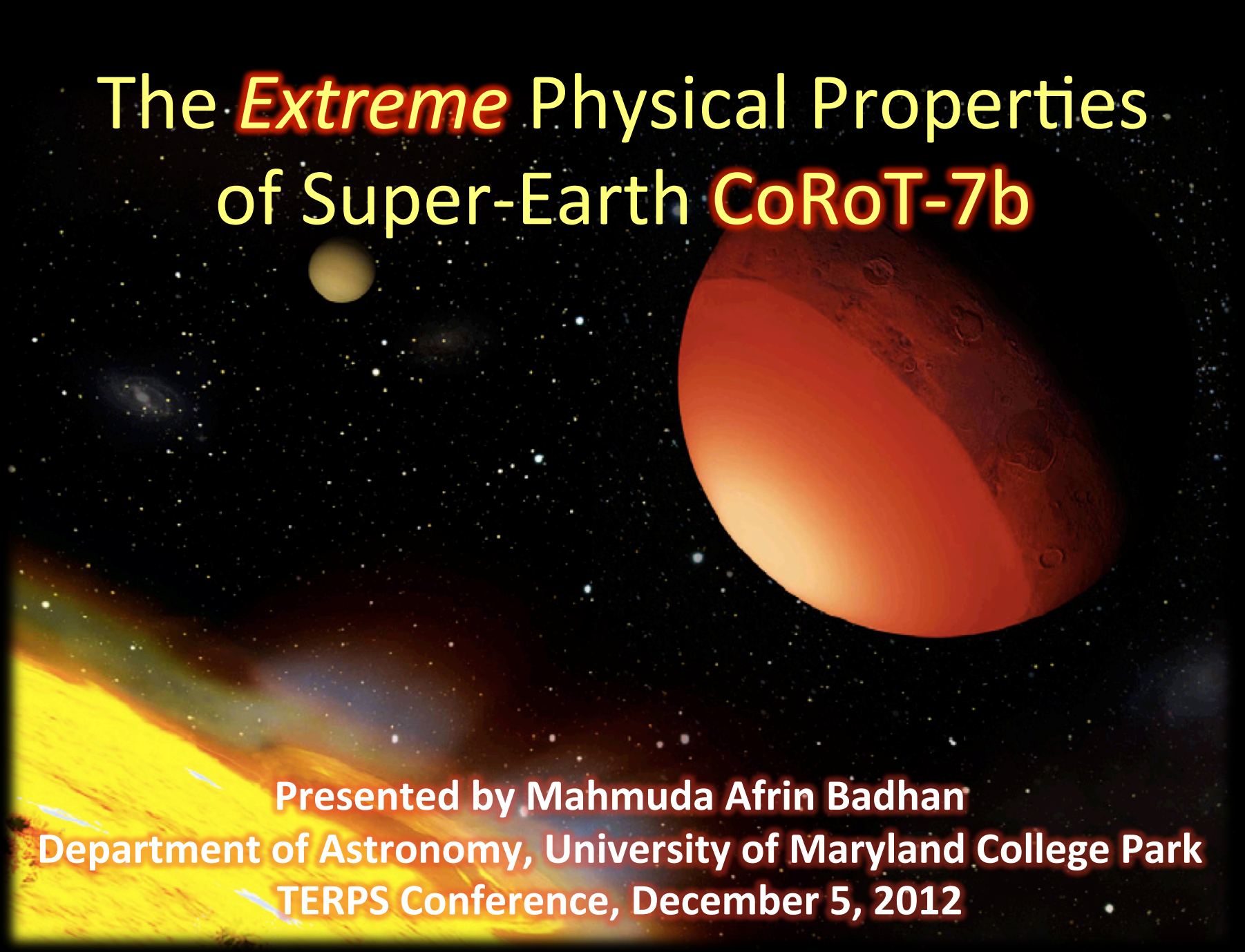
The *Extreme* Physical Properties of Super-Earth CoRoT-7b



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TERPS Conference, December 5, 2012

Motivation for Work

COnvection **RO**tation and planetary **T**ransits (French exoplanet search mission)

One of three detected transiting exoplanets around star CoRoT-7 (G9V).

Why CoRoT-7b over other planets?

- $M > M_E$ (~$6.9M_E$) rocky not gas giant, not too much larger than Earth (~$1.58R_{Earth}$)!

- Close to Sun (a = 0.0171 AU = 4.48 Rst only!)

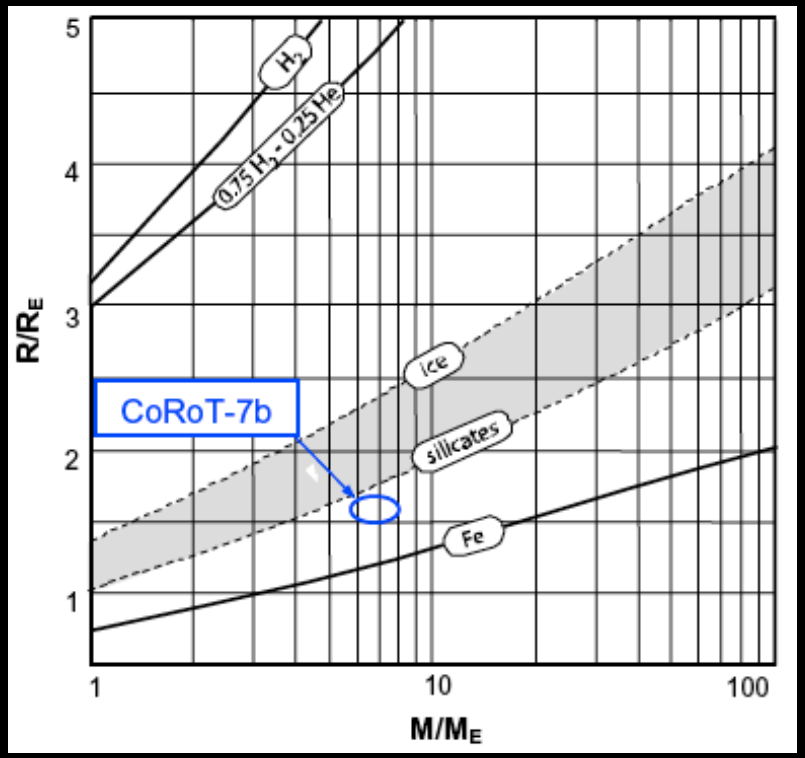
➔ short orbits (~0.8 day ➔ 100 orbits in 4 mos!)

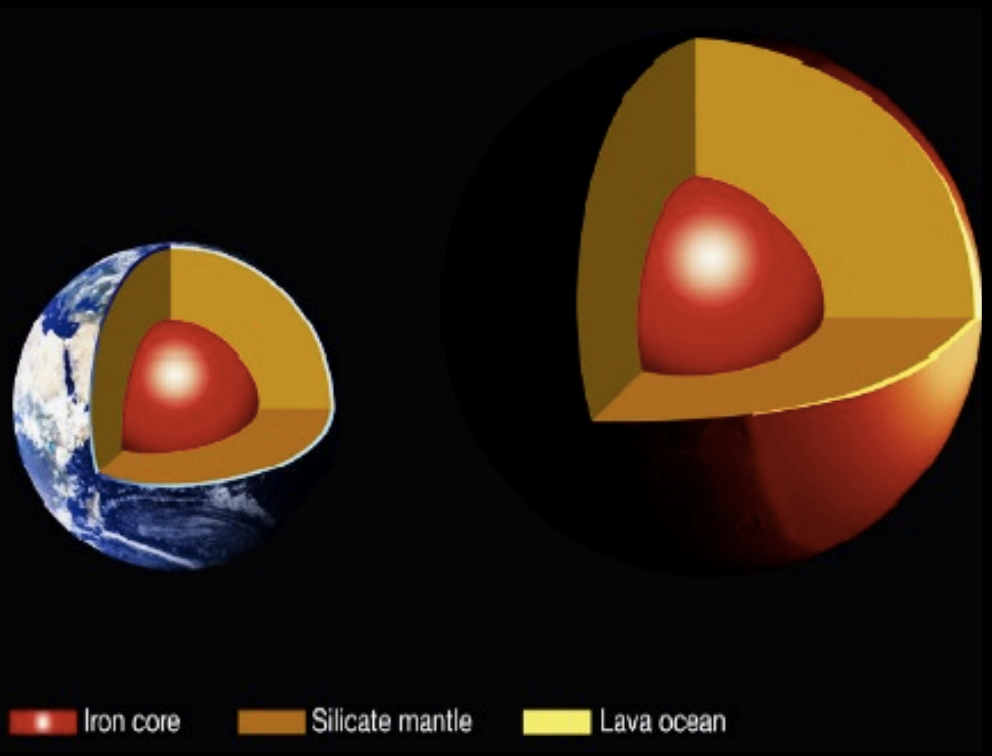
➔ Stronger signals (vary as $a^{-1/2}$)

Tidally phase-locked (spin and orbit synced) thus certain extremes apply such as very thin & cloudless atmosphere, day-side vs night-side temperature dichotomy. Rare and interesting! Pioneer to study of "lava-ocean" planets. Author also states such *"planets would lead to better understanding of planet formation and migration mechanisms."*

Structure and Composition

- Atmosphere eroded by stellar winds → no He-H envelope or water; only major materials remain → dry-earth like composition.
- Complete liquid core (unless $T_{core} = T_{core\_lower\_limit}$) $0.11V_{pl}$, silicate mantle, silicate mantle (like Earth), upper mantle only $0.08V_{pl}$ and completely solid (high *g*) except except day-side surface.





Formation and Orbit

Proposed scenarios

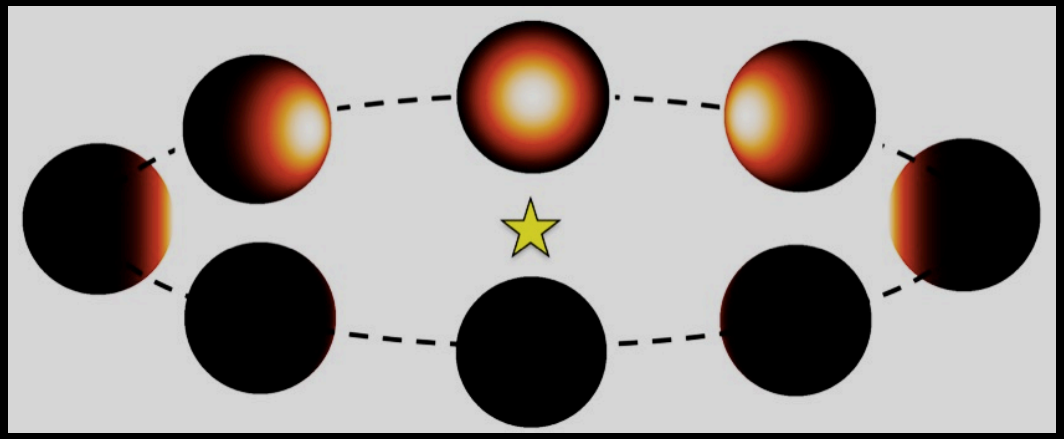
(i) In situ accretion – requires large inner solid densities to initiate process, collisions cause accretion into planet: possible

(ii) Initial formation at larger *a* ➔ inward migration – requires resonant configurations with nearby planets (7a and 7c): possible

(iii) Resonant migration of large planet – requires resonance with gas giants but RV data doesn't support: unlikely

(iv) Photoevaporation– exposed core of hot Neptune/Saturn: possible

(v) Eccentricity of orbit decrease over time, now near circular, timescale of tidal effects = ~time to become circular orbit ➔ tidal-locking



Day-side Temperature Distribution: Background

- Thermal evolution ➔ solely determined by T_{surf}.
- Winds/G.E. ➔ no effect on T distribution on either sides.
- Viscosity of high T lava ➔ need 3D model to know effect.
- Ocean radially symmetric from sub-stellar point.
- Maximum possible extent of ocean, θ_m, found from power emitted by *ocean* = received by *ocean*.

$$\Phi_{\text{em}} = 2\pi\varepsilon_2\sigma T_{oc}^4(1-\cos\theta_m)R_{pl}^2$$

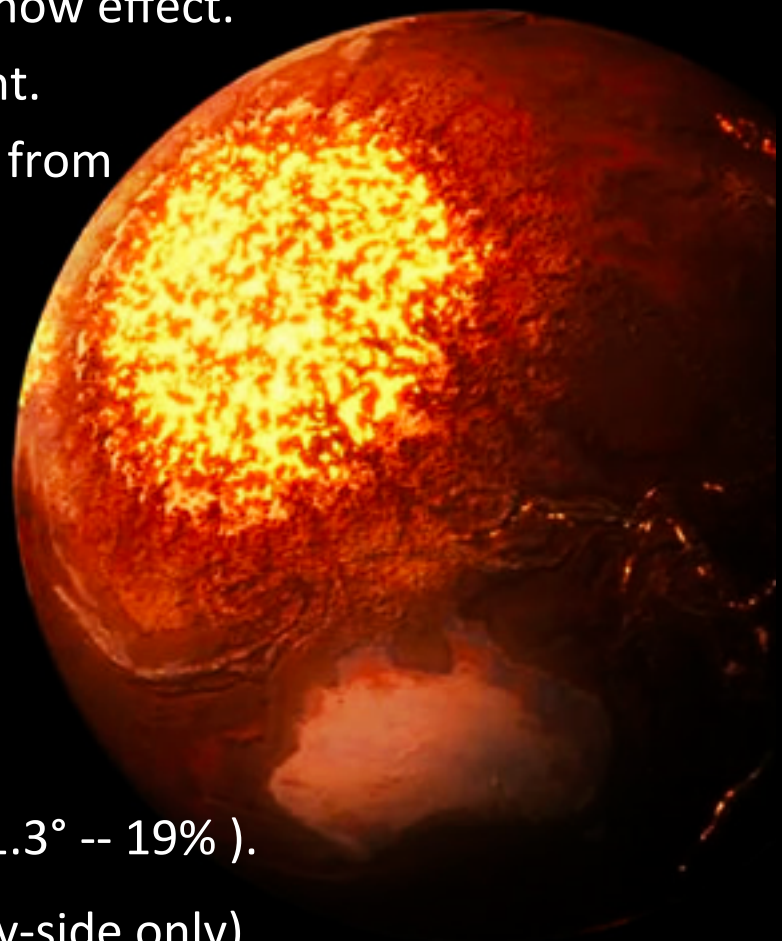
$$\Phi_{\text{rec}} = \pi\varepsilon_5\sigma T_{st}^4\sin^2\theta_m R_{pl}^2$$

$$f(\theta_m) = \frac{1-\cos(\theta_m)}{\sin^2(\theta_m)} = \frac{R_{st}^2}{2a^2}\left(\frac{T_{st}}{T_{oc}}\right)^4\frac{\varepsilon_5}{\varepsilon_2}$$

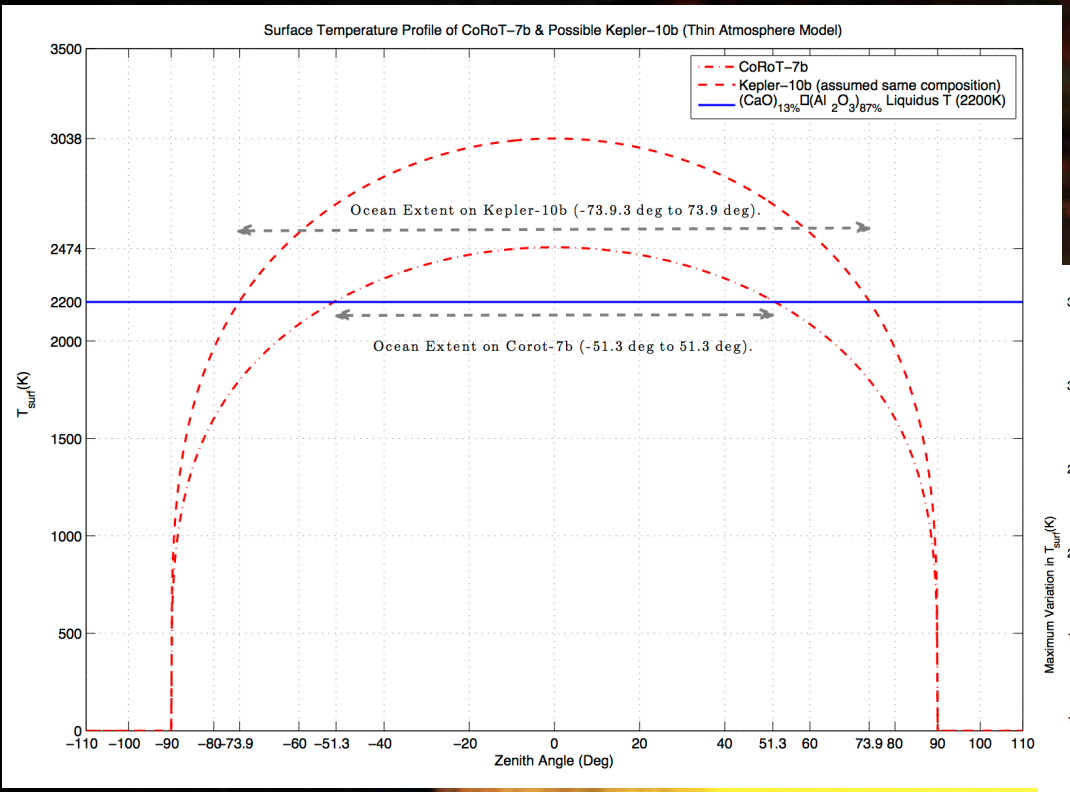
RHS =0.88 (verified) but paper quotes θ_m as 75° (corresponding to 37% ocean coverage)

<u>W.R.O.N.G!</u> – 82° ➔ 43% ocean (actual value is 51.3° -- 19%).

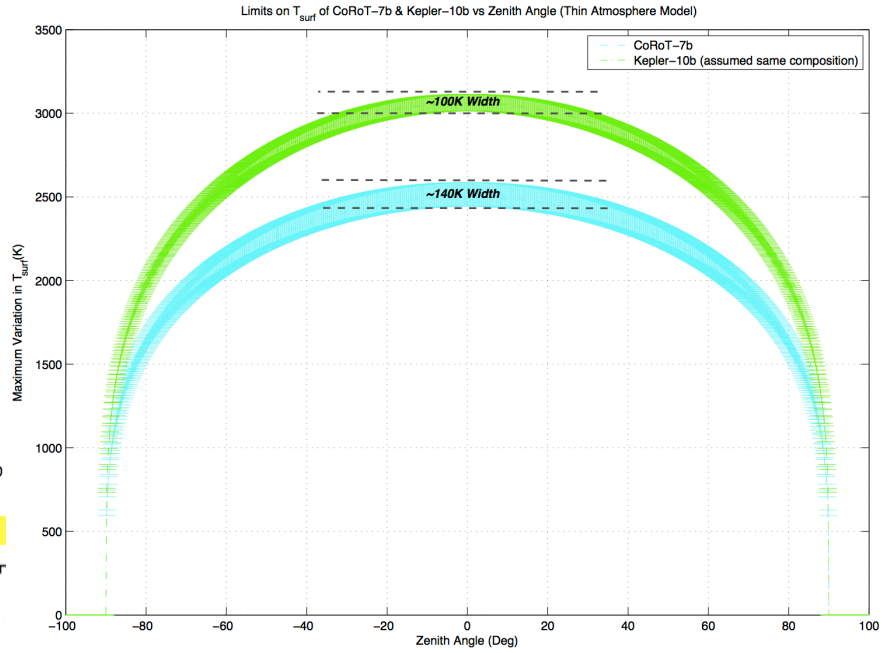
$$T_{\text{surf}} = (\varepsilon_5/\varepsilon_2)^{1/4}(R_{st}/a)^{1/2}(\cos\theta)^{1/4}T_{st}$$ (day-side only)



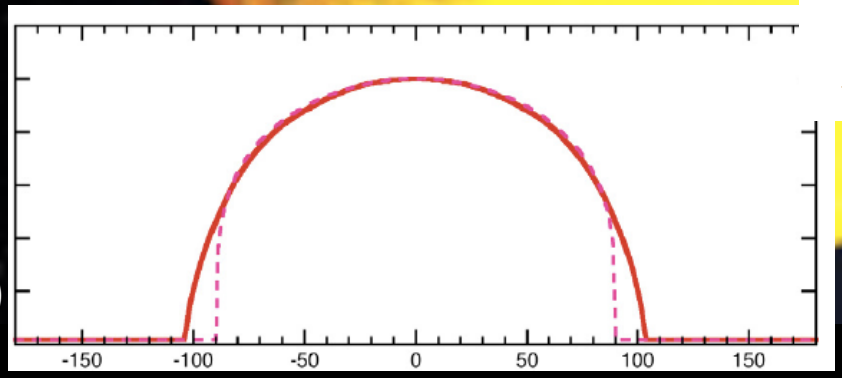
T_{surf} (Day) Distribution: CoRoT-7b + Kepler-10b



Parallel Beam approx.
(neg. angular diameter)



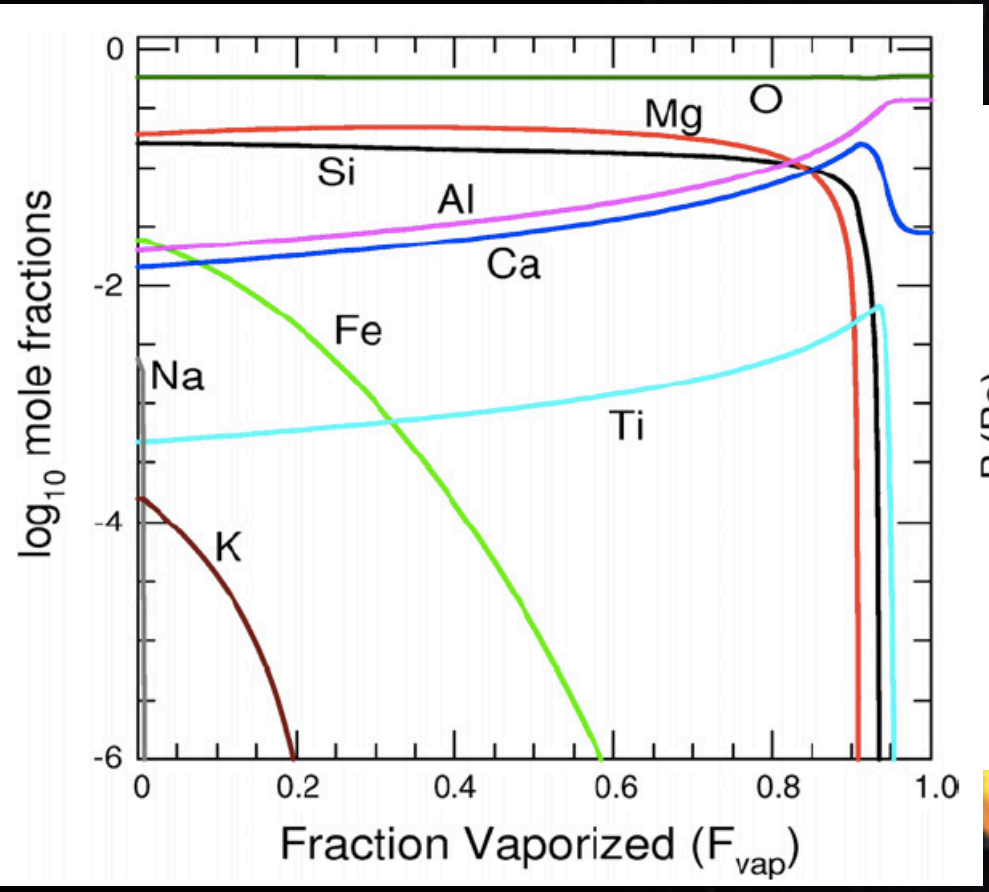
Angular diameter Included (CoRoT-7b)

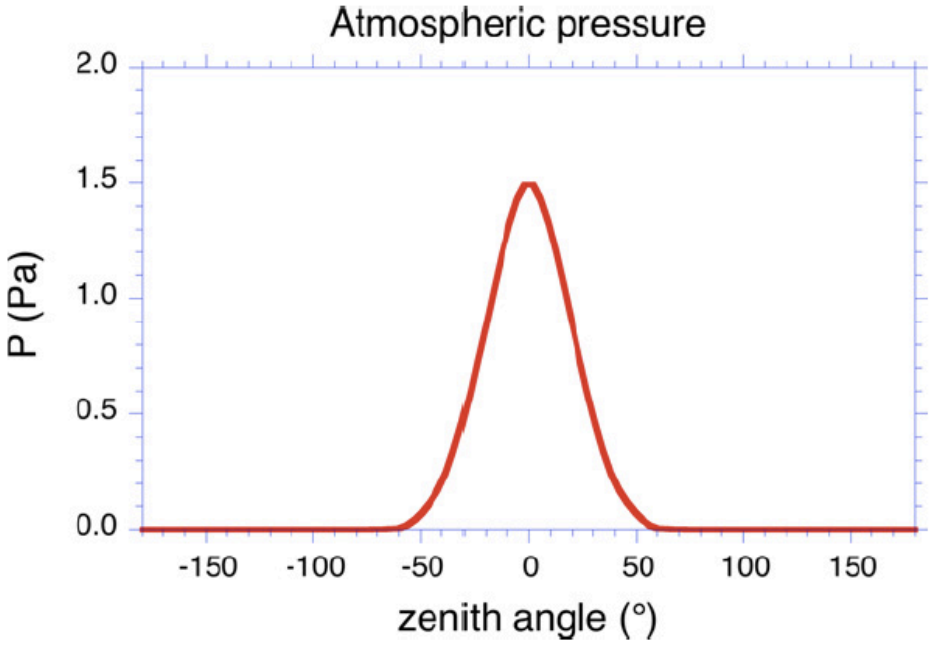


Max. T at sub-stellar point.

Day ➔ night (T_{surf} = 50K-75K) at 102.7°;
Light reaches further when Sun so close.

Atmosphere: Composition + Pressure





- Refractory materials: hard to vaporize! @High T ➔ CaO and Al_2O_3 remain in ocean.
- Pressure 1.5Pa ➔ 10^{-2} Pa (shore).
- vapor/sublim. at surface ➔ atmosphere, so local atm P = vapor P of rock at local T.
- Ocean depth is 45km (assumption: convection in inefficient).

Reference List for Visuals

Title Page Image + Most figures + equations:

Leger, A., Grasset, O., Fegley, B., 2011. *The extreme physical properties of the CoRoT-7b super-Earth*. Icarus 213, 1-11.

Slide 2 image:

http://suptg.thisisnotatrueending.com/archive/6103018/

Slide 4 image:

Rouan, D., Deeg, H.J., Demangeon, O., 2011. *The orbital phases and secondary transit of Kepler-10b*. arXiv:1109.2768

Slide 5 image:

http://danielmarin.blogspot.com/2011/02/planetas-con-oceanos-de-lava.html

Coriolis force:

Wikipedia

Surface temperature discussion:

Léger, A. et al., 2009. *Transiting exoplanets from the CoRoT space mission. VIII. CoRoT-7b: The first super-Earth with measured radius.* Astron. Astrophys. 506, 287–302 (LRS09).

Appendix: Assumptions

Radius → measured with acceptable accuracy (±6%) by transit method

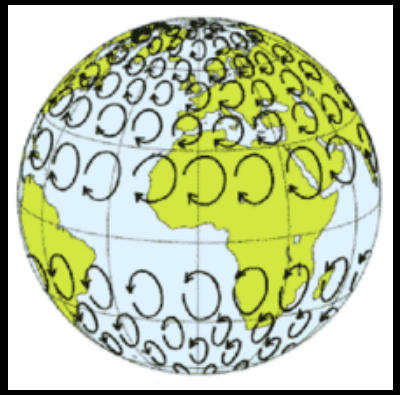
Mass → ±17% accuracy by RV data analyses (median of five different analyses) (stellar activity noise is large ($\propto a^{-1/2}$), cannot be removed in inner regions)

No clouds (A = 0) for day-side → atm pressures are very low, thin atmosphere.

"Dry Earth" atmosphere with no condensible species (mean molecular mass due to SiO and Mg > higher than Earth!).

Coriolis force neglected (for equatorial regions)

- Radial symmetry.
- Heat transport only along equator→ E-W circulation only
- No fishy wind motion!



Remarks about actual ocean circulation mechanisms, shape and distribution require a full 3D treatment.

Appendix: Determined Parameters (so far…)

Parameter	CoRoT-7b	Note	Kepler-10b	Note
Star				
T_{st} (K)	5250 ± 60	(a)	5627 ± 44	(e)
R_{st} (R_{Sun})	0.82 ± 0.04	(a)	1.056 ± 0.021	(e)
L_{st} (L_{Sun})	0.48 ± 0.07	(a)	1.004 ± 0.059	(e)
M_{st} (M_{Sun})	0.91 ± 0.03	(a)	0.895 ± 0.060	(e)
Age (Gyr)	1.2–2.3	(b)	11.9 ± 4.5	(e)
Mag	V = 11.7, R = 11.3	(a)	Kepl = 10.96	(e)
Sp type	G9 V	(a)	~G3 V	
Planet				
$\Delta F/F$ (ppm)	335 ± 12	(b)	152 ± 4	(e)
Tr. dur. (h)	1.25 ± 0.05	(b)	1.81 ± 0.02	(e)
b	0.61 ± 0.06	(b)	0.30 ± 0.08	(e)
i (°)	80.1 ± 0.3	(b)	84.4 ± 1.4	
P_{orb} (day)	$0.85359 \pm 3 \times 10^{-5}$	(b)	$0.837495 \pm 5 \times 10^{-6}$	
R_{pl} (R_{Earth})	1.58 ± 0.10	(b)	1.416 ± 0.034	(e)
M_{pl} (M_{Earth})	6.9 ± 1.2	(c)	4.56 ± 1.23	(e)
ρ (g cm^{-3})	9.7 ± 1.9	(a) + (c)	8.8 ± 2.5	(e)
a (AU)	0.01707 ± 0.00019	(b)	0.01684 ± 0.00033	(e)
a/R_{st}	4.48 ± 0.22	(a) + (b)	3.43 ± 0.10	(e)
F_{st} (MW m^{-2})	2.14 ± 0.24	(d)	4.87 ± 0.33	(e) + (d)
Modelling				
$T_{sub\text{-}st}$ (K)	2474 ± 71	(d)	3038 ± 51	(e) + (d)
θ_{lava} (°)	51.3 ± 5.3	(d)	73.9 ± 1.1	(e) + (d)
$\theta_{day-night}$ (°)	102.7 ± 0.7	(d)	106.7 ± 0.5	(e) + (d)
$2\theta_{st/pl}$ (°)	25.8	(d)	33.9	(e)