

Exploring the atmospheres of exoplanet using the GTC

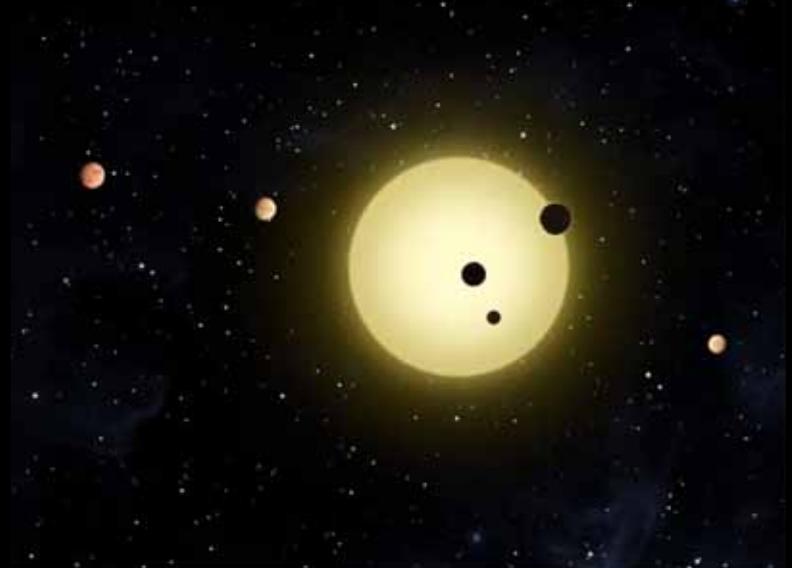


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¿Qué hemos aprendido?

- Por lo menos un 20-30% estrellas “tipo solar” albergan planetas
- Cada estrella tiene por lo menos 1 planeta
- Los sistemas planetarios múltiples son extremadamente comunes
- Los sistemas planetarios con uno o varios planetas terrestres también



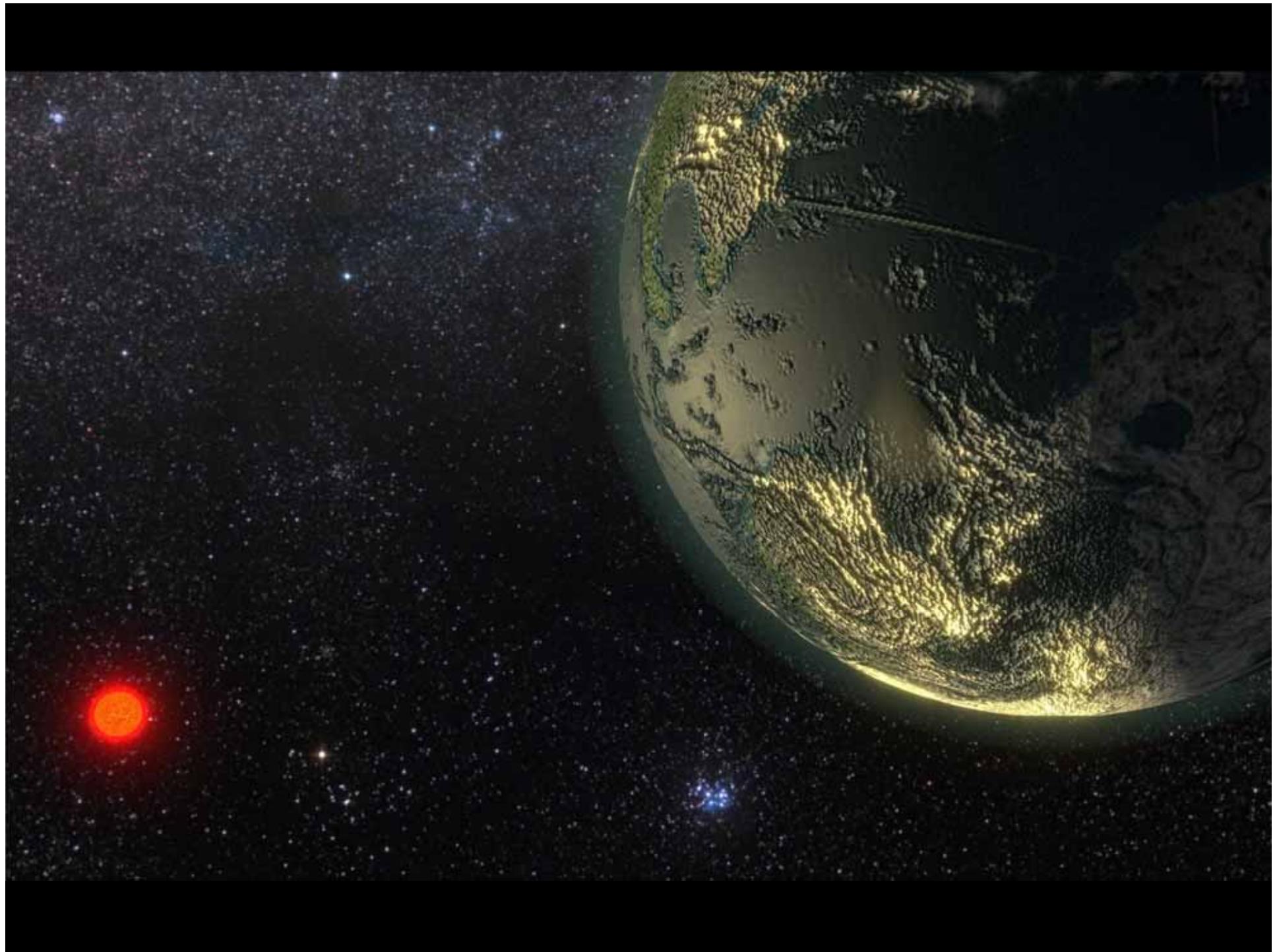
Nuestros vecinos mas cercanos. Un planeta en Alpha Centaury

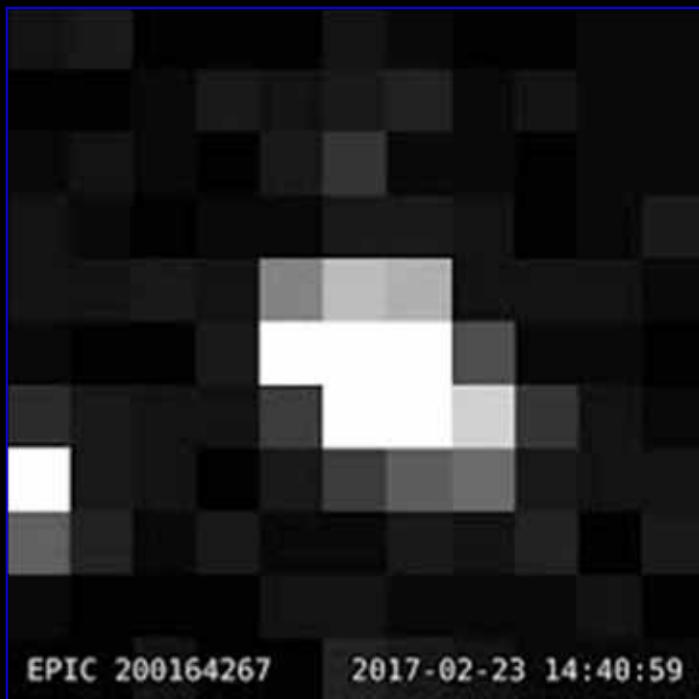


Earth



Proxima b
(artistic representation)



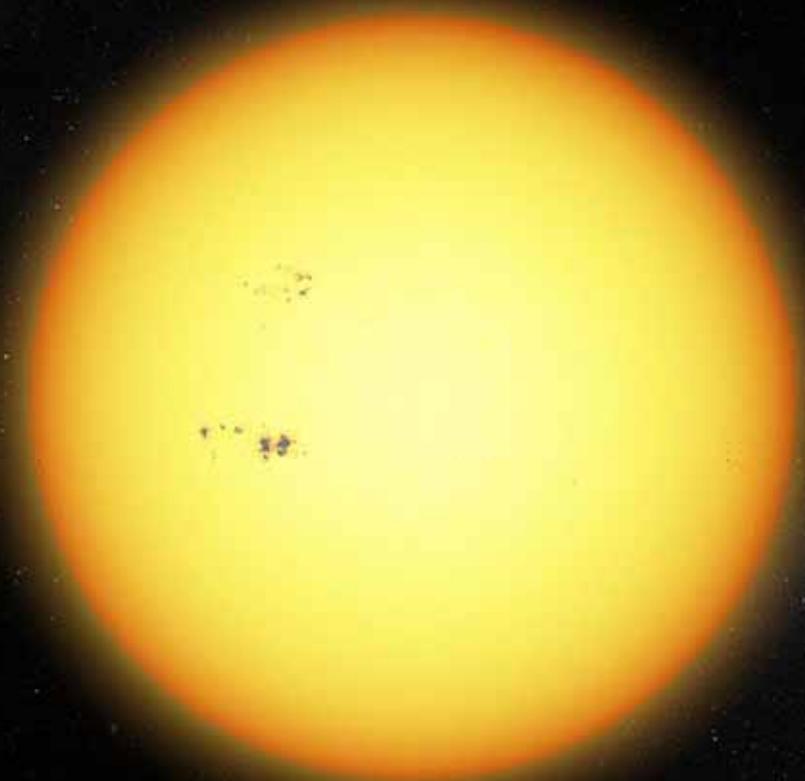


EPIC 200164267

2017-02-23 14:40:59

Planetas TRANSITAN
=
mucho mas fáciles de
caracterizar

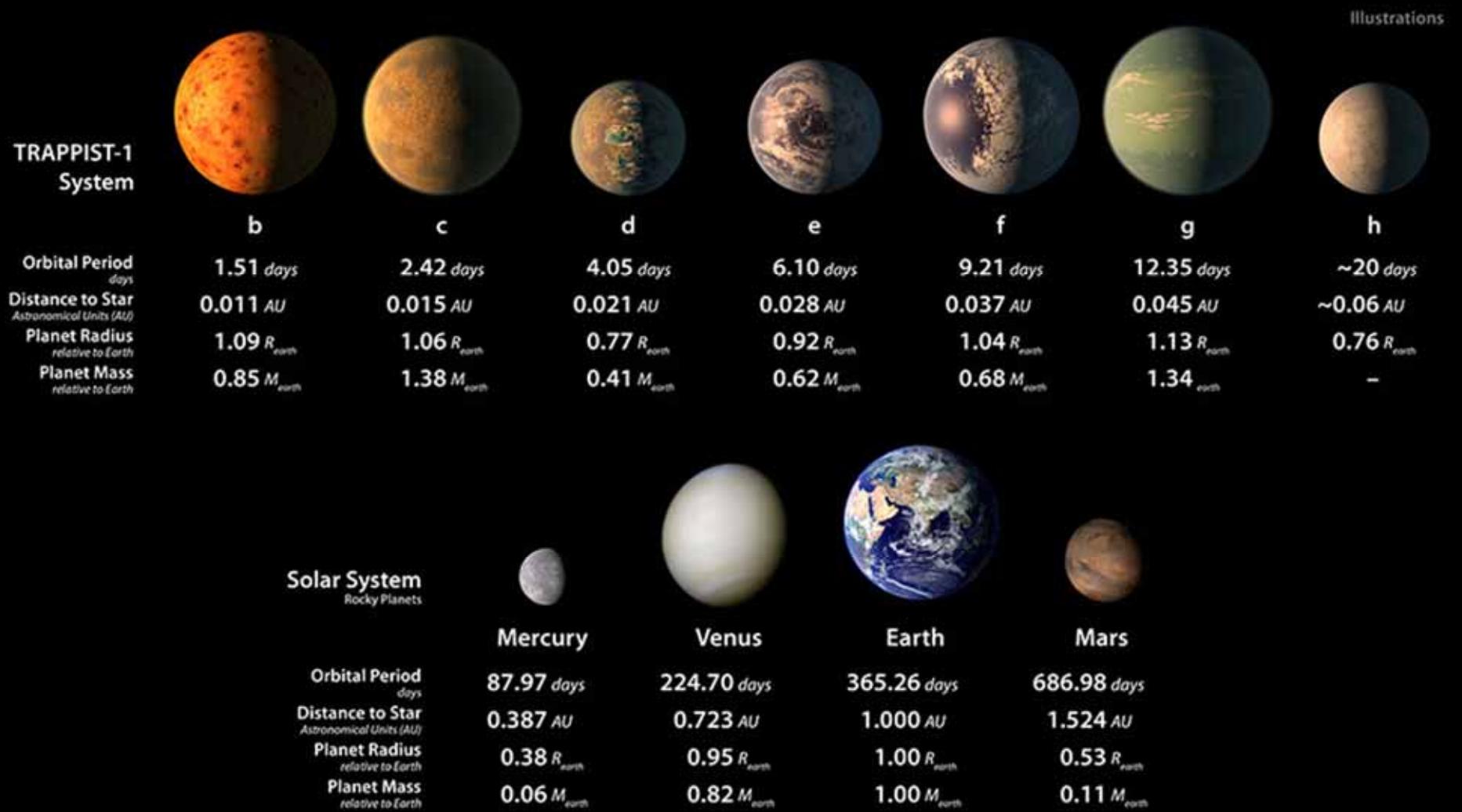




Sun



TRAPPIST-1



Planetas Potenciales

Ordenados por distancia a La



[4.2 ly]
Proxima Cen b



[13 ly]
Kapteyn b*



[22 ly]
GJ 667 C c

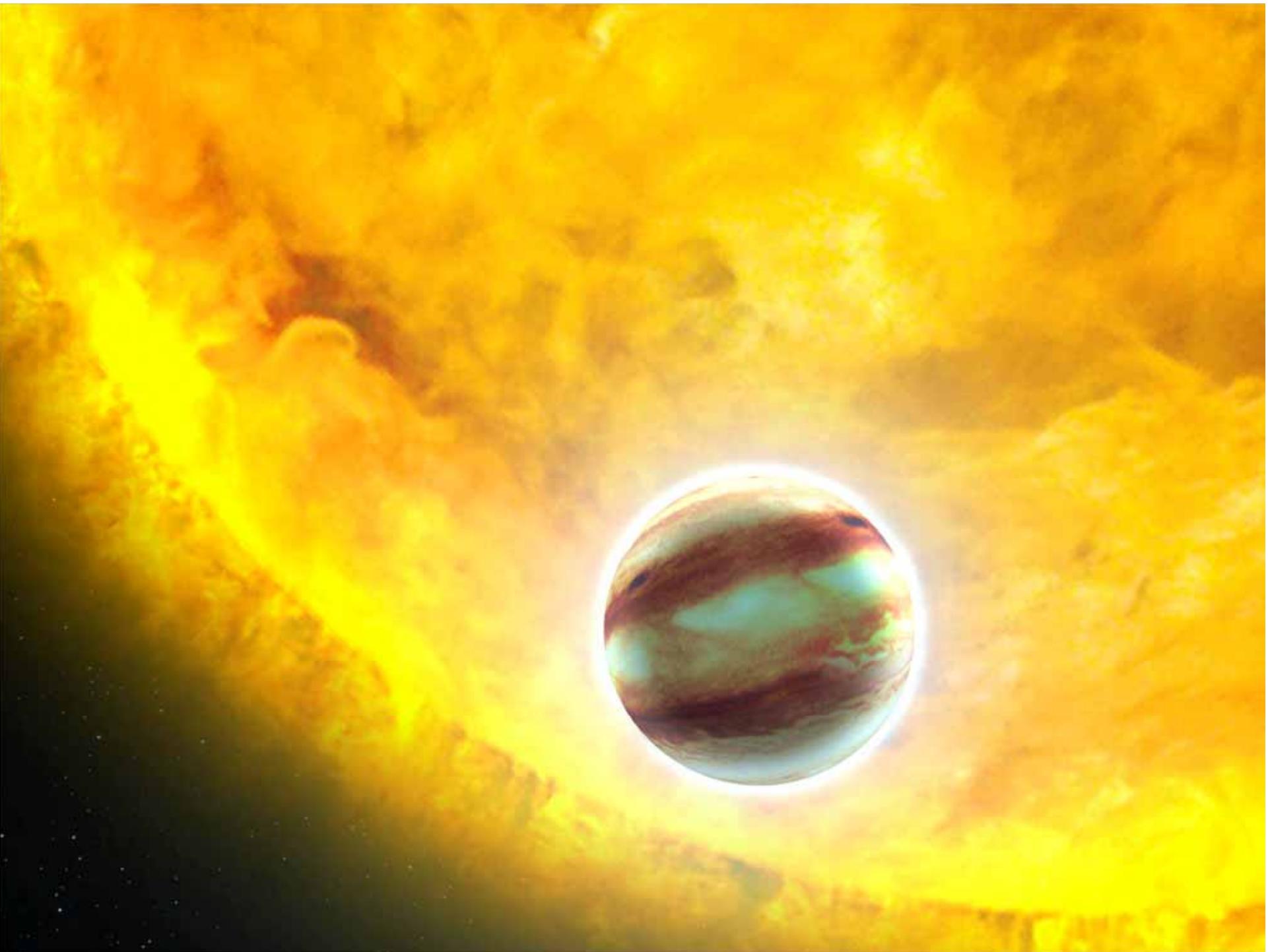


Conservative Sample of Potential

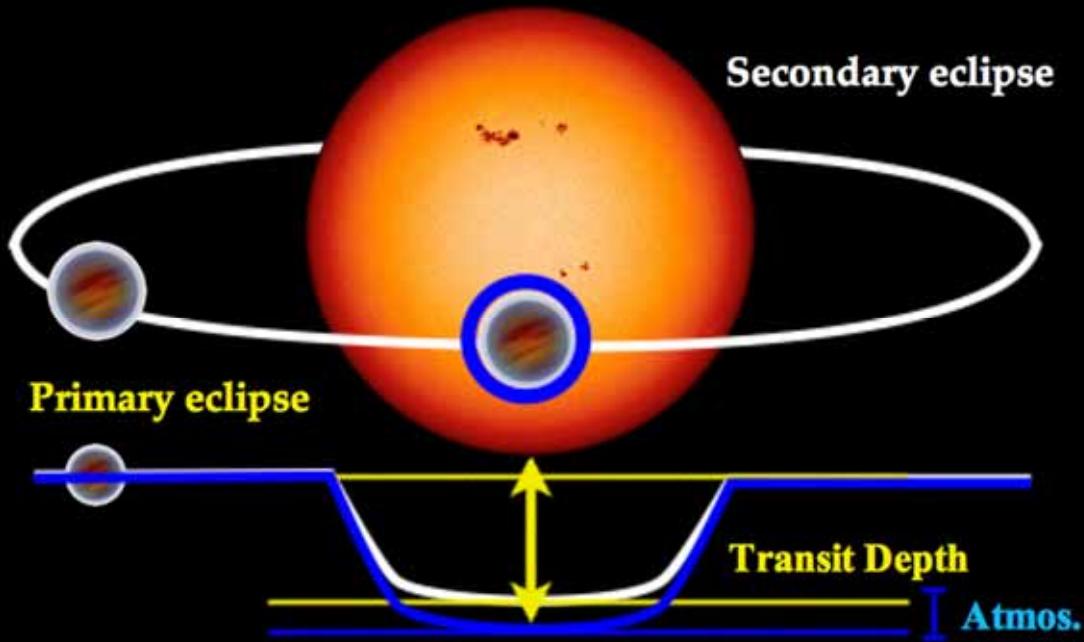
This is a list of the exoplanets that are more likely to have a rocky composition (Planet Radius ≤ 1.5 Earth radii or $0.1 < \text{Planet Minimum Mass} \leq 5$ Earth masses) and are located in the habitable zone. They are represented artistically in the top image.

Name	Type	Mass (M _E)
001. Proxima Cen b	M-Warm Terran	≥ 1.3
002. TRAPPIST-1 e	M-Warm Terran	0.6
003. GJ 667 C c	M-Warm Terran	≥ 3.8
004. Kepler-442 b	K-Warm Terran	8.2 - 2.3 - 1.0
005. GJ 667 C f*	M-Warm Terran	≥ 2.7
006. Kepler-1229 b	M-Warm Terran	9.8 - 2.7 - 1.2
007. TRAPPIST-1 f	M-Warm Terran	0.7
008. Kapteyn b*	M-Warm Terran	≥ 4.8
009. Kepler-62 f	K-Warm Terran	10.2 - 2.8 - 1.2
010. Kepler-186 f	M-Warm Terran	4.7 - 1.5 - 0.6
011. GJ 667 C e*	M-Warm Terran	≥ 2.7
012. TRAPPIST-1 g	M-Warm Terran	1.3

Name	Type	Mass (M _E)	Radius (R _E)	Flux (S _E)	T _{eq} (K)	Period (days)	Distance (ly)	ESI
001. TRAPPIST-1 d	M-Warm Subterranean	0.4	0.8	1.15	264	4.0	39	0.90
002. GJ 3323 b (N)	M-Warm Terran	≥ 2.0	0.9 - 1.3 - 1.6	1.21	264	5.4	-	0.89
003. Kepler-438 b	M-Warm Terran	4.0 - 1.3 - 0.6	1.1	1.38	276	35.2	473	0.88
004. GJ 273 b (N)	M-Warm Terran	≥ 2.9	1.0 - 1.4 - 1.8	1.22	267	18.6	12	0.86
005. Kepler-296 e	M-Warm Terran	12.5 - 3.3 - 1.4	1.5	1.22	267	34.1	737	0.85
006. Kepler-62 e	K-Warm Superterranean	18.7 - 4.5 - 1.9	1.6	1.10	261	122.4	1200	0.83
007. Kepler-452 b	G-Warm Superterranean	19.8 - 4.7 - 1.9	1.6	1.11	261	384.8	1402	0.83
008. K2-72 e	M-Warm Terran	9.8 - 2.7 - 1.2	1.4	1.46	280	24.2	181	0.82
009. GJ 832 c	M-Warm Superterranean	≥ 5.4	1.2 - 1.7 - 2.2	1.00	253	35.7	16	0.81
010. K2-3 d	M-Warm Terran	11.1	1.5	1.46	280	44.6	137	0.80
011. Kepler-1544 b	K-Warm Superterranean	31.7 - 6.6 - 2.6	1.8	0.90	248	168.8	1138	0.80
012. Kepler-283 c	K-Warm Superterranean	35.3 - 7.0 - 2.8	1.8	0.90	248	92.7	1741	0.79
013. tau Cet e*	G-Warm Terran	≥ 4.3	1.1 - 1.6 - 2.0	1.51	282	168.1	12	0.78
014. Kepler-1410 b	K-Warm Superterranean	31.7 - 6.6 - 2.6	1.8	1.34	274	60.9	1196	0.78
015. GJ 180 c*	M-Warm Superterranean	≥ 6.4	1.3 - 1.8 - 2.3	0.79	239	24.3	38	0.77
016. Kepler-1638 b	G-Warm Superterranean	42.7 - 7.9 - 3.1	1.9	1.39	276	259.3	2866	0.76
017. Kepler-440 b	K-Warm Superterranean	41.2 - 7.7 - 3.1	1.9	1.43	273	101.1	851	0.75
018. GJ 180 b*	M-Warm Superterranean	≥ 8.3	1.3 - 1.9 - 2.4	1.23	268	17.4	38	0.75
019. Kepler-705 b	M-Warm Superterranean	? - 12.7 - 4.8	2.1	0.83	243	56.1	818	0.74
020. HD 40307 g*	K-Warm Superterranean	≥ 7.1	1.3 - 1.8 - 2.3	0.68	227	197.8	42	0.74
021. GJ 163 c	M-Warm Superterranean	≥ 7.3	1.3 - 1.8 - 2.4	0.66	230	25.6	49	0.73
022. Kepler-61 b	K-Warm Superterranean	? - 13.8 - 5.2	2.2	1.27	267	59.9	1063	0.73
023. K2-18 b	M-Warm Superterranean	? - 16.5 - 6.0	2.2	0.92	250	32.9	111	0.73
024. Kepler-1606 b	G-Warm Superterranean	? - 11.9 - 4.5	2.1	1.41	277	196.4	2869	0.73
025. Kepler-1090 b	G-Warm Superterranean	? - 16.8 - 6.1	2.3	1.20	267	198.7	2289	0.72
026. Kepler-443 b	K-Warm Superterranean	? - 19.5 - 7.0	2.3	0.89	247	177.7	2540	0.71
027. Kepler-22 b	G-Warm Superterranean	? - 20.4 - 7.2	2.4	1.11	261	289.9	619	0.71
028. GJ 422 b*	M-Warm Superterranean	≥ 9.9	1.4 - 2.0 - 2.6	0.68	231	26.2	41	0.71
029. K2-9 b	M-Warm Superterranean	? - 16.8 - 6.1	2.2	1.38	276	18.4	359	0.71
030. Kepler-1552 b	K-Warm Superterranean	? - 25.2 - 8.7	2.5	1.11	261	184.8	2015	0.70
031. GJ 3293 c*	M-Warm Superterranean	≥ 8.6	1.4 - 1.9 - 2.5	0.60	223	48.1	59	0.70
032. Kepler-1540 b	K-Warm Superterranean	? - 26.2 - 9.0	2.5	0.92	250	125.4	854	0.70
033. Kepler-298 d	K-Warm Superterranean	? - 26.8 - 9.1	2.5	1.29	271	77.5	1545	0.68
034. KIC-5522786 b	A-Warm Terran	5.8 - 1.8 - 0.8	1.2	2.70	305	757.2	-	0.67
035. Kepler-174 d	K-Warm Superterranean	? - 14.8 - 5.5	2.2	0.43	206	247.4	1174	0.61
036. Kepler-296 f	M-Warm Superterranean	28.7 - 6.1 - 2.5	1.8	0.34	194	63.3	737	0.60
037. GJ 682 c*	M-Warm Superterranean	≥ 8.7	1.4 - 1.9 - 2.5	0.37	198	57.3	17	0.59
038. Wolf 1061 d	M-Warm Superterranean	≥ 5.2	1.2 - 1.7 - 2.2	0.28	182	67.3	14	0.56
039. KOI-4427 b*	M-Warm Superterranean	38.5 - 7.4 - 3.0	1.8	0.24	179	147.7	782	0.52

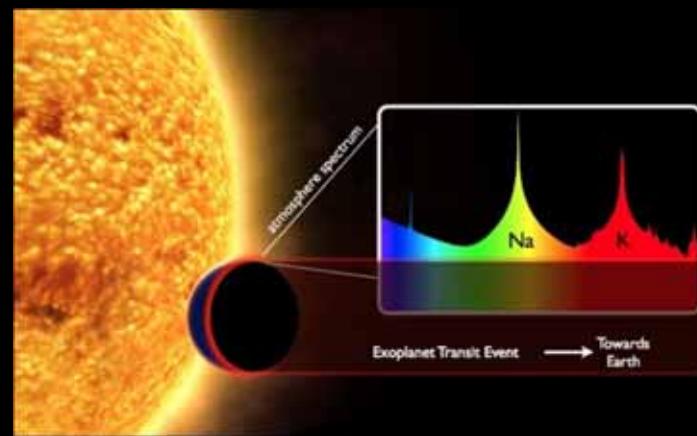


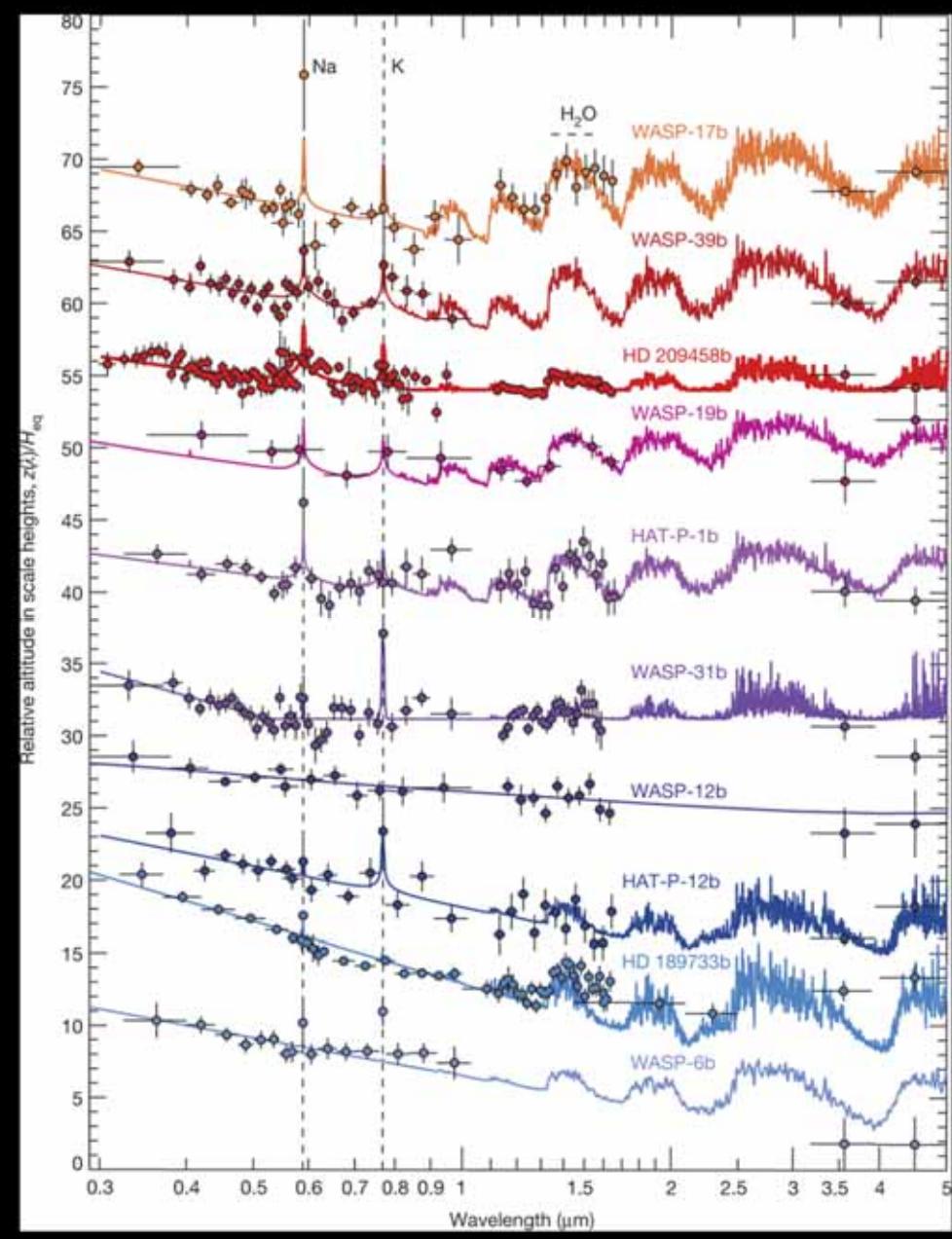
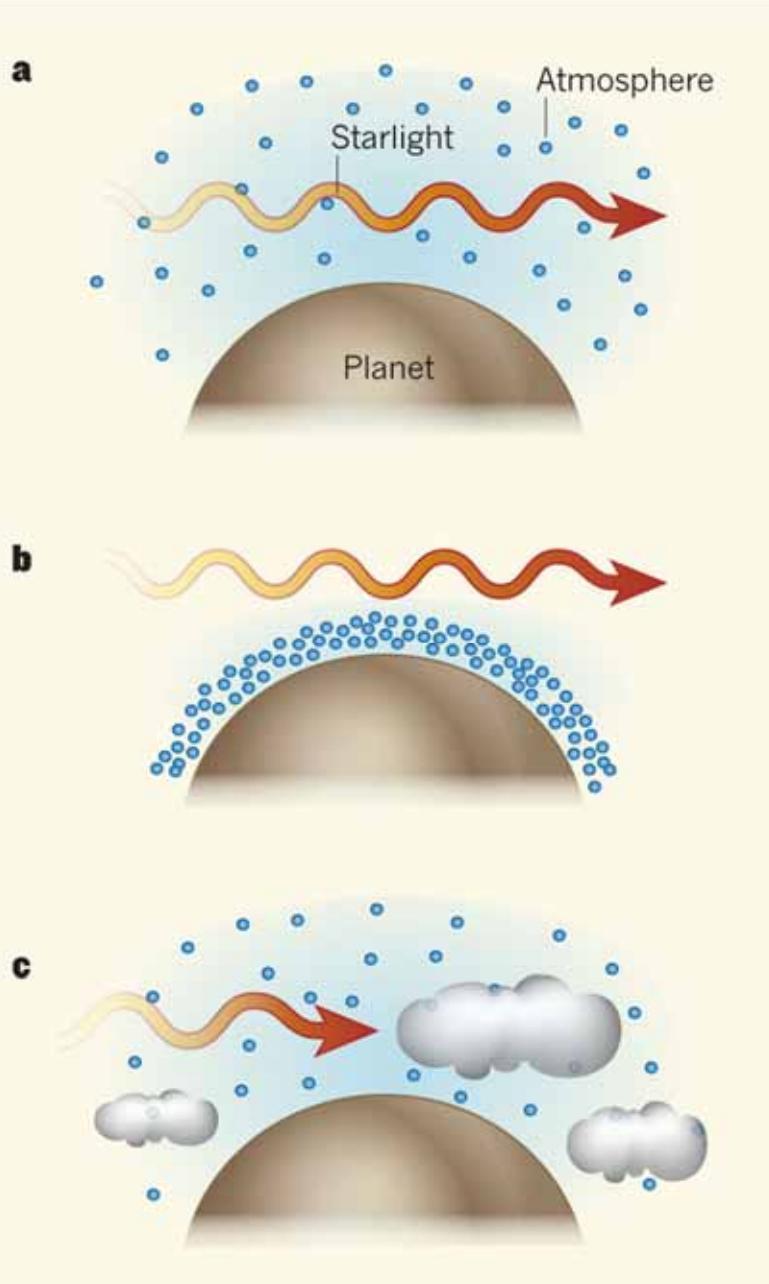
Transmission spectroscopy



What can be learned:

- Chemical composition
- Relative chemical abundancies
- Upper-atmospheric T-P profiles
- Clouds/hazes





The Gran Telescopio Canarias

10.4 m telescope

Segmented mirror



OSIRIS

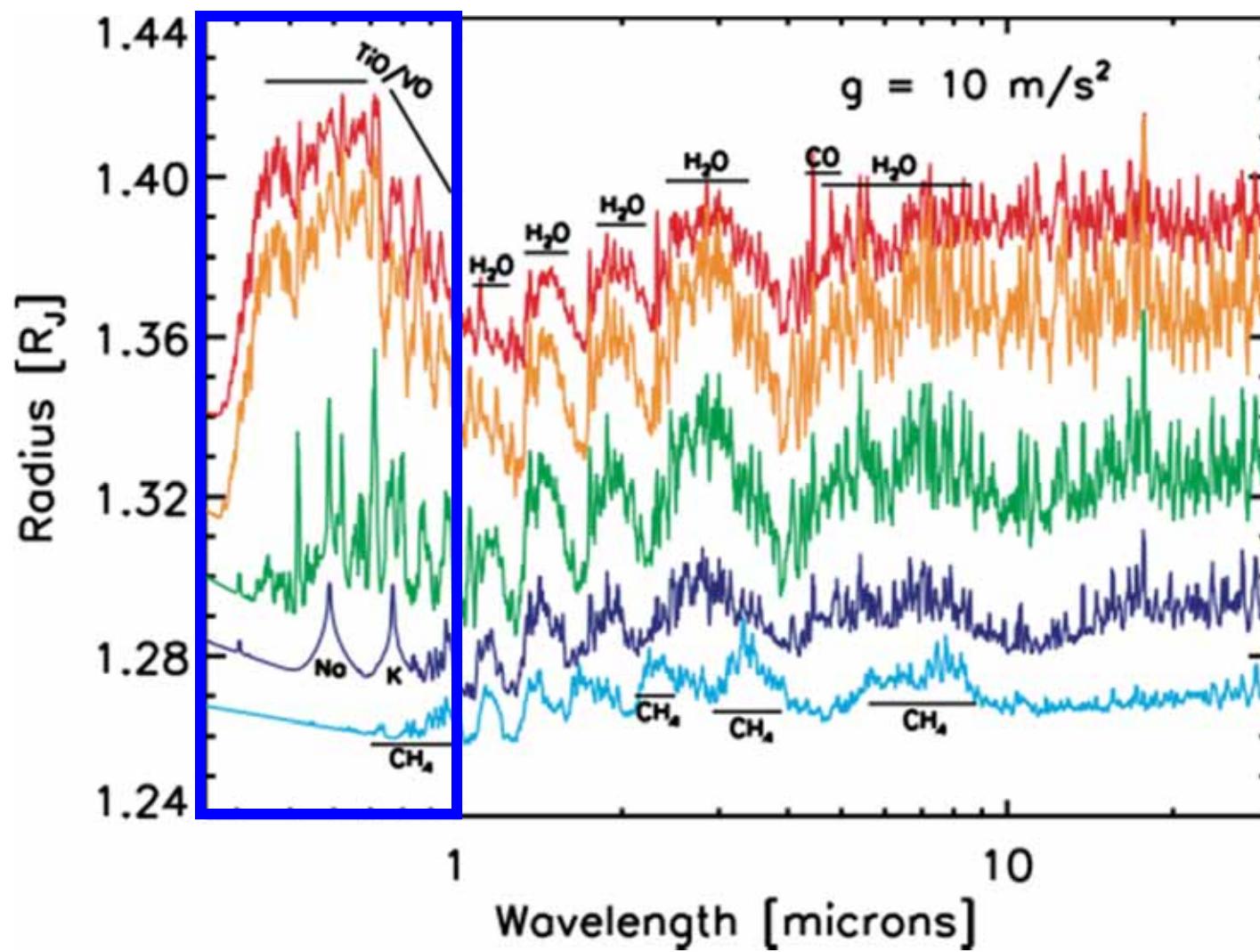
Visible imager and spectrograph

2CCDS, 2048x4096 pix

7.8x7.8 arcmin FOV

- Imaging
- Tunable filter imaging
- Long-slit spectroscopy

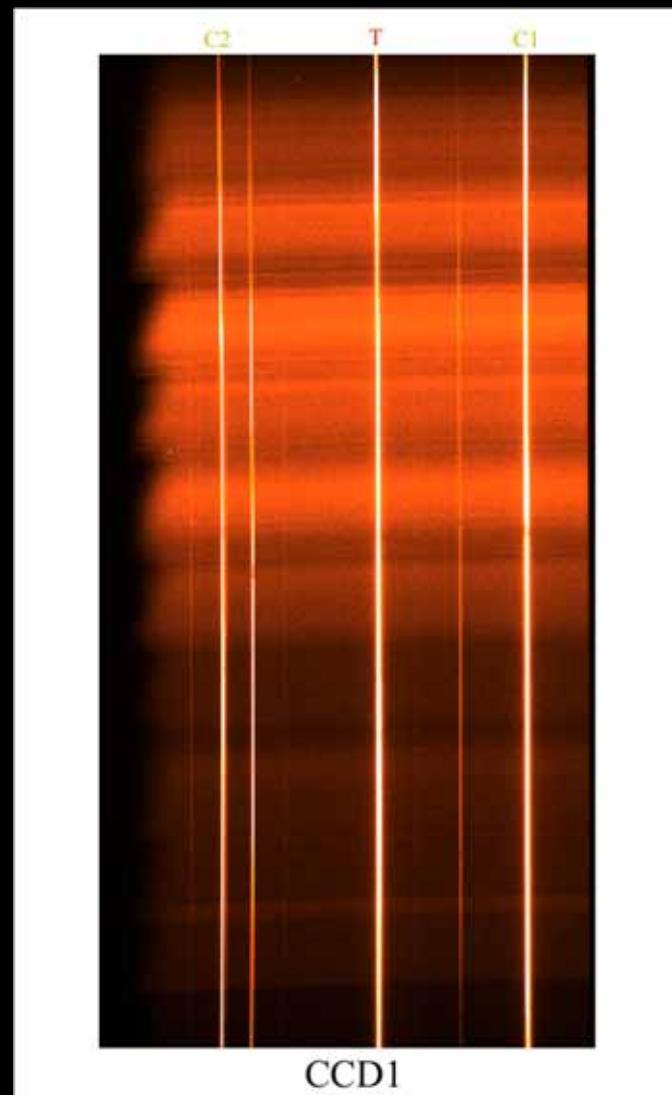
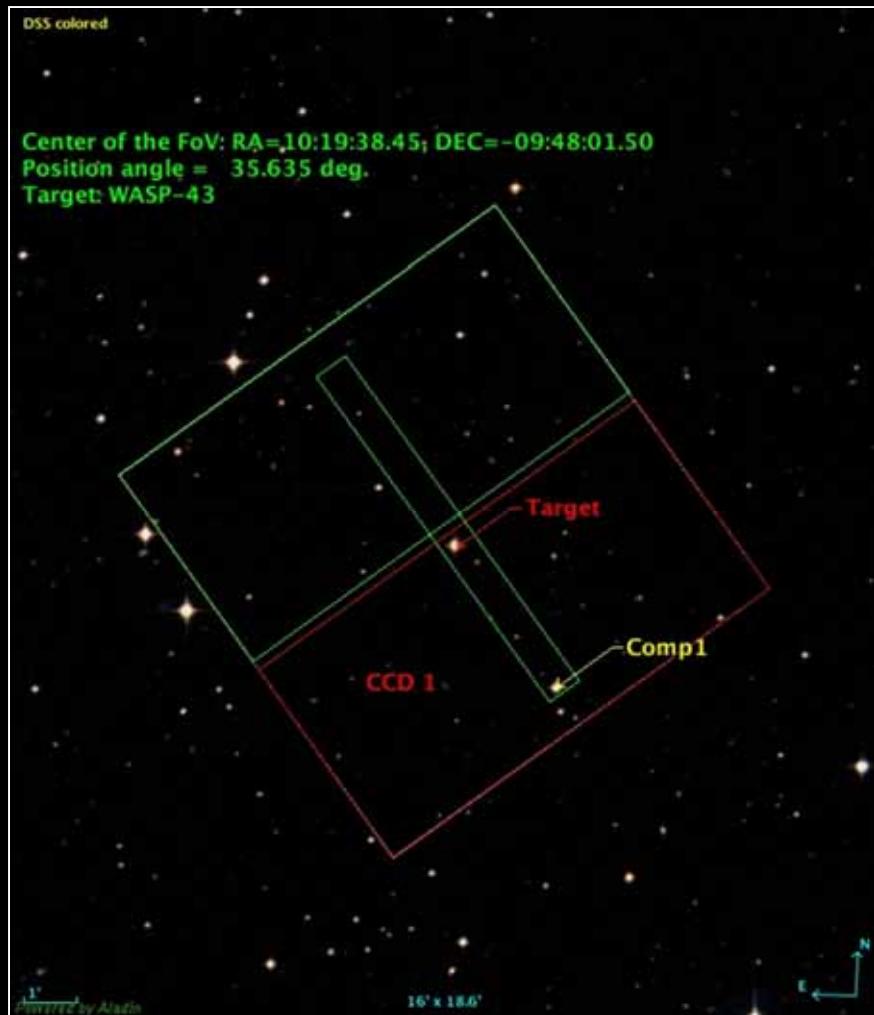
Transmission spectroscopy



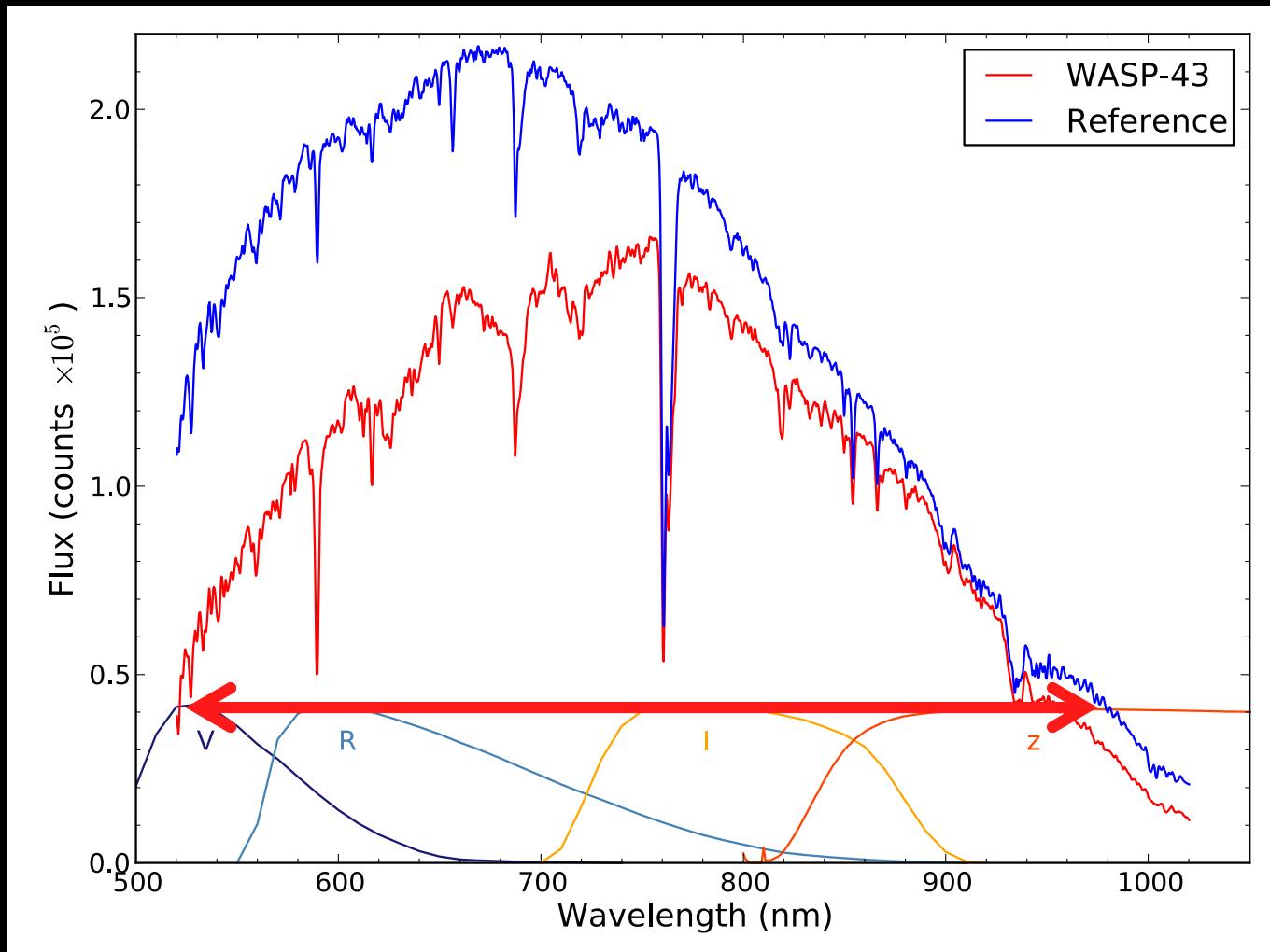
Fortney et al, 2010

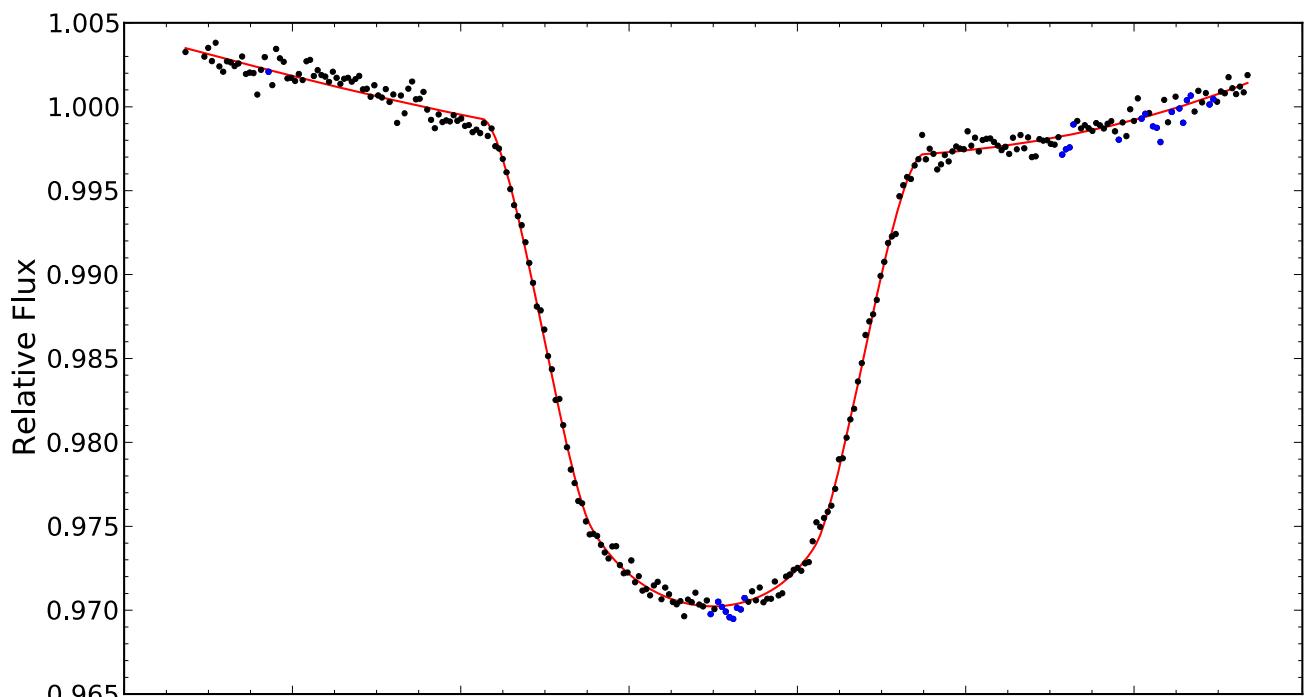
Transit spectroscopy in the visible with OSIRIS @GTC

WASP-43b



Transit spectroscopy in the visible with OSIRIS @GTC

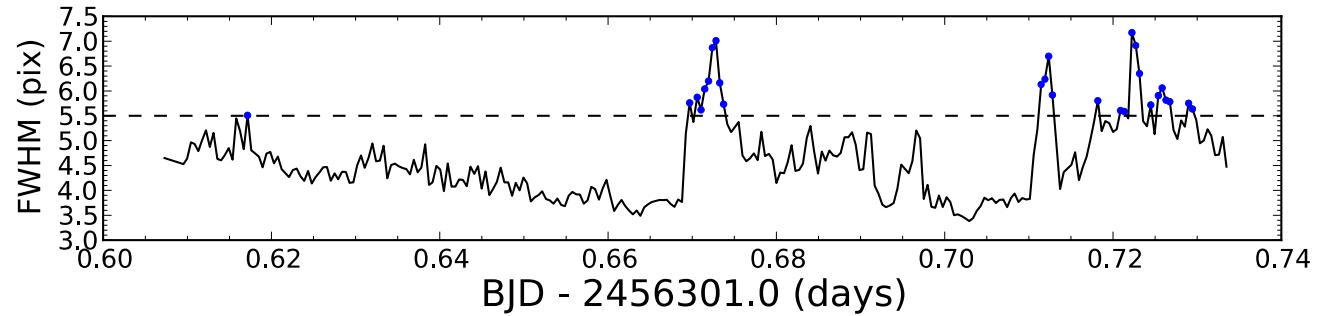
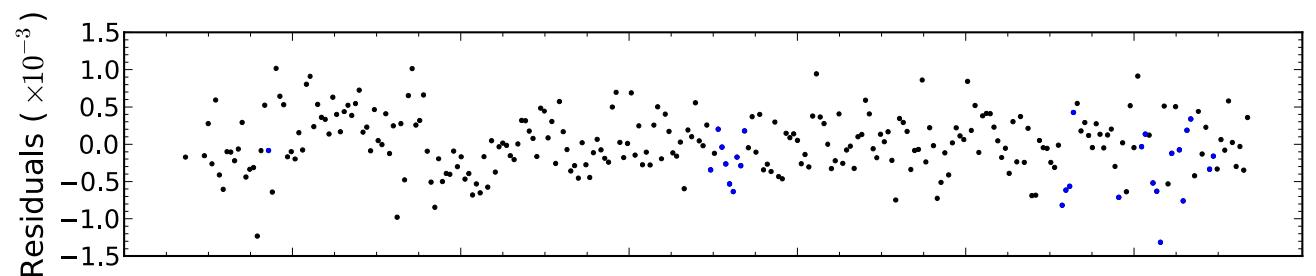




January 2013

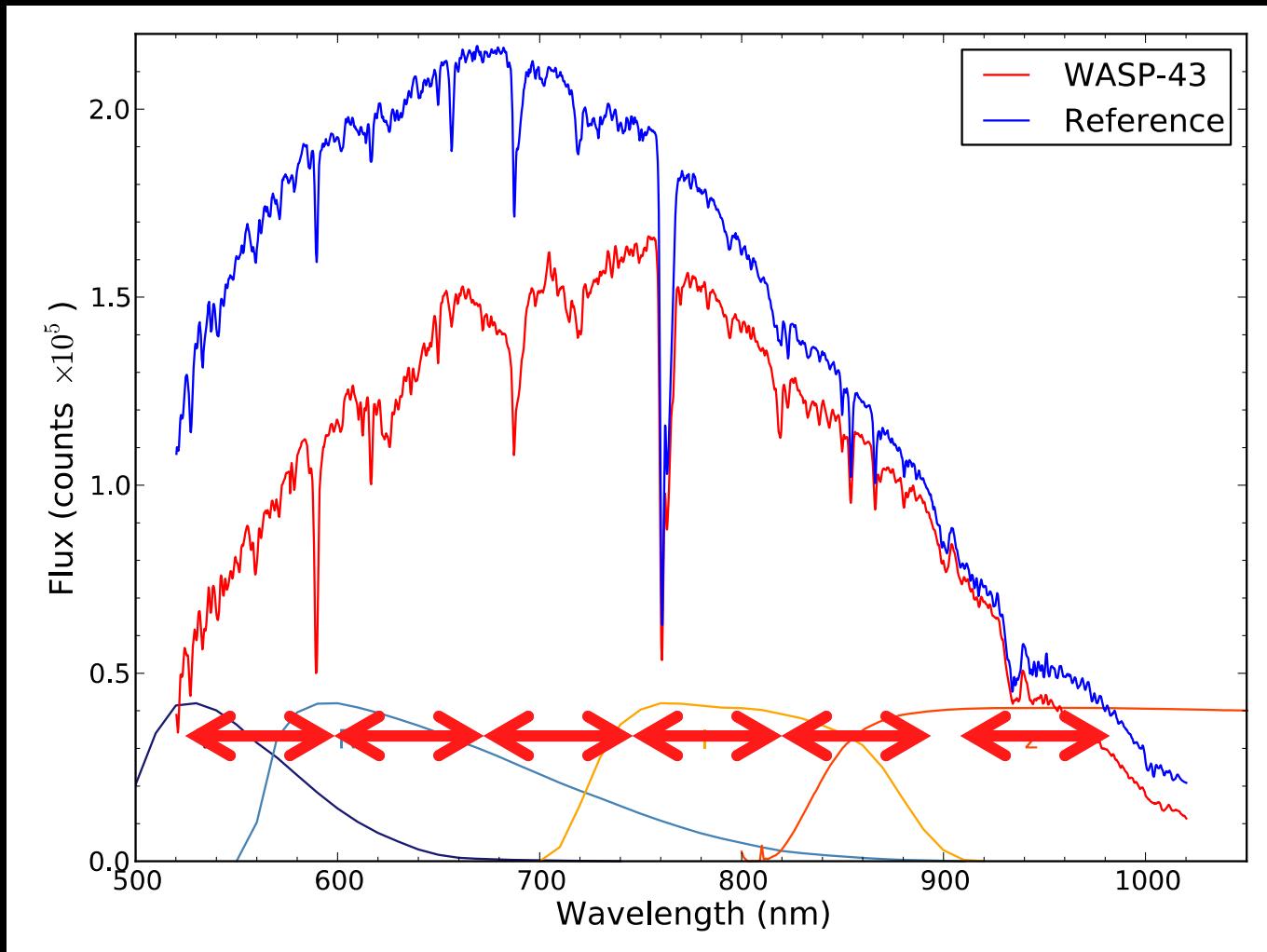
rms: 586.8 ppm

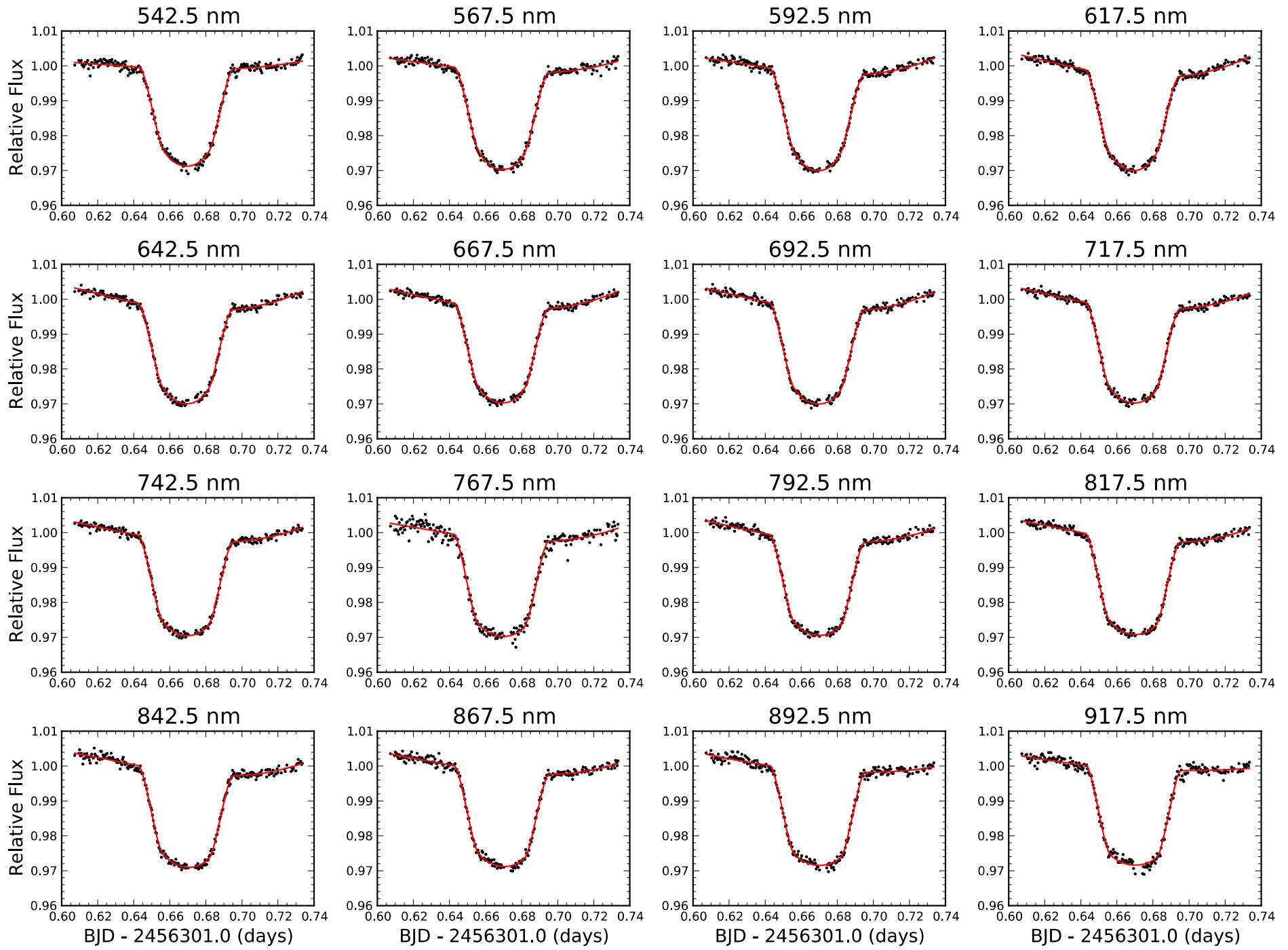
*Room for
improvement !!*



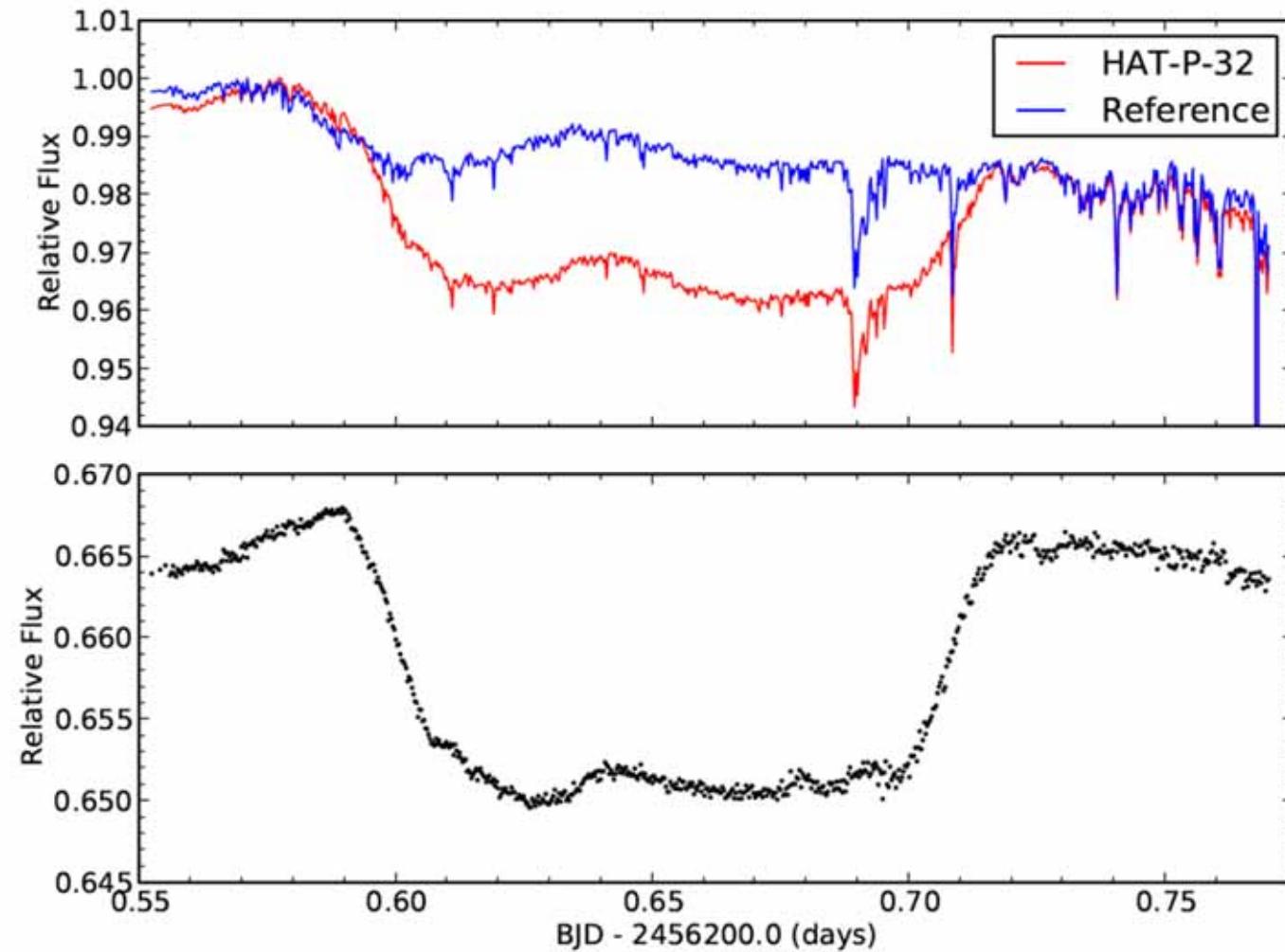
Murgas et al,
ApJ, 2014

Transit spectroscopy in the visible with OSIRIS @GTC

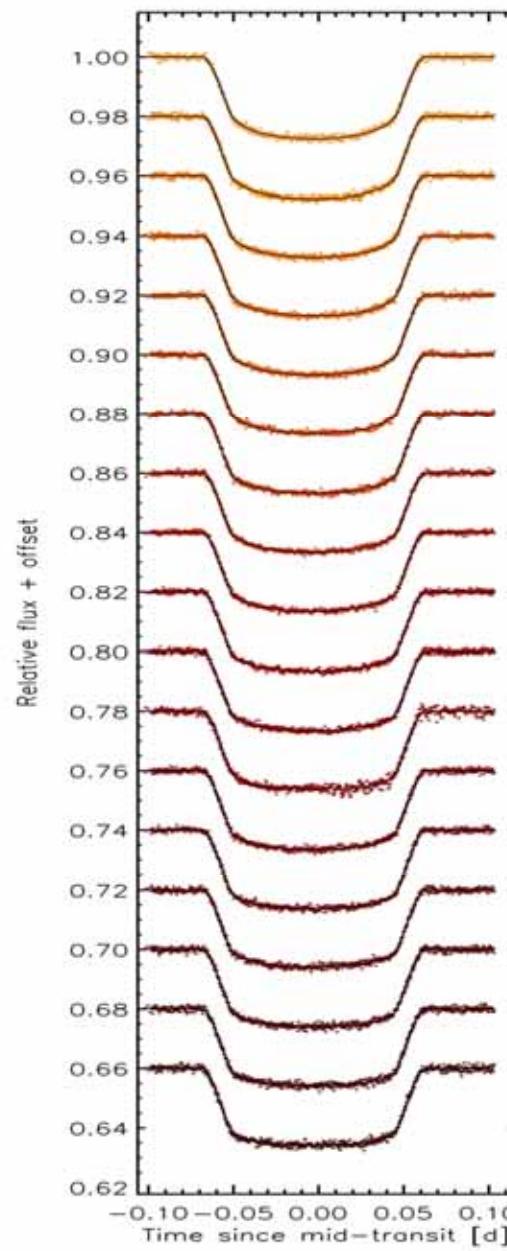
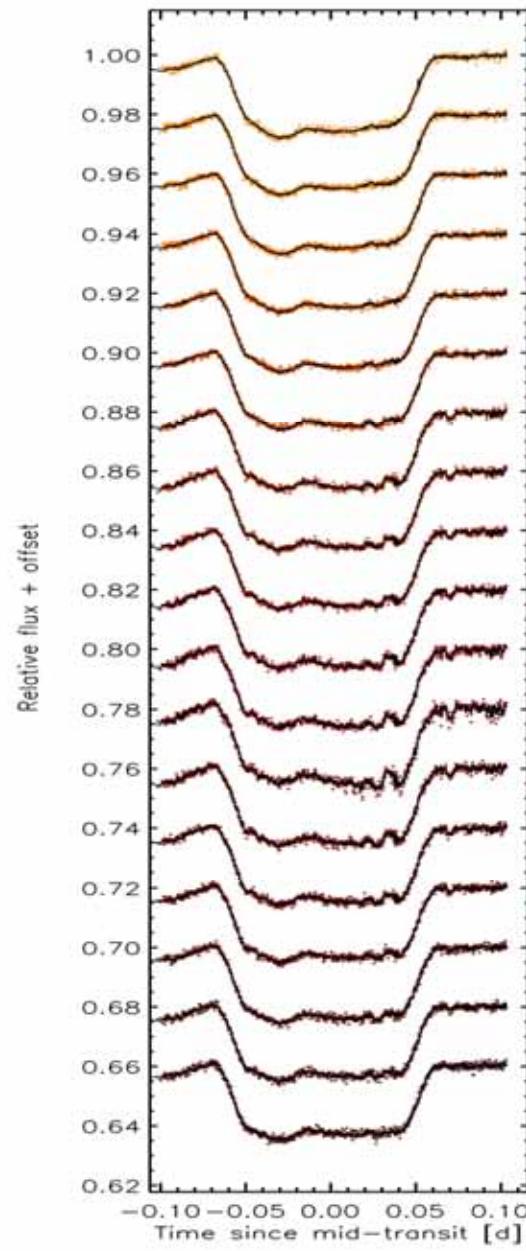




Account for small (big) telescope systematics



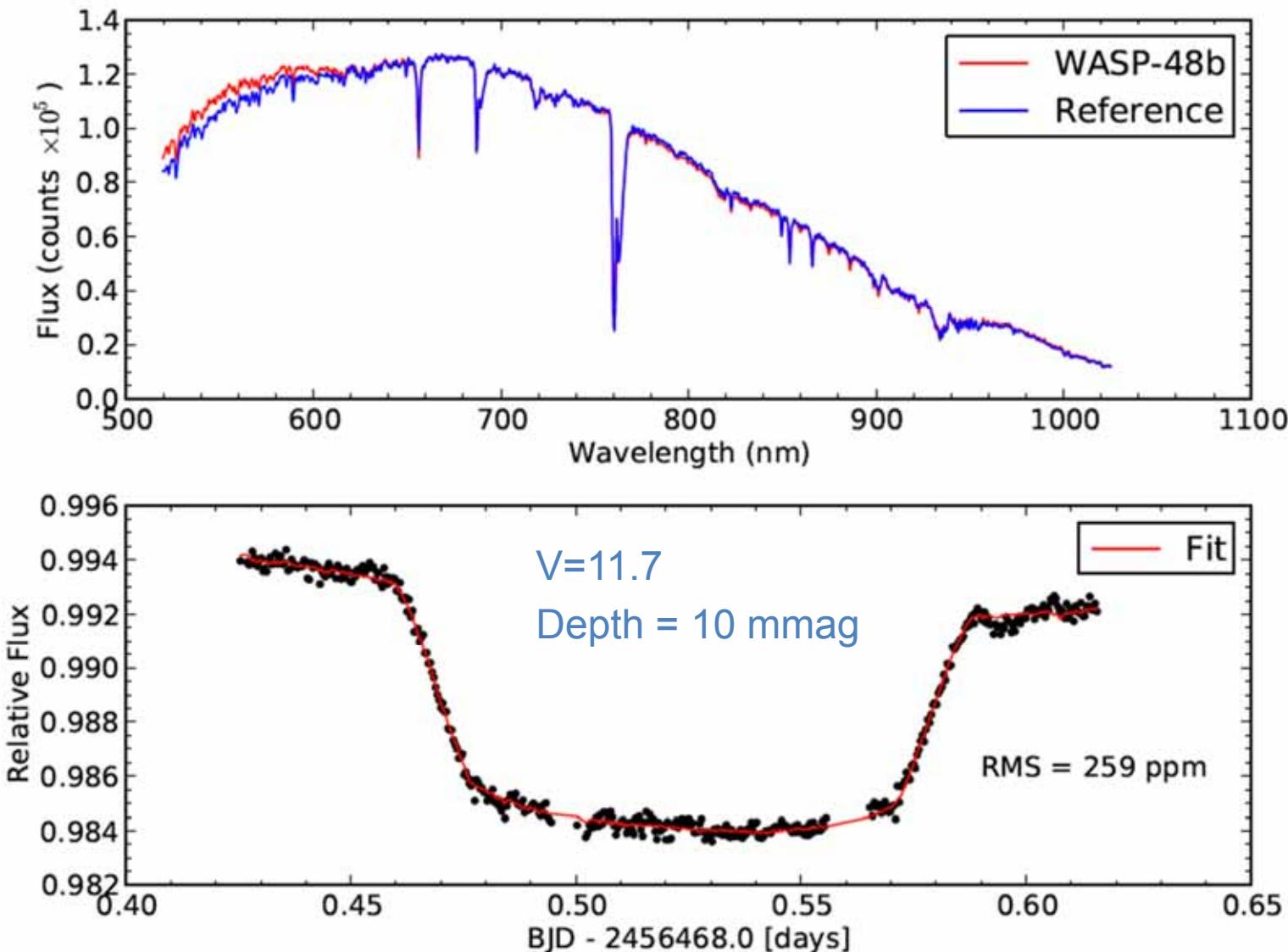
Nortmann et al, 2016



Correct for systematics,
sometimes wavelength-
dependent

It's a kind of magic ...
Queen (1986)

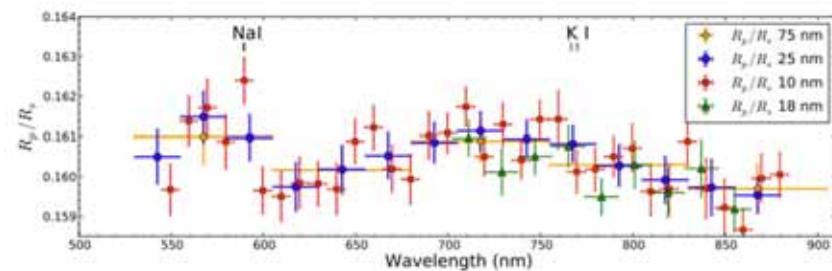
Transit spectroscopy with OSIRIS @GTC



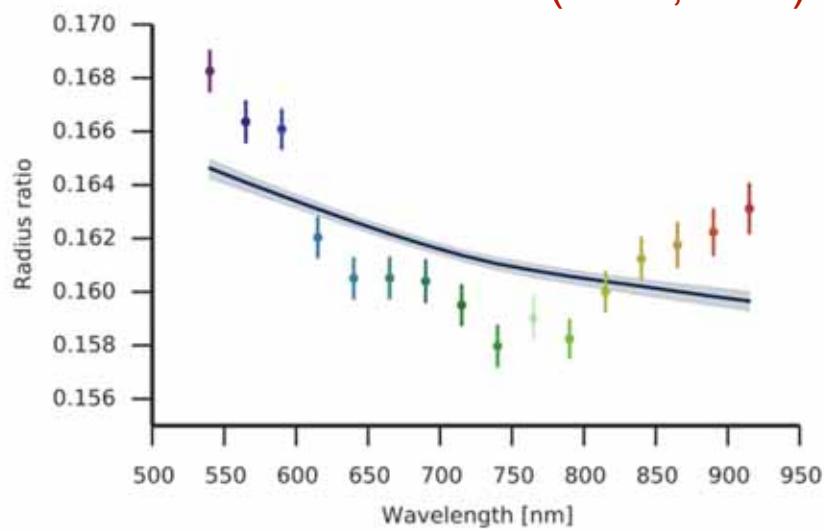
GTC Survey

GUESS TARGETED EXOPLANETS

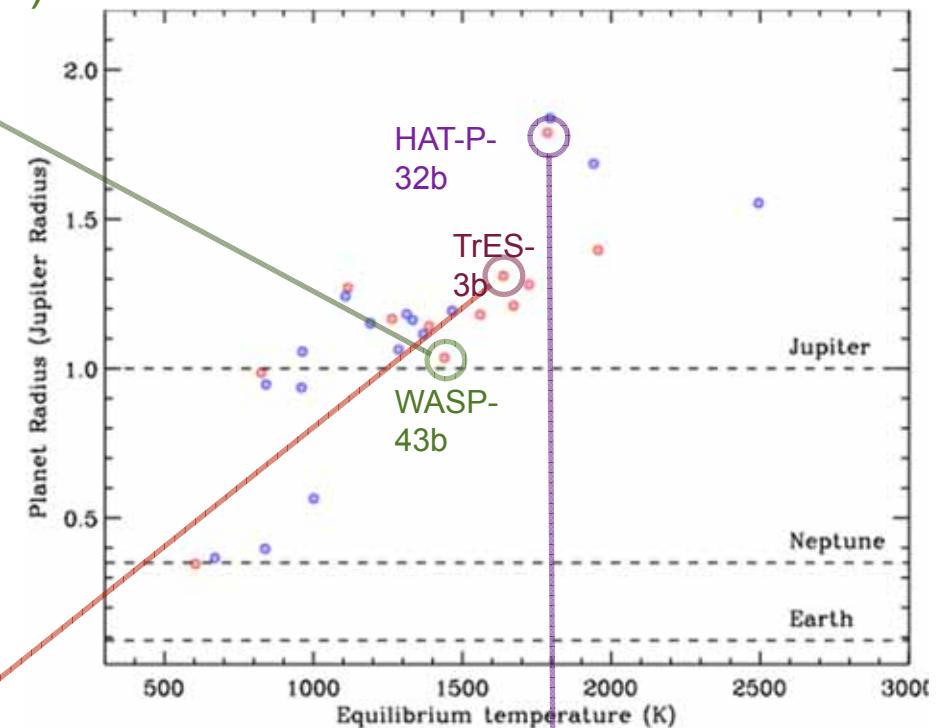
- WASP-43b: tentative Na detection
 - Murgas et al. (2014, A&A, 563, 41)



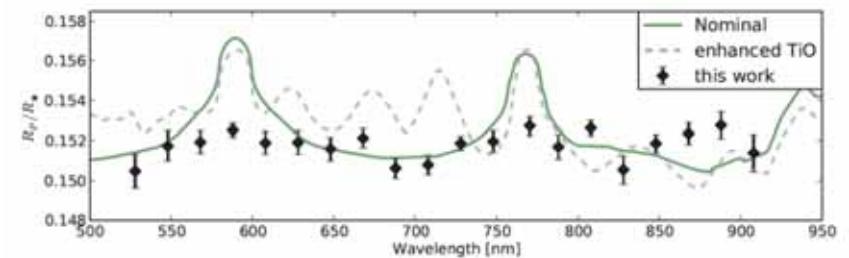
- TrES-3b: enhanced “Rayleigh-scattering”?
 - Parviainen et al. (2016, A&A)



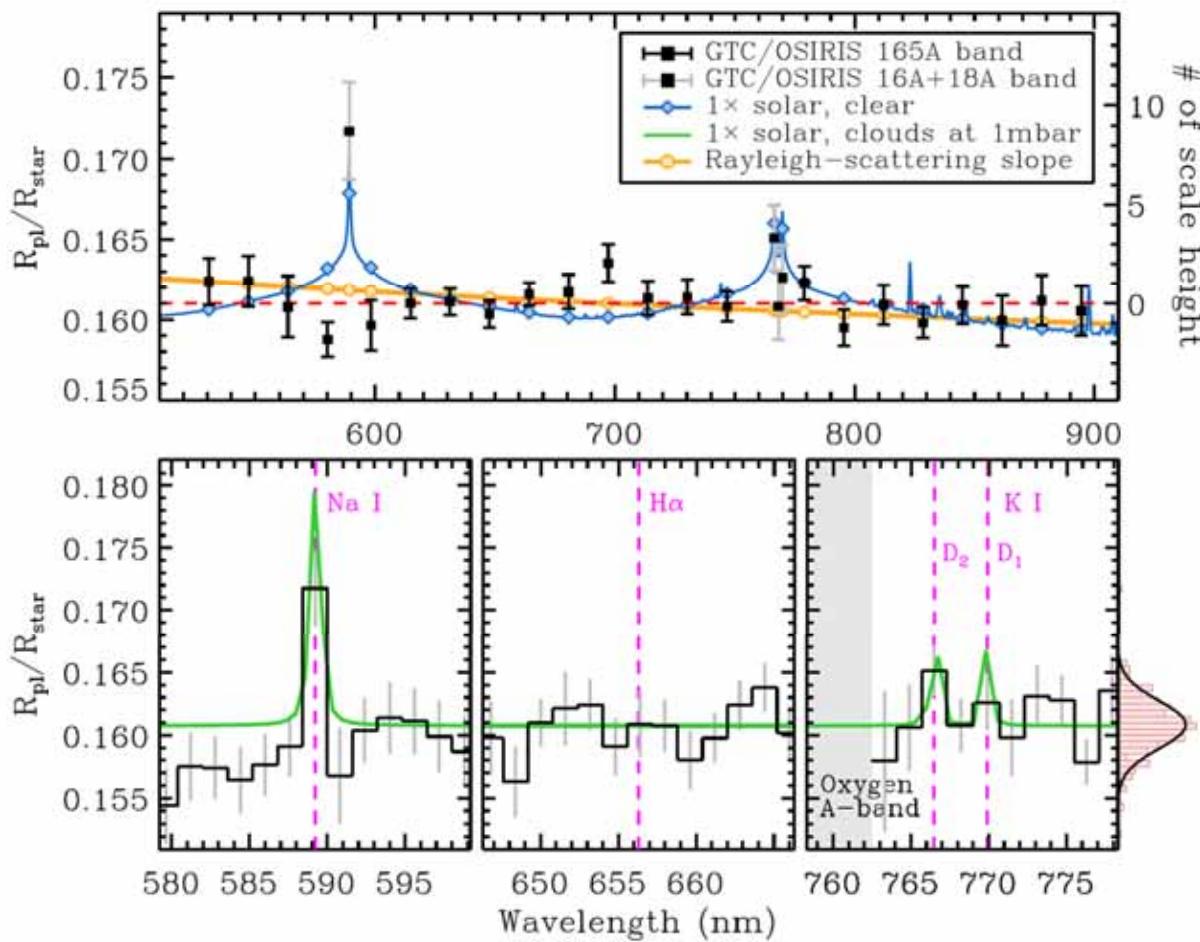
- Planet radius v.s. Eq. temp.



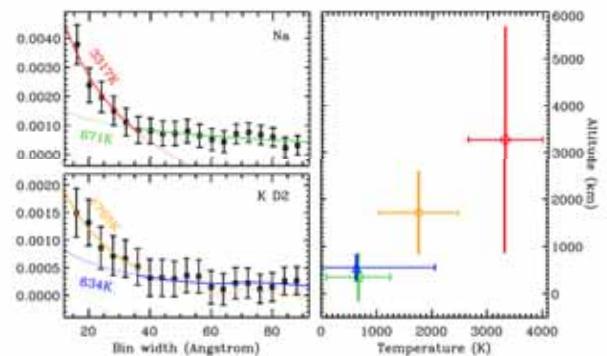
- HAT-P-32Ab: flat and featureless
 - Nortmann et al. (2016, A&A, in press)



WASP-52b



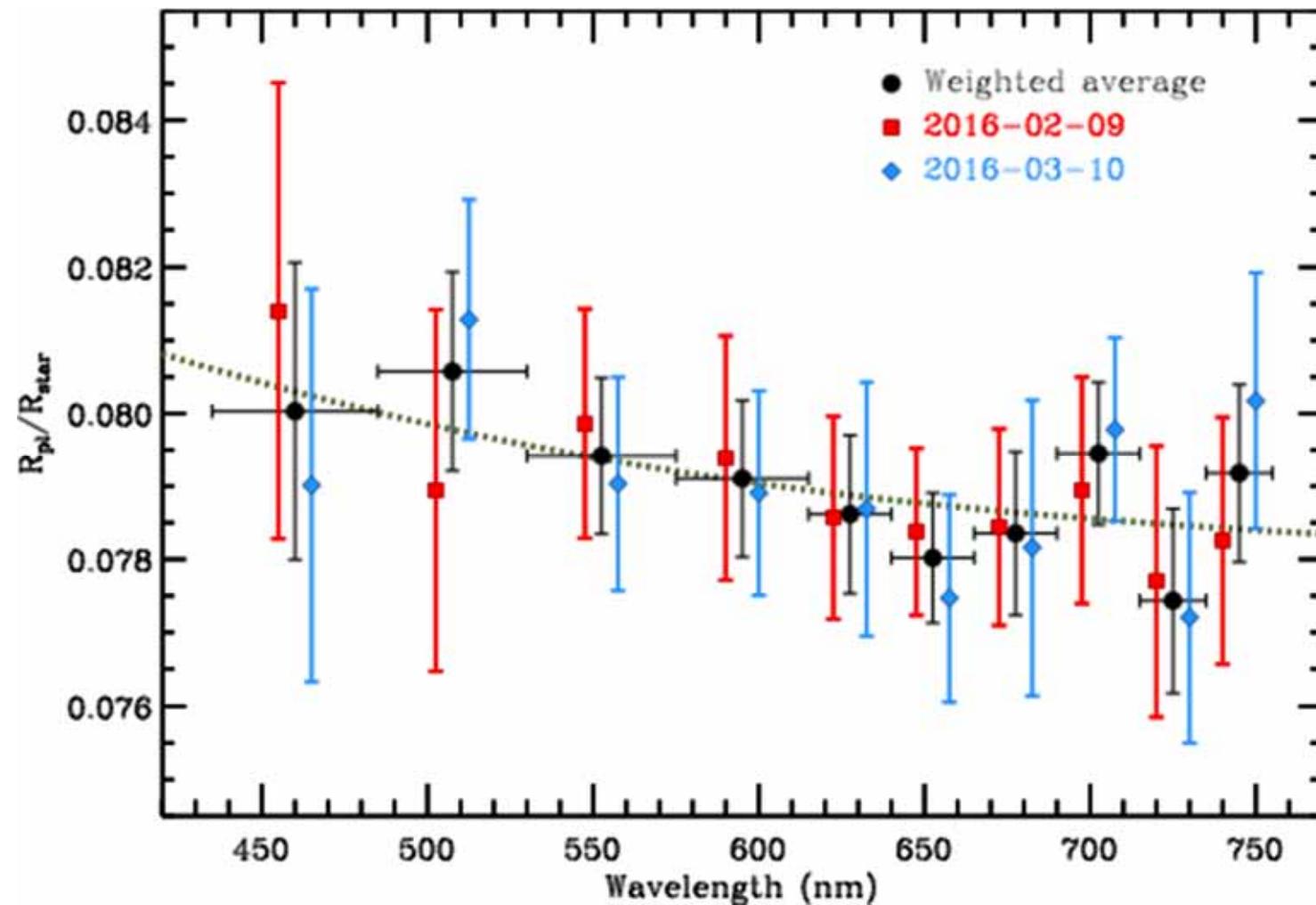
WASP-52b's Facts		
V	12,2	mag
Mass	0,46	M_{Jup}
Radius	1,17	R_{Jup}
Gravity	6,5	m/s^2
T_{eq}	1264	K
H	703	km
H/R_{\star}	0,00138	-



3. The left panels show the absorption depths integrated in different widths for Na (top) and K D₂ (bottom). The red/orange (green/blue) curves present the best-fitting isothermal models for the core (wing) regions. The right panel shows the temperatures of these isothermal models at corresponding altitudes.

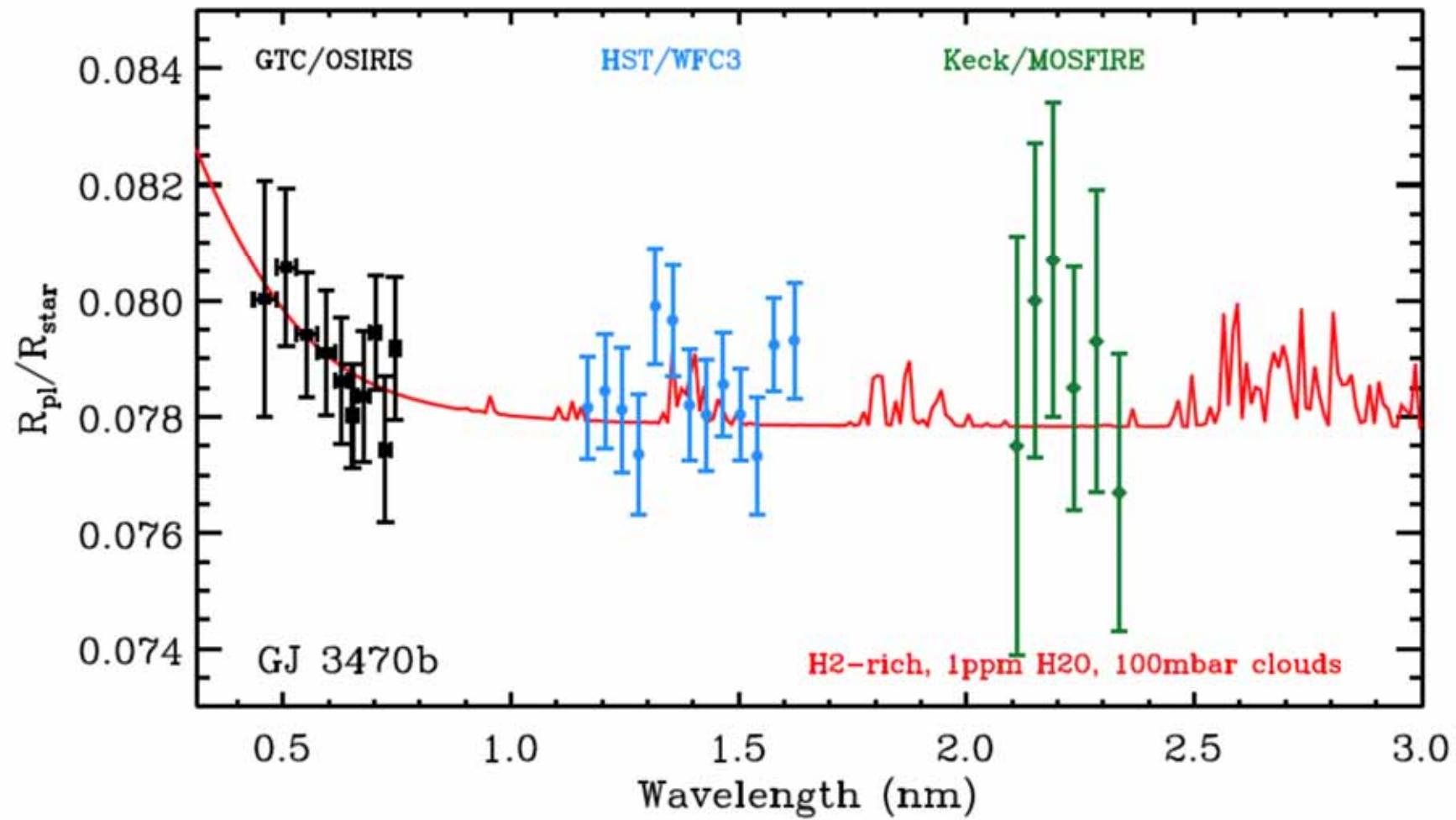
Chen et al, 2017

GJ 3470b: a warm Uranus transiting a nearby M dwarf



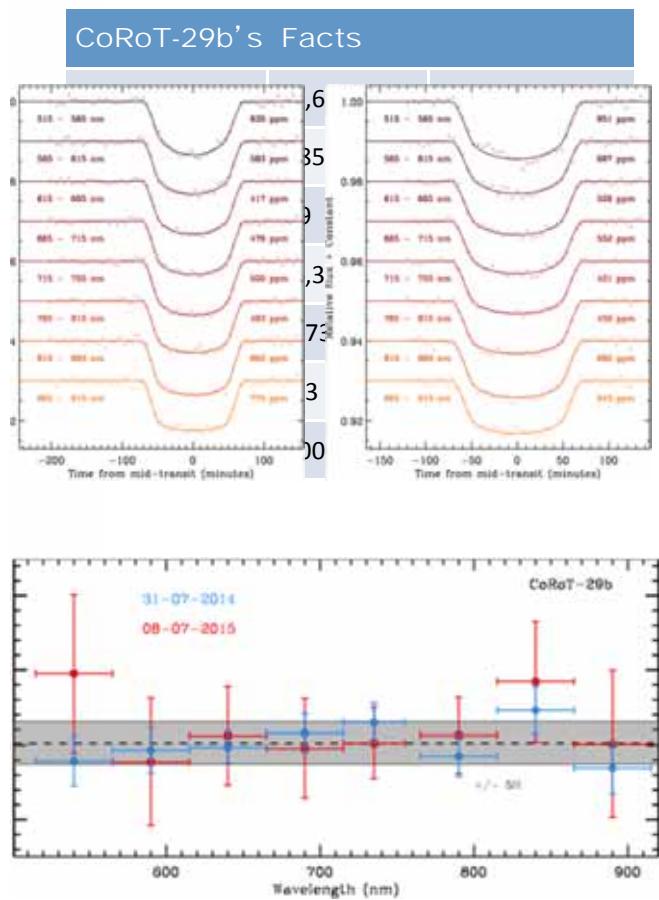
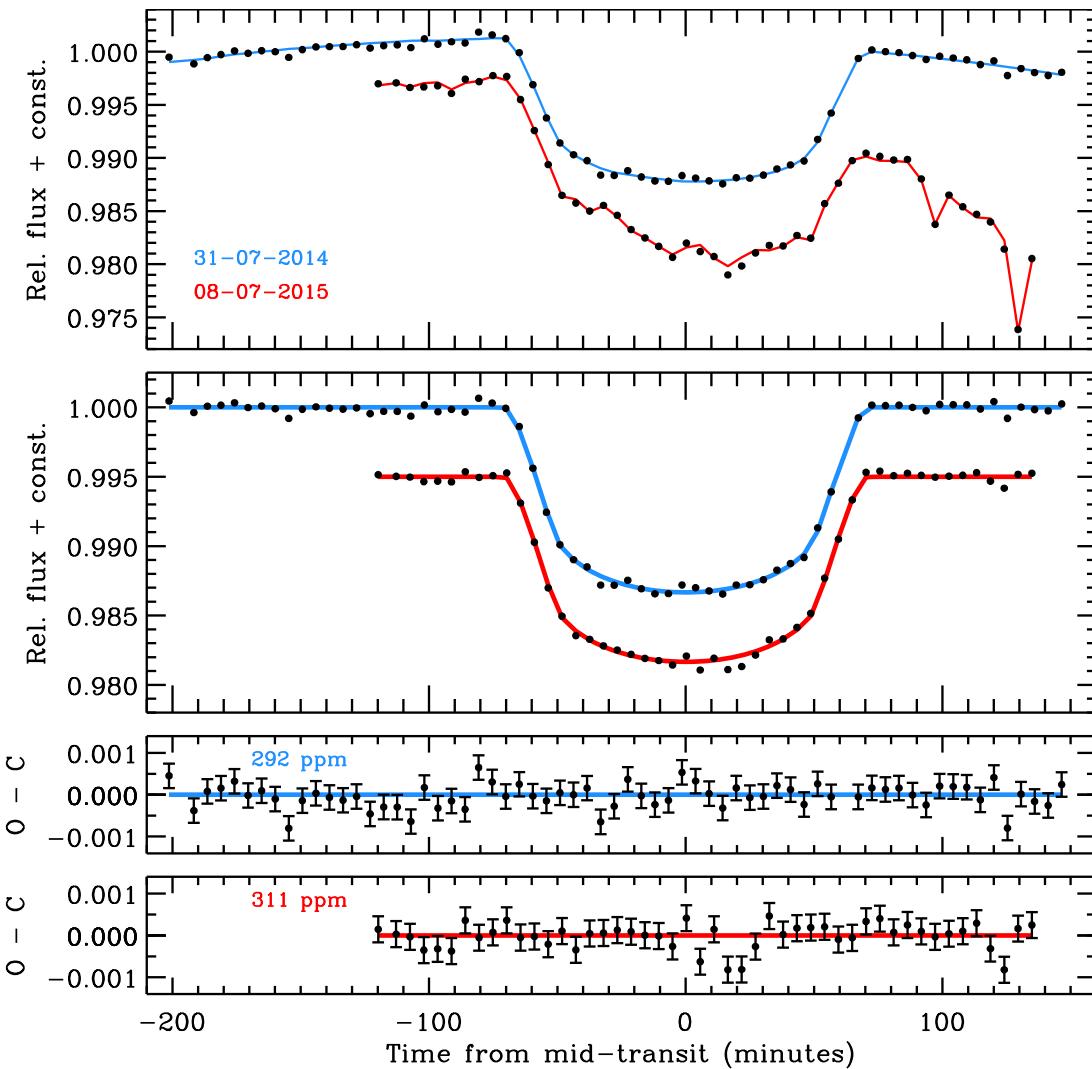
Chen et al, 2017

GJ 3470b: a warm Uranus transiting a nearby M dwarf



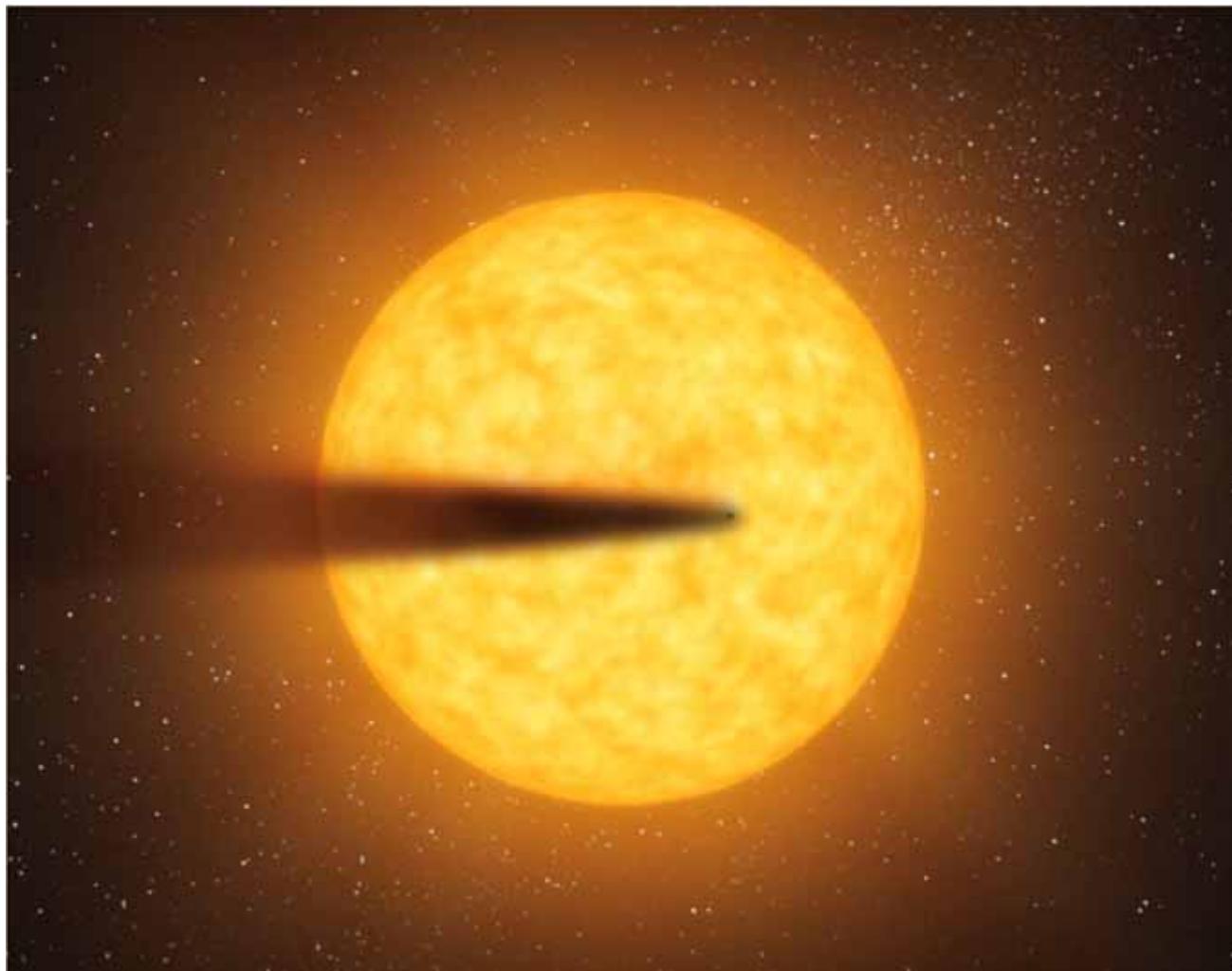
Chen et al, 2016, sub

At the faint end: competitive with space observations



Palle et al, A&A, 2016

Observing an “evaporating” planet



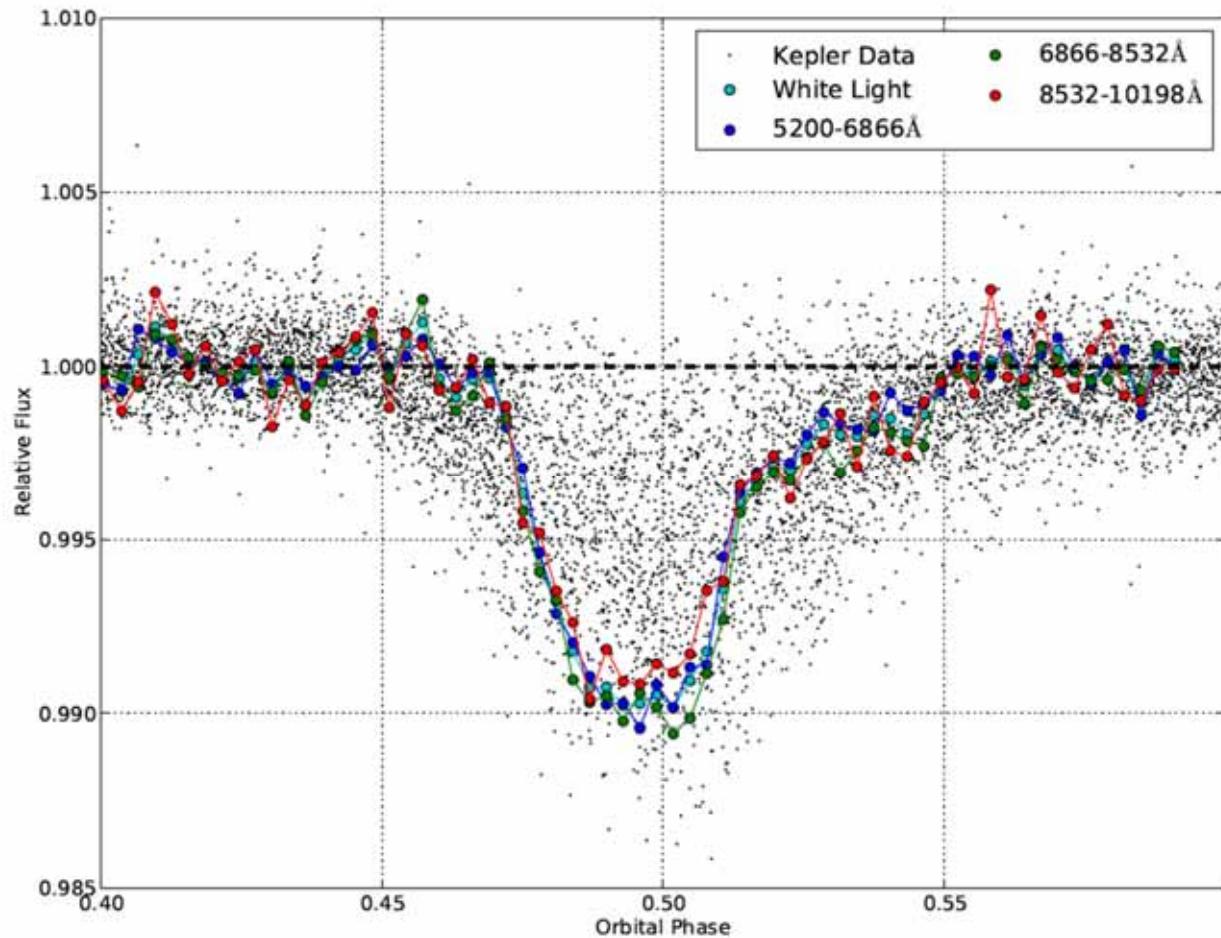
KIC12557548b
K dwarf

$V = 16$
 $P = 15.7 \text{ h}$

Variable transit
depths

Discovered by
Rappaport et al,
2012

Observing an “evaporating” planet: KIC12557548



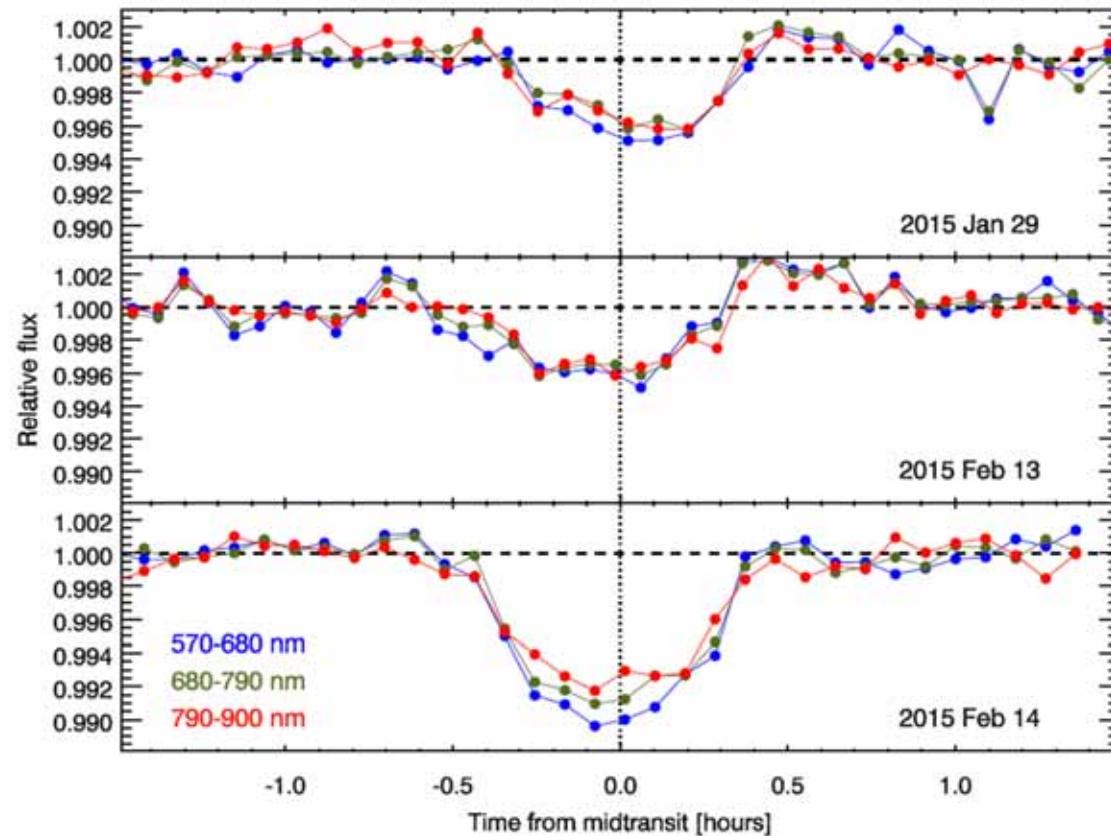
No color differences

Constraints on
the particles
sizes of the
planet/comet tail

Dust silicate
features 0.3-0.4
micron

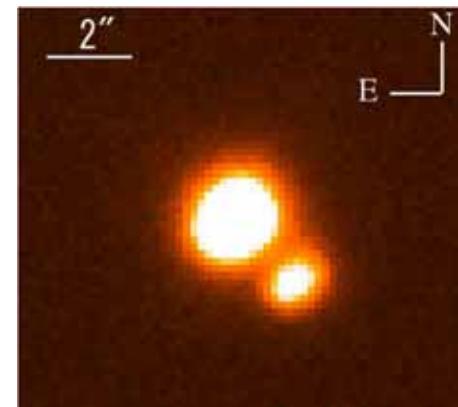
Alonso et al, in prep

A new “evaporating” planet from Kepler (K2-22b)



Chromaticity !

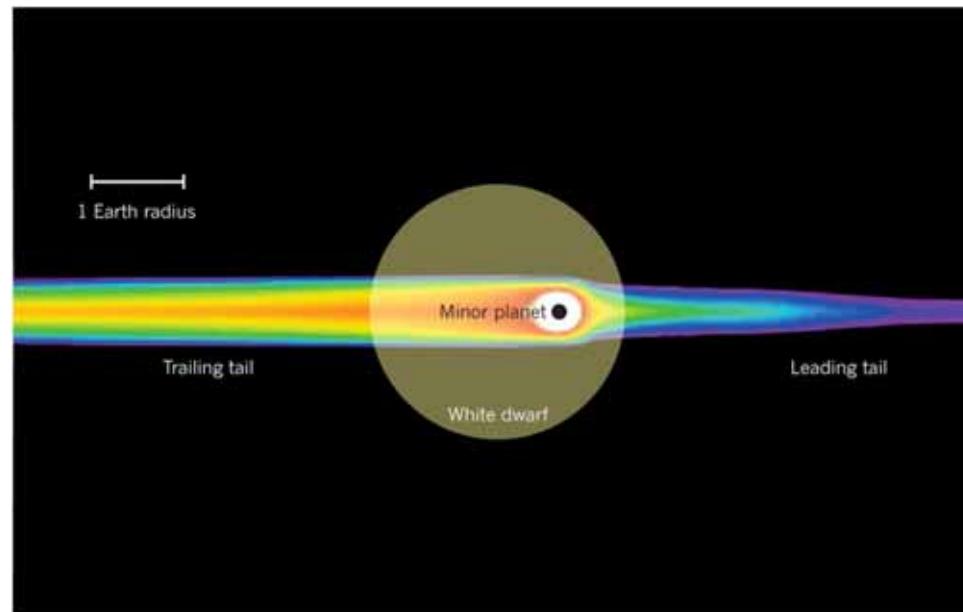
Leading and preceding tails !



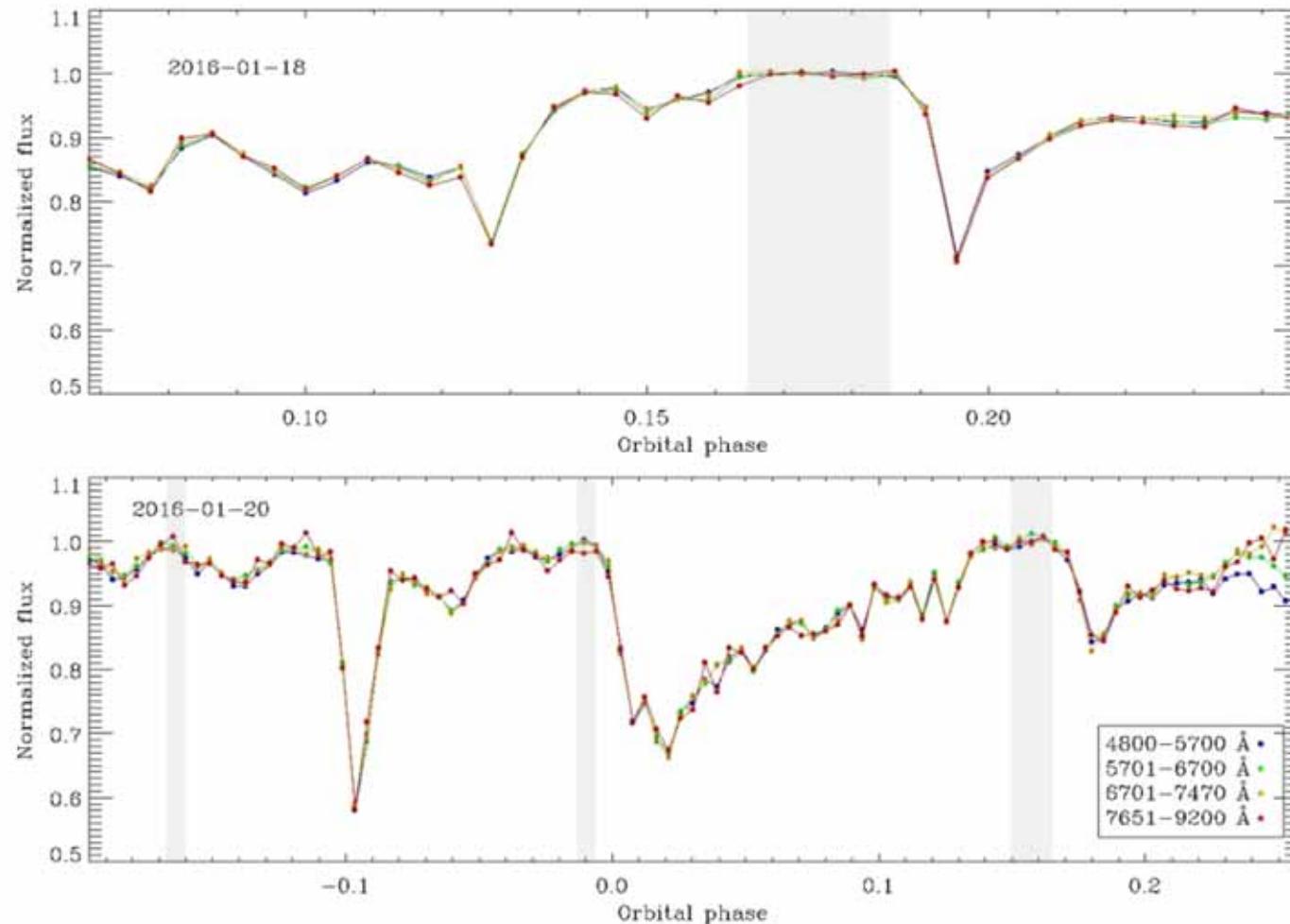
P= 0.38 d M < 1.4 M_J g-mag= 16.44

Sanchis-Ojeda et al, 2015

Grey transits for WD1145+017



Grey transits for WD1145+017



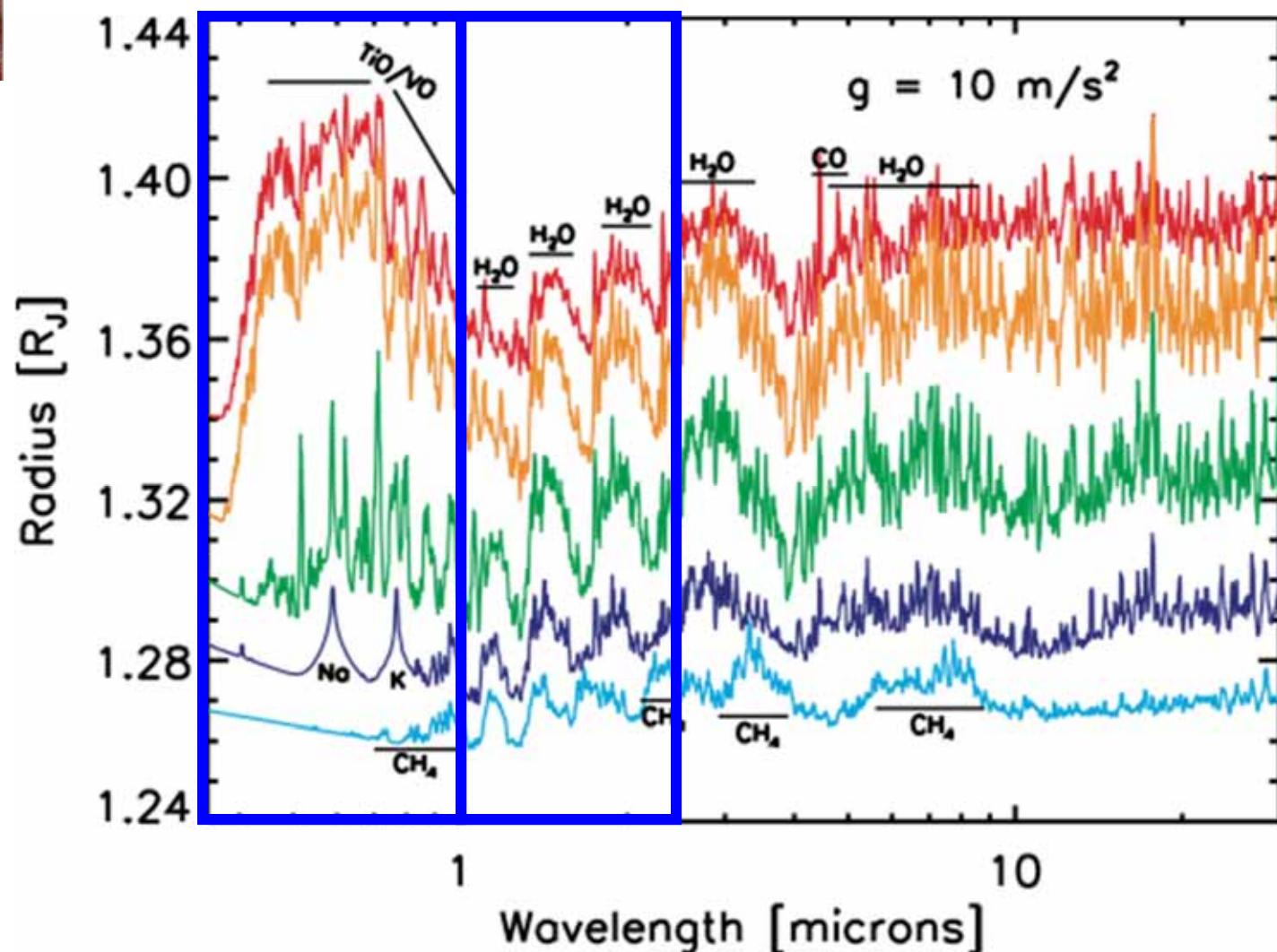
Vmag = 17

For most common minerals, particle sizes $\leq 1 \mu\text{m}$ can be excluded

Alonso et al, 2016



Now: Transit spectroscopy with EMIR@ GTC



The Future: High-resolution spectroscopy

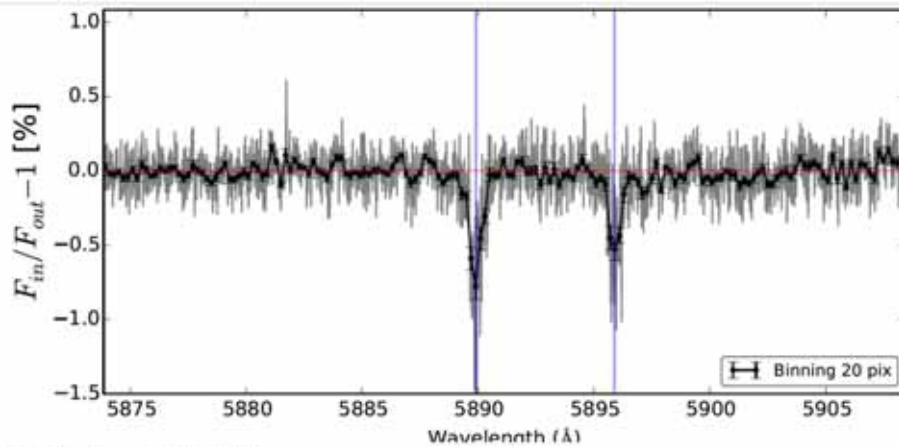


Fig. 10. Sodium detection HD189733b

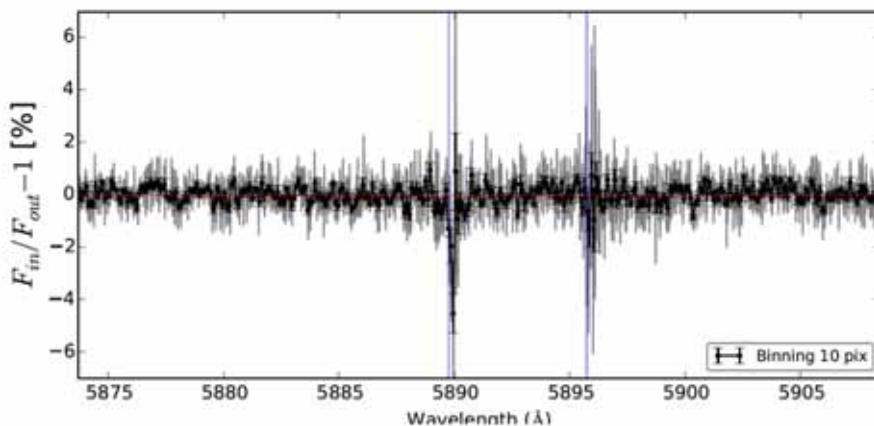


Fig. 11. Sodium detection WASP-69b

CARMENES
Colaboration IAA-
IAC

HIRES@E-ELT

Thanks