Line-of-sight structures as the origin of flux-ratio anomalies in quadruple QSOs

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Outline

- Background & semi-analytic result

  (by K. T. Inoue) Inoue&Takahashi 2012 MNRAS 426

  Inoue arXiv:1410.1033

- Numerical result

  (by R. Takahashi) Takahashi&Inoue 2014 MNRAS 440

Outline

- Line-of-sight structures (LOSS)
- Weak lensing by LOSS
- Astrometric and magnification perturbations
- Semi-analytic estimate
- Differential magnification (if time allows)
- Summary

What is the origin of the flux-ratio anomalies?

Possible origins

- Subhalos in lens
- Complex structures in lens
- Scattering or extinction
- Line-of-sight structures

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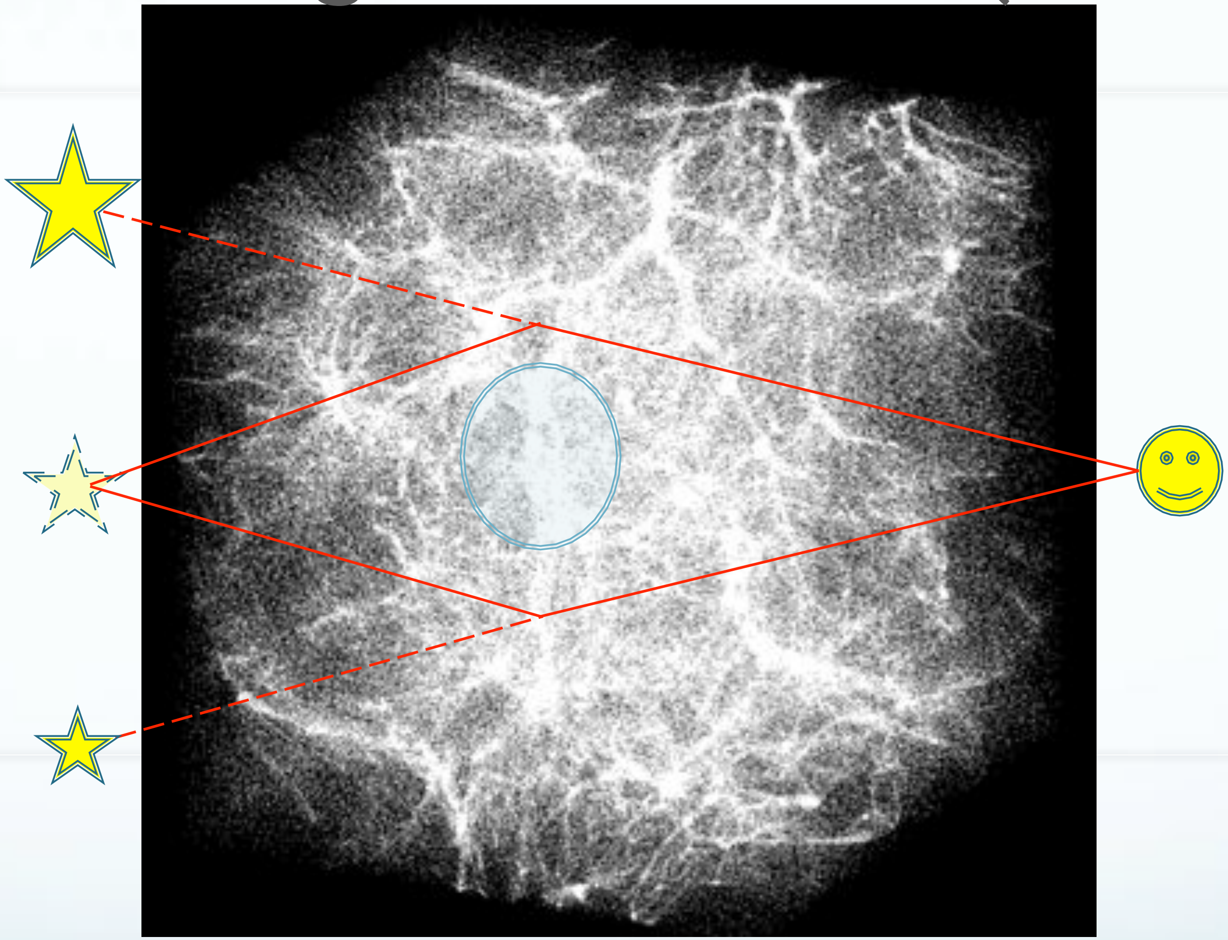
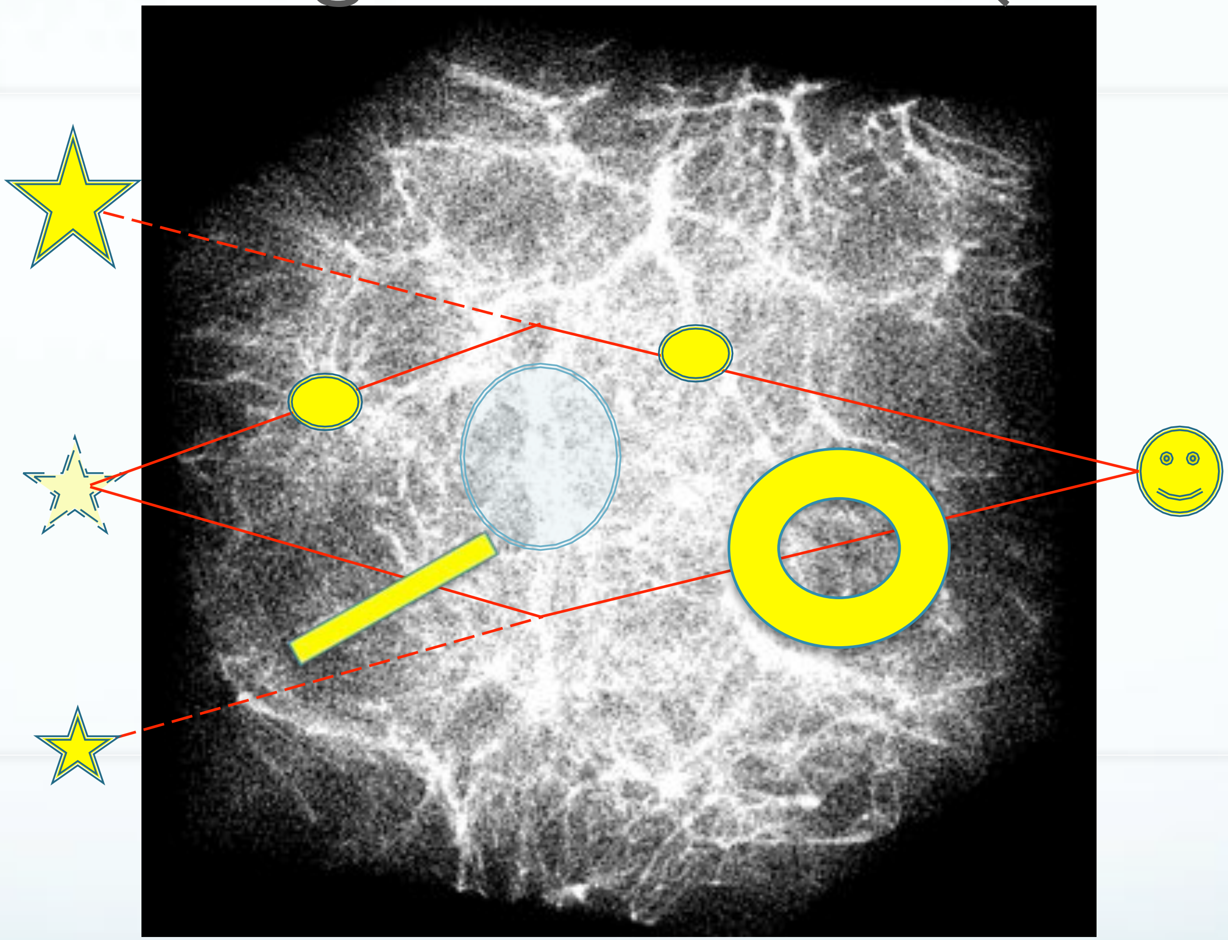
- Subhalos in lens
- Complex structures in lens
- Scattering or extinction
- **Line-of-sight structures**

Line-of-sight structures (LOSS)



Line-of-sight structures (LOSS)



Previous studies

- LOS halos contribute <10% (2003 Chen et al.)
- LOS halos are "enough" for cusp-caustic lenses (2005 Metcalf, 2007 Miranda & Maccio)
- LOS halos contribute 10~20% (2012, Xu et al.)

Mass function + density profile

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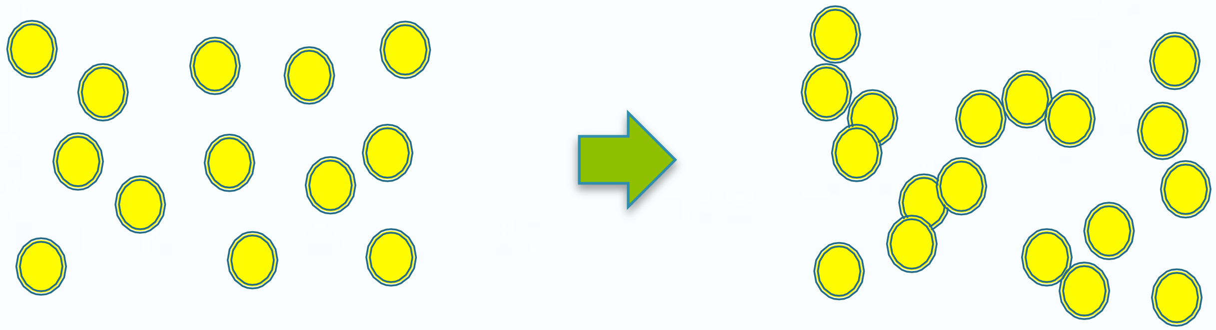
Non-linear clustering could enhance?

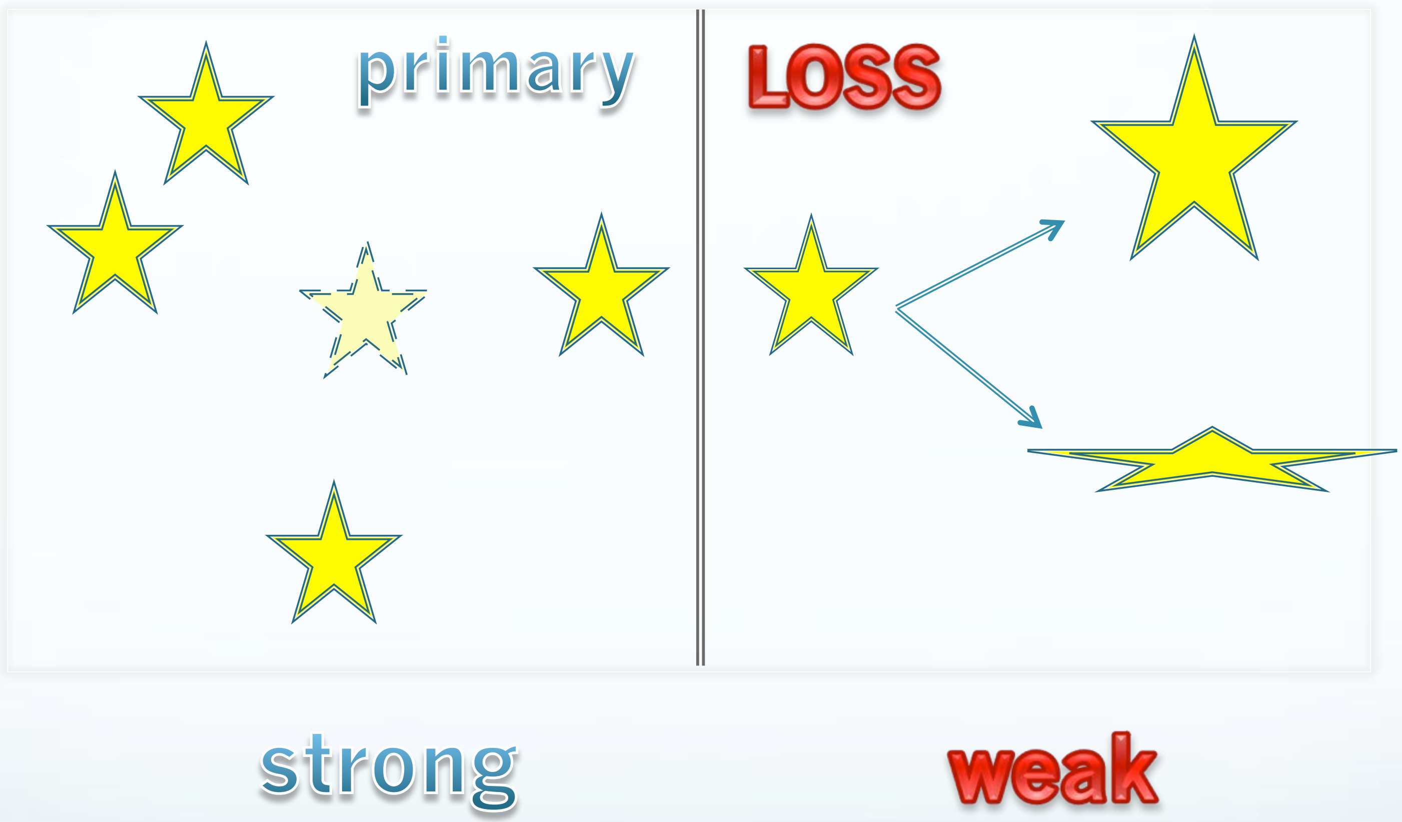
What is New?



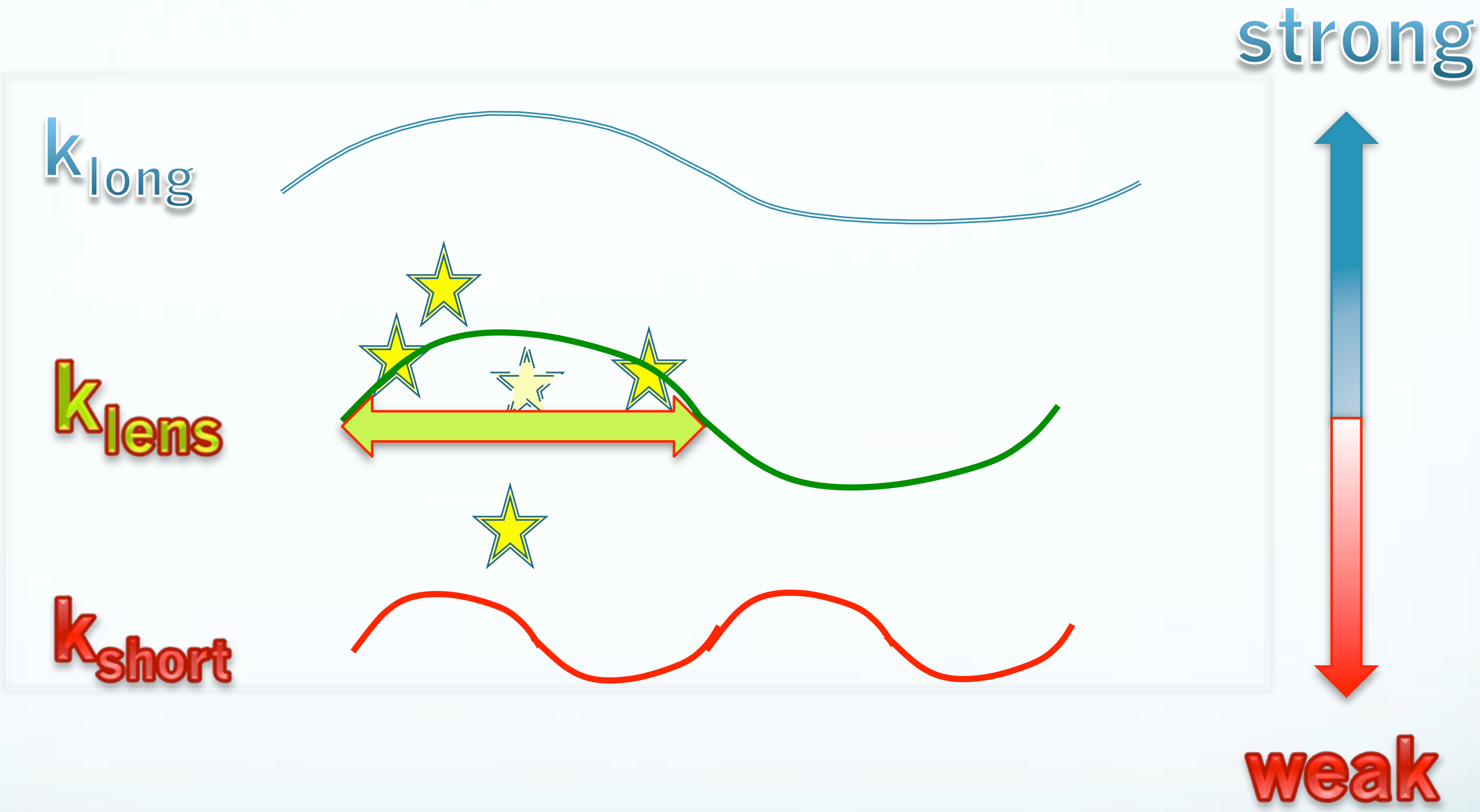
$R_{cusp} \rightarrow \eta$

$\text{Max } M_{halo} \rightarrow \text{Max } \delta\theta$

Weak lensing by LOSS

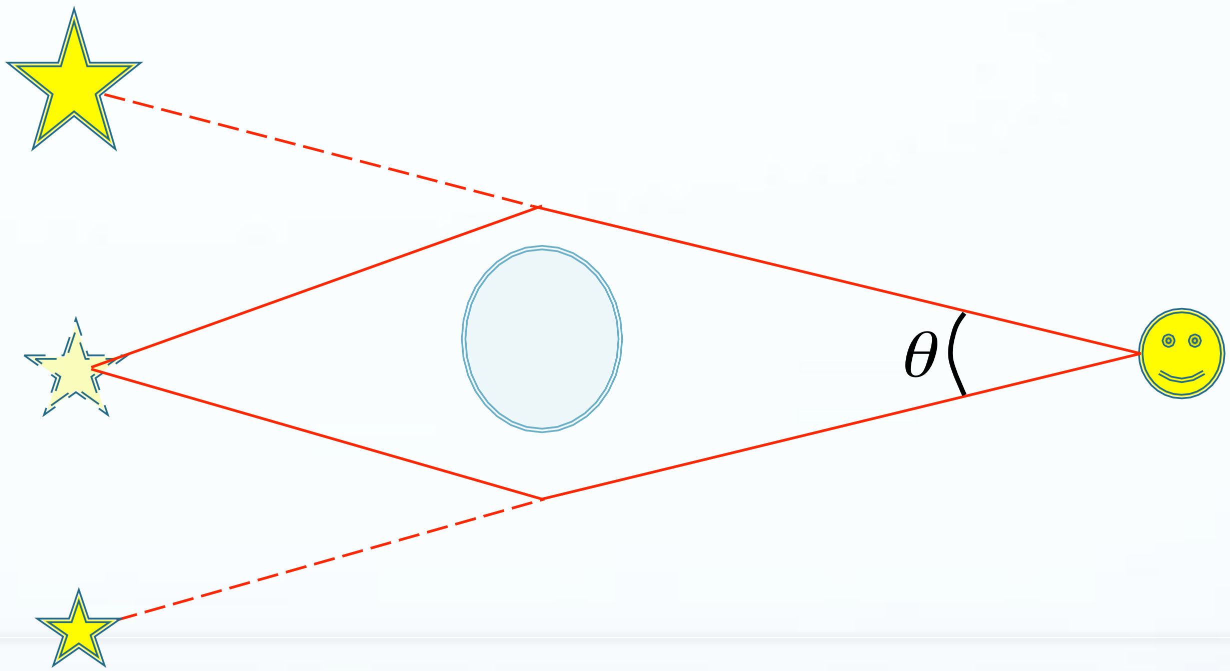


Strong-weak separation

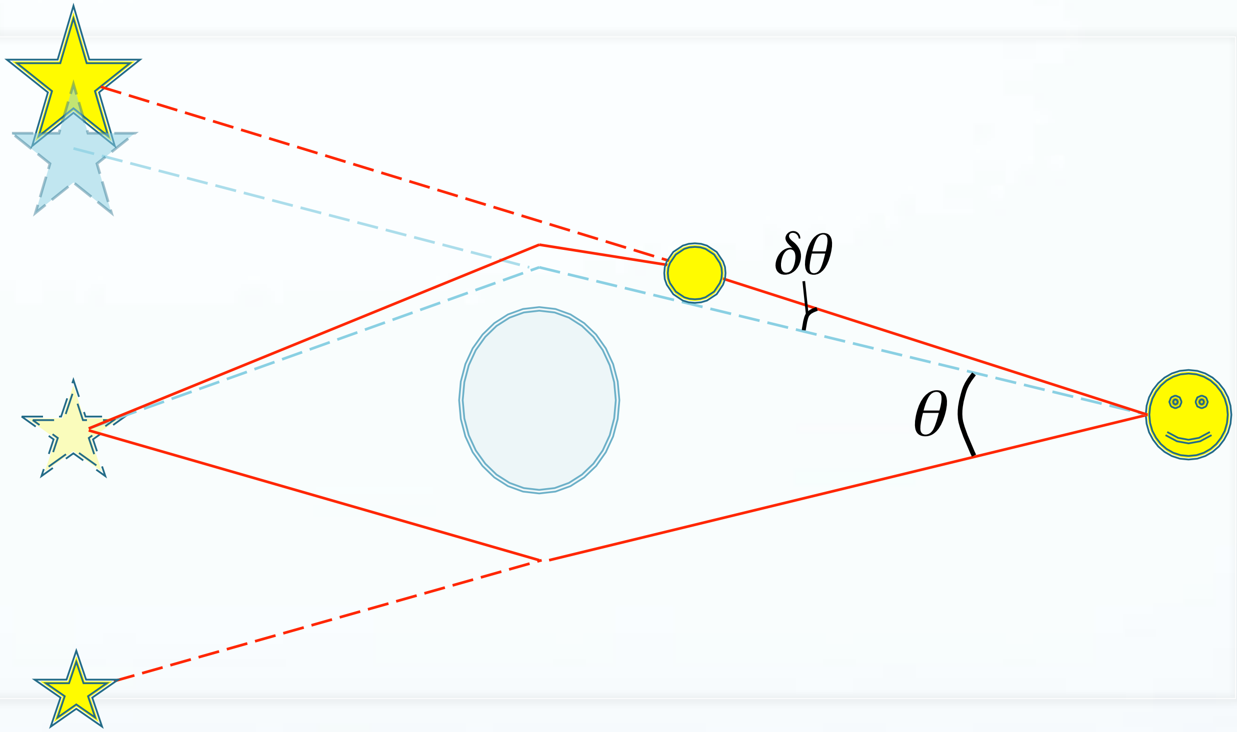


k_{lens} = wave number of 4×Einstein radius

Astrometric perturbation

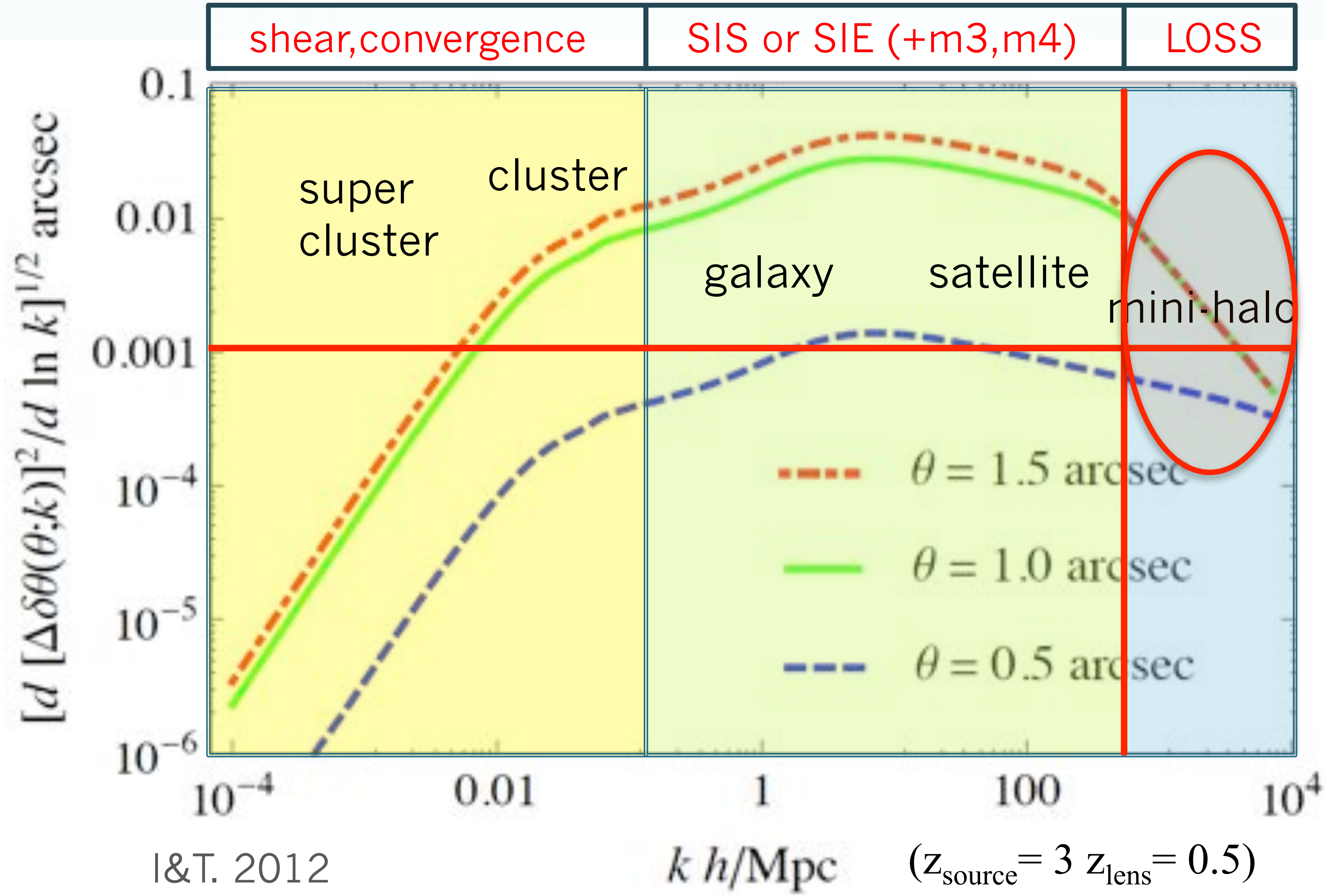


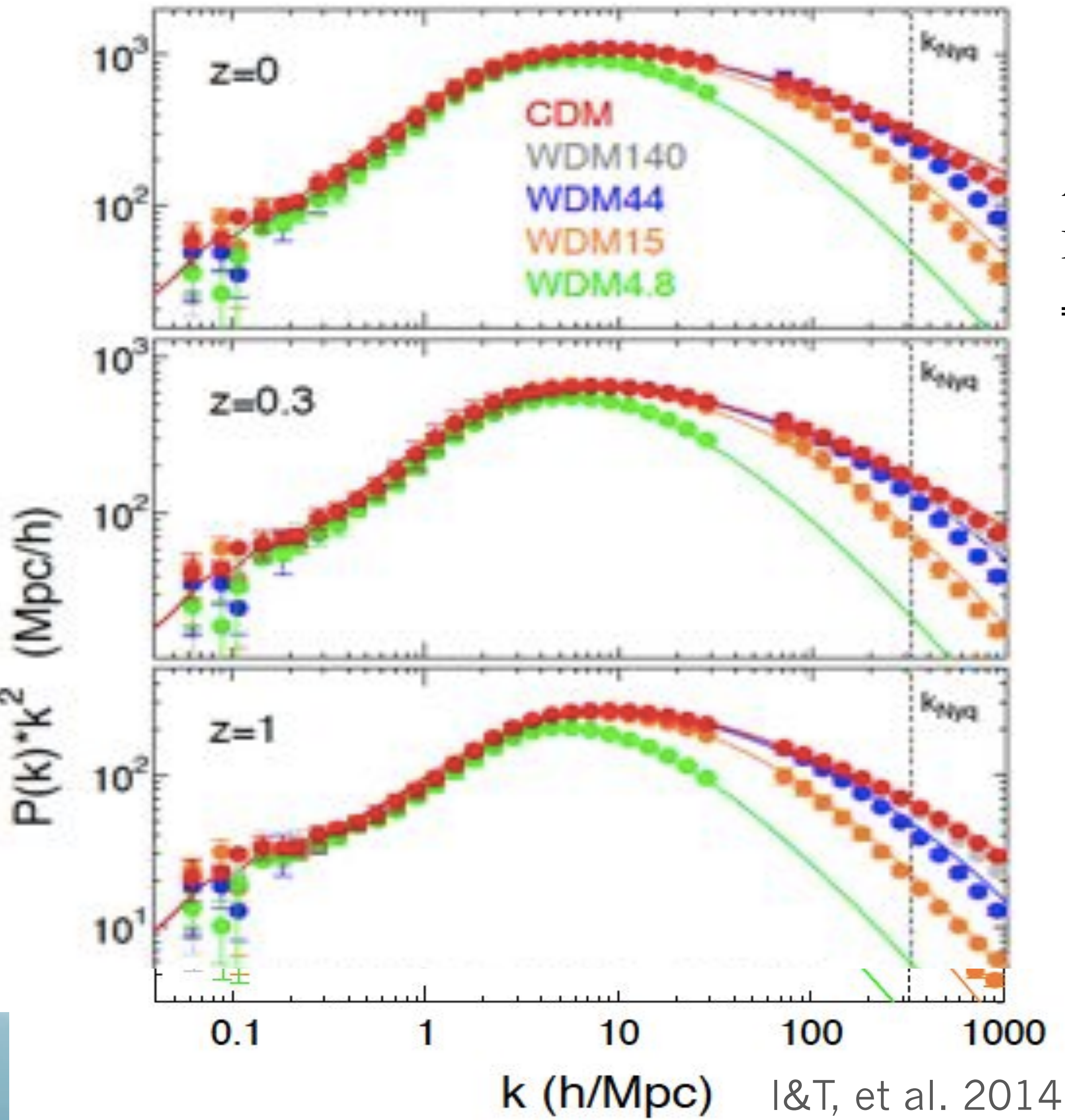
Astrometric perturbation



$$\Delta\delta\theta = \delta\theta(0) - \delta\theta(\theta)$$

Astrometric perturbation





I&T, et al. 2014

$N = 1024^3$

Boxsize

$= 10\text{Mpc}/h$

Magnification perturbation η

A,C: minimum B:saddle, κ_B <1

$\delta_i^\mu \equiv \delta\mu_i/\mu_i.$:magnification contrast

$$\eta^2(\mathrm{A,B,C}) = \frac{1}{4}[(\delta_A^\mu - \delta_B^\mu)^2 + (\delta_C^\mu - \delta_B^\mu)^2].$$

$$\eta^2 \approx \frac{1}{4}\left[\left(\frac{AB_0}{A_0B} - 1\right)^2 + \left(\frac{CB_0}{C_0B} - 1\right)^2\right].$$

η=0.1 means 10% change

Magnification perturbation η

$$\langle \eta^2 \rangle = \frac{1}{4}\Big[(J_A + J_B)\sigma_\kappa^2(0) - 2J_{AB}\xi_\kappa(\theta_{AB})$$
$$+ (J_B + J_C)\sigma_\kappa^2(0) - 2J_{BC}\xi_\kappa^2(\theta_{\rm BC})\Big],$$

where

$$J_i = \mu_i^2(4(1-\kappa_i)^2 + 2\gamma_i^2),$$

and

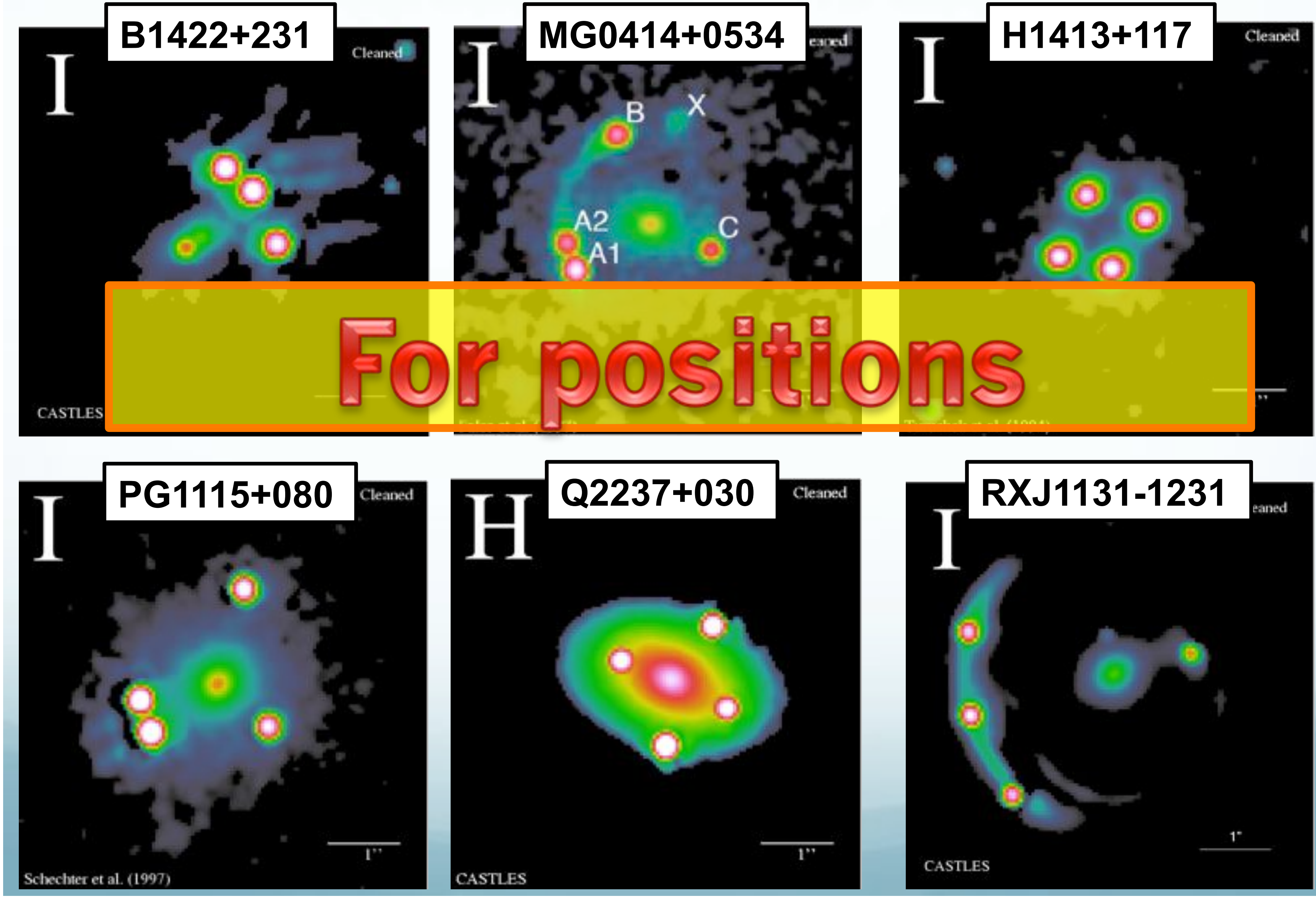
$$J_{ij} = \mu_i\mu_j(4(1-\kappa_i)(1-\kappa_j) + 2\gamma_i\gamma_j),$$

κ: background convergence γ: background shear

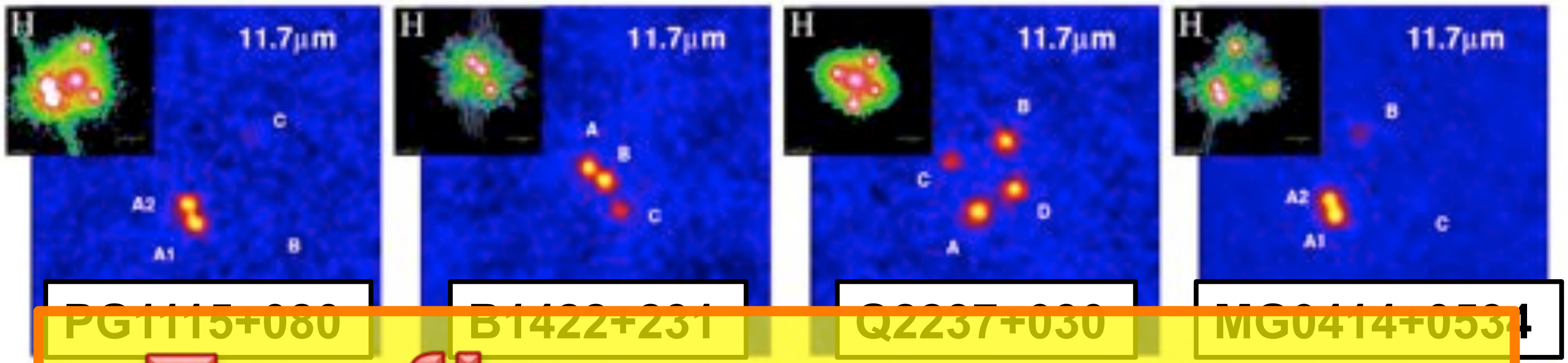
Semi-analytic estimate

- Singular isothermal ellipsoid(SIE) +external shear for the primary lens.
- Astrometric shifts constraints (<0.003”) for a half mean separation of images.
- Power spectrum from N-body simulation. (1024^3 & box size=10 Mpc/h DM only)
- Secondary lenses (SIS/SIE) included in the background lens model

Optical-NIR images (CASTLES)

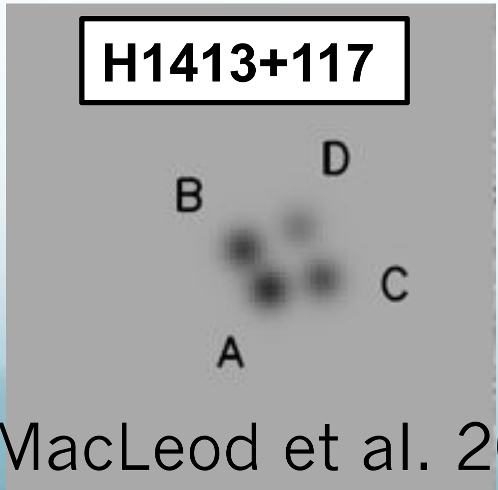


MIR images (Subaru/Keck)

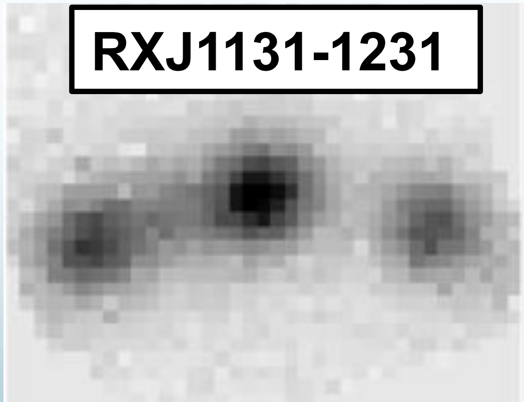


For fluxes microlensing free

(Chiba et al 2005 & Minezaki et al. 2009)



(MacLeod et al. 2009)



(Sugai et al. 2009)

MIR images (Subaru/Keck)

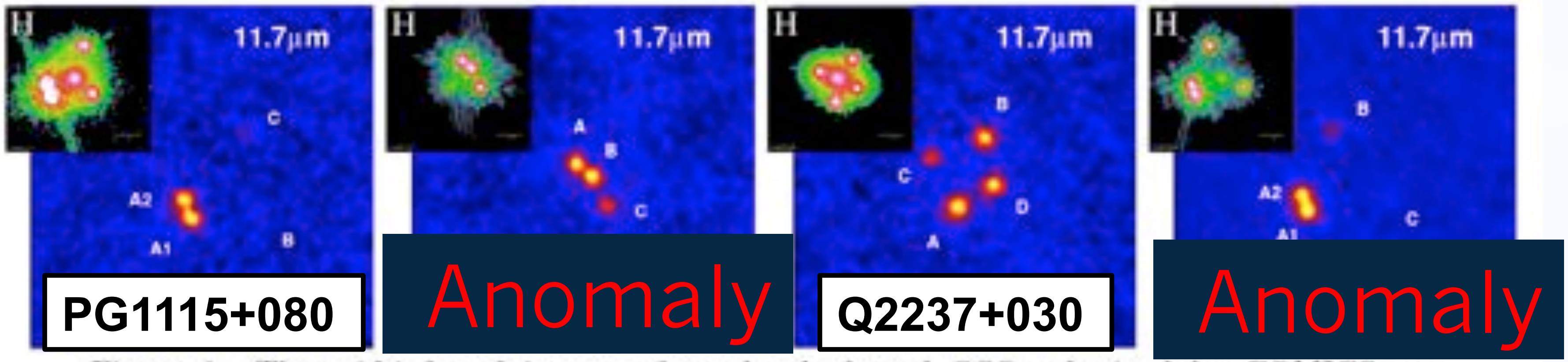
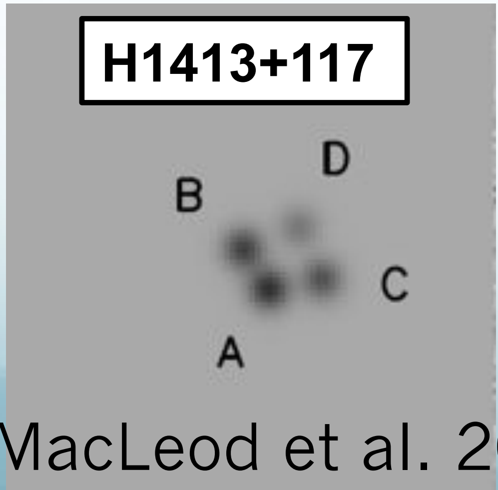


Figure 2: The mid-infrared images of quadruply lensed QSOs obtained by COMICS attached on Subaru telescope. From left to right, PG1115+080, B1422+231, Q2237+030, and MG0414+0534. The insets are their HST images for comparison (taken from CASTLES, http://cfa-www.harvard.edu/glensdata/).

(Chiba et al 2005 & Minezaki et al. 2009)



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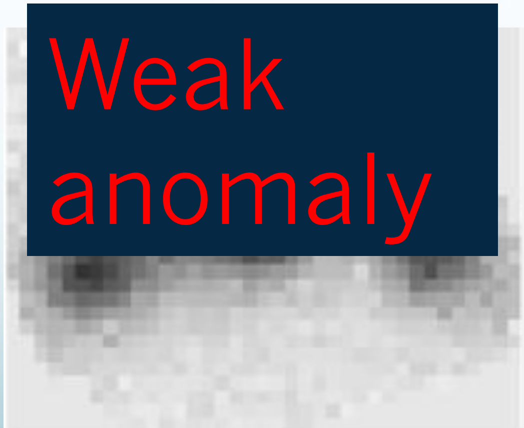
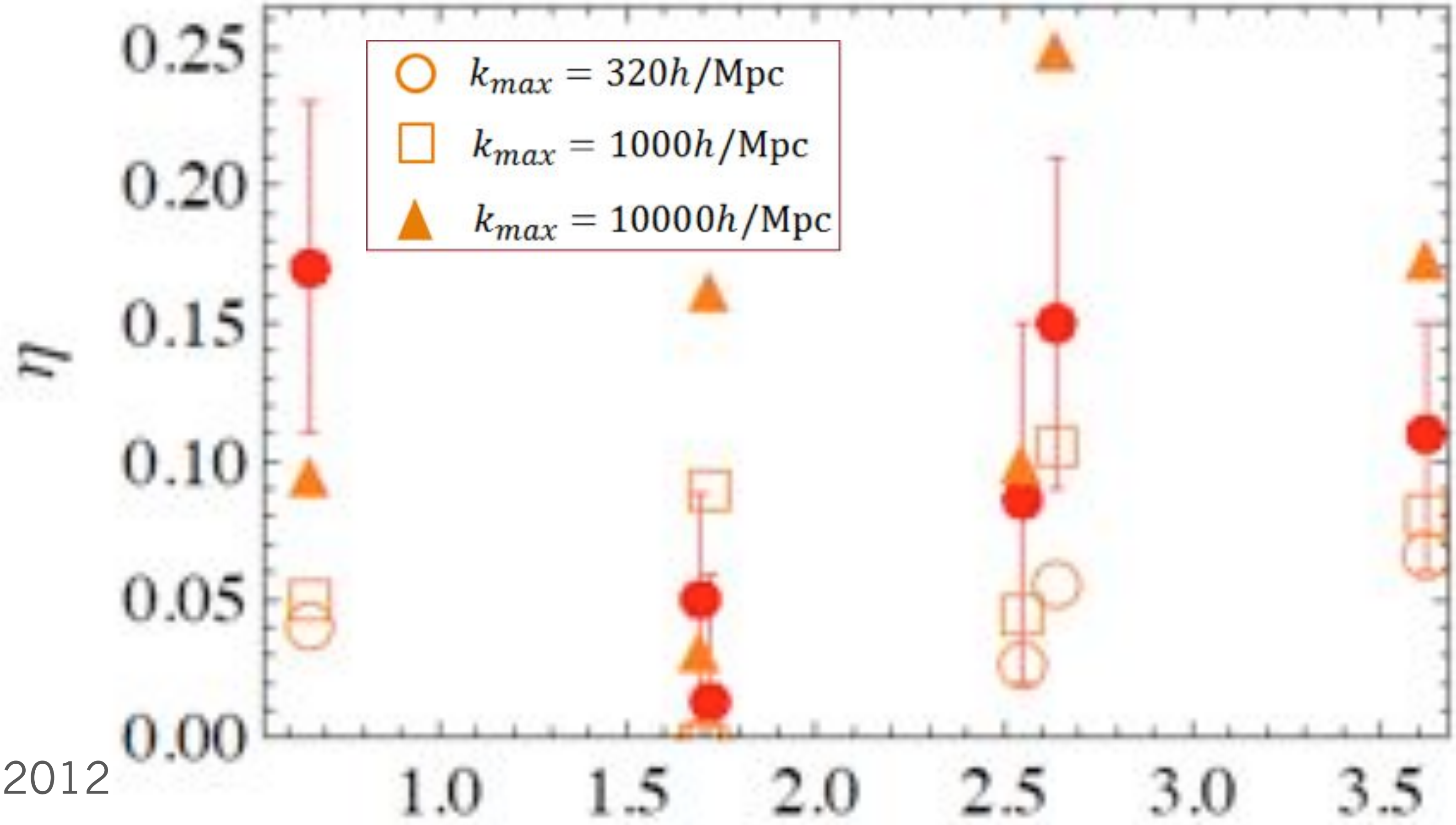


(Sugai et al. 2009)

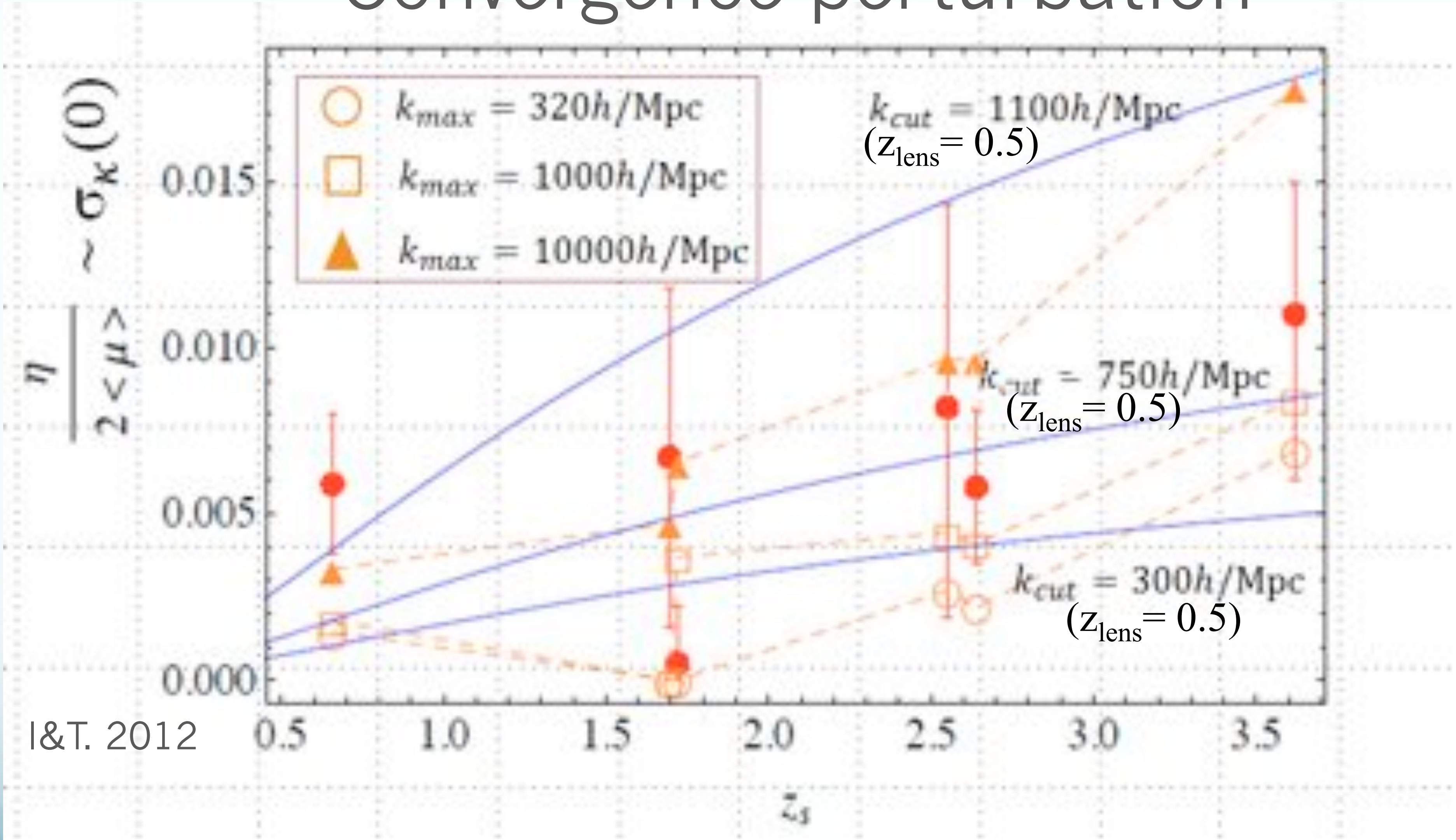
Magnification perturbation



I&T. 2012

Sufficiently perturbed !

Convergence perturbation



I&T. 2012

Convergence perturbation

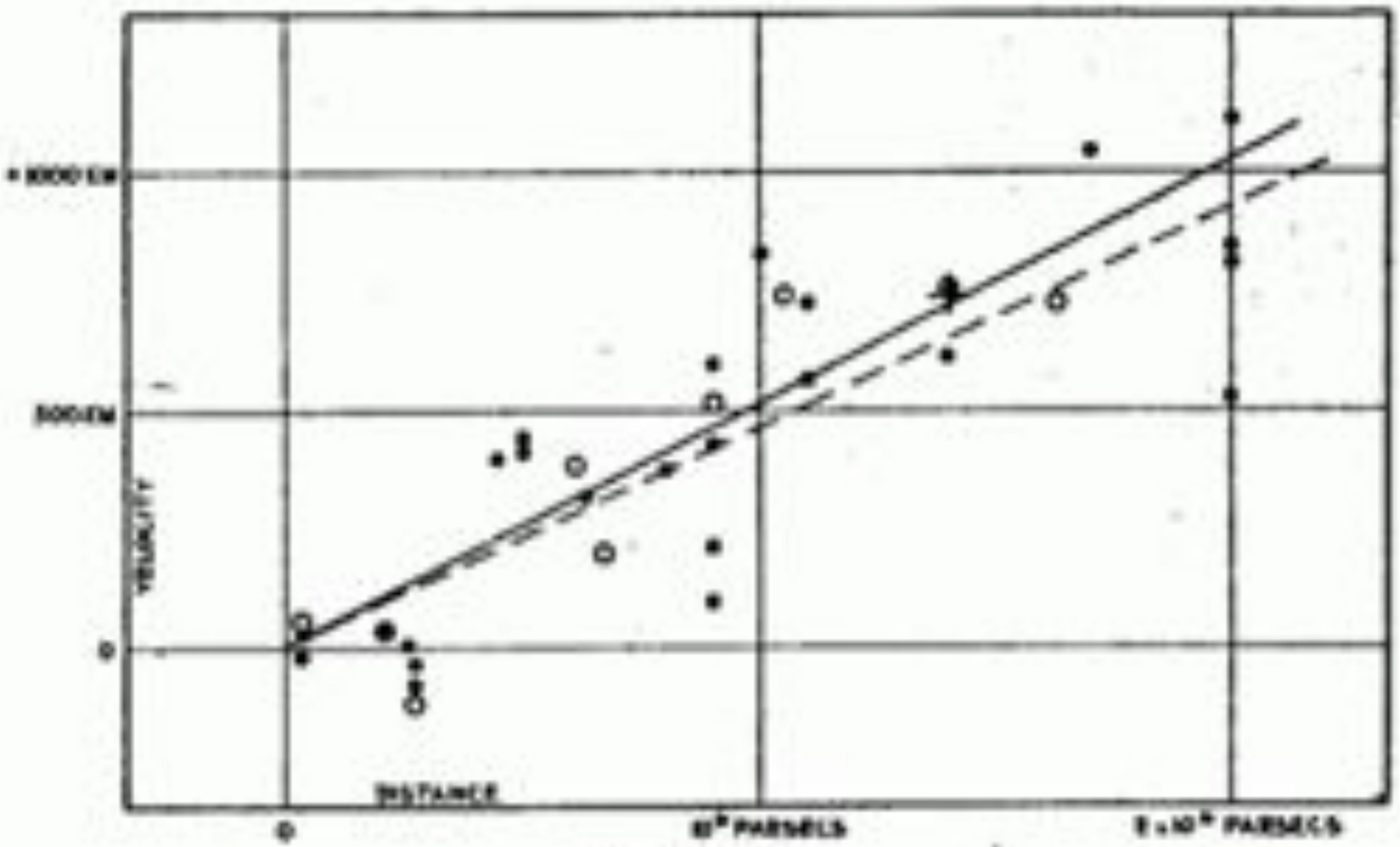
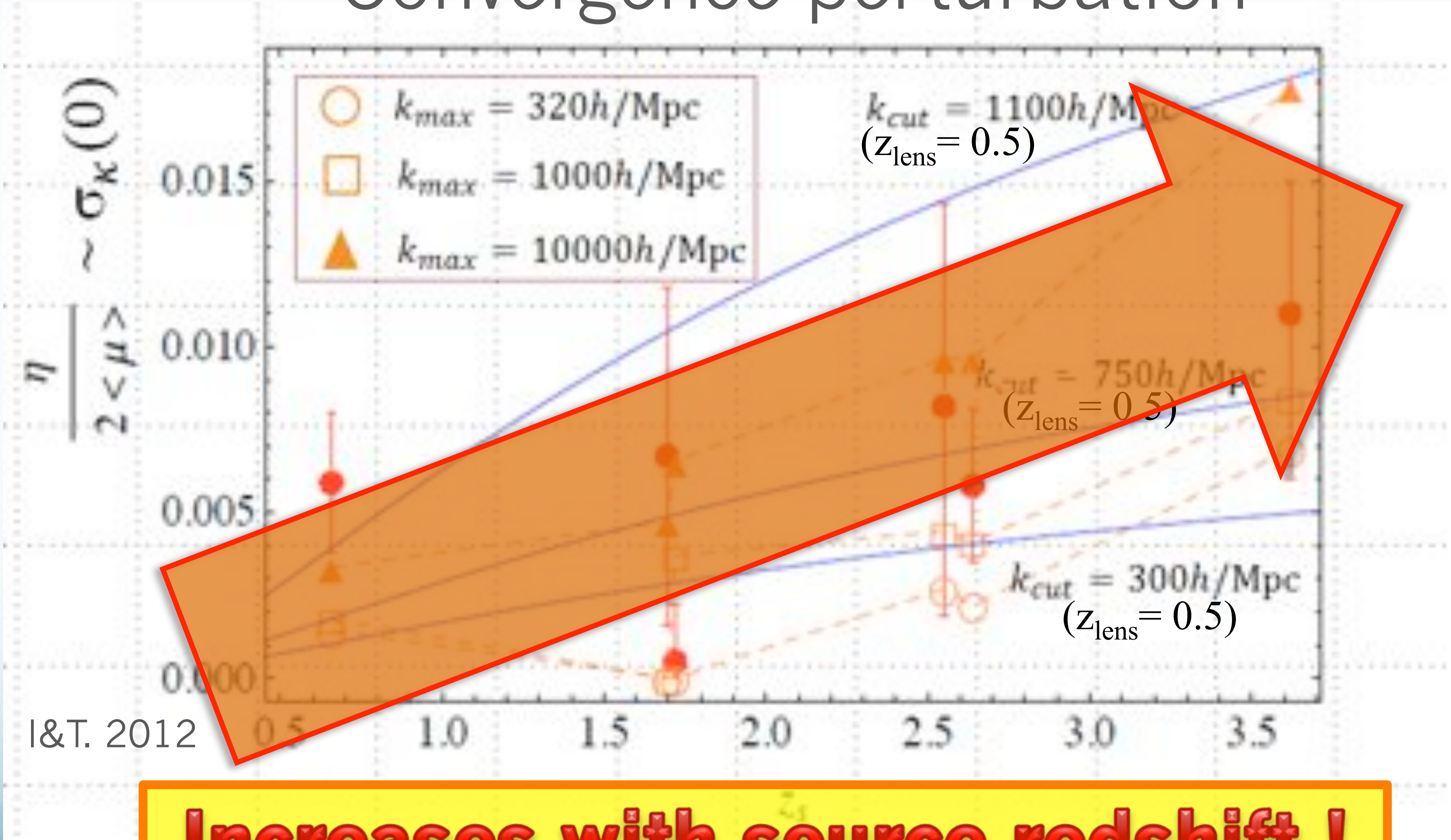


FIGURE 1

E. Hubble

Convergence perturbation



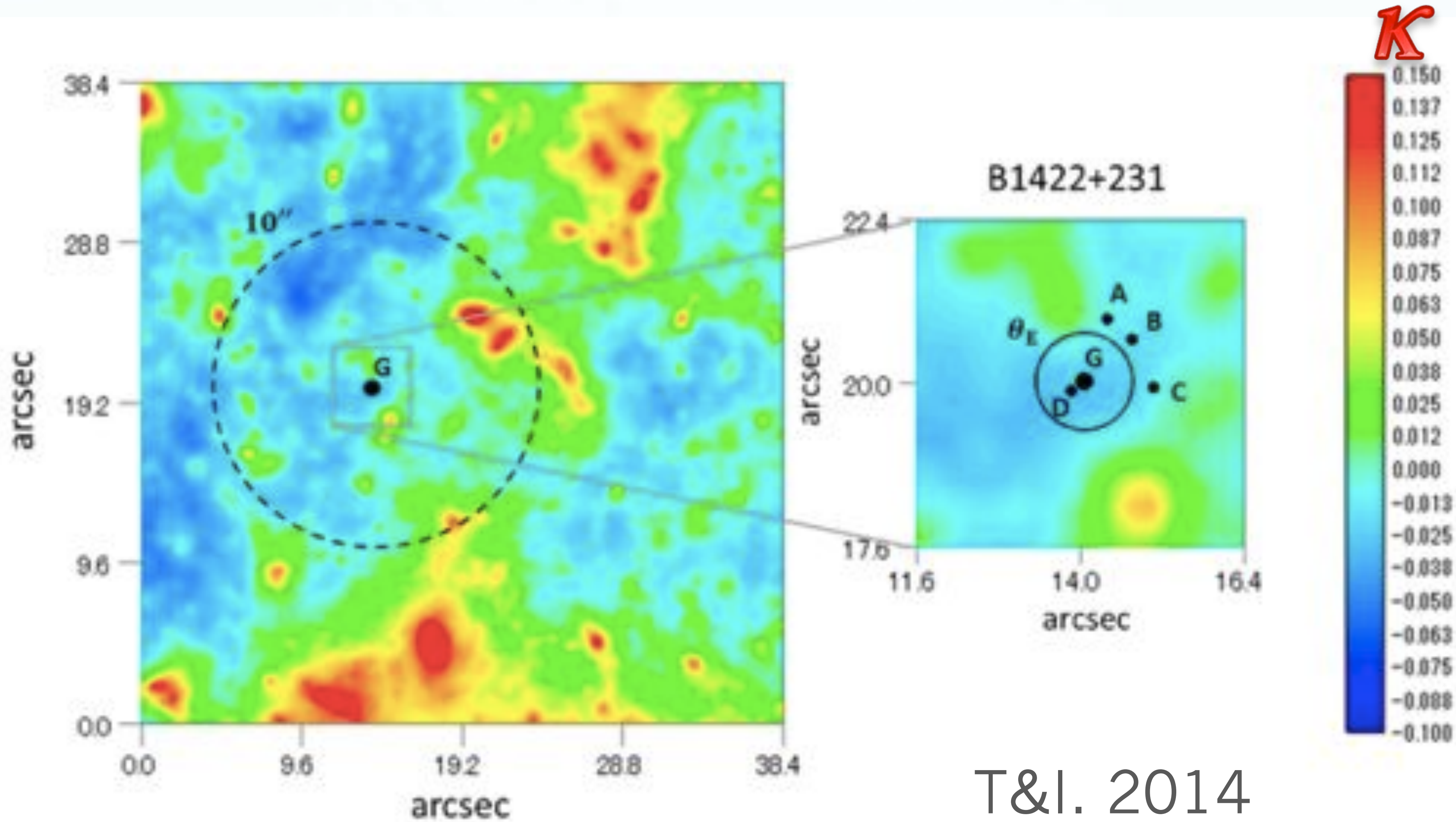
I&T. 2012

Increases with source redshift !

What is the difference LOSS and subhalo?

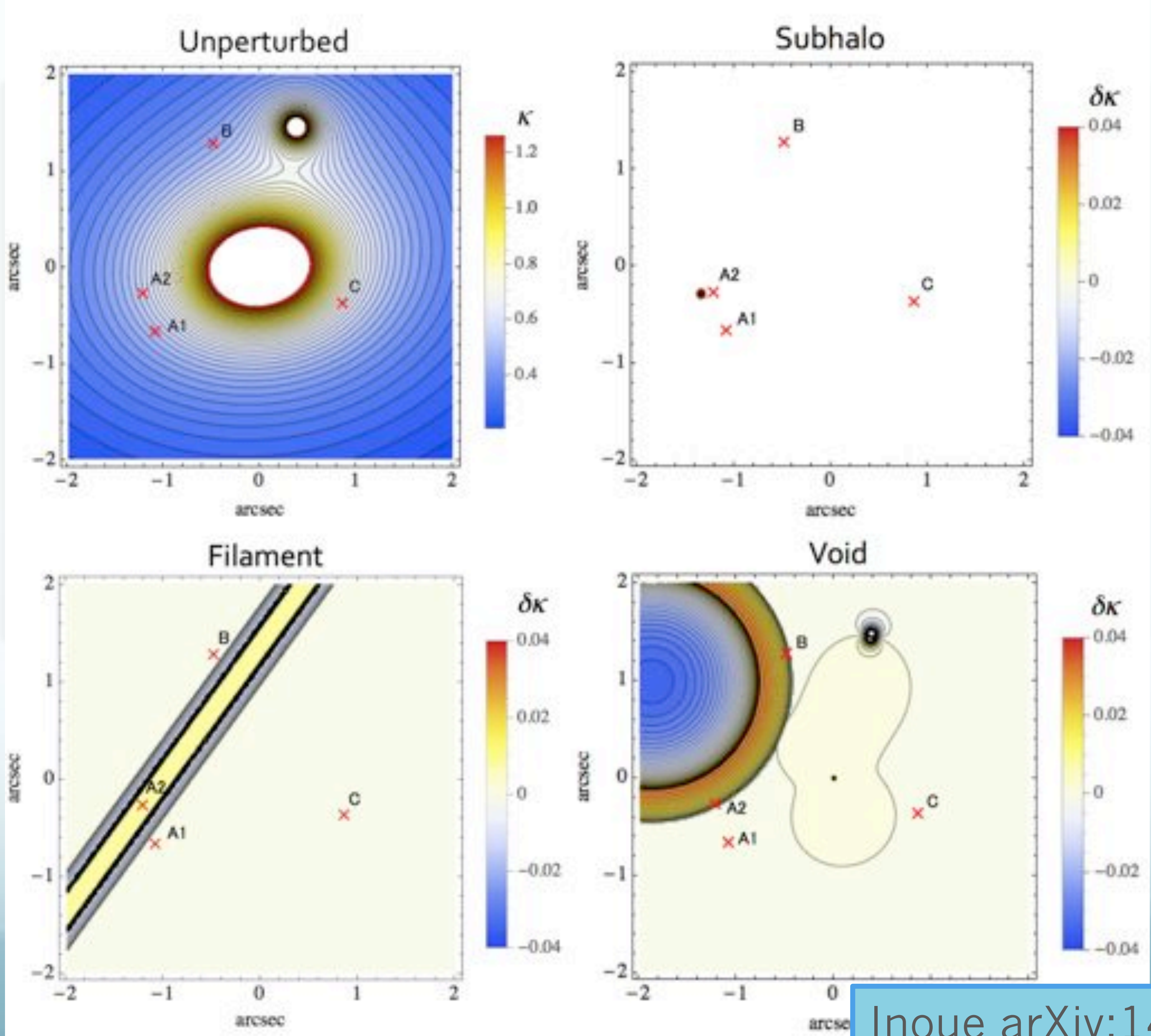
Look for spatial correlations!

LOS convergence map (B1422+231)



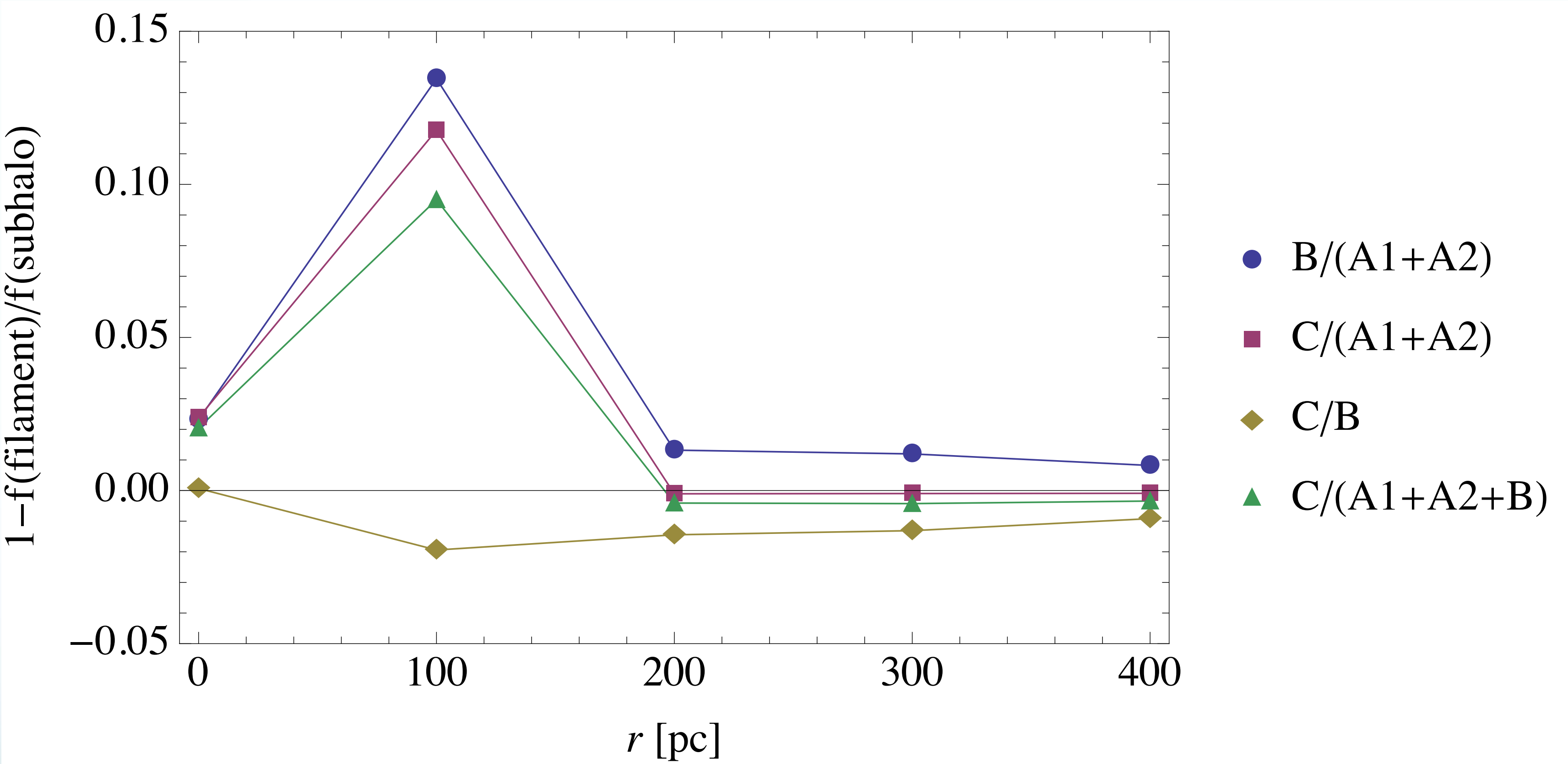
T&I. 2014

Possible lens models (MG0414+0534)



Inoue arXiv:1410.1033

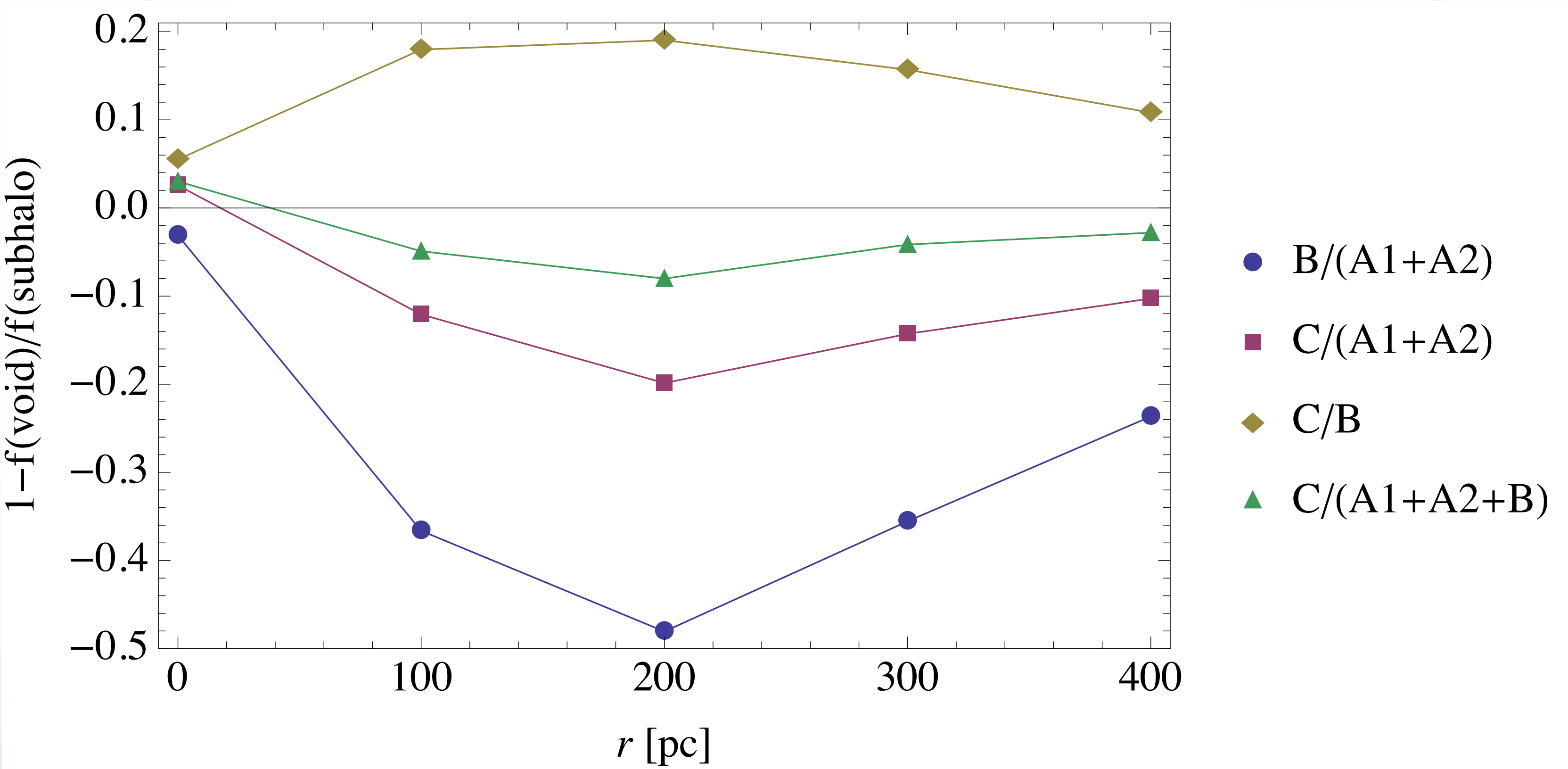
Differential magnification (MG0414+0534)



Flux-ratio difference between filament and subhalo models.

Inoue arXiv:1410.1033

Differential magnification (MG0414+0534)



Flux-ratio difference between void and subhalo models.

Inoue arXiv:1410.1033

Summary

- Flux-ratio anomalies can be explained solely by line-of-sight structures LOSS without taking subhalos into account.

- Convergence perturbations increase with the source redshift.

- Differential magnification may break the model degeneracy (subhalo/LOSS)