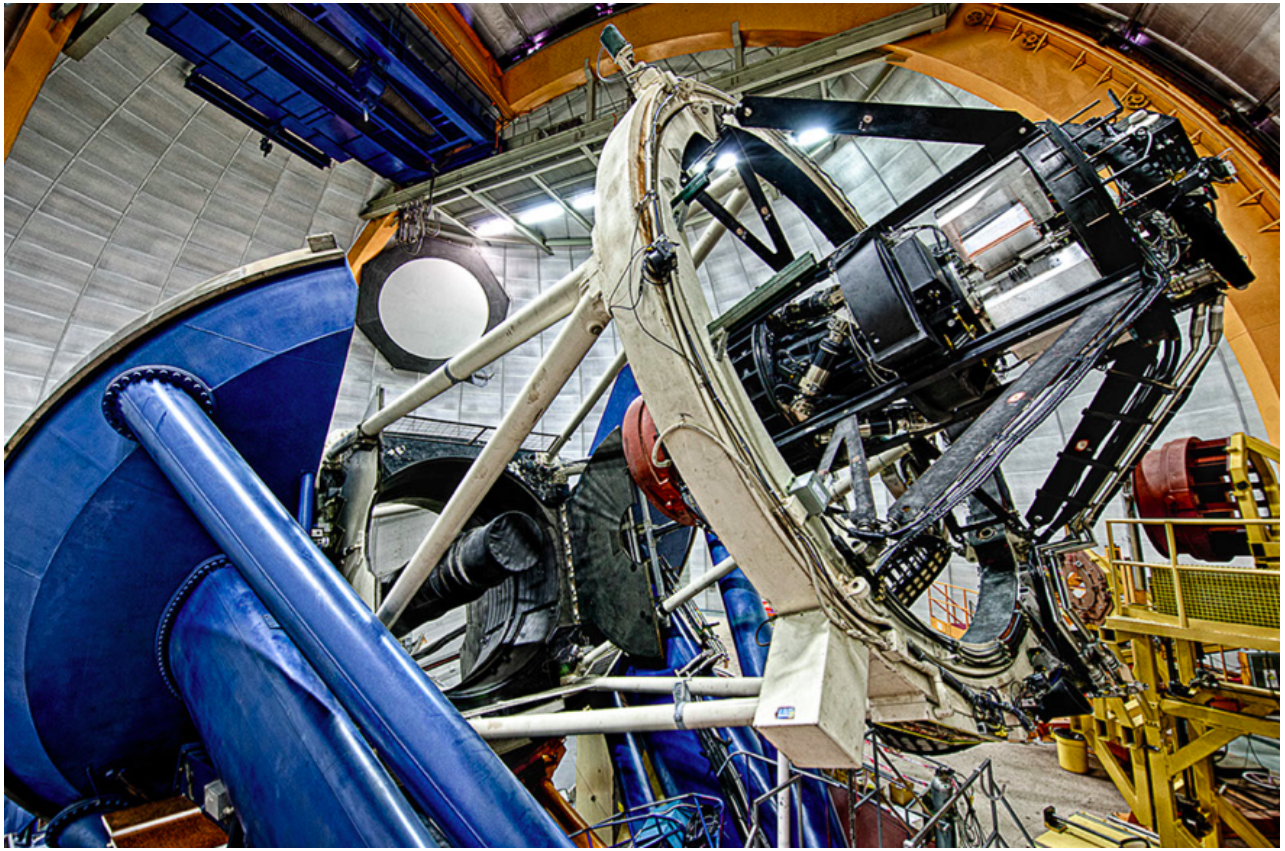
The Dark Energy Survey and the LSST



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The DES-LSST Workshop at Fermilab March 24, 2014

Summary: the DES

- Stage III dark energy project using 4 complementary science platforms from imaging:
  - i supernova
  - ii large scale structure
  - iii clusters of galaxies
  - iv weak lensing
- Two multiband surveys
  - i 5000□° g,r,i,z,y bands to 24th magnitude
  - ii 30□° g,r,i,z band time domain survey, weekly visits, 5 month seasons over 5 years
- 500 megapixel camera & optics, DECam (Fermilab & collaboration)
- new data reduction system for DECam (NCSA & collaboration)
- 4m Blanco telescope for 525 nights over 5 years (NOAO/NSF)
- astronomical community has access to Blanco/DECam for ≈250 nights/year

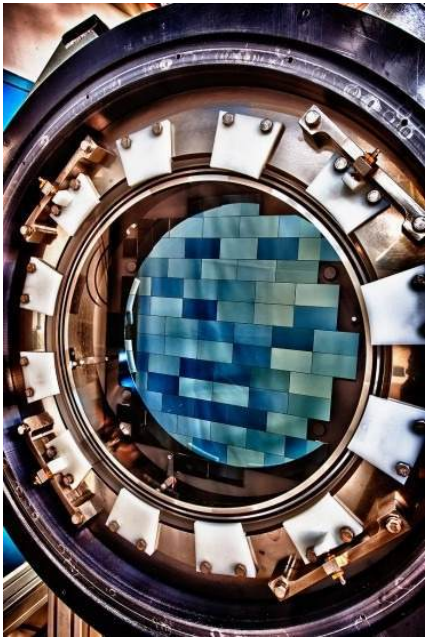
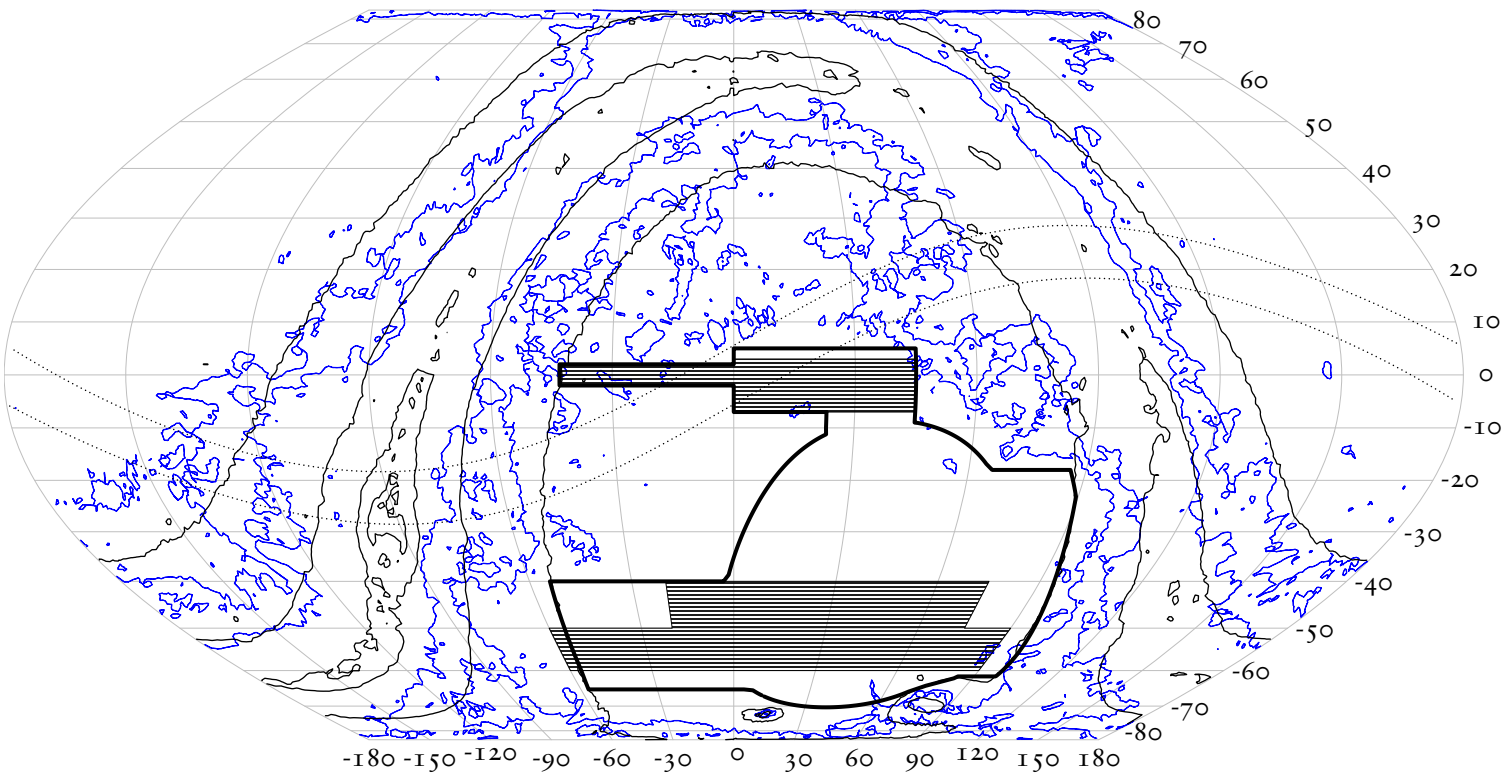


Figure 1: DECam focal plane CCDs- 62 full depletion LBNL ccds with very high red quantum efficiency.

The DES footprint



This is an equal area putnins4 projection of the entire sky.
Black: star densities are at x10, x30, x100, x233 times galactic south pole values.
Blue: galactic dust caused extinction, i-band, at 0.25 and 0.5 mags.

Major differences: scale and complexity

Scale: Quantity has a quality all of its own.

i) The DES used much exisiting technology, like the Blanco and Terapix software. LSST has a new telescope and new measurement codes, new from the ground up.

ii) LSST is a pure survey telescope. DECam is a community instrument (the community gets 250 nights per year). As part of the agreement, we delivered a community pipeline.

iii) The LSST incorporates milky way, solar system, and time domain study in a fundamental way.

   (a) LSST has 10× data rate, w/o an off-season to catch up!

   (b) DES has no u-filter, though DECam does.

   (c) n-visits in DES non-optimal for time domain (though useful for GW/aLIGO followup)

   (d) quasars enter into DES science primarily in the high-z search with VHS collaboration

   (e) the DES SN survey is 10-30% of time.

iv) DES time domain complexity very low, LSST's is high. This is reflected in database design.

The DES has 4 key projects. LSST has those 4 plus N more. The MW, SS, and time domain experiements drove design equally with cosmology in LSST.

DES is evolutionary, LSST is revolutionary.

DES as a LSST prototype

Having said that, there is every reason to think that work done on the DES can be usefully transferred to the LSST program.

DES can be thought of as a 1/10 scale prototype of LSST. We were a bureaucratic pathfinder twixt DOE and NSF. We're certain to provide platform for testing imaging science ideas before LSST data is available.

i) multi-filter point & shoot imaging survey, overlapping images

ii) sky coverage: 20,000/5,000 = 1/4.

iii) 50 visits/5 years vs. 500 visits/5 years.

iv) single visit of DES ≈ single visit of LSST $\left(\frac{30^s}{90^s}\frac{(6.7m)^2}{(3.6m)^2} \approx 1\right)$.

Even the siting is similar; we are using the same channels to transmit data from the camera to the United States.

Of course the dark energy science is very similar.

Notable is that the timeline of the projects works well as a program: The DES started last year; we are working the data now. The LSST will start in 2021- there is time for collaboration.

Prototypes must be useful, otherwise a distraction and should be avioded. In order of closer to being useful:
1. ALMA: no, different wavelength
2. SDSS III: no, it is a spectroscopy project, not imaging
3. SMASH: no, as images are isolani
4. BCS: no, as the scale about 1/100 to DES, too small.
The DES passes these tests.

Status of dark energy

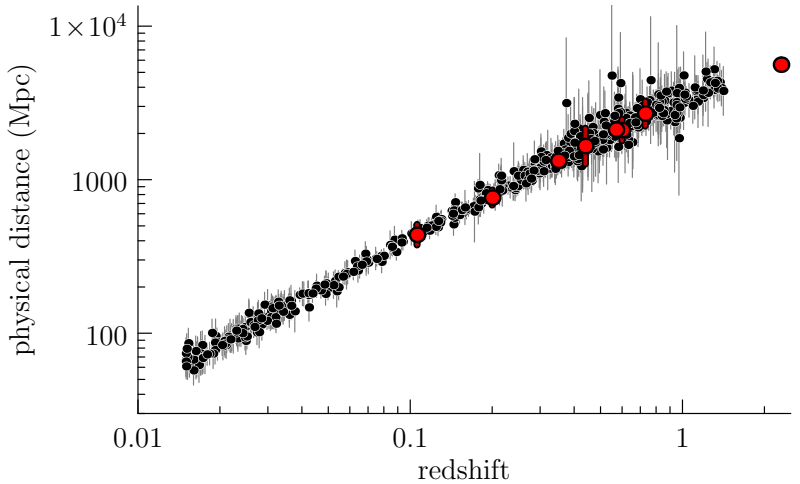


Figure 2: BAO distances superimposed on world supply of SN distances from the Union 2.1 SN sample. The BAO in order from left to right: 6dFGS (beutler2011), the SDSS main galaxies (percival2010), the SDSS LRG (padmanabhan2012), three WiggleZ (blake2011) points, the BOSS LRG (anderson2012), point overlapping the mid WiggleZ point, and the BOSS quasar Ly-α measurement (busca2013) on the far right.

The ability of redshift surveys to perform BAO measurements to combine with CMB measurements (and SN observations) put the measurement of the distance metric on solid footing.

The place where the DES can make a real contribution is in the growth of structure: the distance metric makes a strong prediction for the growth. Modified gravity theories have scales over which gravity is non GR. Measurements of the growth of structure via clusters, weak lensing, and the velocity field can then be used to show consistency or disagreement; if the latter we can rule out scalar fields.

Thus optical clusters with SZ and with weak lensing, and cosmic shear with weak lensing. The latter is at the moment systematics limited; the DES has to push down the systematics floor to reach its true potential.

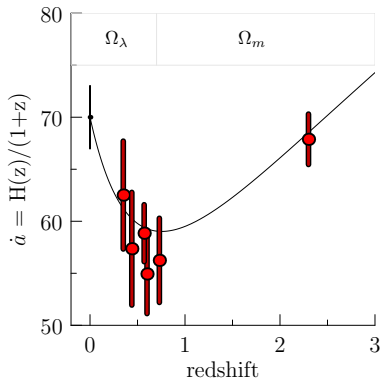


Figure 3: H(z)/(1+z) versus redshift from BAO and Alcock-Paczynski tests. The black point shows the current value of H, with error bars reflecting the Planck versus Riess discrepency. The red points in order from left to right: The in order the SDSS LRG (xu2013), the first WiggleZ (blake2011) point, the BOSS LRG (reid2012) point, two WiggleZ points, and on the far right and the BOSS quasar Ly-α measurement (busca2013).

Weak lensing technology

Measuring the weak lensing signal is the driving technological challenge in the DES.

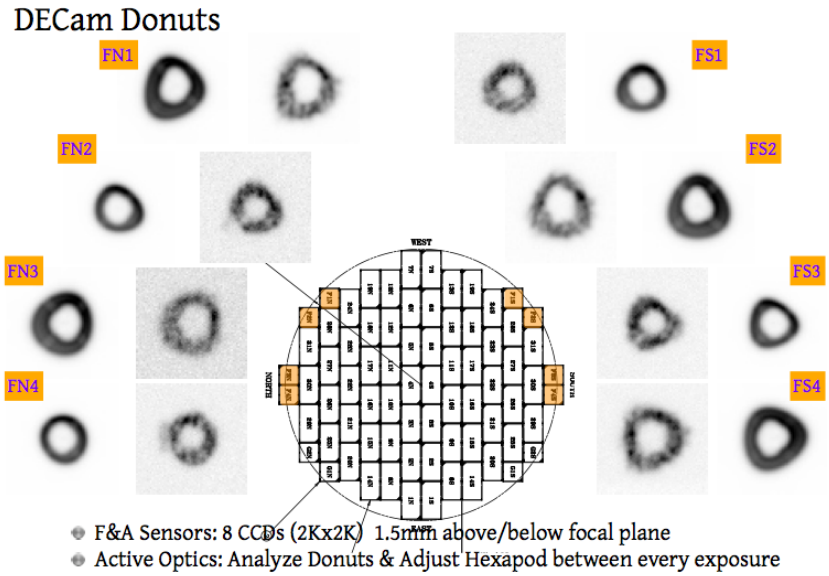


Figure 4: The donut analysis. Aaron Roodman

We monitor the alignment of the camera with the optical axis by watching out of focus stars around the edge of the focal plane and comparing donuts computed from optical models with the observed donuts.

Our ability to correct, both in hardware and software, will improve with experience.

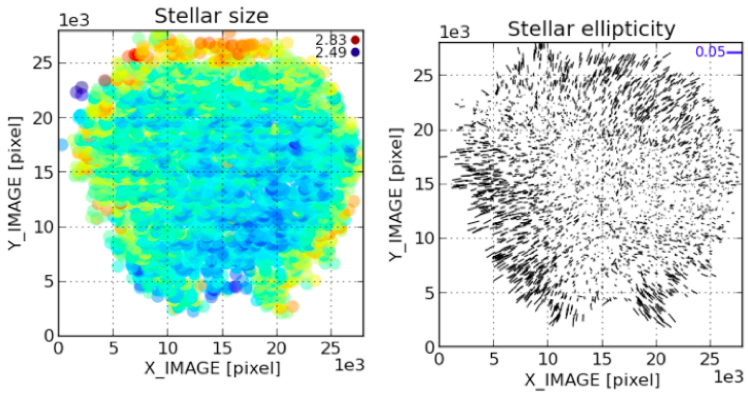


Figure 5: PSF size, left, and ellipticity maps, right, from the cluster weak lensing study in the DES SV data. Peter Melchior and the cluster WG

Supporting technologies, supporting science

The DES has many things to do- how do we make progress? There is a technology that underlies our ability to do our science.

Technology here means knowing the way to do something.

i) a large science collaboration
   (a) > 200 scientists
   (b) US, UK, Spain, Brazil, Germany, Switzerland

This type of collaboration follows the path of the SDSS collaboration; the DES is in many ways the southern descendant of the SDSS

ii) allows the DES to harness the scientific interest of many on an extensive photometric redshift program: precision 5-band photometry must be converted to redshifts accurate at $\Delta z = 0.01\text{-}0.05$; this depends on spectroscopic training samples and, likely, redshift-object correlation techniques.

The weak lensing in particular is sensitive to catastrophic mis-estimates of redshift

iii) and allows the DES to pursue an extensive simulation program: starting from N-body simulations galaxies are added, weak lensing effects are added, and the simulation observed. We depend on the simulations to understand the observed data set.

This is new in astronomy

iv) and lets us perform blind analyses for the very sensitive cosmology measurements

This is new in astronomy

Similarities

None of that last is any surprise to LSST folks. Our approach to science is very similar.

Where we have unsolved problems, we bring members of our large collaborations to bear. Now the DES is grappling with data. I believe that the following are particularily intersting as places where DES experience can transfer to the LSST program:

i) converting precision 5-band photometry into redshifts accurate at Δz = 0.01-0.05

ii) learning how to go beyond the current systematics floor depends on our ability to understand the psf, starting with the donut analysis running on the mountain top.

iii) our ability to trust our major cosmological results lies in our ability to perform analyses on simulations as well as the data

iv) our calibration groups have a similar view to the right approach. I'm carrying the 5 mmag or bust flag: that will require image relative calibration, system response curves, and atmospheric transimission curves.

These are examples outside the purely cosmological science prototyping, and yet science. I'm sure there are other areas. Notable is that the roles that NOAO and NCSA play in each collaboration are similar. Surely the experience that NCSA gains from DES should be useful for their LSST program.

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Genomics: Last year there was a firefight between an independent researcher, Dan Graur, and a large project, the ENCODE consortia, over the interpretation of junk DNA. Graur et al wrote one of those *papers: "In a miraculous feat of "next generation" science, the ENCODE authors were able to determine the frequencies of nonexistent derived alleles.".*

Our interest is in another comment in that paper: "ENCODE's biggest scientific sin was not being satisfied with its role as data provider; it assumed the small-science role of interpreter of the data, thereby performing a kind of textual hermeneutics on a 3.5-billion-long DNA text."

To which Josh Witten wrote: Graur's "paper is less a reflection of the mistakes made by the ENCODE project and more about the deep rifts in the research community, especially amongst genomics researchers. Emphasis on big projects ... leaves small, independent researchers pursuing creative questions feeling left out in the cold. Frankly, in genomics, you cannot compete with the resources these consortia and genome sequence centers can bring to bear on a project."

Both the DES and LSST are in the large project category. We have a responsibility to do it right.

backup slides

The telescope simulator and DECam

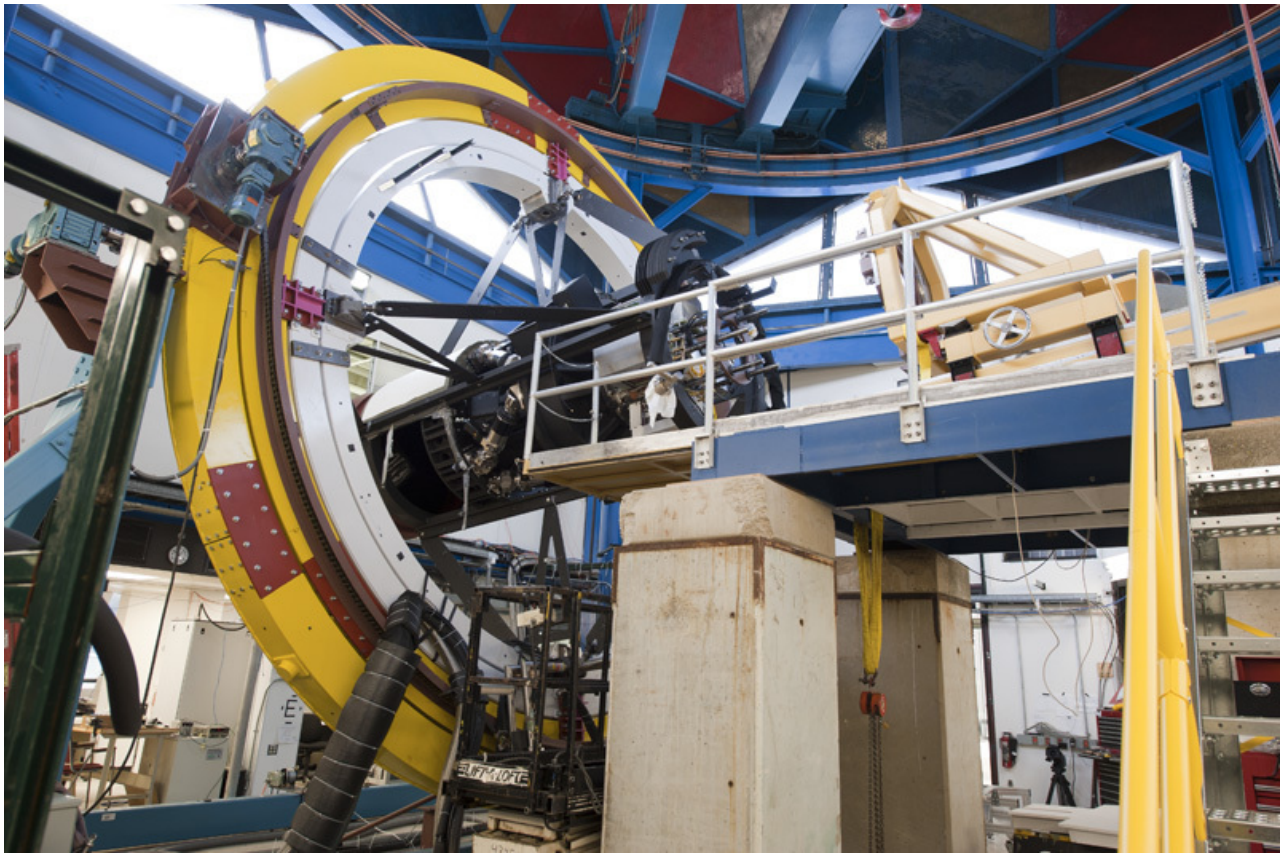

Figure 6: (photo credit: Fermilab)

Instead of a long commissioning at the telescope in Chile, we constructed a telescope simulator at Fermilab and commissioned there. Cooling the focal plane in a moving 3-d environment needed testing.

The telescope

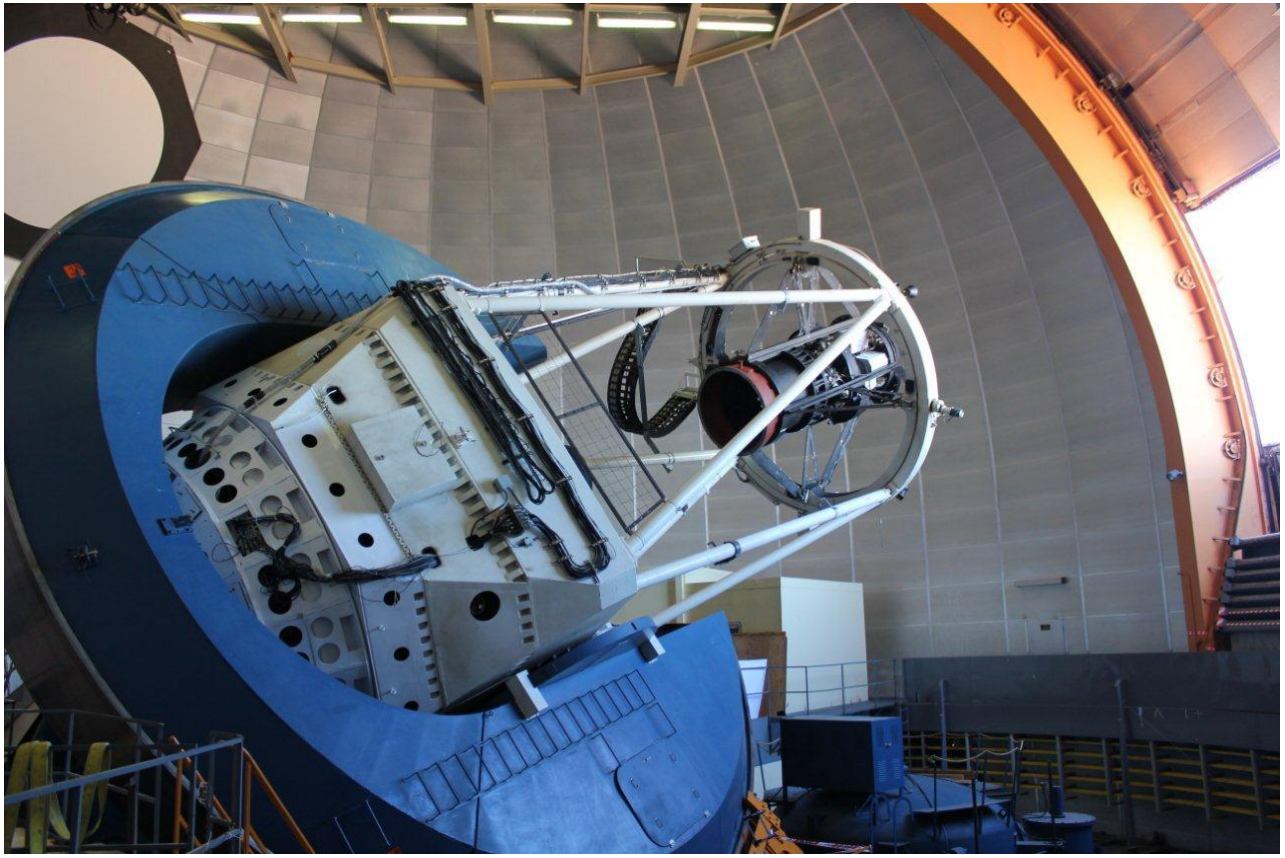

Figure 7: (photo credit: W. Percival)

The Blanco 4^m telescope is a 70^s era design with a beautiful primary mirror.

Supernova

SNe are standardizable candles; they measure a geometric distance $D_L = (1+z)D$, where $D = c\int_0^z dz' H(z)^{-1}$.

The DES will obtain well sampled light curves for ~4000 SNe Ia at 0.1 < z < 1.1. (Bernstein, Kessler, Kuhlmann et al. 2012

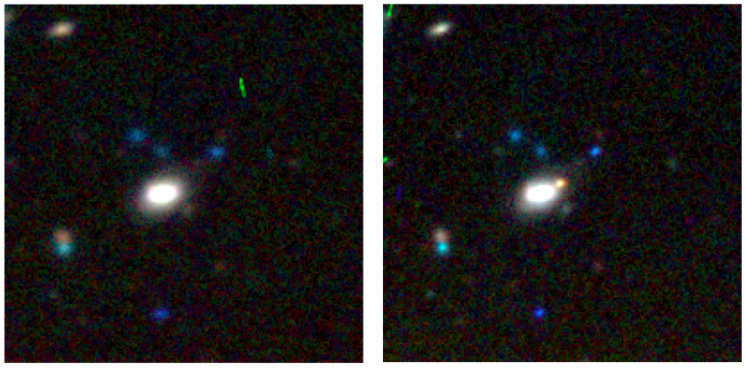

Figure 8: First DES SN. Left, Nov 7, 2012. Right Dec 15, 2012: AAT places it at z=0.2

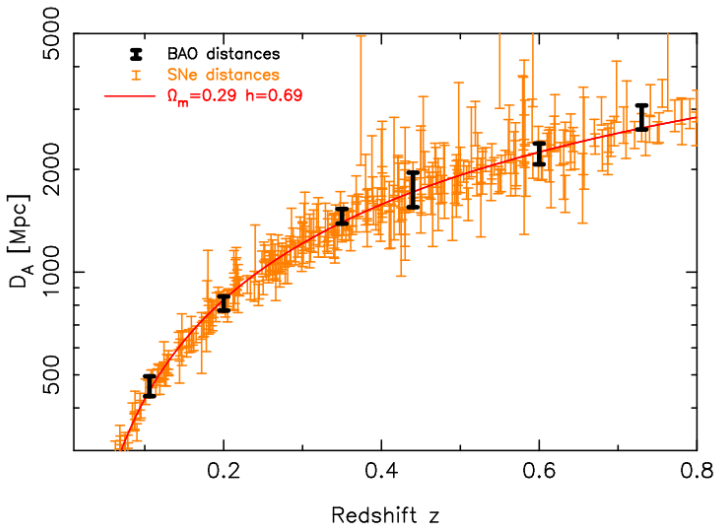

Figure 9: BAO distances superimposed on world supply of SN distances. The BAO in order from left to right: 6dFGS, two SDSS LRG points, three WiggleZ points. From Blake, Kazin, Beutler et al 2011.

SNe distances are similar to BAO in that they are purely geometrical, H(z).

Large scale structure

The galaxy distribution allows measurement of the matter power spectrum in photometric redshift shells, and a form of BAO measurements where only angular modes are used allows $D_A = (1+z)^{-1}D$, where $D = c\int_0^z dz' H(z)^{-1}$.

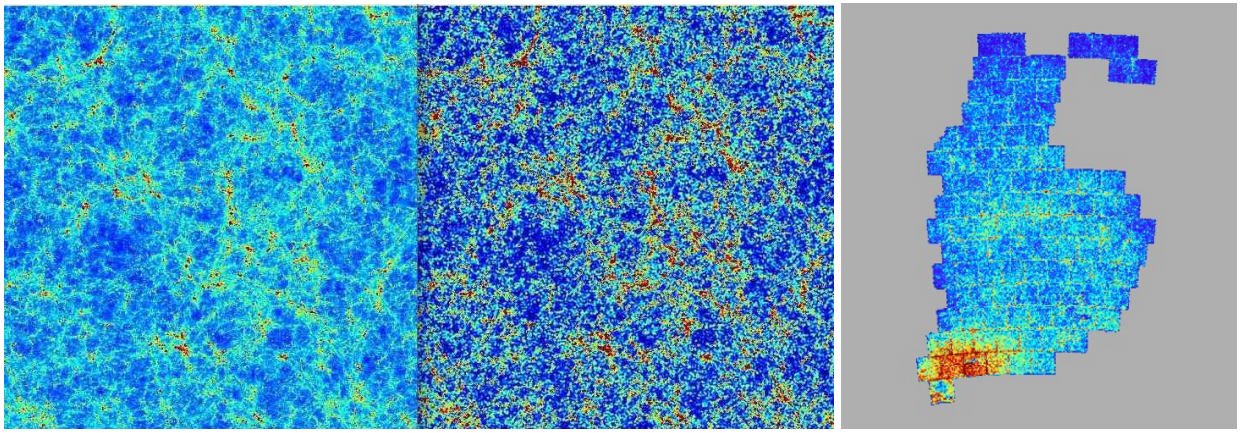

Figure 10: Left: dark matter distribution. Middle, galaxies in a redshift slice at z=1 on the right, both 7°on a side. Simulations from the MICE project. Right: Object map from the DES science verification data. The glow on bottom left is the edge of the LMC. Anne Bauer

These techniques should be considered platforms for a variety of experiments- in LSS, BAO, magnification, and non-Gaussianity.

In the inflationary paradigm, microscopic quantum fluctuations are the seeds of all the structure we see in the CMB and traced by collapsed objects like galaxies and clusters of galaxies. The standard class of single-field, slow-roll inflation models predict nearly zero non-Gaussianity, where other models of inflation predict detectable non-Gaussianity. A detection of primordial non-Gaussianity would rule out single-field slow-roll models, and that increasingly tight upper limits will rule out many other models. The non-Gaussianity limits from galaxy power-spectra are useful as a completely independent cross-check of (usually better) CMB limits.