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Light Curve Errors Introduced by Limb-darkening Models

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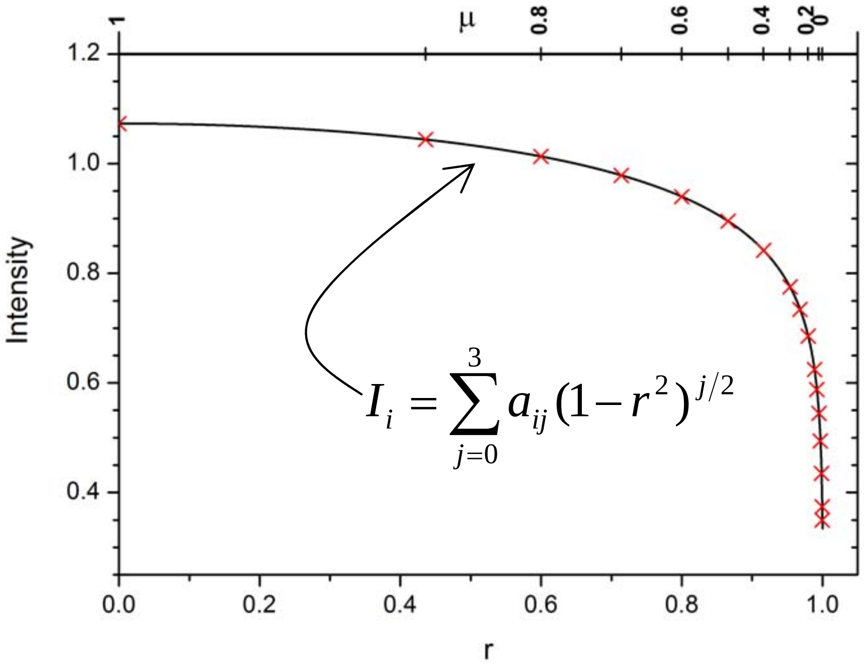
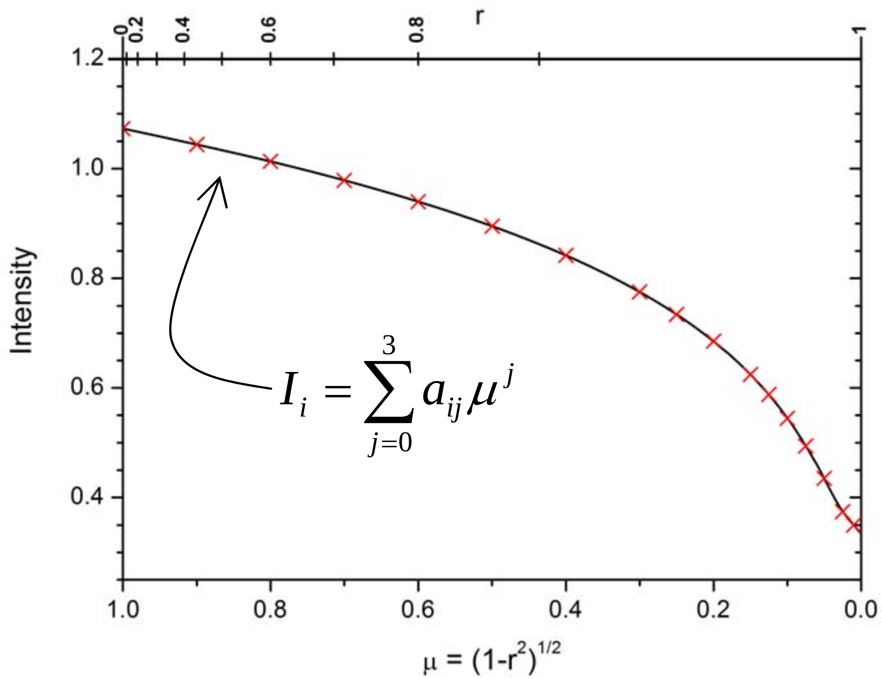
Outline

1. Microlensing a model atmosphere limb-darkening profile
2. Microlensing limb-darkening model fits to profile
3. Amplification residuals
4. Statistical results for Kurucz's ATLAS9 grid in *BVRI*
5. Residual patterns for observed events
6. Sensitivity of binary vs. single-lens caustic-crossing events

Kurucz model intensity profiles

ATLAS9 grid – 9581 stellar model atmospheres (T_{eff}=3500..50000 K);
2 nm resolution in optical; intensity for 17 rays





To compute microlensed flux evaluate

$$J_{ij}(u) = \int_{r_i}^{r_{i+1}} \left(1-r^2\right)^{j/2} \mathrm{A}(u,r)\, r\, dr$$

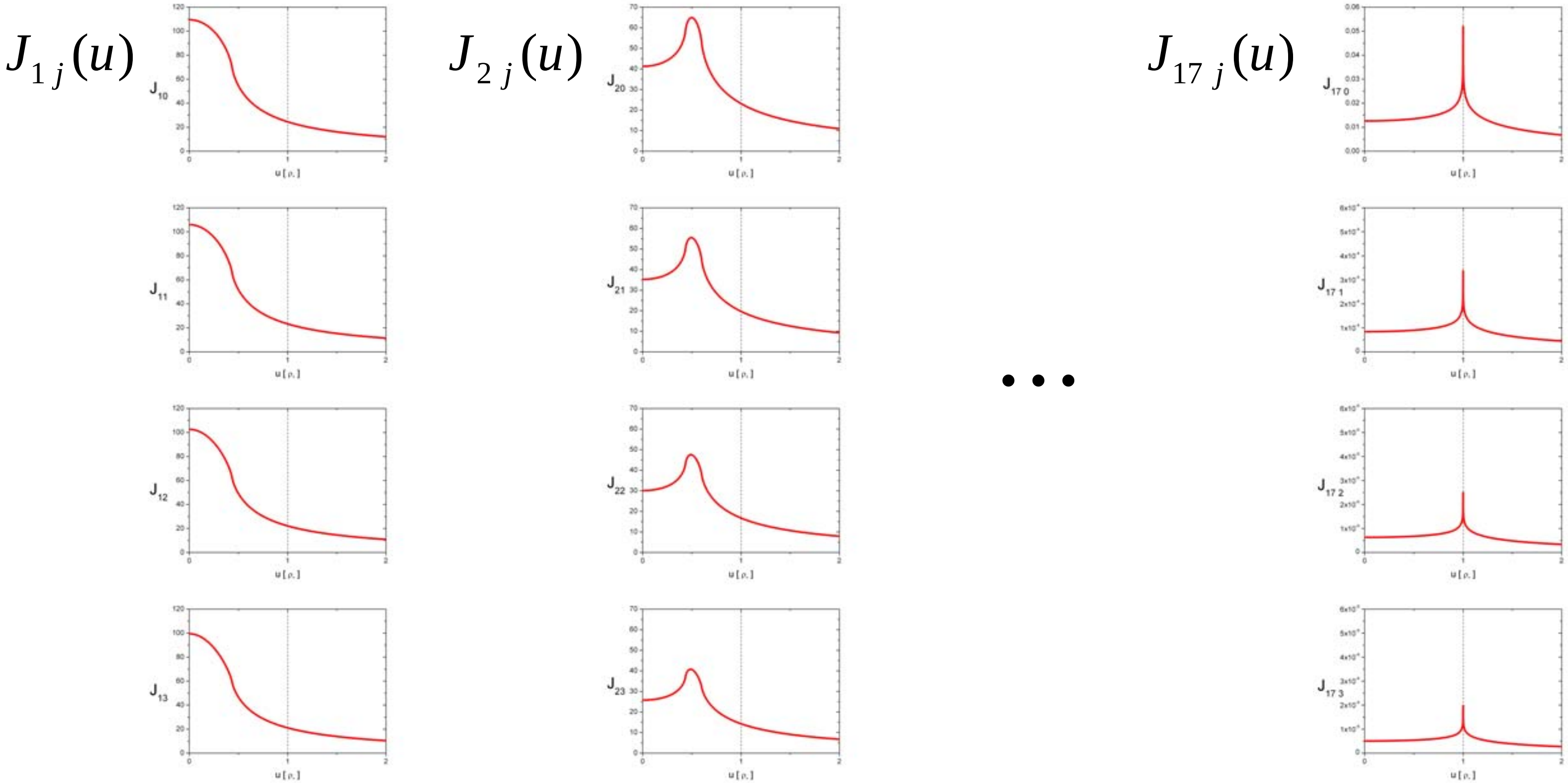
$i = 1\ldots17,\ j = 0\ldots3$

angle-integrated point-source amplification

(analytical expression e.g. Heyrovský 2003)

Computation of Kurucz profile amplification

numerically + analytically across $r = u/\rho_*$ (for $0 < u/\rho_* < 2$, $\rho_* = 0.025$)

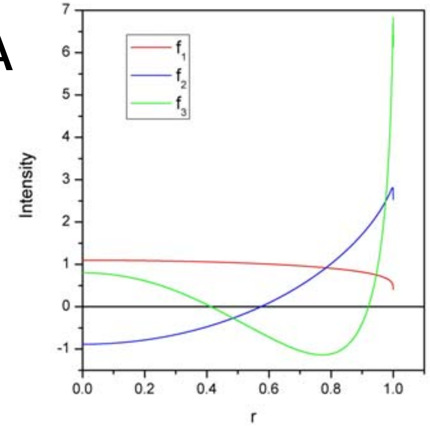


Amplification

$$A_{KURUCZ}(u) = \frac{\sum_{ij} a_{ij} J_{ij}(u)}{2\pi \sum_{ij} a_{ij} \dfrac{\mu_i^{j+2} - \mu_{i+1}^{j+2}}{j+2}}$$

Amplification residuals for LD models

PCA



Linear $$I(r) = I_0[1-(1-\upsilon\sqrt{1-r^2})]$$

PCA-2 $$I(r) = I_0[f_1(r) + \upsilon f_2(r)]$$

Quadratic $$I(r) = I_0[1-\upsilon_1(1-\sqrt{1-r^2}) - \upsilon_2(\sqrt{1-r^2})^2]$$

Square-root $$I(r) = I_0[1-\upsilon_1(1-\sqrt{1-r^2}) - \upsilon_2(1-\sqrt[4]{1-r^2})]$$

Logarithmic $$I(r) = I_0[1-\upsilon_1(1-\sqrt{1-r^2}) - \upsilon_2\sqrt{1-r^2}\ln\sqrt{1-r^2}]$$

PCA-3 $$I(r) = I_0[f_1(r) + \upsilon_1 f_2(r) + \upsilon_2 f_3(r)]$$

Need to evaluate only 2 more

$$J_{3/2}(u) = \int_0^1 (1-r^2)^{1/4} \mathrm{A}(u,r)\, r\, dr$$

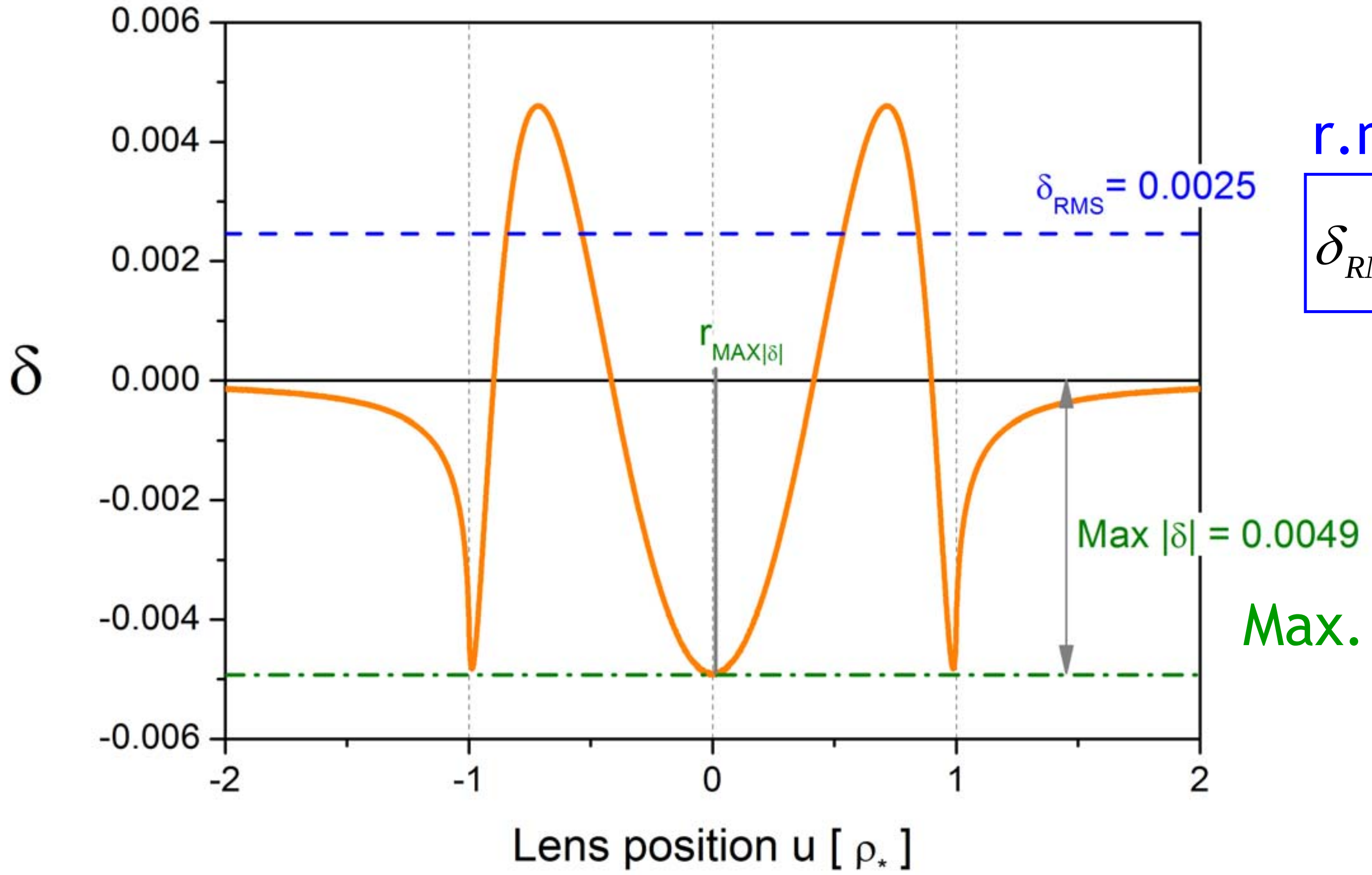
$$J_{2L}(u) = -\int_0^1 (1-r^2)^{1/2} \ln\sqrt{1-r^2}\, \mathrm{A}(u,r)\, r\, dr$$

Residual $$\delta(u) = \frac{A_{MODEL}(u)}{A_{KURUCZ}(u)} - 1$$

Amplification residuals – quantities to check

Example: T_{eff}=3500K, log g=0, [Fe/H]=1, v_t=2 km/s, *V* band

LD model: linear



r.m.s. residual

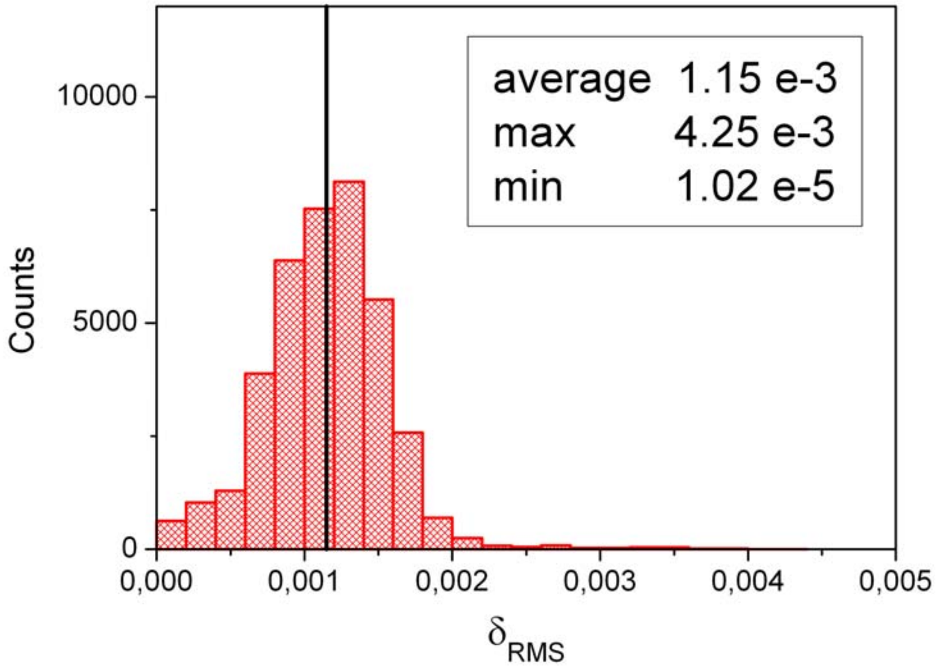
$$\delta_{RMS} = \sqrt{\frac{1}{2}\int_0^2 \delta^2(\tfrac{u}{\rho_*})\, d\tfrac{u}{\rho_*}}$$

Max. abs. residual $Max\,|\delta|$

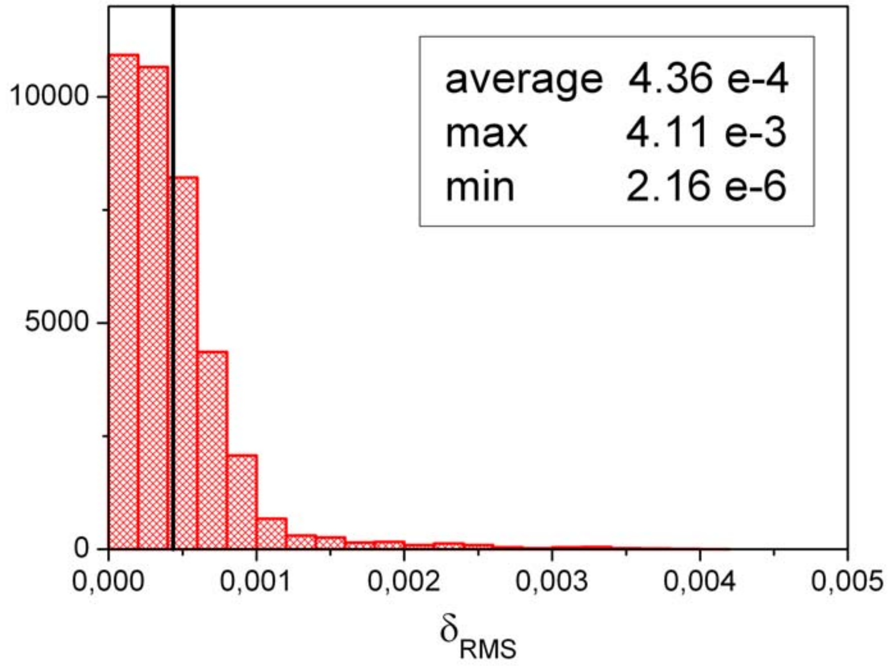
+ position $r_{Max\,|\delta|}$

Full Kurucz grid in *BVRI*: 1-par. LD r.m.s. residual

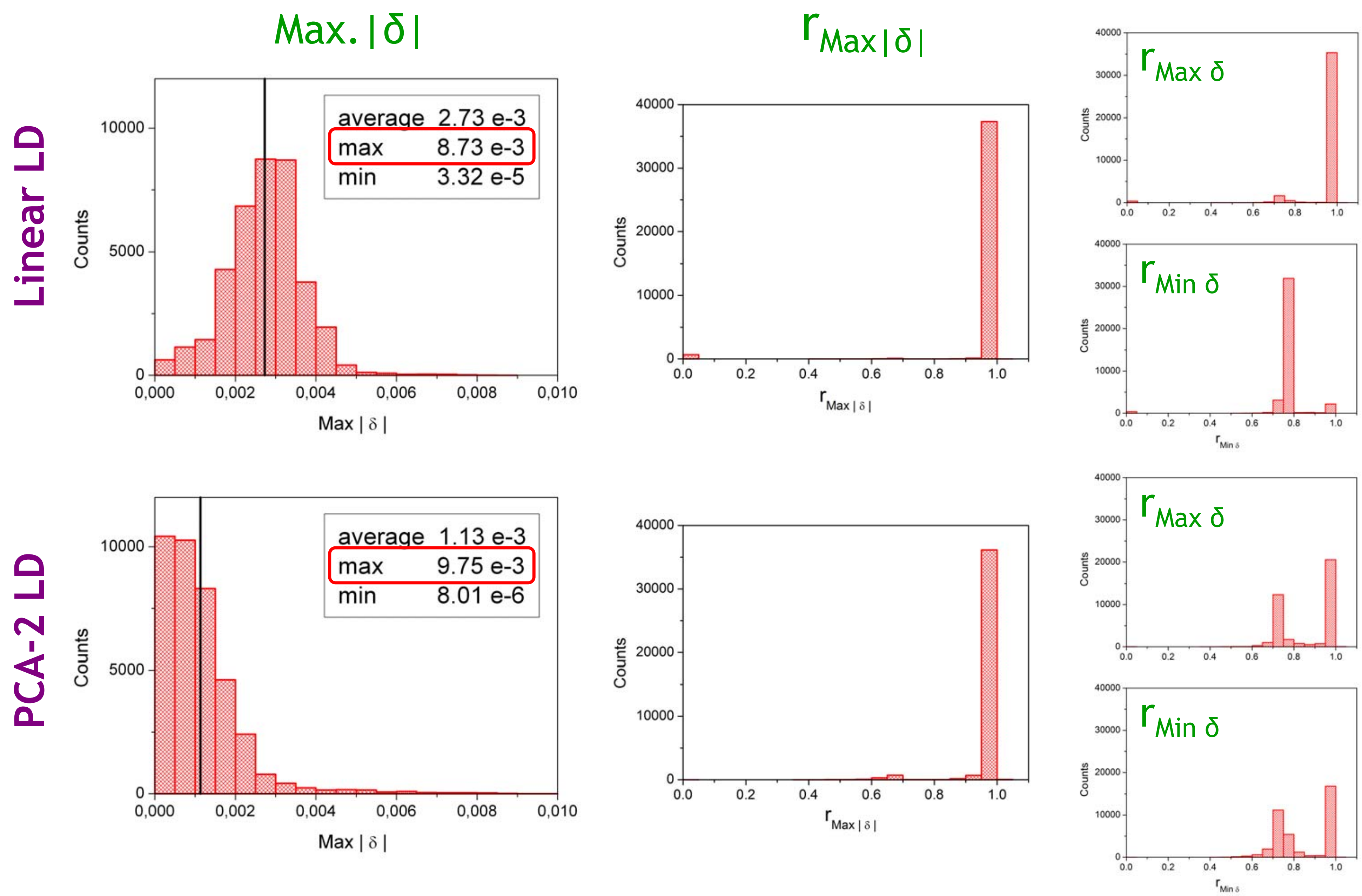
Linear LD



PCA-2 LD

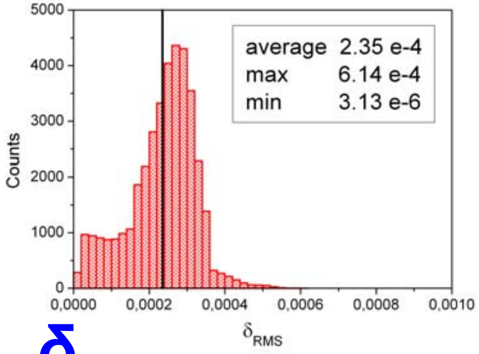


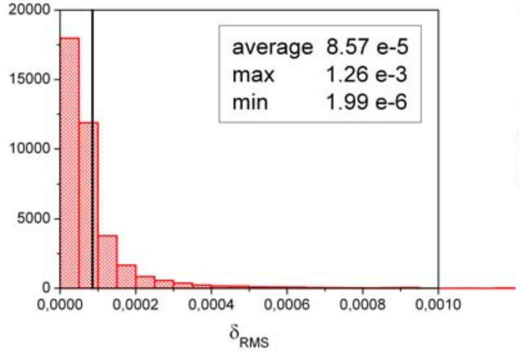
Full Kurucz grid in *BVRI*: 1-par. LD max. residual

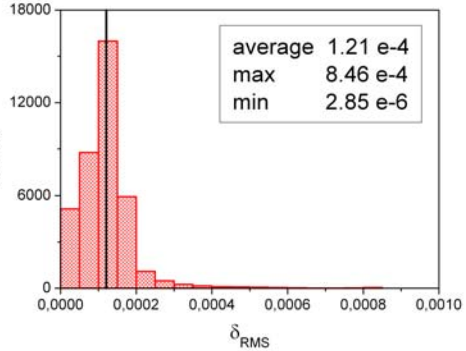


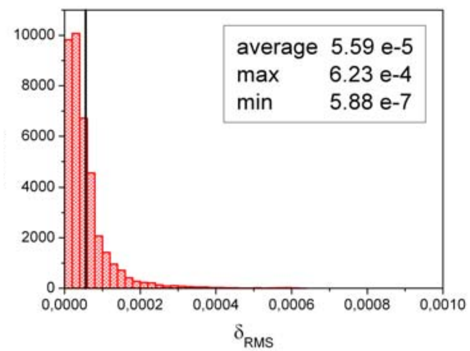
Full Kurucz grid in *BVRI*: 2-par. LD models

Quadratic	Square-root	Logarithmic	PCA-3

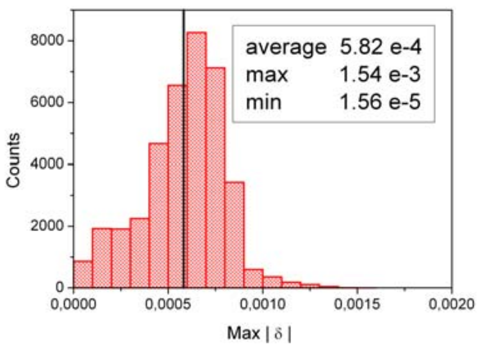


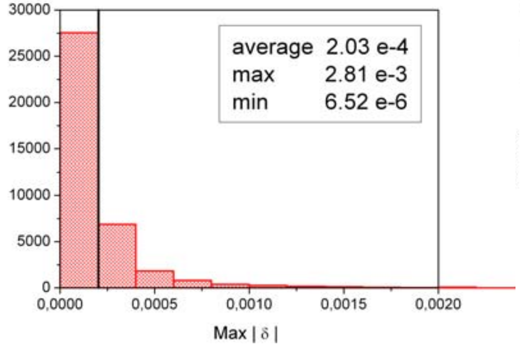


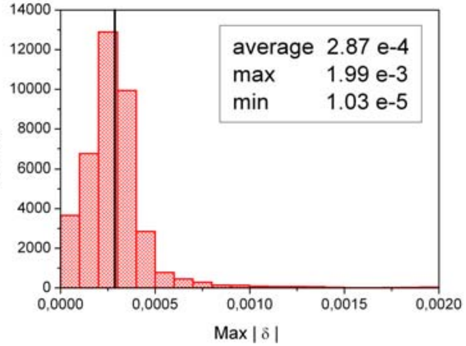


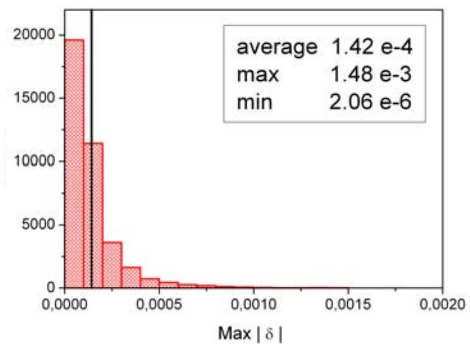


δ_{RMS}









Max. |δ|

	Quadratic	Square-root	Logarithmic	PCA-3
ave	5.82e-4	2.03e-4	2.87e-4	1.42e-4
max	1.54e-3	2.81e-3	1.99e-3	1.48e-3

Observed microlensing events analyzed for LD

R

I

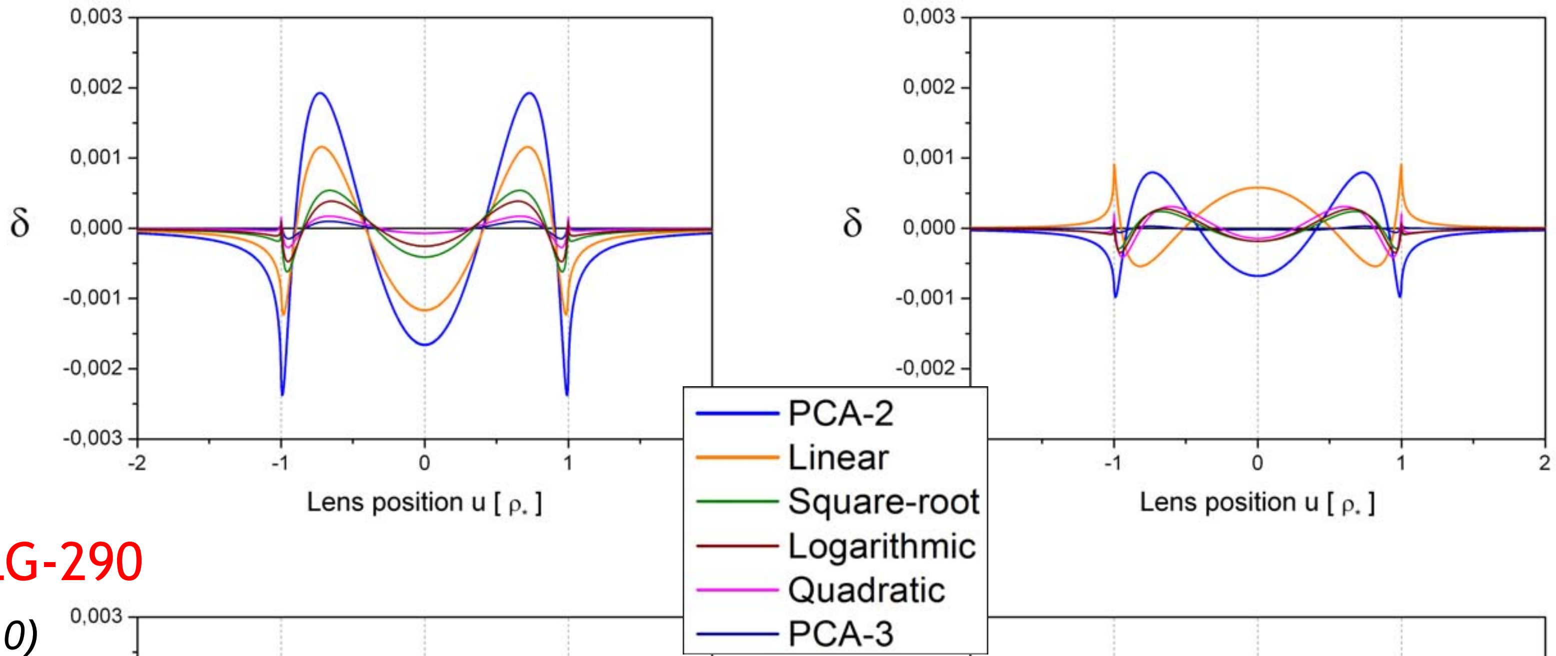
OGLE 2004-BLG-482

(Zub et al.2011)

T_{eff} = 3750 K

log g = 2.0

[Fe/H] = 0



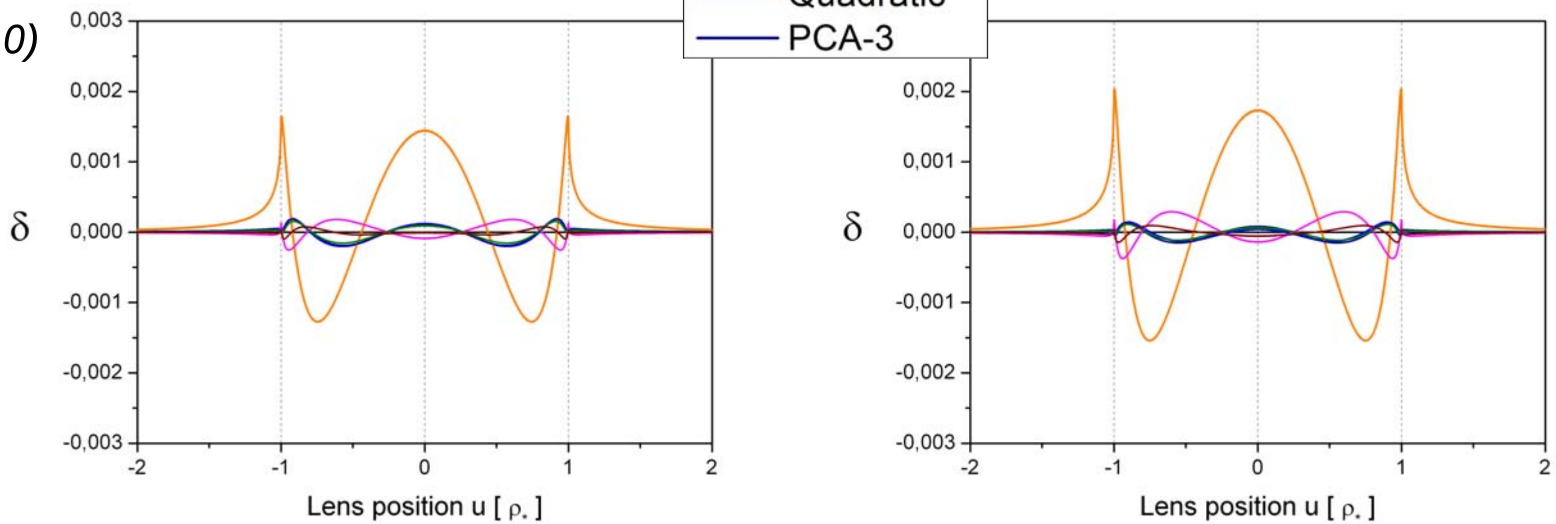
OGLE 2008-BLG-290

(Fouqué et al.2010)

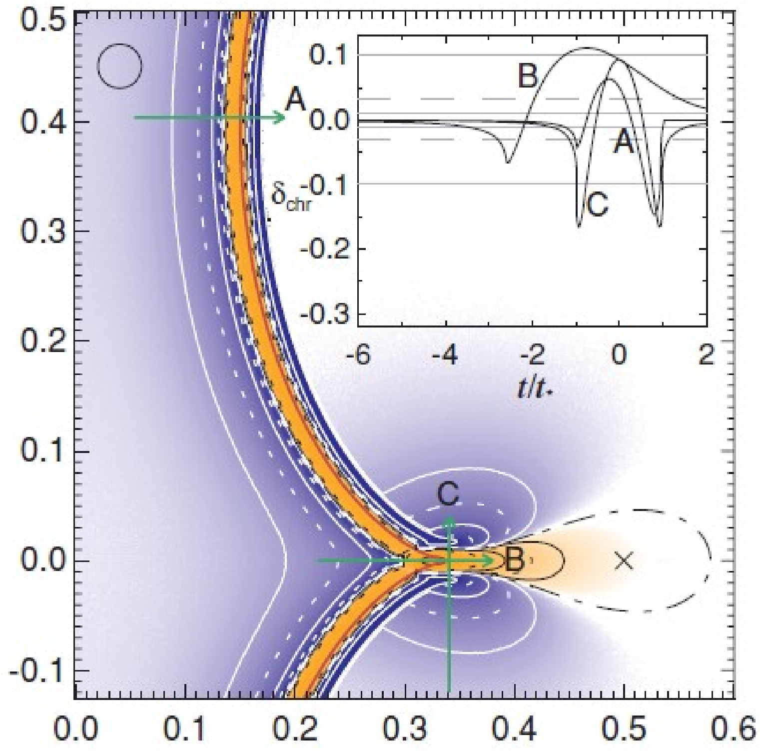
T_{eff} = 4750 K

log g = 3.0

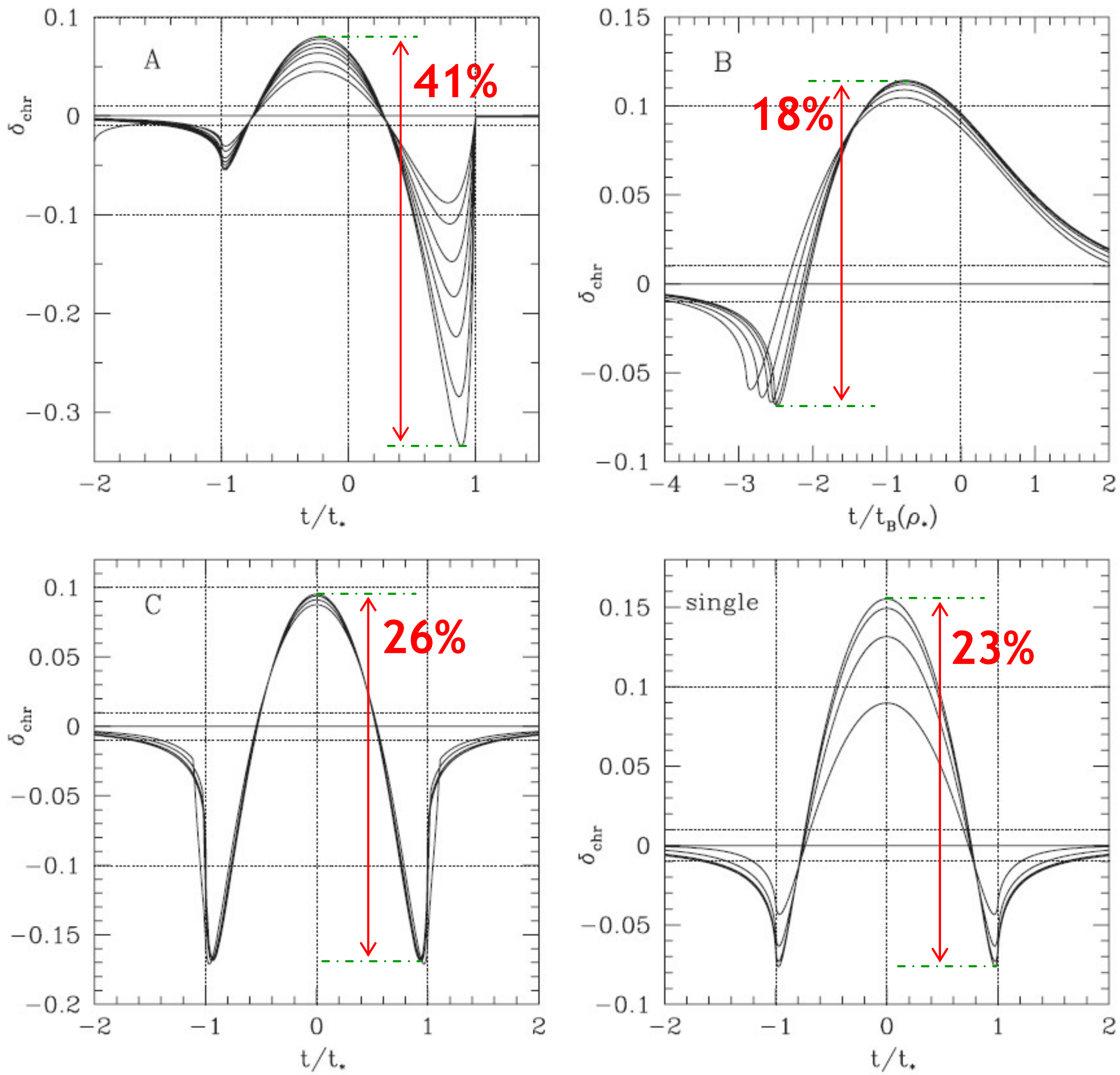
[Fe/H] = 0.3



Binary lenses: comparison of sensitivity



(Pejcha & Heyrovský 2009)



⇨ sensitivity comparable

Conclusions

- check r.m.s. residual for relevant stellar atmosphere parameters
- estimate effect on χ^2 from photometric accuracy and # of points
- if necessary, use higher order LD model
- alternatively, use stellar model atmosphere LD profile in analysis

(as in MOA 2009-BLG-266)