THE LARGE SYNOPTIC SURVEY TELESCOPE

Ian Shipsey
(LSST Collaboration)

PPAP Community Meeting,
RAL, July 22, 2014

Outstanding questions in particle physics circa 2014

Higgs boson and EWSB
- ❑ m_H natural or fine-tuned ?
- → if natural: what new physics/symmetry?
- ❑ does it regularize the divergent $V_L V_L$ cross-section at high $M(V_L V_L)$? Or is there a new dynamics ?
- ❑ elementary or composite Higgs ?
- ❑ is it alone or are there other Higgs bosons ?
- ❑ origin of couplings to fermions
- ❑ coupling to dark matter ?
- ❑ does it violate CP ?
- ❑ cosmological EW phase transition

Quarks and leptons:
- ❑ why 3 families ?
- ❑ masses and mixing
- ❑ CP violation in the lepton sector
- ❑ matter and antimatter asymmetry
- ❑ baryon and charged lepton number violation

Neutrinos:
- ❑ ν masses and and their origin
- ❑ what is the role of H(125) ?
- ❑ Majorana or Dirac ?
- ❑ CP violation
- ❑ additional species → sterile ν ?

The two epochs of Universe's accelerated expansion:
- ❑ primordial: is inflation correct ? which (scalar) fields? role of quantum gravity?
- ❑ today: dark energy (why is Λ so small?) or is GR wrong on large scales?

Dark matter:
- ❑ composition: WIMP, sterile neutrinos, axions, other hidden sector particles, ..
- ❑ one type or more ?
- ❑ only gravitational or other interactions ?

Physics at the highest E-scales:
- ❑ how is gravity connected with the other forces ?
- ❑ do forces unify at high energy ?

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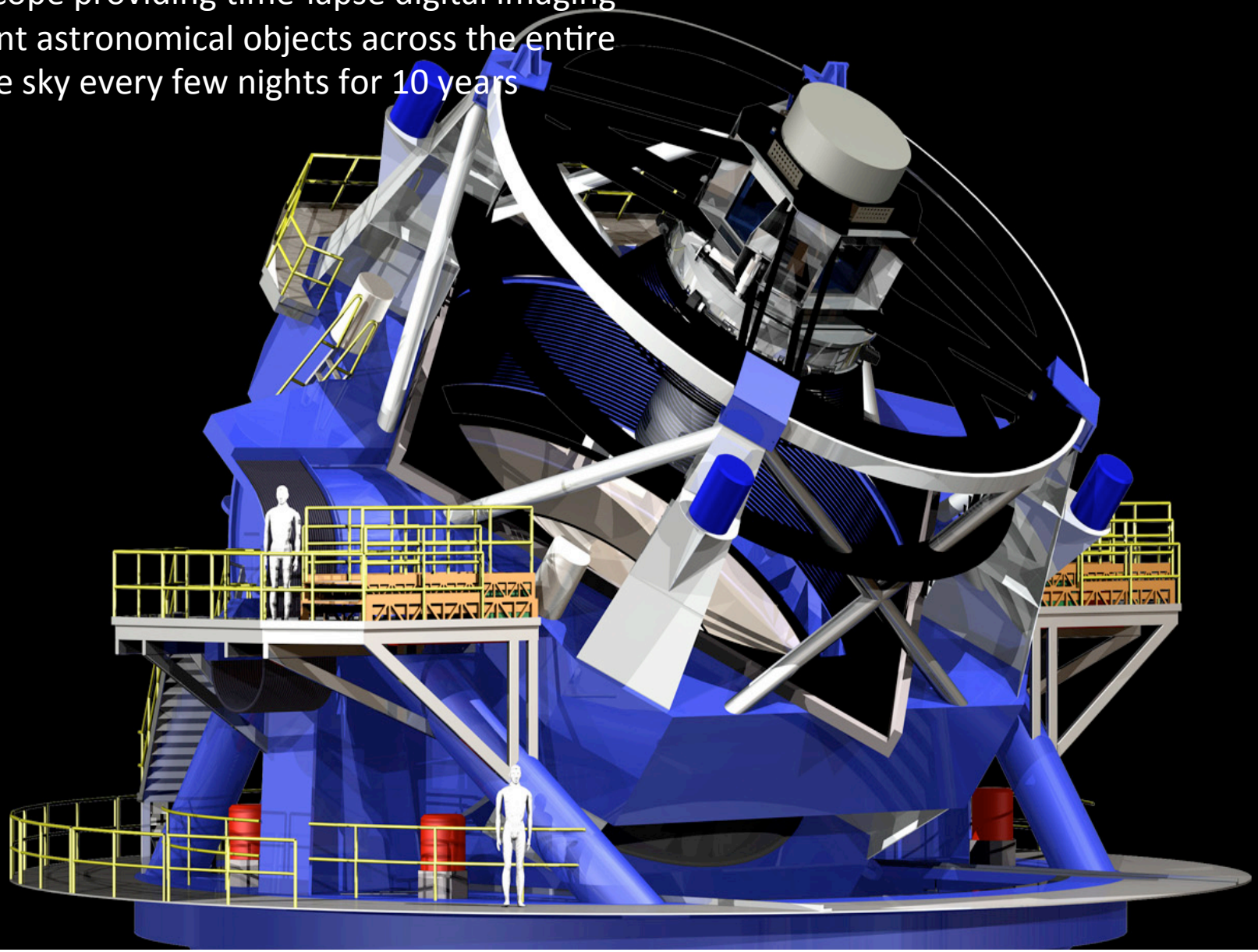
LSST in Context: Progress in Optical Astronomy

- Bigger Telescopes: *Keck to E-ELT*
- Angular resolution: *Hubble to JWST*
- All Sky Survey: *SDSS to LSST*

LSST in a nutshell

Synoptic = Big Picture

LSST: 8 meter, wide-field ground-based telescope providing time-lapse digital imaging of faint astronomical objects across the entire visible sky every few nights for 10 years




LSST
wide fast deep
I. Shipsey

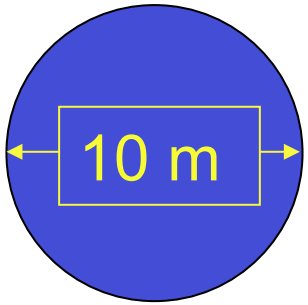
Wide

Comparison of LSST To Keck

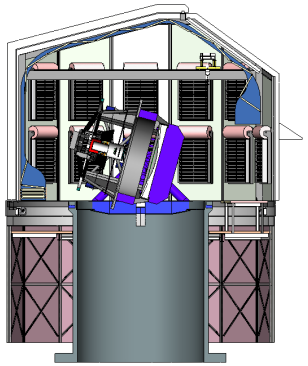
Primary mirror diameter

Field of view
(full moon is 0.5 degrees)

Keck Telescope



0.2 degrees



LSST

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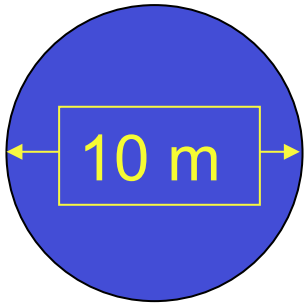

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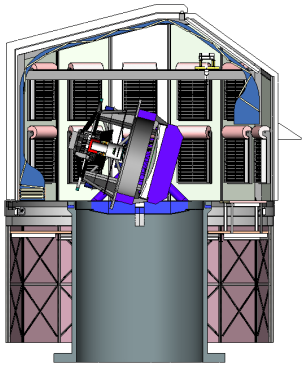
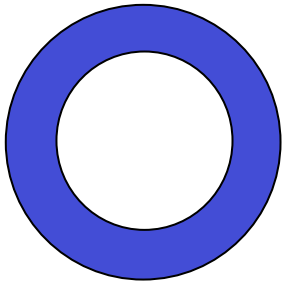
Keck Telescope





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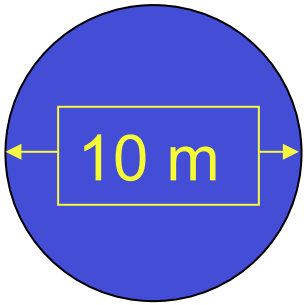
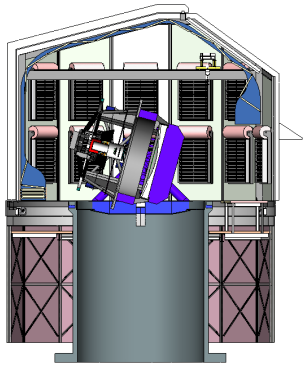
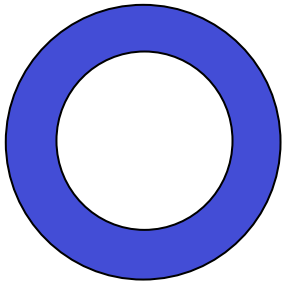
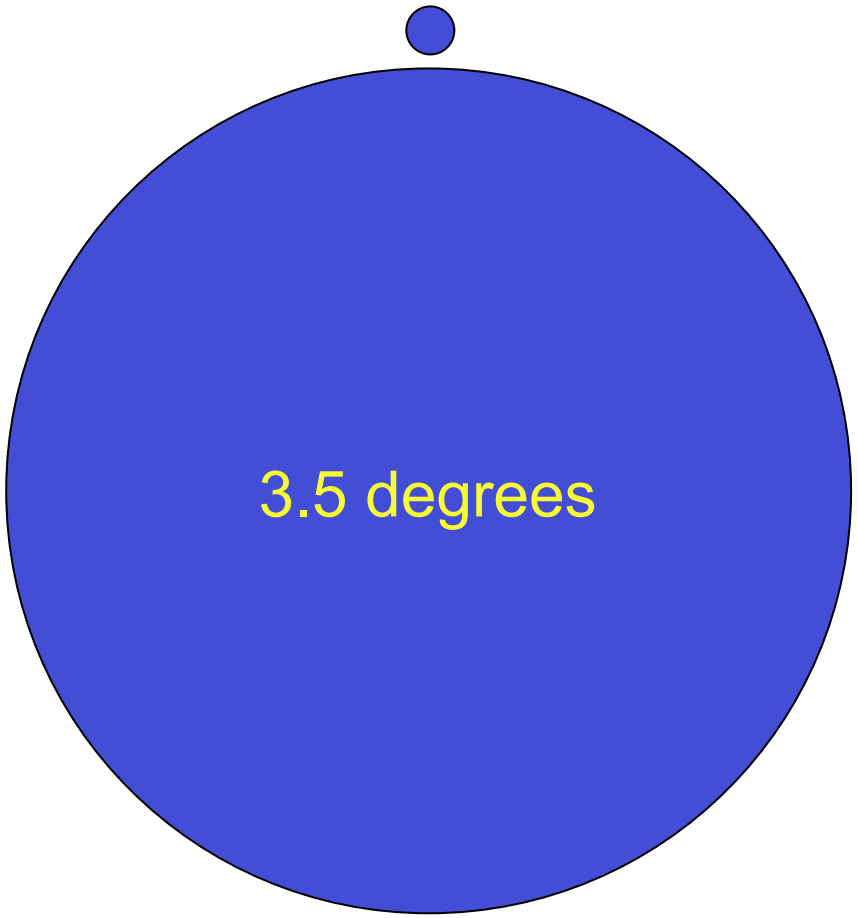




LSST



0.2 degrees

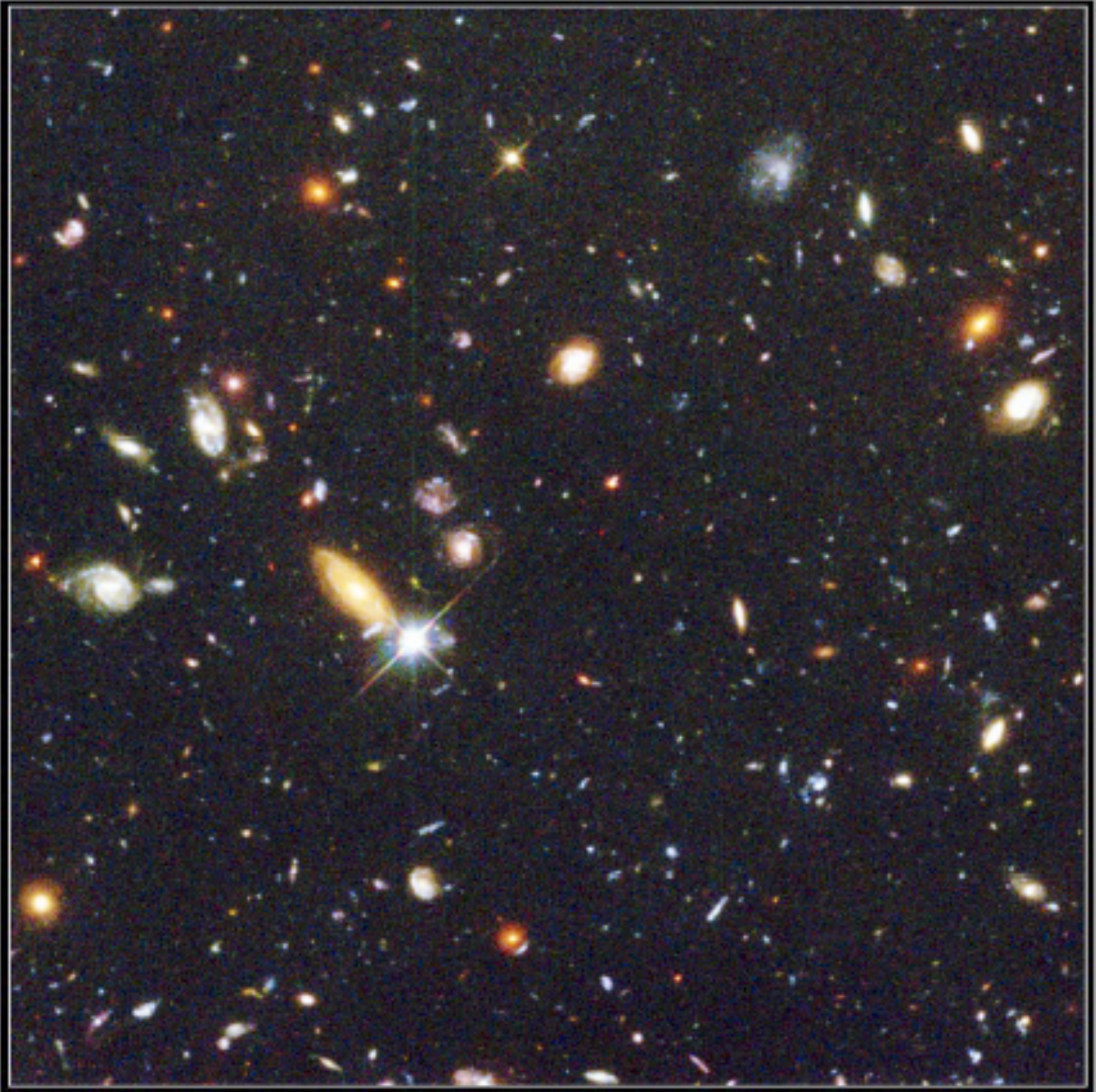


Hubble deep field

UNIVERSE OF GALAXIES

3000 here →

100 billion over entire sky



I. Shipsey


Image sizes LSST, Moon, HST

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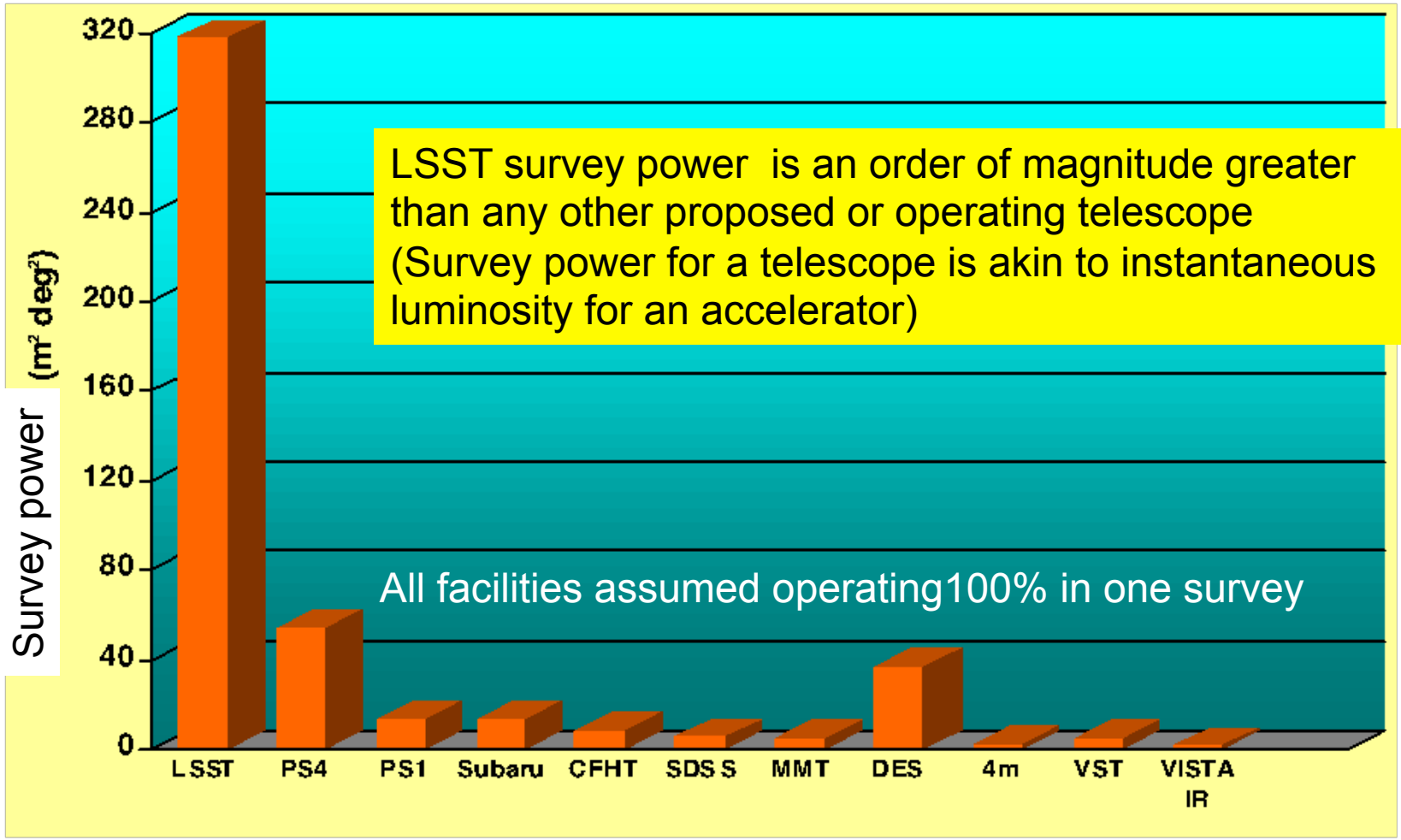
Survey Power = aperture x field of view



WIDE FAST DEEP

LSST

LSST Probes a Volume an Order of Magnitude Larger than Current or Near-Future Surveys

- LSST ~100 times fainter than SDSS
- a legacy dataset ~1000 times as large
- ~800 images of every field will open up the time domain for large-scale study for the first time: a movie of the universe

A survey of 37 billion objects in space and time

30 trillion measurements

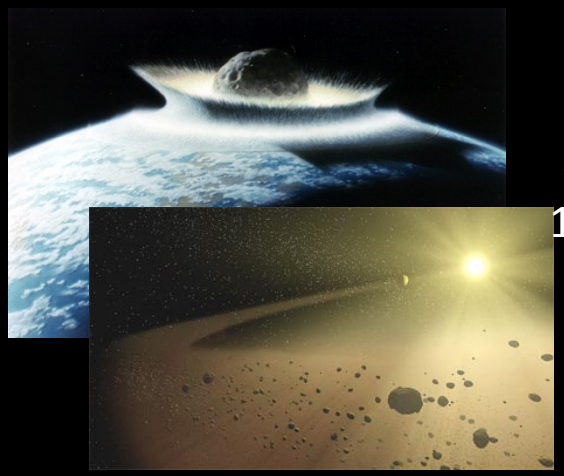
4 billion galaxies with redshifts
Time domain:
5 million asteroids
10 million supernovae
1 million gravitational lenses
100 million variable stars
+ new phenomena

LSST 4 Science Missions

Dark Energy-Dark Matter

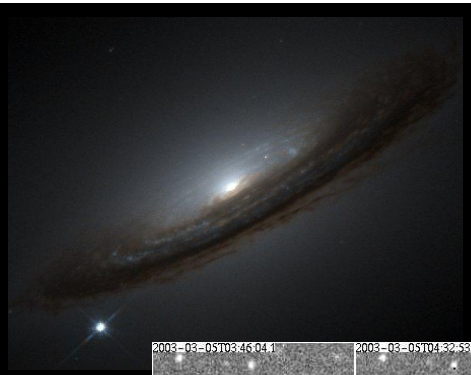
Multiple investigations into the nature of the dominant components of the universe

Inventory of the Solar System

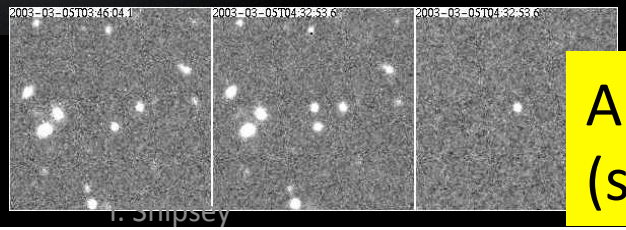


Find 90% of hazardous NEOs down to 140 m over 10 yrs & test theories of solar system formation

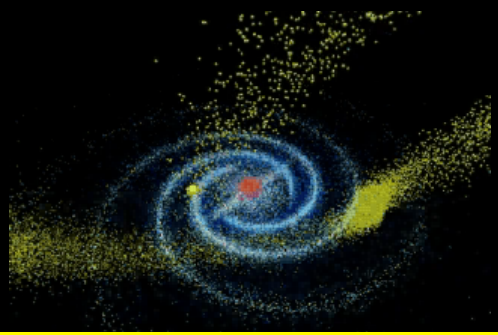
"Movie" of the Universe: time domain



Discovering the transient & unknown on time scales days to years



Mapping the Milky Way



Map the rich and complex structure of the galaxy in unprecedented detail and extent

All missions conducted in parallel
(similar to a general purpose expt @ LHC)

The Science Opportunities are summarized in

Quick read:

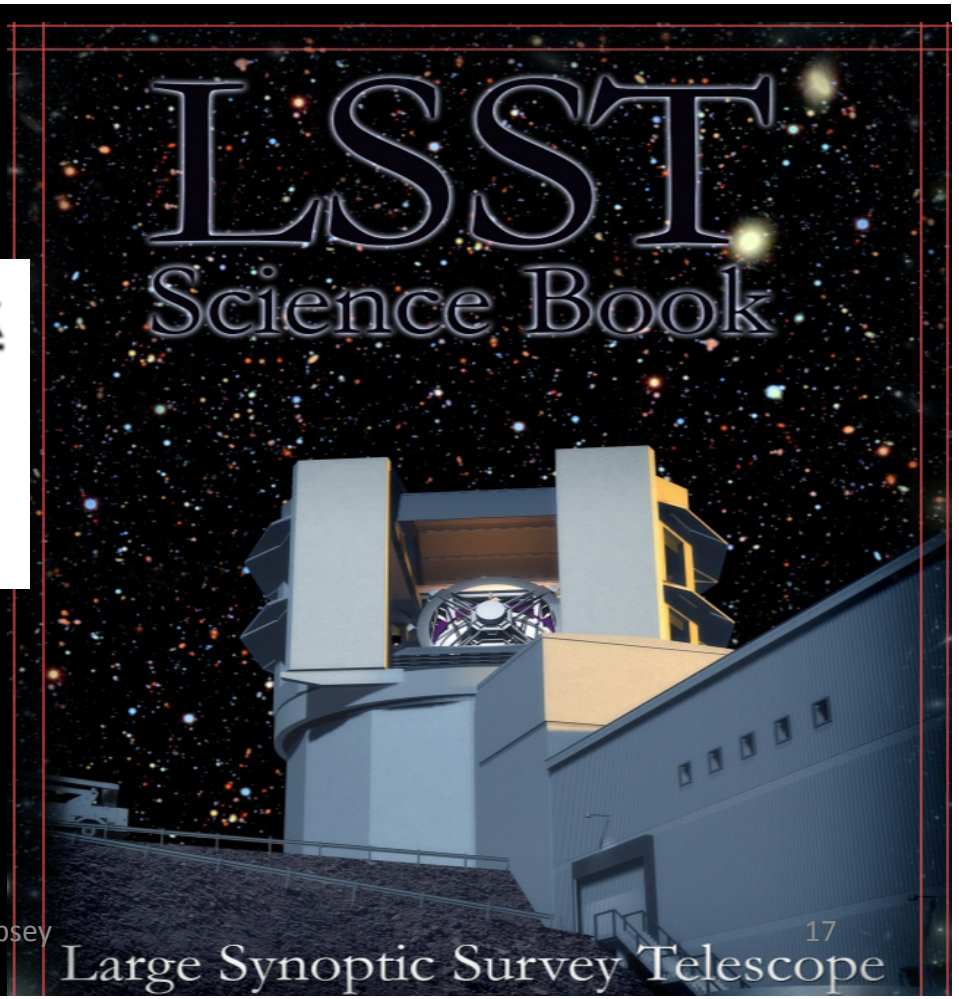
LSST: FROM SCIENCE DRIVERS TO REFERENCE DESIGN AND ANTICIPATED DATA PRODUCTS

http://arxiv.org/pdf/0805.2366v2.pdf
(last update June 2011, new update soon)

Reference:

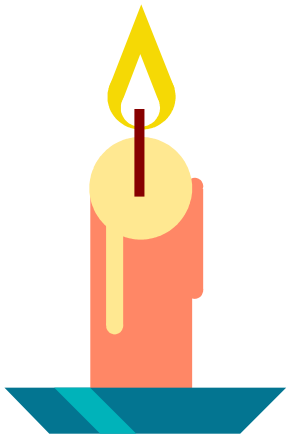
http://www.lsst.org/lsst/scibook

Written by 11 science collaborations

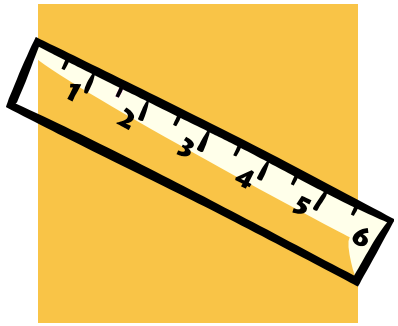


Probing Dark Energy with LSST

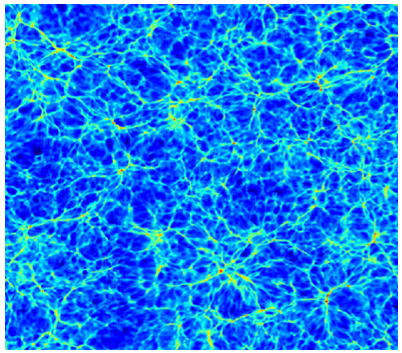
luminosity distances of standard candles (Type 1a SNe)

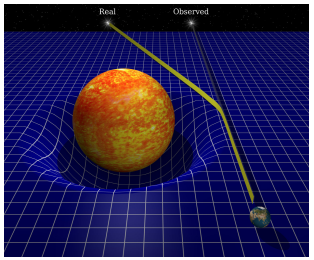


angular diameter distances of standard rulers baryon acoustic oscillations (BAO)



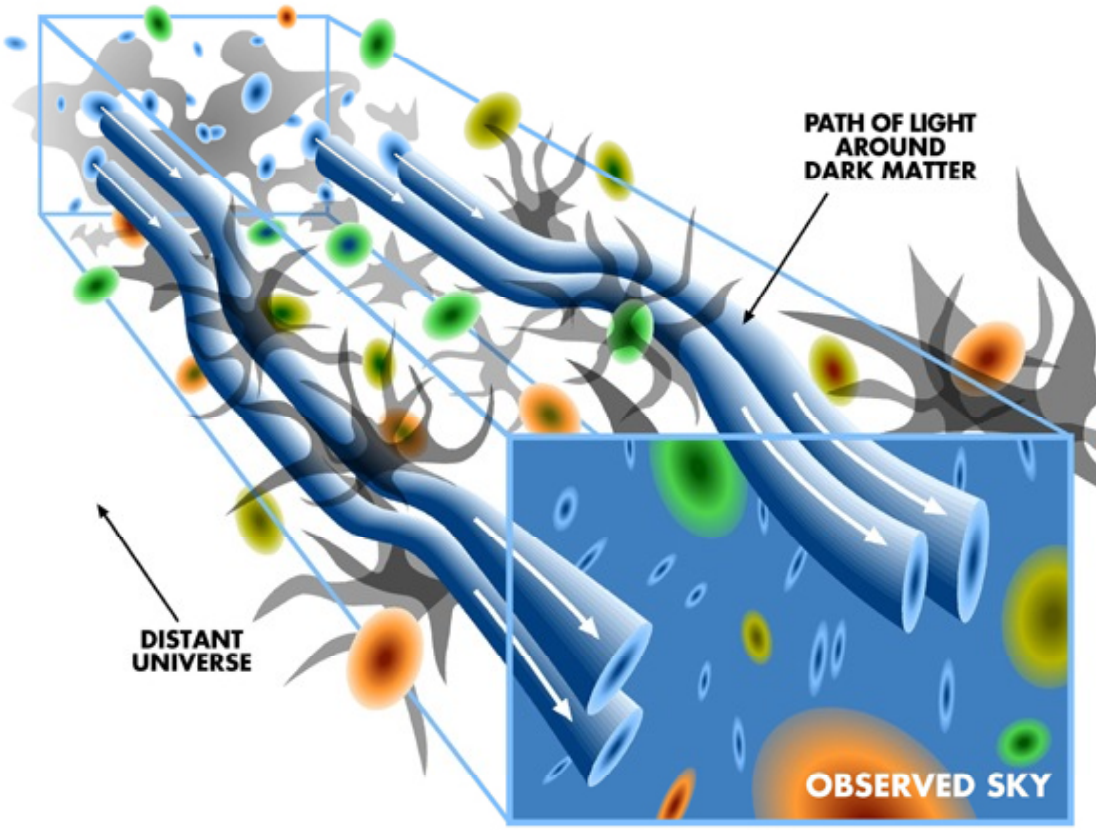
- **measure growth of structure as function of redshift**
- **Galaxy Cluster surveys & Weak Lensing (WL) Surveys**





Weak Lensing & Cosmic Shear

- **Weak lensing: the distortion of the appearance of background galaxies due to the clustering of dark matter in the intervening universe.**
- **A given galaxy image is sheared.**
- ***The shearing of neighbouring galaxies is correlated, because their light follows similar paths on the way to earth. This is cosmic shear***
- **The effect is detectable only statistically**



Tyson et al 2002

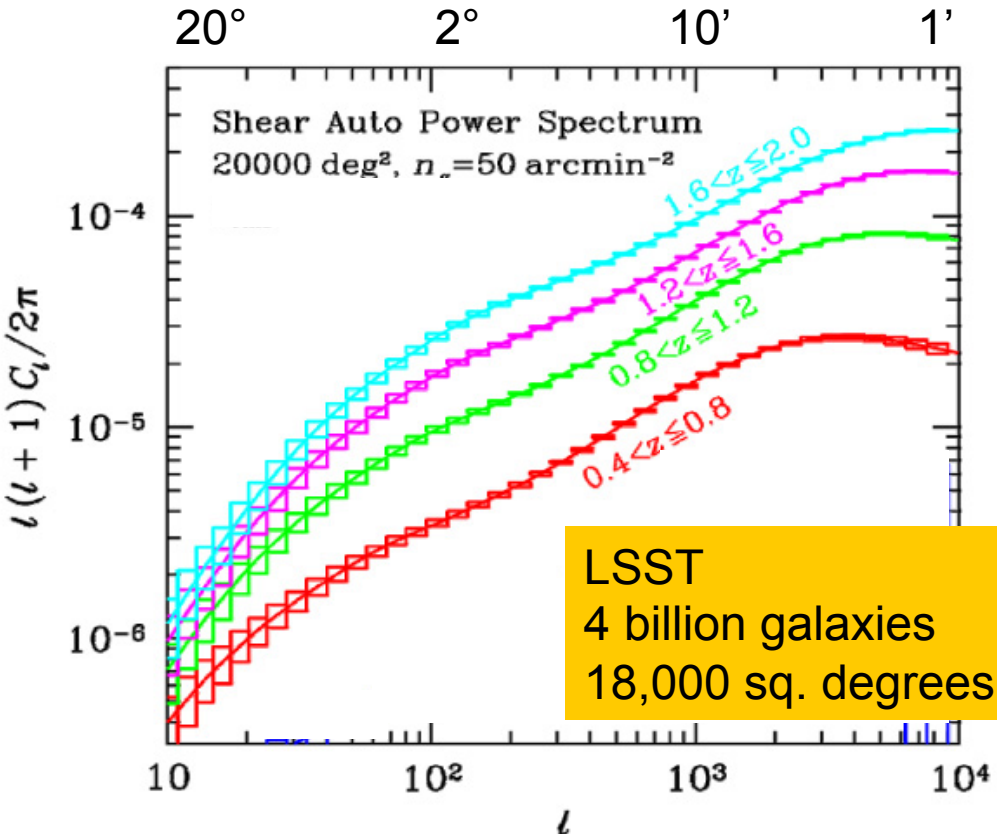
- Massively exaggerated

Cosmic shear: ~ 0.01

e.g. circular galaxy → ellipse with a/b ~ 1.01

LSST and Cosmic Shear

- **Simplest measure of cosmic shear is the 2-pt correlation function measured with respect to angular scale.**
- **Fourier transform → power spectrum as a function of multi-pole moment (similar to CMB temperature maps).**
- **The growth in the shear power spectrum with the red shift of the background galaxies provides the constraints on dark energy.**



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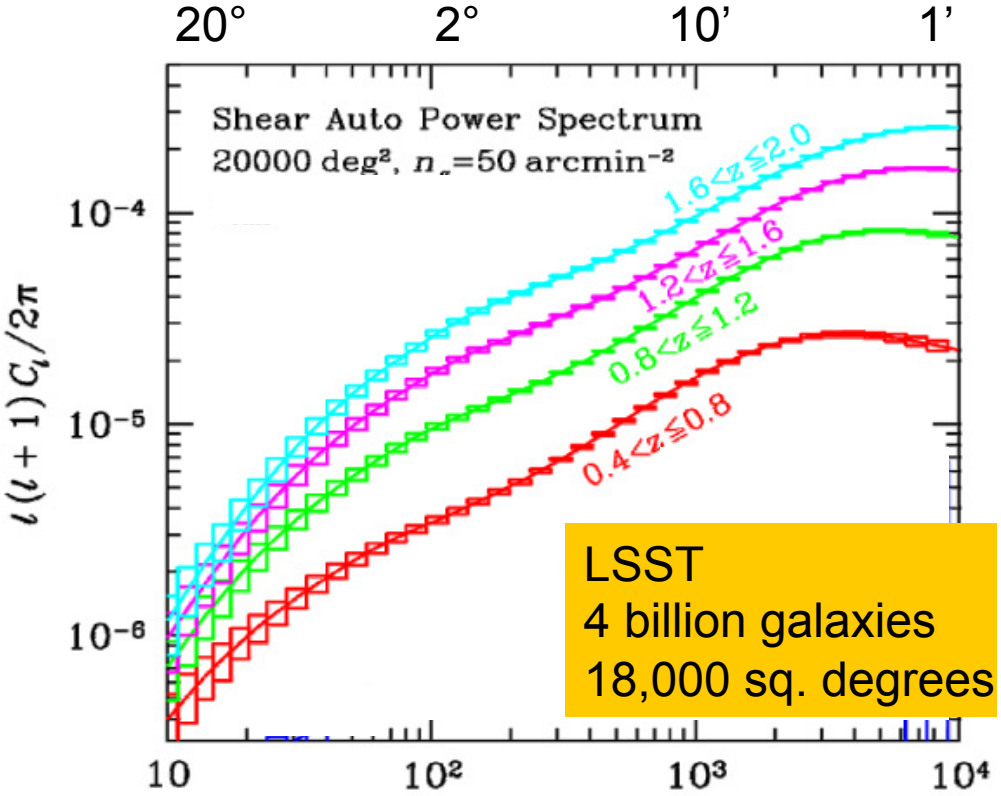
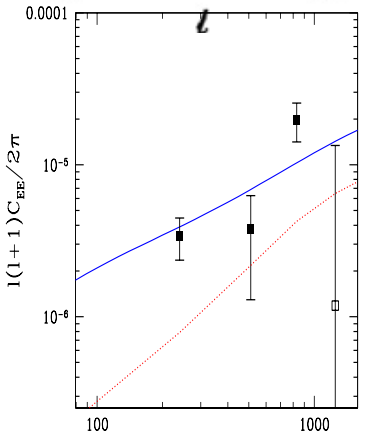


SDSS (2011)
4.7E6 galaxies
~275 sq degree



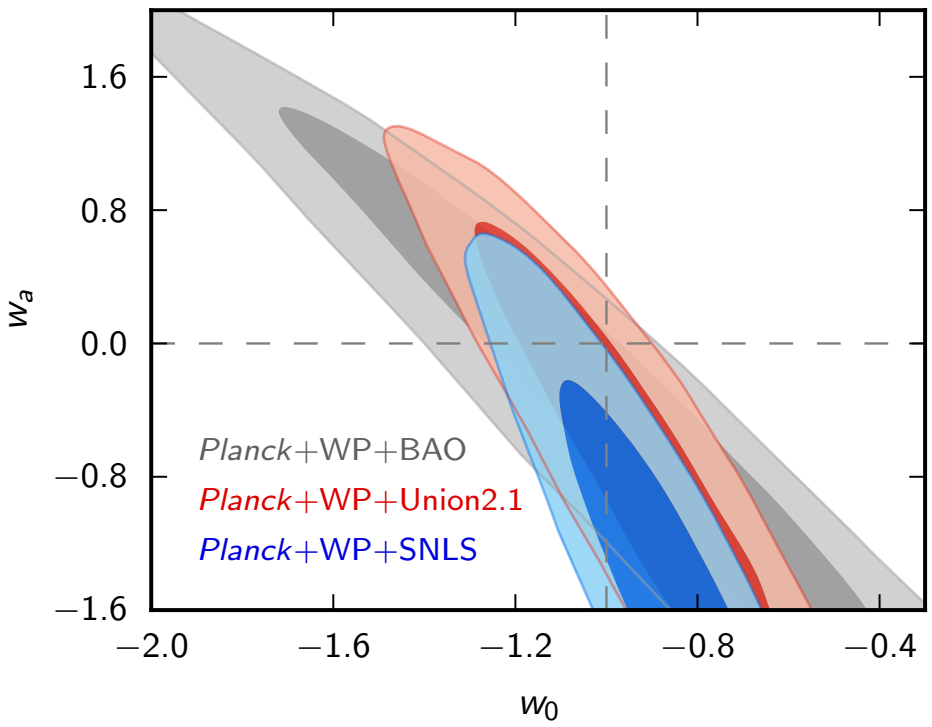
Current constraints on Dark Energy from multiple techniques

$$w = P/\rho$$

$$w = w_0 + w_a\left(\frac{z}{1+z}\right)$$

now

evolution



Planck
arXiv:1303.5076v2
December, 2013

Combined:
SN + BAO + CMB

Predicted LSST Constraints on Dark Energy from multiple techniques

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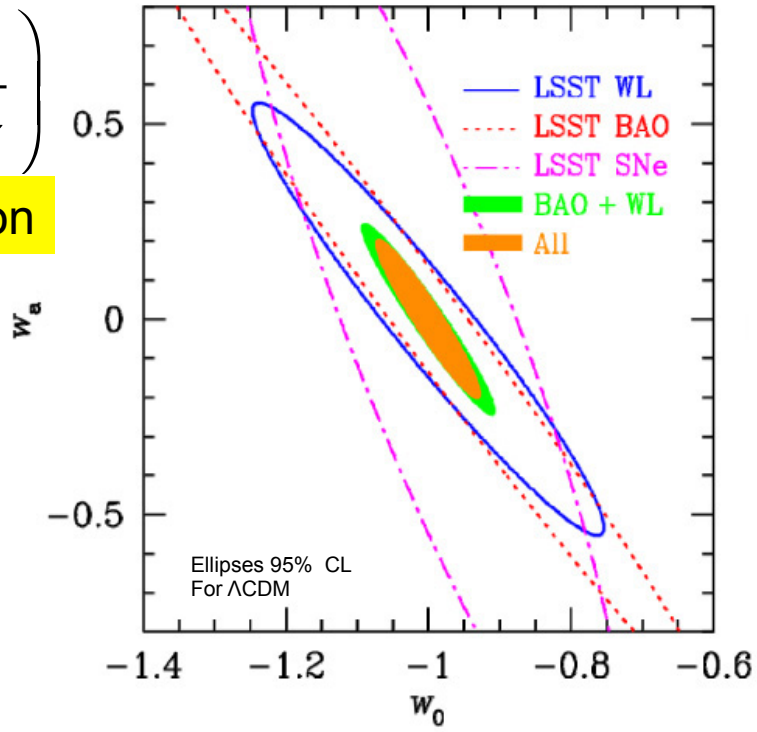
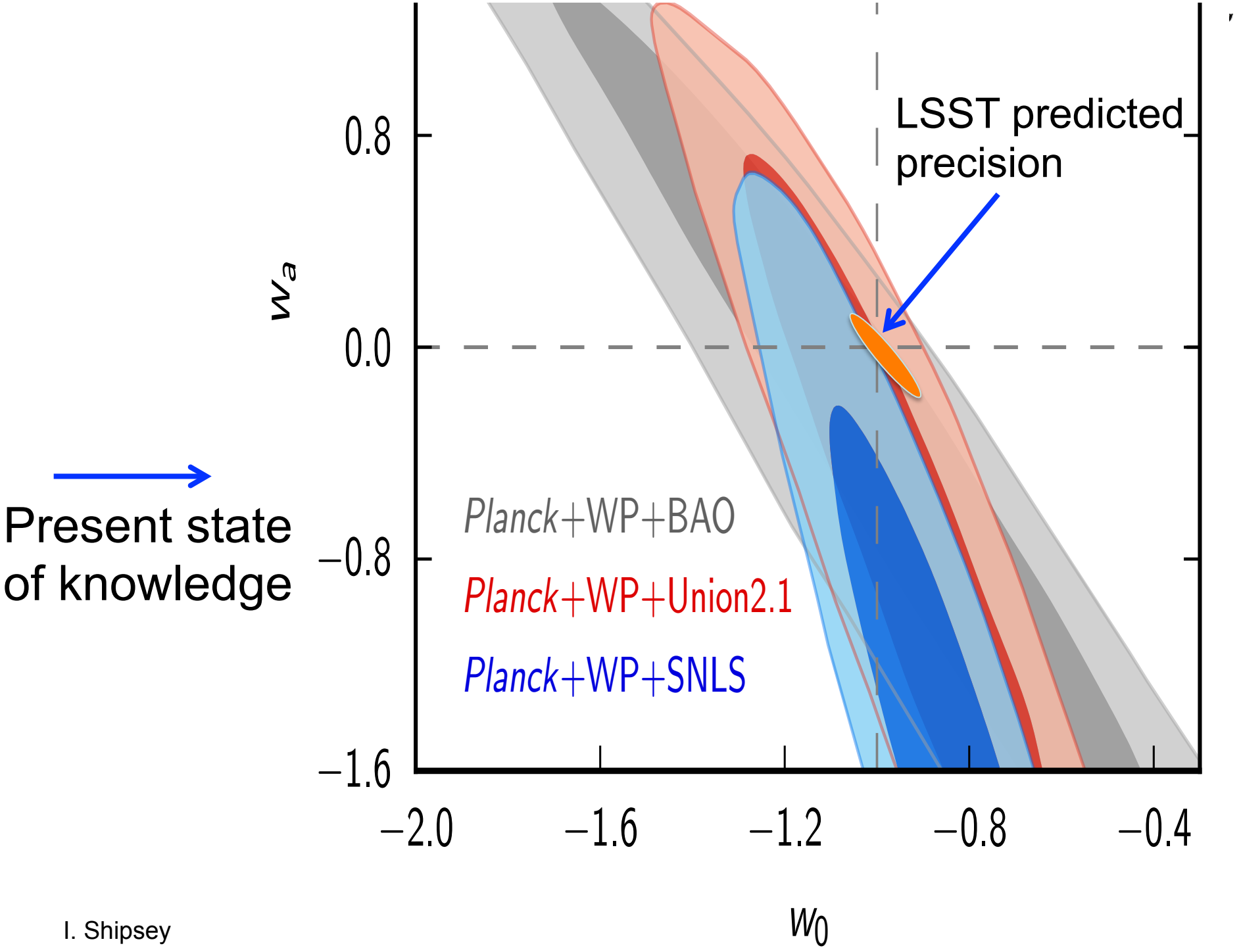
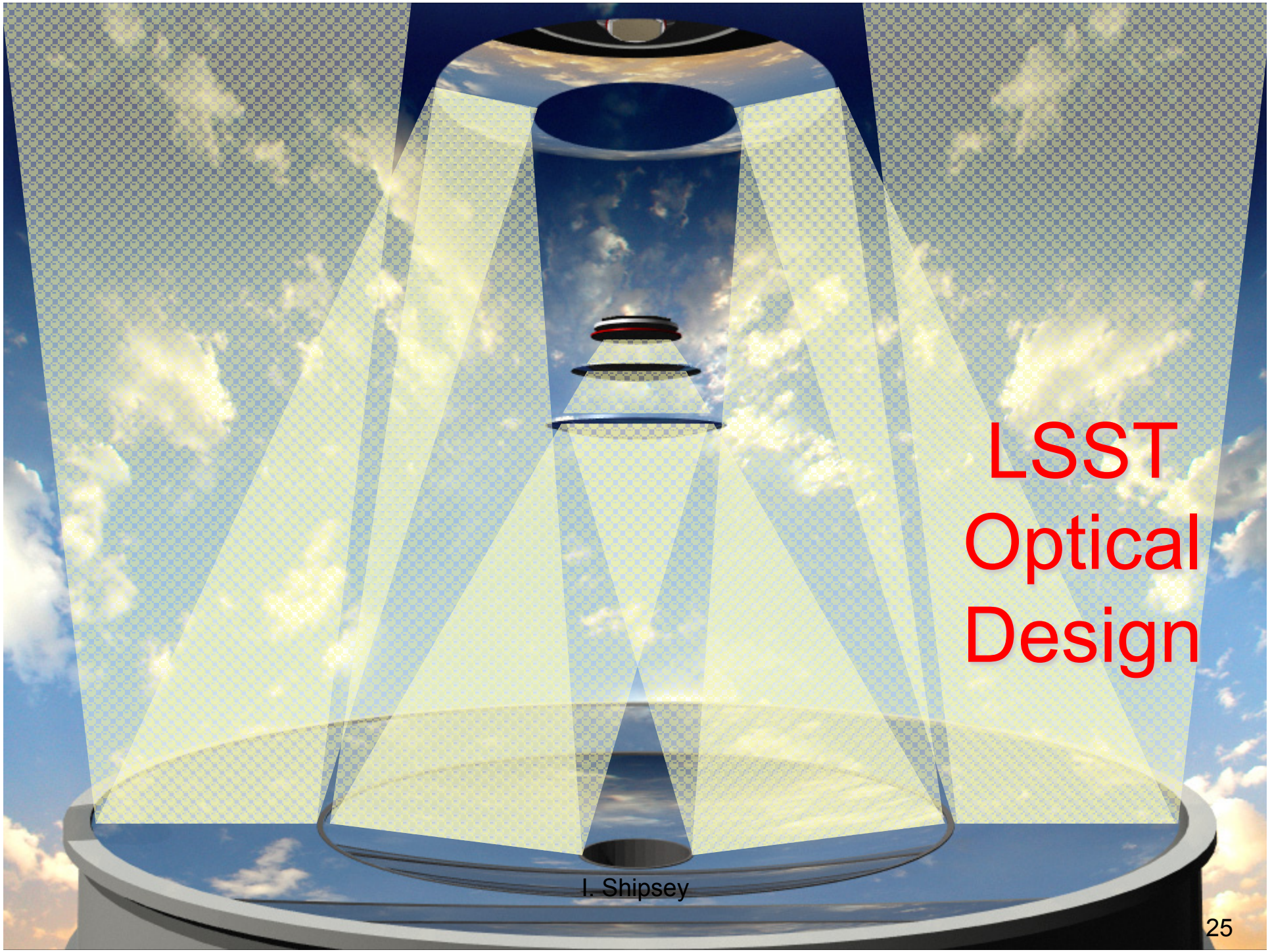


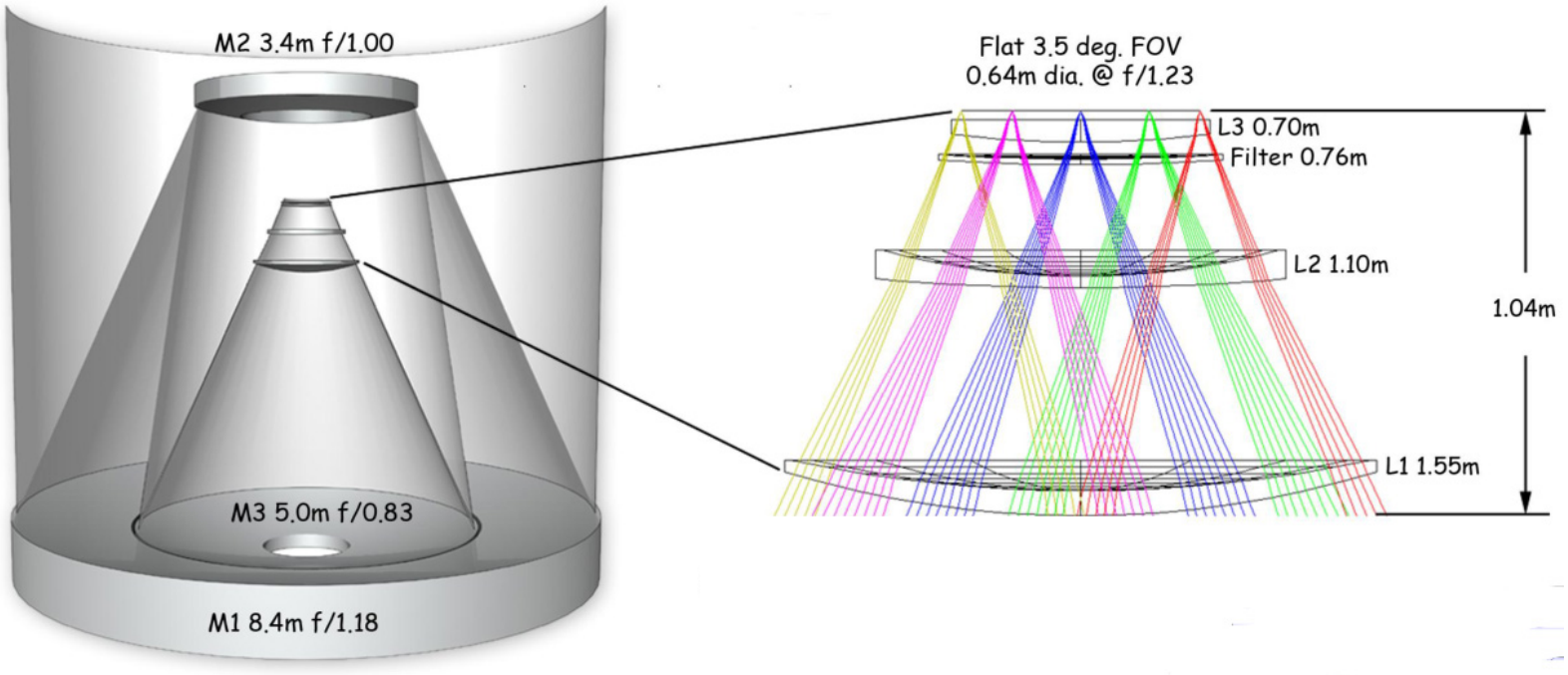

LSST predicted precision
Present state of knowledge
Planck+WP+BAO
Planck+WP+Union2.1
Planck+WP+SNLS
0.8
0.0
−0.8
−1.6
−2.0
−1.6
−1.2
−0.8
−0.4
w_a
w_0



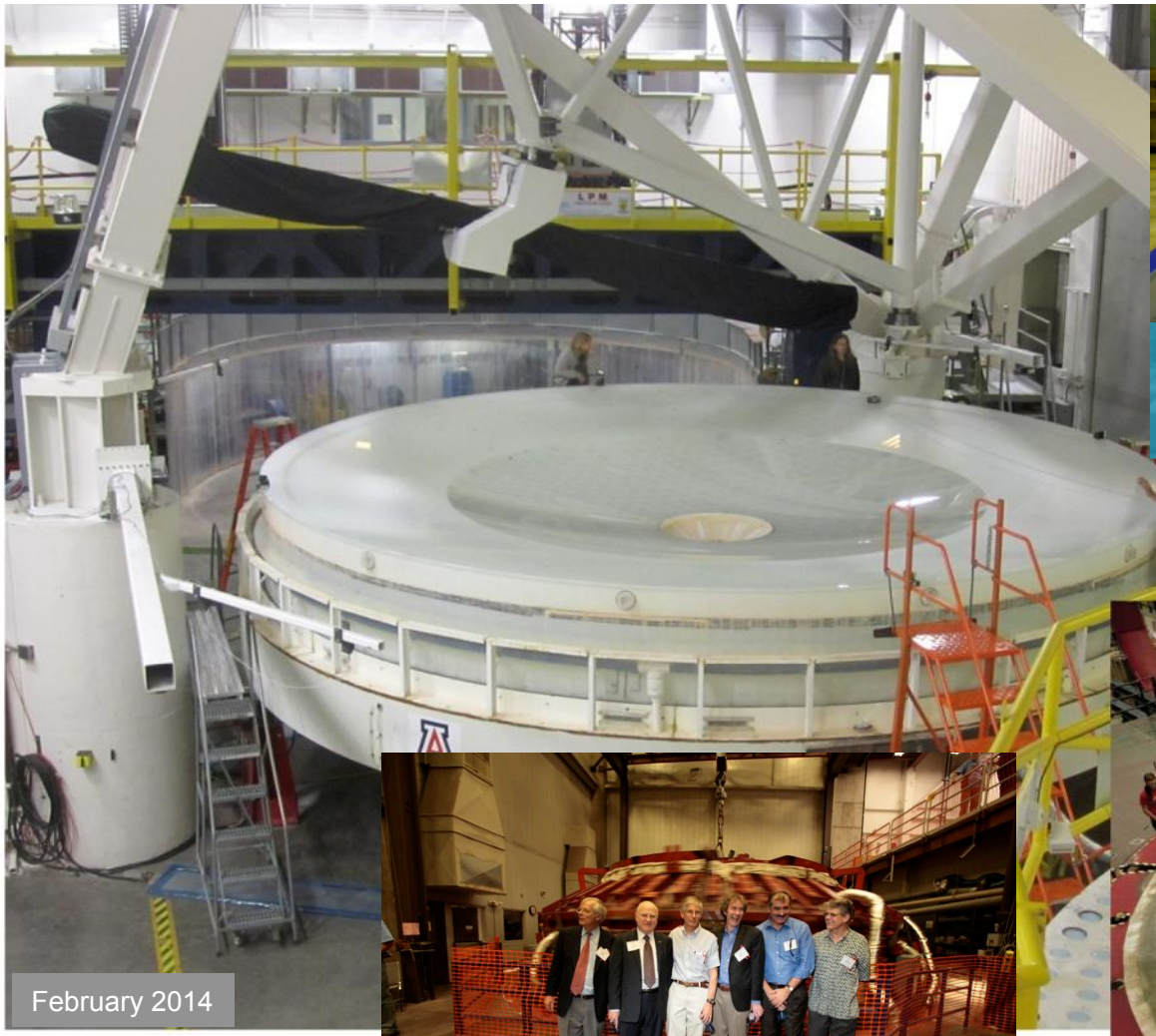
I. Shipsey

LSST Optical Design

- *f/1.23* Very short focal length gives wide field of view for given image size
- 3.5 ° FOV over a 64 cm focal plane, Etendue = 319 m^2deg^2
- < 0.20 arcsec FWHM images in 6 filters u g r z i y : 0.3 – 1 μm



Unique Monolithic M1 / M3 mirror polishing nearly complete - June 2014



Secondary Mirror Substrate ready for optical polishing

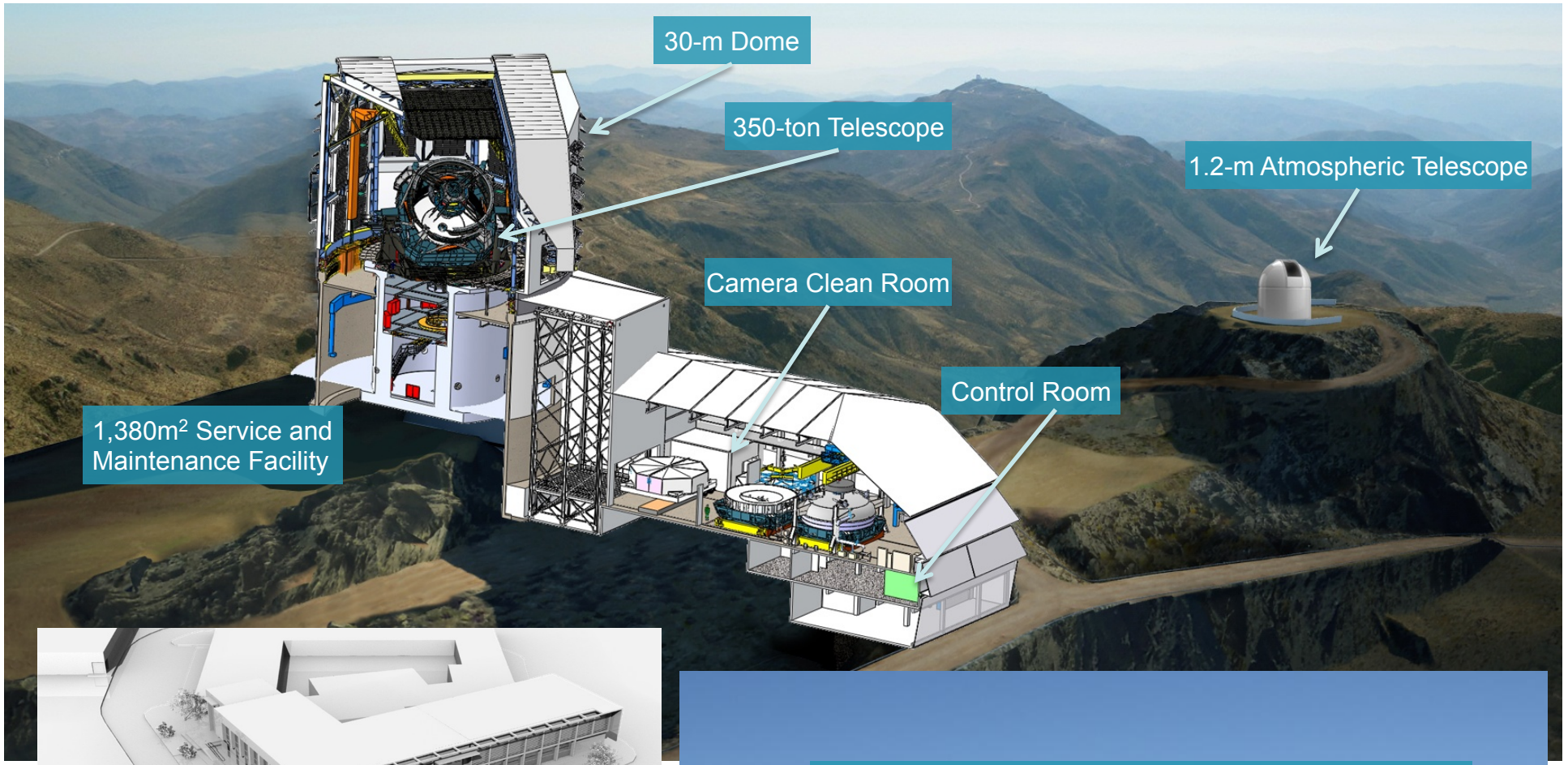
Sept 2008

LSST Will be Located in Central Chile

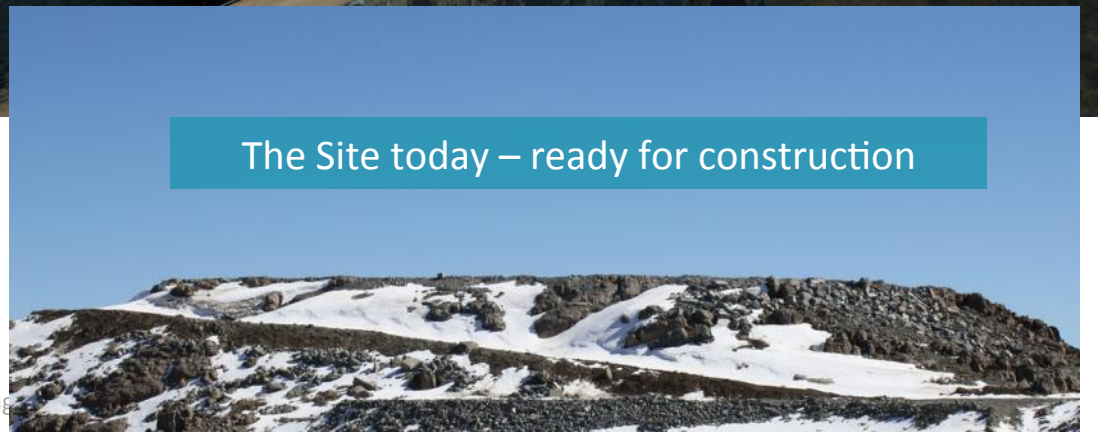
I. Shipsey

LSST is located in an NSF compound near SOAR & Gemini

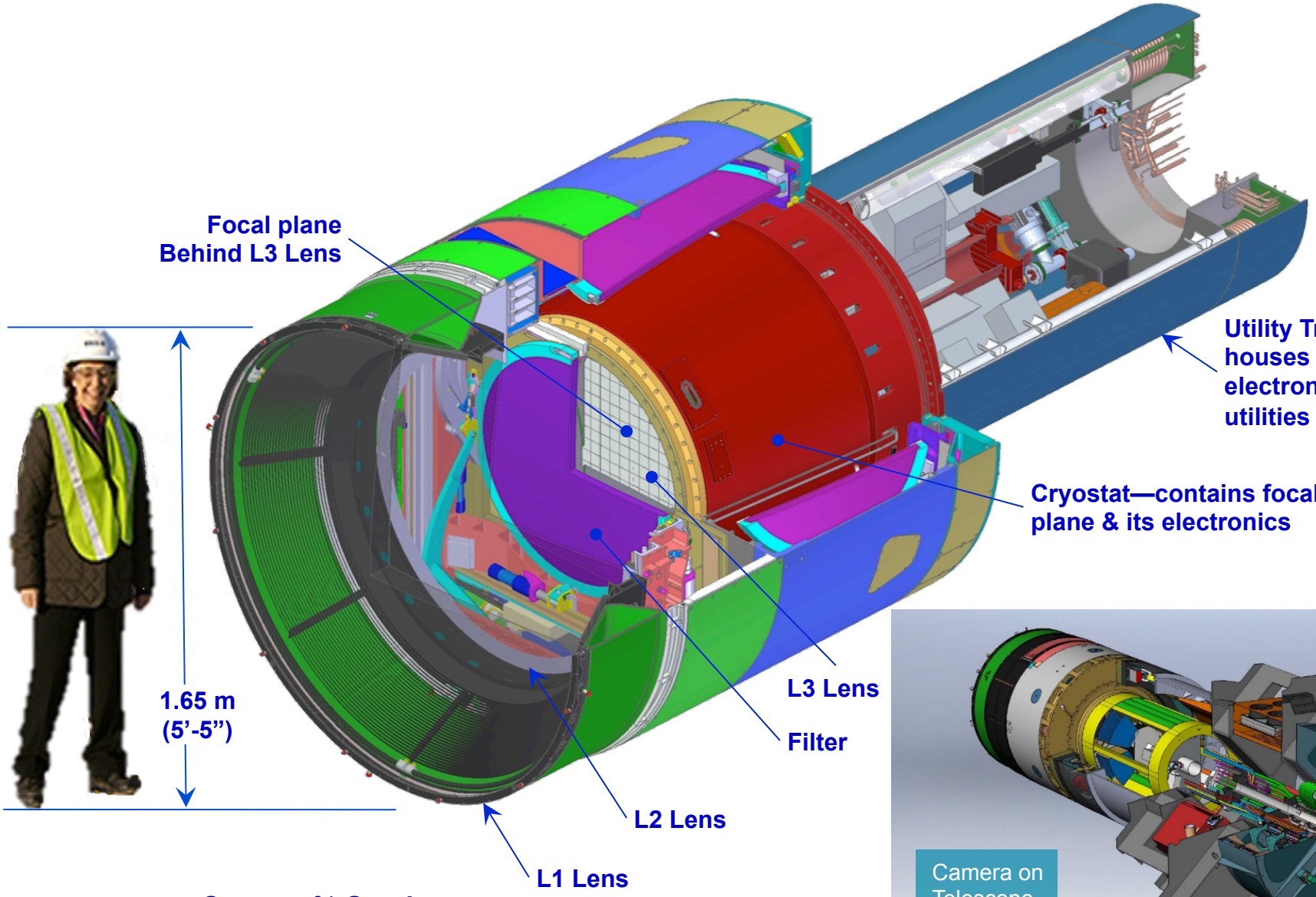
Telescope and Site System has Major Focus on Infrastructure: ready to begin construction in September



Base Facility
Operations Support
Data Access Center

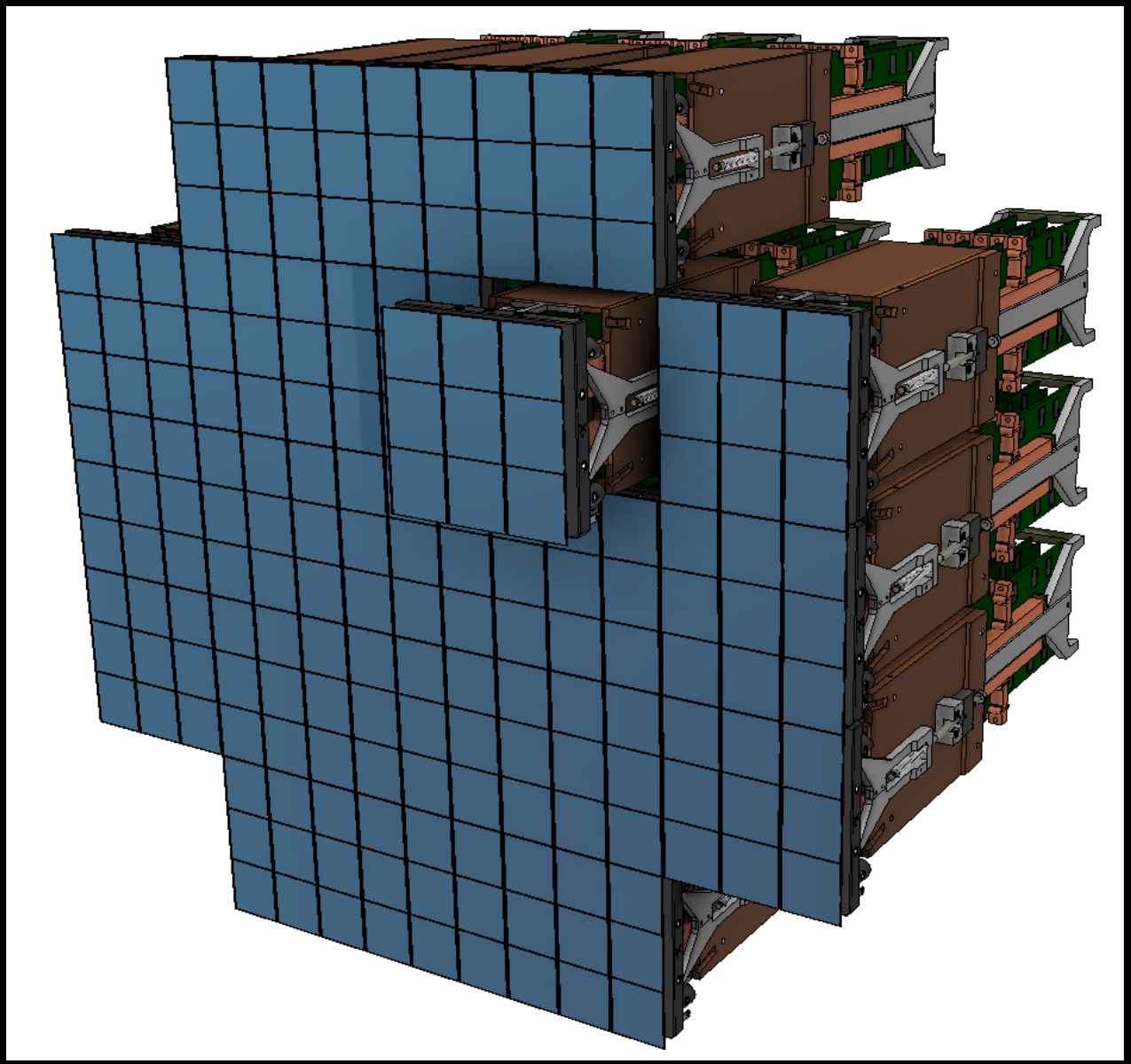


3.2 Gigapixel Camera



Camera ¾ Section

LSST Camera:
21 science rafts, 189 4K x 4K CCDs

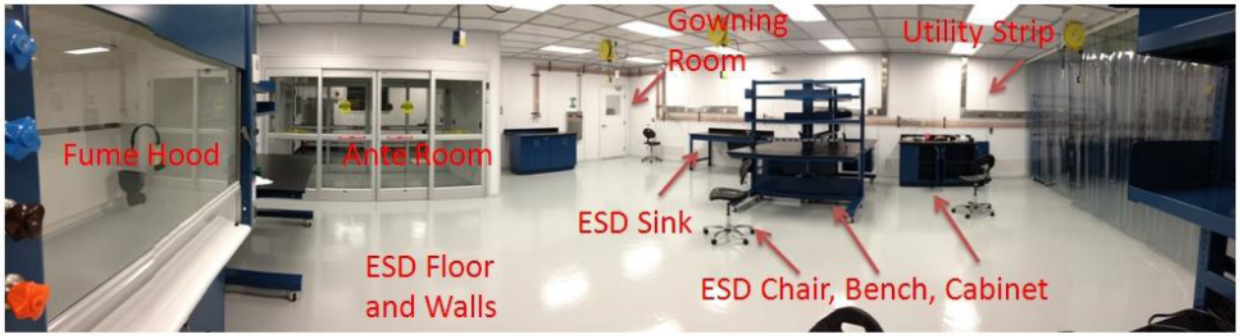


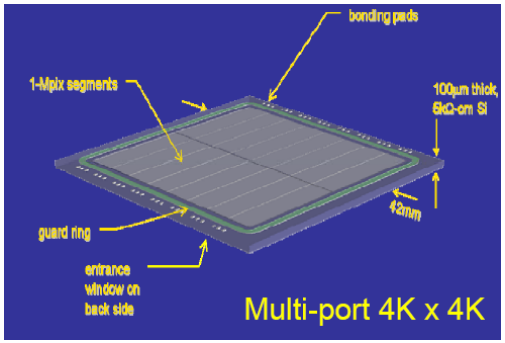
3 Gpix multiport CCDs

Record image in 15 seconds

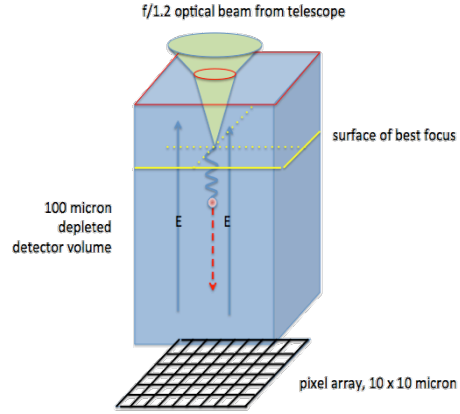
Readout image In 2 seconds

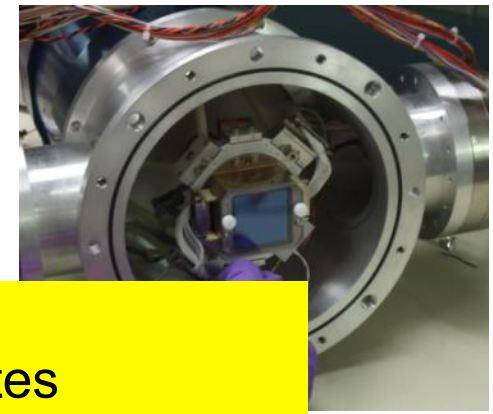
Sensor Status: Procurements now issued

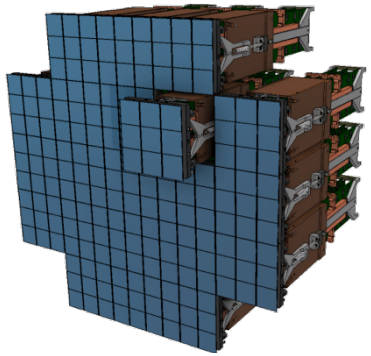




- Sensor prototypes from 2 vendors meet specifications
- LSST team has tested to confirm performance.
- Successful DOE review (CD-3a) held May 6-8, 2014, approval followed mid-june.
- Sensor Procurements now issued.
  - Includes first articles
  - Options for first lots

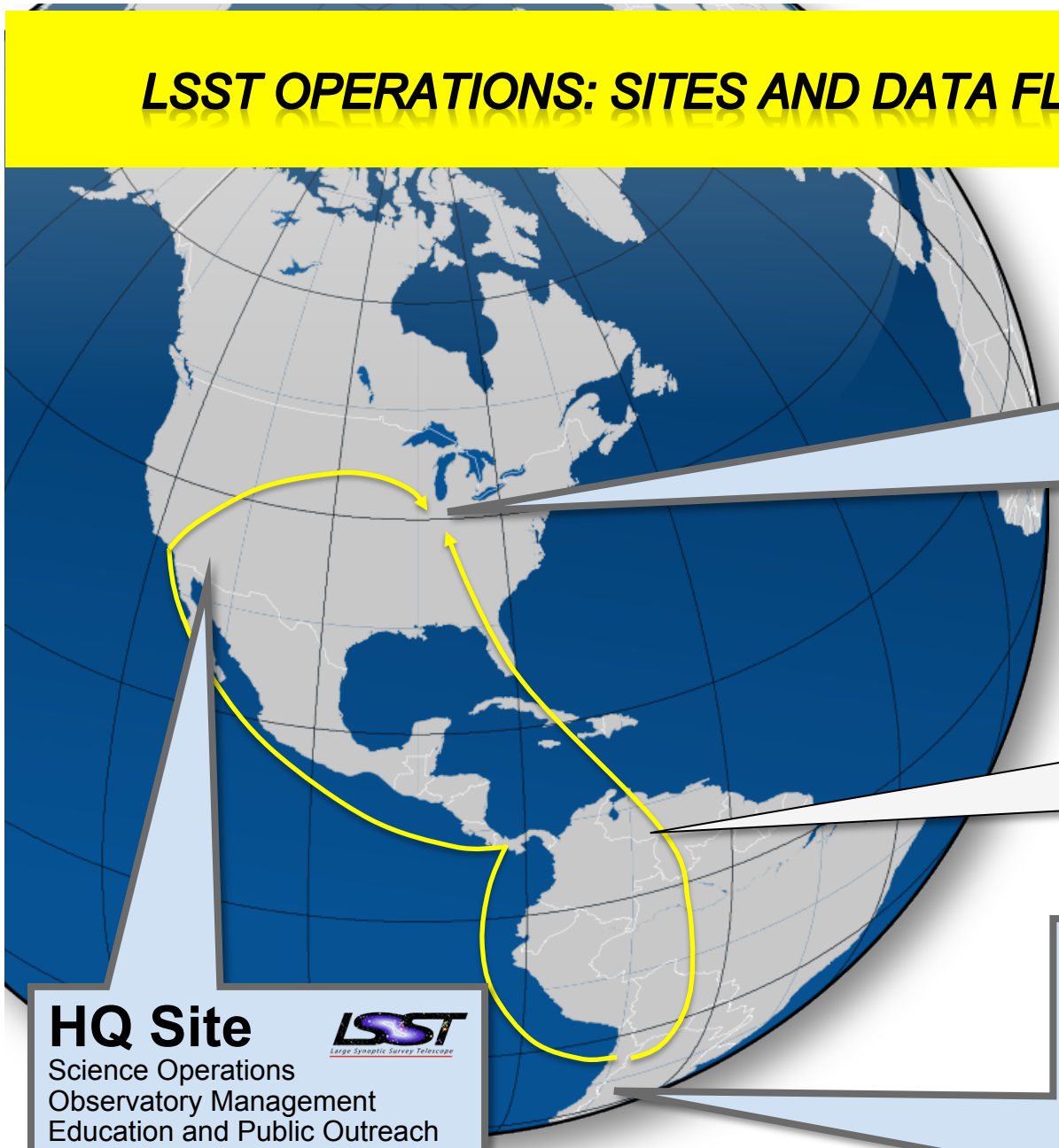






- Every 15 sec: 6GB
- Nightly data generation rate: 15 TBytes
- Yearly data generation rate: 6.8 Pbytes

LSST OPERATIONS: SITES AND DATA FLOWS



Archive Site

NCSA

Archive Center

Alert Production
Data Release Production
Calibration Products Production
EPO Infrastructure
Long-term Storage (copy 2)

Data Access Center

Data Access and User Services

Dedicated Long Haul Networks

Two redundant 40 Gbit links from La Serena to Champaign, IL (existing fiber)

HQ Site

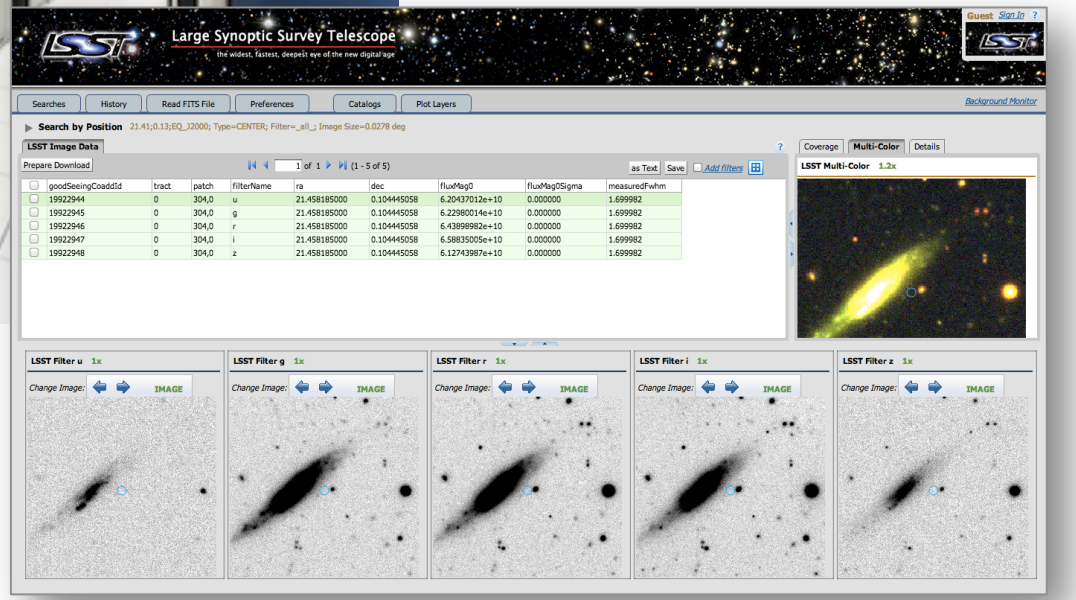
Science Operations
Observatory Management
Education and Public Outreach

Summit and Base Sites

Telescope and Camera
Data Acquisition
Crosstalk Correction
Long-term storage (copy 1)
Chilean Data Access Center

Ultimate LSST Deliverable: Reduced Data Products

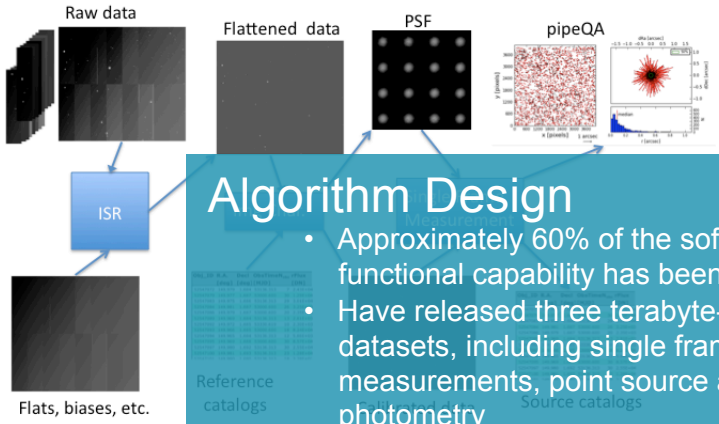
*A petascale supercomputing system at the **LSST Archive** (at NCSA) will process the raw data, generating reduced image products, time-domain alerts, and catalogs.*



***Data Access Centers** in the U.S. and Chile will provide end-user analysis capabilities and serve the data products to LSST users.*

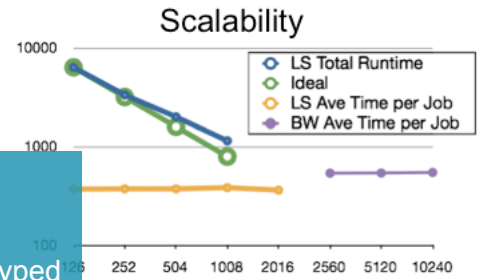
I. Shipsey

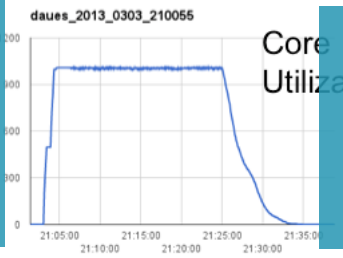
DM Team has Designed and Prototyped Critical Algorithms and Technologies at Scale



Algorithm Design

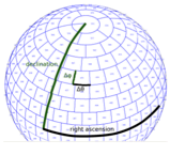
- Approximately 60% of the software functional capability has been prototyped
- Have released three terabyte-scale datasets, including single frame measurements, point source and galaxy photometry
- Pre-cursors leveraged
  - Pan-STARRS, SDSS, HSC

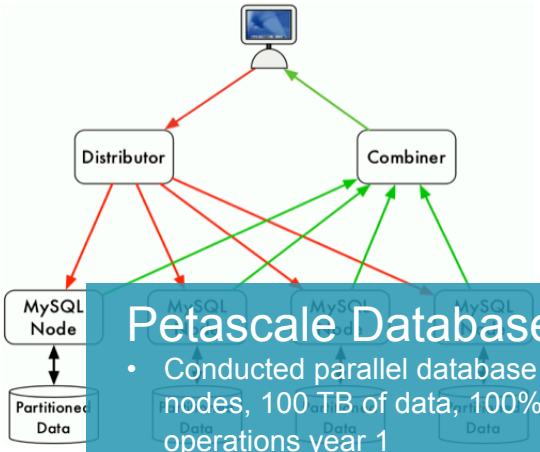




Petascale Computing Design

- Executed in parallel on up to 10k cores (TeraGrid/XSEDE and NCSA Blue Waters hardware) with scalable results





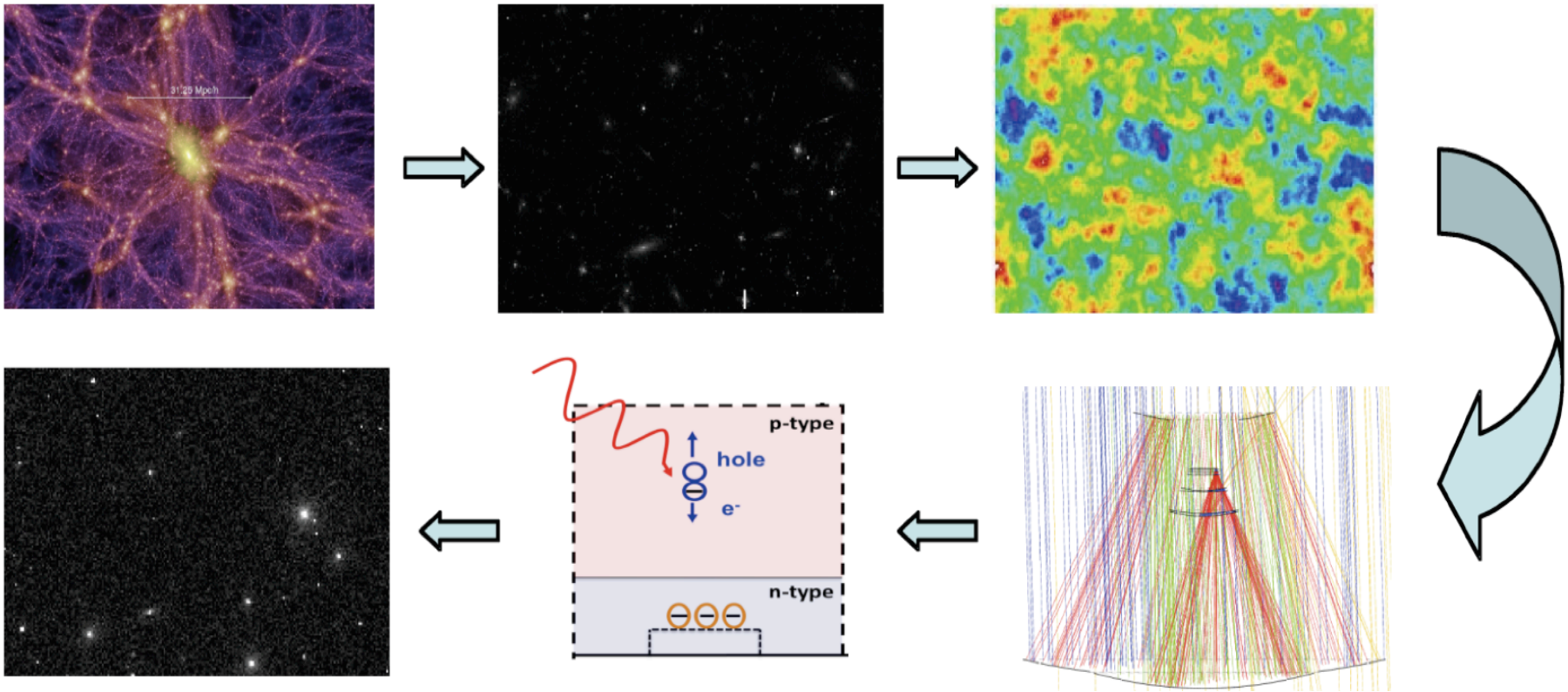
Petascale Database Design

- Conducted parallel database tests up to 300 nodes, 100 TB of data, 100% of scale for operations year 1

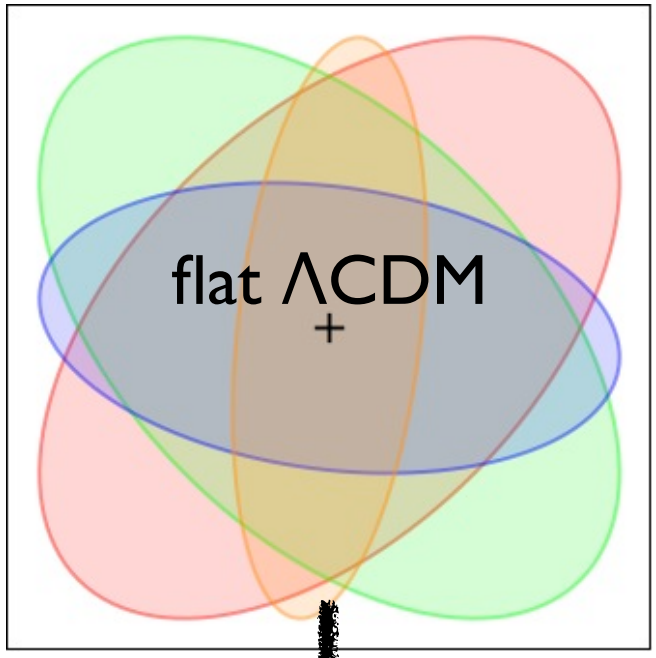
Gigascale Network Design

- Currently testing at up to 1 Gbps
- Agreements in principle are in hand with key infrastructure providers (NCSA, FIU/ AmPath, REUNA, IN2P3)

Image Simulation: Implementing a simulated sky

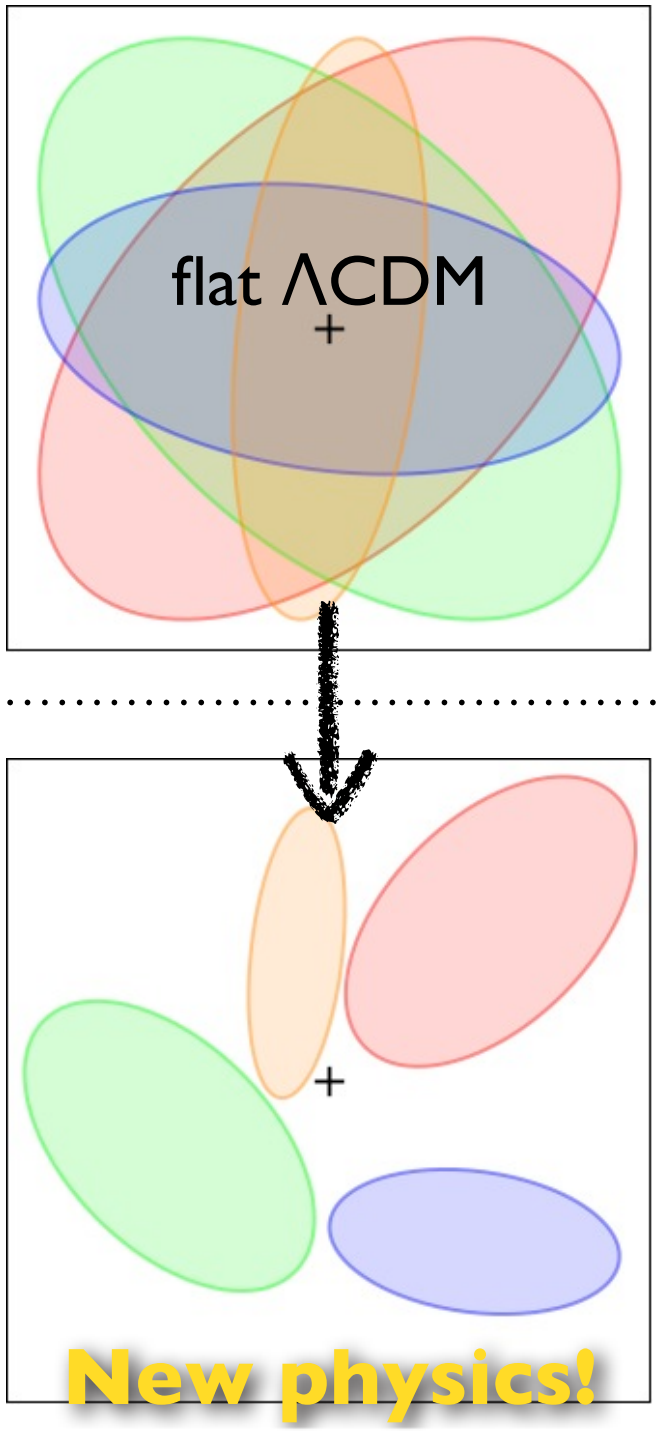


Simulated LSST image (one exposure, 3 bands)



Stage III

LSST
& other stage IV
experiments



Stage III

Stage IV

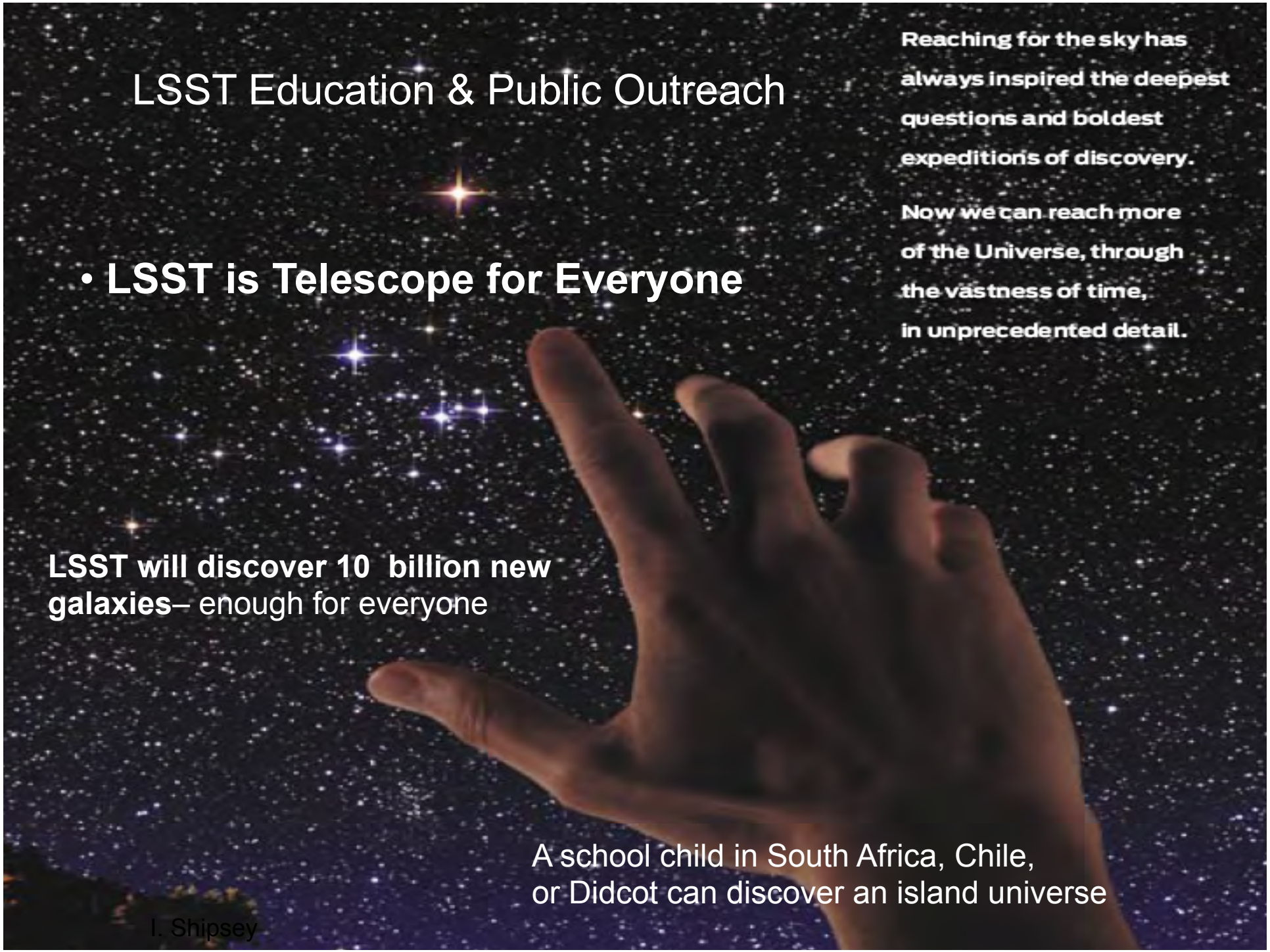
LSST
& other stage IV
experiments

LSST Outreach Data will be used in classrooms, science museums, and online

Classroom Emphasis on:

- Data-enabled research experiences
- Citizen Science
- College classes
- Collaboration through Social Networking

ZOONIVERSE
REAL SCIENCE ONLINE


LSST Education & Public Outreach
Reaching for the sky has always inspired the deepest questions and boldest expeditions of discovery.
Now we can reach more of the Universe, through the vastness of time, in unprecedented detail.
• LSST is Telescope for Everyone
LSST will discover 10 billion new galaxies– enough for everyone
A school child in South Africa, Chile, or Didcot can discover an island universe
I. Shipsey

The Green light

LSST is a private/public interagency project
NSF: Telescope/DM/EPO DOE: Camera
Private: Mirrors. Site prep. early sensor studies

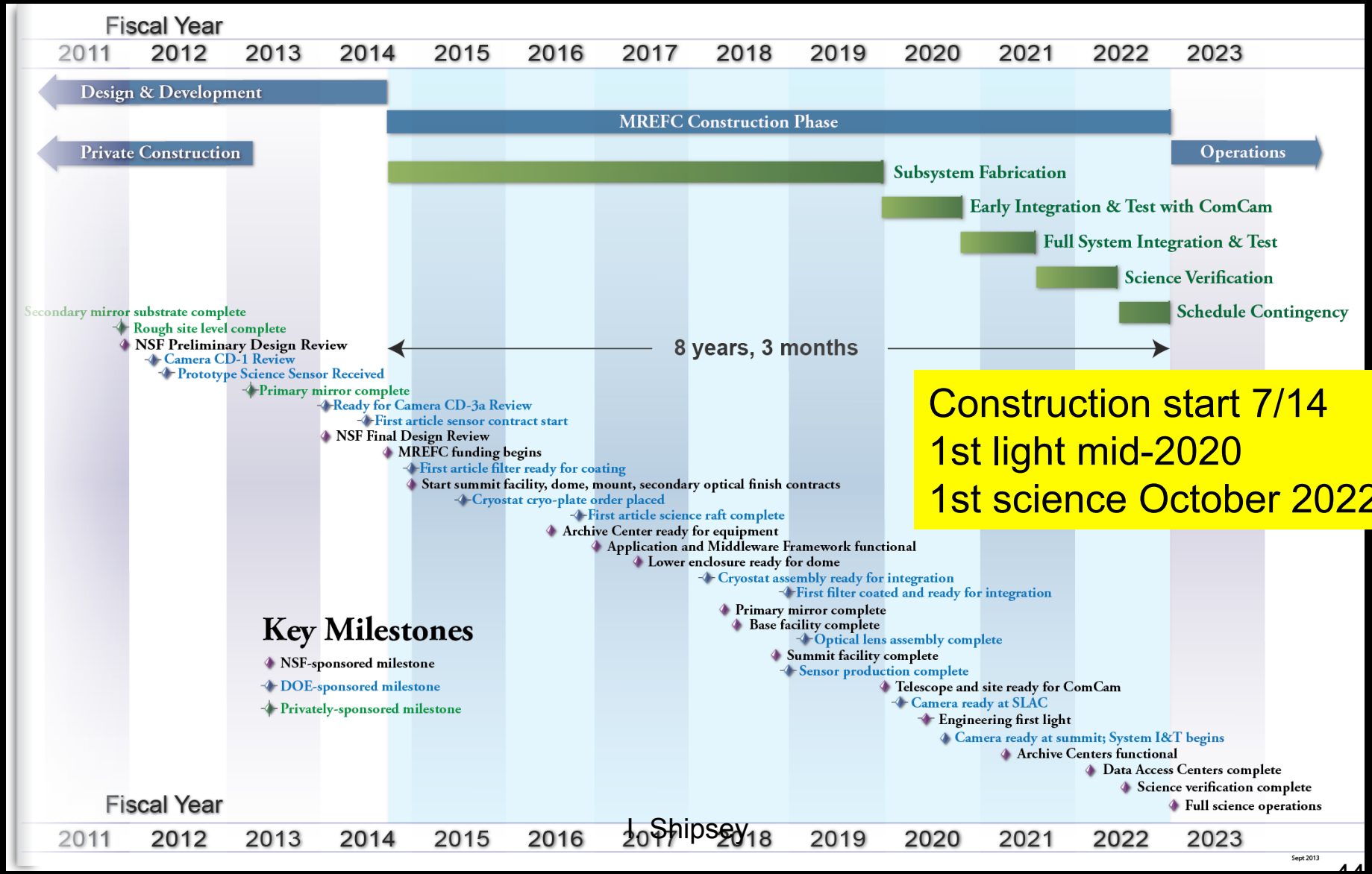
Conception 1996, in current form since 2001

National Science Board approved the project at their meeting on May 6, the *construction start* l in July.

For NSF, expect to receive the full amount requested for construction in FY14, and the FY15 President's Budget Request lays out a funding profile consistent with our current plans, with a MREFC total project cost of $473M.

The DOE budget provided in FY14 for the LSST Camera is also consistent with planned funding profile: estimated camera project cost $165M.

Integrated Project Schedule with Key Milestones



Construction start 7/14
1st light mid-2020
1st science October 2022

J. Shipsey

LSST UK

The UK could contribute and grow its 'Big Data' expertise, and a risk of not participating is that the UK would be at a disadvantage in being unable easily to exploit ESO facilities to follow up the findings that LSST generates. Planning should be made to support such involvement, subject to peer review and at an affordable level.
---- UK Programmatic Review

LSST is the missing piece in the UK's future ground-based astronomy programme

184 Astrophysicists at 33 UK institutions have recently formed LSST:UK and are seeking to join LSST as a national consortium

A proposal was submitted to PPRP yesterday

Part of the LSST Collaboration 8/2012

A partnership of astrophysicists, particle physicists & computer scientists

I. Shipsey

LSST:UK and possible PP involvement

The PP community has a long tradition of building complex detectors and computational systems, designed to perform systematics limited measurements. These skills are in high demand in the LSST

In the US about one third of the members of the LSST collaboration are particle Physicists & about ¼ of the construction funds will come from DOE particle physics

Areas where PP expertise is valuable include: camera, DAQ, database development, simulations, algorithm devlopment, dark energy science, annual data release processing, support for UK Data Access Center

UK PP can add add complementary value to the UK AST contributions to LSST and help secure UK leadership in the science

From the LSST:UK PPRP proposal:

"In the US, LSST is seen as part of both the astronomy and particle physics programmes, as prominent in the recent P5 report as it was in the Astro2010 Decadal Survey. Two particle physicists (Clarke, Shipsey) are included in the LSST:UK Consortium membership listed above, while others from Cambridge, Edinburgh, Oxford and UCL have expressed a strong scientific interest in LSST as a probe of the dark sector and indicated a long-term interest in contributing to a variety of data acquisition, data management and algorithm development tasks….
Physicists from RAL PPD are also interested in the project and would be eager to support the other groups if requested"

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- **Most of the requisite investigations can be performed using data from a single coherent survey program. This is "massively parallel survey astrophysics" in its purest form.**
- **The analyses will be complex and will require significant attention to detailed systematics uncertainties. *There are many opportunities for particle physicists to become involved now or in the next few years to optimize the anticipated science and then perform the science that will come from this marvelous facility.***

Acknowledgment

Sarah Bridle, Andy Connolly, Daniel Calabrese, Zelijko Ivezic, Mario Juric, Iain Goodenow, Steve Kahn, Jeff Kantor, Victor Krabbendam, David Kirby, Bob Mann, Rob McKercher, Paul O'Connor Chris Stubbs, Jon Thaler, Tony Tyson, Sidney Woolf

The LSST Collaboration

At Purdue: Kirk Arndt, Mike Focosi, Bo Xin, Enver Alagoz, John Peterson
+ many undergraduates

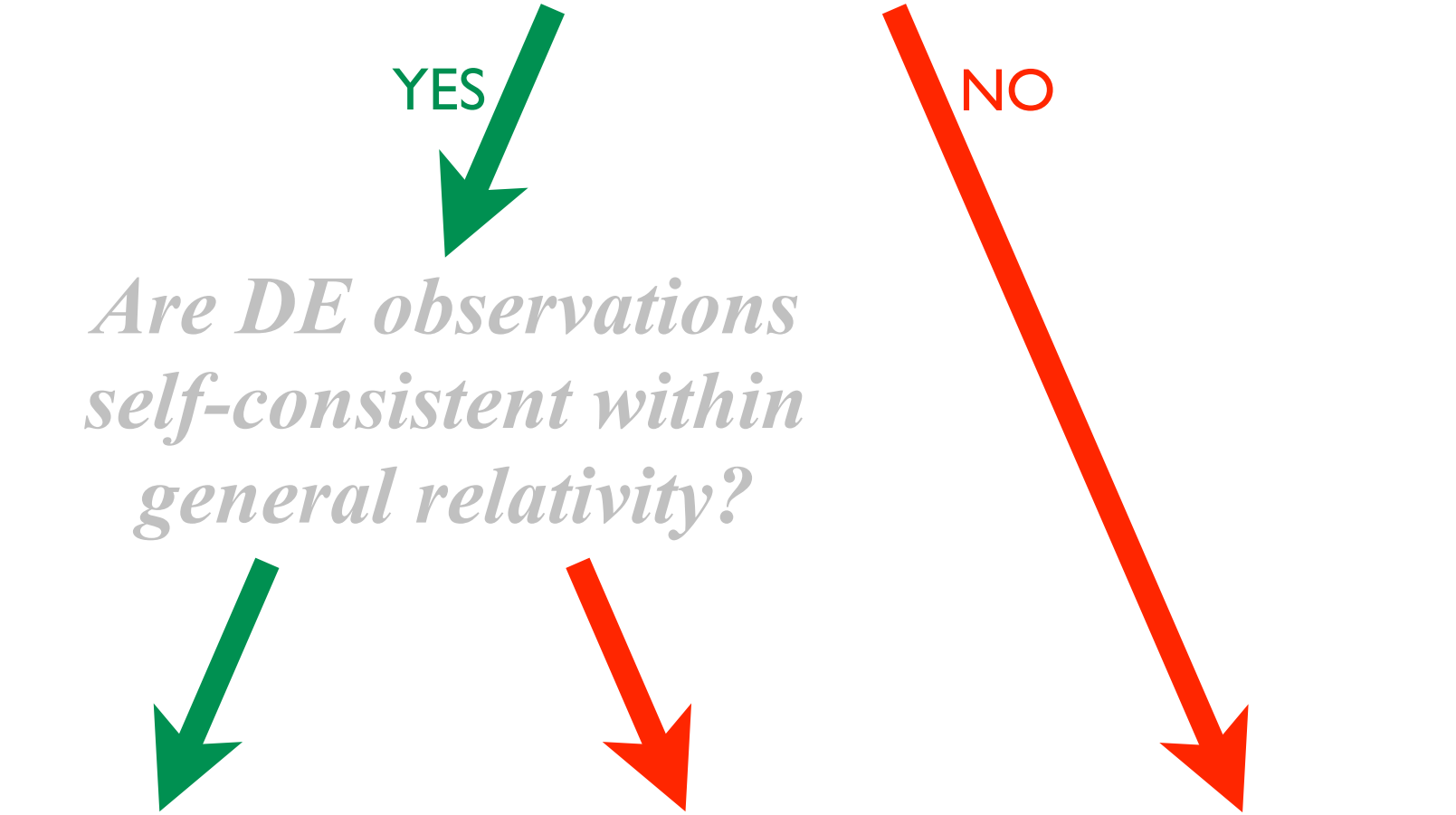
Dark Energy: An unprecedented opportunity

Either:
two thirds of the energy in the Universe is of unknown origin,
Or:
General Relativity is wrong at large scales

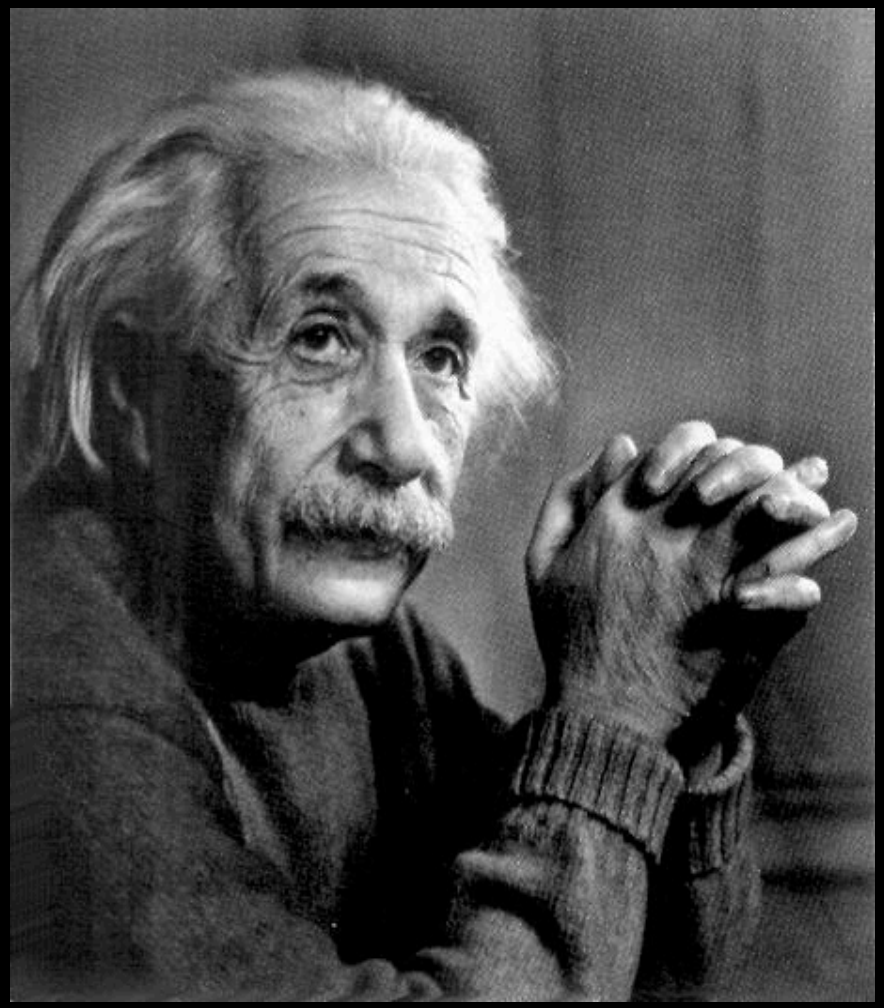
Challenge: determine origin of Dark Energy or disprove GR

Approach: measure the amount of Dark Energy as a function of time to the systematic limit via multiple techniqiues

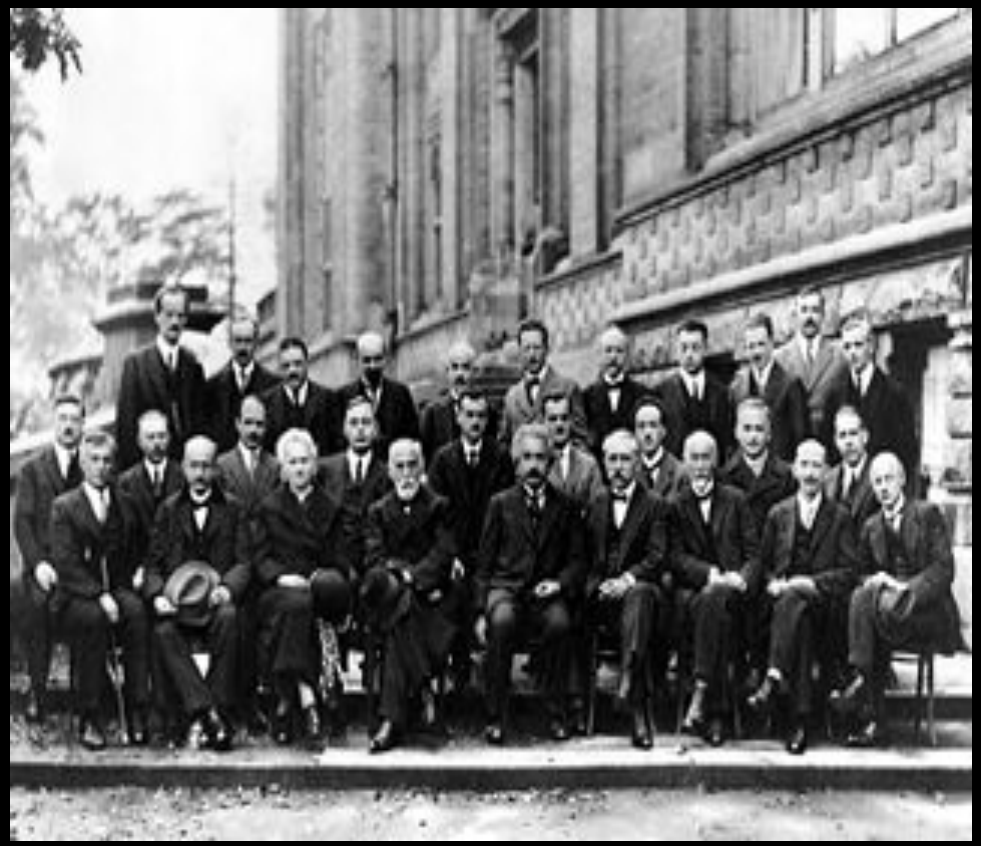
Does DE density evolve?



Studying Dark Energy is one of the ways we may bring within reach reconciliation of the two great edifices



General Relativity

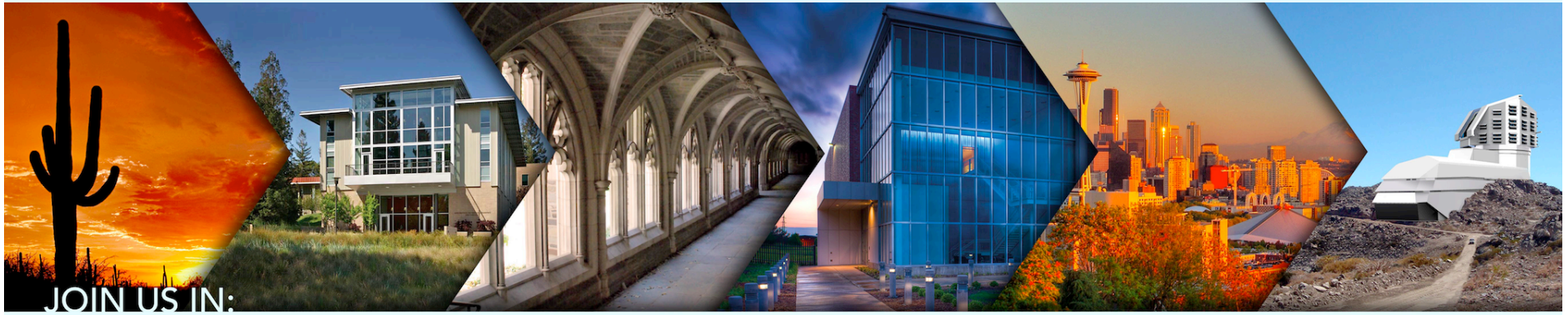


Quantum Mechanics

LSST IS HIRING

Large Synoptic Survey Telescope
LSST.ORG

WE'RE SEEKING TOP TALENT TO WORK IN A TEAM ENVIRONMENT THAT INSPIRES EXCELLENCE.



LSST HEADQUARTERS	SLAC/STANFORD	PRINCETON UNIVERSITY	NCSA / UIUC	UNIVERSITY OF WASHINGTON	LSST OBSERVATORY SITE
TUCSON, AZ	MENLO PARK, CA	PRINCETON, NJ	URBANA-CHAMPAIGN, IL	SEATTLE, WA	CERRO PACHÓN, CHILE

ABOUT US

LSST IS A PUBLIC-PRIVATE PARTNERSHIP AND THE TOP-RANKED LARGE-SCALE GROUND-BASED PROJECT FOR THE NEXT DECADE AS RECOMMENDED BY THE NRC'S ASTRO2010 DECADAL SURVEY. LSST WILL SCAN THE SKY FOR 10 YEARS, PRODUCING A PETABYTE-SCALE, NON-PROPRIETARY DATABASE DESIGNED TO ADDRESS THE MOST PRESSING QUESTIONS IN ASTRONOMY AND PHYSICS, WHILE DRIVING ADVANCES IN BIG-DATA SCIENCE AND COMPUTING.

CAREERS

LSST IS A NEW PARADIGM FOR LARGE SCIENTIFIC FACILITIES: OPEN SOURCE, OPEN DATA, AND AN OPEN, FLEXIBLE WORK ENVIRONMENT. ALL LSST WORK SITES OFFER EXCEPTIONAL BENEFITS PACKAGES AND ROOM FOR PROFESSIONAL GROWTH.

OUR TEAM

PROJECT OFFICE
DATA MANAGEMENT
TELESCOPE & SITE
CAMERA
EDUCATION & PUBLIC OUTREACH
SYSTEM ENGINEERING

@LSST @mjuric
LSST.ORG/HIRING

NSF

U.S. DEPARTMENT OF ENERGY | Office of Science

CHARLES AND LISA SIMONYI FUND
FOR ARTS AND SCIENCES