Derivation of the parameters of CoRoT planets

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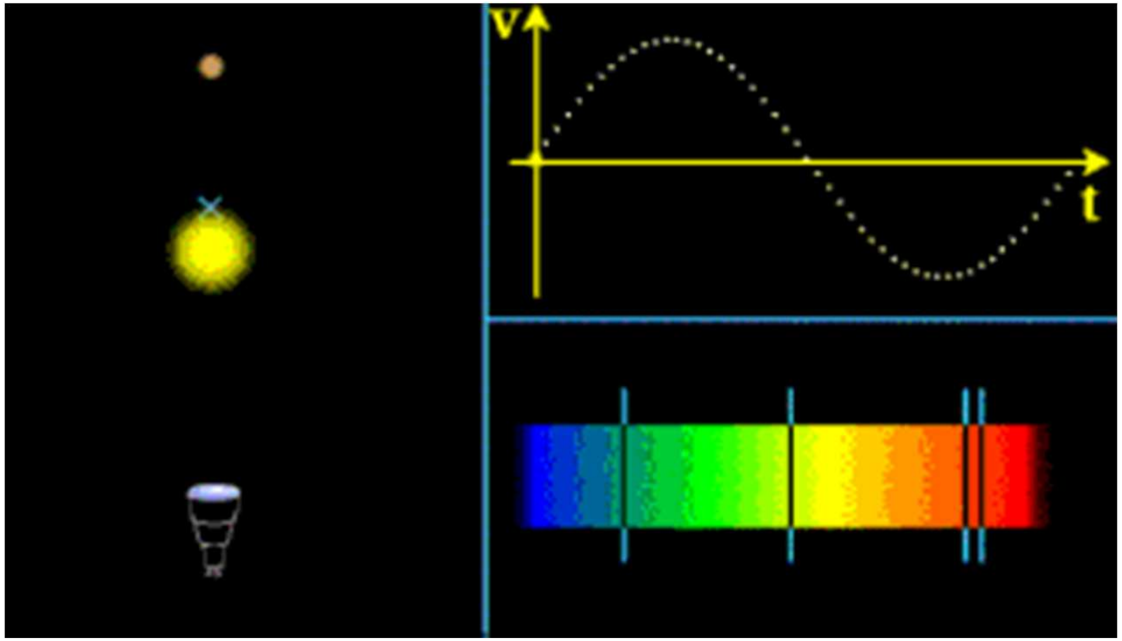
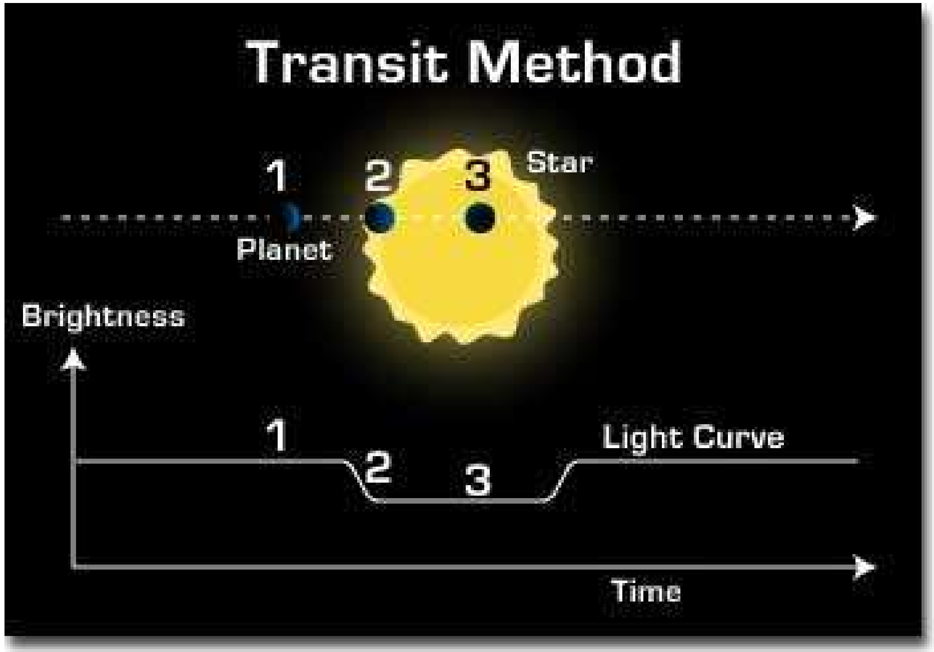
motivation: parameters for transiting planets





-**Radial Velocity**:

-Provides minimum mass (m sin i)

-**Photometry**:

-Provides radius

-Provides orbital inclination

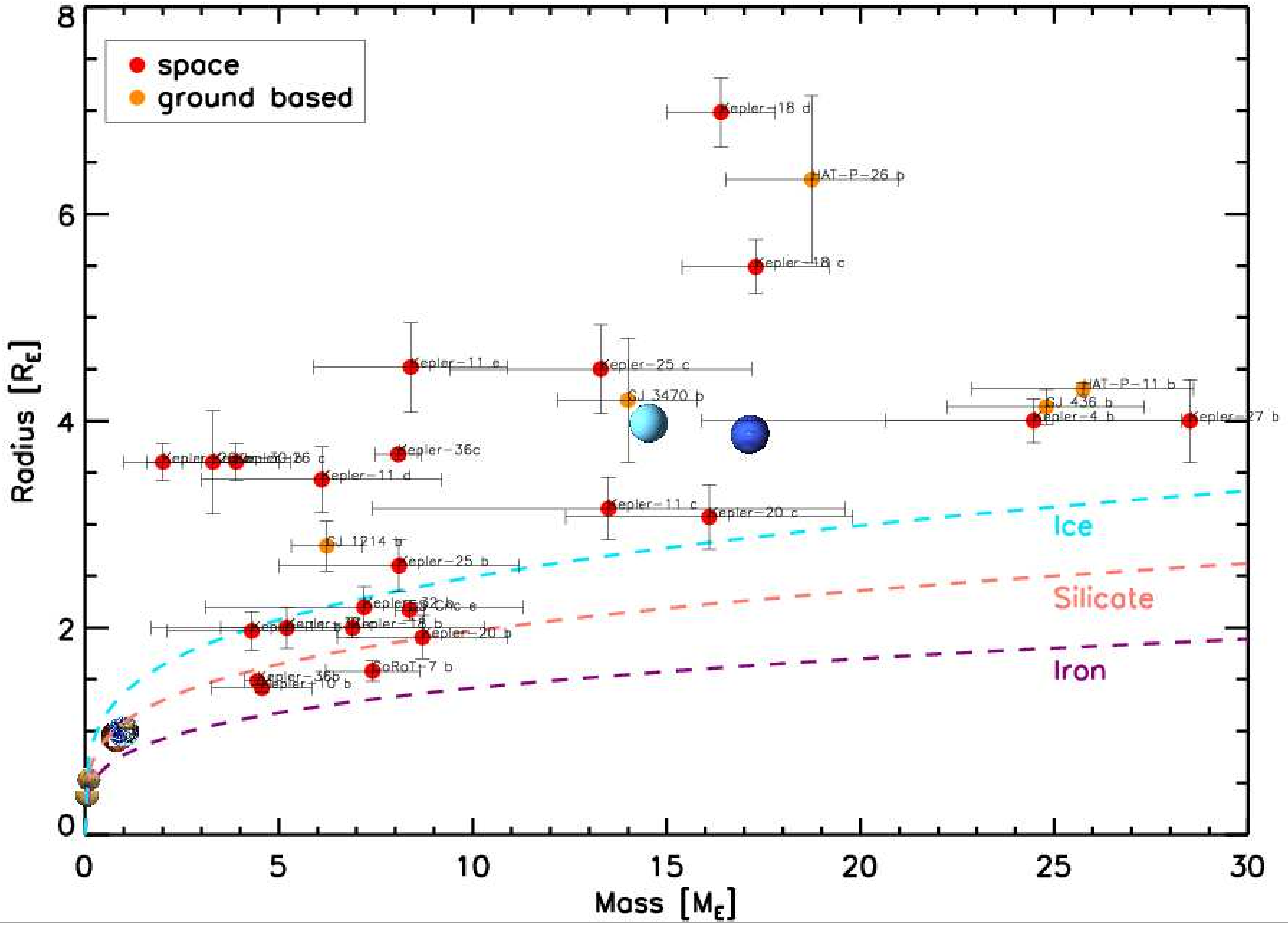
-See, for example.

-*Exoplanet Transits and Occultations*, by J. Winn (Exoplanets, Ed. S. Seager)

-*Exoplanet Detection Methods*, by J. Wright & S. Gaudi (Planets, Stars and Stellar Systems, Ed. T. Oswalt

DLR

motivation: parameters for transiting planets
to which precision?

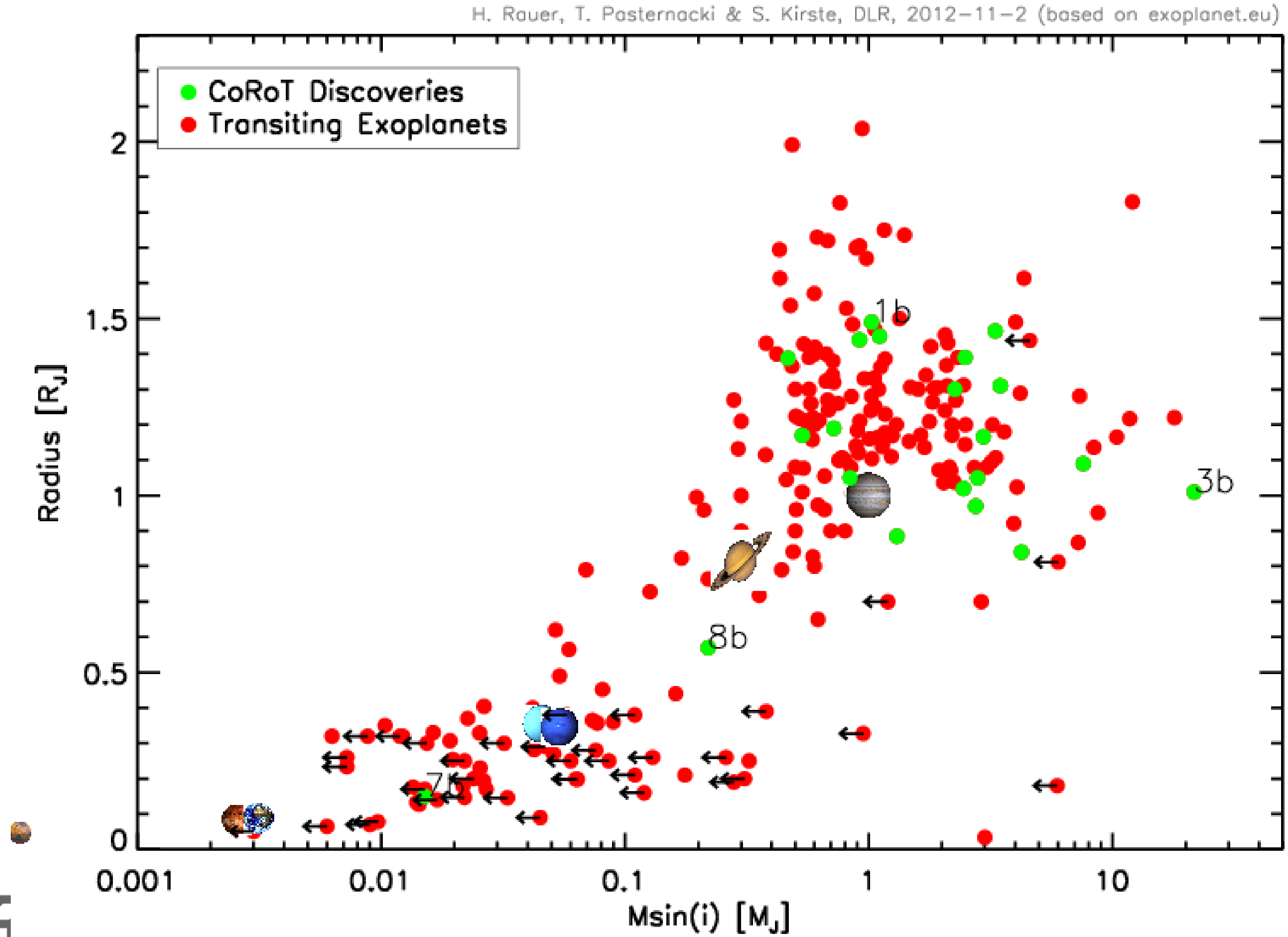


mass to **10%** and radius to **5%** to distinguish between solid rocky and water rich planets

better than **2%** in radius for furhter bulk characterization

(Valencia et al. 2009, ApJ, 665; Grasset et al. 2009, ApJ, 693; Wagner et al. 2011, Icarus, 214...)

motivation: HR diagram for planets?



how are planetary parameters determined?
geometry

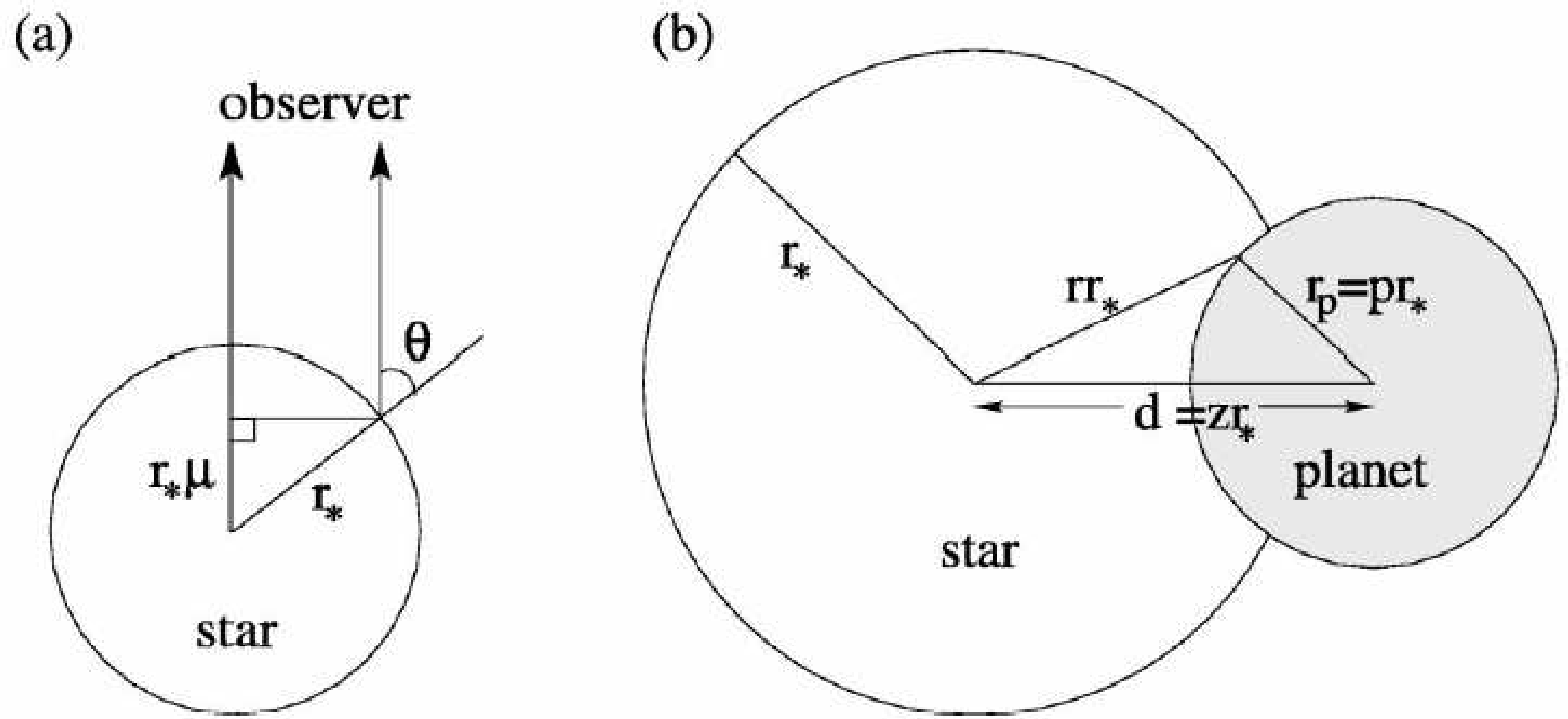


FIG. 1.—(*a*) Geometry of limb darkening. The star is seen edge-on, with the observer off the top of the page. The star has radius r_*, and θ is defined as the angle between the observer and the normal to the stellar surface, while $\mu = \cos\theta$. (*b*) Transit geometry from the perspective of the observer.

Mandel & Agol (2002) ApJ, 580

how are planetary parameters determined?
limb darkening

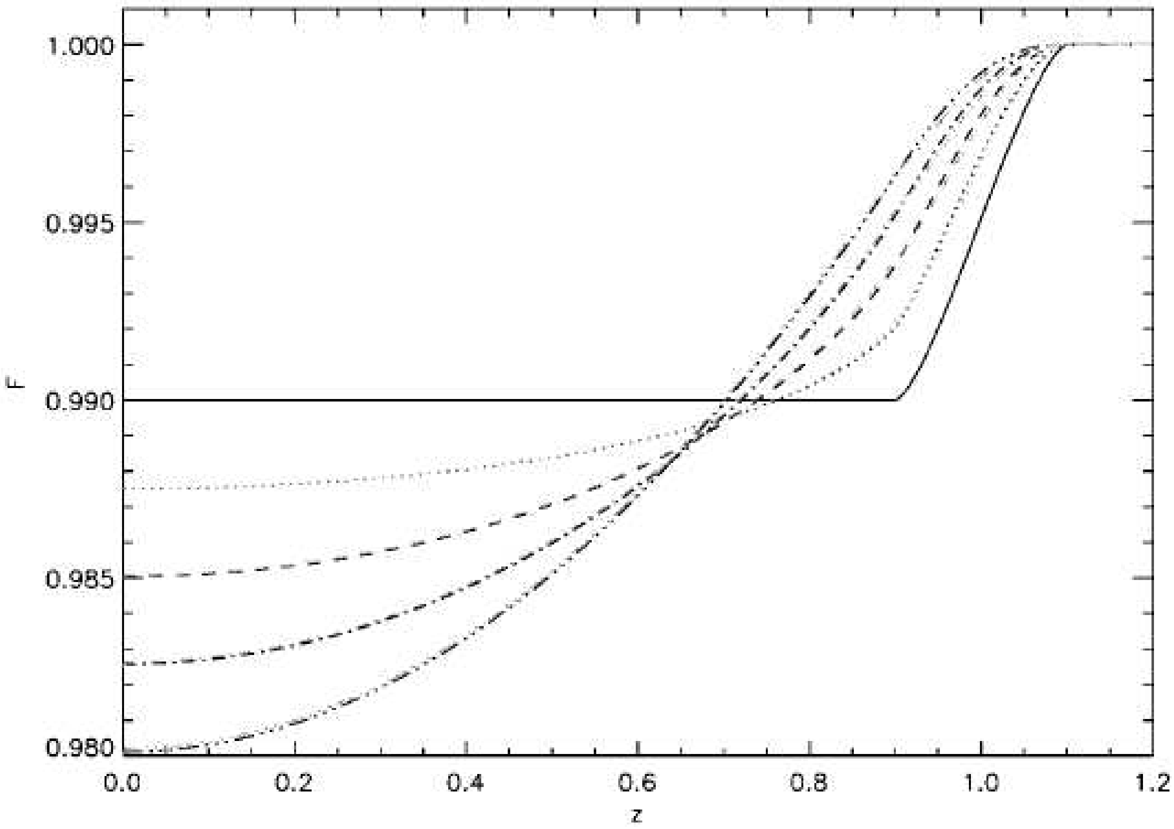


FIG. 2.—Transit light curves for $p = 0.1$ and $c_1 = c_2 = c_3 = c_4 = 0$ (*solid line*), and all coefficients equal zero but $c_1 = 1$ (*dotted line*), $c_2 = 1$ (*dashed line*), $c_3 = 1$ (*dash-dotted line*), or $c_4 = 1$ (*dash–triple-dotted line*). The thinner lines (nearly indistinguishable) show the approximation of § 5.

Mandel & Agol (2002) ApJ, 580

how are planetary parameters determined?
equations

Precise fit is a nonlinear, multi-dimensional problem

- elliptic functions to describe the light curve shape (e.g. Mandel & Agol 2002)
- Jacobi-polynomials as parts of infinite series for the same purpose (Kopal 1989; Gimenez 2006)
- semi-analytic approximations (EBOP: Netzel & Davies 1979, 1981; JKTEBOP Southworth 2006)

- using fully numerical codes, mostly for binary stars (Wilson & Devinney 1971; Wilson 1979; Linnel 1989; Djurasevic 1992; Orosz & Hausschildt 2000; Prsa & Zwitter 2006; Csizmadia et al. 2009 – etc.)

how are planetary parameters determined?
methods

Optimization codes:

- MCMC (HAT, WASP teams, and CoRoT-4b, 5b, 12b, partially 6b, 11b)
- Amoeba (most CoRoT-planets, except: 4b, 5b, 12b, 13b, 16b, 17b, 19b, 21b)
- Genetic Algorithm (for all Corot-planets)

- HAT-team sometimes uses: AMOEBA first and then MCMC (AMOEBA good to find the 'best' fit and then MCMC for deriving uncertainties; see also Kiping & Bakos, 2011)

- TLCM (Csizmadia et al. 2011, A&A, 531) uses at this moment Genetic Algorithms for minimization and Simmulated Annealing for deriving uncertainties. Routinely used at DLR either for BEST candidates and CoRoT exoplanets

- Other examples: EXOFAST (Differential Evolution MCMC, Eastman et al. 2012)…

how are planetary parameters determined?
procedure

1) Photometry:
   - several tests to establish reliability of signal

   (Deeg et al. 2009, A&A, 506; Bakos et al. 2010, ApJ, 710; Collier Cameron et al. 2007, MNRAS, 380)

   - first estimation of planetary parameters: R_p/R_s, a/R_s, b, **l.d.**, L_3, T_0
2) Spectroscopy:
   - spectroscopic characterization of the star (and rejection of false alarms)

   (Moutou et al. 2009, A&A, 506)

   - obtain mass of the planet
   - accurate stellar parameters -> taking *log g* from transit fit

   (Torres et al. 2012, ApJ, 757; see also talk by A. Collier Cameron during Sagan Symposium 2012)
3) Fix final system parameters

$$R_p \propto R_\star \qquad M_p \propto M_\star^{2/3}$$

$$R_\star, M_\star \leftarrow T_{\rm eff}, \log g, [{\rm Fe/H}]$$

{see talk by Jeff Valenti}

how are planetary parameters determined?
procedure

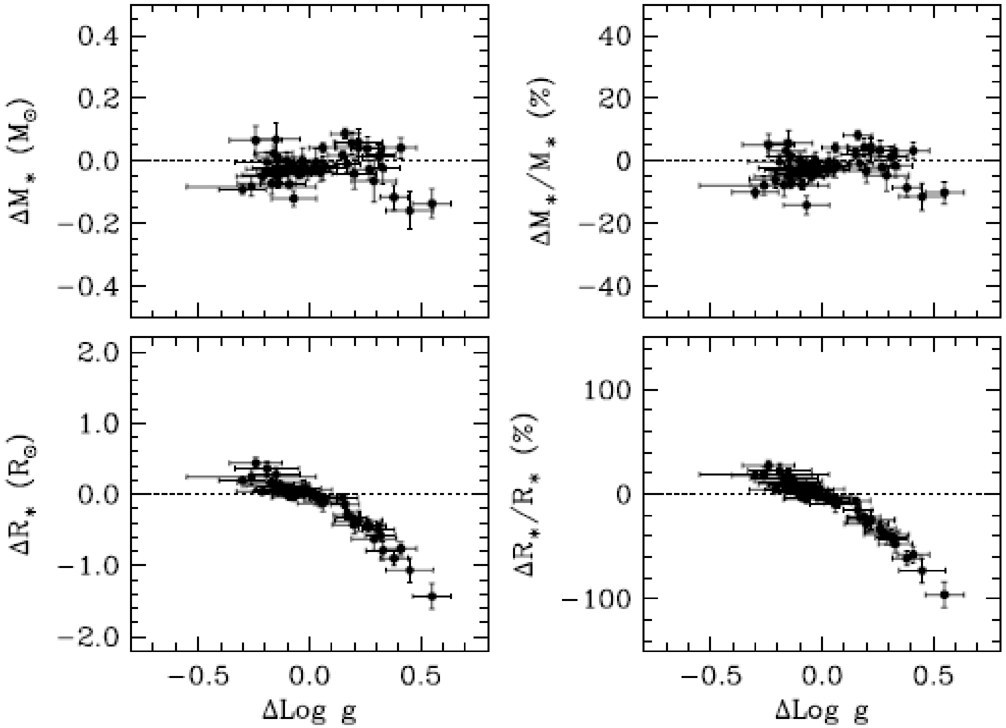


FIG. 10.— Mass and radius differences resulting from the use of constrained and unconstrained spectroscopic properties from SME along with stellar evolution models. Differences in the sense ⟨constrained minus unconstrained⟩ are shown in absolute units on the left, and as a percentage of $M_\star$ or $R_\star$ on the right.

Torres et al. (2012) ApJ, 757

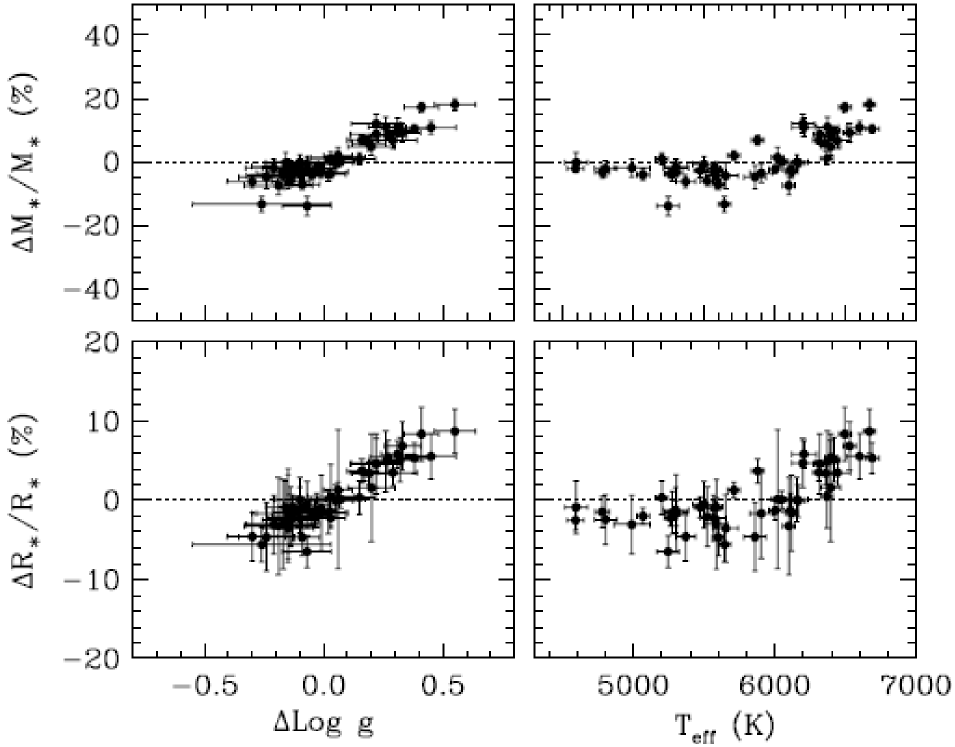
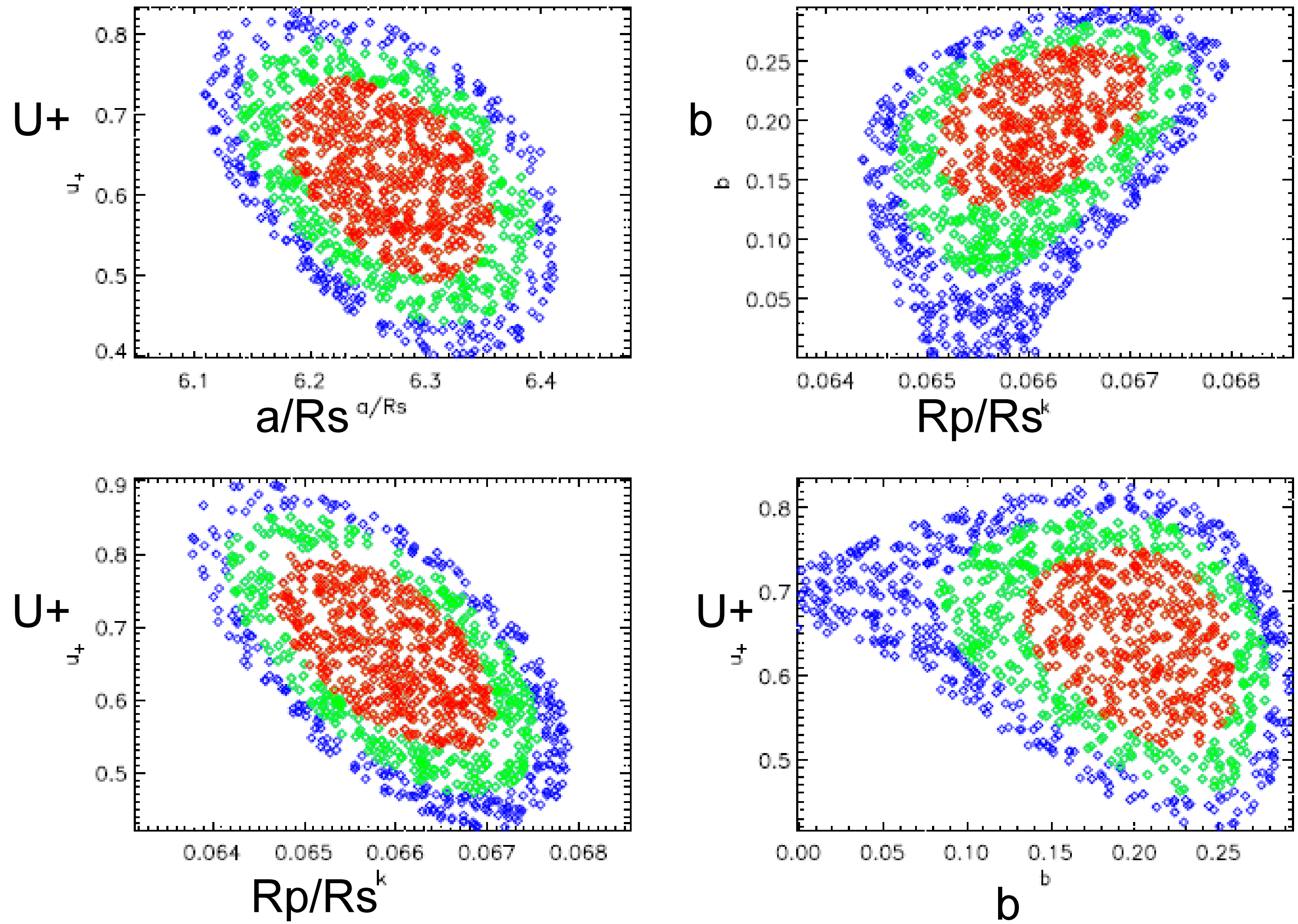


FIG. 11.— Systematic errors in the stellar mass and radius (expressed as a percentage) when using *unconstrained* values of $T_{\rm eff}$ and [Fe/H] from SME together with the external photometric constraint on $\log g$ from the mean stellar density. The differences shown are between the mixed usage just mentioned and the constrained results from a second iteration of SME described in the text, in the sense ⟨mixed minus constrained⟩.

Even in the best case, uncertainties in planetary parameters can be up to **10%**
{only way through is asteroseismology, from space (CoRoT, Kepler) but limited amount of targets (limited by brightness)}

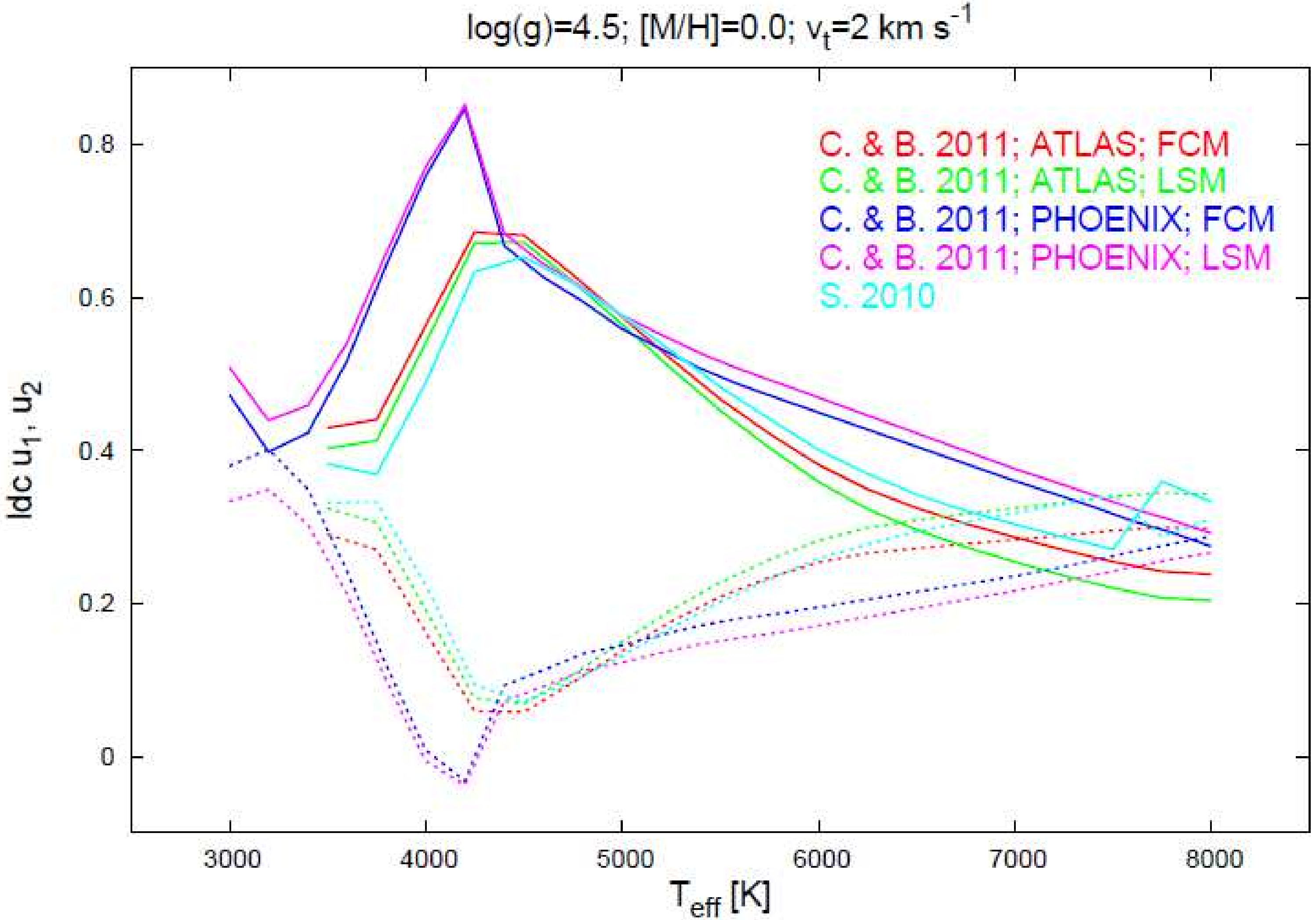
{see talk by Andy Moya}

modelling of planetary parameters:
impact of limb darkening



Csizmadia et al. (2011) A&A, 531 [CoRoT 17b]

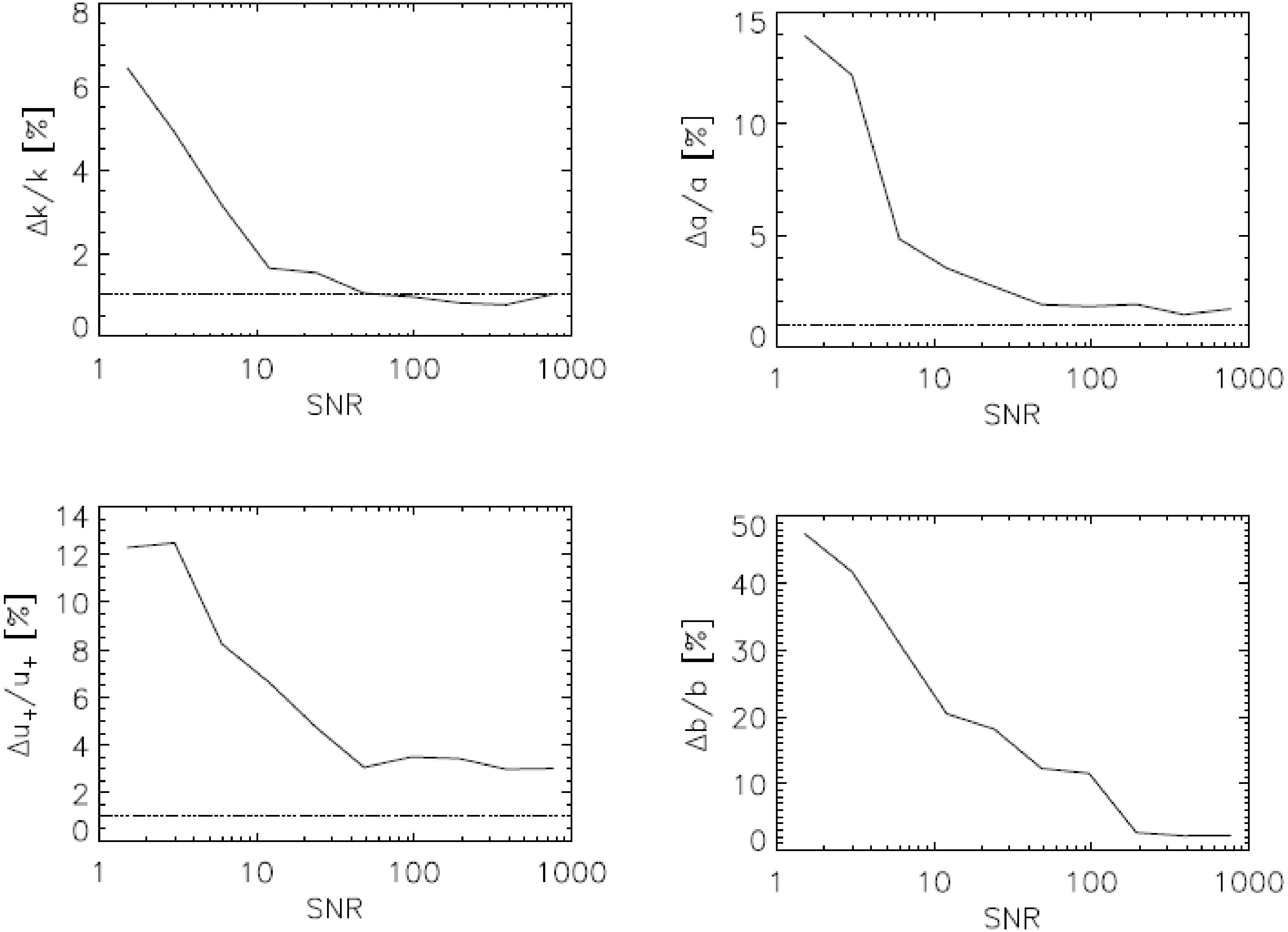
modelling of planetary parameters:
impact of limb darkening



Csizmadia et al. (2012) A&A, in press

{don't forget 3D modeling efforts: Hayek et al. 2012, A&A,539}

modelling of planetary parameters:
impact of limb darkening



Csizmadia et al. (2012) A&A, in press

modelling of planetary parameters:
impact of limb darkening

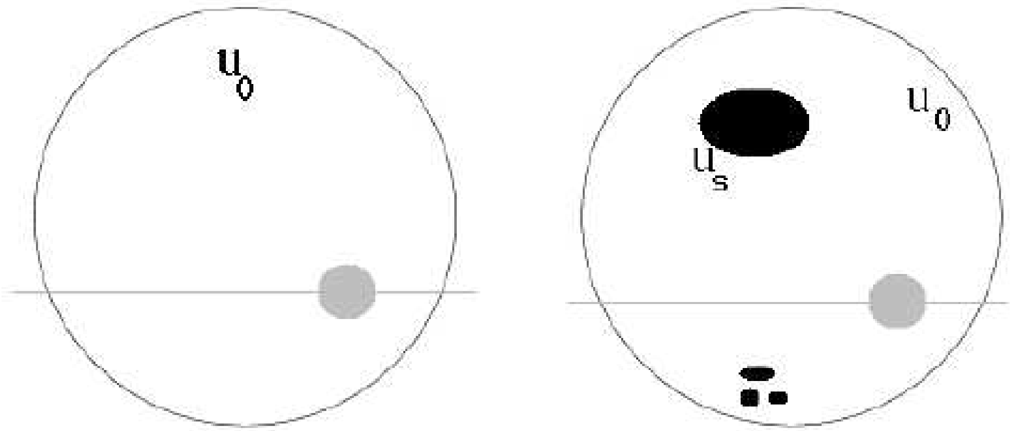


Fig. 4. Illustration of the effect of Type I spots. Left: the planet crosses an unmaculated star that is characterized with some limb darkening coefficient u_0. Right: the planet crosses the apparent stellar disc of a spotted star, where the spots and the planet have different impact parameters, as well as the stellar photosphere and the spots have different limb darkening coefficients (u_0, u_s). Grey area is the planet, black ellipses represent the spots.

Csizmadia et al. (2012) A&A, in press

apparent stellar disk cannot be characterized with single effective temperature
(and not only because of gravity darkening, Von Zeipel 1924; Barnes 2009...)
surface brightness cannot be characterized with single limb darkening coefficient
(associated to a single effective temperature)
{for spot crossing, see Silva-Valio&Lanza 2010; Sanchis-Ojeda&Winn 2011...}

modelling of planetary parameters:
impact of limb darkening

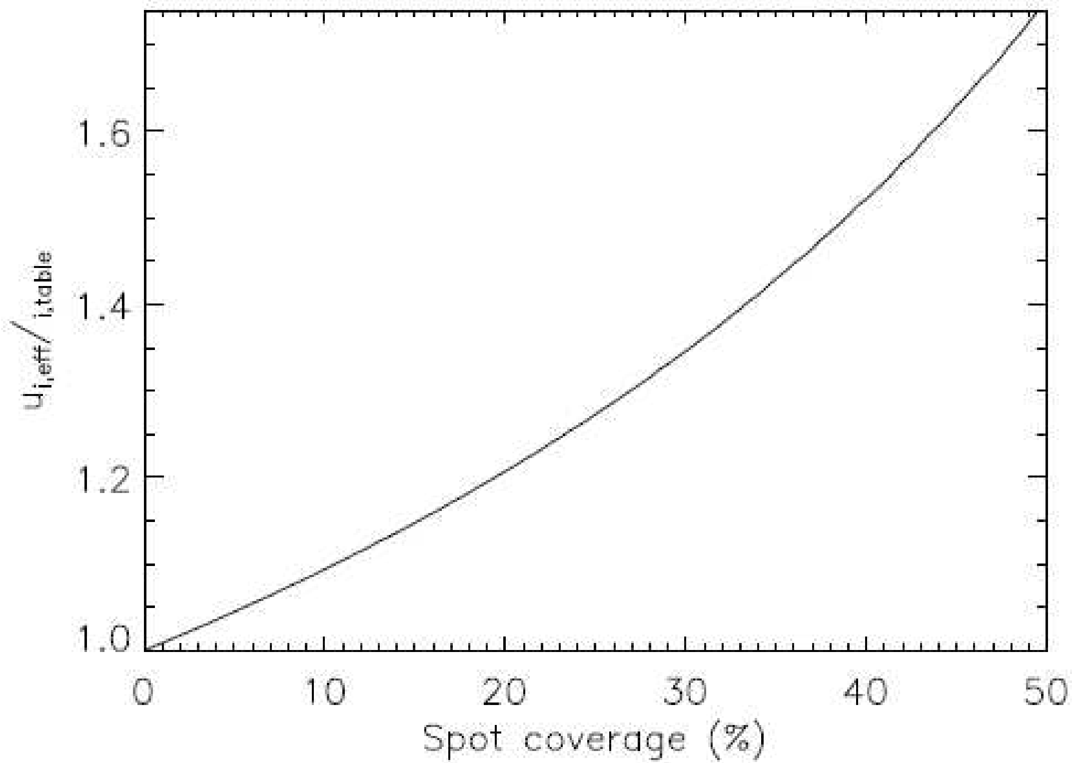
spots act as sources of contamination (third light), but they also change the effective measured limb darkening coefficients

sometimes, theory and observations agree well:
e.g. CoRoT-8b (Bordé et al 2010), CoRoT-11b (Gandolfi et al. 2010)…

sometimes there are large differences:
e.g. CoRoT-13b (Cabrera et al. 2010; Southworth 2011), CoRoT-12b (Gillon et al 2010), HD 209458 (Claret 2009), Kepler-5b (Kipping & Bakos 2011), WASP-13 (Barros et al. 2012)…

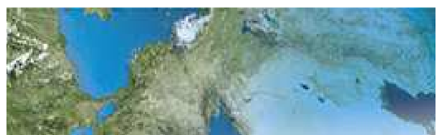
modelling of planetary parameters:
impact of limb darkening

spots act as sources of contamination, but they also change the effective measured limb darkening coefficients



Csizmadia et al. (2012) A&A, in press

Fig. 5. The x-axis is the total spotted area in percentage of the whole stellar surface area. The y-axis is the effective - i.e observed - limb darkening coefficients relative to the table value at the given stellar efffective temperature. For this figure we used $T_{star} = 5775$K and $T_{spots} = 3775$K, and the positions of the spots were chosen randomly on the visible hemisphere. The size of the spots were always the same, so higher spot coverage corresponds to larger number of spots. The limb darken-



conclusion

-precise planetary parameters are needed

-for an accurate study of planetary composition

-for a statistical study of planetary properties (planetology)

-obtaining precise planetary parameters requires

-a careful observational strategy (stars and planets as systems)

-a careful understanding of the modelling assets and limitations

-space photometry (MOST, CoRoT, Kepler, CHEOPS, EChO, PLATO) allows most detailed studies