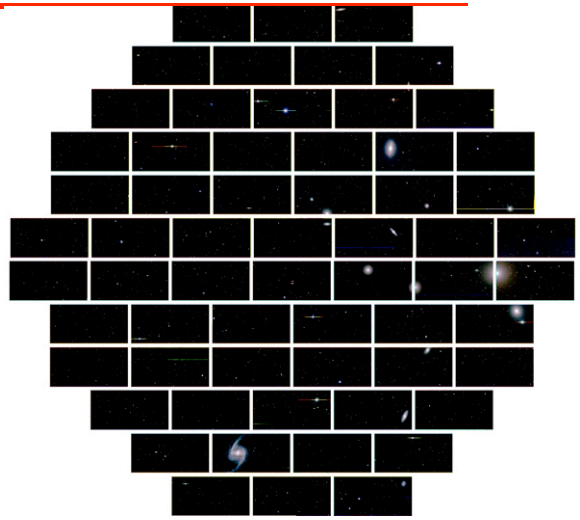
Construction of the Dark Energy Camera

DARK ENERGY SURVEY



Symmetry Magazine July '09

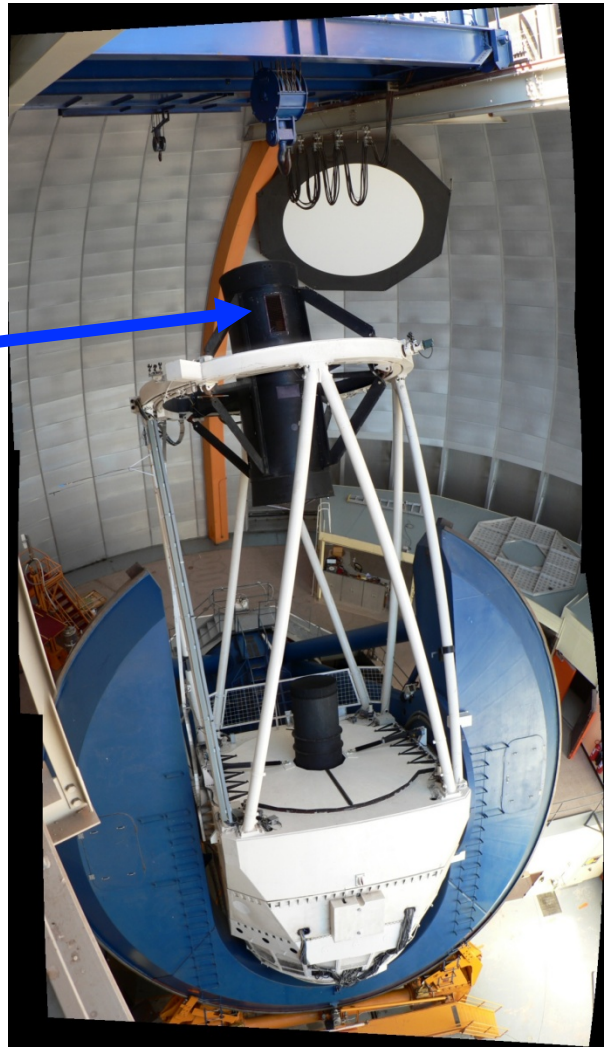
Brenna Flaugher, DECam Project Manager

CTIO Nov. 2012

The Dark Energy Survey (DES)

DARK ENERGY SURVEY

- The General Science Idea:
  - Perform a 5000 sq. deg. survey of the southern galactic cap
  - Measure dark energy with 4 complementary techniques
- New Instrument:
  - Replace this PF cage with a new 2.2 FOV, 570Mega pixel red sensitive CCD camera and optics
- Time scale:
  - R&D and Reviews 2003-2008
  - Instrument Construction 2008-2011
  - Delivery to CTIO 2011-2012
  - Installation Jan.'11 –Aug.'12
- First Light & Commissioning:
  - Sept. 2012
- 525 Night Survey over 5 years



Use the Blanco 4M Telescope at the Cerro-Tololo Inter-American Observatory (CTIO)

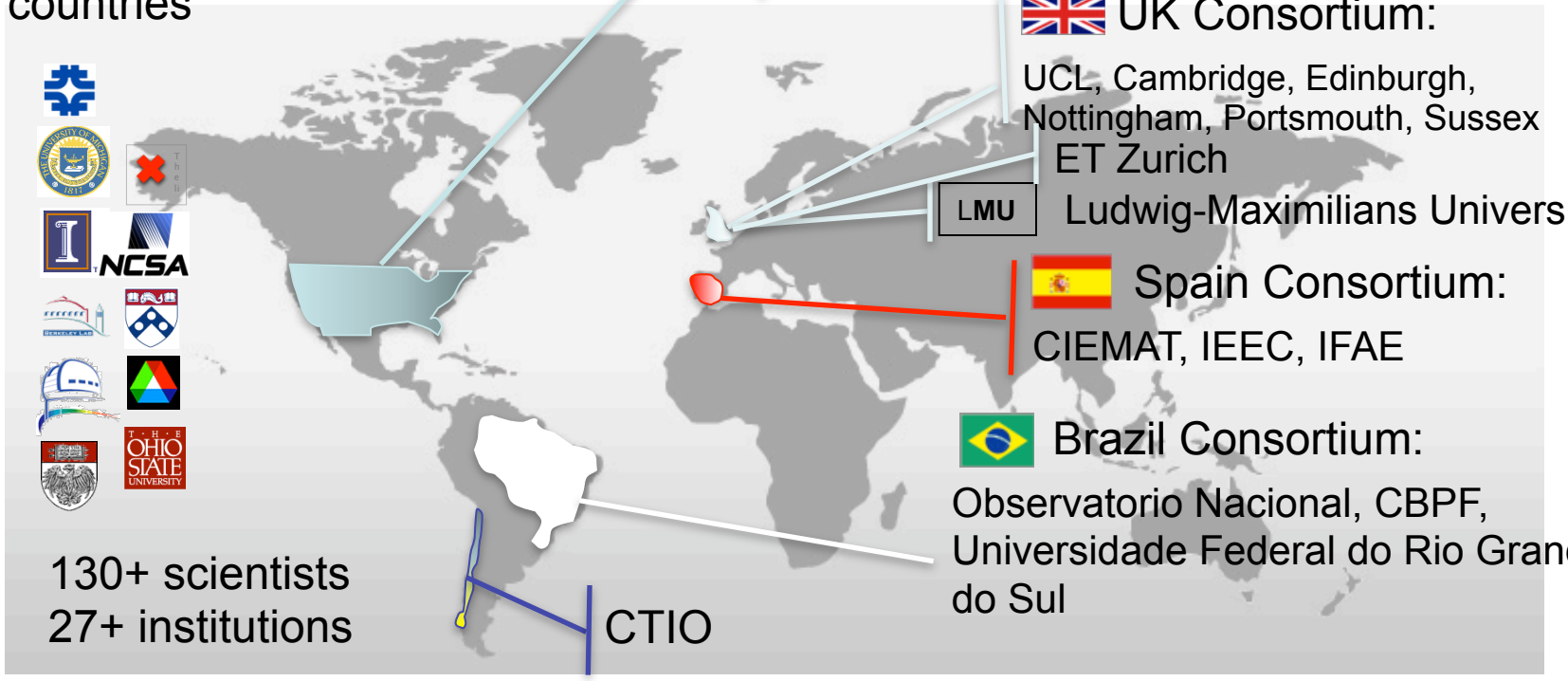
DES Collaboration

DARK ENERGY SURVEY

The DES is an international project to "nail down" the dark energy equation of state.

Funding from DOE, NSF and collaborating institutions and countries

Fermilab, UIUC/NCSA, University of Chicago, LBNL, NOAO, University of Michigan, University of Pennsylvania, Argonne National Laboratory, Ohio State University, Santa-Cruz/SLAC Consortium, Texas A&M



UK Consortium:

UCL, Cambridge, Edinburgh, Nottingham, Portsmouth, Sussex

ET Zurich

Ludwig-Maximilians Universität

Spain Consortium:

CIEMAT, IEEC, IFAE

Brazil Consortium:

Observatorio Nacional, CBPF, Universidade Federal do Rio Grande do Sul

130+ scientists
27+ institutions

CTIO

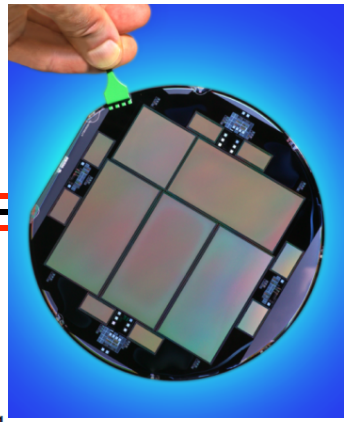
DARK ENERGY SURVEY

Lessons Learned

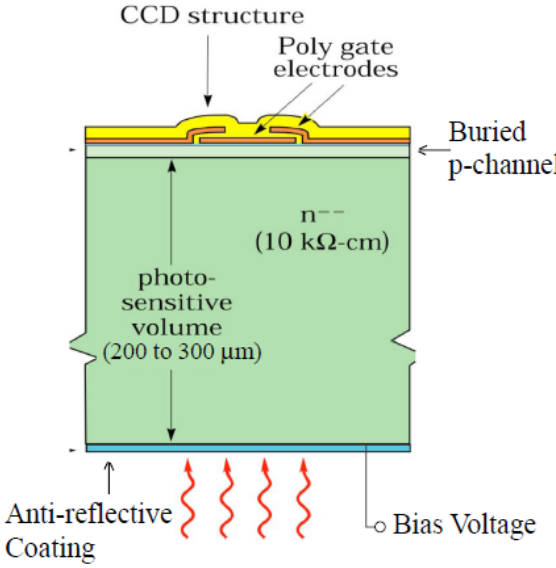
- DES US funding from DOE (DECam) and NSF (NOAO/CTIO, Data Management) have different cultures and styles provided challenges
- DES International Funding: different timescales and proposal requirements
- Management team strongly invested in science of DES: physicists, astronomers and engineers
- Optics, CCDs: Early R&D and early procurements mitigated these risks.
- CCDs from LBNL and with packaging and testing the CCDs at Fermilab was very successful (120 Science Grade CCDS produced, 62 needed!)
- Strong emphasis on integration and testing throughout the project
  - Prototype imager (2006-7, during R&D) and it allowed us to perform integration work early and to continue it throughout the project.
  - Telescope simulator was a big effort but it was essential for testing and debugging all systems prior to shipping and also critical for getting through the DOE technical reviews!
  - Big investment in testing CCDs & how to operate them led to successful project and to spin-offs in astrophysics and dark matter.

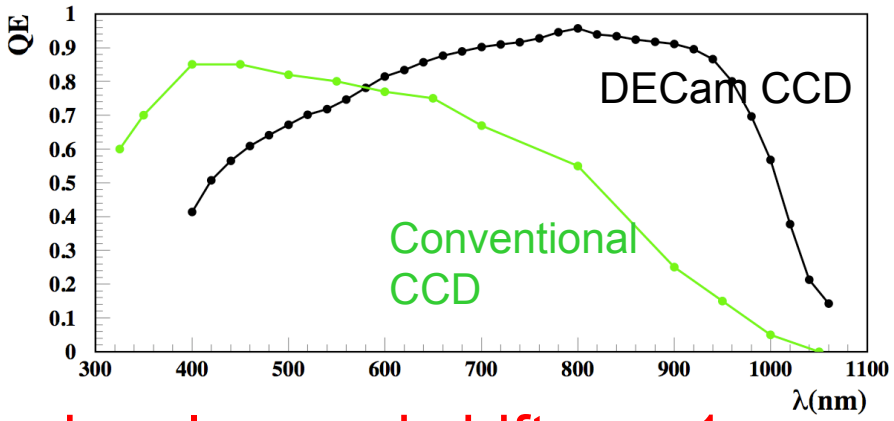
DARK ENERGY SURVEY

DECam CCDs



- The CCDs are thick, back-illuminated, fully-depleted p-channel devices designed by LBNL and manufactured at Dalsa+LBNL
  - thinned to 250 microns for DECam
  - higher QE over broader wavelength range than previous astronomical grade CCD's
  - minimal fringing at long wavelengths even in slow beam
  - small, controllable point spread function (PSF)

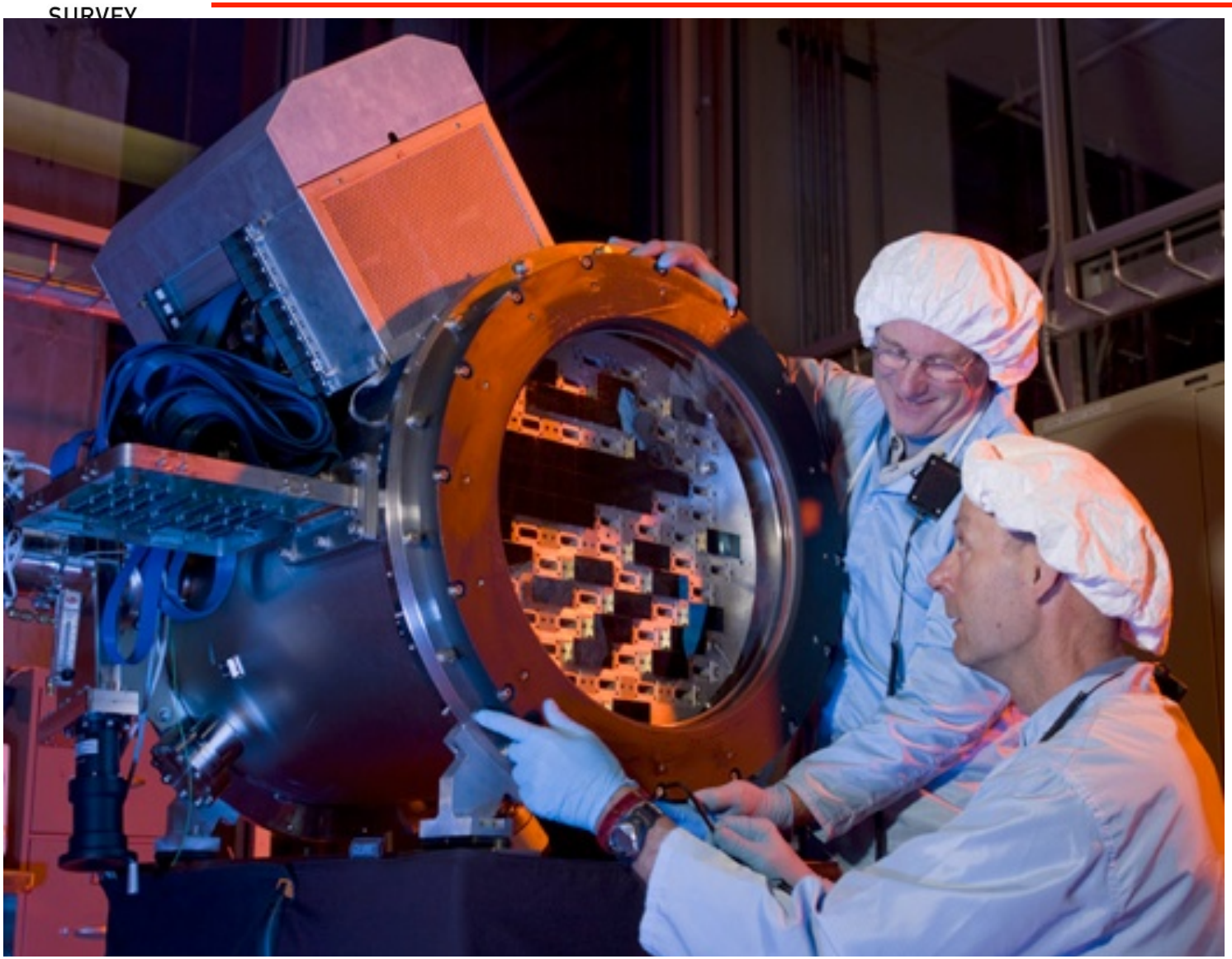




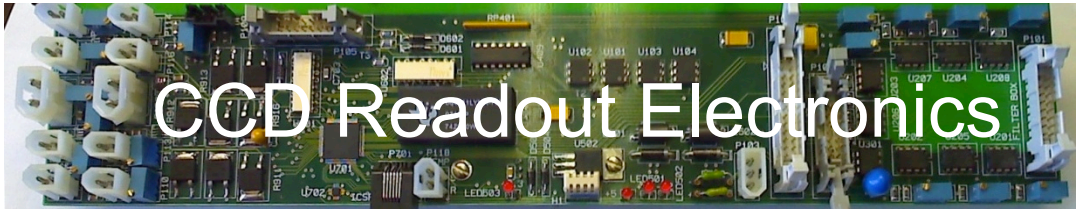
Red response - important to reach galaxy red shifts >~1

Prototype imager and readout crate with Engineering grade CCDs in 2009

DARK ENERGY SURVEY

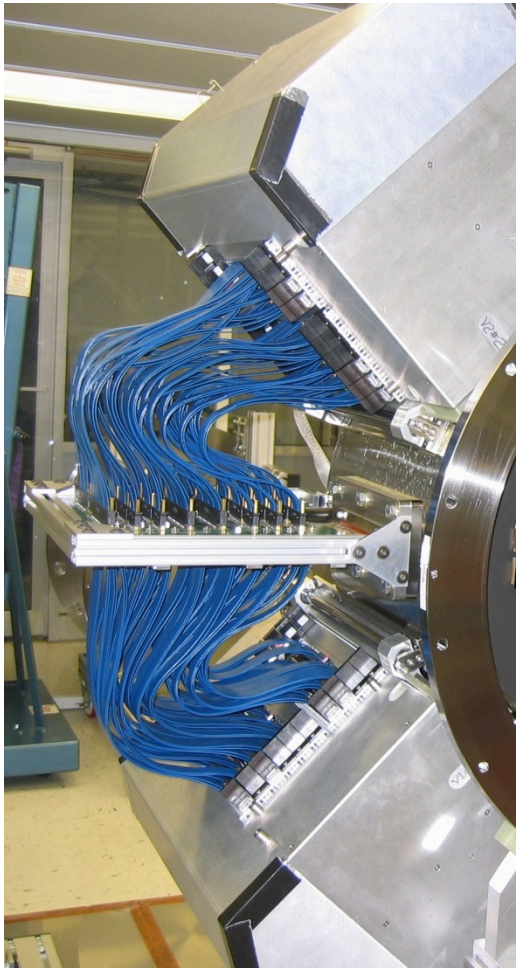


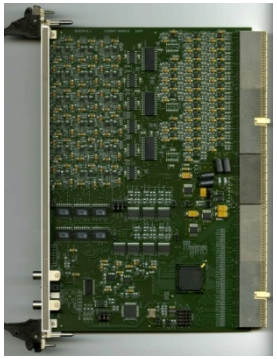
Funding came from early contributions from Chicago and UIUC

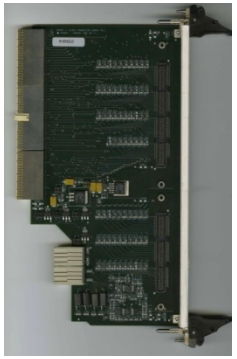


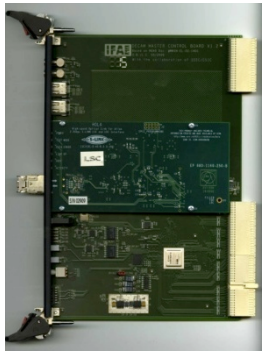
CCD Readout Electronics

DARK ENERGY SURVEY









Clock boards

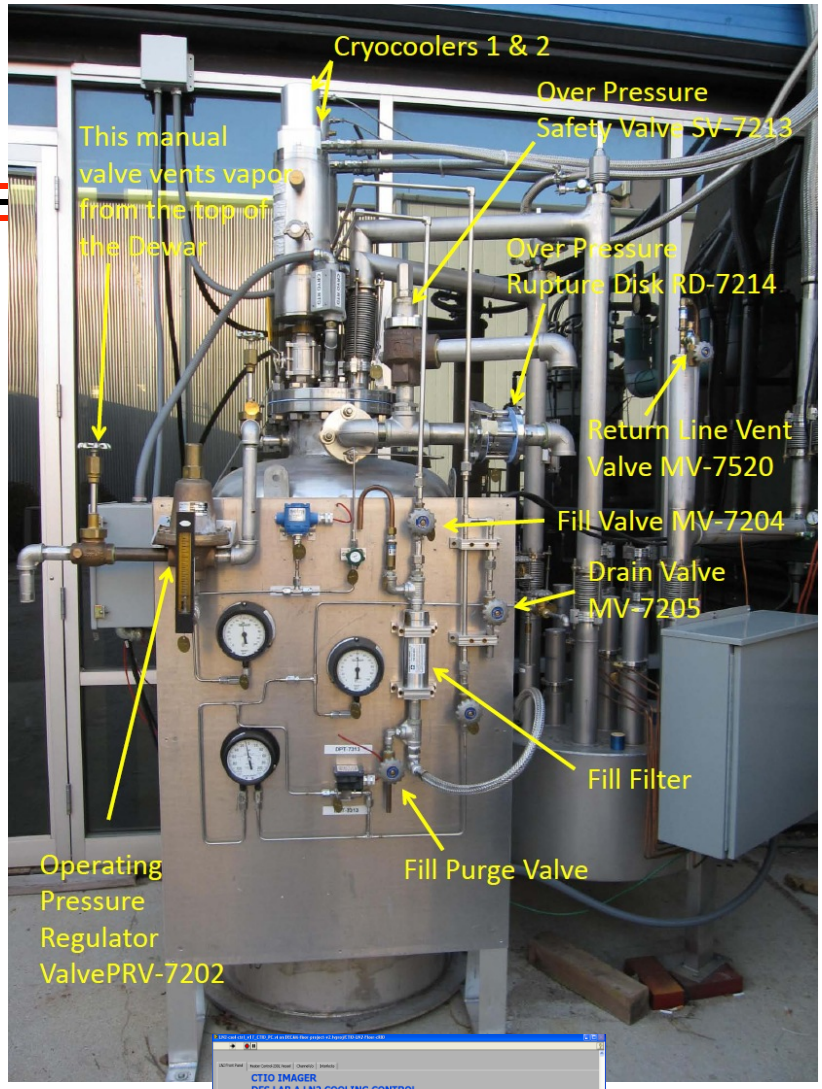
12-channel Acq. cards

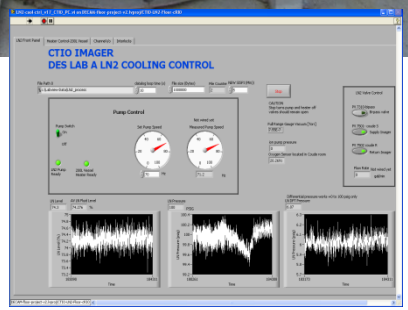
MCB

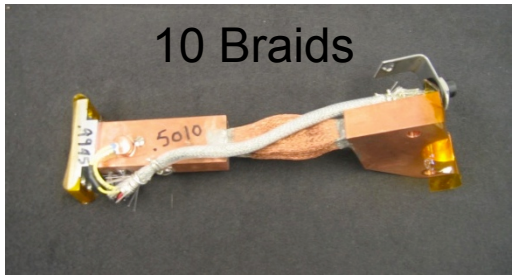
- Clock boards were developed, produced and tested in Madrid (CIEMAT): Control 9 instead of 2 CCDs
- 12 Channel Acquisition cards ((instead of 8) were developed at Fermilab and produced and tested at Barcelona
- Master Control boards developed produced and tested by Barcelona
- Cooled Crates from UIUC
- Having early versions from Spain was critical to system integration!

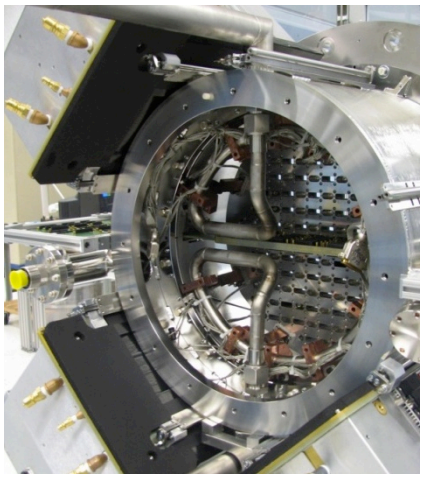
Focal Plane Cooling

- Two-phase N2 is pumped up the telescope to the imager
- 10 Copper braids are mechanically coupled to the cooling ring and the FP.
- Heaters in the braids offset the tendency to overcool the CCD array
- N2 is recirculated and reliquified
- Labview PID-loop and controls.
- Operated at Fermliab June 2010 – April 2011







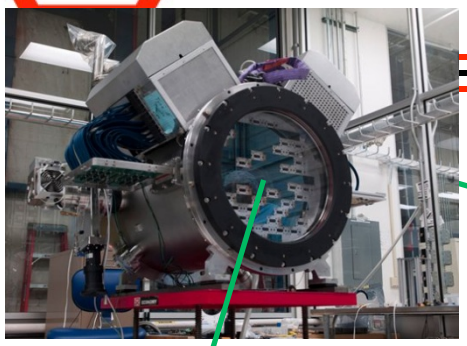


DARK ENERGY SURVEY

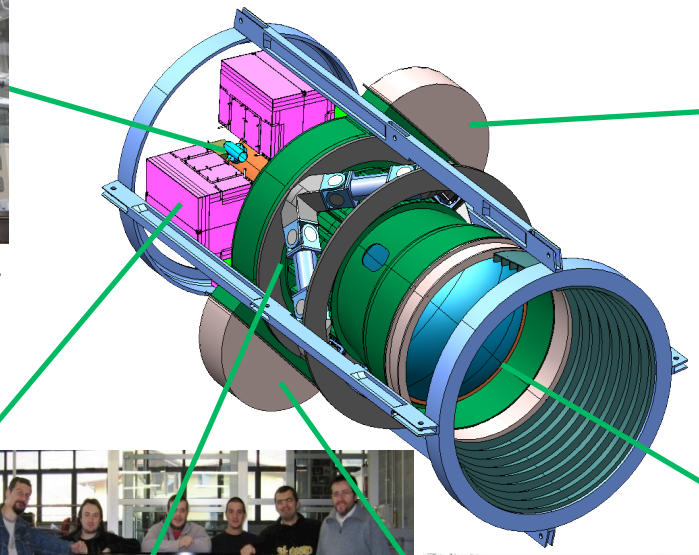
CTIO and Fermilab engineers “discuss” (in engineer language and pictures) Imager Installation at the NW station. Final system was largely the same!

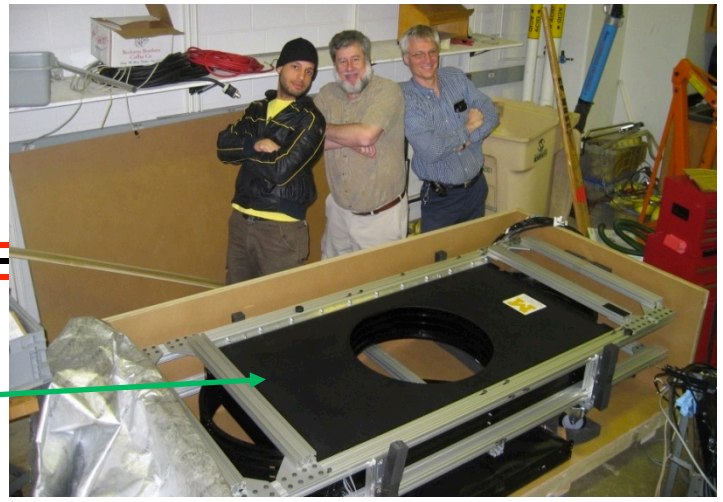
Nov. 2008 DECam Integration Meeting La Serena/CTIO

DECam Systems came together at Fermlab

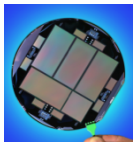


Imager, FNAL





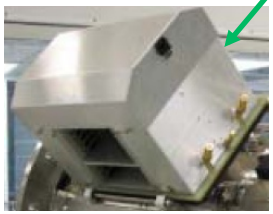
Filter changer, Univ. of Michigan



CCDs, wafer from LBNL, packaged at FNAL

Hexapod, Italy

Barrel and Cage (FNAL, no lenses)



Electronics, Spain and FNAL

Shutter, Germany

Dec. 2010

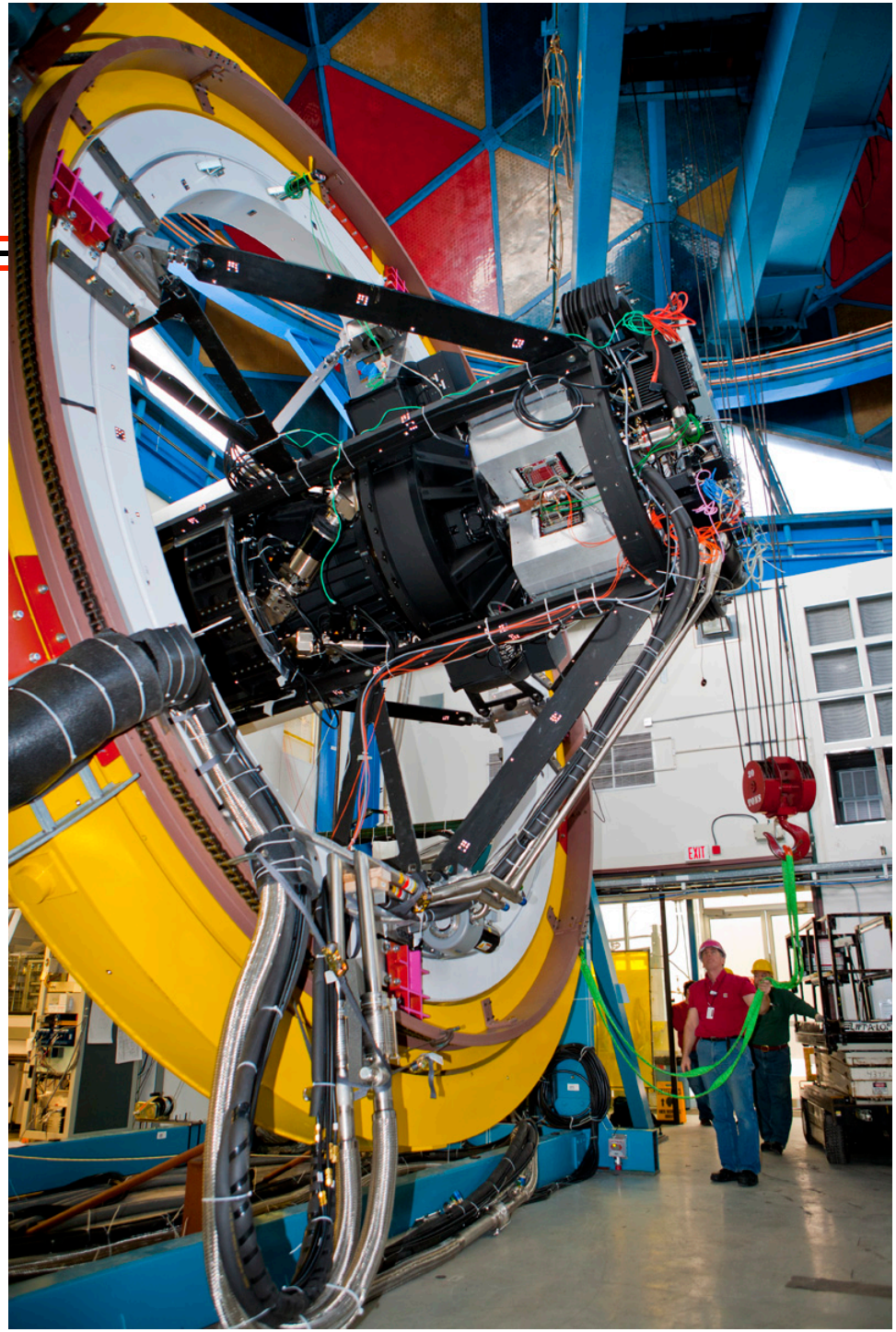
DARK ENERGY SURVEY

- Most DECam systems complete and full system tests (except the optics) on telescope simulator

  Imager with 28 CCDs installed, Filter changer, shutter, hexapod, LN2 cooling, CCD readout crate cooling, all exercised in multiple positions.

- Mock Observing Feb. 2011

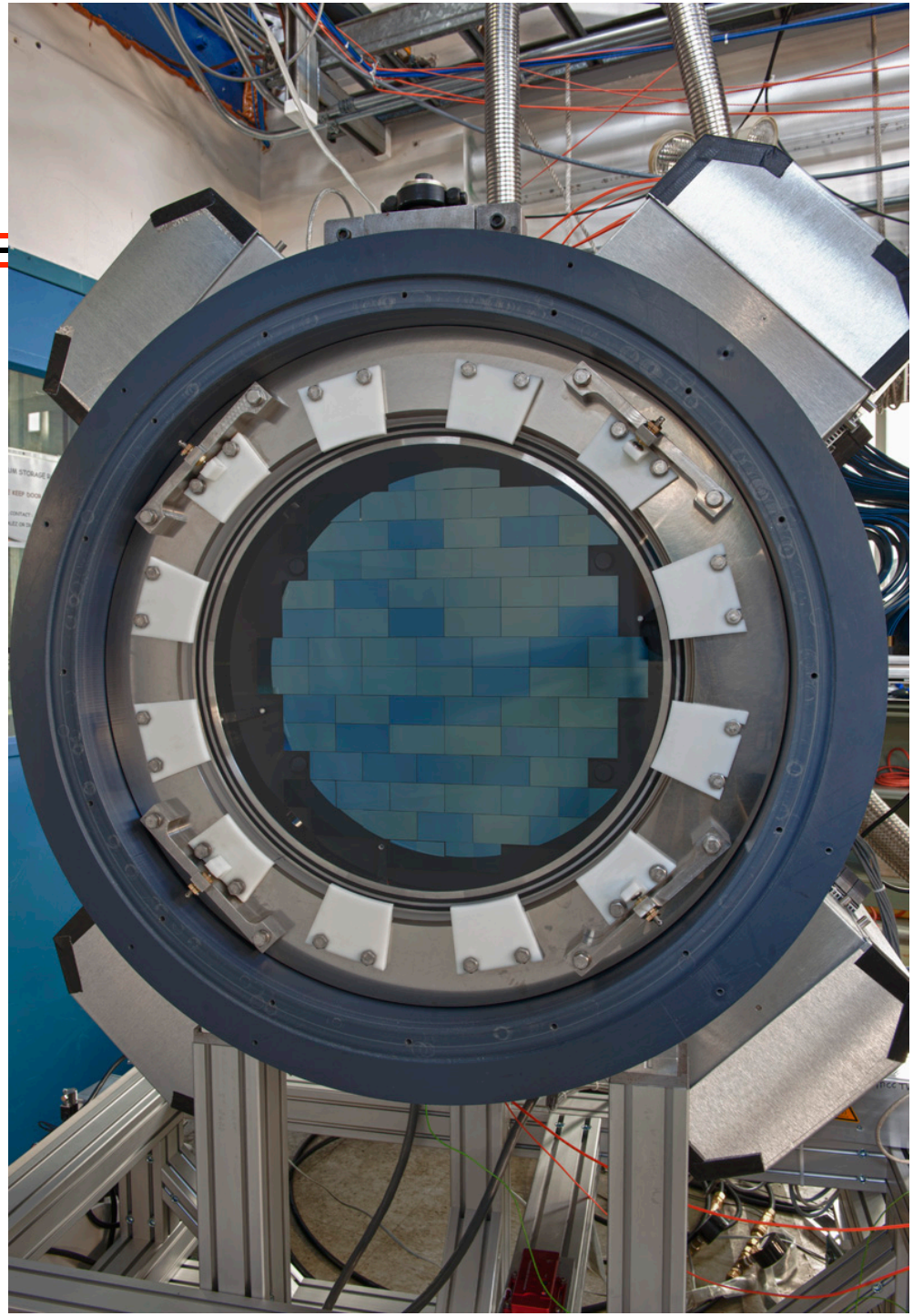
- Rest of 2011:
  - Packing, shipping, checkout in Chile
  - Installation of science CCDs in imager



DARK ENERGY
SURVEY

DECam Imager with all the science CCDs installed and ready to be packed up for shipping to Chile in August 2011

570 Mega pixels!



Shipping

Large heavy parts were shipped by boat

- Oct 2010 F/8 handling system
- June 2011 Cooling system parts
- Aug 2011 Cage, NW platform, etc.
- Dec 2011 Final cooling sys parts

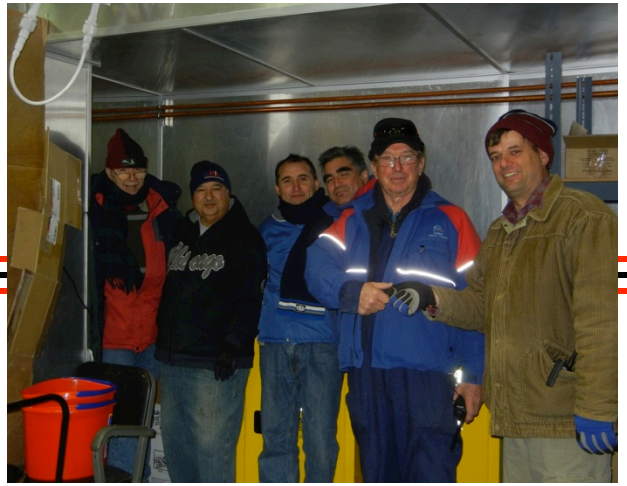
More delicate pieces by air

- May 2011 RASICAM: all sky cloud camera
- June 2011 Hexapod, Filter Changer and Shutter
- June 2011 Delicate parts of LN2 Cooling system
- July/Aug. 2011 r, i, z and y filters (from Japan to Chile)
- Nov 2011 The Imager (with CCDs installed!)
- Dec 2011 The corrector (with lenses installed)
- April 2012 The g filter!

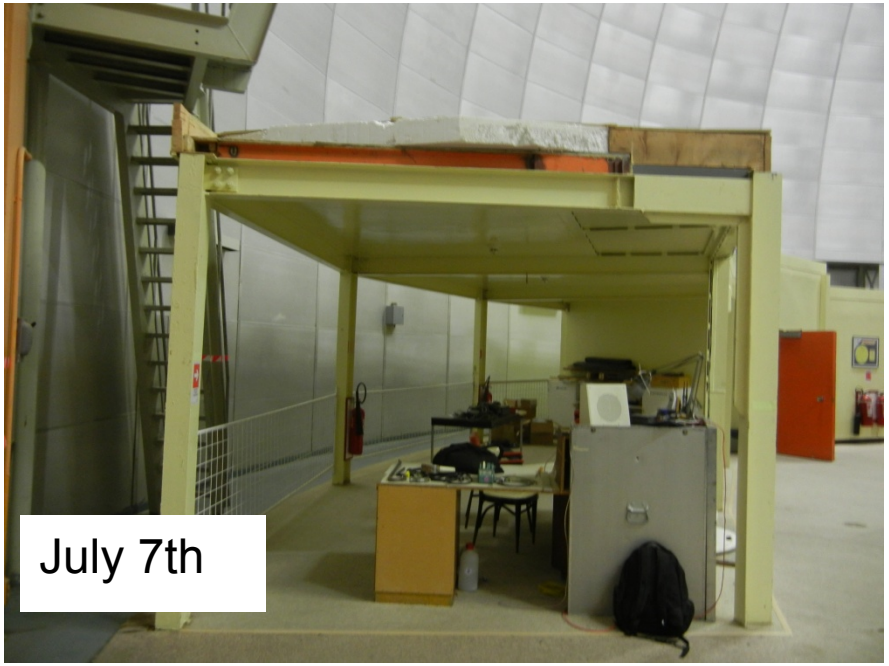
Everything has to leave Fermilab and go from Santiago to the Mt. by truck

DARK ENERGY SURVEY

Cooling installation at CTIO July 2011



- July 7-21 LN2 tank and piping was installed on console roof
- LN2 circulated to Coude room (where imager is serviced and tested)

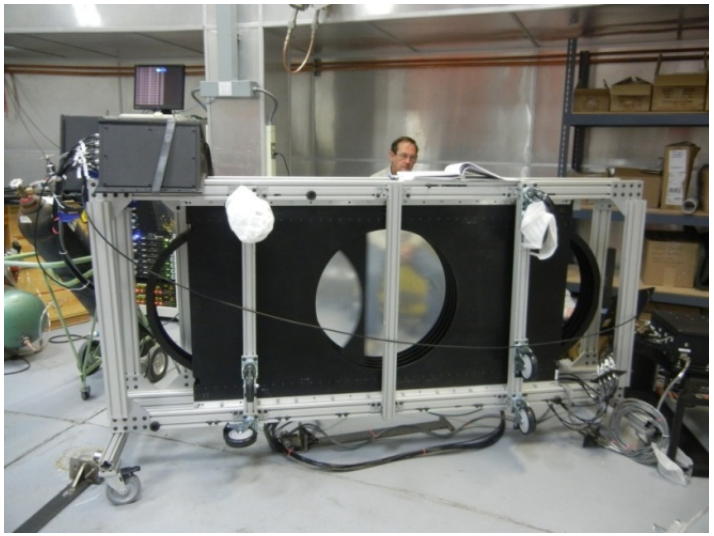


July 25-Aug. 5, 2011: Shutter, FCM, Hexapod testing @ CTIO

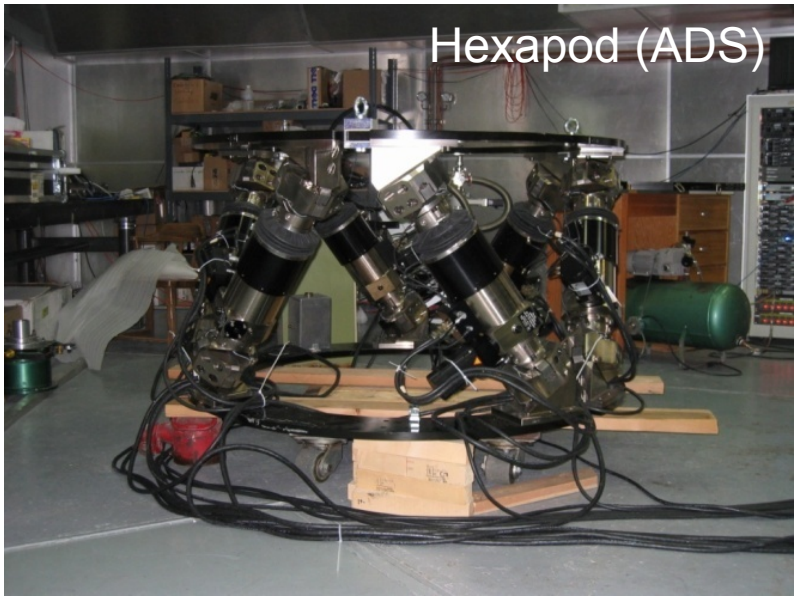
DARK ENERGY SURVEY

Tom Diehl exercising the shutter (Bonn)

Filter changer (UMich) operating in Coude

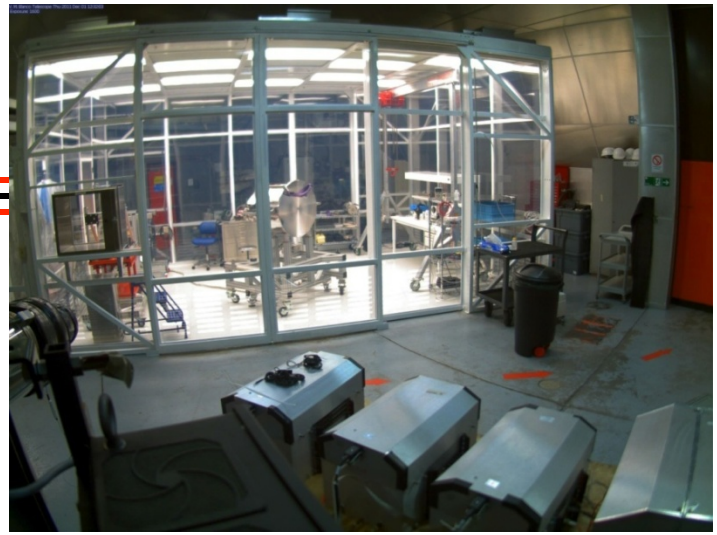


- Hexapod operating at CTIO



Team of 3 -7 people from Fermilab in Chile from early July – Mid August working with CTIO Staff

The Imager's Trip 2011

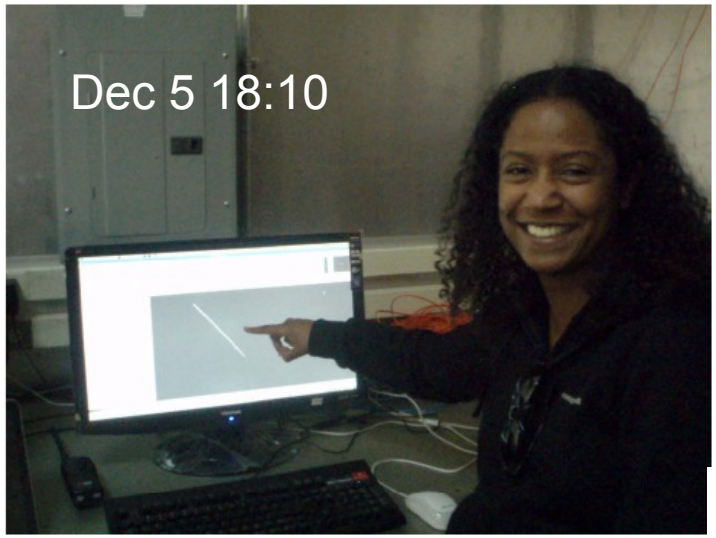


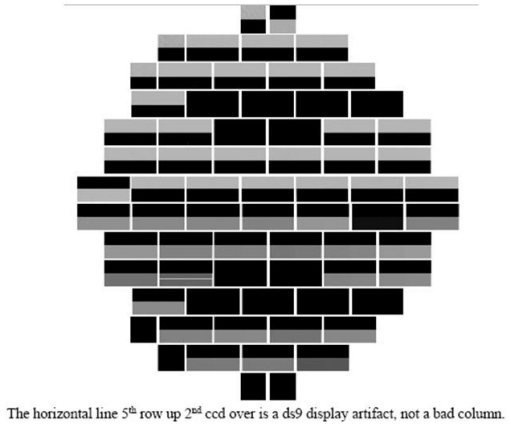
- Science CCD Inst. And testing completed July
- Left Fermilab Nov 17
- Arrived CTIO Nov 23
- Unpacked Nov 30
- Under vacuum Dec 2
- Cooled down Dec 5
- Good full image Dec 6 !!

Team of 12 ME, EE, tech., Sci. traveled to CTIO for imager checkout

Cooled down & Reading Out!

DARK ENERGY SURVEY

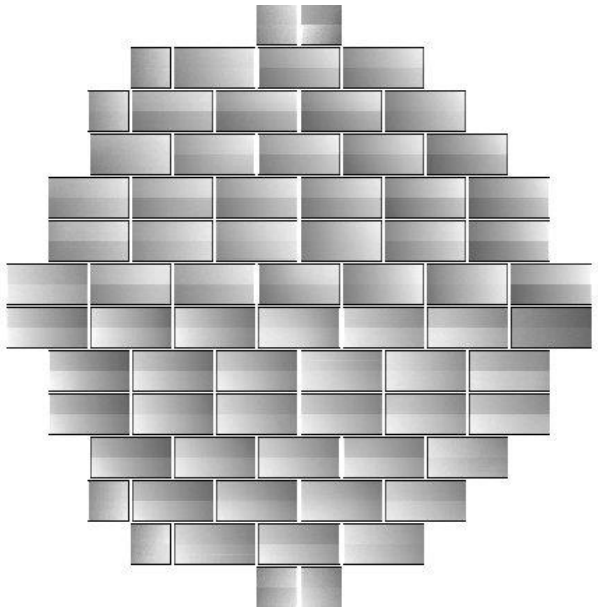




The horizontal line 5th row up 2nd ccd over is a ds9 display artifact, not a bad column.

Later on Dec. 5

DECam has 62 science CCDs
Previous camera had 8 CCDs

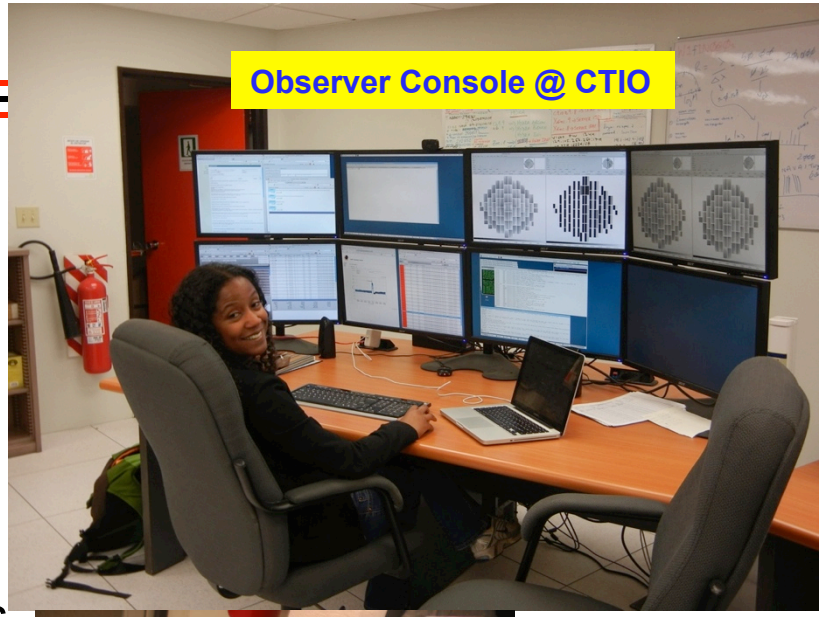


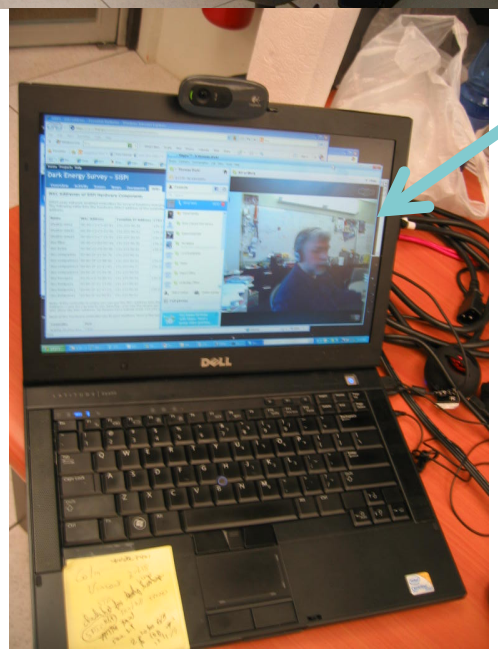
Dec. 6: Beautiful flat field Image!!

SISPI – DECam Readout and Control

DARK ENERGY SURVEY

- OSU led the development of the DAQ system with contributions from Illinois, FNAL, Barcelona, CTIO, SLAC
- Installed on Tololo in April 2011
- Used by DECam team to checkout components as they arrive at CTIO (Shutter, hexapod, filter changer, Bcams, imager, DECal-spectrophometric calib)
- 3 mock observing tests runs improved reliability and usability
- Integrated with Blanco TCS (Feb 2012)
- > 200,000 test images were taken before first light!





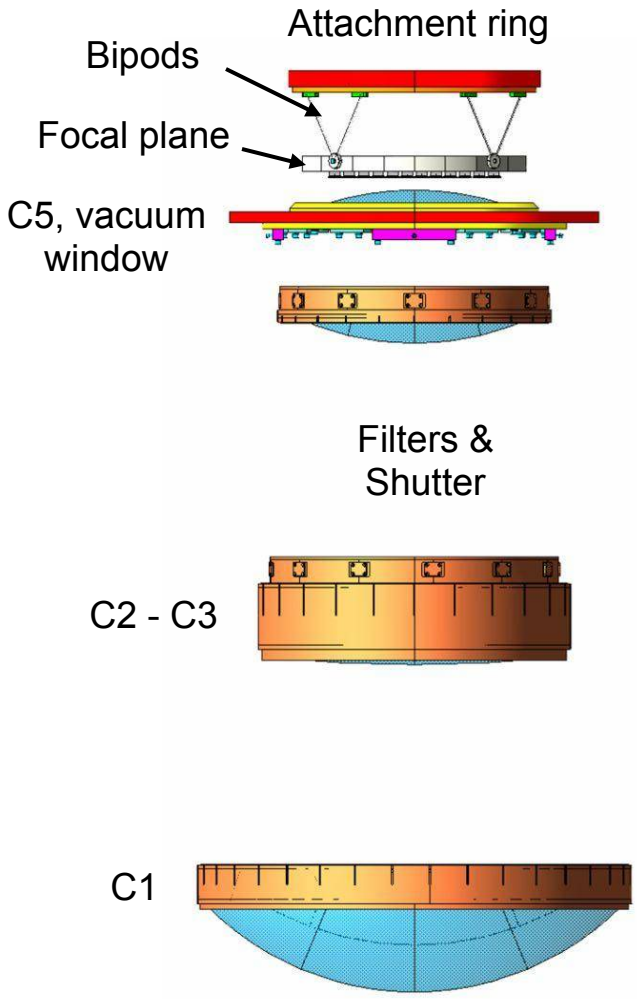
Klaus (OSU) is always available on SKYPE!

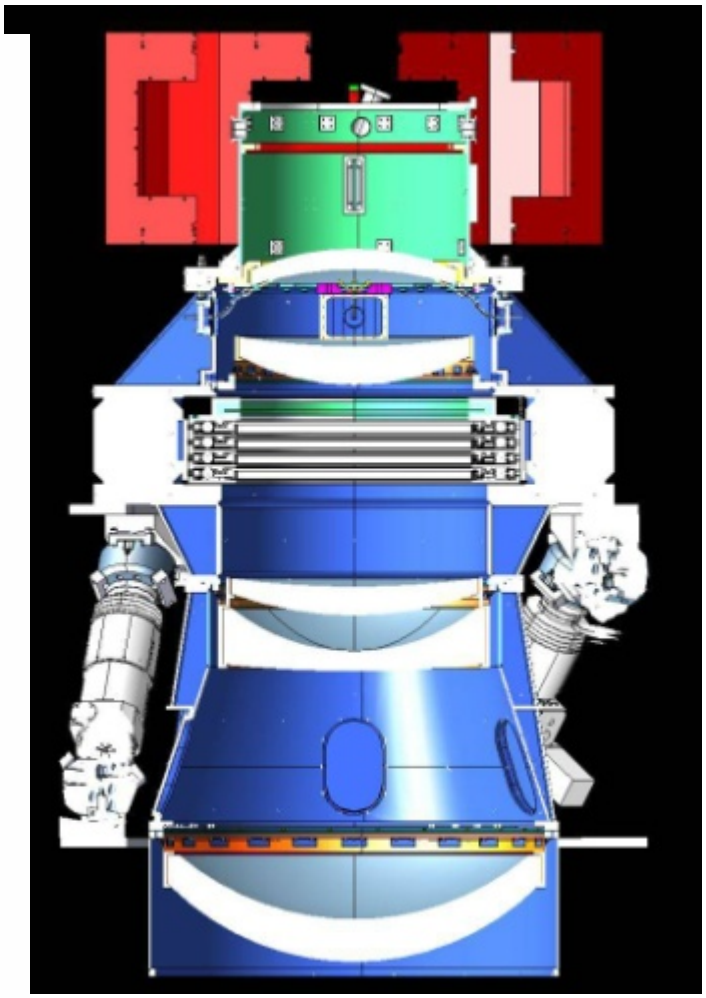
Mock Observing at CTIO Jan. 23 and 24, 2012

Optics

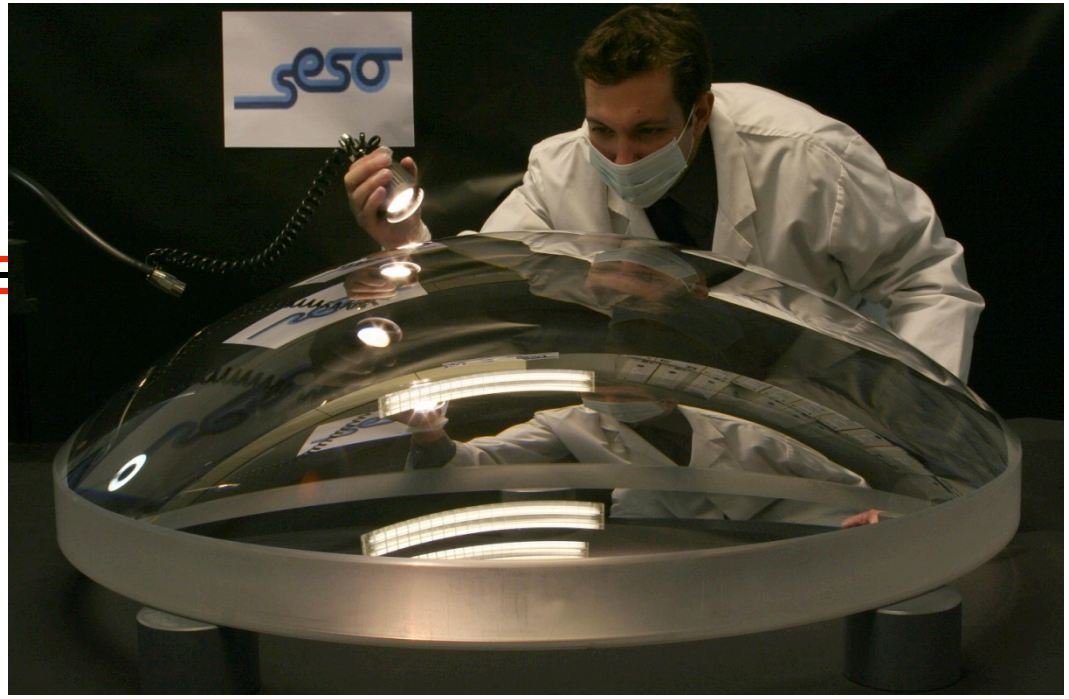
DARK ENERGY SURVEY

- Univ. College London led the production of the optics with funding from STFC
- Ordered the Blanks ~ July 2007 (~1M$) using funds from DES Universities in the UK and US, finished Jan. 2008.
- Polishing and Coating June 2008- June 2011
- 2011: UCL installed the lenses in the cells and barrel @ UCL then shipped barrel in 2 parts to CTIO





Lens Fabrication 2007-2011



Steve Kent inspecting the C1 Blank (980mm diameter) at Corning Jan. 2008

C1 polishing complete Jan. 2011
C4 coating complete June 2011
Barrel delivered to CTIO Dec. 2011

DARK ENERGY SURVEY

Optics Alignment check @ CTIO

Jan. 2012:
UCL alignment frame and rotary table, laser frame in cleanish area on G floor @ CTIO

Alignment of lenses C2,C3, C4 checked with laser alignment system after shipping

Then barrel was assembled and alignment of the whole system was checked.

DARK ENERGY SURVEY

Jan. 19, 2012 Optical corrector assembly at CTIO

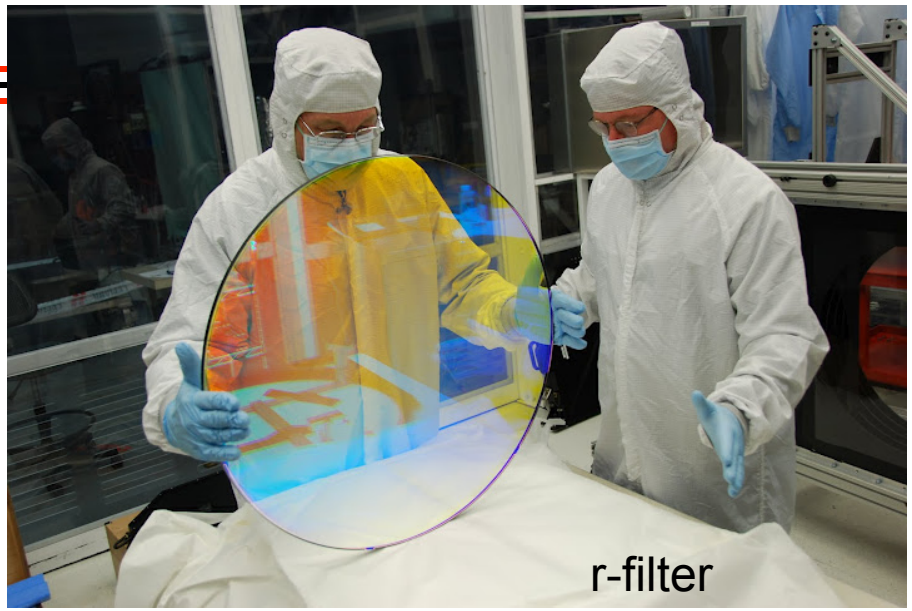
Peter, Mich and David from UCL assembling the DECam optical corrector

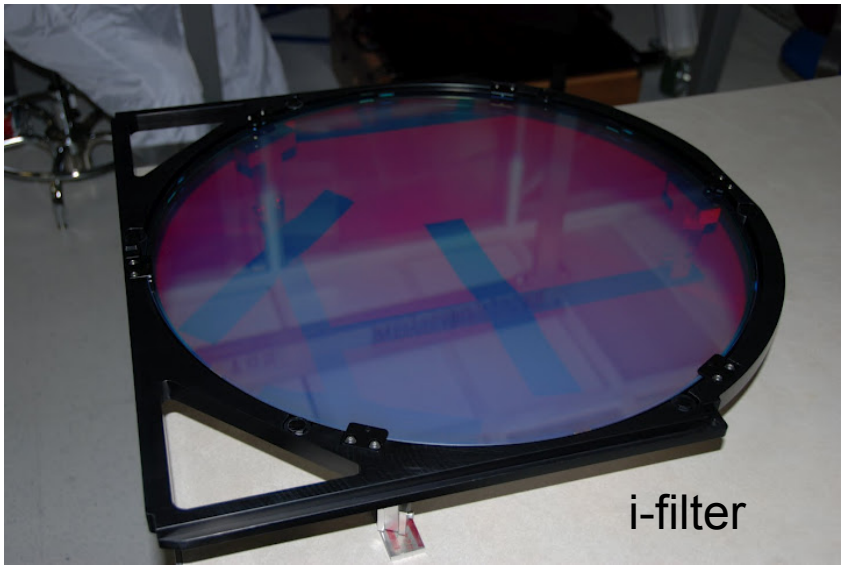
By Jan. 20th we had confirmed that everything is within specifications!

Filters

DARK ENERGY SURVEY

- 620mm substrate, 600mm clear aperture, largest ever, tight uniformity constraints.
- Asahi built and commissioned a huge coating chamber as well as custom cleaning, polishing and testing equip. for our filters.
- It took longer than we all had hoped, but Asahi triumphed (even with the massive earthquake) and all DES filters (g, r, i, z and Y) meet or exceed our requirements.
- At CTIO we installed the filters into cells in the clean room in the Coude room.


r-filter


i-filter

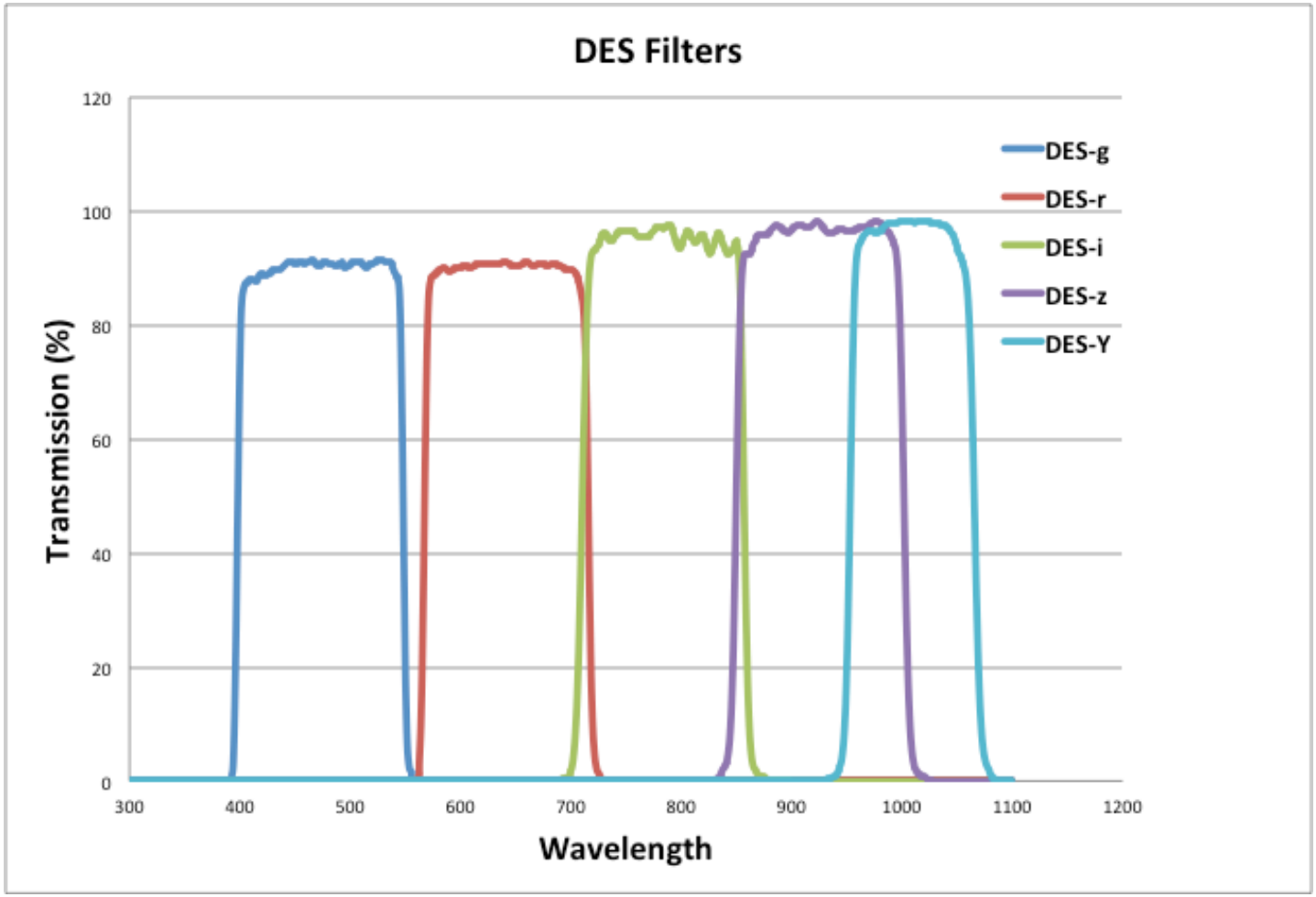
DARK ENERGY SURVEY

Filters beat our requirements!

Excellent transmission

Outstanding Uniformity

CTIO ordered u-band filter too!

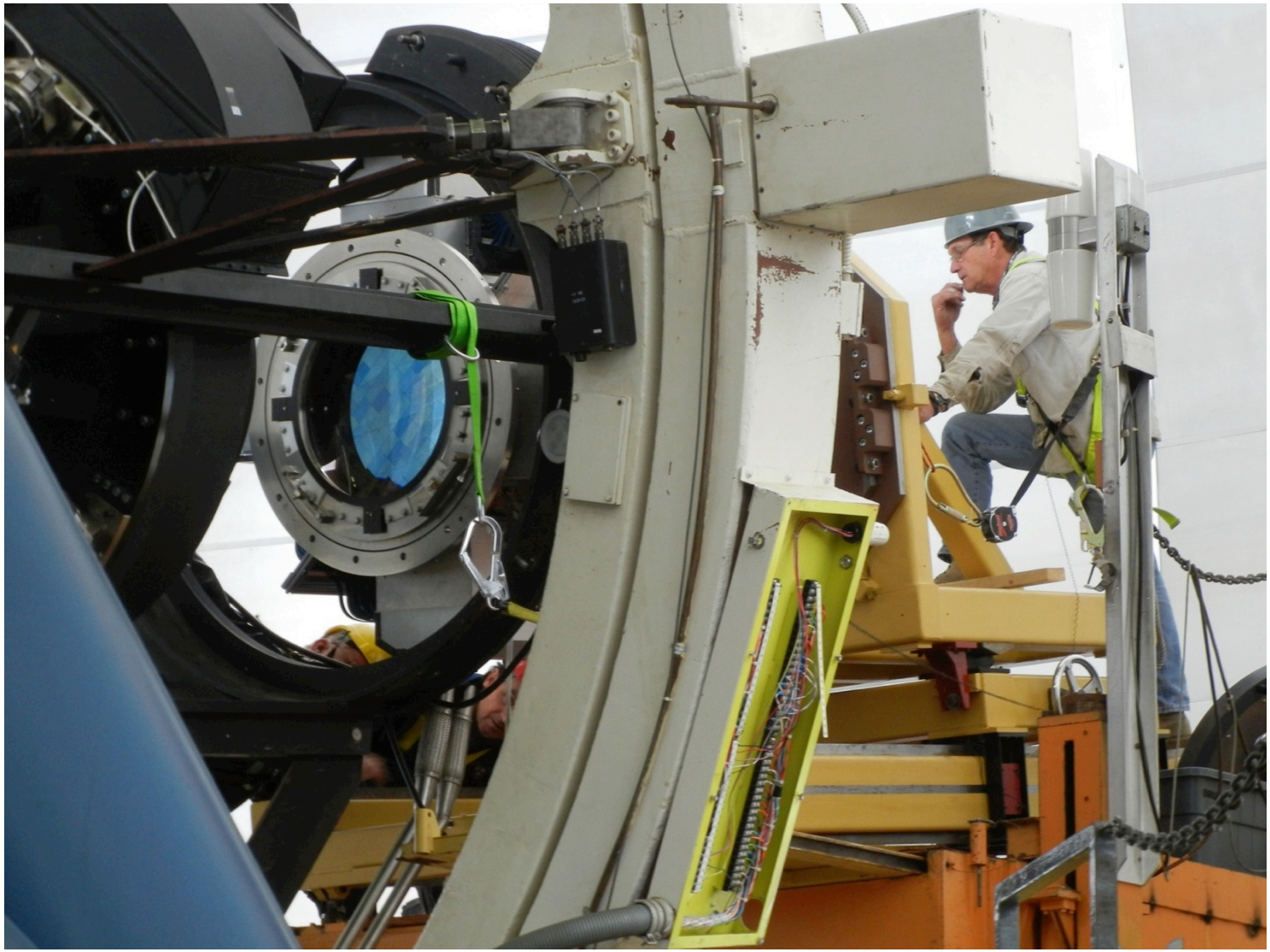


Tom (FNAL) and Patricio (CTIO) install the DECam filters on the telescope Sept. 2012

DARK ENERGY SURVEY

Attaching the Imager to DECam: Late August 2012

DARK ENERGY SURVEY



Project Schedule

DARK ENERGY SURVEY

DOE and Fermilab management monitored progress with
6 Level 1 Milestones and 60 Level 2 Milestones
We wrote 56 Monthly reports and had monthly meetings with the DOE site officer and Fermilab directorate and division heads
Plus annual reviews usually joint with NSF

The milestones were completed on schedule and the DECam project was completed in June 2012, 4 months ahead of schedule!

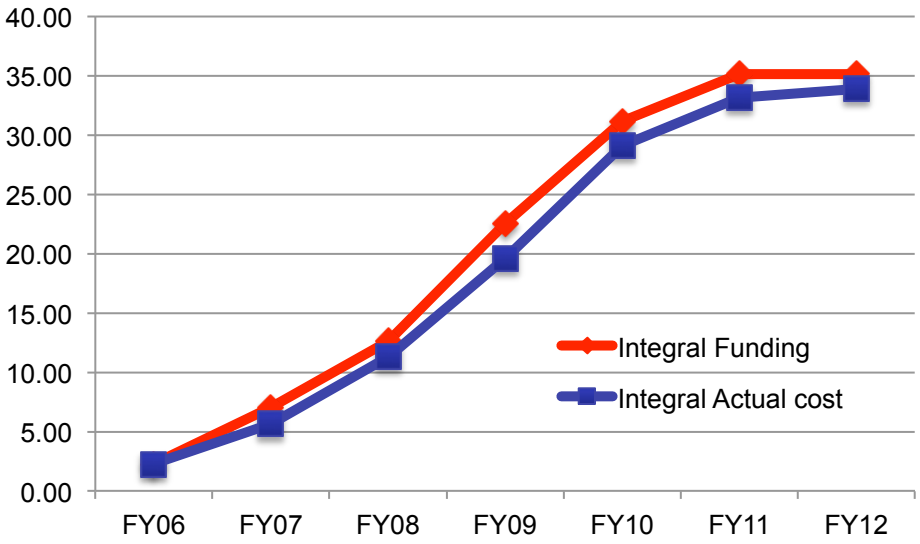
Level 1 Milestones	CD-2 Baseline Date	Actual
All Lens Blanks Complete	August 2008	January 31, 2008
Version 2 CCD Processing and Packaging Review Complete	December 2008	June 2, 2008
CCD's from 30th Production Wafer Delivered to Fermilab	July 2009	January 26, 2009
128 CCDs Tested and Graded	March 2010	October 19, 2009
Prime Focus Cage Complete	July 2010	June 1, 2010
Camera and Telescope Simulator Tests Complete	March 2011	February 22, 2011
Acceptance Testing (prior to shipping) Complete	September 2011	August 31, 2011

Project Funding and Cost

DARK ENERGY SURVEY

	FY2006	FY2007	FY2008	FY2009	FY2010	FY2011	Total
Contruction			**1.65**	**9.19**	**8.61**	**4.00**	**23.45**
R&D	2.28	4.76	3.95	0.71	0	0	11.70
DOE TPC	**2.28**	**4.76**	**5.60**	**9.90**	**8.61**	**4.00**	**35.15**

In 2009 DOE was able to move 1M$ from FY11 to FY09 – this allowed us to purchase the filters earlier than we could have otherwise!



DECam project cost was baselined at $35.2 M and was completed at $34M, leaving $1.2M in contingency!

This has been rolled over into support of DES Operations!

DECam Construction Summary (or where I have been the last 8 years)

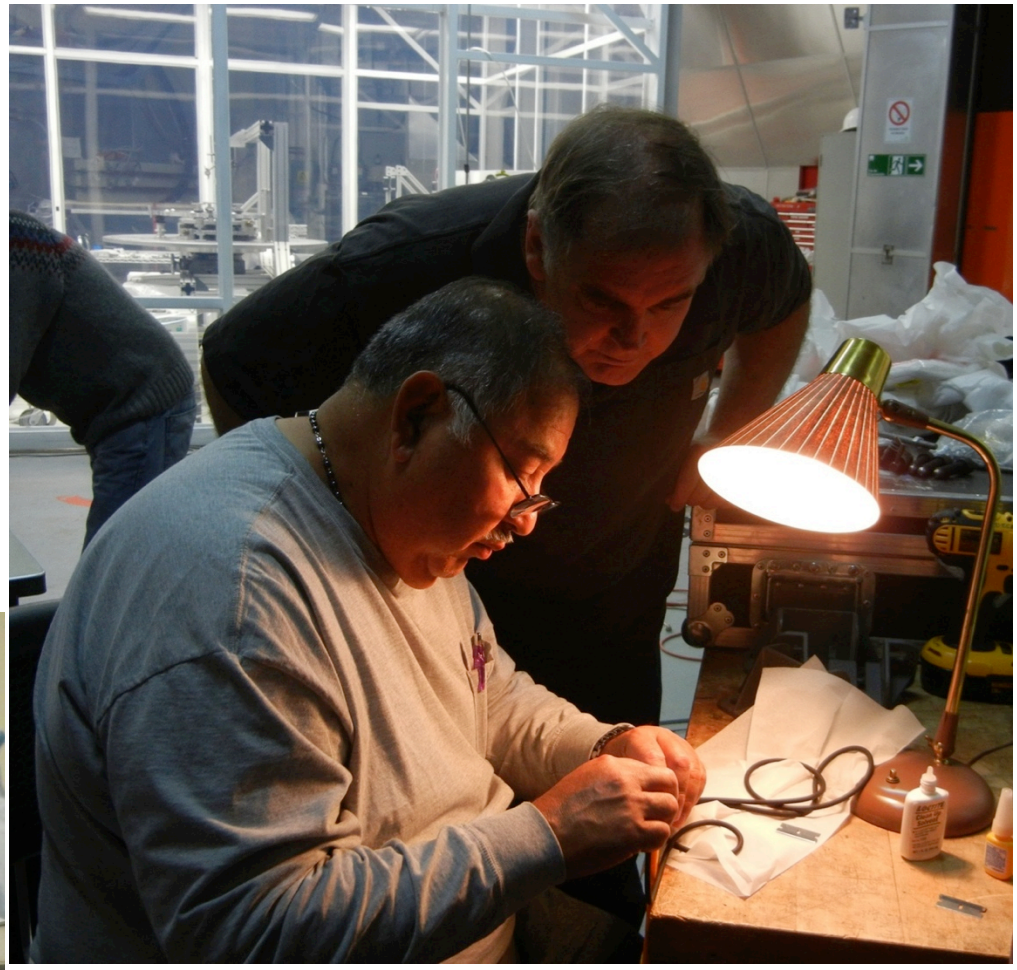
DARK ENERGY SURVEY

Symmetry Magazine

DARK ENERGY SURVEY

Attention to detail and the commitment of everyone who worked on it made the the construction of the Dark Energy Camera a big success! Thank You!!

Freddy Munoz (CTIO) Imager Installation Aug. 2012



Roberto Tighe (CTIO) alignment of imager window July 2012

Rolando Flores(Fermilab) making the o-ring for the vacuum seal on the imager in Chile July 2012

Skipping ahead: Science Verification is in progress now

The DECam Project was complete in June 2012: I'm DONE!

Now we know it works (first light Sept. 2012)

I'm REALLY DONE!!

Conclusions

DARK ENERGY SURVEY

- Dark Energy and Dark Matter make up 96% of the energy in the Universe and yet their properties are mysterious
- I want to thank Fermilab and DOE for providing support of all kinds throughout the DECam Construction project
- Also John and Josh and everyone who has worked hard over the years to make DECam a success! Thank you!
- It has been an honor and privilege to represent DOE and Fermilab in the construction of a huge camera that will extend the life of this majestic 4m telescope for the next decade and enable new measurements of our universe and hopefully help unravel the mysteries of Dark Energy