Dark Matter & Dark Energy with Strong Lensing in Galaxy Clusters

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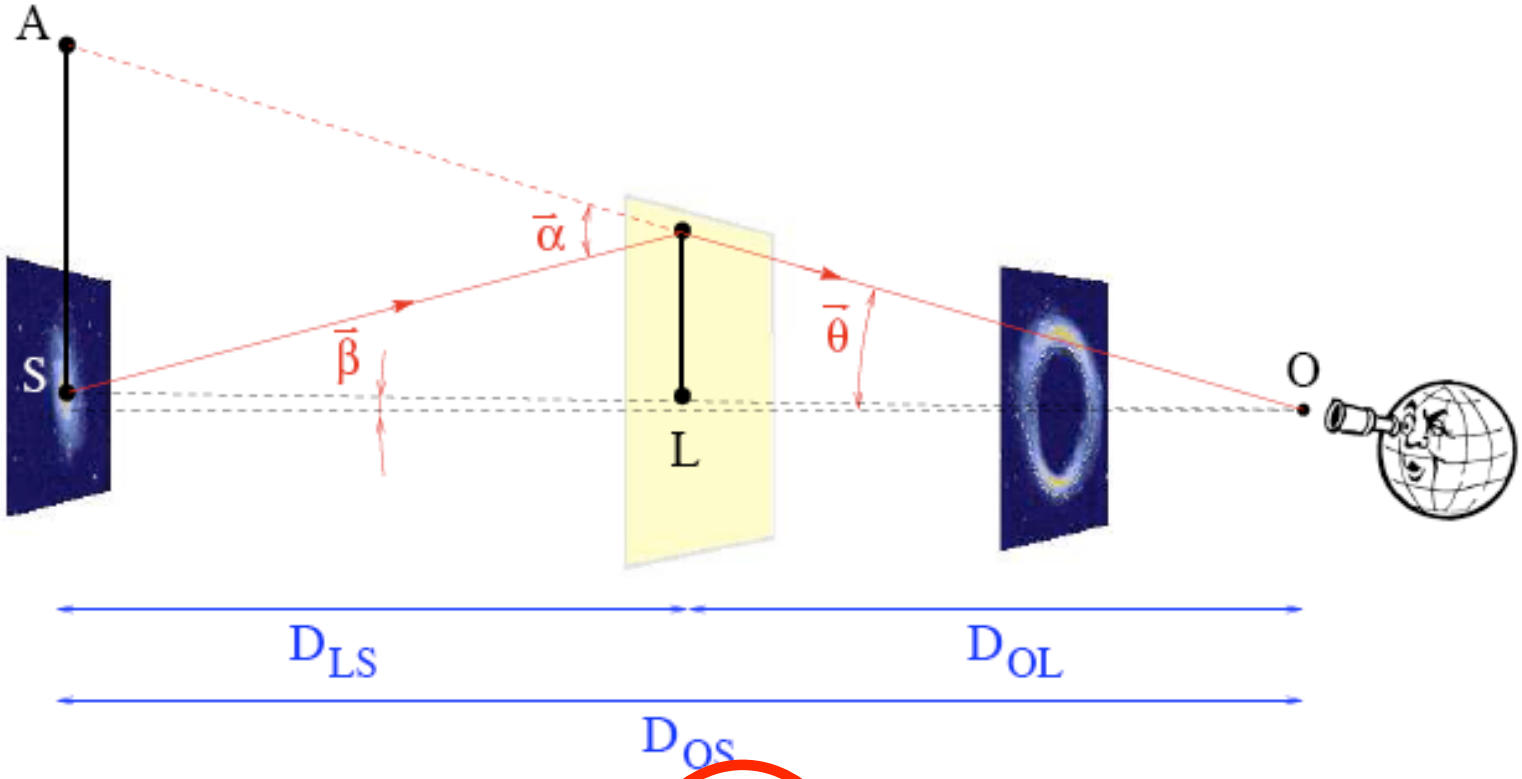
Motivation

- Cosmological probes (CMB, BAO, SNIa, etc)
- Cosmology with clusters
  - Cluster counts dn/dz
  - Mass function dn/dz/dm
  - Luminosity function X-Rays, scaling relations…
  - Arc statistics
  - Cluster Strong Lensing test (CSL)
  - DM indirect detection (gamma rays, axions,…)

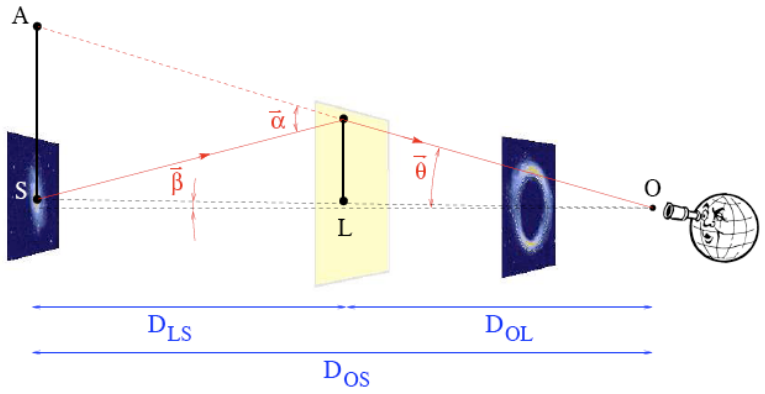
Cluster Strong Lensing test



$$\beta = \theta - \frac{D_{LS}}{D_{OS}} \nabla\phi(\theta)$$

Strength of E1/E2 ratio

$$\beta = \theta - \frac{D_{LS}}{D_{OS}} \nabla\phi(\theta)$$



For 2 Einstein rings and an SIS potential :

$$\theta_{E1} = 4\pi\left(\frac{\sigma_0}{c}\right)^2 E_1$$

$$\theta_{E2} = 4\pi\left(\frac{\sigma_0}{c}\right)^2 E_2$$

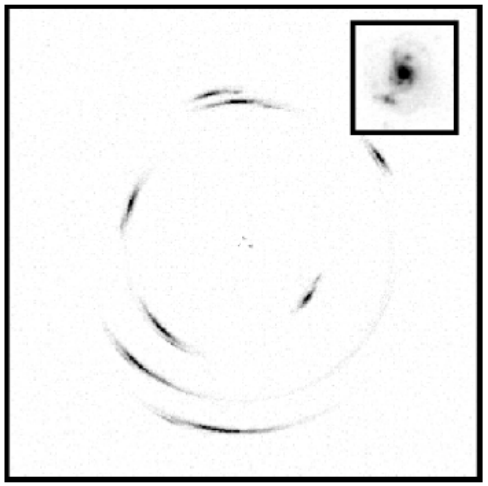
$$\Rightarrow \quad \frac{\theta_{E1}}{\theta_{E2}} = \frac{E_1}{E_2}$$

σ_0 disappears!

History of CSL

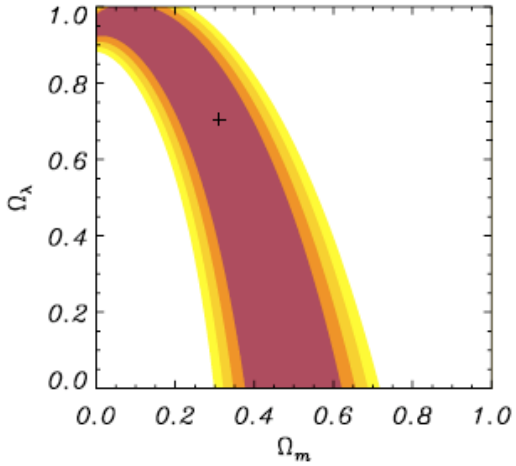
Link & Pierce 1998

- Simulation with SIS and grav. arcs
- Requirements for cosmology:
  - Astrometric uncertainties 0.1”
  - Spectroscopic redshifts

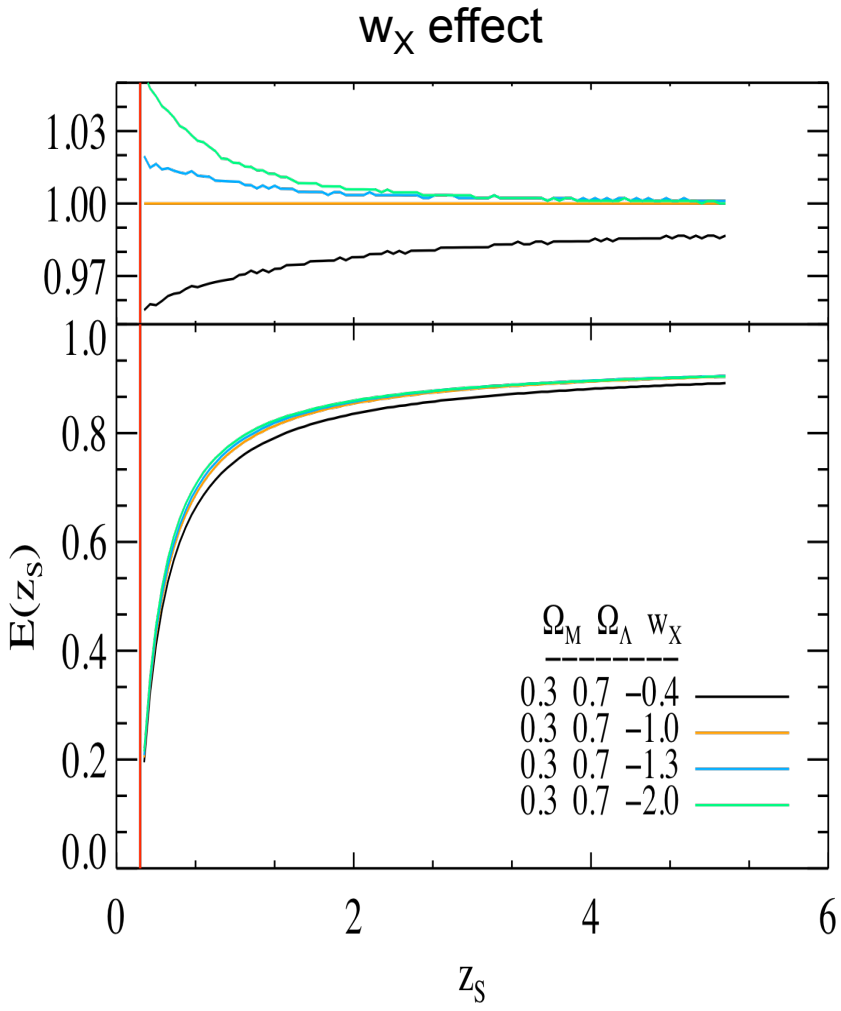


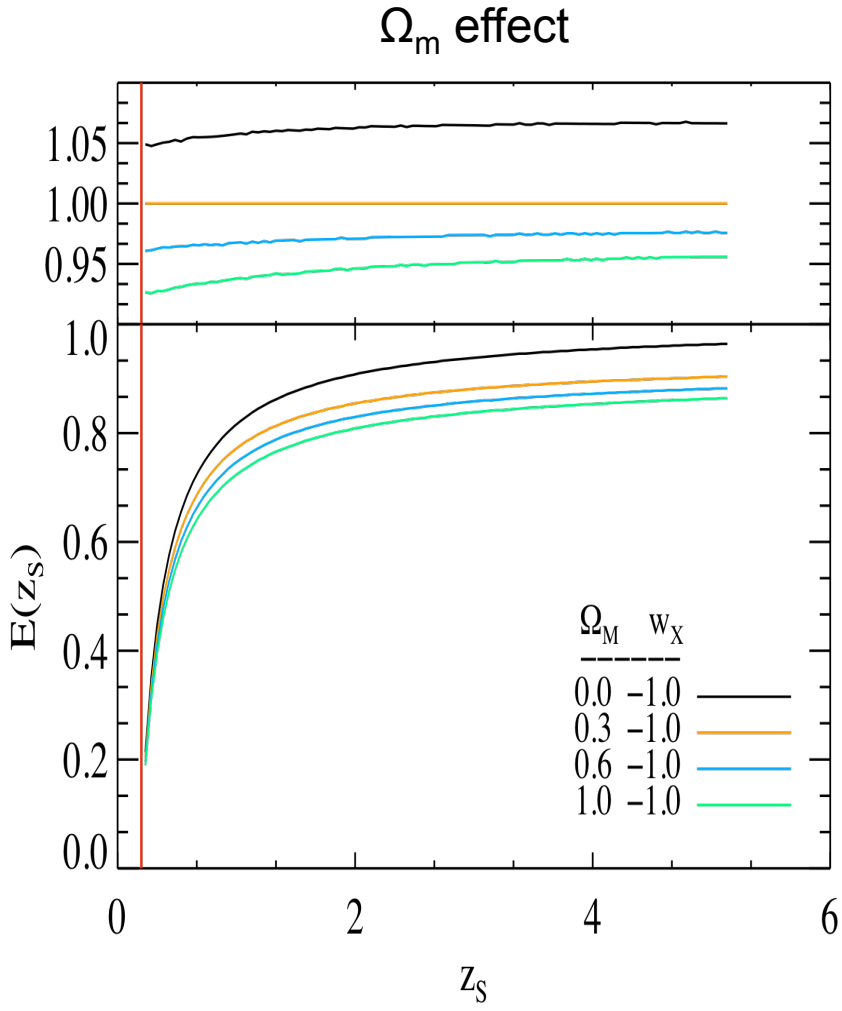
Golse et al. 2002

- number of redshifts > 3
- Detailed lens model with
  - cluster member galaxies
  - bi-modal distribution

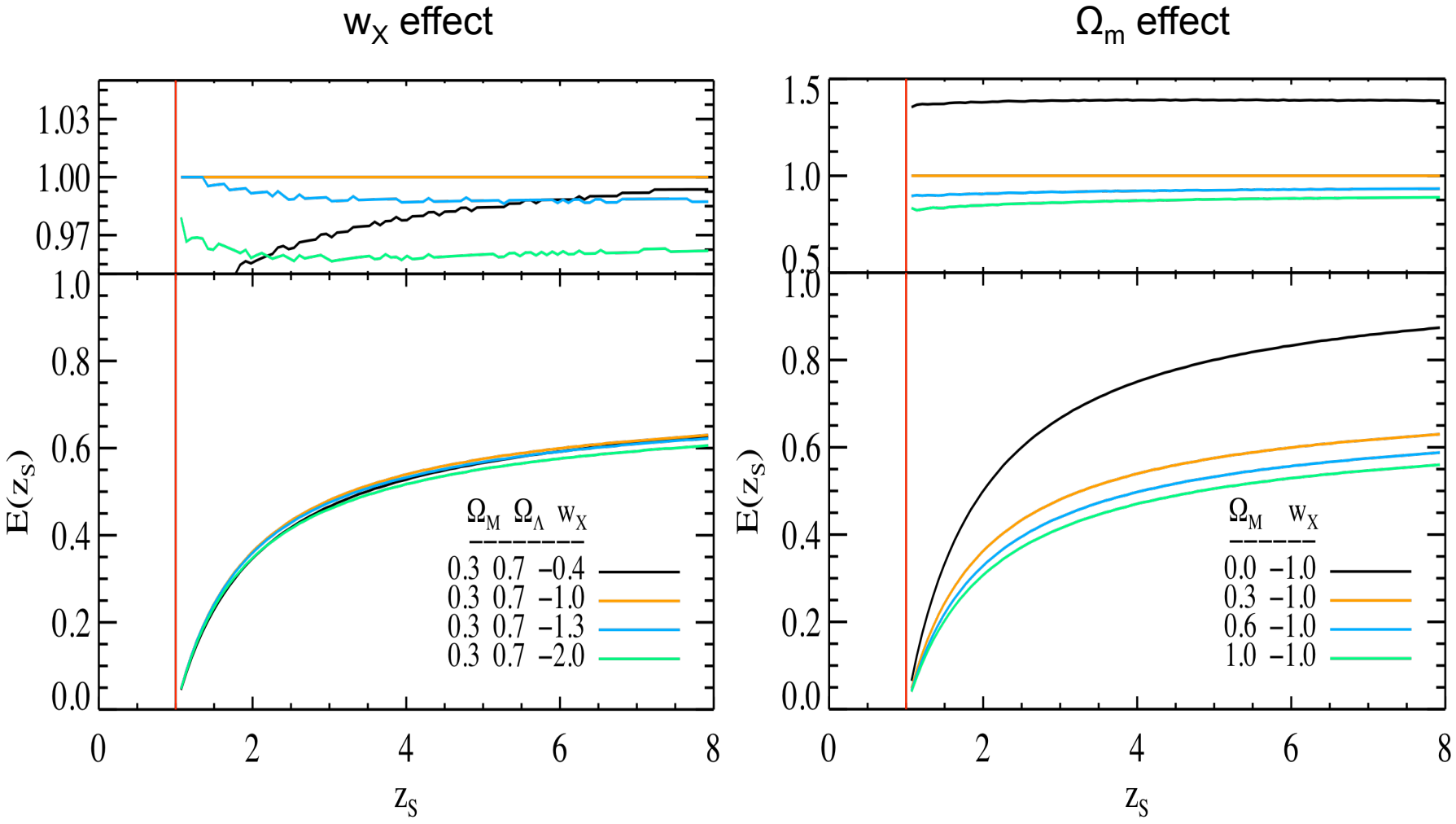


Efficiency ratio E=DLS/DOS (low z_L)





Efficiency ratio E=DLS/DOS (high z_L)



Dark energy with galaxies

Turner et al. 1997 + Flat Universe

$$w \equiv p_X / \rho_X$$

$$\left(\frac{H}{H_0}\right)^2 = \Omega_m (1+z)^3 + (1+z)^{3(w_x+1)} \Omega_X$$

$$\Omega_X = 1 - \Omega_m$$

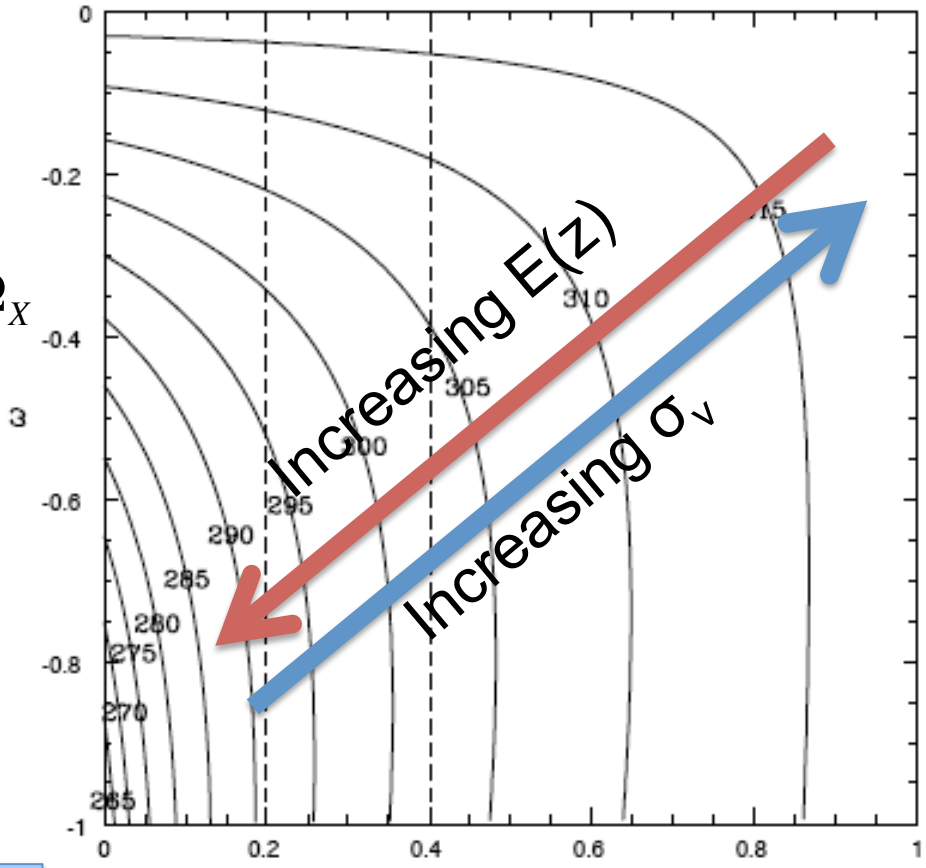
Einstein radius for an SIS :

$$\theta_E = 4\pi \left(\frac{\sigma_v}{c}\right)^2 \frac{D_{ls}}{D_s}$$

σ_0 must be known within ~1%

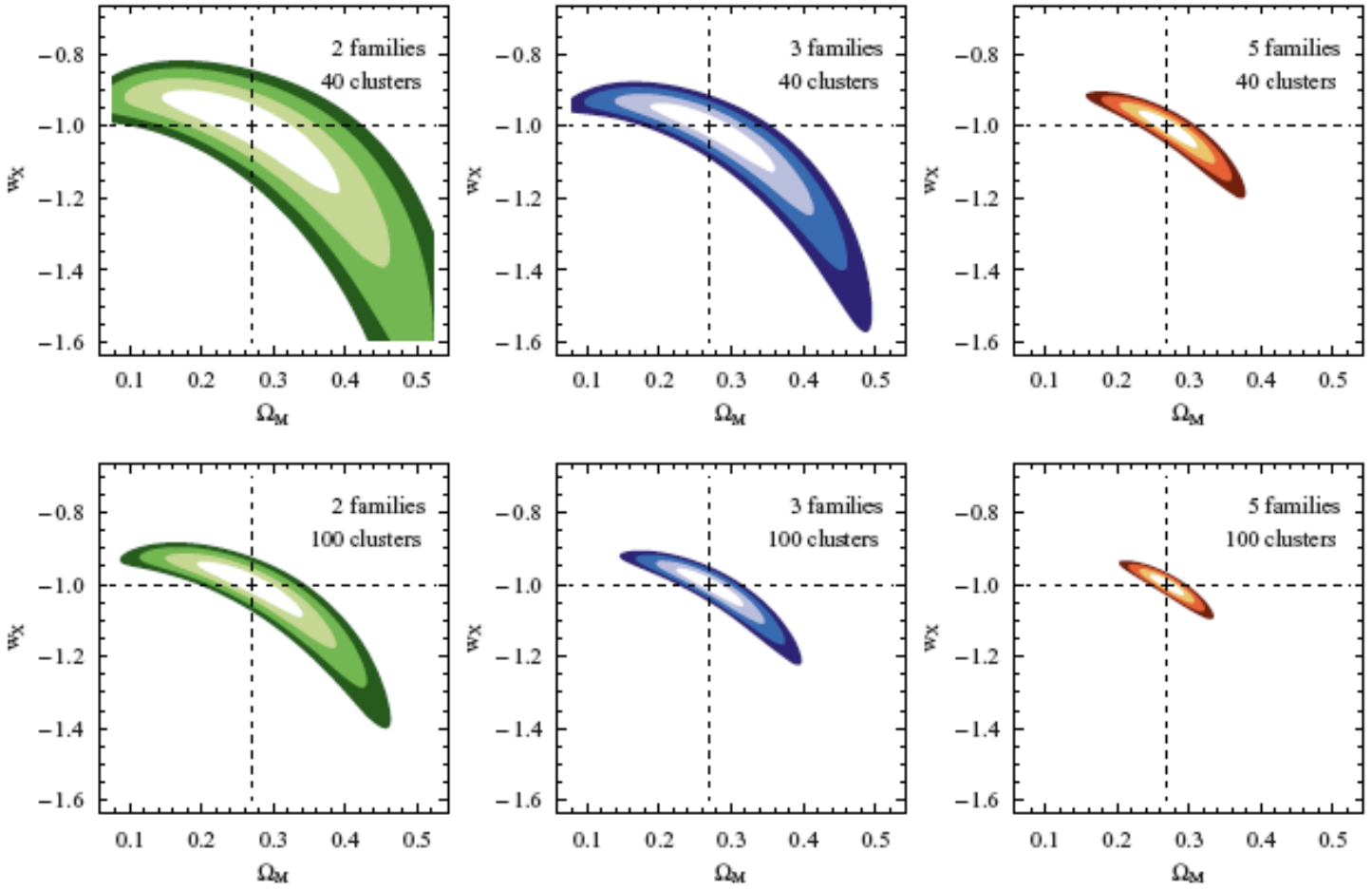
Chiba & Takahashi 2002

---> Too hard



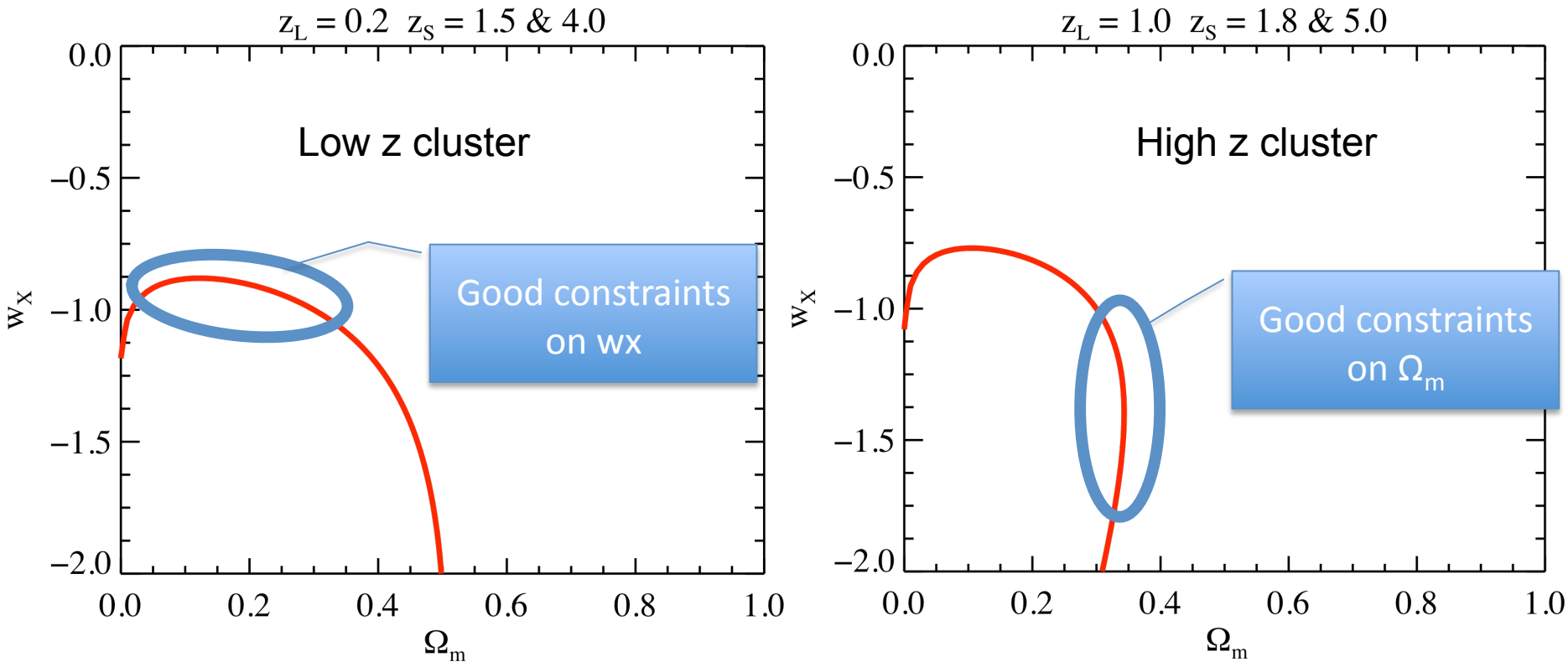
Futamase et al. 2001
Ohyama et al. 2002

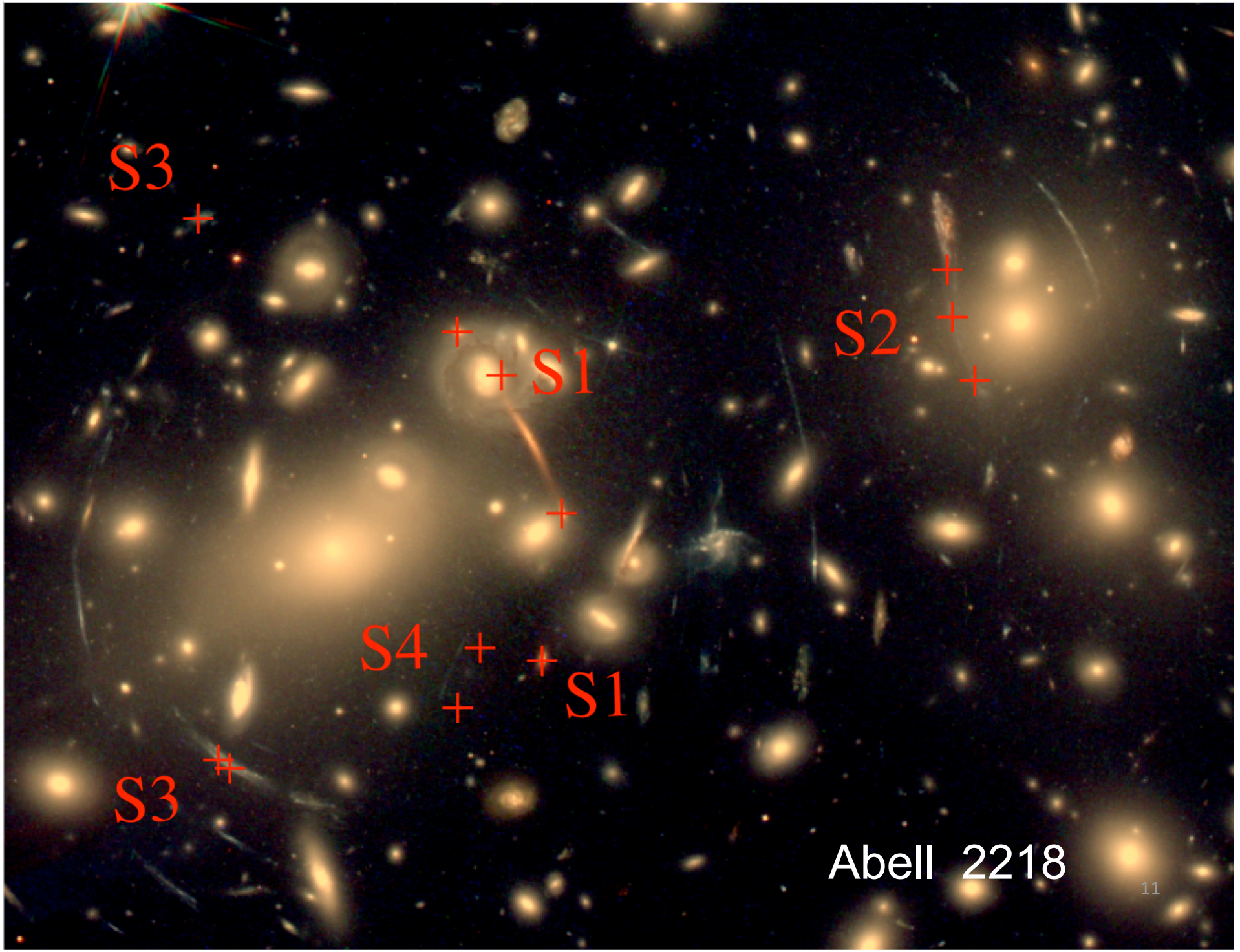
Dark energy estimation with clusters



Gilmore & Natarajan 2009

Combination $E1(z_L,z_{s1})/E2(z_L,z_{s2})$

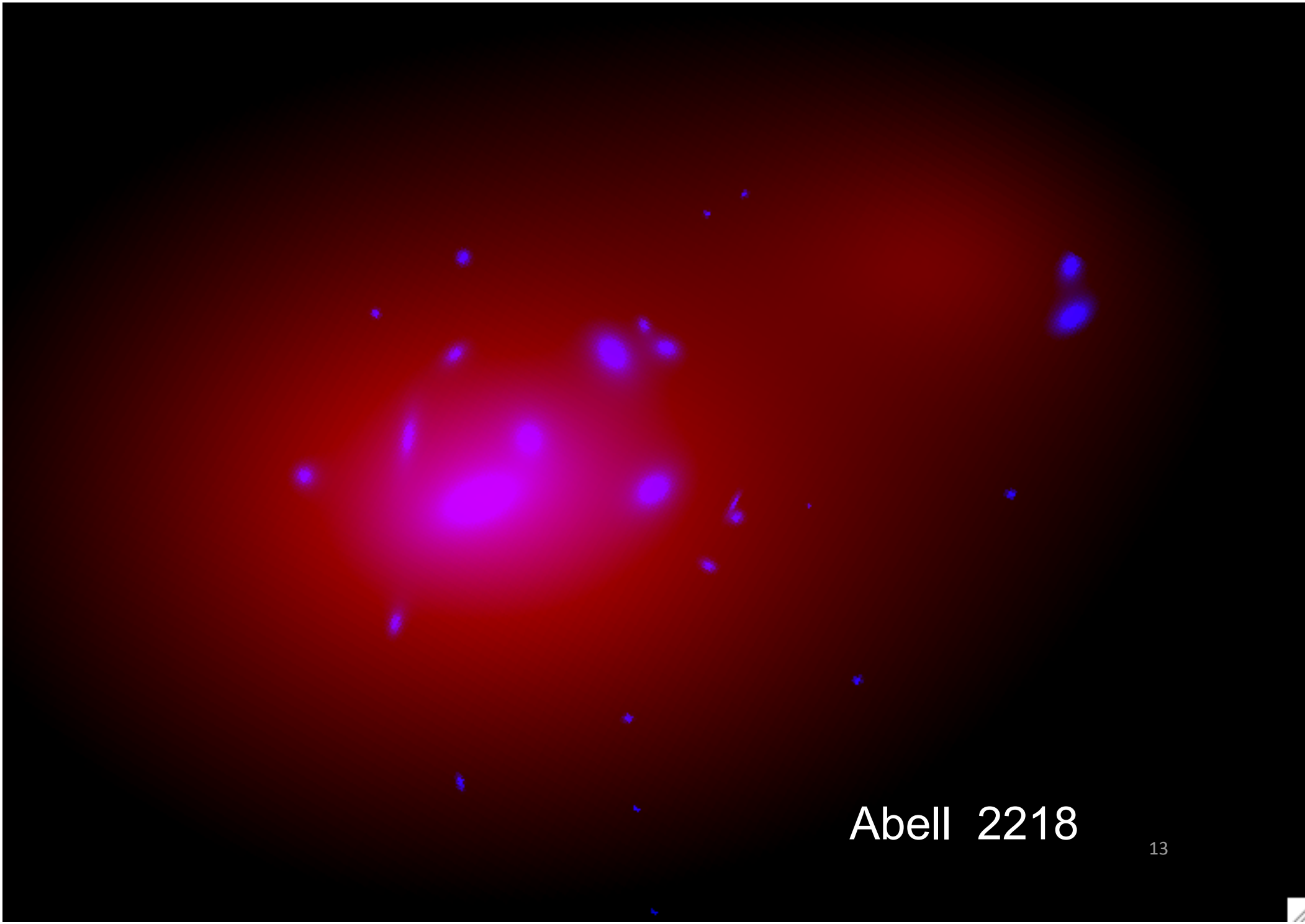



S3
S1
S2
S4
S1
S3
Abell 2218

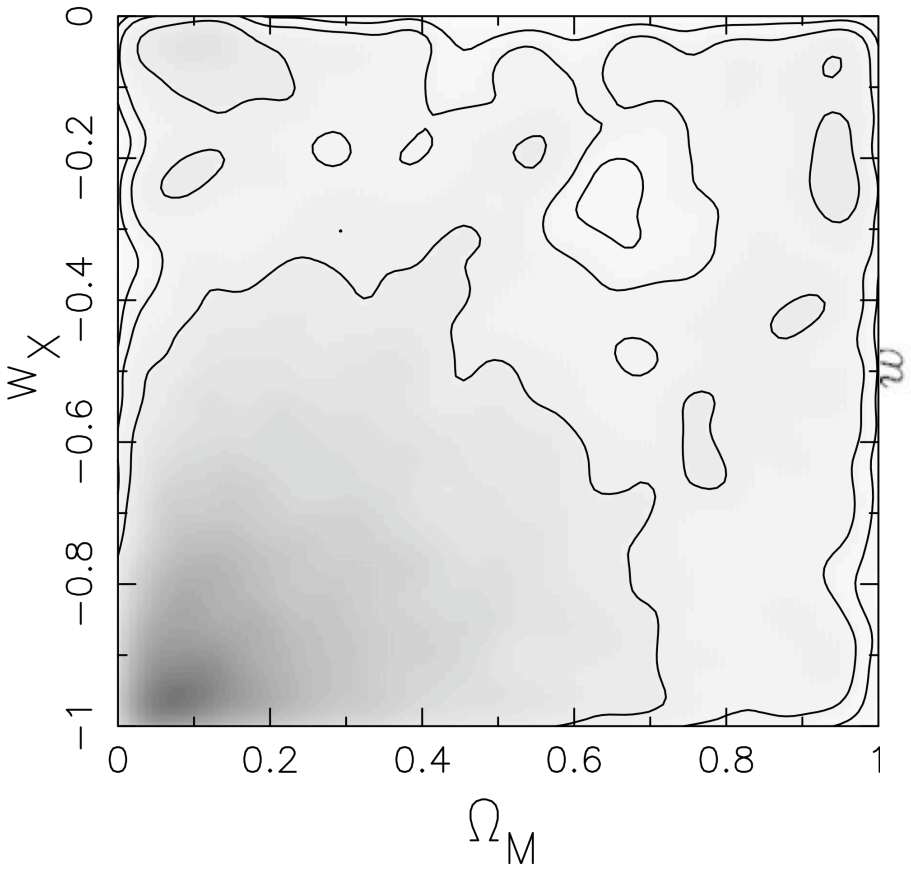
A2218 model

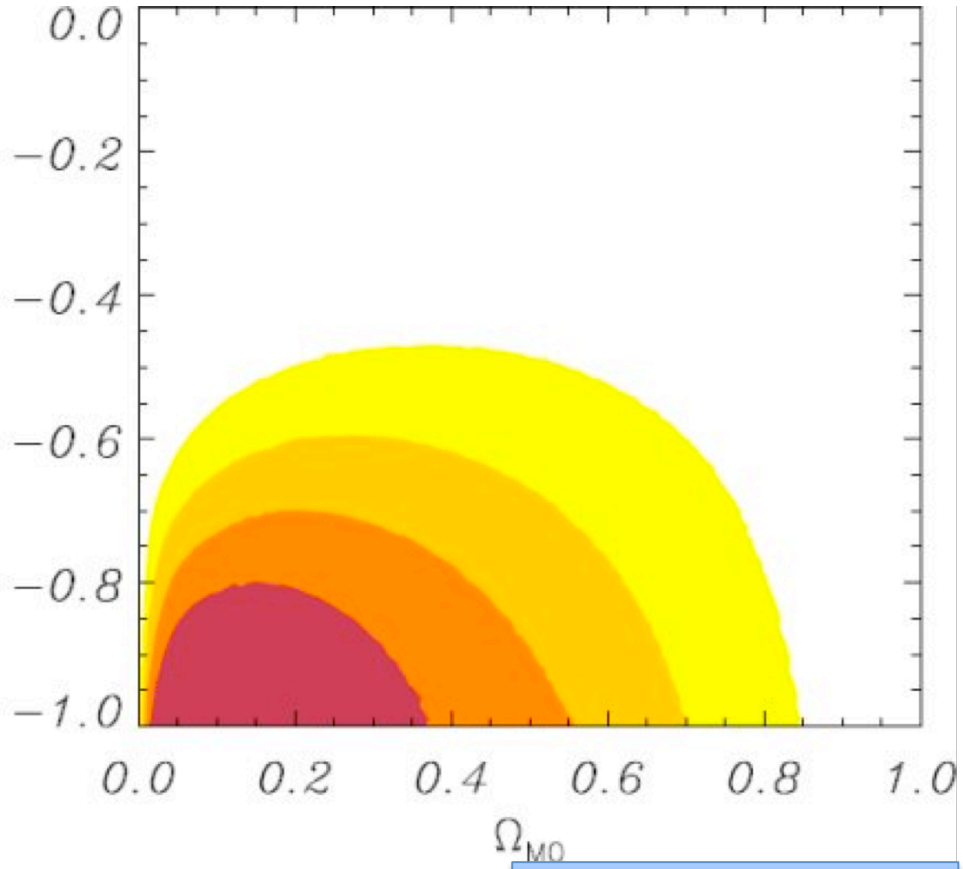
- Parametric model (Soucail et al. 2004)
  - 2 cluster-scale + 3 galaxy-scale (PIEMD potentials)
  - cluster member galaxies (mass scales with luminosity)
  - cosmological parameters (Ω_m & w_X)
  - > 19 free parameters

- Lenstool & Bayesian MCMC sampler (Kneib et al 2003, Jullo et al. 2007)


Abell 2218

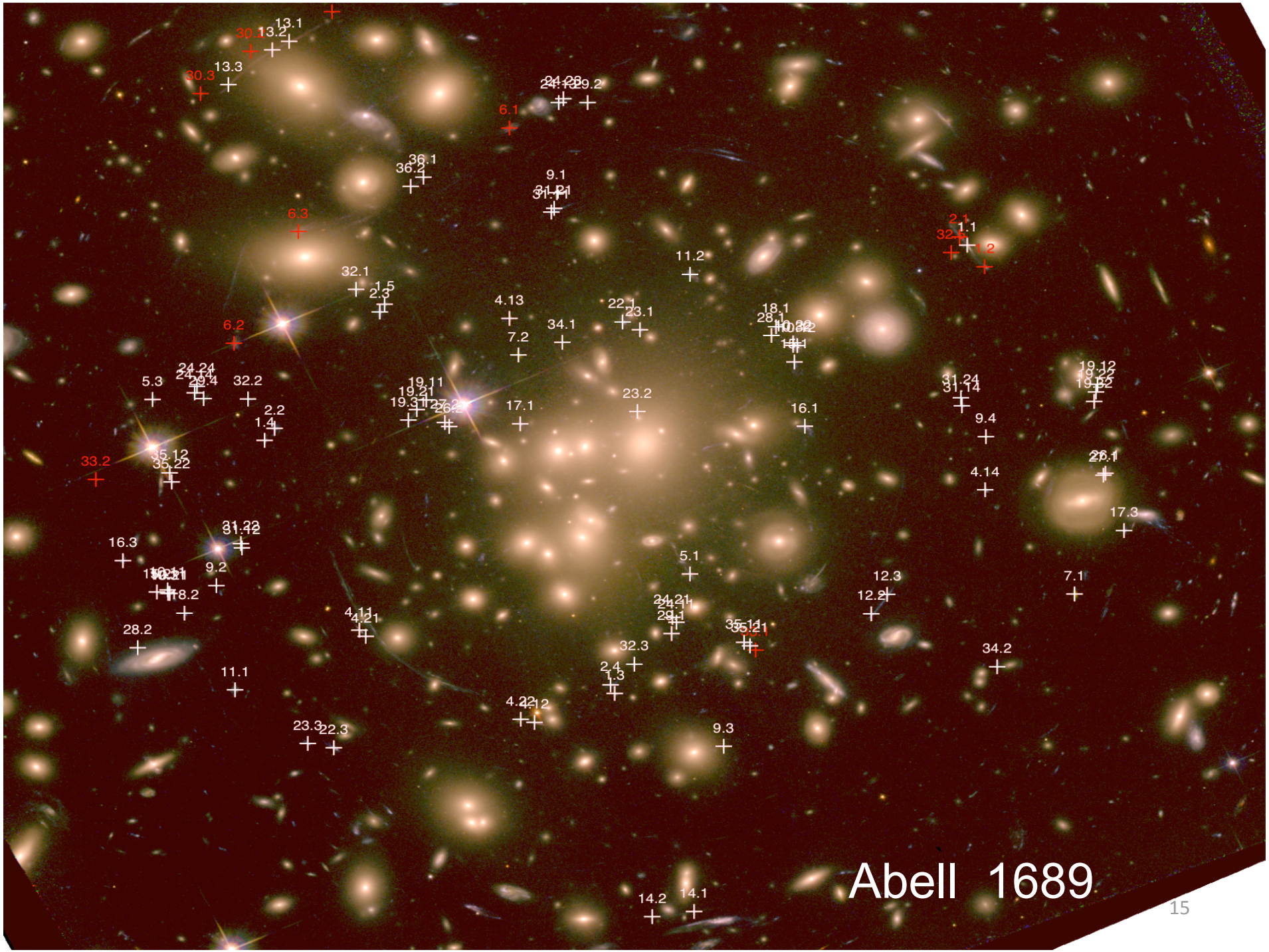
Results





$\Omega_m < 0.7$ & $w_X < 0.4$ @ 1σ

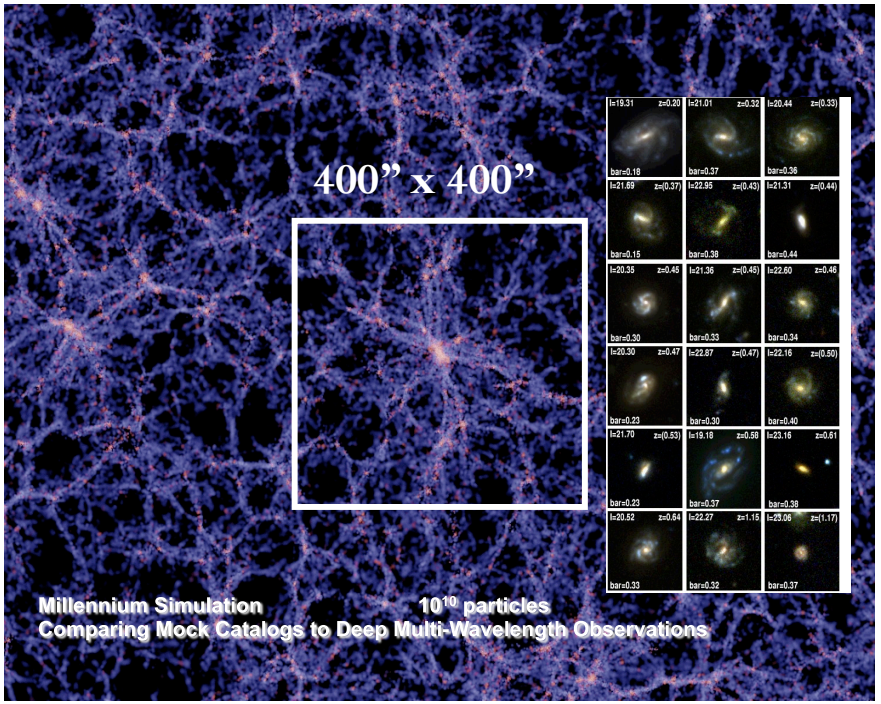
Soucail et al. 2004


Abell 1689

Investigating Systematic errors

Line of Sight perturbations

- LOS induced deflections ~ 2''
  - Halo catalog from Millennium Simulation
    - L = 500 h^{-1} Mp $\sigma_8 = 0.9$ $\Omega_m = 0.25$ $n = 1$ $\Omega_\Lambda = 0.75$
  - 42 snapshots z = 0.06 --> 4.89
  - 1000 Realizations by picking halos in random beams of 400''x400'' along random directions in each snapshot
  - Assign an NFW to each halo
    - c200 = f(M200) (Gao et al. 2008)
  - Multiplane lensing through the 42 planes



Springel et al. 2005

Investigating Systematic errors

Scaling Relations

- Scatter in the scaling relations ~ 1”

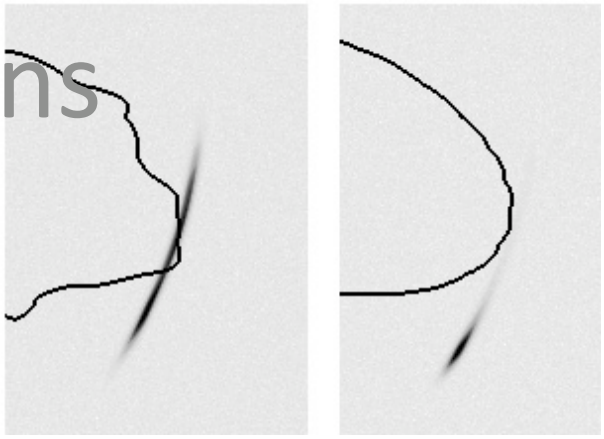
PIEMD parameters
20% scatter

$$\begin{cases} \sigma_0 = \sigma_0^\star \left(\frac{L}{L^\star}\right)^{1/4}, \\ r_{\rm core} = r_{\rm core}^\star \left(\frac{L}{L^\star}\right)^{1/2}, \\ r_{\rm cut} = r_{\rm cut}^\star \left(\frac{L}{L^\star}\right)^{\alpha}. \end{cases}$$

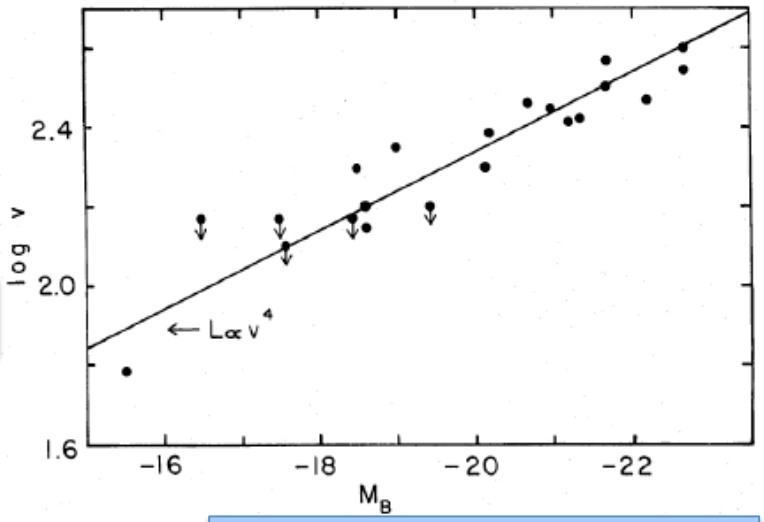
The total mass of a subhalo scales then as:

$$M = (\pi/G)(\sigma_0^\star)^2 r_{\rm cut}^\star (L/L^\star)^{1/2+\alpha},$$

Jullo et al. (2007)

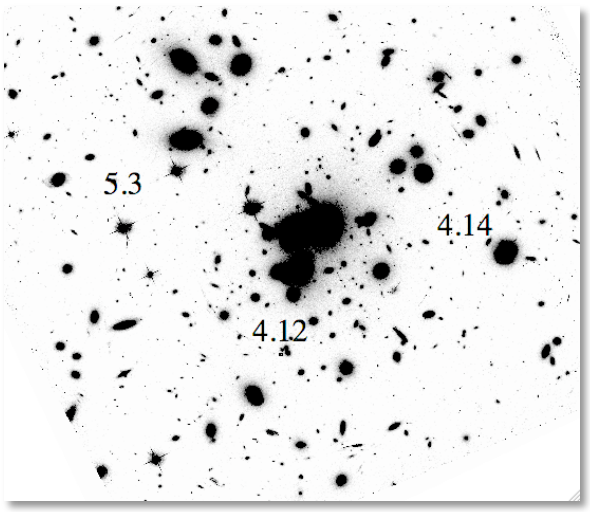


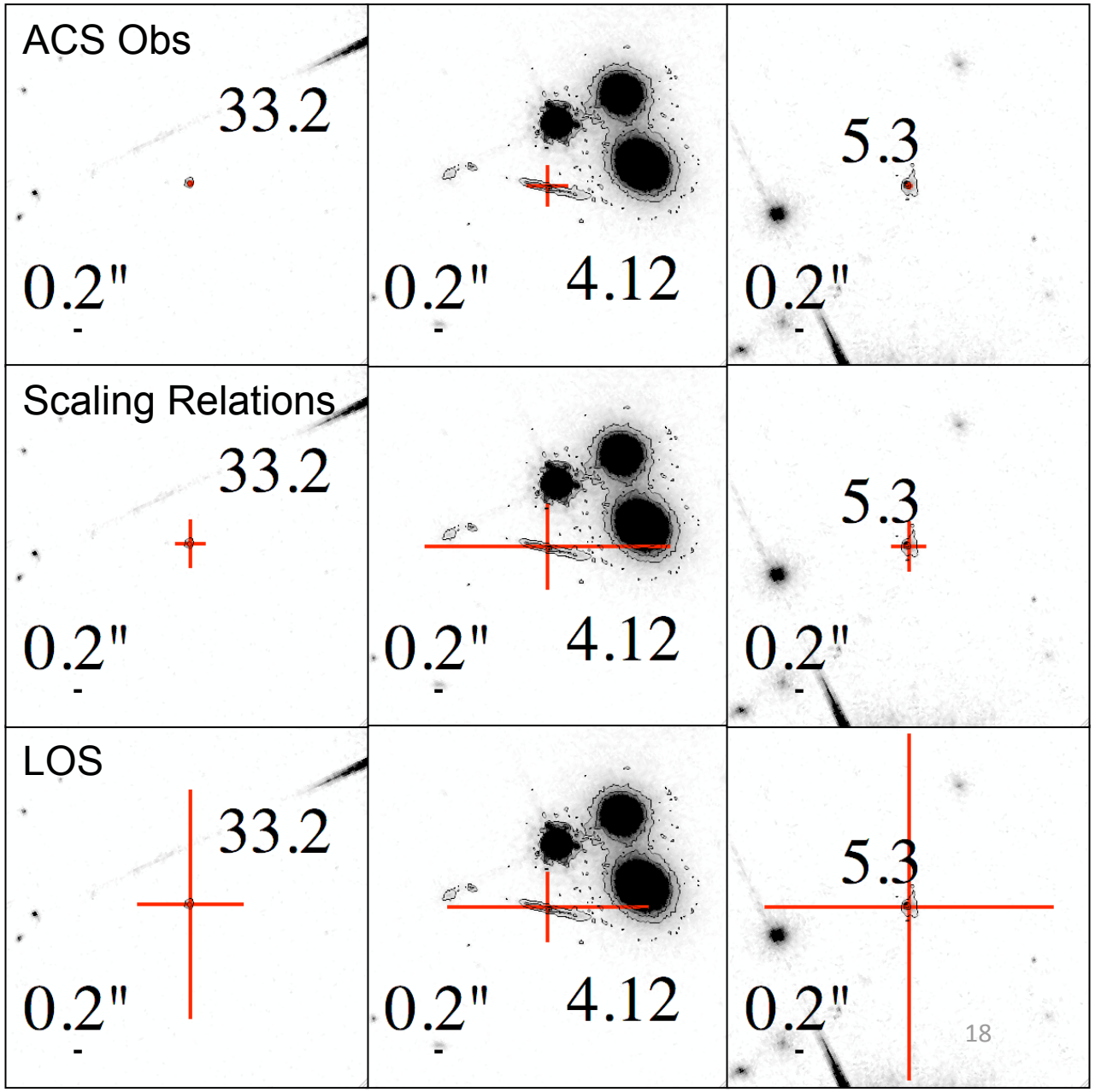
Meneghetti et al. 2007



Faber & Jackson (1976)

– > Images are weighted in χ^2 INDIVIDU


5.3
4.14
4.12

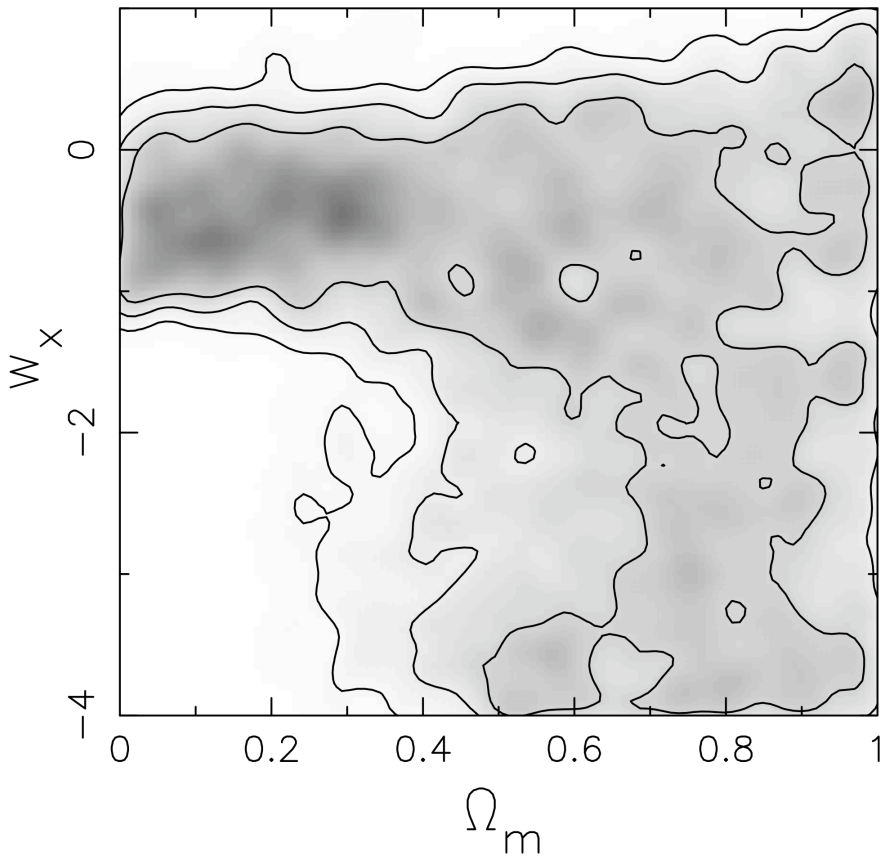

ACS Obs
33.2
0.2"
4.12
0.2"
5.3
0.2"
Scaling Relations
33.2
0.2"
4.12
0.2"
5.3
0.2"
LOS
33.2
0.2"
4.12
0.2"
5.3
0.2"

Abell 1689 model

- Model based on Limousin et al. 2007
  - 2 cluster-scale PIEMD halos
  - 1 galaxy-scale PIEMD halo for the central BCG
  - cluster member galaxies (mass scales with L)
  - cosmological parameters Ω_m & w_X
  - > 21 free parameters

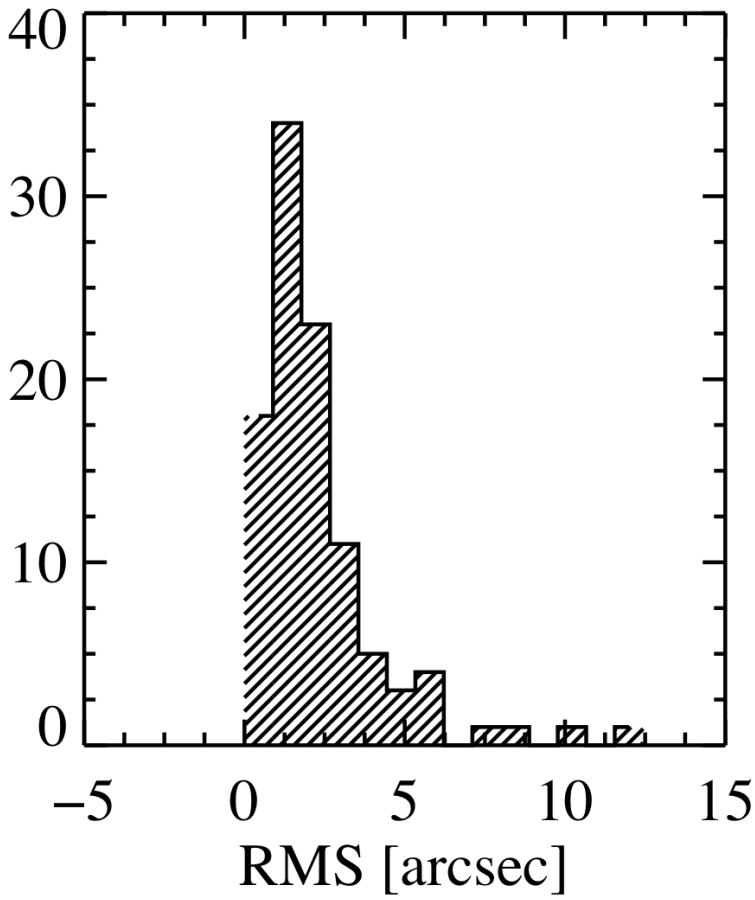
Results with 103 images

- Images with RMS > 10”
  - misidentification
  - badly modeled images



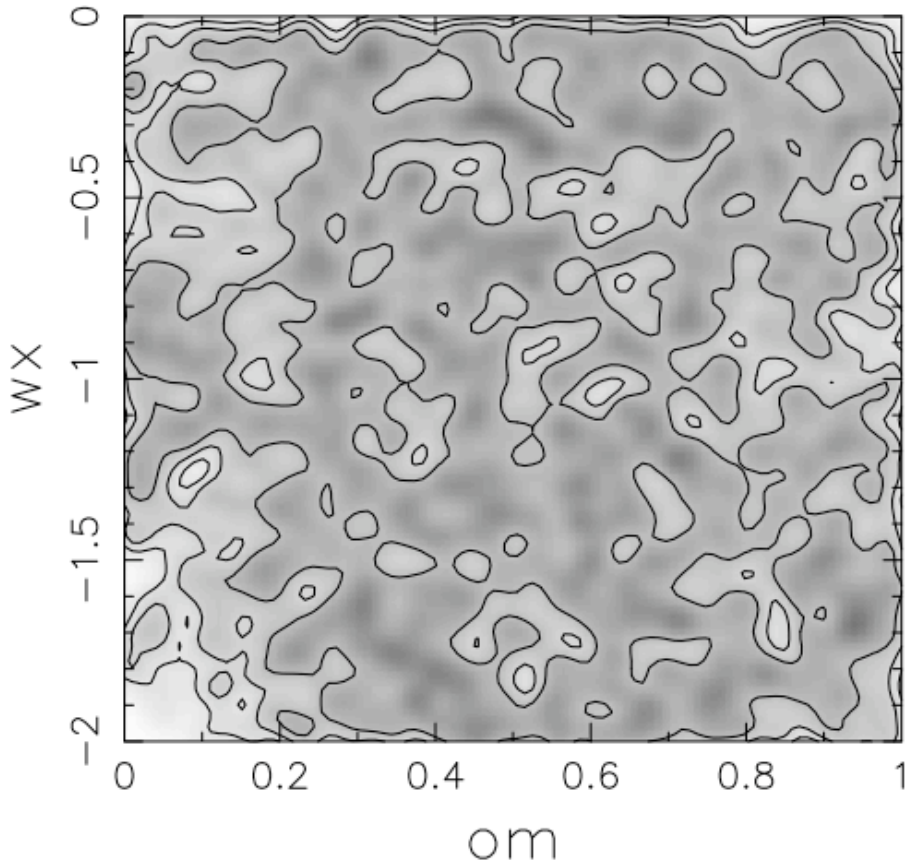
Results with 103 images

- Images with RMS > 10”
  - misidentification
  - badly modeled images
- 2σ clipping < 5’’
  - > 87 images
  - > 24 redshifts

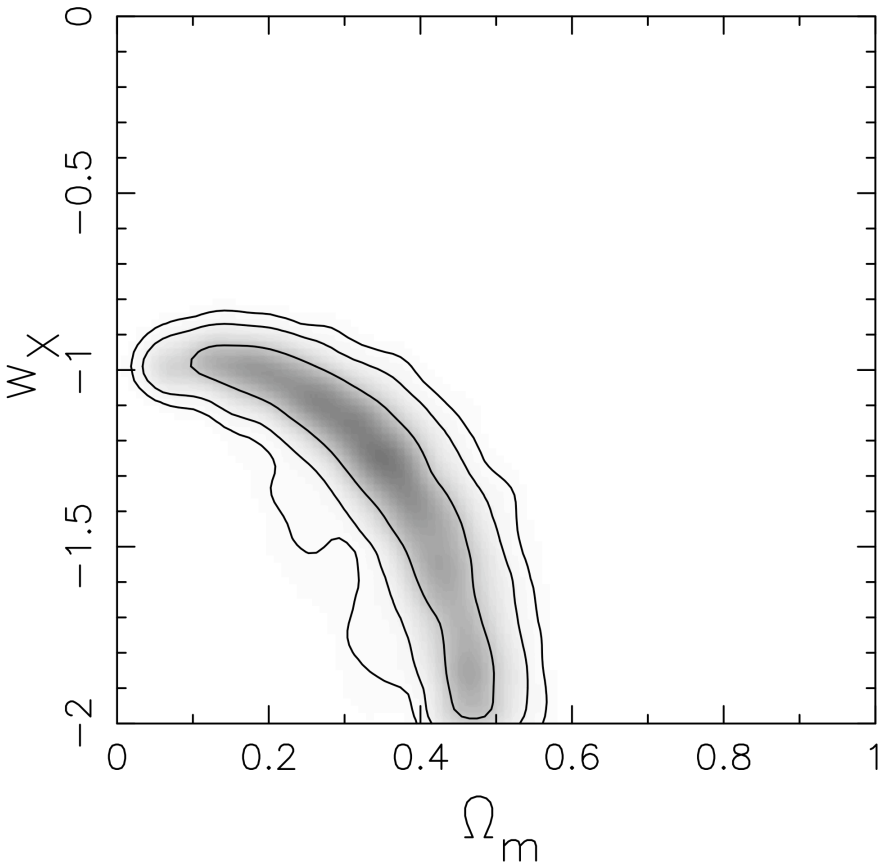


Results with 87 images (big errors)

- No constraints!
- chi2 ~ 0.08
  - > errors are underestimated

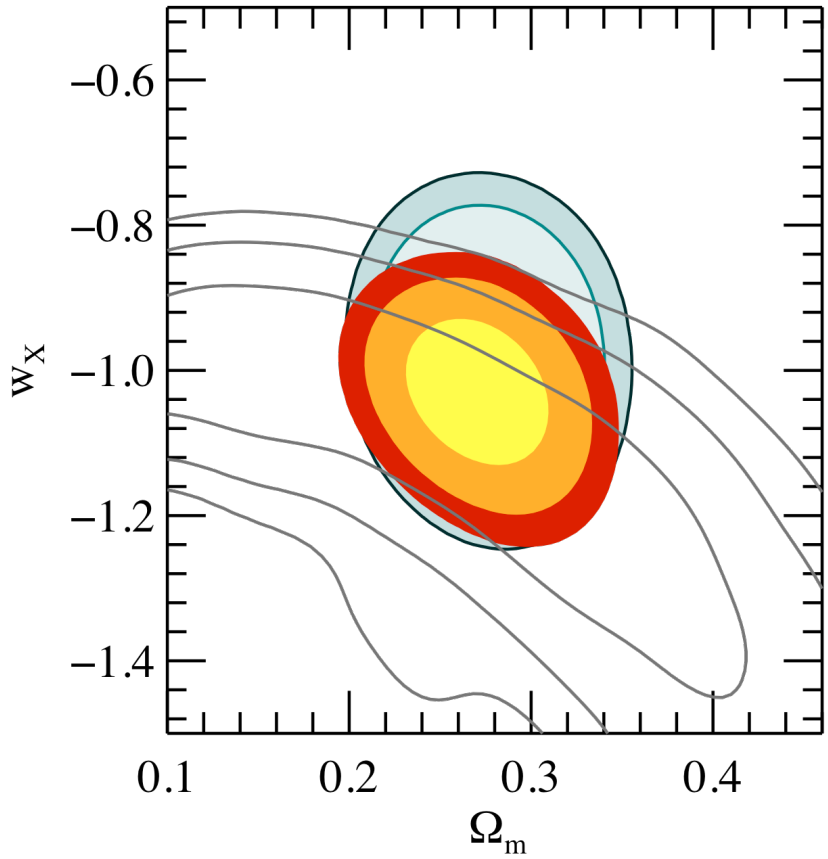


Results with 87 images (small errors)



chi2 ~ 21.4

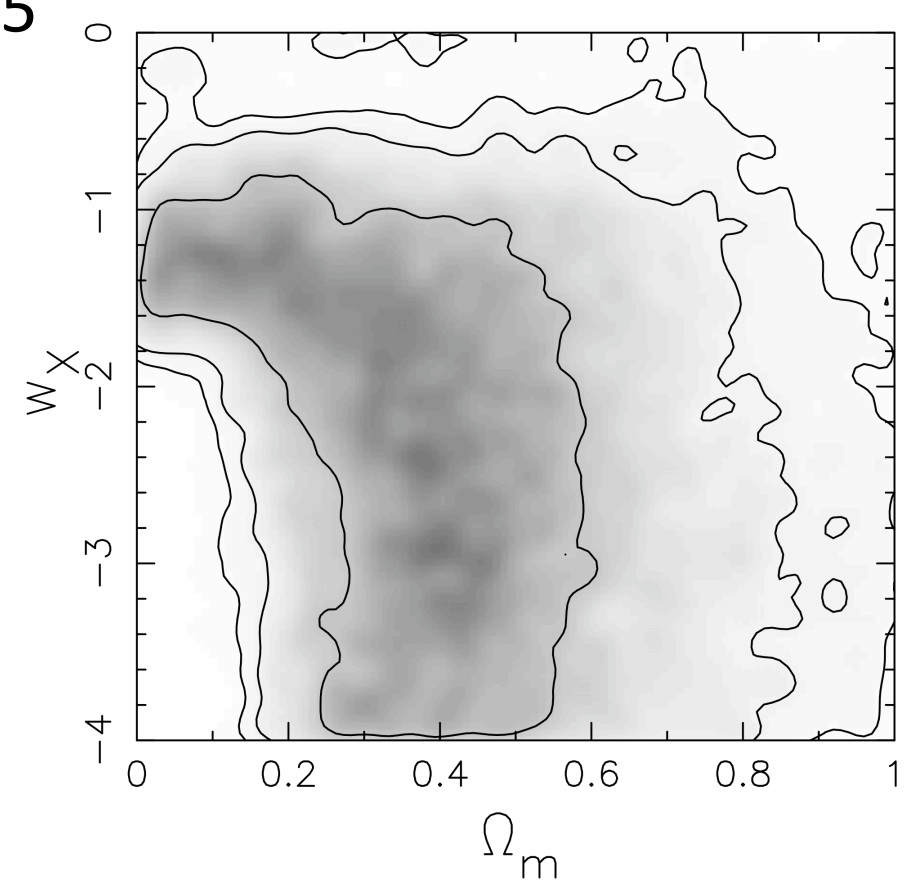
Abell 1689 + CMB + BAO + SNIa



$0.20 < \Omega_m < 0.32 \quad -1.25 < w_X < -0.84$

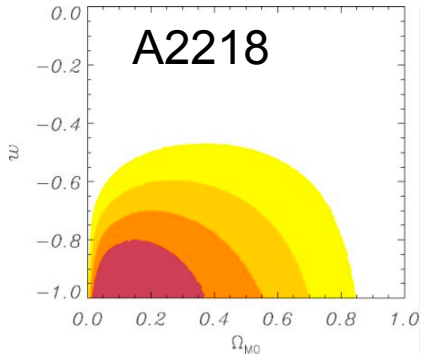
Final test

- Assuming systematics: 0.5’’
- chi2 ~ 1
  - > Constraints are biased if errors are not properly estimated

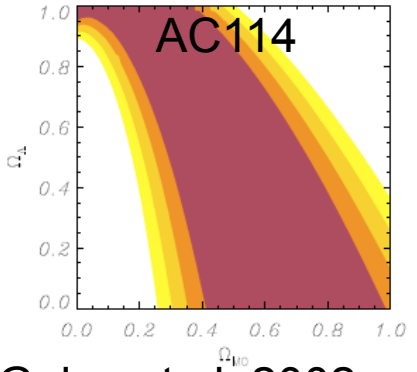


Conclusion

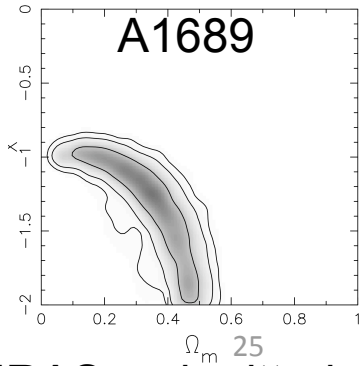
- Now 3 clusters studied with this test
- Lens model biases cosmology
- Clusters combination can:
  - transform systematic to statistic errors
- Low z clusters to constrain w_X
- High z clusters to constrain Ω_m



Soucail et al. 2004



Golse et al. 2002

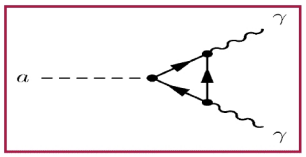


Jullo et al., MNRAS, submitted

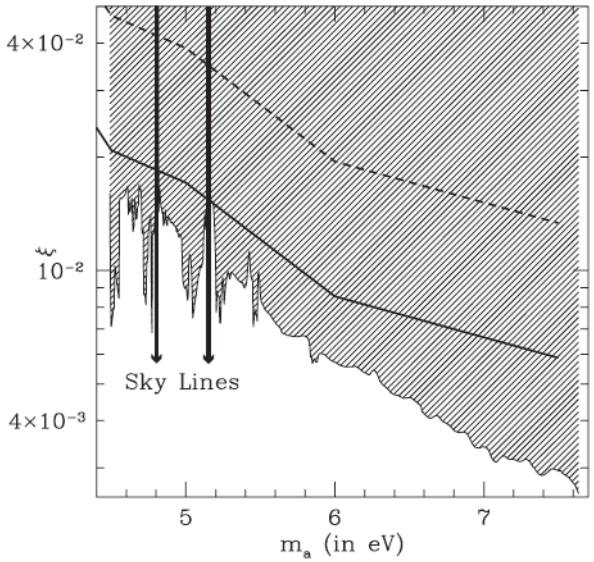
Grin et al. 2007

Indirect detection of Axions

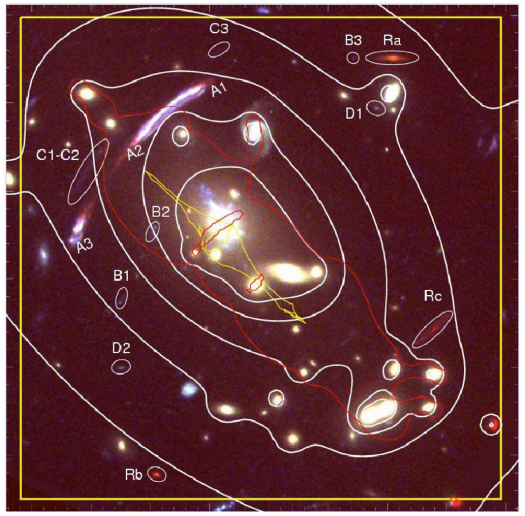
Axion to 2 photons coupling



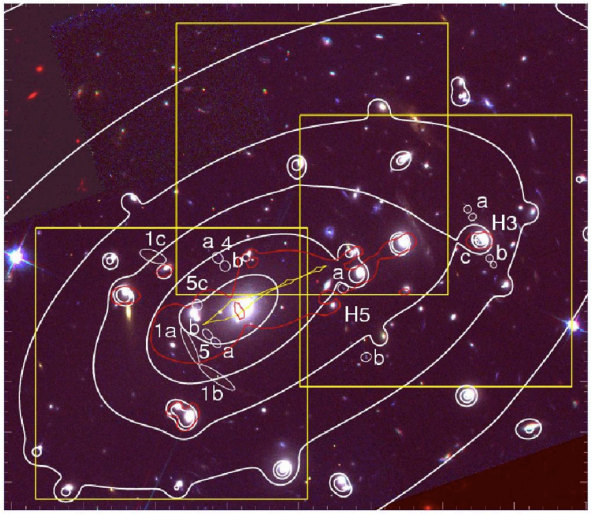
$$I_{\lambda_o} = 2.68 \times 10^{-18} \times \frac{m_{\mathrm{a,eV}}^7 \xi^2 \Sigma_{12} \exp[-(\lambda_r - \lambda_\mathrm{a})^2 c^2/(2\lambda_\mathrm{a}^2\sigma^2)]}{\sigma_{1000}(1+z_{\mathrm{cl}})^4 S^2(z_{\mathrm{cl}})} \ \mathrm{cgs}, \quad (4)$$



Current constraints

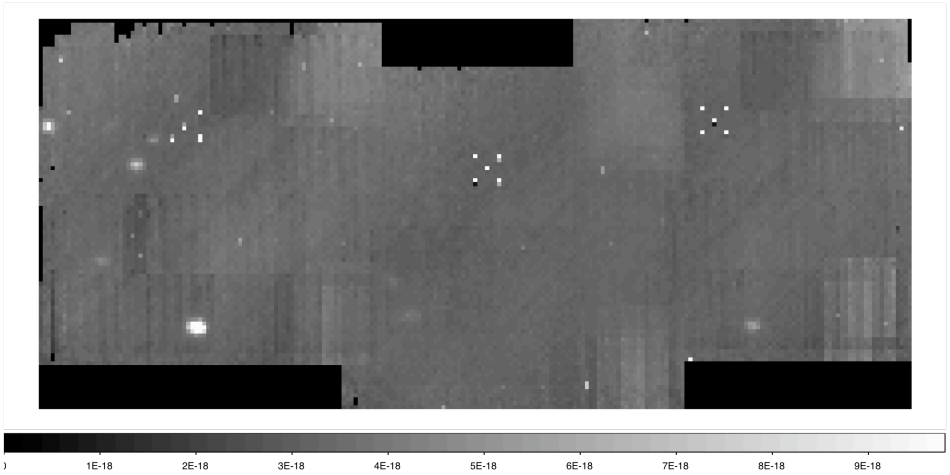


Abell 2667, $z_{cl} = 0.233$

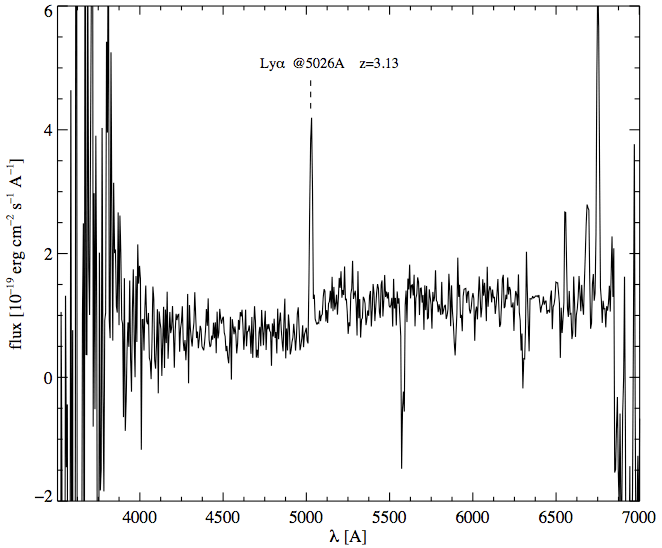


Abell 2390, $z_{cl} = 0.228$

Axions in RDCS1252, z=1.237



Not deep enough to measure many arcs redshifts!!



VIMOS IFU Cube 48.3ks

(non sky subtracted because axion signal is hidden in the sky background)

No emission line found yet!!

Work in progress…