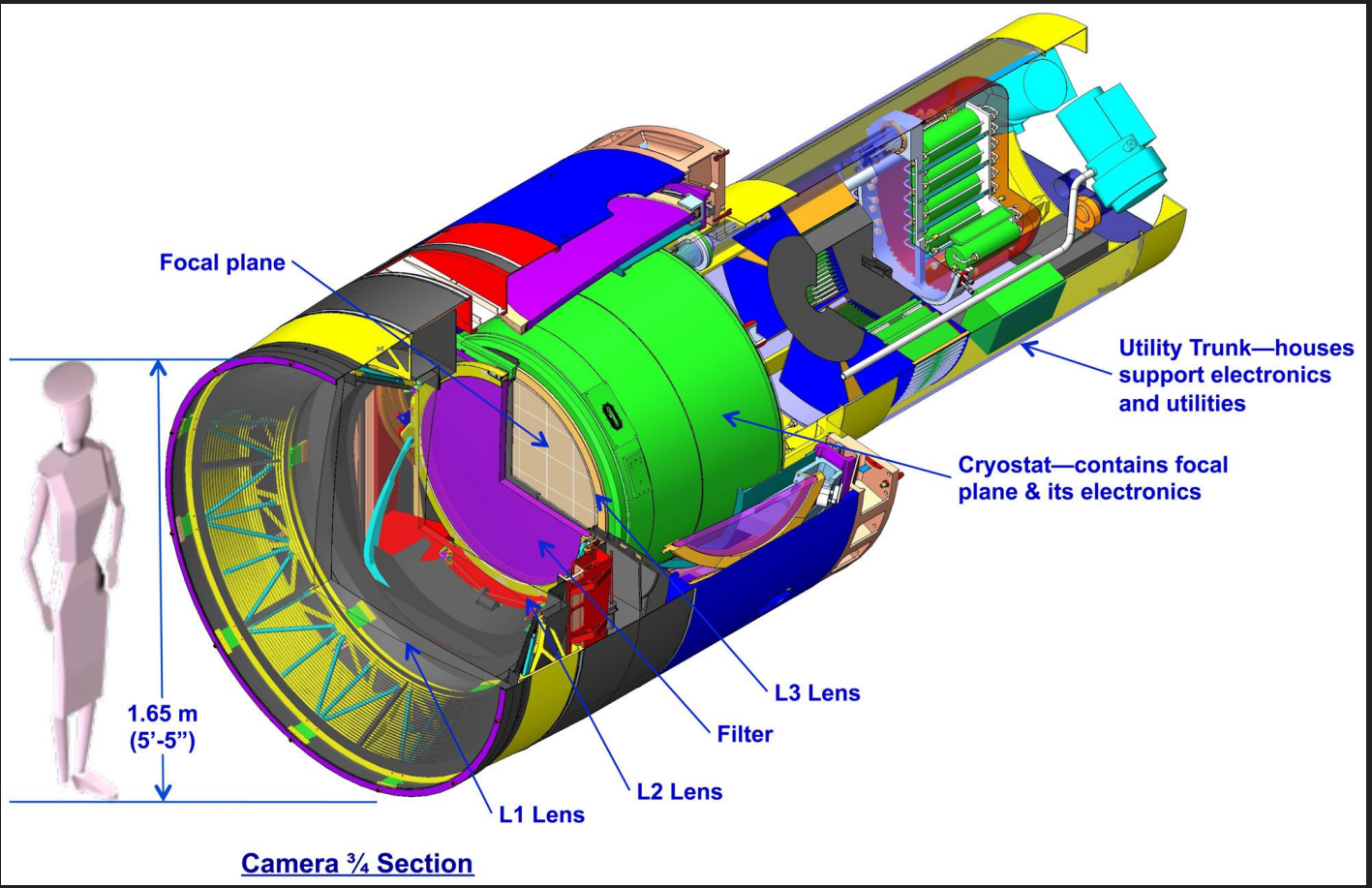
Wide, Fast, and Deep: Why SLAC is building the **world's largest digital camera**

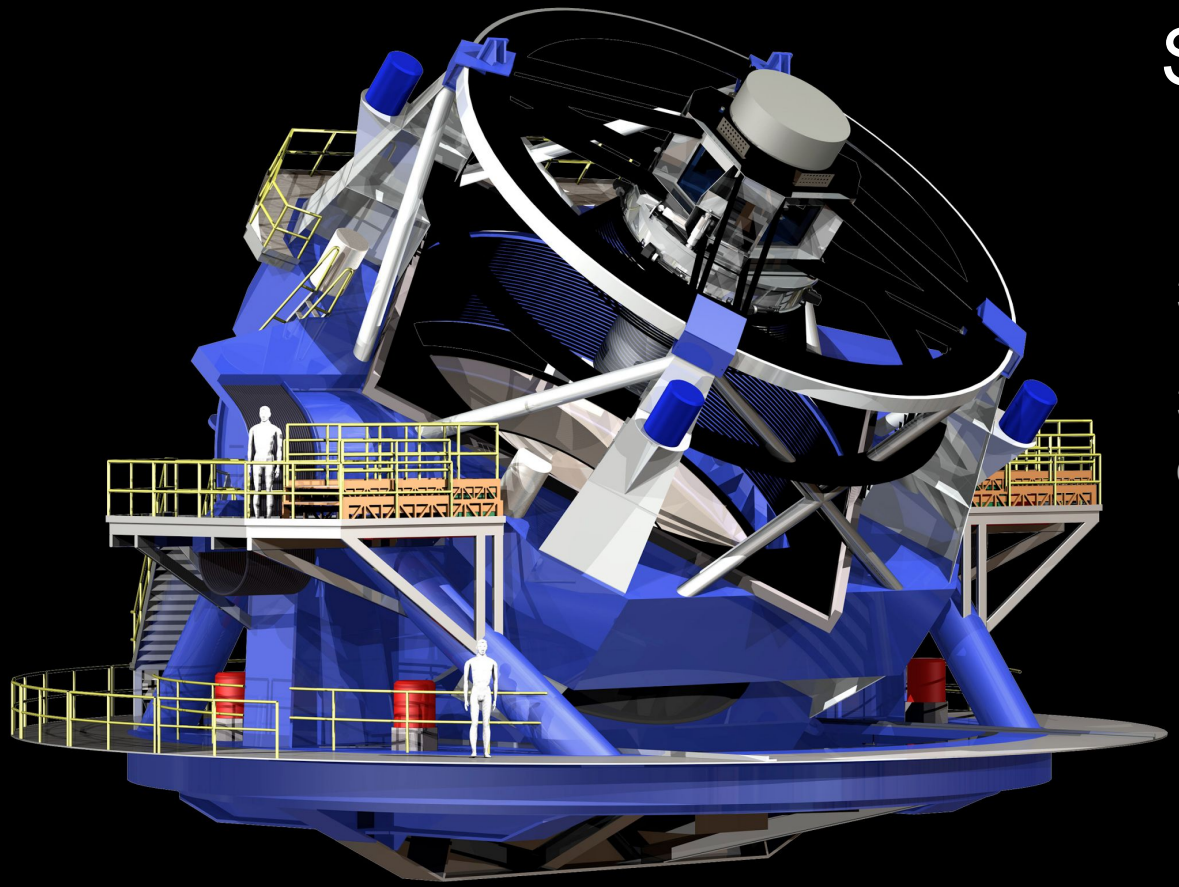
Mike Baumer

Large Synoptic Survey Telescope

KIPAC

SLAC NATIONAL ACCELERATOR LABORATORY


Focal plane
Utility Trunk—houses support electronics and utilities
Cryostat—contains focal plane & its electronics
L3 Lens
Filter
L2 Lens
L1 Lens
1.65 m
(5'-5")
Camera ¾ Section



Large Synoptic Survey Telescope

3.2 gigapixels

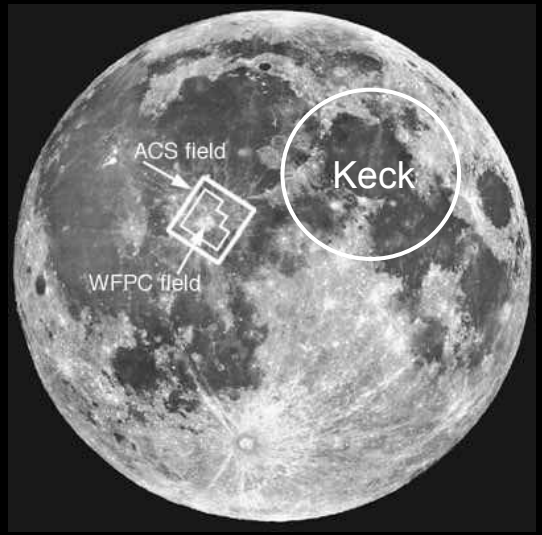
37 billion astronomical objects

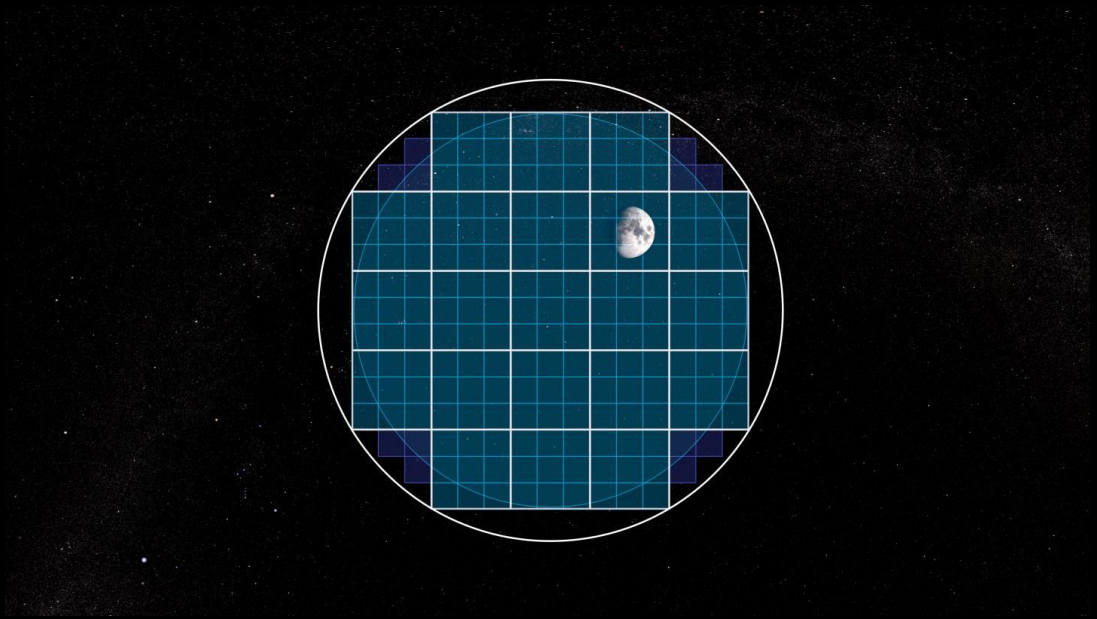
100,000 supernovae

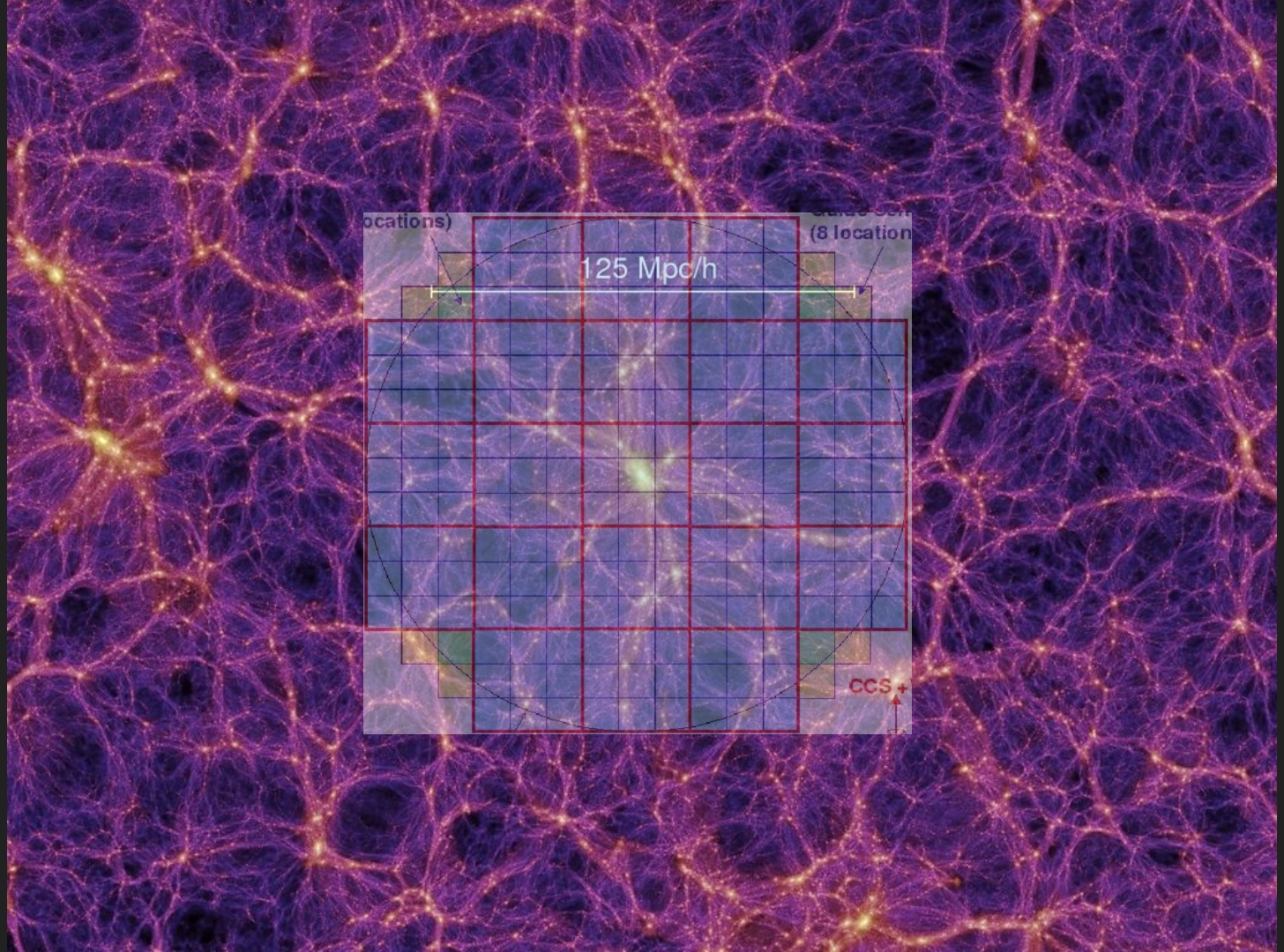
...

Wide, Fast, and Deep

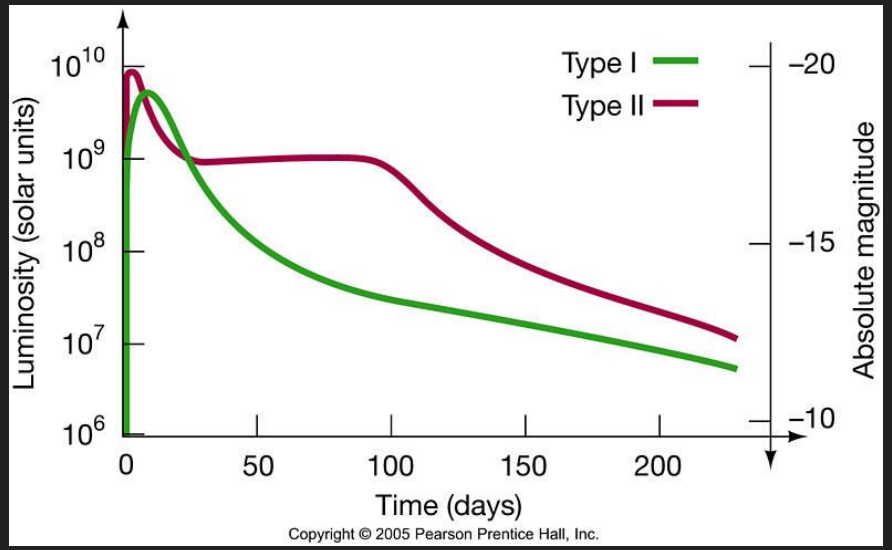
Wide

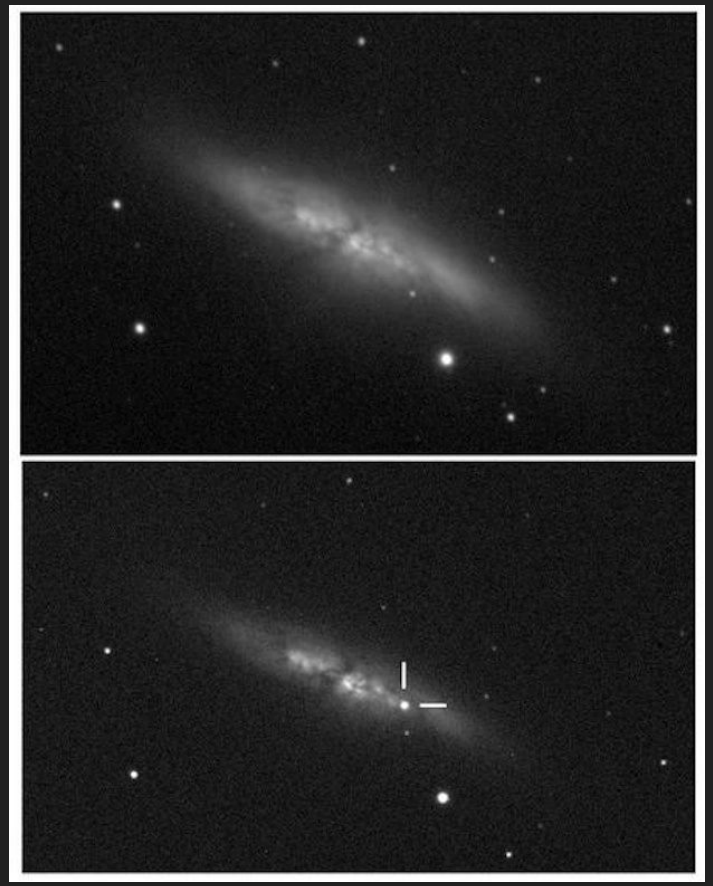




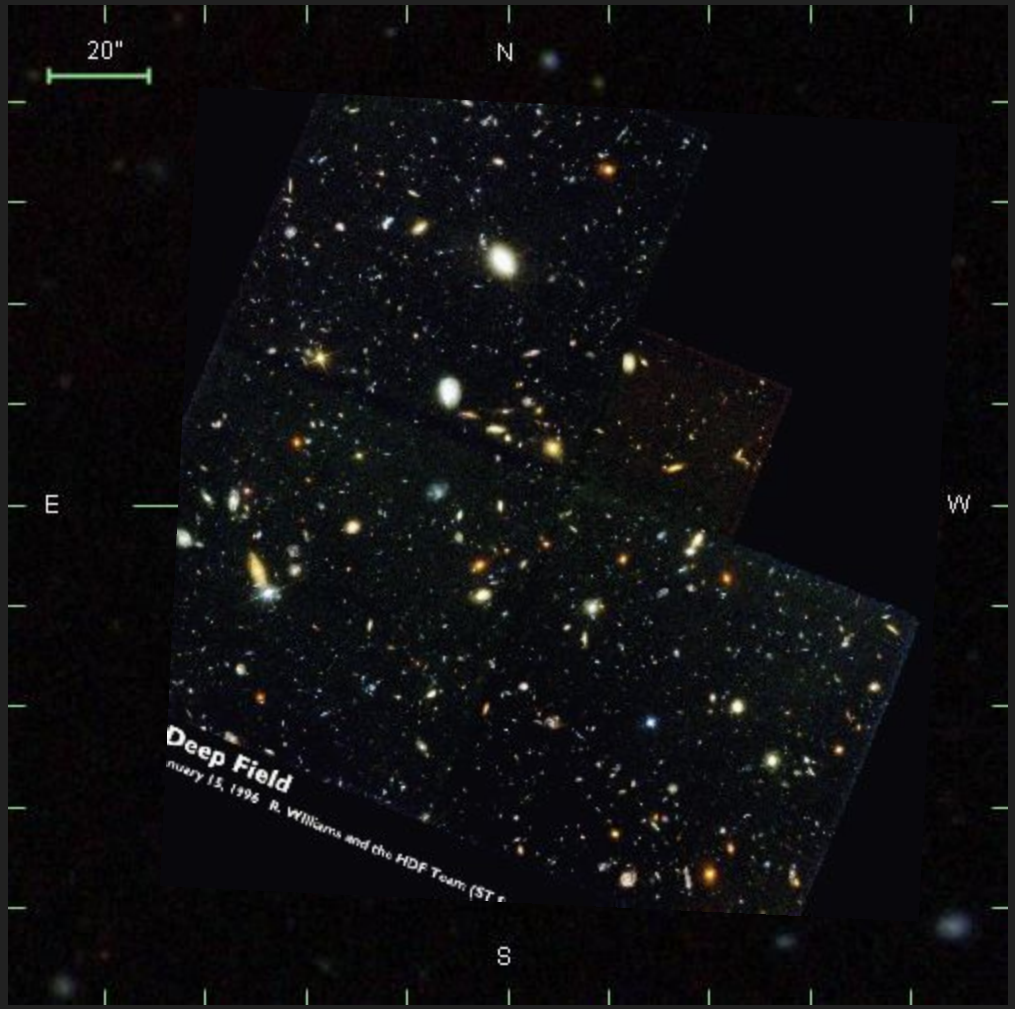

ocations)
(8 location
125 Mpc/h
CCS

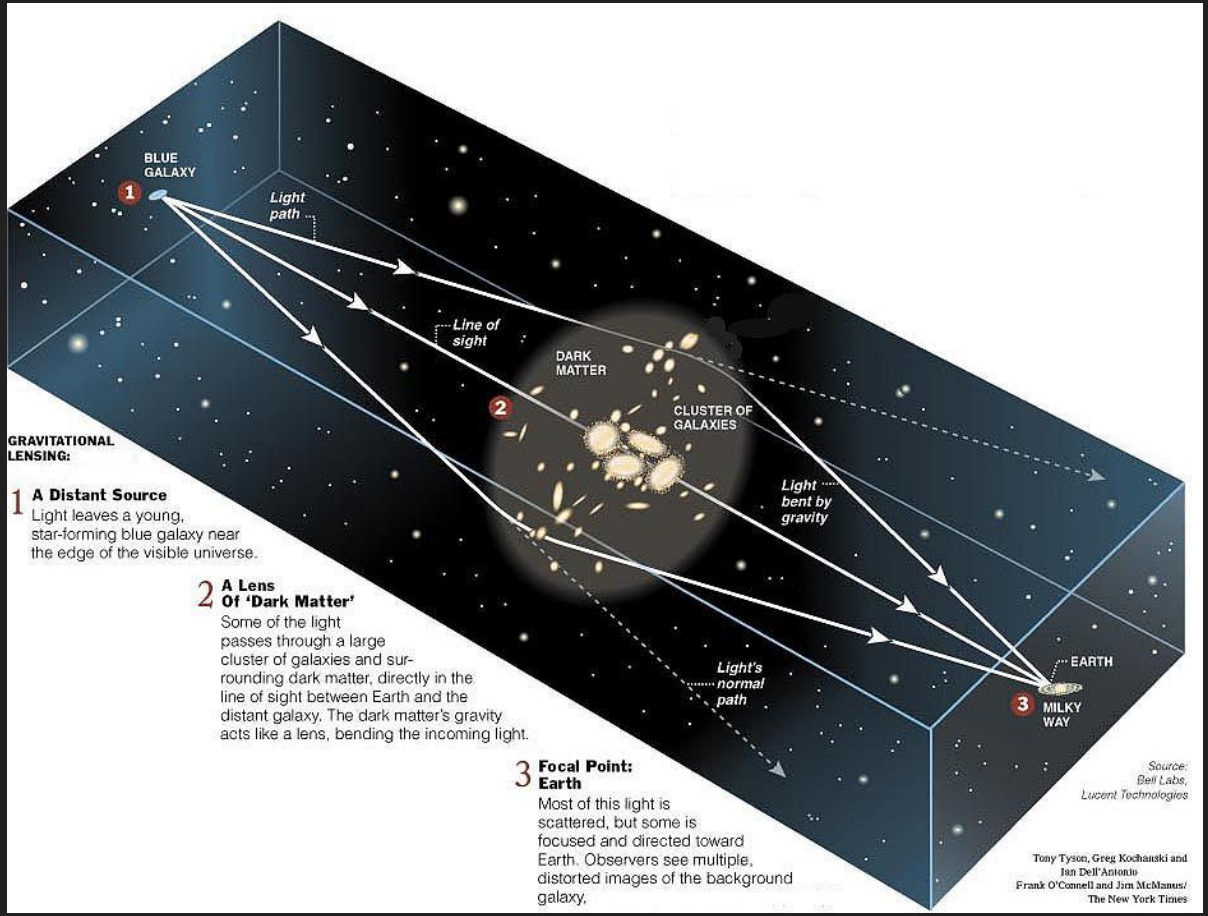
Fast


Type I
Type II
Luminosity (solar units)
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
Absolute magnitude
–20
–15
–10
0
50
100
150
200
Time (days)
Copyright © 2005 Pearson Prentice Hall, Inc.



Deep



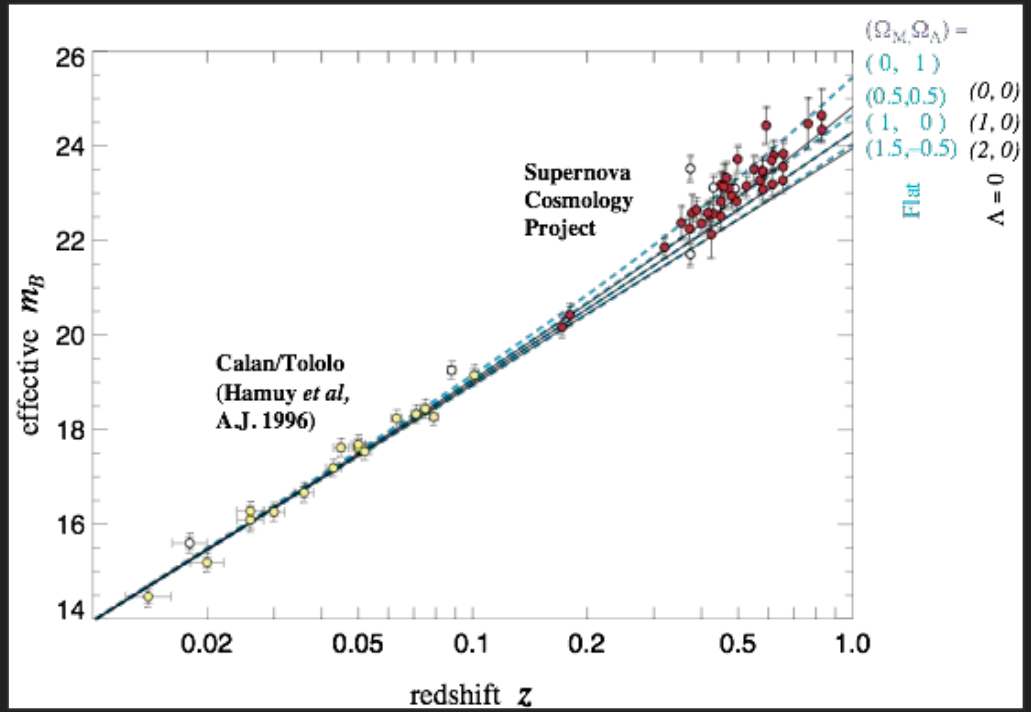

BLUE GALAXY
1
Light path
Line of sight
DARK MATTER
2
CLUSTER OF GALAXIES
Light bent by gravity
Light's normal path
EARTH
3
MILKY WAY
GRAVITATIONAL LENSING:
1 A Distant Source
Light leaves a young, star-forming blue galaxy near the edge of the visible universe.
2 A Lens Of 'Dark Matter'
Some of the light passes through a large cluster of galaxies and surrounding dark matter, directly in the line of sight between Earth and the distant galaxy. The dark matter's gravity acts like a lens, bending the incoming light.
3 Focal Point: Earth
Most of this light is scattered, but some is focused and directed toward Earth. Observers see multiple, distorted images of the background galaxy.
Source: Bell Labs, Lucent Technologies
Tony Tyson, Greg Kochanski and Ian Dell'Antonio
Frank O'Connell and Jim McManus/ The New York Times

Hubble Space Telescope (1990-present)

Timeline

	Wide	Fast	Deep
Hubble	X	X	✅

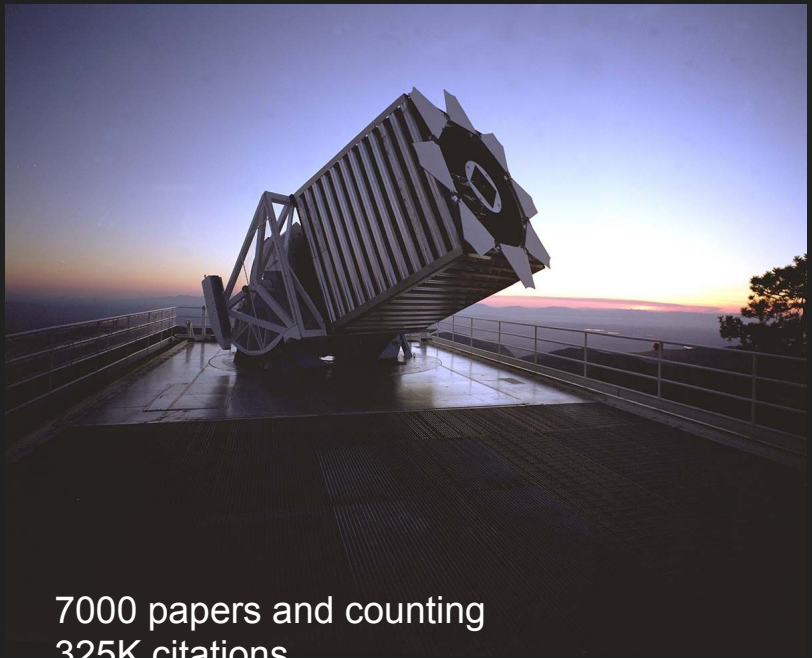
Supernova Cosmology Project (1998)



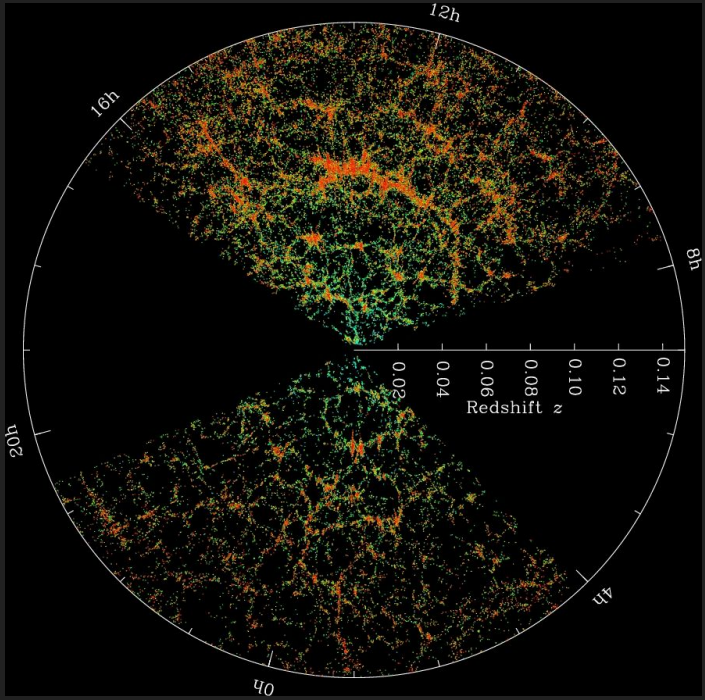
Timeline

	Wide	Fast	Deep
Hubble	X	X	✅
SN	X	✅	X

Sloan Digital Sky Survey (2000-present)



7000 papers and counting
325K citations

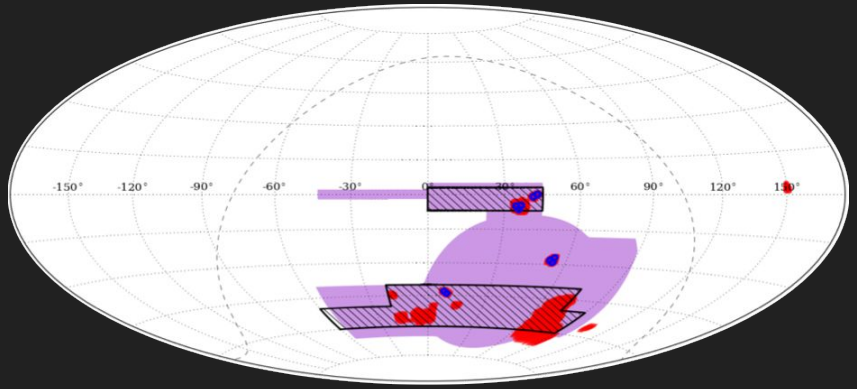


Timeline

	Wide	Fast	Deep
Hubble	❌	❌	✅
SN	❌	✅	❌
Sloan	✅	❌	❌

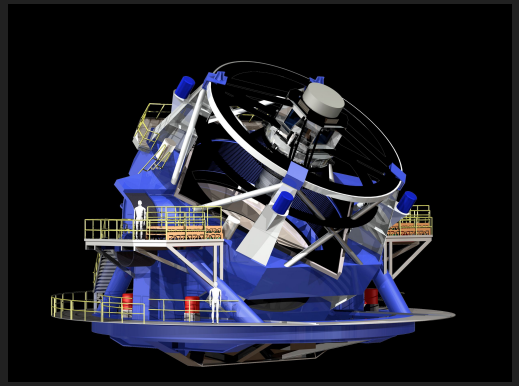
— Prof. Tony Tyson, ~1990s

Dark Energy Survey (2012-present)



Timeline

	Wide	Fast	Deep
Hubble	X	X	✅
SN	X	✅	X
Sloan	✅	X	X
CFHT, KIDS, DLS...	~	X	~
ASASSN, PTF	✅	✅	X
Dark Energy Survey	✅	~	✅

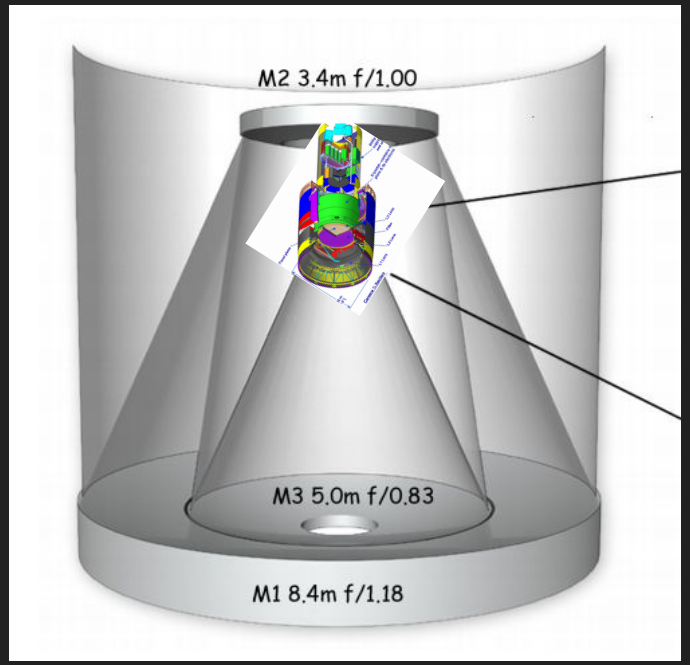


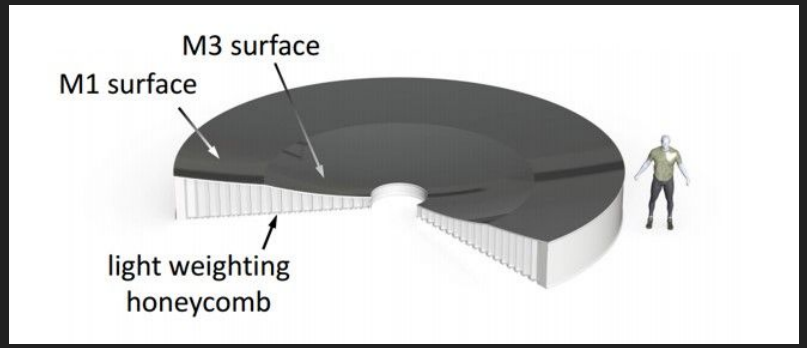
5000 deg^2	¼ of sky in 6 months	Limiting mag 22.5
↓ 4x area	↓ ~200x faster!	↓ 6x fainter
20,000 deg^2	Entire sky in 4 nights!	24.5

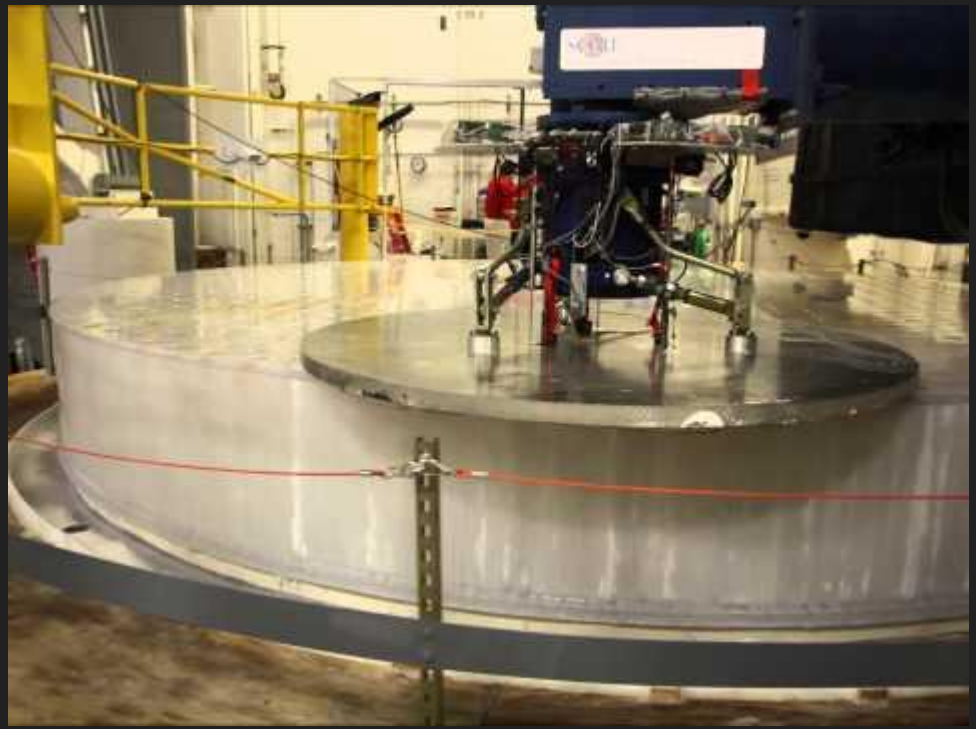
Timeline

	Wide	Fast	Deep
Hubble	X	X	✅
SN	X	✅	X
Sloan	✅	X	X
CFHT, KIDS, DLS...	~	X	~
ASASSN, PTF	✅	✅	X
Dark Energy Survey	✅	~	✅
LSST	😎	😎	😎

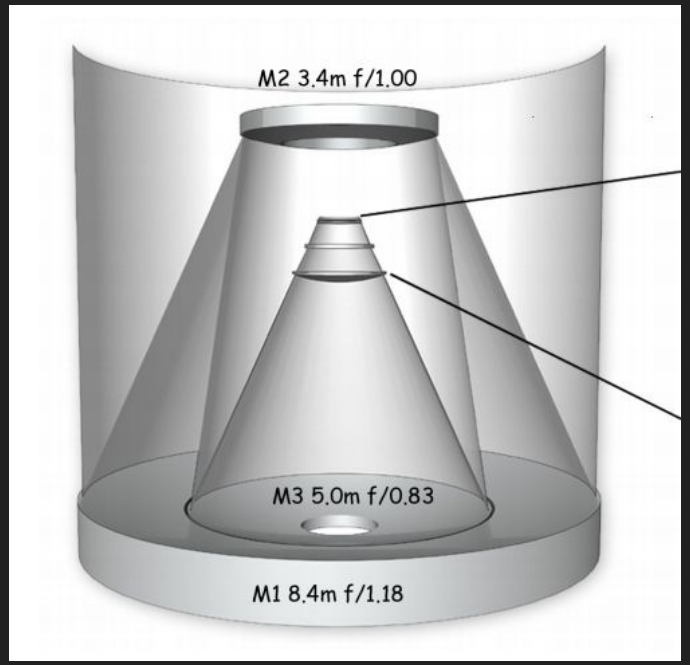
Wide: Giant monolithic mirrors

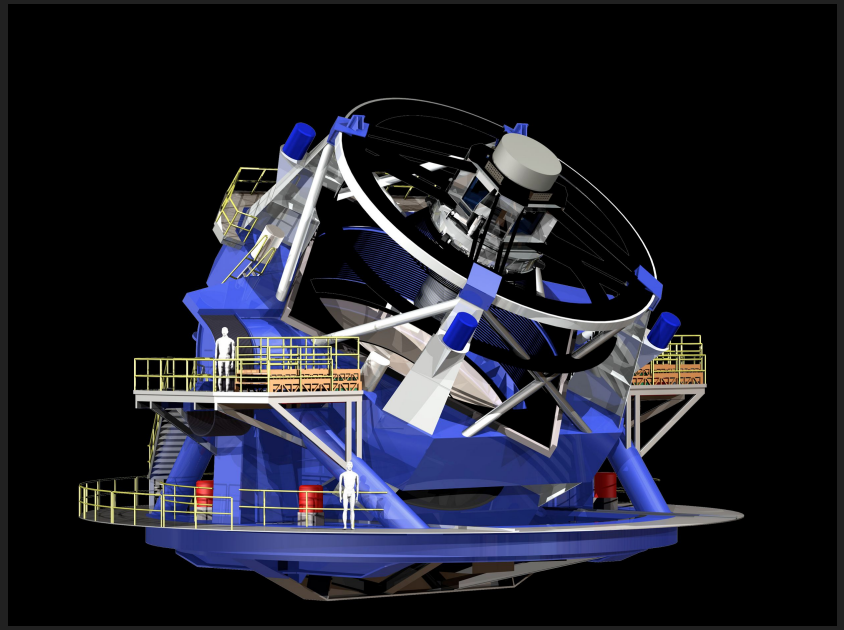




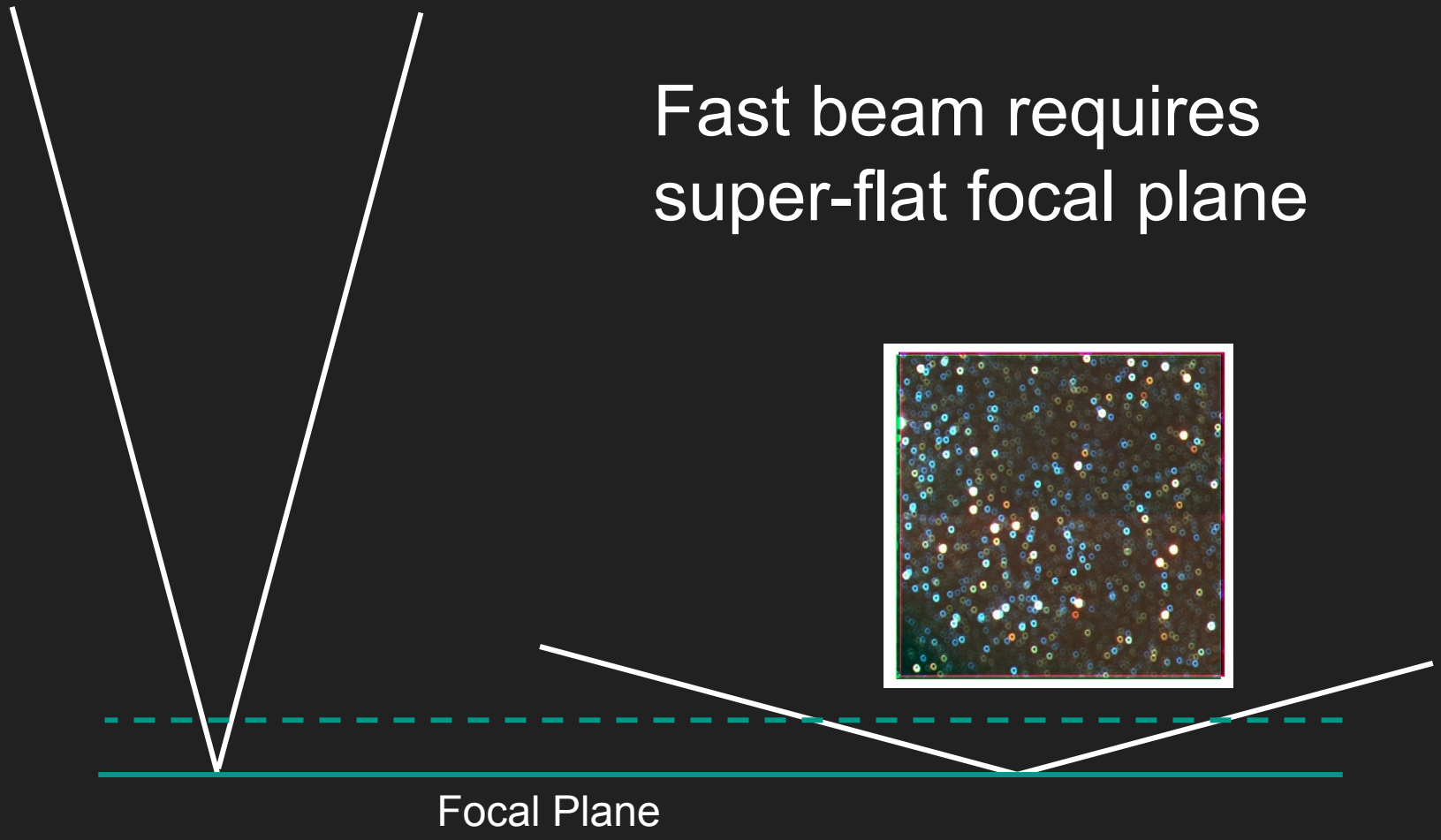


Wide: f/1.2 optical beam

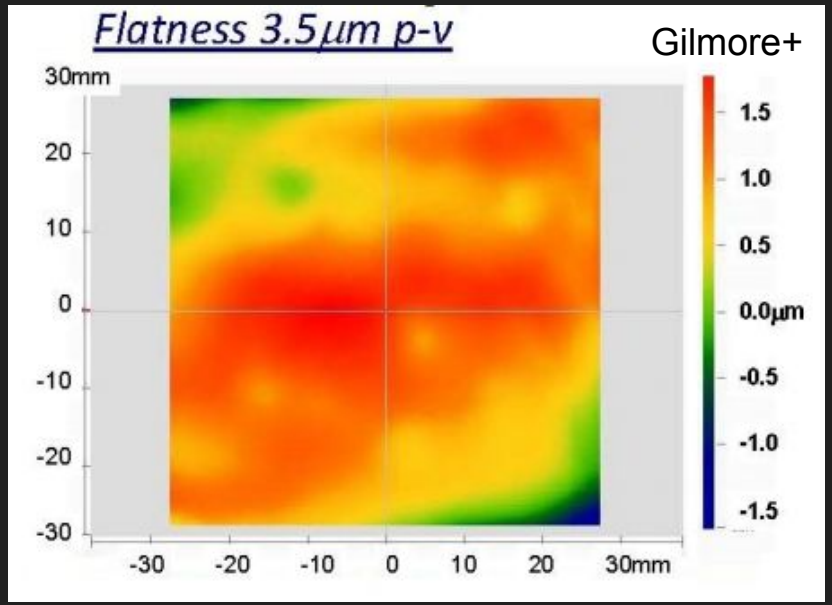


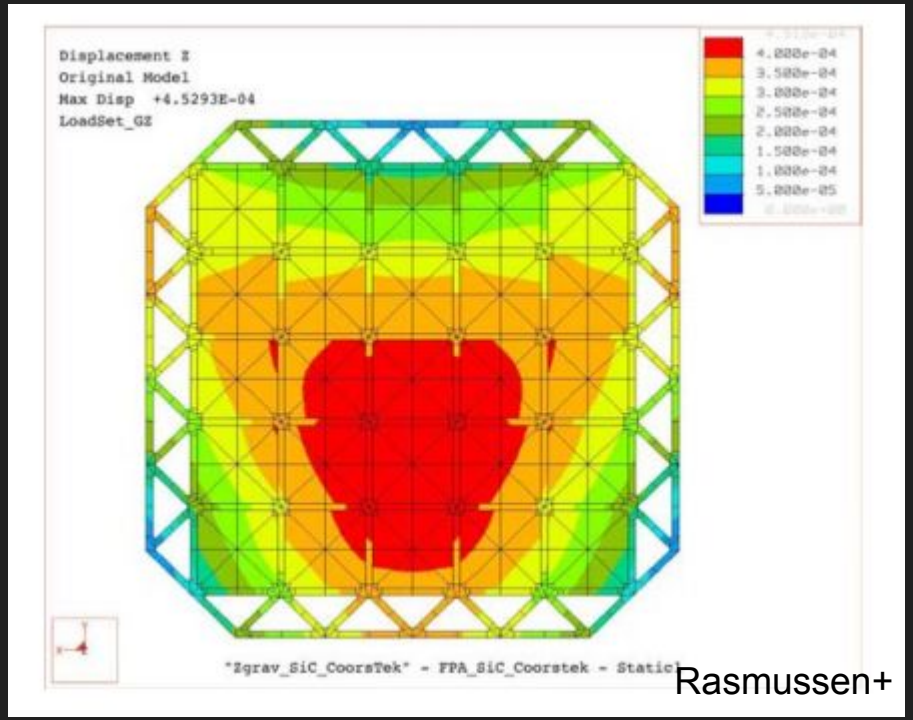


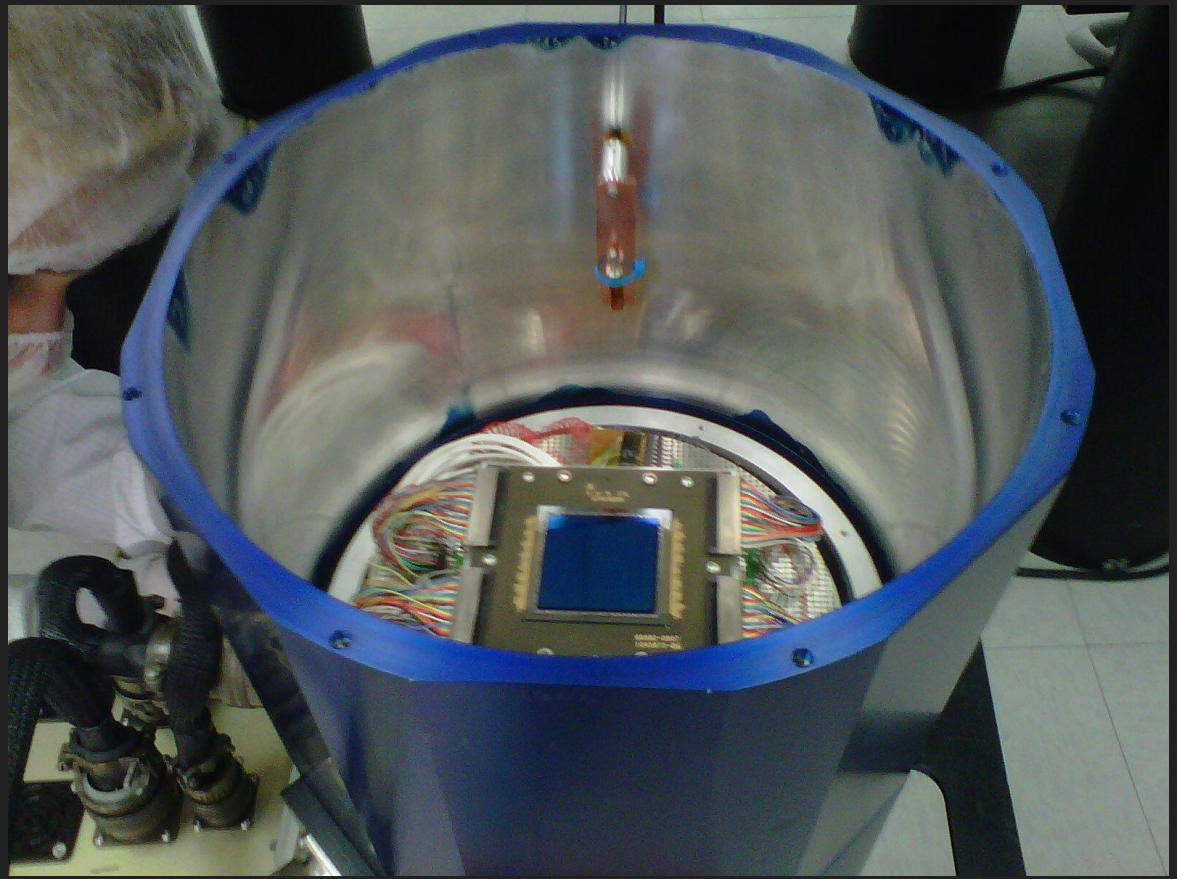
Fast beam requires super-flat focal plane



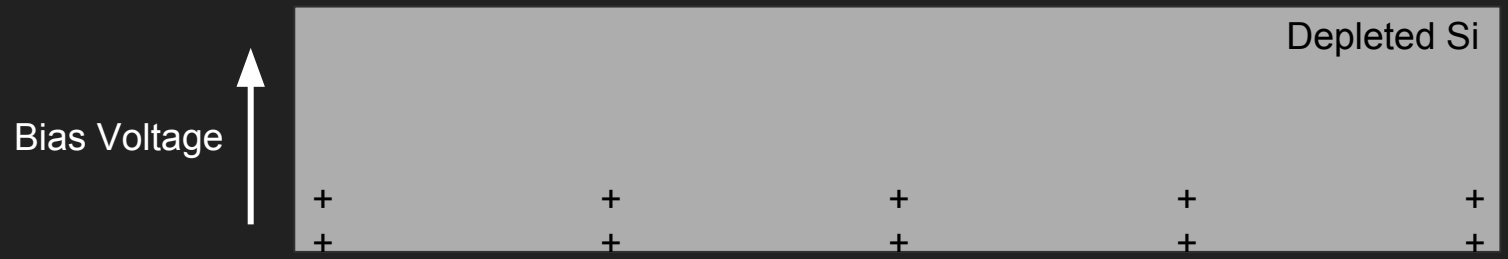
Focal Plane must be flat ± 10 μm!



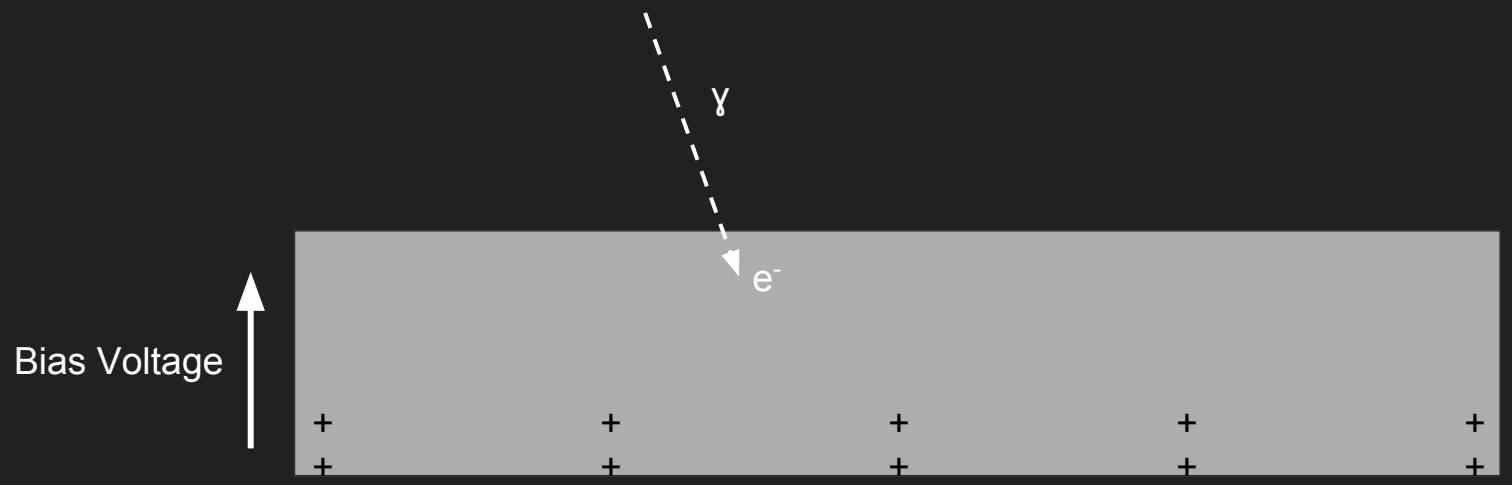




How CCDs work

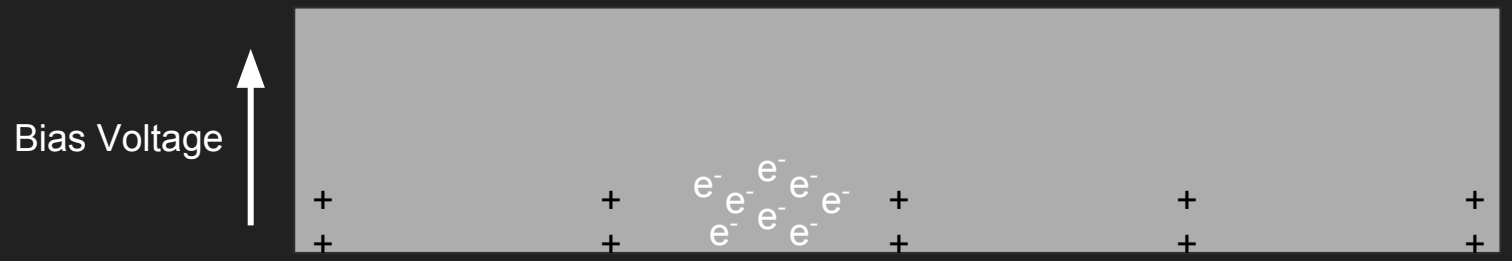


How CCDs work

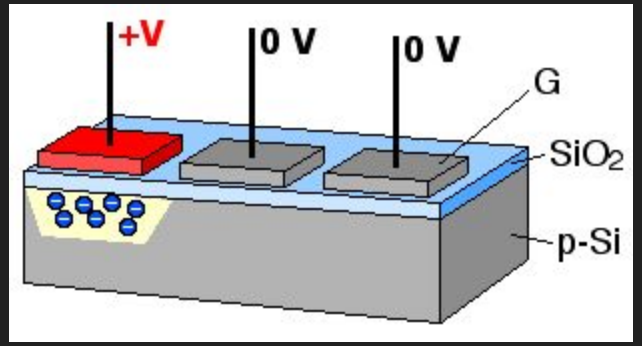


How CCDs work

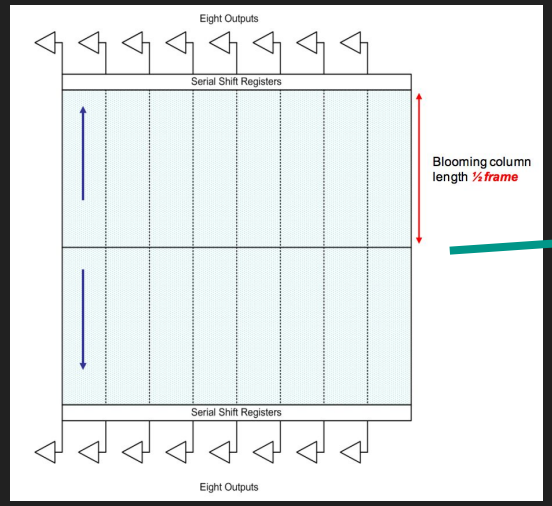
How CCDs work

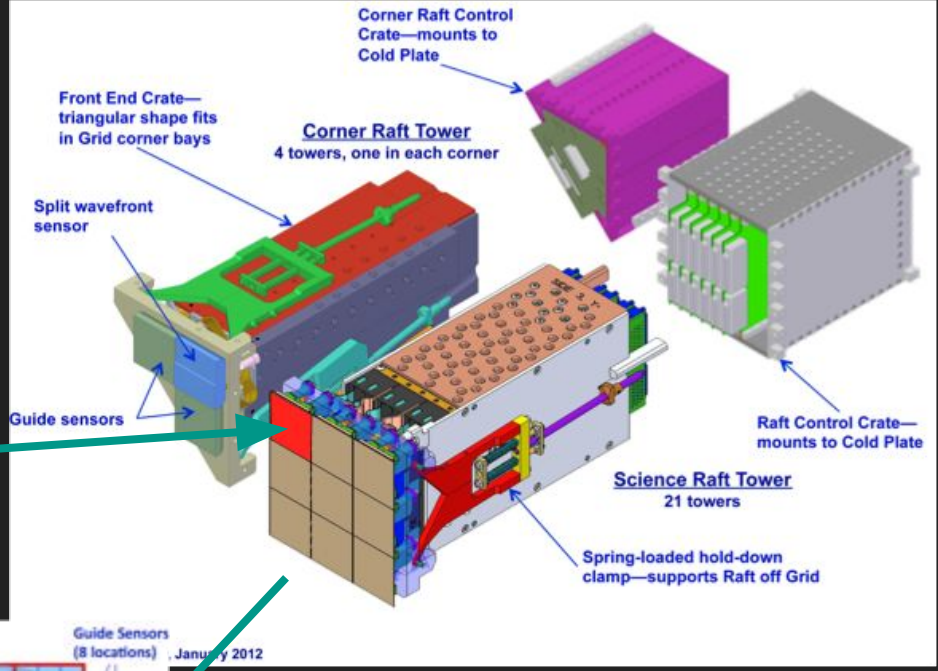


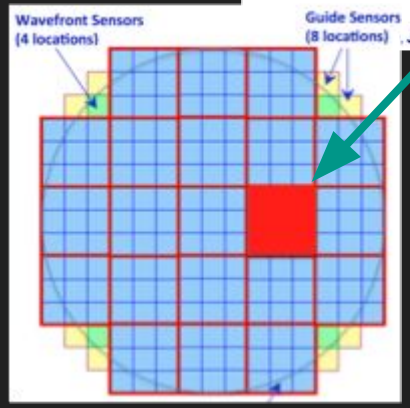
Parallel Transfer



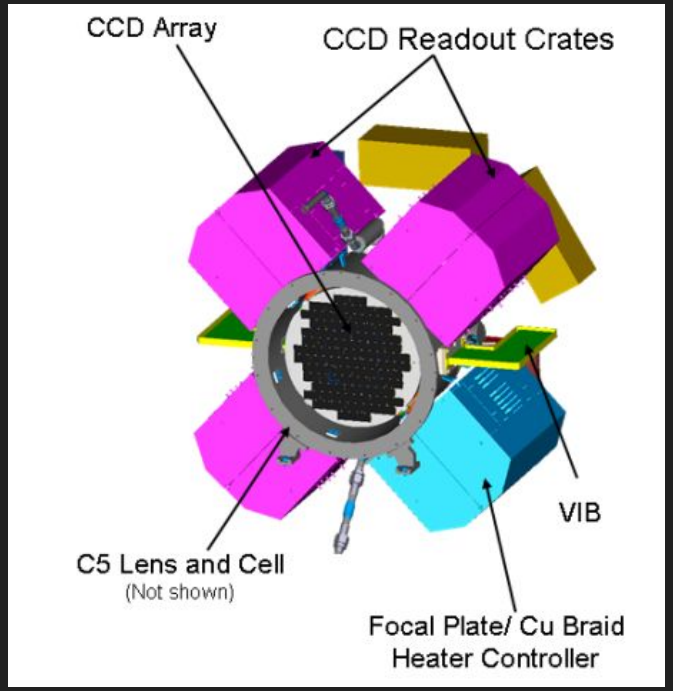
LSST Focal Plane

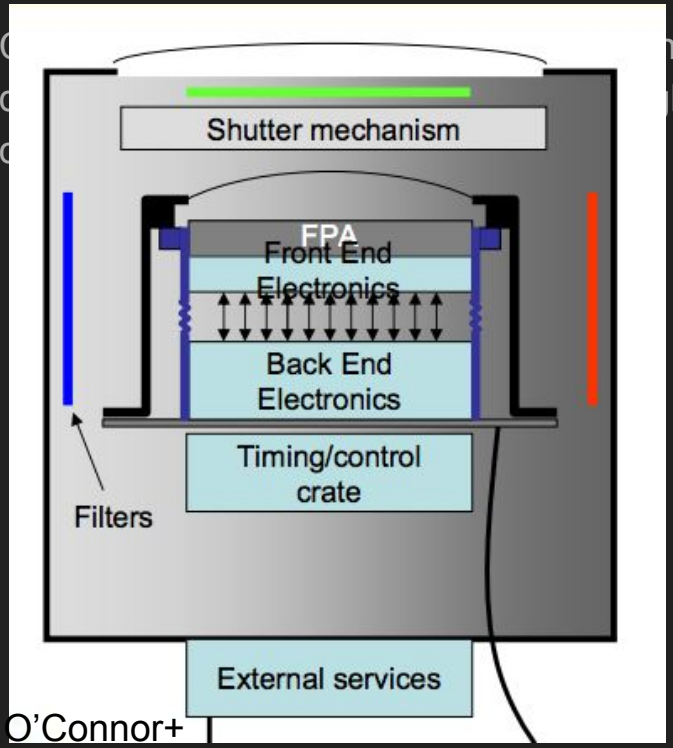






Fast: segmented readout

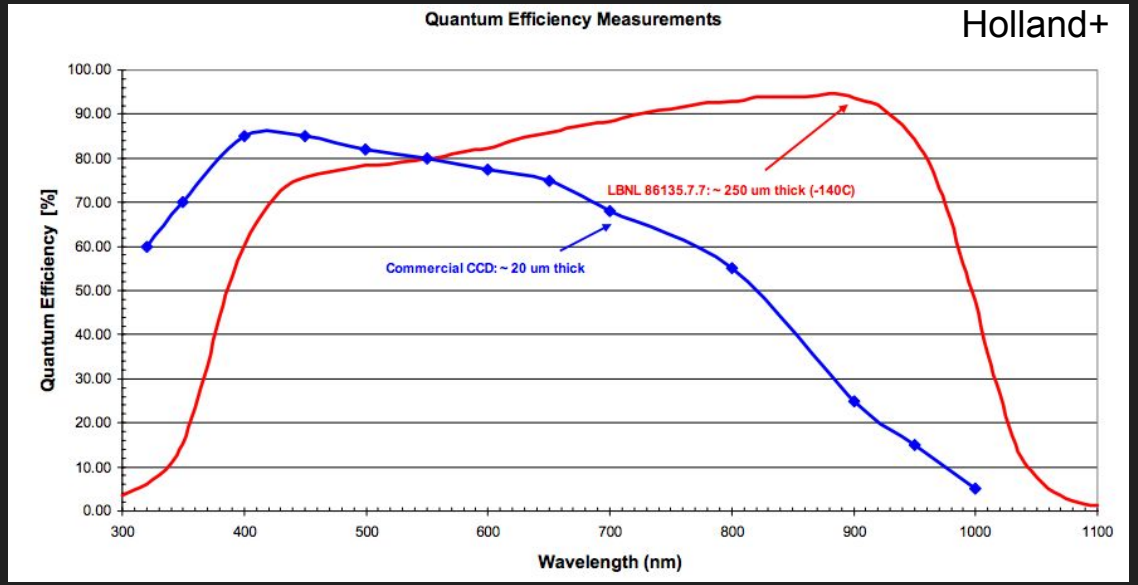




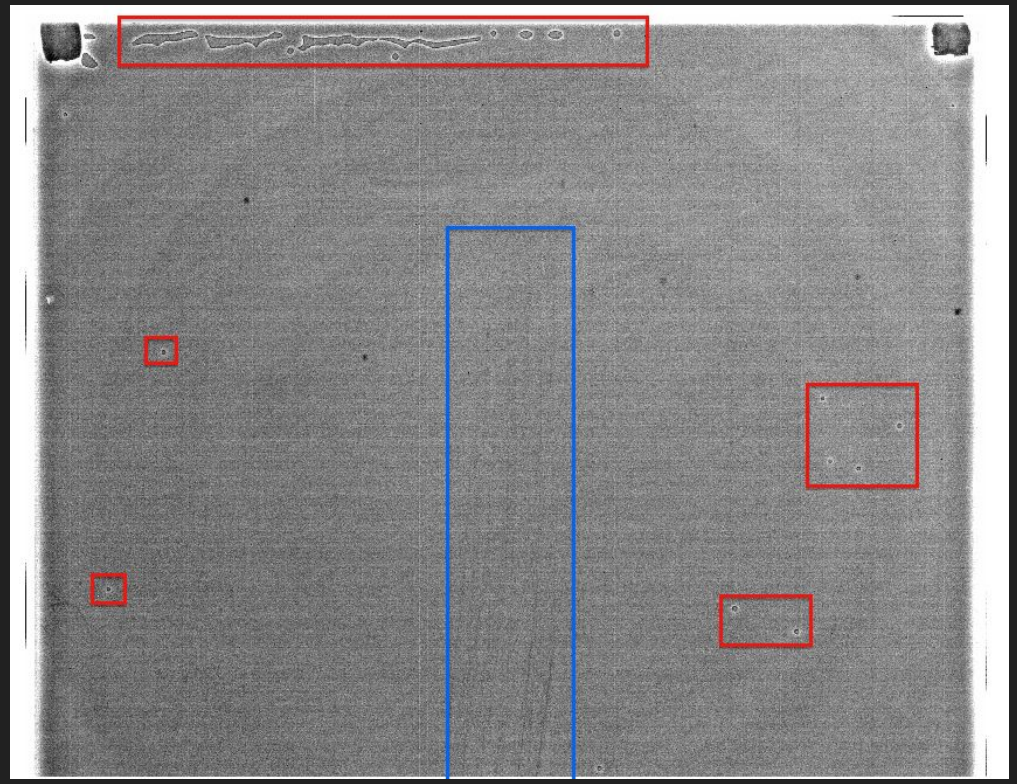
O'Connor+

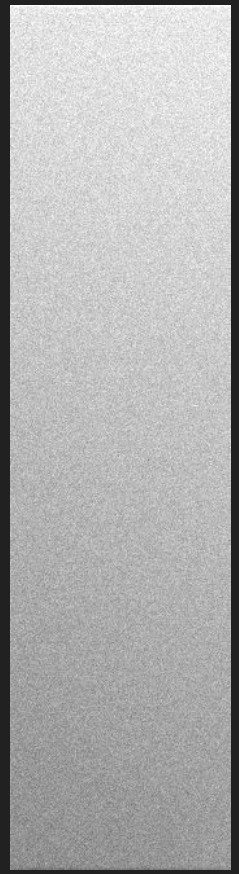
Deep: Red-sensitive CCDs

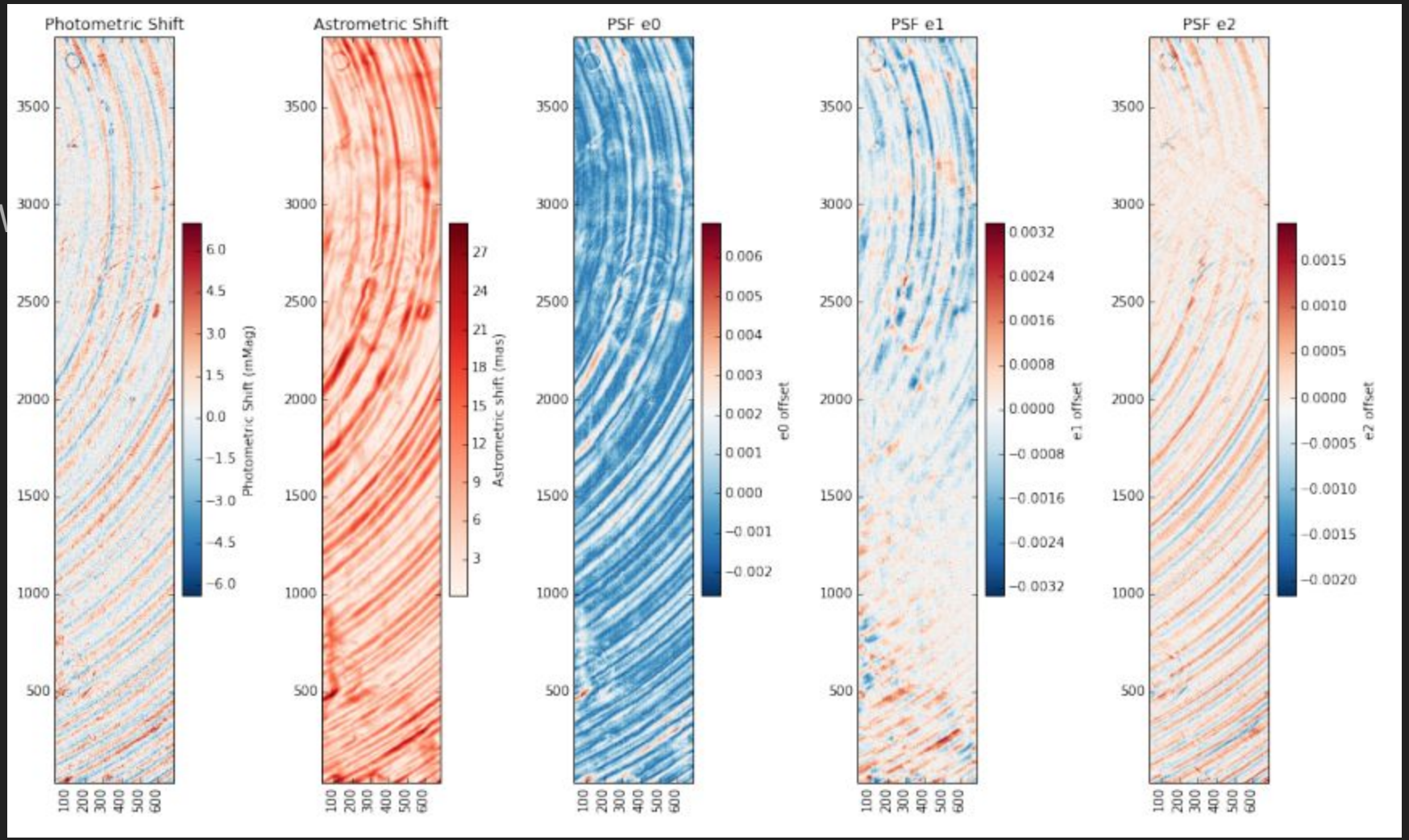
Because you'd hate for red photons to have gone to all that trouble to traverse the universe, only to speed right through your detector...

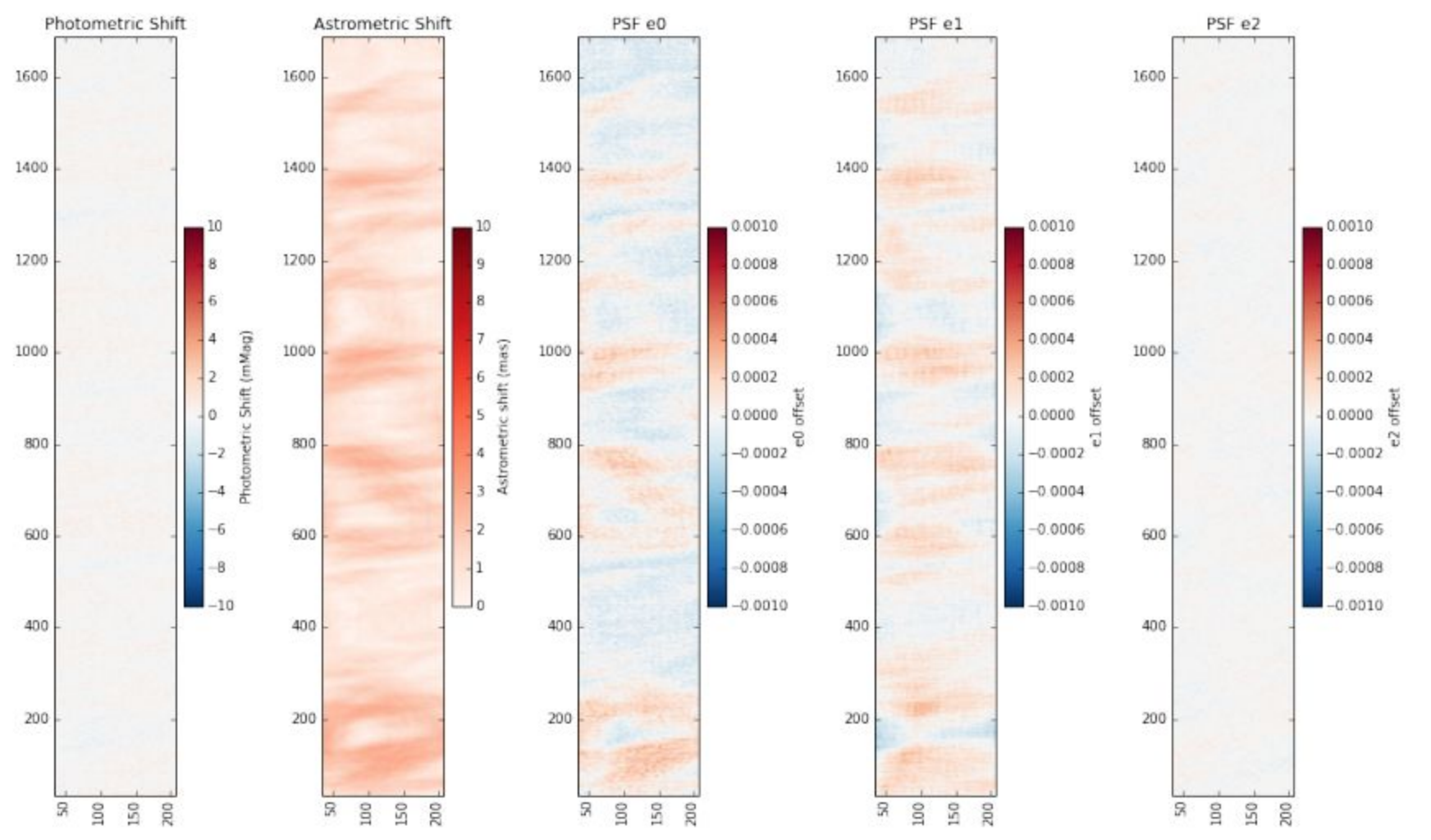


Problems with thick CCDs

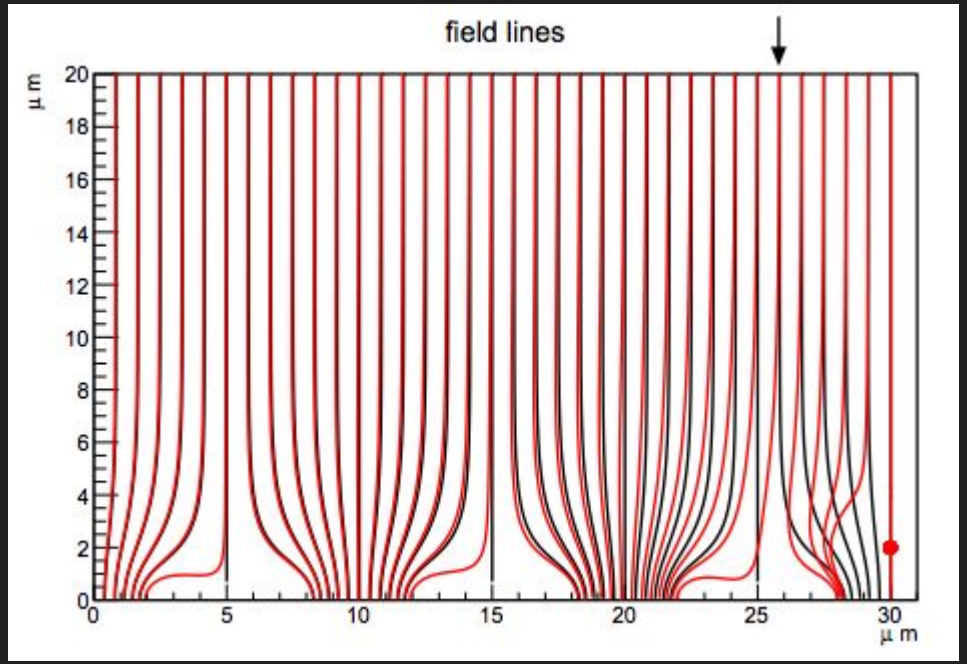





Photometric Shift
Photometric Shift (mMag)
Astrometric Shift
Astrometric shift (mas)
PSF e0
e0 offset
PSF e1
e1 offset
PSF e2
e2 offset


Photometric Shift
Photometric Shift (mMag)
Astrometric Shift
Astrometric shift (mas)
PSF e0
e0 offset
PSF e1
e1 offset
PSF e2
e2 offset

Brighter-Fatter Effect



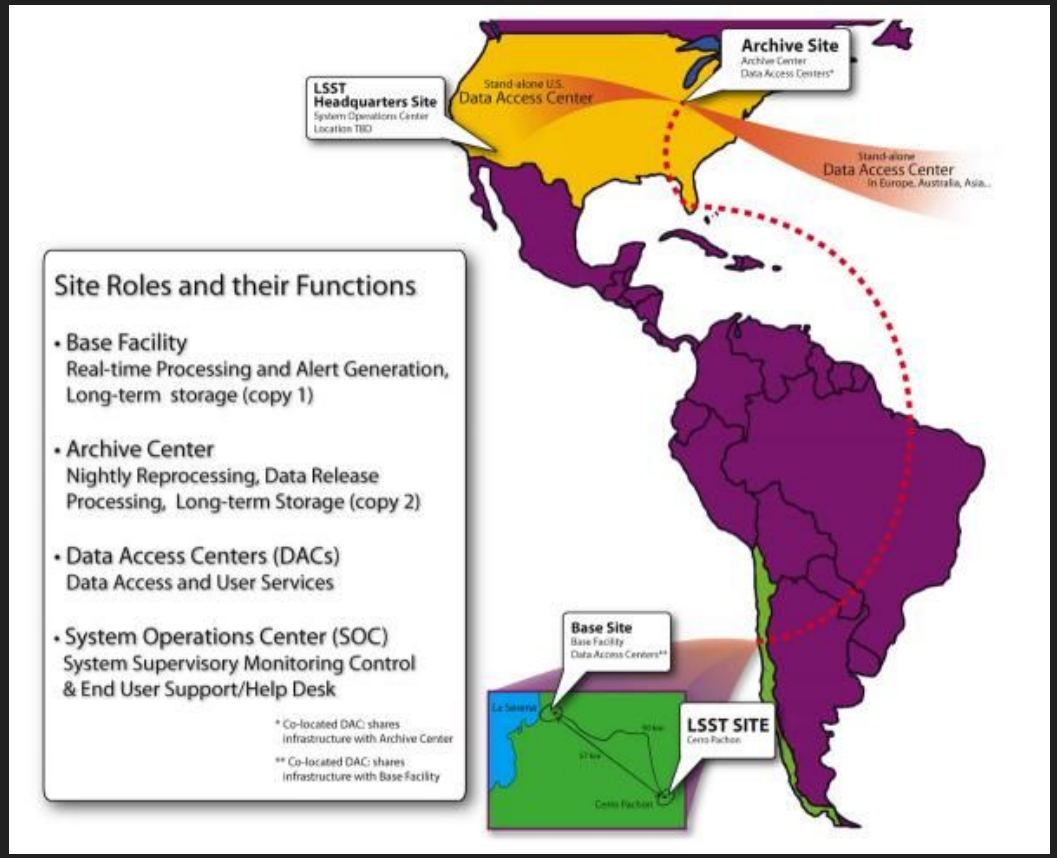
Data

ATLAS to-disk rate: 300MB/sec

LSST average: 750 MB/sec!

Total Disk usage: ~0.5 Exabytes!

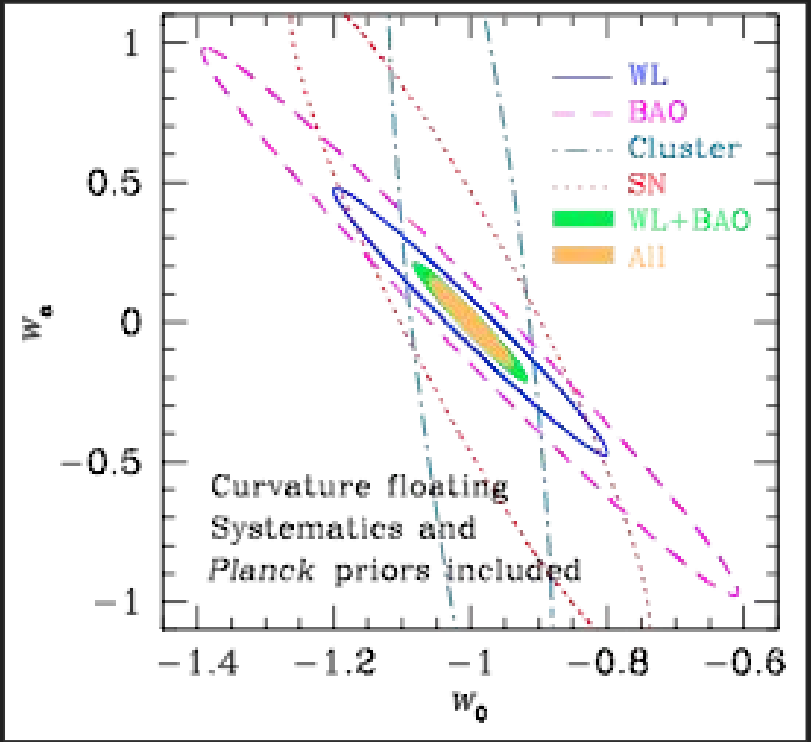
Real-time alerts



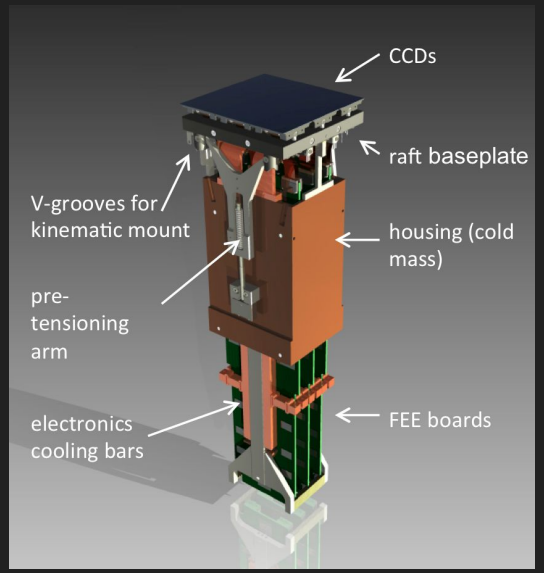
Checklist

- ❑ Large, precise mirrors
- ❑ Rigid telescope structure (minimize vibration)
- ❑ f/1.2 “fast” optics
- ❑ Super-flat sensors and precise mechanical design
- ❑ Fast segmented readout
- ❑ Vaccuum clean electronics
- ❑ Thick, red-sensitive CCDs
- ❑ Exa-scale data management
- ❑ Government-scale project management
- ❑ ...

Reward

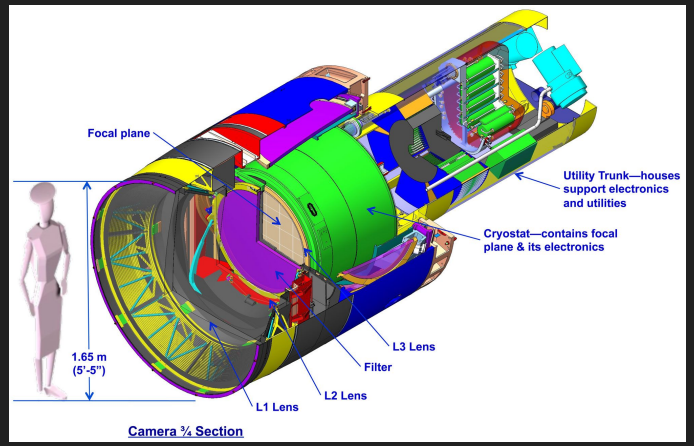

WL
BAO
Cluster
SN
WL+BAO
All
Curvature floating
Systematics and
Planck priors included
1
0.5
0
−0.5
−1
w_a
−1.4
−1.2
−1
−0.8
−0.6
w_0

SLAC's role



x18

Integration + Testing



LSST steps and timeline