Using Simulations To Commission Algorithms And Pipelines

Robert Lupton

12 October 2011

Introduction

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  - Photo
  - Übercal
  - MARVELS
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Unacknowledgments: My unthanks to

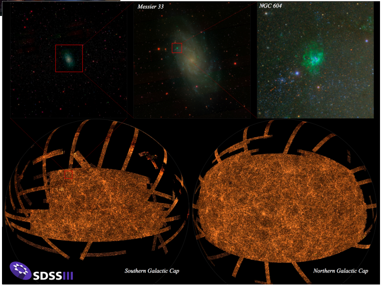
- Nick Kaiser
- Phil Marshall

for covering most of the interesting parts of this talk in their discussion sessions.

SDSS

1994

1998



2011

Motivation for simulating

We can use these simulated data to ask fairly detailed questions. If the sky brightness slowly increases over the duration of a photometric scan, does the photometric calibration software correct properly? What is the relative performance of the system at low and high Galactic latitudes? While the test year will no doubt bring some software surprises, the use of simulations has allowed us to have the data system integrated and largely debugged before the telescope itself is fully operational. The ability to use the same underlying data with varying degrees of complication will help isolate problems during debugging. The existence of a catalog with the "right" answers corresponding to a given simulation allows us to do regression testing in a detailed and quantitative way.

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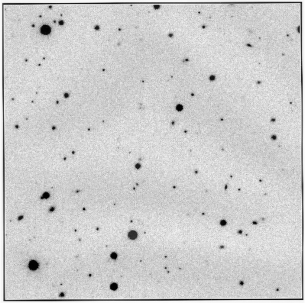

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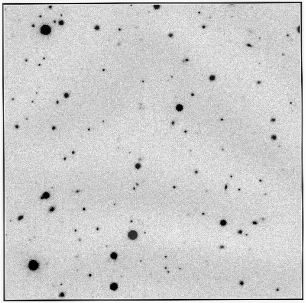

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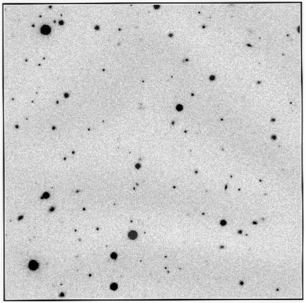

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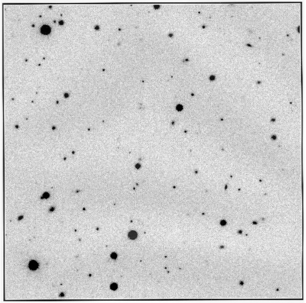

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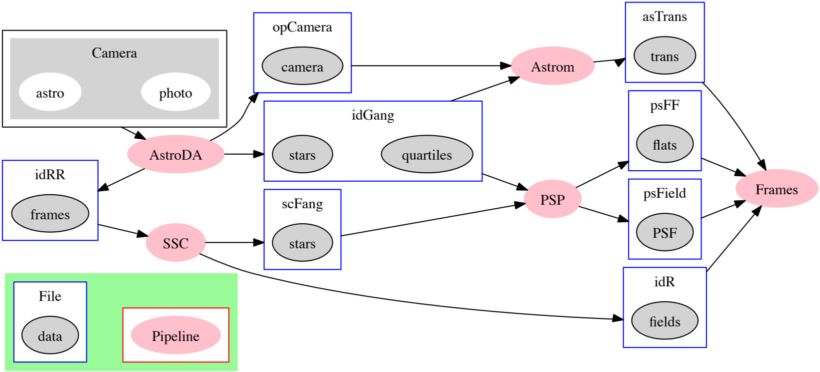

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- First light (full moon, no baffles): 9^{th} May 1998
- First light (dark time, baffles): 29^{th} May 1998
- First QSOs: 14^{th} June 1998

  I.e. We were able to reduce first light data, and start finding QSOs within a month.

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We probably do need images. Interfaces are more than FITS; *e.g.* the flatfields (the `psFF` files) are stored as

```
(unsigned short)((1 << 11)/value + SOFT_BIAS +
                                   0.5*Random()/RANDOM_MAX);
```

This is a contract between the *PSP* and *Frames* that must be kept.

Algorithms

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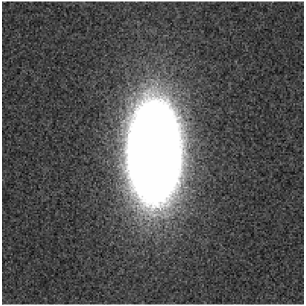
  This was good enough to integrate pipelines, but had no code in common with the pipelines
- Pro: Blind testing
- Con: Hard to keep interfaces in sync
  - *e.g.* what is the value of `SOFT_BIAS`?

jpgtest Simulations

The Japanese P{romotion,articipation} Group wrote their own simulator to test algorithmic issues.



gal15.fits Exponential disk, $r_e = 8$pix

Inputs

```
# Data to test profMean
#
sky=100
#
# with noise
#
...
gal15.fits \
    profMean<2>=4185.28 profMean<3>=2701.29 \
    profMean<4>=1387.53 profMean<5>=578.59 \
    profMean<6>=189.35675
...
```

Photometric Algorithms

SDSS measured circular aperture magnitudes, with smallest radius 0.5642 pixels. We did this by assuming a band-limited image, so we can write

$$
\begin{aligned}
flux &= \int_0^{x^2+y^2<R^2} D\, dx\, dy \\
&= \int_0^{x^2+y^2<R^2} \sum_i D_i \frac{\sin \pi(x-x_i)}{\pi(x-x_i)} \frac{\sin \pi(y-y_i)}{\pi(y-y_i)}\, dx\, dy \\
&= \sum_i D_i \int_0^{x^2+y^2<R^2} \frac{\sin \pi(x-x_i)}{\pi(x-x_i)} \frac{\sin \pi(y-y_i)}{\pi(y-y_i)}\, dx\, dy \\
&= \sum_i D_i c_i
\end{aligned}
$$

N.b. this is exact if the data's truly band limited.

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Solution: be more sophisticated (*I.e.* fix the bug).

Sky Subtraction

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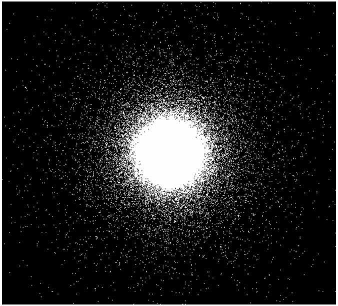
$r_e = 5$pixel log



$r_e = 5$pixel linear

1000×1000 Test images for sky subtraction

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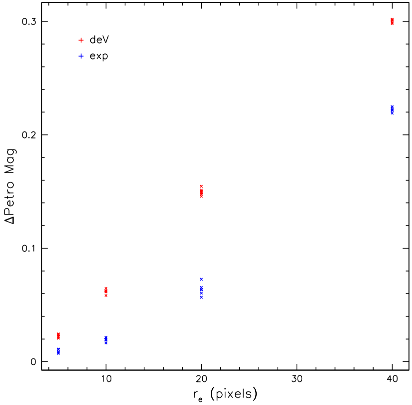

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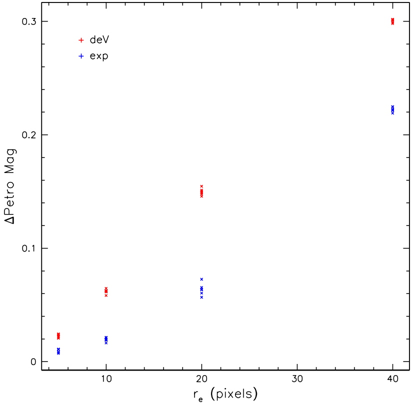

There's a clear signal of problems; what went wrong?

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- We didn't think about the impact on faint sources near the bright ones (*cf.* Mandelbaum *et al.*)

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  I'm describing ancient history, so we didn't use `jUnit`, `unittest`, `boost::test`, `...`; we wrote our own framework in TCL using these `jpgtest` simulations. Unfortunately, the more extensive examination of pipeline outputs was originally done by hand, and could not be captured and automated.

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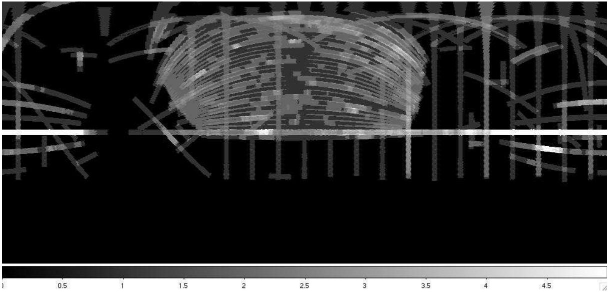
  E.g. the edges of real galaxies triggered the cosmic ray code.
  As first light was just around the corner, we (*i.e.* I) ignored the last generation of simulations, and waited patiently for reality.

Photometry: *Übercalibration*



SDSS-I imaging coverage (white: ≥ 5 visits)

The Problem

Given a set of SDSS 'runs', α, nights, β, the true and measured (at airmass z and time t) magnitude of a star is given by

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It's pretty straightforward to write down the Normal equations, involving very large but very sparse matrices, and easy enough to solve them iteratively.

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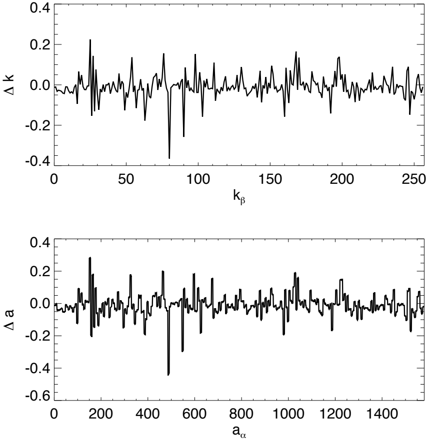
- Start with the actual catalogue of SDSS stars.
- Simulate "true" magnitudes for each of the stars.
- Given an observation of the star, calculate the observed magnitude, assuming values for a and k.
- Simulate k's time variation using a Gaussian random walk.
- Add photon noise to the instrumental magnitudes.

Results: zeropoints and extinction

- The *a* and *k* terms are highly correlated



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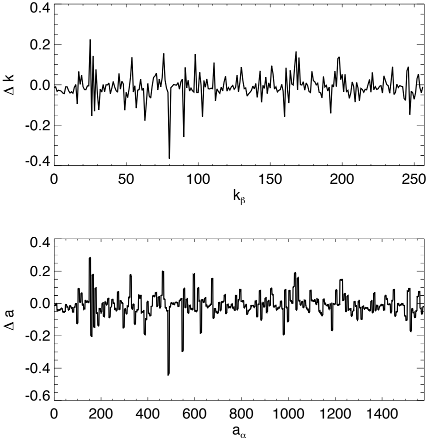

This isn't surprising; we usually scanned at nearly constant z

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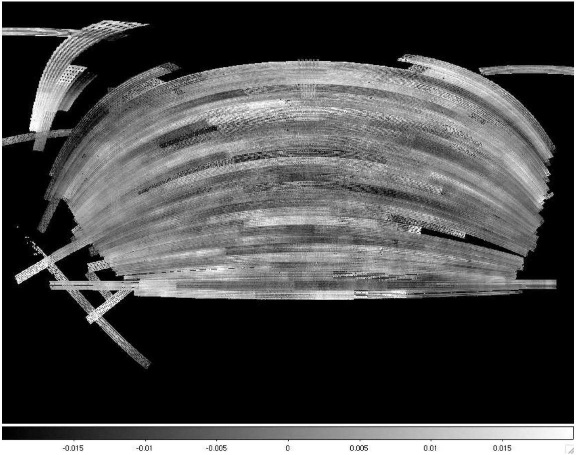


The zeropoints are good to c. 10mmag, with no visible large-scale power

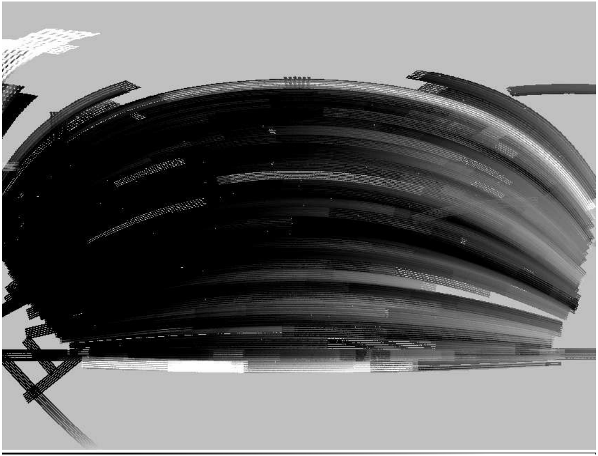
Results: zeropoints

More quantitatively,

Filter	$\langle \Delta m \rangle$	σ	σ_3	$\%(3\sigma)$	σ_0
u	-1.67	13.38	12.53	0.85	7.27
g	0.82	7.79	7.31	0.72	1.77
r	0.93	7.81	7.26	0.81	1.69
i	0.92	6.84	6.38	0.75	1.32
z	0.97	8.06	7.61	0.68	2.70

where all values are in mmag.

Results: dk/dt



The result of setting $dk/dt = 0$ is a slope of c. 10 mmag

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- Changing the magnitude limit leaves the calibrations unchanged. *I.e.* the systematic errors in the atmosphere dominate.
- Including the "Apache Wheel" runs makes very little difference. We should have saved the telescope time, or integrated longer. Further simulations would tell us which.
- The dk/dt slope is our worst systematic. We could have taken data to avoid it — backwards non-constant-airmass scans?

Spectroscopy: *MARVELS*

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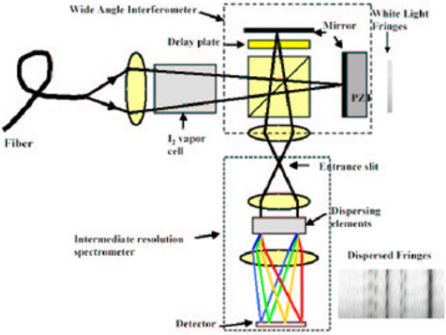
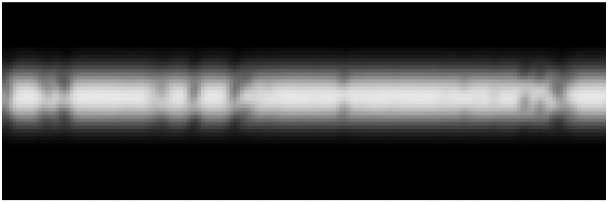


Ge *et al.*, 2002, PASP

A combination of a medium (R $\sim$ 10000) spectrograph and a Michelson interferometer.

Data



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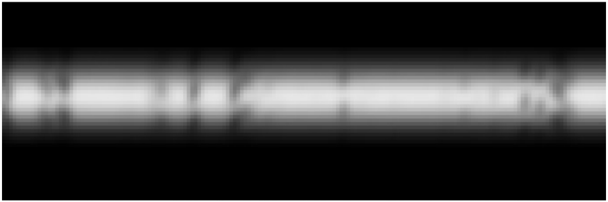
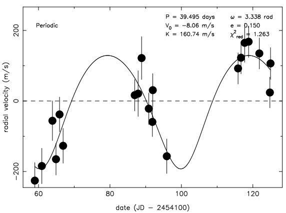
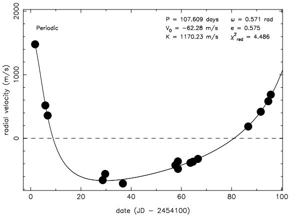



Periodic
P = 39.495 days
V0 = −8.06 m/s
K = 160.74 m/s
ω = 3.338 rad
e = 0.150
χ2red = 1.263
radial velocity (m/s)
date (JD − 2454100)


Periodic
P = 107.609 days
V0 = −62.28 m/s
K = 1170.23 m/s
ω = 0.571 rad
e = 0.575
χ2red = 4.486
radial velocity (m/s)
date (JD − 2454100)

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Brian Lee, Duy Cuong Nguyen, and Nathan De Lee spent 9 months writing a nice simulator.

The MARVELS simulator

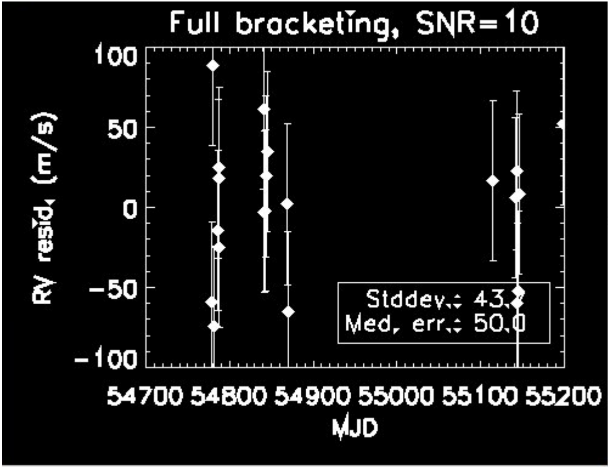
Lots of things included:

- Velocity shift
- Rotational broadening
- Interferometer Comb
- Phase Distortion
- Point Spread Function
- Illumination Profile
- Slant Transform
- Line Spread Function
- Instrument Drift
- Photon Noise
- Readout Noise
- Ghost Contamination

Lessons Learned I: Bugs

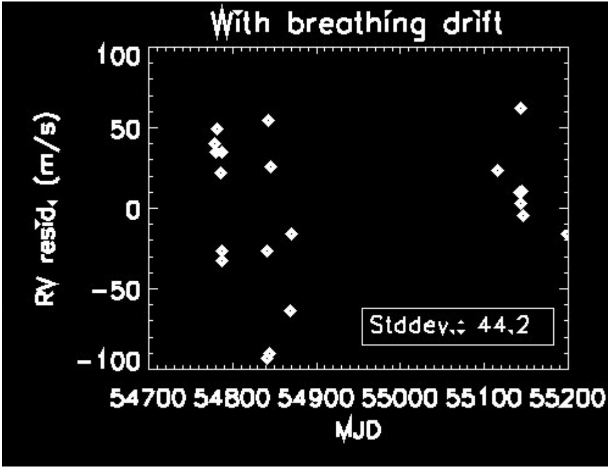
- Sign flip in the fine-scale RV extractor
- Phase-to-velocity conversion approximation improved
- Final Julian Dates were exposure starts instead of flux-centred Julian Dates from header

Lessons Learned II: Things done right



Radial velocity accuracy scales properly with signal to noise

Lessons Learned III: Problems



44 m/s is a lot. . .

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Result: We decided to terminate the MARVELS project early, and did not proceed to build a second spectrograph.

Meta-Lessons Learned

There are unmodelled features in the instrument which were only discovered after taking data for three years. At this point, it was unclear if we could go back and salvage the data given the existing calibrations.
Result: We decided to terminate the MARVELS project early, and did not proceed to build a second spectrograph.
Moral: A simulator, and associated reduction pipeline, delivered at the same time as the instrument could have saved the project.

LSST

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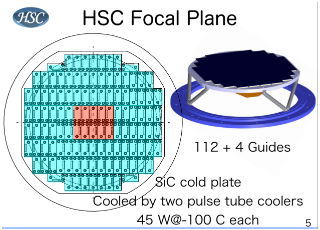

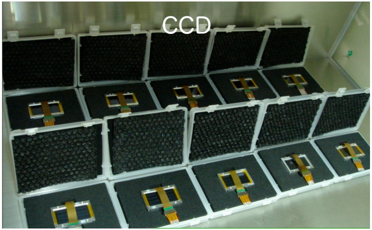

HSC on Subaru (1.8deg^2)

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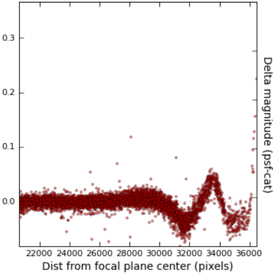
Problems in techniques for simulating objects and background:



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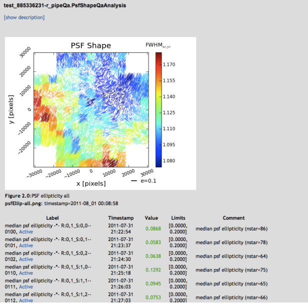

Figure 2.0: PSF ellipticity all
psfEllip-all.png: timestamp=2011-08_01 00:08:58

Label	Timestamp	Value	Limits	Comment
median psf ellipticity -*- R:0,1_S:0,0--0100, Active	2011-07-31 21:22:54	0.0868	[0.0000, 0.2000]	median psf ellipticity (nstar=86)
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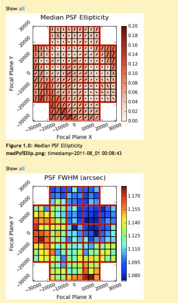

Figure 1.0: Median PSF Ellipticity
medPsfEllip.png: timestamp=2011-08_01 00:08:43

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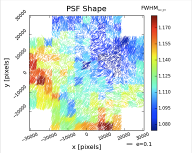

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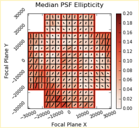

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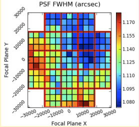

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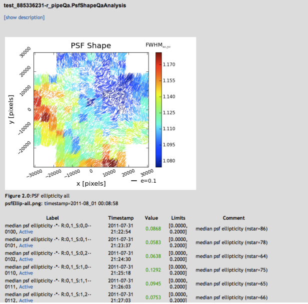

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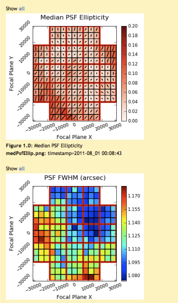

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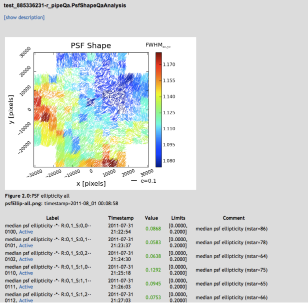

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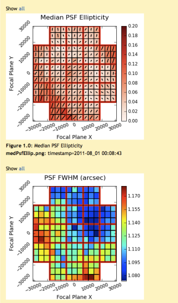

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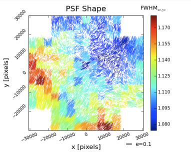

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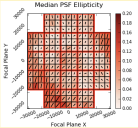

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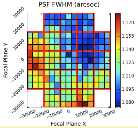

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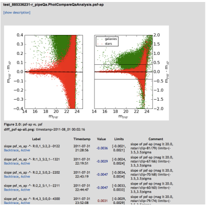
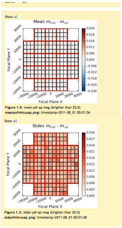
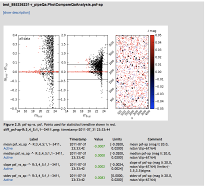
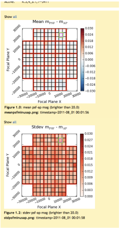
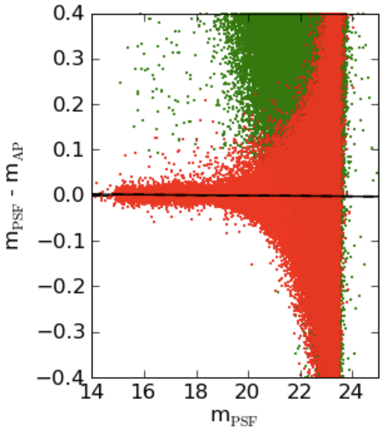




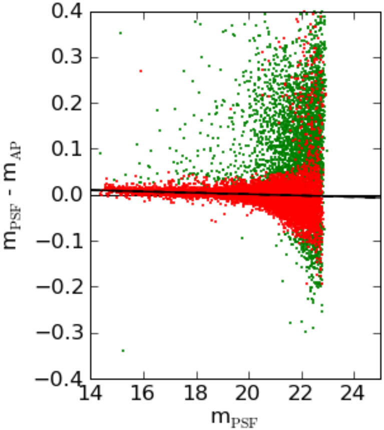




Why Simulate?



LSST ImSim



SuprimeCam

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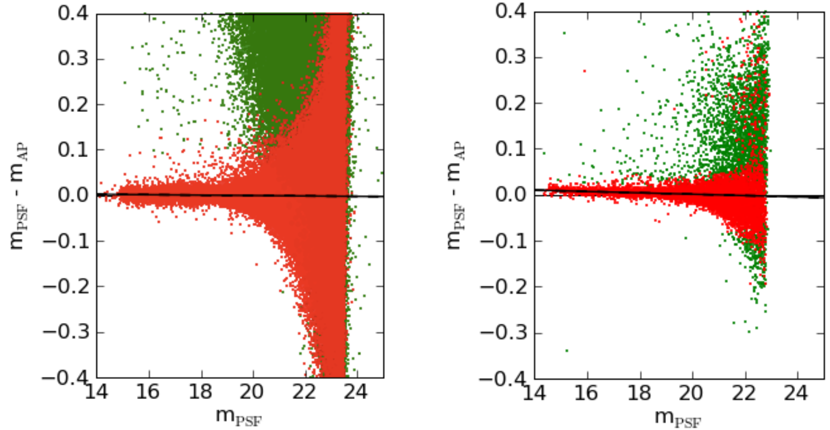

LSST ImSim SuprimeCam

Note slope in SuprimeCam data

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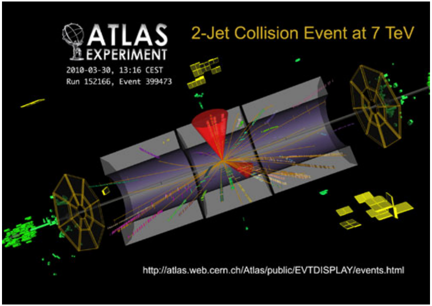
I.e. it's an arms race; the sims must keep a step ahead of the pipelines.

When Should we Stop Simulating?



It's important that we're convinced our Monte Carlo simulation and our data match, because we're deriving our calibrations from the Monte Carlo," explains Kerstin Perez. [Monte Carlo allows us to understand] how jets shower and progress through the detector – "an incredibly complicated process that no-one can really describe fully"