Lensing Time Delays
and Survey Complementarity

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Dark Energy in Detail

How can we measure dark energy in detail, in the next 10 years?

Cosmological complementarity is essential: probes that break each other's degeneracies.

But all distances, and growth, measure H(z), which has a set combination of parameters (differing mildly with redshift).

How do we break out of the rut?

Entry to Beijing, from
卧虎藏龙

Dark Energy in Detail

Distance ratios offer a different combination of cosmological parameters. Linder 2004 identified strong lensing time delays and image separations, as possible ratio probes.

Recently, significant advances have occurred in the lens modeling necessary for the time delay probe, lending it new promise.

Note that WMAP7 (Komatsu+ 2011) used a single time delay distance to complement the CMB.

Lensing Time Delays

We concentrate on strong lensing time delays, which has better (near term) cosmological properties.

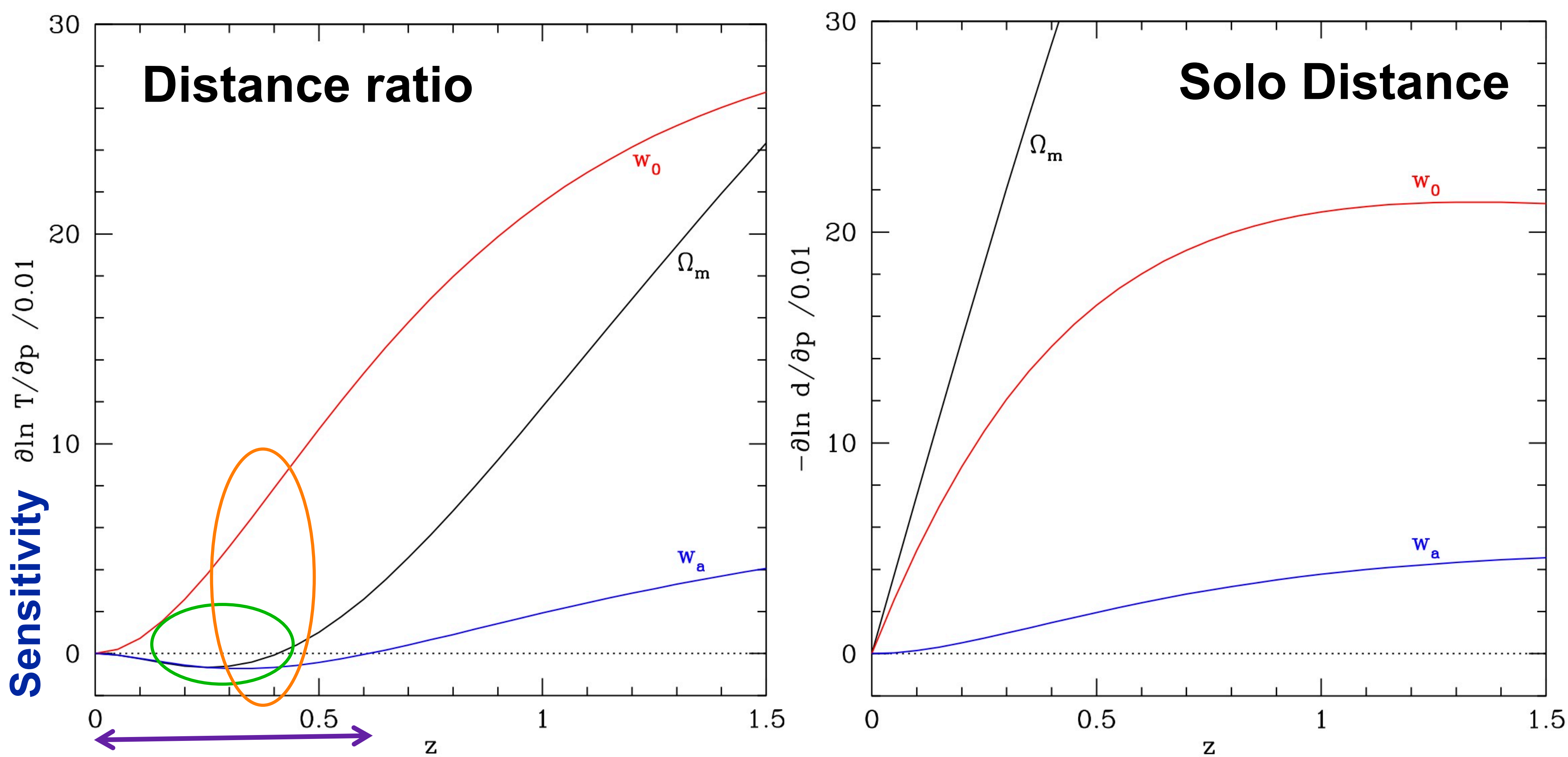
This also allows use of image separations as a check on systematics.

The key quantity is the time delay distance

$$T \equiv \frac{r_l r_s}{r_{ls}}$$

Cosmological Parameter Degeneracy

Strong lensing time delays have very different parameter dependences than solo distances.

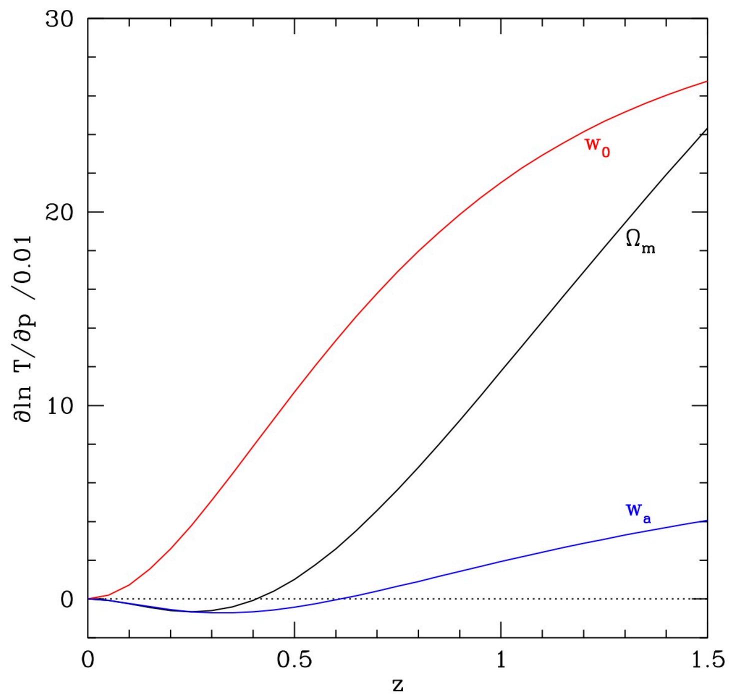


Cosmological Parameter Degeneracy

Sensitive to w_0, insensitive to Ω_m, and positively correlated w_0-w_a for z=0.1-0.6.

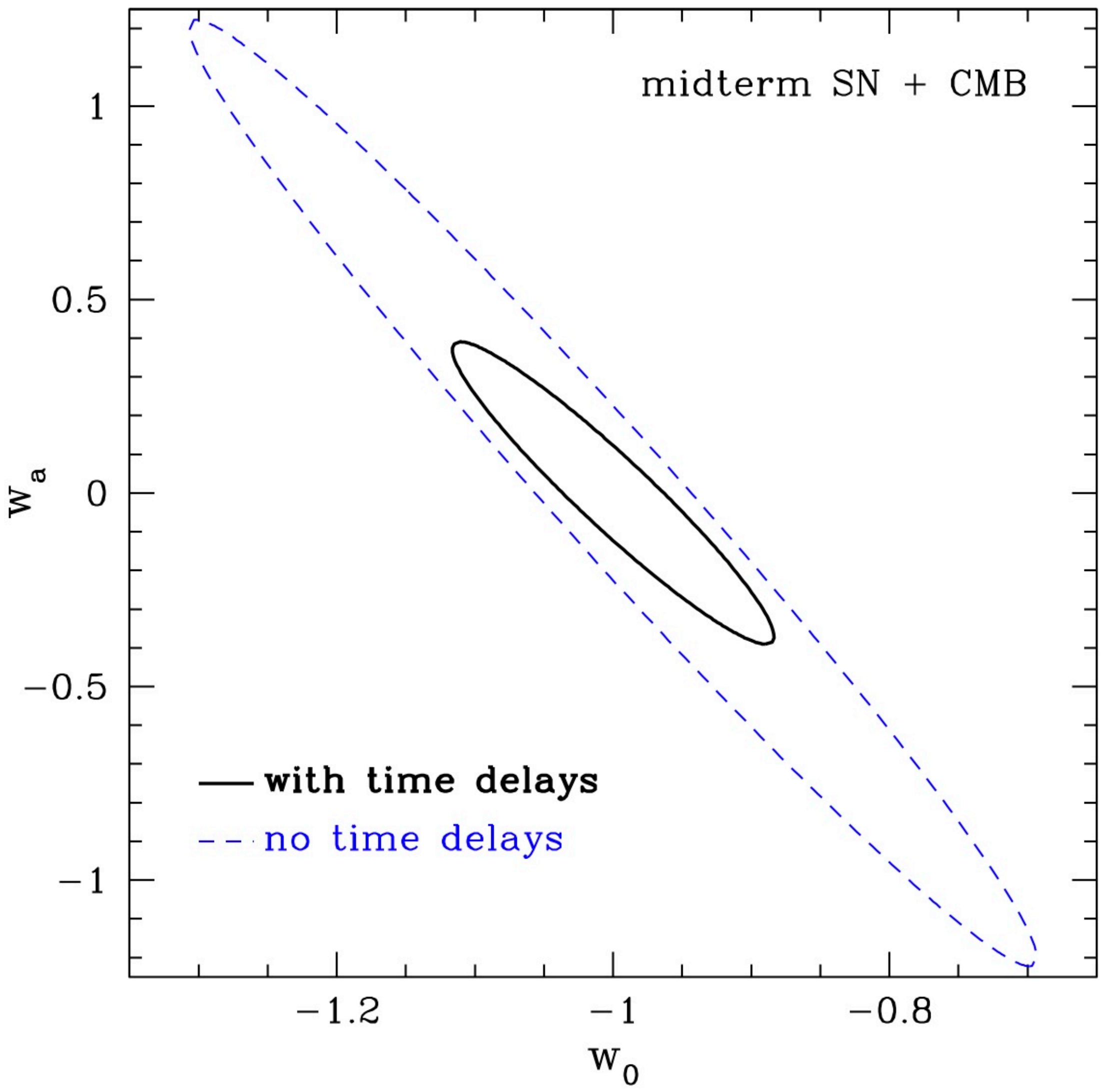
Insensitivity to Ω_m means degeneracies broken. Good sensitivity to w_0 means strong constraints. Positive correlation of w_0-w_a means break degeneracies. (Contours not actually orthogonal though.)

Overall, expect strong complementarity with standard distances.



Time Delays + Supernovae

Lensing time delays give superb complementarity with SN distances plus CMB.



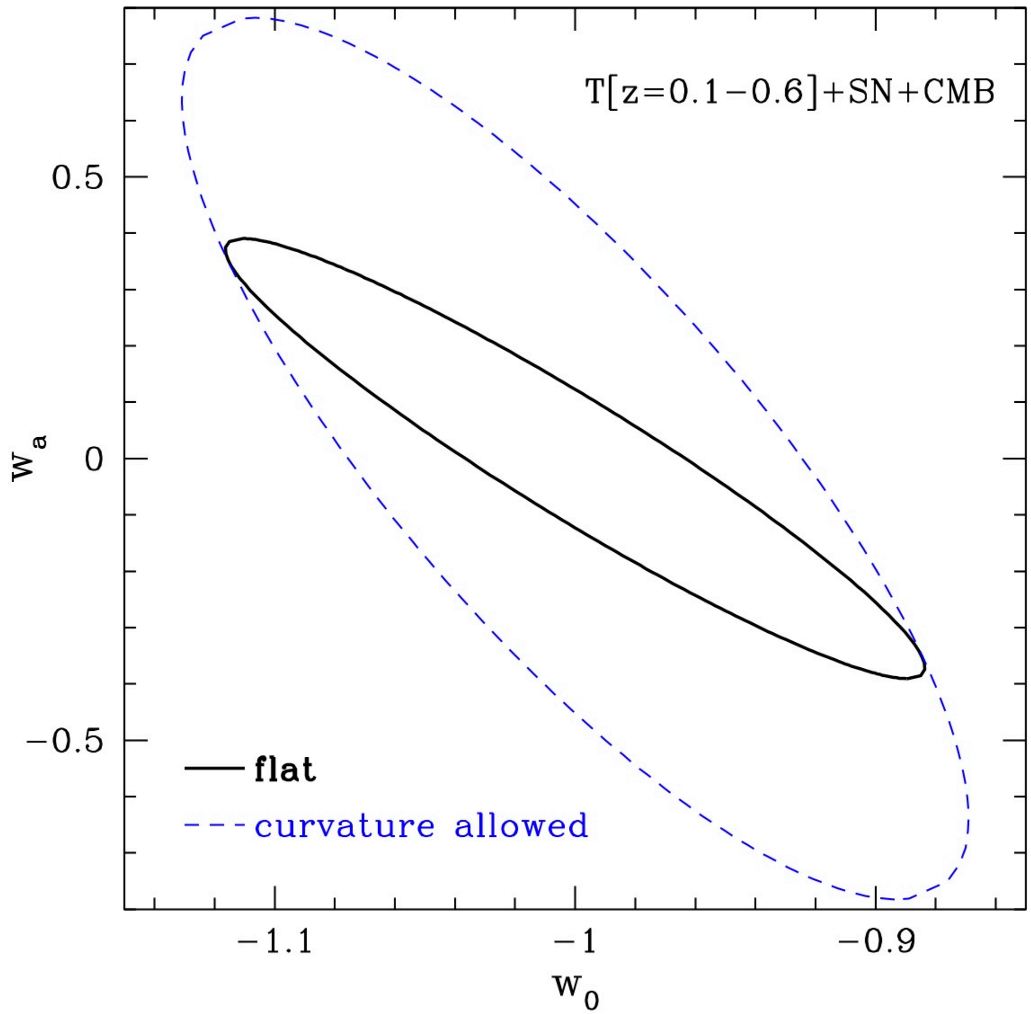
T to 1% for
z=0.1, 0.2,… 0.6

SN to 0.02(1+z)mag
for z=0.05, 0.15... 0.95

Factor 4.8 in area
Ω_m to 0.0044
h to 0.7%
w_0 to 0.077
w_a to 0.26

Time Delays and Curvature

If fit for curvature, time delays reduce degeneracy by factor 5. Except for w_a, estimates degrade by <30%, and find Ω_k to 0.0063.



Time Delay Surveys

Best current time delay systems at 5% accuracy, and there are 16 systems with Δt reasonably measured.

To get to 1%, either improve systematics, increase sample by 1 OOM, or both.

Major groups currently from California+, using HST data, and France (CosmoGrail), using VLT+HST.
Slow progress because HST time rare.

(Alternate approach through high statistics stacking rather than detailed modeling, e.g. Oguri & Marshall 2010, Coe & Moustakas 2009)

Time Delay Surveys

Requirements:

1) **wide field of view for survey to find lensed, varying sources (and SN for complementarity).**

2) **high cadence imaging to measure time delays.**

3) **high resolution imaging for lens mapping and modeling,**

4) **spectroscopy for redshift, lens velocity dispersion.**

Too much for one survey, so look for synergy, and look for ground based high resolution.

Survey Complementarity

Synergy: KDUST + DES.

- **Overlapping southern fields.**
- **NIR/visible partnering.**
- **SN survey included.**
- **Only low redshift z<0.6 needed for lenses.**

Spectroscopy from DES partners, Dome A spectroscopic telescope, or VLT/AAT/SALT/etc.

Systematics

Substructure in lens mass distribution causes microlensing: shows up in anomalous flux ratios of images, and anomalous image separations.

Feature, not bug: learn about dark matter clumping (Keeton & Moustakas 2009).

Characterize microlensing by high cadence. Ideally want $\Delta t < 0.2$ day; can use long time baseline.

Projected mass can be removed with redshift data.

Survey design: resolution ~0.2" (best epoch); cadence <0.5 day ; time baseline ~100 d. Strong match to Antarctic seeing and long night.

Summary

Lensing time delays + SN complementarity can give strong constraints on dark energy before 2020.

H_0 and curvature are also tightly determined (0.7%).

Strong synergy between KDUST and DES. Relies on high resolution at Dome A. Need survey design/reality check.

Only 10 times more time delay systems needed, at current best level of systematics. Time domain science.

Only z<1 observations needed.

Future – radio lensing (Lofar, MWA)? Testing gravity (screening). Early structure.

Institute for the Early Universe

"World Class University" program in Seoul, Korea. BCCP+Ewha