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CHILE

A magnified glance into the dark Sector: Probing cosmological models with strong lensing in A1689

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Outline

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- Dark energy models
- Strong lensing in galaxy cluster A1689
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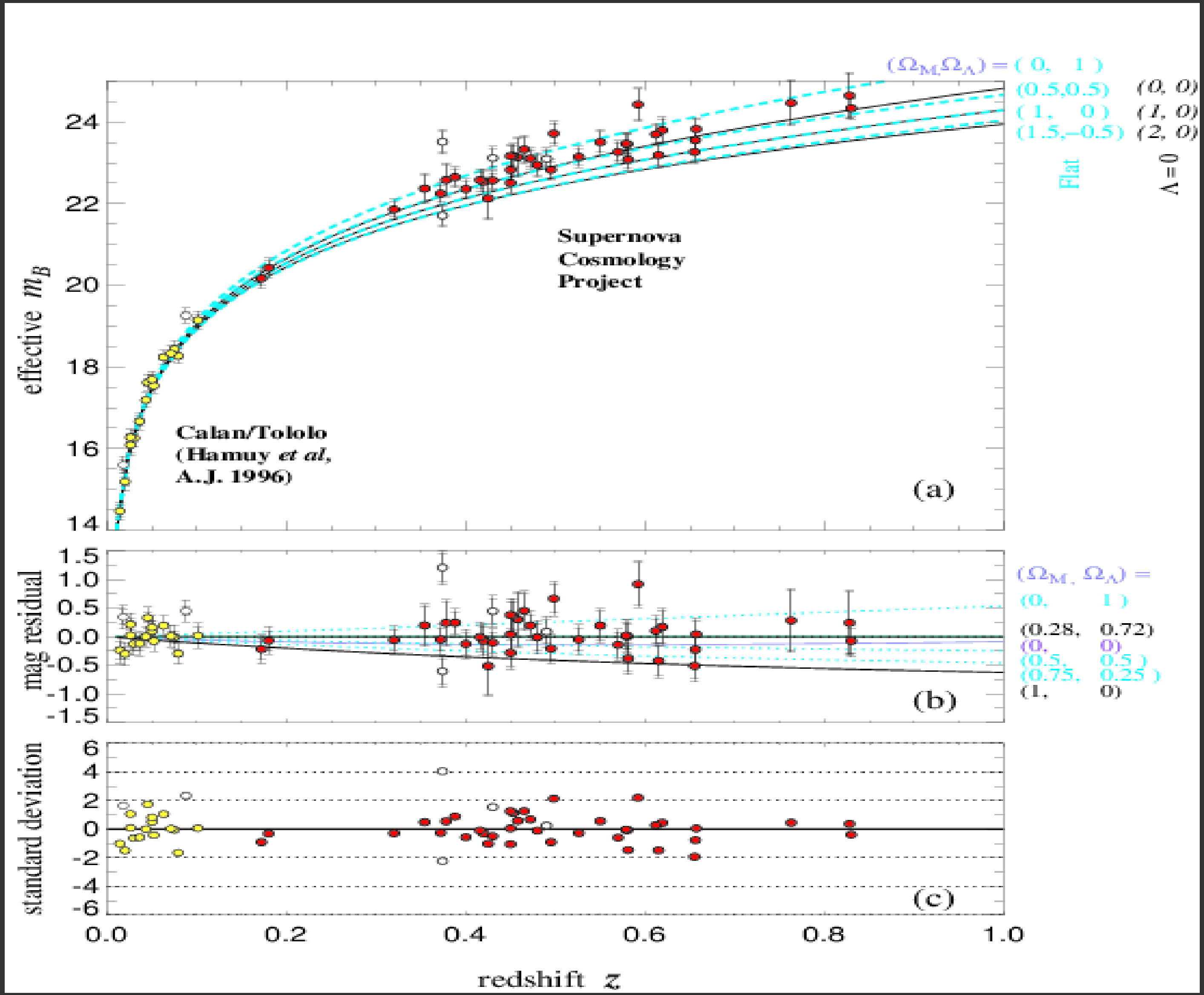
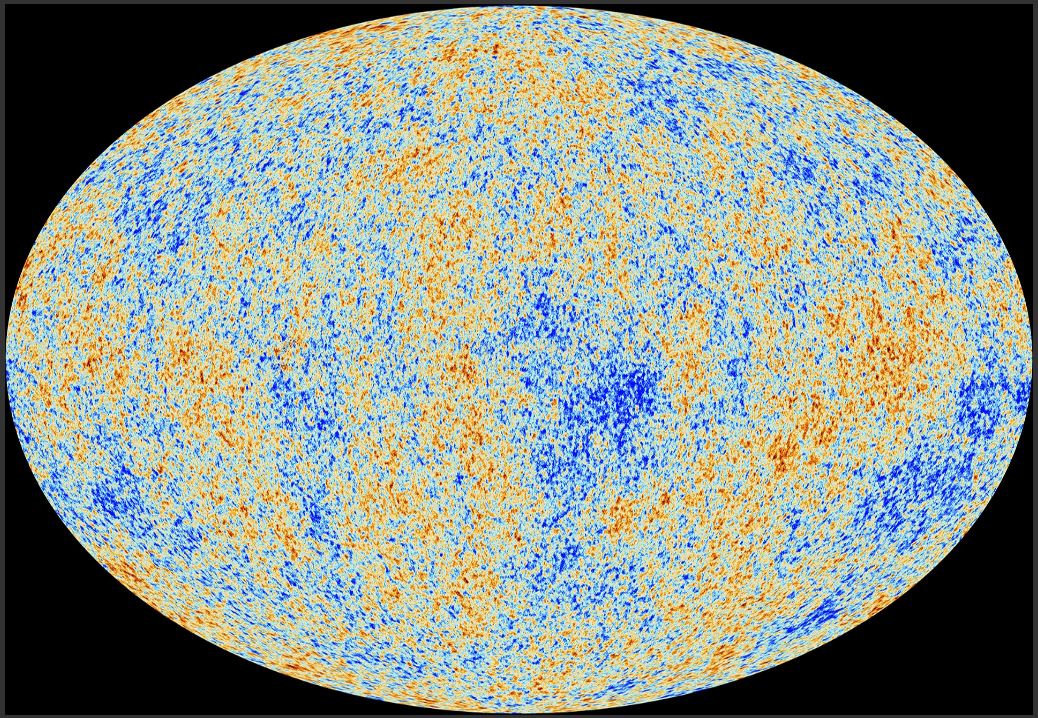
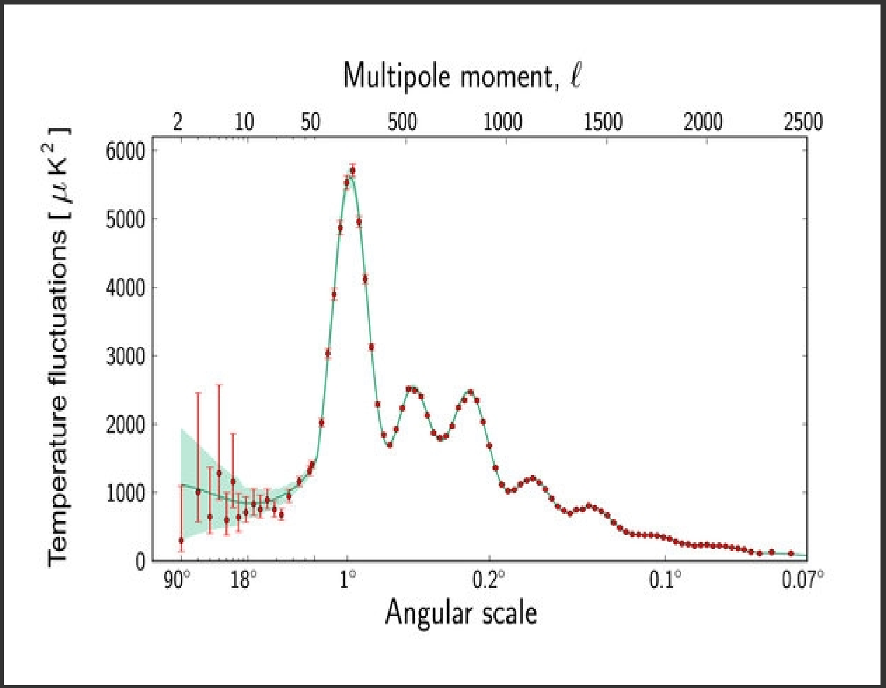
- Summary

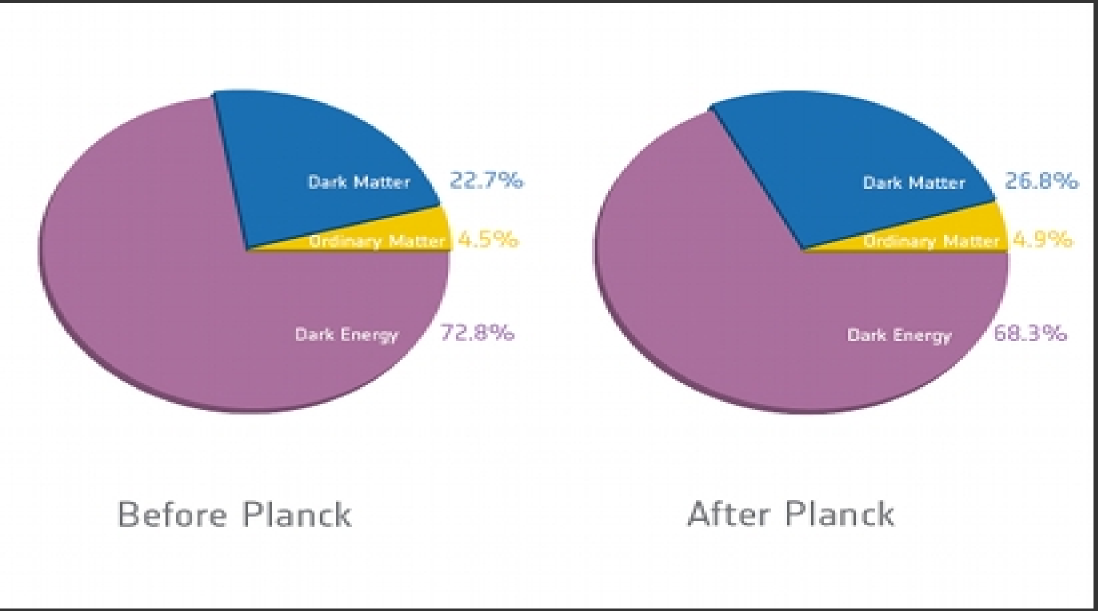


Riess et al. 1998, Perlmutter et al. 1999



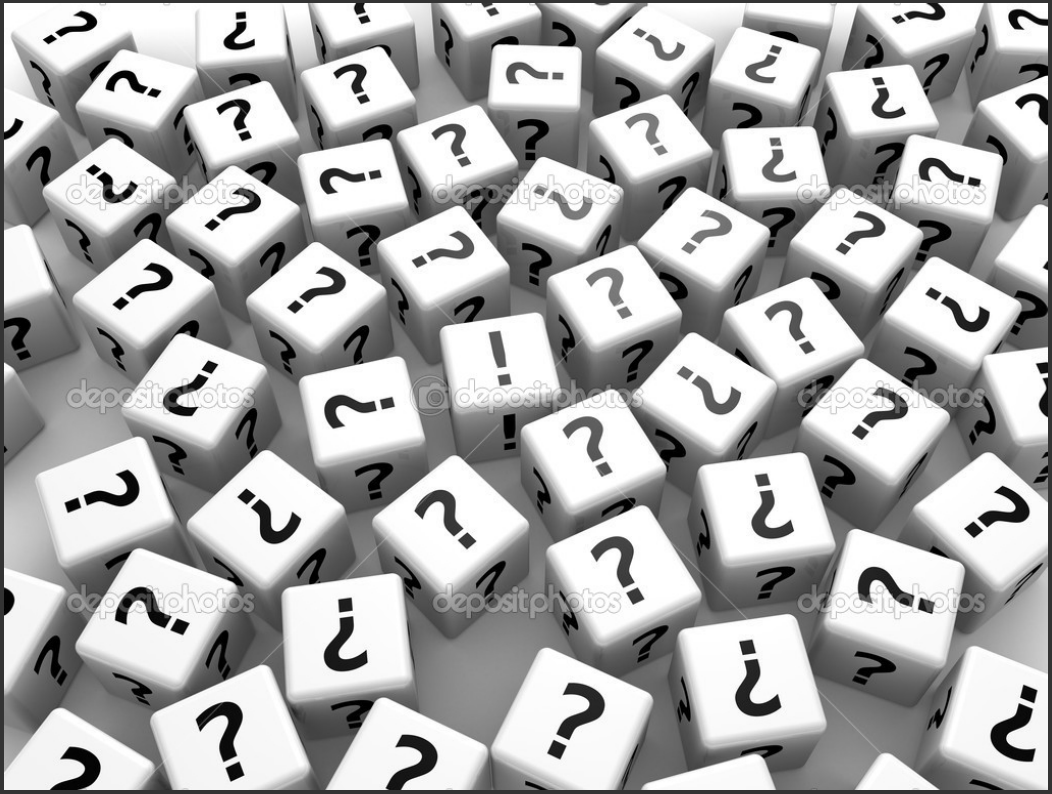


Multipole moment, ℓ
2
10
50
500
1000
1500
2000
2500
Temperature fluctuations [μK²]
6000
5000
4000
3000
2000
1000
0
90°
18°
1°
0.2°
0.1°
0.07°
Angular scale



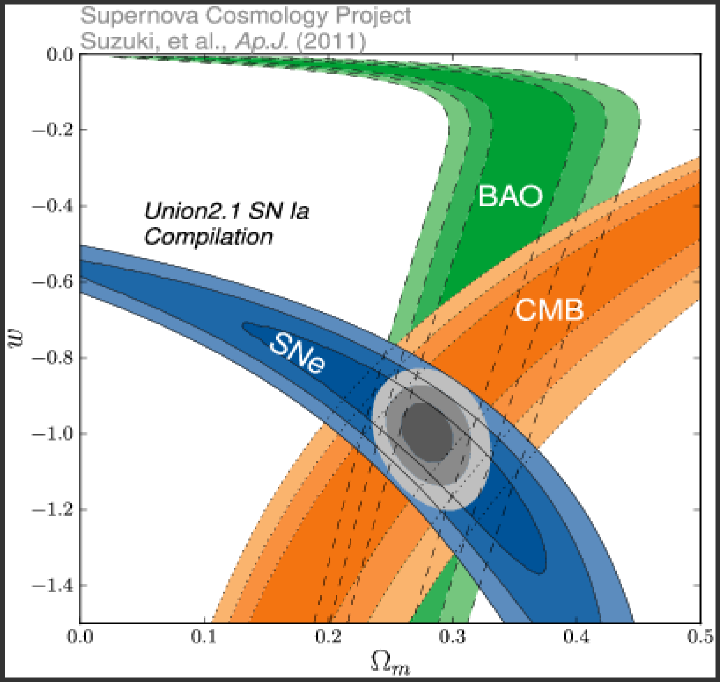
Dark Matter
22.7%
Ordinary Matter
4.5%
Dark Energy
72.8%
Dark Matter
26.8%
Ordinary Matter
4.9%
Dark Energy
68.3%
Before Planck
After Planck

Which is the nature of the dark energy?



Dark energy

Currently, the cosmological constant Λ is the most favored candidate, by the cosmological observations (SNIa, BAO, CMB), to the nature of dark energy whose equation of state (EoS) is $w=P/\rho=-1$.



However, the cosmological constant has some fundamental problems: the coincidence problem and fine tunning.

Several alternatives have been proposed to alleviate the problems of Λ :

- Deviation of the equation of state $w \neq -1$.
- Dynamical EoS. One of the most popular dynamical models is to parametrize the EoS as

$$w = w_0 + \frac{w_1 z}{1+z}$$

This is the well-known Chevallier-Polarsky-Linder (CPL) parametrization.

- Scalar fields: quintessence, phantom field, k-essence.
- Modified gravity.
- Braneworld.

Here, we study the following models: CPL, interacting DE, Holographic Ricci DE and modified polytropic Cardassian

The cosmological models

CPL MODEL:

$$w(z) = w_0 + w_1 \frac{z}{1+z},$$

$$E^2(z,\Theta) = \Omega_{\gamma 0}(1+z)^4 + \Omega_{DM0}(1+z)^3 + (1-\Omega_{DM0}-\Omega_{\gamma 0})(1+z)^{3(1+w_0+w_1)} \exp\left[-\frac{3w_1 z}{1+z}\right],$$

Chevallier&Polarski 2001, Linder 2003

Interacting DE:Q=δHρdm

Guo et al. 2007, Cao & Liang 2013

$$\dot{\rho_{DM}} + 3H\rho_{DM} = Q,$$
$$\dot{\rho_{DE}} + 3H(1+w_x)\rho_{DE} = -Q,$$

$$E^2(z,\Theta) = \Omega_{\gamma 0}(1+z)^4 + (1-\Omega_{DM0}-\Omega_{\gamma 0})(1+z)^{3(1+w_x)} + \frac{\Omega_{DM0}}{\delta+3w_x}\left[\delta(1+z)^{3(1+w_x)} + 3w_x(1+z)^{3-\delta}\right],$$

Holographic Ricci (CPL) DE

$$\rho_{HDE} = \frac{3c^2M_p^2}{L^2},$$

$$L^2 = 6/\mathcal{R}$$

$$\mathcal{R} = 6(2H^2 + \dot{H})$$

Cao et al. 2009, del Campo et al. 2011

Modified Polytropic Cardassian

Gondolo & Freese 2002

$$H^2 = \frac{8\pi G}{3}\rho_m \left[1 + \left(\frac{\rho_{Card}}{\rho_m}\right)^{q(1-n)}\right]^{1/q},$$

$$E^2(z,\Theta) = \Omega_r(1+z)^4 + \Omega_m(1+z)^3 \times \left[1 + \left(\left(\frac{1-\Omega_r}{\Omega_m}\right)^q - 1\right)(1+z)^{3q(n-1)}\right]^{1/q}$$

How to constrain these models?

The common tests use SNIa, CMB,BAO,H0 ...

- We use the LOSS SNIa sample (Ganeshalingam et al. 2013), 586 points in the redshift range $0.01<z<1.4$

- We also use BAO data: 6dFGS (Beutler et al. 2011), the WiggleZ experiment (Blake et al.2011), the SDSS-DR7 (Percival et al. 2010), SDSS-DR9 (Anderson et al. 2012), and the most recent DR11 (Delubac et al. 2015)

- The posterior information from WMAP-9yr data: the shift parameter (R), the acoustic scale (la) and the redshift decoupling epoch

Constraints from strong lensing in galaxy clusters

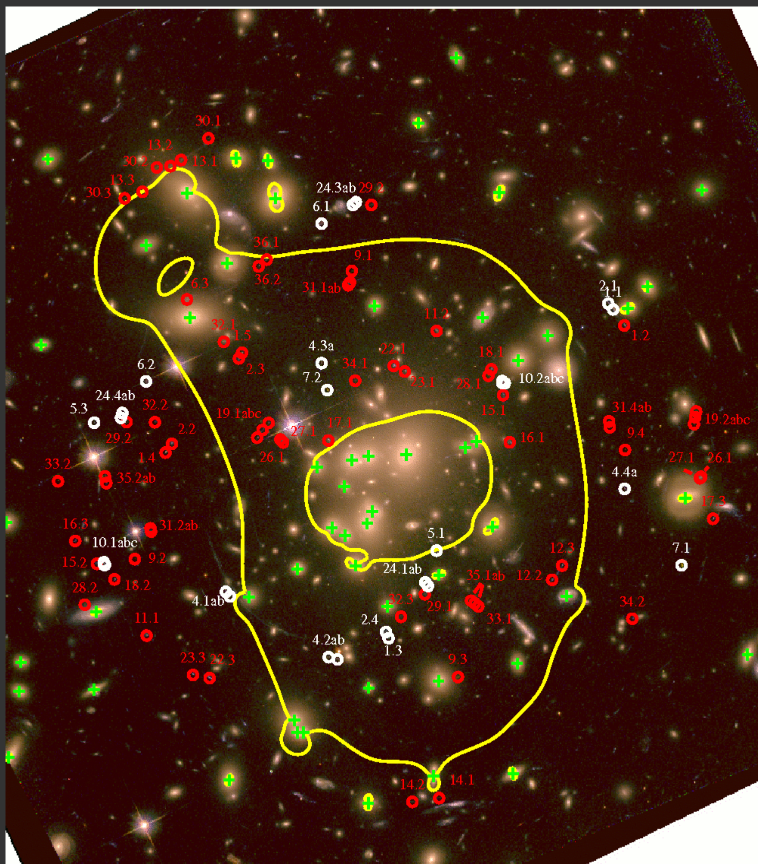
- Gravitational lensing of background sources produced by galaxy clusters are used to infer the matter distributions in the Universe.

- In the SL regime, the light beams are deflected so strongly that they can result in the observation of several distorted images of a background source.

- The positions of the multiple images depend significantly on the characteristics of the lens mass distribution. In addition, they are related to the angular diameter distance ratios between the lens, source and observer, thus retain information about the underlying cosmology.

- The wealth of strong lensing features observed in galaxy clusters offers insights on the nature of dark energy.

The strong lensing in Abell 1689



Limousin et al. 2007

Abell 1689 is among the richest clusters given the number density of galaxies in its core, one of the most luminous of galaxy clusters in X-ray wavelengths (Ebeling et al. 1996).

A1689 was previously used by Jullo et al. (2010) to simultaneously constrain the cluster mass distribution and the cosmological parameter for a flat wCDM model.

In our present work, we use the Jullo catalog, which consist on 28 images derived from 12 families with spectroscopic redshift range $1.15 < zs < 4.86$.

The method

The cosmological models to be tested were implemented in LENSTOOL (this software is publicly available at: http://projets.lam.fr/projects/lenstool/wiki) ray-tracing code, which uses MCMC method (Jullo et al. 2007) to reconstruct a lensing mass model.

The angular diameter distance, *D*, ratios for 2 images from different sources defines the 'family ratio' :

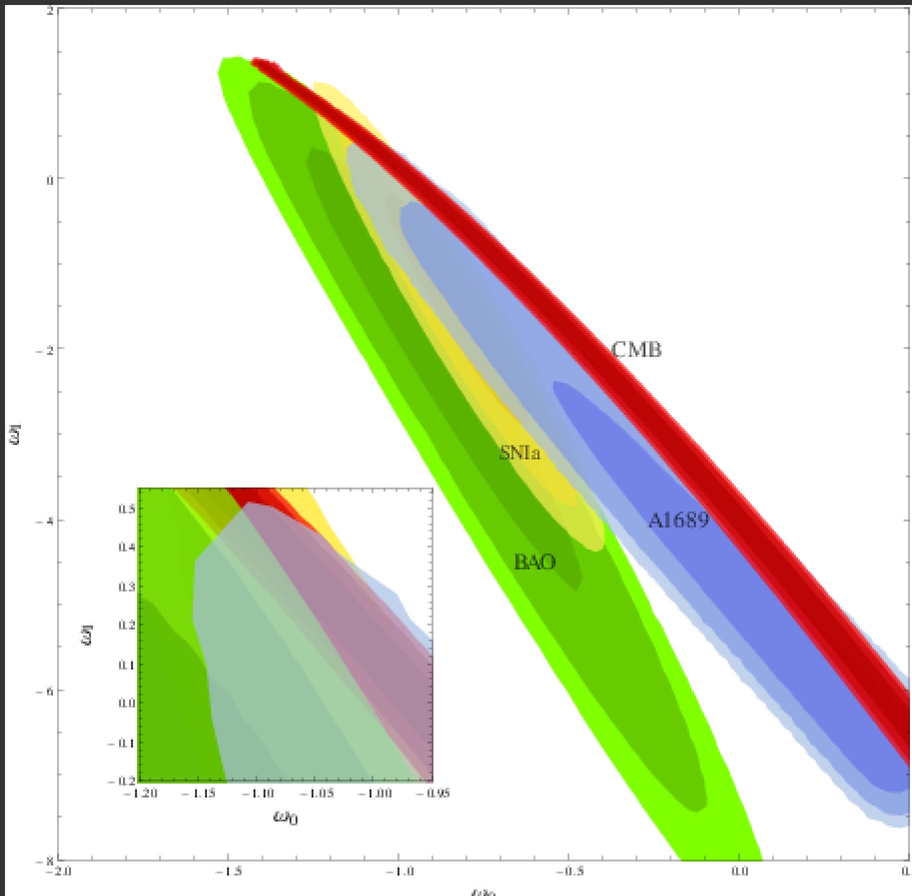
$$\Xi(z_1, z_{s1}, z_{s2}, \Theta) = \frac{D(z_1, z_{s1})}{D(0, z_{s1})} \frac{D(0, z_{s2})}{D(z_1, z_{s2})},$$

INSERT HERE YOUR FAVORITE COSMOLOGICAL MODEL

$$D_A(z) = \frac{r(z)}{1+z}.$$

$$r(z) = \frac{c}{H_0} \int_0^z \frac{dz'}{E(z')}.$$

Results



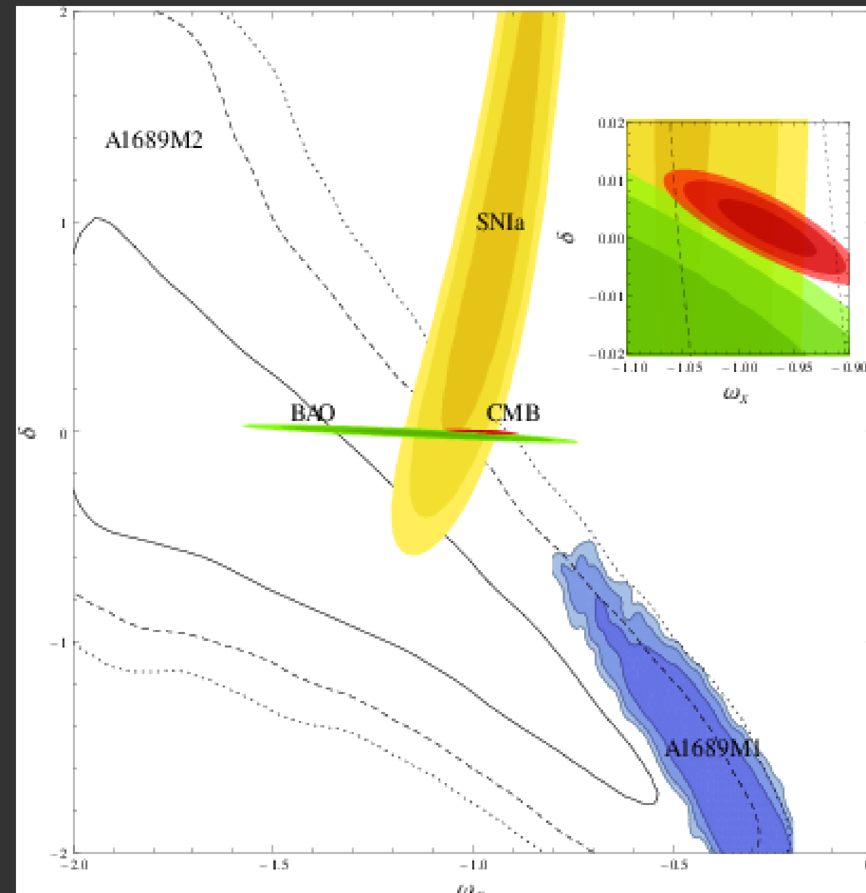
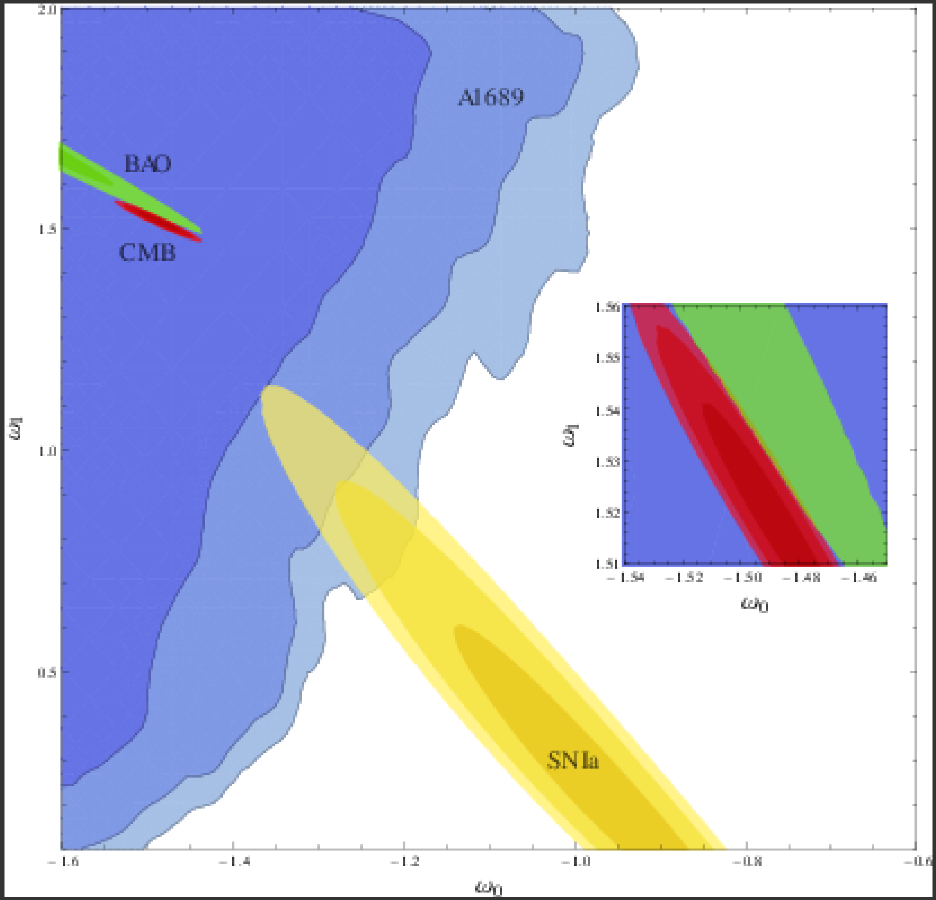


Table 1
CPL model

Data set	χ^2_{min}	FoM [a]	w_0	w_1
A1689	264.9	8.20	0.43 ± 0.48	$-6.45^{+3.60}_{-0.36}$
SNIa	574.13	24.41	-0.82 ± 0.14	-1.51 ± 0.91
BAO	3.77	7.89	-0.94 ± 0.26	-1.55 ± 1.72
CMB	0.363	21.54	-0.59 ± 0.58	-1.38 ± 2.36

Table 2
IDE model

Data set	χ^2_{min}	FoM	w_x	δ
A1689M1	256.7	127.063	-0.32 ± 0.07	$-2.0^{+0.30}_{-0.0}$
A1689M2	25.9	4.55	-1.53 ± 0.42	-0.21 ± 0.80
SNIa	574.95	38.76	-0.95 ± 0.08	0.77 ± 0.69
BAO	4.61	1060.52	-1.10 ± 0.13	-0.0093 ± 0.014
CMB	0.081	18488.1	-0.97 ± 0.02	-0.0017 ± 0.003



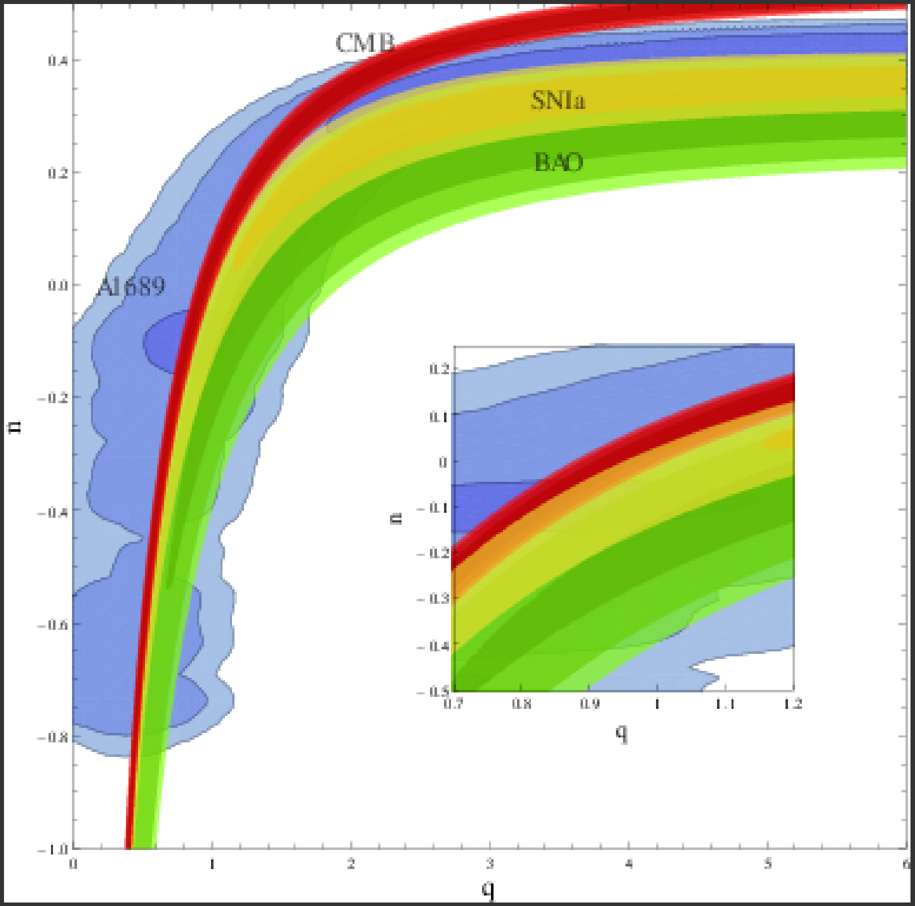


Table 3
HDE model

Data set	χ^2_{min}	FoM	w_0	w_1
A1689	279.82	24.85	$-1.60^{+0.13}_{-0.0}$	$1.97^{+0.01}_{-0.66}$
SNIa	575.135	153.89	-0.96 ± 0.10	0.21 ± 0.22
BAO	5.79	241.52	-2.03 ± 0.21	2.10 ± 0.21
CMB	0.081	14725.7	-1.48 ± 0.01	1.51 ± 0.01

Table 4
MPC model

Data set	χ^2_{min}	FoM	q	n
A1689	266.7	2.54	5.2 ± 2.25	0.41 ± 0.25
SNIa	574.52	18.69	3.20 ± 2.19	0.32 ± 0.08
BAO	3.59	7.97	3.29 ± 3.30	0.26 ± 0.13
CMB	0.363	37.63	4.52 ± 3.27	0.49 ± 0.05

Summary

- We used the SL measurements in galaxy cluster A1689 to put constraints on dark energy models.
- This method is a model-independent because we reconstruct the lensing mass model and simultaneously constrain the cosmological parameters of an underlying cosmology.
- These constrains are competitive with the other cosmological probes. To improve these limits we need to consider other galaxy clusters, for instance, the Frontier Fields clusters.
- We need to further investigate the effect of systematic errors in the SL observations on the cosmological constraints.
- We could extend this analysis for other cosmological (DM, DE) models.