SYNERGIES BETWEEN RADIAL VELOCITIES AND THE ARIEL MISSION

ALEXANDRE SANTERNE

AIX-MARSEILLE UNIVERSITY / LABORATOIRE D’ASTROPHYSIQUE DE MARSEILLE

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Why ARIEL needs RVs?
What ARIEL wants as input:

- The **mass** of exoplanets
- **Precise ephemerides** for both the primary and secondary transits
- To know the host **star activity**
ARIEL needs planets’ mass

Scale Height: $H = \frac{kT}{\mu mg}$
ARIEL needs planets’ mass

Scale Height \[ H = \frac{kT}{\mu mg} \] Planet mass
**ARIEL needs planets’ mass**

Scale Height \[ H = \frac{kT}{\mu mg} \]

Planet mass

\[ K \propto \frac{m_p \sin i}{P^{\frac{1}{3}} M_*^{\frac{2}{3}} \sqrt{1 - e^2}} \]

Mayor & Queloz (1995)
Mass of (giant) exoplanets might be retrieved from transmission spectroscopic data

De Wit & Seager (2013)

Batalha et al. (2017, 2019)
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THIS MIGHT INTRODUCE BIAS IN THE STATISTICAL RESULTS

Precise masses from RVs are still relevant in the context of ARIEL!

Batalha et al. (2017, 2019)
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- Amateur astronomers might help to maintain the ephemerides
- RVs might also contribute for the long-period planets (P>10d) or the shallowest transits
Improving ephemerides: the CHEOPS example

- **CHEOPS** transit-search program targeting RV-discovered exoplanets also needs precise ephemerides
- Few **SOPHIE** re-observations substantially improved predicted transit ephemerides
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<tr>
<th>Planet</th>
<th>Number of observations</th>
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<tr>
<td>HD 46974 c</td>
<td>63 (HIRES) + 21 (SOPHIE)</td>
<td>53753.85</td>
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<td>HD 3651 b (k1)</td>
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<td>52608.73</td>
<td>58090.41 ± 1.85</td>
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Bastien Courcol 2016 (PhD thesis)
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Orbital eccentricities
and secondary transits
Orbital eccentricities and secondary transits

• **Eccentric orbit** might prevent a transiting planet to be occulted by the star (as seen from the Earth)
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source: NASA exoplanet archive
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160 / 850 giant (R>0.3R_{\text{jup}}) planets

RVs can improve orbital eccentricities of **ARIEL** targets

Source: NASA exoplanet archive
Period determination of TESS mono-transit
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- **TESS** is finding interesting **warm giants** with periods > 10 days. They transited **only once** (aka mono-transit) in the 27-days TESS sectors (unless close to CVZ).
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• On-going **SOPHIE** programme on **TESS giant monotransits**. First planets detected!

![Graph showing ΔRV vs Date for a Half Jupiter-mass planet at 18 days.](image)
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Next step: use **CHEOPS** or ground-based observatories to detect a second transit

Half Jupiter-mass planet @ 18 days
TESS extension on monotransit
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• During TESS' extension, a second transit might be detected, a few years after the first transit. It results in a series of possible ephemerides (Δt and all harmonics)
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- Detecting the planetary signal with **RVs** help to select the **correct period** among all the solutions.
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  The case of **HIP41378** …
The case of HIP41378 (V=8.9 - K=7.7)

- Detection of **5 transiting planets** by K2 in **2015**
- Planets b & c are multi-transit while d, e, & f are mono-transit

Vanderburg et al. (2016)
The case of HIP41378 (II)

- **Reobservation** by K2 in 2018 (3 years later)
- Detection of a second transit for planets d & f: 23 different solutions for each planet (519 combinations)

![Graphs showing possible orbital periods for HIP 41378 d and f](image)

**Possible orbital periods for HIP 41378 d**

<table>
<thead>
<tr>
<th>Orbital Period (days)</th>
<th>Normalized Probability</th>
</tr>
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<tbody>
<tr>
<td>1113.4465 ± 0.0034</td>
<td>&lt; 0.1 %</td>
</tr>
<tr>
<td>556.7233 ± 0.0017</td>
<td>&lt; 0.1 %</td>
</tr>
<tr>
<td>371.1488 ± 0.0011</td>
<td>0.1 %</td>
</tr>
<tr>
<td>278.3616 ± 0.0009</td>
<td>0.5 %</td>
</tr>
<tr>
<td>222.6893 ± 0.0007</td>
<td>1.1 %</td>
</tr>
<tr>
<td>185.5744 ± 0.0006</td>
<td>2.4 %</td>
</tr>
<tr>
<td>159.0638 ± 0.0005</td>
<td>4.1 %</td>
</tr>
<tr>
<td>139.1808 ± 0.0004</td>
<td>5.7 %</td>
</tr>
<tr>
<td>123.7163 ± 0.0004</td>
<td>6.7 %</td>
</tr>
<tr>
<td>111.3447 ± 0.0003</td>
<td>7.1 %</td>
</tr>
<tr>
<td>101.2224 ± 0.0003</td>
<td>7.1 %</td>
</tr>
<tr>
<td>92.7872 ± 0.0003</td>
<td>7.0 %</td>
</tr>
<tr>
<td>85.6497 ± 0.0003</td>
<td>6.9 %</td>
</tr>
<tr>
<td>79.5319 ± 0.0002</td>
<td>6.8 %</td>
</tr>
<tr>
<td>74.2298 ± 0.0002</td>
<td>6.8 %</td>
</tr>
<tr>
<td>69.5904 ± 0.0002</td>
<td>6.3 %</td>
</tr>
<tr>
<td>65.4969 ± 0.0002</td>
<td>5.9 %</td>
</tr>
<tr>
<td>61.8581 ± 0.0002</td>
<td>5.5 %</td>
</tr>
<tr>
<td>58.6024 ± 0.0002</td>
<td>5.1 %</td>
</tr>
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<td>55.6723 ± 0.0002</td>
<td>4.8 %</td>
</tr>
<tr>
<td>53.0213 ± 0.0002</td>
<td>4.5 %</td>
</tr>
<tr>
<td>50.6112 ± 0.0002</td>
<td>4.2 %</td>
</tr>
<tr>
<td>48.4107 ± 0.0001</td>
<td>1.4 %</td>
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Becker et al. (2018) ; Berardo et al. (2019)
The case of HIP41378 (III)
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- Intensive RVs observations (450+ epochs) by 4 stabilised spectrographs over 4 years (HARPS, HARPS-N, HIRES, PFS)
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- Detection of the Doppler signals of HIP41378 b, c, and f (+ non-transiting planet g)

- RV signal of planet f perfectly matches with only one solution allowed by the photometry (the 542-day solution)

Santerne et al. (2020)
HIP41378: a good system for ARIEL (\& JWST)

Santerne et al. (2020) (Not for phase curves)
ARIEL needs to know the stellar variability
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- **Stellar activity** is a well known limitation to the interpretation of transmission spectroscopy data
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- **Stellar activity** is a well known limitation to the interpretation of transmission spectroscopy data.

- The **optical channels** of ARIEL will be very important for occulted star spot/faculae.

CoRoT-2 ; Bruno et al. (2016)
Disentangling spot vs faculae

• To understand the impact of stellar activity on transit data, we need to monitor the host stars **over one rotation**.

• Impossible to do with **ARIEL**

HIGH-RESOLUTION SPECTROSCOPY MIGHT HELP

CoRoT-2; Bruno et al. (2016)
Spectroscopic diagnoses for stellar activity

- Chromospheric emission (CaII H&K, Hα, Na D, etc…)
- Line bisector & width
- Spectropolarimetry (Zeeman effect)
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Still need to understand the physical link between these spectroscopic diagnoses and the spot / faculae configuration + impact on transmission spectroscopy
Spectroscopic diagnoses for stellar activity

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• Line bisector & width

• Spectropolarimetry (Zeeman effect)

Still need to understand the physical link between these spectroscopic diagnoses and the spot / faculae configuration + impact on transmission spectroscopy

Stellar activity is a limitation for all of us (RVs, PLATO, ARIEL), we should join our efforts …
Stellar activity campaign

La campagne d'activité K2: données obtenues sur la M100

Time [BJD - 2 458 000]

Radial velocity [m.s⁻¹]

Relative flux

K2 TRAPPIST-N (z') TRAPPIST-N (V)

Analyse préliminaire de la spectropolarimétrie. Crédit: Jean-François Donati

Lopez et al. (in prep.)
Take-home messages

• **RVs** are an important input for the *ARIEL* mission (exoplanet mass, eccentricity, ephemerides)

• We can perform **RV preparatory observations** on *ARIEL* secured targets, at least before *PLATO*’s launch

• Need to perform **spectroscopic observations contemporaneous** with the *ARIEL* observations, at least for the most active stars.

• We need to work together to **model stellar activity** based on spectroscopic diagnoses and correct for it.