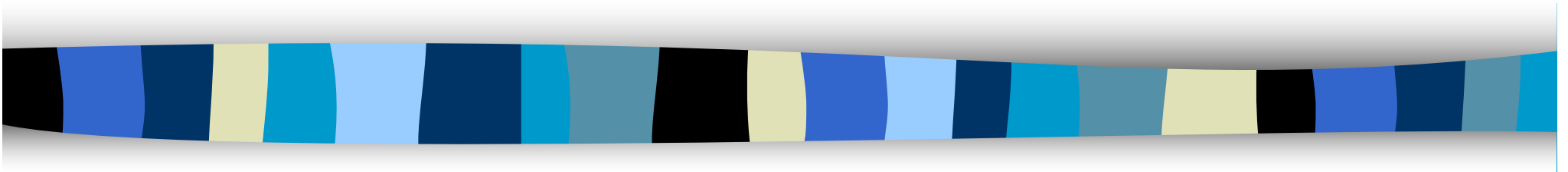


Searching and studying cool giant planets and their systems with SOPHIE at OHP



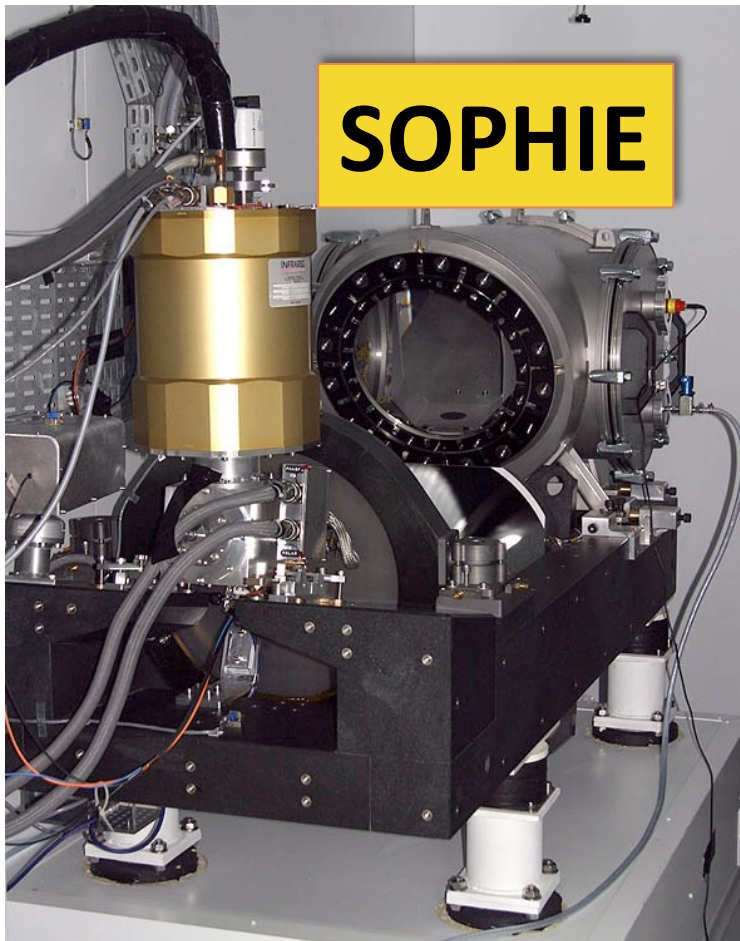
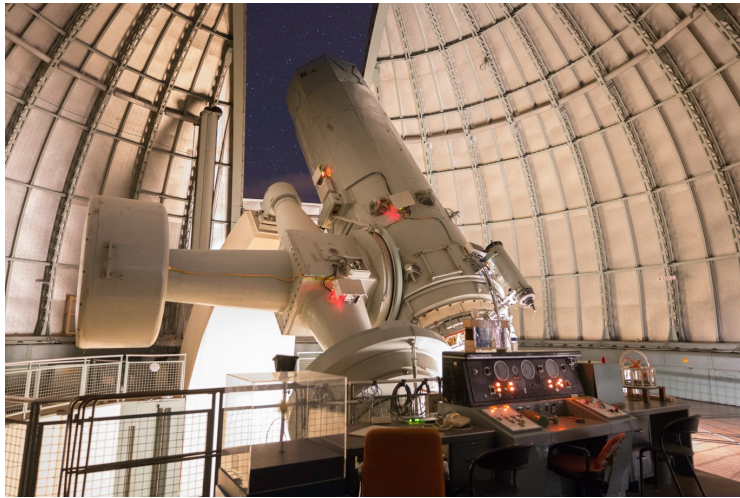
Guillaume Hébrard

CNRS

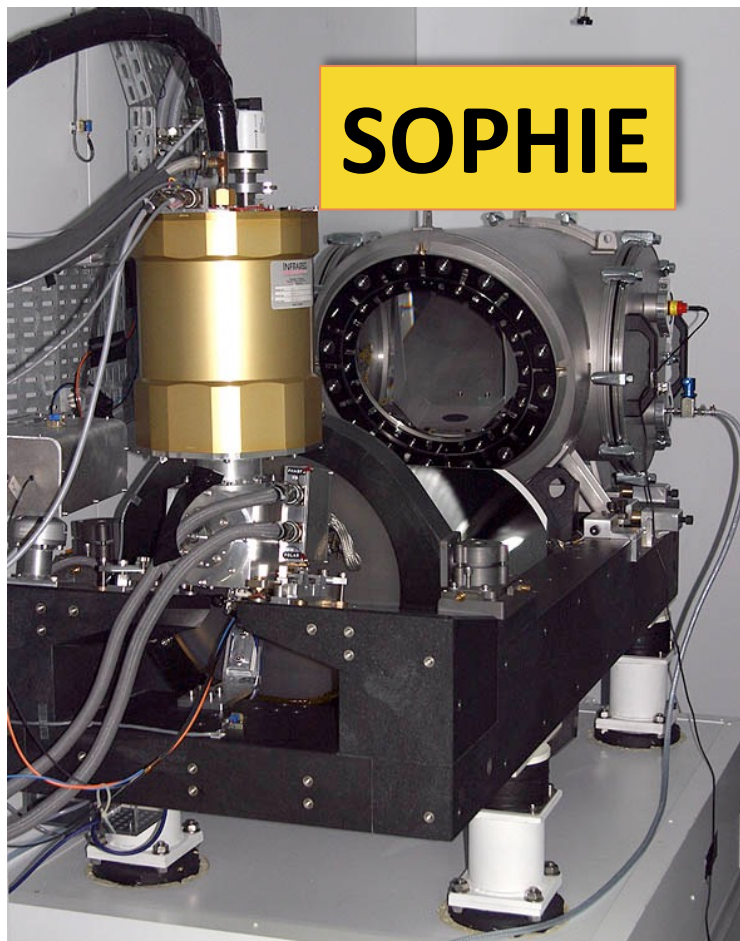
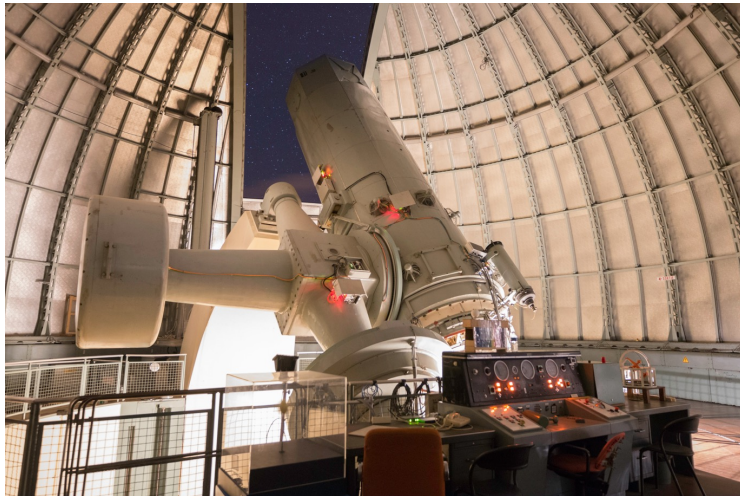
**Institut d'astrophysique de Paris
Observatoire de Haute-Provence**



51 Pegasi b conference, OHP, 7th October 2025



- cross dispersed echelle spectrograph
- 387 – 694 nm
- environnementally stabilized
- dispersive elements: tank with constant pressure & temperature
- optical-fiber fed (16-17m, 100 μ m = 3'')
- thorium/FP wavelength calib.
- 2 modes: $R = 40,000$ or $75,000$
- 2 fiber sets per mode (star/sky/lamps)
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First light in 2006 @ 193-cm OHP telescope

Upgrades in:

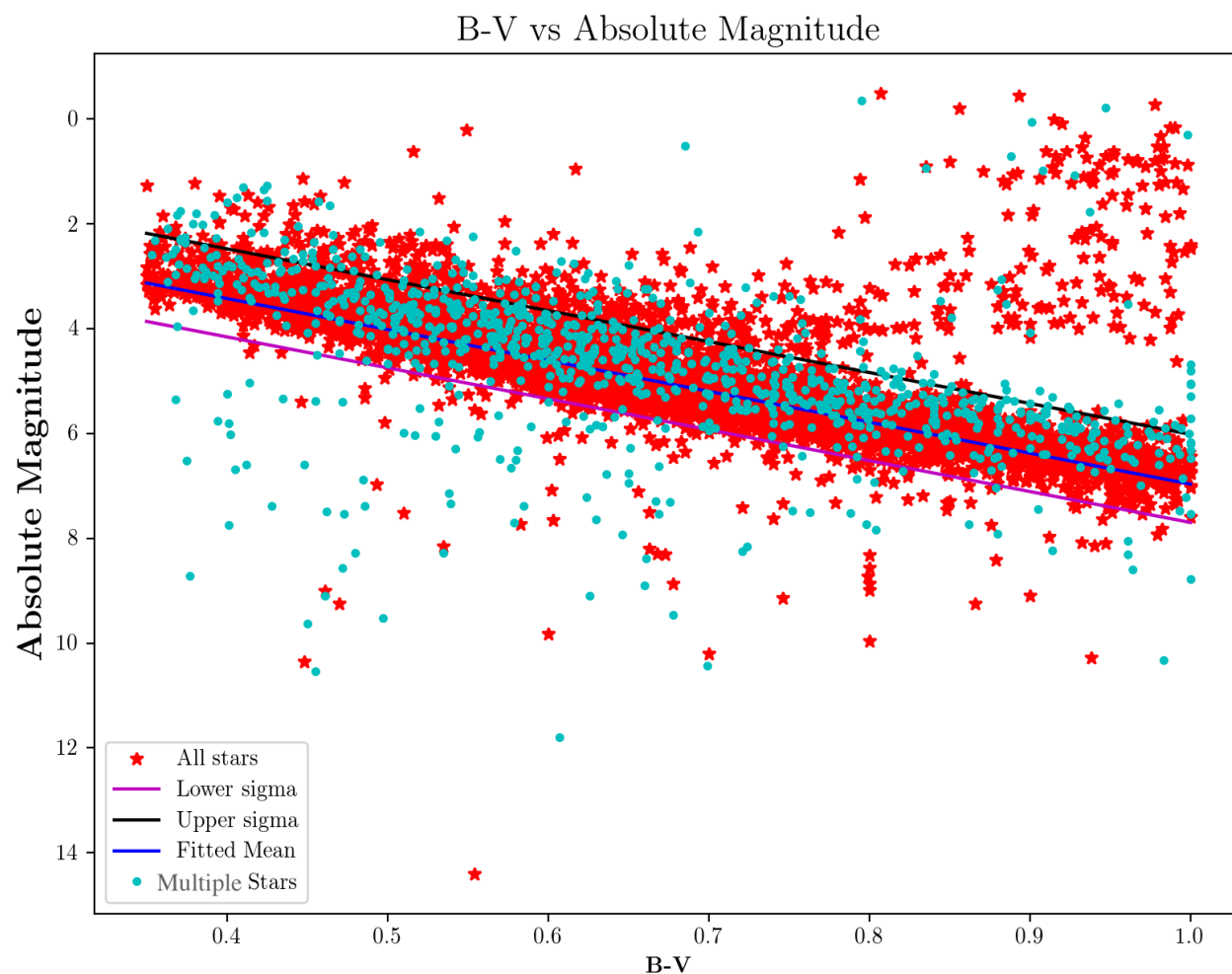
- 2010-2012 (octagonal-section fibers...);
- 2014-2017 (calibration unit...);
- now (detector...).

Programs to search and characterize exoplanets with SOPHIE

- Several programs
- Around 280 nights per year
- Flexibility in scheduling, reactivity
- Cooperation, synergies
- Follow-up and optimization of the instrument

J.M. Almenara, L. Arnold, T. Baycroft, I. Boisse, X. Bonfils, F. Bouchy, V. Bourrier, A. Carmona, P. Cortés, M. Deleuil, X. Delfosse, O. Demangeon, F. Destrieux, R.F. Díaz, S. Grouffal, N. Hara, G. Hébrard, N. Heidari, T. Forveille, F. Kiefer, A.-M. Lagrange, P. Larue, E. Martioli, D. Martin, P. Maxted, C. Moutou, F. Pepe, A. Petit, C. Ranc, N.C. Santos, A. Santerne, D. Ségransan, J. Serrano Bell, M. Standing, P. Strom, S. Sulis, A. Triaud, S. Udry, H. Vivien...

Survey for giant planets



2300 FGK stars

$d < 50$ pc

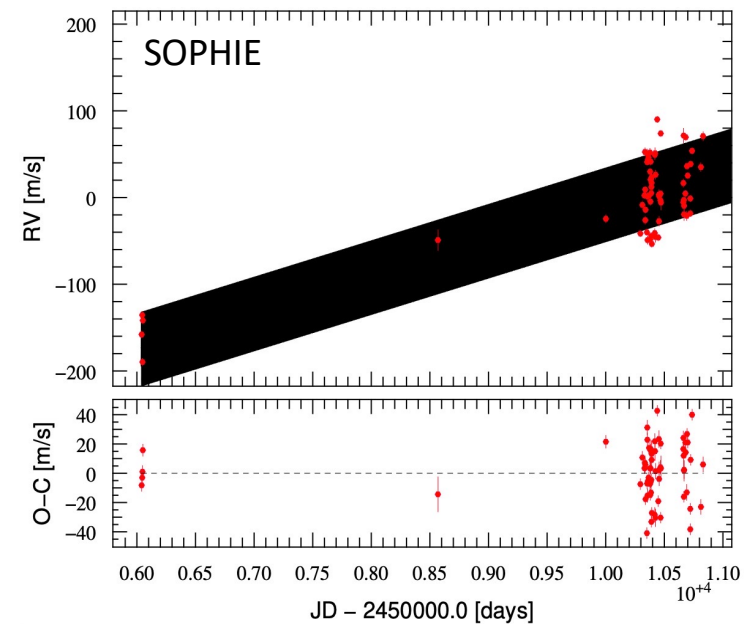
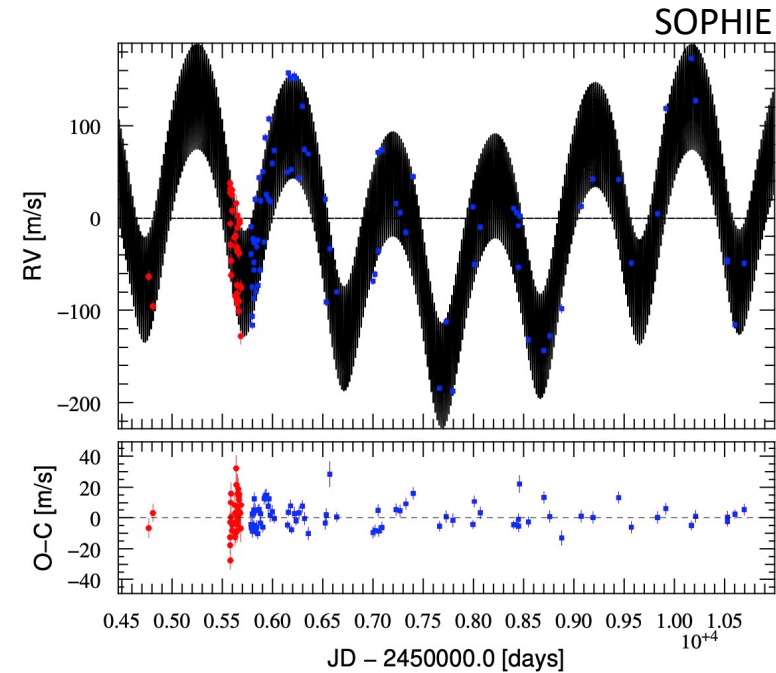
Close-in giant planets in systems

$$\begin{aligned}P &= 13.7 \text{ years} \\ m_p \sin i &= 4.0 M_{\text{Jup}} \\ e &= 0.1\end{aligned}$$

Destrieux et al. (in prep)

$$\begin{aligned}P &= 6.110 \pm 0.001 \text{ days} \\ m_p \sin i &= 0.39 \pm 0.04 M_{\text{Jup}}\end{aligned}$$

Destrieux et al. (in prep)

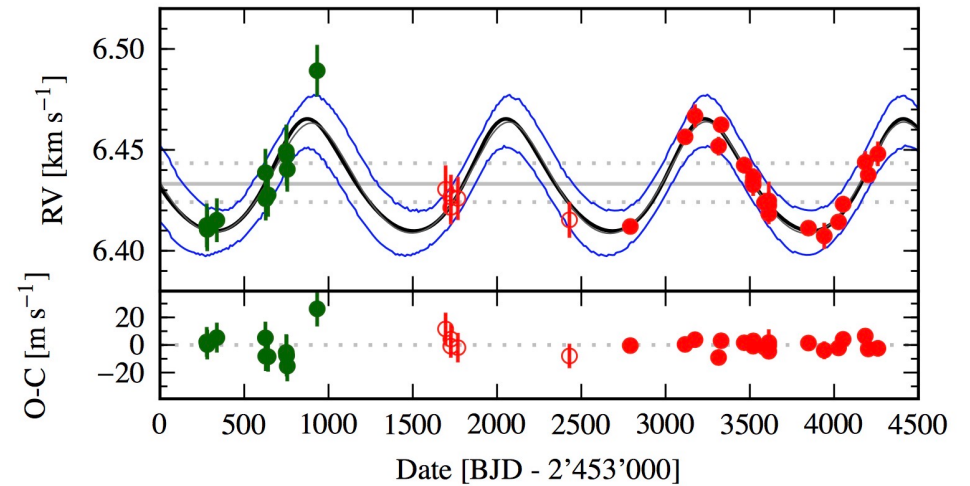


Giant planets on long periods

$$P = 3.21 \pm 0.04 \text{ yr}$$
$$m_p \sin i = 1.61 \pm 0.14 M_{\text{Jup}}$$

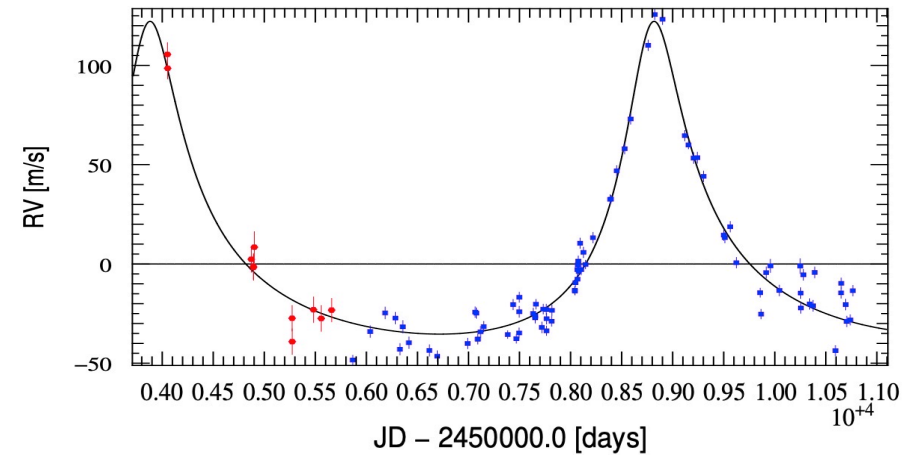
Díaz, Rey, Demangeon et al. (2016)

HD 221585b



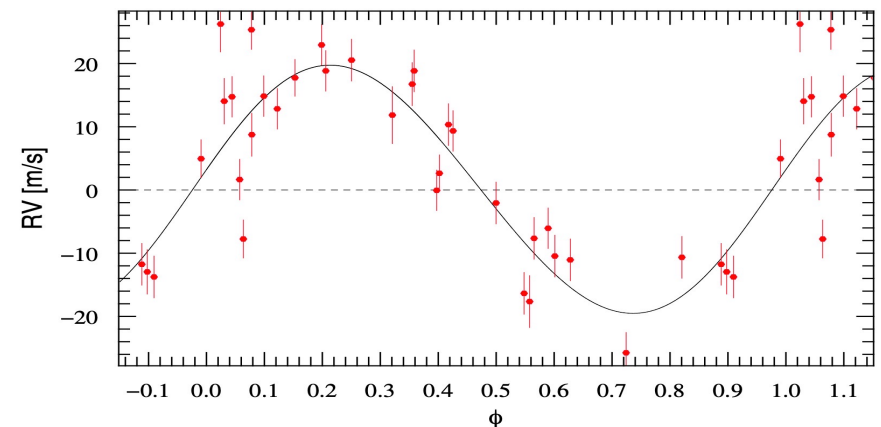
$$P = 13.5 \pm 0.2 \text{ yr}$$
$$m_p \sin i = 5.5 \pm 0.2 M_{\text{Jup}}$$

Kiefer et al. (in prep)



$$P = 1.75 \pm 0.04 \text{ yr}$$
$$m_p \sin i = 0.86 \pm 0.10 M_{\text{Jup}}$$

Hébrard et al. (in prep)

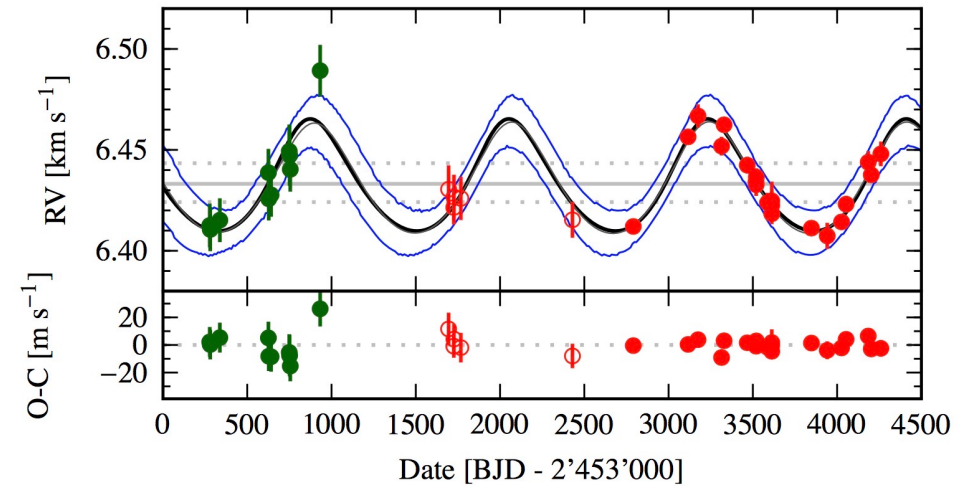
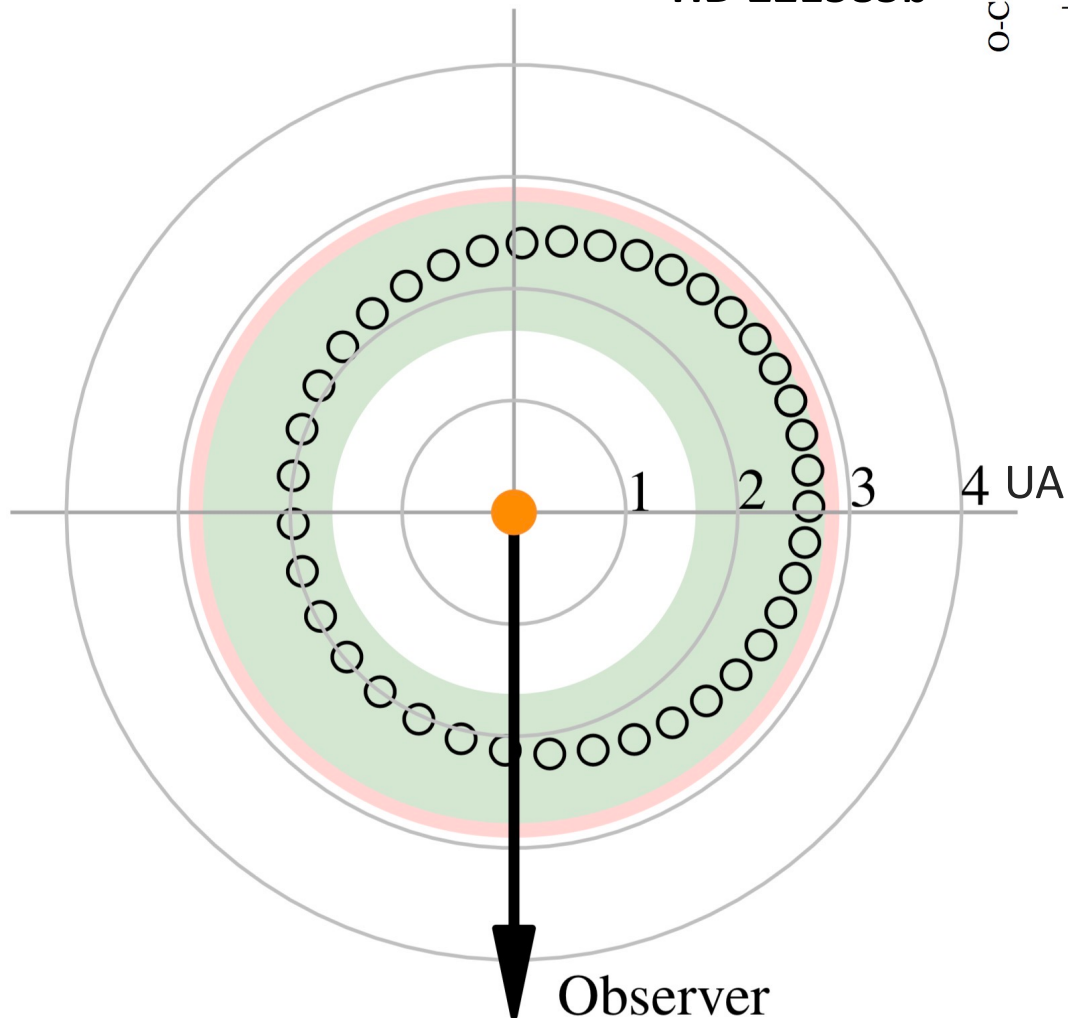


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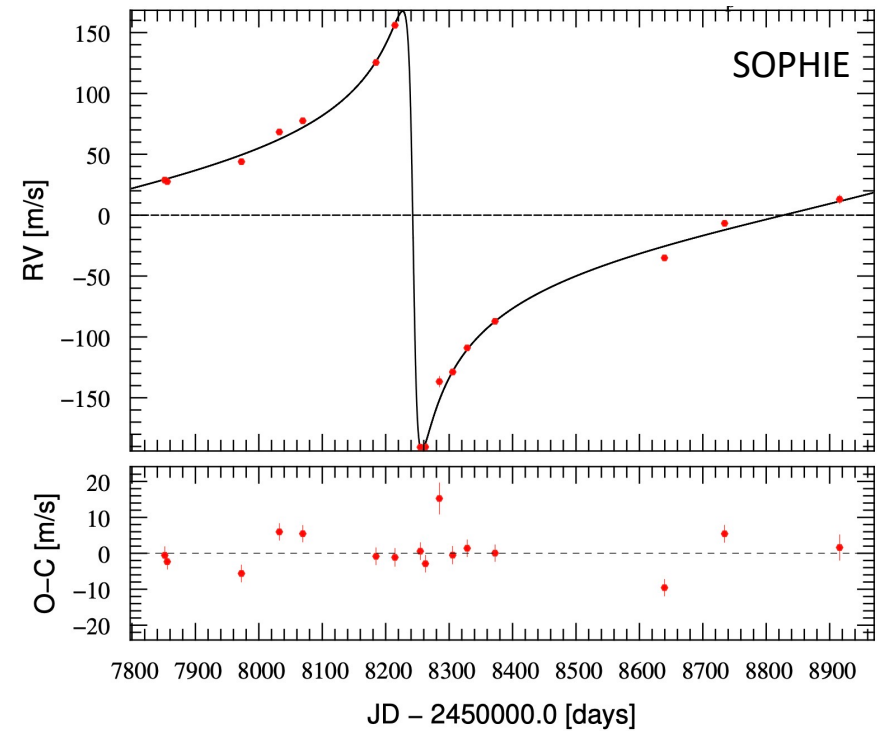
Habitable zone: between "runaway greenhouse" & "maximum greenhouse" limits, or "early Mars" limit (Kopparapu et al. 2013).

Eccentric, long-period, giant planets

$$\begin{aligned}P &= 3.29 \pm 0.16 \text{ yr} \\ m_p \sin i &= 4.0 \pm 0.3 M_{\text{jup}} \\ e &= 0.88 \pm 0.02\end{aligned}$$

Dalal, Kiefer, Hébrard et al. (2021)

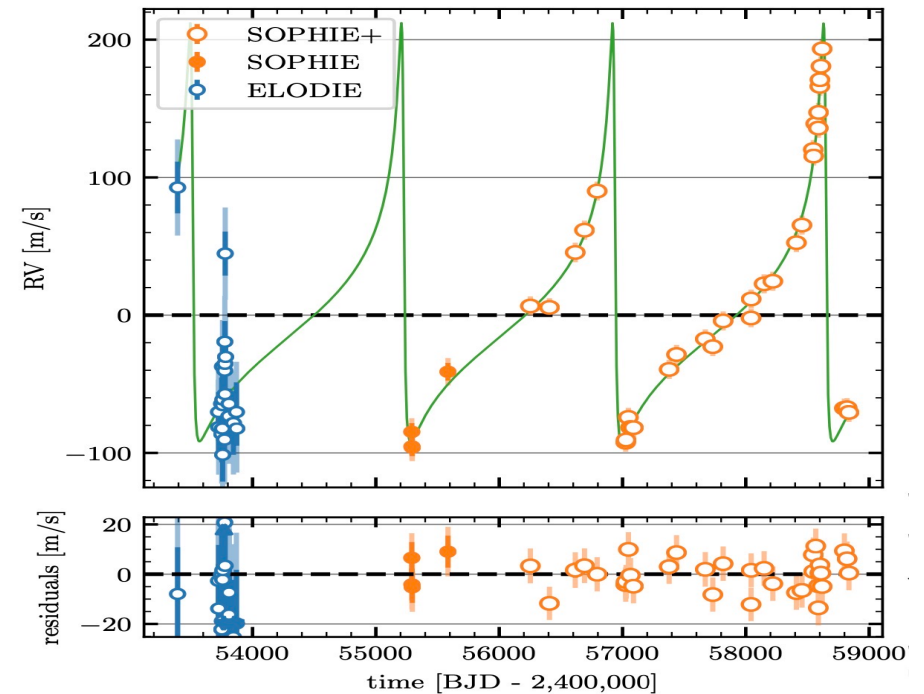
BD+63 1405b



$$\begin{aligned}P &= 4.67 \pm 0.03 \text{ yr} \\ m_p \sin i &= 5.0 \pm 0.5 M_{\text{jup}} \\ e &= 0.87 \pm 0.02\end{aligned}$$

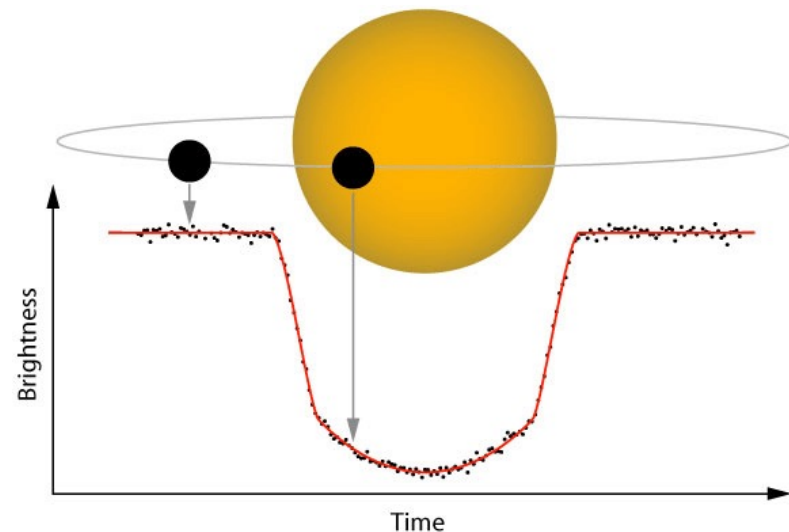
Demangeon, Dalal, Hébrard et al. (2021)

HD 80869b

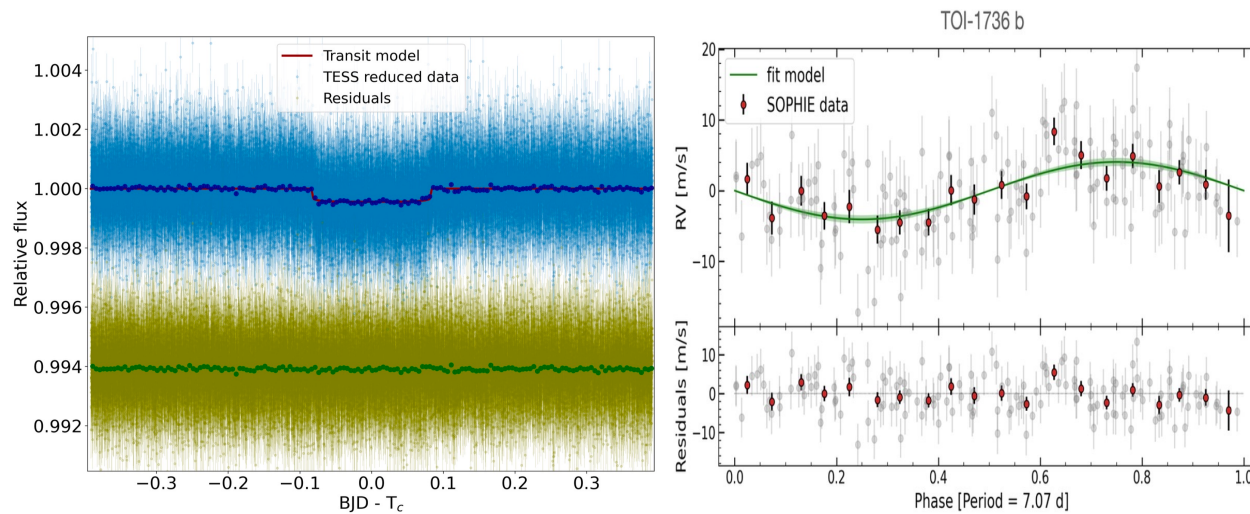


Radial velocity follow-up of transiting planetary candidates from photometric surveys

- Follow-up programs with SOPHIE since 2006
- CoRoT satellite
- From ground: SuperWASP, XO, HAT...
- Kepler, K2
- TESS



TOI-1736: a system including a transiting sub-Neptune



b:

$$P = 7.073088(7) \text{ d}$$

$$K = 4.1 \pm 0.6 \text{ m/s}$$

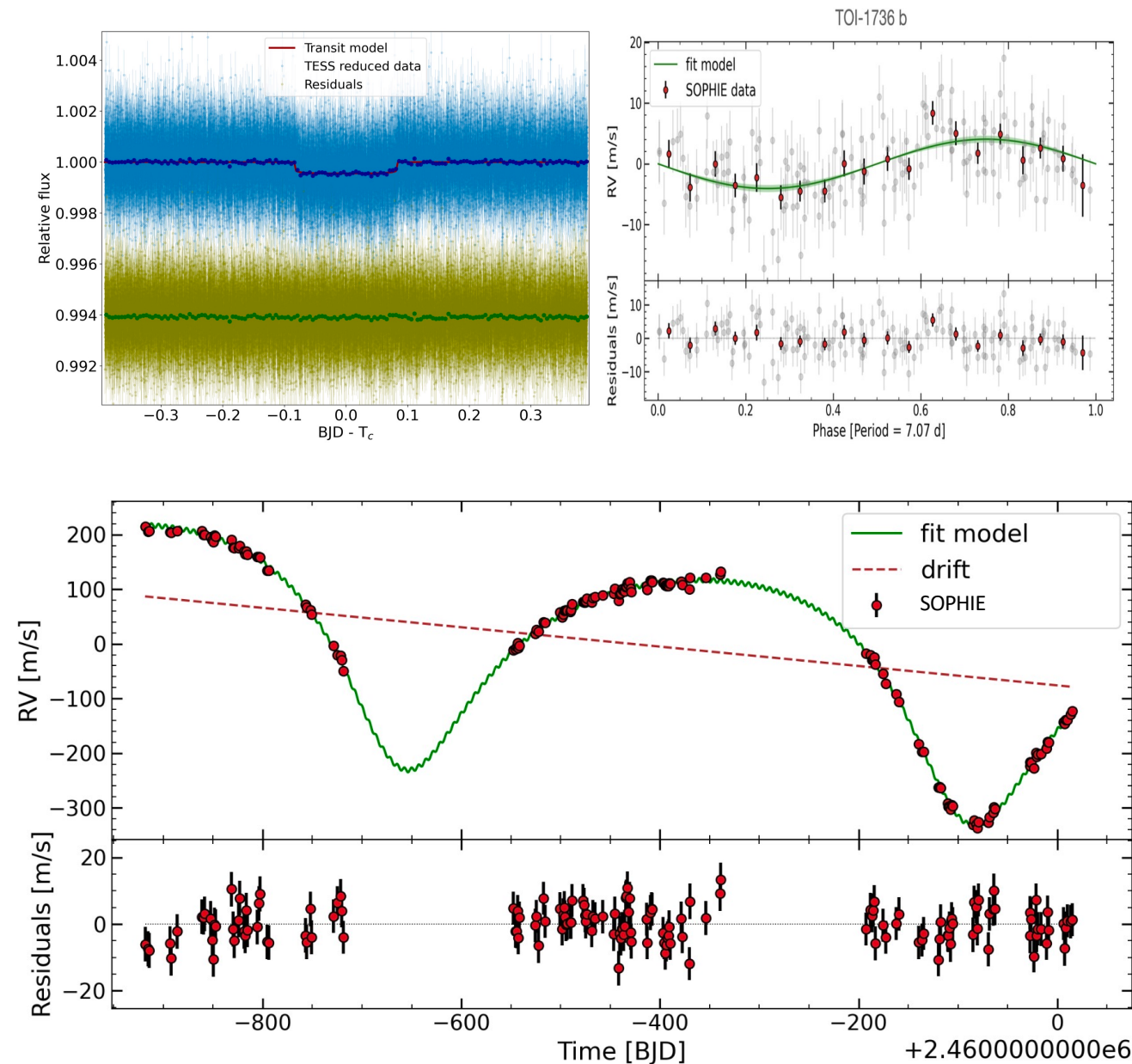
$$e < 0.21$$

$$M = 12.8 \pm 1.8 M_{\text{Earth}}$$

$$R = 2.44 \pm 0.18 R_{\text{Earth}}$$

$$\rho = 4.9 \pm 1.3 \text{ g/cm}^3$$

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c:

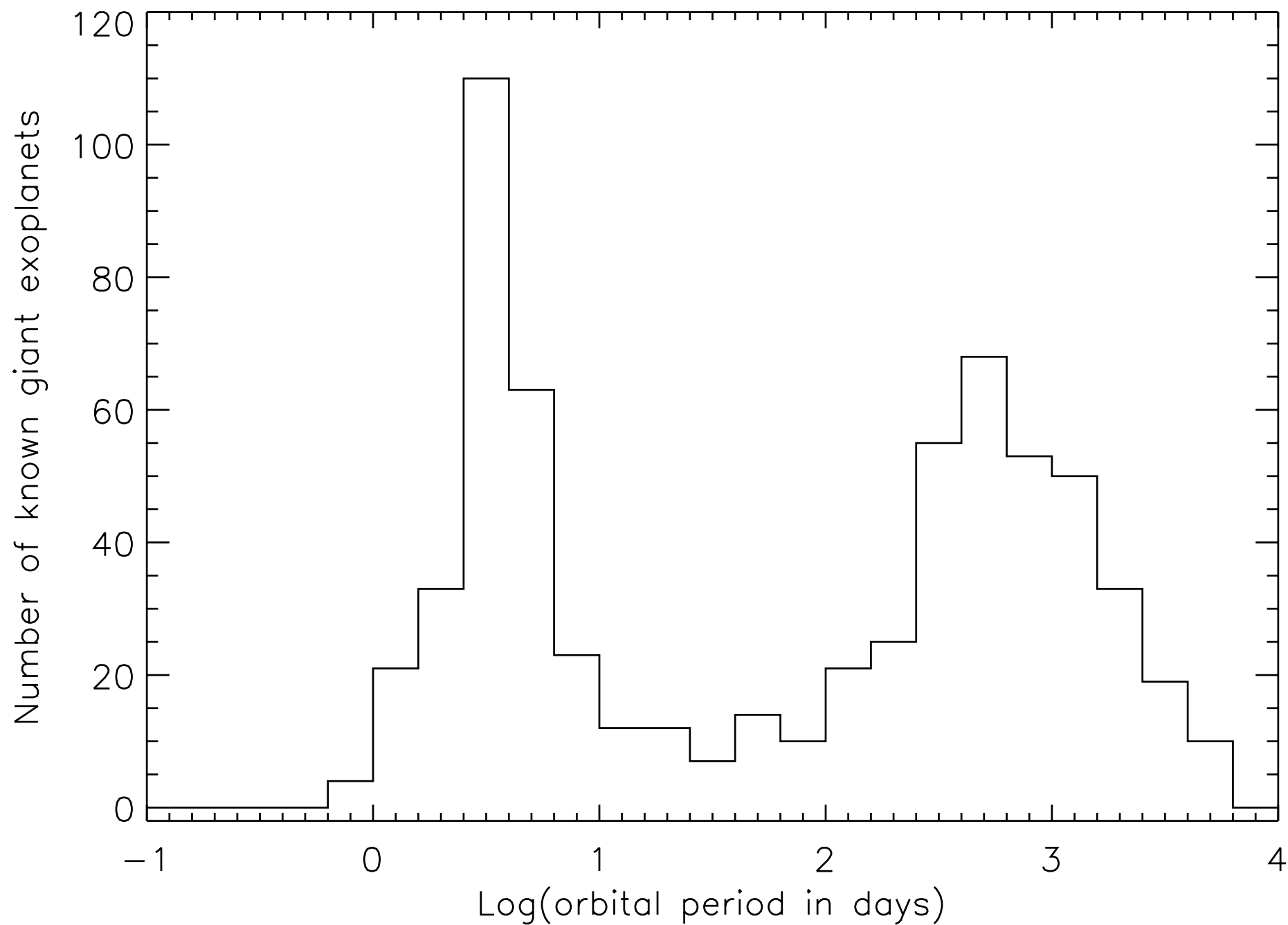
$$P = 570.1 \pm 0.7 \text{ d}$$

$$K = 201.1 \pm 0.7 \text{ m/s}$$

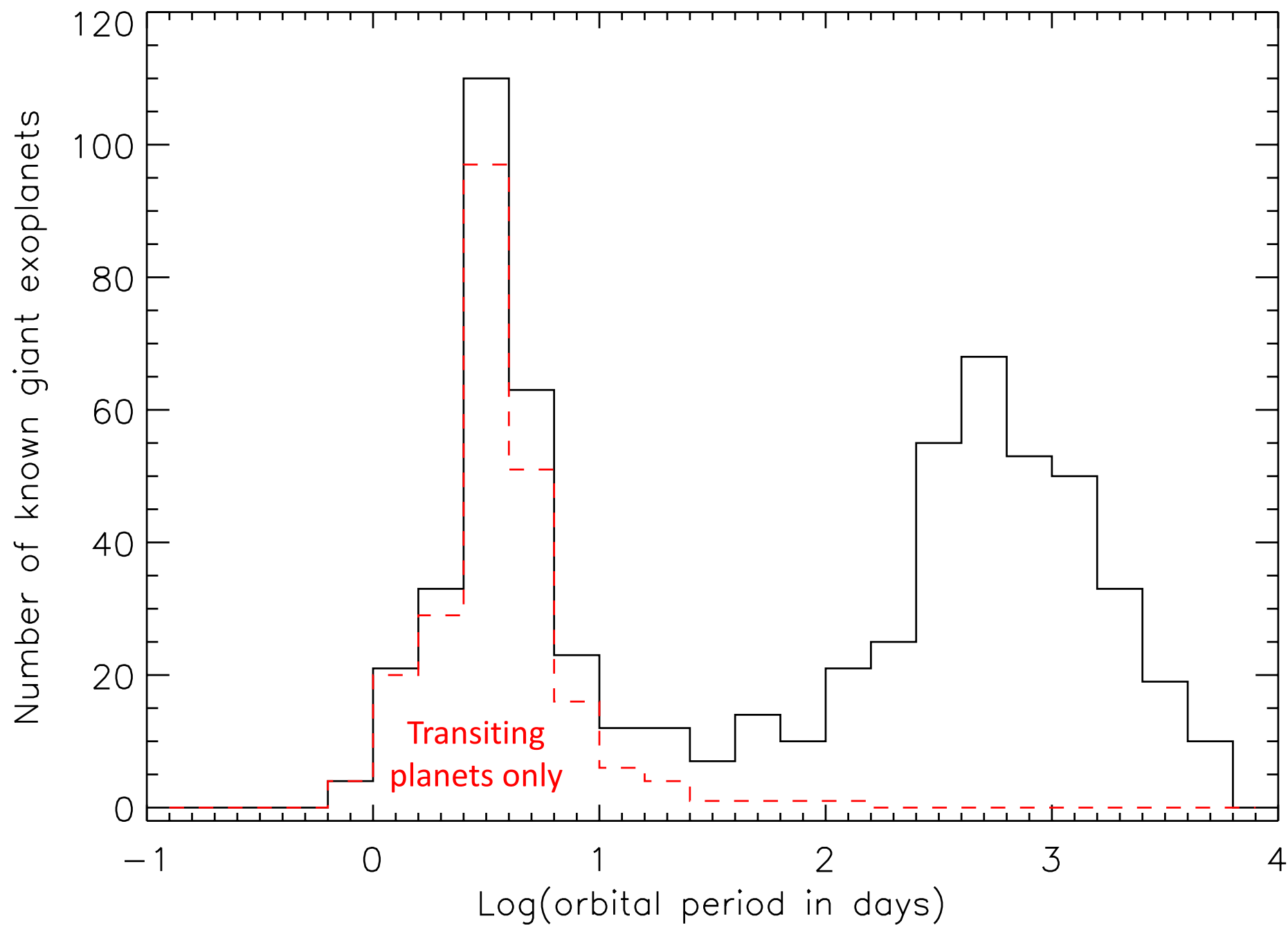
$$e = 0.362 \pm 0.003$$

$$M \sin i = 8.7 (+1.5/-0.6) M_{\text{Jup}}$$

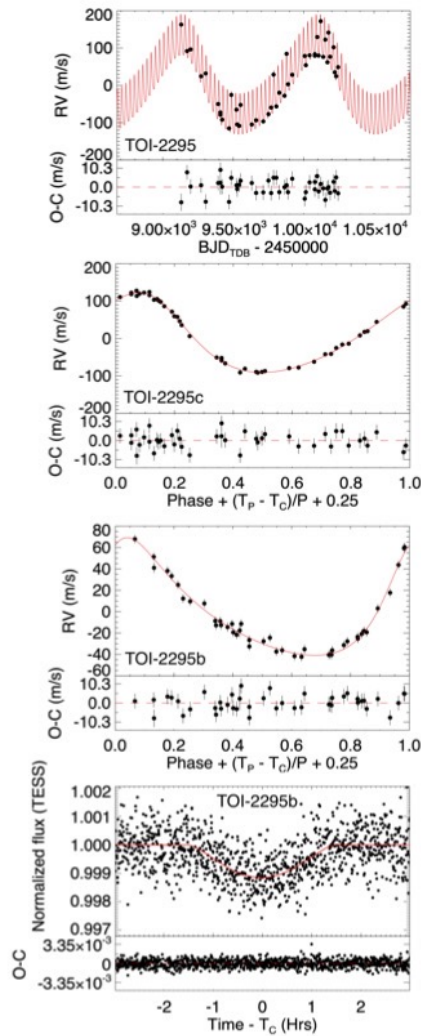
Known giant planets



Known giant planets



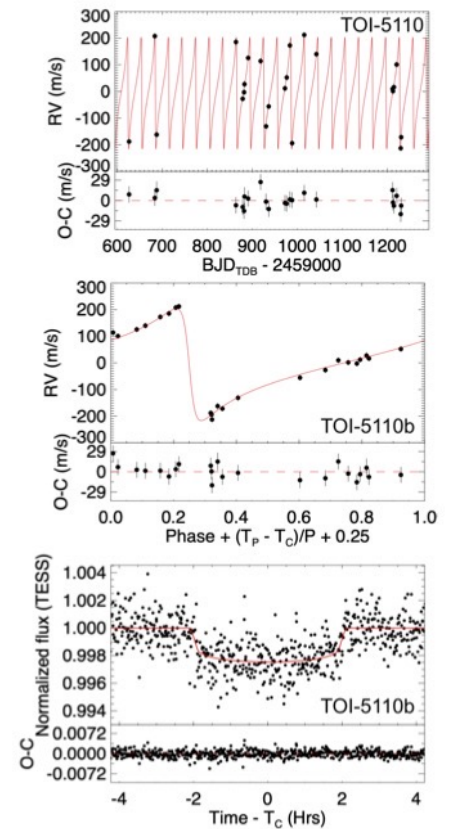
Characterization of new long-period transiting systems



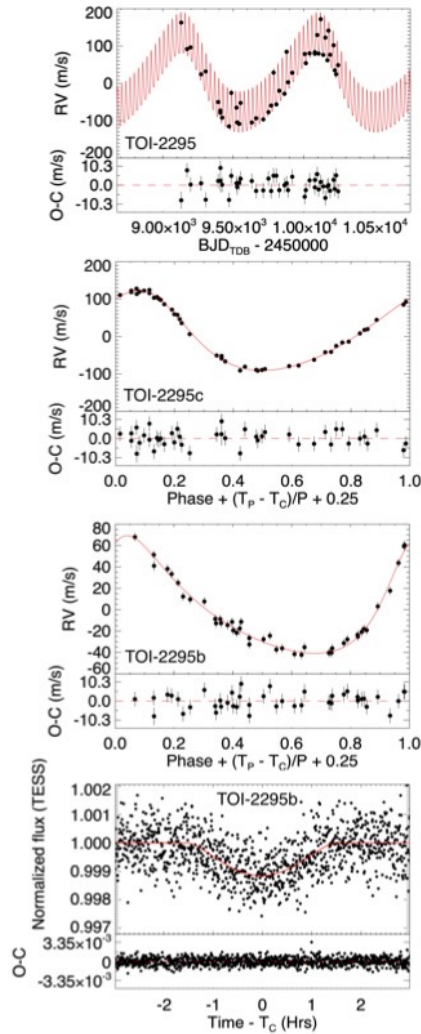
$$P_b = 30.03 \text{ d}$$

$$P_c = 966 \text{ d}$$

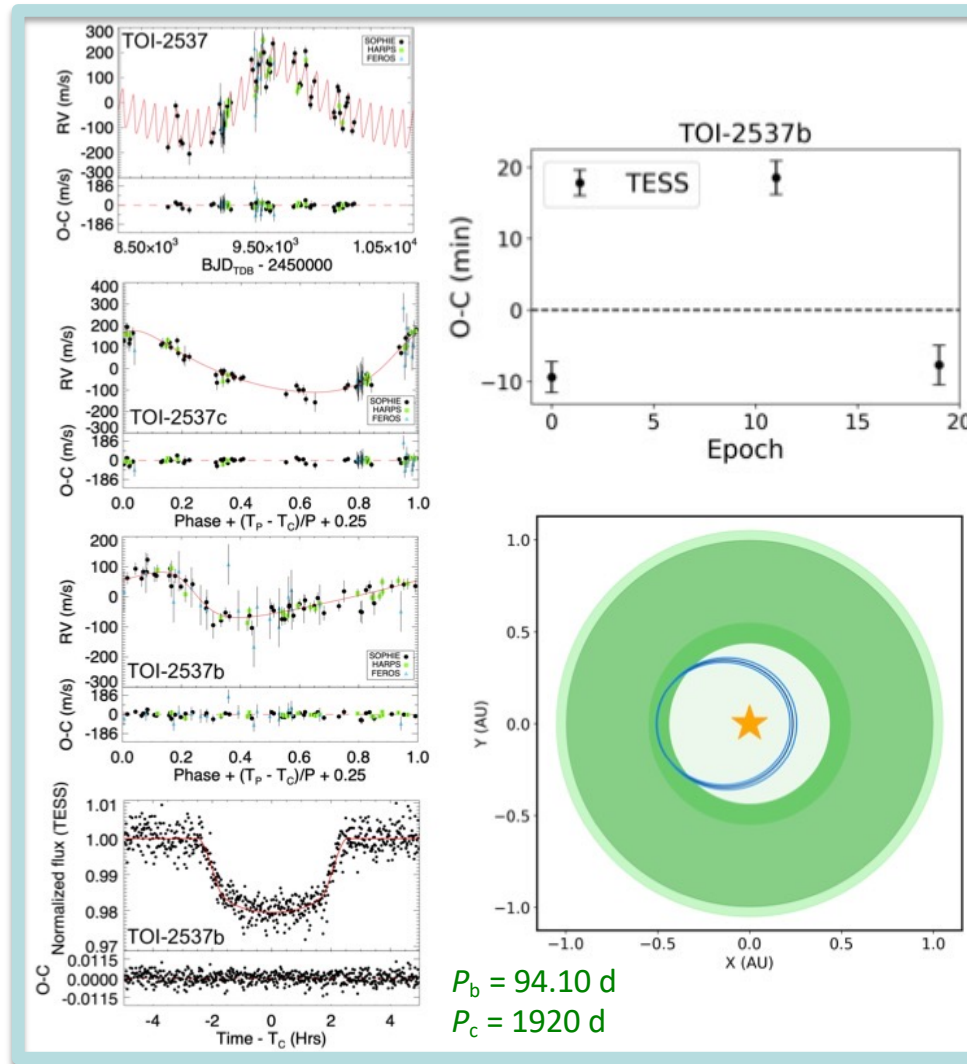
$$P_b = 31.16 \text{ d}$$



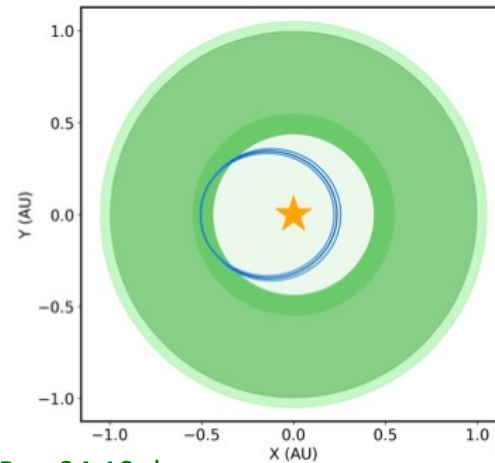
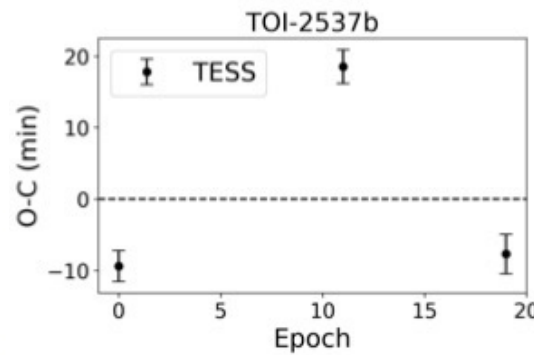
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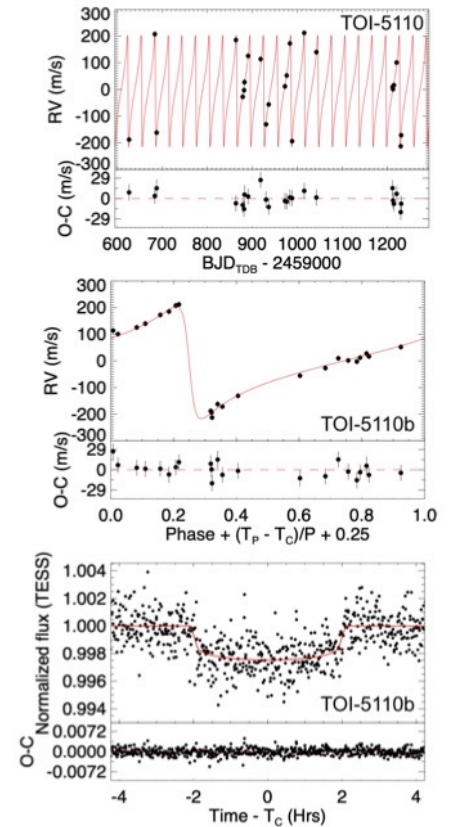
$P_b = 30.03$ d
 $P_c = 966$ d



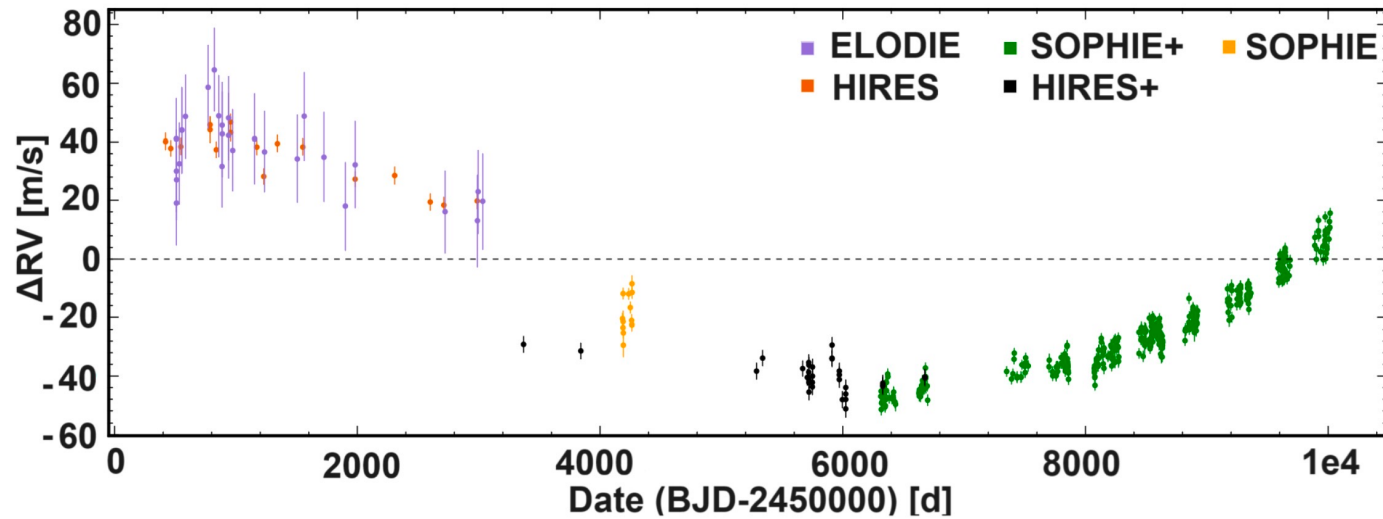
$P_b = 94.10$ d
 $P_c = 1920$ d



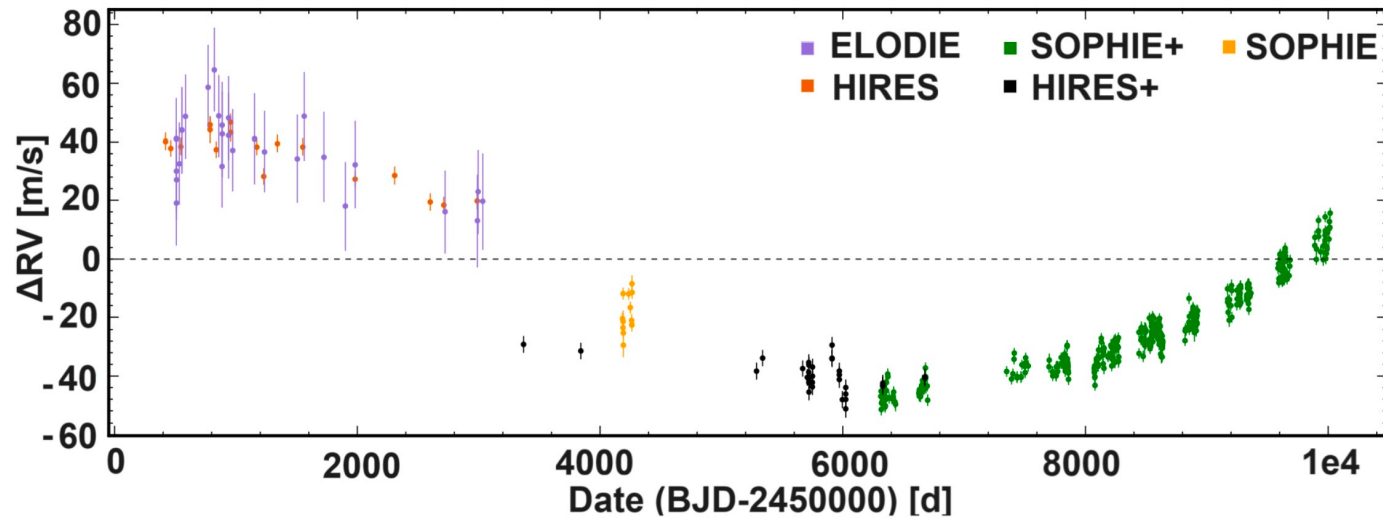
$P_b = 31.16$ d



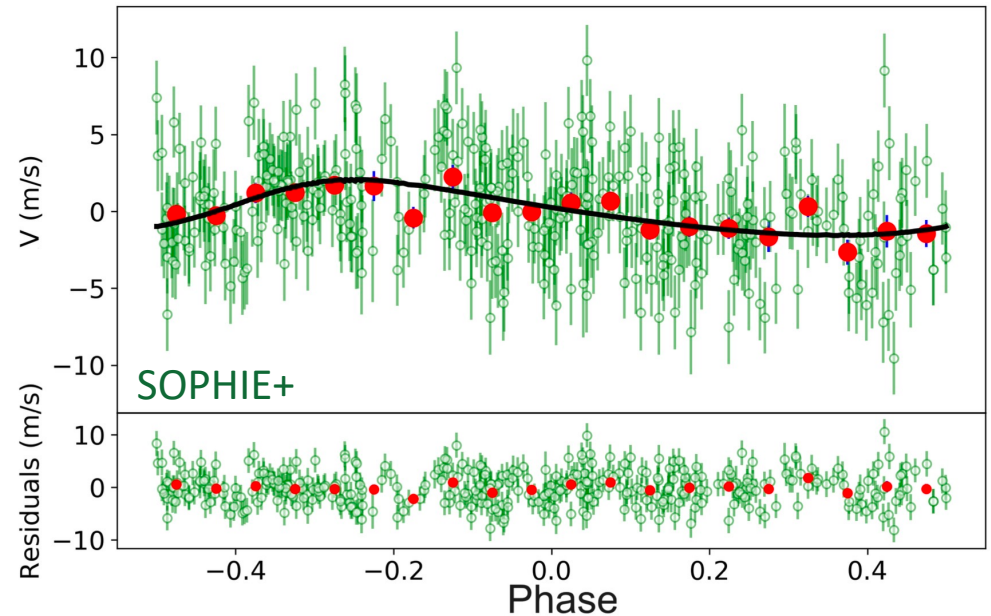
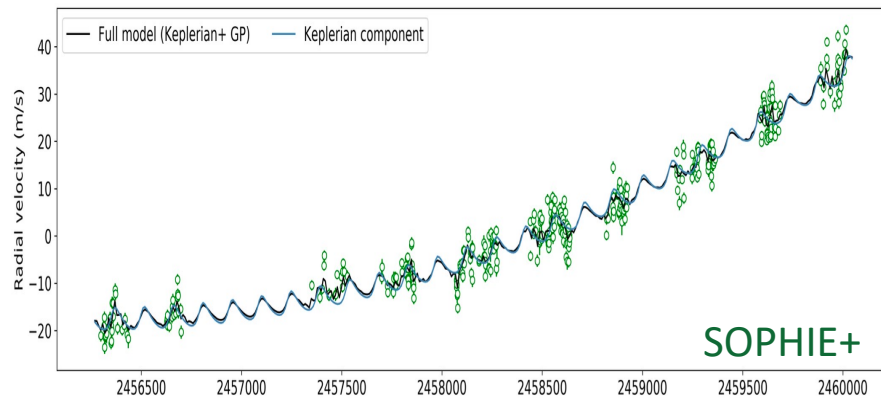
A system including a cold sub-Neptune potentially transiting a $V = 6.5$ star HD 88986



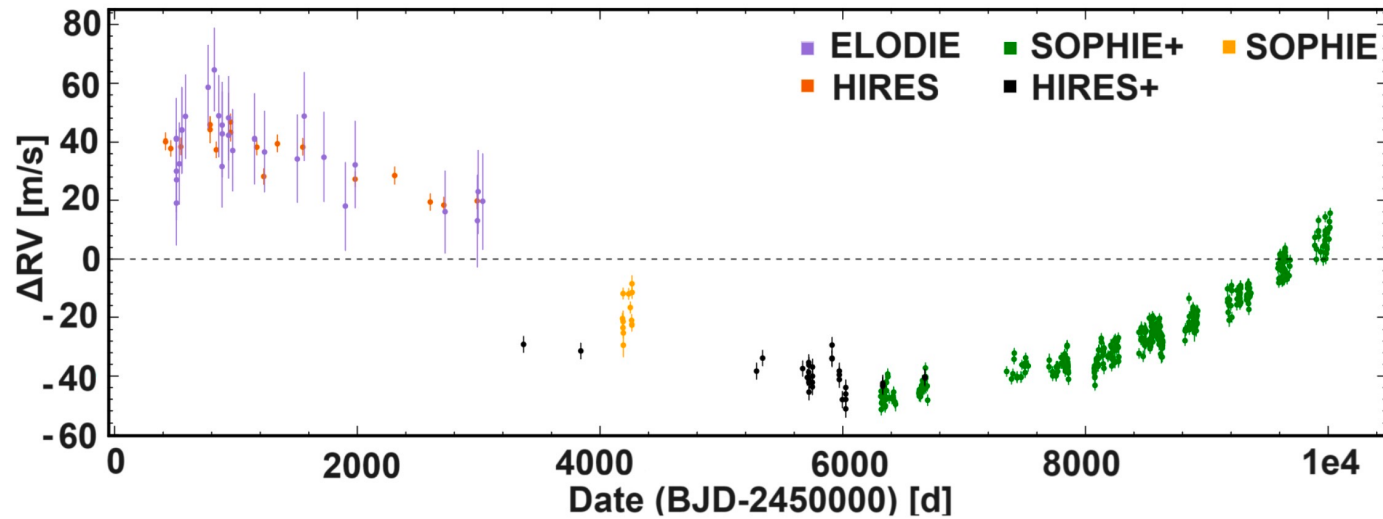
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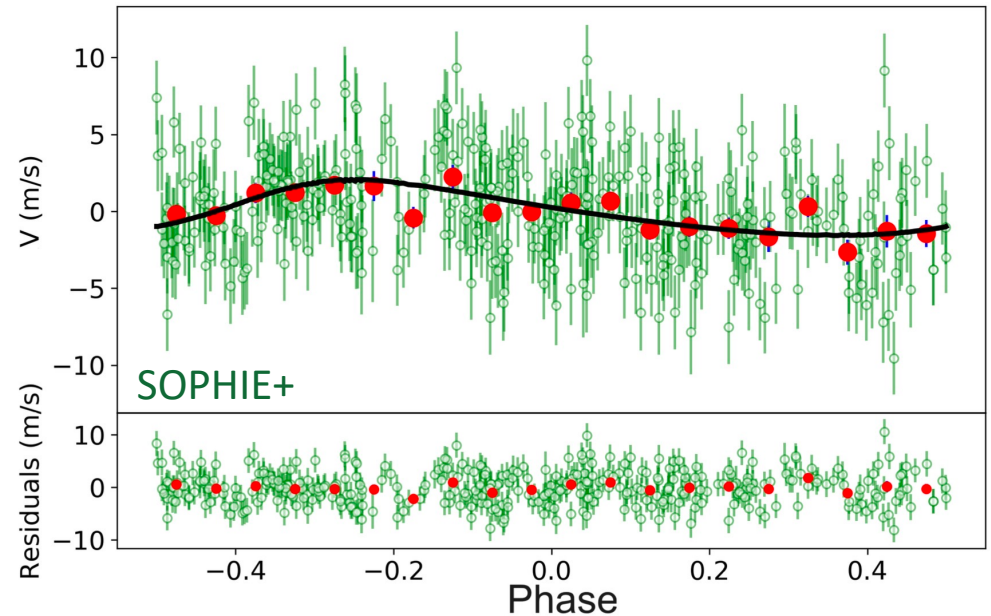
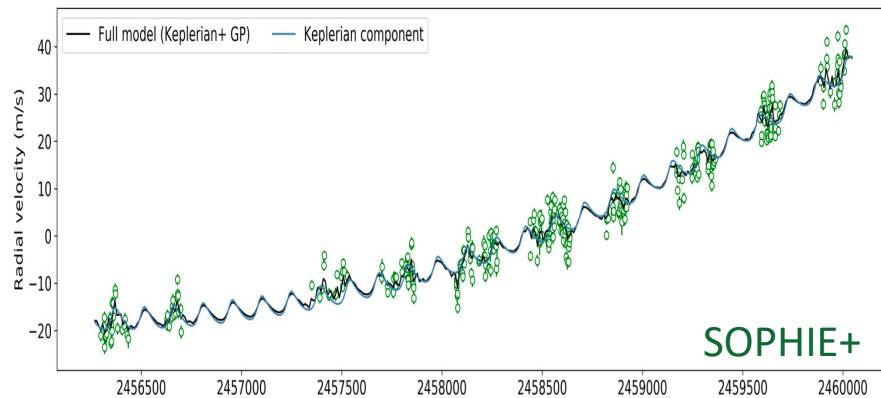
$$\begin{aligned} P &= 146.05 \pm 0.42 \text{ d} \\ K &= 1.85 \pm 0.33 \text{ m/s} \\ e &= 0.24 \pm 0.05 \\ M \sin i &= 17.2 \pm 3.9 M_{\text{Earth}} \end{aligned}$$



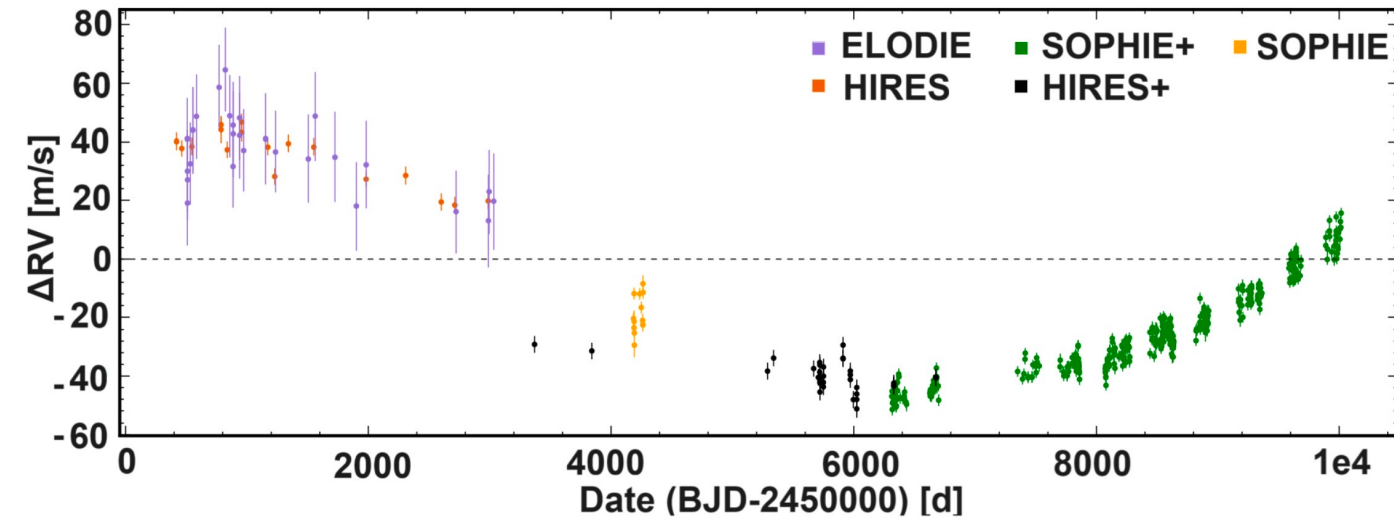
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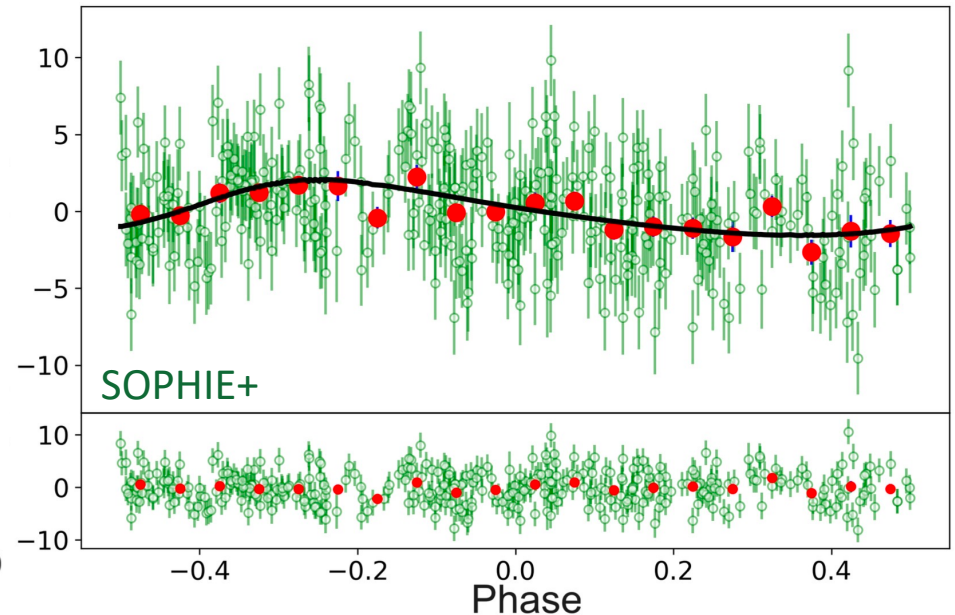
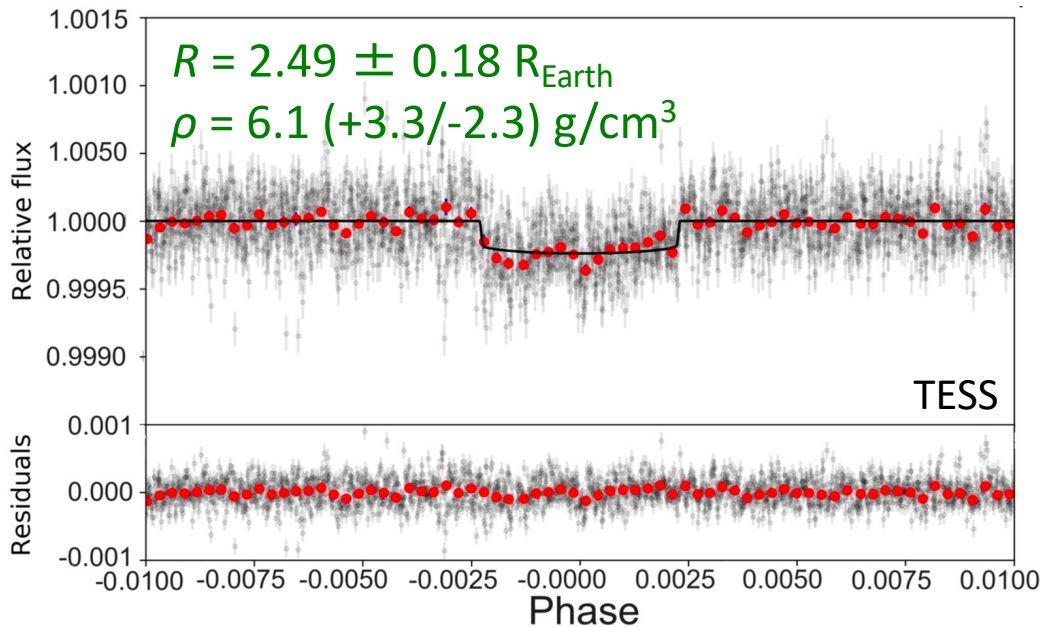
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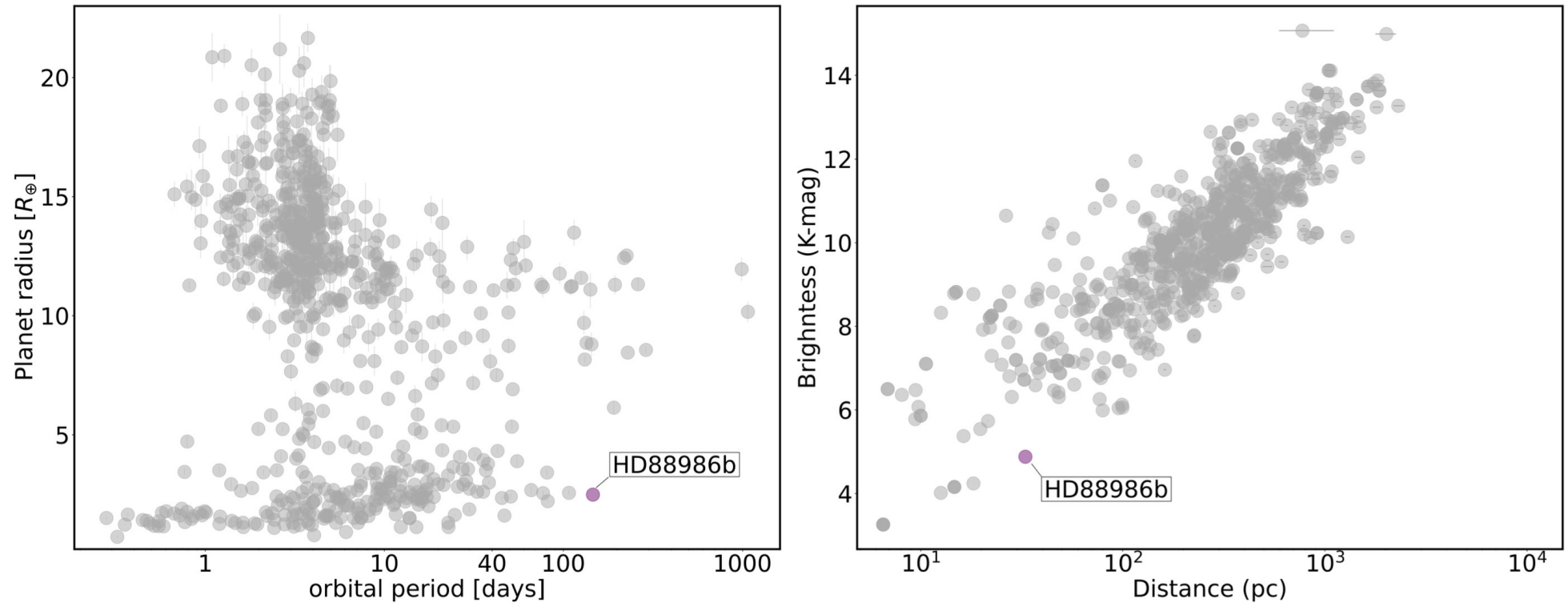
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A system including a cold sub-Neptune potentially transiting a $V = 6.5$ star HD 88986



Summary / Conclusions

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- SOPHIE allows **RV semi-amplitudes K** to be measured with **accuracy down to ± 0.3 m/s**
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- Characterization of **low-mass planets and years-period giant planets** around bright stars using a **2-m telescope, with numerous available nights**
- SOPHIE contributed to the characterization of 400+ planets
- Ongoing RV surveys towards different types of stars
- Ongoing follow-up of photometric surveys
- **Another 20 years?**