Imaging YSOs with the CHARA Array

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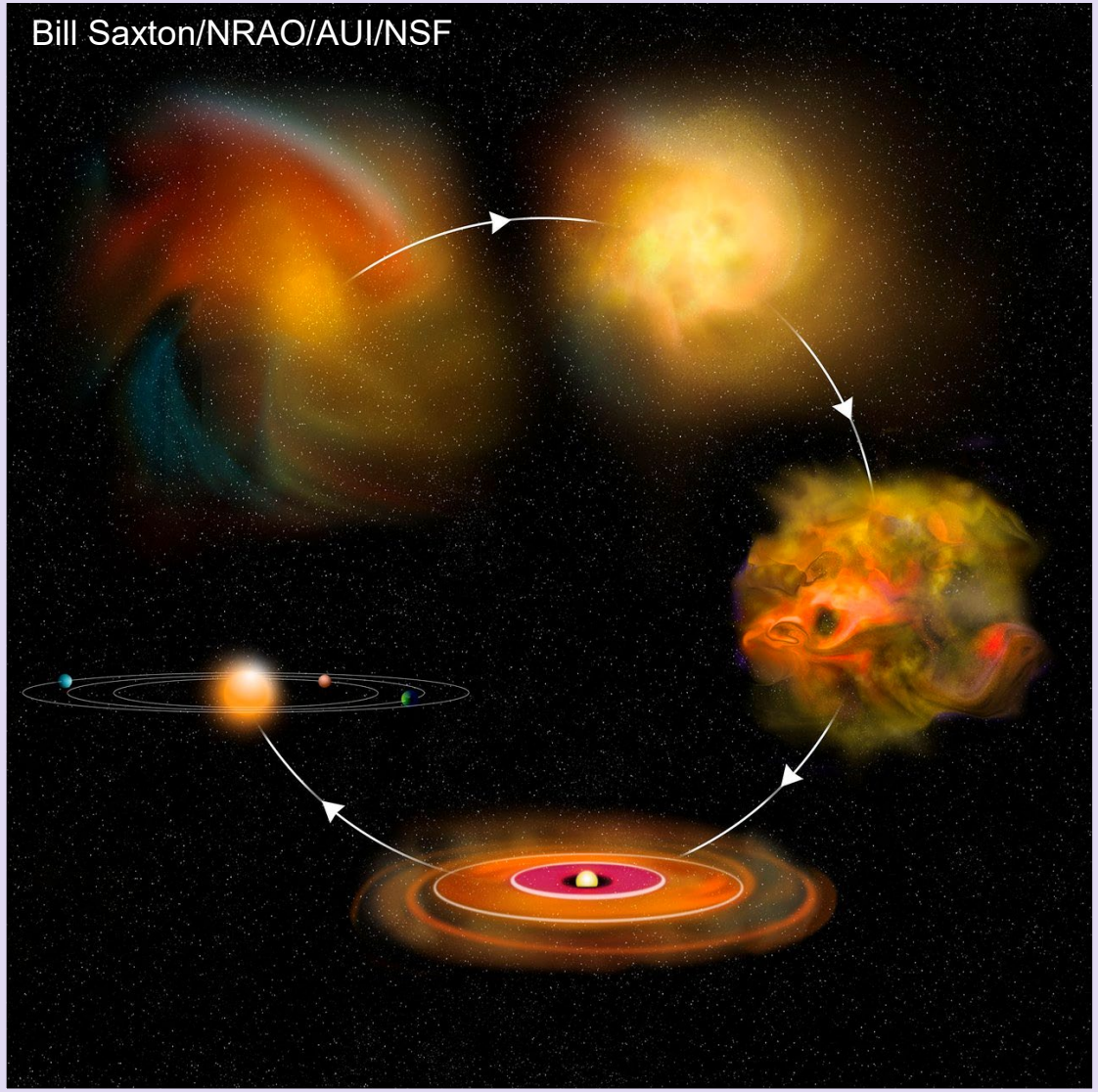
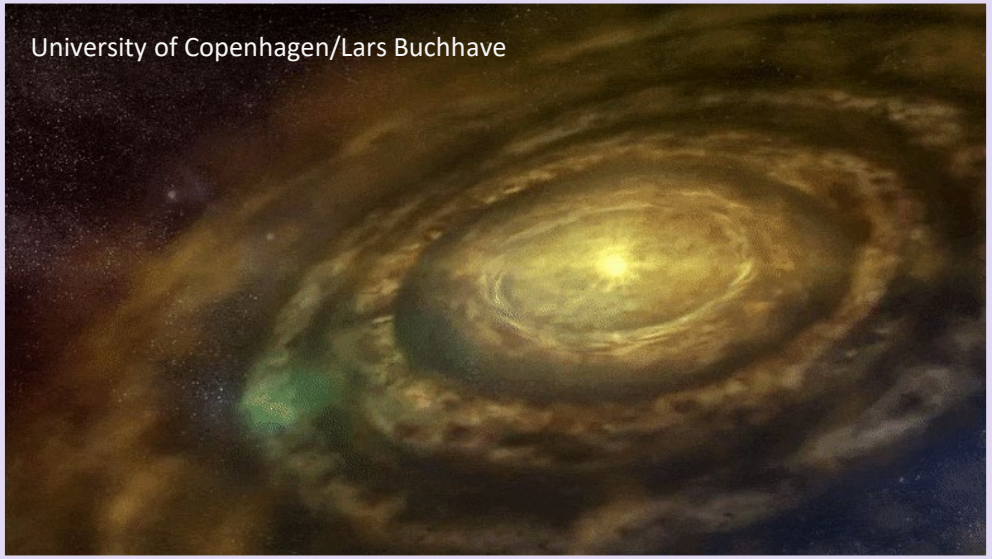
Young Stellar Objects (YSOs)



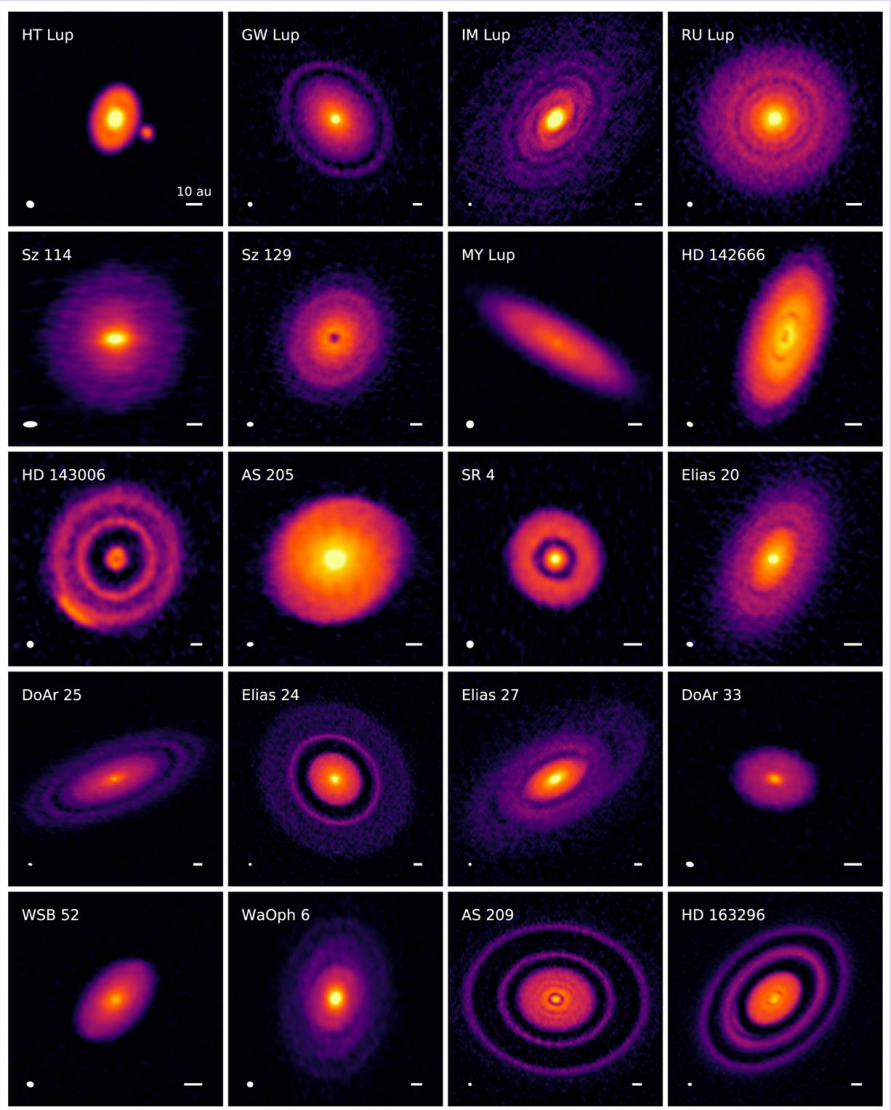


Young Stellar Objects (YSOs)

Sub-Millimeter imaging of protoplanetary midplanes show a diverse sample with distinct structures

Rings, gaps, asymmetries, vortices, and spiral arms

Could be evidence of ongoing planet formation!



(Andrews et al. 2018)

Massive star formation

Rapid Evolution of Massive Stars

- Massive stars evolve quickly, and their protoplanetary stage is short-lived.
- Disk lifetimes disperse up to **2× faster** than those around less massive stars (Ribas et al. 2015).

Role of Photoeavaporation

- High-energy photons (X-ray or UV) heat the disk.
- Increased gas temperature allows material to escape the system.
- Rapid mass loss limits planet formation, especially for gas giants.

Importance of Studying Herbig Be Stars

- Massive star formation is not well understood.
- Herbig B stars help constrain disk evolution and star-disk interactions.
- Provide insights into planet formation in **extreme high-mass environments**.

C.P. Dullemond and J.D. Monnier, 2010

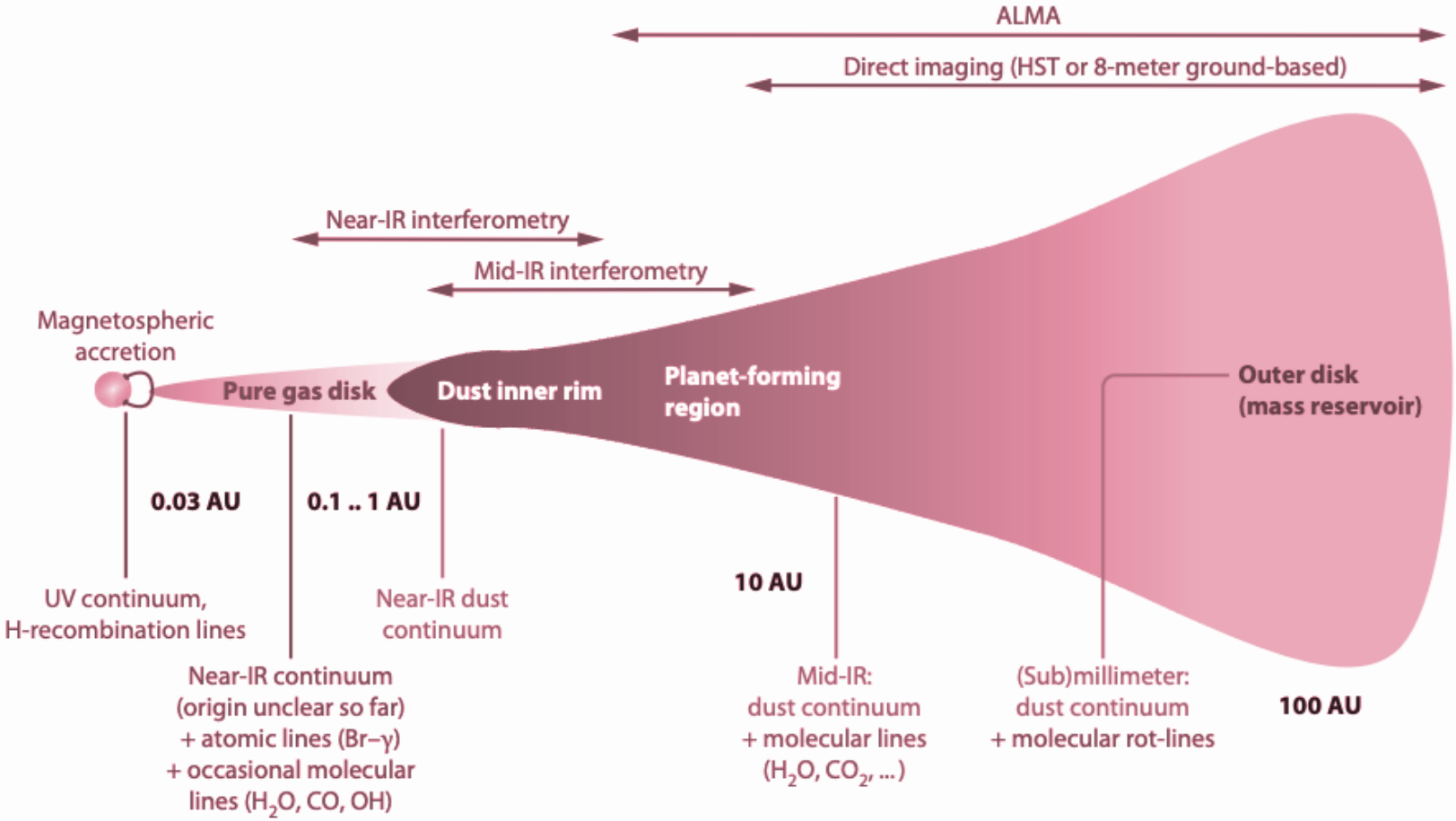


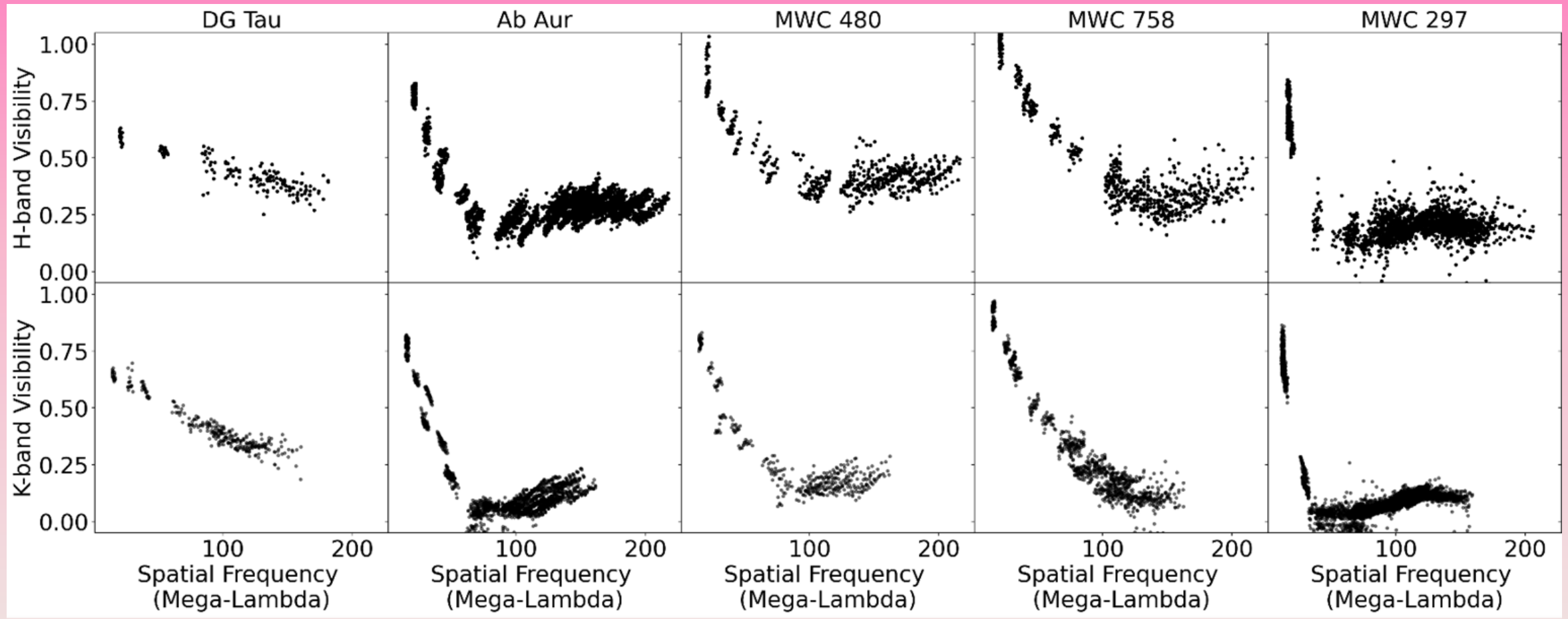
Figure 1

Pictogram of the structure and spatial scales of a protoplanetary disk. Note that the radial scale on the x-axis is not linear. Above the pictogram shows which techniques can spatially resolve which scales. Below shows which kind of emission arises from which parts of the disk.

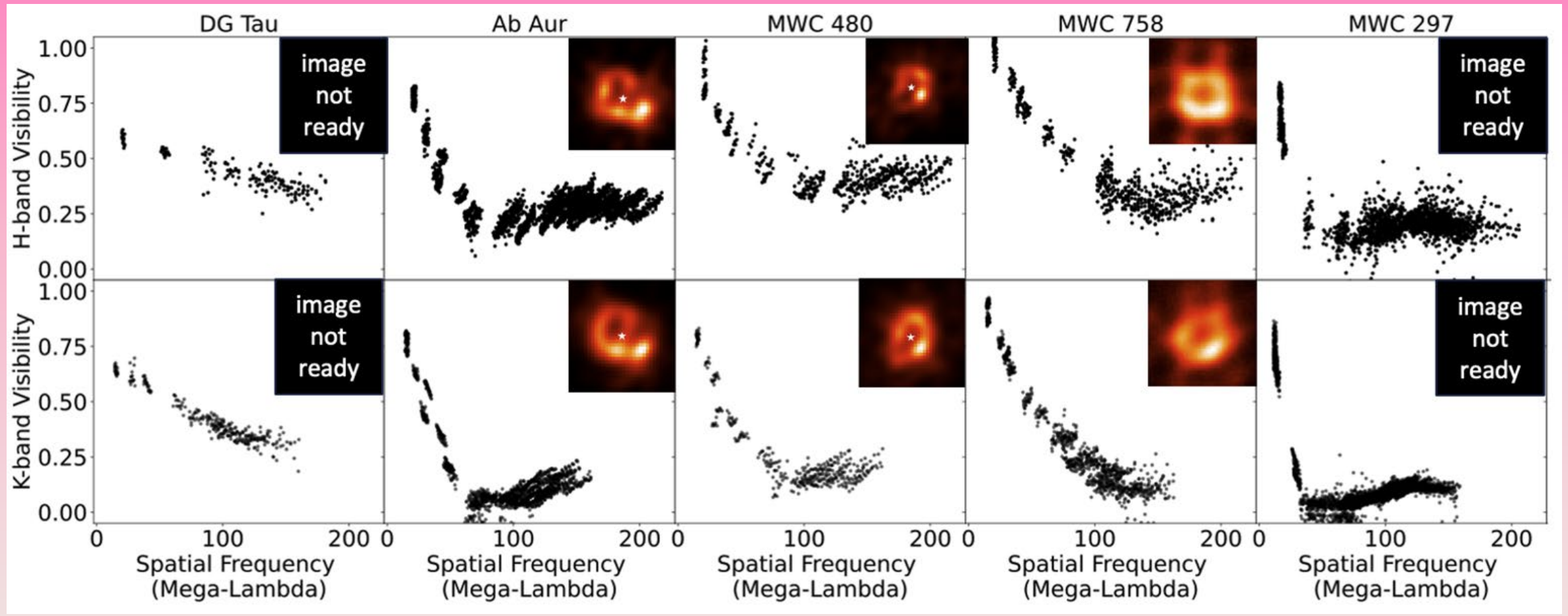
H+K band Herbig Survey

ID	V	H	K	Spectral Type
MWC 297	12.31	4.39	3.04	B1.5Ve
Z CMa	8.80	5.22	3.61	B5/8eq+F5/7
HD 50138	6.67	5.09	4.15	A1Ib/II
AB Aur	7.05	5.06	4.23	A0Ve
HD 200775	7.43	5.47	4.65	B2Ve
HD 163296	6.85	5.53	4.78	A1Vep
MWC 1080	11.85	5.98	4.83	B0eq
HD 31648	7.62	6.26	5.53	A5Vep
MWC 340	10.62	6.79	5.77	B2Ve
HD 36112	8.27	6.56	5.80	A8Ve
HD 190073	7.73	6.65	5.86	A2IVe
MWC 765	10.90	6.96	5.95	A1e
HD 179218	7.39	6.65	6.00	A0Ve
VV Ser	11.80	7.44	6.32	A5Ve
HD 169142	8.16	6.91	6.41	F1VekA3mA3_IB?
HD 250550	9.59	7.53	6.64	B9e
HD 216629	9.36	7.29	7.10	B3IVe+A3

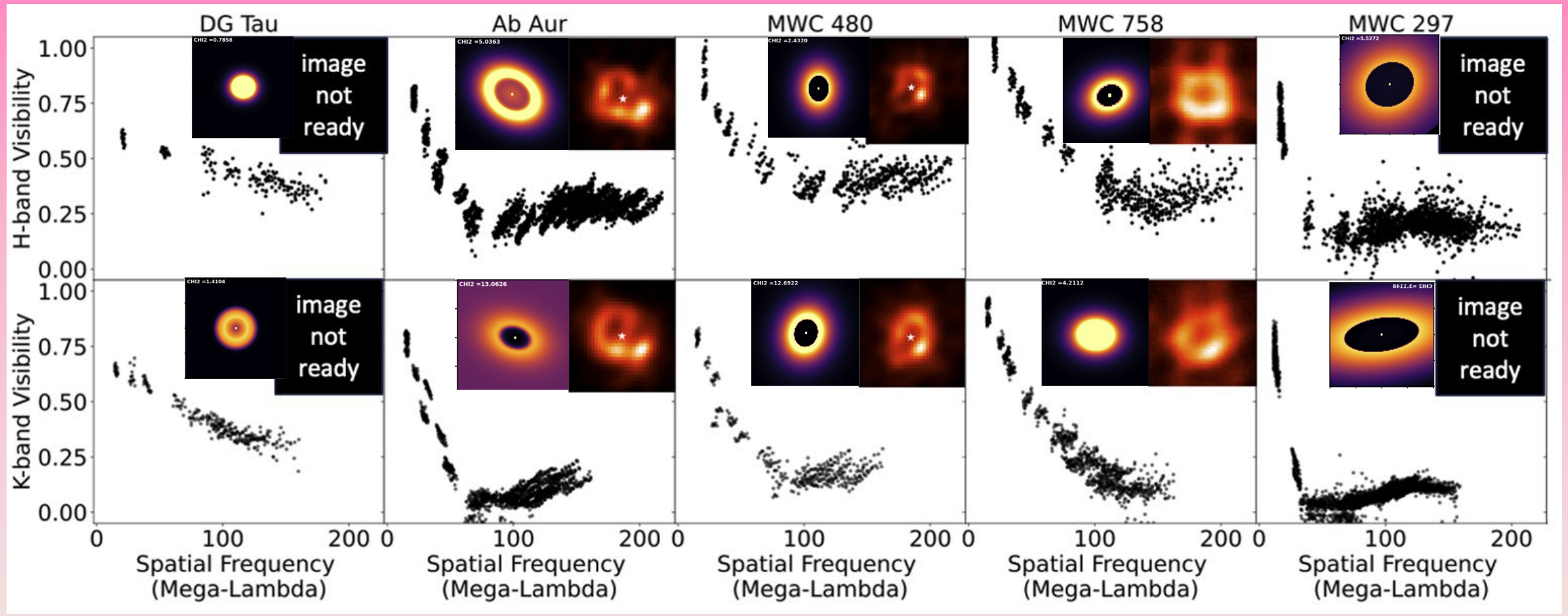
H+K band Herbig Survey



H+K band Herbig Survey



H+K band Herbig Survey



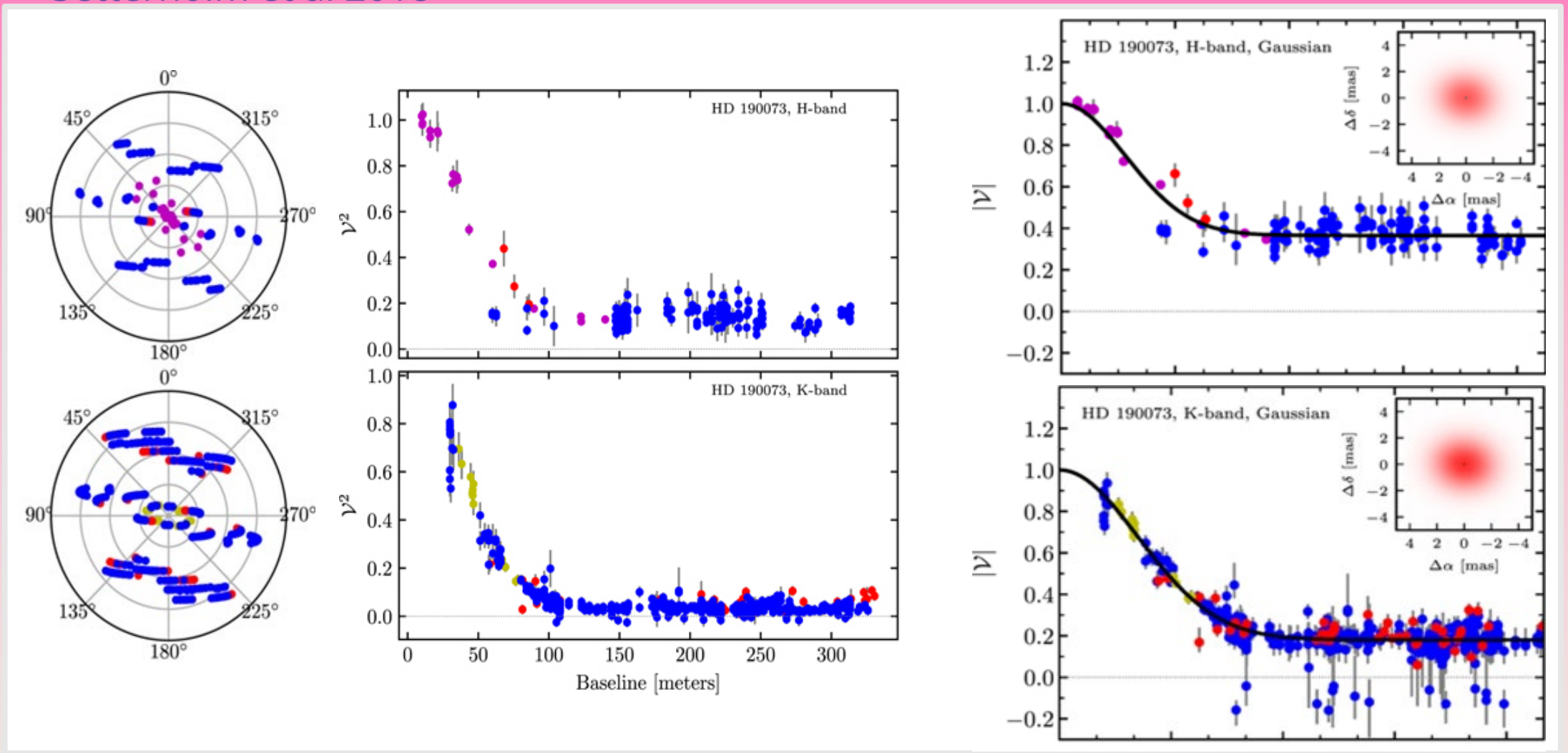
V1295 Aquila (HD 190073) – Really “cool” star :)

- Herbig Be star (spectral type B9)
- 847 pc away
- 780 $L_\odot$
- 6 $M_\odot$
- Narrow emission line feature
- Weak detected magnetic field
- Almost face on!

Simbad

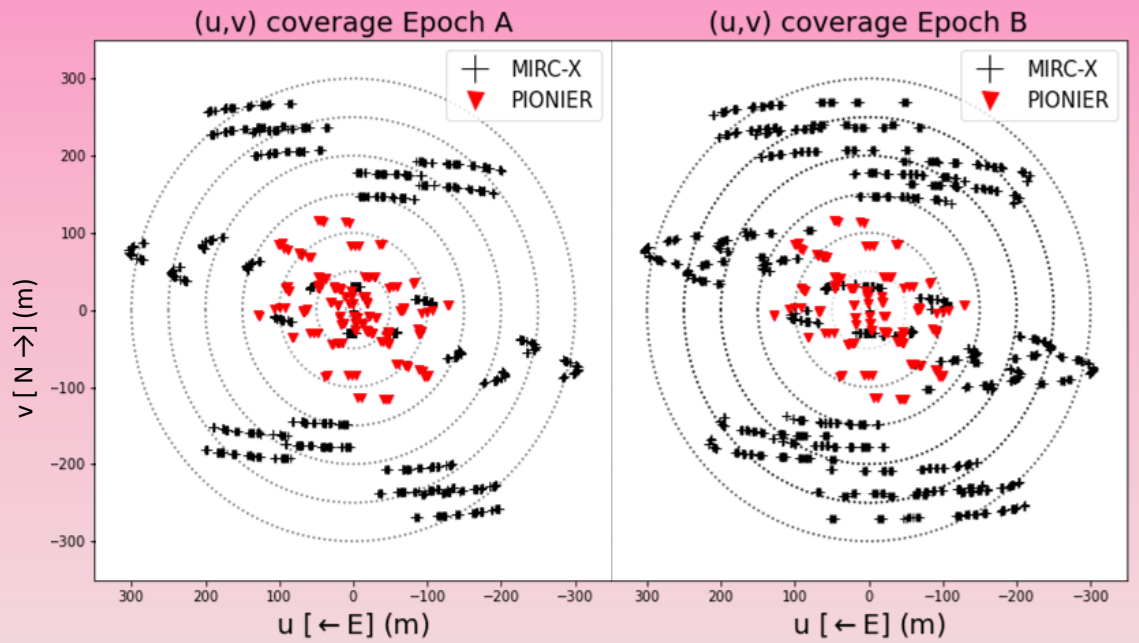
Recent Results

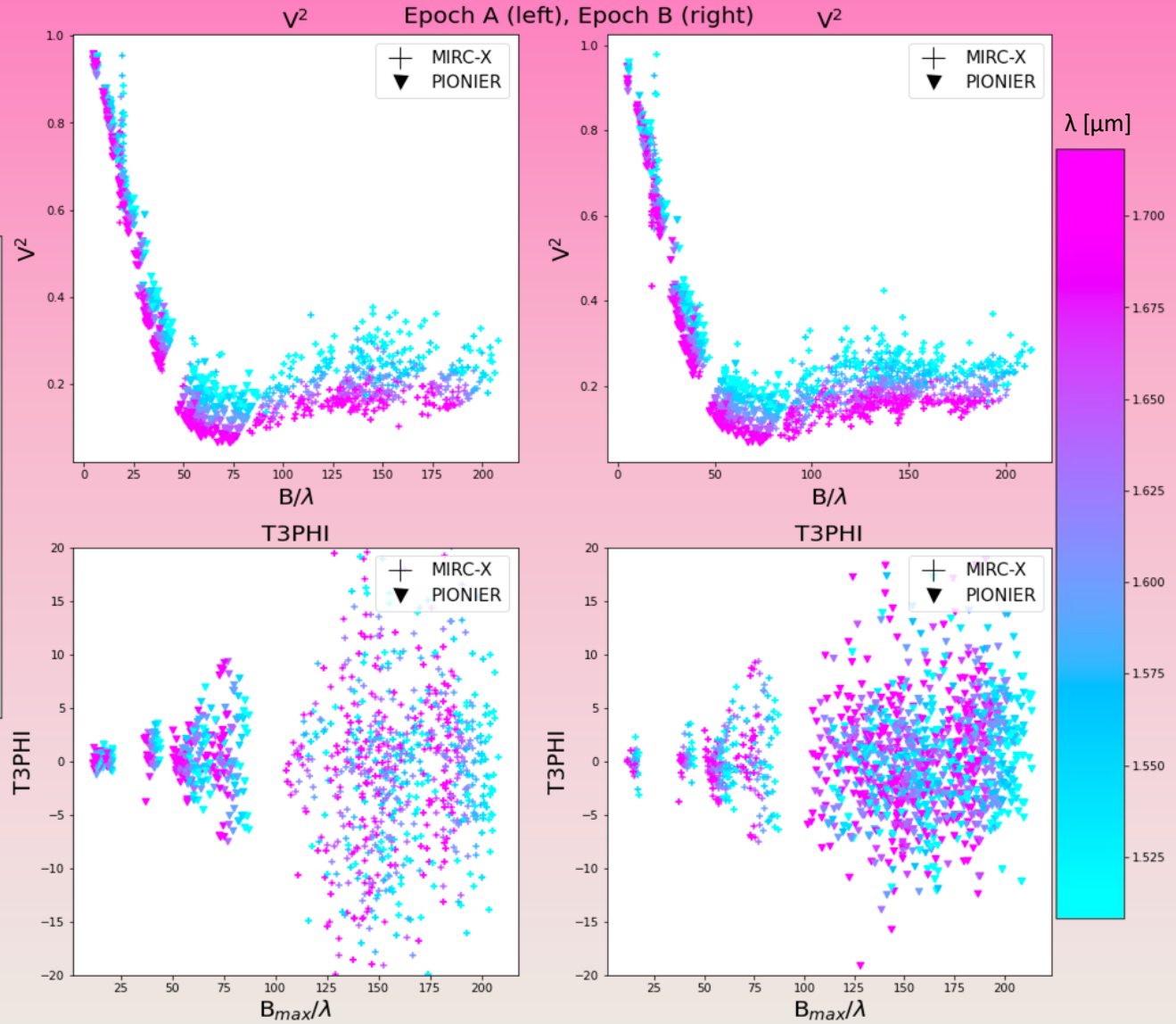
Setterholm et al 2018



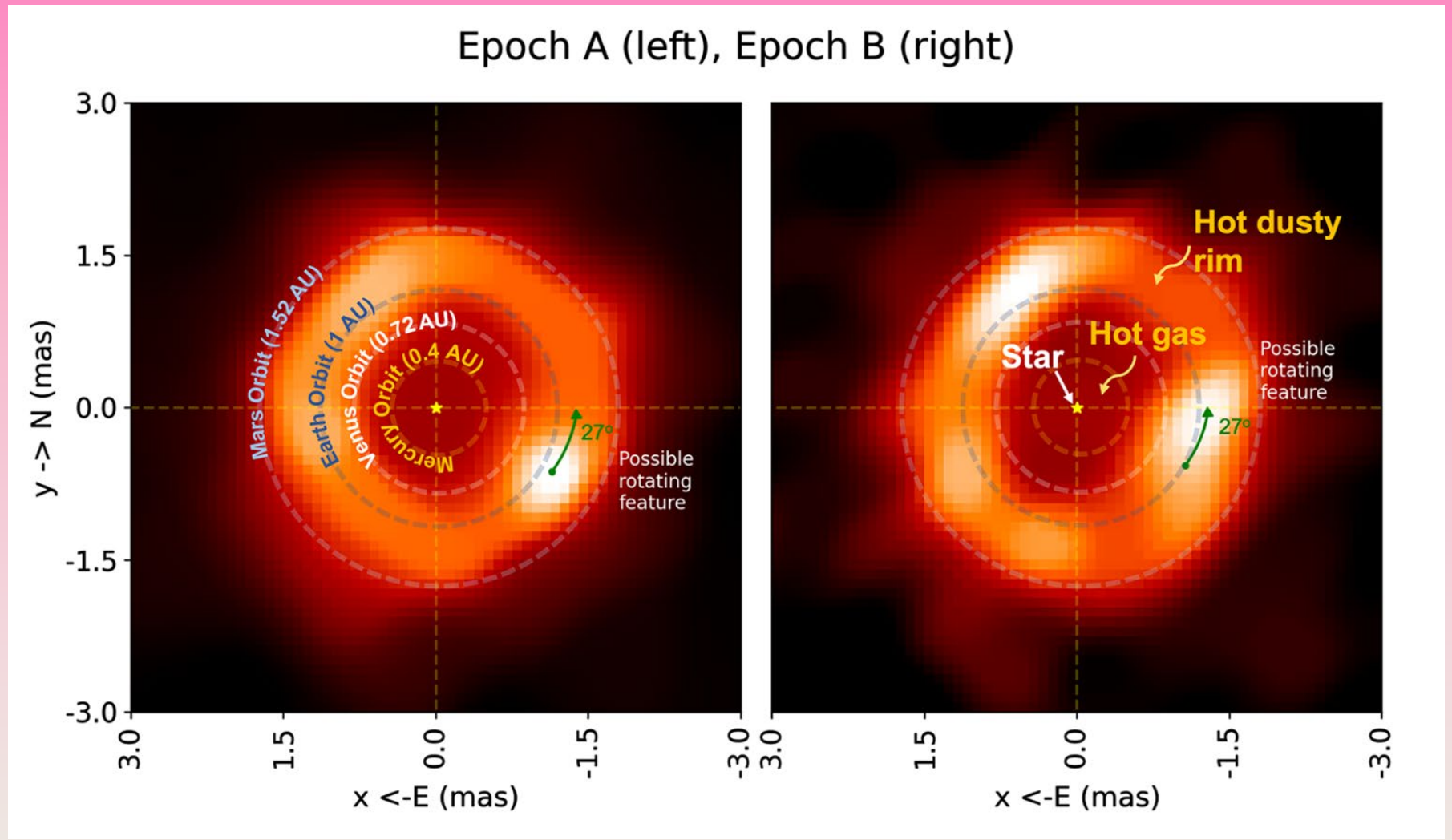
Recent Data

Ibrahim et al, 2023



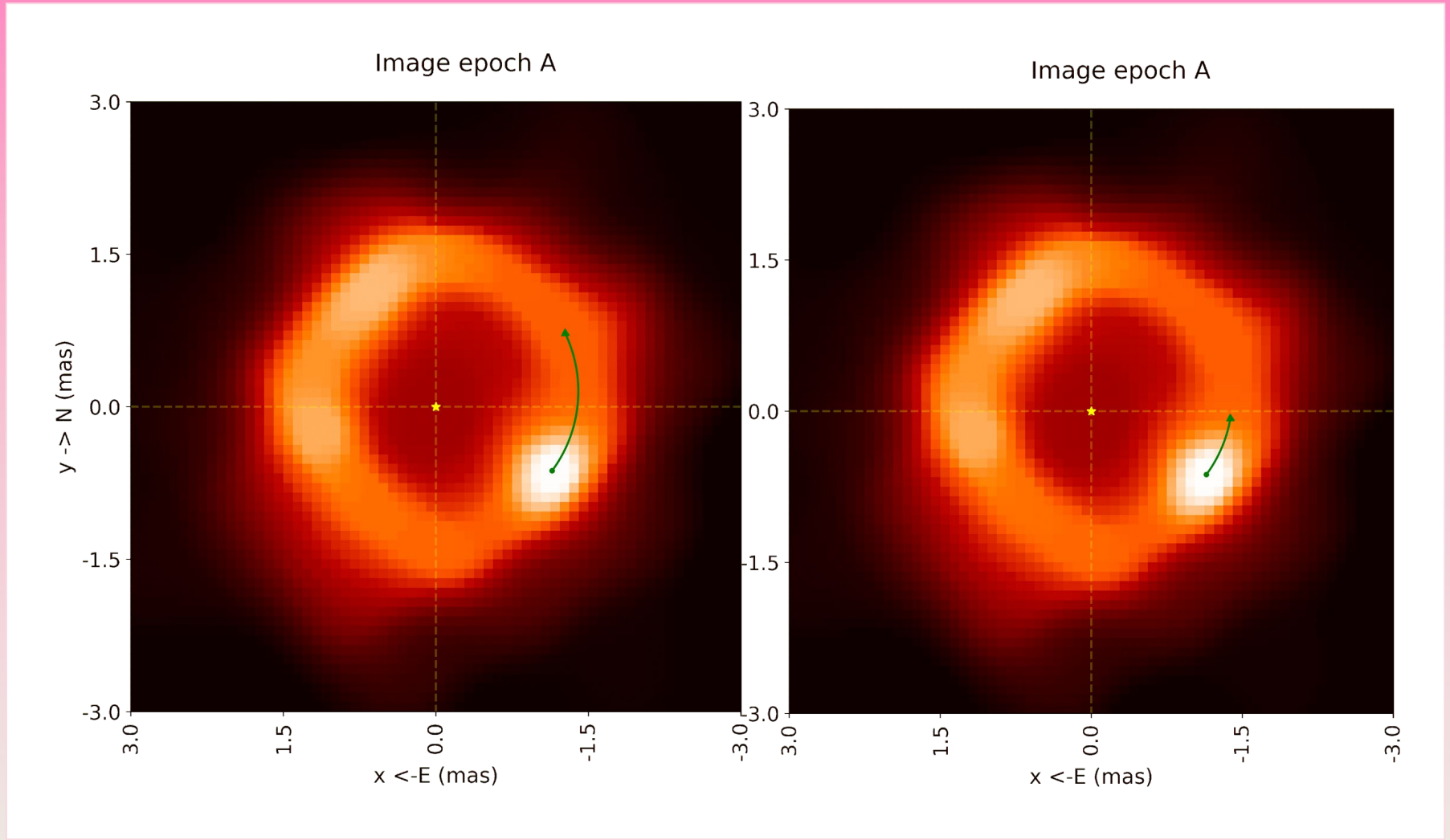


Imaging HD 190073 (V1295 Aql)



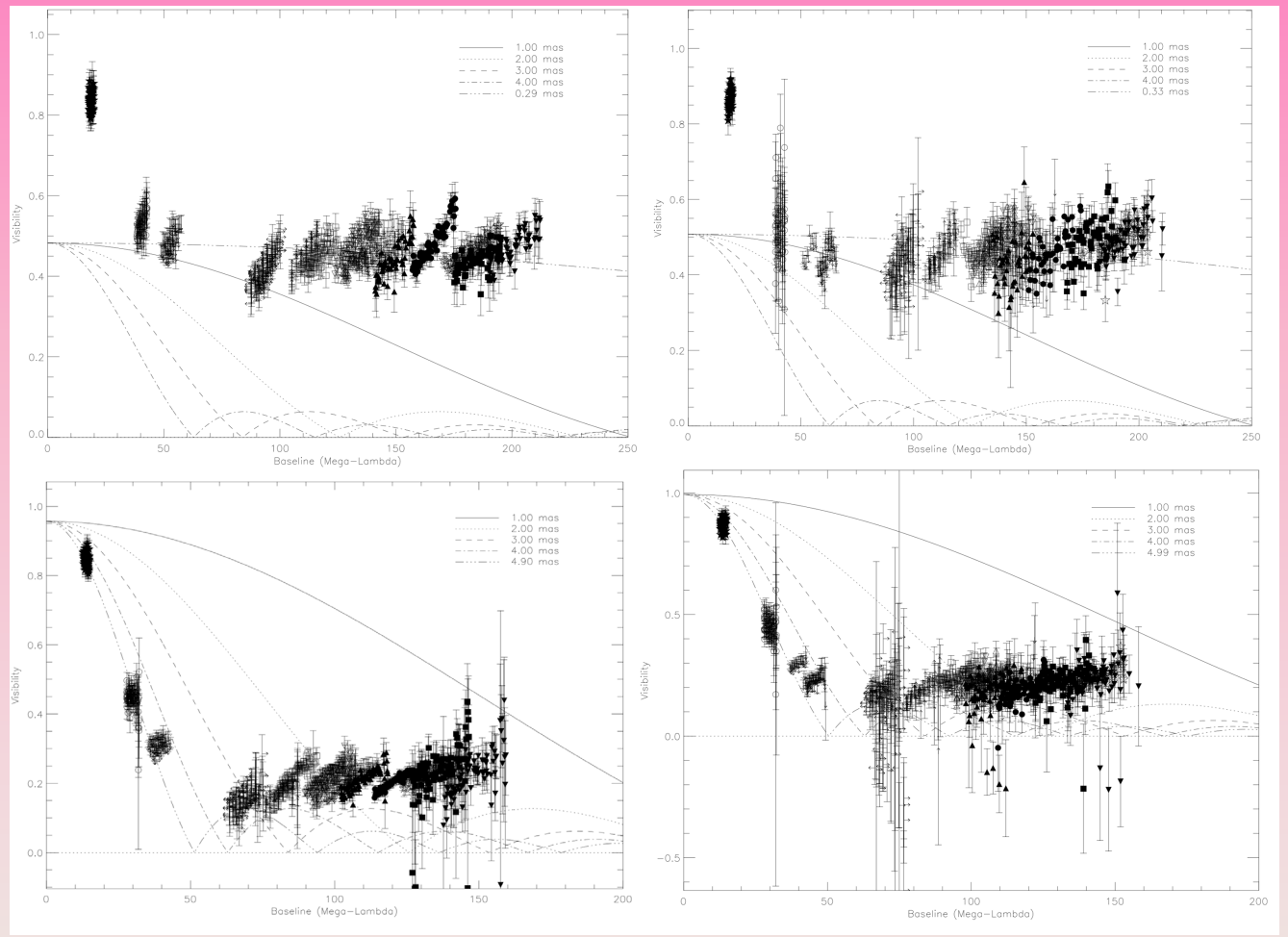
Imaging HD 190073 (V1295 Aql)

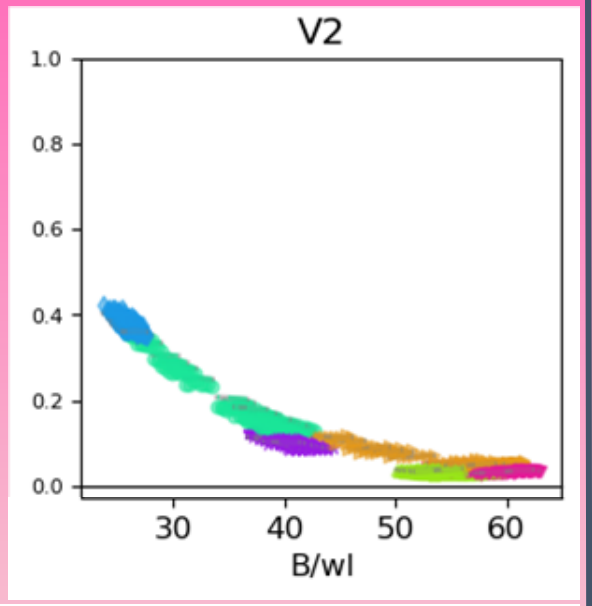
Expect a rotation of 63°

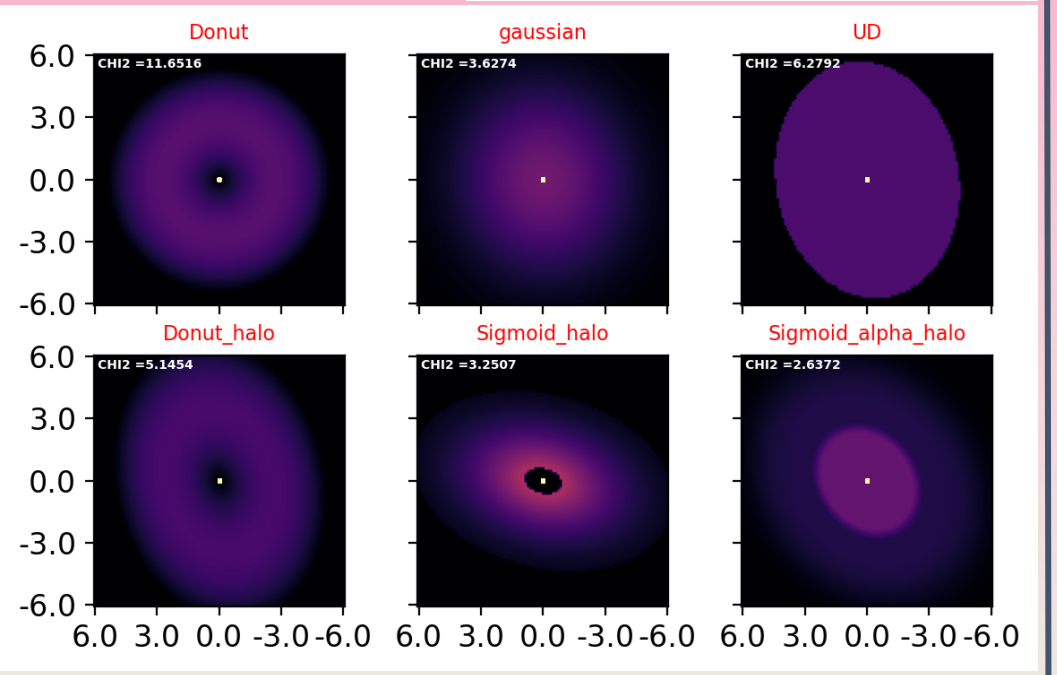


Measure a rotation of 27°

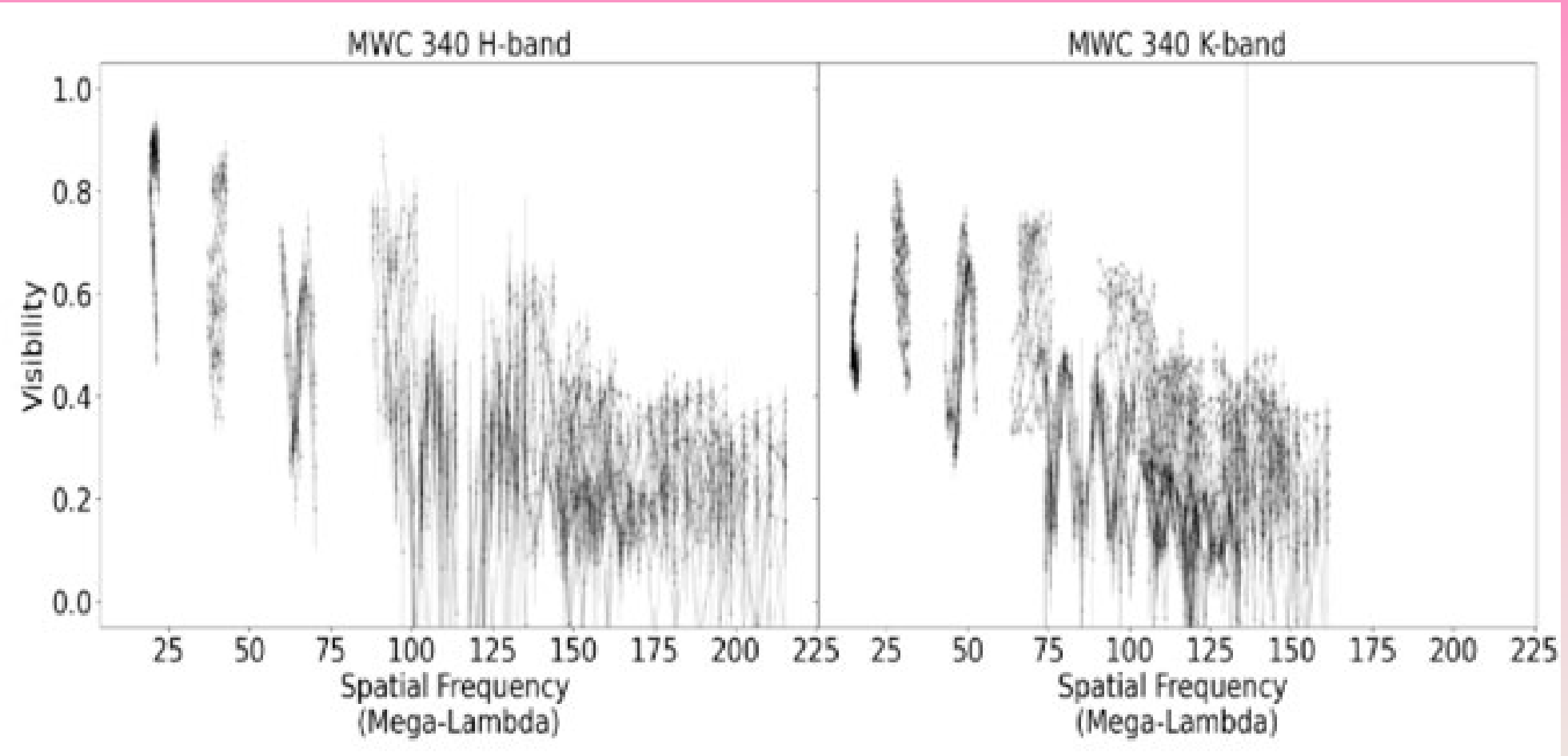
V1295 Aql in K-band



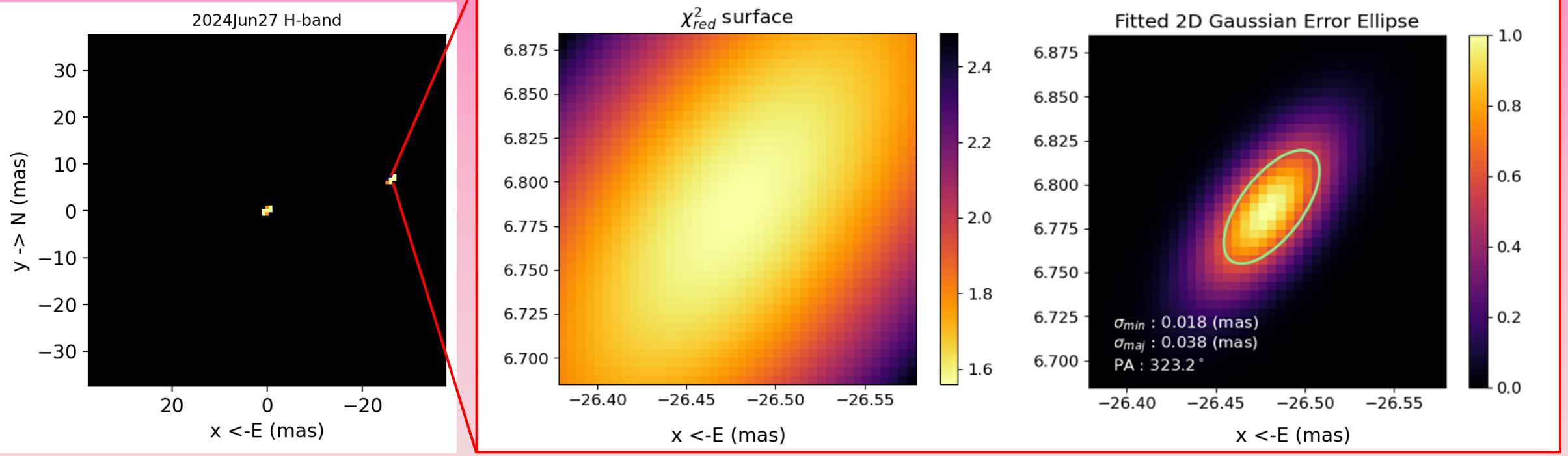


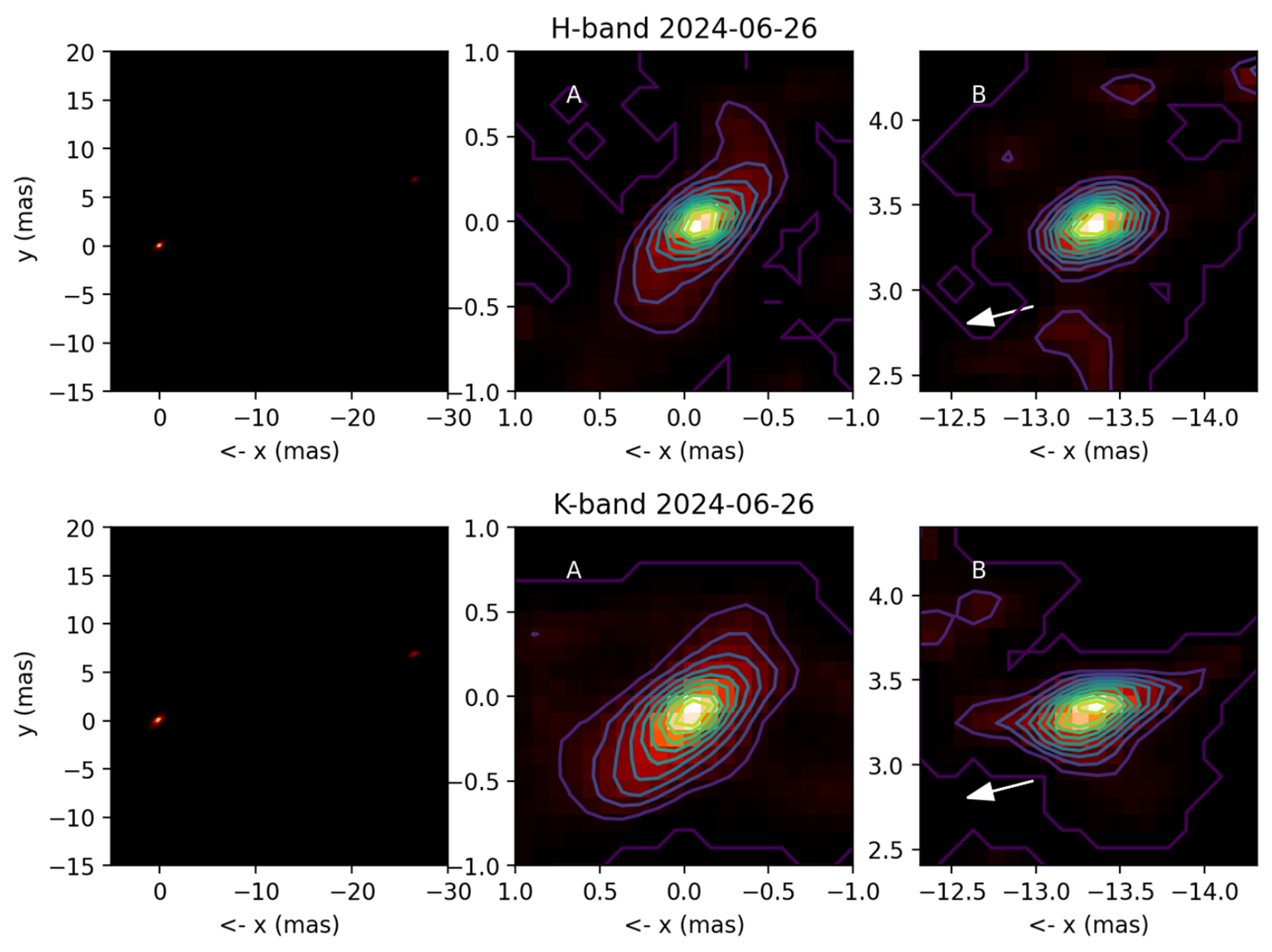


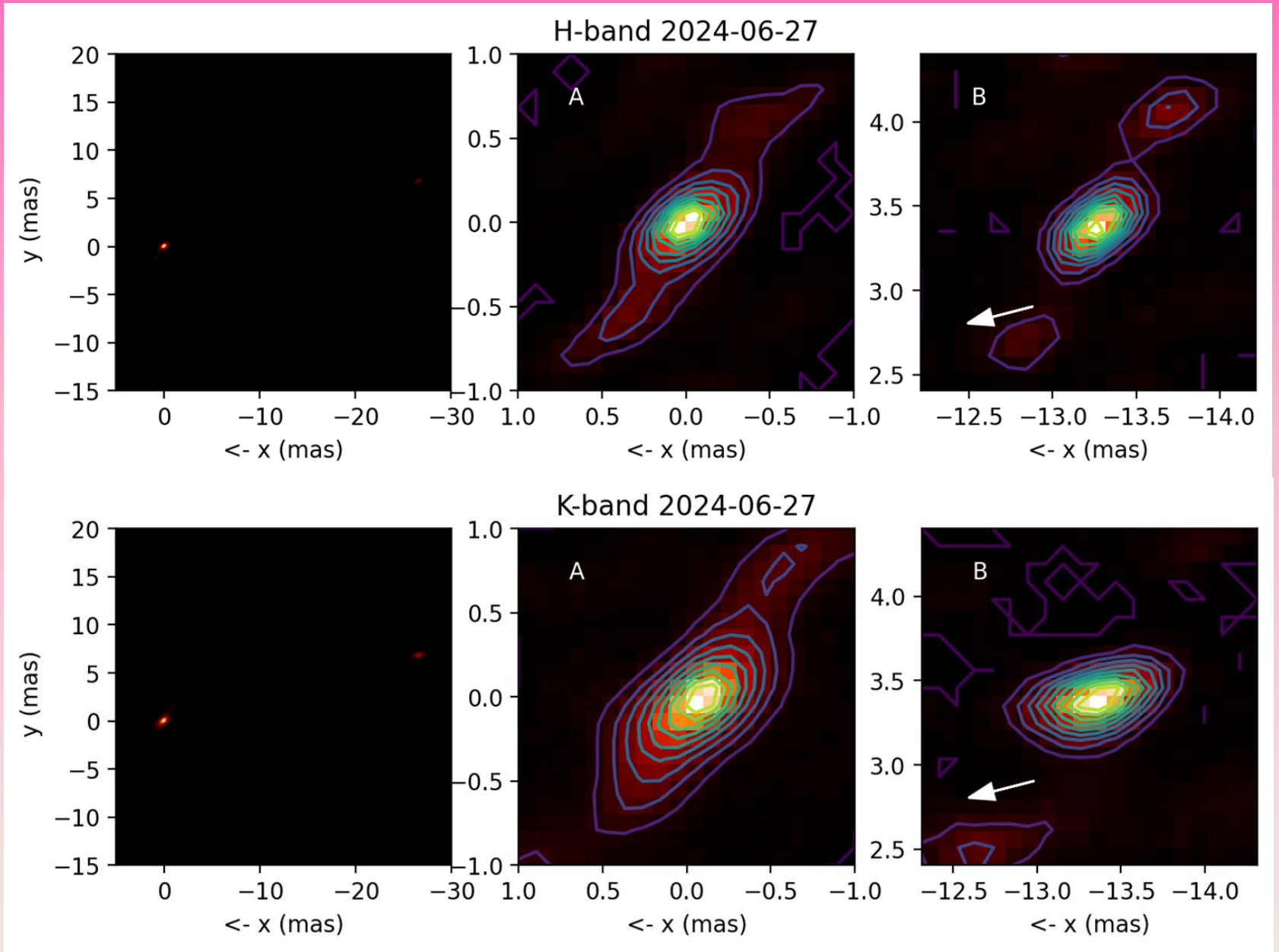
The curious case of MWC340



1. PMOIRED Model
2. Chi2 surface of secondary position
3. Likelihood surface with 2D fit error ellipse

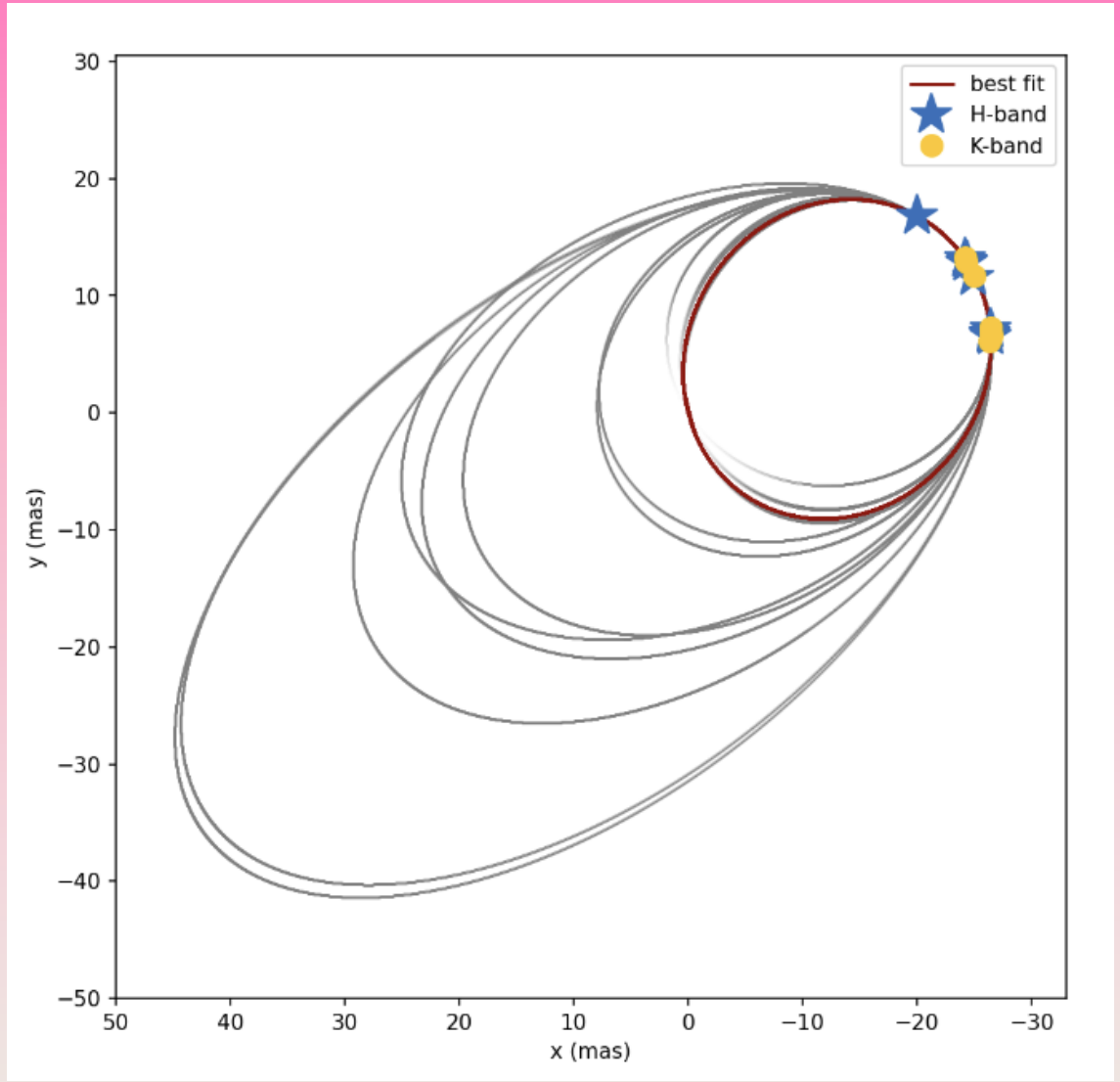



H-band 2024-06-26
K-band 2024-06-26
A
B
y (mas)
<- x (mas)

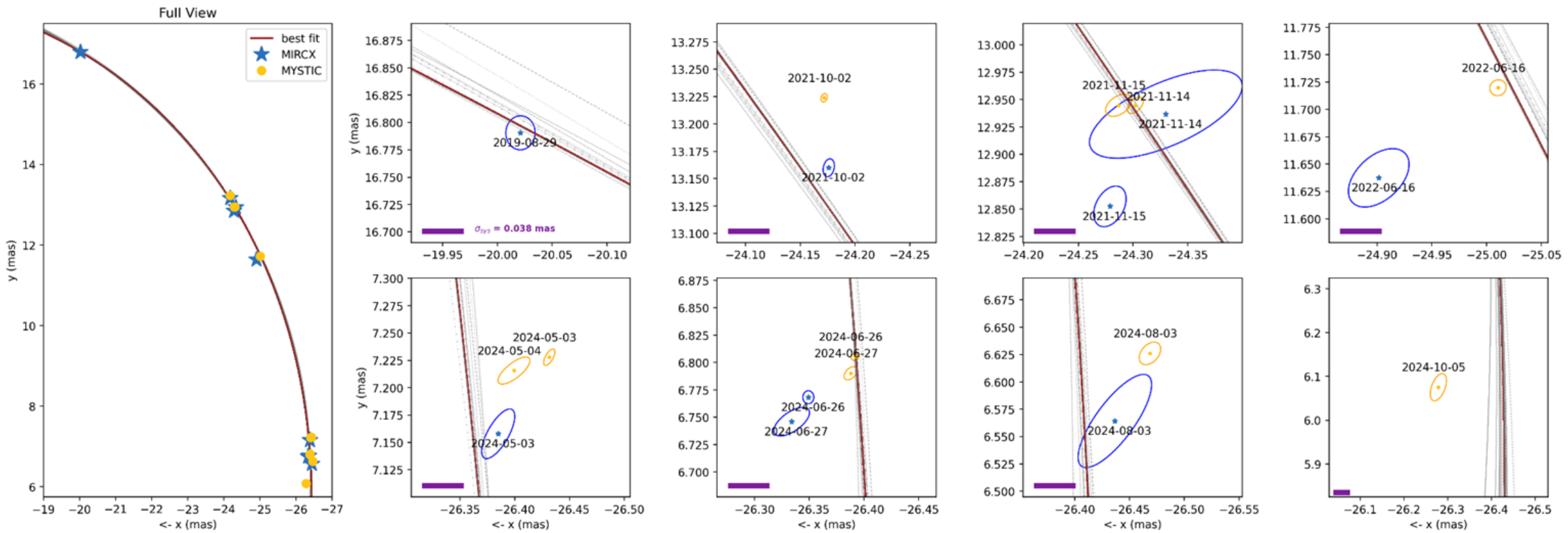

H-band 2024-06-27
A
B
y (mas)
<- x (mas)
<- x (mas)
<- x (mas)
K-band 2024-06-27
A
B
y (mas)
<- x (mas)
<- x (mas)
<- x (mas)

Orbit fit

Orbital Parameter	Min. value	Max. value	Best fit
Semi-major axis (mas)	17.58	300.48	219.65
Eccentricity	0.03	1	1
Inclination (deg)	92.61	180.08	93.59
ω (deg)	30.76	197.81	89.70
Ω (deg)	118.89	293.54	194.66
Period (Yr)	16.21	82.64	16.72
Time of Periastron (MJD)	-2259.2	44971.4	44871.30
System Mass ($M_\odot$)	7.7	72862.476	28571.19



Orbit fit


Full View
best fit
MIRCX
MYSTIC
y (mas)
<- x (mas)
2019-08-29
σ_{sys} = 0.038 mas
2021-10-02
2021-11-15
2021-11-14
2022-06-16
2024-05-03
2024-05-04
2024-06-26
2024-06-27
2024-08-03
2024-10-05

Orbit fit

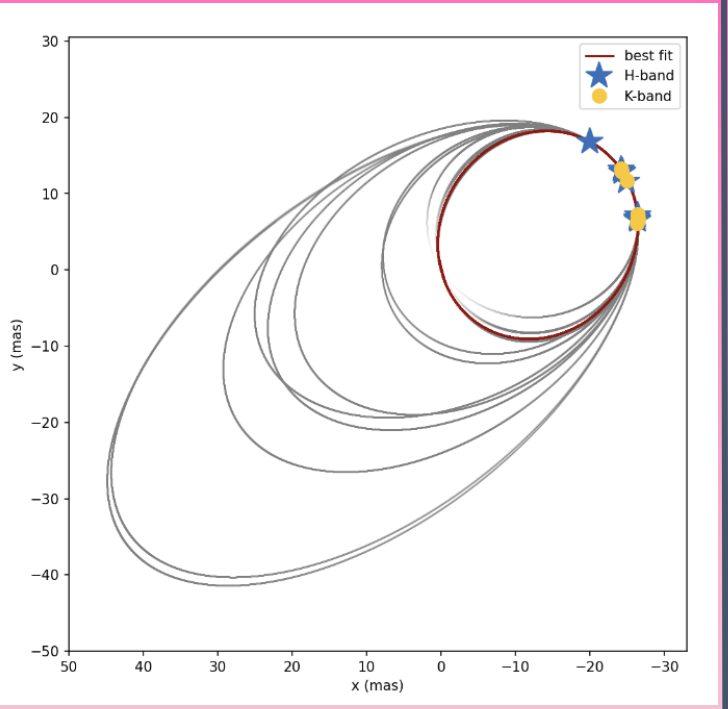
High eccentricity is being driven by 2024-10-05

Could be due to :

A wobble of a third companion
Photo-center shifts from disk emission

Those solutions are disproven by the unphysical system masses they produce

Prefer the shorter periods and masses <20 Msun
Need more epochs over the next few years to really constrain this orbit
CHARA and Gaia will help



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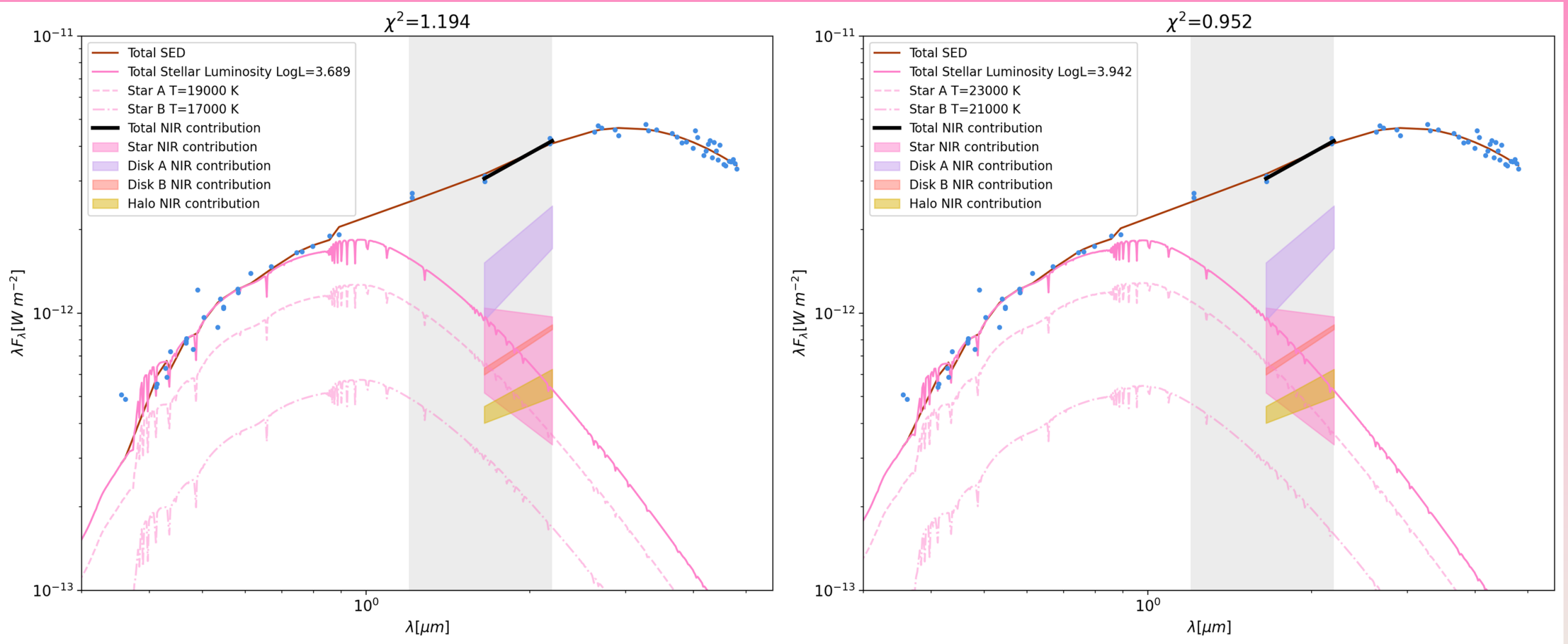
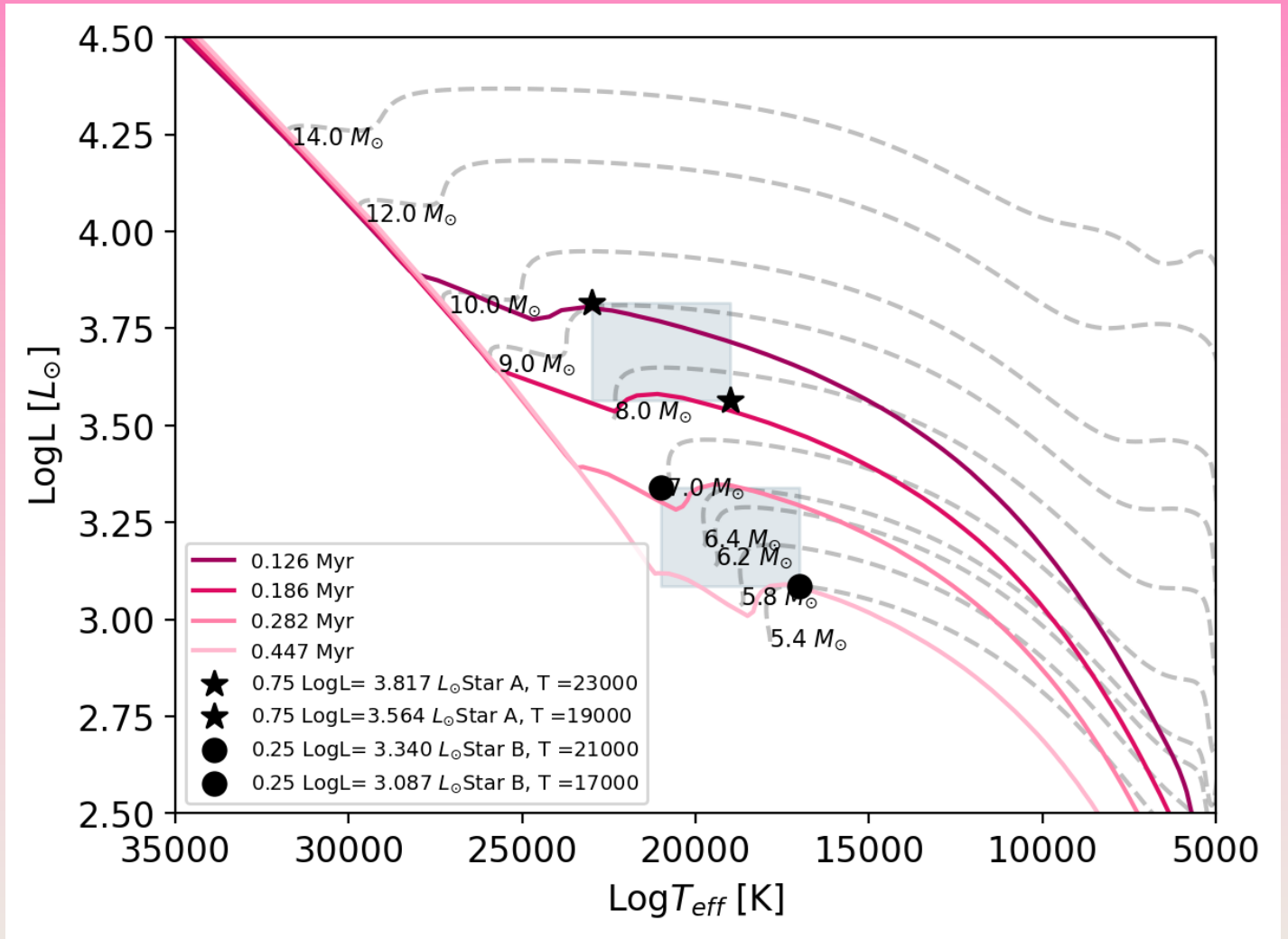
SED fit


χ^2=1.194
Total SED
Total Stellar Luminosity LogL=3.689
Star A T=19000 K
Star B T=17000 K
Total NIR contribution
Star NIR contribution
Disk A NIR contribution
Disk B NIR contribution
Halo NIR contribution
10^{-11}
10^{-12}
10^{-13}
$\lambda F_\lambda [W\,m^{-2}]$
10^0
$\lambda[\mu m]$
χ^2=0.952
Total SED
Total Stellar Luminosity LogL=3.942
Star A T=23000 K
Star B T=21000 K
Total NIR contribution
Star NIR contribution
Disk A NIR contribution
Disk B NIR contribution
Halo NIR contribution
10^{-11}
10^{-12}
10^{-13}
$\lambda F_\lambda [W\,m^{-2}]$
10^0
$\lambda[\mu m]$

Isochrone fit



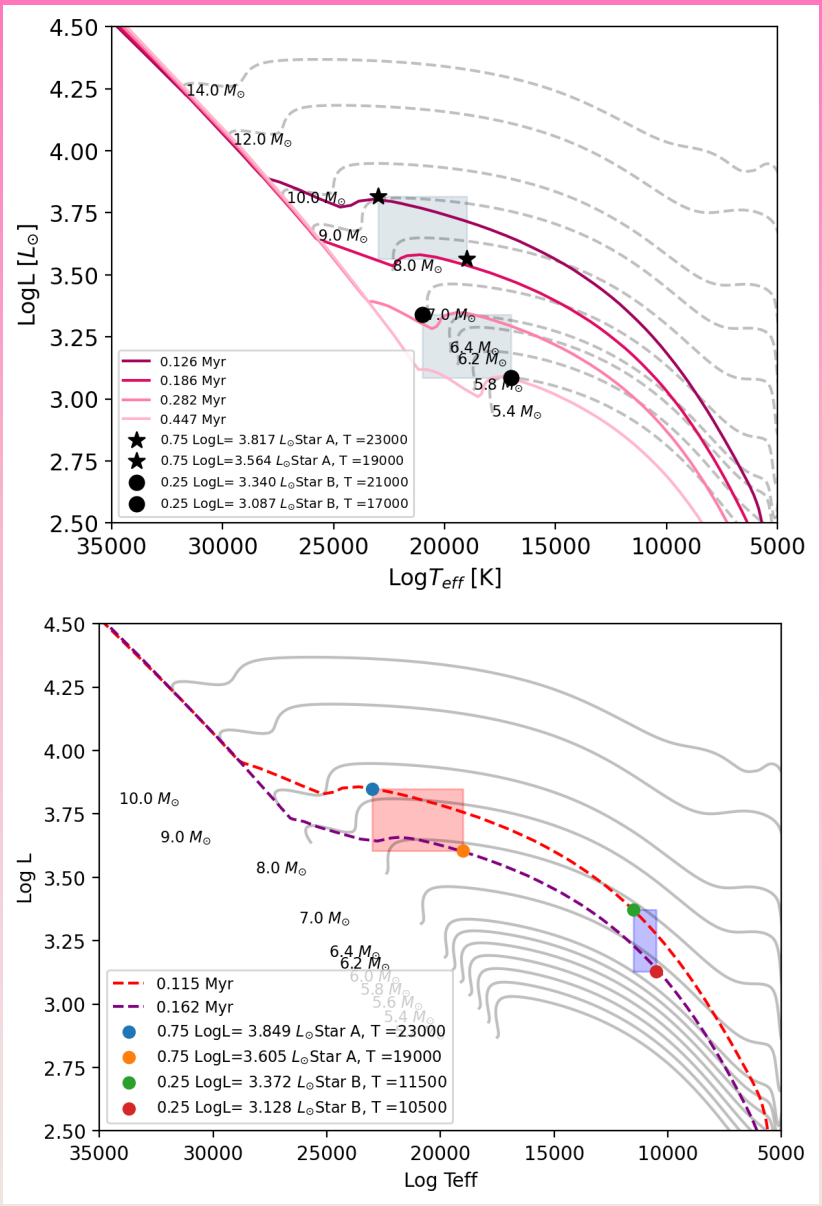
SED + Isochrone fit reflection

Why the discrepancy in ages?

1. A could be differentially reddened making B appear more dominant in the observed flux. Imaging shows A is elongated and almost edge-on, but we cannot resolve B enough
2. Inaccuracies in the luminosity ratio,
3. B still evolving toward the main sequence while A has already reached it. Bigger radius
4. The presence of a third component further complicates the interpretation

Making the stars A and B coeval does not work:

1. The stellar light dominates in the IR
2. The visible light is flipped where B is brighter than A
3. Fixing the luminosity and making B cooler causes it to be brighter in visible light even though it's redder due to a conservation of luminosity



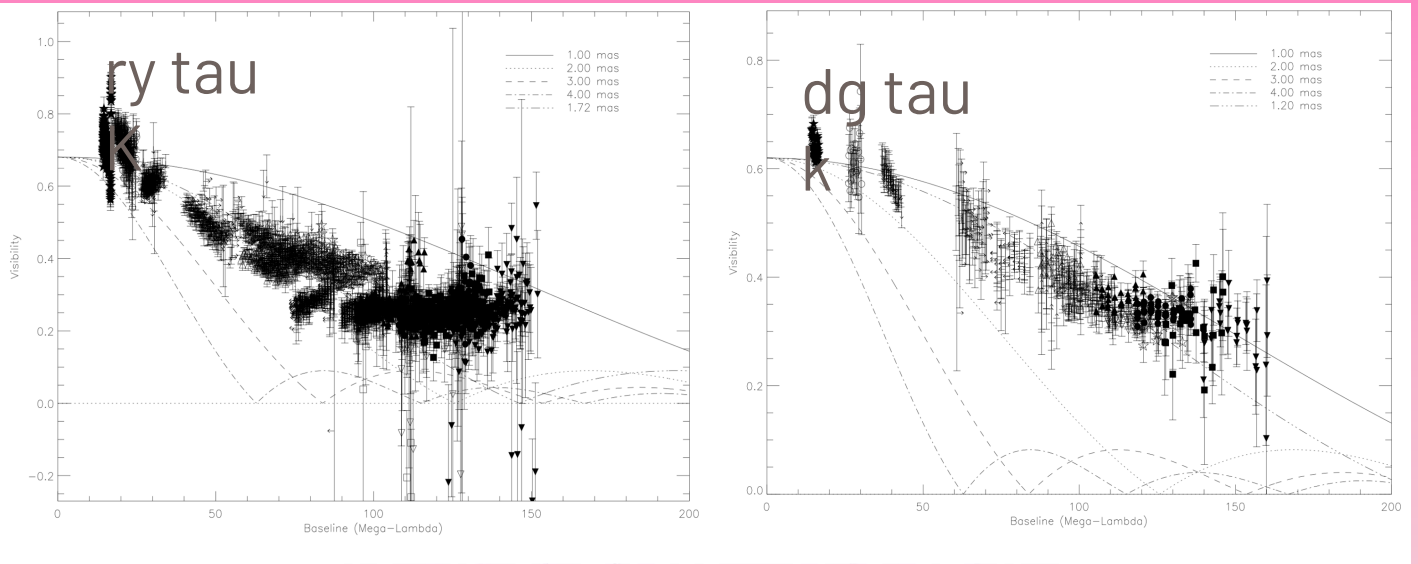
SED + Isochrone fit reflection

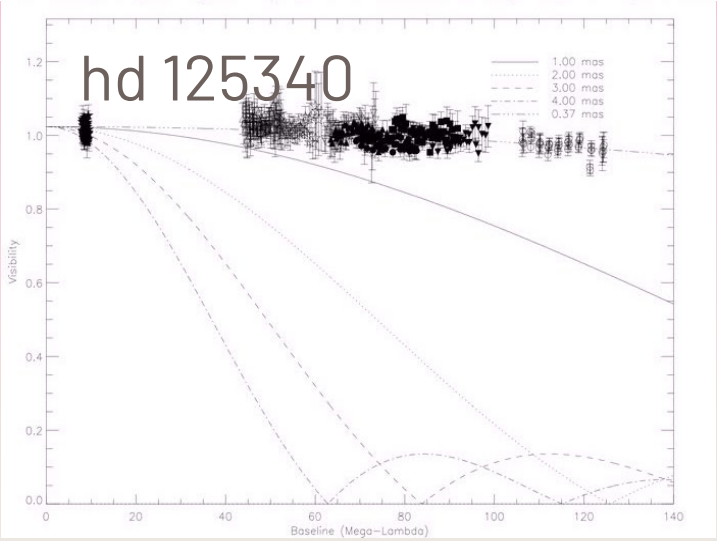
We're able to constrain masses and ages from the fits but there is more work to be done

- Aperture masking visible speckle data to get luminosity ratio
- Luminosity ratio in other wavelengths such as J-band
- Monitoring the orbit with long baseline interferometry and Gaia

Parameter	Lower limit	Upper limit
T_{*A} [K]	19000	23000
$LogL_{*A}[L_\odot]$	3.56	3.82
M_{*A} $[M_\odot]$	7.5	9
t_{*A} [Myr]	0.126	0.186
T_{*B} [K]	17000	21000
$LogL_{*B}[L_\odot]$	3.09	3.34
M_{*B} $[M_\odot]$	5.8	7
t_{*B} [Myr]	0.282	0.447
A_v	3.52	3.66

T Tauri star survey- a few comments





Name	K mag	Spectral Type
HD 25457**	4.18	F7V
RY Tau**	5.40	K1IV/Ve
HD 98800**	5.59	K5V(e)
V866 Sco	5.78	K0e+K5e
SU Aur**	5.99	G2IIIne
HD 142666	6.08	F0V_sh
HD 125340**	6.13	G7III
HD 283447	6.21	K3Ve
LkHA 190	6.23	F7/G3I/IIe
TWA 2**	6.71	M2Ve
DF Tau	6.73	M3Ve
V2508 Oph**	6.86	K6
HD 283572**	6.87	G5IVe
DR Tau**	6.87	K5Ve
AS 209**	6.96	K4Ve
DG Tau	6.99	K6Ve
RW Aur	7.02	K1/5e+K5e
LkHA 330	7.03	F7
HD 143006	7.05	G5IVe
AS 207**	7.21	K5e
TWA 8**	7.43	M3Ve

What's next?

Asymmetric multiwavelength modeling and imaging of V1295 Aql through time (+ PIONIER and GRAVITY please please)

More Herbig snapshot images and models in H+K-band

T Tauri stars!!!!

Observing run happening as we speak

Thank you Issy and Ashley for covering :)

Thank you!

Any questions ?
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