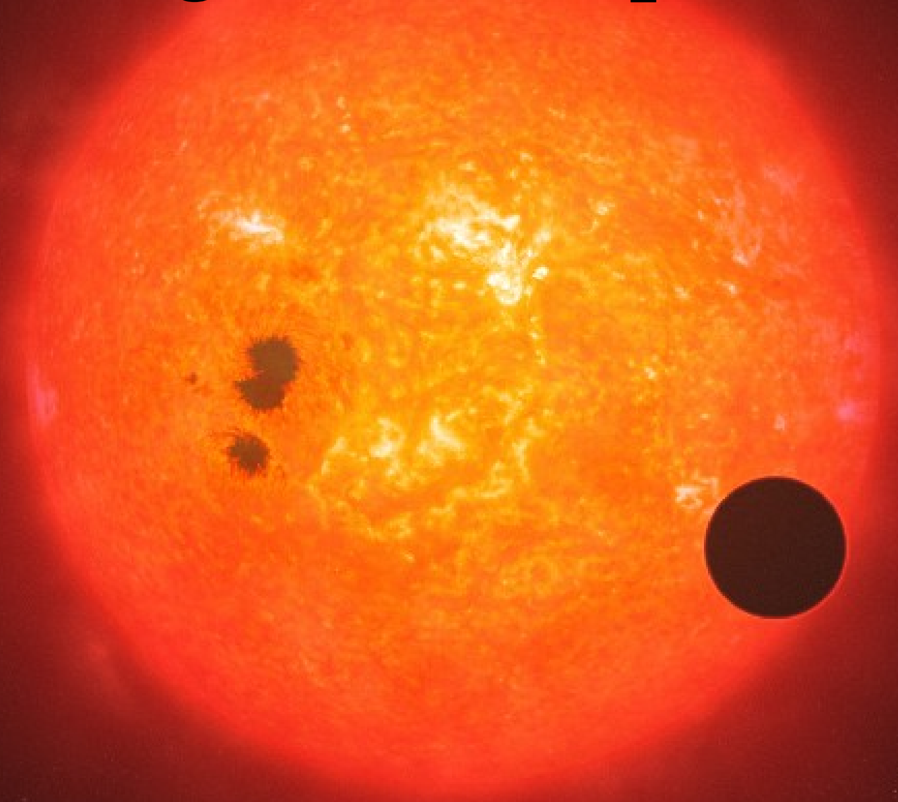
Unveiling a Neptunian atmosphere through transit photometry



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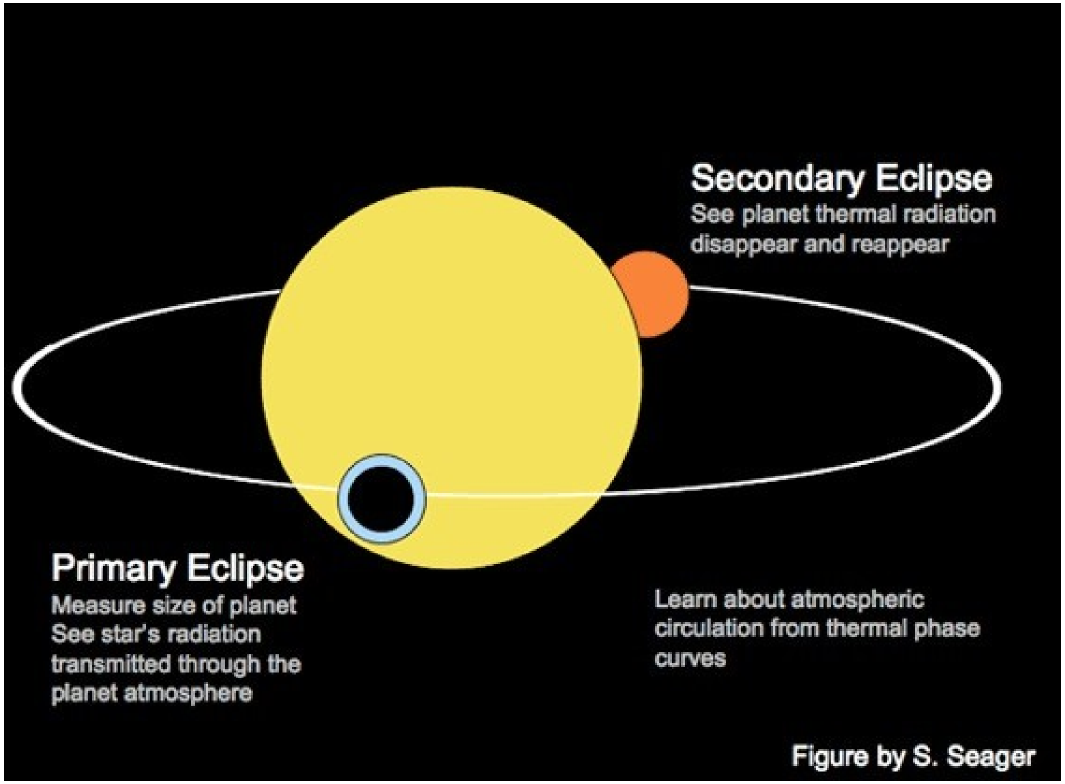
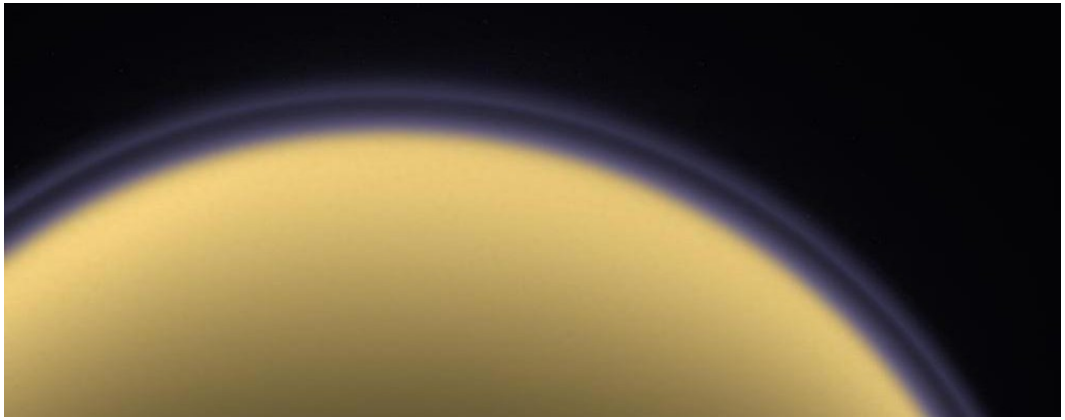
How to probe planetary atmospheres?

Studying exoplanetary atmospheres is crucial to investigate their evolutionary history and inner structure.

They can be probed through trasmission or occultation (spectro)-photometry to search for signatures from:

- Atomic species (Na, K, …)
- Molecular bands (H_2O, CO, CH_4, …)
- Scattering processes affecting the continuum

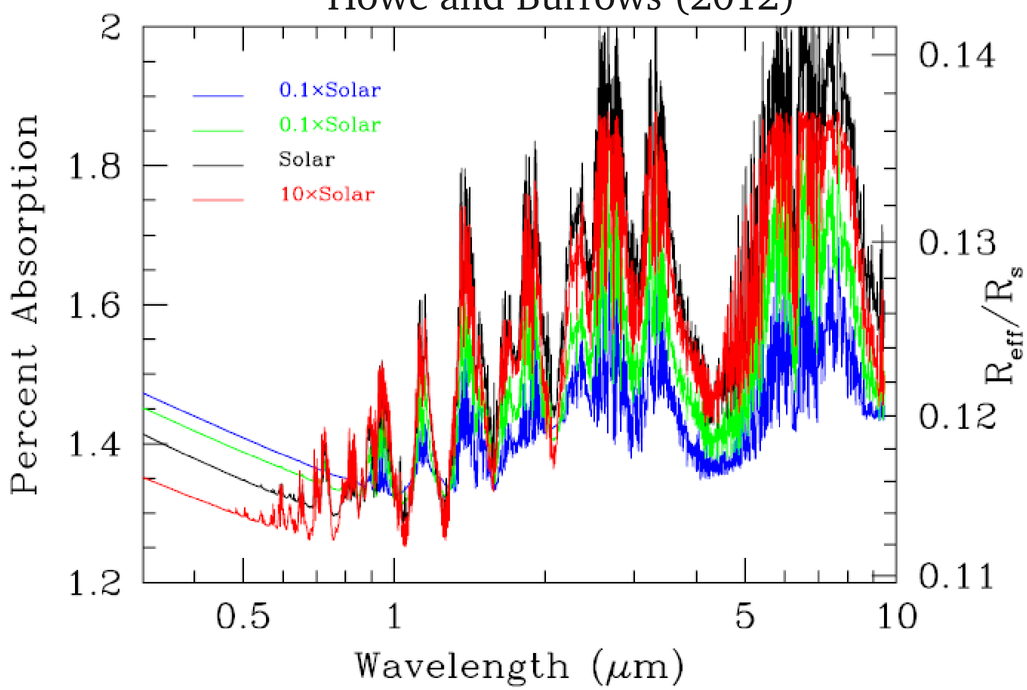


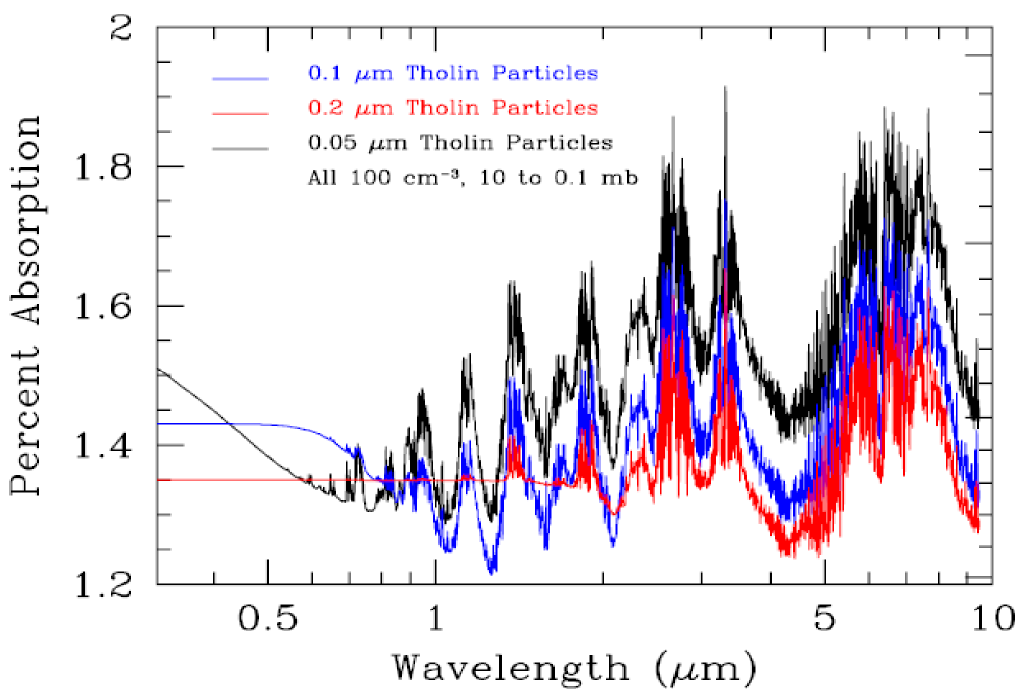


Rayleigh scattering in action

The simplest case is **Rayleigh scattering**, due to molecular hydrogen (H_2) or to small condensate particles (Tholins, etc). It manifest itself as a steep increase of apparent planetary radius towards shorter wavelengths ($\propto\lambda^{-4}$)

Howe and Burrows (2012)



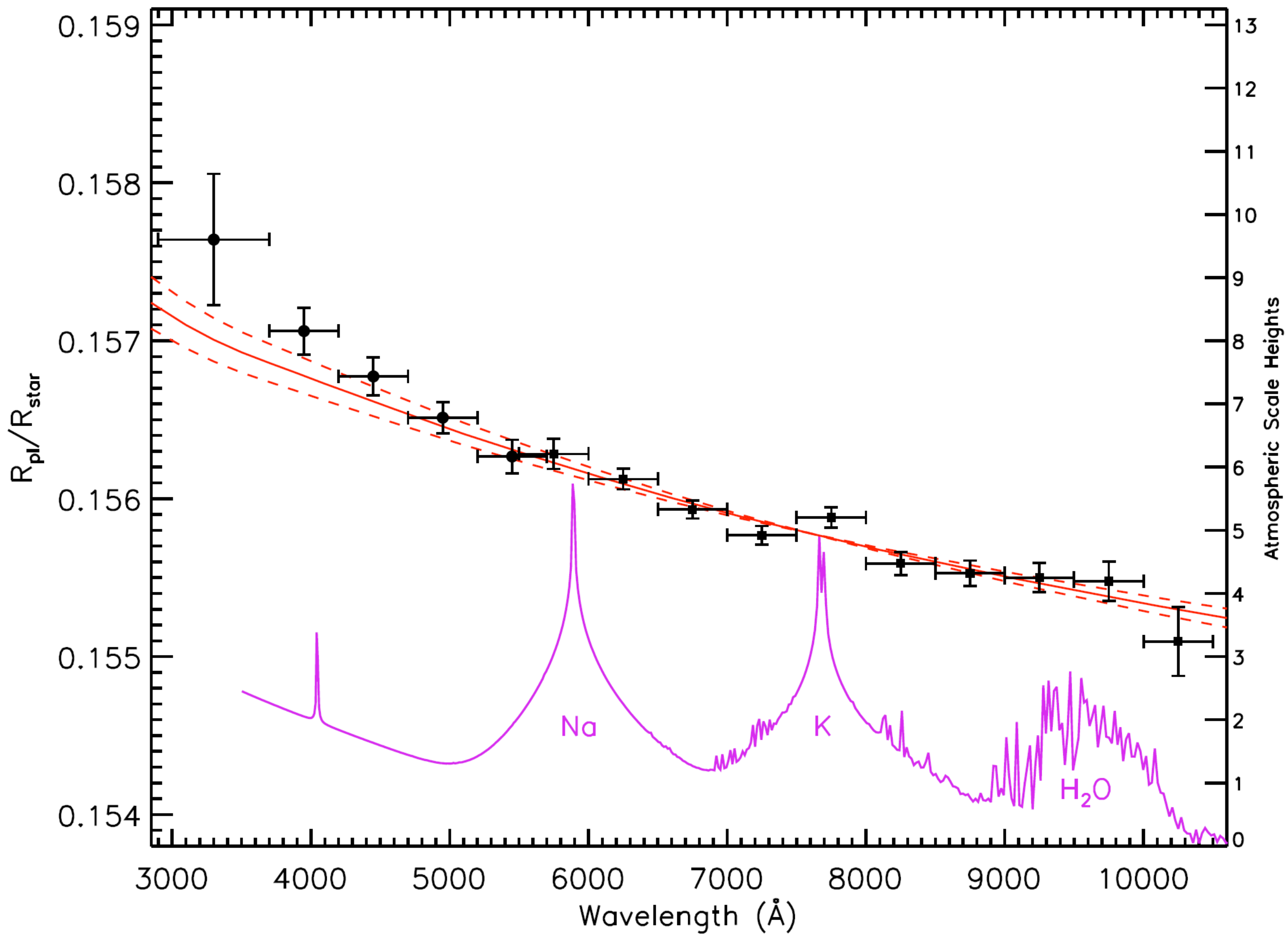


Scattering processes can be exploited to obtain an independent estimate of the atmospheric **scale height** of the planet

$$H = \frac{k_b T_{eq}}{\mu g}$$

Rayleigh scattering in action

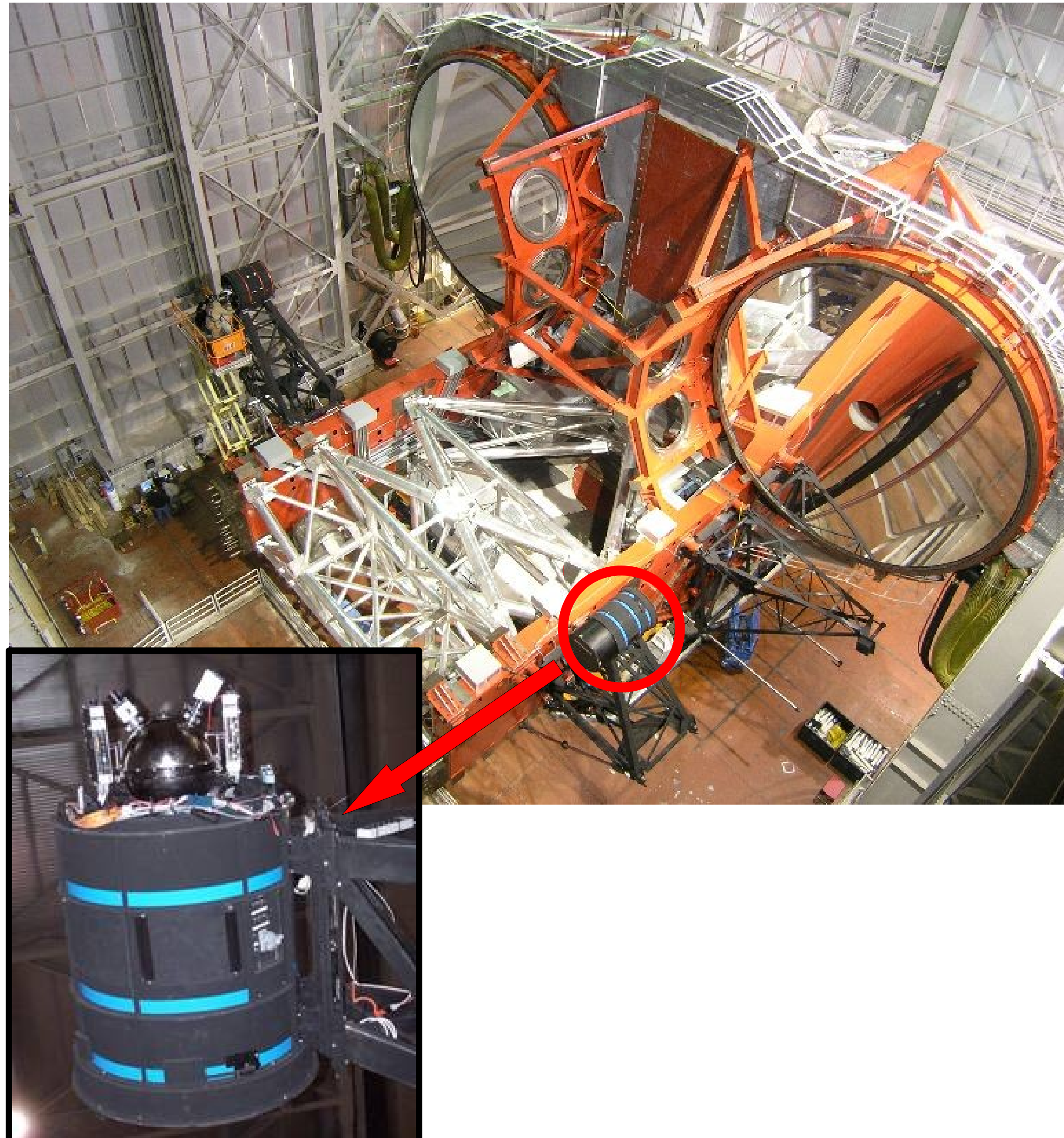
Sing et al. 2011, HD 189733, STIS



Why the Large Binocular Camera?

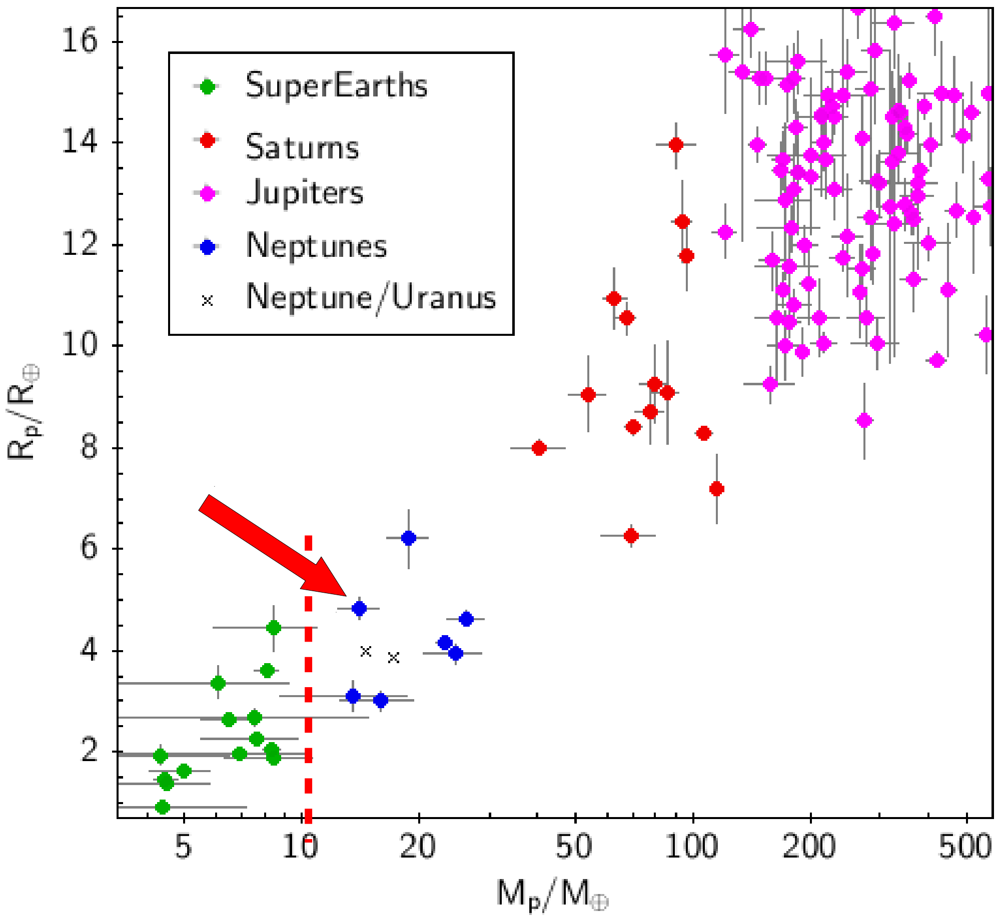
Dual-channel prime focus imager mounted at the 2×8.4m Large Binocular Telescope (LBT)

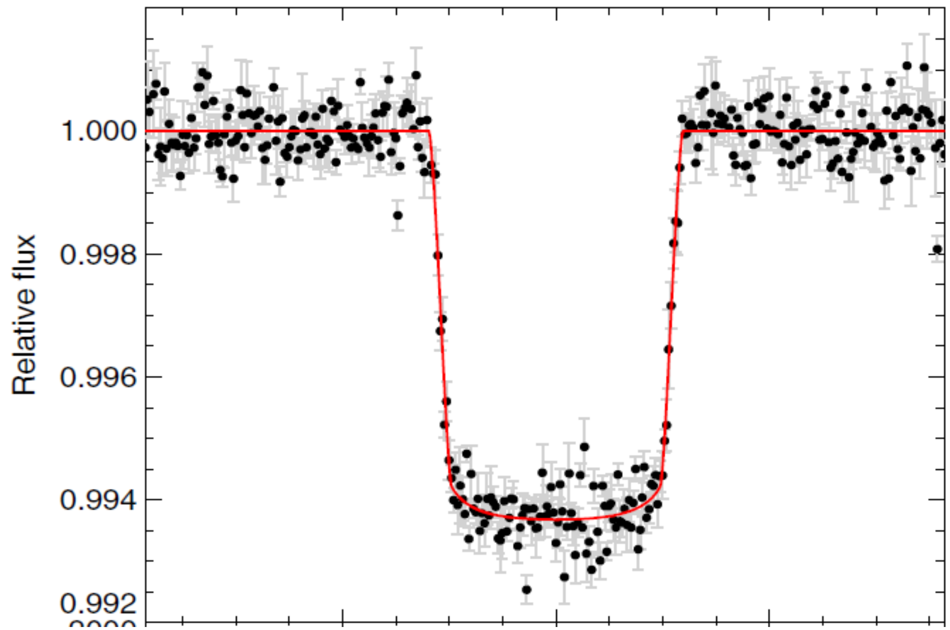
- High efficiency on the blue channel (*U*/*B*), where Rayleigh scattering is strongest
- Simultaneous dual-band photometry, to monitor telluric/instrumental drifts and chromospheric effects



Why GJ3470b?

- 14 M⊕, 3.8 R⊕ "hot Uranus" at the boundary between SuperEarths and Neptunes (Bonfils et al. 2012)
- Hosted by a M1.5V dwarf (transit depth ~6 mmag): V=12.3, J=8.8, K=7.9

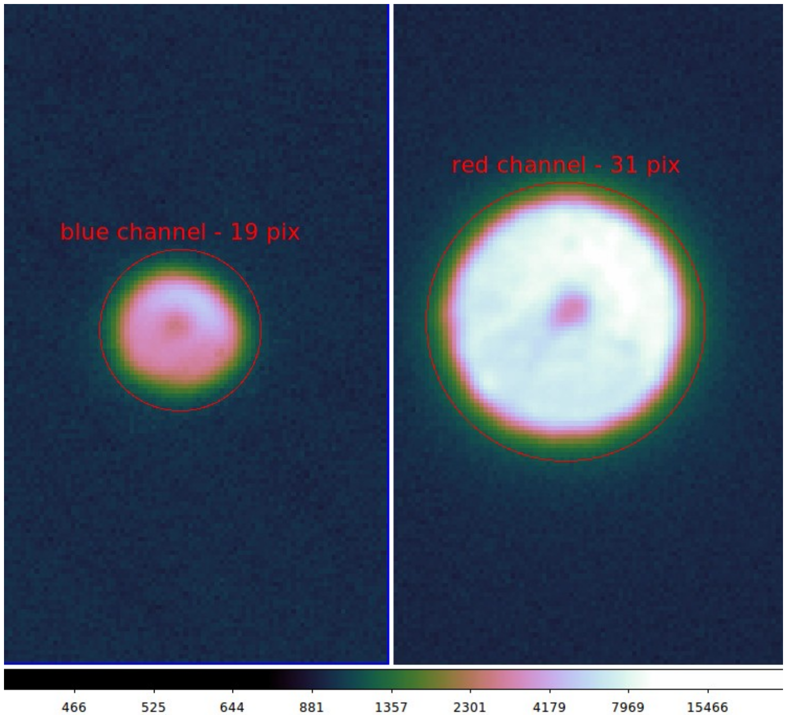


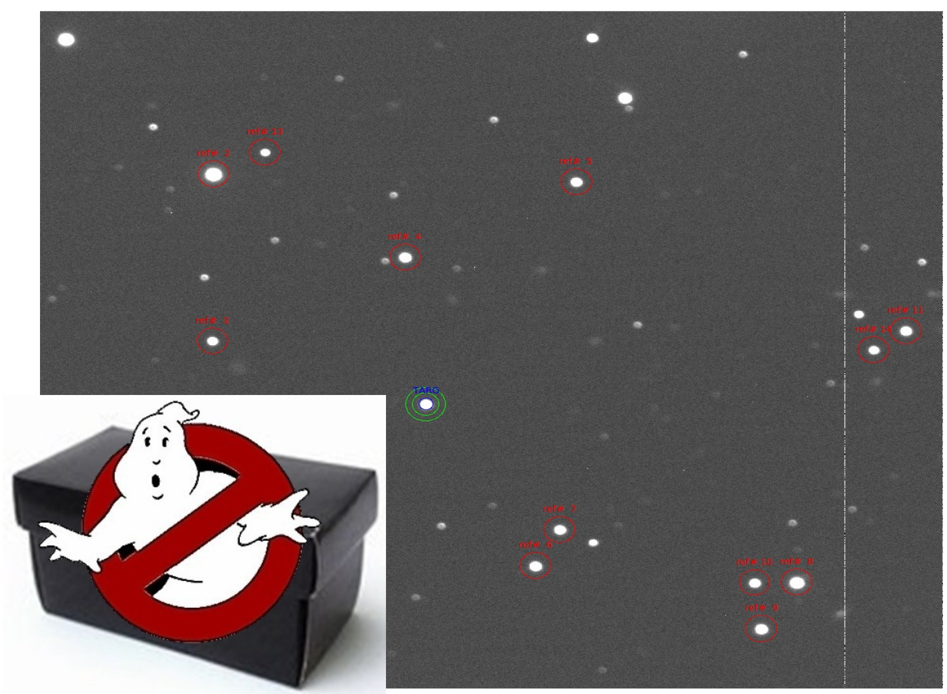


Very inflated, mean density ~0.7 g cm-3. Impossible to explain with an ice-dominated model, it is expected to have a large envelope of primordial H/He (Demory et al. 2013)

Observing strategy

- High-precision differential photometry with hard defocus (7”-13” FWHM)
- Blue channel *U_spec*: very similar to a high-efficiency Sloan u filter (357 nm)
- Red channel *F972N20*: intermediate-band filter centered at 963 nm (FWHM)





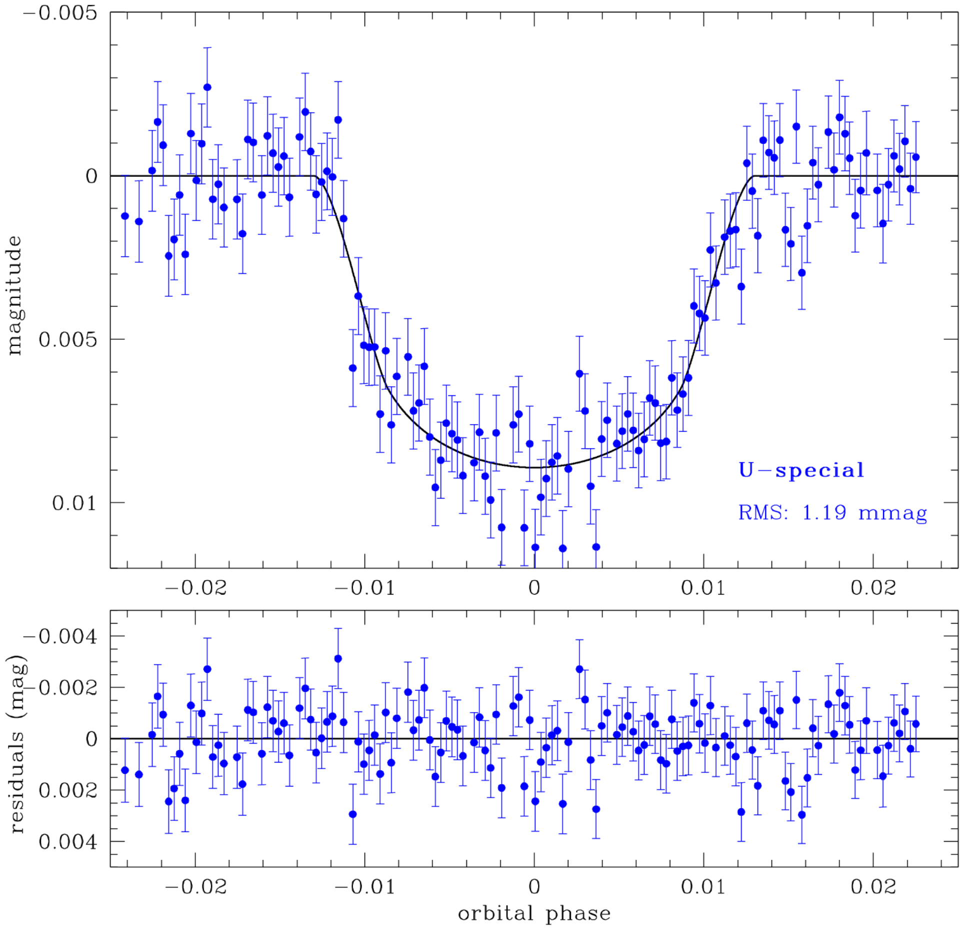
Avoiding black boxes: STARSKY photometric pipeline (Nascimbeni et al. 2011a, 2011b, 2013) to iteratively apply optimal weights and decorrelate systematic errors

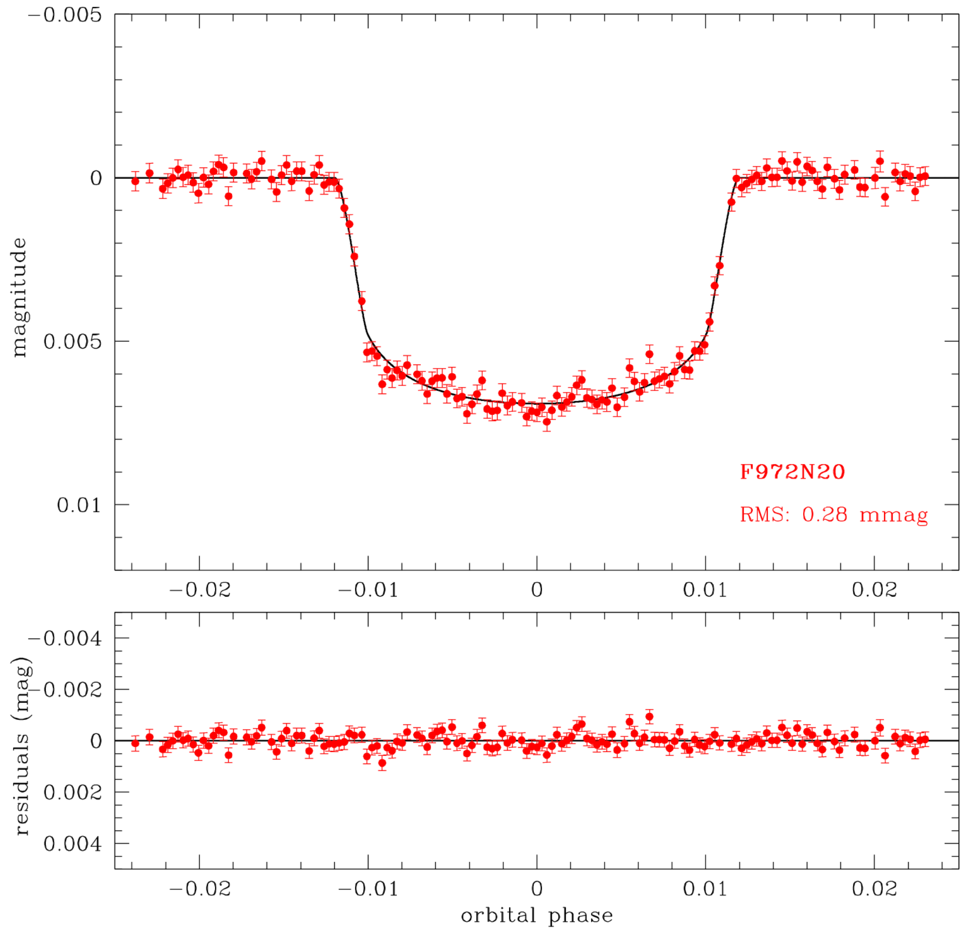
GJ3470b: the light curves

Extremely high photometric precision (0.28 mmag in the red channel)

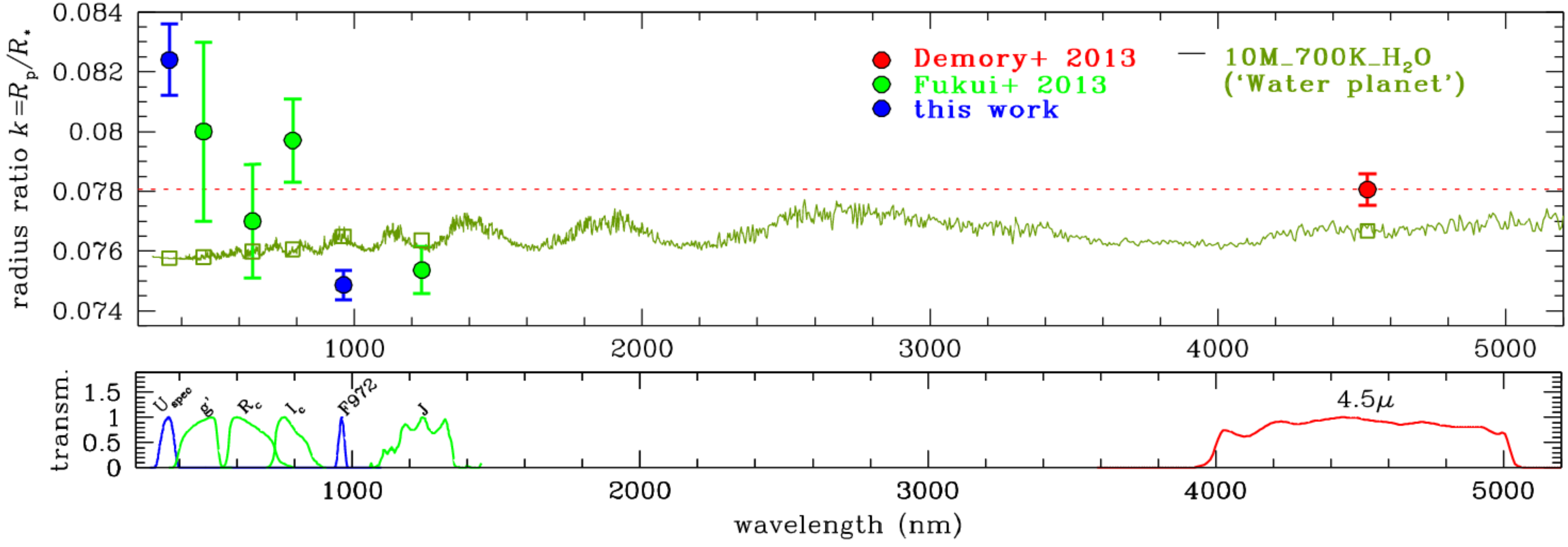
No signature from starspots/active regions

Significantly larger depth (i.e. effective radius) in the blue channel at 6 sigma, even after accounting for limb darkening and activity effects





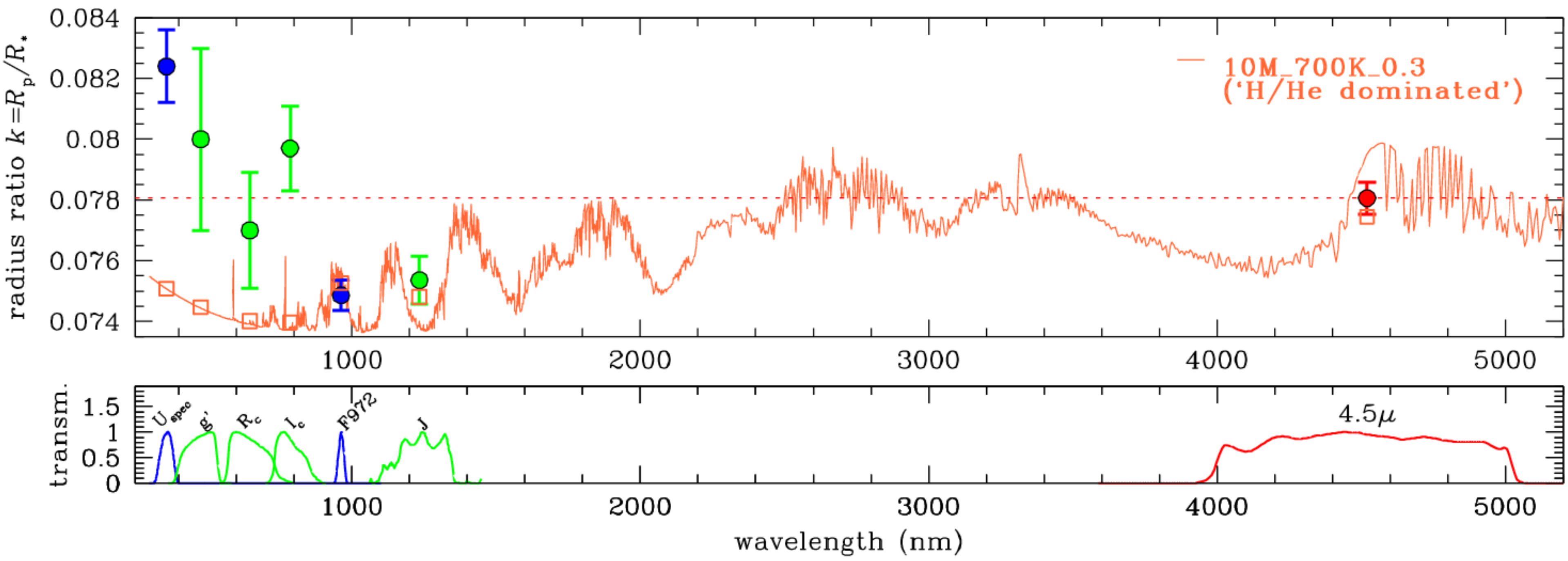
GJ3470b: water atmosphere?



Our LBC data points exclude a constant radius by more than 6 sigma. After adding literature data (Demory et al. 2013; Fukui et al. 2013), the increase of radius in the optical region is even more significant

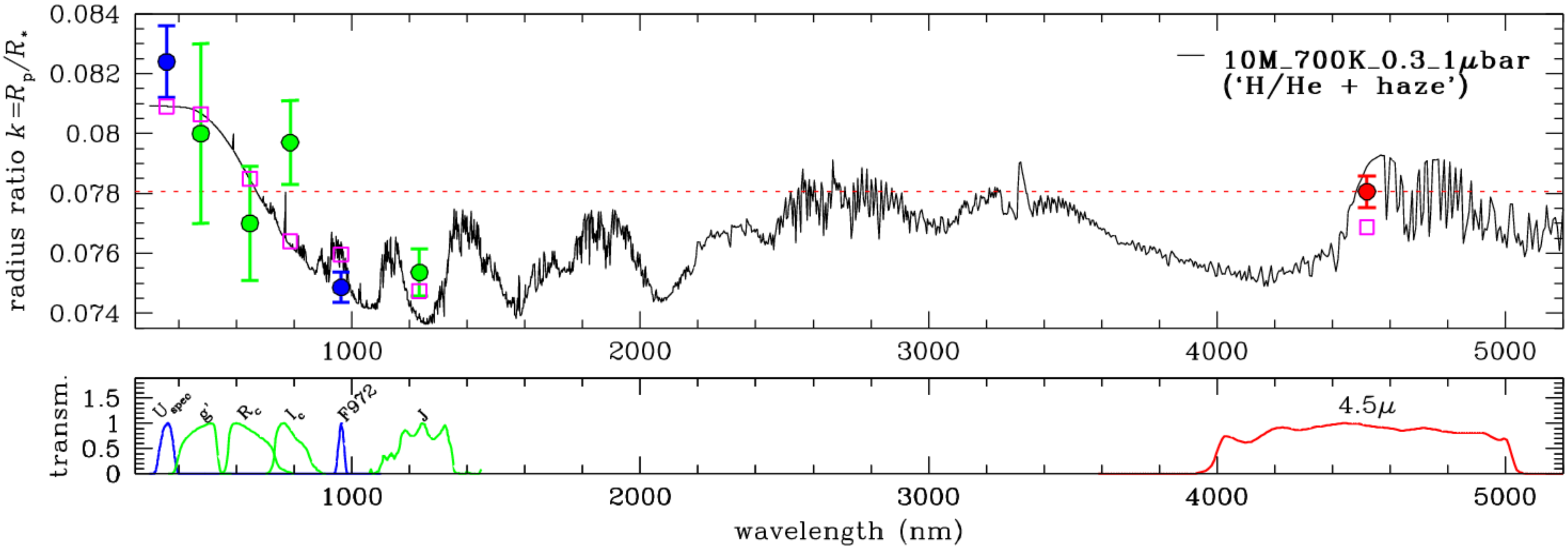
High-μ atmospheric models from Howe & Burrows (2012) such as pure H_20 or CH_4 atmospheres are incompatible with the observed spectrum

GJ3470b: H/He dominated?



Low-μ, H/He-dominated HB12 models reproduce well the red part of the spectrum, but still fail at reproducing the steep increase in the blue/UV region. H_2 alone cannot be the only source of scattering

GJ3470b: H/He dominated with haze?



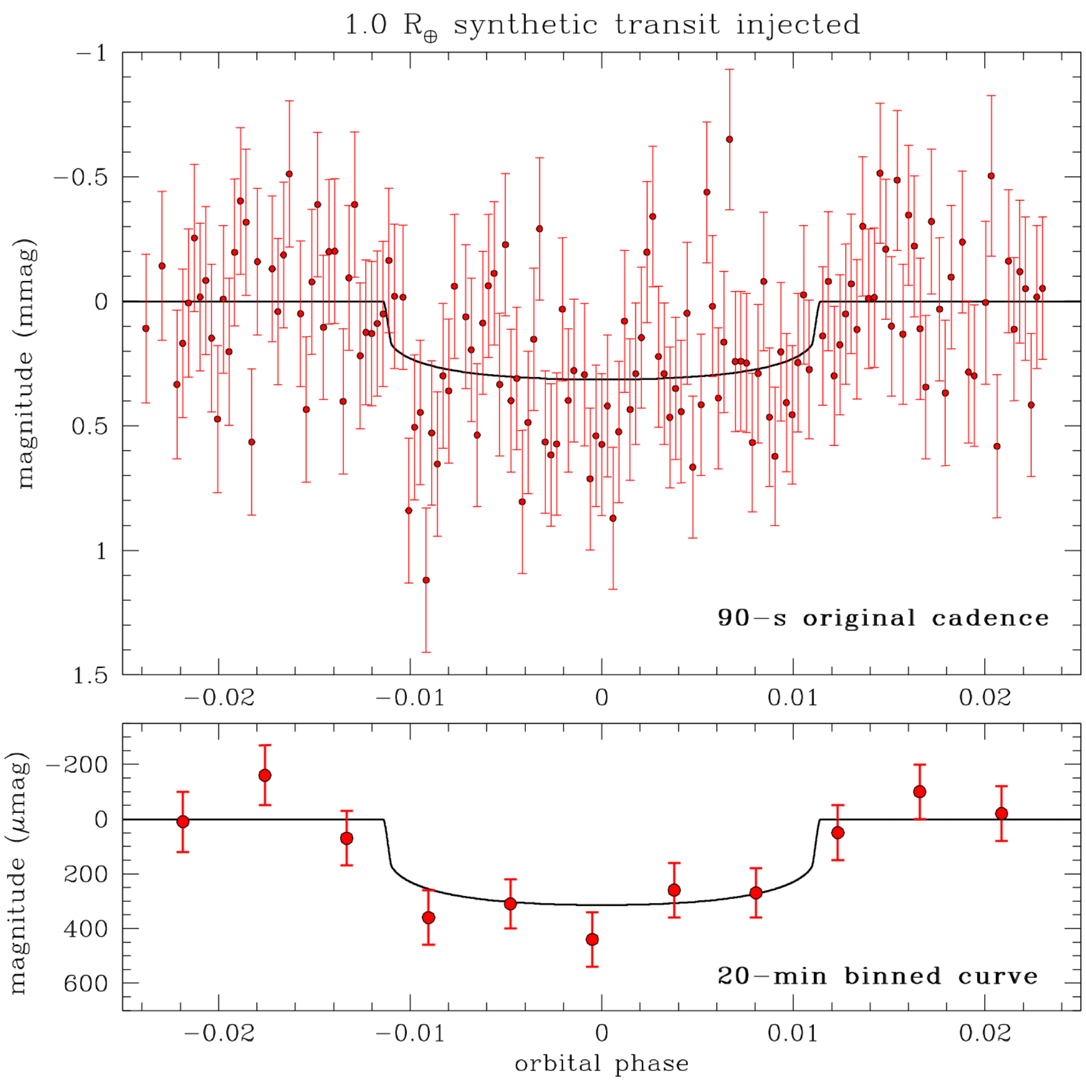
Low-μ, H/He-dominated models with scattering from condensate particles such as Tholins provide the best fit to our data

Additional follow-up is required to confirm this hypothesis (e.g., NIR spectrophotometry)

Measuring 1-R⊕ planets on short periods around M dwarfs could be already feasible with ground based 8m-class telescopes!

Test with a 0.3 mmag transit injected over the residuals of our F972N20 light curve → accounting for real-world systematics and astrophysical noise...

The synthetic transit is clearly detectable at ~9 sigma!



Conclusions

- Dual-band ground-based photometry from large telescopes is able to probe the atmospheric continuum of low-mass planets in the U/B region
- GJ3470b has an anomalously large radius at blue wavelengths, which could be explained as due to scattering by condensate particles. A cloudless atmosphere of pure H/He as well as a high-μ atmosphere (pure $H_2 0$, CH_4, etc) are ruled out by our observations (Nascimbeni et al. 2013b, submitted)
- High-precision differential techniques allows us to detect earth-sized planets from the ground, provided that a transit window is exploitable