Multicolor Photometry
as a tool to investigate exoplanet structures and atmospheres

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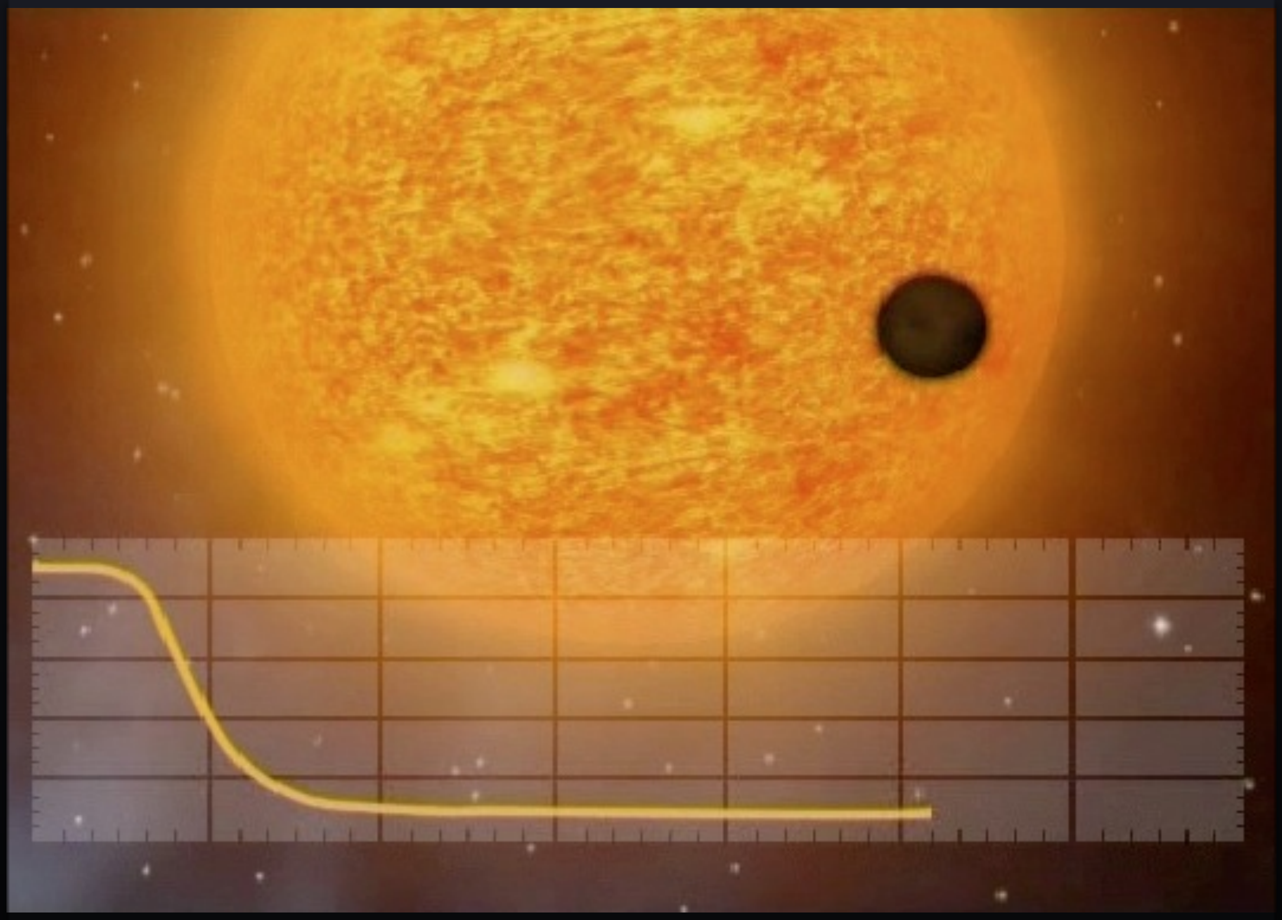
OUTLINE

- General Introduction & Motivation
- Methods
- Preliminary Results
- Summary & Outlook



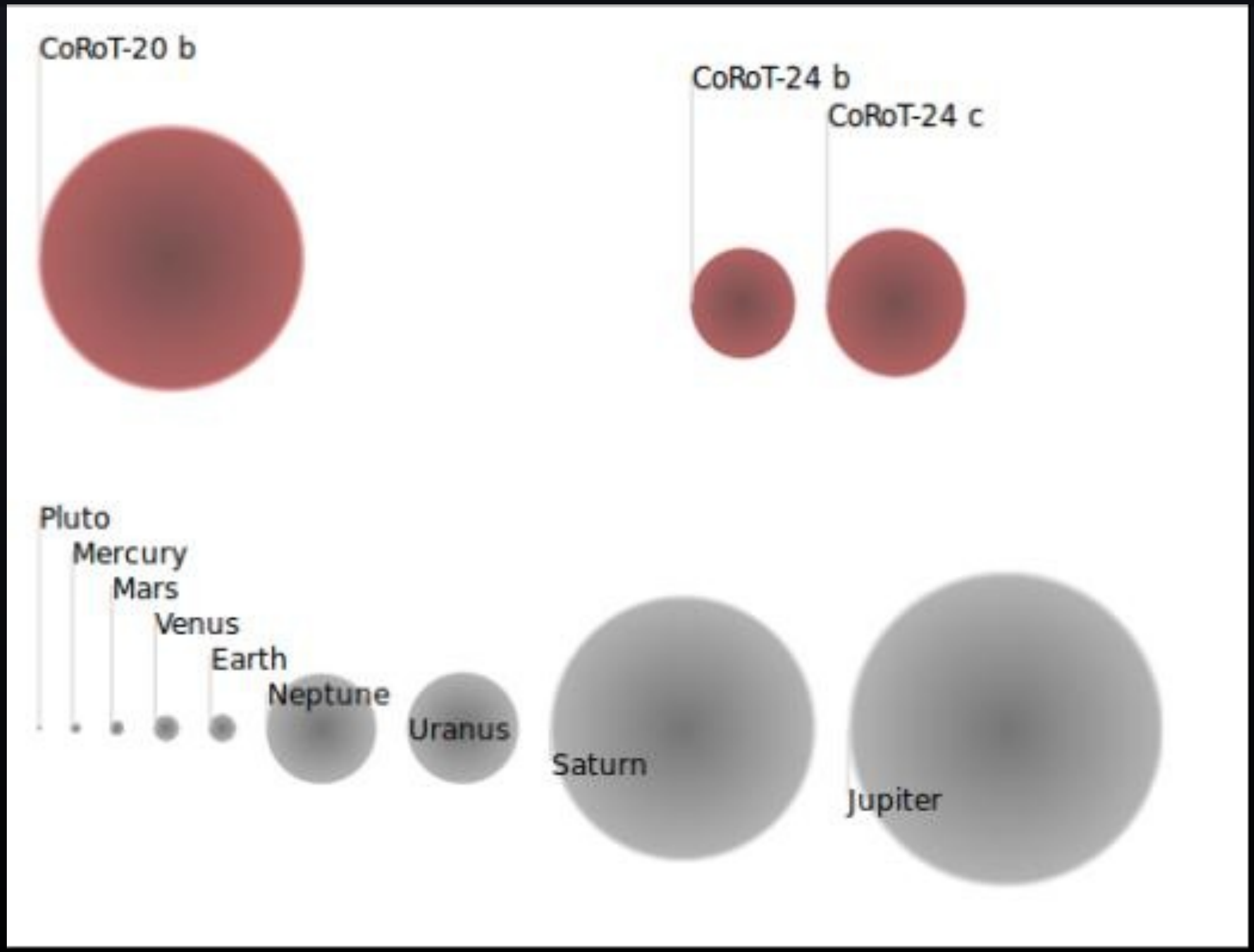
INTRODUCTION → ***BACKGROUND***

- **characterization of exoplanets** (structure, atmosphere and formation)
  - shift from detection to characterization of exoplanets
- **transiting exoplanets**
  - offer unique opportunities for characterization of their atmospheres (multicolor photometry; transmission spectroscopy)
- **recent discoveries & studies**
  - new class of planets detected (super-Earths & mini-Neptunes; no Solar System analogs)
  - studies show radius anomalies
- **definition of reference radii**
  - reference radius not always at 1 bar level for exoplanets
- **future space missions**
  - CHEOPS, PLATO,…

INTRODUCTION → *IDEAS & AIMS*

- CoRoT Mission
  - CoRoT offers simultaneous multicolor transit observations
  - use chromatic light curves as an exoplanet characterization tool
  - determine radii as a function of wavelength (transmission spectra)
  - lots of data available, *efforts could be rewarding!*

- Targets
  CoRoT-20b,
  CoRoT-24b (2 cases),
  CoRoT-24c



INTRODUCTION → *IDEAS & AIMS*

- **Rayleigh Scattering**
  - study how RS can be used to understand the structure & evolution of super-Earths & mini-Neptunes
  - assume RS as the dominant extinction process (as a first estimate)
  - interpretation of transmission spectra

- **Stellar Conditions**
  - take stellar radiation / XUV-heating of upper atmosphere into account

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→ develop a method that allows one to determine the reference radius of planetary models from transit observations

→ optimize the method for CHEOPS target selection (derive “real“ reference radii, optimization for follow-ups)

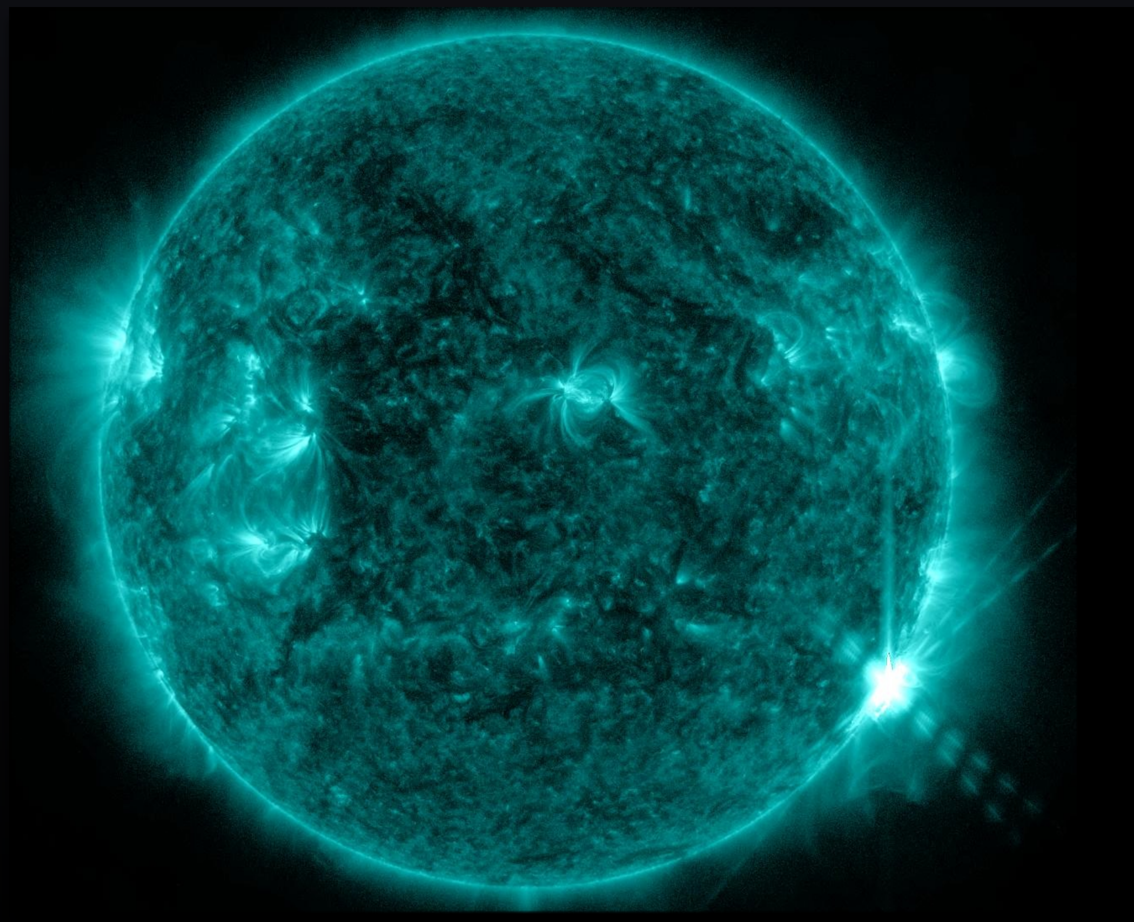
METHODS

1. CoRoT White Light Curve Radii
   - get exact effective wavelength values + white light radii from the observation ✔
2. Rayleigh Scattering (H_2) & Lecavelier des Etangs (2008a,b)
   - as a first estimation, assume that H_2 is responsible for RS
   - use white light radii → get value for partial pressure & volume density ✔
3. Stellar Conditions Code (Johnstone et al. 2015a,b)
   - calculate stellar wind conditions and XUV-Flux for host star ✔
4. Hydrodynamic Code (Erkaev et al. 2013; Lammer et al. 2014)
   - calculate the theoretical upper atmosphere structure for CoRoT targets ✔
5. CoRoT Multicolor Light Curve Radii
   - get radii from multicolor observations as a function of wavelength (3 codes) ✗
   - comparison with theoretical results
   - recalculate partial pressures & theoretical upper atmosphere structure
6. Extend Theory to Mie Scattering if necessary ✗

ISSUES

Things to consider…

- plague regions / stellar activity
- stellar conditions code (error of input values - stellar age & activity)
- proper treatment of stellar limb darkening (CoRoT white light & colors)
- correction for observational contaminations
- find reliable errors (MCMC)
- target issues (CoRoT-24b, c)
- hazes & clouds in exoplanet atmospheres
- *follow-ups needed!!!*



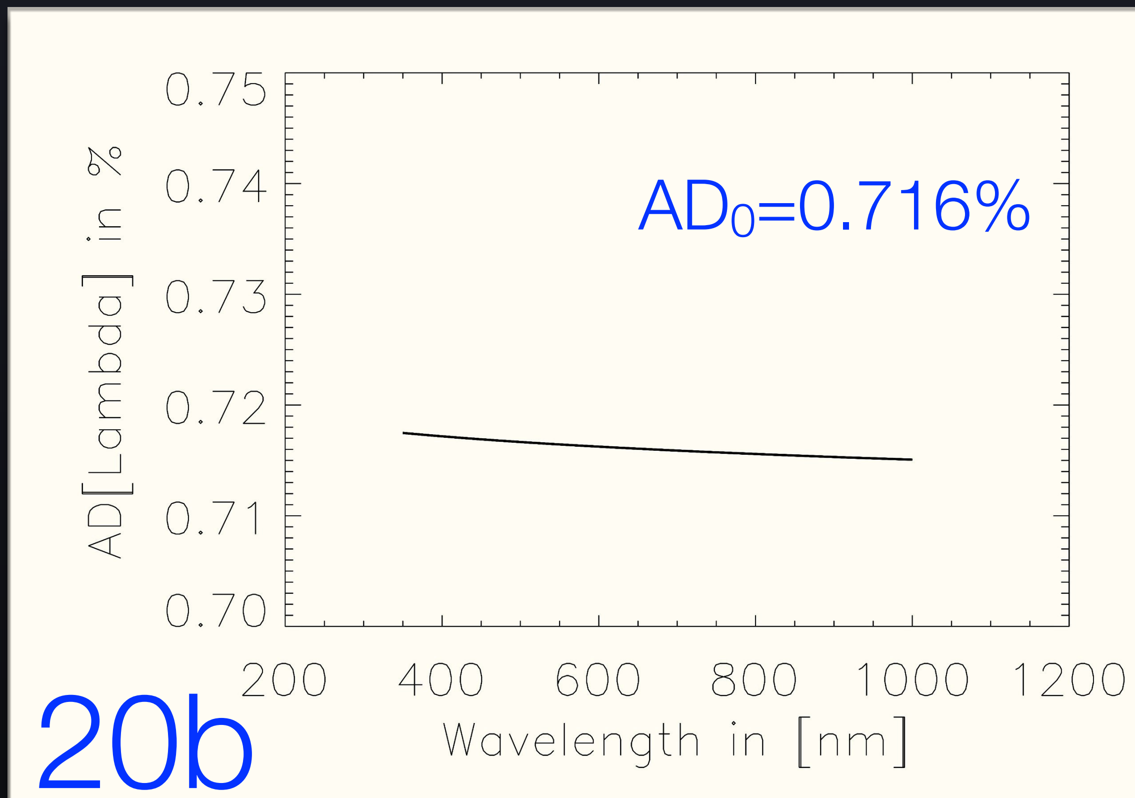
First Results

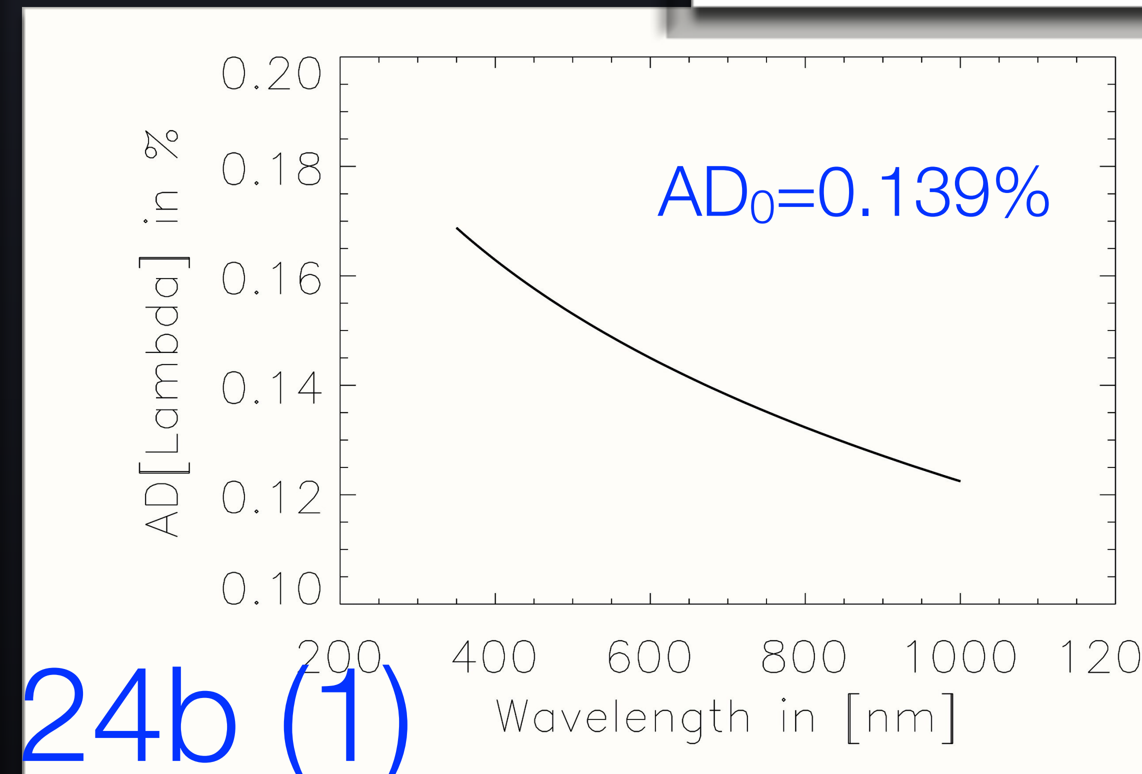
I … Input Values
L … Lecavelier d. E. Output
H … Hydrocode Output

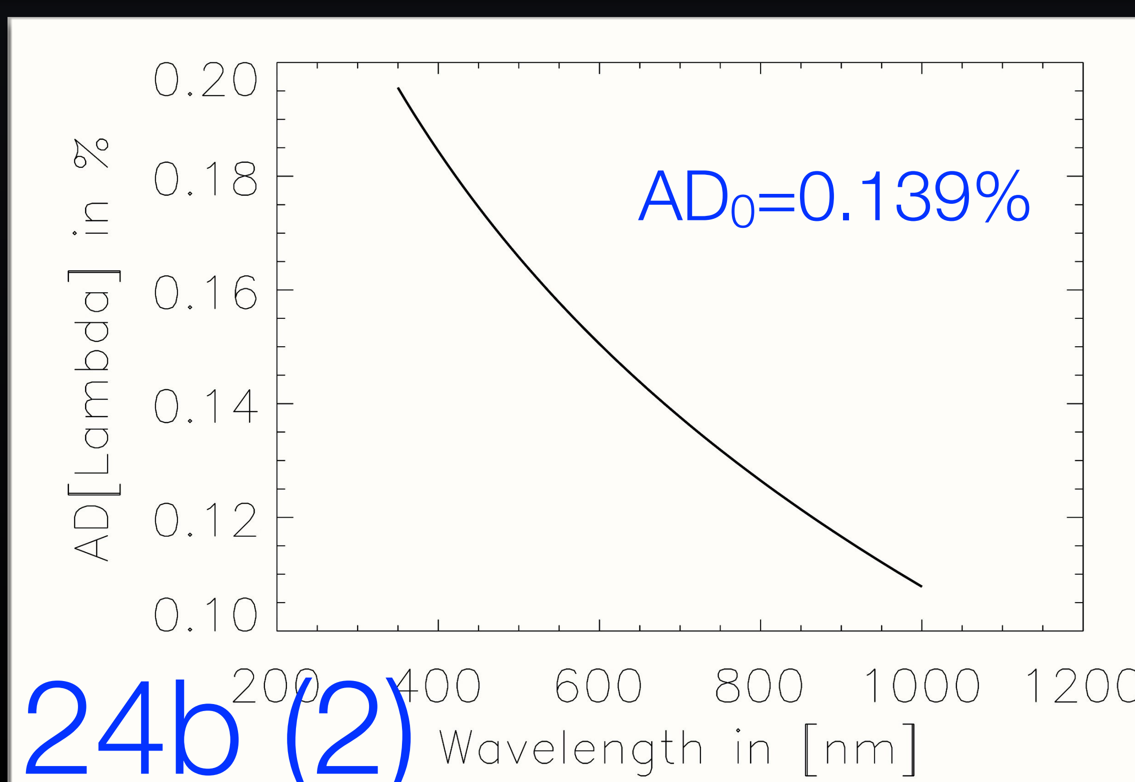
		CoRoT-20b	CoRoT-24b (1)	CoRoT-24b (2)	CoRoT-24c
I	λ [nm]	670	690	690	690
	R_T [R_{Jup}]	0.84 +/- 0.04	0.33 +/- 0.04	0.33 +/- 0.04	0.44 +/- 0.04
	M [M_{Jup}]	4.24 +/- 0.23	< 0.018	< 0.0095	0.088 +/- 0.035
	T [K]	1002 +/- 24	1070 +/- 140	1070 +/- 140	850 +/- 80
L	g [m/s²]	148.95 +/- 16.33	< 4.1	< 2.2	11.27 +/- 4.93
	H [km]	24.14 +/- 2.7	< 937.16	< 1775.75	270.72 +/- 121.04
	$P_{z=0}$ [mbar]	636.85 +/- 5	< 210.13	< 206.9	253.01 +/- 7
H	β	- >2000	11	5.9	52
	R_{dis}/R_T	-	3	3.3	1.5
	R_{xuv}/R_T	-	4	4	1.3

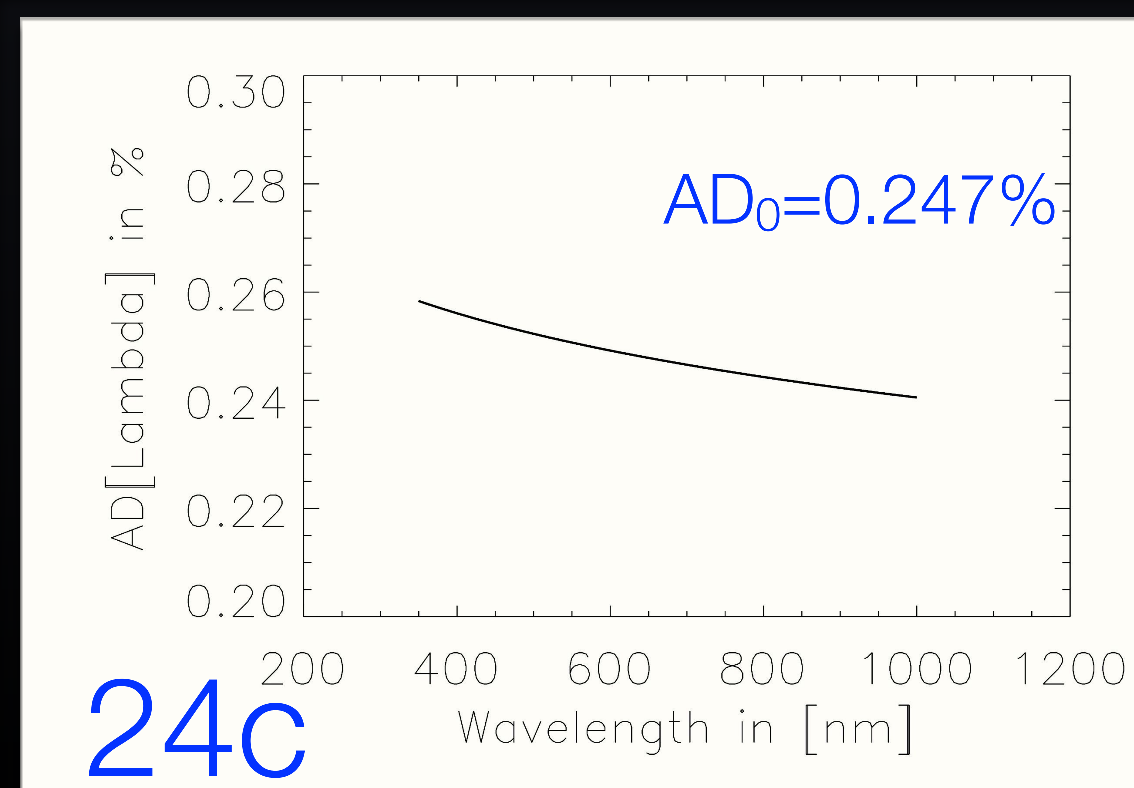
Absorption Depths of RS: AD(λ)

$$AD = AD_0\left(1 - \frac{8H}{R_p}\ln\frac{\lambda}{\lambda_0}\right)$$

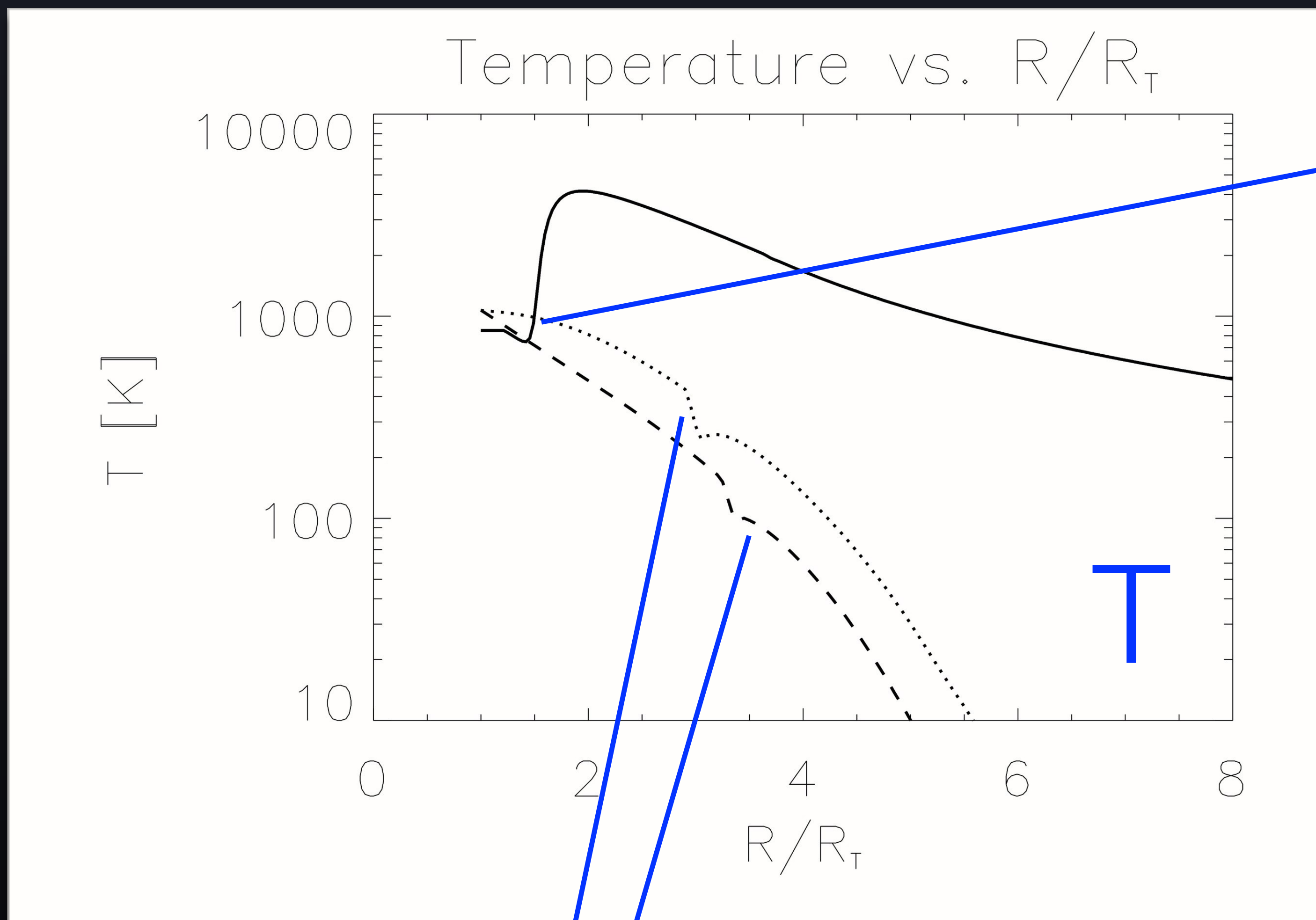




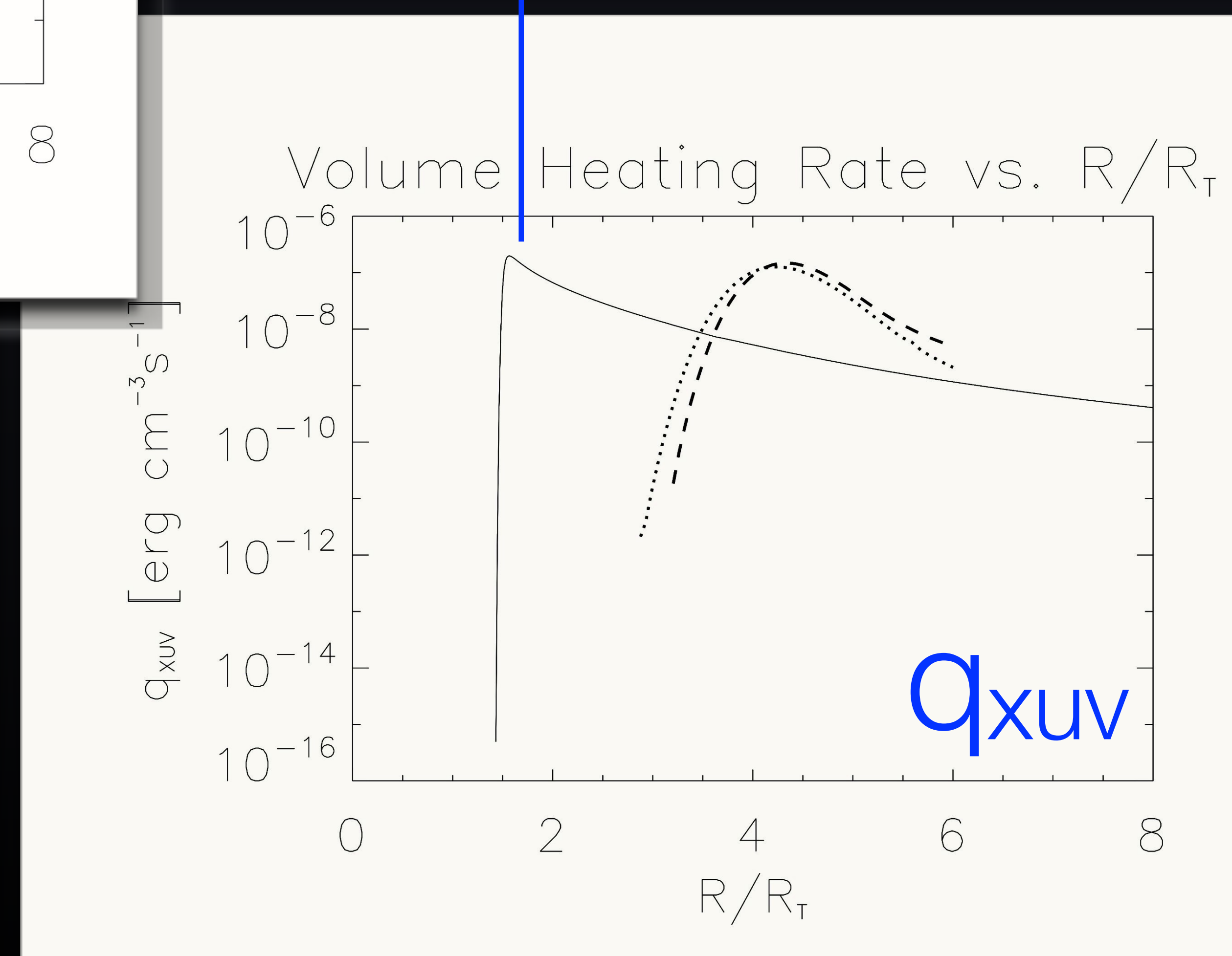




T & q_{XUV} - Profiles (Hydrocode)



heating by stellar XUV flux

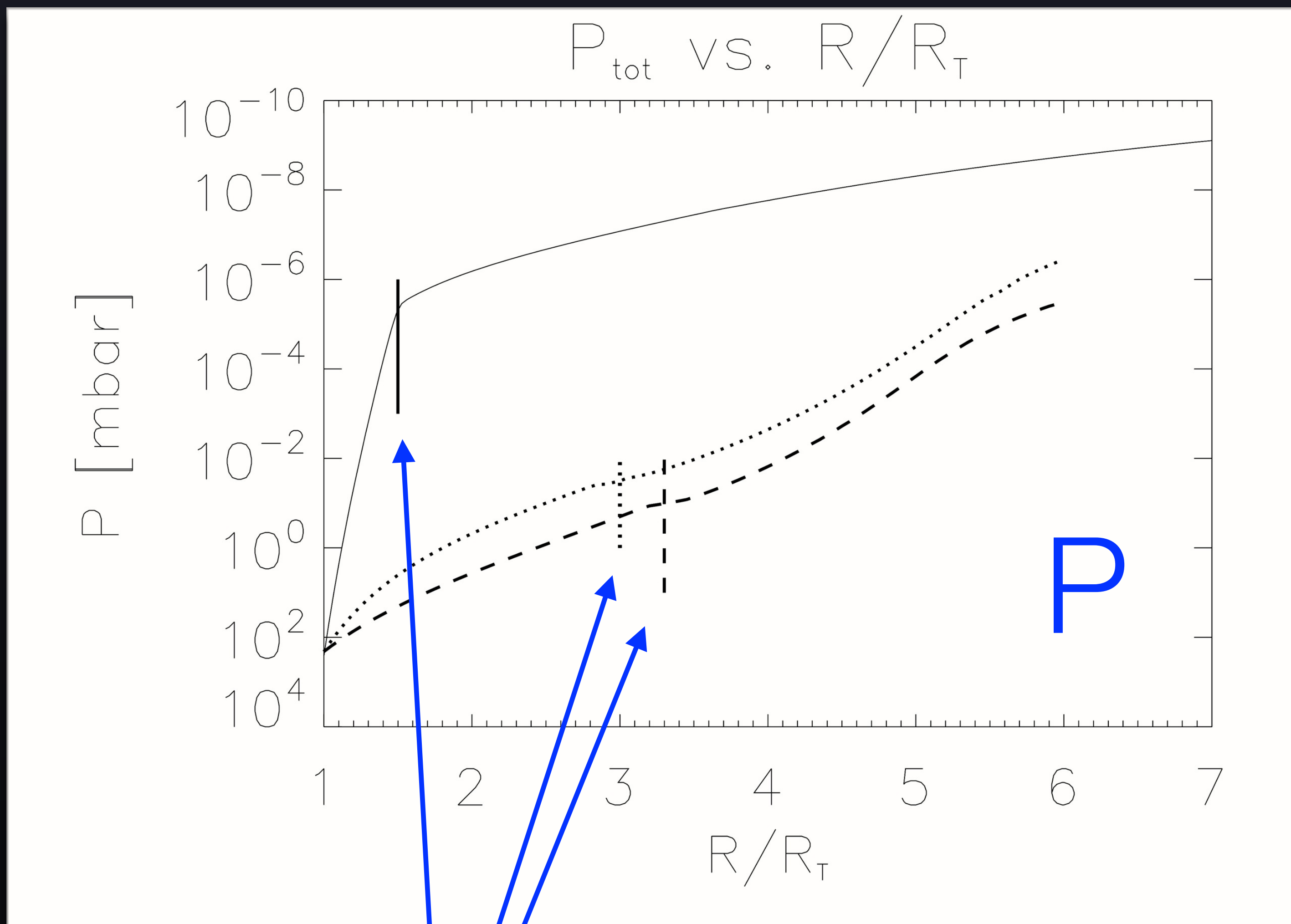


Dissociation: $H_2 \rightarrow H+H$

solid line … CoRoT-24c

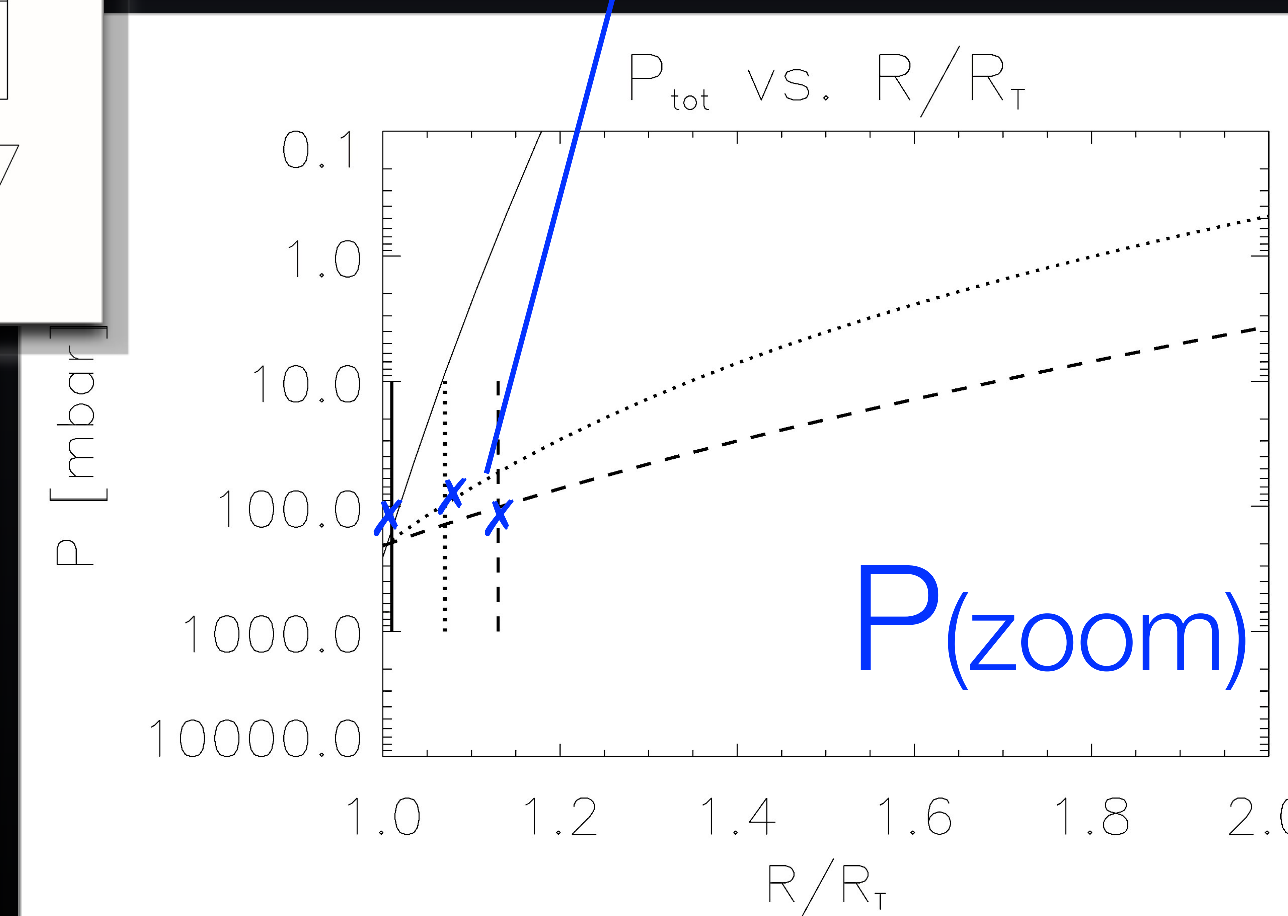
dotted line … CoRoT-24b (1); dashed line … CoRoT-24b (2)

Pressure Profiles (Hydrocode)



R_DIS/R_T

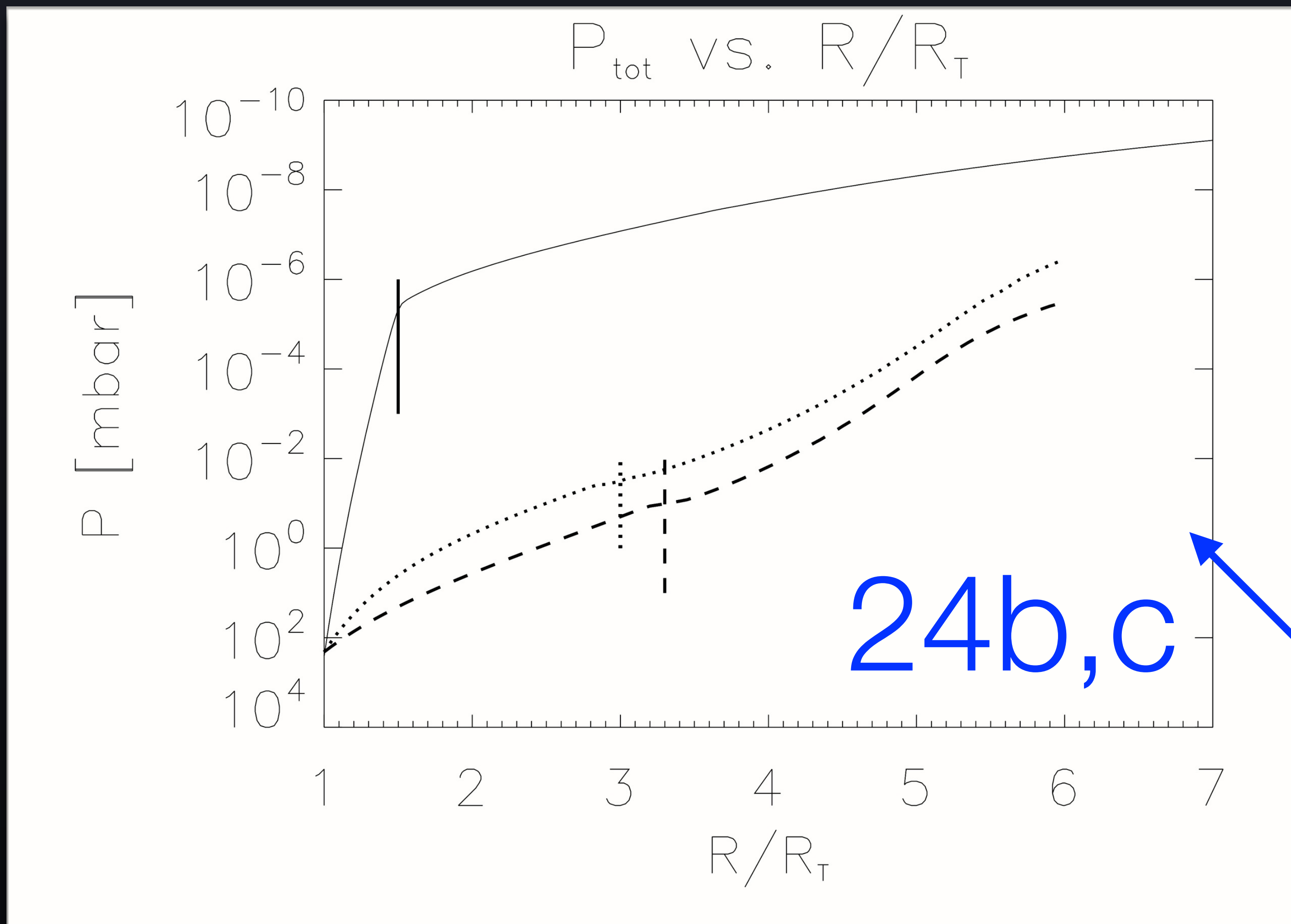
expected radii at 440 nm (from RS); AD(λ)

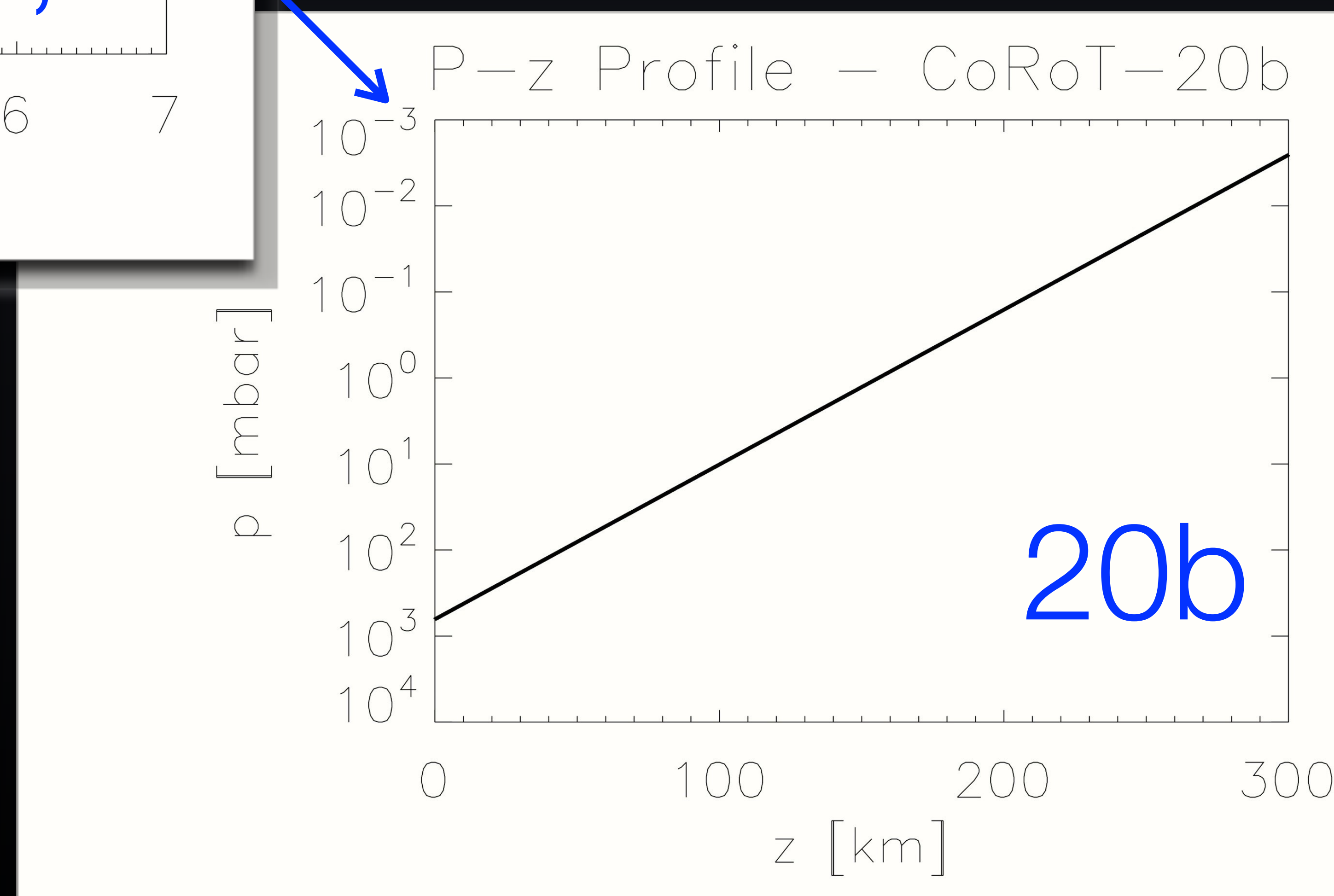


solid line … CoRoT-24c

dotted line … CoRoT-24b (1); dashed line … CoRoT-24b (2)

P-z Profile for CoRoT-20b in comparison





CoRoT-20b:

- no hydrodynamic regime
- target is too massive

→ *hydrostatic regime !!*

CONCLUSIONS

- ***exact* effective wavelengths (λ_0) need to be known**
  → determine the partial pressure (P_0) at reference radius (R_T)
- **white light reference radii of targets**
  ↛ *do not* correspond to a 1 bar pressure level
- **mass of CoRoT-20b**
  → assume *hydrostatic* regime
  → no radius anomalies expected
- **have to question stellar conditions / parameters of CoRoT-24**
- ***follow-ups & further investigation* of CoRoT-24 system necessary!!**

SUMMARY & OUTLOOK

- Rayleigh / Mie Scattering in atmospheres of transiting low mass planets
- initially analyze existing CoRoT data
  - careful evaluation of CoRoT chromatic light curves
  - need exact effective wavelength
- take XUV heating of upper atmosphere into account
- develop method that allows to determine reference radii of planetary models from transit observations
- ***optimize method for CHEOPS target selection***

Thank you for your attention

Effective Altitudes z(λ)