LSST status and plans

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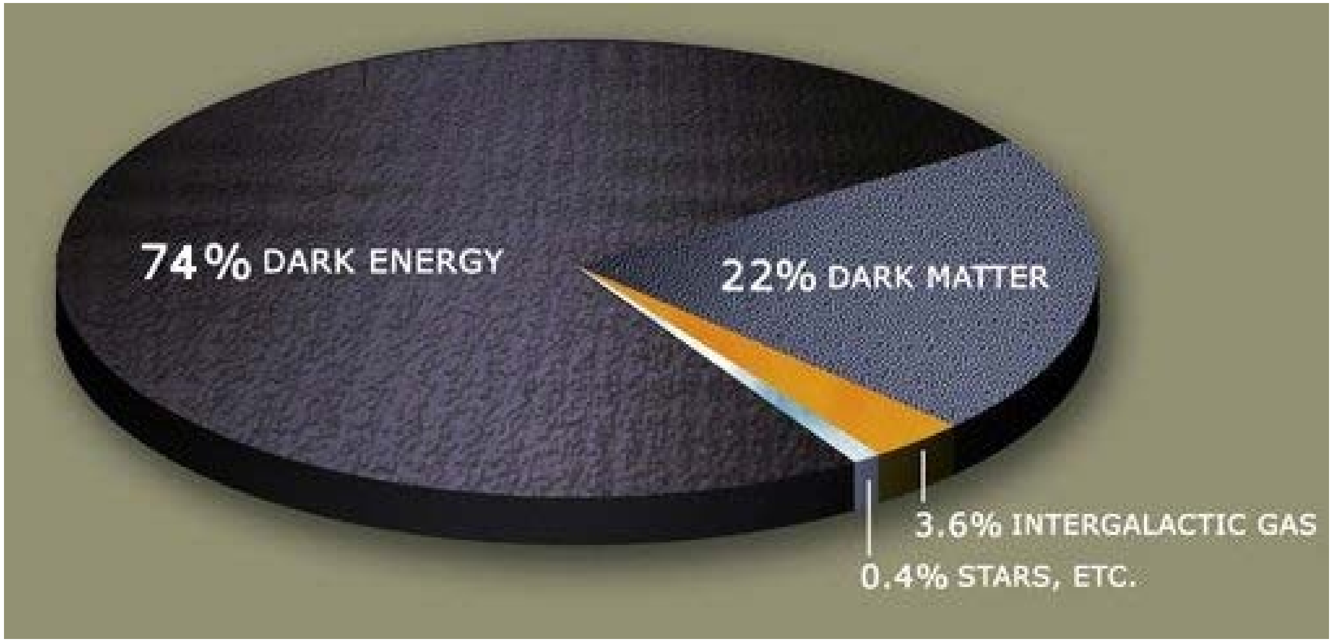
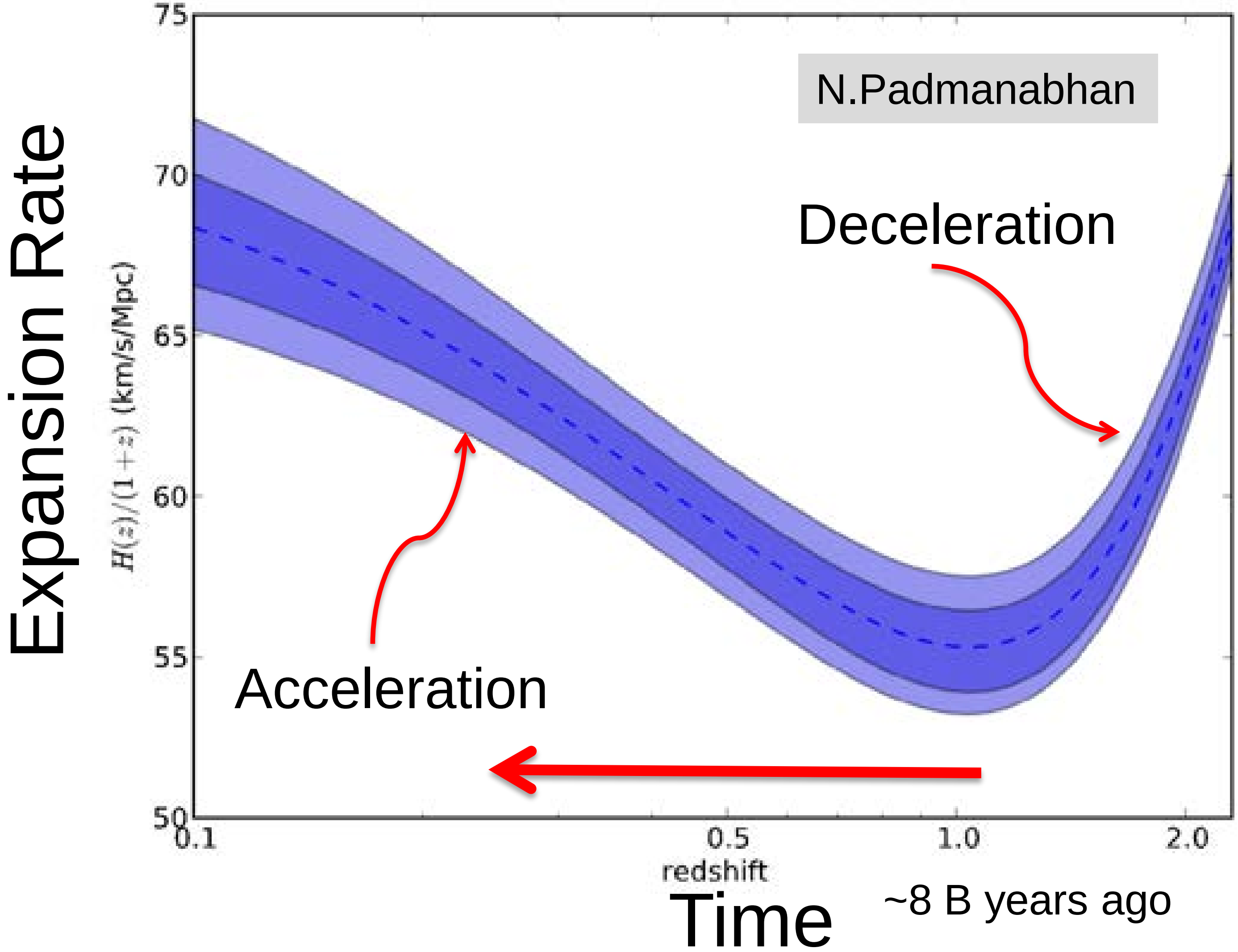
Physics Institute CAS, Prague

12 April 2017

The Universe



Where are we today?

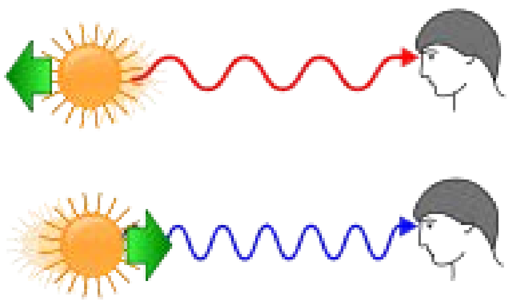


Supernovae

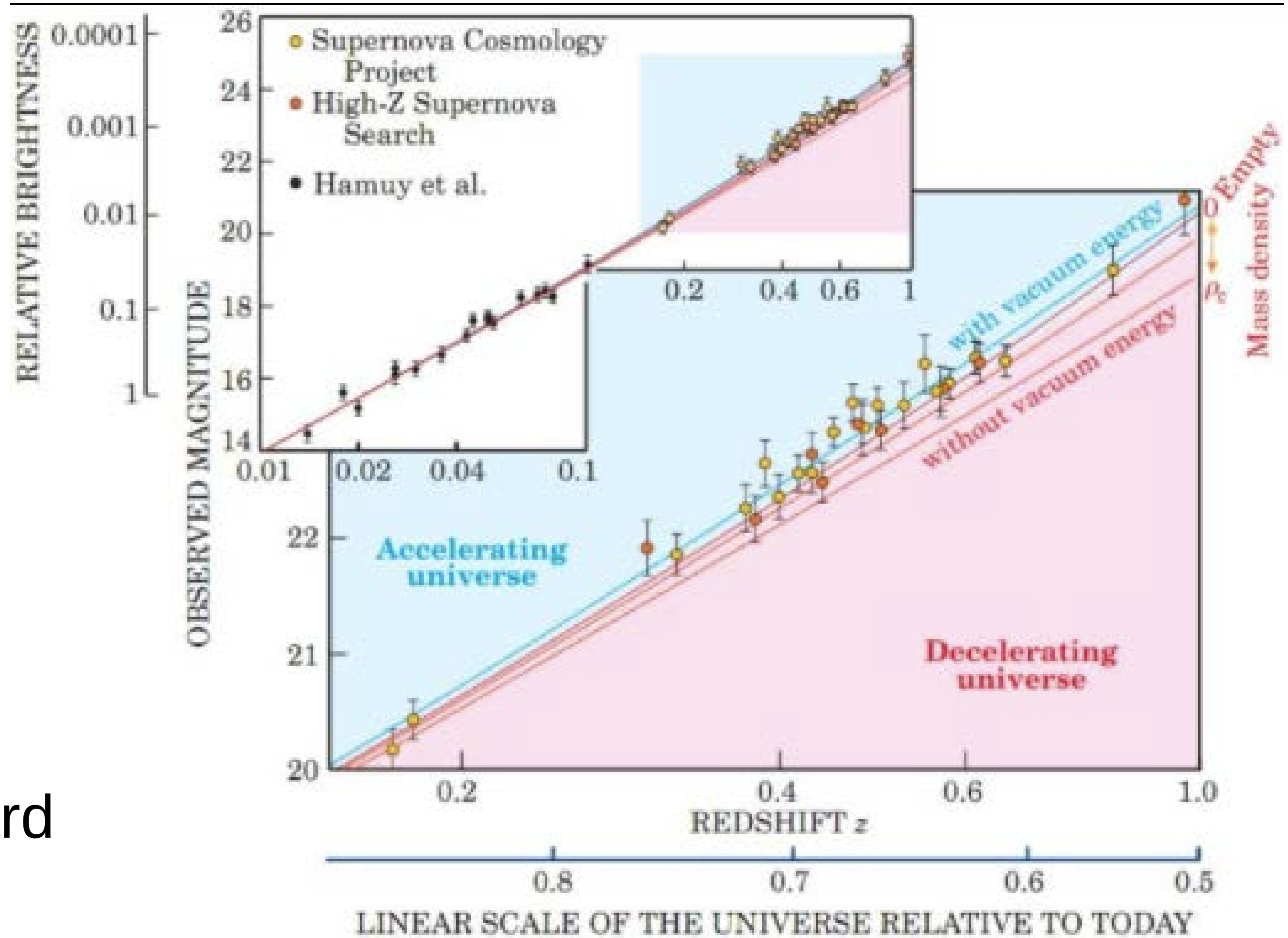
- Hubble's law:

  Velocity = H x Distance

- Velocity can be determined from redshift



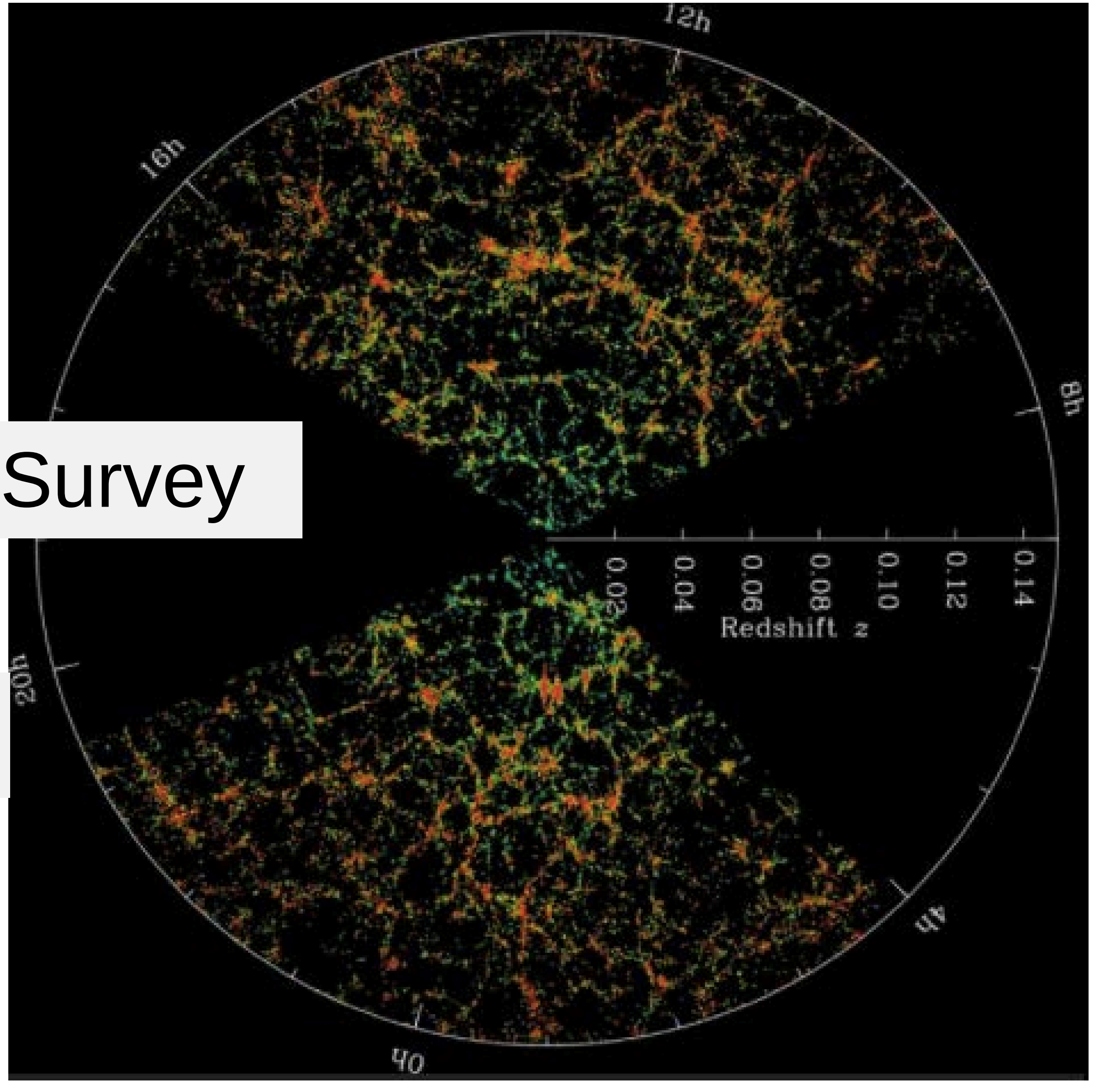
$$z = \frac{\lambda_{\text{obsv}} - \lambda_{\text{emit}}}{\lambda_{\text{emit}}}$$



- SN1a are standard candles
  – can determine distance using their brightness

www.darkenergysurvey.org

Large Scale Structure



Sloan Digital Sky Survey

Distribution of galaxies
consistent with~ 30% of matter

What is Next ?

- More statistics, new probes

- Surveys : map the sky fast and deep
  - Can be done with telescopes with improved IR response: 350 – 1050 nm
  - HSC, DES, PanSTARRS …

- **LSST**

Ultimate Survey: LSST

- What if one needs to image the whole Universe as fast as possible and as deep as possible?

The answer : LSST

Transition similar in importance to transition from still photography to cinematography

Large Synoptic Survey Telescope

- Surveys half of the sky every 2-3 nights

- Get ~1000 images of everything in 6 colors over 10 years to ~27 magnitude

- Pairs of 15 sec exposures
- 10TB of data every night

- First science observations in 2021

www.lsst.org

LSST: Joint US DOE/NSF Project

NSF:

- Telescope and site
- Data Management

DOE:

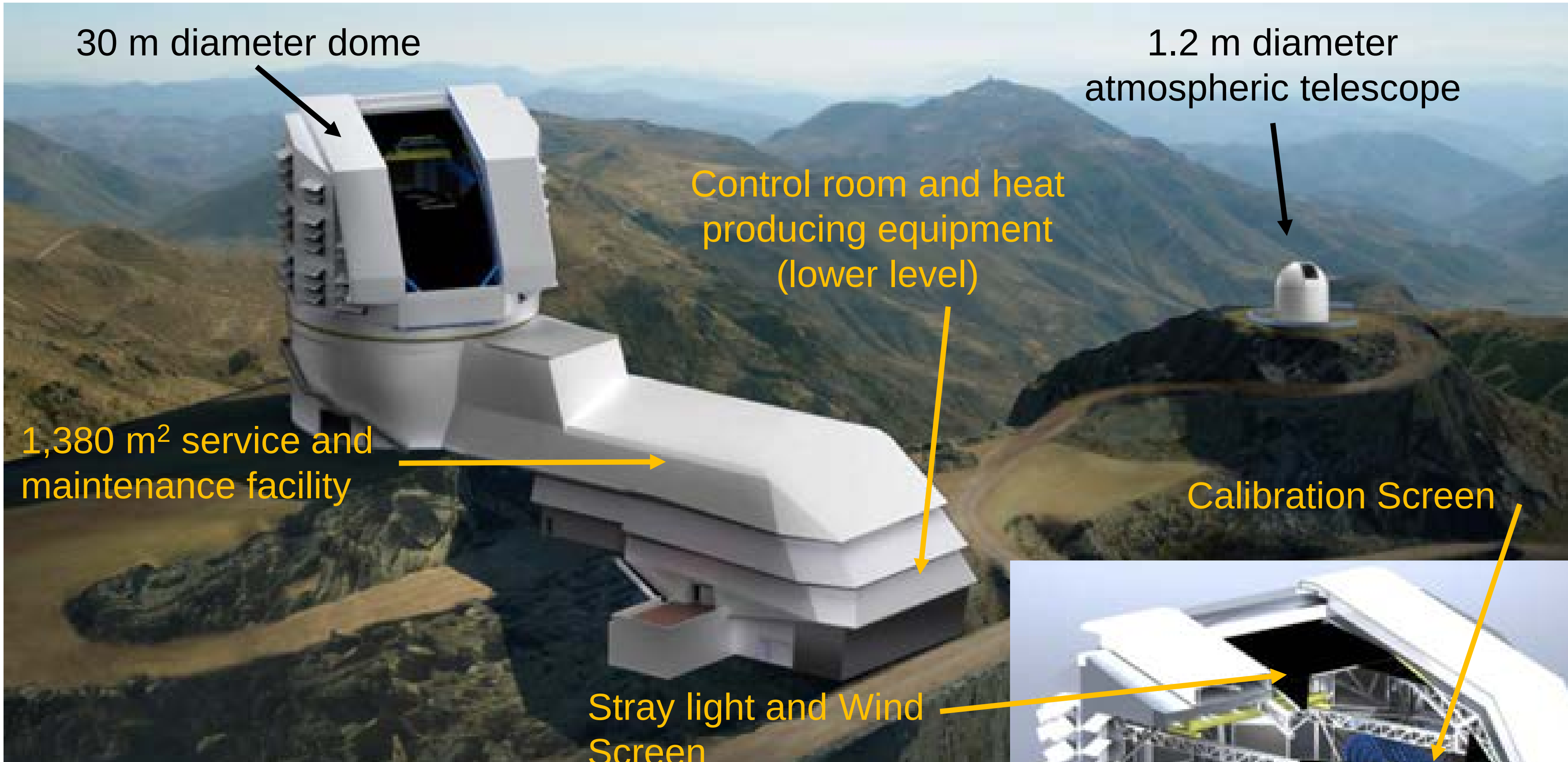
- 3 Giga-pixel camera

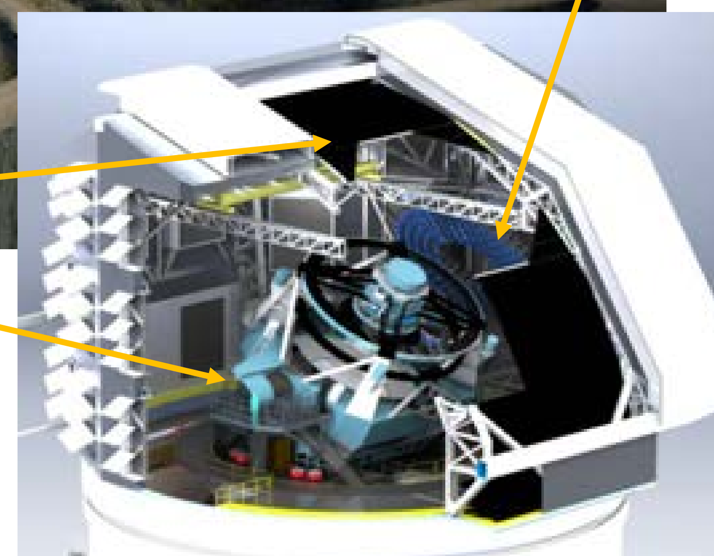
LSST Director : Steve Kahn

LSST Operations will include international contributions

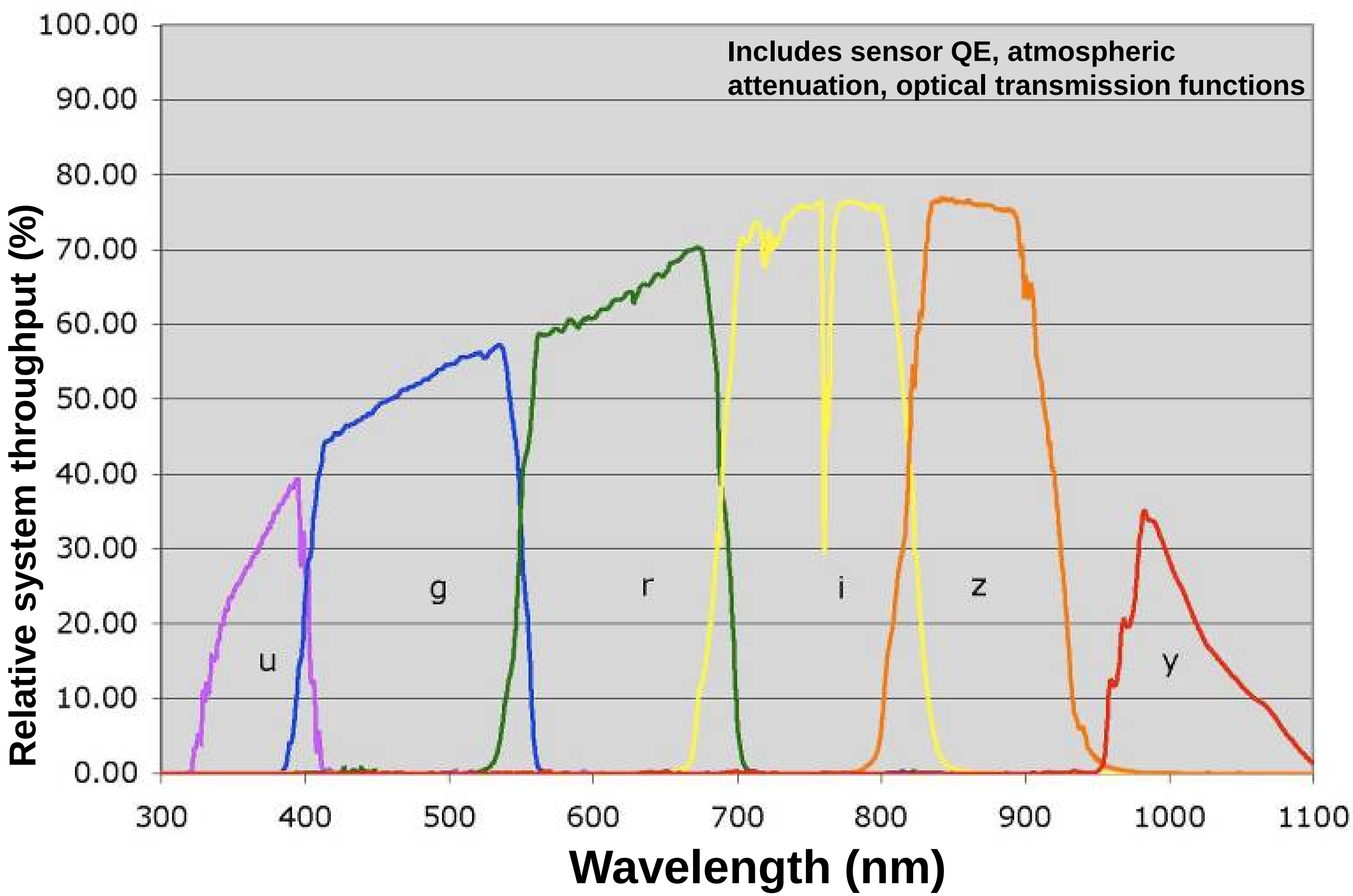
Site selection based on weather, seeing conditions and existing infractructure

Telescope and Site



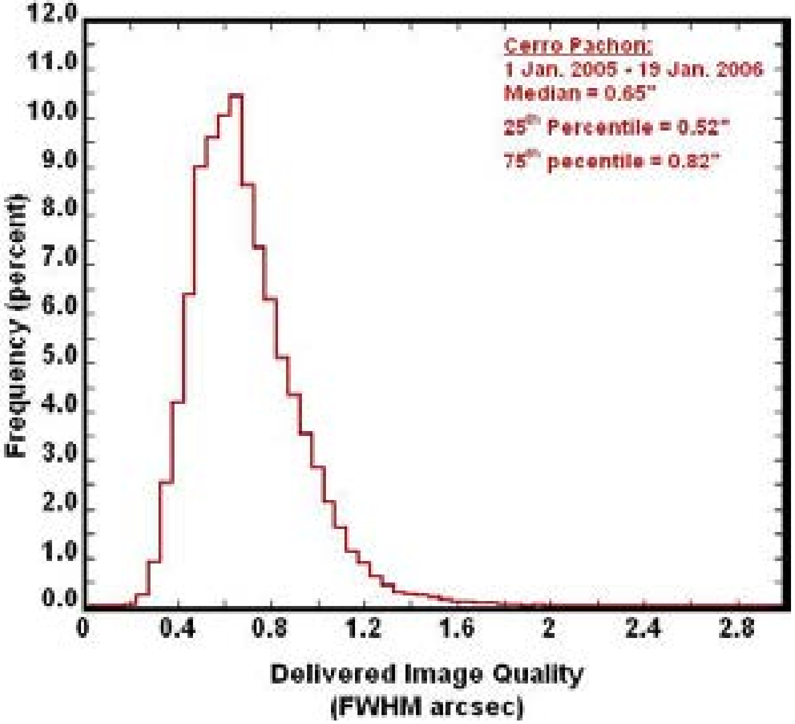


LSST six color system: redshifts

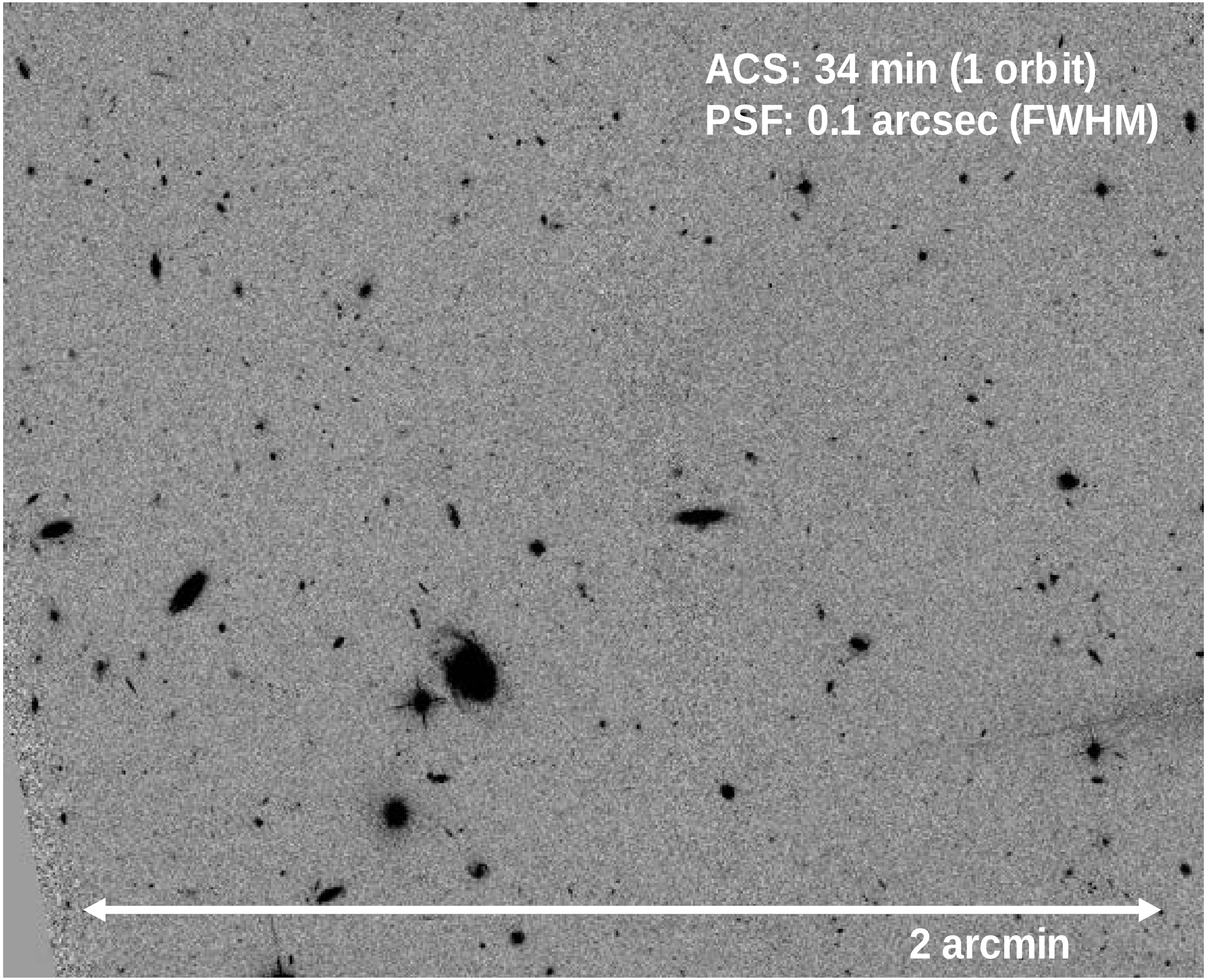


Seeing

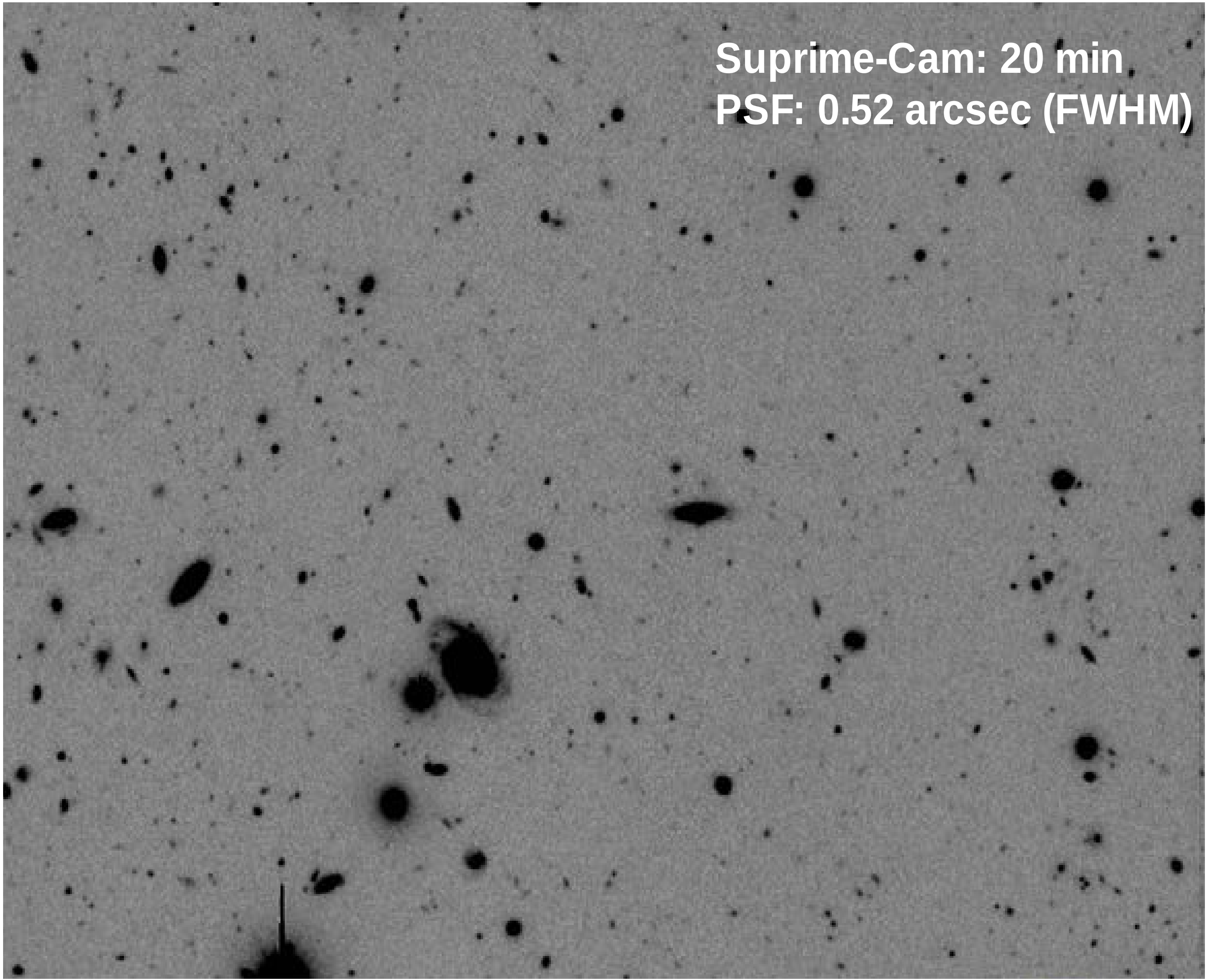
- Blurring due to turbulence of atmosphere



Space: Hubble Space Telescope



Ground: Subaru Telescope



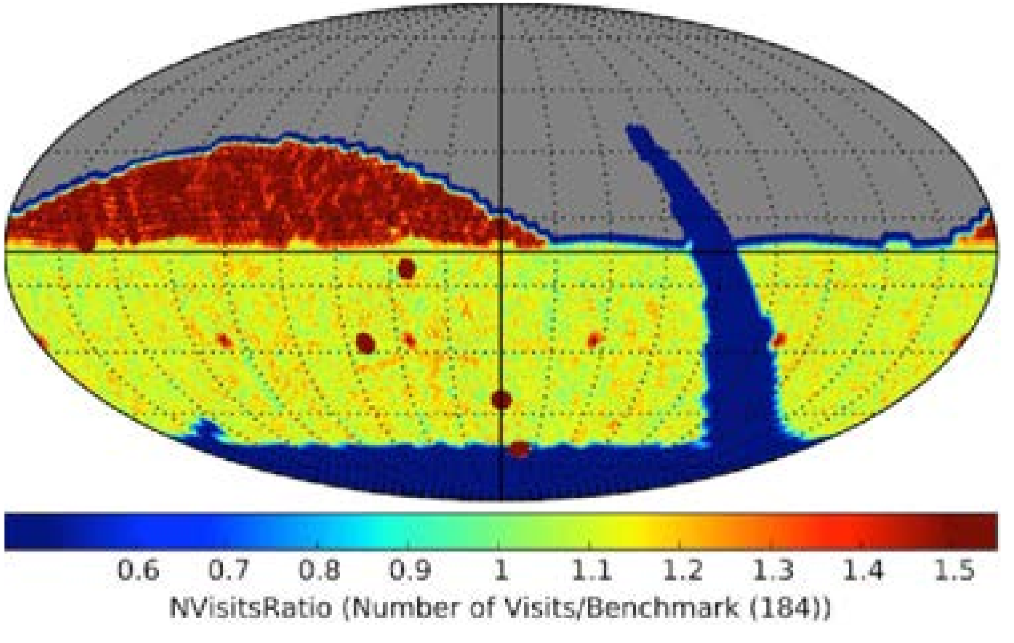
Simulated LSST image (one exposure, 3 bands)

- Composite image, representing 10^{-9} of the LSST data
- A single 15-sec exposure

Connolly

Map of Visits

- Main survey and mini-surveys with deep drilling fields
- Strategies actively discussed at cadence workshops



LSST Wide-Fast-Deep survey

- **4 billion galaxies with redshifts**
- 10 billion stars

- ***Time domain*:**

  1 million supernovae

  1 million galaxy lenses

  1 million alerts per night

LSST 4 Science Missions

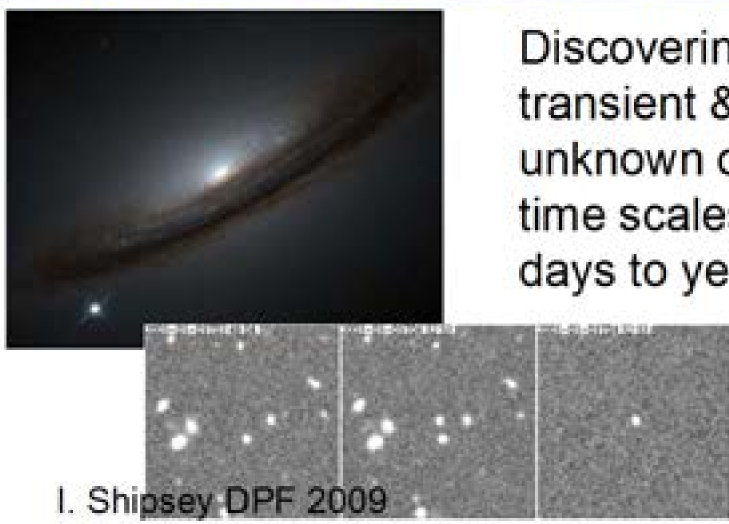
Dark Energy-Dark Matter

Multiple investigations into the nature of the dominant components of the universe

Inventory of the Solar System

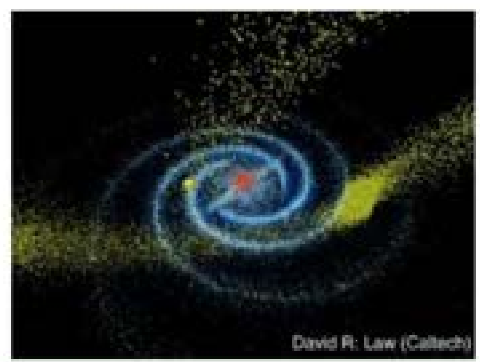
Find 90% of hazardous NEOs down to 140 m over 10 yrs & test theories of solar system formation

"Movie" of the Universe: time domain



Discovering the transient & unknown on time scales days to years

Mapping the Milky Way



Map the rich and complex structure of the galaxy in unprecedented detail and extent

All missions conducted in parallel

I. Shipsey DPF 2009

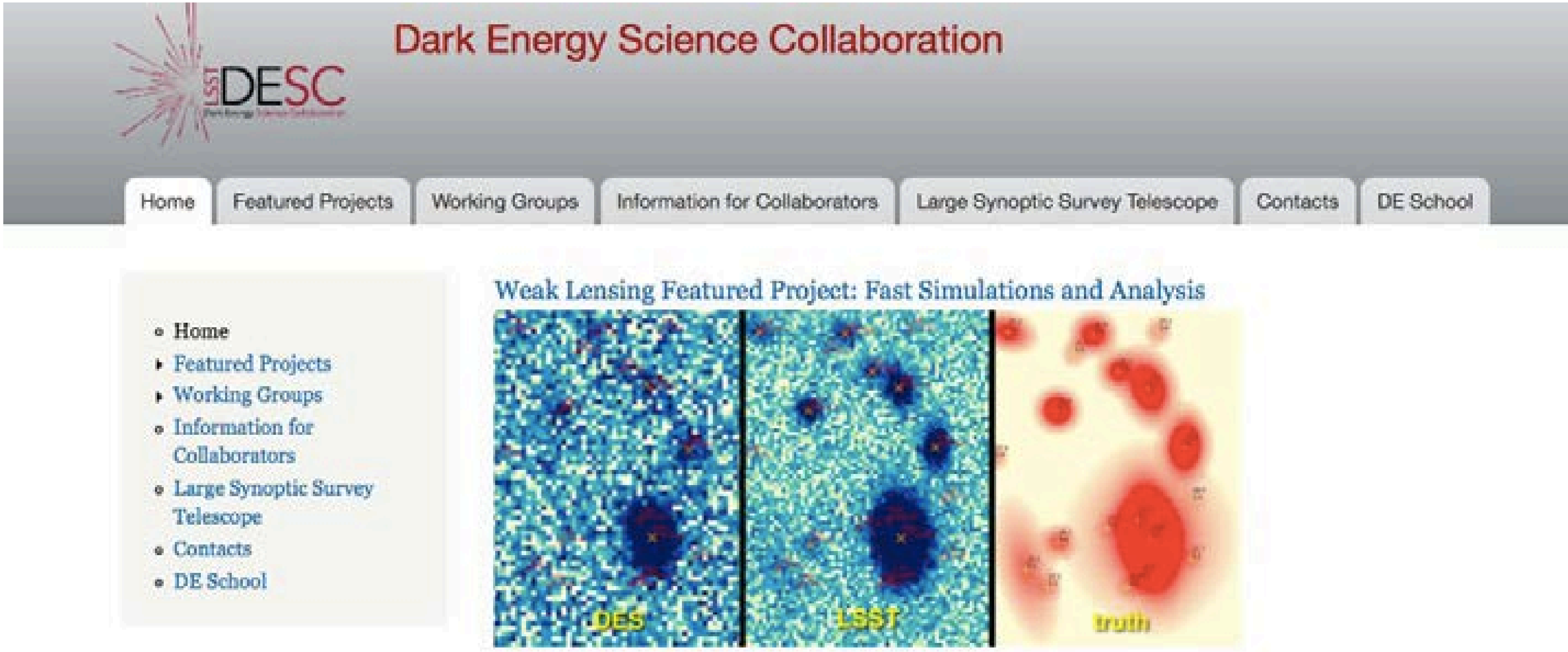
Dark Energy Science Collaboration (DESC)

- Formed in 2012
- http://www.lsst-desc.org

Collaboration meeting at SLAC, February 2017

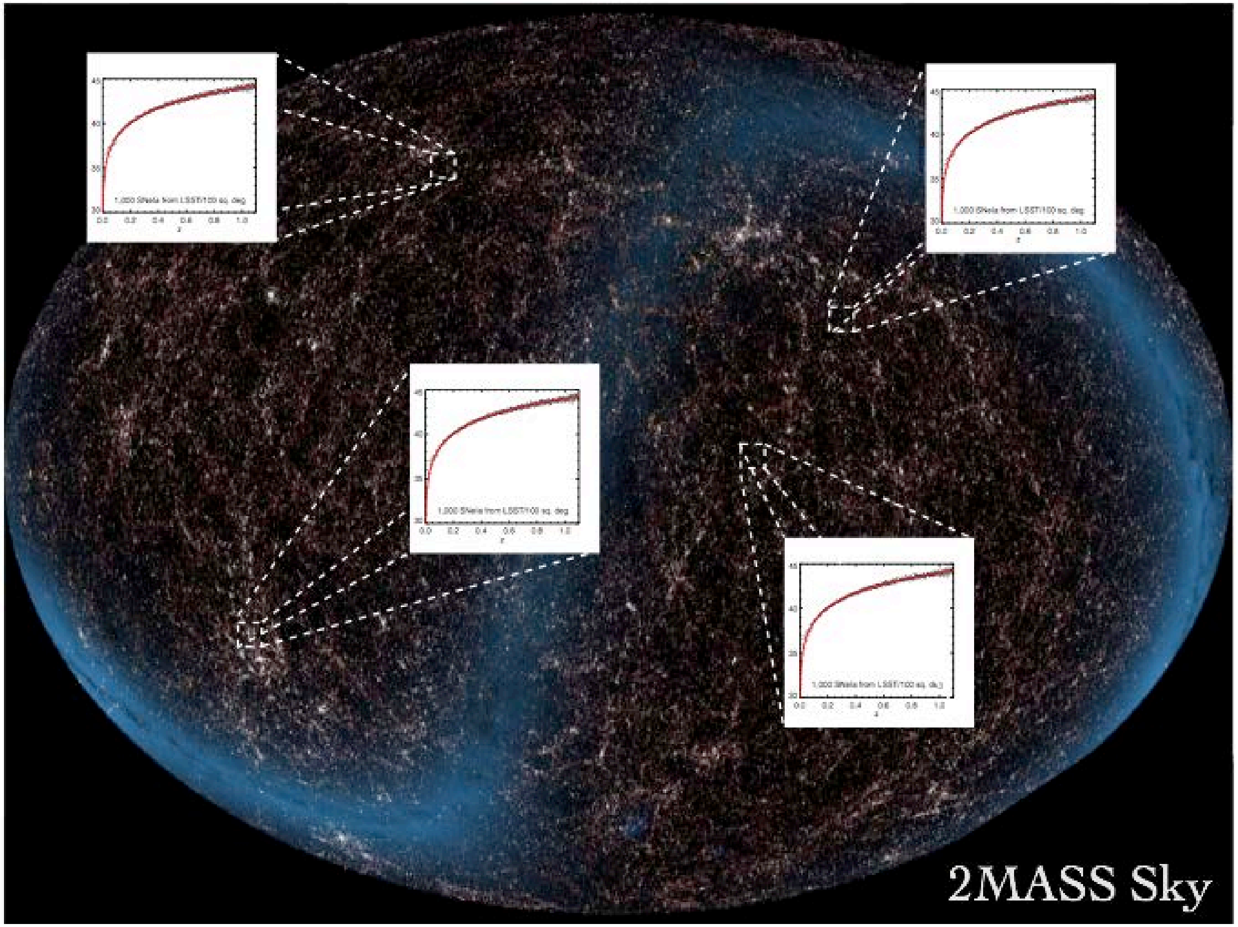
DESC

- White paper (2012) https://arxiv.org/abs/1211.0310
- Science Roadmap (2015 → 2020)
  – Data Challenges 1, 2, 3



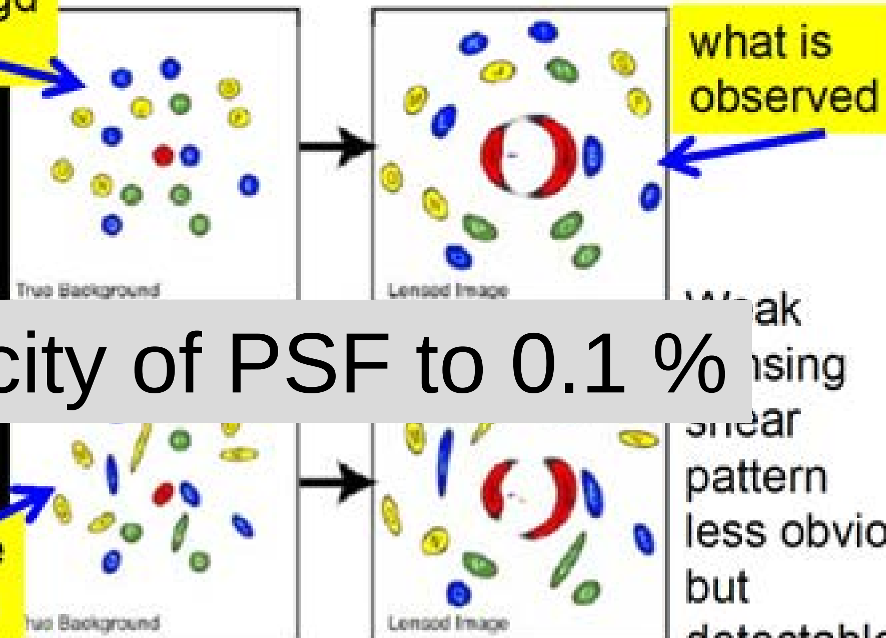
Supernovae and LSST

- 1000 (!) times larger sample of SN1a than above
  - Measure uniformity of cosmic acceleration as function of direction and many other things



Gravitational Lensing & Shear

Red galaxy on axis strongly lensed. other galaxies weakly lensed: sheared images



Want to know ellipticity of PSF to 0.1 %

shear pattern less obvious but detectable statistically

- **Cosmic Shear** **is the *systematic and correlated* distortion of the appearance of background galaxies due to weak gravitational lensing by the clustering of dark matter in the intervening universe.**

The shearing of neighboring galaxies is correlated, because their light follows similar paths on the way to earth.

Cosmic shear: ~ 0.01 e.g. circular galaxy → ellipse with a/b ~ 1.01

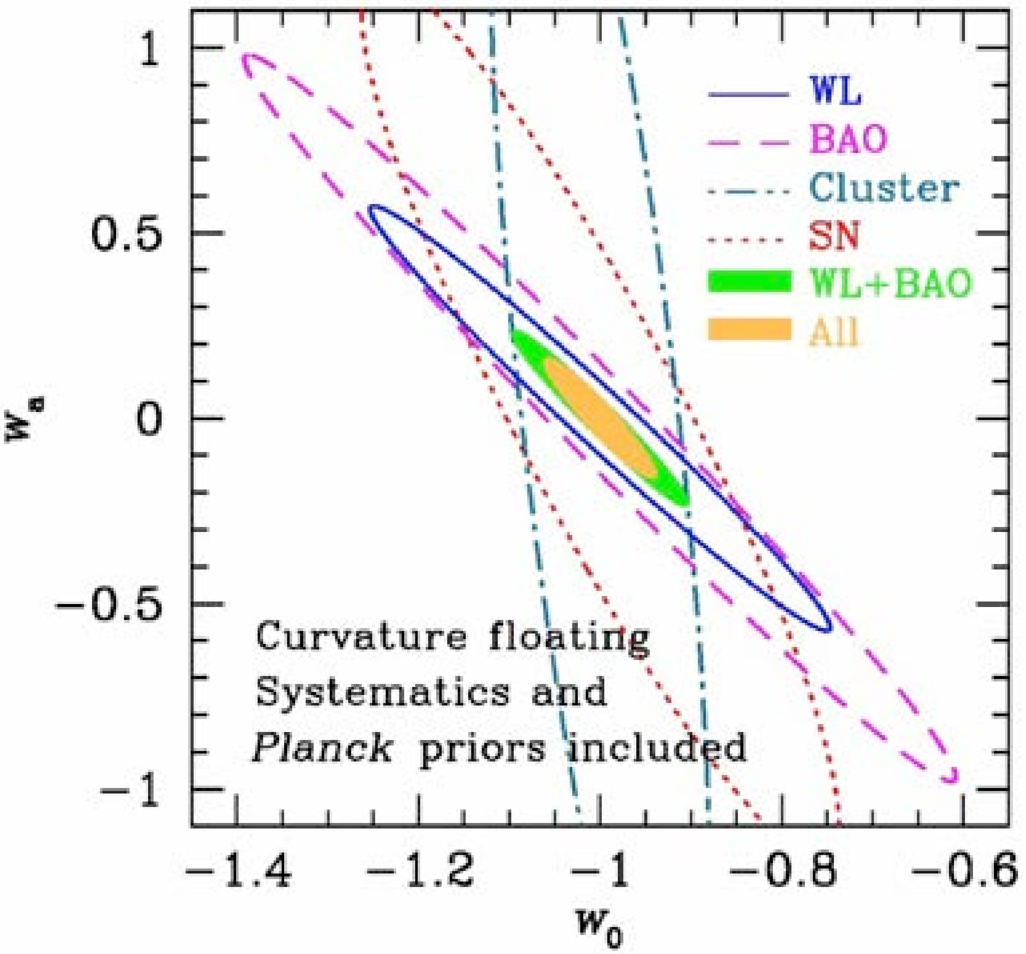
Shear Correlations

- 40 galaxies/arcmin^2 for lensing measurements
- ~ 50 shear two point correlation functions in multiple redshift bins
- Higher order shear and other observables (for ex. shear peaks)

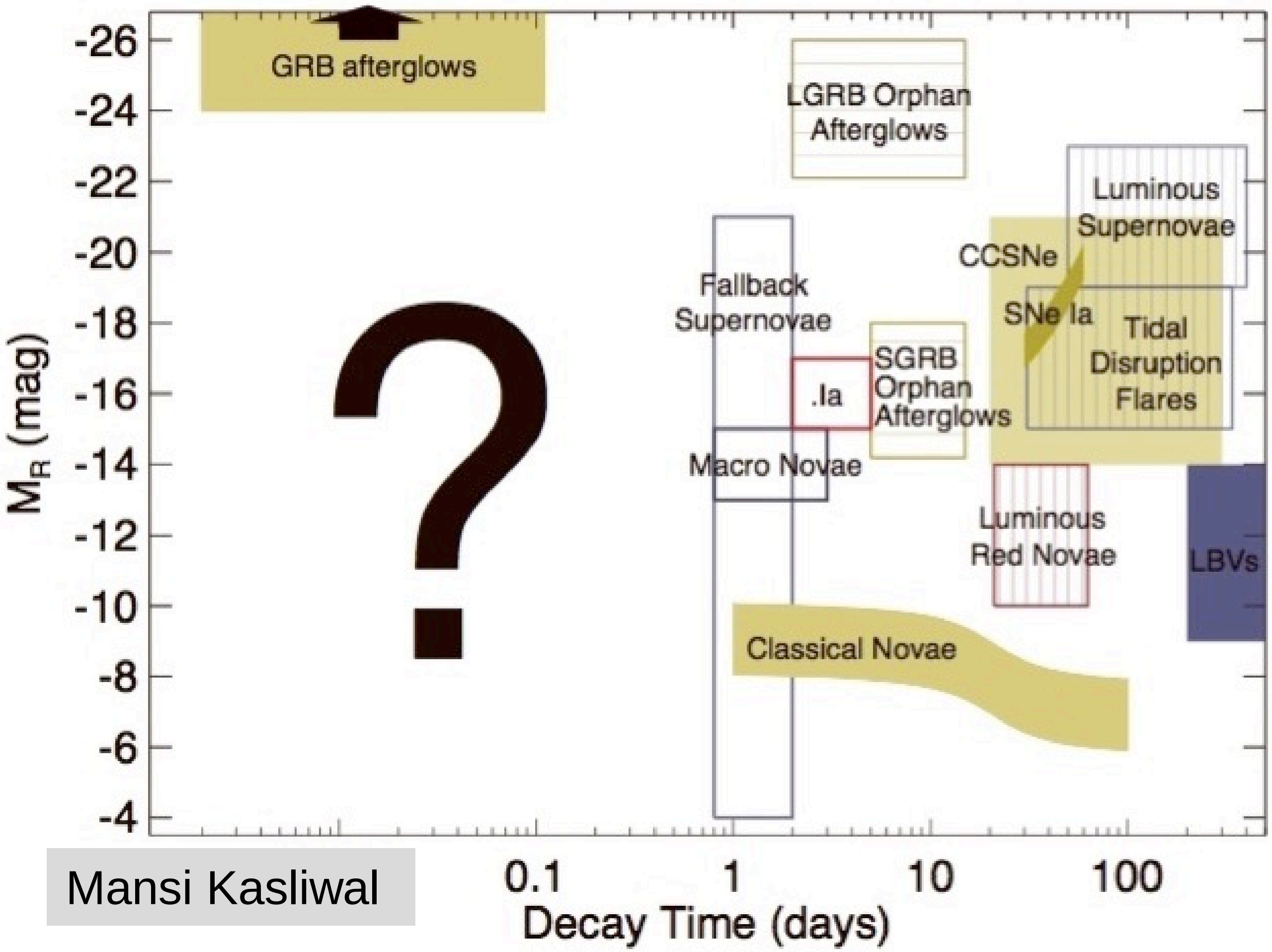
Curves : ΛCDM model

Combination of Multiple Probes

x 100 better discriminatory power to distinguish between cosmological constant and various models than for present experiments



The Variable Universe



Mansi Kasliwal

Variety of time scales from 10 sec in a single image to whole sky in 3 nights. Up to 10 years.

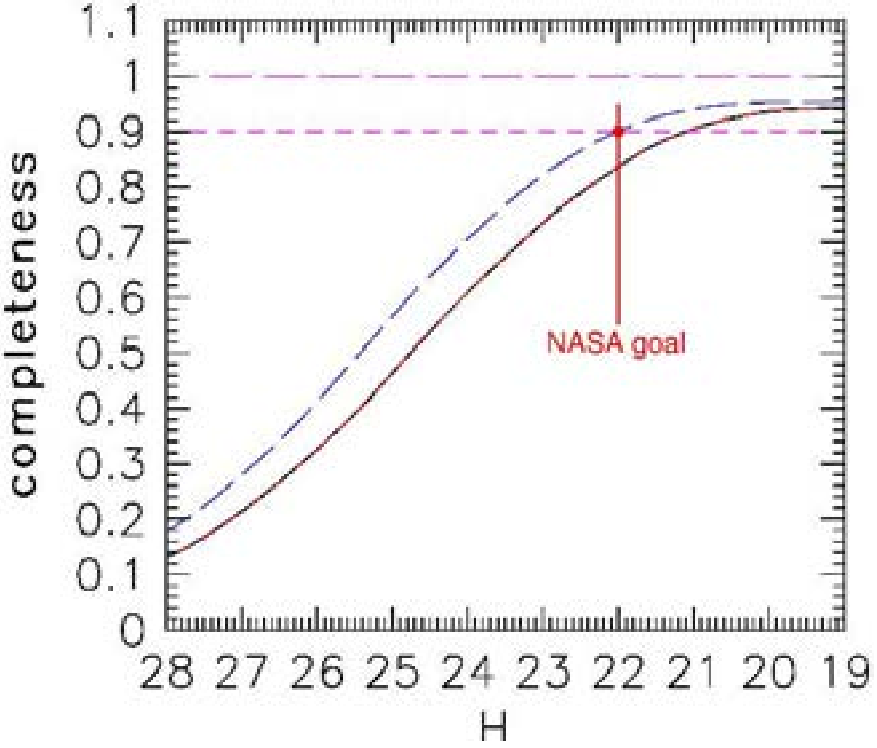
Are there new populations of transients at faint magnitudes In the distant Universe?

LSST will extend time-volume space > 100 times

Lots of opportunities including optical identification of counterparts for gravitational waves (LIGO) and neutrinos (ICE-CUBE etc)

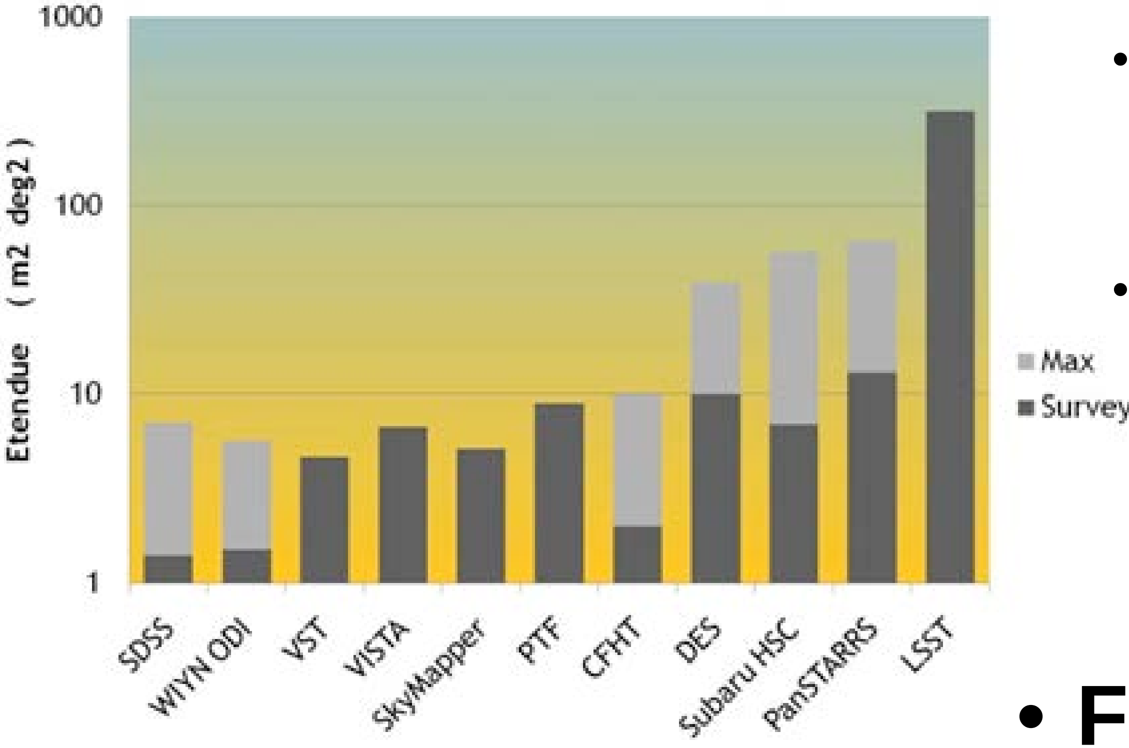
Completeness (= Efficiency)

- 22 mag = 150 m asteroid
- 24 mag = 50 m asteroid



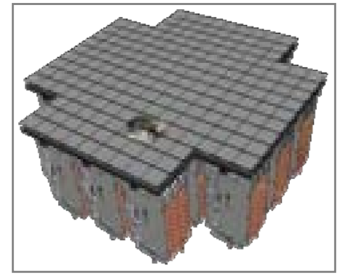
- For 45 m objects, the LSST warning time would be about 1-3 months, depending on their orbit

How does LSST do this? Etendue



- **Etendue = (Area x Field of View)**
  - To get more area simply build a large camera
  - To get higher field of view, favor designs with shorter focal lengths and reasonable off-axis image quality
- **Fast and low noise CCDs**

- # Pixel/chip count
  - LSST: 3.1Gpix (189 CCDs)
  - PanSTARRS GPC1: 1.4Gpix (60 CCDs)
  - HyperSuprimeCam: 940Mpix (112 CCDs)
  - DECam: 500Mpix (62 CCDs)
  - CFHT MegaCam: 340Mpix (36 CCDs)



LSST

Only large mosaic with **ASIC** readout

- # Focal ratio
  - LSST: f/1.23
  - SuprimeCam: f/1.87
  - DECam: f/2.7
  - PanSTARRS: f/4
  - CFHT MegaCam: f/4.2

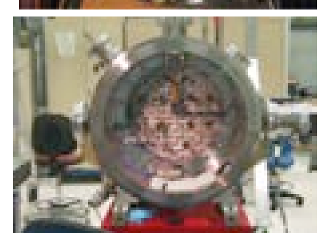
GPC1

- # Readout time
  - LSST: 2s
  - PanSTARRS GPC1: 6s
  - DECam: 17s
  - CFHT MegaCam: 40s
  - Suprime-Cam: 18s

MegaCam

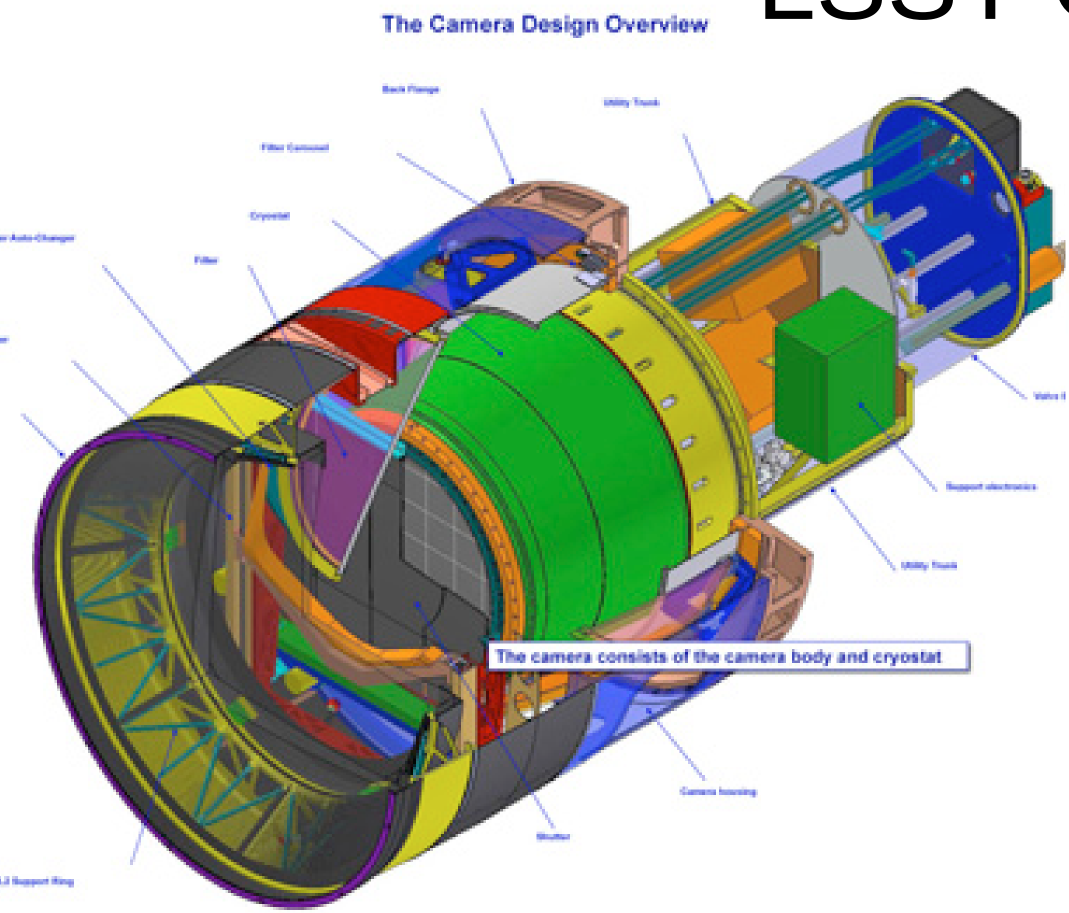
HSC

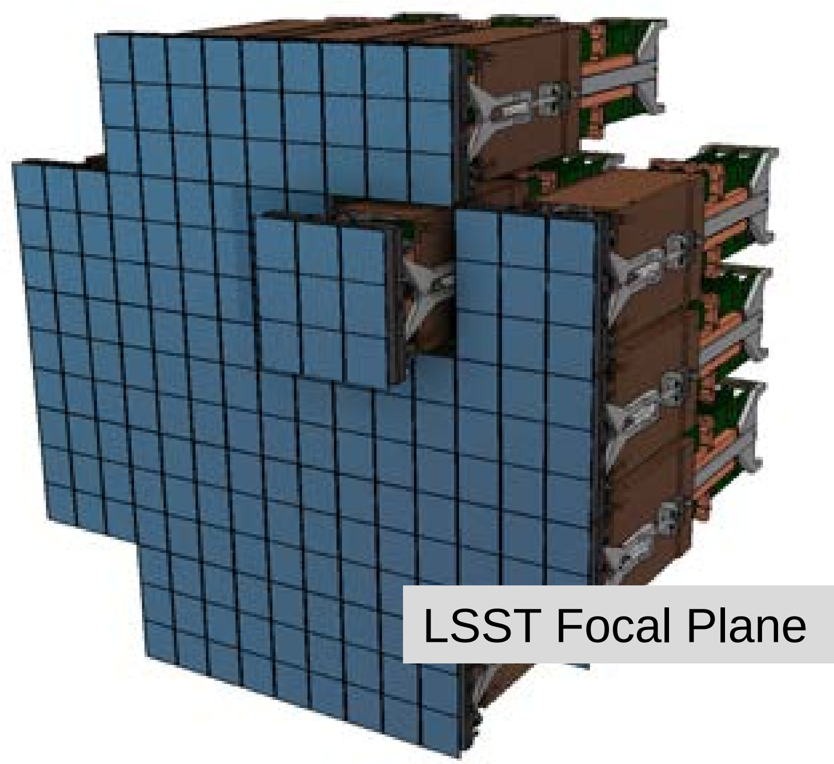
- # Data rate
  - LSST: 1.0TB/hr
  - PanSTARRS GPC1: 0.22
  - HSC 0.03
  - DECam: 0.004
  - CFHT MegaCam: 0.003



DECam

LSST Camera

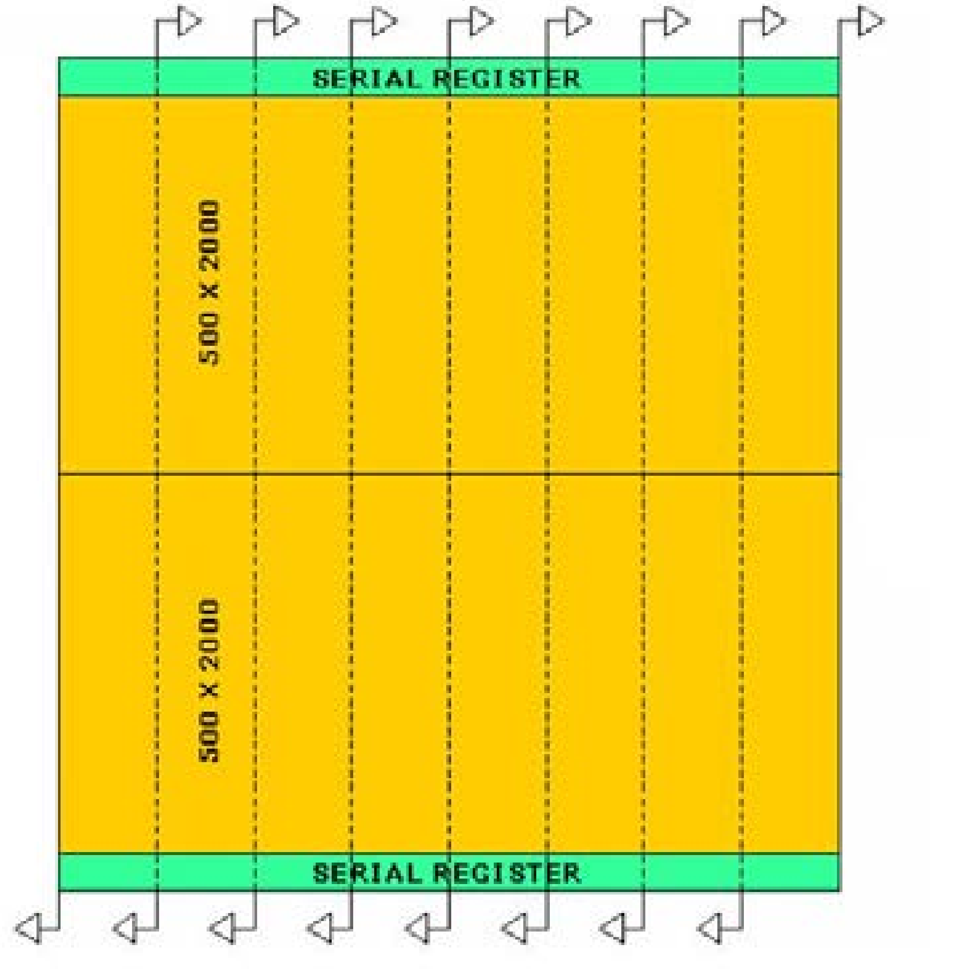




- 64cm diameter → 3.5°
- 189 4K × 4K CCDs → 3 Gigapixels
- 21 “rafts” with integrated electronics for nine CCDs in shadow of sensor focal plane
- At -100 deg C

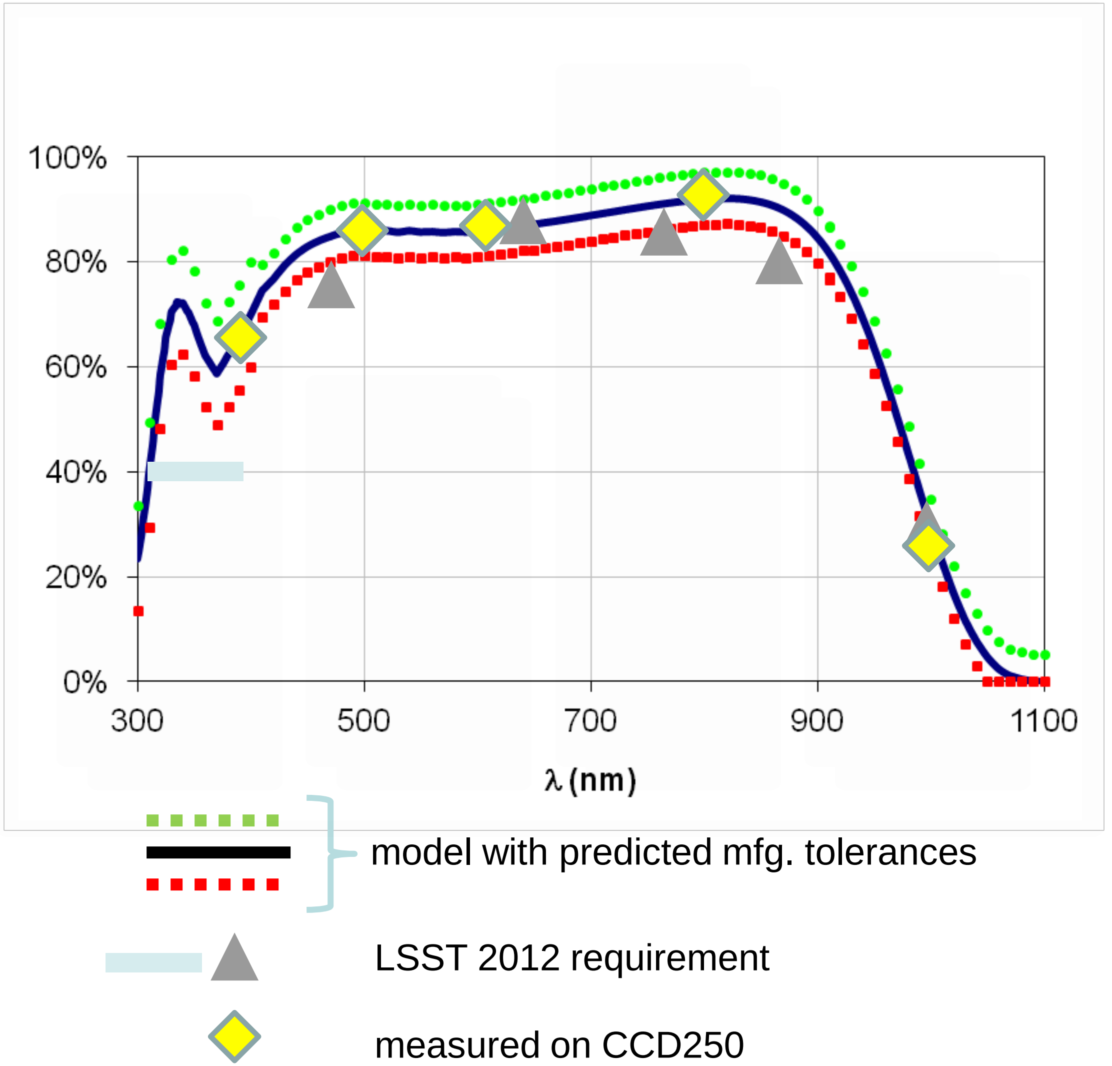
LSST CCD Sensor

- 2 second readout time spec → 16 amplifiers per 16 Mpix CCD
- Noise spec 8 e-, based on anticipated sky noise; limits pixel rate
- Pixel read rate is 550 Kpix/s



- 4k x 4k = 16 Mpixels
- 10x10 microns pixel
- Si thickness 100 micron →
  Enhanced infrared response
- Anti-reflective coating

Quantum Efficiency (QE)



Current Status

LSST Site in 2013

LSST Site in 2016

LSST Site: a month ago

M1M3 Mirror Assembly

Recent Accomplishments:

- Cell cover machining complete.
- Mirror cell flooring installed.
- Deck plate machining system installed and commenced setup testing.
- M1M3 cart components ordered.
- M1M3 surrogate mirror design completed.

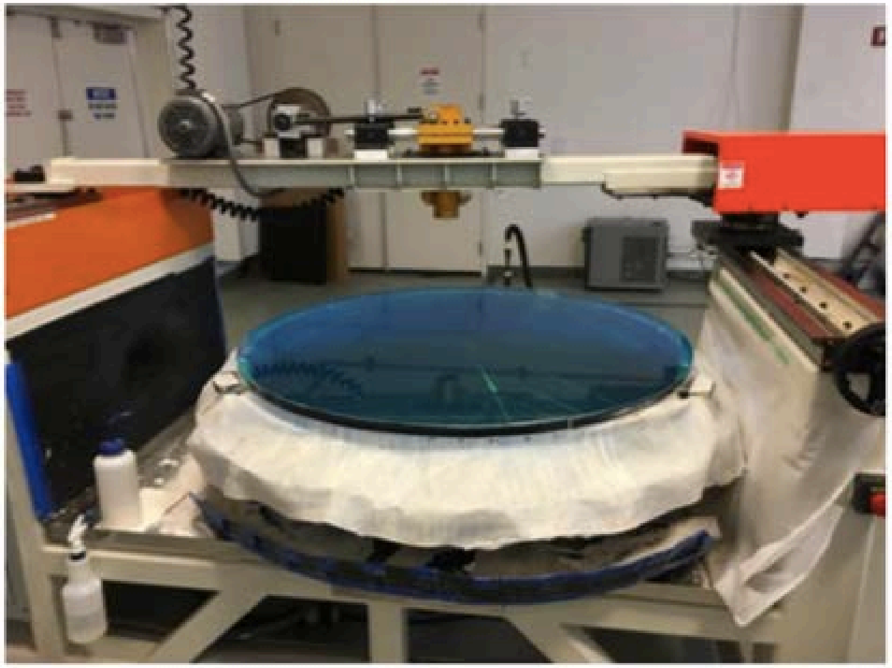
Telescope Mount Assembly

Hexapod Rotator

Camera Optics

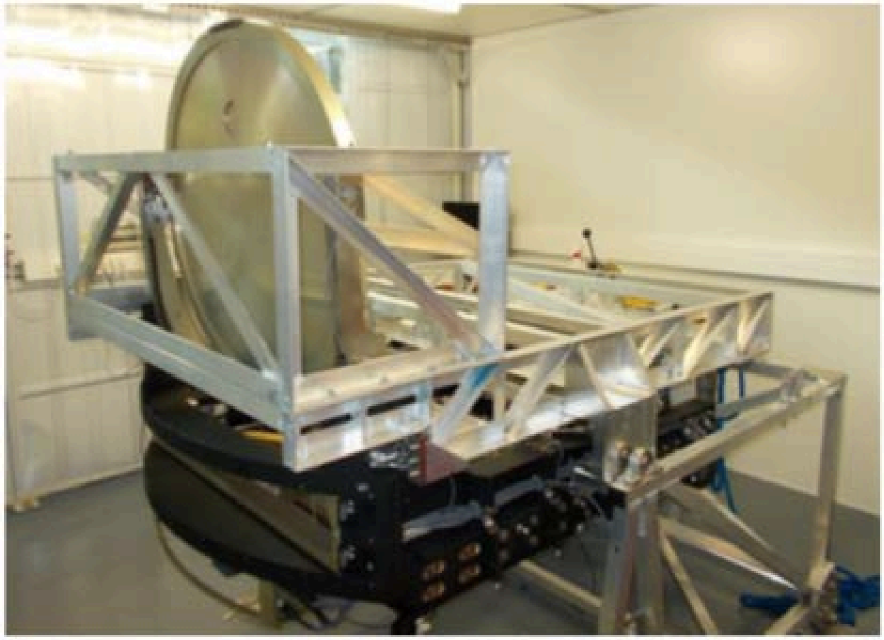
Recent Accomplishments:

- L2S1 grinding was completed at AOS and polishing is underway.
- L2S2 polishing was completed earlier.
- Transmitted wavefront error testing of L2 will begin soon.
- L1S1 grinding started after minor incident repair.

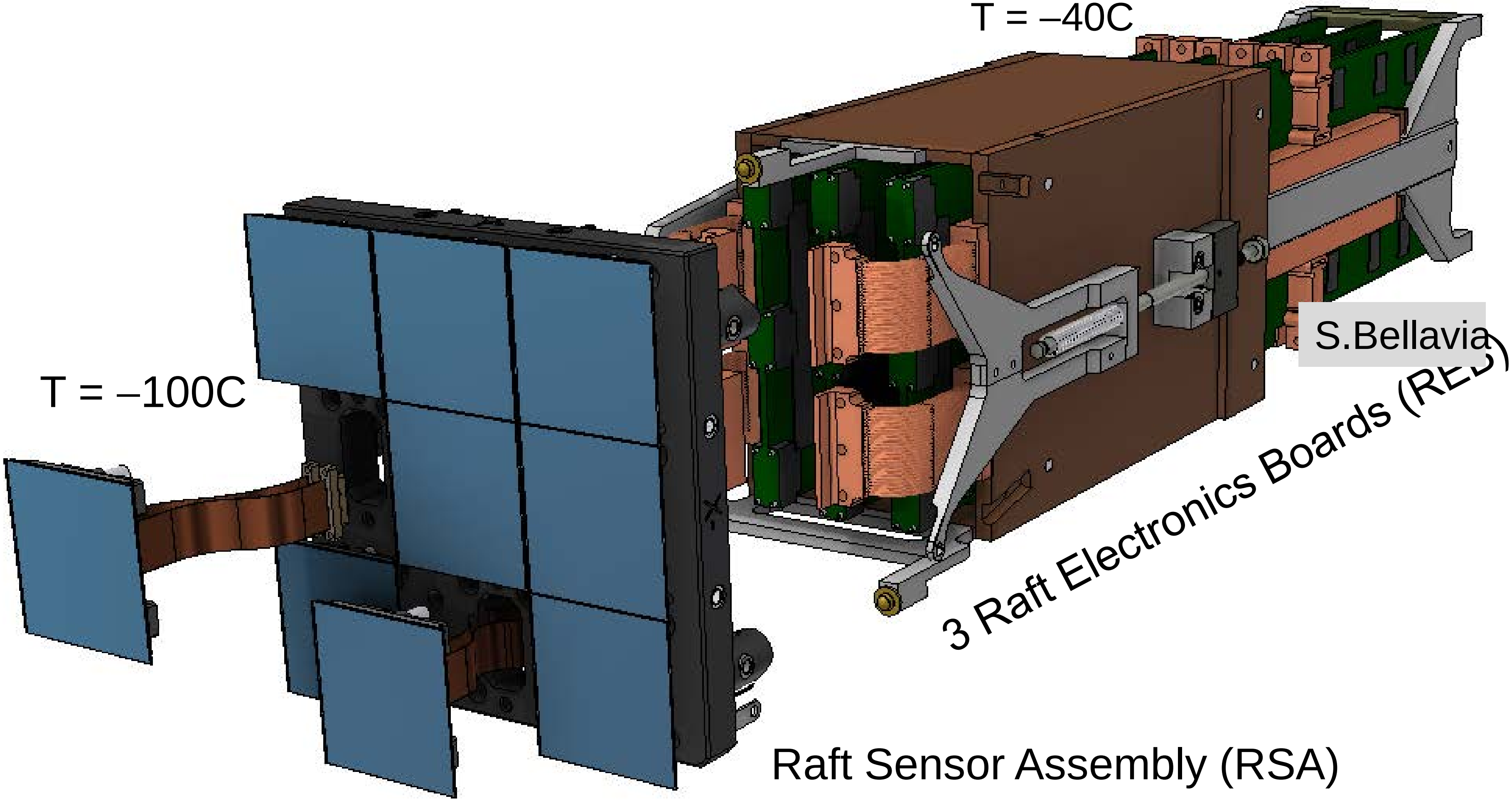


Filter Autochanger

- Testing of the autochanger prototype continued at CPPM in Marseille.
- A standalone autochanger test bench was assembled to evaluate the travel time of a filter from the online position to the standby position.



Raft Tower Module (RTM)



Science Raft Comprises 9 CCDs

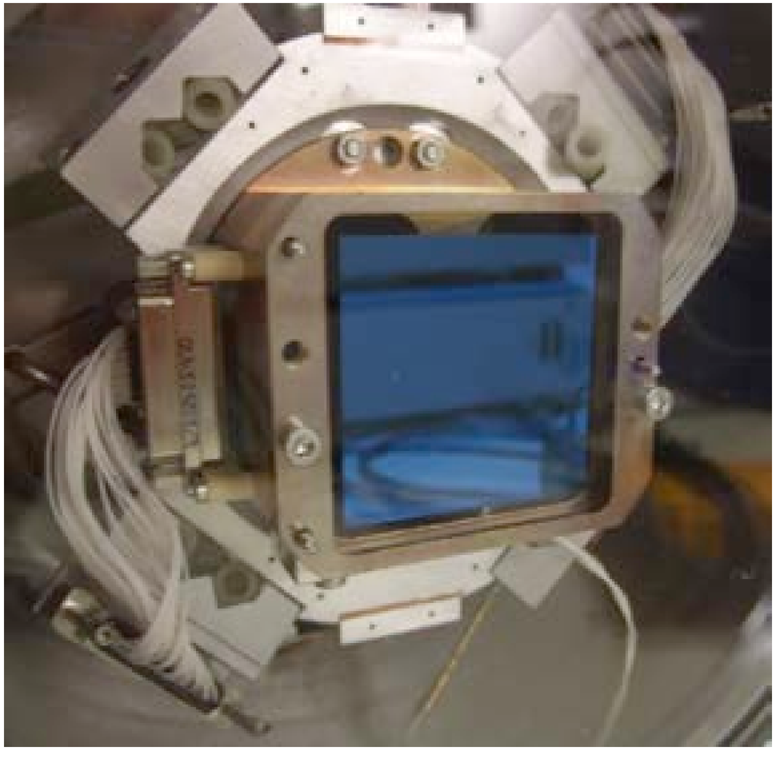
LSST at BNL

- BNL is involved in LSST since 2004
- Dedicated LSST cleanroom class 1000 and 10000
  - Tests of all LSST sensors and production of all Science Rafts in 2016-2019

Petr Kubanek and Michal Vrastil
(M.Prouza group, Institute of Physics, CAS)
in BNL cleanroom

LSST Prototype CCDs

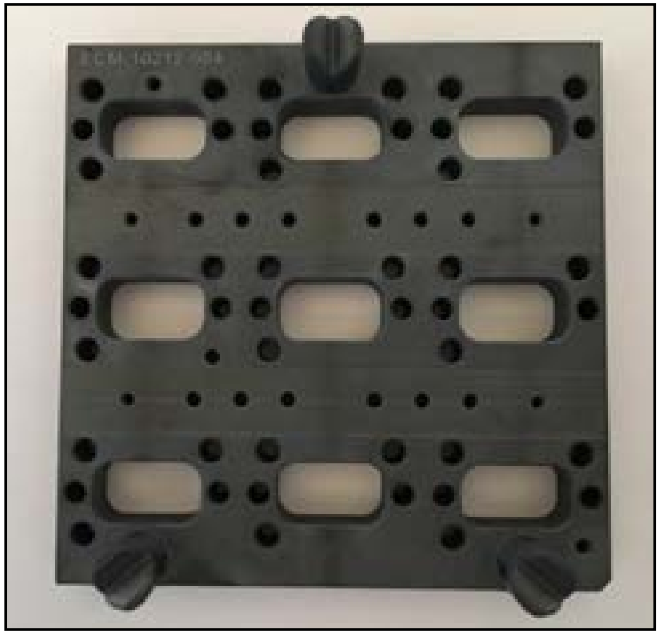
CCD250



STA3800

Raft Base Plate

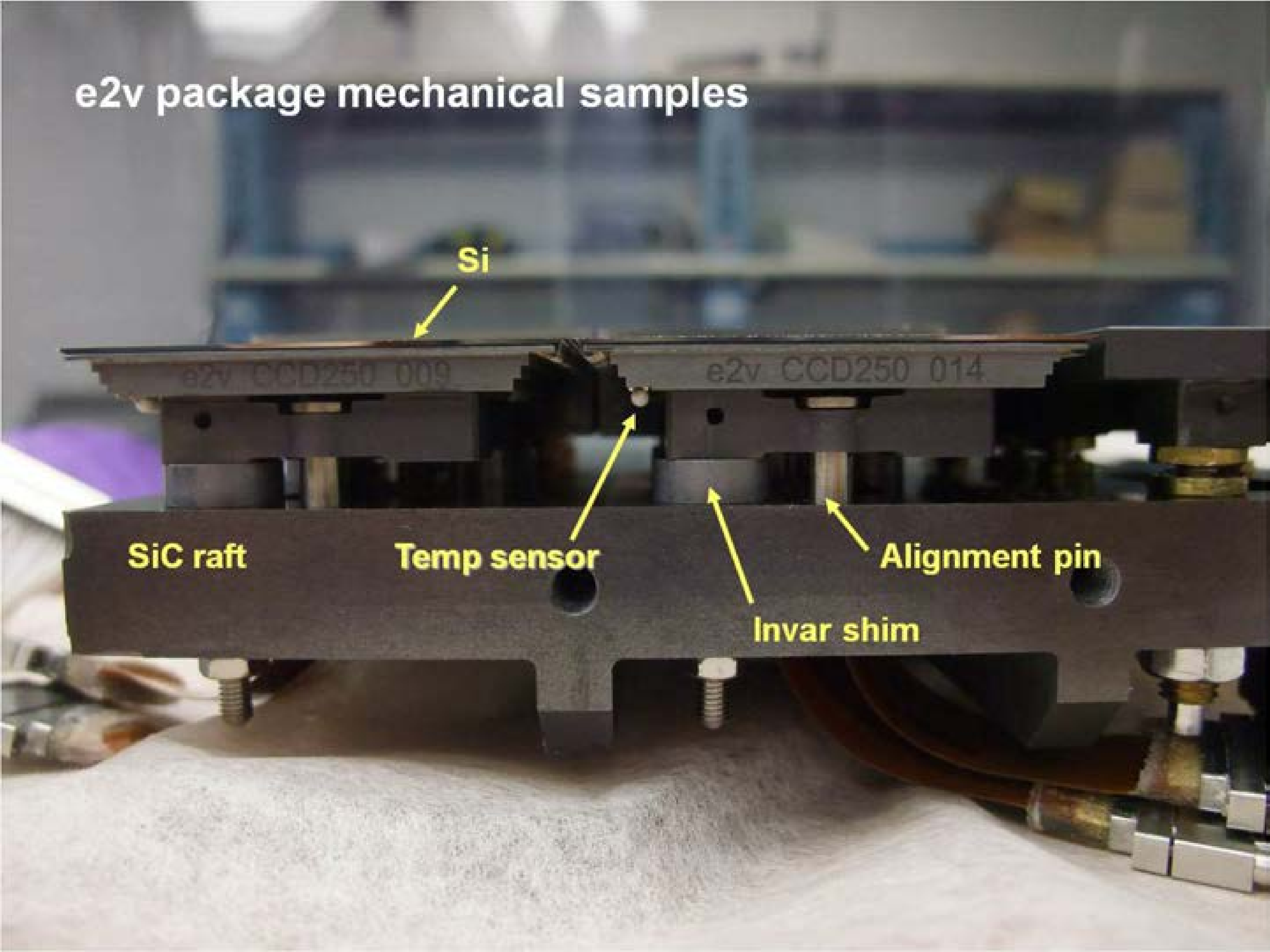
Material:
Carbon Fiber Reinforced silicon carbide (Cesic)
(chosen for low CTE)



Demanding fabrication specifications

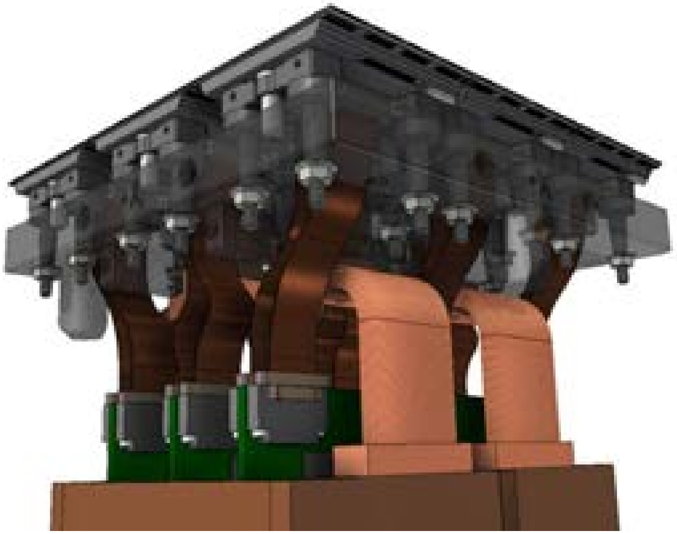
- All units must be produced within a 2 micron band of each other in terms of absolute height.
- Hole diameters with +/- 5 micron tolerance applied and a true position tolerance of 10 microns
- All edges must be chamfered or have radii to avoid chipping.

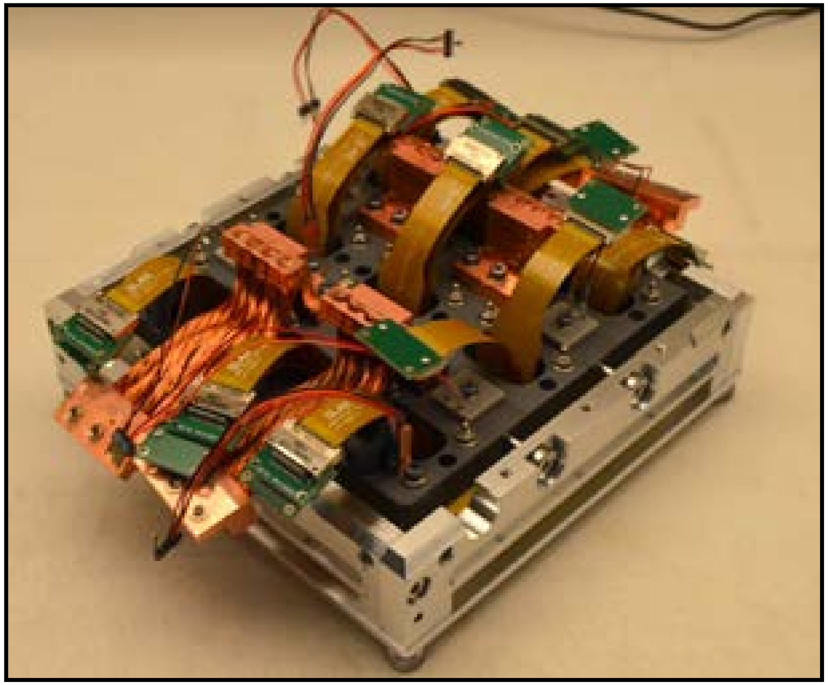
High precision metrology needed

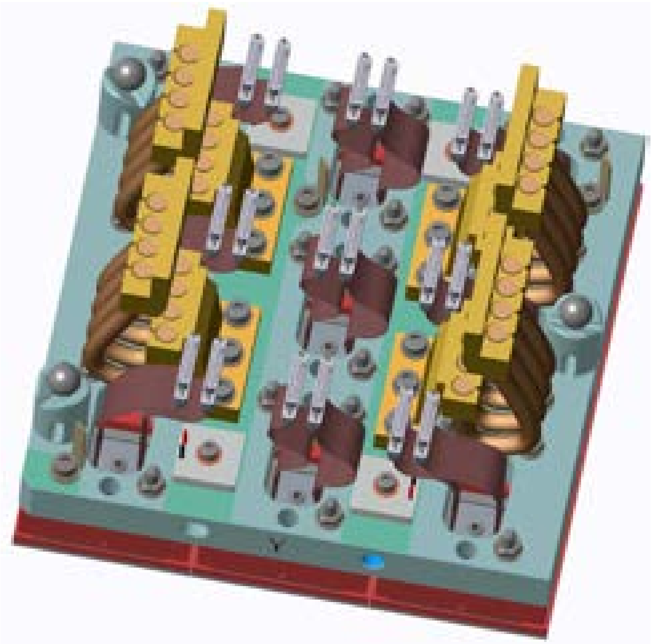

e2v package mechanical samples
Si
e2v CCD250 009
e2v CCD250 014
SiC raft
Temp sensor
Alignment pin
Invar shim

Raft Sensor Assembly (RSA)

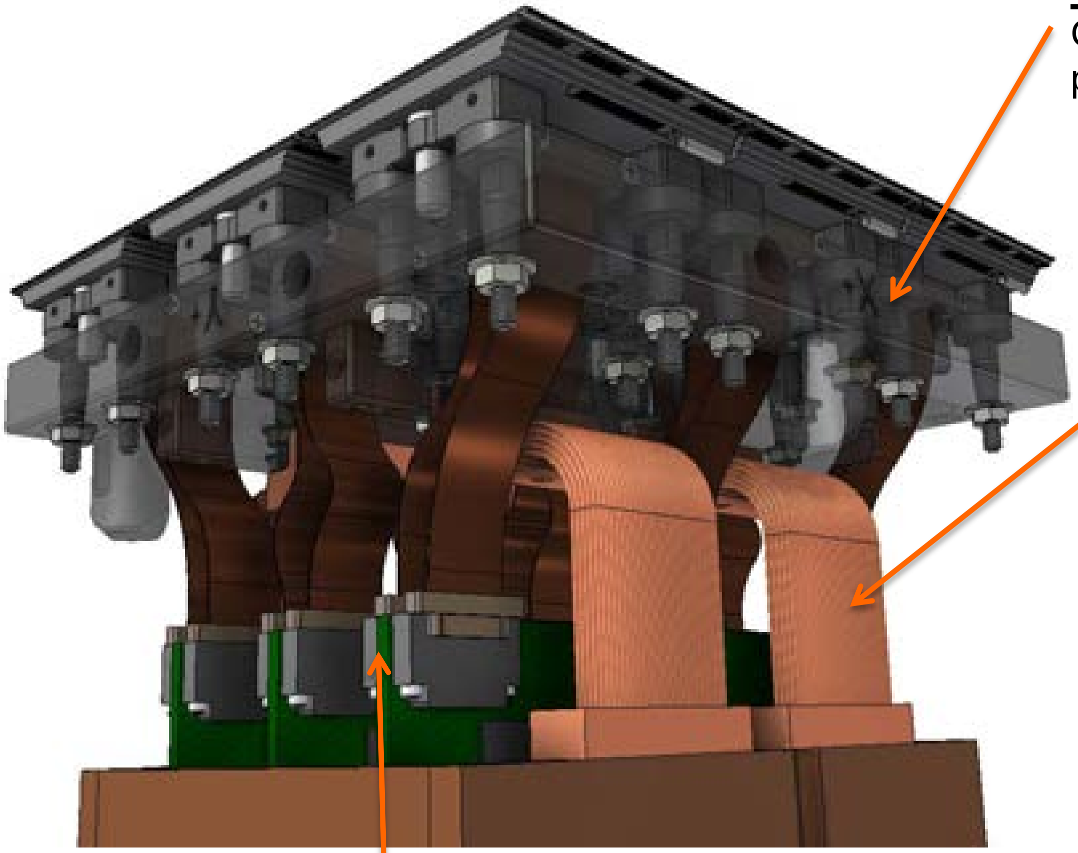
- CeSiC baseplate
- Imaging sensors with flex cables
- Thermal straps, for heat removal
- Heaters, for stabilizing sensor temperatures
- Temperature sensors (RTDs) for feedback/control







RSA Thermal Paths



Raft Base Plate

CCD frame is both mechanical registration and primary thermal path from Sensors to RSA.

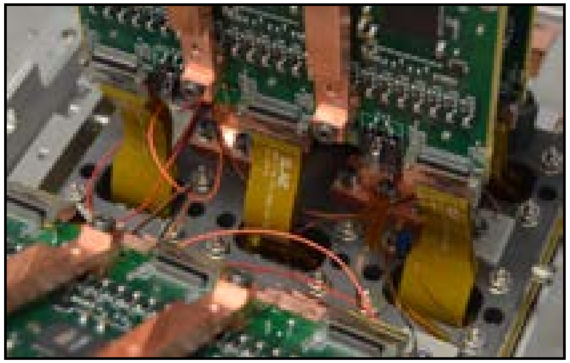
Thermal Straps

(4) Flexible braid Thermal Straps extract heat generated by the Raft Sensor Assembly

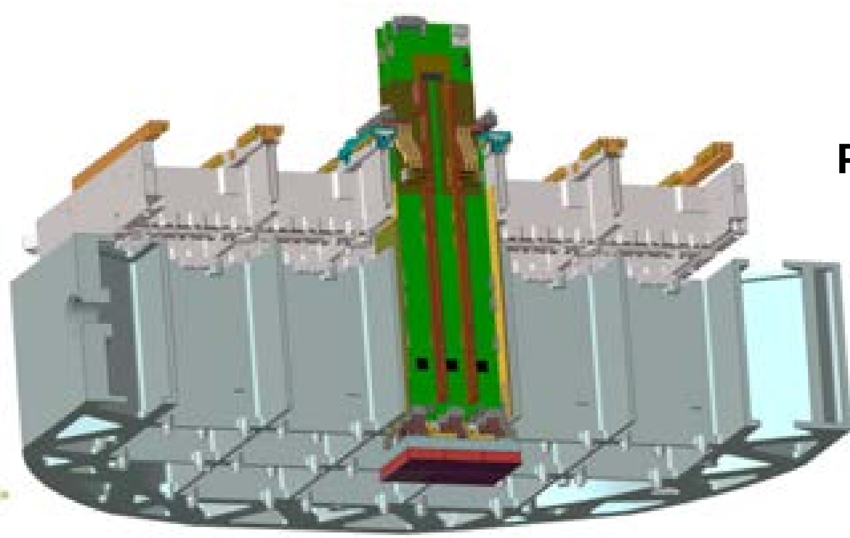
Removes 2 Watts per Strap (8 Watts total for RSA)

Electrical interface:

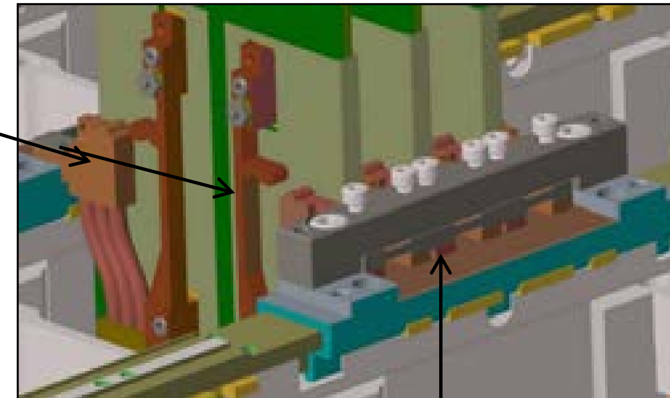
Flex cables are a conductive heat path to the Raft Electronics Boards (REBs)



REB Thermal Straps
(Thermal path between REBs & Cold Plate)

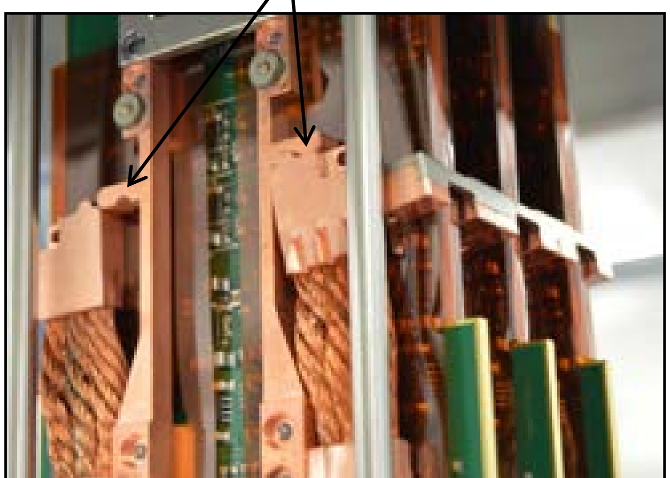


REB – Cold Plate Thermal Strap

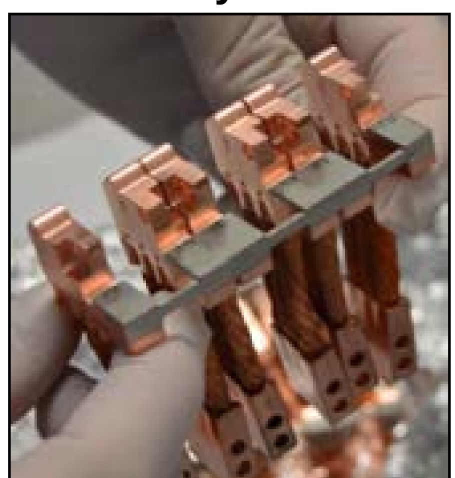


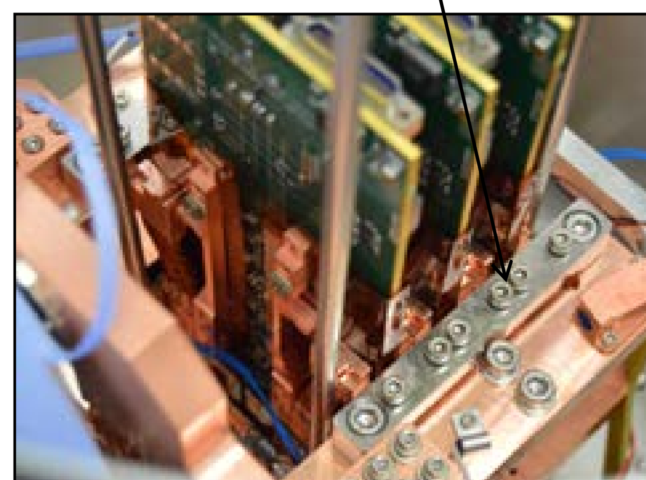
Clamping Force

Stowage Feature

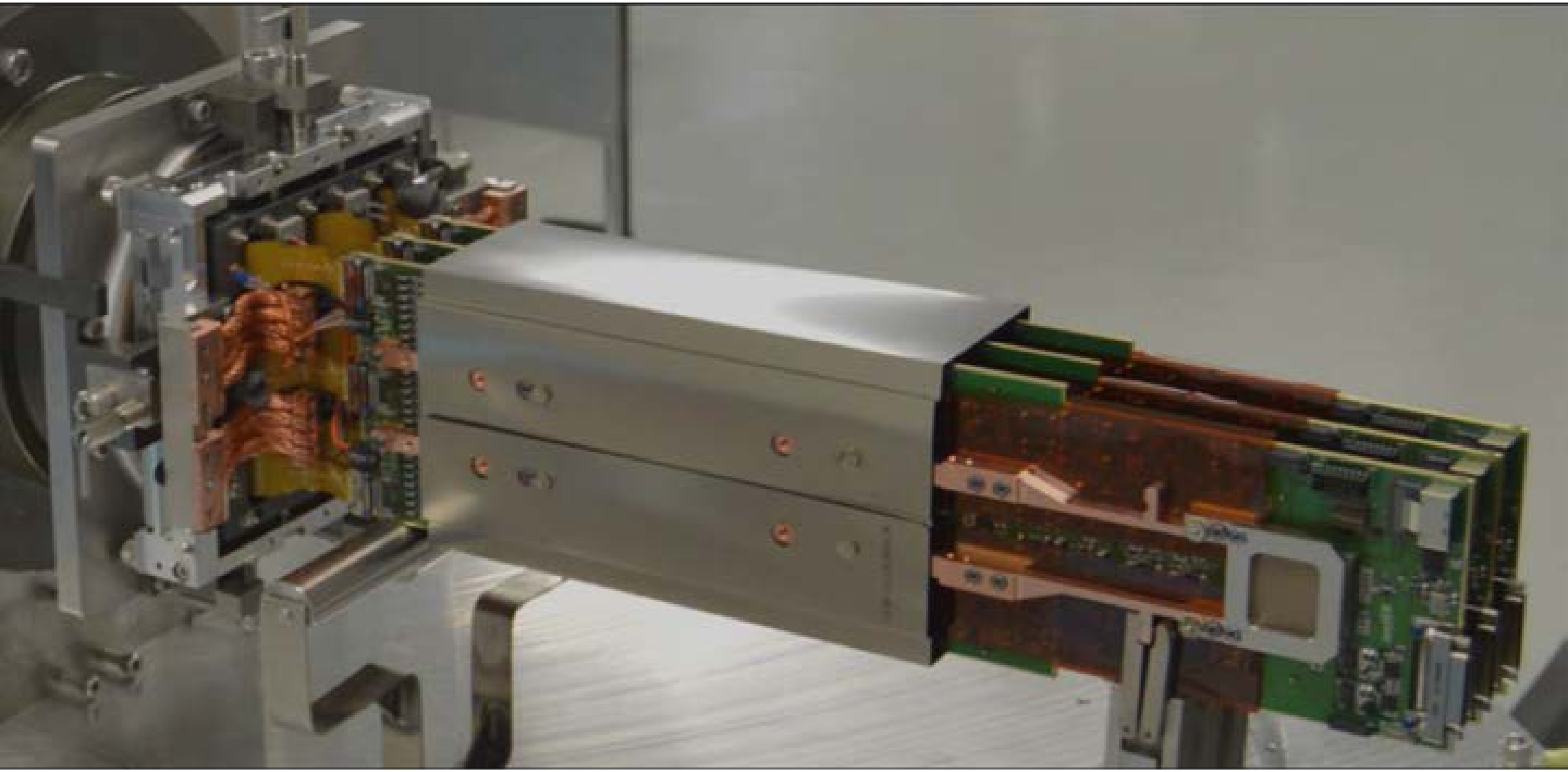


Thermal Strap Assembly

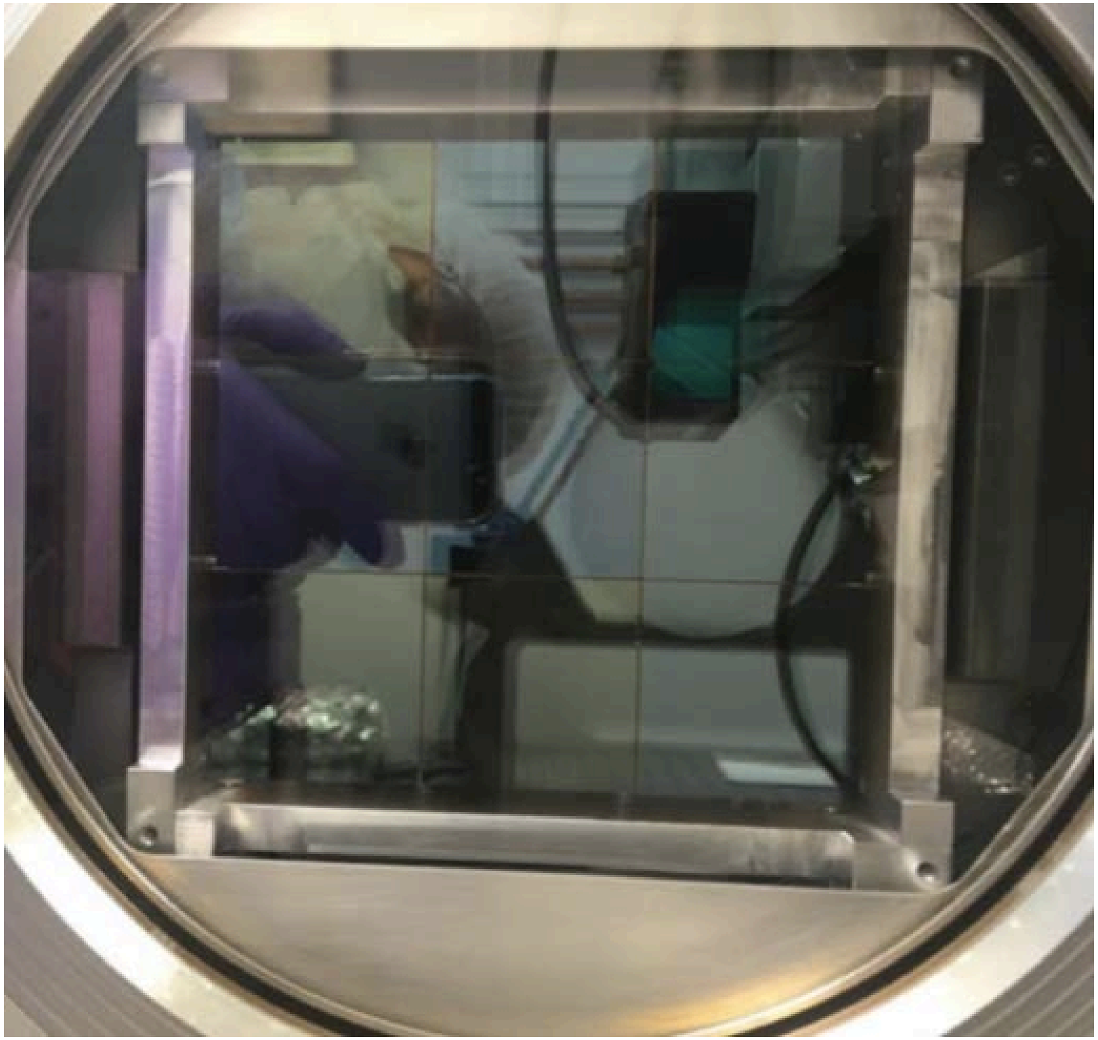




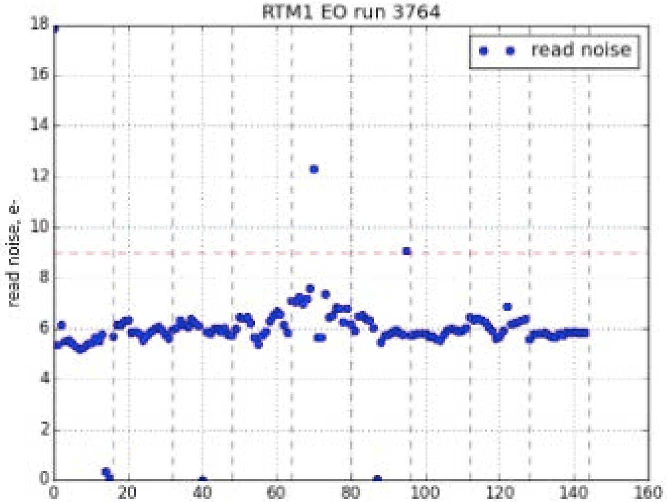
First Science Raft at BNL

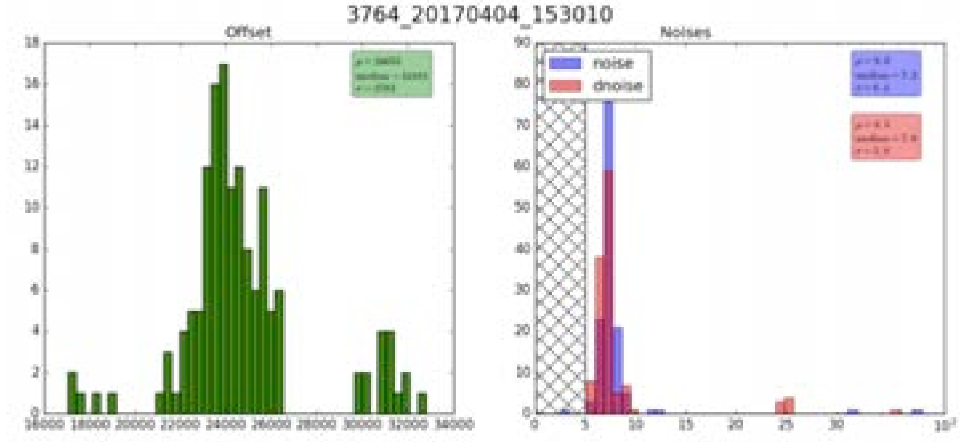


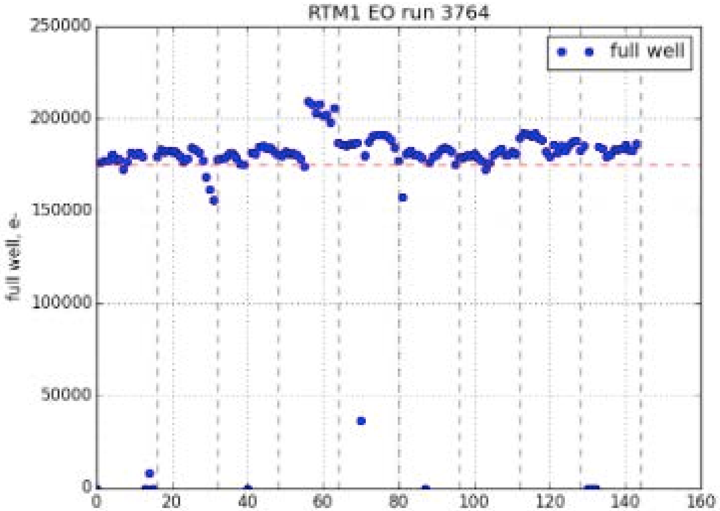
9 CCDs in RTM-1

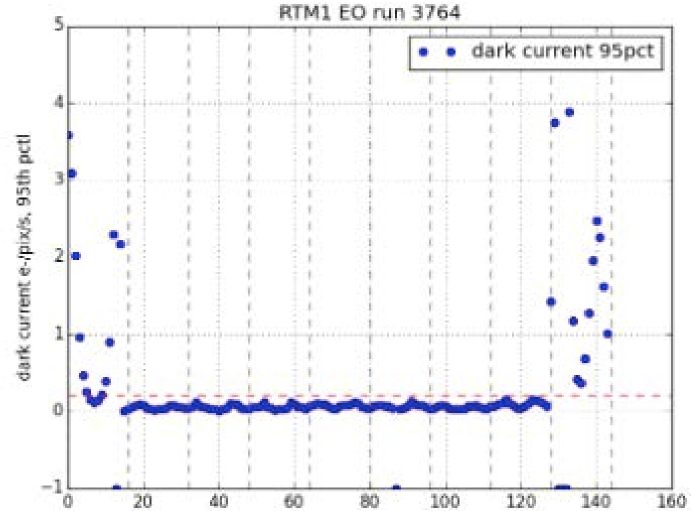


RTM-1: First Results





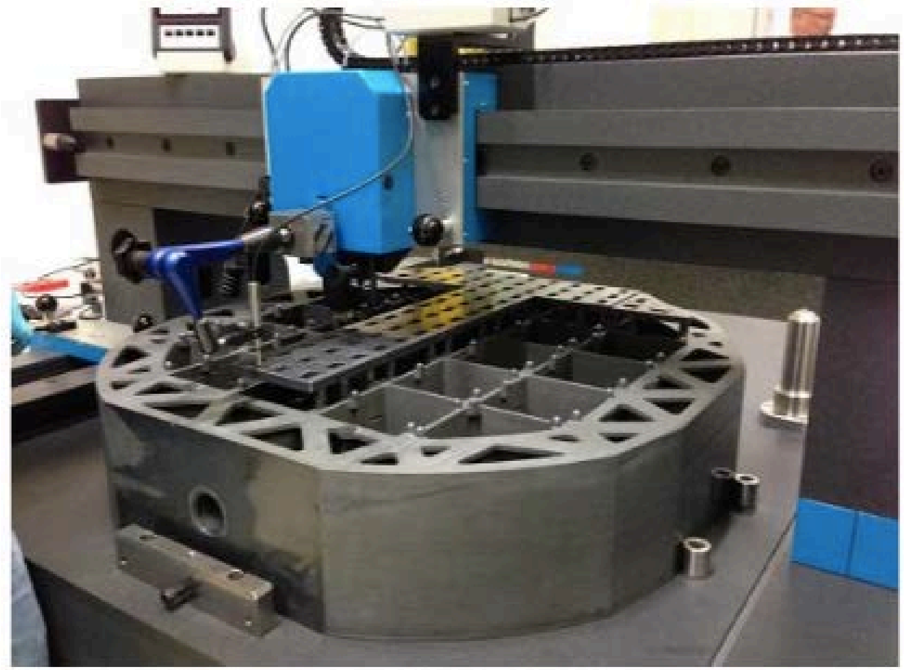




M.Vrastil & P.O'Connor

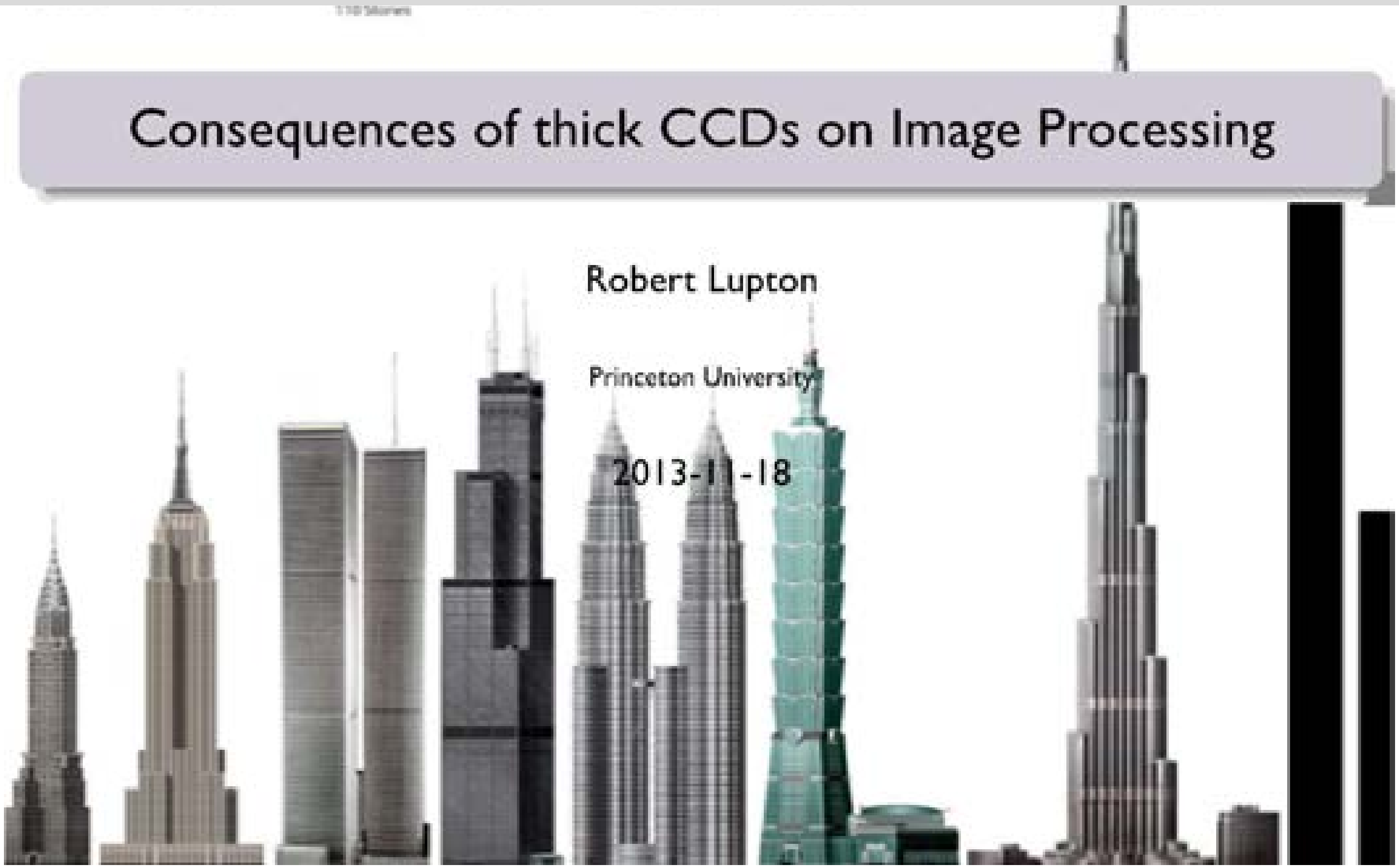
Camera Cryostat

- Cesic grid successfully completed and shipped to SLAC.
- Cryostat vacuum vessel completed and received at SLAC.
- Critical cryoplate fabrication underway.



LSST pixel : 10 x 10 x 100 micron^3
→ Pixels are skyscrapers

Want to know ellipticity of PSF to 0.1 %



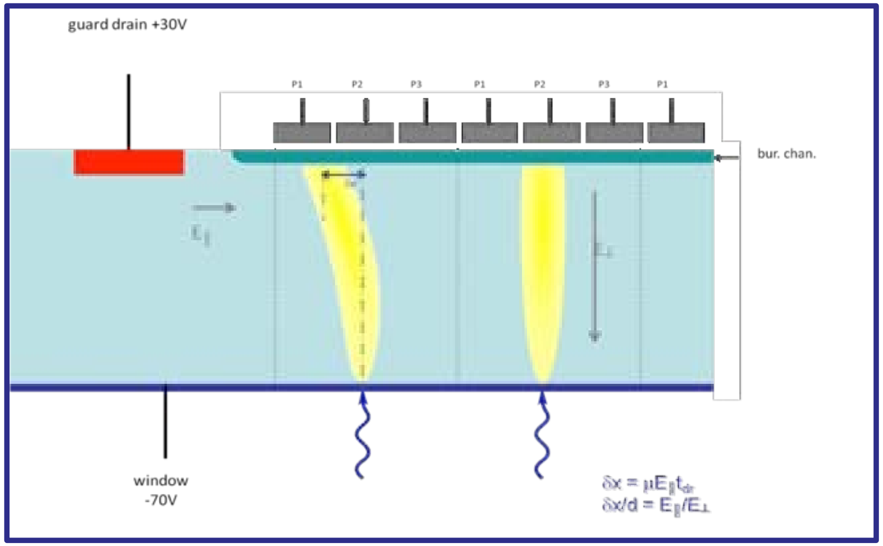
What’s the problem with thick CCDs?

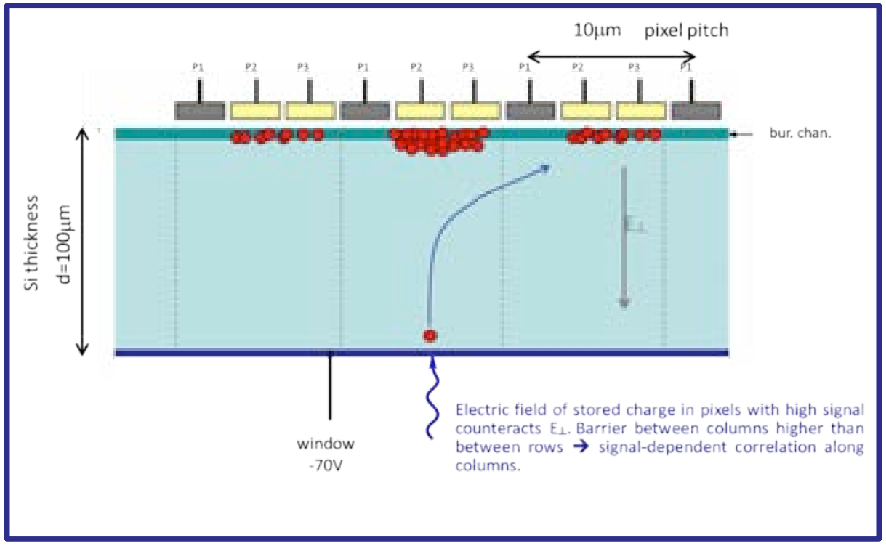
Fully depleted CCD have a non-trivial electrostatics which lead to astrometric biases and PSF distortions

– Difficult to disentangle from photometric effects

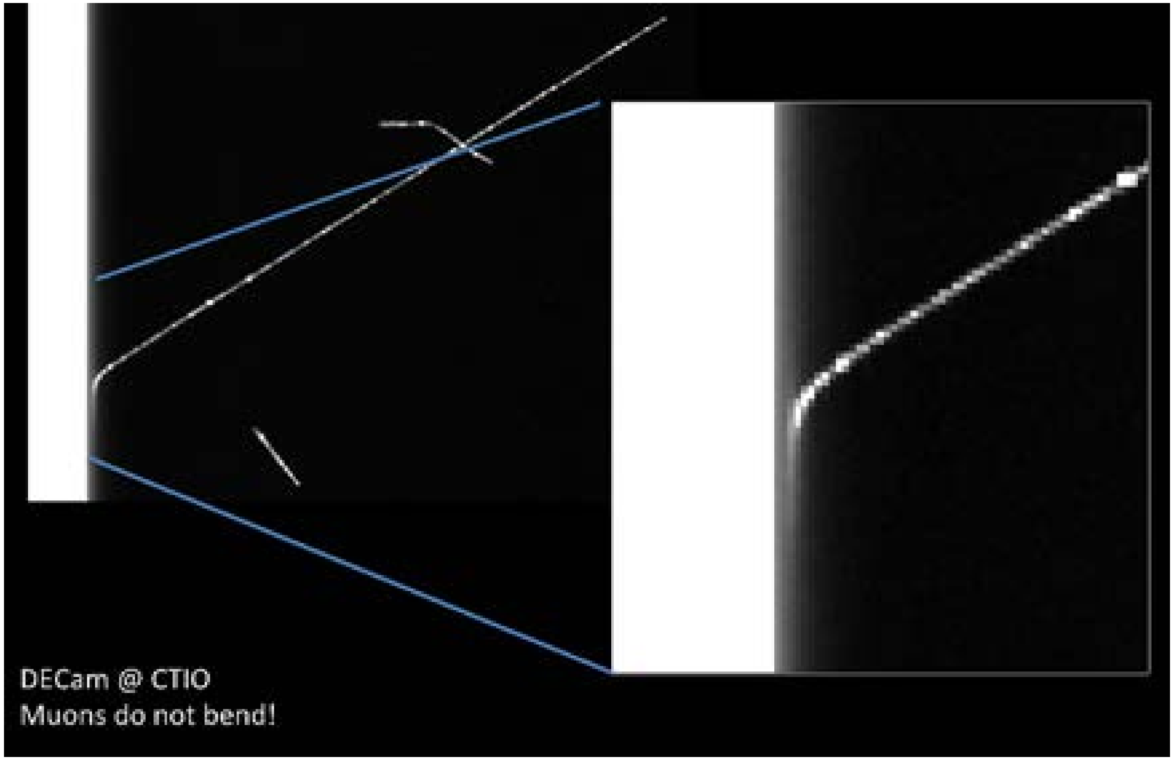
Static : edge effects, tree-rings

“Dynamic” : brighter-fatter effect



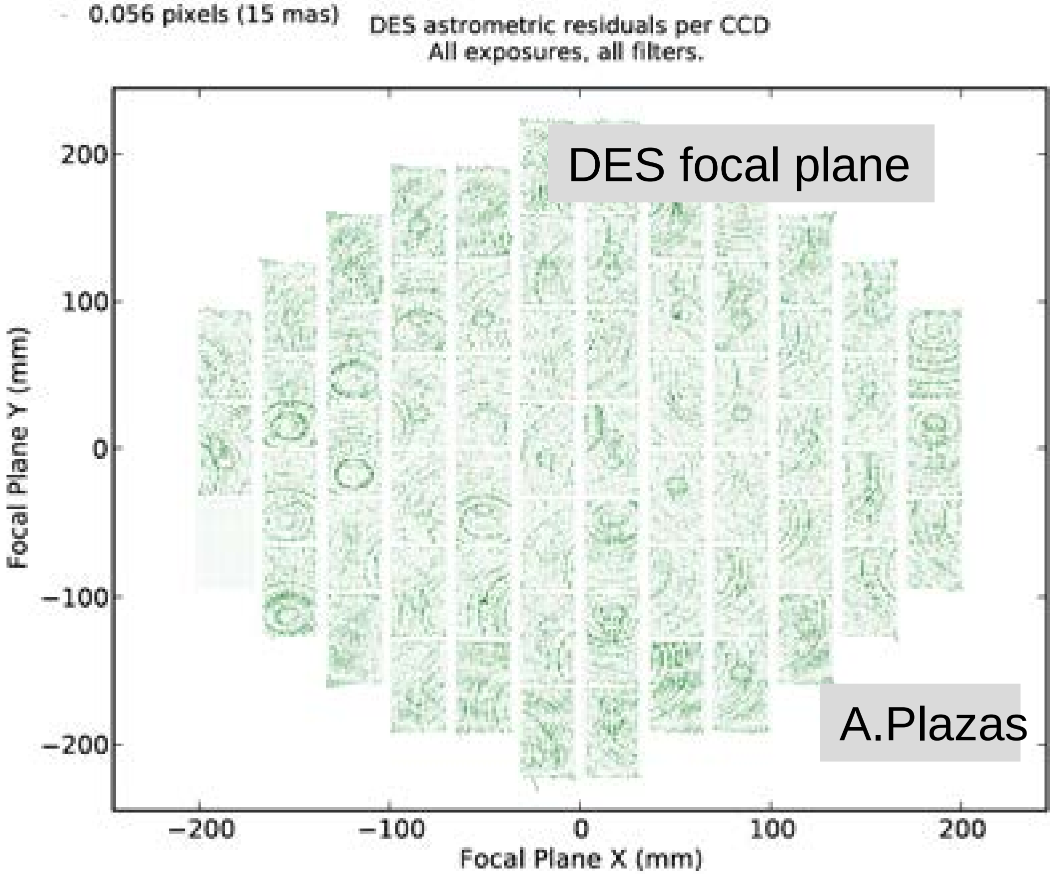


Edge Effects in CCDs with Cosmic Rays



Similar effects in DES CCDs for cosmic muons (J.Estrada)

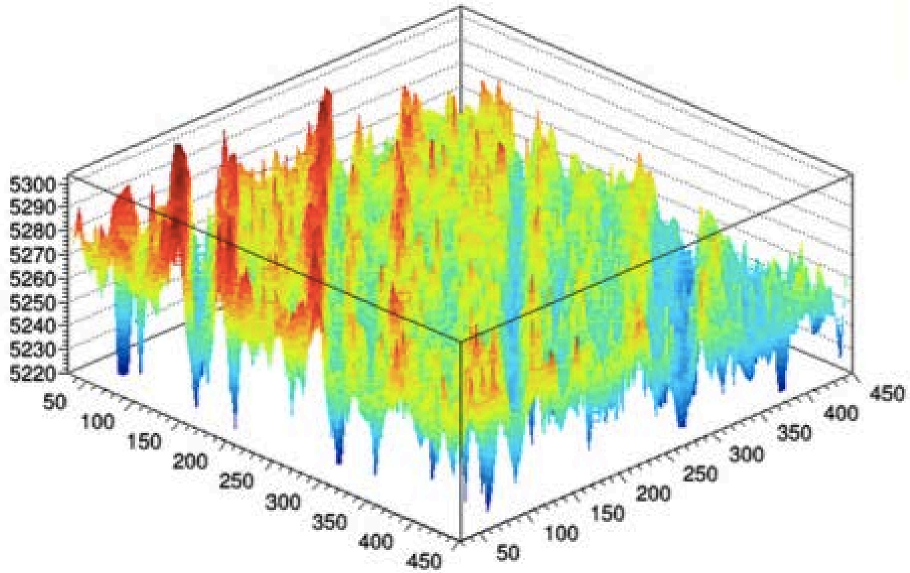
Tree Rings

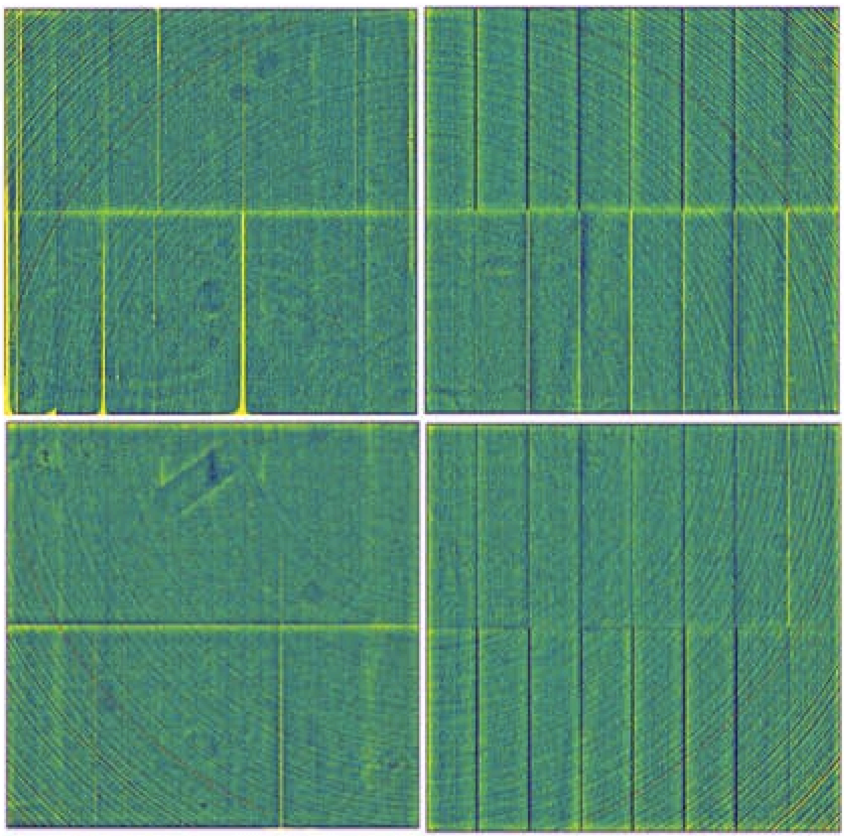


- Due to uneven doping (~1%) of silicon wafers during production
- Has cylindrical symmetry due to rotation of ingots

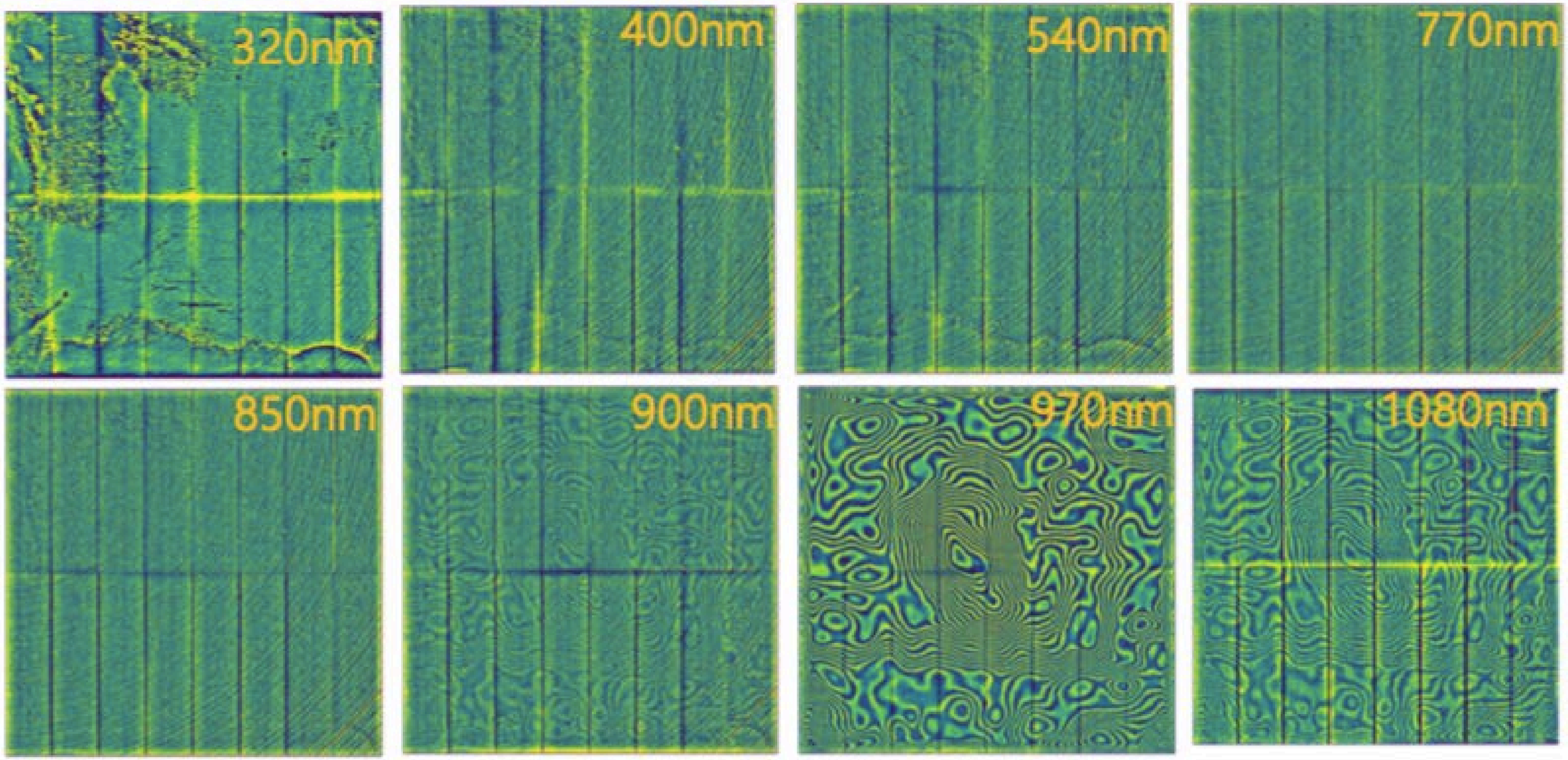
Tree rings

Dopant concentration
->variation in electric fields
-> shape of sources distorted



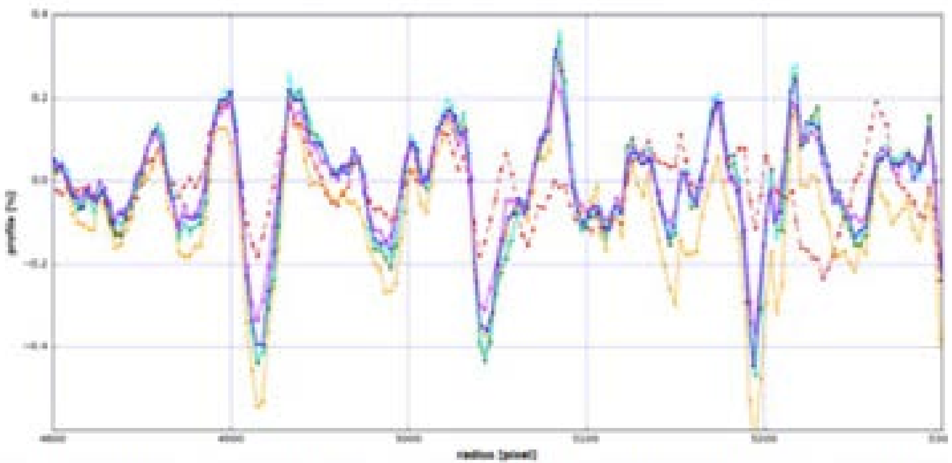


Wavelength dependence

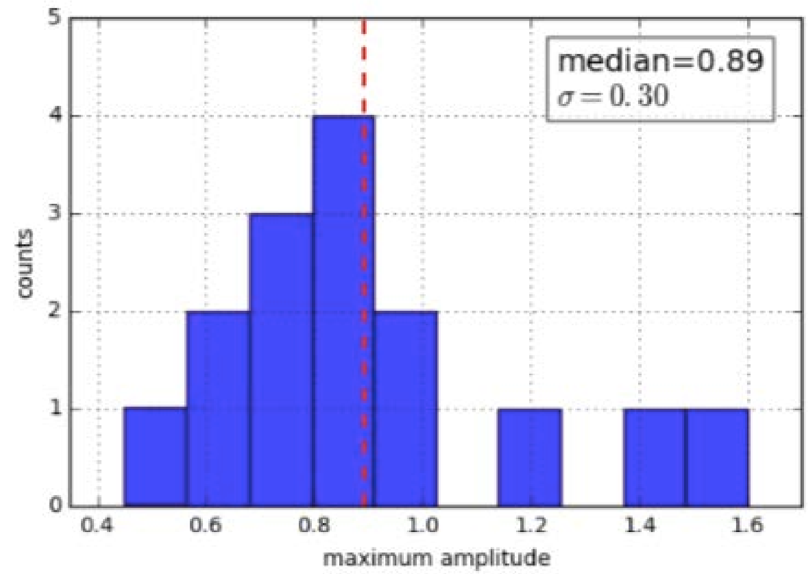


Tree Rings in ITL sensors

Wavelength dependence

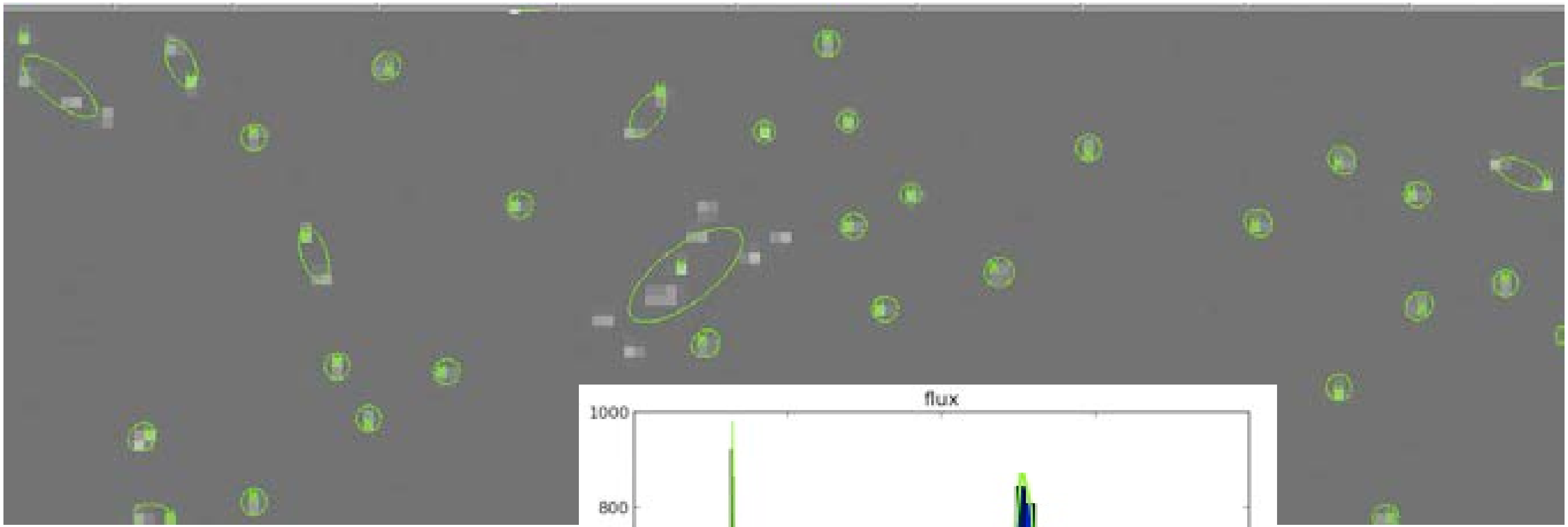


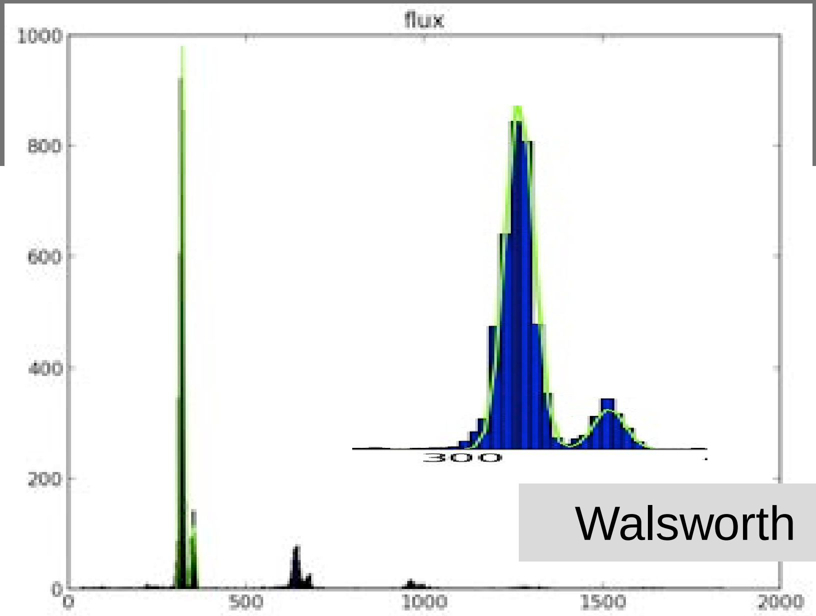
- Orange(320nm),green(400nm),cyan(540nm),blue(770nm),magenta(850nm),



^{55}Fe x-rays

Ellipse fits of DM footprints in ^{55}Fe data (5.9 keV x-rays)

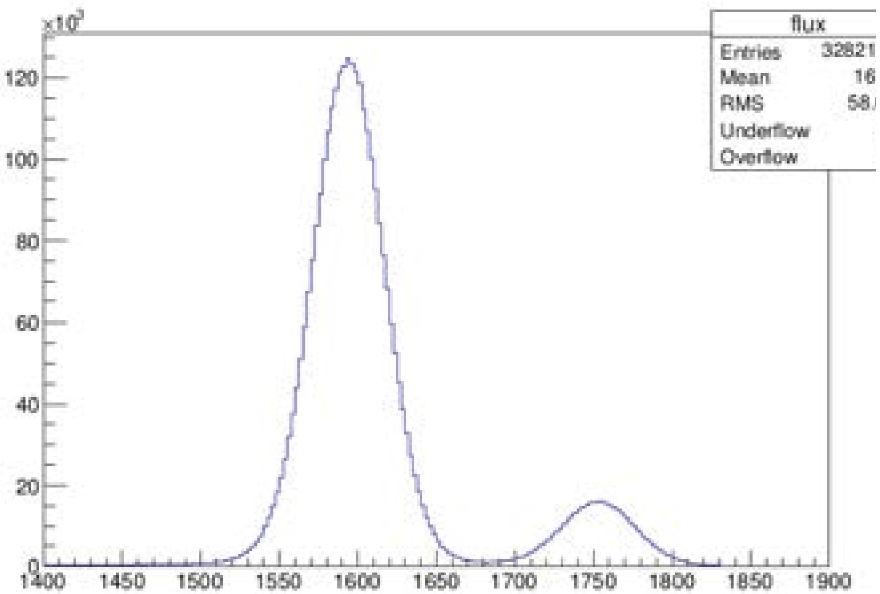




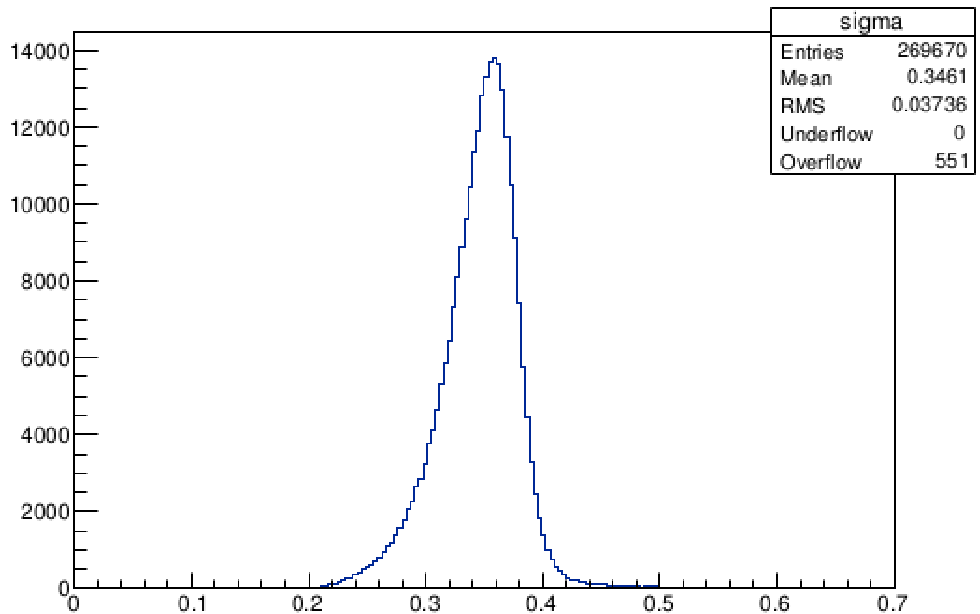
Walsworth

Flux

- 2D Gaussian (flux, centroid, sigma, shear) was fitted using Max Likelihood fitter
- Gain corrected, include all 16 amplifiers
- Resolution 3.4%
  - fit error 1.2%



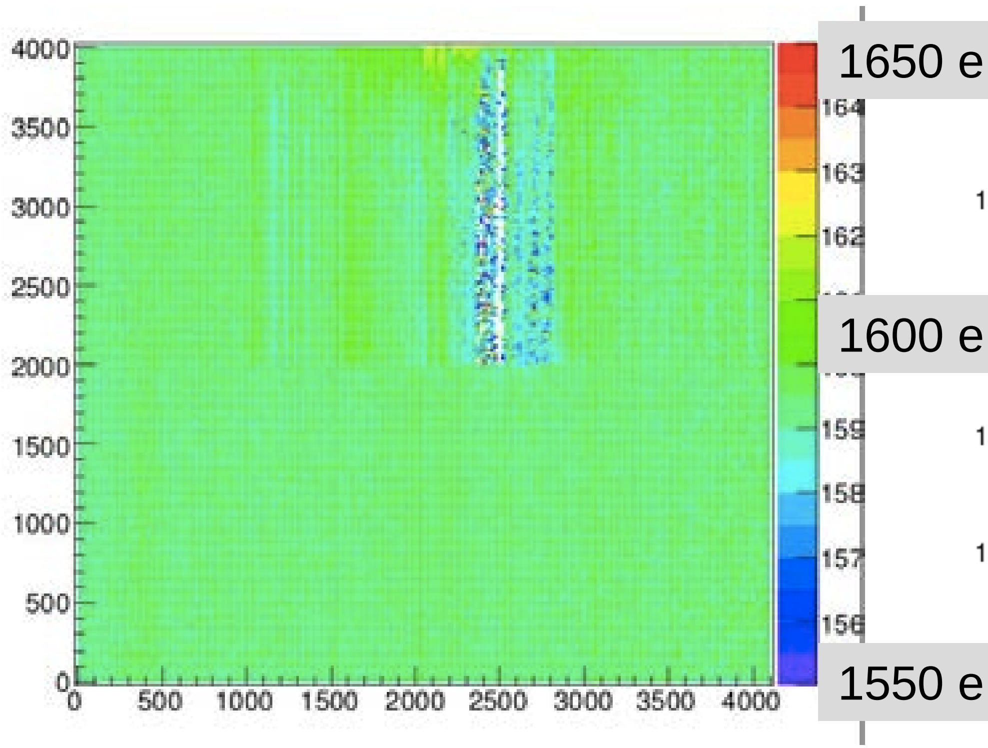
Flux, electrons



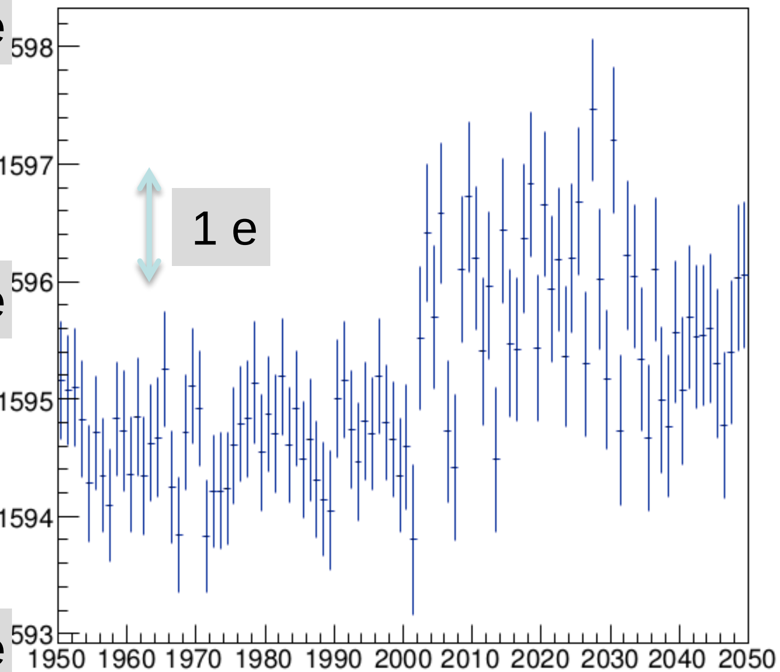
sigma, pix

Gain calibration

- Excellent calibration
  - 0.1% difference between sections



Flux (x,y) map, electrons



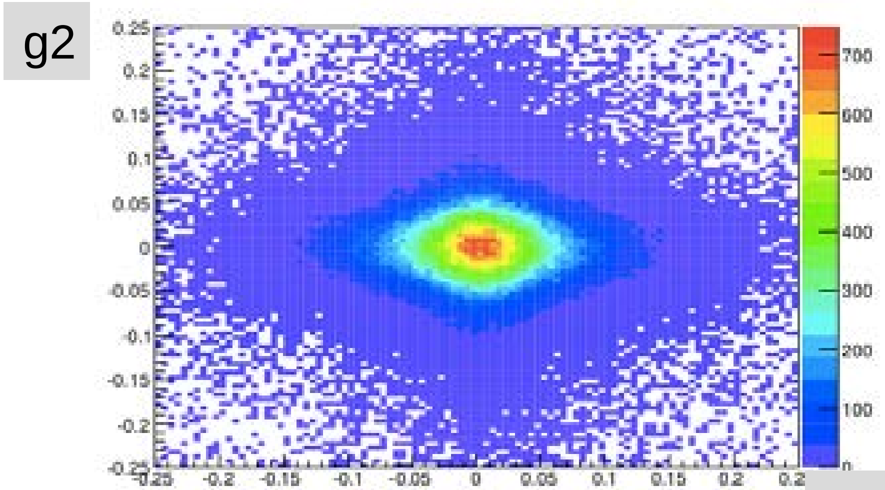
Border between two sections

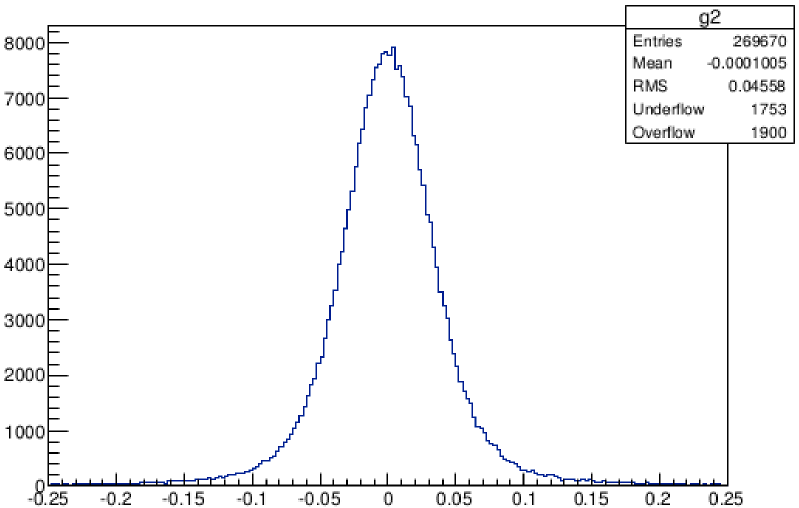
Shear (Ellipticity) of Hits

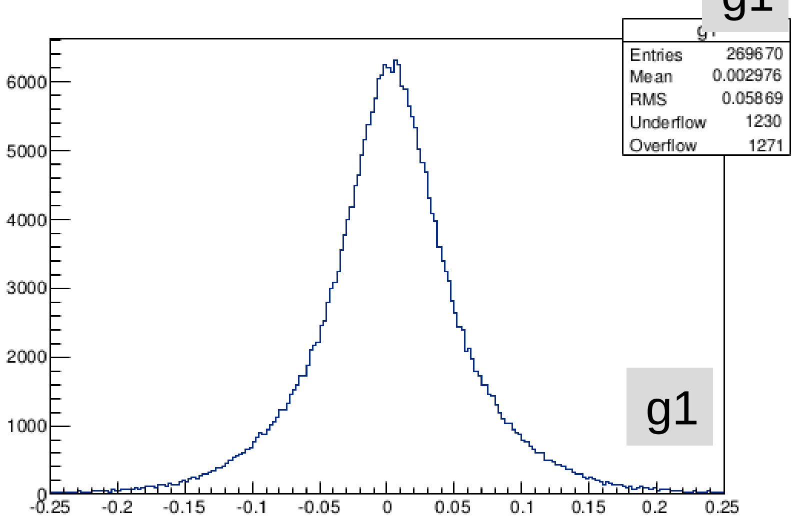
Weak lensing definitions for g1, g2 shear

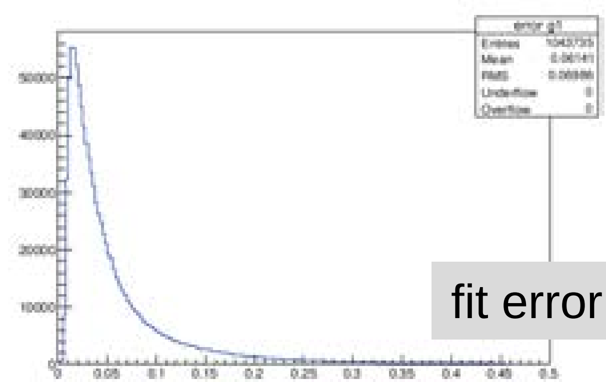
$g1 = (a-b)/(a+b)$

$\tan(2\theta) = g2/g1$

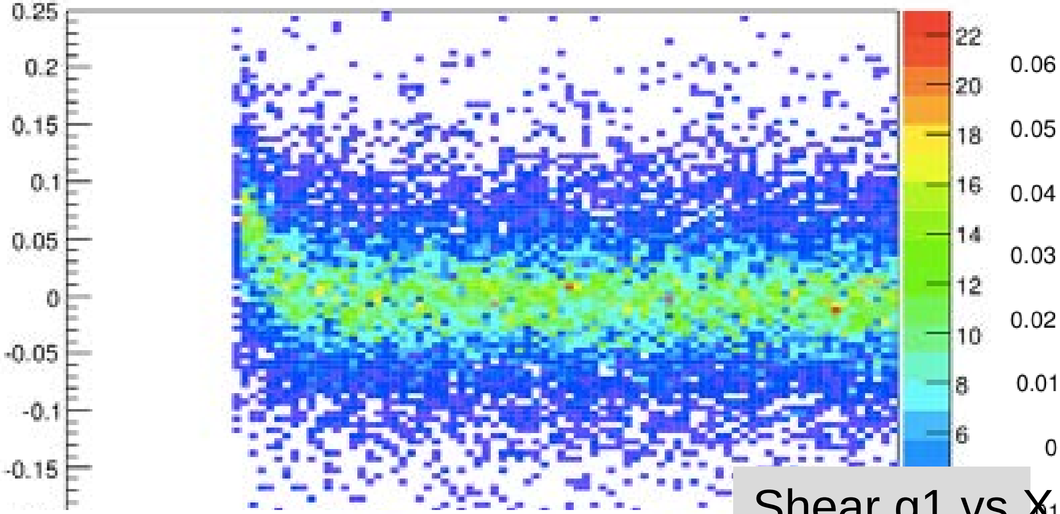


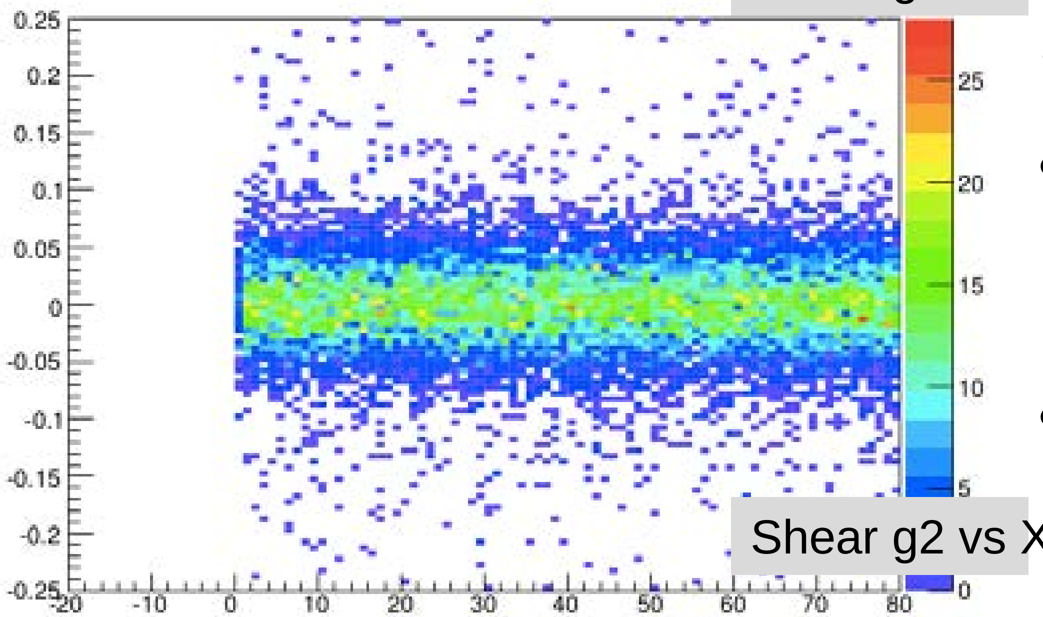


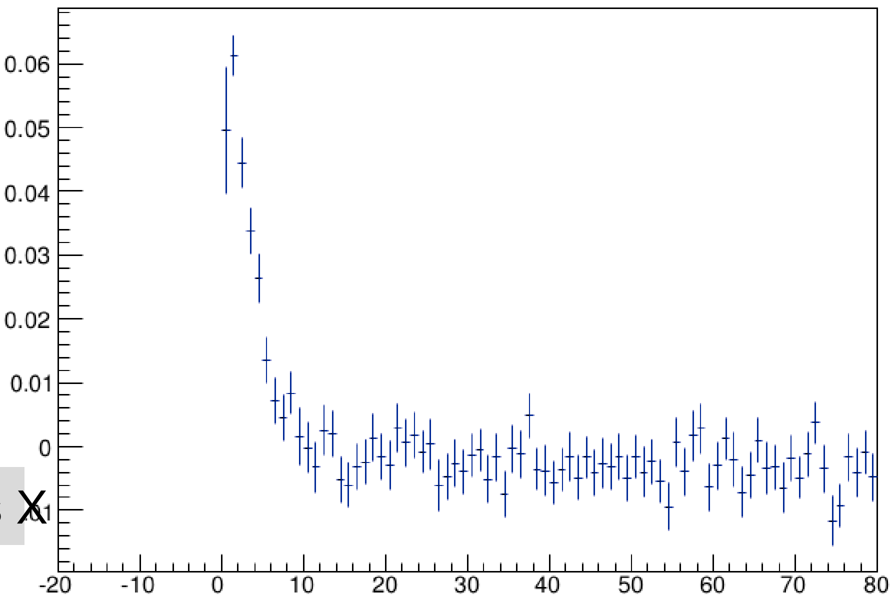




Edge Effect seen in Fe55 flats!



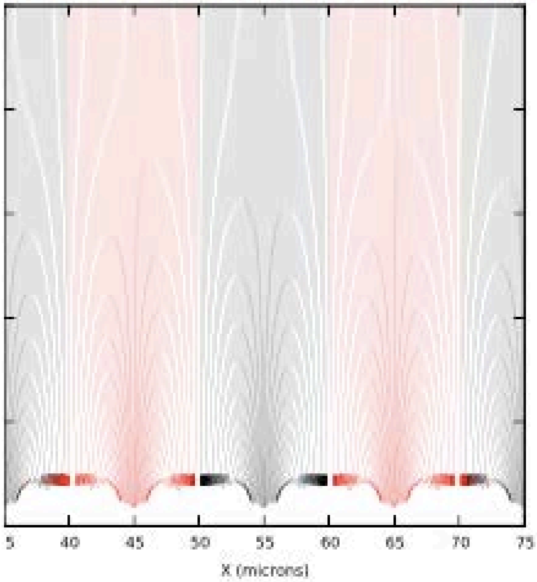




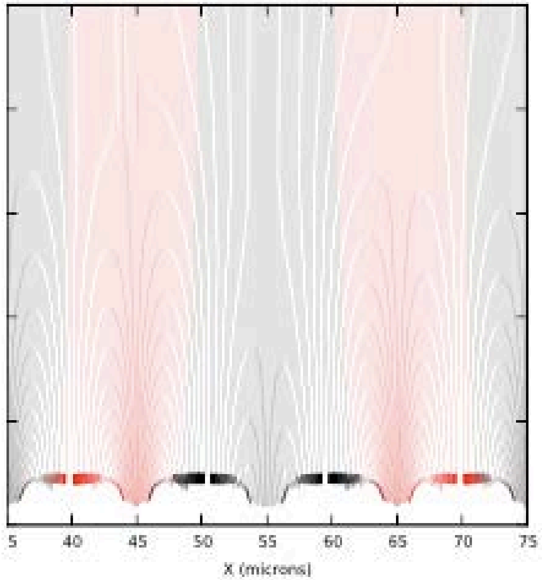
- g1 positive → elongation along x, affects ~ 10 pixels
- g2 does not change → no 45° component

Basics of the Brighter-Fatter Effect

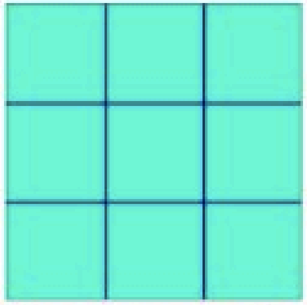
Diffusion turned off here.



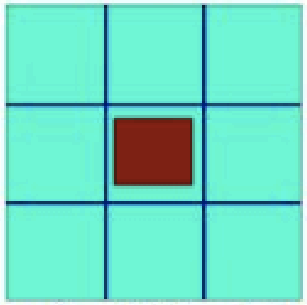
Diffusion turned off here.



C.Lage



Pixel empty of charge

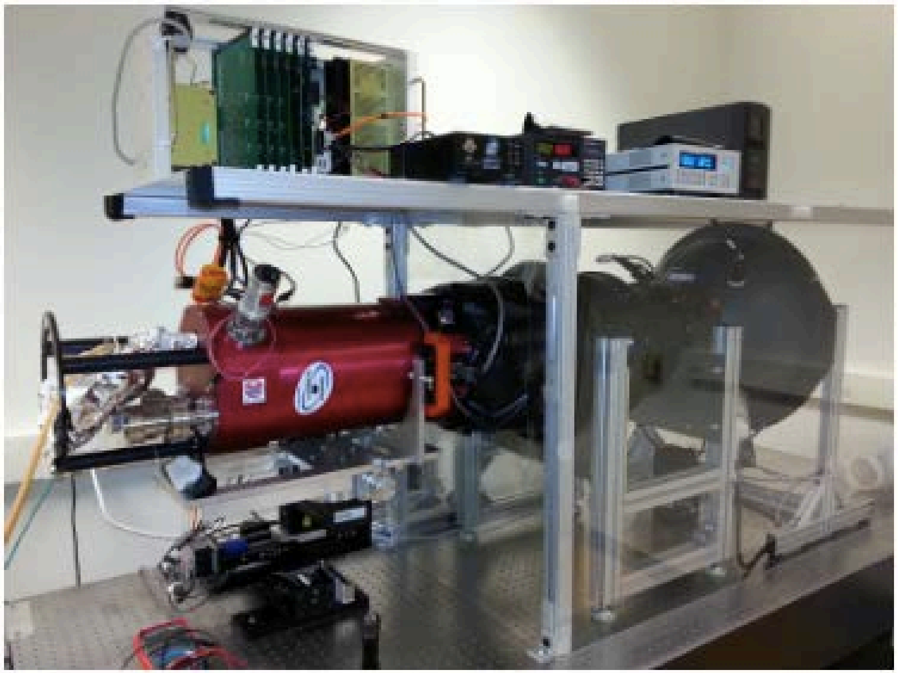


Pixel with 100K e-

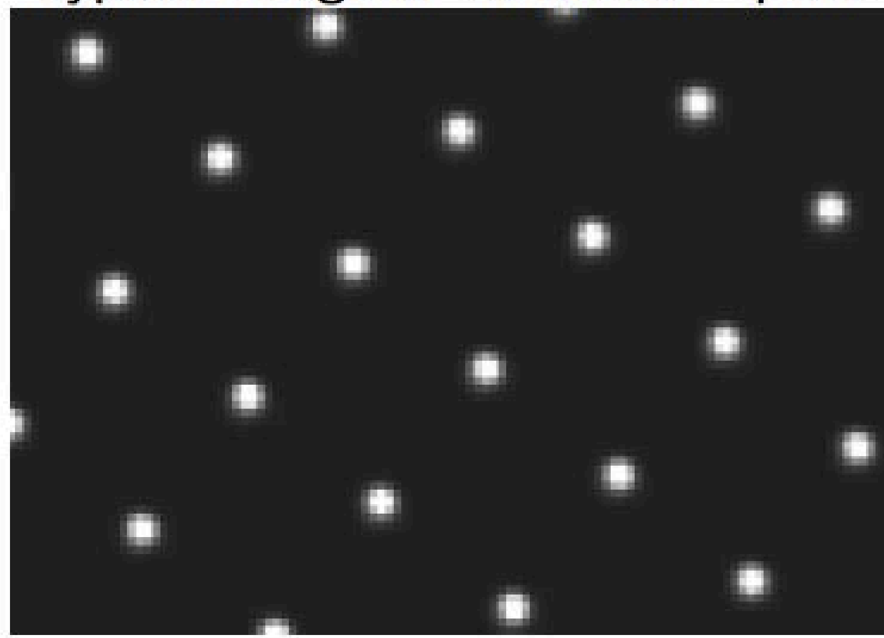
- Electrons stored in the potential well repel incoming electrons and push them into surrounding pixels.

LSST Optical Simulator and Typical Spot Images

UC Davis 1:1 Re-Imager



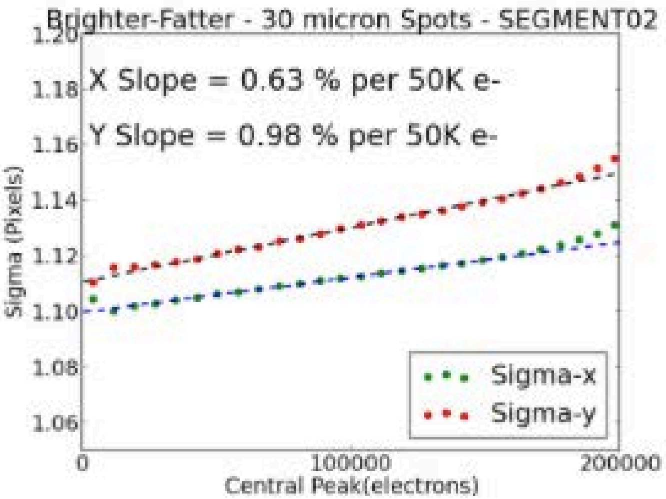
Typical Image of 30 micron Spots:



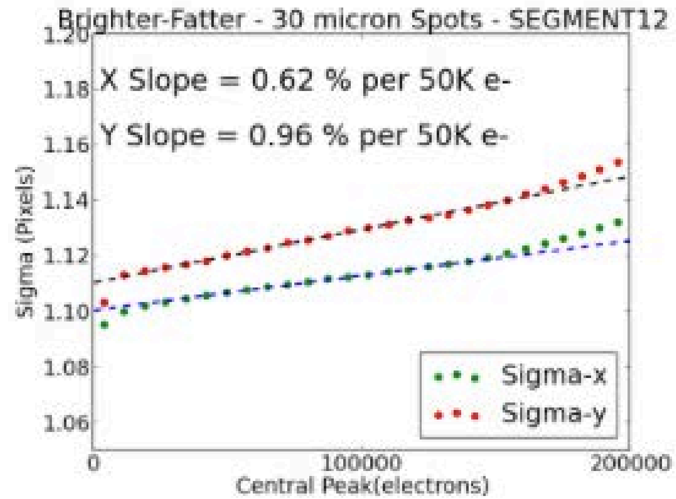
Tyson, et.al., "The LSST Beam Simulator", SPIE 9154-67 (2014), arXiv:1411.5667.

Typical Brighter-Fatter Effect Measurements - ITL 3800

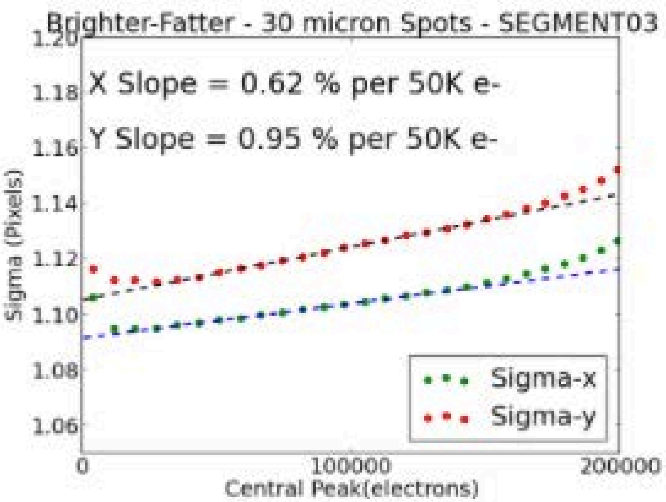
C.Lage



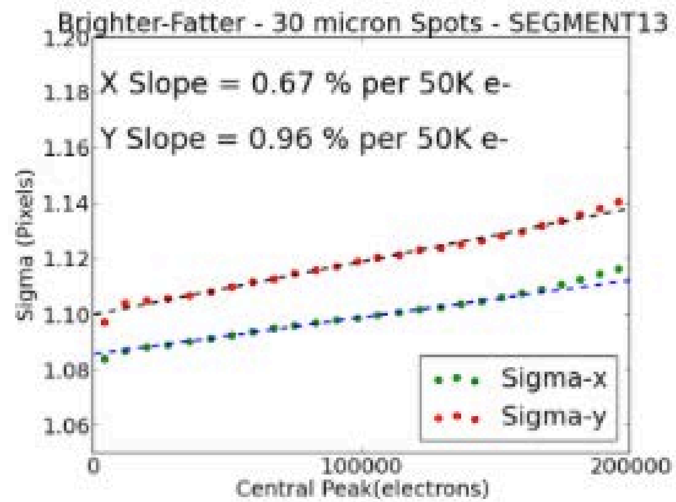
SEGMENT02



SEGMENT12



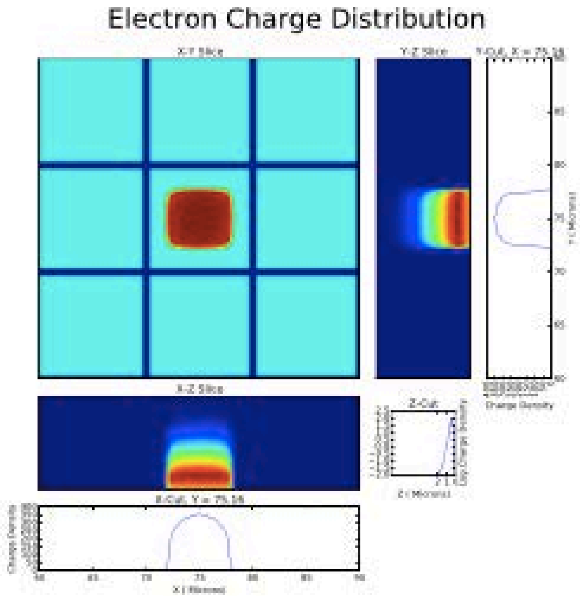
SEGMENT03



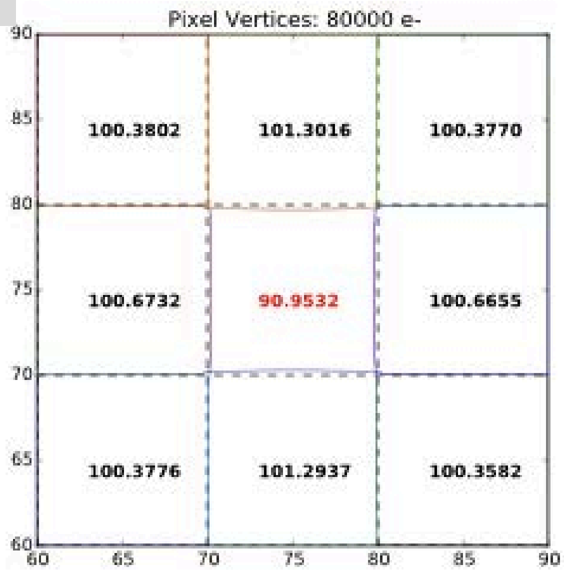
SEGMENT13

Many measurements have been made under different conditions.

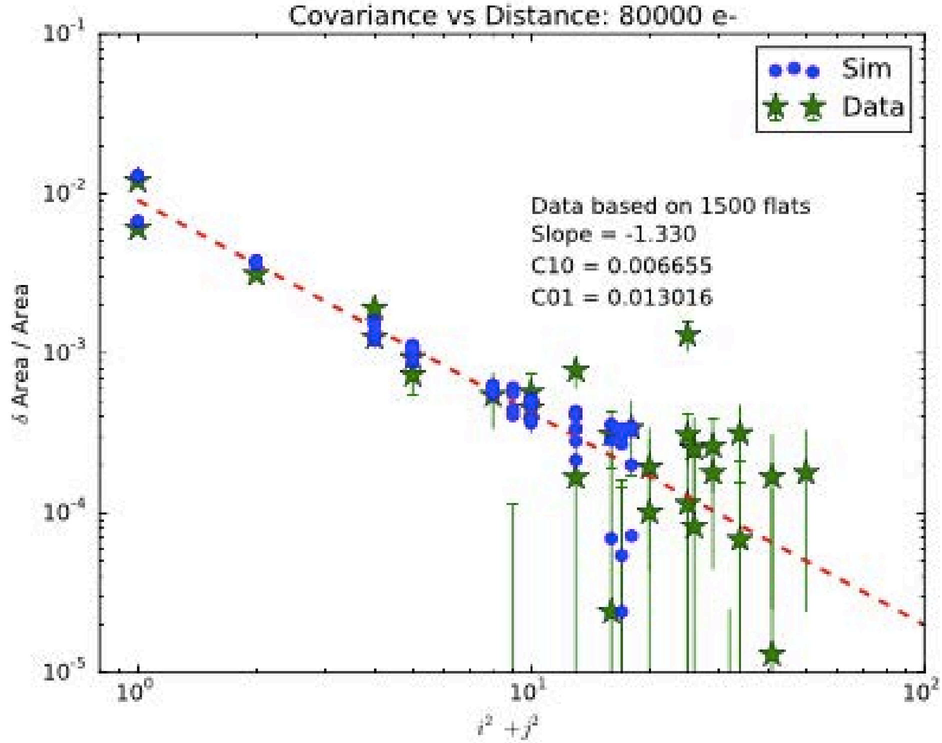
Pixel Areas and Correlations



C.Lage



Simulations vs ITL 3800 Measurements



- Antilogus, et al., JINST 9C3048 (2014), arXiv:1402.0725.
- Rasmussen, A., JINST 904027 (2014), arXiv:1403.3317.

Near Full Well Behaviour

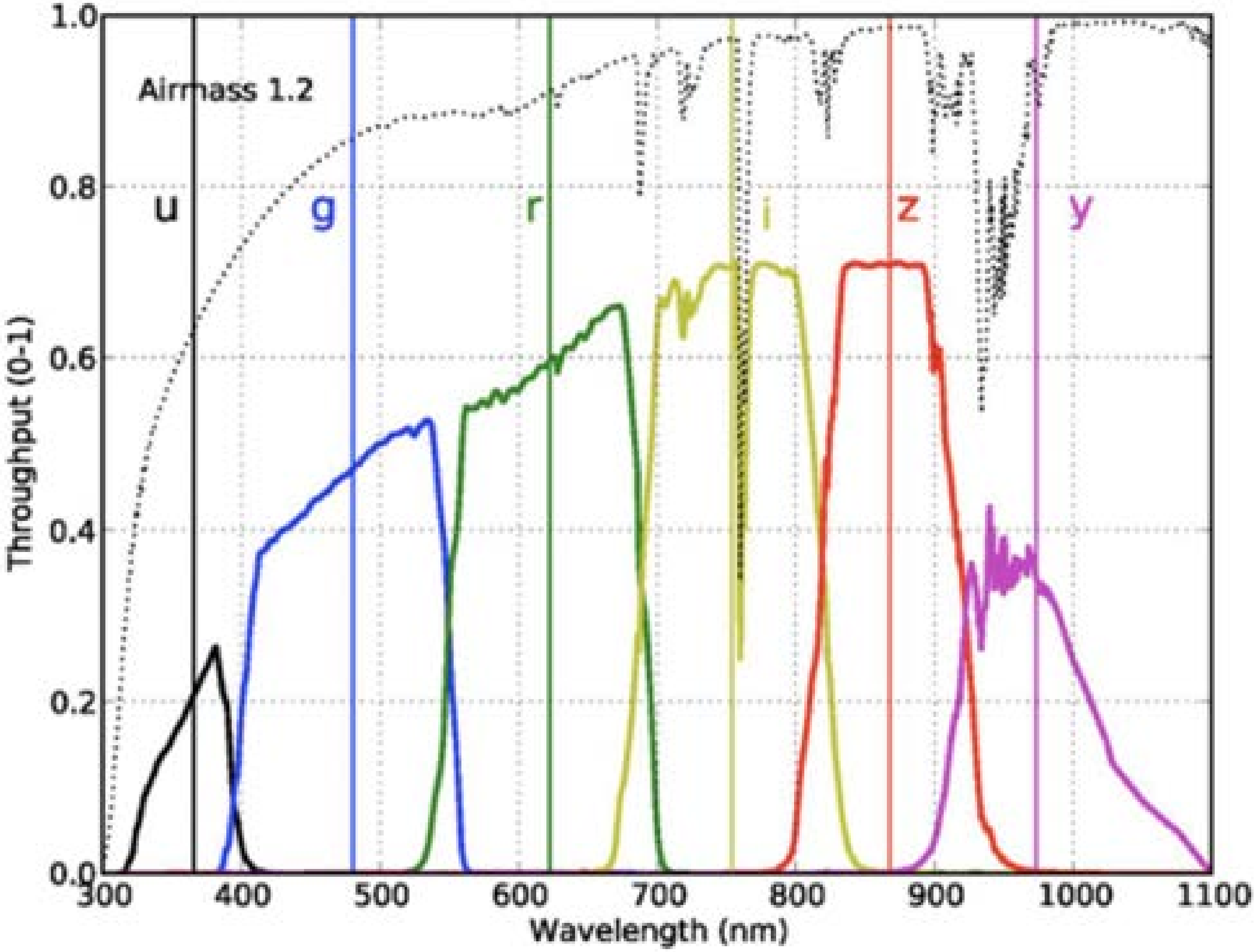
- movies

Fringing with Monocam at 1.3m

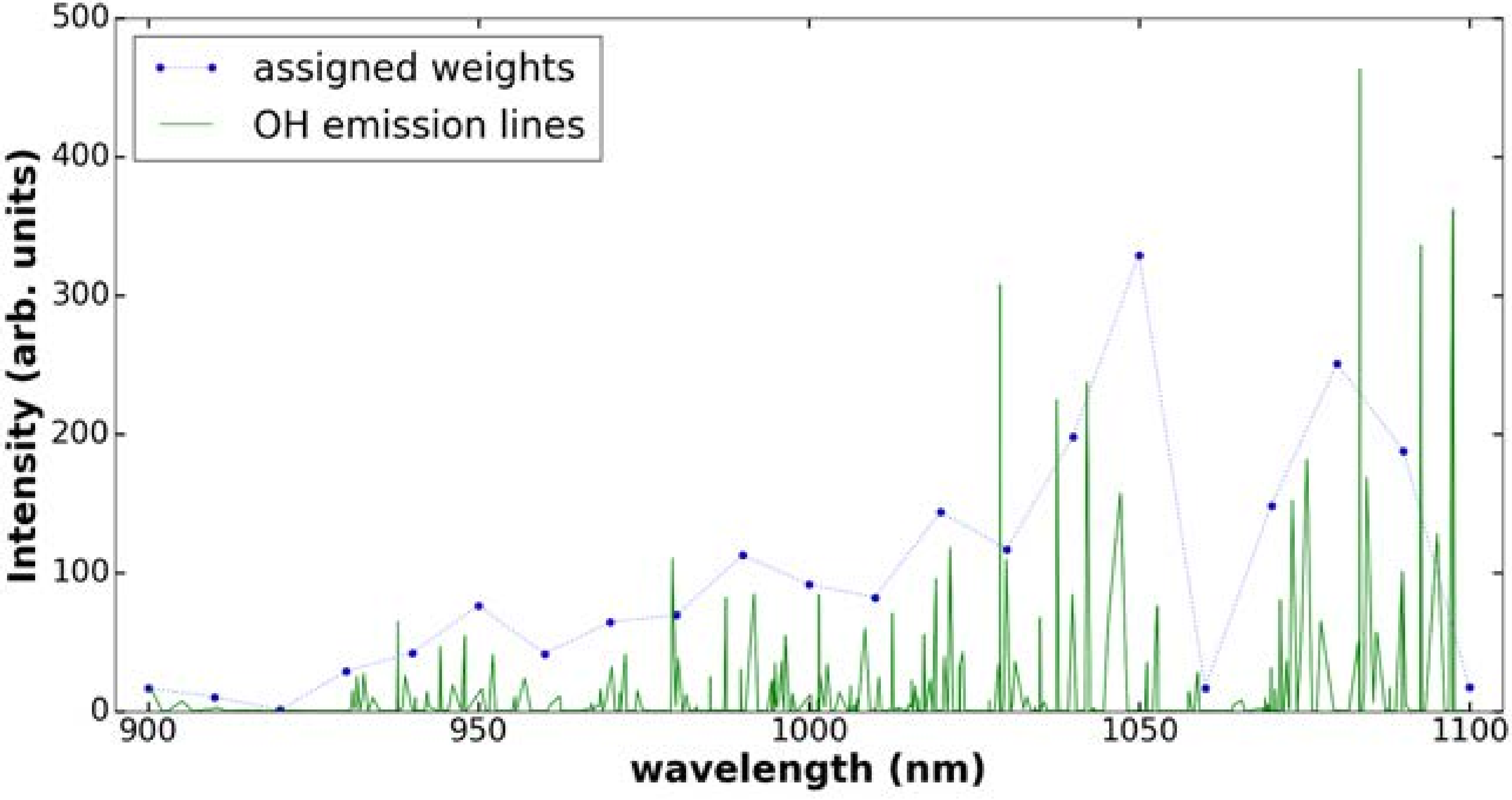
1.3m Telescope

- scale 40.0 arcsec/mm
- f/4.0
- FOV 0.44 x 0.44 sq.deg.
- Blank field CABlank5
  - RA 16 24 33
  - DEC +55 43 59
- y4 filter

LSST Filter Throughput

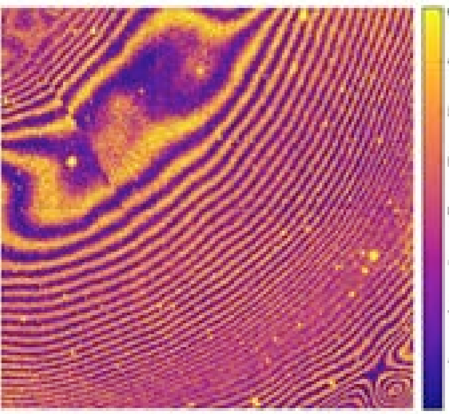


OH emission spectral lines

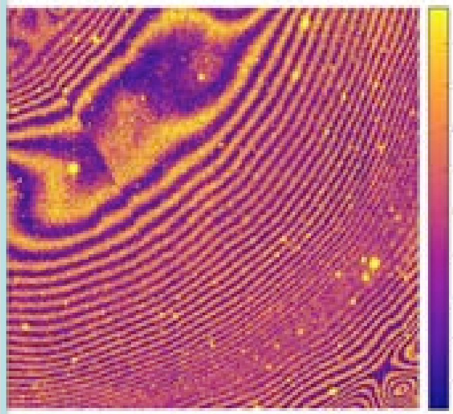


Fringes through the night

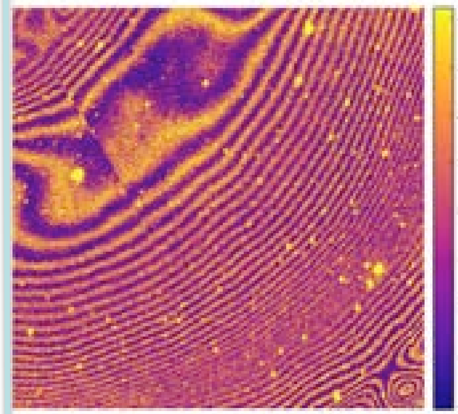
8:25 pm 230ADU



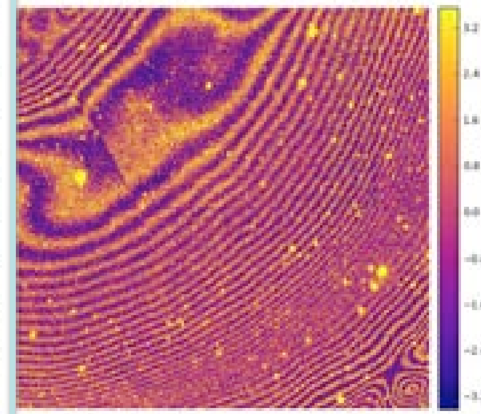
9:36 pm 156ADU



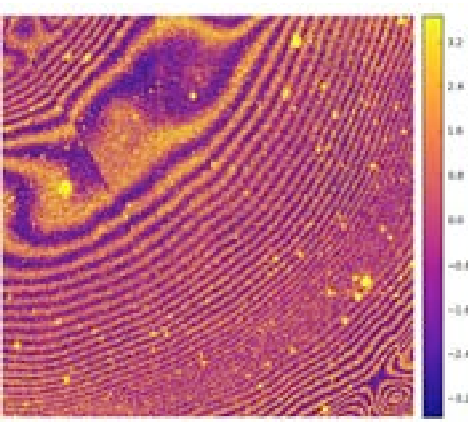
10:36 pm 127ADU



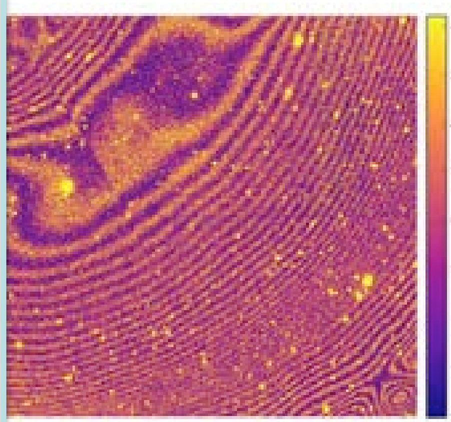
11:37 pm 96ADU



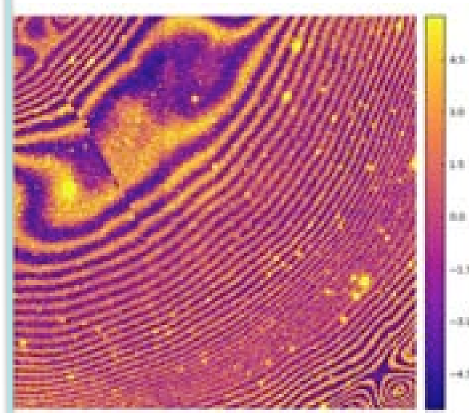
12:33 am 102ADU



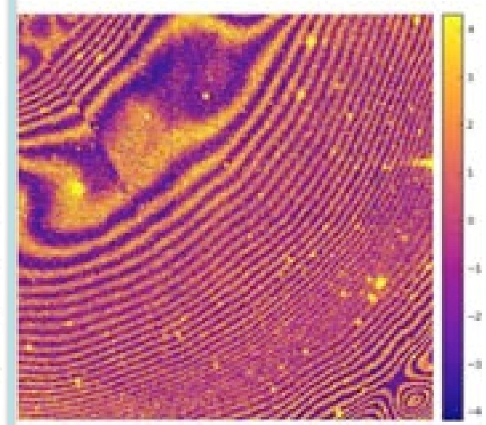
1:43 am 92ADU



2:41 am 206ADU

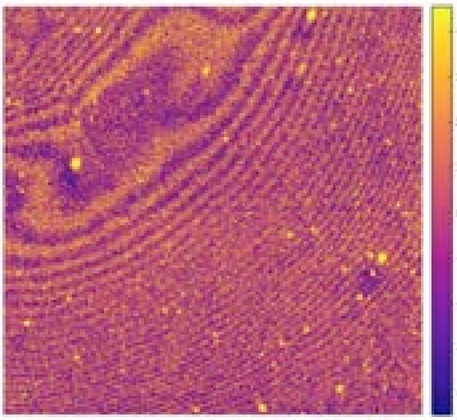


4:04 am 134ADU

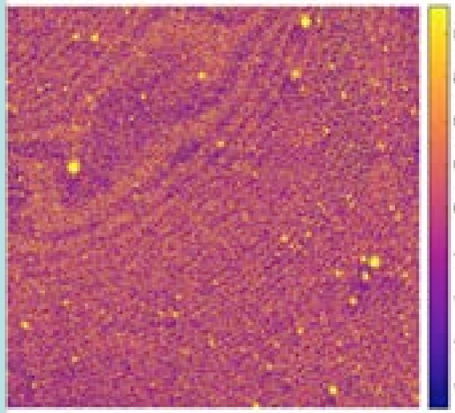


All averaged raw images with mean fringe subtraction

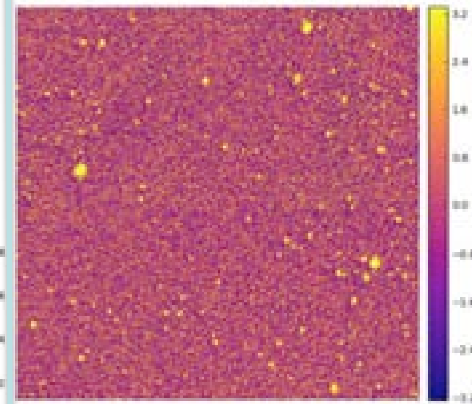
8:25 pm 230ADU



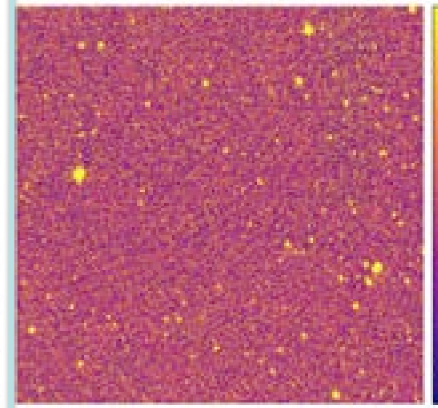
9:36 pm 156ADU



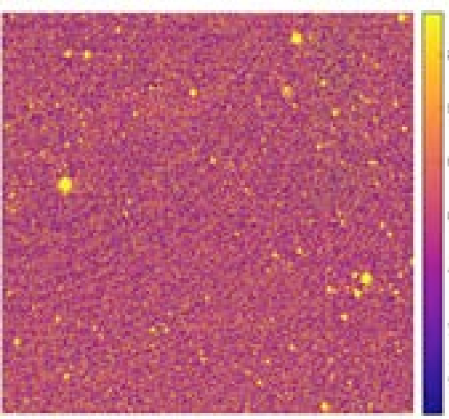
10:36 pm 127ADU



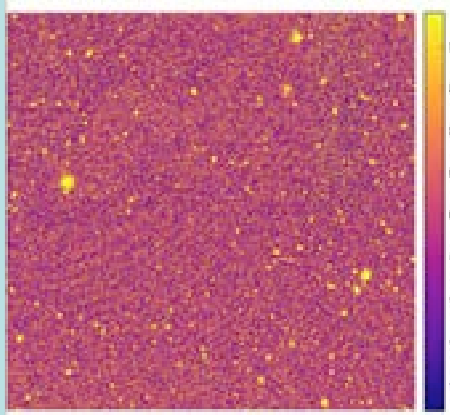
11:37 pm 96ADU



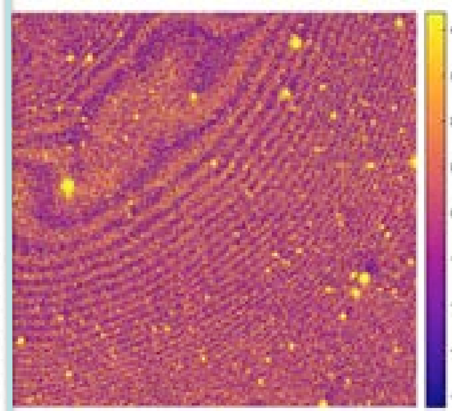
12:33 am 102ADU



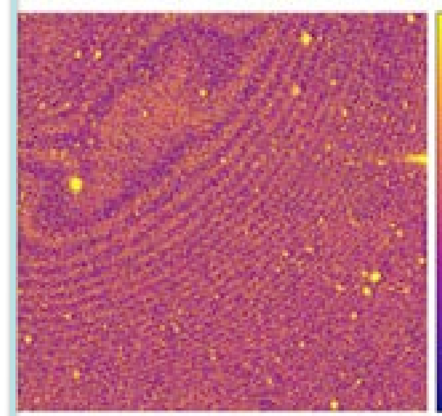
1:43 am 92ADU



2:41 am 206ADU

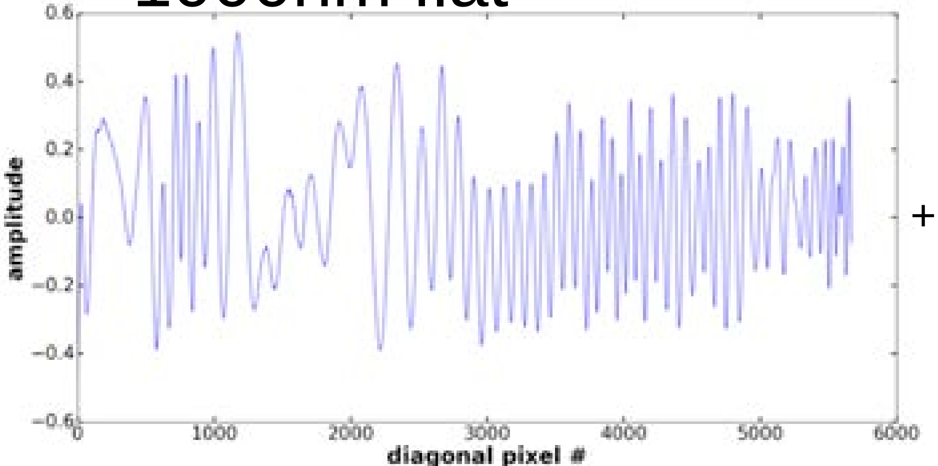


4:04 am 134ADU



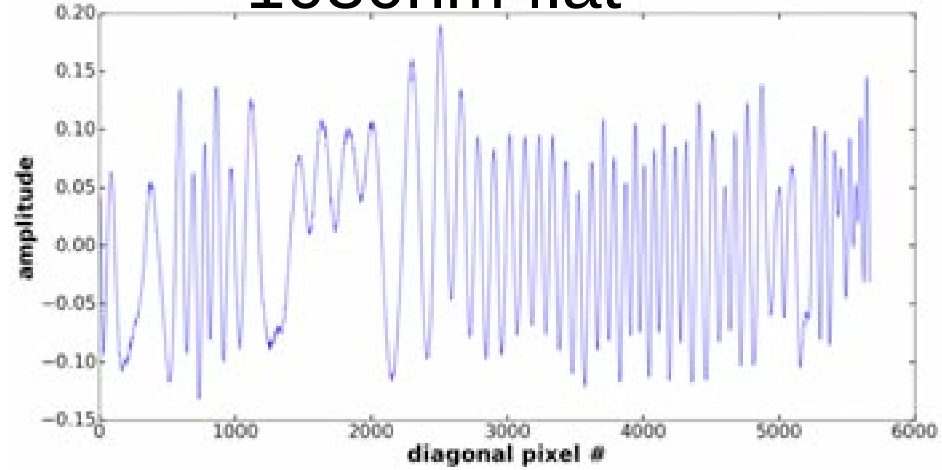
Lab flats vs sky data

1000nm flat



+

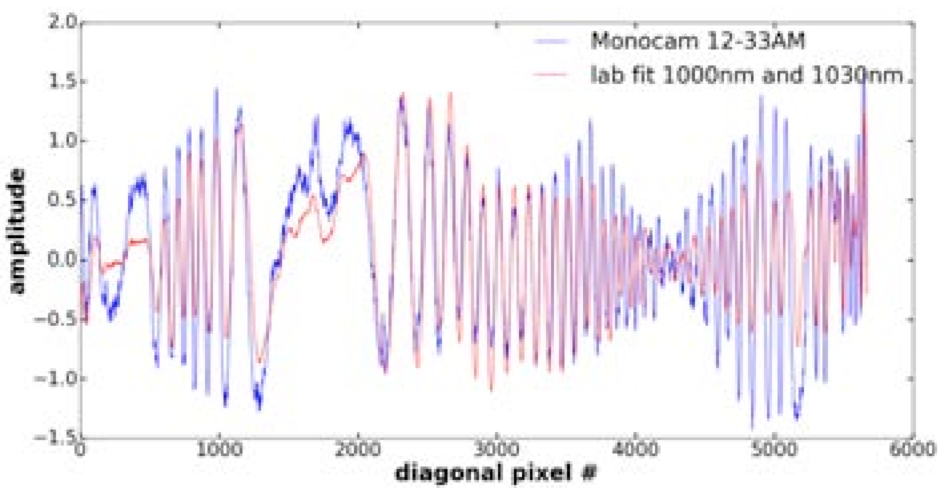
1030nm flat



24 periods

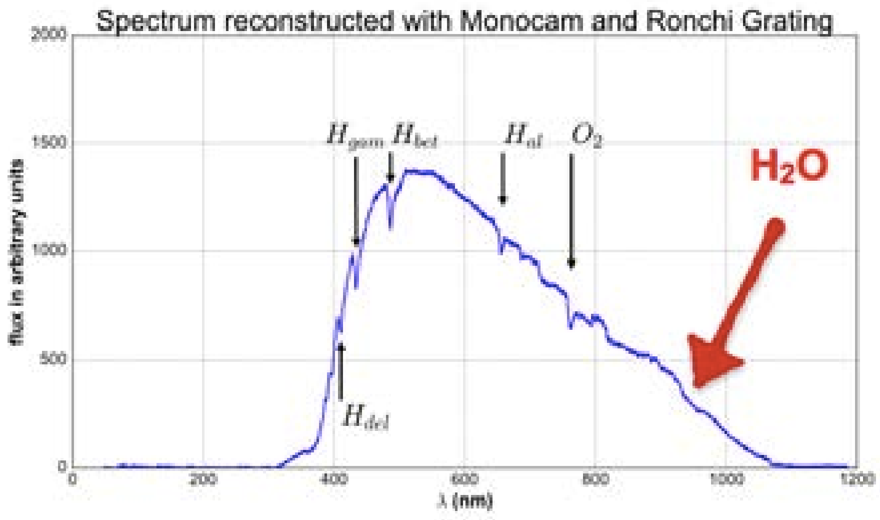
23 periods

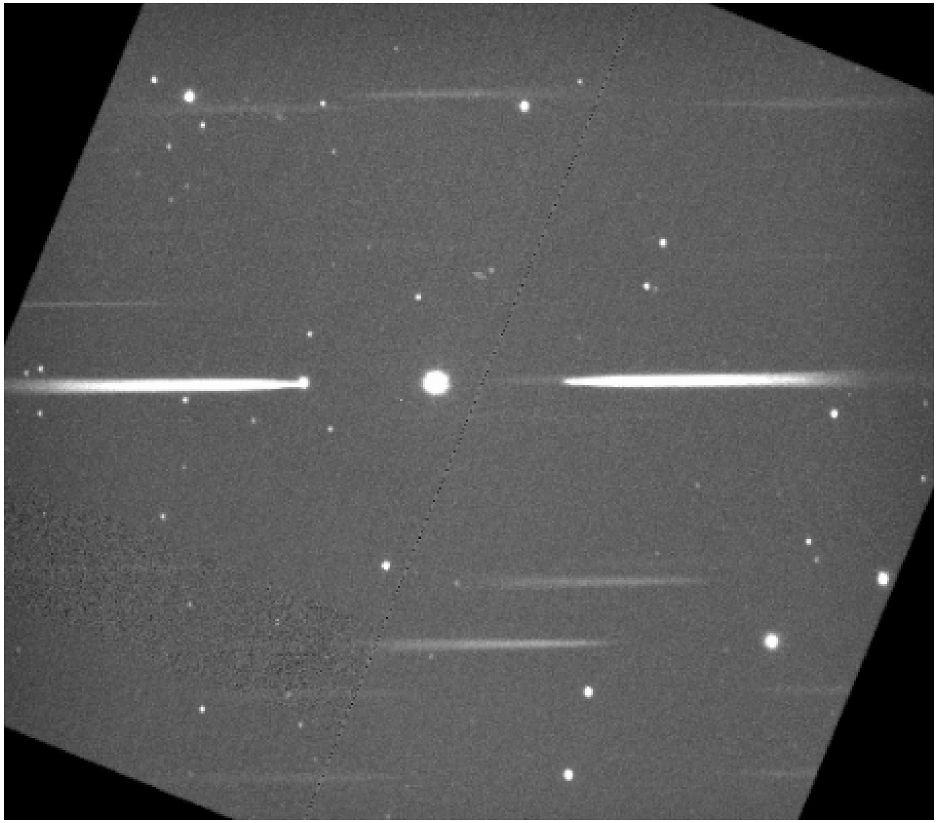
=



Ronchi grating analysis

- Ronchi grating analysis (Sylvie Dagoret-Campagne and also Harvard)





LSST Schedule