Weak Lensing With WFIRST

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Outline

1. Science with WL
2. Some Recent Results
3. The Future and the Role of WFIRST

What is Weak Lensing?

- Slight (~1%) distortion of the image of a galaxy due to matter along the line of sight.
  - Shear = l.o.s. integral of tidal field
    - Manifest in the ellipticity of a galaxy.
    - Since shear << intrinsic ellipticity, must do statistics.

  - Magnification = l.o.s. integral of density
    - Less mature – not this talk.

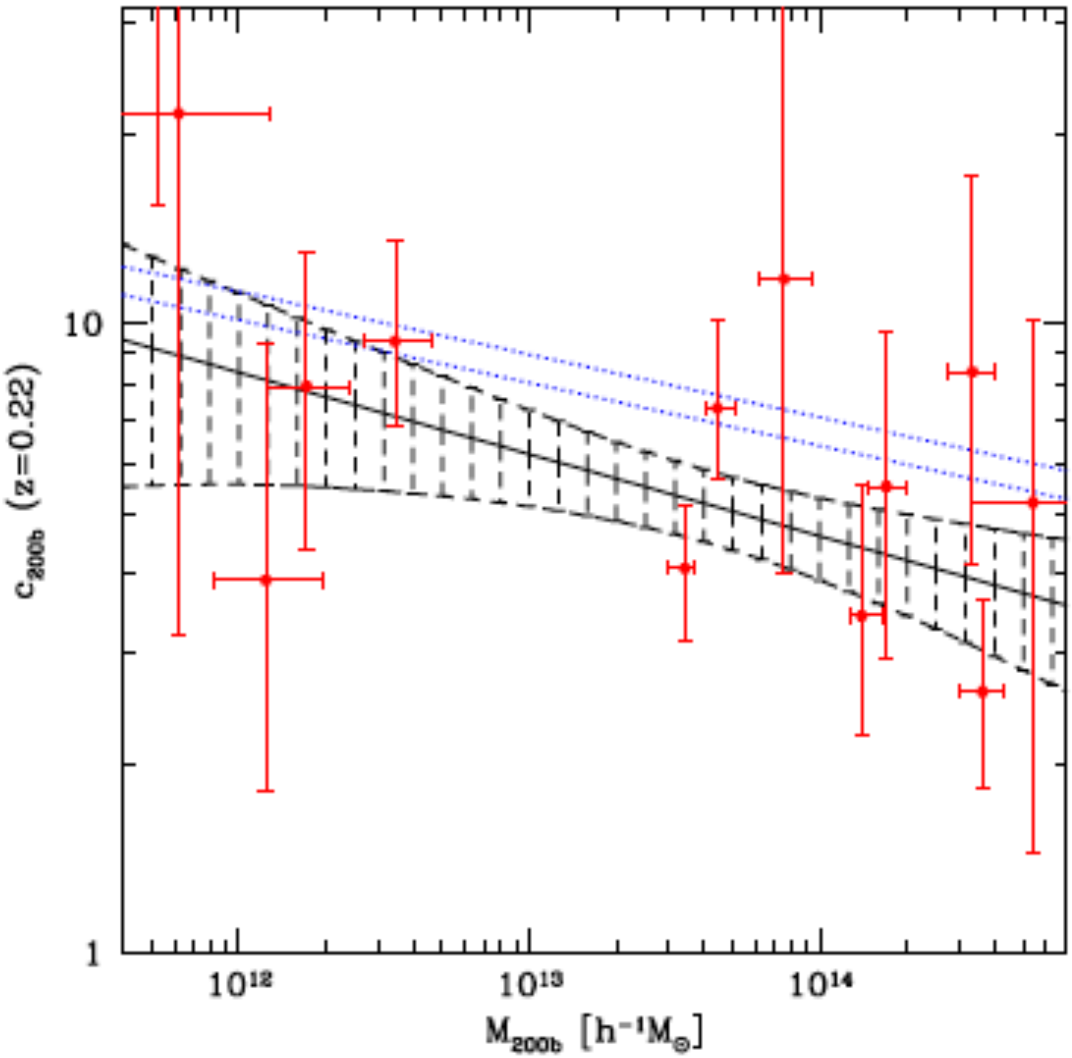
Thanks to B. Jain for the cartoon.

Major Uses

WL serves both cosmology and galaxy evolution

1. The growth of large scale structure via the statistics of weak lensing.
2. The connection between galaxies and their host dark matter haloes.
3. Galaxy “biasing” – the relation between galaxies and their large-scale environment.

Example of Non-DE Science with WL Halo Mass-Concentration Relation

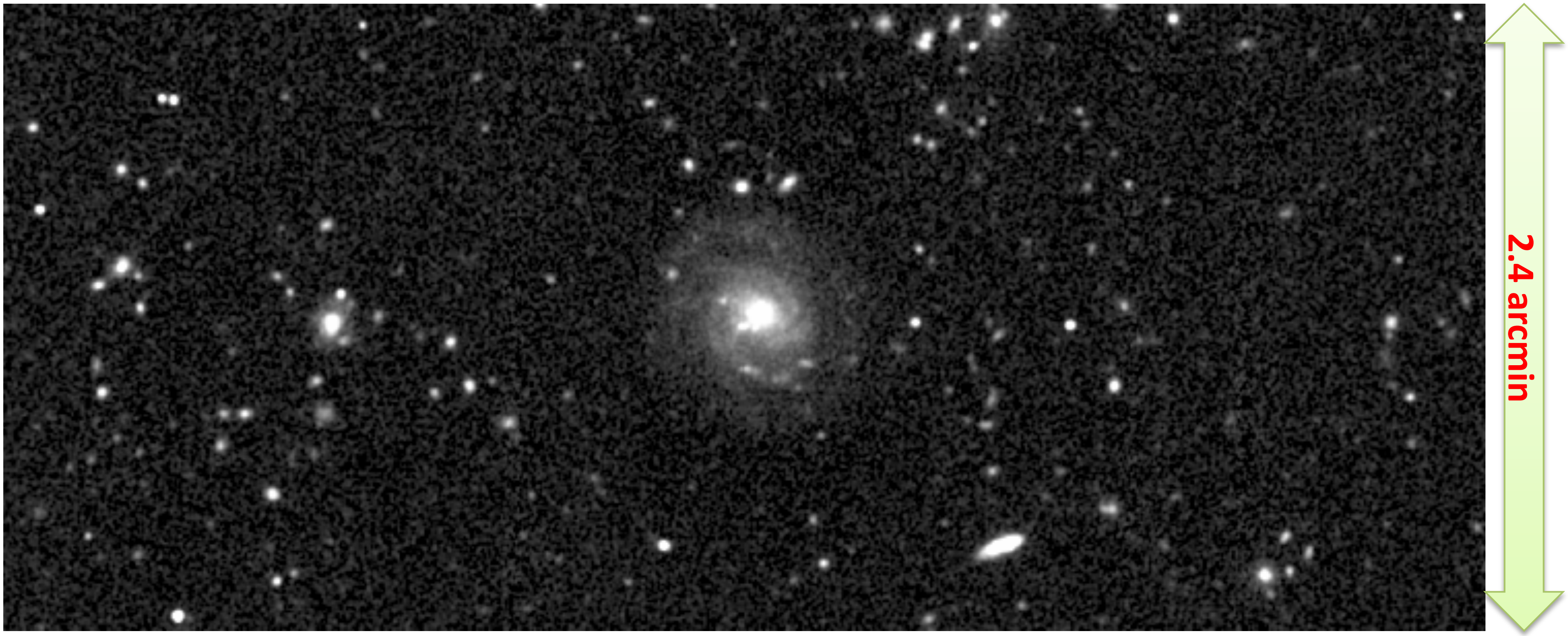


Mandelbaum et al 2008

c(M) measured over 3 orders of magnitude in halo mass in SDSS

Inverse relation predicted by simulations, but only measured at 2σ. Stay tuned!

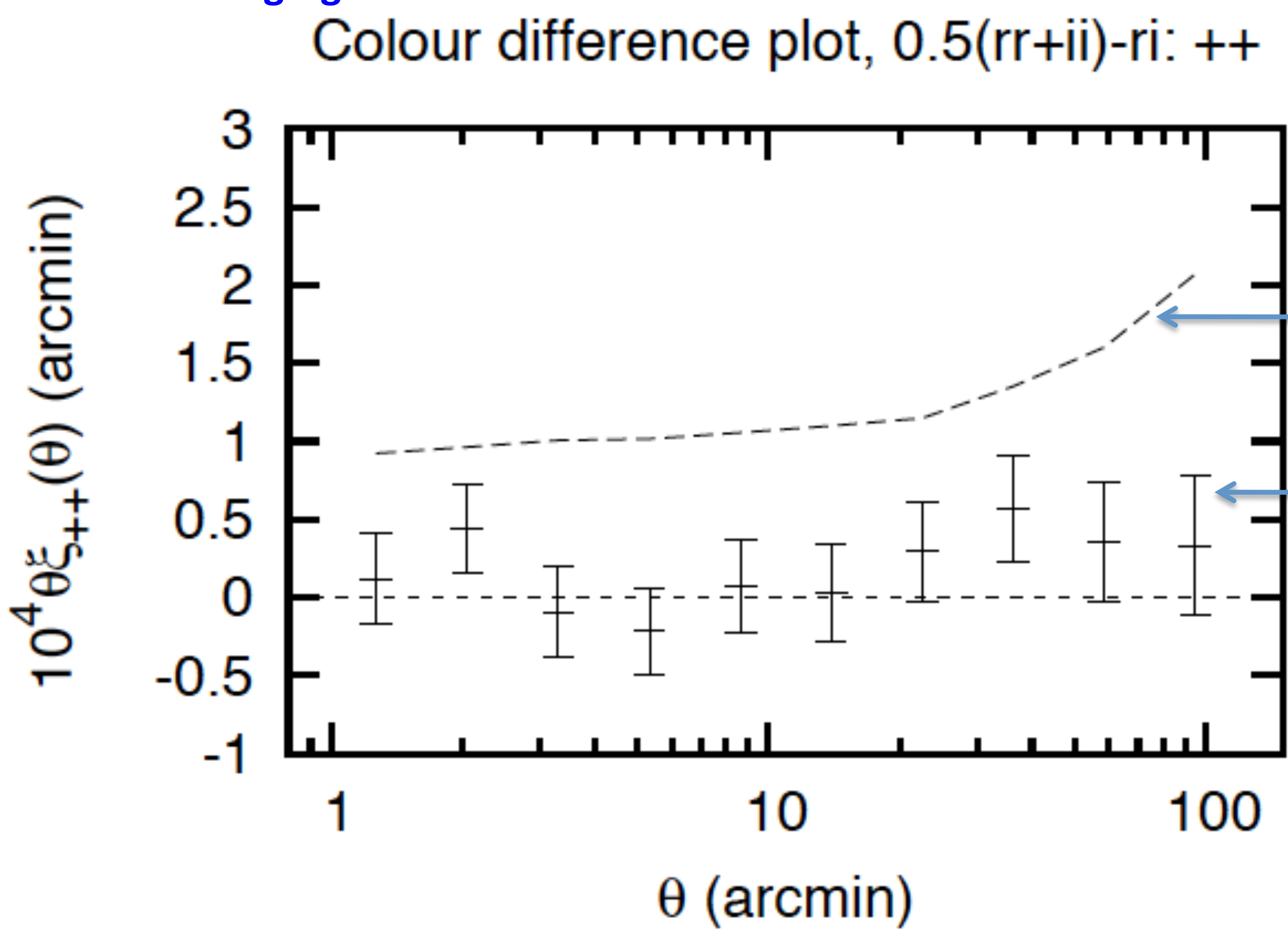
To shamelessly promote some recent work …
[Eric Huff et al, Dec 2011]



- Cosmic shear measurement in the Sloan Digital Sky Survey!
- SN Survey Stripe (along the equator, scanned many times)
- 1.3” FWHM PSF, 170 deg^2, ~50 exposures (variable) coadded using fancy math
- 2.2 galaxies per $arcmin^2$, shapes to r = 23.5

Tests for Residual Systematics

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.



Statistical error on shear correlation function

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

SDSS Results

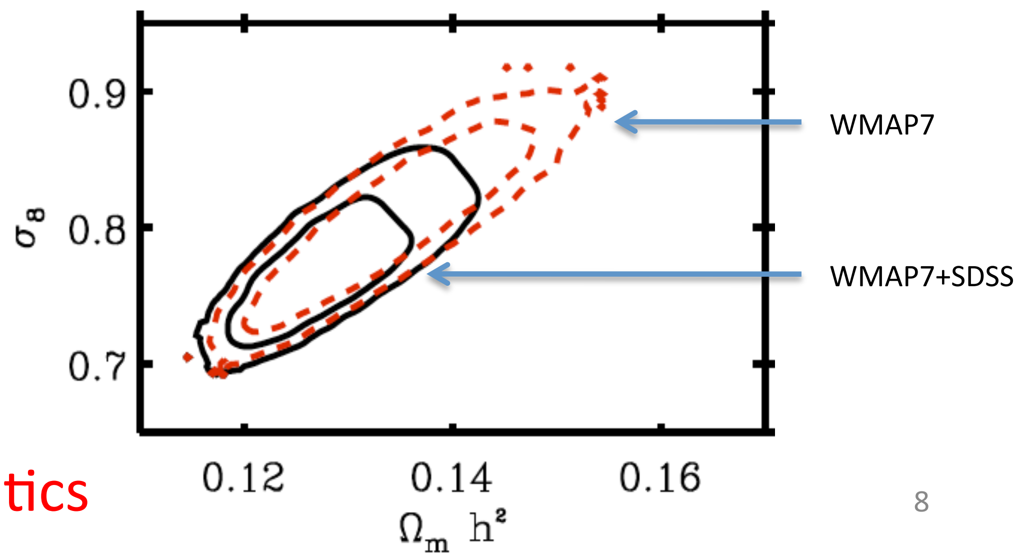
- Amplitude of fluctuations (Huff et al):
  - Fixed other parameters to WMAP values

$$\sigma_8 = 0.64^{+0.10}_{-0.15}(1\sigma)$$

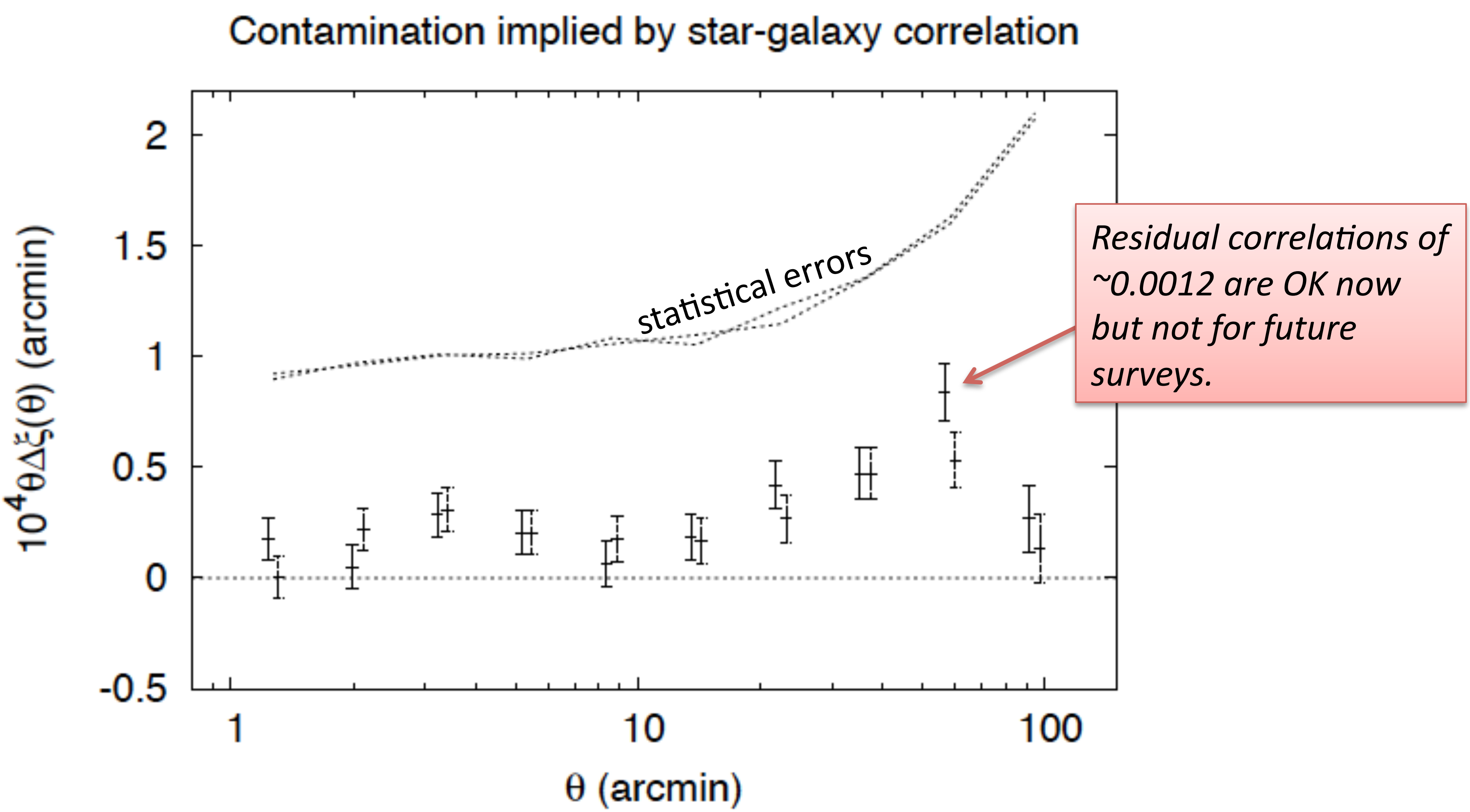
- Independent analysis of the same dataset by Fermilab group (Lin et al):
  - Includes e.g. different image stacking algorithm, sky subtraction, etc.

$$\sigma_8 = 0.64^{+0.08}_{-0.13}(1\sigma)$$

- This worked but:
  - Statistical errors are large
  - Limited redshift baseline
  - There are residual systematics



Residual Systematics are Not Zero



The Future

- Stage III
  - Dark Energy Survey and Hyper Suprime Cam are “soon” (survey complete in this decade)
- Stage IV
  - LSST on the ground
  - Euclid & WFIRST in space

What Do We Need These For?

- Cosmology
  - Measure the amplitude of low-z large scale structure as well as the CMB can measure high-z [~1%; **ground**]
  - Chart the growth of structure across cosmic time. Measure the suppression due to DE to a few percent.* [Requires resolving tiny high-z galaxies with low systematics – **space**]
  - Tests of GR at similar accuracy
- Also extend SDSS galaxy scaling relations to higher z, rare objects (mergers, AGN, …)

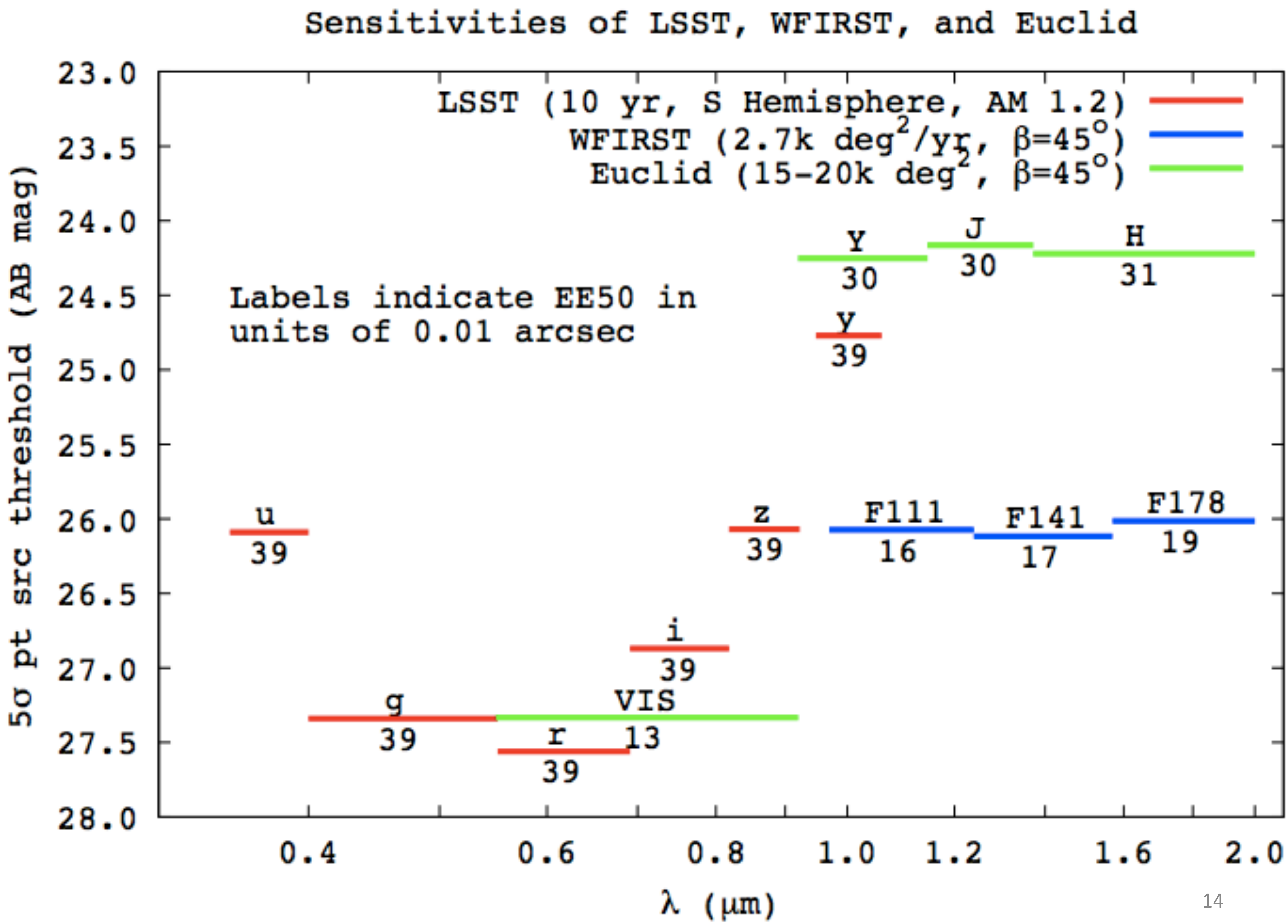
* "Current" forecast for CMB + homogeneous probes + WFIRST-WL = 4%.
Remember entire suppression of growth is ~20% from z=1000 to today!

What's Needed for a Great WL Program

- More area & depth
- Much better "seeing"
  - Only way to resolve more galaxies, especially at high z, is at an excellent ground based site, or (better) in space
- More filters for photo-z (including NIR)
- Plenty of redundancy
  - Needed for the aforementioned tests – should include multiple filters to check color corrections.
  - The foundation of science is the reproducibility of results, especially where small effects are concerned.
- More stable, better characterized PSF
  - On the ground, the PSF often varies by tens of percents within an exposure.
  - Includes detector response, in addition to optics.

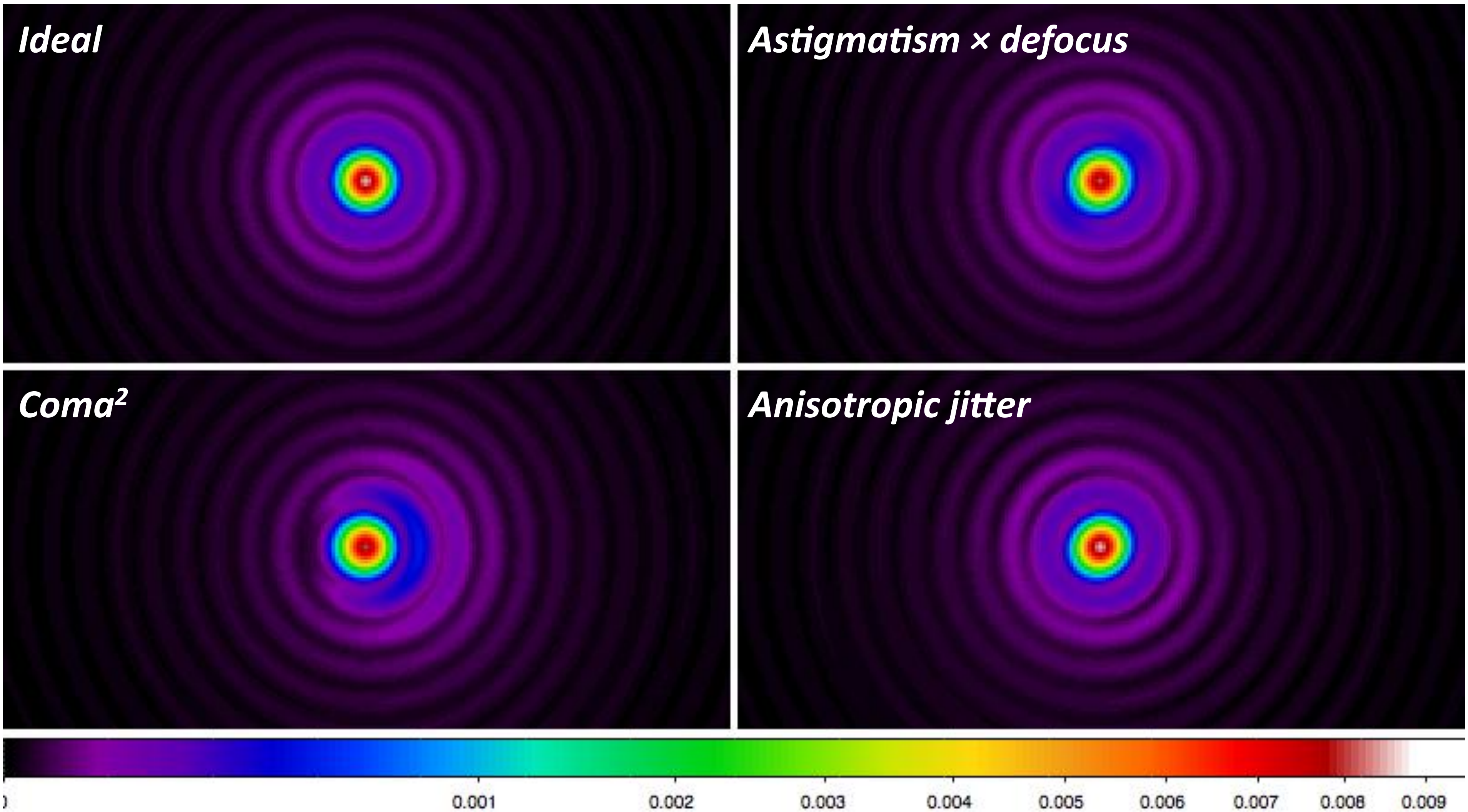
Imaging Capabilities

- Each of the 3 surveys provides a unique imaging capability. They are not the same.
- LSST:
  - 6 band optical imaging; time domain
- Euclid:
  - High resolution optical imaging (highest resolution of the 3 surveys)
- WFIRST:
  - Deep, high resolution NIR imaging (full-sampled in 2 bands)
    - SDT recently voted to add a K band; would expect to do WL in H+K
  - While it sacrifices area, this is the only survey with space quality PSF, multiple shape filters, and redundant data in each.

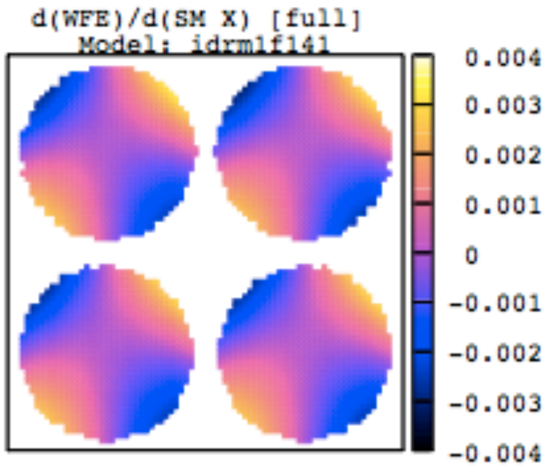


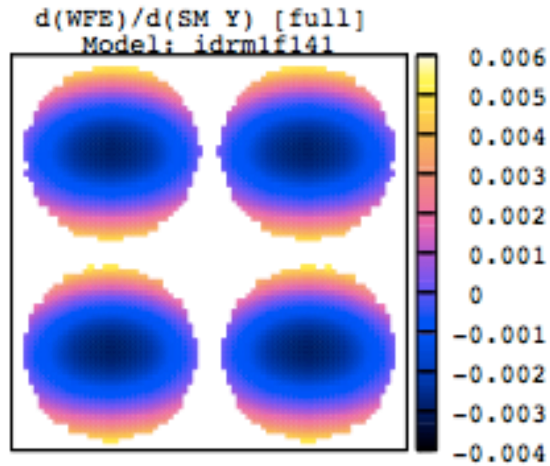
Sensitivities of LSST, WFIRST, and Euclid
LSST (10 yr, S Hemisphere, AM 1.2)
WFIRST (2.7k deg²/yr, β=45°)
Euclid (15-20k deg², β=45°)
Labels indicate EE50 in
units of 0.01 arcsec
5σ pt src threshold (AB mag)
λ (μm)
23.0
23.5
24.0
24.5
25.0
25.5
26.0
26.5
27.0
27.5
28.0
0.4
0.6
0.8
1.0
1.2
1.6
2.0
u
39
g
39
r
39
i
39
z
39
y
39
VIS
13
Y
30
J
30
H
31
F111
16
F141
17
F178
19

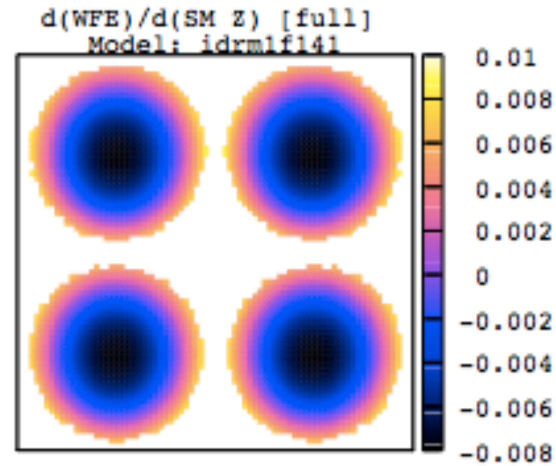
Sources of PSF Ellipticity in Space

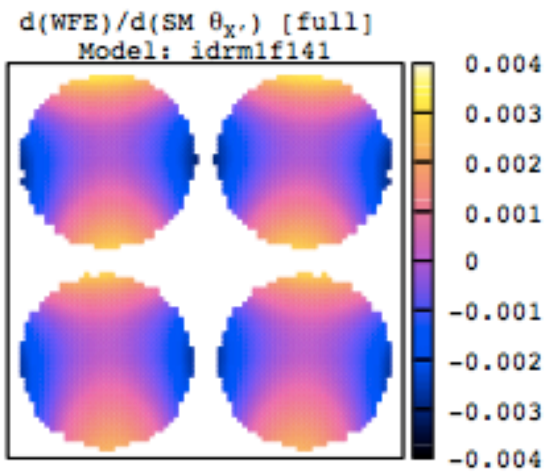


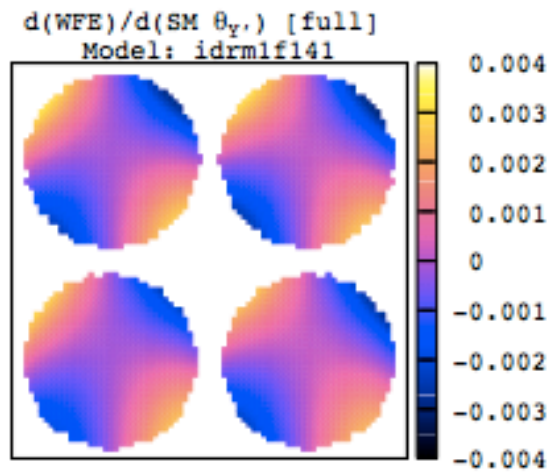
WFIRST SM Perturbation Map

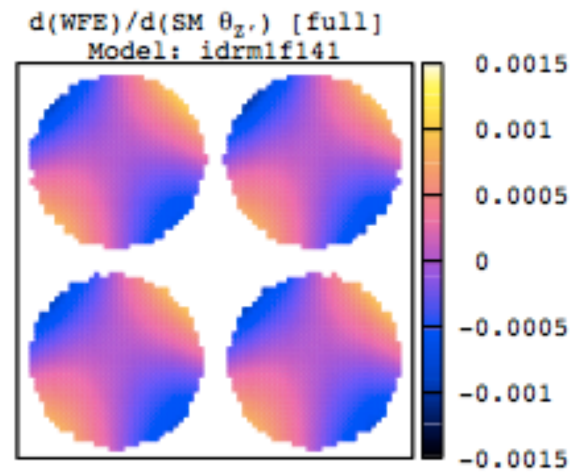






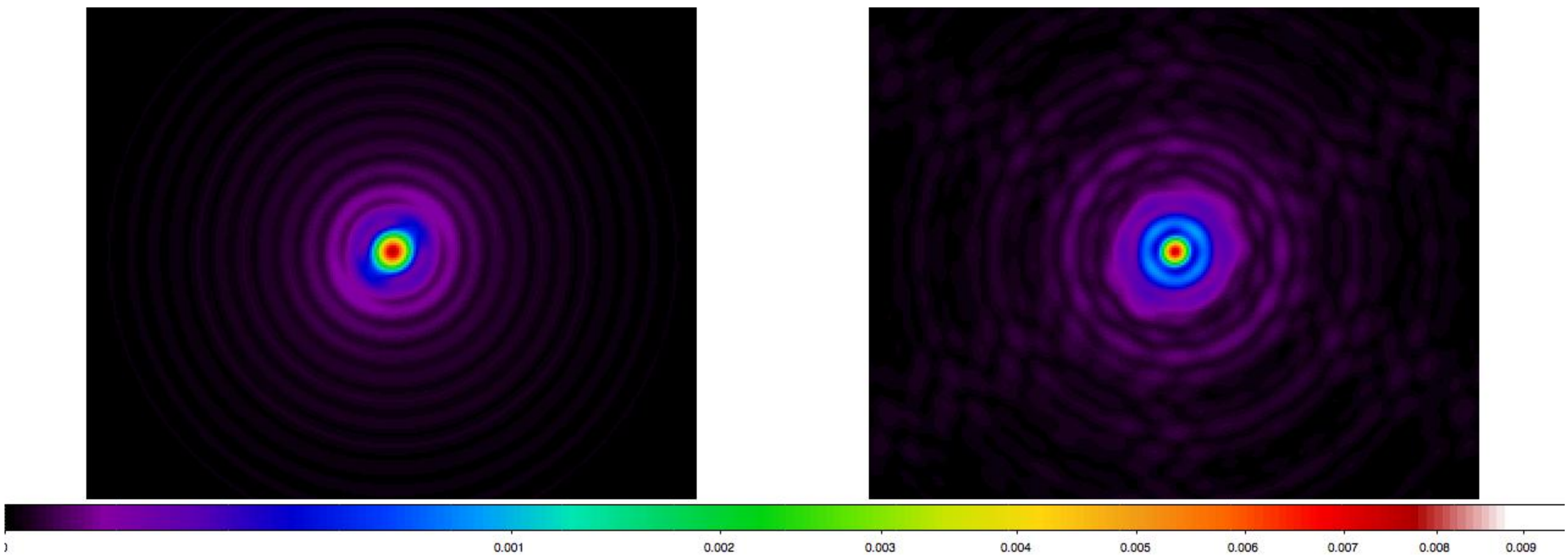






Unobstructed telescope

1.255 m unobstructed **1.500 m obstructed**



- Both on the same scale, square root stretch
- λ = 2 µm, 9 arcsec across
- Aberration: 106 nm RMS, split 50:50 focus:astigmatism
    - Just for illustration – outside of WFIRST specifications
- Jitter: 40 mas rms per axis, isotropic

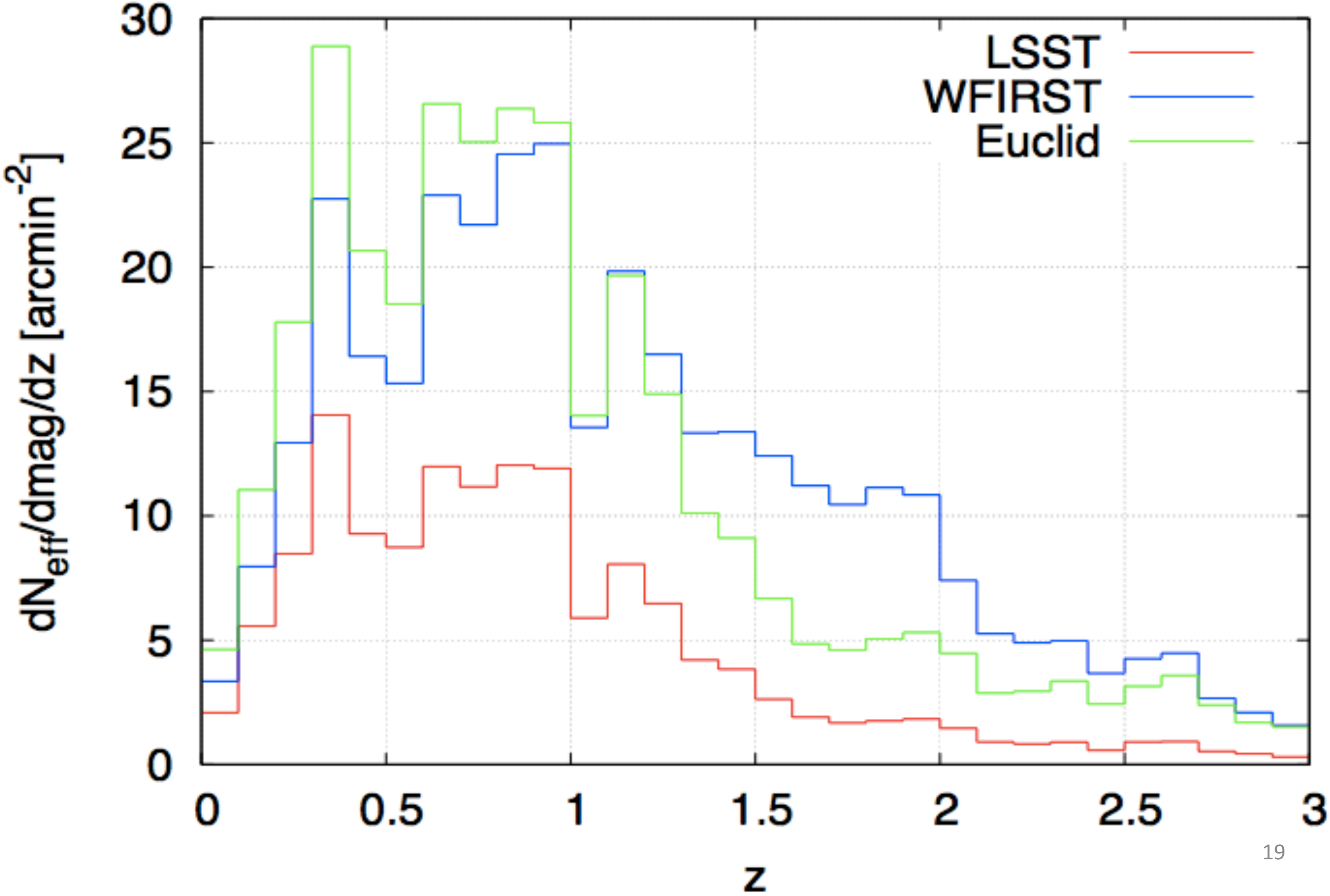
WL Capabilities

	LSST	Euclid	WFIRST
Area [deg^2]	~12,000 (S Hemisphere)	≥15,000	2,700 (1 year - deep)
Source density n_{eff} [gal am^{-2}] Res>0.4, S/N>18, σ_e<0.2	14	33	35 (union catalog) 30 F141 + 32 F178
Median z	0.80	0.84	1.02
Shape measurement filter	r & i	VIS (550—920 nm)	F141 & F178
Detectors	CCD	CCD	HgCdTe
Photo-z filters	6 (ugrizy)	4 (VIS + YJH)	3 (F111/141/178)
Location	Ground	Space	Space
Exposures in filled shape survey	~700× 15 s (r+i)	3× 600 s	10× 160 s (5+5)

Number densities based on the COSMOS Mock Catalog – S. Jouvel et al (2009)

This set of cuts gave 2.7 gal/am^2 predicted in SDSS vs 2.2 actual – difference probably due to masking effects. More on this later.

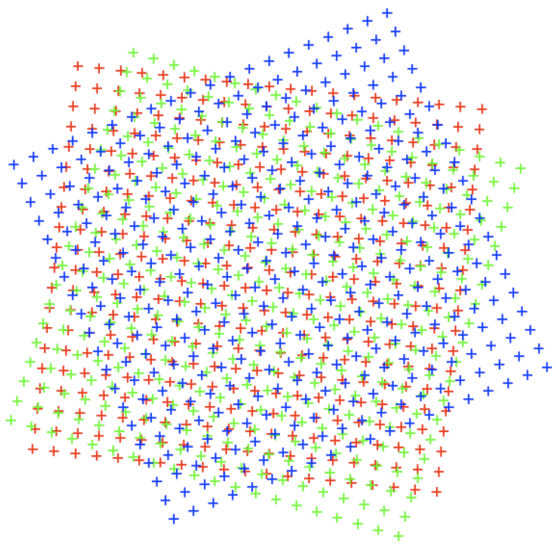
Redshift Distributions



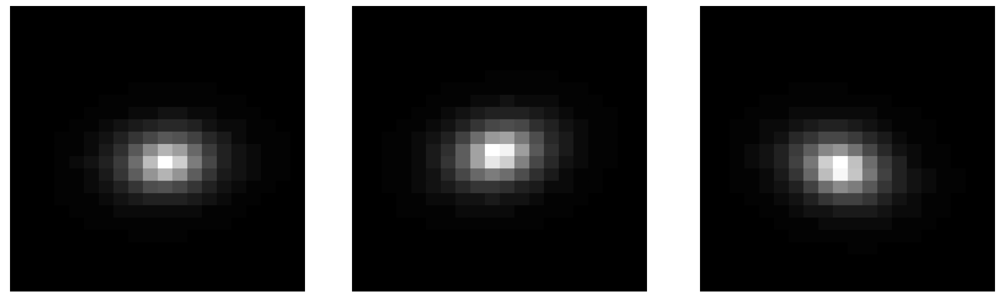
Sampling Considerations

- All of the proposed space missions achieve full sampling through dithering.
  - Depends on number and spacing of positions and sampling parameter Q = [λ_{min}/D]/[pixel scale] – see sims by B. Rowe.
  - Q>2 for full sampling at native scale.
  - Q>1 to avoid intrapixel sensitivity variations (one of nasty issues for photometry on NIR detectors).
  - With unobstructed telescope, can combine rolled images.
  - Need at least 1 more dither position than the sims say
    - P[CR track within 3 pixels] = 0.09 for WFIRST, 0.24 for Euclid (per exposure).
- Implementations
  - Q = 0.94 for Euclid VIS, 1.11 or 1.41 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

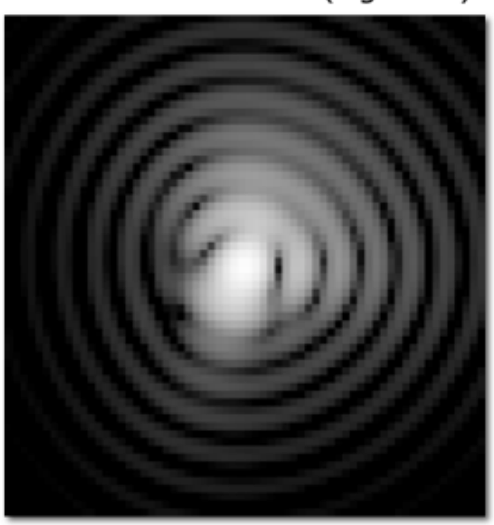
Example – Combining Rolled Inputs



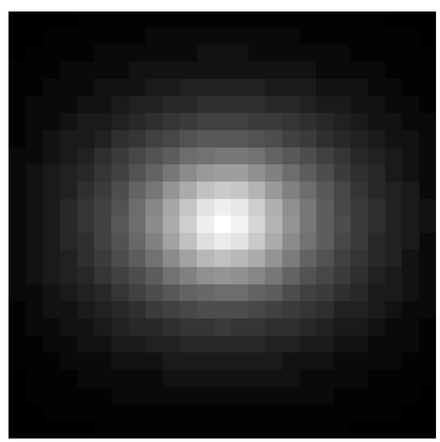
INPUT IMAGES



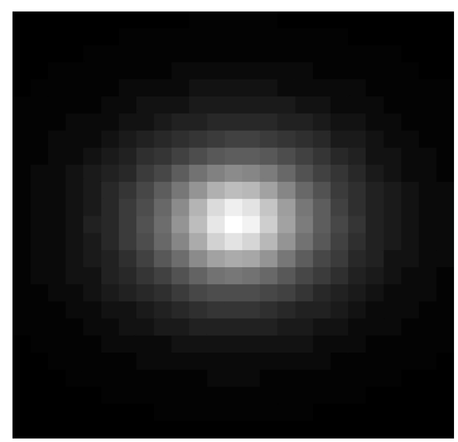
Simulated JDEM PSF (log-scale)



DESIRED OUTPUT



ACTUAL OUTPUT



B Rowe

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 is 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.