Looking above the cloud deck of GJ 3470b

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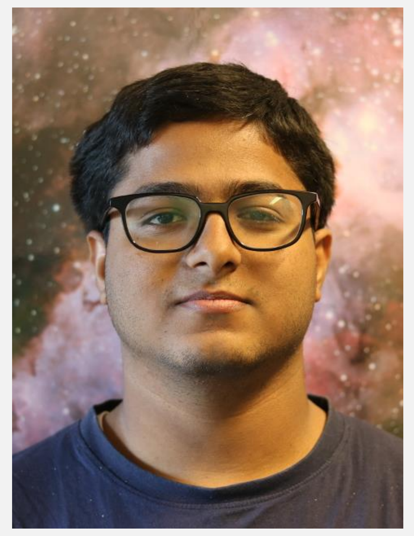


INTRODUCTION

GJ 3470b Properties

- Neptune sized but slightly less massive (14 M_E < 17.2 M_E for Neptune) [4]
- **P = 3.88 days**, Transit time = 1.918 hours [4]
- **Eccentric orbit** – values of e vary quite a lot in literature – can go from slightly eccentric 0.017 to quite eccentric 0.114! [4]
- Orbits an **M-dwarf** [4] but in a polar orbit [5]
- Equilibrium temperature **600 K** – Hence, warm Neptune – **with evidence of clouds** [1].

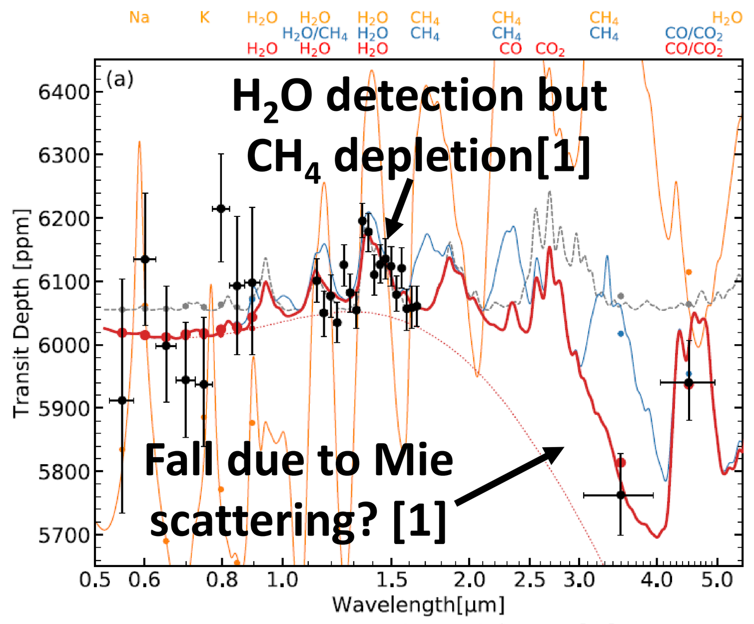


Figure reproduced from [1].

High Resolution spectroscopy can look above a higher layer of clouds which proves difficult for low res!

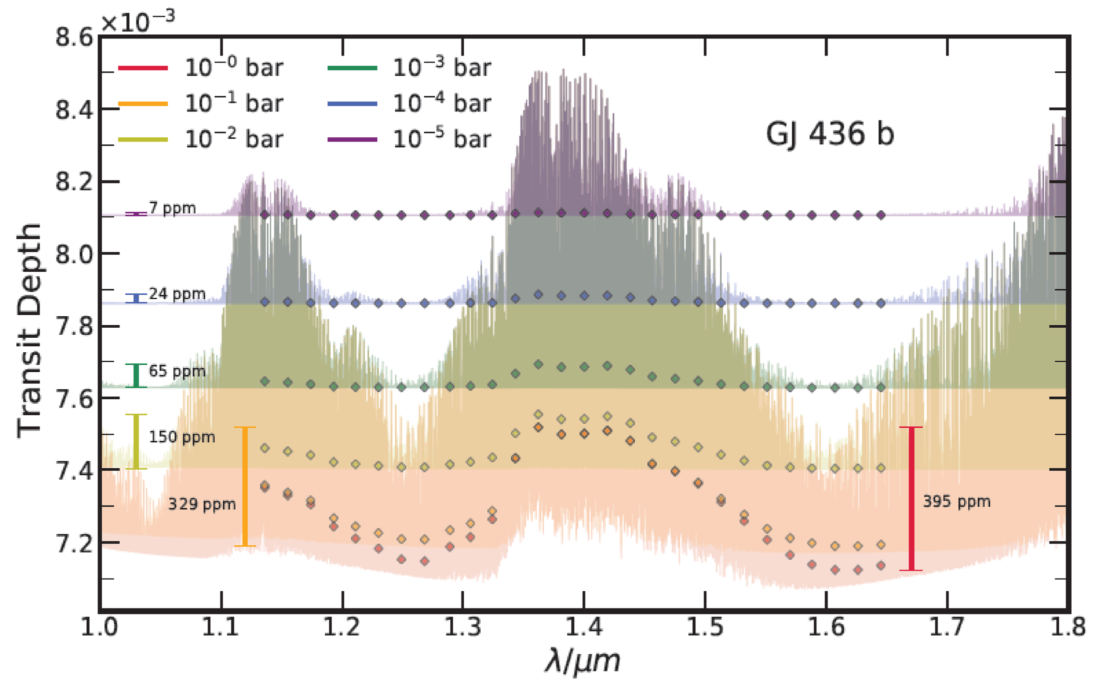
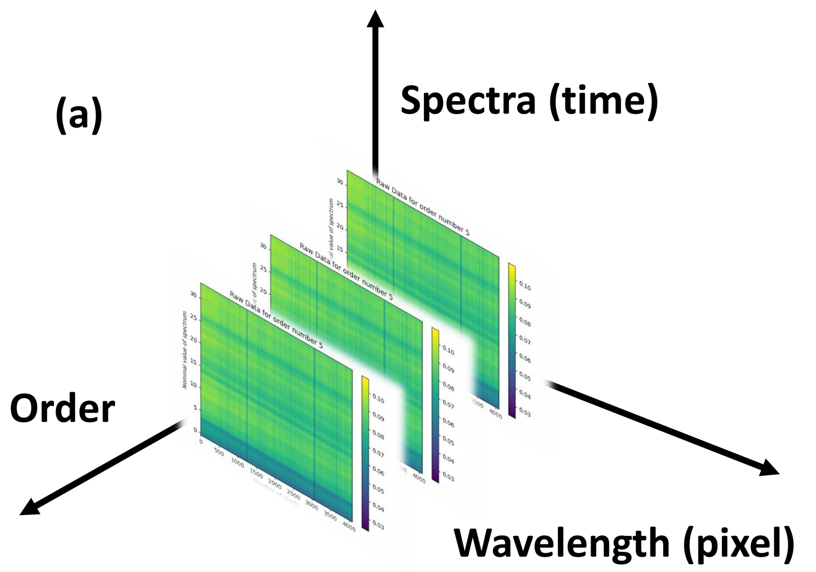


Figure reproduced from [2].

The figure above shows that detection of molecules with high res spectroscopy becomes much easier even at high cloud decks because the cores of molecular lines at high res extend much above the deck.

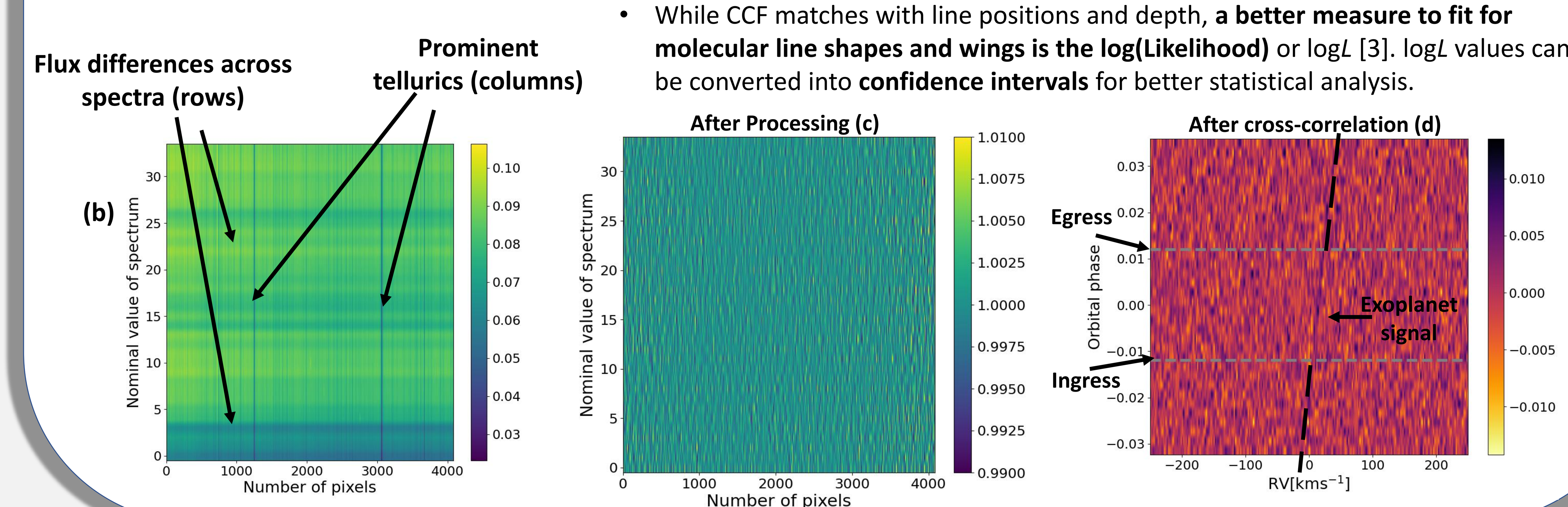
Accordingly, [2] fit a high res model to the low res observations of [1] and **simulated that the model could be detected using 4 good nights of observations**. In this study, **we try and validate it by using 2 nights of actual observations using CARMENES.**

METHODOLOGY



3D flux cuboid for each night

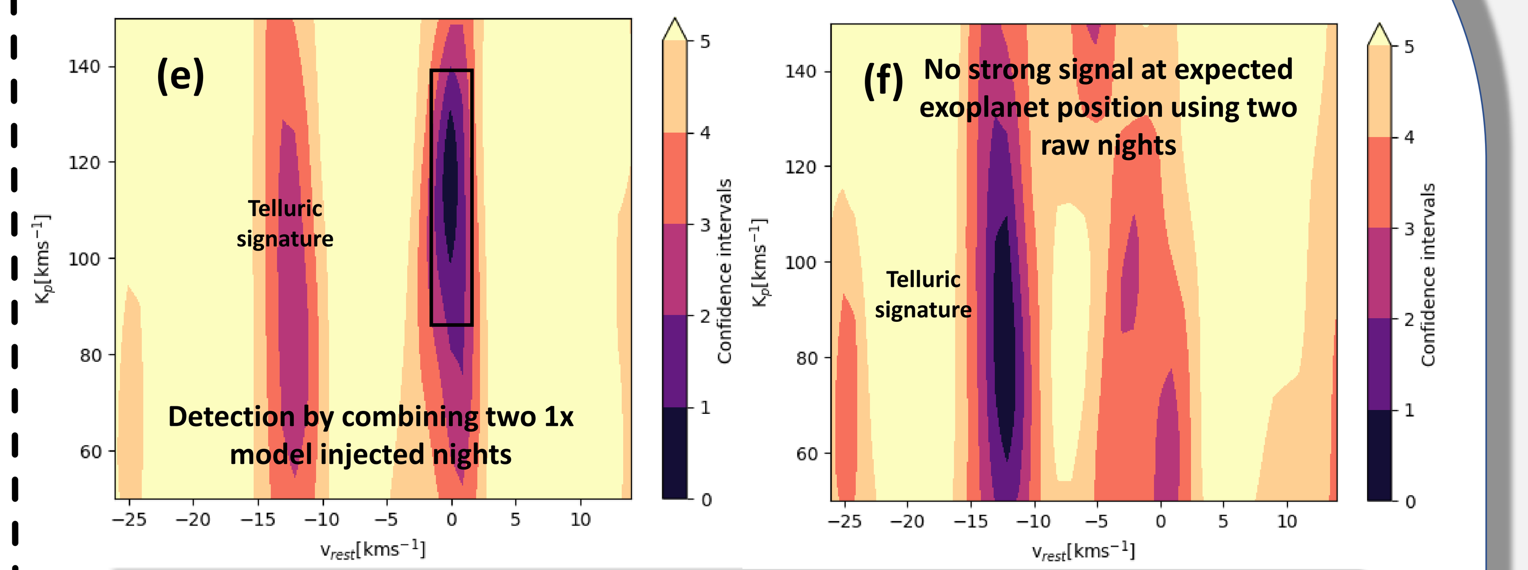
- **Data from each night** is usually in form of a **data cuboid** as shown in **Panel (a)**. Data processing is done per order and hence **one of those orders showing flux variation** is visualized in **Panel (b)**.
- A **moving faint injected exoplanet signal** should **vary in velocity** on the **order of kms^{-1}**. A **custom built Principal Component Analysis based algorithm** is used to **remove features that do no significantly shift in velocity**, with (hopefully) only variations due to the moving injected exoplanet signal remaining **(Panel (c))**.
- The best fit model we have is **doppler shifted** across time by a given Radial Velocity (RV), then **processed as the data above (Model Reprocessing)**, and then **cross-correlated** with the matrix in **Panel (c)**. **Evidence of orbital motion** in cross-correlation is generally seen as a **streak** as shown in **Panel (d)**.
- **CCFs** along an orbit can be **co-added for all orders** to make **(v_{rest}, K_p) plots** for detections. v_{rest} is the rest frame velocity and K_p is the exoplanet RV semi-amplitude. **Division with the standard deviation of noise gives S/N**.
- While CCF matches with line positions and depth, **a better measure to fit for molecular line shapes and wings is the log(Likelihood)** or log*L* [3]. log*L* values can be converted into **confidence intervals** for better statistical analysis.



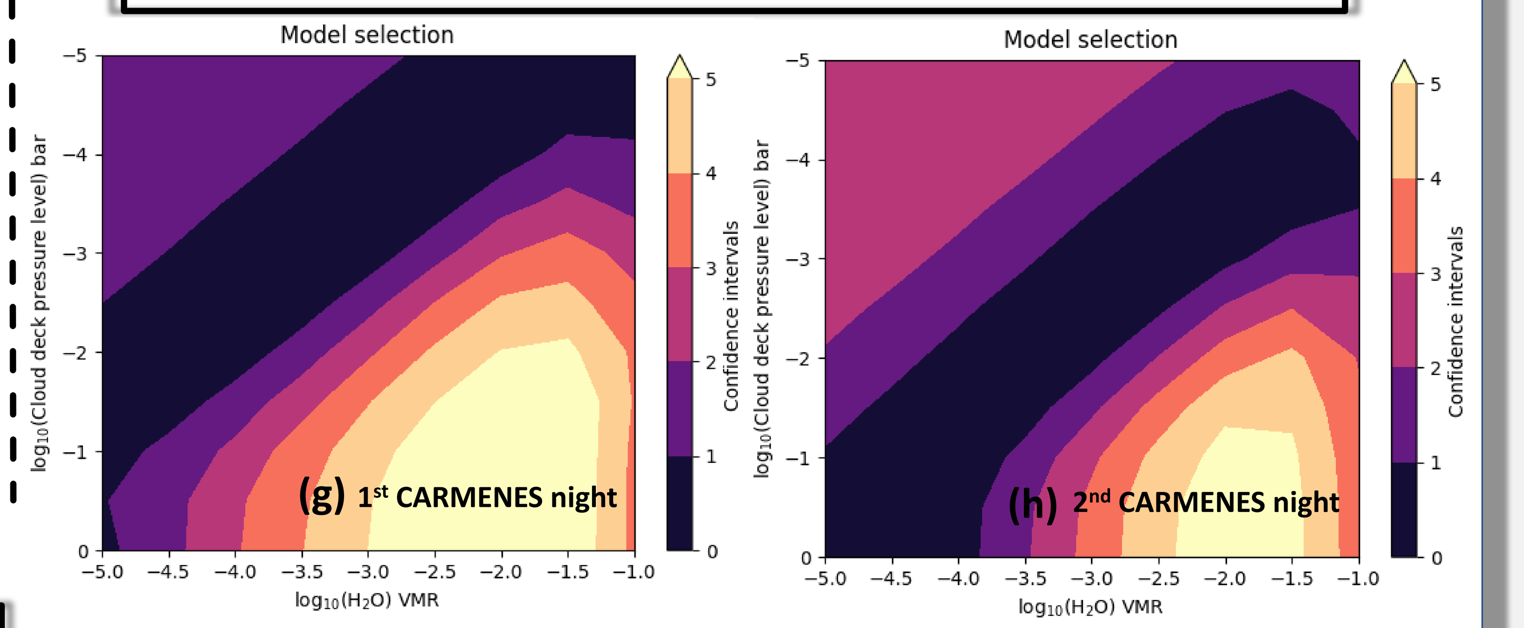
RESULTS and DISCUSSION

- 'Goodness' of a night is determined by whether we can detect 1x of an artificial exoplanet signal injected into the data. **Possible using both nights of CARMENES by processing data between the ingress and egress phases.**
- Our best fit model to low res observations using just H_2O and a cloud cover at $10^{-2.3}$ bar shows a **detection (>5σ for Panel (e)) by combining both nights of observations with 1 times the best fit model injected in them.**
- In comparison, raw observations **show no direct detection (Panel (f)) and prominent telluric contamination away from the exoplanet position.**
- Repeating the previous analysis for a grid of models will provide an estimate of how well a group of models are selected against the entire grid. Performing this on an isothermal grid with varying H_2O abundances and cloud deck pressures results in **both nights (Panels (e) and (f)) giving mostly consistent plots in terms of parameter selection**. Combining nights **strengthens the choice of selection to a strip of degenerate models,** not all of which are in line with the finding in [1].

Best fit H_2O model to low resolution data



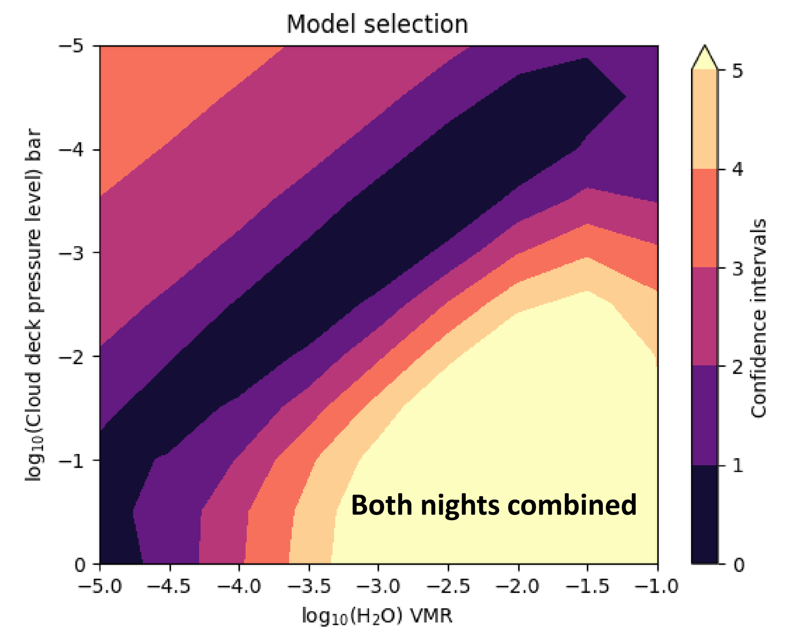
Model Selection on a grid



Take home message

Combining 2 nights of observations with CARMENES **does not show any direct detection of H_2O above the cloud deck in the atmosphere of GJ 3470b**. However, **more good nights are necessary to conclude anything definite**. A strong residual telluric feature also suggests the need for more aggressive detrending.

Model Selection on an isothermal grid with varying H_2O abundances and cloud deck pressures **suggests a preference for a set of degenerate models with similar variances from the continuum** which **is wider than the finding from low resolution HST+Spitzer data**. However, **the grid assumed is not the same as previous studies** and **a more accurate grid of models with possible inclusion of two other molecules (CH_4 and NH_3) can be a potential solution** to this non-conformity. This is currently being investigated.



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