Metal Oxides and Hydrides in Hot Exoplanet Atmospheres

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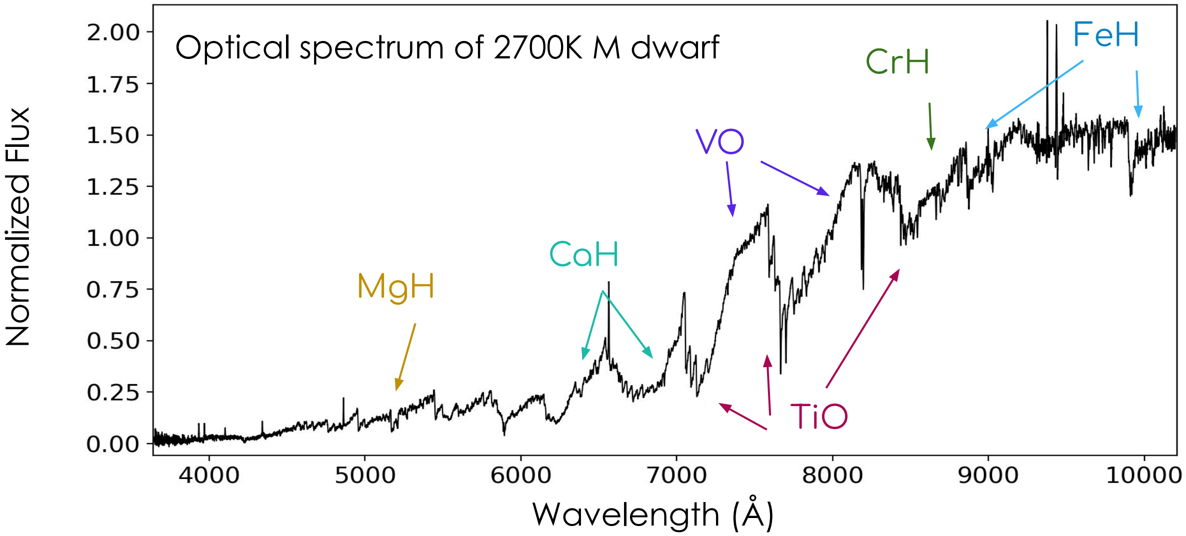
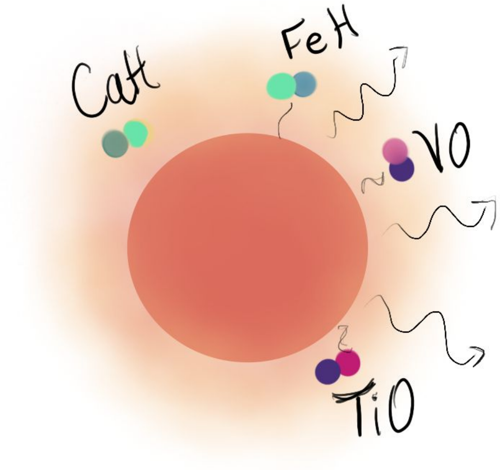
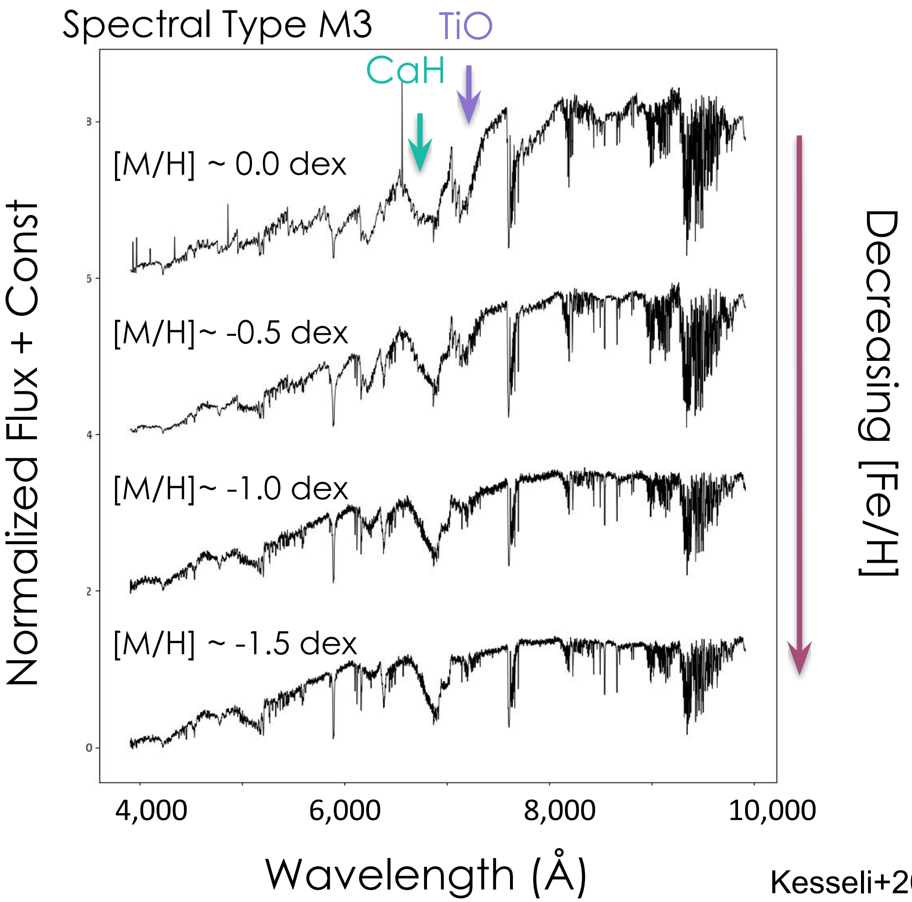
Atmo 2021

Low-mass stars are dominated by ***metal hydrides*** and ***oxides***





Metal hydrides and ***oxides*** in low-mass stars

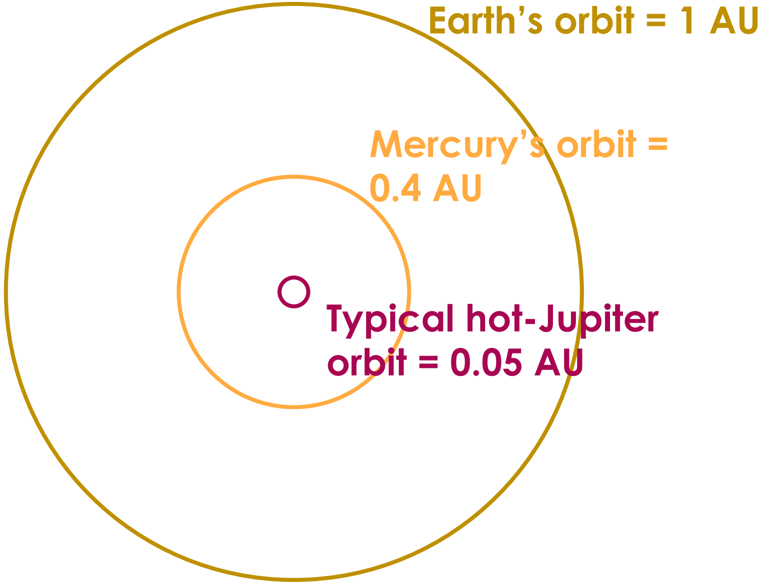


Kesseli+2019

Metal oxides and ***hydrides*** are used to measure:

- ★ surface gravity
- ★ metallicity
- ★ cloud formation/ weather
- ★ magnetic field strength

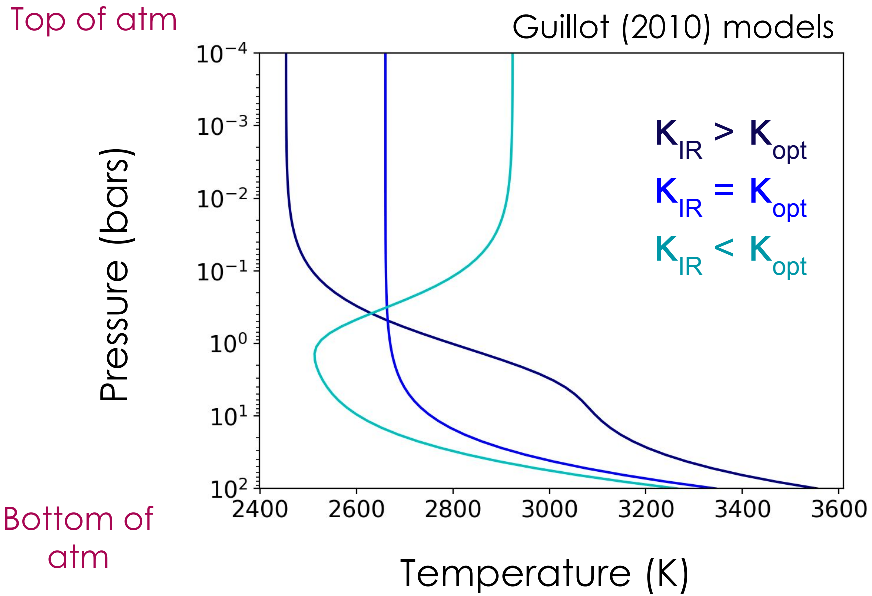
Hot Jupiters have similar temperatures to low-mass stars



T_{eq} ~1000 - 4000 K

Similar temperature, similar atmosphere?

Metal hydrides and ***oxides*** can cause large changes in hot Jupiter atmospheres

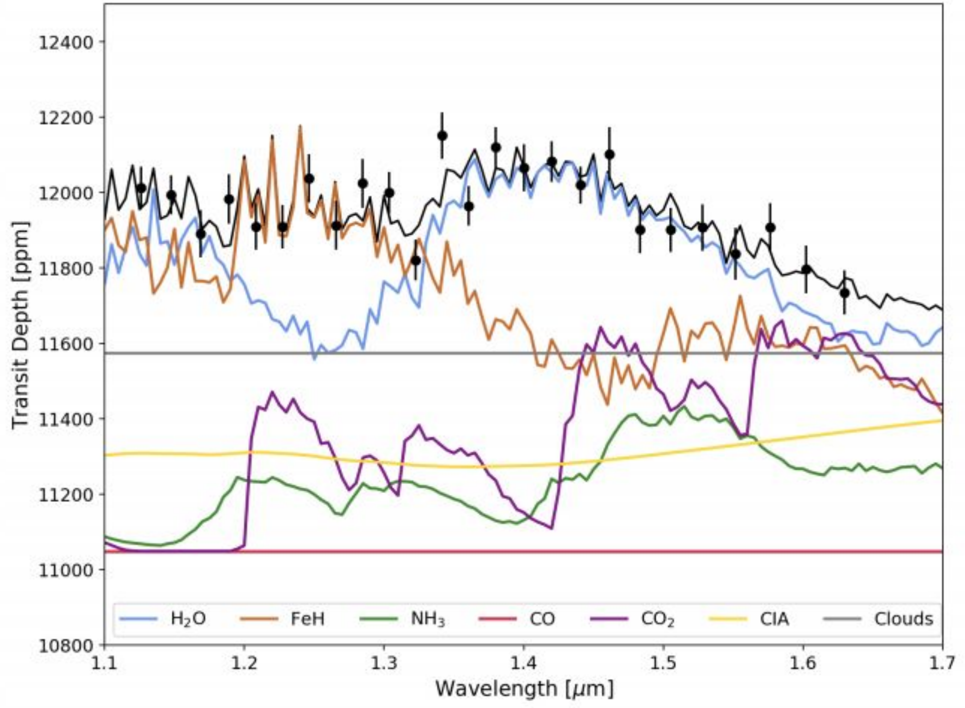


Regulate energy budget: thought to cause temperature inversions (Hubeny+2003, Fortney+2008)

Temperature inversions have been detected in many hot Jupiter atmospheres (e.g., Haynes+2015, Mansfield+2018)

Detecting ***metal oxides*** & ***hydrides*** at low res

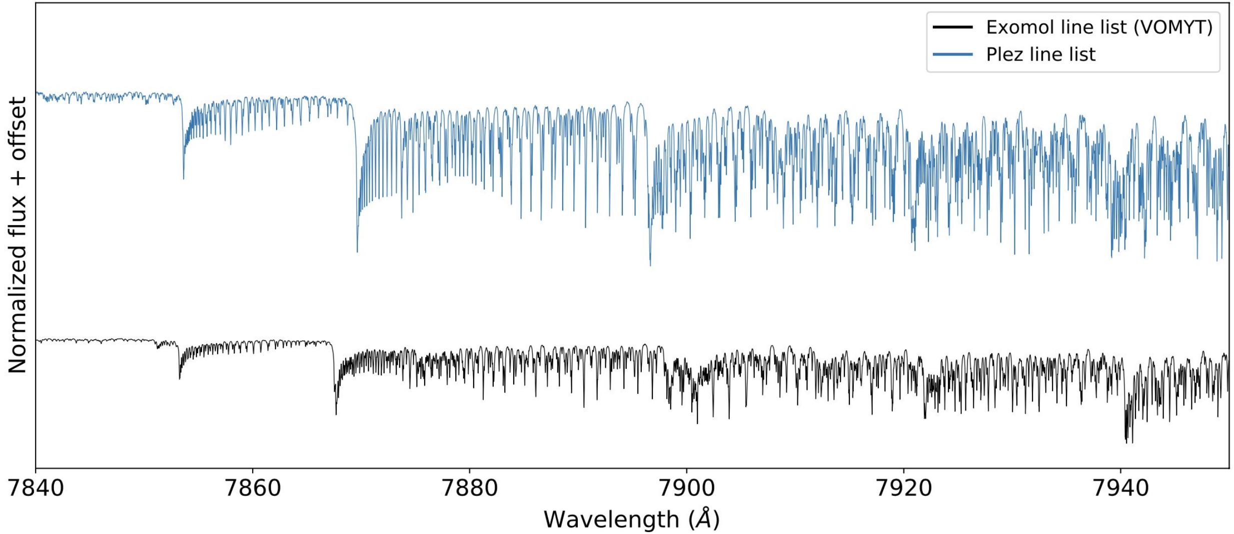
WASP-62b HST G141 grism spectrum



- ★ **Pros**: wide wavelength coverage, high precision, continuum included
- ★ **Cons**: metal oxides/hydrides may be degenerate with continuum opacity (CIA, clouds, H^-) and other molecules (CO_2, etc.)

Skaf+2020

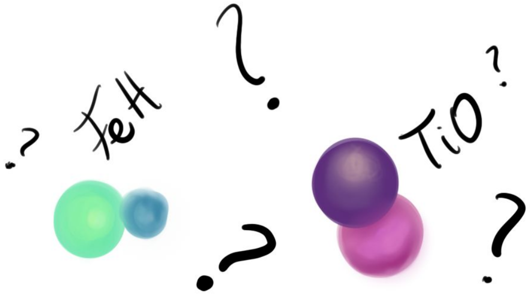
Detecting ***metal oxides*** & ***hydrides*** at high res



Pros: with high res. **Individual lines can be resolved** so no confusing species

Cons: Need **very accurate line lists** for many molecules (very difficult for transition metals such as TiO, VO)

So are ***metal oxides*** and ***hydrides*** present in hot Jupiters?



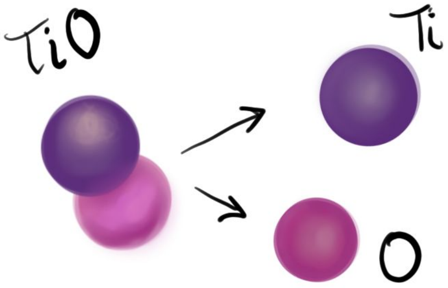
…. So far it is unclear!

- Low resolution tentative detections of metal hydrides including: FeH, CrH, TiH, ScH (Evans+2016, MacDonald+2019, Skaf+2020, Sotzen+2020, Marrick+2020, von Essen+2020)
- Low resolution tentative detections of metal oxides including TiO, VO, AlO (Evans+2016, von Essen+2019, Tsiaras+2018) but also non-detections on the same planets (Edwards+2020, Wilson+2021)
- High resolution detection of TiO (Nugroho+2017) followed by less clear results or non-detection in the same planet (Herman+2020, Serindag+2021)
- Many other non-detections of VO, TiO at high res. (Merritt+2020, Hoeijmakers+2020, Tabernero+2021)

If not, why?

CAUTION: Hot Jupiters are very different from self-luminous BDs and low-mass stars…

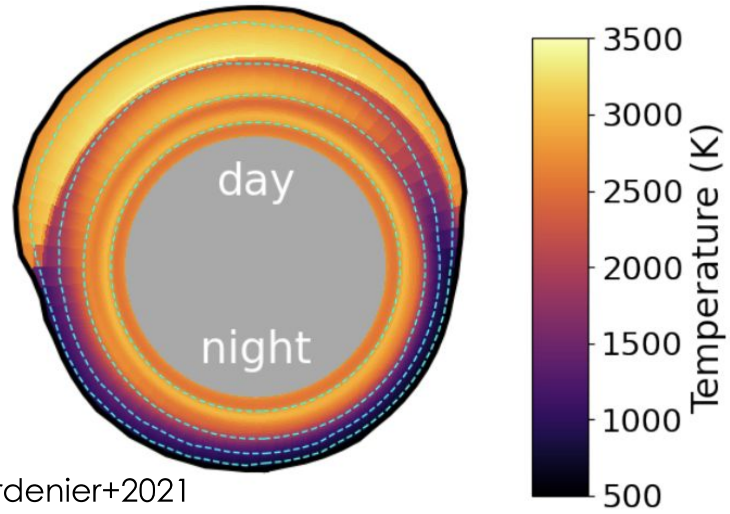
- Much lower surface gravity → dissociation?
- Externally heated → photodissociation?



If not, why?

CAUTION: Hot Jupiters are very different from self-luminous BDs and low-mass stars…

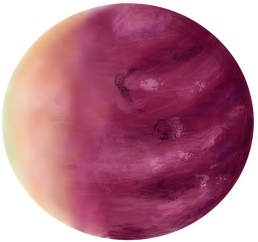
- Much lower surface gravity → dissociation?
- Externally heated → photodissociation?
- Large day-night contrasts → cold trapping? (e.g., Spiegel+2009, Parmentier+2013)



Wardenier+2021

1. Searching for FeH in 12 hot Jupiters

From Kesseli, Snellen, et al. 2020



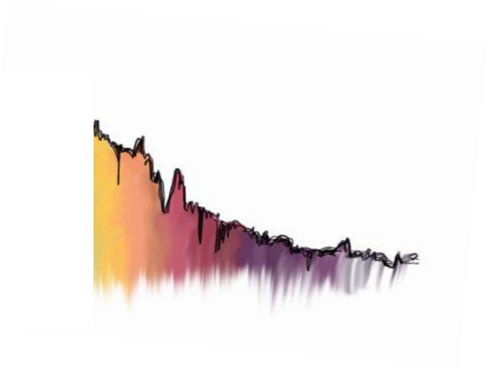
The Sample

12 gas giant exoplanets

$600 < T_{eq} < 4000$ K

$2.5 < \log g < 3.5$

Host star spectral type of M to A



The Data

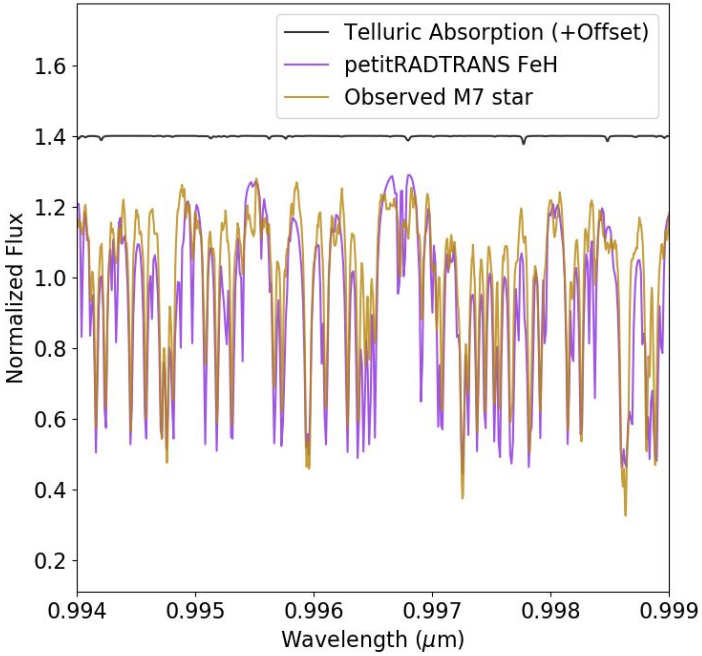
NIR (0.96 — 1.71 μm) CARMENES spectra

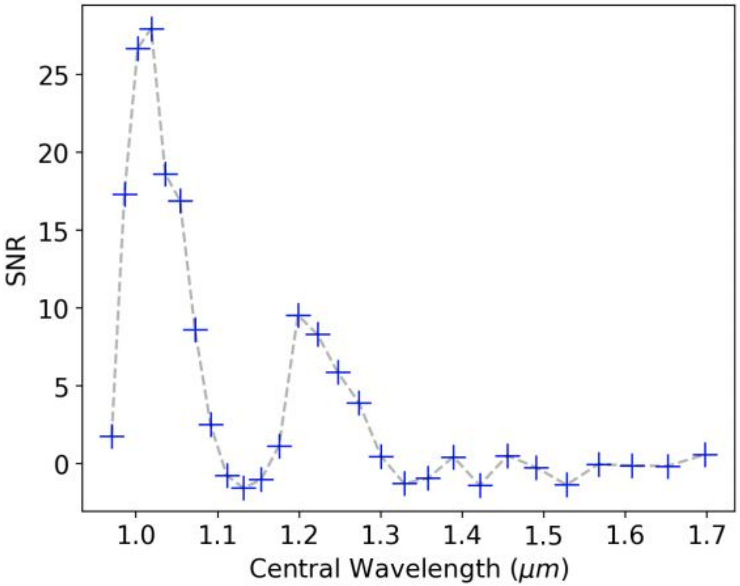
R ~ 80,000 (Quirrenbach+2018)

Publicly available on CAHA archive

Reduced with CARACAL pipeline (Caballero+2016)

FeH line list is accurate

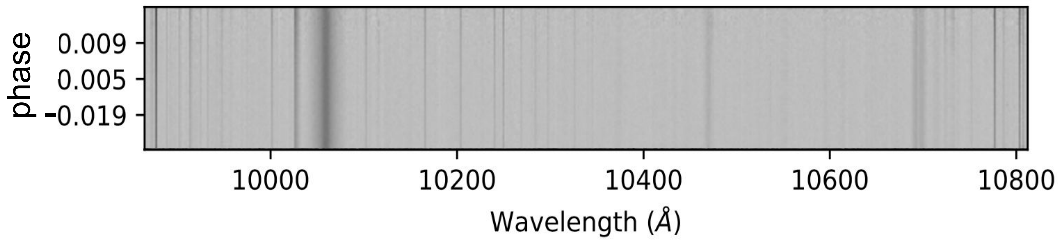




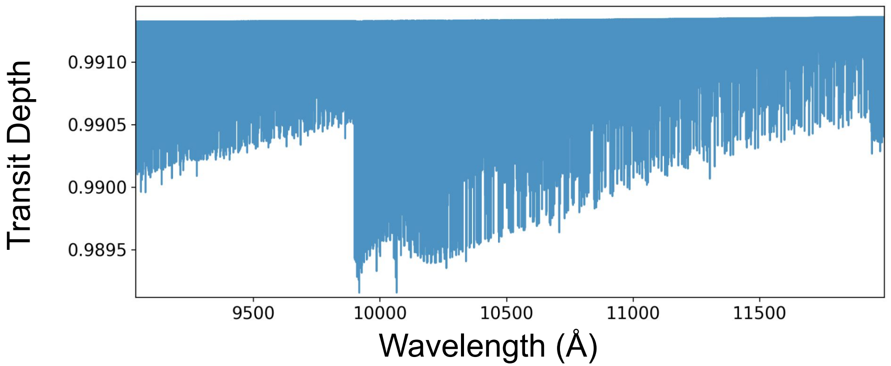
Line list from Wende+2010 is accurate, especially at 1.0 micron bandhead conveniently located between two telluric water bands

Cross correlation to combine many weak lines

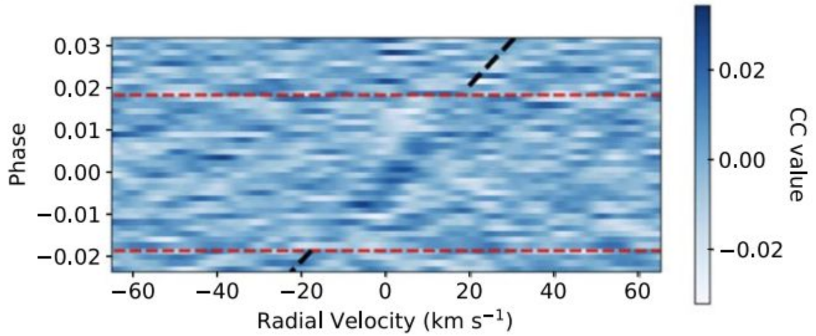
Time series spectra of star + planet



Model of FeH

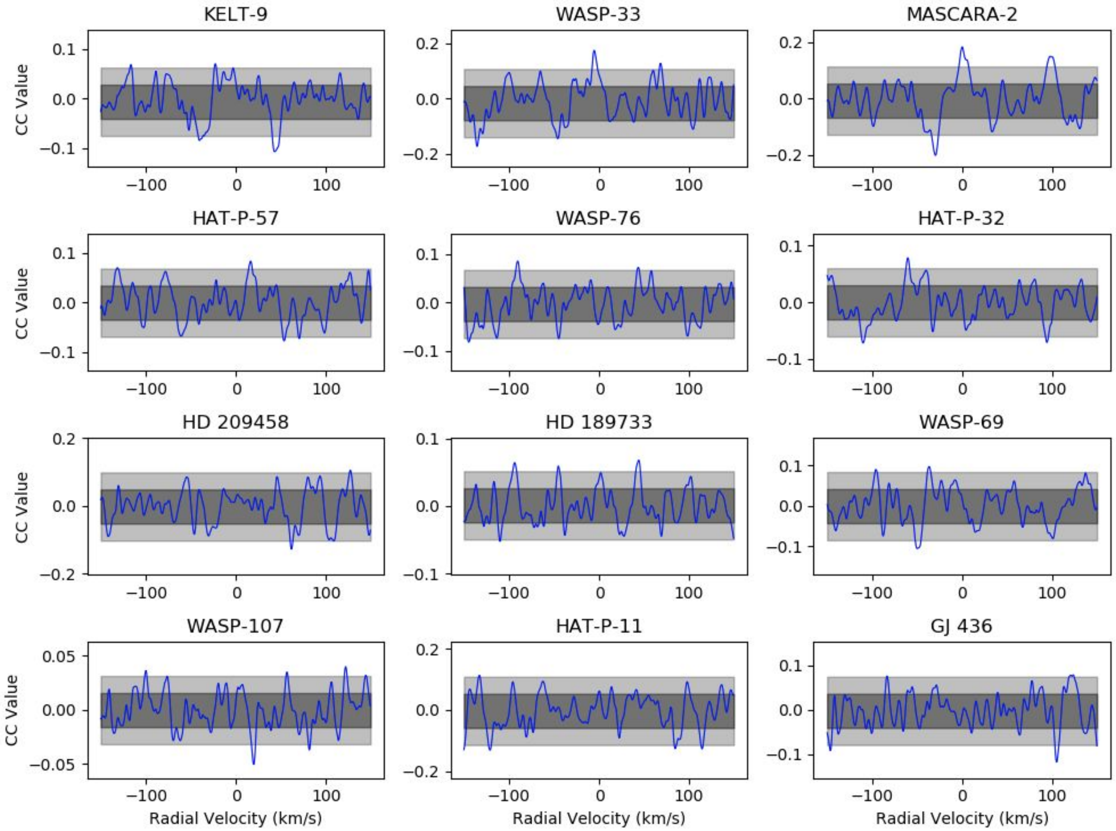


Resulting cross correlation matrix



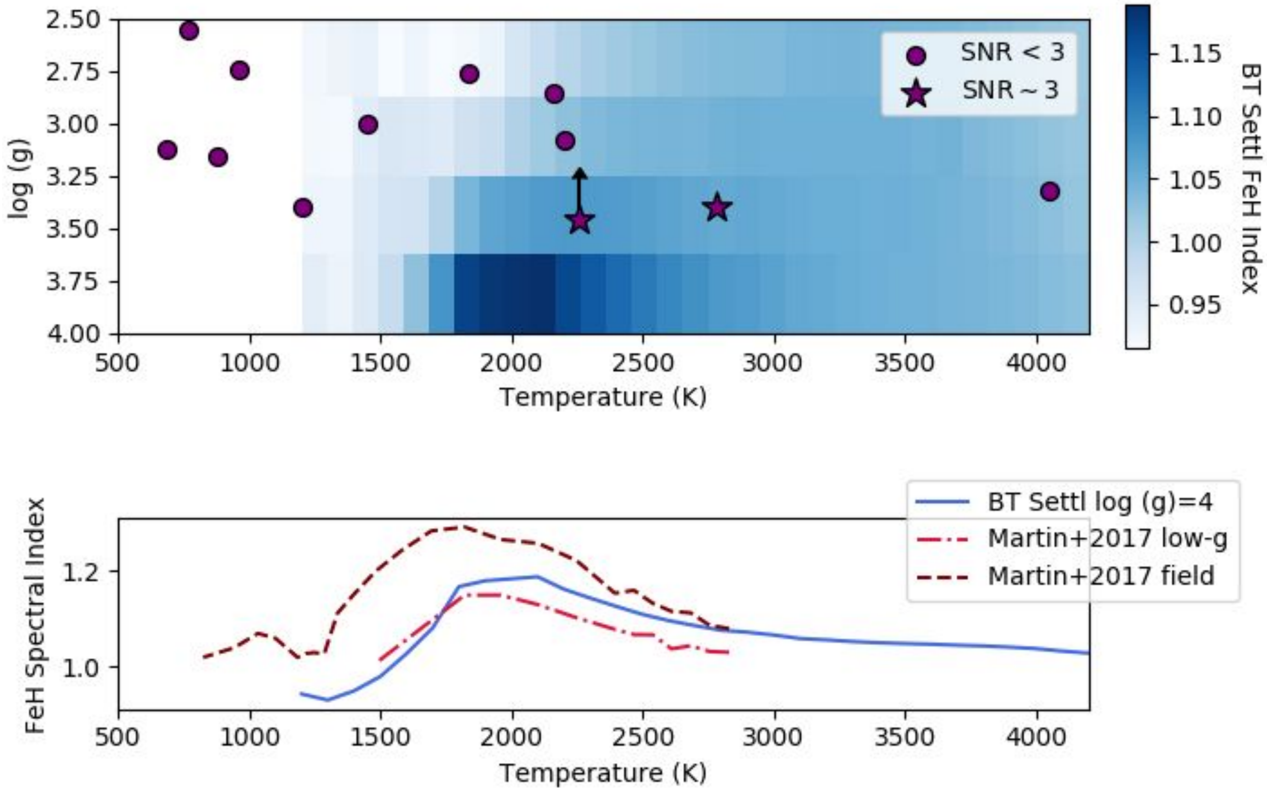
A **detection can be seen as positive correlation** between the line list and residual spectra at the planet's expected velocity

No conclusive FeH detections



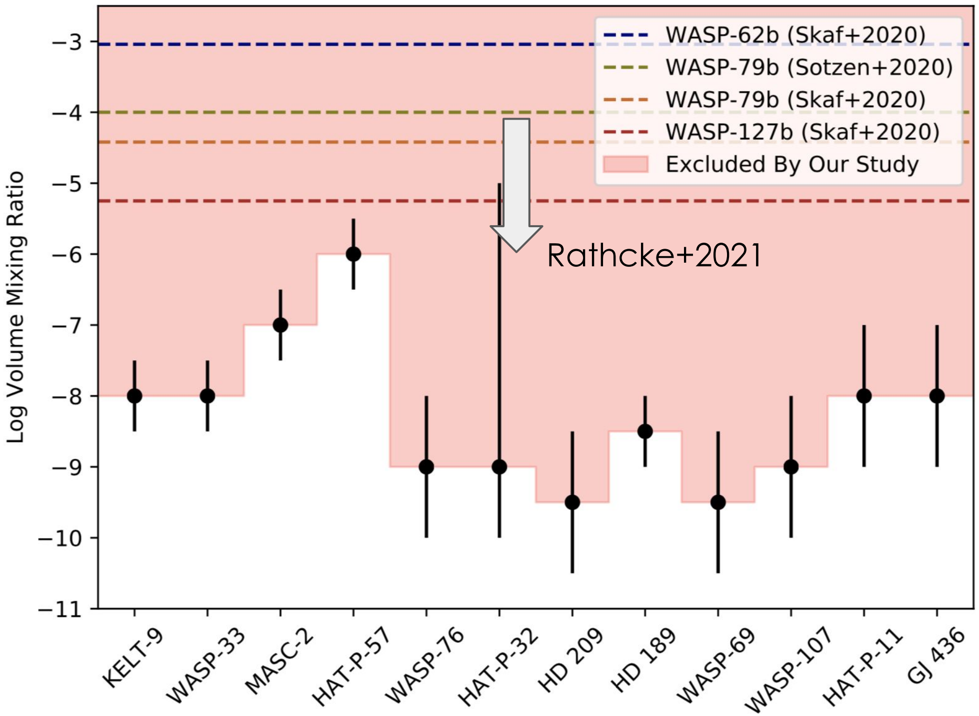
Potential hint of FeH in two planets: WASP-33b and MASCARA-2b

Comparison with brown dwarfs



FeH is expected for planets with **higher surface gravities** and temperatures between **1600 - 4000 K**

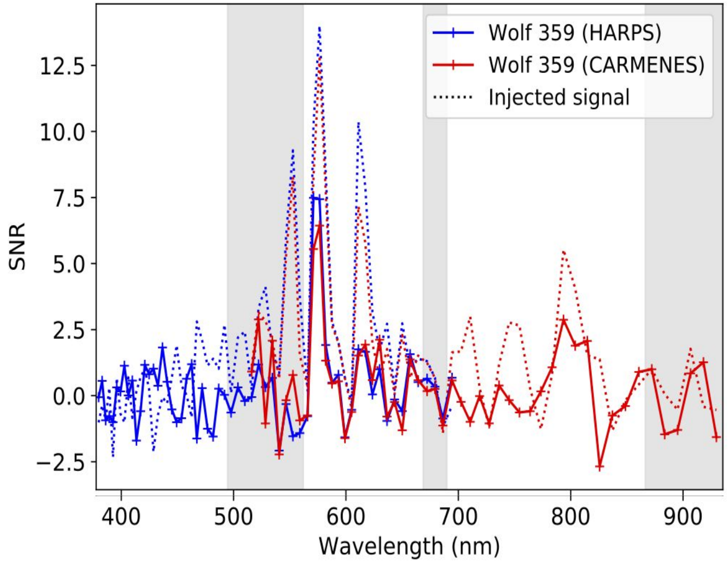
Injection and Recovery Tests

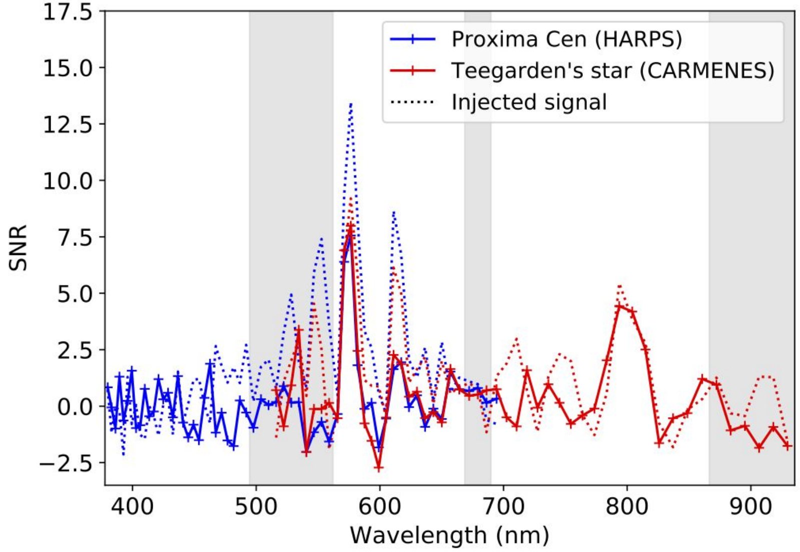


★ We can rule out FeH at a volume mixing ratio of 10^{-6} in every planet and in some as low as $10^{-9.5}$

★ FeH may be present but probably not at extremely high abundances

2. Testing the VO line lists using M dwarfs

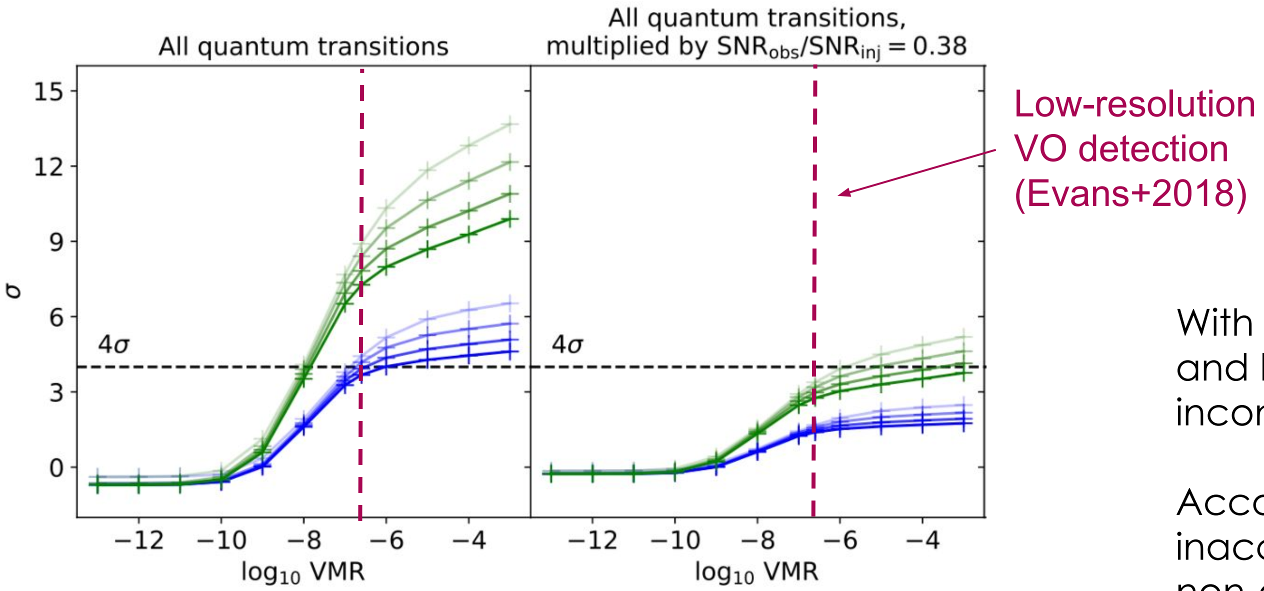




Only recover ~38% of potential VO signal

de Regt, Kesseli, et al. (in prep)

VO line list not accurate enough



Data of WASP-121b from UVES presented in Merritt+2020

With full line list low-res and high-res are inconsistent

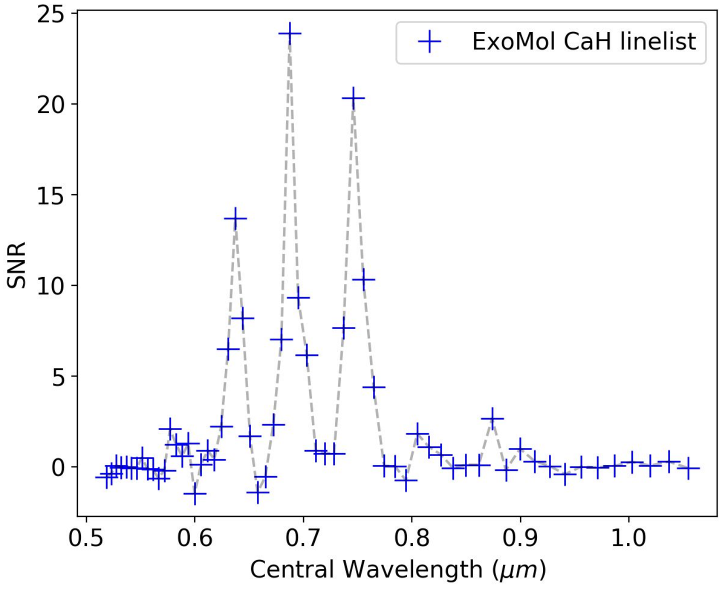
Accounting for line list inaccuracies high-res non-detection is expected!

de Regt, Kesseli, et al. (in prep)

3. In the works…

➔ Checking for the other metal hydrides w/ high resolution: CaH, MgH, CrH, …

Line lists seem accurate!



Conclusions 1

★ Metal hydrides and oxides are ubiquitous in low-mass stars and brown dwarfs, but so far the story is unclear as to whether they are prominent in exoplanets
  - Low-res studies often infer high abundances, but maybe over-estimated if continuum opacity not included
  - High-res studies often show non-detections and rule out very low VMRs, but could be due to poorly modeled line lists
  - Combo of low and high-res is key, new models, high quality datasets

Conclusions 2

★ Discovering whether they exist in exoplanets will help us understand day-to-night side temperature contrasts, cold-traps, and more!

★ If they do exist, they could be used as probes of exoplanet properties like metallicity, weather, and magnetism