Exo-atmospheres with Transmission Spectroscopy

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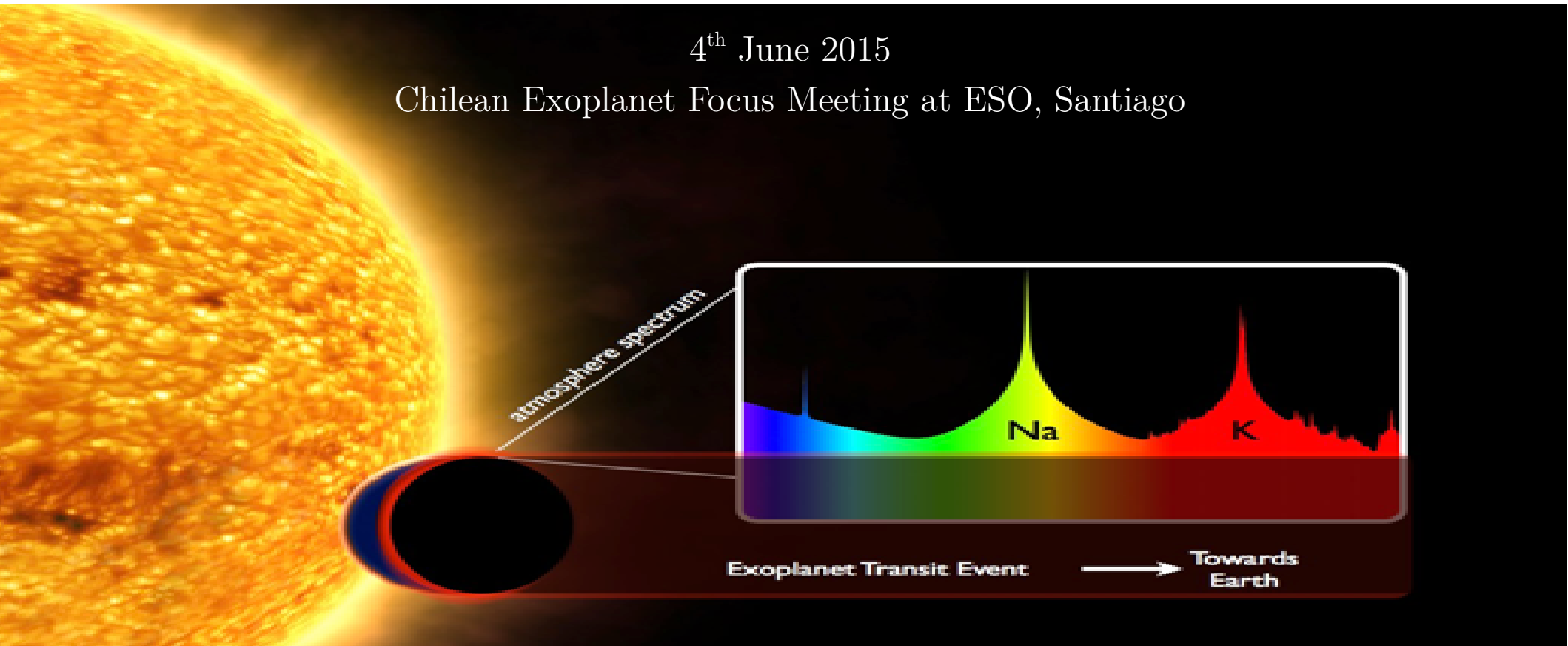
Chilean Exoplanet Focus Meeting at ESO, Santiago

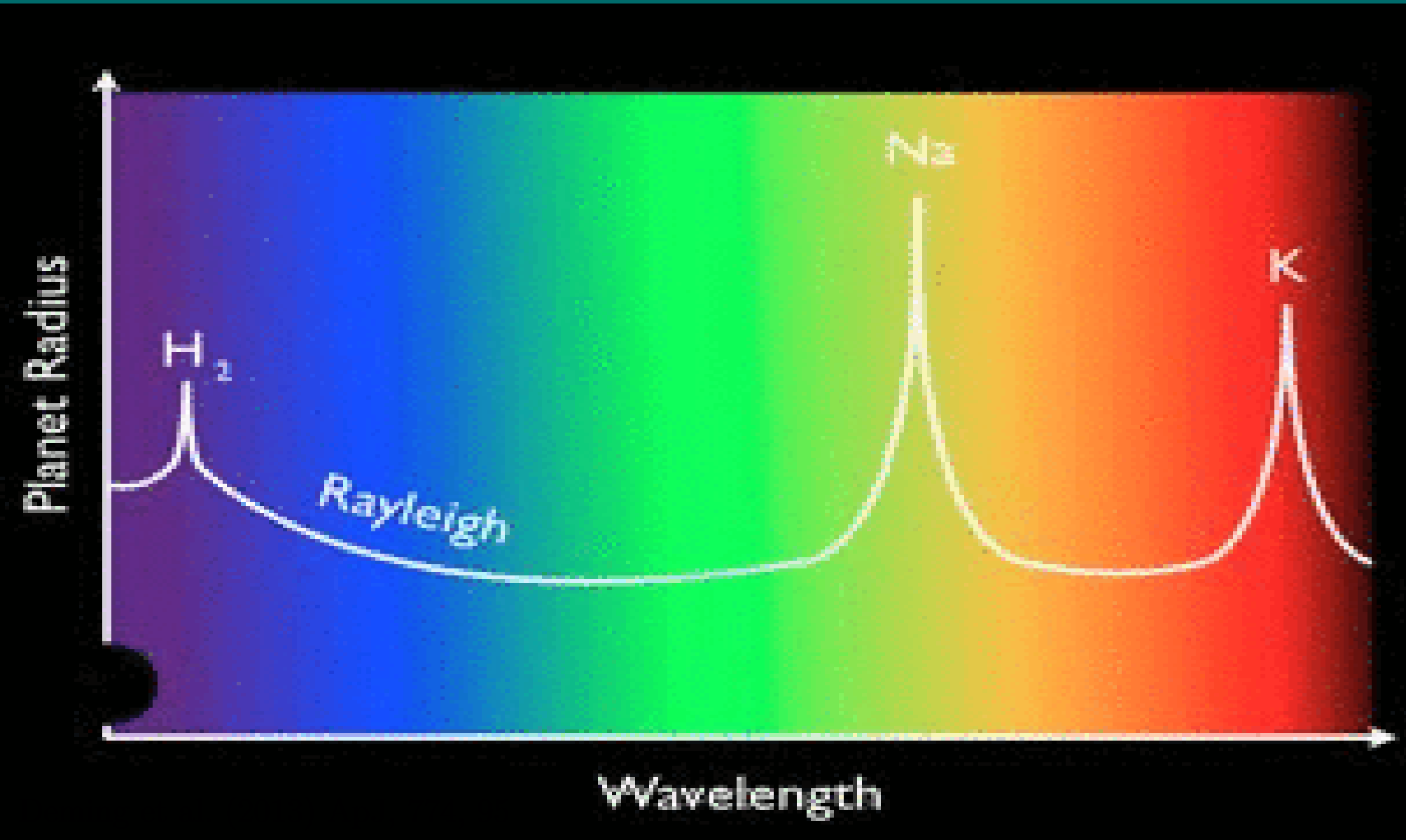


Overview

- Transmission spectroscopy
- Instrumentation & Methodology
- FORS2 improvements
- WASP-19b observations
- Conclusions & Outlook

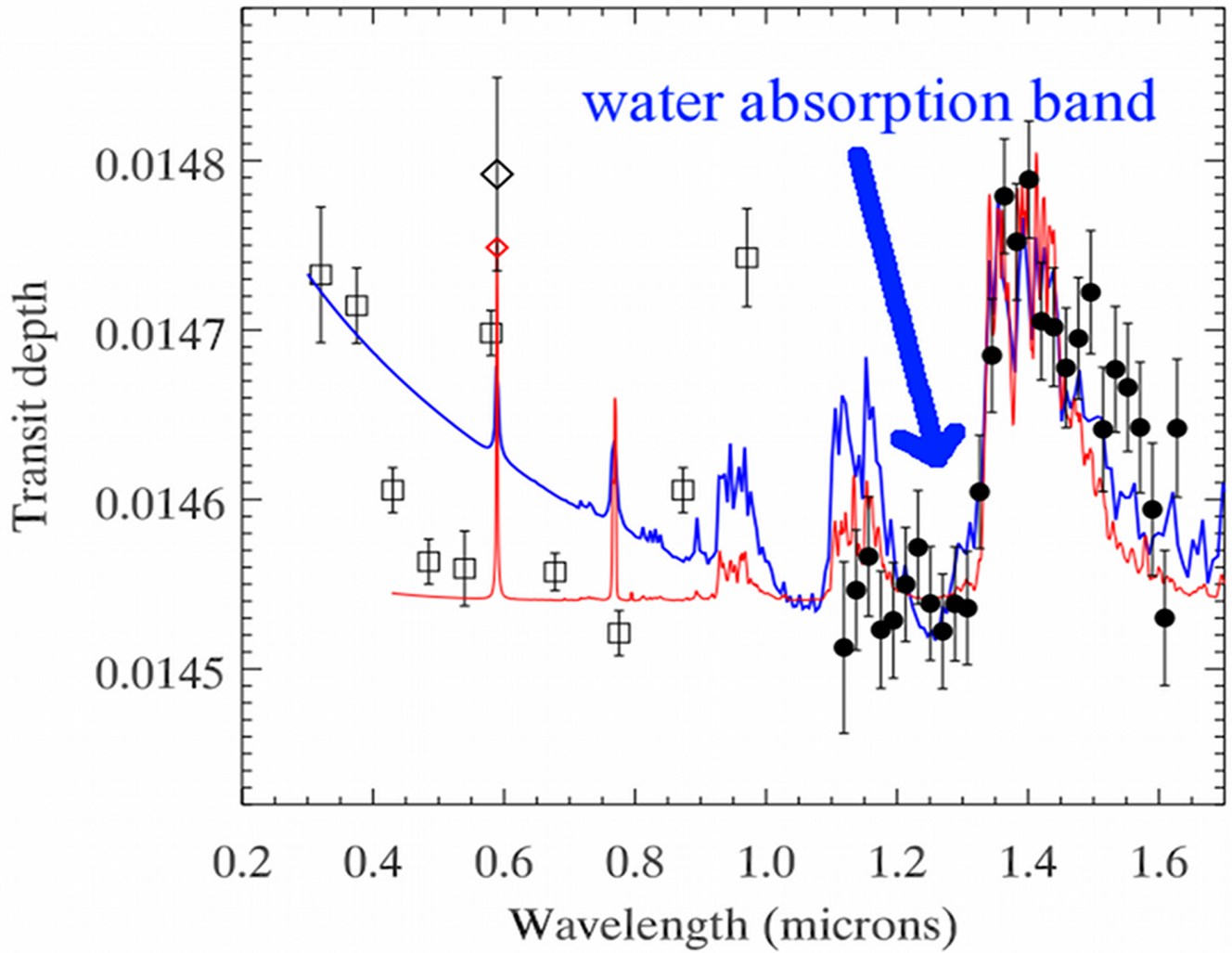
Transmission Spectroscopy

HD209458b

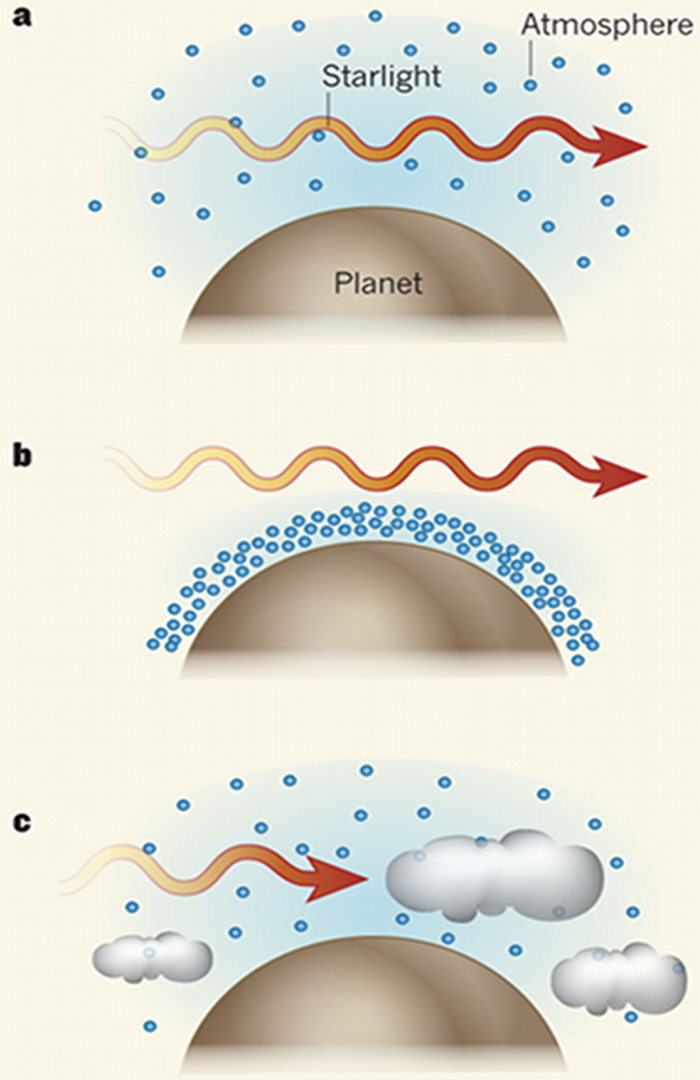


Transmission Spectroscopy

HD209458b

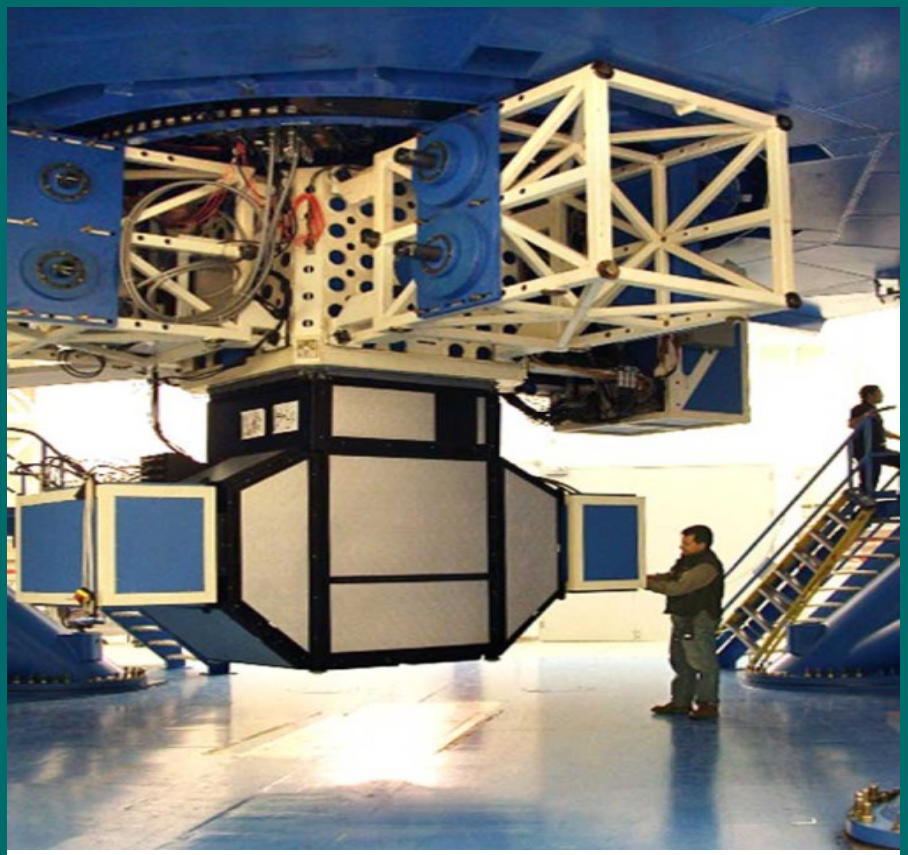


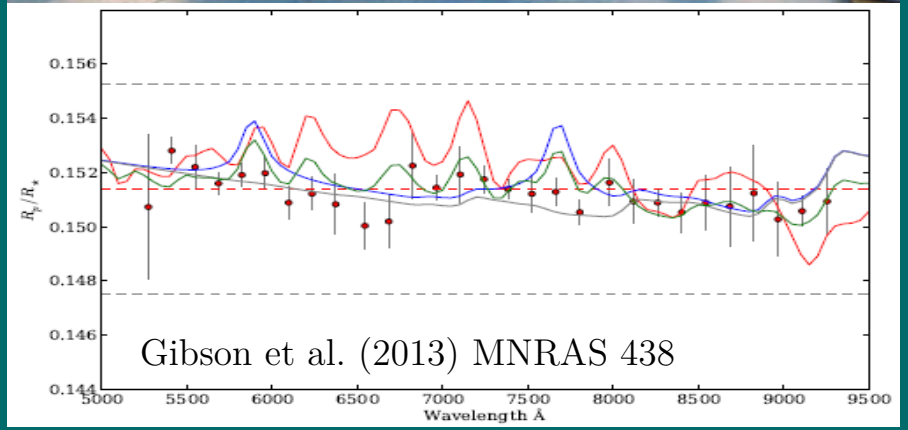
Deming et al. (2013) ApJ, 774, 95



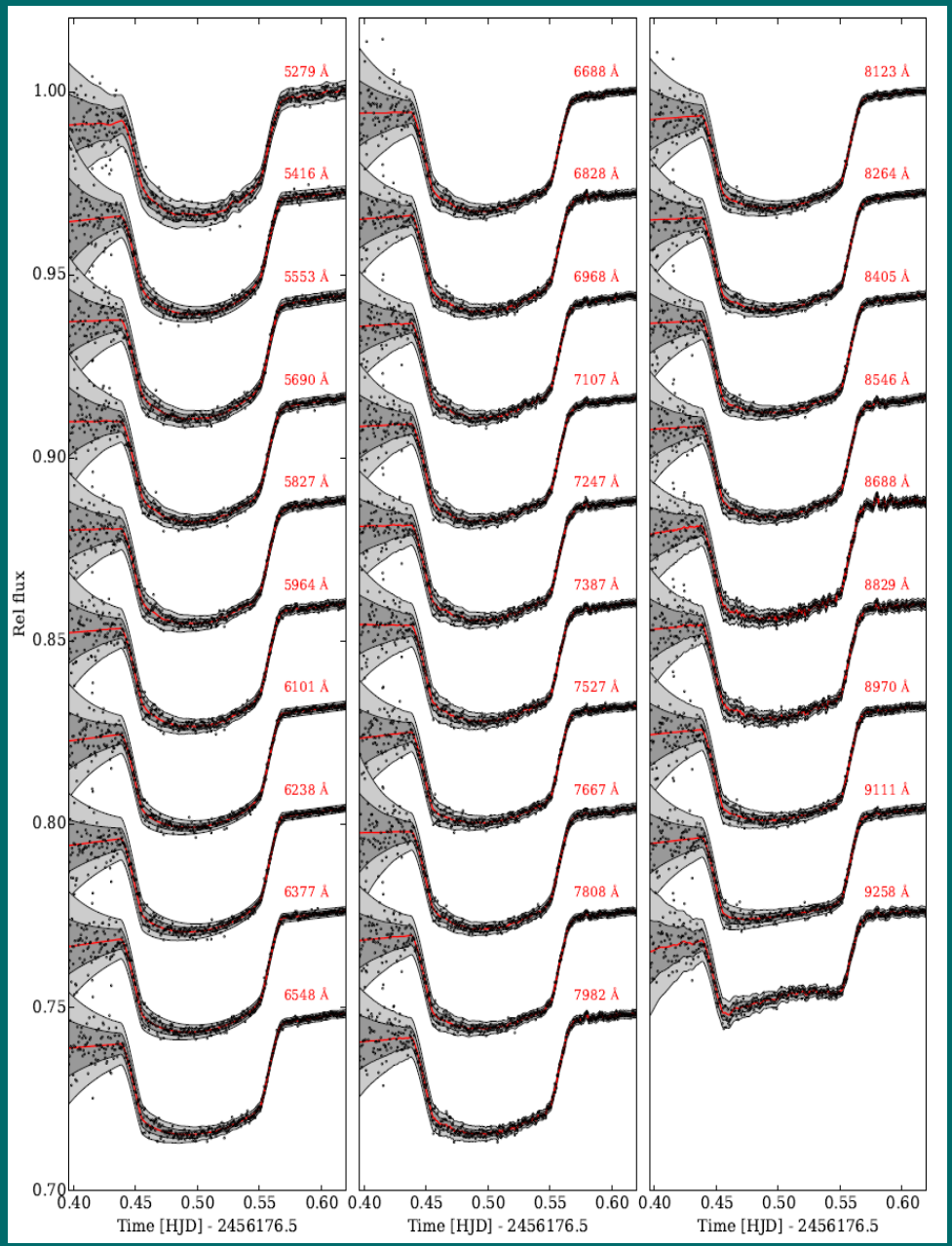
What ground-based instruments?

GMOS on 8.1m Gemini @ Cerro Pachón



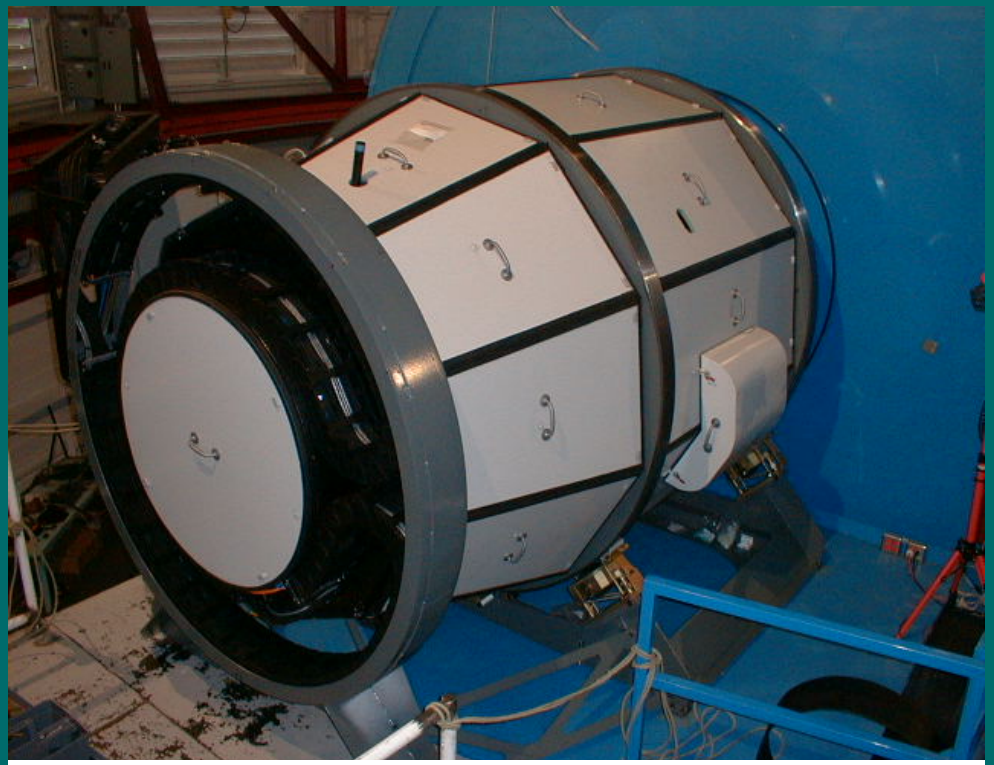


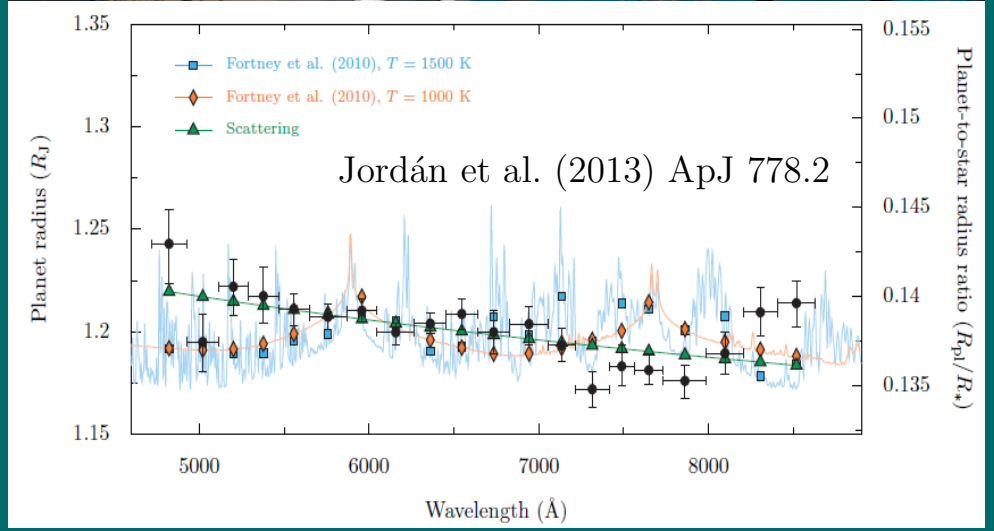
Gibson et al. (2013) MNRAS 438

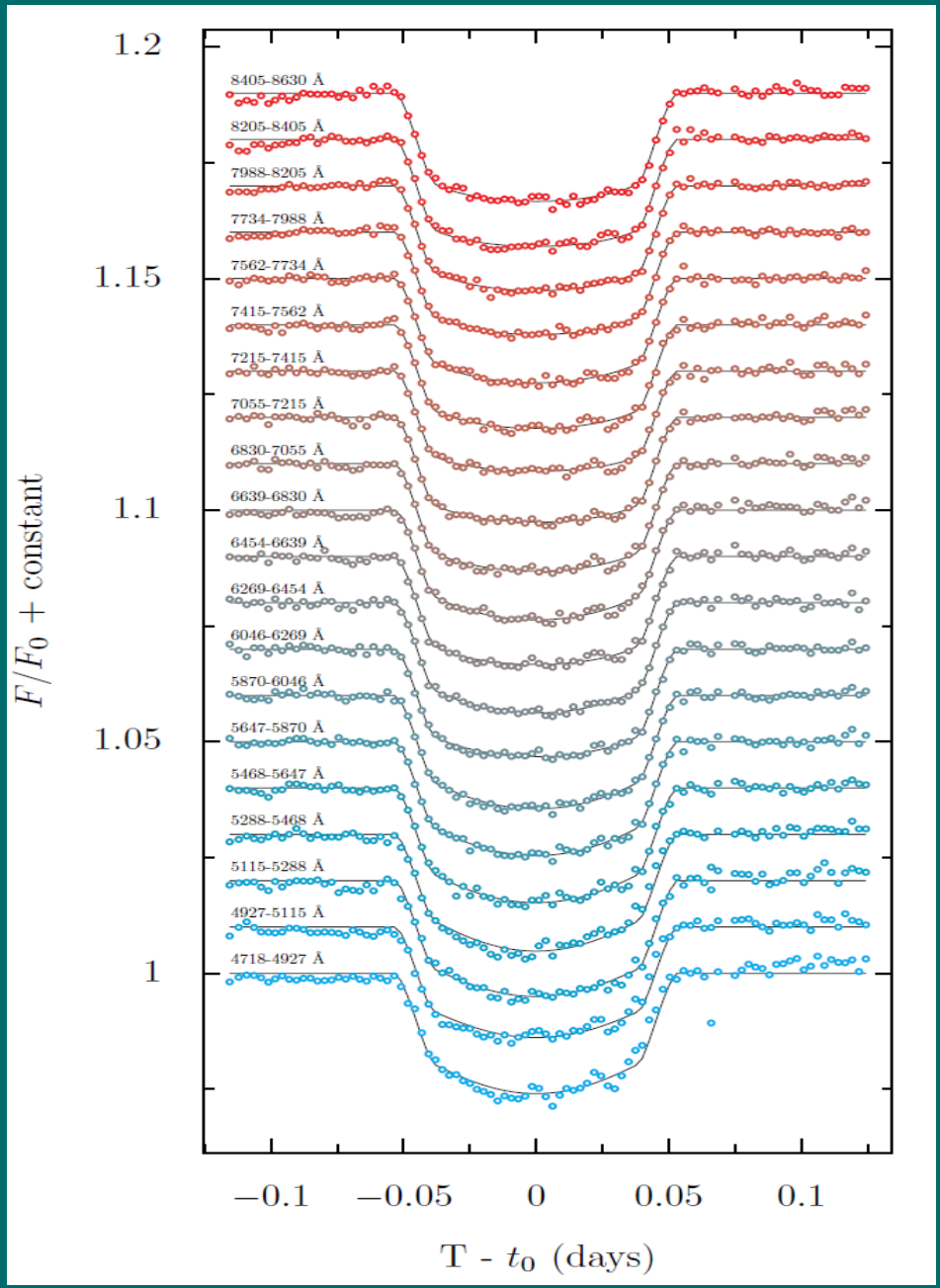


What ground-based instruments?

IMACS on 6.5m Magellan at Las Campanas

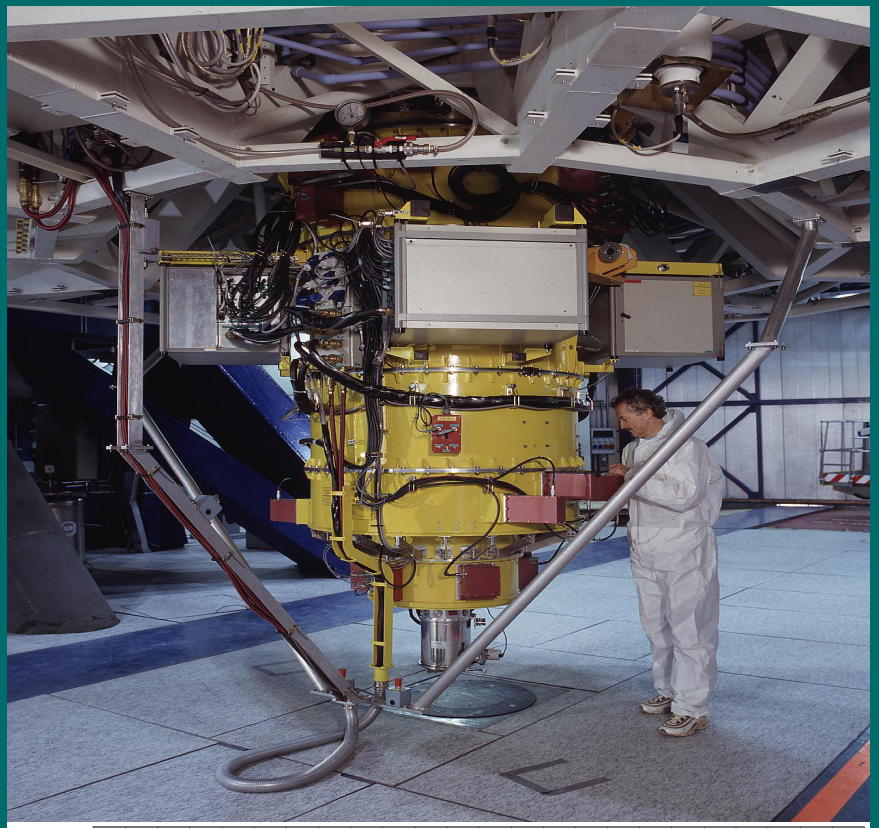


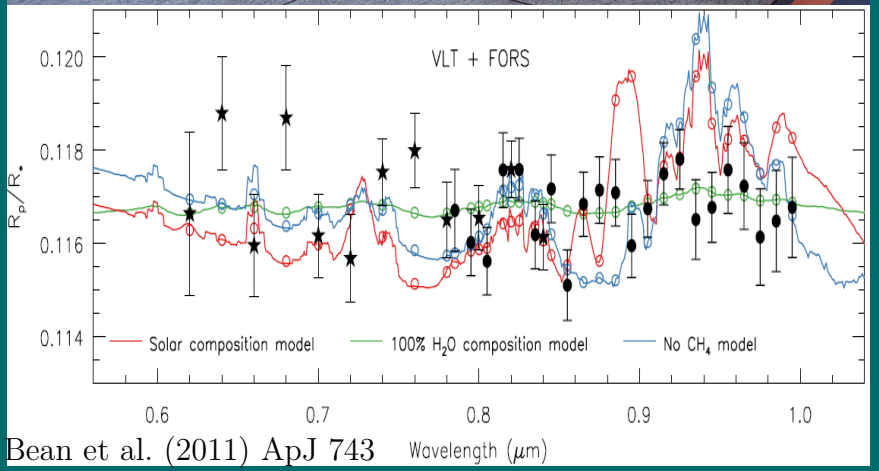




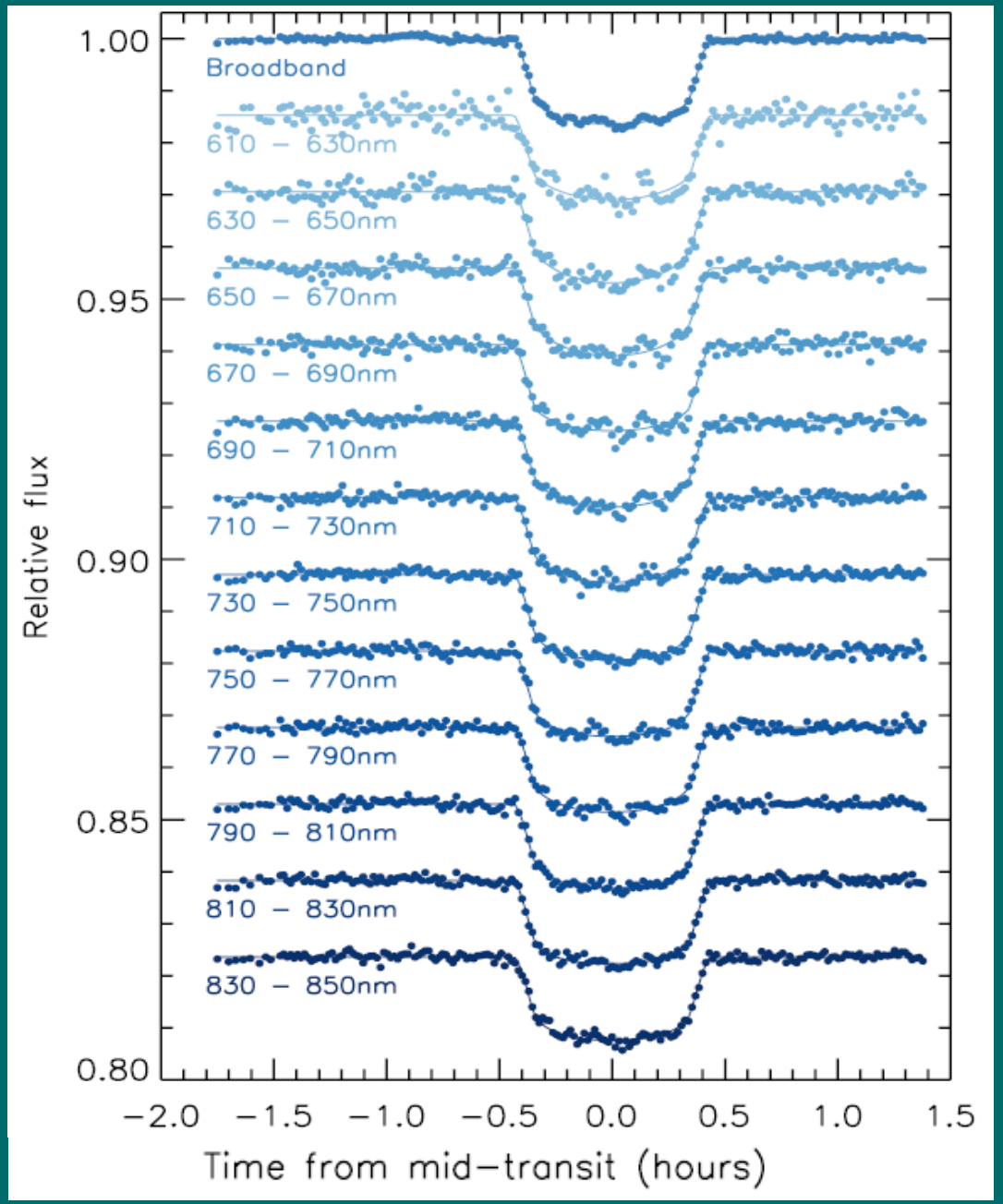
What ground-based instruments?

FORS2 on 8.2m VLT(UT1) at Paranal





Bean et al. (2011) ApJ 743



How is it done?

GJ1214b observations from Bean et al. (2010) ApJ 743

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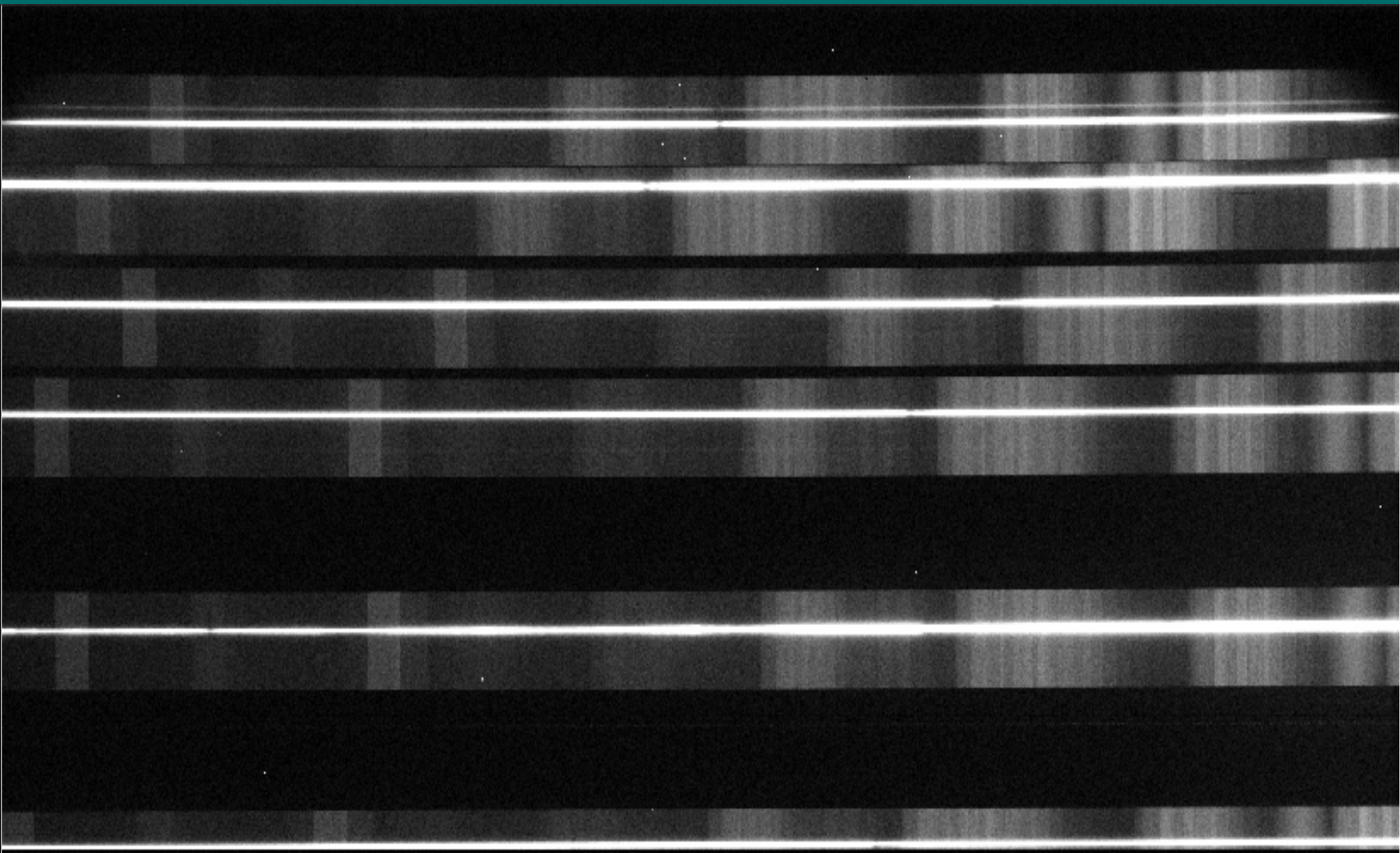
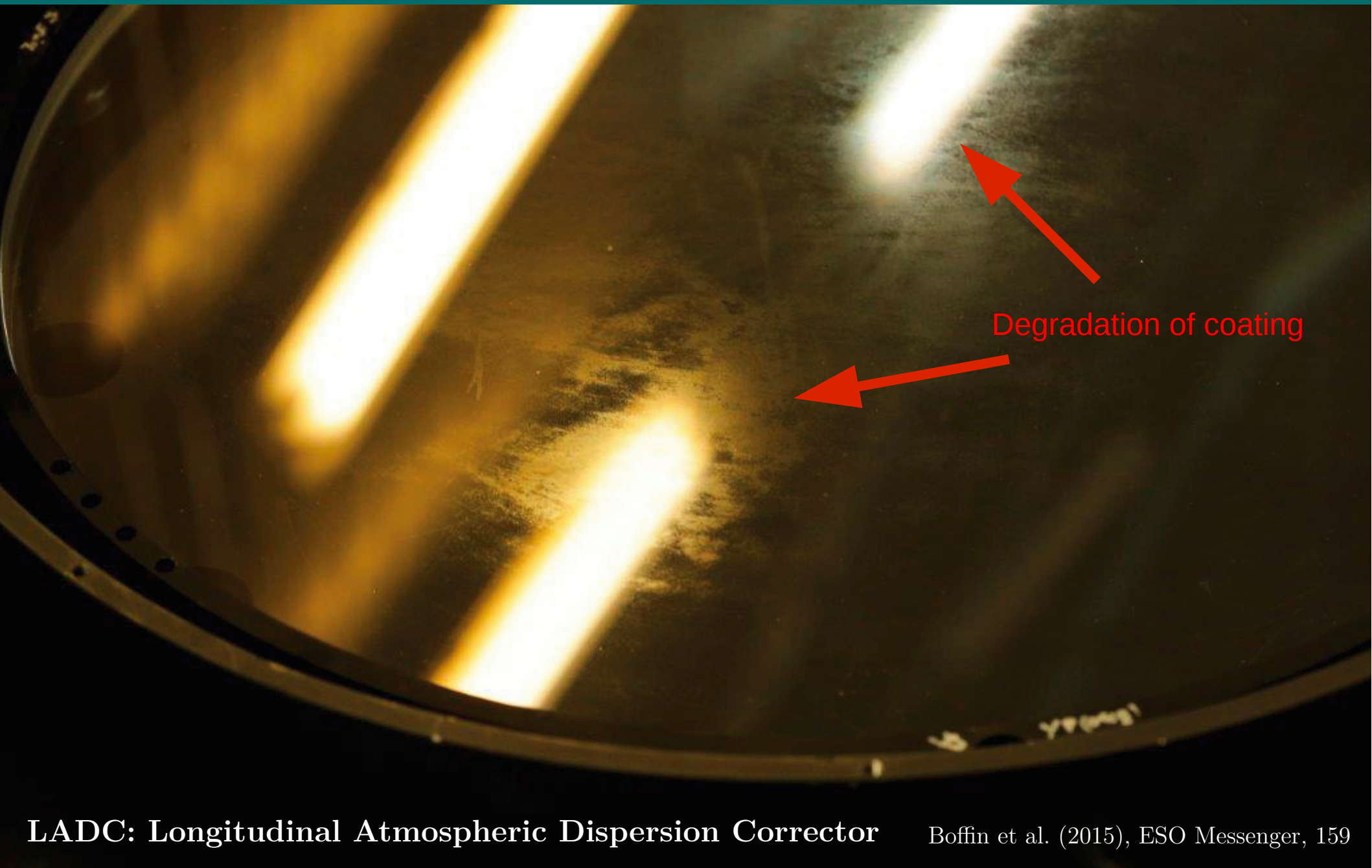


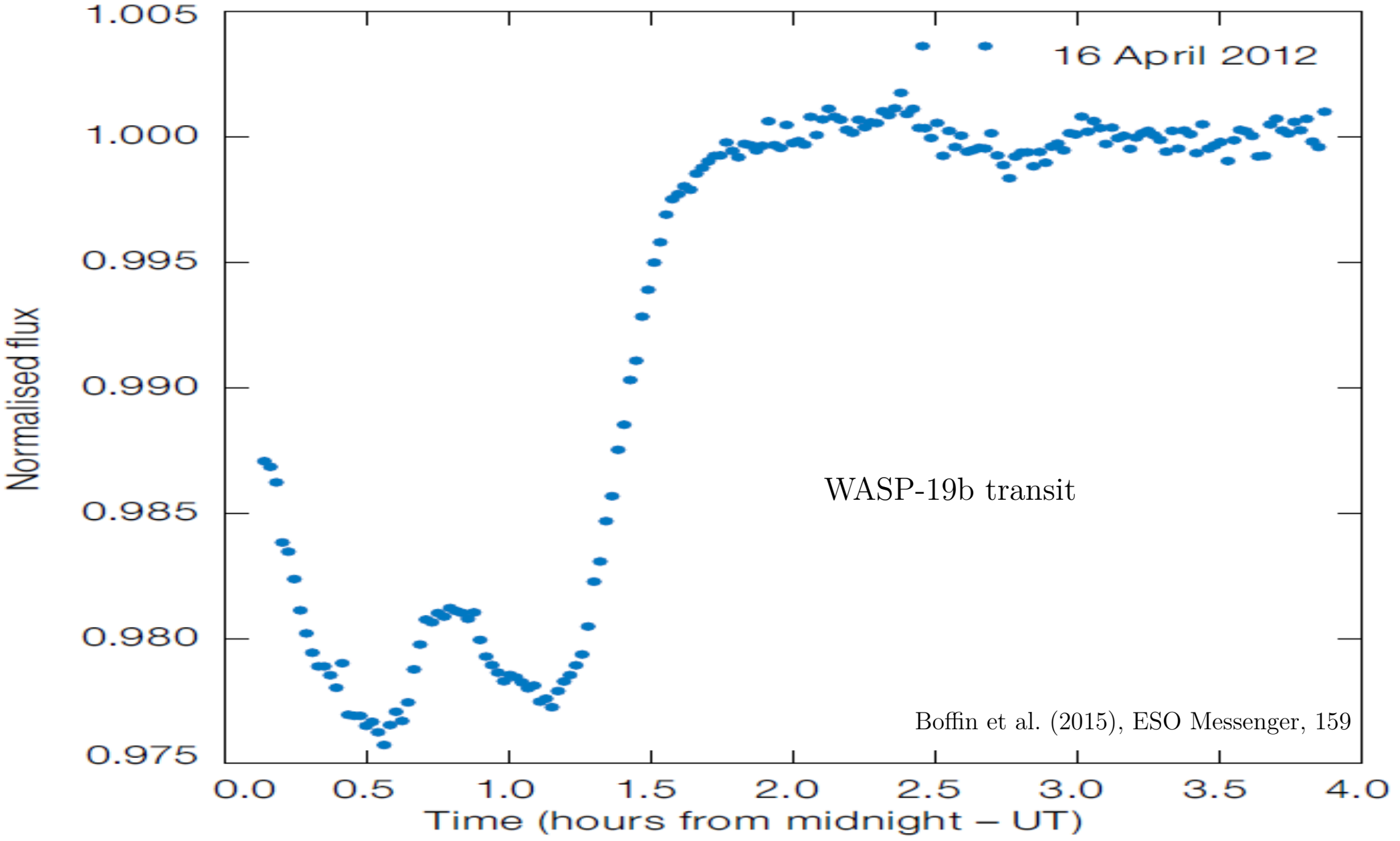
Systematic problems with FORS2



LADC: Longitudinal Atmospheric Dispersion Corrector

Boffin et al. (2015), ESO Messenger, 159

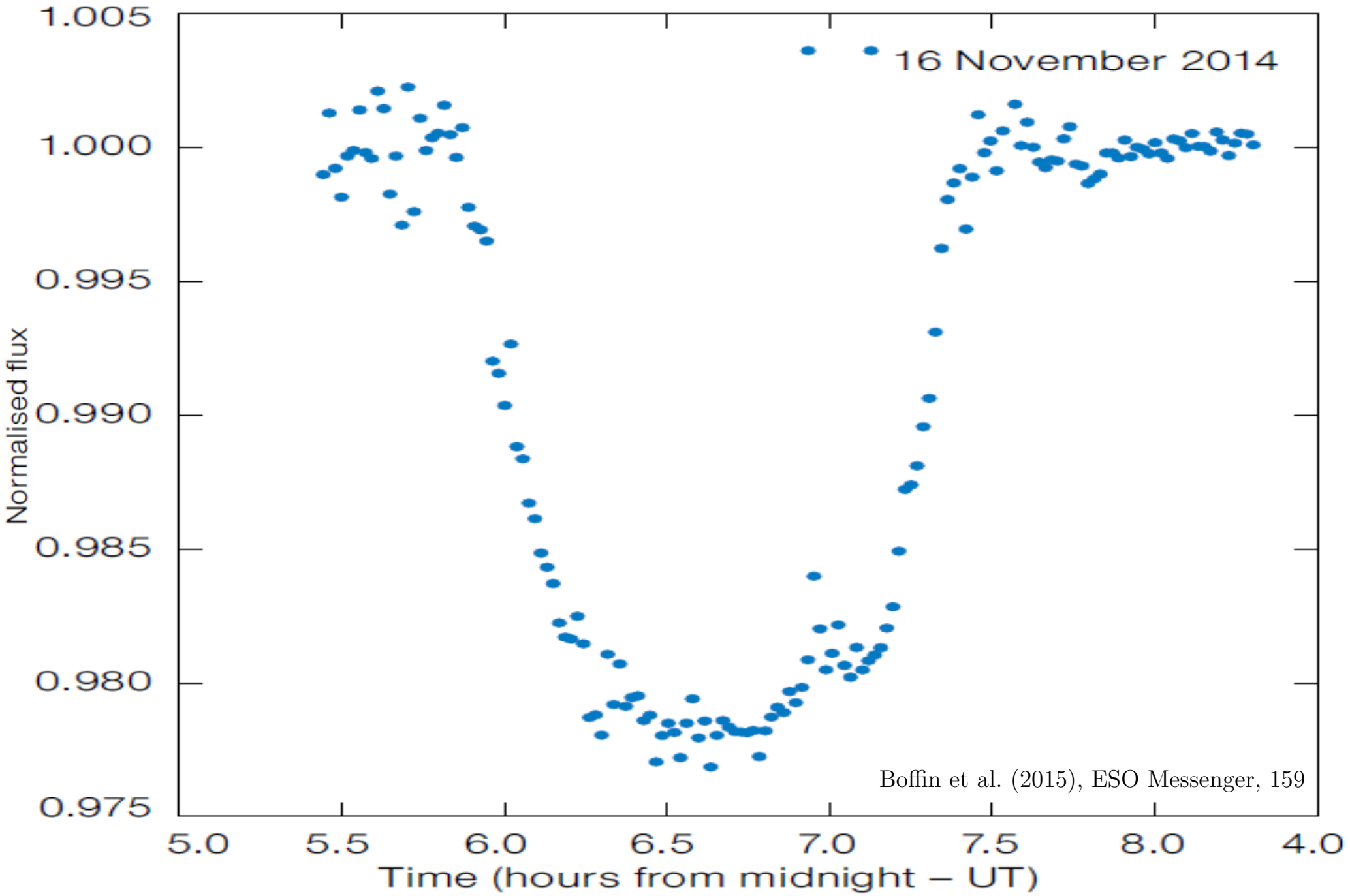
Manifestation in the light curve



Problem eradicated

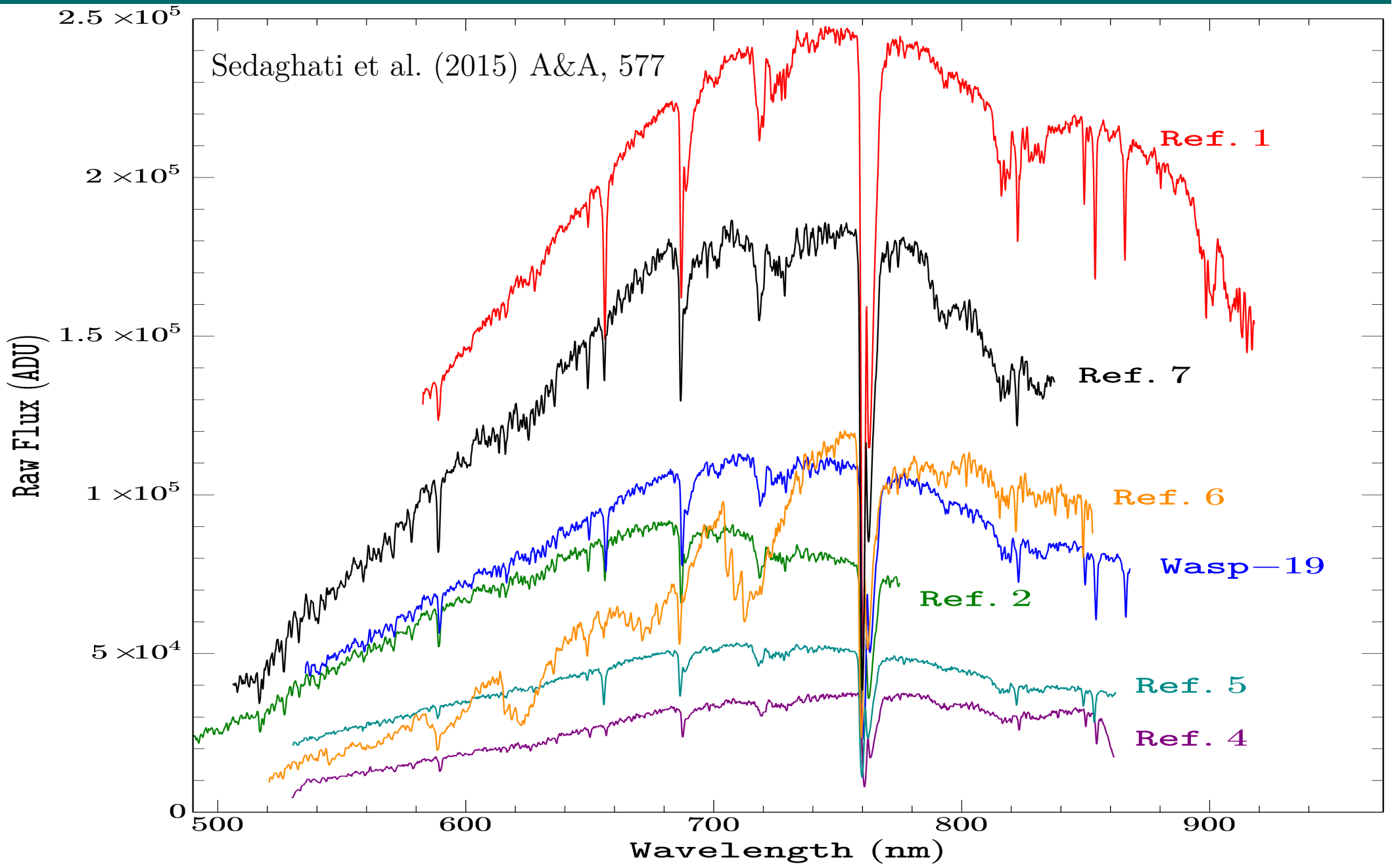
Boffin et al. (2015), ESO Messenger, 159

FORS is back!


16 November 2014
Normalised flux
1.005
1.000
0.995
0.990
0.985
0.980
0.975
5.0
5.5
6.0
6.5
7.0
7.5
8.0
4.0
Time (hours from midnight – UT)
Boffin et al. (2015), ESO Messenger, 159

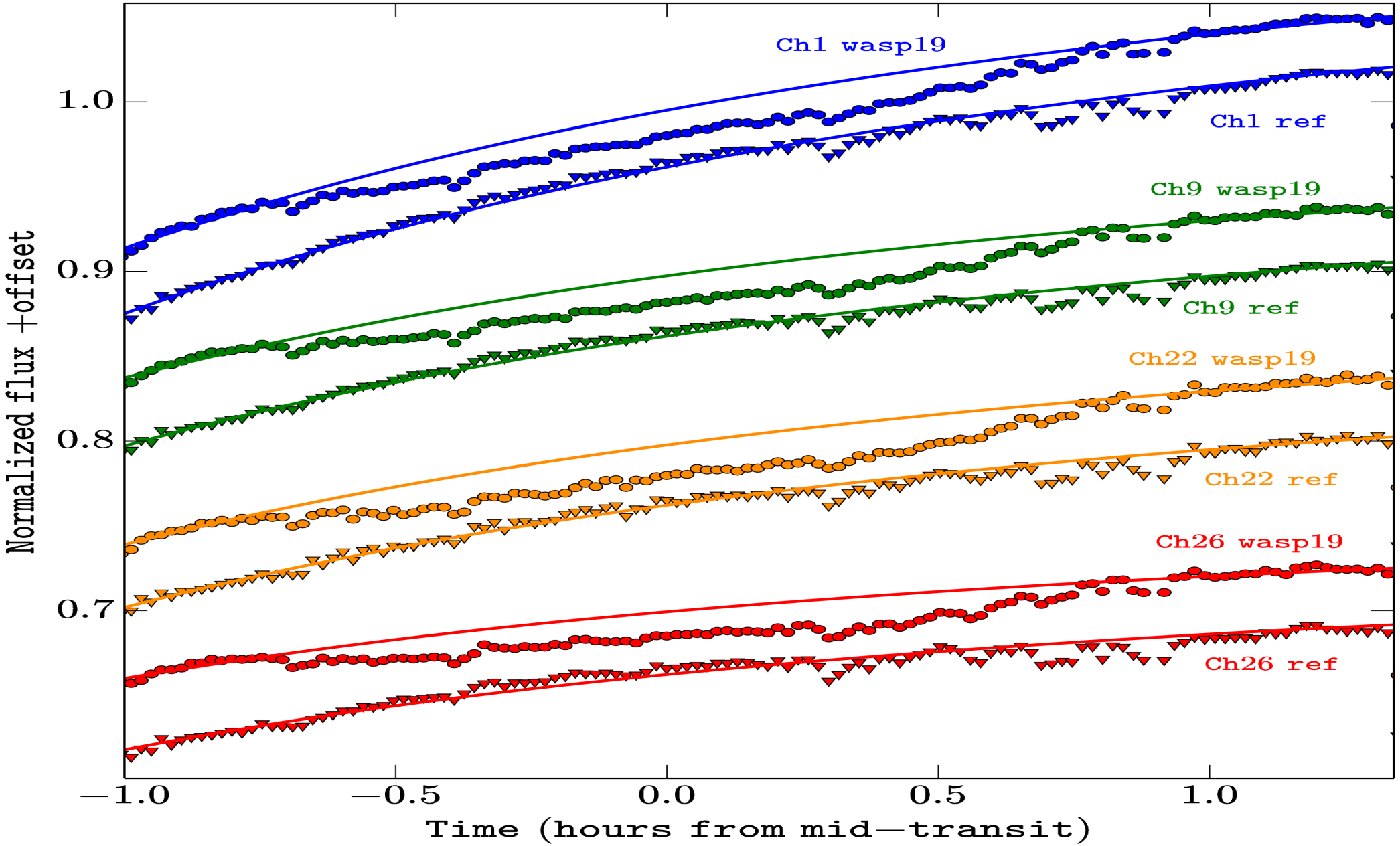
Transmission Spectroscopy with FORS2

Raw Spectra



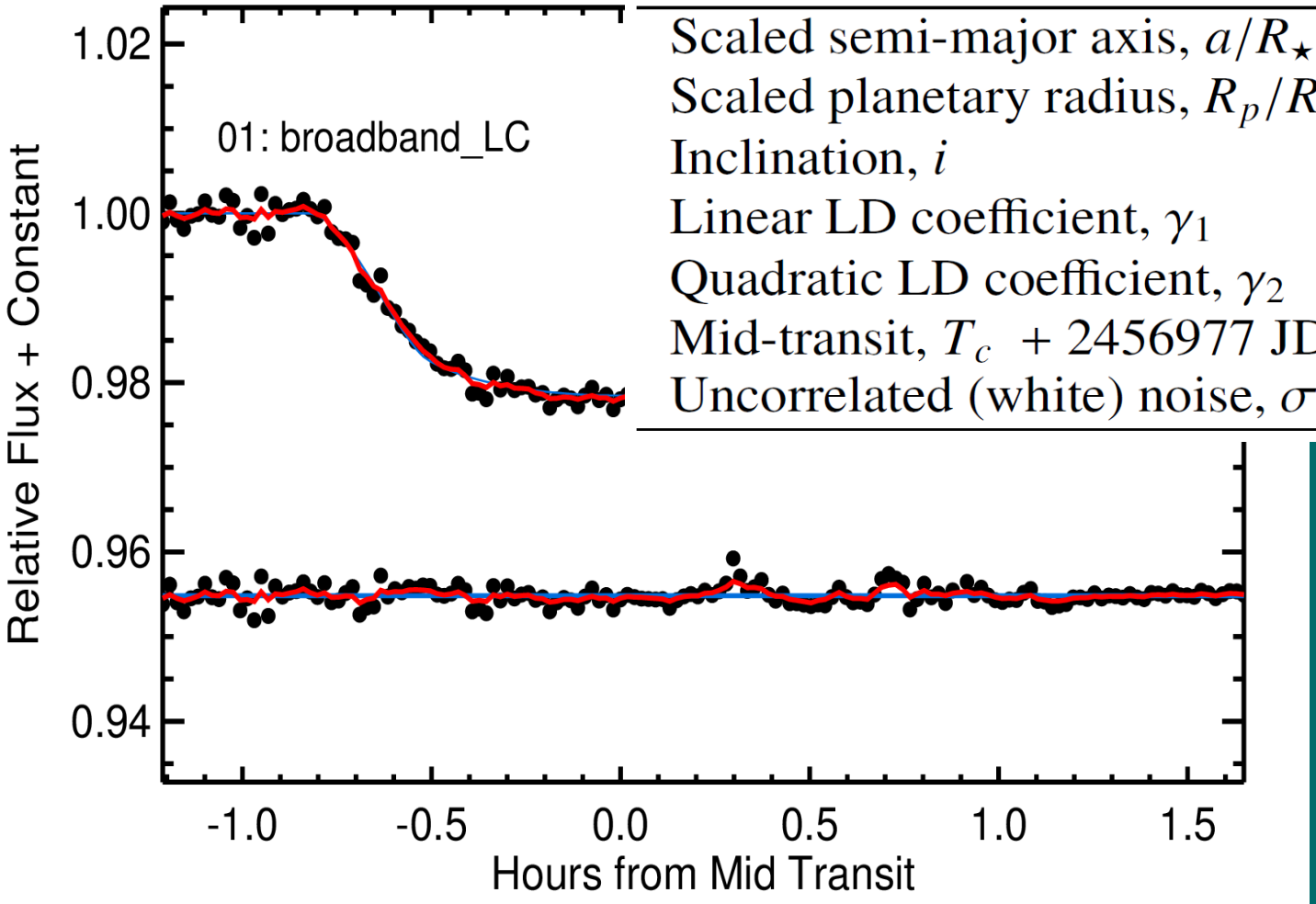
Transmission Spectroscopy with FORS2

Time-series light curve



Transmission Spectroscopy with FORS2

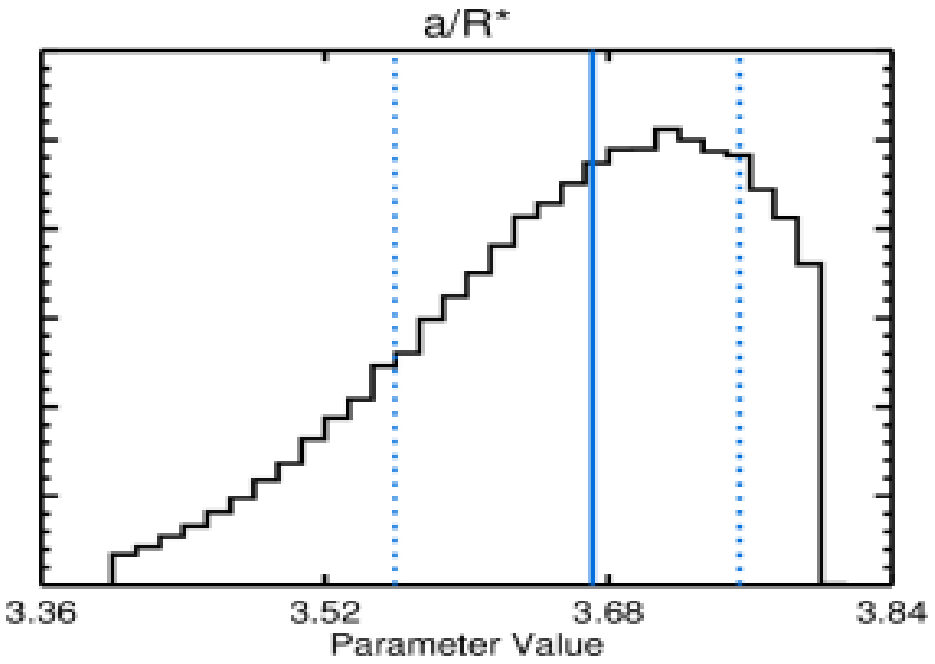
Broadband (white) light curve model

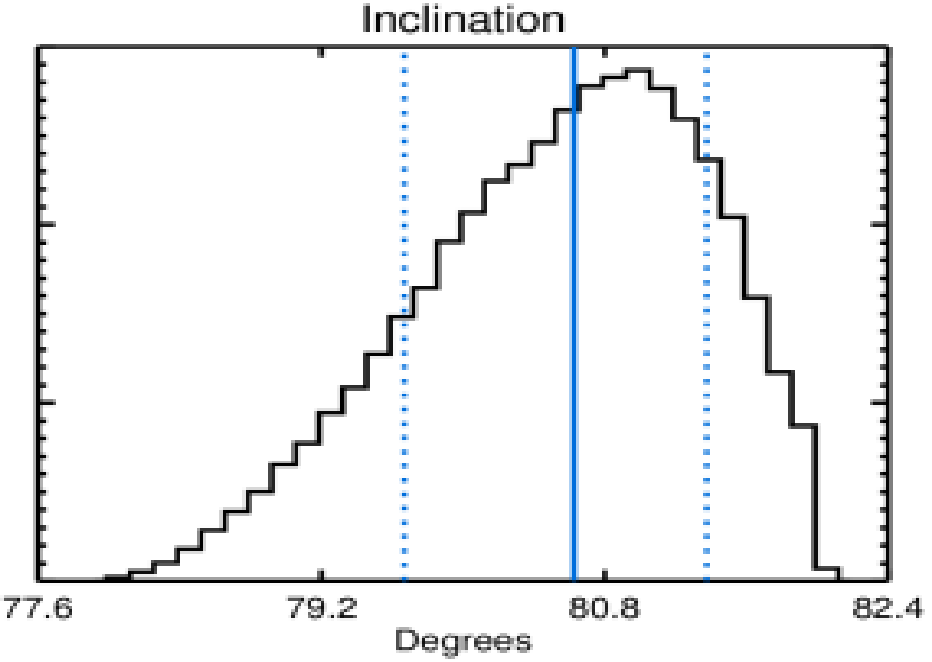


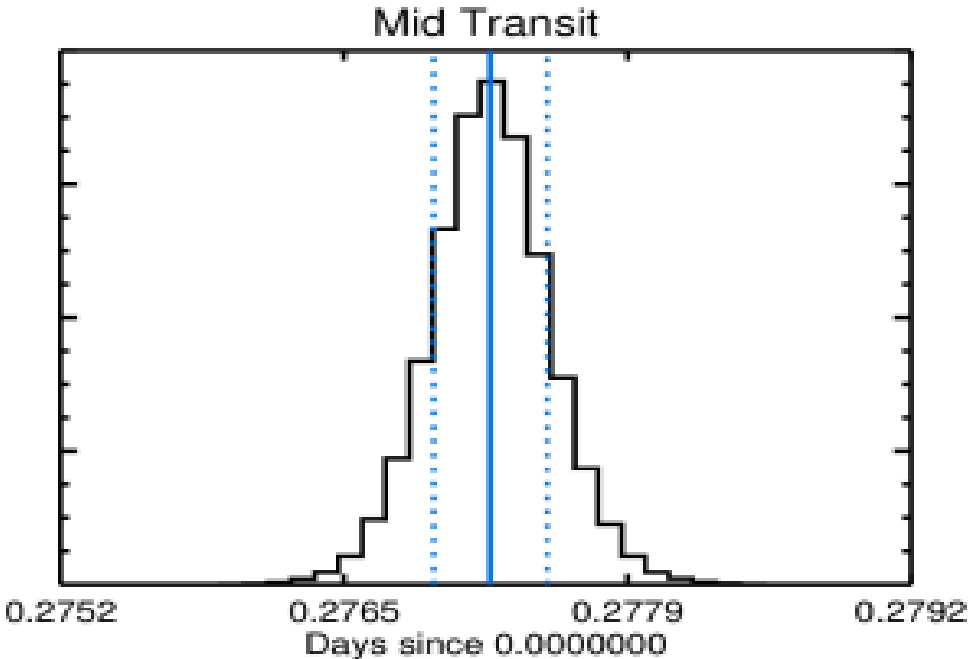
Parameter	Value
Scaled semi-major axis, $a/R_\star$	$3.656\ ^{+0.086}_{-0.097}$
Scaled planetary radius, $R_p/R_\star$	$0.1416^{+0.0019}_{-0.0018}$
Inclination, i	$80.36^\circ\ ^{+0.76}_{-0.81}$
Linear LD coefficient, γ_1	$0.391\ ^{+0.092}_{-0.096}$
Quadratic LD coefficient, γ_2	$0.225\ ^{+0.052}_{-0.050}$
Mid-transit, T_c + 2456977 JD	$0.77722 \pm 1.3\times10^{-4}$
Uncorrelated (white) noise, σ_w	697 ± 65 μmag

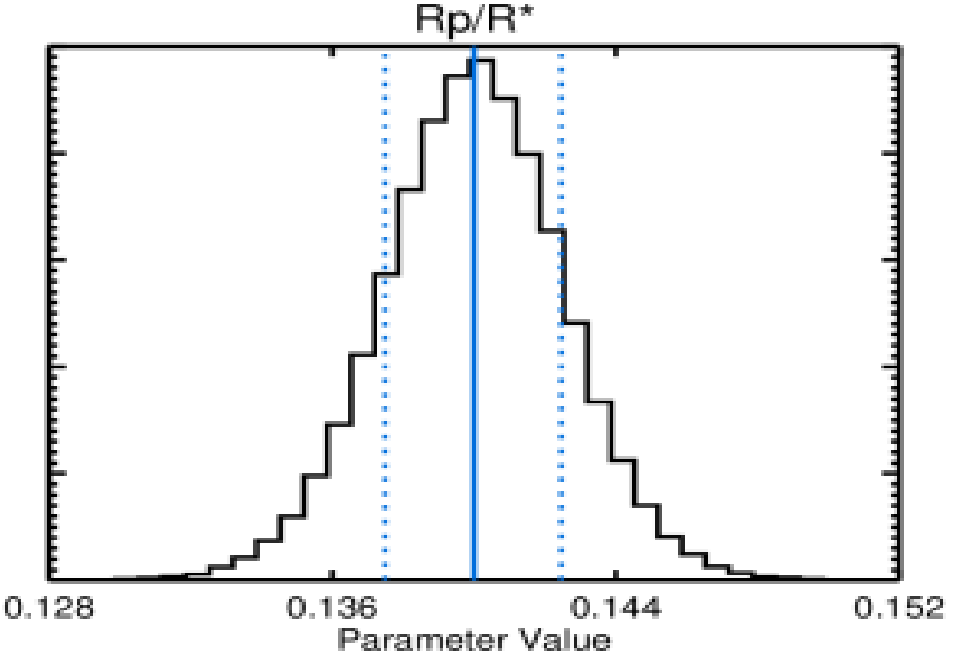
Sedaghati et al. (2015)

Parameter extraction









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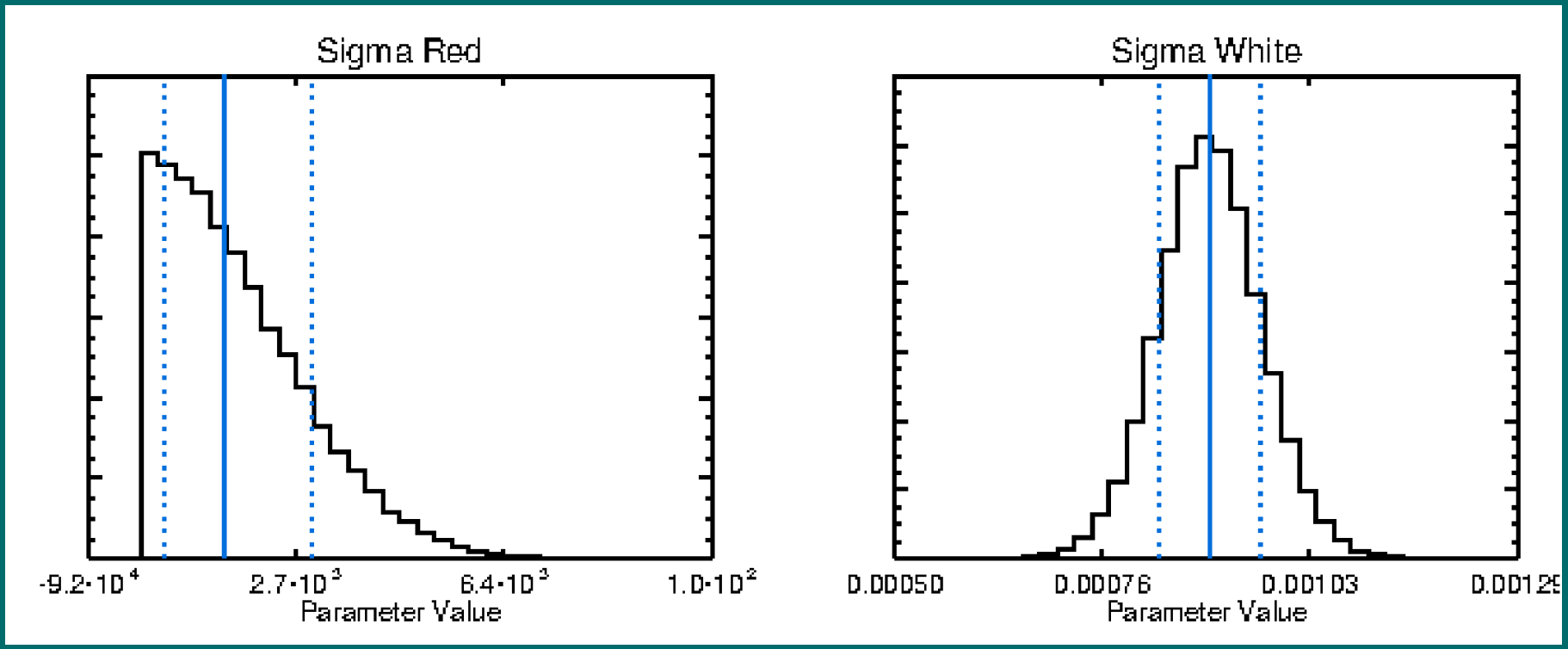
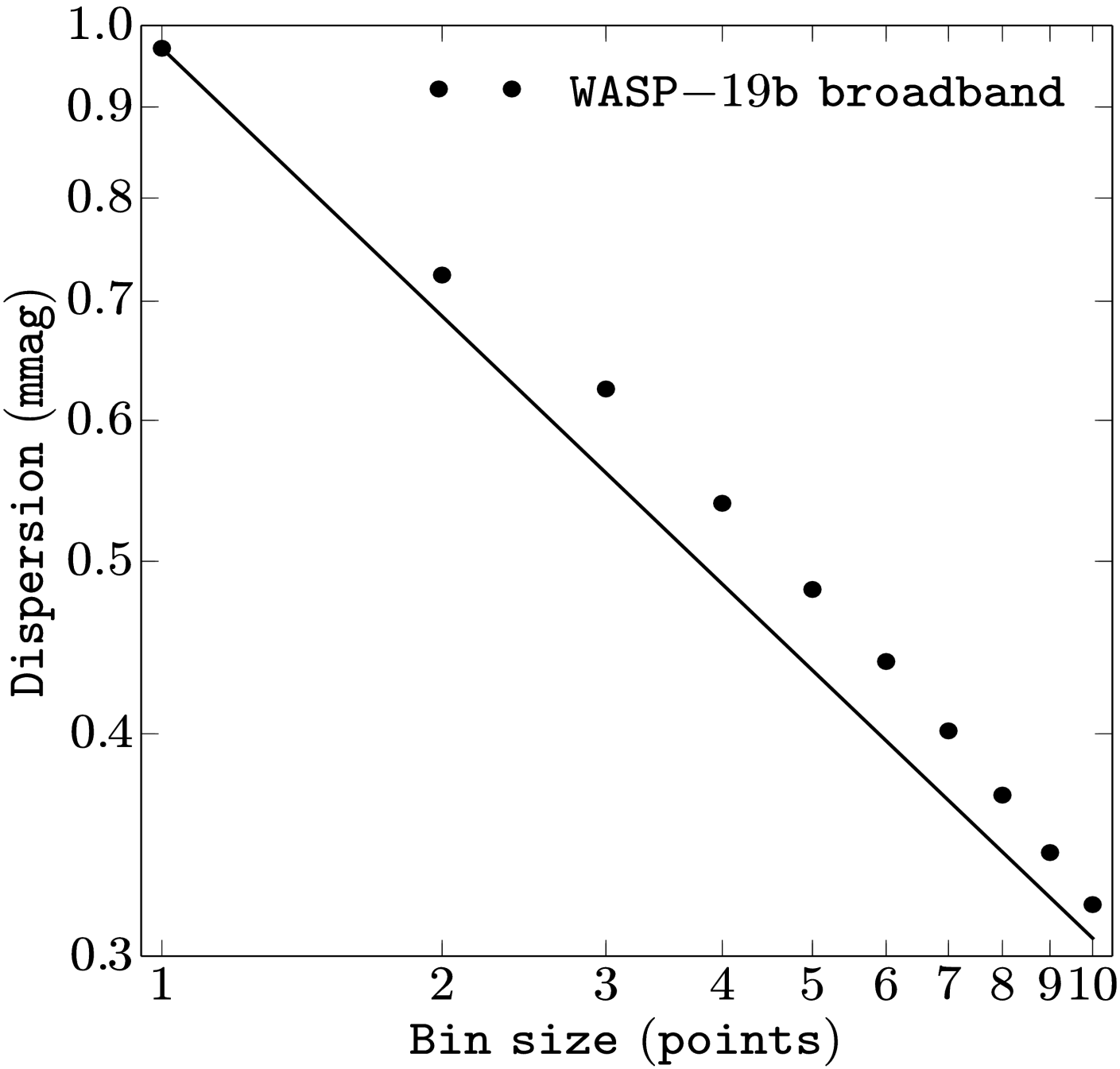


Correlated (red) noise very much minimized!!

Systematics under control ☺ ☻

A closer look at the systematics



From:

$$\sigma_1^2 = \sigma_w^2 + \sigma_r^2$$

$$\sigma_{10}^2 = \frac{\sigma_w^2}{10} + \sigma_r^2$$

Gillon et al. (2006)A&A,459,249

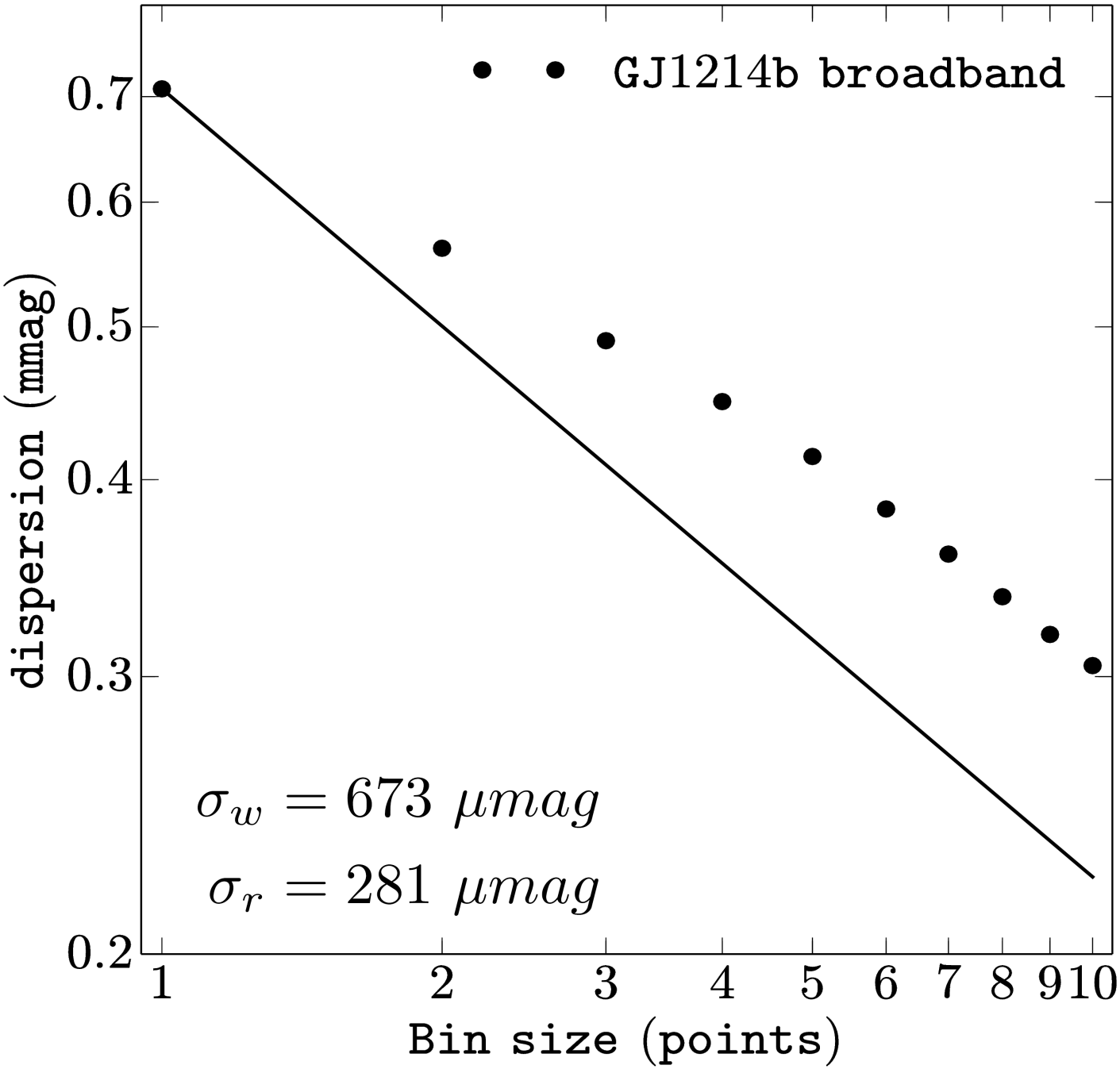
we estimate:

$$\sigma_w = 579\ \mu mag$$

$$\sigma_r = 169\ \mu mag$$

for the broadband LC.

A closer look at the systematics



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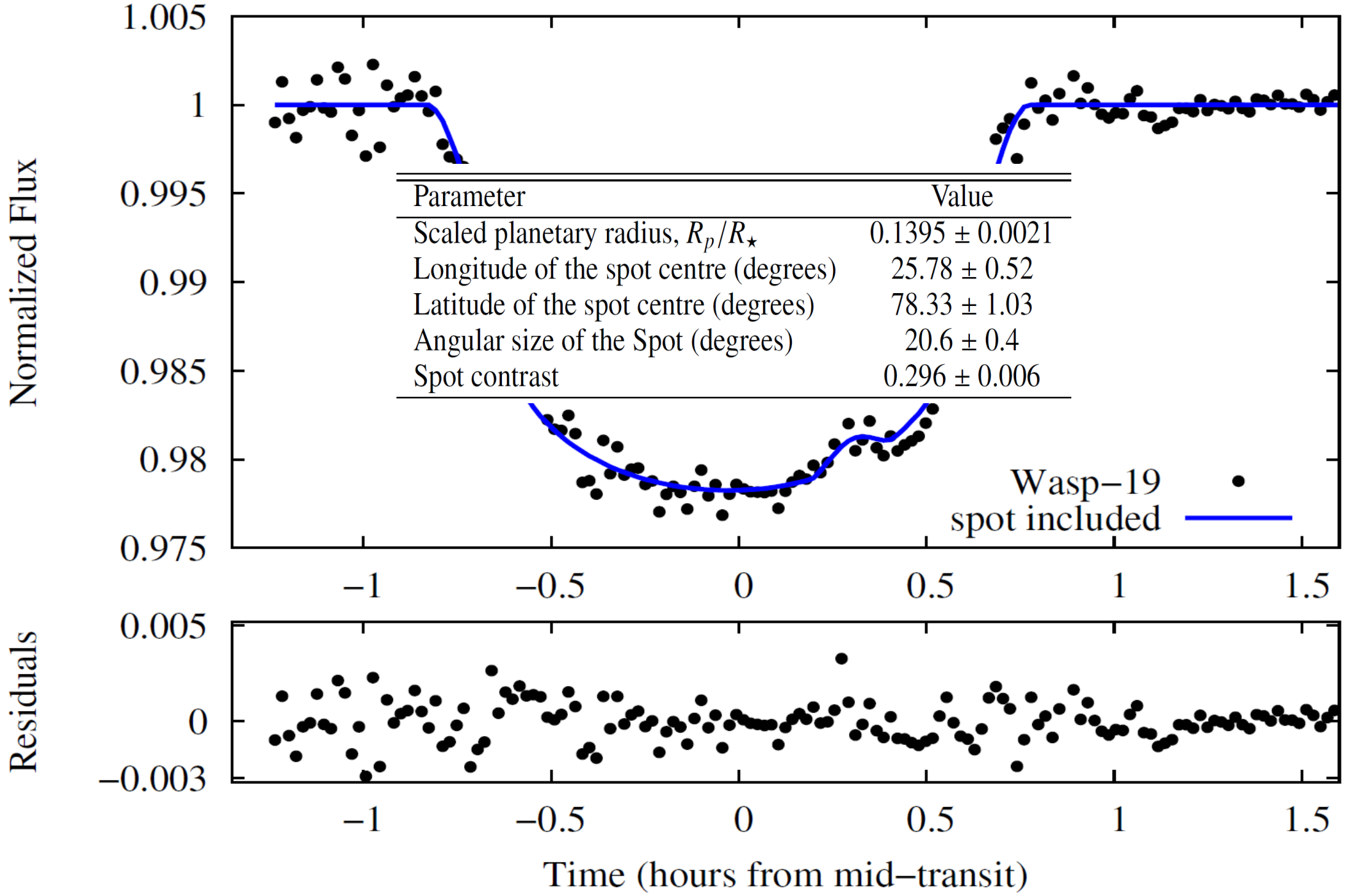
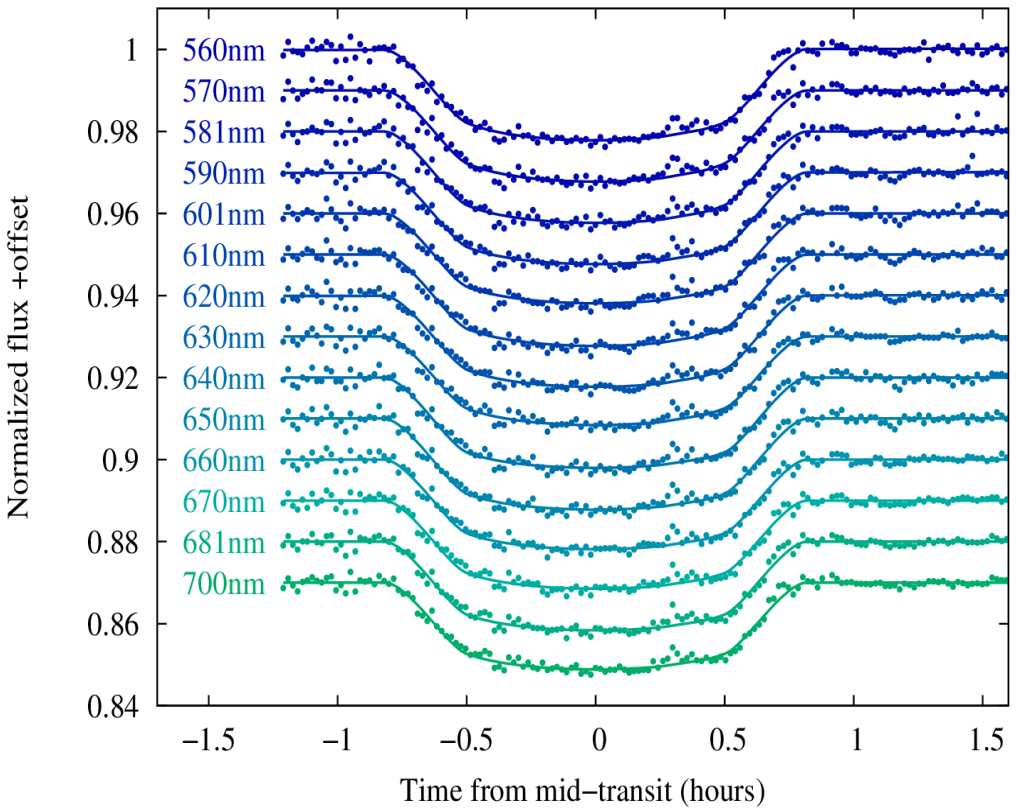
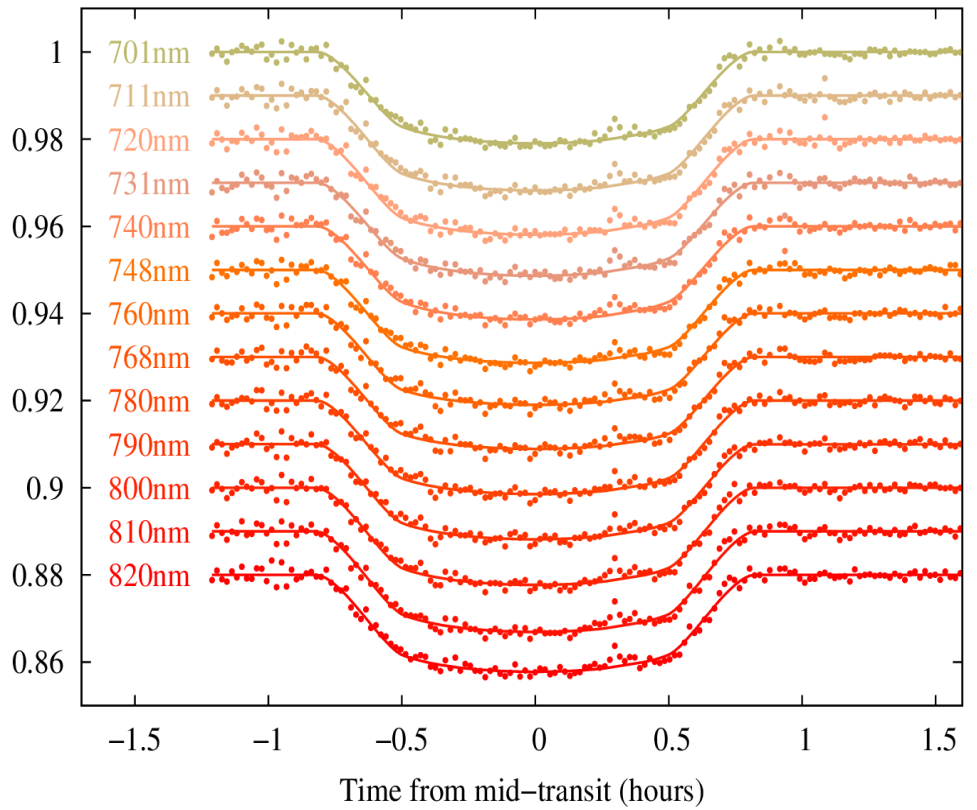
Spotting a spot?



Parameter	Value
Scaled planetary radius, $R_p/R_\star$	0.1395 ± 0.0021
Longitude of the spot centre (degrees)	25.78 ± 0.52
Latitude of the spot centre (degrees)	78.33 ± 1.03
Angular size of the Spot (degrees)	20.6 ± 0.4
Spot contrast	0.296 ± 0.006

Spectrophotometric light curves

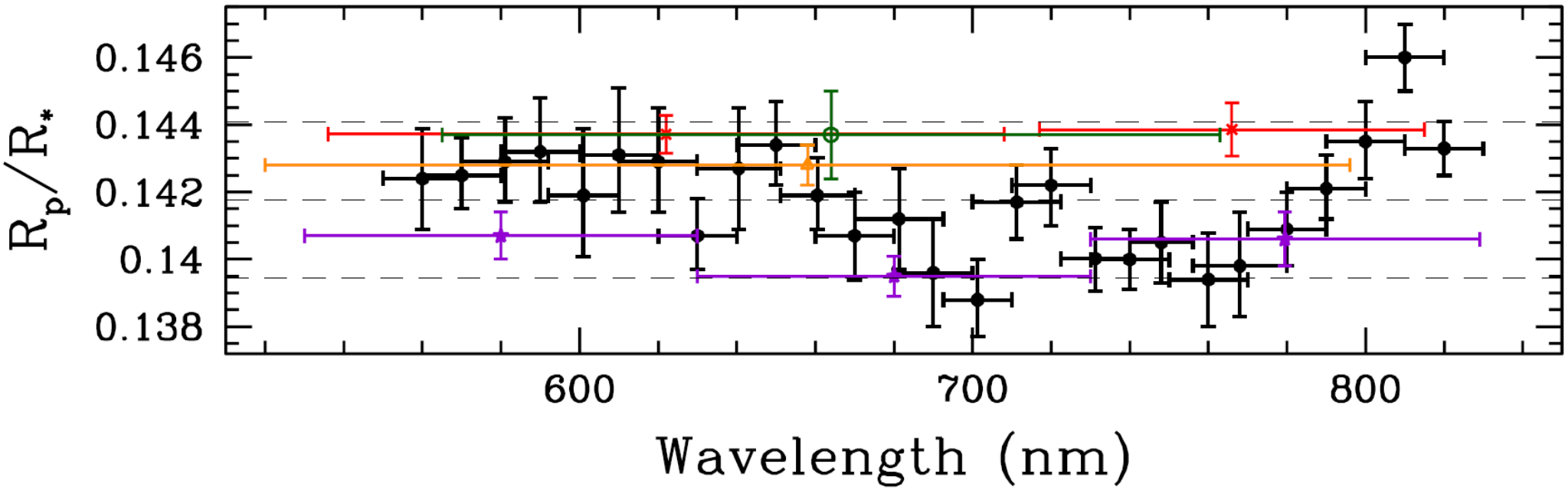




- All non-wavelength dependent parameters fixed to the white LC solution
- Only scaled planetary radius, Limb darkening coefficients & noise model parameters free

Transmission spectrum

Literature comparison



Black filled circles: Sedaghati et al. (2015), FORS2+VLT spec.

Purple filled stars: Huitson et al. (2013), STIS+HST spec.

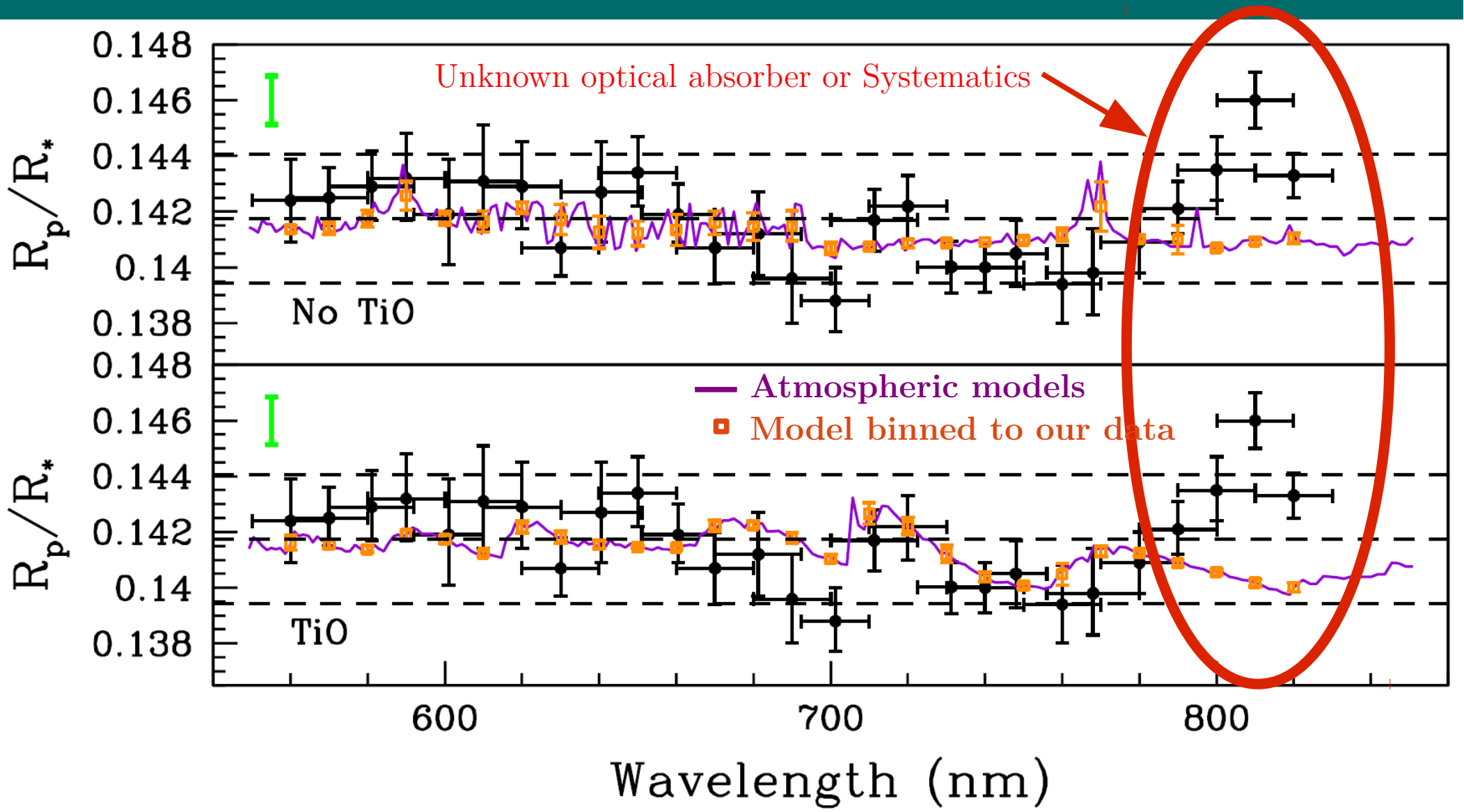
Red crosses: Mancini et al. (2013), 1.54 Danish, PEST, GROND phot.

Green cricle: Lendl et al. (2013), HAWK-I/VLT, EulerCam phot.

Orange triangle: Tregloan-Reed (2013), EFOSC2/NTT phot.

Transmission spectrum

Atmospheric model comparison

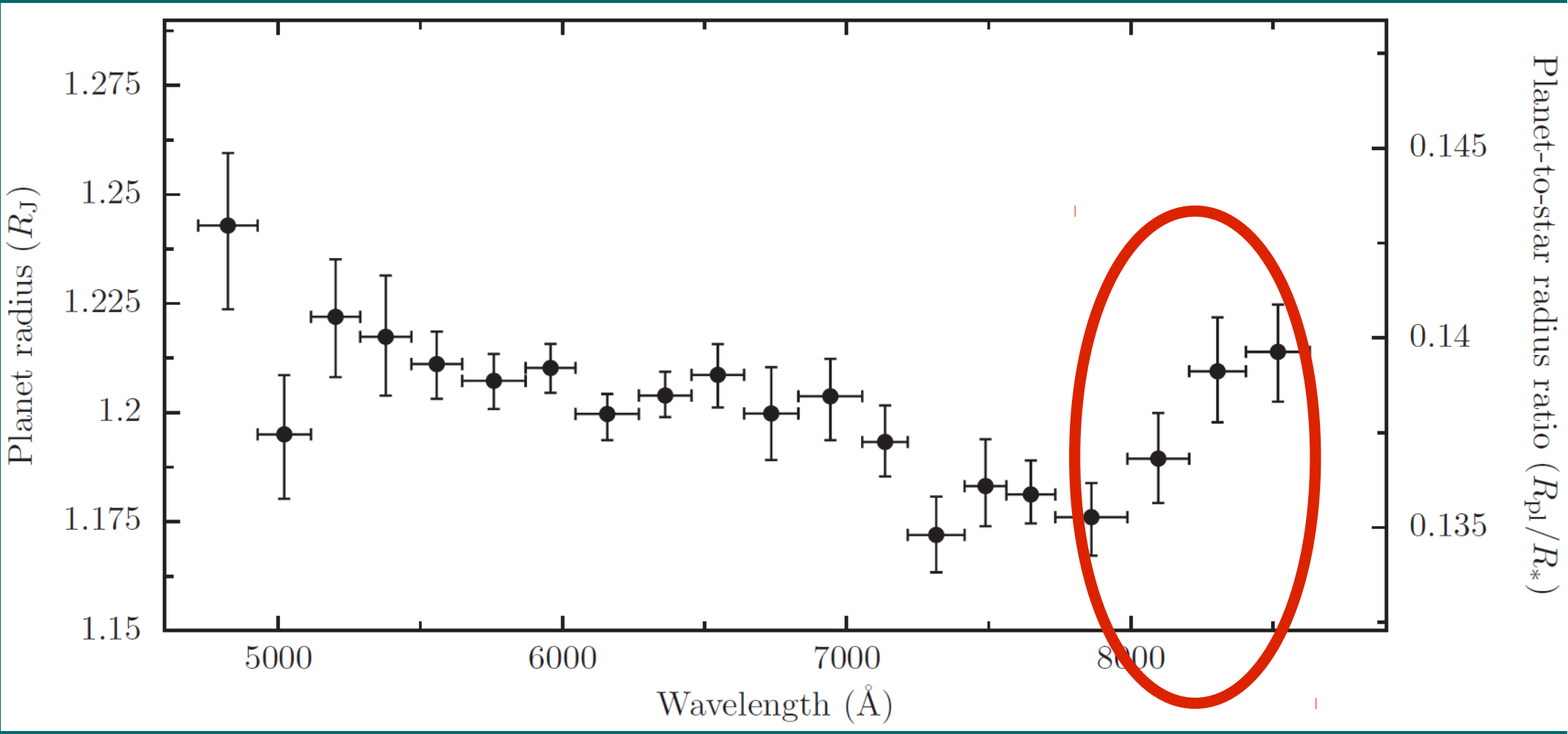


Sedaghati et al. (2015)

Atmospheric models from Burrows et al. (2010) ApJ, 791, 341

Transmission spectrum

Coincidence??



Transmission spectrum of WASP-6b with IMACS/Magellan

Jordán et al. (2013) ApJ, 778, 184

Conclusions & Outlook

- FORS2 now ready for multi-object spec. obs.
- Transmission spectrum of WASP-19b with feature due to unknown optical absorbers
- Global effort required to obtain a statistically large sample of atmospheric spectra
- FORS2 will be key to this effort

Estimating spot impact