

Nordic-Baltic Astro Days 2026

# Blown Away: Tracing the imprints of external irradiation on protoplanetary disks

Mari-Liis Aru

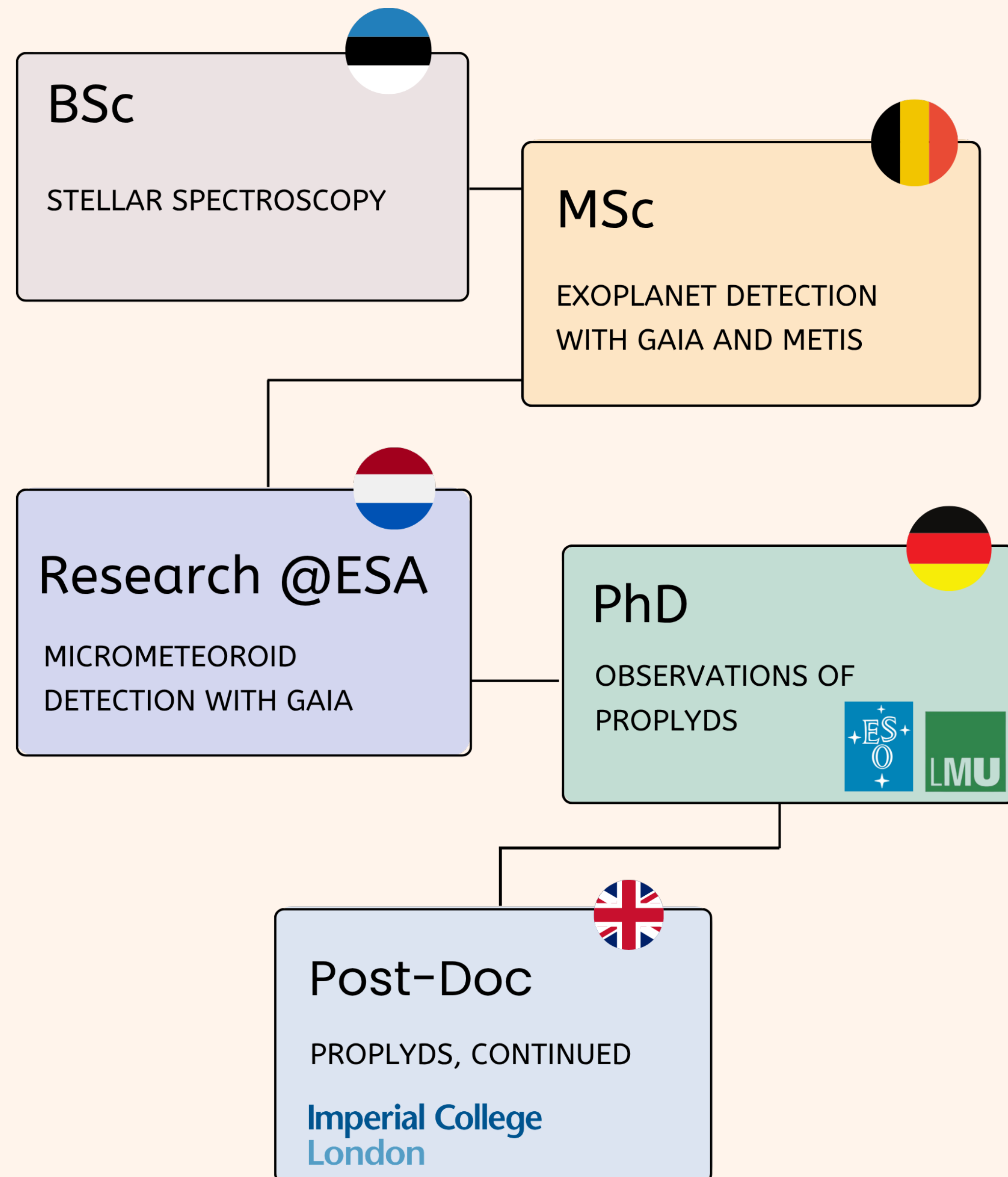
Postdoc @ Imperial (UK) with James Owen

*With Carlo F. Manara, Karina Maucó, T. Haworth,  
S. Facchini, G. Rosotti, A. Winter et al.*

MAY 2026



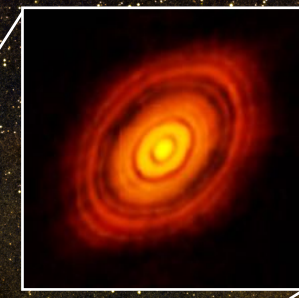
# BRIEFLY ABOUT MY PATH



# THE BIRTH CONDITIONS OF PLANET FORMATION

Low UV, low mass regions

HL Tau

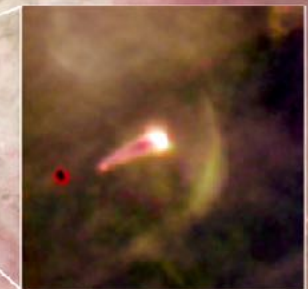


e.g., Ricci+ (2010), ALMA Partnership (2015), Long+ (2019), Manara+ (2023), Henning+ (2024), Arulanantham+ (2025)

ESO/Digitized Sky Survey 2

High UV, high mass clusters

UV source

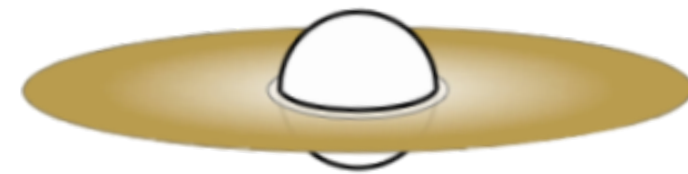


e.g., Johnstone+ (1998), Henney & O'Dell (1999), Facchini+ (2016), Ansdell+ (2017), van Terwisga+ (2019–2020), Boyden & Eisner (2023)

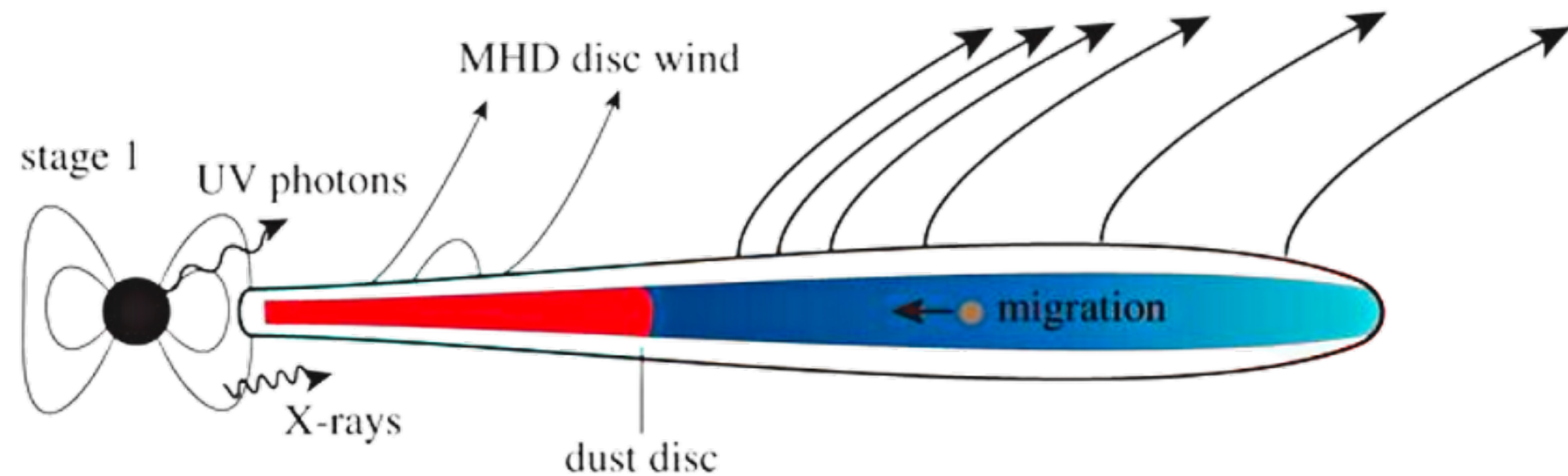
ESA/Hubble Space Telescope

# PROTOPLANETARY DISKS IN LOW UV ENVIRONMENTS

## Isolated disk



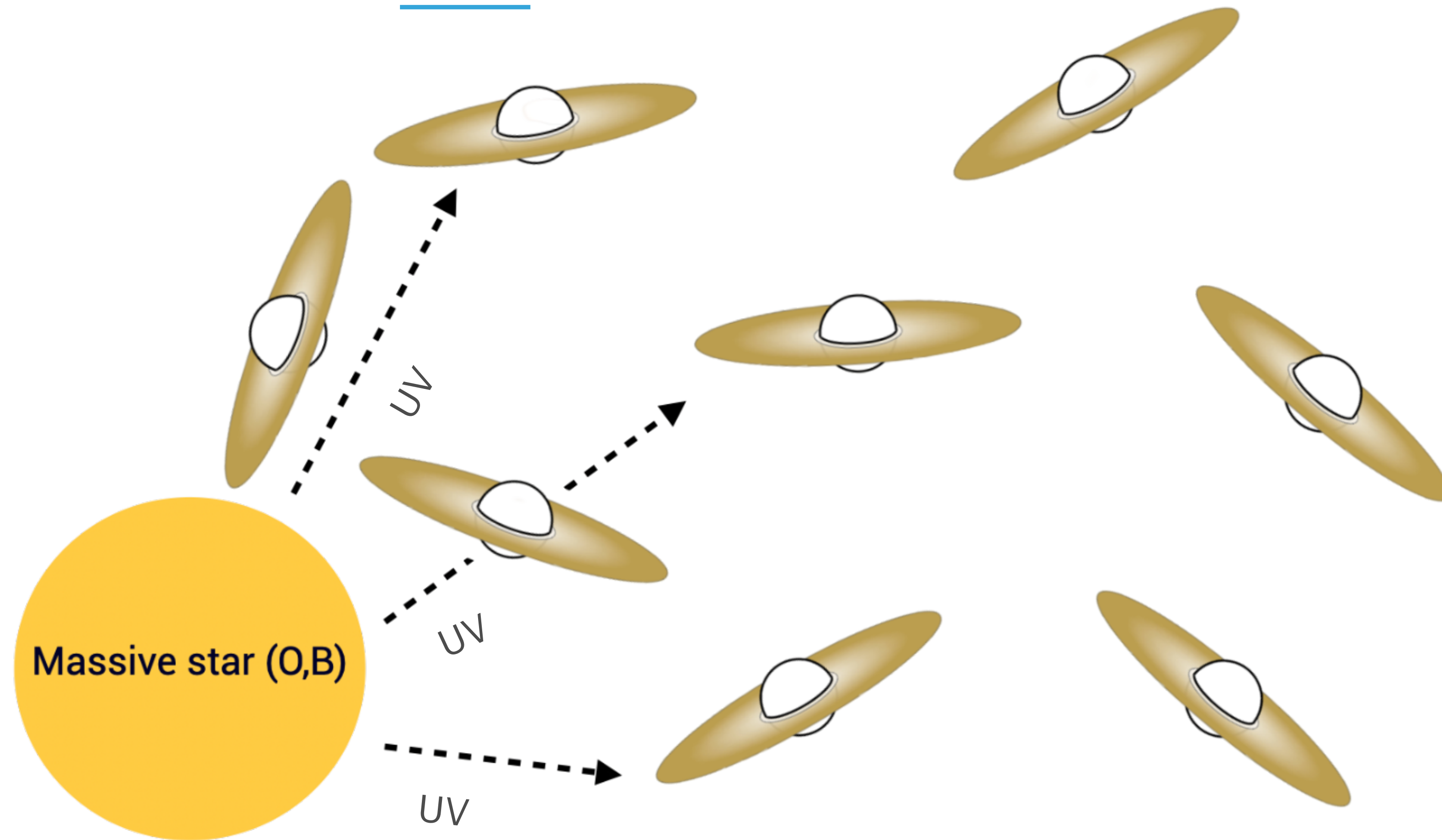
## (INTERNAL) PHOTOEVAPORATION, MHD WINDS



ERCOLANO & PASCUCCI (2017)

- ▶ Internal photoevaporation: inside-out depletion. Driven by photons from the central host star (e.g., Ercolano+ 2008; Picogna+ 2019)
- ▶ *Method: forbidden line emission*

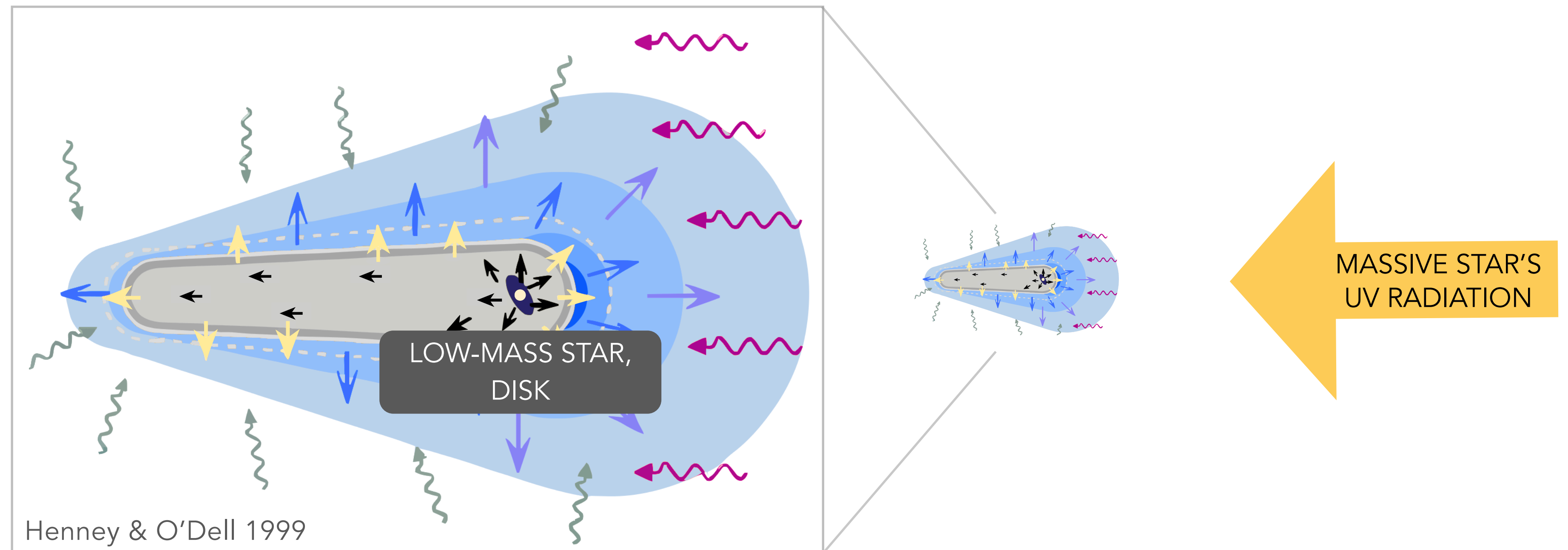
# PROTOPLANETARY DISKS IN HIGH UV ENVIRONMENTS



UV photons heat the disk material externally.

ILLUSTRATION: C. F. MANARA

# PROPLYDS



- Heating --> Material becomes unbound, escapes  
--> Cloud of ionized gas with an ionization front
- Dispersal of the disk, reduction of its lifetime

Proplyds allow us to study how the surrounding environment affects the evolution of disks and their ability to form planets. Observed in various forbidden lines.

# HOW TO DISENTANGLE THE TWO EFFECTS?

## INTERNAL WINDS

in both low mass and massive SFRs

## EXTERNAL WINDS

in massive SFRs

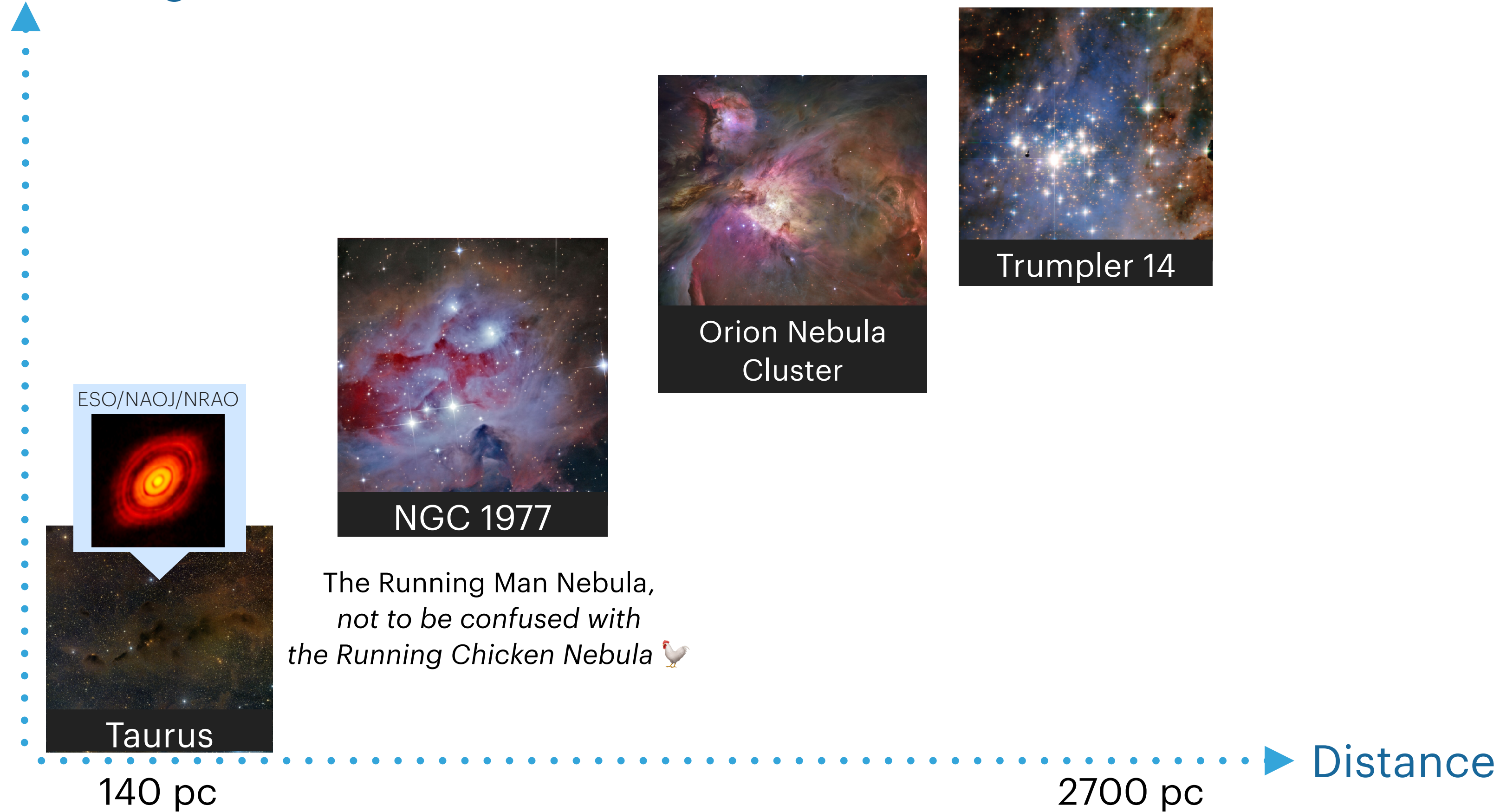


forbidden line emission, e.g. [O I] 5577 Å, [O I] 6300 Å, [S II] 4068 Å

**Which lines or line ratios allow us to disentangle the two?  
Let's look at proplyds in depth.**

# ORION NEBULA CLUSTER: OUR STEPPING STONE TO CLUSTER ENVIRONMENTS

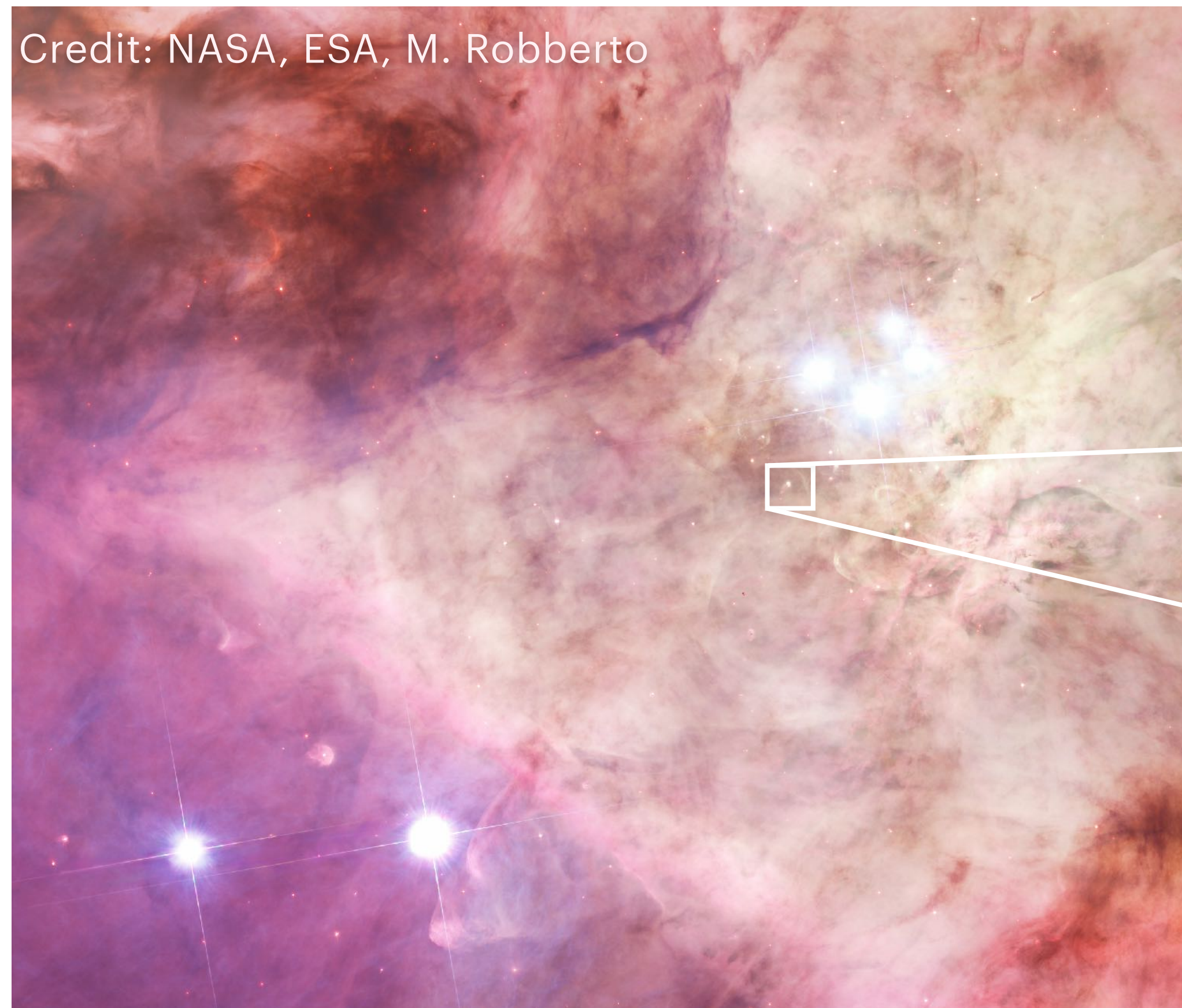
Stellar density  
UV field strength



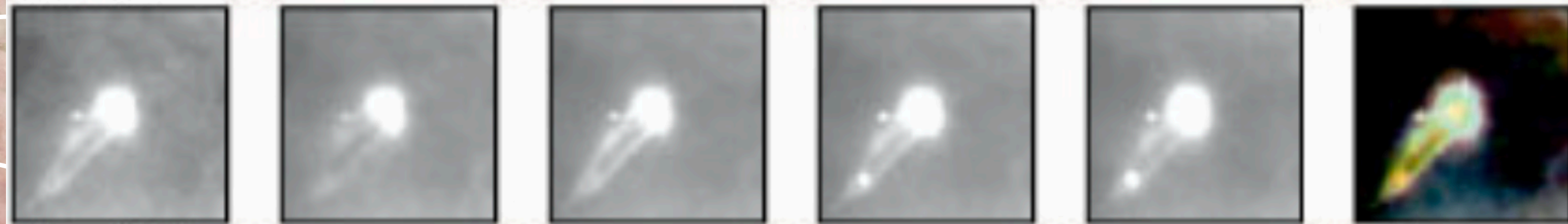
Credits: ESO/Digitized Sky Survey 2 (Taurus); NASA, ESA, M. Robberto (STScI/ESA), Hubble Space Telescope Orion Treasury Project Team (ONC); NASA & ESA, Jesús Maíz Apellániz (CSIC-INTA, Spain) (Tr 14)

# “PROTOTYPE” PROPLYDS AND HST

Credit: NASA, ESA, M. Robberto



177-341W



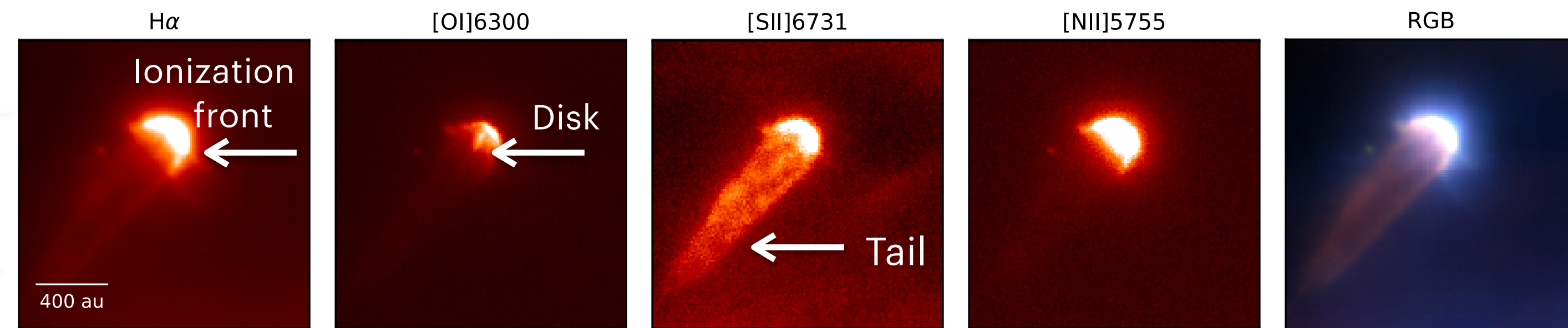
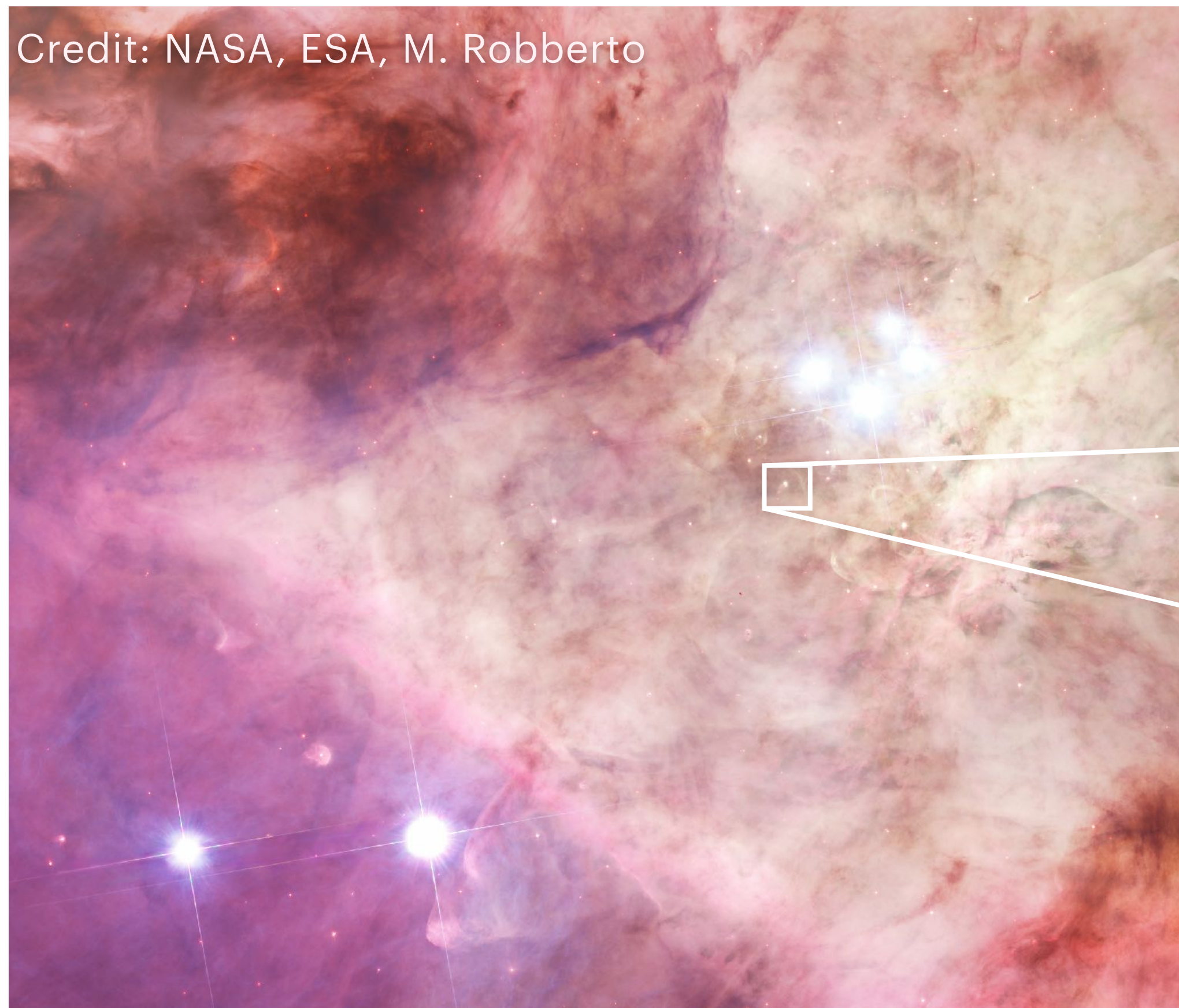
RICCI+ 2008

- ▶ Observational properties of proplyds studied in a limited number of filters: O’Dell et al. 1993; O’Dell & Wen 1994; McCaughrean & O’Dell 1996; Ricci et al. 2008

# ESO'S VLT/MUSE (4750–9350 Å)

Aru+ 2024a

Credit: NASA, ESA, M. Robberto



—> Spatially distinguish different parts of the system

▸ FWHM ~ 0.07" (28 au)

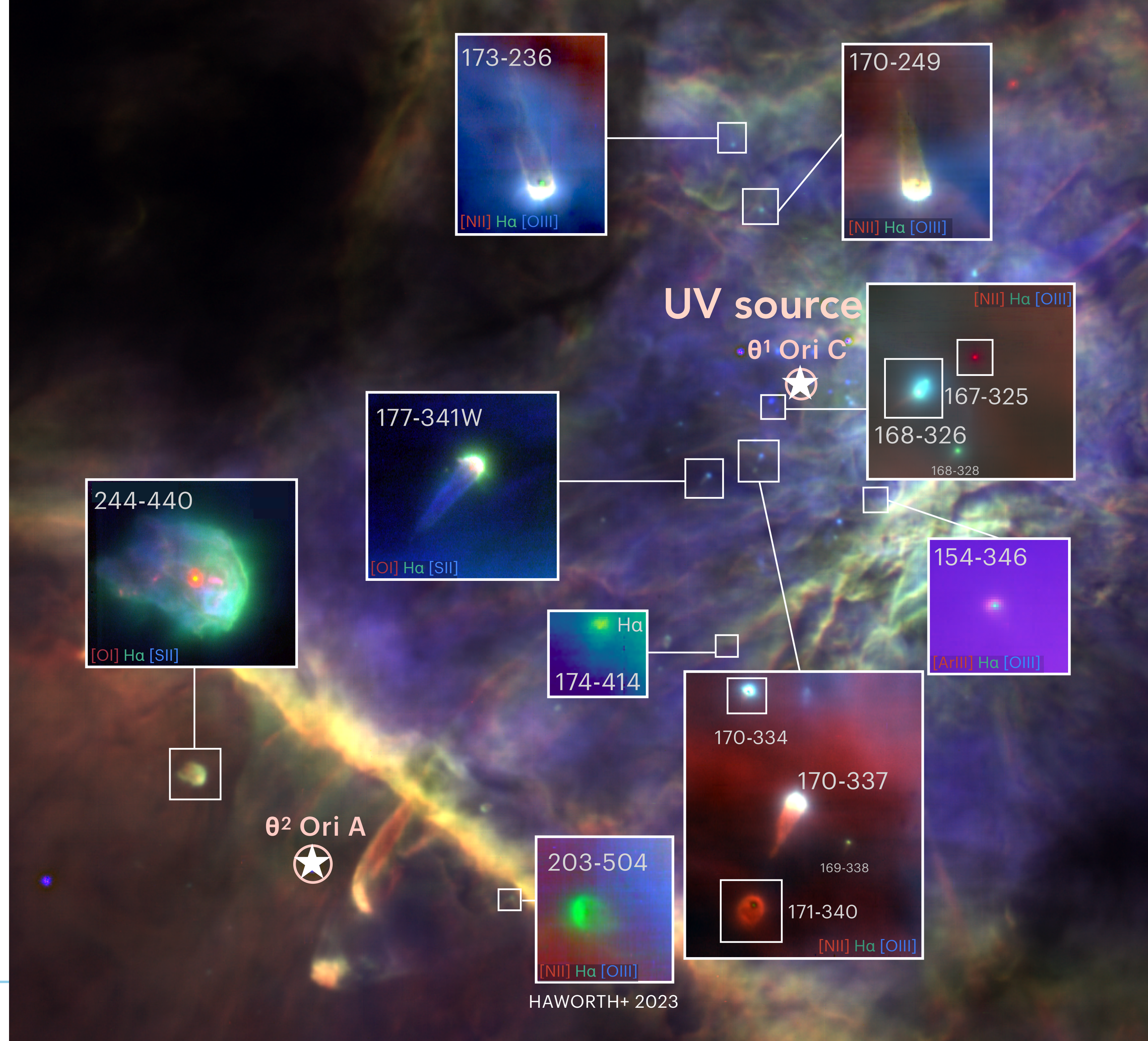
# OUR SAMPLE

Aru+ 2024a

Background: Weilbacher+ 2015

- ▶ MUSE NFM observations of 12 proplyds in the ONC (insets)
- ▶ Different distances from the main UV source  $\theta^1$  Ori C
- ▶ Partial overlap with ALMA

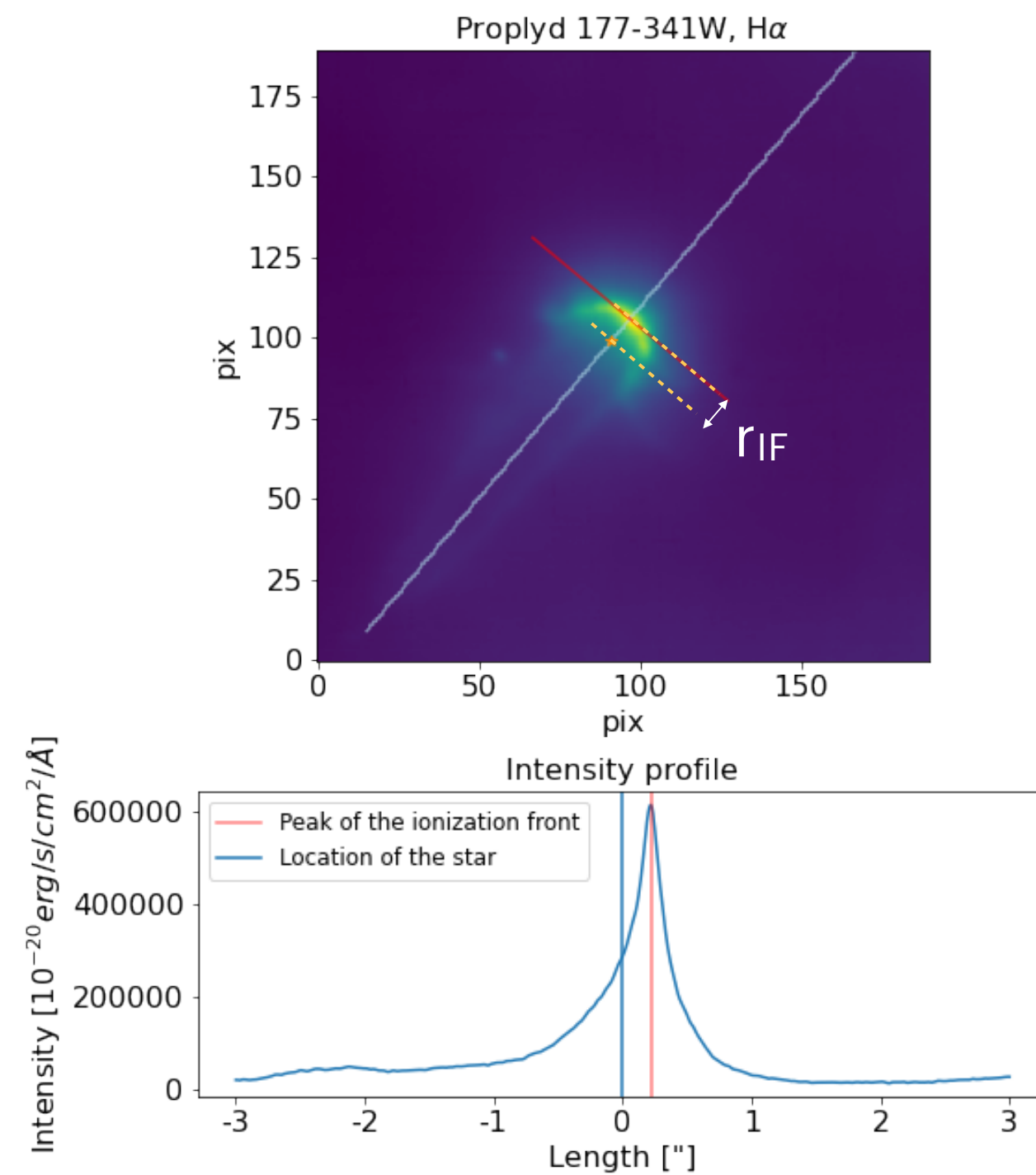
Insets: MUSE, continuum-subtracted single-line integrated flux images



# IONIZATION FRONT RADIUS: AN OBSERVABLE PARAMETER TO ESTIMATE MASS-LOSS RATE

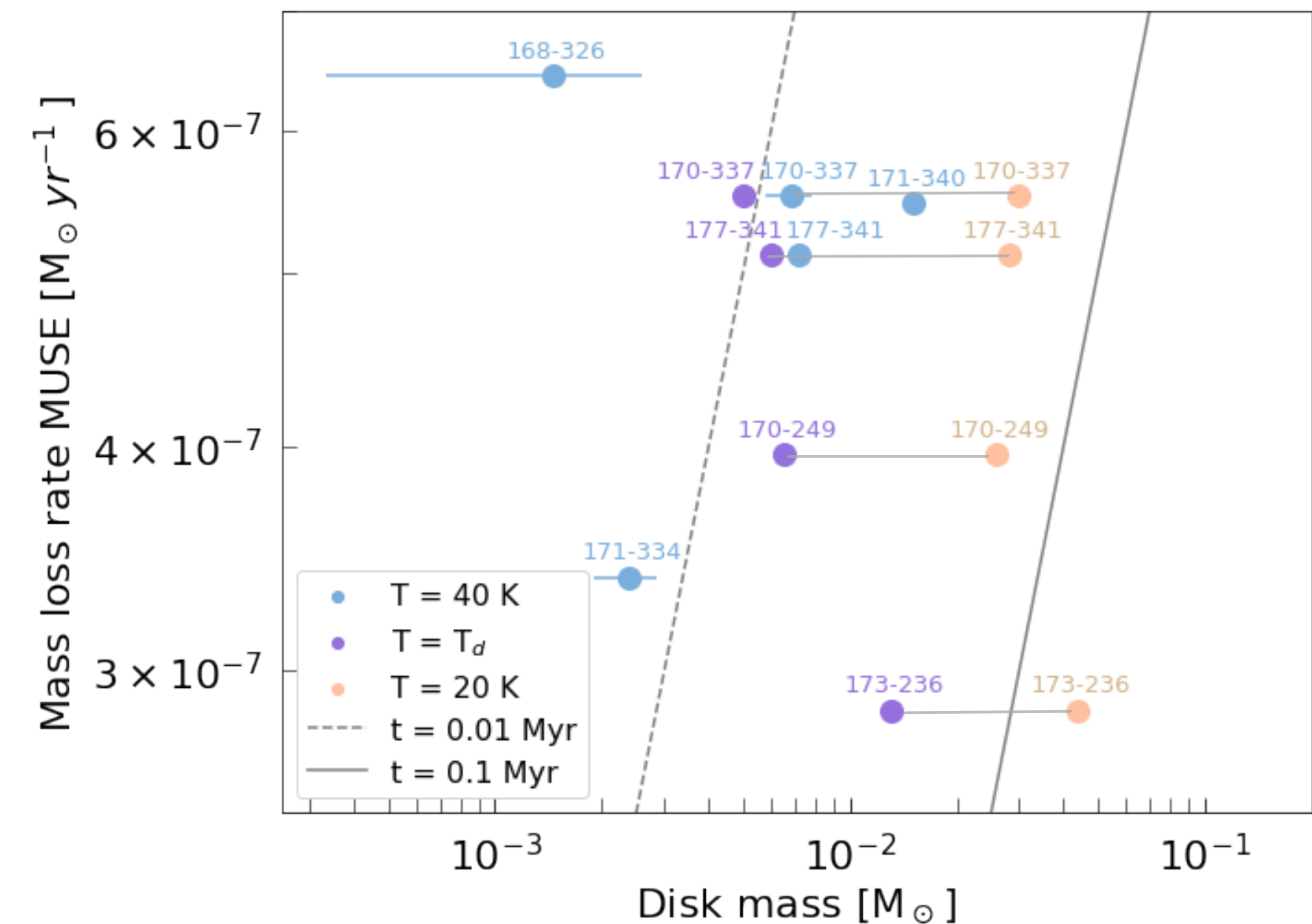
Aru+ 2024a

- ▶ We can measure the ionization front radius ( $r_{IF}$ ) in different levels of ionization



Combine with disc masses from ALMA

- ▶ Proplyd lifetime  $t = \dot{M}/\dot{M}_{disc}$
- ▶  $t = 2.4$  to 130 kyr



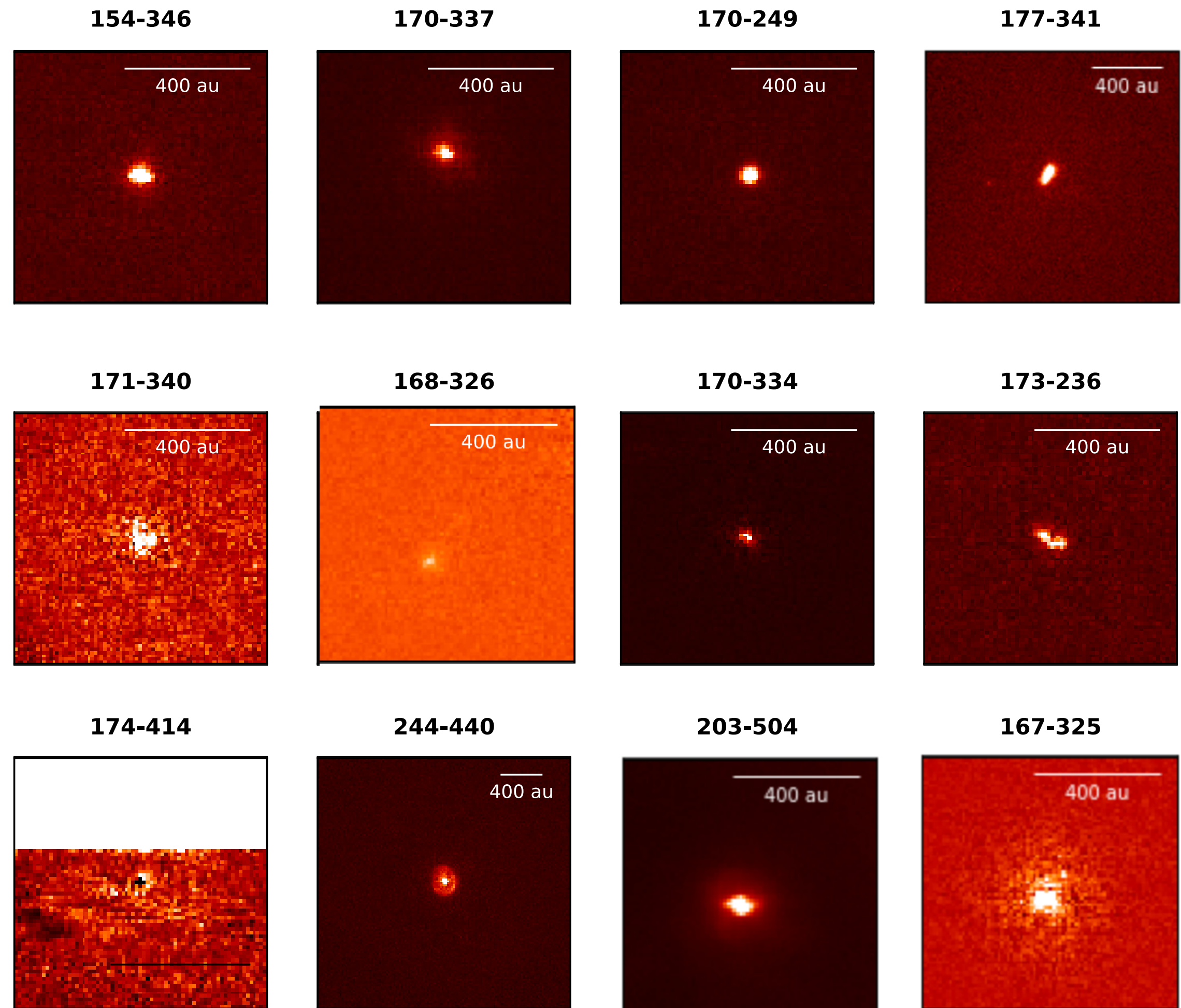
- Plotted: Disc gas mass, 100 x disc dust mass
  - Colors: different assumed dust temperature
- Disc masses: Mann+ 2014,  $T=40$  K, Ballering+ 2023,  $T_d=62-108$  K

# TRACING DISCS WITH MUSE: [CI] EMISSION LINE AT 8727 Å

Aru+ 2024b

- ▶ First presented in two discs by Haworth+ 2023.
- ▶ We find [CI] 8727 Å detection in each 12 proplyds.

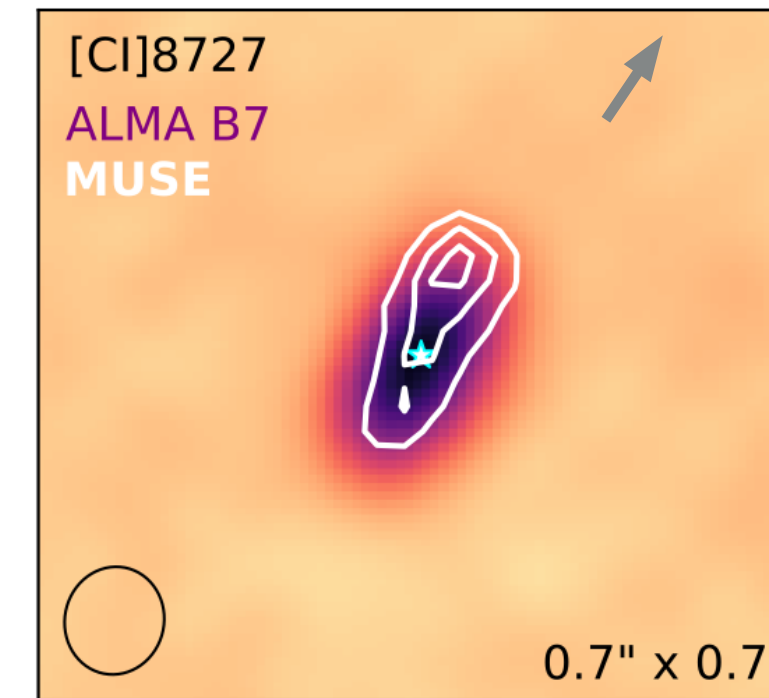
*Goicoechea+ 2024: line emitted via FUV-pumping*



# SPATIAL COMPARISON OF SIX TARGETS: MUSE [C I] 8727 Å + ALMA OVERLAP

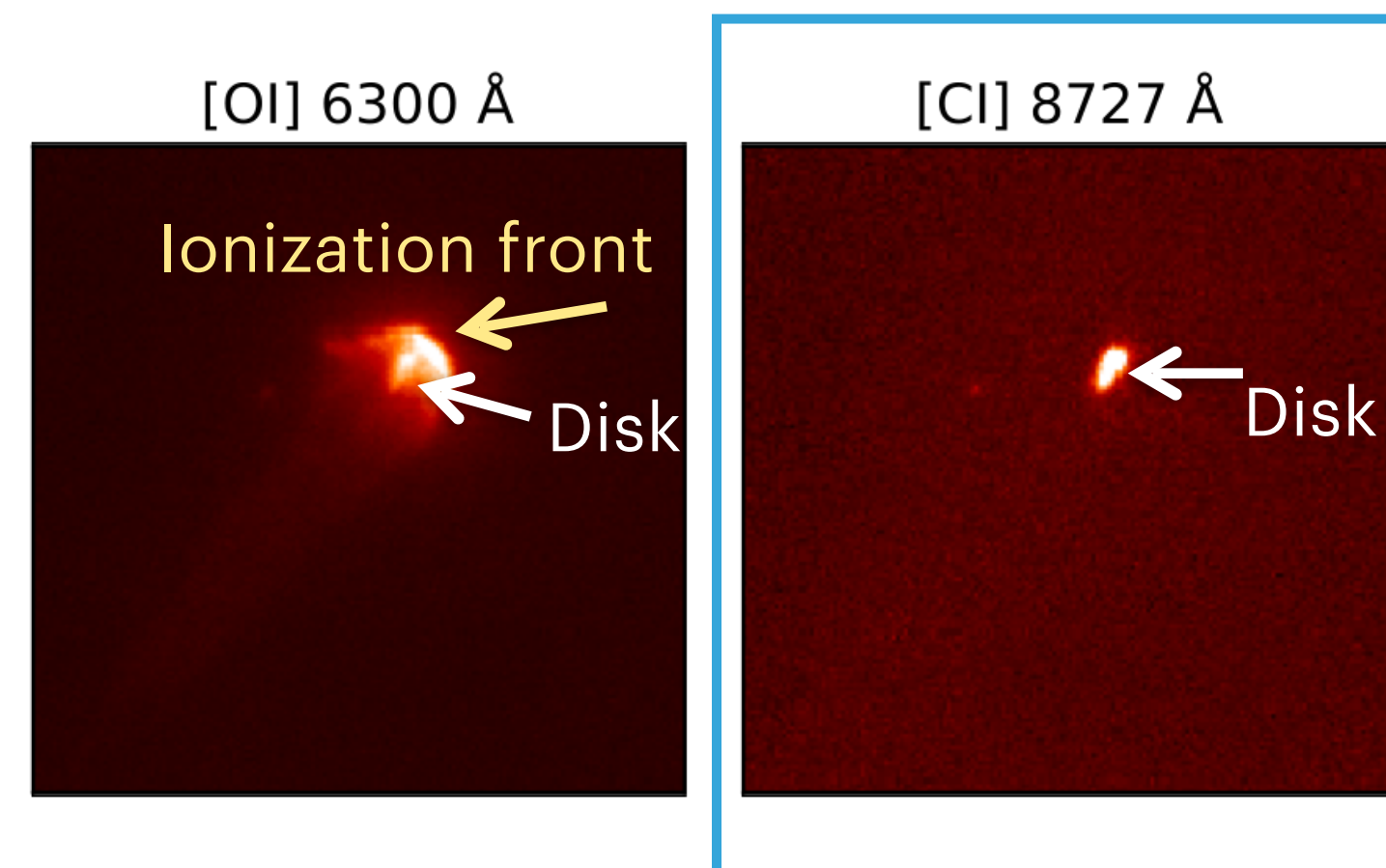
Aru+ 2024b

- ▶ Using ALMA overlap with our sample, [C I] coincides with the disk
- ▶ Example: Proplyd 177-341W



Theta 1 C location

Colormap: ALMA disk dust emission, Band 7 (0.86 mm)  
White: MUSE emission line contours at 50%, 70% and 90% of the peak intensity



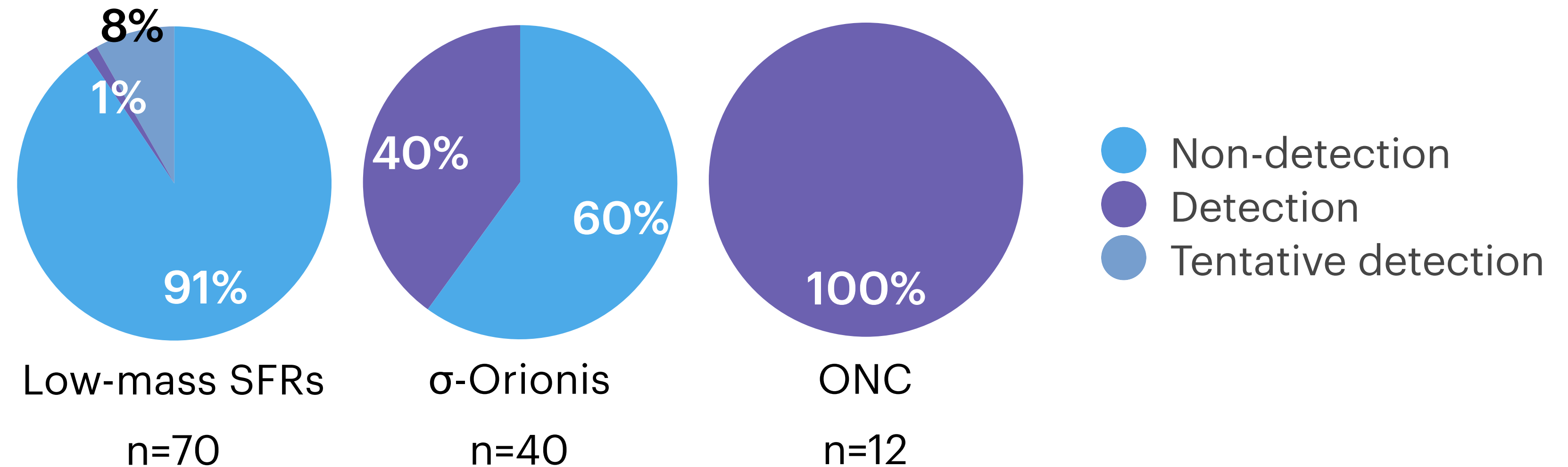
Angular resolution: MUSE ~0.07" , ALMA: 0.09"

ALMA data: Eisner+ 2018

# [CI] 8727 Å AS A SIGNATURE OF EXTERNAL PHOTOEVAPORATION

Aru+ 2024b

- ▶ [OI] lines: very common in low-UV environments (internal photoevaporation)
- ▶ However, [CI] rarely detected (<10% of targets and tentative), based on 77 X-Shooter spectra



☑ Goicoechea+ 2024: intensity of the IR carbon lines scales with UV field strength,  $G_0$ .

# MOVING ONWARD

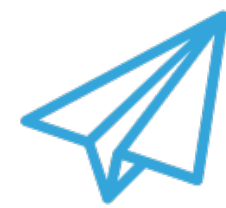
- We also present the complementary study using data and photoionization models (Peake, Haworth, Aru, McCaughrean 2025), and report a [NII]/[SII] ratio distinct for proplyds (Aru+ in prep.)
  - Measure the chemical abundances and compare with model predictions
  - How does the UV environment modify the chemical composition of protoplanetary disks?
    - Observations of some irradiated disks with distinctive photochemistry (e.g., 203-506, Schroetter+ 2025), while others with composition similar to isolated disks (XUE program, e.g., (Ramírez-Tannus et al. 2023))

# CONCLUSIONS

- MUSE allows us to characterise the morphology of proplyds in detail.
- [CI] 8727 A, [NII]/[SII] ratio - distinct for proplyds.  
—> Distinguish external photoevaporation.
- ▶ Next: How does the UV environment modify the chemical composition of protoplanetary disks?



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