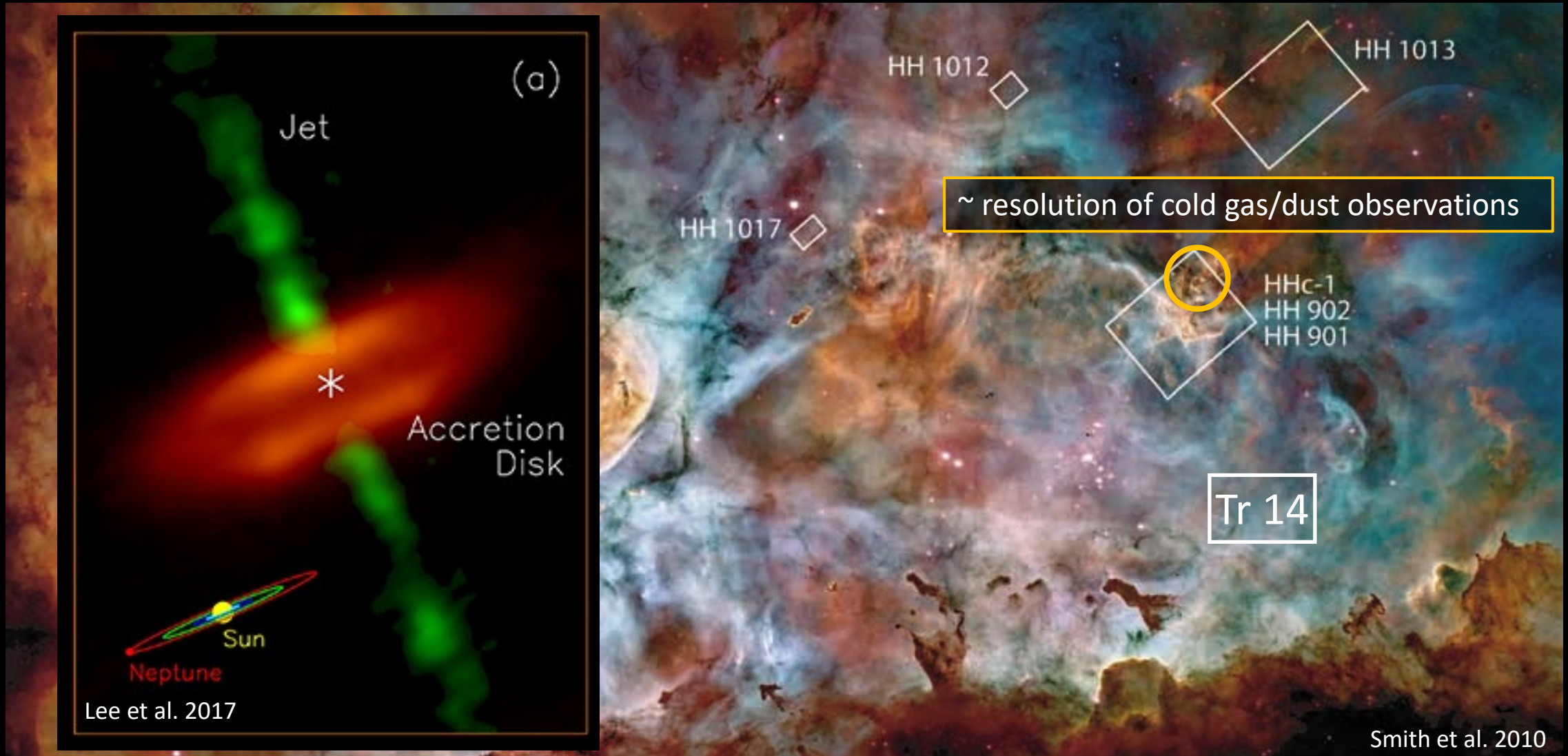
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3. Ecosystem: gas and dust affect dynamical evolution, protect disks, may aid enrichment, regulate demographics, ...



Quantify the ecosystem role: connect output from high-mass stars with impact on hot/cold gas and star/planet formation.

