THE HIGH PRECISION SEARCH FOR NORTHERN NEPTUNES AND SUPER-EARTHS WITH *SOPHIE*

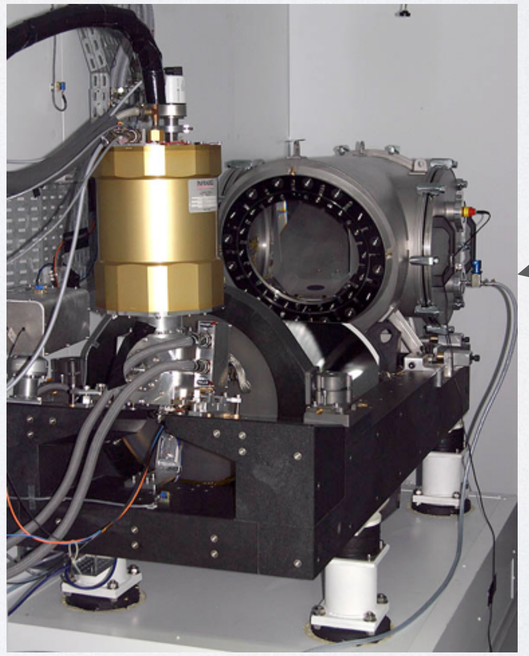
Bastien Courcol - Laboratoire d'Astrophysique de Marseille

F. Bouchy, S. Udry, G. Hébrard, X. Delfosse, M. Deleuil, C. Moutou, I. Boisse, X. Bonfils, A. Santerne, T. Forveille, D. Ehrenreich, P. A. Wilson, N. Santos, F. Pepe, D. Ségransan, L. Arnold, N. Astudillo, V. Bourrier, R. Diaz, J. Rey, O. Demangeon

31st IAP Colloquium — 30/06/2015

THE *SOPHIE* SPECTROGRAPH

- Environmentally stabilized Echelle spectrograph (387-694 nm)
- Simultaneous Thorium-Argon reference, R = 75 000
- Installed on the 1.93 m telescope at the Observatoire de Haute Provence (OHP)
- Active since 2006 (replacement of ELODIE), octogonal fibers since 2011 : **2 m/s precision**



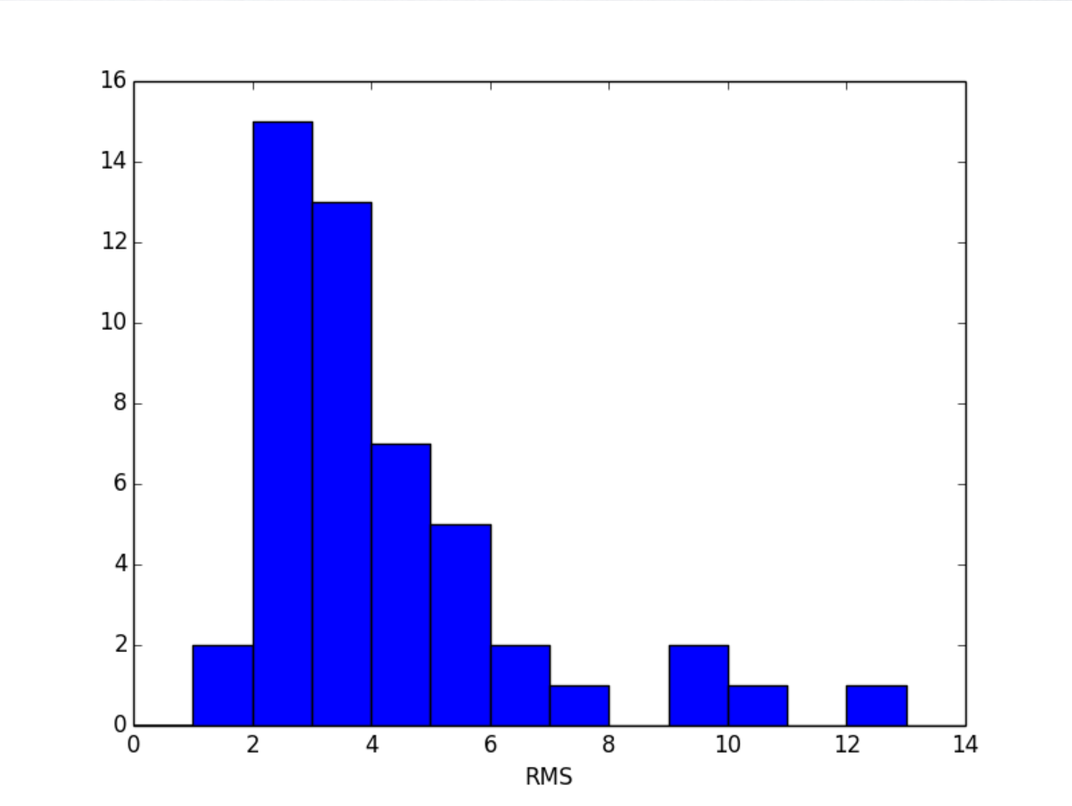
THE HIGH PRECISION SURVEY

PI : F. Bouchy

- Started in june 2011, ~50 nights/year
- 190 bright stars (V<10) :
  - G & K spectral type and 0.6 < B-V < 1.4 and volume limited to 35 pc
  - Slow rotators, non active stars
  - Single stars, without any already known companion
  - Not part of HARPS-N GTO survey

Bouchy, F., Hébrard, G., Udry, S., et al. 2009

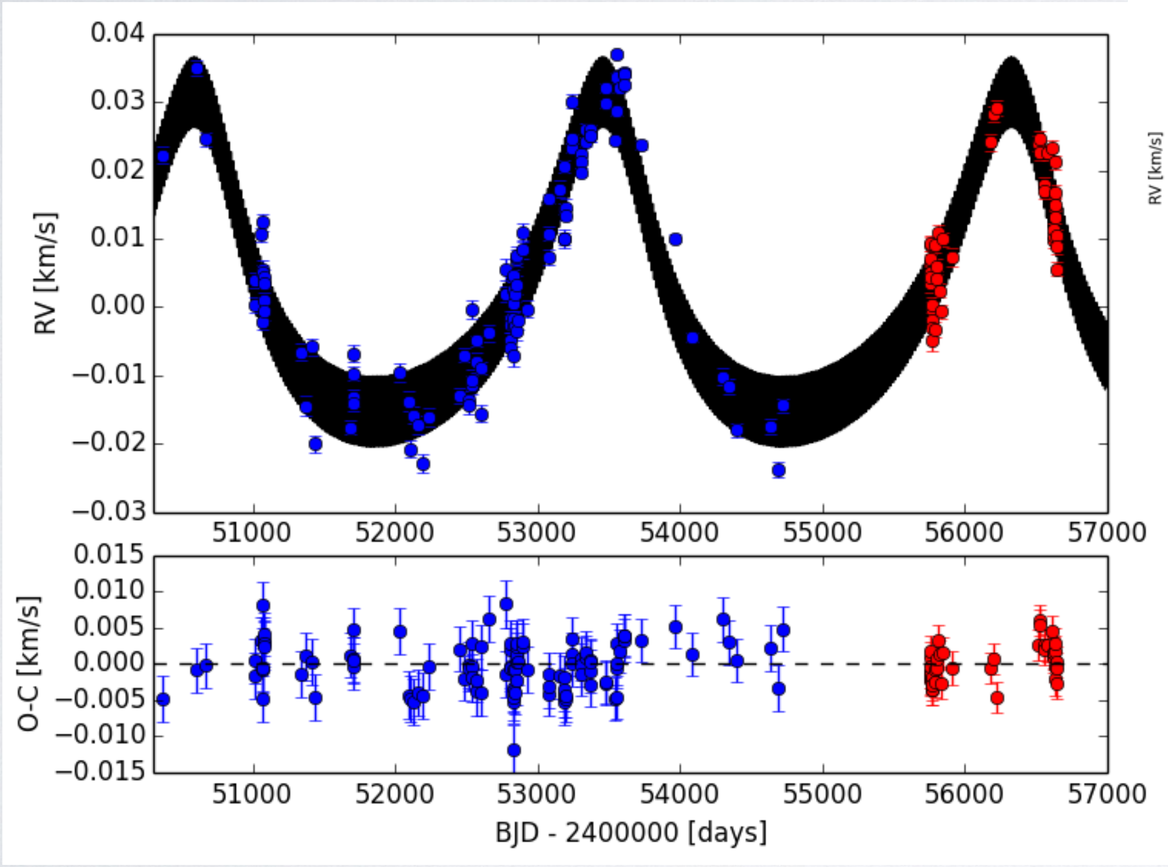
RMS distribution of targets with at least 20 measurements



VALIDATING THE UPGRADED *SOPHIE* PRECISION

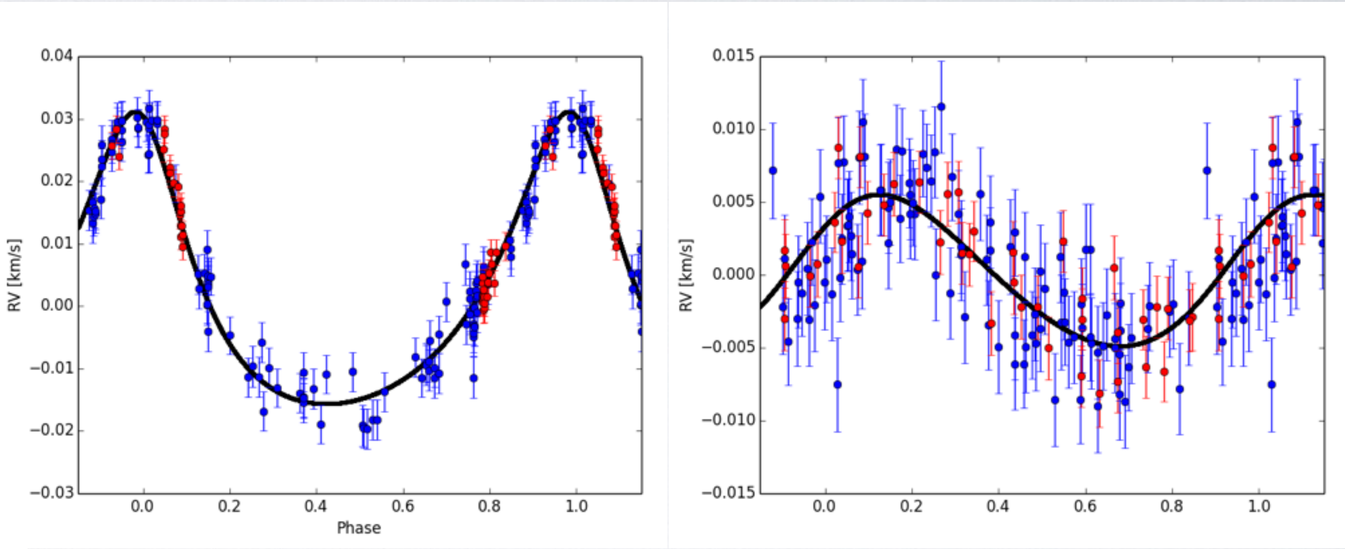
Courcol, B., Bouchy, F., et al. 2015, A&A, in press (arXiv 1506.07144)

HD190360 : Two-planets system



HIRES
σ = 3.3 m/s

SOPHIE
σ = 2.4 m/s



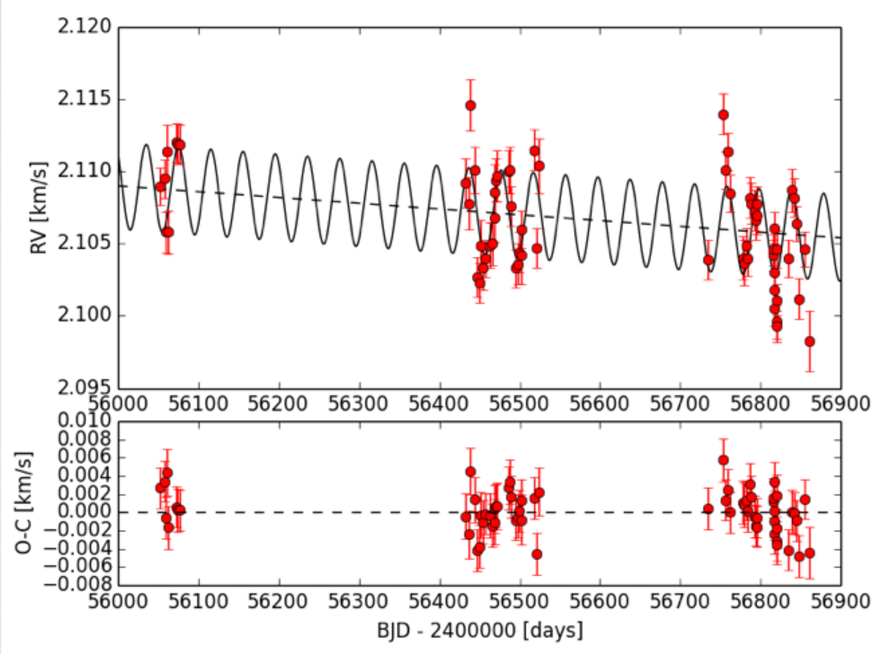
Phase folded RVs for HD190360 b (left) and c (right)

Parameter	HD190360b	HD190360c
P [days]	2867.9 ± 7.7	17.1186 ± 0.0016
T_0 [BJD]	59271 ± 19	$55570.3^{+1.5}_{-2.9}$
e	0.343 ± 0.017	0.107 ± 0.07
ω [deg]	14.7 ± 32	305.8^{+39}_{-280}
K [$m\,s^{-1}$]	23.39 ± 0.46	5.20 ± 0.37
msini [$M_\oplus$]	475.16 ± 49.0	20.28 ± 3.16

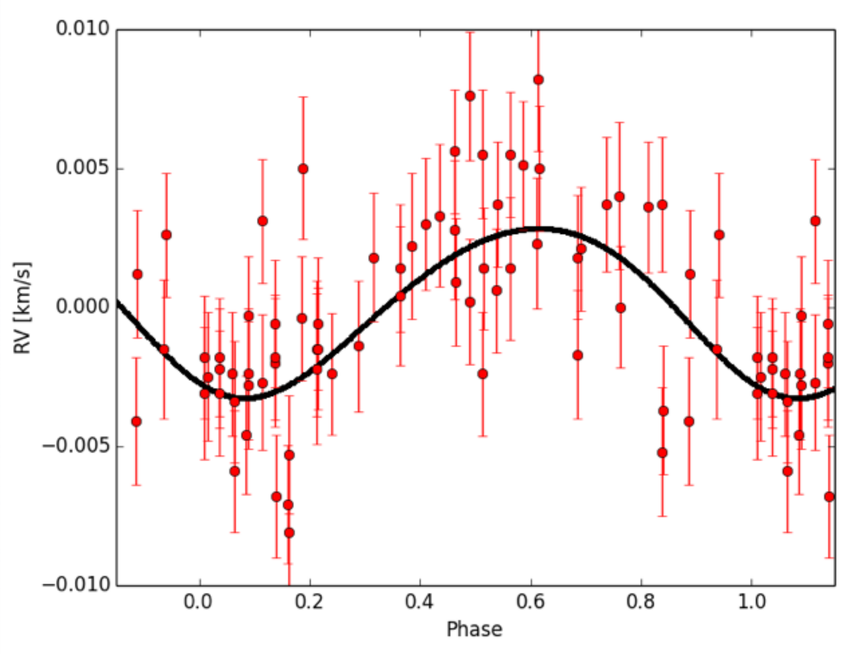
Updated parameters for the HD190360 system

A NEW NEPTUNE AROUND THE SOLAR ANALOG HD164595

Courcol, B., Bouchy, F., et al. 2015, A&A, in press (arXiv 1506.07144)



RVs of HD164595



Phase folded RVs of HD164595

Parameter	HD164595b
P [days]	40.00 ± 0.24
T_0 [BJD]	56280 ± 12
e	$0.088^{+0.12}_{-0.066}$
ω [deg]	145^{+160}_{-110}
K [$\mathrm{m\,s^{-1}}$]	3.05 ± 0.41
msini [$M_\oplus$]	16.14 ± 2.72
a [AU]	0.23
drift [m/s/yr]	-2.34 ± 0.44
N_{meas}	66
Data span [days]	809
σ (O - C) [$\mathrm{m\,s^{-1}}$]	2.3
Jitter [$\mathrm{m\,s^{-1}}$]	1.8

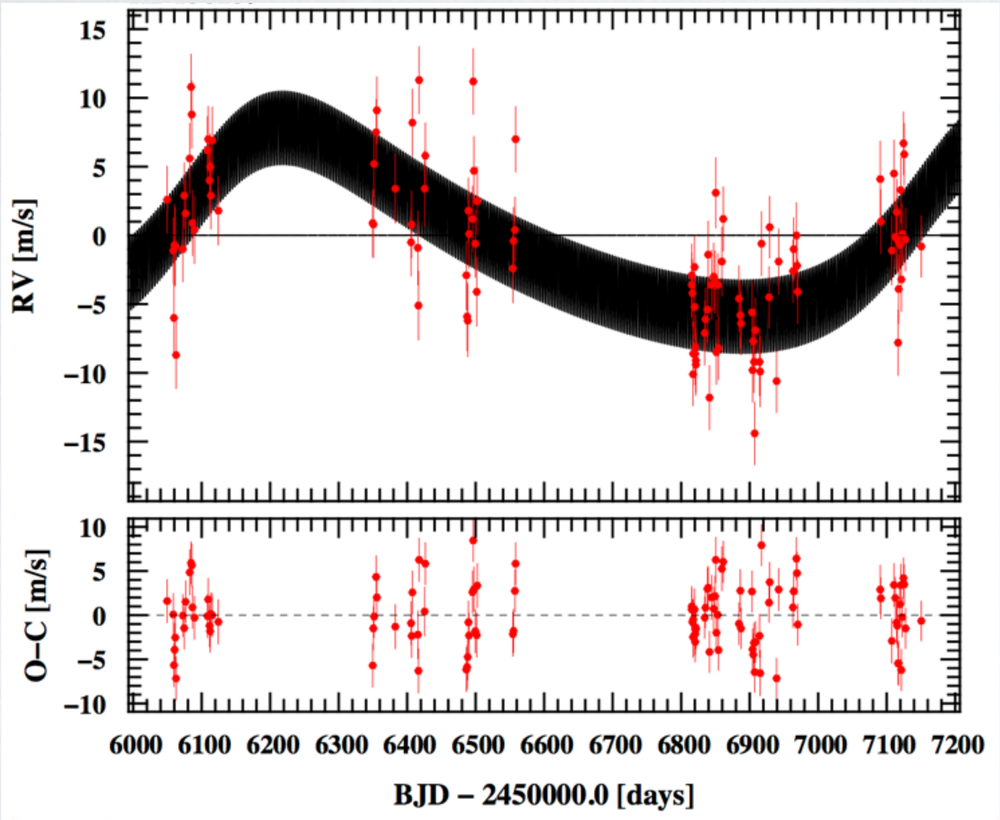
Orbital and physical parameters of HD164595b

Smallest planetary signal ever detected with SOPHIE !

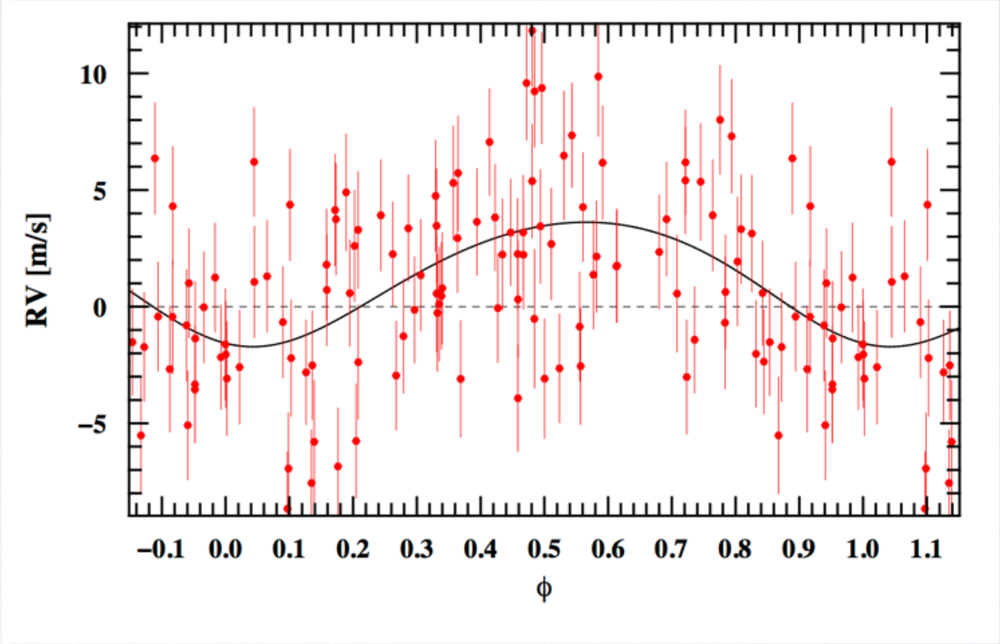
A TWO-PLANETS SYSTEM CANDIDATE

RV time series (~110 points)

Long period Saturn-like planet



Phase folded RVs of the inner candidate



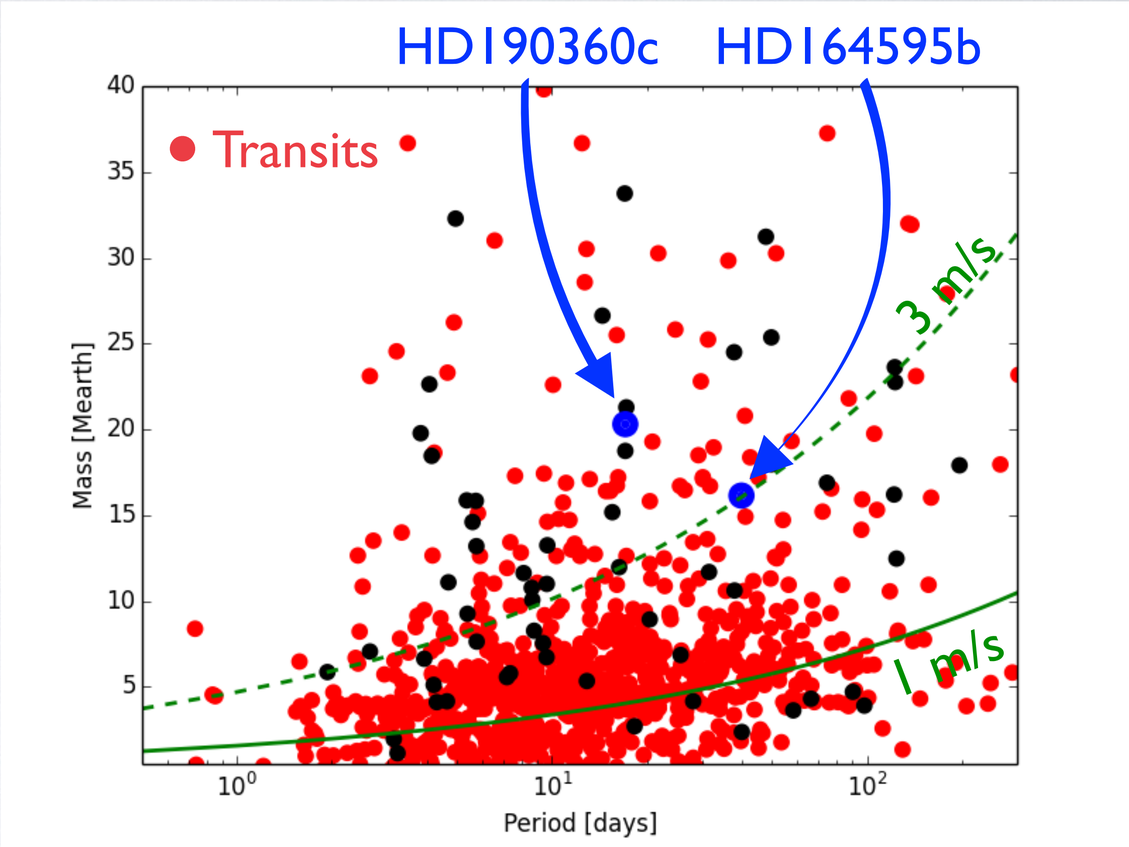
3.4 days Super-Earth :

K=2.6 m/s !

Msini=6.3 Mearth

THE SMALL PLANETS POPULATION

- Number of small planets known : **>900**

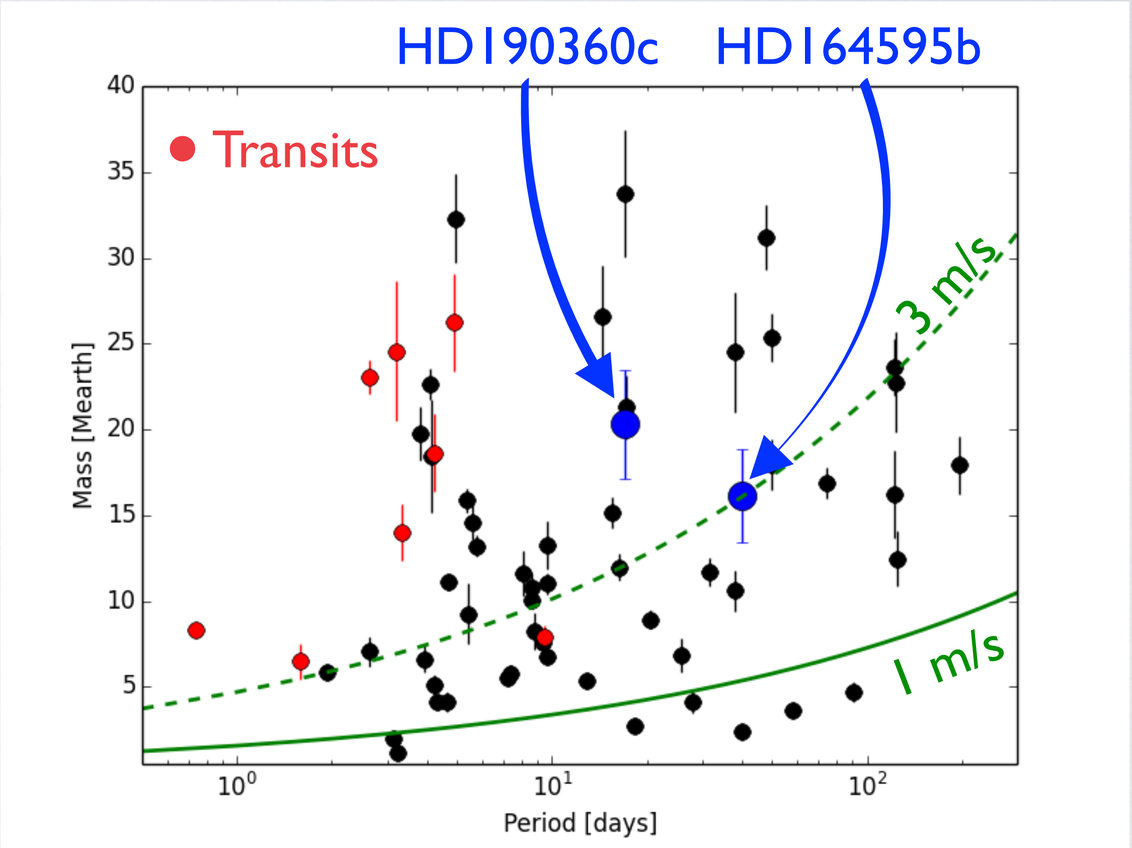


Known small planets

Source : exoplanets.org

THE SMALL PLANETS POPULATION WITH PRECISE RV MASS MEASUREMENTS

- Number of small planets known : **>900**
- Number of small planets with **precise RV mass measurements** : **~60**
  - 12 Neptunes in the 20-100 days range + HD164595b
  - **8 transiting planets only !**
    No period >10 days
  - Overall transit probability : ~300%
    (HD164595b transit probability : 2%)



Known small planets with a precision on Msini better than **20%**
Source : exoplanets.org

SYNERGIES WITH CHEOPS

CHARACTERISING EXOPLANET SATELLITE

CHEOPS : Transit follow-up ESA mission, launch in 2017-2018

- CHEOPS and SOPHIE both focus on **bright stars** to :
  - **Precisely characterize « hot » to « warm » objects** (>10 days) => golden targets for atmospheric spectroscopy
  - **Cover the parameters space of the Neptune/Super-Earth transition** : period, mass, radius, density, stellar masses, metallicities, irradiation, planet multiplicity…
    => we need more planets !
- In practice, SOPHIE is a target provider for CHEOPS in the northern hemisphere (~**15 expected new planets in 2018**) and perform preliminary observations

CONCLUSION

- **Lack of planets** with precise mass (and radius) to cover the parameters space of the Neptune/Super-Earth transition
- Low mass planets require **dedicated telescopes** (100+ measurements) with **high precision spectrographs** (1-2 m/s)
- **SOPHIE is now able to detect and characterize such low mass planets**
- Upcoming software and hardware improvements on SOPHIE, **objective : 1m/s**