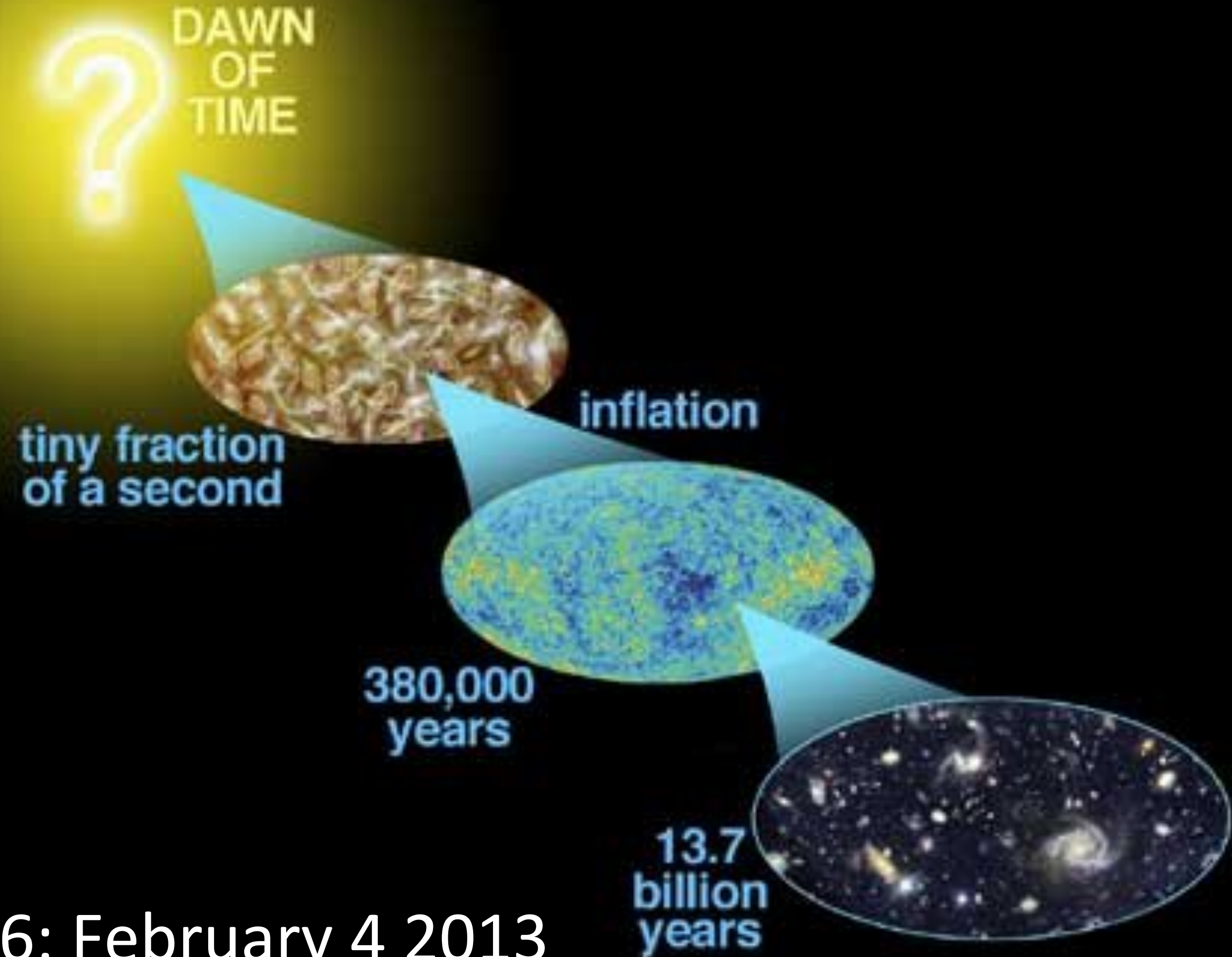
Cosmology W13



Lecture 6: February 4 2013

Papers for your final presentations

- Furlanetto, Oh, Briggs, 2006, Phys. Rep., 433, 4, 181
- Weinberg et al. 2012, arxiv1201.2434

Revised plan for exams

- In class midterm on 2/25
- Presentations:
  - 3/11 12:30->3:30 PM
  - 3/12 1:00->4:00 PM
- Two teams of 6 and 7 people. Each team shoul be prepared to present for 3 hours including interruptions
- You will be graded on quality of presentation as well as questions and answets

Weak Lensing

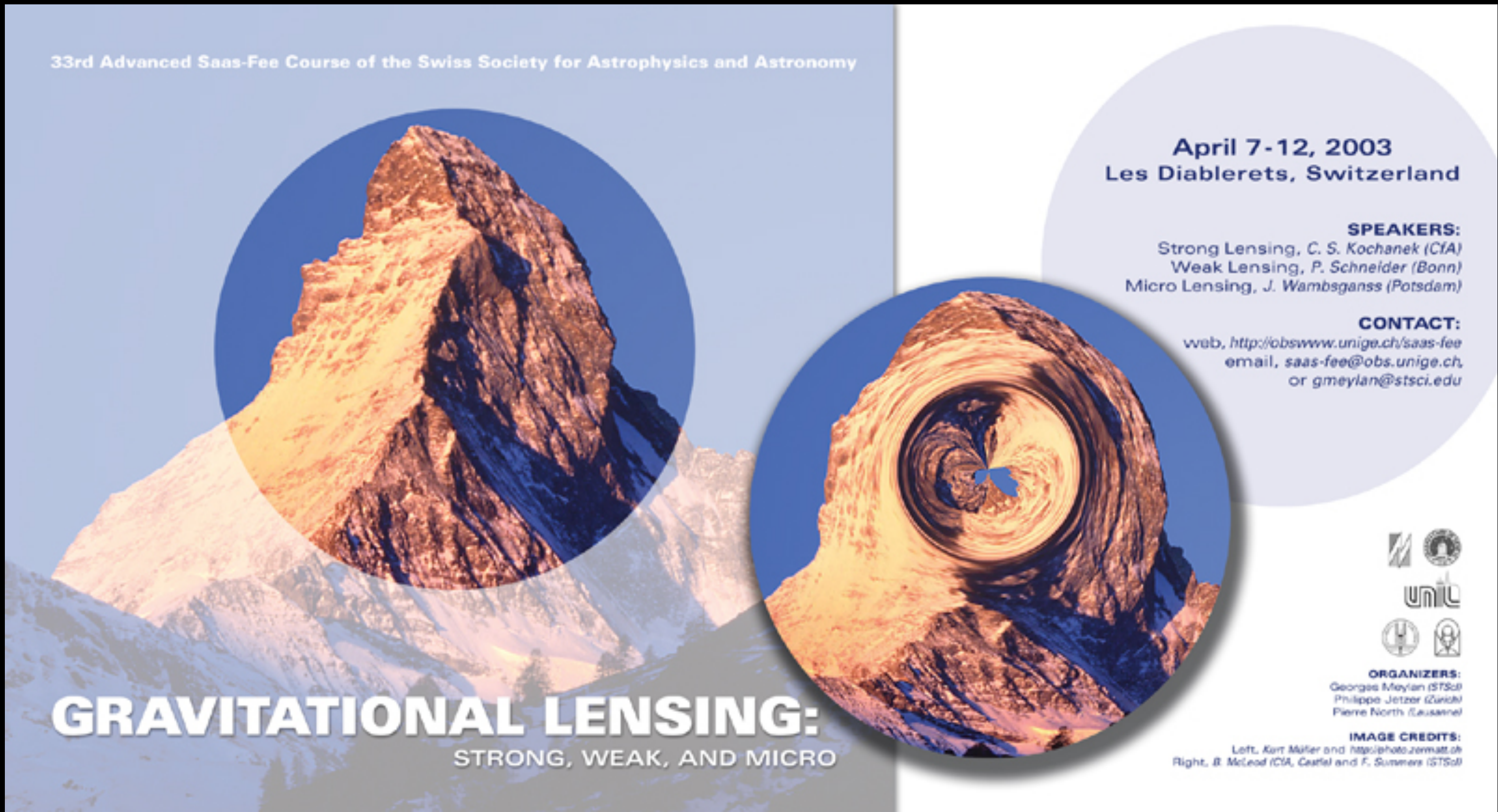
- Introduction to weak gravitational lensing
- The mass and mass profile of clusters
- Cosmic shear

References

- General
  - Schneider, Kochanek and Wambsganss 2006
  - Bartelmann 2010

A very useful reference

- http://www.astro.uni-bonn.de/~peter/SaasFee.html

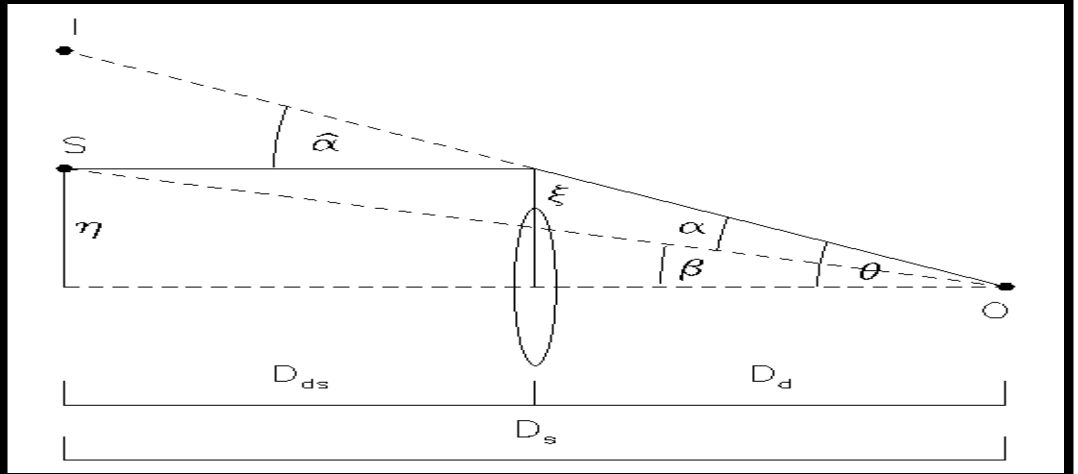


Read Schneider's chapter on weak lensing

Strong vs weak lensing

- Strong and weak lensing are complementary:
- Strong lensing gives you high precision measurements at high angular resolution for a few special objects
- Weak lensing gives you lower precision measurements at lower angular resolution for every object

Recap of useful formulae - notation



$$\mathcal{A}(\boldsymbol{\theta}) = \frac{\partial \beta}{\partial \boldsymbol{\theta}} = \left(\delta_{ij} - \frac{\partial^2 \psi(\boldsymbol{\theta})}{\partial \theta_i \partial \theta_j}\right) = \begin{pmatrix} 1-\kappa-\gamma_1 & -\gamma_2 \\ -\gamma_2 & 1-\kappa+\gamma_1 \end{pmatrix}$$

$$\gamma \equiv \gamma_1 + \mathrm{i}\gamma_2 = |\gamma| \mathrm{e}^{2\mathrm{i}\varphi}$$

$$\gamma_1 = \frac{1}{2}(\psi_{,11} - \psi_{,22}) \ , \quad \gamma_2 = \psi_{,12}$$

$$\mu = \det M = \frac{1}{\det \mathcal{A}} = \frac{1}{(1-\kappa)^2 - |\gamma|^2}$$

Recap of useful formulae - notation

$$\mathcal{A}(\boldsymbol{\theta}) = (1-\kappa)\begin{pmatrix} 1-g_1 & -g_2 \\ -g_2 & 1+g_1 \end{pmatrix}$$

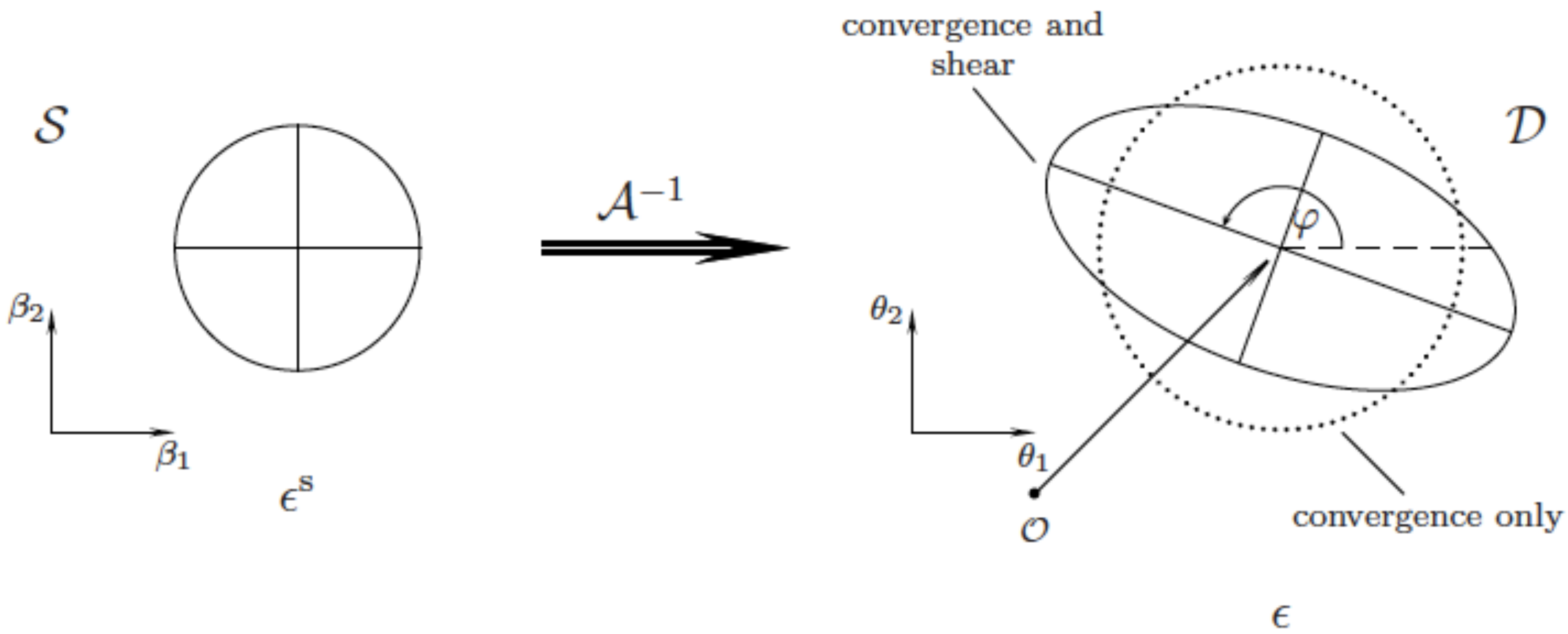
$$g \equiv \frac{\gamma}{1-\kappa} = \frac{|\gamma|}{1-\kappa}\,\mathrm{e}^{2\mathrm{i}\varphi}$$

$$\mu = \left[\int \mathrm{d}^2\beta\, I^{(\mathrm{s})}(\boldsymbol{\beta})\right]^{-1} \int \mathrm{d}^2\beta\, I^{(\mathrm{s})}(\boldsymbol{\beta})\,\mu_{\mathrm{p}}(\boldsymbol{\beta})$$

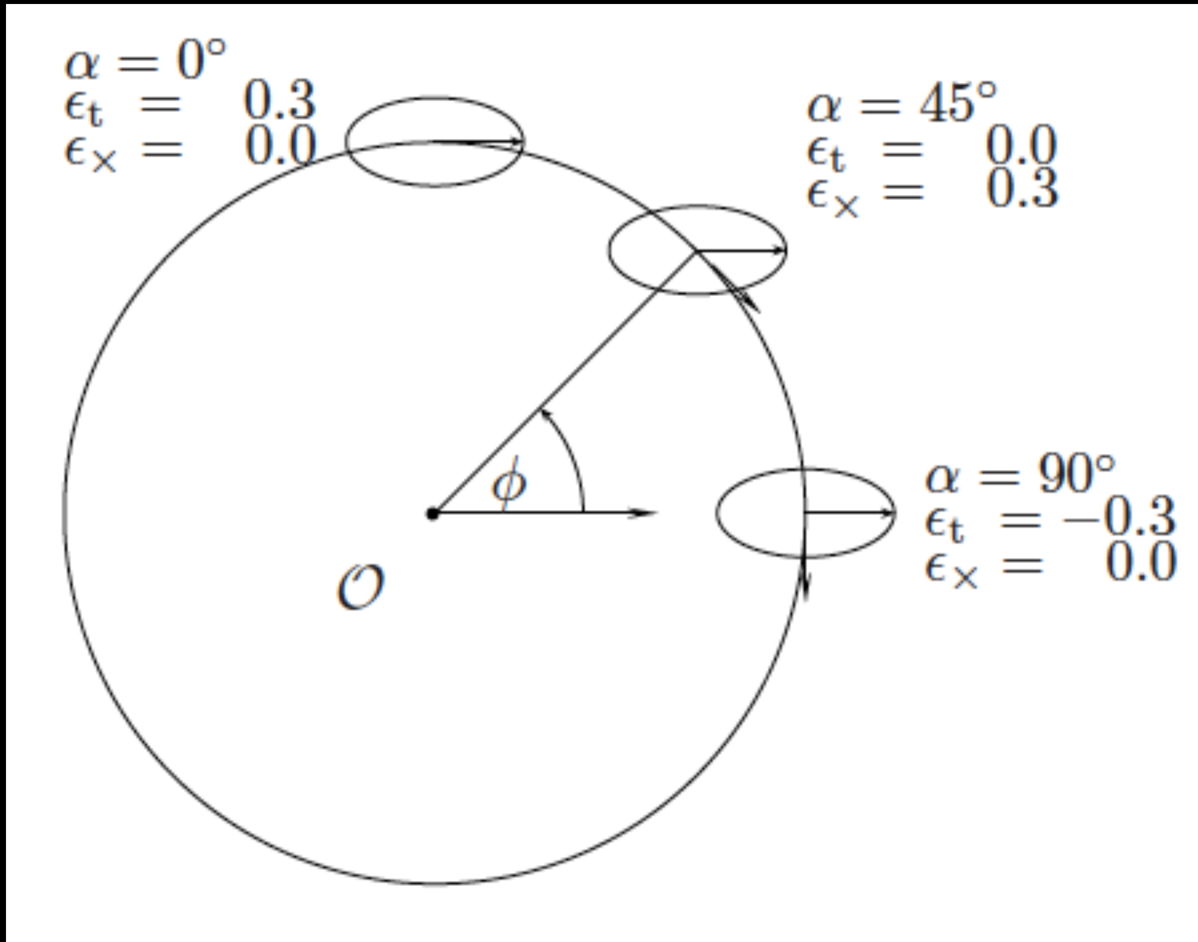
$$\gamma \approx g \approx \langle\epsilon\rangle \approx \frac{\langle\chi\rangle}{2}$$

Weak lensing regime

Shear: what does it mean?



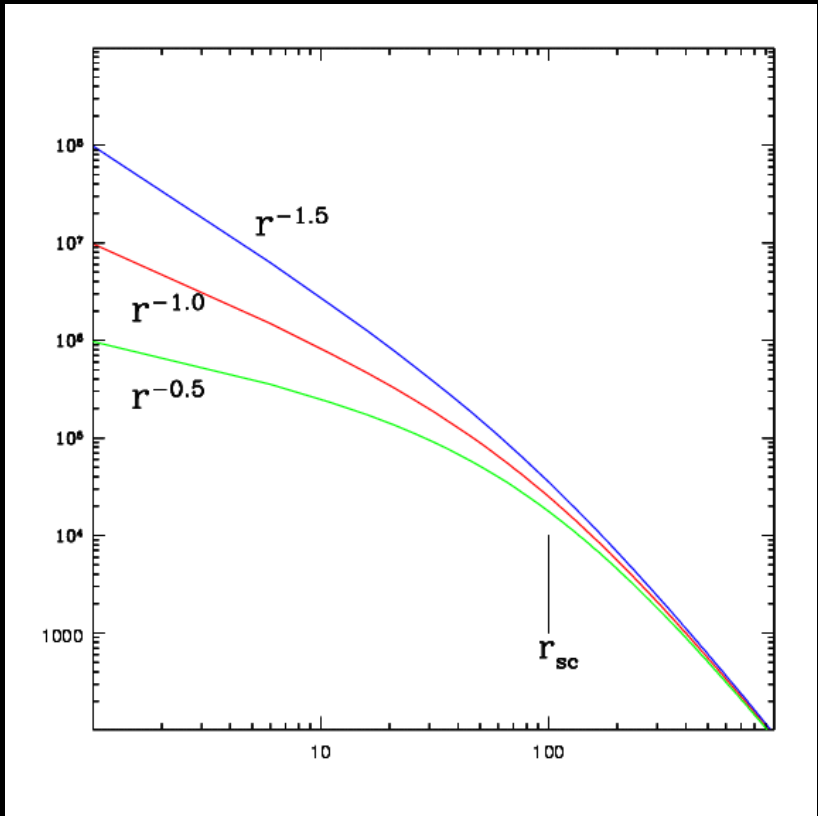
Shear: what does it mean?



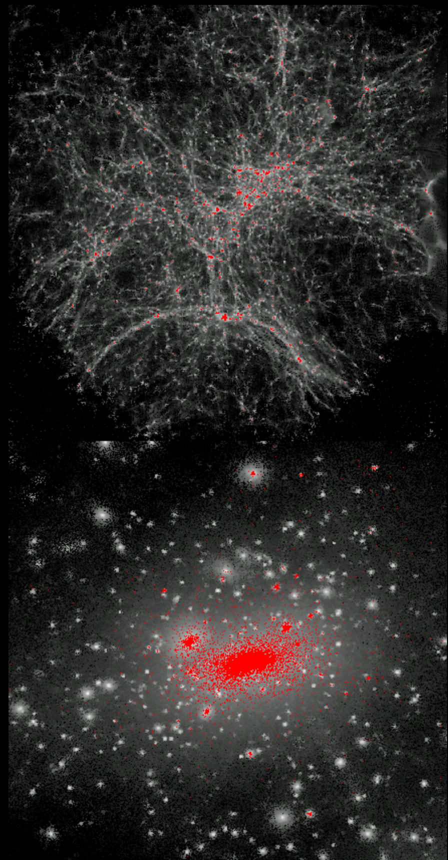
Some challenges of weak-lensing measurements

- Shape noise
- Point spread function and image artifacts
- Mass sheet degeneracy
- Projected mass vs mass
- How to identify and measure the redshift of background sources?

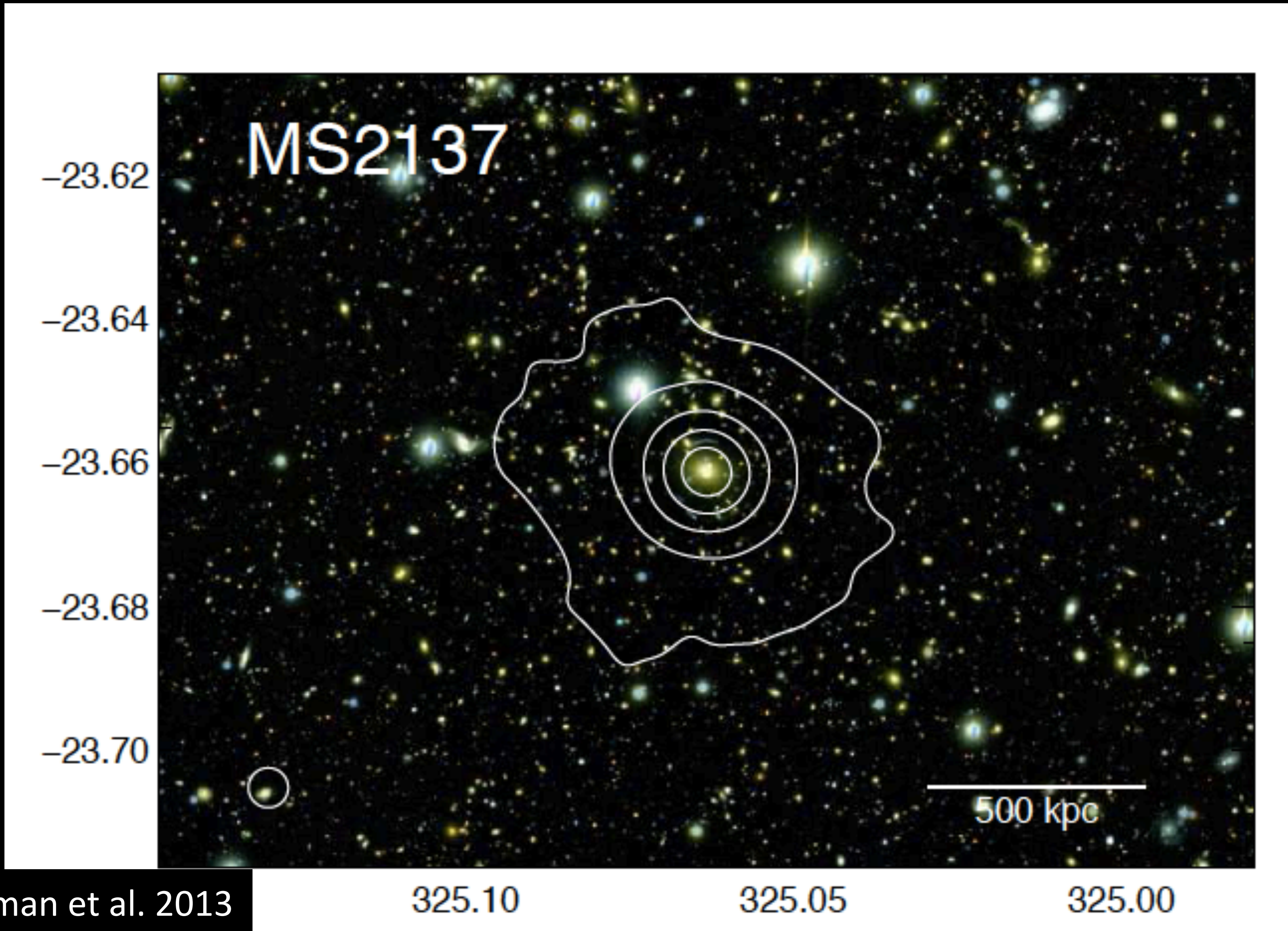
Application of weak lensing: the mass of clusters



$$\rho(r) = \frac{\delta_c \rho_c}{(r/r_s)^{\beta}(1 + r/r_s)^{3-\beta}}$$

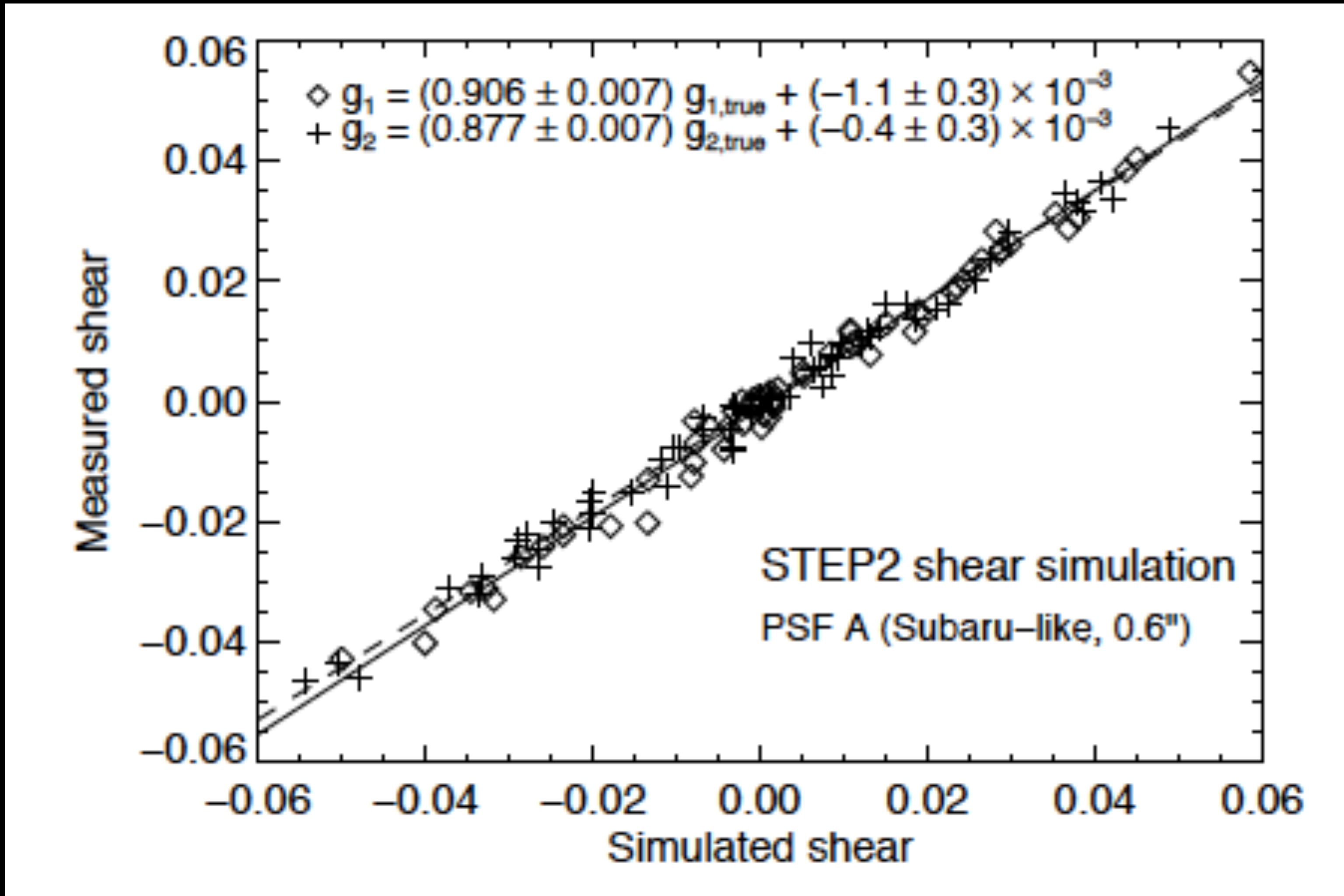


Application of weak lensing: the mass of clusters



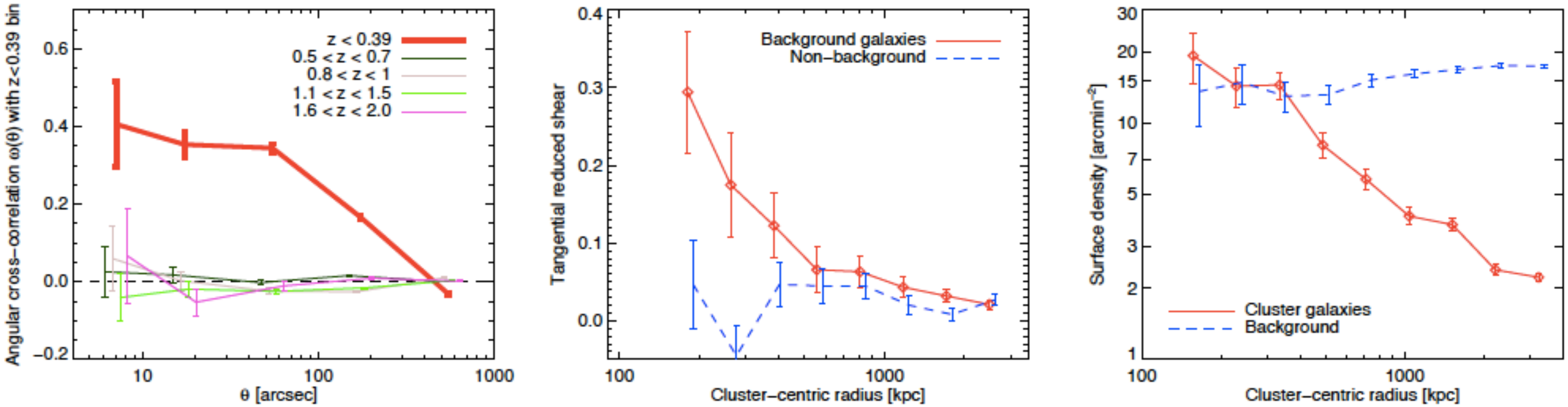
Newman et al. 2013

Application of weak lensing: the mass of clusters



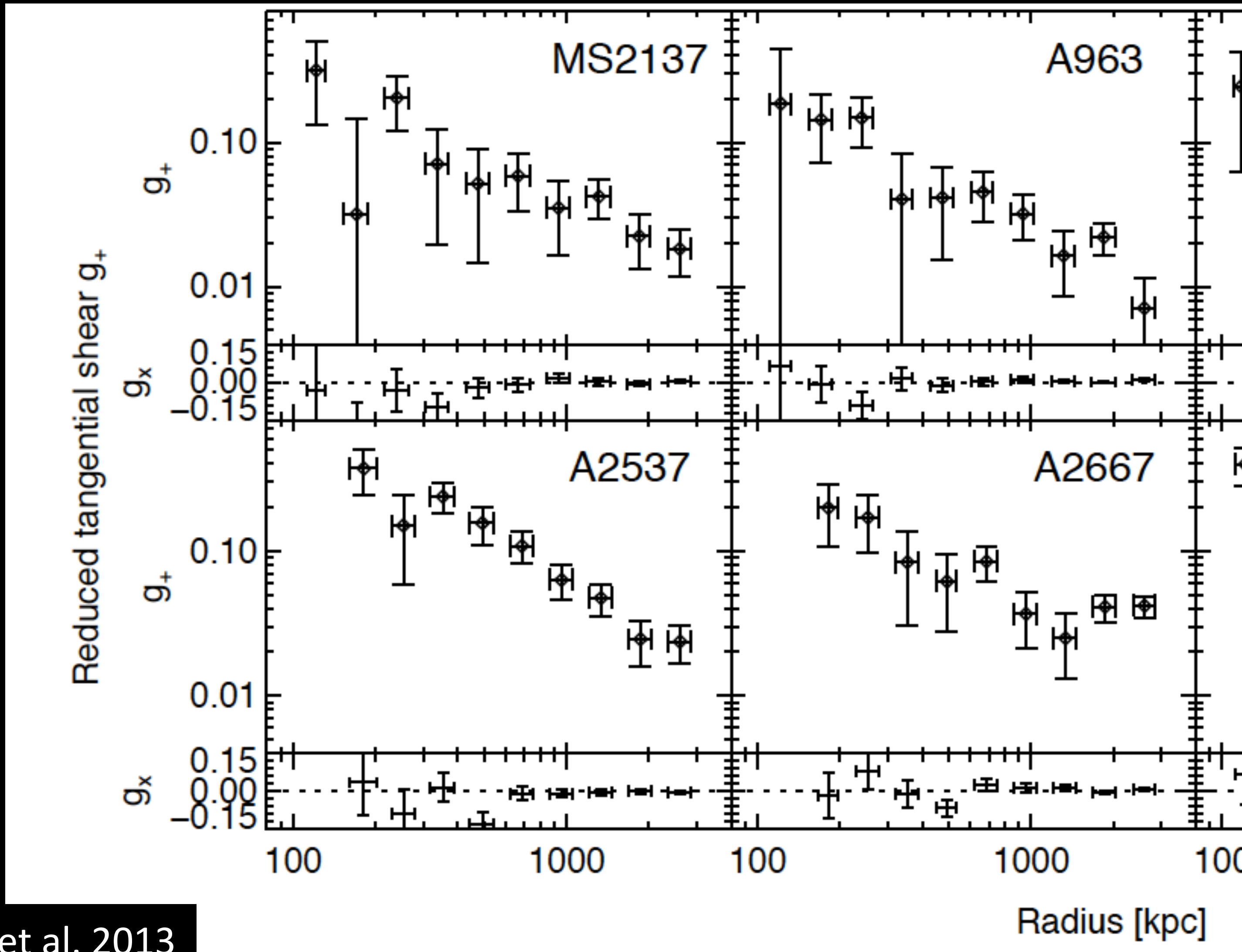
Newman et al. 2013

Application of weak lensing: the mass of clusters



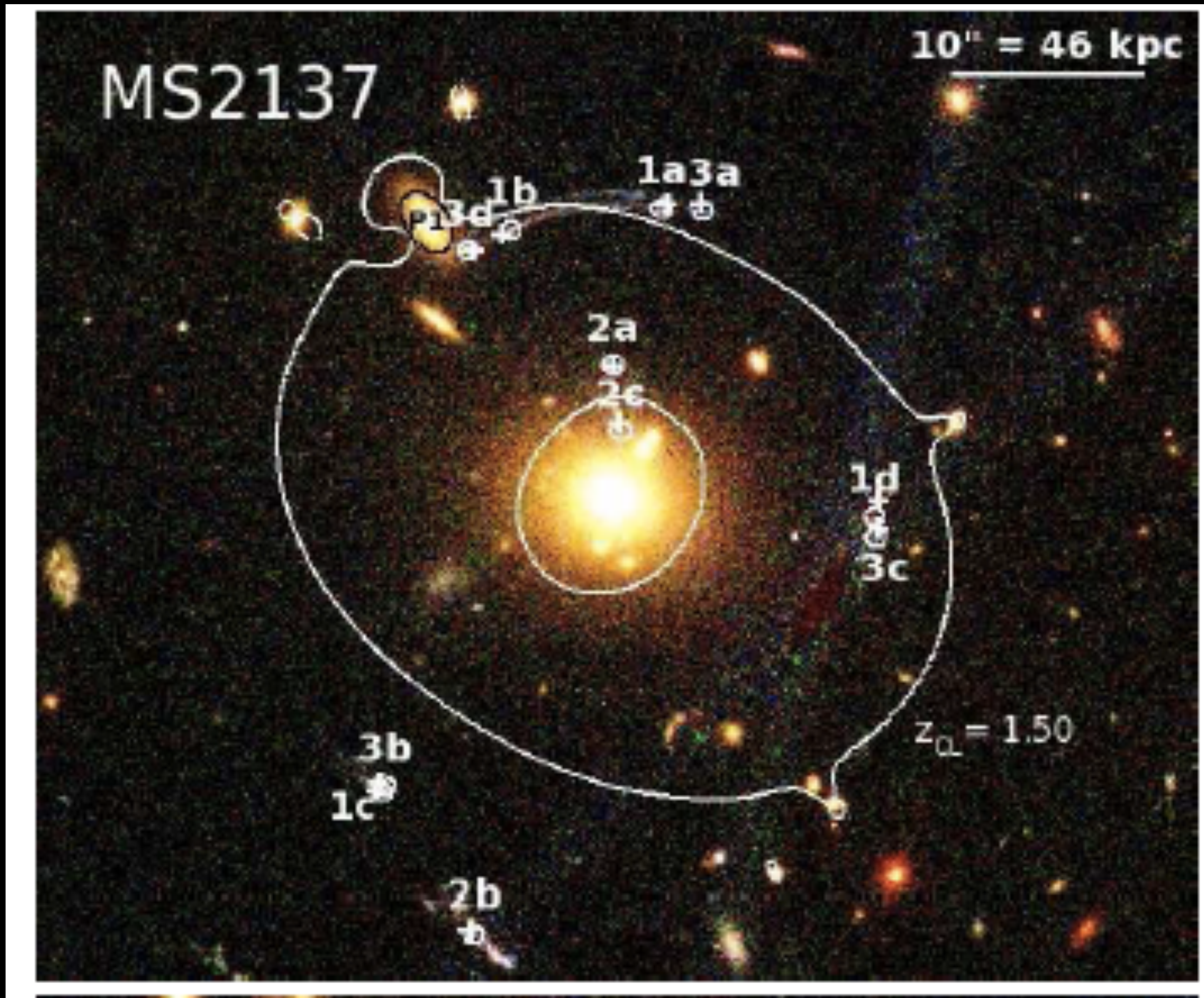
Newman et al. 2013

Application of weak lensing: the mass of clusters



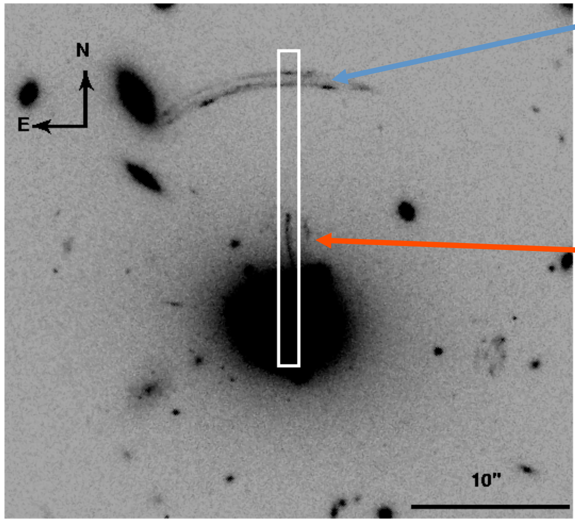
Newman et al. 2013

Weak+Strong lensing



Newman et al. 2013

Strong lensing in MS2137



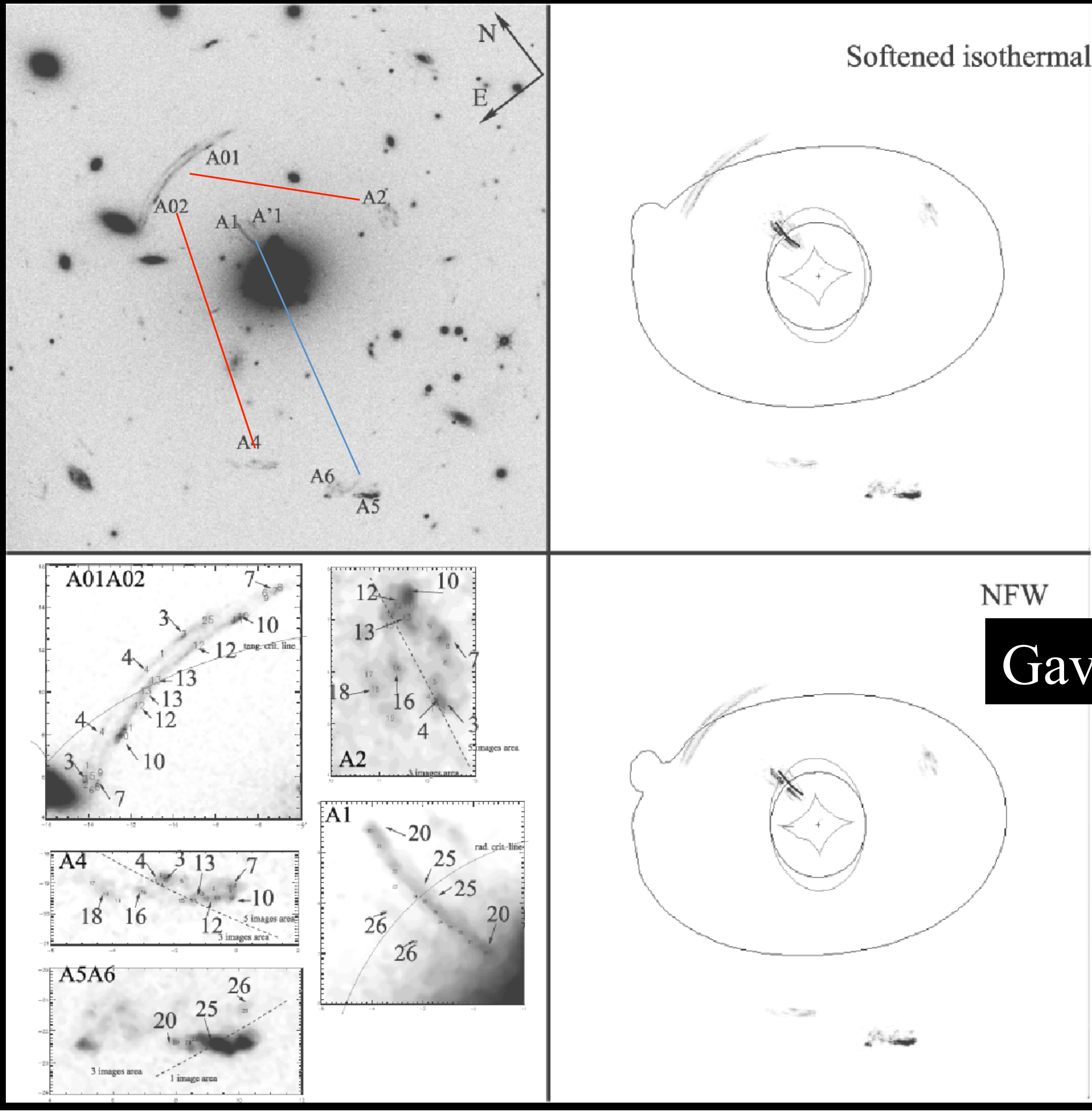
Tangential arc

Radial arc

$$1 - \frac{d}{dx}\frac{m(x)}{x} = 0 \quad 1 - \frac{m(x)}{x^2} = 0$$

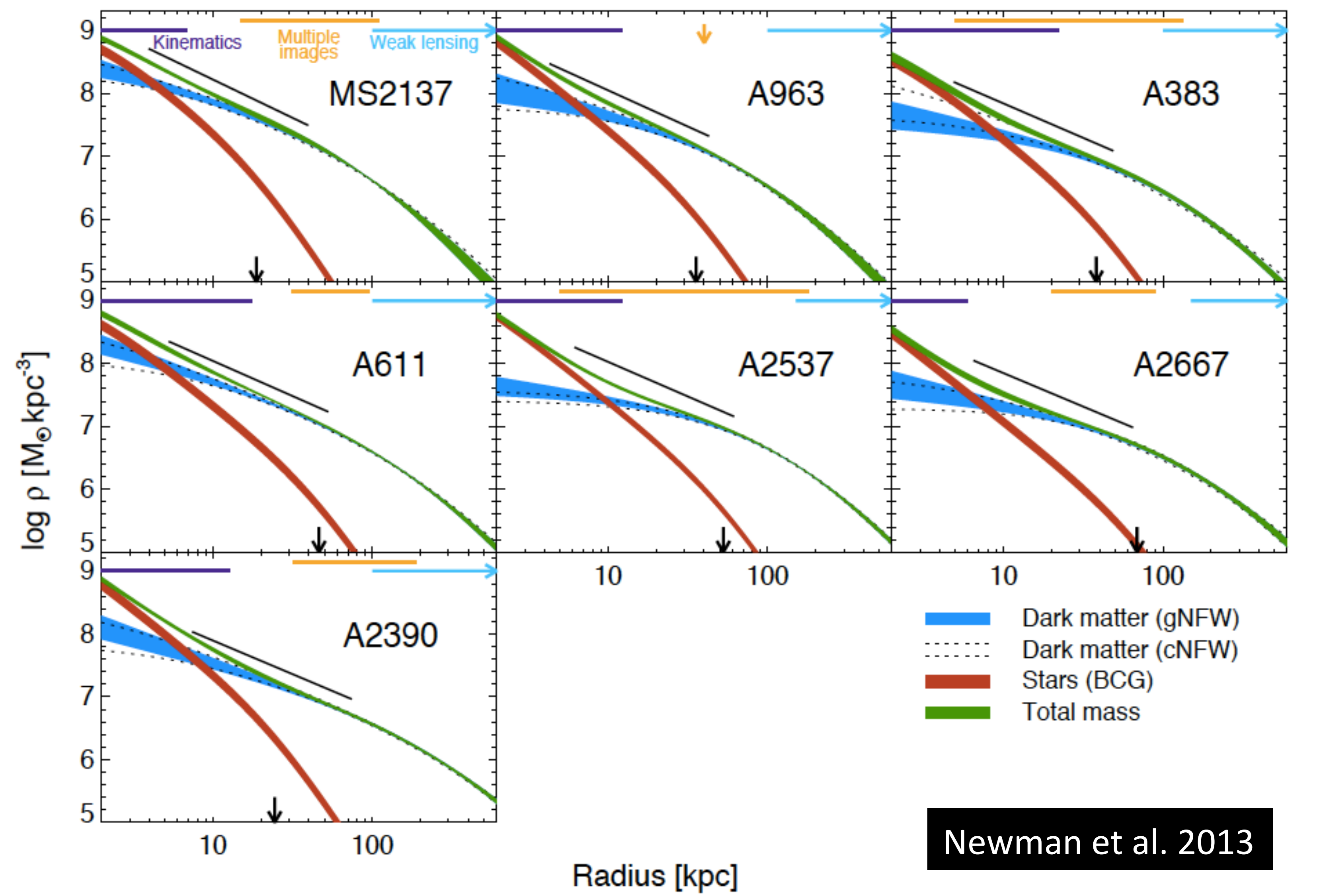
Sand, Treu & Ellis 2002

Strong lensing in MS2137

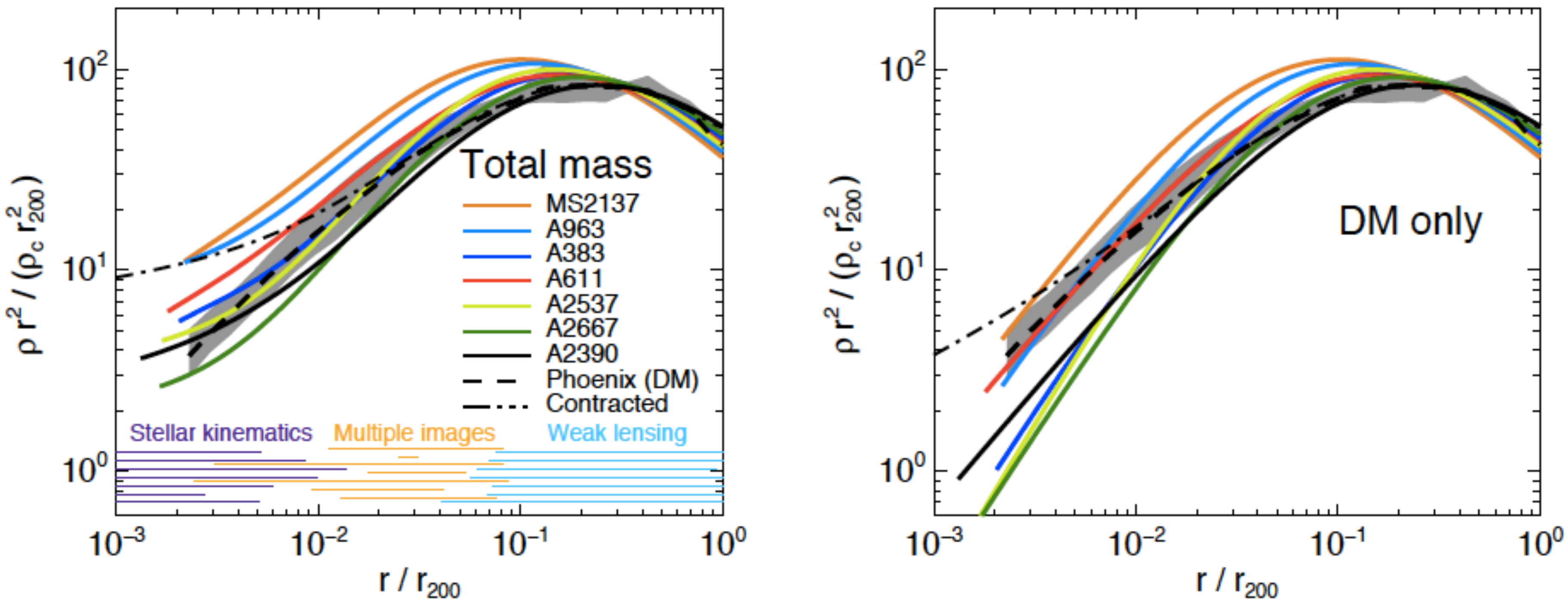


Gavazzi et al. 2003

Weak+Strong lensing+



Comparison with simulations



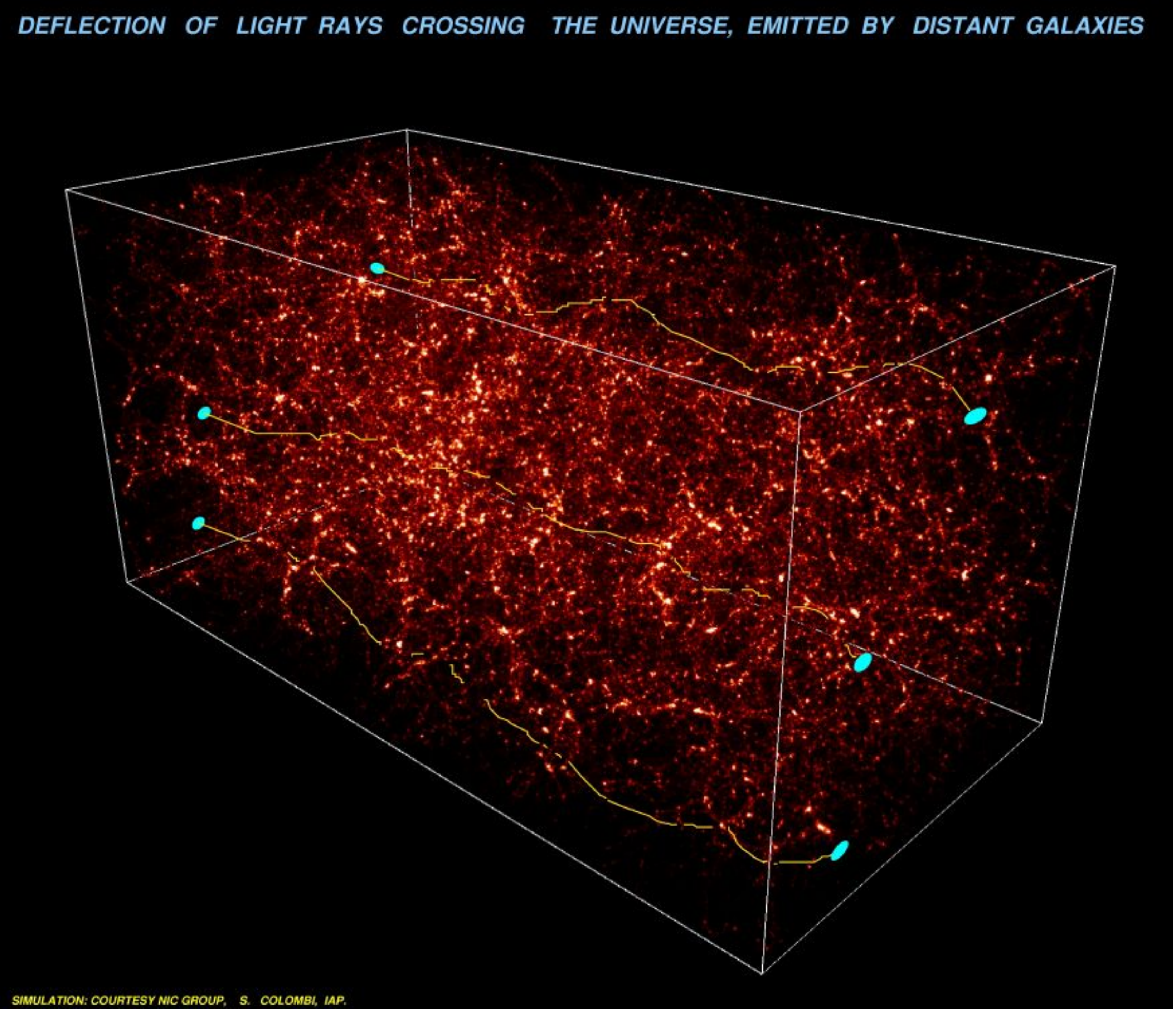
Baryons? Self interacting Dark matter?

Newman et al. 2013

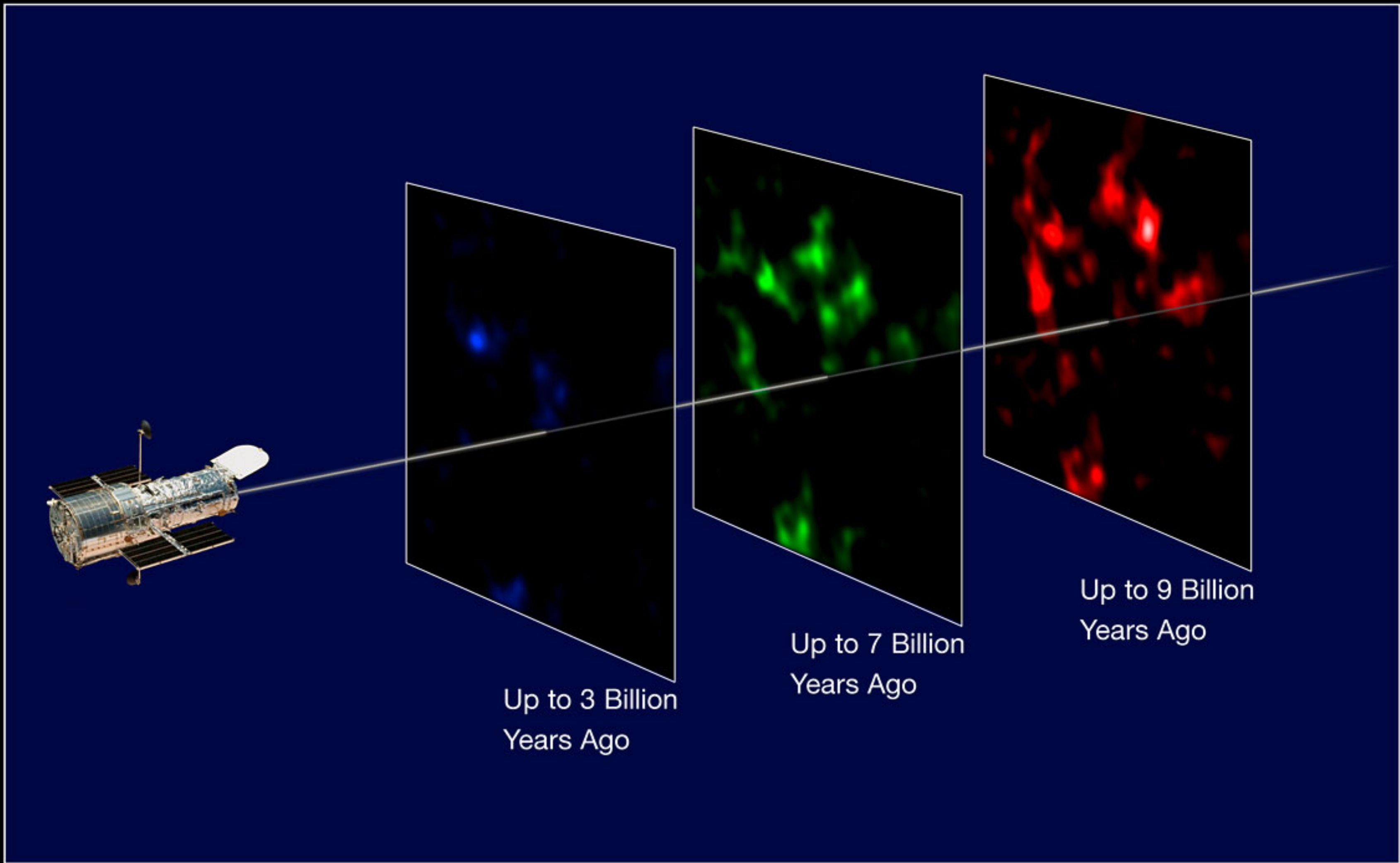
Lensing by LSS

- This is a vast topic that we won't have time to cover in any detail. If you are interested you can read all about in Schneider's chapter of the Saas Fee lectures.
- I'll give you just a brief introduction on the basic concepts

Weak Lensing by Everything



Tomography


Up to 3 Billion
Years Ago
Up to 7 Billion
Years Ago
Up to 9 Billion
Years Ago

Cosmic shear

- Cosmological information is better extracted from *cosmic shear statistics, which are simple functions of the underlying matter distribution*
  - identify lens plane and source plane galaxies (preferably by redshift)
  - measure background galaxy ellipticities
  - combine (noisy) ellipticities into noisy shear statistics

Correlation function:

$$\xi_{\pm}(\theta) = \langle \gamma_1(\boldsymbol{\phi})\gamma_1(\boldsymbol{\phi}+\boldsymbol{\theta}) \pm \gamma_2(\boldsymbol{\phi})\gamma_2(\boldsymbol{\phi}+\boldsymbol{\theta}) \rangle$$

$$\xi_{\times}(\theta) = \langle \gamma_1(\boldsymbol{\phi})\gamma_2(\boldsymbol{\phi}+\boldsymbol{\theta}) + \gamma_2(\boldsymbol{\phi})\gamma_1(\boldsymbol{\phi}+\boldsymbol{\theta}) \rangle$$

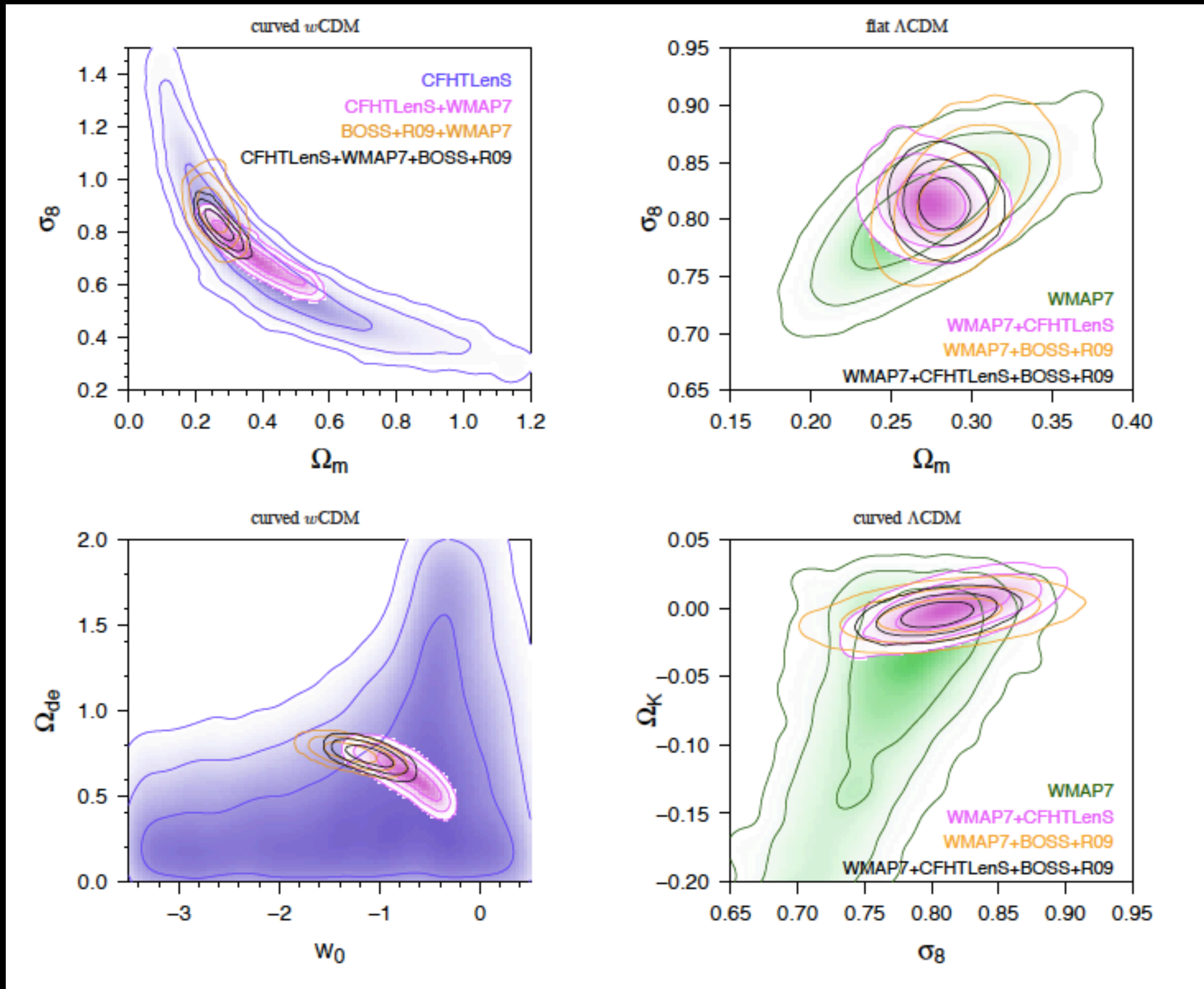
Shear variance:

$$\langle |\gamma|^2 \rangle(R) = \frac{1}{2}\int \frac{\theta^2}{R^2}\xi_{+}(\theta) S_{+}\left(\frac{\theta}{R}\right)$$

Aperture mass:

$$M_{\rm ap} = \int Q(R)\gamma_T(x,y)\,dx\,dy$$

Recent results from Cosmic Shear



Kilbinger et al. 2012

Some challenges with cosmic shear and tomography

- Shape measurements
- Intrinsic shape alignements
- Photo-zs

The end