Weak Lensing by Intergalactic Mini-Structures in Quadruple Lens Systems: Simulation and Detection

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refs: Inoue & Takahashi 2012, MNRAS, 426, 2978

Takahashi & Inoue 2014, MNRAS, 440, 870

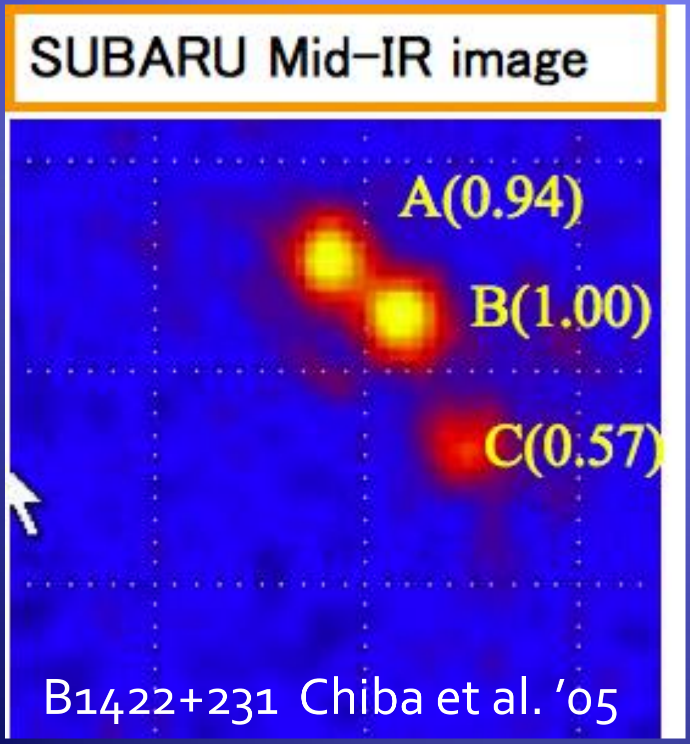
Abstract & Summary

We study effects of Line-of-Sight（LOS）structures on magnifications of multiple images（especially on flux-anomaly problem）using ray-tracing simulations

The LOS structures can explain the flux-anomaly problem

refs: Inoue & Takahashi 2012, MNRAS, 426, 2978
Takahashi & Inoue 2014, MNRAS, 440, 870

Anomalous Flux- ratio in quasar-galaxy lens system



- Image positions can be well fit to the model.
- Flux-ratios fits are poor.

(e.g. Mao & Schneider 98, Metcalf & Madau 01, Chiba 02, Dalal & Kochanek 02)

Flux- ratio anomalies

- Sub halos in main lens

  but predicted subhalos too low for anomalies

  (Maccio & Mirranda 2006, Amara et al. 2006;

  Xu et al. 2009, 2010; Chen 2009; Chen et al. 2011)

- Luminous satellites may contribute significantly

  (McKean et al. 2007, Shin & Evans 2008;

  MacLeod et al. 2009)

- Line-of-sight structures?

  (Chen et al. 2003, Metcalf 2005, Xu et al. 2011)

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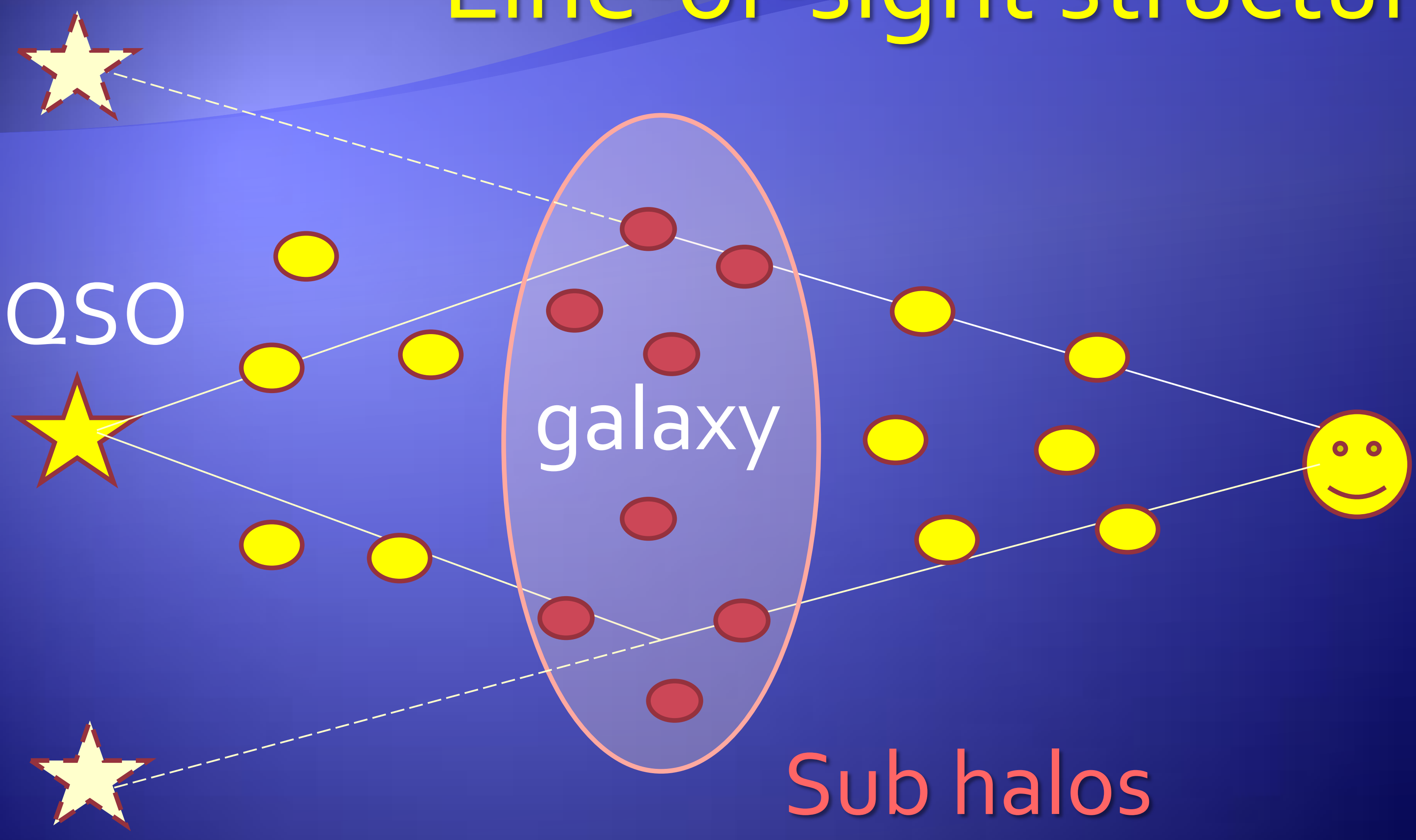
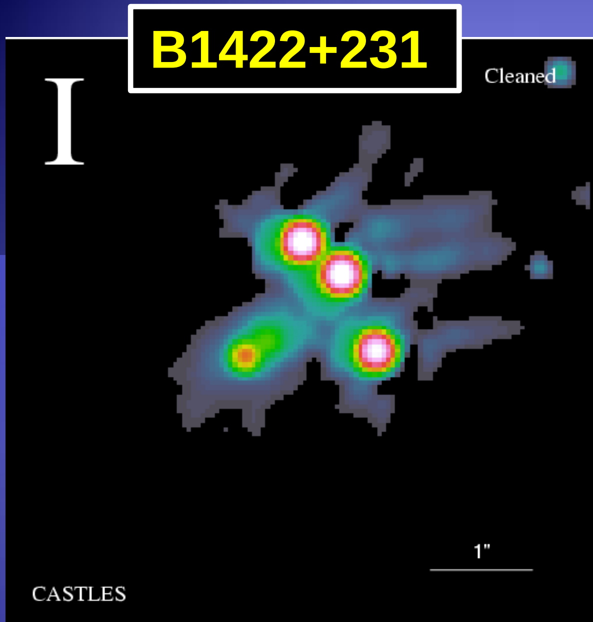
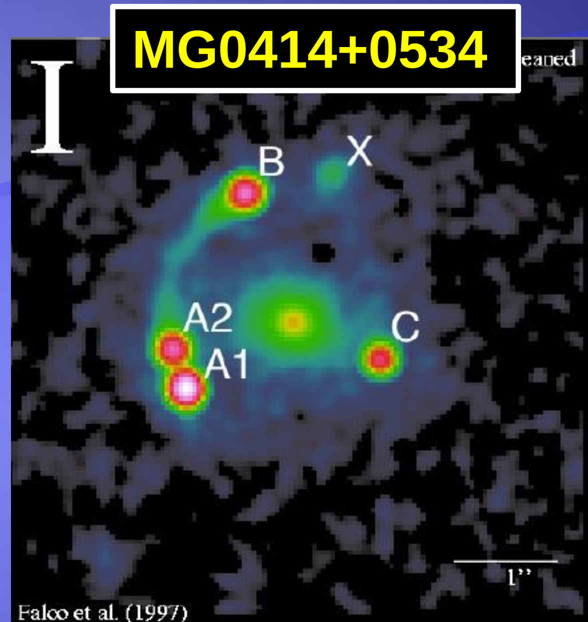
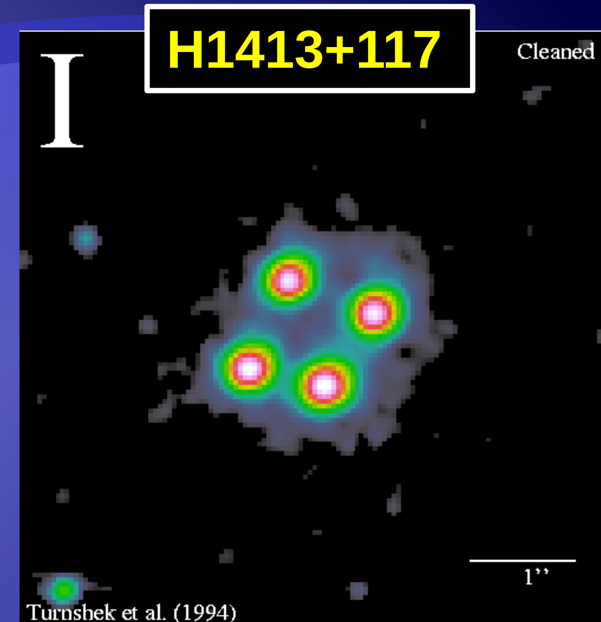
Line-of-sight structures

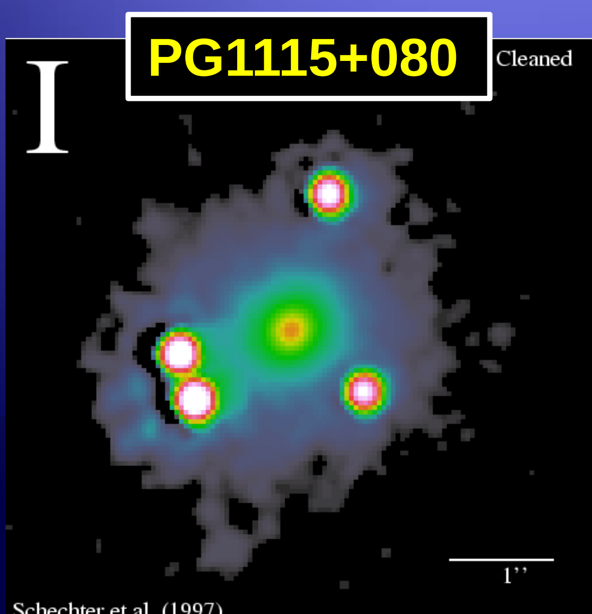


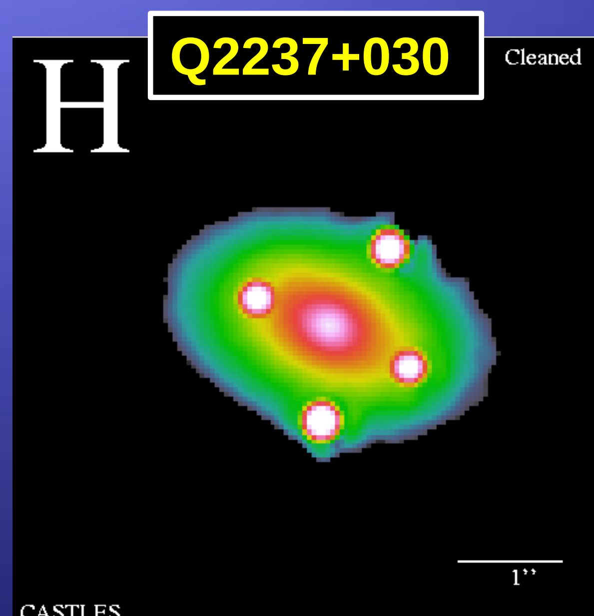
6 quadruple lenses

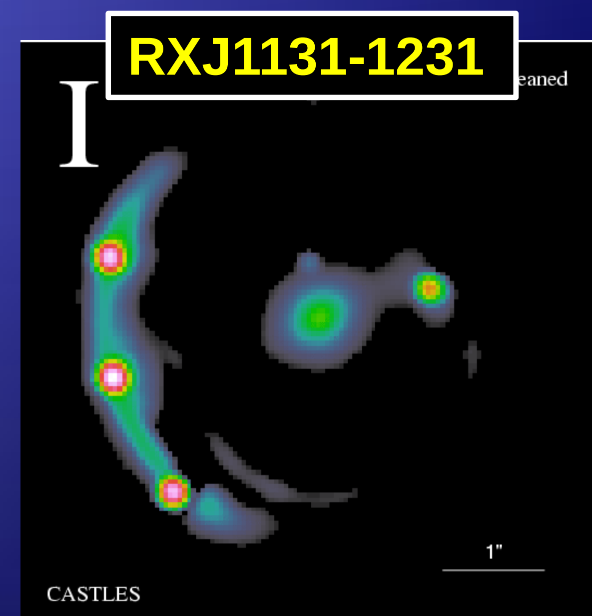












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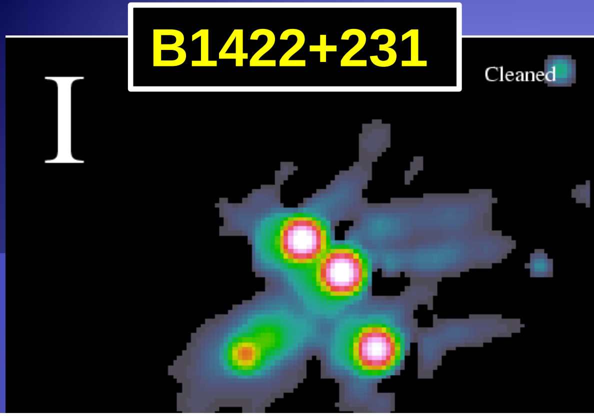
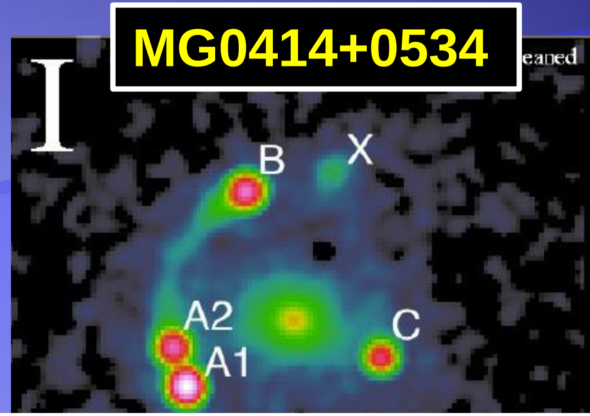
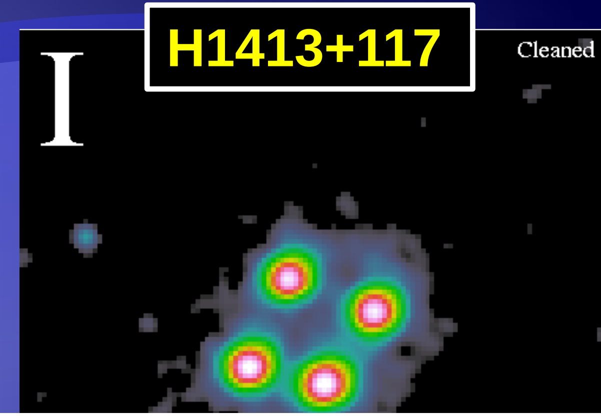
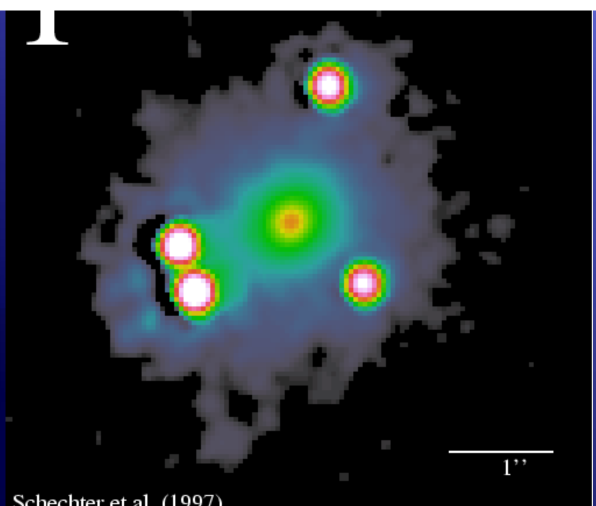


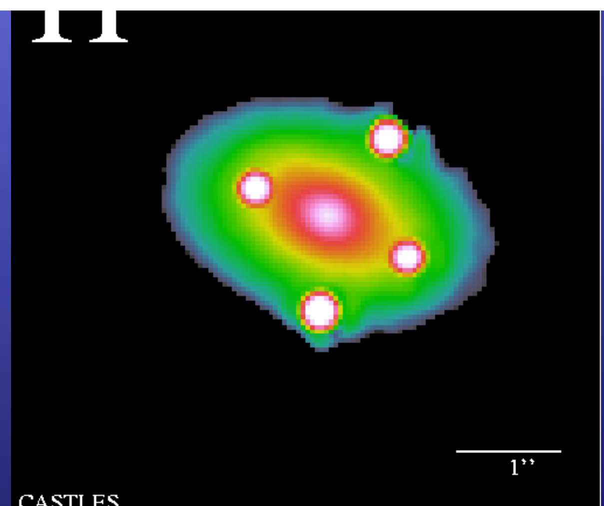


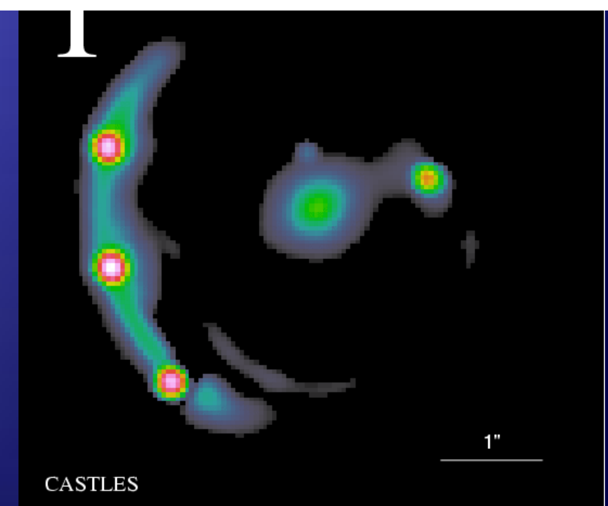


- Image positions ← Optical-NIR data（CASTLES）
- fluxes ← MIR data

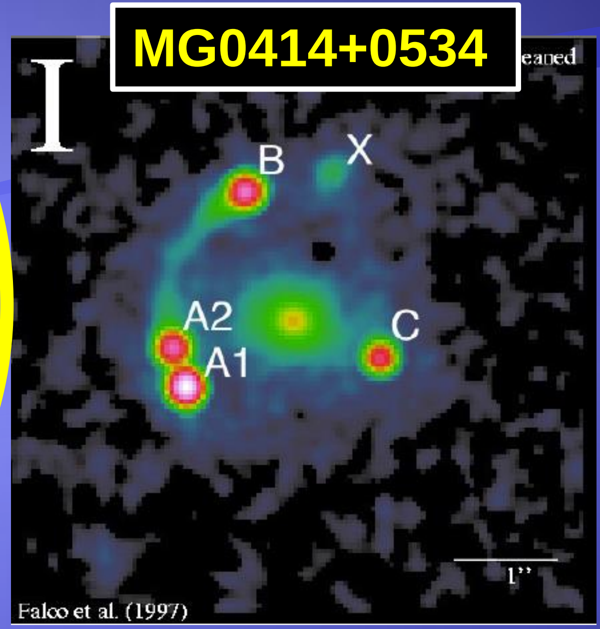
（MIR source is so large（～1pc）that
we can neglect stellar microlensing）

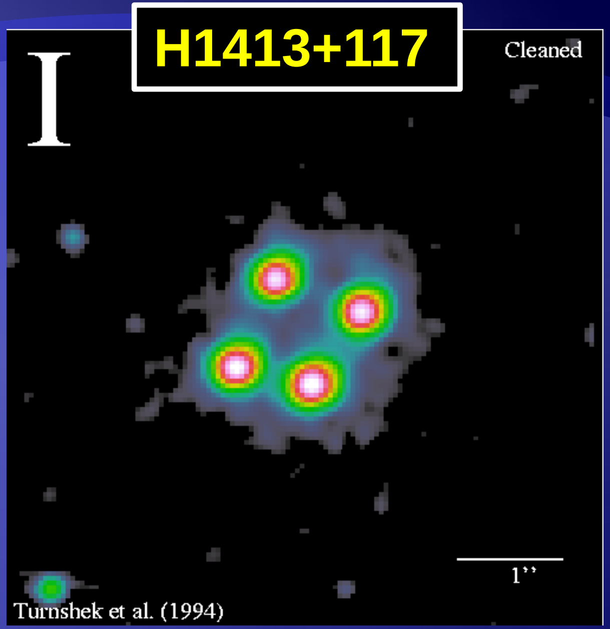


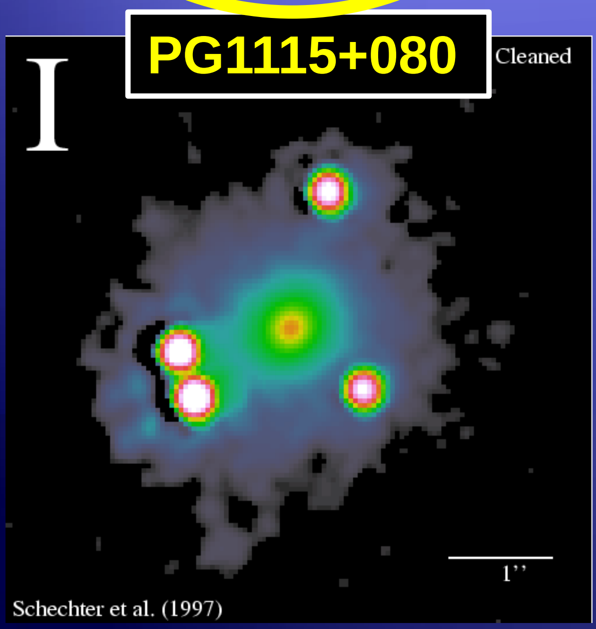


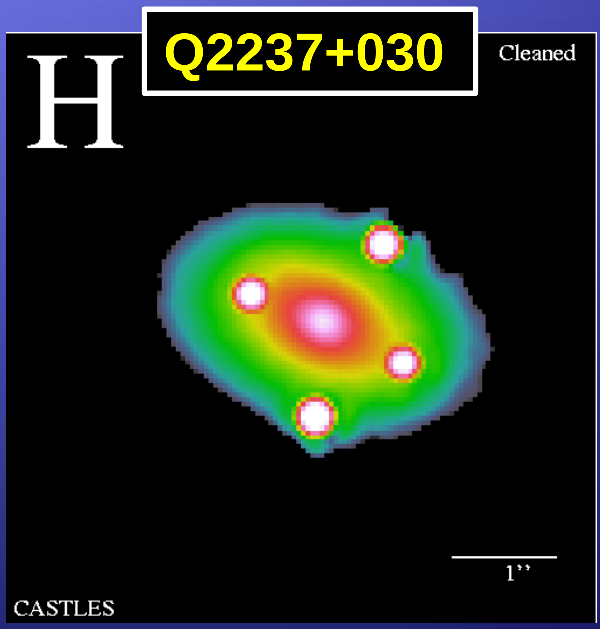


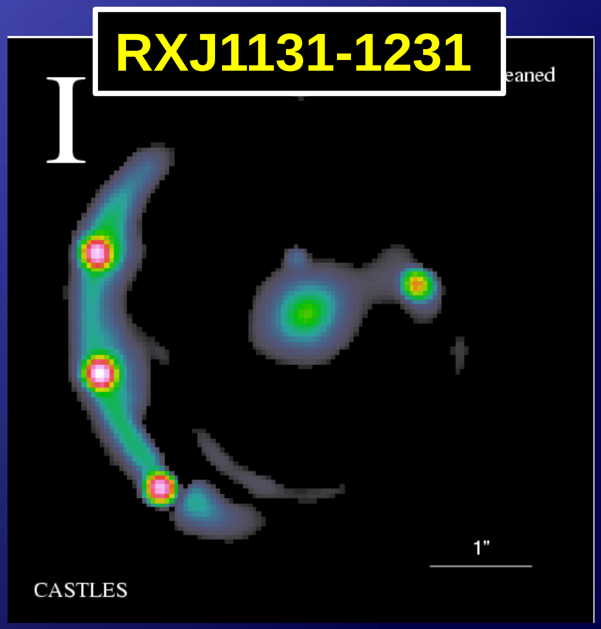
6 quadruple lenses











Ray tracing simulation

We used two publicly available codes:

1. Cosmological N-body code of Gadget2 (Springel)

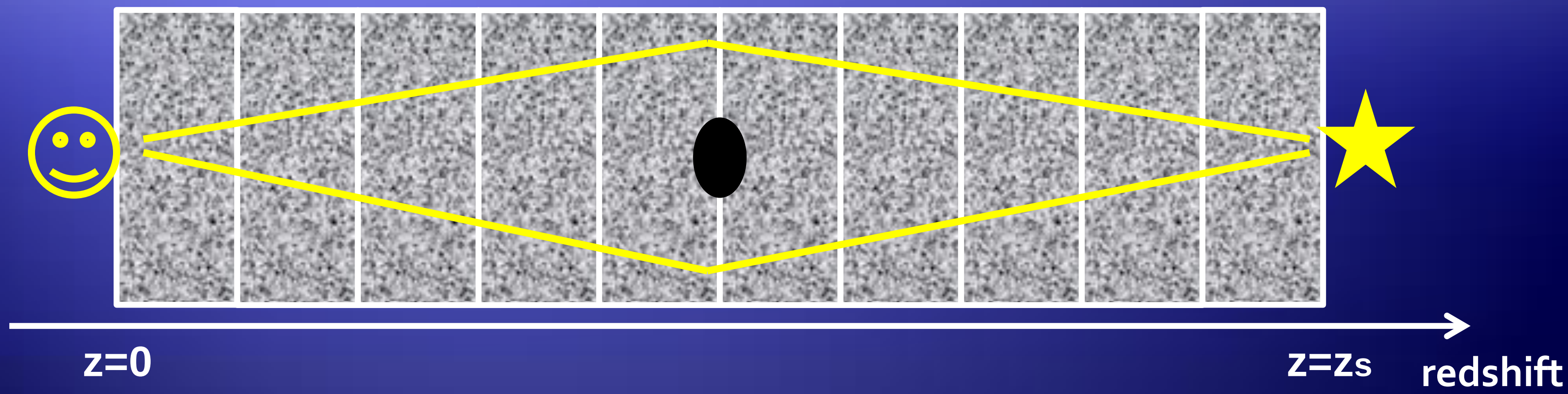
   to evaluate non-linear gravitational evolution of dark matter particles

2. Raytracing code of Raytrix (Hamana)

   to calculate perturbed convergence & shear along the line-of-site to the source in intervening mass distributions

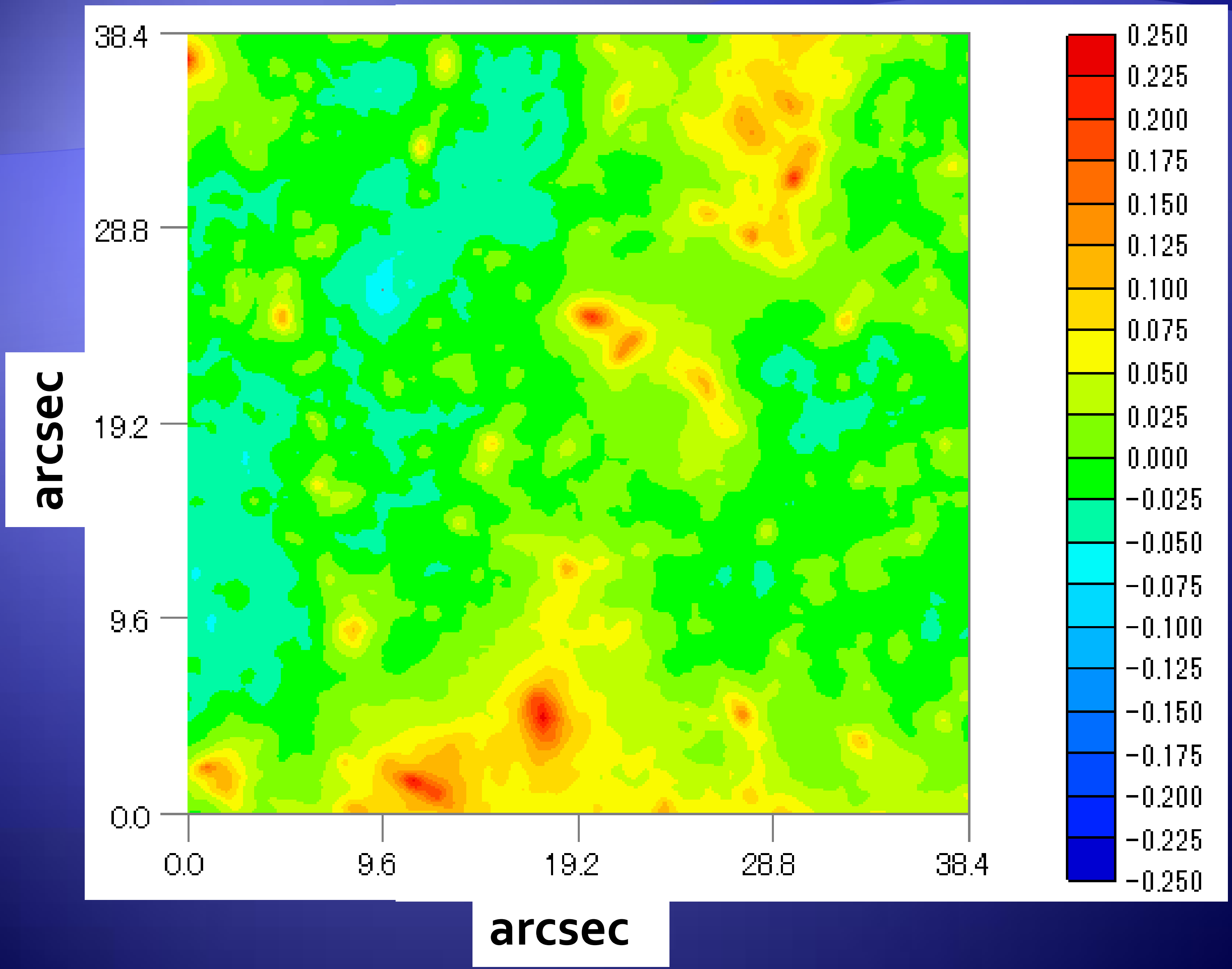
Ray tracing simulation

1. Prepare simulation boxes of 10Mpc/h on a side with 1024^3 particles
2. Place the boxes in the line up to the source
3. Evaluate perturbed convergence $\delta\kappa$ & shear $\delta\gamma$ along the light path under the Born approximation



Field of view 38.4”×38.4” , 100 maps prepared

a convergence map for B1422+231 （@z_s=3.62）

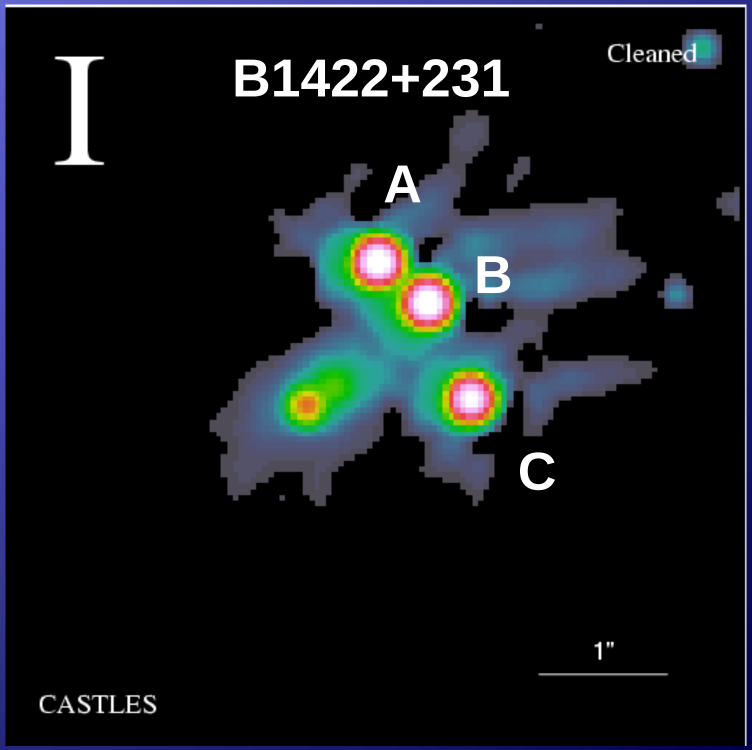


Modeling main lens

1. Model a main lens to fit the observed image positions

   ↑ singular isothermal ellipsoid + external shear model

2. Calculate convergences κ, shears $\gamma_{1,2}$, magnifications μ of the images



Adding perturbed quantities

For the convergences κ, shears $\gamma_{1,2}$ and magnifications μ, we add the perturbed quantities （$\delta\kappa', \delta\gamma'_{1,2}$） due to intervening structures

$$\delta\kappa', \delta\gamma'_{1,2} \approx 0.1 - 1\%$$

$$\begin{cases} \kappa \rightarrow \kappa + \delta\kappa' \\ \gamma_{1,2} \rightarrow \gamma_{1,2} + \delta\gamma'_{1,2} \\ \mu \rightarrow \mu + \delta\mu \end{cases}$$

magnification perturbation

$$\delta\mu = 2\frac{(1-\kappa)\delta\kappa' + \gamma_1\delta\gamma'_1 + \gamma_2\delta\gamma'_2}{[(1-\kappa)^2 + \gamma^2]^2}$$

$$\approx \mu^2\delta\kappa'$$

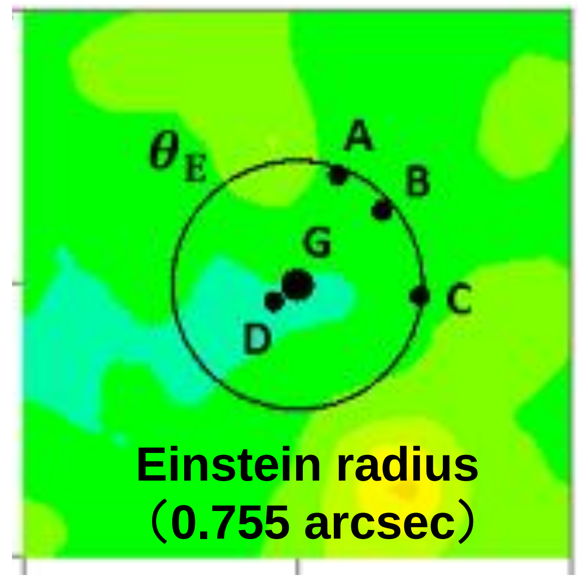
$$\frac{\delta\mu}{\mu} \approx \mu\delta\kappa' \approx 10\%$$

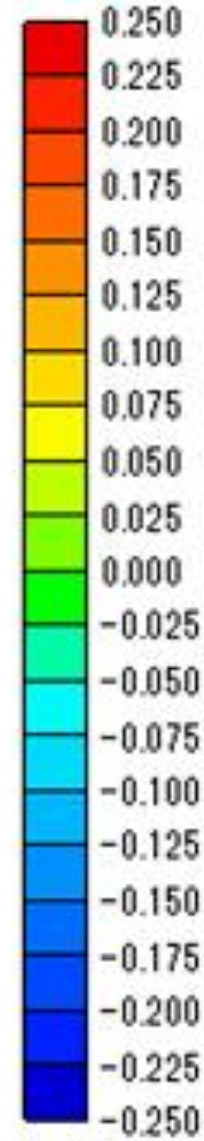
Subtract mean perturbed convergence & shear in a circles around the lens galaxy with Einstein radius

$$\begin{cases} \delta\kappa' = \delta\kappa - \delta\overline{\kappa} \\ \delta\gamma'_{1,2} = \delta\gamma_{1,2} - \delta\overline{\gamma}_{1,2} \end{cases}$$

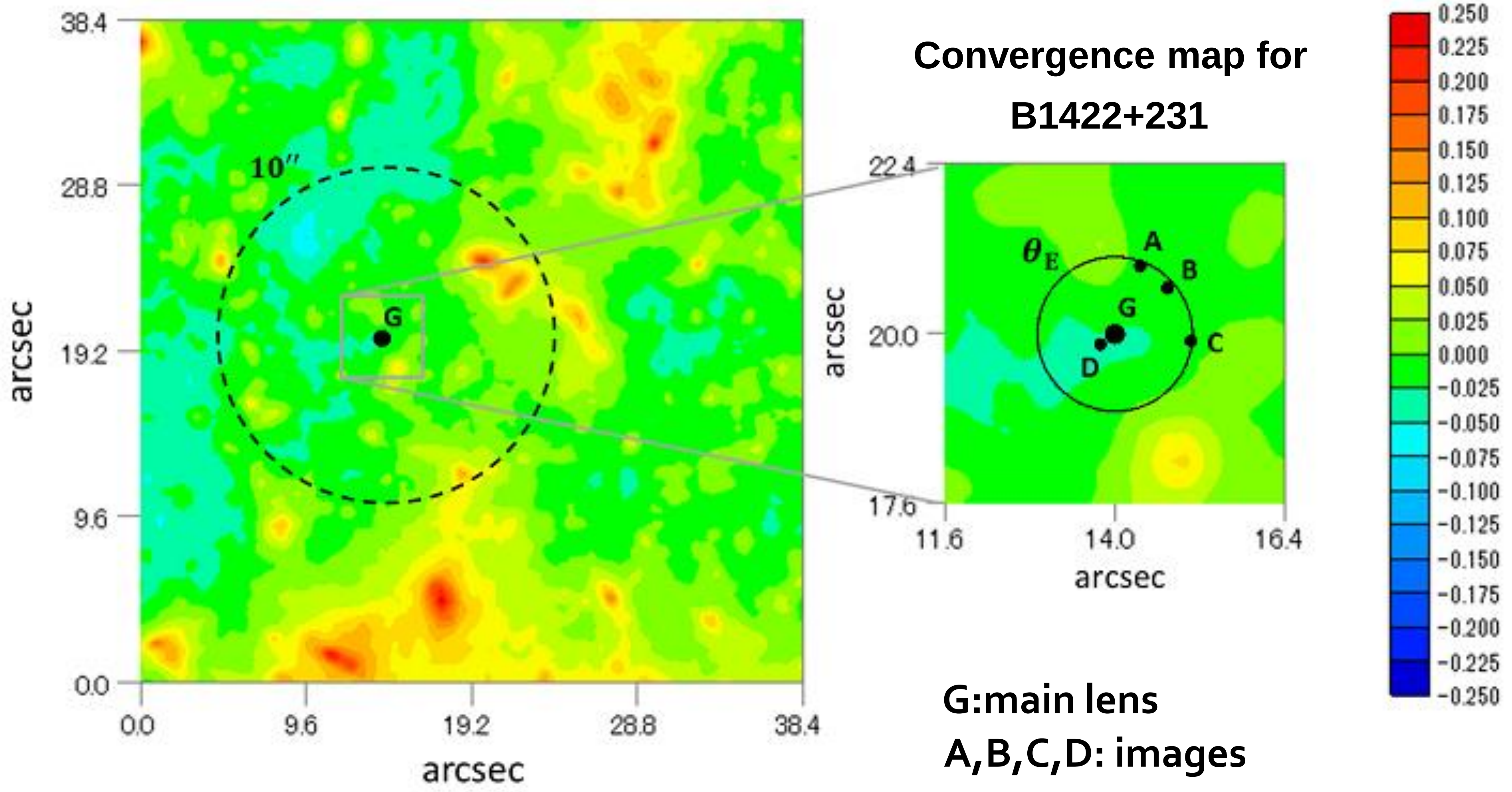
The mean quantities（$\delta\overline{\kappa}, \delta\overline{\gamma}_{1,2}$）are already included in the main lens（SIE+external shear）

Convergence map for B1422+231





G:main lens
A,B,C,D: images



add the perturbed quantities for each image

$$\begin{cases} \kappa \to \kappa + \delta\kappa' \\ \gamma_{1,2} \to \gamma_{1,2} + \delta\gamma'_{1,2} \\ \mu \to \mu + \delta\mu' \end{cases}$$

New statistic η

magnification contrast

$$\delta^{\mu} = \delta\mu/\mu$$

η : effective magnification perturbation

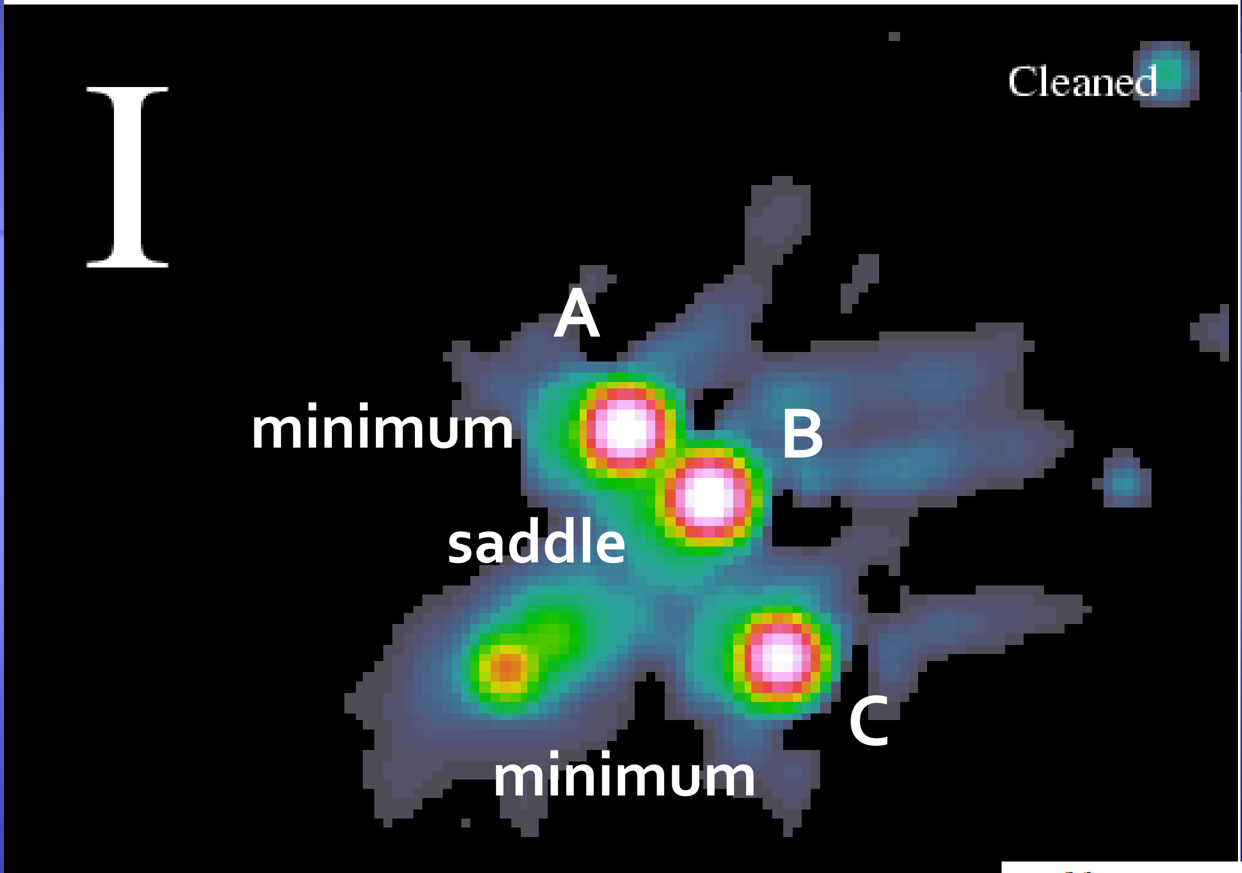
$$\eta^2(\mathrm{A,B,C}) = \frac{1}{4}[(\delta^{\mu}_A - \delta^{\mu}_B)^2 + (\delta^{\mu}_C - \delta^{\mu}_B)^2].$$

A,C: minimum B:saddle

observed value

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

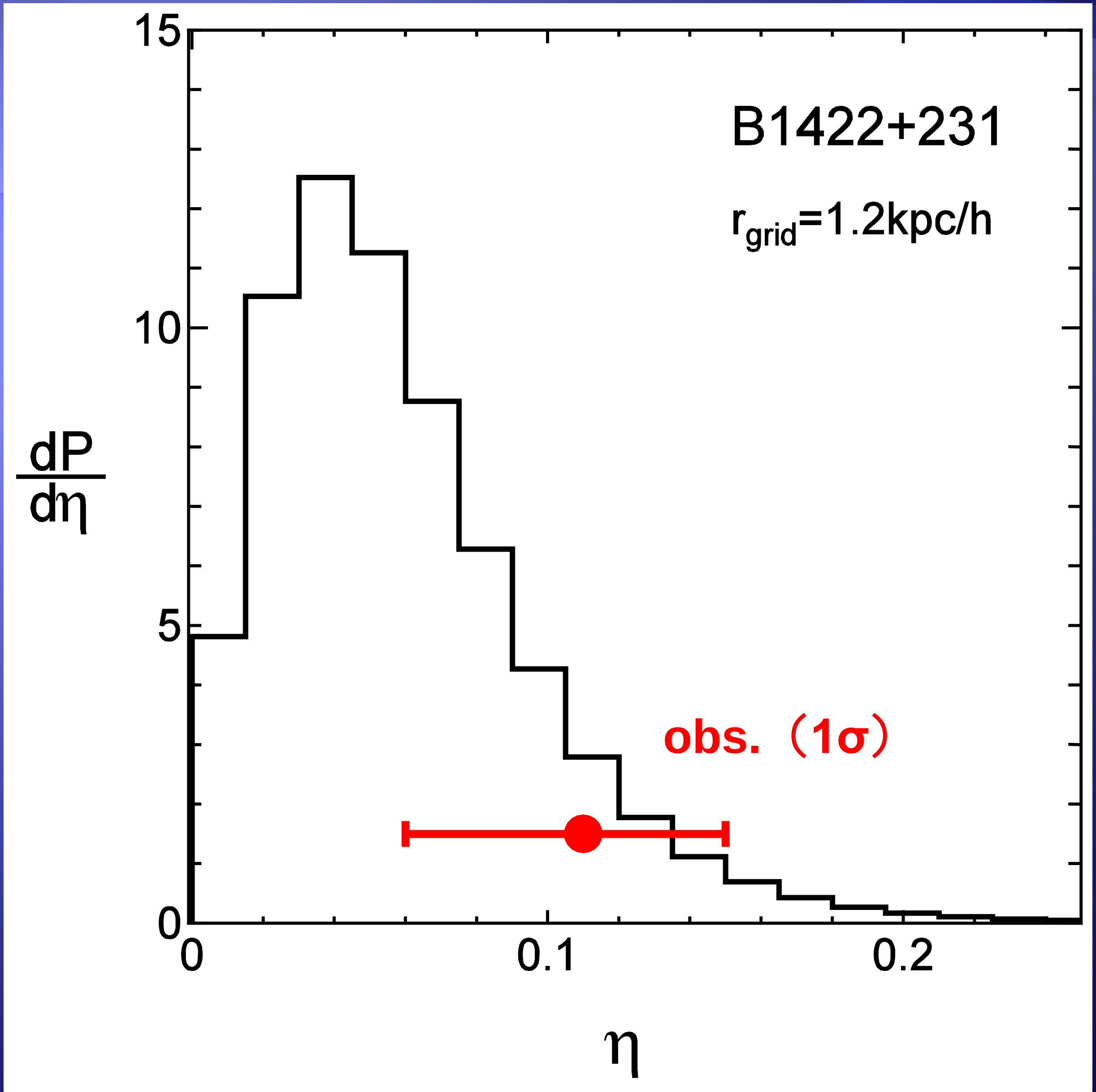
B1422+231



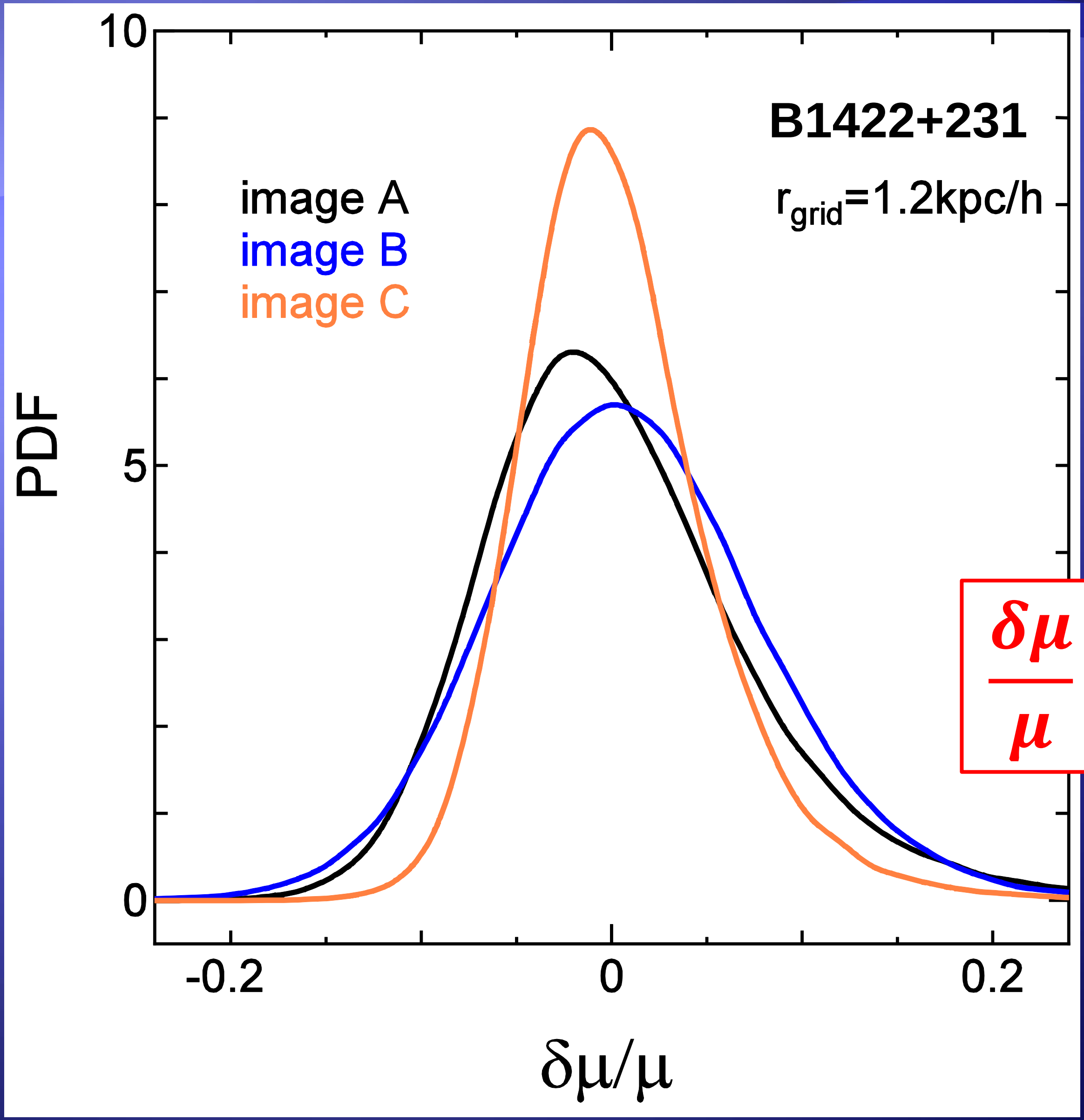
$$\delta_i^\mu \equiv \delta\mu_i/\mu_i.$$

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

probability distribution of η

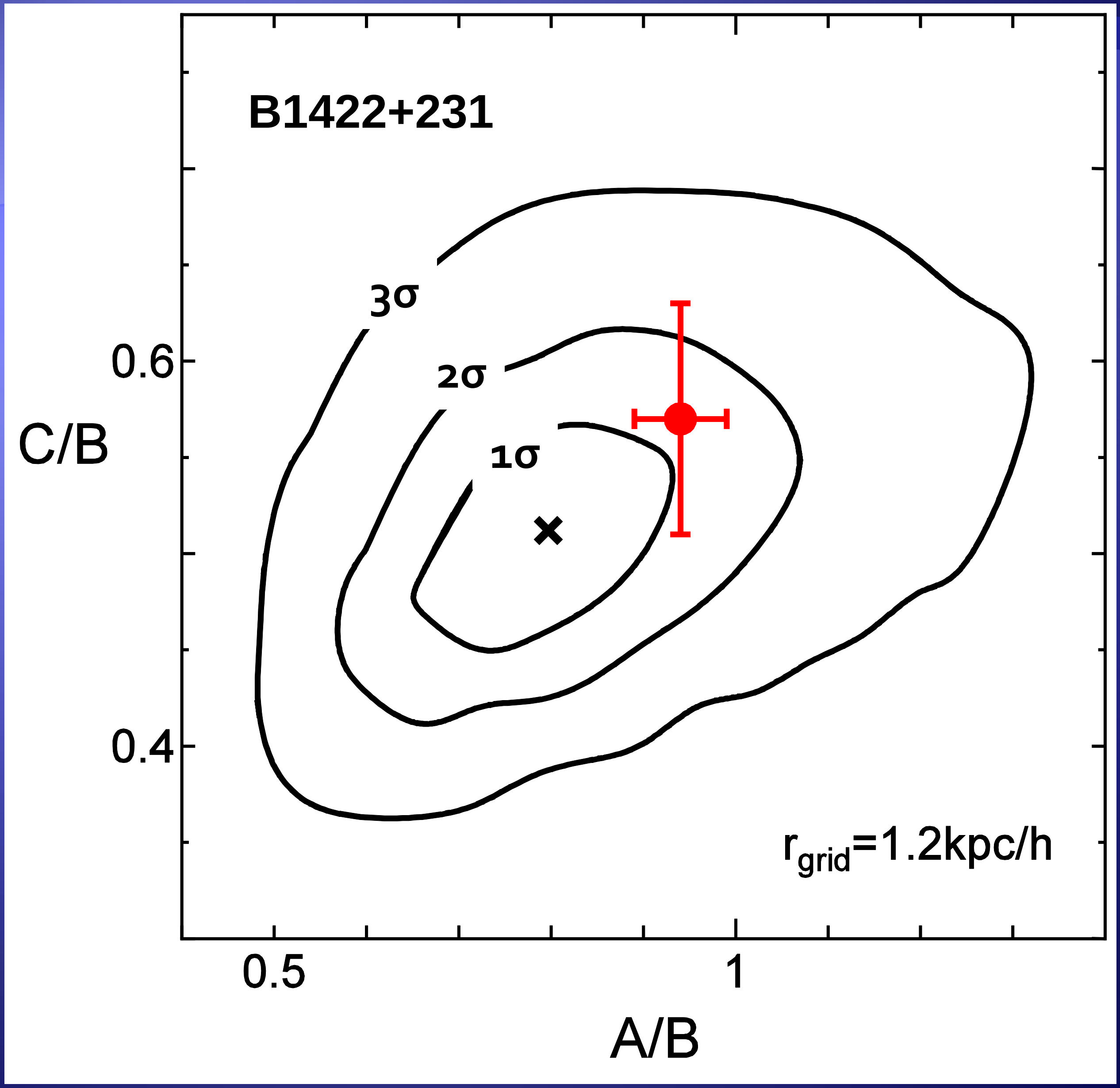


magnification perturbation

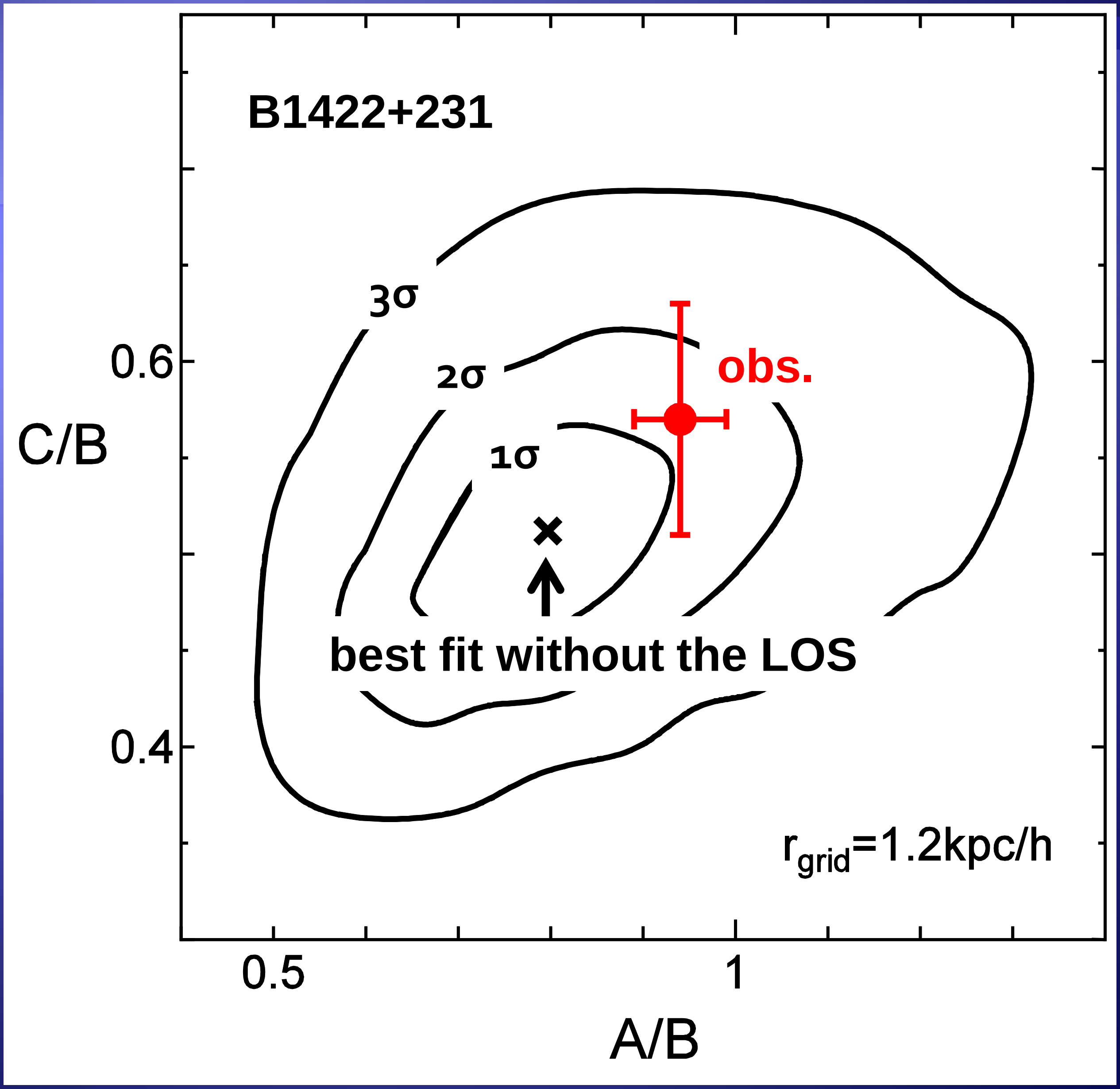


$$\frac{\delta\mu}{\mu} \approx 10\%$$

Flux ratio



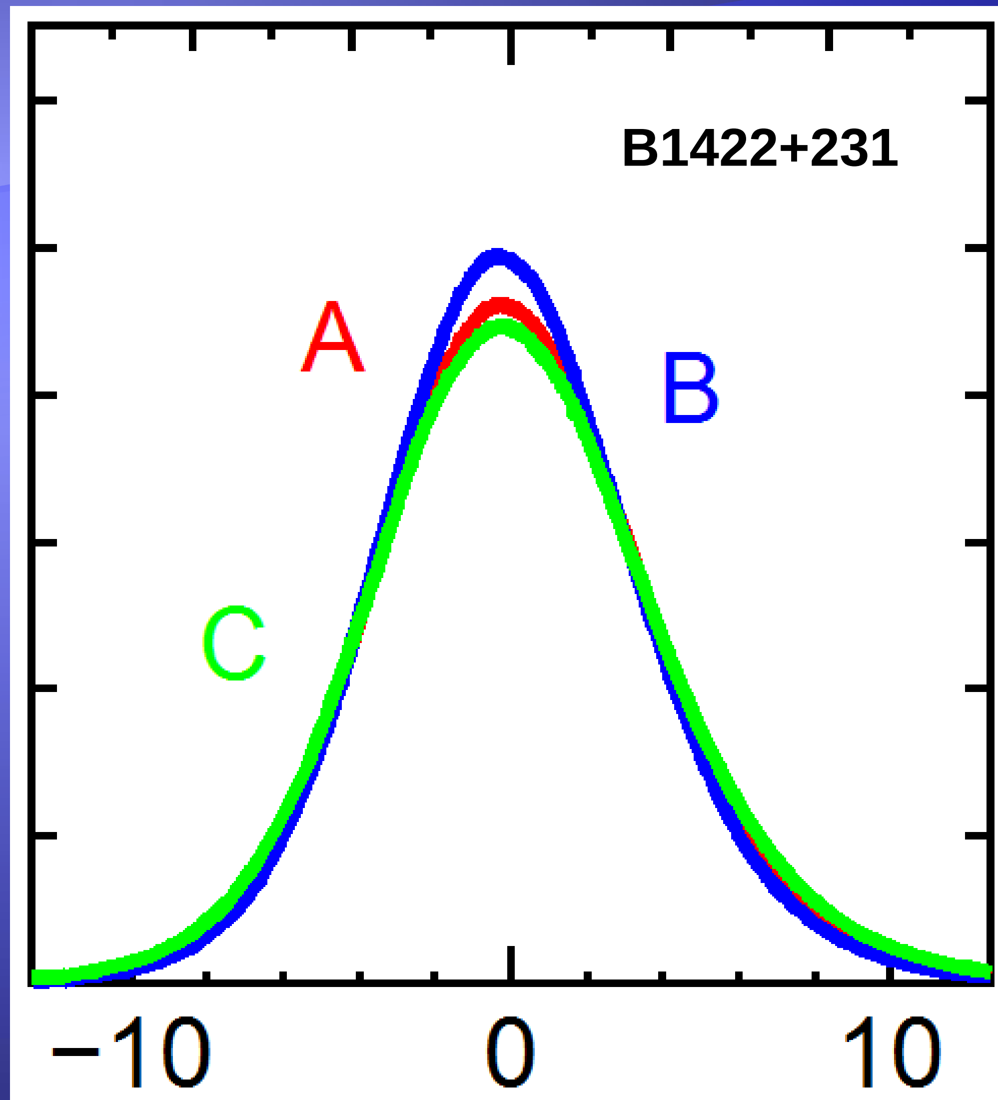
Flux ratio



B1422+231
3σ
2σ
1σ
obs.
best fit without the LOS
0.6
0.4
C/B
0.5
1
A/B
r_grid=1.2kpc/h

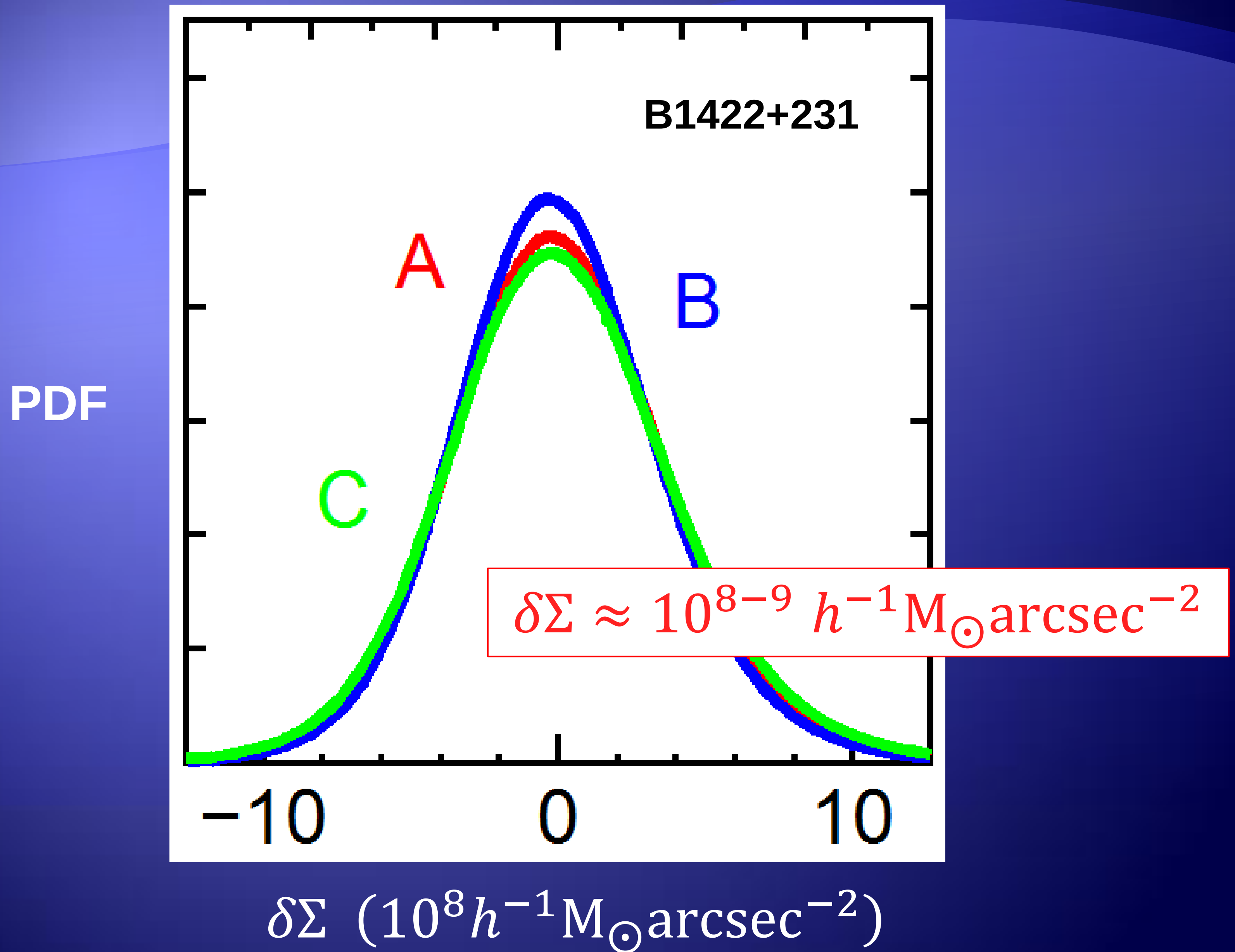
surface mass density of the intervening structures

PDF

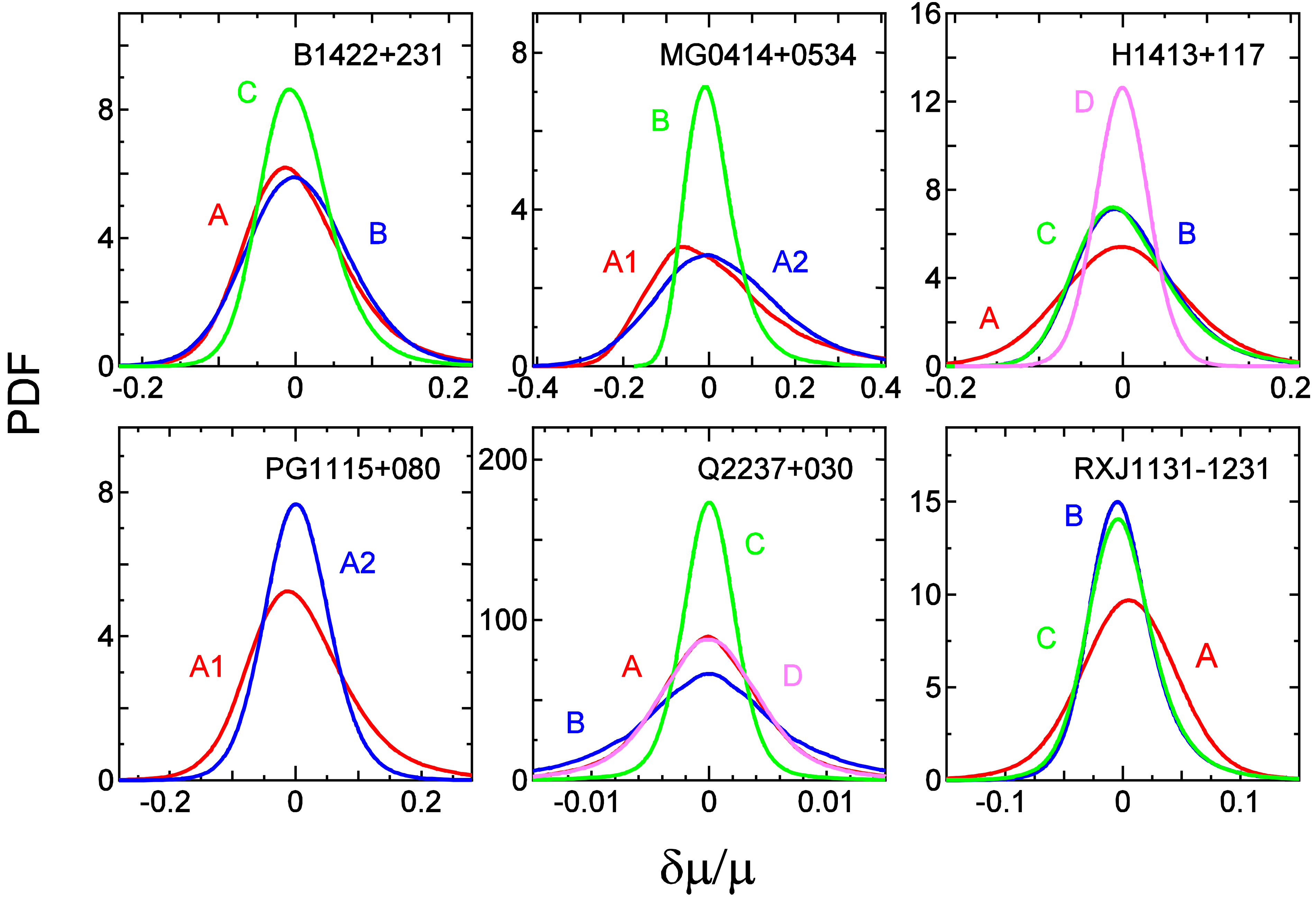


$\delta\Sigma\ (10^8 h^{-1} \mathrm{M}_\odot \mathrm{arcsec}^{-2})$

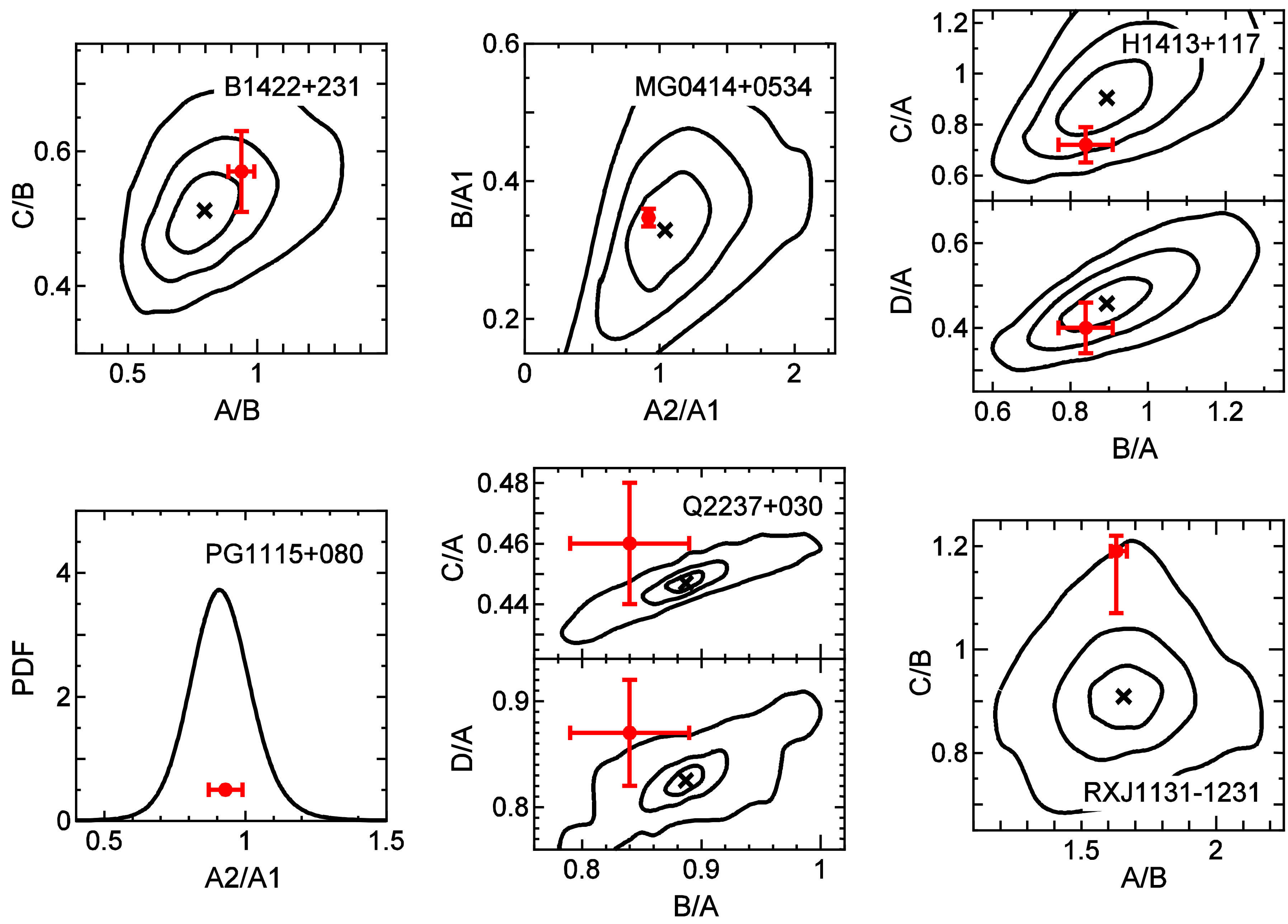
surface mass density of the intervening structures



magnification perturbation for the 6 lens systems



Flux ratios of the 6 lens systems



Summary

The LOS structures can explain the flux-anomaly problem for the 6 lens systems

The raytracing simulation agrees with an analytical estimate in Inoue & RT 2012 within 20% accruracy

Future Work

Consider multiple lens plane scattering instead of the Born approx.

Include baryonic cooling, which naively enhance small-scale clustering（<~1Mpc）