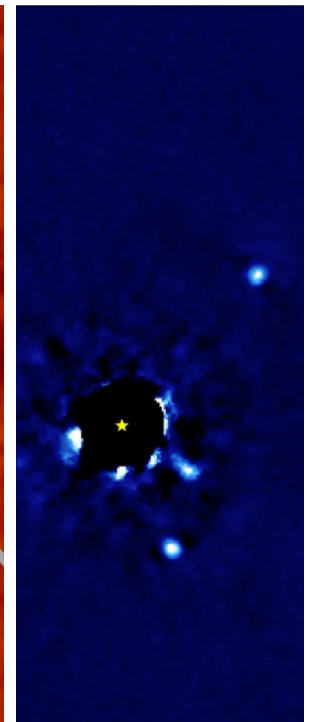
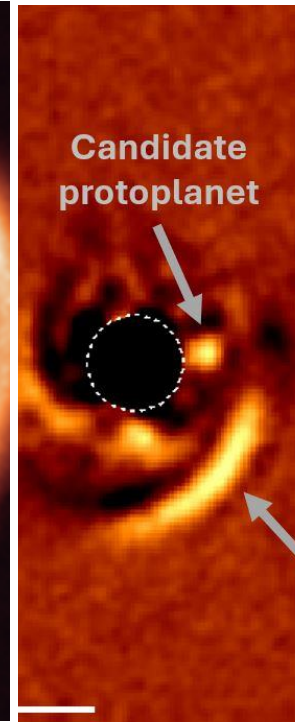
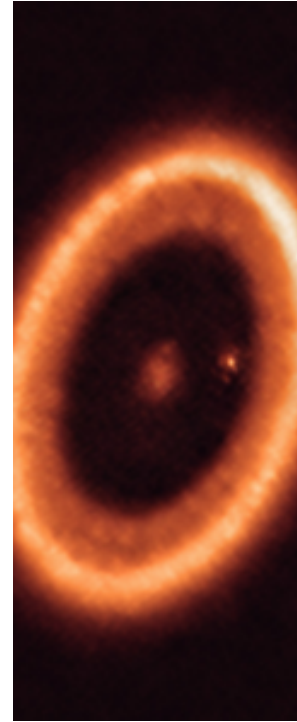
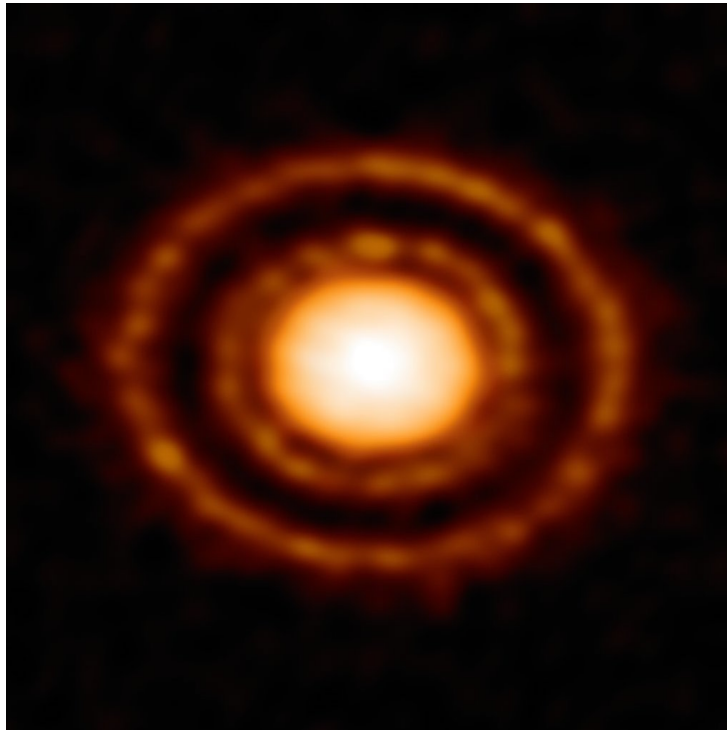




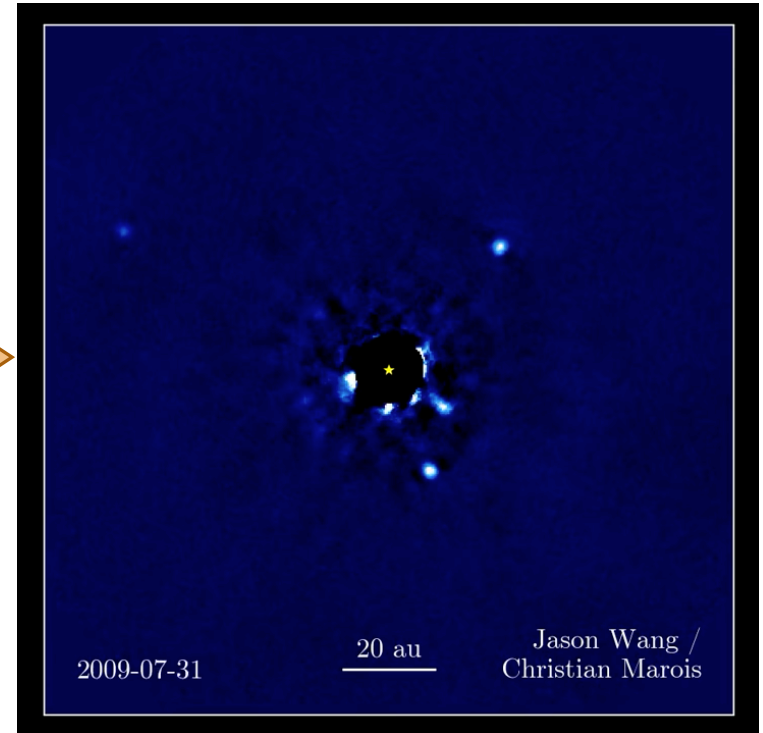
Exploring the formation and evolution of giant planets at a.u. scales with the ELT

D. FEDELE, F. ANNIBALI, S. ANTONIUCCI, C. ARCIDIACONO, **A. ALAGUERO**, S. DESIDERA, G. DUCHENE, S. FACCHINI, A. GARUFI, C. LAZZONI, G. LI CAUSI, **F. MAIO**, D. MESA, **P. PALMA-BIFANI**, F. PEDICHINI, L. PINO, L. PODIO, V. ROCCATAGLIATA, L. TESTI, C. TOCI

From disks to planets



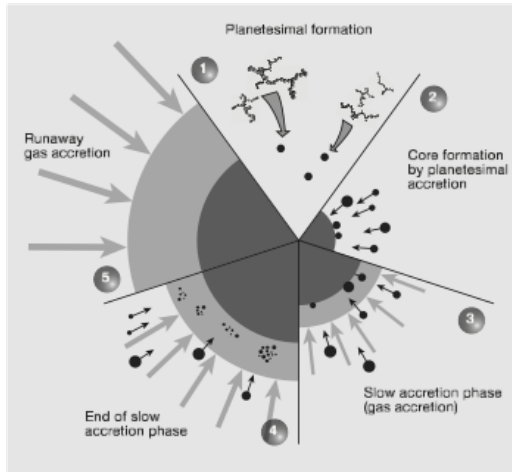
ALMA dust continuum of the protoplanetary disk around AS 209 (Fedele et al. 2018)



Time-lapse of the planetary system HR 8799 with SPHERE

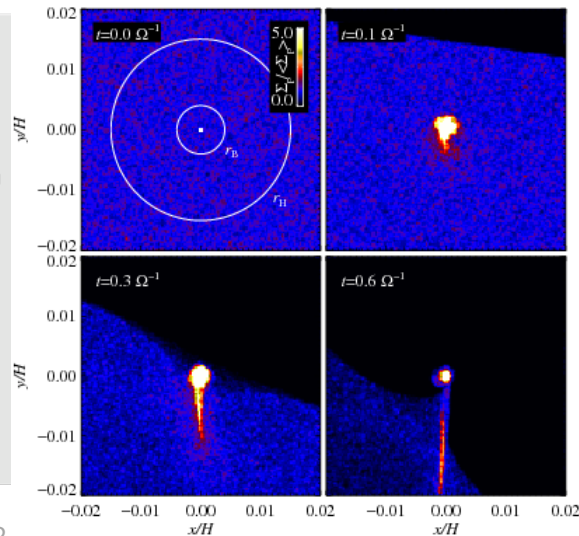
Planet formation theories

Core-accretion



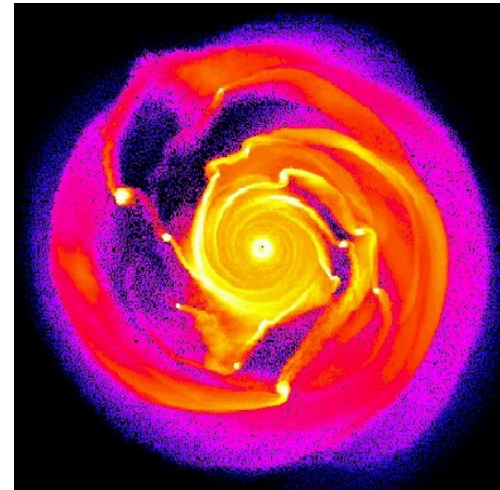
e.g., Mizuno+ 1980, Lissauer+ 1993, Pollack+ 1996

Pebble accretion



e.g., Lambrechts+. 2014

Gravitational instability



e.g., Adams+ 1989, Boss 1997, Durisen+ 2007

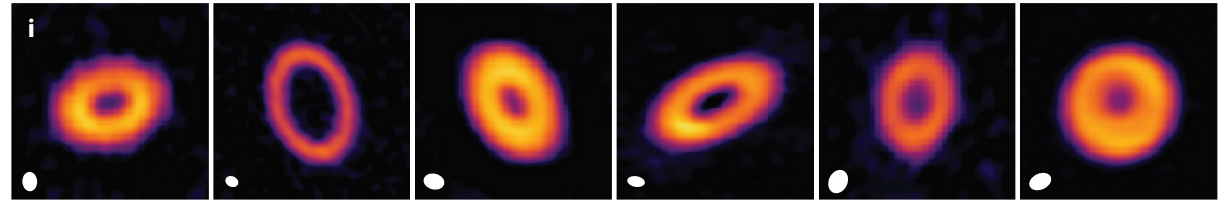
How do planets form?

Where planets preferentially form in the disk ?

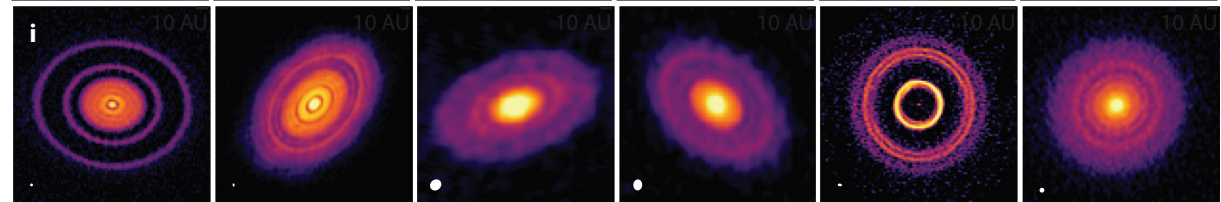
Planet-disk interaction: migration, primordial atmosphere?

Planet formation: indirect proofs

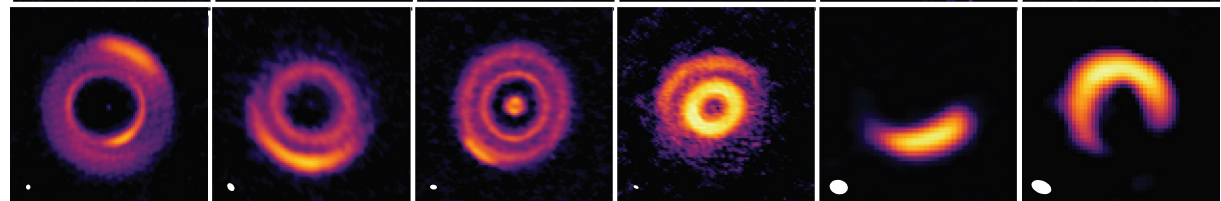
Rings with cavity



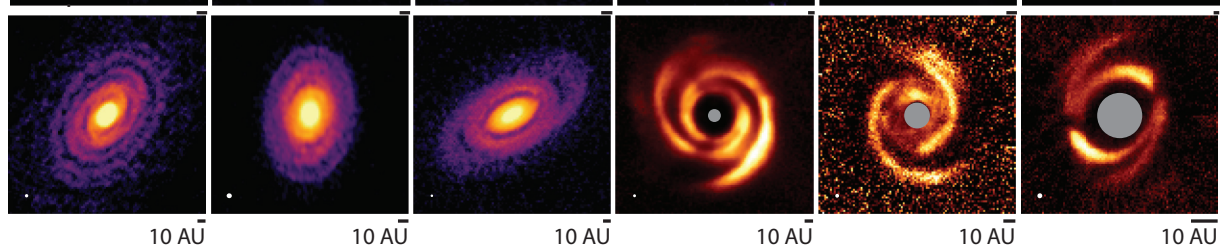
Rings with gaps



Arcs



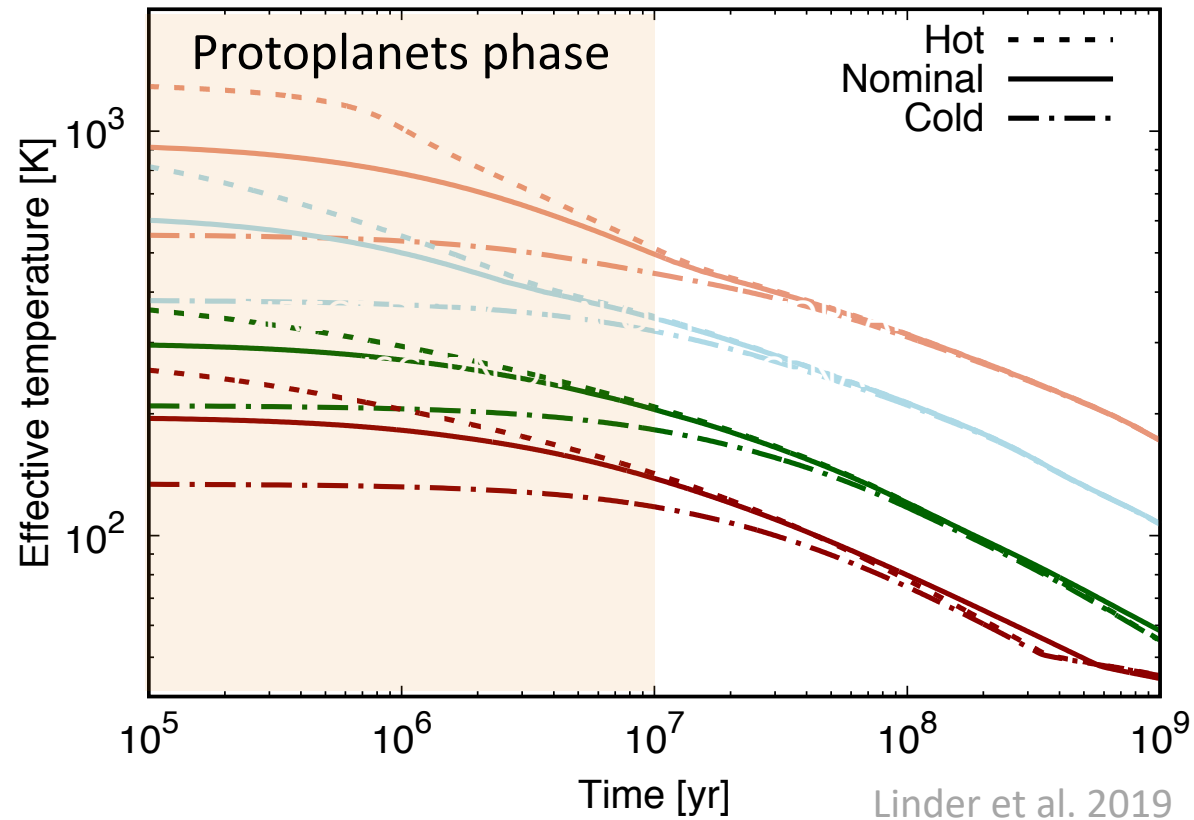
Spirals



e.g., Garufi et al. 2018, Andrews 2020

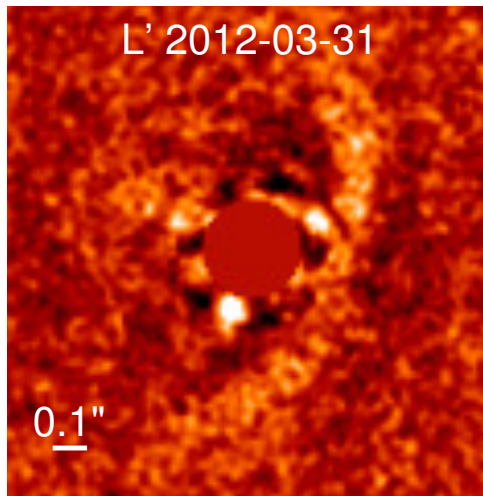
Sub-structures hint at the presence of embedded protoplanets

Planet formation: evolutionary tracks

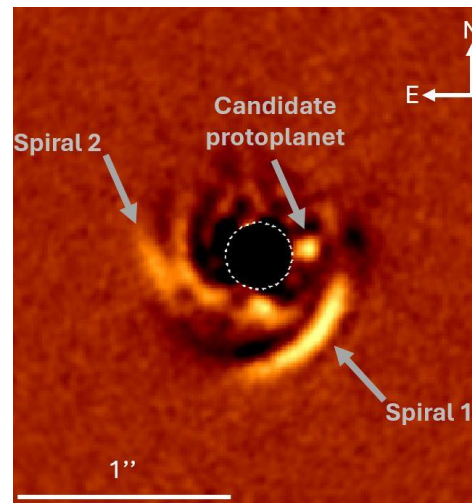


Tracing the thermal evolution of protoplanets to discern different formation scenarios

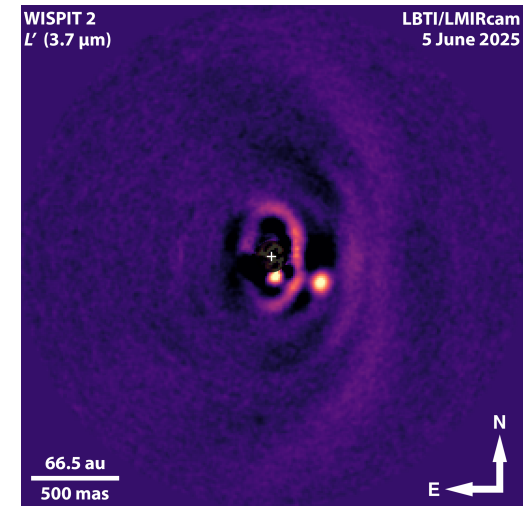
Detection of protoplanets



*PDS 70: VLT/SPHERE & NACO
Keppler et al. 2018, Mesa et al. 2019*



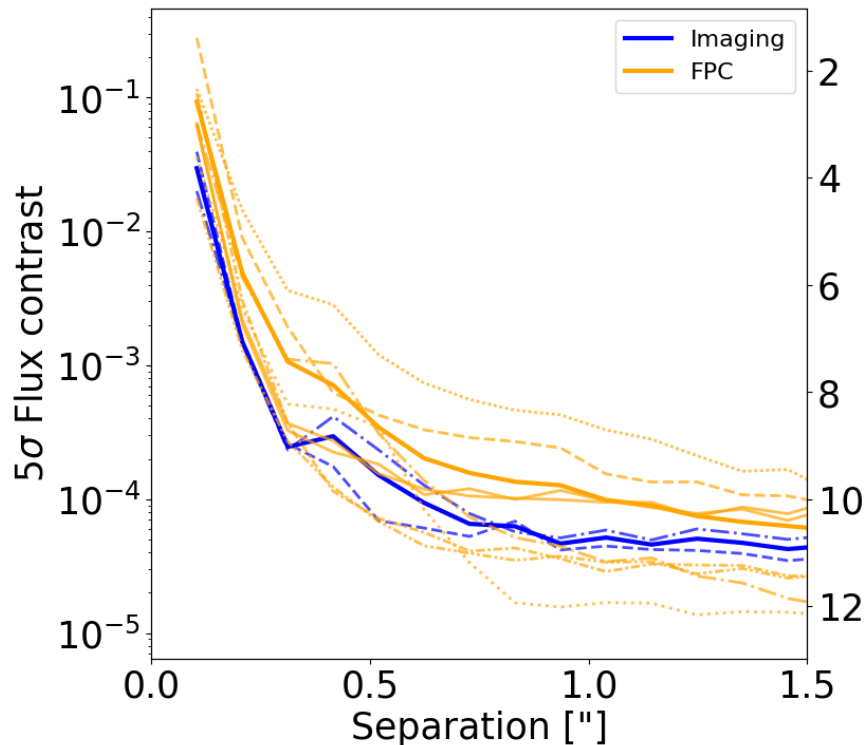
*HD 135344 B: VLT/ERIS
Maio et al. 2025*



*Wispit 2: LBT/LMIRCAM
Close et al. 2025*

A couple of confirmed detections, several debated cases
Planets $< \text{a few } M_{\text{Jupiter}}$ heavily obscured by local dust extinction
Confusion with disk dust emission and self-subtraction

Detection of protoplanets: current limitations



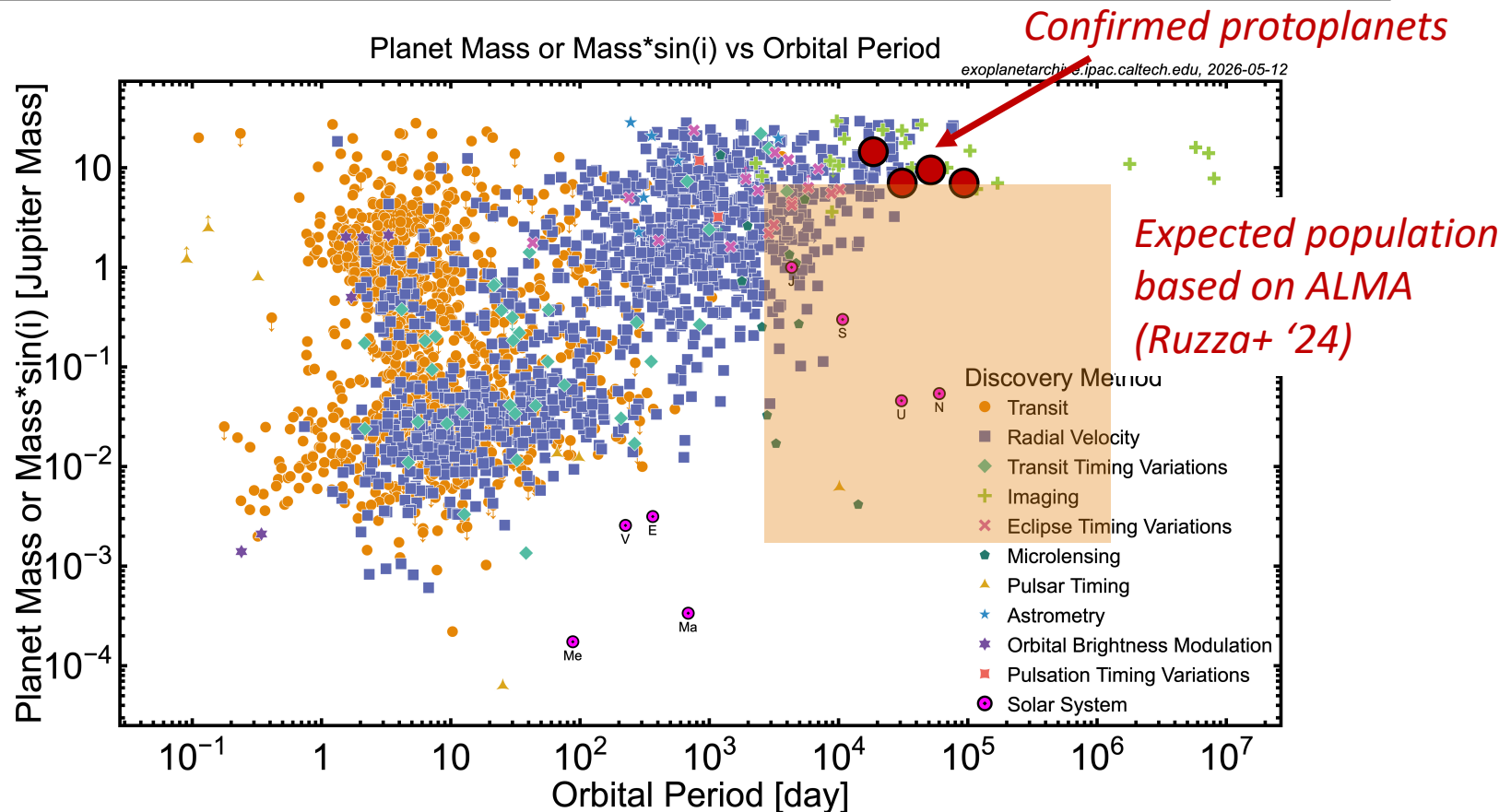
Indirect methods (RV, transits, astrometry?) not applicable to protoplanets

Star-to-planet flux contrast $< 10^{-4}$ in K-band, decreasing with planet's mass and age

Limitations of current facilities:

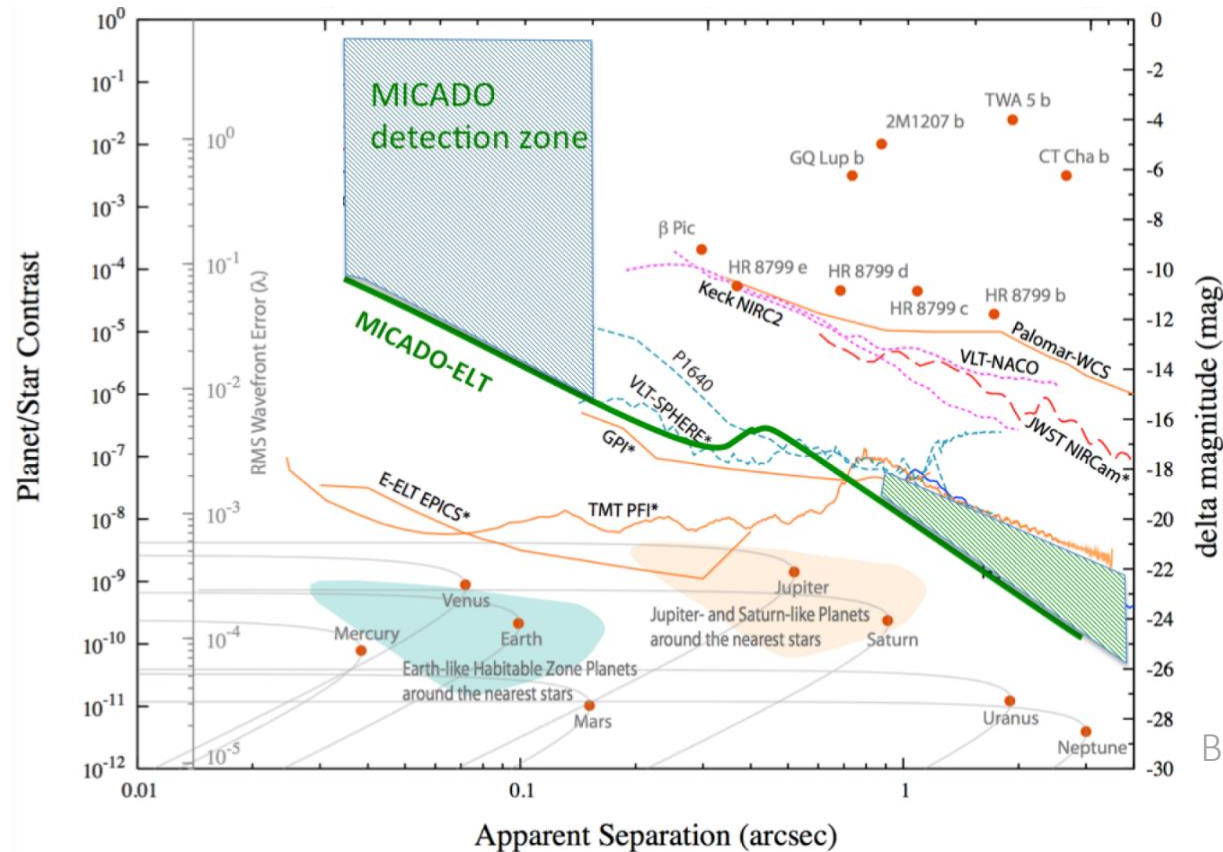
- Probe only scales $> 0.15''$ (> 20 AU)
- Seeing-dominated at large scales ($> 0.5''$)
- Limited to NGS R = 10-11 mag

Detection of protoplanets: in context



Current instruments/techniques limited to massive planets on wide orbits
Dust cavity/gaps size & width hint at sub-Jovian mass planets (inaccessible)
Most planets expected to form in the inner 10-20 au region (unexplored)

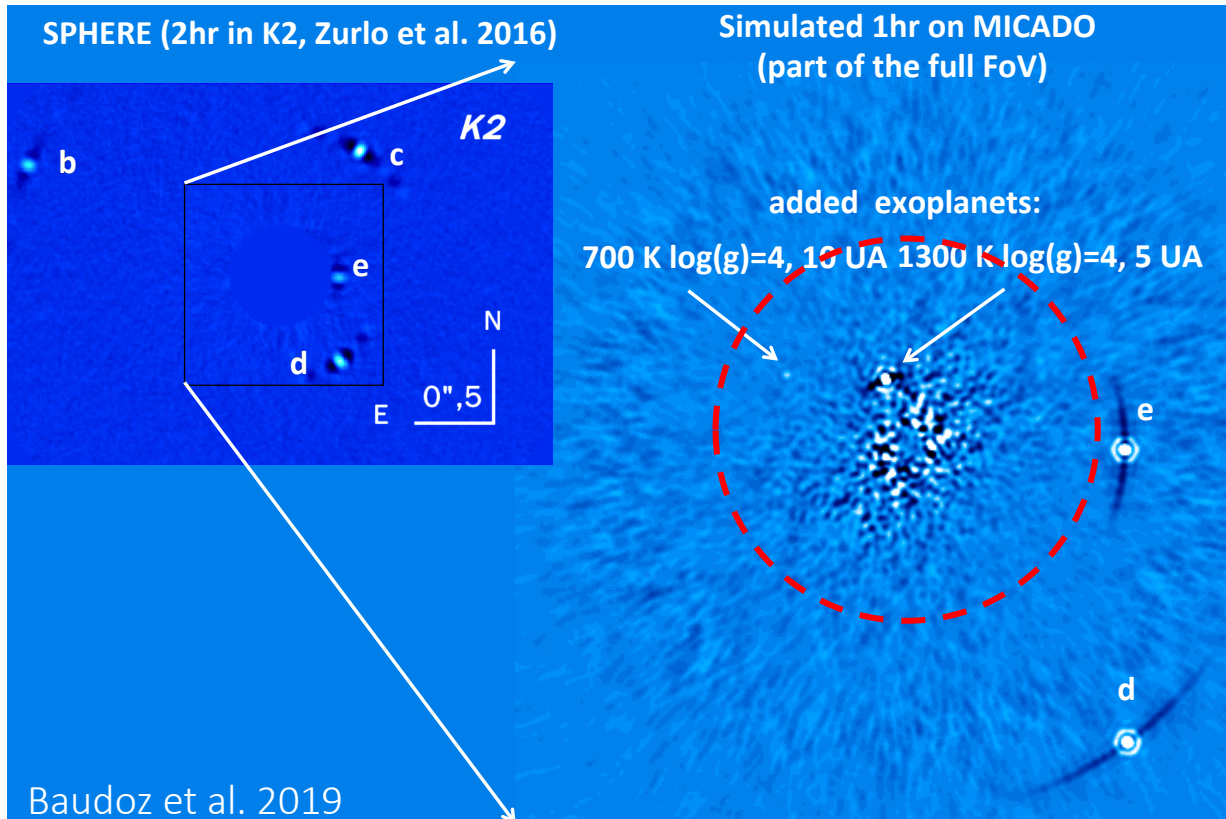
Getting closer and fainter with MICADO



Baudoz et al. 2019

- First instrument capable of direct detection within 0.15'' (down to 50 mas)
- Gain of ~ 4 in terms of NGS magnitude limit compared to SPHERE
- Gain of > 3 in terms of Δmag contrast compared to SPHERE at scales $> 1''$

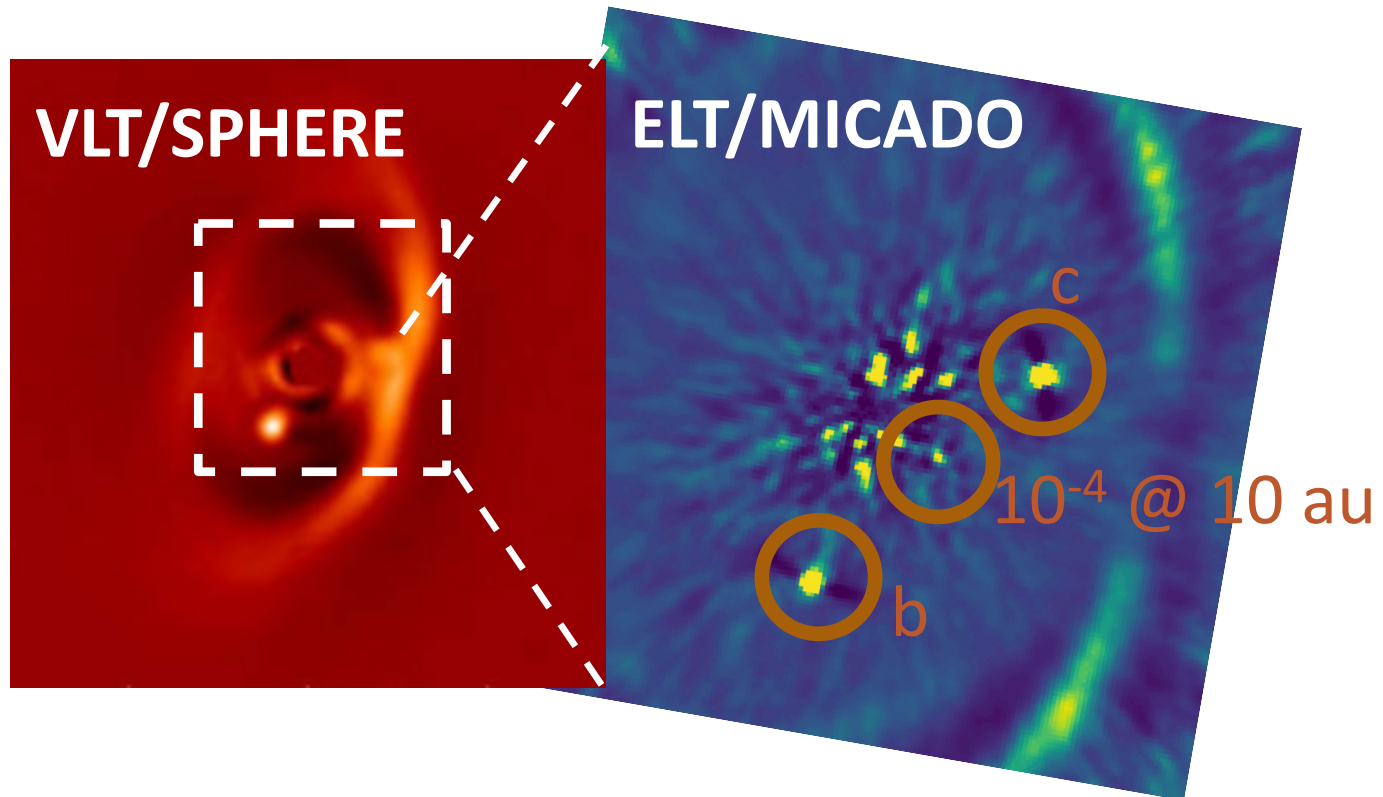
Getting closer



MICADO-SCAO will detect giant protoplanets down to 5-10 au in nearby star forming regions (0.1 – 5 Myr, $d < 200$ pc), down to 2-3 au (**snowline**) in moving groups (5-20 Myr, $d \sim 20$ -60 pc)

PDS 70 with MICADO

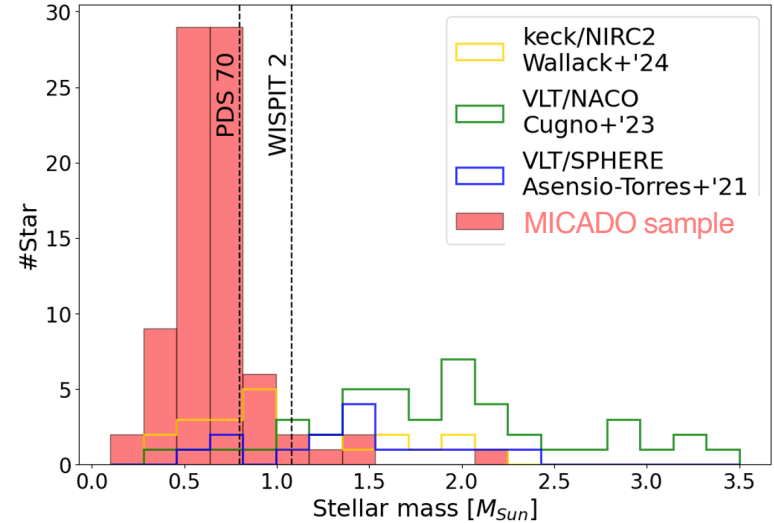
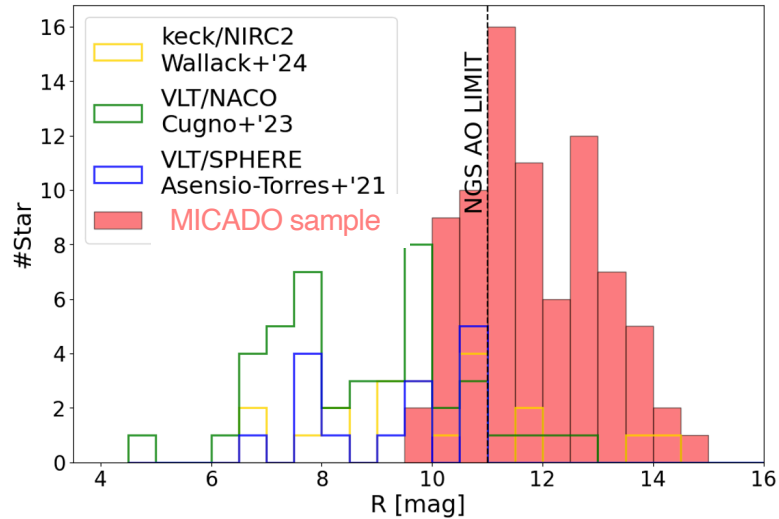
SPH+RT: Toci et al. (2020) w. PHANTOM
(Price et al. 2018)
PSF: MISTHIC E2E (Huby et al. 2024)
ADI-PCA: F. Maio, A. Alaguero



PDS 70 c signal clearly separated from disk signal
Detection of an inner (fake) planet at 0.08'' (10 au), contrast 10⁻⁴

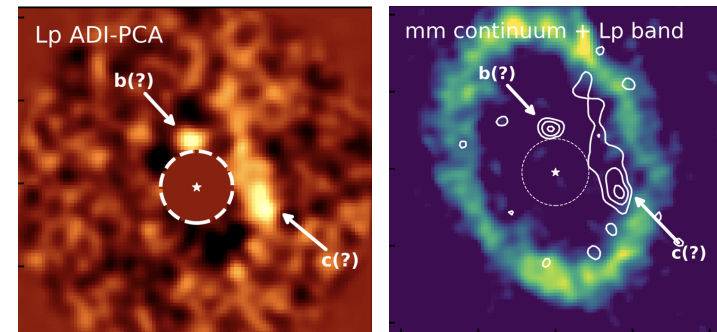
Planet-disk interaction (see talk by A. Garufi & V. Roccatagliata)

Going fainter



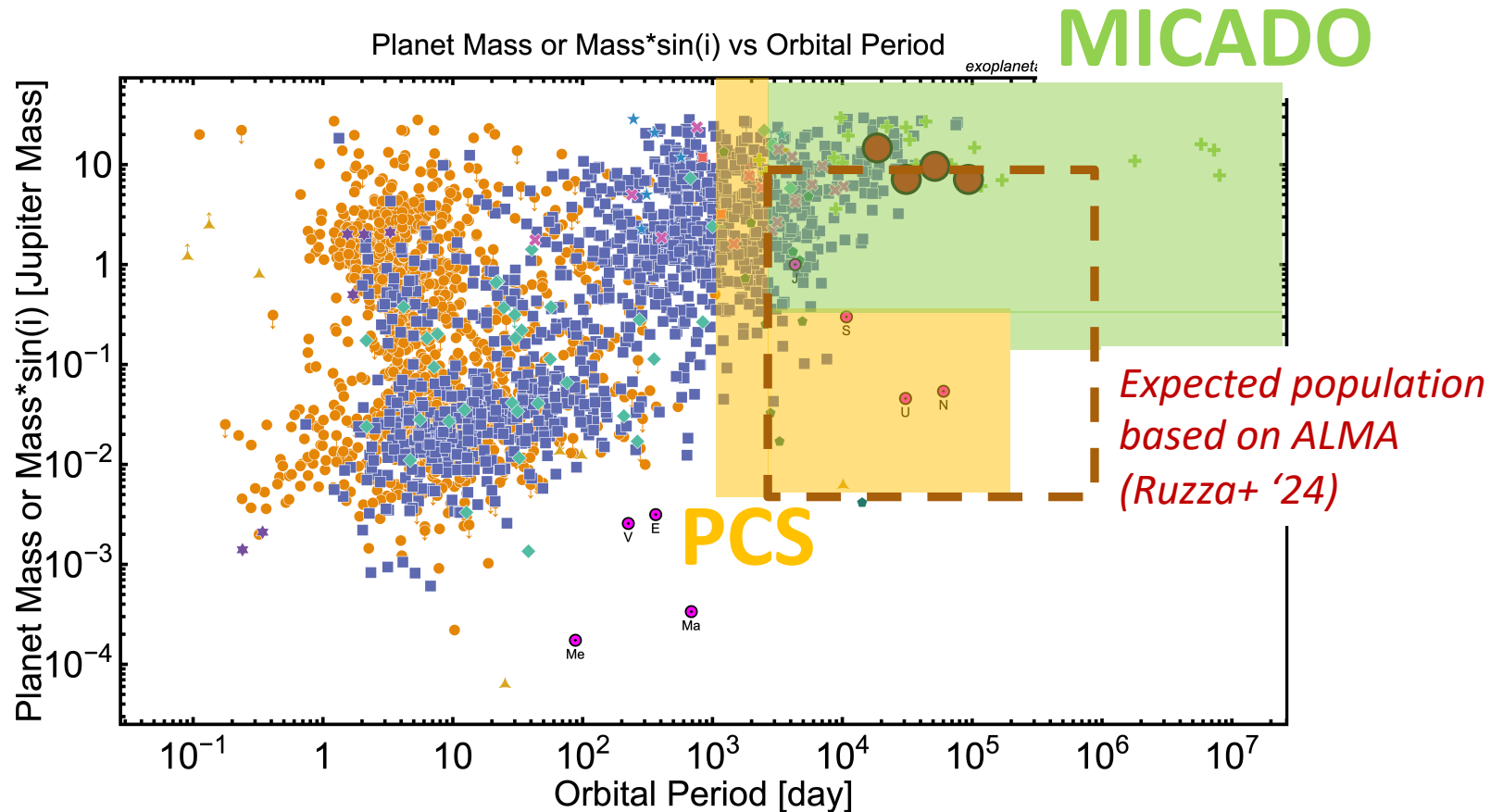
Previous surveys focused on bright and massive stars

MICADO-SCAO will address the bulk disk population



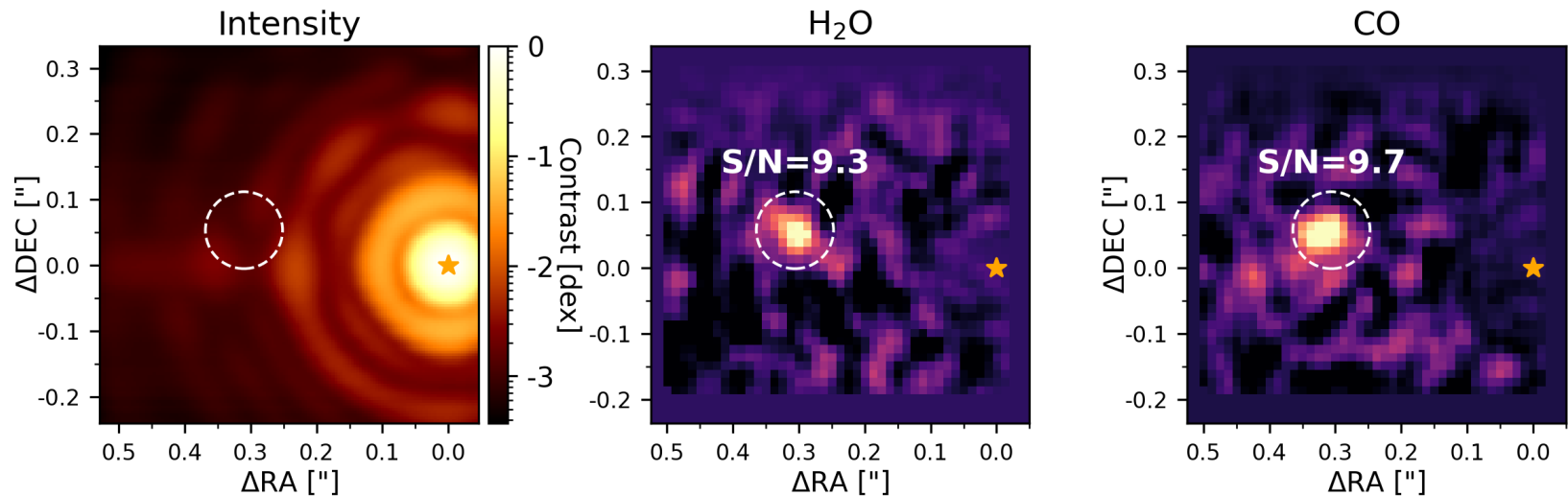
ERIS candidates around R = 14 mag (Maio in prep.)

ELT discovery space for protoplanets



Unveiling the protoplanets population from the outer disk down to a few au with MICADO and PCS (see S. Desidera talk on Thursday)

Primordial atmospheres



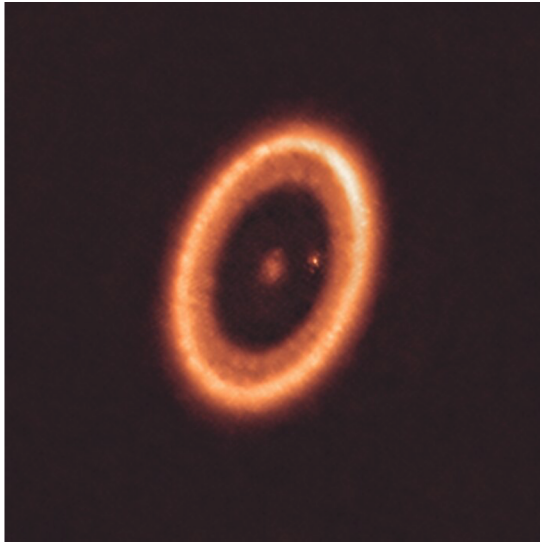
Hayoz et al. 2025, 2026 w. ERIS/SPIFFIER

Spectroscopic follow-up (MICADO-IFU / HARMONI / ANDES) for composition of primordial atmospheres (see also talk by F. Borsa)

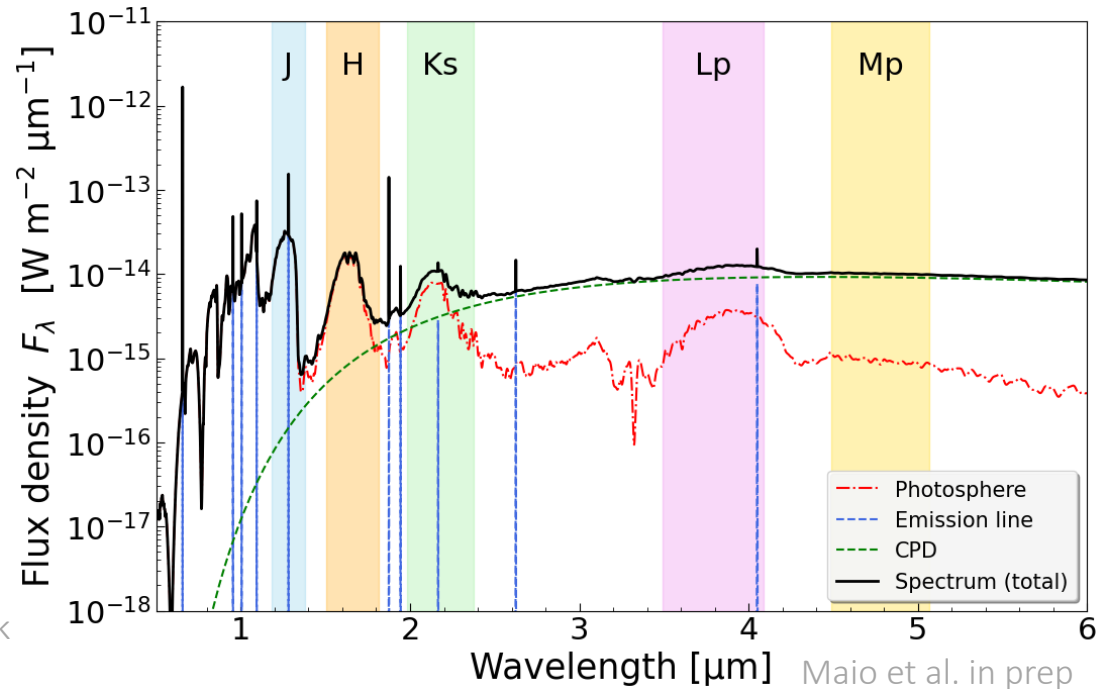
Ongoing tests with CRIRES+ (Cheng, Pino, Testi)

Link atmospheric composition to disk chemical composition (ALMA)

Circuplanetary disks and accretion shock

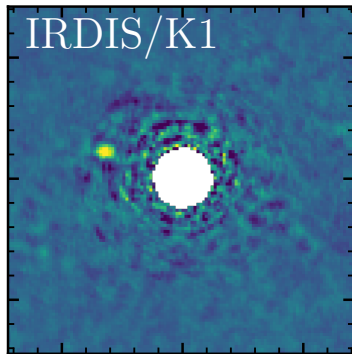
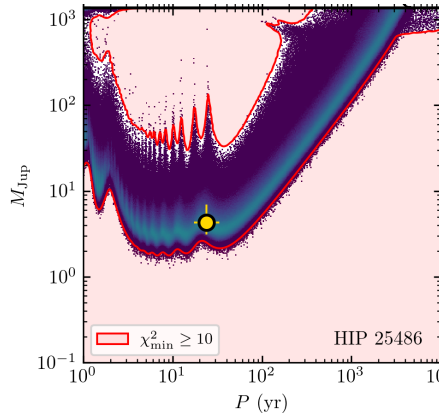


ALMA detection of a circumplanetary disk
Benisty et al. 2021)



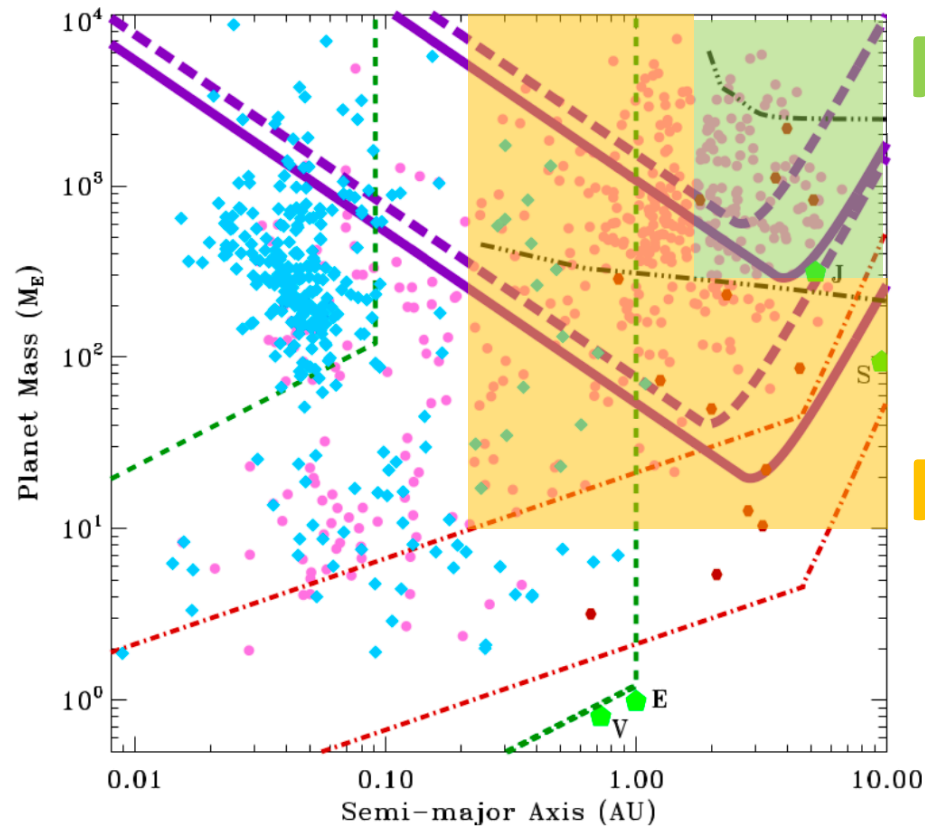
Spectro-photometric characterization of circumplanetary disk (METIS & ALMA)
and accretion shock (M-IFU / HARMONI / ANDES) (poster by E. Fiorellino)

Giant planets in the Solar neighborhood



e.g. De Rosa et al. 2023

Mesa et al. 2023



MICADO

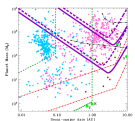
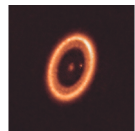
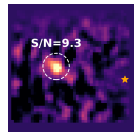
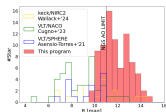
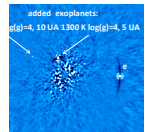
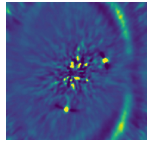
PCS

Sozzetti & de Bruijne 2013

MICADO (and PCS) follow-up of RV and Gaia DR4 candidates

Towards a global view of planetary systems (see poster by C. Lazzoni)

Recap



MICADO will be the first instrument capable of direct detection of protoplanets planets in the inner star forming region ($< 10\text{-}20\text{ au}$)

Jupiter-like planets detectable at the snowline in the nearest moving groups

NGS down to $R \sim 14$ mag (or more if NIR WFS) will allow to observe the bulk disk population in the nearby star forming region

M-IFU/HARMONI/ANDES spectroscopic follow-up for primordial atmospheric composition

Synergy with METIS and ALMA to characterize circumplanetary disk and accretion shocks

Approaching the discovery space of indirect methods – precise measurement of mass and radius, global view of planetary systems



VLT/ERIS



LBT/ SHARK-NIR
LBT/SHARK-VIS

