Science with a Wide-field Infrared Telescopes in Space,
Pasadena, Feb 13, 2012

Laboratory Emulation
of Observations from Space

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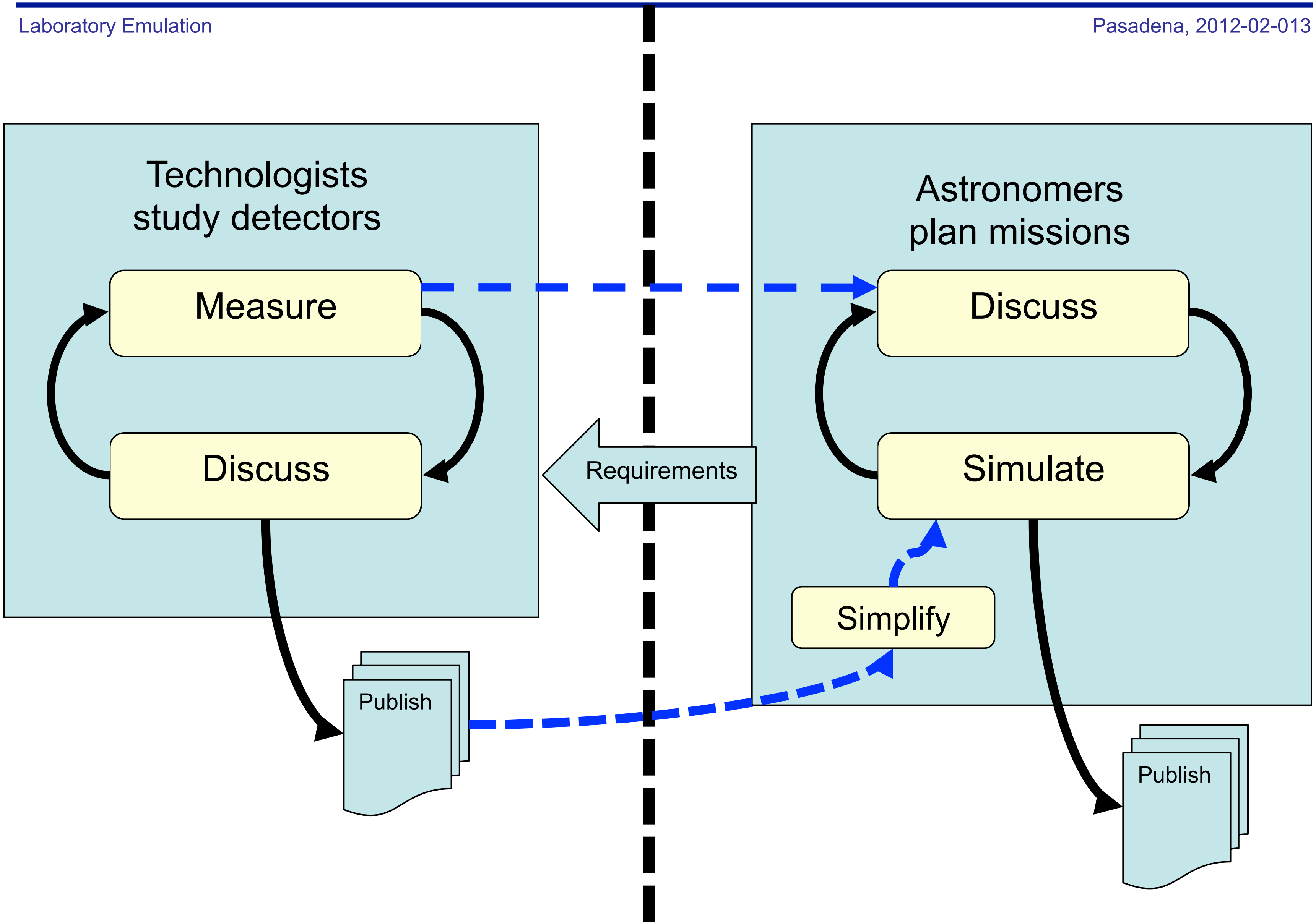
Previous culture, friendly collaboration but somewhat separate

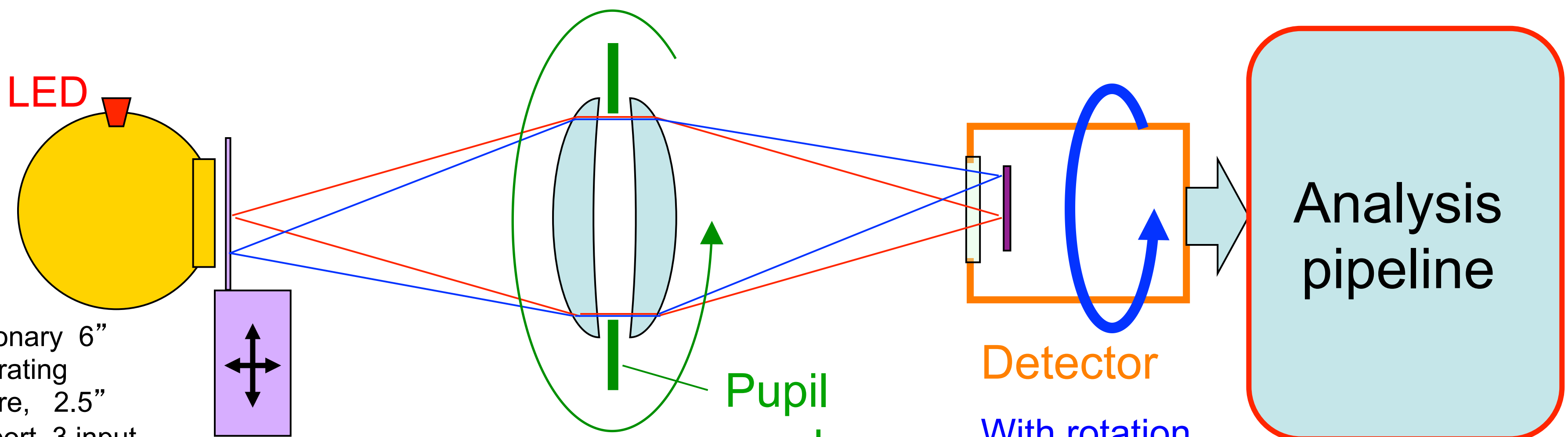


Different paradigm needed

- Simulation is good to evaluate sensitivity of science to a given effect but is not sufficient.
  - At best, it is only as good as our understanding.
  - Simulation is often a simplified version of that.
- NASA "Technical Readiness Level" is not intrinsic to a component or technology.
  - It is not just environmental testing !!
  - Must meet requirements ***of the specific science case***, using a faithful model of the component or system, … including the intended operating modes, control software, timing, calibration and data processing.
- We need emulation not simulation.
  - Hardware not (just) software !

Typical Lab emulation

Reimage **thousands** of very accurate apertures onto detector using optics producing radially symmetric PSFs over 40mm x 40mm detector so that **good statistics** obtained over full detector.



Stationary 6" integrating sphere, 2.5" exit port, 3 input ports.

Stable flux.

Mask on motorized 6 axis stage;

50nm res.

1μm min feature

Fixed relay optics

Pupil mask, rotatable

Detector

With rotation about optical axis

Key feature:

- Make "errors" (pointing, PSF, flux, etc) smaller than required by mission so sensitivity can be verified.

Why practice in the lab? …in mission definition phase.

- End to end test of real hardware is makes proposal more credible.
  – Numerical simulations are most useful for testing sensitivities,
  – Are we asking the right questions?

- Verify accuracy / precision limits.

- Develop/test mission requirements.
  - pointing, PSF quality/uniformity, image scale, thermal stability, etc

- Test how well calibration methods work. New ideas?

- Improve TRL: detectors, electronics, algorithms.

Important “cultural” benefits

- Builds credibility of team as well as the technology.
- Gets scientists and technologists working together at the start.
- Focuses on the problem first and technologies second.
- Build analysis algorithms, expertise, and test facilities from start.

Examples

To be presented:

- WFIRST: undersampled NIR survey for Weak Lensing

Other recent or planned:

- ELEKTRA: all sky NIR search for transiting planets
- FINESSE: NIR spectroscopy of transiting planets.
- ZEBRA: Zodiacal and Extra Galactic Background light.
- SPRITE: AO assisted high precision astrometry at south pole.

Lab emulation of WFIRST

SHAPE MEASUREMENT FOR WL

Detector issues for WL

- Detector may imprint different ellipticity on galaxies and stars used as PSF calibrators.
- Detector must not prevent accurate recovery of PSF from undersampled data.

Hazards for CCDs ?...

- CTE and its rate of change with radiation damage. Change in CTE with signal
- Row-column difference in pixel size variability.
- Pixel size dependence on signal?
- Transient response on video.
- Image persistence ?
- Intrapixel response variation

Hazards for IR arrays ?...

- Interpixel capacitance.
- Reciprocity failure and linearity.
- Image persistence when dithering.
- Row-column difference in pixel size variability.
- Pixel size dependence on signal.
- Transient response on video.

Some test objectives

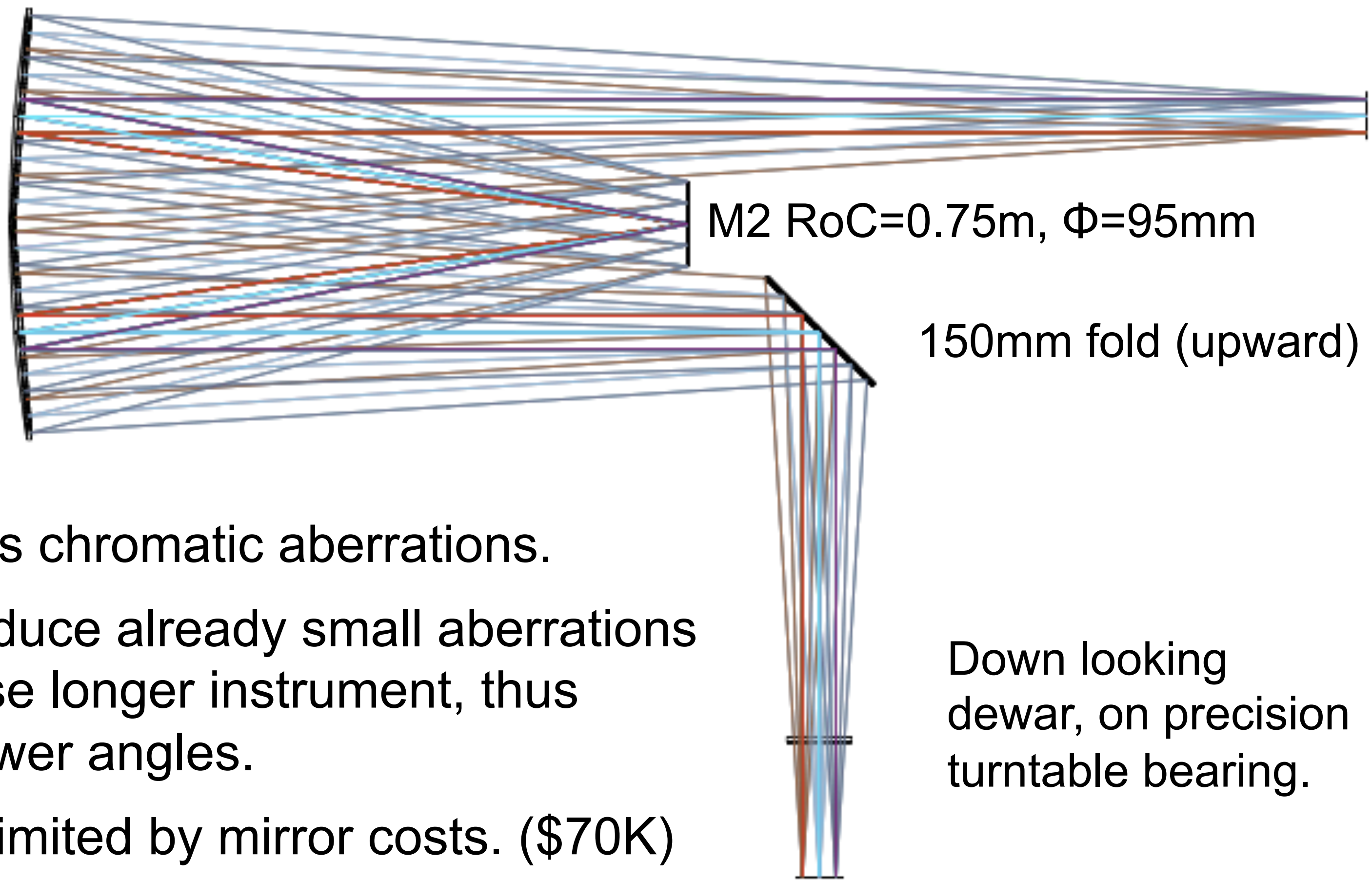
- Show how well systematic ellipticity errors due to detectors can be controlled when emulate undersampling, object shape and intensity distributions.
- Same….versus image scale => mission requirements.
- Measure distribution of errors => detector requirements.
- Test effectiveness of calibrations.
- Validate analysis methods:
  - dither and image recombination methods.
  - Calibration methods.
- Test how stars and galaxies and stars are affected differently by detector behavior.
- (eventually) test correction of PSF variation (vs. rate of change)

Key system requirements

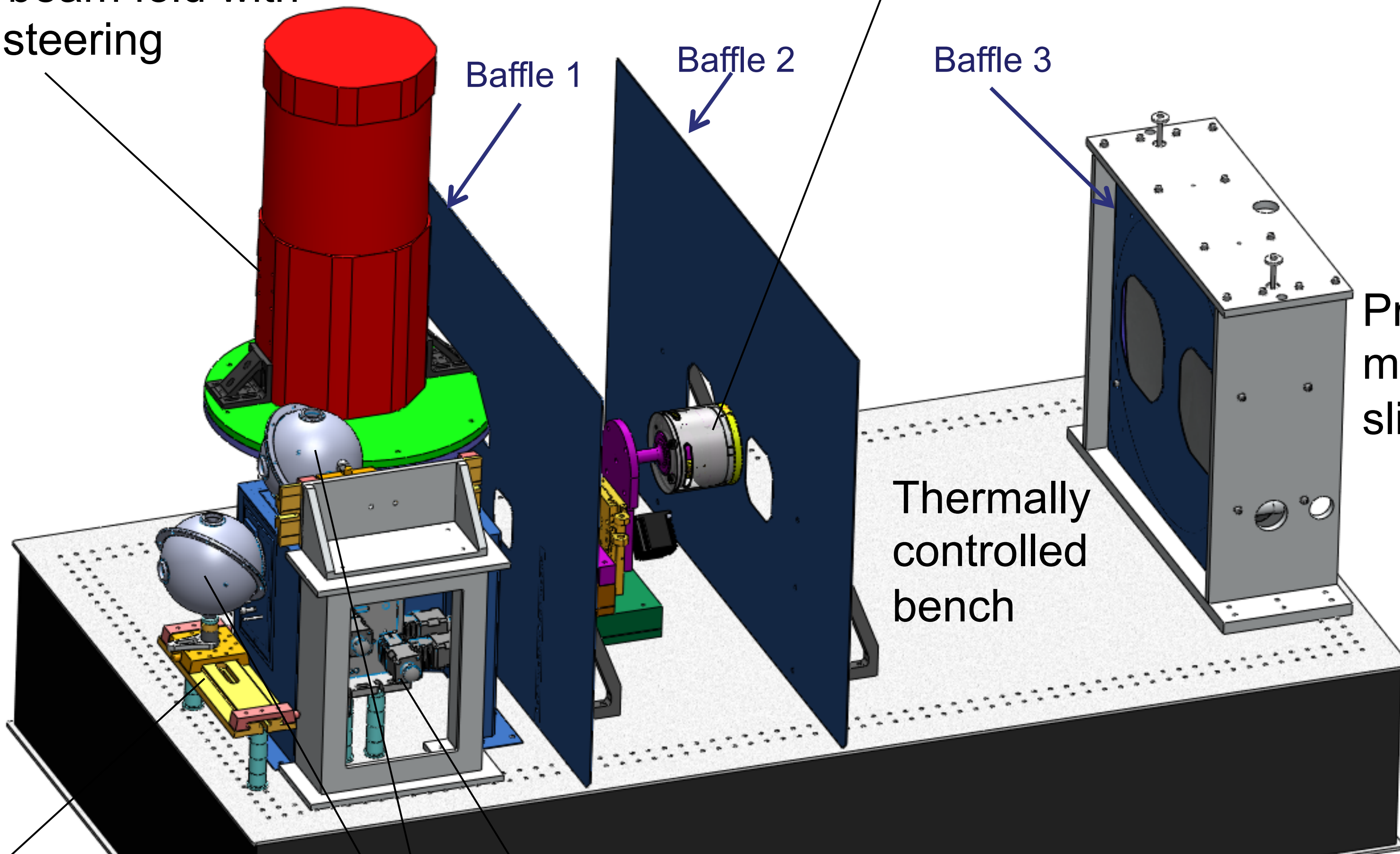
- Exquisite image quality ***over full detector area*** (40mm)
- Achromatic (400nm – 1.7μm)
- Focal ratio ≥ f/8
- Low ghosting and scattered light.
- Well baffled; flat illumination; flats at any time.
- High resolution lithographic input masks
- Precise pupil: circular or elliptical, rotatable
- Low image motion (<20nm rms)
- Stable lamps; wide intensity range.
- Test automation
- Computing hardware & analysis pipeline (144 core, 50TB)

f/8 Offner relay

RoC=1.5m
Φ=460mm



- Avoids chromatic aberrations.
- To reduce already small aberrations choose longer instrument, thus narrower angles.
- Size limited by mirror costs. ($70K)
- λ/100 surface quality to preserve strehl ratio >99.6% !!!

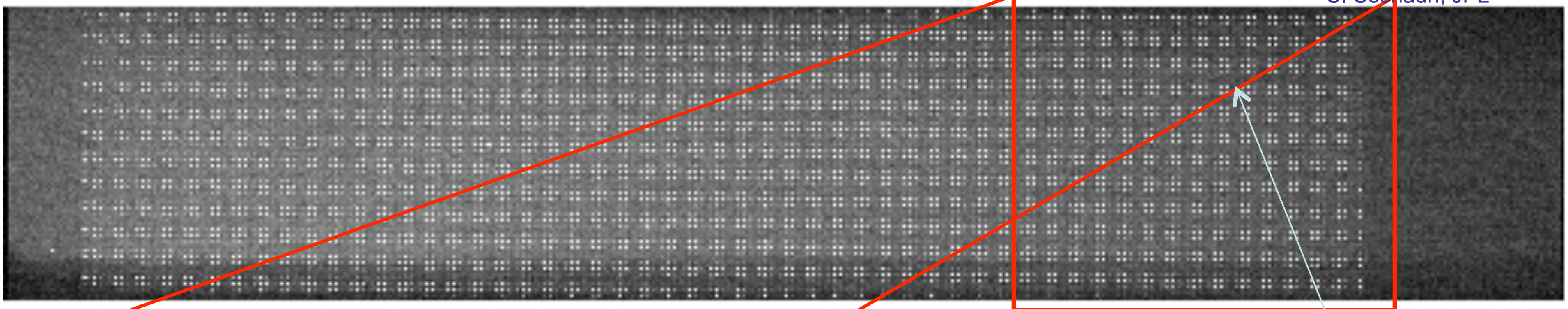

NIR dewar on precision turntable with detents, above beam fold with active steering
Secondary mirror mount
Baffle 1
Baffle 2
Baffle 3
Primary mirror in sling mount
Thermally controlled bench
Motorized 6 axis flexure stage (1µm precision over 4mm)
Integrating spheres on slides to allow access to kinemtically mounted masks
Two input sources, beam combiner not visible
Not shown: Vibration isolation, Insulating covers

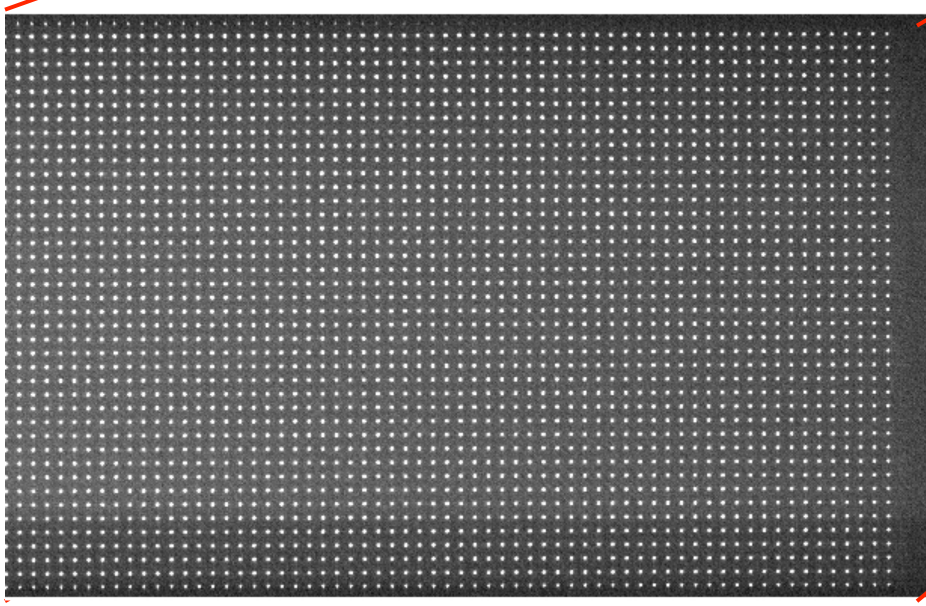
How ?

- Masks contain a range of known shapes and rotations.
  - Do we get back what we put in?
- Rotate and translate input mask.
  - Do different pixels give same results?
  - Partition ellipticity between mask and detector+optics.
- Rotate detector on pedestal.
  - Partition ellipticity between detector and optics+mask
- Rotate elliptical pupil.
  - Is Δellipticity what we expect?
  - Does Δellipticity depend on angle?

4K wide CCD (fully depleted LBNL p-ch)

S. Seshadri, JPL





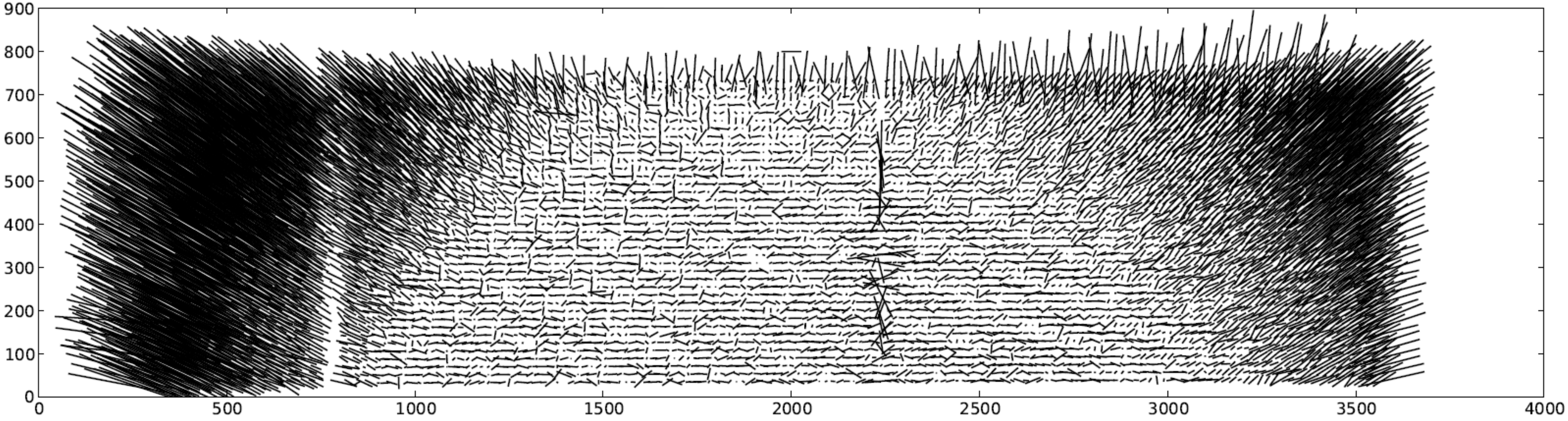
Quad spot feature in image is a viewing resolution artifact, not present in magnified image

3μm pinholes, f/11 at 880nm

10μm spots are undersampled

Ellipticity vectors, after random dither and IMCOM

S. Seshadri, JPL



- Ellipticity ~1% across large portions of the FOV, but not everywhere
- Features at the corners and in a single central column are NOT due to reconstruction
  - Highly elliptical edge effects are present even in the undersampled data
  - IMCOM is detecting detector defect causing long single trails in central column feature

Ellipticity map vs. pedestal rotation (CMOS imager)

Ellipticity map
(length = magnitude)
(tilt = angle)

Histogram
(magnitude)

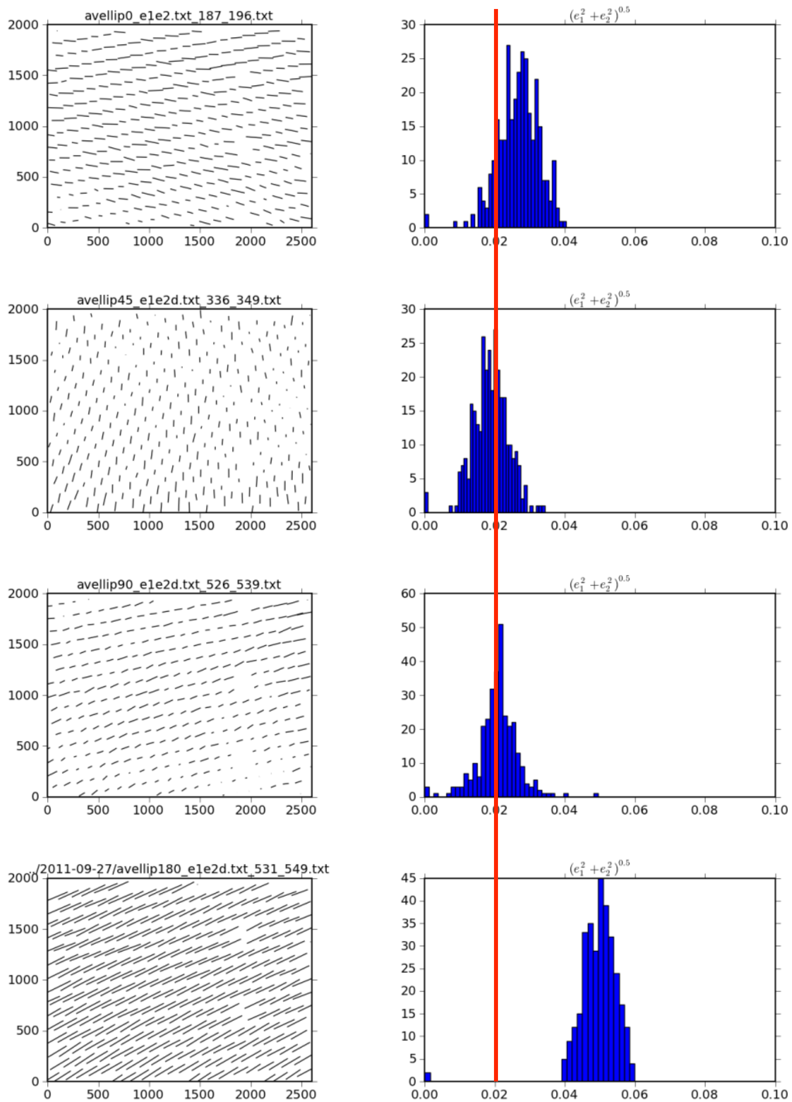
Pedestal angle

0°

45°

90°

180°



http://www.astro.caltech.edu/~goodsall/spots/2011-09-23/rotationcomparison.png

<u>Key features</u>

- Ellipticity is changing at ~*twice* the pedestal angle.
- Mean is *not* constant.
- Nearly uniform across image
  - low distortion across the field
- Noise is low

Applications of Precision Projector

- Shape measurement
  - NIR and optical.
  - Wide achromatic FoV can be used to test effects of CCD CTE.
- Flat fielding precision
- Photometric stability
  - pointing jitter simulation
  - weak signal against strong background (use beam combiner)
- Precision astrometry.
  - motion of individual stars vs ensemble.

Abstract

A substantial motivation for conducting wide-field surveys from space is the desire for increasing measurement precision, and calibration accuracy. In many cases the limits of performance of detectors, optics, calibration techniques and even image processing algorithms are being pushed, while budgetary constraints drive mission designs to coarser sampling of the PSF requiring recombination of dithered images to recover the optical resolution. We describe current and (possible) future examples of laboratory experiments conducted by Caltech/JPL, which are designed to build confidence that the planned detector technology is capable of delivering the necessary control of systematic errors. We note how these experiments bring about a paradigm shift by promoting close collaboration between scientists and engineers to address real world issues, during the concept development phases. This leads to stronger proposals based on experimental confirmation that calibration methods and algorithms will (still) work, and that specifications for space mission parameters such as PSF sampling, pointing jitter, observing cadence, calibration plans, and data processing needs are neither over or under-specified. A number of these issues can have profound effects on the technical or fiscal viability of a mission.

Lab emulation of ELEKTRA

PLANETARY TRANSITS

Setup

<Labelled picture of hardware>

<Explain how image motion is controlled>

Allan Deviation curves

- Briefly explain analysis and what these curves are.
- Show results for range of intensities.
- Point to hint of floor.

Test for pointing sensitivity

- Show centroids vs time
- Show allan deviation curves with and without PCA applied.