Combining space- and ground-based data to optimise exoplanet atmospheric characterisation

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Thea Hood                                                                                            Journée ARIEL France 2024

Space-based observations

VS

Ground-based observations
Low-resolution spectroscopy:
➢ Broad wavelength coverage
➢ No tellurics
➢ Global slope of the spectrum
High-resolution spectroscopy:

➢ Resolution of individual lines
➢ Can detect above clouds
➢ Access to wind dynamics
Precise mass measurements:
➢ SPIRou (Spectropolarimètre Infra rouge\(^1\)): radial velocity accuracy ~ meters/second over several years

\(^1\) Donati et al. 2020
Combining data sets

➢ Highly complementary observables

<table>
<thead>
<tr>
<th>LRS</th>
<th>HRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broad wavelength coverage</td>
<td>Most instruments with narrow or non-</td>
</tr>
<tr>
<td></td>
<td>continuous wavelength coverage</td>
</tr>
<tr>
<td>No tellurics</td>
<td>Tellurics</td>
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<tr>
<td>Global slope of the spectrum</td>
<td>Loss of continuum information</td>
</tr>
<tr>
<td>Probes lower atmosphere</td>
<td>Probes higher atmosphere</td>
</tr>
<tr>
<td>Can be “blocked” by clouds</td>
<td>Can detect above clouds</td>
</tr>
<tr>
<td>Resolution too low for individual lines</td>
<td>Resolution of individual lines</td>
</tr>
<tr>
<td>Resolution too low for access to wind</td>
<td>Access to wind dynamics</td>
</tr>
<tr>
<td>dynamics</td>
<td></td>
</tr>
</tbody>
</table>
Combining data sets

Previous work:

➢ Brogi et al. 2017 (HD 209458b)
➢ Brogi & Line 2019 (HD 209458b, HD 189733b)
➢ Ghandhi et al. 2019 (HD 209458b)
➢ Khalafinejad et al. 2021 (WASP-69b)
➢ Kasper et al. 2023 (KELT-20b/MASCARA-2b)
➢ Boucher et al. 2023 (WASP-127b)
➢ Smith et al. 2023 (WASP-77b)
Combining data sets

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Combining low- and high-resolution provides more powerful probes of exoplanetary atmospheres, and lifts degeneracies affecting retrievals.
30 members
5 PhD
11 universities or institutes
2 papers accepted, 3 submitted, contribution to 2 other papers, few targets waiting
Pipeline\textsuperscript{1,2,3}:

Data reduction

Models

Cross-Correlation Maps
Detection validity

Nested Sampling Algorithm
Value constraints

\textsuperscript{1} Klein et al. 2024
\textsuperscript{2} Debras et al. 2024
\textsuperscript{3} https://github.com/baptklein/ATMOSPHERIX_DATA_RED
Pipeline\textsuperscript{1,2,3}:

1. Data reduction
2. Models
3. Cross-Correlation Maps
   \textit{Detection validity}
4. Nested Sampling Algorithm
   \textit{Value constraints}

\textsuperscript{1} Klein et al. 2024
\textsuperscript{2} Debras et al. 2024
\textsuperscript{3} https://github.com/baptklein/ATMOSPHERIX_DATA_RED
Joint retrieval:

➢ High- and low-resolution models created with petitRADTRANS

➢ For each step:
  ‣ Likelihood for high- and low-resolution models calculated separately
  ‣ Return sum of these likelihoods
WASP-127 b:

- H₂O
- CO
- CO₂
- T_p
- P_{cloud}

SPIRou
HST + Spitzer
SPIRou + HST + Spitzer

(Boucher et al. 2023)
WASP-127 b:

**H₂O**

**CO**

**CO₂**

**Tp**

**P_{cloud}**

SPIRou + HST + Spitzer

SPIRou

HST + Spitzer

SPIRou + HST + Spitzer

(Boucher et al. 2023)

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**WASP-76 b:**
- HST data: Tsiaras et al. 2018, Fisher & Heng 2018
- SPIRou data: Hood et al. submitted
Perspectives

➢ Improve joint likelihood calculation
➢ Implement more complex profiles for chemical abundances and temperature
➢ Apply to other exoplanets
➢ Extend wavelength coverage of data sets
Thank You

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(Currently searching for a post-doc)