Large Synoptic Survey Telescope

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How to Measure Dark Energy with LSST's Strong Lenses

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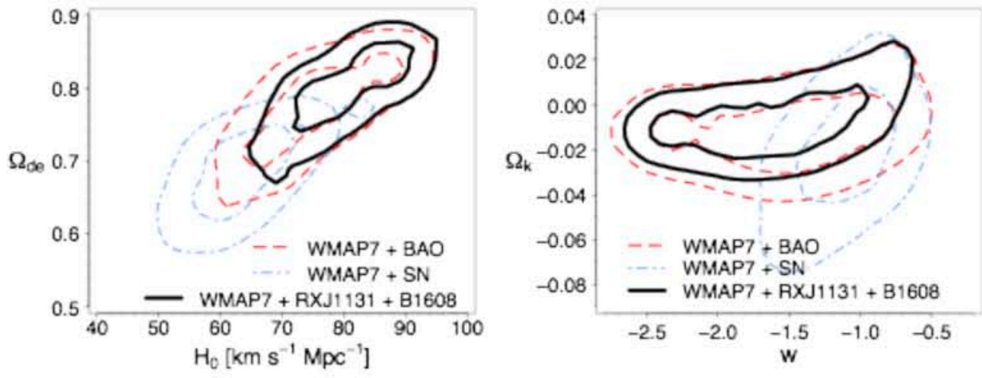
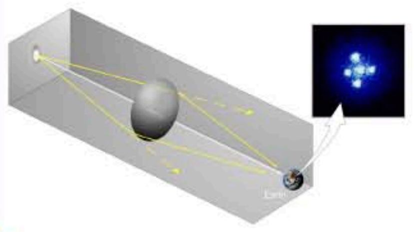
Strong gravitational lensing is sensitive to dark energy (DE) via the combinations of angular diameter distances that appear in model predictions of the lens strength. Lenses with variable sources offer the most promise: the corresponding time delay distance has recently been shown to be measurable to 5% precision: large samples of lensed quasars and supernovae will enable the most direct access to the DE parameters, while multiple source plane, compound lens systems may provide an interesting alternative probe. Its wide field survey and high cadence will enable LSST to provide a sample of several thousand measured time delays, two orders of magnitude larger than the current sample, and allow an independent, competitive Stage IV DE parameter measurement to be made. In this poster we outline the LSST strong lensing cosmography analysis pipeline that will be required, and identify the practical problems to be solved in the next few years.

Each lens time delay distance can be measured with 5% precision

Time delays between the lightcurves of multiply-imaged AGN and SNe enable a direct physical measurement of the cosmological "time delay distance" in the system. $D_{\Delta t}$ depends mainly on H_0, but is also sensitive to the influence of dark energy.

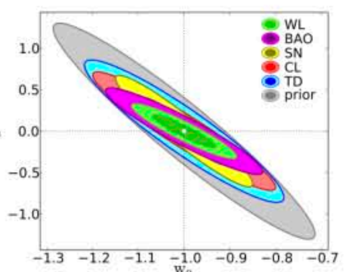


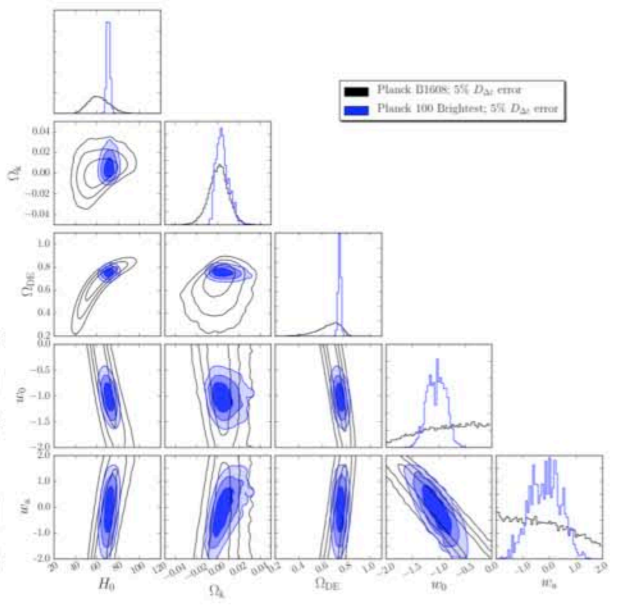


Suyu et al. (2010, 2012) have used high precision (2-4%) time delays from radio and optical monitoring campaigns, combined with flexible modeling of the lens mass and source light distributions constrained by high signal to noise, high resolution HST optical imaging data, to make 5% time delay distance measurements in two lens systems, B1608 and RXJ1131. The mass distribution external to the lens must be included explicitly and marginalized over. These two lenses are as informative as other cosmographic probes (see above figures from Suyu et al. 2012).

A large sample of lenses can provide an independent, competitive cosmological probe

Forecasts of parameter constraints from samples of 60-100 lenses show that time delay distances can be competitive in the next decade (Coe & Moustakas 2009, Marshall et al. 2011). Sampling a range of lens redshifts allows the w0-wa degeneracy to be broken. Modeling out systematic errors will absorb some information, pushing us to even larger samples.





DESC Task TJP H-1: incorporate time delay distances into the LSST dark energy analysis pipeline, and iterate forecasts including nuisance parameter marginalisation and residual systematic errors

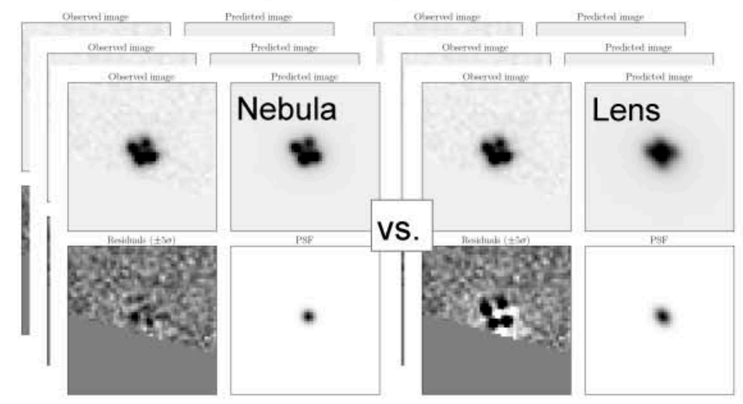
How do we scale up this experiment with LSST?

See also the LSST DESC White Paper (2012)

Lensed quasars and supernovae look distinctive to us, but having a machine find them in the LSST database and image store is a significant challenge.

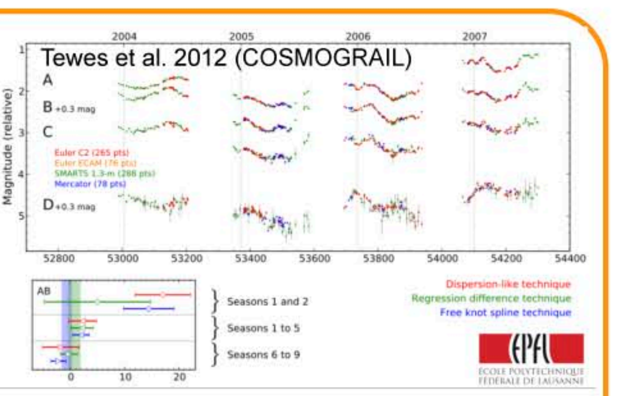
Find Thousands of Lenses

Identification of lens candidates based on their catalog entries will depend on the object detection and deblending software in resolving the multiple images. Then, modeling the pixels in each candidate (as "lenses" vs "nebulae") should allow a Bayesian classification, and optimal lightcurve extraction.



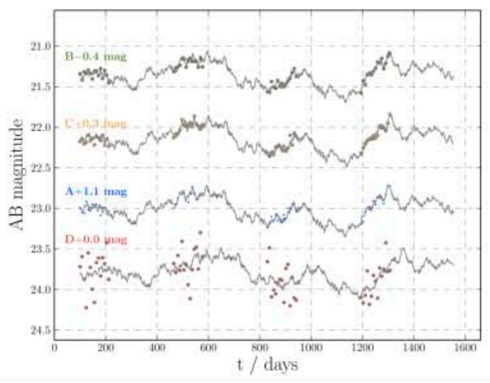
DESC Task SL H-2: *Use simulated and real Stage III catalogs and images to (a) test the level 2 deblending software, (b) develop algorithms for fully-automated catalog-based lens candidate selection, (c) develop algorithms for fully-automated image-based lens classification and measurement, and (d) implement these algorithms using the level 3 API.*

Optical lightcurves are contaminated by microlensing: this can be modeled out at the cost of some precision.



Measure Time Delays

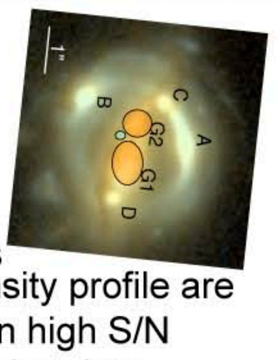
Methods for measuring time delays in the presence of microlensing need to be accurate, that is, leaving no significant residual error.

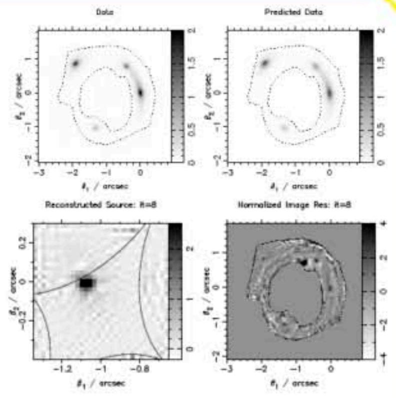


As well as microlensing, the challenge with LSST will be it's long, sparse, lightcurves. Left: this simulation (G. Dobler & B. Brewer) shows the typical single filter cadence and season.

DESC Task SL H-3: Use simulated lightcurves in 6 filters, sampled at realistic OpSim-generated cadence, to probe the available time delay precision and accuracy, using both "standard" and newly-developed algorithms. Realistic microlensing and intrinsic variability must both be included, as must realistic observing conditions.

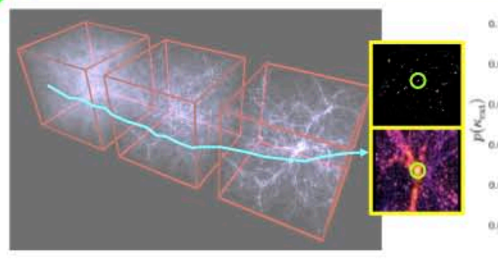
Suyu et al's detailed modeling shows that precision measurements of the lens density profile are possible - given high S/N HST/ACS imaging data.

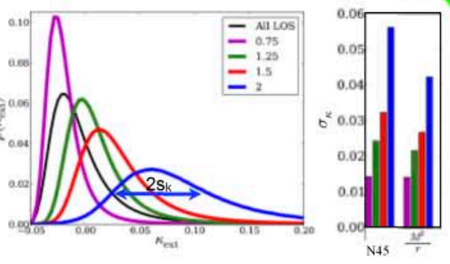




Follow-up with High Resolution Spectro-Imaging

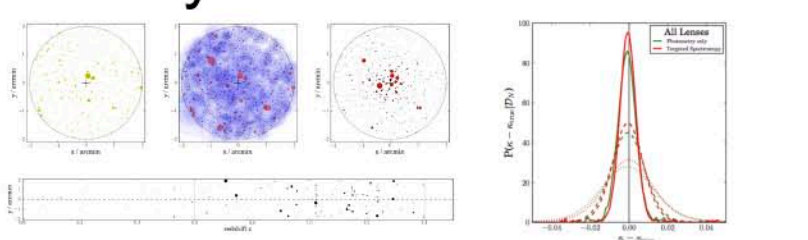
Facilities in the 2020's will enable the necessary follow-up data to be obtained in large but feasible campaigns on thirty-meter class telescopes and JWST. The IFU spectrographs at these observatories offer new opportunities: better lens light removal and dust correction, more lens model constraints from the source, and simultaneous redshifts and kinematics.



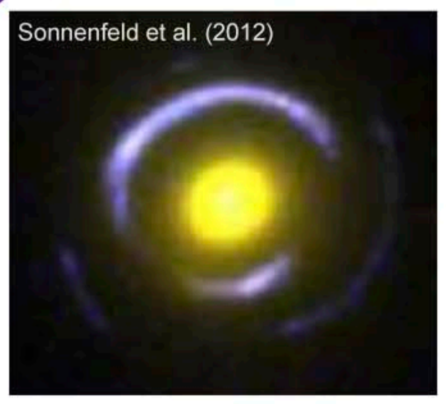


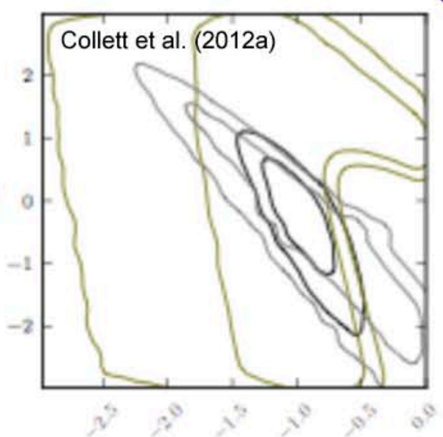
The external convergence, κ_{ext}, can be estimated by comparing the galaxies observed around a given lens with predictions from cosmological simulations where κ_{ext} is known (Suyu et al. 2010). "Lens-weighted" overdensity gives more precise estimates (Greene et al. 2012, above). A halo model of all the mass in the field allows all the photometric information we have to be incorporated (Collett et al. 2012b, below). These investigations agree that selecting low density lines of sight reduce the uncertainty due to κ_{ext}.

Accurately Model All the Mass



DESC Task SL H-1: Use ray-traced cosmological simulations to investigate the methodology of light-cone mass reconstruction given LSST-grade photometric object catalogs and provide an optimal estimate of Pr(κ_{ext}), and test its accuracy in LSST-sized mock lens samples.



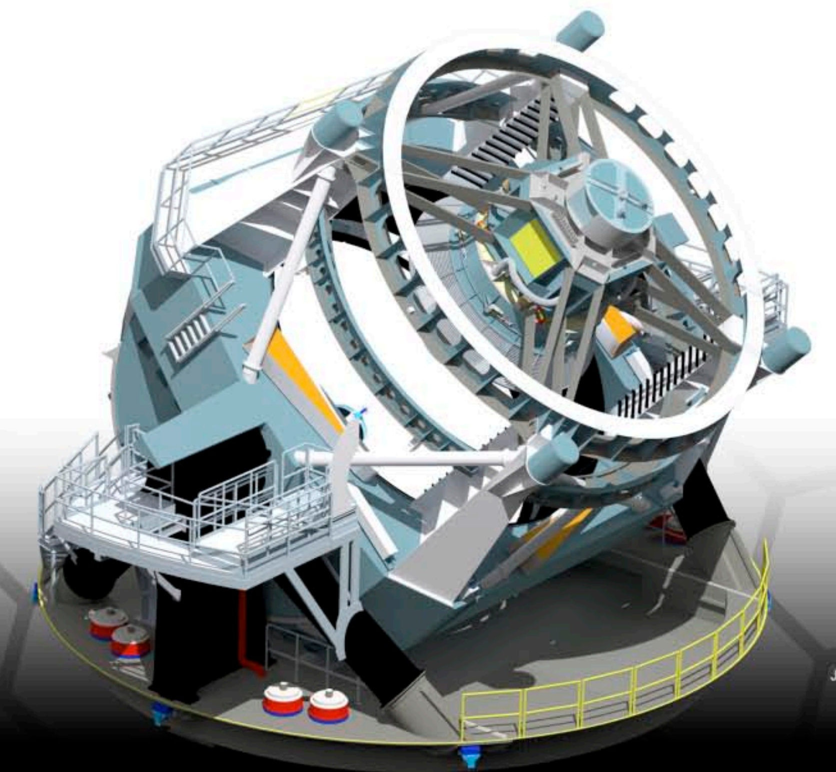


Multiple Source Plane Lenses?

Time delay lenses are currently competitive, but they may not be the only way to probe Dark Energy with strong lensing. Lenses with multiple sources at different redshifts allow both the mass model and a ratio of distance ratios to be constrained.
Even small numbers of either galaxy or cluster-scale lenses could give interesting constraints, provided all the mass (including the line of sight) can be modelled (eg Jullo et al. 2010, D'Aloisio & Natarajan 2011, Collett et al. 2012a).

DESC Task SL LT-1: Explore multiple source plane cosmography as a competitive Dark Energy probe, using realistic simulations of compound lenses and their observations, on both galaxy and cluster scales.

References: Coe & Moustakas 2009, ApJ, 706, 45 ● Collett et al. 2012a, MNRAS, 424, 2864 ● Collett et al. 2012b, in preparation ● D'Aloisio & Natarajan 2012, ApJ, 411, 1628 ● Greene et al. 2012, ApJ submitted
Jullo et al. 2010, Science, 329, 924 ● LSST Dark Energy Science Collaboration 2012, arxiv.org/1211.0310 ● Marshall et al. 2011 AAS meeting ● Sonnenfeld et al. 2012, ApJ, 752, 163 ● Suyu et al. 2010, ApJ, 711, 201
Suyu et al. 2012, ApJ submitted, arxiv.org/1208.6010 ● Tewes et al. 2012, A&A submitted, arxiv.org/1208.5598



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