The Dark Energy Survey and the Quest to Determine the Fate of the Universe

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Argonne National Laboratory

Wisconsin Lutheran College
"The Heavens and the Earth"
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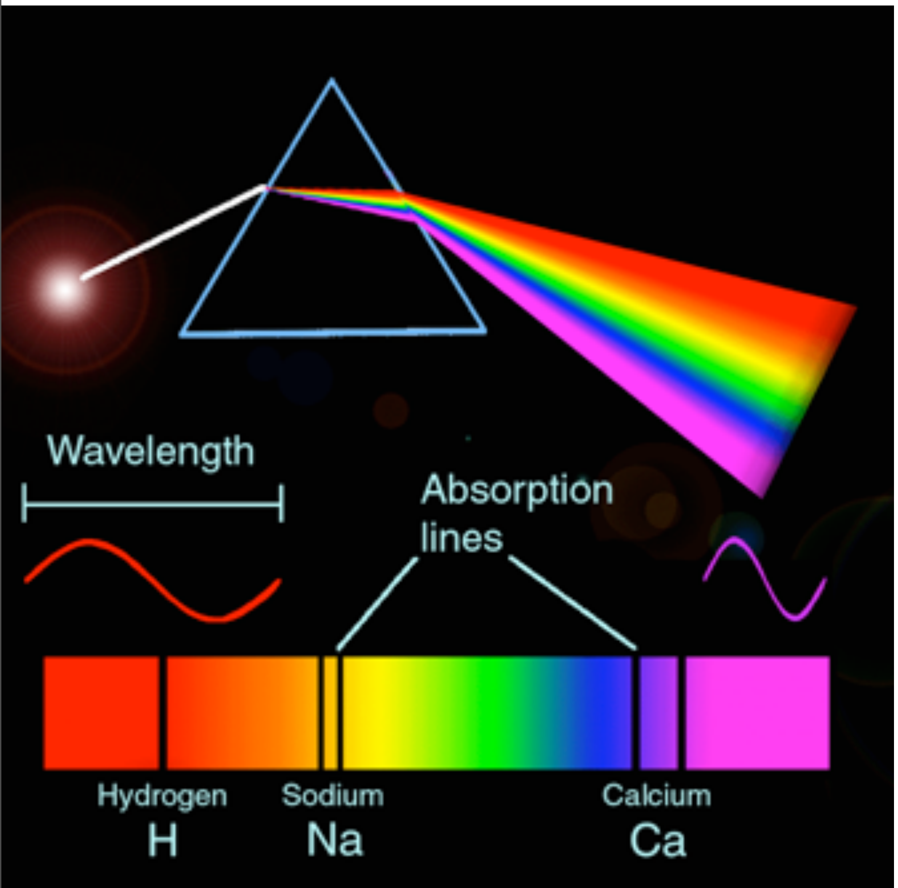
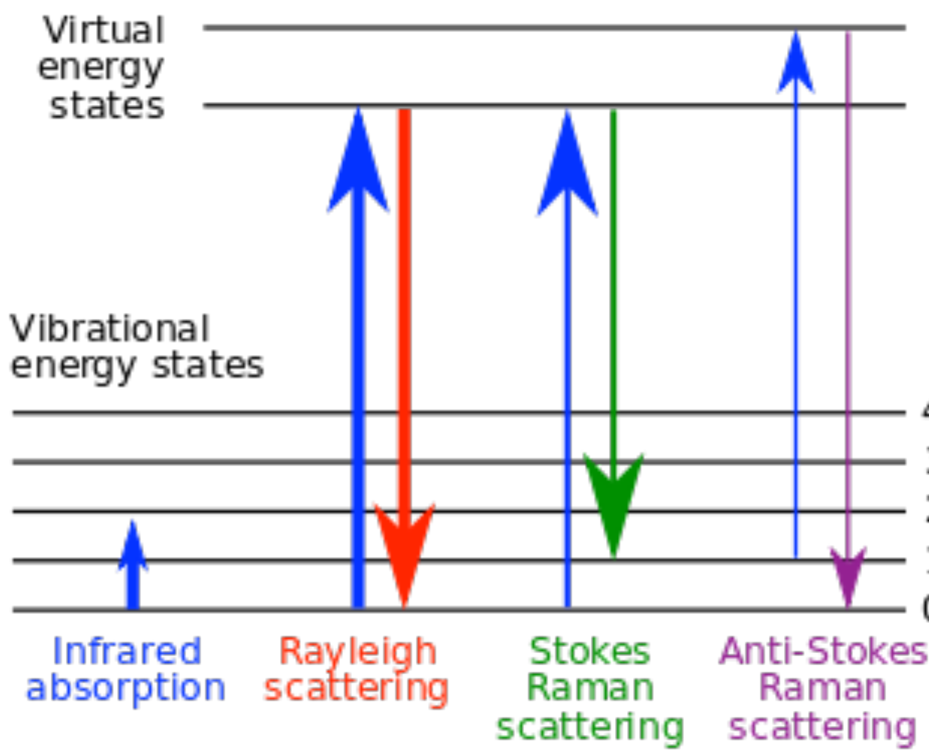
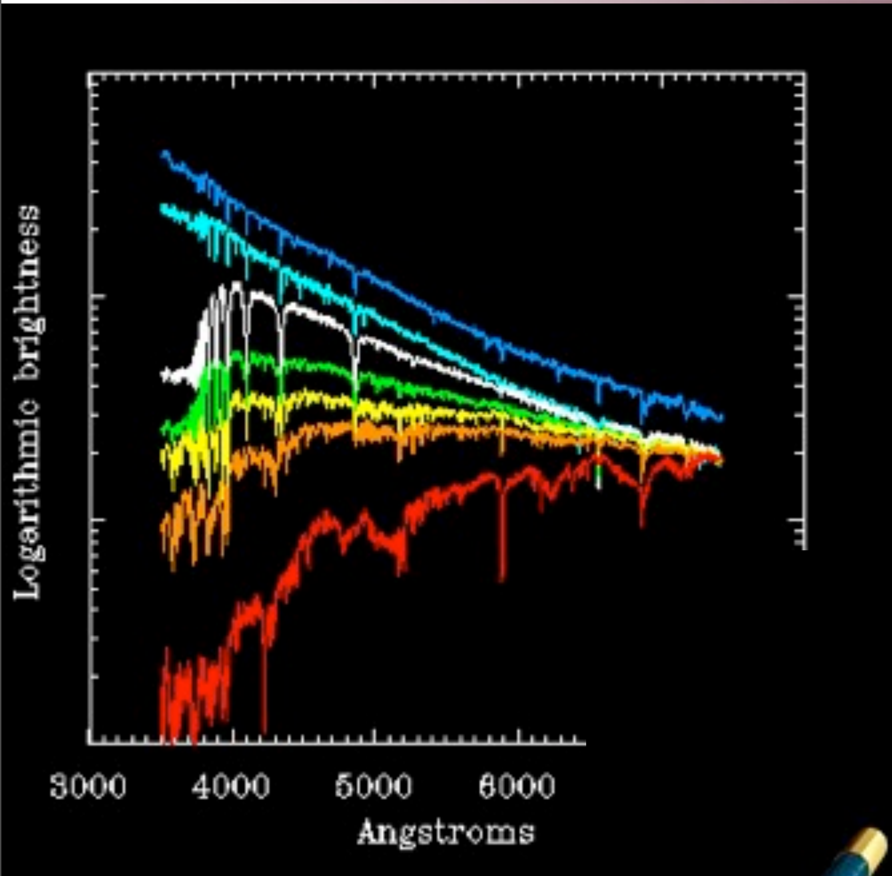
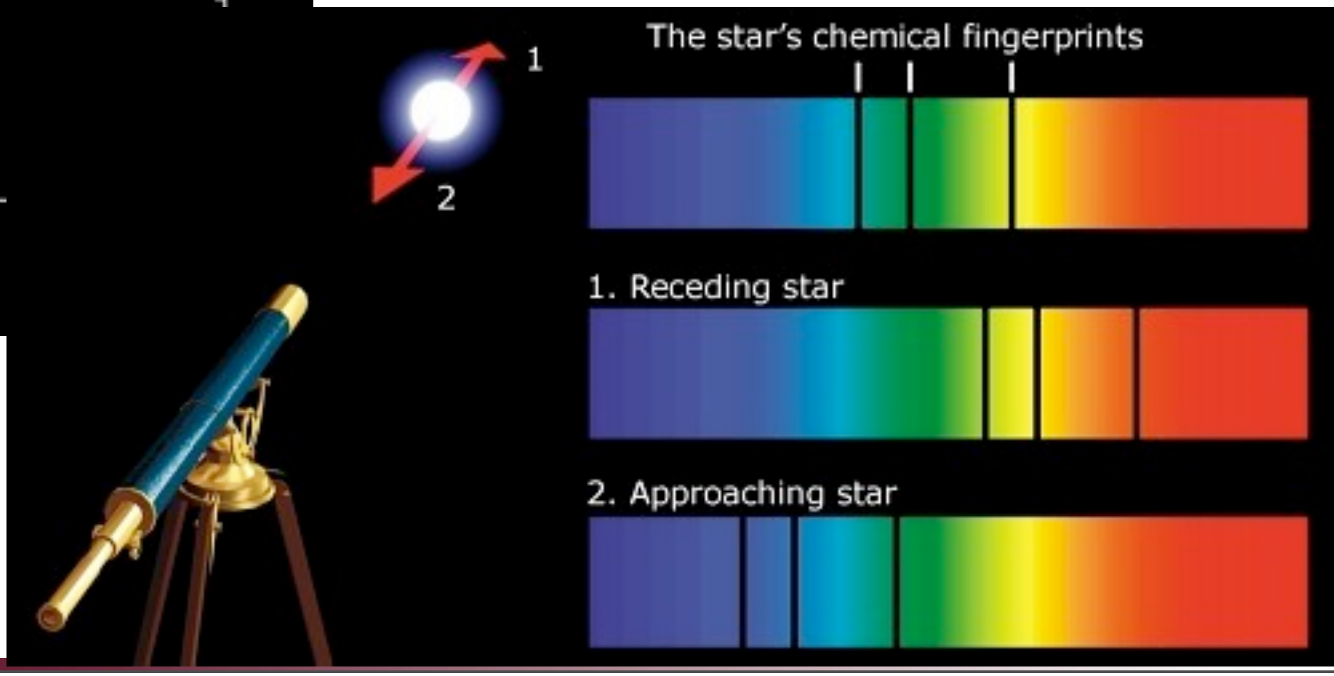
Spectroscopy--How does it work?





Spectroscopy II: How we measure distance from the speed of a star





The Era of Observational Cosmology

Two (competing!) observations of supernovae showed that the cosmos is dominated by a mysterious "Dark Energy" that drives the accelerated expansion of the universe, and subsequent observations utilizing different probes (e.g. CMB) have confirmed this result.

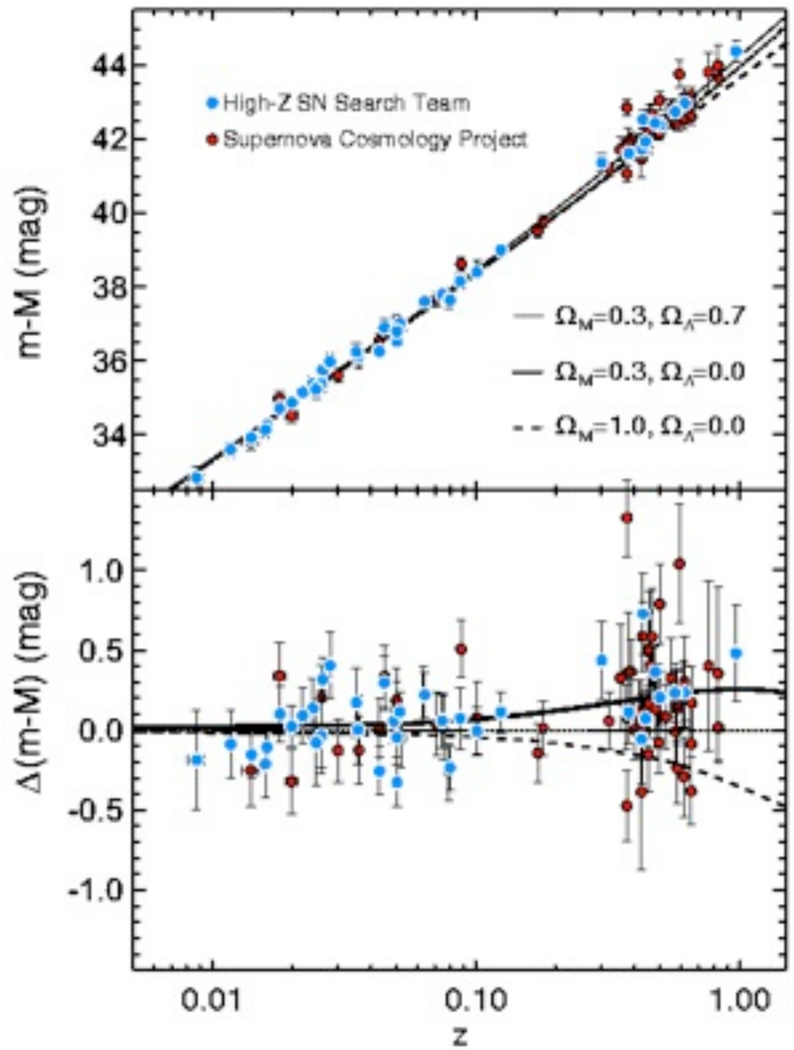
The properties of Dark Energy can be expressed in terms of its Equation of State at different redshifts:

$w(z) = p/\rho$

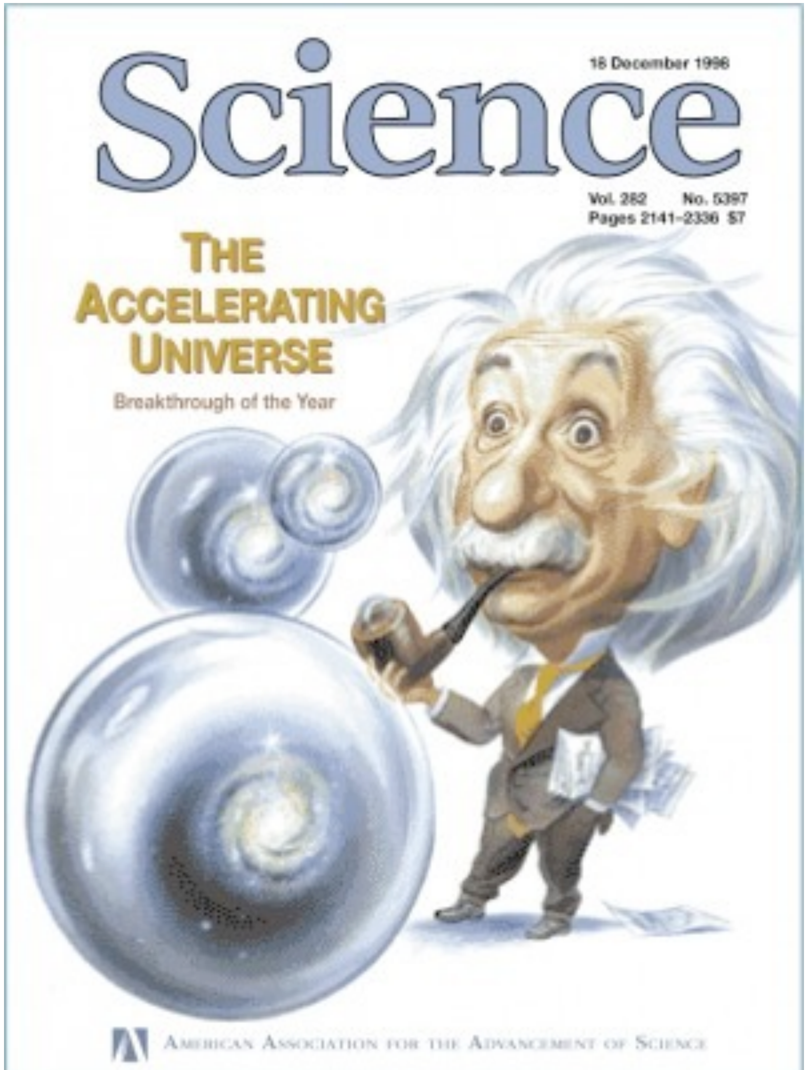
We parameterize w(z) as follows:

$w(z) = w_0 + w_a(1-a)$, where **$a = (1+z)^{-1}$**

$w_0 = w_\Lambda$ (i.e. the cosmological constant) if $w_a = 0$.



The Discovery of Dark Energy is Big News...



Science Magazine,
December 18, 1998

Nobel Prize in Physics, 2011

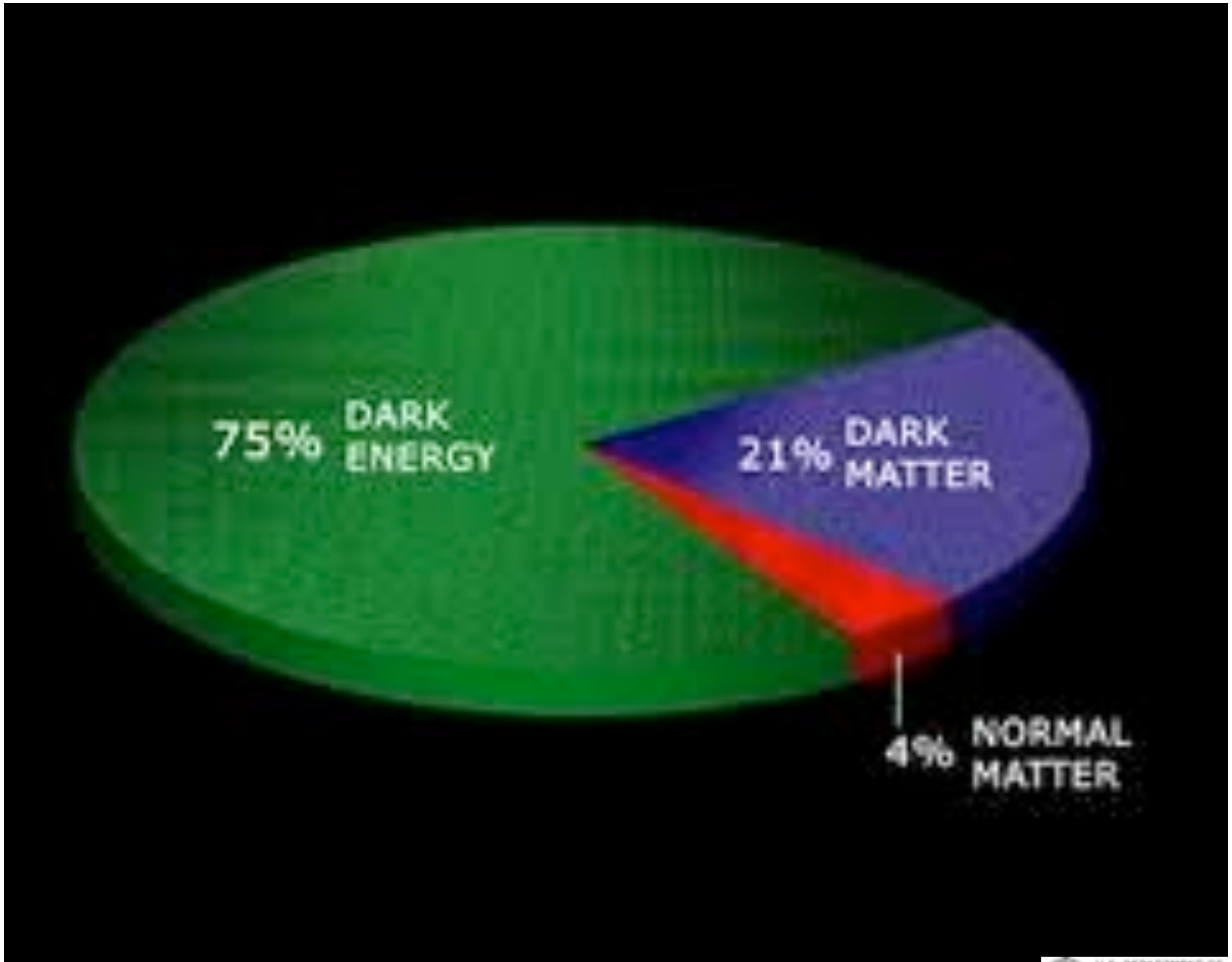
So, what is it...?

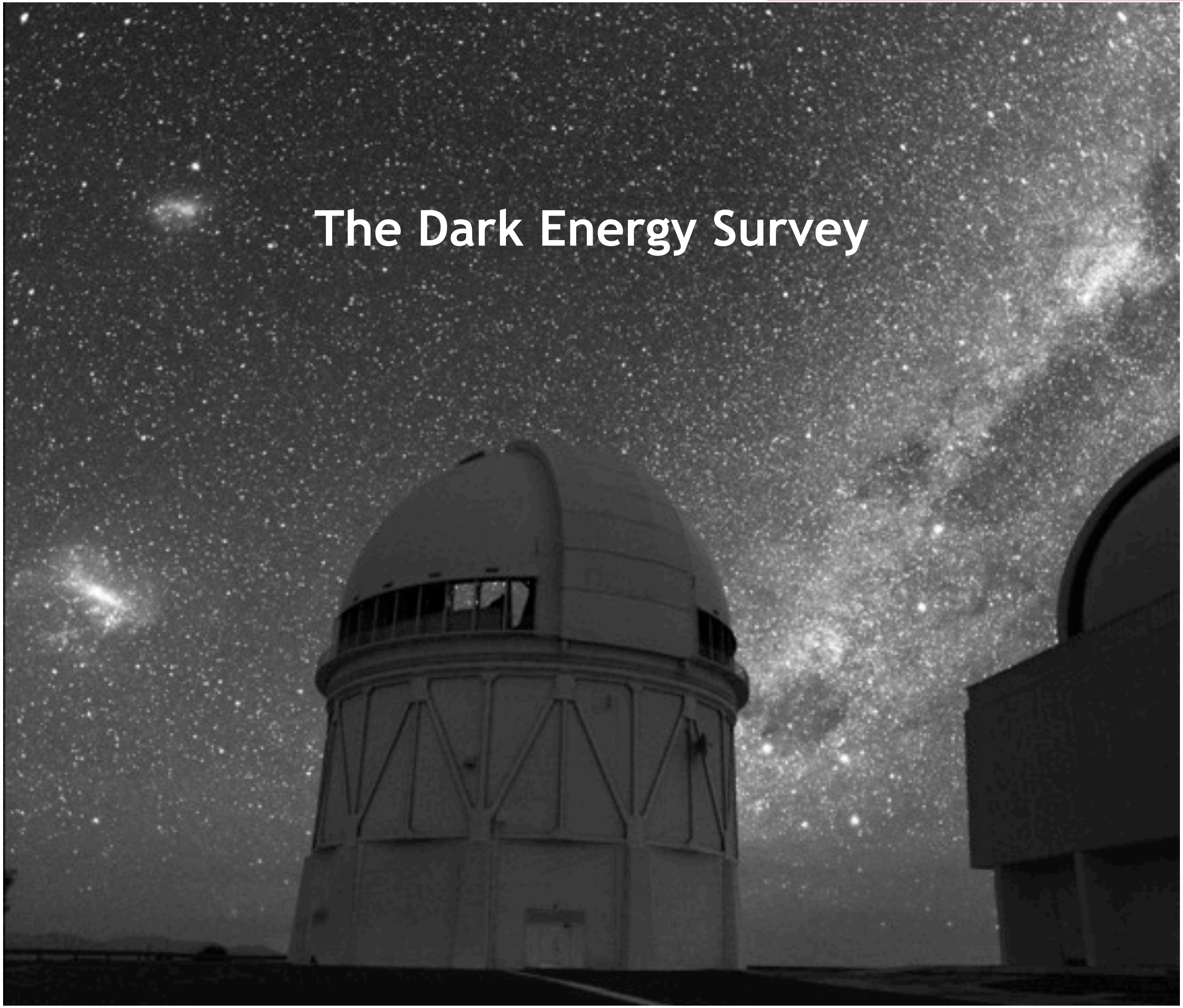
- Cosmological Constant?
- 10^{120} problem

- Dynamical Dark Energy?
- Modification of Gravity?

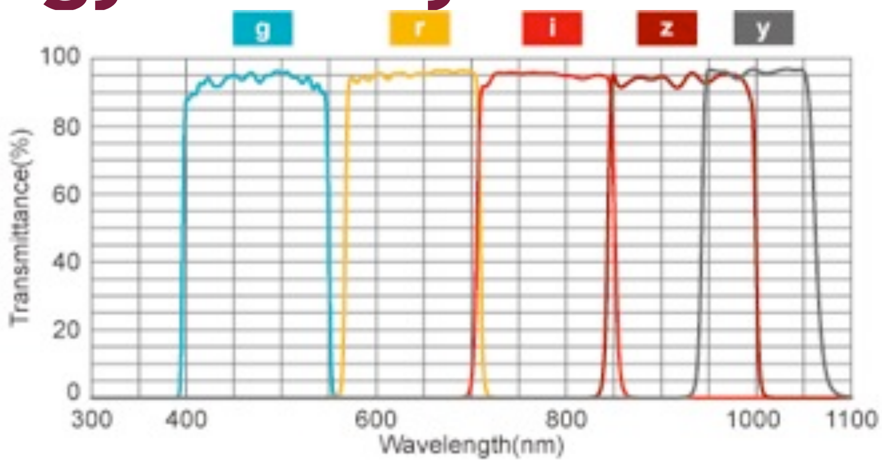
- Voids?
- Disfavored by HST Observations

- We don't know, yet...

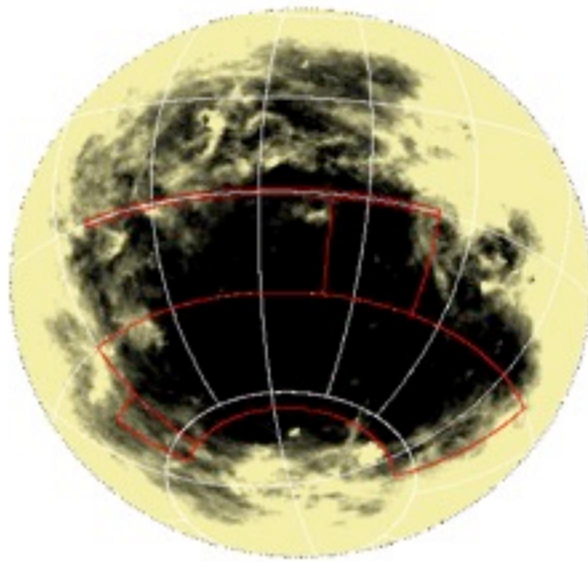



The Dark Energy Survey

The Dark Energy Survey



Starting in November 2012, DES will observe 1/4 of the southern sky over 6 years with (SDSS-like) grizY filters. The DES “footprint” overlaps with VISTA Hemisphere Survey (DES Y-band data will be exchanged for VHS JHK data), as well as SDSS, SPT, and Skymapper.



DES uses four complementary methods to constrain the Dark Energy Equation of State:

Supernovae

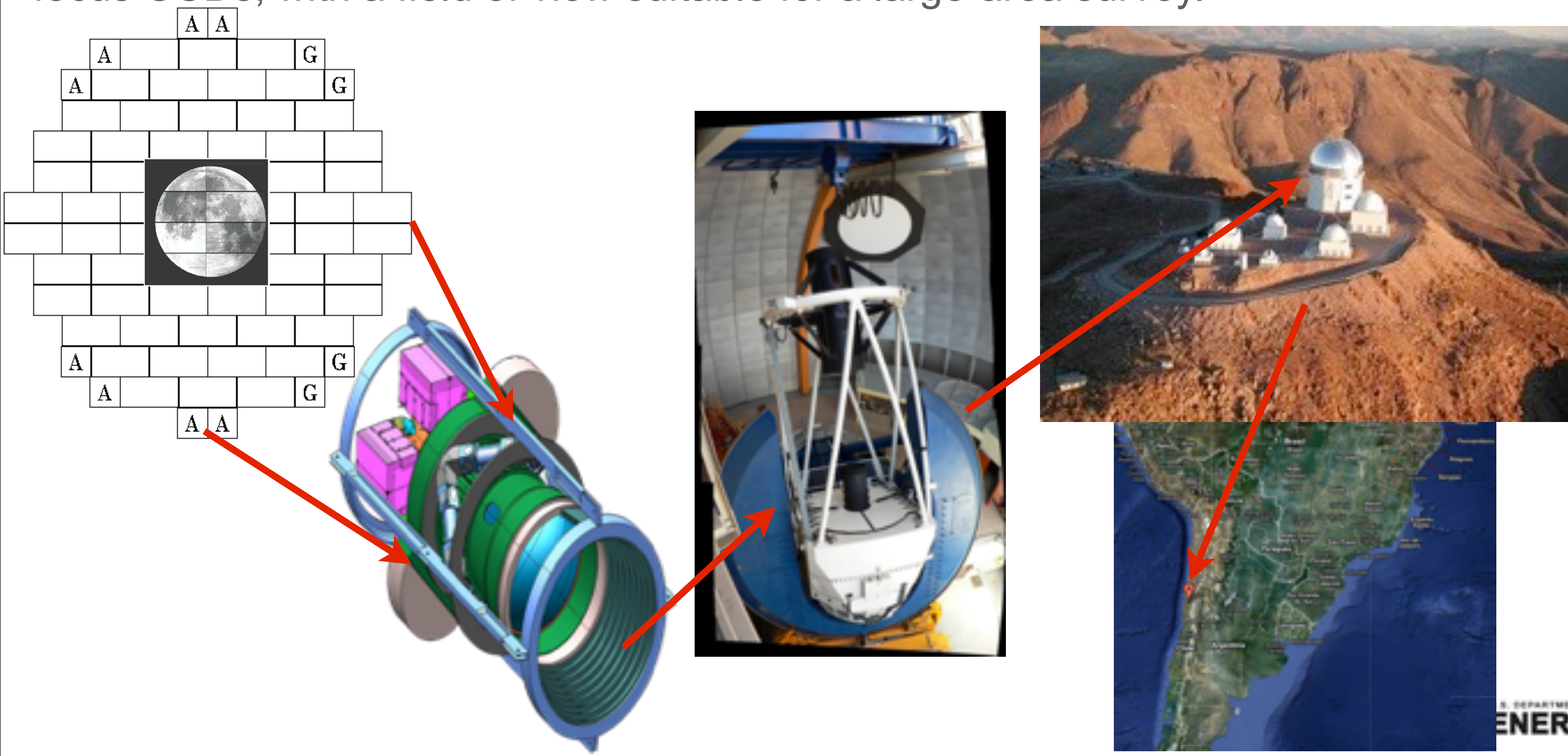
Galaxy Clusters

Weak Lensing

Large Scale Structure

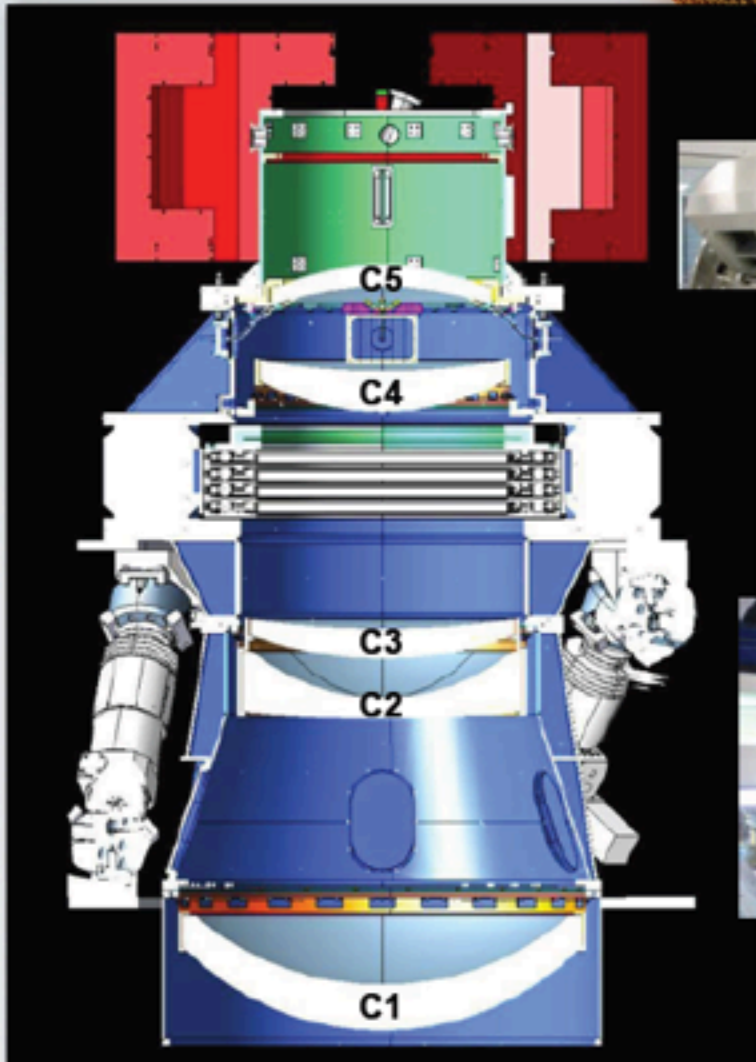
The DES Instrument: DECam

The newly-constructed Dark Energy Camera has been installed at the prime focus of the 4m. Blanco Telescope at Cerro Tololo Inter-American Observatory in Chile. DECam consist of 62 2k x 4k extremely red-sensitive CCDs, plus associated guide/focus CCDs, with a field of view suitable for a large-area survey.



DECAM

CCD focal plane is housed in a vacuum vessel (**the imager**)



CCD readout electronic crates are actively cooled to eliminate thermal plumes

Hexapod provides focus and lateral alignment capability for the corrector-imager system

Filter changer with 8 filter capacity and **shutter** fit between lenses **C3** and **C4**

Barrel supports the **5 lenses** and imager

LN2 is pumped from the telescope floor to a heat exchanger in the imager: cools the CCDs to -100 C

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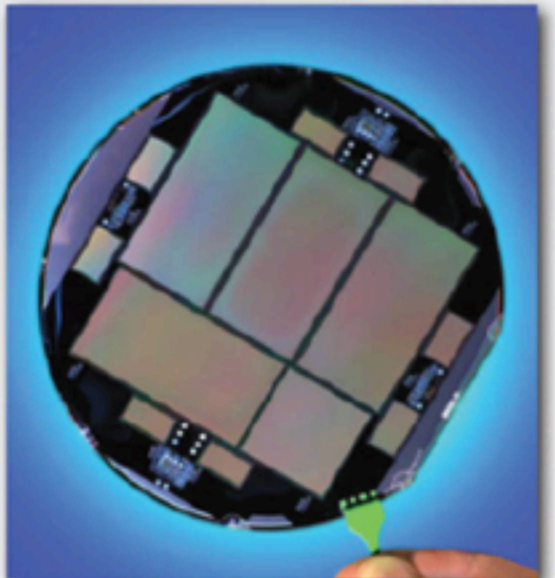
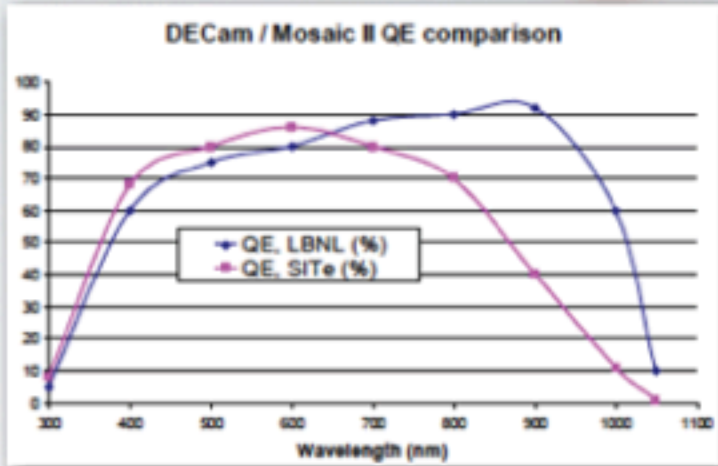
DECAM CCDS

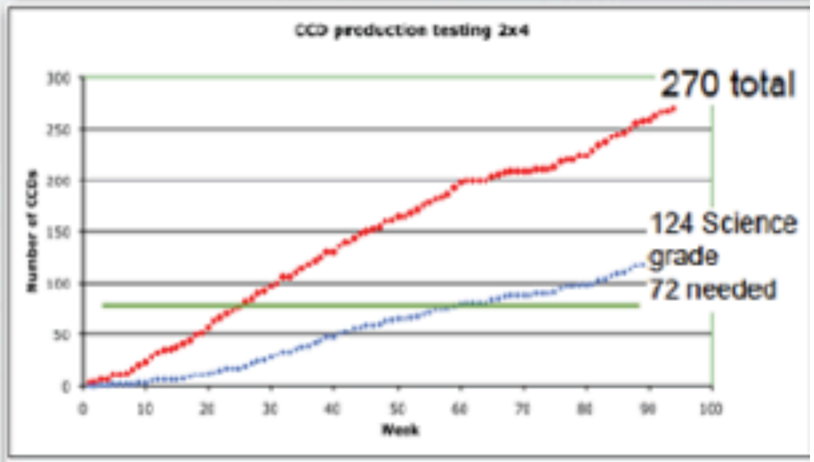
Red Sensitive CCD wafers, designed by LBNL, processed at DALSA and LBNL:

- QE> 50% at 1000 nm
- 250 microns thick
- readout 250 kpix/sec
- 2 RO channels/device
- readout time ~17sec





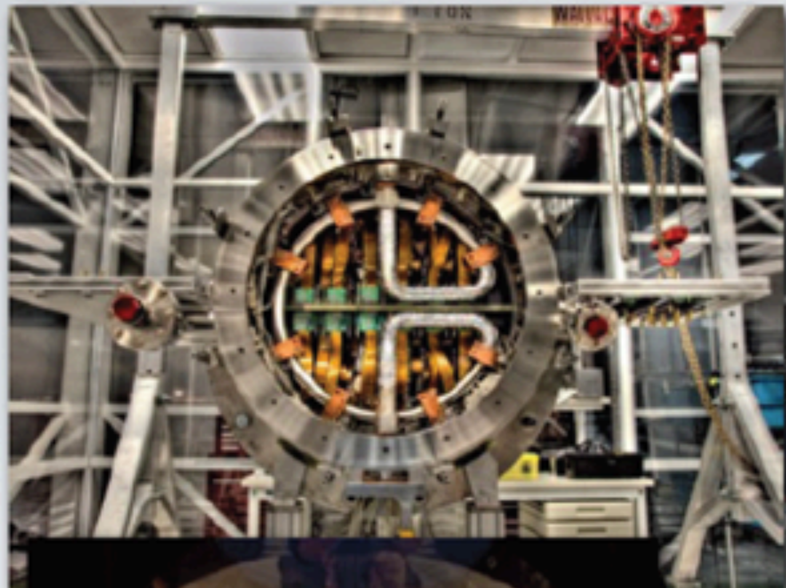
CCDs are packaged and tested at Fermilab.

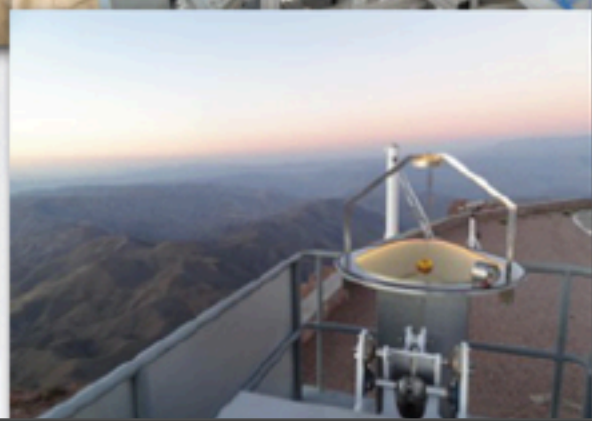


DECam Simulator at Fermilab

Extensive component and integration testing prior to installation

DECAM IN CHILE





From
Dec 2011
to
Jan 2012

We checked out the imager at CTIO!

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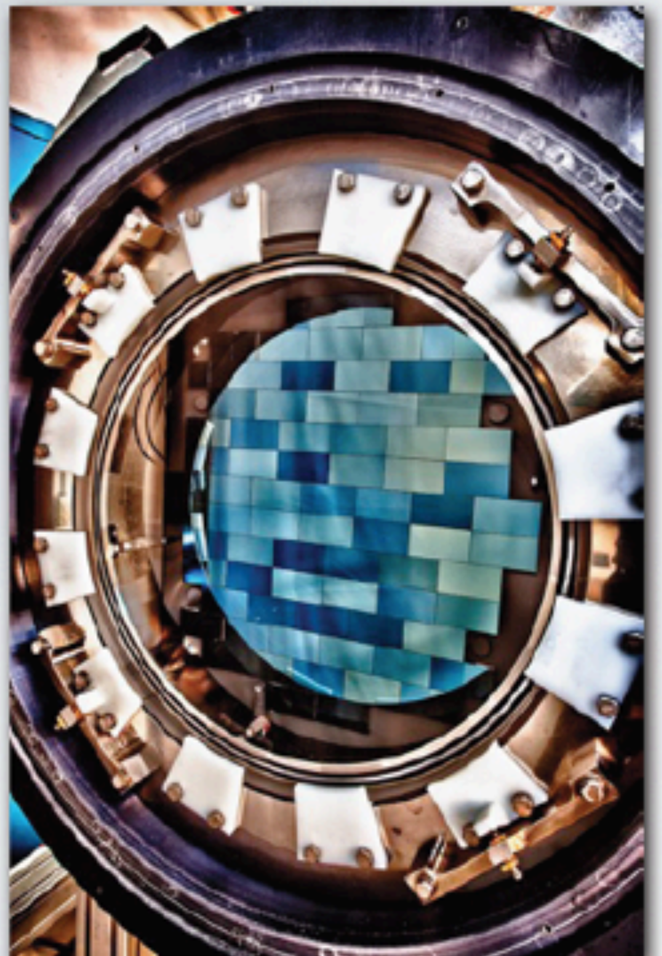

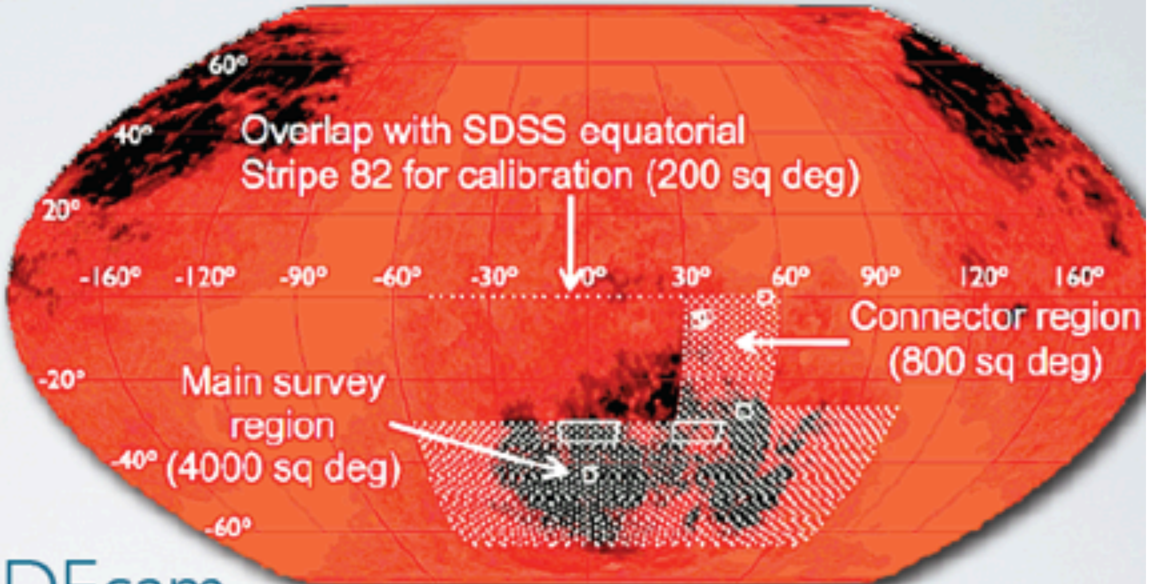

DEcam

3 sq deg FOV, **570 Mpix** optical CCD camera

Facility instrument for **CTIO Blanco 4-m telescope in Chile**

First light: Sep 2012

Survey

5000 sq deg grizY to **24th mag** overlaping with SPT and VISTA

30 sq deg repeat (SNe)

0.9 arcseconds seeing

525 nights: 2012-2017

U.S. DEPARTMENT OF ENERGY

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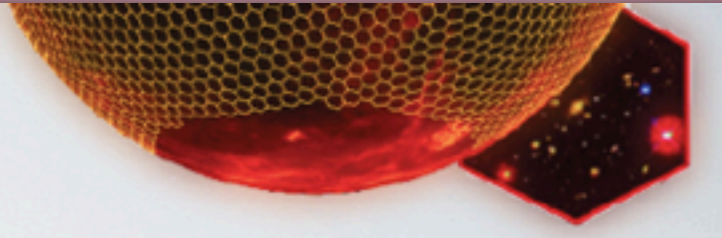
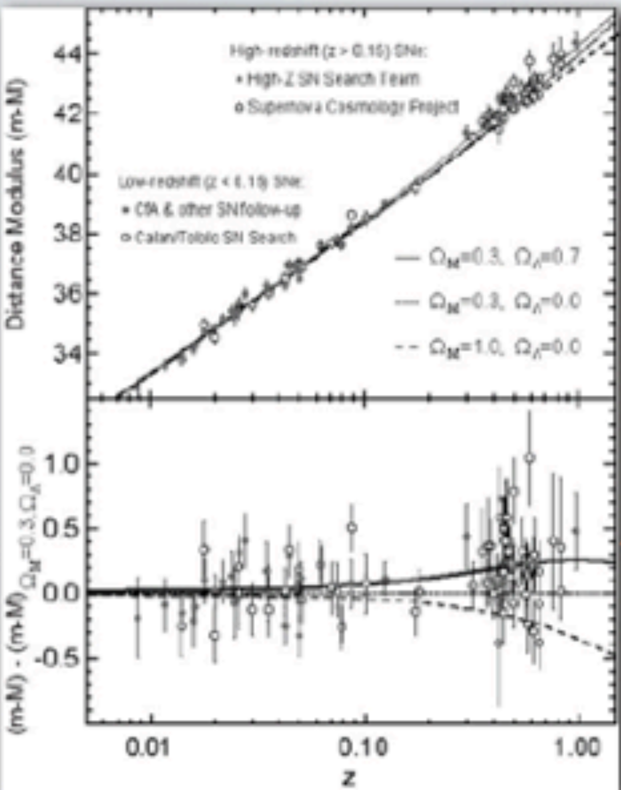
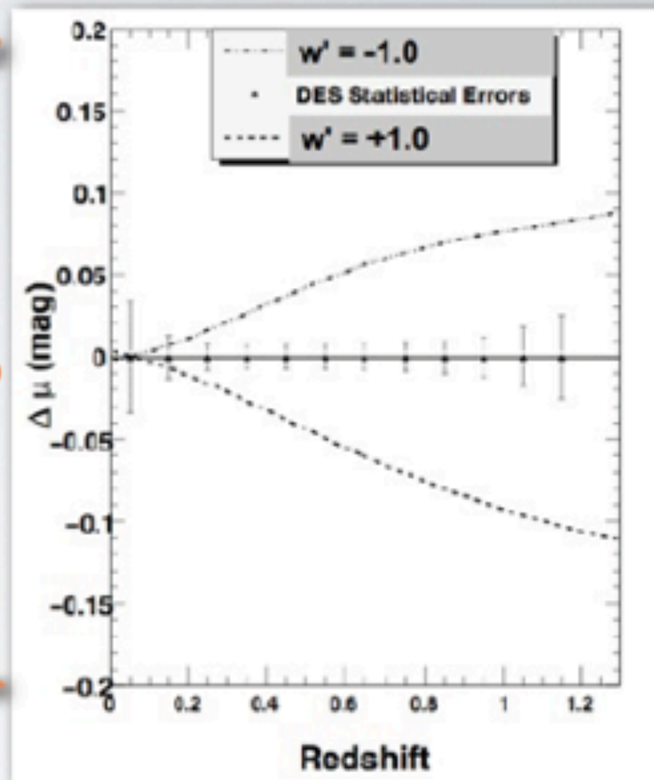
DES SCIENCE: SN





4000 SNe up to z ~ 1.2

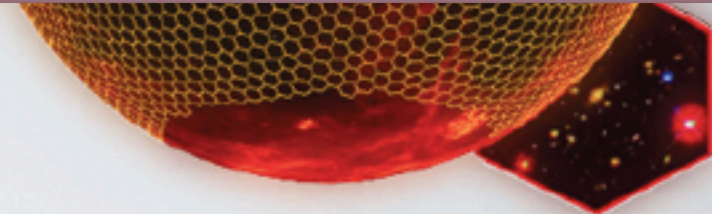
30 sq deg

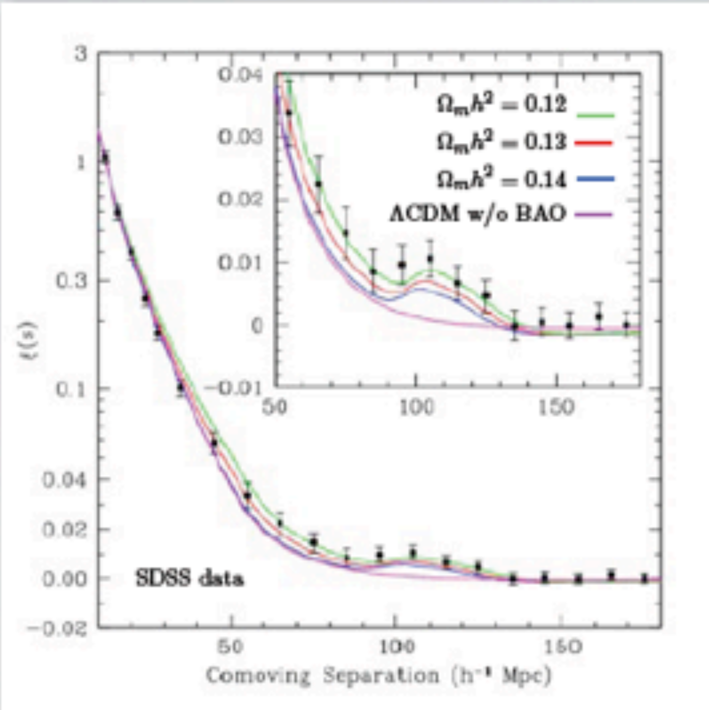


First results: ~ 100 SNe. Measured w.
(Riess et al. 1998, Perlmutter et al. 1999).

DES expected sensitivity. Large and deep sample for measurement of w(a).

DES SCIENCE: BAO

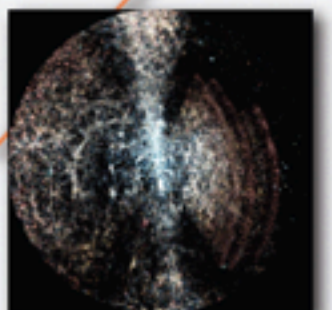


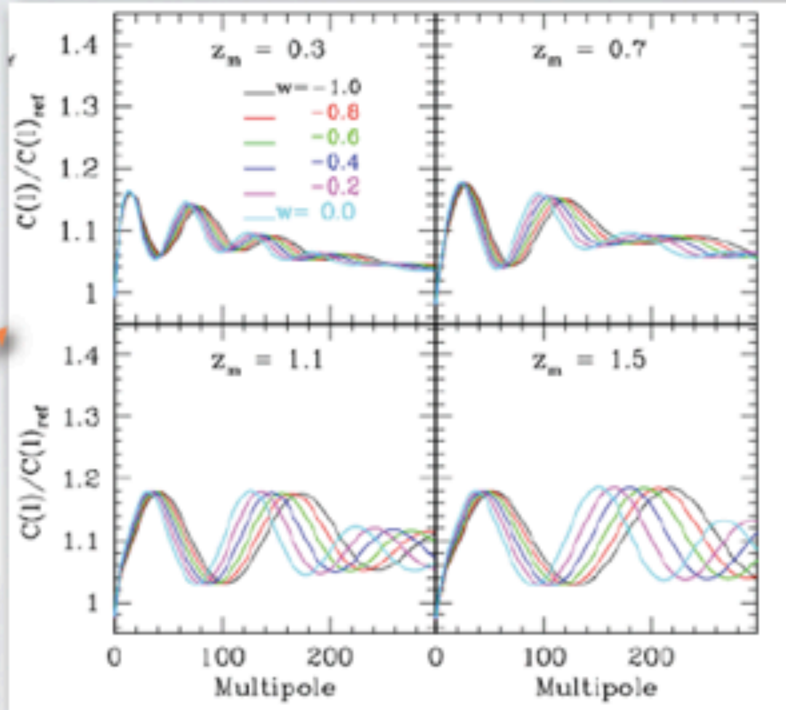


First results: mean spectroscopic redshift ~ 0.35. Measured Ω_m (Eisenstein et al. 2005)

mean photometric redshift~0.7

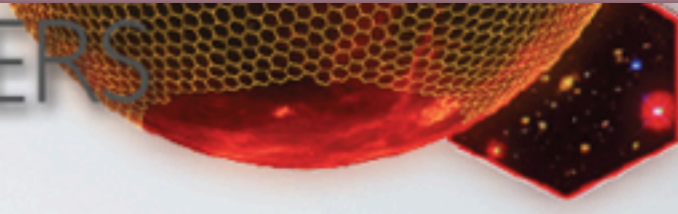
300M glxs

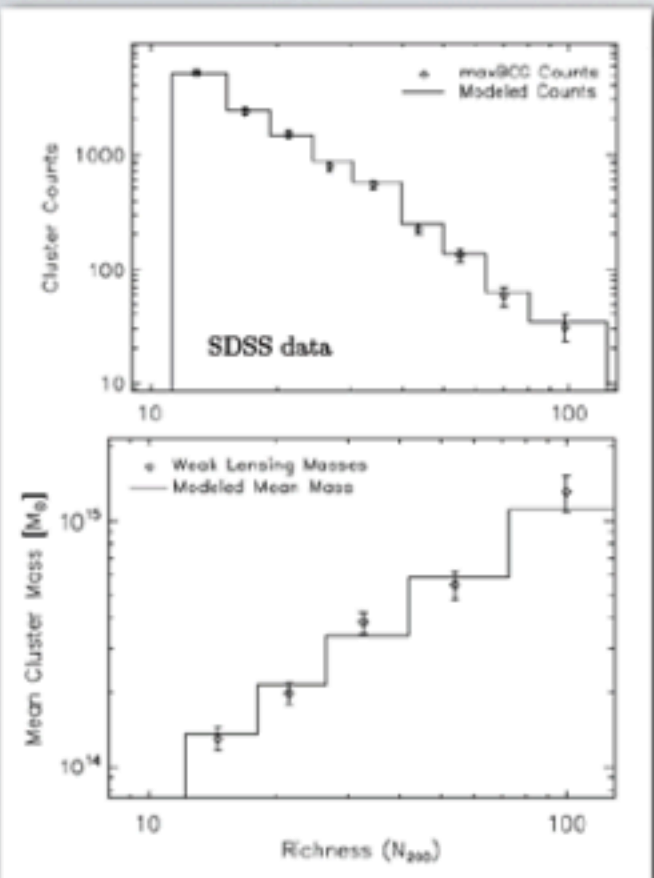




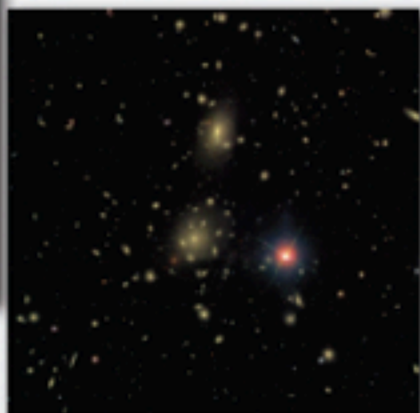
DES expected sensitivity. Can measure w by probing deeper.

DES SCIENCE: CLUSTERS

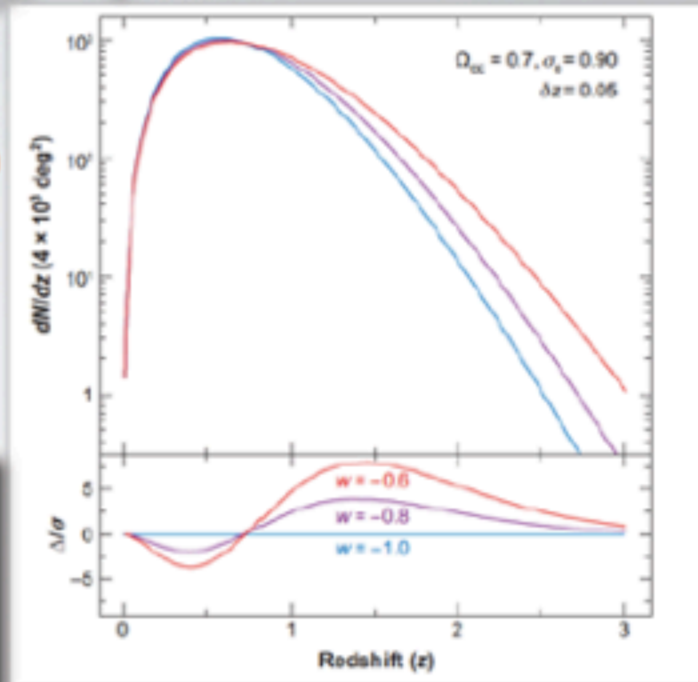




Current results: 6000 clusters, z ~0.35
Measured Ω_m (Rozo et al. 2010)



100,000 clusters z ~ 1



DES expected sensitivity. Measure w with deep & wide survey.

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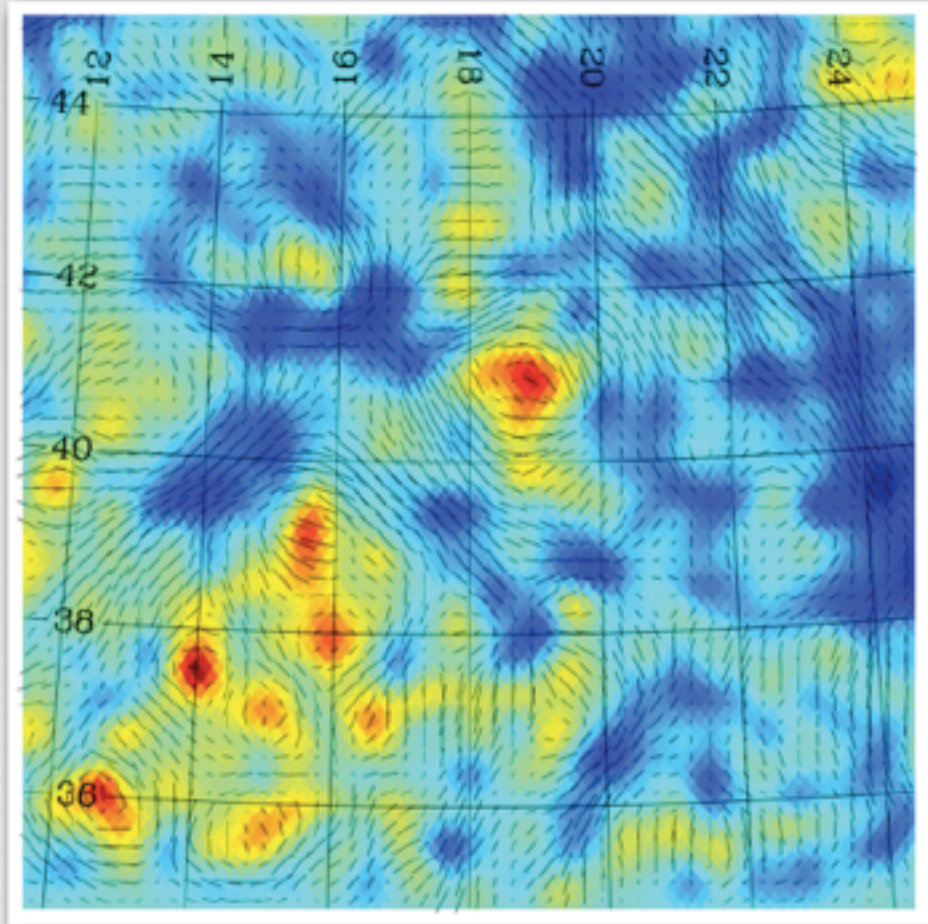
DES SCIENCE: WL

Map of DES "DC6B" 200 deg^2 simulated convergence and shear fields



Colors indicates convergence ∝ surface mass density

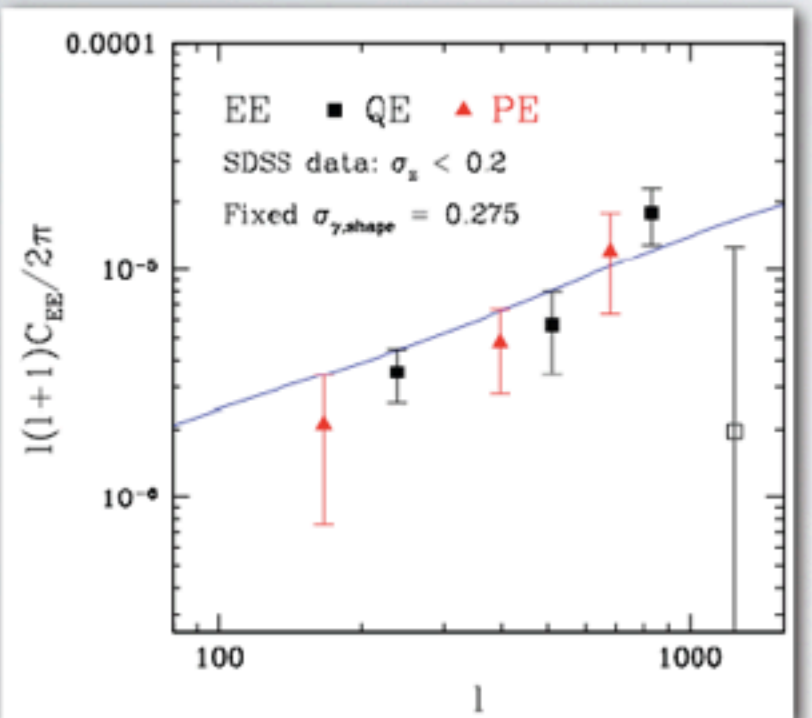
red ==> high density
blue ==> low density

Black "whiskers" show lensing shear field

Whiskers indicate magnitude and direction of lensing distortions acting on galaxy shapes

Figure from M. Becker

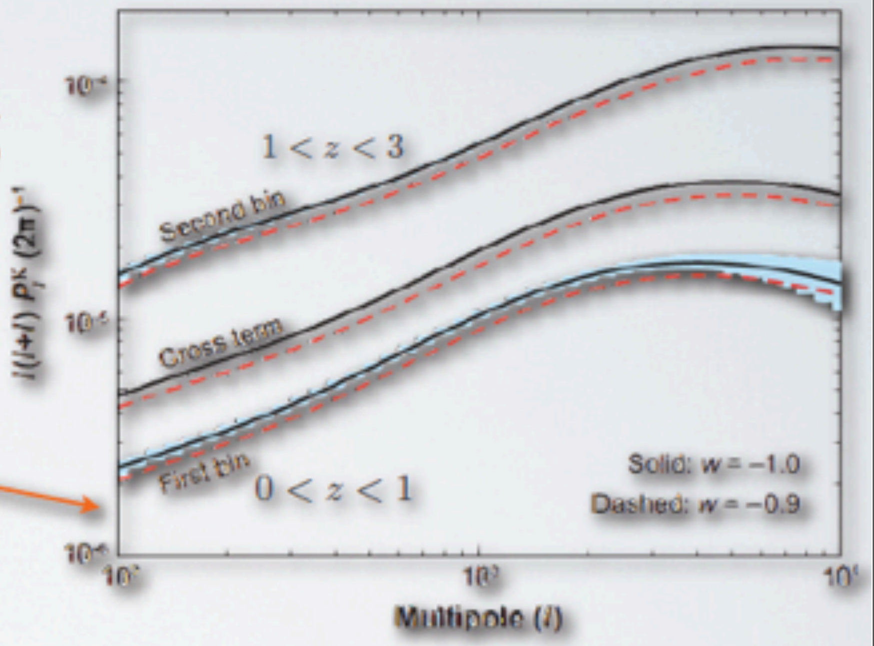
DES SCIENCE: WL



Current results: 275 sq deg, 24th magnitude.
Measured Ω_m.

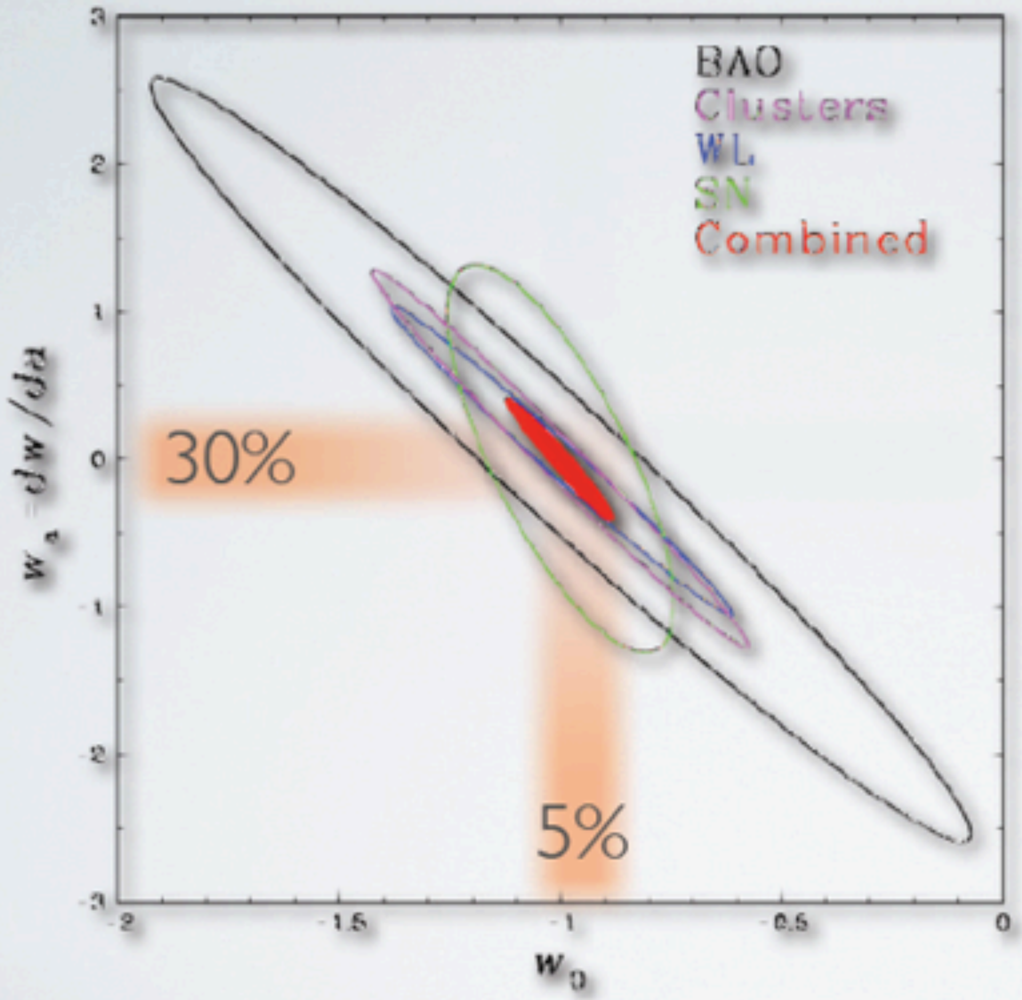
5000 sq deg

300M glxs



DES expected sensitivity. Source galaxies in first bin only. Can measure w by going wider.

DES PROJECTED LIMITS



5000 deg^2, 0.9" seeing, 24th mag (redshift~1.4)

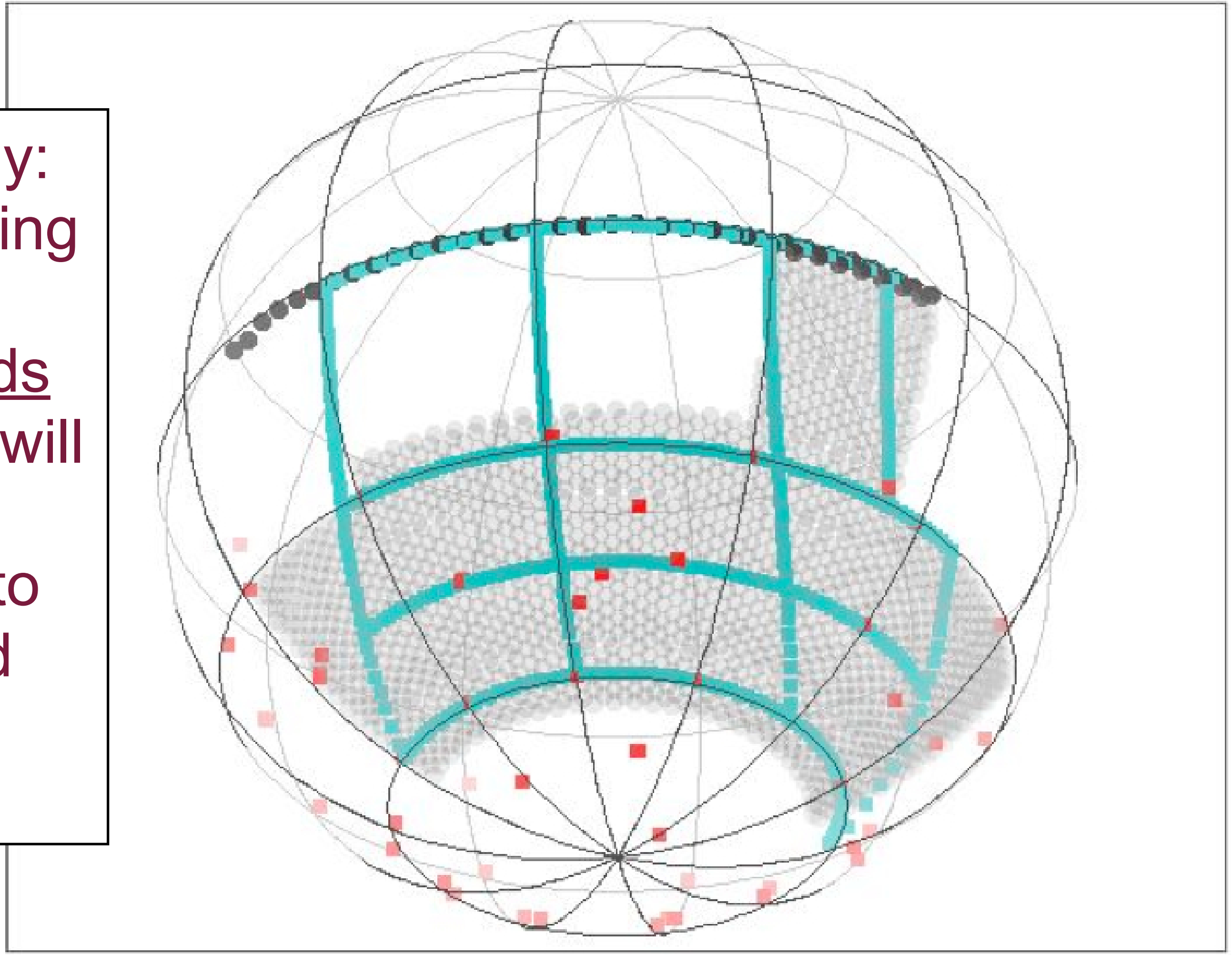
300M galaxies, shapes, 100K clusters, 4K SNe

4 combined probes

3-5x improved Dark Energy measurement

Calibrating the DES: PreCam Grid & DES Footprint

Rib & Keel Strategy:
Every ~20 min during the DES, a field containing hundreds of calibrated stars will be observed.
These will be tied to SDSS, USNO, and Southern u'g'r'i'z' Standard Stars.



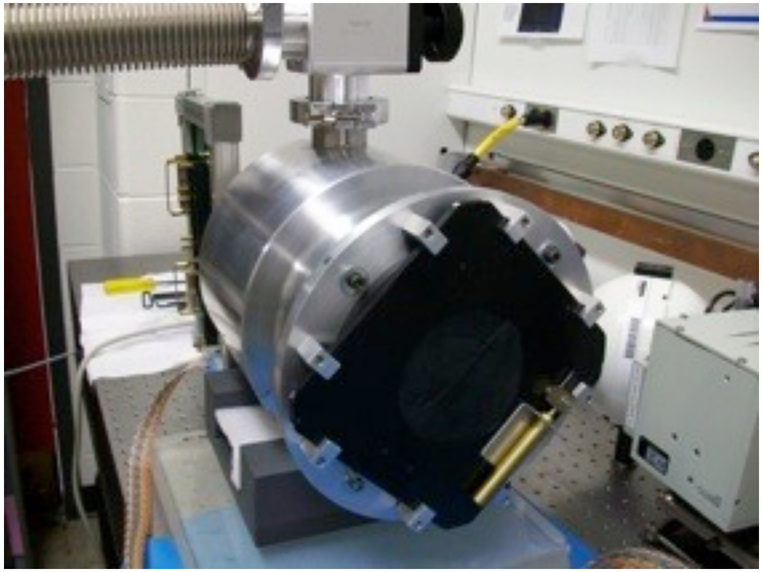
PreCam Goals and Timeline

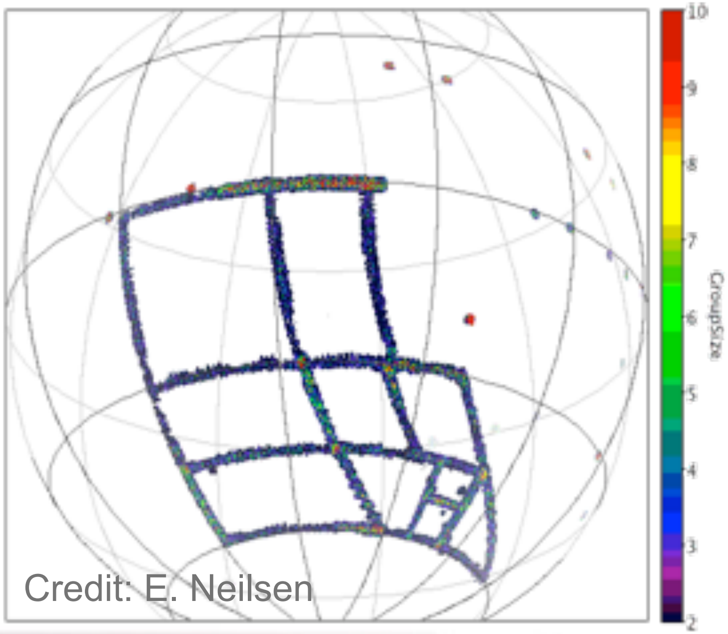
PreCam is a scaled down (2 CCD) version of the DECam that was used (in part) for development and testing of DECam hardware and software.

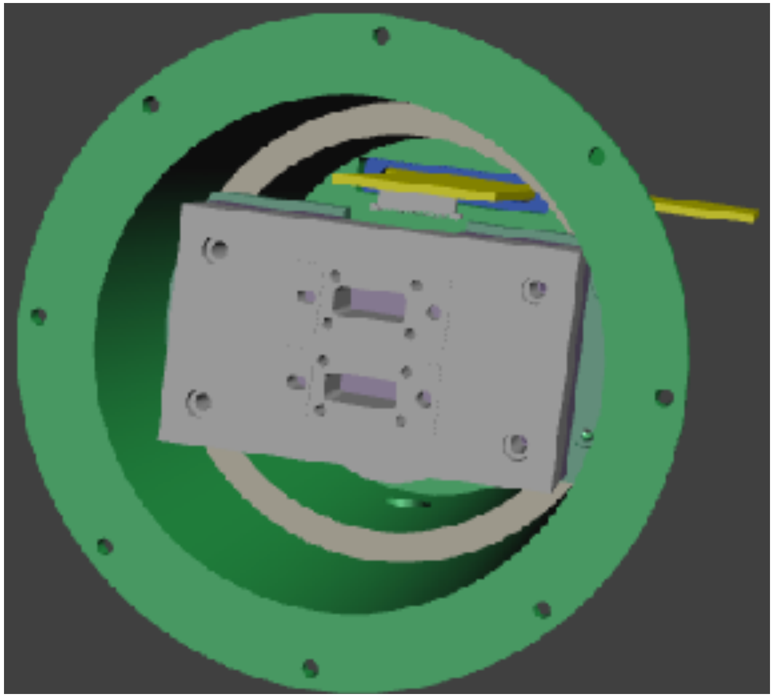
PreCam's primary goal was to observe a sparse grid of southern hemisphere standard stars ahead of the DES (especially in Y).

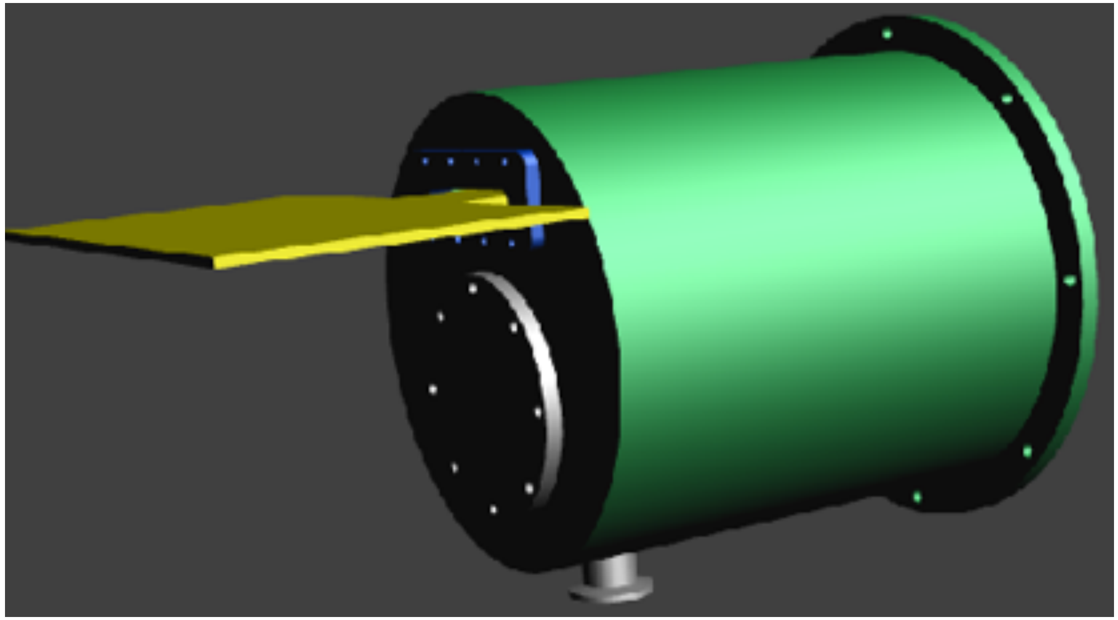
It was designed and constructed in less than one year. First orders for parts were placed in January 2010 and it achieved first light that August.

Precursor observations will allow DES to begin with photometric standards and save up to 10% of the DES observing time that would otherwise be devoted to calibration efforts.









PreCam Vessel

Focal Plane Support Plate

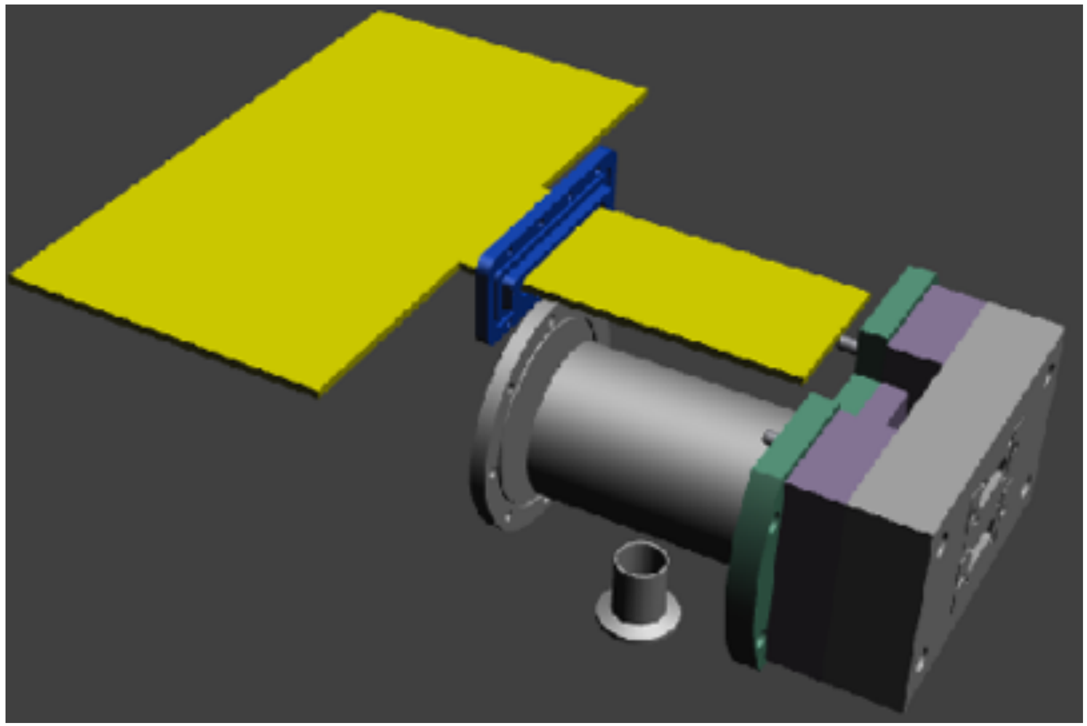
Thermal Transfer (Cu) Block

G-10 Mounting Block

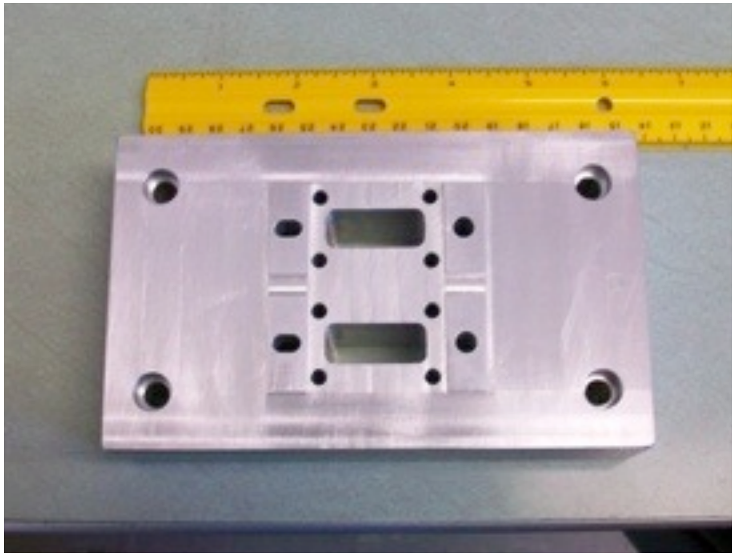
CryoTiger

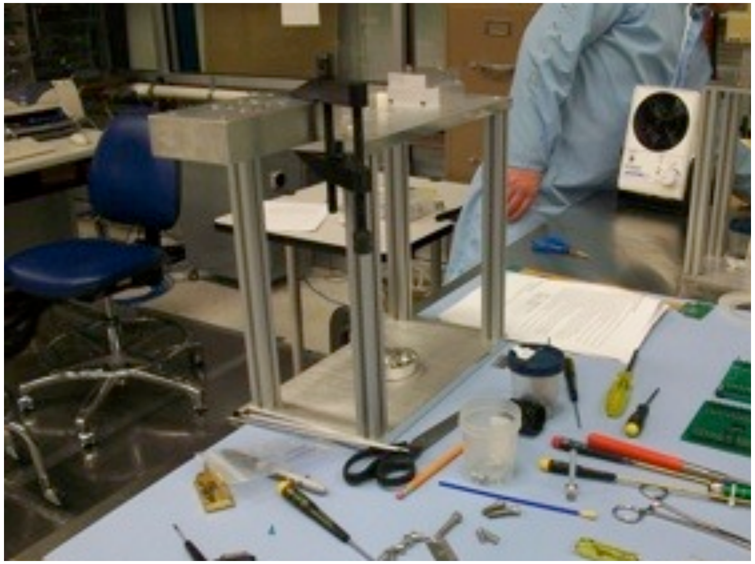
Vacuum Interface Board

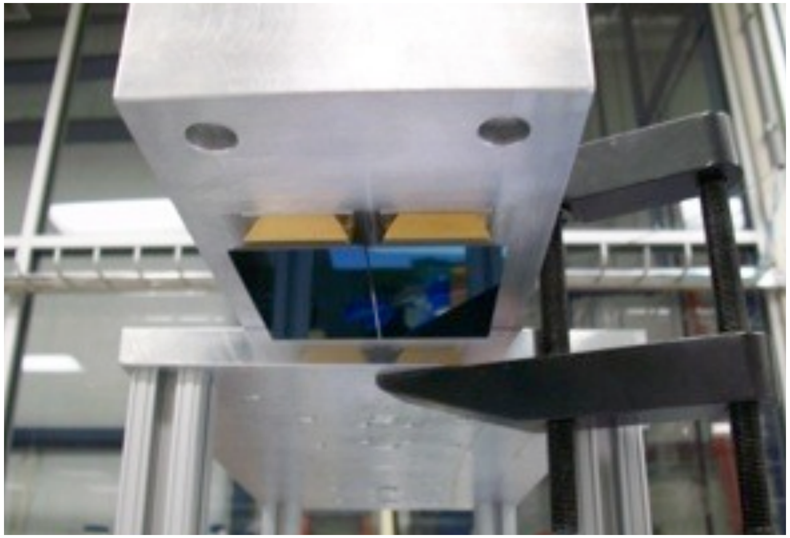
Dewar



Focal Plane Support Plate & CCD Installation

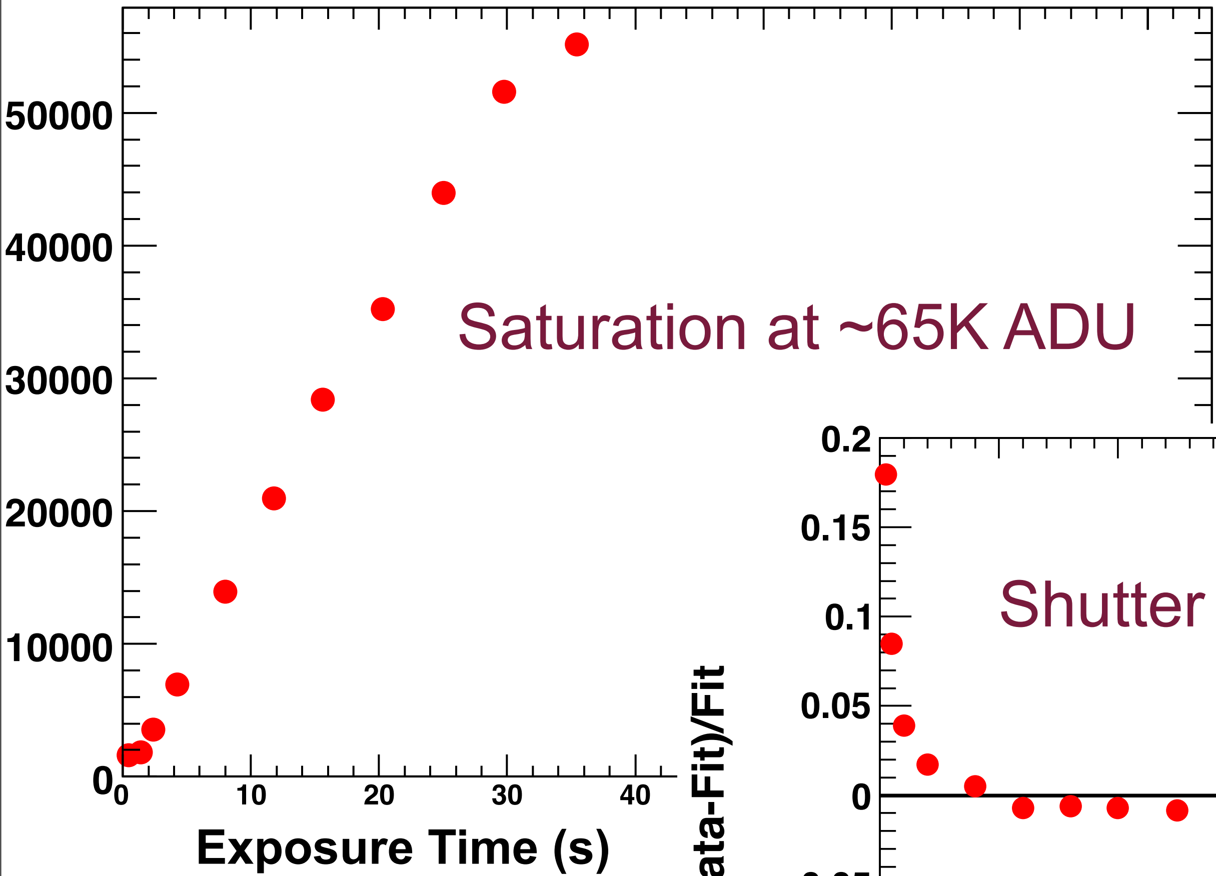


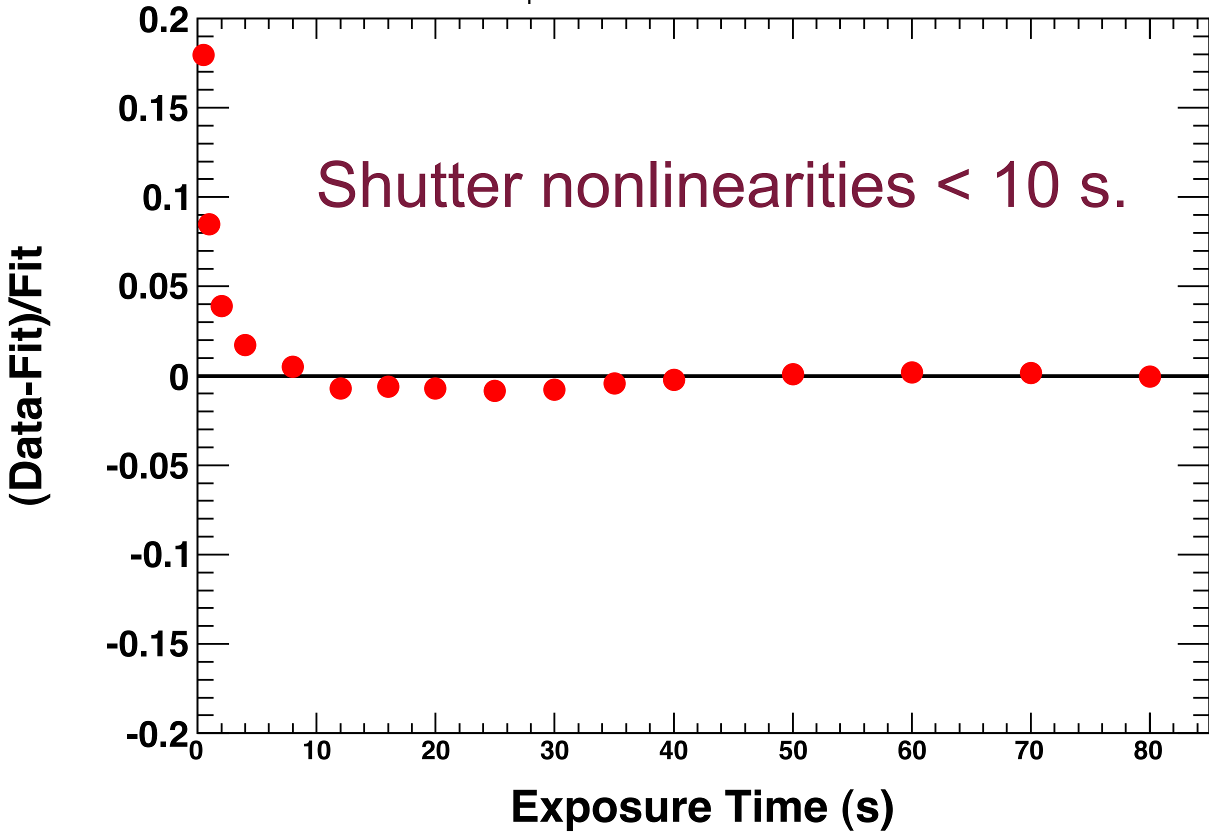


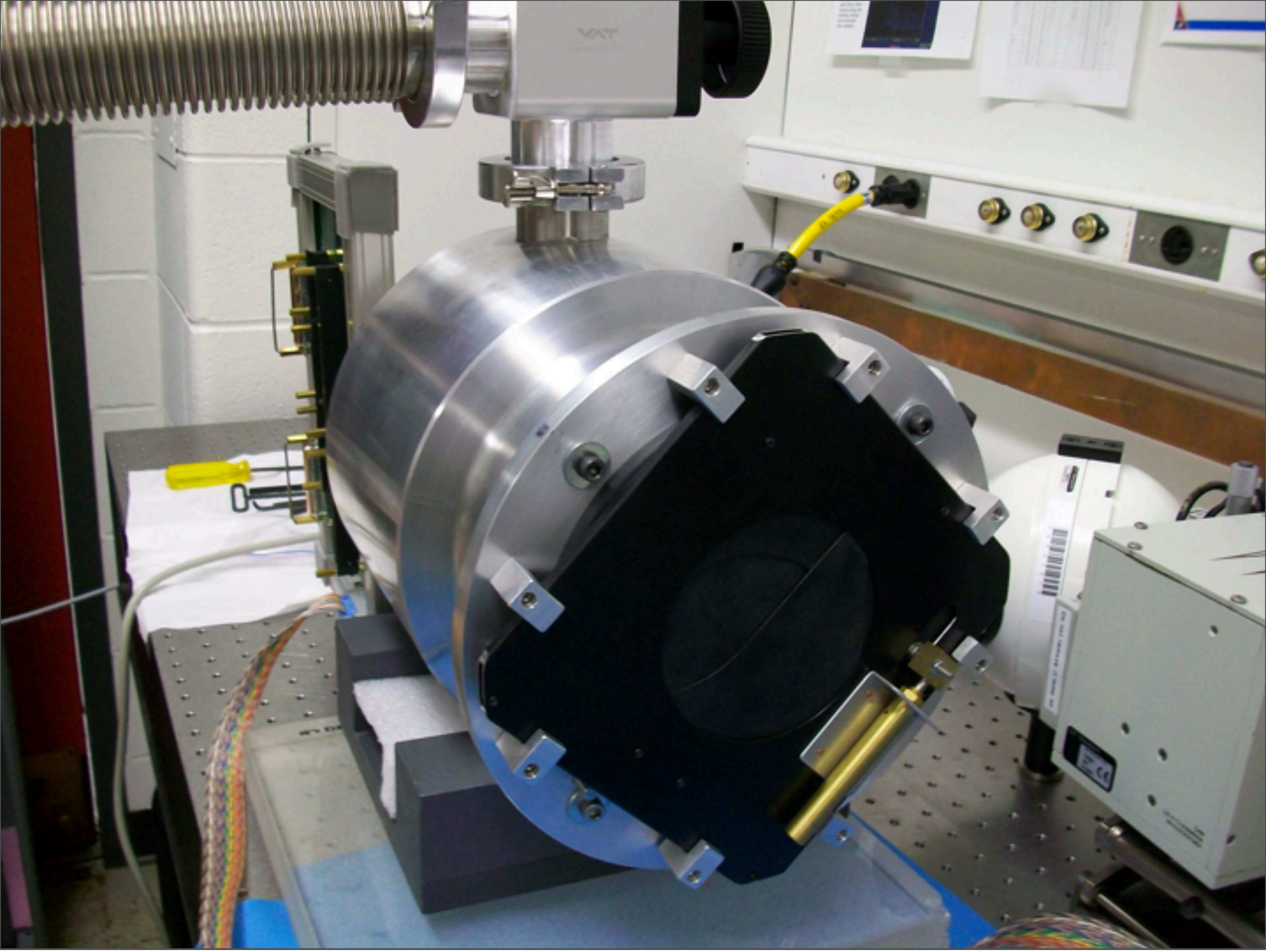


Bench Tests I: Laboratory Setup

Bench Tests II: Linearity, Full Well

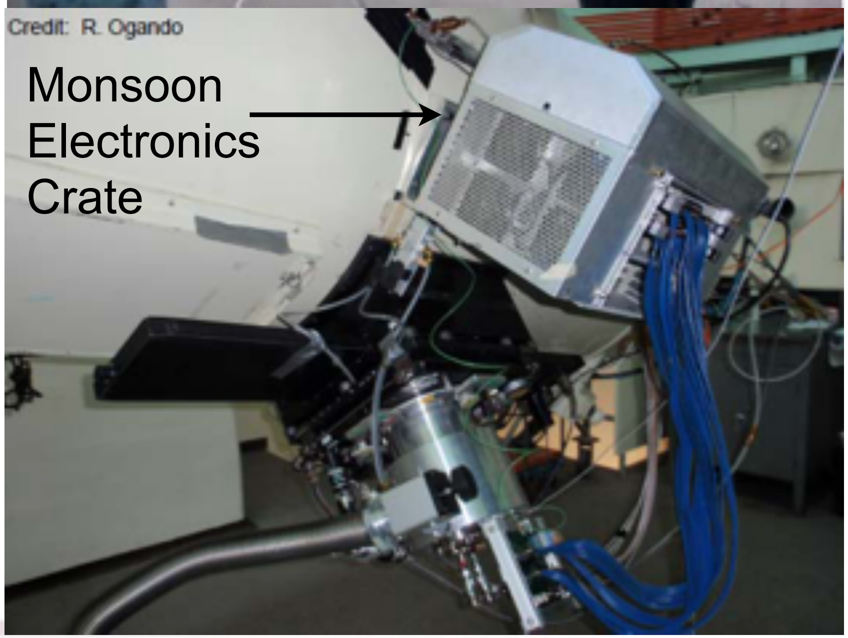





VAT

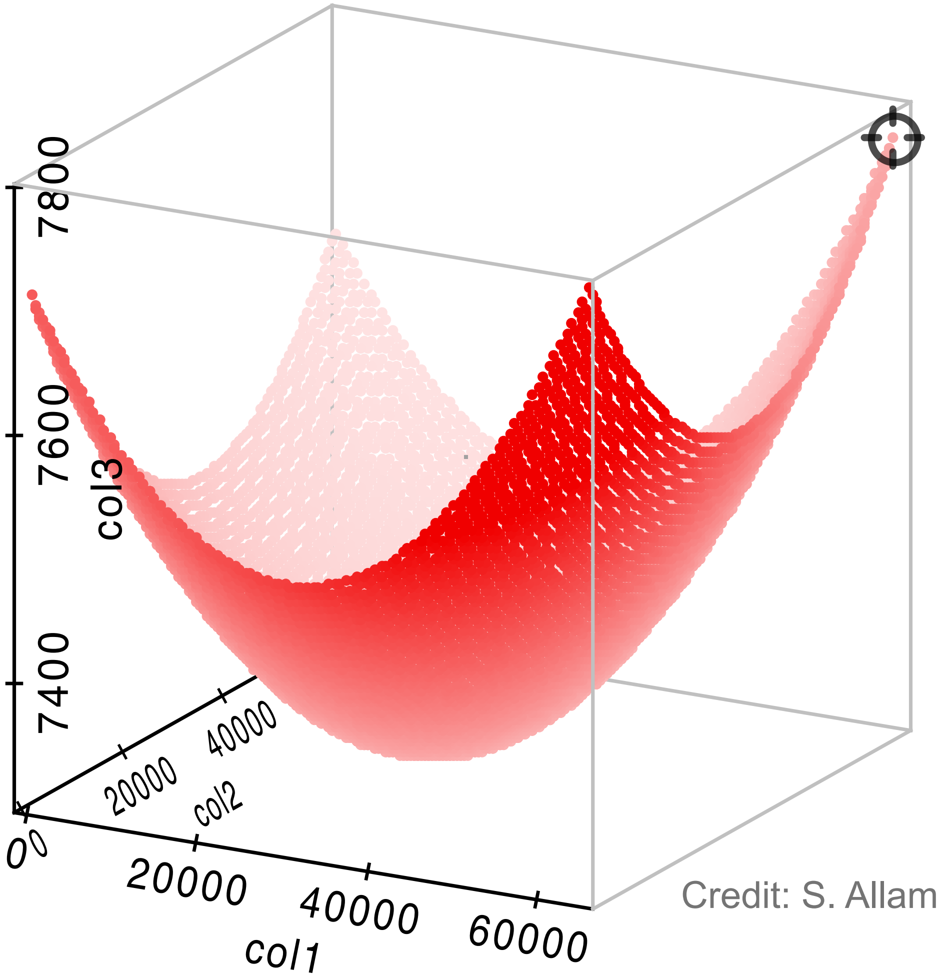
Installation on the Curtis-Schmidt Telescope at CTIO

Credit: UofM Astronomy

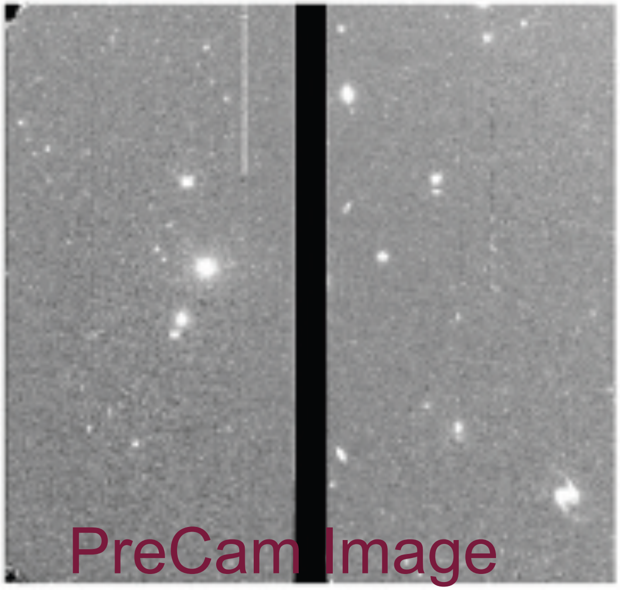


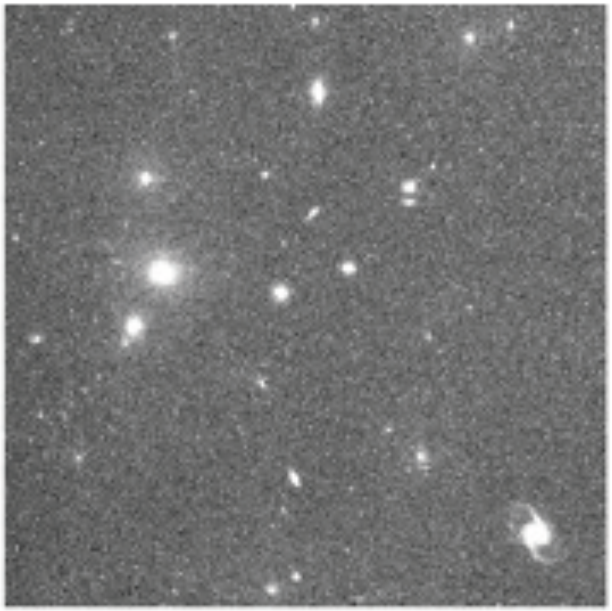
Credit: R. Ogando

Commissioning I: Best Focus Surface, Early Images



Note curved focus surface due to lack of field flattener

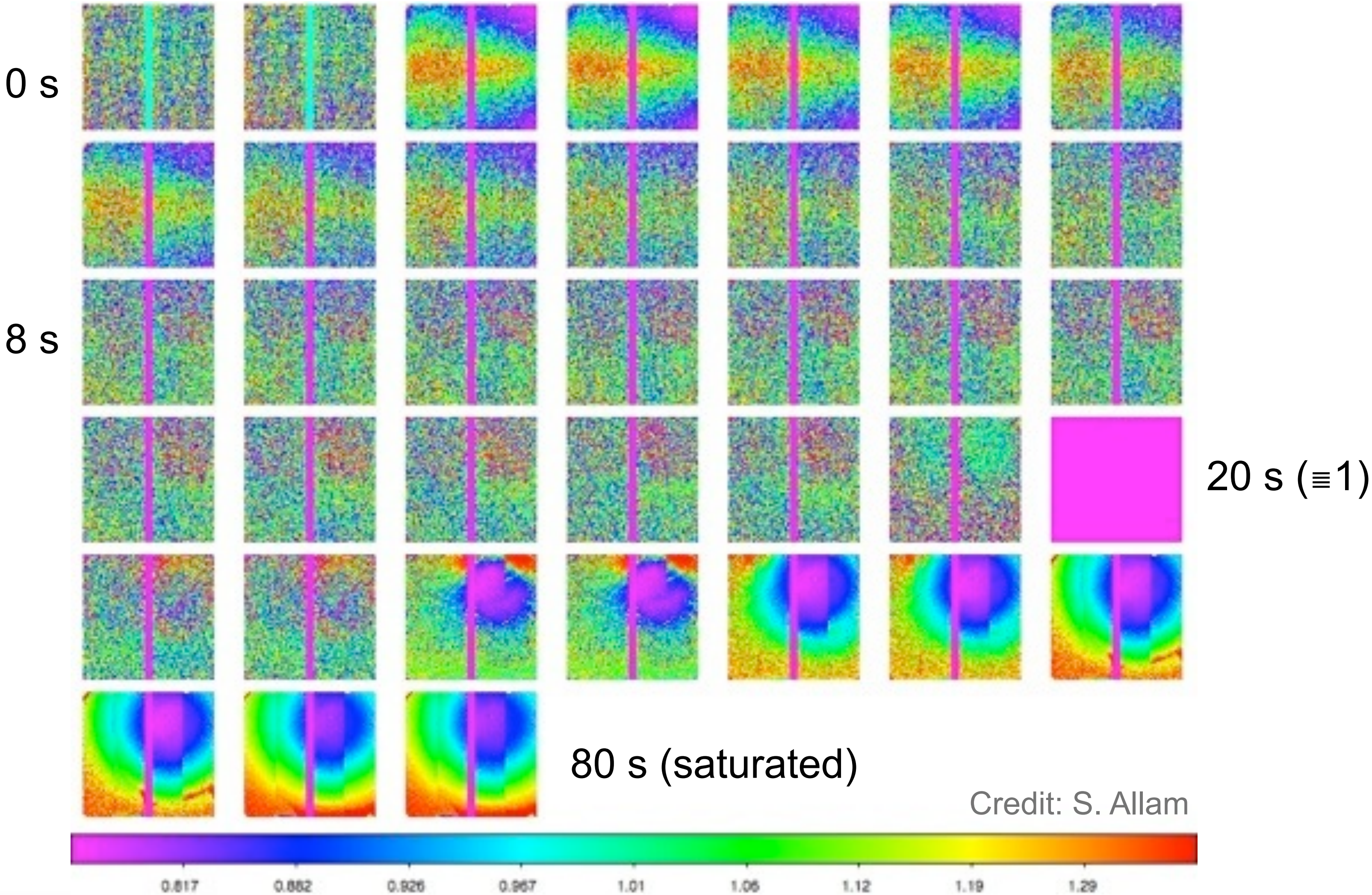




Prior Sky Survey Image

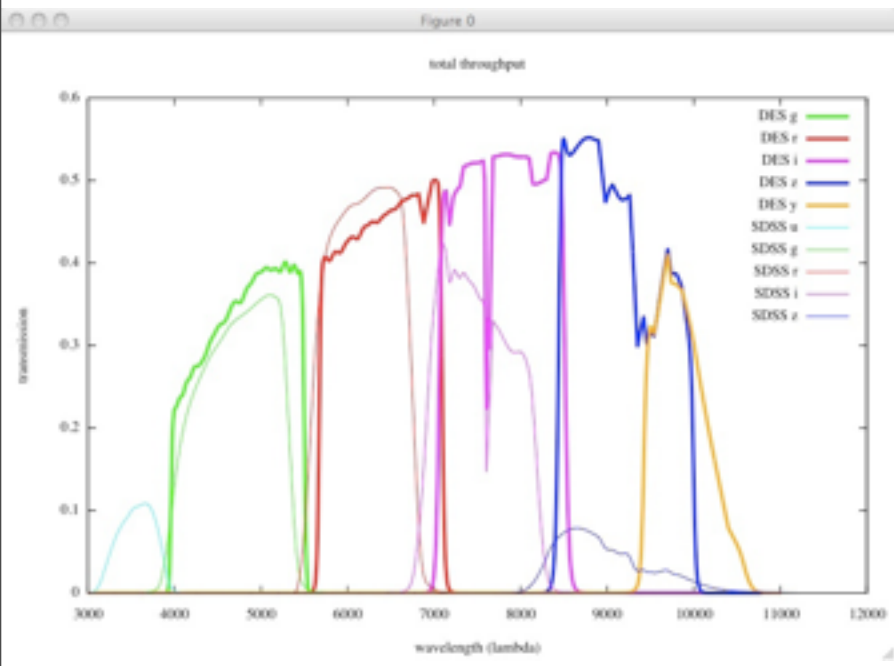
Commissioning II: Shutter Timing from On-Sky Data

nonzero shutter actuation time effects are negligible beyond ~8s, <u>confirming results</u> of bench tests

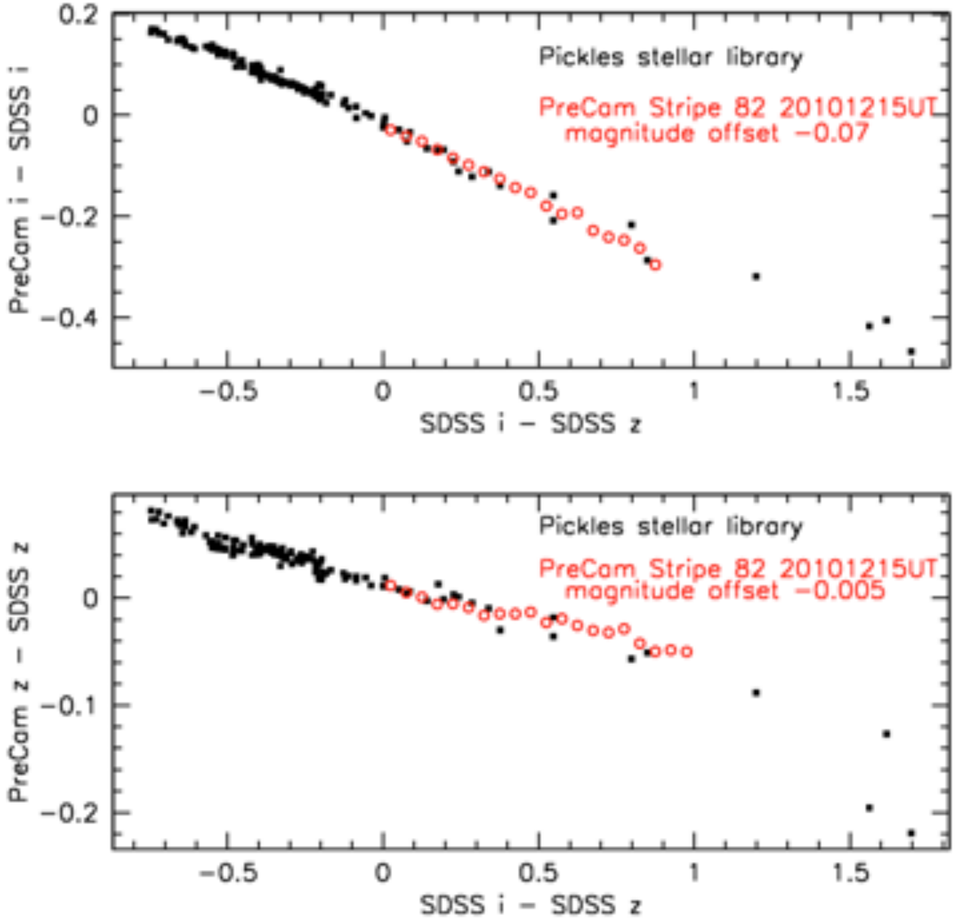


Commissioning III: Filter Performance

Transmission vs. Wavelength: DES Filters vs. Sloan Filters



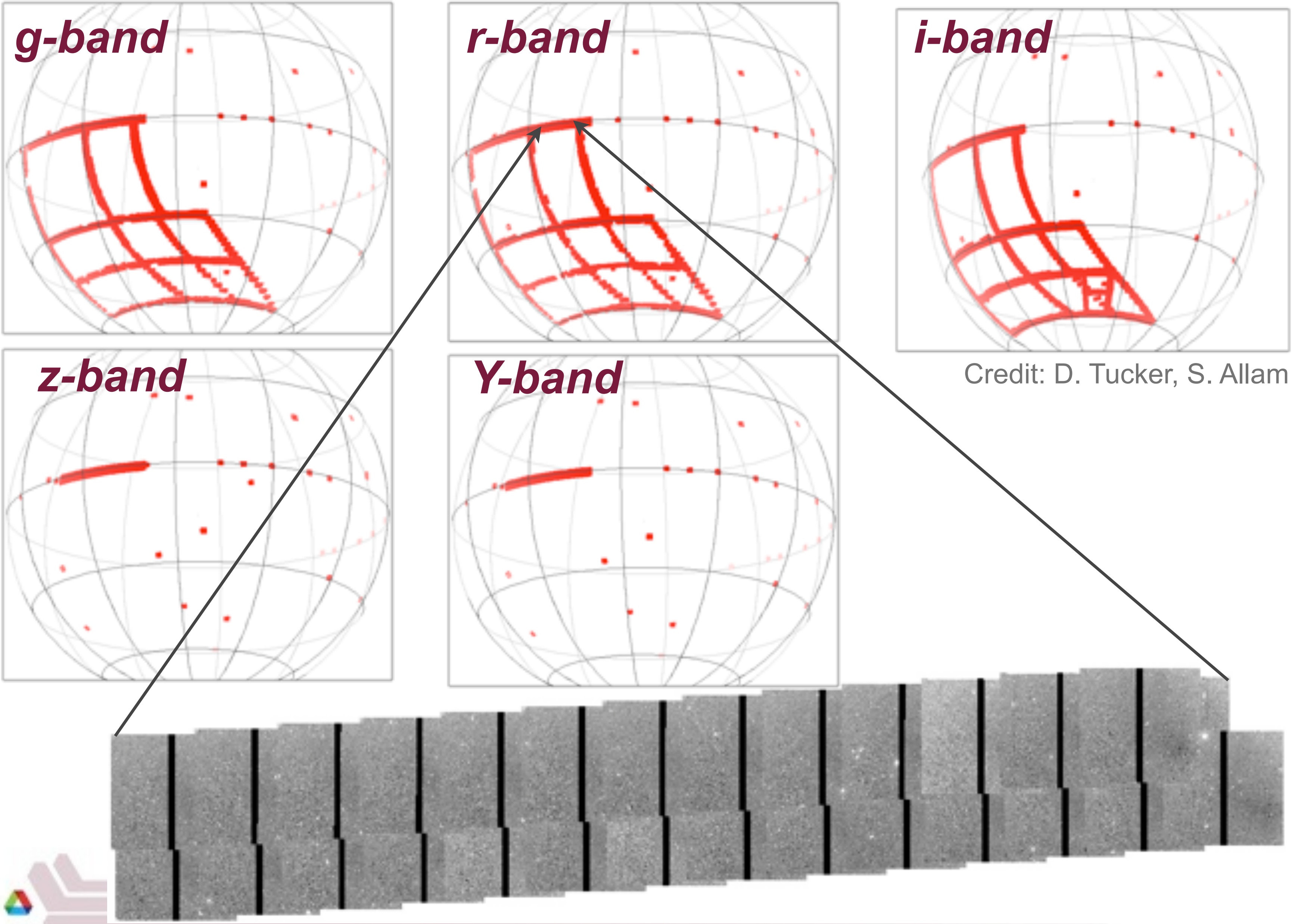
DES/PreCam Color Response



Credit: D. Tucker

PreCam Observations by Filter

Steps to the PreCam Southern Hemisphere Standard Star Catalog

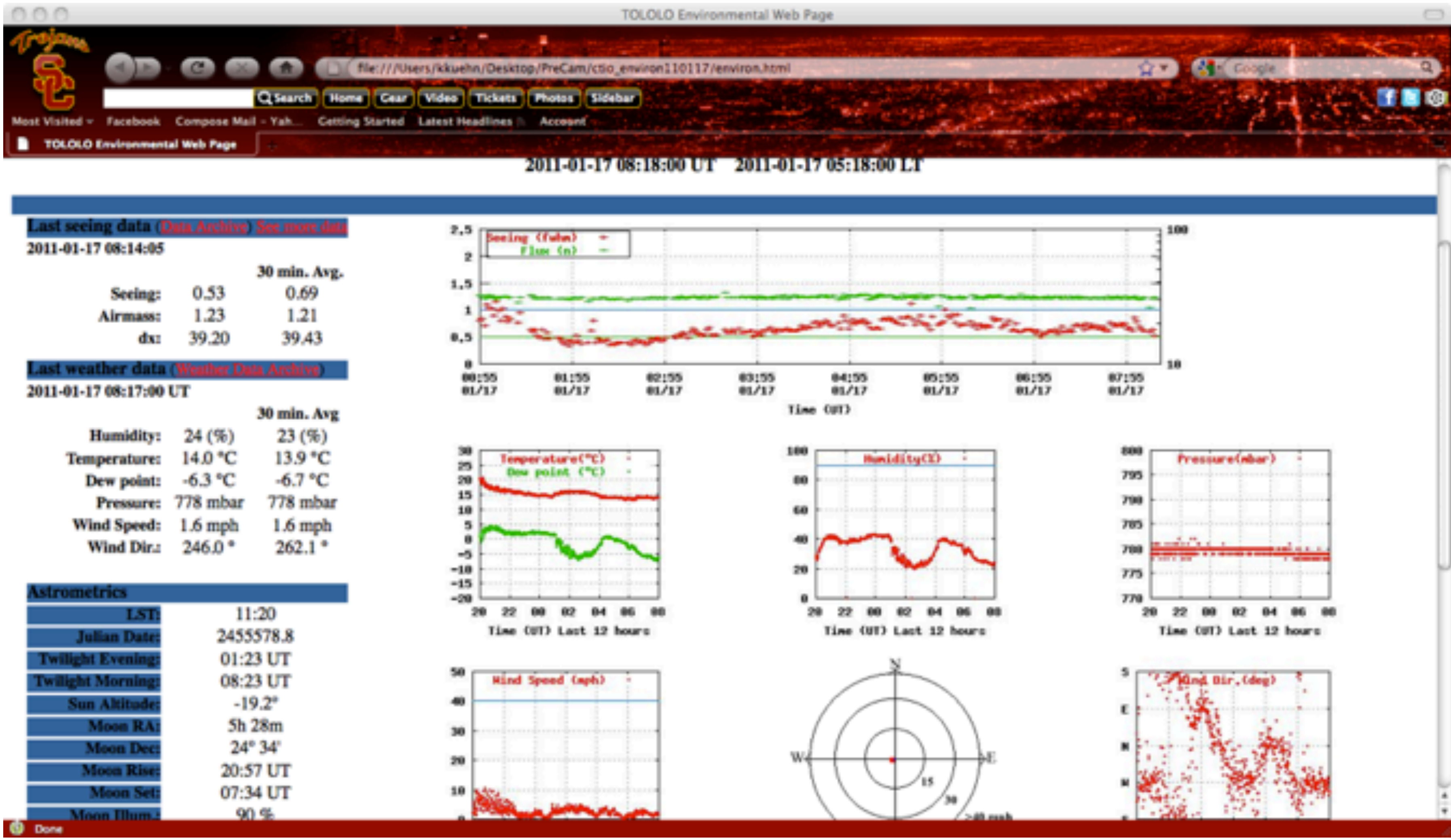


Credit: D. Tucker, S. Allam

How is the weather?

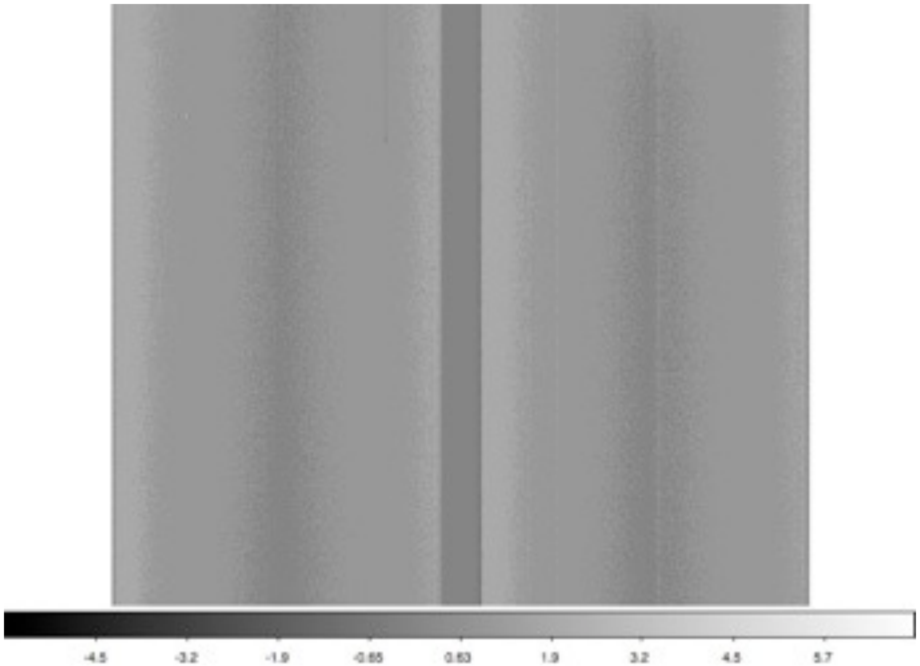

CTIO Sat 2011/11/05 14:38:18 2011
Up: 16+20:28:04, Frame: 224277, Exp: 617, T: +35.0

Recording the Environment at Cerro Tololo

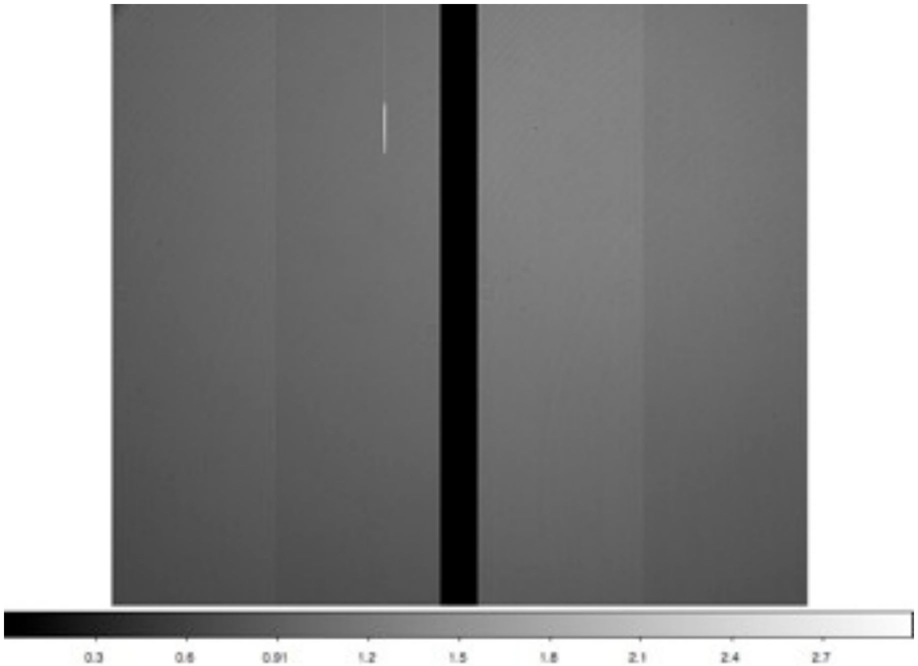


Data Processing at FNAL & ANL

- Fermilab developed processing pipeline consisting primarily of shell/py scripts for bias subtraction, flat-field corrections, etc.
- Each iteration added functionality--crucial improvements include banding/streaking removal, astrometry
- Further processing/analysis scripts developed in parallel at ANL



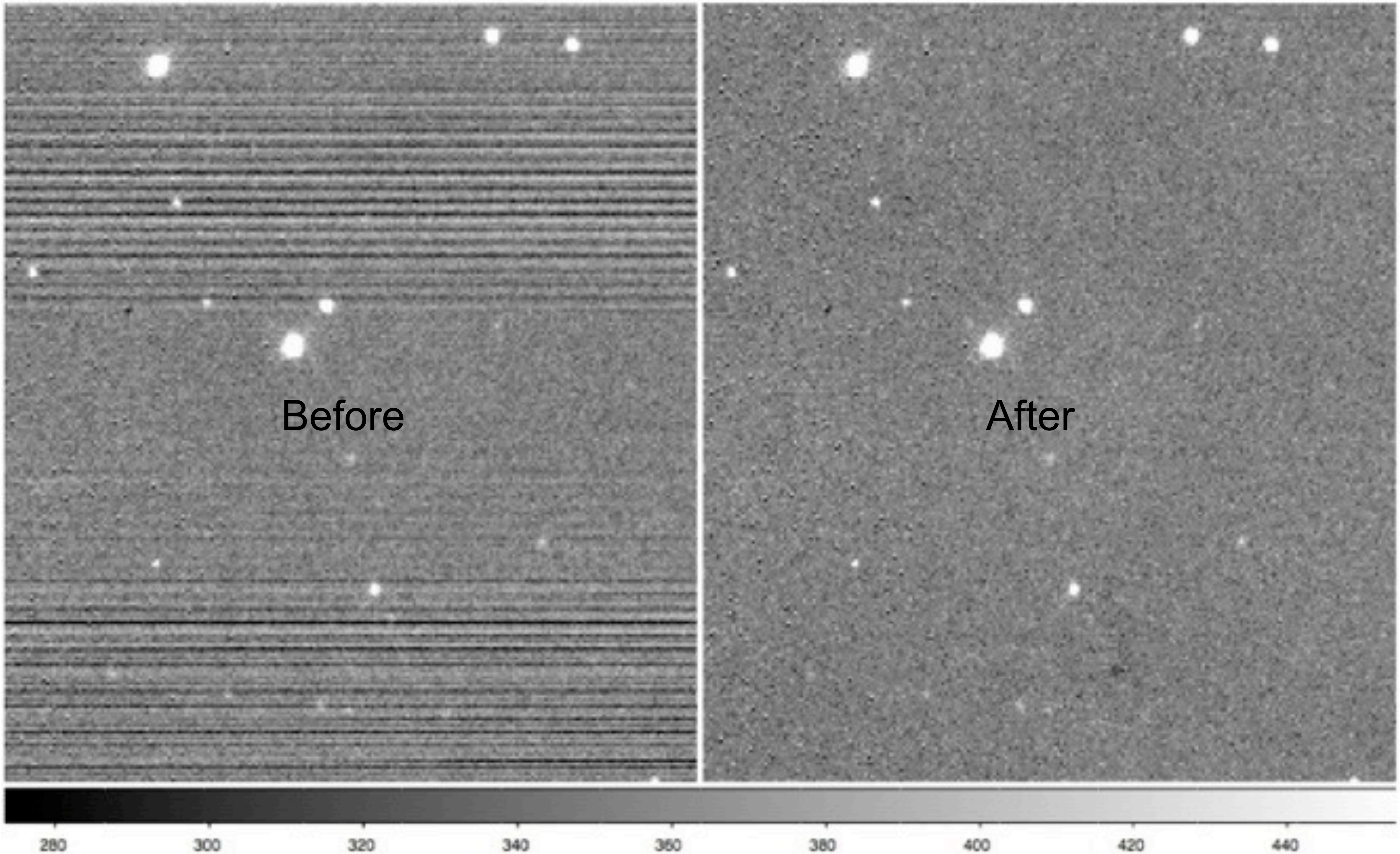
Bias



Flat

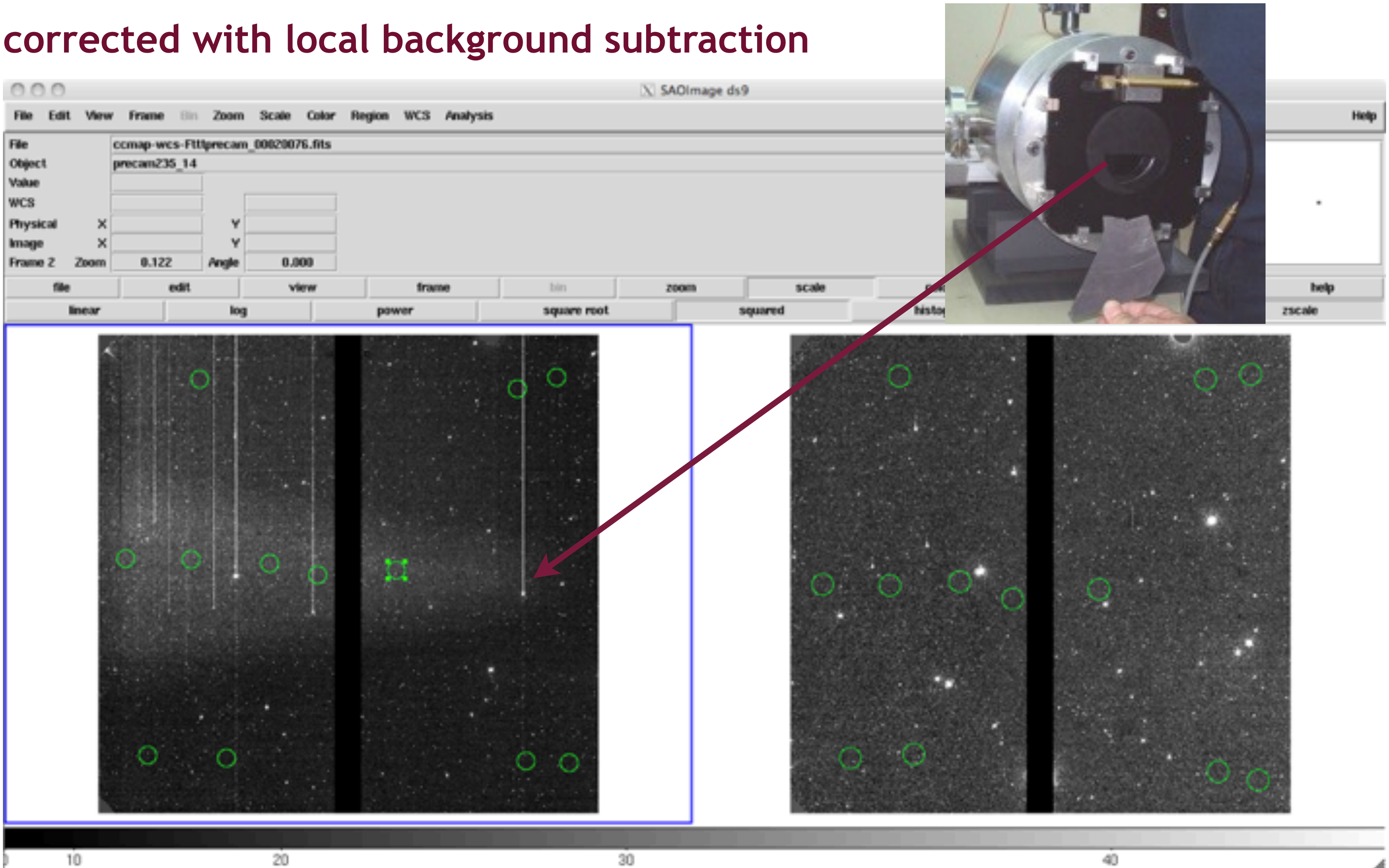
Cosmic Rays in the PreCam CCDs

Data Processing II: Streaking/Banding & Software Corrections



Data Processing III: Identifying Problematic Shutter Images

corrected with local background subtraction



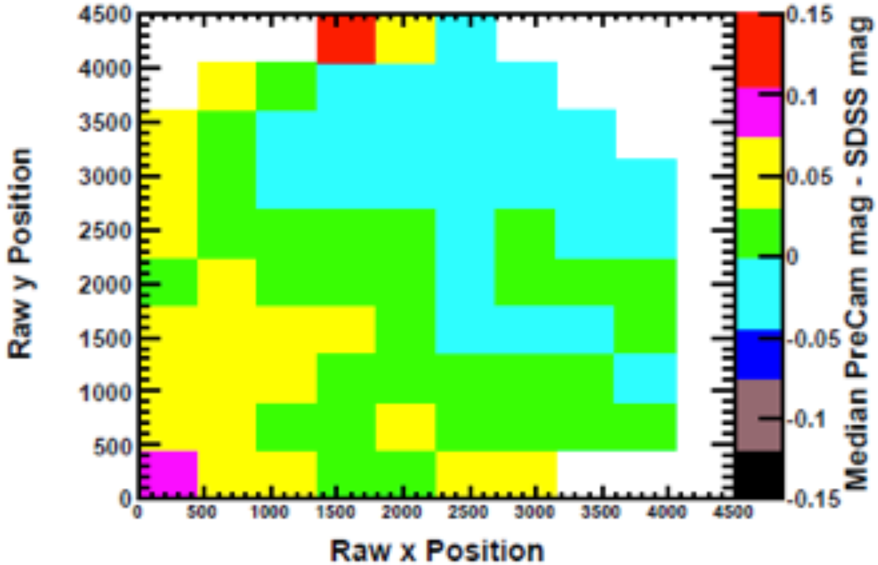
Hardware Fix: Slow-Release Valve <u>increases shutter blade lifetime</u> by ~3x

Date	Zero-Point Offset (USNO)	Standard Deviation (USNO)	Zero-Point Offset (Southern Standards)	Standard Deviation (Southern Standards)	Zero-Point Offset (SDSS)- RA40to50	Standard Deviation (SDSS)- mag<15	Standard Deviation (SDSS)-NoMagCut
20101215			g: 2.3372 r: 2.1269 i: 2.2864 z: 2.5072	g: .05323 r: .05176 i: .05021 z: .06227	g: 2.17425 r: 1.95941 i: 2.12993 z: 2.32859	g: .05258 r: .04194 i: .0581 z: .05982	g: .08925 r: .09445 i: .1065 z: .08172
20110107	g: 2.08978 r: 1.899857 i: 2.05227 z: 2.247	g: .02374 r: .03213 i: .03222 z: .02319	g: 2.0802 r: 1.91872 i: 2.05298 z: 2.263	g: .02843 r: .04228 i: .02944 z: .04915	g: 2.0645 r: 1.9346 i: 2.07891 z: 2.2993	g: .04711 r: .04305 i: .05134 z: .05304	g: .09277 r: .09258 i: .09468 z: .08514
20110108	g: 2.1784 r: 1.98041 i: 2.1281 z: 2.3587	g: .07305 r: .06301 i: .05031 z: .05476	g: 2.12746 r: 1.93154 i: 2.24 z: 2.3044	g: .03003 r: .04221 i: .04874 z: .03008	g: 2.1617 r: 1.94502 i: 2.10669 z: 2.3456	g: .05267 r: .03744 i: .05214 z: .05843	g: .1057 r: .09614 i: .1025 z: .07865
20110112	g: 2.1035 r: 1.932 i: 2.0765 z: 2.248	g: .03165 r: .05489 i: .04316 z: .04514	g: 2.07424 r: 1.905615 i: 2.06179 z: 2.21012	g: .02947 r: .03518 i: .03624 z: .03695	g: 2.11098 r: 1.92643 i: 2.07017 z: 2.25469	g: .04387 r: .03939 i: .04554 z: .05621	g: .08868 r: .08243 i: .102 z: .08538
20110113	g: 2.08618 r: 1.90392 i: 2.05038 z: 2.21058	g: .02186 r: .02544 i: .02691 z: .02033	g: 2.07 r: 1.89748 i: 2.06527 z: 2.20684	g: .03127 r: .03662 i: .04353 z: .03638	g: 2.143606 r: 1.9298 i: z: 2.26745	g: .02575 r: .04268 i: z: .06571	g: .09088 r: .08401 i: z: .0936

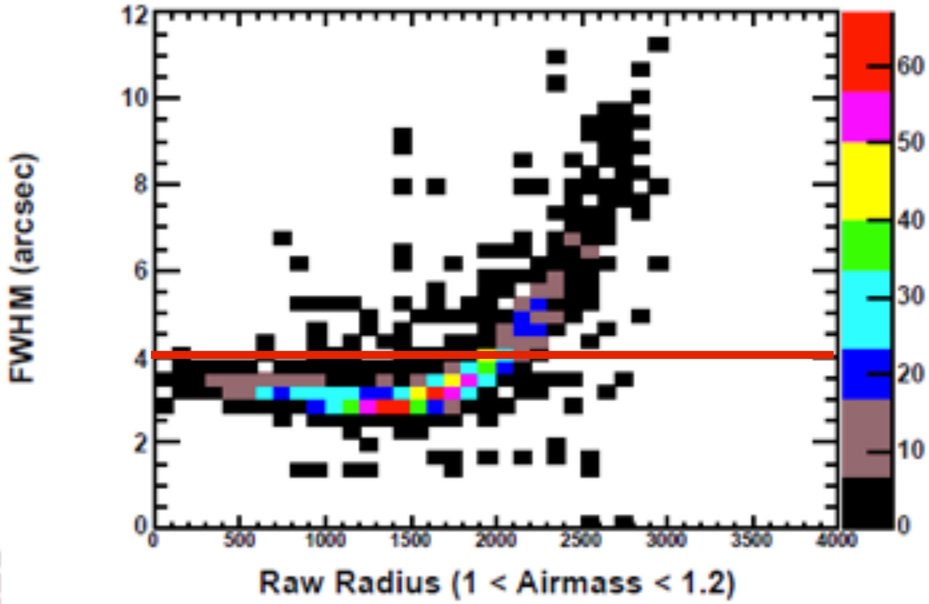
Final Data Analysis Steps: Star Flats + Data Quality Cuts

added "flat field" to remove final CCD response gradient prior to analysis

- USNO, Southern u'g'r'i'z', and SDSS standards
- SDSS airmass correction and Star Flat correction applied
- Selection Criteria:
- magerr, FWHM, Stellarity

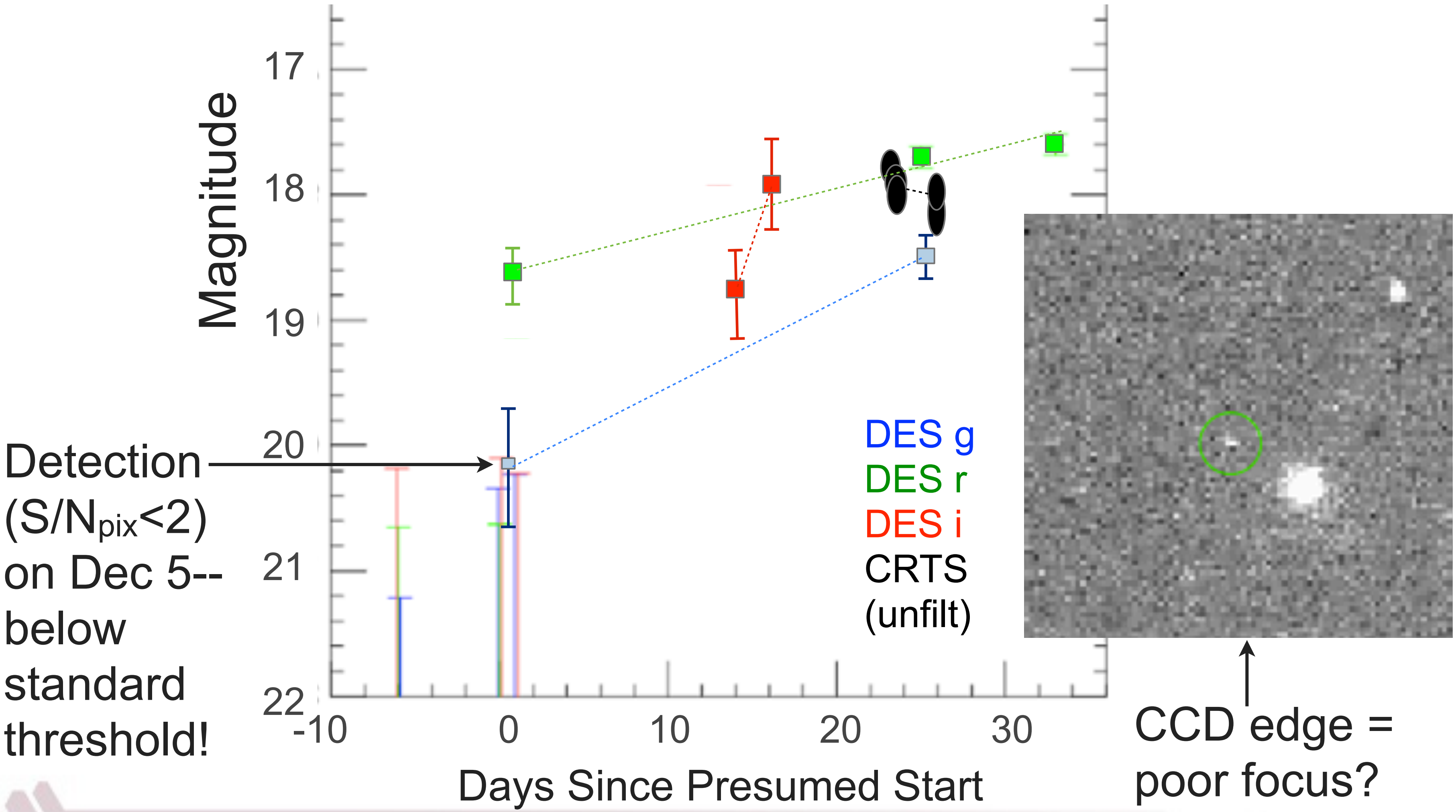


v3aper12	.06871
v3aper12, stellarity > .95	.04901
v3aper10, stellarity > .95	.048496
v3aper10, stellarity > .95, fwhm < 4.	.048434
v3aper10, stellarity > .95, fwhm < 4. , pixels cut	.048447
v3aper10, stellarity > .95, fwhm < 4. , pixels cut, starflats	.040106
v3aper10, stellarity > .95, fwhm < 4. , pixels cut, starflats, mag < 17.	.03838

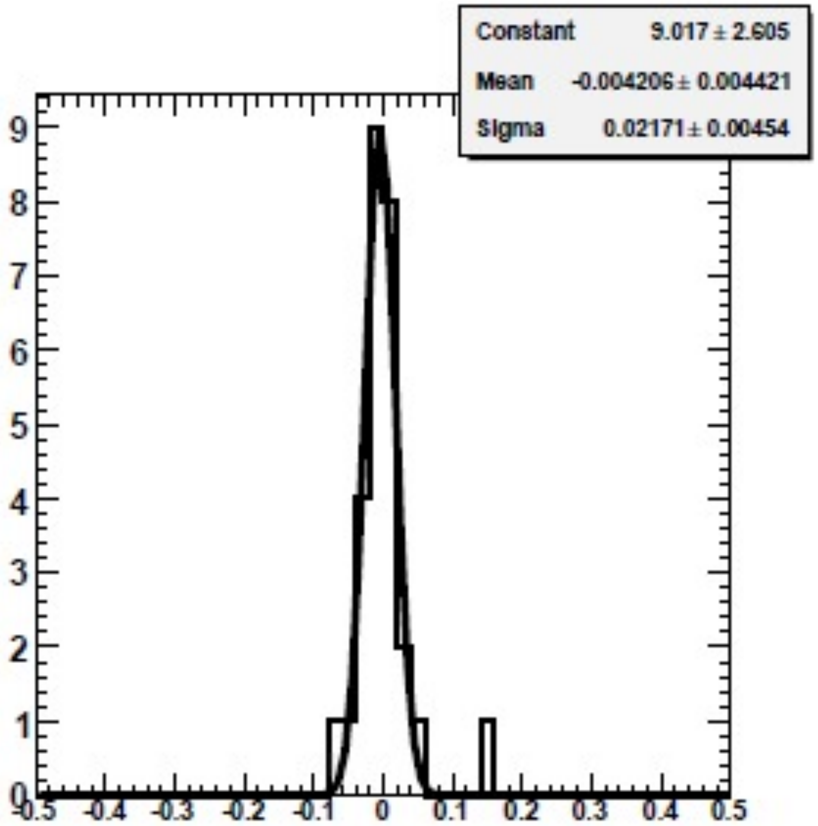


Data Quality Checks/DES Proof-of-Concept

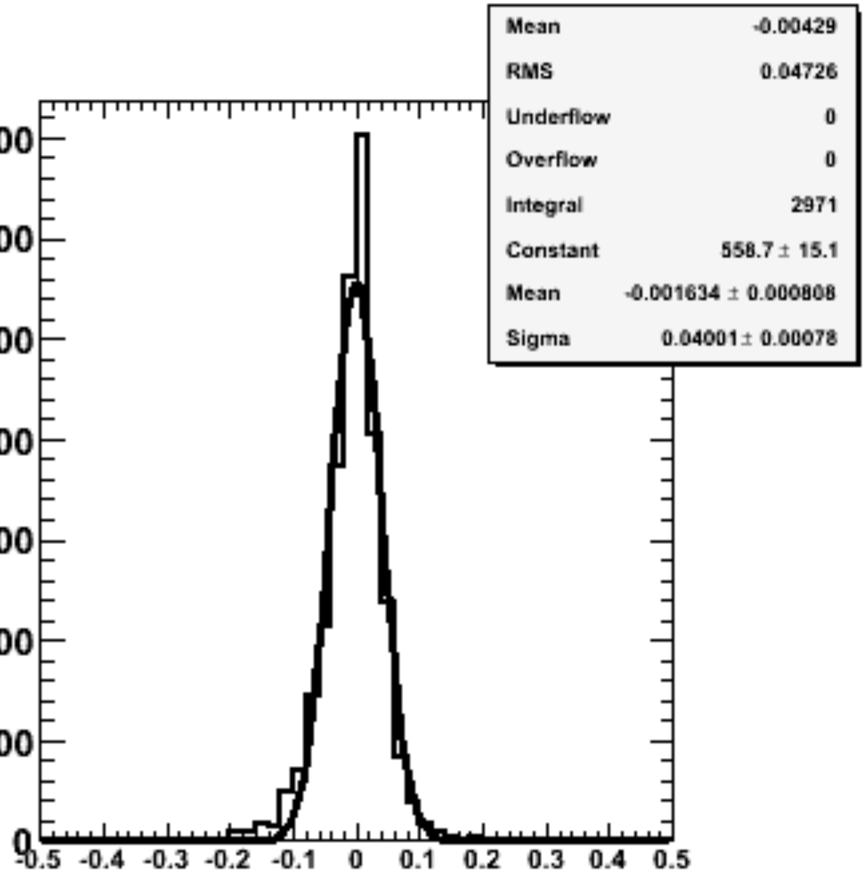
PreCam gri observations from 11/29/2010 to 01/01/11 of SN2010lr, a <u>spectroscopically confirmed SNIa</u> associated with host galaxy 2MASX J00023401-3044061 at z ~ 0.062 (Drake et al., Prieto et al.)



Preliminary Results I: Single-Epoch Photometry



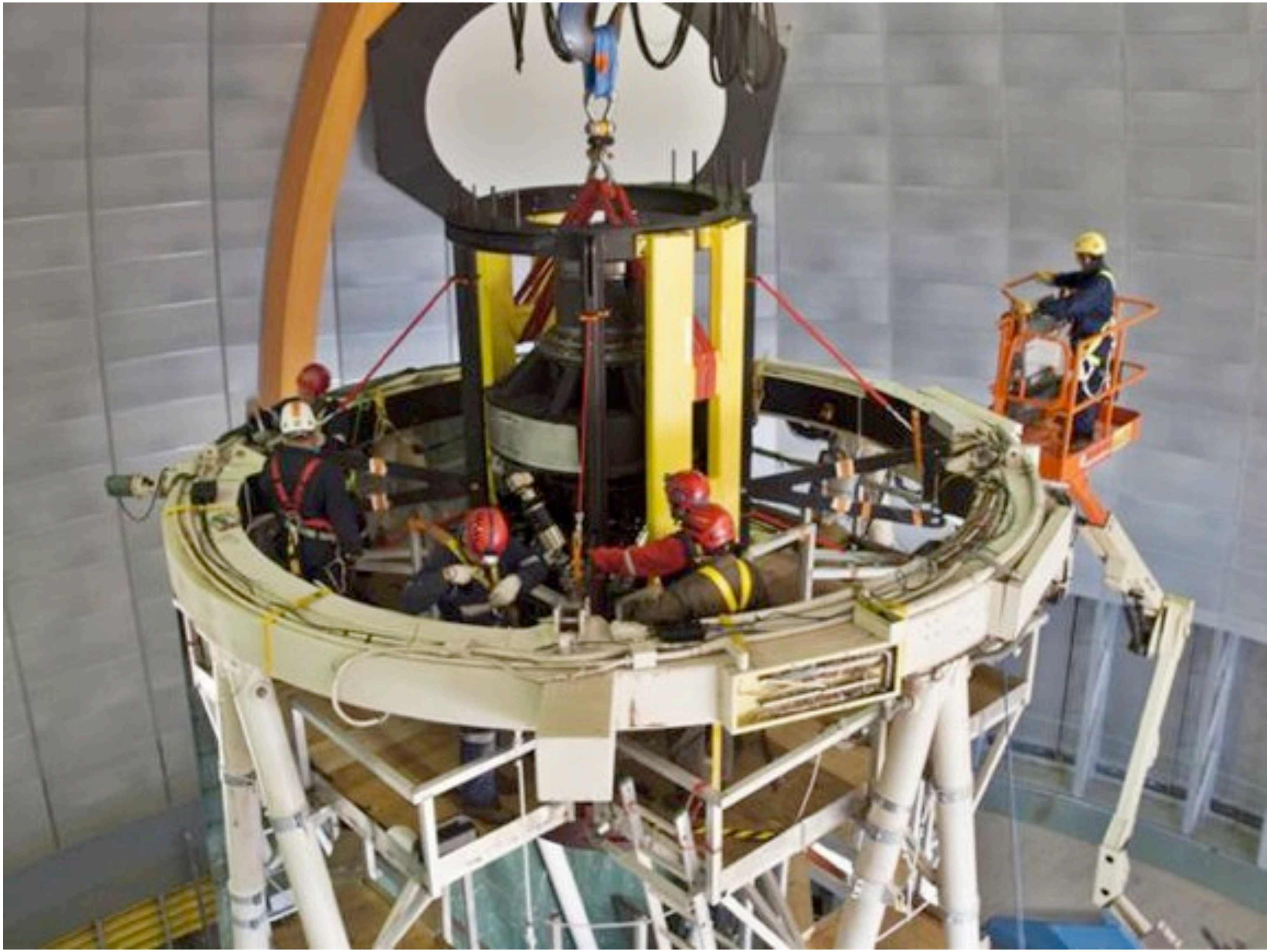
PreCam z - USNO z Bright



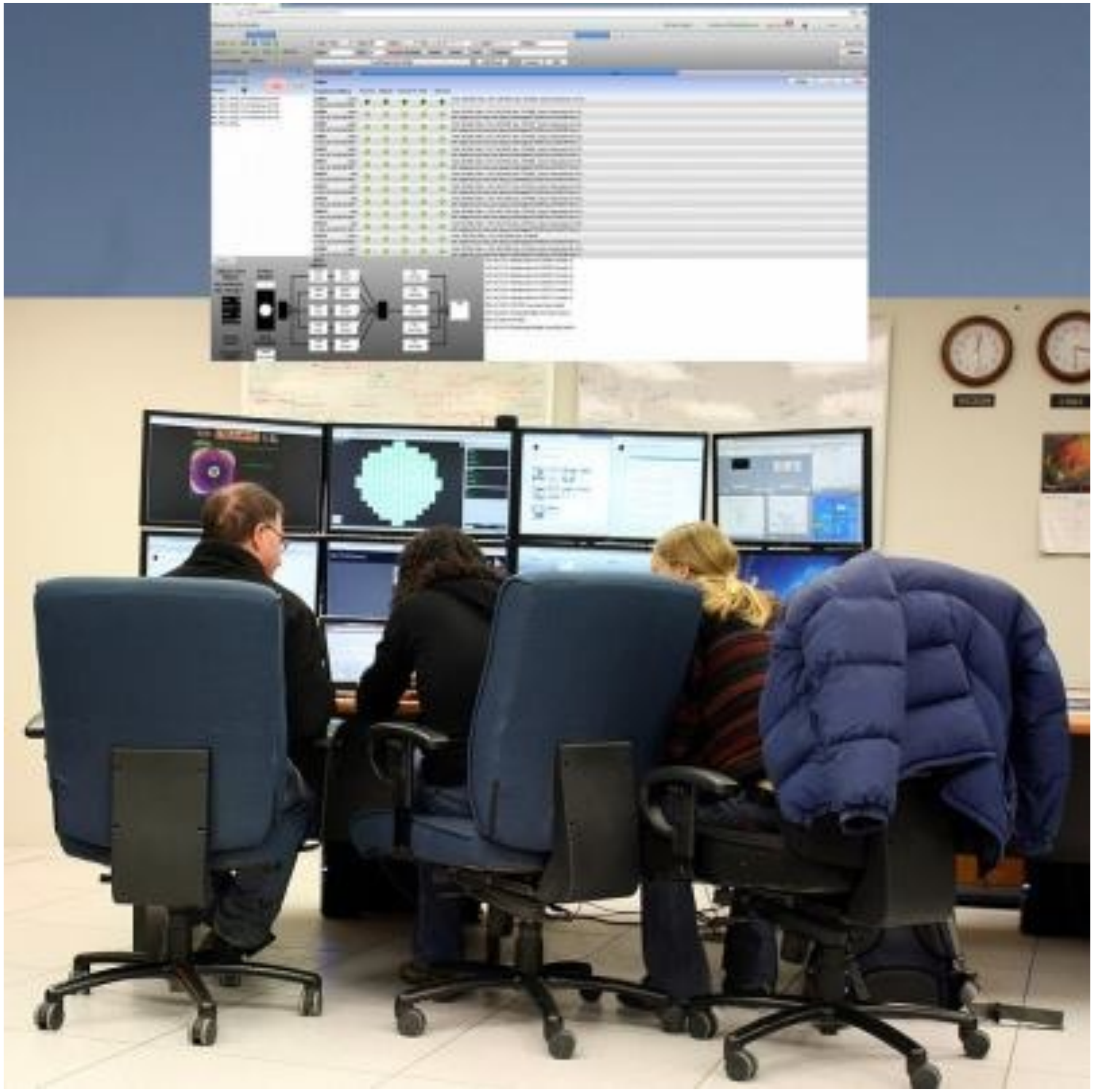
PreCam r - SDSS r

Preliminary Single-Image Photometric Accuracy:
4.0% (SDSS r,i); 3.2% (SDSS z); or 2.2% (USNO z, mag<14)

DECam on the Blanco Telescope!



Observing with DECam

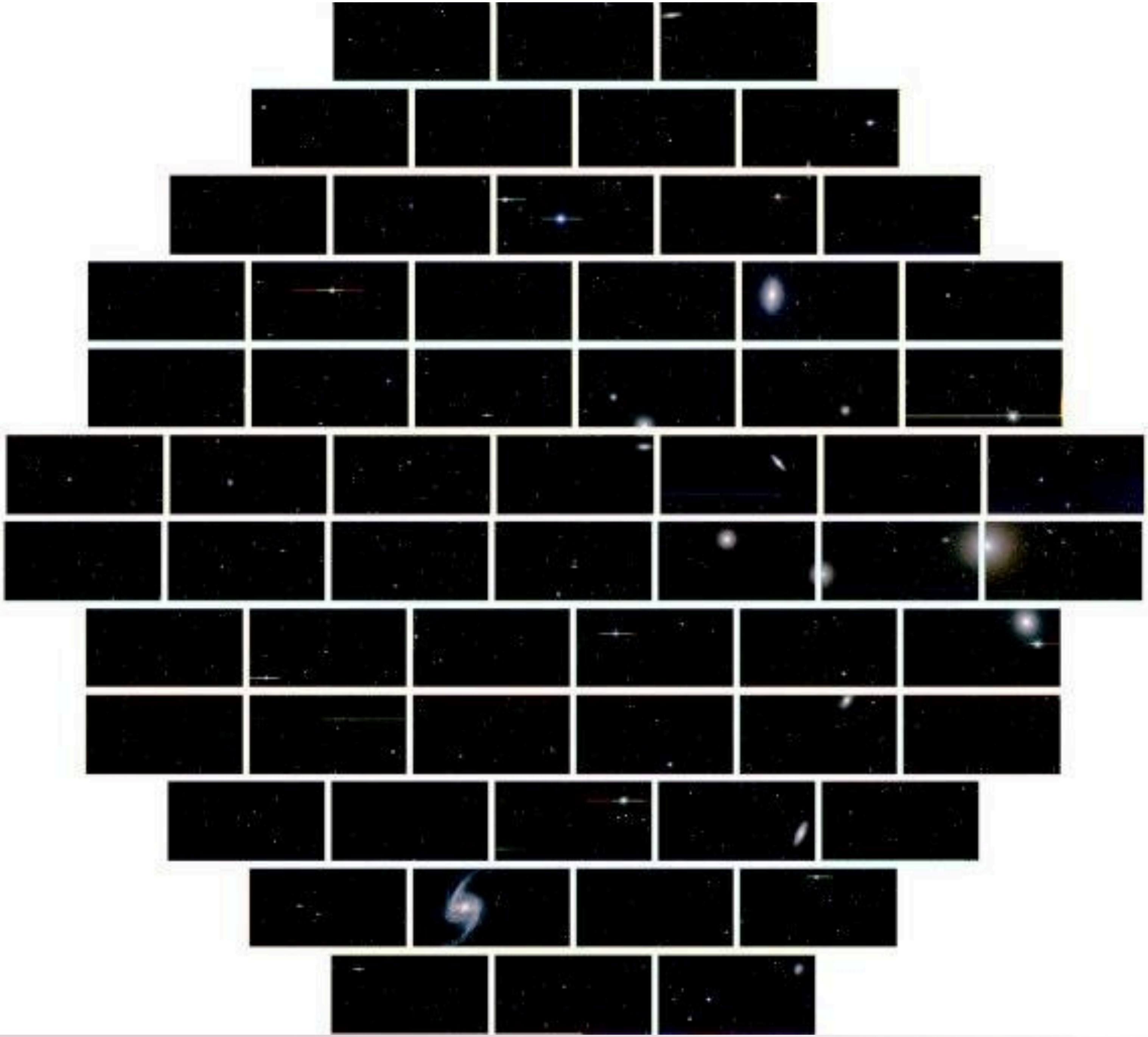


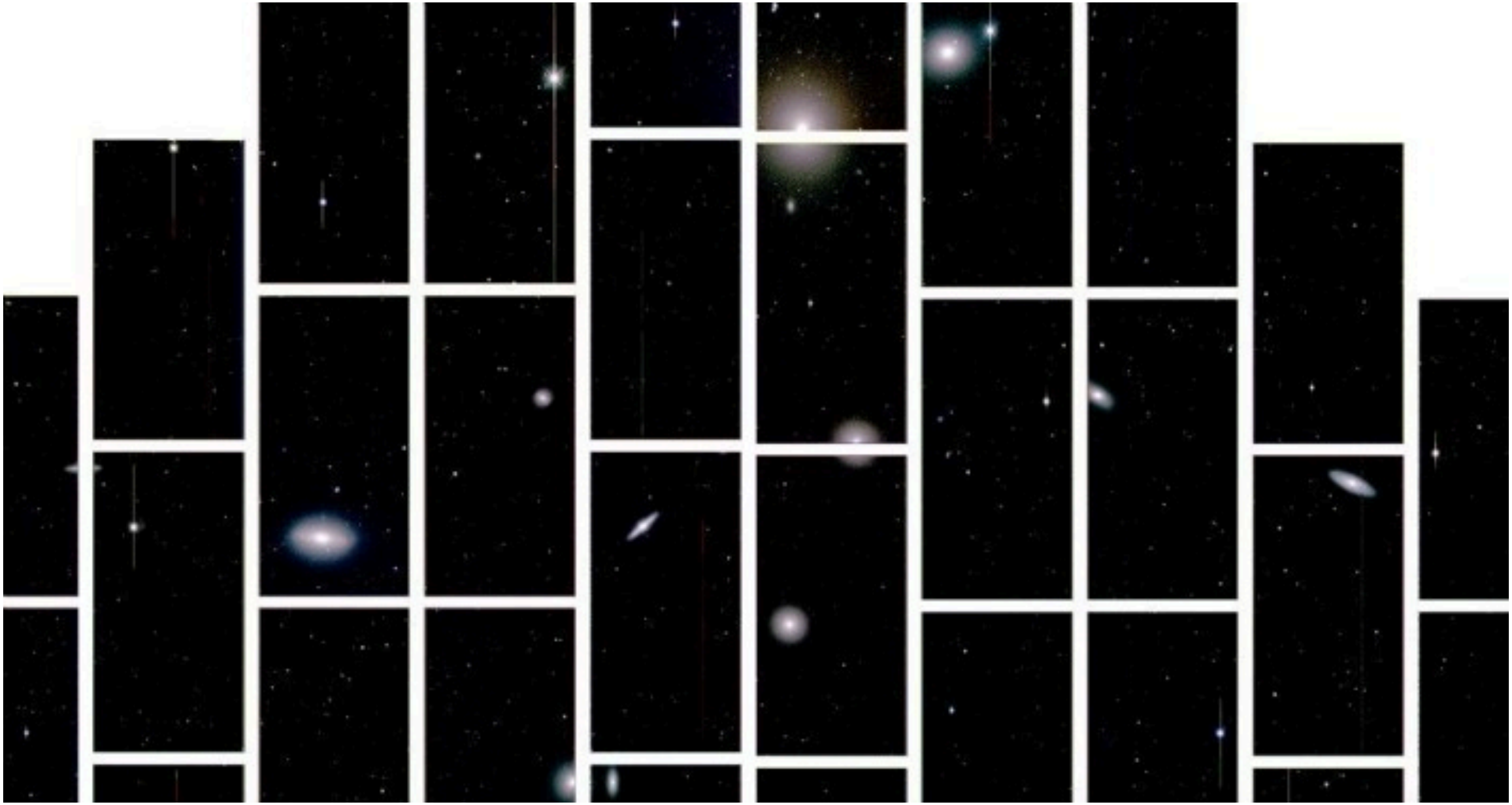
First Light Images!

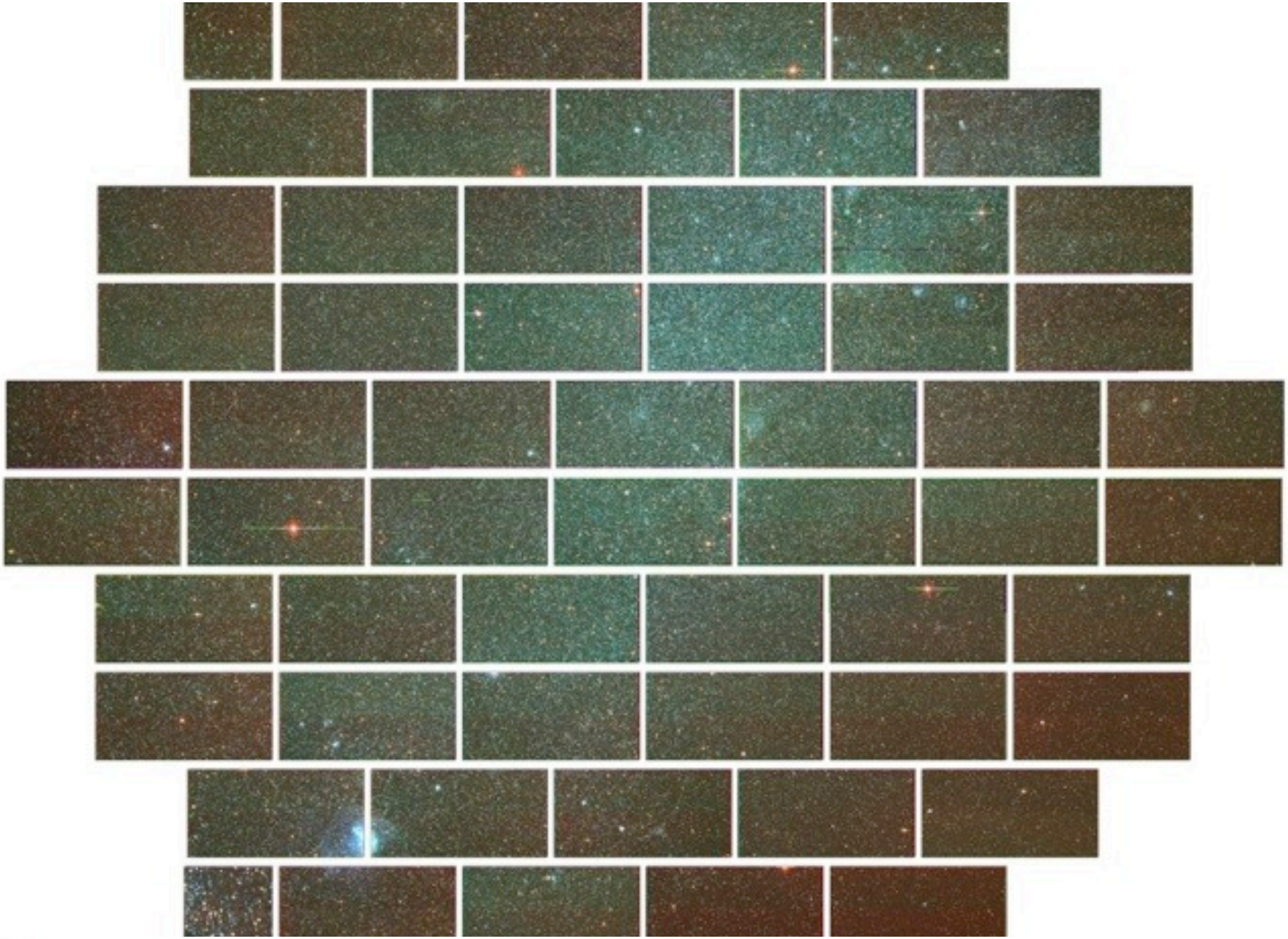
0".8 images with nearly uniform PSF across the focal plane, all *without* optimization of collimation, guider, hexapod, telescope control.

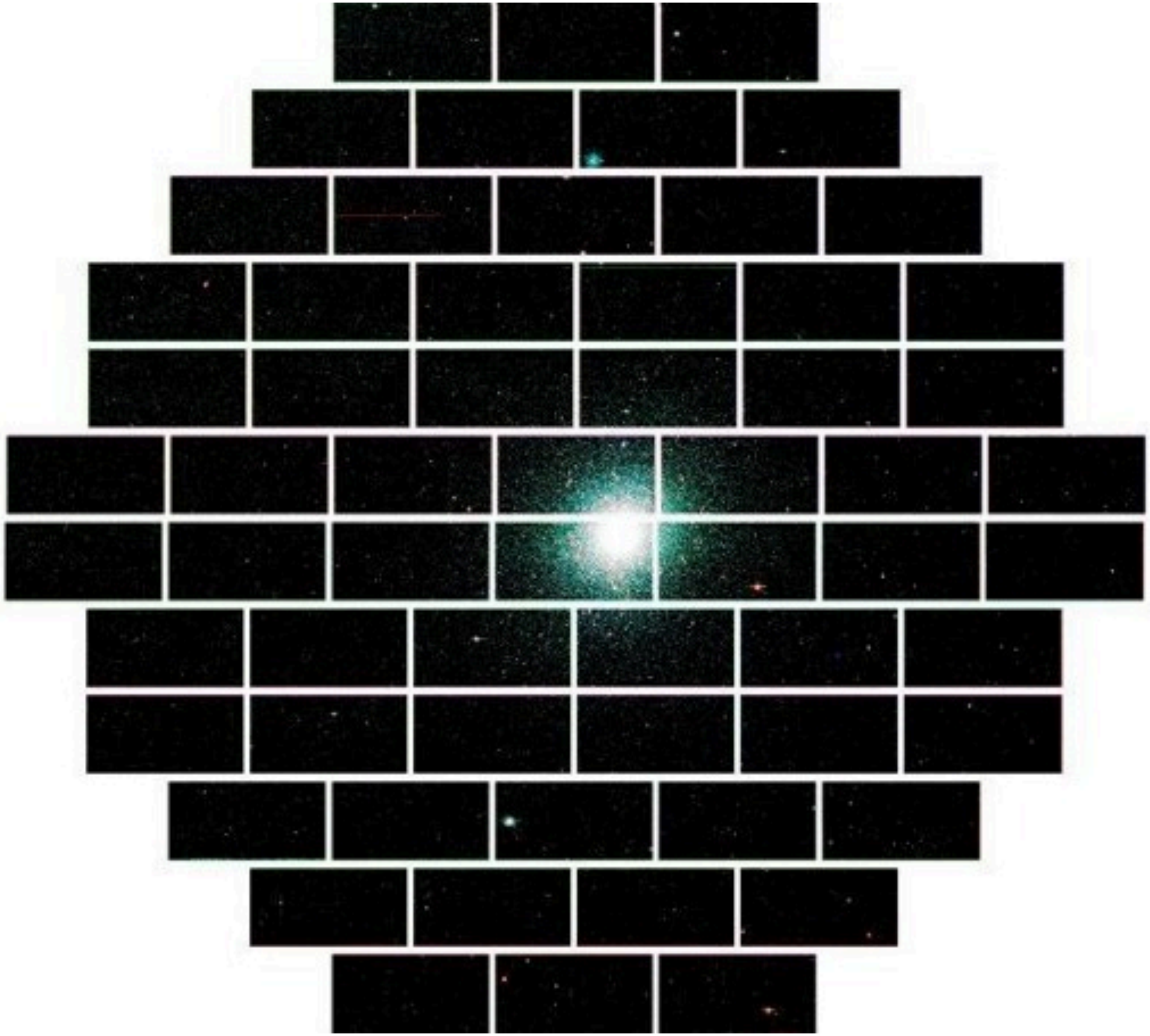
Images of the Fornax Cluster, NGC 1365, Small Magellanic Cluster, and 47 Tucanae...

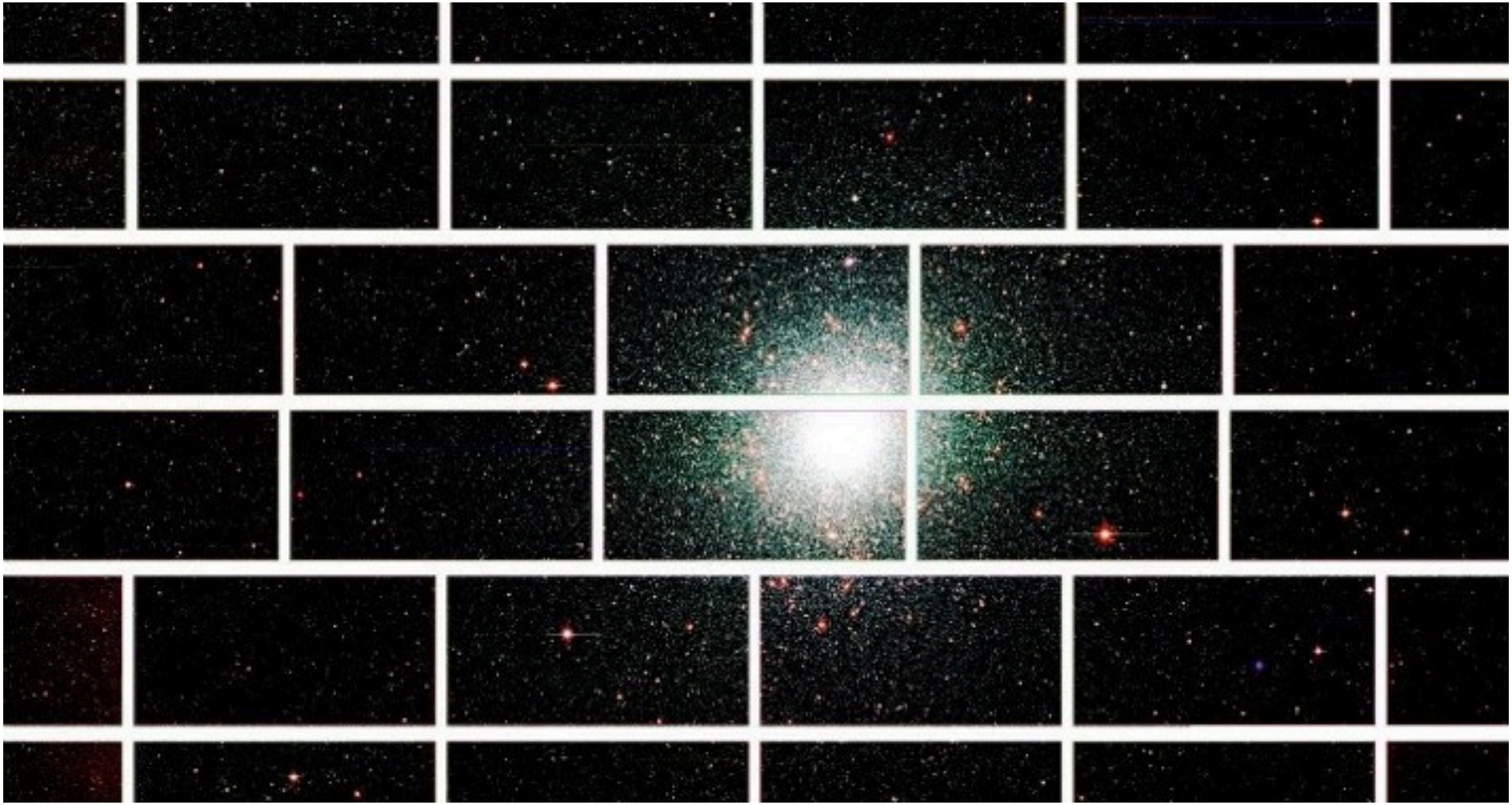
see http://www.wired.com/wiredscience/2012/09/dark-energy-survey/
http://www.nature.com/news/cameras-to-focus-on-dark-energy-1.11391
and http://www.symmetrymagazine.org/ for press release information







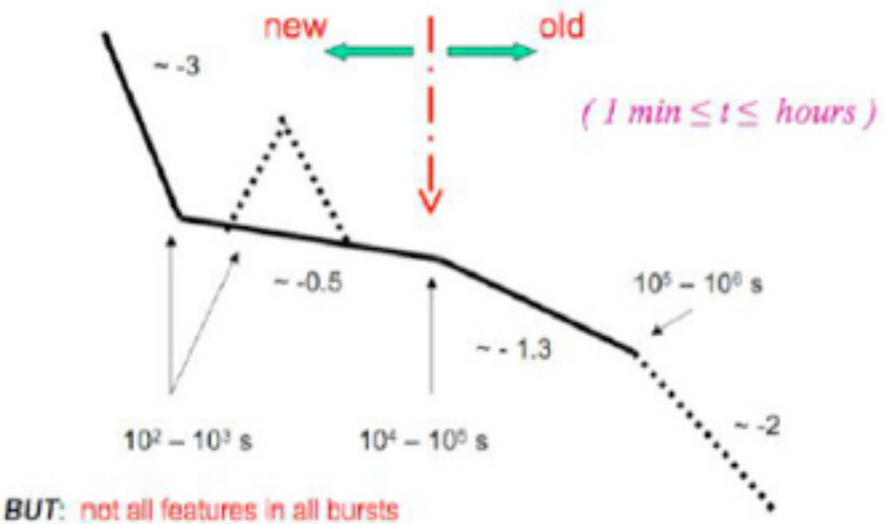


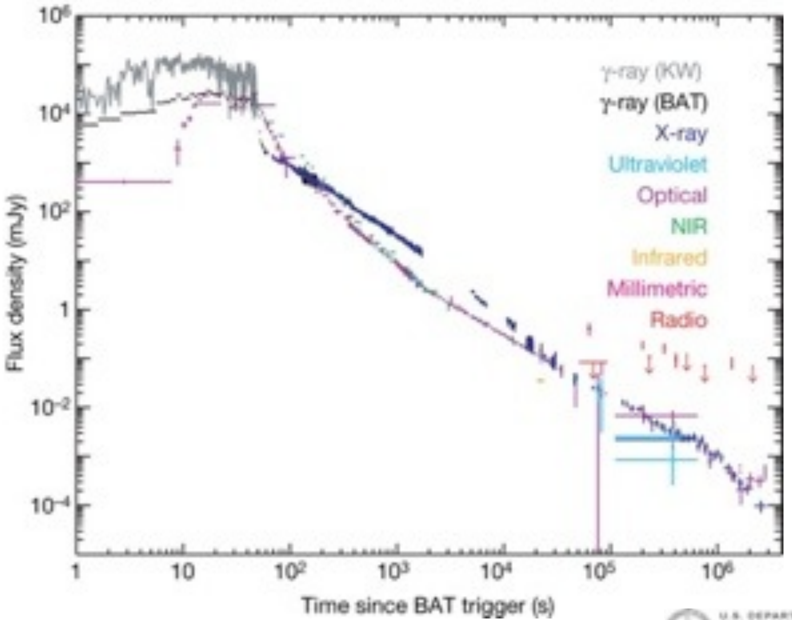


Non-SN Transient Science with the DES

Gamma Ray Bursts (GRBs) are bright transient sources at cosmological distances.

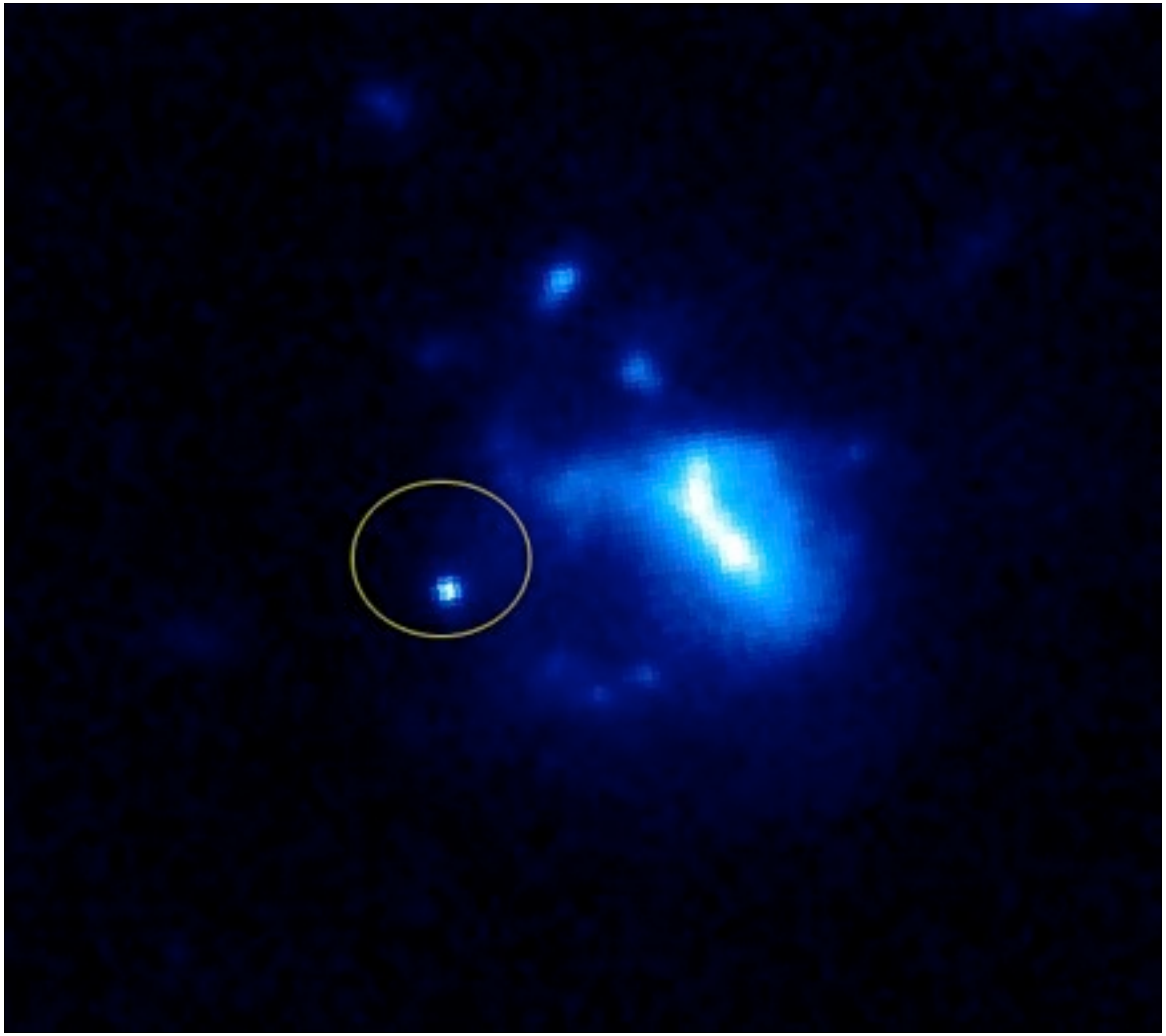
In the time you can hold your breath, they output **more energy than the sun** does in its entire lifetime: $>10^{51}$ ergs (isotropic) in 10^{-1} to 10^{3} s. They are correlated with the collapse of massive stars (long GRBs) or neutron star mergers (short GRBs). The end result is expected to be a black hole; observations show prompt broadband emission ("**fireball**") followed by long-timescale "**afterglow**".





Lightcurves courtesy of Fox & Mészáros 2006, Racusin et al. 2008.

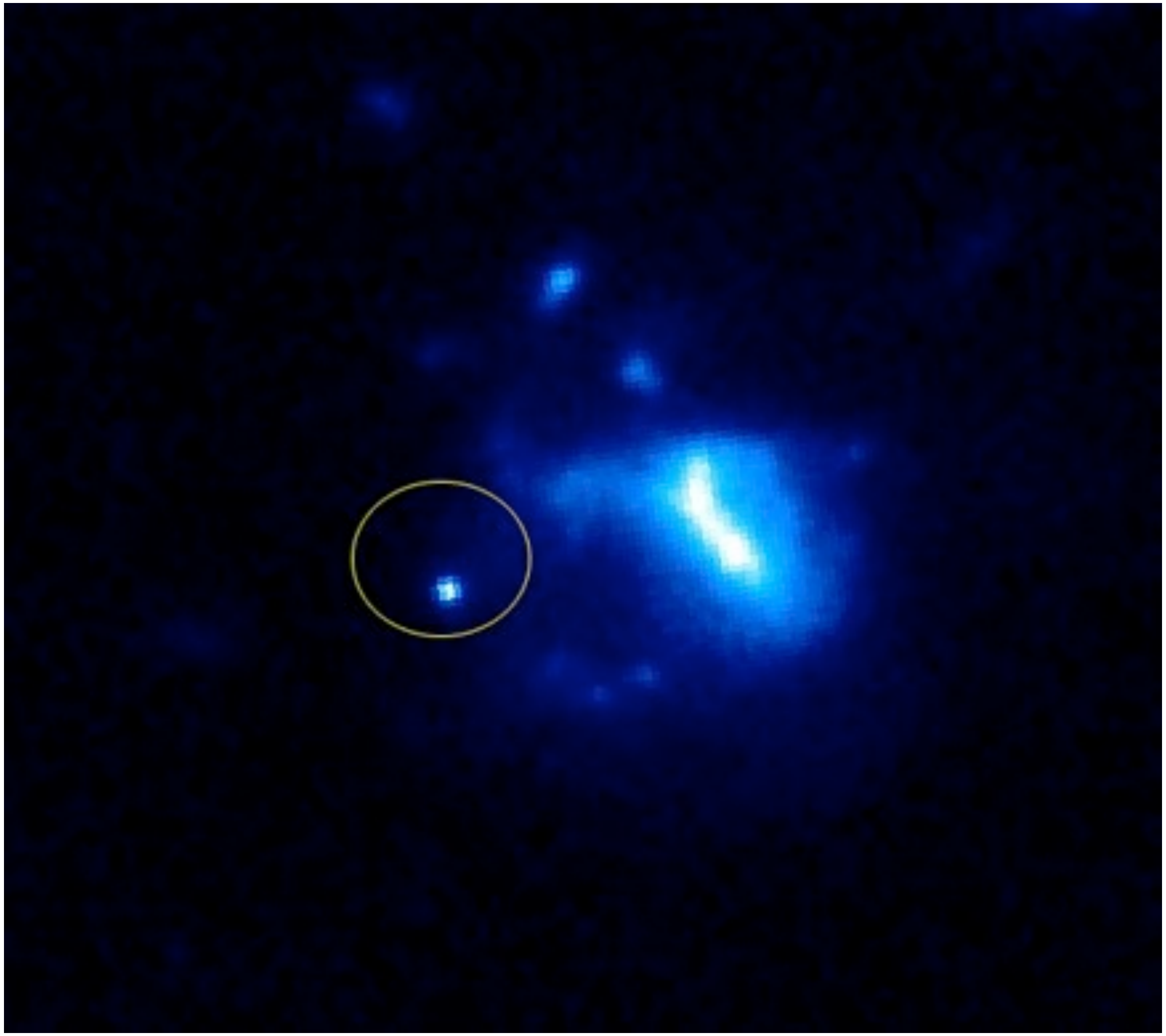
Multi-Wavelength/Multi-Messenger GRB Follow-Up



Host Galaxy for, e.g., GRB050709 observed with HST and many other instruments, both photometric and spectroscopic, to determine characteristics:
z = 0.16
E_{iso} ~10^{50} erg

Relevant observations and/or flux limits for many hundreds of GRBs in:
Gamma Rays
X Rays
UV/Optical/IR
Radio
Gravitational Radiation
and

Multi-Wavelength/Multi-Messenger GRB Follow-Up



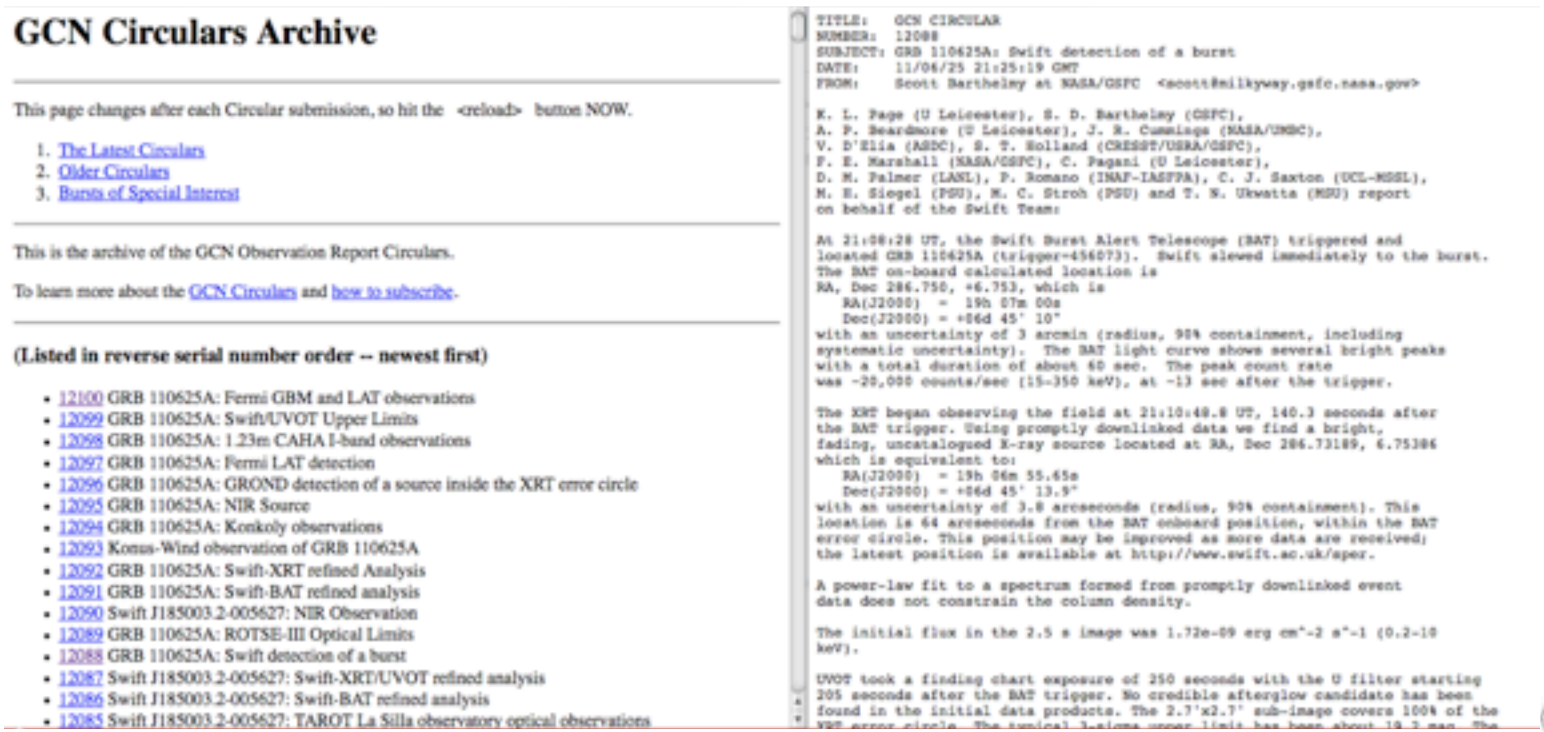
Host Galaxy for, e.g., GRB050709 observed with HST and many other instruments, both photometric and spectroscopic, to determine characteristics:
$z = 0.16$
$E_{iso} \sim 10^{50}$ erg

Relevant observations and/or flux limits for many hundreds of GRBs in:
Gamma Rays
X Rays
UV/Optical/IR
Radio
Gravitational Radiation
and ***Neutrinos***

Argonne NATIONAL LABORATORY

1. Providing DES data to the Community in Real Time

* Parse GCN Notices (RA, Dec, position uncertainty, time) for all bursts in footprint
* Identify potential GRB hosts from pre-discovery images
* Calculate relevant host characteristics (e.g photo-z) “on the fly”
* Distribute data products and links to “finder images” via GCN Notices
* **Entire process must be automated for fastest response**



GCN Circulars Archive

This page changes after each Circular submission, so hit the <reload> button NOW.

1. The Latest Circulars
2. Older Circulars
3. Bursts of Special Interest

This is the archive of the GCN Observation Report Circulars.

To learn more about the GCN Circulars and how to subscribe.

(Listed in reverse serial number order -- newest first)

- 12100 GRB 110625A: Fermi GBM and LAT observations
- 12099 GRB 110625A: Swift/UVOT Upper Limits
- 12098 GRB 110625A: 1.23m CAHA I-band observations
- 12097 GRB 110625A: Fermi LAT detection
- 12096 GRB 110625A: GROND detection of a source inside the XRT error circle
- 12095 GRB 110625A: NIR Source
- 12094 GRB 110625A: Konkoly observations
- 12093 Konus-Wind observation of GRB 110625A
- 12092 GRB 110625A: Swift-XRT refined Analysis
- 12091 GRB 110625A: Swift-BAT refined analysis
- 12090 Swift J185003.2-005627: NIR Observation
- 12089 GRB 110625A: ROTSE-III Optical Limits
- 12088 GRB 110625A: Swift detection of a burst
- 12087 Swift J185003.2-005627: Swift-XRT/UVOT refined analysis
- 12086 Swift J185003.2-005627: Swift-BAT refined analysis
- 12085 Swift J185003.2-005627: TAROT La Silla observatory optical observations

TITLE: GCN CIRCULAR
NUMBER: 12088
SUBJECT: GRB 110625A: Swift detection of a burst
DATE: 11/06/25 21:25:19 GMT
FROM: Scott Barthelmy at NASA/GSFC <scott@milkyway.gsfc.nasa.gov>

K. L. Page (U Leicester), S. D. Barthelmy (GSFC),
A. P. Beardmore (U Leicester), J. R. Cummings (NASA/UMBC),
V. D'Elia (ASDC), S. T. Holland (CRESST/USRA/GSFC),
F. E. Marshall (NASA/GSFC), C. Pagani (U Leicester),
D. M. Palmer (LANL), P. Romano (INAF-IASFPA), C. J. Saxton (UCL-MSSL),
M. H. Siegel (PSU), M. C. Stroh (PSU) and T. N. Ukwatta (MSU) report
on behalf of the Swift Team:

At 21:08:28 UT, the Swift Burst Alert Telescope (BAT) triggered and
located GRB 110625A (trigger=456073). Swift slewed immediately to the burst.
The BAT on-board calculated location is
RA, Dec 286.750, +6.753, which is
RA(J2000) = 19h 07m 00s
Dec(J2000) = +06d 45' 10"
with an uncertainty of 3 arcmin (radius, 90% containment, including
systematic uncertainty). The BAT light curve shows several bright peaks
with a total duration of about 60 sec. The peak count rate
was ~20,000 counts/sec (15-350 keV), at ~13 sec after the trigger.

The XRT began observing the field at 21:10:48.8 UT, 140.3 seconds after
the BAT trigger. Using promptly downlinked data we find a bright,
fading, uncatalogued X-ray source located at RA, Dec 286.73189, 6.75306
which is equivalent to:
RA(J2000) = 19h 06m 55.65s
Dec(J2000) = +06d 45' 13.9"
with an uncertainty of 3.8 arcseconds (radius, 90% containment). This
location is 64 arcseconds from the BAT onboard position, within the BAT
error circle. This position may be improved as more data are received;
the latest position is available at http://www.swift.ac.uk/sper.

A power-law fit to a spectrum formed from promptly downlinked event
data does not constrain the column density.

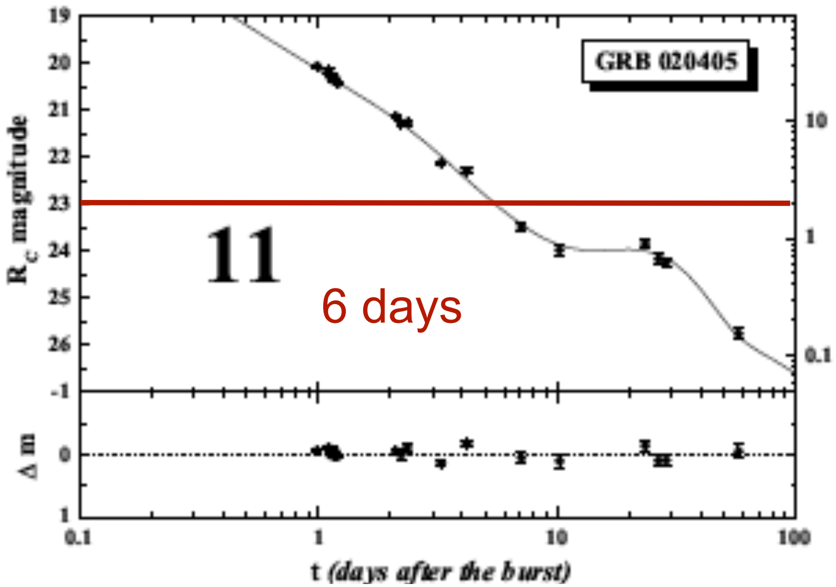
The initial flux in the 2.5 s image was 1.72e-09 erg cm^-2 s^-1 (0.2-10
keV).

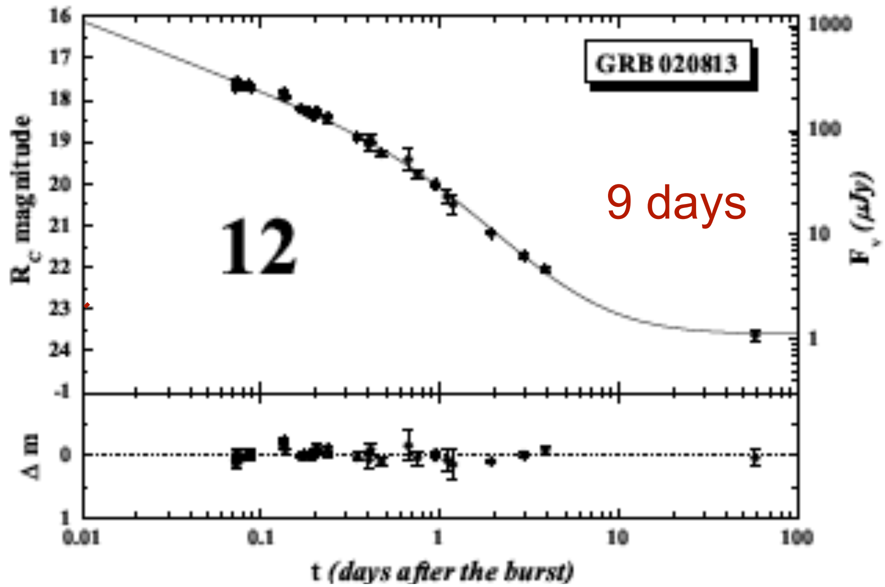
UVOT took a finding chart exposure of 250 seconds with the U filter starting
205 seconds after the BAT trigger. No credible afterglow candidate has been
found in the initial data products. The 2.7'x2.7' sub-image covers 100% of the

U.S. DEPARTMENT OF ENERGY

2. Afterglow follow-up within DES footprint

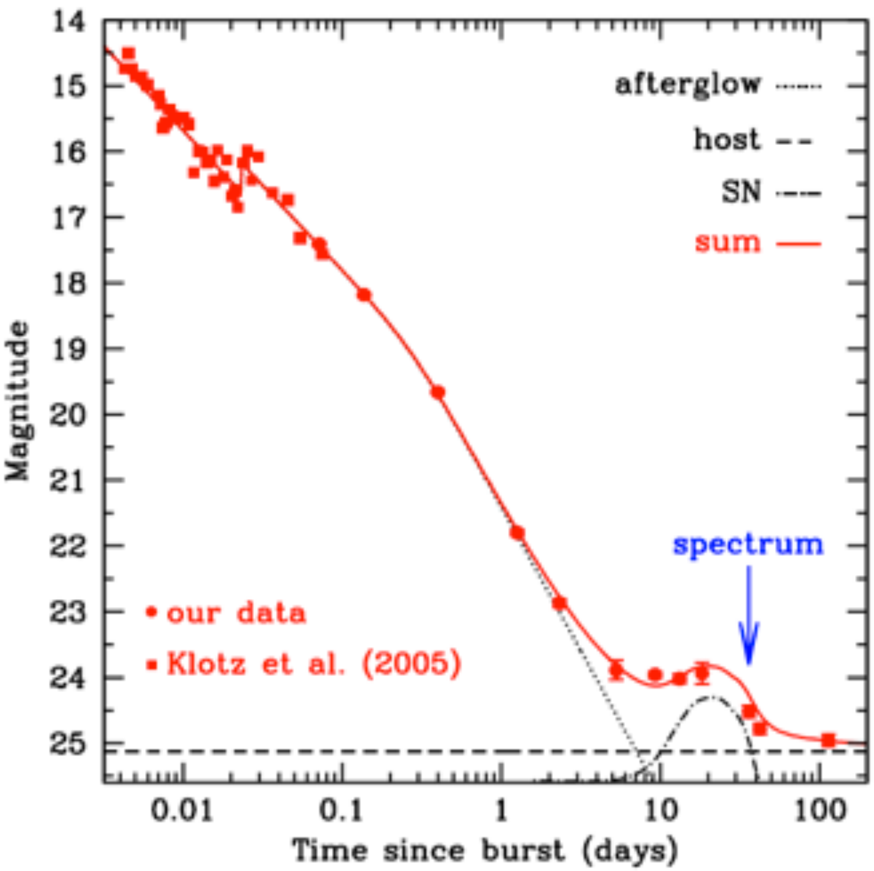
* Most dedicated GRB telescopes are meter-class (or smaller); KPNO, Keck, etc. are used very rarely for follow-up of individual bursts.
* Multi-filter observations with DECam can be obtained "for free" during Survey.
* With 300 bursts/year, footprint covering 1/8 of sky, and (a few) afterglows brighter than 23rd magnitude for up to 1 month: 1-4 observable at any time.
* For poorly-localized bursts, DECam has the field of view to find them!

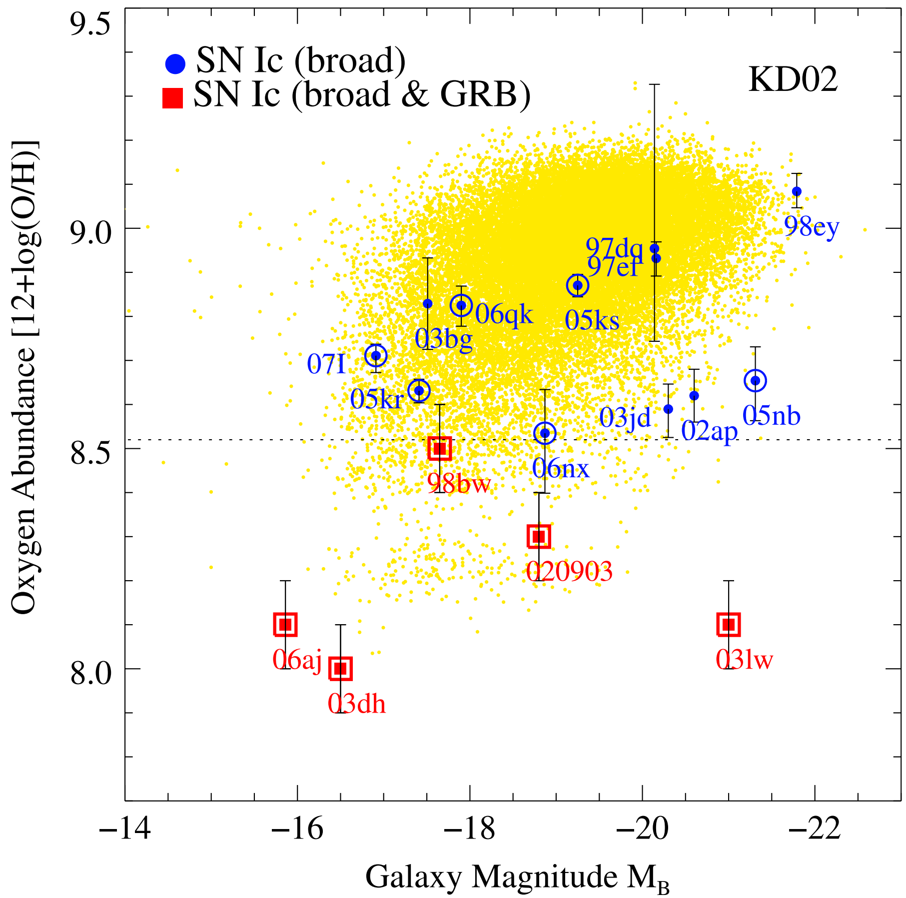




The GRB-SN Connection

One of the Most Interesting GRB-Related Discoveries in the Last Decade...

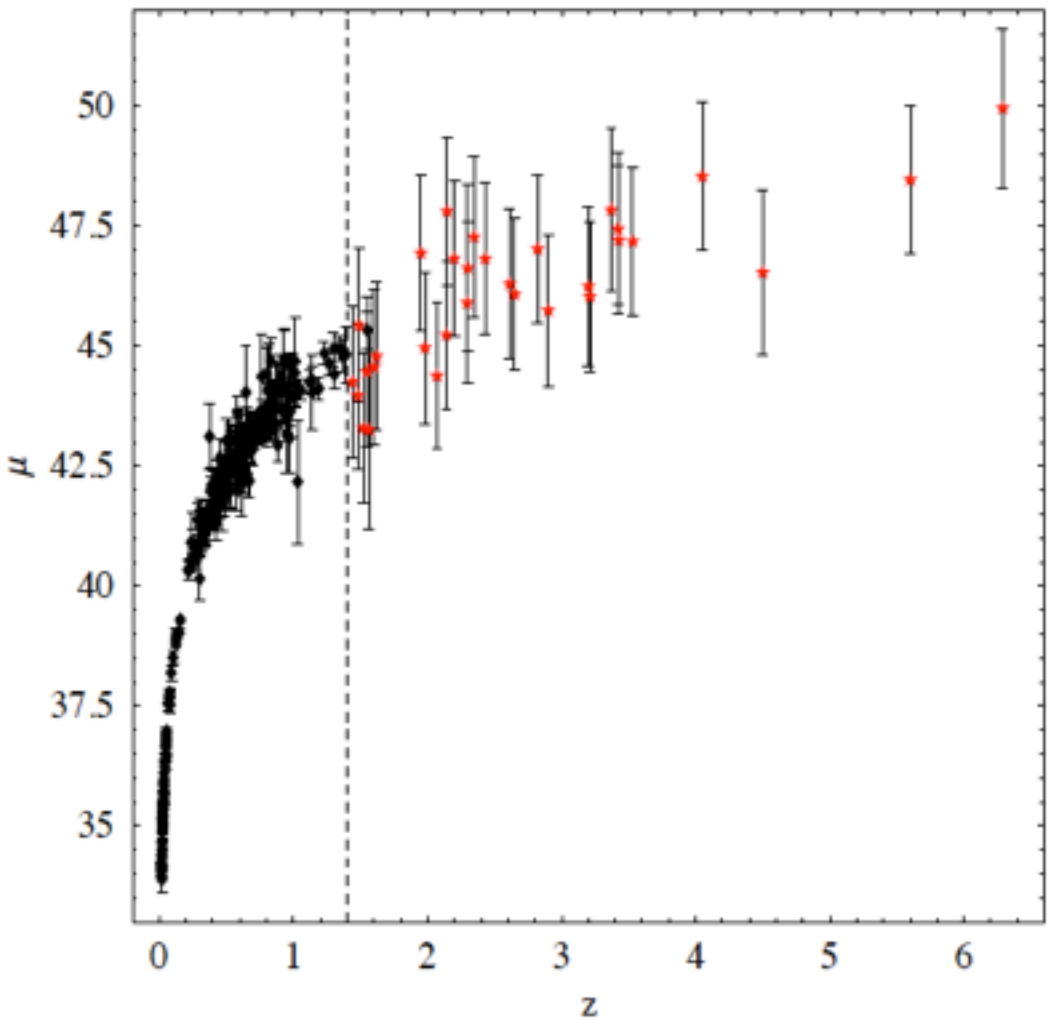




Images Courtesy of Della Valle et al. (2006), Modjaz et al. (2008)

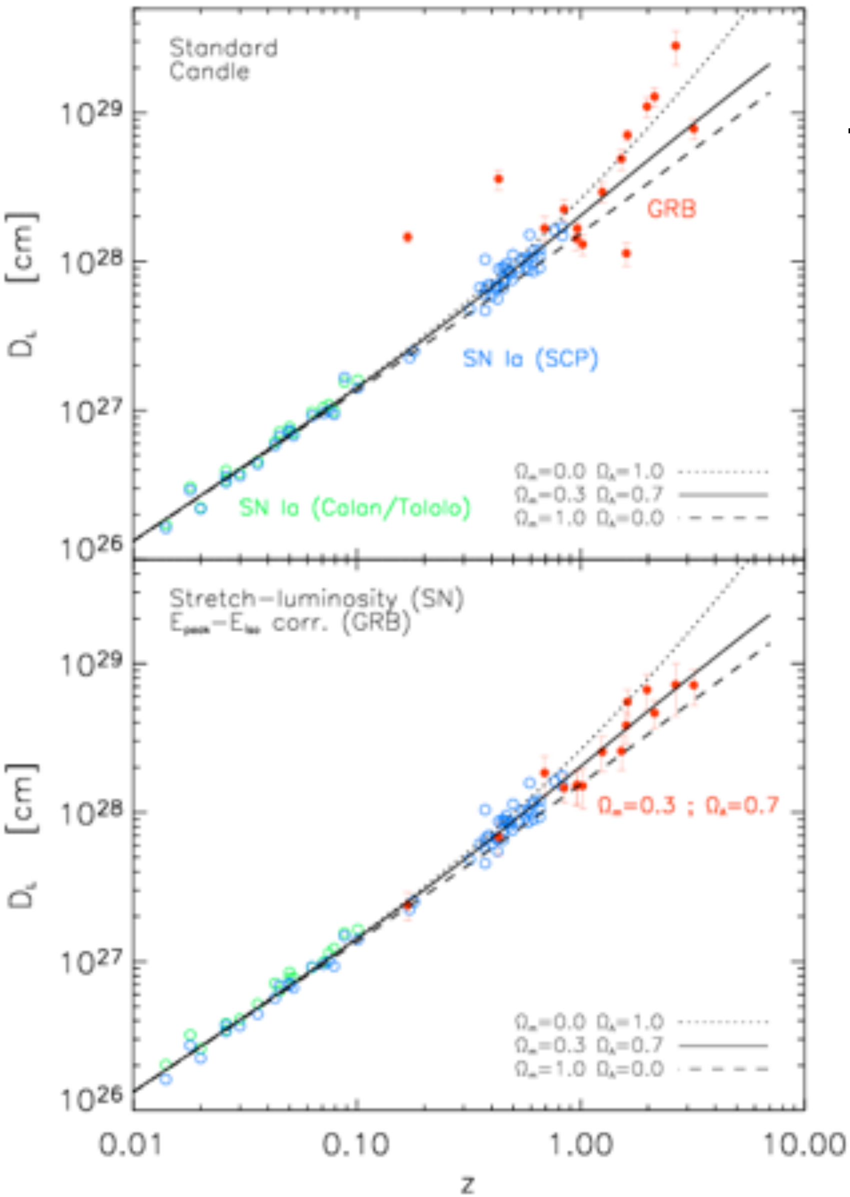
GRB Cosmology: Extrapolating Calibrated GRBs to High z

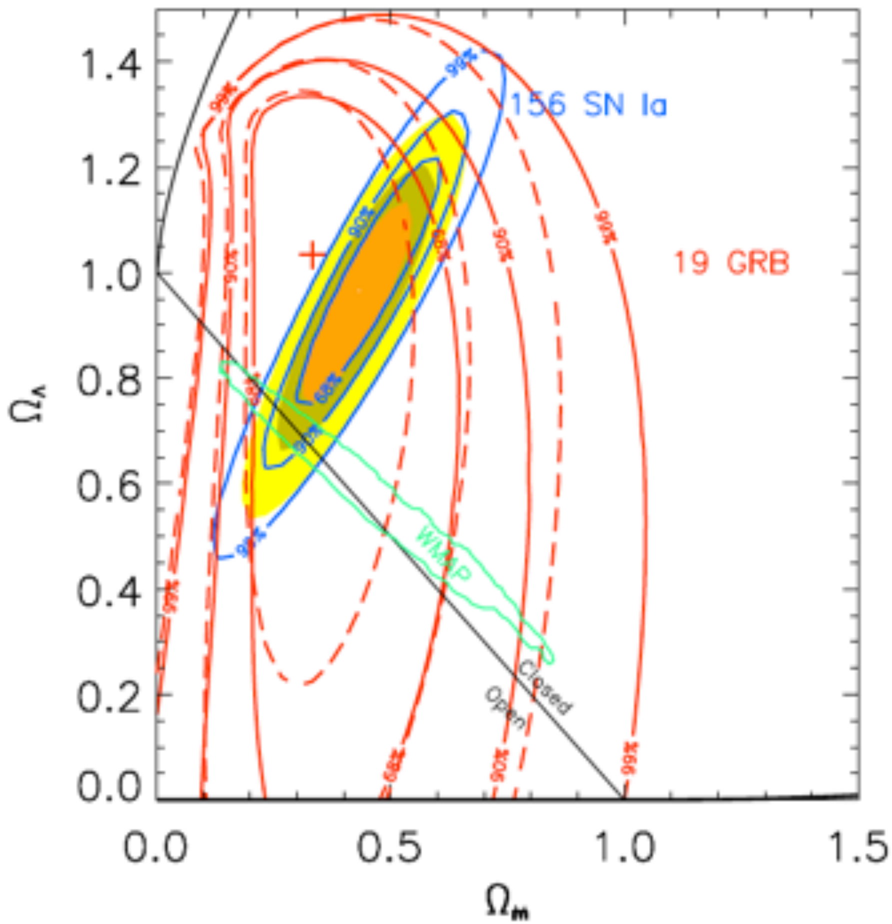
* GRBs have been calibrated against SNe Ia up to z~1.4
* Assuming standard(izable) candle characteristics, GRBs can constrain cosmology in a similar fashion to SNe Ia.
* Large error bars currently--every high z GRB can be of benefit!



Wei & Zhang (2006)

GRB Cosmology: Constraints on Parameters





Ghirlanda et al. (2004), Lazzati et al. (2006)

Technologies for Atmospheric OH Suppression

Kyler Kuehn, Ph.D.
High Energy Physics
Cosmic Frontier Group
Argonne National Laboratory

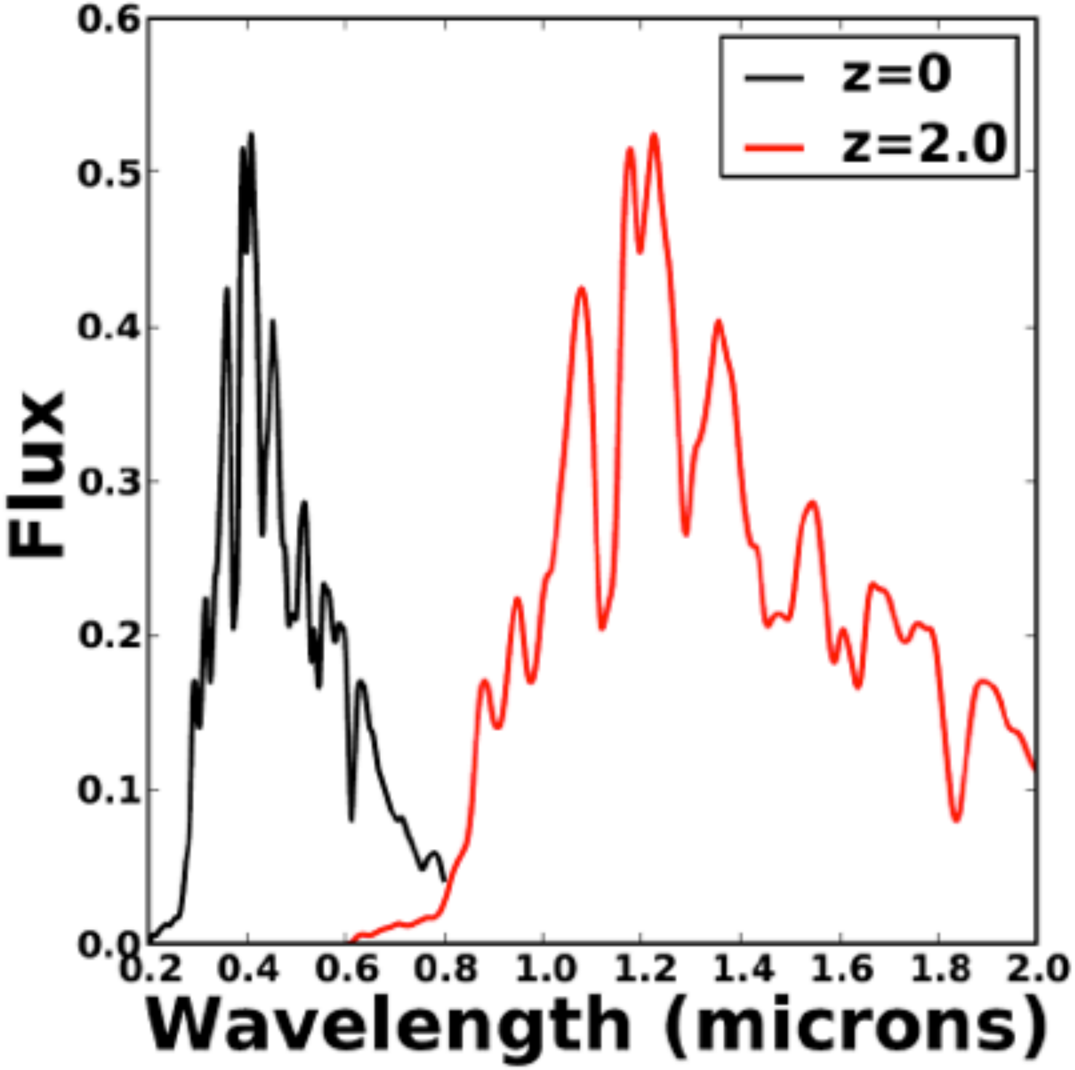
Wisconsin Lutheran College
“The Heavens and the Earth”
January 7, 2013

Further resources linked from
http://www.hep.anl.gov/des/oh/

Outline

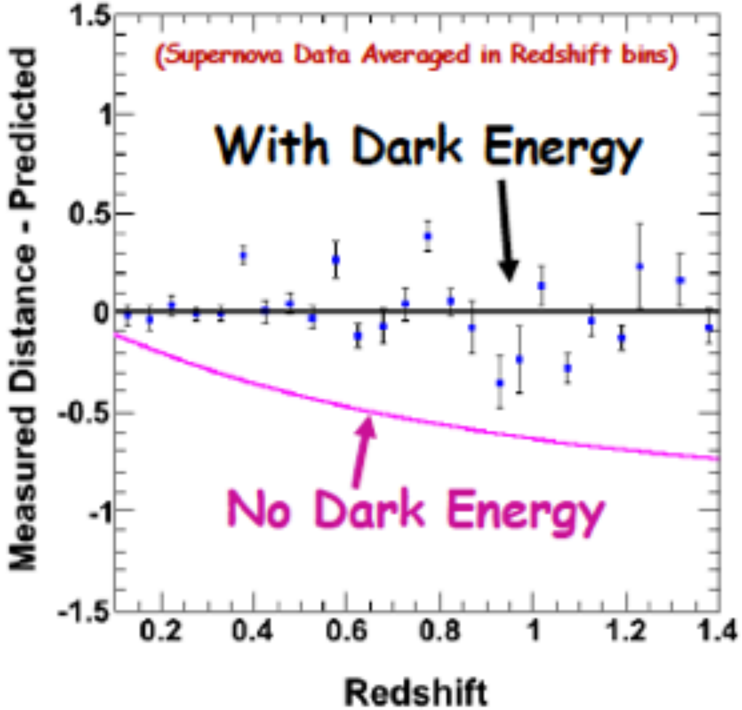
- Science Motivation
  - Supernova observations and Cosmology with IR Spectroscopy
  - IR Spectroscopy hampered by OH lines
  - Existing Systems for measurement (FIRE on Magellan)
    - Modeling of measured lines above ~1.5um: Can we improve wing suppression?
    - Line wings or zodiacal light or... still contributing to continuum below ~1.5um
- Suppression Technologies
  - Fiber Bragg Grating
    - GNOSIS using IRIS2 at AAT (suppression up to ~1.7 um)
    - Purchased for use at ANL
  - Ring Resonators
  - Volume Phase Holography
- Test stand setup

Supernova Spectrum $(1+z=\lambda_{observed}/\lambda_{emitted})$



Cosmology Motivation ($1+z=\lambda_{observed}/\lambda_{emitted}$)

Redshift (z)	Time since Big Bang (Billion years)	Distance of Light Travel (Billion light-years)
1100	0.000372	49713 (Cosmic Microwave Background)
20	**0.182**	**745**
3	2.2	84
2	**3.3**	**51**
1	5.6	21
0.9	**6.4**	**19**
0.7	7.4	14
0.5	**8.6**	**9.0**
0.3	10.3	4.8
0.1	**12.4**	**1.2**
0.01	13.5	0.14
0.001	**13.652**	**0.014**
0.0002	13.663	0.003 (Andromeda galaxy)



New experiment Dark Energy Survey will increase the statistics below redshift $z<1$ by about x10.

Currently depend on ~$1B satellites to collect supernovae above $z>1$, at ~10/year. Can collect hundreds/year from the ground if we can remove OH Emission Lines.

IR Spectroscopy Hampered by Atmospheric OH

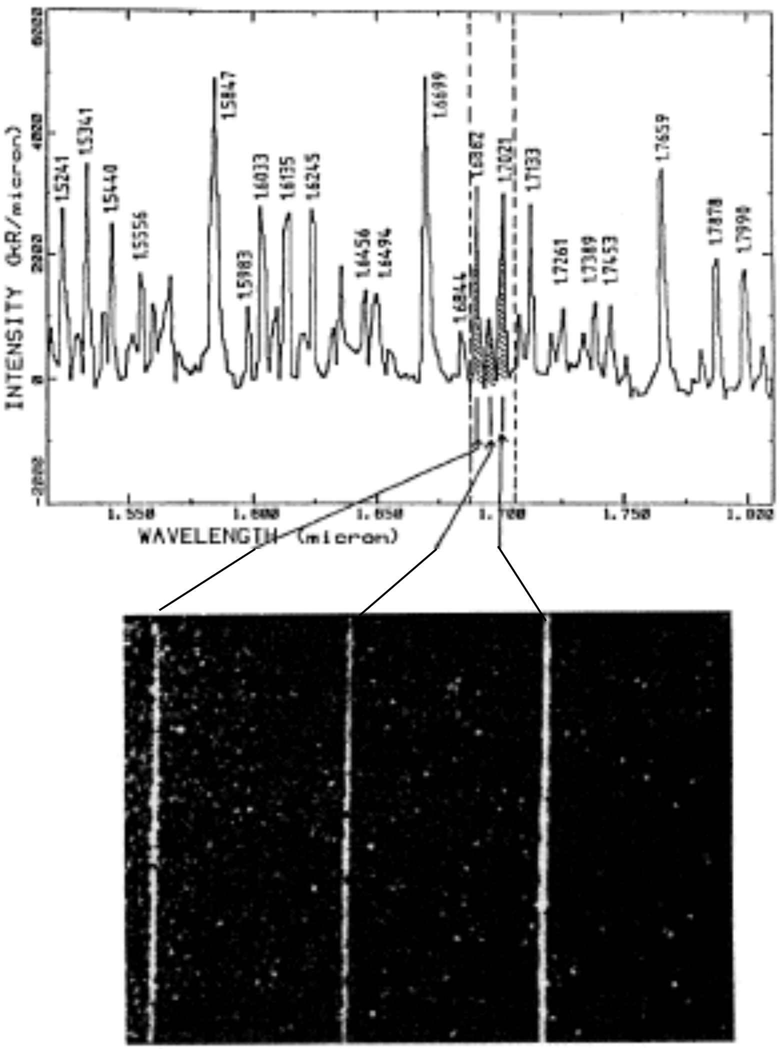


TABLE 2a
Detected Lines in the J Band

Number	Wavelength λ μm(in vacuum)	Intensity γ s⁻¹m⁻²arcsec⁻²	λ (Steed & Baker) μm(in vacuum)	Intensity kR
1	1.14398	22	1.14384	0.40
2	1.14516	17		
3	1.15390	45	1.15395	0.32
4	1.15912	54	1.15925	0.35
			1.16285	0.12
5	1.16517	38	1.16515	0.30
			1.16965	0.08
6	1.17164	92	1.17165	0.10
			1.17875	0.08
7	1.19744	25		
8	1.19880	30		
9	1.20009	11	1.20016	0.12
10	1.20068	44	1.20075	0.20
11	1.20241	25	1.20256	0.18
12	1.20313	85	1.20316	0.24
13	1.20564	26	1.20559	0.07
14	1.21234	111	1.21226	0.54
15	1.21384	40	1.21350	0.20
16	1.21560	18	1.21550	0.05
17	1.21968	38	1.21964	0.11
18	1.22290	109	1.22293	0.40
19	1.22579	59	1.22578	0.18
20	1.22871	113	1.22870	0.46
21	1.23258	22	1.23259	0.17
22	1.23508	82	1.23516	0.30
			1.24509	0.11
23	1.24235	114	1.24230	0.19
24	1.25038	31	1.25024	0.09
			1.25891	0.05
25	1.26857	80		
26	1.26951	64		
27	1.27020	37		
28	1.27104	39		
29	1.27261	20		
30	1.27445	24		
31	1.27529	45	1.27528	0.15
32	1.27636	76	1.27644	0.21
33	1.27760	32		
34	1.27831	149	1.27825	0.24
35	1.27980	57		
36	1.28065	107	1.28070	0.23
37	1.28248	25		
38	1.28345	58	1.28346	0.08
39	1.28450	35		
40	1.28660	31		
41	1.29054	261	1.29057	0.57
42	1.29213	84	1.29212	0.17
43	1.29434	26	1.29431	0.09
44	1.29861	67	1.29857	0.15
45	1.30218	187	1.30216	0.32
46	1.30533	82	1.30528	0.21
47	1.30861	277	1.30852	0.39
48	1.31285	90	1.31278	0.18
49	1.31577	77	1.31567	0.19
50	1.32115	47	1.32110	0.10
51	1.32368	104	1.32366	0.27
52	1.33244	29	1.33247	0.04
53	1.34223	26	1.34208	0.06

FIRE spectrograph on Magellan Telescope:
Observation + modeling of OH lines
(including spectrograph performance based on ThAr lamp)

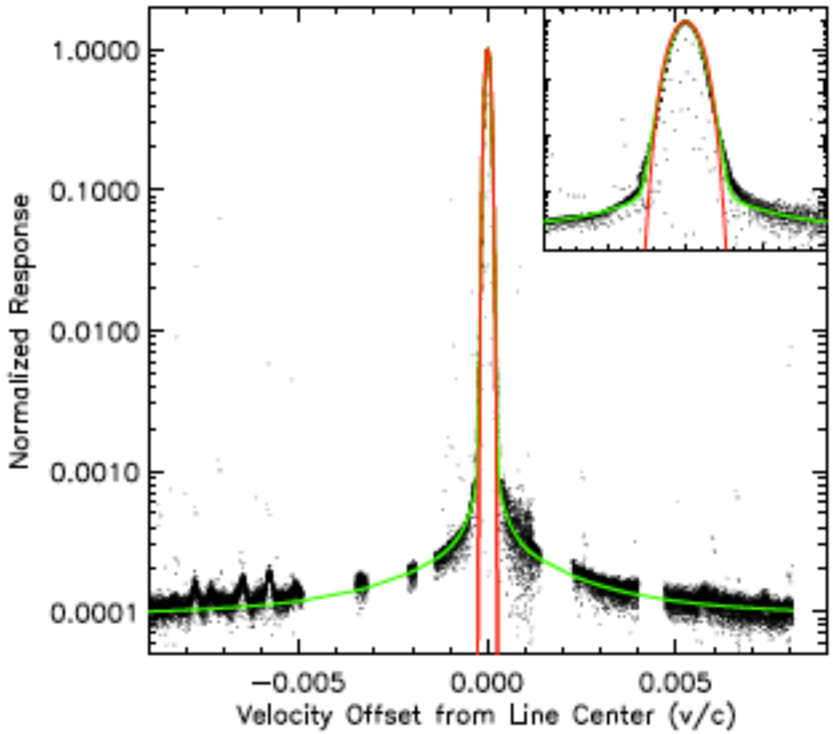


Fig. 4.— The spectral Line Spread Function for FIRE measured from a ThAr lamp.

FIRE:

Observations (dis)agree with models depending on wavelength.

Unclear what is causing continuum emission above Read Noise and Zodiacal Light... the spectrograph itself?

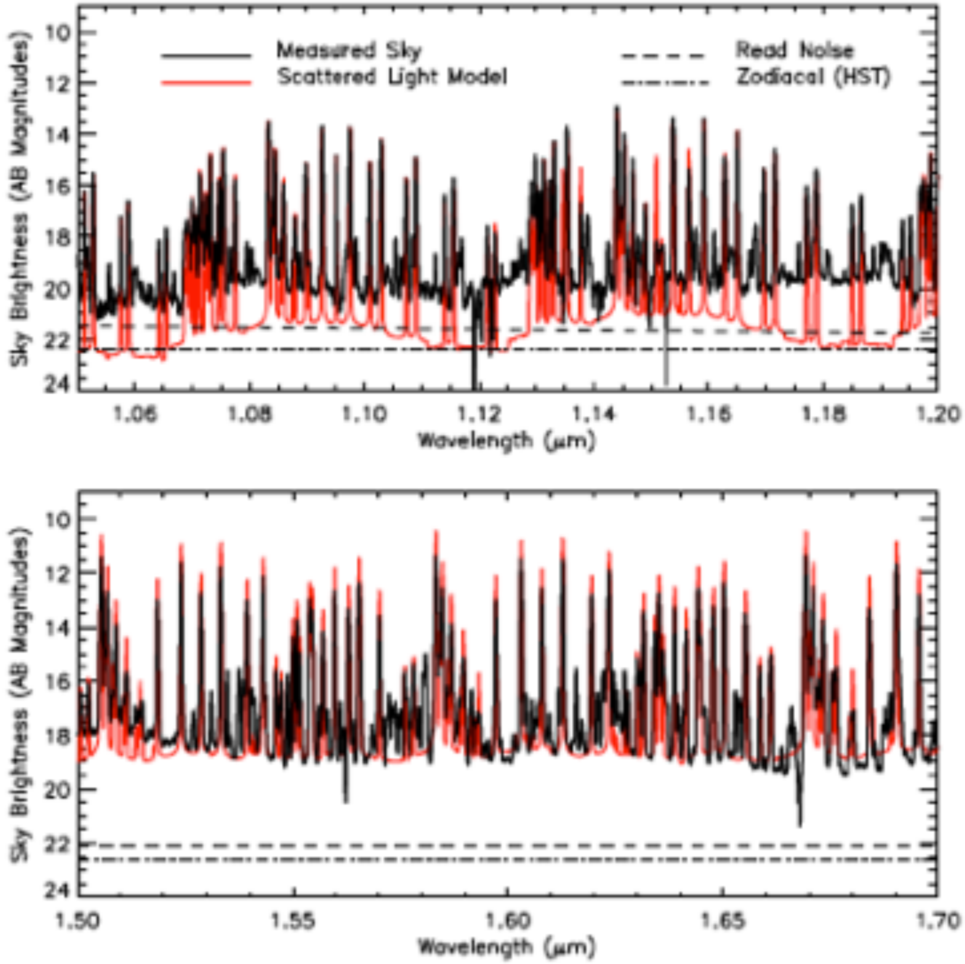
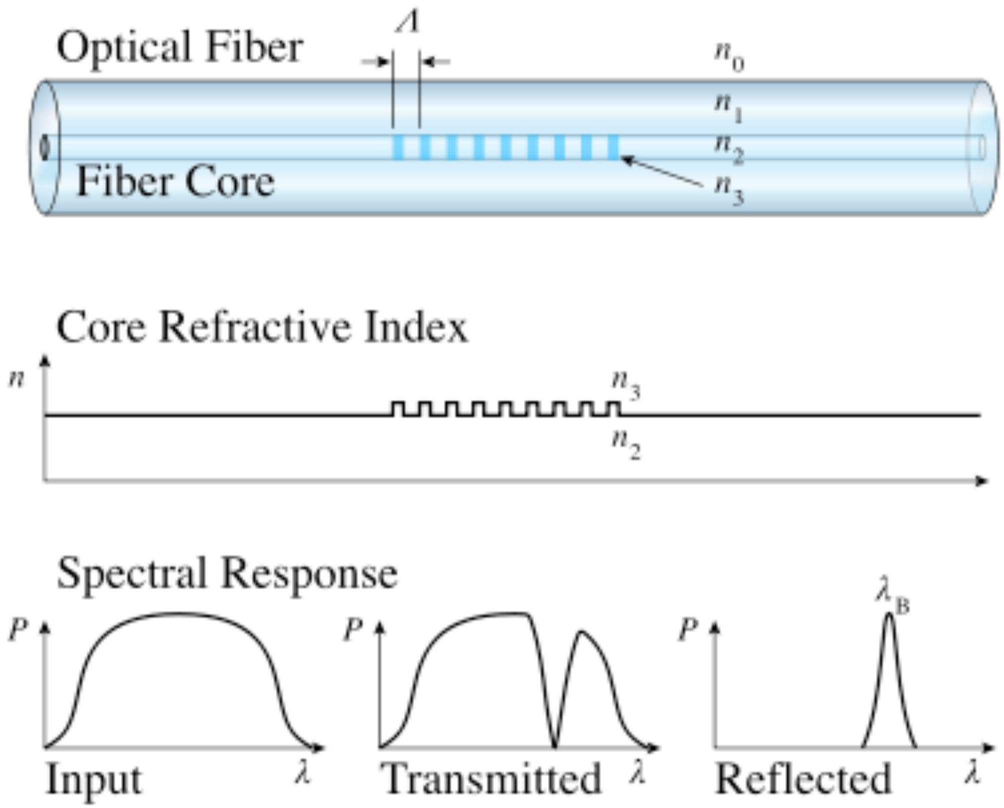
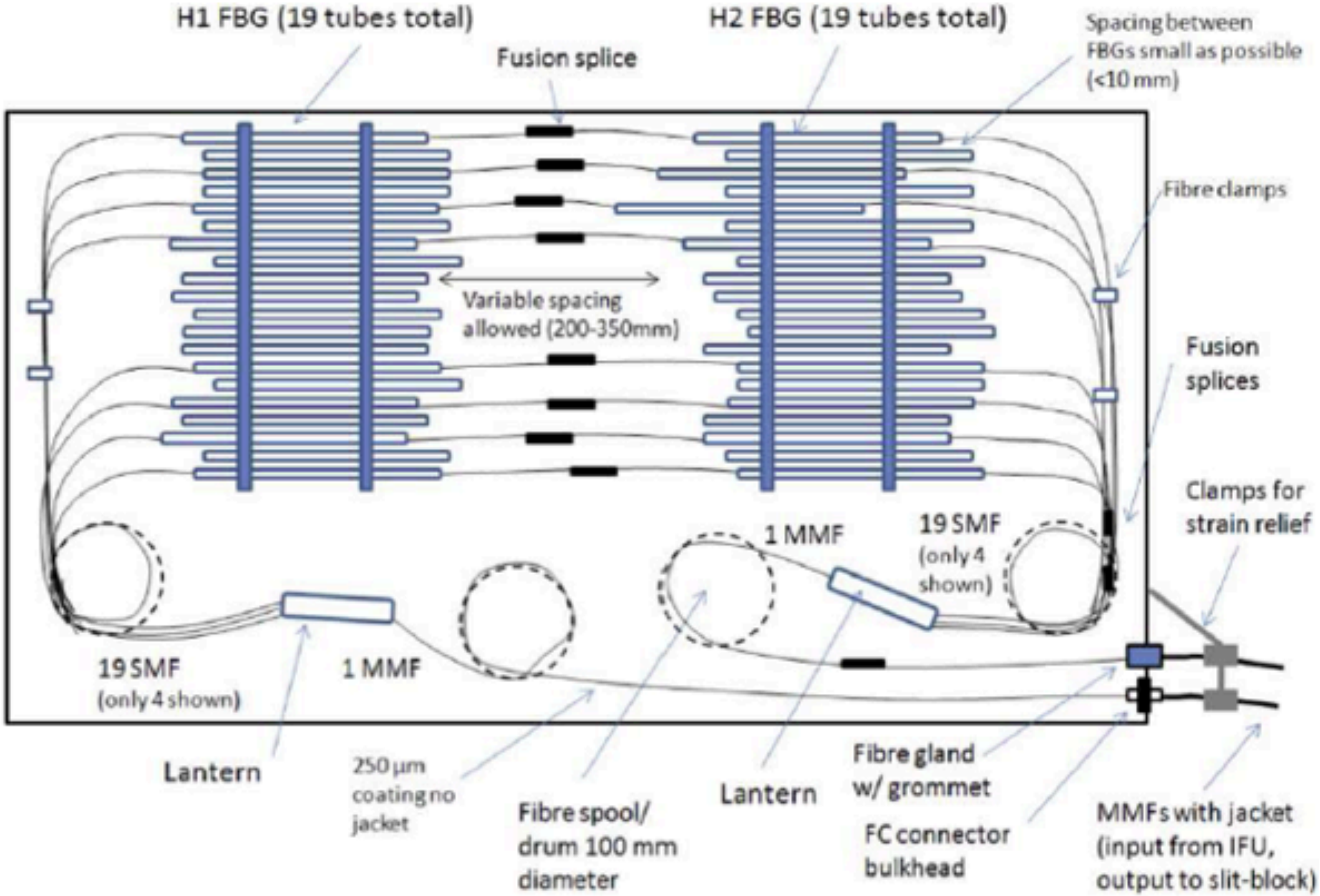


Fig. 9.— In the H band (lower panel), the convolution of our empirically-determined LSF with an OH linelist (red) shows good agreement with the measured sky spectrum (black). Across the Y and J bands (upper panel), the measured sky spectrum shows a higher continuum level than the LSF convolution would predict. In all three bands, the measured continuum level is well above the read noise floor and Zodiacal light.

Suppression Technology: Fiber Bragg Grating



Existing Systems: GNOSIS



Existing Systems: GNOSIS

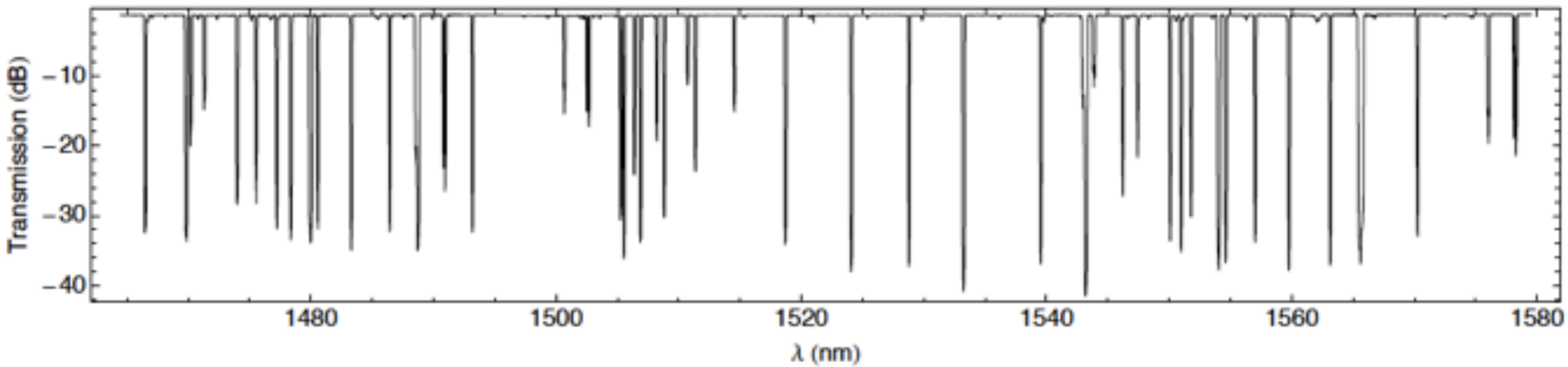


Figure 1. The wavelength response of a single aperiodic FBG with 50 notches. GNOSIS uses two aperiodic FBGs in series to suppress the 103 brightest OH doublets in the range 1.47–1.7 μm.

GNOSIS Suppression Results

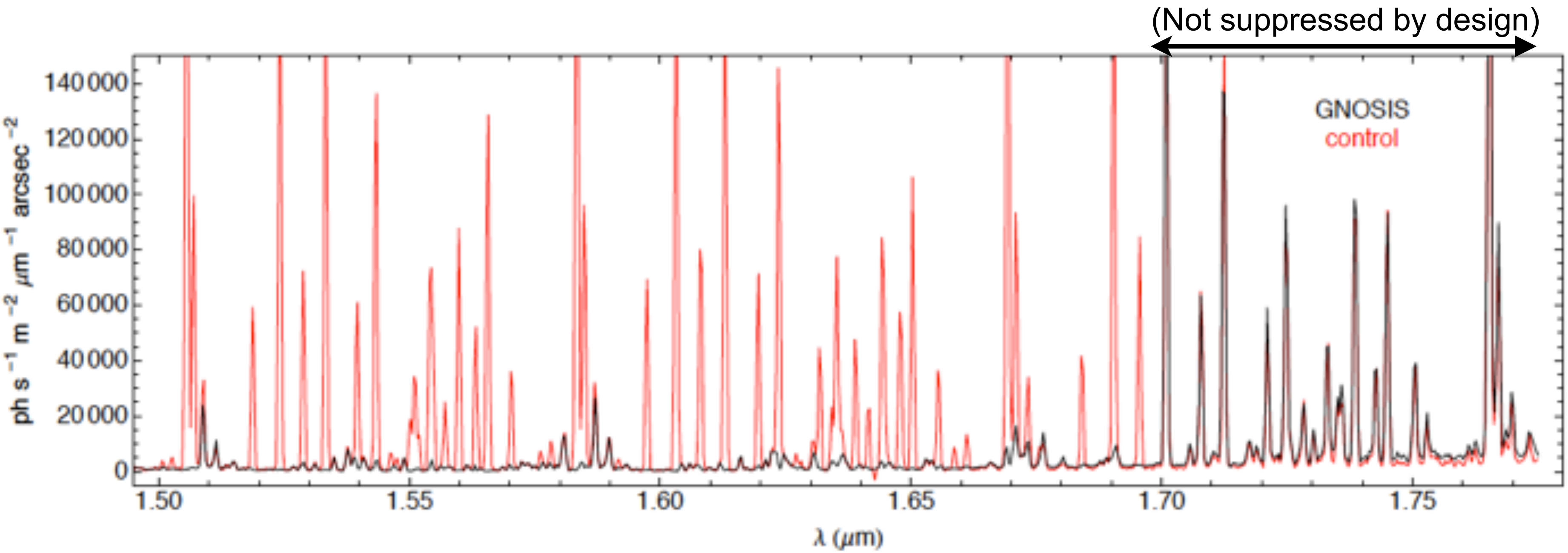


Figure 10. Spectrum of the night sky with (black) and without (red) OH suppression. The spectrum comes from 21 exposures (8.75 hr total) from 1-4 September at various locations on the sky. The reduction in the OH lines in the range 1.5–1.7 μm is clear.

Addresses continuum; obviously useful for low R spectroscopy.
But...
Current system is noise dominated:
Are there non-modeled lines?
Is light scattered into non-suppressed wavelengths?

GNOSIS

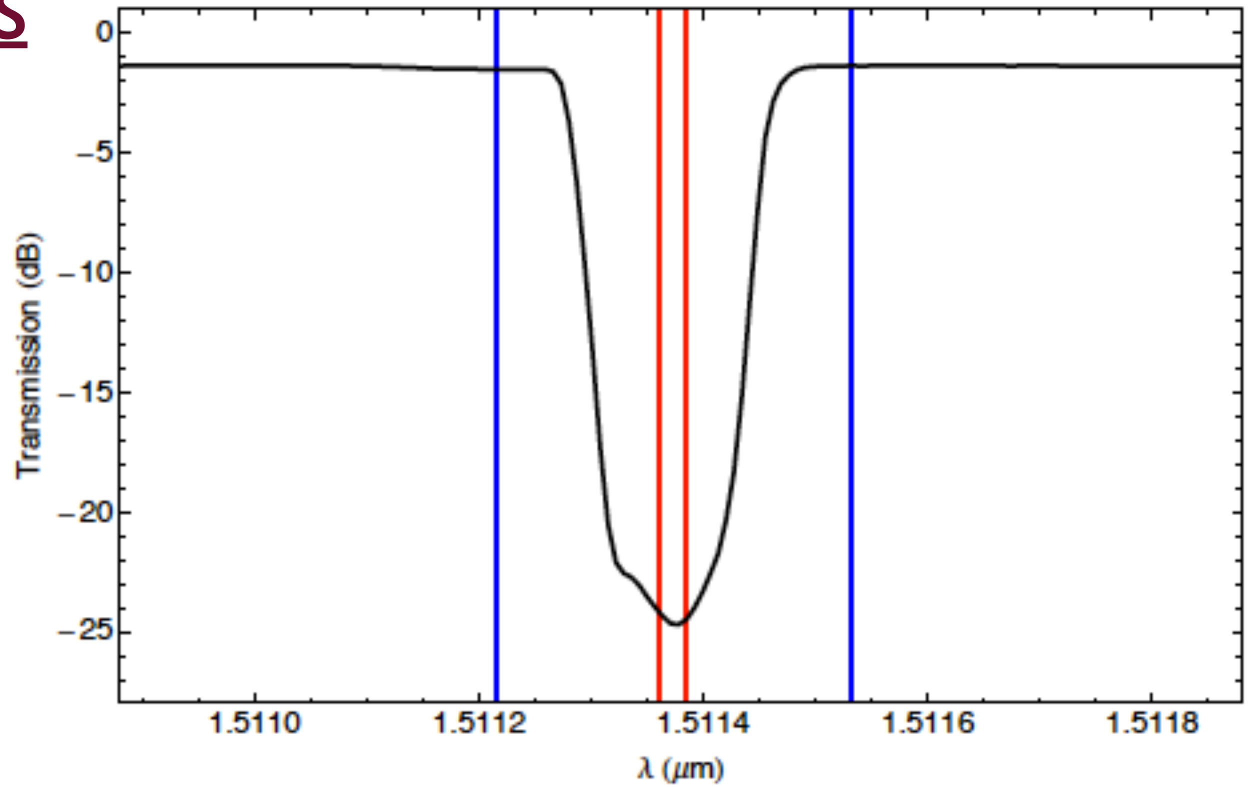


Figure 11. The H1 FBG notch (black) designed to suppressed the 3-1 Q1 (4.5) OH doublet. The notch position was selected based on the mean wavelength of the doublet (red) according to Rousselot et al. (2000). The mean wavelength of the doublet (blue) according to Abrams et al. (1994) is the same, but the spacing is much wider. This may be responsible for the strong residual seen at this wavelength in the OH suppressed sky spectrum.

Suppression Technology: Ring Resonator

In future photonic instruments based entirely on two-dimensional waveguides, a different approach will be needed. One promising technology is the micro-ring resonator used in telecommunication devices for adding or dropping discrete wavelengths. If a ring-shaped light-guiding track is placed close to a linear track, light in the latter couples to the ring if its wavelength λ satisfies $m\lambda = 2\pi r n_0$, where r is the ring's radius, n_0 is its effective refractive index, and m is a positive integer. Such wavelengths are essentially removed from the linear track.

J. Bland-Hawthorn and P. Kern
Physics Today **65** (5), 31 (2012)

Multi-Wavelength Selectivity with Ring Resonators

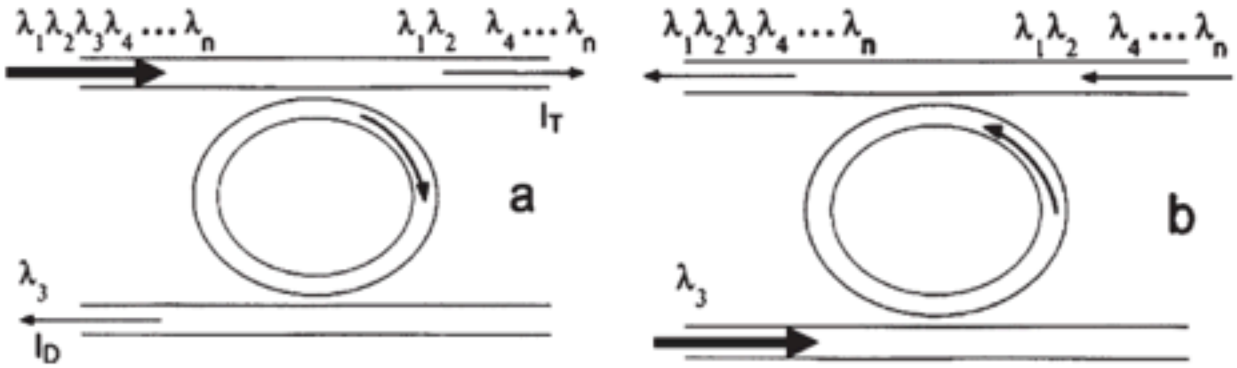


Fig. 11. Ring resonator used as a (a) demultiplexing or (b) multiplexing filter.

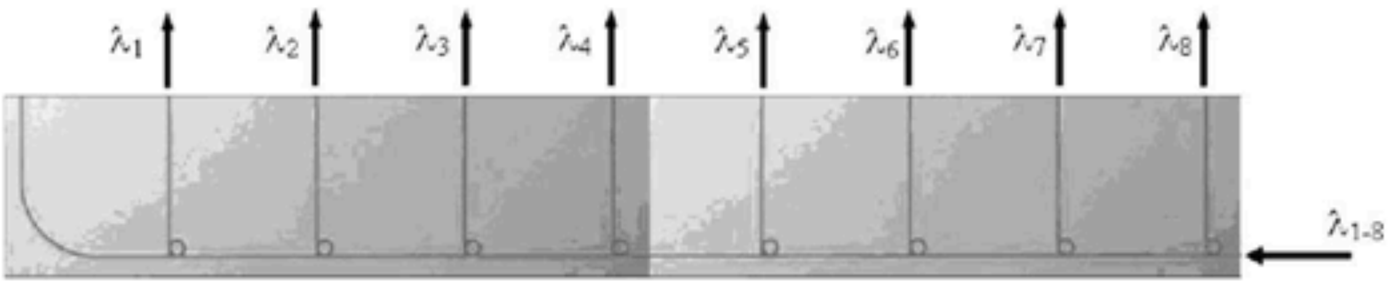


Fig. 12. Micrograph of a 1 × 8 multiplexer using multiple ring resonators.

Another Multi-Wavelength Ring Resonator Design

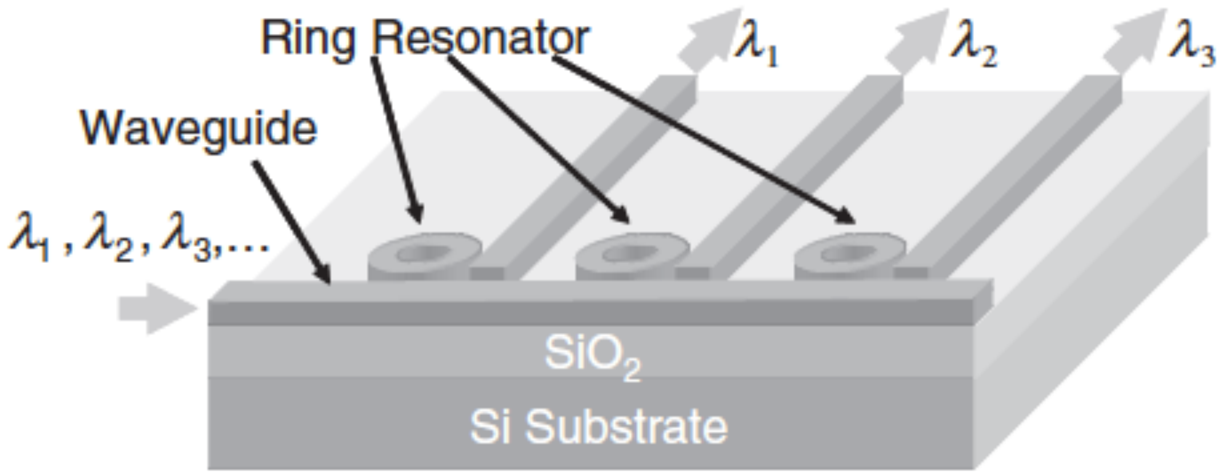


Fig. 1. Schematic of wavelength division multiplexing optical interconnection on ULSI. The ring resonators are used as optical filters.

Ring Resonator Performance: Power

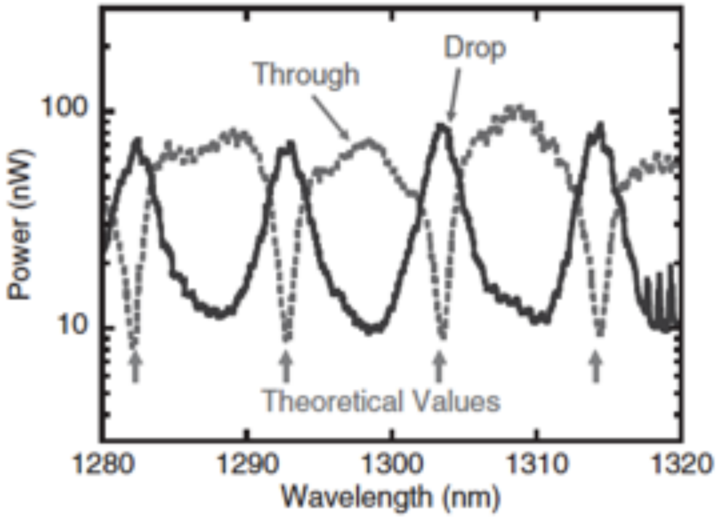


Fig. 7. Wavelength dependence of optical power for the ring resonator with $W = 2.0\,\mu m$ and $g = 0.10\,\mu m$. The valleys of the through port correspond well to the peaks of the drop port. The measured resonance wavelengths agree with theoretical values, which are indicated by arrows. Clear subpeaks caused by the second-order mode are hardly observed.

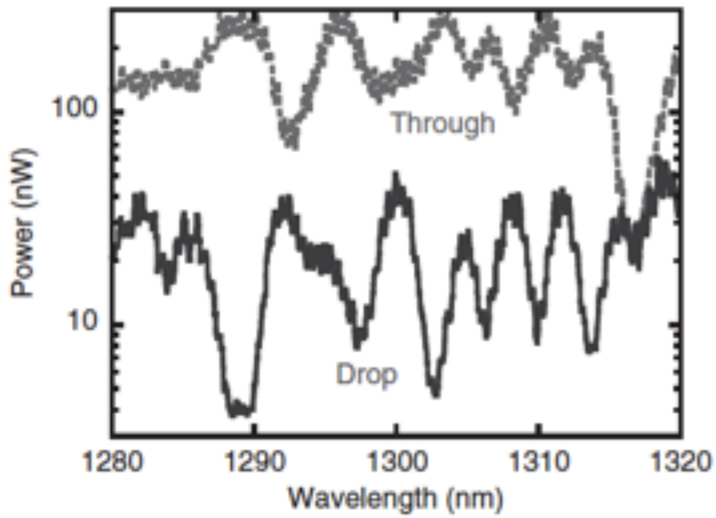


Fig. 9. Wavelength dependence of optical power for the ring resonator with $W = 3.0\,\mu m$ and $g = 0.10\,\mu m$. Subpeaks caused by the higher-order modes are observed.

Suppression Technology: Volume Phase Holography

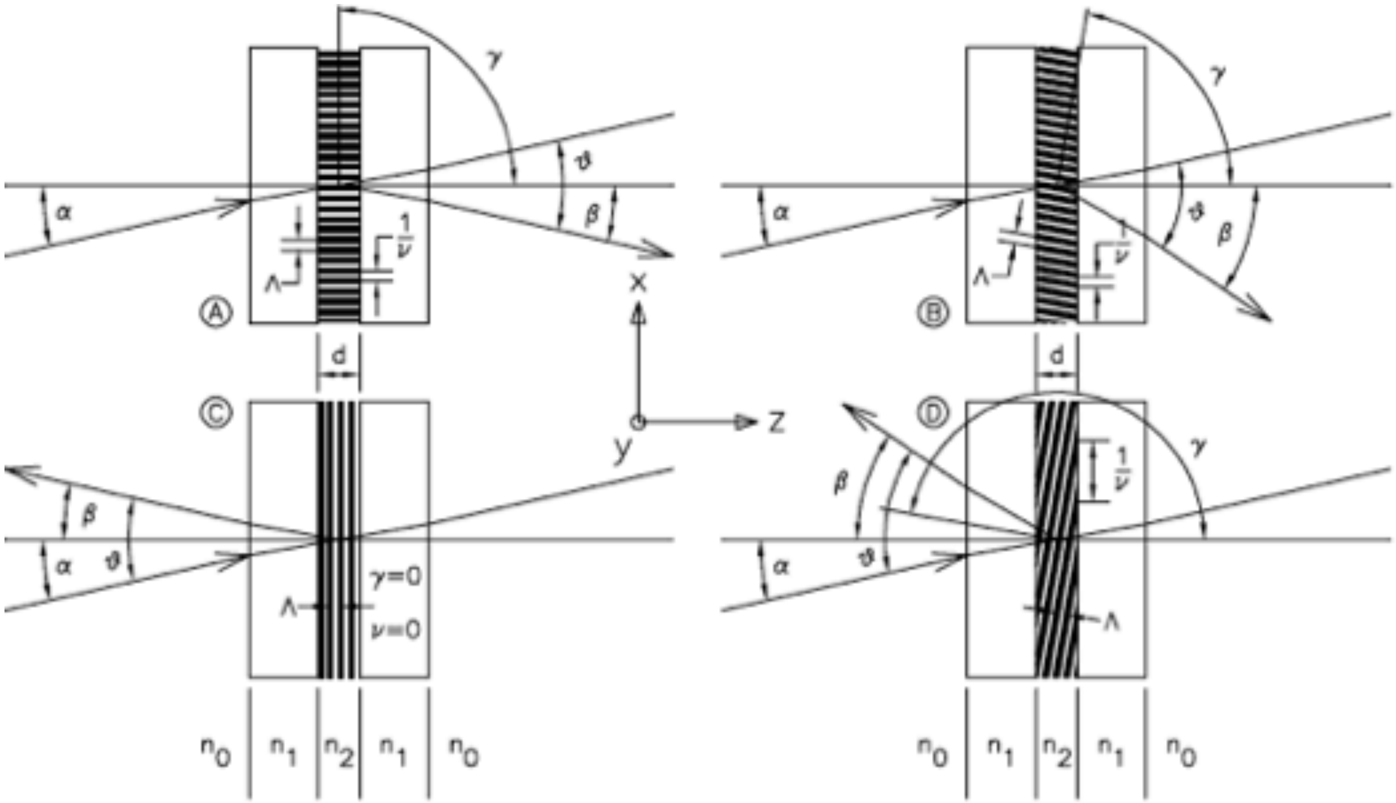


Fig. 1.— Four possible fringe structures for VPH gratings: A) Littrow transmission grating. B) Non-Littrow transmission grating. C) Non-dispersive reflection grating (notch filter). D) Dispersive reflection grating.

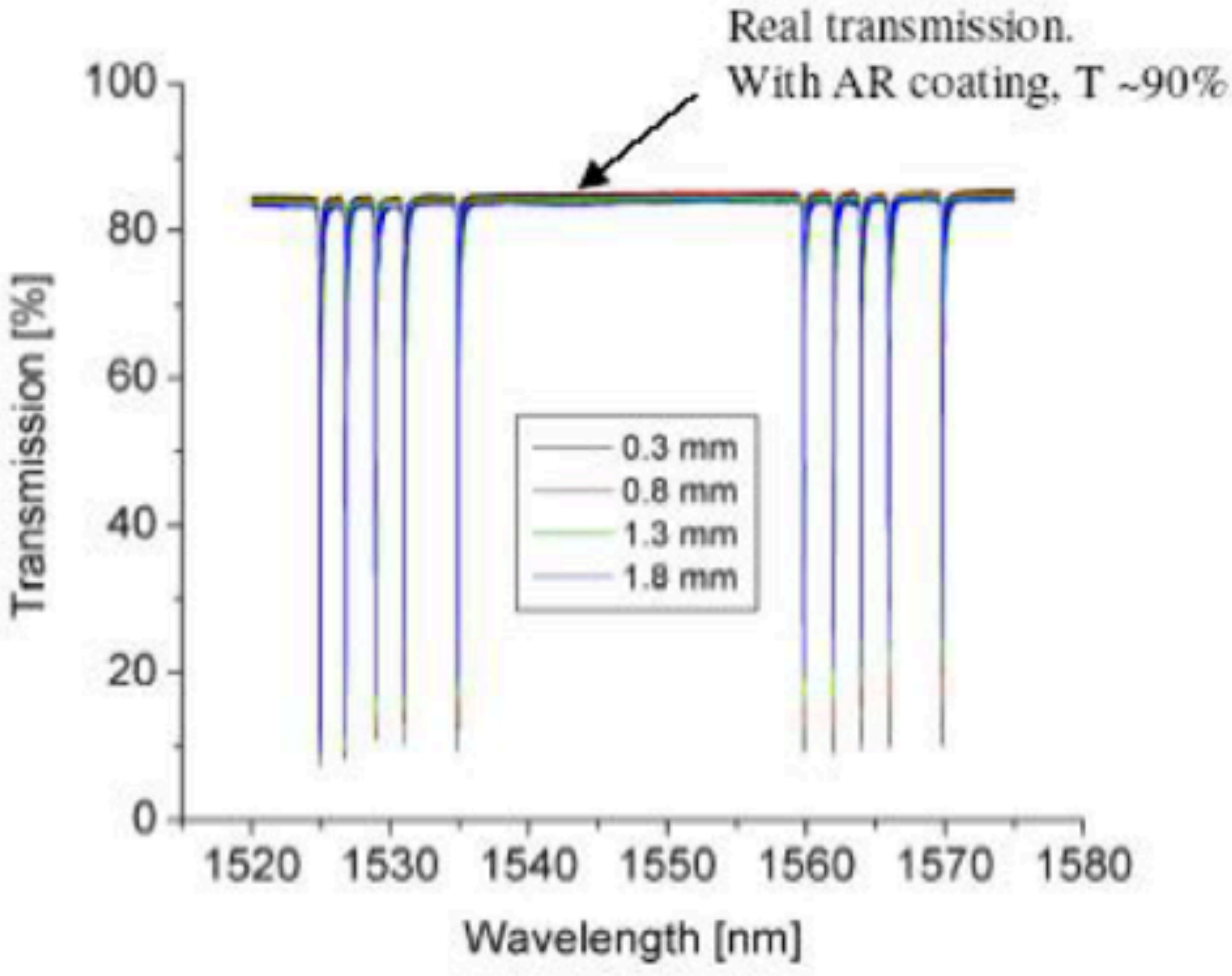
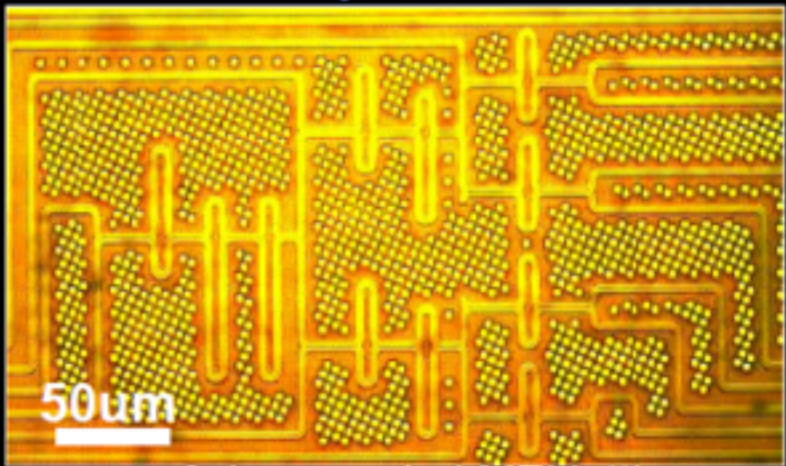
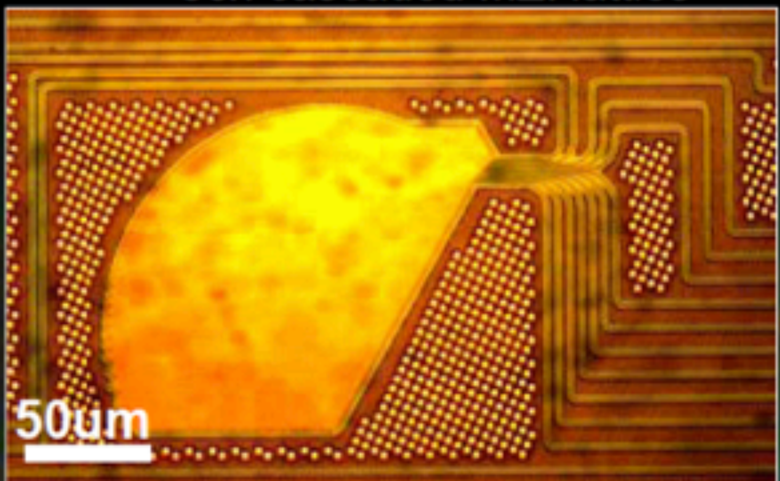


Figure 8. Transmission spectrum of a 10 line filter.

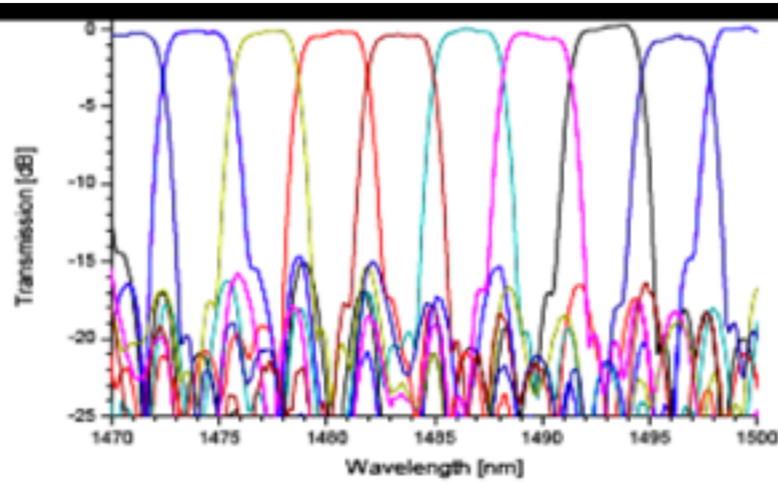
WDM multiplexers



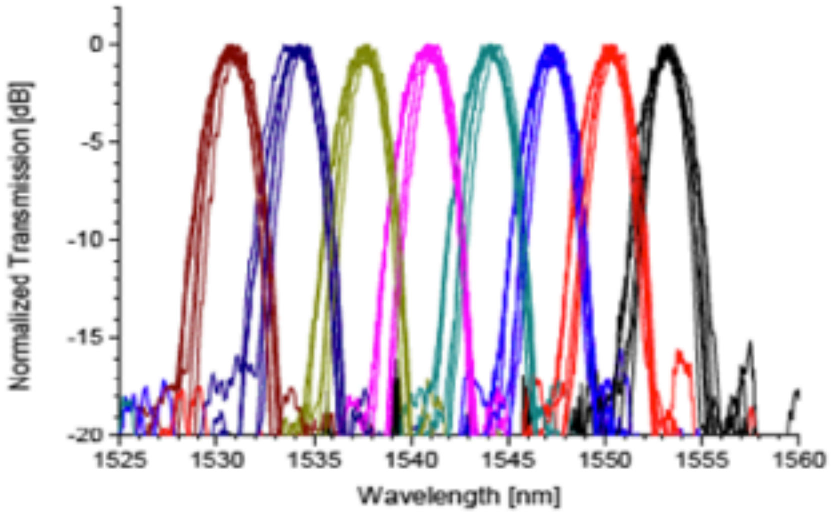
8ch cascaded MZI lattice



10ch Echelle grating



Overlay of 6 devices



Folkert Horst (IBM Zurich) Invited talk OFC 2011

Other Technologies

Photodiodes?
SWIFTS
Array Waveguides (cf. PT **65** (5), 31 (2012))
Femtosecond laser-etched bulk Si
Volume Bragg Gratings

a

b

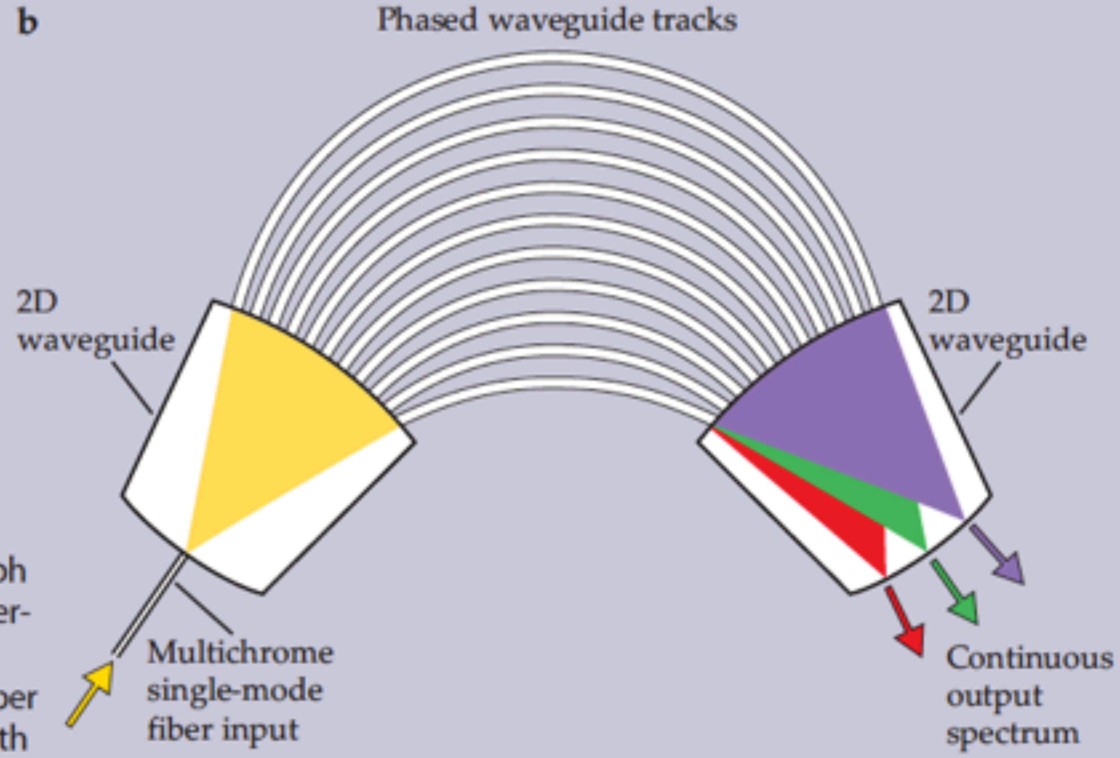
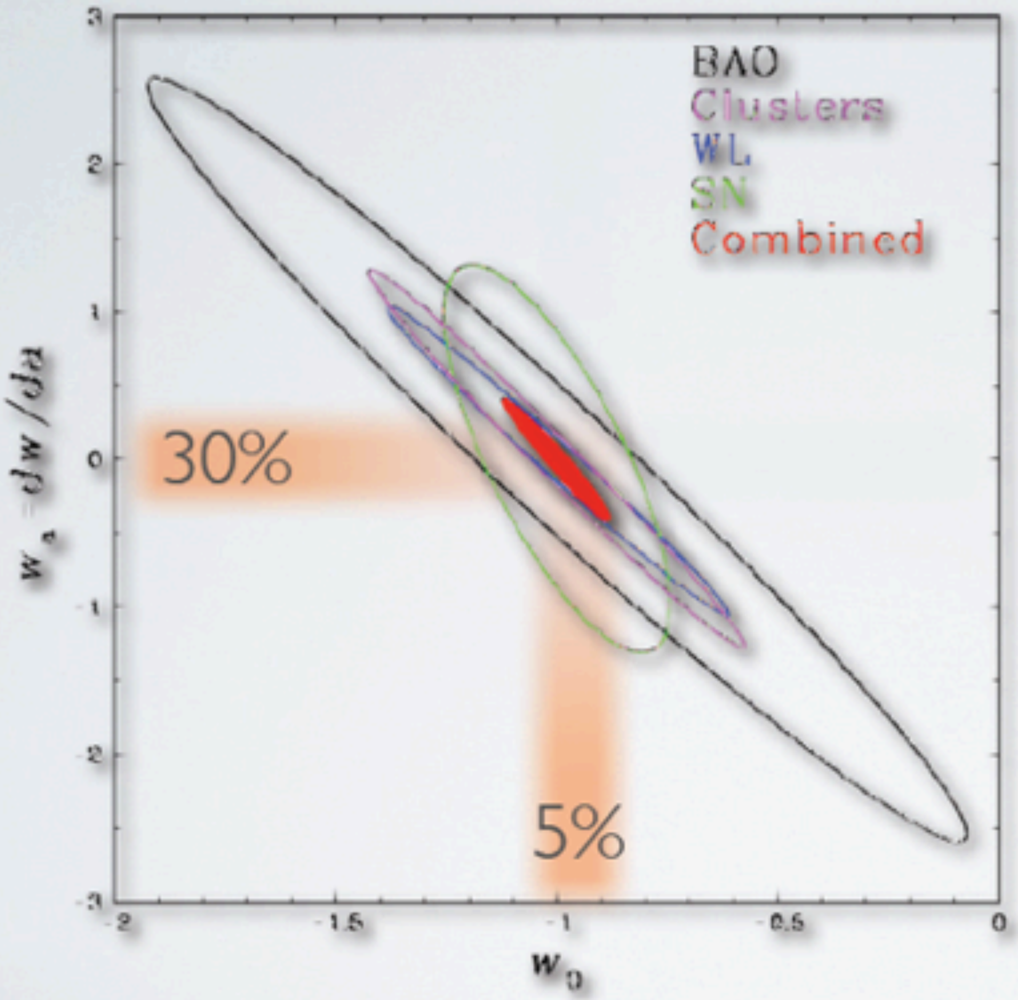


Figure 3. The fully integrated photonic spectrograph shown in **(a)** (Courtesy of J. Lawrence, Macquarie University) uses the array waveguide grating schematically shown in **(b)**. Multichrome light from a single-mode fiber enters a phased array of etched tracks differing in length by a fixed small increment such that interference at the downstream waveguide produces spectral separation. (Courtesy of A. McGrath.)

Laboratory Setup for Bench Tests

DES PROJECTED LIMITS



5000 deg^2, 0.9" seeing, 24th mag (redshift~1.4)

300M galaxies, shapes, 100K clusters, 4K SNe

4 combined probes

3-5x improved Dark Energy measurement

Conclusions

- Dark Energy is (probably) causing the accelerated expansion of the universe. The Dark Energy Camera has been successfully built and tested, and is ready to engage in the Dark Energy Survey.
- The Precursor to the Dark Energy Camera (PreCam) has been successfully built and deployed at Cerro Tololo Interamerican Observatory for the purpose of calibrating the DECam.
- Preliminary results show single-epoch photometric accuracy of 3-4%, with accuracy better than 2% expected for final PreCam Southern Hemisphere Standard Star Catalog.
- In addition to the Key Science goals with the four probes (operating independently and collectively), the DES will accomplish an enormous amount of auxiliary science (e.g. non-SN transients).
- The Dark Energy Survey has recently achieved first light, and will begin science operations later this fall, with the goal of providing unprecedented constraints on the time-(in)dependent component of the dark energy equation of state over the next five years.

The Dark Energy Survey Collaboration

More than 200 scientists and engineers from...

Fermilab — The Fermi National Accelerator Laboratory
UIUC/NCSA — The University of Illinois at Urbana-Champaign
Chicago — The University of Chicago
LBNL — The Lawrence Berkeley National Laboratory
NOAO — The National Optical Astronomy Observatory
United Kingdom DES Collaboration

- UCL - University College London
- Cambridge - University of Cambridge
- Edinburgh - University of Edinburgh
- Portsmouth - University of Portsmouth
- Sussex - University of Sussex
- Nottingham - University of Nottingham

Spain DES Collaboration

- IEEC/CSIC - Instituto de Ciencias del Espacio,
- IFAE - Institut de Fisica d'Altes Energies
- CIEMAT - Centro de Investigaciones Energeticas, Medioambientales y Tecnologicas

Michigan — The University of Michigan
DES-Brazil Consortium

- ON - Observatorio Nacional
- CBPF - Centro Brasileiro de Pesquisas Fisicas

UFRGS - Universidade Federal do Rio Grande do Sul
Pennsylvania — The University of Pennsylvania
ANL — Argonne National Laboratory
OSU — The Ohio State University

TAMU — Texas A&M University

Santa Cruz-SLAC-Stanford DES Consortium

- Santa Cruz - University of California Santa Cruz
- SLAC - SLAC National Accelerator Laboratory
- Stanford - Stanford University

Munich—Universitäts-Sternwarte München

- Ludwig-Maximilians Universität
- Excellence Cluster Universe

Committee on the Internationl Freedom of Scientists

http://www.aps.org/about/governance/committees/cifs/index.cfm

DARK ENERGY SURVEY

- "To achieve its full potential and to benefit all mankind, science requires that governments respect basic human rights, allow open communication, and avoid interference with the rights of scientists as they carry out their professional work."
  -- from the APS Statements on Human Rights

- "This Committee shall be responsible for monitoring concerns regarding human rights for scientists throughout the world. It shall apprise the [Society] of problems encountered by scientists in the pursuit of their scientific interests or in effecting satisfactory communication with other scientists and may recommend appropriate courses of action designed to alleviate such problems."
  -- from the APS CIFS Statement of Purpose

- Cases currently being reviewed from China, Cuba, Gaza Strip/Israel, Iran, Iraq, Mexico, Saudi Arabia, Turkey, Russia, and the United States, involving allegations of everything from scientists being unfairly tried and incarcerated to students prevented from traveling internationally to participate in educational opportunities.

- CIFS also participates in the awarding of the APS Andrei Sakharov Prize, "to recognize outstanding leadership and/or achievements of scientists in upholding human rights."

APS physics

Thank You!