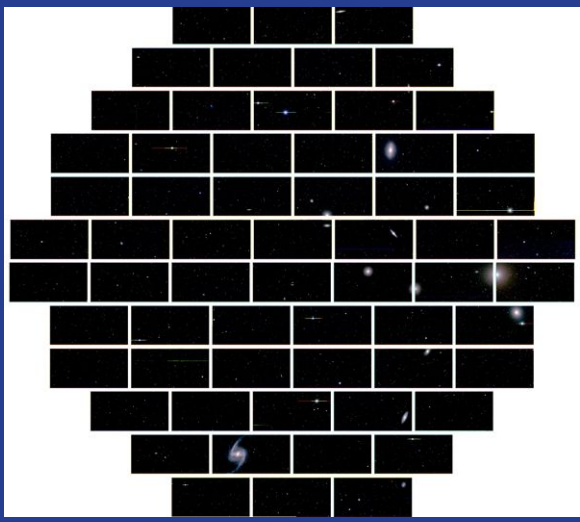
From High Energy to Dark Energy: the Creation of DECam



Symmetry Magazine July '09

Brenna Flaugher

Sept. 12, 2022

U.S. DEPARTMENT OF ENERGY

Fermilab

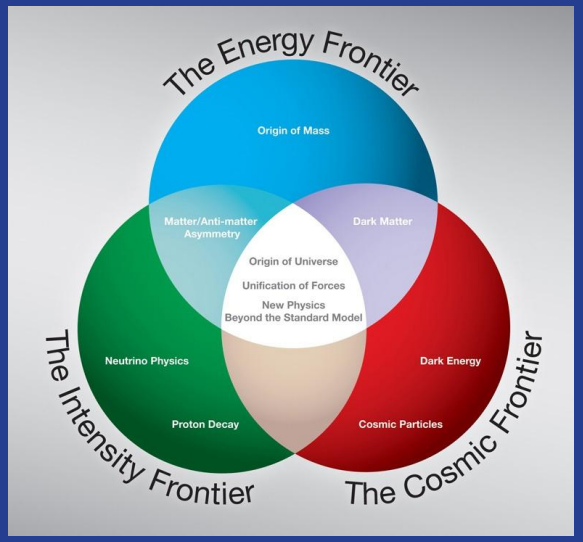
Who Am I

Brenna Flaugher
Distinguished Scientist at Fermilab
APS Fellow
PhD Rutgers University

2022- present Deputy Division Head Particle Physics Division
2013-2022 Fermilab Astrophysics Department Head

Experiments
2016-present CMB-S4 L2 Scientist for Detector Fabrication (interim), Technical Integration Scientist
2012-2016 DESI Project Scientist and L2 Scientist for Integration and Commissioning
2003-2012 DES, DECam Project Manager
2000-2005 Deputy Head of Fermilab Silicon Detector Facility
1999-2004 L2 manager for CDF Run IIB Silicon Vertex Detector
1986-2005 CDF: Run IIA Silicon vertex detector assembly, QCD convenor, Operations manager

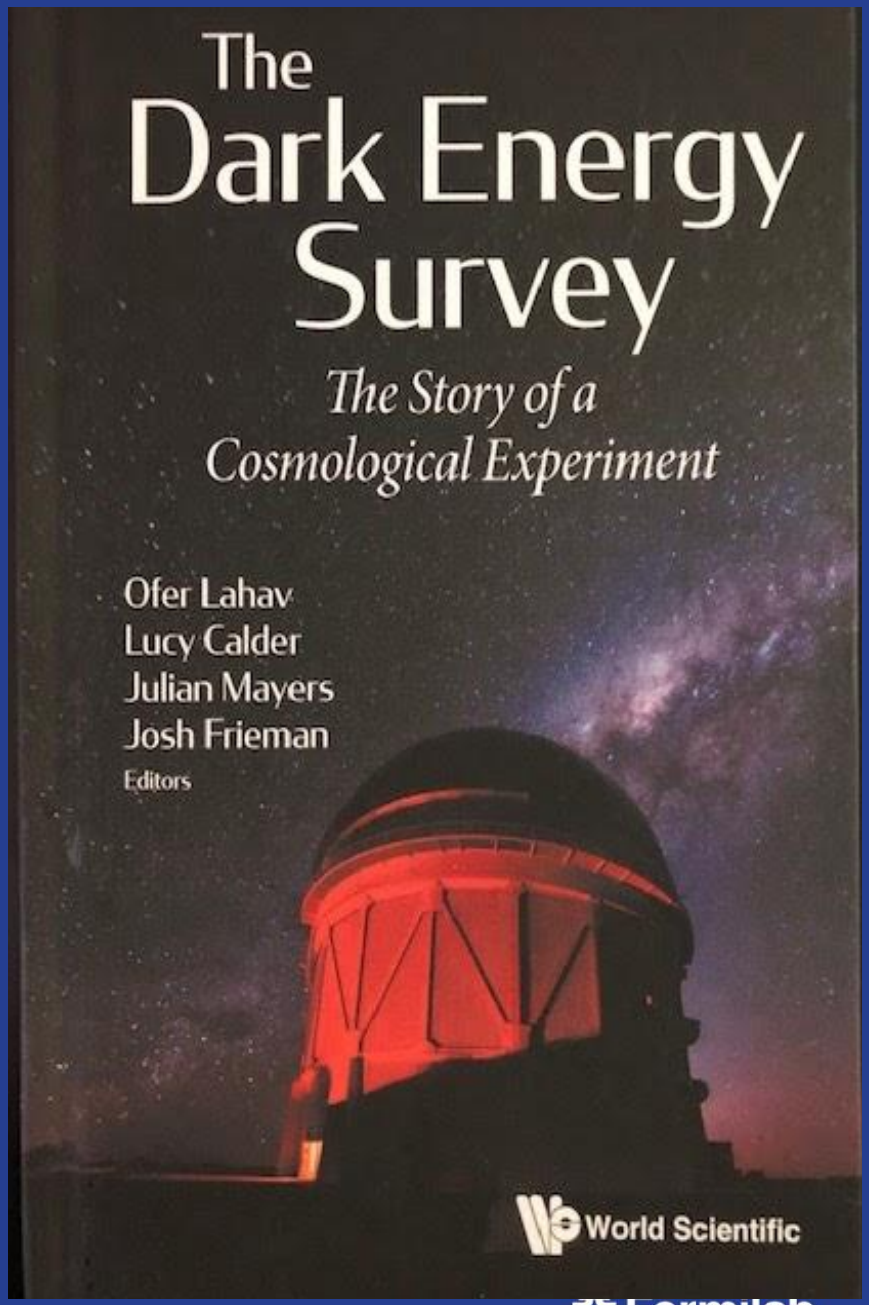
Fermilab Program



Fermilab

- A Personal view of how the Dark Energy Camera came to be

- For the full story we wrote a BOOK! Available on Amazon



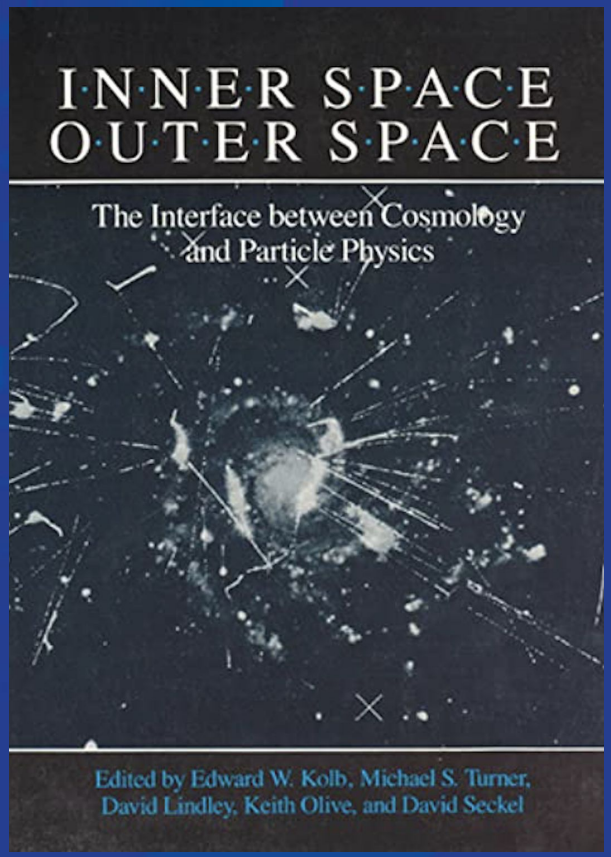
Fermilab

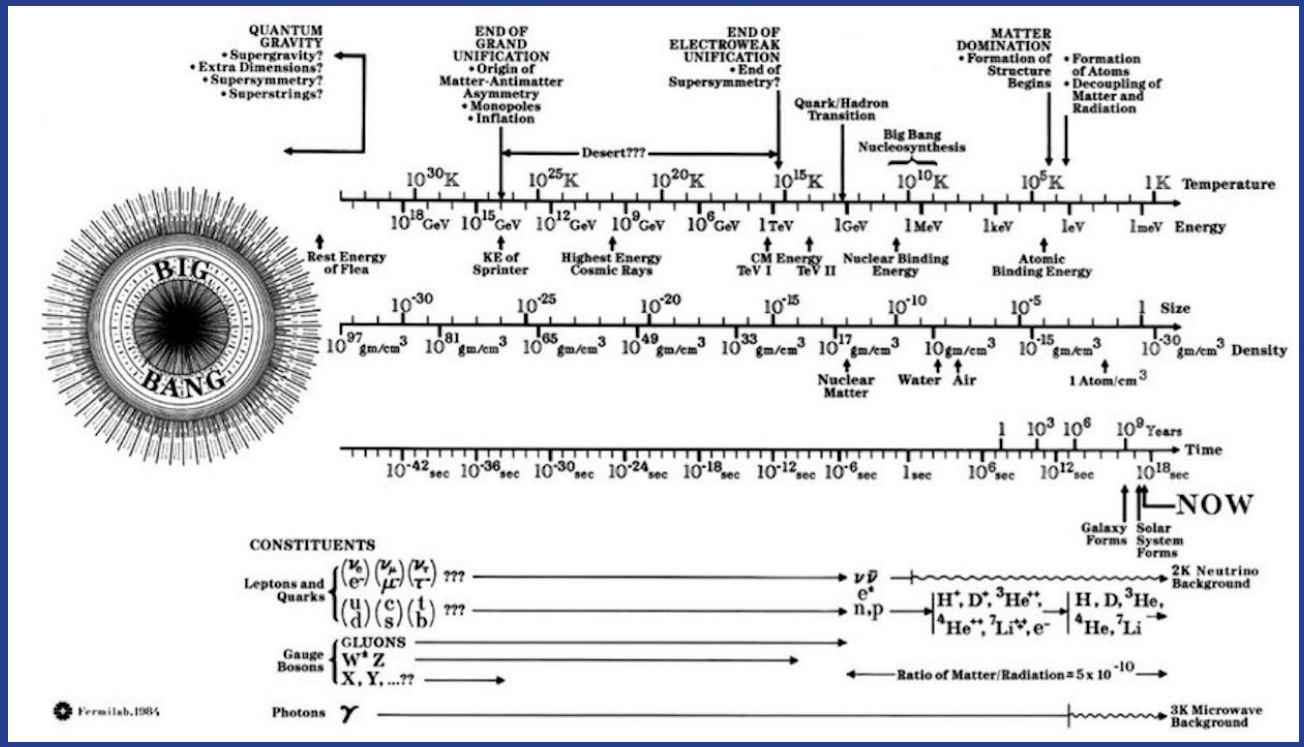
Outline

- Key elements to DECam
  - Timing
  - Strong director
  - Right price and multiple funding sources
  - Science case
  - Technical team
- Thoughts for Future projects

1970's and 80s: Fermilab was building the Tevatron – to produce the highest energy ppbar collisions, but making the connection to cosmology was being being discussed

- Workshop in 1984 on connections of High Energy Physics and the formation of the universe

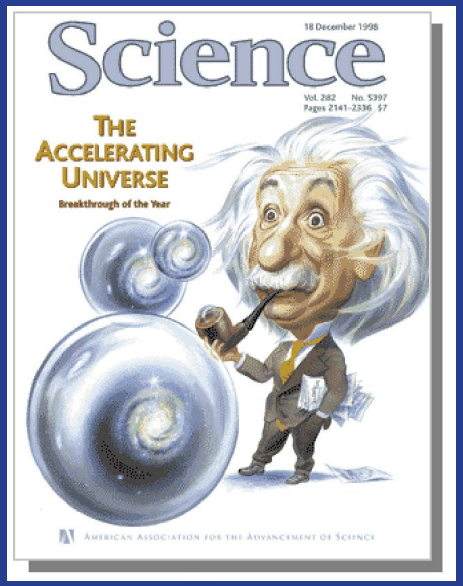




Fermilab

1990's: Top Quark, Dark Energy (setting the stage for DES)

- High Energy: Fermilab experiments discover the top quark, build main injector and prepare for Run 2
  - John Peoples was Fermilab Director
  - I was analyzing the highest energy collisions and building Silicon Vertex detectors
- Dark Energy: Fermilab and University of Chicago Astro theory groups conspired to get Fermilab involved in SDSS
  - Chicago/FNALAstro theory: Josh Frieman, Scott Dodelson , Rocky Kolb, Rich Kron, Mike Turner, Albert Stebbins,…etc
  - Fermilab joined SDSS in 1991, hired Steve Kent, formed a group that was critical in building SDSS
  - 1999 John stepped down as FNAL director, to keep busy he became SDSS director until 2003 (science data started in 2000)
- 1998 DOE HEPAP subpanel report recommended strengthening Non-accelerator program
- 1999 Discovery that the expansion of the universe is accelerating (2011 Nobel Prize!)



Fermilab

2003: Cosmic Convergence: DOE is interested in cosmology, NSF/CTIO looking for a new instrument for the Blanco

- Josh, John others were talking about new project: Provide Photometric redshifts for ~20,000 SPT clusters plus measure ~ 3000 SN, constraints on w
- Announcement of opportunity to build a new instrument for the Blanco in exchange for telescope time
- Recognition that the wide field capability of the Blanco and a new large camera could take a big step in constraining Dark Energy
- Sept. – My silicon vertex project was cancelled. I joined the DES discussions: what a Cool project! I took role as project manager, transferred SVX team.
- Nov. - Trip Kitt Peak – We Can Do This! Not so different from silicon vertex detectors!
- Dec. 1st DES Meeting at Fermilab

Science Breakthrough of the Year: WMAP and SDSS LSS results: Universe is ~ 70% DE, 25% DM 5% normal matter

The Dark Energy Camera was Designed for the Dark Energy Survey

www.darkenergysurvey.org

- Dark Energy Survey – multiple probes
  - Distance vs redshift
  - Growth of Structure
- Two Multicolor surveys:
  - 300 M galaxies over 5000 sq.deg. with photometric red shifts grizY to 24th mag
  - ~ 3000 SN
- Replace the existing camera on the Blanco in exchange for 30% of the telescope time over 5 years
- DOE /Fermilab would lead the Camera Construction, NSF would upgrade the telescope and cover Data Management
- Plan (circa 2004) : Construction 2004-2008, – this was very optimistic!

Key steps to approval (~ 4 years)

- 2003 NOAO Announcement of opportunity
- Dec. 2003 1st DES meeting
- June 2004: Fermilab held a Temple review of DES and Stage 1 approval from Fermilab Director
- August 2004 National Optical Astronomy Observatory (NOAO) BIRP (Blanco Instrumentation Review Panel) review. Approval came a couple months later.
- 2005: Nov. DOE approved CD-0 (Mission Need) for a ground based DE project . (DOE's way of saying they are interested in looking into maybe doing a DE project, not necessarily DES)
- 2006: P5 review and the Dark Energy Task Force report (multiple probes are important, DES viewed as cost effective, and low risk)
- 2007: May 2007 CD-1 review, Oct. CD-1 approval for DES
- 2008: Approval to start Construction!

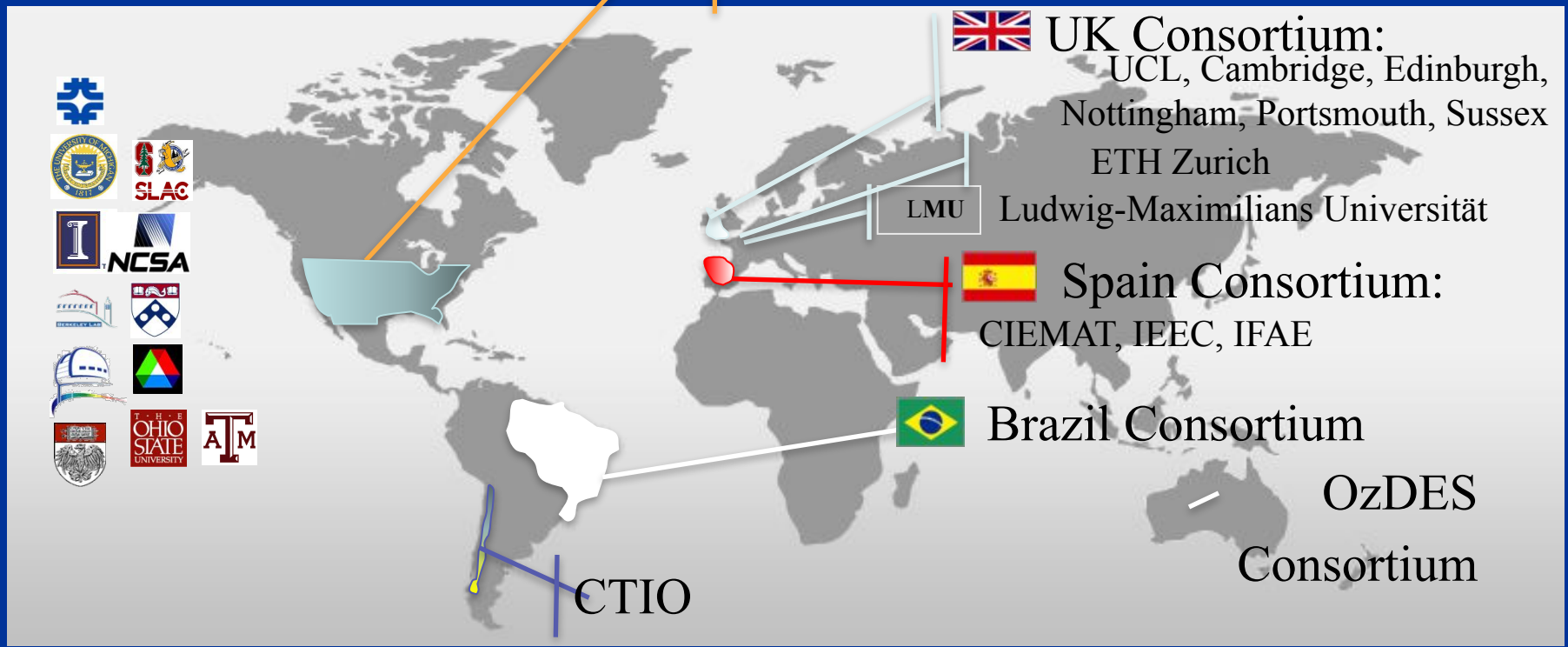
Many Reviews from 2008-2012 (How funding agencies and lab directors express their love for your project)

Dark Energy Survey Collaboration

~400 scientists;

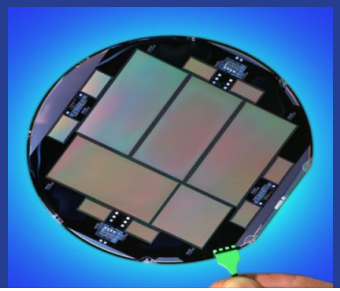
US support from DOE & NSF

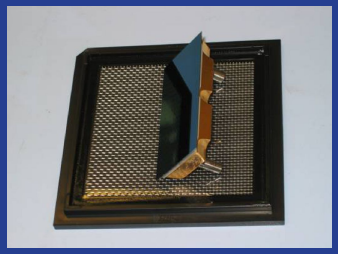
Fermilab, UIUC/NCSA, University of Chicago, LBNL, NOAO, University of Michigan, University of Pennsylvania, Argonne National Lab, Ohio State University, Santa-Cruz/SLAC/Stanford, Texas A&M

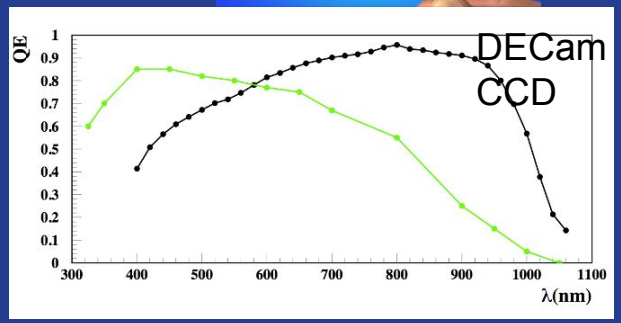


Key features of early project development: multiple labs, international partners and strong university groups

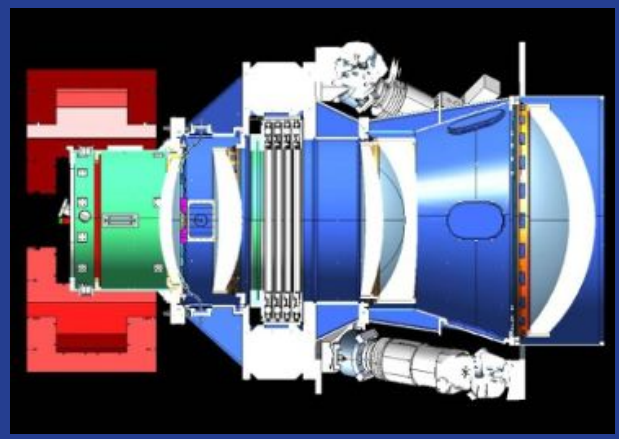
- LBNL CCDs – Steve Holland was developing CCDs for SNAP, these could be used for DES. Main challenge increase production rate and yield.
- CCDs Packaged and tested at Fermilab







- Large Lenses 0.5m-1m diameter! Optical expertise and international support brought in by Ofer Lahav, University College London (he also led the book writing!)
- DESI Followed the same Path



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Lens Fabrication 2007-2011

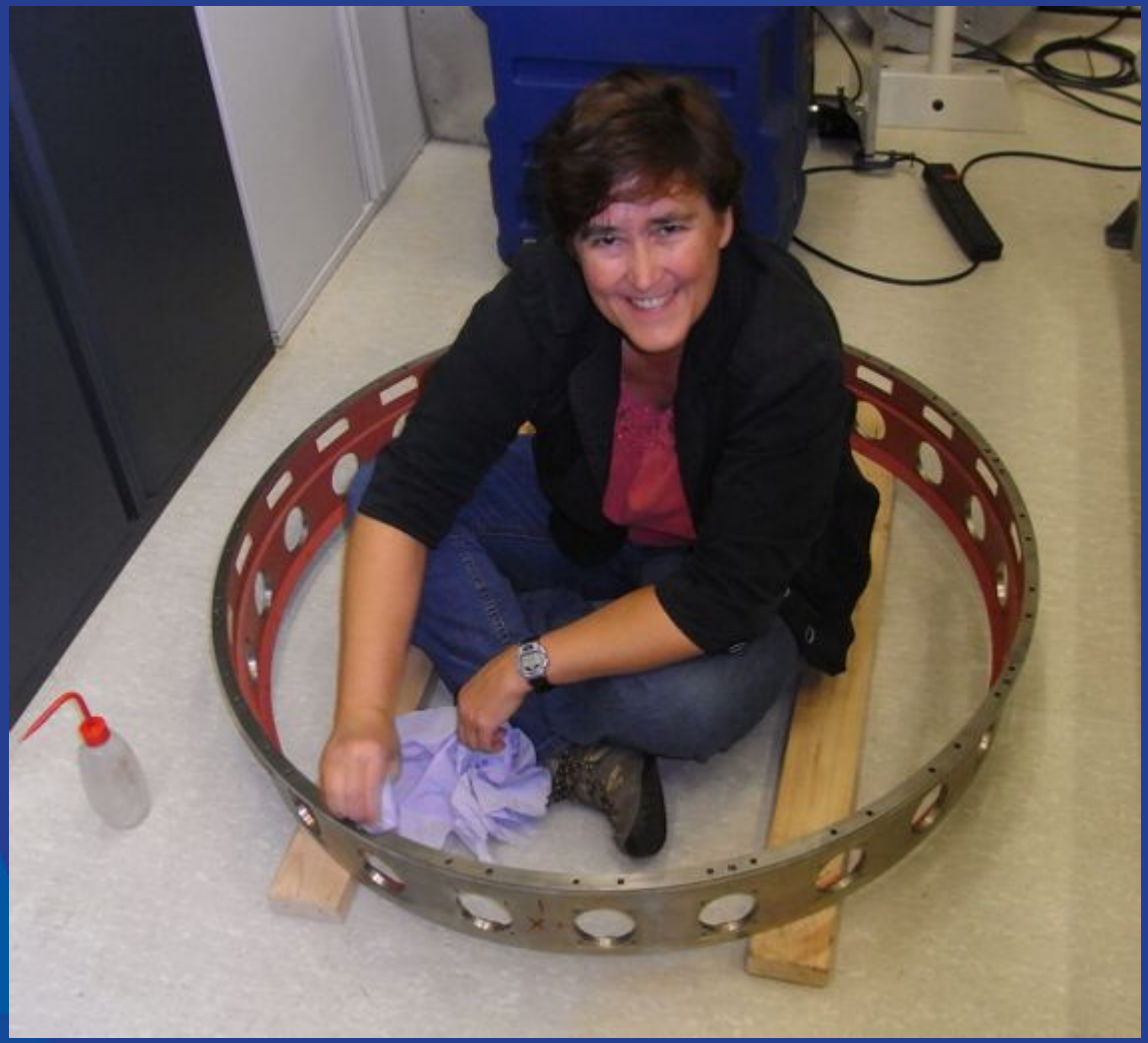
Steve Kent inspecting the C1 Blank (980mm diameter) at Corning New York Jan. 2008

Polishing/Coating in France

Delivered to UCL Early 2011

Barrel delivered to CTIO Dec. 2011

The huge lenses were glued into metal rings that were precisely aligned to each other - all rings cleaned and painted black to reduce reflections



Jan. 19, 2012

Optical corrector assembly at CTIO

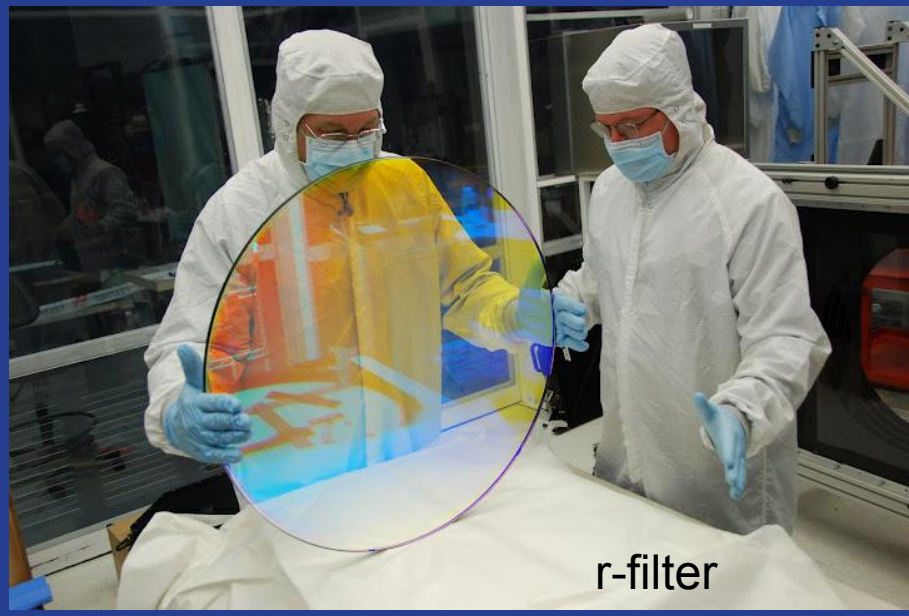
Peter, Mich and David from UCL assembling the DECam optical corrector

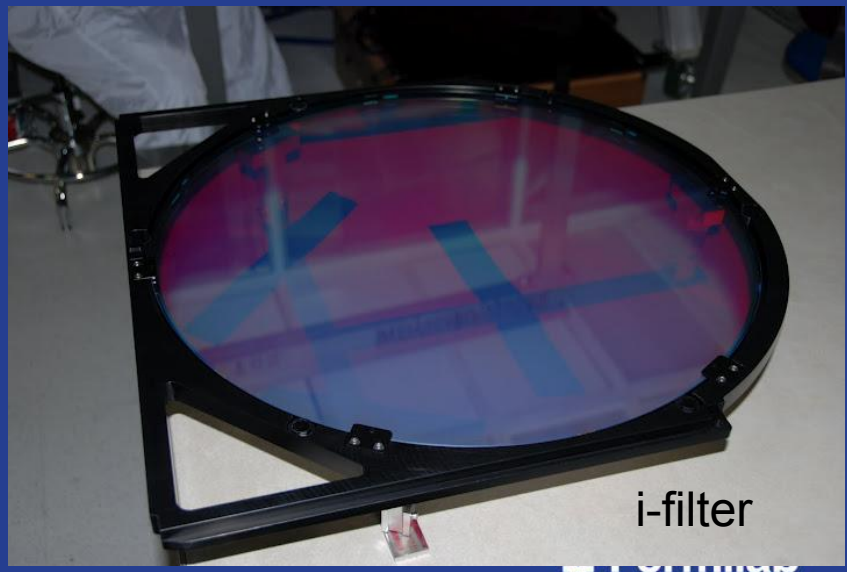
By Jan. 20th we had confirmed that everything is within specifications!

Fermilab

Filters

- 620mm substrate, 600mm clear aperture, 10mm thick, 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) exceeded our requirements.
- At CTIO we installed the filters into cells in the clean room in the Coude room.


r-filter

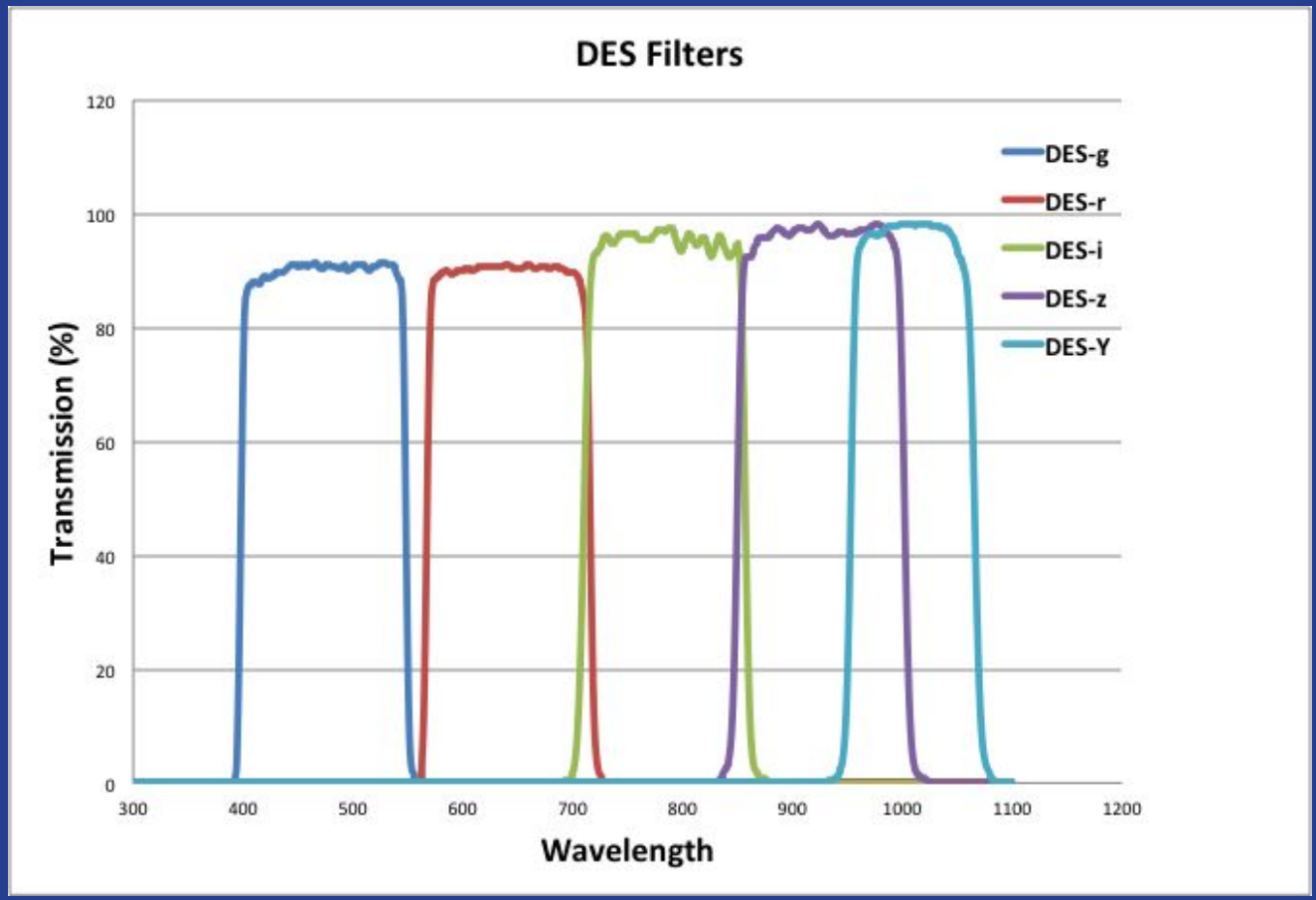

i-filter

Filters beat our requirements!

Excellent transmission

Outstanding Uniformity

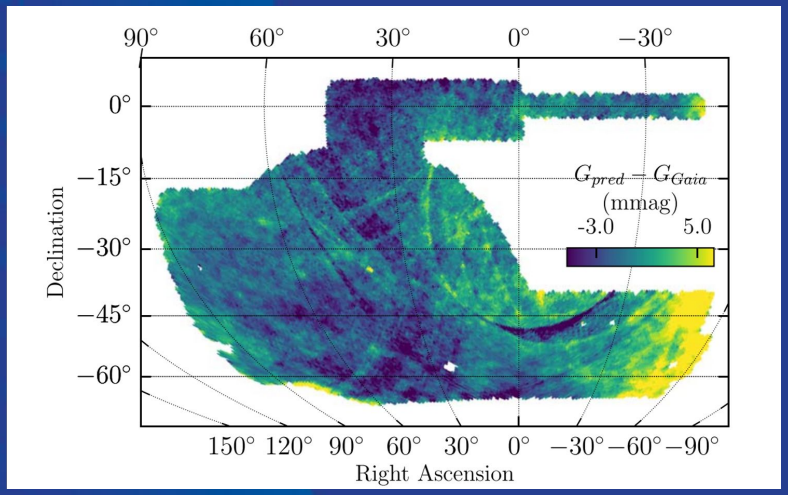
CTIO ordered more filters!

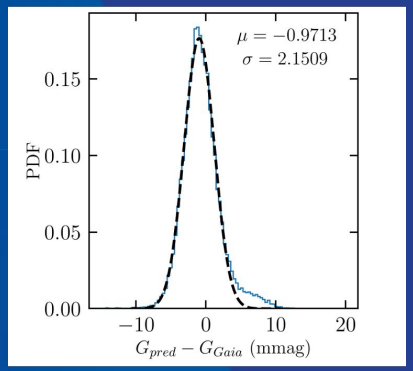


Fermilab

Unprecedented High Precision Photometry achieved by DES - See Ting's talk!

Dark Energy Survey Data Release 2



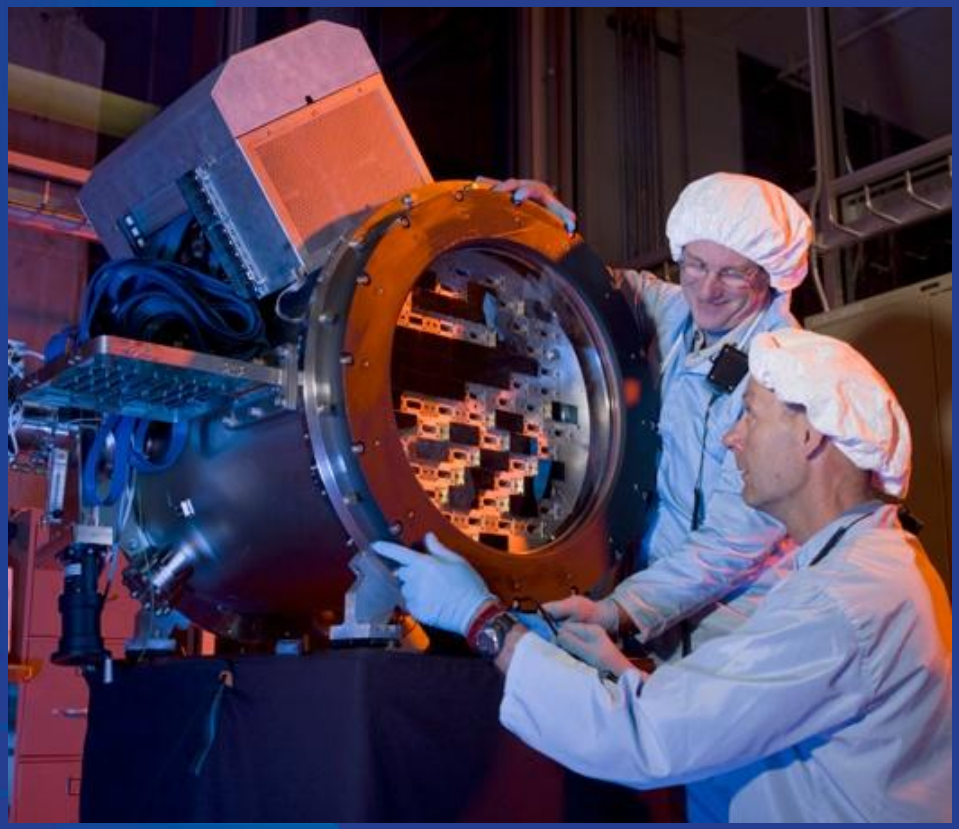


- Photometric Uniformity vs. Gaia: 2.15 mmag
- Single-epoch Photometric Repeatability: 2-3 mmag
- Achieved with efforts from many aspects
- Auxiliary Calibration Systems: DECaLS, aTmCam, GPS Monitor
- Forward Global Calibration Method (FGCM, Burke, Rykoff+2018) for photometric zeropoint
- Chromatic Correction and Interstellar Reddening Task Force

Reviewers expressed concern about our lack of experience

- Strong emphasis on testing and integration
  - prototype imager,
  - telescope simulator
  - tested individual components
  - mock observing runs

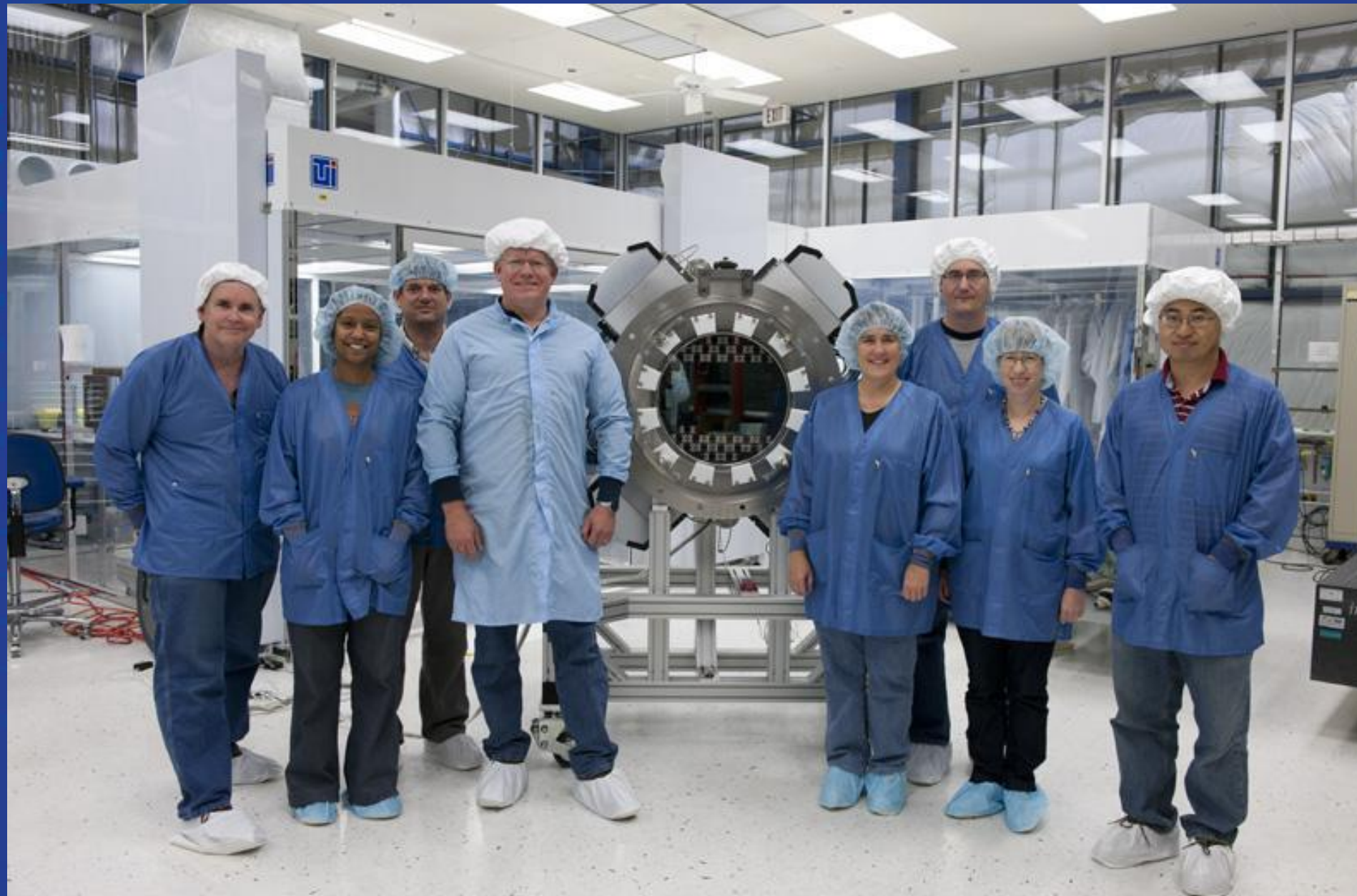
Prototype imager and readout crate with Engineering grade CCDs in 2009



Funding came from early contributions from Chicago and UIUC

Pinhole camera picture with prototype vessel and DAQ/Readout from OSU (Klaus Honscheid)

Part of the DECam team with the camera about half full of CCDs in the Lab C Clean room at Sidet



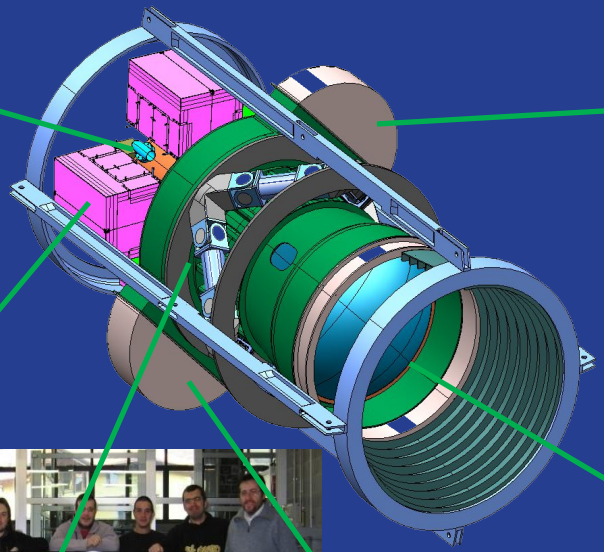
CTIO and Fermilab engineers “discuss” (in engineer language and pictures) Imager Installation at the NW station. Final system was largely the same!

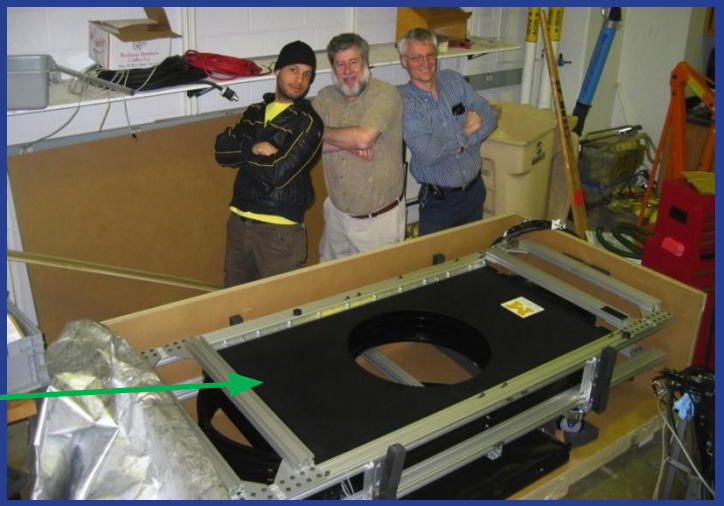
Nov. 2008 DECam Integration Meeting La Serena/CTIO

In Lab A at Sidet we used the Telescope Simulator to practice installation of DECam on the telescope

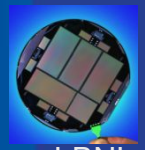
DECam Systems came together at Fermilab

Imager, FNAL





Filter changer, Univ. of Michigan

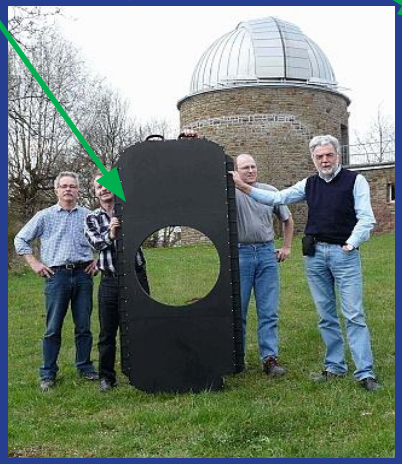


CCDs, wafer from LBNL, packaged at FNAL

Hexapod, Italy

Barrel and Cage (FNAL, no lenses)

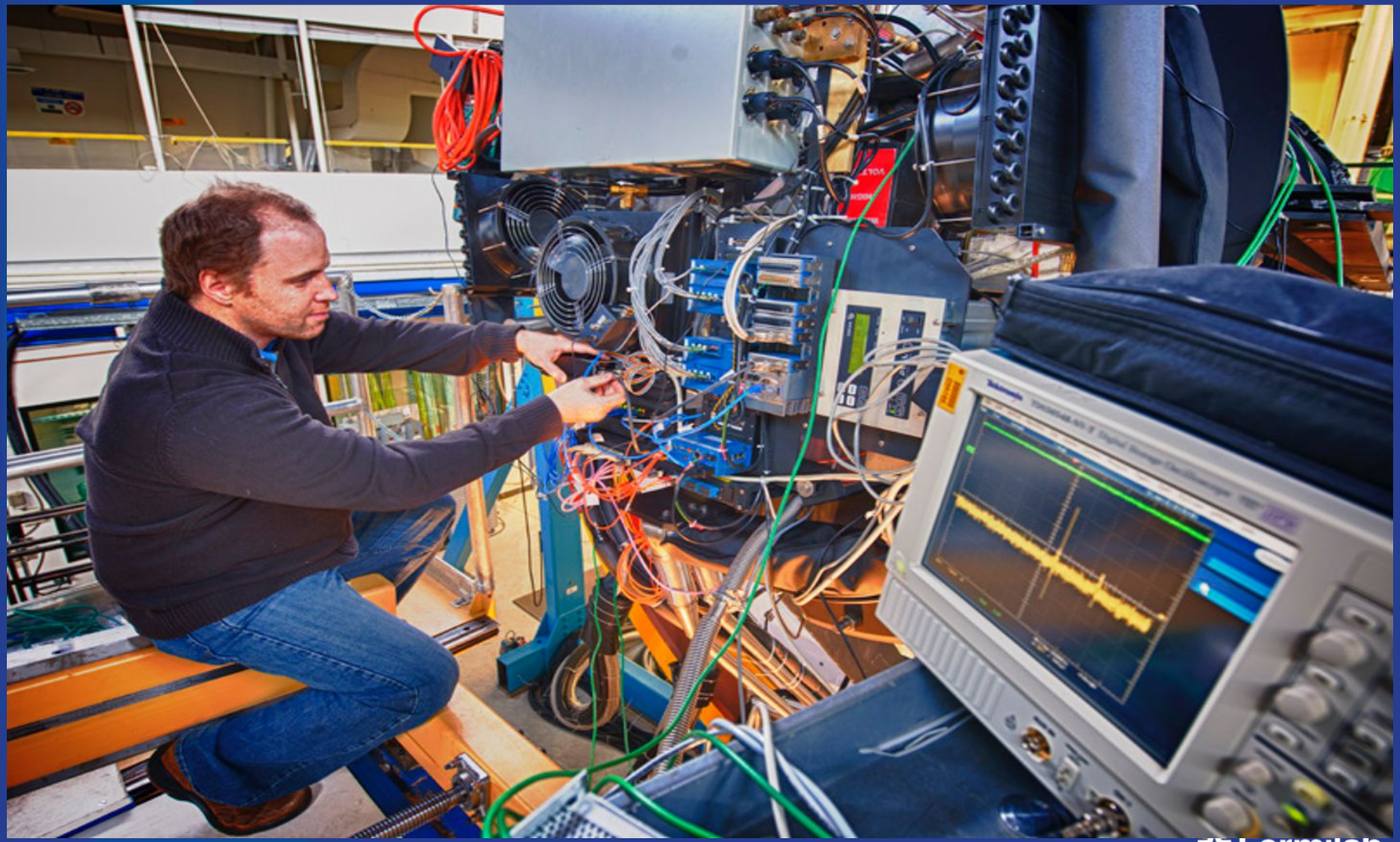
Electronics, Spain and FNAL



Shutter, Germany

Fermilab

The guts of DECam: hooking up cables for full system test at Fermilab on the telescope simulator



DECam Construction Summary (where I spent my time during the construction years)

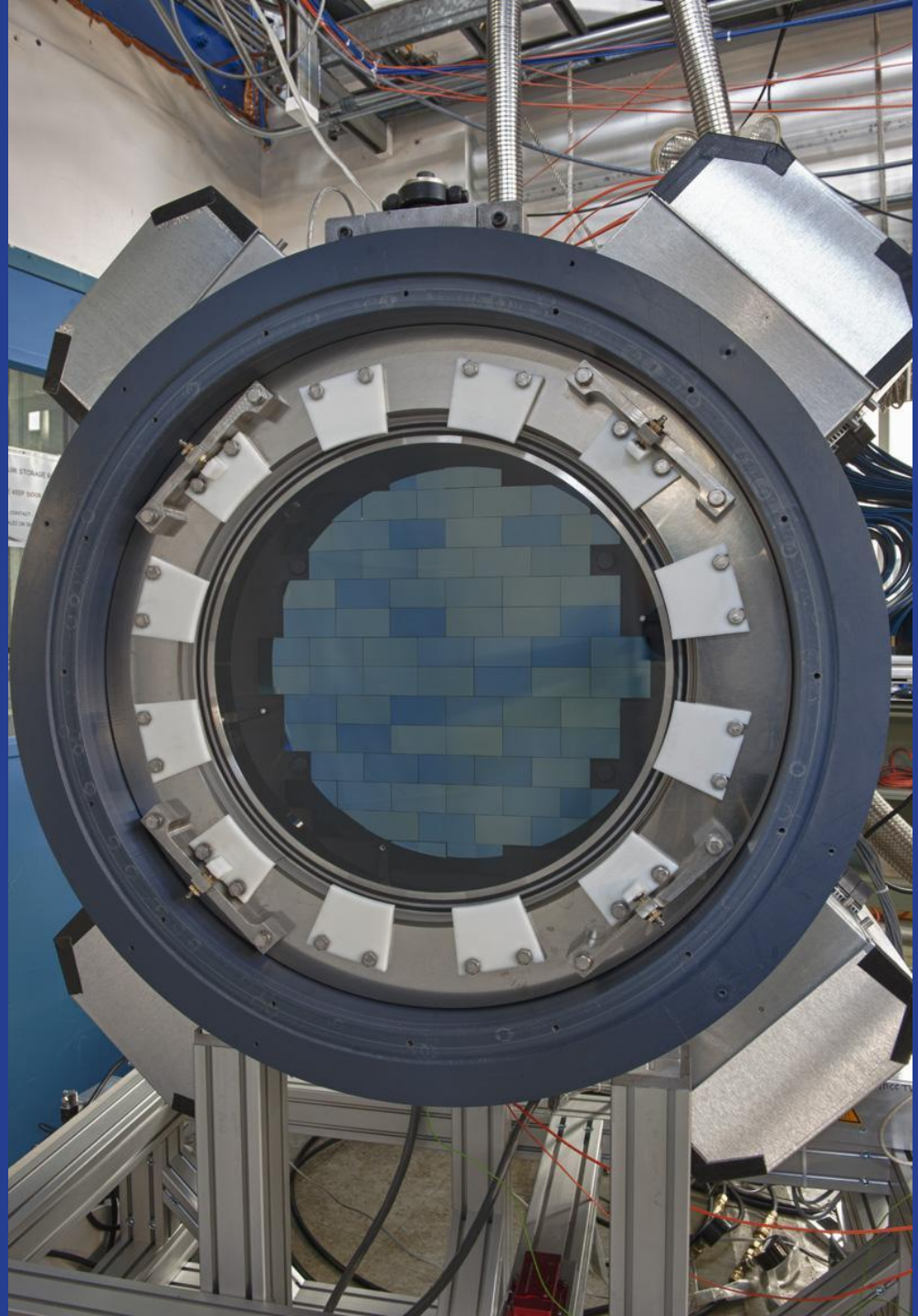
Symmetry Magazine

DECam Imager with all the CCDs installed and ready to be packed up for shipping to Chile.

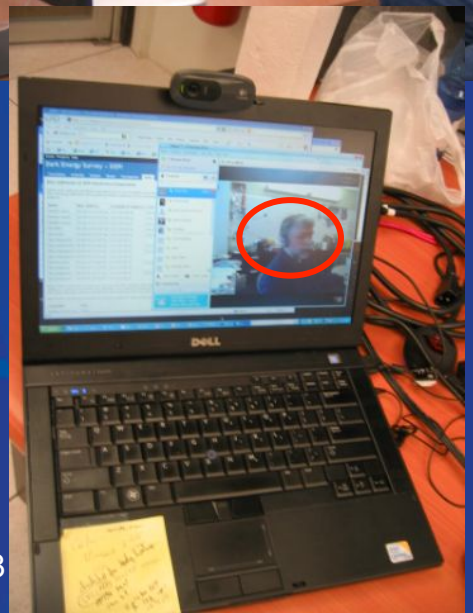
570 Mega pixels!

It arrived safely in Chile in Nov. 2011

Good images Dec. 6!

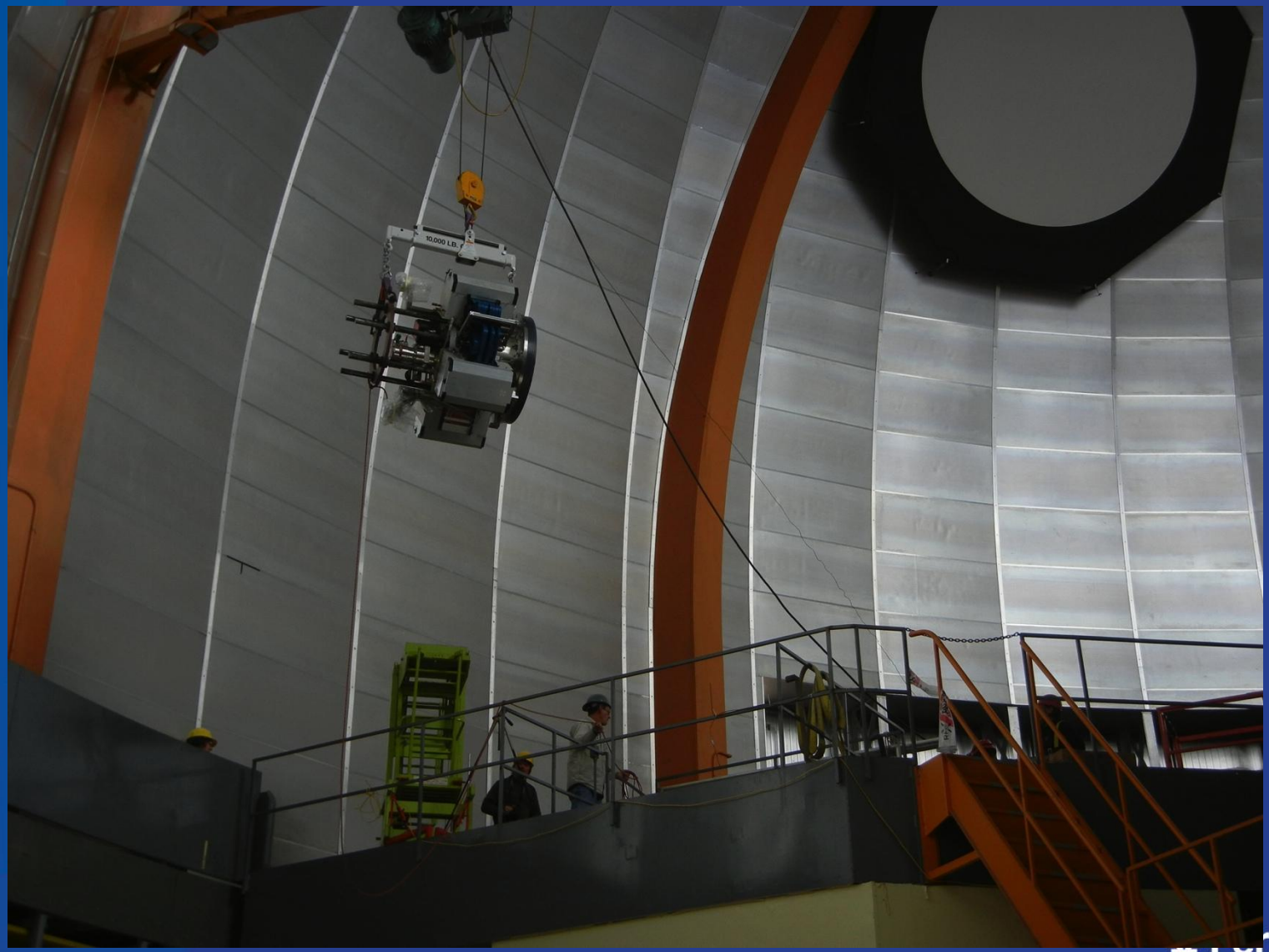


Mock Observing runs Jan. 23,24 2012 >200,000 images before first light!



Klaus (OSU) tuning up operations software - many hours on SKYPE!

August 2012 DECam installation: 74 CCDs, all the electronics, and a lens all hang from the crane!



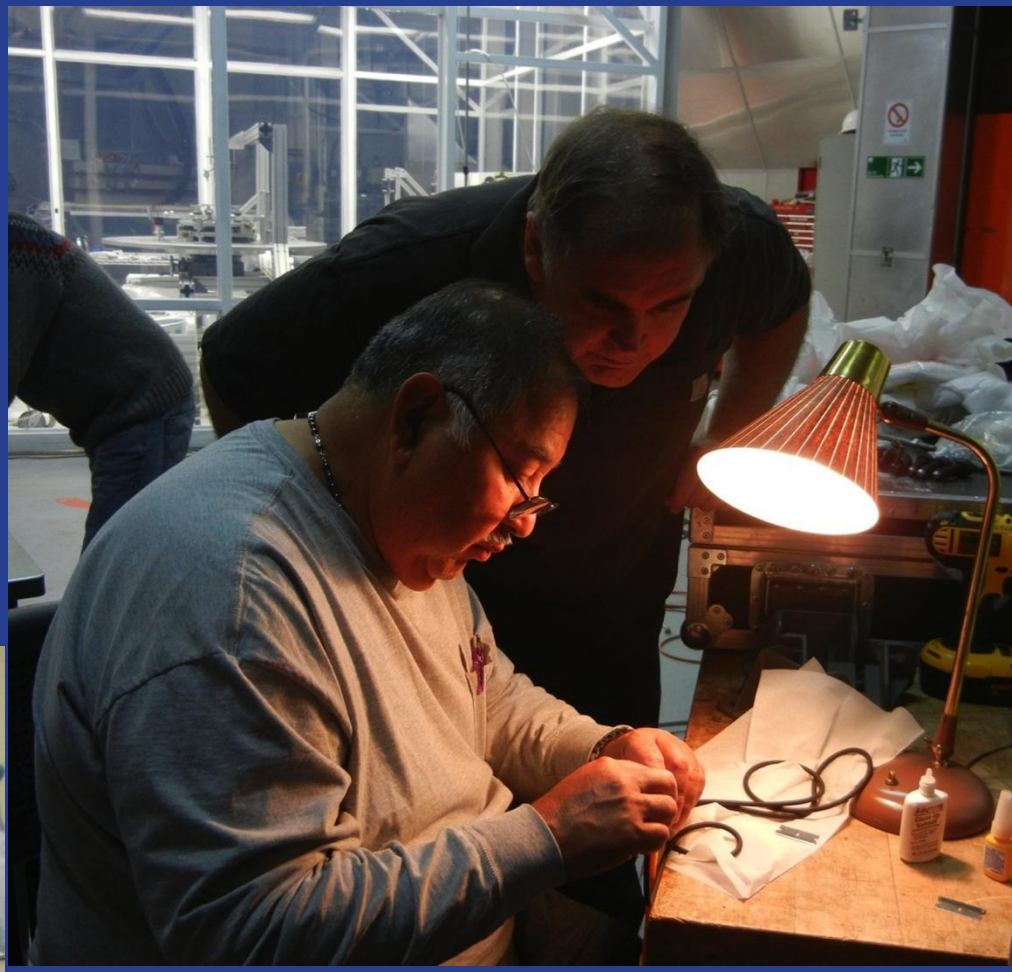
Handoff to CTIO staff

Fermilab and CTIO Staff working together

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

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

Fermilab

DECam Dedication Nov. 2022

Nov. 2012 DECam Dedication

Nov. 2012: Science Verification in progress and CTIO at 50 Celebration !

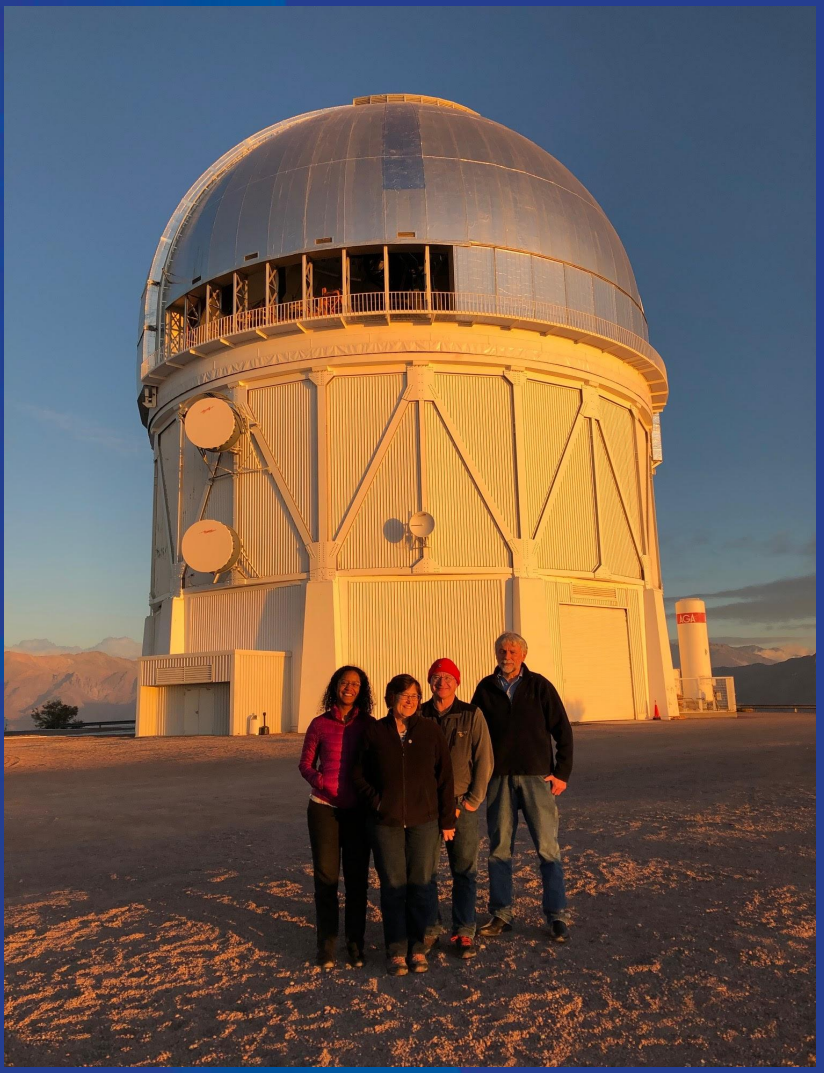
The DECam Project was complete in June 2012, on budget and on schedule! (huge relief)

First light Sept. 2012 – It works! (even more relief!)

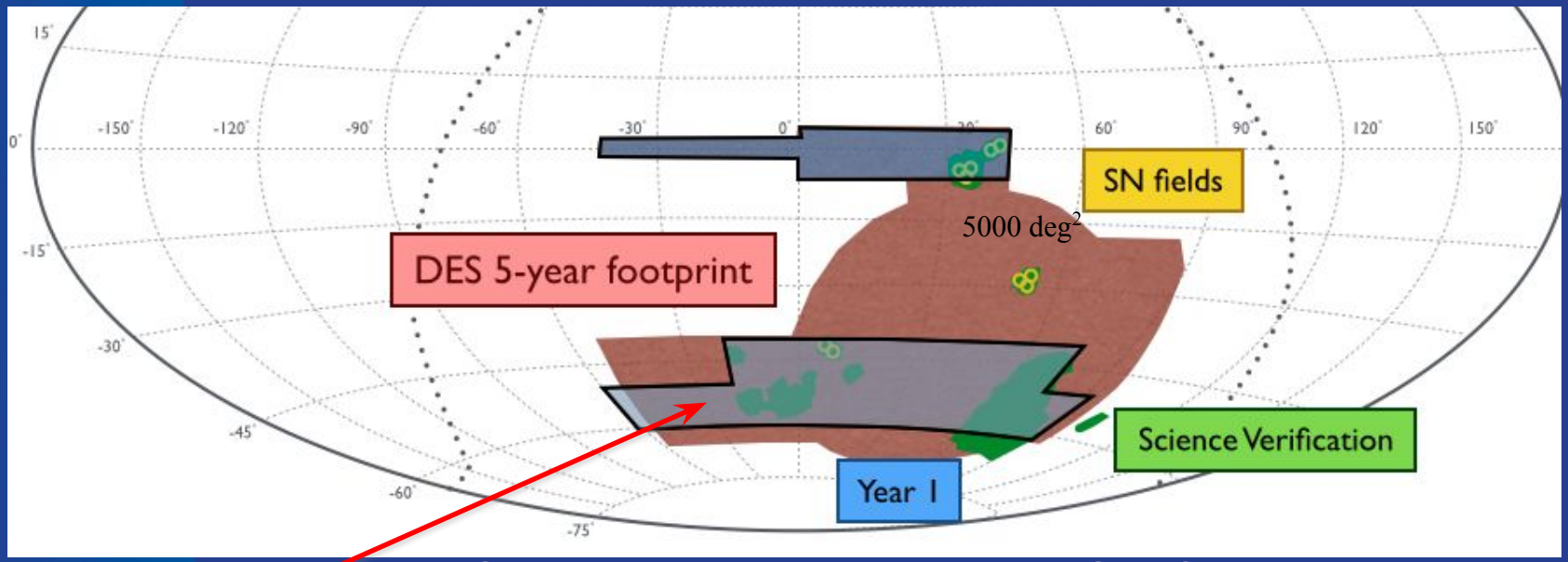
Fermilab

DES Y4: 76 full nights and 68 half nights.

DES observing completed Jan. 2019



DES analysis is paving way for future surveys

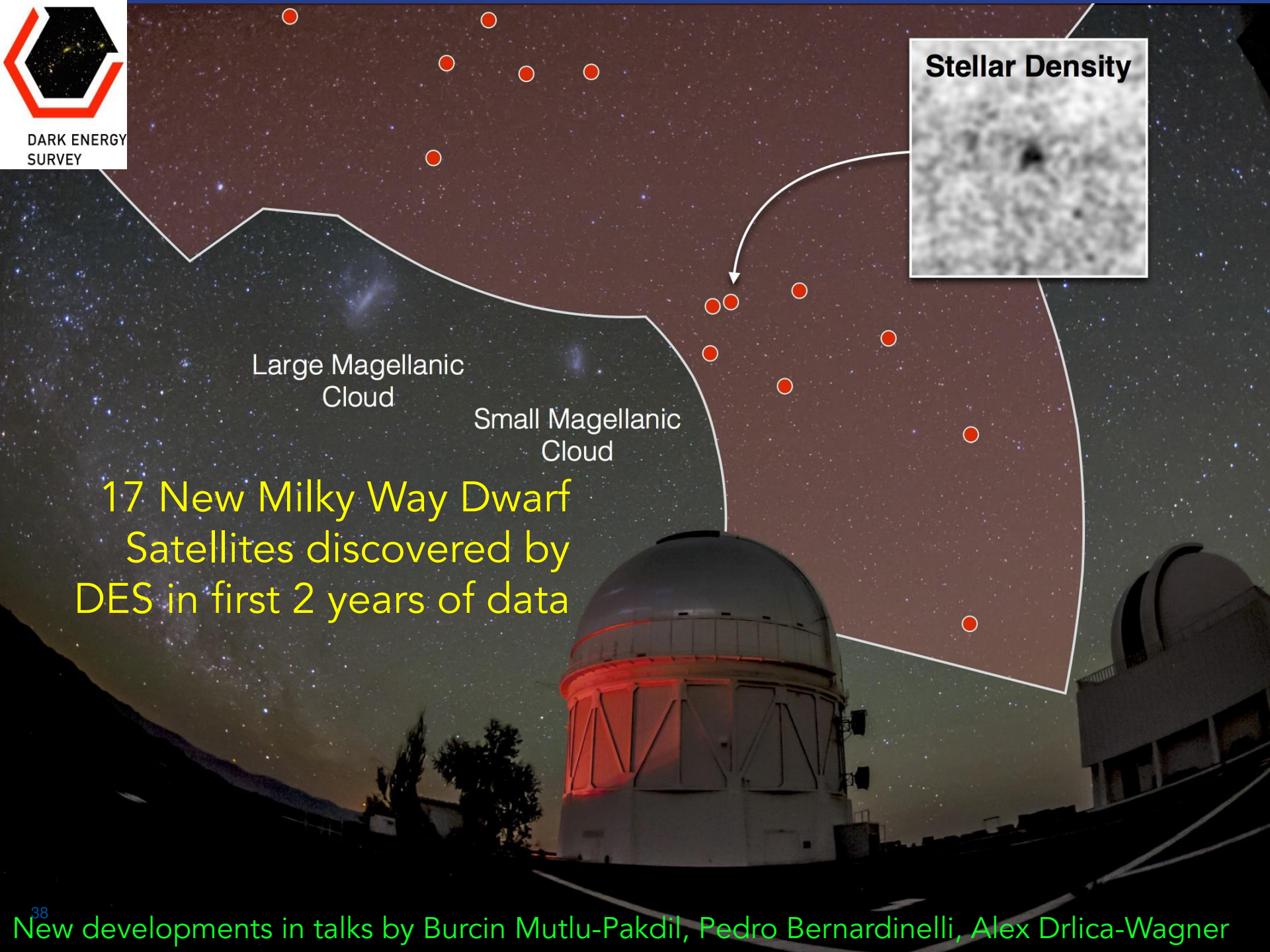


DES survey area designed to overlap SPT Sunyaev-Zel'dovich Cluster Survey (SZ Effect: decrement in CMB photons due to Compton scattering by energetic electrons in hot cluster gas) – SZ flux is proxy for cluster mass – DES provides redshifts - different systematics, promising path for future surveys

Recent Paper: Joint analysis of DES Year 3 data and CMB lensing from SPT and Planck II: Cross-correlation measurements and cosmological constraints https://arxiv.org/pdf/2203.12440.pdf

Chihway's talk will have lots of highlights

Fermilab



New developments in talks by Burcin Mutlu-Pakdil, Pedro Bernardinelli, Alex Drlica-Wagner

Some Lessons Learned

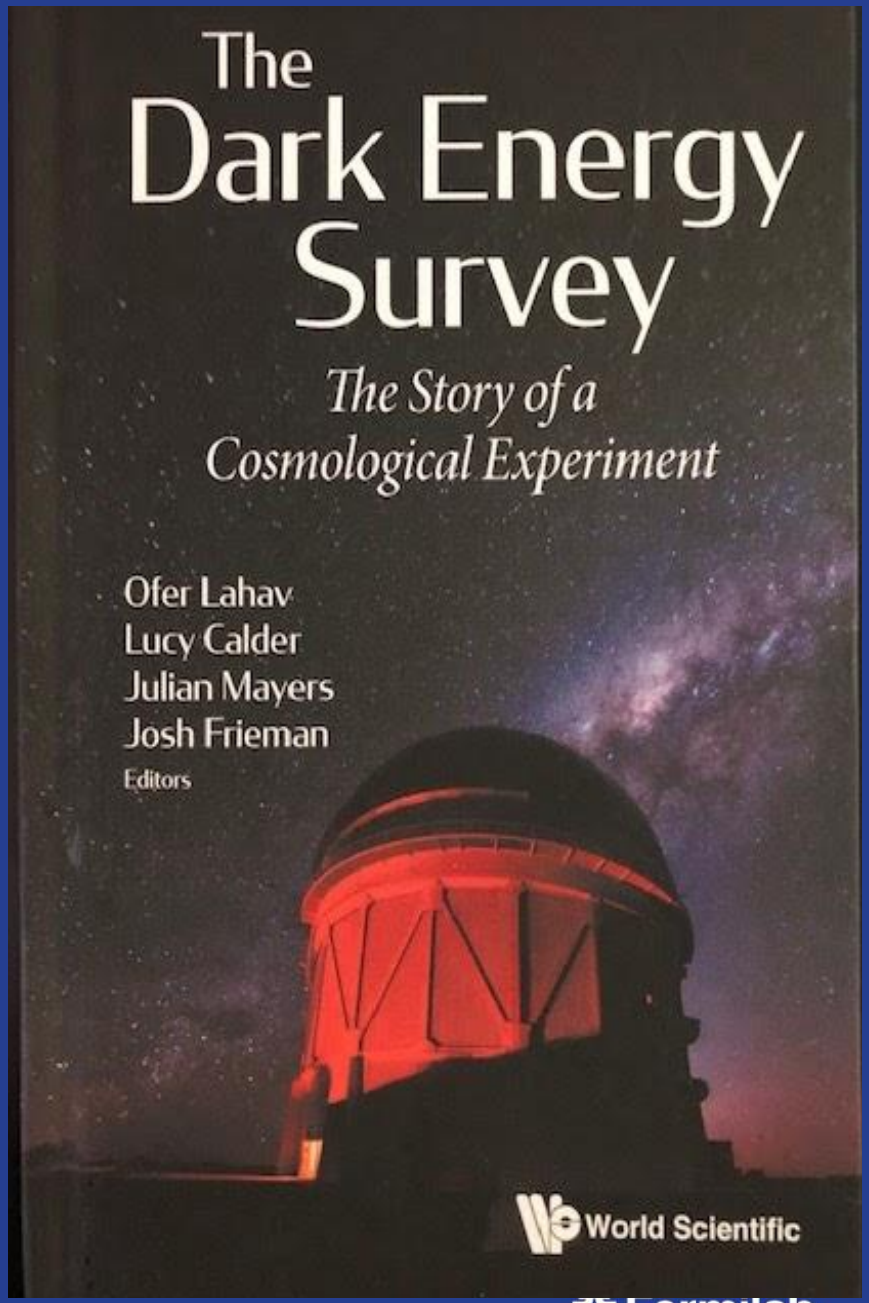
- DOE (DECam) and NSF (NOAO/CTIO, Data Management) have different cultures and styles. This provided opportunities and challenges
- International Funding: different timescales and proposal requirements
- Management team strongly invested in science of DES: physicists, astronomers and engineers
- **Right Price** (~$35M DOE + ~ $7M in kind contributions) at the **Right Time**
- Optics, CCDs: Early R&D and procurements were critical
- CCDs from LBNL plus packaging and testing the CCDs at Fermilab was novel: very successful (120 Science Grade CCDS produced, 62 needed!)
- Strong emphasis on integration and testing throughout the project
  - Prototype imager 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 packaging and testing CCDs led to other projects (DESI), spin-offs in astrophysics and dark matter**

Thoughts for Future Projects

- Expect the unexpected:
  - When we started DES Weak lensing was unproven and yet it provides the tightest constraints!
  - Dwarf galaxies and strong lensing provide constraints on dark matter that we didn't anticipate
  - Many others!
- DES and DECam paved the way for DESI - What next?
- We are about to enter era of LSST/Rubin and LIGO and then the ELTs
  - Wide field, 4m telescopes have unique opportunity to follow-up transients, new constraints on cosmology
- Future massive spectroscopy - obvious next step scientifically, many options discussed at Snowmass – a first step to engaging DOE

Summary/Conclusions

- Big thank you to DOE, NSF and international partners for their contributions and support of DECam and DES
- DECam is what it is because of the effort of many people but in particular John Peoples and Alistair Walker who got it started
- It was an honor and privilege to represent DOE and Fermilab in leading the construction of DECam
- I'm particularly proud of the high number of women on the project team
- I'm looking forward to hearing about all the great science that's coming out of DECam in the next few days!

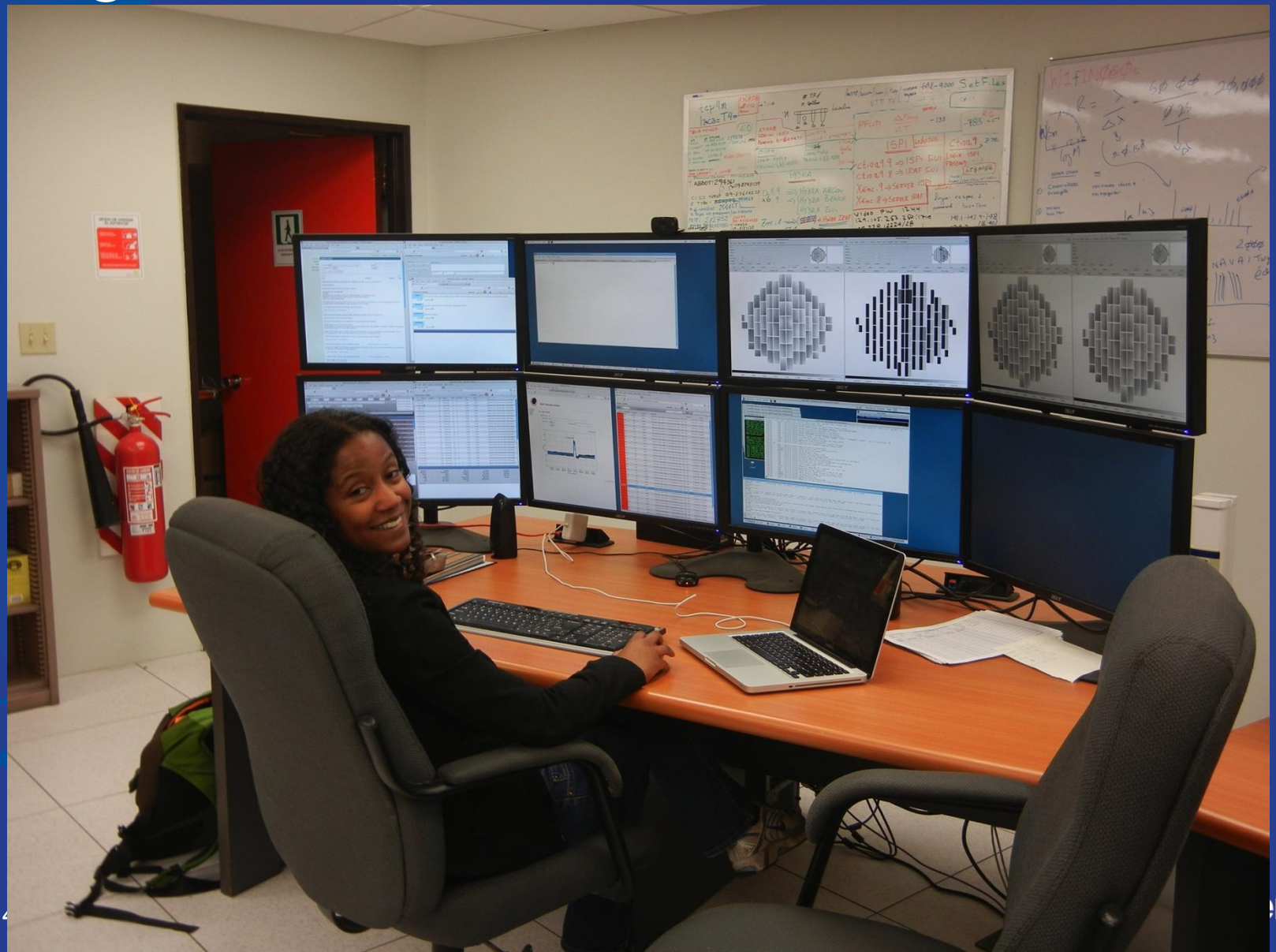


Questions?

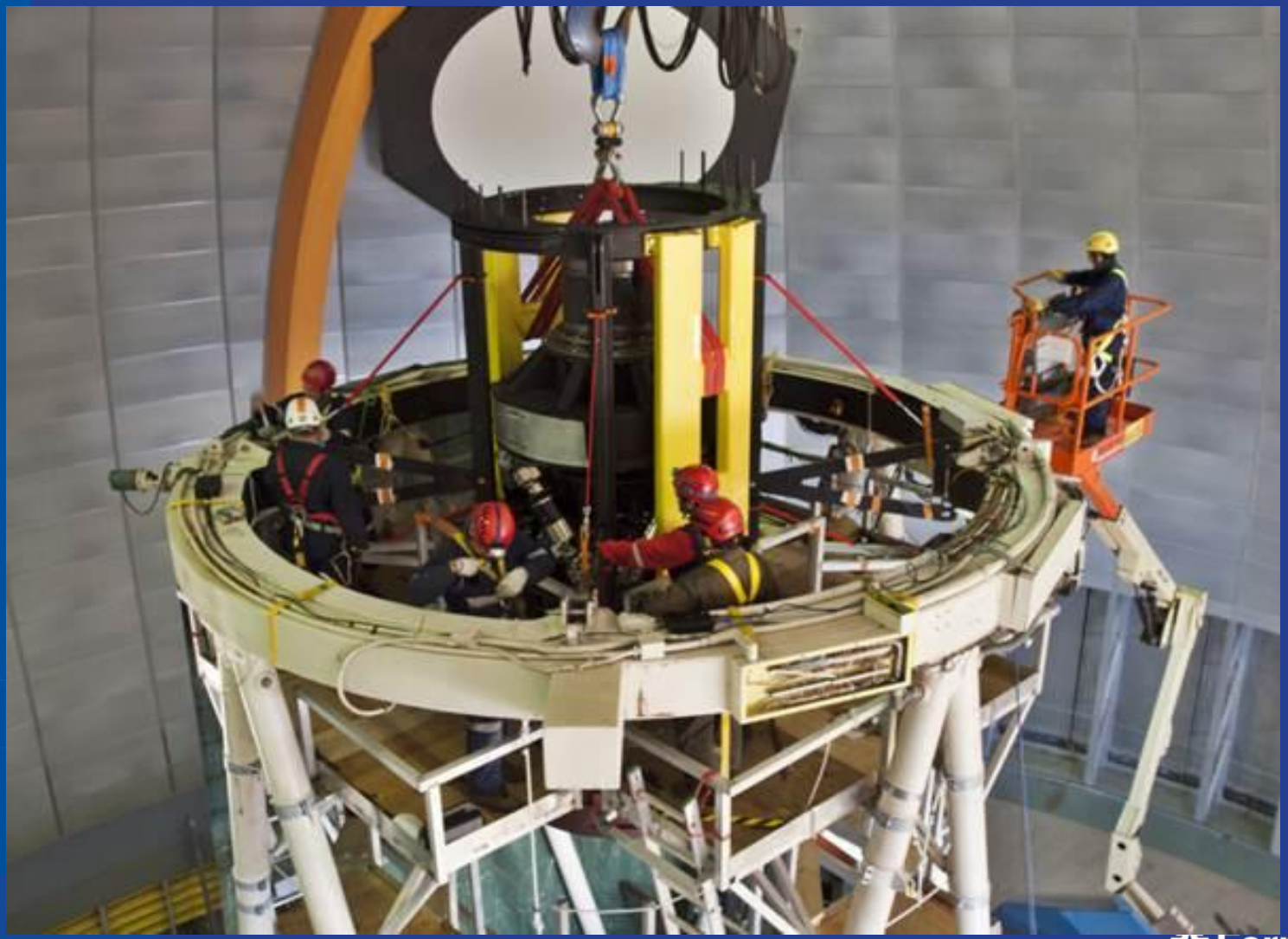
Wildlife on the Mountain: Viscacha

Extra slides

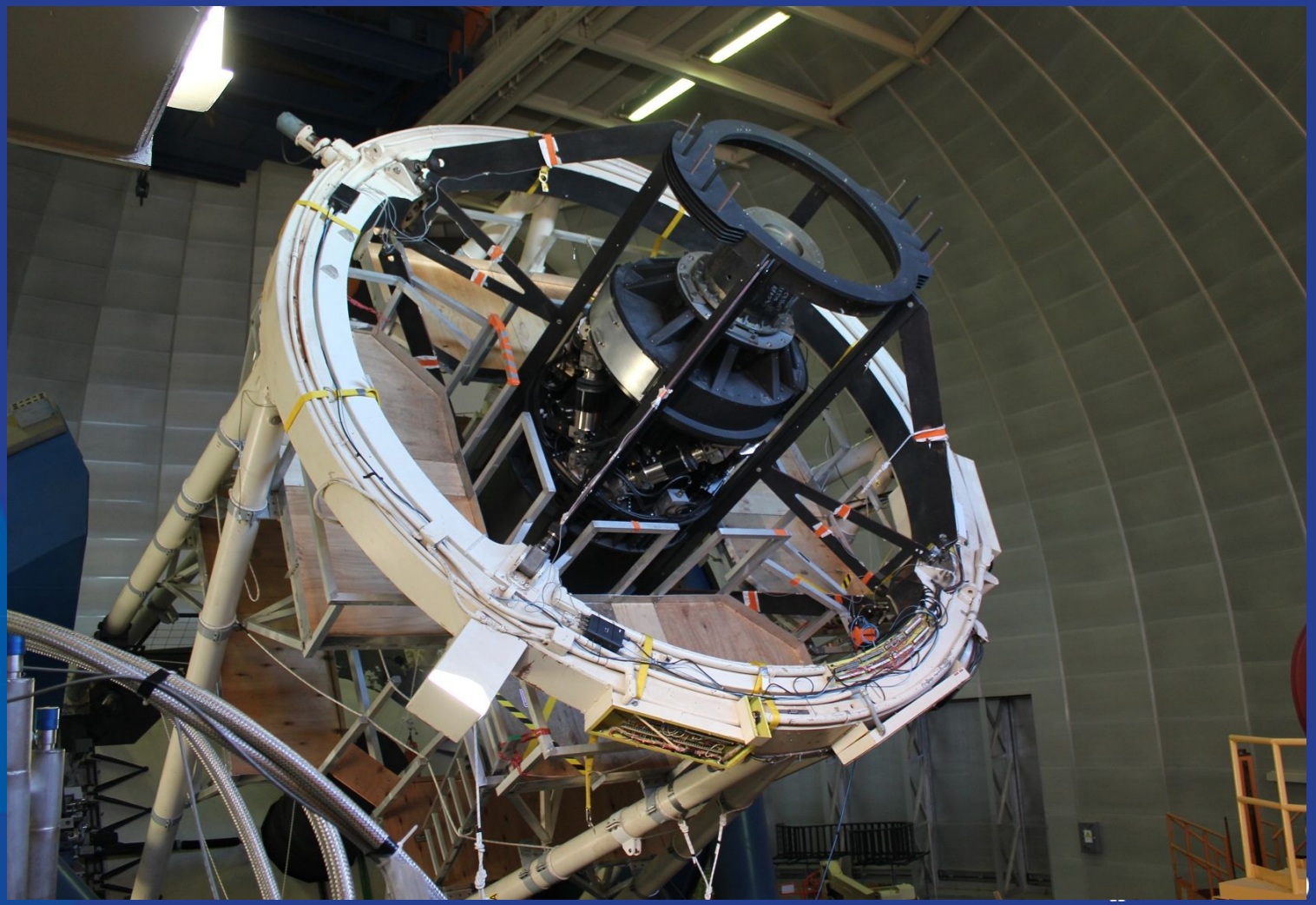
Postdocs take over and start taking images! ! Marcelle Soares-Santos



Installation of the DECam cage, and lenses! May 2012



June: the telescope moves again with DECam lenses installed! In August we installed the imager (with the CCDs) on the telescope!



DECam was designed to measure Dark Energy

Science Goals

- 5000 deg2 of the So. Galactic Cap in 525 nights (5 yrs)
- photometric-redshifts to z=1.3 with dz < 0.02.
- A small and stable point spread function (PSF) < 0.9" FWHM median

Technical Requirements

A large camera, on the Blanco 4m

3 deg^2 camera with ≥ 2.2 deg FOV

Data Management system

300GB/night, automated processing

Publicly available data archive after 1 yr

Filters, CCDs, Read noise

SDSS g,r,i,z filters; 400 - 1100nm

QE > 50% in the z band (825-1100nm)

Read noise <10 e-

Optical Corrector with excellent images

Pixel size <0.3” /pixel

< 0.4” FWHM in the i and z bands

August 2012 imager installation crew from Fermilab

Everyone got to wear harnesses!

Our new Director (2010), Josh Frieman, prefers more formal attire