Probing the disks around young stellar objects in terrestrial orbits with GRAVITY at VLTI

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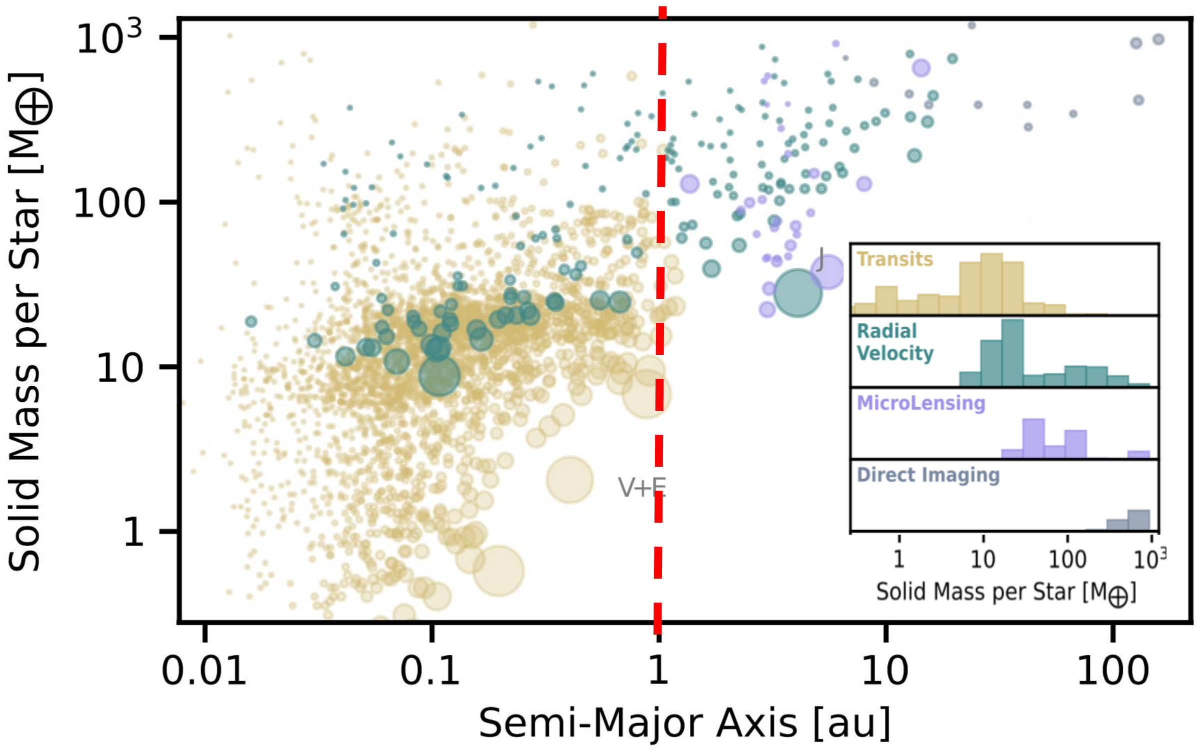
Université Grenoble Alpes / CNRS, IPAG, Grenoble (France)

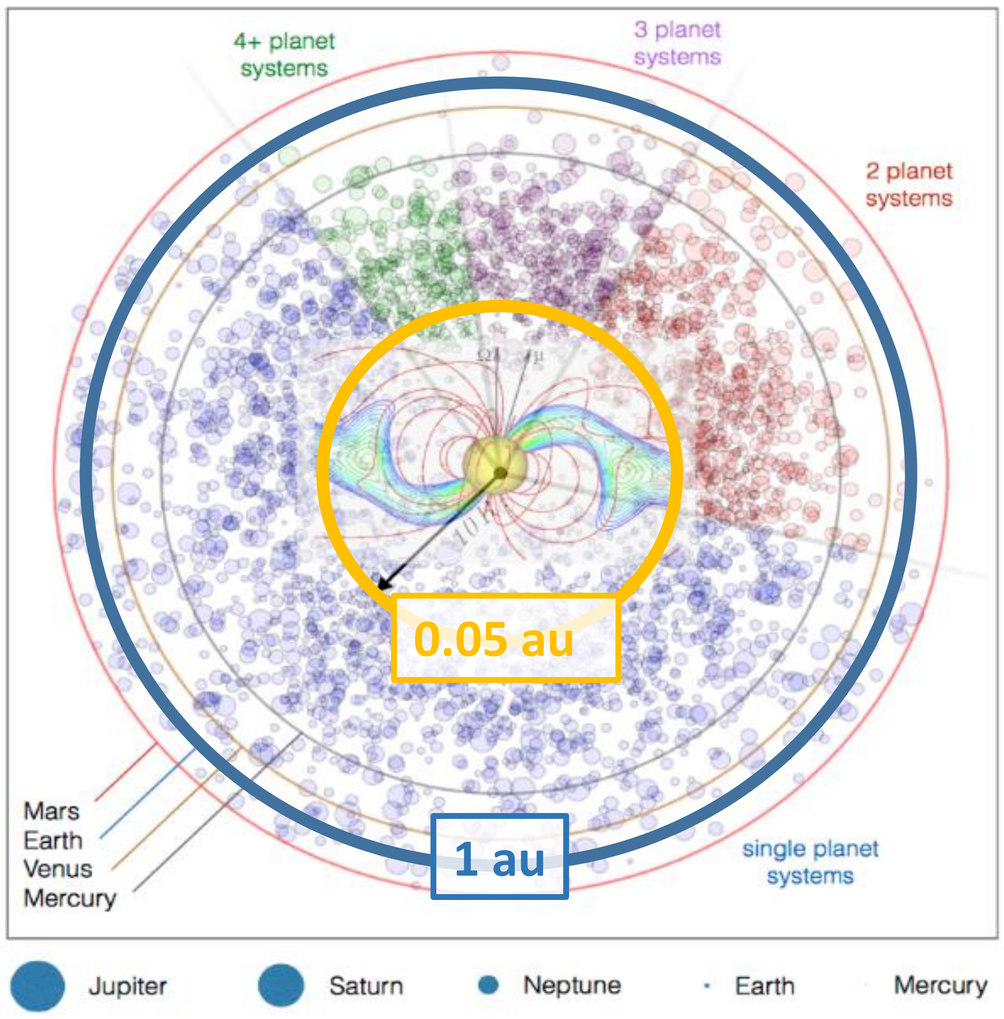
On behalf of the GRAVITY collaboration

Current population of known exoplanets exhibit
a wide diversity in nature and architecture



[Drazkowska+2023]

« Kepler » population

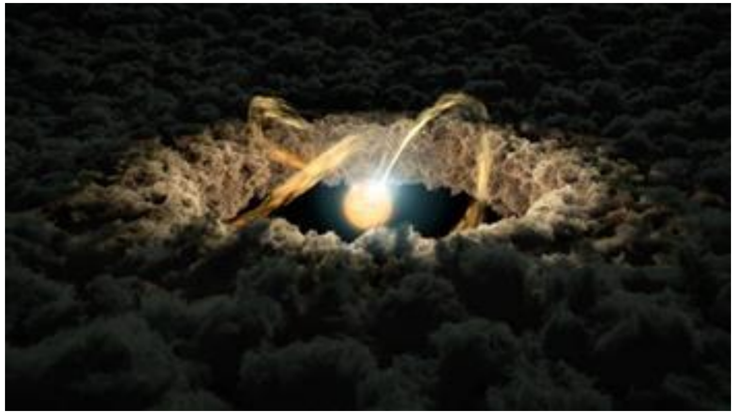


[Batygin&Laughlin 2015, Blinova+2016]

Exploring the birthplace of these planets

The protoplanetary disks:

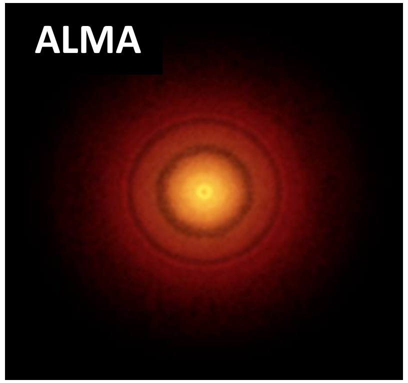
- **Material reservoirs** from which matter is accreted onto the star and from which planets are built.
- Mostly constituted of **gas**, with a small fraction in **dust grains**
- Star formation, planet formation, and disk evolution influence each other.
- **Interactions star-planet(s)/host disk**:
  - Brief (a few Myr) but foundational
  - Set stellar and planetary properties persisting for billions of years
  - Impact the evolution of the planet-star-disk system.

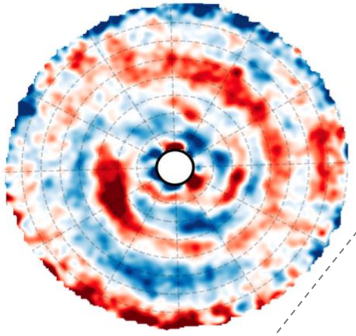


Observe **structures** and **evolution** of protoplanetary disks *while* planet formation is happening

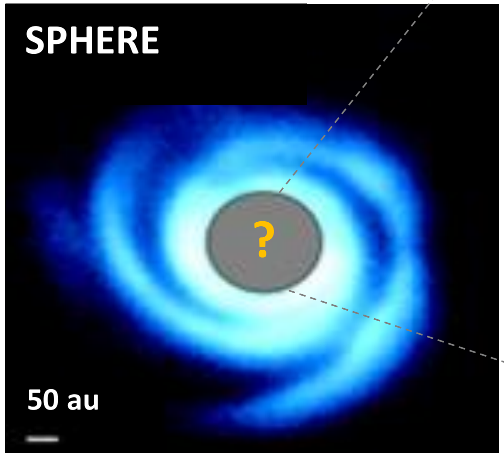
Toward a global view of the protoplanetary disks

[DSHARP, Rosotti+2019, Teague+ 2020, 2021]

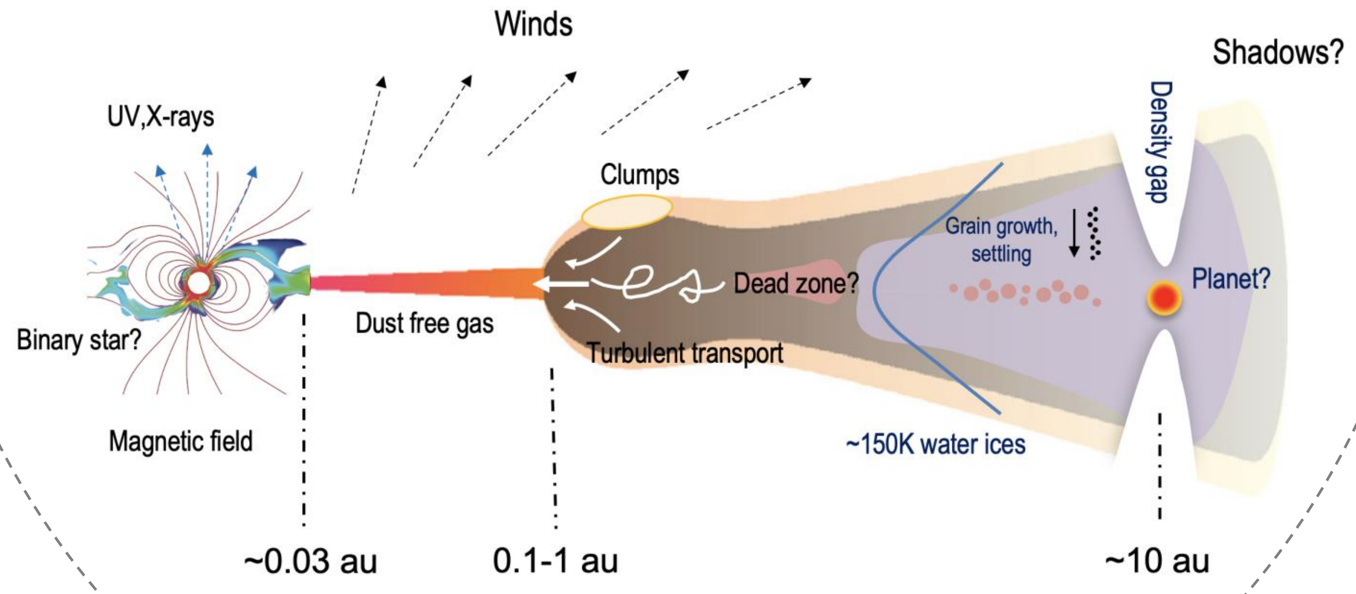




CO map



Within **multi-technique** and **multi-λ** approaches (visible/NIR/MIR, interferometry/spectroscopy/spectro-polarimetry, …)



[adapted from Henning 2013]

The GRAVITY YSO Large Program
(started end 2017)

Aims.

- Use the 4 telescopes, the sensitivity and accuracy of GRAVITY in K-band to investigate the findings of the pioniering works [Millan-Gabet+2001; Eisner+2005; 2007; 2014; Monnier & Dullemond 2010; Kraus 2015] within a statistical approach.

- Spatial structure of the inner ~1 au disk
  - ✓ Properties of the inner dust rim
  - ✓ Asymmetries and their temporal variability at short orbital timescales
  - ✓ Inner/outer disks misalignment

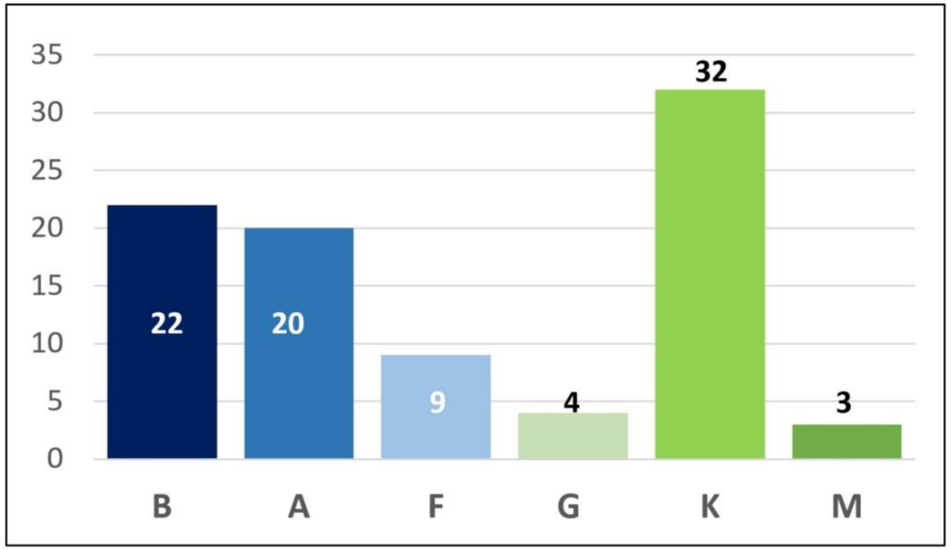
- Study of hot H and warm CO
  - ✓ Spatial location of line-emitting region, excitation mechanism (accretion, winds), kinematics

- Focuses on individual objects with peculiar properties

GRAVITY Coll., 2017, A&A, 608, 78
GRAVITY Coll., 2019, A&A, 632, 53
GRAVITY Coll., 2020, A&A, 635, 12
GRAVITY Coll., 2020, Nature, 584, 546
GRAVITY Coll., 2020, A&A, 642, 162
GRAVITY Coll., 2021, A&A, 645, 50
GRAVITY Coll., 2021, A&A, 648, 37
GRAVITY Coll., 2021, A&A, 654, 97
GRAVITY Coll., 2021, A&A, 655, 73
GRAVITY Coll., 2021, A&A, 655, 112
GRAVITY Coll., 2023, A&A, 669, 59
GRAVITY Coll., 2023, A&A, 674, 203
GRAVITY Coll., 2024, A&A, 682, 165
GRAVITY Coll., 2024, A&A, 684, 43
GRAVITY Coll., 2024, A&A, 684, 200
GRAVITY Coll., 2024, A&A, 690, 123

16 papiers
~230 citations

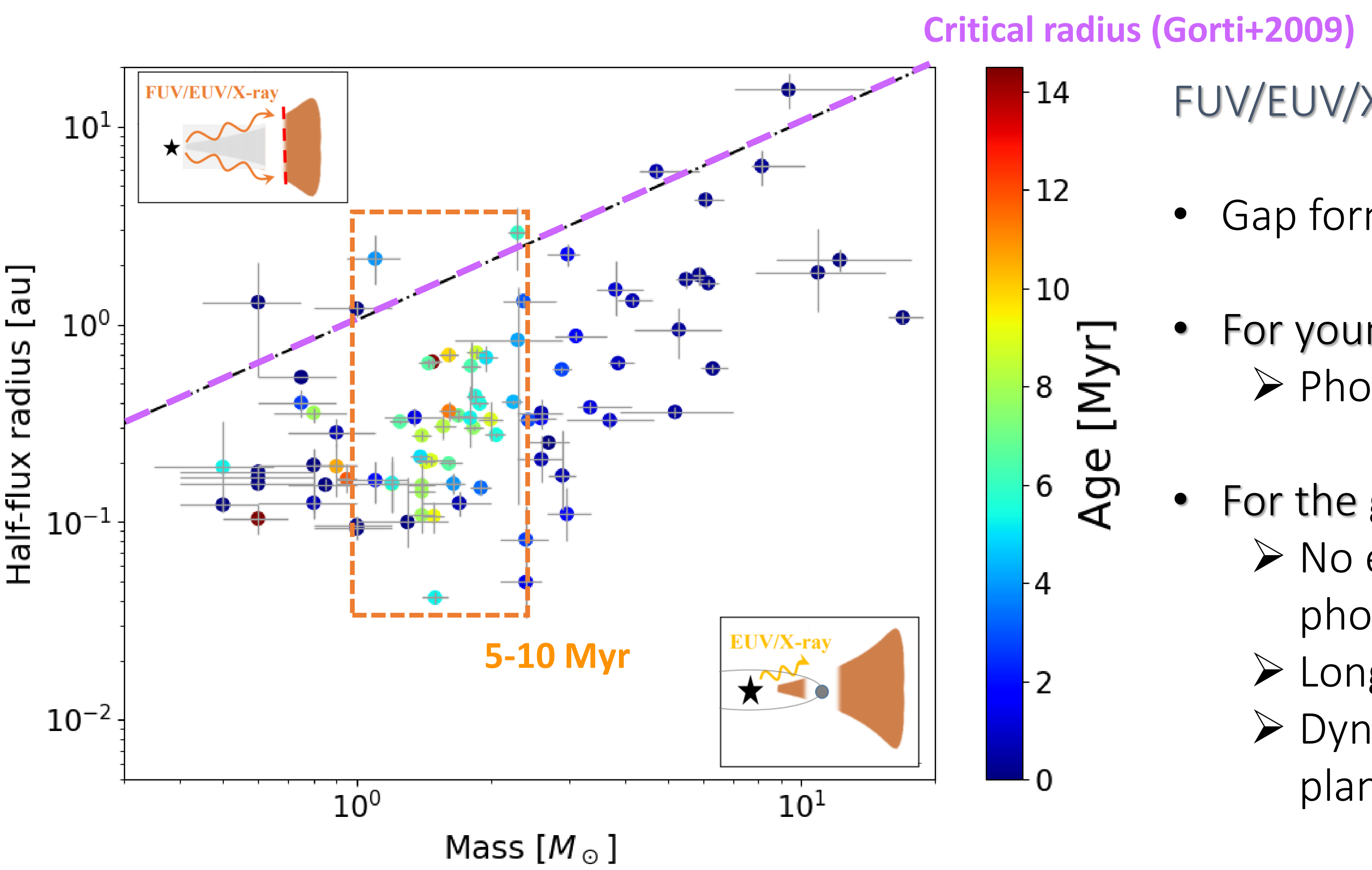
90 single YSOs



[~ 3-10 $M_\odot$]   [~ 1-2 $M_\odot$]

Testing disk evolution and gap formation

GRAVITY Coll. Perraut+2019; in prep



FUV/EUV/X photoevaporation:

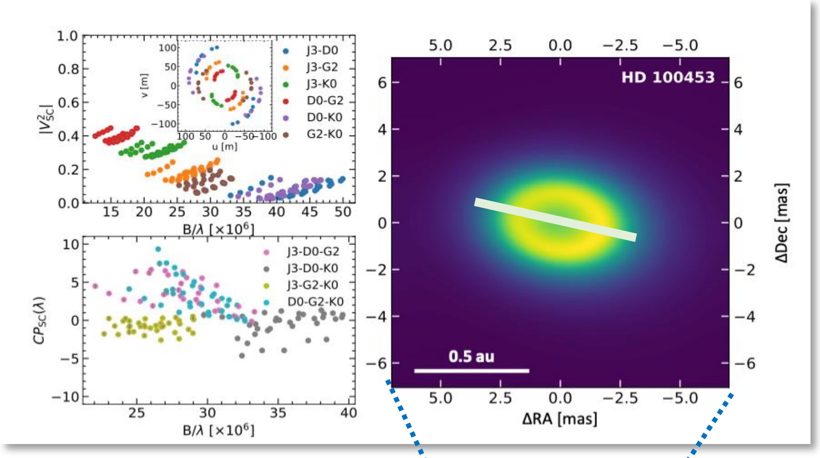
- Gap formation takes less than 4 Myr
- For younger sources:
  - ➢ Photoevaporation has just started?
- For the gapped, 5-10 Myr objects:
  - ➢ No effect of EUV/FUV/X-ray photoevaporation?
  - ➢ Longer timescales?
  - ➢ Dynamical clearing from young planets?

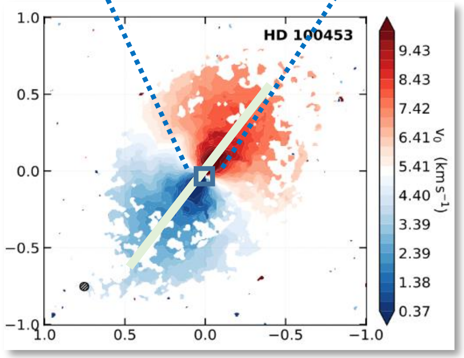
The link between inner and outer disk

Bohn, Benisty, Perraut+2022

Statistical study on 20 disks with dust-depleted cavities: 6 with inner/outer disk misalignment

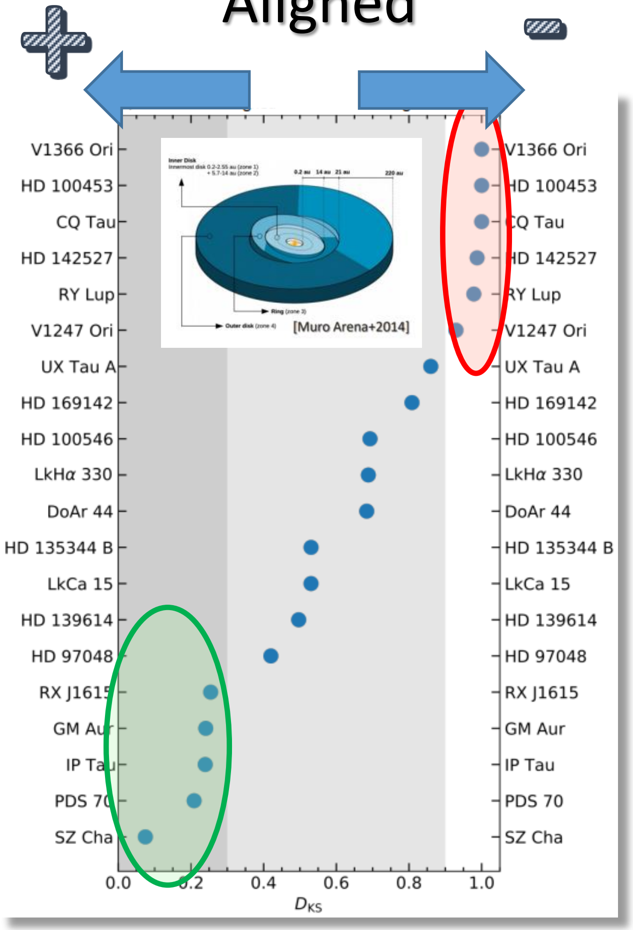
GRAVITY K-band inner disk



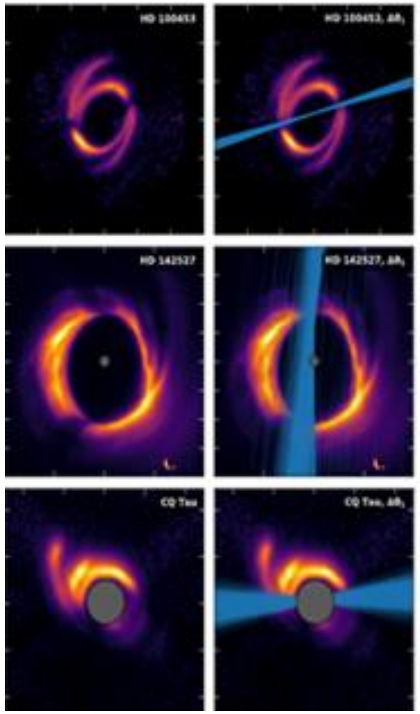


ALMA CO outer disk

Aligned



SPHERE shadows

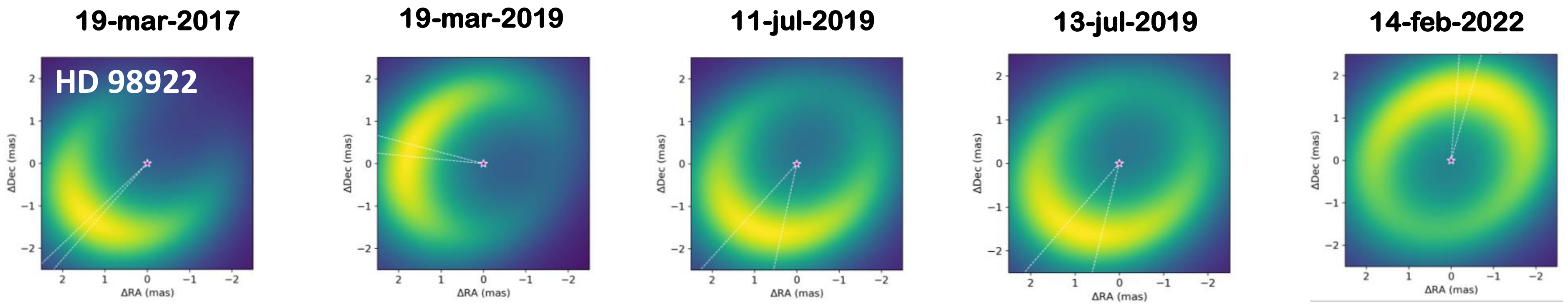


Warps?
Massive companion?
Outcome of earlier stages?

Temporal variability in the innermost regions

GRAVITY Coll. Ganci+2024

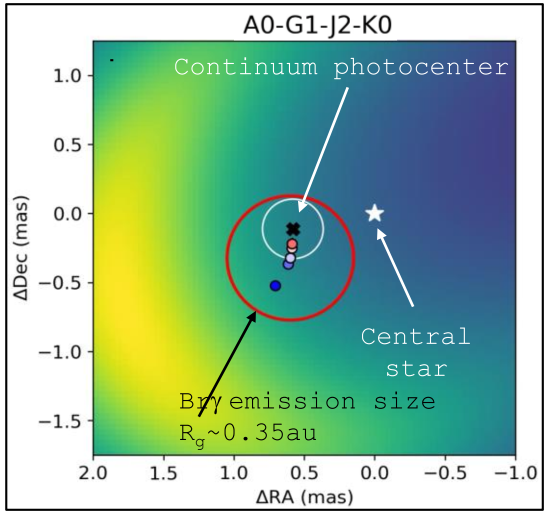
GRAVITY (K-band)



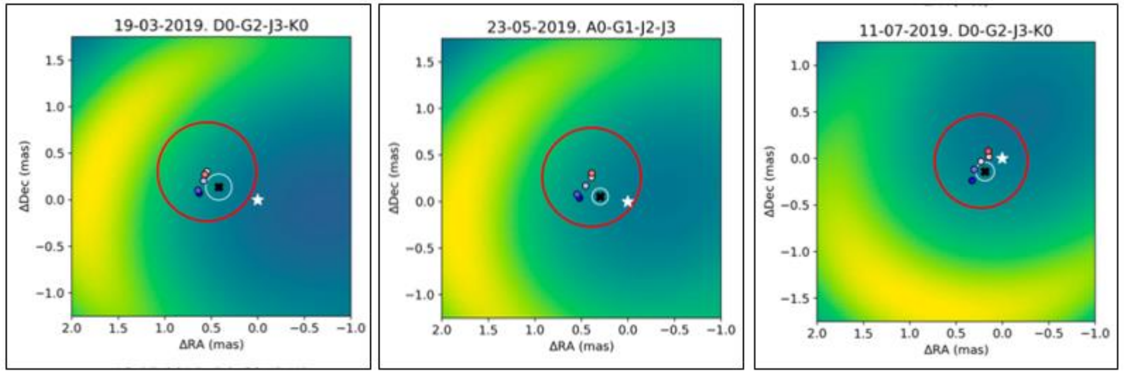
$R_{Dusty\ ring}$ ~ 1.3 au

Large vortex at ~1 au triggered by hydrodynamical instabilities

GRAVITY (Bry)

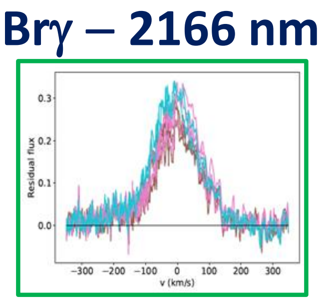


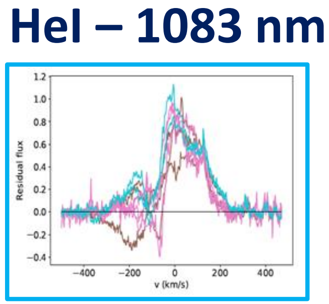
$R_{Br\gamma}$ ~ 0.35 au

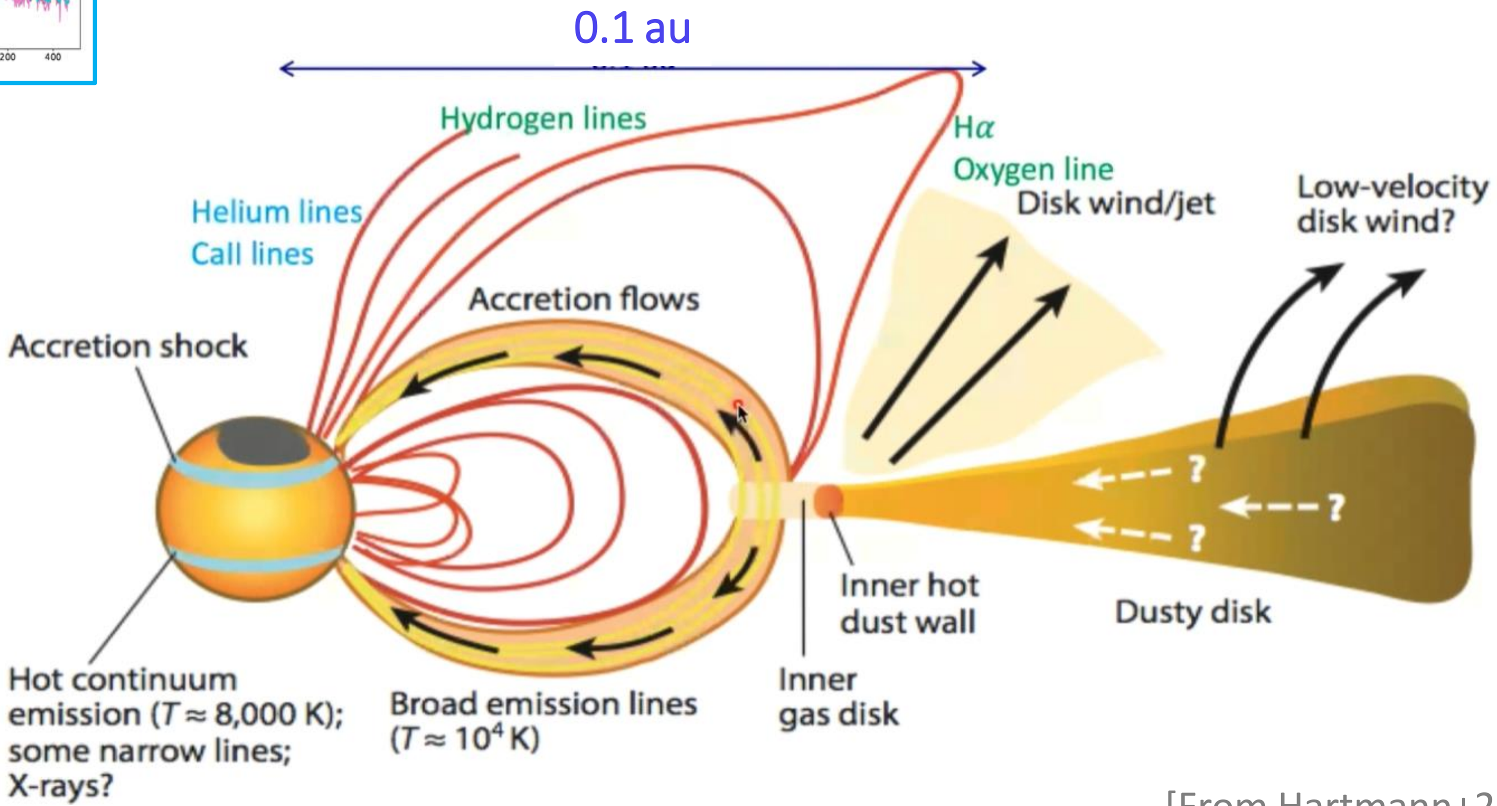


Asymmetric disk wind?
Sub-stellar/planetary accreting companion?

Accretion-ejection in the star-disk interaction region



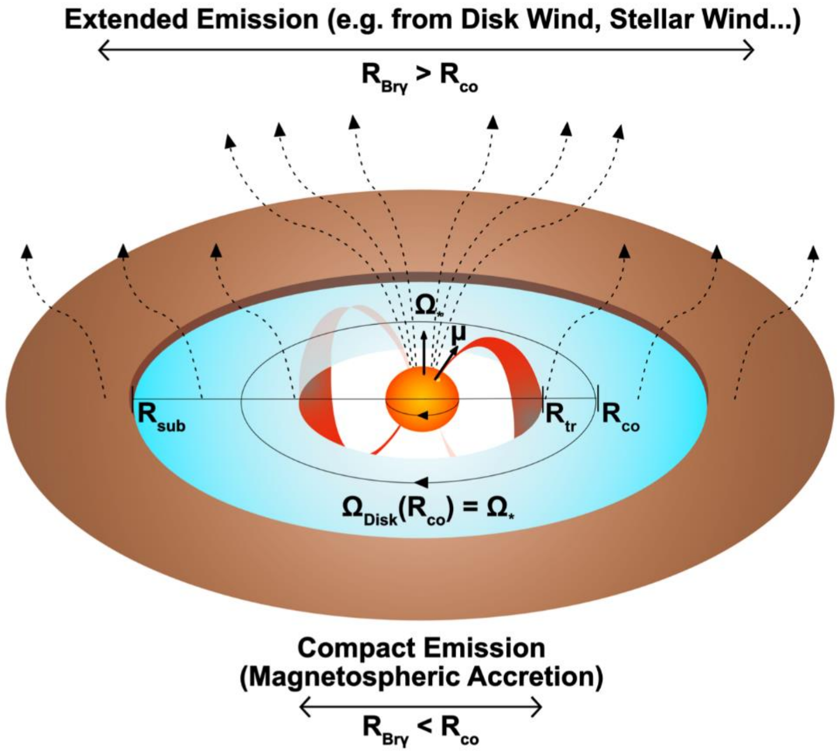




[From Hartmann+2016]

Probing the magnetosphere region in T Tauri stars

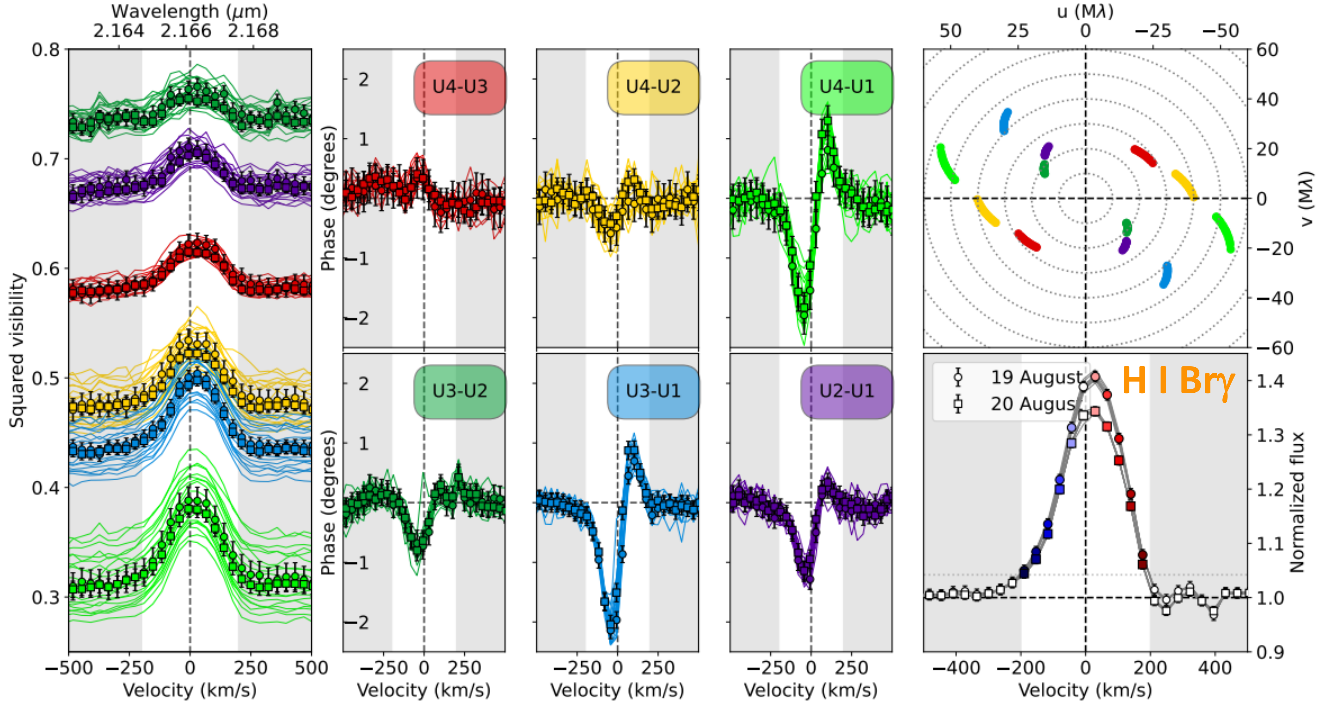
GRAVITY Coll. Wojtczak+2023
GRAVITY Coll. Nowacki+2024



Inflow/outflow mechanisms:

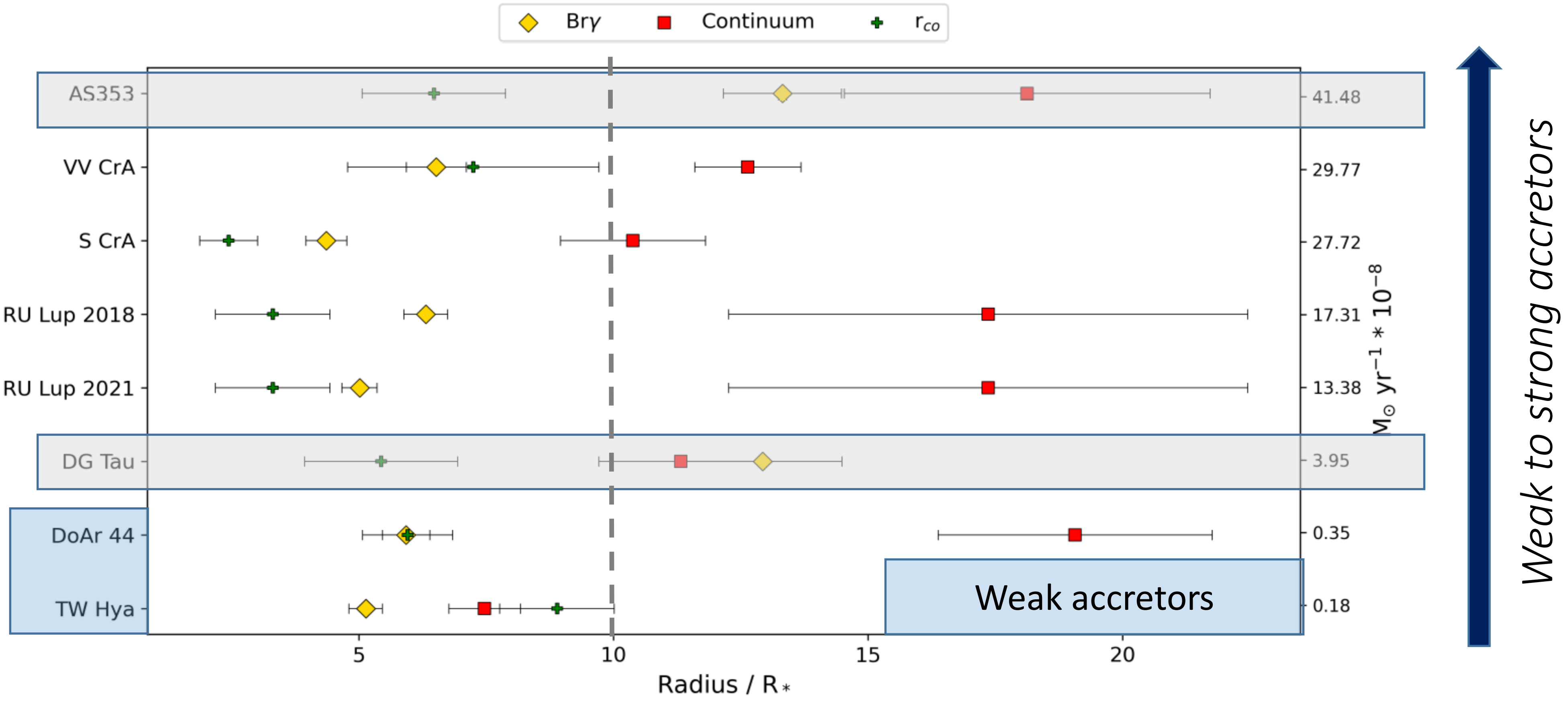
- Stable/unstable magnetospheric accretion?
- MHD winds?

GRAVITY interferometry ($\mathcal{R}$ ~ 4000)



Emitting region of the H I Brγ line in a sample of T Tauri stars

GRAVITY Coll. Wojtczak+2023



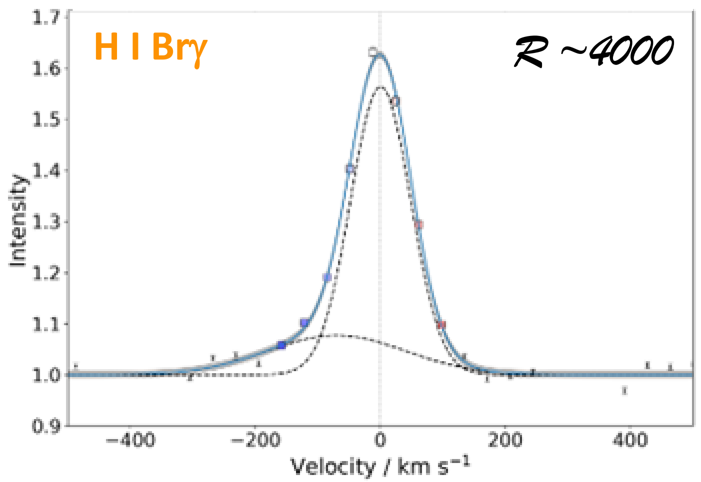
Magnetospheric accretion is not always the dominant contribution in the Brγ line emission

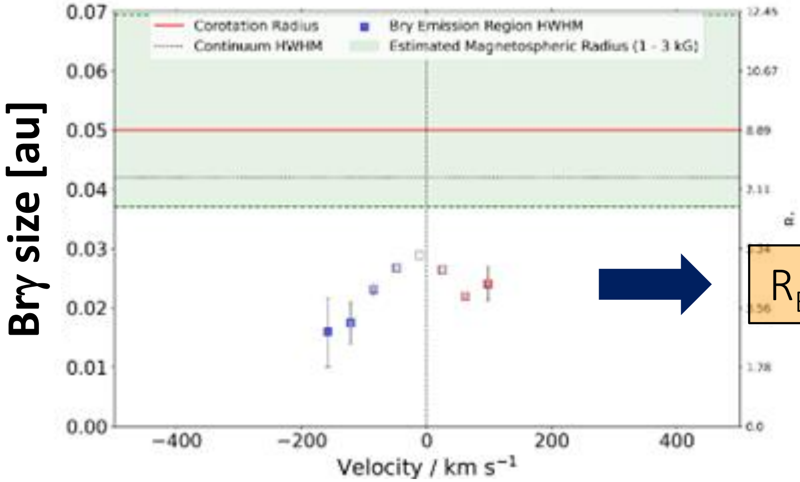
Probing the magnetospheric accretion in TW Hya

spidi-eu.org

GRAVITY Coll. Garcia-Lopez+2020

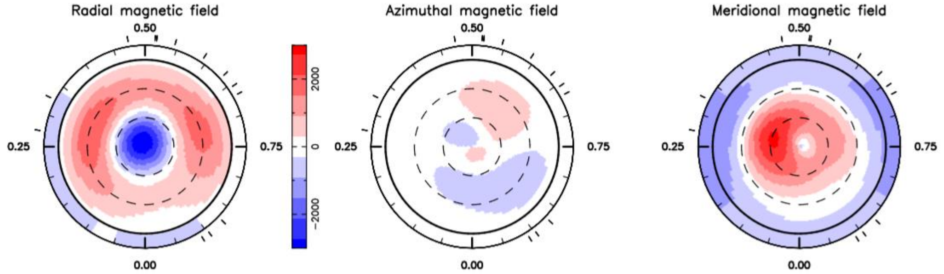
GRAVITY interferometry





$R_{Br\gamma} \sim 4.5\ R_{\odot}$

ESPaDOnS spectro-polarimetry

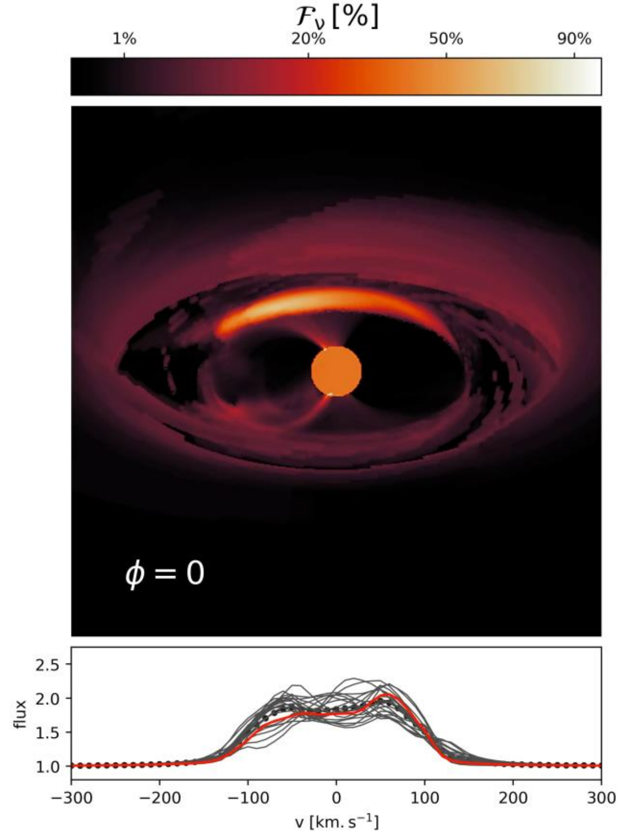


$R_{mag} \sim 3.6\text{-}4.8\ R_{\odot}$

[Bessolaz+2008]

[Donati+2011]

Radiative Transfer accretion model

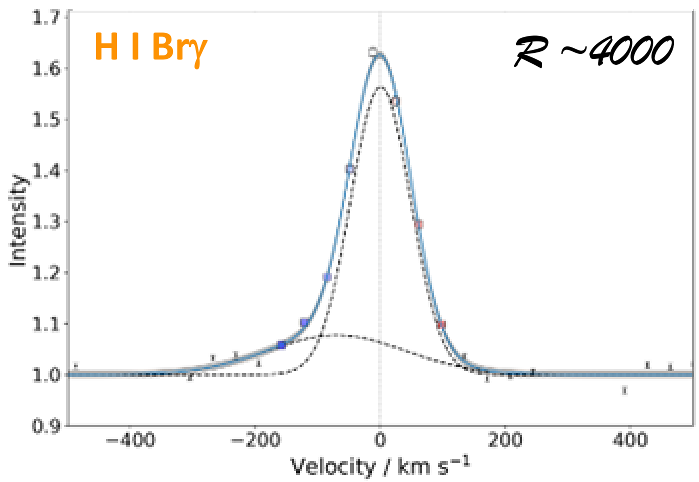


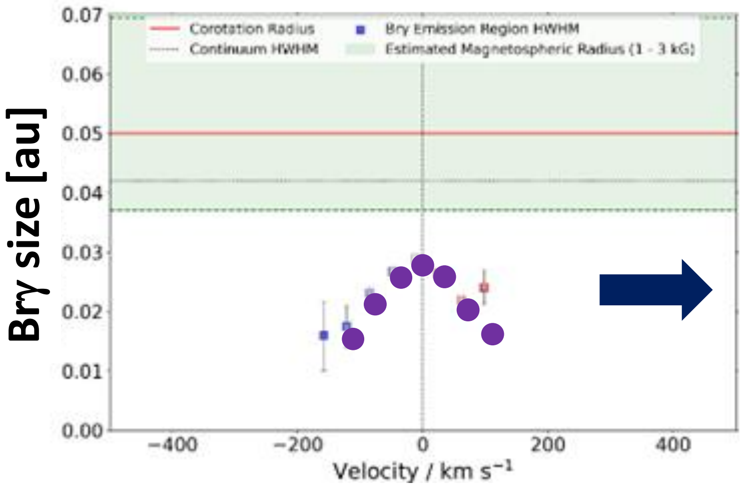
Probing the magnetospheric accretion in TW Hya

spidi-eu.org

GRAVITY Coll. Garcia-Lopez+2020
GRAVITY Coll. Wojtczak+2023

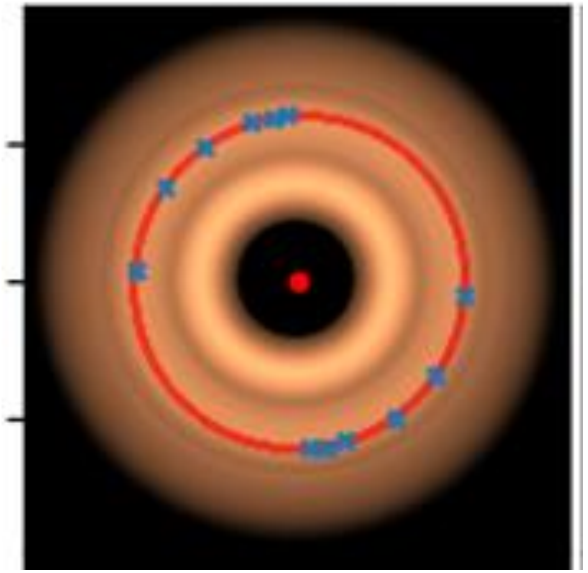
GRAVITY interferometry



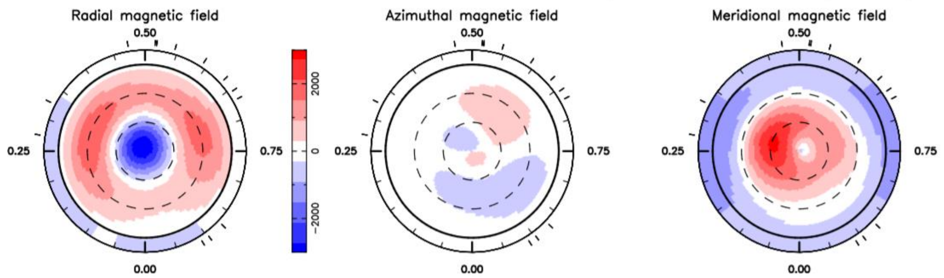


$R_{Br\gamma} \sim 4.5\ R_\odot$

- Radiative Transfer accretion model



ESPaDOnS spectro-polarimetry

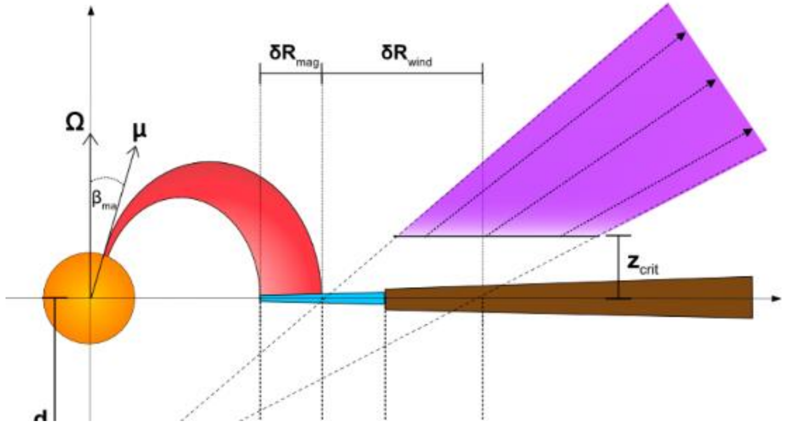


$R_{mag} \sim 3.6\text{-}4.8\ R_\odot$

[Bessolaz+2008]

[Donati+2011]

The case of the strong accretors



Non- axisymmetric accretion flow

R_{mag} = 6-7 R_* ; T_{mag} = 7000-8600 K

Conical Disk Wind

*Rwind = 7-15 R**

spidi-eu.org

Tessore+2021
Tessore+2023
Wojtczak+2024

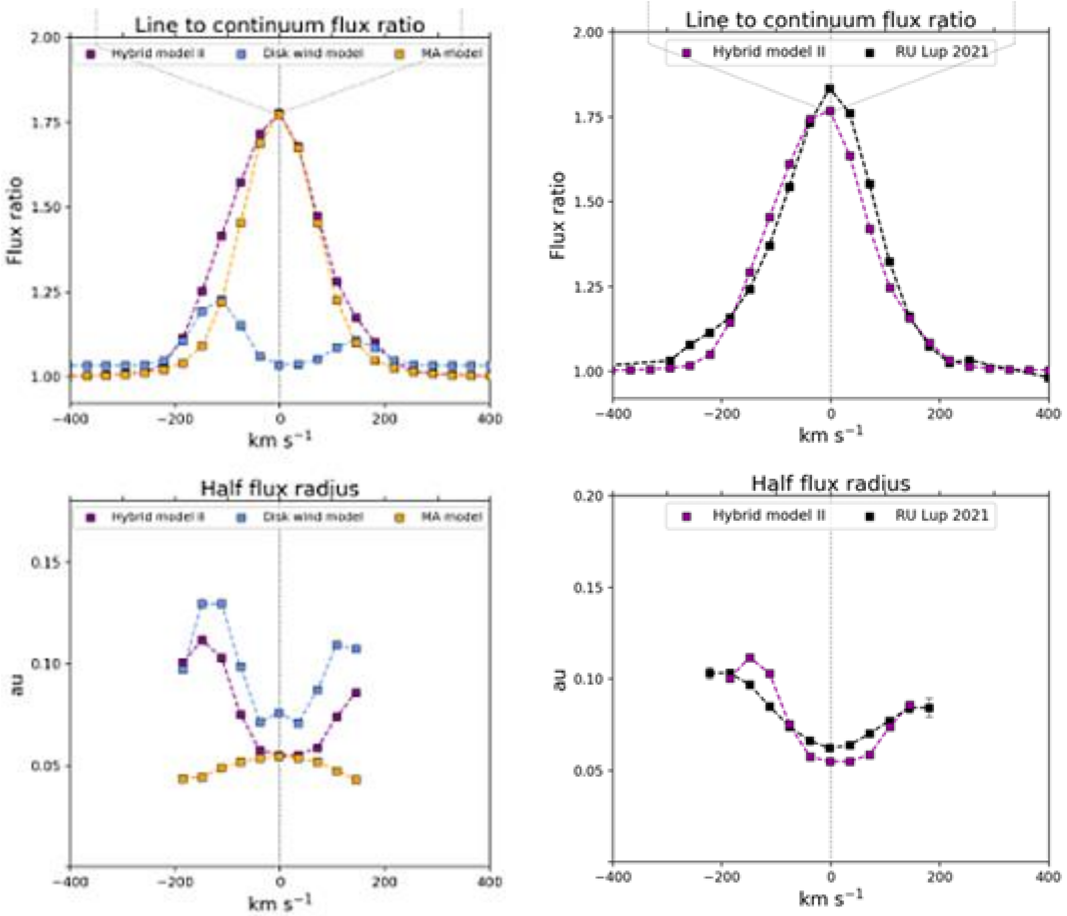
Disk wind alone
Magnetospheric Accretion alone
Hybrid model

RU Lup

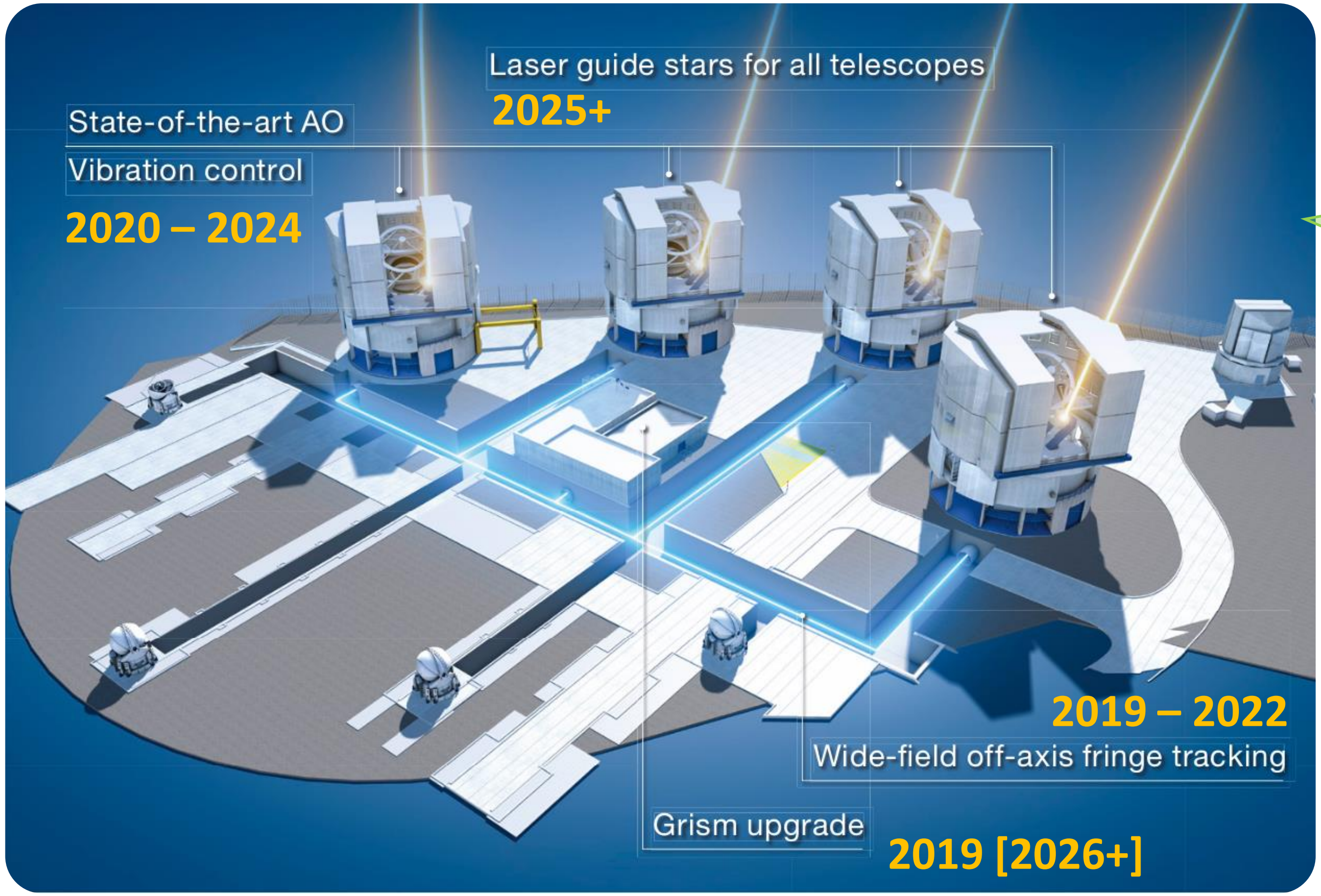
GRAVITY data
Modelling

H I Brγ line

Size of the Brγ emitting region

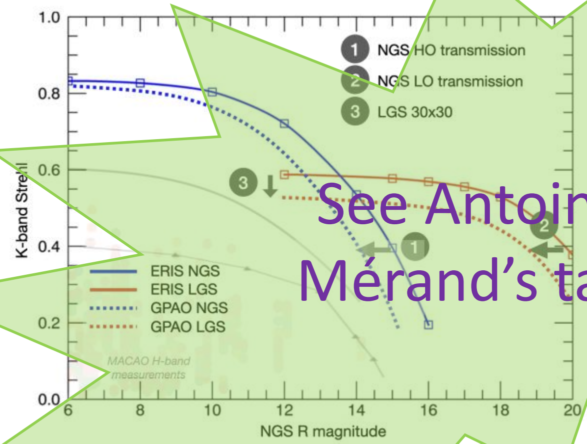


Opportunities of GRAVITY+ for YSOs



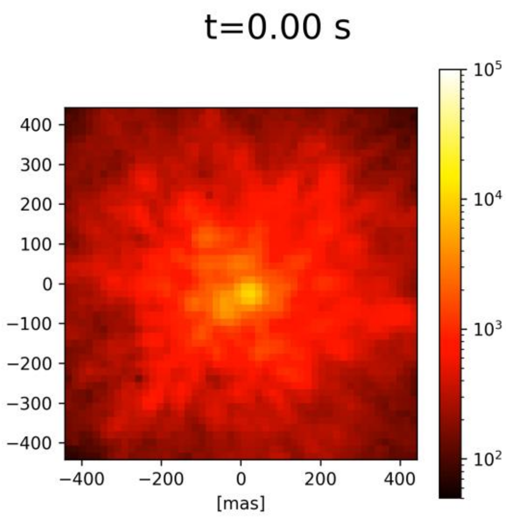
[The Messenger 189, dec. 2022; GRAVITY+Coll, 2022; Abuter+2024]
[Nowak+2024; Berdeu+2024]

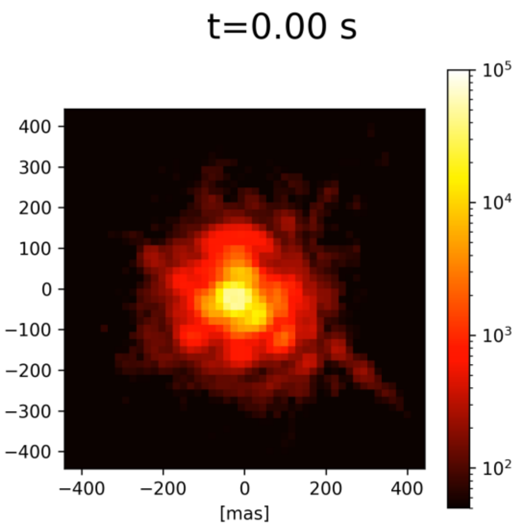
State-of-the-art adaptive optics



See Antoine Mérand's talk

- *New wavefront sensors and deformable mirrors*
- *NGS and LGS modules*





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Different Star Forming Regions and access to new classes

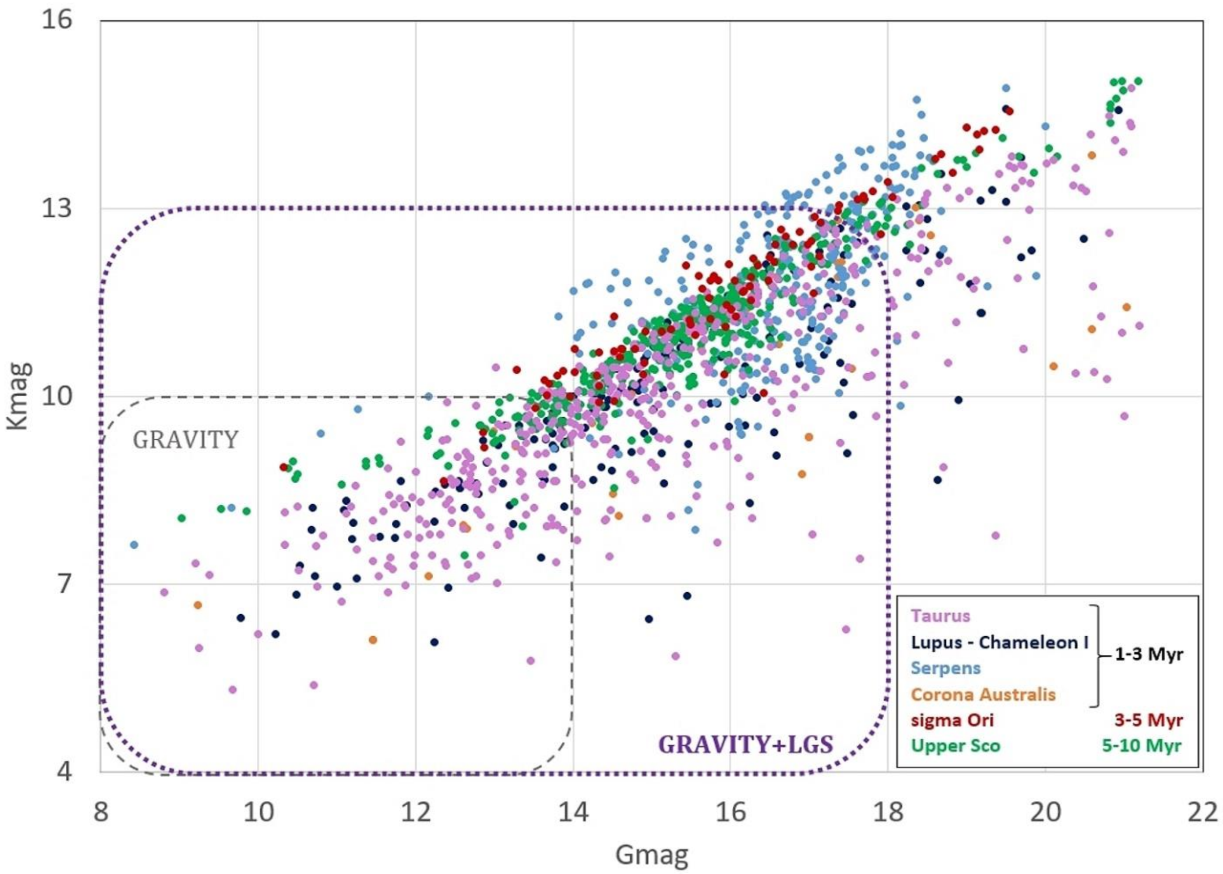
Thanks to LGS and off-axis fringe tracking:

- Less biaised samples
- Demographic studies
- Test advanced models

Access to lower mass stars and to a larger sample of high-mass YSOs, including extra-galactic as e.g. in the magellanic clouds

Access to Class-I sources:

- Younger sources
- Different regime of accretion
- Stronger and more complex magnetic fields

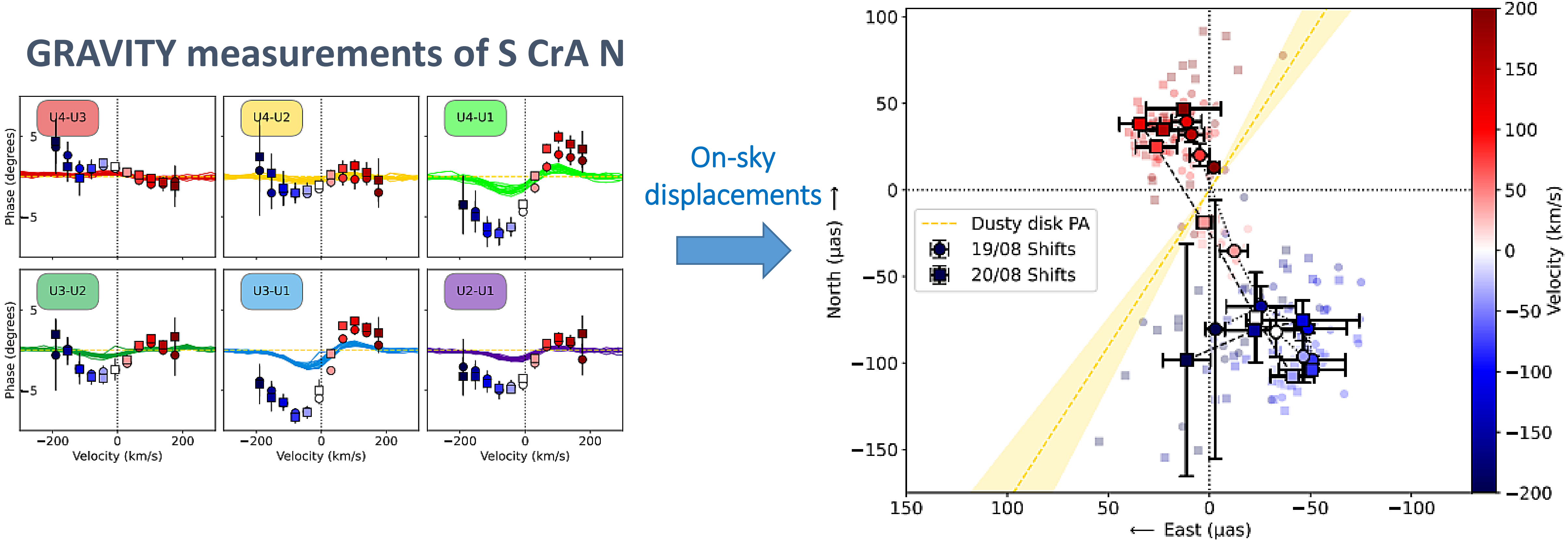


GRAVITY Coll. Nowacki+2024

Monitoring accretion-ejection in T Tauris

- Monitoring accretion flows over rotation periods to better probe their origin
- Link accretion flows, magnetic field topology, inner rim shaping

GRAVITY measurements of S CrA N



Take away messages

GRAVITY YSO Large Program – an invaluable **homogeneous data set**

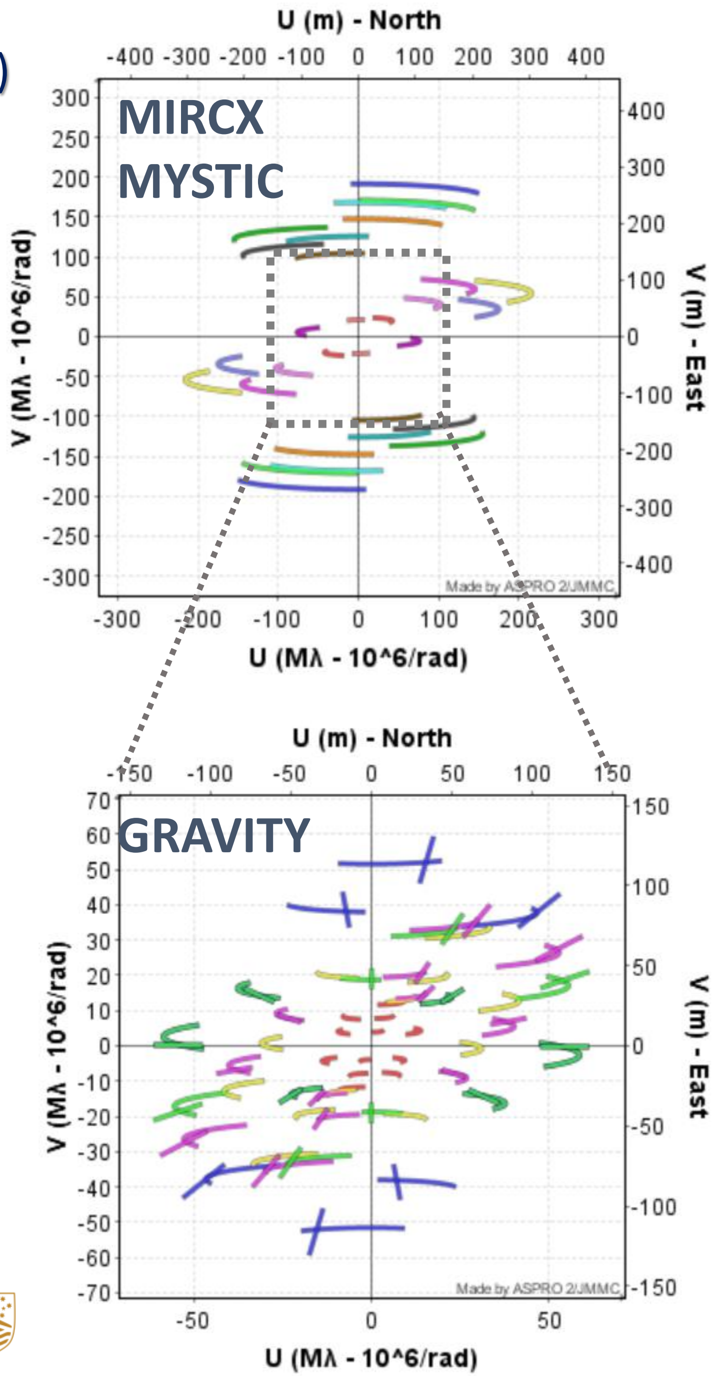
- √ Demographic studies
- √ Variability follow-up
- √ Test advanced disk structure and accretion/ejection models

Exciting times to come with **GRAVITY+ and LGS**

High complementarity between CHARA and VLTI:

- √ Snapshot imaging with CHARA (see Noura Ibrahim's talk)
- √ High sensitivity of GRAVITY (up to K = 13)
- √ Interest of combining the (u, v) planes for imaging
- √ Interest of simultaneously study dust and gas

HD 190073
(a.k.a. V1295 Aql)



Some of these works are part of the ANR funded project (2024-2028)
IRYSS – Inner Regions of Young Stellar Systems
led by K. Perraut (IPAG) & J.F. Donati (IRAP)

Deadline to apply for the IRYSS fellow position: May, 25th

[These works have been funded by ANR-23-EDIR-0001-01]

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