Cosmology with Strong Lensing in Galaxy Clusters

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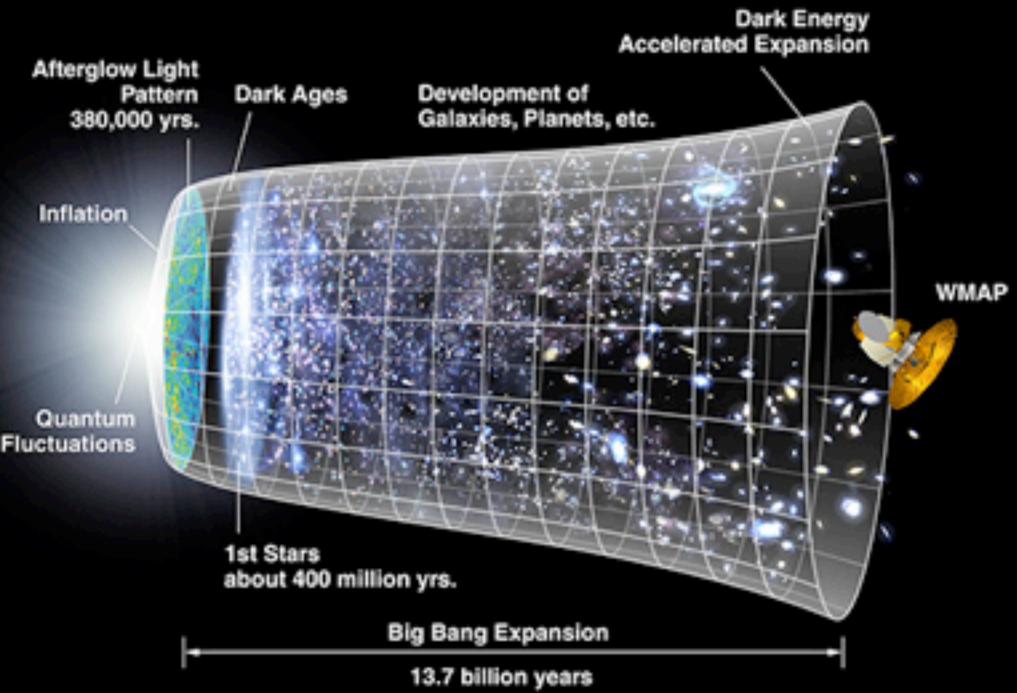
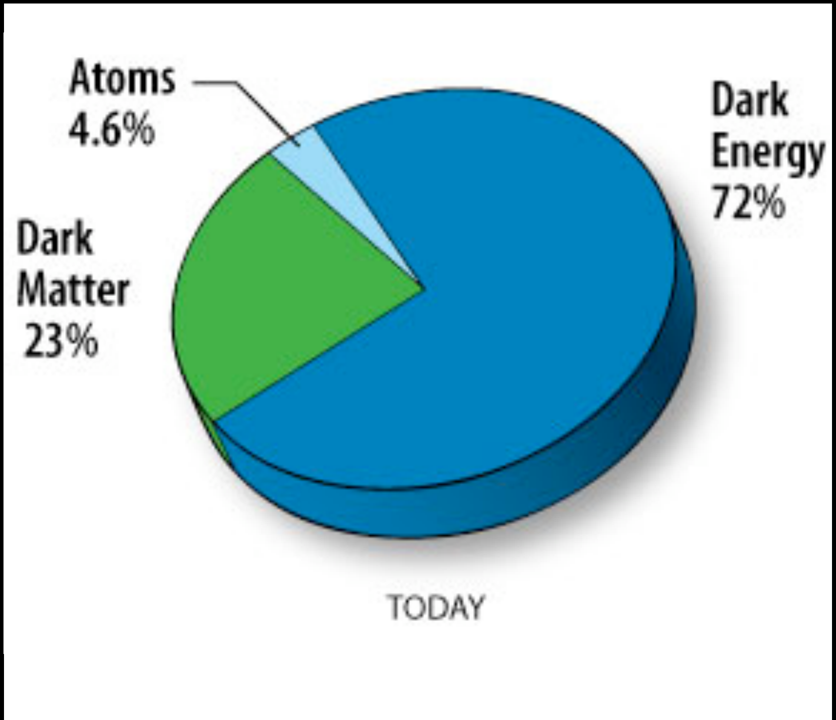
SF2A -- Nice -- 7 Juin 2012

OUTLINE

- Motivation for a new DE probe
- Mapping DM in Gal. Clusters with S.L.
- Cosmography with SL in galaxy clusters
- Future prospects

THE BROAD PICTURE

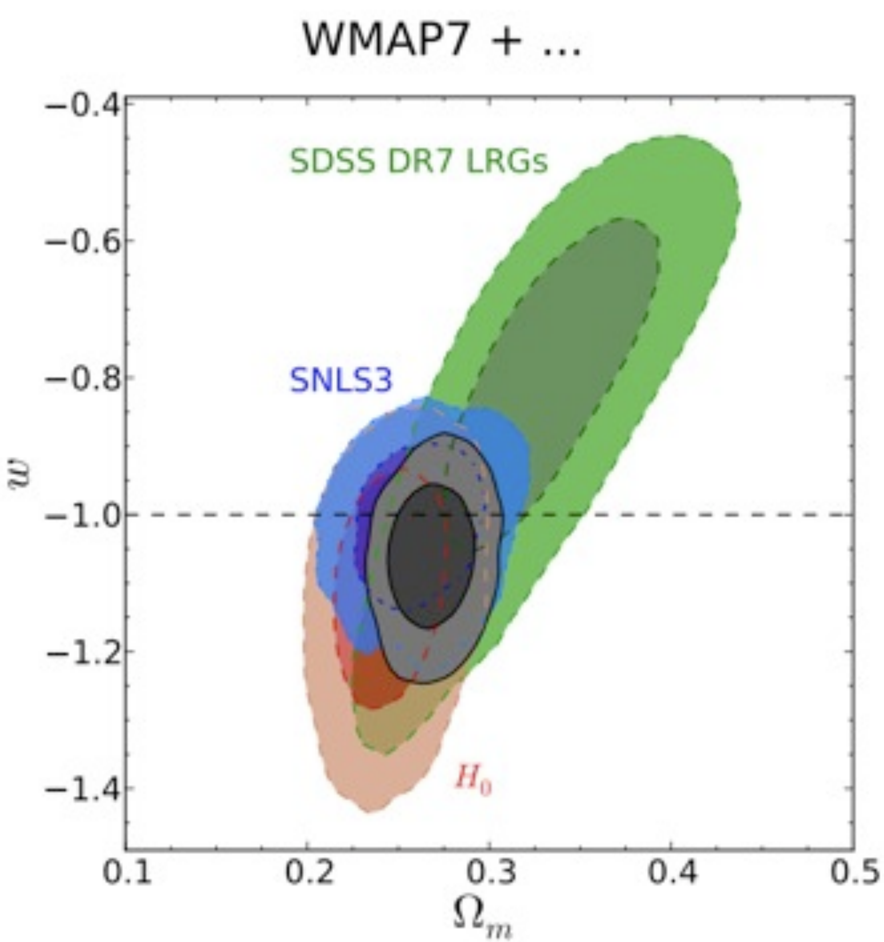


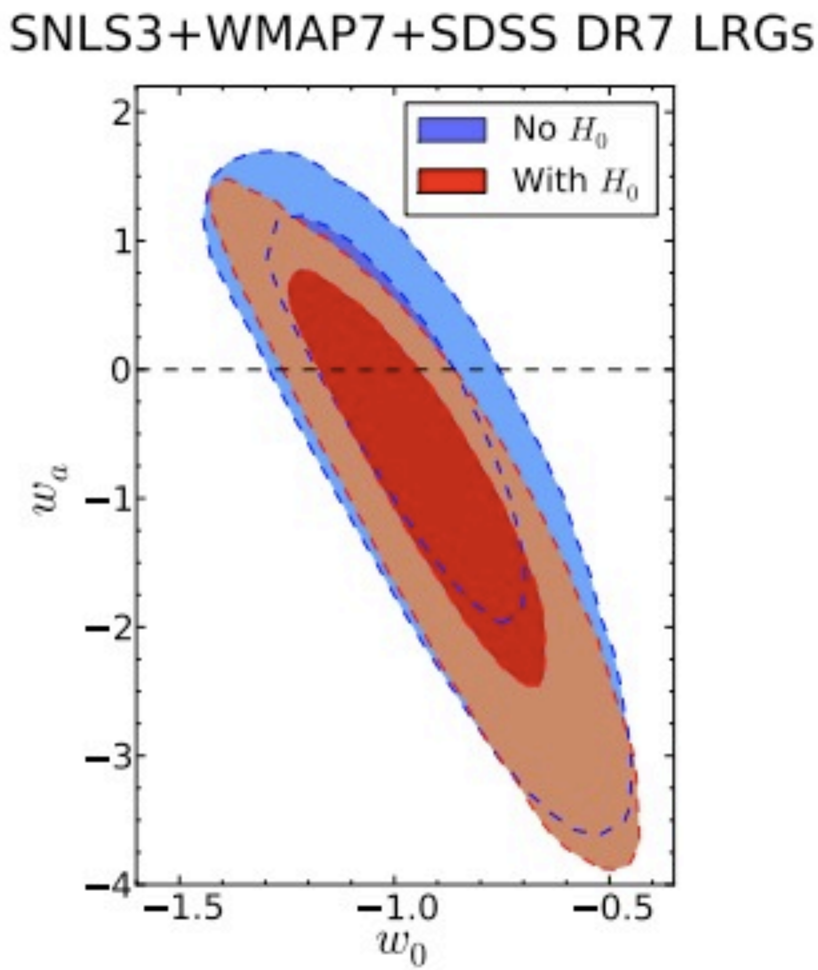


Dark energy

- Explains the recent acceleration of Universe expansion
- Slows down the formation of cosmological structures

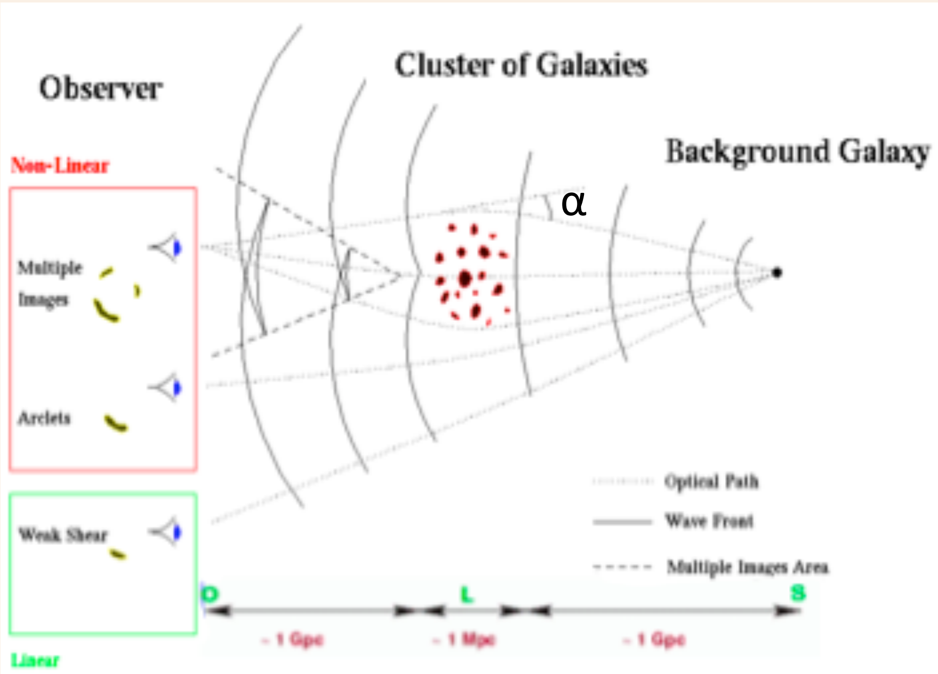
Recent Results on DE





Sullivan+ 2011

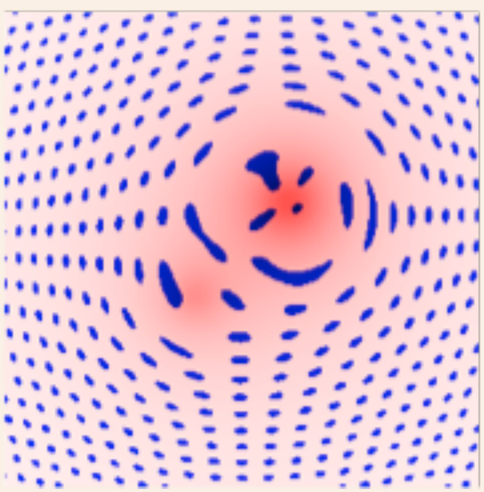
GRAVITATIONAL LENSING

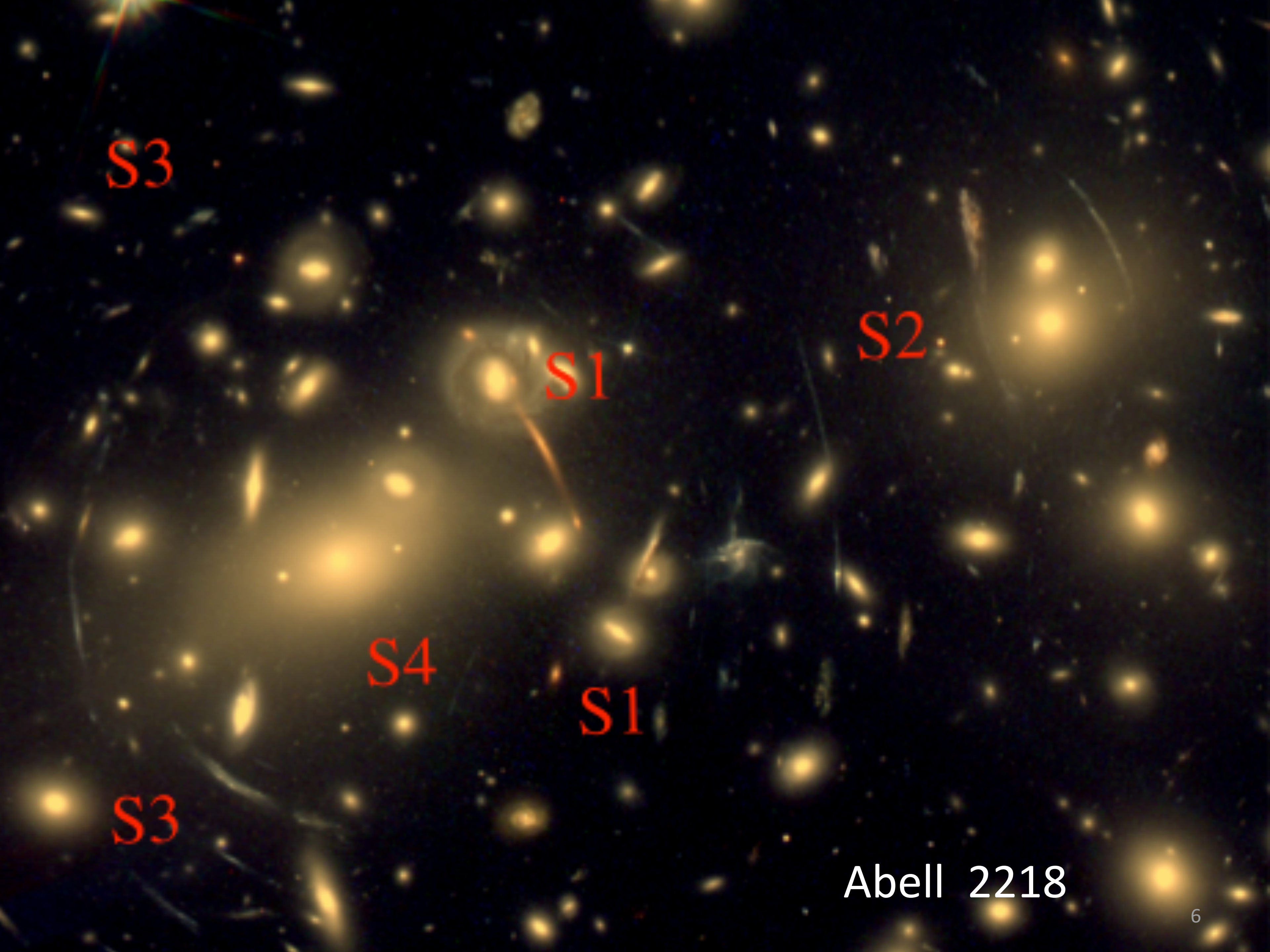


$$\alpha = \frac{D_{LS}}{D_{OS}} \nabla \varphi(\theta_I)$$

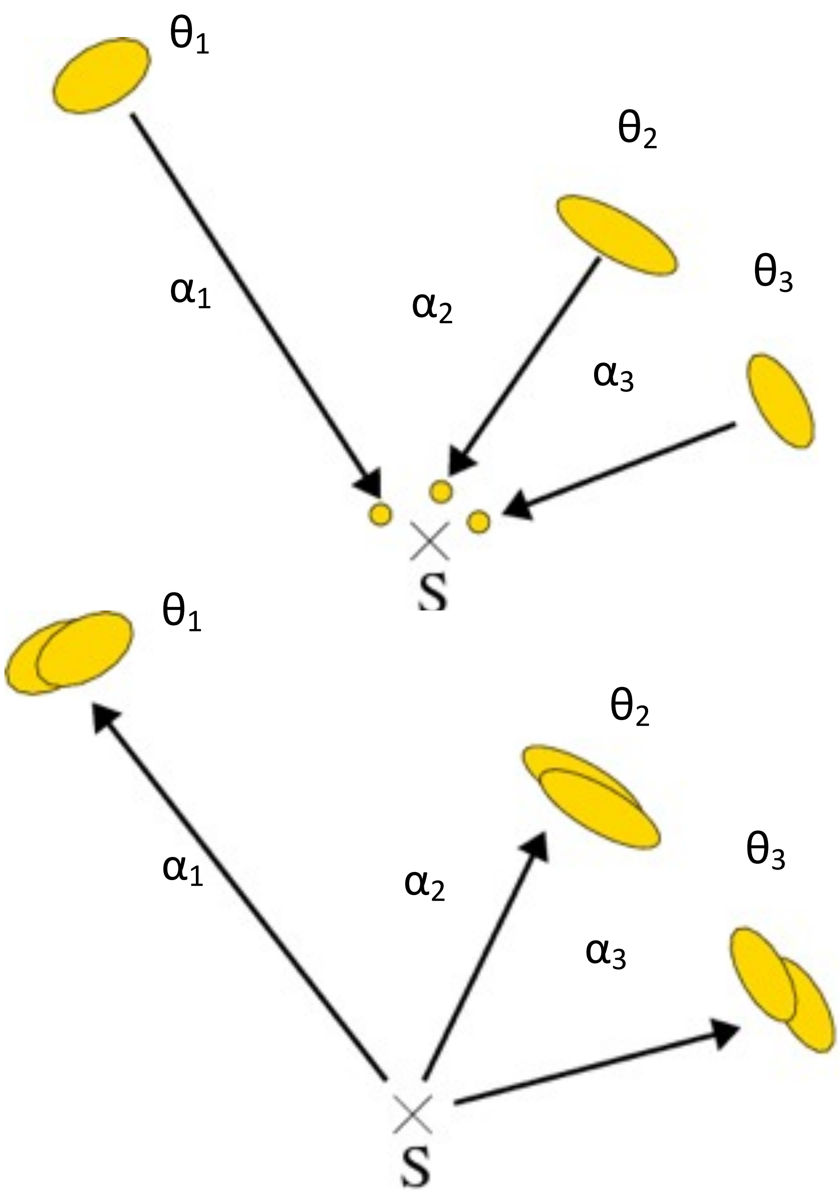
Cosmology

mass




S3
S2
S1
S4
S1
S3
Abell 2218

STRONG LENSING FIT



- Multiple images of a single source
- Multiple images identification with
  - **Same color**
  - **Same redshift**
  - **Same features (bright knots)**
  - **Be symmetric to each others**
- The model is validated when predicted and observed images fall at the same location

$$\chi_i = \sum \frac{\theta_{obs} - \theta_{pred}}{\sigma_{ij}}$$

GALAXY CLUSTERS

What is a cluster made of	Observable
• 80% dark matter	SL/WL
• 15% hot gas (~10^7 K)	Xray/SZ
• 5% stars	Kinematic

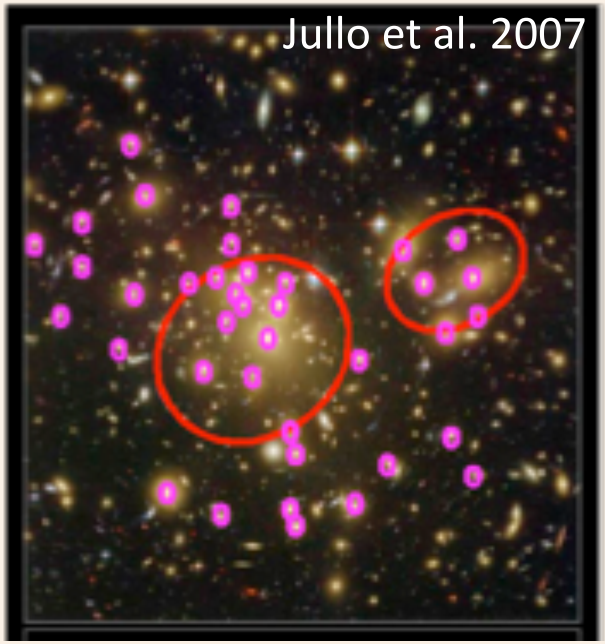
Mass distribution measurement

What is the most difficult to measure?

1. Mass distribution with WL and SL
2. Inner mass profile with SL (requires radial arcs)
3. Substructure sizes and mass
4. Structures along the Line Of Sight

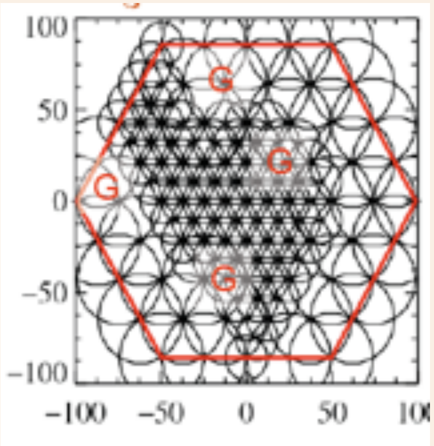
Strong Lenses Models

Observational models	Grid-based models
Decomposition into halos **+ M∝L$^{\alpha}$ for the substructures**	Decomposition into grid cells **+ M∝L$^{\alpha}$ for the substructures**
Simple clusters	Complex clusters
Need few multiple images	Need lots of multiple images
Fast	Slow



Bayesian MCMC sampler to draw posterior PDF

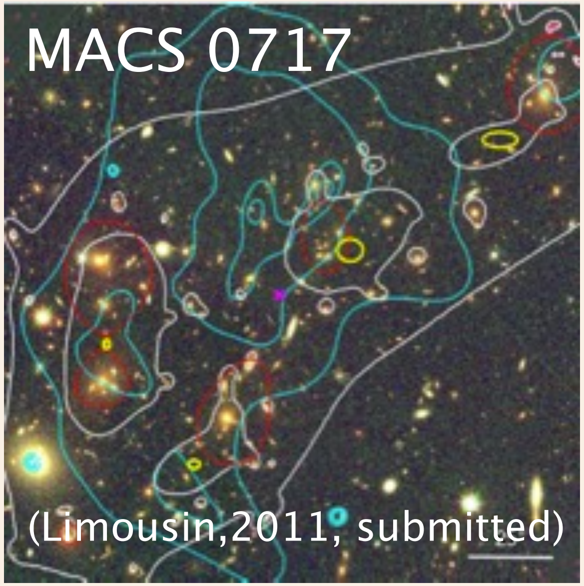
These models are available in LENSTOOL[1]

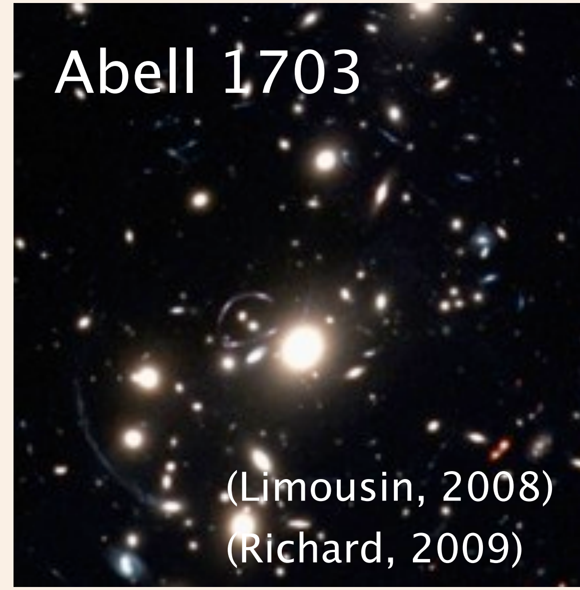


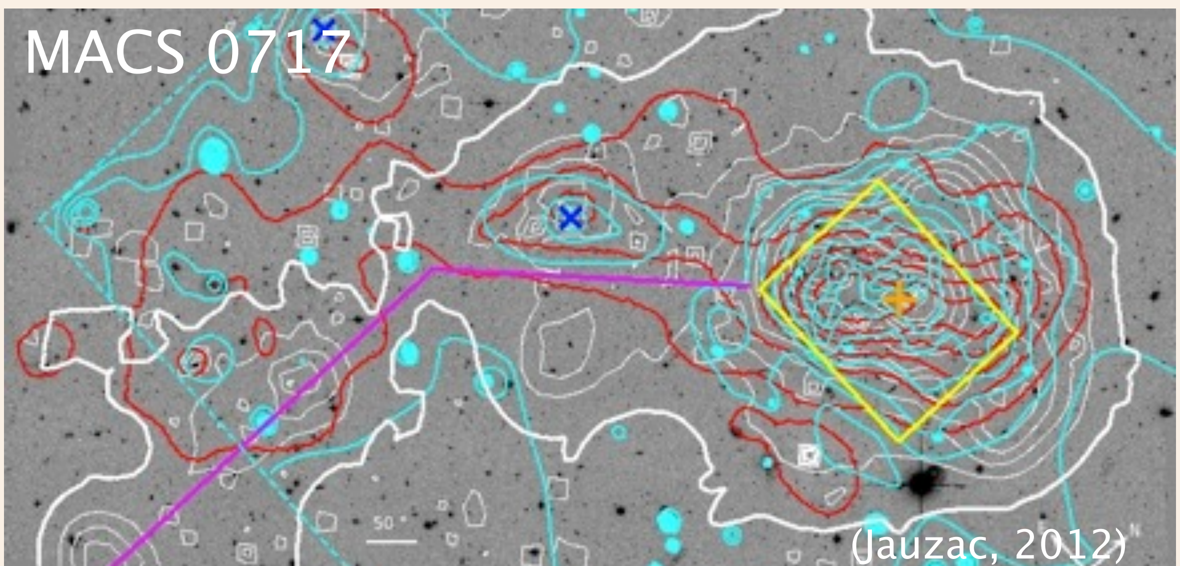
Jullo & Kneib 2009

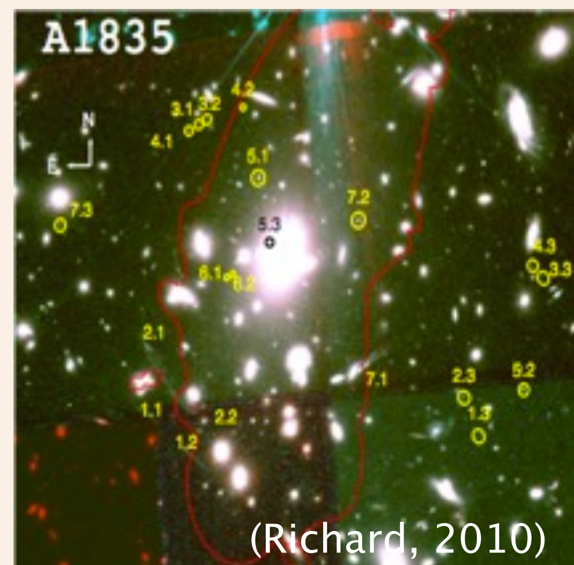
[1] http://www.oamp.fr/cosmology/lenstool

Some clusters modeled with Lenstool



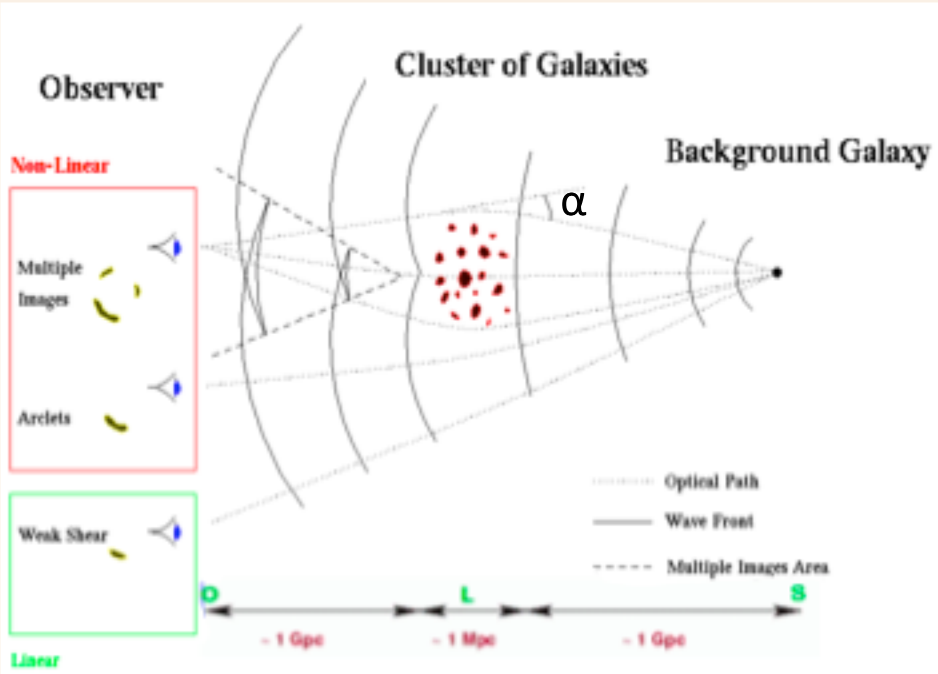






Cosmography

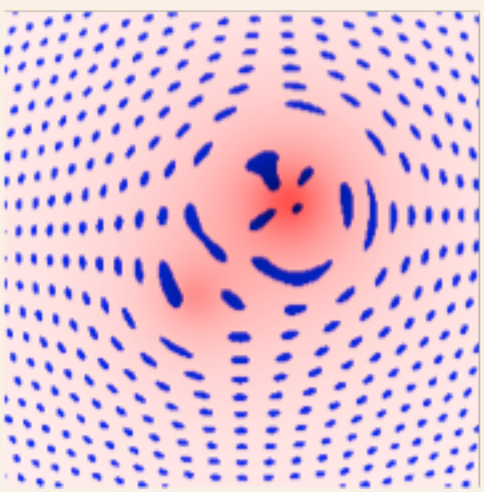
GRAVITATIONAL LENSING



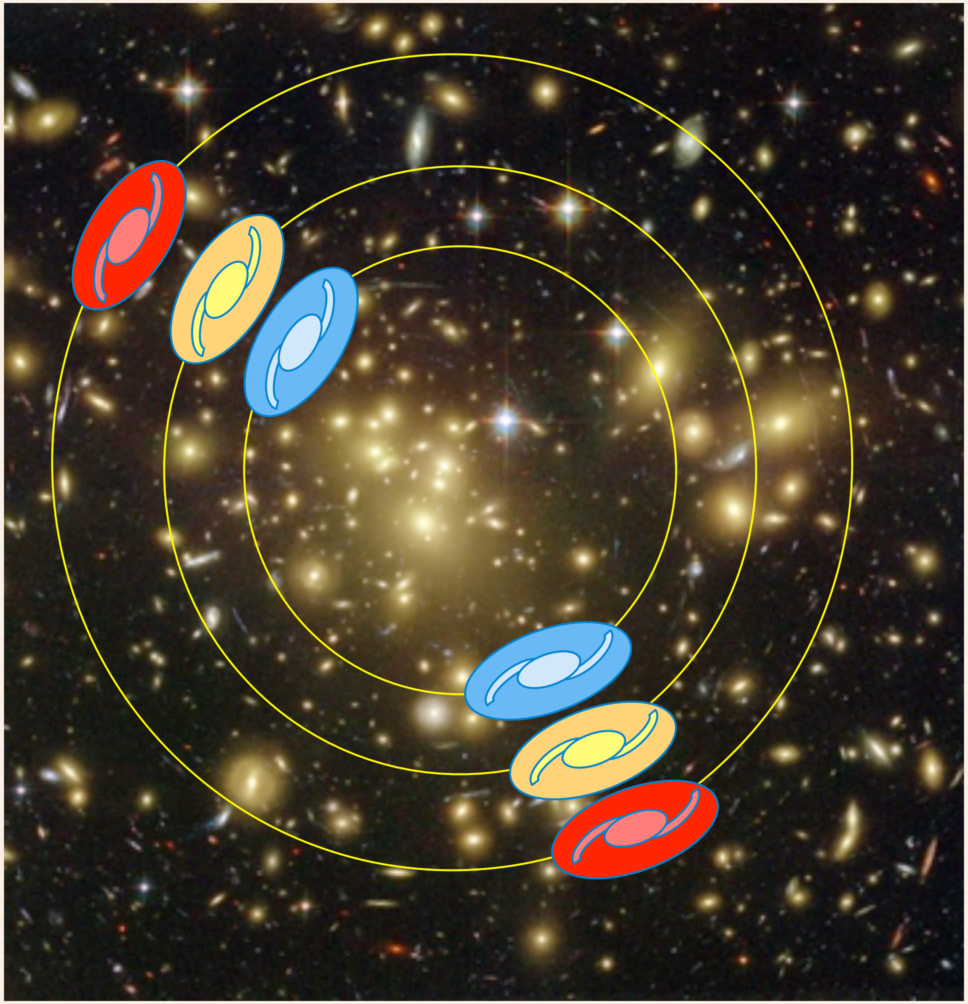
$$\alpha = \frac{D_{LS}}{D_{OS}} \nabla \varphi(\theta_I)$$

Cosmology

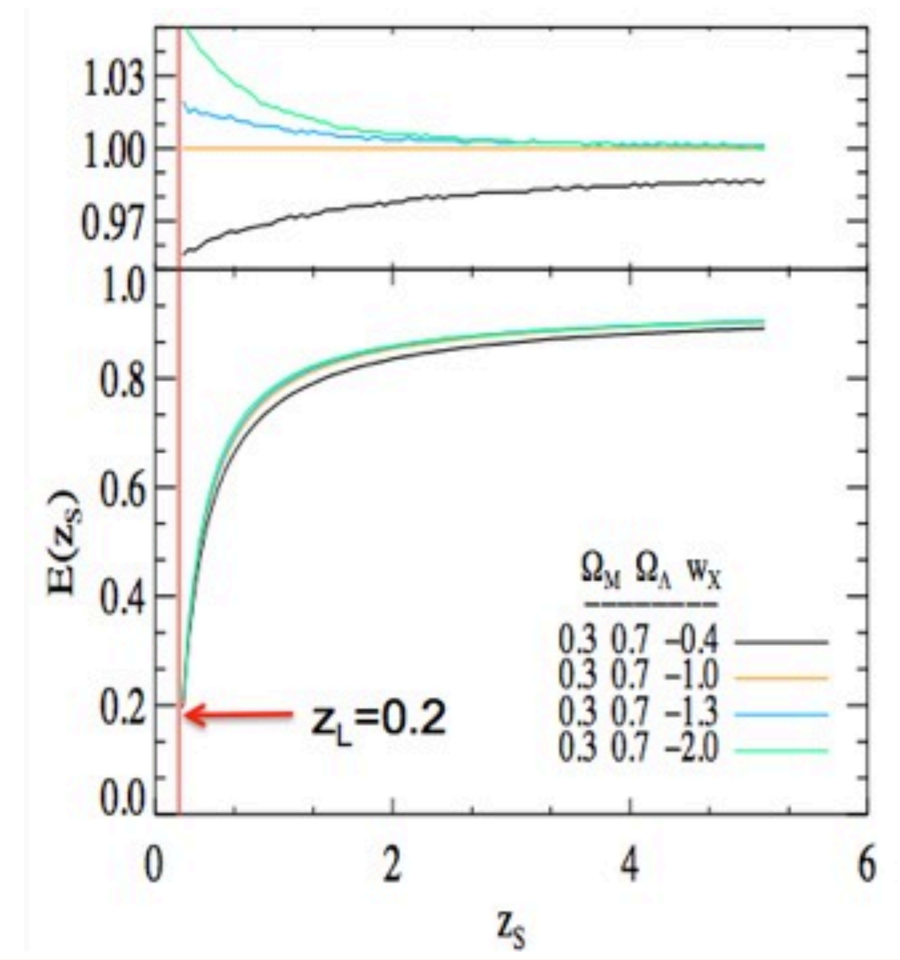
mass

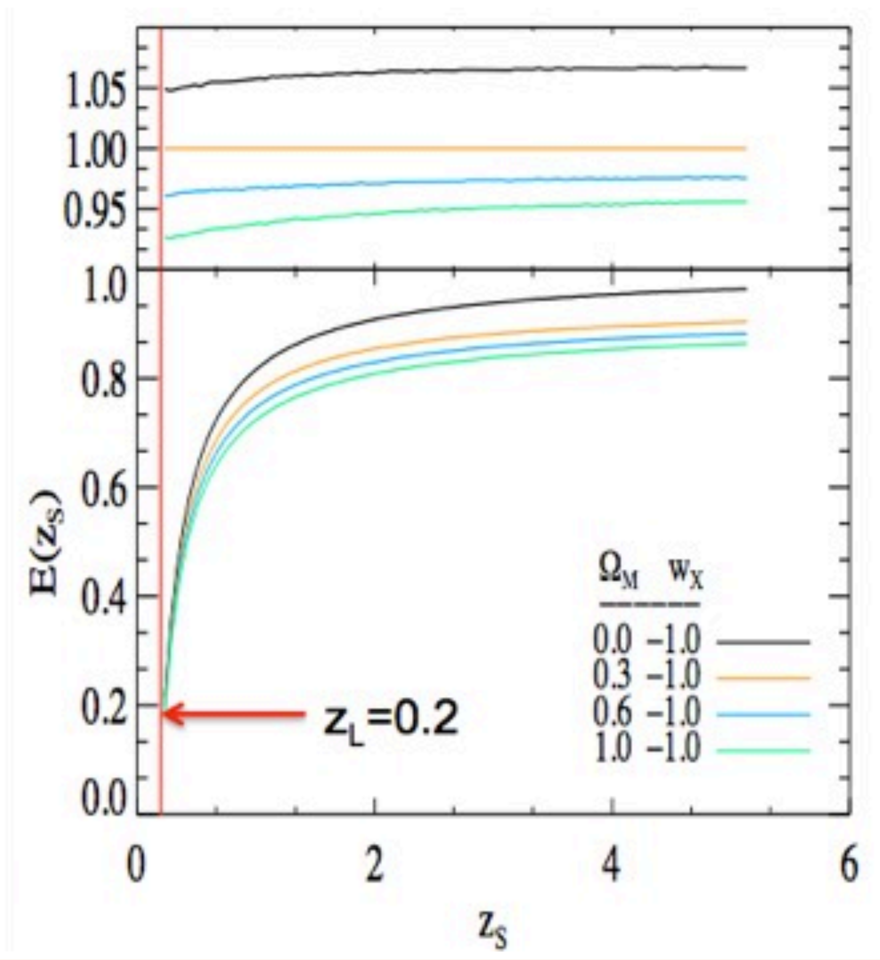


Scaling with cosmology or mass?



Efficiency ratio $E = D_{LS}/D_{OS}$

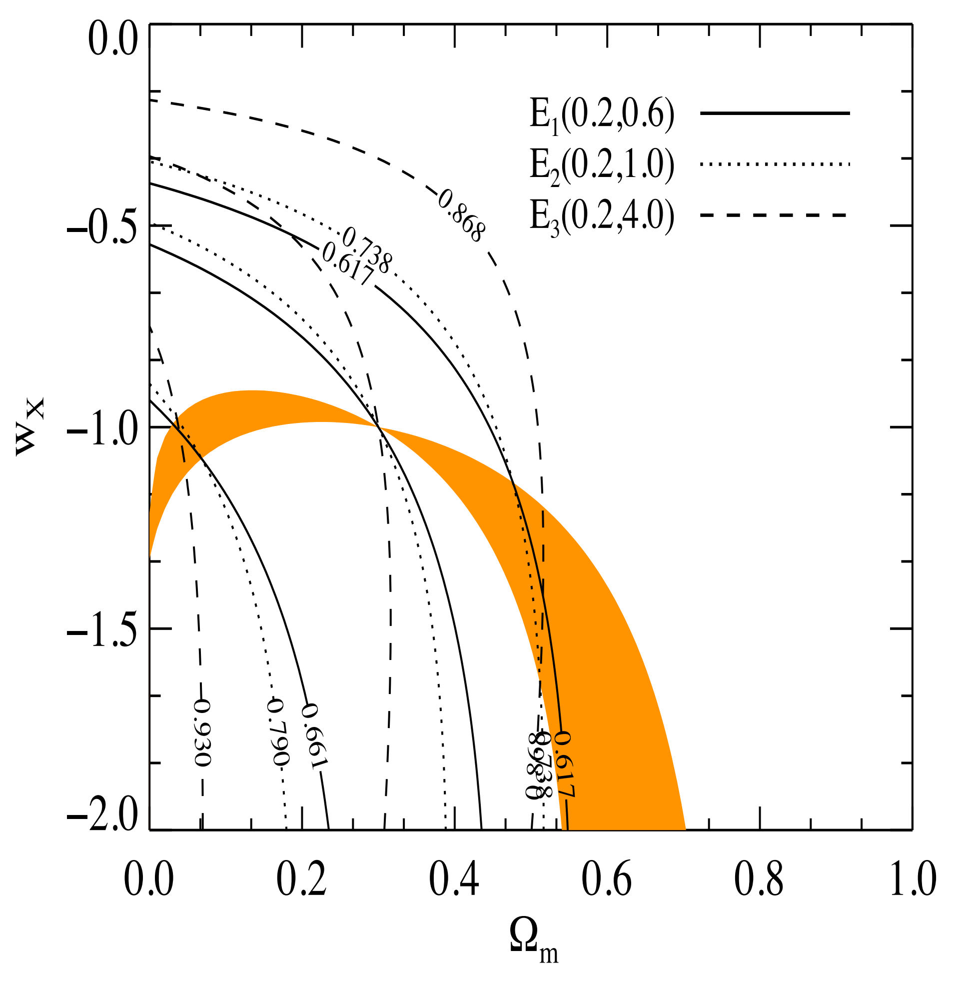


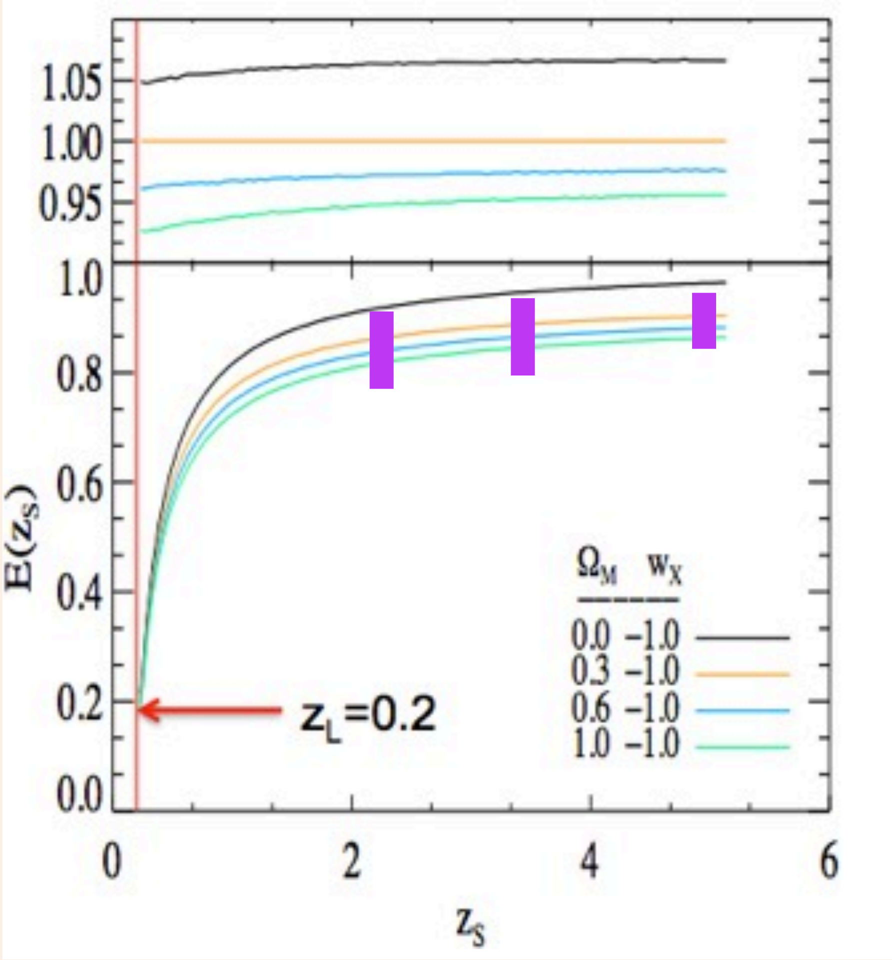


w_X effect

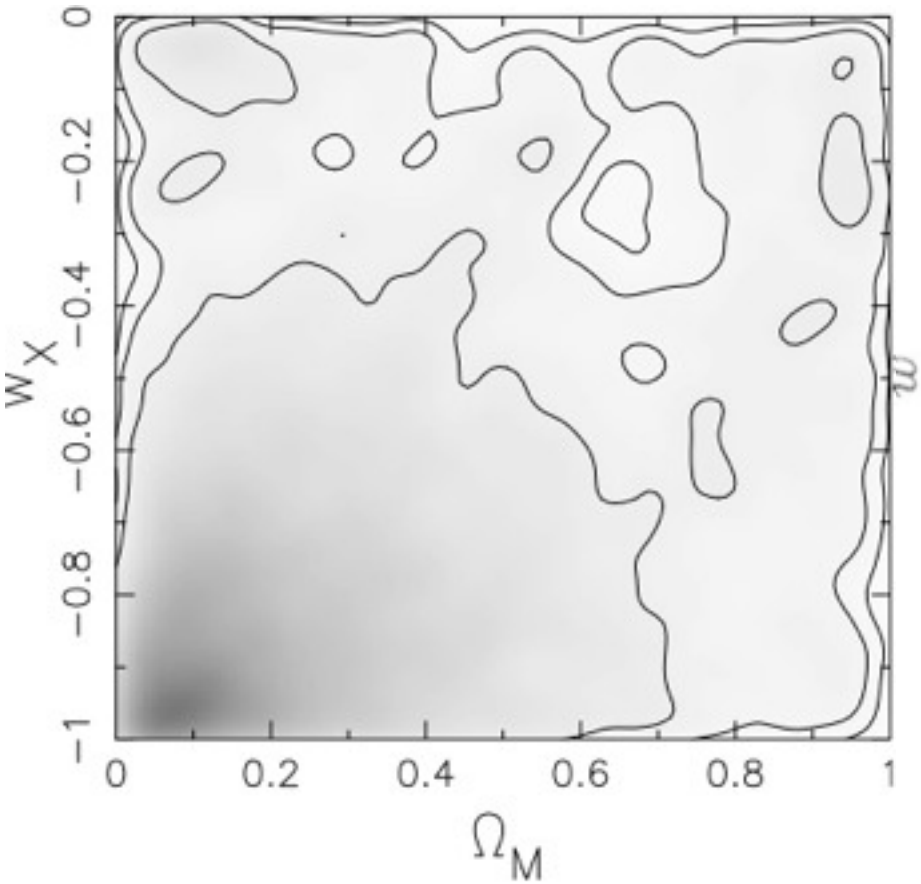
Ω_m effect

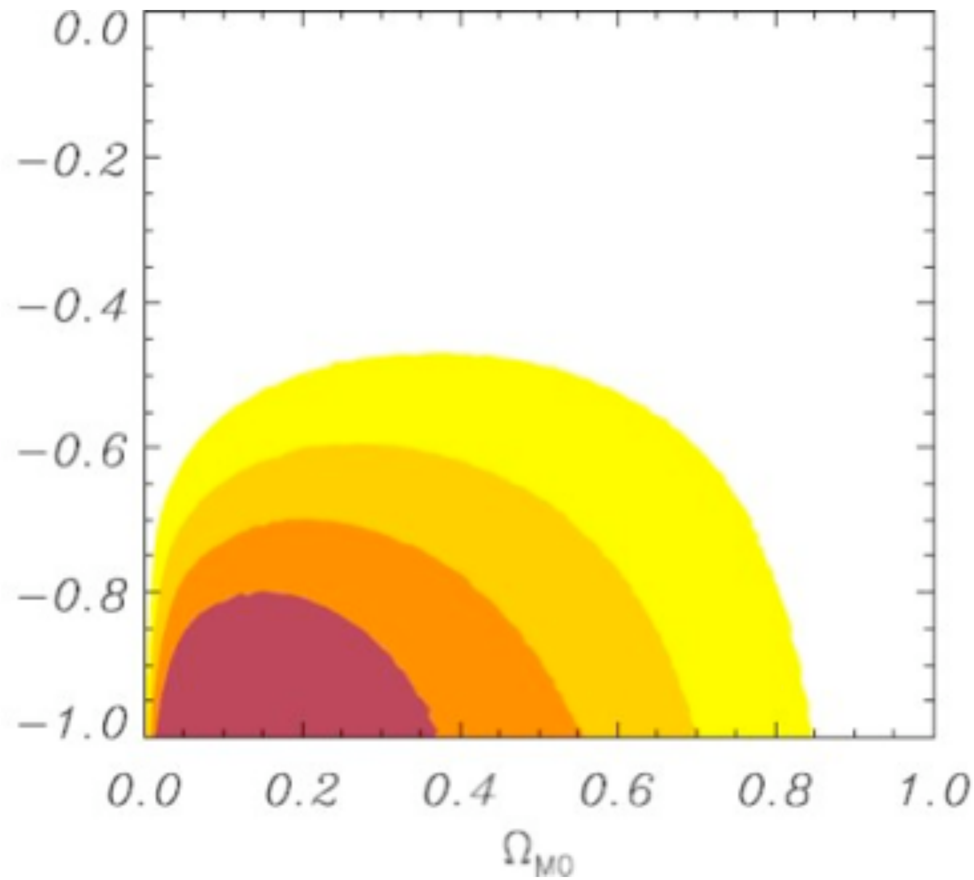
Combination of 3 D_{LS}/D_{OS}





A2218 RESULTS





4 sources with $0.7 < z_s < 5.5$

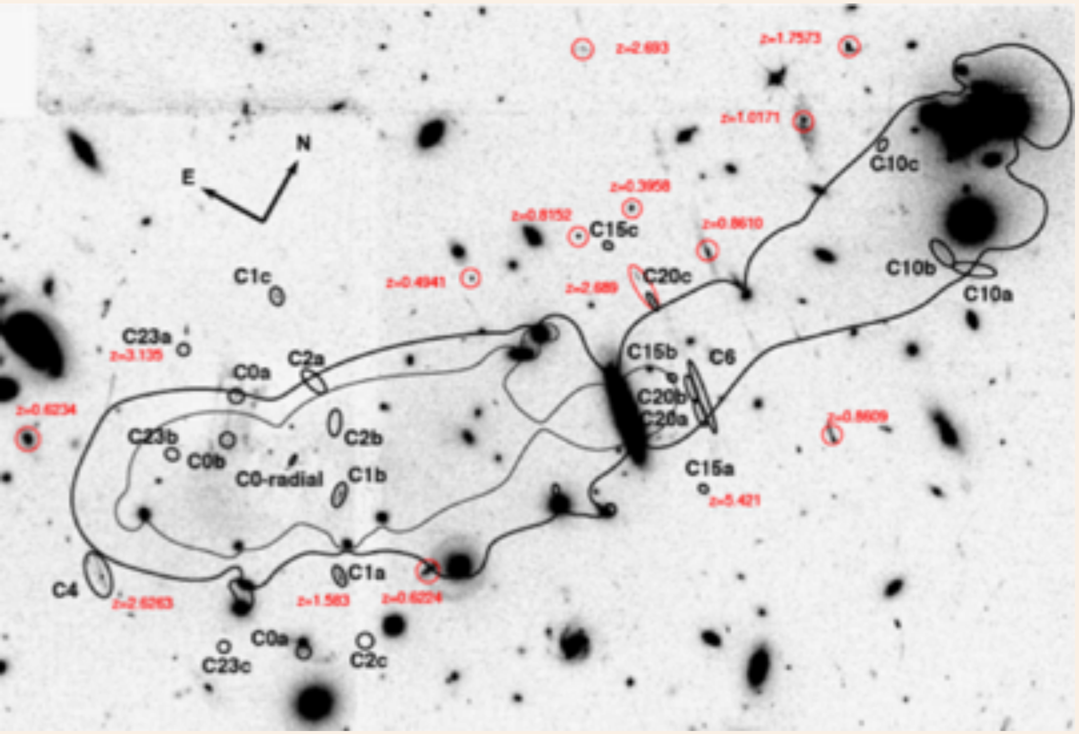
$\Omega_m < 0.7$, $w_X < 0.4$ @ 1σ

Soucail et al. 2004

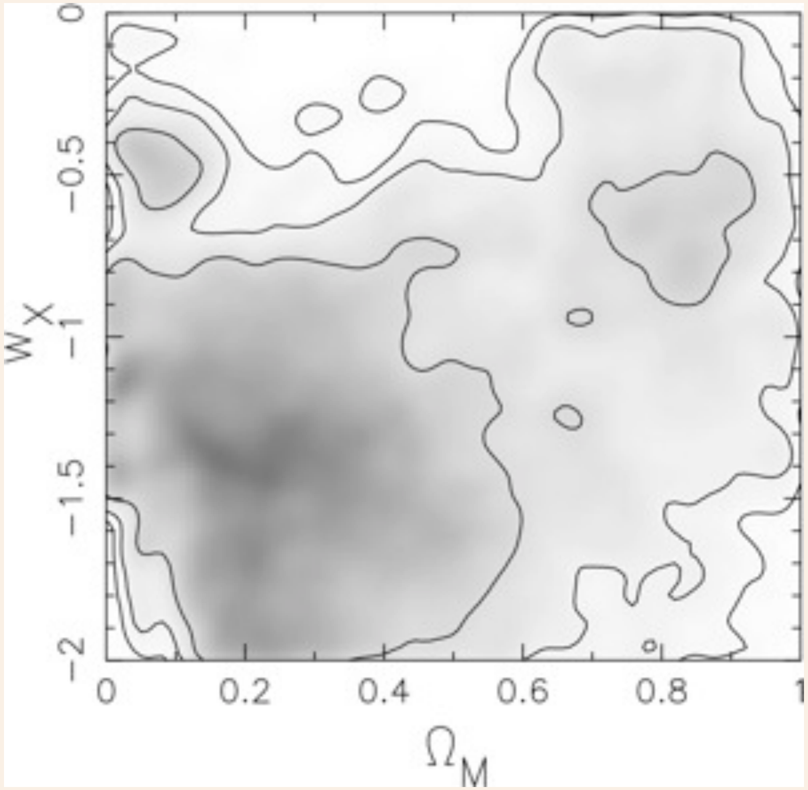
Cosmography with Abell 68

Mass model with 7 multiple image systems (5 with known redshifts, $0.6 < z_s < 5.4$).

Optimizing cosmography (Ω_M , w_X) for a flat Universe



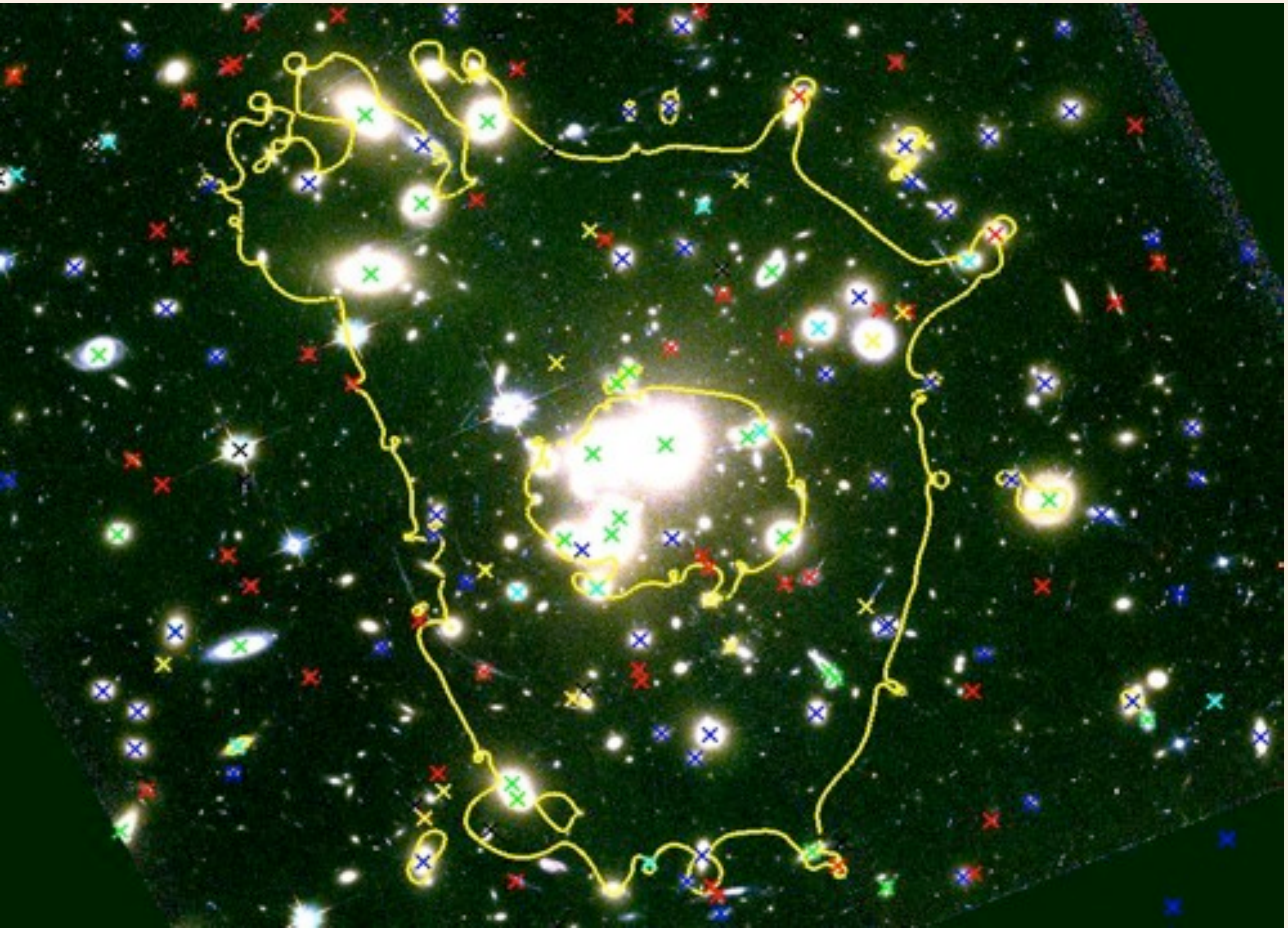
Richard et al 2007



EJ PhD 2008

COSMOGRAPHY WITH ABELL 1689

- Mass models from different groups w. or w/o weak lensing
- Massive spectroscopic surveys (2003-2006) [Richard et al 2011]
- 43 multiple image systems, 24 with spectro-z with 1.1 < z < 4.9

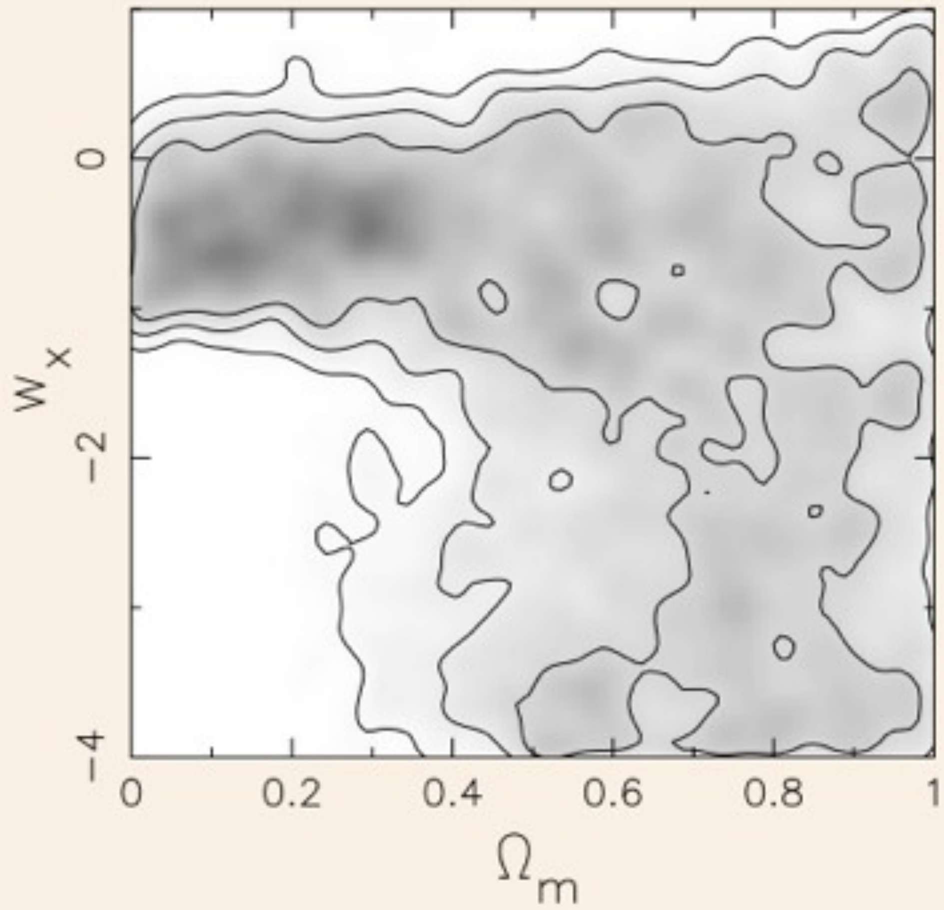


Broadhurst et al 2005
Halkola et al 2007
Limousin, et al. 2007
Richard et al. 2007
Frye et al 2007
Leonard et al 2007
Jullo & Kneib 2009
Coe et al 2010

X KECK/LRIS
X VLT/FORS
X CFHT/MOS
X MAGELLAN /LDSS2
X Litterature

Results with all identified multiple images in A1689

- All Images
  - potential misidentification
  - badly modeled images: locally complex mass distribution



ERRORS DUE TO GALAXIES MODELING

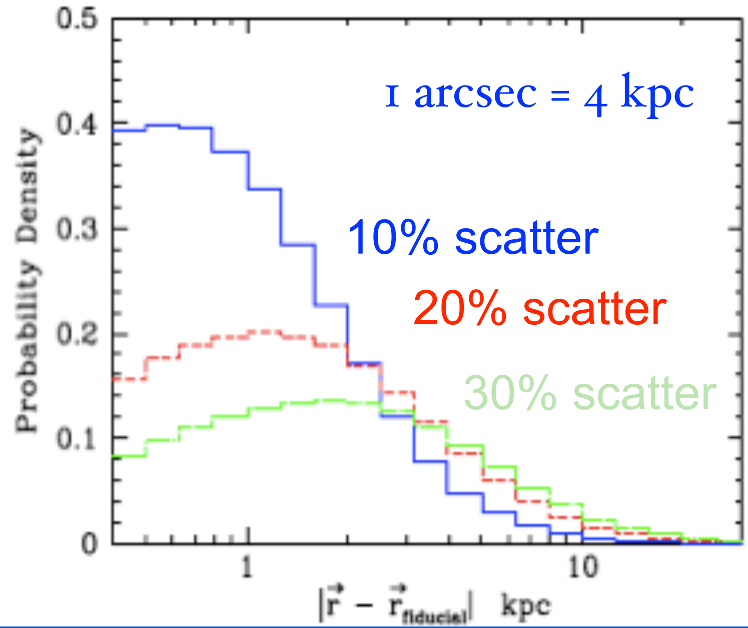
PIEMD parameters
20% scatter

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

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+07



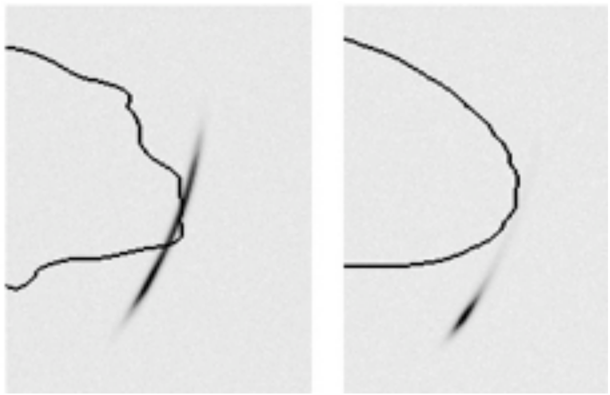
Simulations: D'Aloisio & Natarajan 10

For A1689

- Scatter in the scaling relations ~ 1"

– > Scatter for each image

– > Images are weighted in χ^2 INDIVIDUALLY



Meneghetti+07

Errors due to deflections by LOS structures

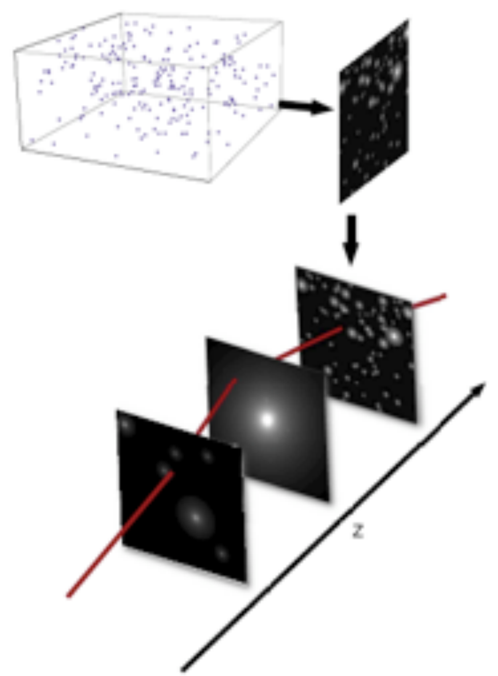
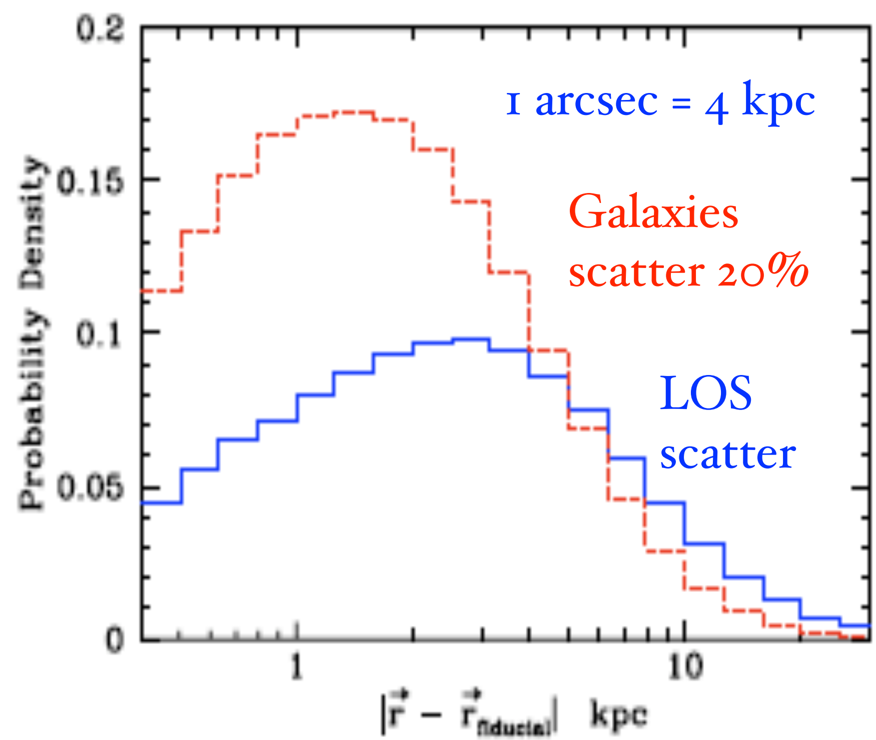

Cosmography with cluster strong lenses 7

Figure 5. Schematic diagram illustrating the creation of lensplanes to quantify the effects of LOS halos. A rectangular slice of the Millenium Simula-



Simulations: D'Aloisio & Natarajan 10

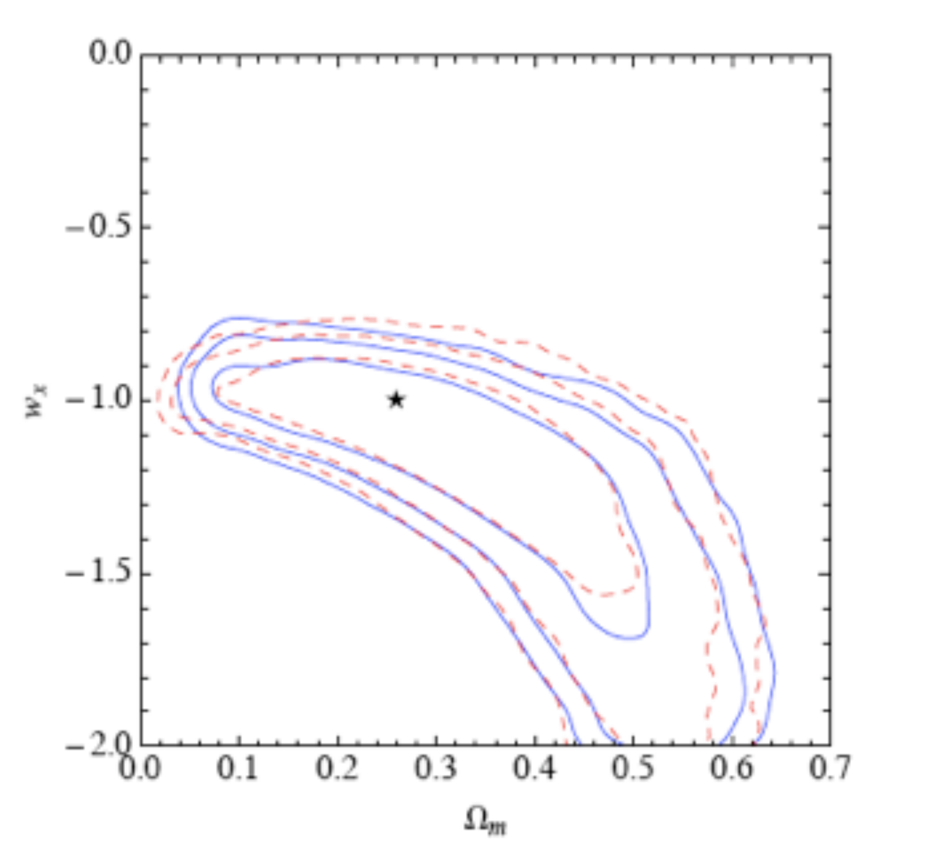
For A1689

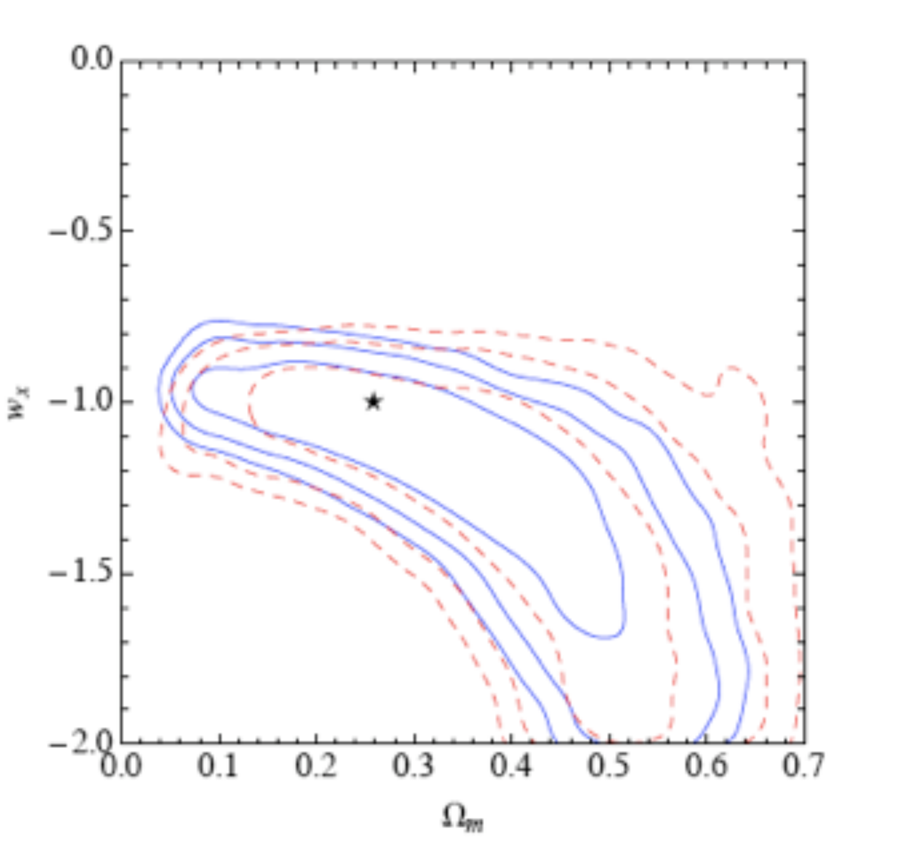
- 1" of scatter due to structures in the lens plane & along L.O.S.

Correlated LOS (infalling subclusters, filaments)

Uncorrelated LOS (primary contribution to the errors) ~

NO BIAS DUE TO CHOICE OF DENSITY PROFILE, CLUSTER BIMODALITY



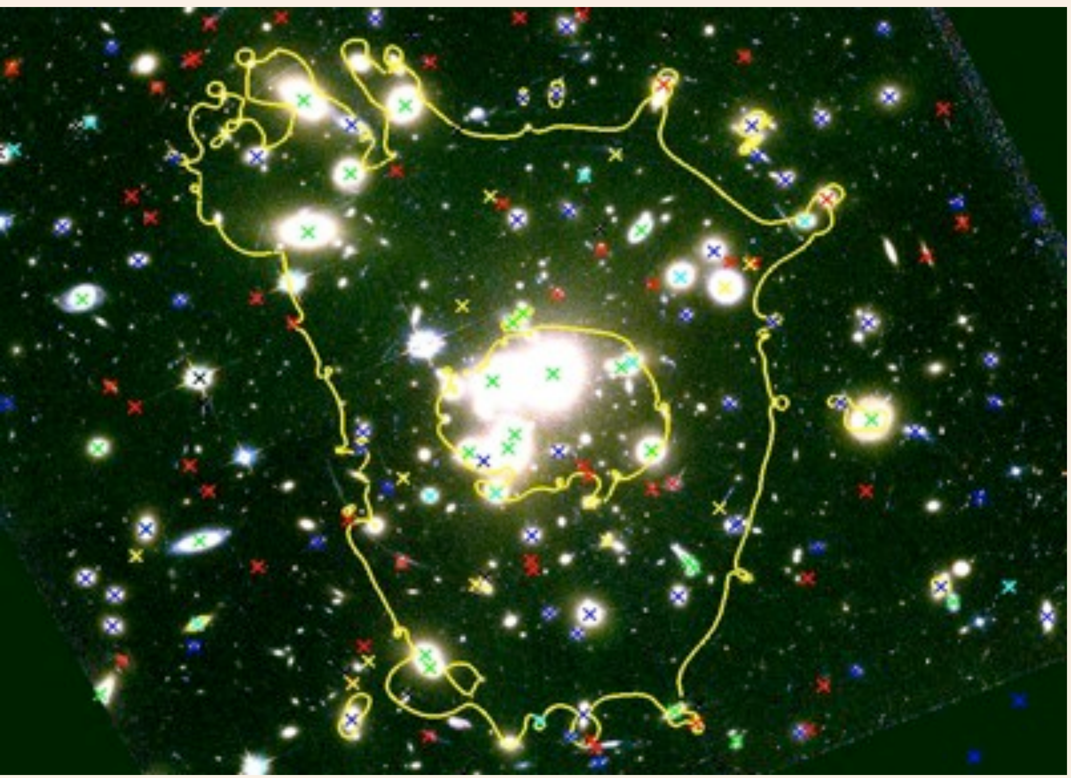


Not particularly sensitive to the inner slope/outer slope of the density profile

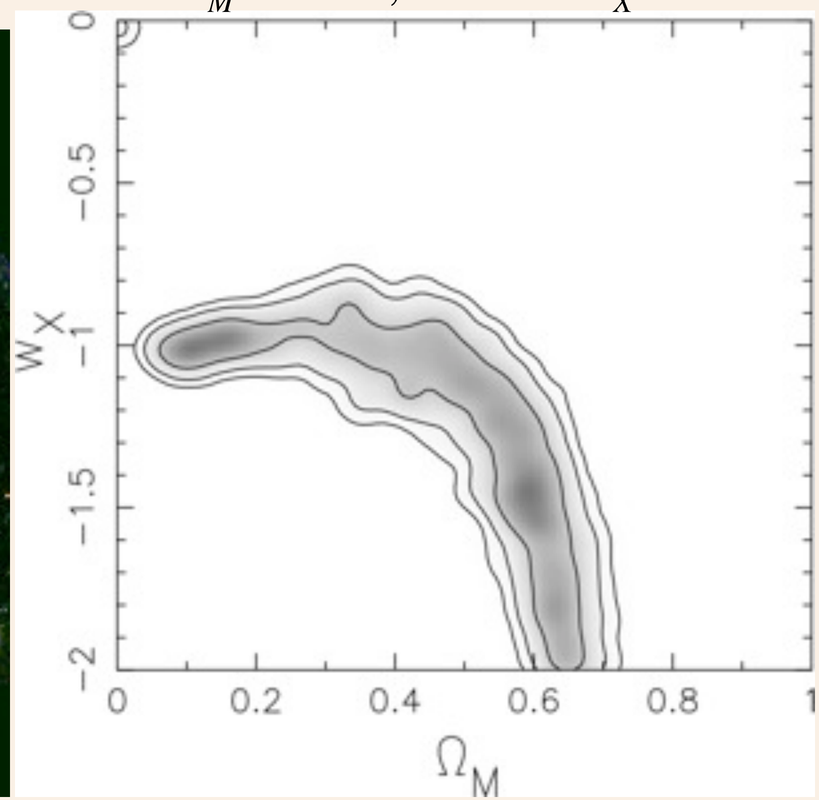
No bias from choice of profile NFW vs. PIEMD or bi-modality

COSMOGRAPHY WITH A1689

Mass model with 3 PIEMD potentials; 58 cluster galaxies
Bayesian optimization: 32 constraints, 21 free parameters;
RMS = 0.6 arcsec; 28 multiple images from 12 sources with spec z, flat Universe prior

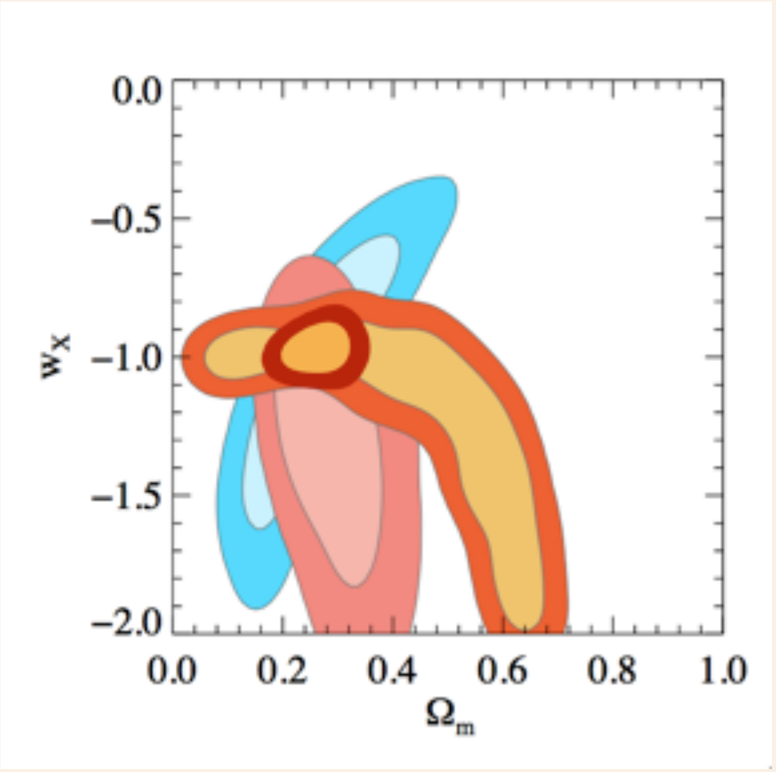


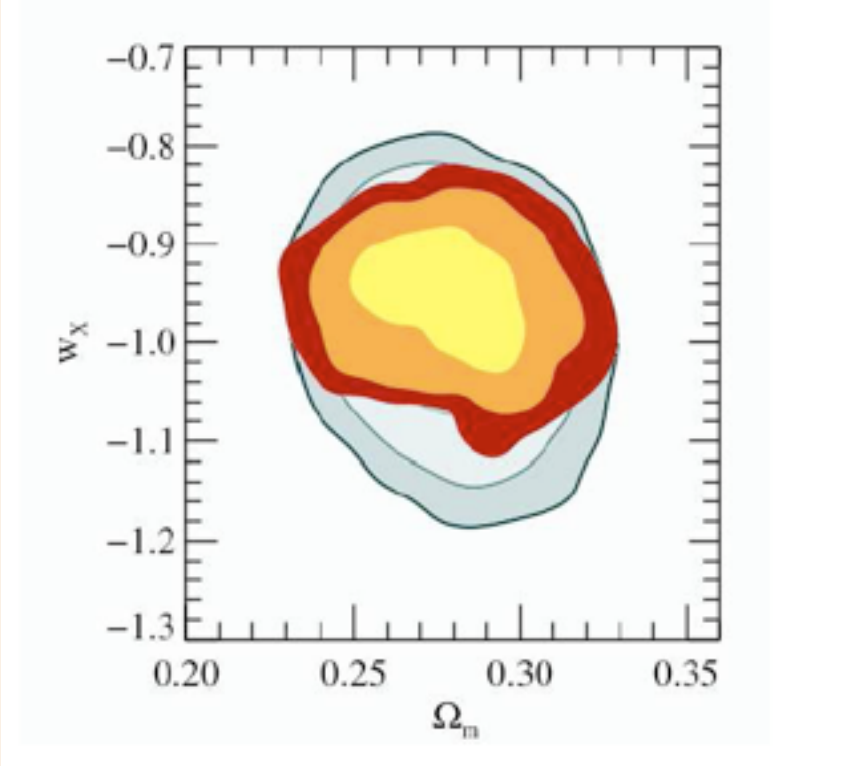
$$0.1 \leq \Omega_M \leq 0.58; -1.57 \leq w_X \leq -0.85$$



Jullo+ (Science, August 2010, 329, 924)

CURRENT CONSTRAINTS INCLUDING CSL

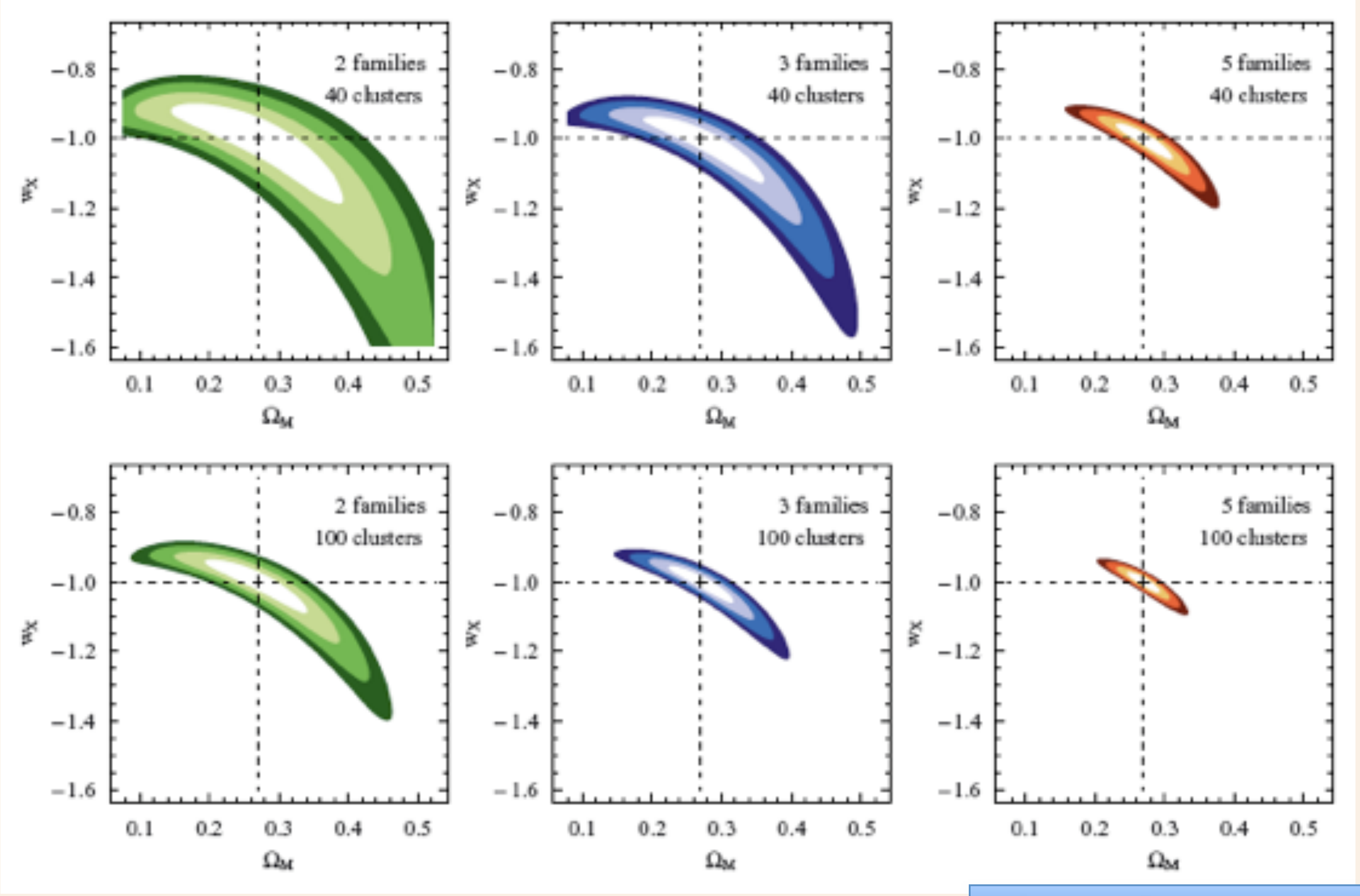




Combining X-ray clusters, WMAP5, strong lensing competitive with WMAP5 + SNe + BAO

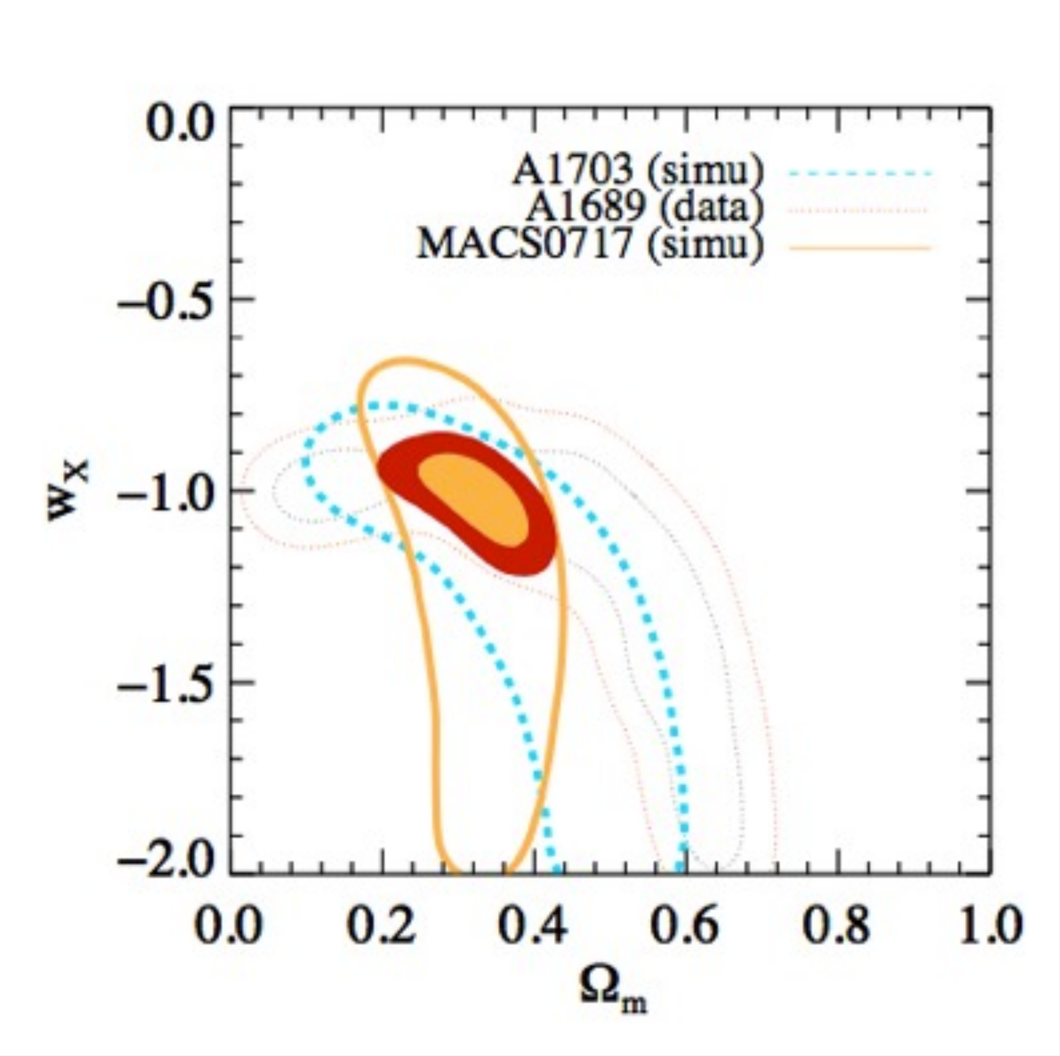
Jullo, PN, Kneib + 10

COMBINATION OF MANY CLUSTERS



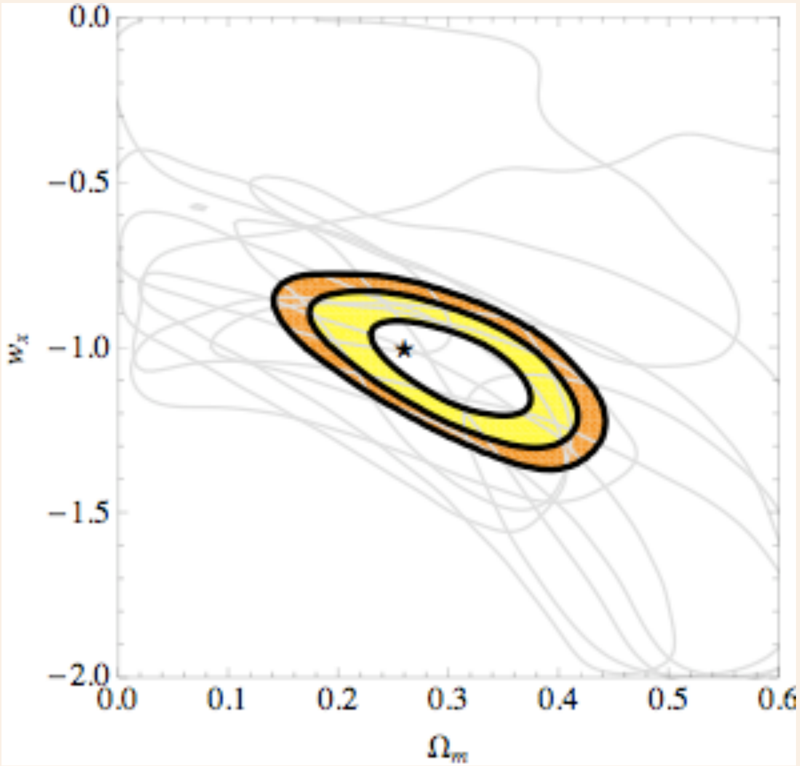
Gilmore & Natarajan 2009

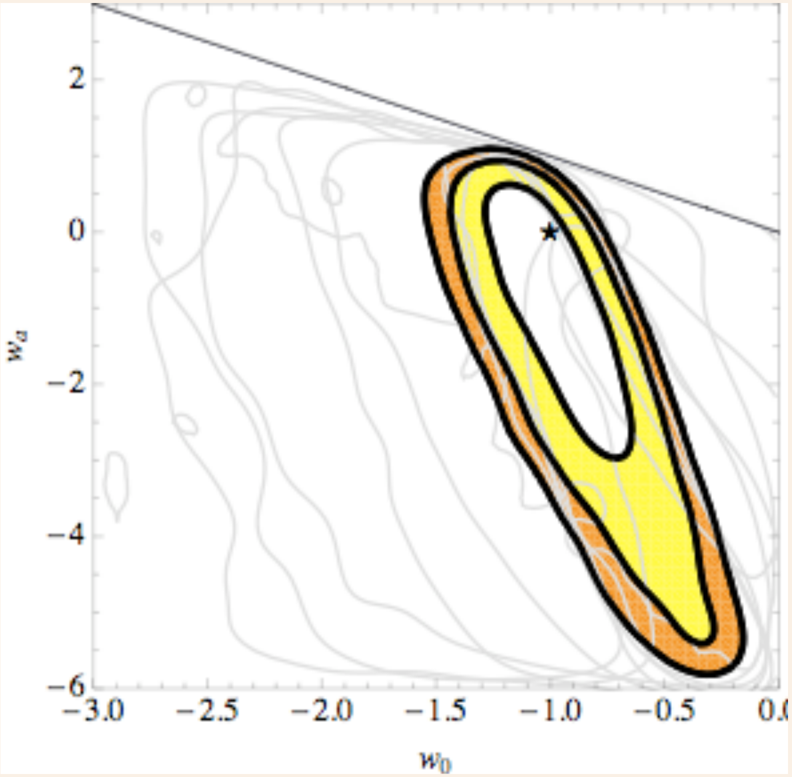
HIGH AND LOW-Z CLUSTERS



PROBING W(Z)

10 clusters, 20 families! Flat prior, input w = -1; evolving wa





D'Aloisio & Natarajan 2010

$$w_x = w_0 + w_a \frac{z}{(1+z)}$$

CONCLUSIONS & PROSPECTS

- *Cluster cosmography is a promising probe*
- Cheap and likely Competitive
- Requirements:
  - HST multiband imaging (CLASH survey & HST archive)
  - Ground based spectroscopy on 8-10m telescope
- *Complementary output: Mass distribution to the % level => unique way to characterize DM properties.*

- VLT/MUSE will improve model accuracy (z_s, σ gals)
- JWST will be a key player (deeper images & spectroscopy)
- EUCLID imaging (~5000 clusters with arcs L/W>10)

The END