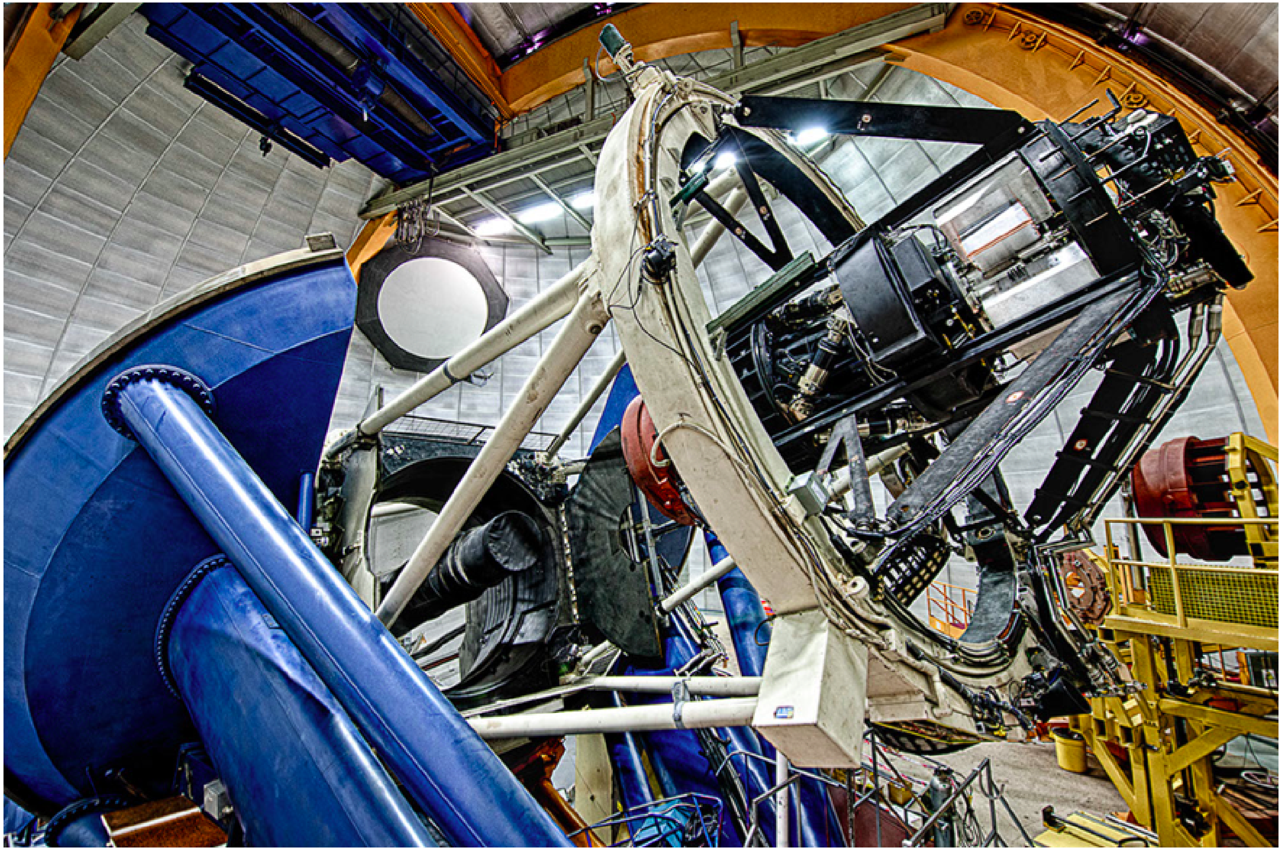
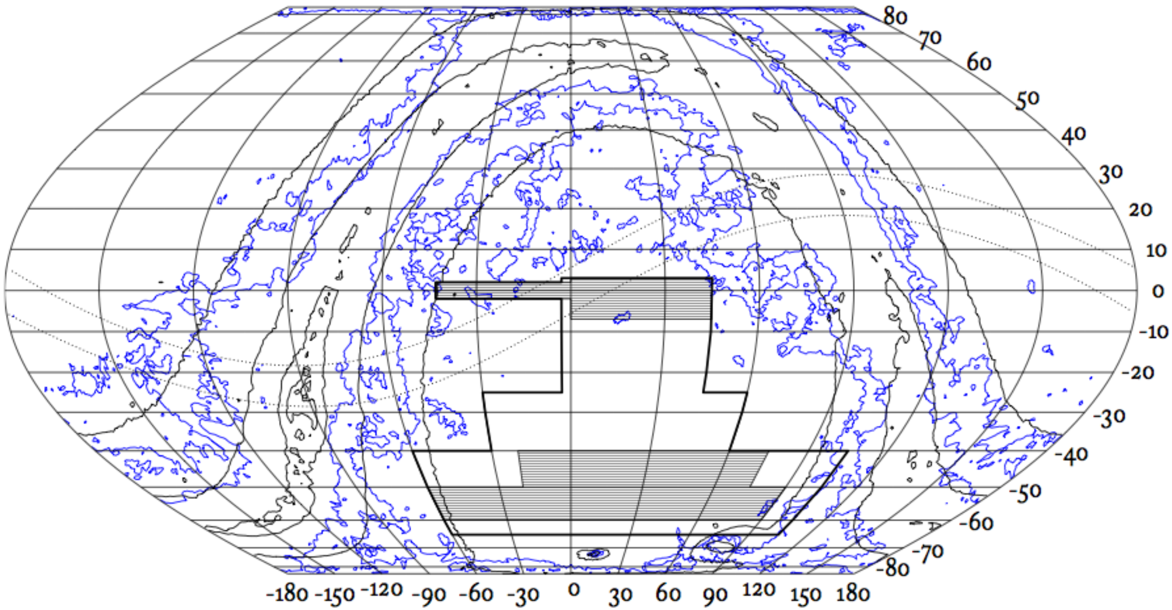


The Dark Energy Survey commences in 5 days on August 31, 2013

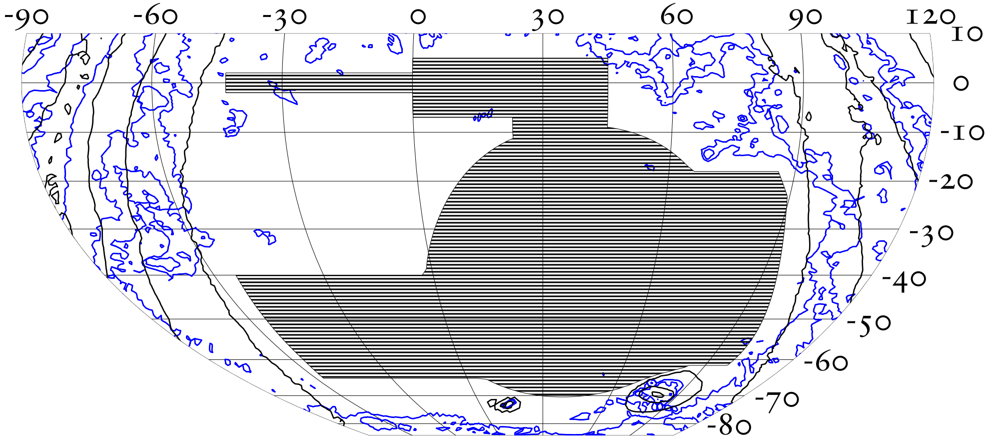
MKIDs and Cosmology: Following up the DES

James Annis, Center for Particle Astrophysics, Fermilab



The (now) old footprint, round82 plus the first year areas.

This is an equal area putnins4 projection
Blue: star densities are at x10, x30, x100, x233.
Black: extinctions, i-band, are at 0.25 and 0.5 mags.



The proposed DES round13 footprint: all shiny, new, and un-approved.

This is an equal area flat-polar quartic projection.
Blue: star densities are at x10, x30, x100, x233.
Black: extinctions, i-band, are at 0.25, 0.5 and 3.0 mags.

The thought experiment is this:

Imagine three years into the survey we find ourselves on a 4^m telescope on Cerro Pachon on a beautiful night in sub-arcsecond seeing.

Imagine that you have a instrument capable of measuring individual photon energies and spatial locations: R $\approx$ 300 and $0.28''$pixels, say.

What do you want to look at?

Being a Desie, I'd follow up DES objects. In particular, the natural progression of the EAG fermi-folk would be:

i Clusters: expect 10^5 out to z=1.2

ii Arcs: expect about 10^3 giant arcs

iii Lensed quasars: expect about 150 quad lensed quasars

There are two classes of projects in this thought experiment. Projects that are:

i made cheaper than multislit spectroscopy and we find ourselves at telescope

ii made newly possible because of the instrument.

In the following, only the quad lensed quasars enters the new territory.

Fast cluster redshifts for cluster cosmology

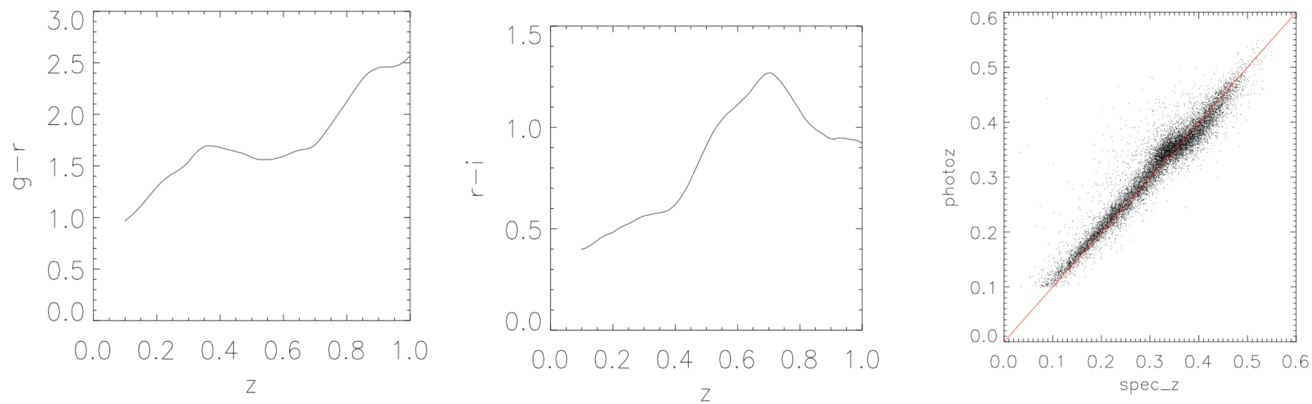


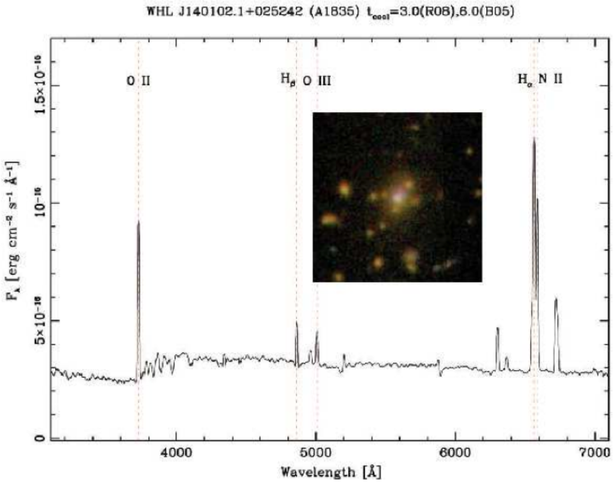
Photo-z for clusters are quite good, except at filter degeneracies, as at z=0.35 in g-r on the left, and z= 0.7 in r-i in the middle. At these points there isn't information for the photo-z to distinguish the redshift, and a higher scatter ensues, as on the right.

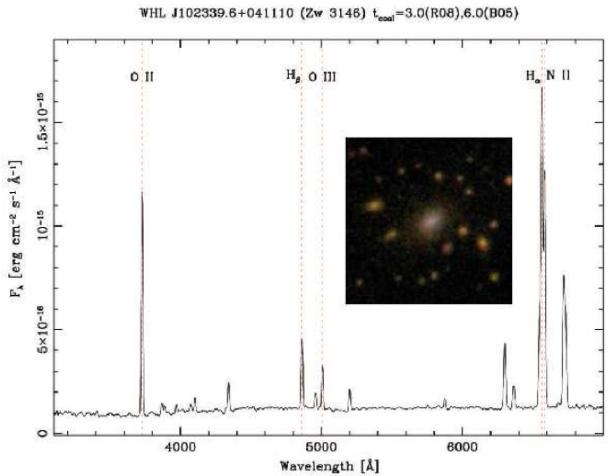
In analyses, we'll eliminate those regions.

Unless, say, we could go get redshifts of the brightest cluster galaxy (BCG)in the affected clusters. BCG redshifts are sufficient, but confirming that the galaxy is in not an interloper is important. There should be about 4000 clusters for which this could be useful at the g-r break at z=0.35.

These figures are from the Hao, McKay, Koester et al (2011, arxiv/1010.5503) cluster catalog covering 8240 sq-degree of the SDSS.

BCG as interesting targets





BCGs and their close environments are interesting in themselves.

Emission lines from BCGs are fairly common:

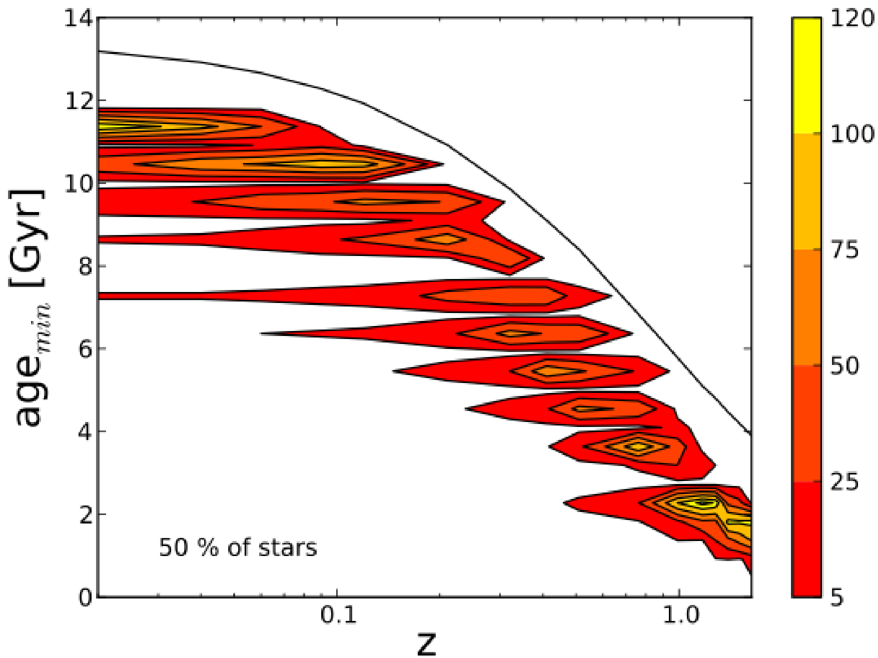
i x-ray luminous clusters x10 more likely than optically selected clusters

ii if there is star formation, it correlates with more massive BCG and richer cluster

iii cooling flows are often indicated by flat continuum spectra

These and the figures are from Liu, Mao, Ming (2012, arxiv/1203.1840).

BCG as the oldest galaxies



The age of the 50% star population in model BCGs as a function of z.

i BCG are old: half the stars are of an age equal at least to half the age of the universe

ii the BCG population ages as the universe does, the line: passive evolution

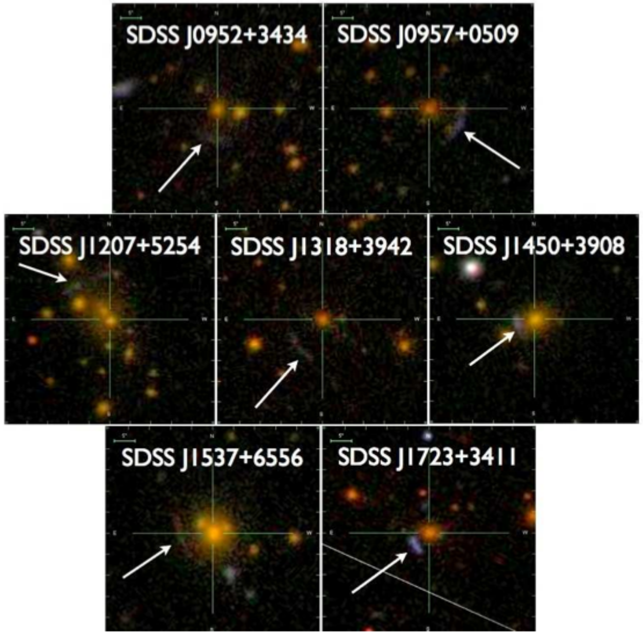
iii the BCG population has a larger range of ages lower z

This figure is from Tonini, Bernyk, Croton, Maraston, and Thomas (2012, arxiv/1209.1204).

BCG with giant gravitational lensed arcs

Each image is roughy 30″ on a side. These are nearly perfect MKIDS targets.

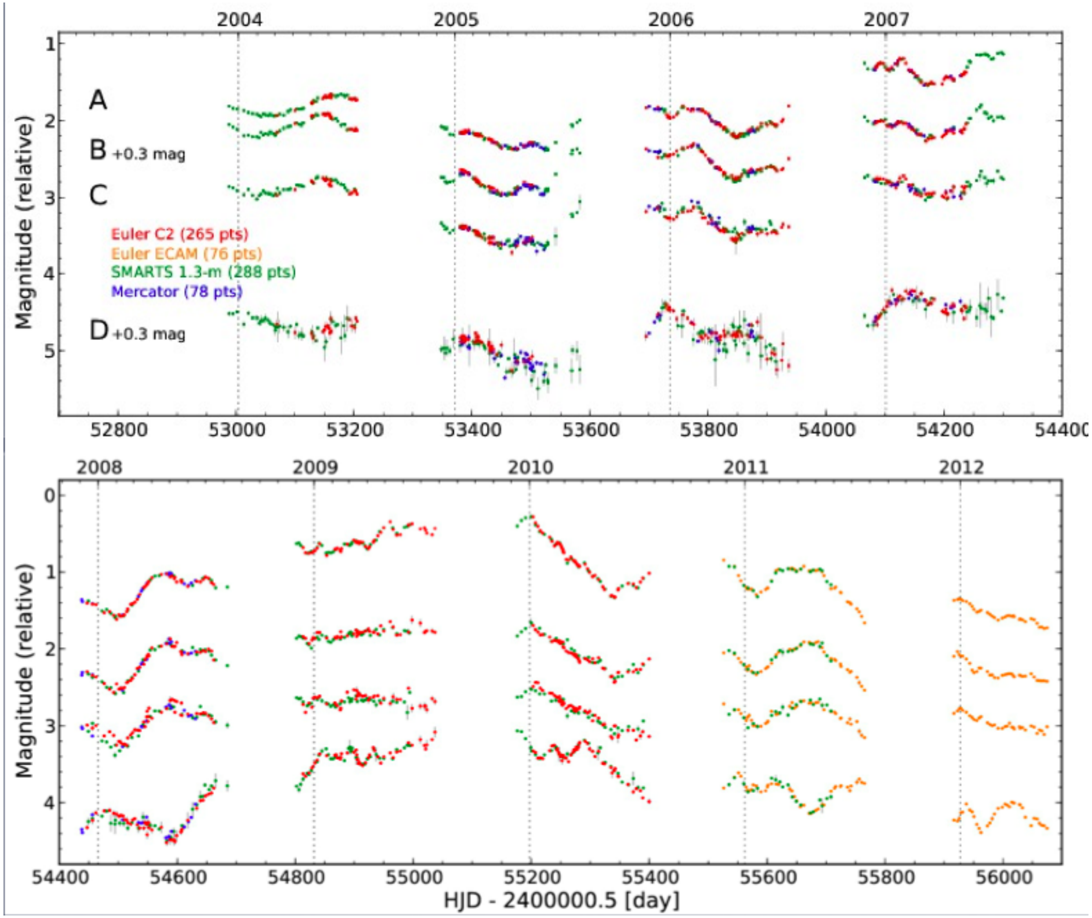
The arcs, usually curved, are always the most interesting target. The lensing galaxy and the galaxies around are also interesting to lensing modelers.



In the DES there are groups of people interested in strong lensing here, in Brazil, and at Cambridge. And there is Strides coming from UCSB.

From Kubo, Allam, Drabek et al (2011, arXiv/1010.3037), and also Wiesner, Lin, Allam et al (2012, arXiv:1211.1421) &
Buckley-Geer, Lin, Drabek et al (2012, arXiv:1108.4681) &
Kubo, Allam, Annis et al (2009, arXiv:0812.3934) &
Diehl, Allam, Annis et al (2009, arXiv:0910.4600) &
Allam, Tucker, Lin et al (2007, arXiv:0611138) &
Estrada, Annis, Diehl et al (2007, arXiv:0701383

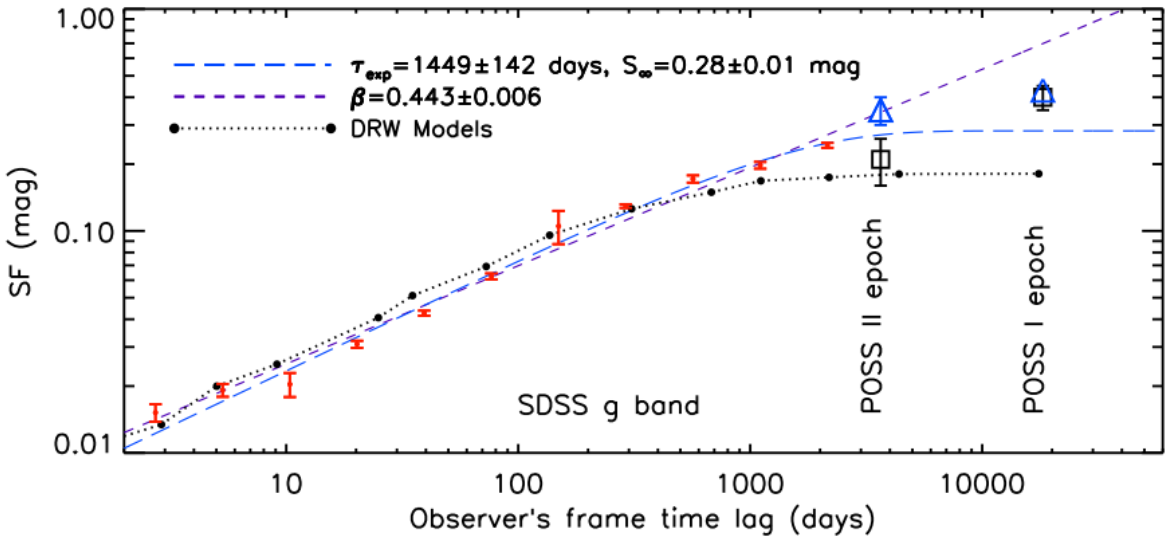
Quad lensed quasars monitoring for cosmology



From Tommaso Treu's Strides talk (2013, docdb-7118).

It takes years. Unless it takes days.

Quad lensed quasars



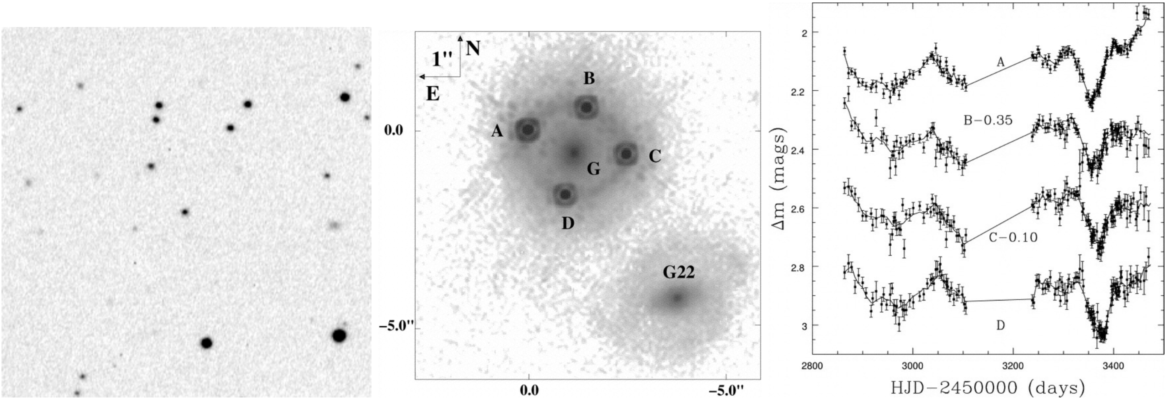
What does this plot tell you? That at 10 minute scales the variability of quasars is on order of 0.1%. Given photon statistics, one needs 10^6 photons to reach 0.1% precision. Given a 4^m class telescope with a DECam like camera, one sees 10^6 photons in a 15^m observation on a g=19 object. In g-band alone.

Quasar structure function from MacLeod et al 2012, using SDSS and POSS data (arxiv/1112.0679v2).

The structure function here is $SF(\delta t) = 0.74(IQR)/N^{1/2} - 1$, though other conventions exist (e.g., $SF(\Delta t) = (\langle \Delta m \rangle^2)^{1/2}$).

It reduces to the rms if the variations are gaussian. Quasar variations are a damped random walk, it seems.

Quad lensed quasars



The quad lensed quasar HE 0435-1223. The box on the left shows 5′on a side, the box in the middle 5″on a side, the right a time series covering 600 days. Observations from from Kochanek, Morgan , Falco et al, 2005.

The time delays between the intrinsic quasar variations are t_{AD} = -14.37, t_{AB} = -8.00, and t_{AC} = -2.10 days.

What the standard program does is to uses 1^{m} telescopes to take 1% observations over long time scales to take advantage of the rising quasar structure function. I approve of that program, actually; I think we should consider taking over the SMARTS $1^{m}$for this, in part. But here we open a firehose of data.

What did the last slide tell you? That at 10 minute scales the variability of quasars is on order of 0.1%. Given photon statistics, one needs 10^6 photons to reach 0.1% precision. Given a 4^m class telescope with a DECam like camera, one sees 10^6 photons in a 15^m observation on a g=19 object. In g-band alone.

A MKIDS on the SOAR could nail this. The individual objects are 16< i <18, the diameter is >2″, the RA puts it in the good seeing late austral summer, early austral fall season, and it is only 20°off SOAR's zenith.

Why look at these?

The fluctuation are from the central source, and the time scale one is measuring at is (1+z) that at the source; we would be measuring, presumably in the central light hour of a supermassive black hole.
Astrophysically, this has to be interesting.

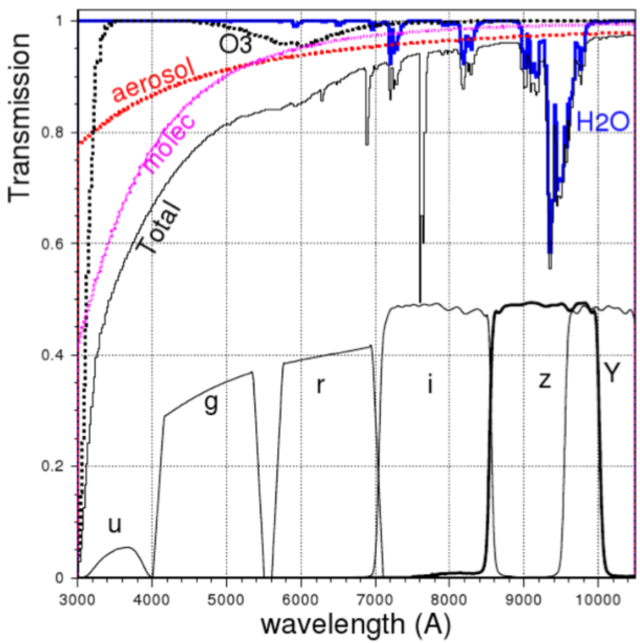
These quasars are quads. Each has 4 different 9.6×10^9 light-year light-like paths from a near point source to us.
Physically, that has to be interesting.

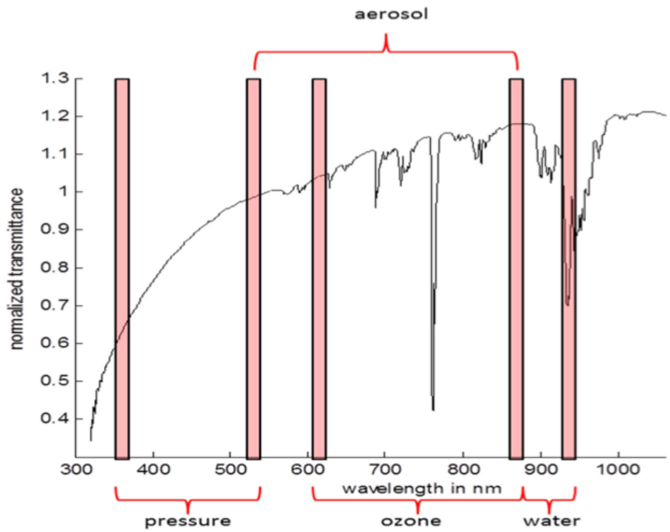
In fact, these lens systems are, other than the lens, so simple as to resemble pure thought experiments—like Wheeler's delayed choice experiment.
Physically, that has to be interesting.

One can, in fact, measure cosmological parameters as well as galaxy mass parameters using these systems. See Linder (2011, arXiv:1109.2592) or the Snowmass white paper by Treu, Marshall, Cyr-Racine et al (2013 arXiv:1306.1272).

Wait- 0.05% photometry?

Its purely relative photometry- back to back images of the same fields with ccds reach 0.5% easily. What about the rest? Time varying atmosphere and the PSF for measuring the quad.
Measuring the spectral transmission of the atmosphere.





These figures, from Ting Li, Depoy, Kessler et al (2012, arxiv/1302.5738) shows the atmospheric transmission function over CTIO, and the means by which the aTmcam for the DES is meant to measure the atmosphere in a cost effective way.

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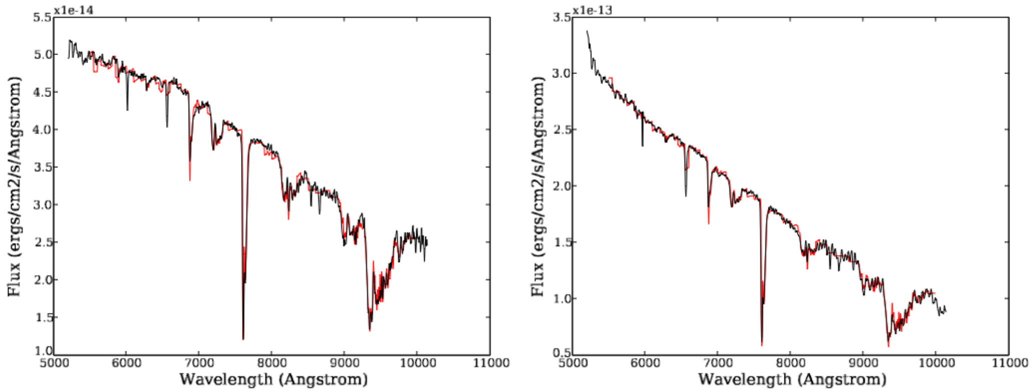

Figure 4. Spectrum of the G-star LTT 9239 taken at 1.57 airmass on 2007 November 3 (left). Spectrum of the F-star CD-35 534 taken at 1.50 airmass on 2008 July 23 (right). The flux is $F_\lambda(\lambda)$ (erg cm^{-2} s^{-1} Å^{-1}), and the fitted spectra are overlaid in red in both cases.

The above figure, from Burke, Axelrod, Blondin et al (2010 ApJ 720, 811), shows the LSST program; use a R ≈400 spectrograph to measure stars and then use spectral synthesis to back out the effect of the atmosphere.

What is easy is measuring the relative magnitude between two objects very close in space, time. What is hard is transfering it to another time and place, mostly due to the atmosphere. The current art to measuring the atmosphere invovles low resolution spectroscopy.

Given a stable instrument and a 30″FOV, Calibration down at 0.05 mmag inside repeated exposures of the same field should be possible.

MKIDs might well be the calibration dream machine, actually.

What about the PSF?

I don’t know. It’s a research problem.

I will mention two words: speckle interferometry

Summary

All of the programs imagined are interesting.

i Clusters: expect 10^5 out to z=1.2
ii Arcs: expect about 10^3 giant arcs
iii Lensed quasars: expect about 150 quad lensed quasars

Right at the moment I'm bemused and spellbound by the quad lensed quasars followup.

One could even start with MKIDs on the 1^m and measure bright quasar structure functions...