Demographics of young super Jovian planets beyond the snowline

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on behalf on the SHINE consortium

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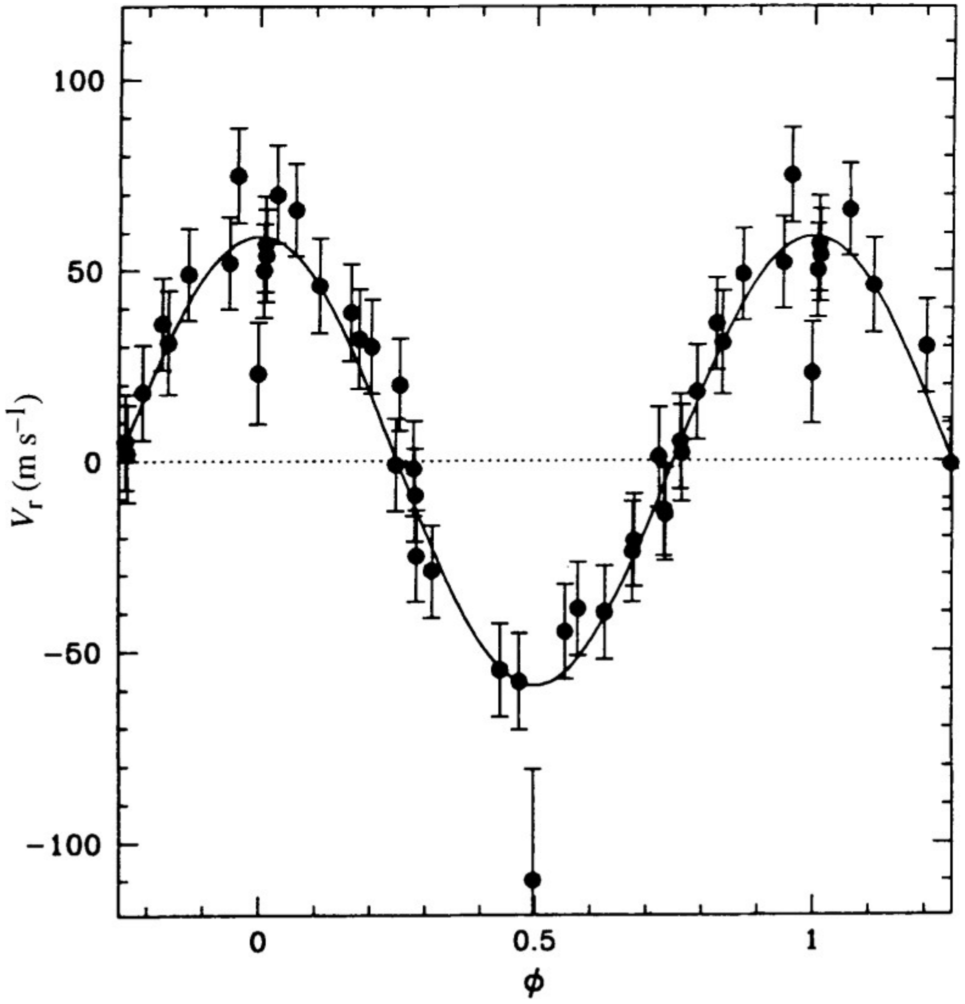
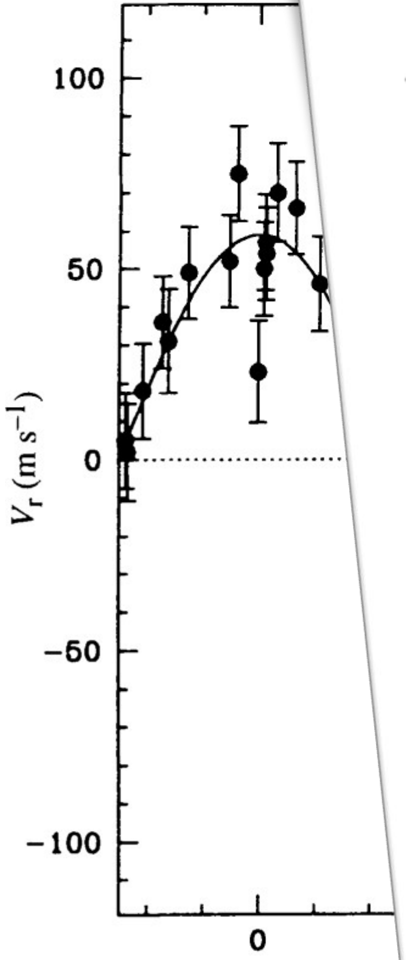
51 Pegasi b: Cool Giant Planets And Their Systems

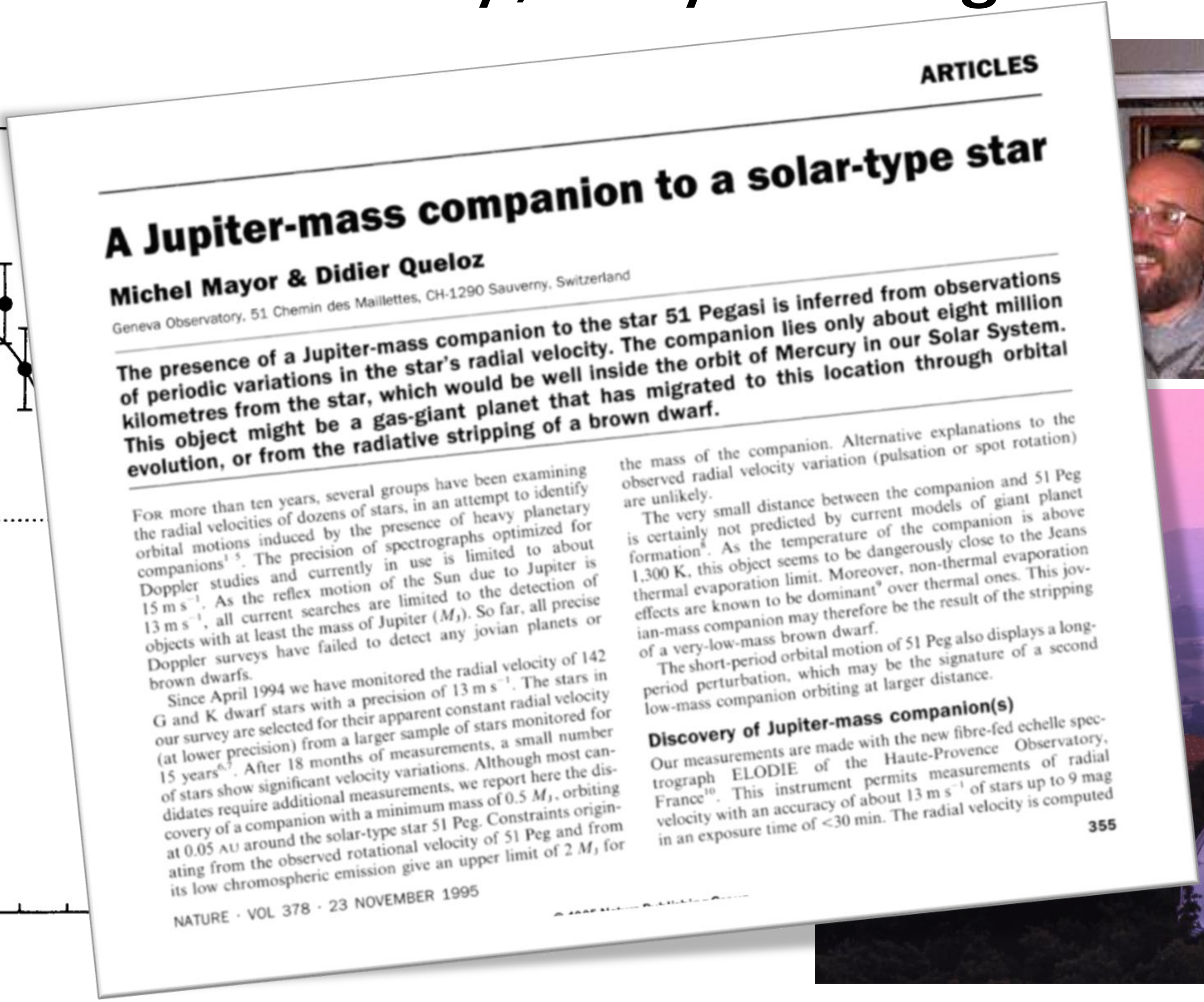
Saint-Michel-l'Observatoire, France – 6 Oct 2025

On this day, 30 years ago...



On this day, 30 years ago…





ARTICLES

A Jupiter-mass companion to a solar-type star

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The presence of a Jupiter-mass companion to the star 51 Pegasi is inferred from observations of periodic variations in the star's radial velocity. The companion lies only about eight million kilometres from the star, which would be well inside the orbit of Mercury in our Solar System. This object might be a gas-giant planet that has migrated to this location through orbital evolution, or from the radiative stripping of a brown dwarf.

For more than ten years, several groups have been examining the radial velocities of dozens of stars, in an attempt to identify orbital motions induced by the presence of heavy planetary companions[1-5]. The precision of spectrographs optimized for Doppler studies and currently in use is limited to about 15 m s^{-1}. As the reflex motion of the Sun due to Jupiter is 13 m s^{-1}, all current searches are limited to the detection of objects with at least the mass of Jupiter (M_J). So far, all precise Doppler surveys have failed to detect any jovian planets or brown dwarfs.

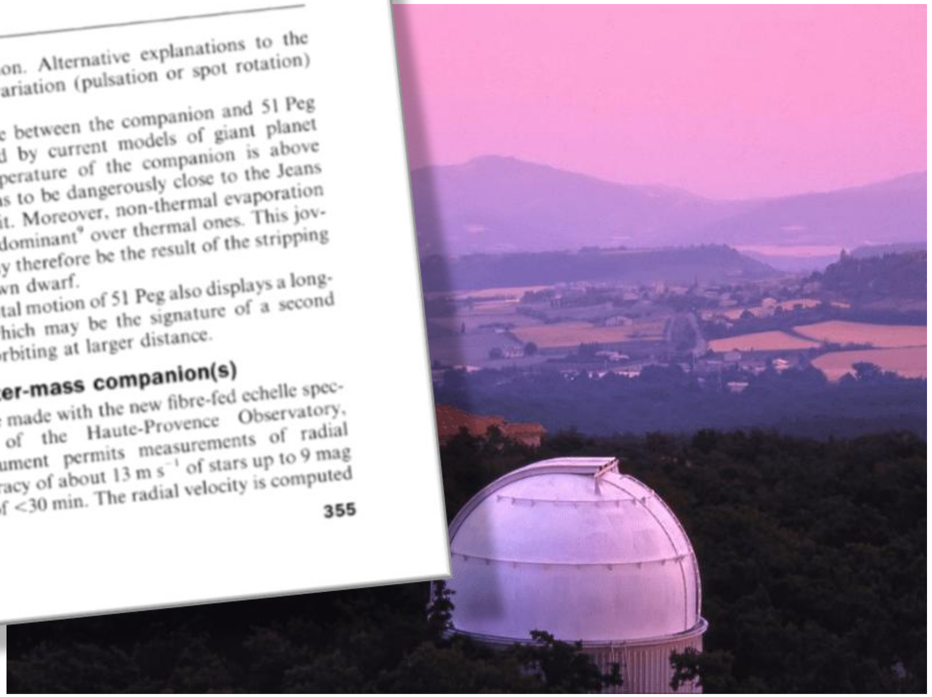
Since April 1994 we have monitored the radial velocity of 142 G and K dwarf stars with a precision of 13 m s^{-1}. The stars in our survey are selected for their apparent constant radial velocity (at lower precision) from a larger sample of stars monitored for 15 years[6,7]. After 18 months of measurements, a small number of stars show significant velocity variations. Although most candidates require additional measurements, we report here the discovery of a companion with a minimum mass of 0.5 M_J, orbiting at 0.05 AU around the solar-type star 51 Peg. Constraints originating from the observed rotational velocity of 51 Peg and from its low chromospheric emission give an upper limit of 2 M_J for the mass of the companion. Alternative explanations to the observed radial velocity variation (pulsation or spot rotation) are unlikely.

The very small distance between the companion and 51 Peg is certainly not predicted by current models of giant planet formation[8]. As the temperature of the companion is above 1,300 K, this object seems to be dangerously close to the Jeans thermal evaporation limit. Moreover, non-thermal evaporation effects are known to be dominant[9] over thermal ones. This jovian-mass companion may therefore be the result of the stripping of a very-low-mass brown dwarf.

The short-period orbital motion of 51 Peg also displays a long-period perturbation, which may be the signature of a second low-mass companion orbiting at larger distance.

Discovery of Jupiter-mass companion(s)

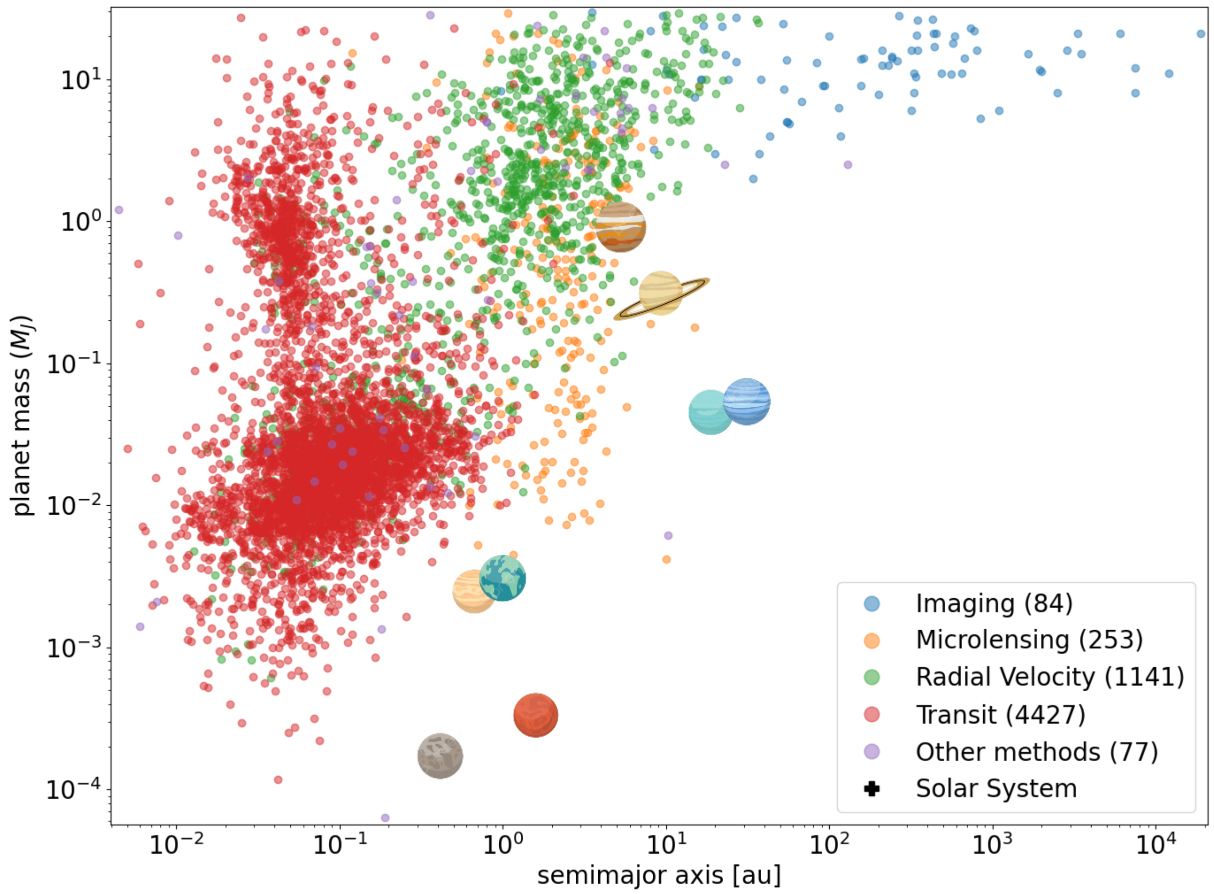
Our measurements are made with the new fibre-fed echelle spectrograph ELODIE of the Haute-Provence Observatory, France[10]. This instrument permits measurements of radial velocity with an accuracy of about 13 m s^{-1} of stars up to 9 mag in an exposure time of <30 min. The radial velocity is computed



Three decades later

P: space of all physical, orbital and stellar-host properties of confirmed exoplanets

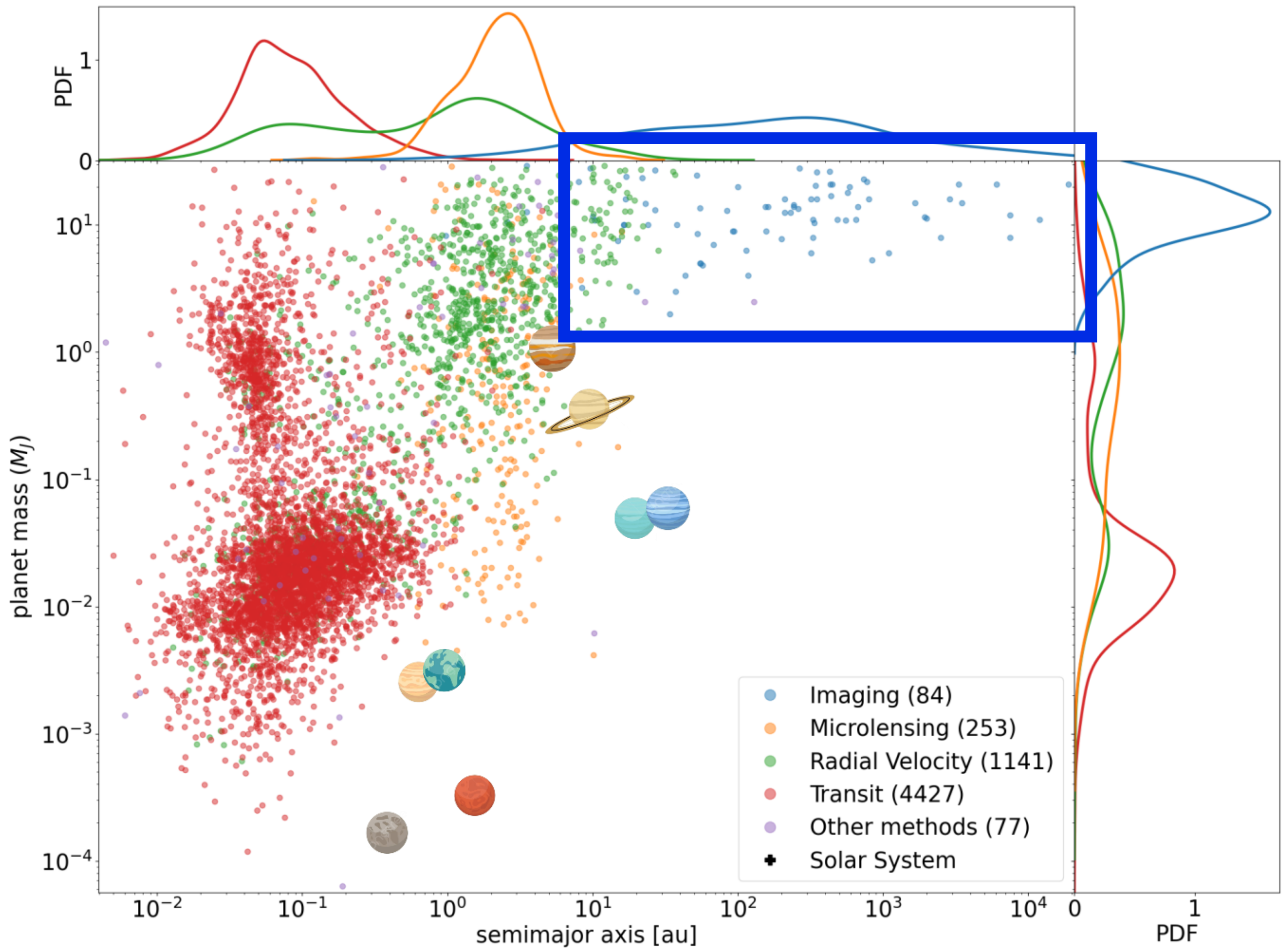
- A huge diversity of exoplanets
- No detection technique can probe the entirety of P
- A complete and unbiased coverage of P is the key to understanding planet formation processes



Why direct imaging?

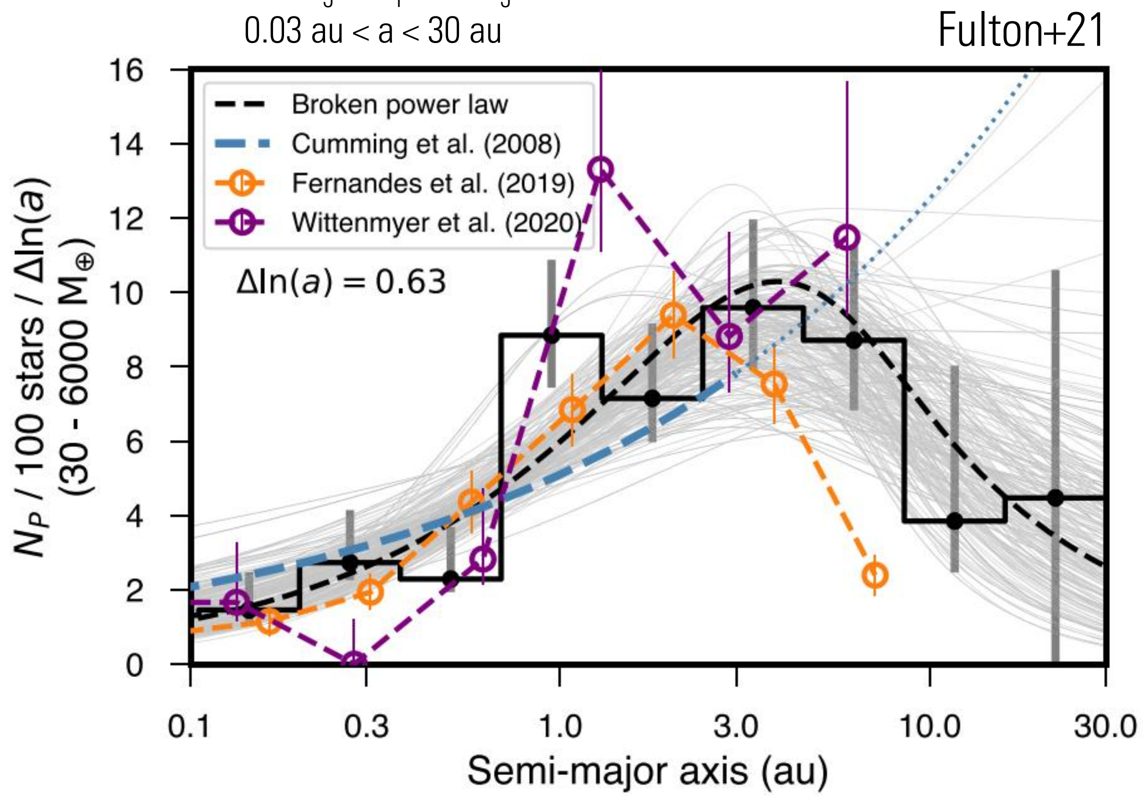
P: space of all physical, orbital and stellar-host properties of confirmed exoplanets

- A huge diversity of exoplanets
- No detection technique can probe the entirety of *P*
- A complete and unbiased coverage of *P* is the key to understanding planet formation processes
- Direct imaging (DI) enables the detection of giant planets in the outer regions ($\gtrsim$10 au) around young ($\lesssim$500 Myr) stars

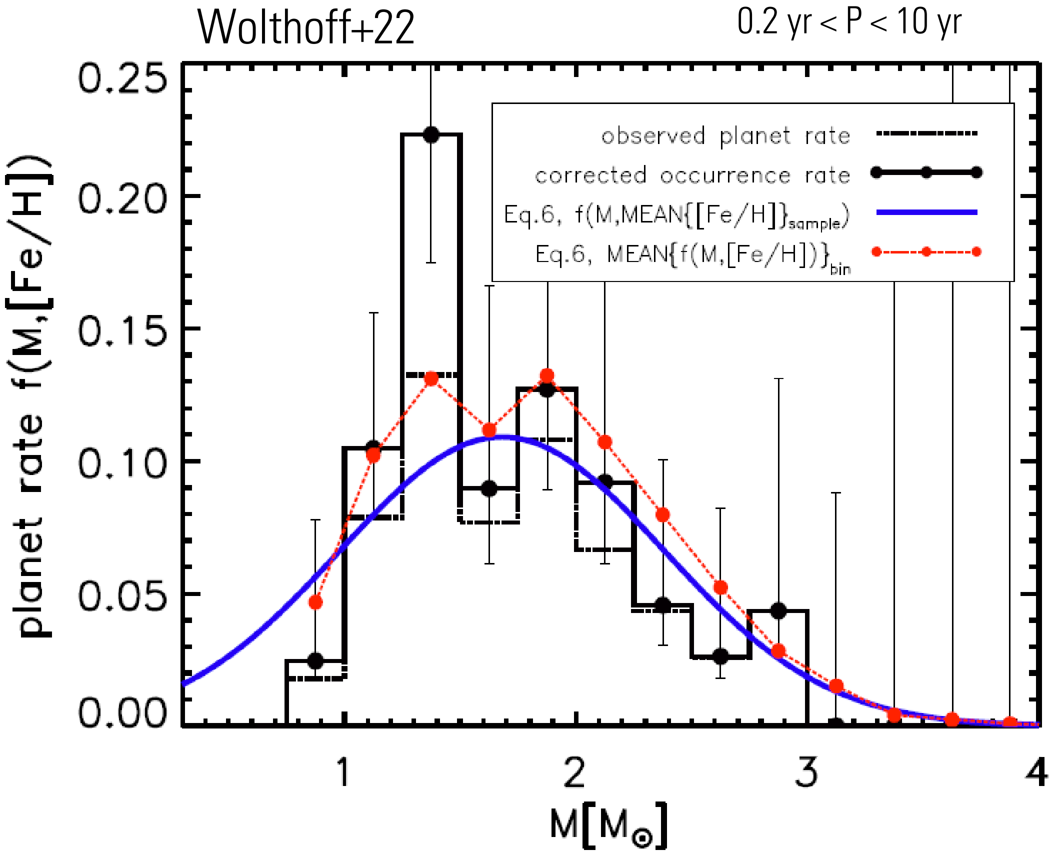


Why direct imaging?

$0.1\,M_J < M_P < 20\,M_J$
0.03 au $< a < 30$ au



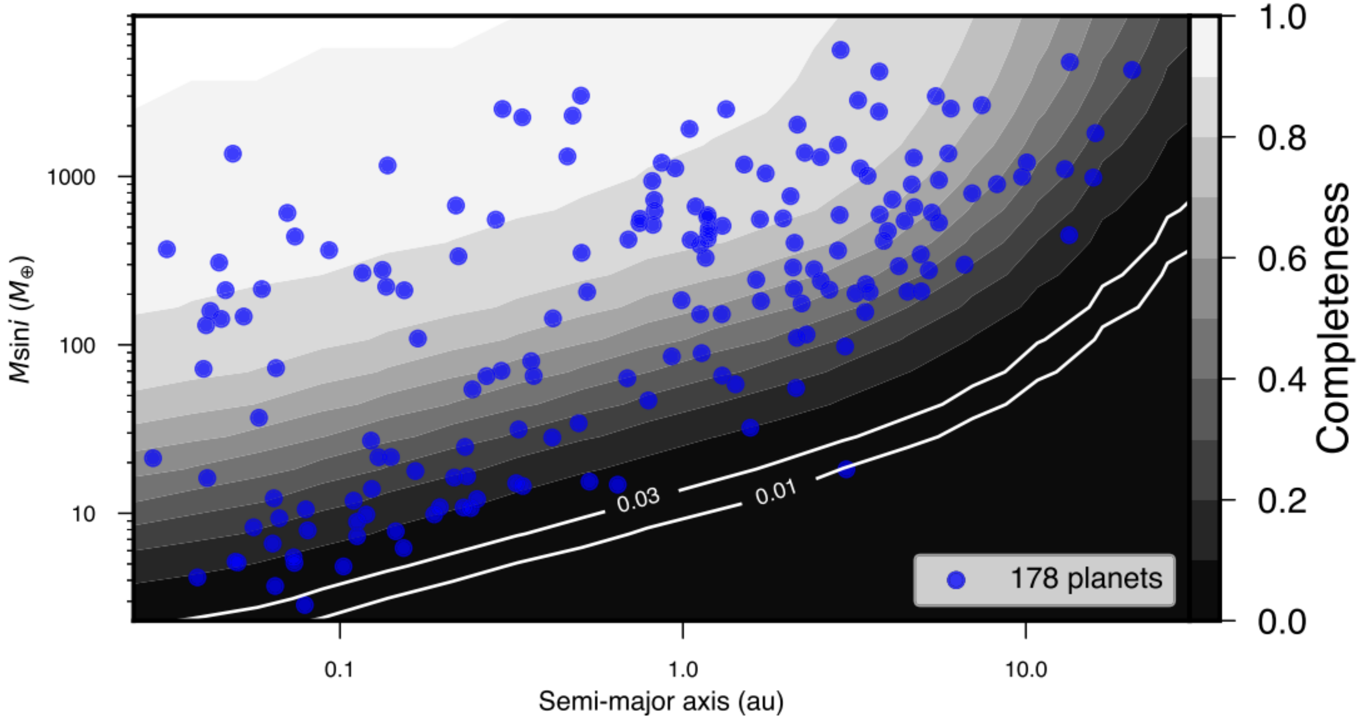
$0.5\,M_J < M_P < 30\,M_J$
0.2 yr $< P < 10$ yr



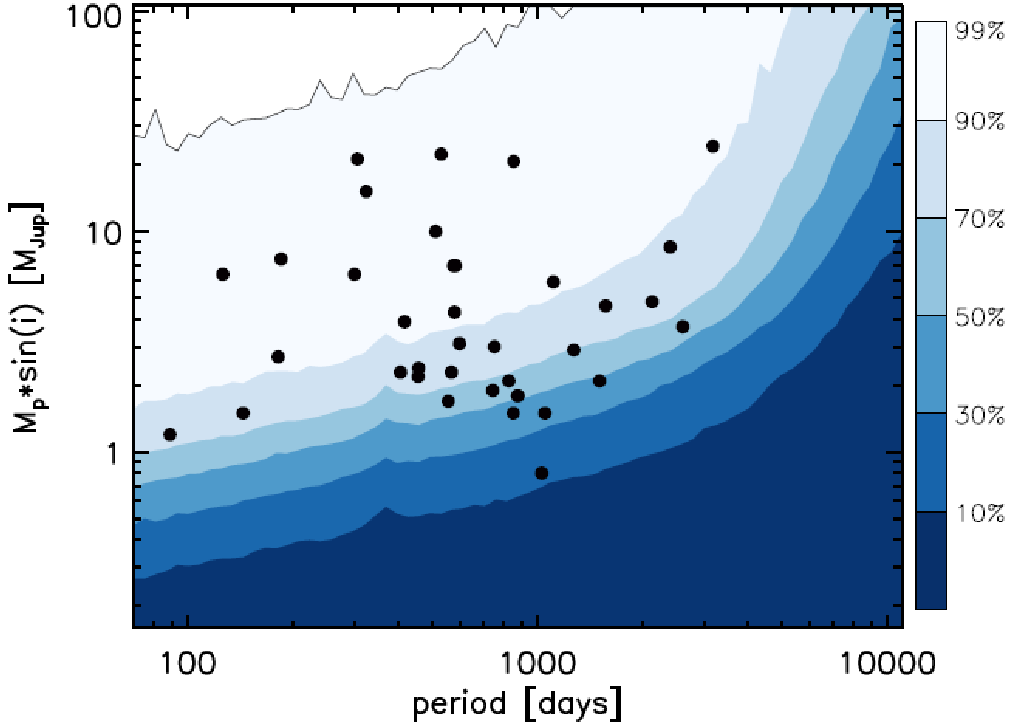
- Our current understanding of the (cold) giant population is based on radial velocity studies

Why direct imaging?

Fulton+21



Wolthoff+22



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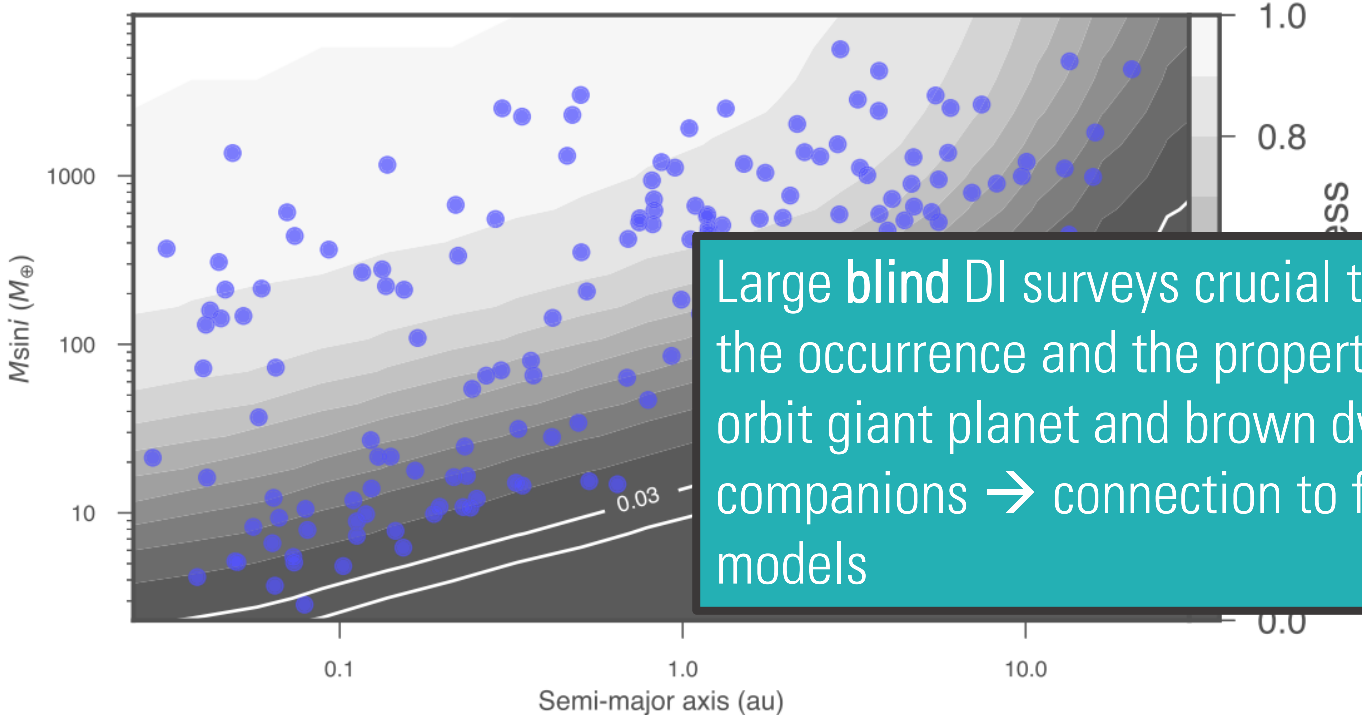

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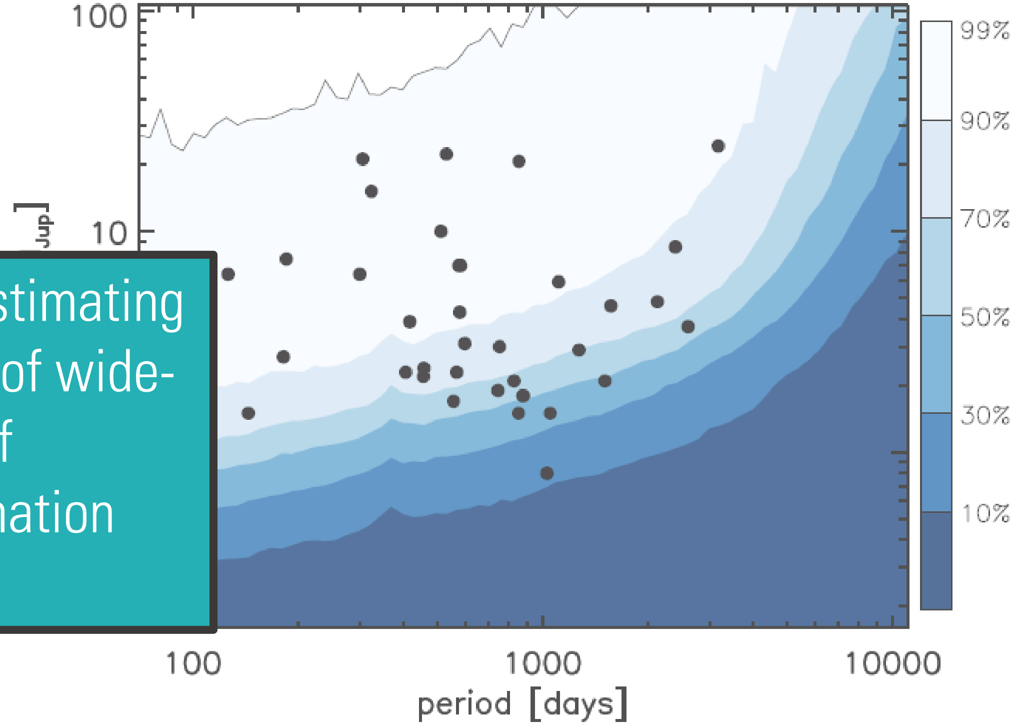

Large **blind** DI surveys crucial to estimating the occurrence and the properties of wide-orbit giant planet and brown dwarf companions → connection to formation models

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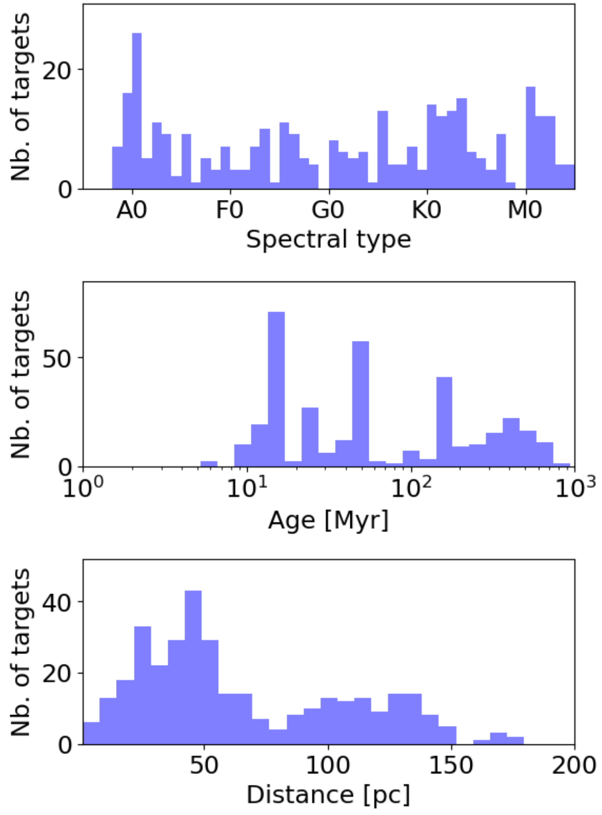
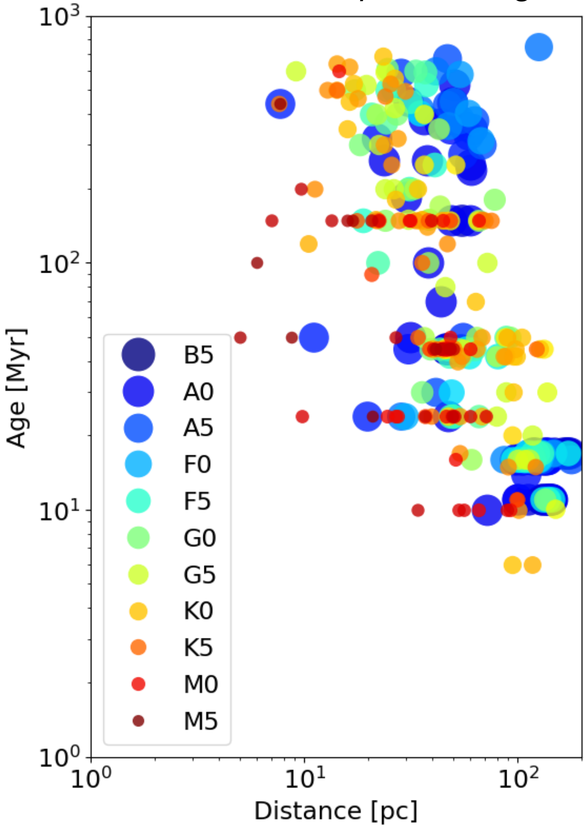
The SHINE survey: sample

- A GTO survey of 400 young close-by stars at SPHERE/VLT, 200 nights, between 2015 and 2021 (Desidera+21, Squicciarini+ in prep.)
- Biggest DI survey together with the 600-star GPIES survey @ Gemini South
- Targeted single stars: excluded known spectroscopic and close binaries to enhance detection limits and to build a uniform sample
- Ages computed from membership to young moving groups and associations, youth indicators (lithium, activity, rotation), isochrone fitting
- Stellar masses uniformly derived using PARSEC isochrones via the tool MADYS (Squicciarini & Bonavita 2022)



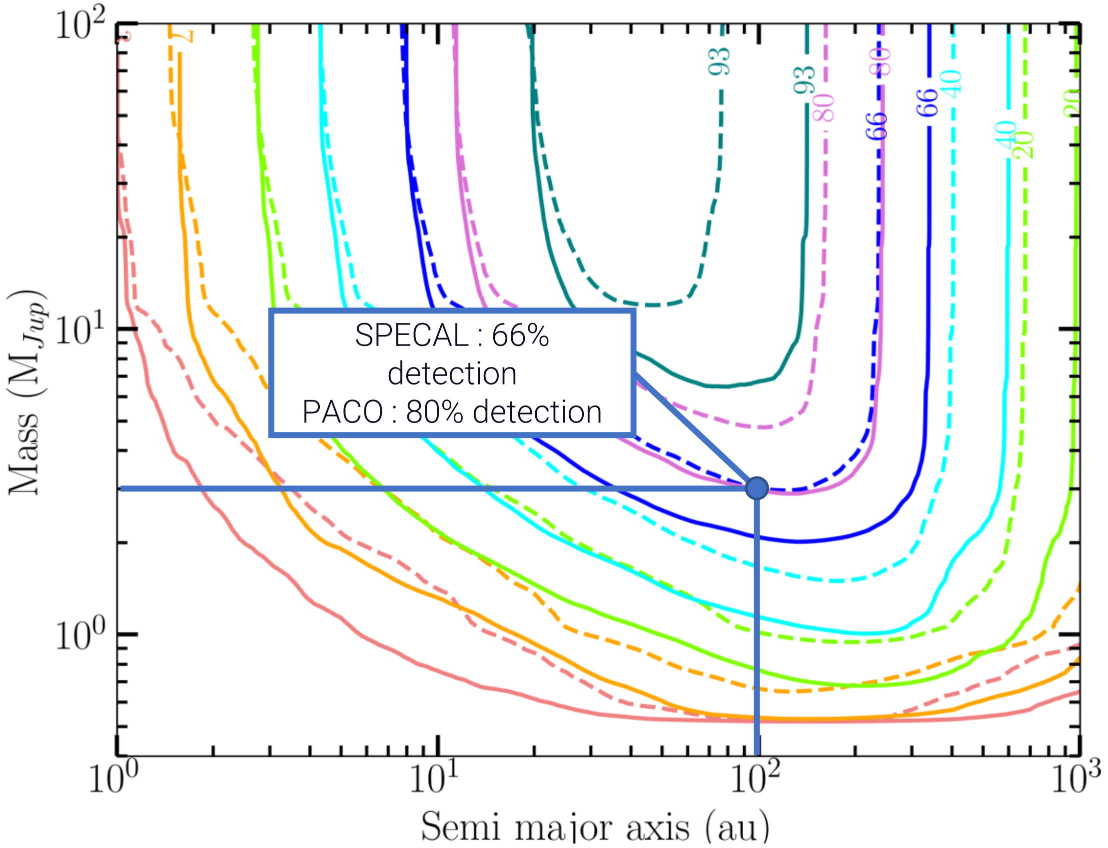
Courtesy of A. Vigan



The SHINE survey: data reduction

- Instruments aboard AO-fed 8-m-class telescopes reach planet-to-star flux contrast $\sim 10^{-4}$ at 1 arcsec
- A significant (10^2) improvement can be reached through post-processing algorithms

Chomez+25, compared to mid-survey analysis (Langlois+21, Vigan+21)



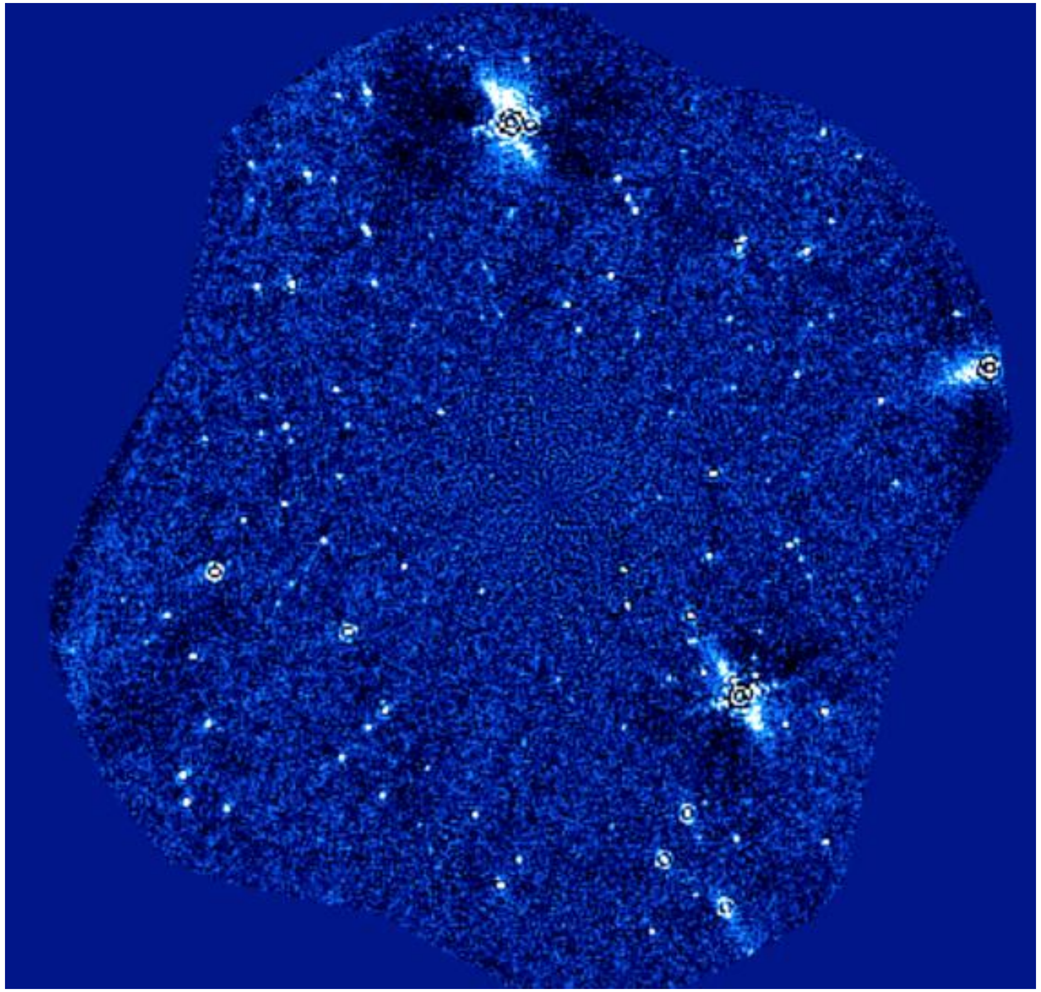
PACO (Flasseur+18, 20): a post-processing algorithm based on angular and spectral differential imaging; increased sensitivity compared to classical algorithms (Chomez+23)

State-of-the-art post-processing algorithms can yield significant performance improvement over classical methods

The SHINE survey: vetting candidates

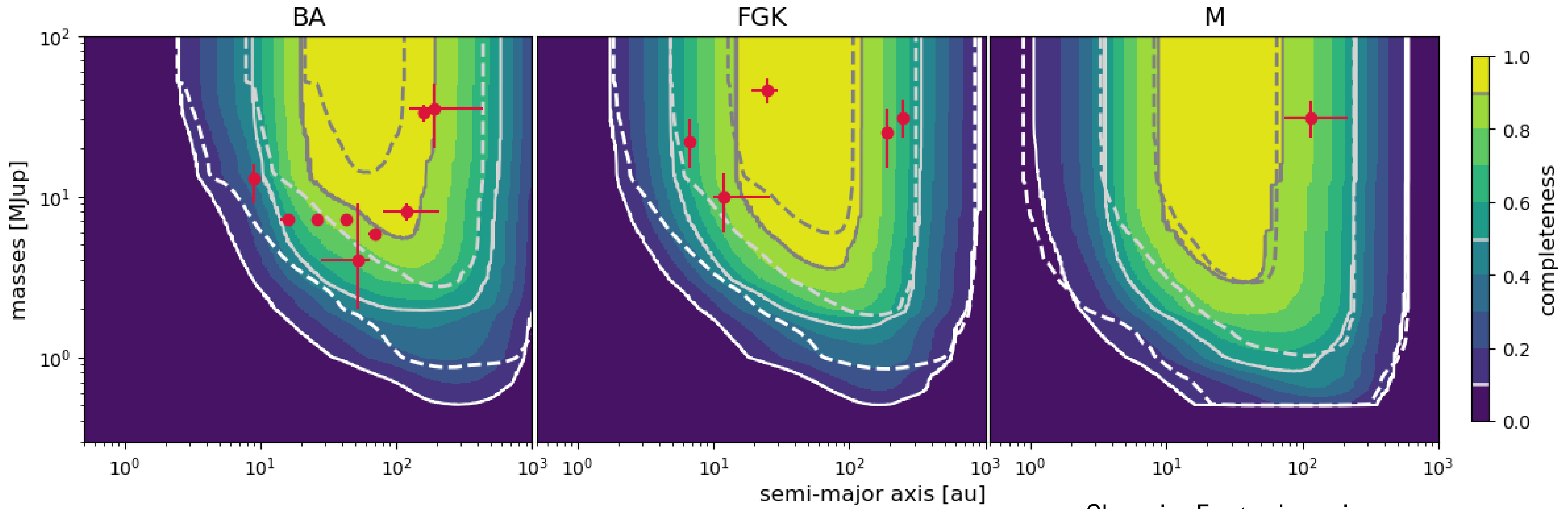
- Thousands of sources detected
- Most of them are unrelated background stars projected at short separation
- Proper motion and color analysis to identify substellar companions
- New companions: HIP 64892 B (Cheetham et al. 2018), HIP 65426 b (Chauvin et al. 2017)

15 companions around 400 stars. No confirmed new planet yet after the new reduction, but still following up a few companion candidates



The SHINE survey: statistical analysis

- Splitted the sample into BA (120), FGK (135), and M (91) hosts to investigate the dependence of the occurrence frequency on mass
- Significant completeness increase over previous analyses (Langlois+21, Vigan+21)

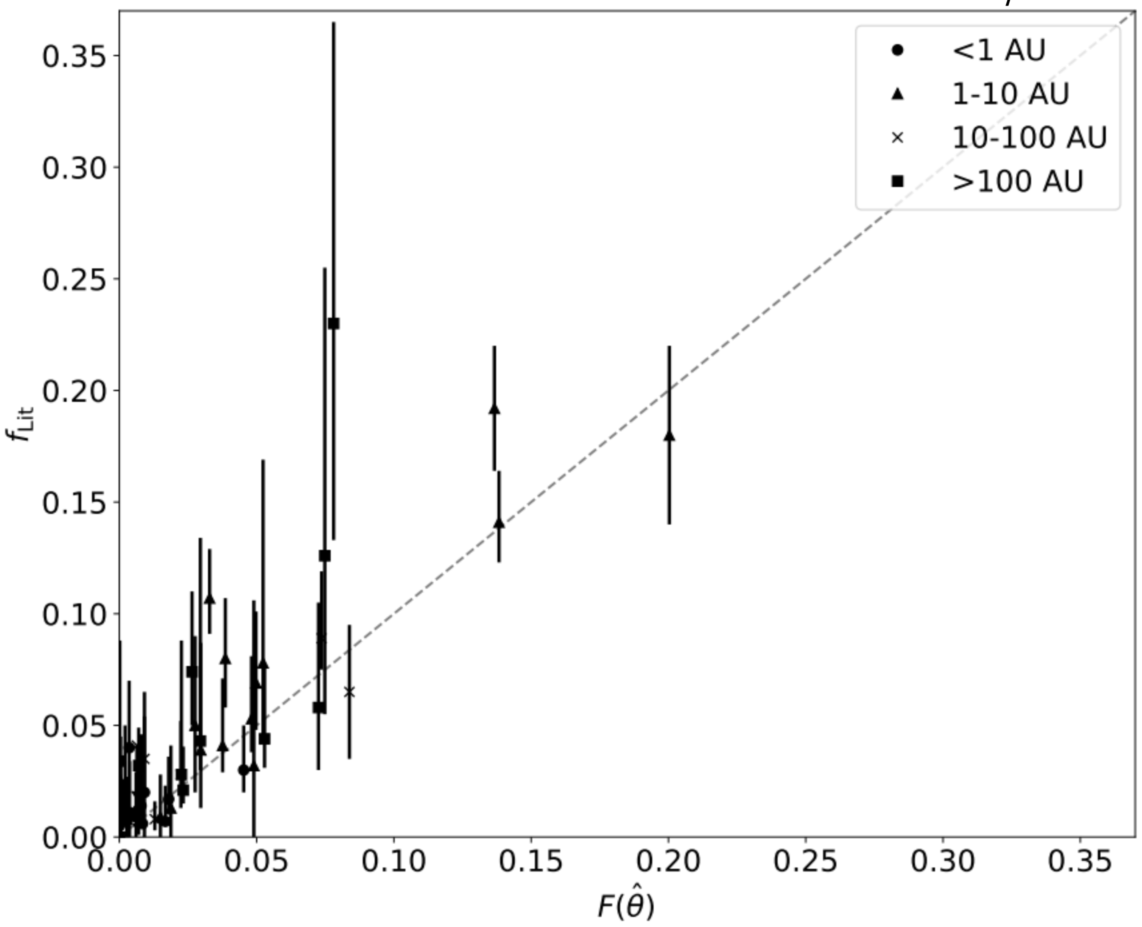


Chauvin, Fontanive + in prep.

The SHINE survey: statistical analysis

- Two-population empirical model (Meyer+25)
  - Planet-like population (bottom-up process ~ core accretion)
  - Star-like population (top-down process ~ gravitational instability)
- Assumptions:
  - log-normal distribution in semi-major axis, power law in mass ratio
  - The mass ratio part does not depend on semi-major axis
- Data to derive the model's parameter from radial velocity and direct imaging surveys

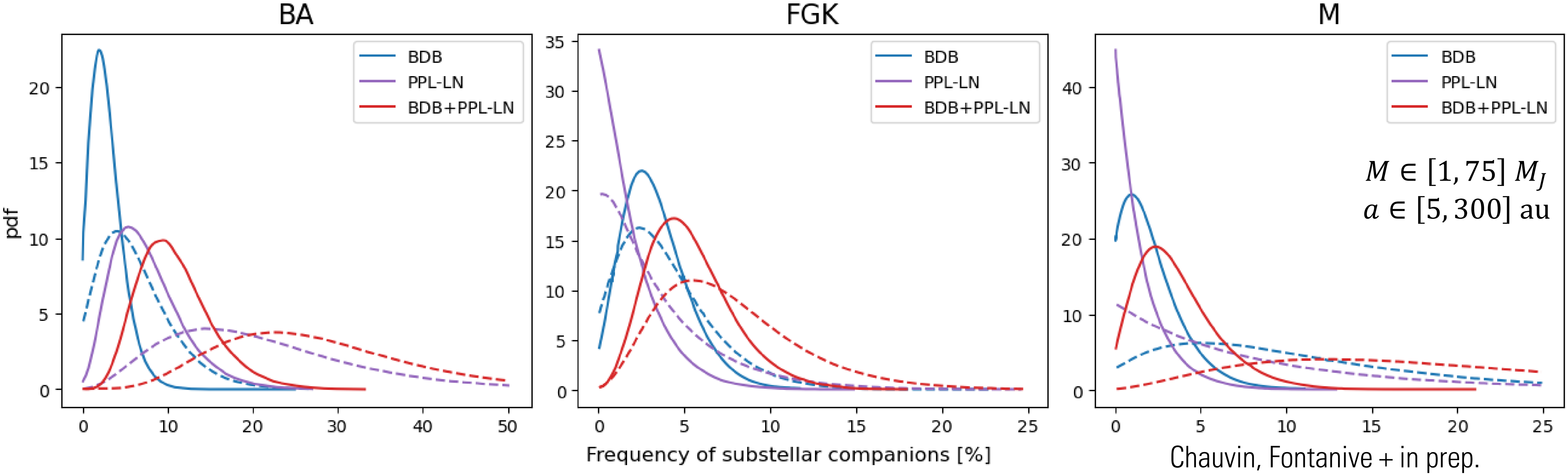
Meyer+25



Yields from the literature vs predictions from the model

The SHINE survey: statistical analysis

- The overall frequency of substellar companions is **higher** around BA stars than around FGK and M stars (cp. BEAST, Delorme+24)
- While for BA stars the planet-like part dominates, the star-like part dominates for FGK and M stars

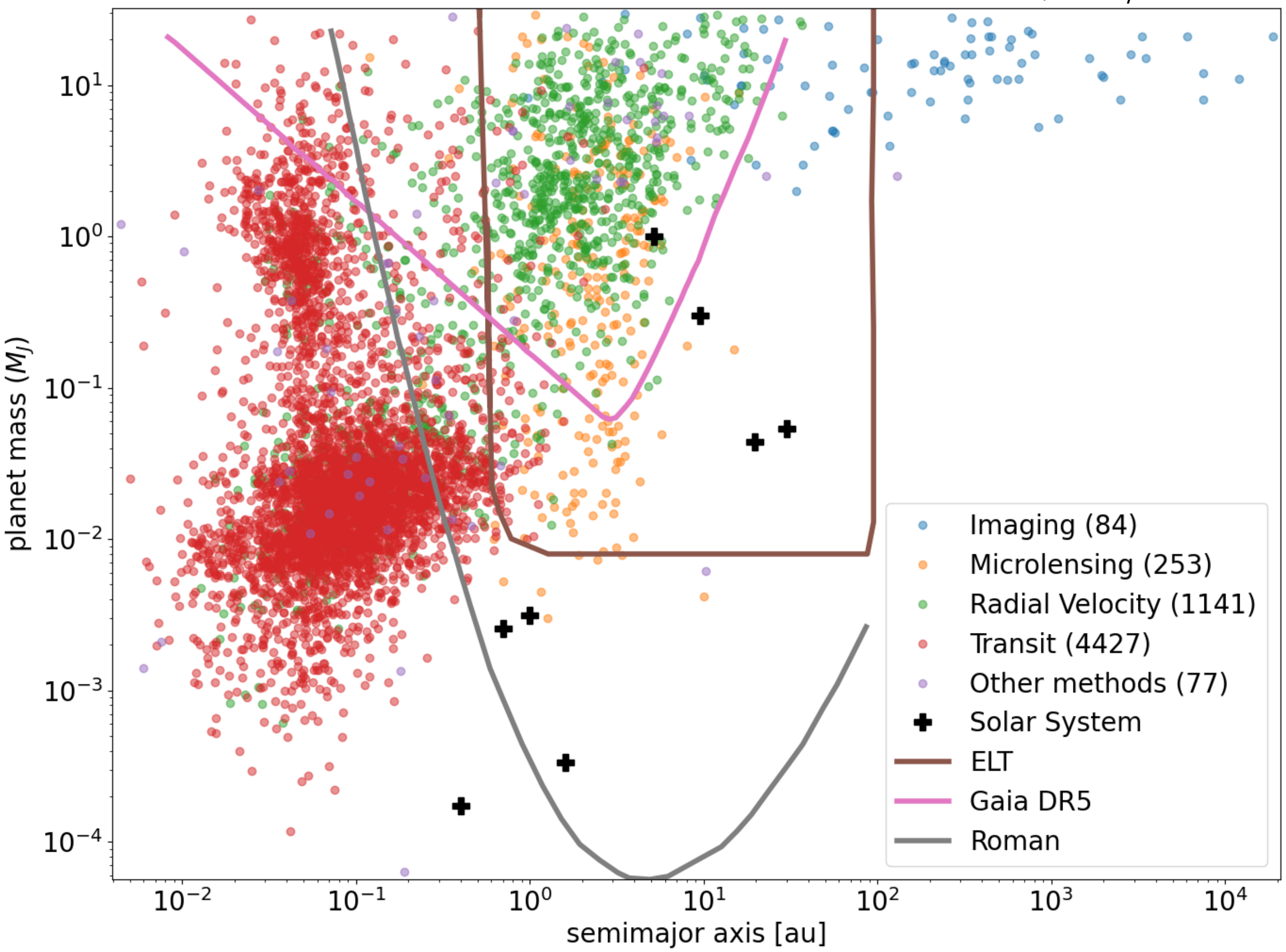


Chauvin, Fontanive + in prep.

Future perspectives

Based on G. Chauvin, Sozzetti & de Bruijne 2018, Penny+19

- Coupling latest results from GPIES (Squicciarini+25) and SHINE (Chauvin, Fontanive + in prep) to get the best DI constraints to substellar companion frequency (Squicciarini + in prep)
- Piercing the sub-Jupiter regime: DI surveys with JWST, Roman and the ELT
- Astrometry: Gaia DR4 & DR5
- Merging direct imaging, radial velocity, microlensing and astrometry results and comparison to formation models



Thank you for your attention!

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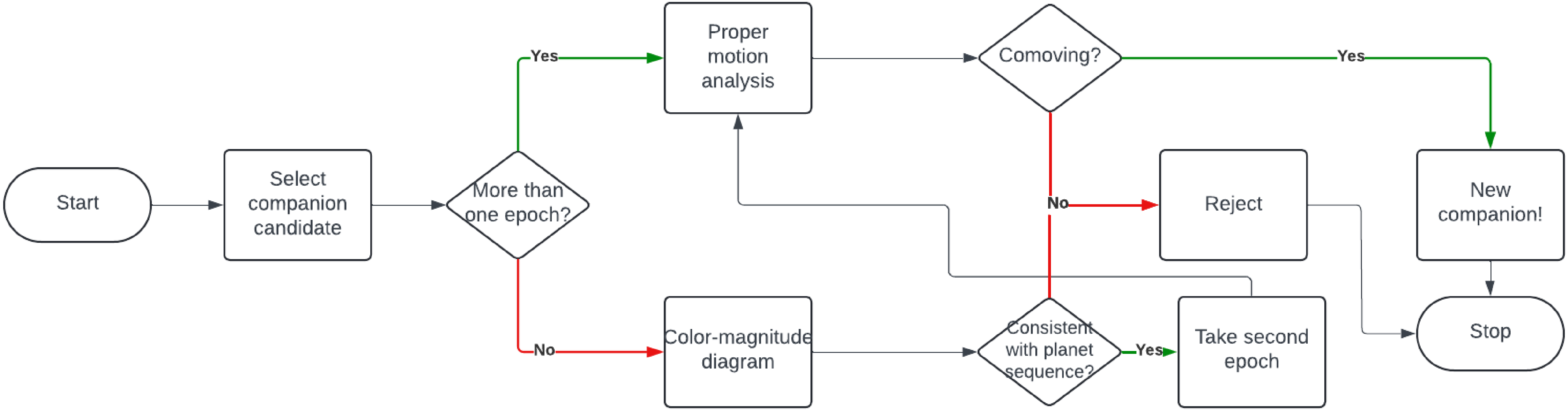
Backup slides

Vetting candidates

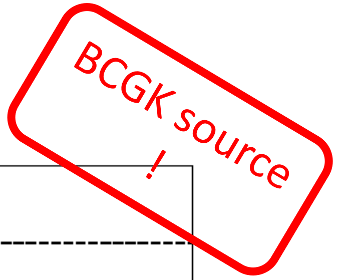
- Thousands of sources detected during the reanalysis
- How can we distinguish bound companions from unrelated background objects which happen to be in the field of view (FOV) *by chance*?



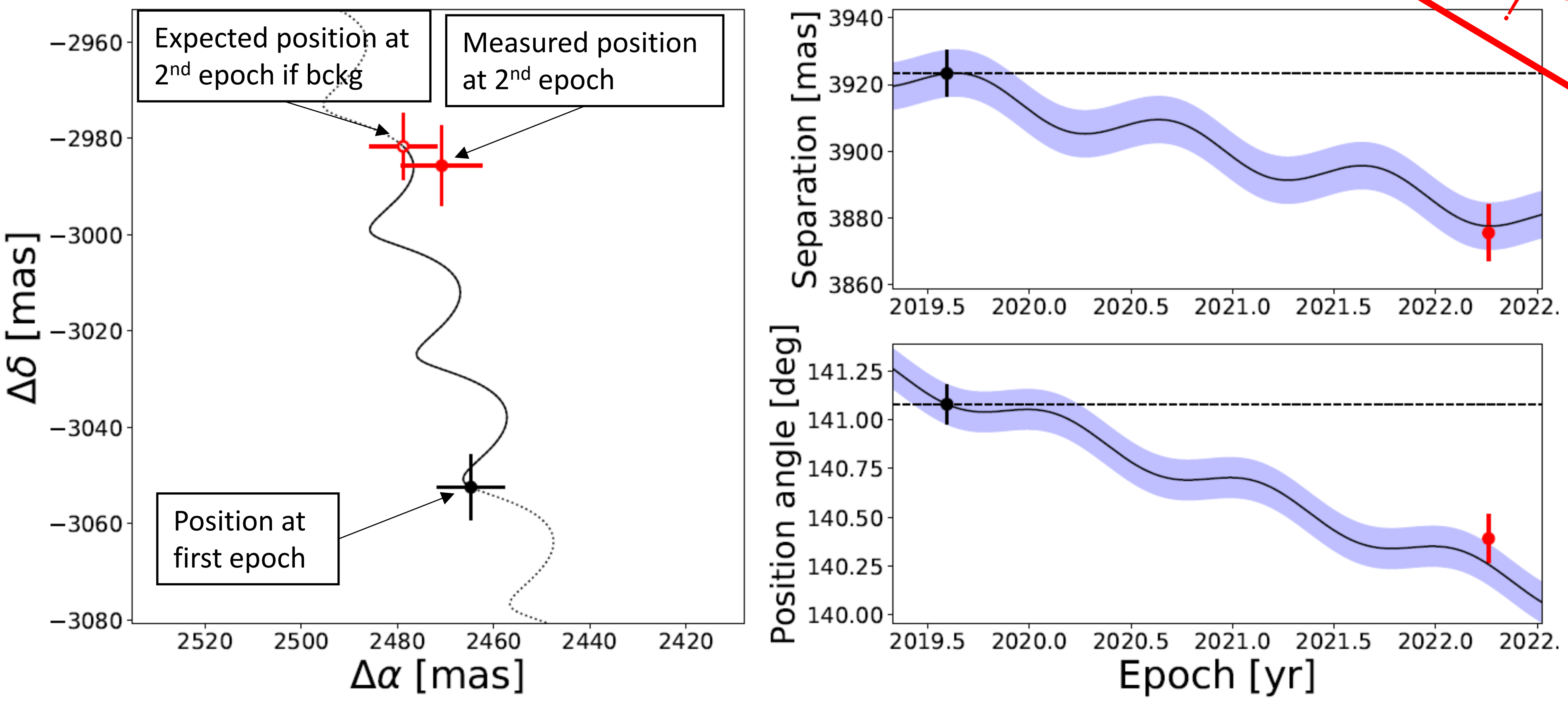
Common proper motion

Proper motion ∝ distance^{-1}

→ background stars usually much slower than the close-by stars targeted by imaging



credits: A. Chomez



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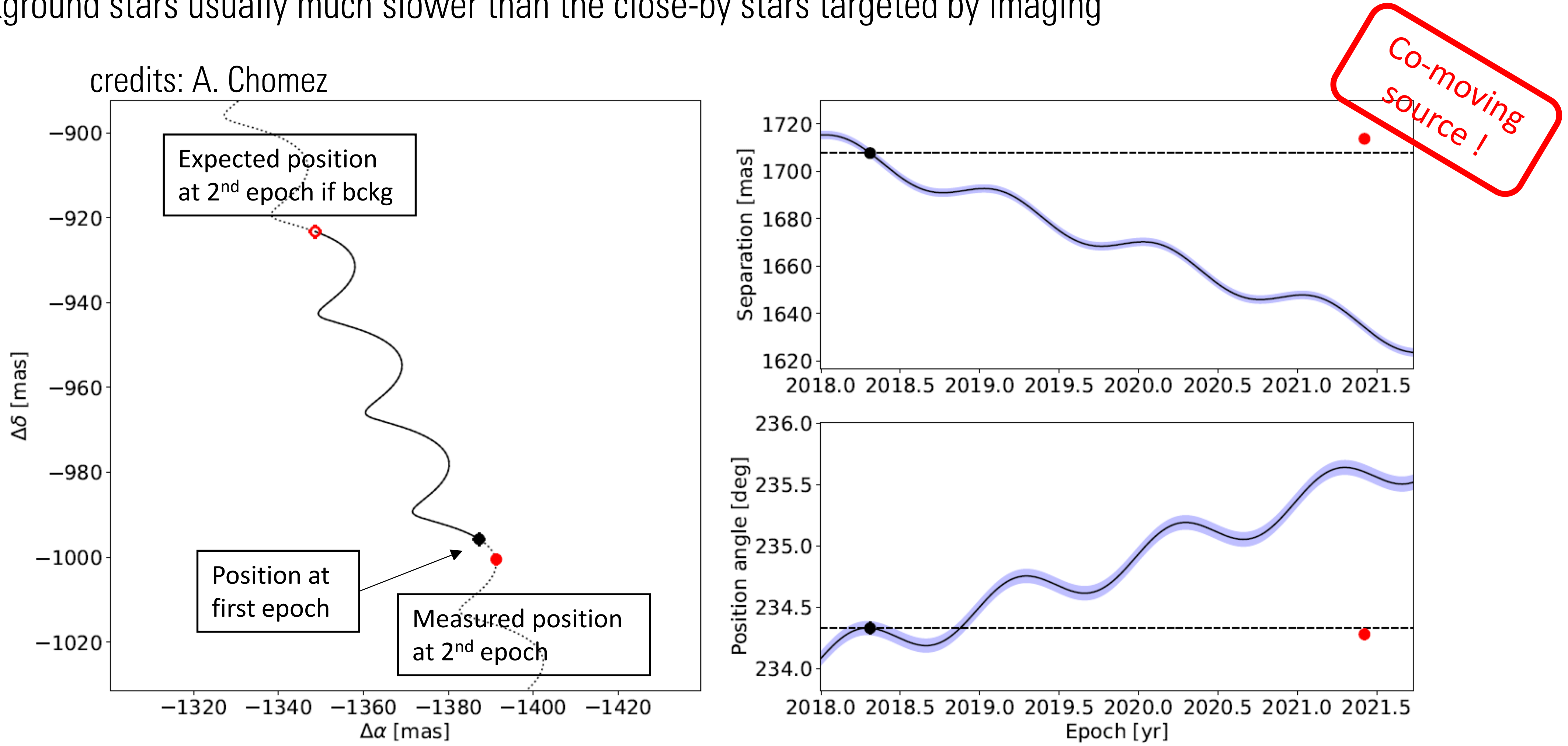

The SHINE survey: vetting candidates

- Young self-luminous companions are not randomly distributed in a color-magnitude diagram (CMD)
  - They follow a vertical sequence which bends to bluer colors at the L-T transition (~1400 K)
- Background sources (=hotter st distance modulus) stay close to
- Based on background stars confirmed via proper motion, we built an exclusion zone as the 5σ locus of colors as a function of absolute magnitude (gray area)

No confirmed new planet yet, but still following up a few companion candidates