Constraining Cosmological Parameters through Double Source Plane Lensing

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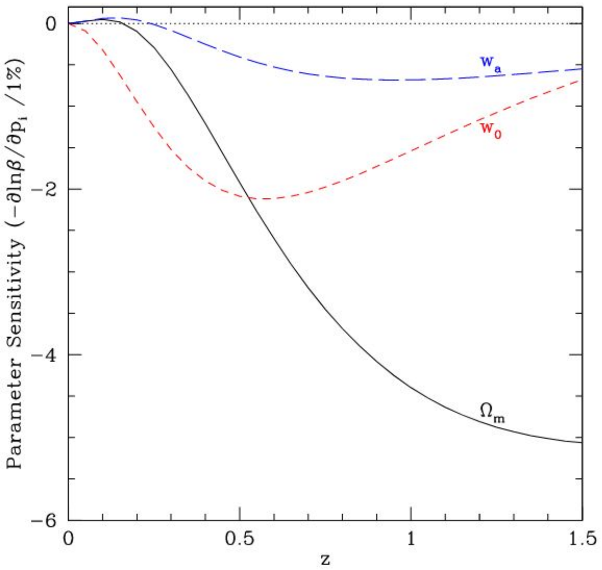
Motivation

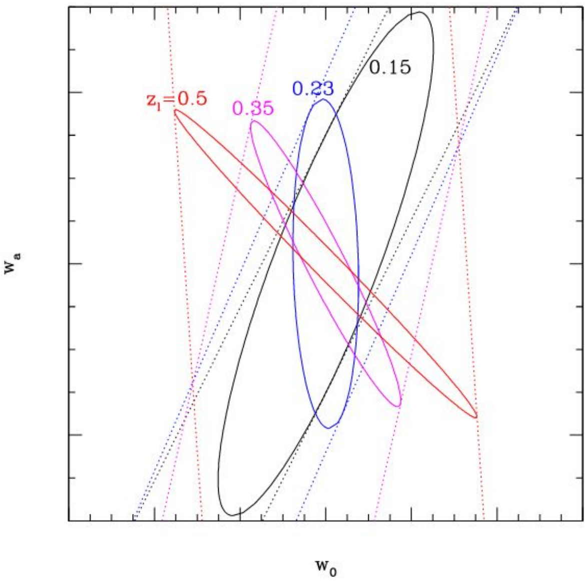
Einstein angular radius:

$$\theta_E^2 = \frac{4GM}{c^2} \frac{D_{LS}(z, z_1)}{D_L(z) D_s(z_1)}$$

Ratio of distance ratios:

$$\beta = \frac{D_{LS}(z, z_1)}{D_s(z_1)} \frac{D_s(z_2)}{D_{LS}(z, z_2)}$$

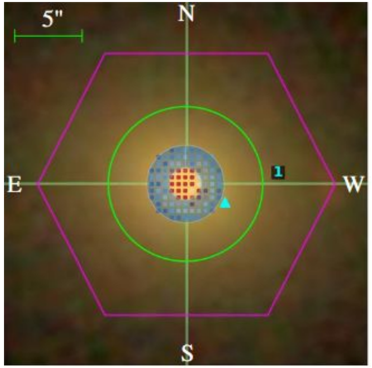




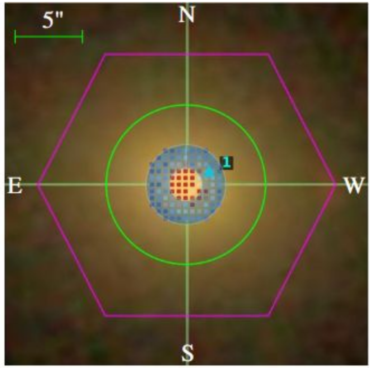
Results exhibited for $z_1 = 2z$ and $z_2 = 1.5z_1$

E. Linder. Doubling strong lensing as a cosmological probe. 2019

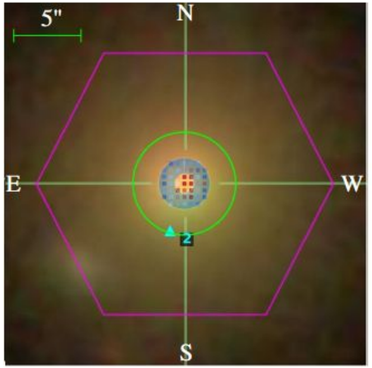
SDSS-IV MaNGA - Systems



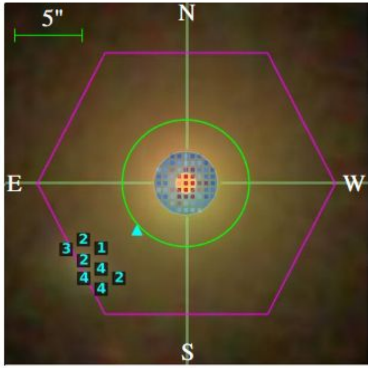
(1a)



(1b)



(2a)



(2b)

System 1 Plate-IFU: 8131-6102

$$z = 0.04956, \;\; z_1 = 0.694, \;\; z_2 = 0.954$$

$$\theta_1 = 2.74^{+0.13}_{-1.56}, \;\; \theta_2 = 2.77^{+0.19}_{-1.57}$$

System 2 Plate-IFU: 8947-6104

$$z = 0.04865, \;\; z_1 = 0.165, \;\; z_2 = 0.264$$

$$\theta_1 = 1.85^{+0.06}_{-1.13}, \;\; \theta_2 = 2.27^{+0.08}_{-1.50}$$

Talbot, M., Brownstein, J., Bolton, A., Bundy, K., Andrews, B., & Cherinka, B. et al. (2018). SDSS-IV MaNGA: The Spectroscopic Discovery ofStrongly Lensed Galaxies. Retrieved from https://arxiv.org/pdf/1803.03604.pdf

Theory

Comoving distance $$d_c = \frac{c}{H_0}\int_0^z \frac{1}{E(z')}dz'$$

$$E(z) \equiv \frac{H(z)}{H_0} = \sqrt{\Omega_{rad}a^{-4} + \Omega_m a^{-3} + \Omega_k a^{-2} + \Omega_{DE}a^{-3(1+w)}}$$

$$a = \frac{1}{1+z}$$

Generalization to curvature

$$d_M = \begin{cases} \frac{d_H}{\sqrt{\Omega_K}} \sinh\left(\frac{\sqrt{\Omega_k}d_c}{d_H}\right) & \Omega_k > 0 \\ d_c & \Omega_k = 0 \\ \frac{d_H}{\sqrt{\Omega_K}} \sin\left(\frac{\sqrt{\Omega_k}d_c}{d_H}\right) & \Omega_k < 0 \end{cases}$$

Angular diameter distance

$$D = \frac{d_M}{1+z}$$

Theory & Methodology

Flat & matter and dark energy dominated universe:

$$\Omega_{rad} = 0,\ \Omega_k = 0,\ \Omega_m = 0.27,\ \Omega_{DE} = 0.73$$

Dark energy equation of state parametrization

$$\omega(a) = \omega_0 + \omega_a \frac{z}{z+1}$$

$$E(z) = \sqrt{\Omega_m a^{-3} + \Omega_{DE} a^{-3(1+\omega_0+\omega_a)} e^{-3\omega_a(1-a)}}$$

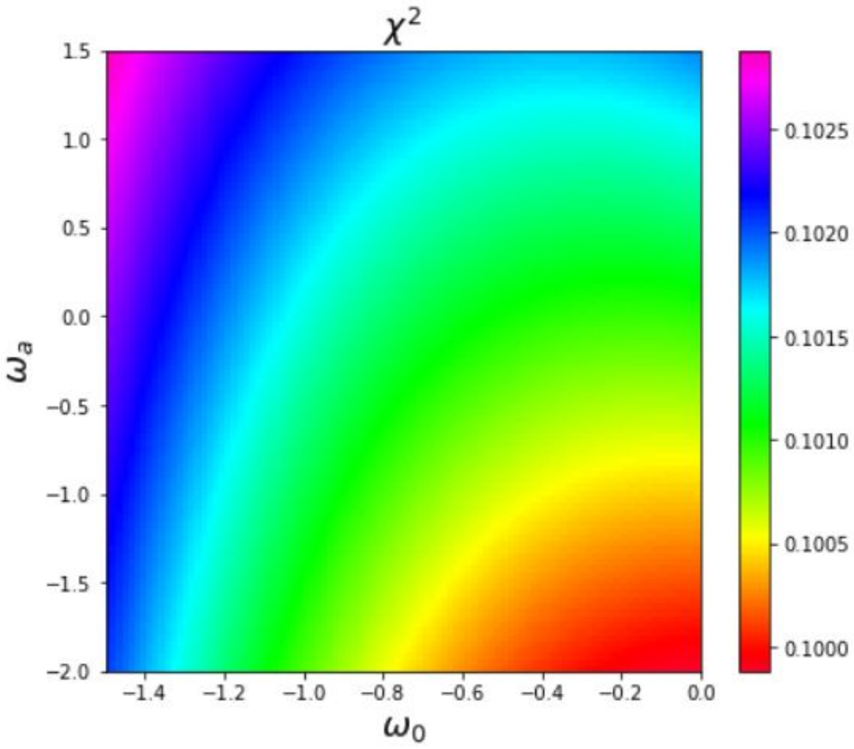
$$D = \frac{d_h}{1+z} \int_0^z \frac{1}{E(z')} dz'$$

Statistical Analysis

$$\chi^2 = \sum_i \frac{\left(\beta_i - \tilde{\beta}_i\right)^2}{\sigma_i^2}$$

$$\beta = \frac{\theta_{E,1}^2}{\theta_{E,2}^2} = \frac{D_{LS}(z, z_1)}{D_s(z_1)} \frac{D_s(z_2)}{D_{LS}(z, z_2)}$$

Results



$$\beta_1 = 0.97846 \pm 0.86644$$

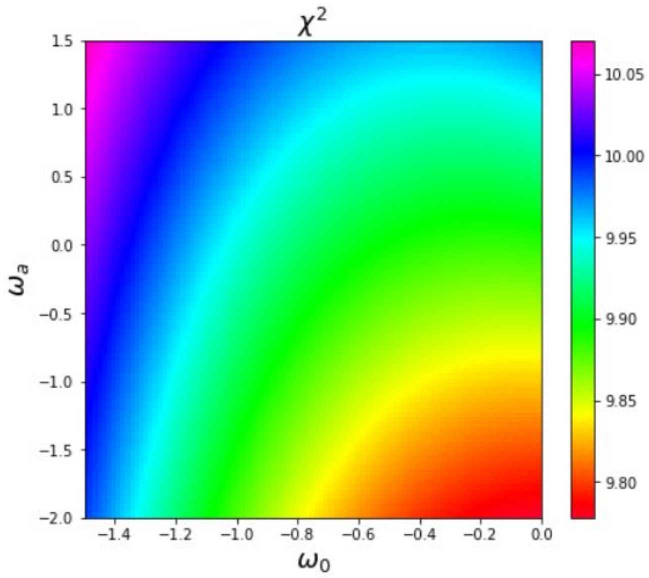
$$\frac{z_1}{z} = 14.00, \quad \frac{z_2}{z_1} = 1.374$$

$$\beta_2 = 0.66419 \pm 0.62948$$

$$\frac{z_1}{z} = 3.392, \quad \frac{z_2}{z_1} = 1.6$$

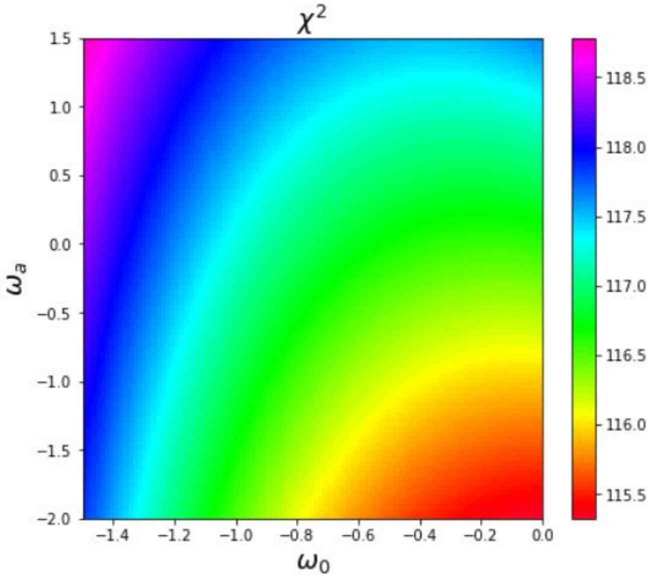
Results

Using only upper limits:



$$\beta_1 = 0.97846 \pm 0.16321$$
$$\beta_2 = 0.66419 \pm 0.06362$$

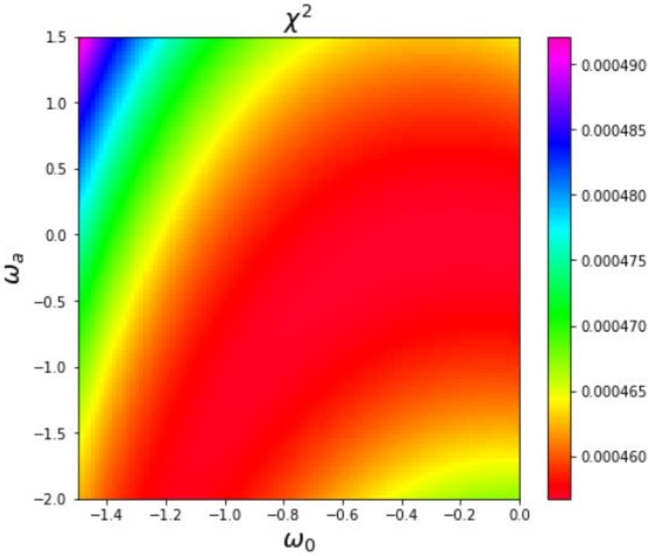
Reducing uncertainties



$$\beta_1 = 0.97846 \pm 0.02009$$
$$\beta_2 = 0.66419 \pm 0.01853$$

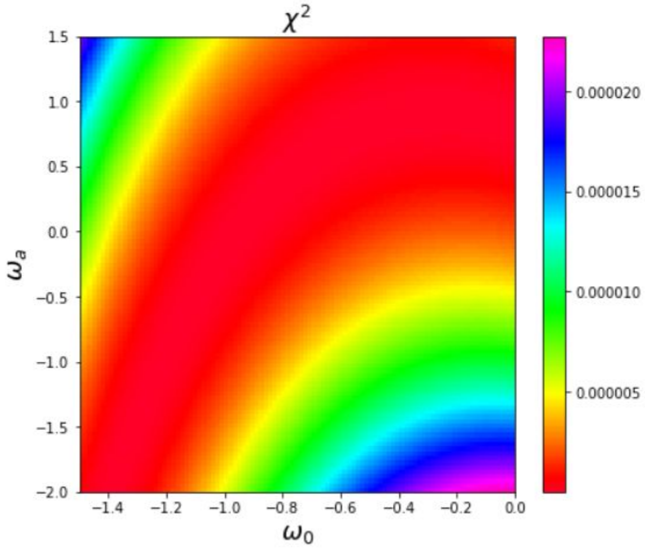
Results

Using effective redshift distribution & close to predicted Einstein Radii



$$\beta_1 = 0.74649 \pm 0.22836$$
$$\beta_2 = 0.75342 \pm 0.22988$$

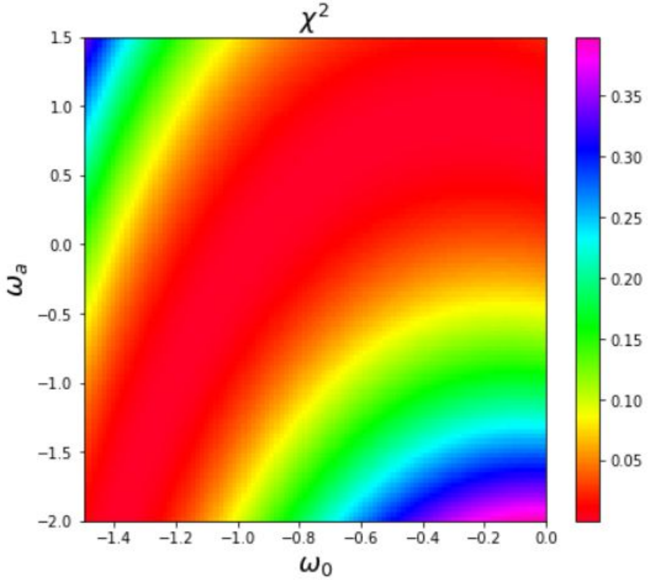
Using effective redshift distribution & almost predicted Einstein Radii



$$\beta_1 = 0.75013 \pm 0.22916$$
$$\beta_2 = 0.75013 \pm 0.22916$$

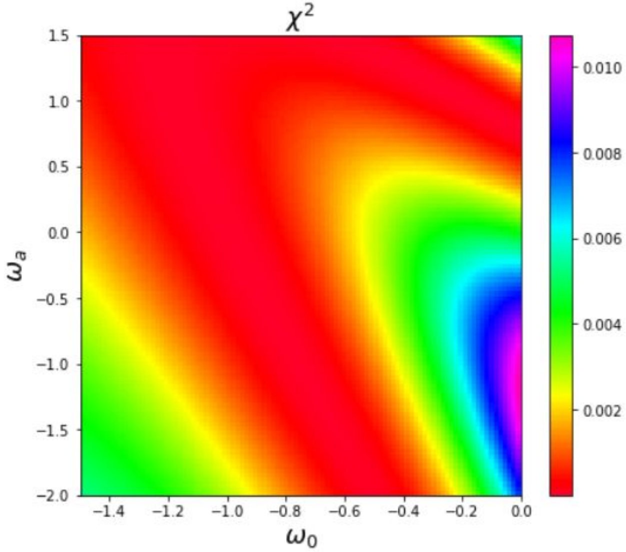
Results

Using effective redshift distribution & predicted Einstein Radii



$$\beta_1 = 0.75013 \pm 0.00173$$
$$\beta_2 = 0.75013 \pm 0.00173$$

Using higher effective redshift distribution & predicted Einstein Radii



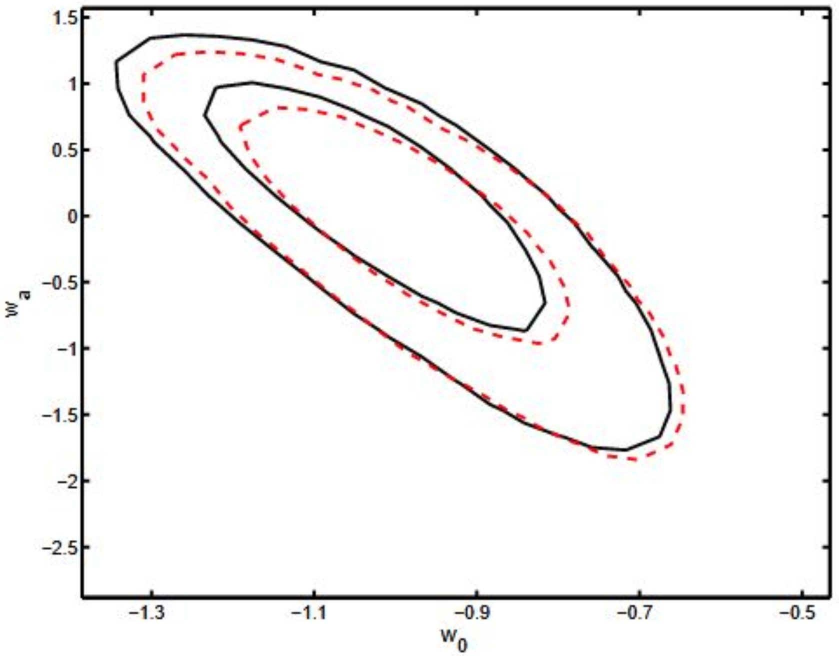
$$\beta_1 = 0.75568 \pm 0.23037$$
$$\beta_2 = 0.75603 \pm 0.23044$$

Conclusions

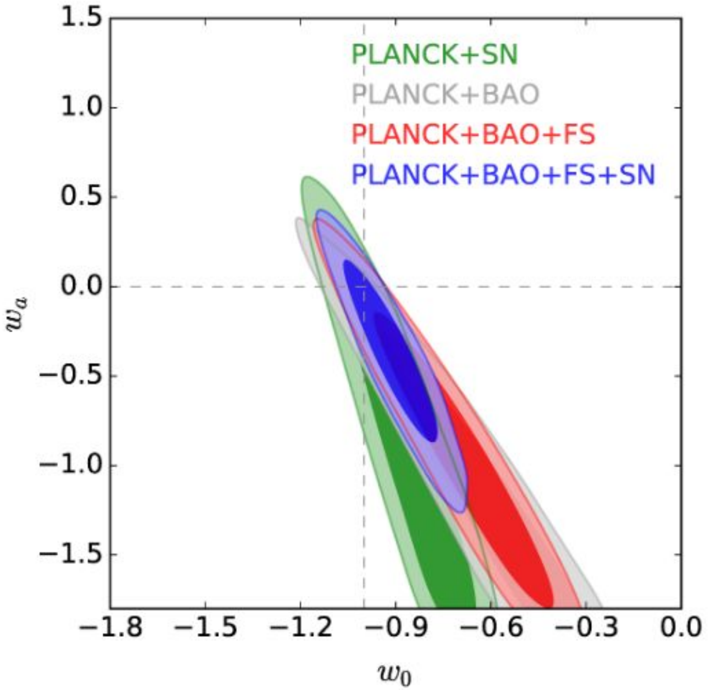
- The information of these systems cannot be used to determine constraints on the dark energy equation of state parameters. Even by reducing the uncertainty of the Einstein radii the contour shape does not change significantly.
- The variable beta is more sensitive to systems that have redshift distribution similar to the effective redshift distribution: $z_1 = 2z \quad z_2 = 1.5z_1$
- For higher lens redshifts (close to 0.5) the variable beta is more sensitive to the dark energy equation of state parameters, but the ellipse leans to the left (as in classical cosmological probes).

Thank you! Questions?

Just in case



Hong Li and Jun-Qing Xia. Constraints on dark energy parameters from correlations of cmb with lss. Journal of Cosmology and Astroparticle Physics, 2010(04):026-026,Apr 2010.



M. Tanabashi et al. (Particle Data Group), Phys. Rev. D 98, 030001 (2018).