

# Dynamic masses of Rocky Planets in near- by planetary systems

Prof. Dr. Stefan Dreizler

Institut für Astrophysik und Geophysik, Georg-August-Universität  
Göttingen

*In collaboration with*

(Dr.) Paul Schwarz

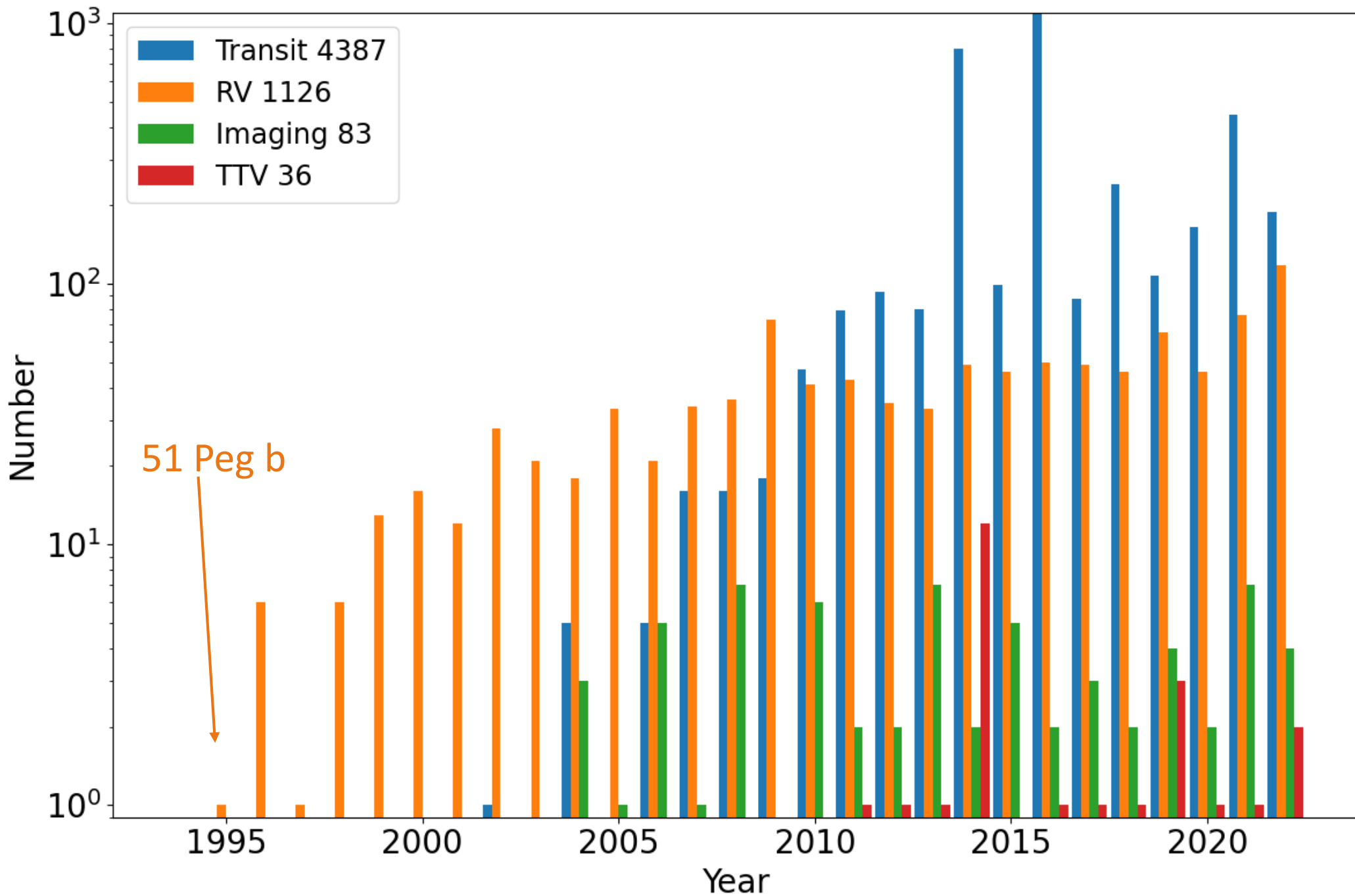
RedDots Consortium

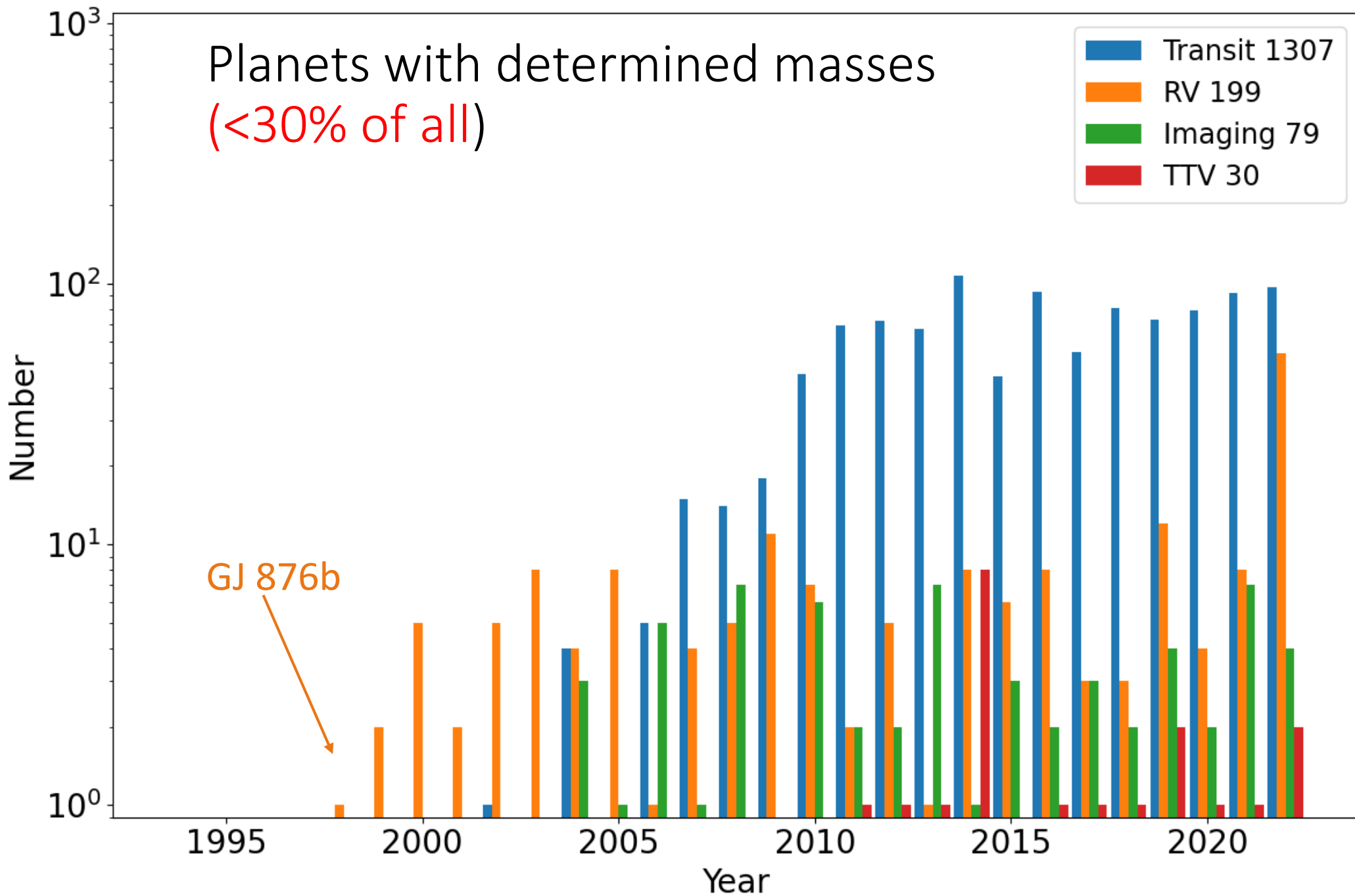
CARMENES Consortium

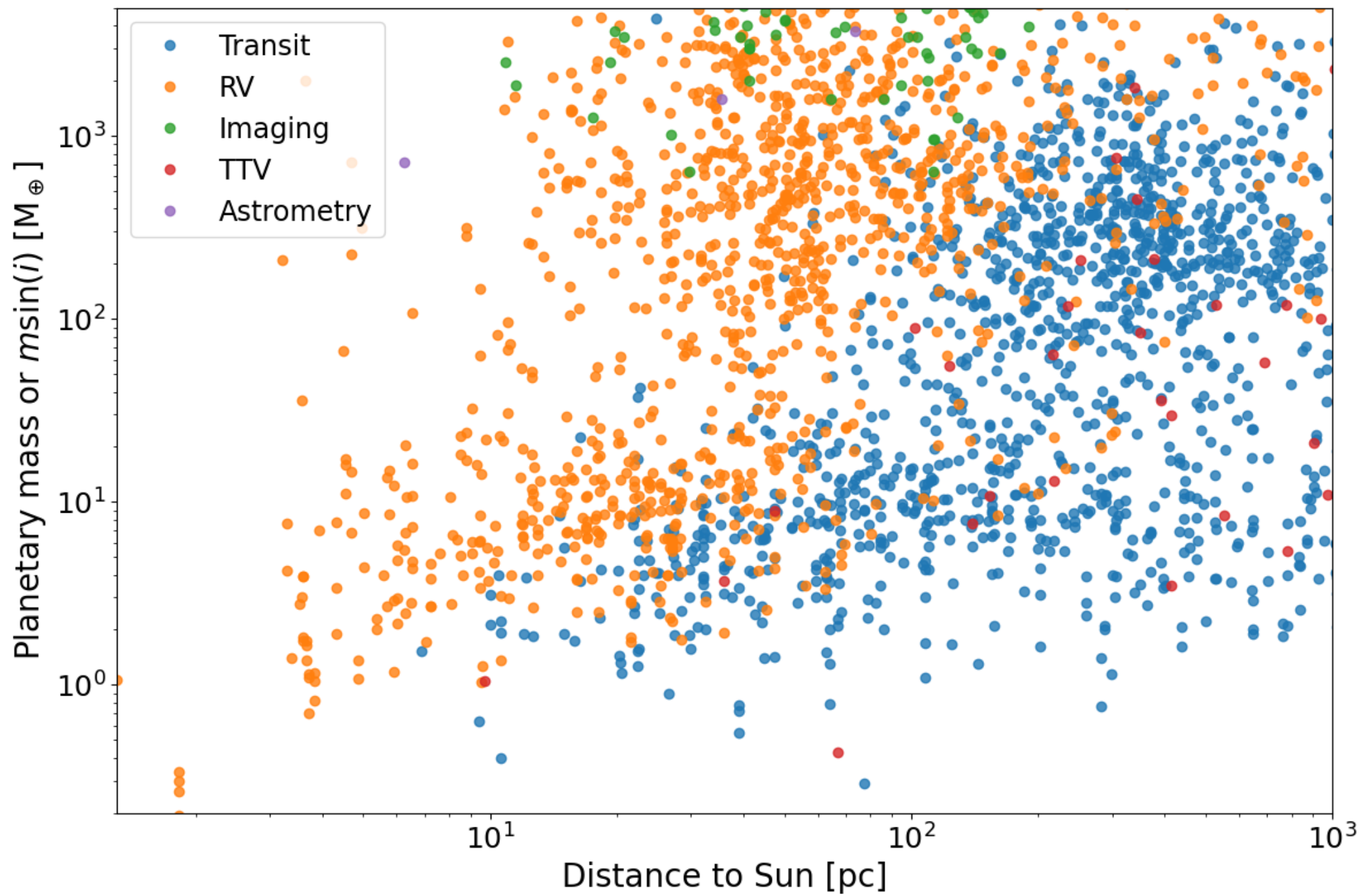


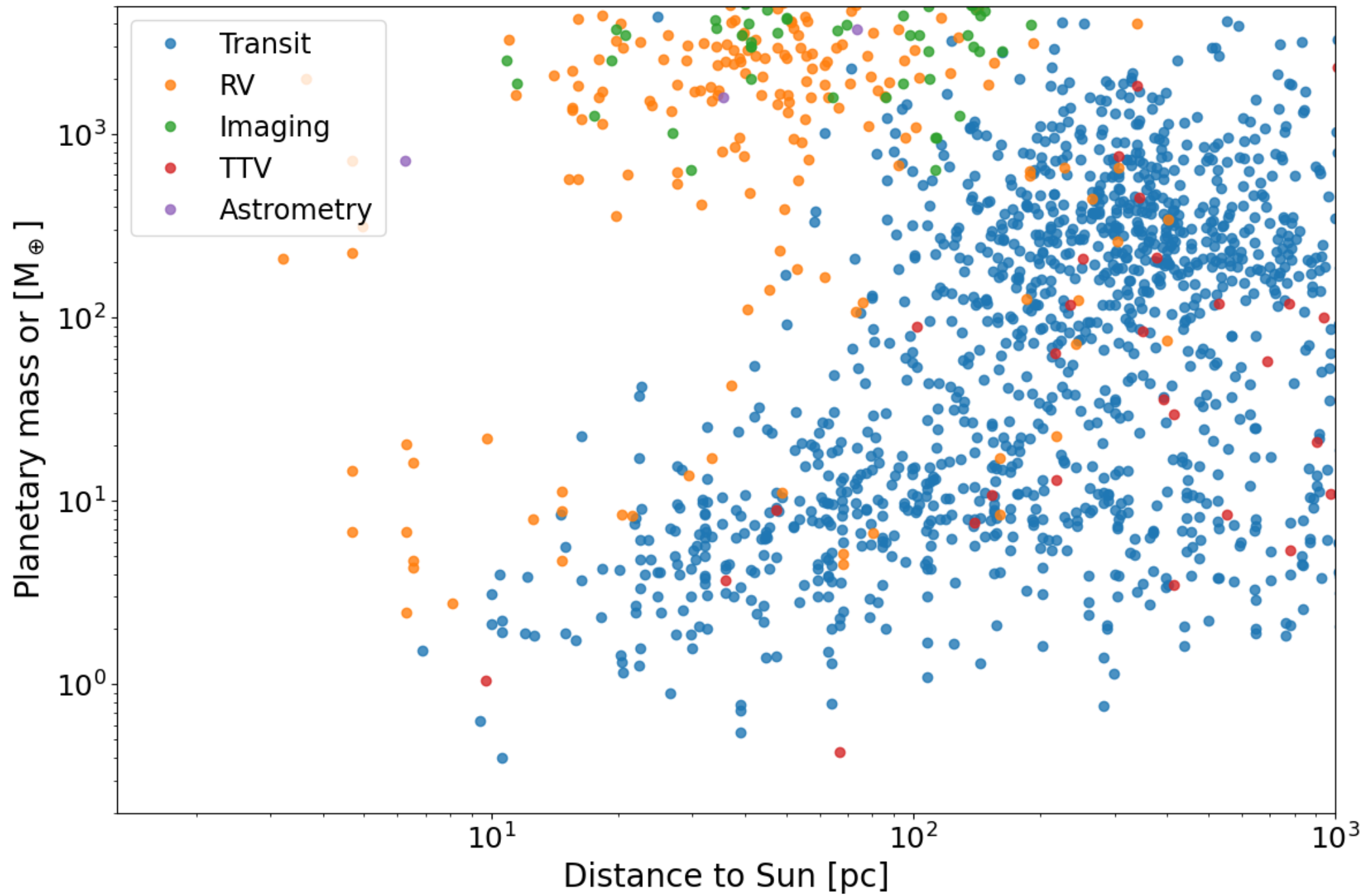
# Determination of Planet Masses

- Planets detected by...
  - Radial Velocity: needs orbital **inclination** (Transits or Astrometry)
  - Transits: needs a **mass determination** (Radial Velocity or TTVs)

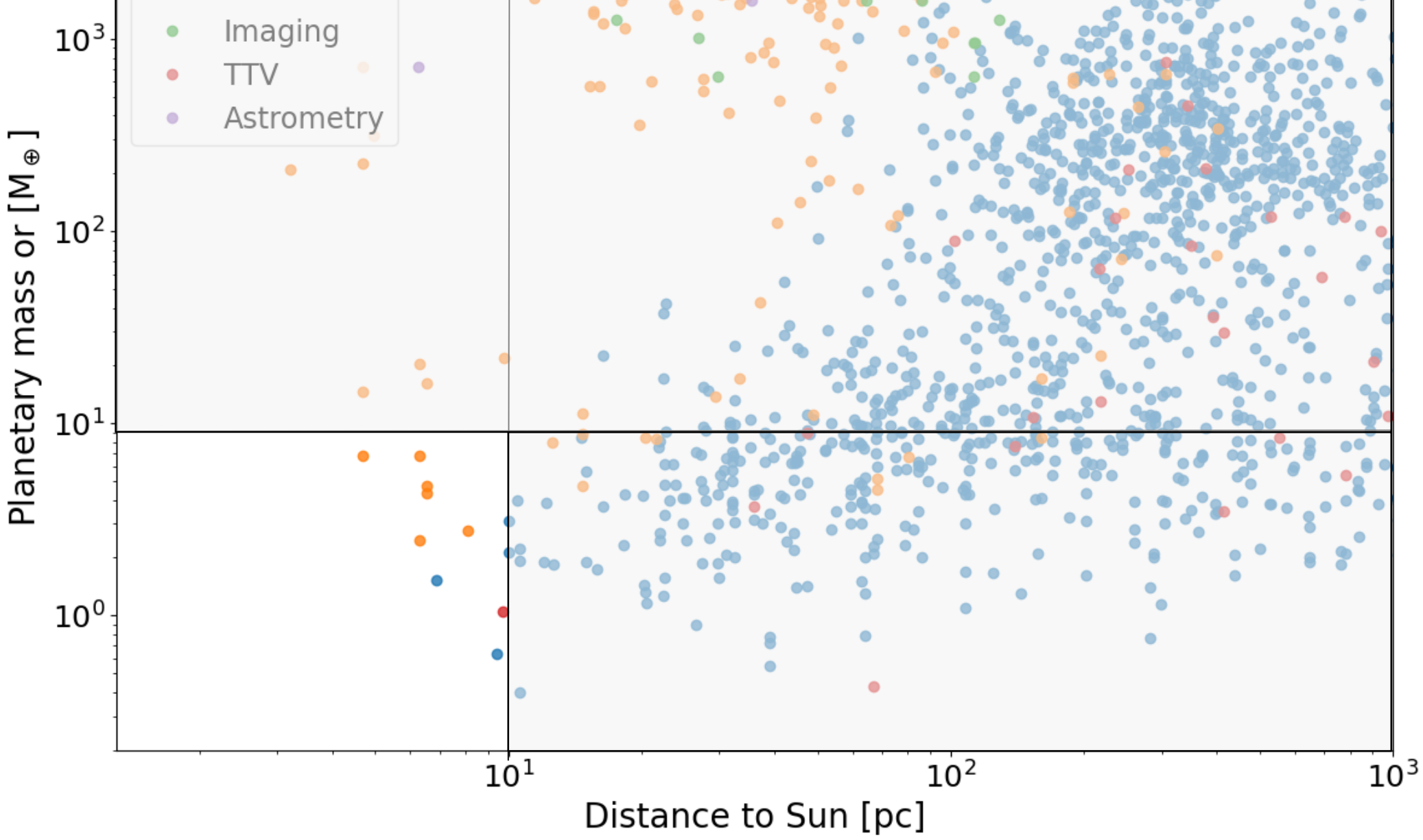


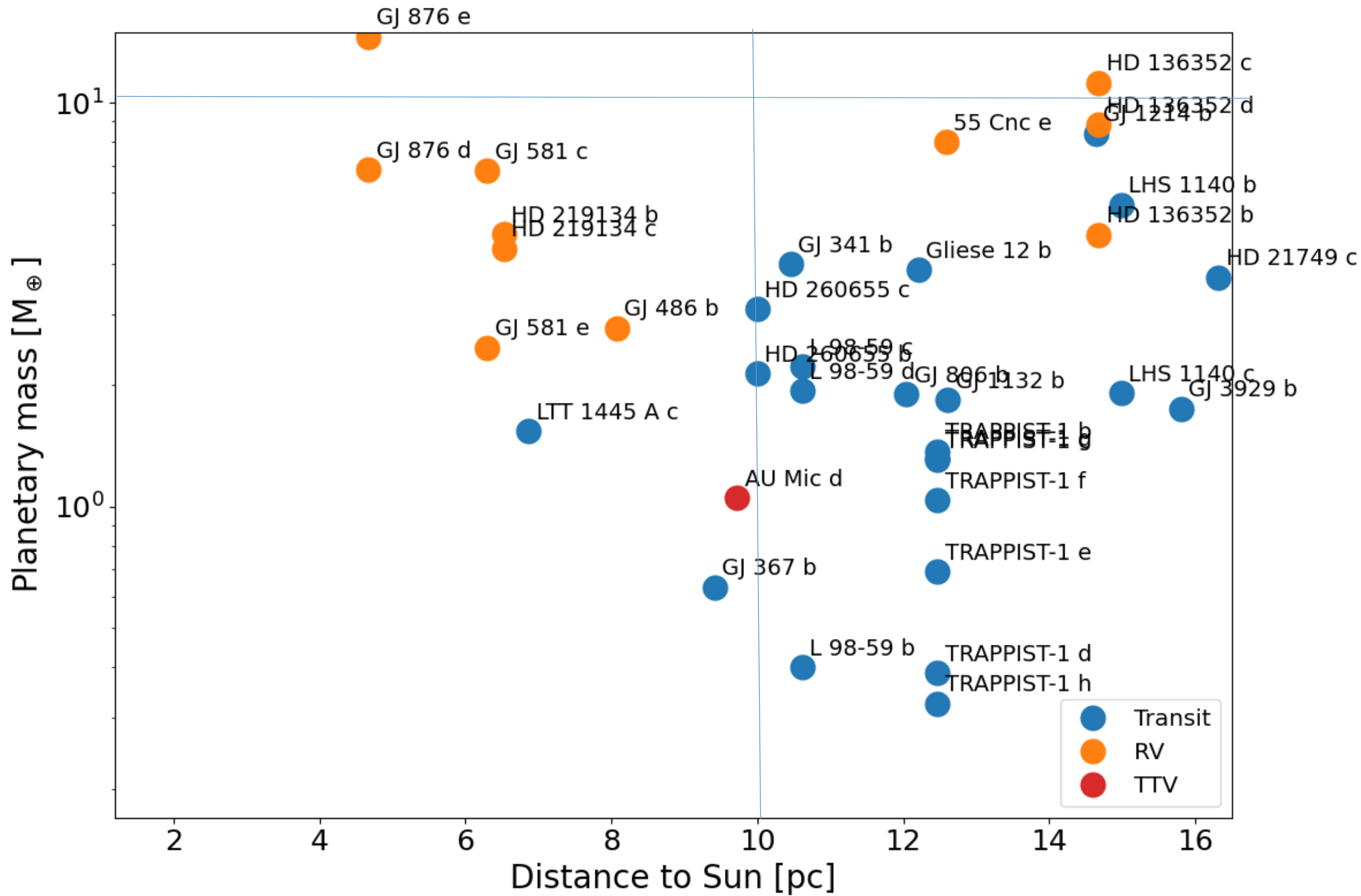


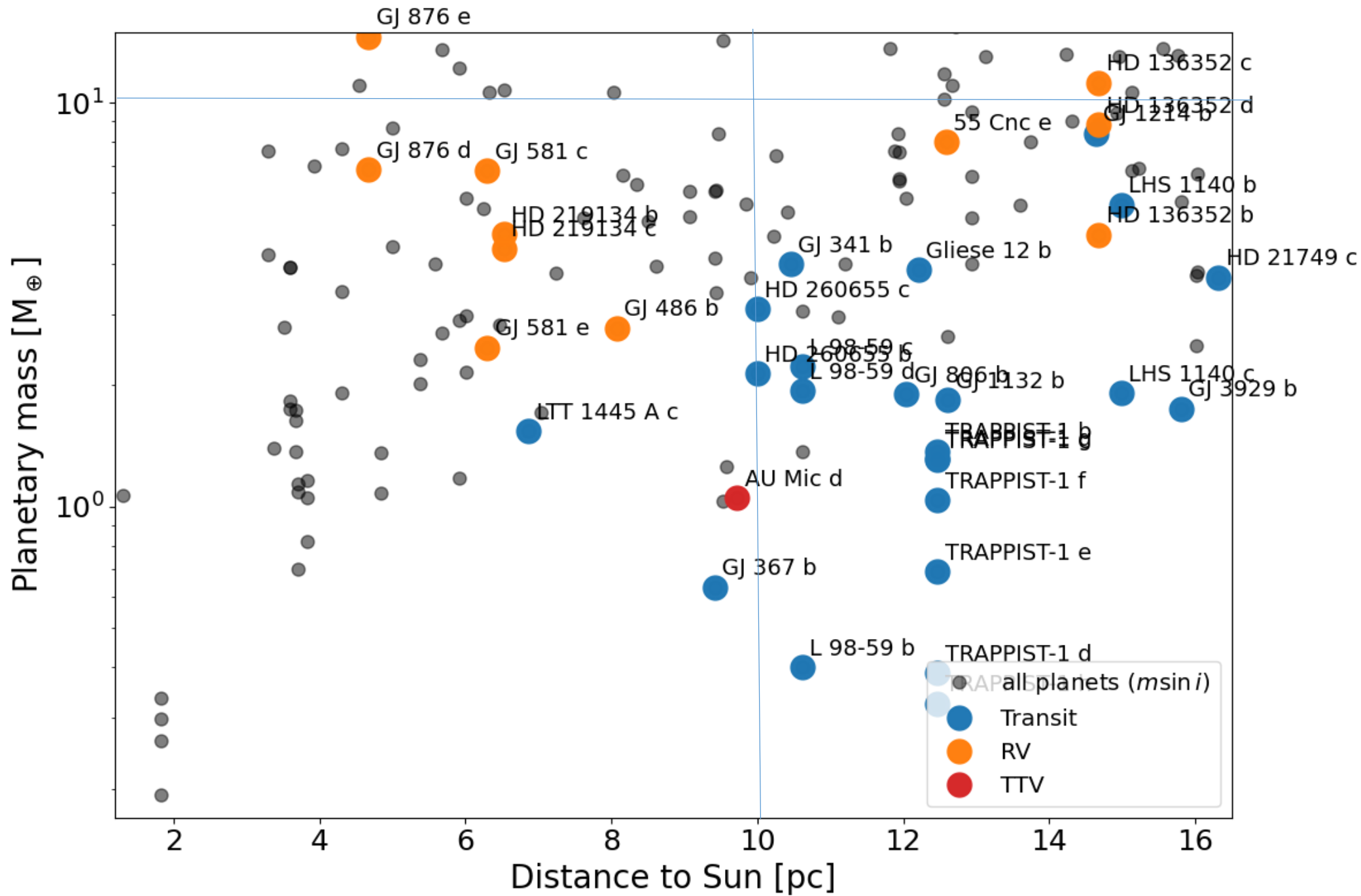




# Near-by Super-Earth Planets with known masses

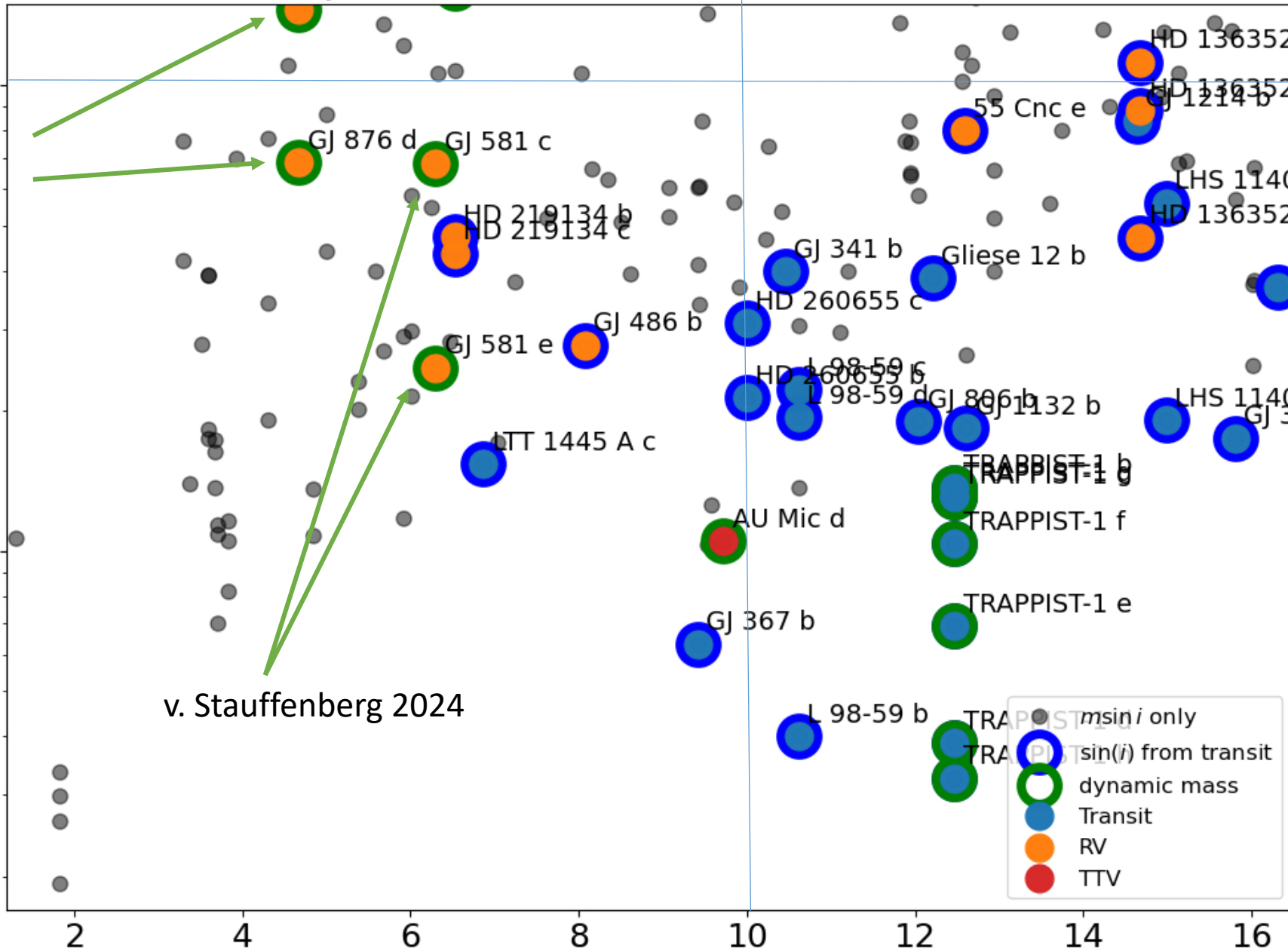




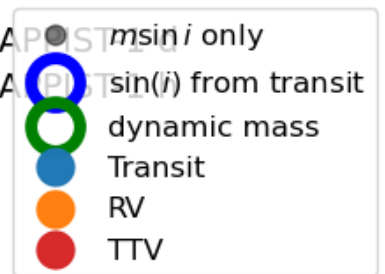


Rivera et al. 2010  
Rivera et al. 2005

Planetary mass [ $M_{\oplus}$ ]



v. Stauffenberg 2024



Distance to Sun [pc]

2

4

6

8

10

12

14

16

GJ 876 e

GJ 876 d

GJ 581 c

HD 219134 b

HD 219134 c

GJ 581 e

GJ 486 b

TTT 1445 A c

AU Mic d

GJ 367 b

L 98-59 b

GJ 341 b

HD 260655 c

HD 19859 b

L 98-59 d

Gliese 12 b

GJ 806 b

GJ 1132 b

TRAPPIST-1 b

TRAPPIST-1 c

TRAPPIST-1 d

TRAPPIST-1 e

TRAPPIST-1 f

HD 136352 c

HD 136352 d

GJ 1214 b

55 Cnc e

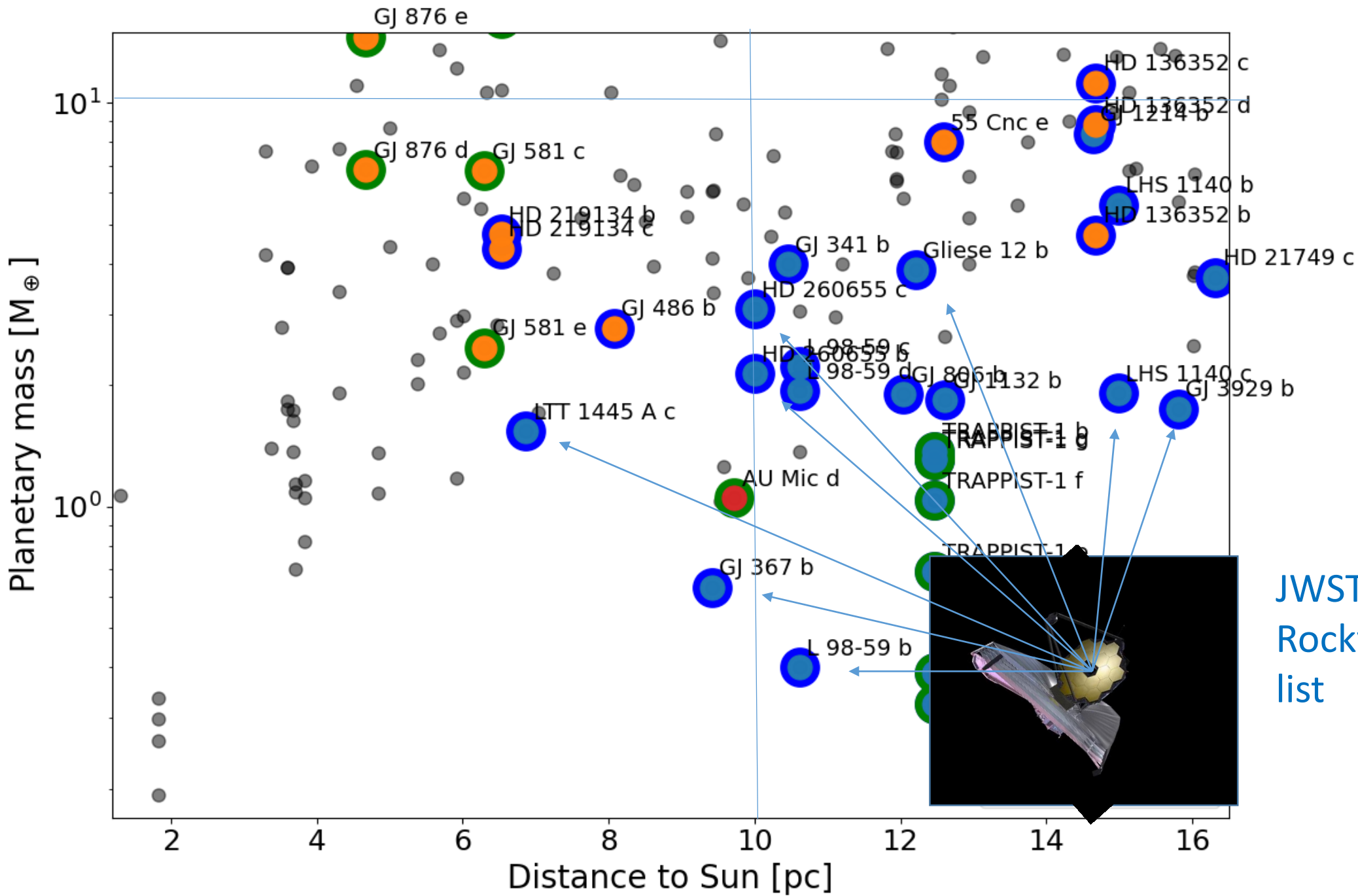
LHS 1140 b

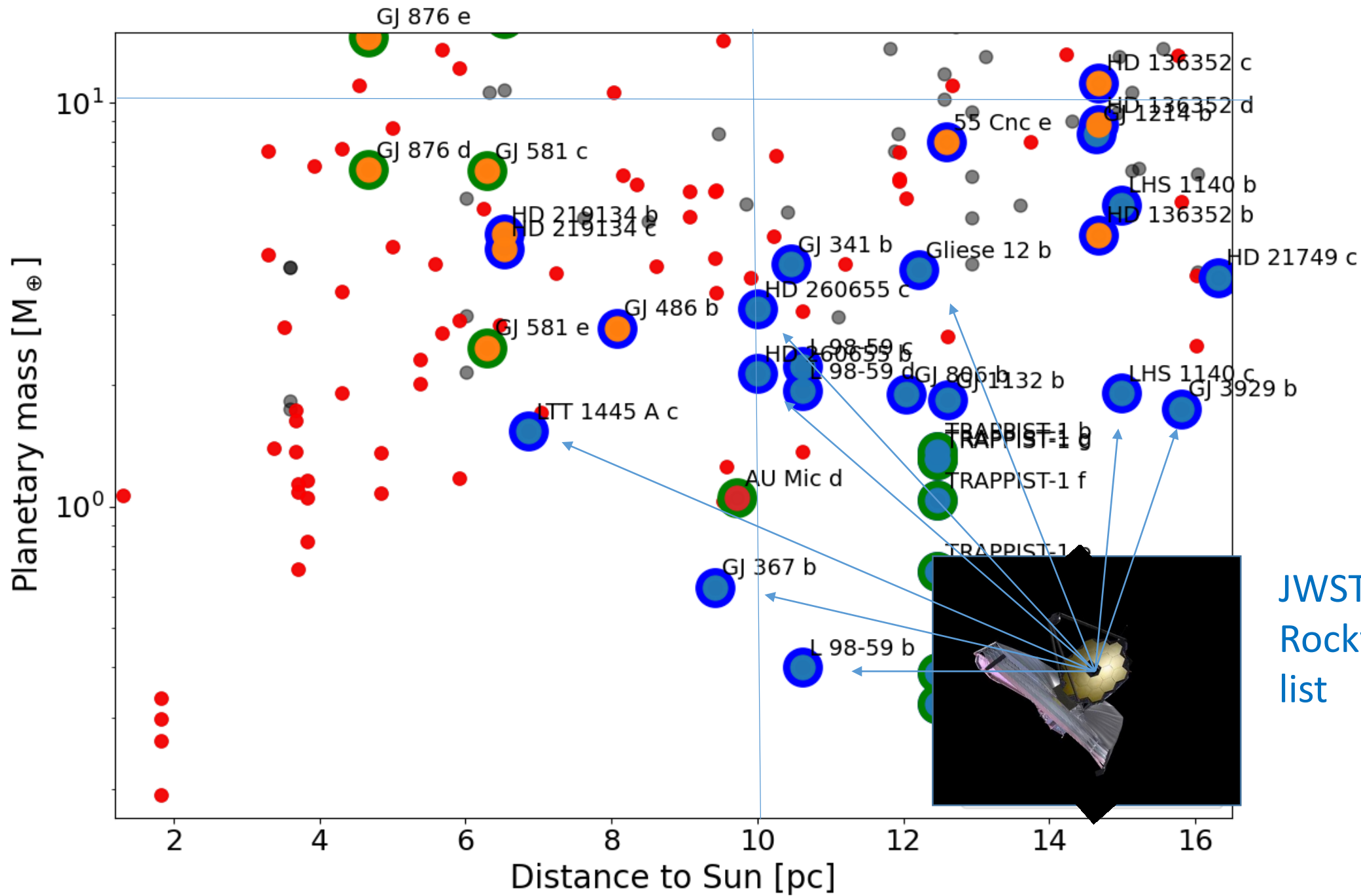
HD 136352 b

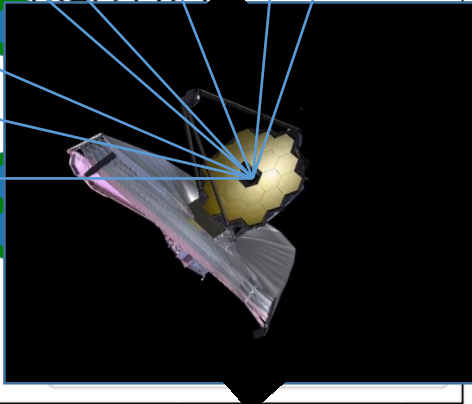
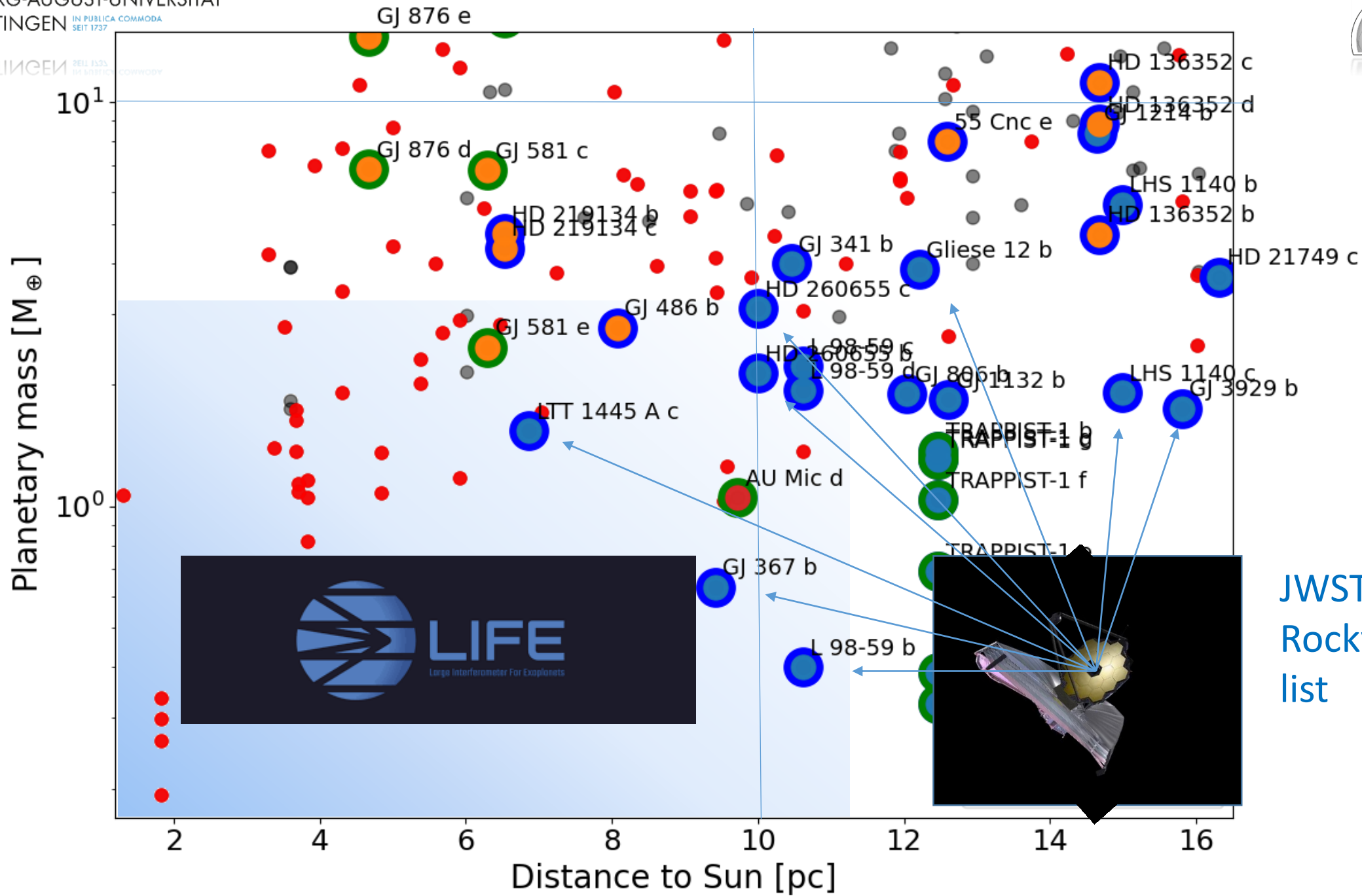
LHS 1140 c

GJ 3929 b

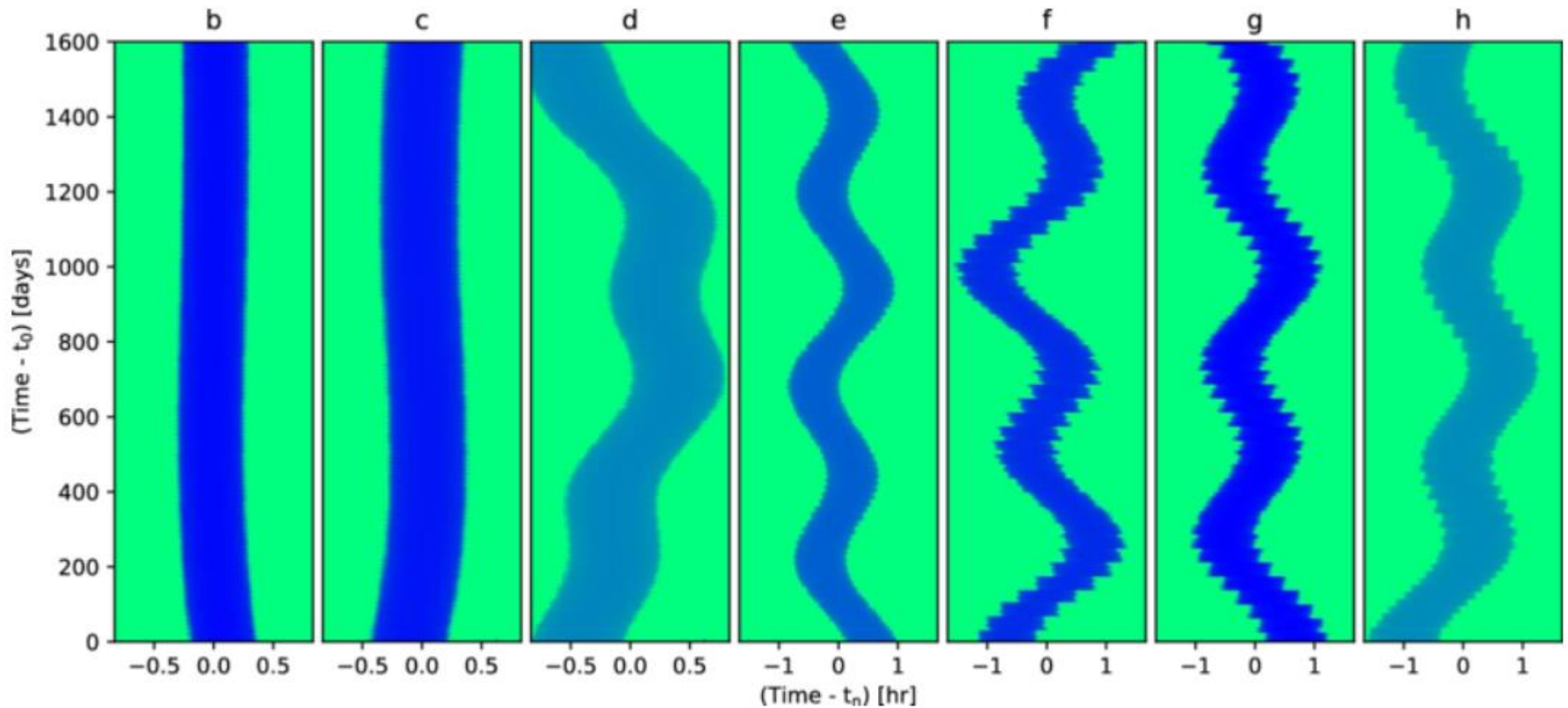
HD 21749 c



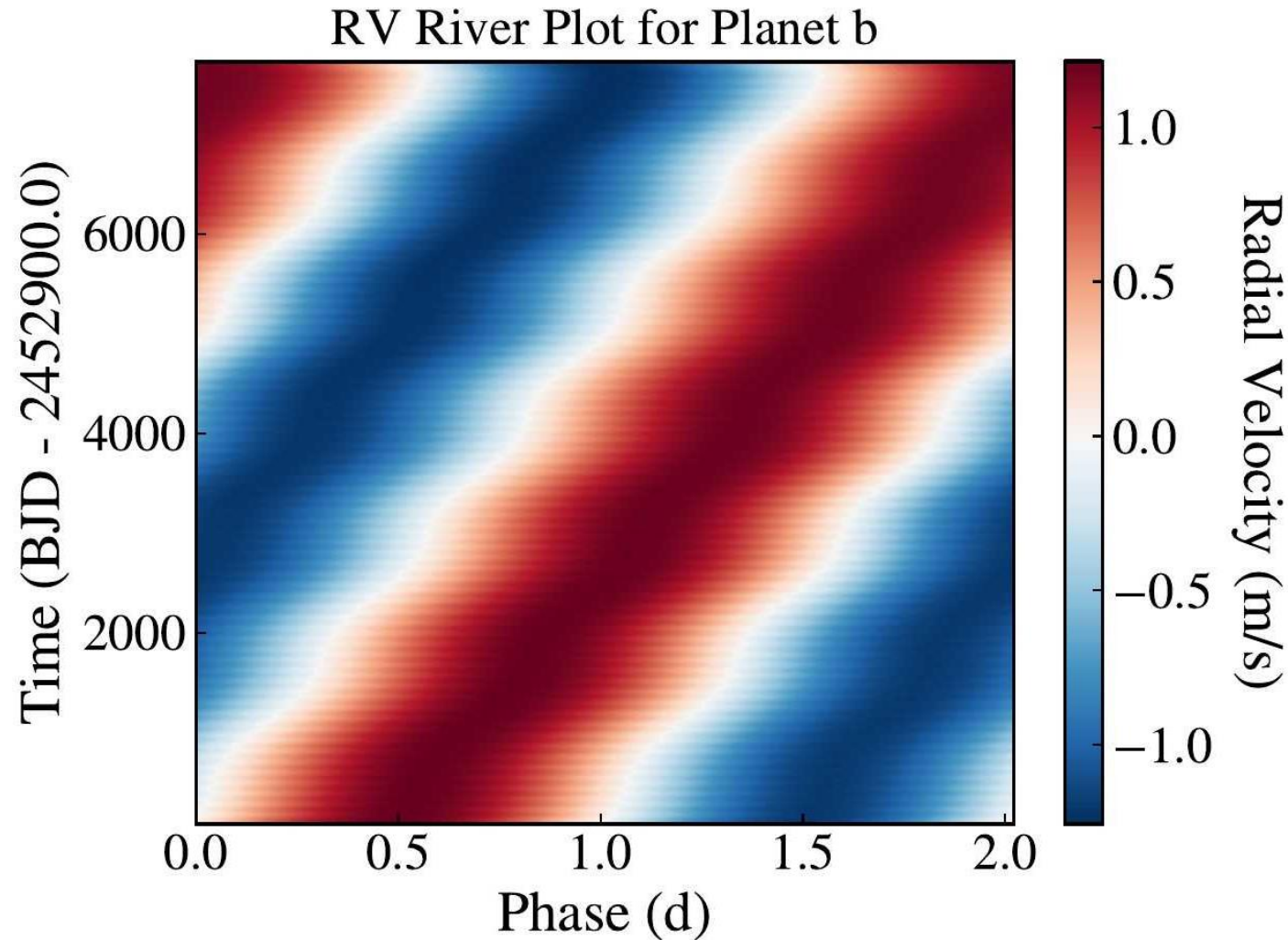




# Planet-Planet interaction from Transit Timing Variations TTVs: Trappist-1 River Plot (Agol et al. 2021)



# Planet-Planet interaction: Radial Velocity Variations(RVV)



Schwarz, priv.  
comm

# Determination of **dynamical** Planet Masses

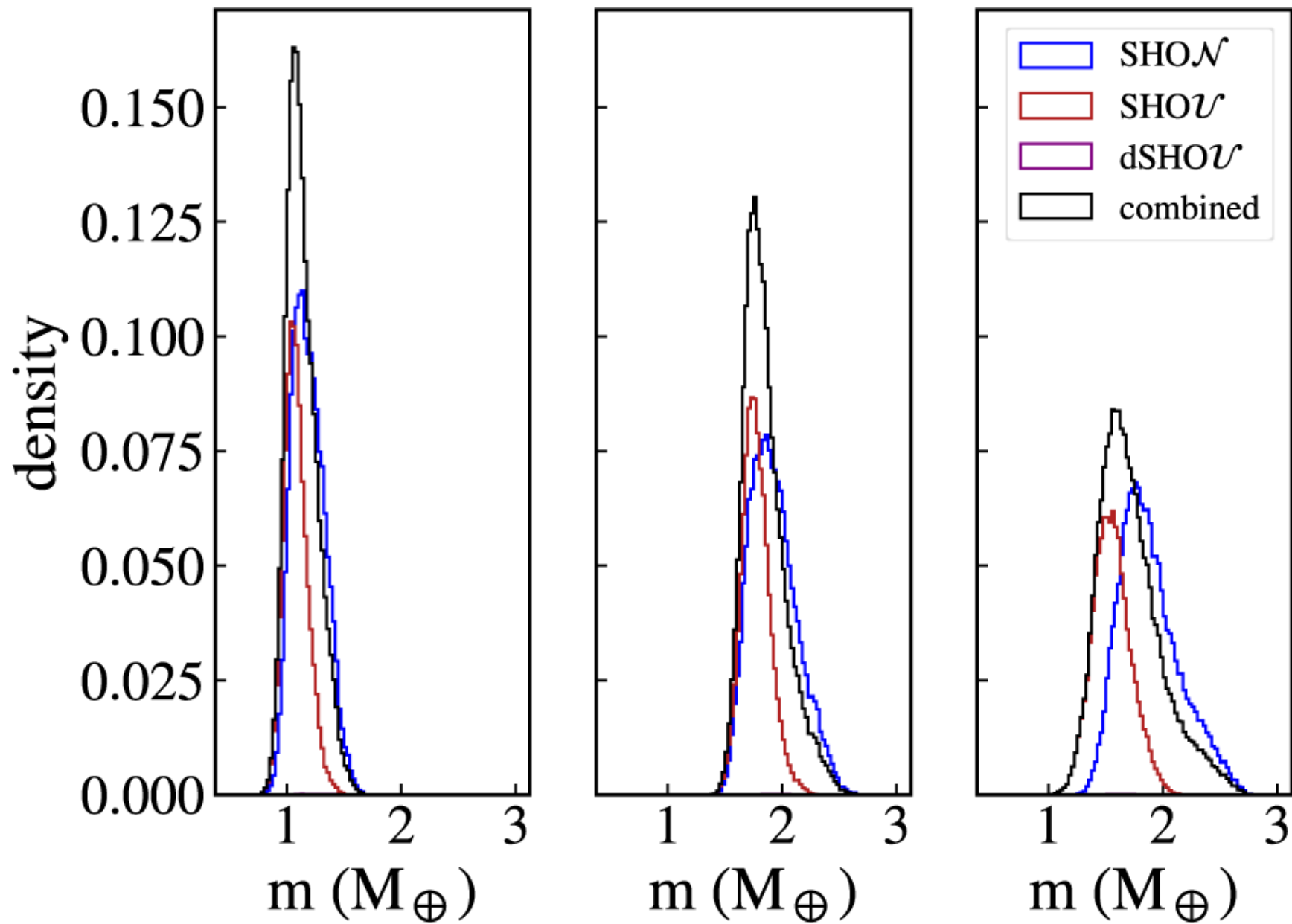
- Needs  $>1$  planet in the system
- Preferentially in dynamical **compact** configuration
- Needs **long** (decades) observational baseline
- High RV **precision** (ESPRESSO data highly welcome)
- Requires a direct **N-body integration** of the equations of motion (or an analytical approximation)
- REBOUND + DYNESTY (Rein et al. 2012...2023, Speagle 2020)

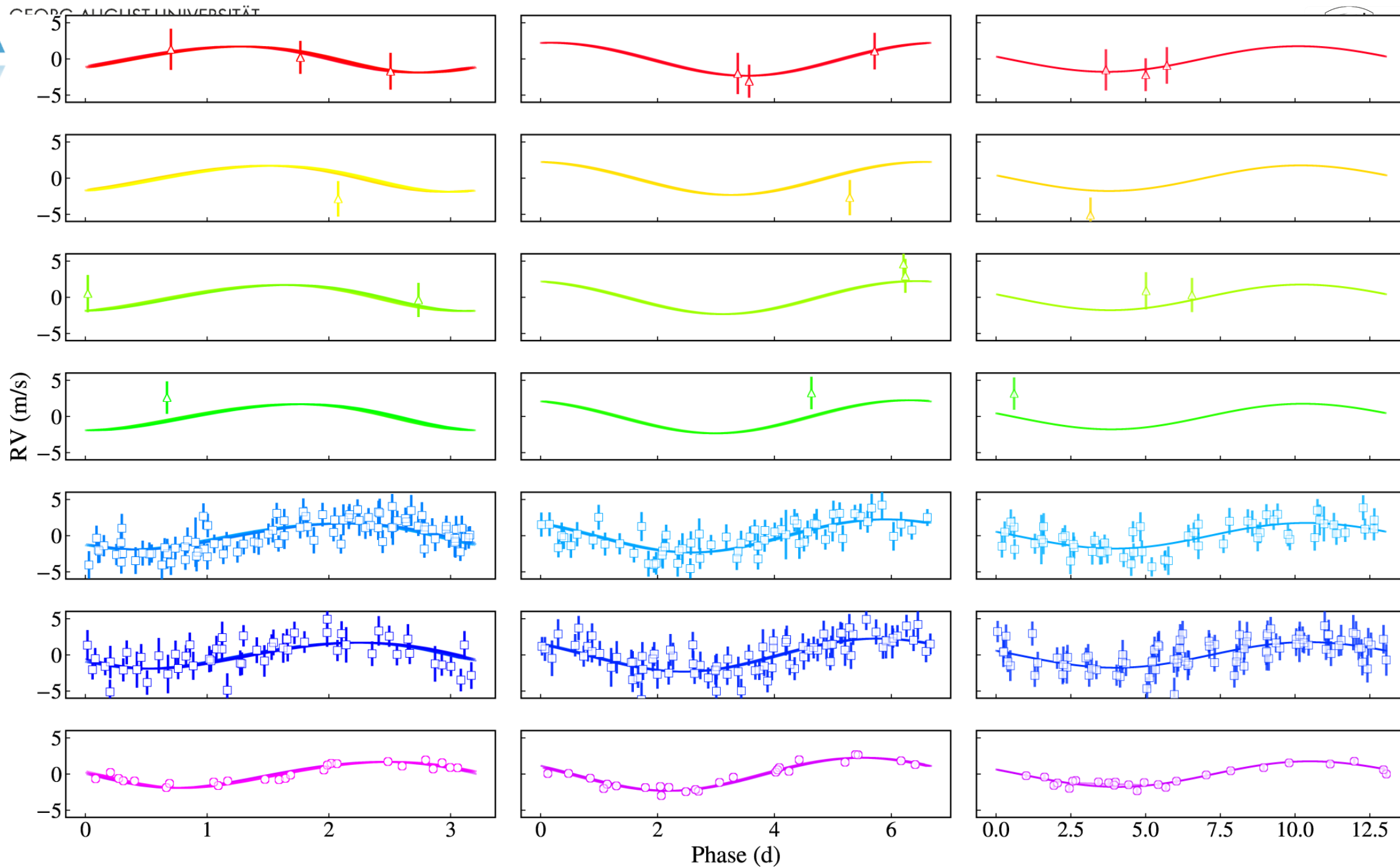
## RedDots: Planetary masses in the GJ 1061 system from planet-planet interaction★

 S. Dreizler<sup>1★★</sup>,  S. V. Jeffers<sup>2</sup>, F. Liebing<sup>3,★★★</sup>,  P. Gorrini<sup>1</sup>,  C. A. Haswell<sup>4</sup>,  E. Gaidos<sup>5,6</sup>,  
 J. R. Barnes<sup>4</sup>,  F. Del Sordo<sup>7,8,9</sup>,  H. R. A. Jones<sup>10</sup>,  E. Rodríguez<sup>11</sup> and  Y. Tsapras<sup>12</sup>



- **Nearby** (3.7pc), very low mass ( $0.12 M_{\odot}$ ) M5.5 star
- Slow rotator ( $P \sim 125d$ )
- 184 HARPS + **26 ESPRESSO** spectra, covering **7320d**
  
- Kepler models, N-body models, various GP kernels, 0 to 5 planets
- Best model: N-body model, 3 Planets (3.2d, 6.7d, 13.1d) , SHO Kernel

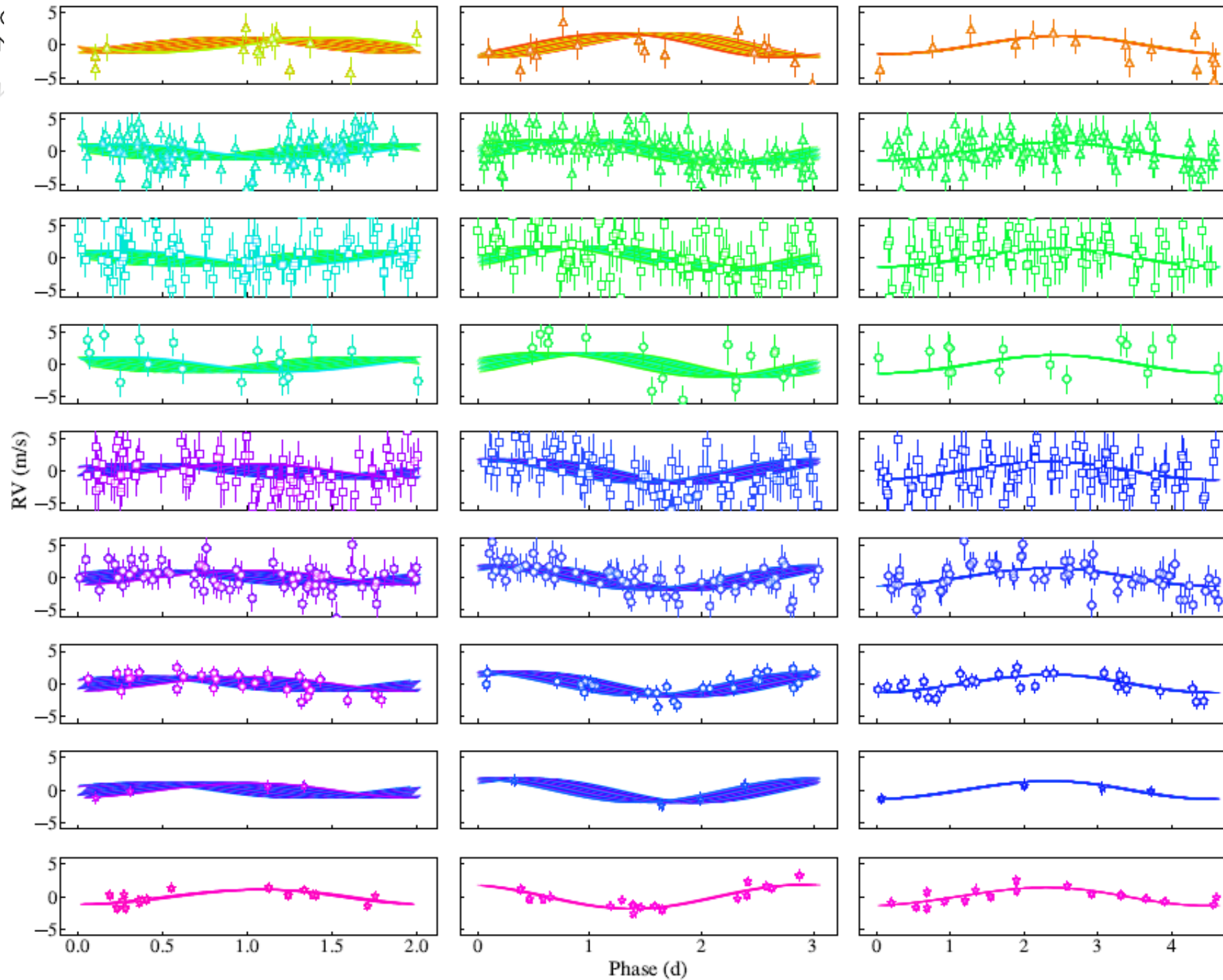




# RedDots: Self-consistent dynamic analysis of the compact multi-planet system YZ Ceti

Paul I. Schwarz<sup>1</sup>, Stefan Dreizler<sup>1</sup>, Sandra V. Jeffers<sup>2</sup>, and et al.

- **Nearby** (3.7pc), very low mass ( $0.14 M_{\odot}$ ) M4.5 star
- Slow rotator ( $P \sim 70d$ )
- 324 HARPS + 110 CARMENES + **54 ESPRESSO** spectra, covering **7700d**
- Kepler models, N-body models, various GP kernels, 0 to 3 planets
- Best model: N-body model, 3 Planets (2.0d, 3.1d, 4.7d) , SHO Kernel



# Determination of Planet Masses

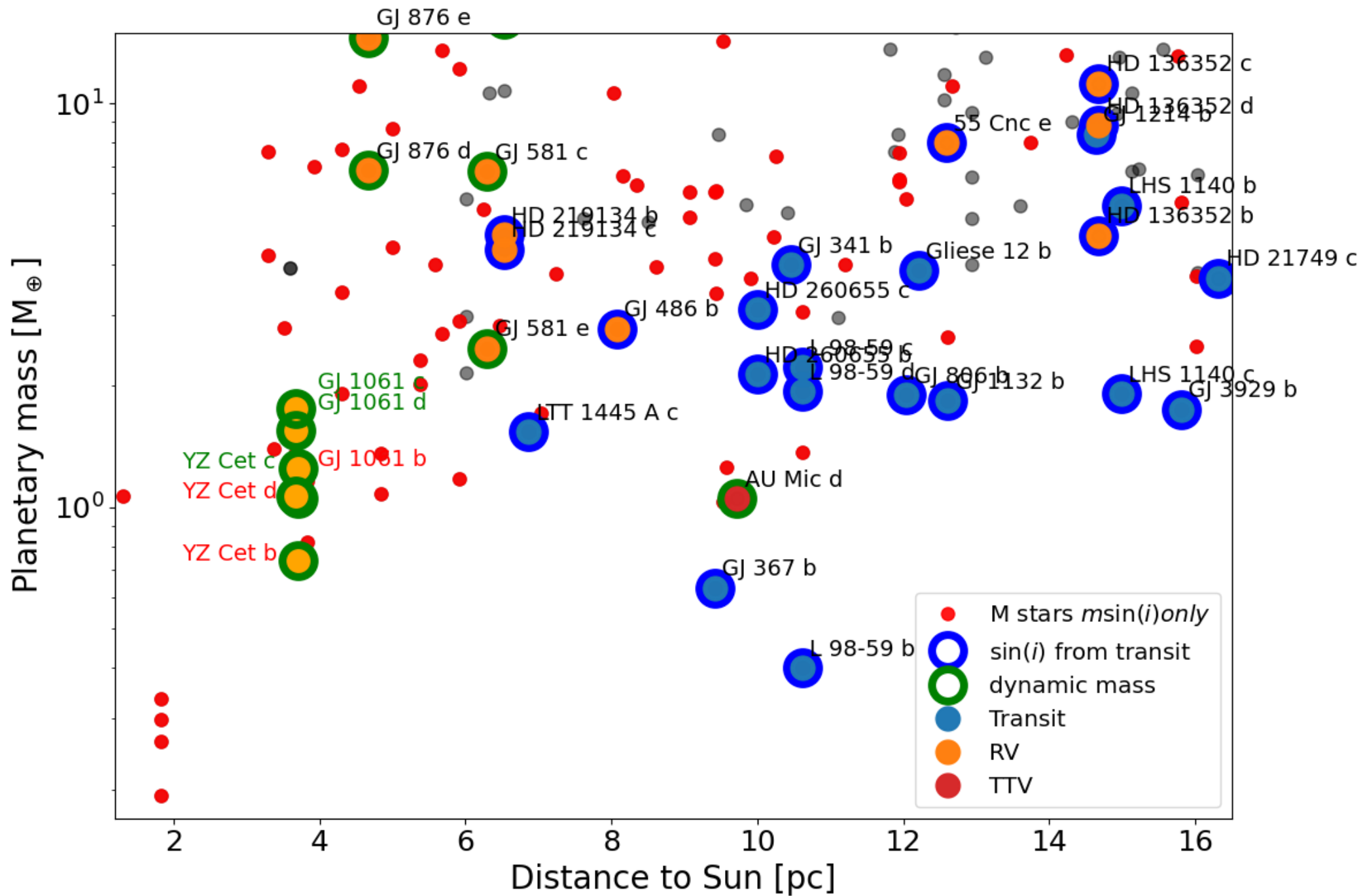
- Planets detected by...
  - Radial Velocity: needs orbital **inclination** (Transits or Astrometry or **planet-planet interaction**)
  - Transits: needs a mass determination (Radial Velocity or TTVs)

# Results

## YZ Cet planets

## GJ 1061 planets

- $m_b$ : 1.07 (+0.11, -0.09)  $M_{\oplus}$
- $m_c$ : 1.76 (+0.13, -0.11)  $M_{\oplus}$
- $m_d$ : 1.55 (+0.17, -0.16)  $M_{\oplus}$
  
- $P_b$ : 3.12d
- $P_c$ : 6.68d
- $P_d$ : 13.07d
  
- $i = 77 \pm 12^\circ$



# Summary

- GJ 1061: **dynamical masses** of three **Earth-mass planets**, two in the conservative habitable zone
- YZ Cet: **dynamical masses** of three **Earth-mass planets**, one in the conservative habitable zone
- Coming soon: Checking the **feasibility for other systems**