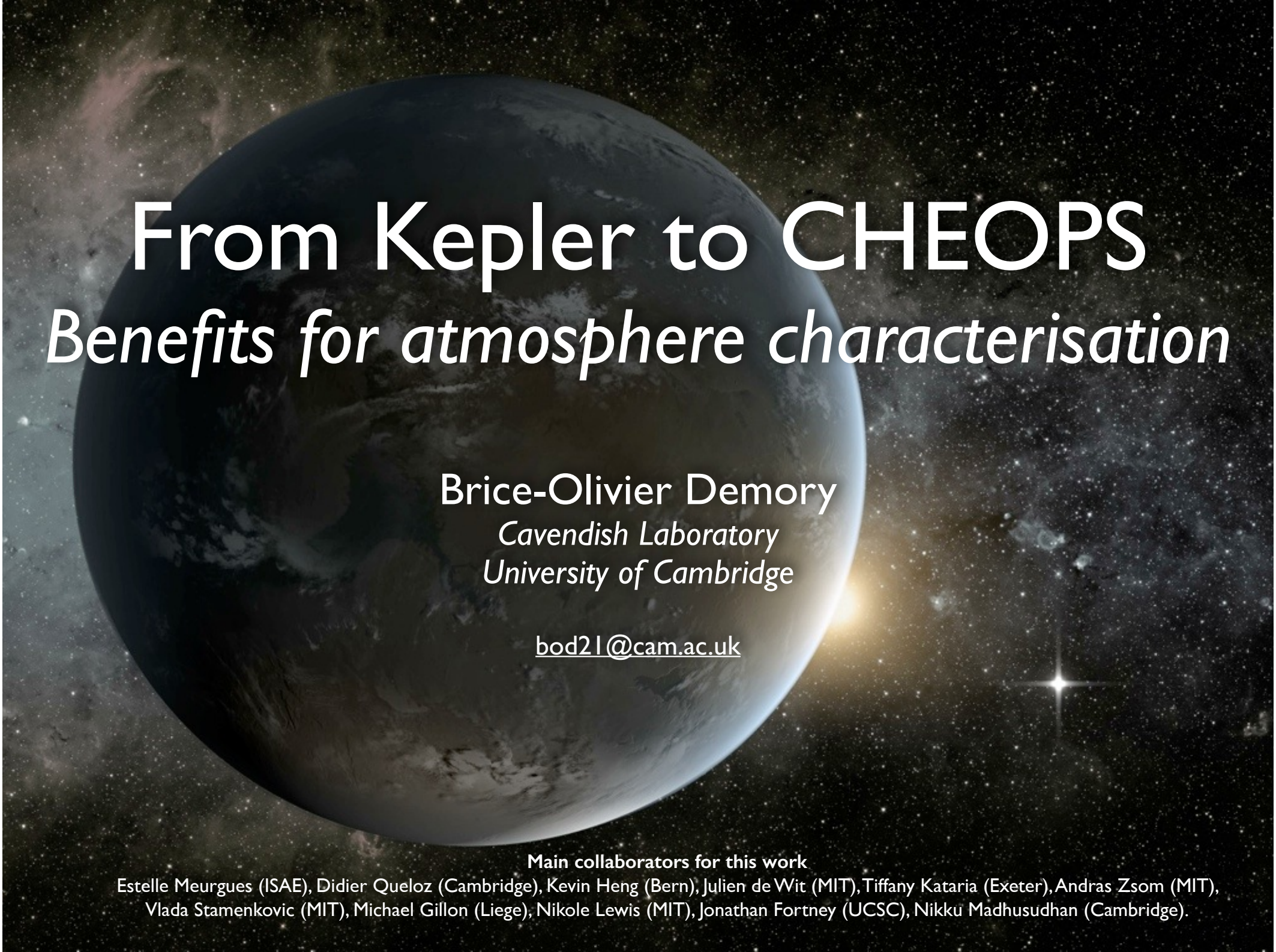

From Kepler to CHEOPS

Benefits for atmosphere characterisation

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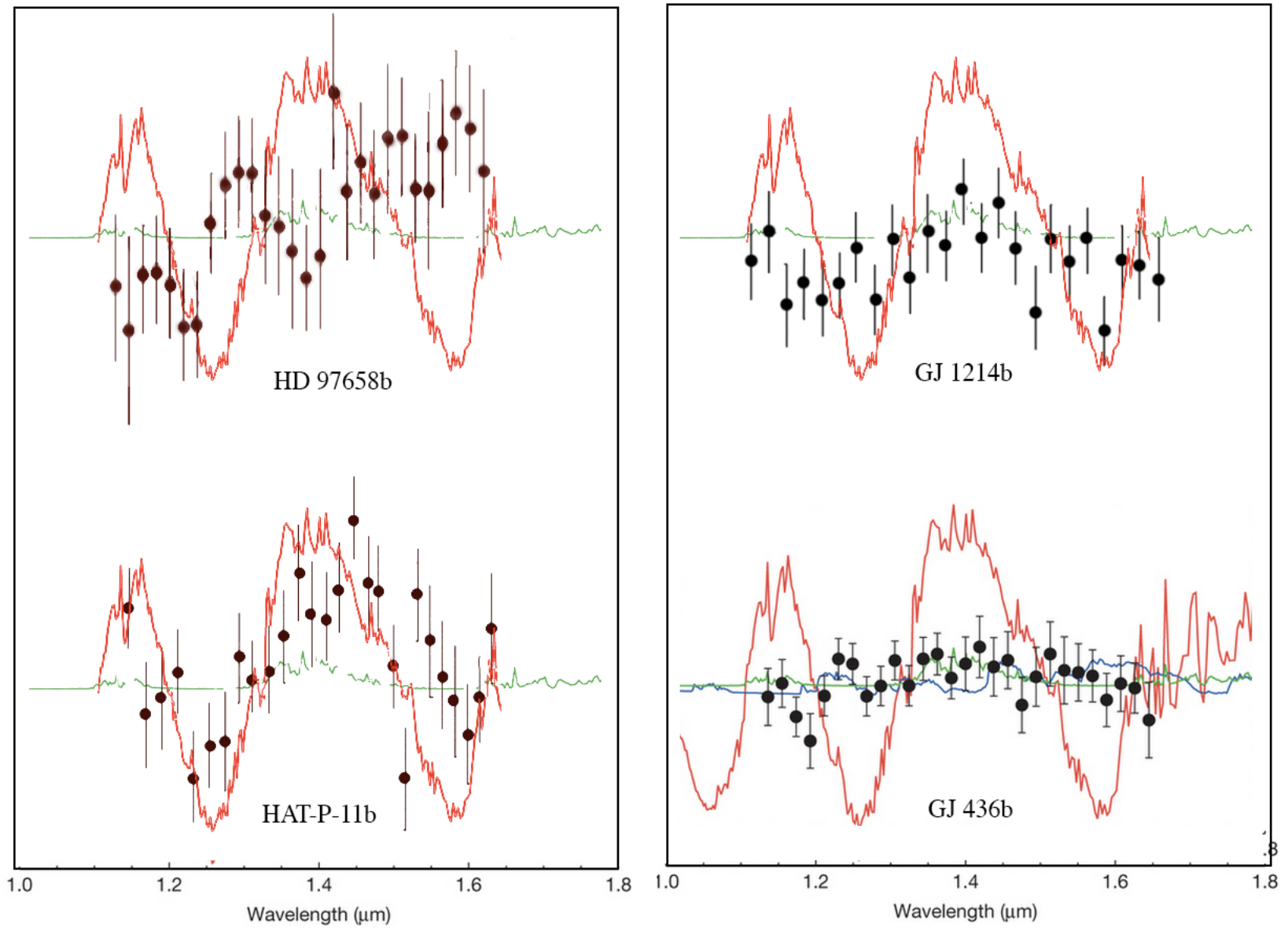
Main collaborators for this work

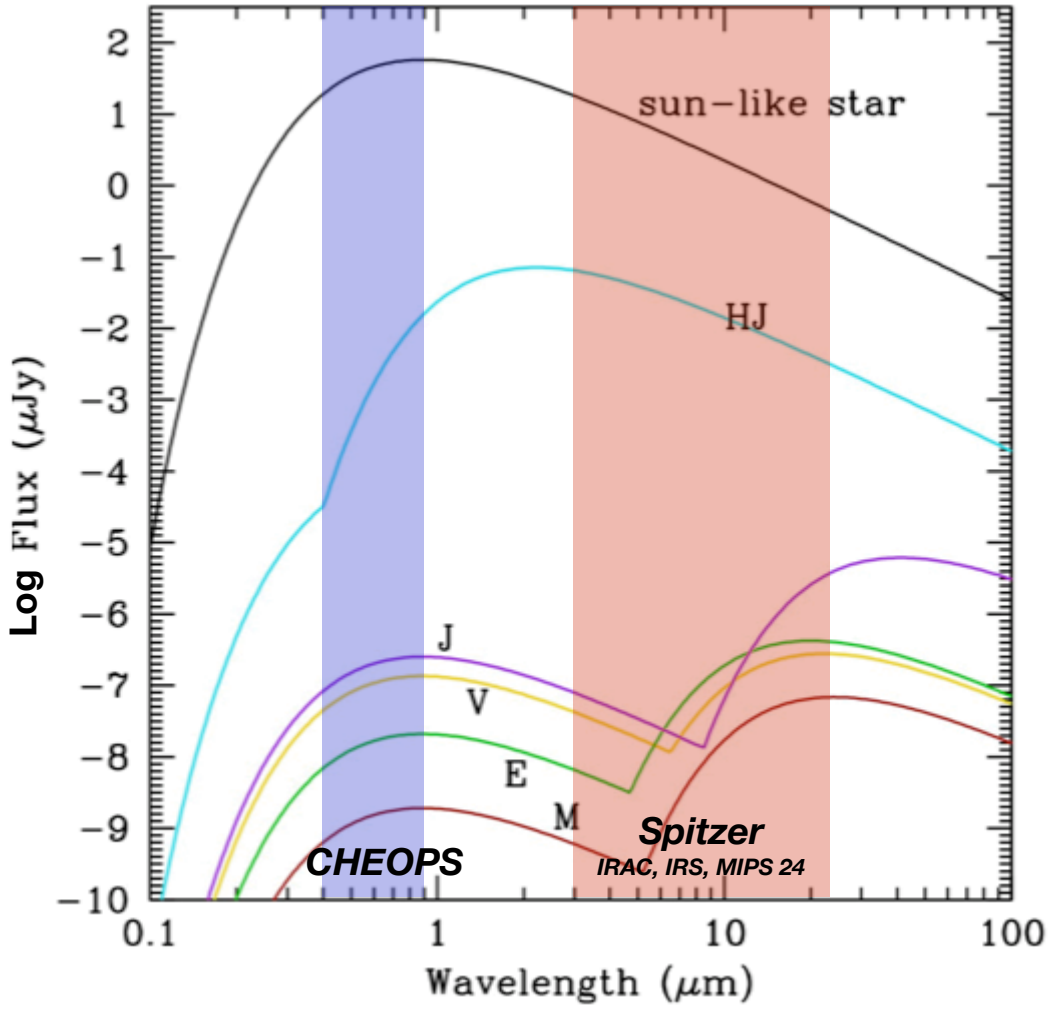
Estelle Meurgues (ISAE), Didier Queloz (Cambridge), Kevin Heng (Bern), Julien de Wit (MIT), Tiffany Kataria (Exeter), Andras Zsom (MIT), Vlada Stamenkovic (MIT), Michael Gillon (Liege), Nikole Lewis (MIT), Jonathan Fortney (UCSC), Nikku Madhusudhan (Cambridge).

Clouds are limiting our knowledge of exoplanets



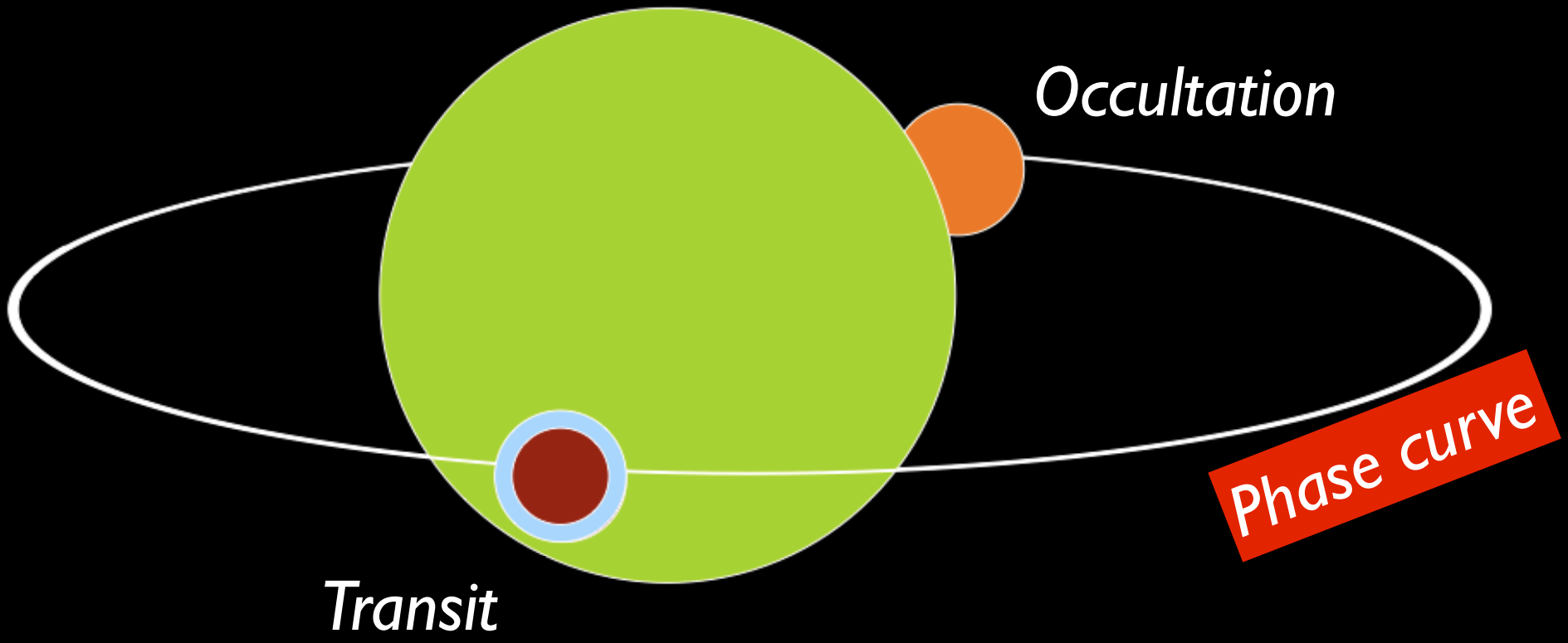
F. Pont, exoclimes.com

Coupling Visible and IR observations is crucial

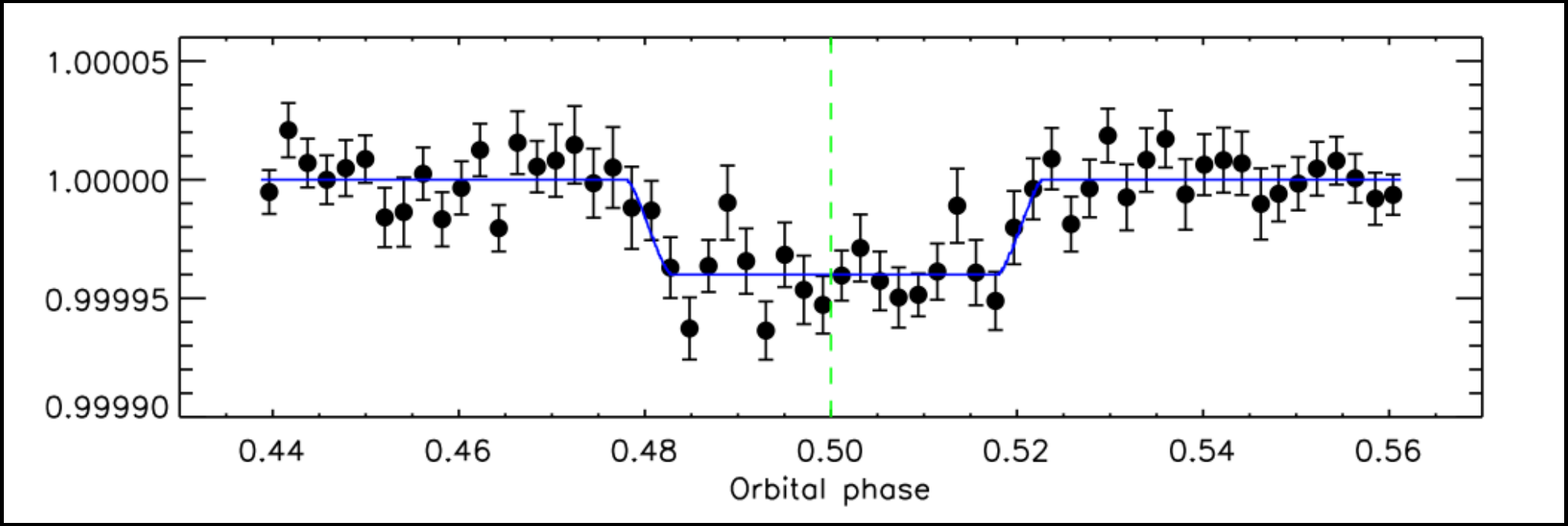


Seager et al., 2003

Transiting Exoplanets



Planetary light of Kepler-7b

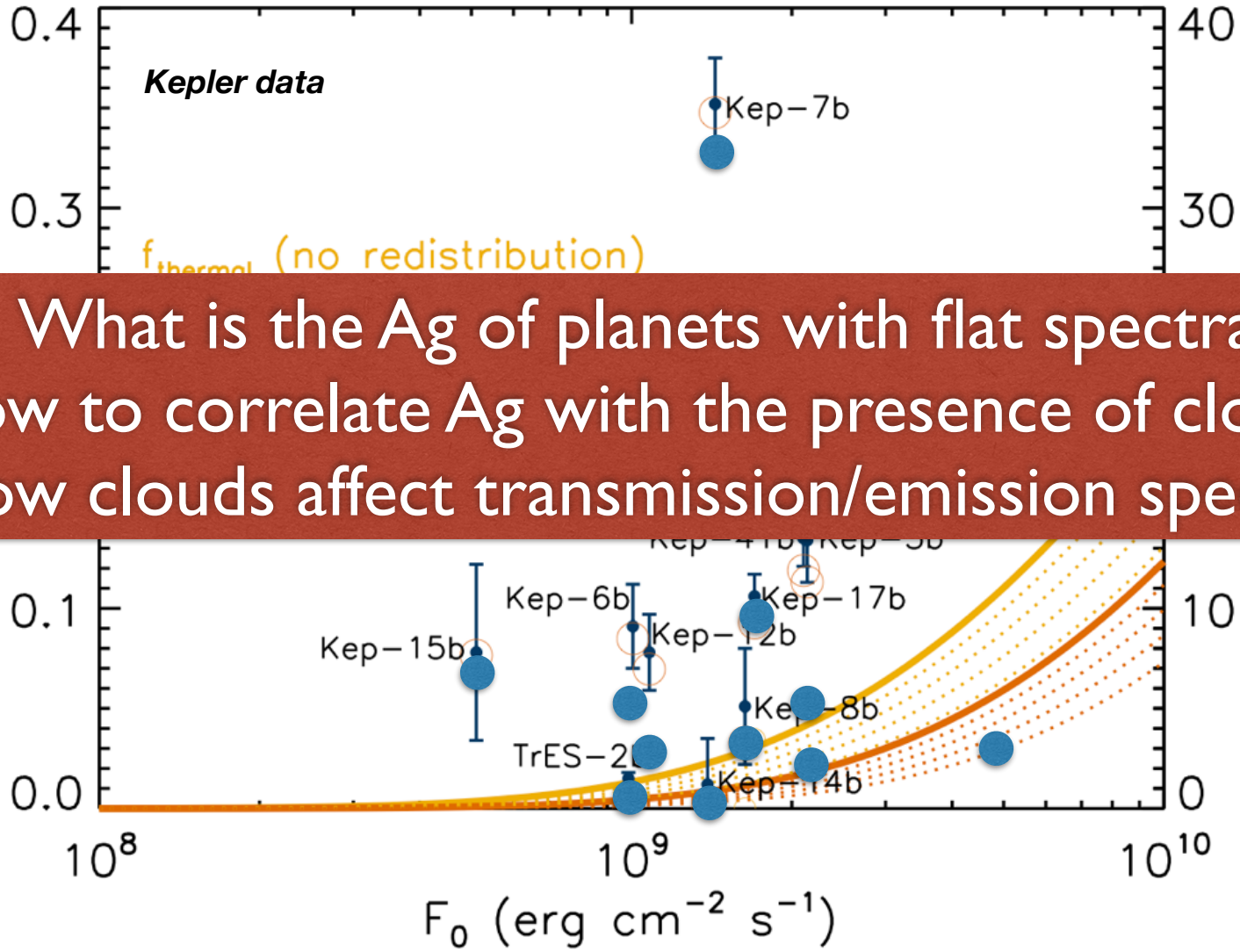


Kepler-7b
5-day period
1.5x Jupiter's size
0.5x Jupiter's mass
15% Jupiter's dens.

Occultation in the *visible*
(Q0-Q4 Kepler data)

Demory et al., 2011

The surprisingly large albedo of Kepler-7b

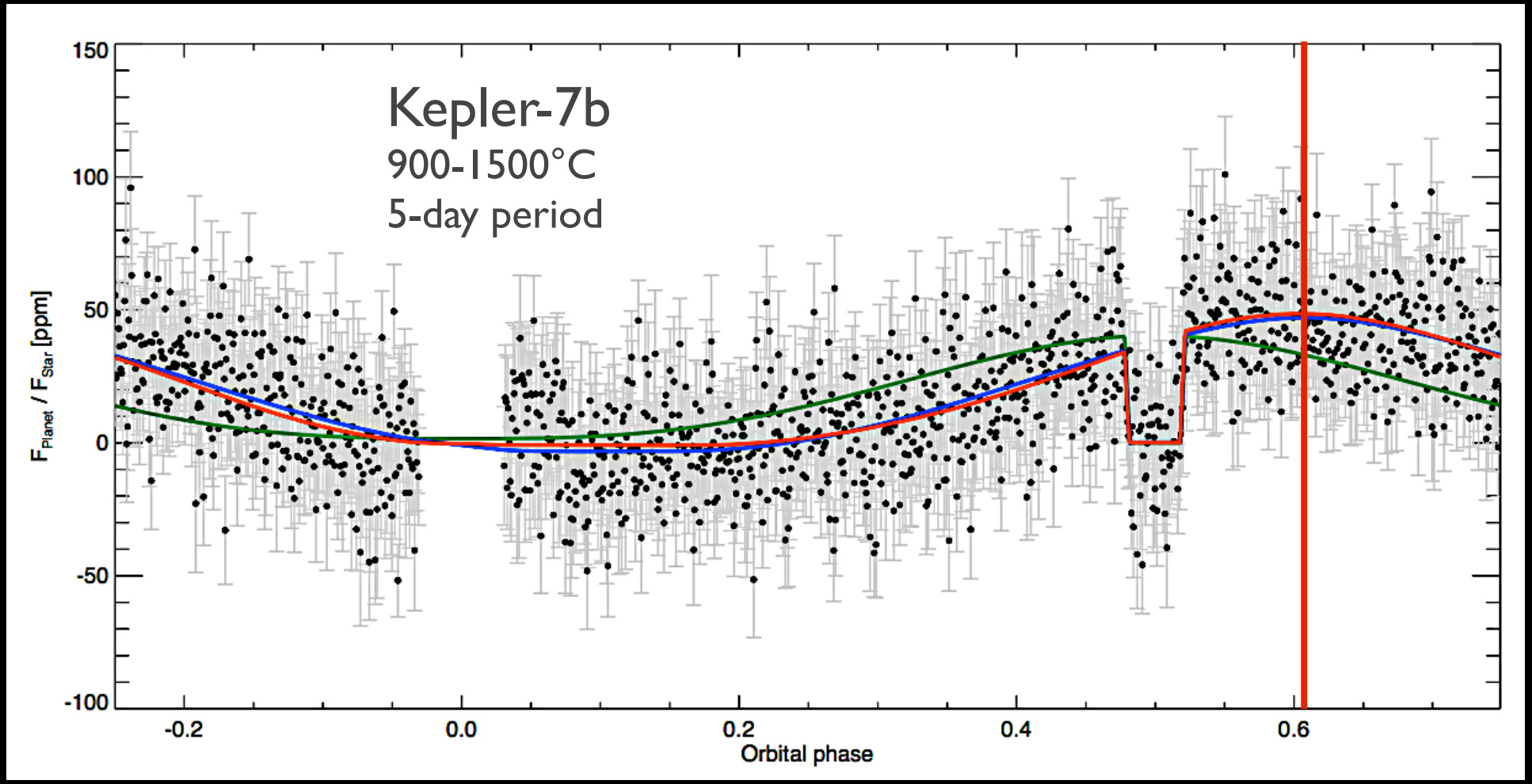


What is the Ag of planets with flat spectra?
How to correlate Ag with the presence of clouds?
How clouds affect transmission/emission spectra?

Kepler A_g **(hot Jupiters) : 0.06 - 0.11**

Heng & Demory 2013

VIS Phase-curve of Kepler-7b



Phase curve in the *visible*

Demory et al., 2013

See also Esteves+ 2014

First map of clouds of an exoplanet

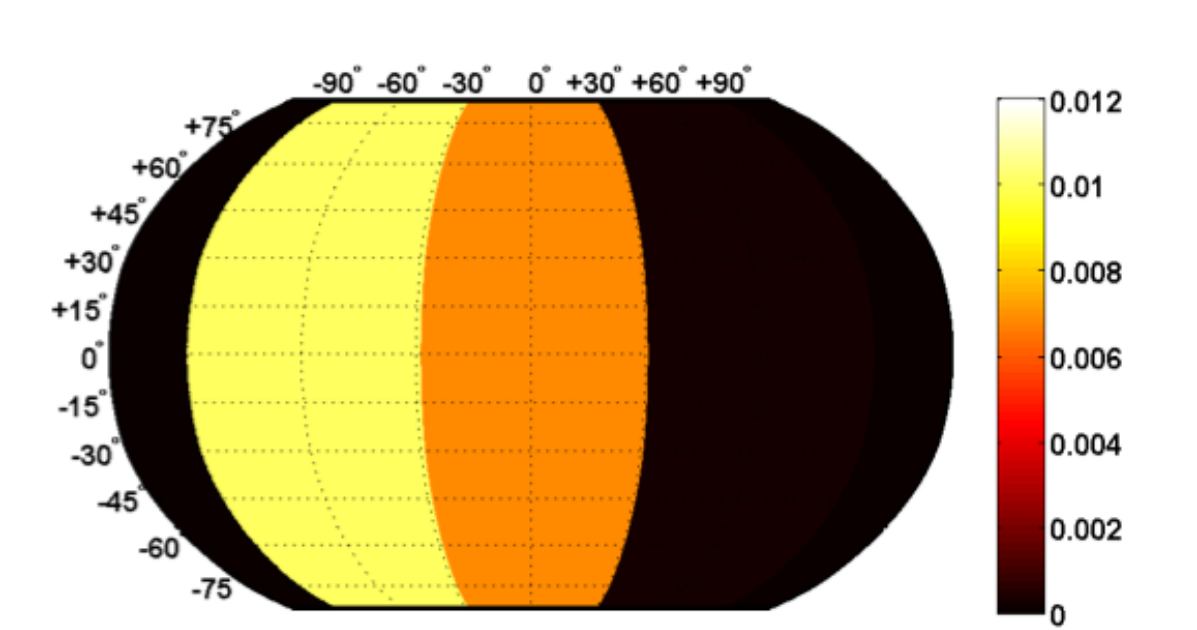
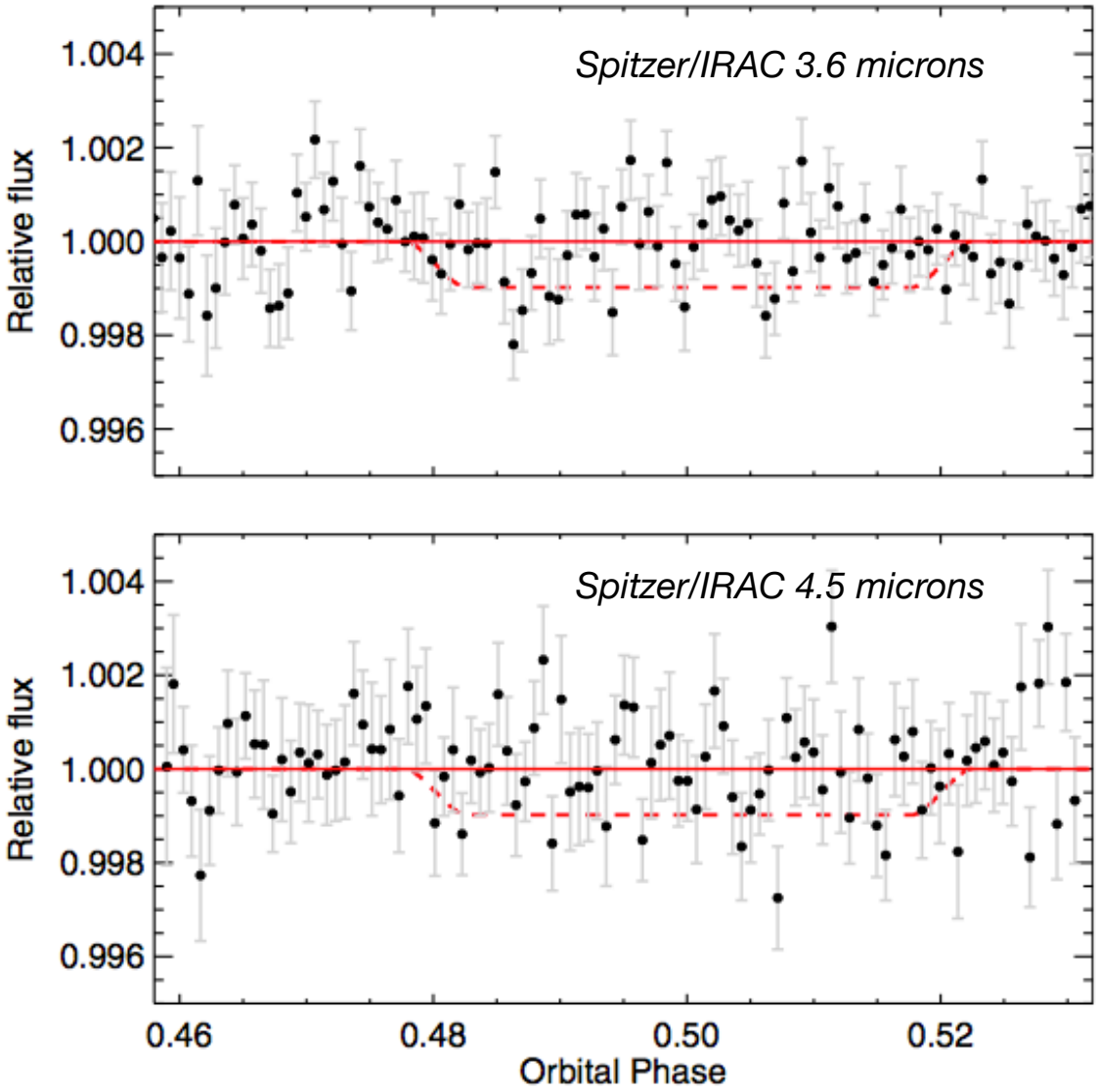


Figure by J. de Wit

Demory et al., 2013

Reflected light as the dominant source of A_g



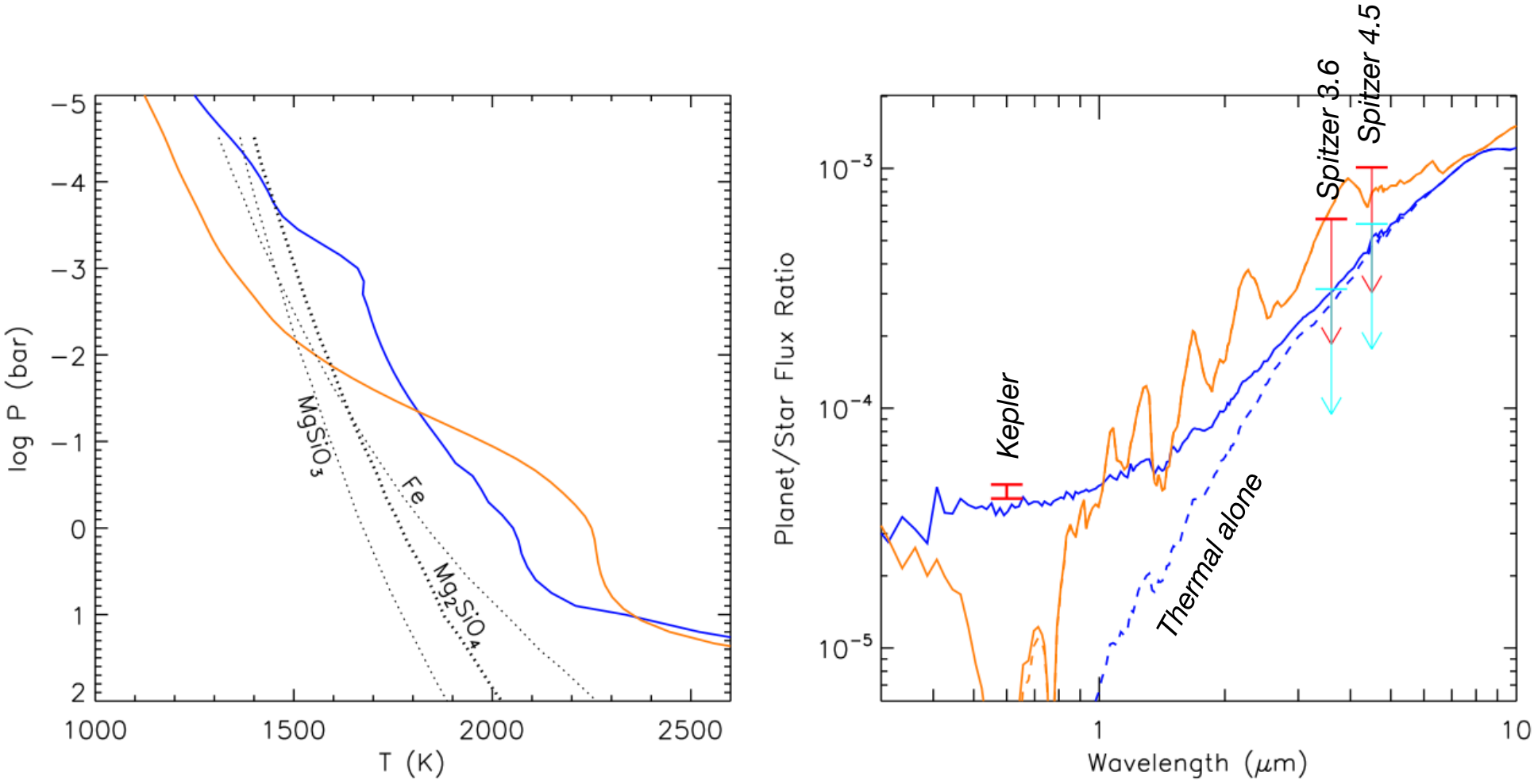
Kepler-7b

IR occultations with depths ~2mmag were expected.

Therefore the origin of planetary light seen in the visible is not primarily of thermal origin.

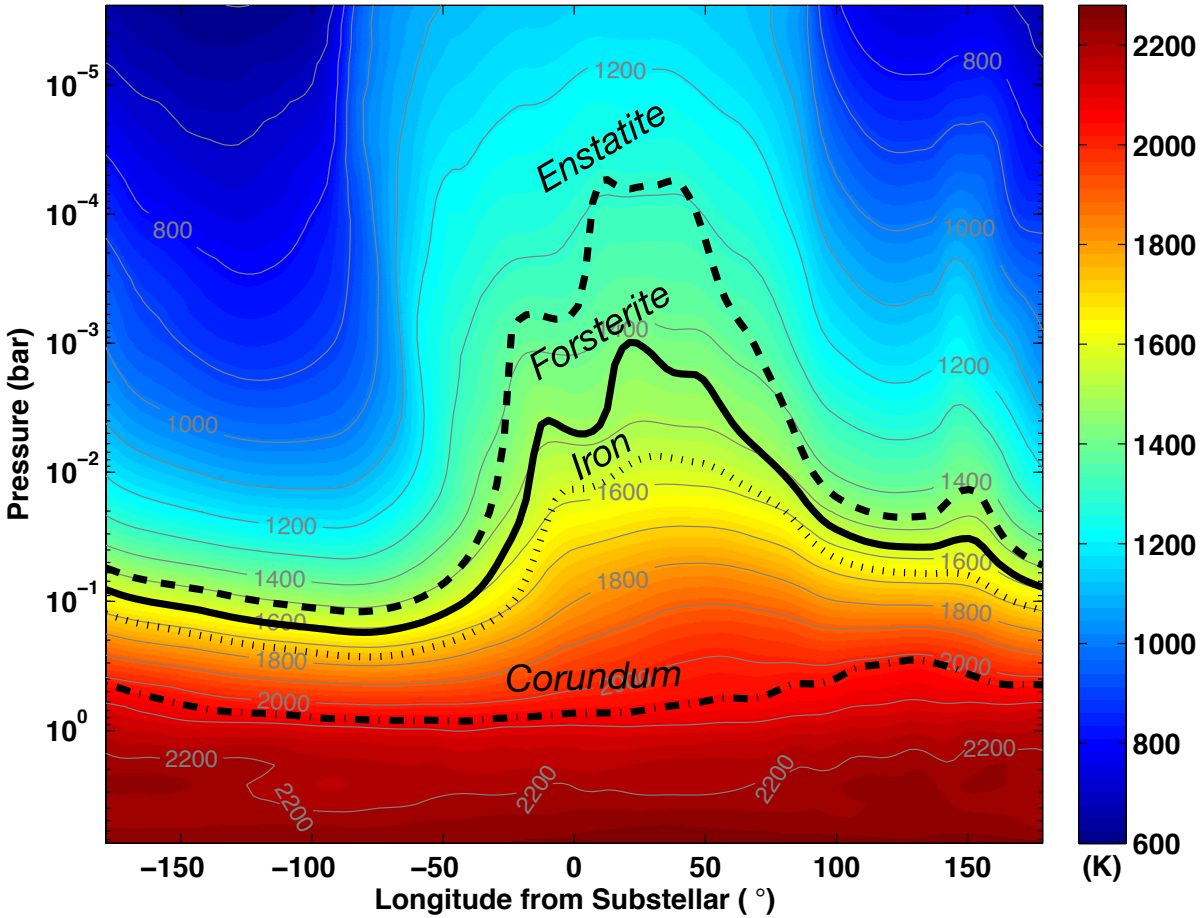
Demory+ 2013

Occultations: 1D nature of clouds



Demory+ 2013

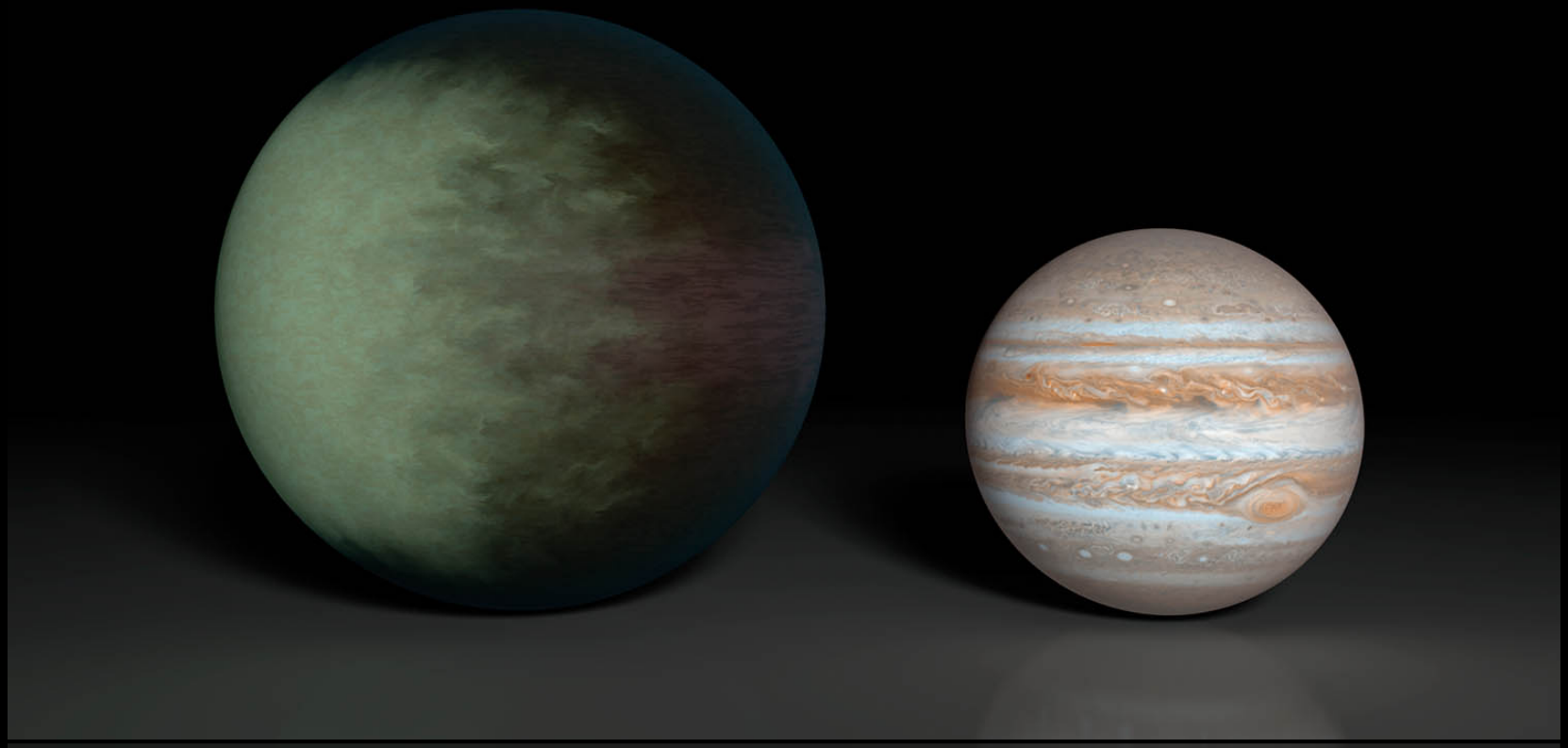
GCMs: toward the 3D nature of clouds



More about cloud properties: see talk from Antonio Garcia Munoz

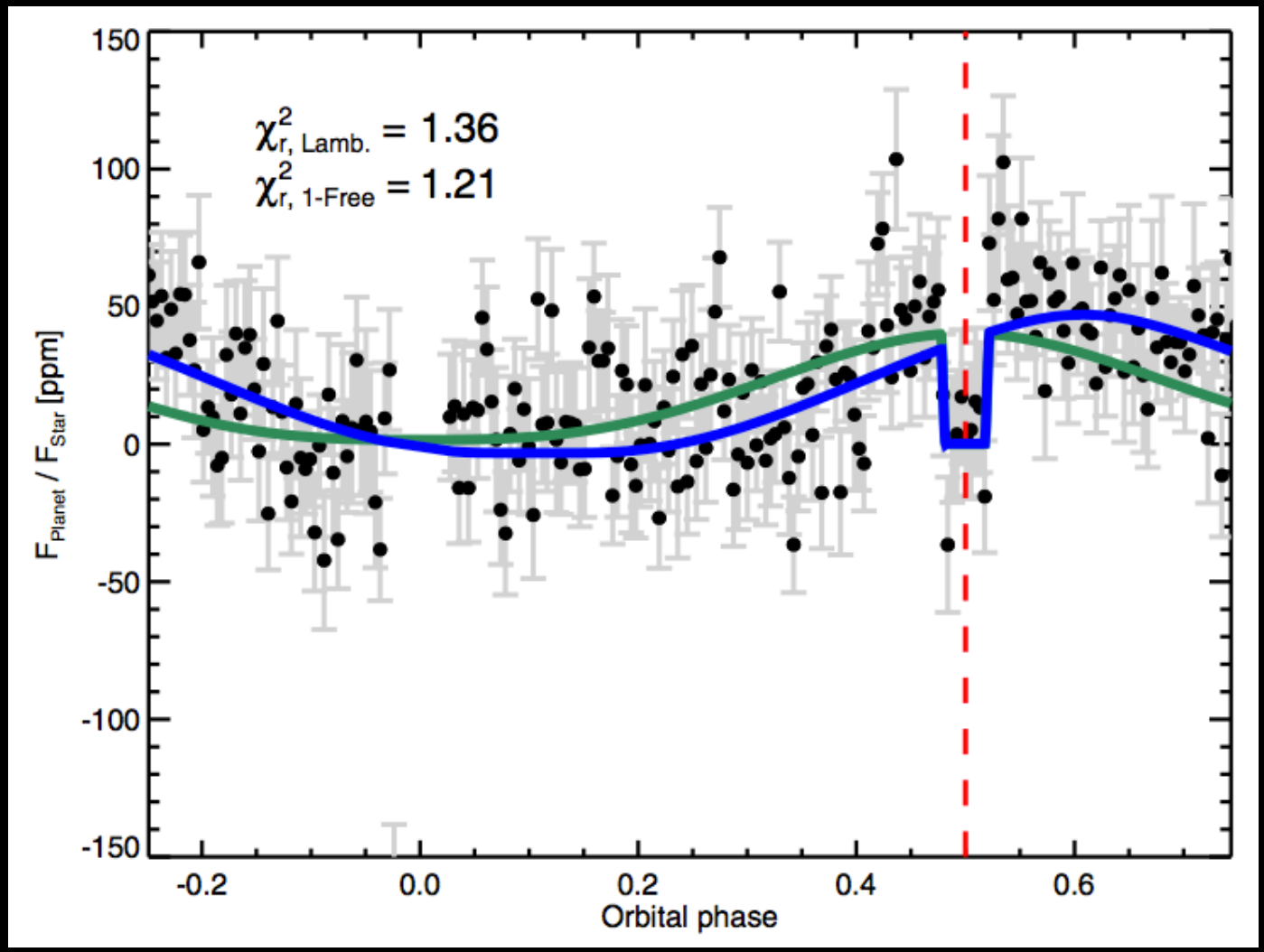
Lewis+ in prep.

Kepler-7b



NASA/JPL press release

Phase-curve studies similar to K7b are feasible with CHEOPS



Kepler-7b - Q1 data (Demory et al. 2013)

CHEOPS potential for exoplanet phase-curves

Assumptions

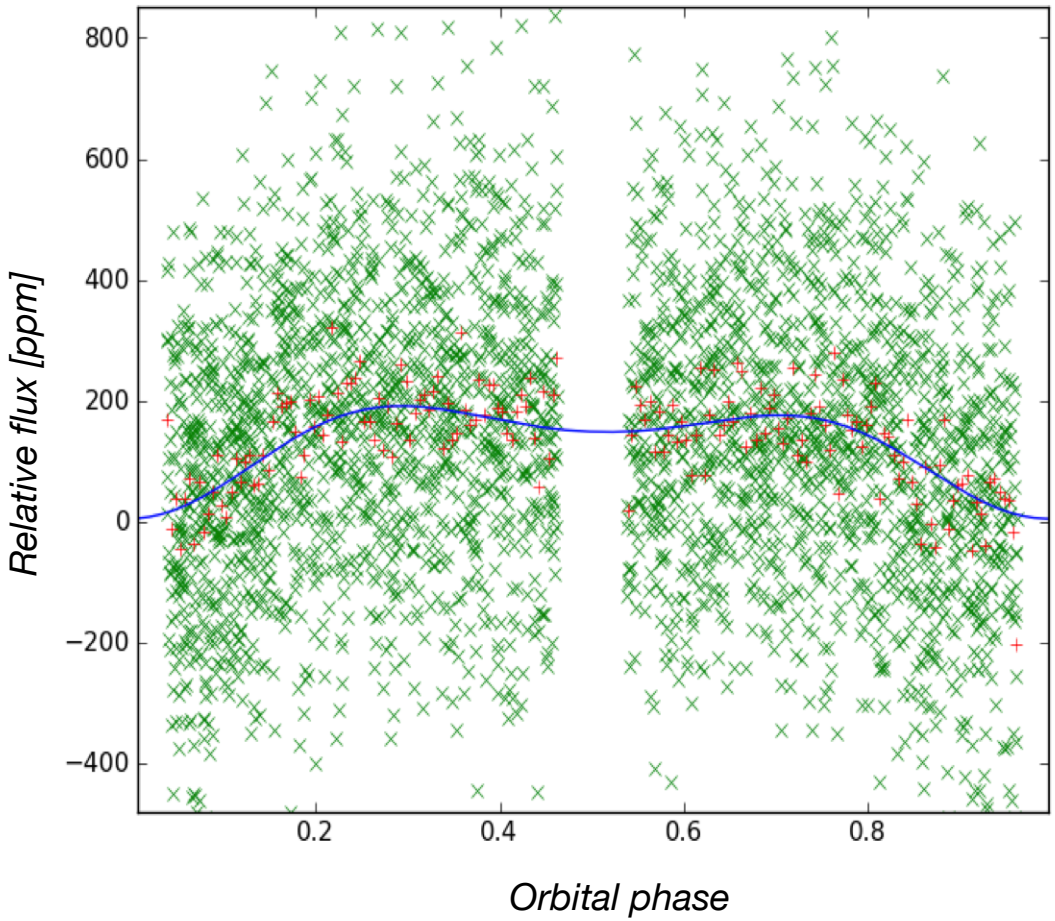
- White noise: 150 ppm/minute for a Vmag=9 star in the V-band (*)
- Red noise: 20 ppm for a Vmag=9 star in the V-band (*)
- Orbit-to-orbit systematics (temperature) similar to HST.

(*) source: CHEOPS Definition Study Report, ESA, November 2013

E. Meurgues' summer project

CHEOPS potential for exoplanet phase-curves

Test case: KOI-13A (Vmag = 12) - 50 days of observations



Includes:

- reflective, Doppler, ellipsoidal components.
- CHEOPS simple noise model

E. Meurgues' summer project

CHEOPS potential for exoplanet phase-curves

Results

- 15 orbits
- Low (0.1) and high (0.3) albedos
- Small (10 deg) and large (40 deg) phase offsets

			High albedo and high offset		High albedo and low offset		low albedo and high offset		low albedo and low offset	
			Ratio signal to noise S/N for the bootstrap values							
Name	Mag.	Duration of observation (in days)	offset	Ap	offset	Ap	offset	Ap	offset	Ap
HD 209458 b	**7,65**	**53,6**	**16,727**	**29,120**	**3,866**	**33,258**	**3,716**	**10,200**		
HD 189733 b	**7,67**	**34,0**	**23,986**	**47,201**	**5,560**	**42,742**	**5,588**	**11,929**		
HD 149026 b	8,16	43,8	3,553	7,566						
WASP-33 b	**8,30**	**19,00**	**30,416**	**50,887**	**6,251**	**55,551**	**7,876**	**15,134**		
KELT-2 A b	8,71	62,41	6,171	13,085						
HAT-P-2 b	8,71	85,20	4,794	8,130						
WASP-18 b	**9,39**	**14,82**	**14,218**	**37,274**	**5,342**	**29,453**	**4,533**	**10,745**		

⋮

E. Meurgues' summer project

CHEOPS potential for exoplanet phase curves

PLANET	TEQ [K]	REQ. TIME [d]	*HST* obs	*Spitzer* obs
HD 189733 b	1185	34	x	x
WASP-7 b	1377	75	x	x
HD 209458 b	1428	54	x	x
WASP-77Ab	1688	21	x	
HAT-P-8 b	1749	47	x	x
HAT-P-23 b	2024	19	x	x
WASP-19 b	2039	12	x	x
WASP-18 b	2367	15	x	x
WASP-12 b	2551	17	x	x
WASP-94Ab	*1604*	*59*		

129 days (4 months)

Summary

- **Clouds** are becoming a limiting factor in exoplanet characterisation
- **CHEOPS** can **constrain** cloud properties (distribution, **climate patterns**) that would lead to a better handling of the **impact on exoplanet spectra**
- Large time commitment (**3-4 months**) necessary for a meaningful sample but **no scheduling constraints**.