Demography

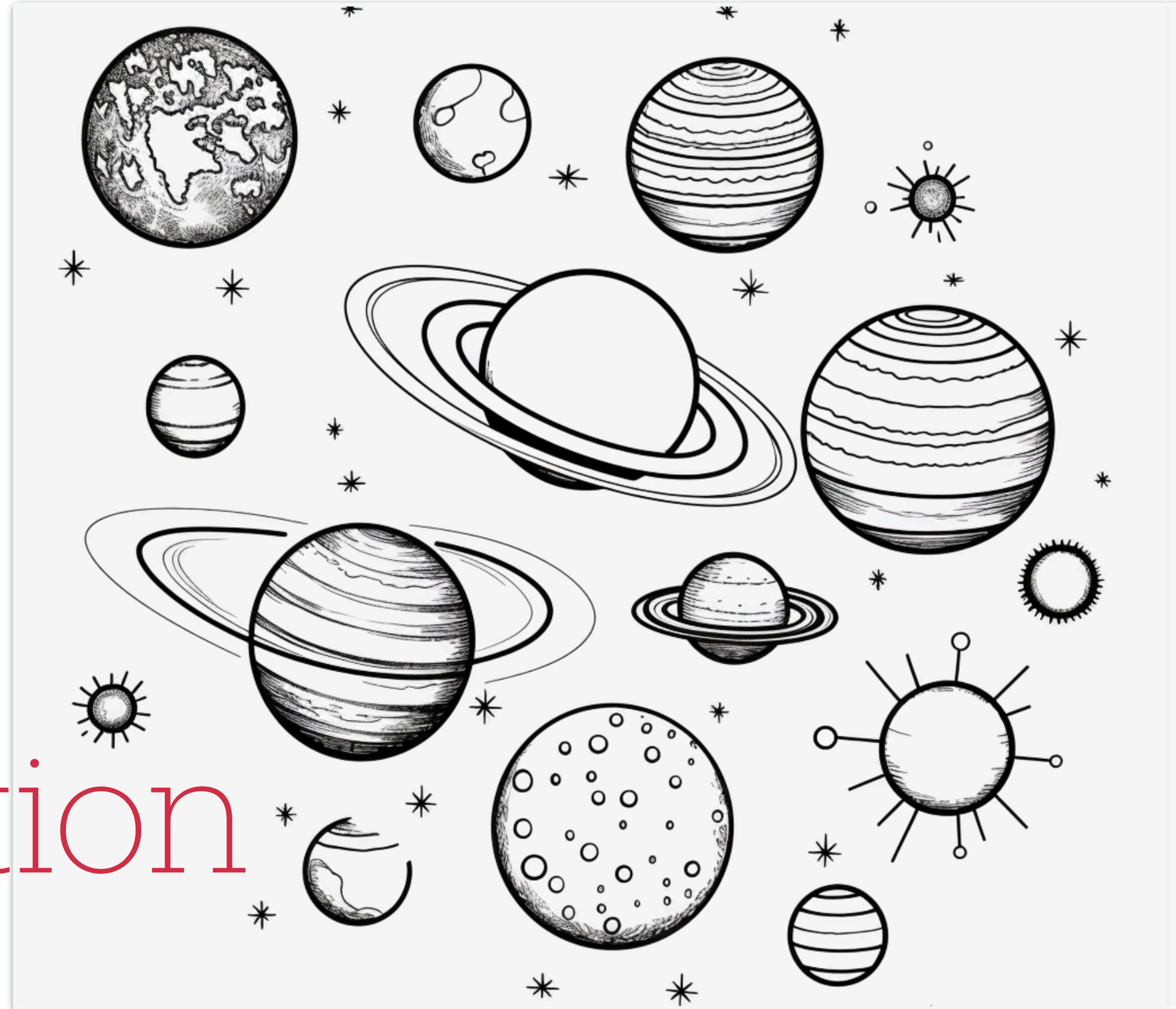
Of giants exoplanets

Isabelle Boisse (LAM/OHP) - Roman Coronography School - 12/03/26

Demography of giant exoplanets

Overview of the lecture

1. Introduction
2. Which planets for Roman ?
3. Observed features of giant exoplanet population
4. Impact of stellar activity on parameter characterization
5. Eccentric or multiple long-period Jupiter planets ?
6. Futur prospects for Roman targets



Introduction

Demography of giants exoplanet population

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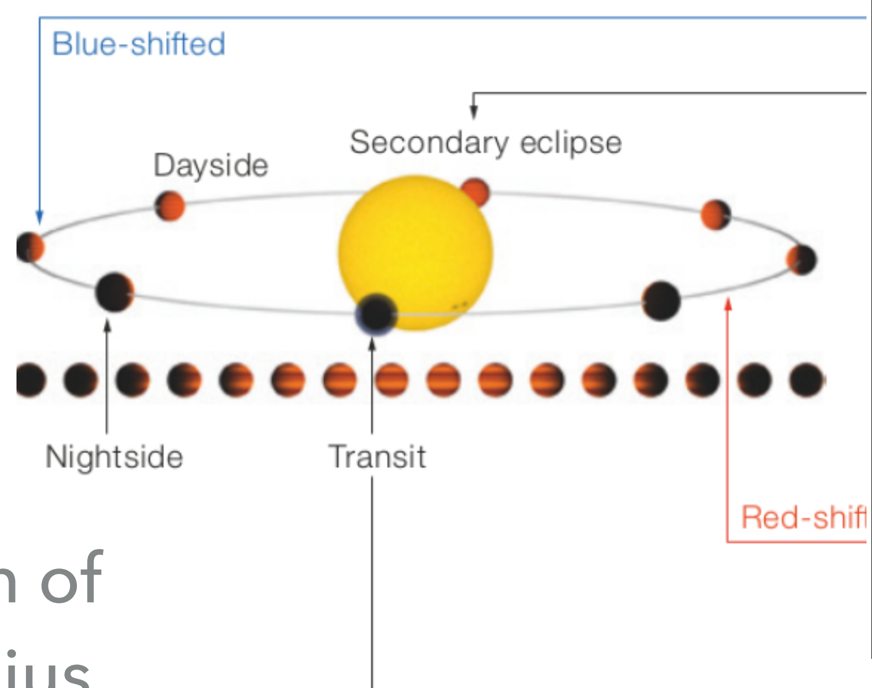
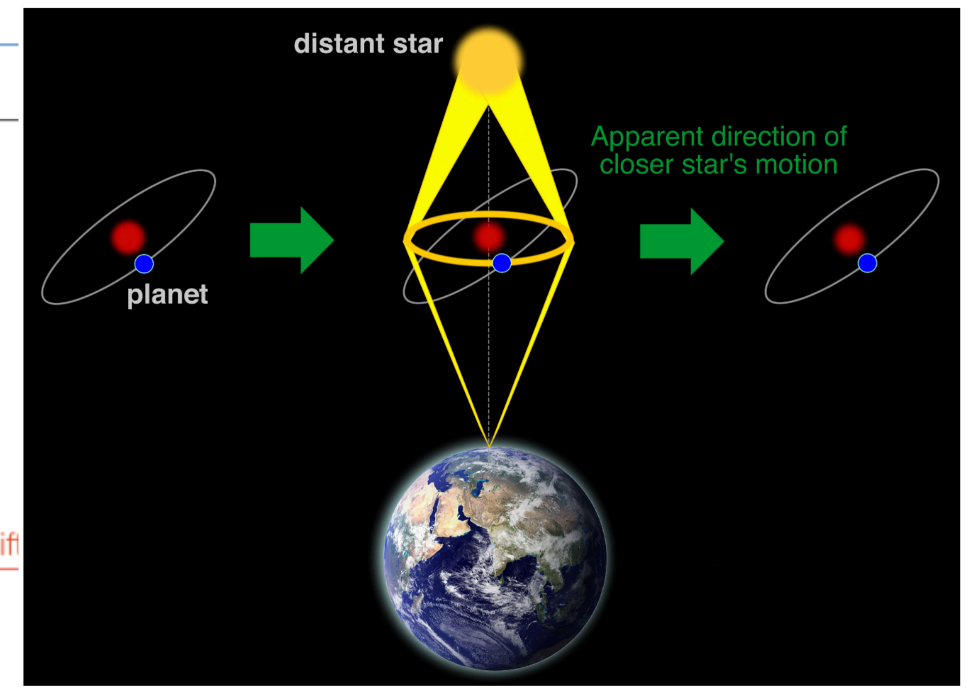
30 years of discovery

A DIVERSITY OF OBJECTS

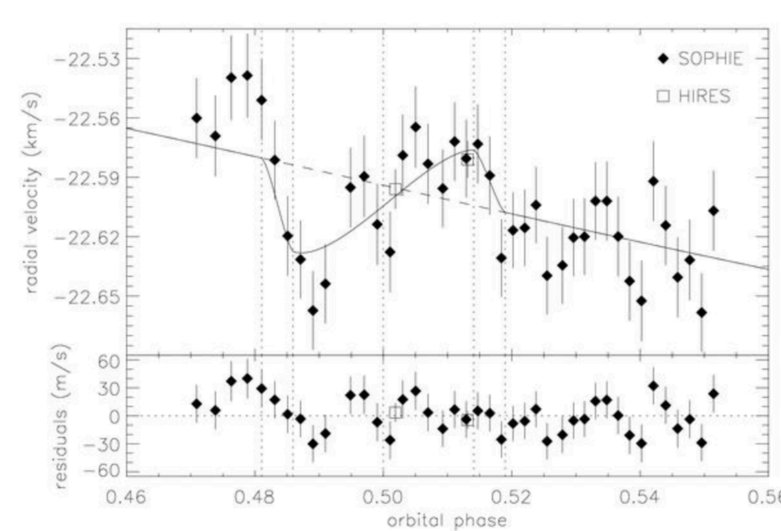
First one at Observatoire de Haute-Provence

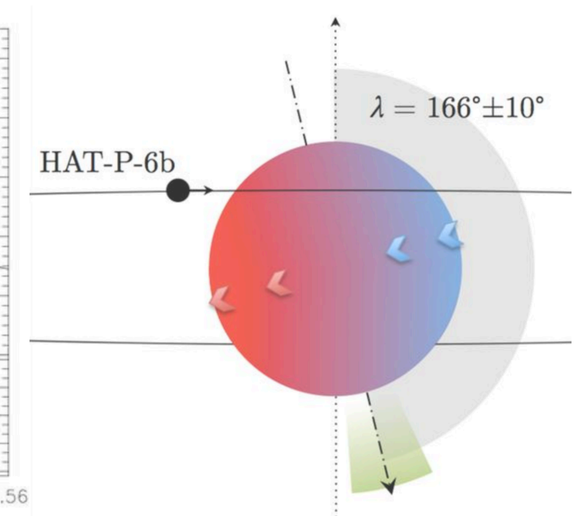
Several techniques





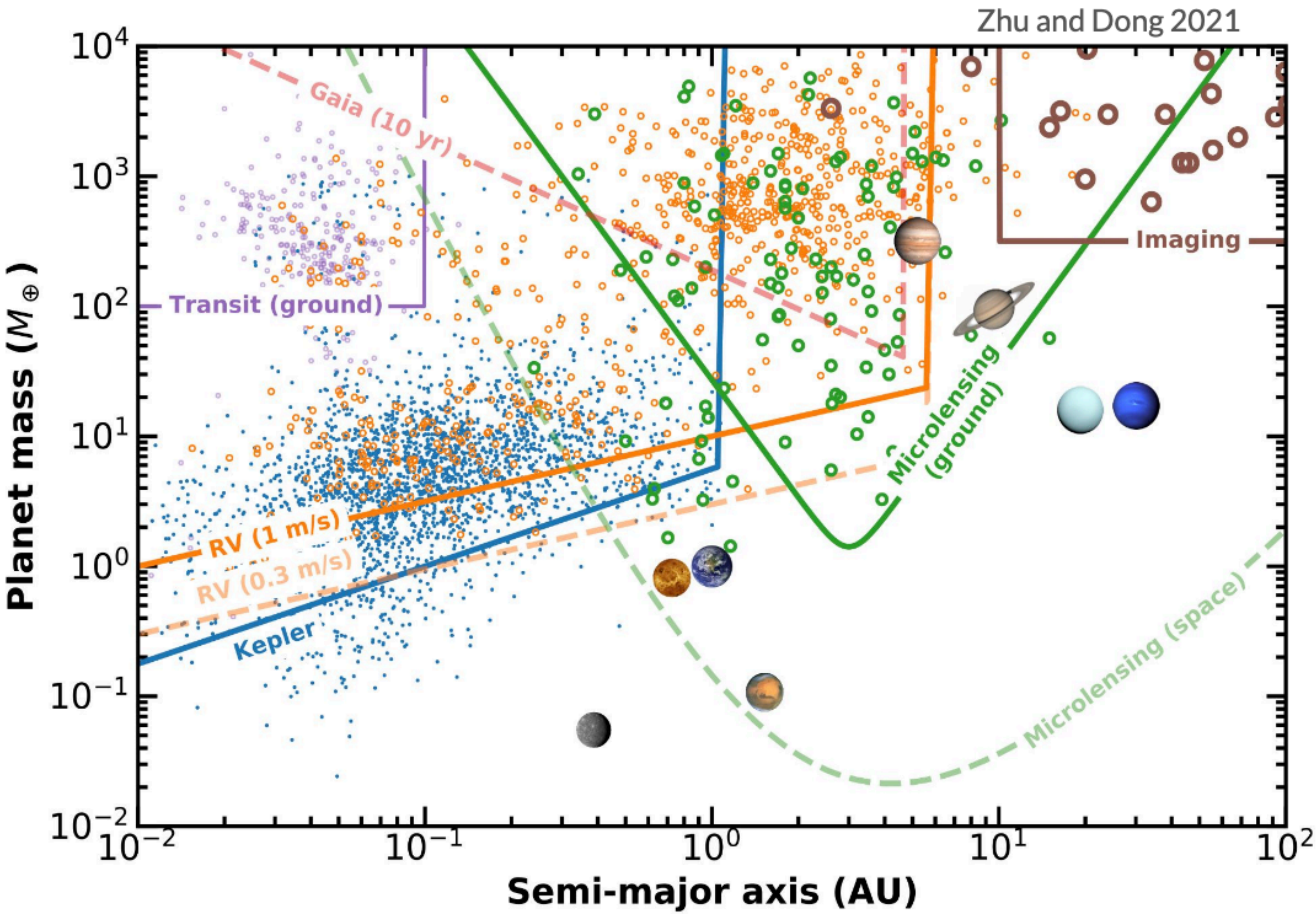
And access to a wealth of information: mass, radius, density, orbit, atmospheres (composition, albedo, etc.), surface, etc.





Hébrard et al. 2011

Panorama of current exoplanets detection

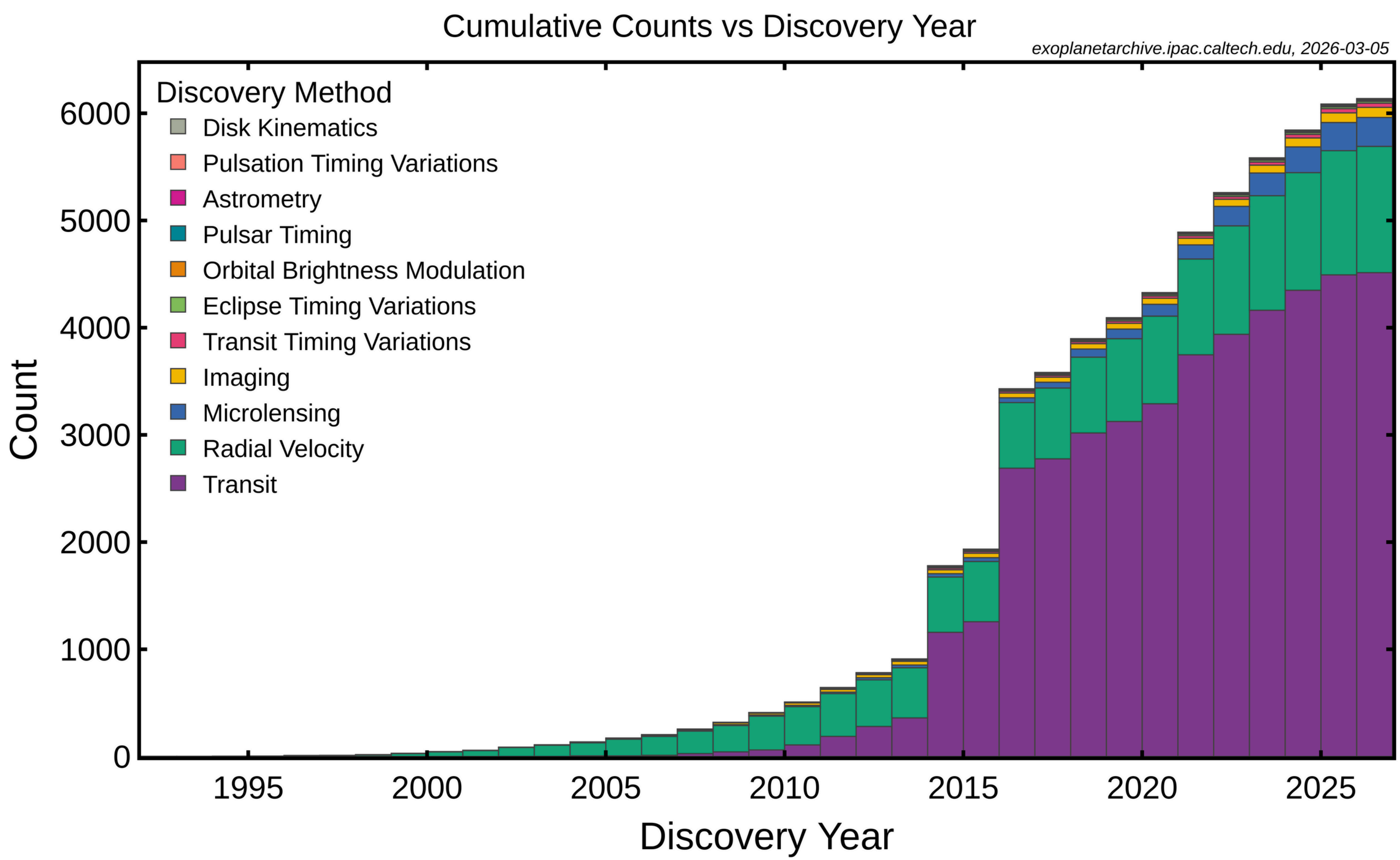


Panorama of current exoplanets detection

Some numbers

More than 6000 exoplanets known

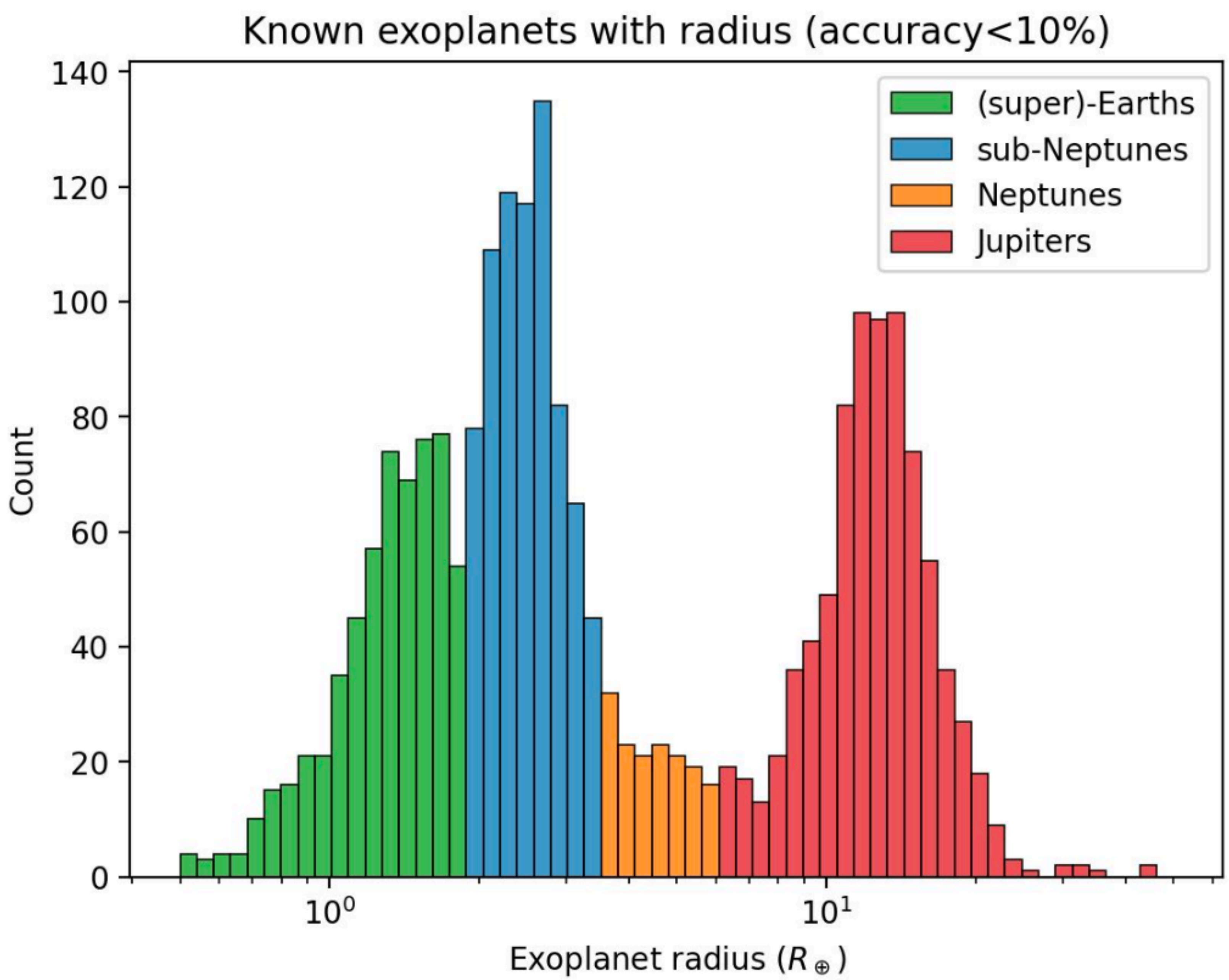
Half of them are in around 1000 multiple systems



Panorama of current exoplanets detection

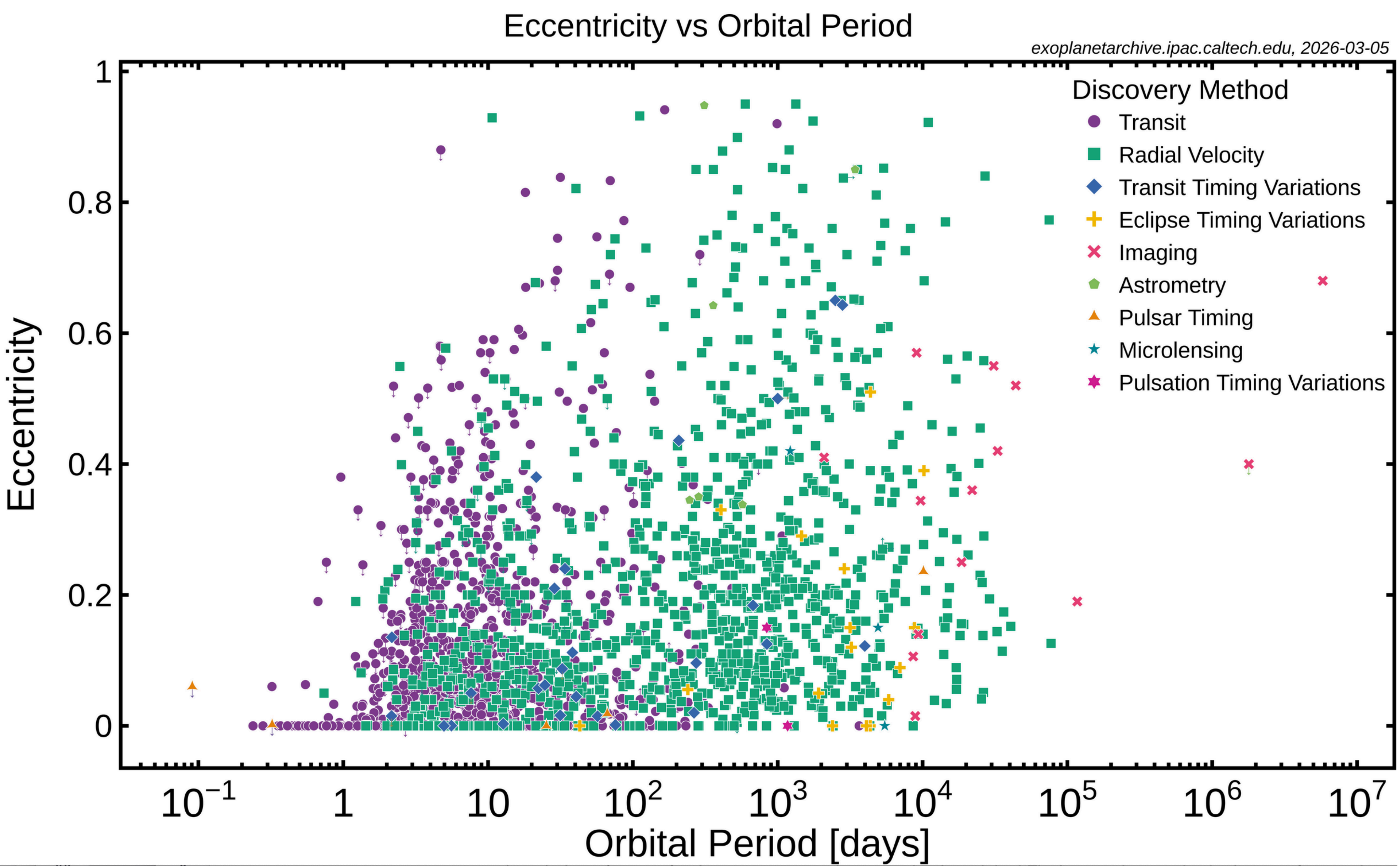
Some features

More than 4500 exoplanets with radius known



Panorama of current exoplanets detection

Some features



Panorama of current exoplanets detection

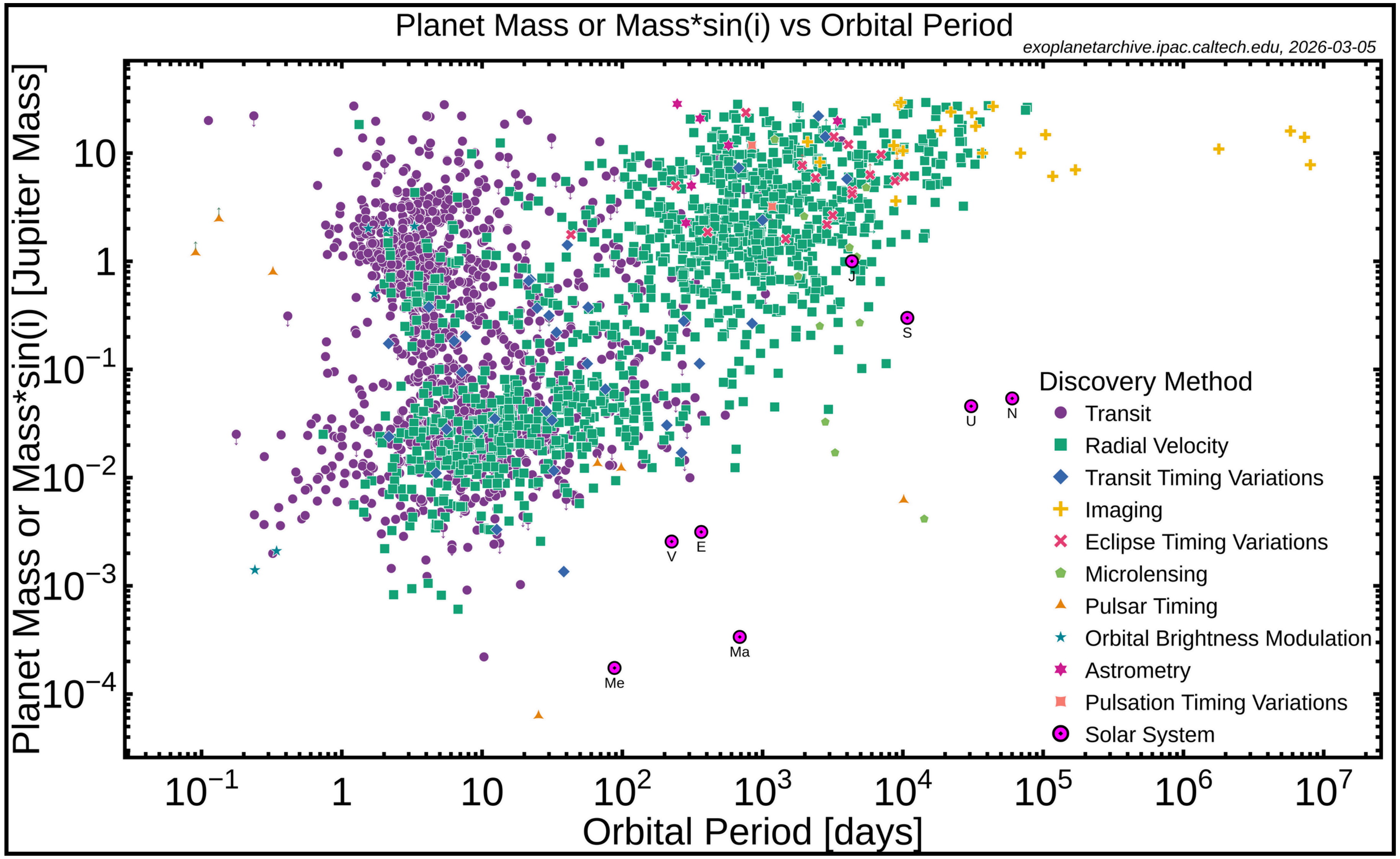
Some features

More than 2000 exoplanets with mass measurements

Jupiter valley

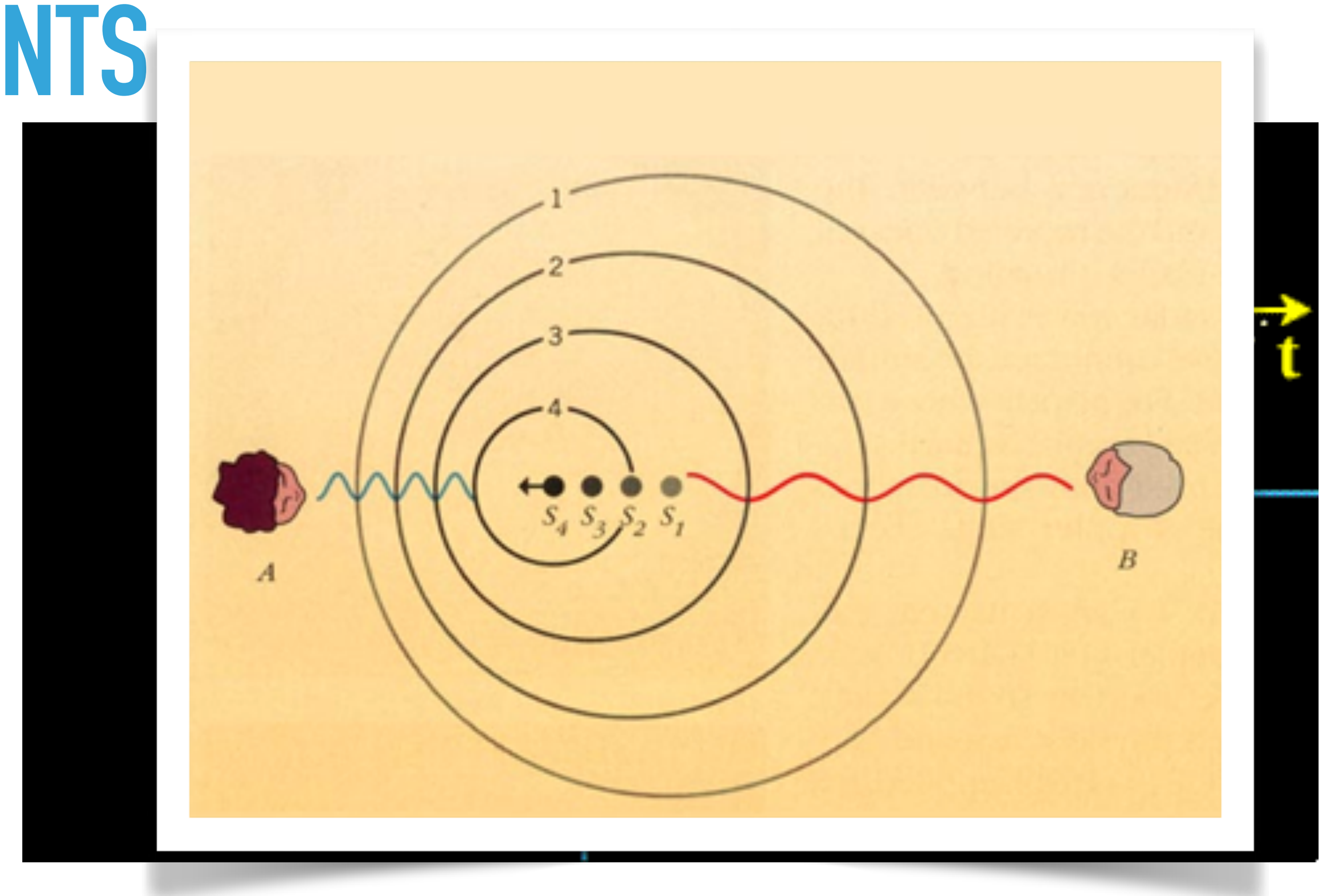
Hot-Neptune desert

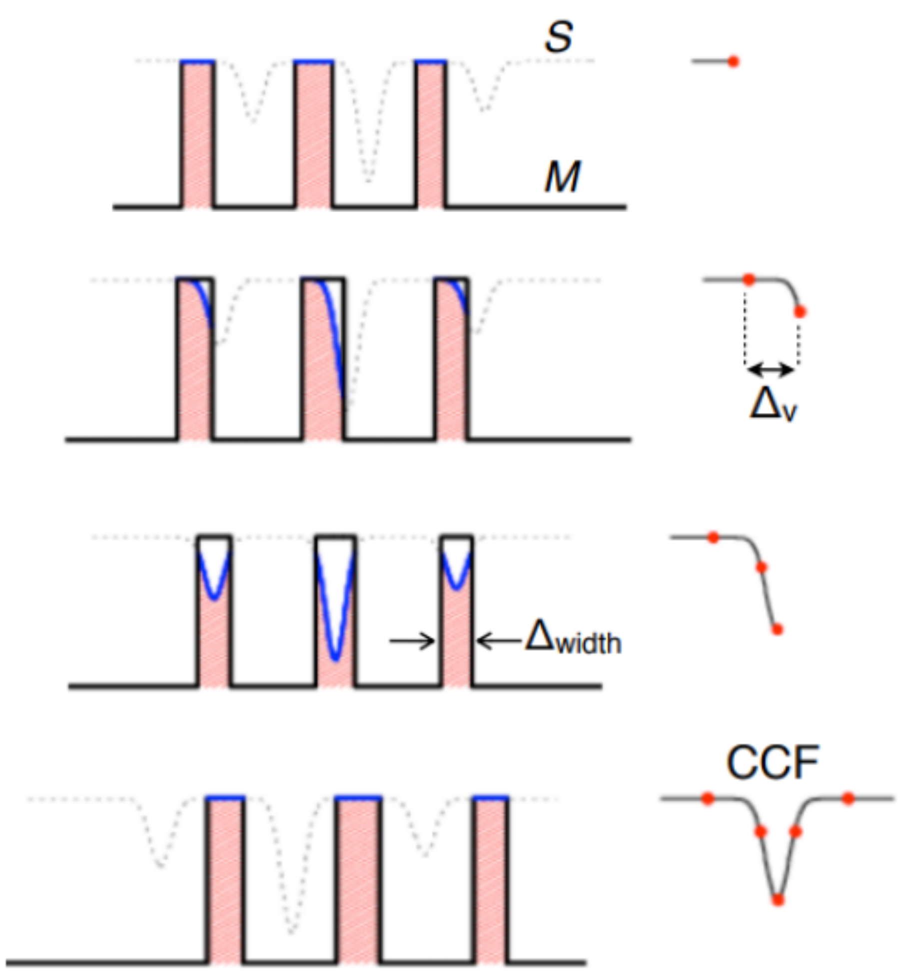
Stellar activity barrier

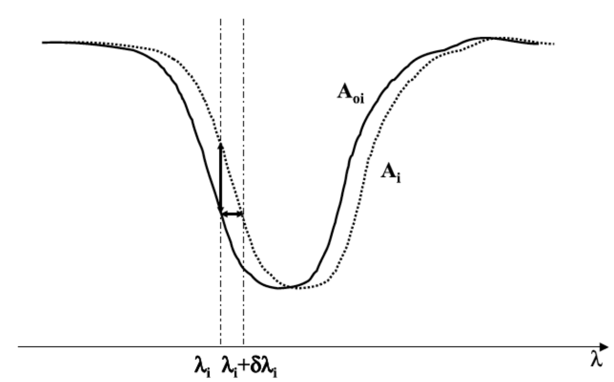


RADIAL VELOCITY MEASUREMENTS

- Doppler-Fizeau effect
- Spectral correlation with a template or a line mask
- Need thousands of lines







$$CCF(v) = \sum_i \sum_l M_{li}(v).A_i.w_l$$

$$A(i) - A_0(i) = \frac{\partial A_0(i)}{\partial \lambda(i)} \delta\lambda(i).$$

- Fitted by a gaussian

RV = RV star - RV BERV - RVinstru

RADIAL VELOCITY MEASUREMENTS

Keplerian signal

Semi- amplitude

Planet mass

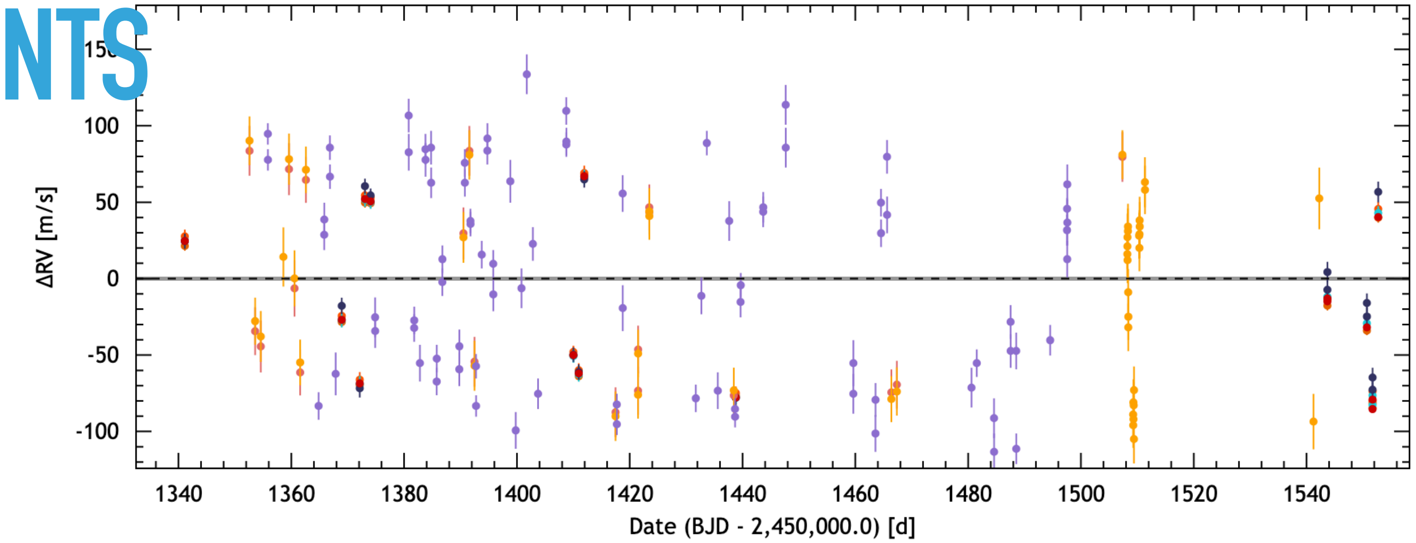
Inclination

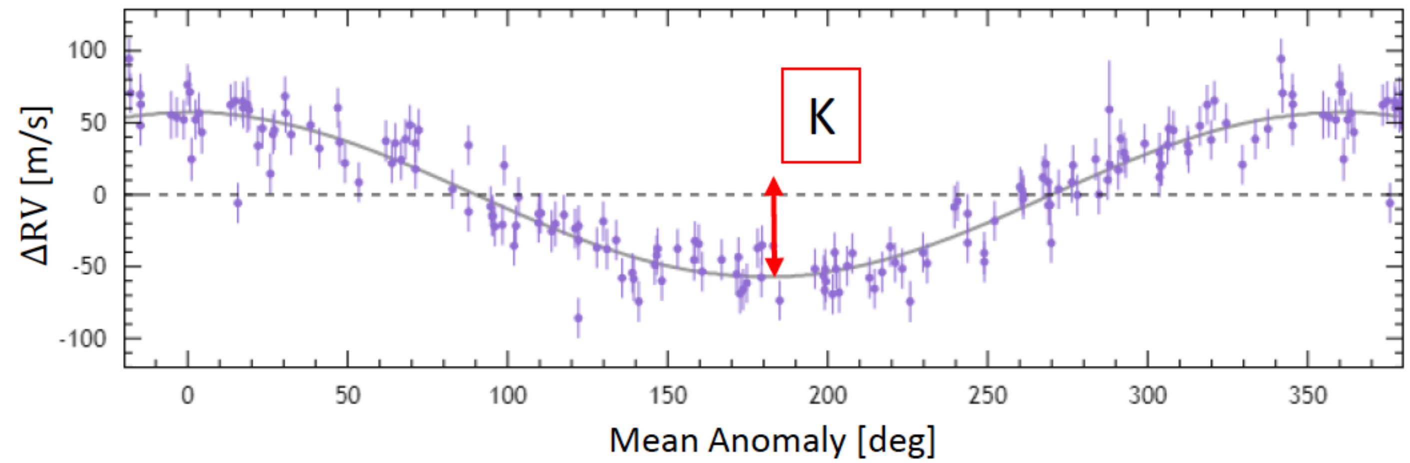
$$K = \frac{M_p * \sin i}{(M_* + M_p)^{\frac{2}{3}}} \left(\frac{2\,\pi\, G}{P}\right)^{\frac{1}{3}} \frac{1}{\sqrt{1-e^2}}$$

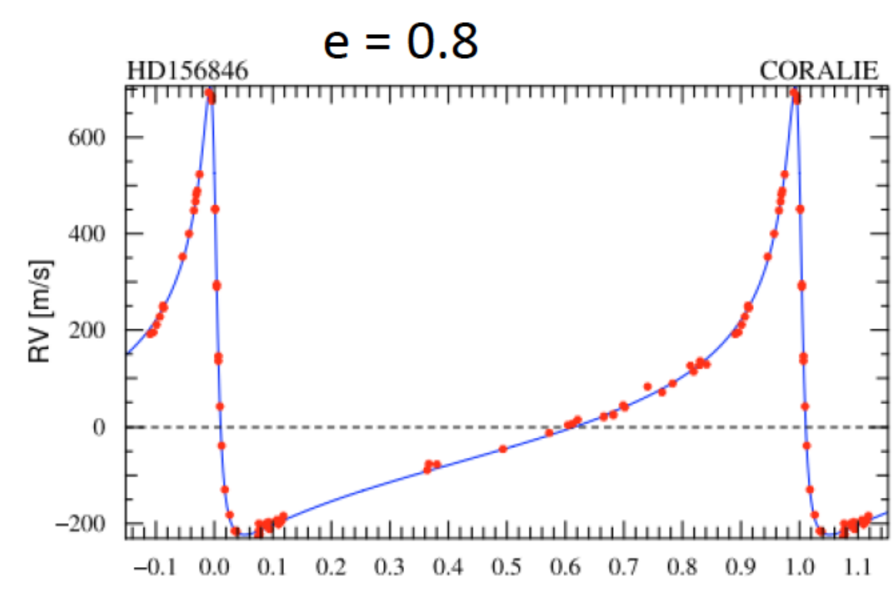
e

Planet period

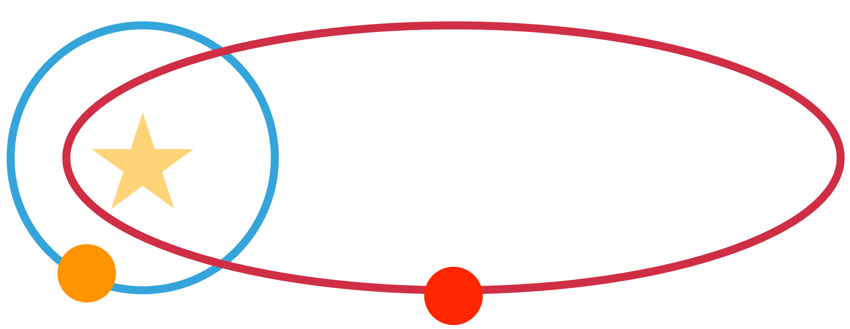
Star mass





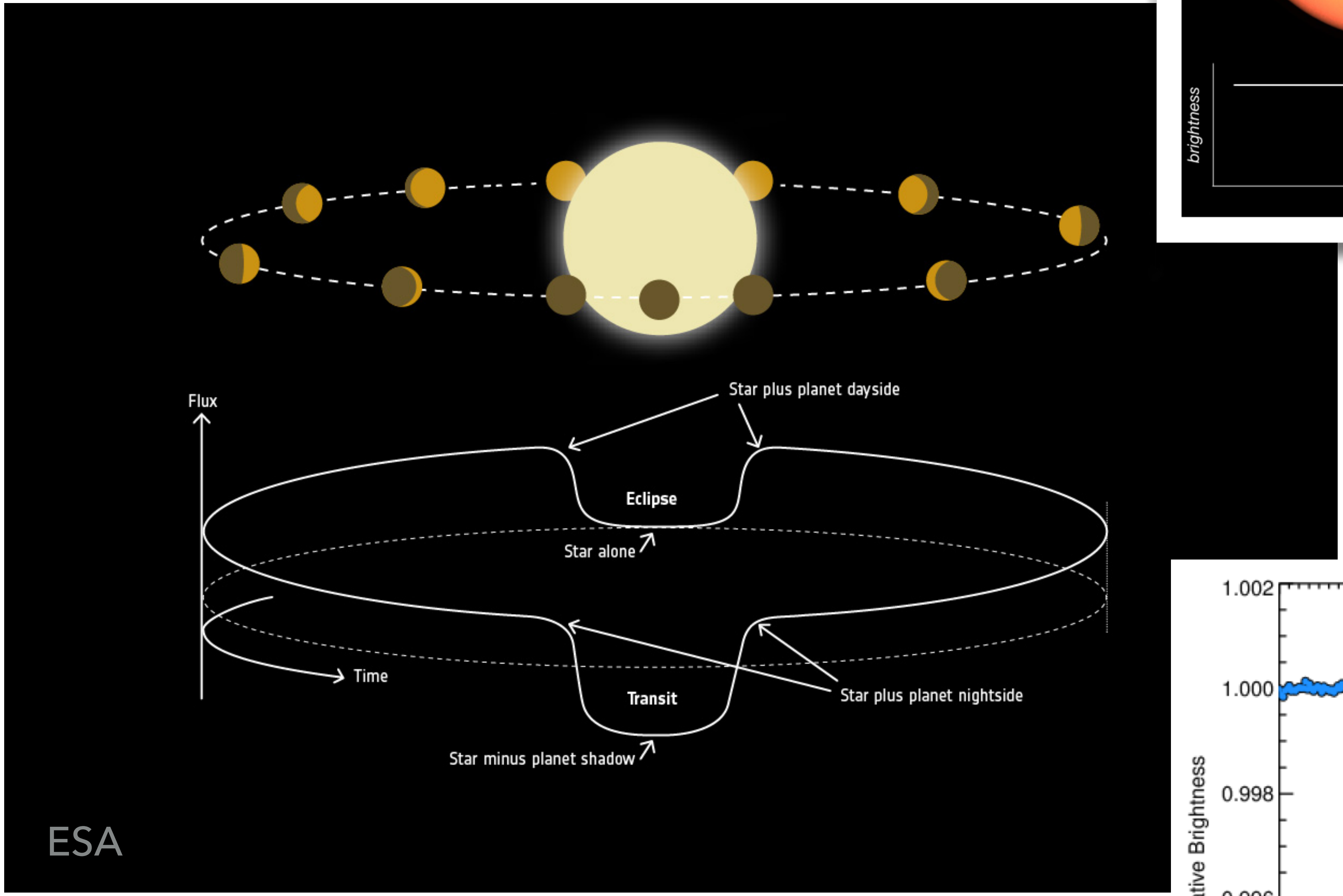


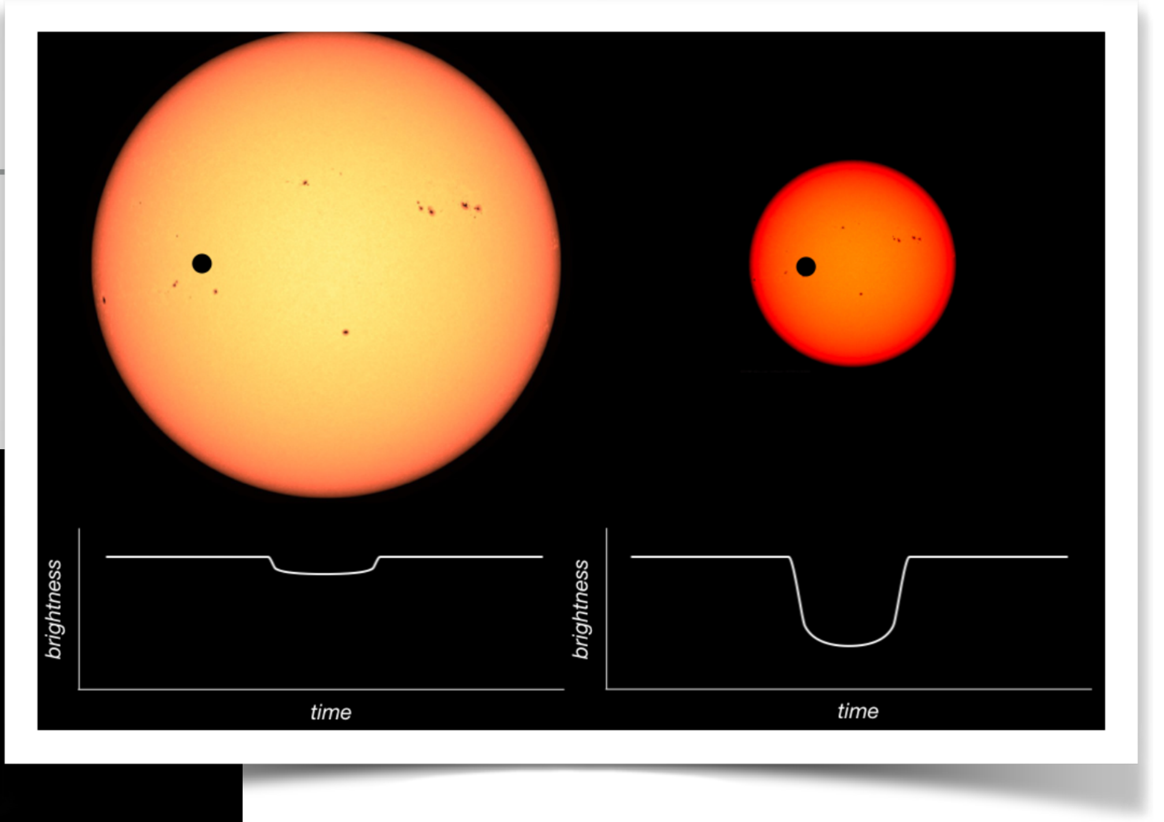
- Bias towards higher mass and closer planets

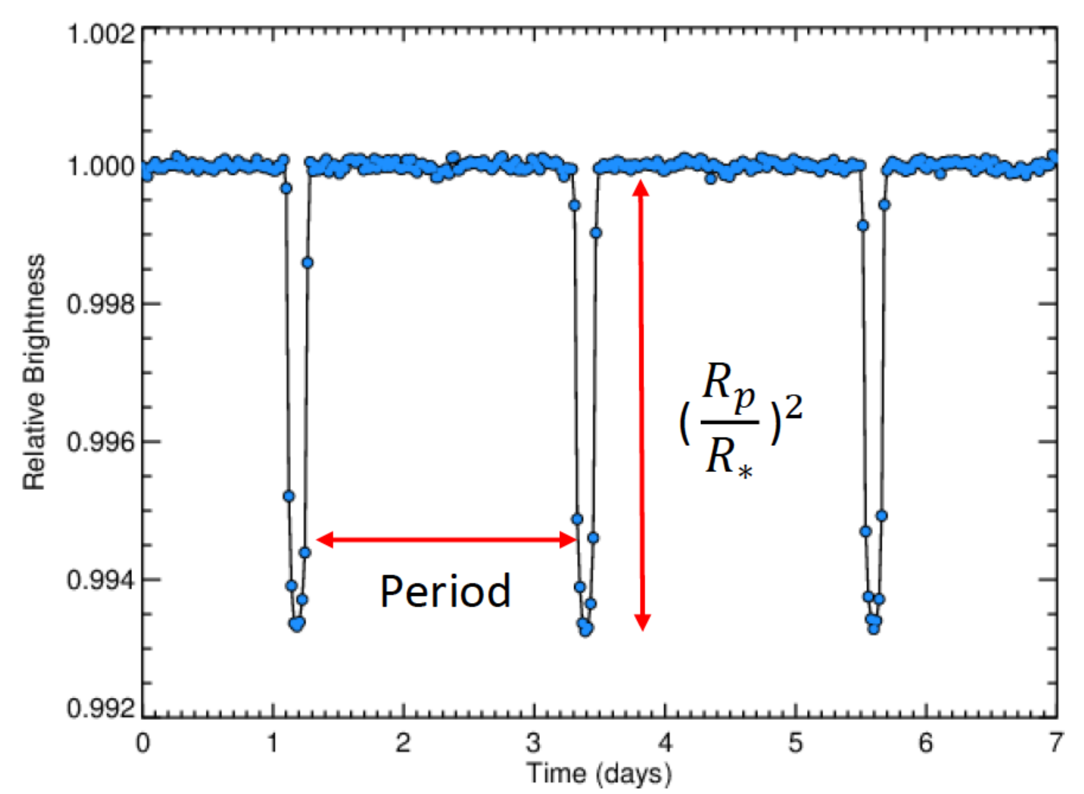


- Inclination of the orbit relative to the plan of the sky is undetermined

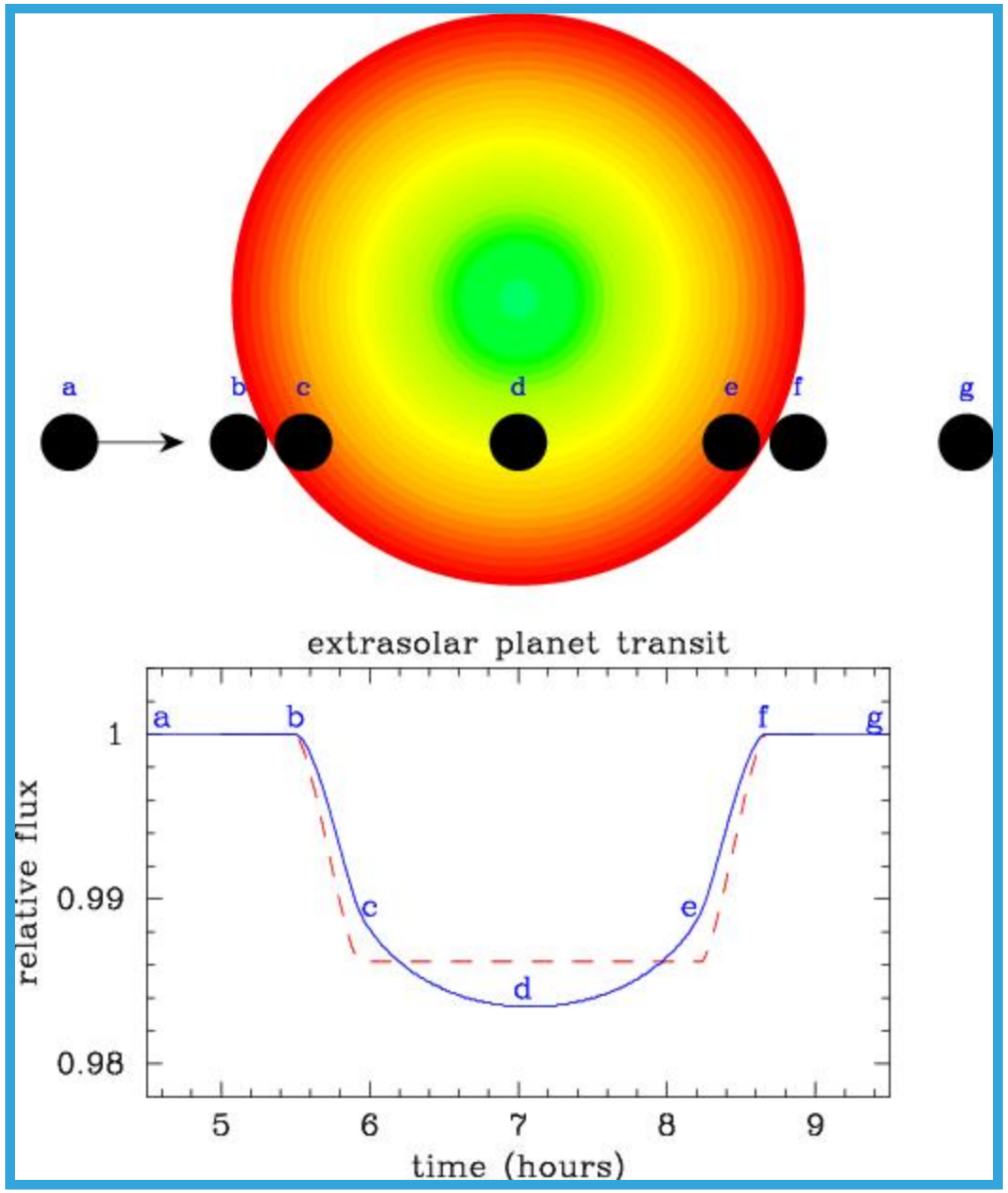
TRANSIT MEASUREMENTS

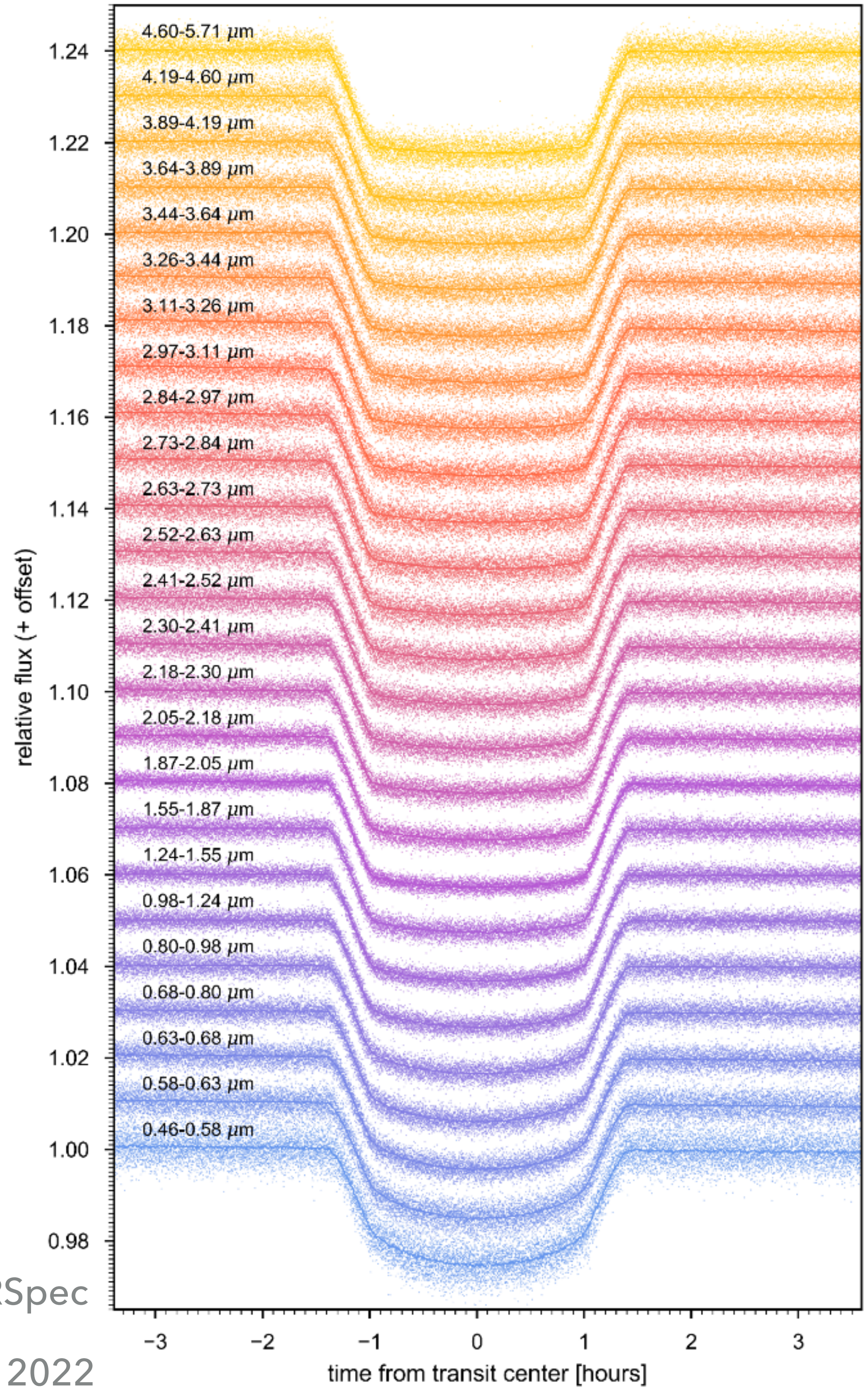






TRANSIT MEASUREMENTS

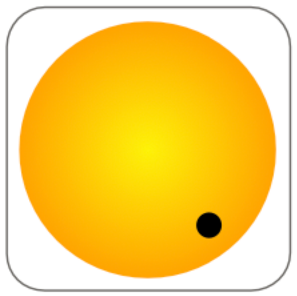




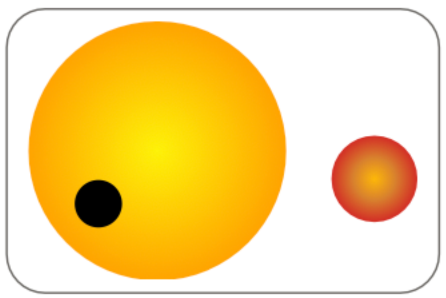
JWST WASP-39 NIRSpec

Rustamkulov et al. 2022

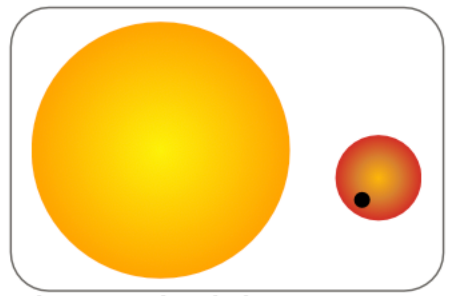
RV COMPLEMENTARITY WITH TRANSIT DETECTION



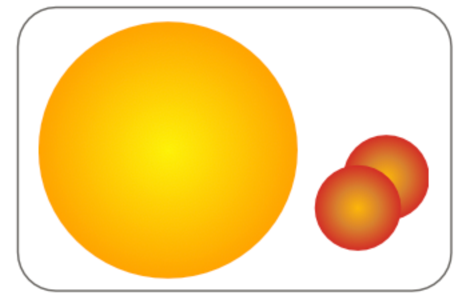
Planet



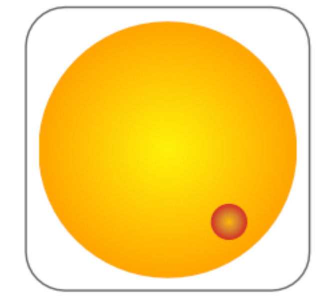
Planet in binary system



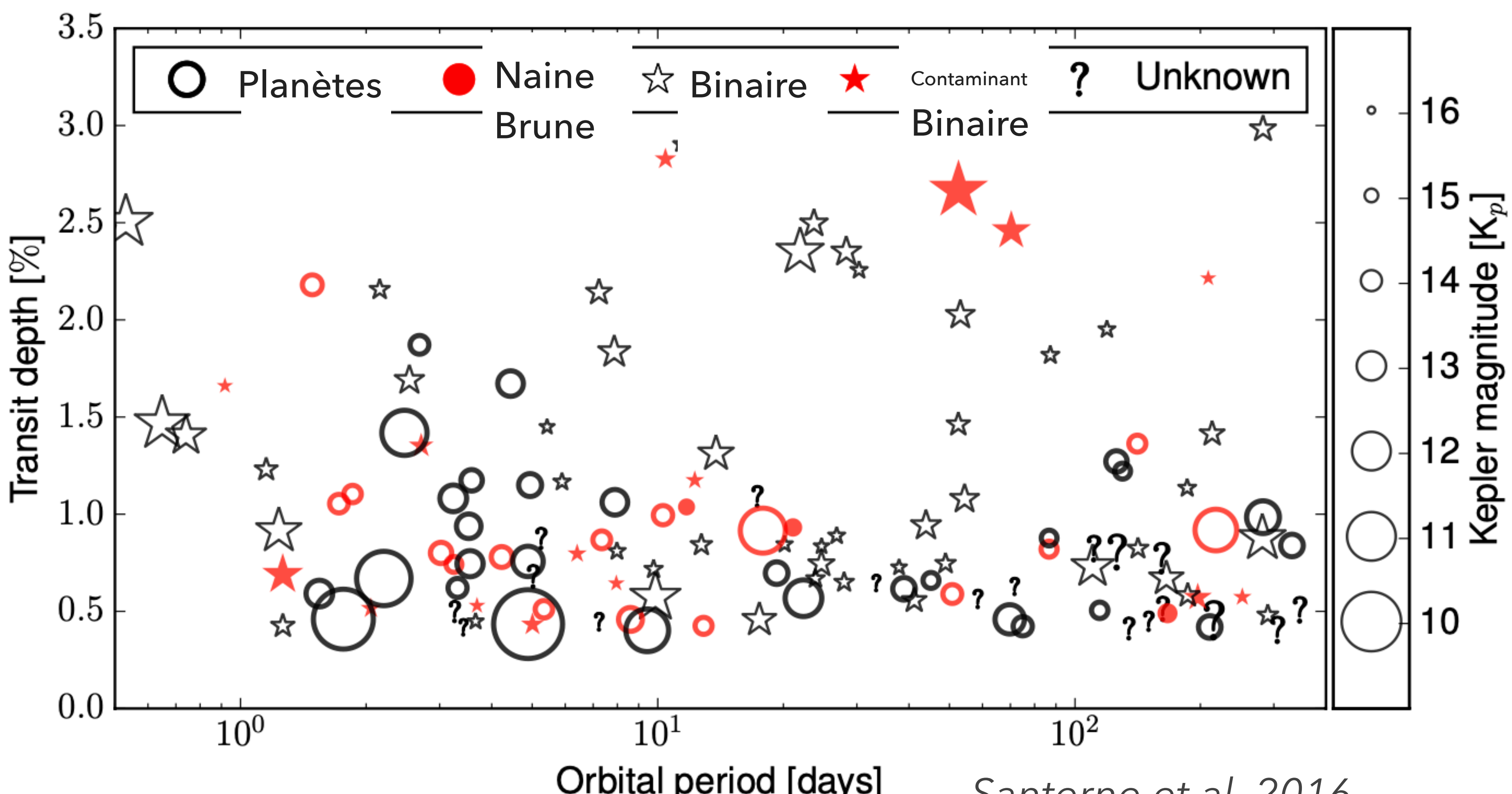
Planet around a background star



Triple system



Binary or Brown dwarf



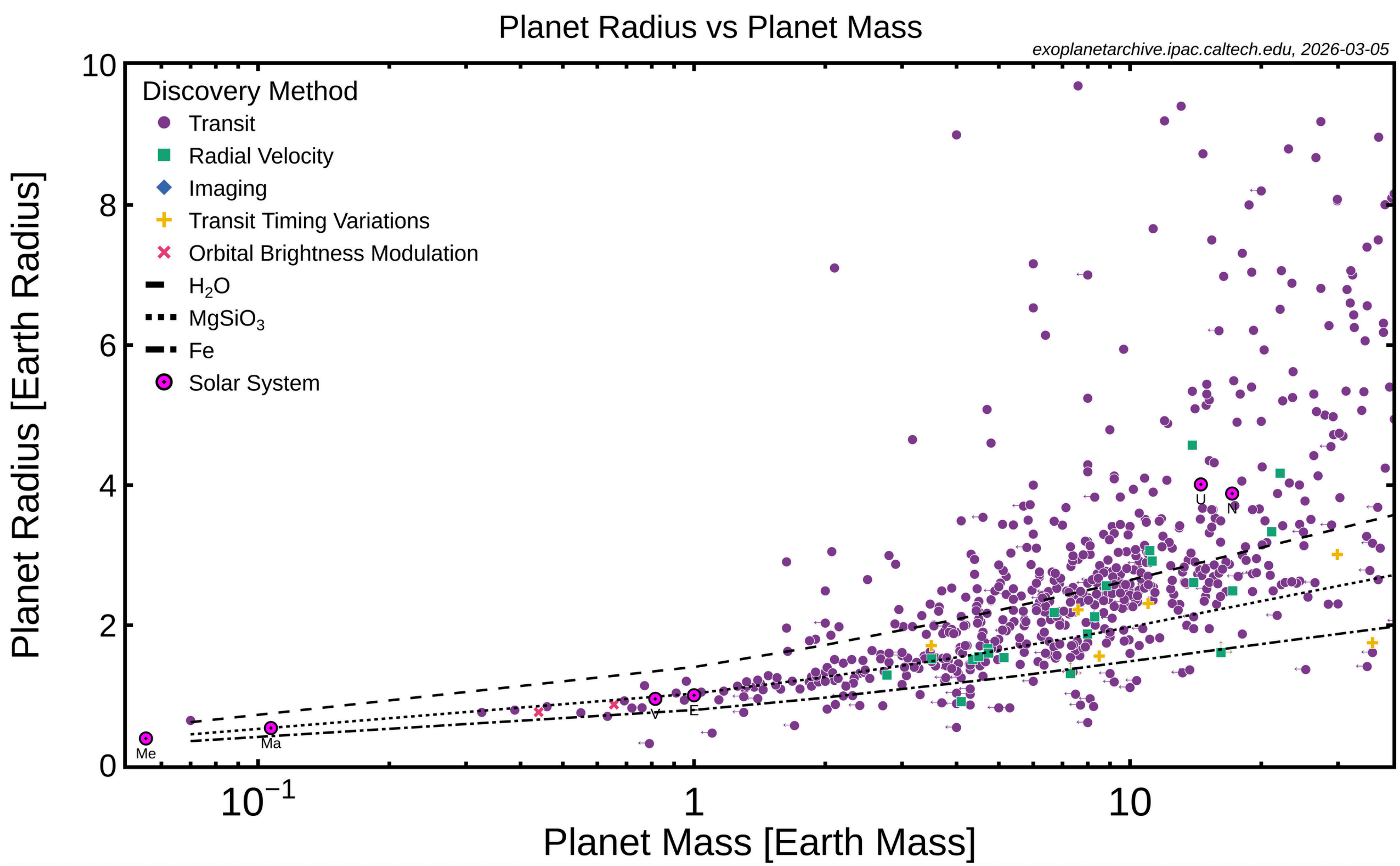
Santerne et al. 2016

- Follow-up of several ground or space-based surveys

HAT, WASP, CoRoT, Kepler, K2, TESS, …

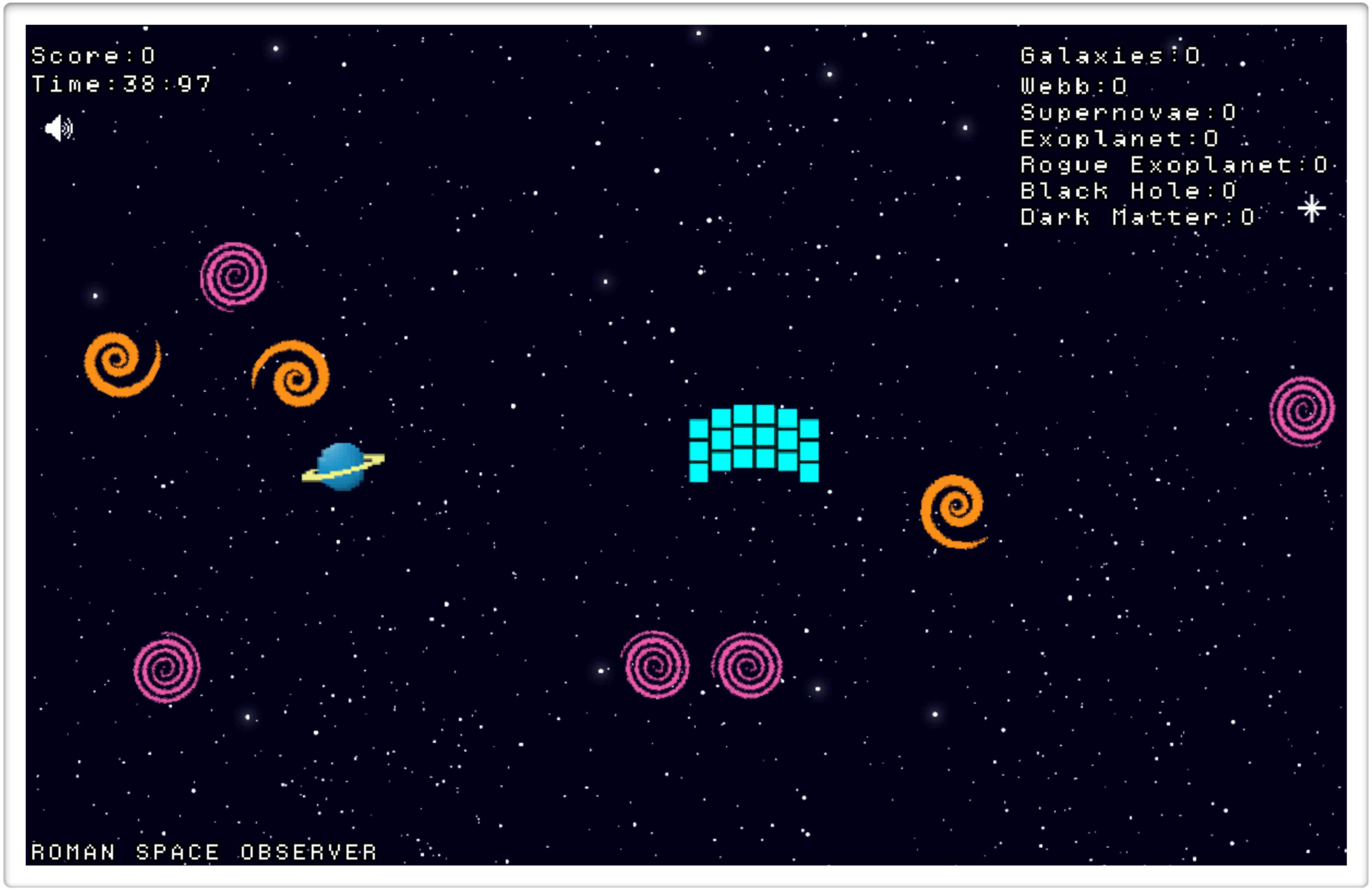
Panorama of current exoplanets detection

Some features



2. Which planets

For Roman coronograph ?

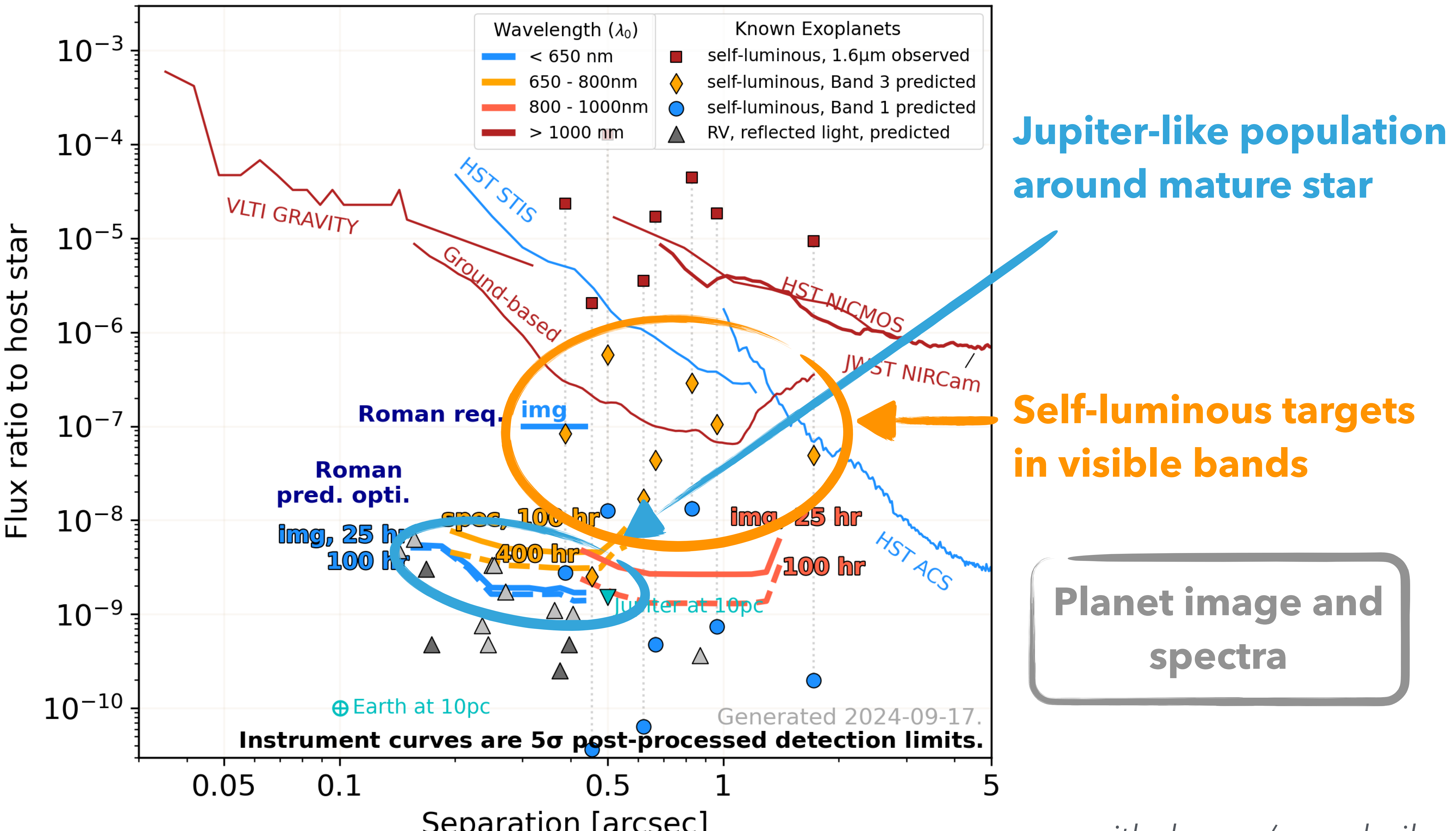


Roman Game

Catch exoplanets and others

Roman for exoplanets

Coronographic Mode capabilities



github.com/nasavbailey

Roman coronograph

Observing modes

λ_{center}	Mode	Approx. FOV radius	FOV Coverage	Support
575 nm	**NFOV:** Narrow FOV Imaging	**0.15" – 0.45"**	**360°**	**Required (full support)**
730 nm, 660 nm	**SPEC**: Slit + R~50 Prism Spectroscopy	0.2" – 0.55"	slit	Best Effort
575 nm, 825 nm	**WFOV**: "Wide" FOV Imaging	0.3" – 1.4"	360°	Best Effort
575 nm, 825 nm	Imaging Polarimetry (WPs)	0.15" – 1.4"	360°	Best Effort
any	Other coronagraph mask combinations	0.15" – 1.4"	various	Unsupported
any	Other technology demonstrations: binary star, transmissive Zernike wavefront sensor, alternative wavefront sensing algorithms	various	various	Unsupported

Roman for exoplanets

Coronographic Mode capabilities

Young and massive planets

Complement nIR observations

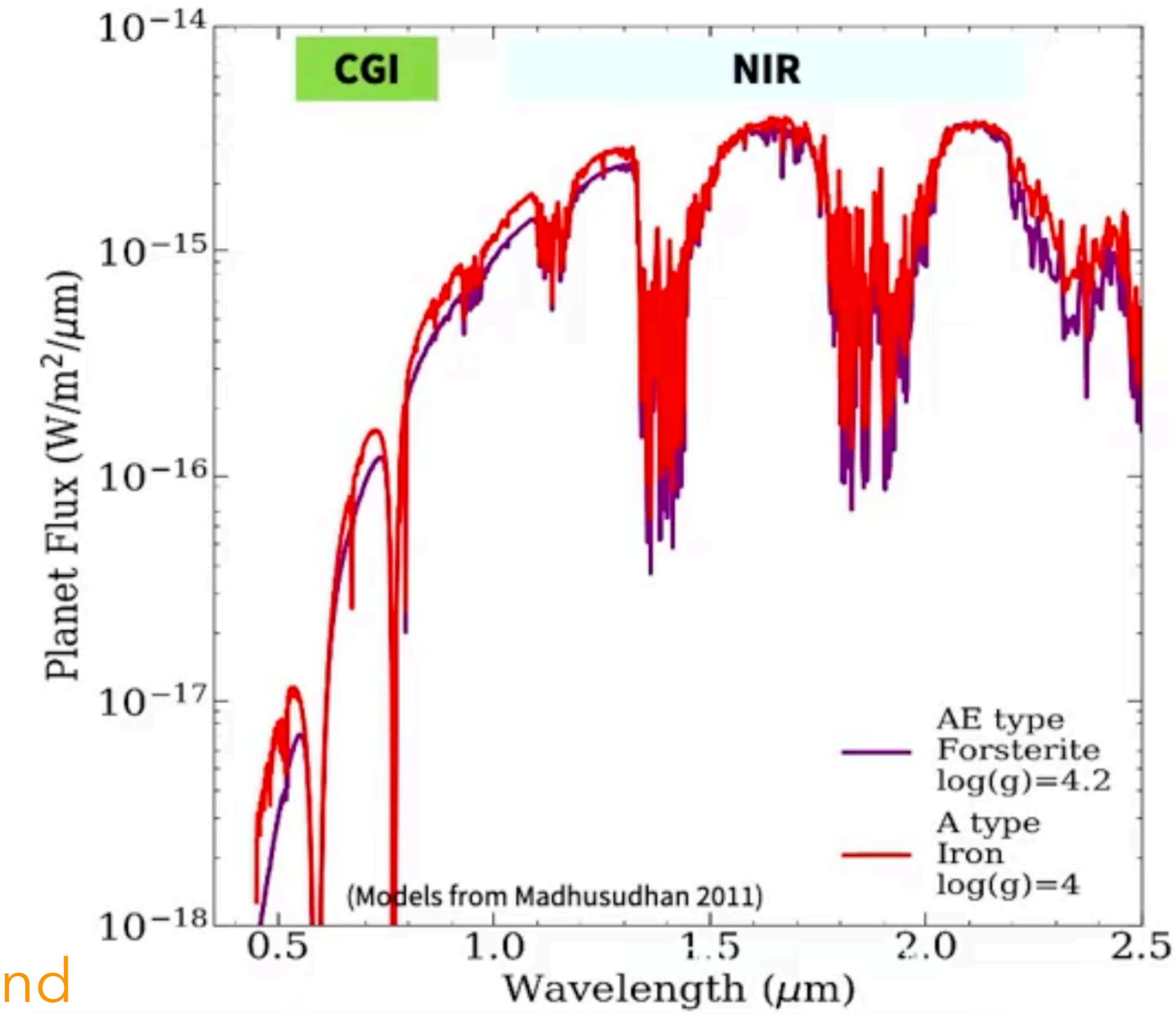
For the first time in the V band, even if very faint

What are the clouds properties ?
How inflated are they ?

Are they metal-rich (e.g. Na and K searches) ?

→ Filled out SED with broadband photometry and spectroscopy

Self-luminous targets in visible bands



Roman for exoplanets

Coronographic Mode capabilities

Reflected light of mature Jupiter-analogs

Imaging:

- Measuring the orbit by constraining the inclination of the system with two or three imaging epochs

→ True mass

- Measure albedos in V bands

→ Cold Jupiters cloudy or clear ?

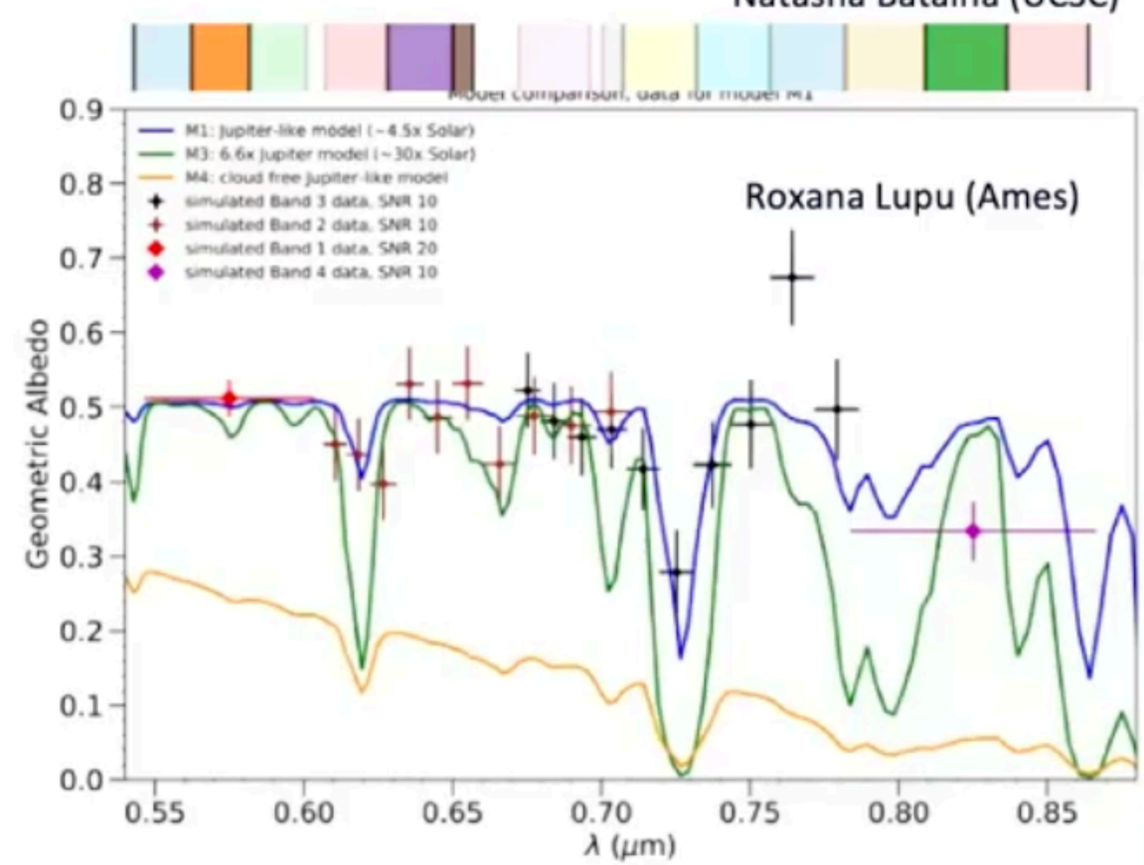
Spectroscopy:

Need more time

- Constrain metallicity if cloudy (high albedo)

→ Are Jupiter analogs metal-rich ?

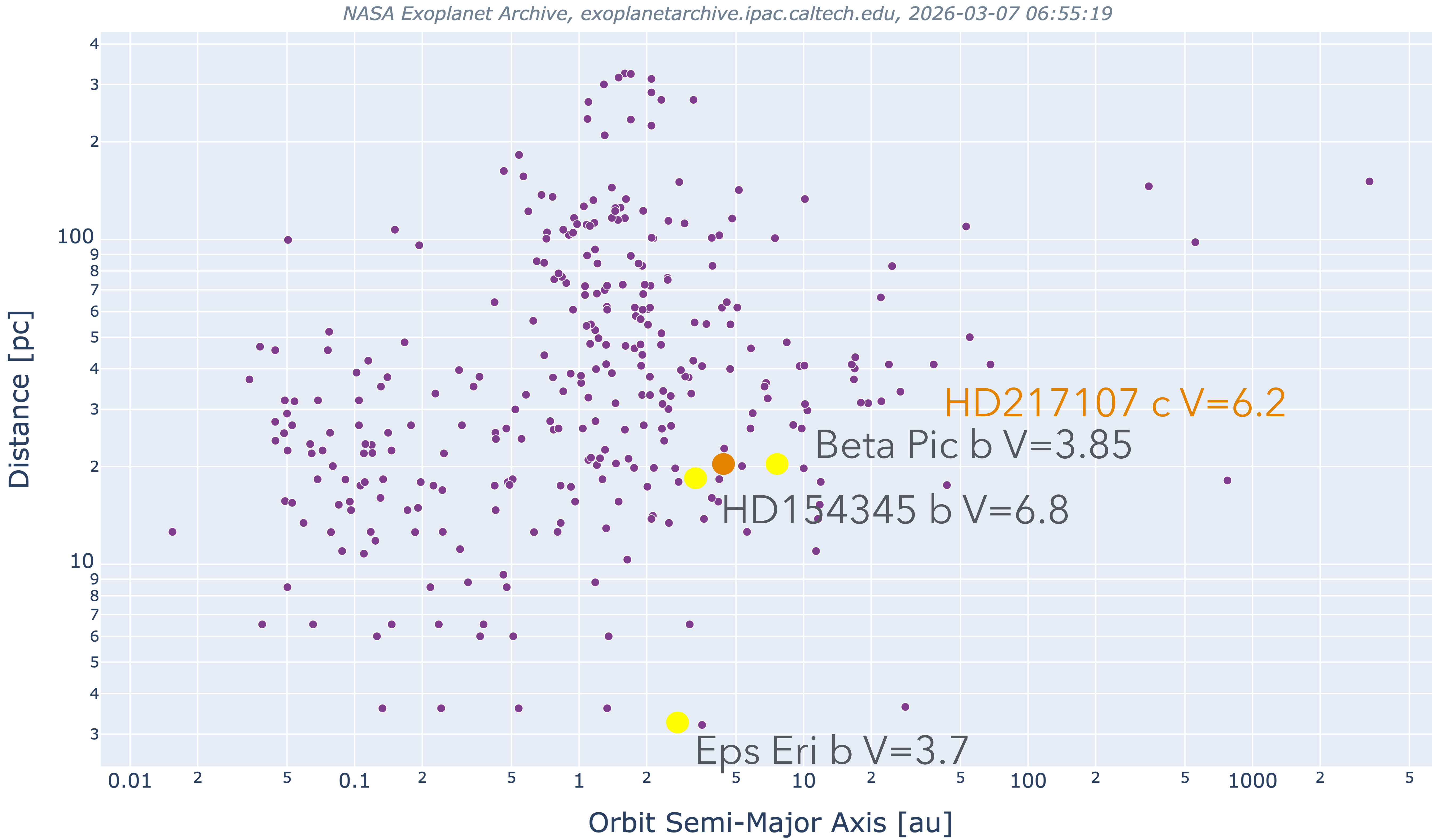
Natasha Batalha (UCSC)



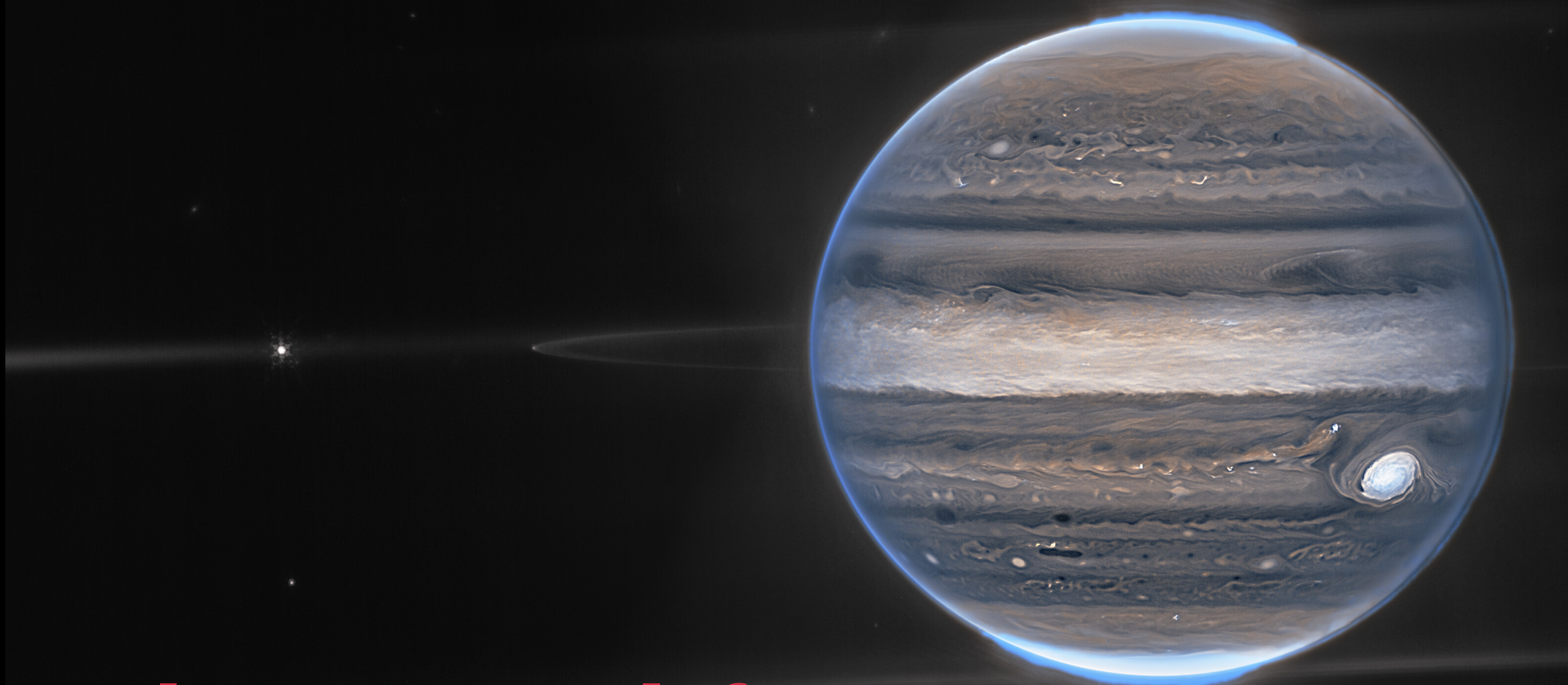
660nm spectroscopy is an unofficial observing mode

→ Optical polarimetric observations ?

Example of targets planned



+ constrained on reference stars position ?



3. Observed features

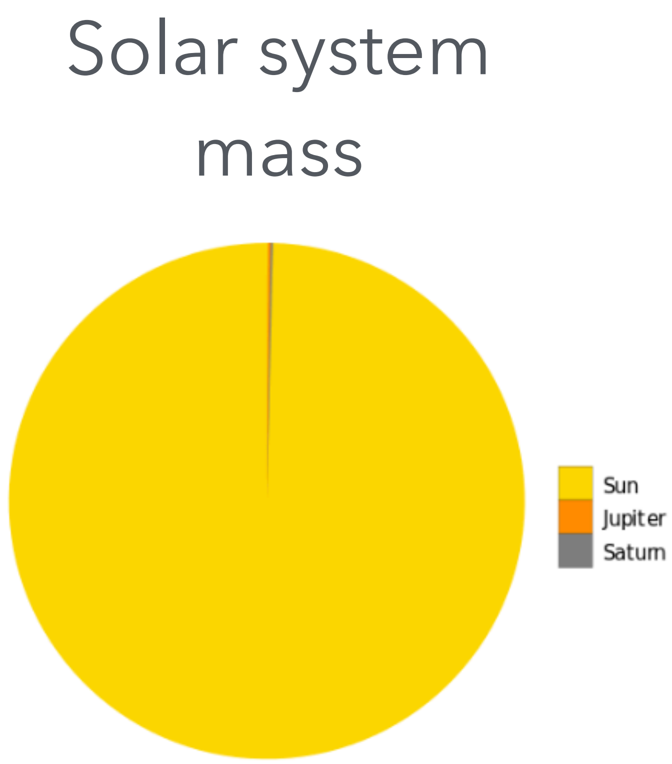
Of giants exoplanet population

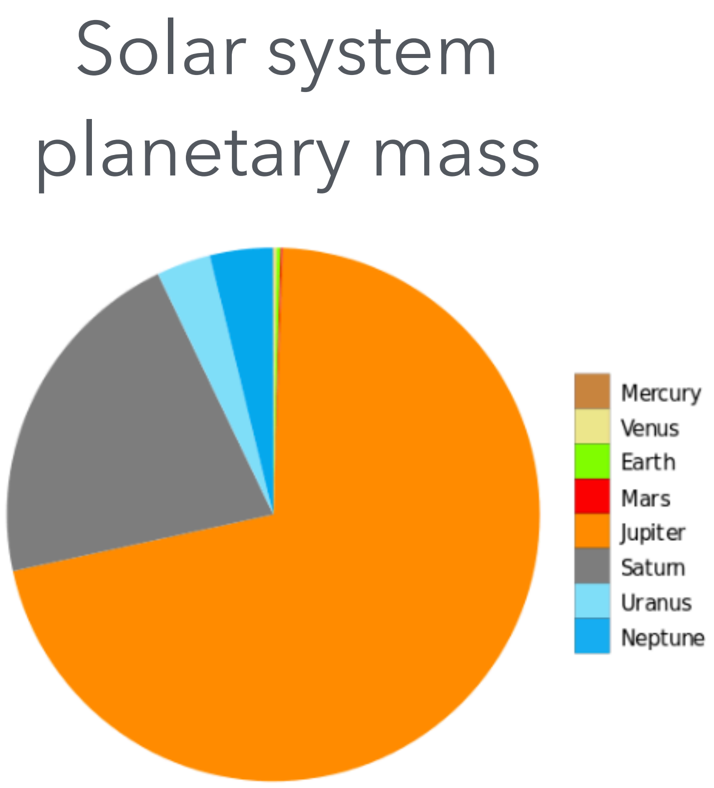
Isabelle Boisse (LAM/OHP) - Roman Coronography School - 12/03/26

Demography of giant exoplanets

Giant planets dominate almost everything in planetary systems.

- Masses



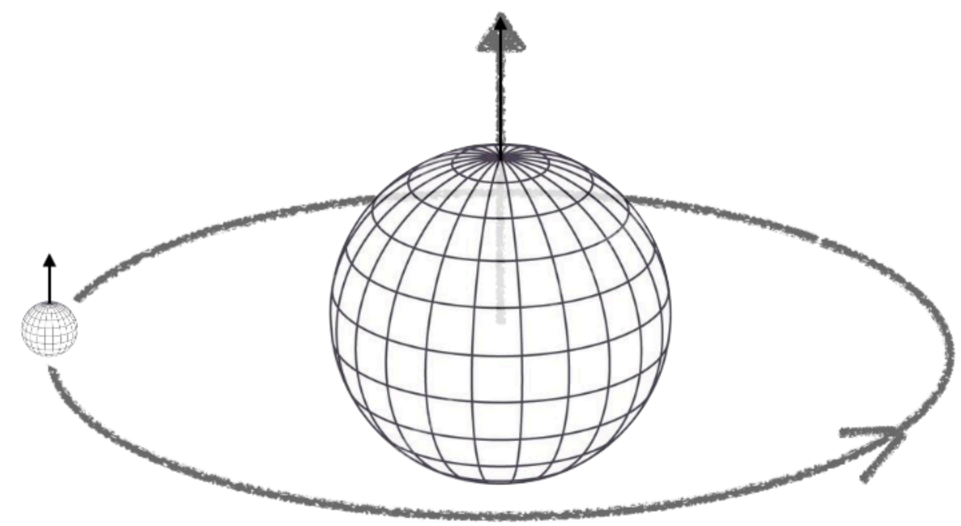


Jupiter + Saturn: **~0.1%** **~92%**

Demography of giant exoplanets

Giant planets dominate almost everything in planetary systems.

- Masses
- Angular momentum

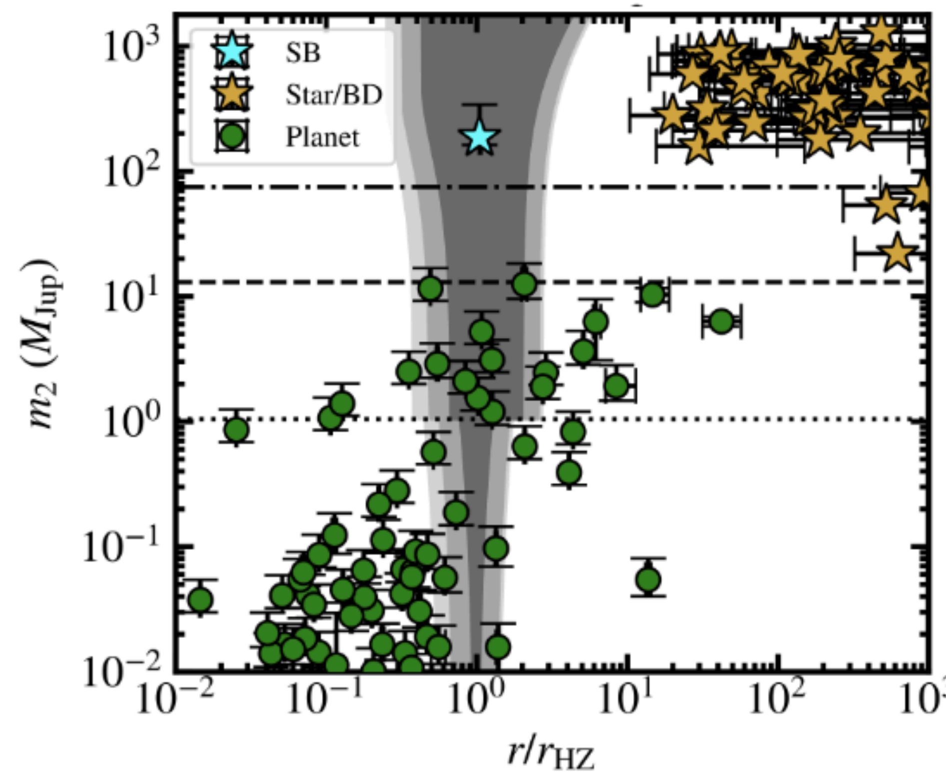


$$\frac{L_{\text{Jupiter + Saturn}}}{L_{\text{SS}}} = \mathbf{\sim 87\%}$$

Demography of giant exoplanets

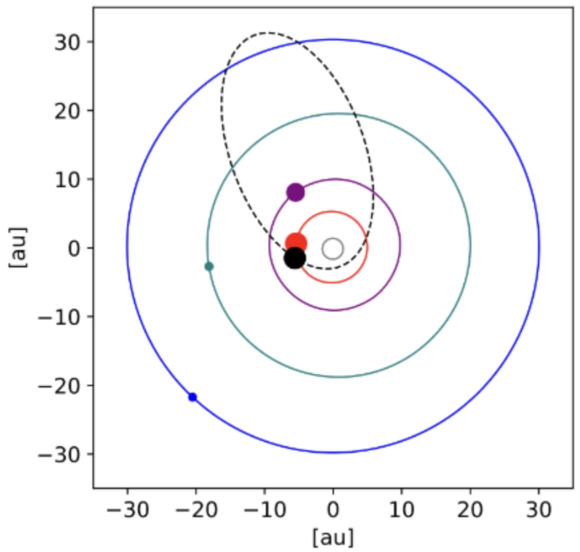
Giant planets dominate almost everything in planetary systems.

- Masses
- Angular momentum
- Dynamic



Painter et al. 2025

Habitable Zone



Blunt et al. 2019

Eccentricity

Demography of giant exoplanets

Giant planets dominate almost everything in planetary systems.

- Masses
- Angular momentum
- Dynamic
- Detection

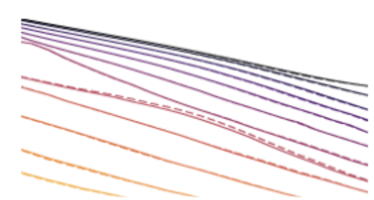
Transit depth

$$\delta \propto R_p^2$$

RV semi-amplitude

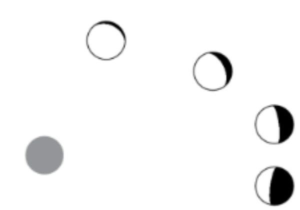
$$K \propto m_p$$

Bolometric brightness



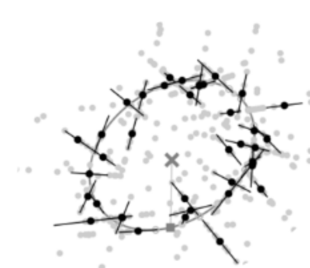
$$L_{\mathrm{bol}} \propto m_p^{5/2}$$

Star-planet contrast



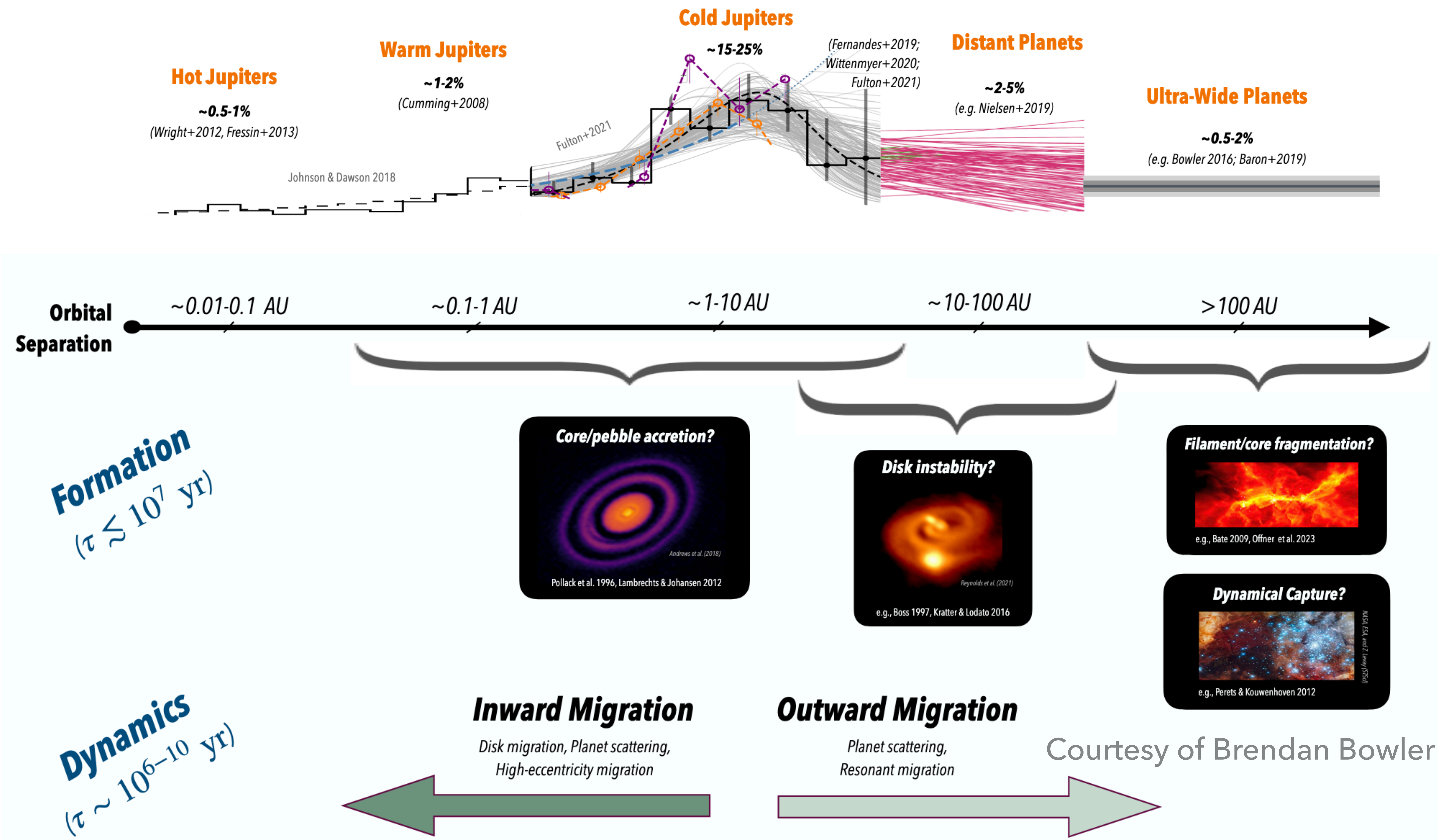
$$f_p / f_* \propto R_p^2$$

Proper astrometric motion



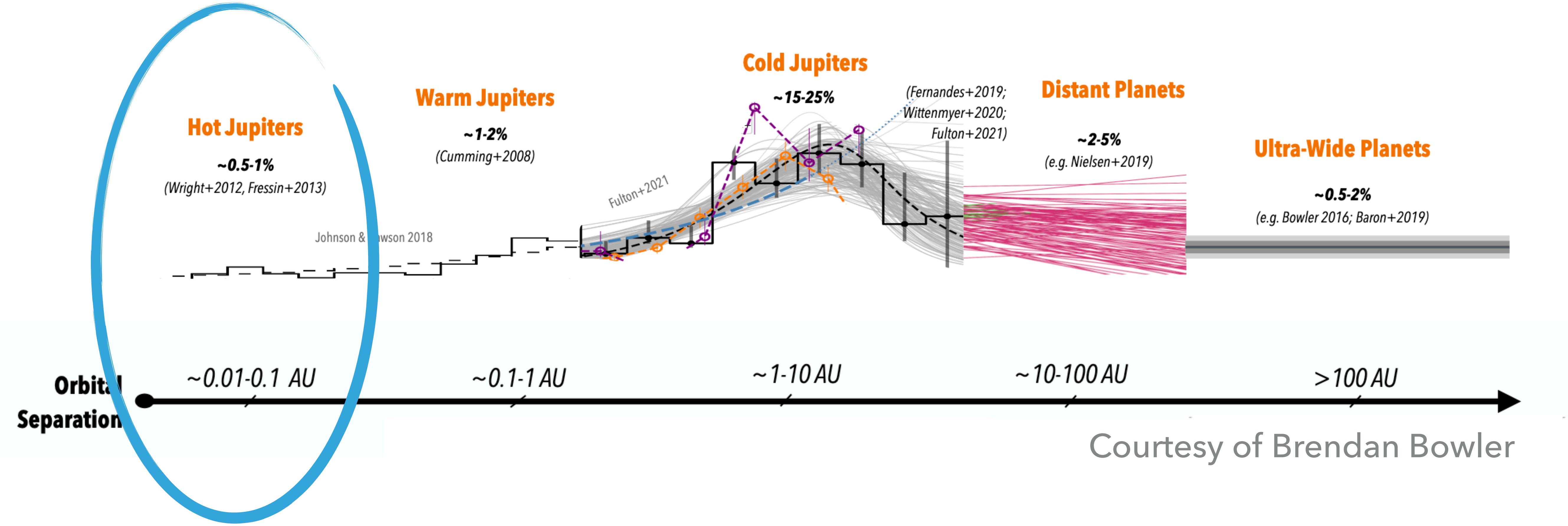
$$\theta \propto m_p$$

SURVEYS FOR GIANT PLANETS CENSUS



Courtesy of Brendan Bowler

SURVEYS FOR GIANT PLANETS CENSUS

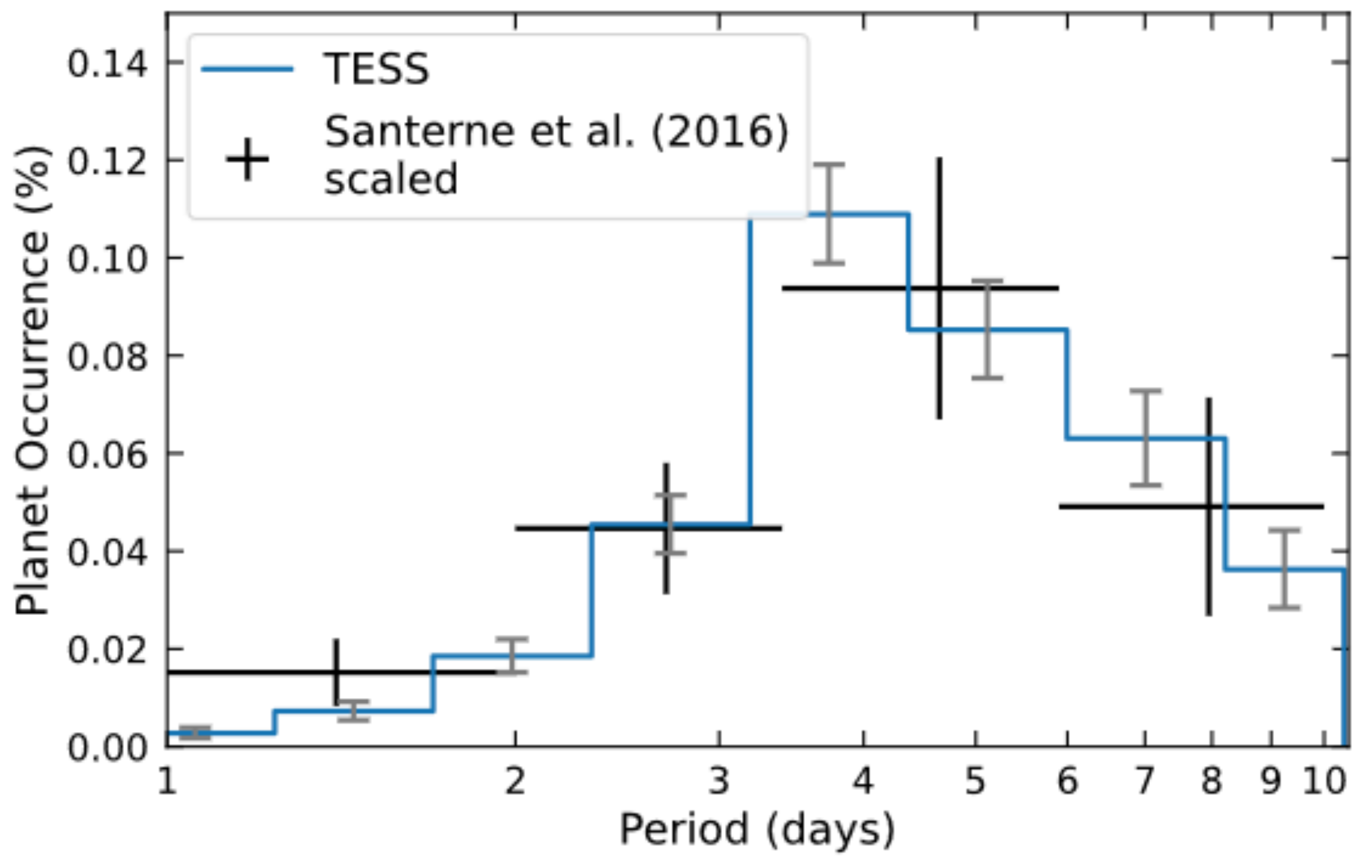


Courtesy of Brendan Bowler

→ **Hot Jupiters : a relatively rare outcome of planetary formation**

HOT JUPITERS P < 10 days

- P peak at 3-5 days



Yee & Winn 2023, Yee et al. 2025

→ A stop on the internal inward migration mechanism ?

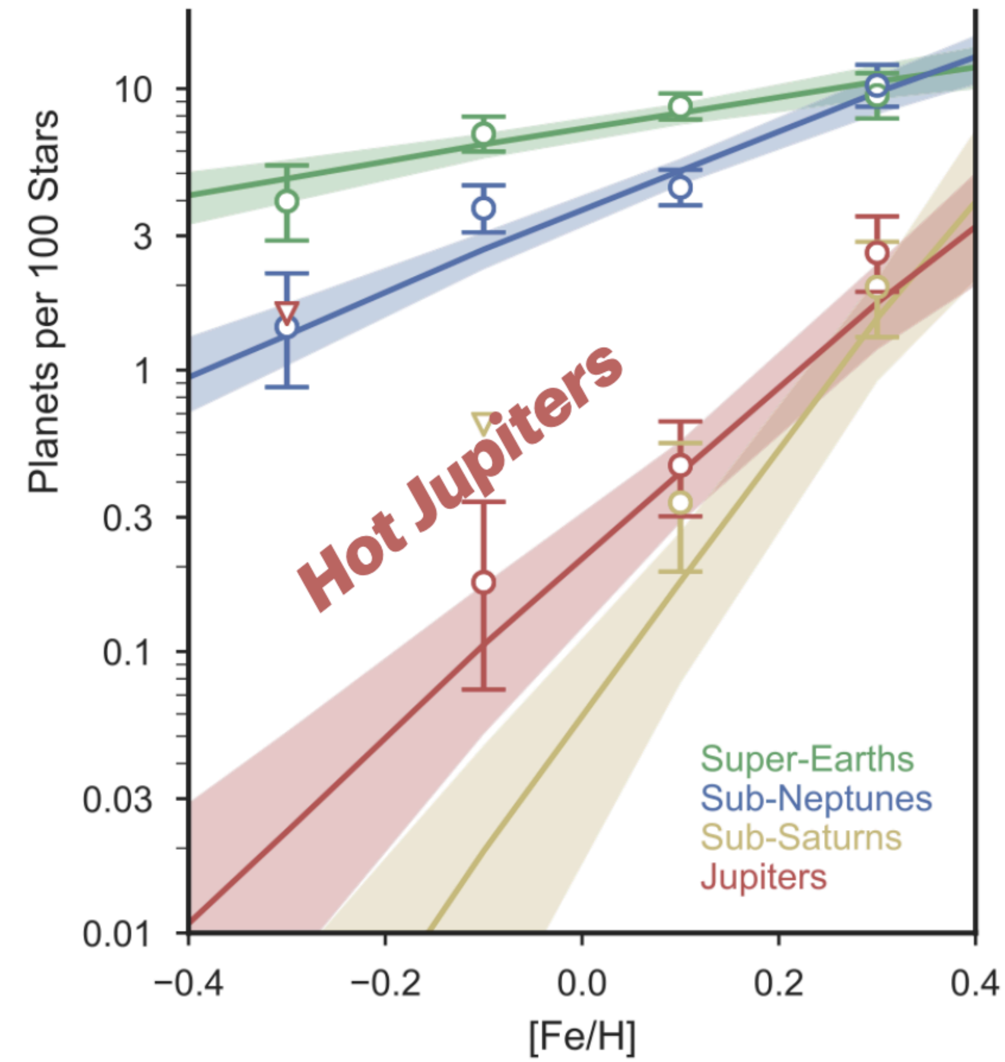
HOT JUPITERS

P < 10 days

- P peak at 3-5 days
- Strong dependency with stellar metallicity

$$\frac{df}{d[\mathrm{Fe/H}]} \propto 10^{\beta[\mathrm{Fe/H}]}$$

$$\beta = 3.4^{+0.9}_{-0.8}$$



Petitgura et al. 2018

Osborn & Bayliss 2020

The occurrence rate increases by a factor of 10 over 0.5 dex of metallicity.

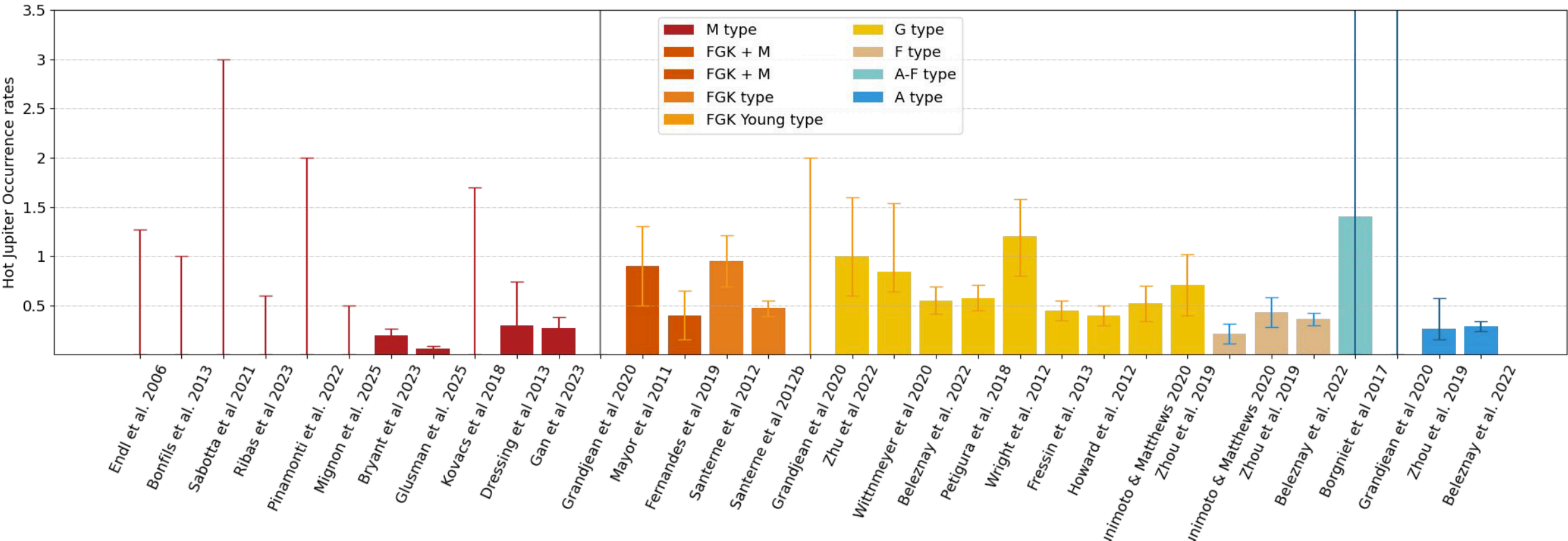
→ Signature of planet-planet scattering ?

A more efficient internal migration ?

HOT JUPITERS   P < 10 days

- P peak at 3-5 days
- Strong dependency with stellar metallicity
- Dependency with host stellar mass

Courtesy of Lucile Mignon

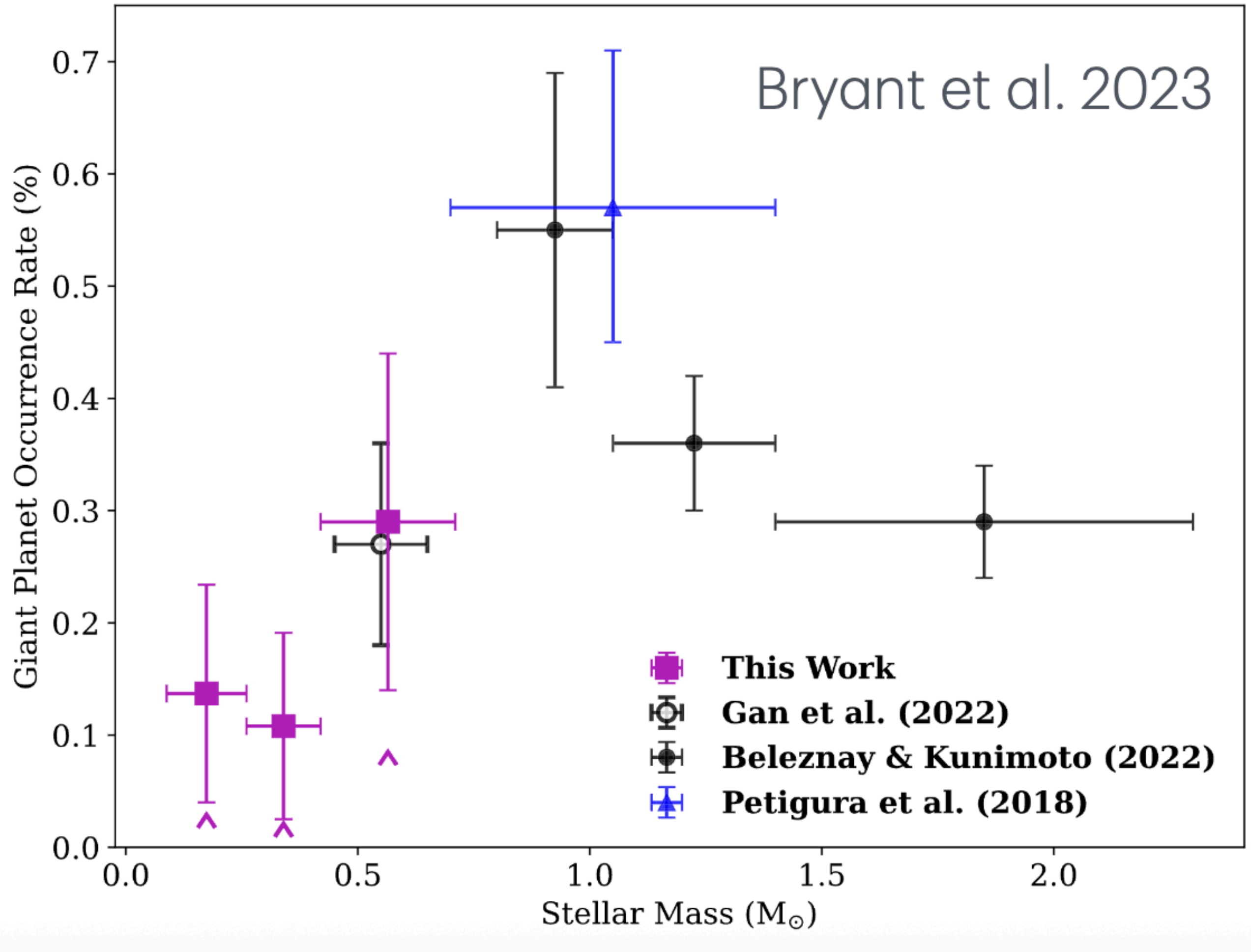


HOT JUPITERS

P < 10 days

- P peak at 3-5 days
- Strong dependency with stellar metallicity
- Dependency with host stellar mass

The occurrence rate increases with the mass of the star, peaking at 1 Msun.



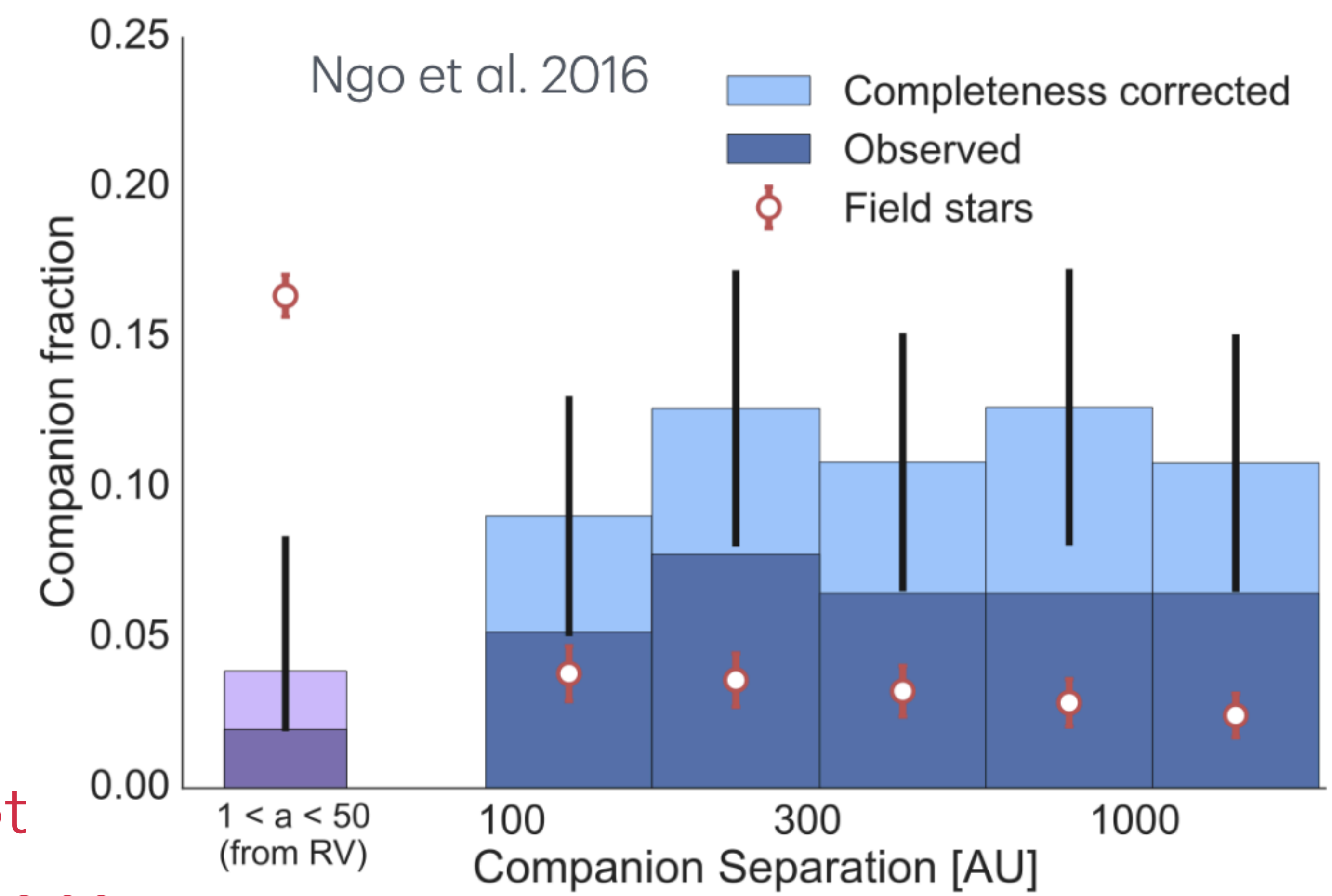
In agreement with theoretical predictions: core accretion for low stellar masses and rapid disc dispersion for high masses.

HOT JUPITERS

P < 10 days

- P peak at 3-5 days
- Strong dependency with stellar metallicity
- Dependency with host stellar mass
- Has long distance companions

50% of hot Jupiters have distant companions (beyond 100 AU).



→ Linked to the formation of hot Jupiters via dynamic interactions

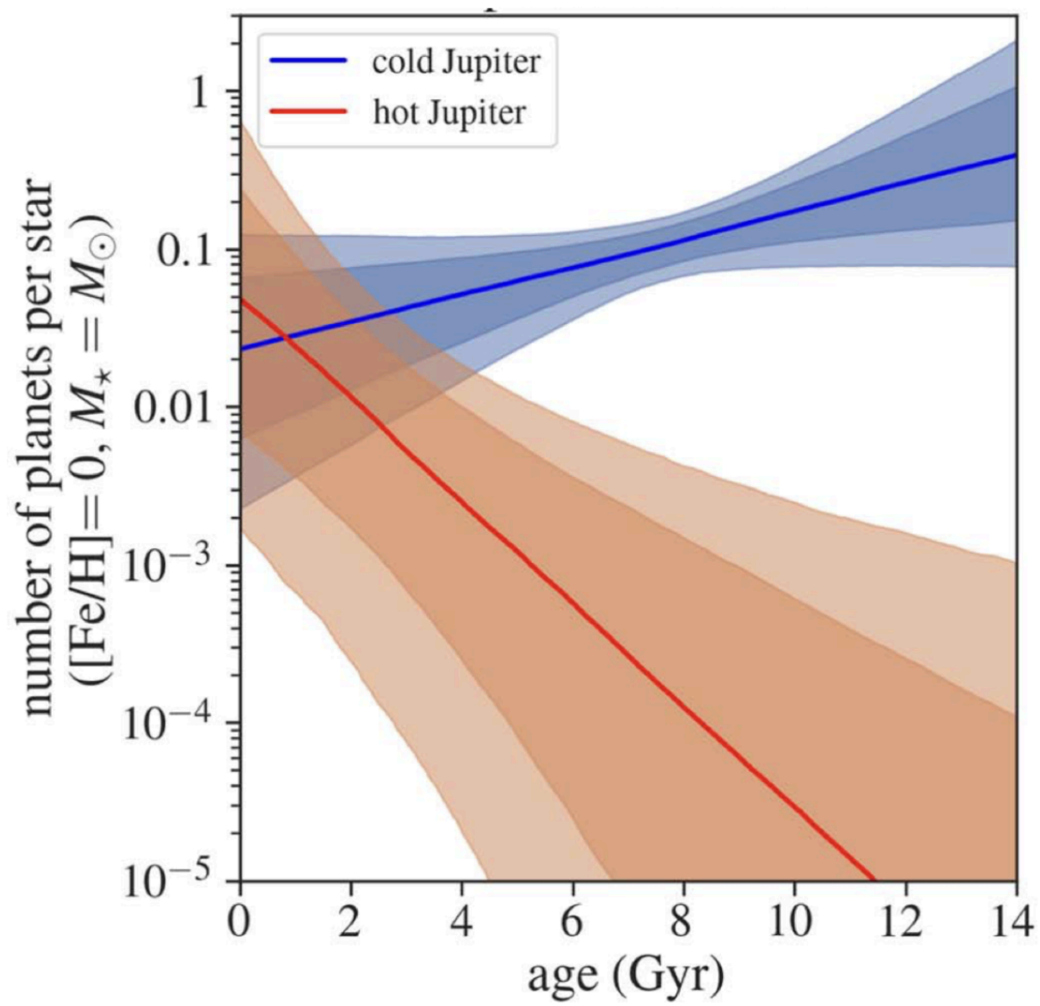
HOT JUPITERS

P < 10 days

- P peak at 3-5 days
- Strong dependency with stellar metallicity
- Dependency with host stellar mass
- Has long distance companions
- Evolved along time ?

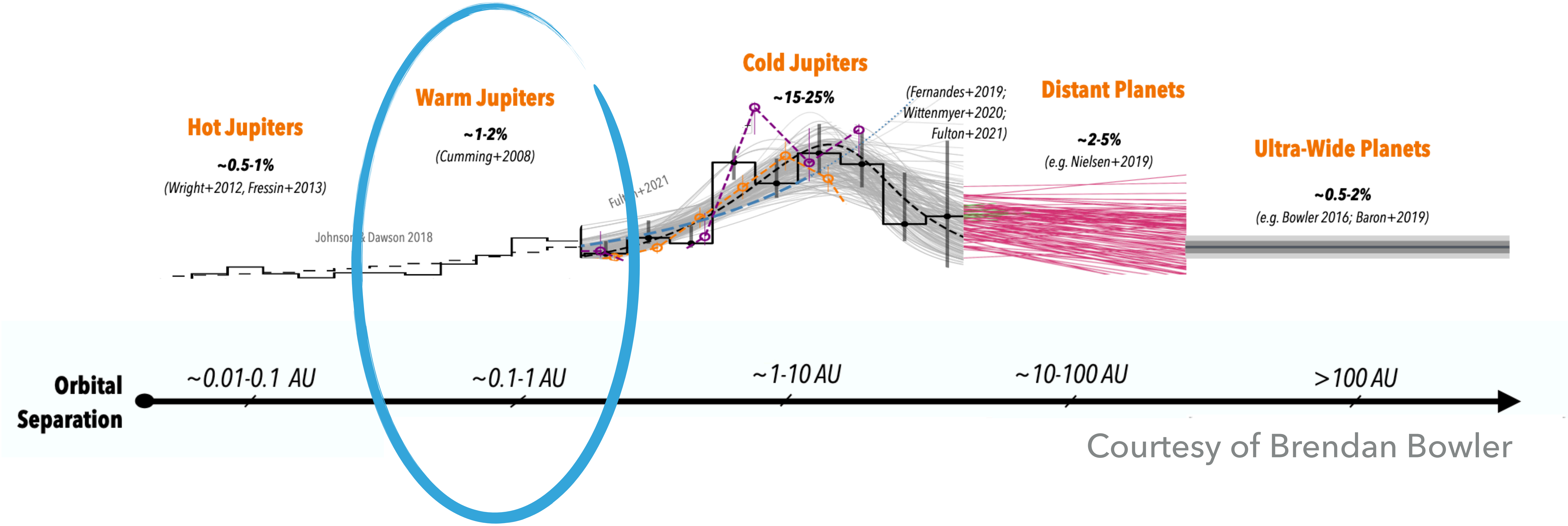
Signs that hot Jupiters are less common around older stars

→ A signature of tidal decay ?



Miyazaki & Masuda 2023

SURVEYS FOR GIANT PLANETS CENSUS



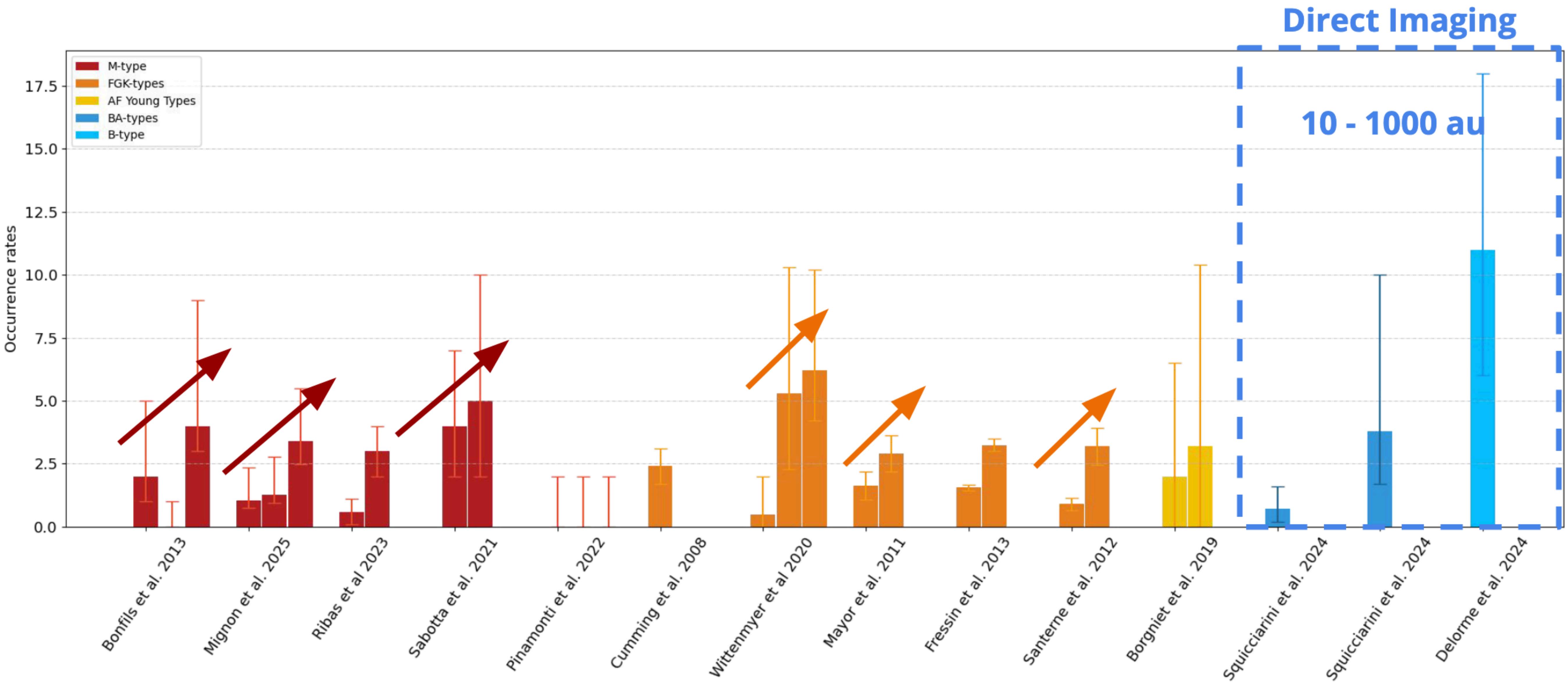
Courtesy of Brendan Bowler

Warm Jupiters :

WARM JUPITERS

Env. 0.1 < a < 1 AU

- Dependency with host stellar mass



Courtesy of Lucile Mignon

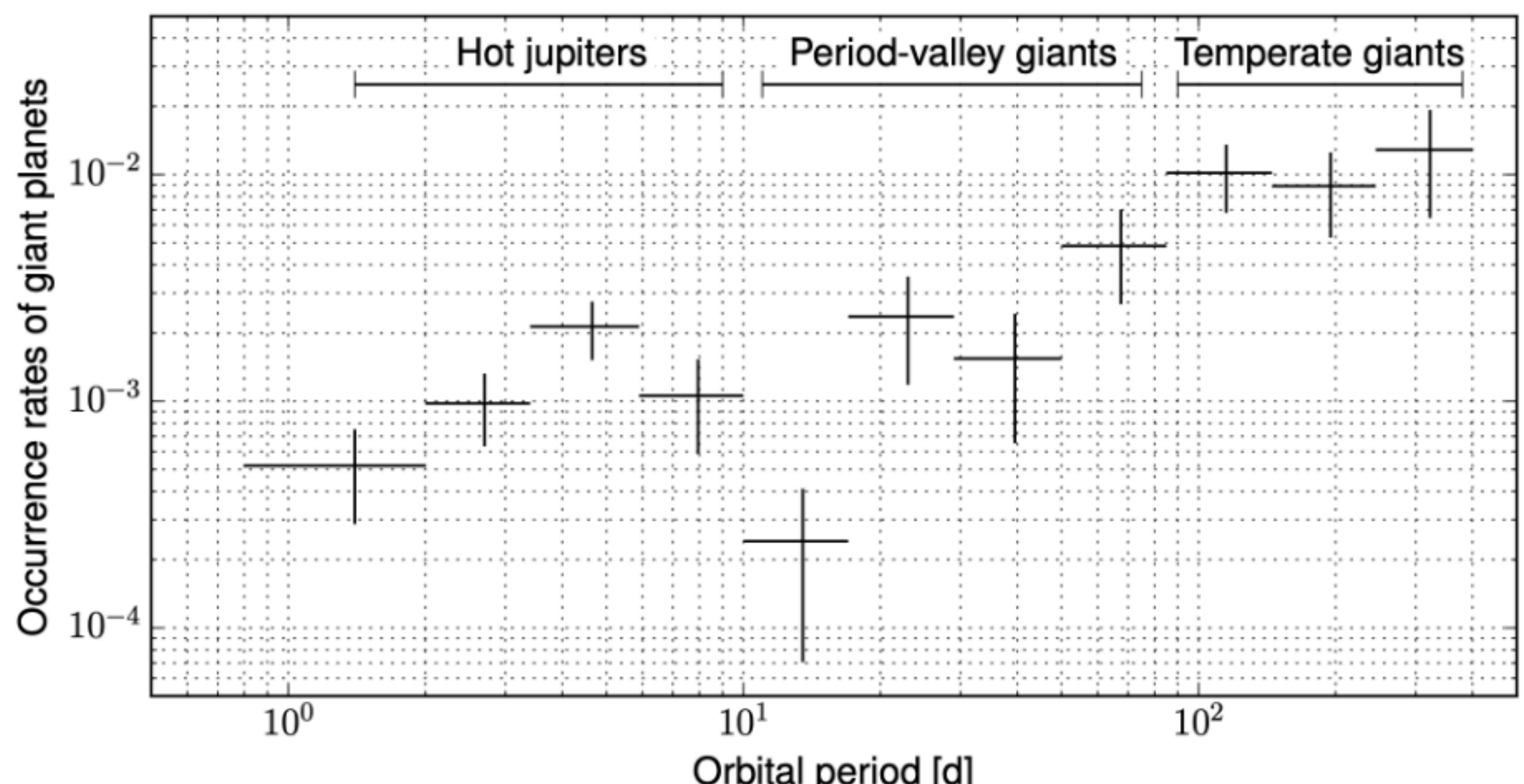
WARM JUPITERS

Env. 0.1 < a < 1 AU

- Dependency with host stellar mass
- Gradual increase with the period

Quite rare

Increase above 1 AU

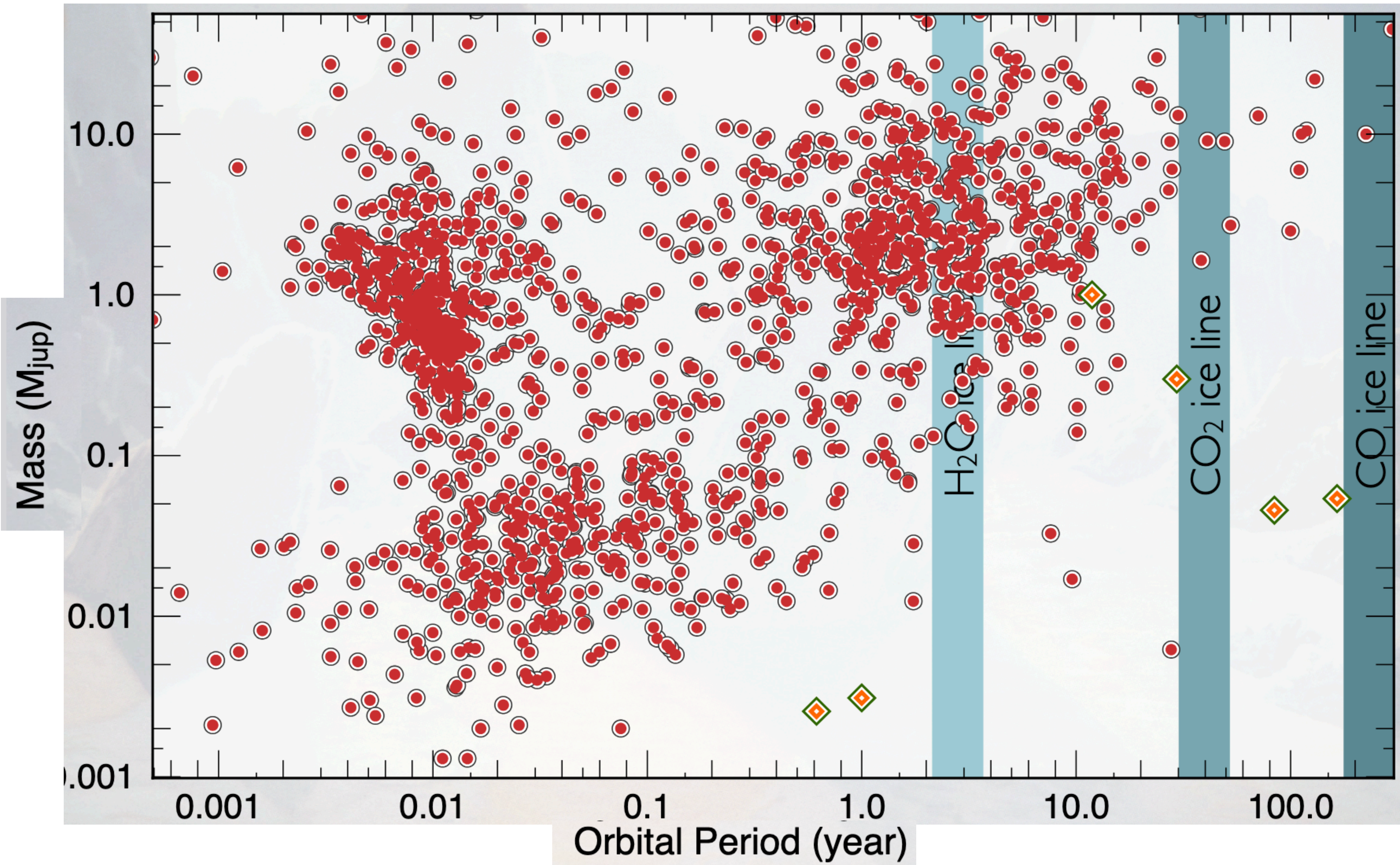


Santerne et al. 2016

→ A signature of water ice line ?

WARM JUPITERS

Env. 0.1 < a < 1 AU

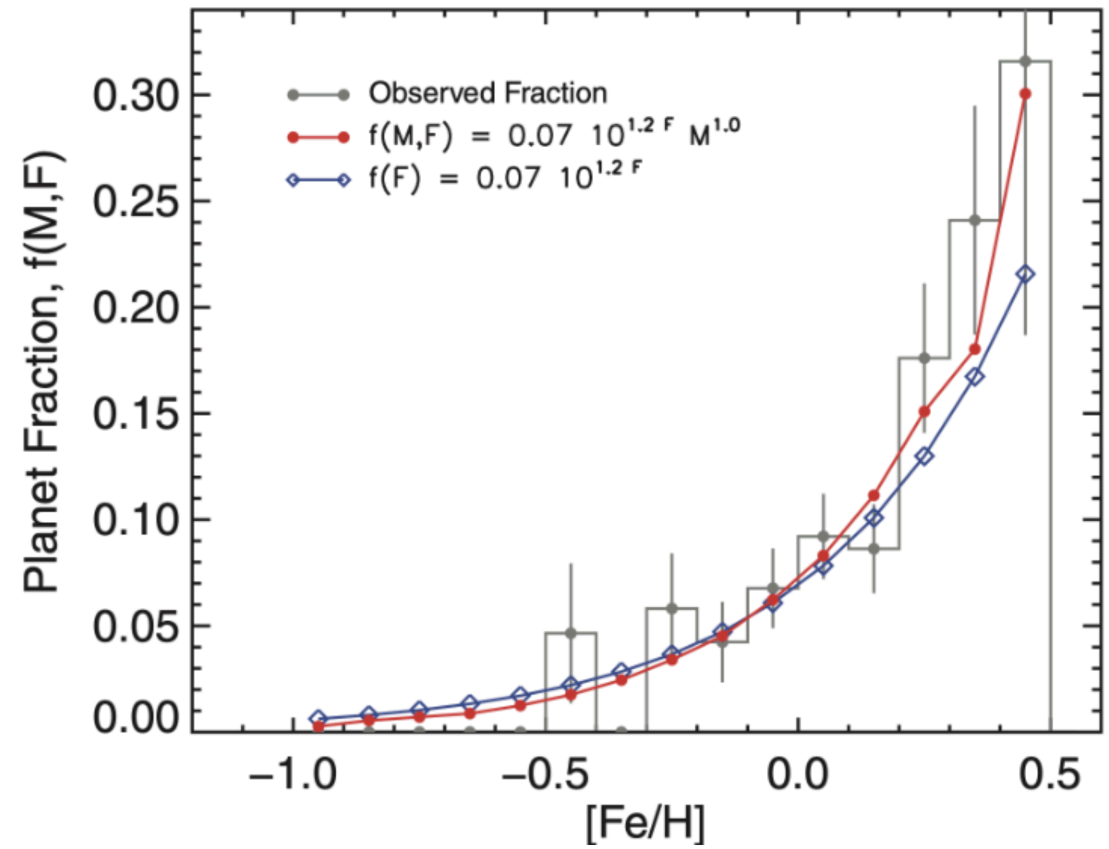


WARM JUPITERS

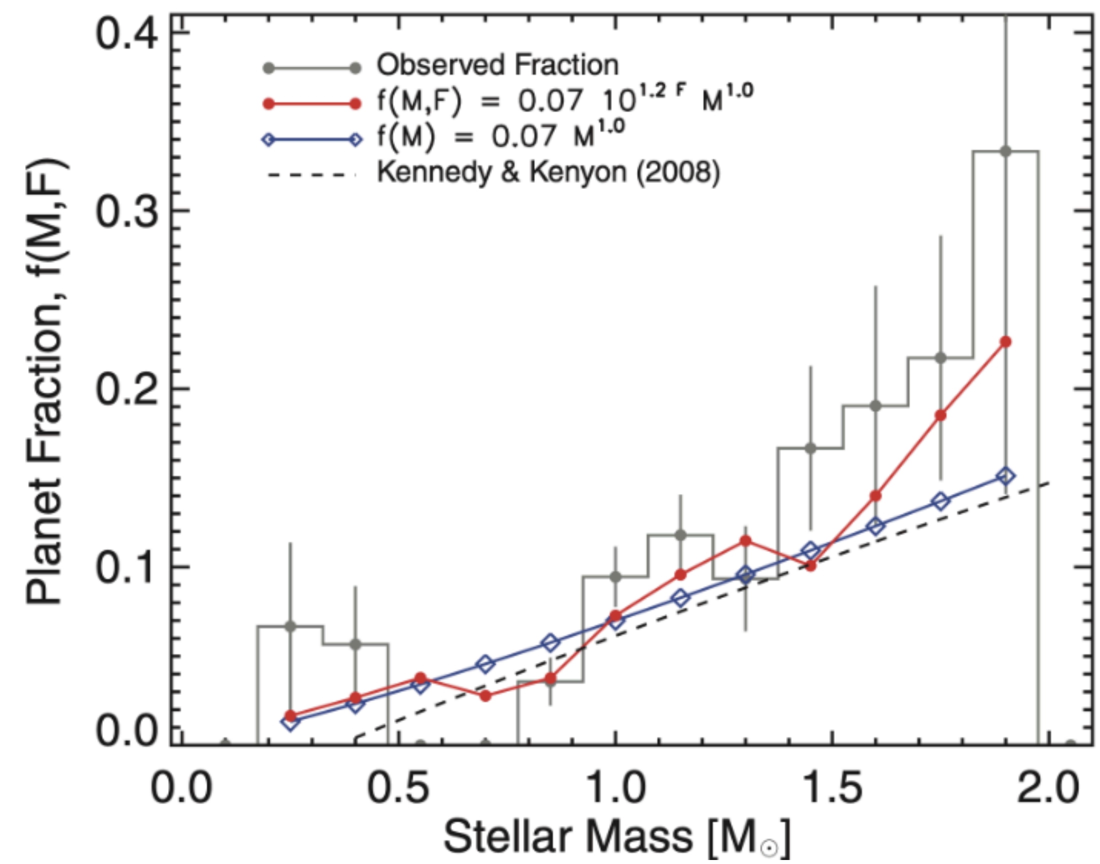
Env. 0.1 < a < 1 AU

- Dependency with host stellar mass
- Gradual increase with the period
- Strong dependency with stellar mass
- Strong dependency with metallicity

→ A more effective signature for core accretion formation?



Johnson et al. 2010



WARM JUPITERS

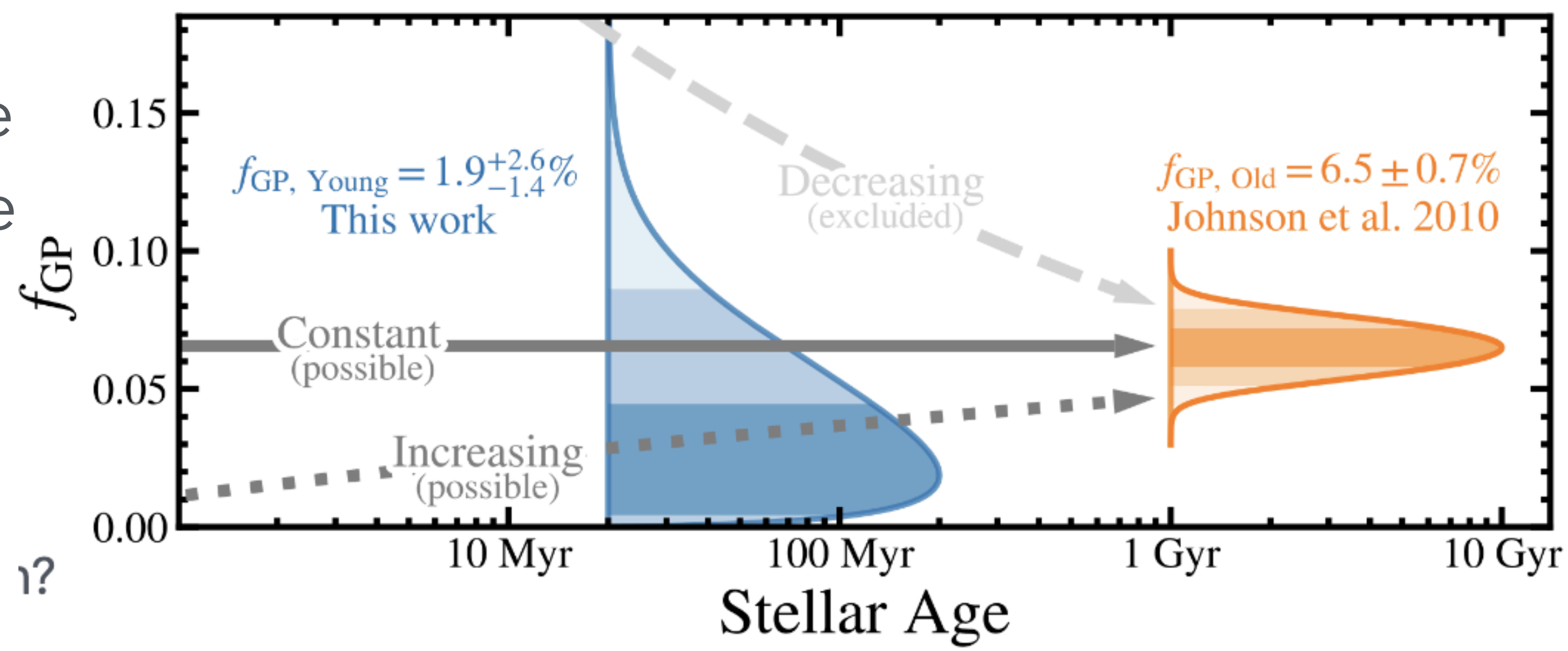
Env. 0.1 < a < 1 AU

- Dependency with host stellar mass
- Gradual increase with the period
- Strong dependency with stellar mass
- Strong dependency with metallicity

VR surveys around young stars find fewer giant planets than around middle-aged stars.

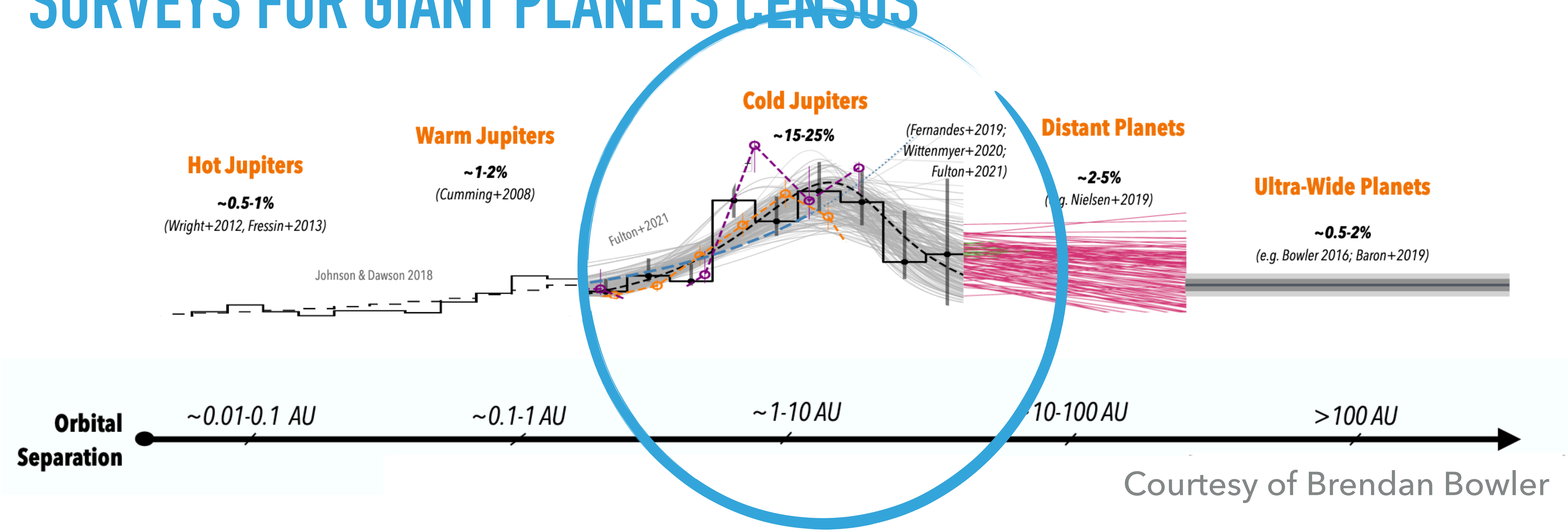
Tran et al. 2025

- Indicators of an increase in the rate of occurrence over time



A late internal migration signature?

SURVEYS FOR GIANT PLANETS CENSUS



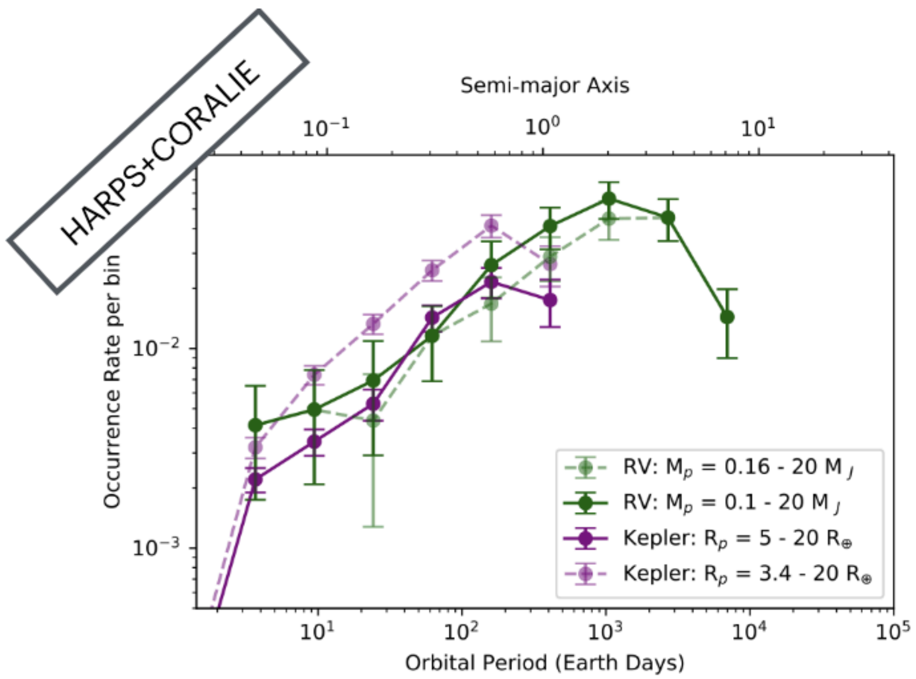
Courtesy of Brendan Bowler

→ **Cold Jupiters : a peak in the distribution of giant exoplanets**

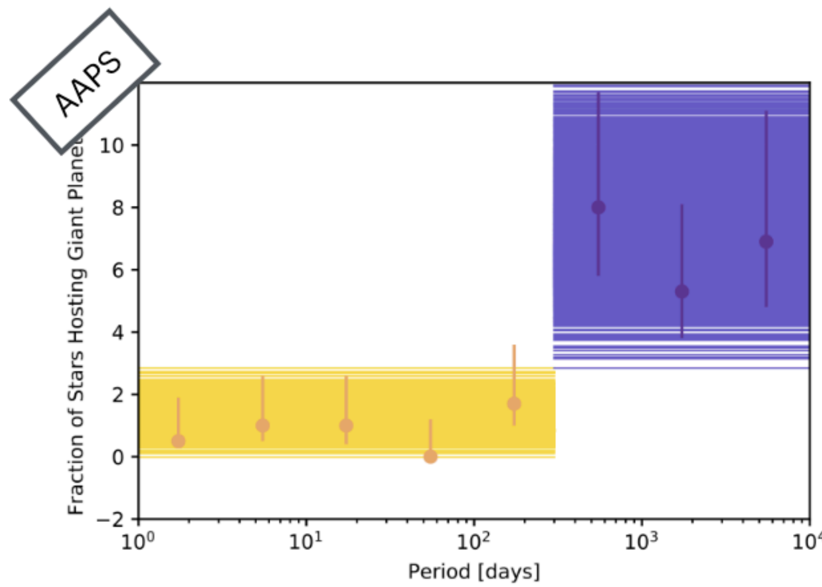
COLD JUPITERS

Env. 1 < a < 10 AU

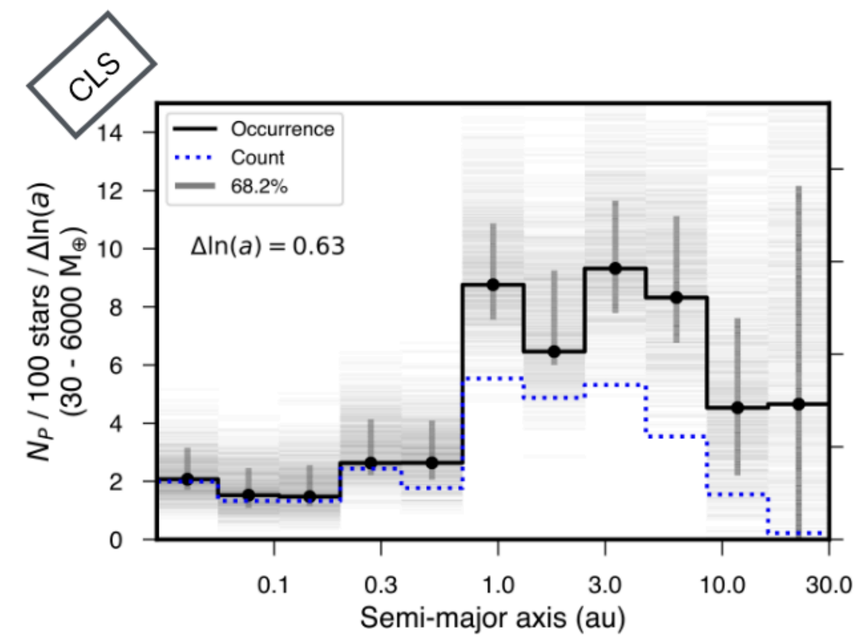
- A peak in the RV surveys



Fernandes et al. 2019



Wittenmyer et al. 2020



Fulton et al. 2021

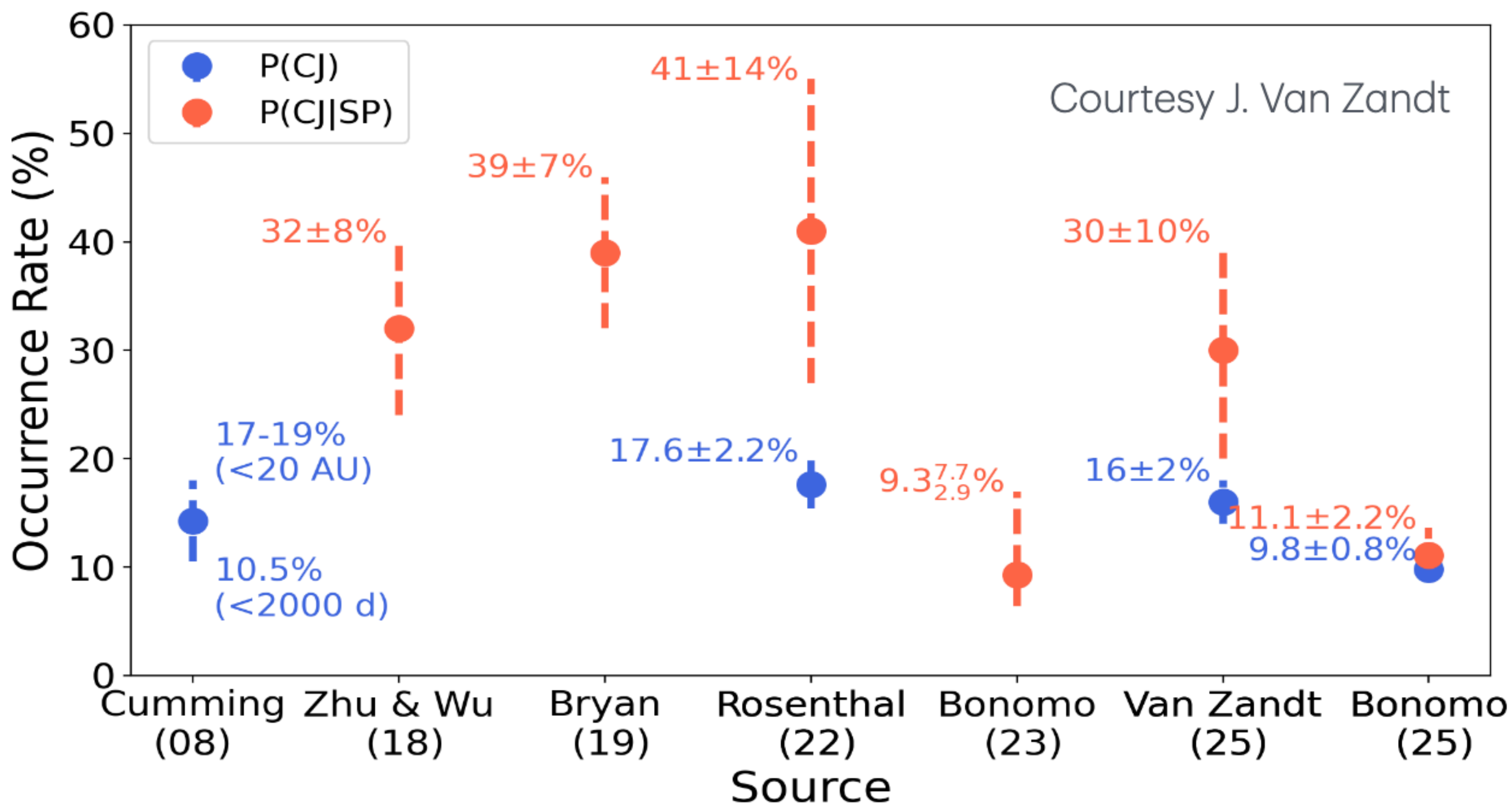
Courtesy of B. Bowler

COLD JUPITERS

Env. 1 < a < 10 AU

- A peak in the RV surveys
- Impact on the population of small inner planets

Cold Jupiters may be more common around stars with small inner planets.



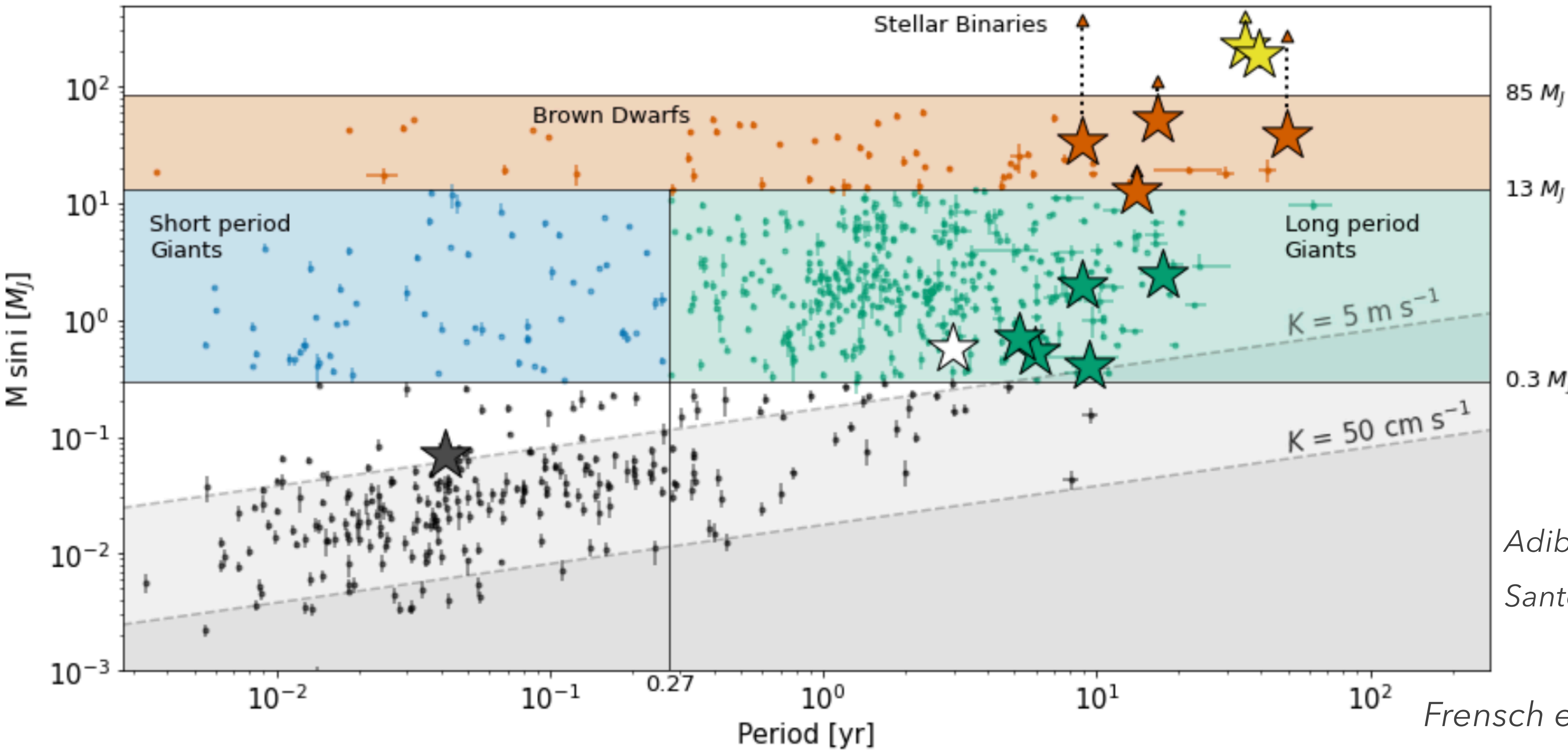
COLD JUPITERS

Env. 1 < a < 10 AU

More eccentric than shorter periods ?

Not strong dependency with metallicity

- A peak in the RV surveys
- Impact on the population of small inner planets

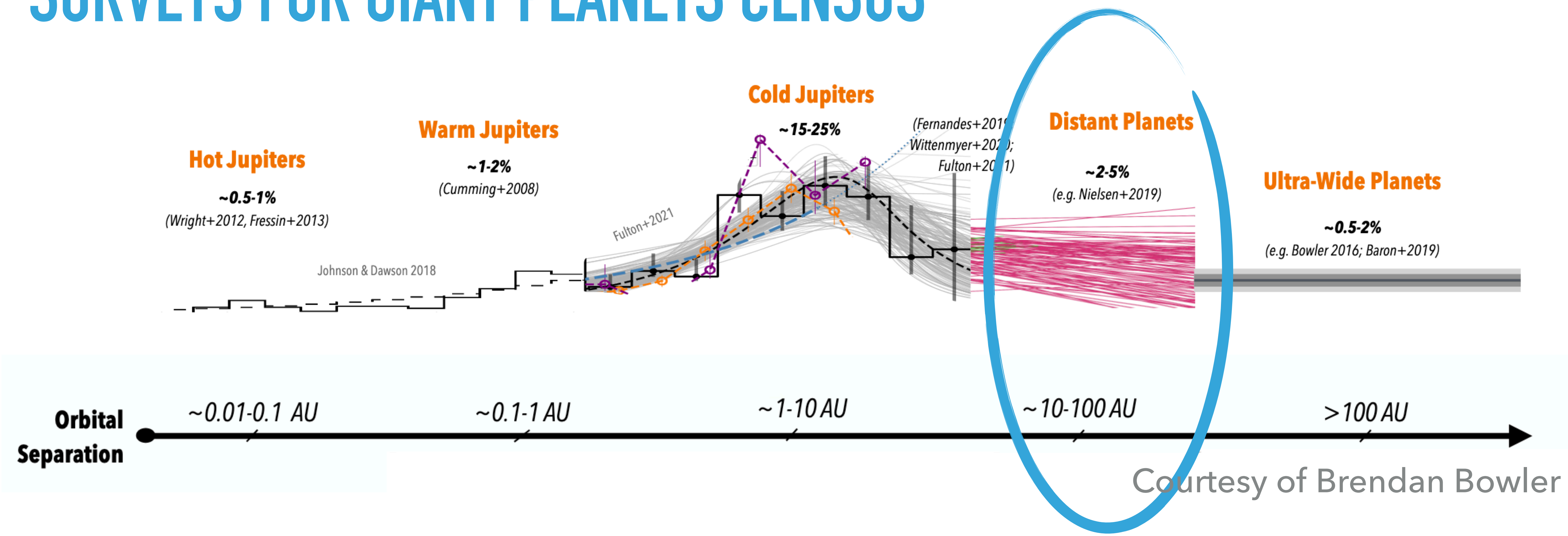


Adibekyan et al. 2013

Santos et al. 2017

Frensch et al. 2023

SURVEYS FOR GIANT PLANETS CENSUS



Courtesy of Brendan Bowler

→ **Distant Jupiters**

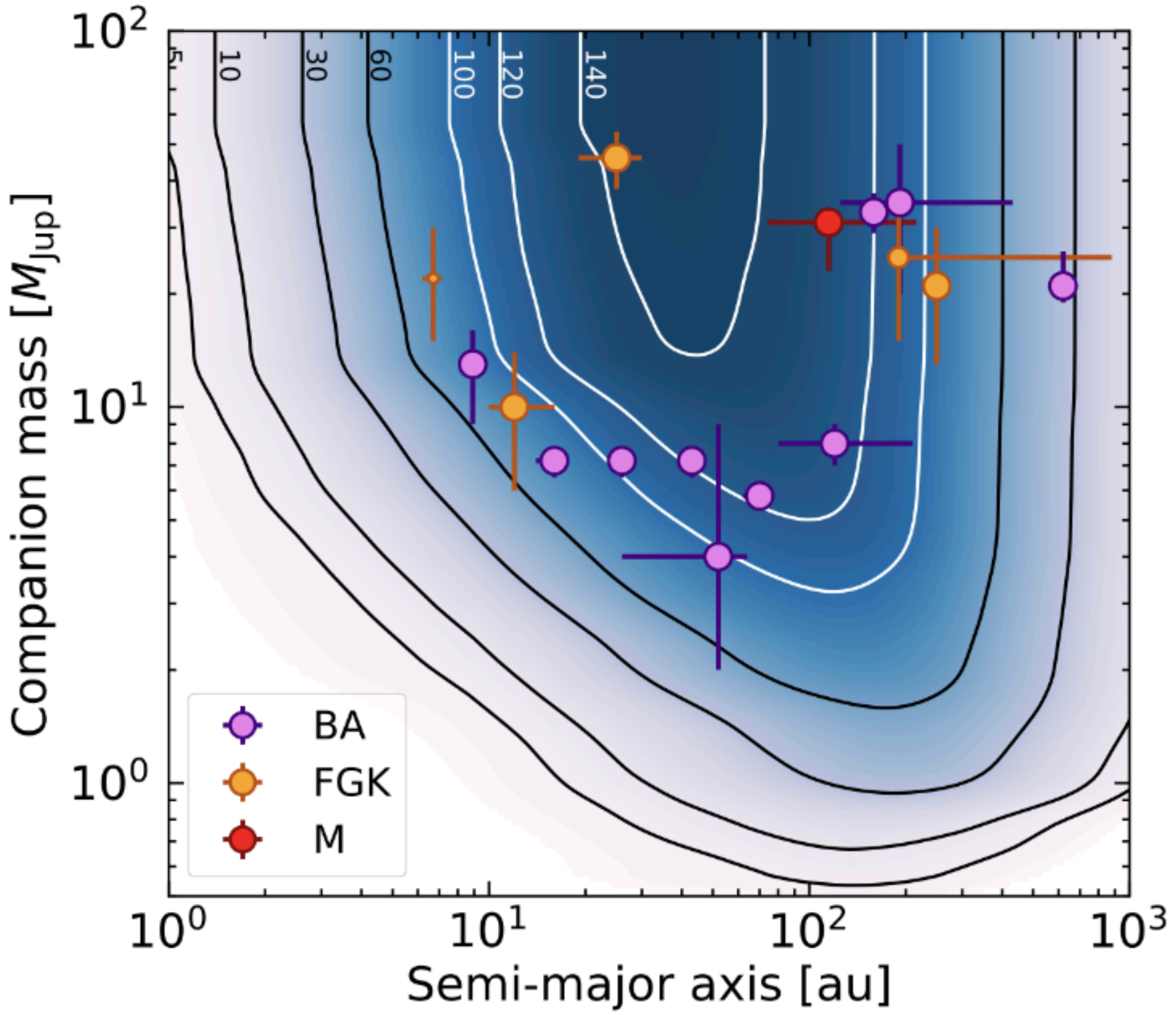
DISTANT JUPITERS

Env. 10 < a < 100 AU

- The occurrence rate decreases with distance for massive planets.

2-5% for 5-13 Mjup in 10-100 AU

1% for 5-13 Mjup in 30-300 AU



Vigan et al. 2021

DISTANT JUPITERS

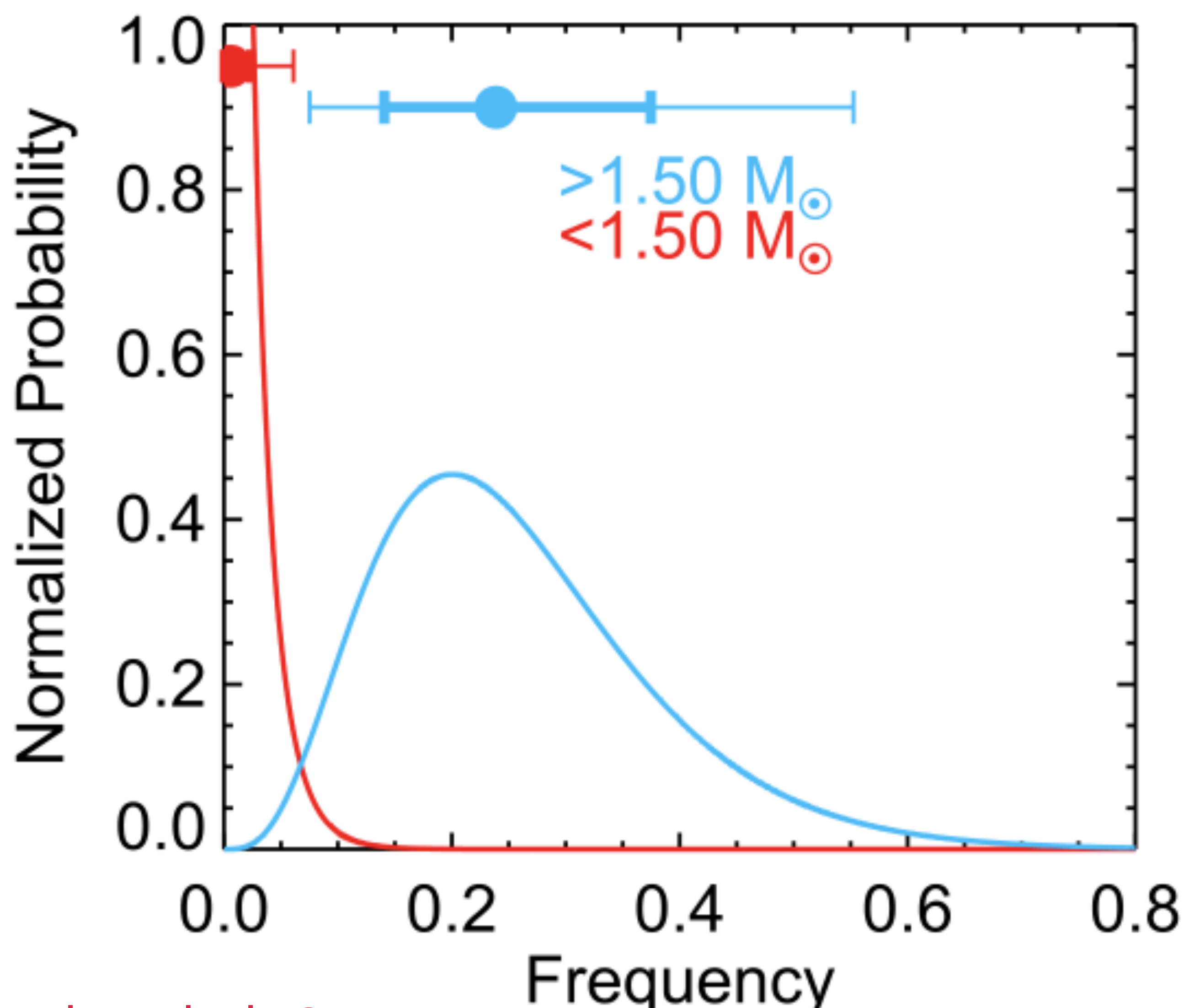
Env. 10 < a < 100 AU

- Occurrence rate decreases with distance for massive planets.

- Occurrence rate proportionnal to stellar mass

Massive planets at long distance

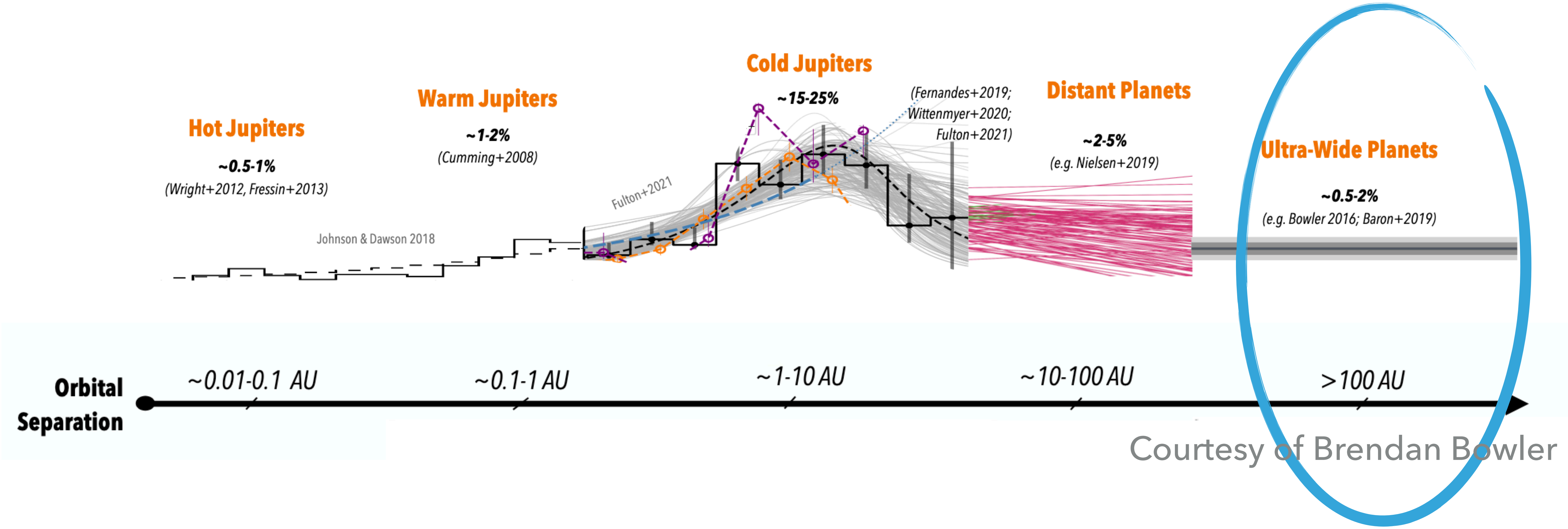
Preference for young massive stars



→ Mass reservoir more important in the disk ?

Formation by disk instability ?

SURVEYS FOR GIANT PLANETS CENSUS



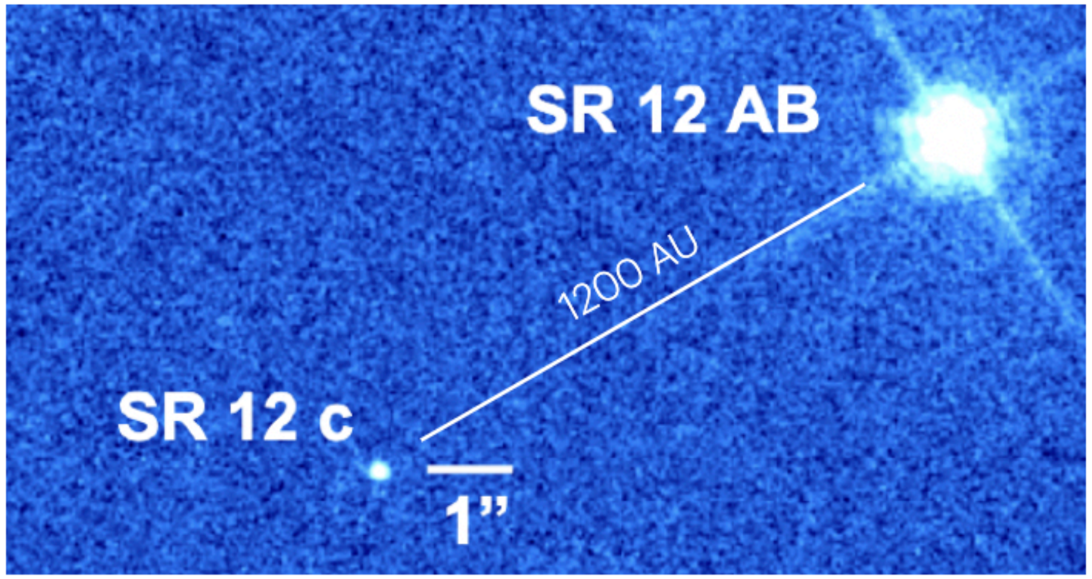
Courtesy of Brendan Bowler

→ Ultra-wide planets

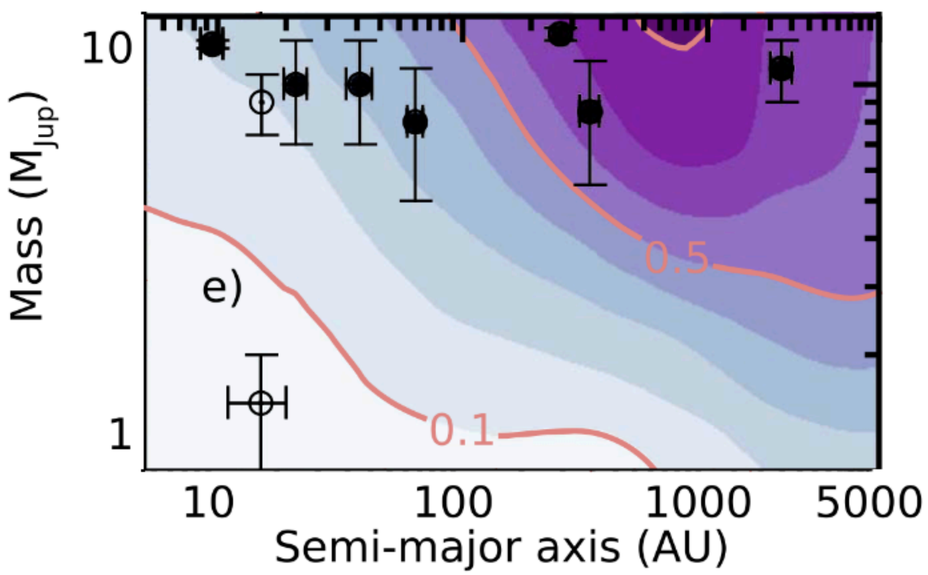
ULTRA WIDE JUPITERS

Env. a > 100 AU

- Very rare but can be found at thousands of AU



Finley et al., in prep.



Baron et al. 2019

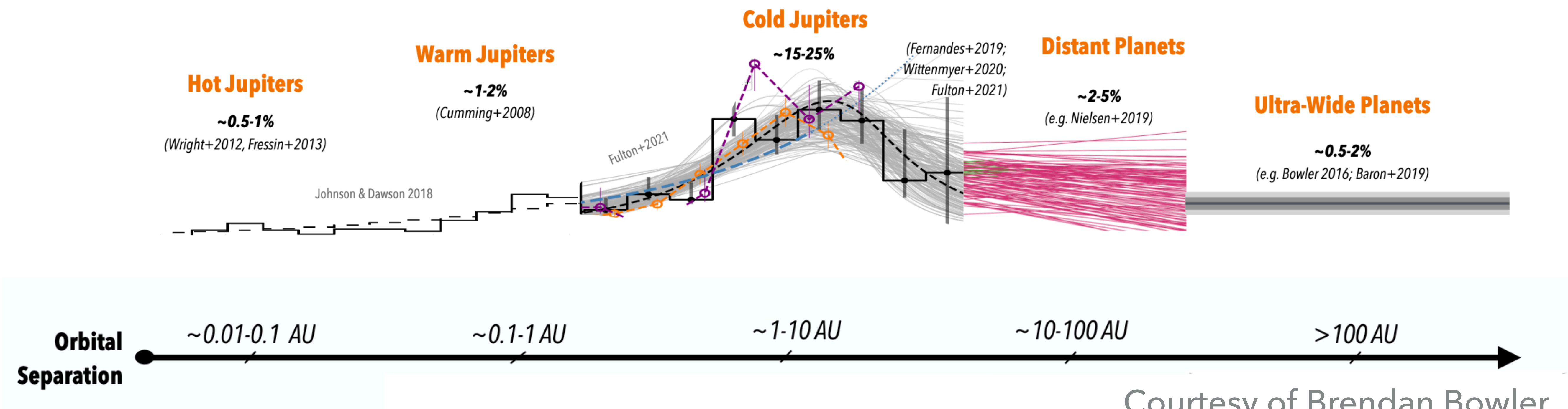
20-1000 AU, f ~ 2%

1000-5000 AU, f ~ 0.3%

→ Ejected planets ?

Tail of the distribution with disk fragmentation ?

SURVEYS FOR GIANT PLANETS CENSUS



Courtesy of Brendan Bowler

Accross 5 orders of magnitudes

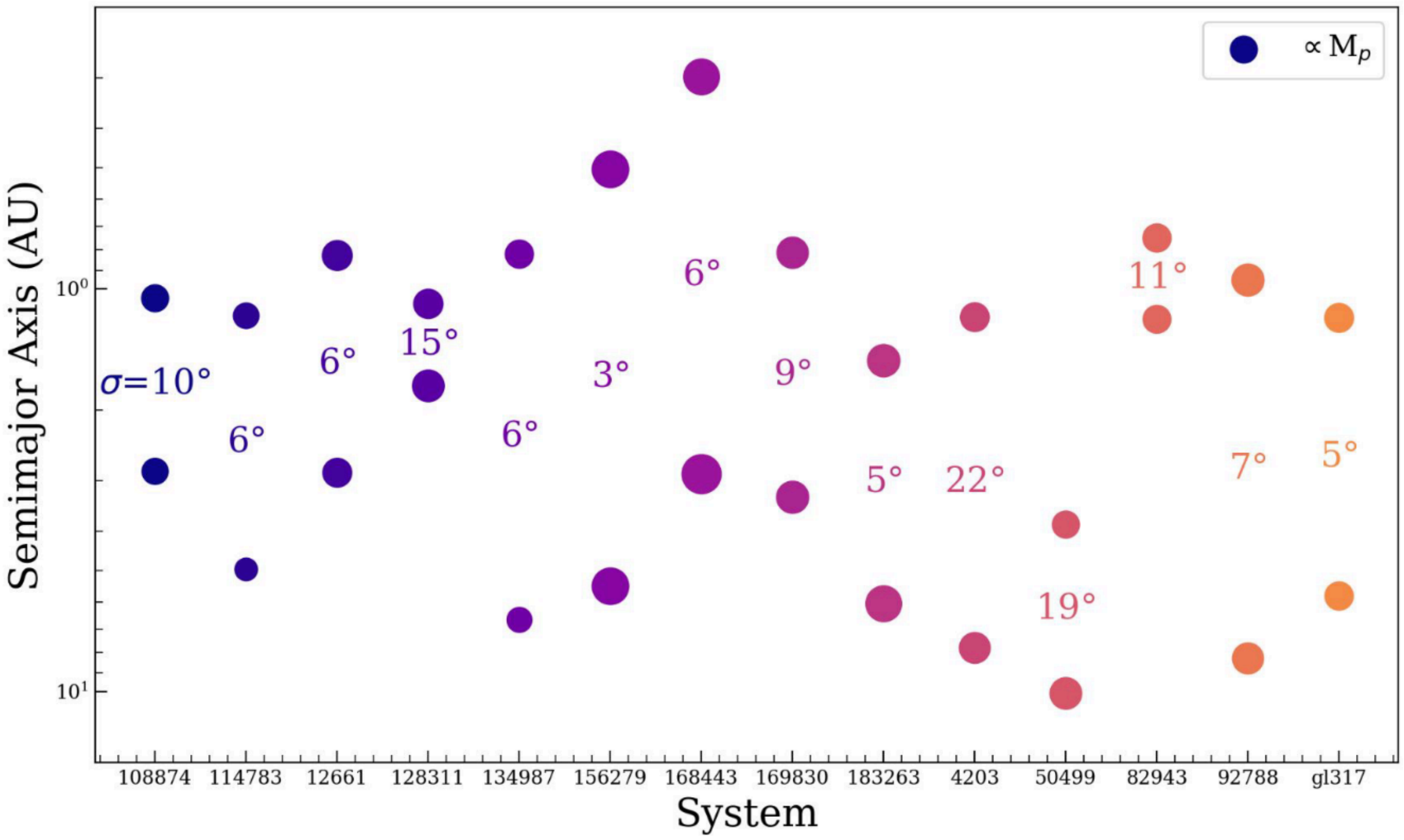
$$f_{GP} \sim 19 - 35\,\%$$

~0.3-15 M_{Jup} ~0.1-1000 AU

For solar-type stars that can be considered more or less alone

STILL OPENED QUESTIONS

- Occurence rate of giant planets in multiple systems ?

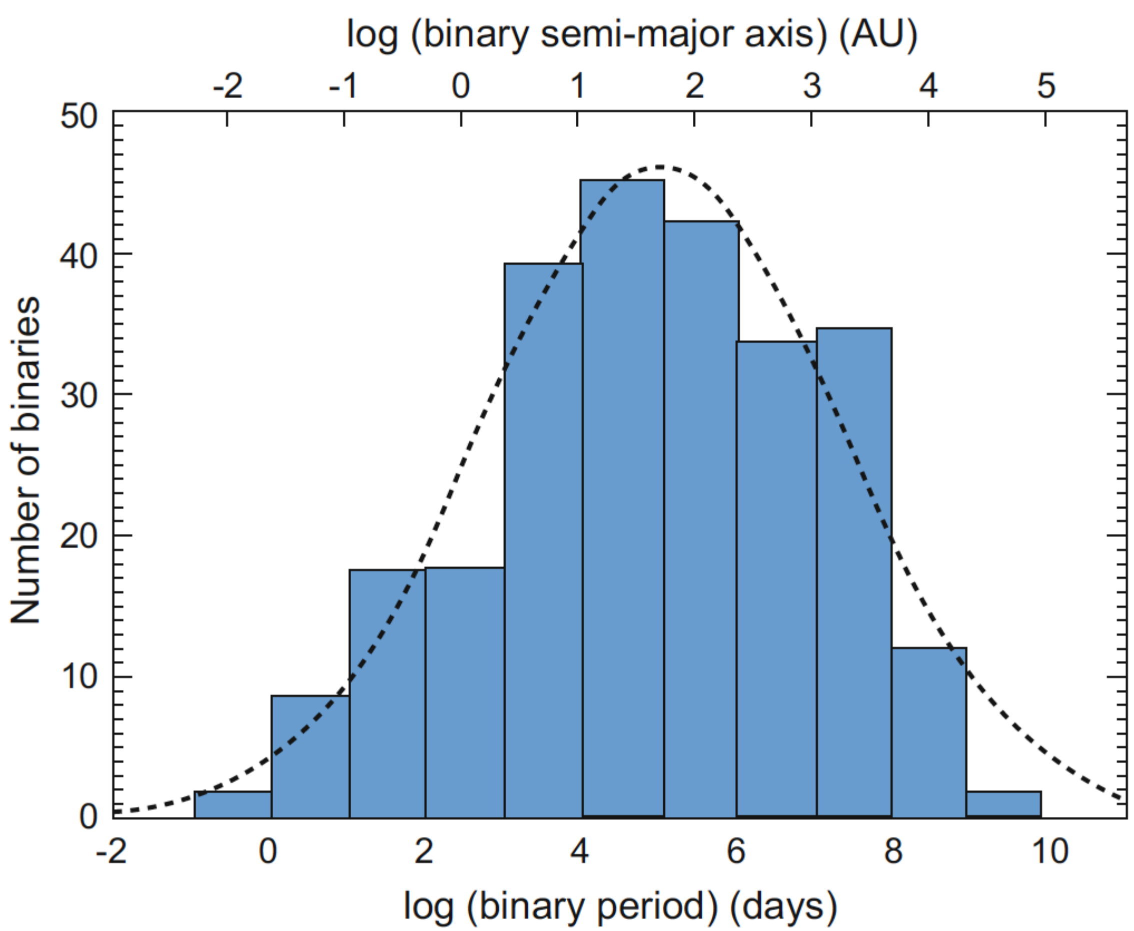


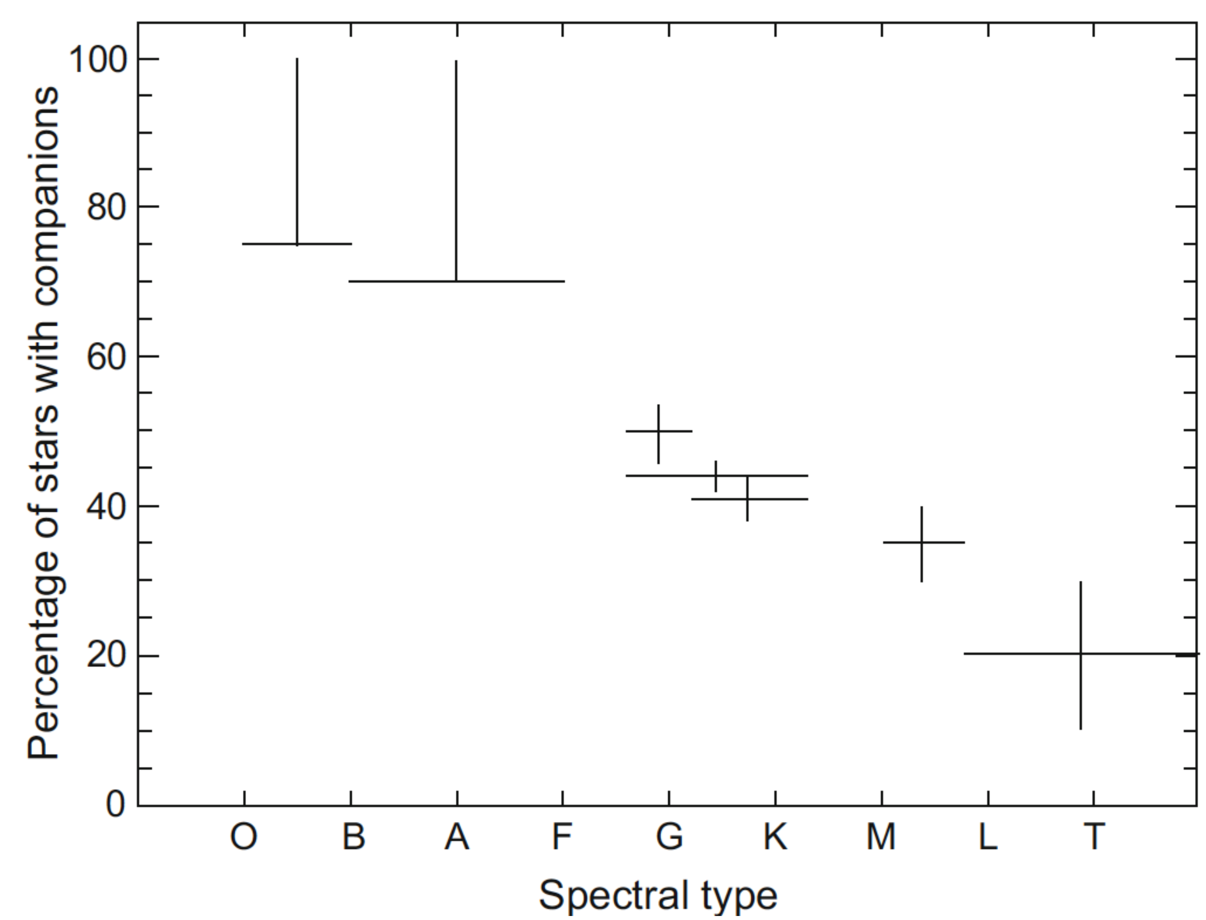
STILL OPENED QUESTIONS

- Occurence rate of giant planets in multiple systems ?
- When and how giant planets develop eccentricity ?
- Is there a link with giant planets and the habitability of inner planets ?
- What are the differences with giant planets in binary star systems ?

BINARY SYSTEMS

- 50% of the stars in the MW are in multiple systems : binary or more
- 50% of the stars in the MW have masses < 25% Solar mass





Martin 2018

PLANETS IN BINARY SYSTEMS

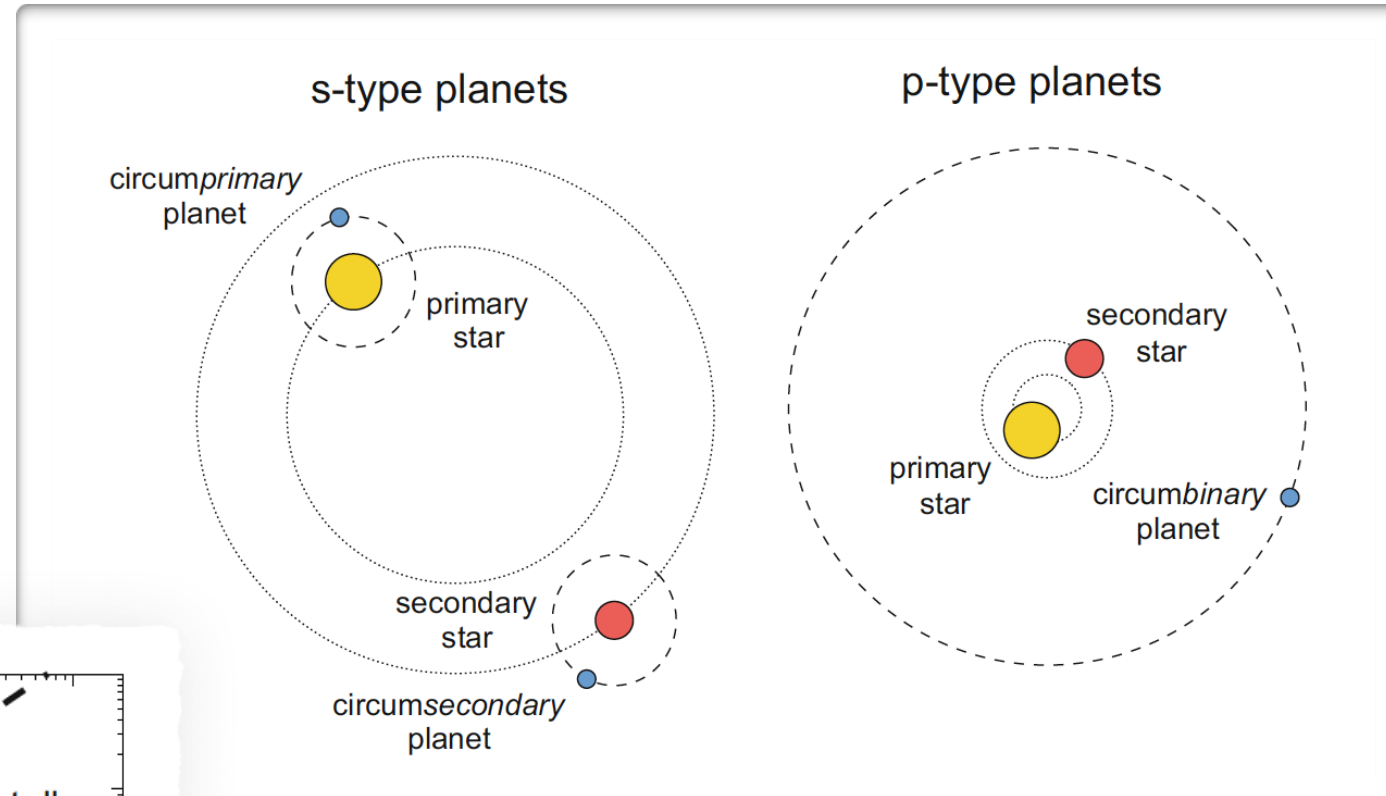
- Two orbital types

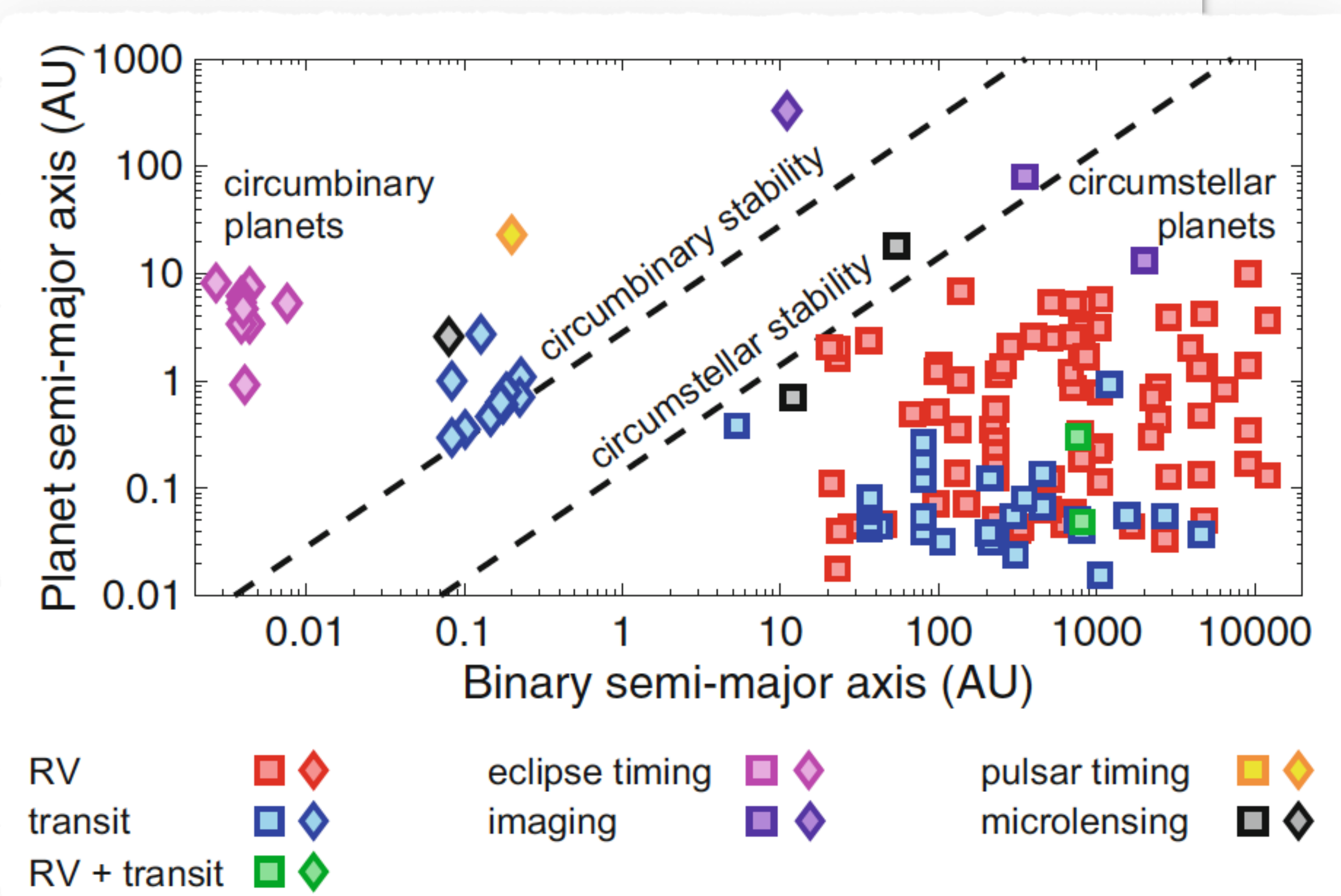
  Satellite-type

  → Circumstellar planets

  Planetary-type

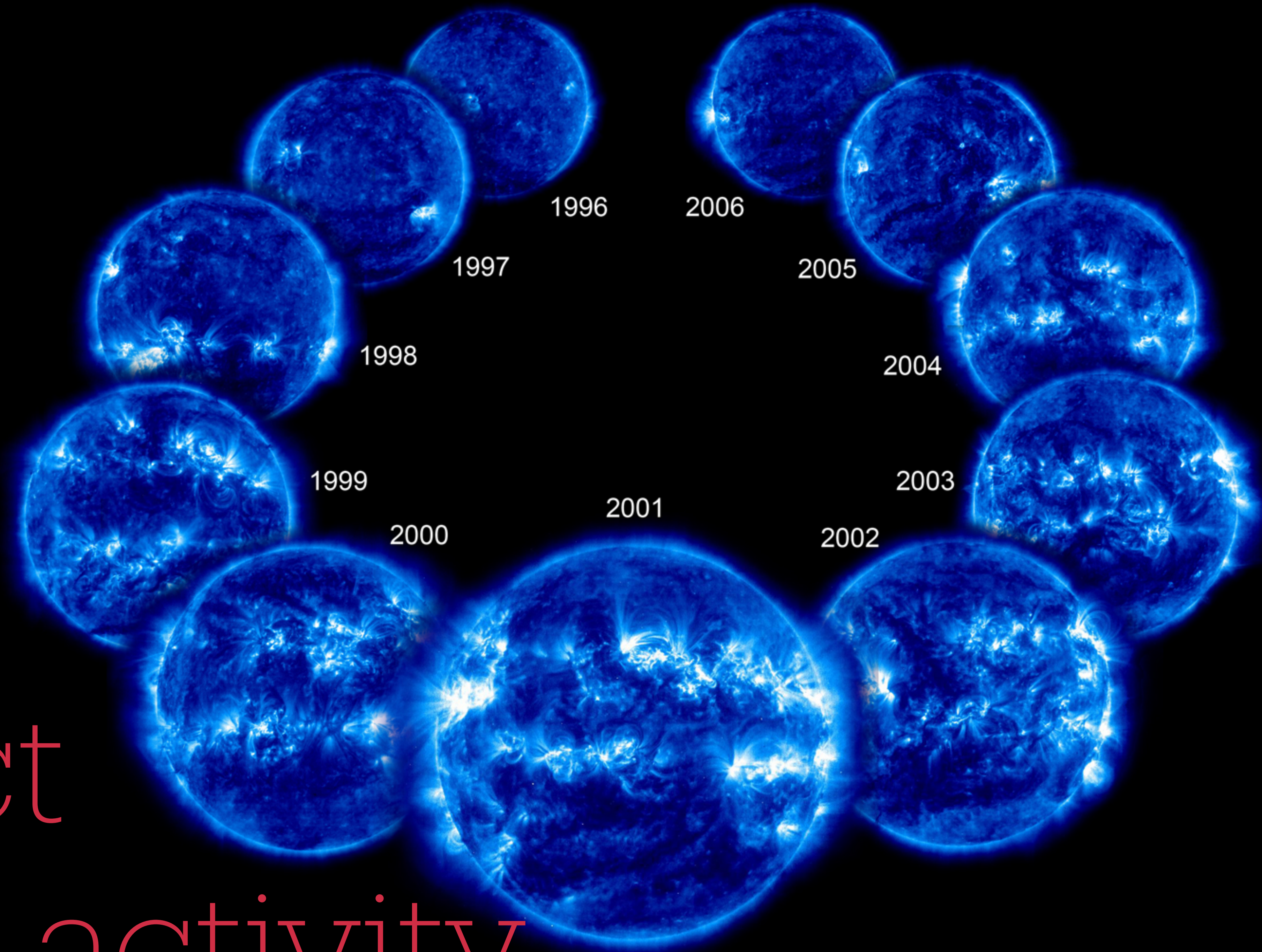
  → Circumbinary planets





- Very different characteristics

Martin 2018



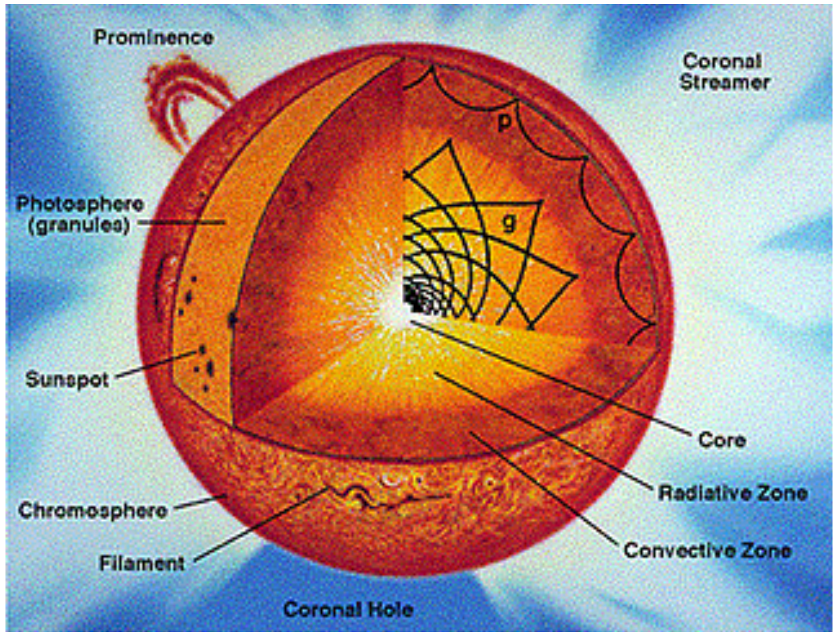
4. Impact of stellar activity

On the characterization of exoplanet parameters

Isabelle Boisse (LAM/OHP) - Roman Coronography School - 12/03/26

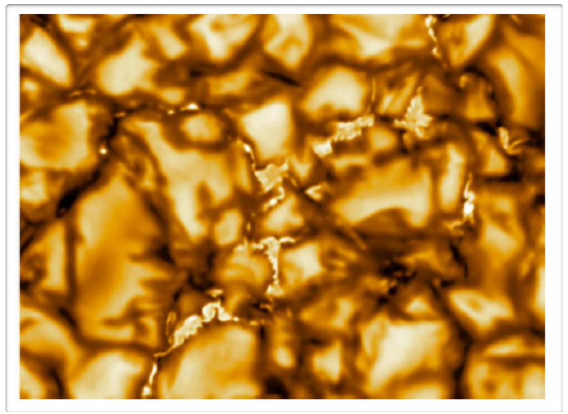
All stars are active

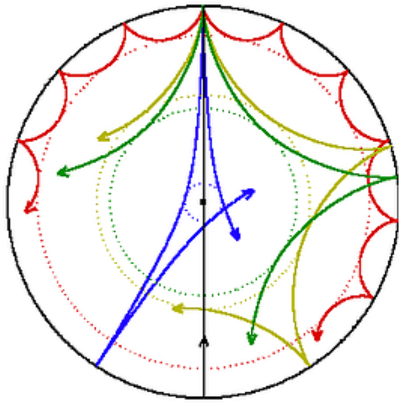
Impact on the exoplanet characterization



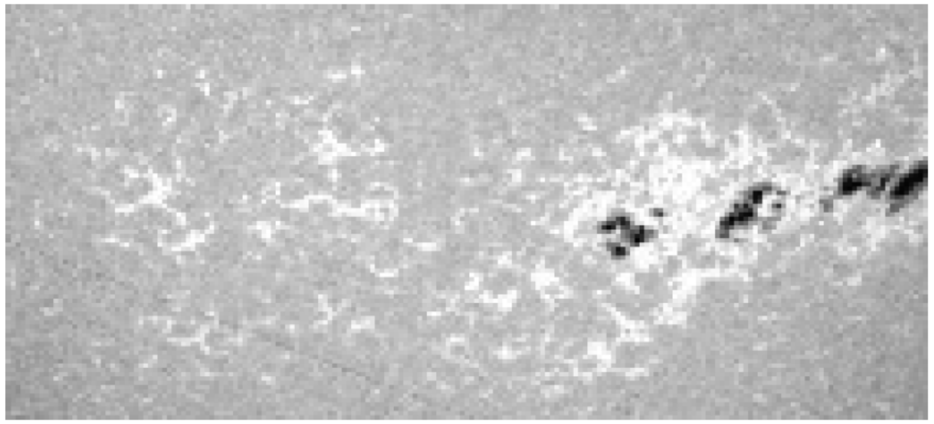
The signal received from the star also get the mark of stellar activity

- **Granulation**
- **Pulsations**

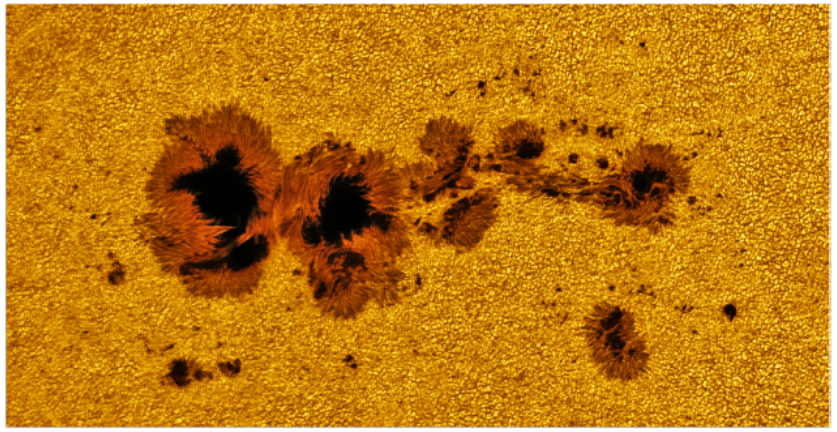


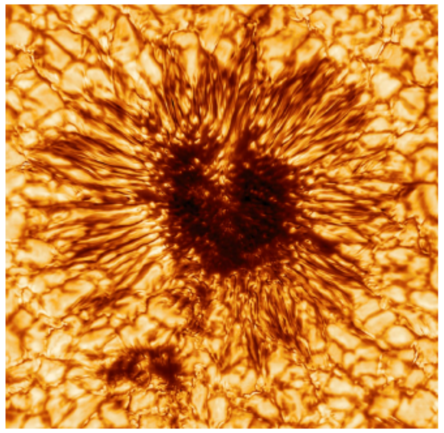


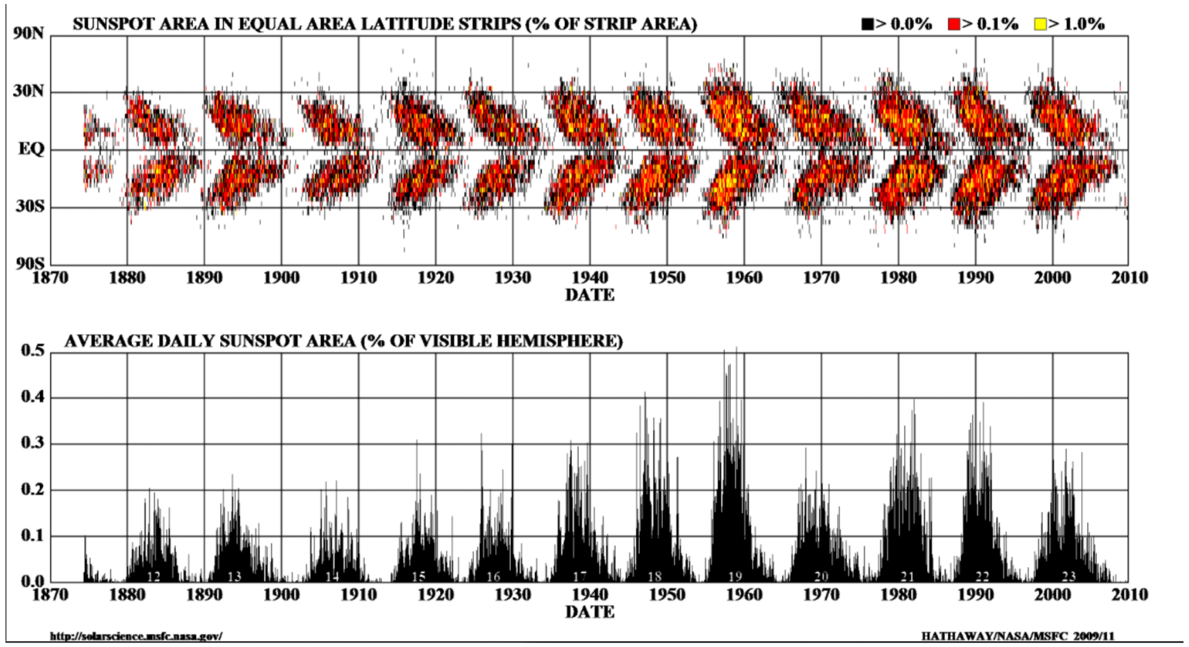
- **Dark spots / bright plages and the star's rotation period**



- **Long term activity involving magnetic cycle**



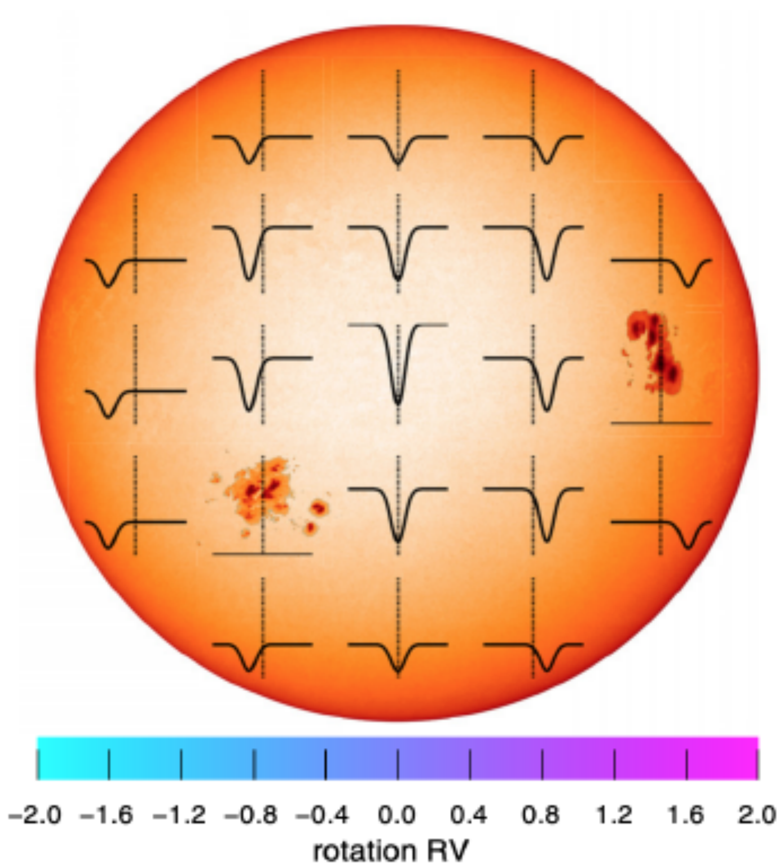


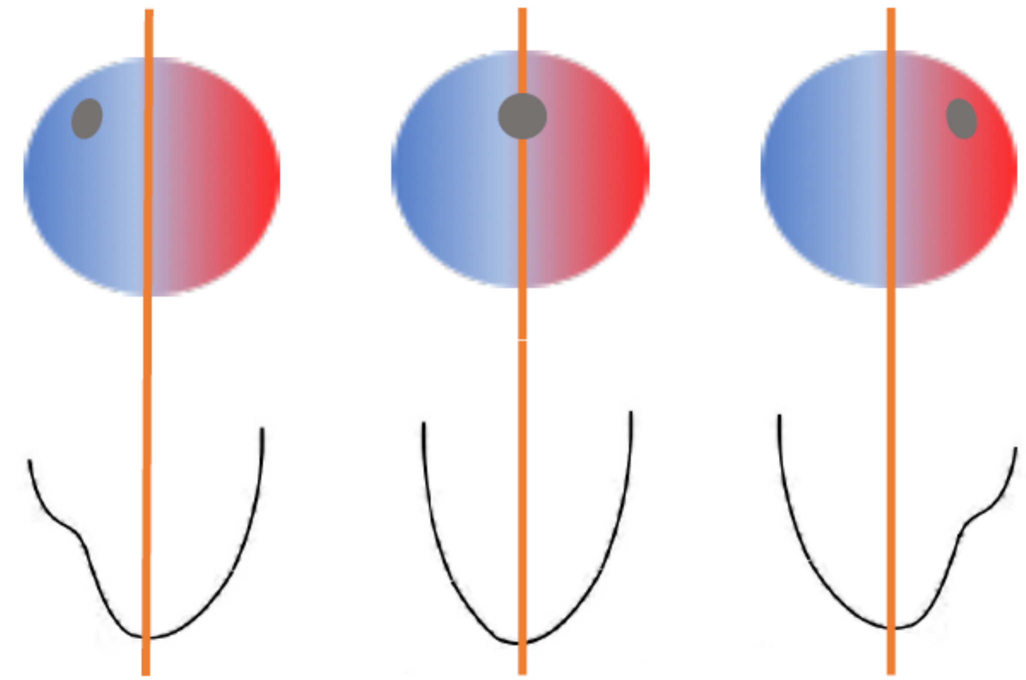


All stars are active

Impact on the exoplanet characterization

RV variations induced by distortion of the lines





BIS - Vspan - FWHM

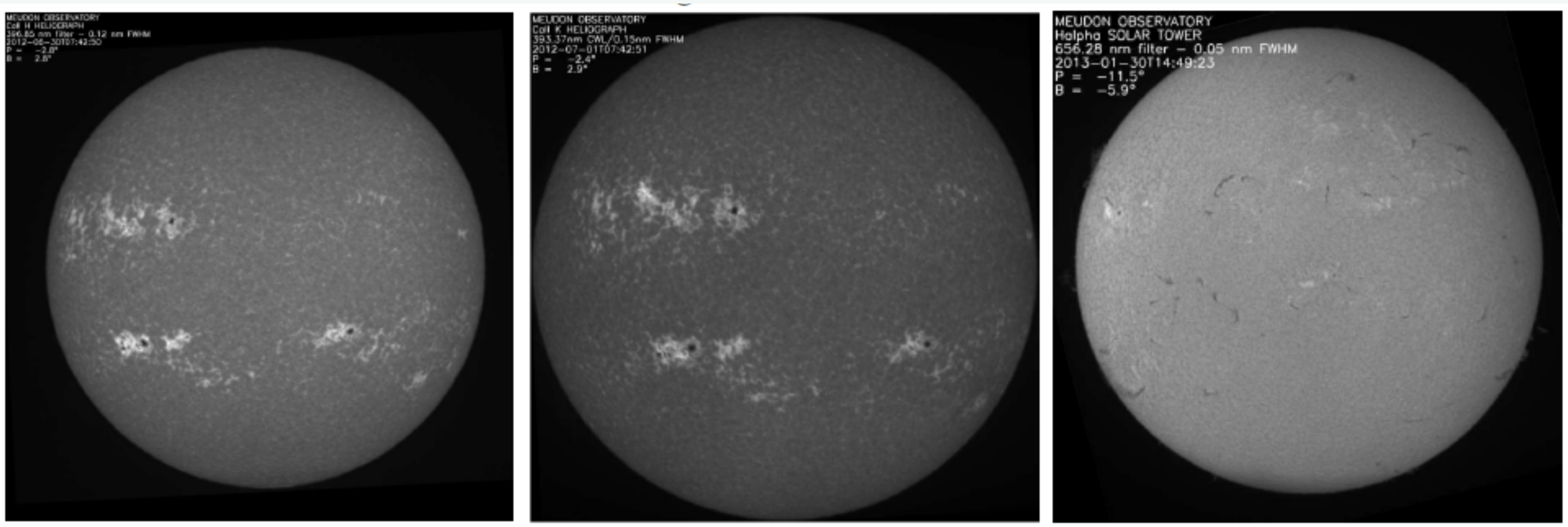
+ convection is blocked in strong magnetic field

e.g. Boisse et al. 2011, Meunier et al. 2023

Dumusque et al. 2014, 2015

All stars are active

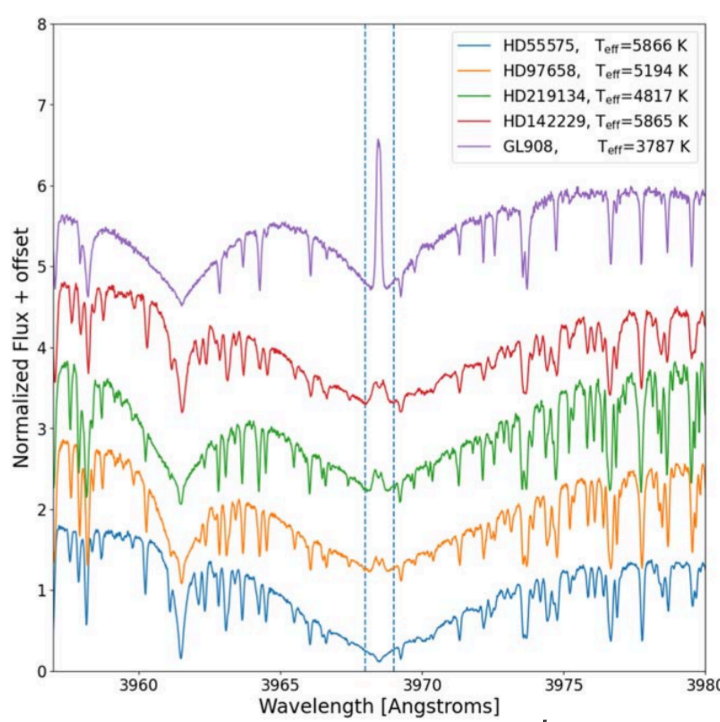
Impact on the exoplanet characterization



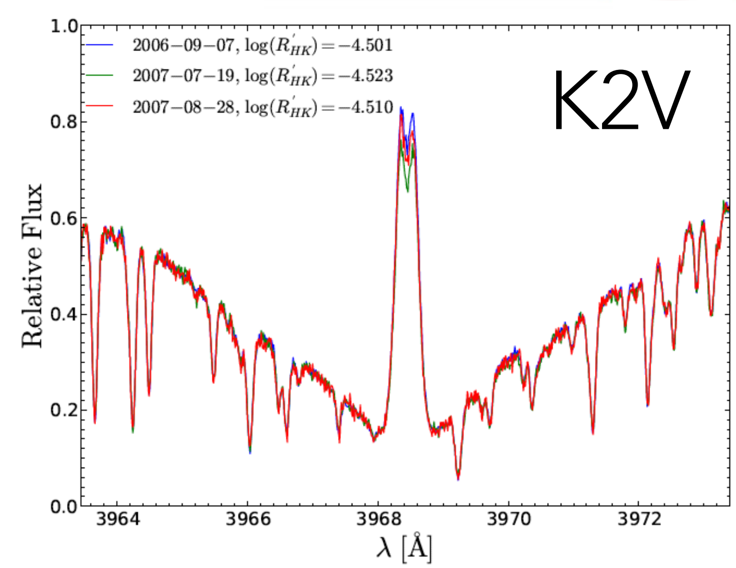
(b) Ca II H - 2012 (c) Ca II K - 2012 (d) $H\alpha$ - 2013

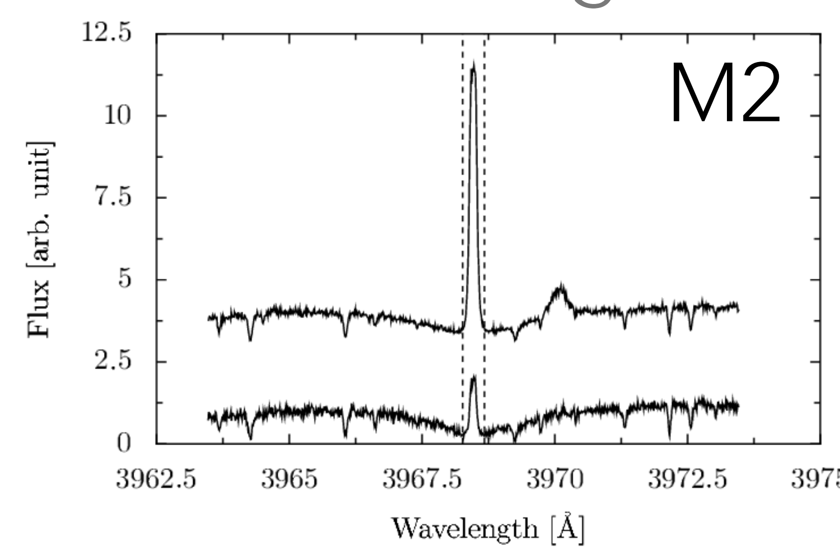
Lines sensitive to stellar activity

Sun seen in lines "sensitive to activity"
Forbidden transitions induced by magnetic heating



Isaacson et al. 2024

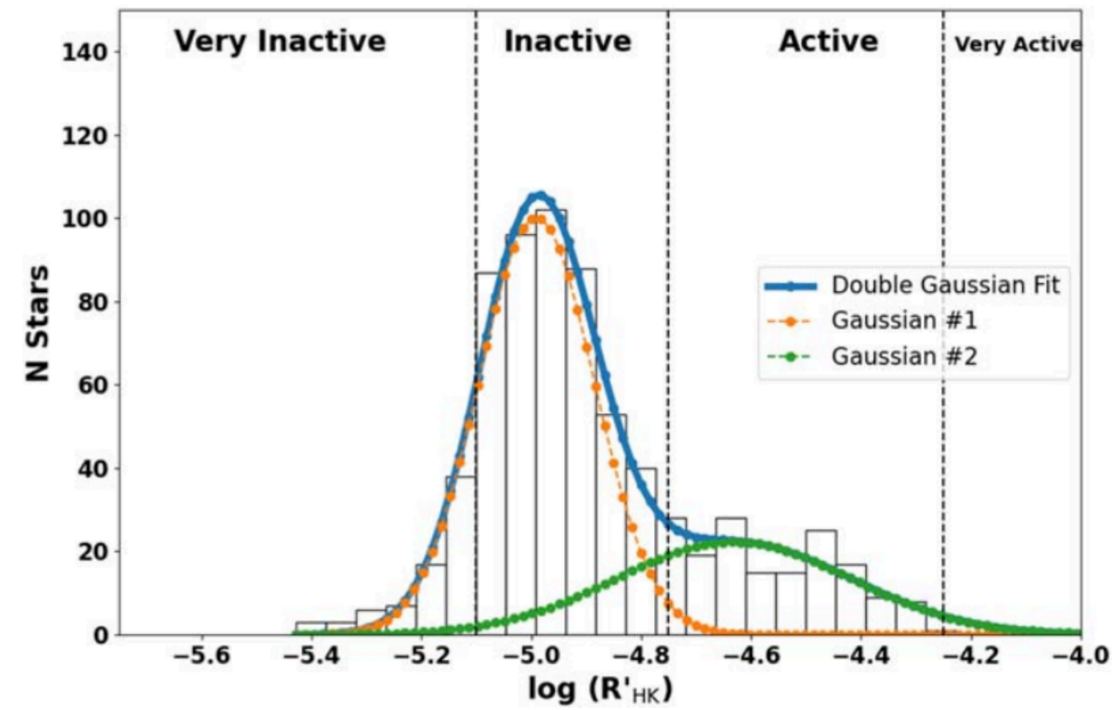




CA H&K ENV. 390NM

All stars are active

Impact on the exoplanet characterization



Gomes da SIlva et al. 2021

Isaacson et al. 2023

Some lines in the visible

Ca infrared triplet around 850nm

No evident lines in the nIR

e.g.Cortes-Zuleta et al. 2023
Schöfer et al. 2019

RV impact is different in different bandwidth

e.g. Carmona et al. 2023
Larue et al. 2025

Different technics are used and being developed to identify and remove the signal

e.g. Cretignier et al. 2023

Al Moulla et al. 2025

→ Strong field of research - motivated by the search of earth-like objects

All stars are active

Impact on the exoplanet characterization

For ROMAN targets, the main impact I see is for reflected light targets:

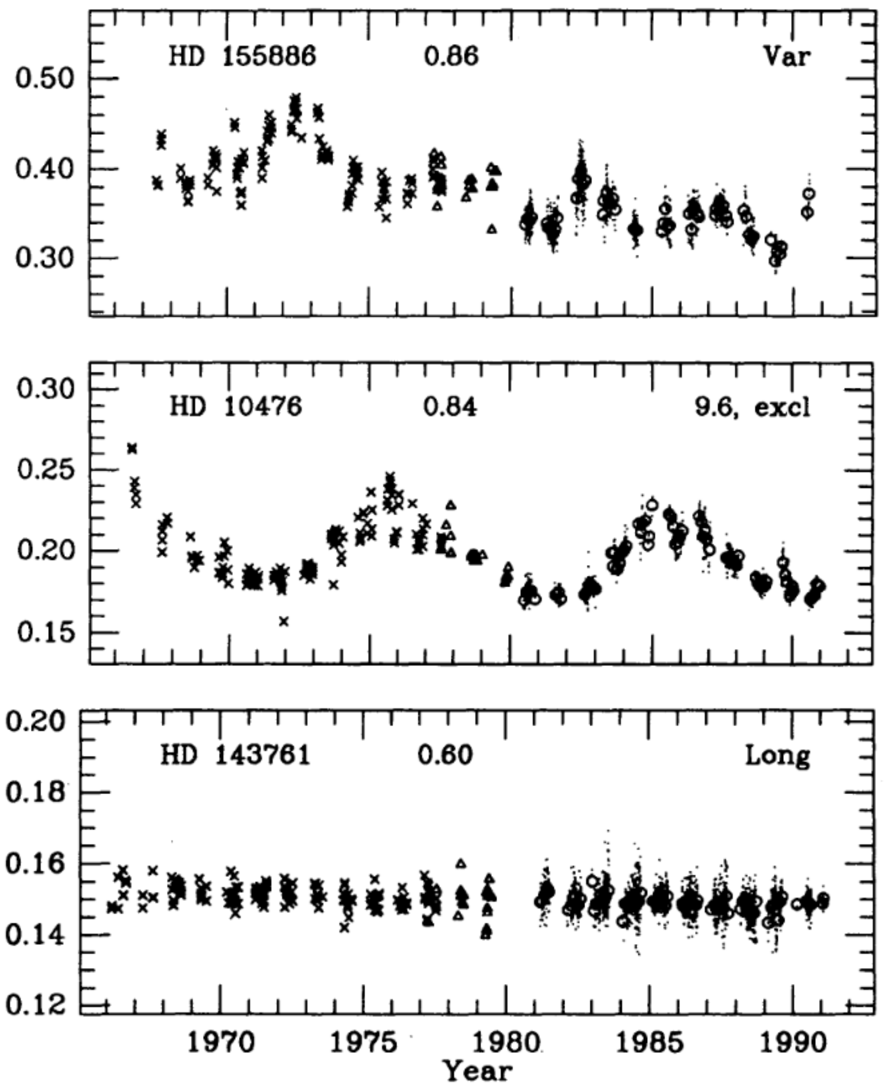
1. Selection of the targets can be biased by the magnetic cycle

2. Reflected light can be polluted by stellar irradiation variations

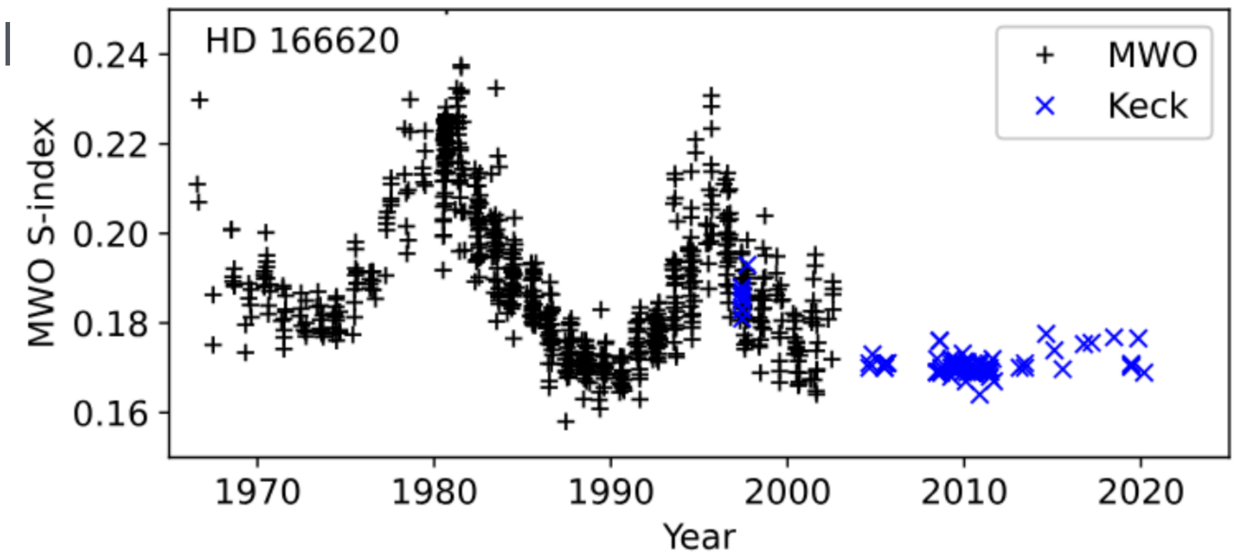
All stars are active

Impact on the exoplanet characterization

Long term variation are known on other stars



Mount Wilson CaII monitoring



Olah et al.. 2016 *Baum et al.. 2022*

Cycling and enter a Maunder minimum star

Baliunas et al.. 1995

30% variables

30% calm

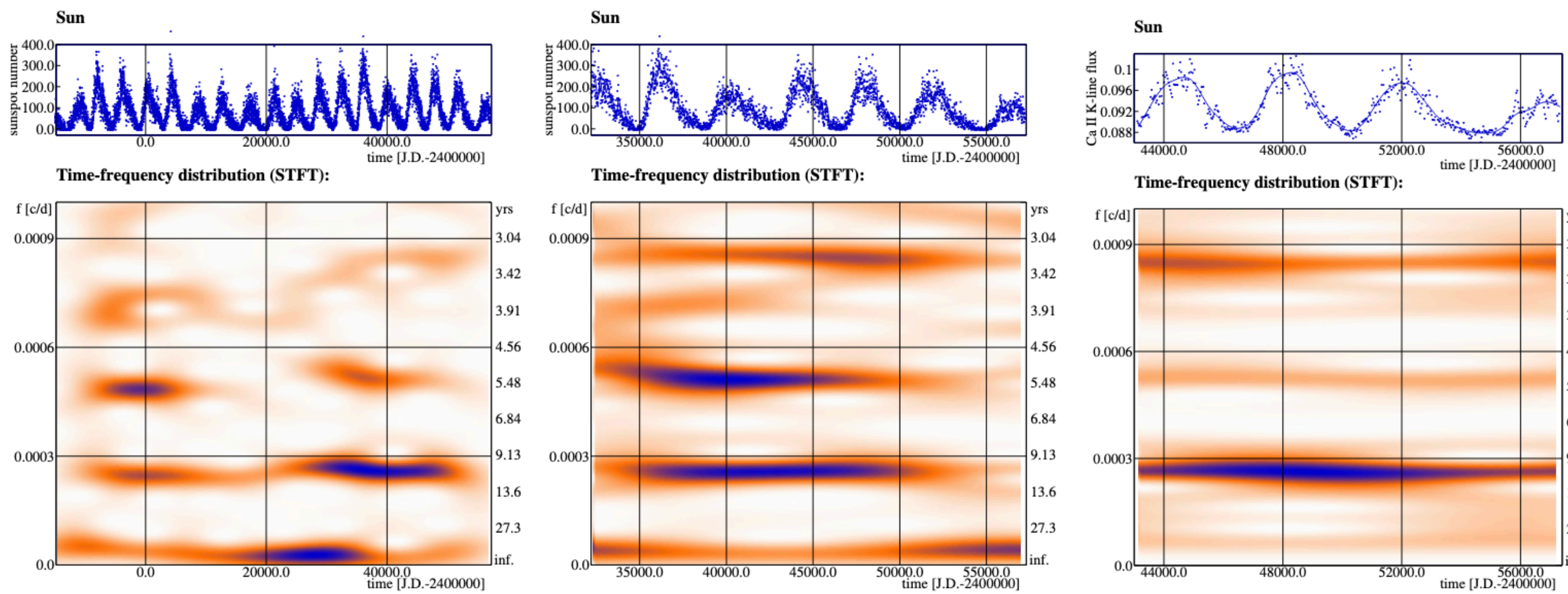
30% cycles

→ Cycles can mimic Jupiter-like planet

All stars are active

Impact on the exoplanet characterization

Sun several cycles : 100 yrs, 11yrs, (1/2, 1/3 of 11 yrs) and a 4-5 yrs variability

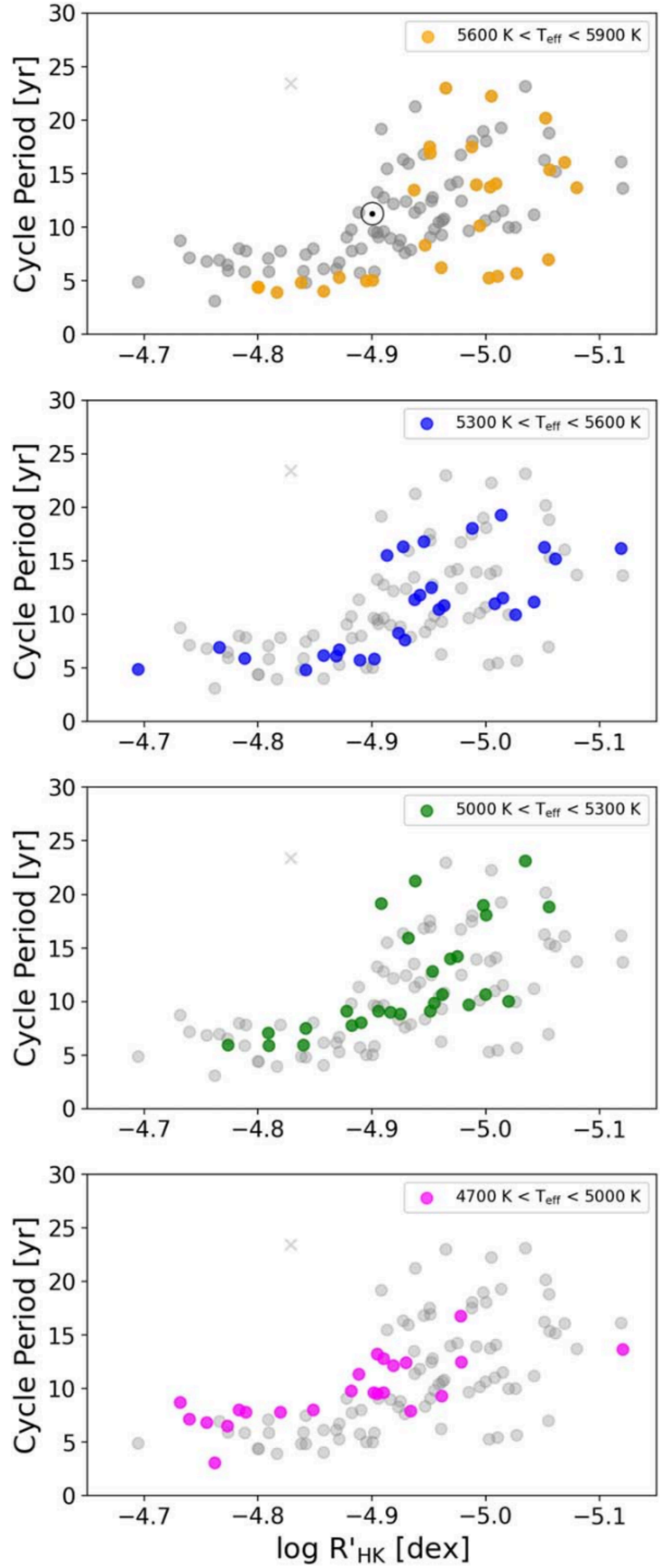


Olah et al. 2016

Magnetic reversal measured on stars e.g. Jeffers et al. 2023

Two cycles measured on the same star

Metcalfe et al. 2013



Isaacson et al.. 2023

Have a look yourself

Go the DACE platform: https://dace.unige.ch/dashboard/

- Observations -

Radial Velocity

All stars are active

1. Impact of the magnetic cycles

HD24040 b   G2 V=7.5

Wright et al. 2007	Detection
Boisse et al. 2012	Confirmation
Rosenthal et al. 2021	2nd planet detection
Qier et al. 2025	Long term astrometry : true masse and orbital inclination

All stars are active

1. Impact of the magnetic cycles

Jupiter twin HD154345 b

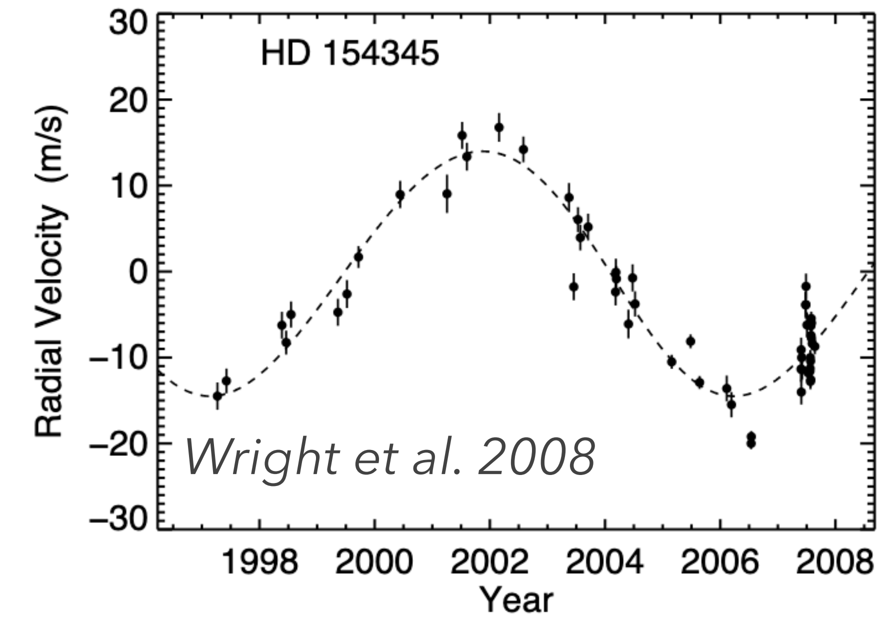
G8 V=6.76

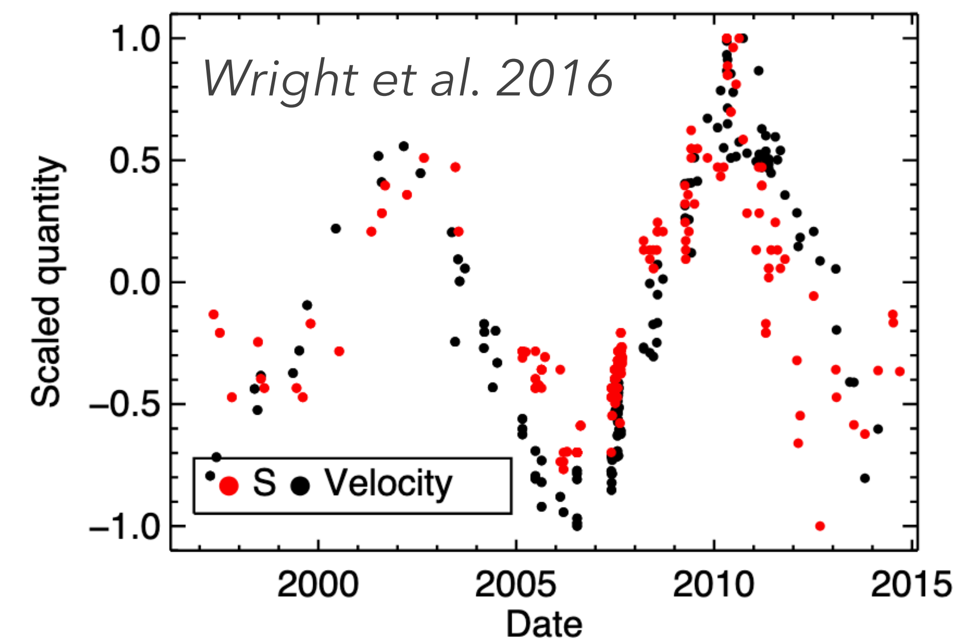
P = 9.2 yr or a = 4.2 AU

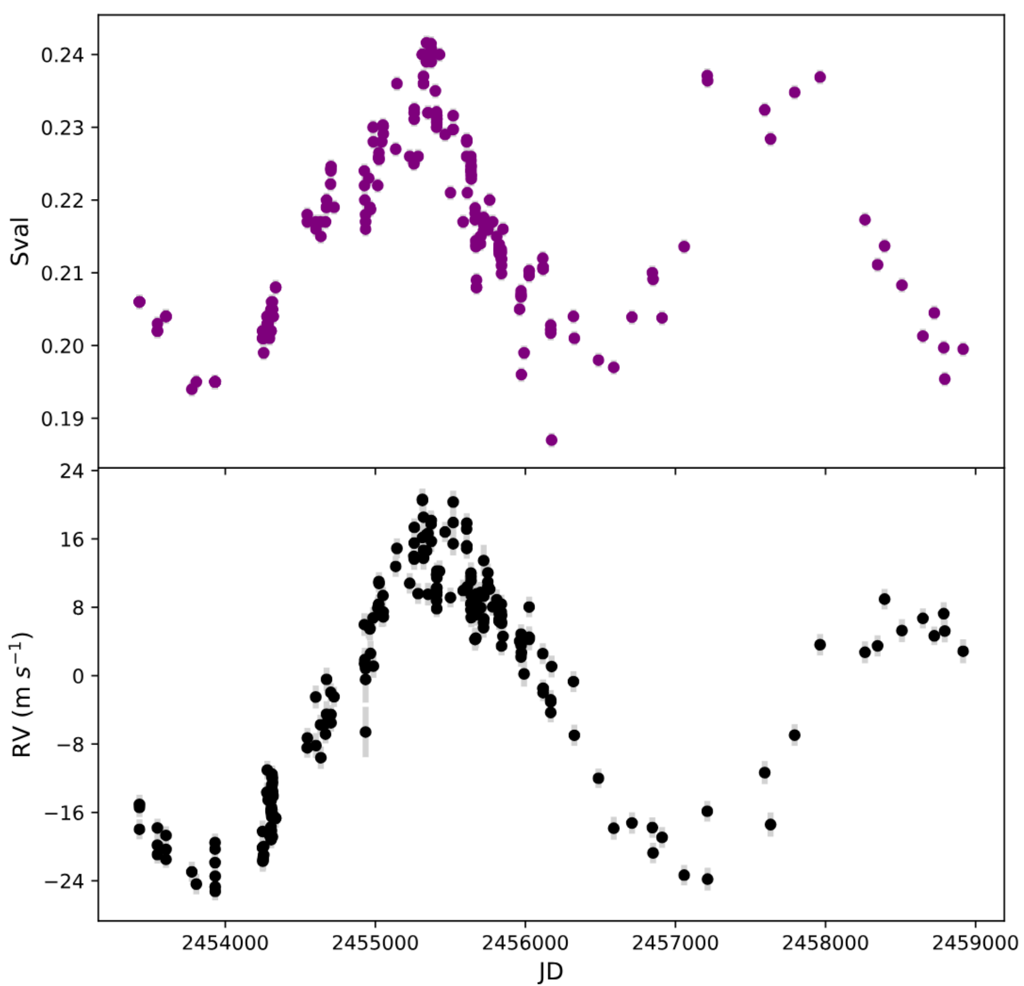
Msini = 0.95 M jup

Maybe a false positive

Magnetic cycle of 9 years







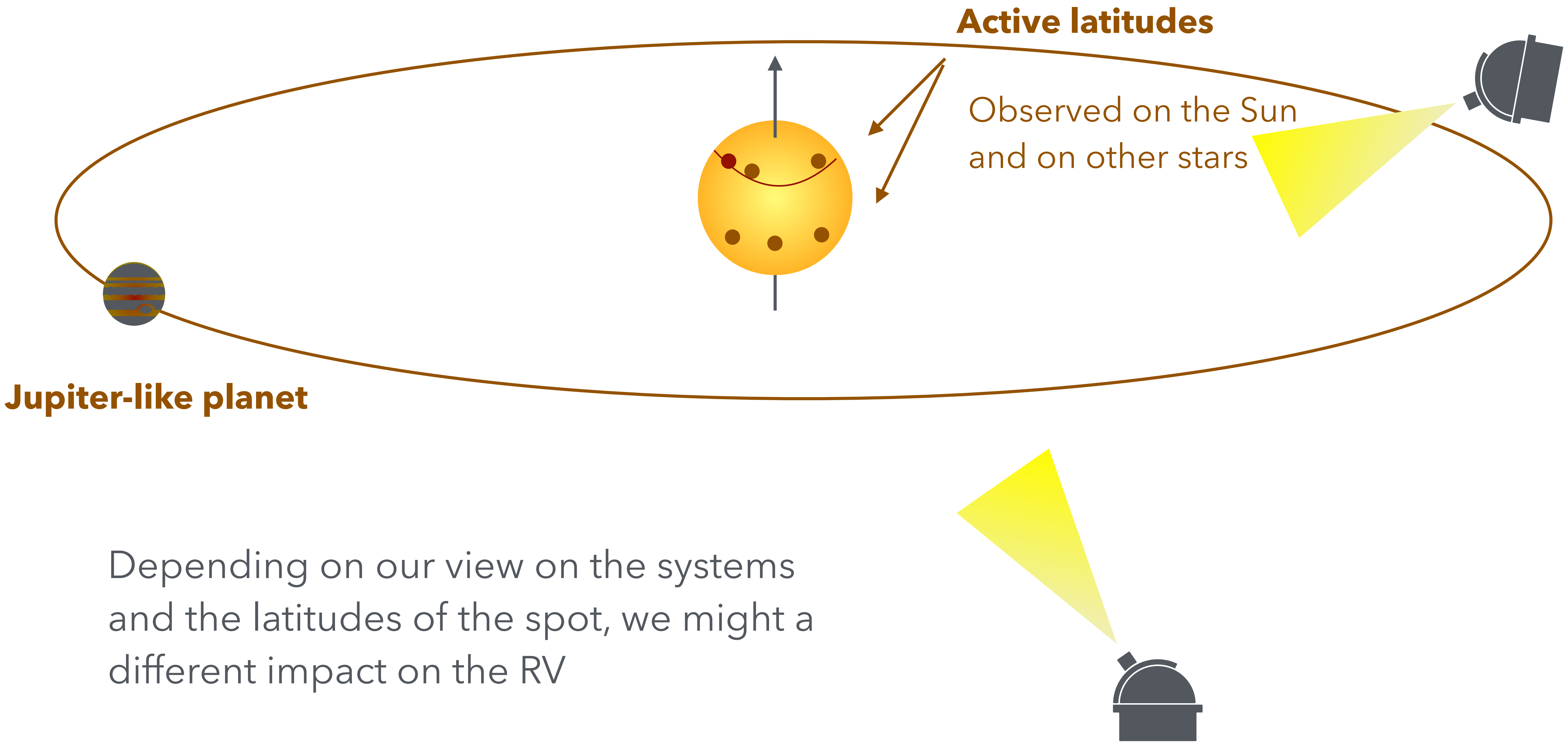
Confirmation

Rosenthal et al. 2021

All star are active

1. Impact of the magnetic cycles

What do we see ?



Depending on our view on the systems and the latitudes of the spot, we might a different impact on the RV

All stars are active

2. Impact on the reflect light measurements

The reflected light depends on the planetary albedo.

Planetary albedo measurements could be limited by stellar activity

Martins et al. 2015 *Serrano et al. 2018*

Effect of stellar variability on the detectability of phase curves in the optical.

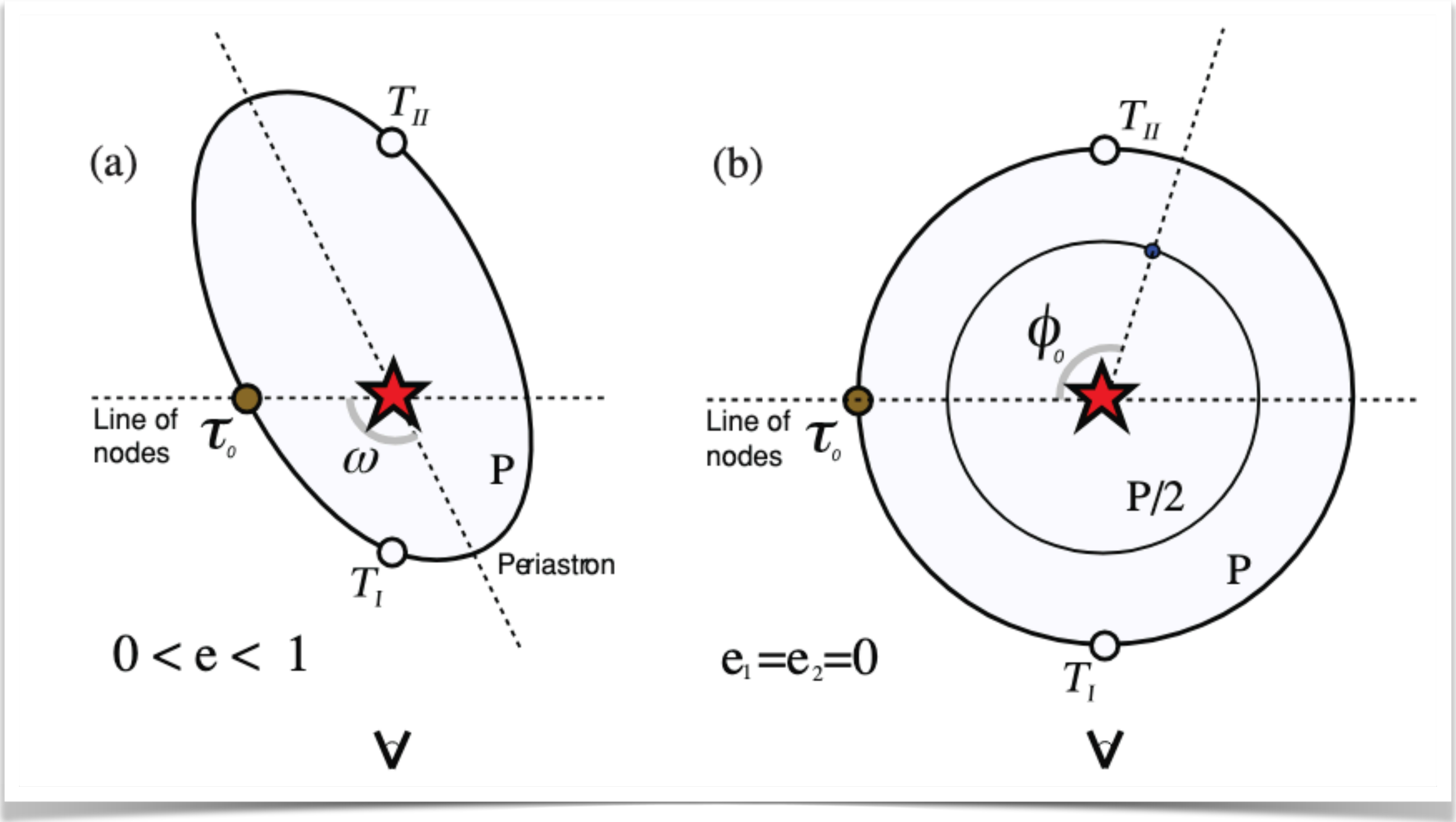
Hidalgo, Alonso & Pallé 2019

→ Separated observations of reflected light of a same planet may be illuminated by different flux due to stellar activity

Mainly caused by stellar spots (higher temperature contrast)

Not clear on the true impact

Variability caused by stellar activity should be captured by other spaxels

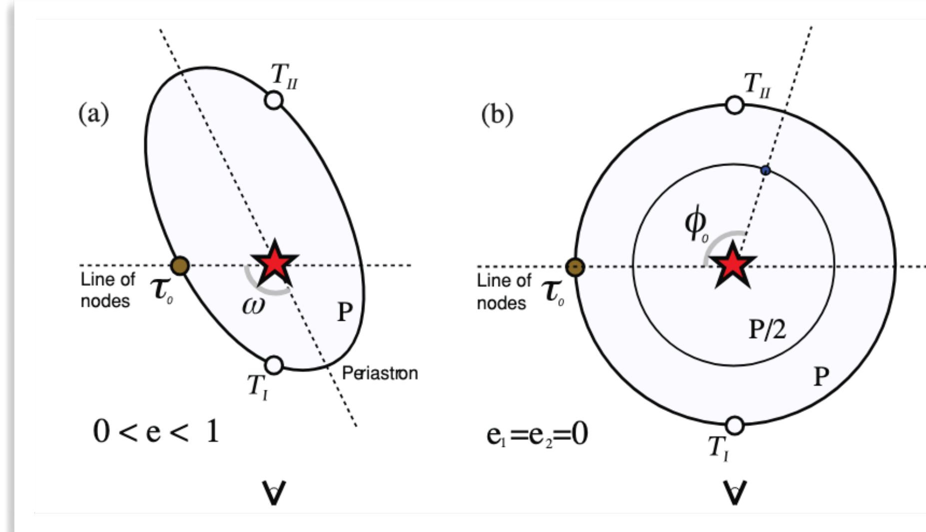


5. Eccentric or multiple ?

Long-period giant planets

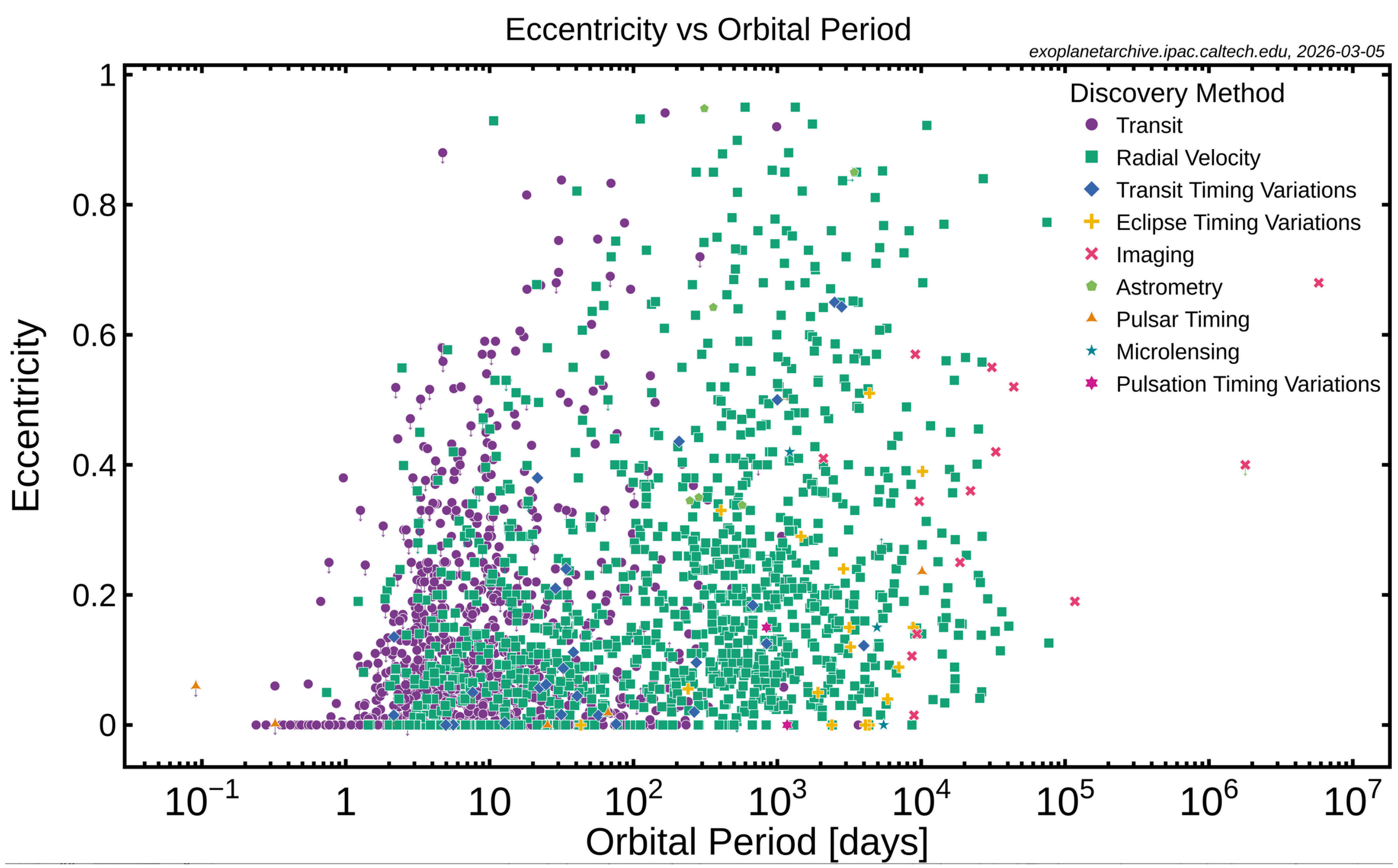
Eccentric or multiple ?

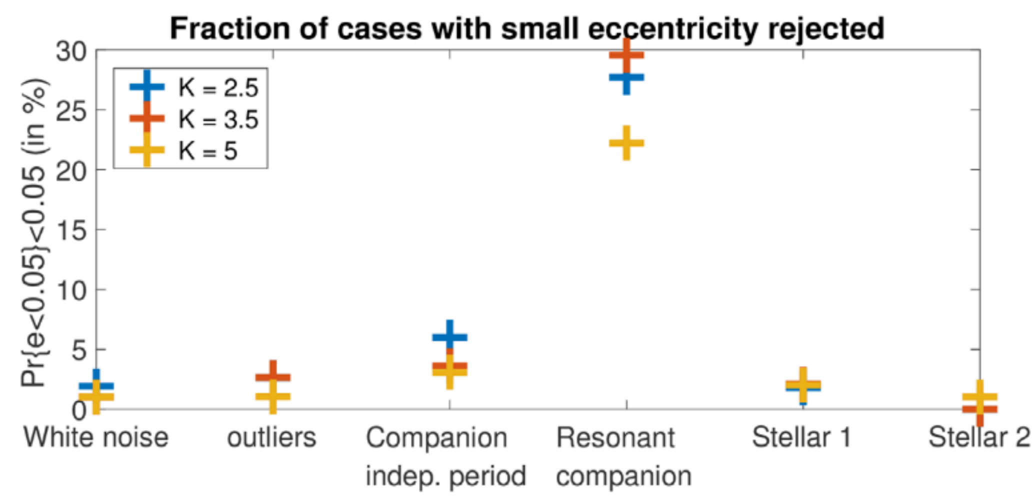
A survey for Roman ?



Eccentricity is a parameter informative of the past history

Badly well constrained by RV





Hara et al. 2019

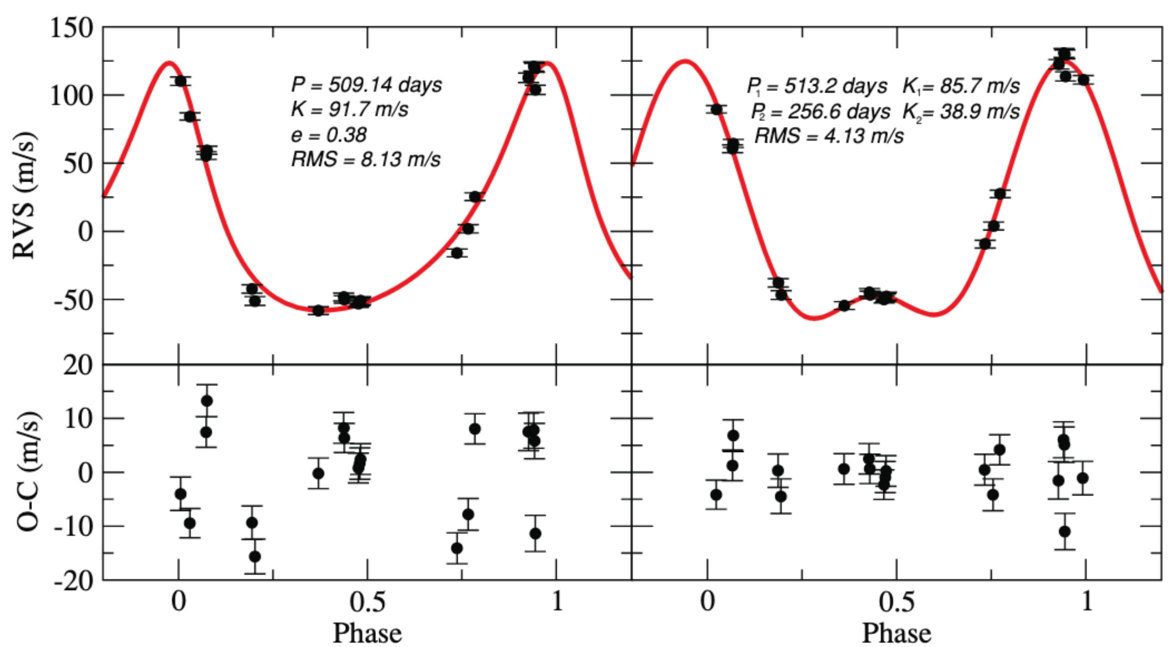
Eccentric or multiple ?

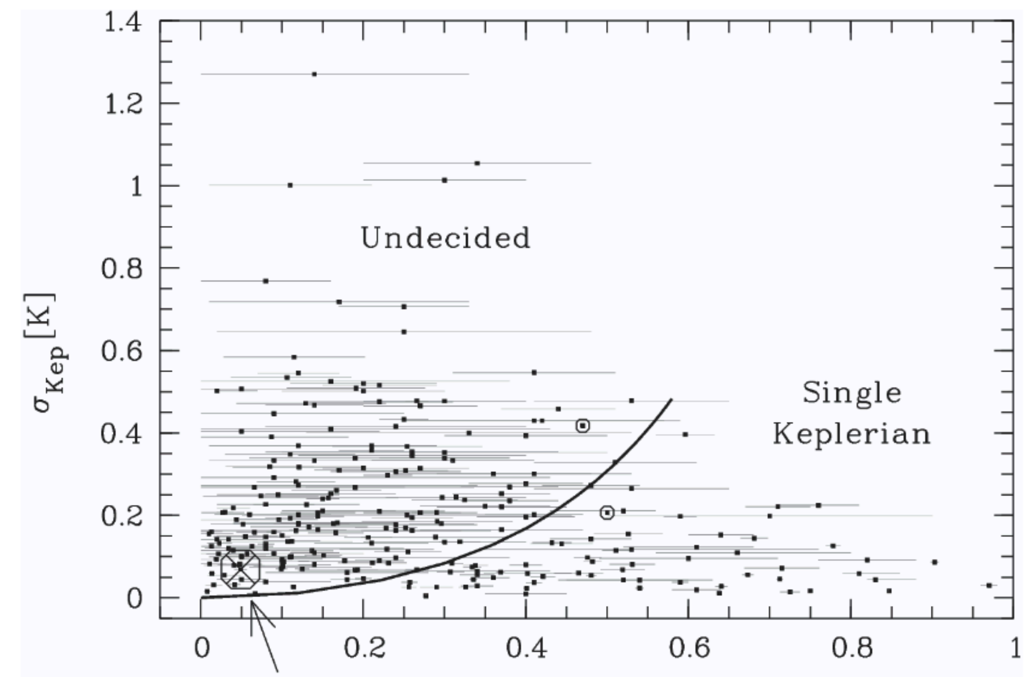
A survey for Roman ?

Two planets in 2:1 MMR can appear as an eccentric planet

e.g. Anglada-Escudé, Lopez-Morales & Chambers 2010

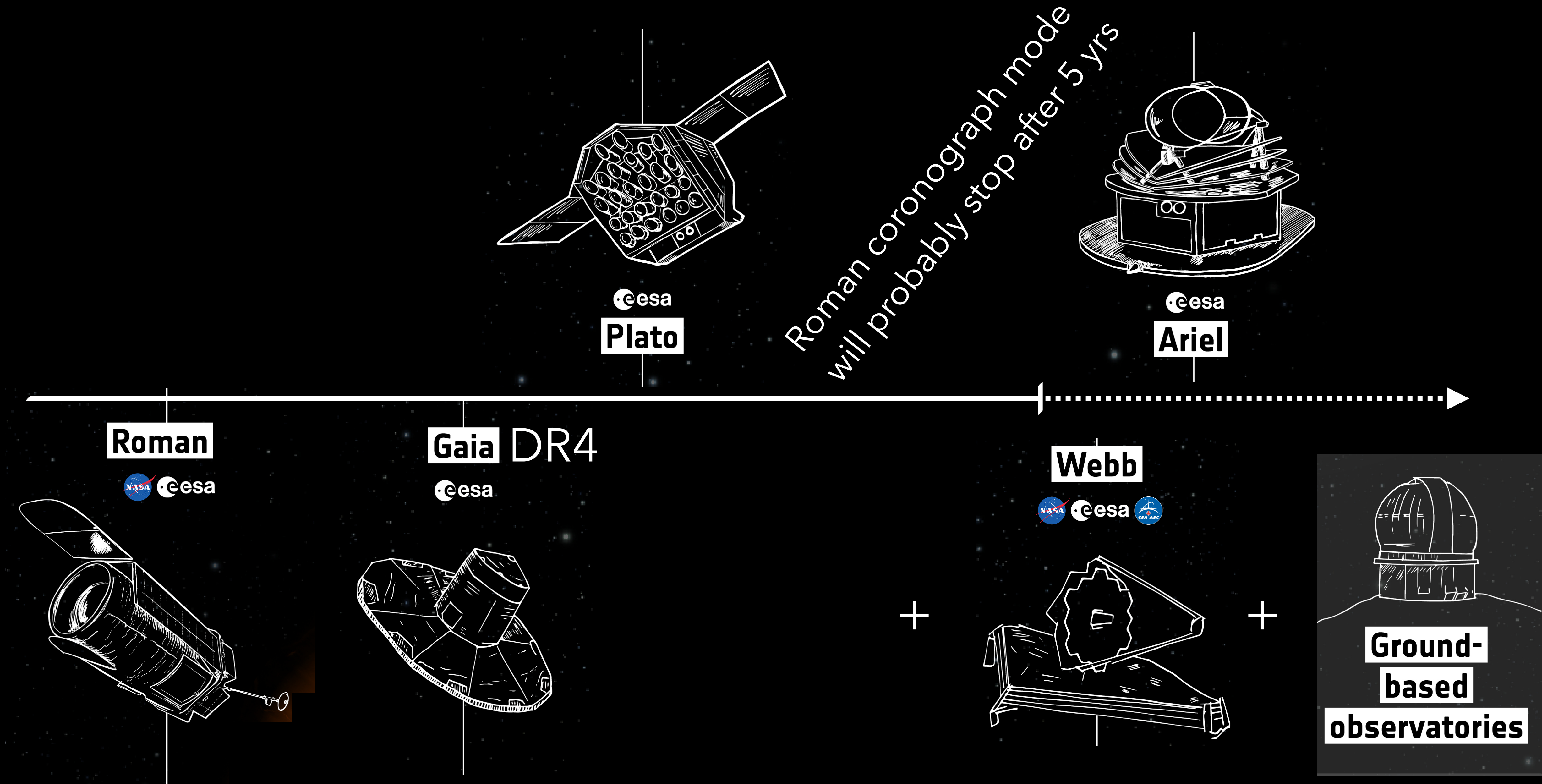
Wittenmeyer et al. 2013, 2019a,b   *Kurster et al. 2015*





Yahalomi et al. 2025

- Planets with e > 0.5 cannot be reproduced by two signals
- Same limitation in astrometry, except for mutually inclined systems
- Moderate eccentric planets should be monitored to disentangle the different scenarios

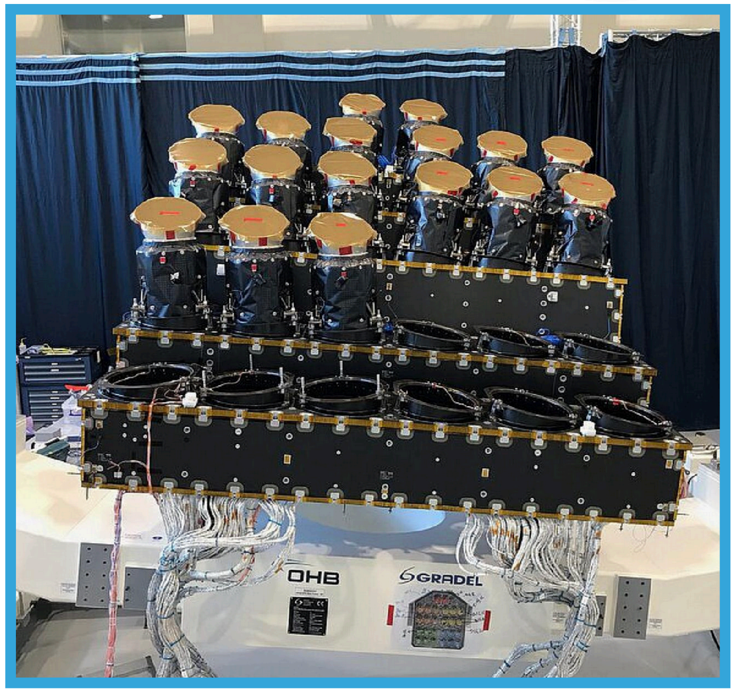


6. Futur prospects

For Roman coronograph targets

Isabelle Boisse (LAM/OHP) - Roman Coronography School - 12/03/26

PLATO



- **Planetary Transit and Oscillation of stars**

  Launch planned for dec. 2026

  Mission of 4 to 8 yrs

- Objectives : detect Earth-like planets in transit

- Same observation fields for 2-3 years

→ will enable the detection of terrestrial planets around solar-type stars
In the habitable zone

around bright stars - will enable us to obtain the masses, and therefore the density

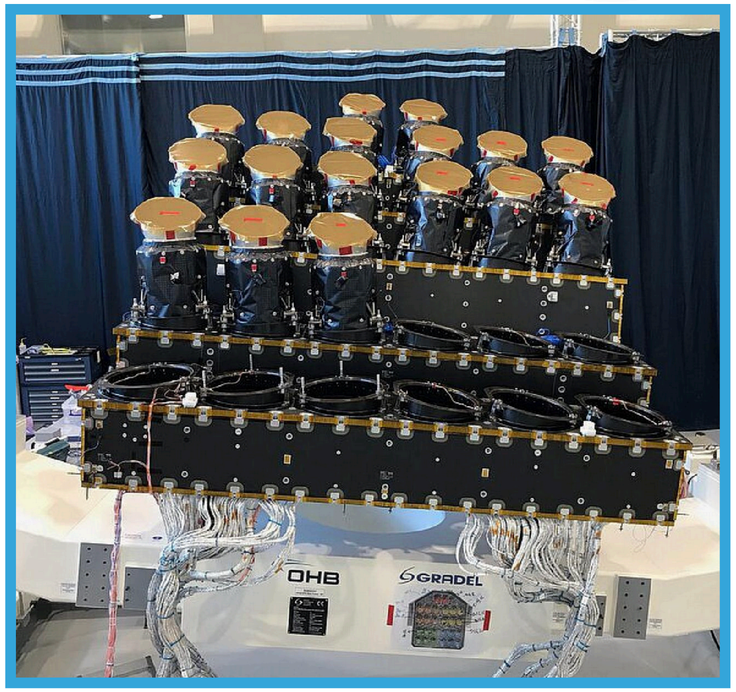
- Ground measurements required to confirm candidates, measure masses and complete the systems

PLATO

- **Planetary Transit and Oscillation of stars**

→ will not deliver Jupiter-like objects before years

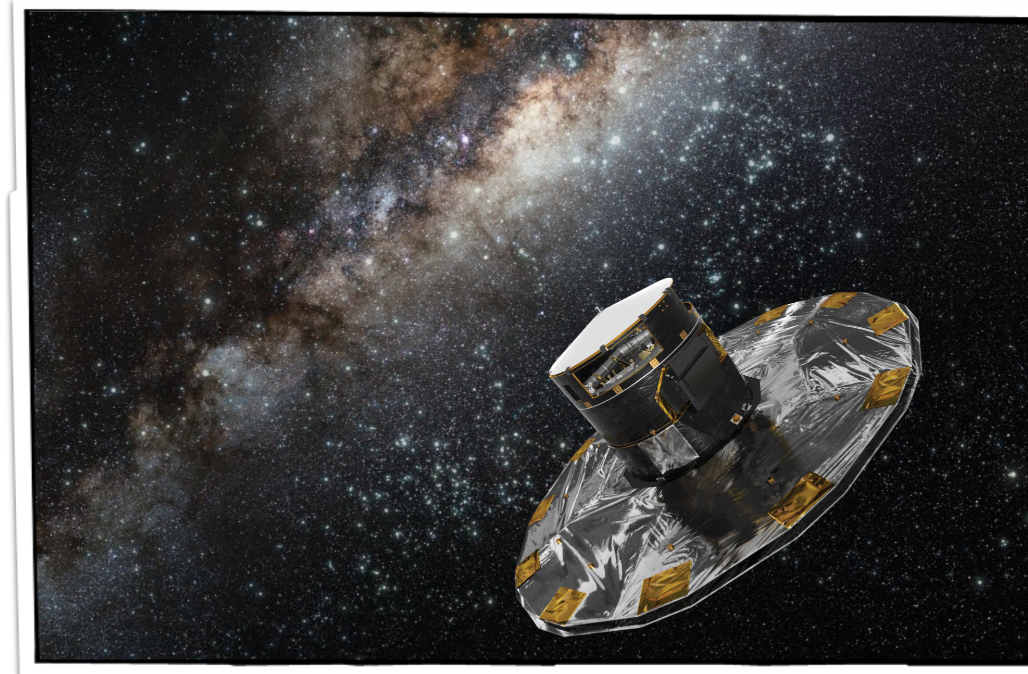
→ Has a limited accuracy for very bright stars



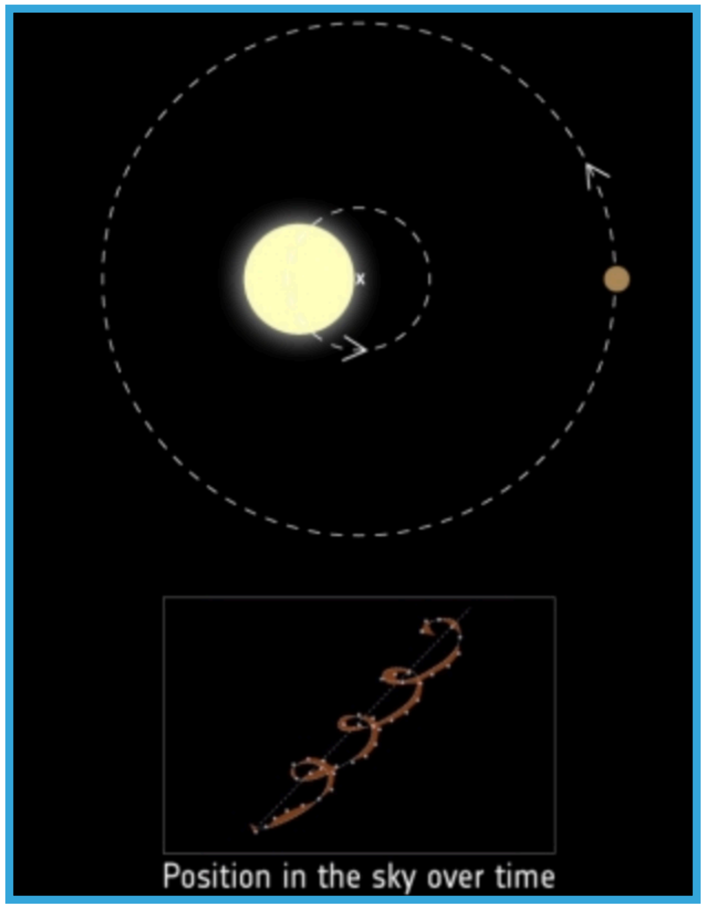
Matuszewski, et al. 2023

GAIA'S FUTURE HARVEST

Launched in 2013 - End of operation 2025



Mapping the nearby universe:
our galaxy and its nearby satellites



Detection methods :

Astrometry and transit

Jupiter-like planets

Until 200pc

> DR4 release
end of 2026

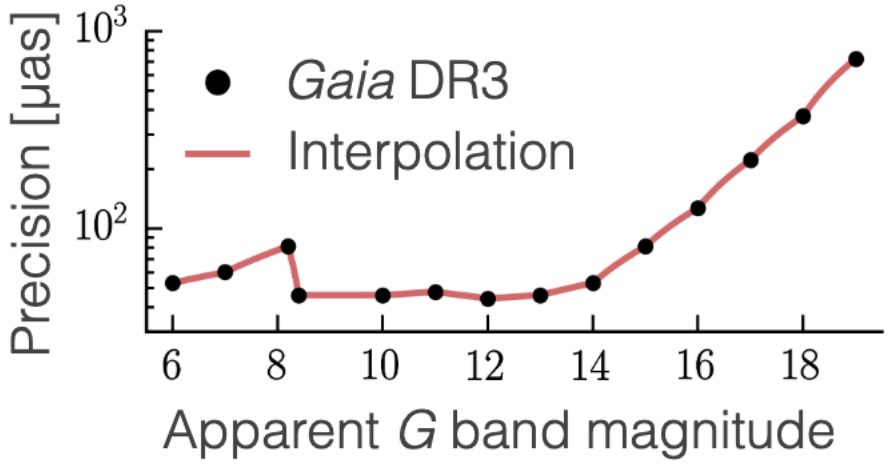
- Thousands of long-period Jupiters

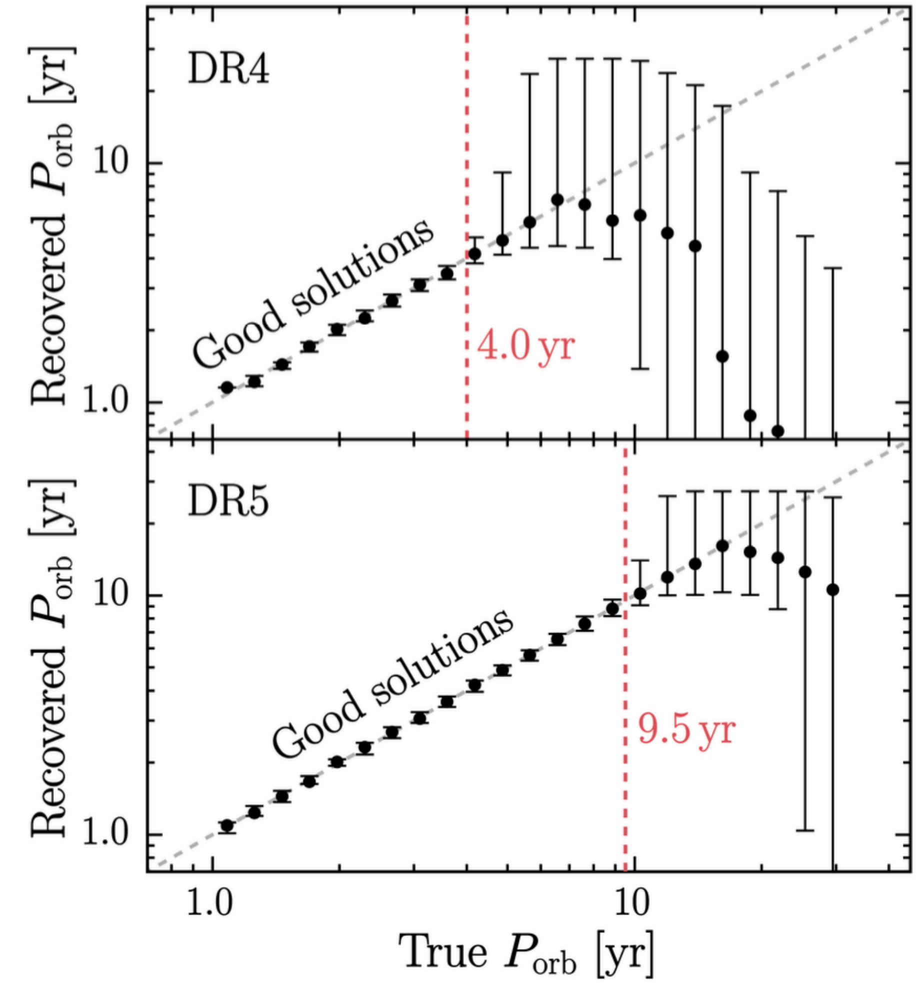
- Need ground measurements to confirm the candidates, measure the masses
  And get a complete view of the architectures of the systems (RV and imaging)

GAIA DR4

News planets for Roman ?

- Probably very few





Caleb & Winn 2026

Should deliver the orbital inclination of the known planets targeted by Roman : improve detection and less observation exposure time + deliver true masses

- On very bright stars, GAIA DR 4 will not have the accuracy to constraint orbits but will point strange variability

RV programs are planned to characterize these targets

Ground based RV

News planets for Roman ?

Census will be done in the South in order to prepare for ELT : should deliver all giant planets with period < 1 yr

Pearce et al. 2025

Several high precision spectrographs opened in the North

That conduct RV survey or will do follow-up of GAIA DR4

→ Highest chance to deliver new targets around very bright (and close) stars

\+ RV measurements should be continued on Jupiter-like objects

Detection is improved if the exact location of the planet is known

Pearce et al. 2025

Call to the community ?

Thanks

For your attention !

QUESTIONS?

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