Astronomical Surveys

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Detectors for Astronomy
Garching
Oct. 2009

BOARD ON PHYSICS AND ASTRONOMY

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- BPA HOME
- ATOMIC, MOLECULAR, AND OPTICAL SCIENCES
- COMMITTEE ON RADIO FREQUENCIES
- PLASMA SCIENCE
- SOLID STATE SCIENCE
- ASTRO 2010 DECADAL SURVEY
- PHYSICS 2010
- STUDY COMMITTEES
- BPA REPORTS
- BPA MEMBERSHIP & STAFF
- STANDING COMMITTEES
- DEPS HOME

Astro2010: The Astronomy and Astrophysics Decadal Survey

Home Page

Astro2010, the current astronomy and astrophysics decadal survey, is the latest in a series of surveys that are produced every 10 years by the National Research Council (NRC) of The National Academy of Sciences. The survey statement of task, structure, committee/panel membership, and community input processes are described on these pages, along with an FAQ.

Position Papers submission window is open!

> > > Click here to submit your state of the profession position paper < < <

The submission window will close at 11:59 p.m. EST on March 15th, 2009.

Spotlight

The **Science White Papers** are now available for download! Also available is a list of the **Science White Paper titles**.

Agendas are available on the Science Frontier Panels webpage for the first meetings of these Panels.

State of the Profession Position Papers* are requested and this call is open.

The **Programs Subcommittee Request for Information*** is open.

The Programs Subcommittee call for White Papers request has been revised to clarify the **Technology Development** call and to issue a new parallel call for papers on **Theory, Computation, and Laboratory Astrophysics**. Please see the updated request and the March 3 Chair's

Chair's Communications

March 3rd, 2009 Chair's Bulletin

Archive of Chair's Bulletin

January 6, 2009 AAS Invited talk
PDF version of the talk given by Astro2010 Survey Committee Chair Roger Blandford at the 213th AAS meeting in Long Beach, CA.

A note from the Astro2010 chair on TOWN HALL MEETINGS is now available (click here)

Astro2010 Charge

- The Astro2010 committee will survey the field of space- and ground-based astronomy and astrophysics, recommending priorities for the most important **scientific and technical** activities of the decade 2010-2020.
- The principal goals of the study will be to carry out an assessment of activities in astronomy and astrophysics, including both new and previously identified concepts, and to prepare a **concise report** that will be addressed to the agencies supporting the field, the Congressional committees with jurisdiction over those agencies, the scientific community, and the public.

[http://www.nationalacademies.org/astro2010]

2009 Status of Initiatives

- Spitzer, WMAP, Fermi(GLAST), CARMA, VERITAS, SPT
- JWST, ALMA, SOFIA, Herschel(FIRST), Planck, Kepler, SM4, WISE, NuSTAR, MWA, LWA, ACT...
- SIM, Con-X(IXO), TPF, SAFIR,GSMT, LSST, LISA, EXIST, ARISE, ATST, SKA, FASR, JDEM, CMBPOL, CCAT...
- Many new proposals
- Cross-disciplinary projects

Good News: Superabundance of scientifically exciting projects
Bad News: No credible budget can support starting all of them
Conclusion: Many opportunities must be passed up

Projected list of funded projects recommended by Astro 2010 committee

Dark Energy Measurements

1. Four observational techniques dominate White Papers:
   a. Baryon Acoustic Oscillations (**BAO**) large-scale surveys measure features in distribution of galaxies. BAO: $d_A(z)$ and $H(z)$.
   b. Cluster (**CL**) surveys measure spatial distribution of galaxy clusters. CL: $d_A(z)$, $H(z)$, growth of structure.
   c. Supernovae (**SN**) surveys measure flux and redshift of Type Ia SNe. SN: $d_L(z)$.
   d. Weak Lensing (**WL**) surveys measure distortion of background images due to gravitational lensing. WL: $d_A(z)$, growth of structure.
2. Different techniques have different strengths and weaknesses and sensitive in different ways to dark energy and other cosmo. parameters.

Dark Energy Measurement Techniques

4. Four techniques at different levels of maturity:
   a. **BAO** only recently established. Less affected by astrophysical uncertainties than other techniques.
   b. **CL** least developed. Eventual accuracy very difficult to predict. Application to the study of dark energy would have to be built upon a strong case that systematics due to non-linear astrophysical processes are under control.
   c. **SN** *presently* most powerful and best proven technique. If photo-*z*'s are used, the power of the supernova technique depends critically on accuracy achieved for photo-*z*'s. If spectroscopically measured redshifts are used, the power as reflected in the figure-of-merit is much better known, with the outcome depending on the ultimate systematic uncertainties.
   d. **WL** also emerging technique. Eventual accuracy will be limited by systematic errors that are difficult to predict. *If* the systematic errors are at or below the level proposed by the proponents, it is likely to be the most powerful individual technique and also the most powerful component in a multi-technique program.

Survey Astrophysics

Major Surveys

2MASS - First 2μ All Sky Survey (less extinction than optical)
DLS - Deep Lens Survey - Tyson (Blanco and Mayall)
DEIMOS - Spectra of ~5K faint galaxies with redshifts $z > 0.7$
SDSS (z and BOSS) - 100's of papers with wide range of topics
UKIDSS - NIR equivalent of SDSS - deeper than 2MASS
WISE - Wide Field IR Survey Explorer - 4 bands (3.3, 4.7, 12, 23μm)
VISTA - Visable and IR Survey Telescope (IR Z,Y,J,H,K)
CFHTLS - Largest cosmic shear survey to date
PanSTARRs - Max étendue per unit cost - PS1 on-sky
DES - Blanco -Optical+NIR 5000^2 deg to 24th
LSST - Survey equivalent of SDSS every few days - 20TB's/night
Hyper-Suprime Cam - Subaru 8m

BigBOSS - Kitt Peak and Cerro Tololo (30 million galaxies)
JDEM - Current Study of HgCdTe and no CCDs for focal plane
EUCLID - SPACE+DUNE DE/DM spectroscopy and imaging

Science Objectives Drive System Requirements

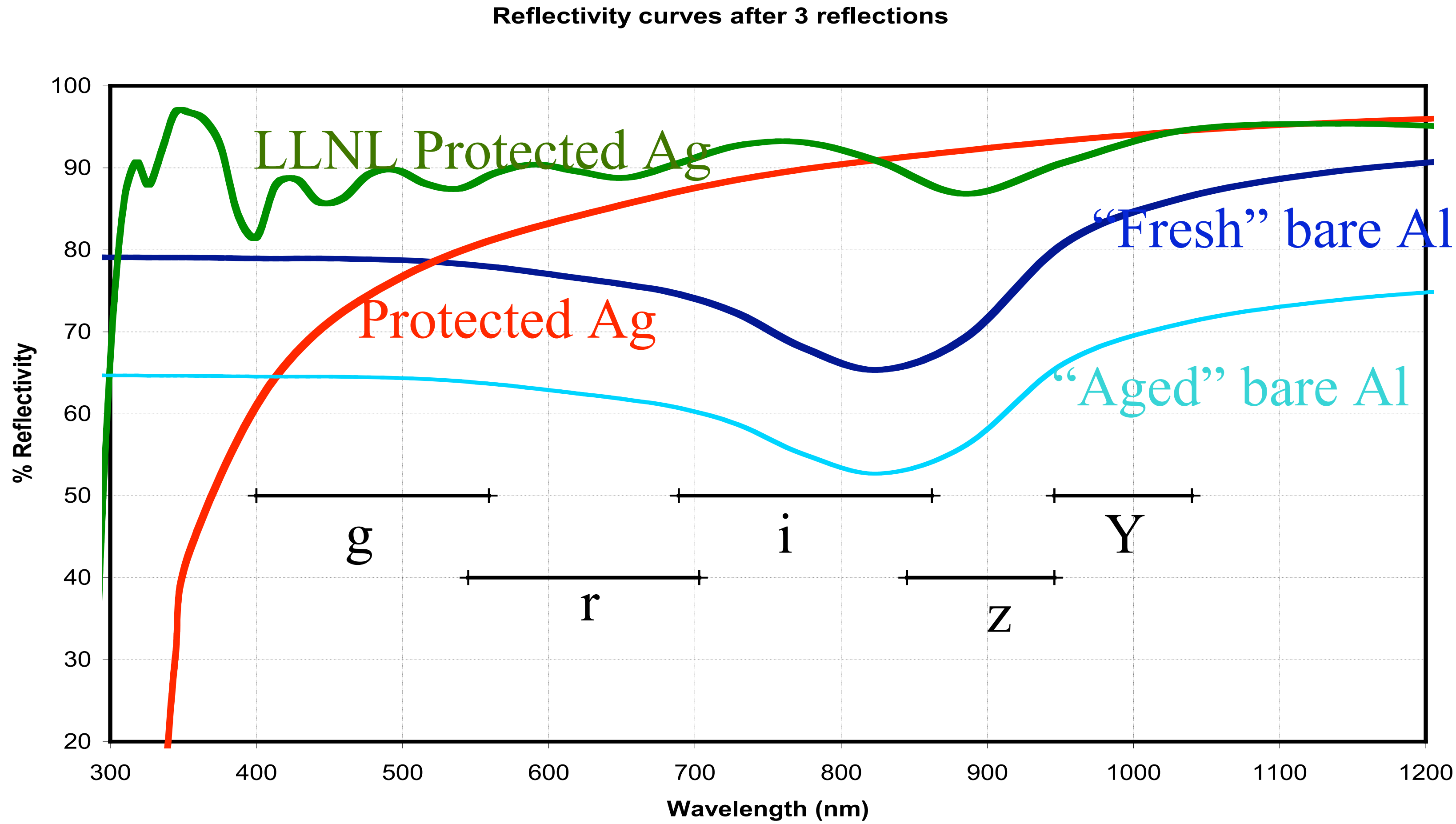
- Dark Energy / Matter
  - –Weak lensing - PSF
  - –Shape/ Depth / Area
  - –Super Novae + Photo z
  - –Filters (ugrizy)
- Map of Solar System Bodies
  - –NEA – Cadence
  - –KBO
- Optical Transients and Time Domain
  - –GRB Afterglows
  - –Image Differencing
- Assembly of the Galaxy
  - –Galactic Halo Structure

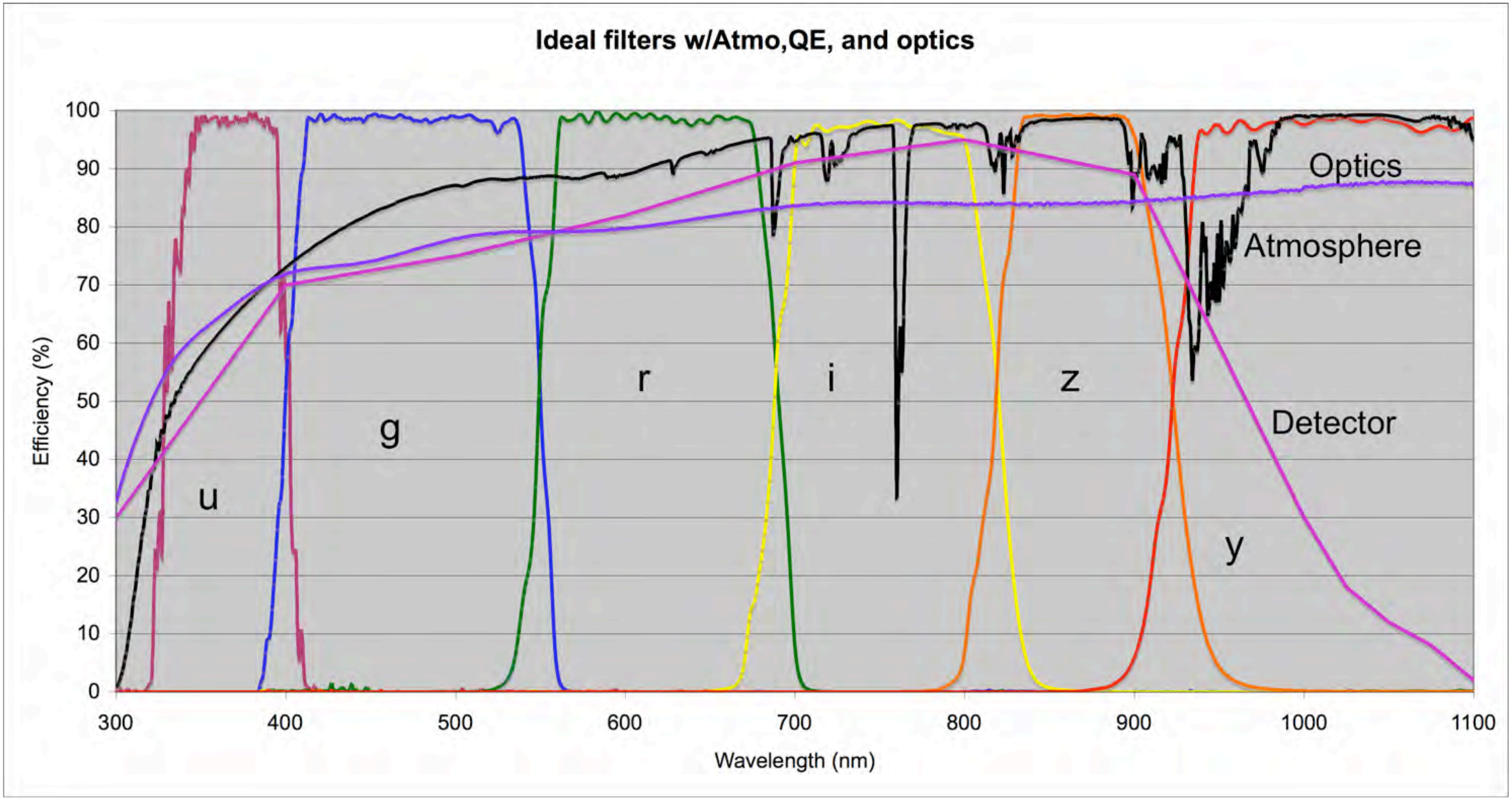
- Image Quality
- fast beam
- Large focal Plane
- Construction Techniques

Science Goals	Observational Requirements	Telescope/Camera/Site Requirements
Nature of Dark Energy 1 *w* to 2% 2 d*w* / dt to 5% 3 *w* (φ) over 2π 4 correlate with CMB All sky weak lensing (WL). Rapid revisit SN (2nd param studies)	5 WL shear > 0.001 vs z 6 15,000 sq deg to V=26.5 AB mag (WL) 7 σ color-z to 0.1(1+z) 8 ~200 exposures per sky patch per filter 9 Photometric calibration: 0.02 mag goal 10 900 sec/filter/field/night, repeat every 5 nights on small # of fields (SN)	11 Image quality: < 0.7" FWHM in V, R, or I bands, PSF quad moment stable < 1% per 10 sec. Shear systematics < 0.0002 in 200 image stack 12 5 bands, for photometric redshifts (WL) & 2nd parameter studies (SN): 350 nm to 1 μm 13 Southern site to match Antarctic SZ surveys? 14 A Ω > 250, noise/read < 5e 15 Dark sky equal to best sites
Optical Transients 16 Extreme physics 17 Rare new objects 18 Orphan GRB statistics 19 SNe in arcs + μlensing	20 Broad coverage in cadence, 20 sec to year time scale 21 Evolution of spectral energy distribution 22 Requires deep initial multiband template 23 Frequent revisits, max sky coverage	24 Requires multi-colors 25 Target latency of <1 min for alerts, high throughput pipeline 26 AΩ > 200 in a single camera to see events as rare as 1/night over 1/5 of the sky: fast pace. Noise/read < 5e.
Solar System 27 PHAs down to 100m 28 Small KBOs + colors 29 MBA statistics, colors	30 Max coverage in ecliptic. Magic elongation 31 6 visits, 15 min sep, per sky patch per lunation 32 Area coverage > 11000 square degrees 33 Sufficient AΩ to get 90% completeness for PHAs in	34 Maximum exposure of 15 sec to avoid trailing losses 35 Image quality < 1" FWHM 36 AΩ > 200 per camera, noise/read < 5 e. 37 Multiple 500-800nm filters

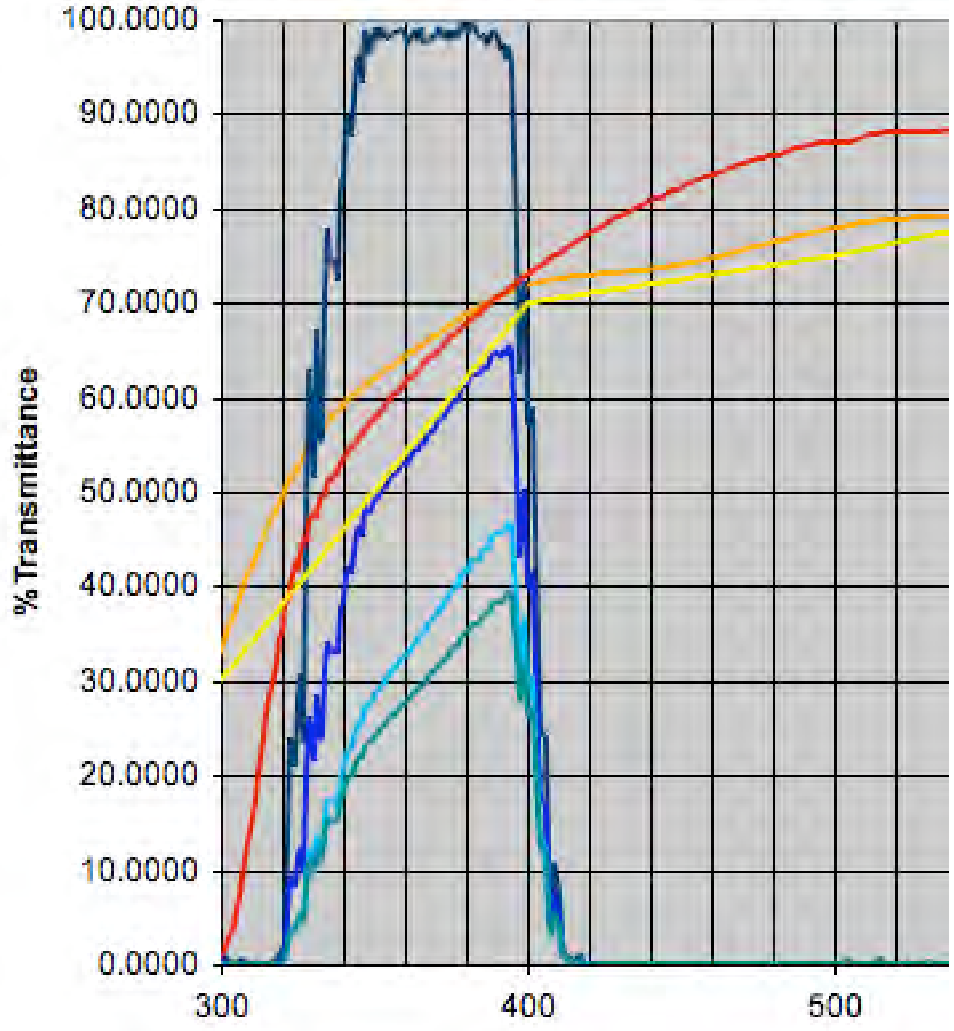
Optical and Throughput Issues

COATINGS TEST PROGRAM




Ideal filters w/Atmo,QE, and optics
Efficiency (%)
100
90
80
70
60
50
40
30
20
10
0
300
400
500
600
700
800
900
1000
1100
Wavelength (nm)
u
g
r
i
z
y
Optics
Atmosphere
Detector

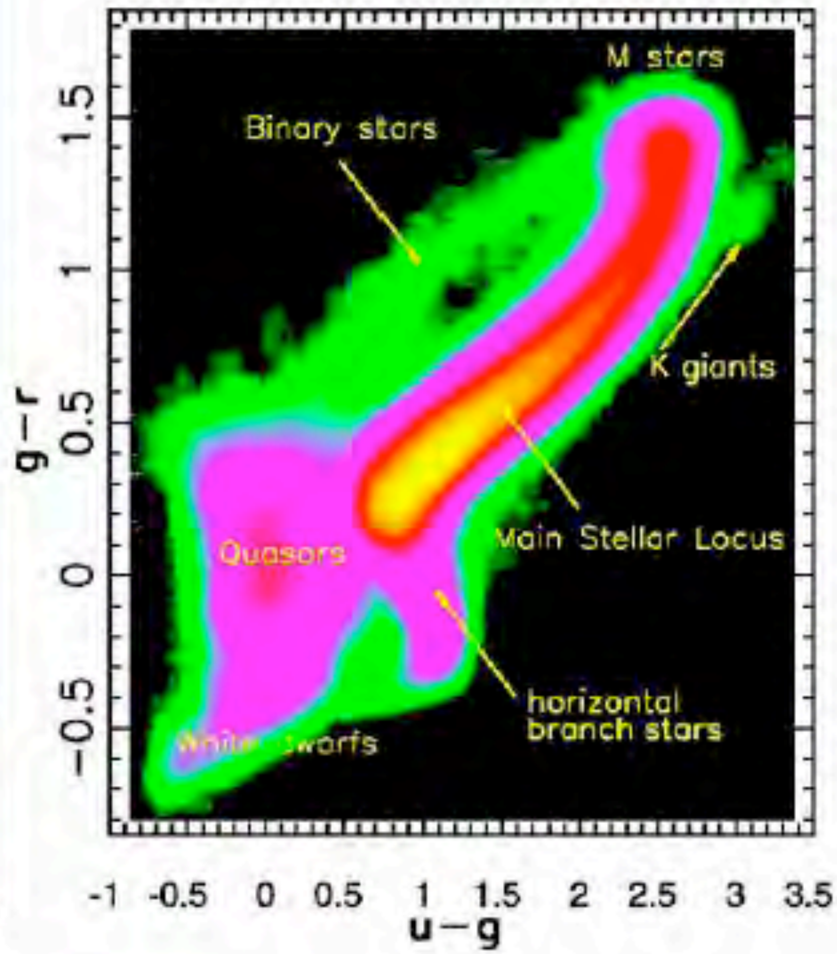
U-Band Profile



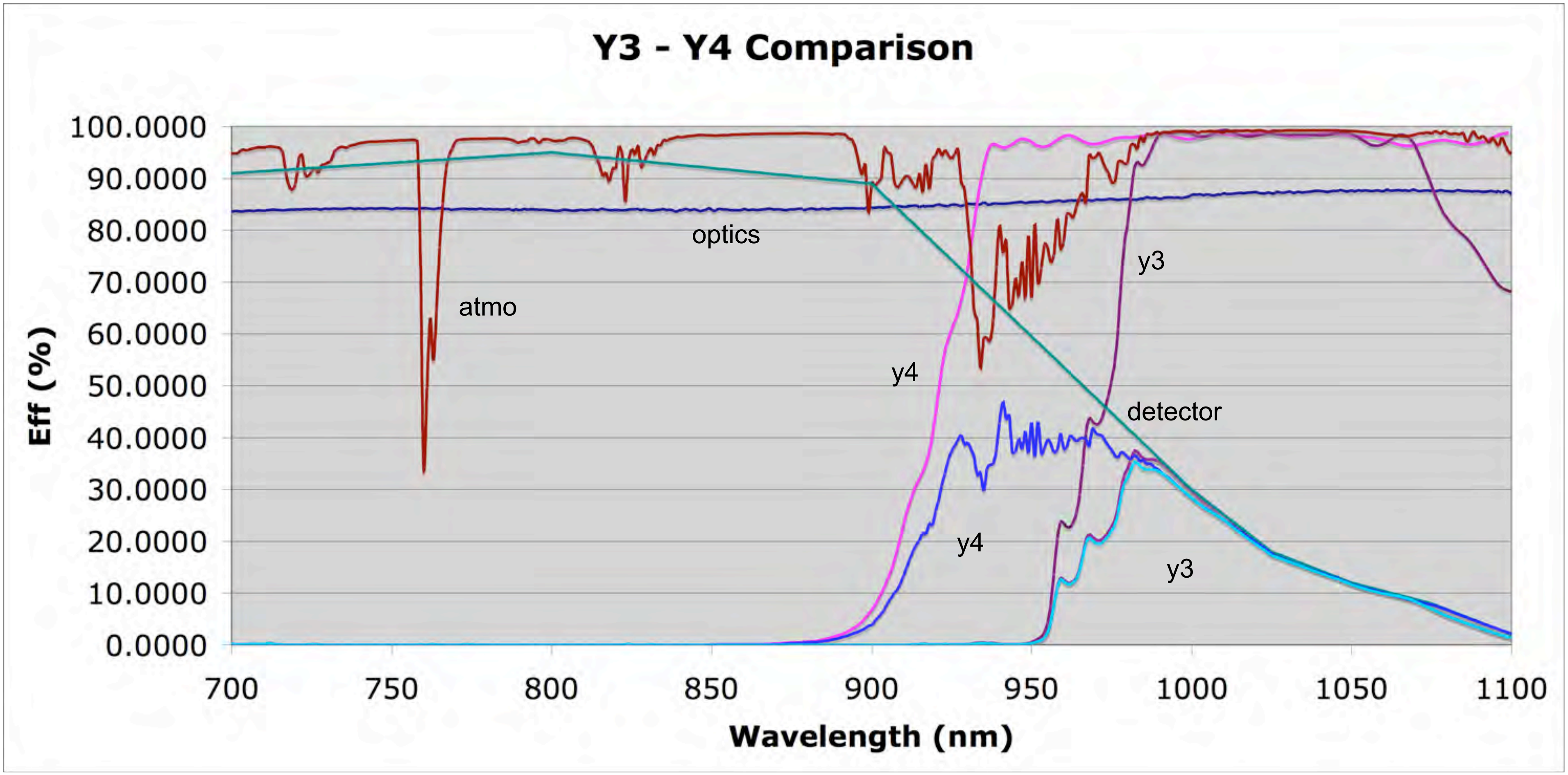
The u-band is critical for:

- Galaxies: photometric z, SFR
- SNe: typing, redshifts …
- QSOs: UV excess, phot-z <3
- Stars: metallicity, WDs
- Transients: UV
- ISM: dust in the Milky Way

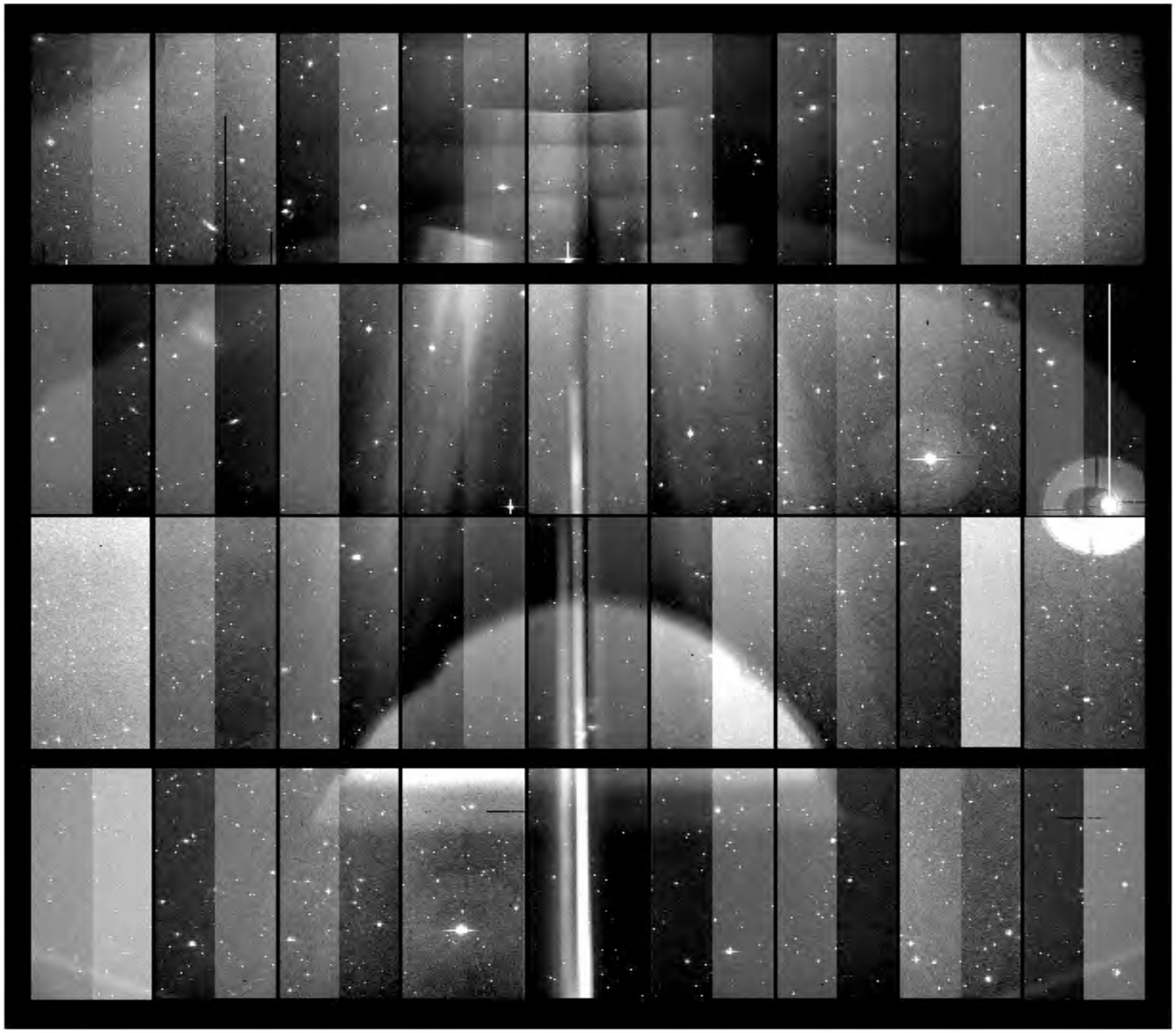
The complexity of the g-r vs u-g color-color diagram for point sources vividly illustrates the value of the *u*-band data



Y-band Choices for Thick Sensors

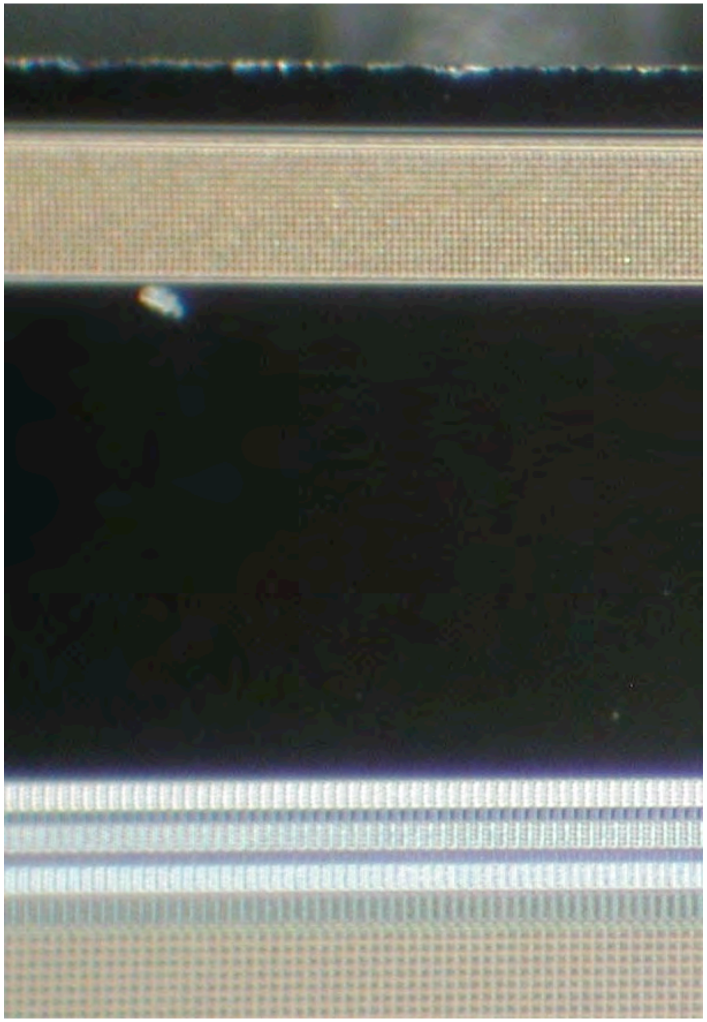


Stray and Scattered Light

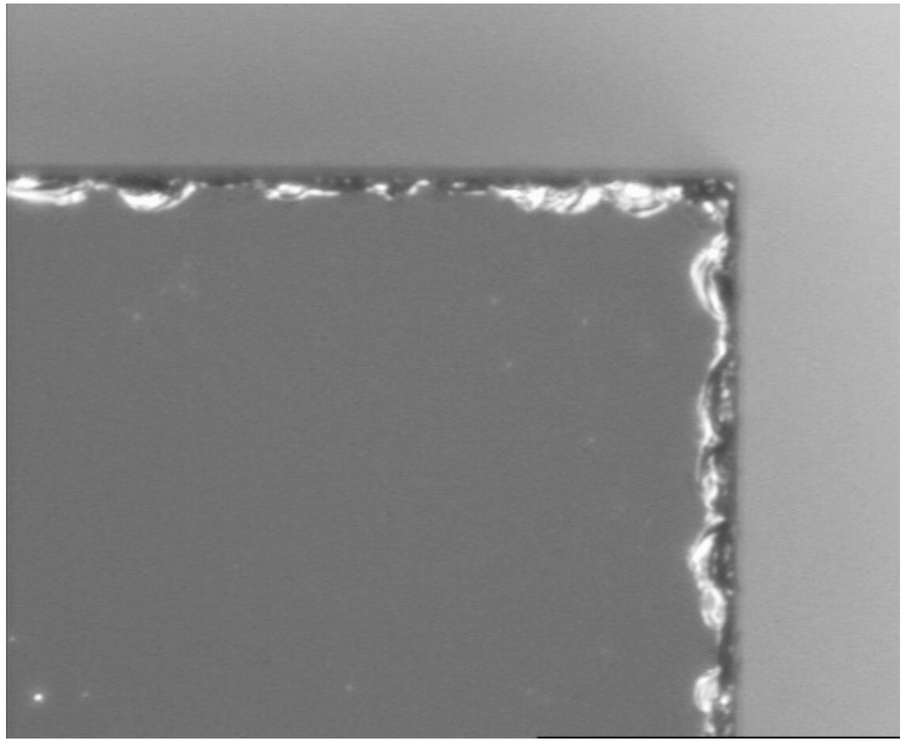


Saw/cut Lines on Sensor Die (Glints)

Clean



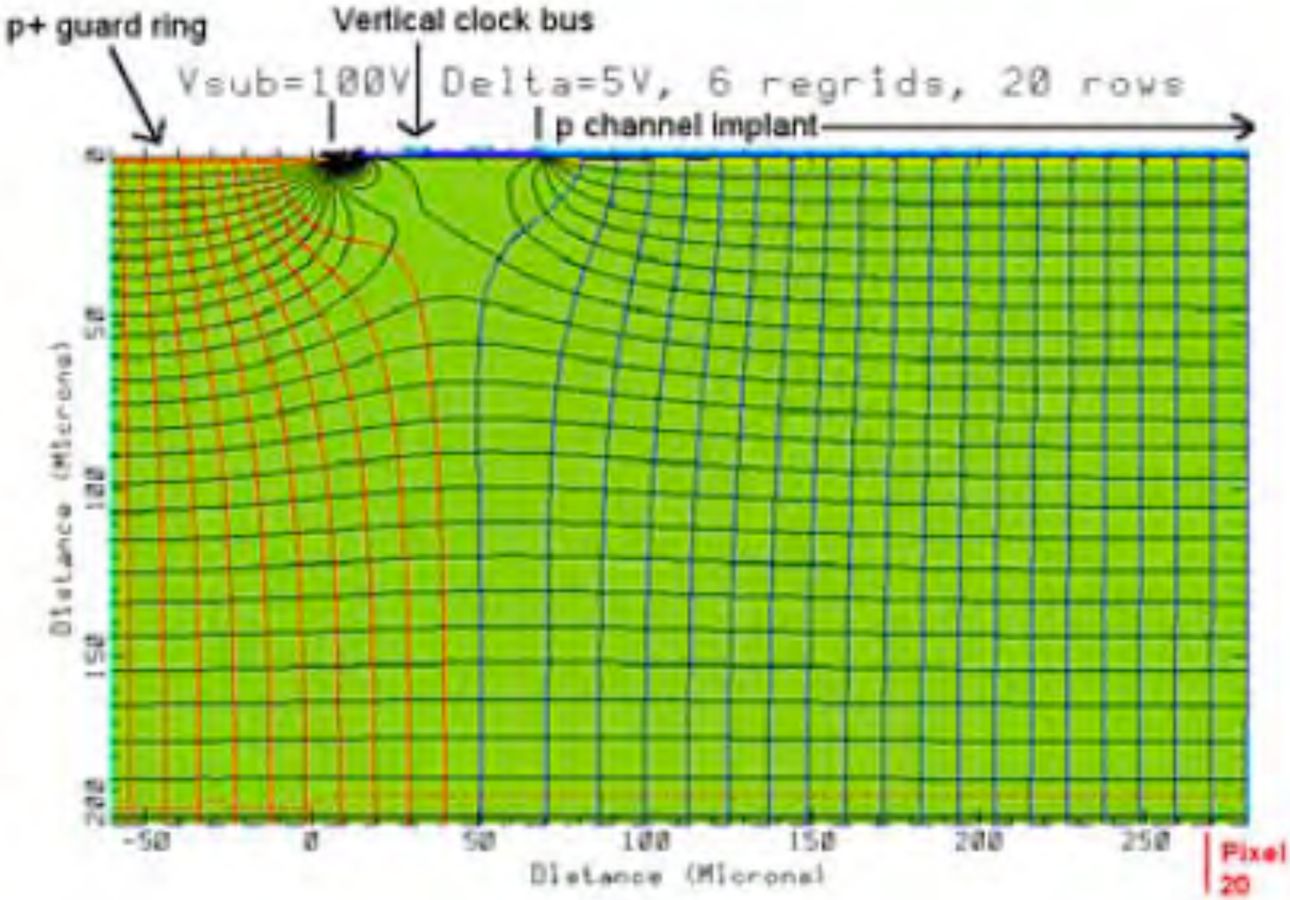
Not so clean



NGC 5907

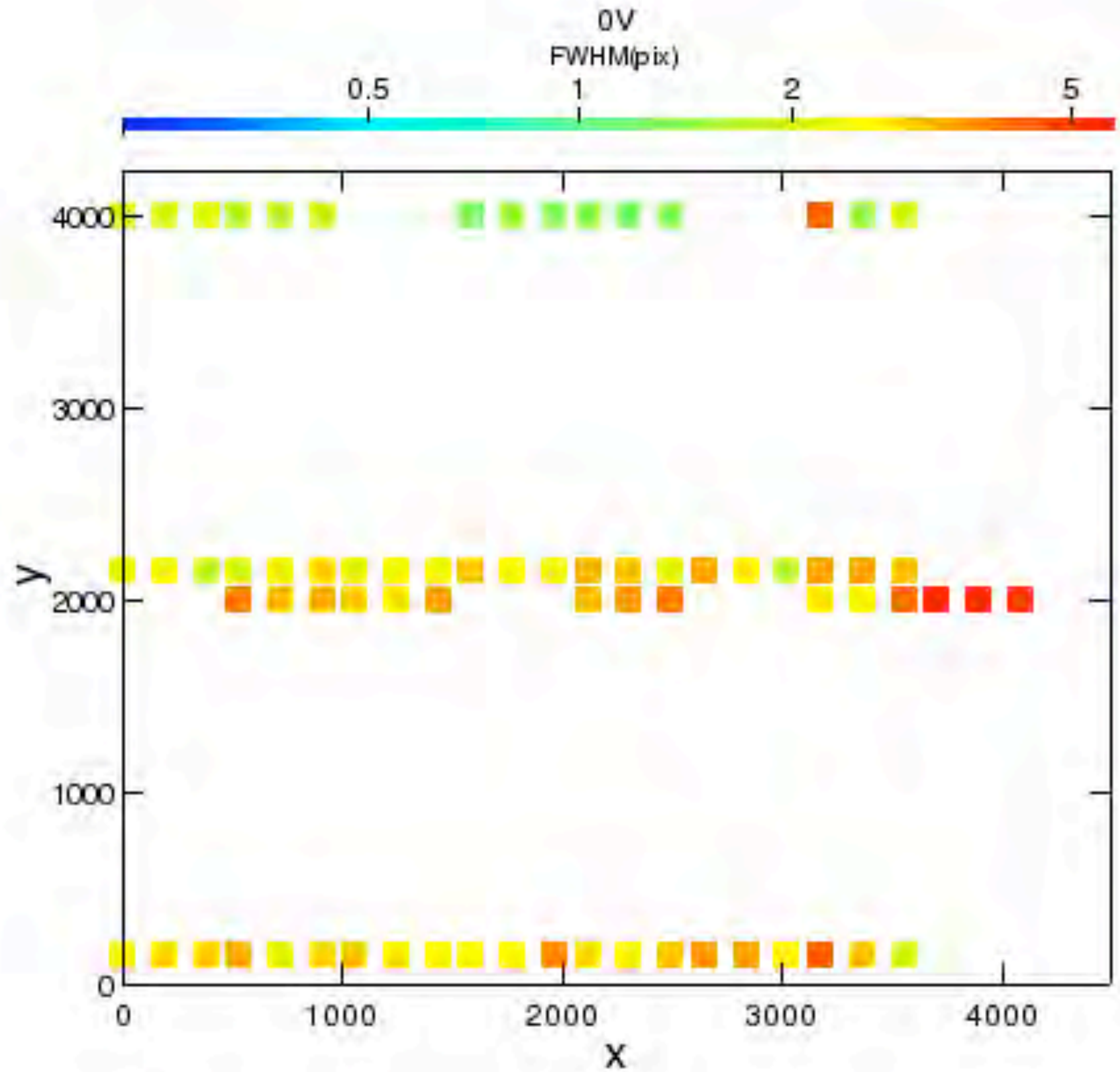
NGC 5907

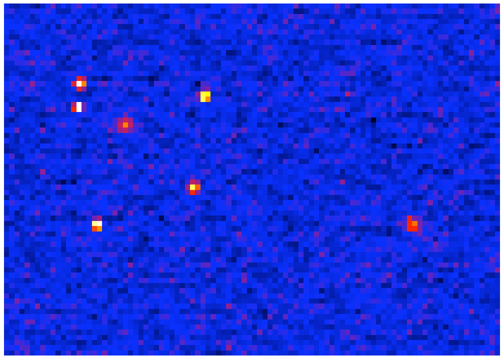
Detector Issues



p+ guard ring
Vertical clock bus
Vsub=100V Delta=5V, 6 regrids, 20 rows
p channel implant
Distance (Microns)
Distance (Microns)
Pixel 20

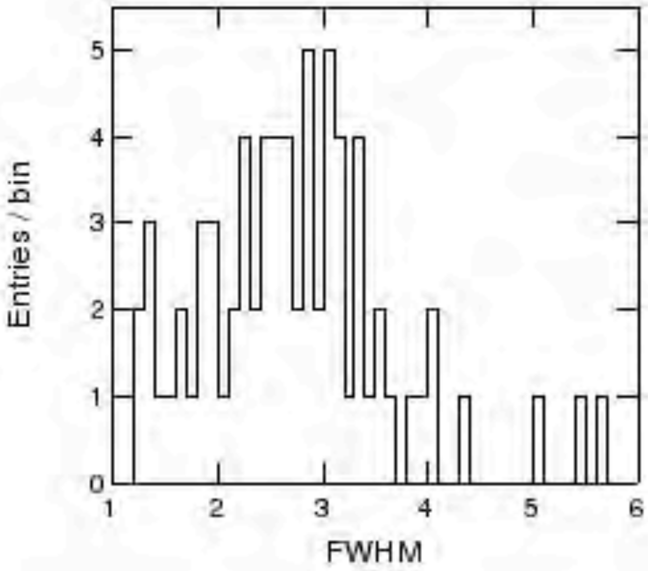
Fe_{55} Tests



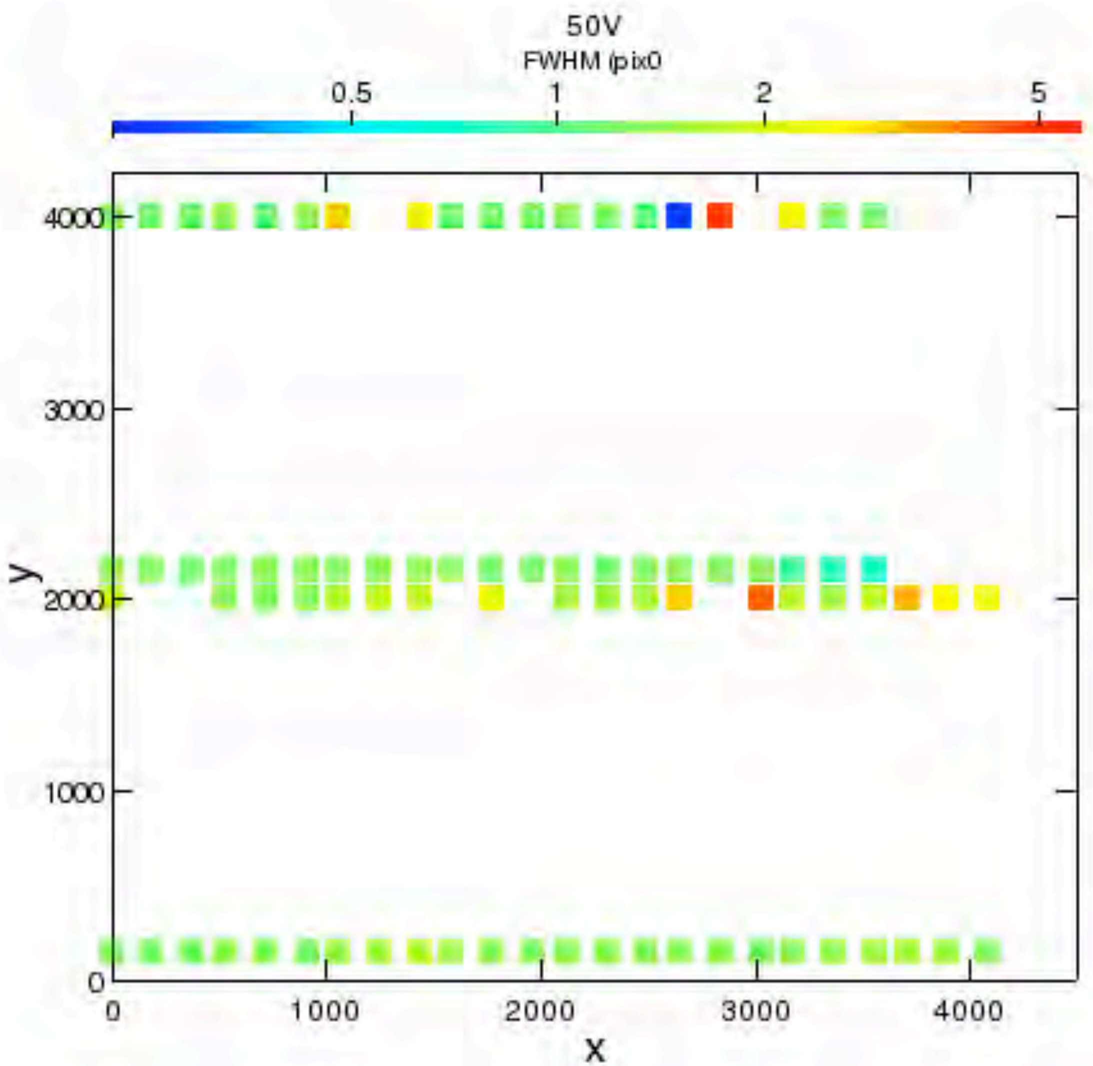


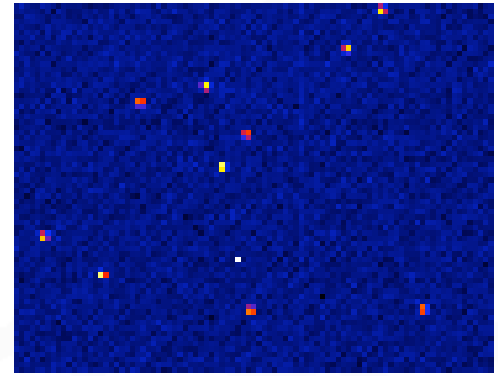
Total_entries = 72

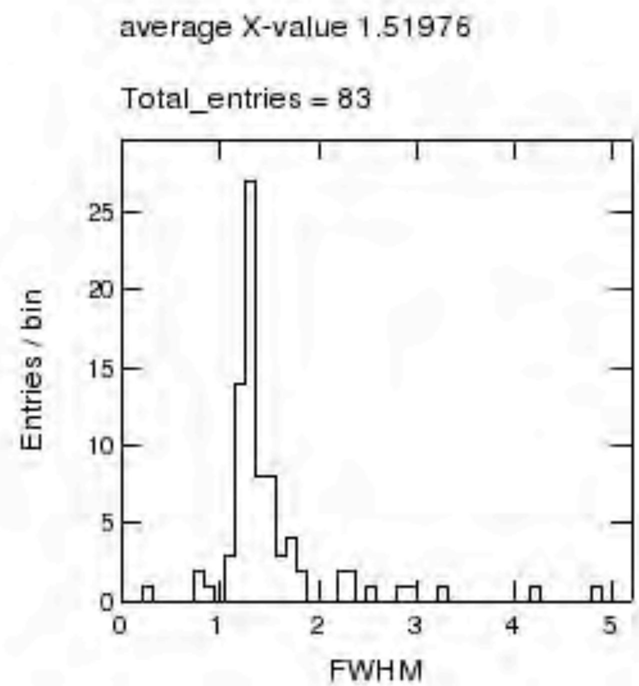
average X-value 2.74611



Fe_{55} Tests


50V
FWHM (pix0
0.5
1
2
5
4000
3000
2000
1000
0
y
0
1000
2000
3000
4000
x




average X-value 1.51976
Total_entries = 83
Entries / bin
25
20
15
10
5
0
0
1
2
3
4
5
FWHM

Point Spread Function

The Forward Process.

Galaxies: Intrinsic galaxy shapes to measured image:

PSF measurement

Shear variance

(Galaxy size / PSF size)^4

PSF ellipticity

Uncertainty on PSF ellipticity

Uncertainty on PSF size

$$\sigma^2_{\mathrm{sys}} = (P^{\gamma})^{-2} \left\langle \left(\frac{R_{\mathrm{PSF}}}{R_{\mathrm{gal}}}\right)^4 \right\rangle \times \left[2\sigma^2[\epsilon_{\mathrm{PSF}}] + \left(\left\langle |\epsilon_{\mathrm{gal}}|^2 \right\rangle + \left\langle |\epsilon_{\mathrm{PSF}}|^2 \right\rangle \right) \left(\frac{\sigma[R^2_{\mathrm{PSF}}]}{R^2_{\mathrm{PSF}}} \right)^2 \right]$$

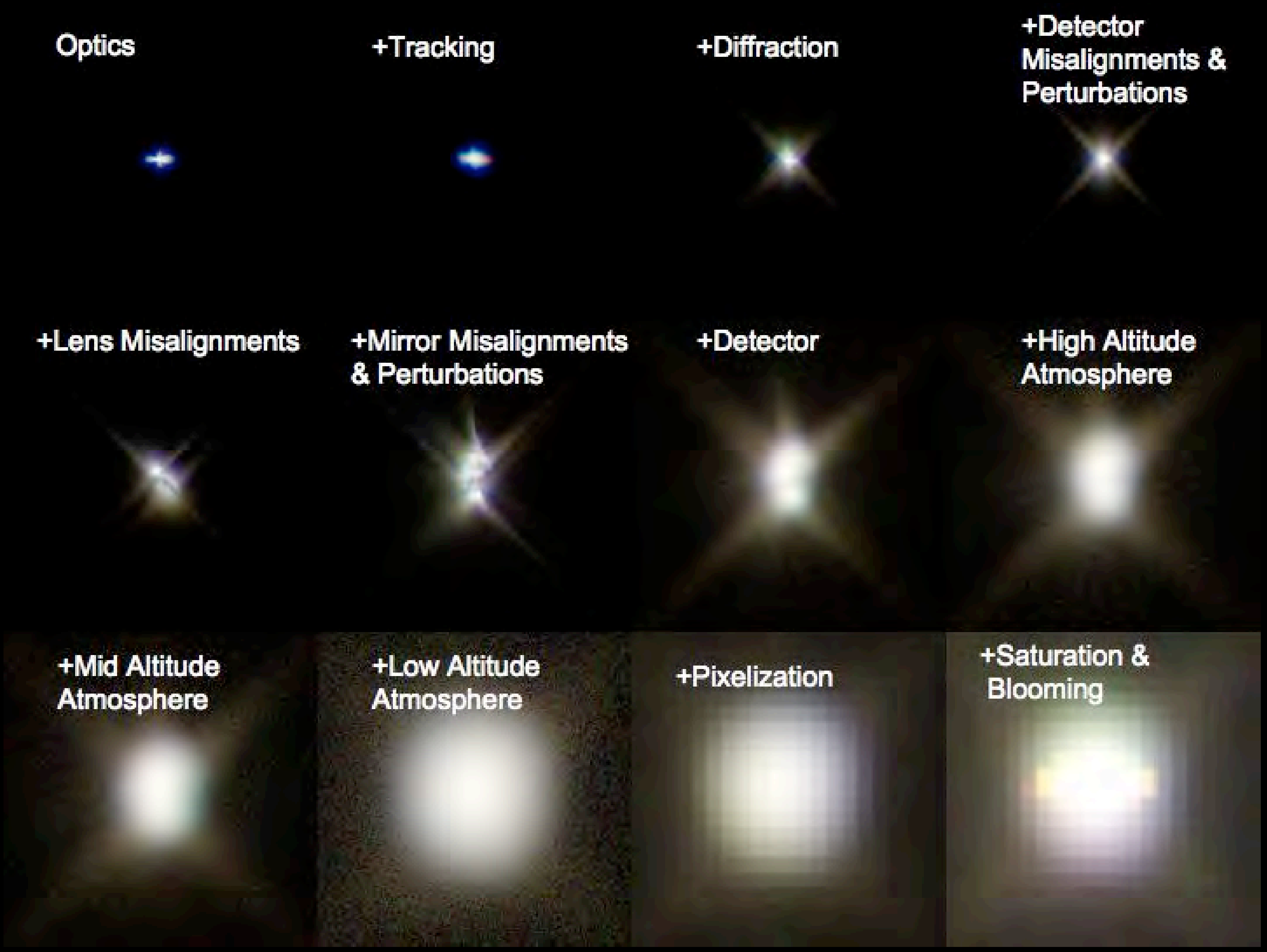
$\Rightarrow$ **Need small round PSF**

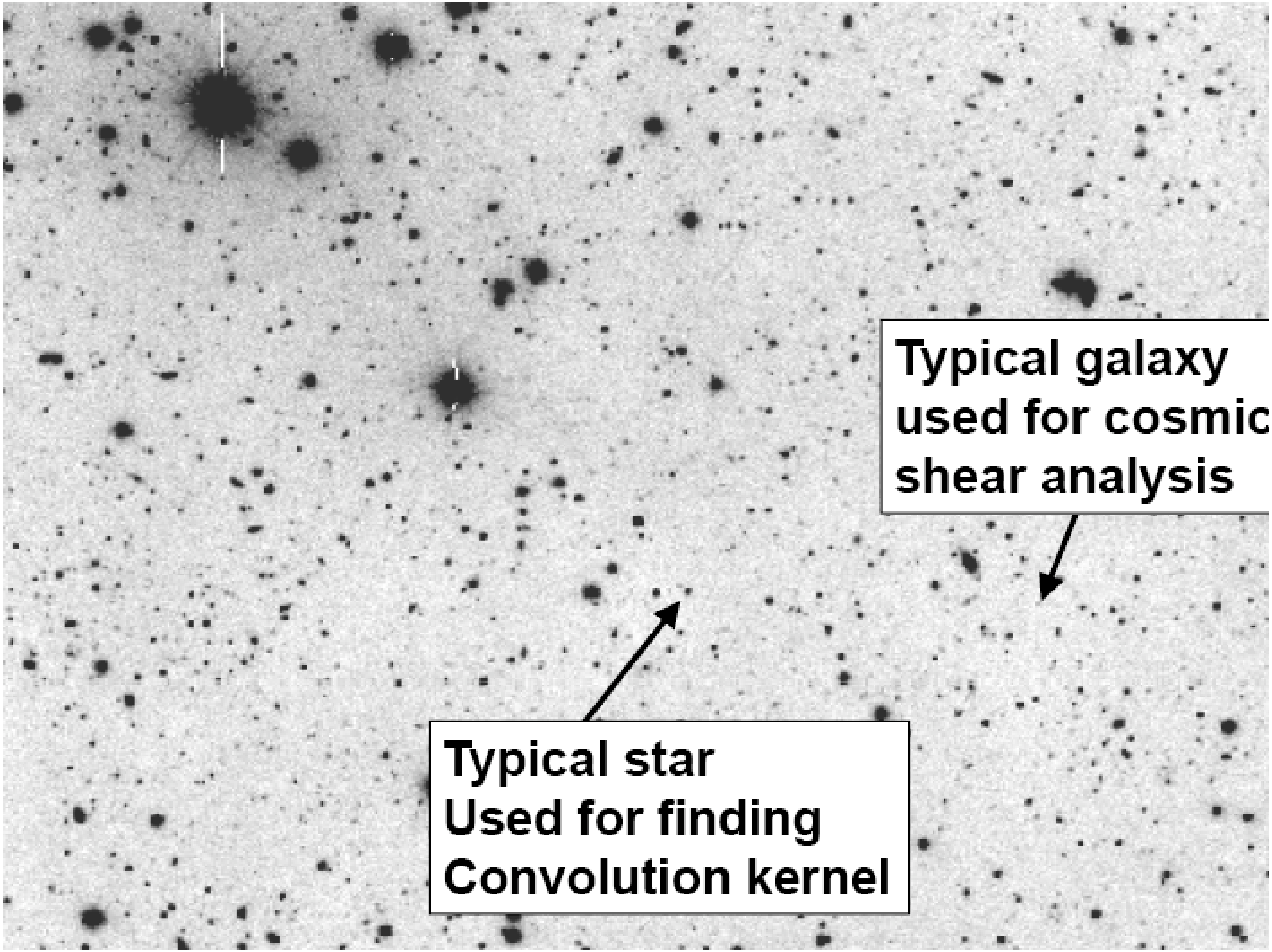
$\Rightarrow$ **Need stable PSF**

Why is this hard?

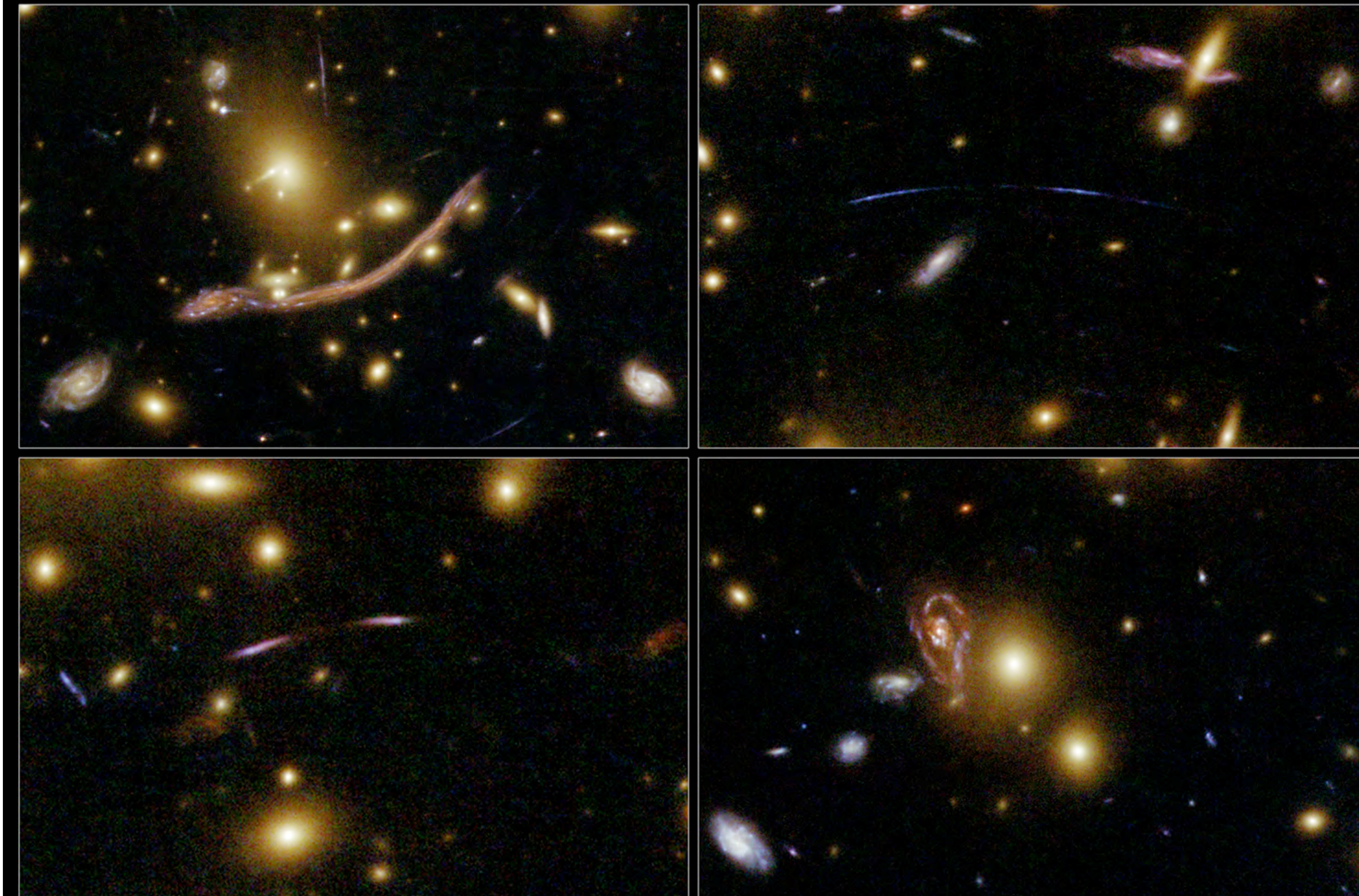
- Galaxies are not circles or ellipses
- Galaxy orientations may align during formation
- Telescope and atmosphere convolve image
  = point spread function (psf)
  – spatially varying
  – time varying
- CCD responsivity, cosmic rays, metors, unresolved sources, variable atmosphere, saturated stars
- Pixelisation of images (~sum of light over pixel)
- Partial and patchy sky coverage
- We don’t have galaxy distances
- Mass distribution is not Gaussian

Image Simulations




Typical galaxy
used for cosmic
shear analysis
Typical star
Used for finding
Convolution kernel

Abell370



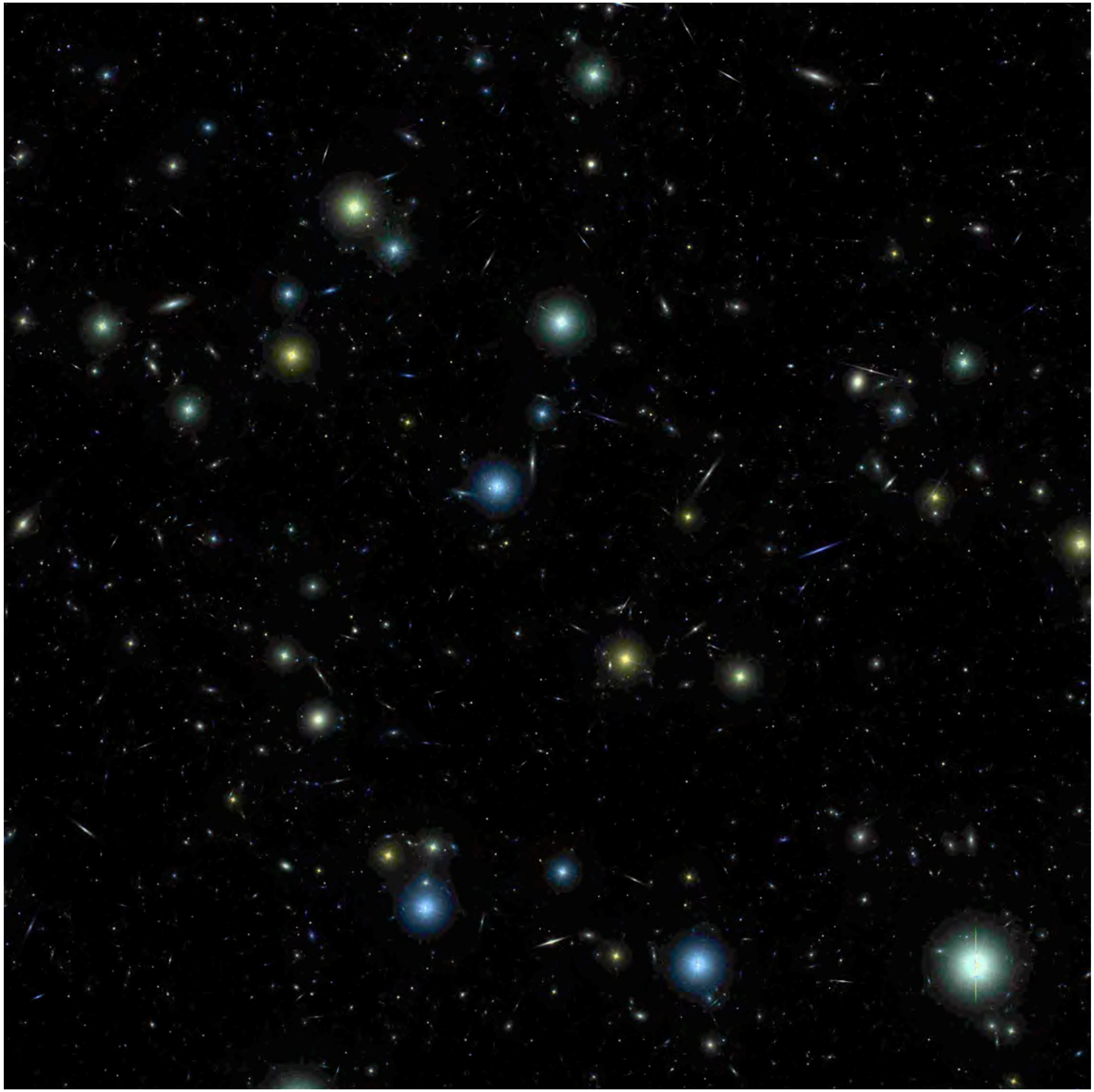
Goals of Image Simulation

- Primary Drivers
  - High fidelity simulations to develop/test data management systems
    - Test and optimize pipeline framework
    - Develop and test algorithms for source detection/subtraction/linkage/classification
    - Determine the impact of uncertainties on outputs (astrometric and photometric)
    - Determine sensitivity to systematics in the system (glints and ghosts, coherent errors)
- Secondary Drivers
  - Astronomically meaningful simulations
    - Provide realistic data for the science collaborations to develop science applications
    - Test design of the system for science goals

14'^{2}

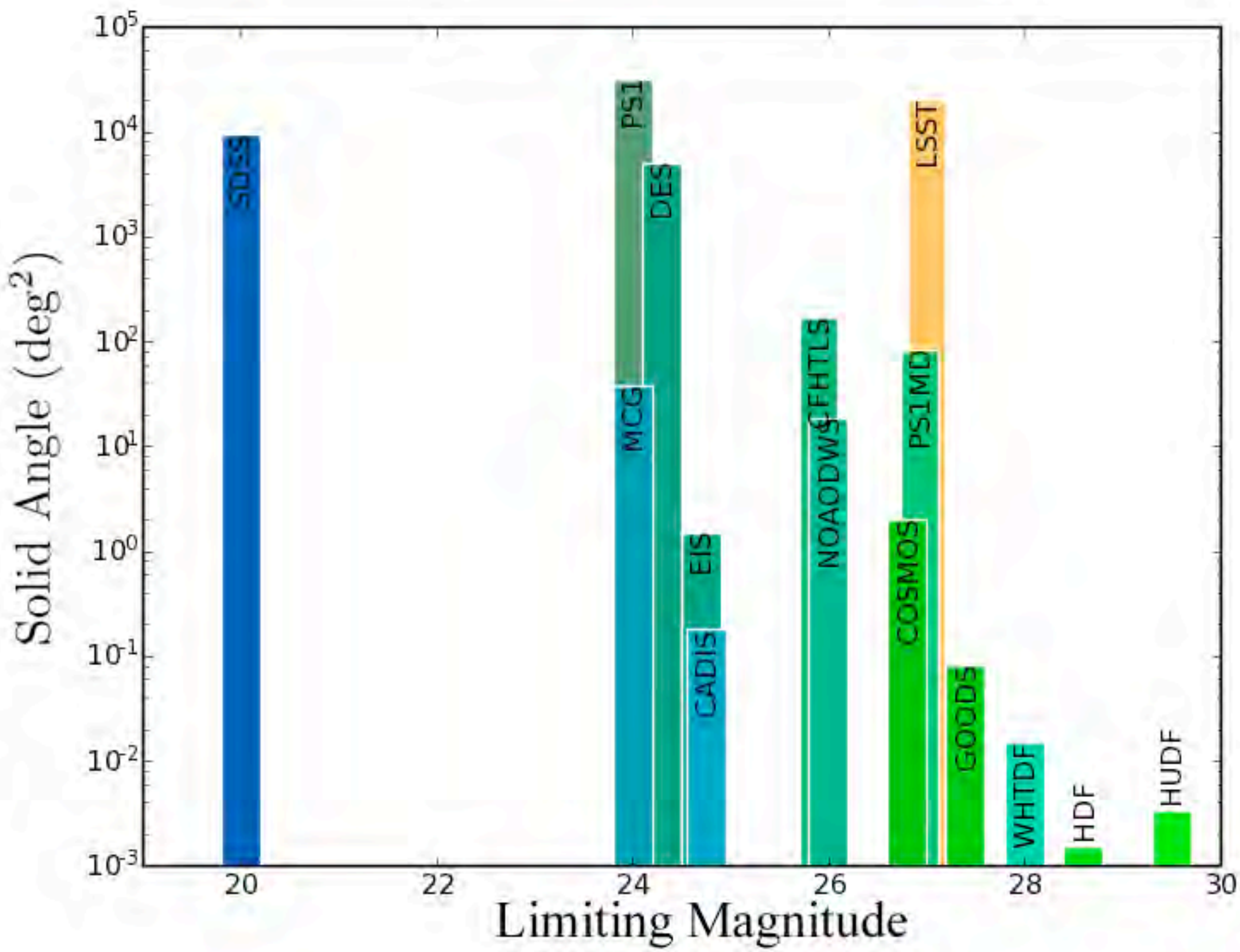
12th-40th mag

G, r, I filters

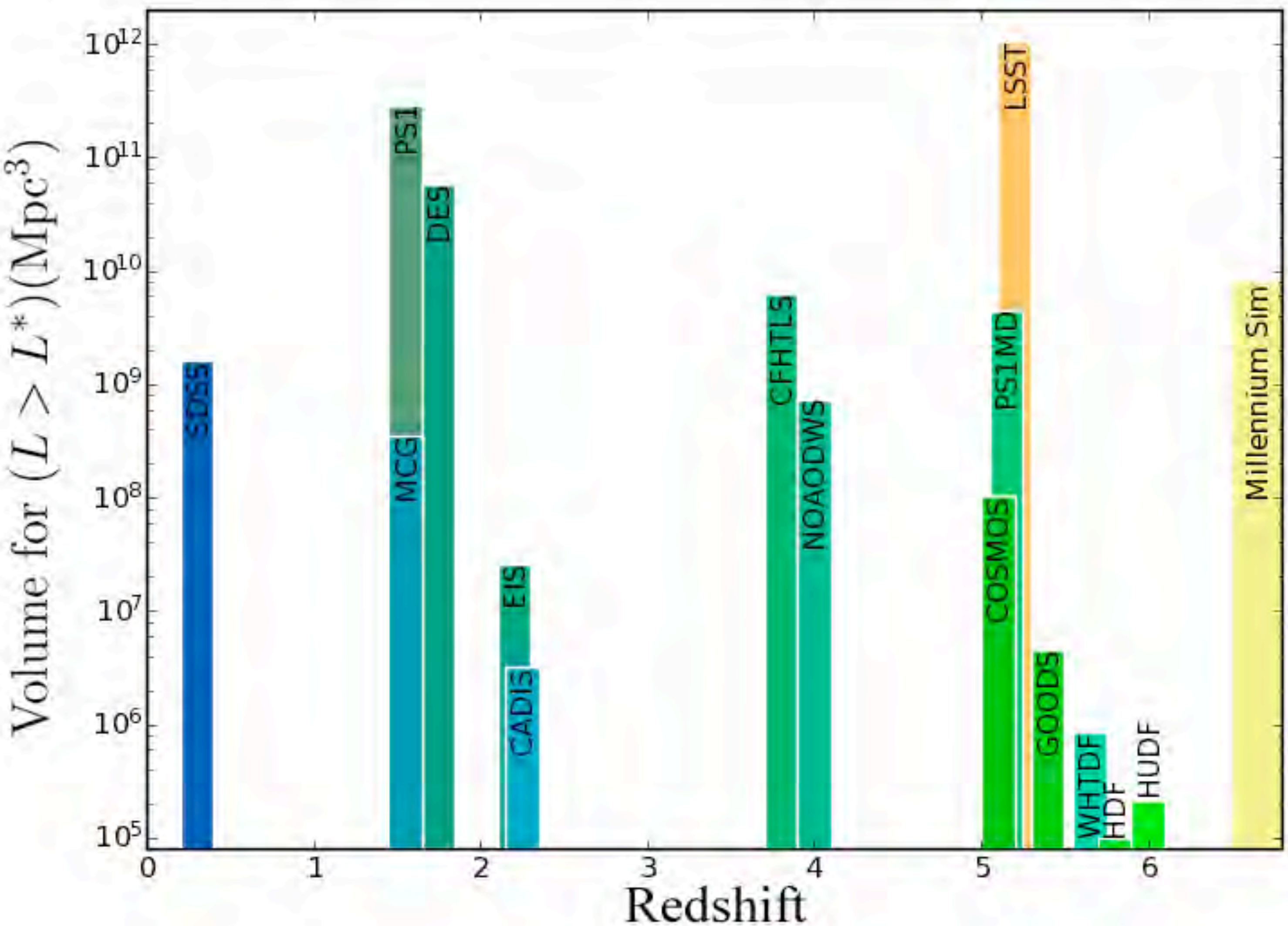


Surveys

Limiting Magnitude Survey Comparisons



Redshift Survey Comparisons



LSST Baseline Design and Survey Parameters

Quantity	Baseline Design SpeciΛcation
Optical ConΛg.	3-mirror modiΛed Paul-Baker
Mount ConΛg.	Alt-azimuth
Final f-Ratio, aperture	f/1.234, 8.4 m
Field of view, Atendue	9.6 deg^2, 318 $m^2 deg^2$
Plate Scale	50.9 ϵ m/arcsec (0.2" pix)
Pixel count	3.2 Gigapix
Wavelength Coverage	320 – 1050 nm, *ugrizy*
Single visit depths[a] (5ϵ)	23.9, 25.0, 24.7, 24.0, 23.3, 22.1
Mean number of visits	70, 100, 230, 230, 200, 200
Final (coadded) depths[a]	26.3, 27.5, 27.7, 27.0, 26.2, 24.9

Large Synoptic Survey Telescope

Statistics by Filter

Filter	N_{obs}	Average V_{sky}
u	156783	21.39 $\pm$ 0.12
g	252765	21.26$\pm$ 0.39
r	562431	21.14 $\pm$ 0.47
i	575893	20.81 $\pm$ 0.74
z	616089	18.71 $\pm$ 1.19
y	516998	19.09 $\pm$ 1.17

Table 9: Average V_{sky} is the average of the sky brightness in V for all the observations taken in each filter.

U=5.8%
G=9.4%
R=21%
I=21.5%
Z=23%
Y=19.3%

Comparison of BOSS, JDEM-BAO and BigBOSS

	BOSS	BigBOSS-N	JDEM	BigBOSS-N+S
Redshift	$0.2<z<0.7$	$0.2<z<3.5$	$0.7<z<2.0$	$0.2<z<3.5$
Sky Coverage	10000 deg^2	14000 deg^2	20000 deg^2	24000 deg^2
Field-of-View	7.0 deg^2	7.0 deg^2	0.6 deg^2	7.0 deg^2
Number of Fibers	1000	4000	Slitless	4000
Angular size of Fibers	2"	1.5"	n/a	1.5"
Wavelength Range	360-1000 nm	340-1130 nm	1100–2000 nm	340nm–1130 nm
Spectral Resolution	1600-2600	2300-6100	200	2300-6100
DETF FoM	57	175	250	286
DETF FoM w/Stage III	107	240	313	338

Table 1. BigBOSS-North and the full BigBOSS experiment compared to the current BOSS experiment (under construction) and JDEM-BAO (the only other stage-IV BAO project currently proposed). The Dark Energy Task Force (DETF) Figures-of-Merit (FoM) include Planck priors or Plank plus Stage III supernova and weak lensing experiments.

Note: JDEM-BAO FOM does not include the weak lensing and Type Ia supernova components of the JDEM mission.

From LBNL Technical Overview
http://nigboss/lbl.gov/technical_overview.html

The End of Survey Discoveries?

- In the early 1900's the universe seemed to consistof stars, and a sprinkling of dust. Optical observations gave way to:

- X-ray - Collapsed object binaries and inter-cluster medium
- Radio - Radio galaxies and pulsars
- µwave - Molecular clouds and big bang fossil background
- IR - Ultraluminous starburst galaxies and brown dwarfs
- Sub-mm - epoch of galaxy formation

- Also revealed new states of matter (relativistic plasma, black holes…)
- At this point, orders of magnitude improvements are unthinkable

The future:

- Detailed Spectroscopy is key technique of modern astrophysics
- Spatial Resolution - Point of ELT's w/MCAO
- Polarization - Surveys to 0.1%
- Neutrino Astrophysics and VHE cosmic rays - Best bet for 21st century?
- Gravitational Waves - They have to be there somewhere

Tonry and Onaka - The Real World