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

Bastien Courcol - Laboratoire d’Astrophysique de Marseille


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


RMS distribution of targets with at least 20 measurements
VALIDATING THE UPGRADED SOPHIE PRECISION


HD190360 : Two-planets system

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

<table>
<thead>
<tr>
<th>Parameter</th>
<th>HD190360b</th>
<th>HD190360c</th>
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</thead>
<tbody>
<tr>
<td>P [days]</td>
<td>2867.9 ± 7.7</td>
<td>17.1186 ± 0.0016</td>
</tr>
<tr>
<td>$T_0$ [BJD]</td>
<td>59271 ± 19</td>
<td>55570.3$_{+1.3}^{-2.9}$</td>
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<tr>
<td>$e$</td>
<td>0.343 ± 0.017</td>
<td>0.107 ± 0.07</td>
</tr>
<tr>
<td>$\omega$ [deg]</td>
<td>14.7 ± 32</td>
<td>305.8$_{+39}^{-38}$</td>
</tr>
<tr>
<td>K [m s$^{-1}$]</td>
<td>23.39 ± 0.46</td>
<td>5.20 ± 0.37</td>
</tr>
<tr>
<td>msini [M$_\odot$]</td>
<td>475.16 ± 49.0</td>
<td>20.28 ± 3.16</td>
</tr>
</tbody>
</table>

HIRES
$\sigma = 3.3$ m/s

SOPHIE
$\sigma = 2.4$ m/s

Updated parameters for the HD190360 system
A NEW NEPTUNE AROUND THE SOLAR ANALOG HD164595

Smallest planetary signal ever detected with SOPHIE!

RVs of HD164595

Phase folded RVs of HD164595

Orbital and physical parameters of HD164595b

A TWO-PLANETS SYSTEM CANDIDATE

RV time series (~110 points)

Phase folded RVs of the inner candidate

Long period Saturn-like planet

3.4 days Super-Earth:
K=2.6 m/s!
Msini=6.3 Mearth
**THE SMALL PLANETS POPULATION**

- Number of small planets known: >900

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**Known small planets**

Source: exoplanets.org
• Number of small planets known: $>900$

• Number of small planets with precise RV mass measurements: $\sim 60$
  
  • 12 Neptunes in the 20-100 days range + HD164595b
  
  • 8 transiting planets only!
  No period $>10$ days

• Overall transit probability: $\sim 300\%$
  (HD164595b transit probability: 2%)

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

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: 1 m/s