

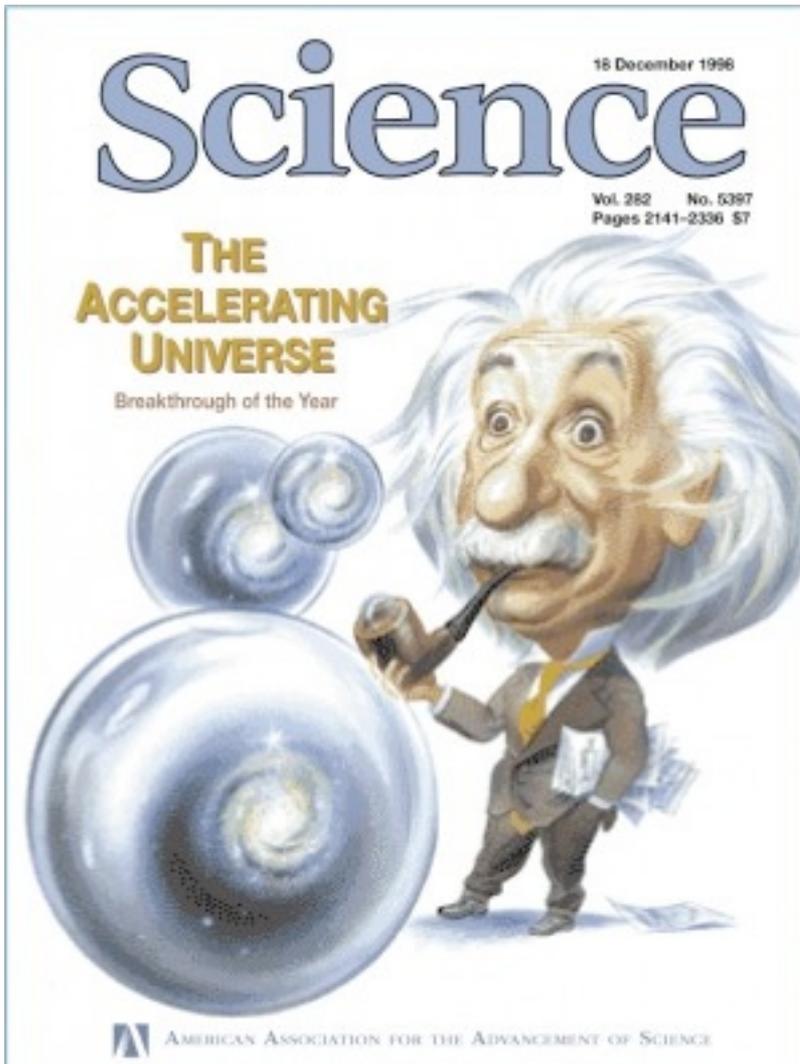
# The Dark Energy Survey and the Quest to Determine the Fate of the Universe

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High Energy Physics  
Cosmology & Astrophysics Group

Yerkes Observatory  
July 25, 2012

<http://www.hep.anl.gov/kkuehn>

# The Discovery of Dark Energy is Big News...

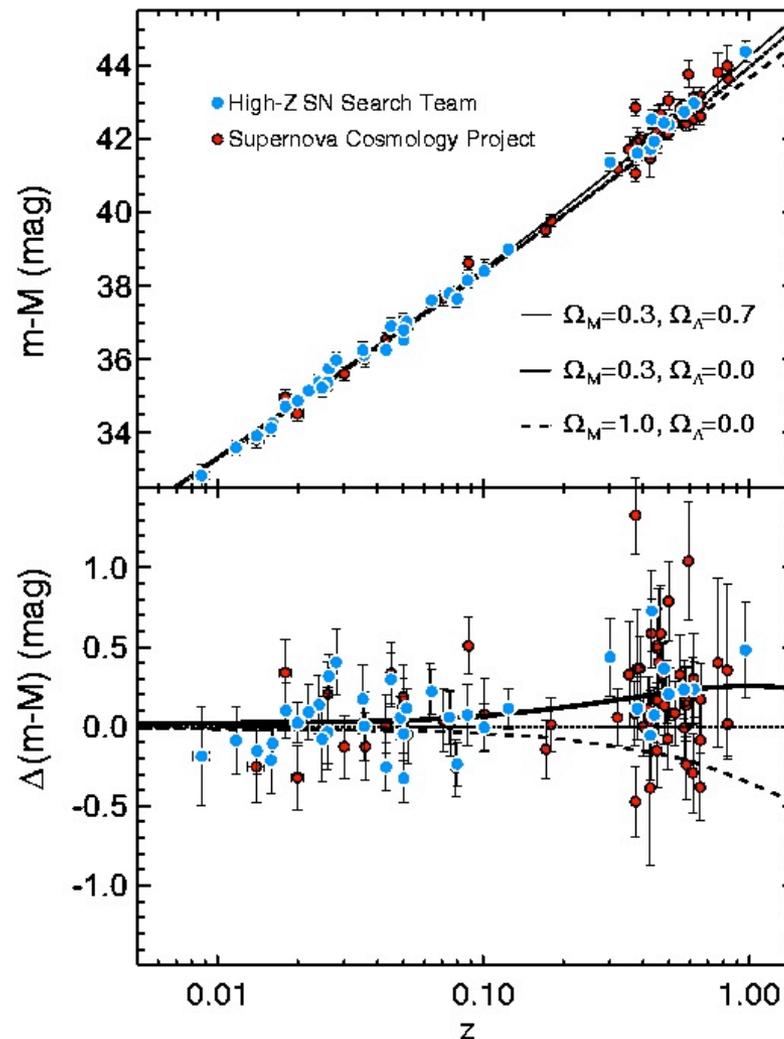


Science Magazine,  
December 18, 1998



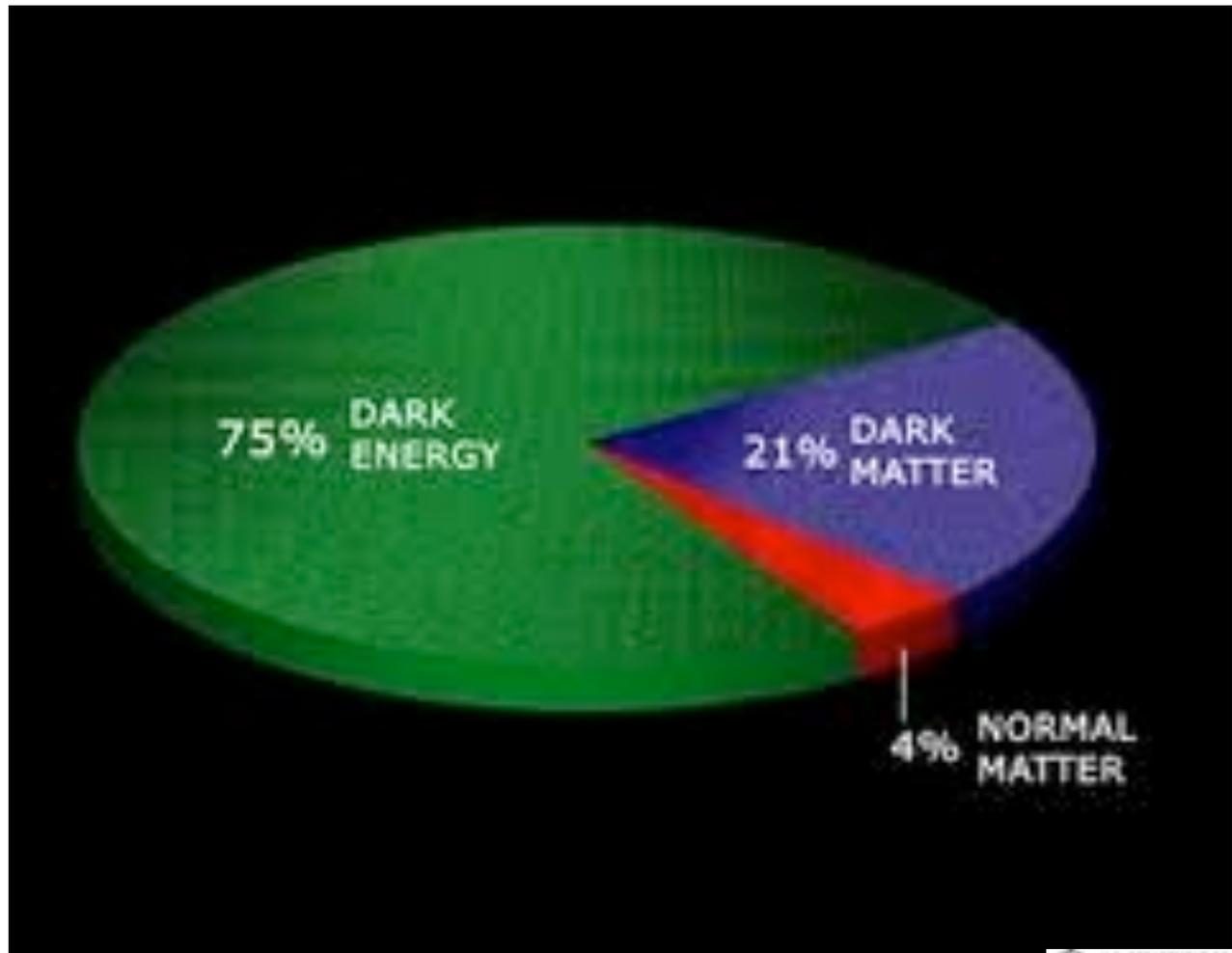
Nobel Prize in Physics, 2011

# The Era of Observational Cosmology



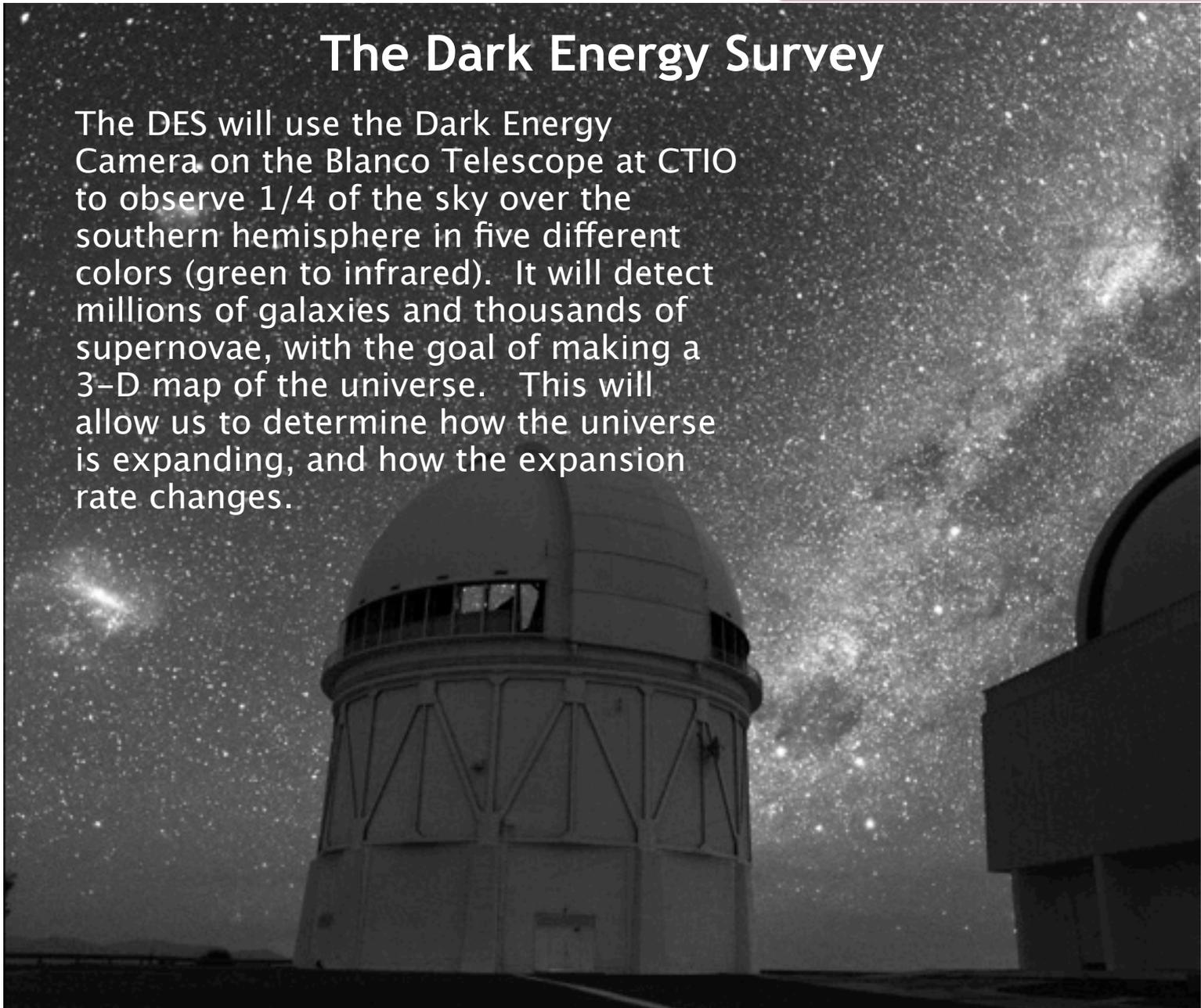
## So, what is it...?

- Cosmological Constant?
- $10^{120}$  problem
- Dynamical Dark Energy?
- Modification of Gravity?
- Voids?
- Disfavored by HST Observations
- We don't know, yet...



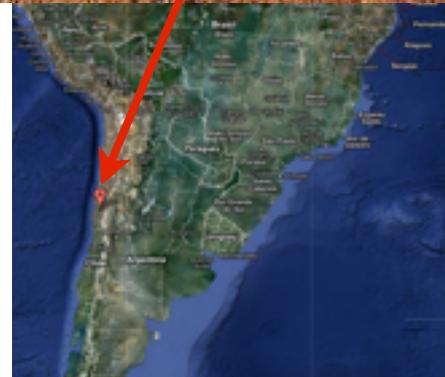
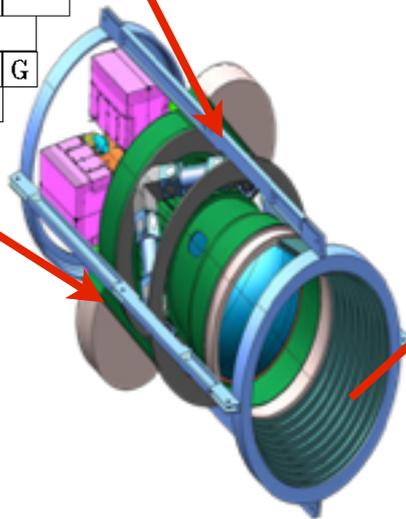
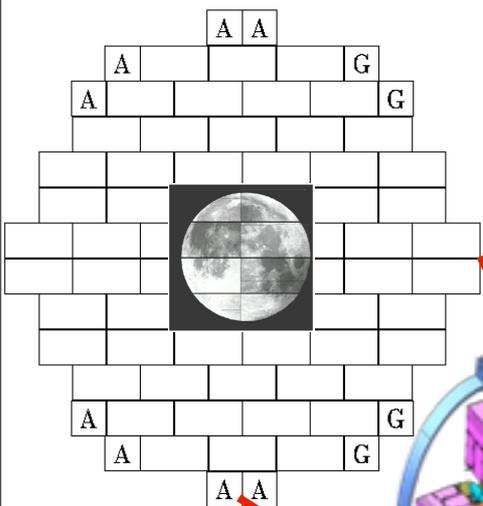
# The Dark Energy Survey

The DES will use the Dark Energy Camera on the Blanco Telescope at CTIO to observe 1/4 of the sky over the southern hemisphere in five different colors (green to infrared). It will detect millions of galaxies and thousands of supernovae, with the goal of making a 3-D map of the universe. This will allow us to determine how the universe is expanding, and how the expansion rate changes.

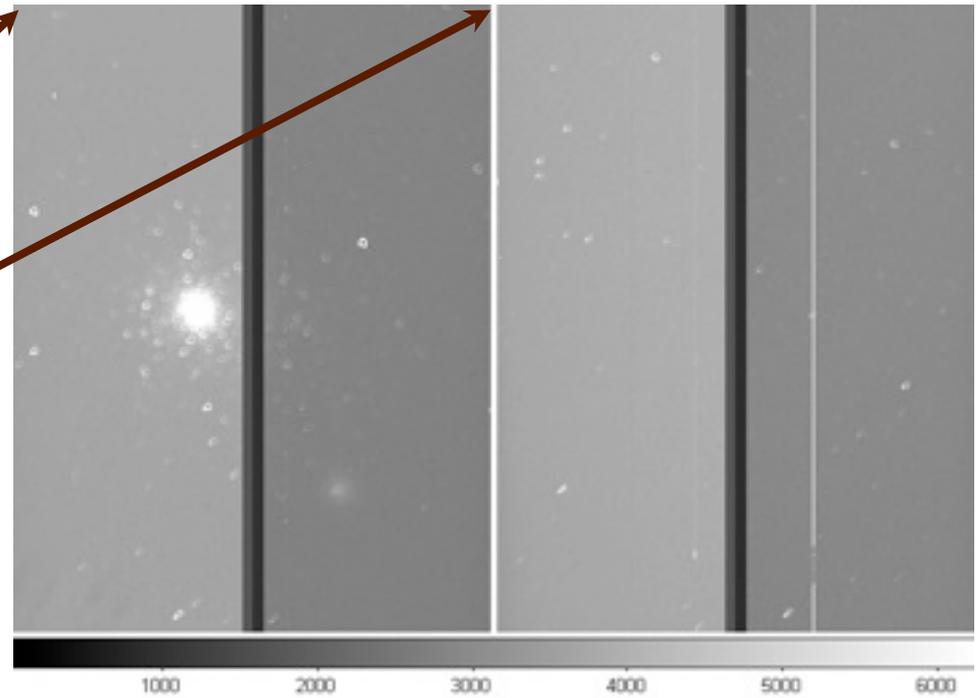
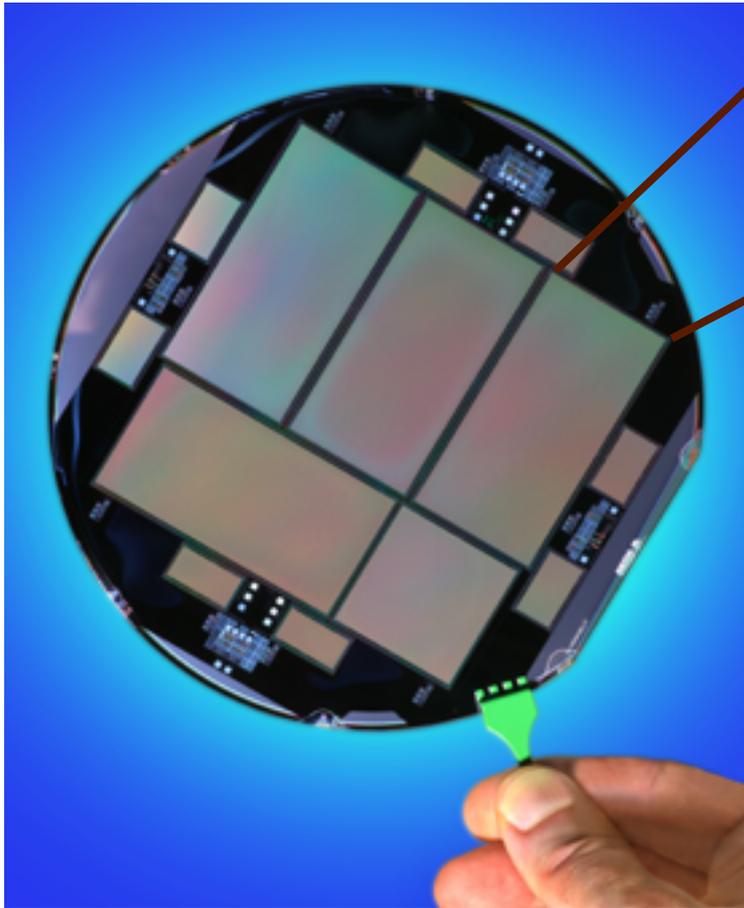


# The DES Instrument: DECam

The newly-constructed Dark Energy Camera will be installed at the prime focus of the 4m. Blanco Telescope at Cerro Tololo Inter-American Observatory in Chile. DECam has a field of view of approximately 3 square degrees.



# Dark Energy Camera Charge-Coupled Devices



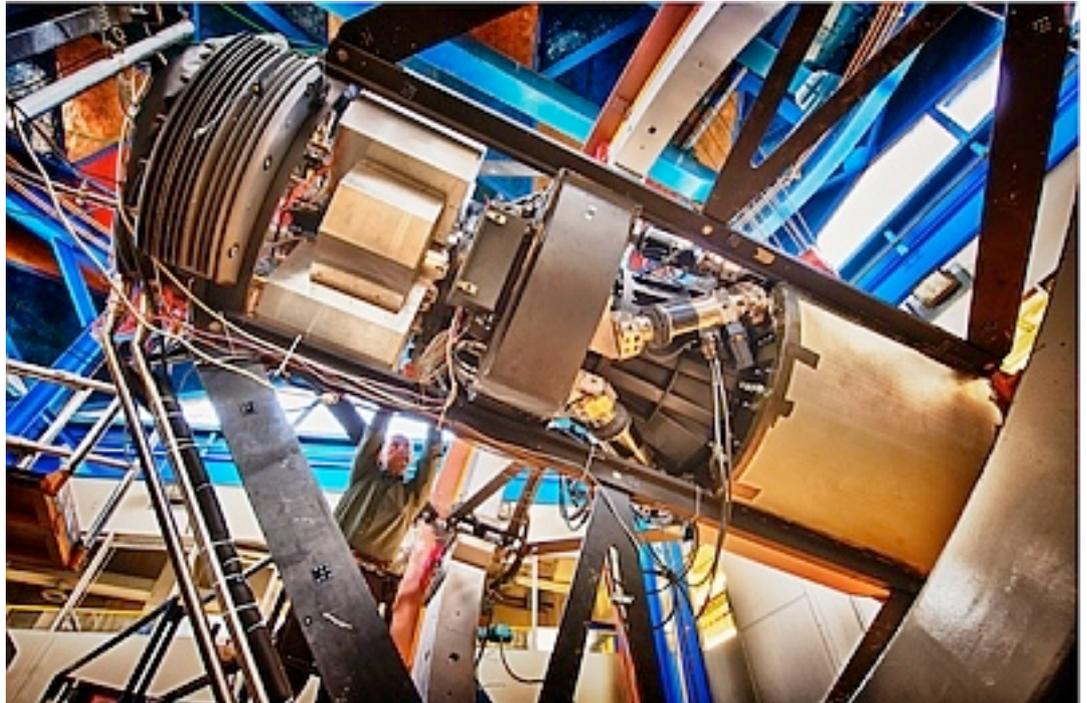
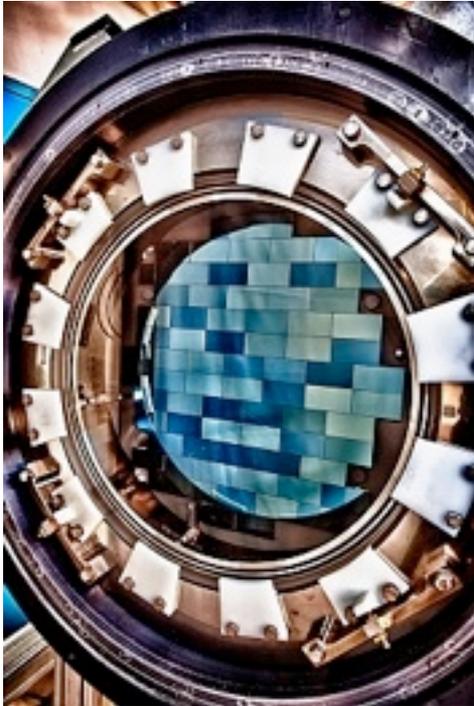
# Argonne Contributions to the Dark Energy Camera

- Instrument Control System
- Mirror Handling System
- Telemetry/Alarms
- PreCam



# The Dark Energy Camera

DECam is a 570 Megapixel camera consisting of 62 extremely red-sensitive CCDs. DECam is currently undergoing testing and installation at the Blanco Telescope prior to Dark Energy Survey observations.

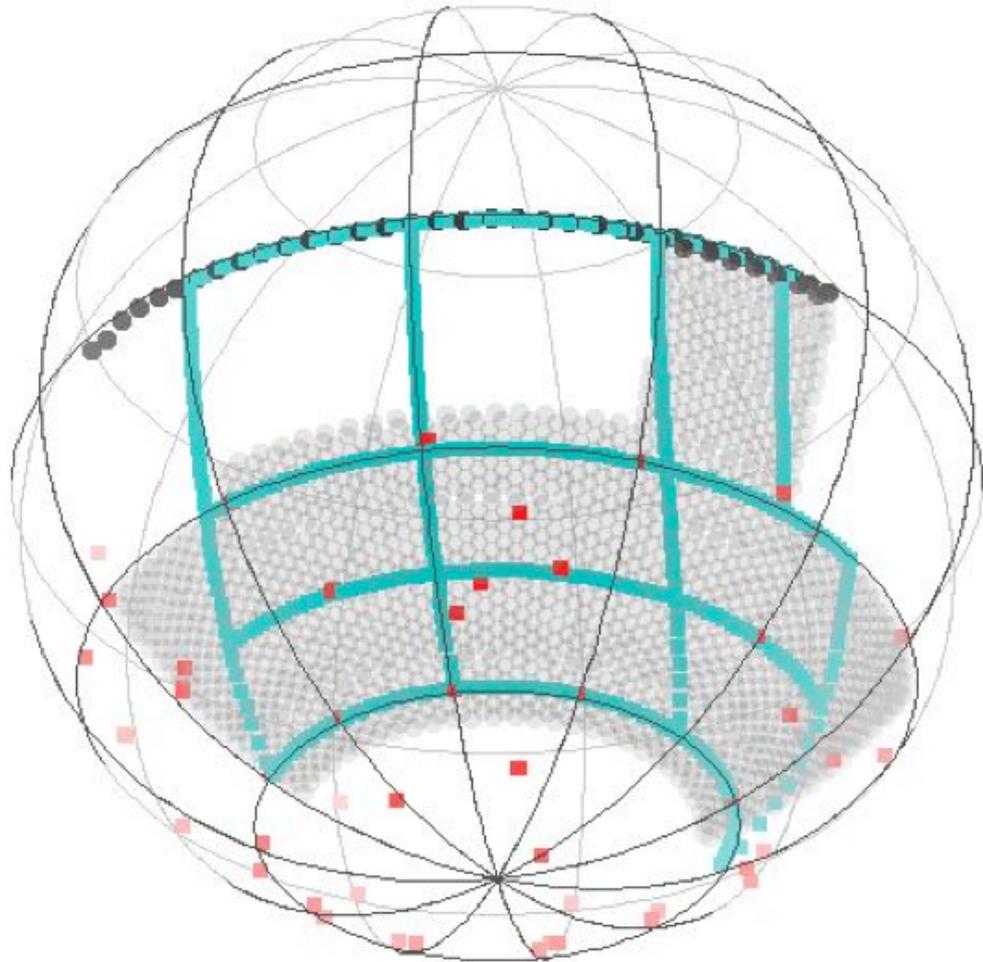


To be able to accurately measure faint astronomical objects with the Survey starting late this year, we need to have “standard” stars: objects of known brightness, spread out across the Southern Hemisphere, so we can make comparison measurements anywhere we look in the sky.



# 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.



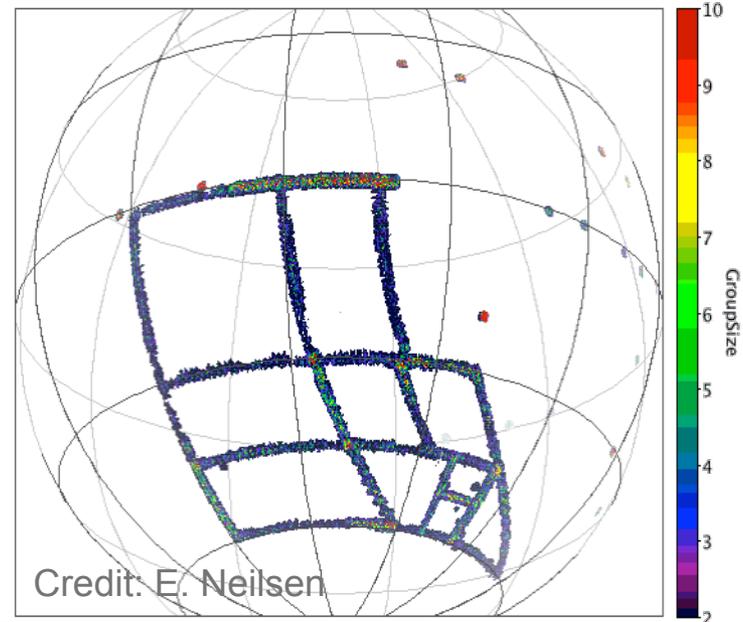
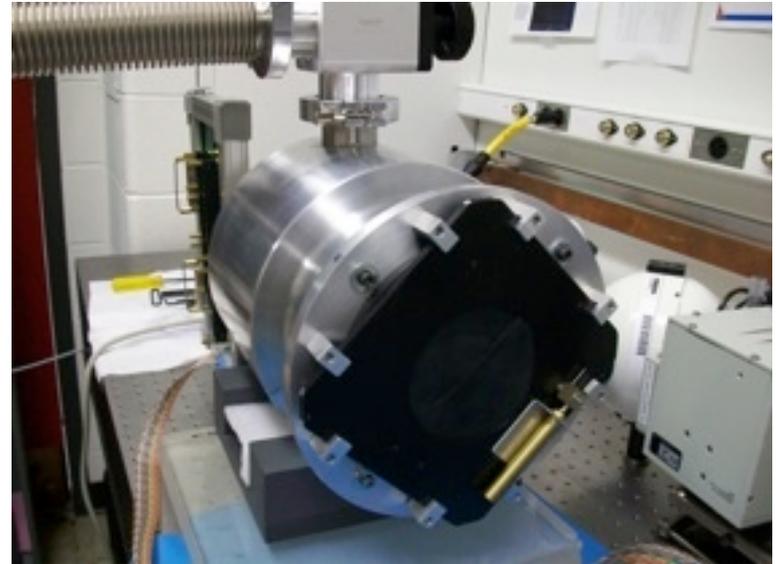
# PreCam Goals and Timeline

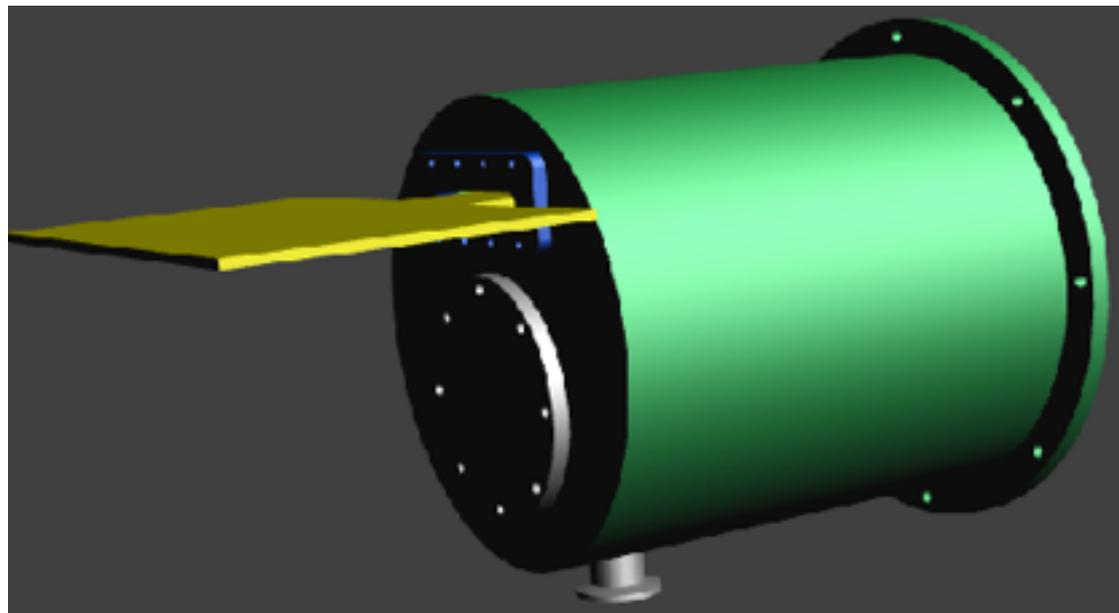
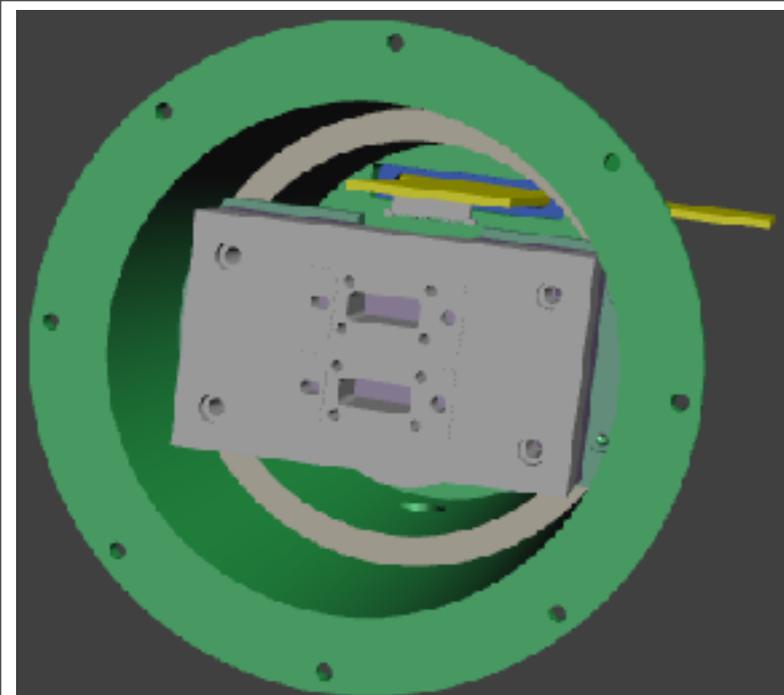
PreCam is a scaled down (2 CCD) version of the DECam that was used (in part) for development and testing of DECam hardware and software.

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

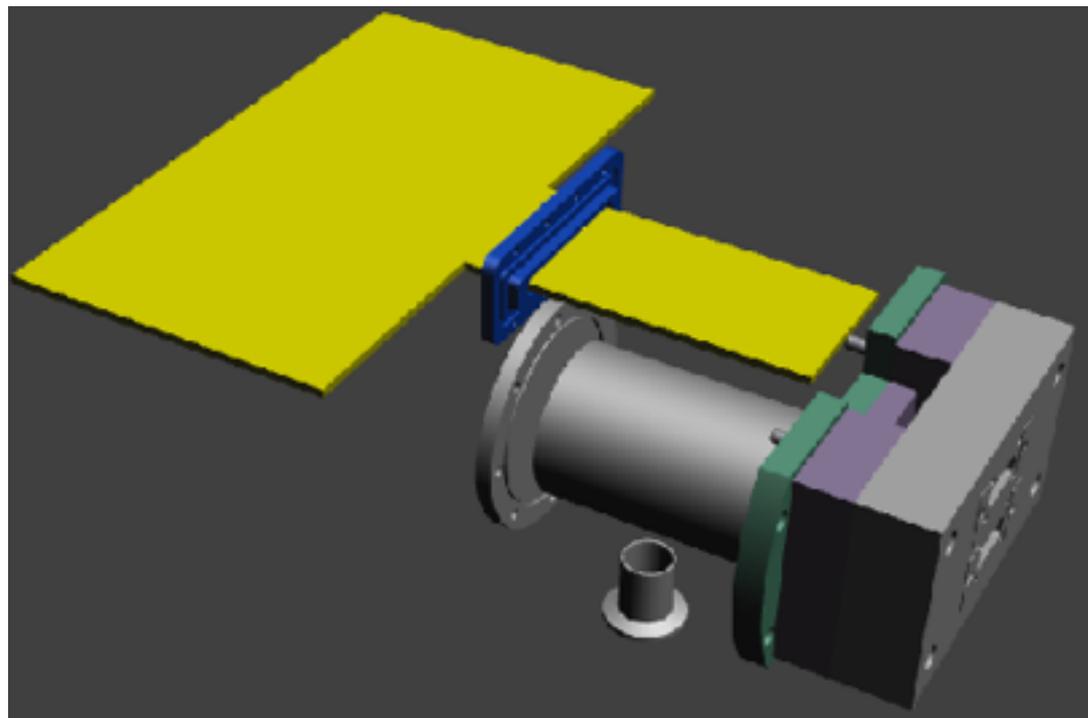
Thermal Transfer (Cu) Block

G-10 Mounting Block

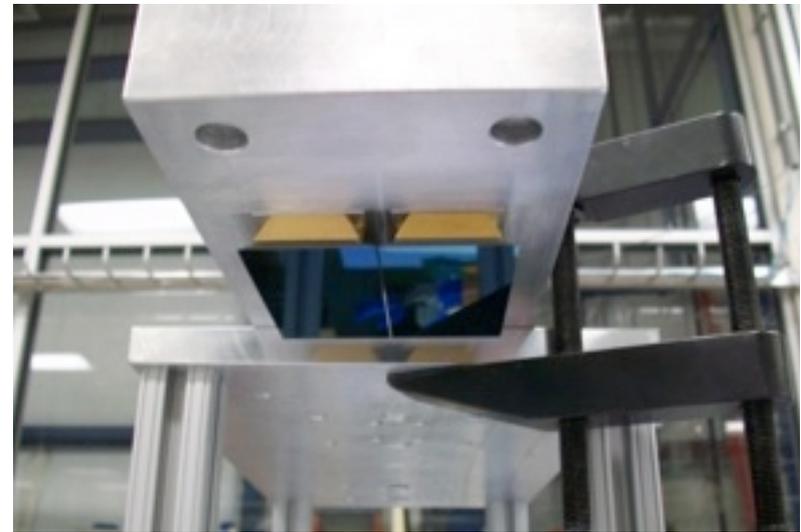
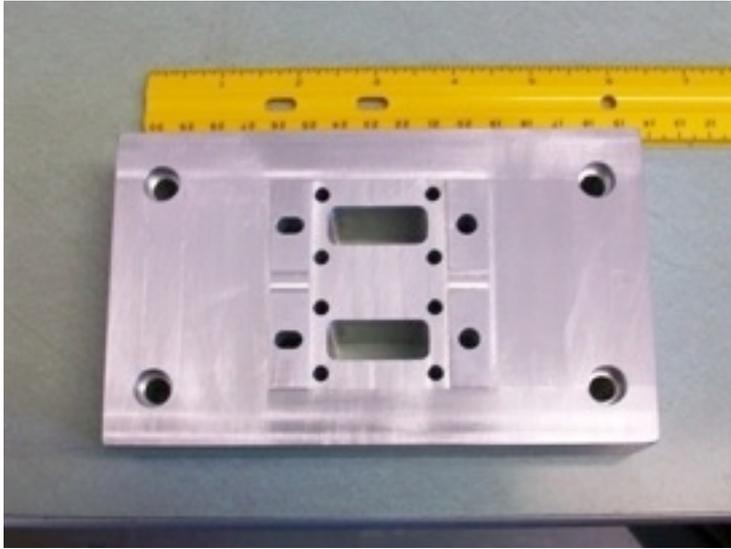
CryoTiger

Vacuum Interface Board

Dewar



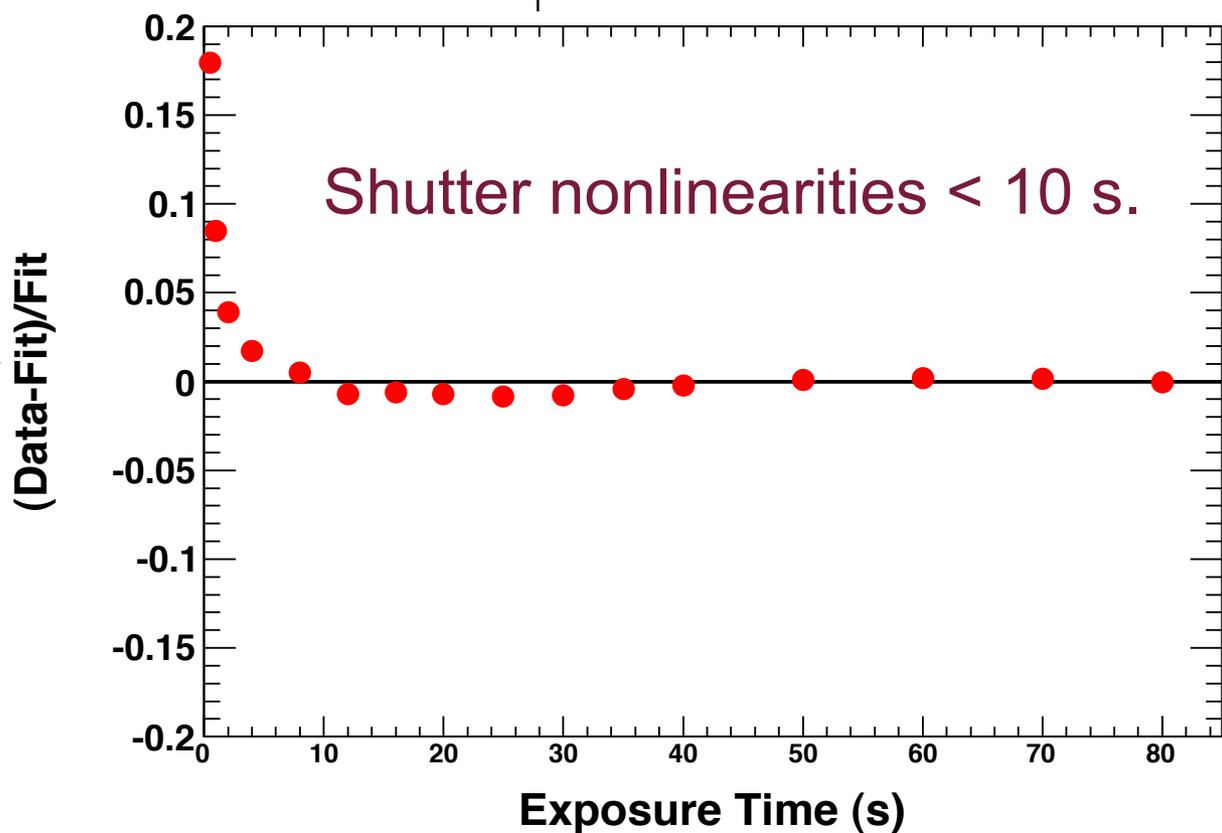
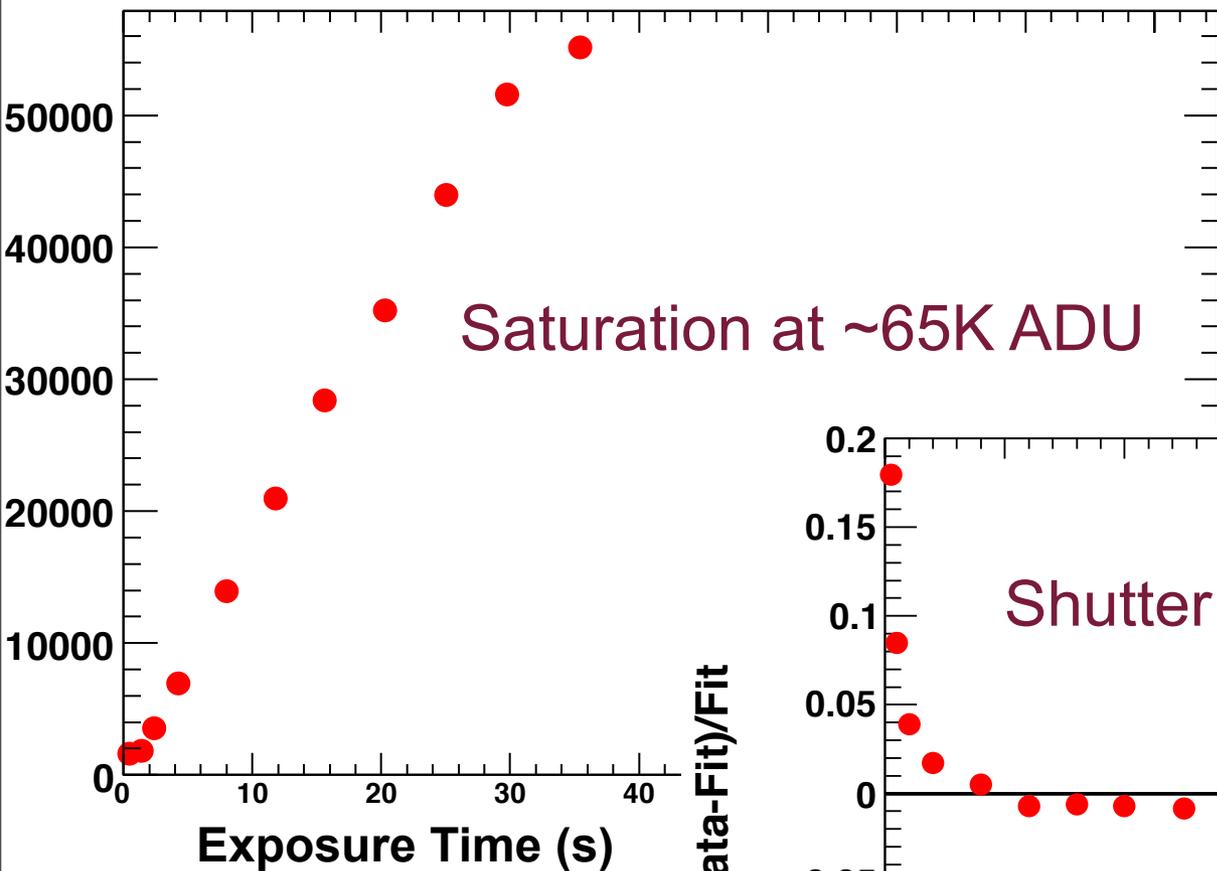
# Focal Plane Support Plate & CCD Installation



# Bench Tests I: Laboratory Setup



# Bench Tests II: Linearity, Full Well



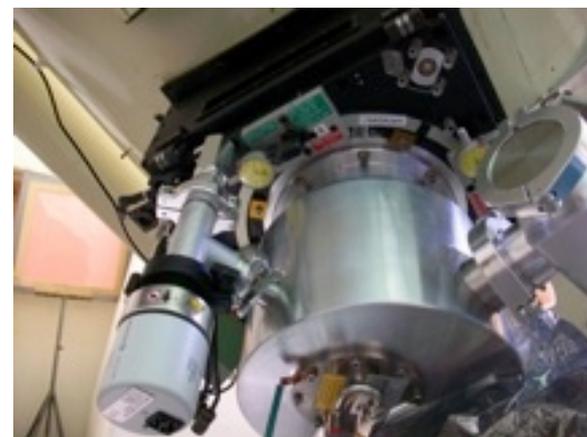
## PreCam Status (as of 2010-09-07)



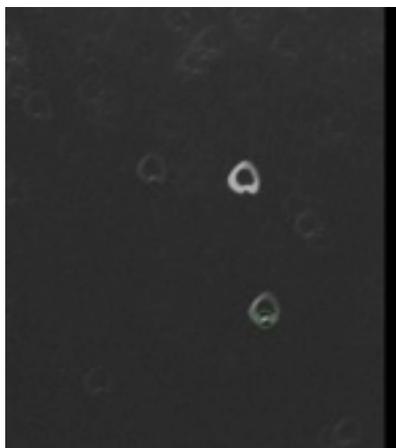
Shipped to Cerro Tololo, Chile



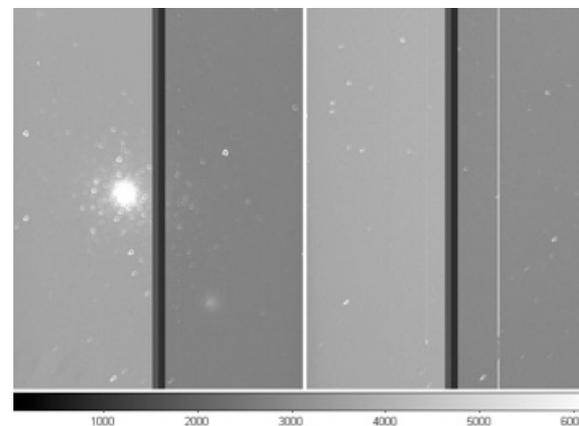
Installed on the Curtis-Schmidt



Commissioning Completed



Optical Alignment Underway



First Light Image of 47 Tuc



Wednesday, July 25, 2012



Wednesday, July 25, 2012



Wednesday, July 25, 2012







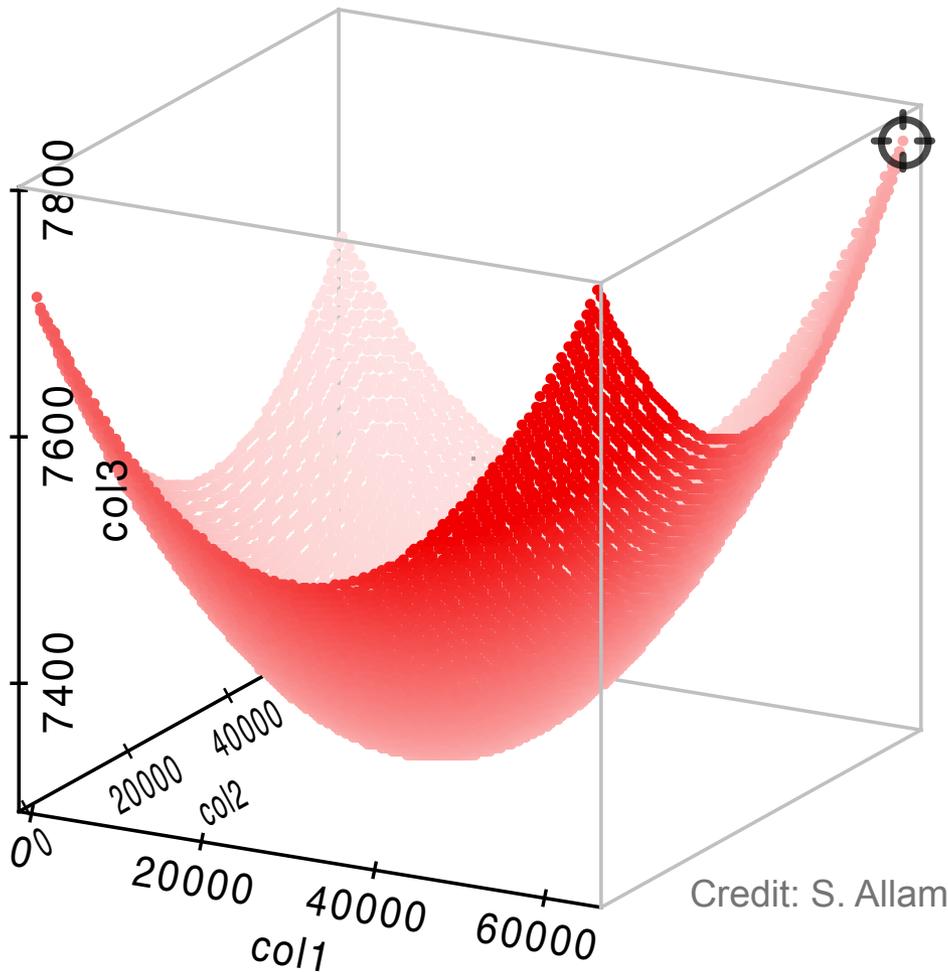
Wednesday, July 25, 2012



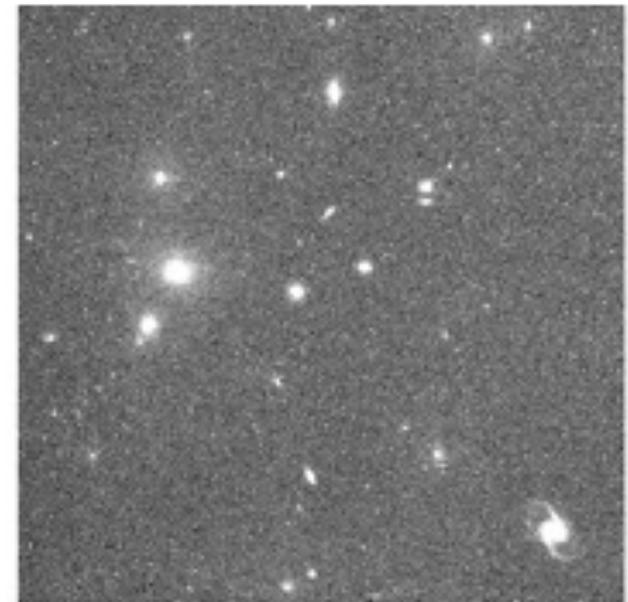
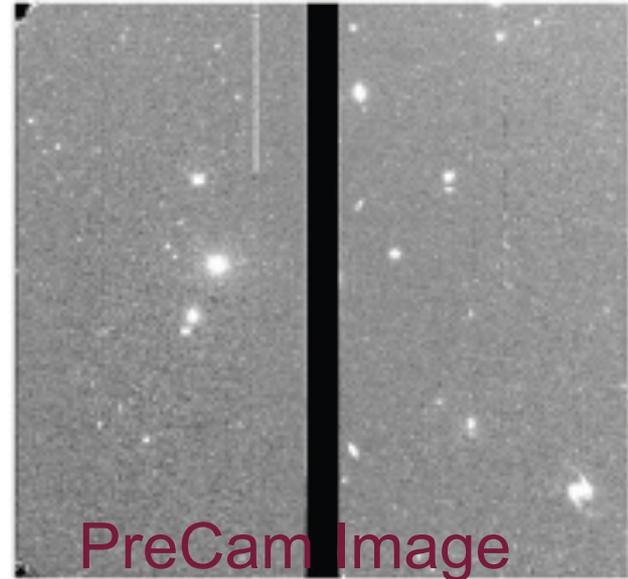
## Vacuum Pump, Camera, and Telescope



# Commissioning I: Best Focus Surface, Early Images



Note curved focus surface  
due to lack of field flattener

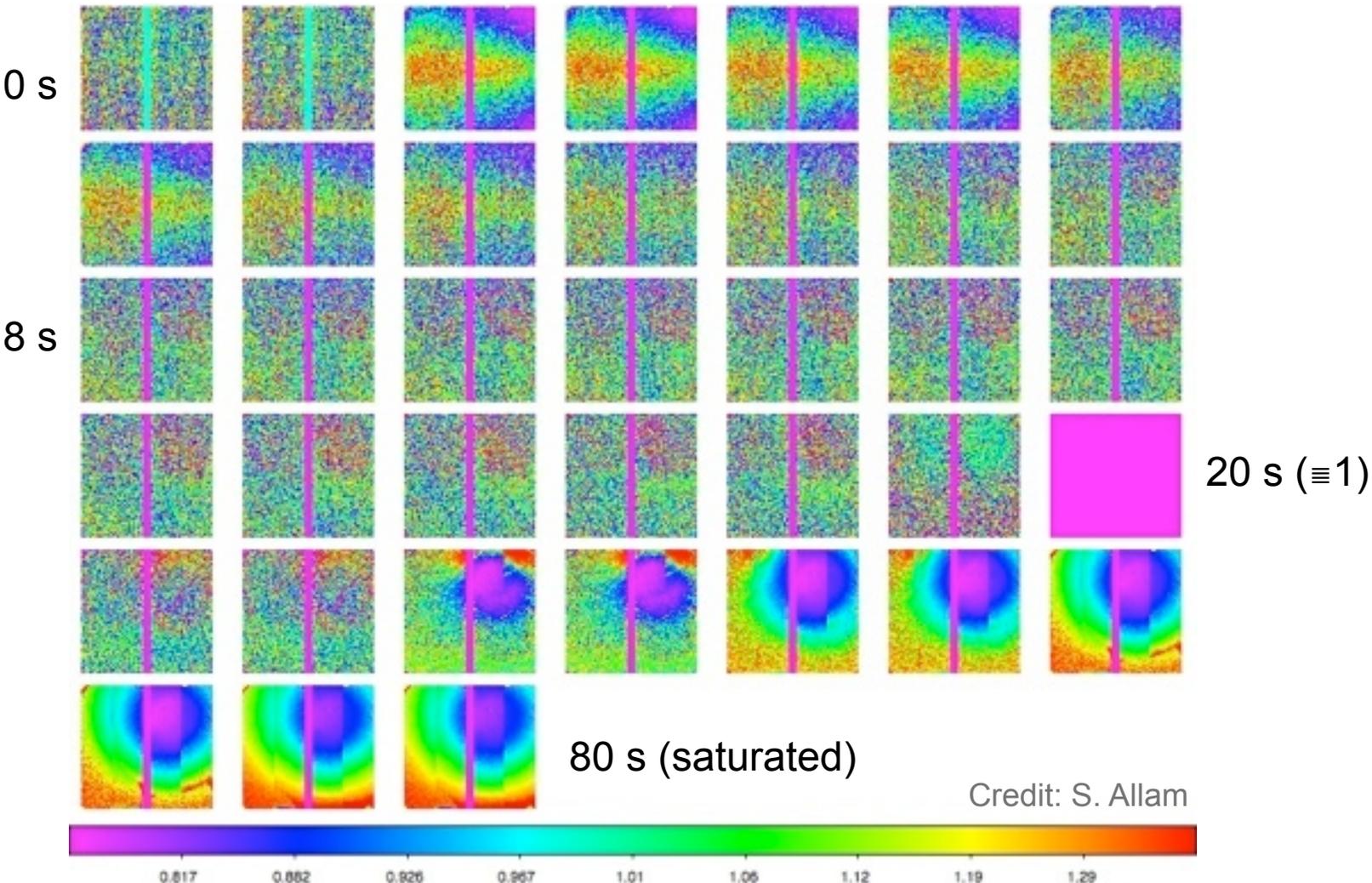


Prior Sky Survey Image



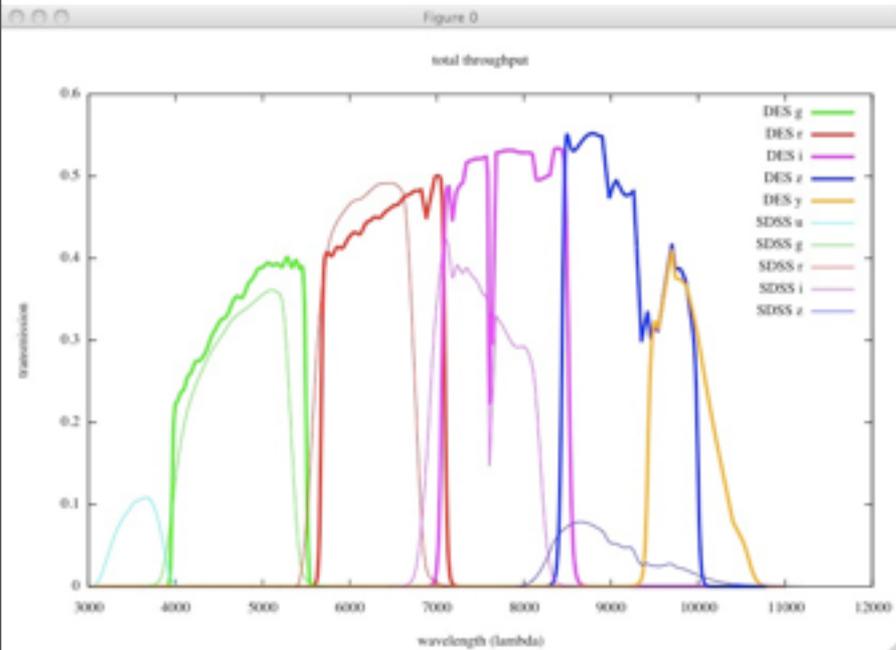
# Commissioning II: Shutter Timing from On-Sky Data

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

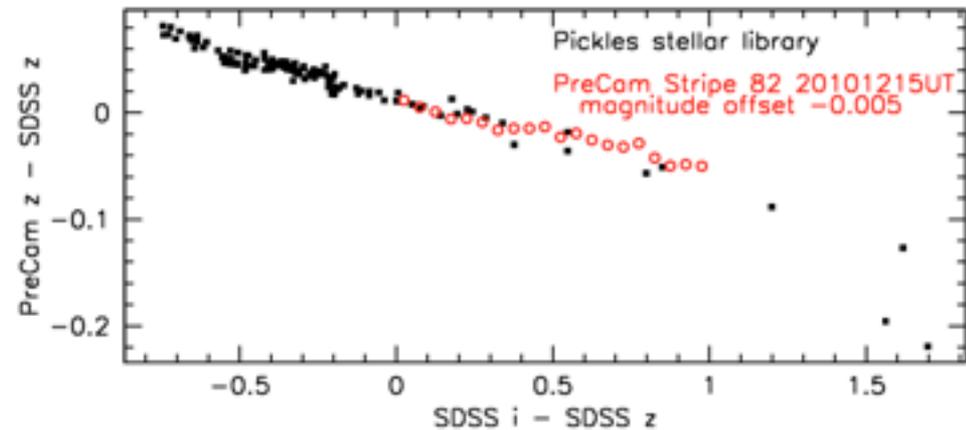
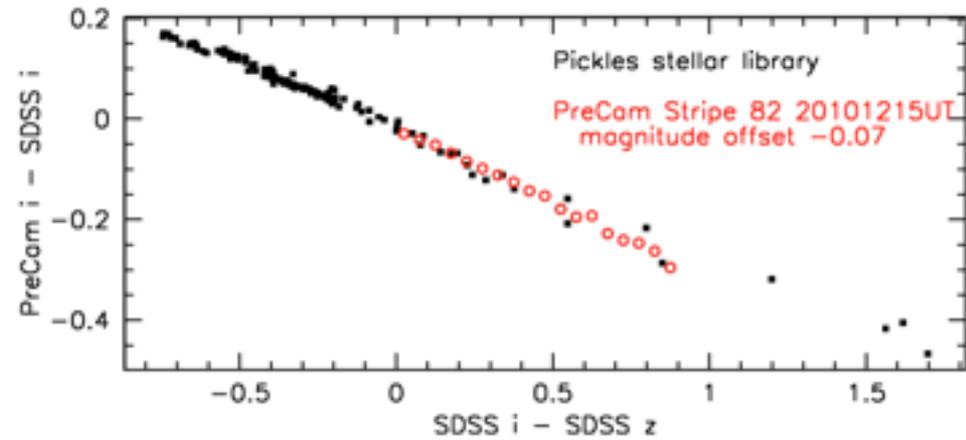


# Commissioning III: Filter Performance

## Transmission vs. Wavelength: DES Filters vs. Sloan Filters



## DES/PreCam Color Response



Credit: D. Tucker



## How is the weather?

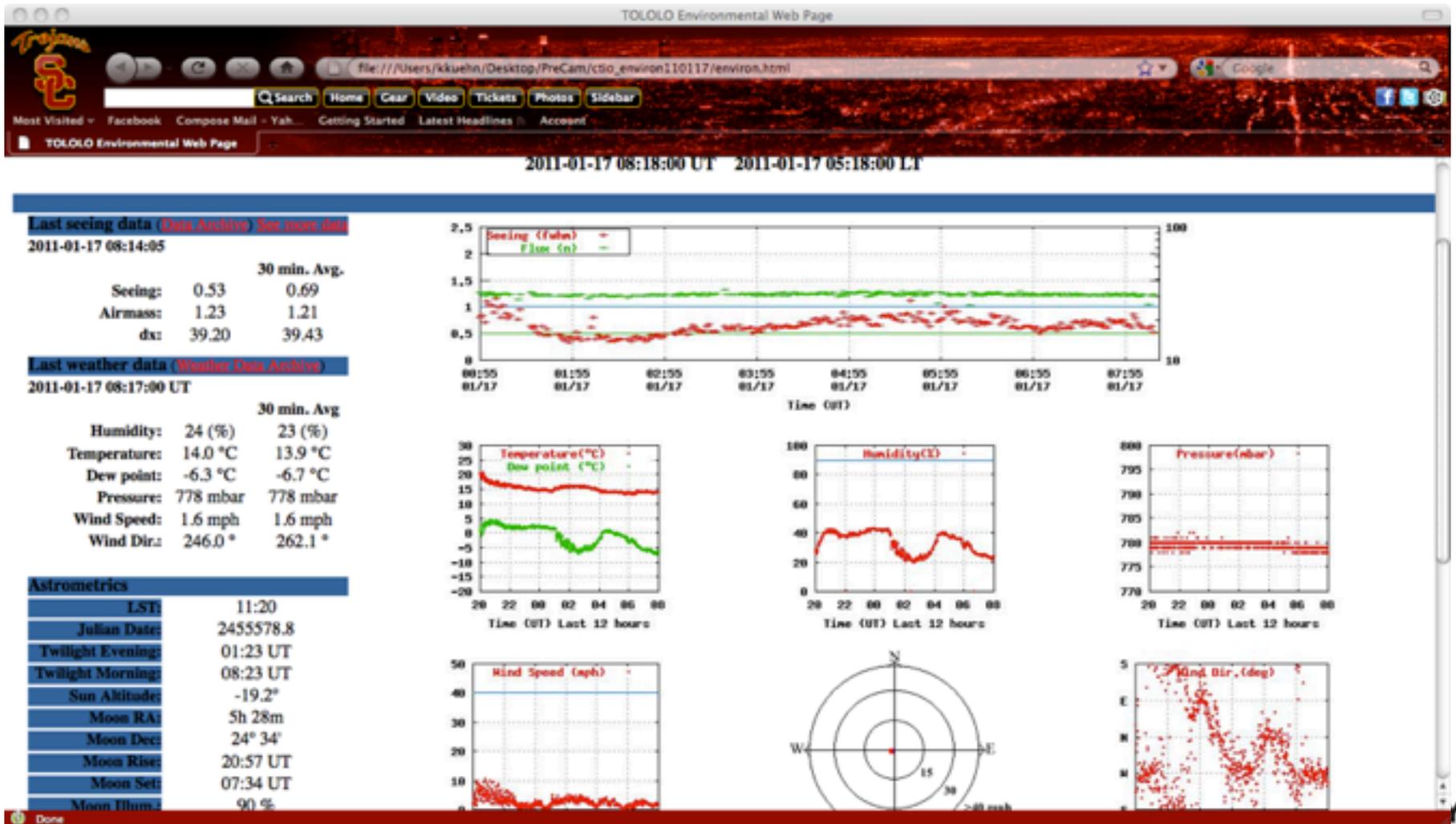




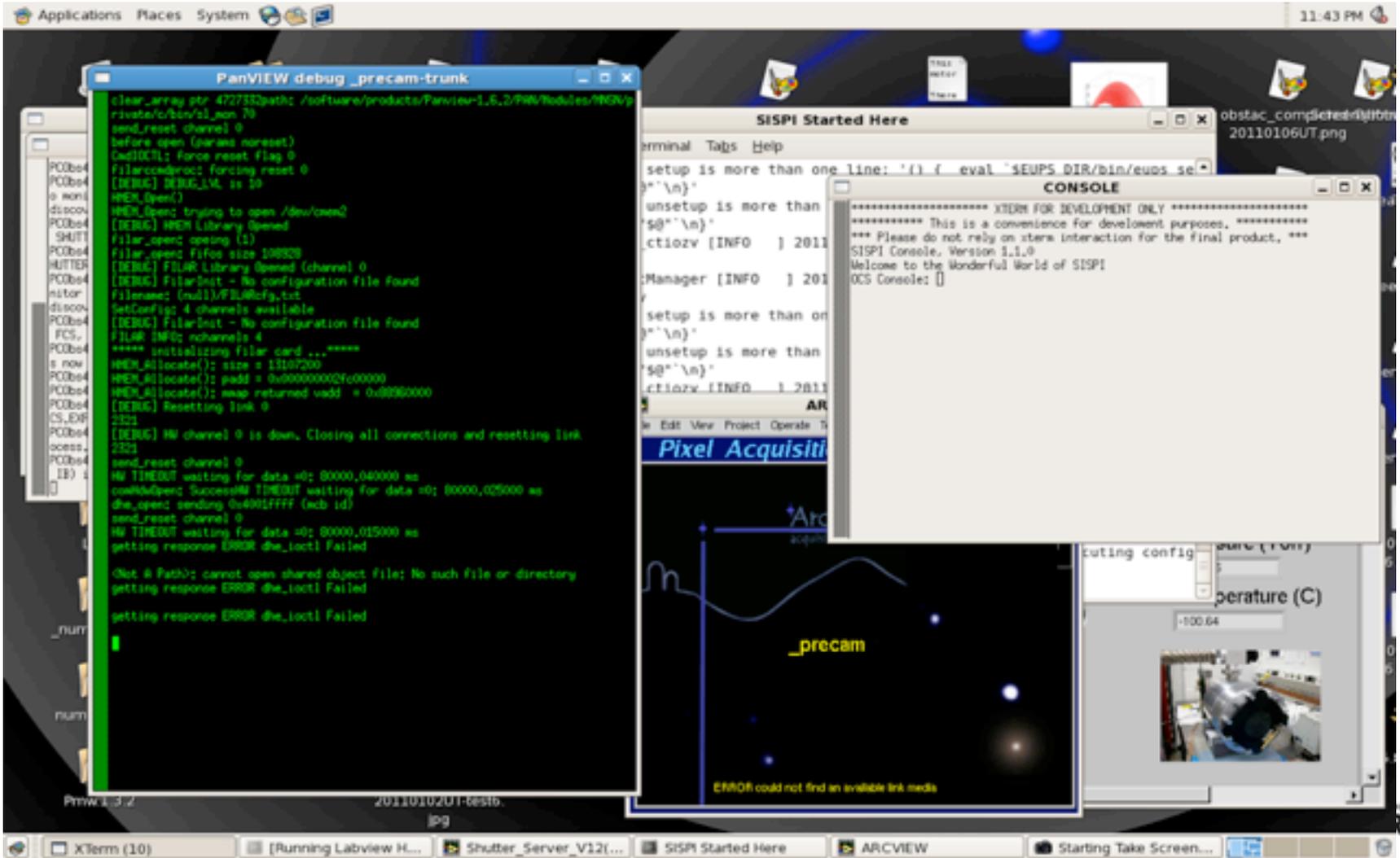
CTIO Sat 2011/11/05 14:38:18 2011

Up: 16+20:28:04, Frame: 224277, Exp: 617, T: +35.0

# Recording the Environment at Cerro Tololo



# Meanwhile, in the Control Room...



The screenshot shows a control room interface with several windows:

- PanVIEW debug\_precam-trunk**: A LabVIEW debug window showing the following code and output:
 

```
clear_array ptr=472732;path: /software/products/Panview-1.6.2/PANModules/PRECA...
private/c/bon/s1_xon 70
send_reset channel 0
before open (various noreset)
OutDIOCTL: Force reset flag 0
Fillarcobject forcing reset 0
[DEBUG] DEBUG_1/A, ss 10
HREN_Open()
HREN_Open() trying to open /dev/cwcn2
[DEBUG] HREN Library Opened
Filearc_openc opening (1)
Filearc_openc Fifos size 1048576
[DEBUG] FILEAR Library Opened (channel 0)
[DEBUG] FileArc - No configuration file found
Filename: (null)/FILEARcfg.txt
SetConfig 4 channels available
[DEBUG] FileArc - No configuration file found
FILEAR INFO: nchannels 4
**** initializing filearc card ****
HREN_allocate(): size = 13107200
HREN_allocate(): padd = 0x000000002f000000
HREN_allocate(): mmap returned vadd = 0x009060000
[DEBUG] Resetting link 0
2321
[DEBUG] NI channel 0 is down. Closing all connections and resetting link
2321
send_reset channel 0
NI TIMEOUT waiting for data #0: 80000,040000 as
connhdOpen: SuccessNI TIMEOUT waiting for data #0: 80000,025000 as
dhw_openc sending 0x4001ffff (acb id)
send_reset channel 0
NI TIMEOUT waiting for data #0: 80000,015000 as
getting response ERROR dhw_loactl Failed

Out & Path0: cannot open shared object file: No such file or directory
getting response ERROR dhw_loactl Failed

getting response ERROR dhw_loactl Failed
```
- SISPI Started Here**: A terminal window showing system setup commands and status messages like "setup is more than one line: '{f \_eval `SEUPS\_DIR/bin/euops se...'"
- CONSOLE**: A console window displaying a welcome message:
 

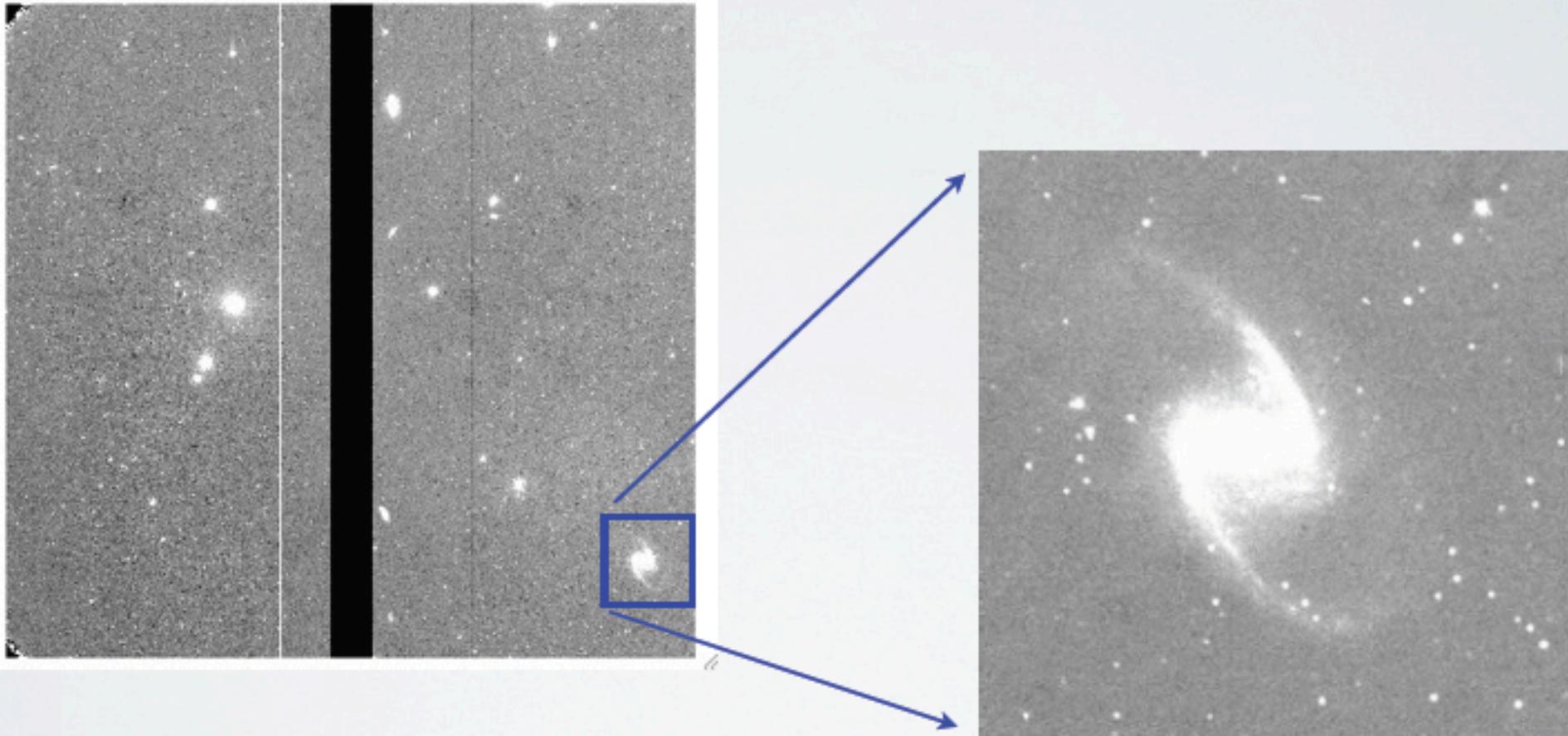
```
***** XTDM FOR DEVELOPMENT ONLY *****
***** This is a convenience for development purposes. *****
**** Please do not rely on stera interaction for the final product. ****
SISPI Console, Version 1.1.0
Welcome to the Wonderful World of SISPI
OCS Console: []
```
- Pixel Acquisition**: A plot window showing a graph with a blue curve and the label "\_precam". Below the plot, it says "ERROR could not find an available link media".
- Temperature (C)**: A window showing a temperature reading of -100.64 and a small camera view of the control room.

The taskbar at the bottom shows several running applications: XTerm (10), [Running Labview H..., Shutter\_Server\_V12(...), SISPI Started Here, ARCVIEW, and Starting Take Screen...

## Eight to Sixteen Hours a day...

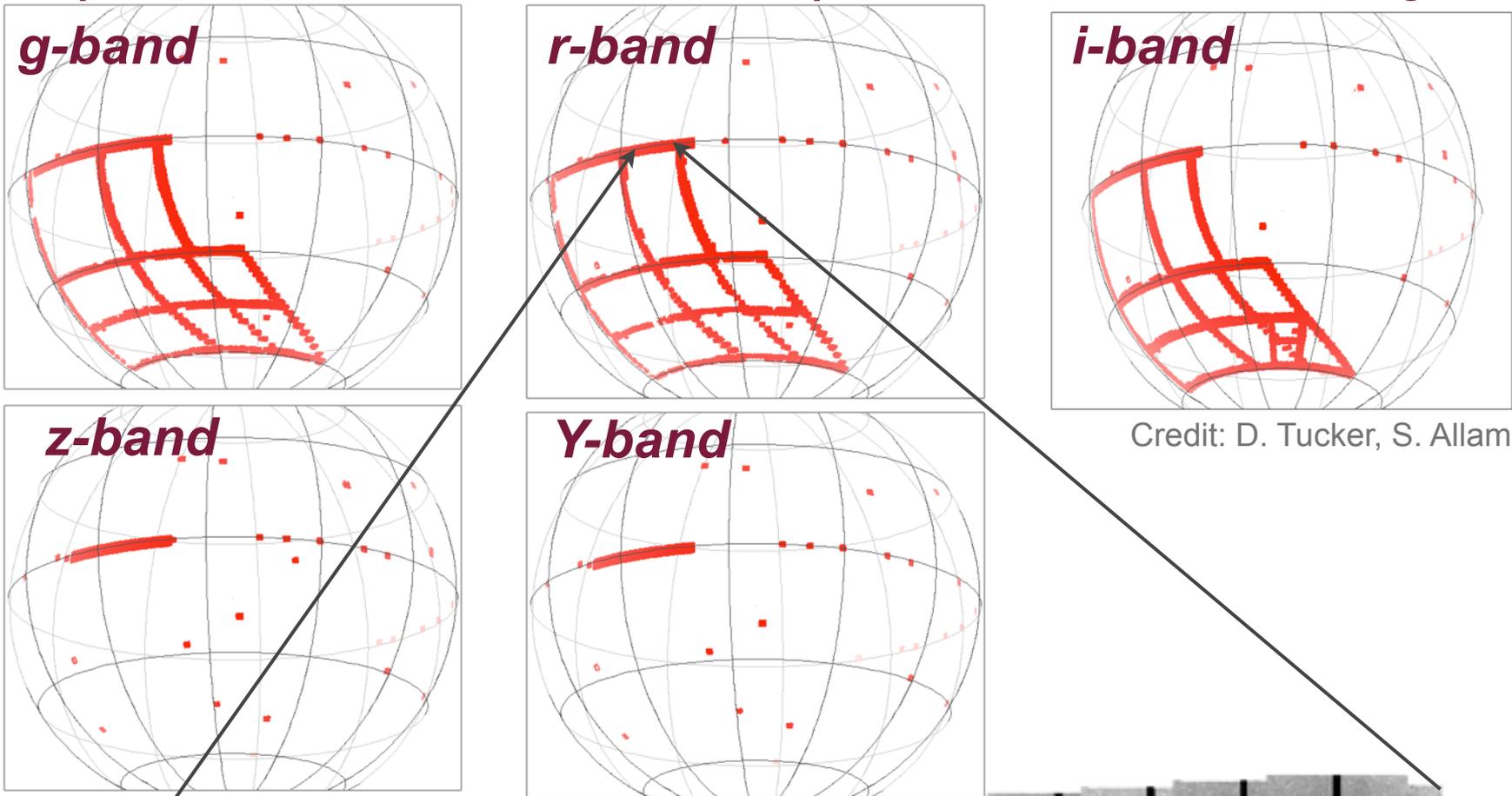


## PreCam Image of a Barred Spiral Galaxy



# PreCam Observations by Filter

## Steps to the PreCam Southern Hemisphere Standard Star Catalog

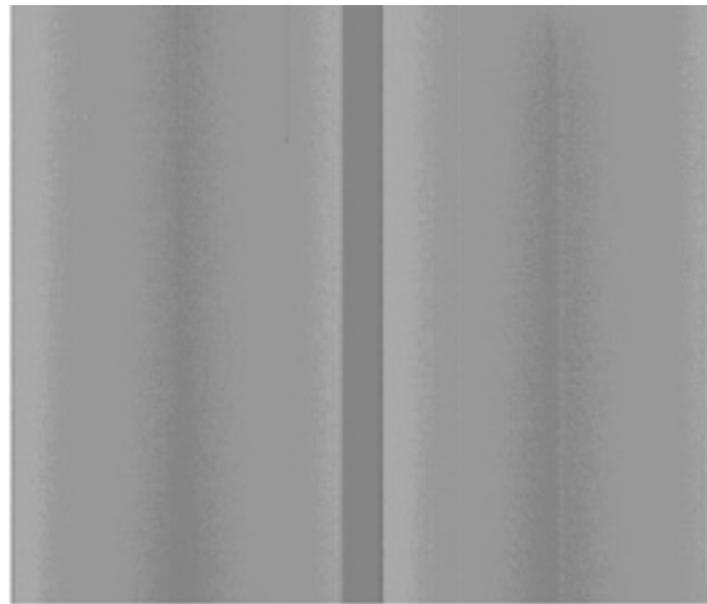


Credit: D. Tucker, S. Allam

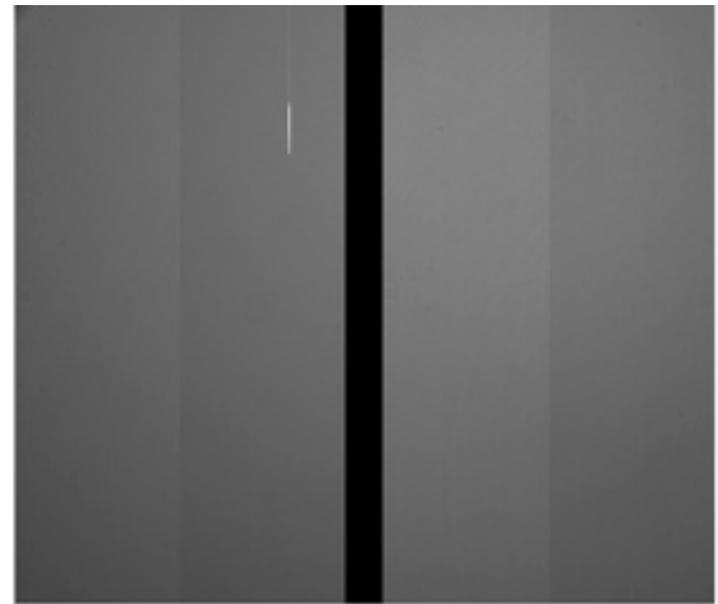


# Data Processing at FNAL & ANL

- 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



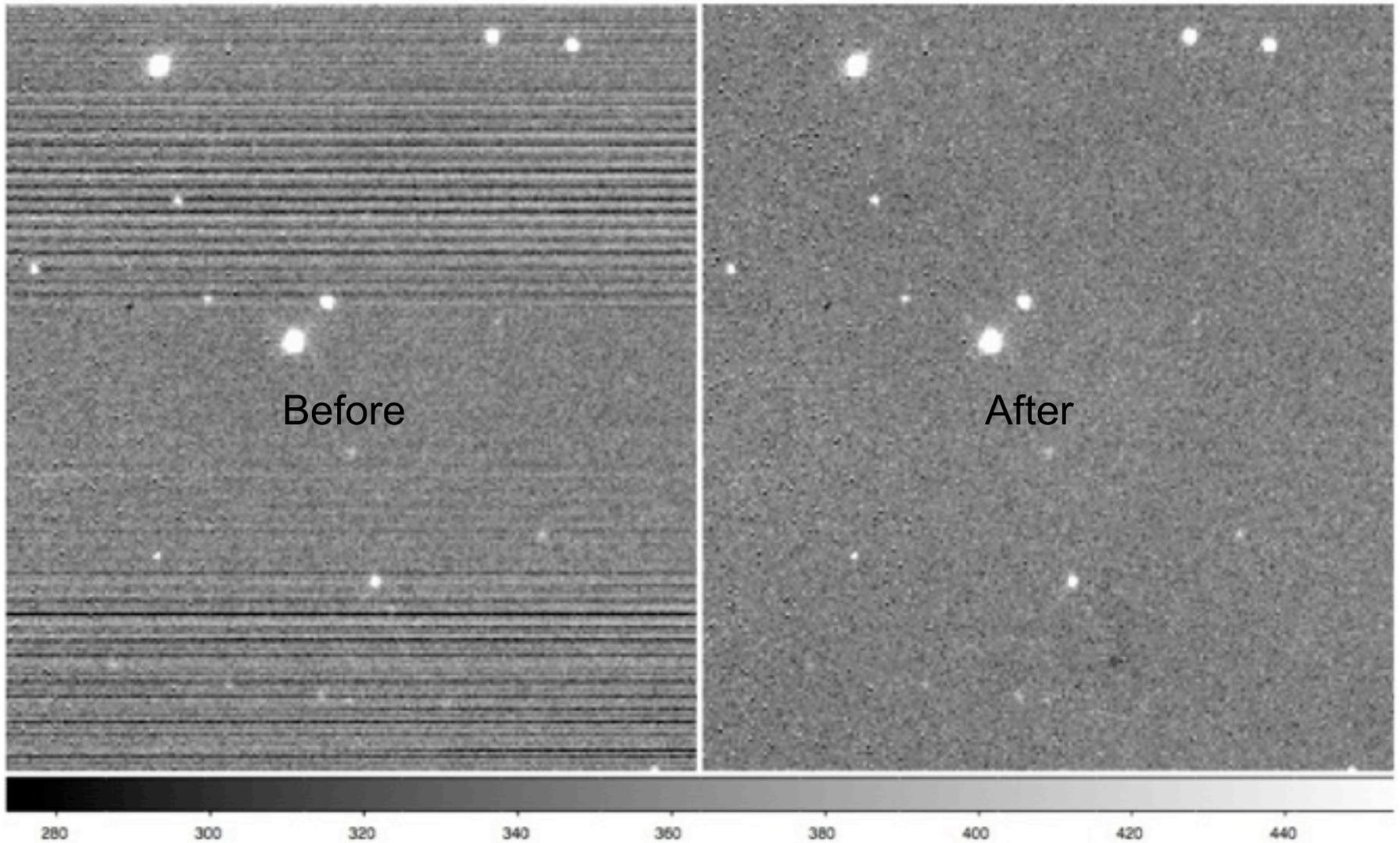
Bias



Flat



# Data Processing II: Streaking/Banding & Software Corrections



Before

After

280

300

320

340

360

380

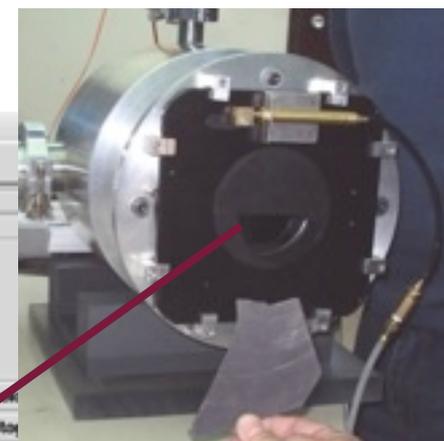
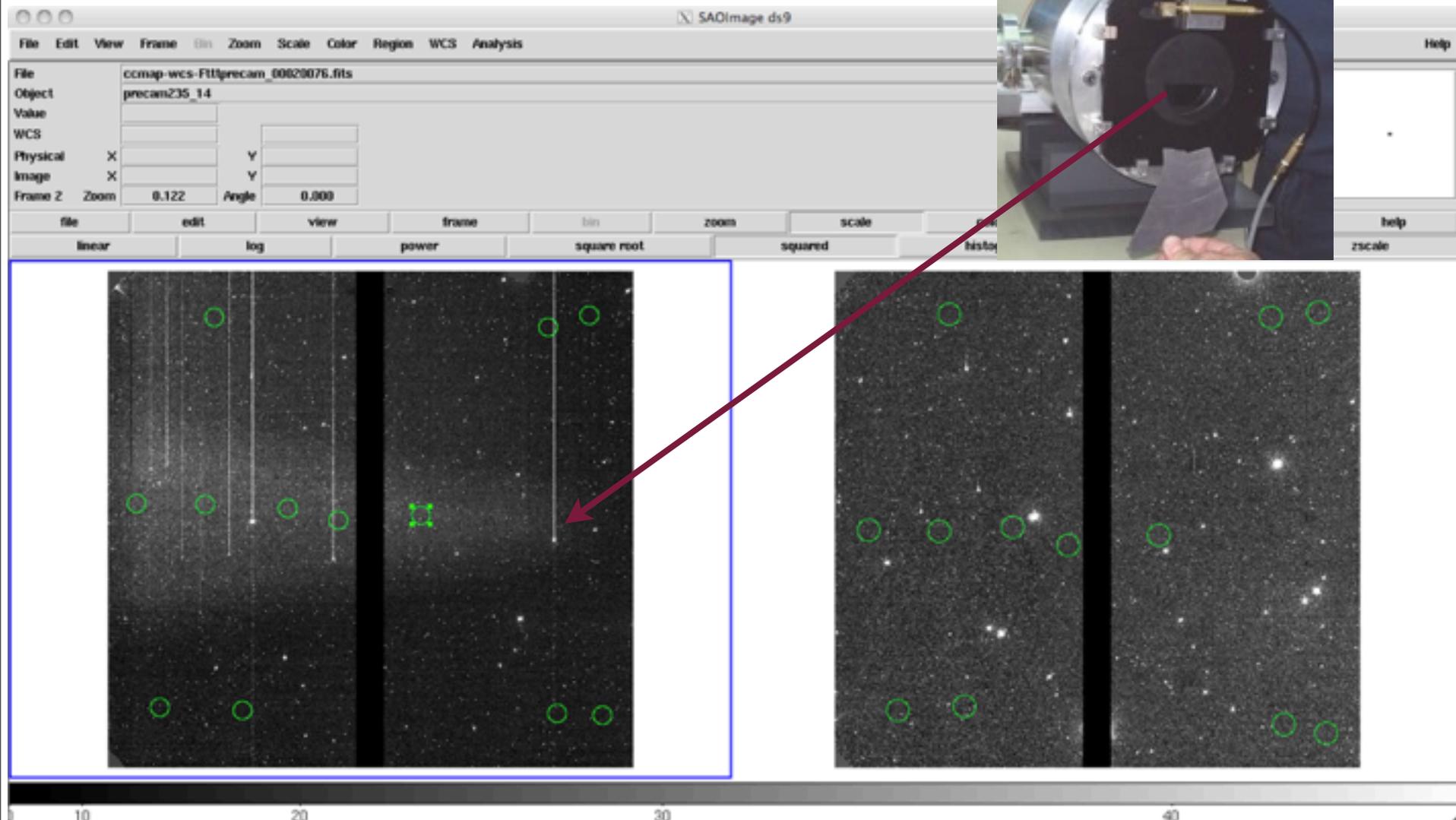
400

420

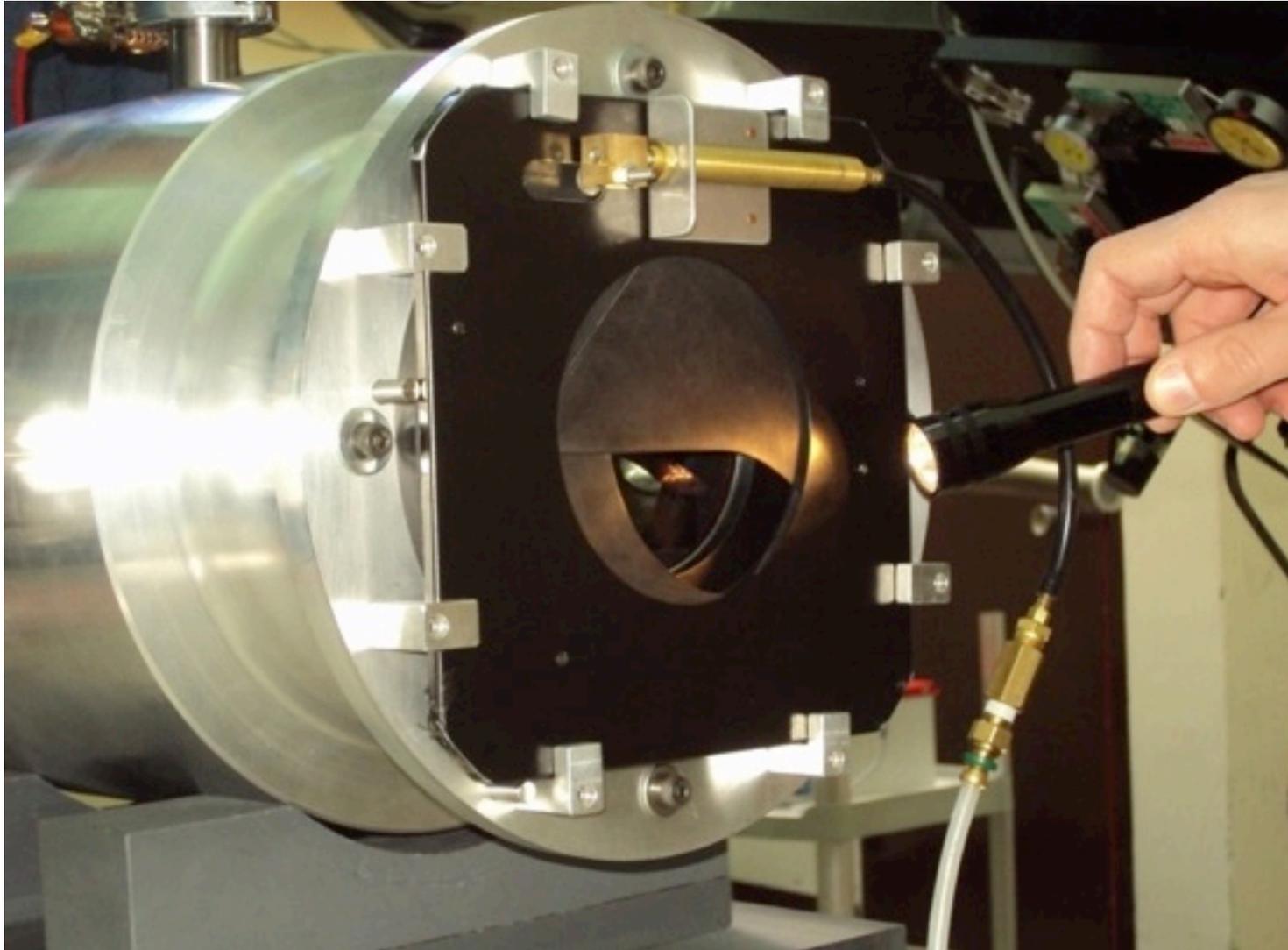
440

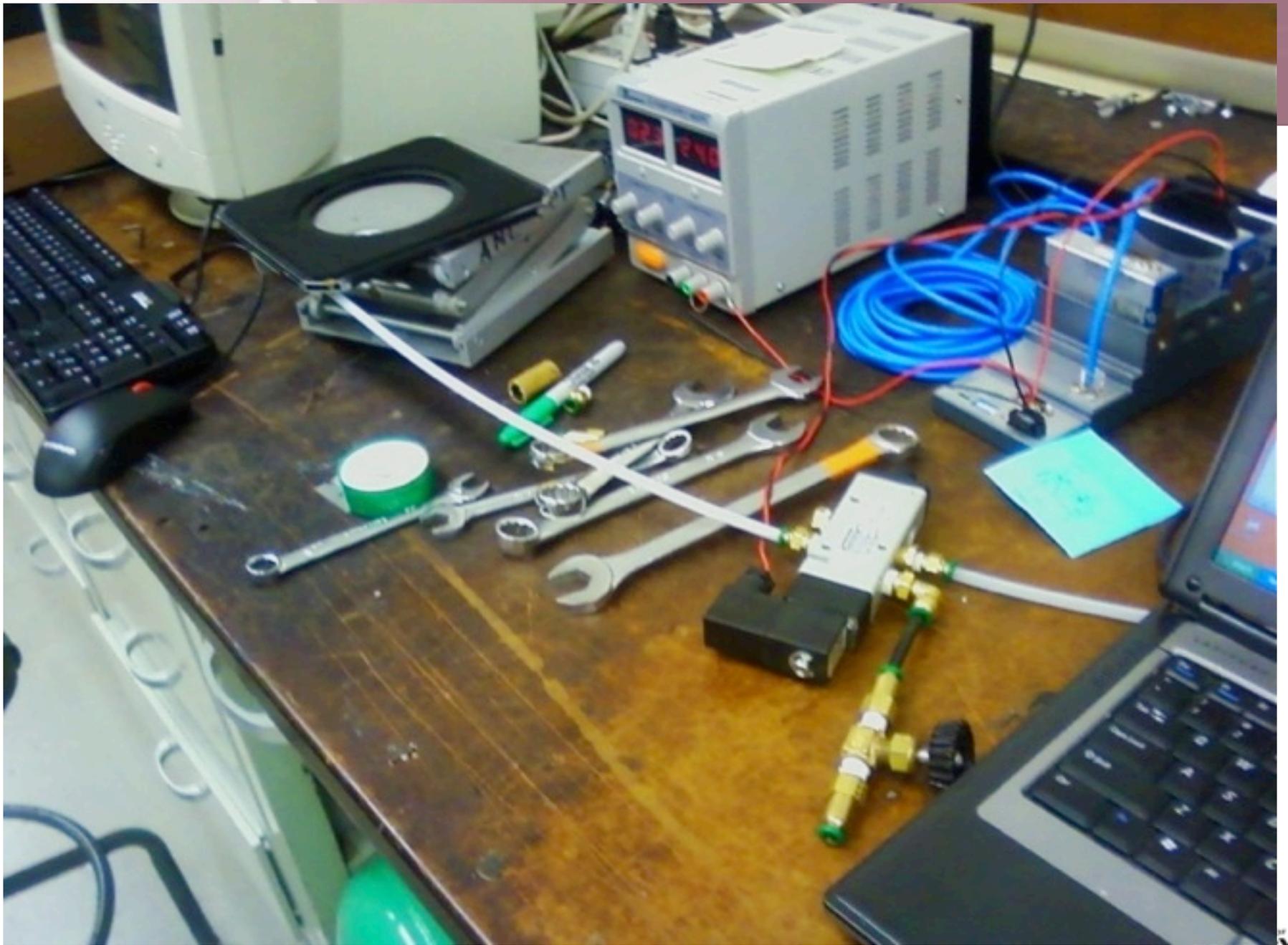


# Data Processing III: Identifying Problematic Shutter Images corrected with local background subtraction



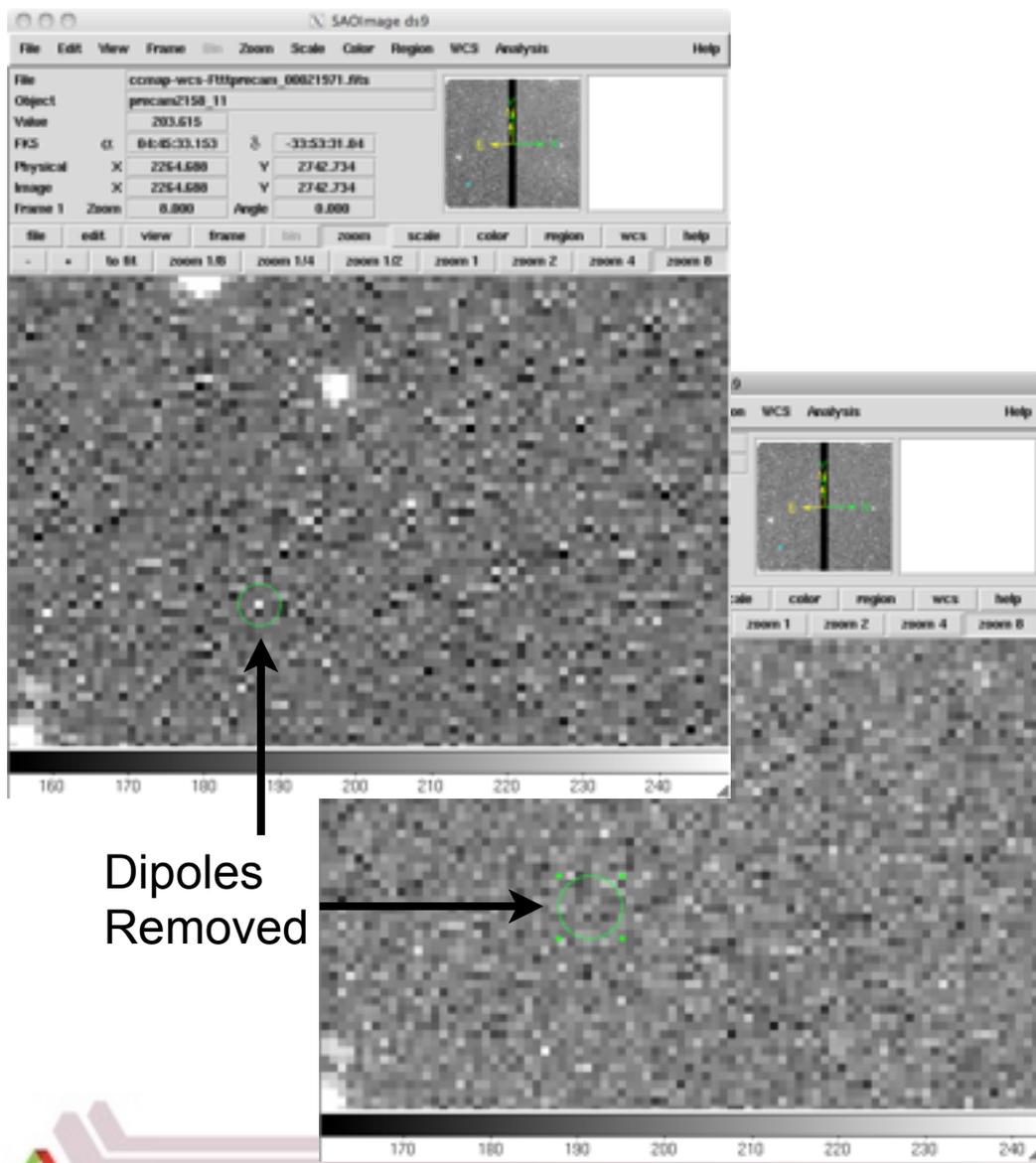
Oops...



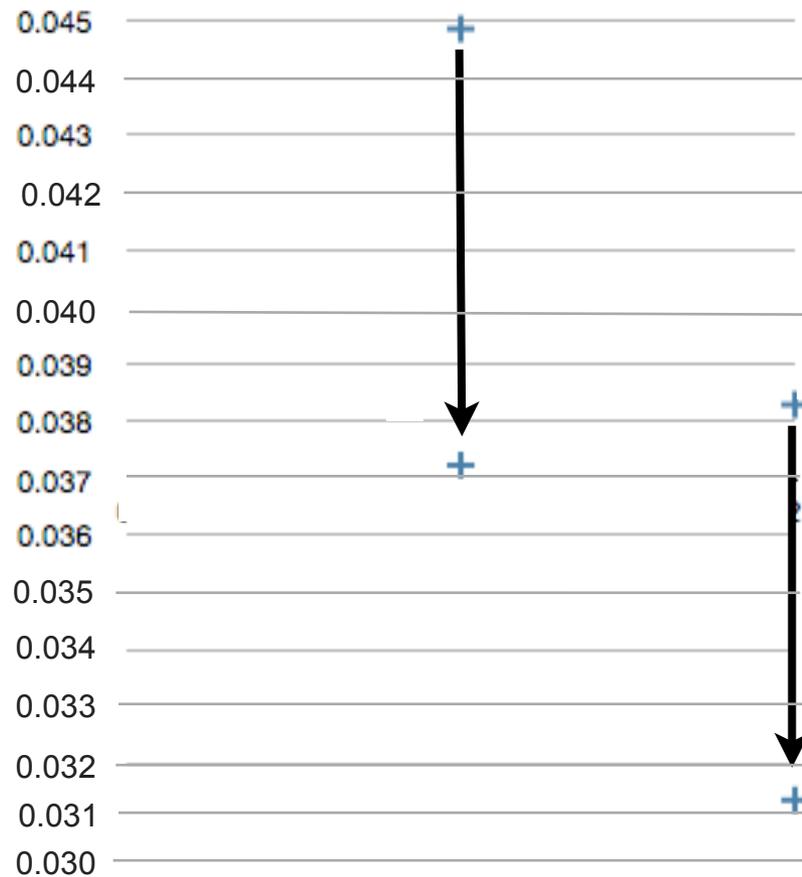


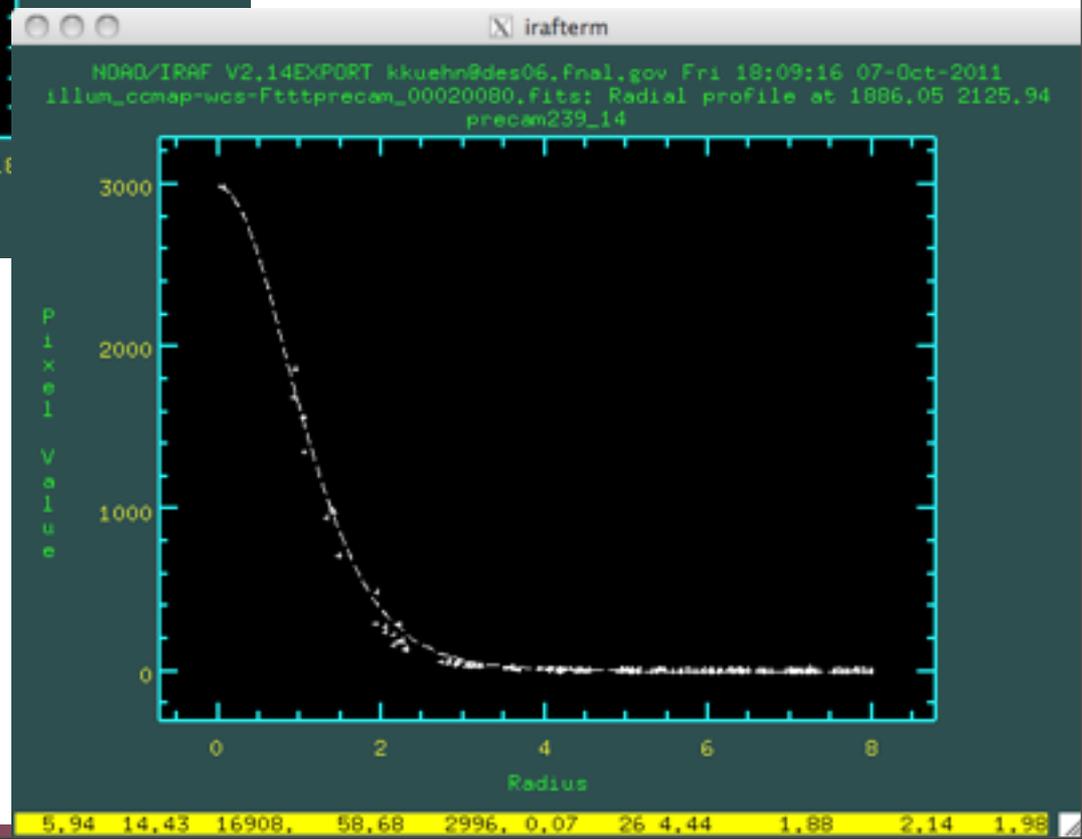
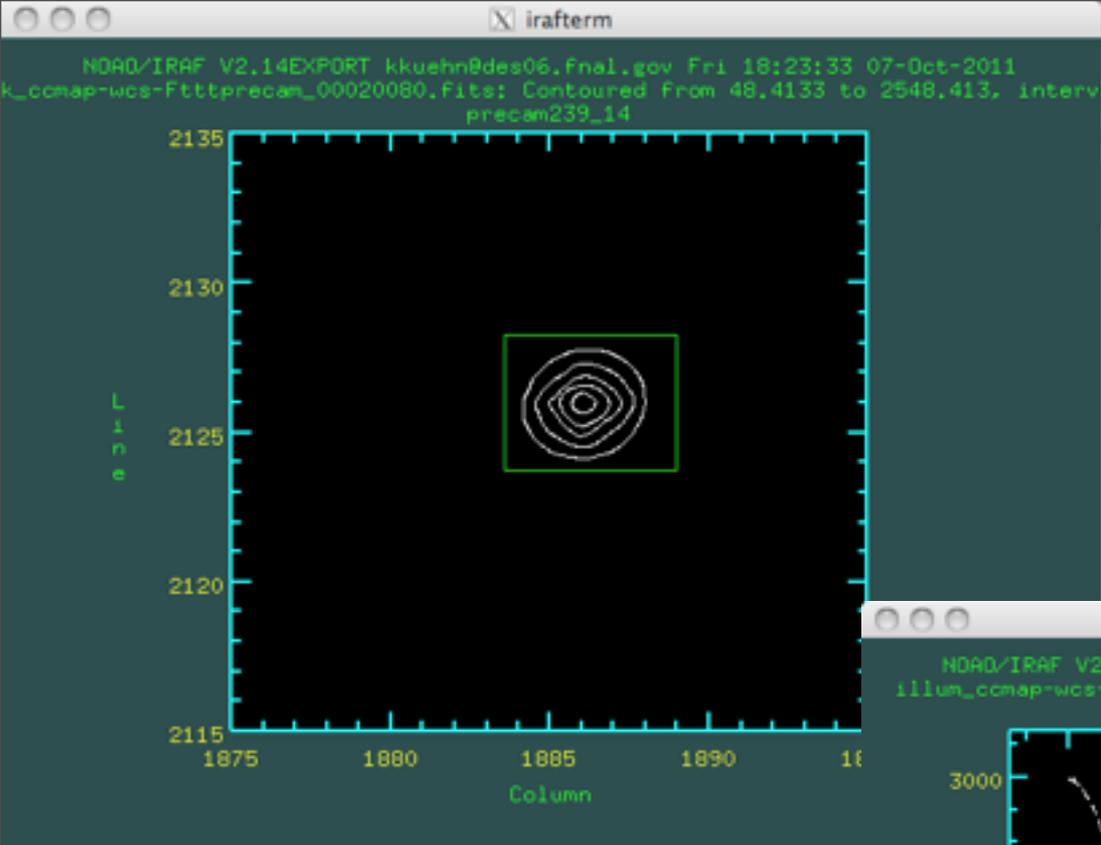
# Data Processing IV: Illumination Correction

~ 1% improvement to i,z band photometry



CCMAP vs. ILLUM, Z band



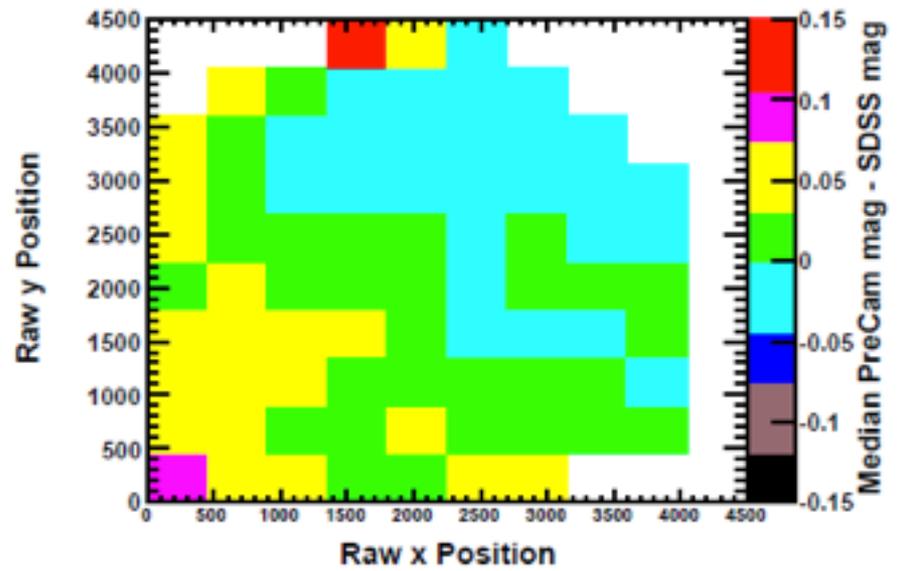


Date	Zero-Point Offset (USNO)	Standard Deviation (USNO)	Zero-Point Offset (Southern Standards)	Standard Deviation (Southern Standards)	Zero-Point Offset (SDSS)- RA40to50	Standard Deviation (SDSS)- mag<15	Standard Deviation (SDSS)-NoMagCut
20101215			g: 2.3372 r: 2.1269 i: 2.2864 z: 2.5072	g: .05323 r: .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

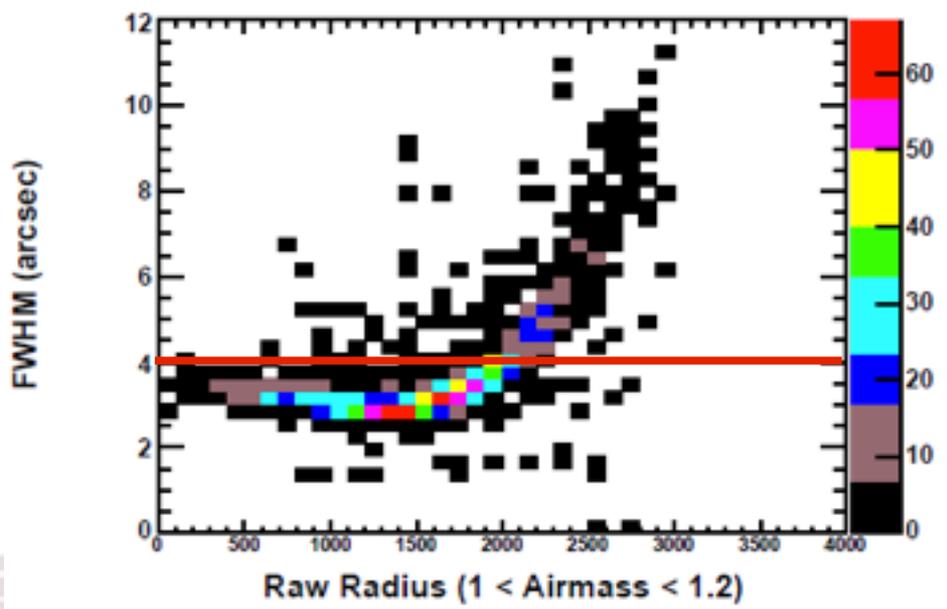
# Final Data Analysis Steps: Star Flats + Data Quality Cuts

added “flat field” to remove final CCD response gradient prior to analysis

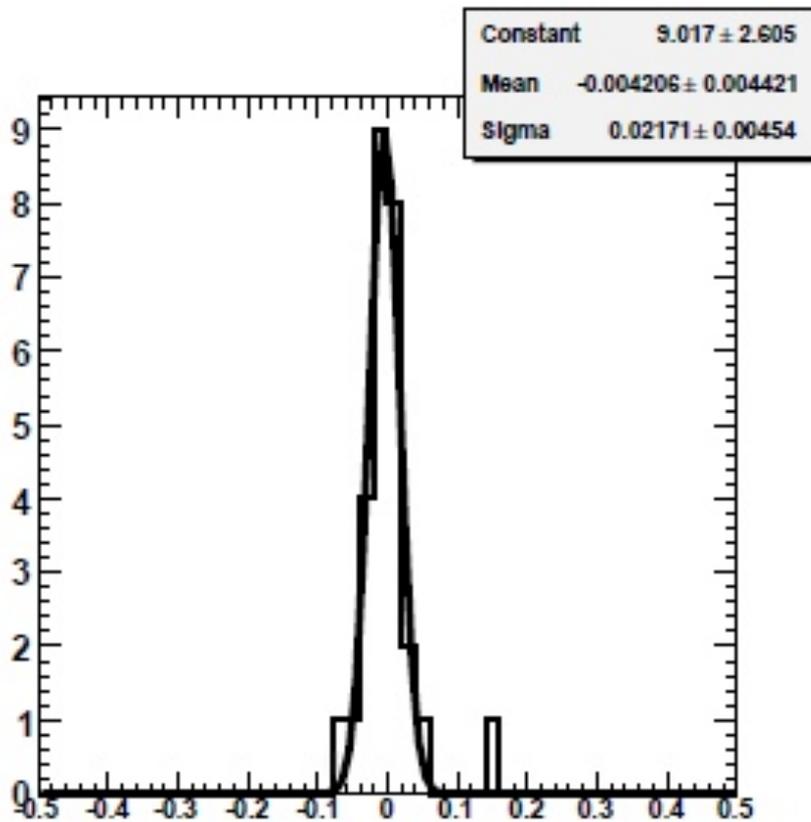
- USNO, Southern u’g’r’i’z’, and SDSS standards
- SDSS airmass correction and Star Flat correction applied
- Selection Criteria:
- magerr, FWHM, Stellarity



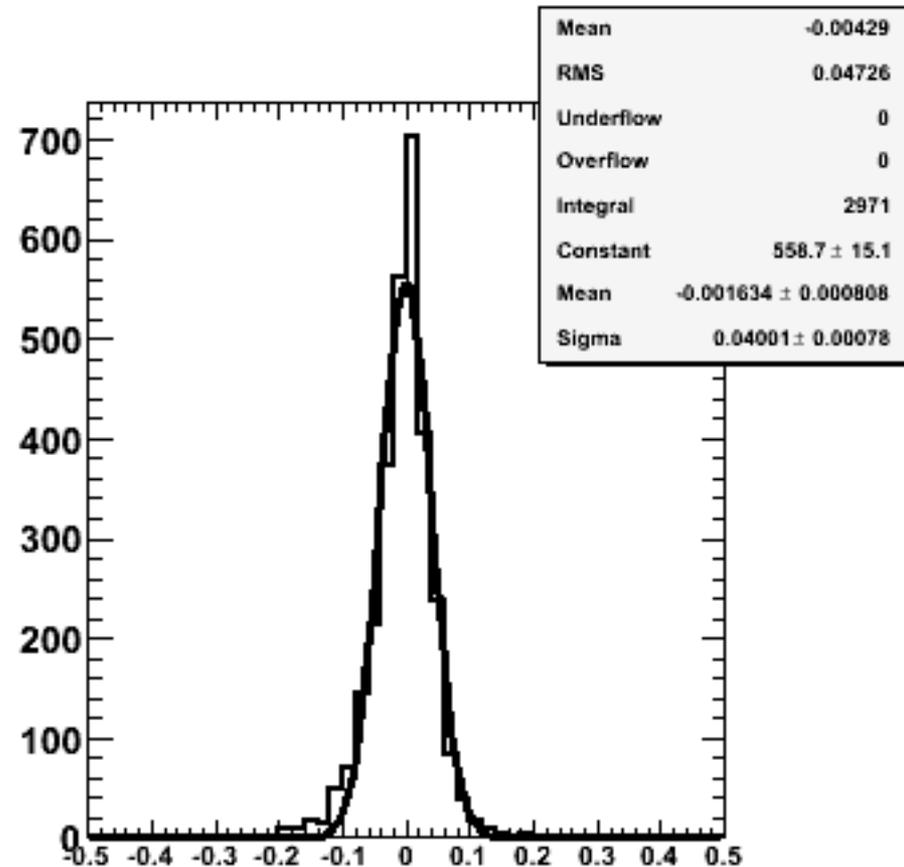
v3aper12	.06871
v3aper12, stellarity > .95	.04901
v3aper10, stellarity > .95	.048496
v3aper10, stellarity > .95, fwhm < 4.	.048434
v3aper10, stellarity > .95, fwhm < 4. , pixels cut	.048447
v3aper10, stellarity > .95, fwhm < 4. , pixels cut, starflats	.040106
v3aper10, stellarity > .95, fwhm < 4. , pixels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



# Preliminary Results I: Single-Exposure 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)

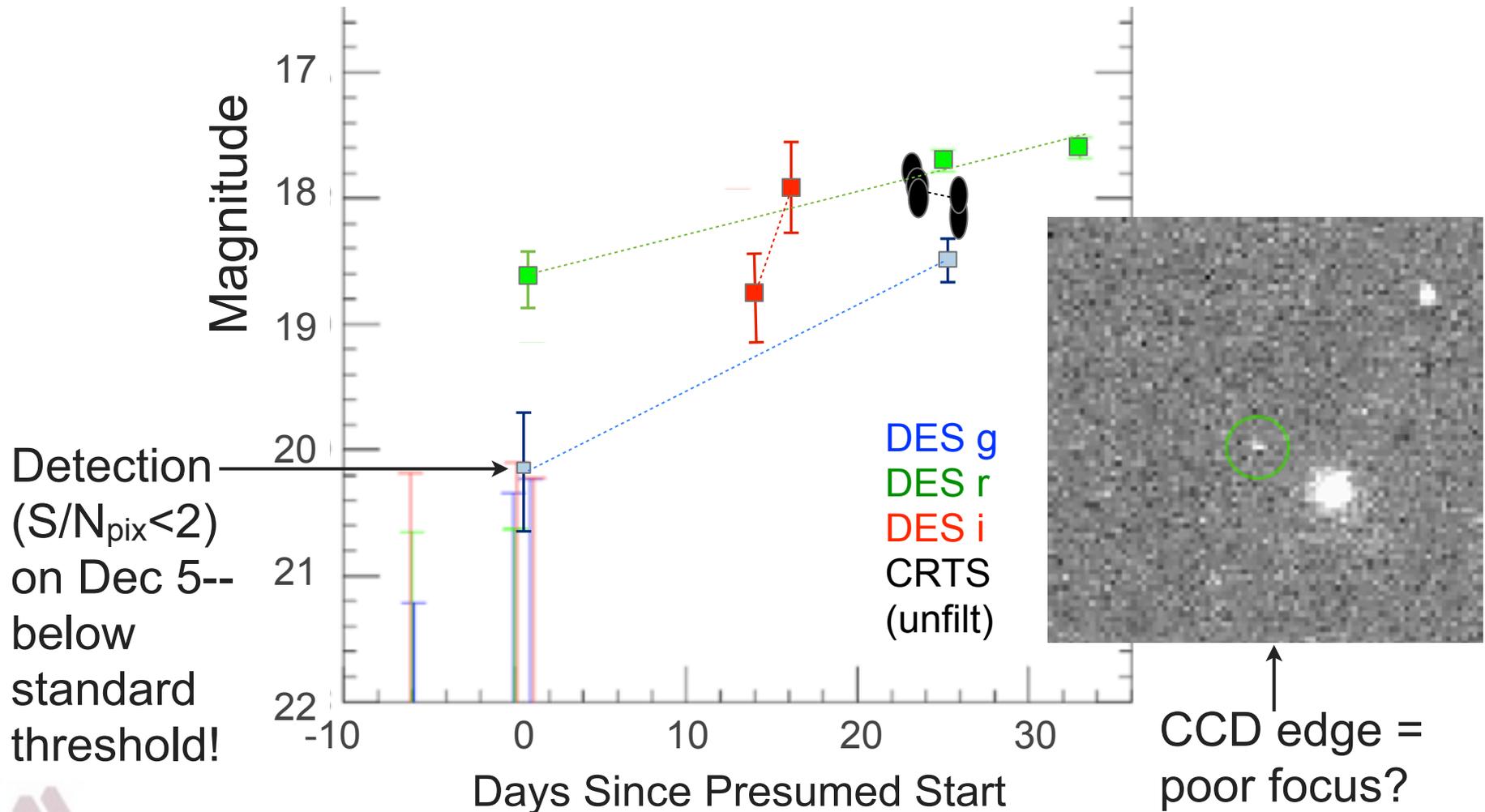


## Cosmic Rays in the PreCam CCDs



# Data Quality Checks/DES Proof-of-Concept

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

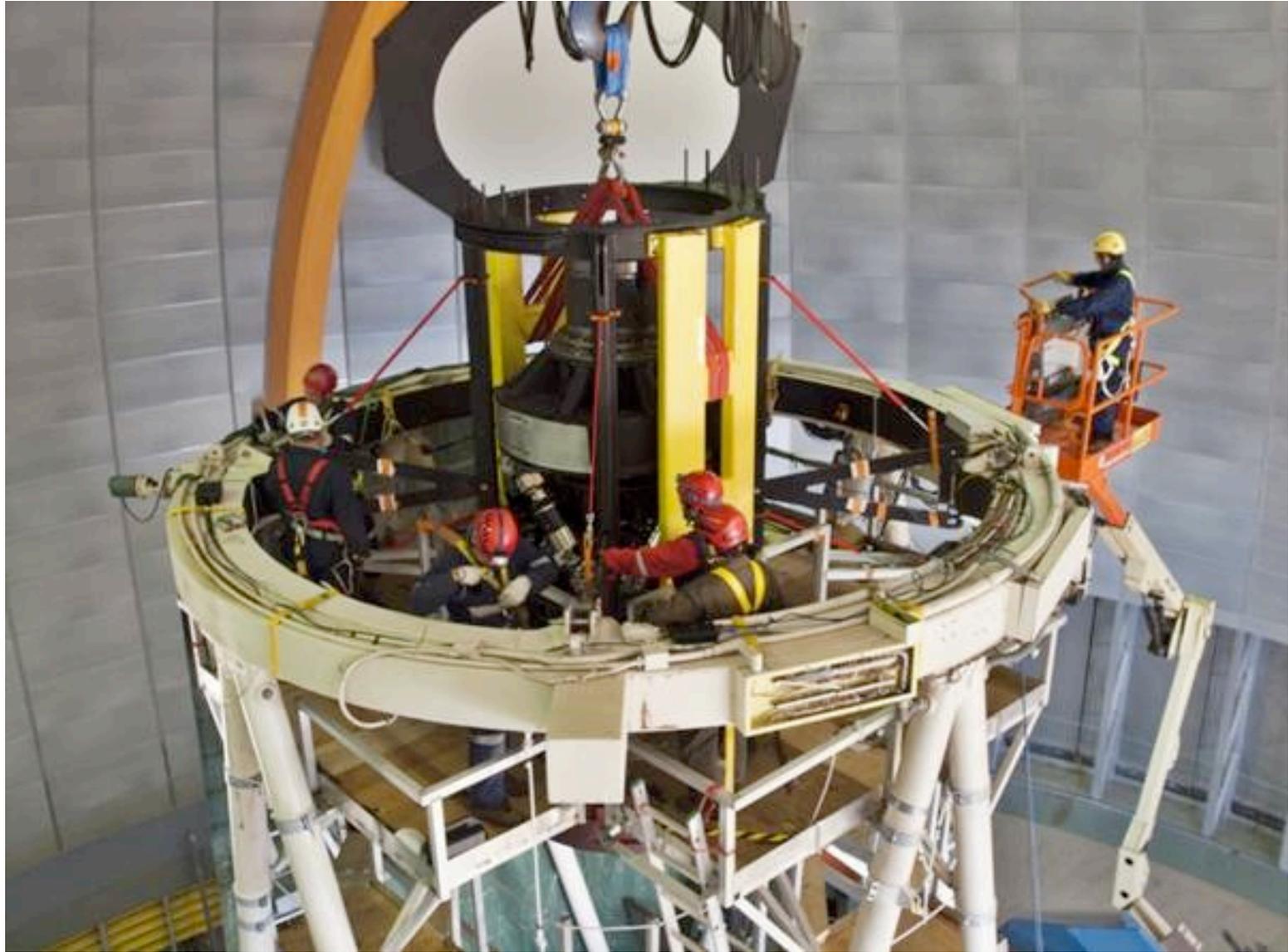


# Conclusions

- Dark Energy is causing the accelerated expansion of the universe
- The Dark Energy Camera has been built to engage in the Dark Energy Survey, in order to constrain the possible source(s) of Dark Energy.
- The Precursor to the Dark Energy Camera (PreCam) has been successfully built and deployed at Cerro Tololo Interamerican Observatory
- PreCam observed a significant fraction of its total planned footprint; a second season of observations is being explored
- Preliminary results show single-epoch photometric accuracy of 3–4%, with accuracy better than 2% for brighter (<14th mag) stars.
- The Dark Energy Survey will begin later this fall!



# DECam on the Blanco Telescope!



# 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](#)

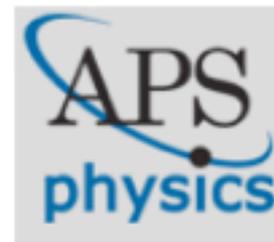


# Committee on the International Freedom of Scientists

<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.”





Wednesday, July 25, 2012

# Thank You!

