LSST Science End-to-End Simulator "A Tool to Aid Camera Design ?"

LSST Camera Face-to-Face Meeting
BNL October 17, 2005

Garrett Jernigan

Science End-to-End Simulator Overview and Status

Large Synoptic Survey Telescope

Jernigan October 17, 2005

(Definition of End-to-End: History of photons from Galaxy to Si)

Design and Implementation

Goals: Very fast [realtime];10% science accuracy; available early

Next Phase: Accurate filter model (from Gilmore);
Control System Model; autoguider + wavefront sensor
(coordinate with Pinto; leverage the work of others)

Physics of Atmospheric PSF Effects

Goals: Av initio understanding of PSF; predict weak lensing performance

Next Phase: Solve bottleneck problem: normalization of ellipticity of the PSF

Applications (Opportunities for others to help; coordinate with Pinto)

Goals: Trade studies; verify science and engineering requirements; informs design (Catch-22);

Next Phase: Autoguider Theory (request from Althouse); Stacks for 10s of images for weak lensing study;

User Interface (Opportunities for others to help; coordinate with Pinto)

Goals: Flexible and extendable implementation; Borrow from astronomy heritage (ds9,tcl,iraf);

Next Phase: Improved User Interface (need more resources; very expensive 1 FTE year)
Virtual LSST (optimal way to amplify utility for the full LSST team - 1/4 FTE year)

Science End-to-End Simulator Design and Implementation

Large Synoptic Survey Telescope

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*** Sky and Cosmology Simulation (external input)**
*** LSST Operations Simulator defines Atmospheric Conditions (external input)**

*** LSST Science End-to-End LSST Simulator**

- Three major components (full wavelength dependence included)
  - A) Atmospheric Model (external input parameters; simple log normal model; full operations simulator model; Kolmogorov refractive layers)
  - B) Optics Model (currently passive response to atmosphere; needs feedback with atmosphere; missing a model for the telescope/camera control system; geometric ray trace with perturbations)
  - C) Detector Model (detailed physical approach for photon to charge conversion)
- Quantum Monte Carlo approach (jump from 10^6 X-rays to 10^9 Optical Photons)
- Top-Down science driven code design (primary target: weak lensing)
- Rapid prototype coding approach
- Light weight efficient software methodology (C code + Tcl for parameters)

Science End-to-End Simulator
Physics of Atmospheric PSF Effects

Large Synoptic Survey Telescope

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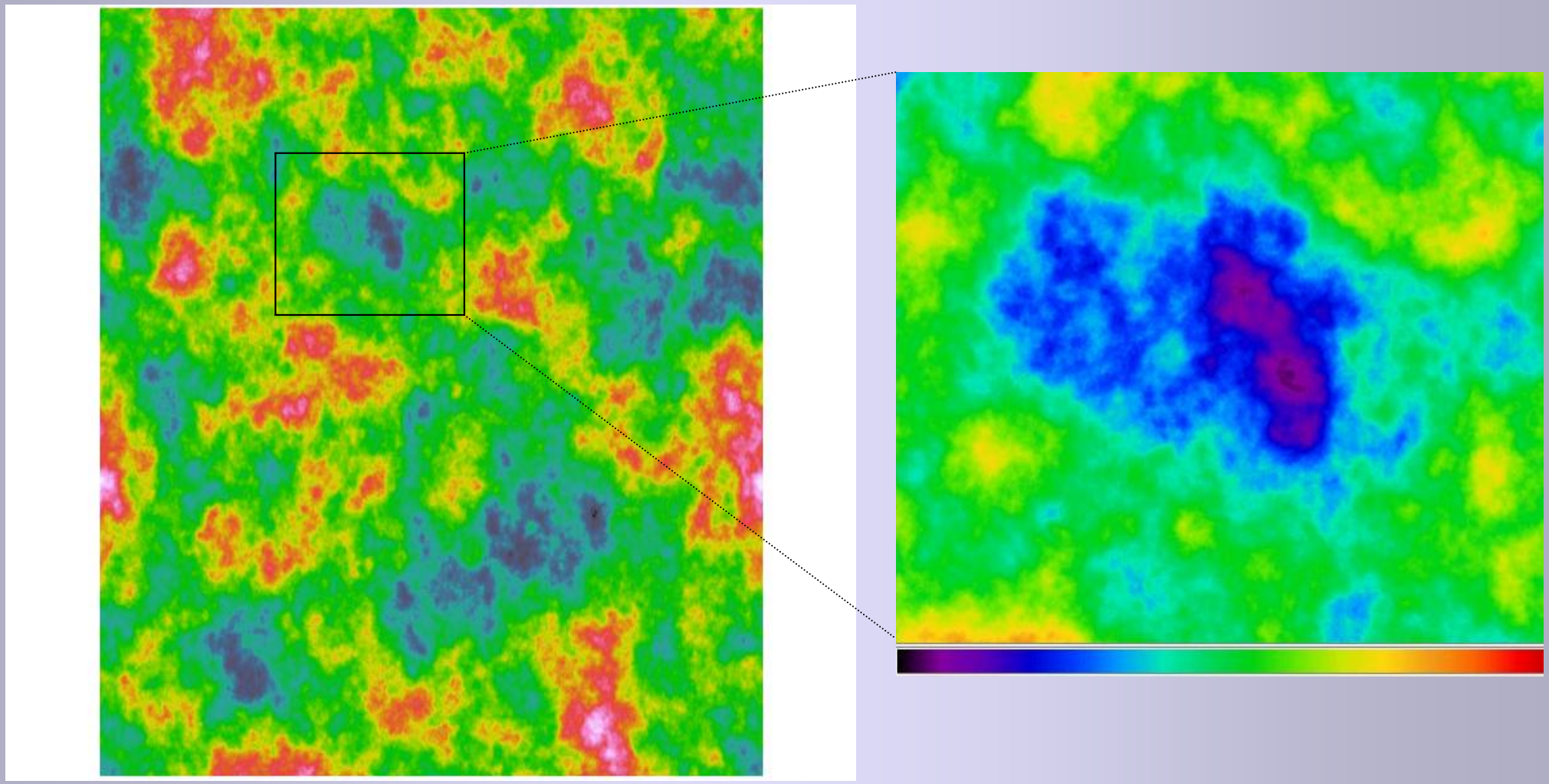
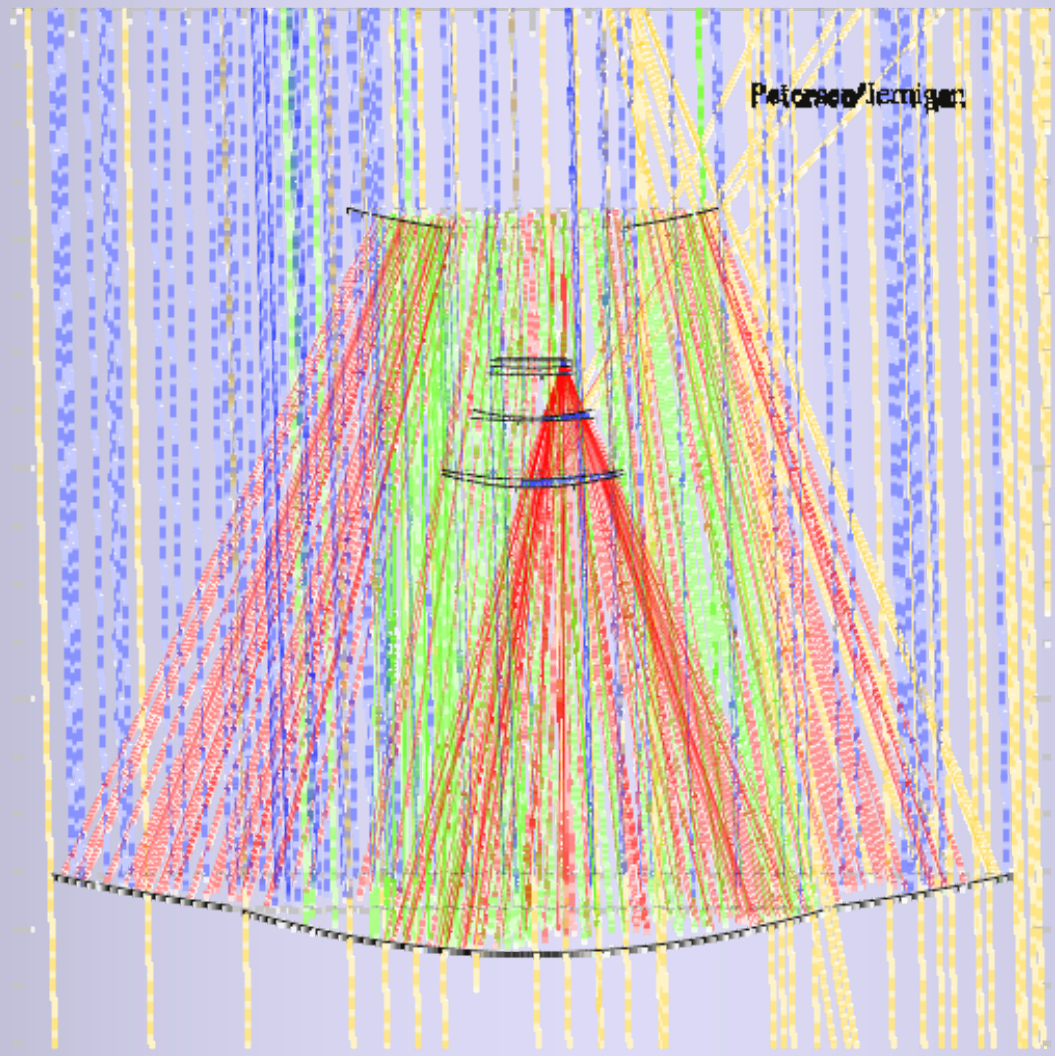
Phase Screen Proportional to Refractive Index
Single Layer (2048x2048)



200 meters

Science End-to-End Simulator
Physics of Atmospheric PSF Effects

Fast optics raytrace for every photon; Arbitrary rotations, translations and perturbations of M1, M2, M3, L1, L2 and L3.



Science End-to-End Simulator
Physics of Atmospheric PSF Effects

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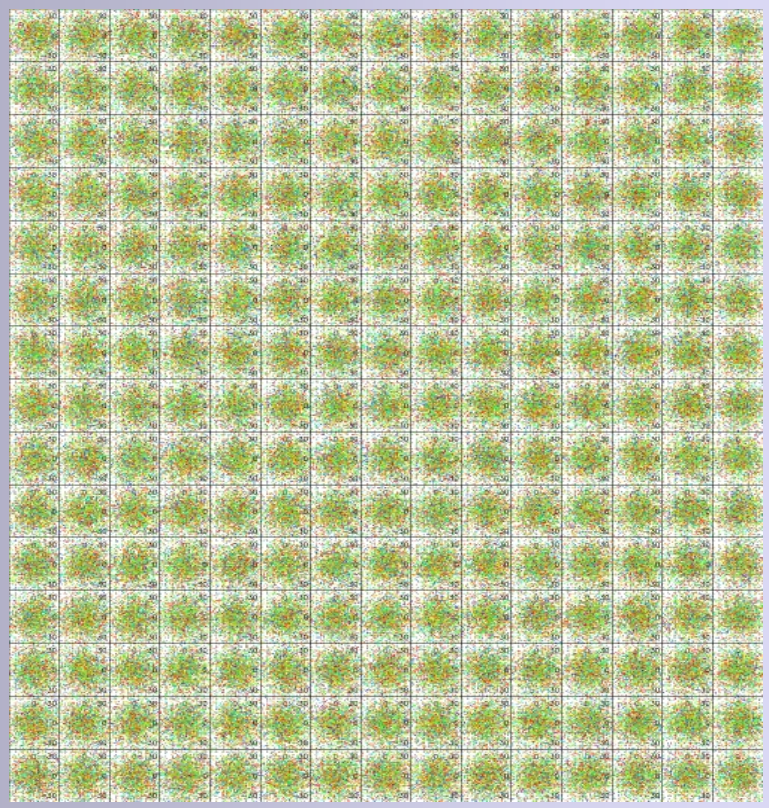
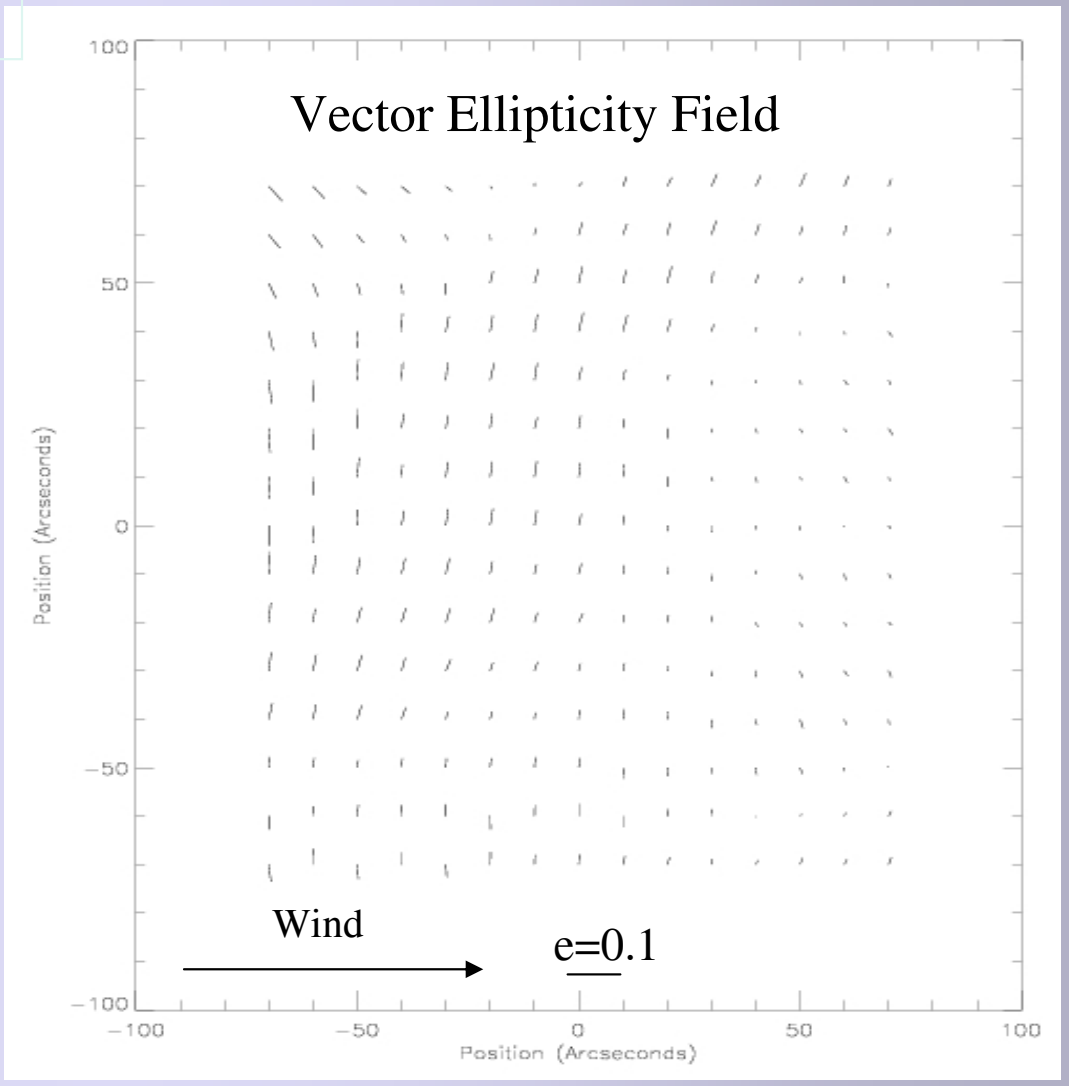
15x15 Grid of Stars (10” Spacing)
Atmosphere Only: 1 Layer with Wind (15 m/s)

150 ’’



Star Images

(10^5 Photons per Star)



Science End-to-End Simulator
Physics of Atmospheric PSF Effects

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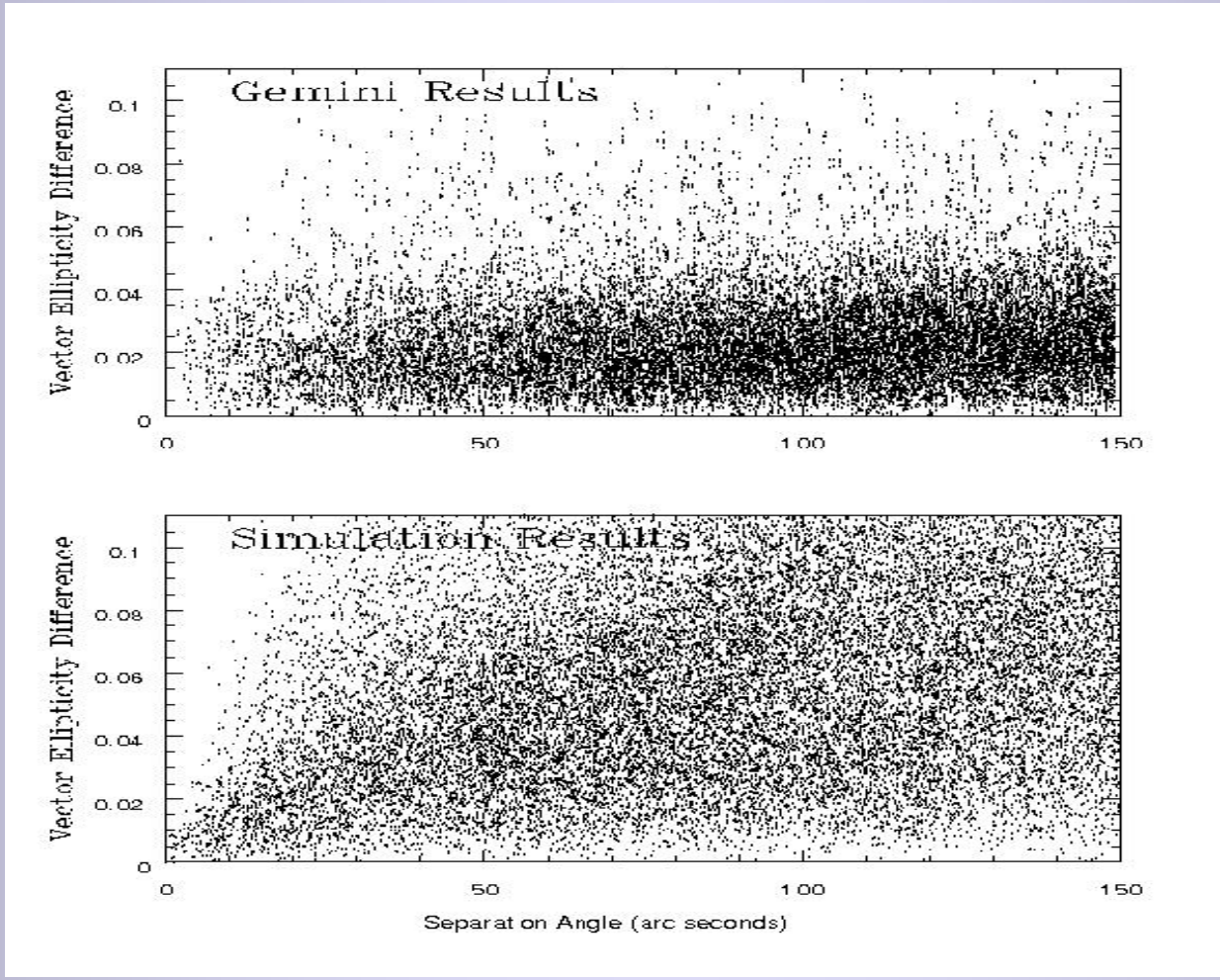
Vector ellipticity difference as a function of angle for simulation (bottom) and Gemini data (top). Gemini data was taken from a single 15 s exposure with a Sloan r filter and the GMOS instrument (243 stars in a 5.5'x5.5" field).



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Physics of Atmospheric PSF Effects

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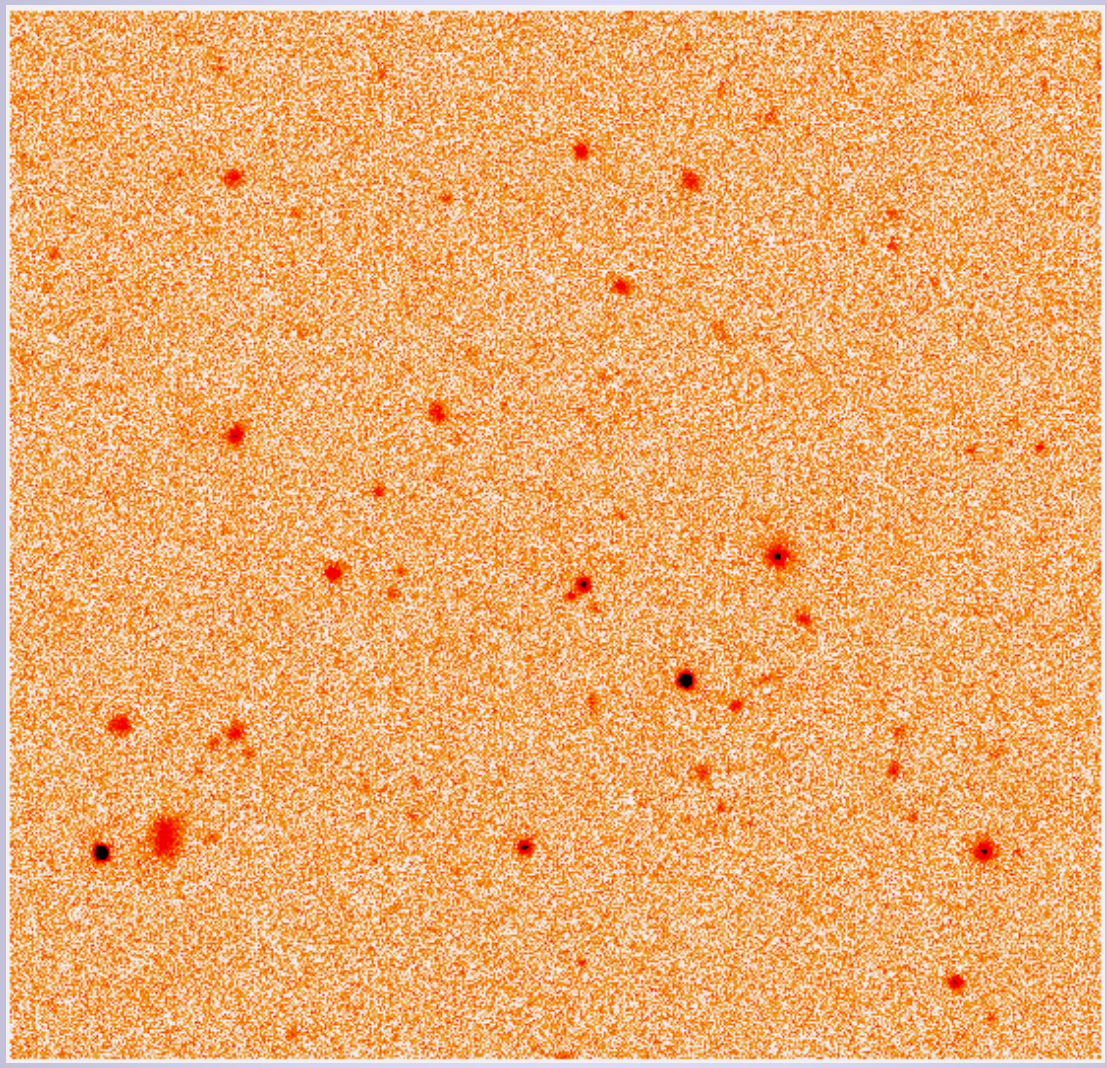
Portion of Hubble Ultra Deep Field (3 x 10^8 photons from Galaxies and Stars; 30,000 seconds with G5 processor; 800" x 800" or 1% of LSST field)



Science End-to-End Simulator
Physics of Atmospheric PSF Effects

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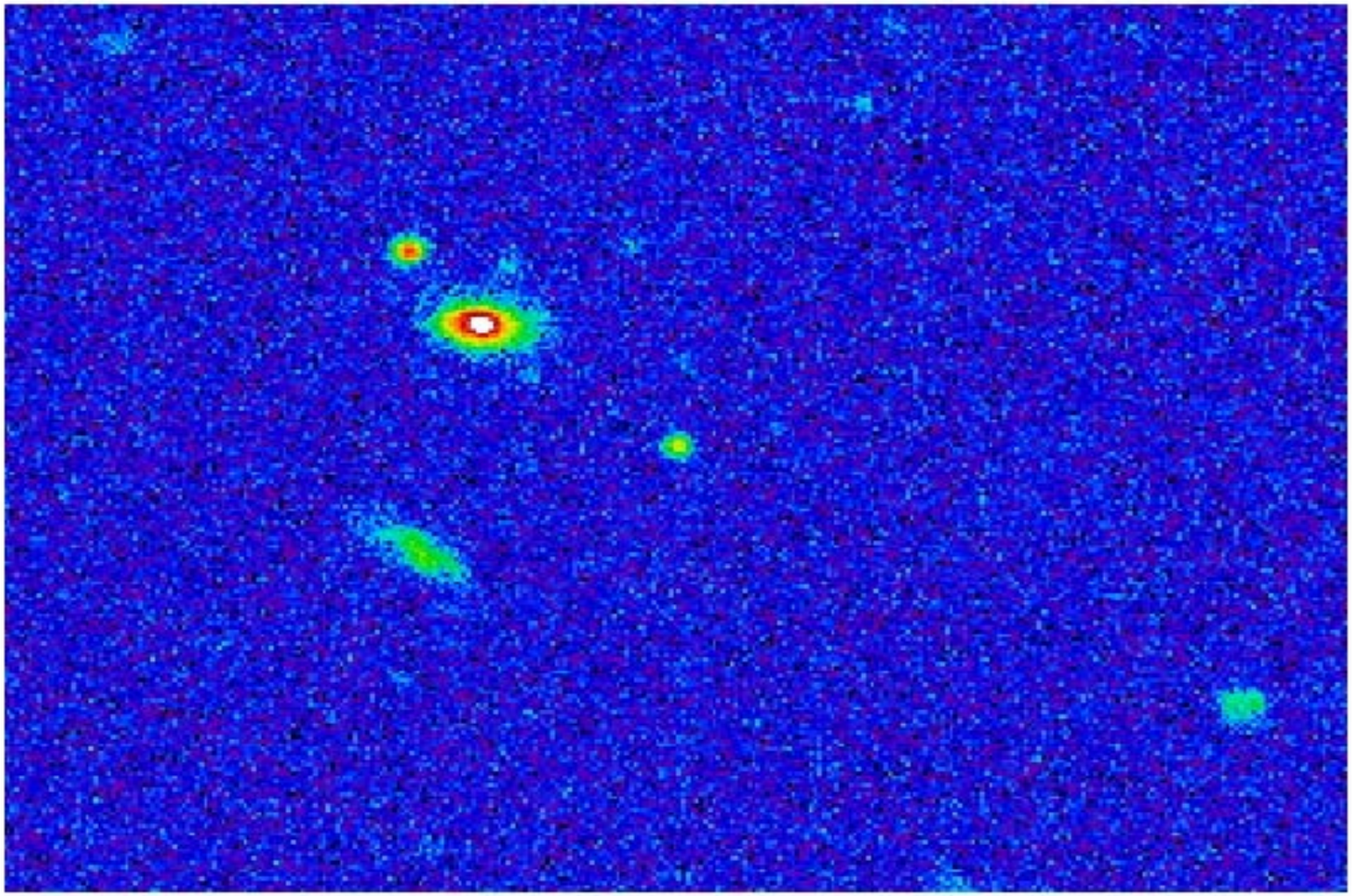
"Blink" Between Two LSST Simulations of a UDF Image



Science End-to-End Simulator Applications

Large Synoptic Survey Telescope

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PSF Properties and Weak Lensing

- Atmospheric Model: primary (nears completion)
- LSST Optics Model: secondary (needs much more work)
- Goal: precise weak lensing metric (test with SOAR/Gemini)

Auto-guider and Focus

- Significant effect on PSF (likely field coherent)
- Optimize in two parameters (guiding and ellipicity)
- Coupling to focus

Wavefront Sensors and Control

- Significant effect on PSF (complex field dependence)
- Optimize for minimal effect on PSF
- PSF interpolation based on derived atmospheric parameters
- Testbed for proposed integrated software methology (Claver)
- Test models with SOAR wavefront sensor data

Field Dependent Filter Effects

- Corrections to photometry
- Evaluation of accuracy

"Blink" Image Project

- Need all the "dirty" details
- Long term goal: Transient science evaluation

Calibration Simulation

- Photometry and Astrometry
- Routine image processing (bias; flatfield; effect of scattering)

Effects of "Dirty" details

- Cosmic Rays (GEANT with a full telescope/camera structure
  80e per micron for minimum inonizing particle)
- Detector Details - pixels, gaps, alignments
- Bright Star Problem
- Diffraction effects - spider (FFT problem) + new photon method
- Ghost Images
- Scattering off dust (Baffles ?)
- CCDs + CMOS issues (mechanical model; thermal model ?)

Science End-to-End Simulator Applications

Example Application (work in progress requested by Althouse):

Conjecture:
The autoguider algorithm should simultaneously minimize the size and ellipticity of the PSF induced by tracking errors.

Common mode effect across full field of view: possible bad systematic error.

Problem looks like a combination of a diffusion away from the unit circle in a 2D space (e^{-1}) due to a Kolmogorov atmosphere modified by an attractor caused by the tracking errors.

Complex behavior for the addition of ellipticities

Sometimes "|" + "-" = "+" ==> 1 + 1 = 0
"/" + "\" = "X"

Similar to constructive and destructive interference (phase dependent).

Separate models for PSF distortions and astrometric offsets

Science End-to-End Simulator
User Interface: (Virtual LSST; Heritage Software)

Large Synoptic Survey Telescope

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WEBSpec

WebSpec is a WWW interface for the X-ray spectral fitting package, **XSPEC.** Currently, it can be used to *simulate* spectral data for a variety of X-ray missions/instruments.

I haven't really looked at the page yet; but I already know that I need **HELP!**

Choose a Mission/Instrument

ASCA GIS

Specify the desired model expression by clicking on a model in the scroll box and indicating via the checkbox whether you want photoelectric absorption or not.

Click the box to apply **Photoelectric Absorption**. X

Available Models

- Black Body
- Power Law
- Broken Pow Law
- Power Law with cutoff
- Power Law + Black Body
- Power Law + Gaussian

Here is a description of the **models** currently available through WebSpec.

Attention Advanced XSPEC users:

For the more experienced XSPEC users, a more **advanced version of WebSpec** is available with up to 8 component models possible.

Set Model Parameters | Clear all fields | Okay, I have read this page; but I still need **HELP!**

For feedback or questions on WebSpec, please contact **Stephan Fantasia**.
fantasia@milkyway.gsfc.nasa.gov

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THE END

Justification for Quantum Monte Carlo Approach for Large Field Simulations for LSST

Large Synoptic Survey Telescope

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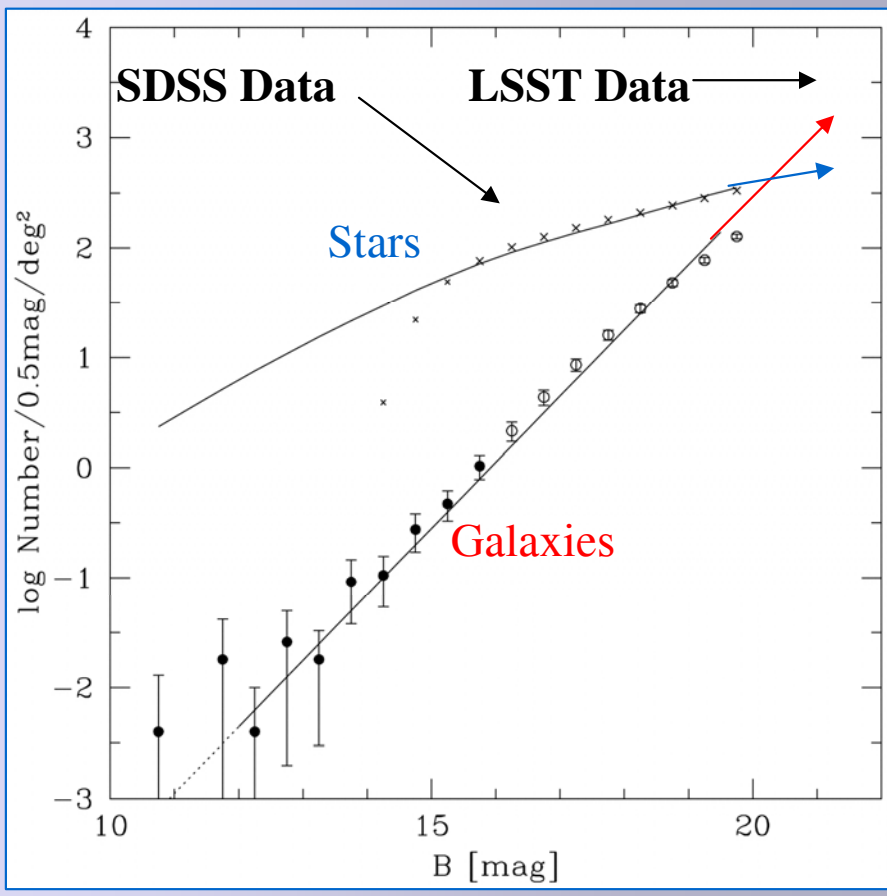
* Example: 800''x800'' R band image (1 CCD for 10s)
  - ~$3x10^{10}$ background photons
  - few 10^4 Stars >12 mag (~10^8 photons)
    (few tens of stars per sq. arc min.)
  - ~10^6 Galaxies (~10^8 photons)
    (~1 galaxy per sq. arc sec)

  (Common Approach in High Energy Astronomy)

* Galaxies and Stars must be simulated to deep S/N levels in stacks of hundreds of separate images.
* New PSF every 5'' with an accurate atm. model
* Each photon from a faint galaxy requires a private PSF
  ~20 us per photon for fast ray trace through atm.
  ~10 ms per photon for full diffraction through atm.

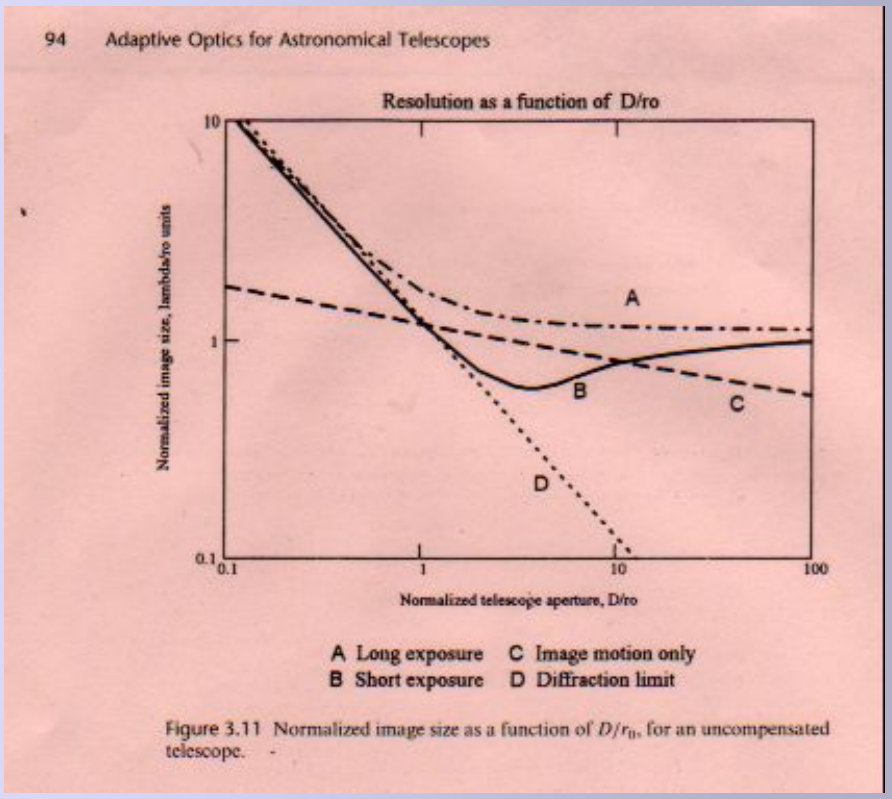


From Yasuda et al., 2001, ApJ, 122,1104 (figure9)

Atmospheric Model Validation Code

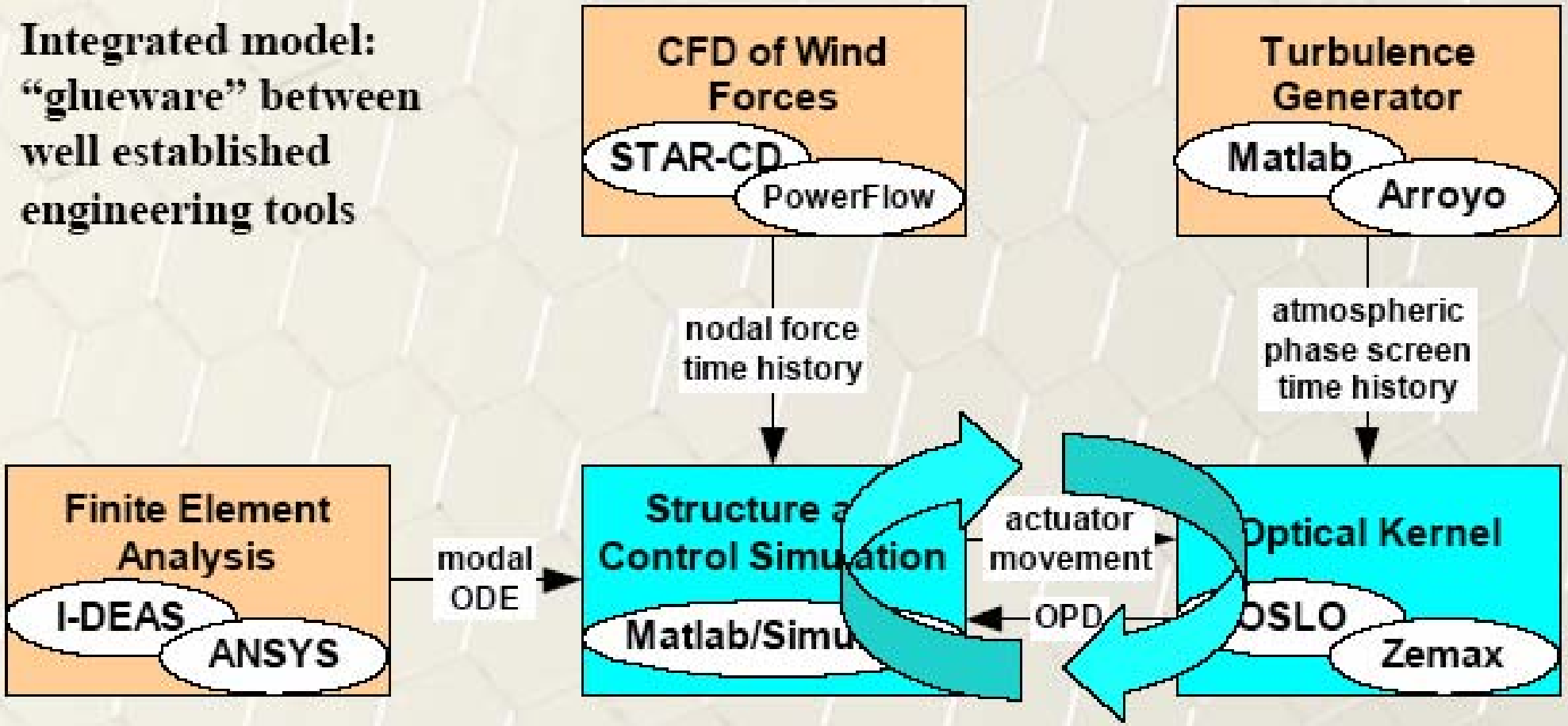
Current Kolmogorov Model:
- PSF determined from multiple phase screen with full diffraction (FFTs required)
- Translating Frozen field assumption
- Simplification in the D>R0 limit
- Normalization (work in progress)

Future Non-Kolmogorov Model:
- Non-Kolmogorov Models (atmospheric wedge, wind sheer driven flows)
- Time Dependent Kolmogorov Models (drop frozen screen assumption)
- Numerical Hydrodynamic Simulations



From Hardy 1998 (p.94)

Computation kernels

Time domain simulations

Integrated model: "glueware" between well established engineering tools