What Titan's phase curves can teach us about exoplanet atmospheres

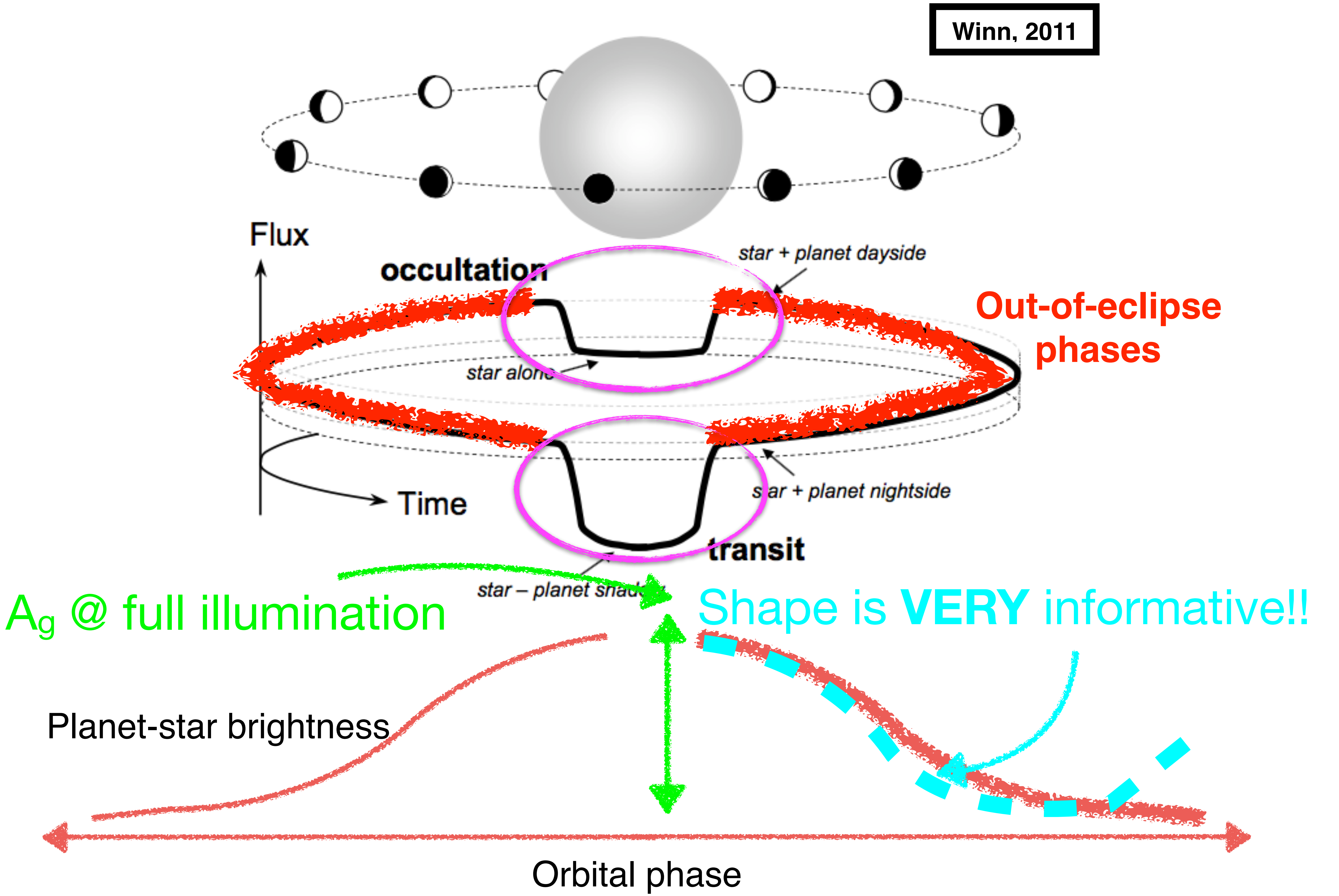
A. García Muñoz
Technische Universität Berlin, Berlin, Germany

Collaborators:

P. Lavvas (U. Reims, France), R.A. West (JPL, US)
&
J. Cabrera (DLR Berlin, Germany)

EPSC, 20.09.2017, Riga , Latvia

Phase curves



A classical problem in solar system science

E.g.: Venus, Mercury, Titan

- Phase curve shape **—>** ***atmospheric optical properties.***
- Reflected sunlight **—>** Energy budget.

…*which is highly relevant for exoplanets.*

- We use solar system objects as benchmarks & motivation.
- In this exercise, we learn about Titan too!

Our work — Cassini Imaging Science Subsystem

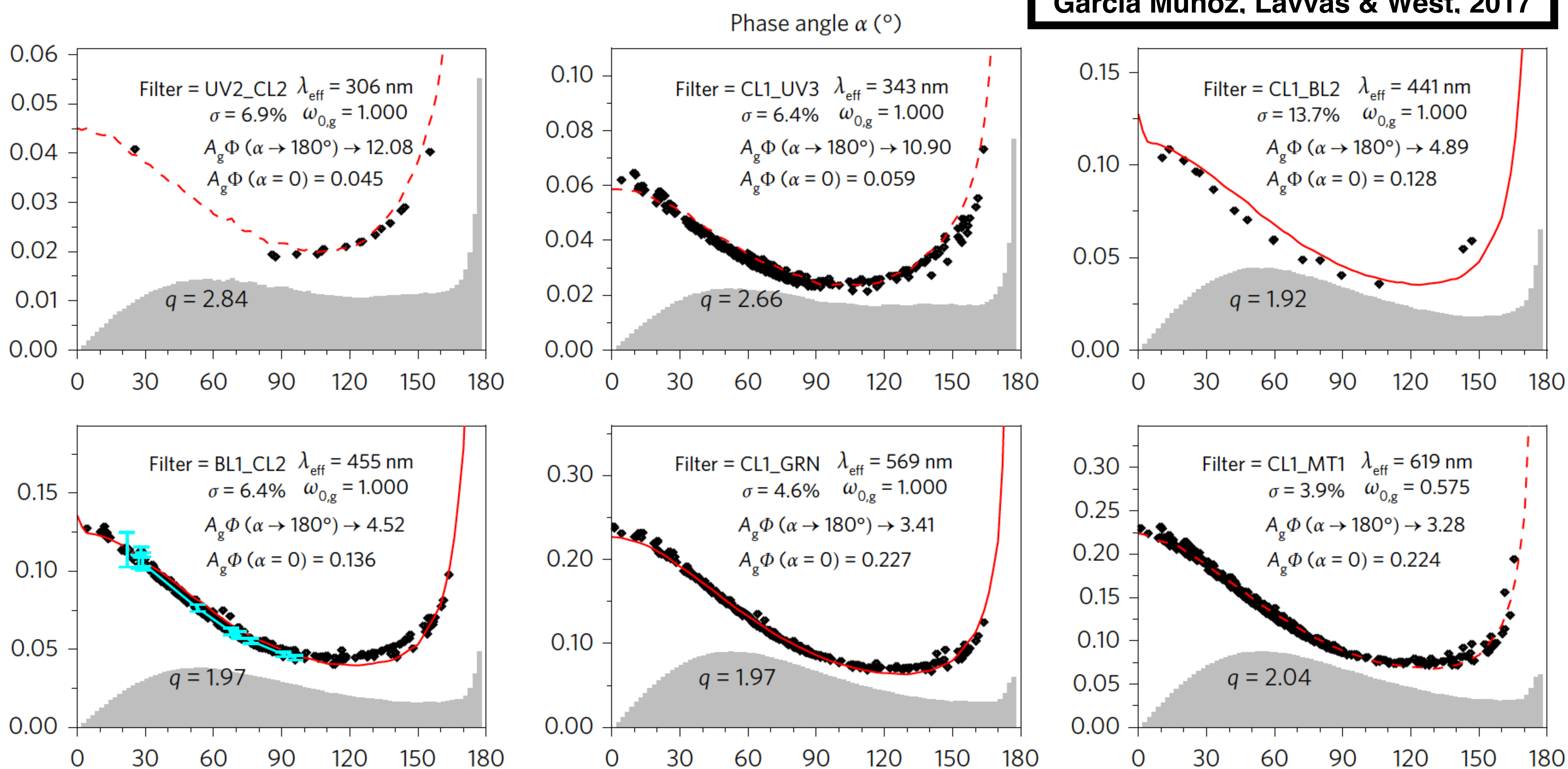
García Muñoz, Lavvas & West, Nature Astronomy, 2017

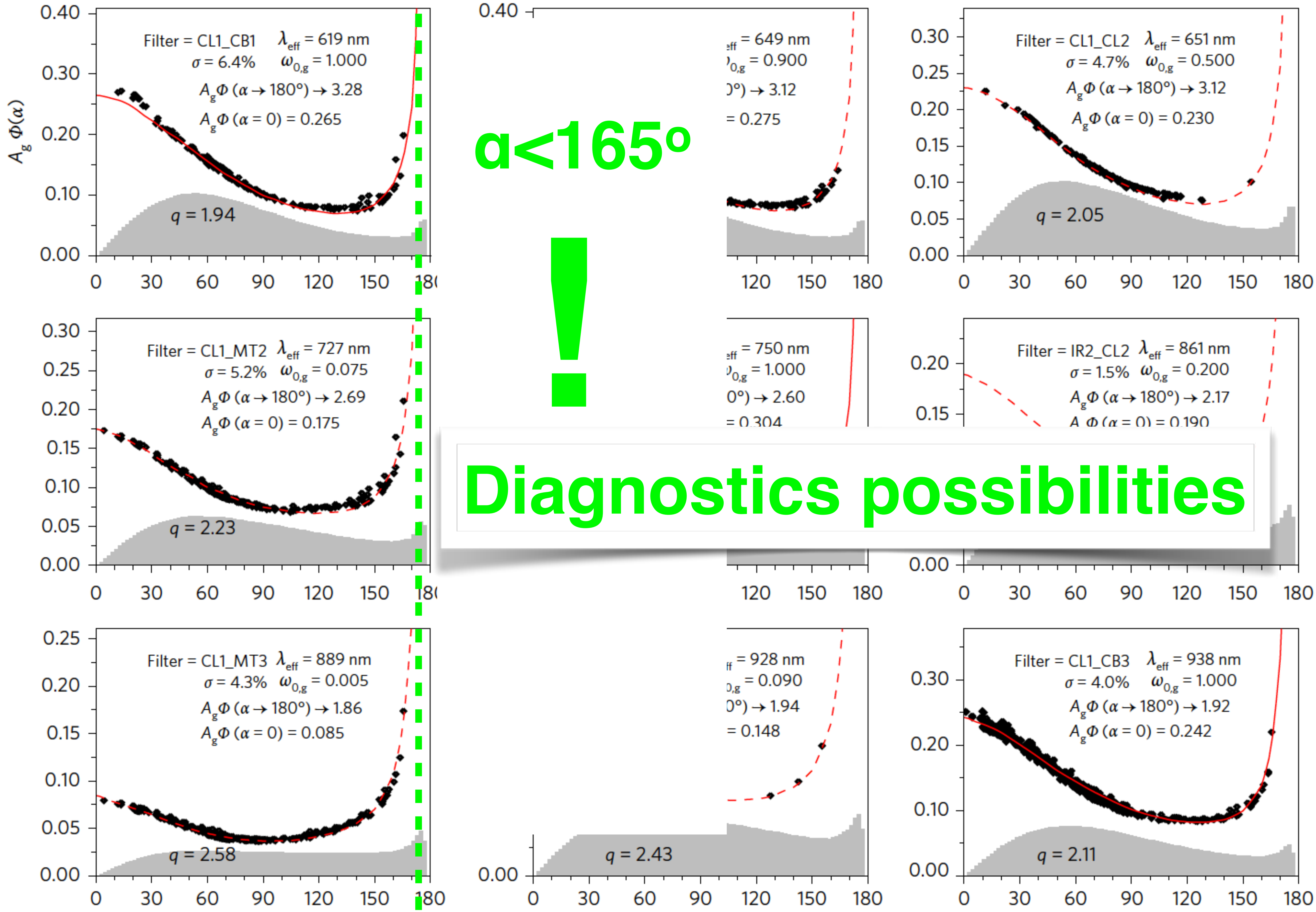
Images:

- Total of ~6,000
- 12 years: 2004 — 2015
- 15 filters: 300 nm —> 940 nm
- Phase angles: 0 —> 165°

Our work — Cassini Imaging Science Subsystem

García Muñoz, Lavvas & West, 2017





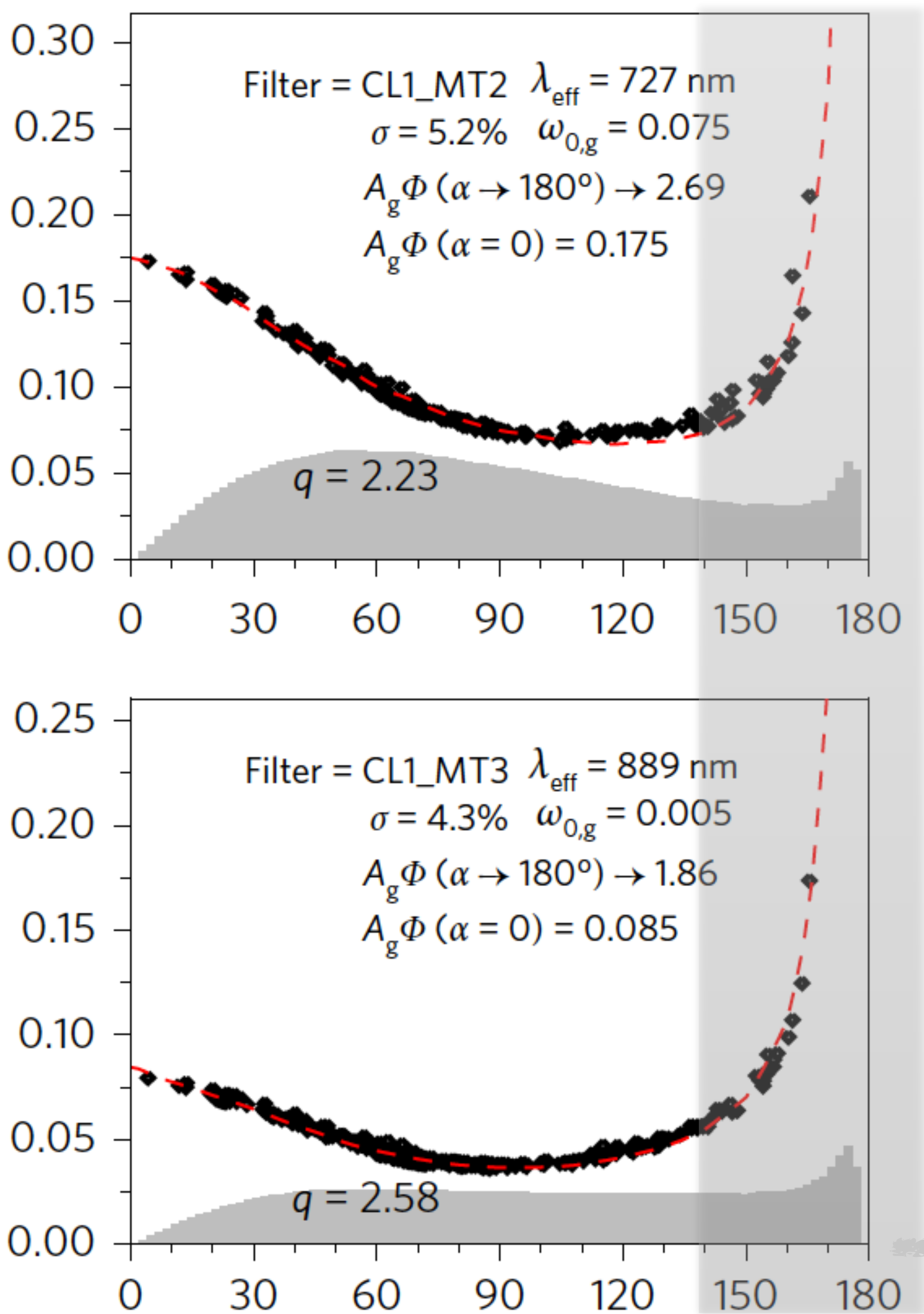
α<165º

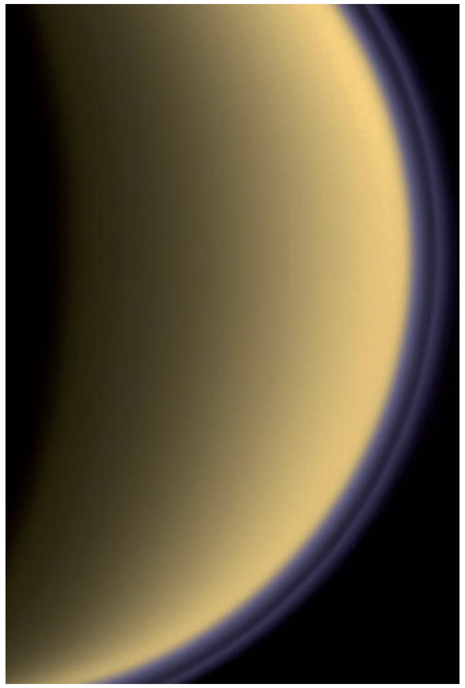
!

Diagnostics possibilities

What's special with Titan

- **Puffy** atmosphere, H_a/R_T~0.015 >> other solar system planets
- **Hazy** atmosphere.
- (Photochemical) haze is strongly **forward scattering** (r_{eff}~3 μm).



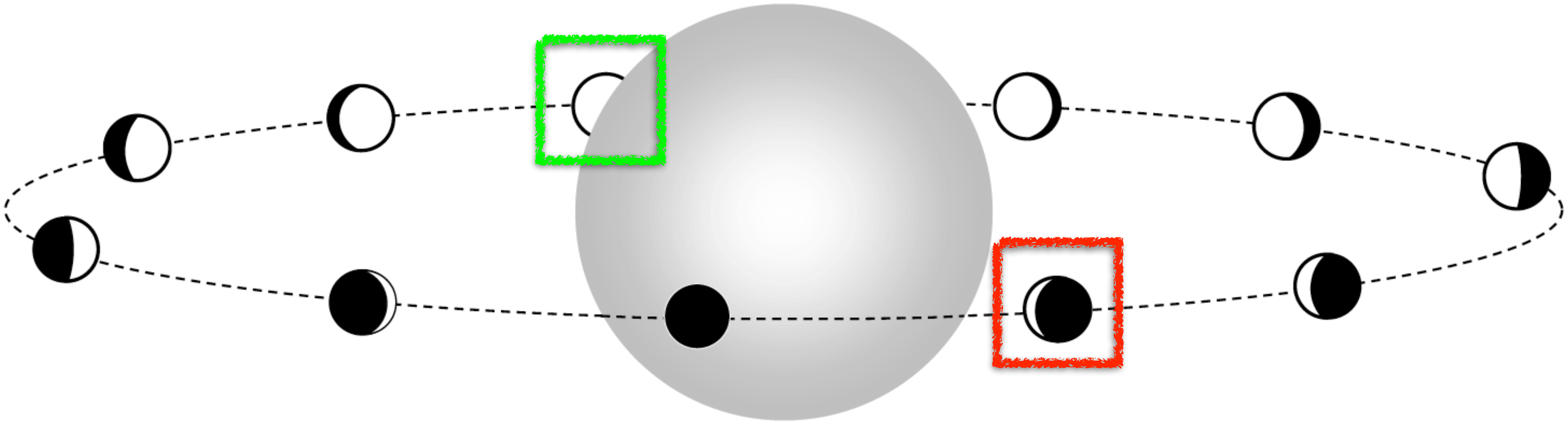


Interpretation:

- Forward scattering of whole moon.
- Excellent match of model (**red**) and observations (**black symbols**)… Reliable prediction based on DISR aerosol properties…

Brightness at **large phase angles**
significantly exceeds
brightness **at full illumination**

$$A_g\Phi(\alpha=180) \sim 10-200\ A_g\Phi(0)$$



Diagnostics. Theory.

- *Exponential atmosphere*, scale height $H_g=kT/\mu g$.
- Haze distributed vertically with $H_a=H_g$.
- Haze particles of prescribed size r_{eff}.
- Single scattering dominates scattered signal.

Planet-to-star contrast at $\alpha=180^o$:

$$\frac{F_p}{F_\star} = \frac{1}{a^2} \times 2\pi H_a R_p \times p_a(\theta=0)\varpi_{0,a}$$

Sensitive to haze size

Area of ring

Microphysical models are needed!!

Brightness surge occurs ONLY when:

- Atmosphere is puffy, H_a/R_p ~0.01 or more.

AND

- $p_a(\theta=0)$ is large (**—>** large haze particles).

Inversely:

Detection of brightness surge will impose joint constraint on H_a/R_p $p_a(\theta=0)$

At exoplanets?

Considerations (I):

- Inflated (~**puffy**) exoplanets do exist —> large H_a/R_p.
- **Hazy** atmospheres. Plenty of them!

- Estimating $p_a(\theta=0)$ (particle size) is **very uncertain**.

$$\frac{F_p}{F_\star} = \frac{1}{a^2} \times 2\pi H_a R_p \times p_a(\theta = 0)\varpi_{0,a}$$

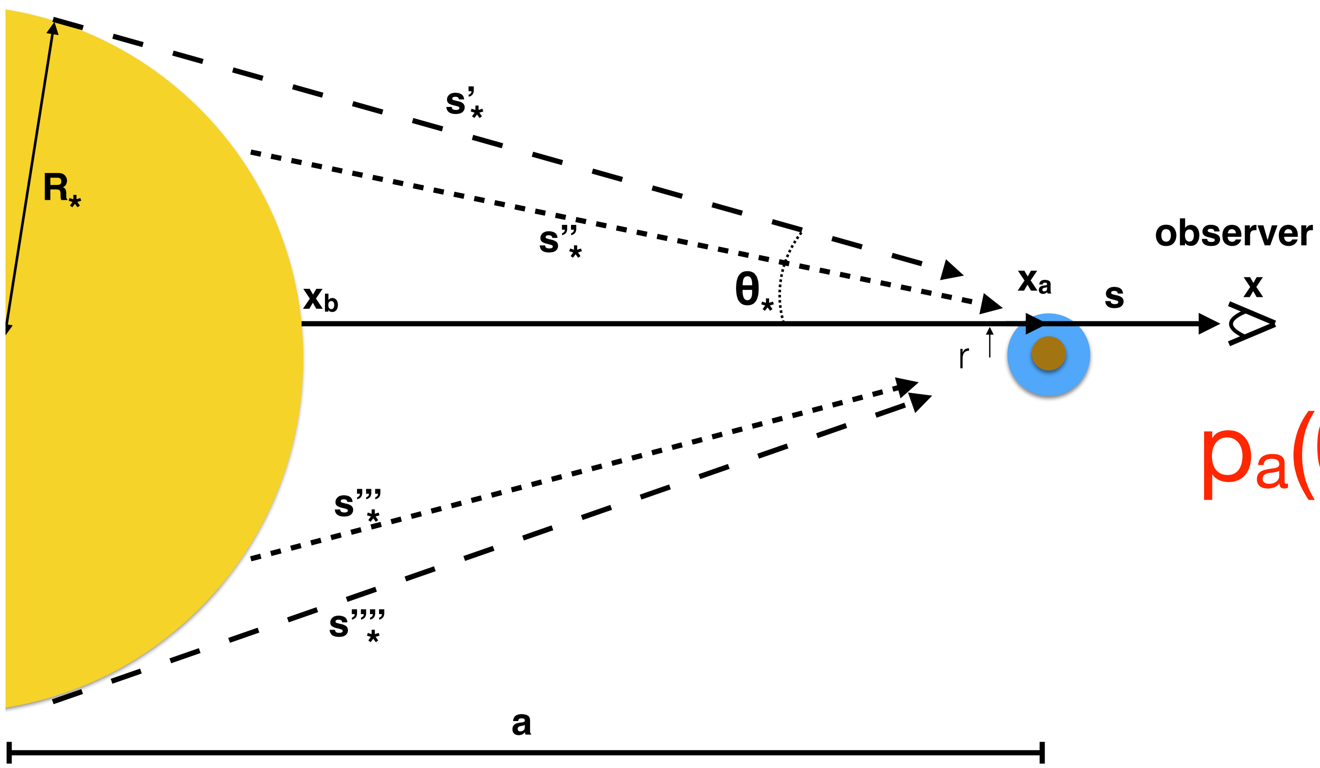
$$\frac{H_a}{R_p} \propto \frac{kT_{\mathrm{eq}}}{GM_p/R_p}$$

$$T_{\mathrm{eq}} = T_{\mathrm{eff}}(R_\star/2a)^{1/2}$$

Considerations (II):

$$\frac{F_p}{F_\star} = \frac{1}{a^2} \times 2\pi H_a R_p \times p_a(\theta = 0)\varpi_{0,a}$$

For very close-in planets, star is not point like!
Finite angular size must be taken into account

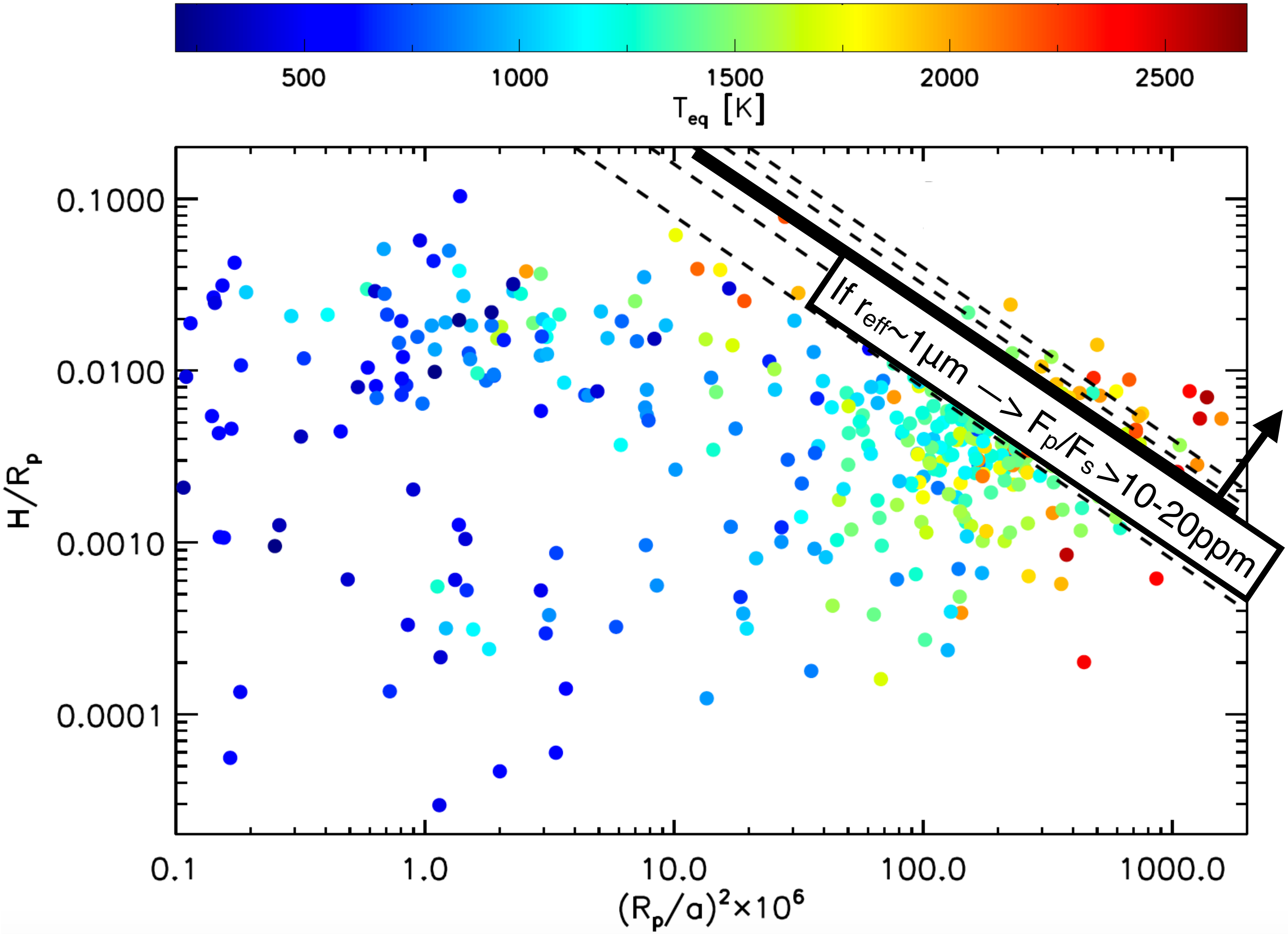


pa(θ) and < pa(Θ)> may differ by orders of magnitude

—>—>—>

stronger signal out of transit

Contrast at α=180º



García Muñoz & Cabrera, 2017

CoRoT-24 b & other super-puffy Neptunes

(Lammer et al. 2016)

- Much more puffy than Titan, ***H/R_T~0.035 > 0.015 of Titan***
- Occultation. If A_g~0.3 —> $F_p/F_s(\alpha=0)$~**2.3 ppm**

Forward scattering:

- If r_{eff}~1-2μm —> $F_p/F_s(\alpha=170–175^o)$~**10 ppm**

These objects would be easier to characterize in forward scattering than in occultation.

…if they occur around bright stars…

What Titan's phase curves can teach us about exoplanet atmospheres

- ***Phase curves contain valuable diagnotics information***
- ***At large phase angles:***
  info on aerosol stratification and particle sizes
- Non-detection of forward scattering sets a constraint.
- A way to probe puffy Neptunes?
- Real phase curves are **NOT** Lambertian. This should be a conclusion, not an assumption.
- Forward scattering has impact on:
  - Scattering of energy, phase integral q~3>1.5 (Lambertian)
  - M_p determination from Doppler-Ellipsoidal fitting.