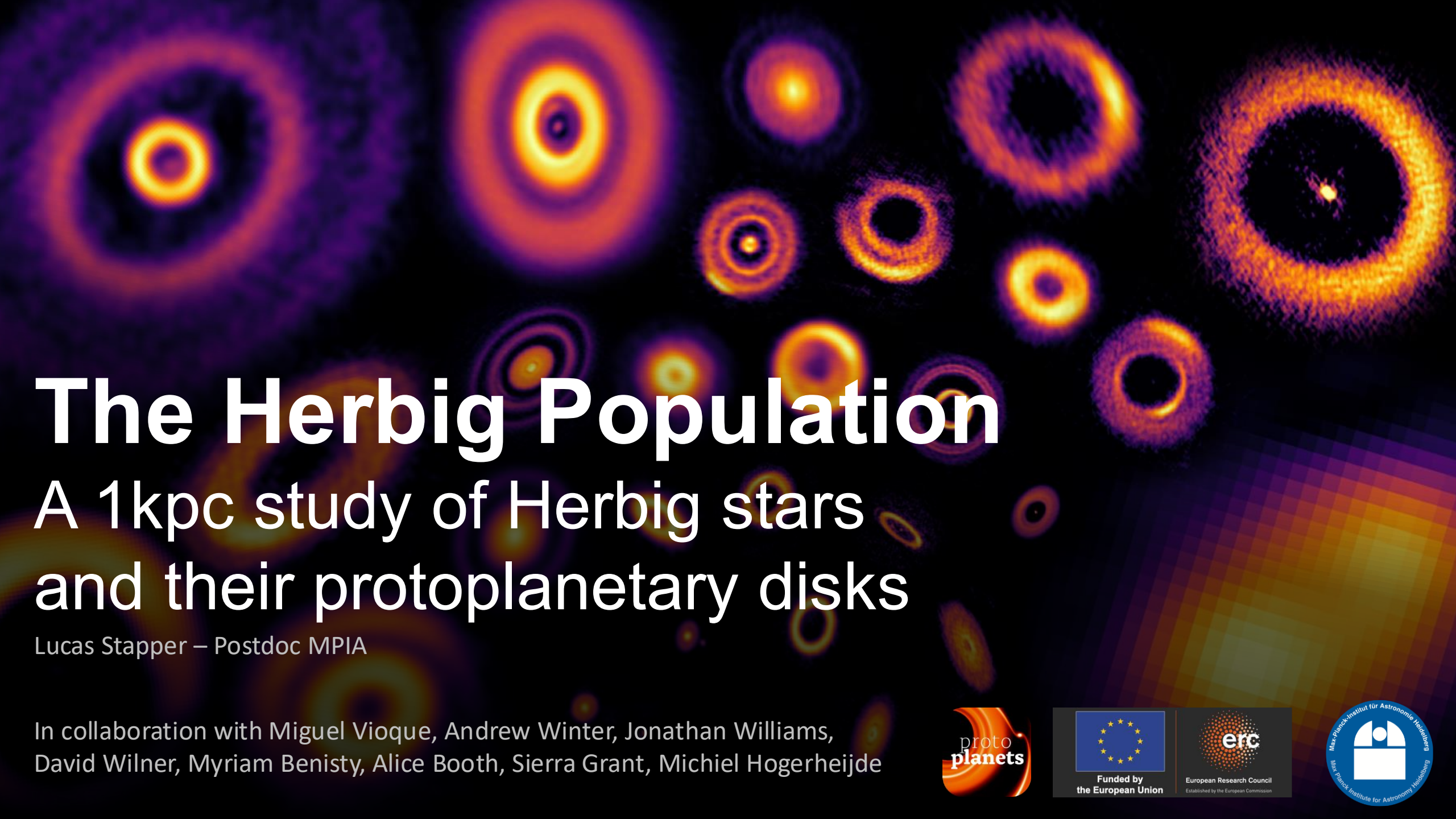


The Herbig Population

A 1kpc study of Herbig stars and their protoplanetary disks

Lucas Stapper – Postdoc MPIA

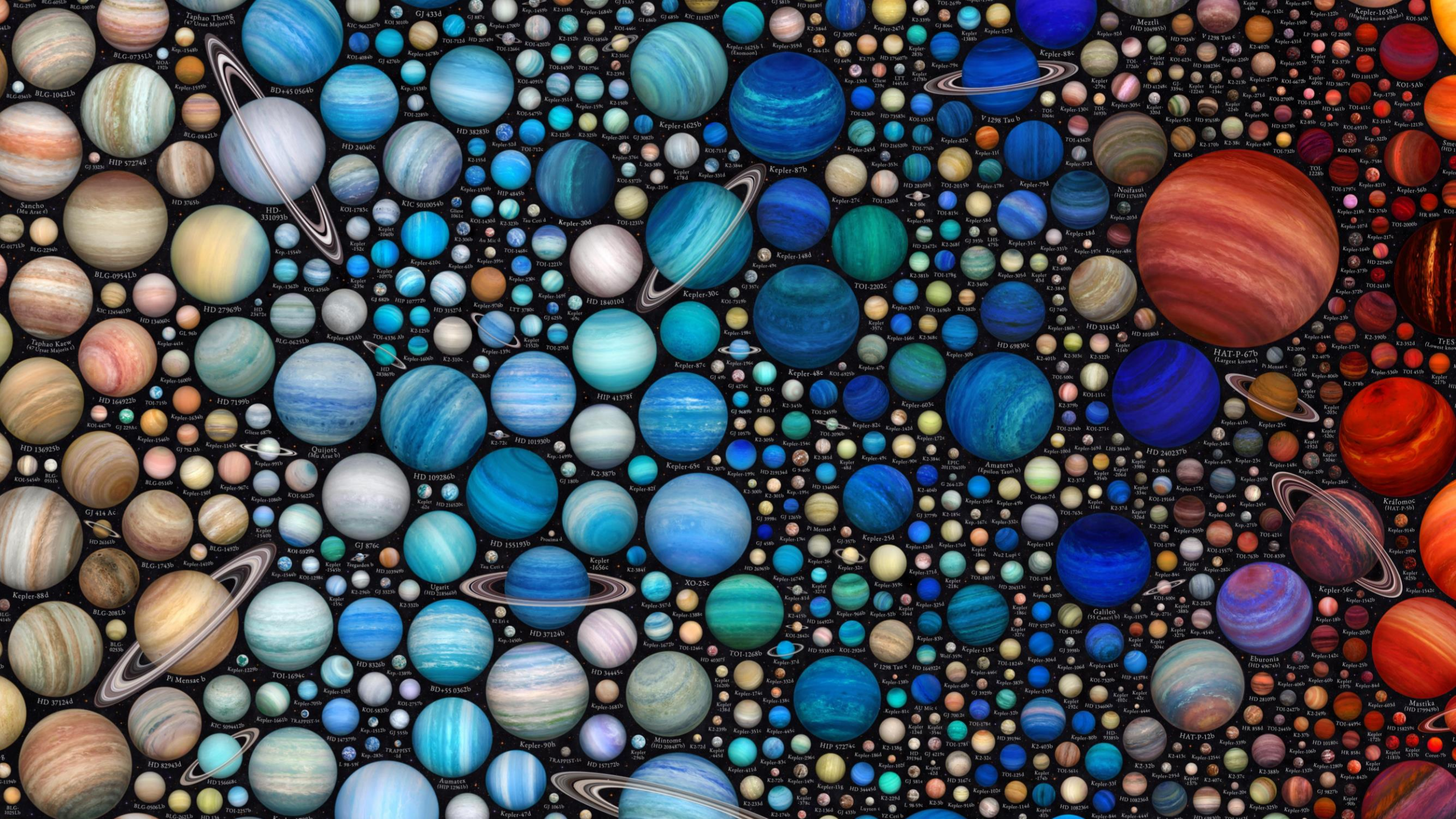
In collaboration with Miguel Vioque, Andrew Winter, Jonathan Williams, David Wilner, Myriam Benisty, Alice Booth, Sierra Grant, Michiel Hogerheijde

proto planets

Funded by the European Union

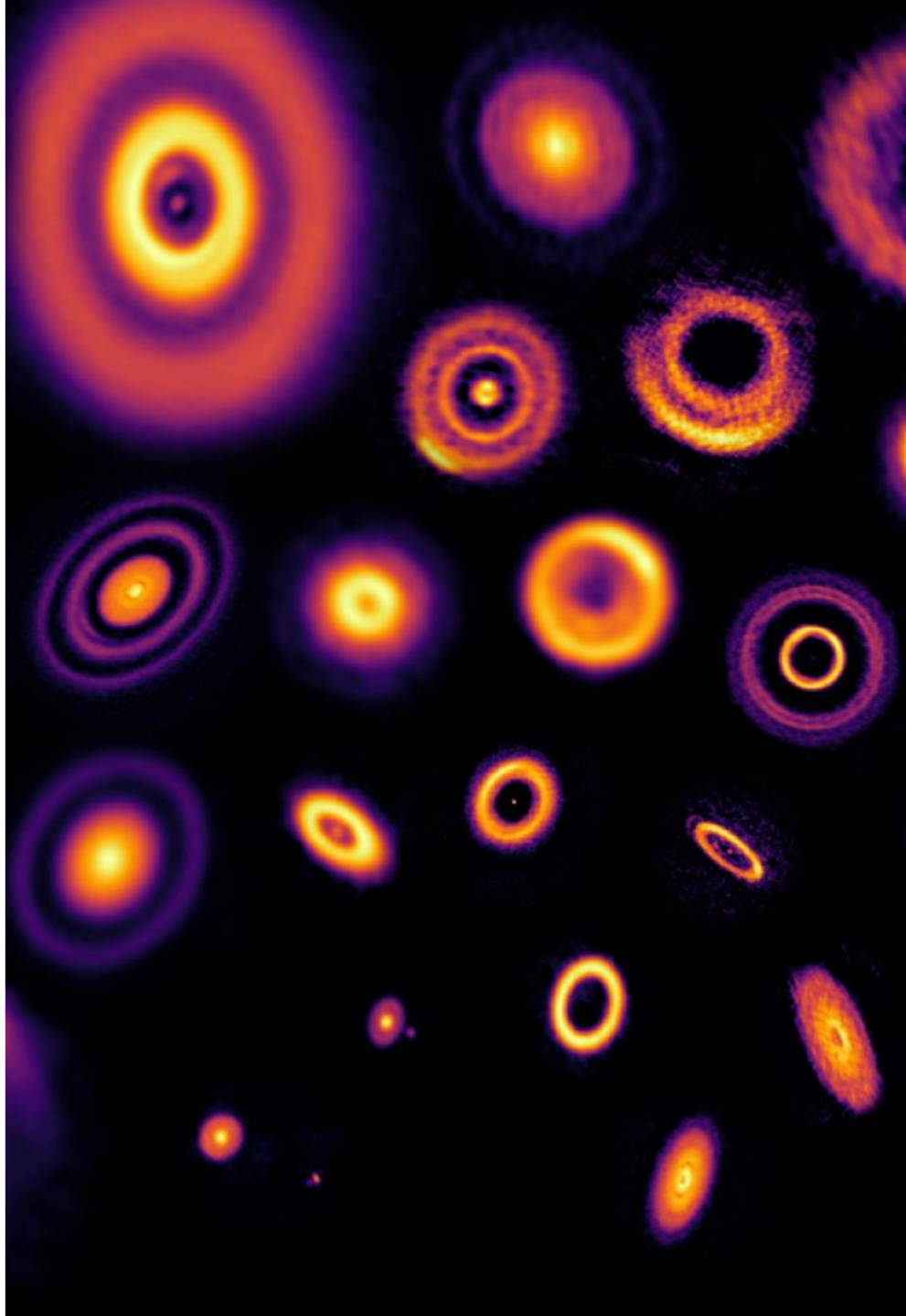
erc European Research Council Established by the European Commission

Max-Planck-Institut für Astronomie Heidelberg
Max Planck Institute for Astronomy Heidelberg


Taphao Thong (47 Ursae Majoris b)
GJ 433d
Meztli (HD 104985b)
Kepler-1658b (Highest known albedo)
BLG-07351Lb
BLG-1042Lb
BD+45 0564b
Kepler-88c
V 1298 Tau b
HIP 57274d
Sancho (Mu Arae e)
HD 24040c
Kepler-1625b
Kepler-87b
KOI-5Ab
HD 3765b
HD 38283b
KIC 5010054b
Kepler-30d
Noifasui (HD 117618b)
BLG-0954Lb
HD-331093b
Kepler-30c
Kepler-148d
TOI-2202c
HD 184010d
HD 27969b
HAT-P-67b (Largest known)
HD 33142d
Taphao Kaew (47 Ursae Majoris c)
HD 69830c
HD 164922b
HD 7199b
Kepler-87c
Kepler-48e
Kepler-603c
HD 240237b
HD 136925b
Quijote (Mu Arae b)
HIP 41378f
Amateru (Epsilon Tauri b)
Kepler-65c
Kepler-25d
Kráfomoc (HAT-P-5b)
GJ 414 Ac
HD 109286b
K2-387b
CoRot-7d
HD 155193b
GJ 876c
Kepler-1656c
XO-2Sc
Galileo (55 Cancri b)
Kepler-56c
Kepler-88d
Ugarit (HD 218566b)
TOI-1268b
Kepler-118c
Eburonia (HD 49674b)
Pi Mensae b
HD 37124b
HD 37124d
BD+55 0362b
HIP 57274c
HAT-P-12b
Mastika (HD 179949b)
HD 82943d
Kepler-90h
Mintome (HD 208487b)
Aumatex (HIP 12961b)
Kepler-47d


Taphao Thong
(47 Ursae Majoris b)
BLG-0735Lb
BLG-1042Lb
BD+45 0564b
HD 24040c
HIP 57274d
Sancho
(Mu Arae e)
HD 3765b
HD-
331093b
KOI-1783c
BLG-0954Lb
HD 27969b
Taphao Kaew
(47 Ursae Majoris c)
HD 164922b
HD 7199b
HD 136925b
Quijote
(Mu Arae b)
GJ 414 Ac
BLG-1492b
BLG-1743b
Kepler-88d
BLG-208Lb
Pi Mensae b
TOI-1694c
HD 37124d
HD 82943d

?




Taphao Thong
(47 Ursae Majoris b)
BD+45 0564b
HD 24040c
HIP 57274d
Sancho
(Mu Arae e)
HD 3765b
HD-
331093b
KOI-1783c
BLG-0954Lb
HD 27969b
HD 134060c
GL 96b
Taphao Kaew
(47 Ursae Majoris c)
HD 164922b
HD 7199b
Quijote
(Mu Arae b)
HD 136925b
BLG-0516b
GJ 414 Ac
HD 26161b
BLG-1743b
BLG-1492b
KOI-5622b
GJ 876c
Kepler-88d
BLG-208Lb
Pi Mensae b
TOI-1694c
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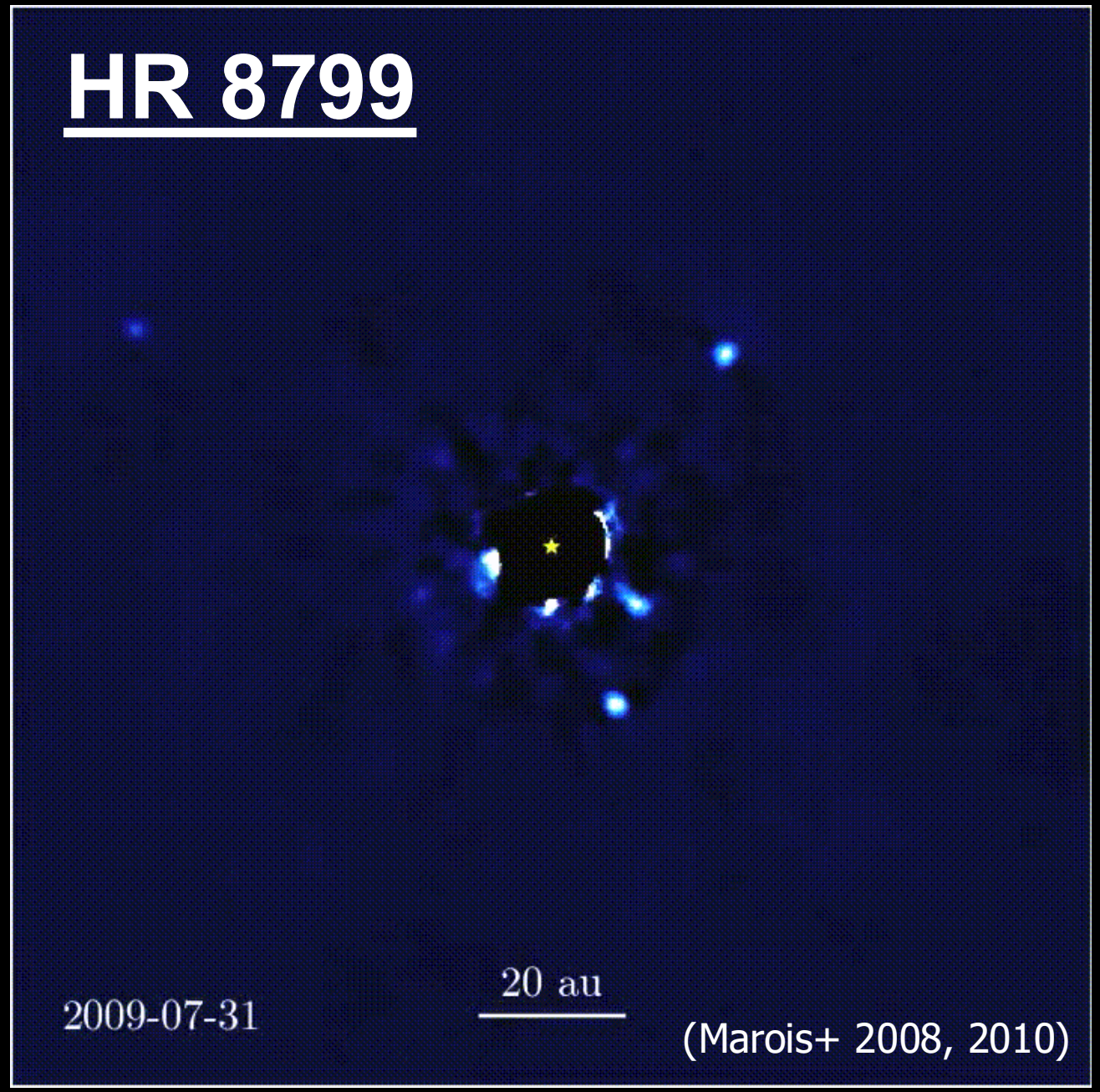
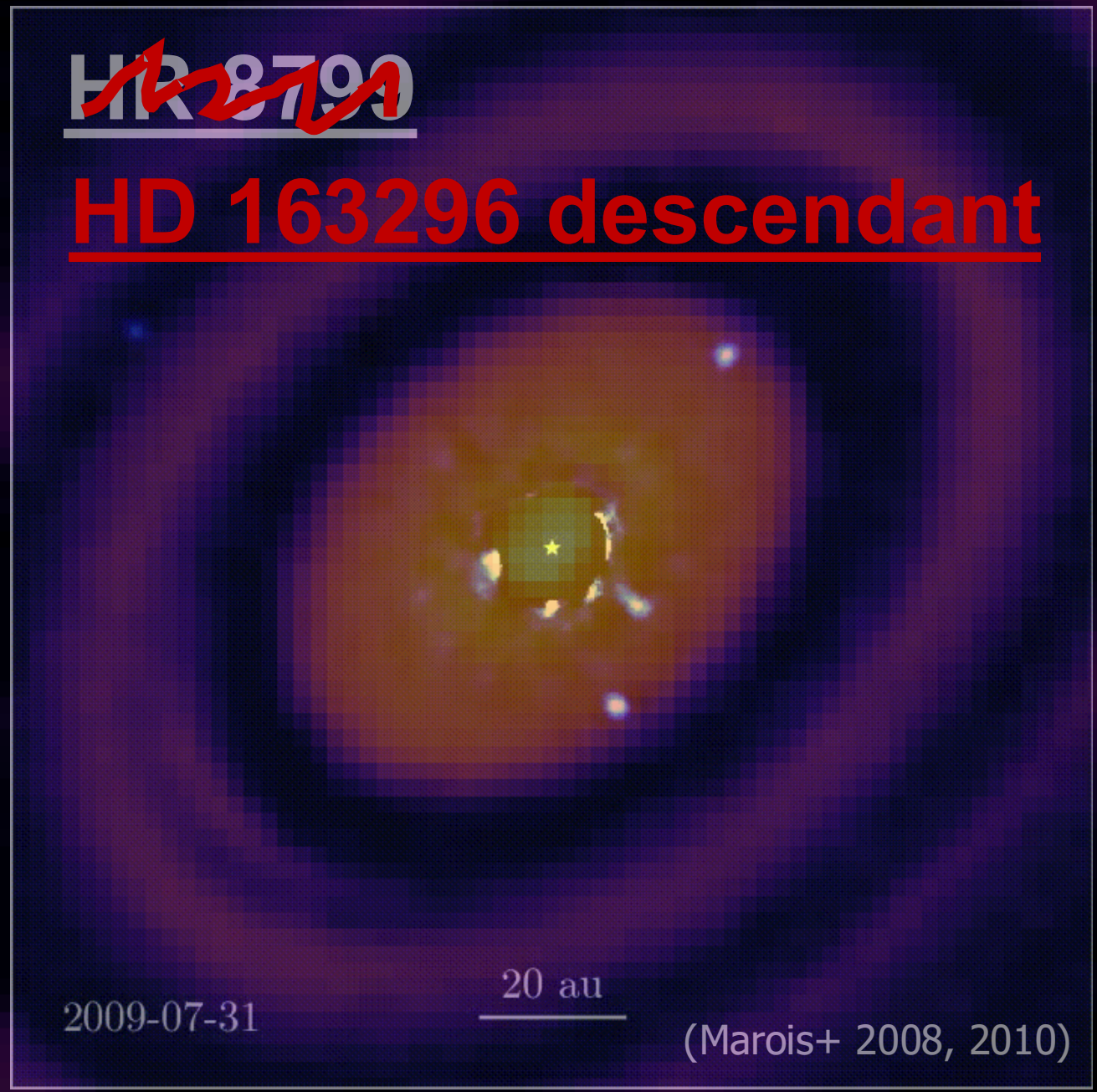
KIC 5094412b
HD 156668c
BLG-0506Lb
TOI-2257b

HR 8799

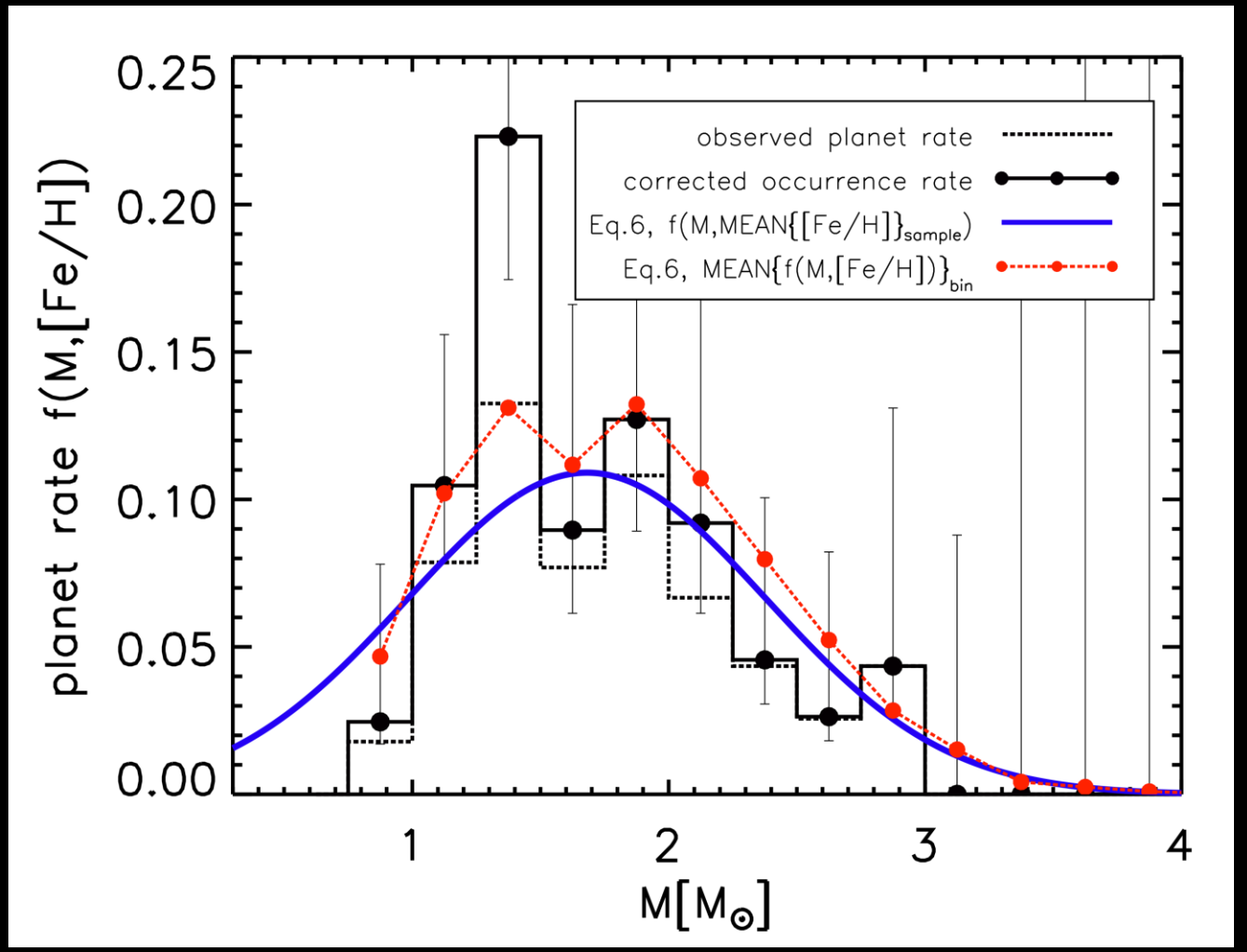

2009-07-31
20 au
(Marois+ 2008, 2010)

~~HR 8799~~

HD 163296 descendant

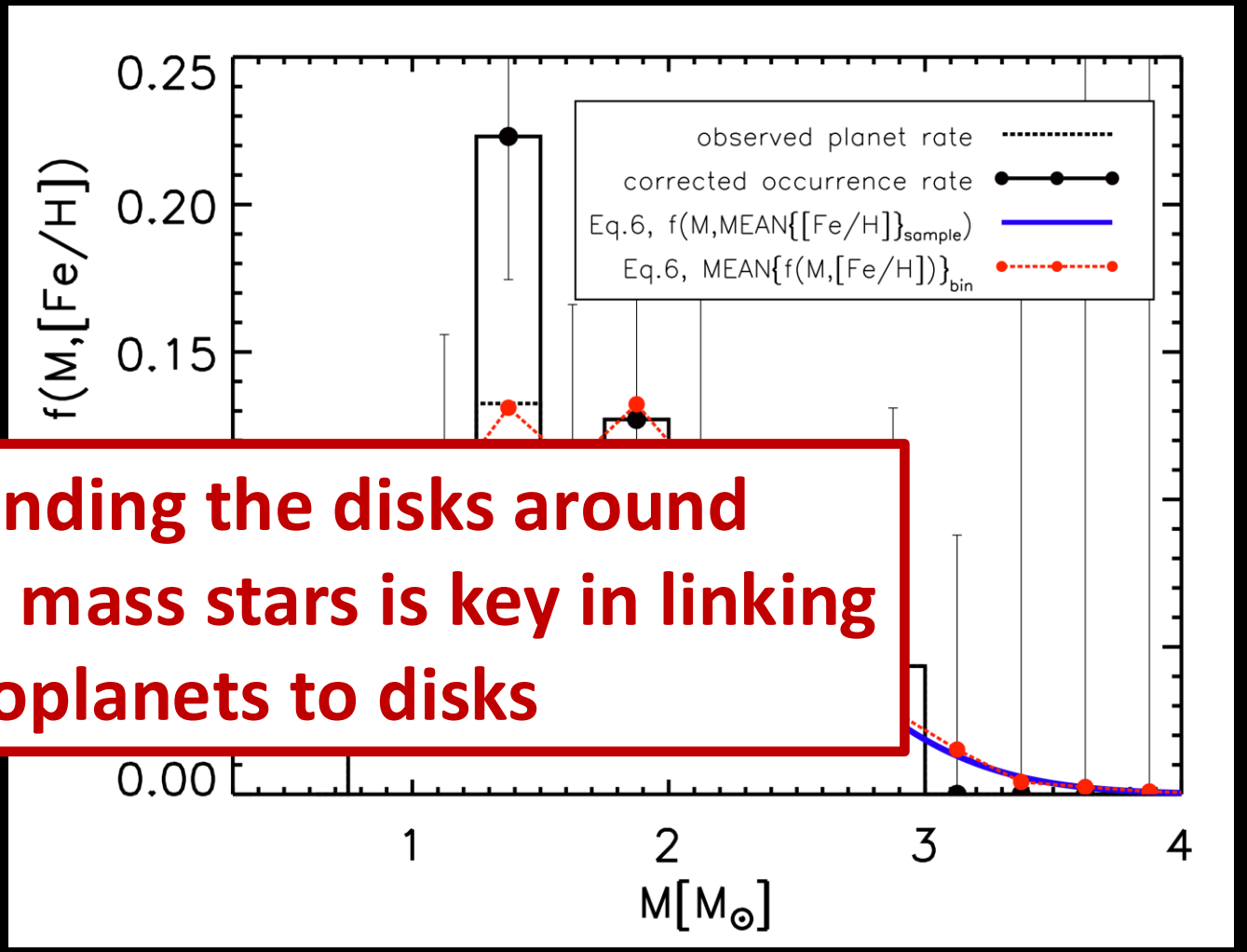


Giant planet occurrence rate peaks at intermediate mass stars!



(from Wolthoff+2022 , others e.g., Johnson+2010, Fulton+ 2021)

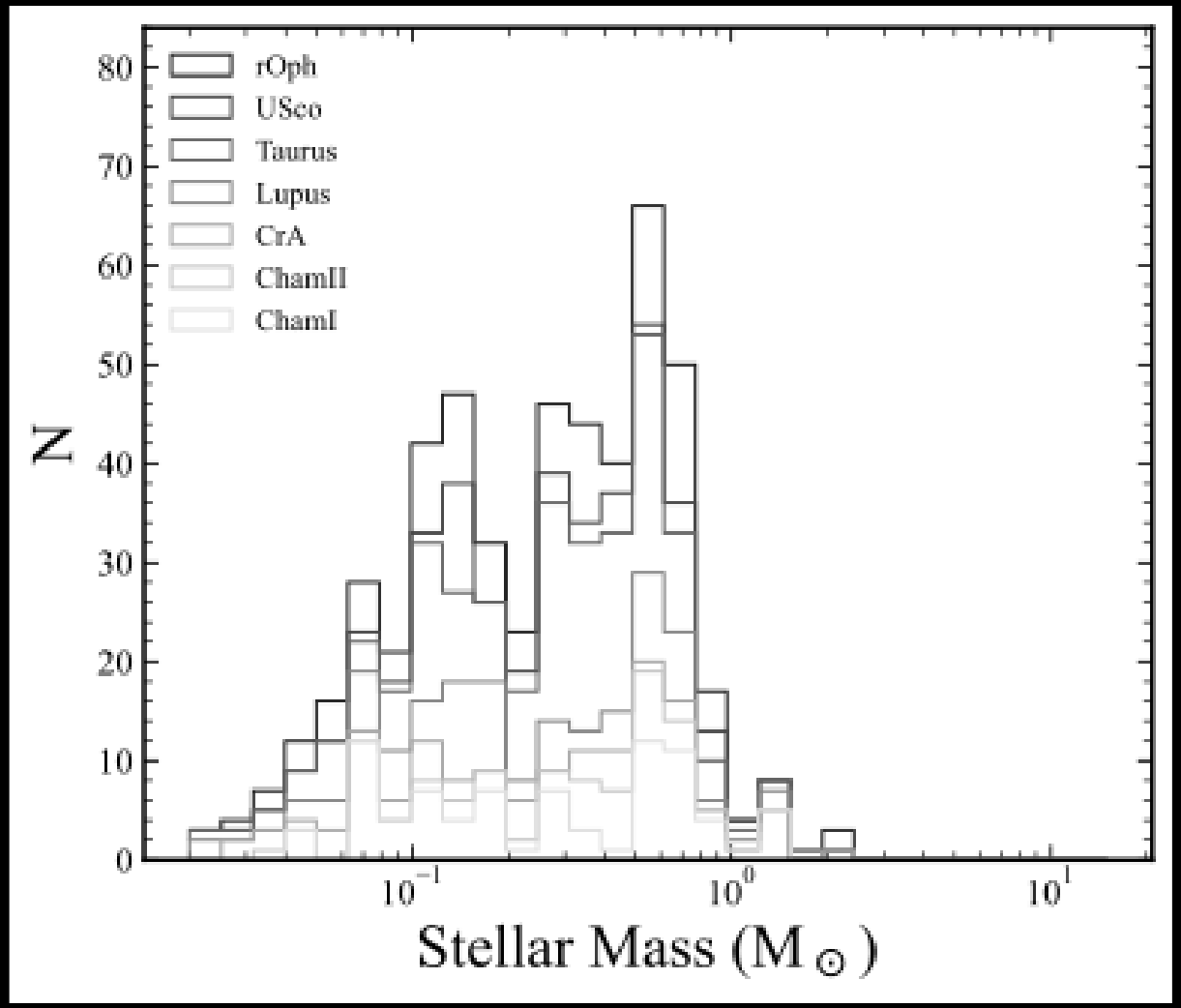
Giant planet occurrence rate peaks at intermediate mass stars!



Understanding the disks around intermediate mass stars is key in linking exoplanets to disks

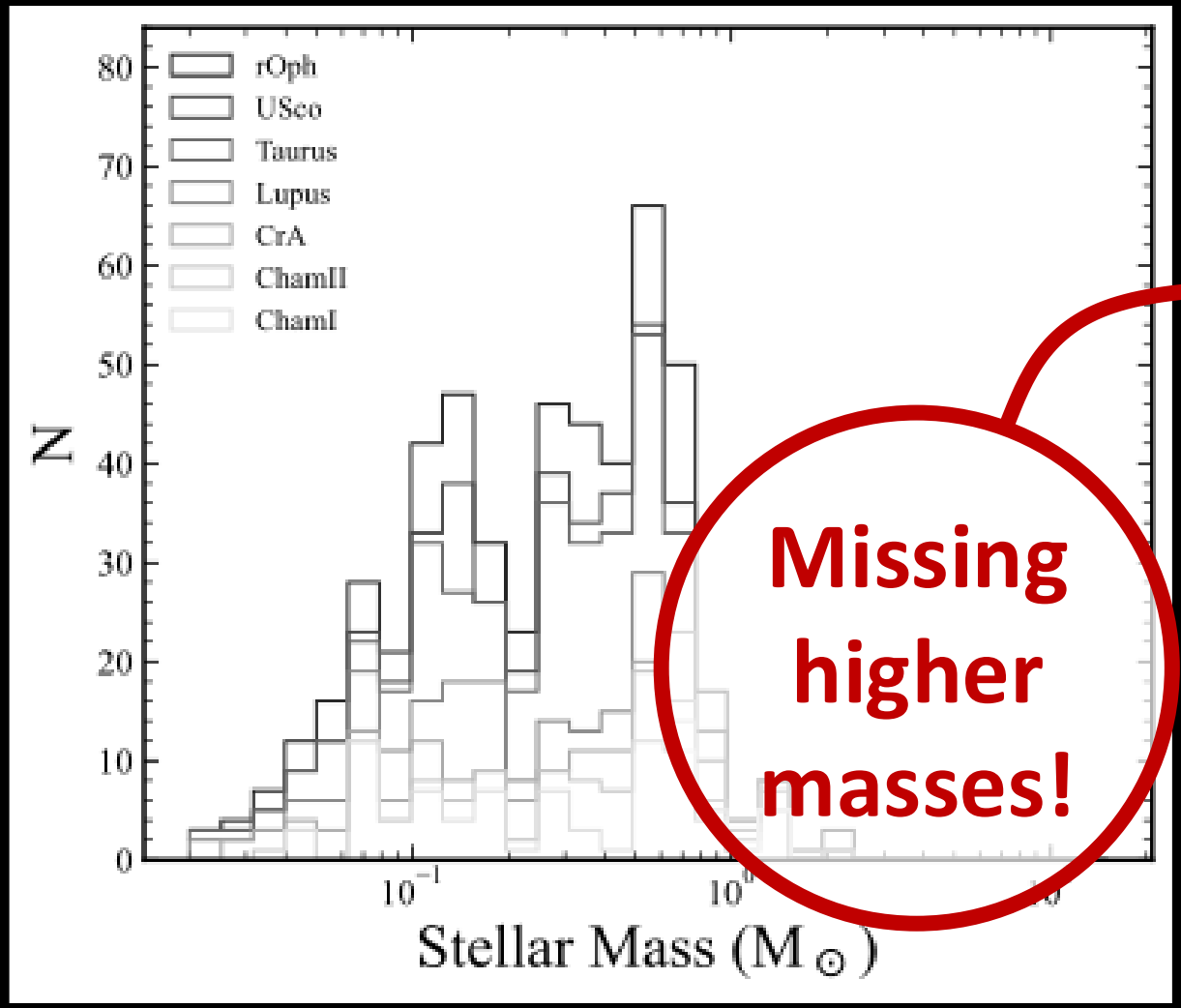
(from Wolthoff+2022 , others e.g., Johnson+2010, Fulton+ 2021)

Protoplanetary disk population studies lack higher mass stars!



Data from Manara+23

Protoplanetary disk population studies lack higher mass stars!



Missing higher masses!

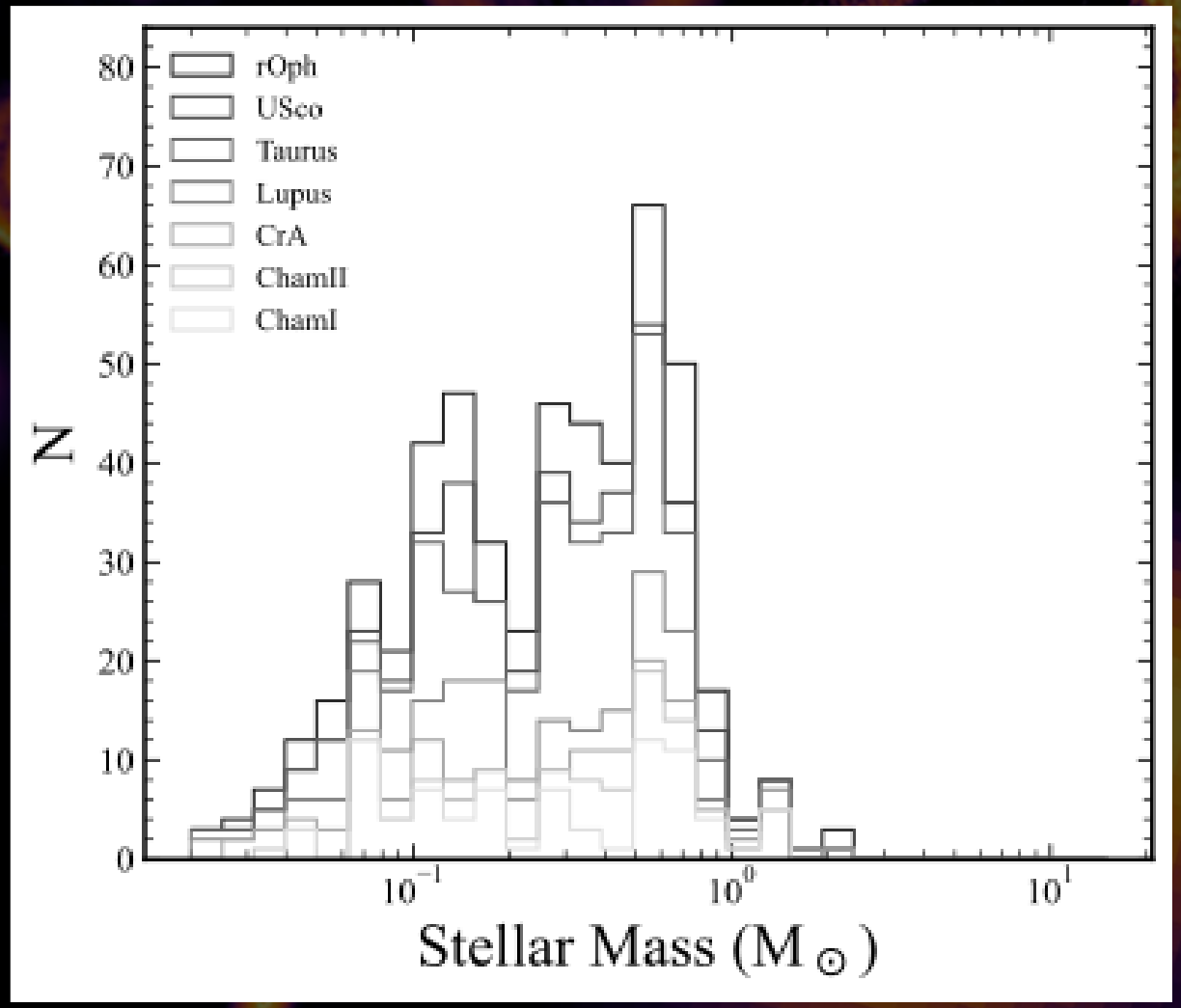
Data from Manara+23

Herbig stars!

Herbig stars are the more massive counterparts of T Tauri stars:

1. **Stellar mass > 1.5 $M_\odot$**

2. **Infrared excess is detected and/or**
3. **Hα emission is detected**



(Herbig 1960; Waters & Waelkens 1998; Vioque+18/22/23; Guzman-Diaz+21; Valegård+21; Brittain+23)

Herbig stars!

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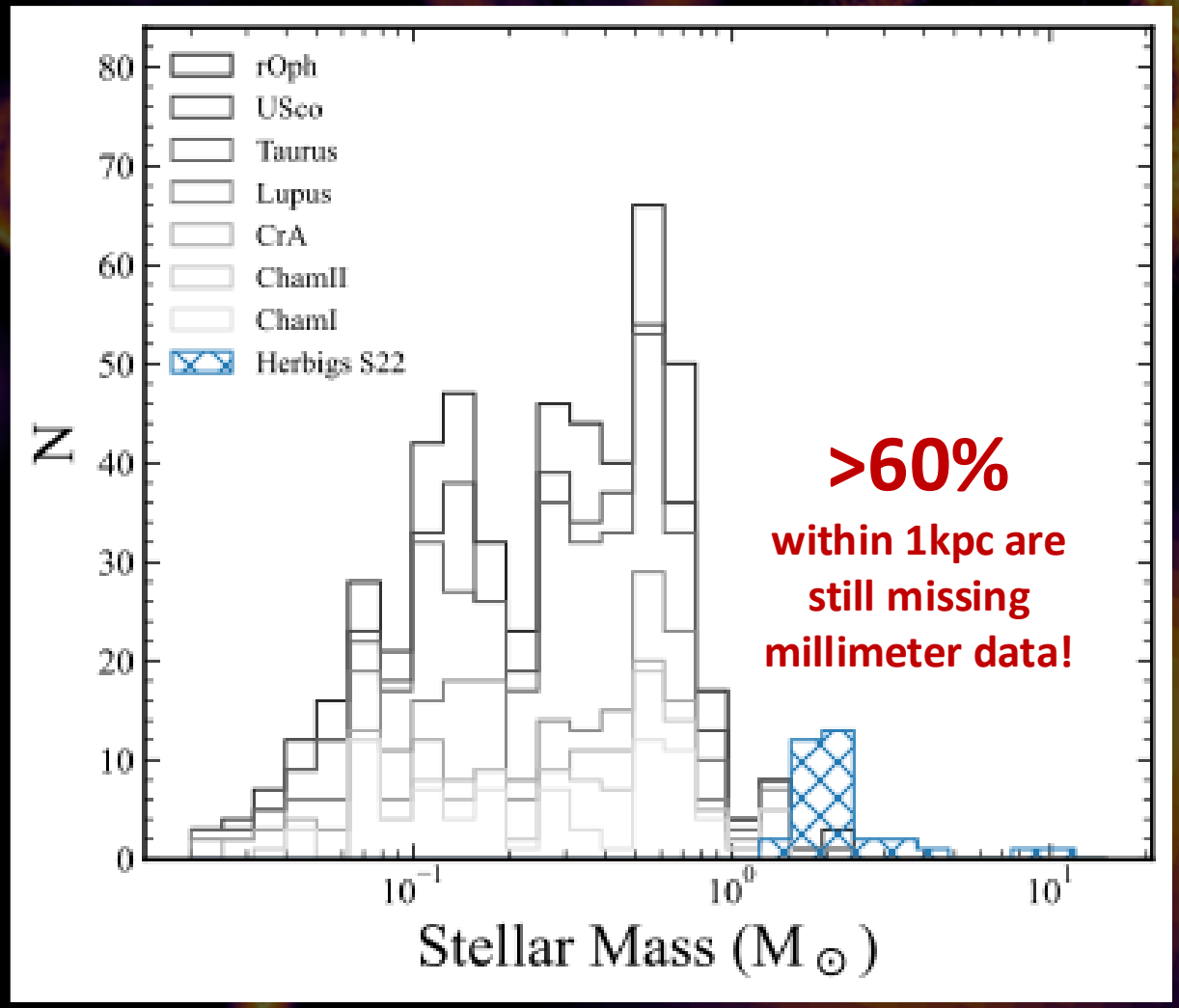
Stapper+22/24/25a/25b



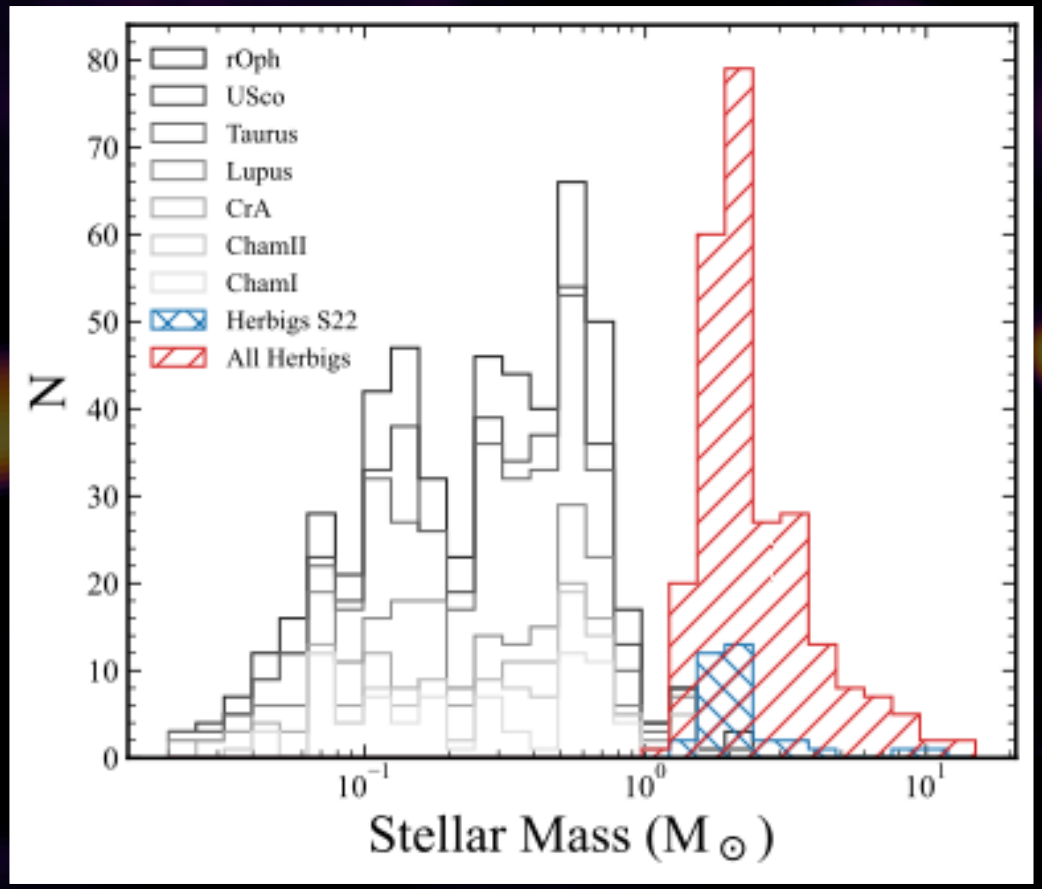
(Herbig 1960; Waters & Waelkens 1998; Vioque+18/22/23; Guzman-Diaz+21; Valegård+21; Brittain+23)

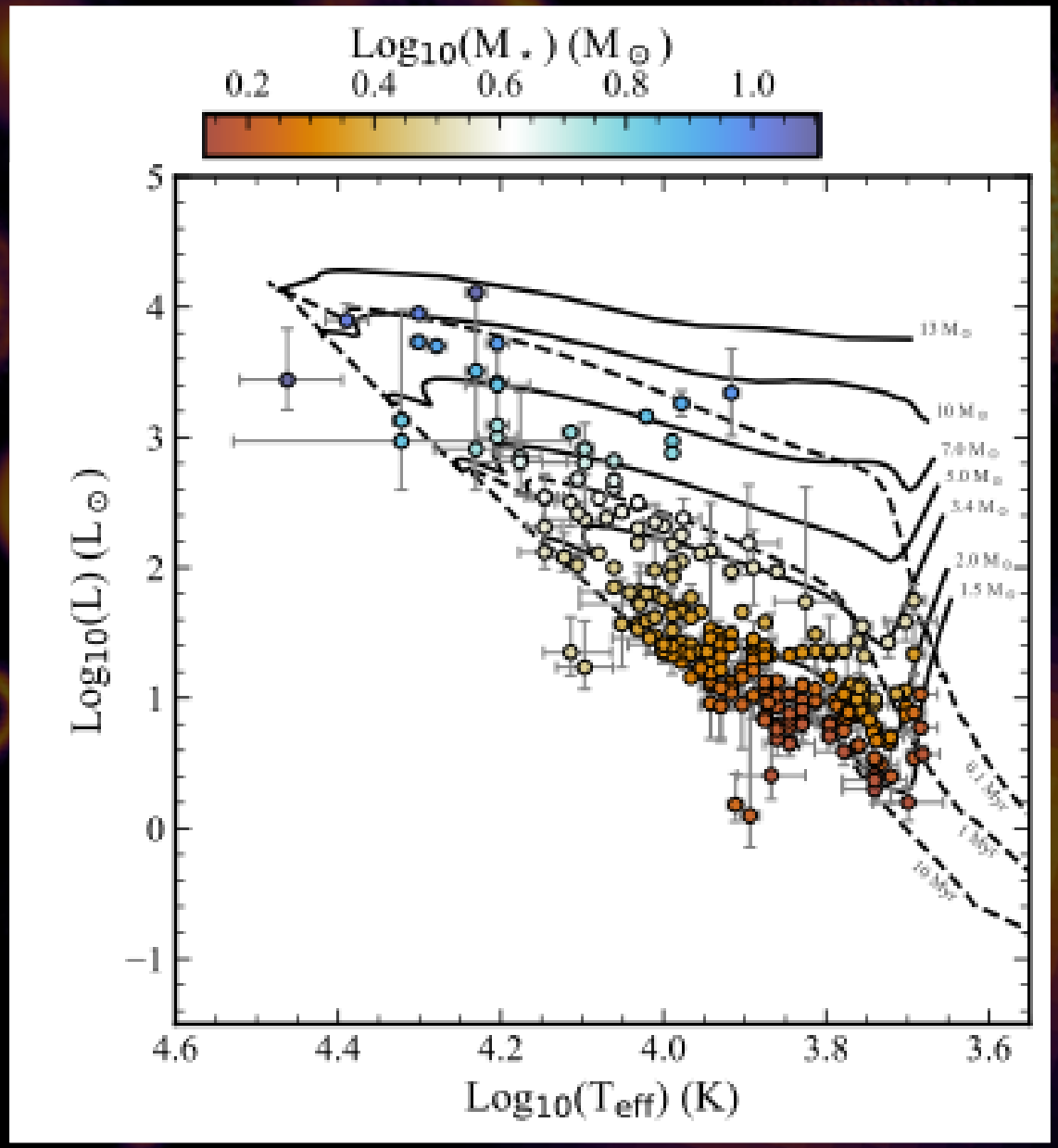
A survey within 1 kpc

Combination of different works:
Vioque+18/22/23, Guzman-Diaz+21, Valegård+21

Total targets: 243

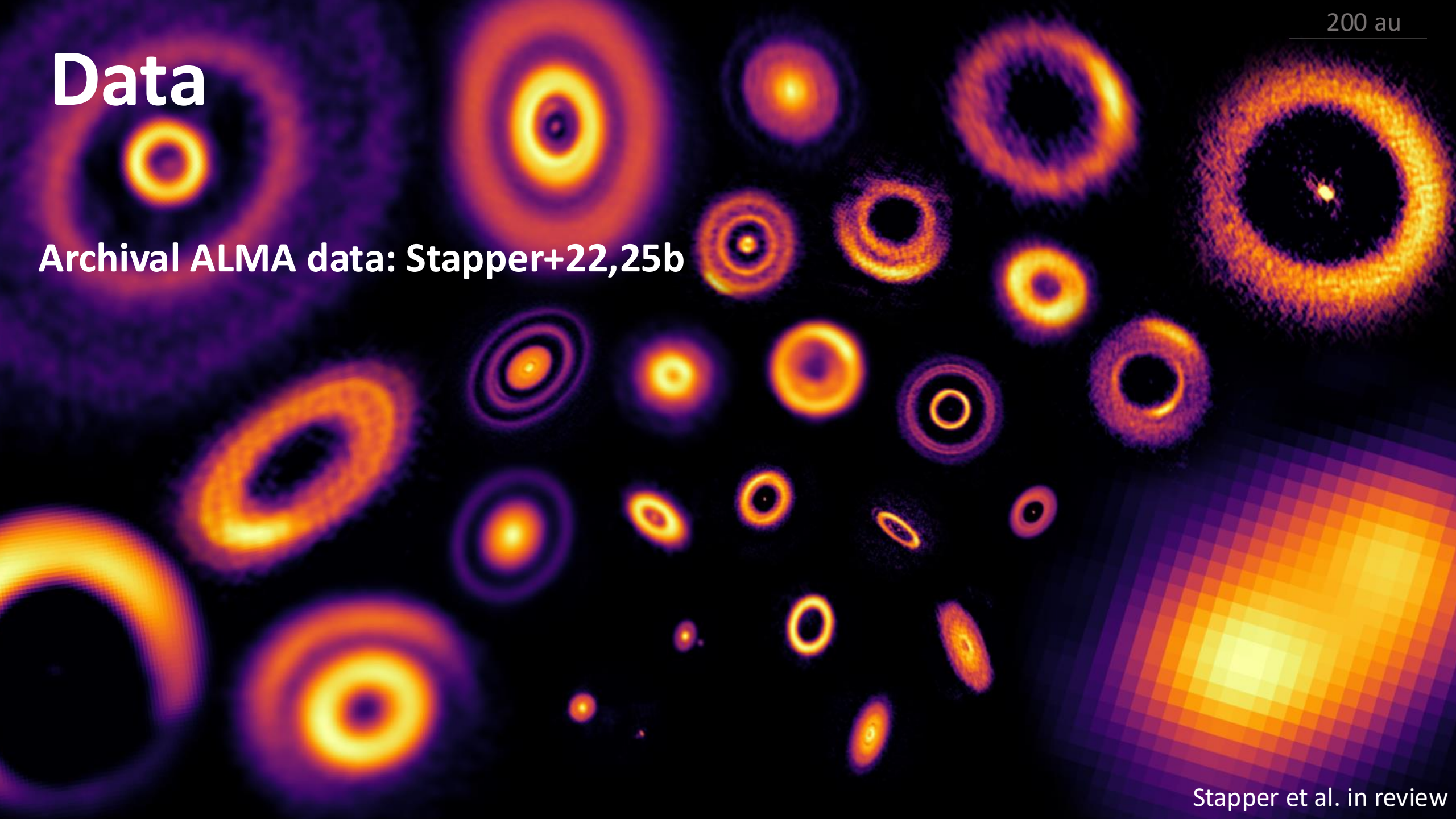
Catalog with archival, recalibrated, and newly derived stellar parameters, accretion rate properties, and disk masses





Stapper et al. in review

Data



Archival ALMA data: Stapper+22,25b

Stapper et al. in review

Data

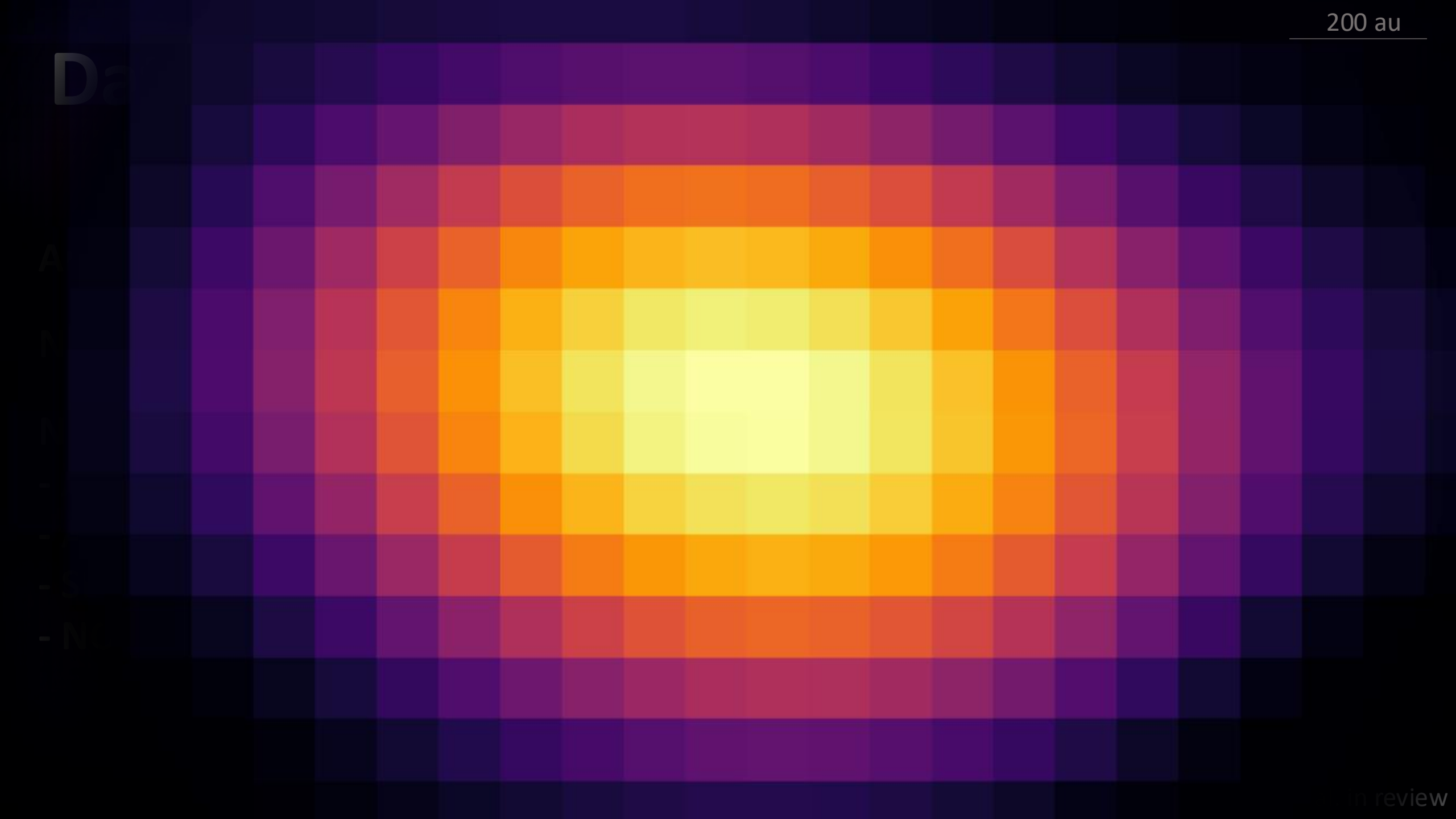
Archival ALMA data: Stapper+22,25b

NOEMA data: Stapper+24,25a

New data:

- **ALMA** (P.I.: M. Vioque)
- **ACA** (P.I.: M. Vioque, J. Williams)
- **SMA** (P.I.: M. Vioque)
- **NOEMA** (P.I.: L. Stapper)

Stapper et al. in review


200 au

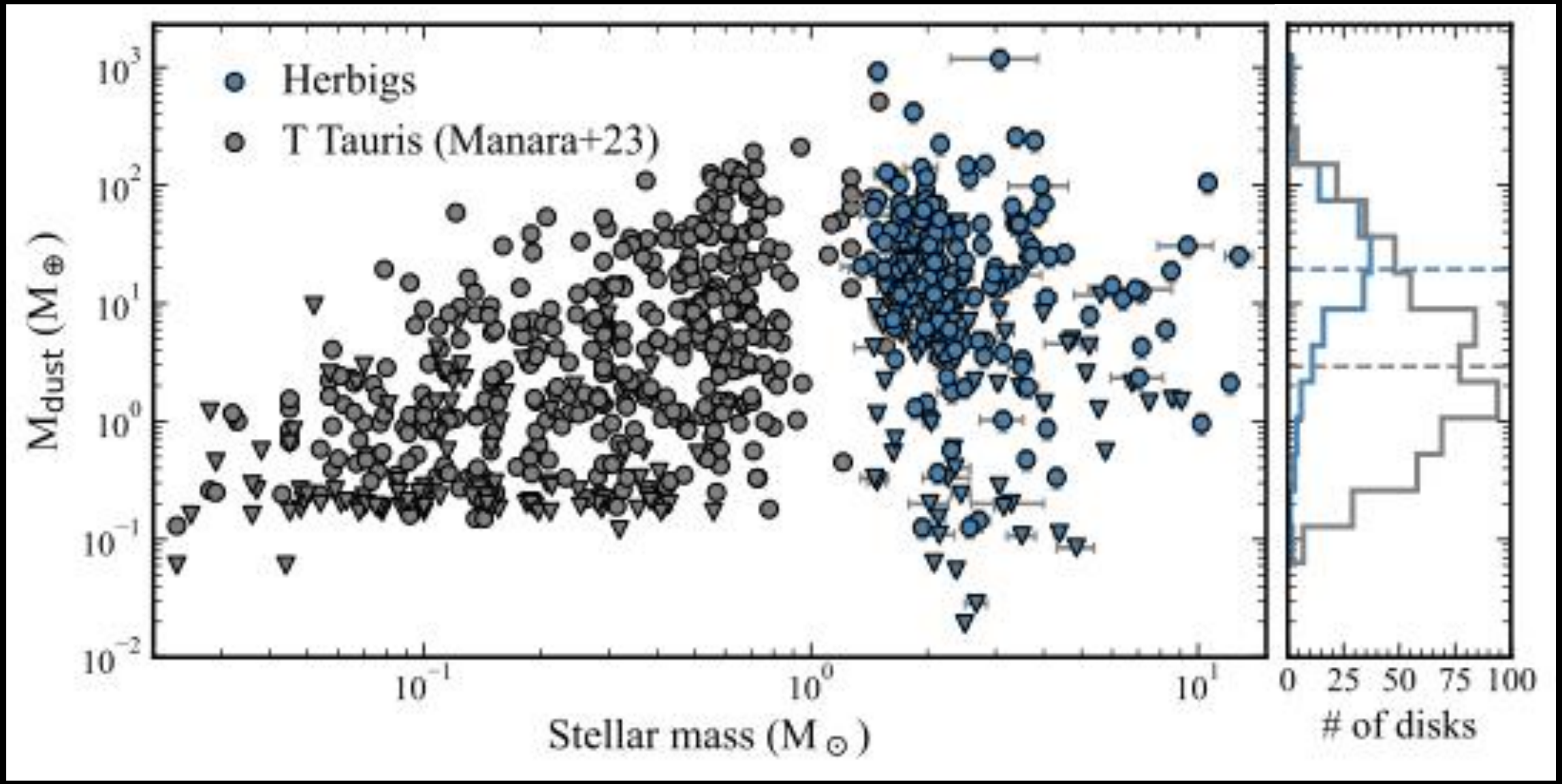
$$M_{dust} = \frac{F_\nu \, d^2}{\kappa_\nu B_\nu(T)}$$

Assumptions

1. Optically thin
2. Opacity power-law index
3. Dust temperature

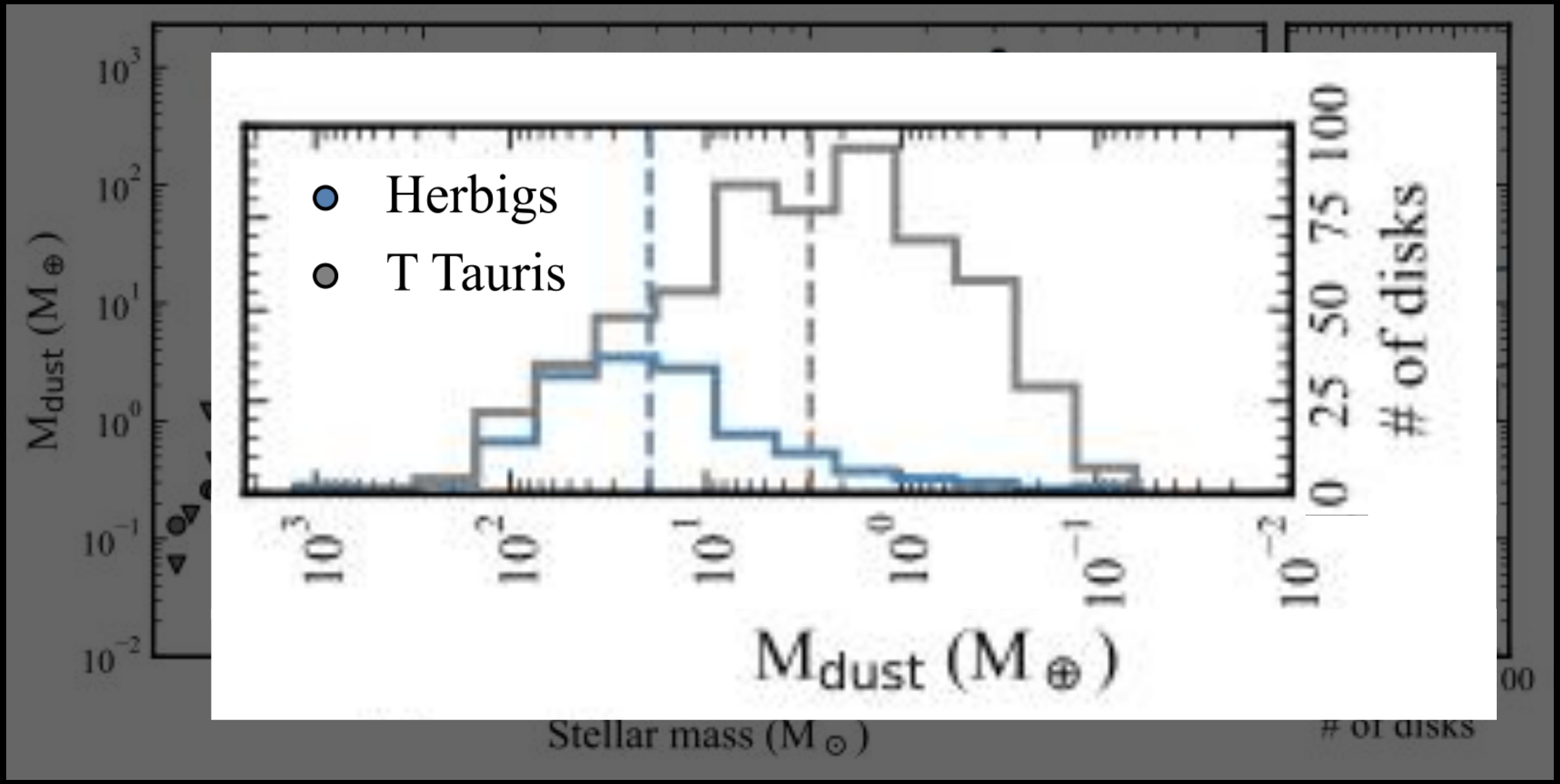
Stapper et al. in review

Disk mass vs Stellar mass



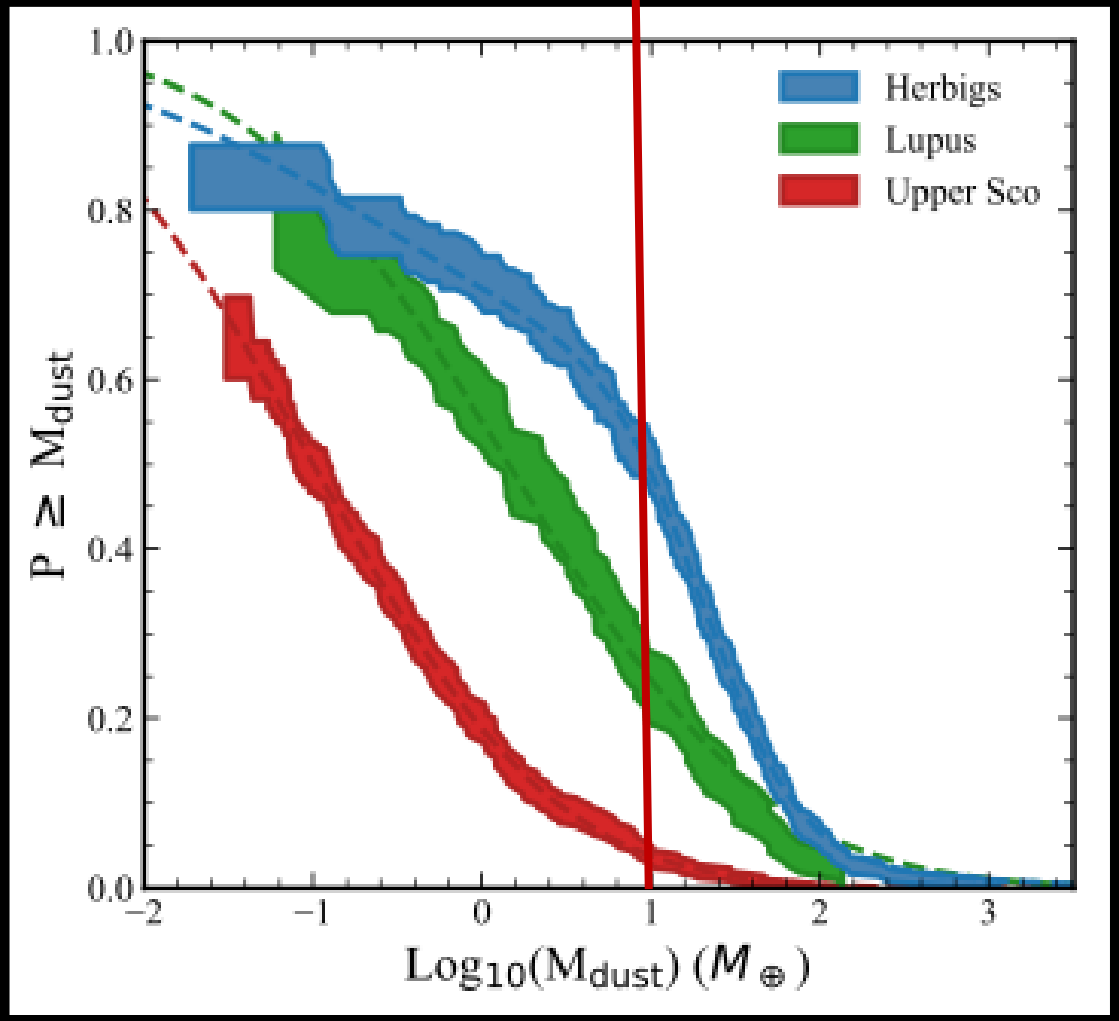
Stapper et al. in review

Disk mass vs Stellar mass



Stapper et al. in review

Disk masses



Disks with masses >10 $M_\oplus$

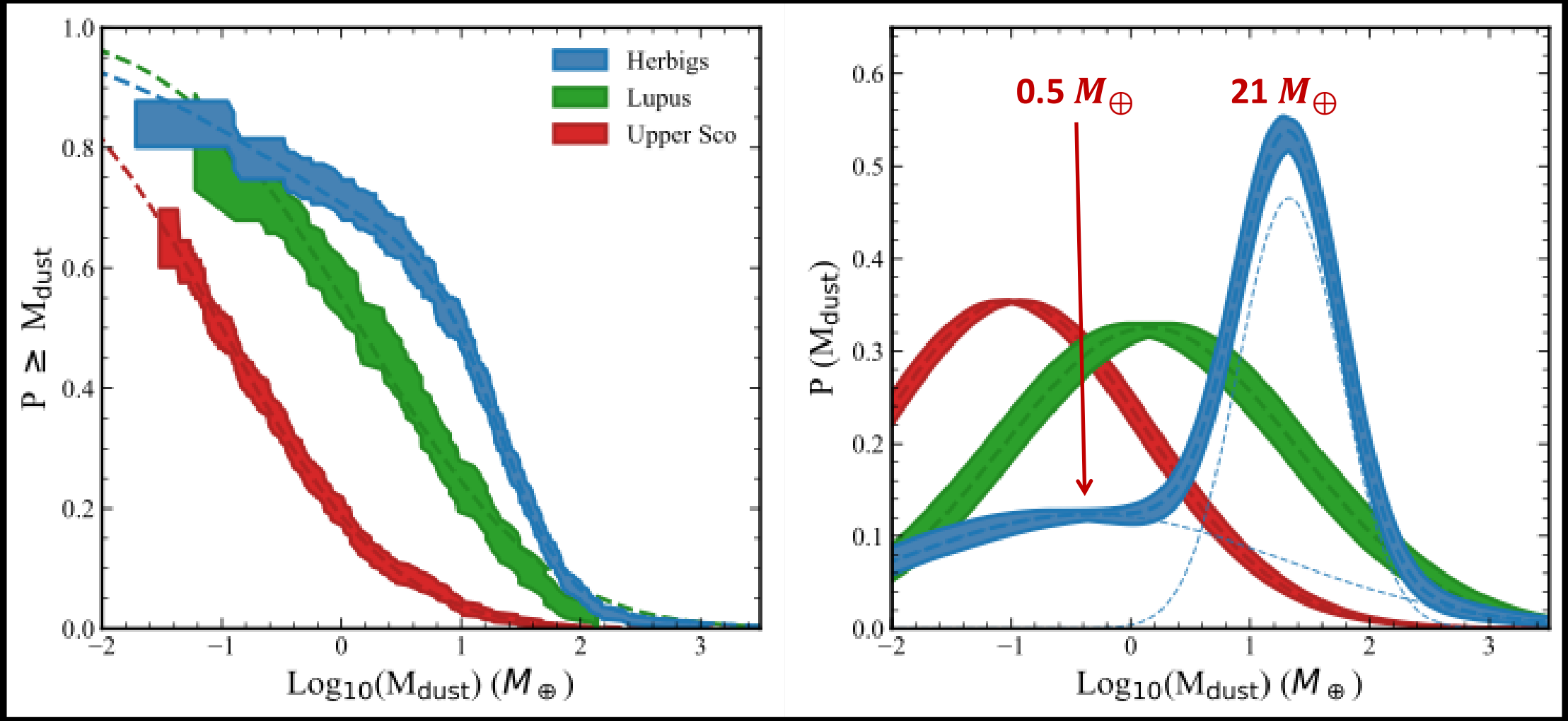
- **Upper Sco 5%** (Carpenter+25)
- **Lupus 20%** (Manara+23)
- **Herbig disks 50%**

→Herbig disks are significantly more massive!

Consistent with Stapper+22,25a,25b

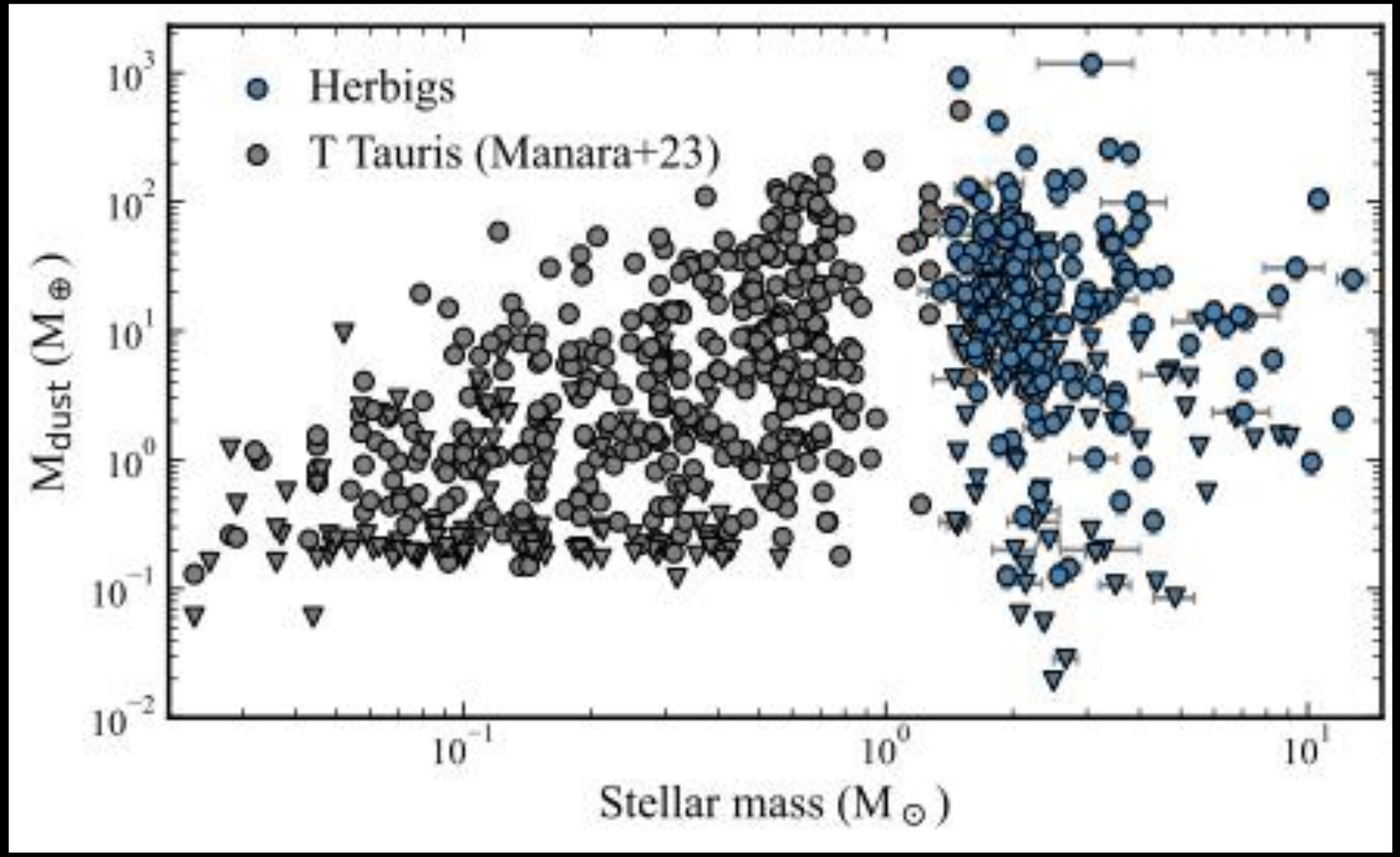
Stapper et al. in review

Disk masses



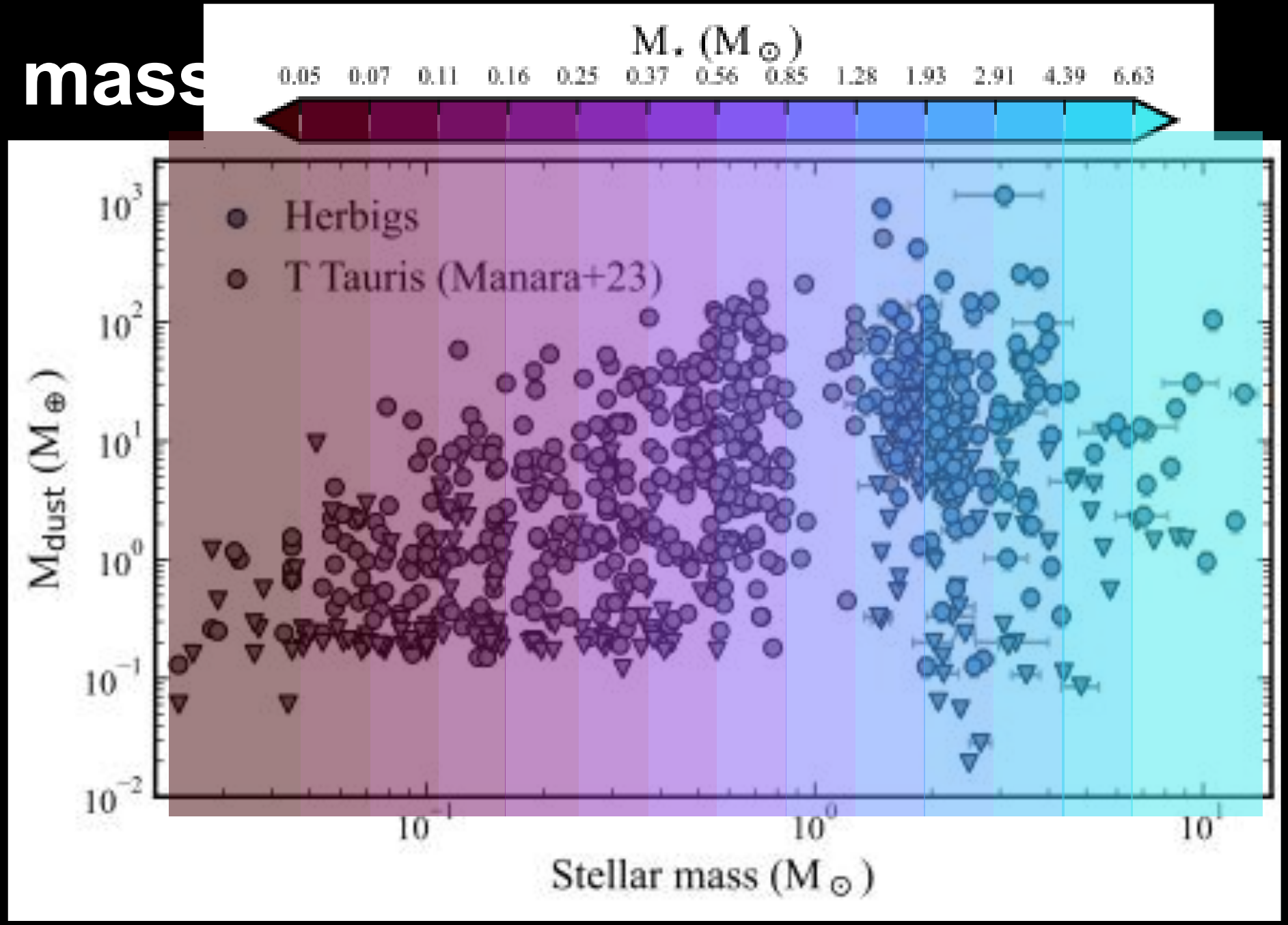
Stapper et al. in review

Disk mass vs Stellar mass



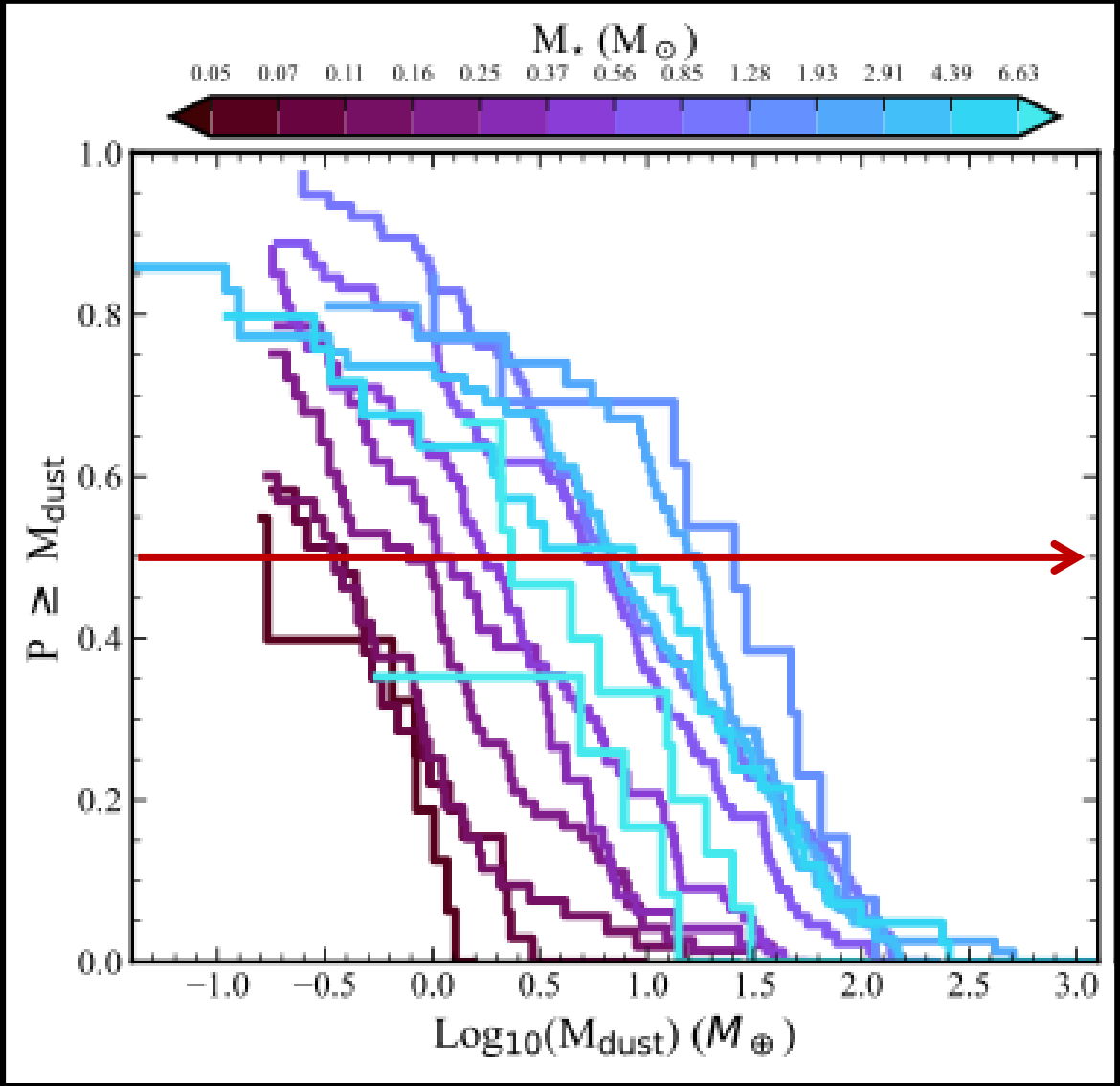
Stapper et al. in review

Disk mass

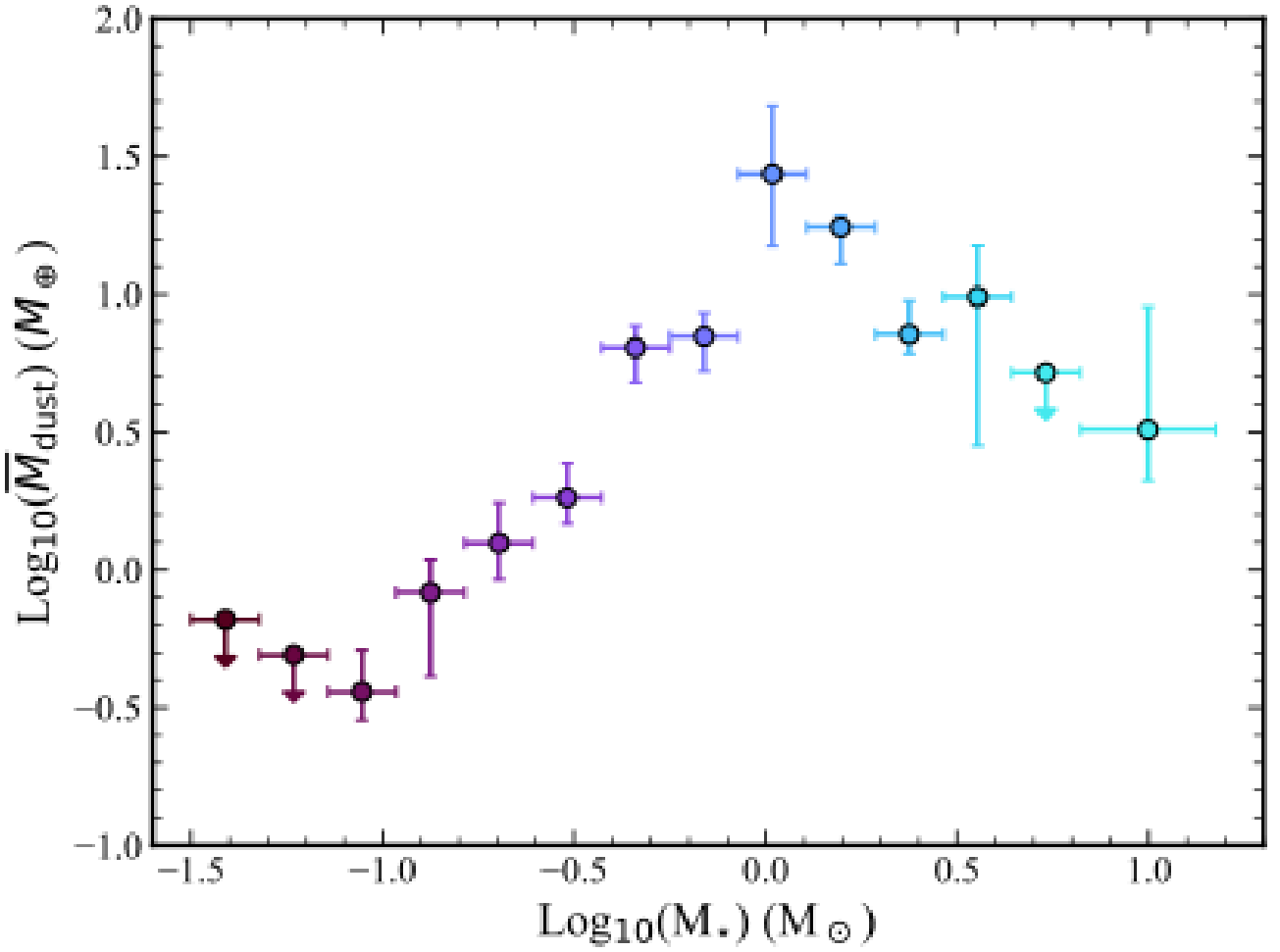


Stapper et al. in review

Disk mass vs Stellar mass

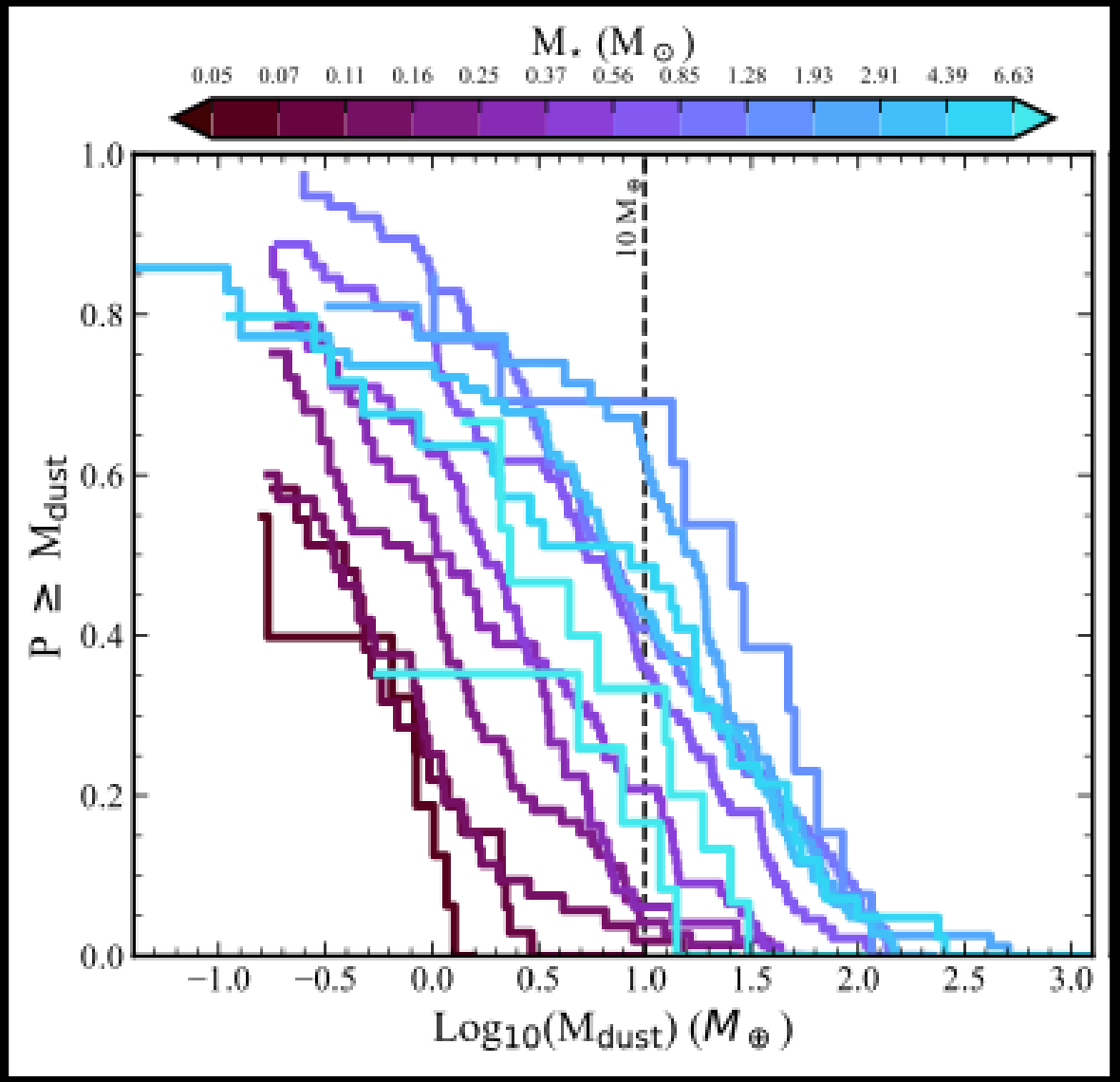


Disk masses peak at 1-2 $M_\odot$!

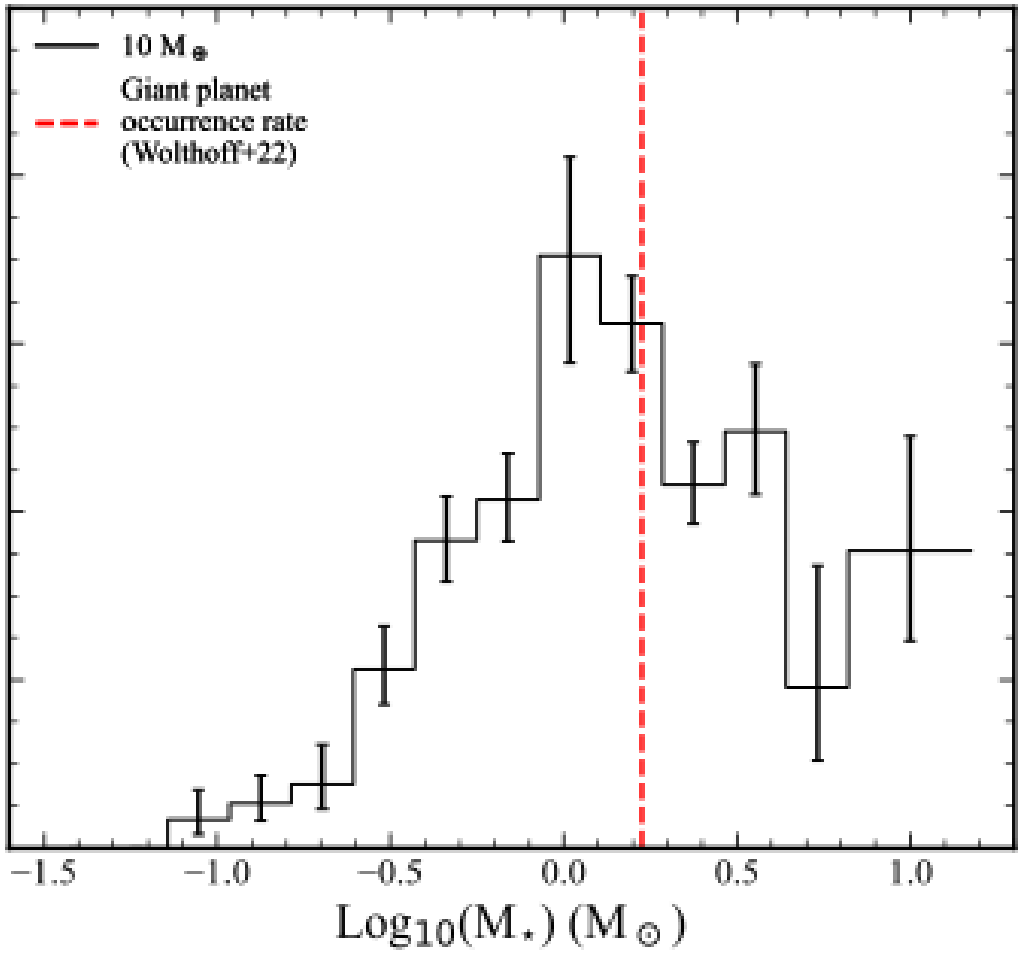


Stapper et al. in review

High disk mass occurrence rates



High disk mass occurrence rate peaks at the giant planet occurrence rate!

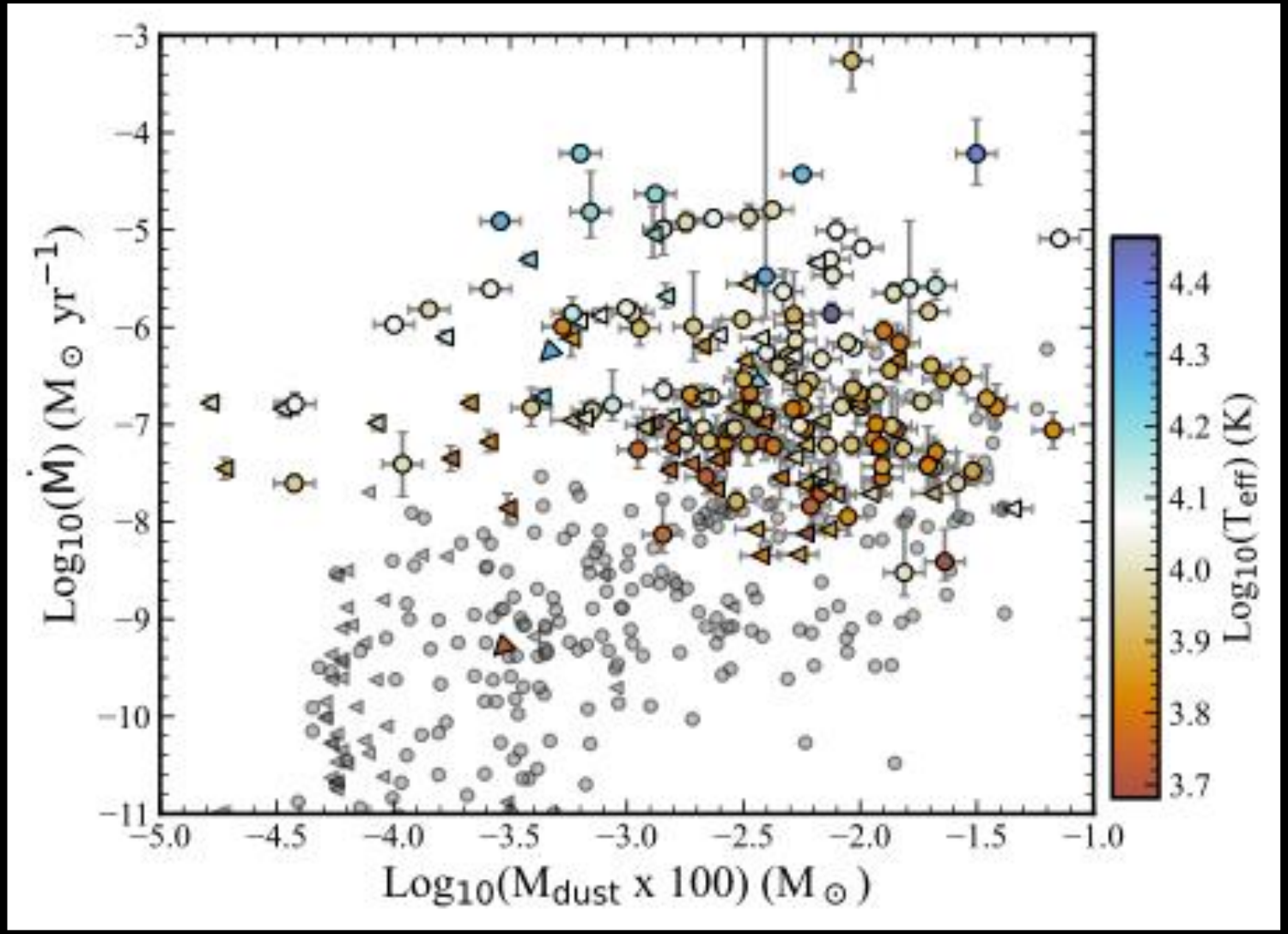


Stapper et al. in review

Accretion rates and dust masses

178 Herbig stars with accretion rate properties

- **Accretion rate – disk mass relationship is flat**
- **No low disk mass / low accretion rate objects**

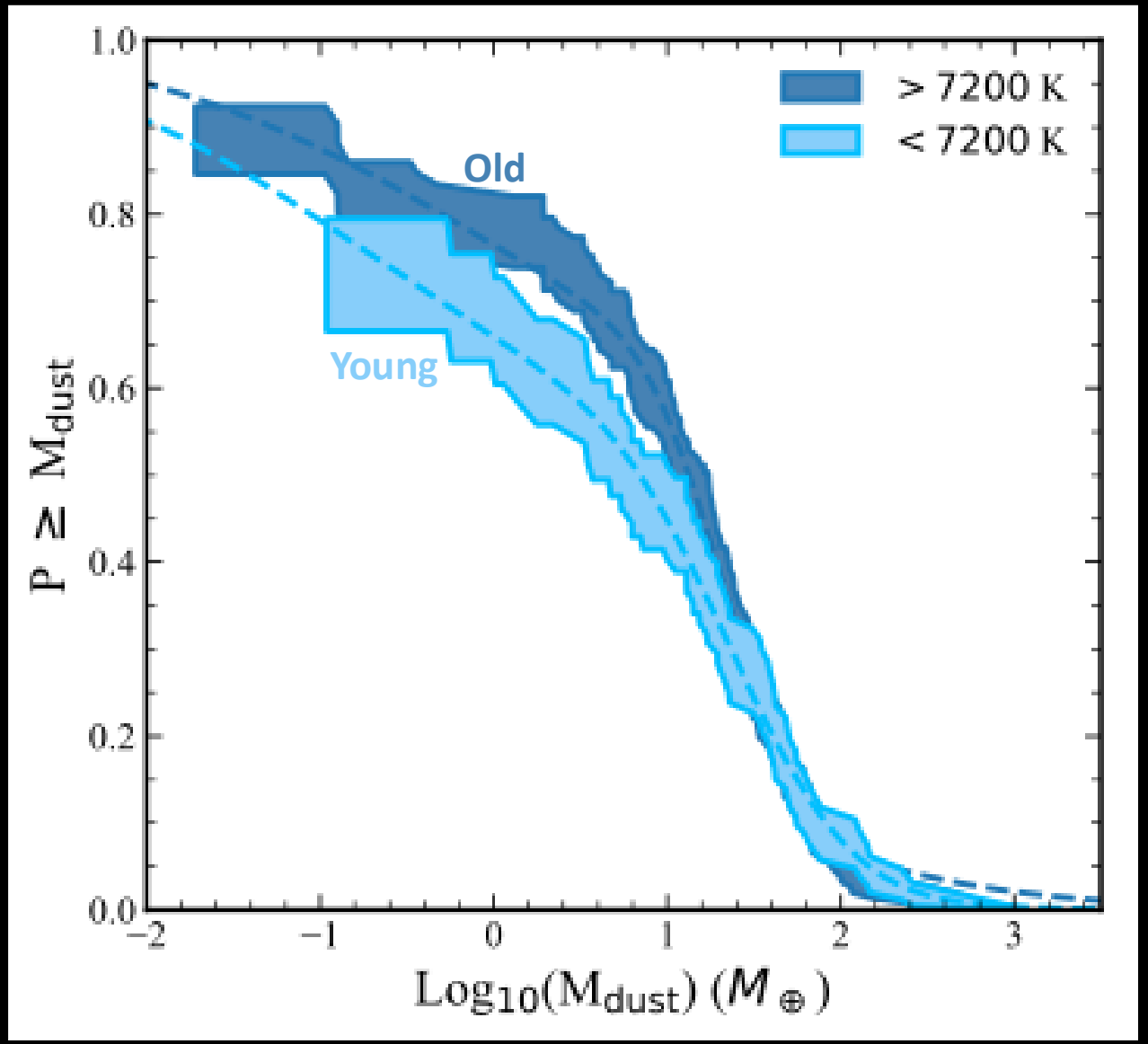


Stapper et al. in review, see also Grant+23

No change with age

- No low disk mass / low accretion rate objects
- No significant changes with age

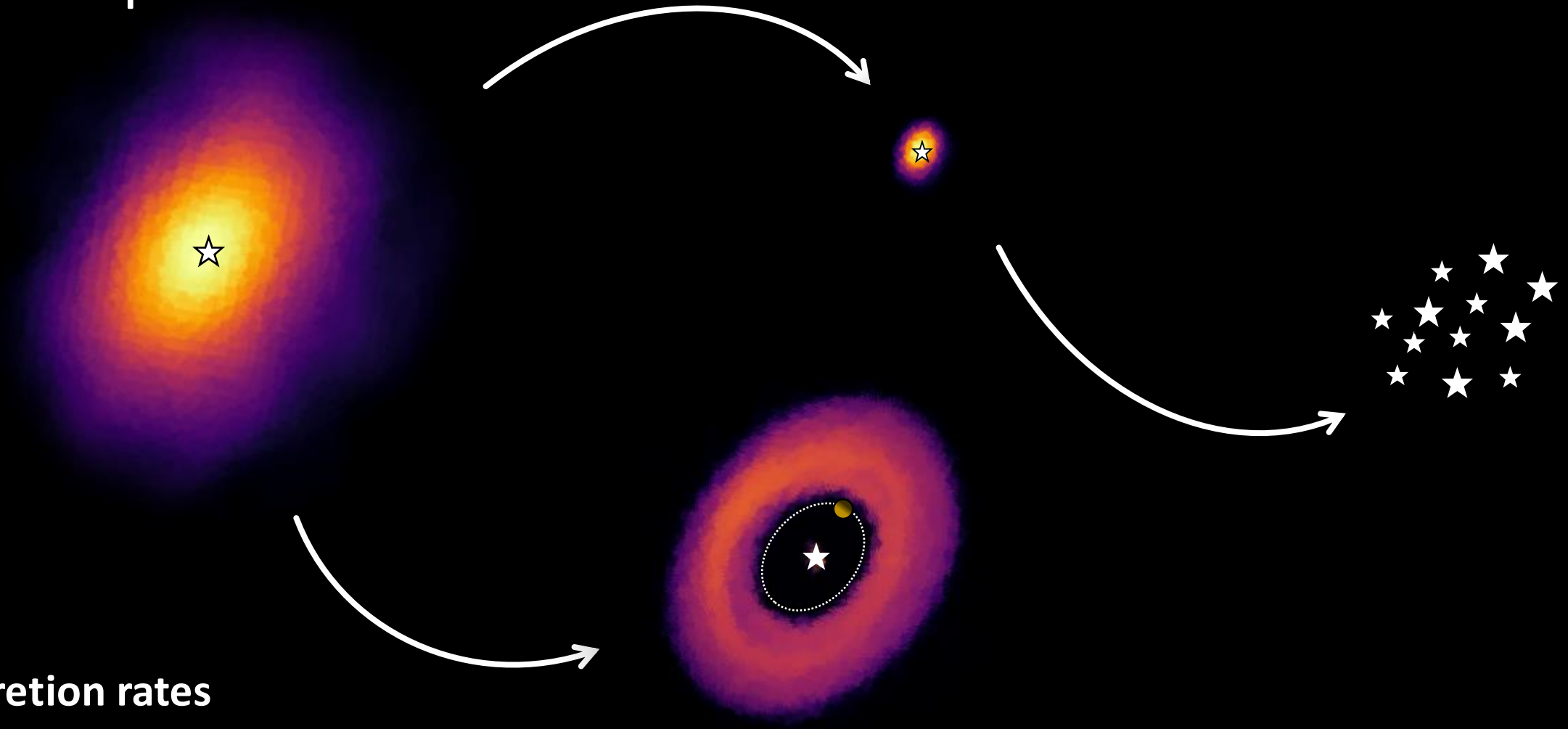
→ Surviving population of intermediate-mass pre-main sequence stars with disks



Stapper et al. in review, see also Stapper+25b

The long lived disks of Herbig stars

Case 1: planet driven

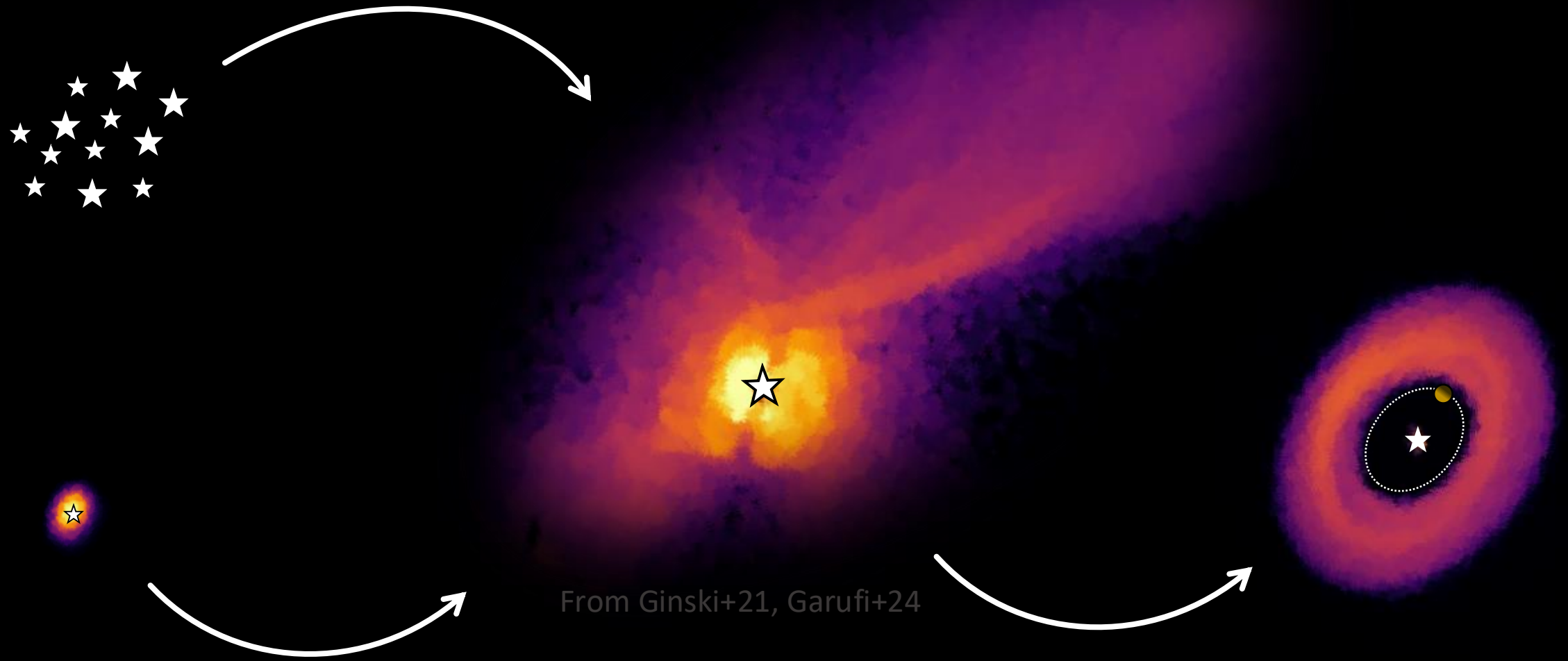


Accretion rates are still very high

Stapper et al. in review, see also Stapper+22/25b

The long lived disks of Herbig stars

Case 2: infall driven



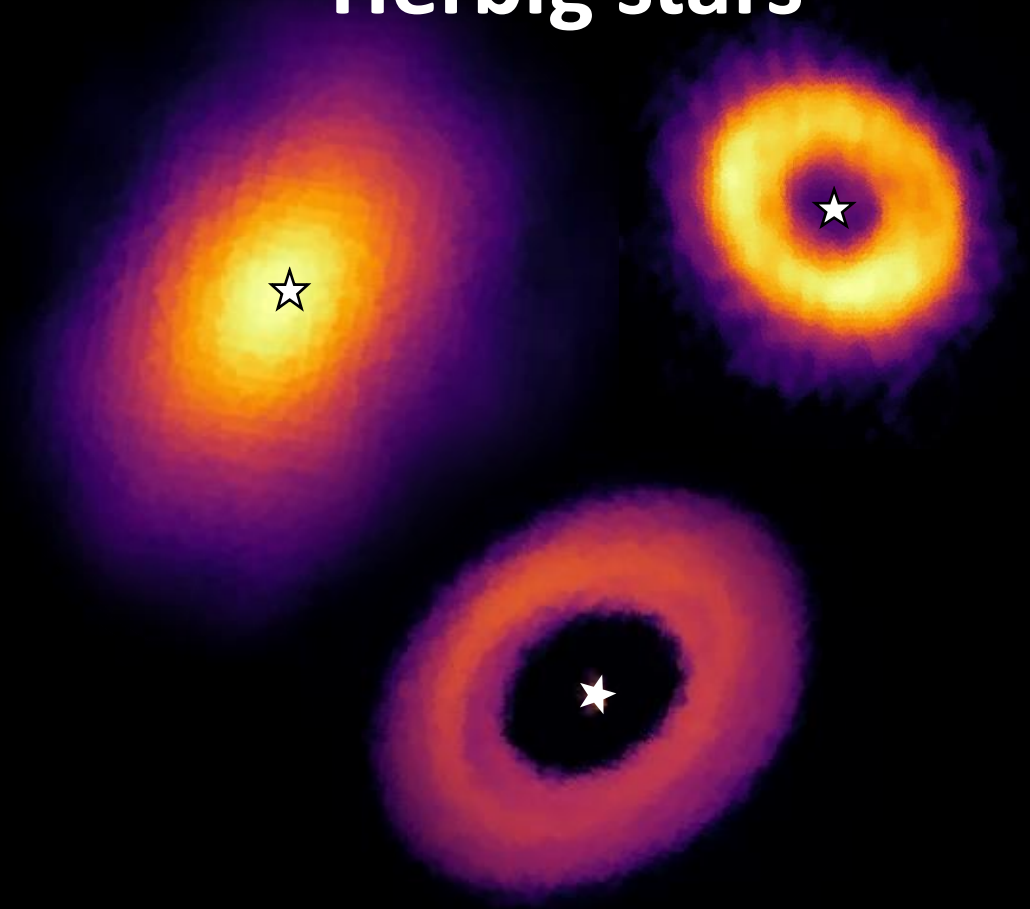
From Ginski+21, Garufi+24

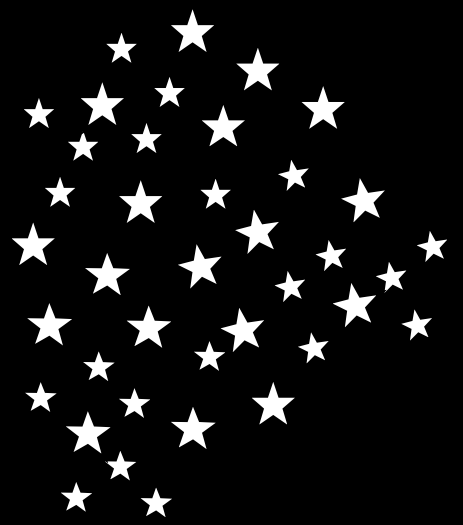
Stapper et al. in review

The long lived disks of Herbig stars

Result:

Herbig stars + **Disk-less IM PMS stars**





(see e.g. Iglesias+23, Anania+25, van Terwisga+22)

Stapper et al. in review

Conclusions

- Catalog of 243 Herbig stars within 1 kpc with stellar parameters, accretion rate properties, and disk masses
- Disks around Herbig stars are more massive than the disks around T Tauri stars and we find a bimodal dust distribution for Herbig disks
- Clear evidence of a decrease in dust mass above 2 $M_{\odot}$, and the peak occurrence rate of massive disks coincides with that of giant exoplanets
- Herbig stars are the surviving disk-hosting population part of a much larger underlying population mostly consisting of disk-less stars