# The WFIRST Weak Lensing Program

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August 25, 2012

… with many thanks to the Project and Science Definition Team

*We heard yesterday about all the wonderful things you can do with weak lensing.*

*WL is still in the early stages -- ~10% errors in* $\sigma_8$ *from several experiments, systematics ~ statistics*

*I'll give an example here of some of the considerations in actually designing an experiment to make these measurements.*

# Outline

1. WFIRST – An Overview
2. The WL Program (or: What is unique about WFIRST?)
3. Concluding thoughts

# WFIRST Incarnations

- JDEMΩ (2009) – Submission to Astro2010, recommended as "template" for WFIRST hardware.
- IDRM (2011) – Interim Design Reference Mission
- DRM1 (2012) – Full-up version of WFIRST
- DRM2 (2012) – Downsized version of WFIRST with all identified cost savings.
  - *DRM1/2 report now online – arXiv:1208.4012*
- DRM0 – Option using 2.4 m telescope from NRO

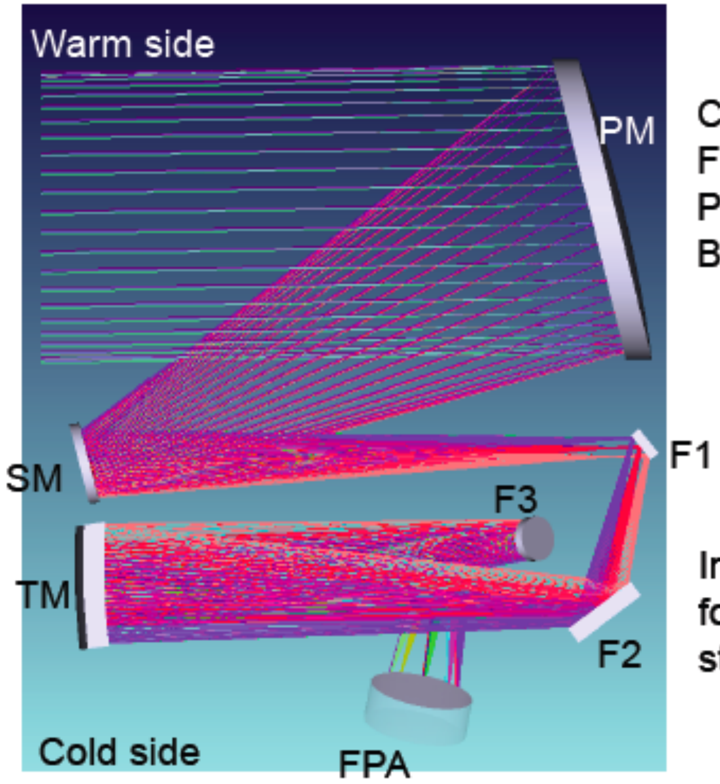
I will focus on DRM2 in this presentation.

**But this is not a final design. When working on future programs, one must keep both the science case and technology up-to-date via continued studies, analyses, and technology development work.**

# DRM2

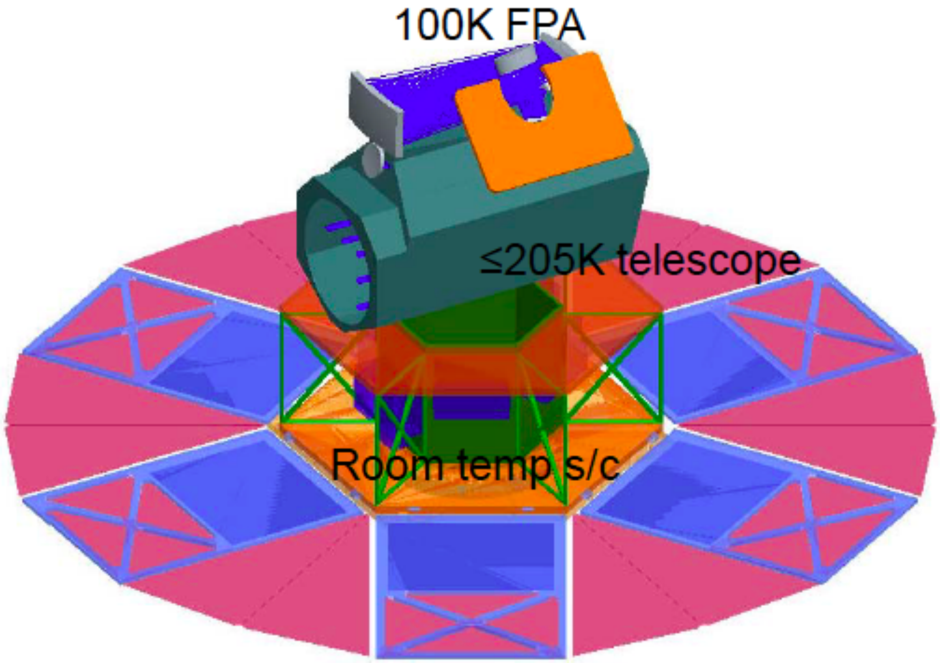
*Aperture: 1.1 m, unobstructed*
*Mirrors: Au-coated, ≤205 K*
*Detectors: 14x H4RG-10, 2.5 μm cutoff*
*Pixel scale: 0.18”*
*Field of view: 0.585 deg$^2$ (7x2 layout)*
*Sun angle: 56—124 deg*

*Number of pixels: 234M*
*Filters: Z, Y, J, H, K, W*
*Prisms: 0.6-2.0 μm R=75, 1.7-2.4 μm R=200*
*Filter & prism wheels in series at exit pupil*
*Mass: 1980 kg*
*Power: up to 2250 W (9 m$^2$ solar array)*



Cold stop & Filter wheel, Prism wheel, Behind F3

Intermediate focus; field stop

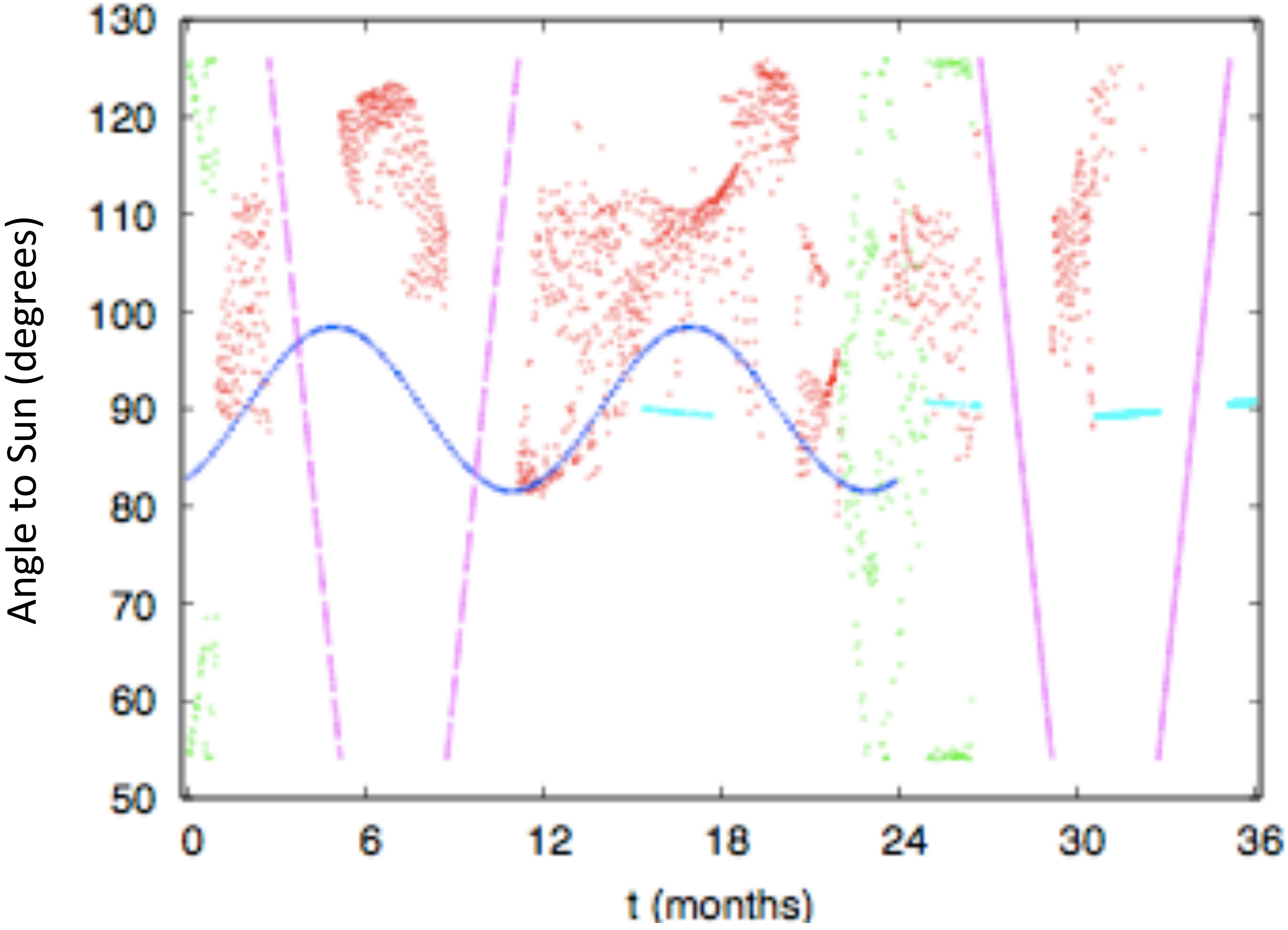


# Surveys

*I will talk only about the WL program today due to time constraints.*

- Extragalactic imaging + weak lensing
  - YJHK to m=26 AB, diffraction limited resolution
  - 31 galaxies per arcmin$^2$
  - Area 2400 deg$^2$ in notional 3 yr primary mission
  - Could get more <u>if</u> mission extended
- Galaxy redshift survey
  - K band: $10^{-16}$ erg/cm$^2$/s ~$1.2L_*$ in H$\alpha$ @ $7\sigma$, $1.6<z<2.6$
  - Same area as imaging survey
  - [JDEMΩ wide/low-z program dropped → do with Euclid + ground.]
- SN Ia
- Galactic plane imaging
- Microlensing
- Guest observer program (10% of time)

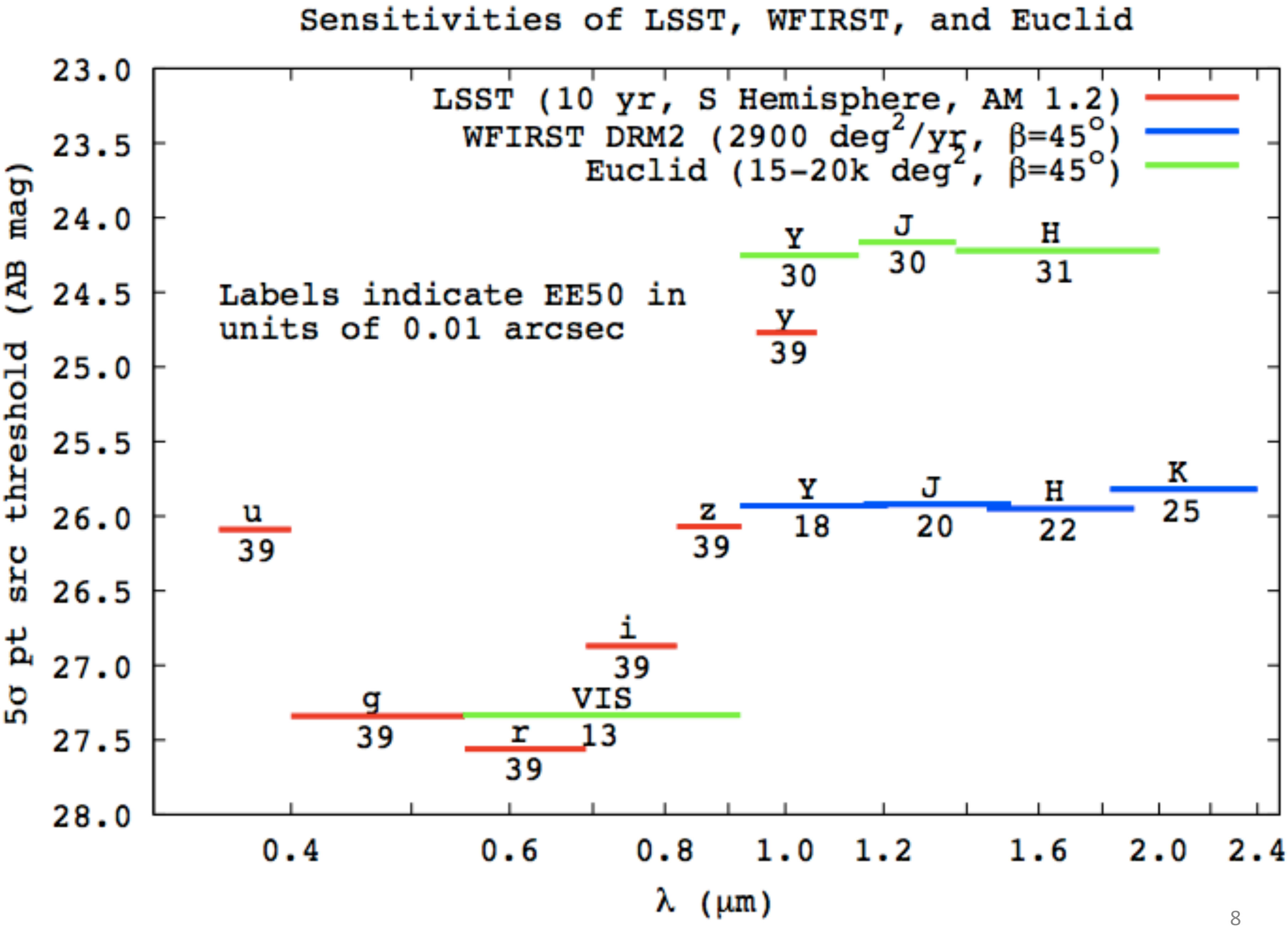
## *And yes, the programs do all fit …*



Example of 3 yr primary mission

**Extragalactic**
**Supernova**
**Microlensing**
**Galactic plane**
**Guest observer**

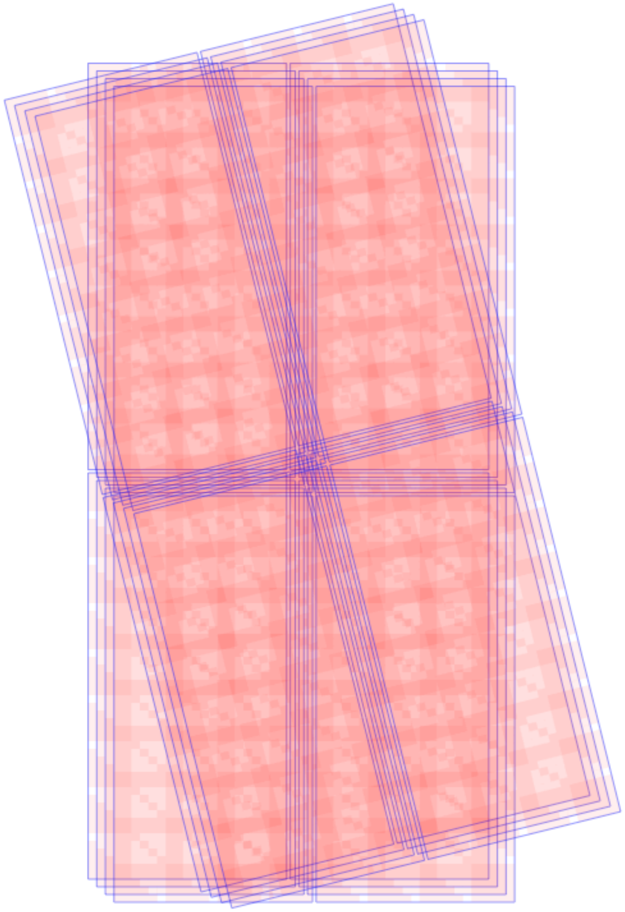
Consumables budget for 10 yr mission; mission continuation contingent on Senior Review.


Sensitivities of LSST, WFIRST, and Euclid
LSST (10 yr, S Hemisphere, AM 1.2)
WFIRST DRM2 (2900 deg$^2$/yr, β=45°)
Euclid (15-20k deg$^2$, β=45°)
Labels indicate EE50 in units of 0.01 arcsec
5σ pt src threshold (AB mag)
λ (μm)
23.0
23.5
24.0
24.5
25.0
25.5
26.0
26.5
27.0
27.5
28.0
0.4
0.6
0.8
1.0
1.2
1.6
2.0
2.4
u 39
g 39
r 39
i 39
z 39
y 39
VIS 13
Y 30
J 30
H 31
Y 18
J 20
H 22
K 25

# WFIRST-DRM2 Observing Strategy

| Mode | Exposure Time | Survey Time (days per 1k deg$^2$) | Sensitivity 5σ pt src |
|---|---|---|---|
| Imaging-Y | 5 x 247 s | 31.5 | 25.93 AB |
| Imaging-J | 5 x 247 s | 31.5 | 25.92 AB |
| Imaging-H | 5 x 247 s | 31.5 | 25.95 AB |
| Imaging-K | 5 x 247 s | 31.5 | 25.82 AB |
| Spectro-K | 6 x 567 s | 83.4 | 6x10$^{-17}$ erg/cm$^2$/s |
| Total | | 209.2 | |

**Photo-z also requires ugriz photometry (from LSST).**

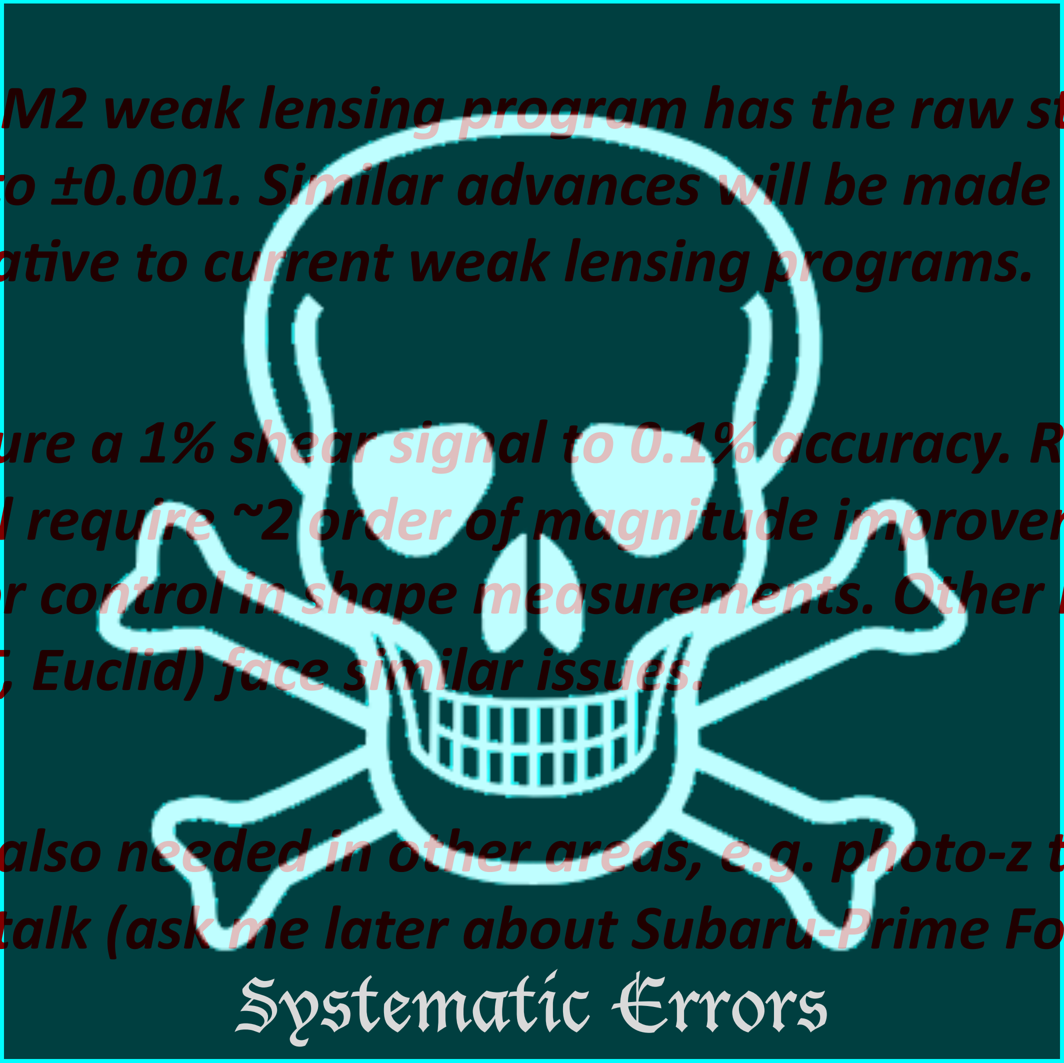


*2-pass rolled strategy allows efficient tiling and internal relative calibration under relevant conditions.*

*The WFIRST DRM2 weak lensing program has the raw statistical power to measure $\sigma_8$ to ±0.001. Similar advances will be made on the other parameters relative to current weak lensing programs.*

*Trying to measure a 1% shear signal to 0.1% accuracy. Reliable results at this level will require ~2 order of magnitude improvement in systematic error control in shape measurements. Other big WL programs (LSST, Euclid) face similar issues.*

*Improvements also needed in other areas, e.g. photo-z training → but that's another talk (ask me later about Subaru-Prime Focus Spectrograph)*



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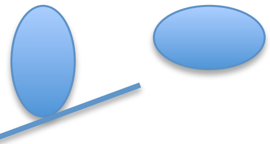
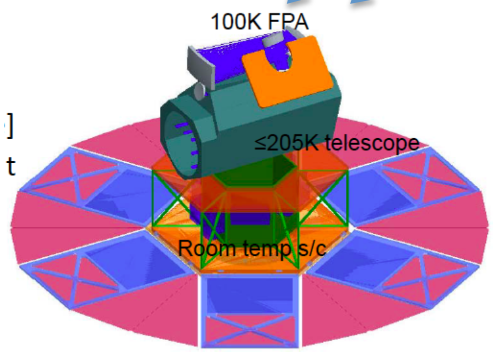
***You should be really scared!***

# The Major Systematic Errors

Intervening matter:
- Nonlinear power spectrum?
- Baryonic corrections?
- Higher-order lensing corrections?



Source galaxies:
- Redshifts?
- Intrinsic alignments?



Telescope/instrument:
- Point spread function?
- Flats, astrometry … ?
- Detector non-idealities?

Data analysis:
- Image processing algorithms?
- Source selection?
- Shape measurement?

# Problems

- Point spread function (PSF) varies with position, time
  - Turbulence, etc. in the atmosphere
  - Optical aberrations, pointing stability, focal plane topography
  - These issues beat against each other and vary even within an exposure
- Can measure with stars but color, flux dependence
  - Diffraction, atmosphere, filter transmission, pixel response (depth of charge deposition) all λ-dependent; galaxy SED not known a priori.
  - Semiconductor detectors with depletion regions, charge traps etc. are not linear
- Must have sufficient internal checks to prove at the end of the program that the problems have been solved.

# Advantages of WFIRST Architecture

1. Observations at L2 with a temperature-controlled telescope eliminate both the atmosphere and the thermal fluctuations experienced on the ground and on HST.

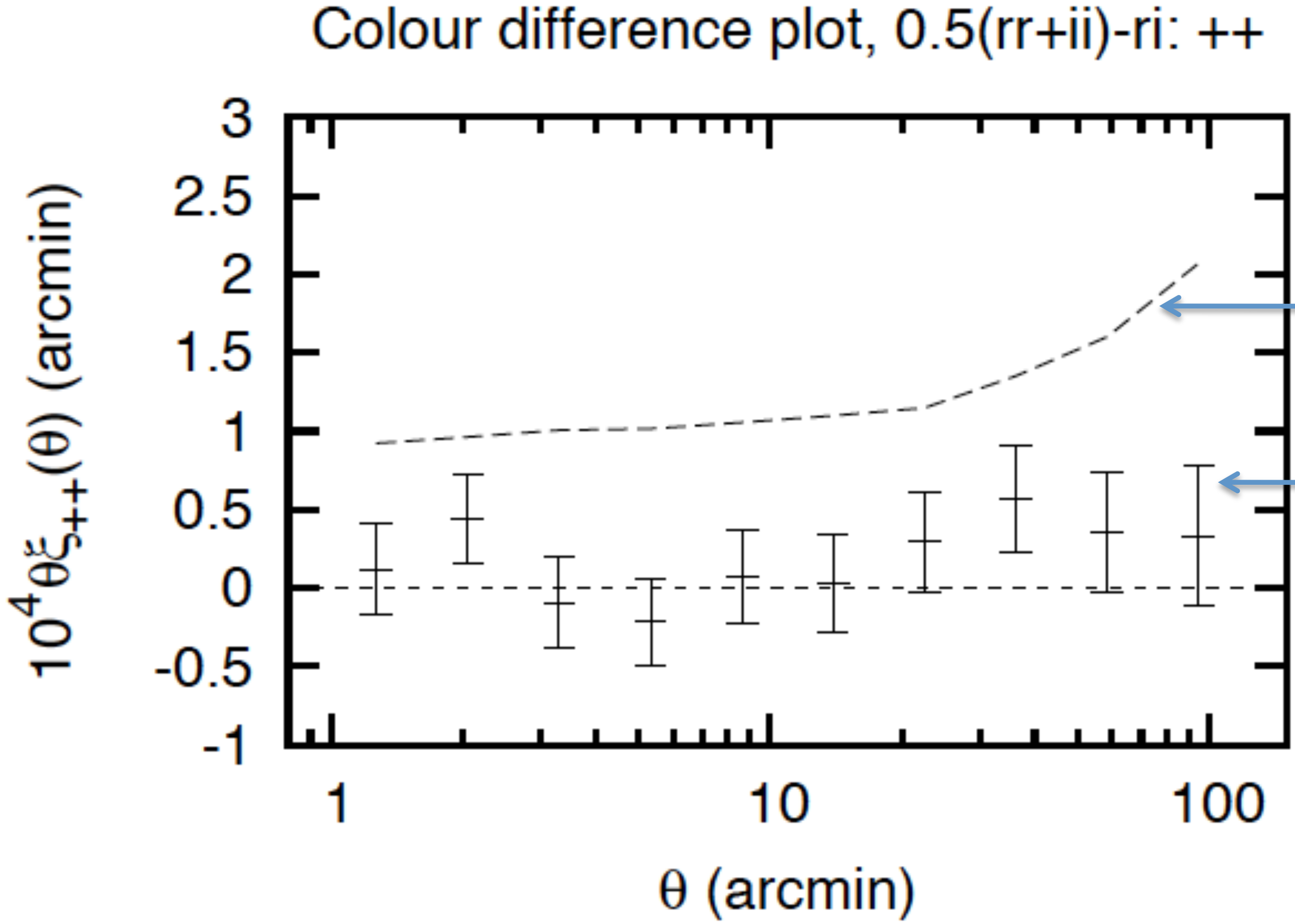
2. Fully-sampled images in 3 shape measurement filters (JHK) enable internal cross checks and color corrections on every galaxy.

3. Redundant passes in each filter support calibration and null tests internal to the science data itself.

4. Unobstructed telescope allows simple, compact PSF even in the NIR (where galaxies are bright).

# Example of a Null Test – SDSS

**In a survey observed multiple times, can search for differences between the shear signals measured in 2 passes. This was needed to convince me that we were doing something right.**



Colour difference plot, 0.5(rr+ii)-ri: ++

**Huff et al. (2011)**

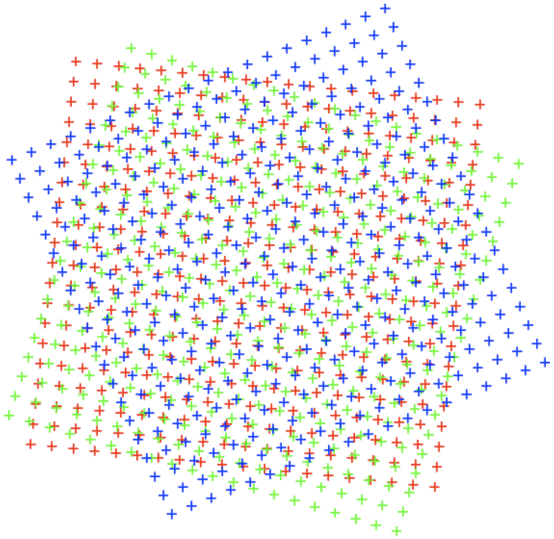
*Statistical error on shear correlation function*

*Difference between the auto-correlations (rr,ii) and cross-correlations (ri)*

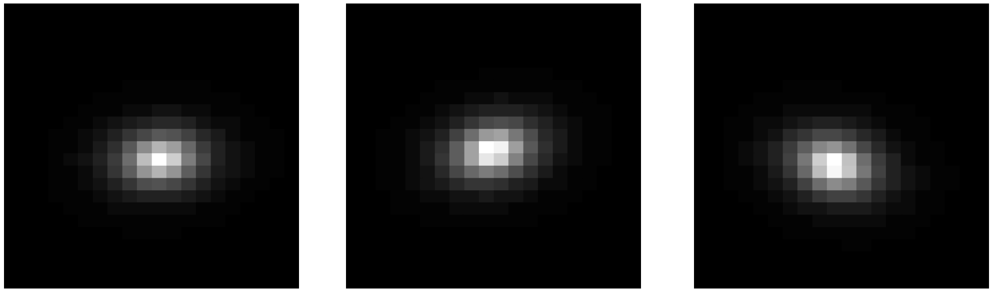
# Sampling Considerations

- Most space imaging missions (including WFIRST & Euclid) achieve full sampling through dithering.
  - Depends on number and spacing of positions and sampling parameter $Q = [\lambda_{min}/D]/[\text{pixel scale}]$ – see sims by B. Rowe.
  - Q>2 for full sampling at native scale.
  - Q>1 to enable band limit set by optics, not detector.
    - Cleanly disitinguish PSF ellipticity from jitter, astigmatism, coma.
  - Cosmic rays
    - At L2: expect **~5 particles per cm$^2$ per second**
    - P[CR track within 3 pixels] = 0.044 for WFIRST, 0.24 for Euclid (per exposure).
- Implementations
  - Q = 0.94 for Euclid VIS, ≥1.21 for WFIRST bands
    - But Euclid band limit in the blue is set by charge diffusion so the effective Q is somewhat larger.
  - Baseline is 3—4 positions for Euclid, ≥5 per filter for WFIRST

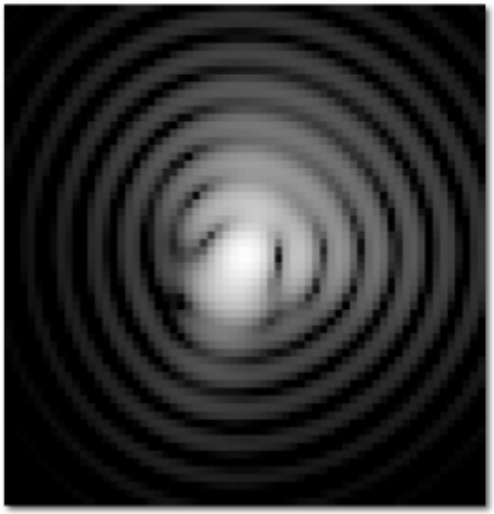
# Example – Combining Rolled Inputs



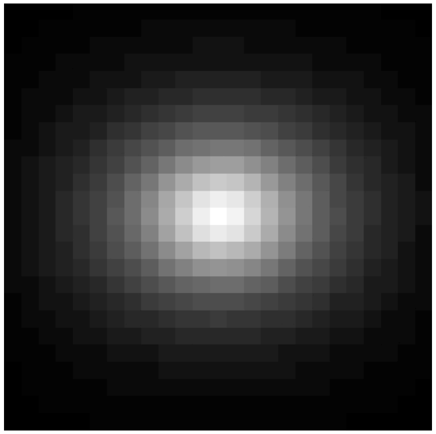
INPUT IMAGES



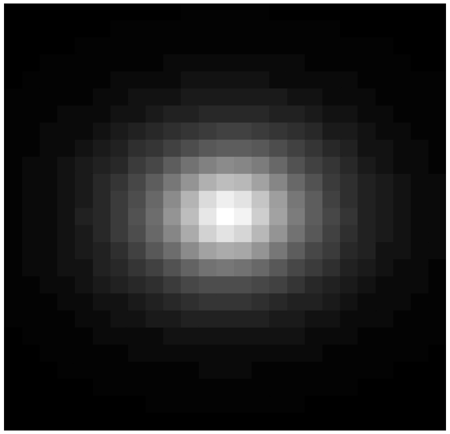
Simulated JDEM PSF (log-scale)



DESIRED OUTPUT



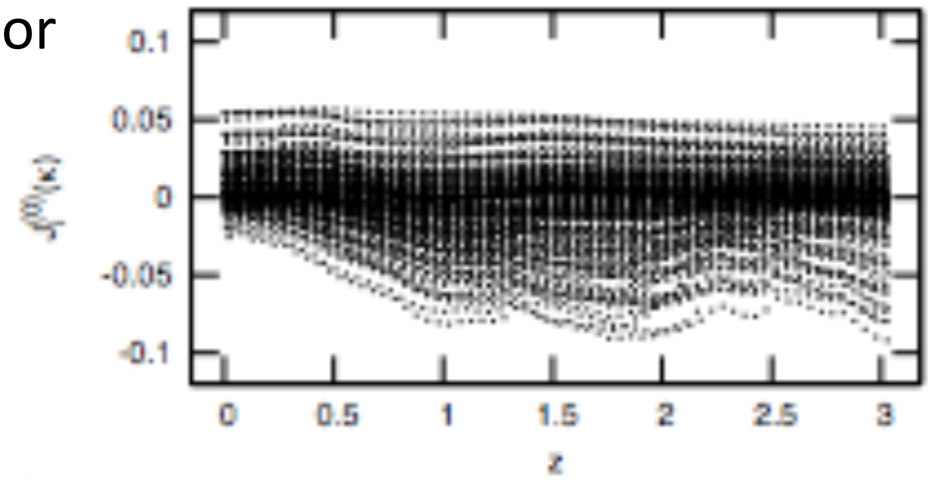
ACTUAL OUTPUT

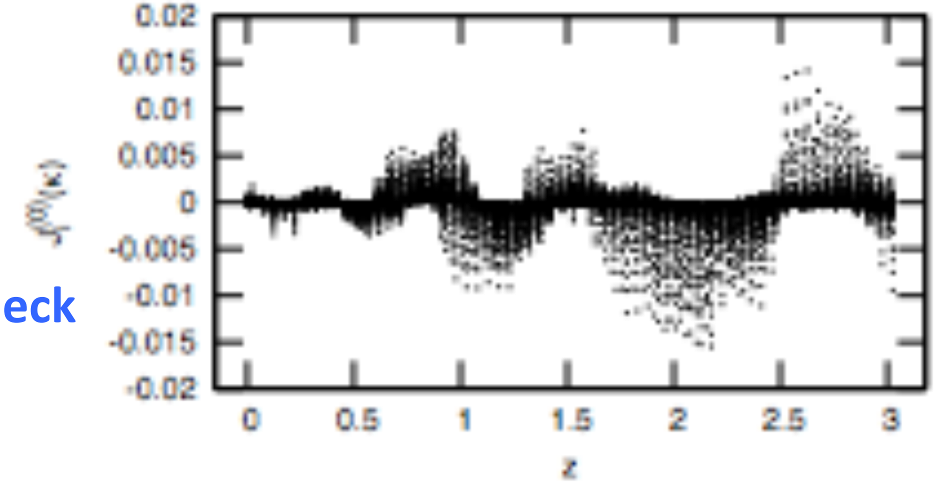


**B Rowe**

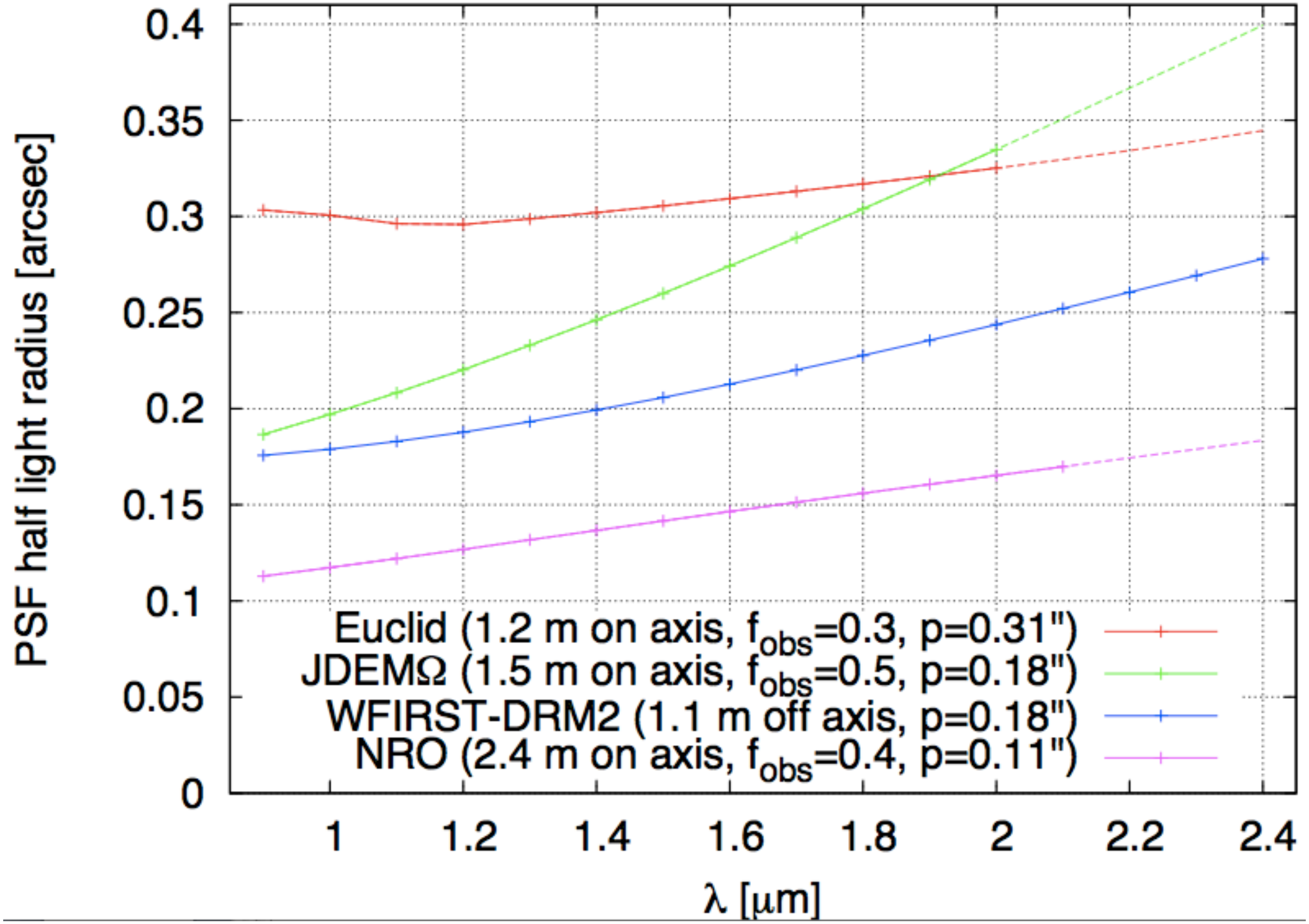
# Colors

- Color dependence of PSF is a major issue since it causes stars and galaxies to have *different* PSF!
  - Biases are easily several %.
  - Complex z dependence.
  - Airy worse than Gaussian.
- Here optical (Euclid/LSST) & WFIRST are complementary:
  - Main source of color dependence is different – **Balmer/4000Å break** vs **Hα+[N II] complex**.
  - **Need multiple survey filters as a check on any correction scheme.**
  - ≥4 filters (optical + WFIRST-J, H, K) enable us to “dodge” particularly nasty features.

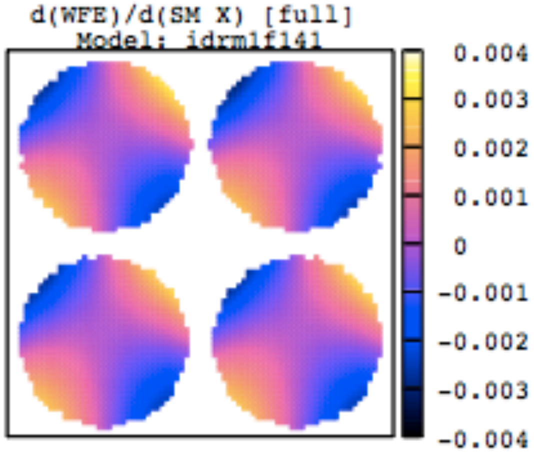

(a) Model II RIZ Native [Stellar]

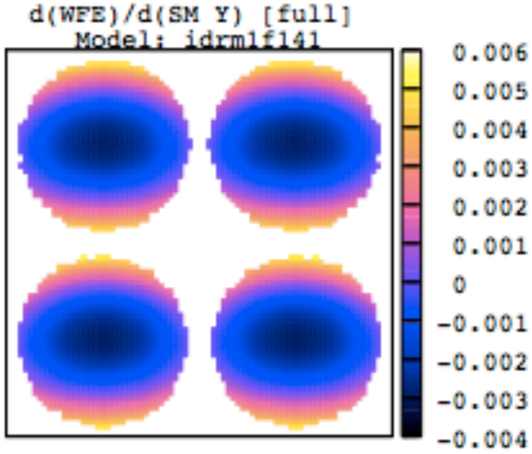

(c) Model II RIZ Corrected [Stellar]

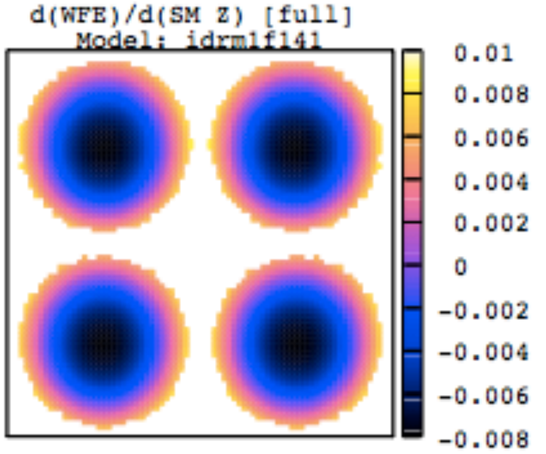
# Advantage of Off Axis Telescope

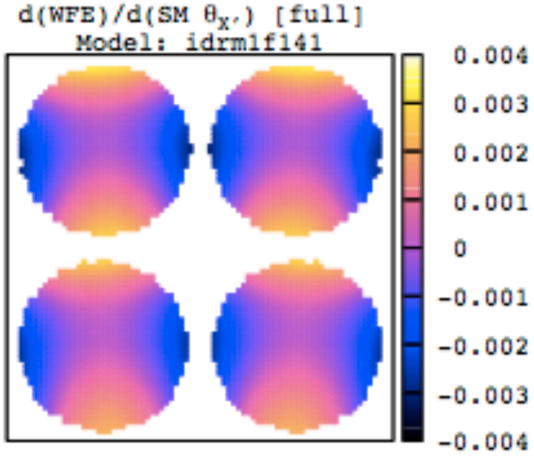


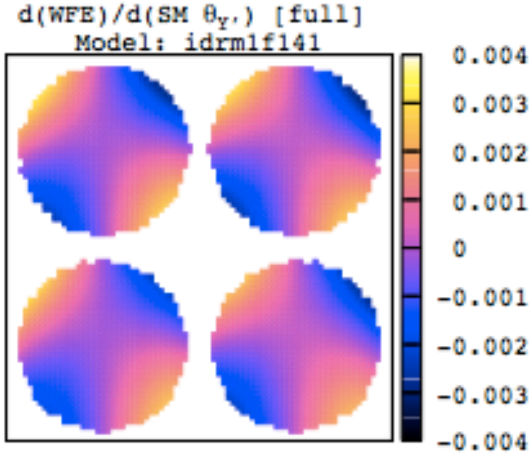
# WFIRST-IDRM Wavefront Distortion Map
# (Sensitivity to Secondary Mirror Perturbations)

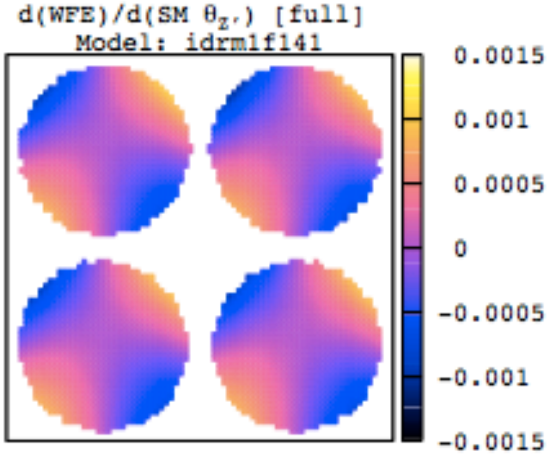












- *Significant astigmatism from de-centering SM, but highly uniform across field.*

# New Detectors

- NIR detectors are not CCDs
  - Longer wavelengths – use $Hg_{1-x}Cd_xTe$ rather than Si as sensitive medium
  - Si readout circuit non-destructively reads individual pixels
  - Both advantages and disadvantages for WL
- JWST, Euclid will fly 2k×2k NIR detectors with 18 μm pixels (H2RG-18)
- WFIRST has pursued development of H4RG-10 (4k×4k @ 10 μm).
  - The initial effort in 2011 was successful but not free of issues, and more work is needed before we can "start" a mission based on these detectors. **This work is identified as the highest priority for WFIRST in the immediate future.**

**H2RG**
**2K x 2K**

**H4RG-10**
**4K x 4K**

# Programmatic Issues

- Independent estimate (Aerospace Corp.) was that JDEMΩ = $1.6B. Not likely to be viable in present climate.
- Cost savings in DRM2 achieved via:
    - Smaller spacecraft fits on Falcon 9 launch vehicle
    - Reduced from 3→1 science instruments
    - Reduced from 1.5→1.1 m primary
    - 36→14 detectors (H4RG-10 enables this with increased pixel count)
    - 5→3 year primary mission
- Target ≤$1B; independent costing of DRM2 underway.
    - JDEM-ISWG Option A was estimated at $1.1B for similar size/complexity; some further savings (1 instrument, Falcon 9 LV) identified.
    - Launch in 2024 if the community continues to identify this as a priority, despite constrained budget.
    - Next "gate" is 2014/5 Mid-Decadal review, which will recommend whether to proceed with WFIRST.
    - Too early for definitive statements about NRO options.

# Conclusions

- Weak Lensing: A powerful way to measure the mass distribution in the Universe, if one can control systematics well enough to see signal, not PSF.

- The ultimate WL experiment includes a wide field space telescope with redundant data and many dither positions in multiple filters, including the NIR, an unobstructed pupil, not too undersampled, and as much observation time as we can get …

- And also requires optical imaging and multiplexed spectroscopy at large ground based telescopes.