Correcting Exoplanet Transmission Spectra for Stellar Activity with an Optimised Retrieval Framework

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Chromatic contamination arising from heterogeneities e.g. spots and faculae on the photosphere of the host star presents a significant noise source for exoplanet transmission spectra. If this contamination is not corrected for it can introduce substantial bias in our analysis of the planetary atmosphere. Here we present ASteRA, a stellar activity plugin used with the retrieval framework TauREx3 that has been validated with synthetic spectra and subsequently applied to real observations with HST STIS and WFC3.

1. Context

- A substantial fraction of exoplanet host stars are likely to be moderately to highly active.
- Correcting transmission spectra for stellar contamination is challenging as it is both highly chromatic, with the strongest effects occurring in the optical/near-UV regime, and temporally variable, predominantly modulated on timescales of rotation.
- The magnitude of the contamination as a function of wavelength is influenced by many factors, primarily the filling factor and temperature contrast of active regions. In addition, the location of a feature on the stellar disk also becomes important at high activity regimes as this governs the interaction with the limb darkening effect.

2. Methodology

- In Thompson et al. (2024), we validate the **ASteRA** model and explore its performance and accuracy under differing levels of stellar activity using a retrieval grid of 27 spot contaminated, synthetic idealised spectra. The 27 spot configurations considered are shown below in Fig. 1.
- We use a slightly more complex model, **StARPA**, as the input forward model followed by **ASteRA** and the **TauREx 3** retrieval framework (Al-Refaie et al. 2021) to perform a combined star-planet retrieval.
- The principal difference between the two models is that **StARPA** accounts for the position of the spot on the stellar disk and therefore its interaction with the limb darkening effect whereas this is neglected within **ASteRA**.
- The rationales behind using a simplified retrieval model are to enhance computational efficiency and mitigate against potential degeneracies between spot parameters at low resolution.

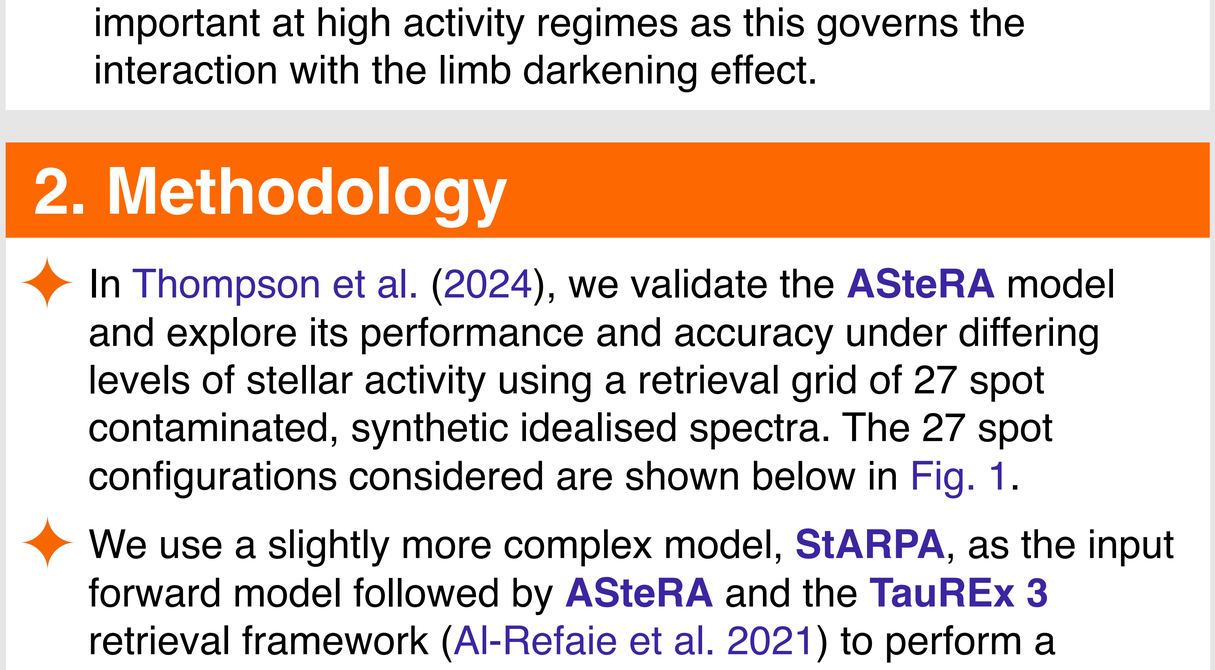

Fig. 1 *- Visual representations of the 27 single spot cases investigated in this study. The spot colour corresponds to its temperature contrast with respect to the quiescent photosphere (T_{phot} = 4750 K). Cases 7, 8 and 9 represent the worst case scenarios.*

3. Model Validation

- We ran 2 retrievals on each synthetic observation, one accounting for stellar contamination with **ASteRA,** and one in which the stellar contamination was neglected.
- Not correcting for stellar contamination when it is present introduces substantial bias in the retrieved planetary parameters: log(H_2O) is underestimated by over two orders of magnitude in the worst-case scenario, Case 7 (Fig. 2)
- For scenarios of low-moderate stellar activity, the **ASteRA** correction results in T_p and log(H_2O) being recovered to a 1σ accuracy.

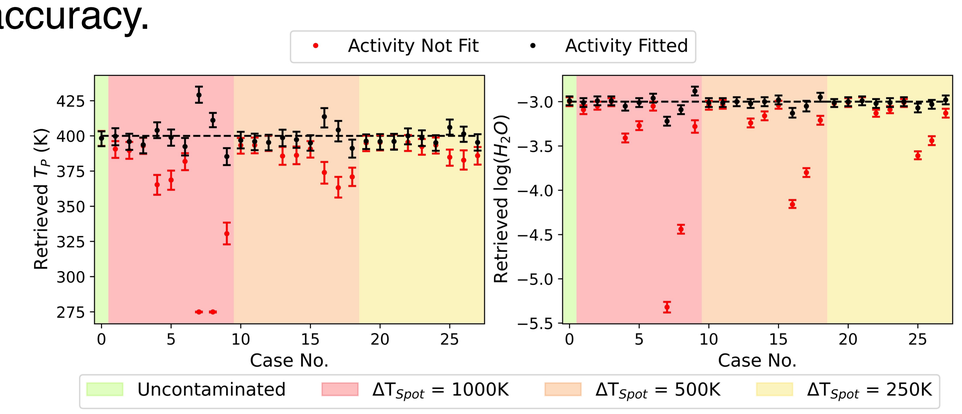

Fig. 2 *– Retrieved planetary parameters obtained with (black) and without (red) simultaneously retrieving for the spot parameters.*

- For the highest activity cases a small amount of residual bias remains due to neglecting the limb darkening effect.

4. Application to Real Observations

- In Saba et al. (2024) we use **ASteRA** to account for potential stellar contamination in a population study of 20 planets observed with HST STIS and WFC3.
- We also define two new metrics to indicate the extent of contamination in each observation e.g. Fig. 3

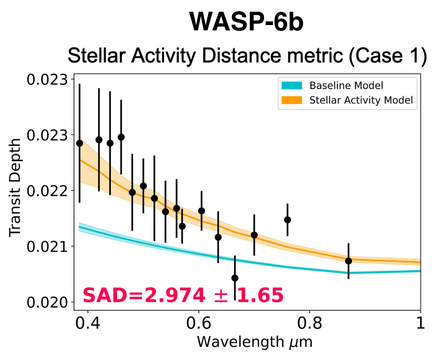

Fig. 3 *– The STIS dataset for WASP-6b and its SAD metric*

5. Conclusions

- Stellar activity correction with a simplified stellar model is always better than no correction at all.
- In high activity regimes the limb darkening-spot interplay starts to become important.
- The ASteRA model is sufficient to explore and remove contamination biases in HST STIS data.

References

A. F. Al-Refaie *et al* 2021 *ApJ* **917** 37
A. Saba *et al* 2024 arXiv.2404.15505
A. Thompson *et al* 2024 *ApJ* **960** 107

Thompson + 24

Saba + 24

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