The Need of Precise Planetary Parameters:
How To Get Radius with PLATO

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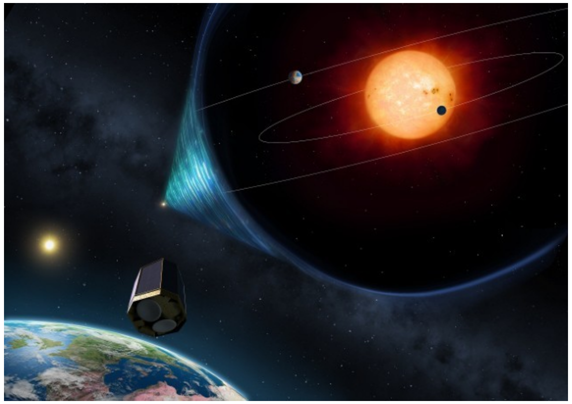

PLATO 2.0 Science Workshop
ESTEC, Noordwijk, The Netherlands

Wissen für Morgen

DLR
Institut für Planetenforschung | Institute of Planetary Research
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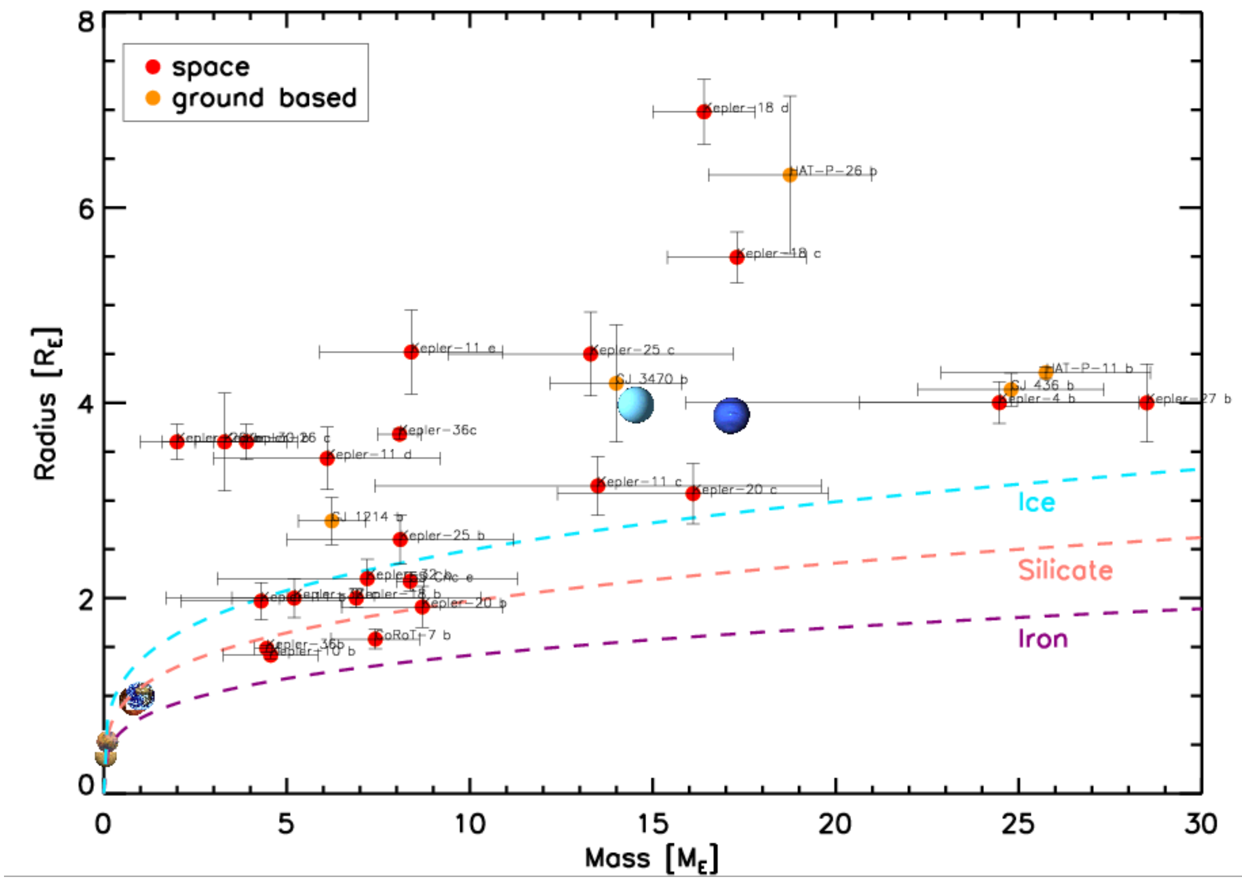
Berlin | Berlin

motivation: parameters for transiting planets

to which precision?



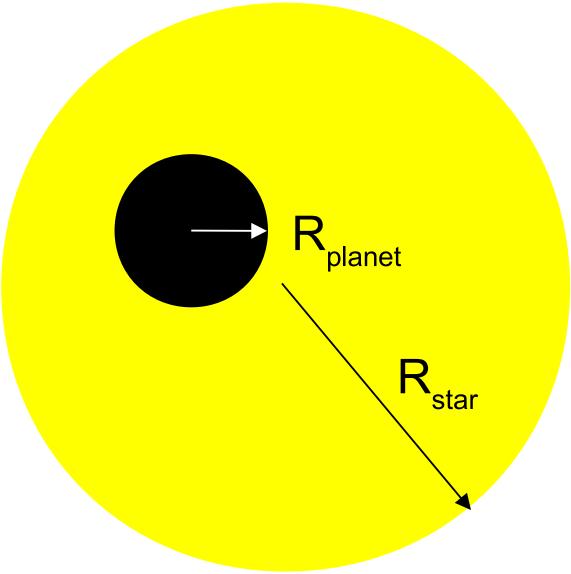
mass to **10%** and radius to **5%** to distinguish between solid rocky and water rich planets

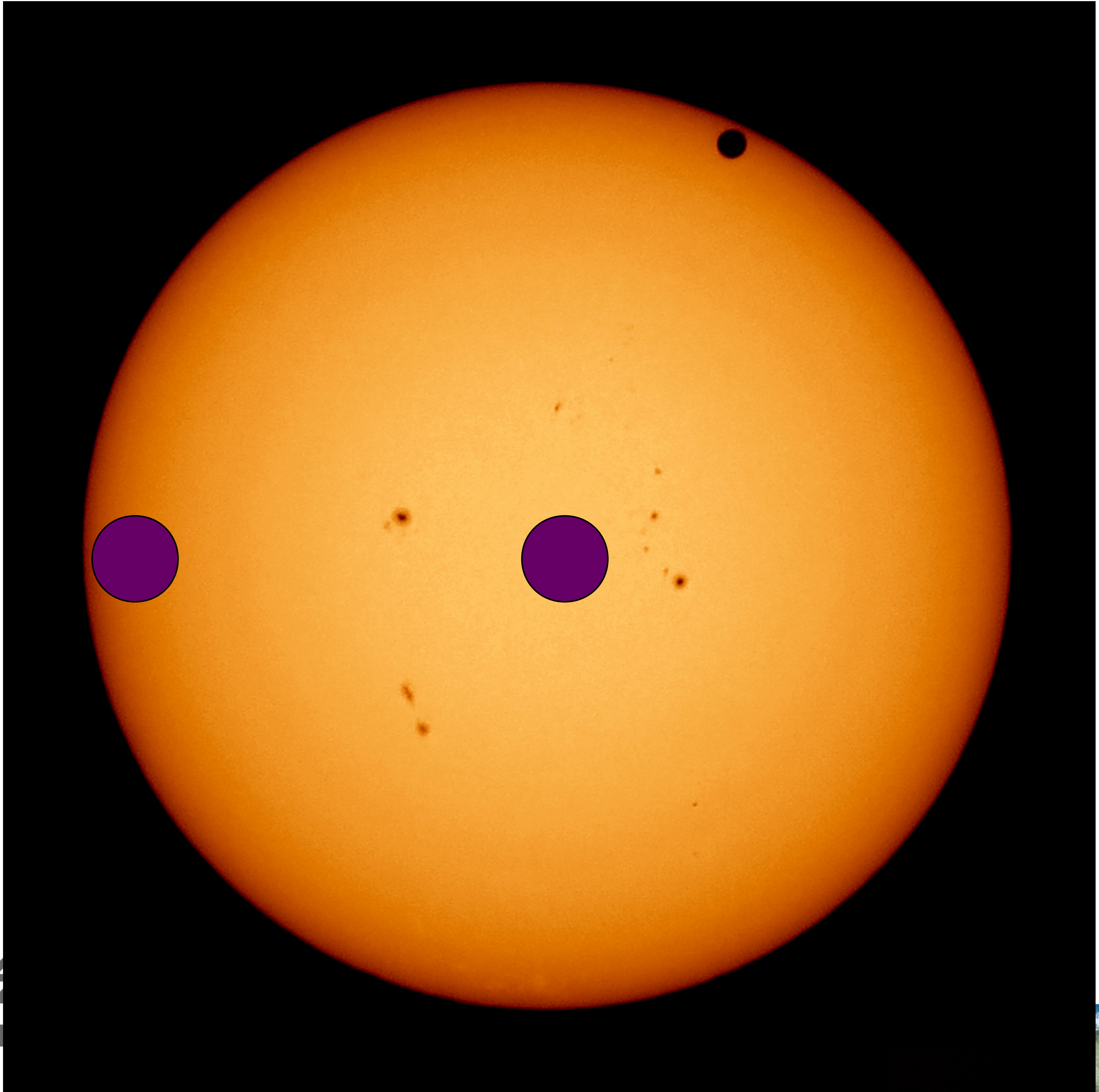
better than **2%** in radius for further bulk characterization. Atmosphere studies: ~0.1%.

(Valencia et al. 2009, ApJ, 665; Grasset et al. 2009, ApJ, 693; Wagner et al. 2011, Icarus, 214, 366; Bean et al. 2011, ApJ 743, 92)

Among other factors, the radius determination of the exoplanet is affected by:

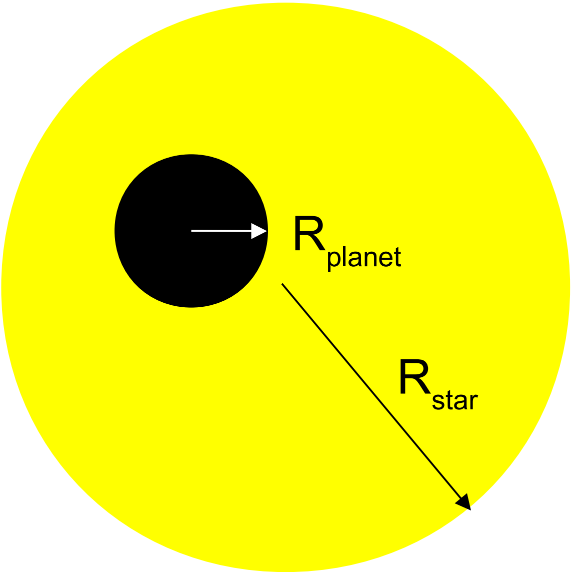
$$\Delta F = k^2, \qquad k = \frac{R_{planet}}{R_{star}}$$





Among other factors, the radius determination of the exoplanet is affected by:

$$\Delta F \pm dilution = factor \times k^2, \qquad k = \frac{R_{planet}}{R_{star}}$$



- S/N ratio
- dilution (crowding, physical companion, spots etc)
- limb darkening
- planet rotational, tidal distortion, etc.

- knowledge of stellar radius (GAIA: ~2%)
- therefore the goal is to minimize uncertainty of the radius ratio *k*.

Spots affect the shape and depth of transits:
Timing, so TTVs (see e.g. Oshagh et al. 2013)
Transit depth, so radius ratio determination (Csizmadia et al. 2013).

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Effect of limb darkening on transit depth and shape

~50% precise approximation:

$$\Delta F = k^2, \qquad k = \frac{R_{planet}}{R_{star}}$$

Precise:

$$\Delta F = k^2 L_D(T_{eff}, g, \lambda, [M/H] \ldots)$$

See Csizmadia et al. (2013) for a list where theoretical and observed limb darkening coefficients disagree.

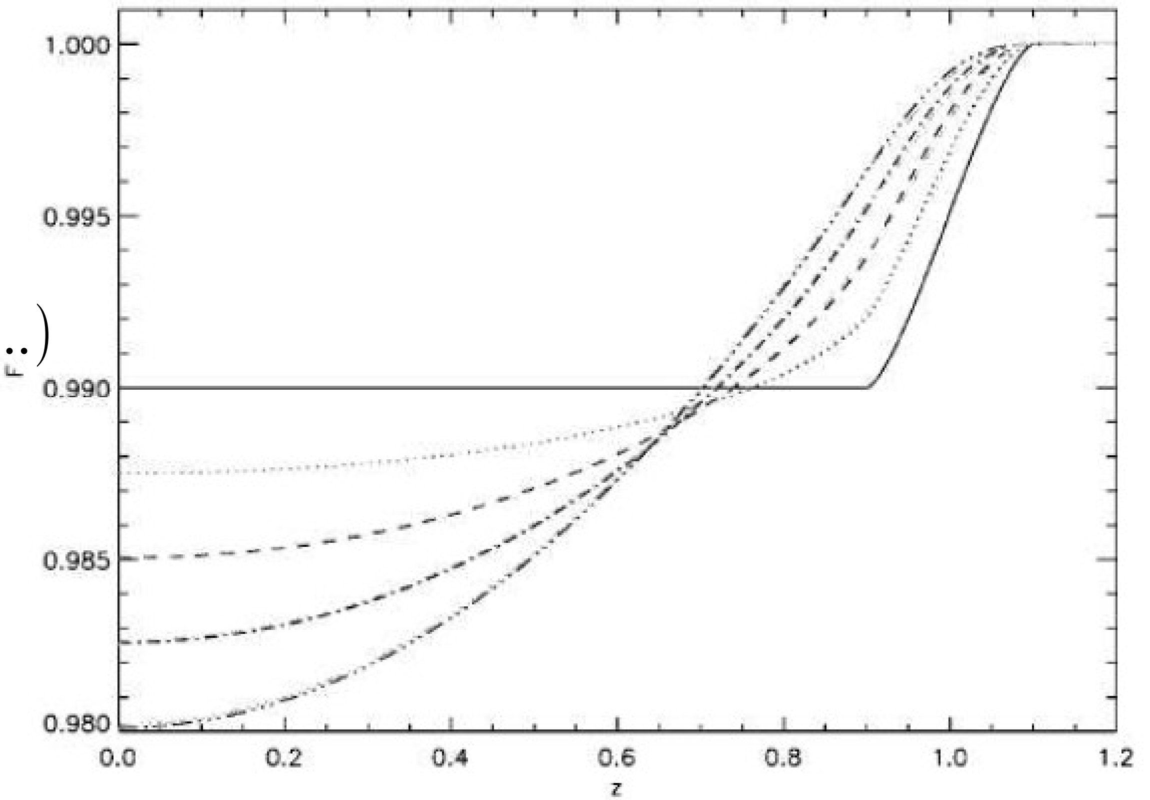

FIG. 2.—Transit light curves for $p = 0.1$ and $c_1 = c_2 = c_3 = c_4 = 0$ (*solid line*), and all coefficients equal zero but $c_1 = 1$ (*dotted line*), $c_2 = 1$ (*dashed line*), $c_3 = 1$ (*dash-dotted line*), or $c_4 = 1$ (*dash–triple-dotted line*). The thinner lines (nearly indistinguishable) show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

Mandel & Agol (2002) ApJ, 580

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Calculation shows (Csizmadia et al. 2013, A&A 549, A9): to measure the planet-to-stellar radius ratio with 5% uncertainty, you need to know the limb darkening with at least 0.5% precision.

In general, we do not have this precision.

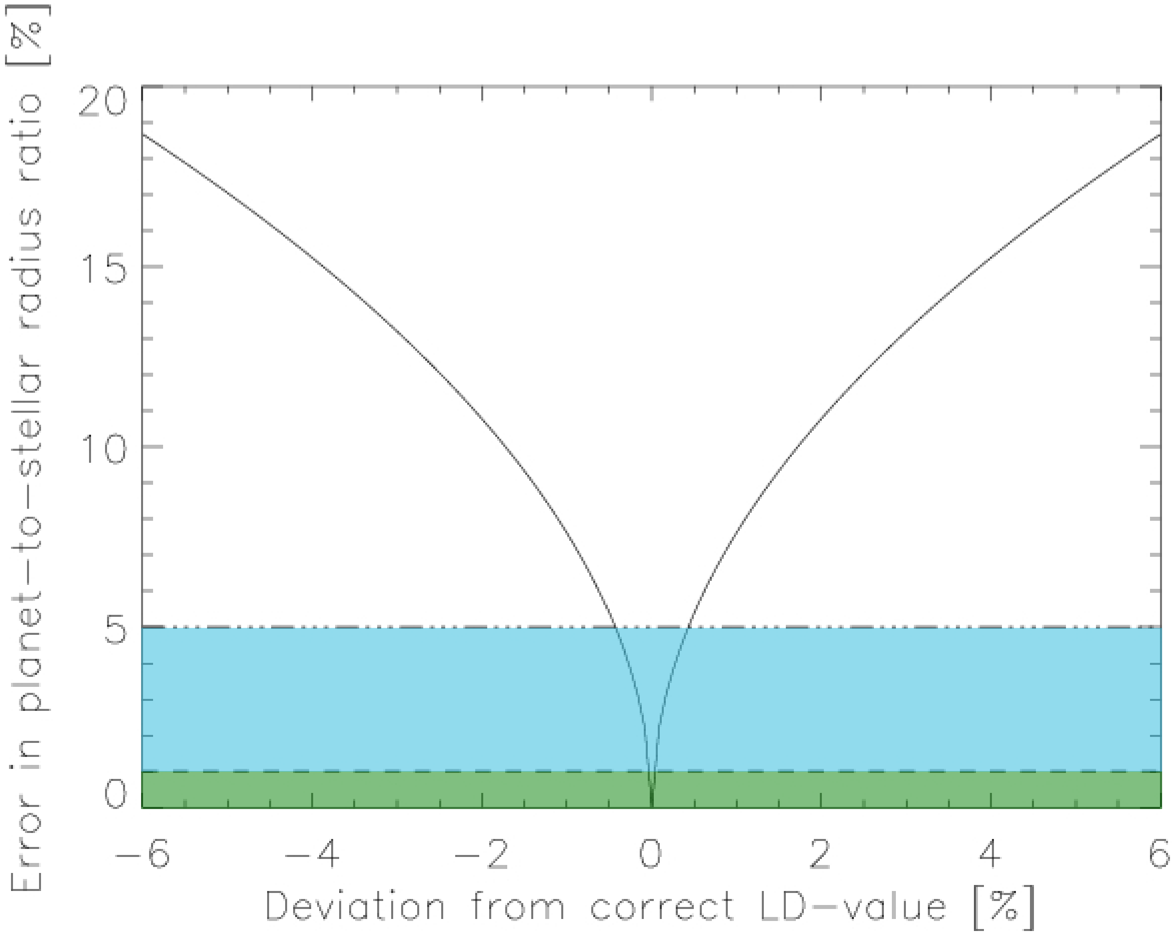
Stellar parameters:

±100K in Teff

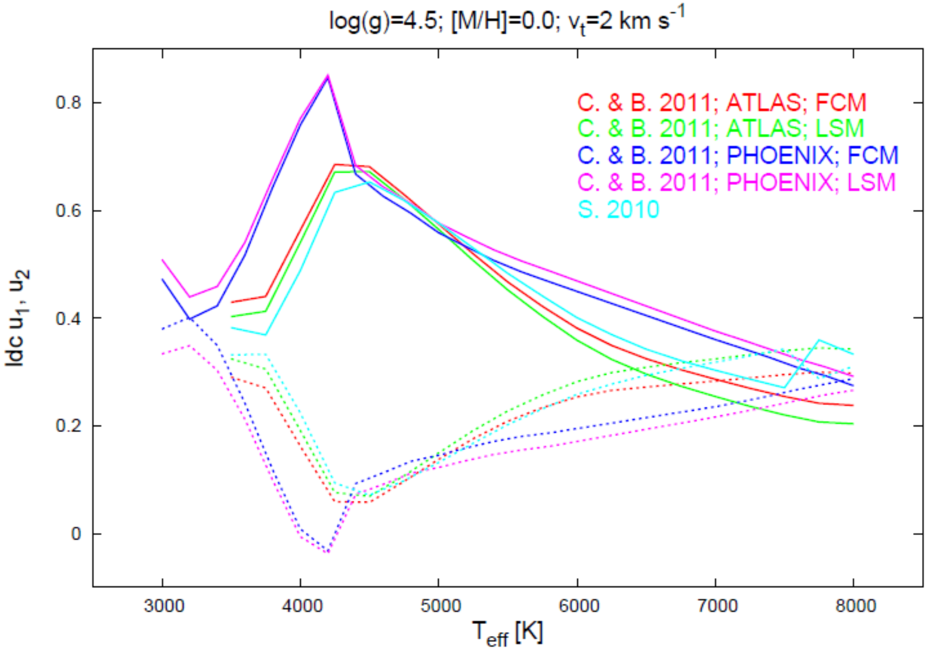
±0.1 in logg

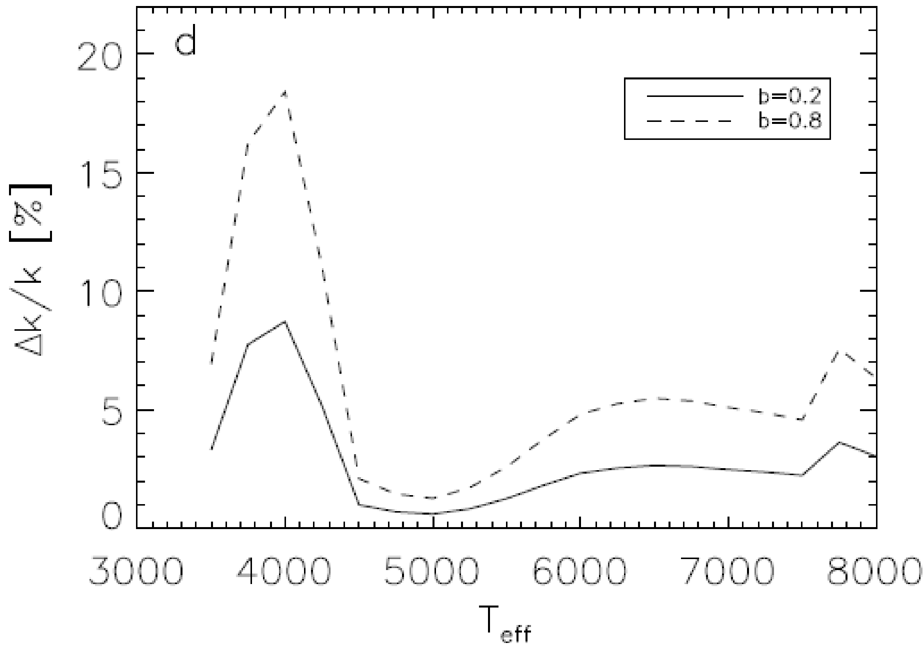
±0.1 in [M/H]:

5% in limb darkening coefficients.



Theoretical uncertainties of 1D limb darkening



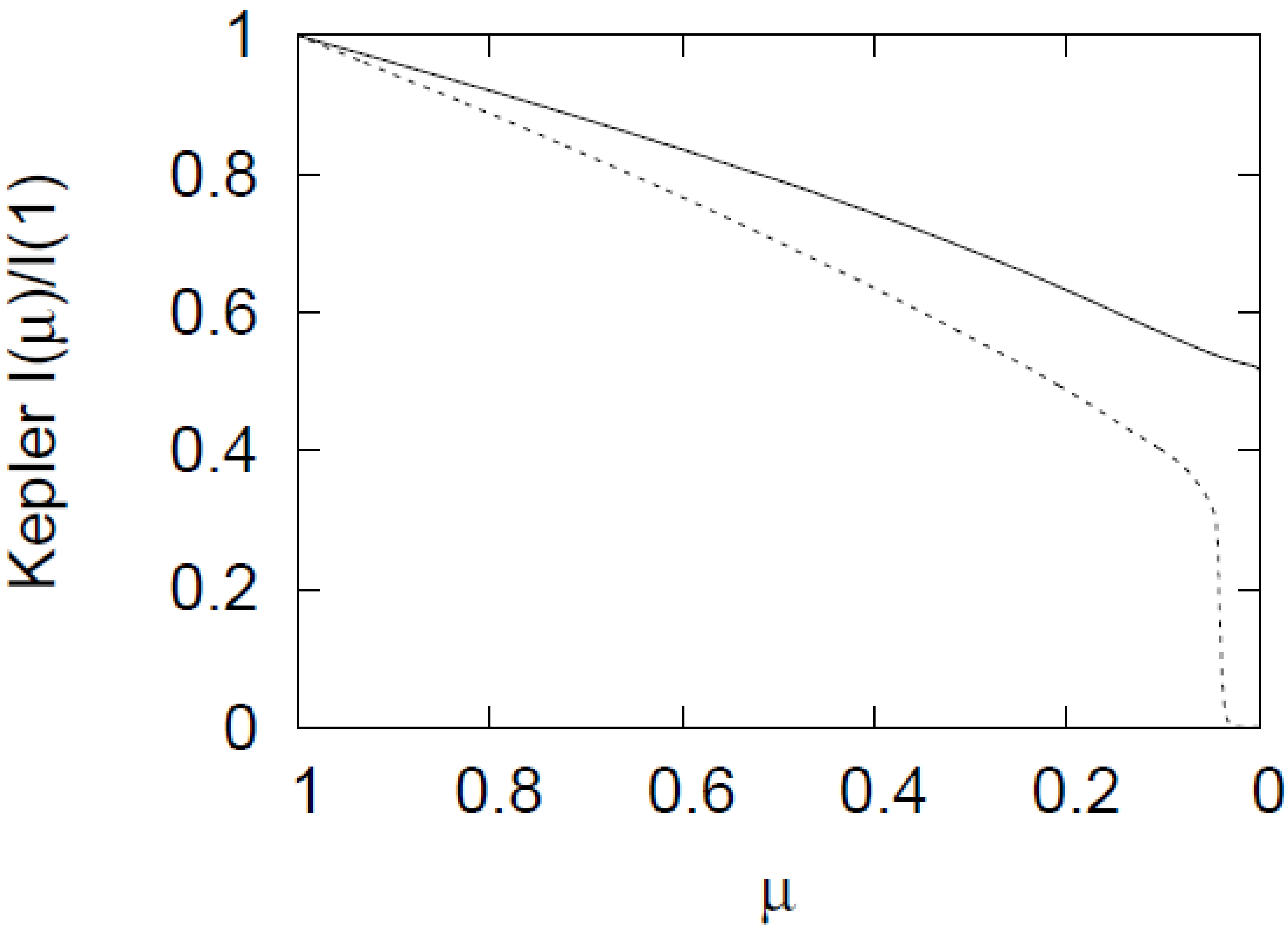


Csizmadia et al. (2013) A&A 549

{3D modeling efforts: Hayek et al. 2012, A&A,539}

Figure from
Neilson & Lester
(2013, A&A).

Similar curves
by Claret et al.
(2012, 2013, A&A)



Stellar center

Stellar limb

Fig. 1. Predicted *Kepler*-band intensity profiles for plane-parallel (solid line) and spherically symmetric (dotted line) model stellar atmosphere with $T_{\rm eff} = 5800$ K, $\log g = 4.5$ and $M = 1.1\ M_\odot$.

modelling of planetary parameters:
impact of limb darkening

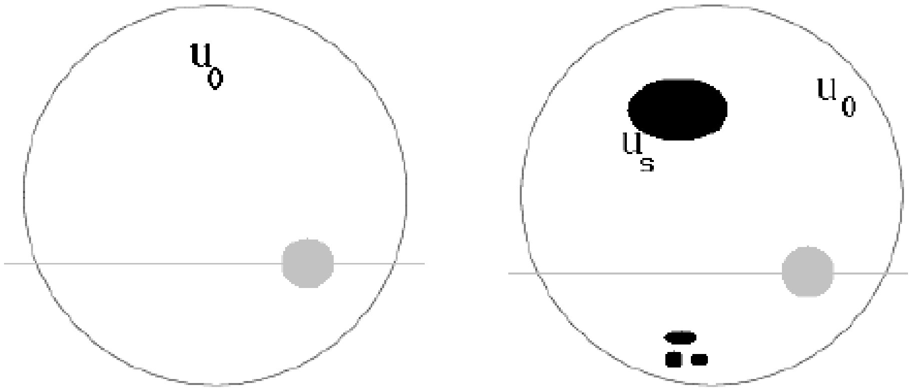


Fig. 4. Illustration of the effect of Type I spots. Left: the planet crosses an unmaculated star that is characterized with some limb darkening coefficient u_0. Right: the planet crosses the appareant stellar disc of a spotted star, where the spots and the planet have different impact parameters, as 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. (2013) A&A

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

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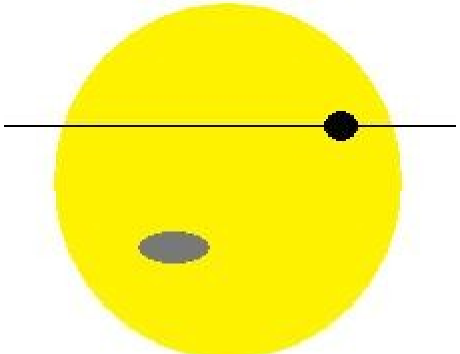
Stellar spots and faculae

Type I

Short life-time,

not occulted

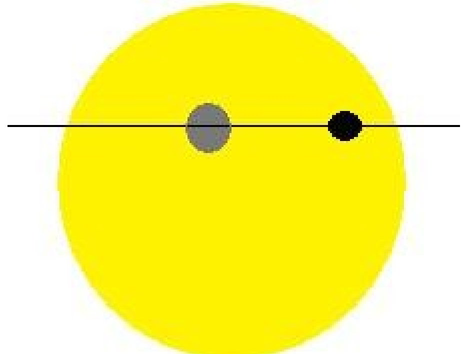


↑Can be removed by baseline-fitting

Type II

Short life-time,

occulted



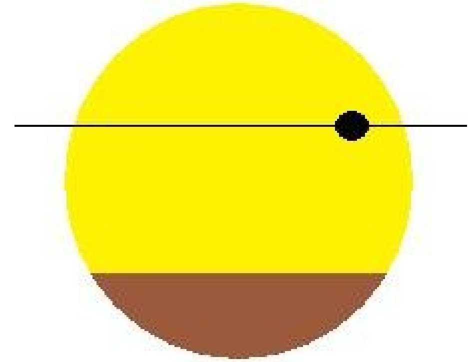
↑Can be removed by spot-modeling

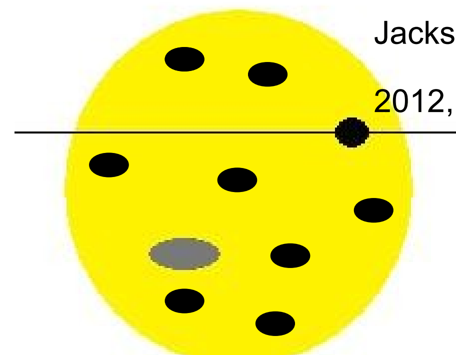
{for spot crossing, see Silva-Valio&Lanza 2010; Sanchis-Ojeda&Winn 2011...}

Type III

Long life-time, pole-on,

slow rotation, no modulation



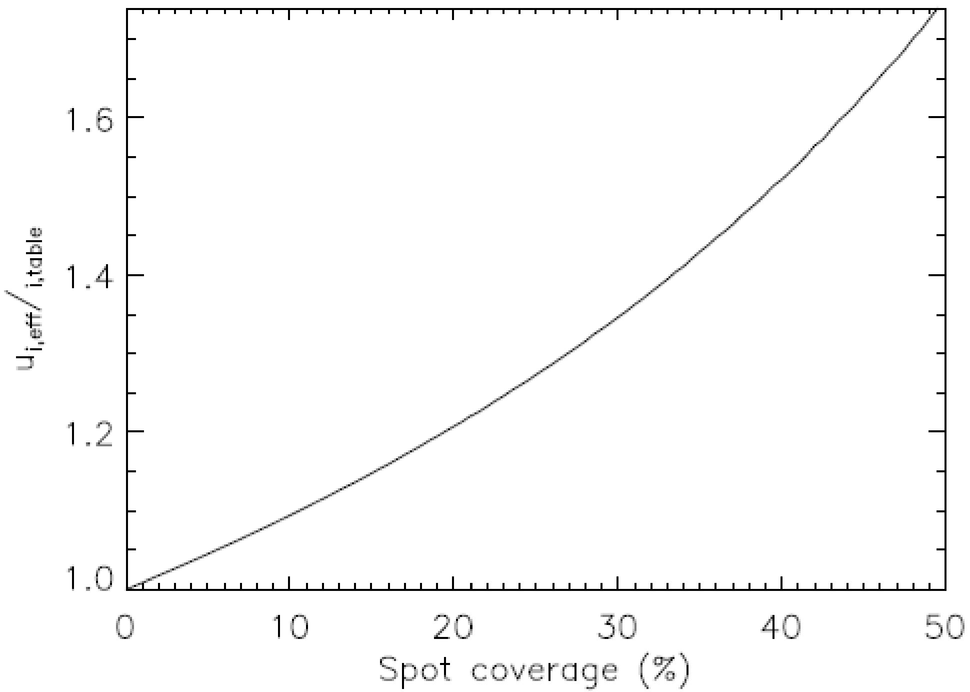


Jackson & Jeffries 2012, MNRAS 423

EXTRA ± CONTAMINATION!!

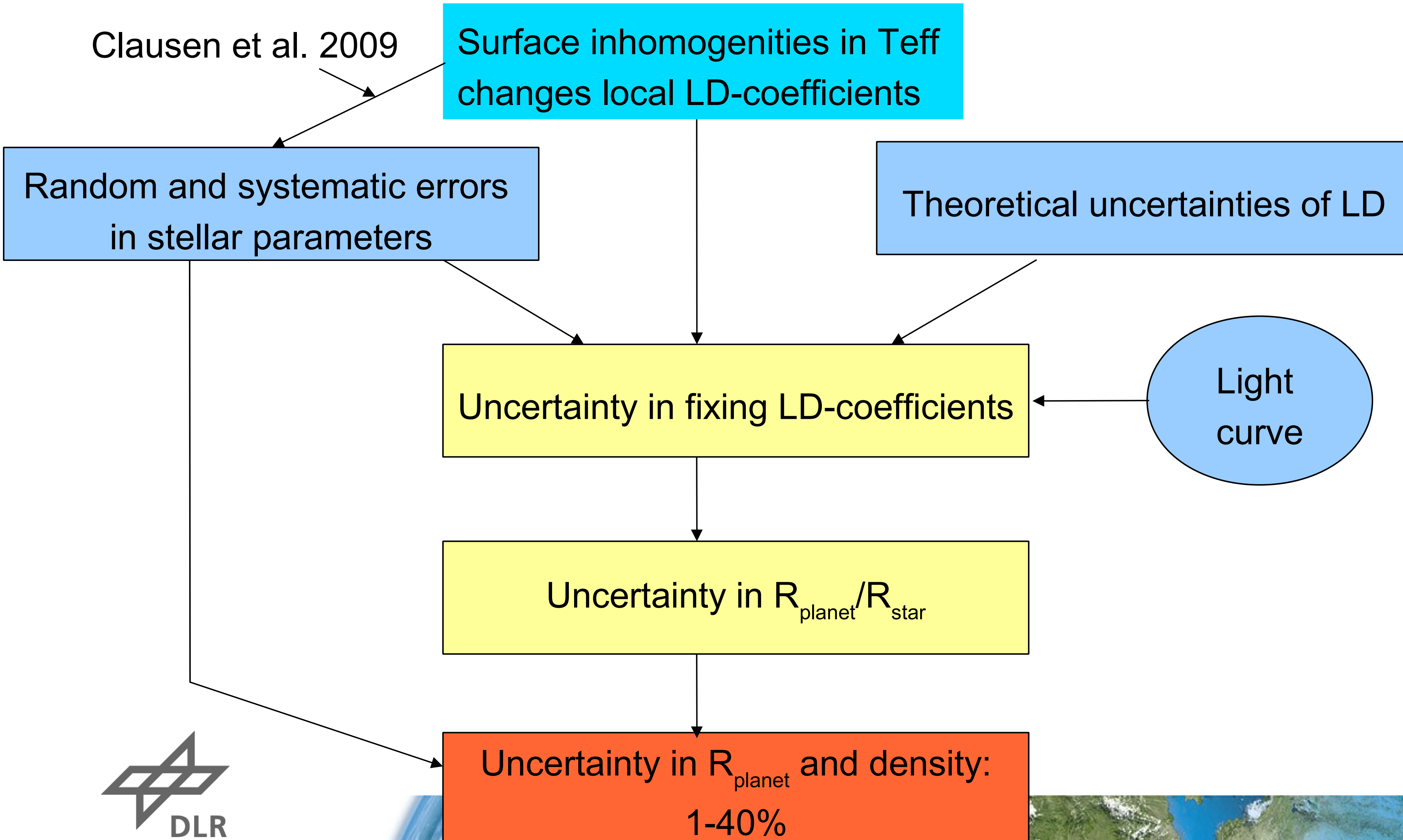
modelling of planetary parameters:
impact of limb darkening

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

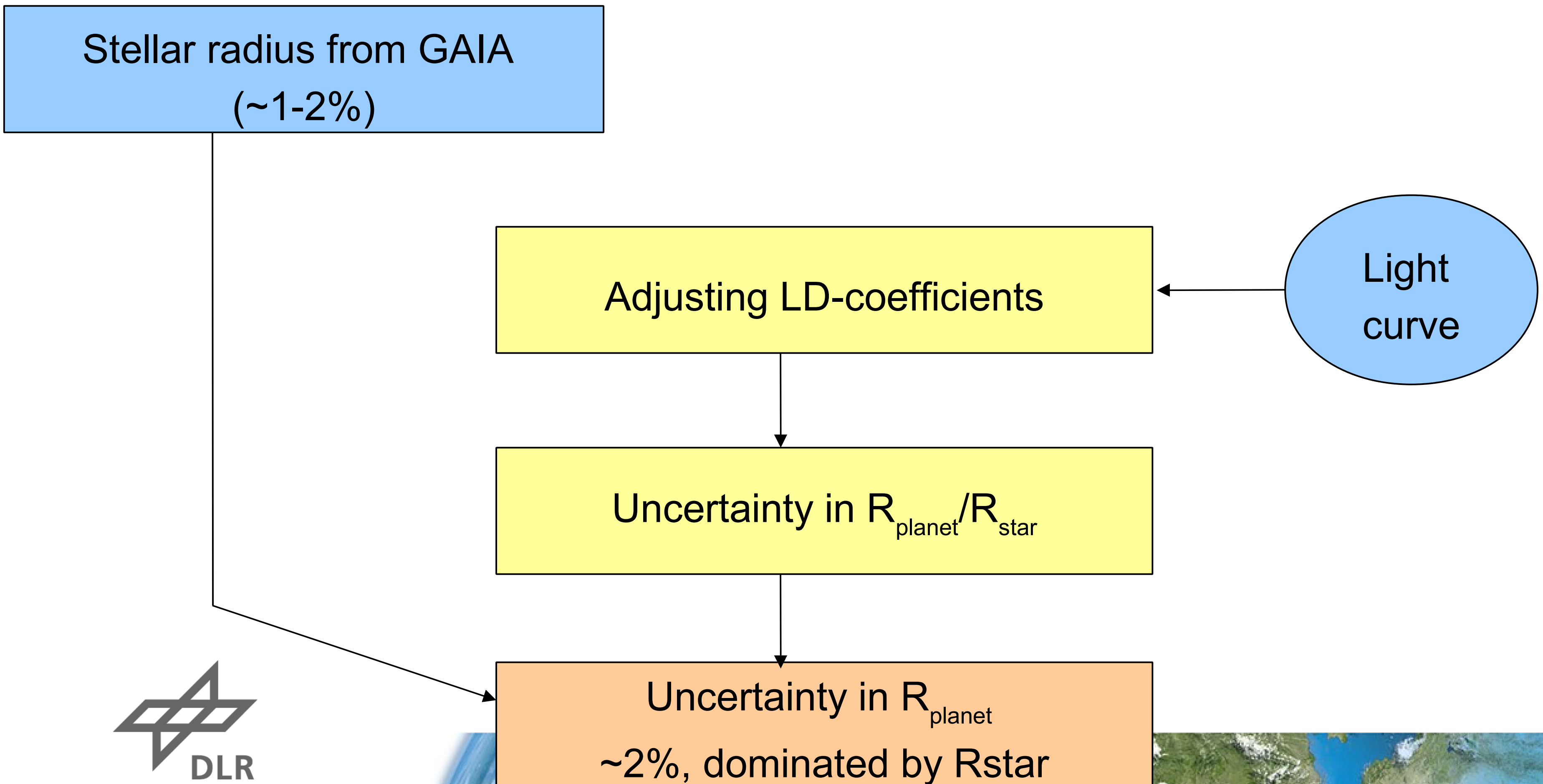


Csizmadia et al. (2013) A&A

Factors which affect the planetary radii determination



Factors which affect the planetary radii determination



CONCLUSIONS

1D, plane-parallel, unspotted stellar atmosphere models (poorly checked, but bad ones)

→

3D, spherical symmetric, spotted stellar atmosphere models

(3D+spherical exists since 2013,

but observationally not checked yet

- theory of convection etc. can be improved)

The ultimate limit of precision of planetary characteristics is the precision of stellar parameters. Radius mostly will be dominated by stellar radius (~2%).

Transits light curves require careful analysis and a lot of accurate stellar physics. We learned a lot from CoRoT & Kepler and we are prepared to interpret the light curves of PLATO.