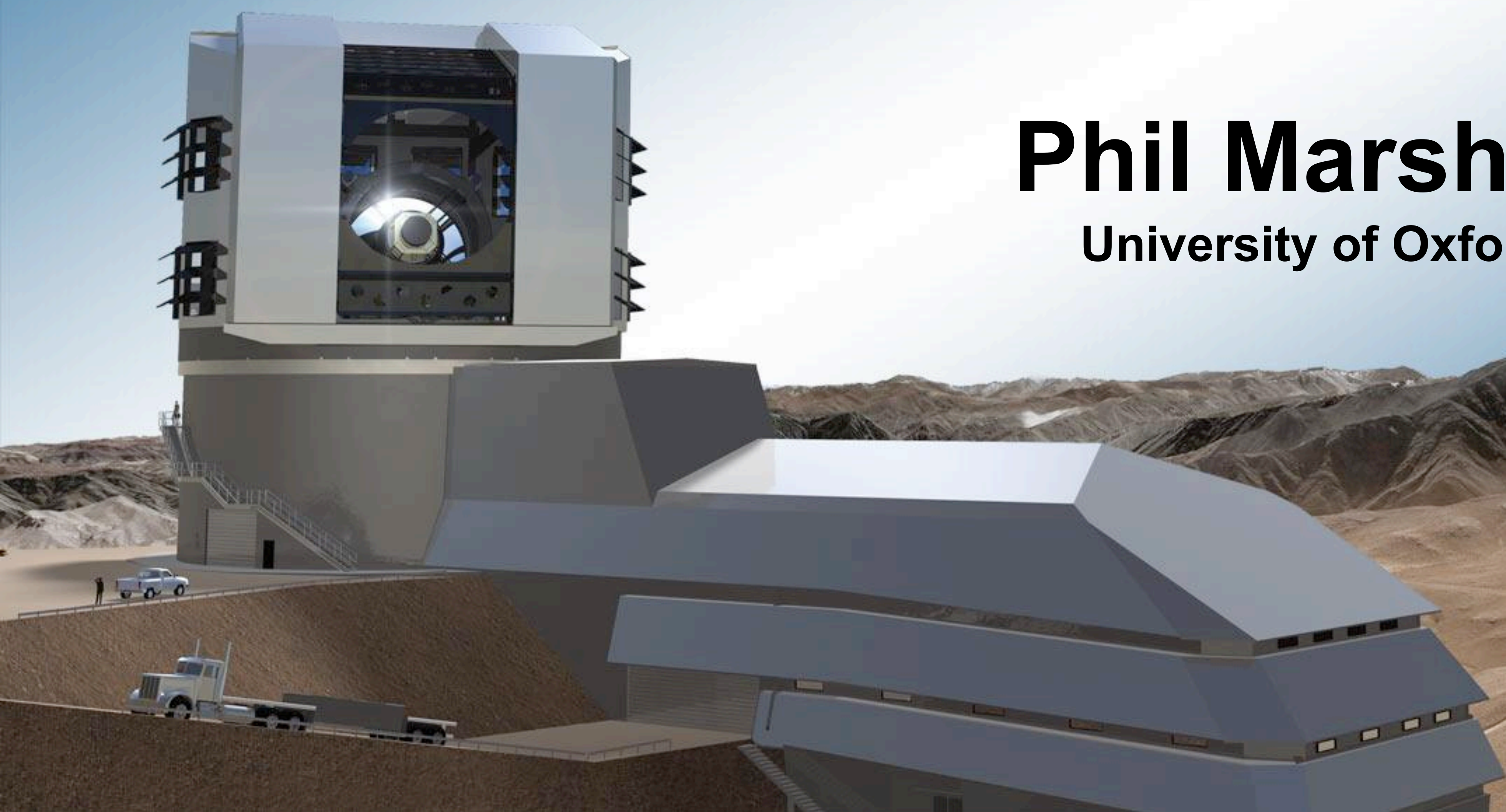
ESA workshop “Feeding the Giants: ELTs in the era of Surveys”
Ischia, Italy, August 2011

LSST



Phil Marshall

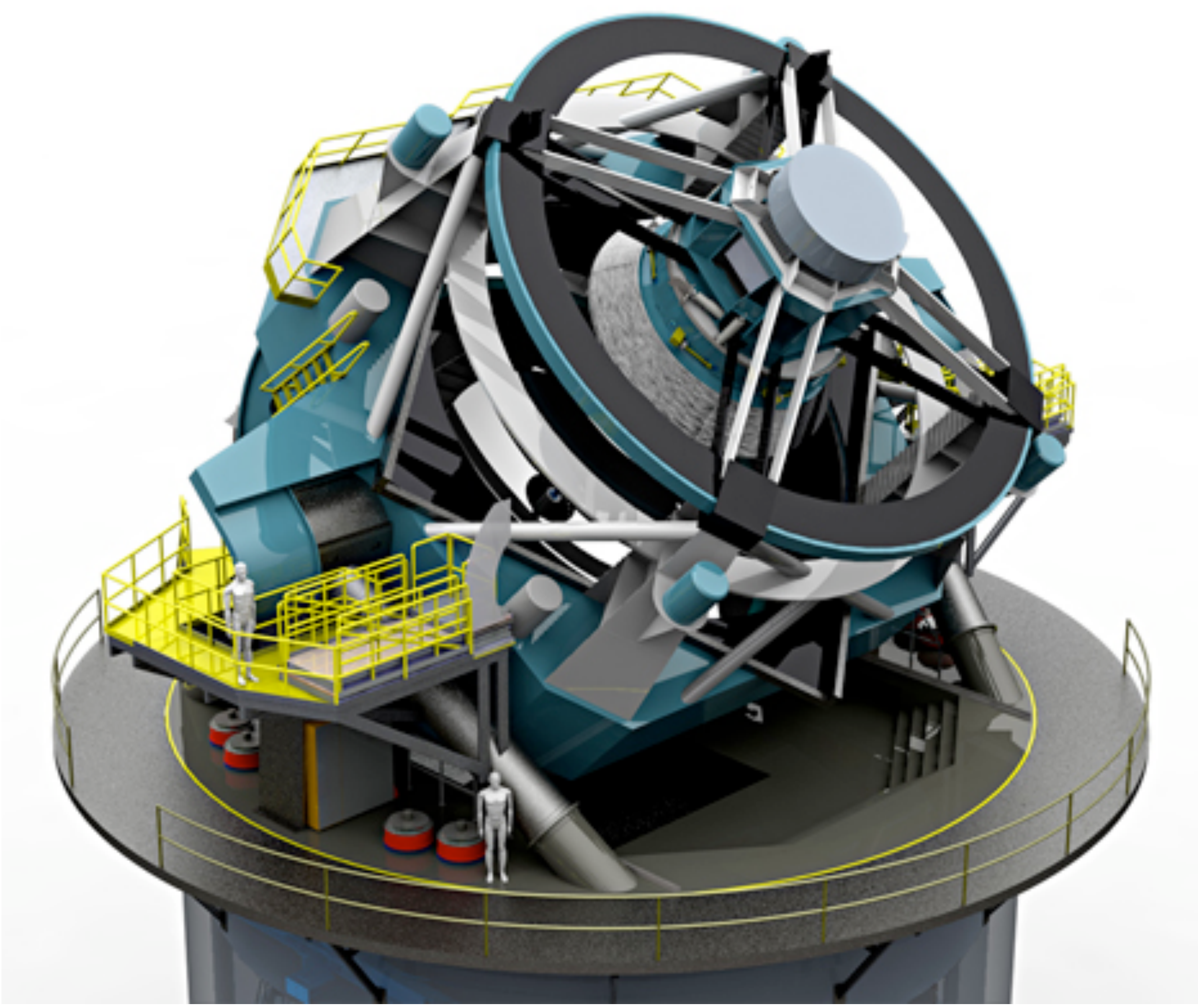
University of Oxford

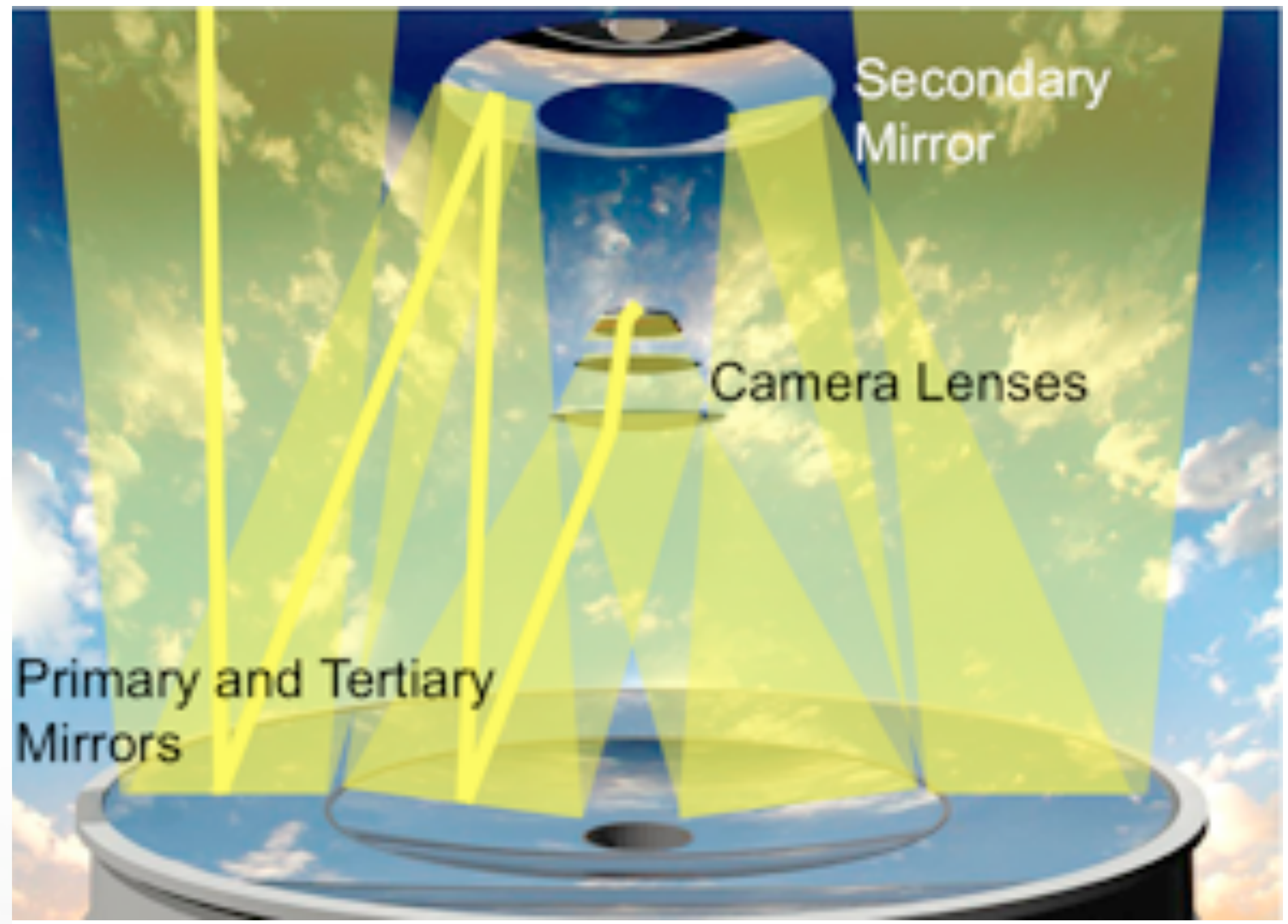
Plan

- What is the LSST?
  - 8m class survey telescope, deep ugrizy imaging
  - 10 sq deg field to 24th mag in 30 secs, 900 visits per night
  - Petascale database astronomy, software instrumentation
  - 35 member institutes, 11 science collaborations
  - NSF PDR next week, construction start goal 2014
- What science will it enable?
  - Solar system inventory, mapping the Milky Way, transient universe, dark matter and dark energy
- How *might* it be used to feed the giants?
  - New transient objects, including distant supernovae. Photo-z calibration? Weighing the missing satellites, making the most of even larger telescopes...

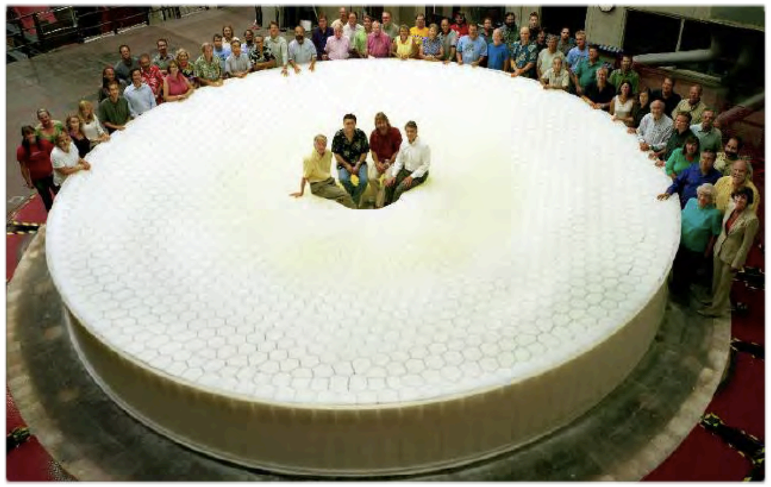
The Telescope

Little Synoptic Survey Telescope:
- 8.4m primary, **6.7m effective, 9.6sq deg field of view**
- Tertiary and primary mirrors one piece of glass
- Image quality limited by natural seeing
- 350 ton moving structure





The Mirrors



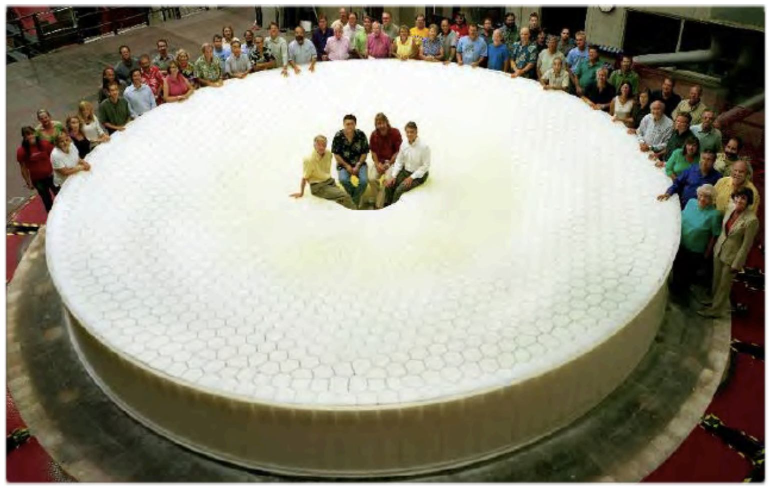
Private funding from Simonyi, Gates foundations

8.4m primary/tertiary, being ground and polished at Steward Lab

The Mirrors

Large Synoptic Survey Telescope

Private funding from Simonyi, Gates foundations

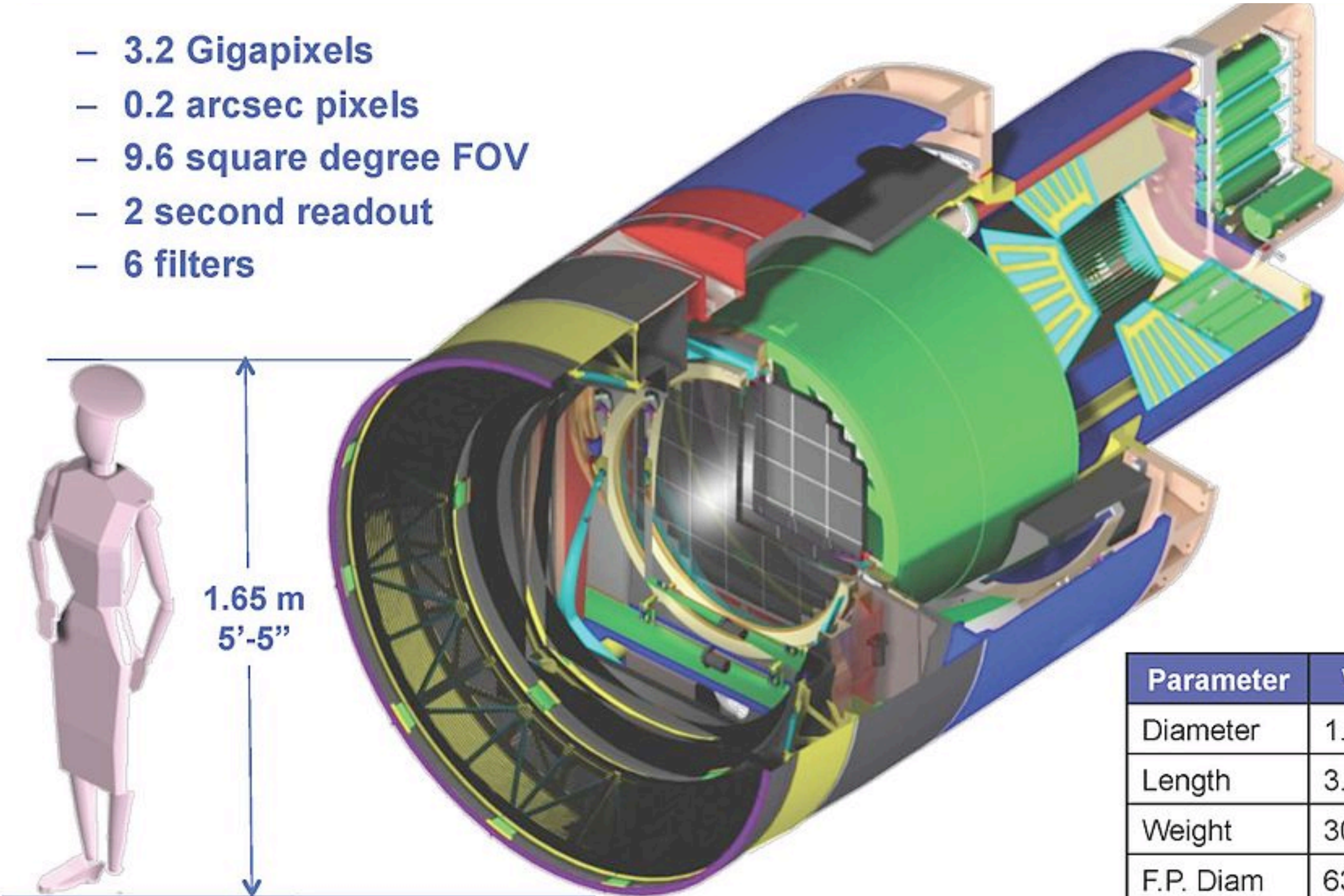


8.4m primary/tertiary, being ground and polished at Steward Lab

5.4m secondary blank at Corning, now in storage

The Camera

- 3.2 Gigapixels
- 0.2 arcsec pixels
- 9.6 square degree FOV
- 2 second readout
- 6 filters



Parameter	Value
Diameter	1.65 m
Length	3.7 m
Weight	3000 kg
F.P. Diam	634 mm

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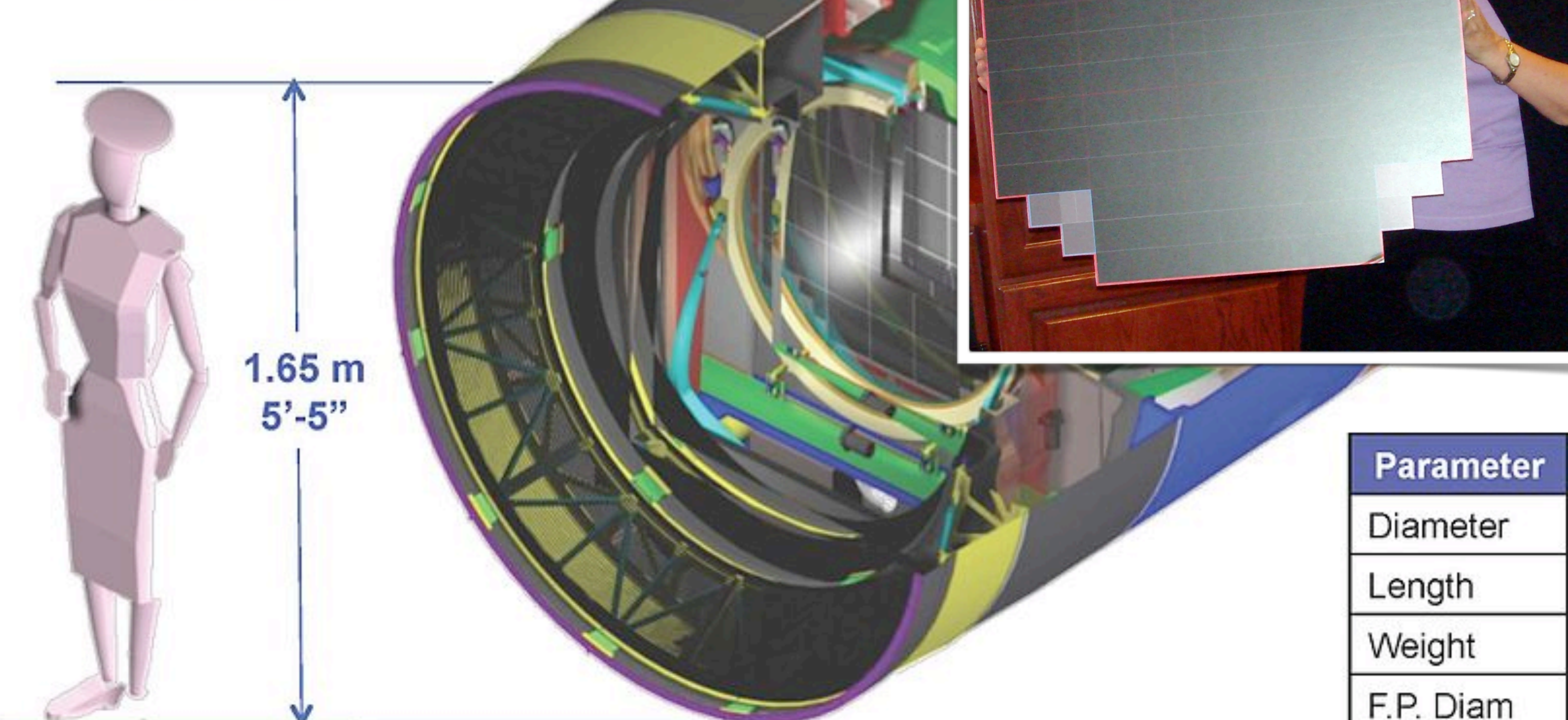

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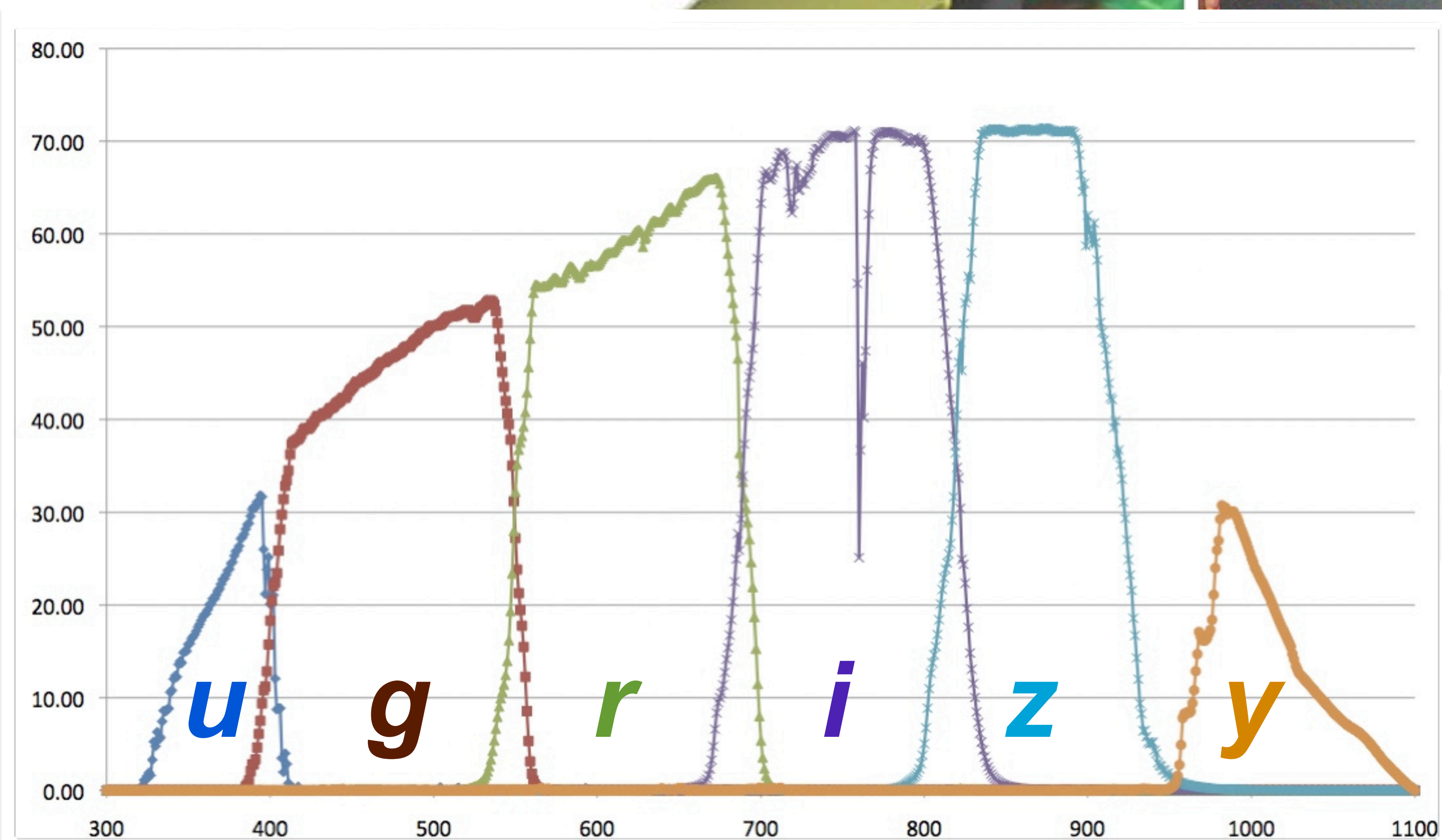


Parameter	Value
Diameter	1.65 m
Length	3.7 m
Weight	3000 kg
F.P. Diam	634 mm

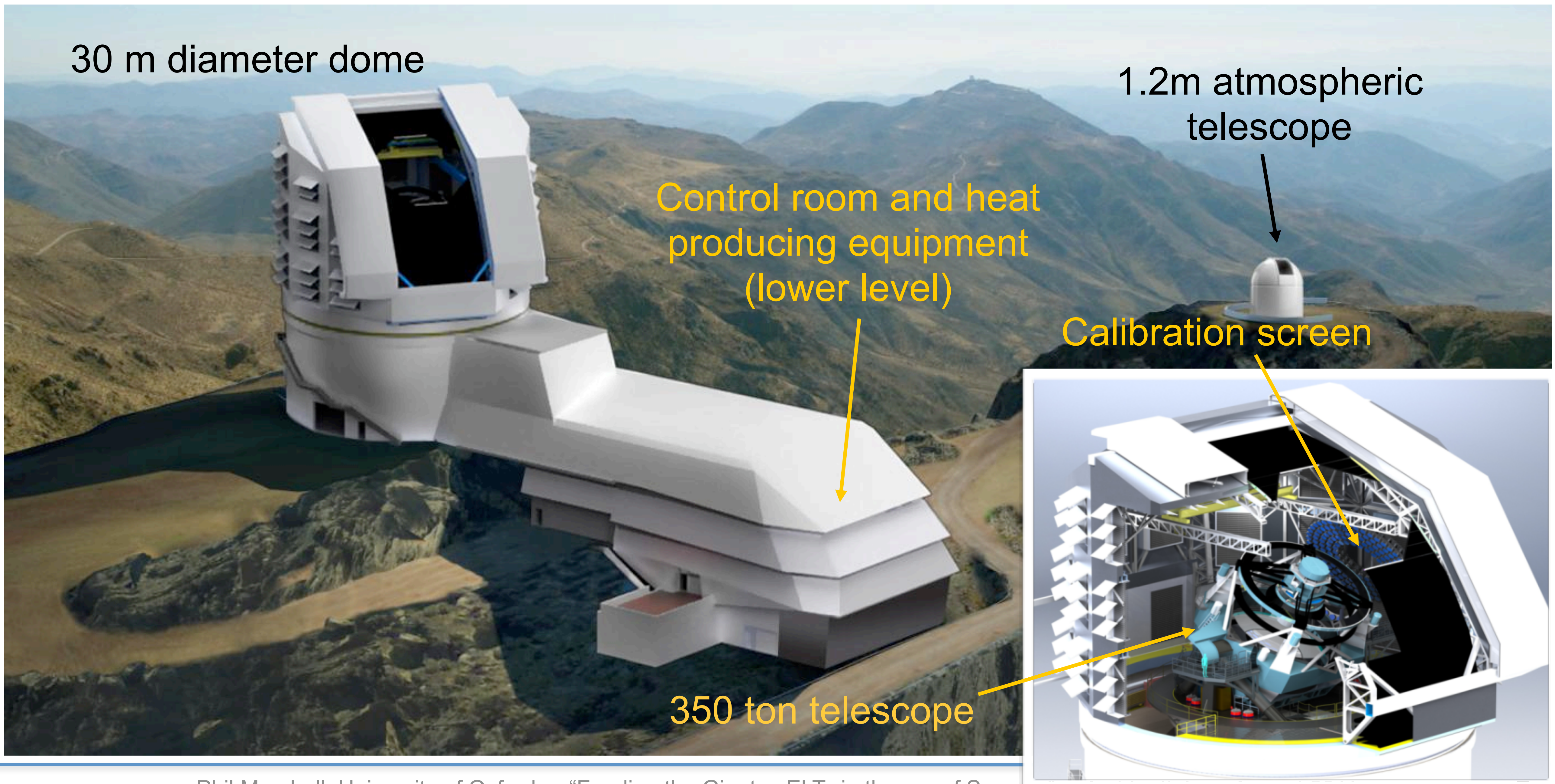
The Site

Large Synoptic Survey Telescope

Cerro Pachon, Chile chosen in 2006 after 2-year evaluation by international committee.

The Observatory

- 30m diameter ventilated cylindrical dome, aerodynamic service and maintenance facility
- First blast, March 8th, 2011; site now levelled for building

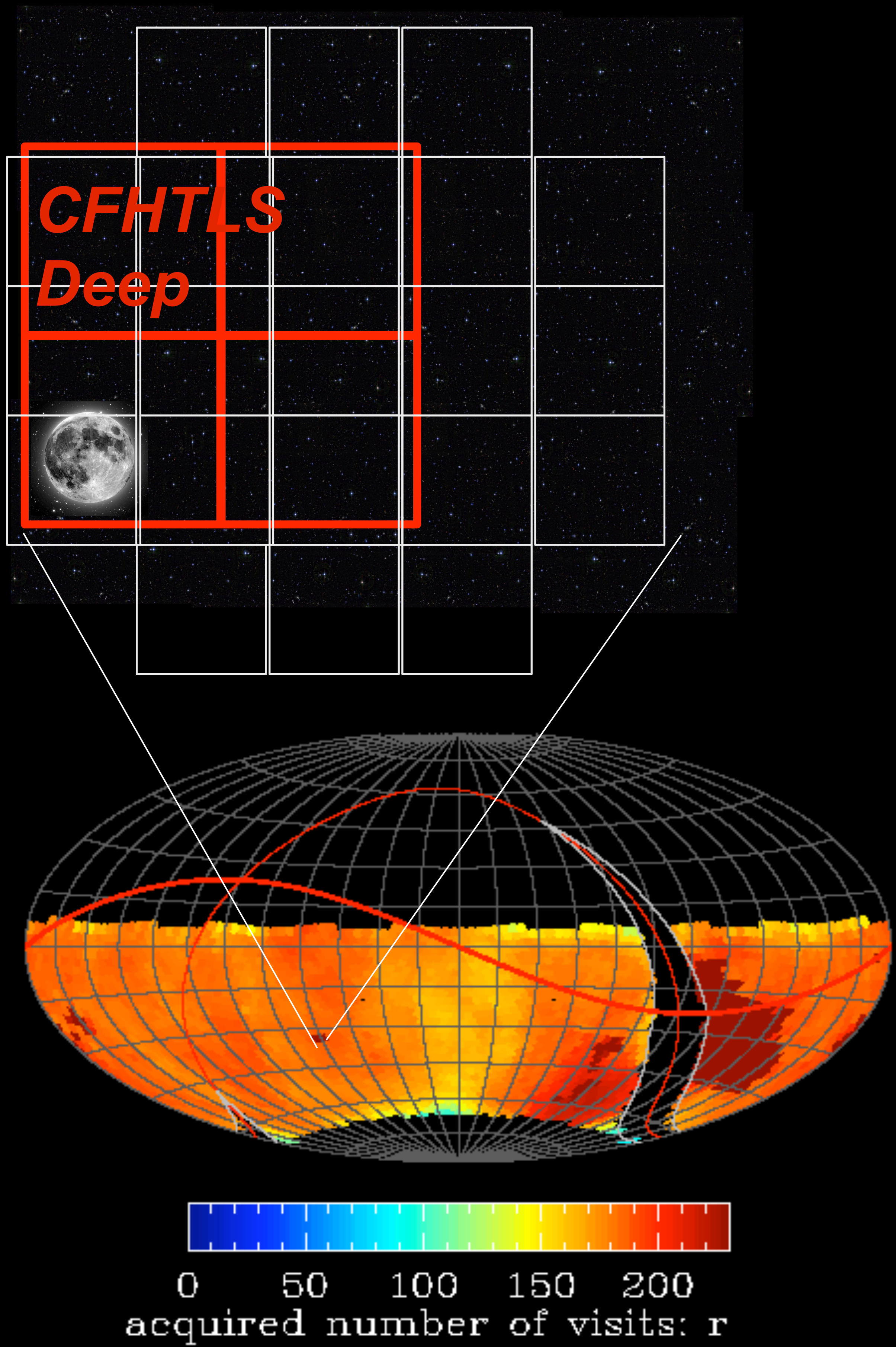


The Observatory

LSST
Large Synoptic Survey Telescope

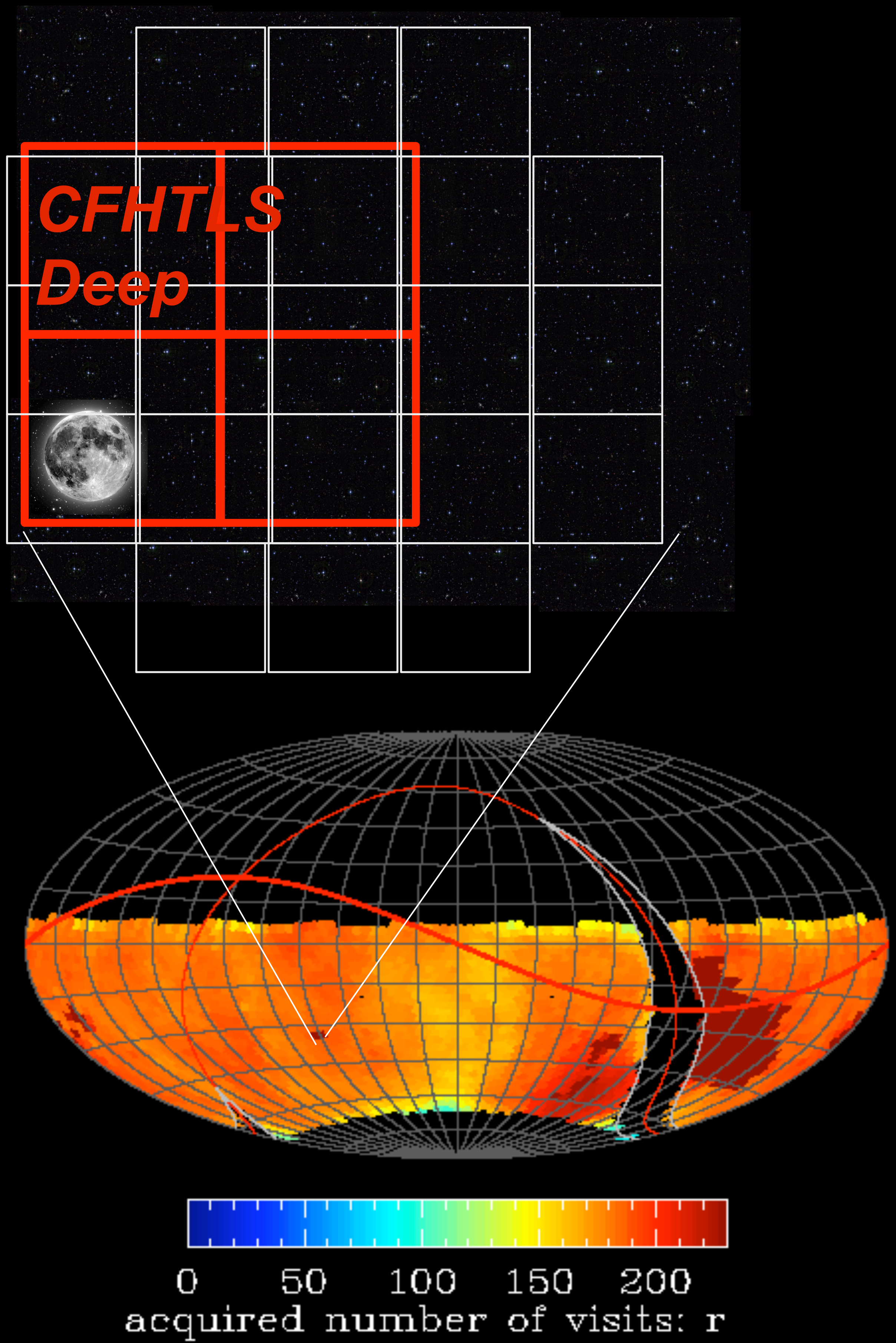
- 30m diameter ventilated cylindrical dome, aerodynamic service and maintenance facility
- First blast, March 8th, 2011; site now levelled for building

The Survey



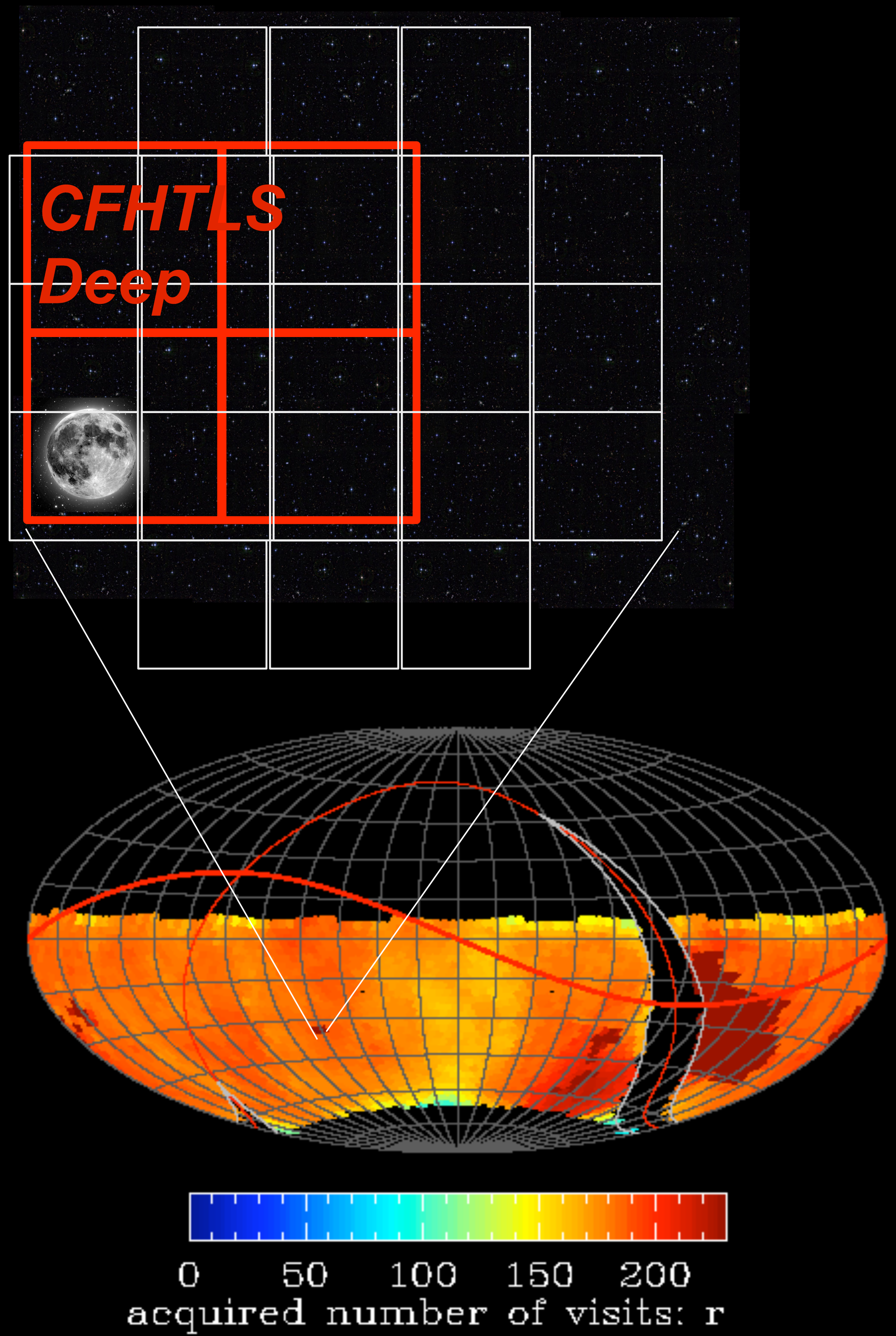
The Survey

- **20,000** sq deg, plus galaxy



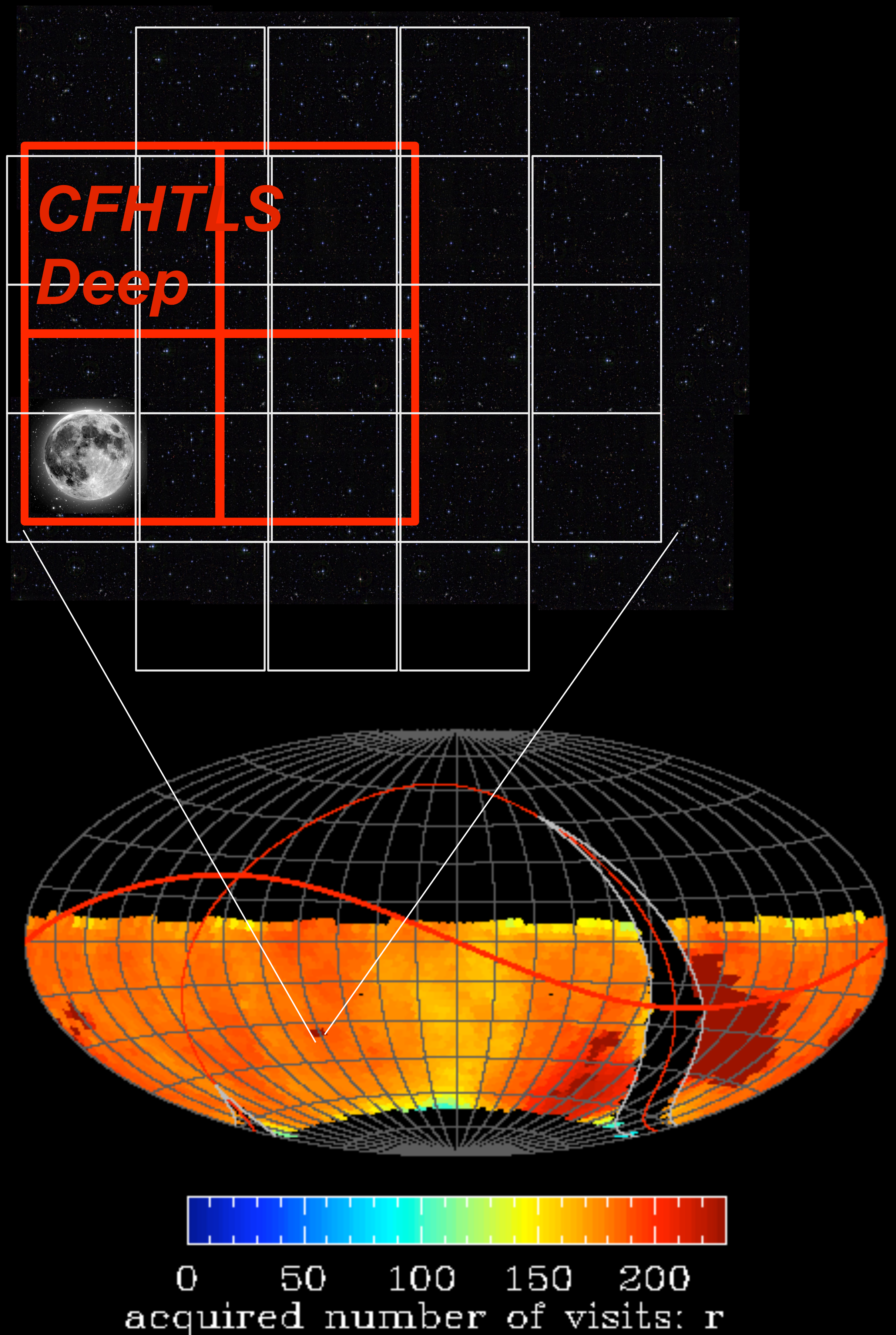
The Survey

- **20,000** sq deg, plus galaxy
- **10 years**, 3-5 month seasons



The Survey

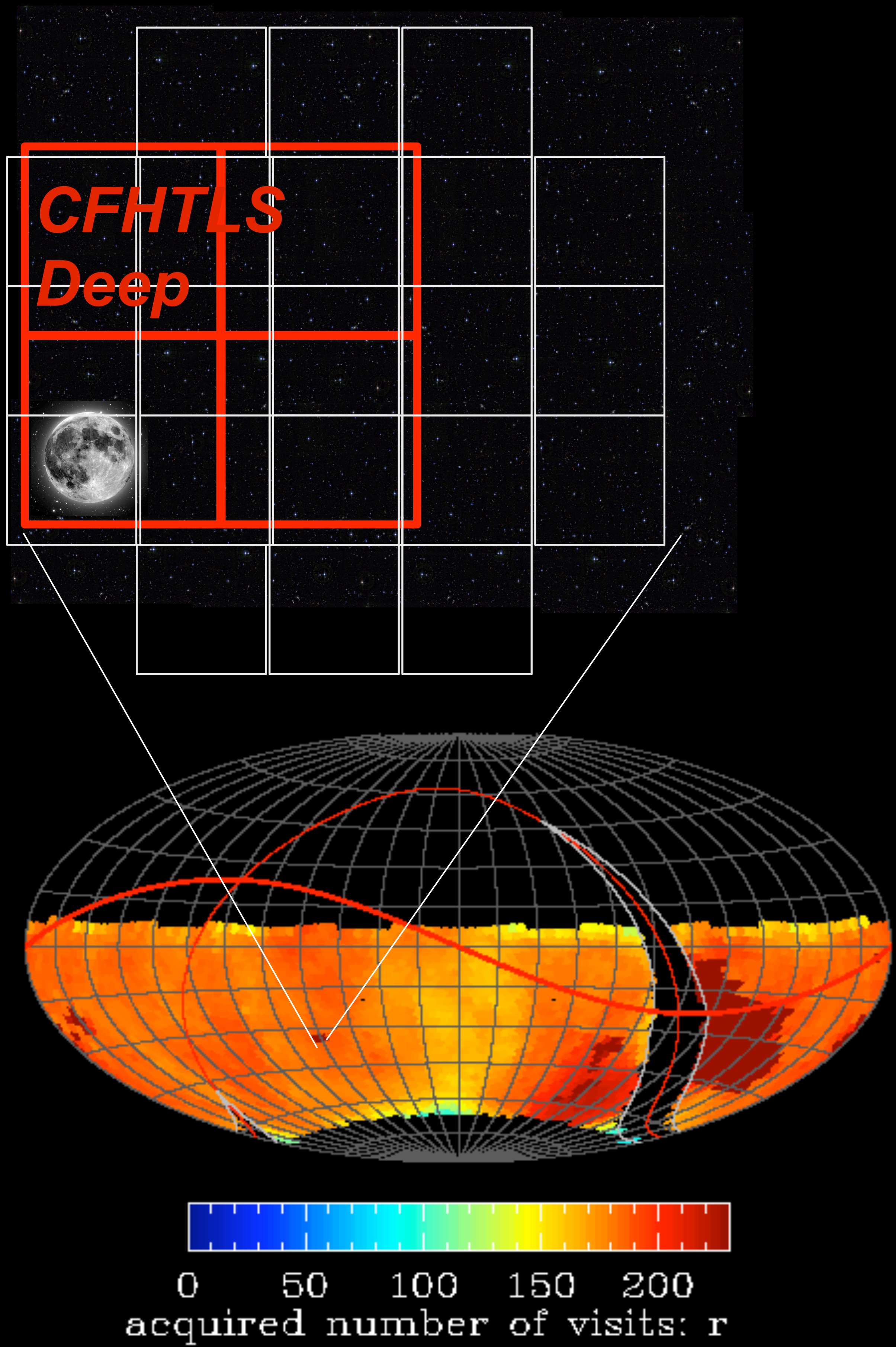
- **20,000** sq deg, plus galaxy
- **10 years**, 3-5 month seasons
- Logarithmic cadence

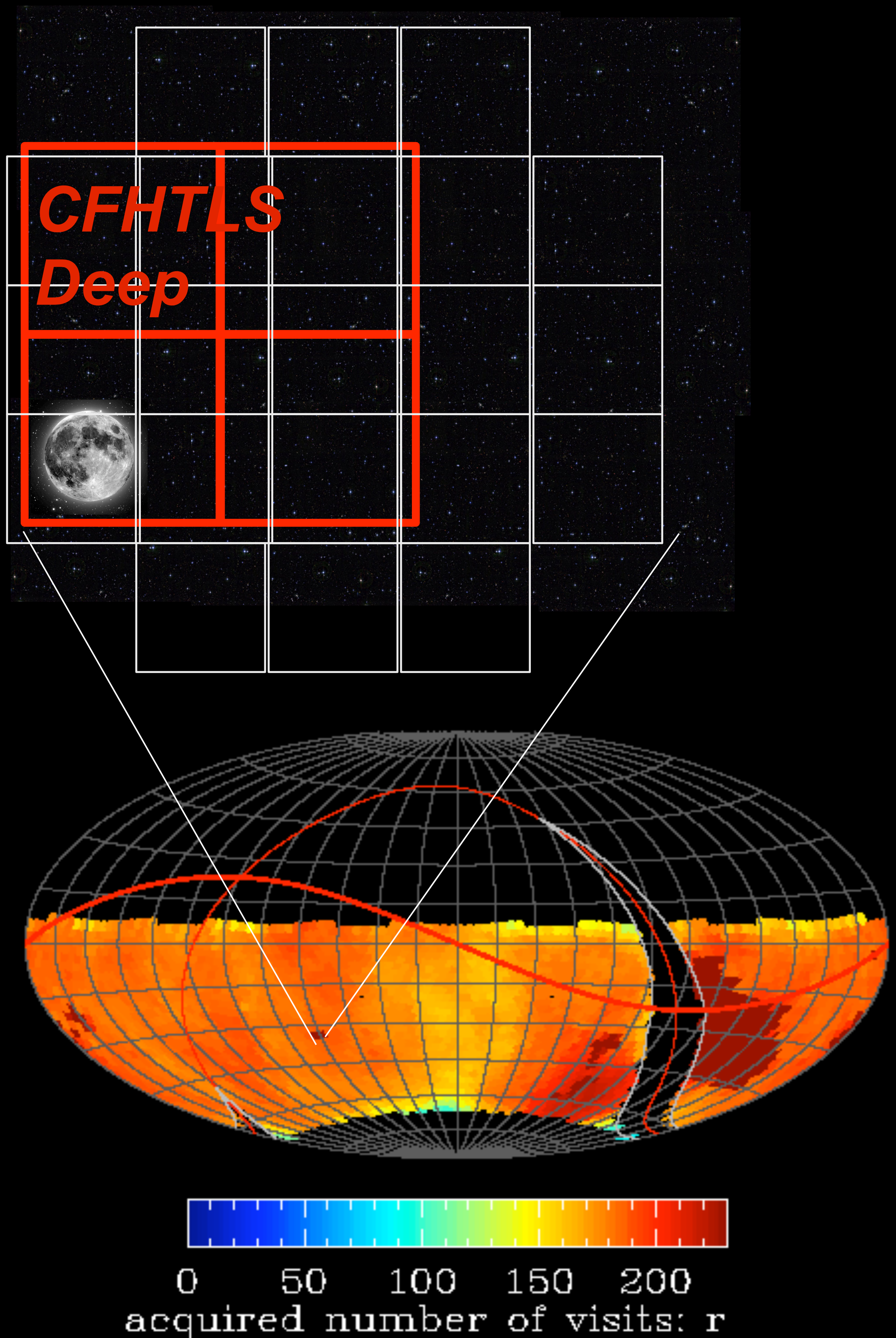


The Survey

- **20,000** sq deg, plus galaxy
- **10 years**, 3-5 month seasons
- Logarithmic cadence

(15sec, 30min, ~1,2,4 weeks, 1,2,4 years)





The Survey

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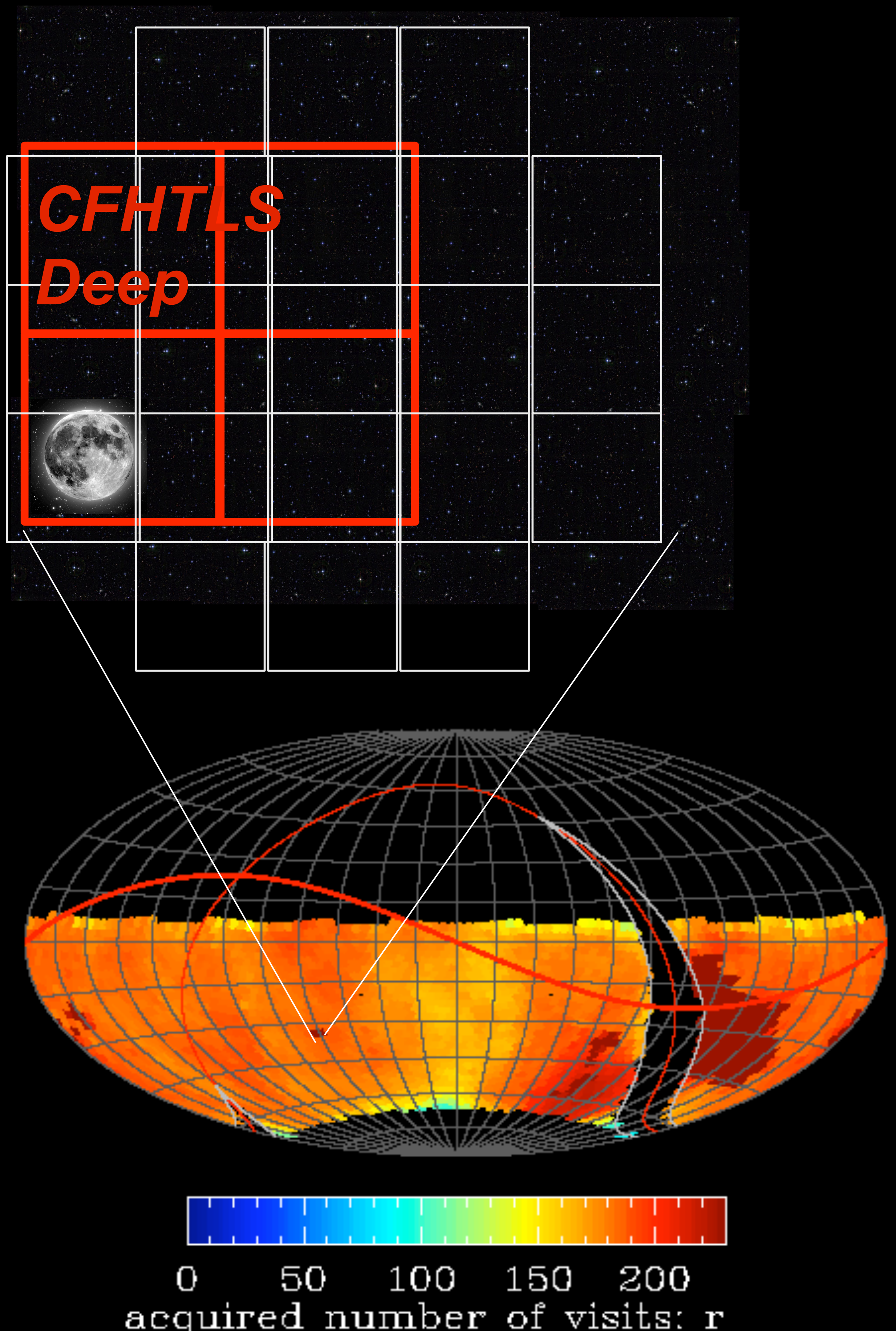
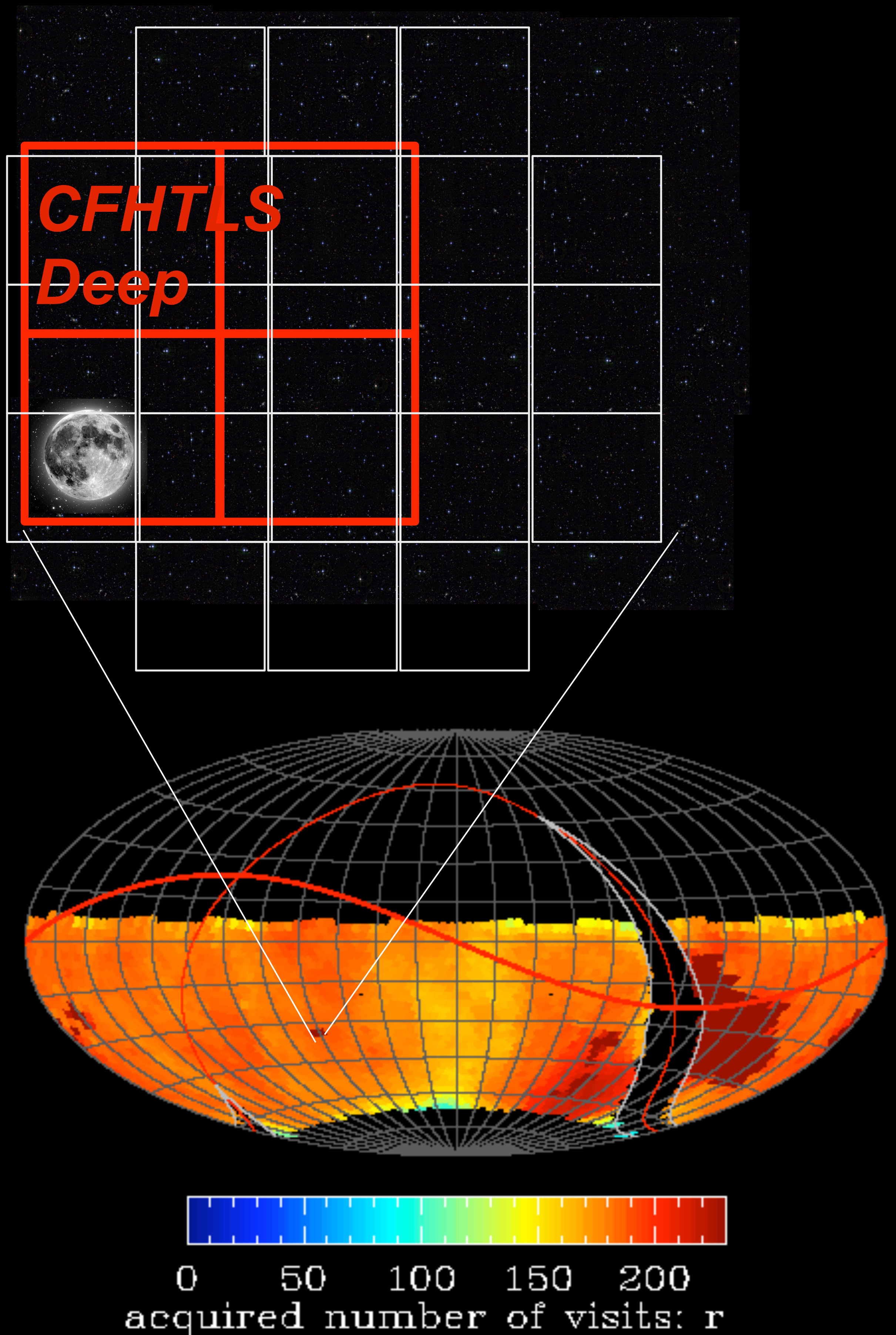
- 2x15s exposures per visit
- depth: **24** mag per visit



The Survey



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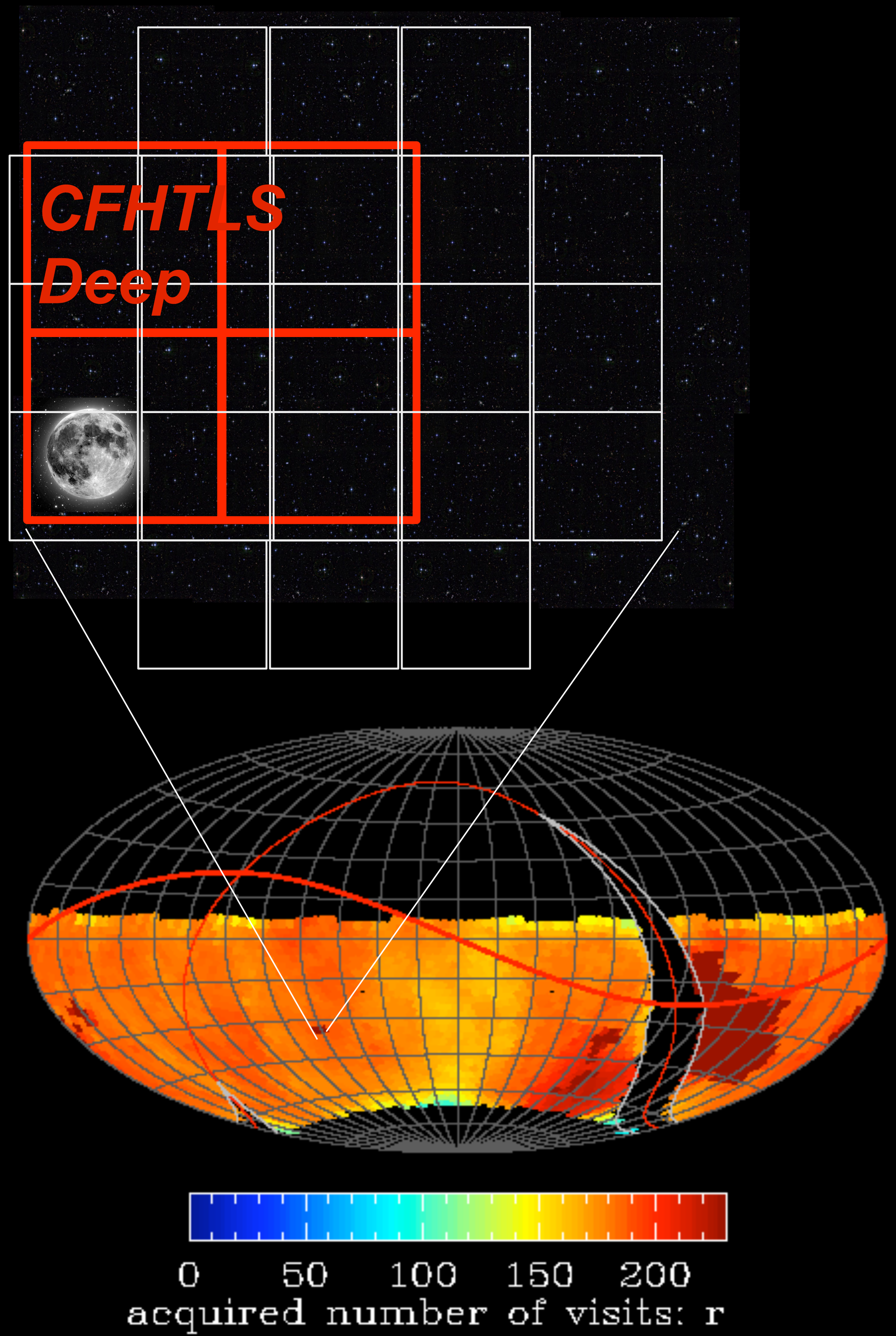
(u=23.9, g=25.0, r=24.7, i=24.0, z=23.3, y=22.1)



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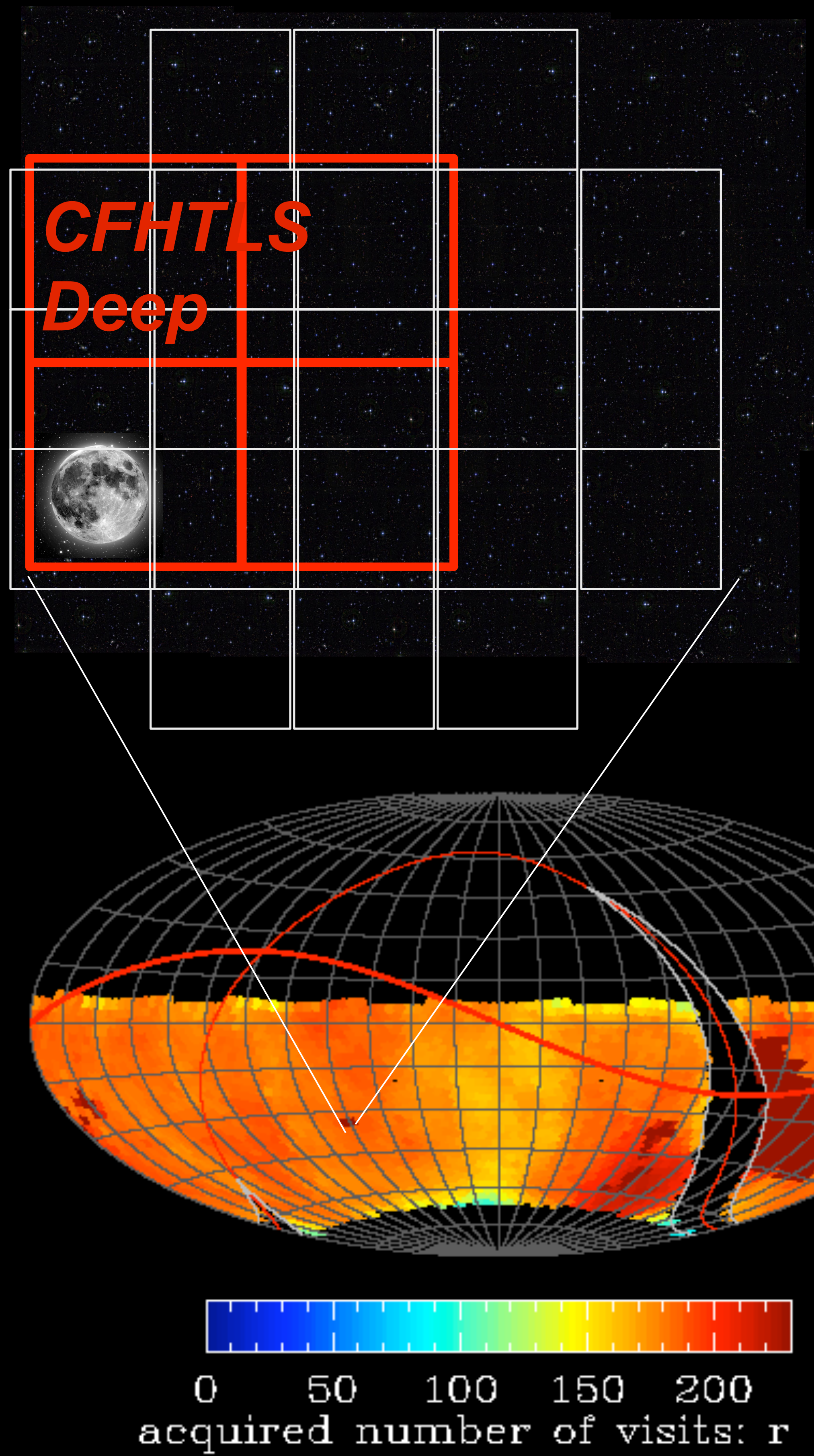
- 1-200 visits in each filter

The Survey



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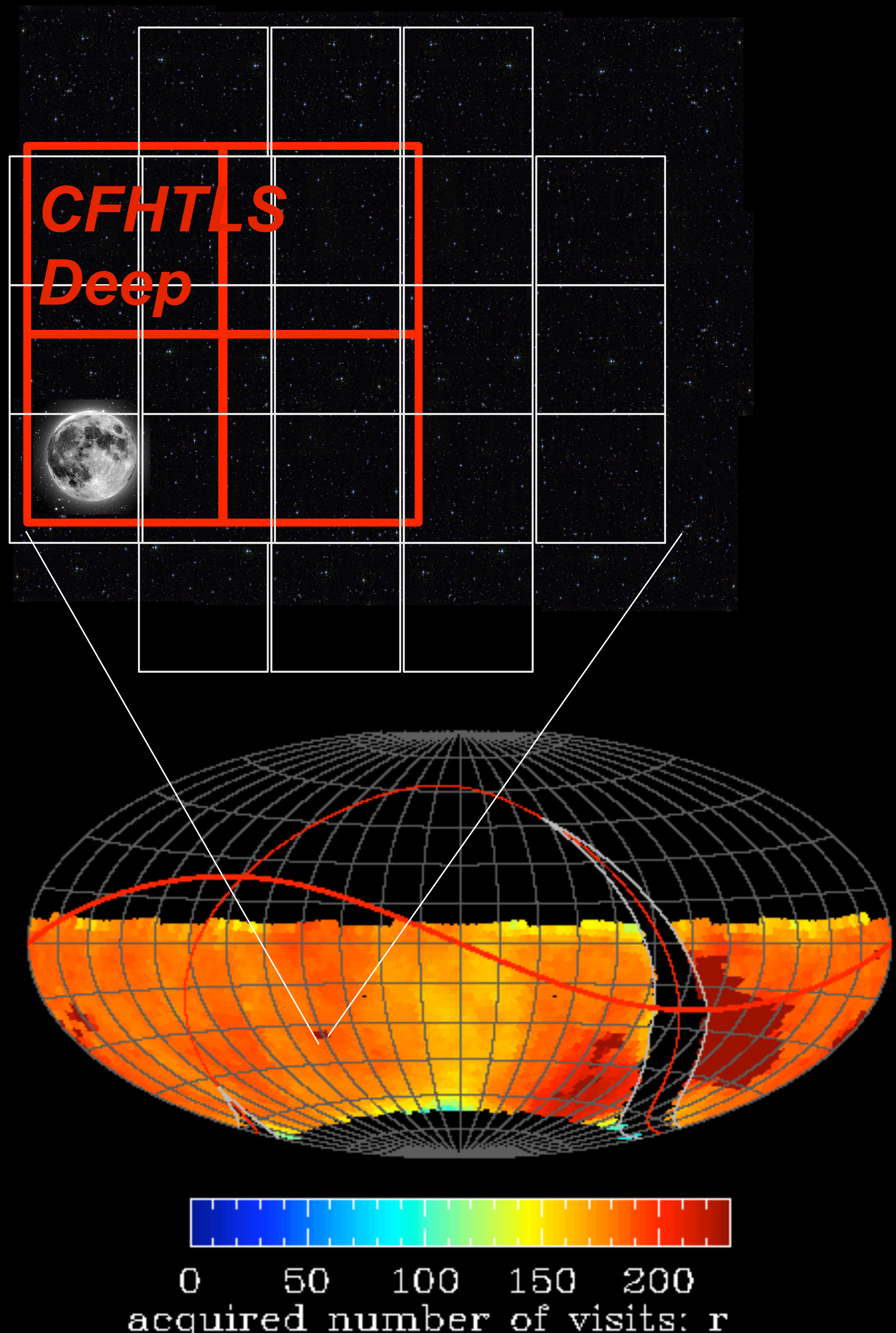
(u=23.9, g=25.0, r=24.7, i=24.0, z=23.3, y=22.1)

- 1-200 visits in each filter
- stacked depth **27** mag



The Survey

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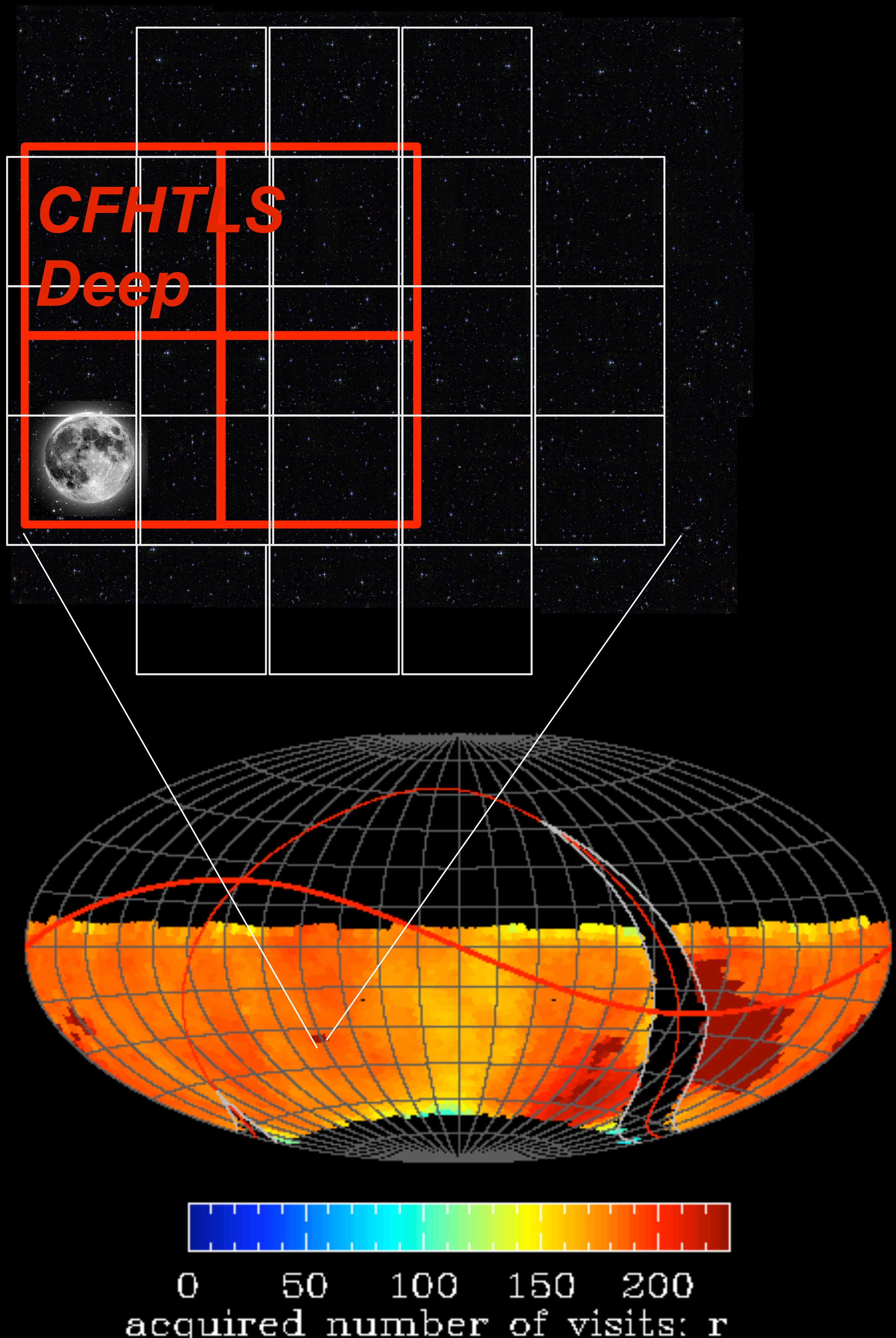
- 1-200 visits in each filter
- stacked depth **27** mag

(u=26.3, g=27.5, r=27.7, i=27.0, z=26.2, y=24.9)



The Survey

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- **10 years**, 3-5 month seasons
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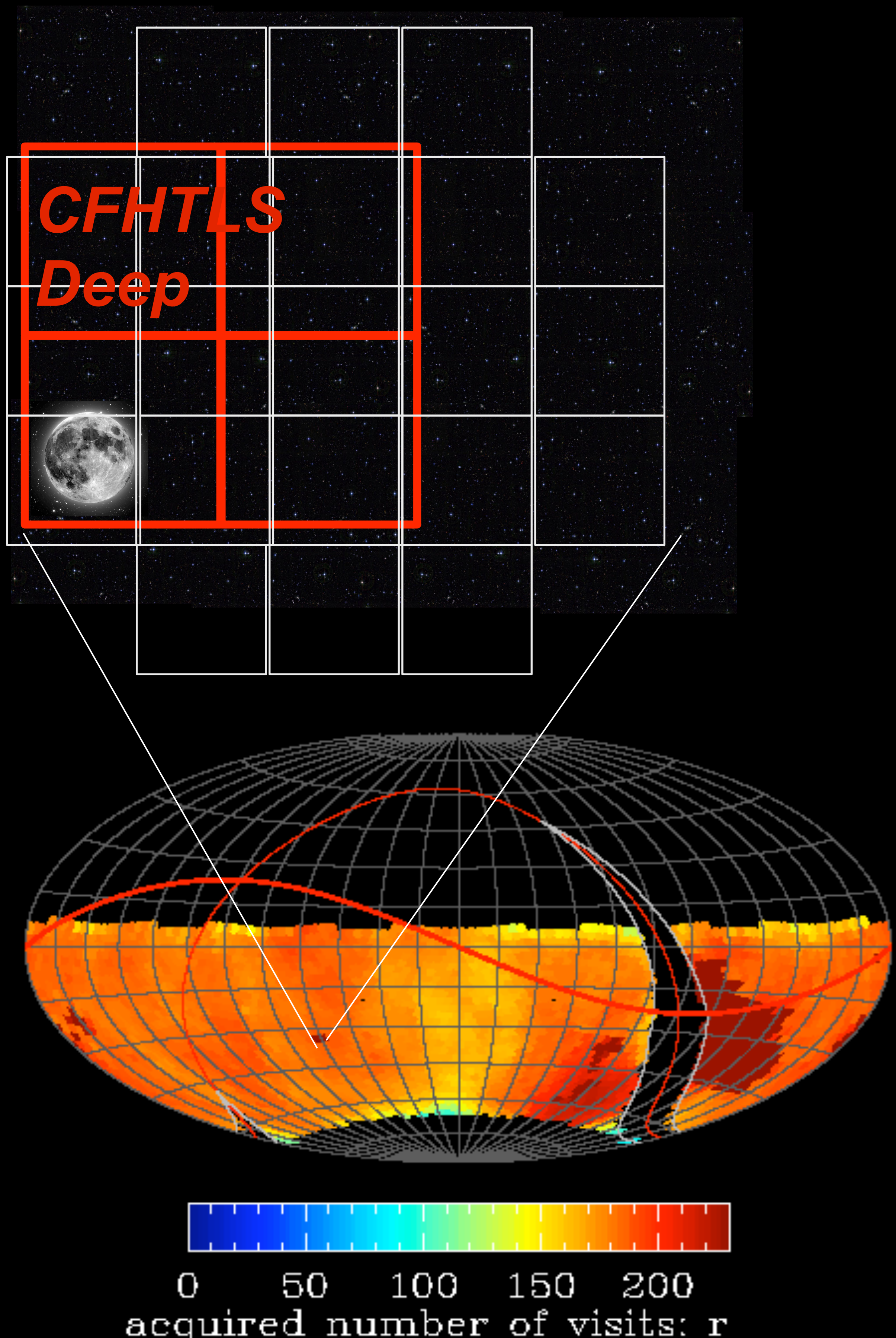
(u=26.3, g=27.5, r=27.7, i=27.0, z=26.2, y=24.9)
- median IQ **0.7”** FWHM



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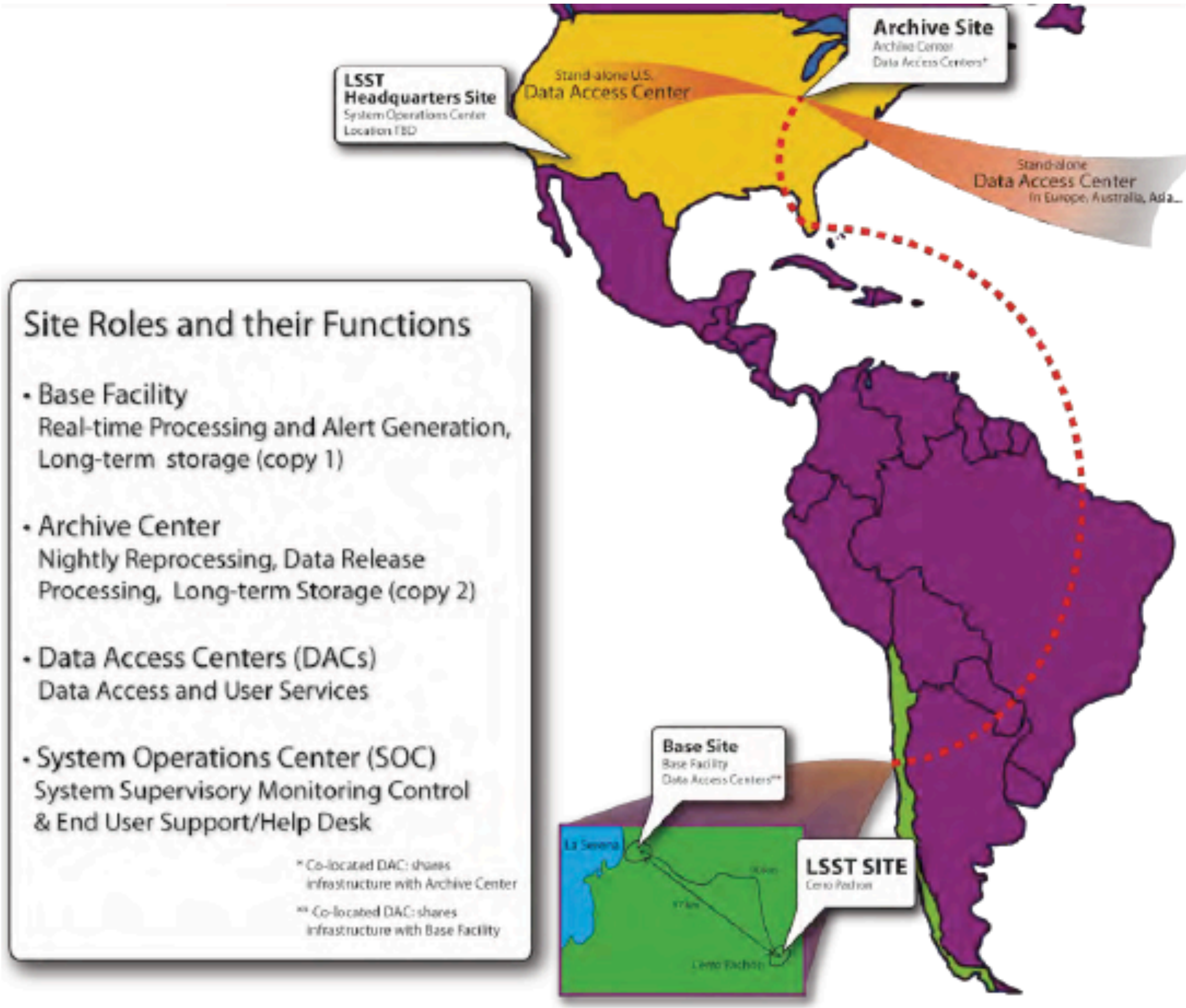
(u=26.3, g=27.5, r=27.7, i=27.0, z=26.2, y=24.9)
- median IQ **0.7”** FWHM

10% of time spent on “deep drilling fields”

calibration of main survey, high cadence monitoring, special sky positions etc

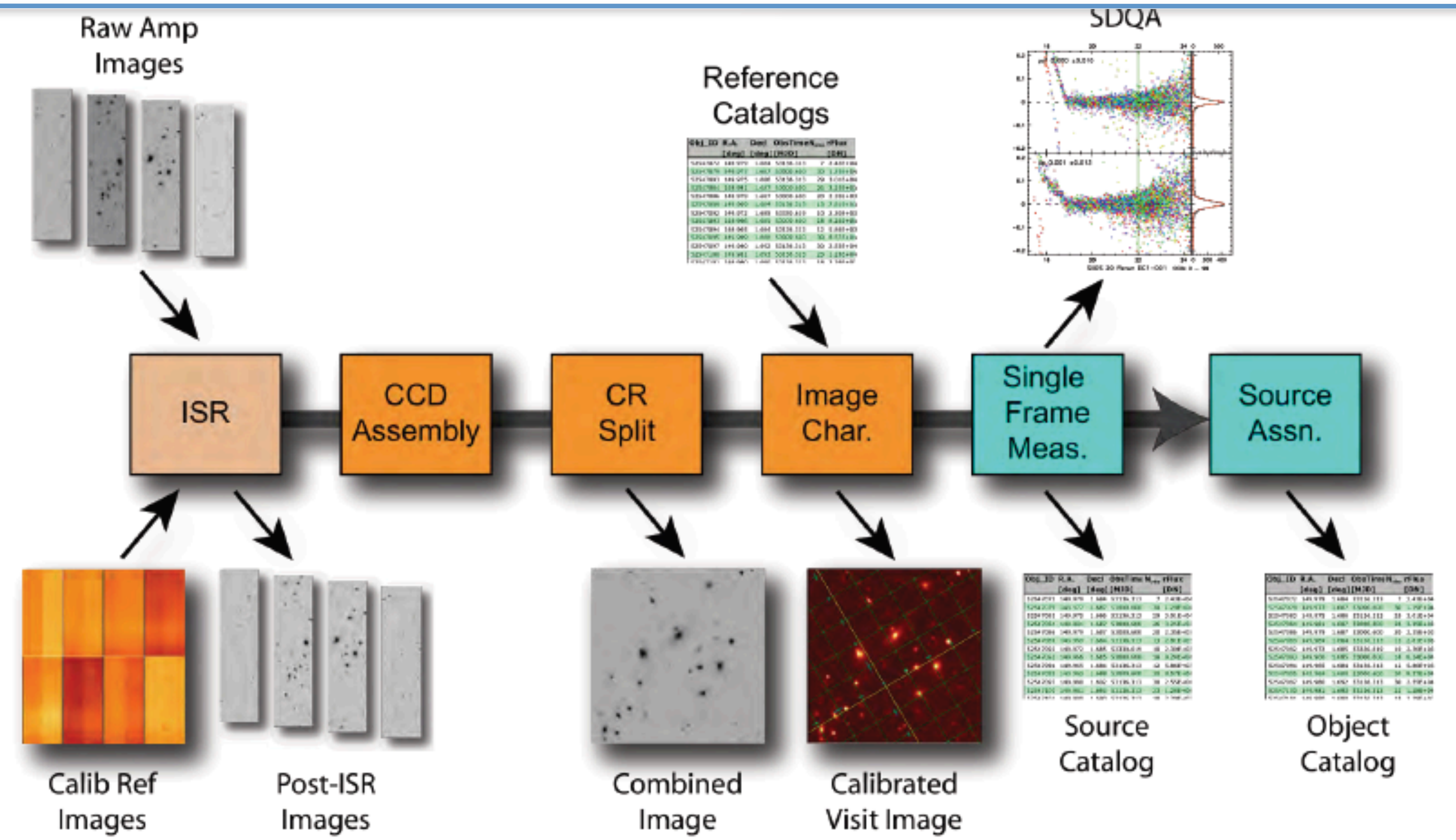
The Data



- 6.4Gb per 15s exposure, **15Tb raw data per night**
- **10^6 alerts per night,** each generated within 60s
- Archive after 10 years: **100Pb** of images, **20Pb** of catalogs

(about the same as a digital library of every book ever published, translated into every language ever written)

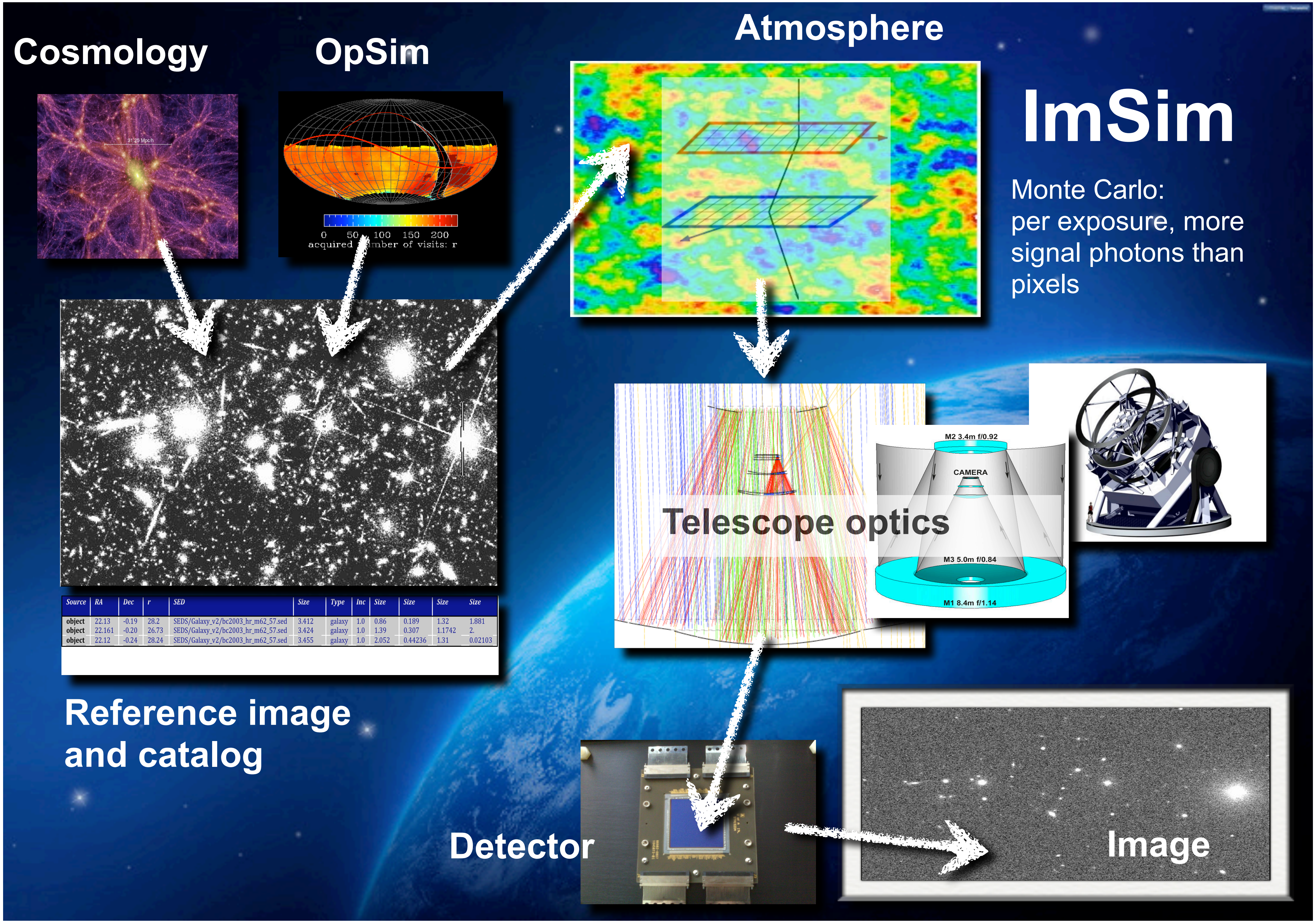
The Software



- Data management will be instrumental in the success of LSST: helpful to think of ***software as instrumentation***
- The incorporation of new algorithms into the data management system is LSST's equivalent of an *instrument development program*
- Open source Python and C++ software stack available for use:

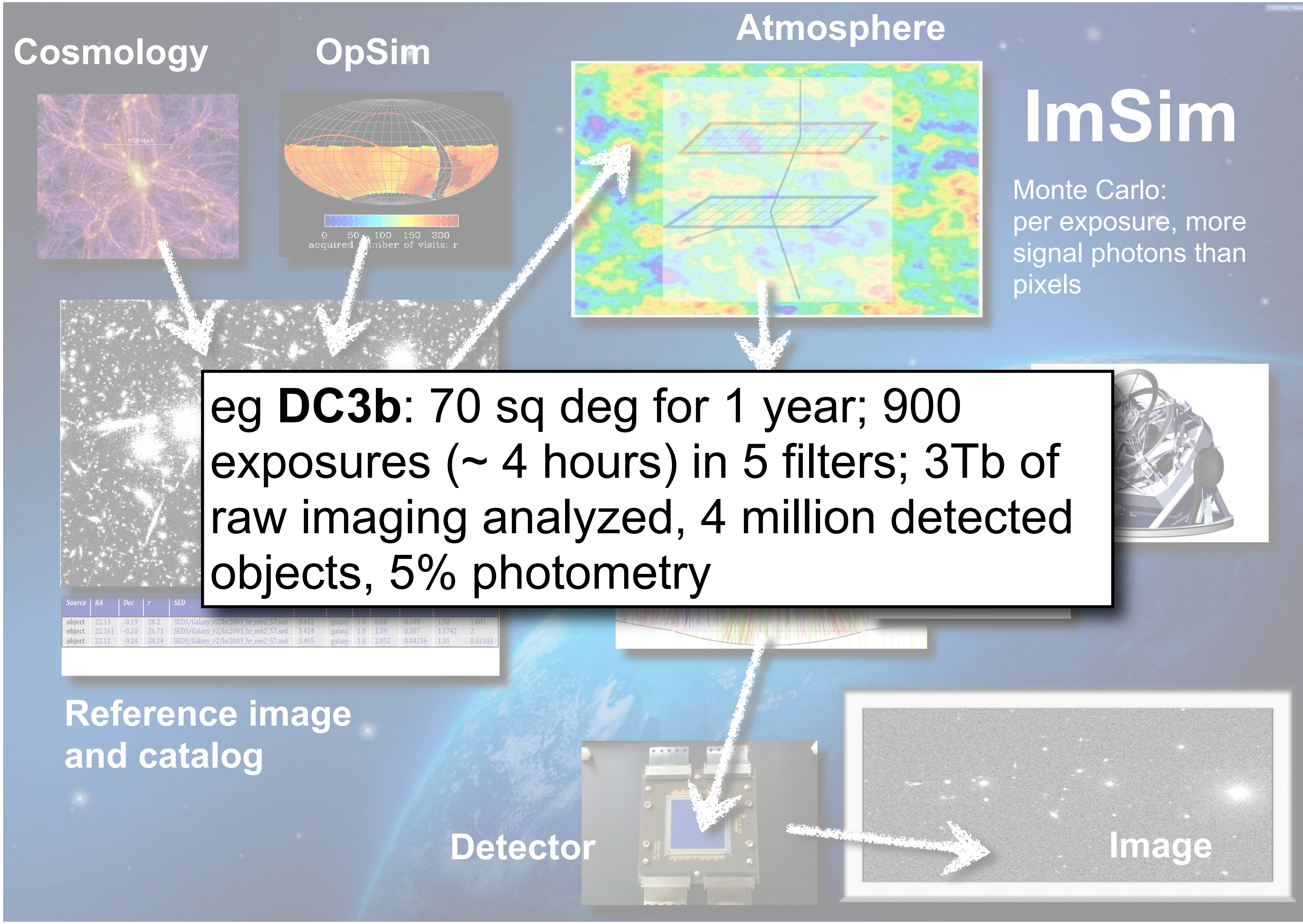
  `http://lsstdev.ncsa.uiuc.edu/trac/browser`

The Simulations



Source	RA	Dec	r	SED	Size	Type	Inc	Size	Size	Size	Size
object	22.13	-0.19	28.2	SEDS/Galaxy_v2/bc2003_hr_m62_57.sed	3.412	galaxy	1.0	0.86	0.189	1.32	1.881
object	22.161	-0.20	26.73	SEDS/Galaxy_v2/bc2003_hr_m62_57.sed	3.424	galaxy	1.0	1.39	0.307	1.1742	2.
object	22.12	-0.24	28.24	SEDS/Galaxy_v2/bc2003_hr_m62_57.sed	3.455	galaxy	1.0	2.052	0.44236	1.31	0.02103

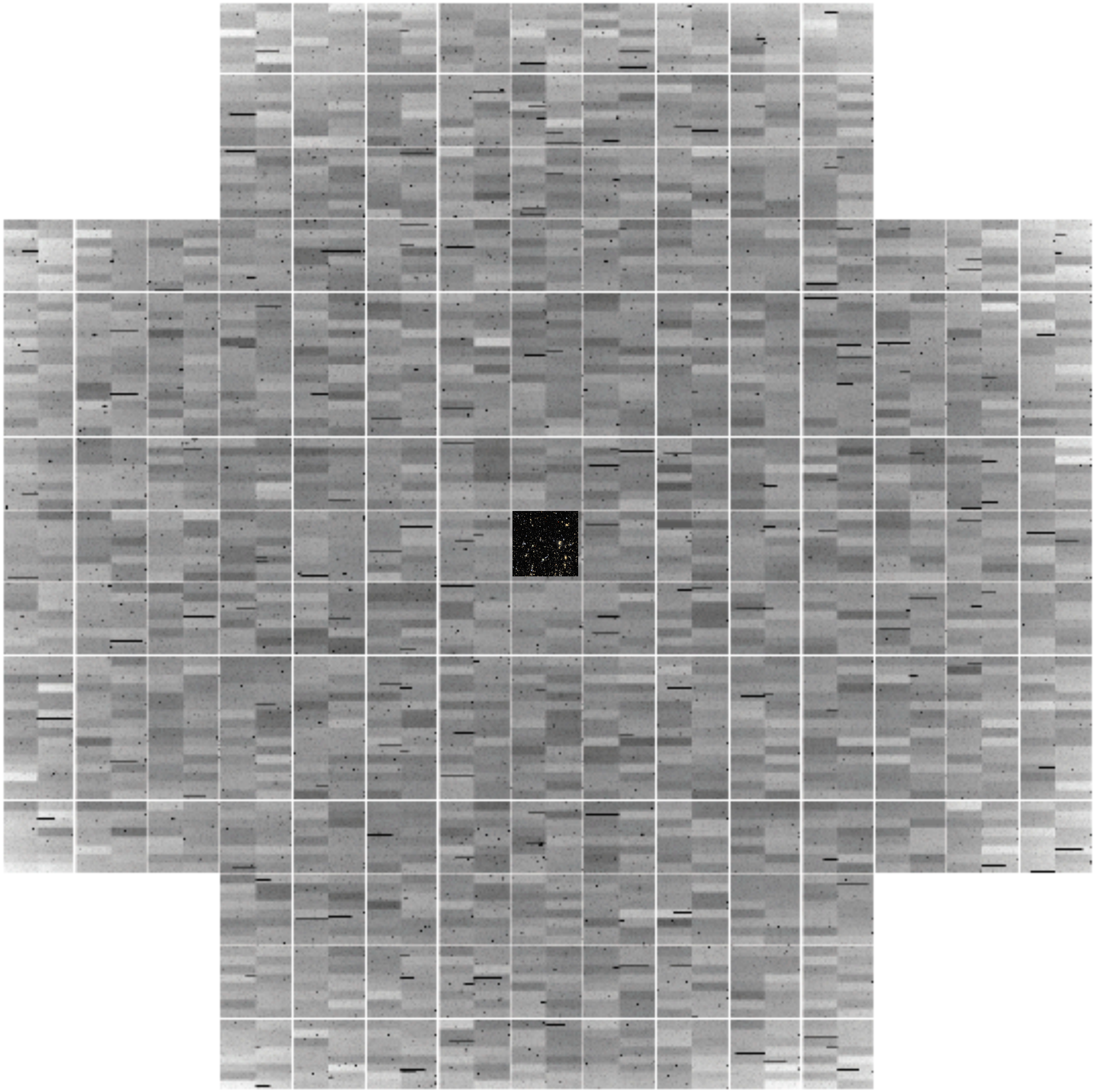
The Simulations



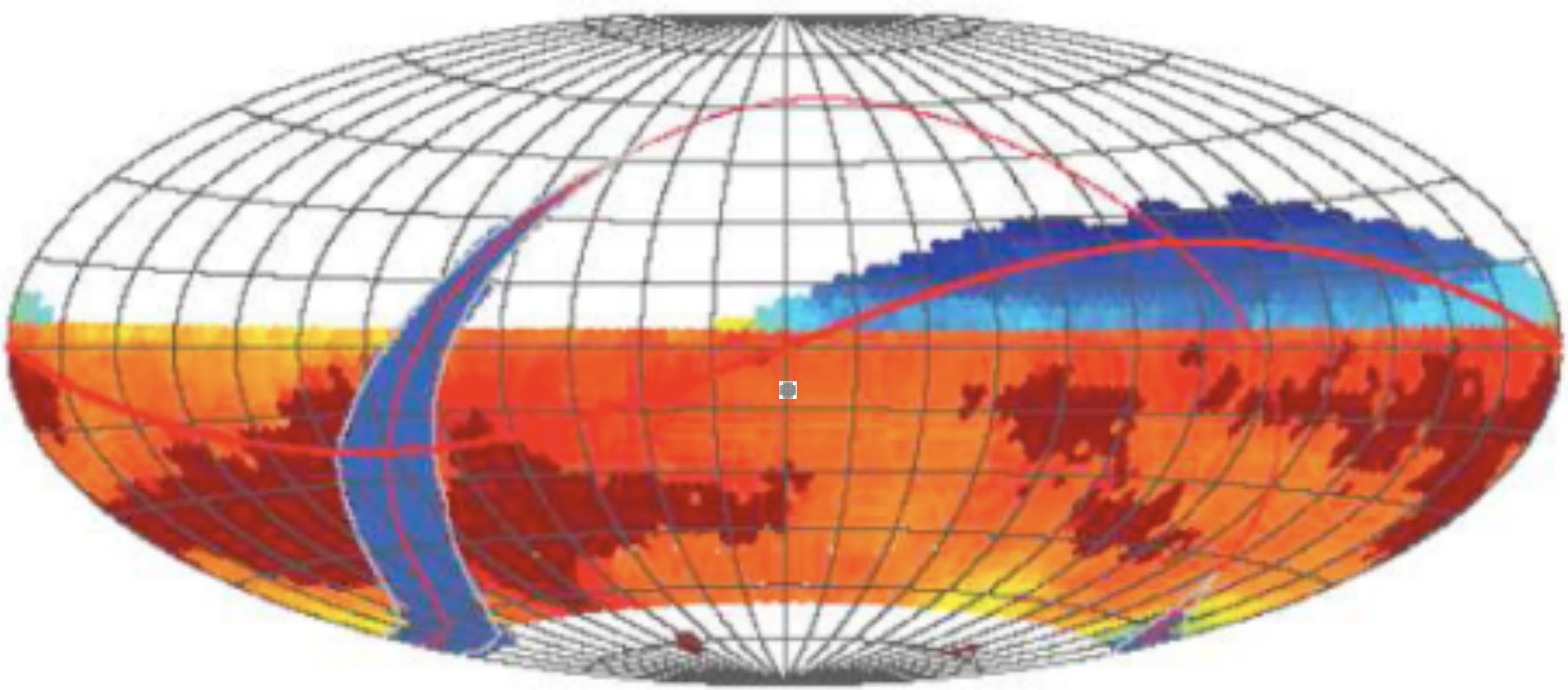
eg **DC3b**: 70 sq deg for 1 year; 900 exposures (~ 4 hours) in 5 filters; 3Tb of raw imaging analyzed, 4 million detected objects, 5% photometry

The Simulations

The Simulations



The Simulations

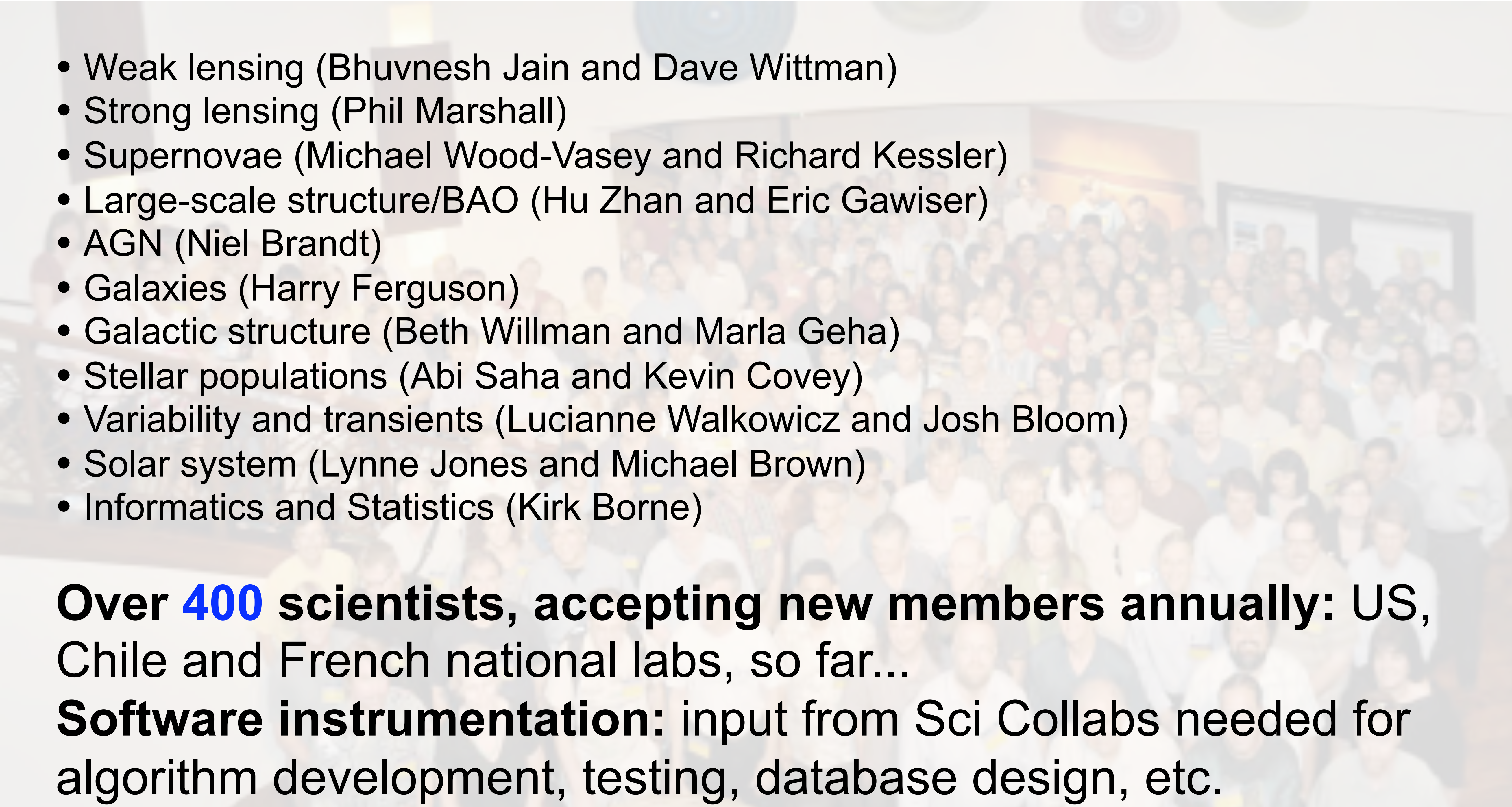


The Member Institutes

Large Synoptic Survey Telescope

- Adler Planetarium
- Brookhaven National Laboratory
- California Institute of Technology
- Carnegie Mellon University
- Chile
- Cornell University
- Drexel University
- Fermilab
- George Mason University
- Google Inc.
- Harvard-Smithsonian Center for Astrophysics
- IN2P3 Labs France
- Johns Hopkins University
- Kavli Institute for Particle Astrophysics and Cosmology at Stanford University
- Las Cumbres Observatory Global Telescope Network, Inc.
- Lawrence Livermore National Laboratory
- Los Alamos National Laboratory
- University of Michigan
- National Optical Astronomy Observatory
- Princeton University
- Purdue University
- Research Corporation for Science Advancement
- Rutgers University
- Space Telescope Science Institute
- SLAC National Accelerator Laboratory
- Texas A&M University
- The Pennsylvania State University
- The University of Arizona
- University of California, Davis
- University of California, Irvine
- University of Illinois at Urbana-Champaign
- University of Pennsylvania
- University of Pittsburgh
- University of Washington
- Vanderbilt University

The Science Collaborations



- Weak lensing (Bhuvnesh Jain and Dave Wittman)
- Strong lensing (Phil Marshall)
- Supernovae (Michael Wood-Vasey and Richard Kessler)
- Large-scale structure/BAO (Hu Zhan and Eric Gawiser)
- AGN (Niel Brandt)
- Galaxies (Harry Ferguson)
- Galactic structure (Beth Willman and Marla Geha)
- Stellar populations (Abi Saha and Kevin Covey)
- Variability and transients (Lucianne Walkowicz and Josh Bloom)
- Solar system (Lynne Jones and Michael Brown)
- Informatics and Statistics (Kirk Borne)

Over 400 scientists, accepting new members annually: US, Chile and French national labs, so far...

Software instrumentation: input from Sci Collabs needed for algorithm development, testing, database design, etc.

Access to commissioning/early science data; codes run on LSST infrastructure

Status

- **Top-ranked ground-based project** in the Astro 2010 Decadal Survey of US astronomy
- PDR **Aug/Sep 2011** (next week!) to decide if we can join the NSF construction queue, DoE CD-1 review in November.

- Proposed federal construction start date: **2014**
- Primary/Tertiary mirror is now being polished
- Goal: **first light in 2018**
- Then 2 years commissioning, **survey to start in 2020**
- **Transient alerts** broadcast within 60 secs
- **Annual data releases**

LSST science

Large Synoptic Survey Telescope

- Overview

  Some highlights from the science book, and some remarks on spectroscopic and AO follow-up

- Example projects that would benefit from ELT follow-up

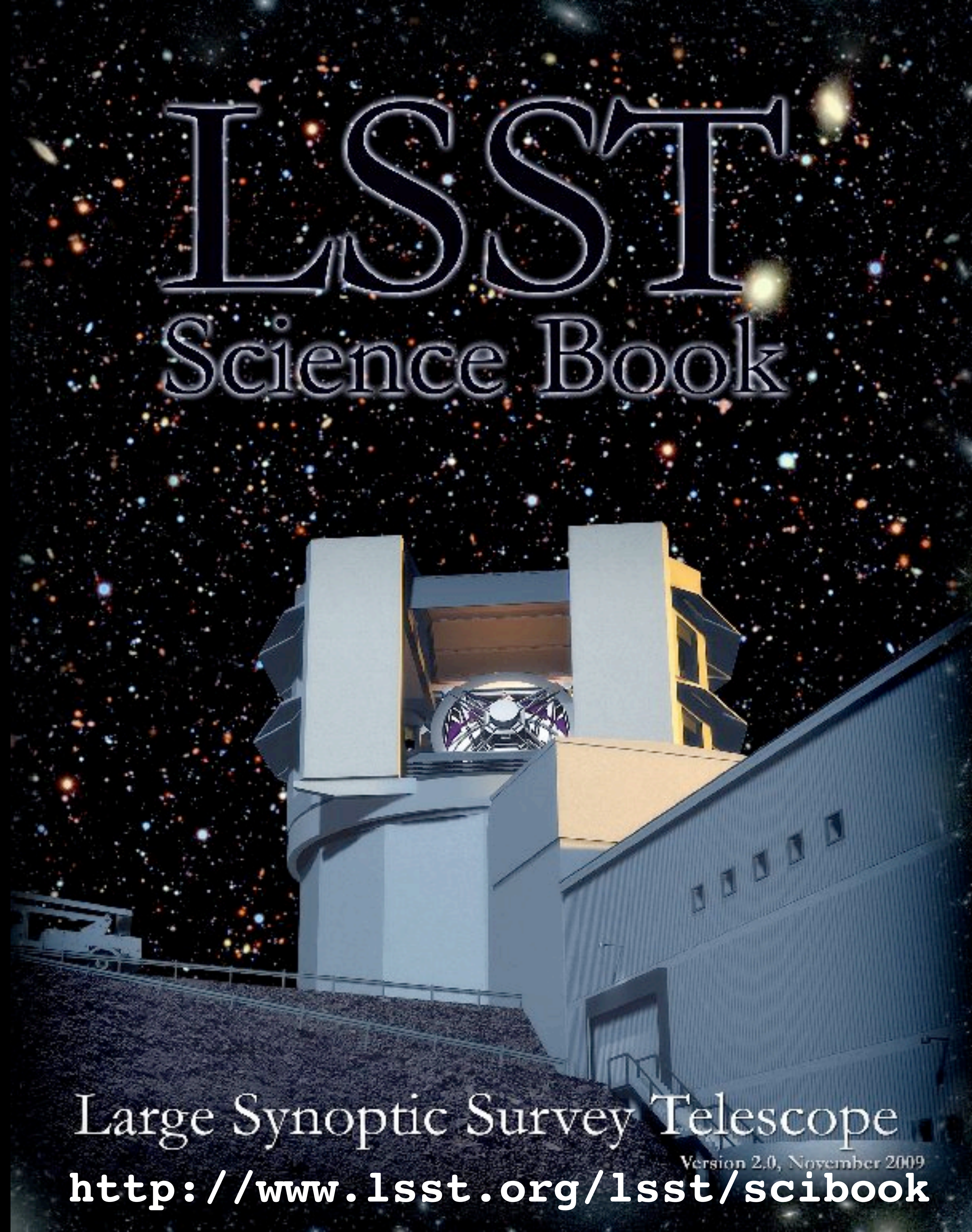
  Science collaborations were polled for suggestions:

  1. *Spectra of new transients - for example, distant, exotic supernovae. How did the first stars die?*
  2. *Spectroscopic stellar velocity measurements in new, low-mass, distant Milky Way dwarf satellites. What's the mass function?*
  3. *How about in other galaxies? Detecting and measuring CDM subhalos with very high astrometric precision measurements of gravitational lenses*

  A purposely incomplete list...

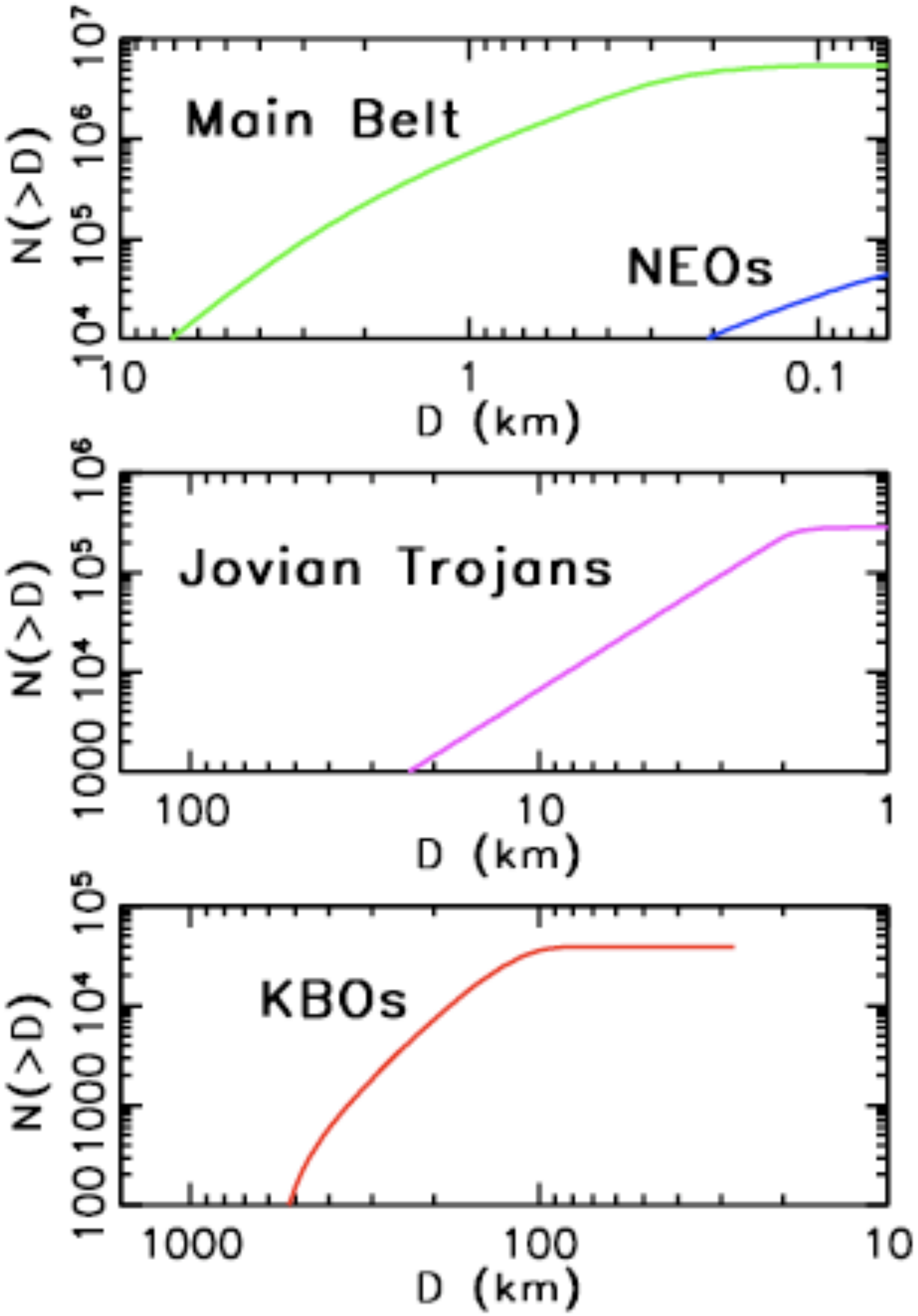
Nearly 250 authors,
nearly 600-pages,
still growing

arxiv/0912.0201

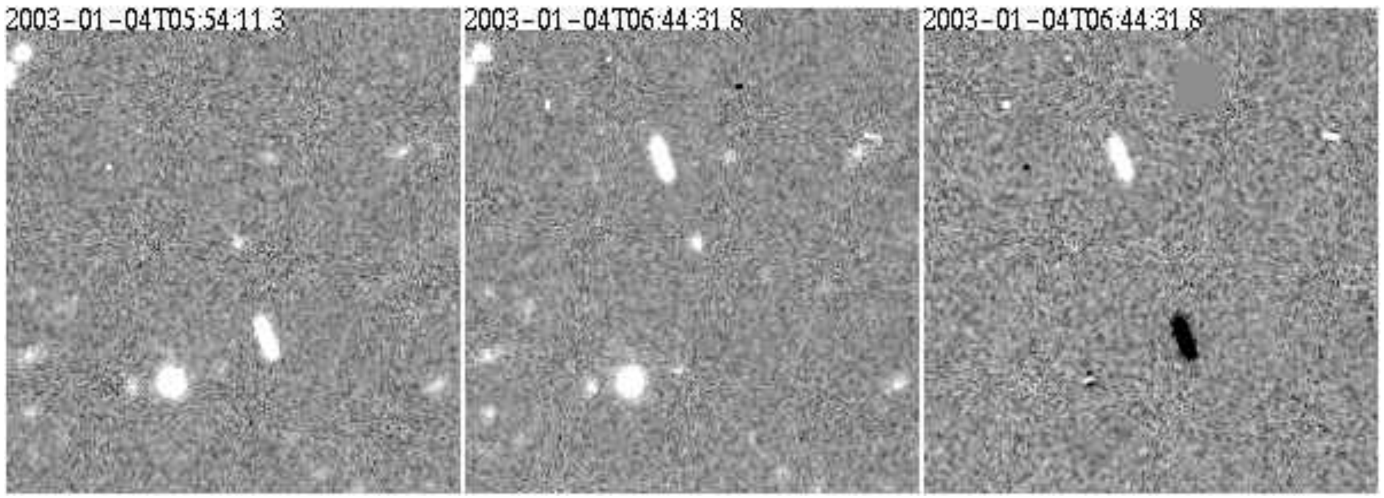


http://www.lsst.org/lsst/scibook

A Solar System Inventory



LSST Science Book

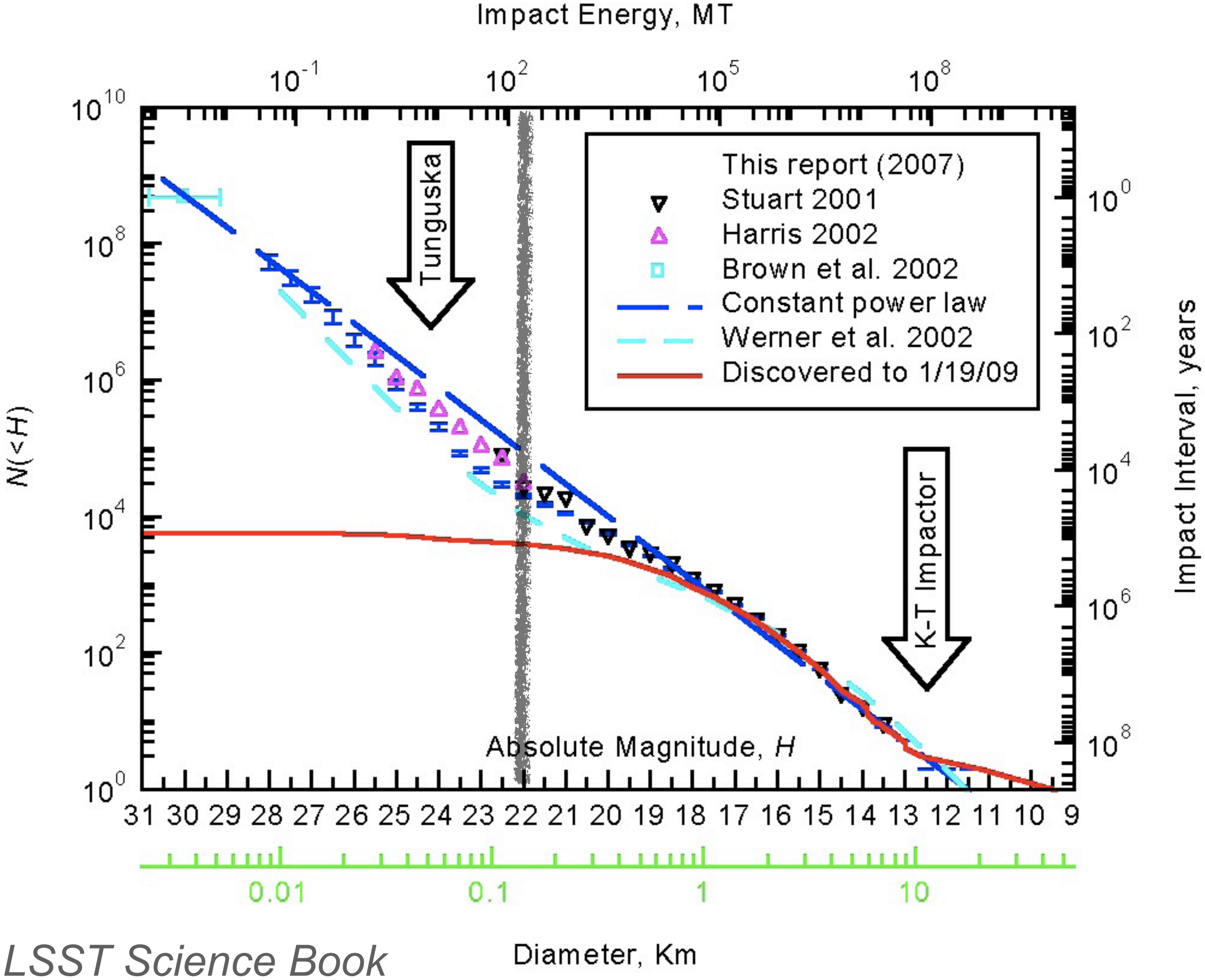


Moving Objects pipeline: intra-night (30-45 min) “tracklets” linked into inter-night (3-4 day) “tracks” and tested for orbit validity.

5.5 million main belt asteroids,
100,000 NEOs,
280,000 Jovian Trojans,
40,000 TNOs

Potentially Hazardous Asteroids

LSST will detect **nearly 90% of all 140-m and larger PHAs**



LSST Science Book

100m = large nuclear explosion, and/or tsunami;

1km = climate catastrophe, significant fraction of global population lost

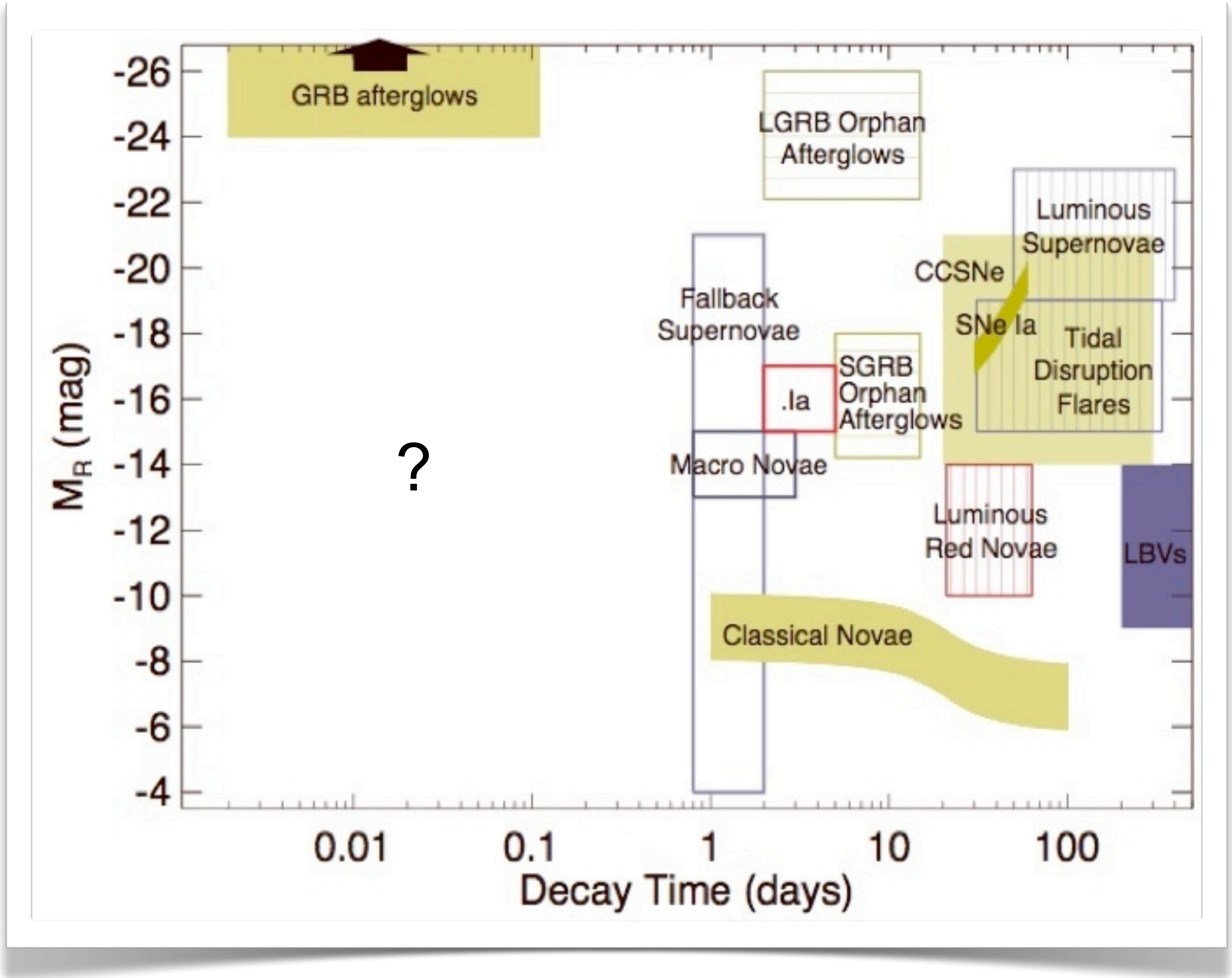
The Transient Universe

Large Synoptic Survey Telescope

LSST will explore an enormous volume of parameter space:
6 decades in time,
22 mag in L

Each year, LSST will detect and measure:
- **200,000 SNe Ia**
- **100,000 SNe II**
- **1000 GRB afterglows**
- **6000 AGN tidal disruption events**

...



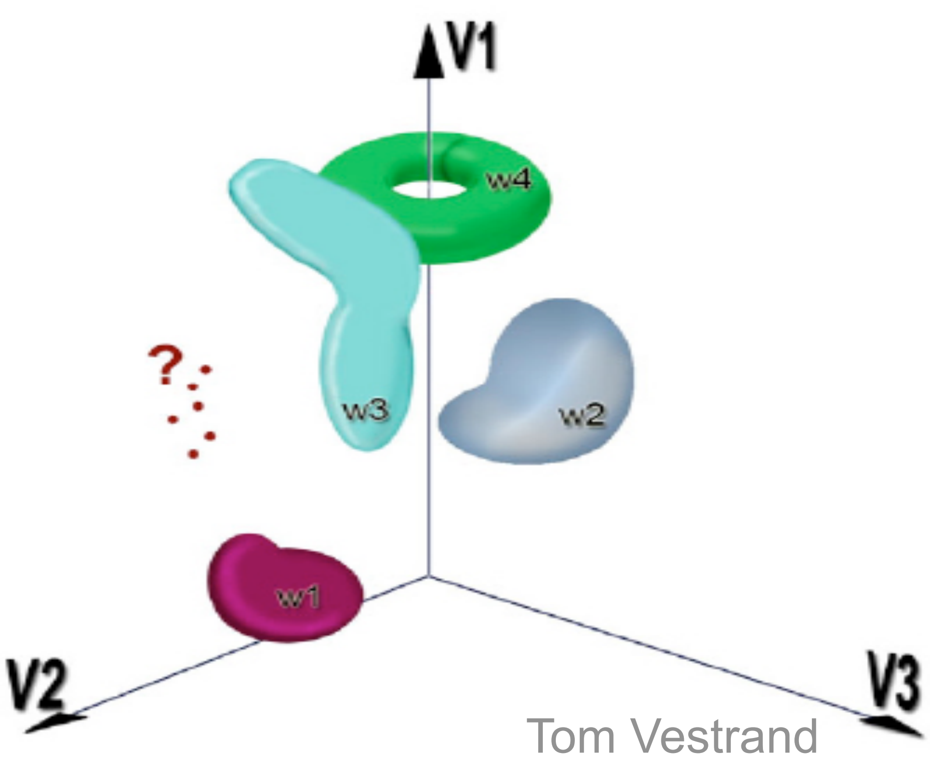
from Rau et al (2008)

Transient Classification

- The LSST transient pipeline will issue 10^5 alerts per hour
- Most will be moving objects, but 10^4 will be flares, or bursts, *including entirely new kinds of object*

Identification spectra will be important - but **the target list must be manageable,** and therefore **well-understood:**

Any giant feeder needs highly trusted event classification, fast



Tom Vestrand

Active area of research within LSST science collaborations - but not part of the project.

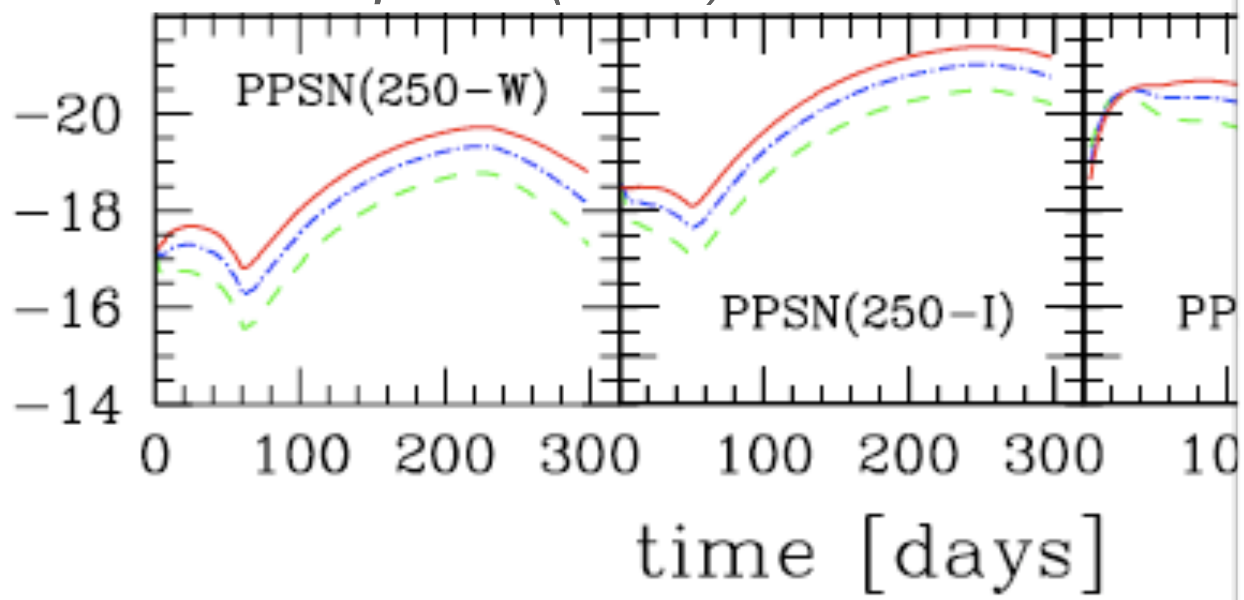
Very large data sets enable:

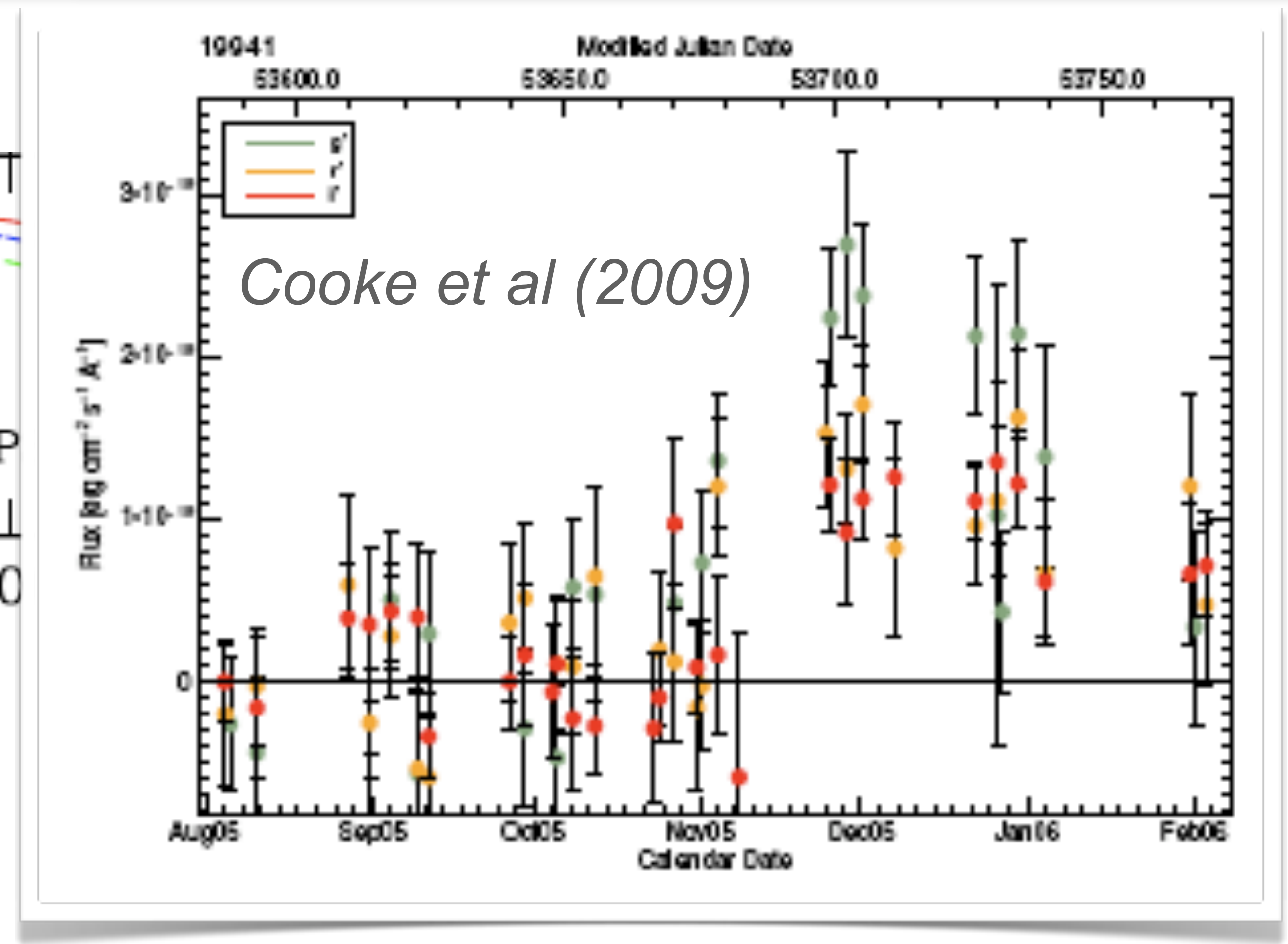
- high quality statistical analysis of "typical" events, and then
- automated searches for "rare" events

Access to the whole database will be vital

LSST archive science: exotic SNe

Scannapieco (2005)





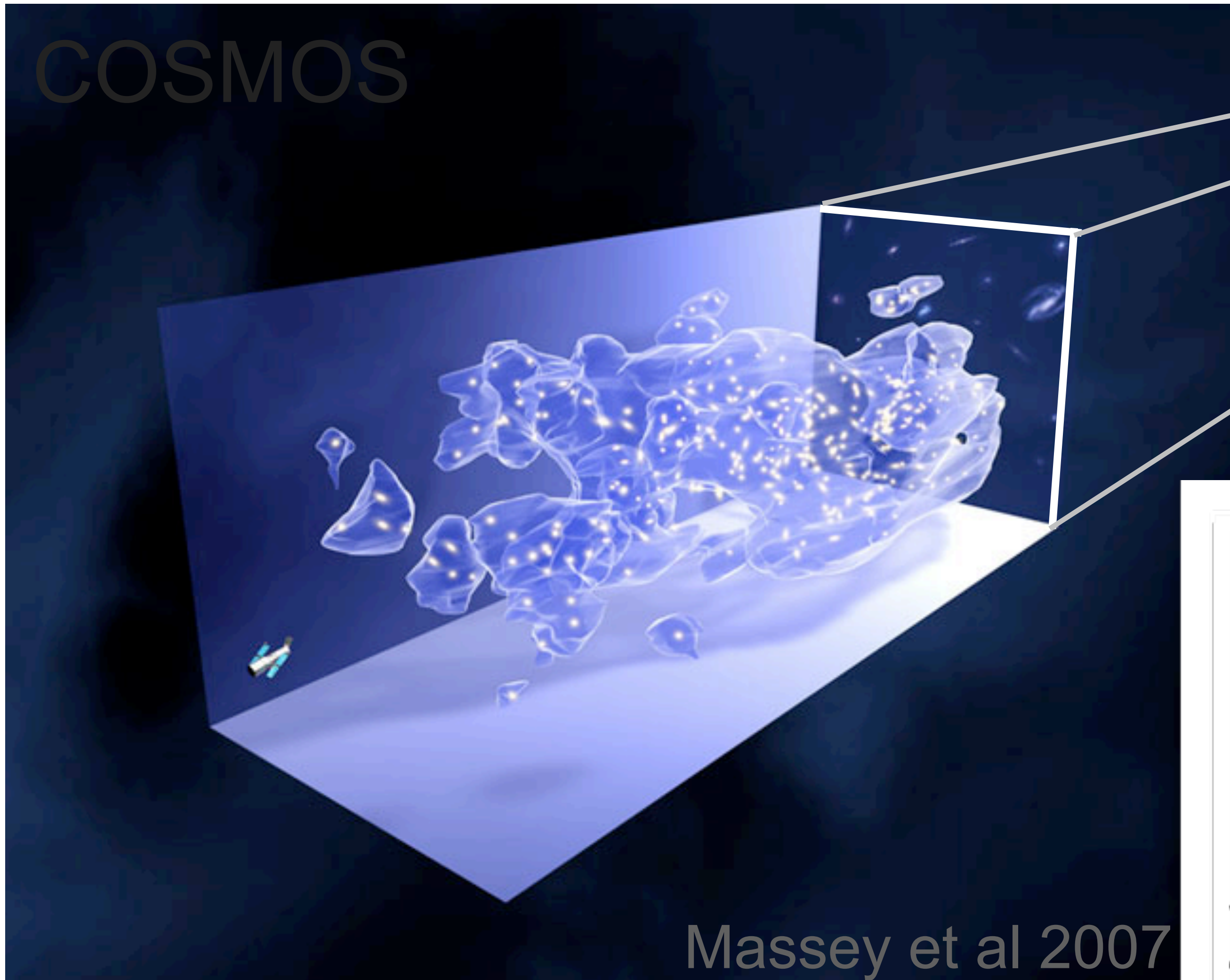
Luminous and **long duration** SNe at **high redshift:**

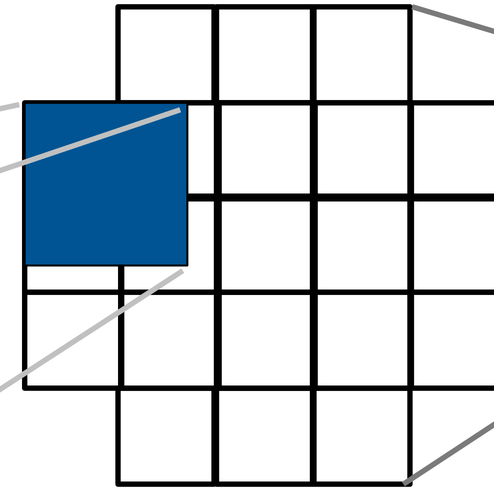
- Pair-production instability SNe (150-250$M_{\odot}$ progenitors)
- Extreme Type II supernova events to z~6
- Insight into the earliest generations of stars - *ELT follow-up req'd*

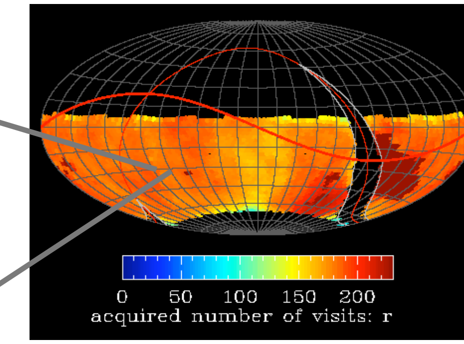
Cooke et al (2009) detection at z=2.4 (r=25.6) in CFHTLS yearly stacks, confirmation and redshift with 1-2 hours Keck LRIS

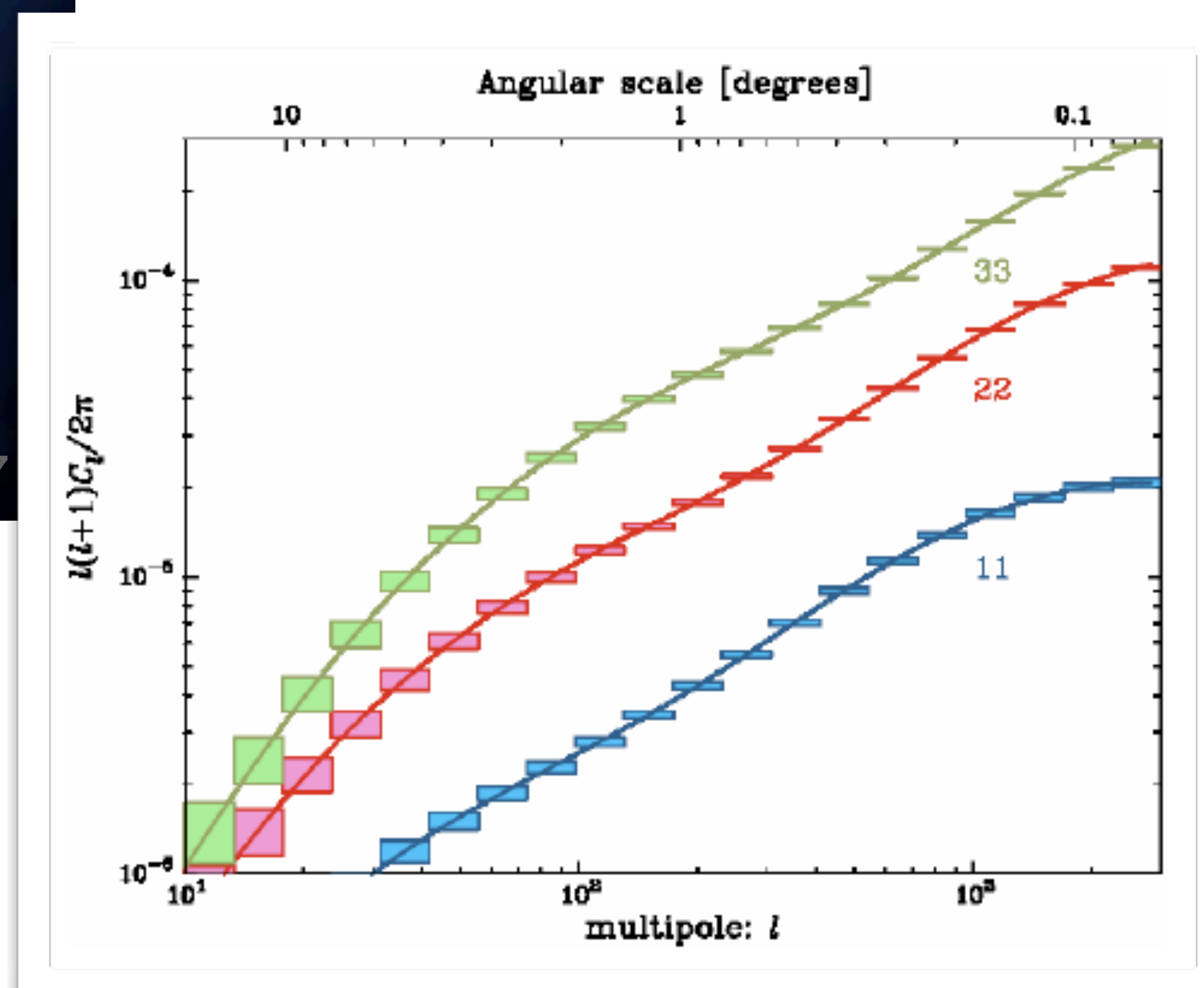
Dark Matter Everywhere

Large Synoptic Survey Telescope









Weak lensing by large scale structure: tomographic mapping, 3D correlations, high precision cosmology

Depends on photo-z accuracy

Aside: photo-z calibration

Plans to calibrate photo-z's down to r ~25 with spectroscopic samples of size 10^{4-5} do not *depend* on ELTs, but they will increase the accuracy:

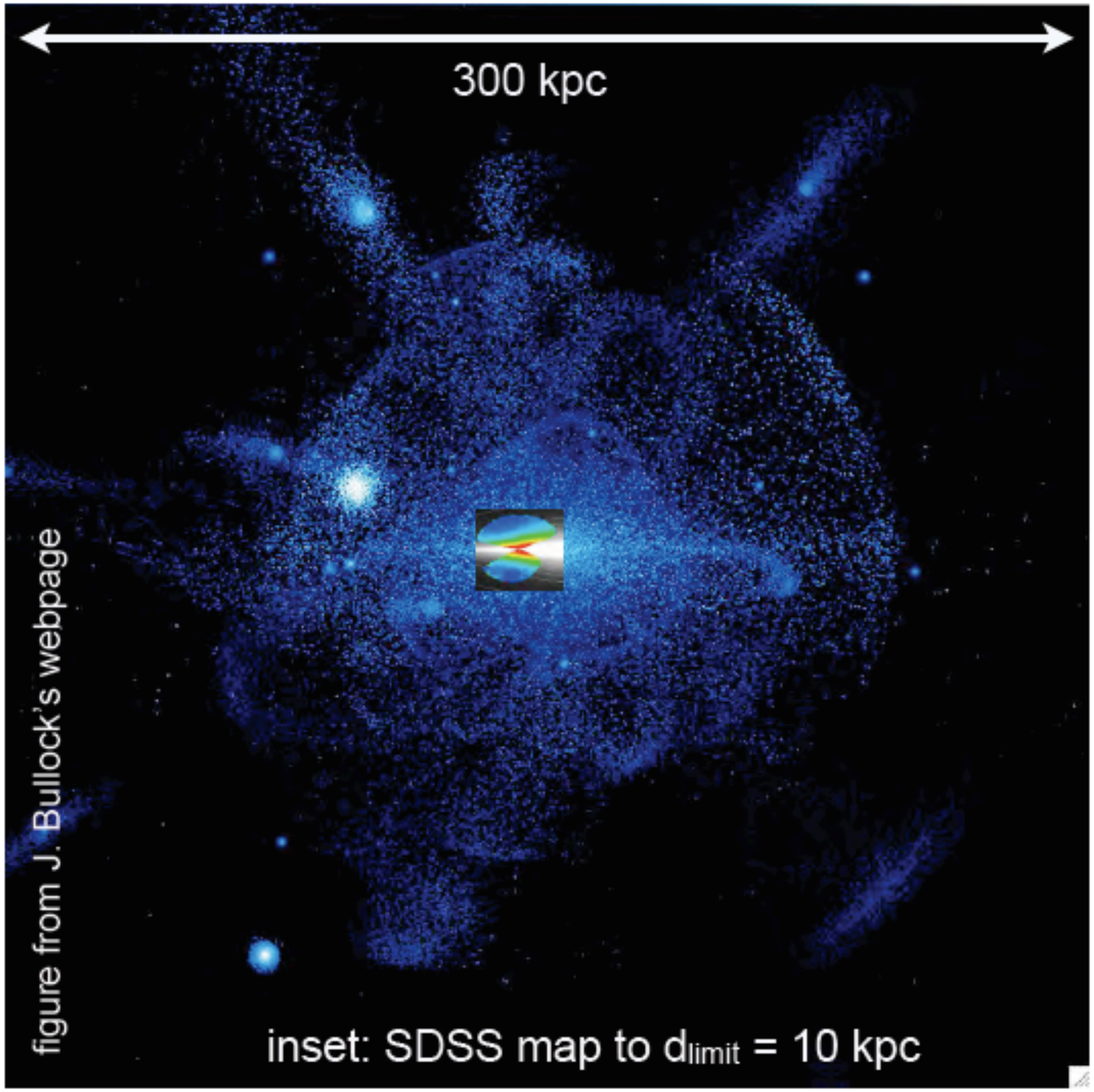
- *angular cross correlation with the faint photometric sample* will calibrate photo-z statistically (eg Newman)
- large spectroscopic samples improve knowledge of evolution of galaxy SEDs - *ELTs will help at the faint end*

There are currently 13 telescopes 8m and larger with spectrographs that can reach the LSST survey area

Wide field multi-object spectroscopy on both 8-10m and 30-40m class telescopes will be the most important tool for weak lensing photo-z calibration

For free(!): stellar population and galaxy evolution science

Mapping the Milky Way



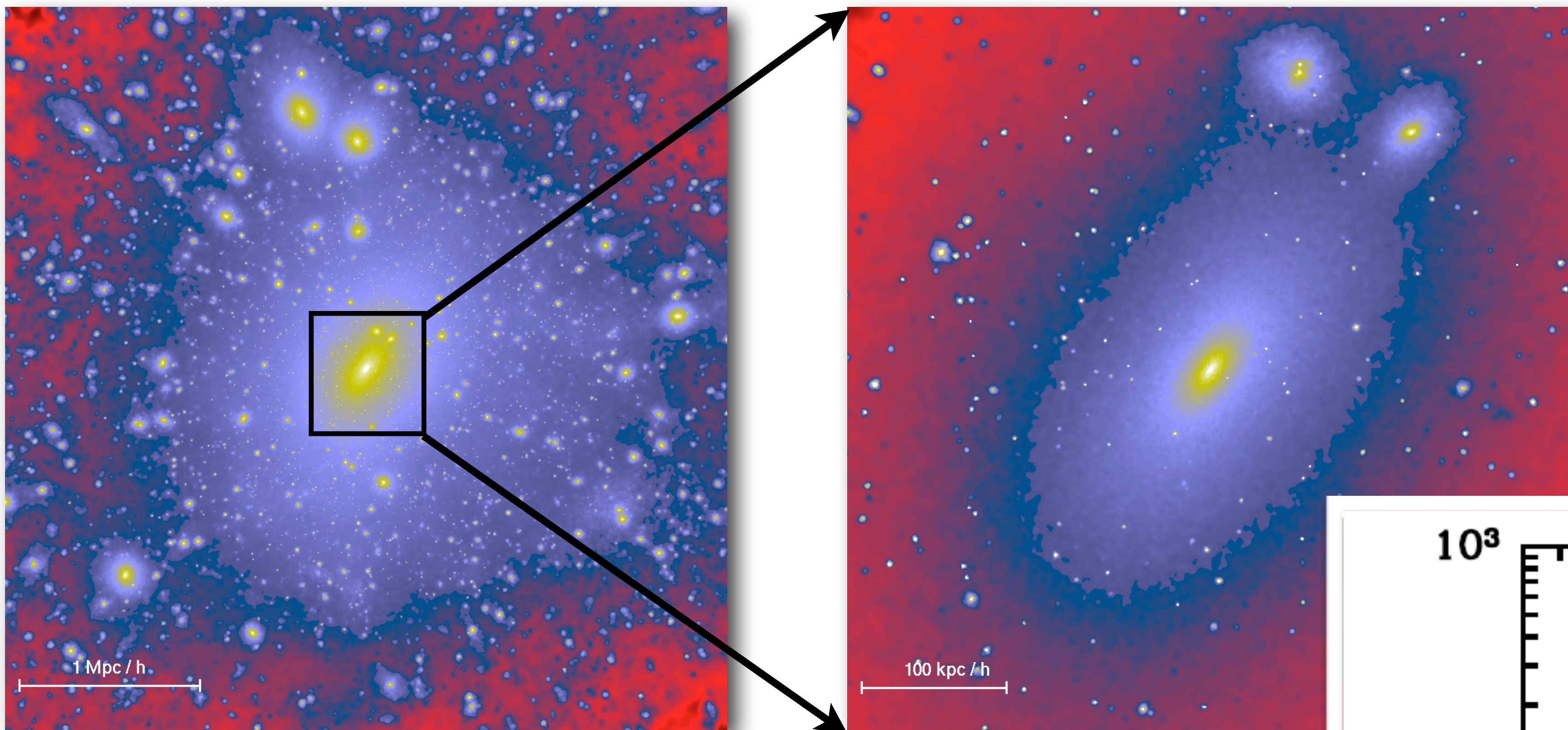
- Old, metal-poor main sequence turnoff stars detected **to 300 kpc.** Photometric [Fe/H] as precise as 0.1-0.2 dex for **200 million stars to 100 kpc.**
- Proper motions: tangential velocity field **to 10 kpc (at 10 km/s precision)** and as far as 25 kpc (at 60 km/s precision).

Slide from Beth Willman

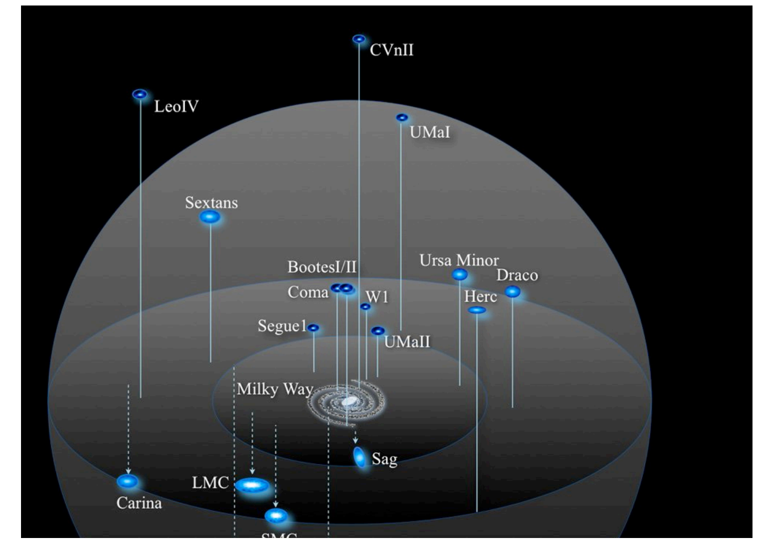
CDM structure on small scales

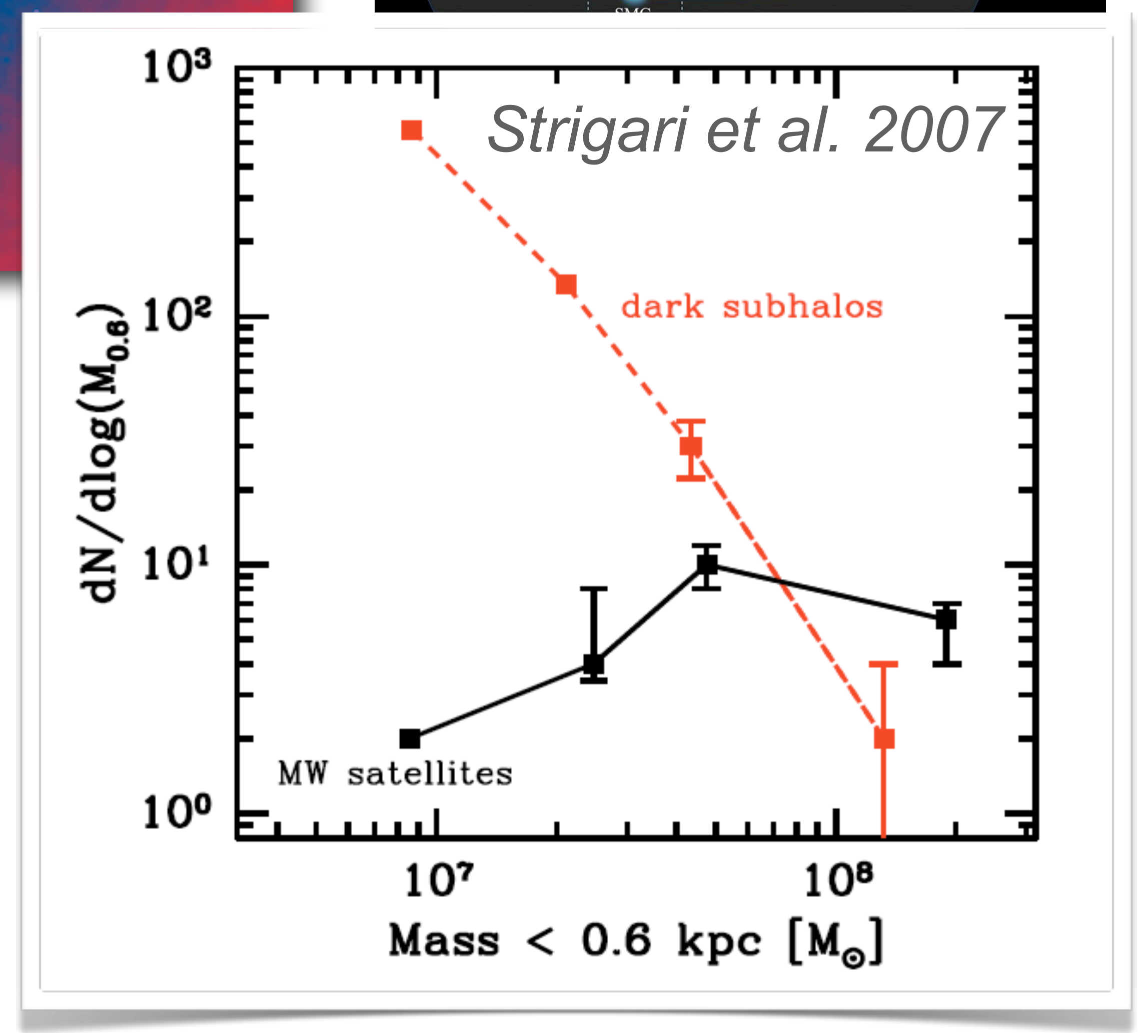
LSST Large Synoptic Survey Telescope

Slide from Leon Koopmans



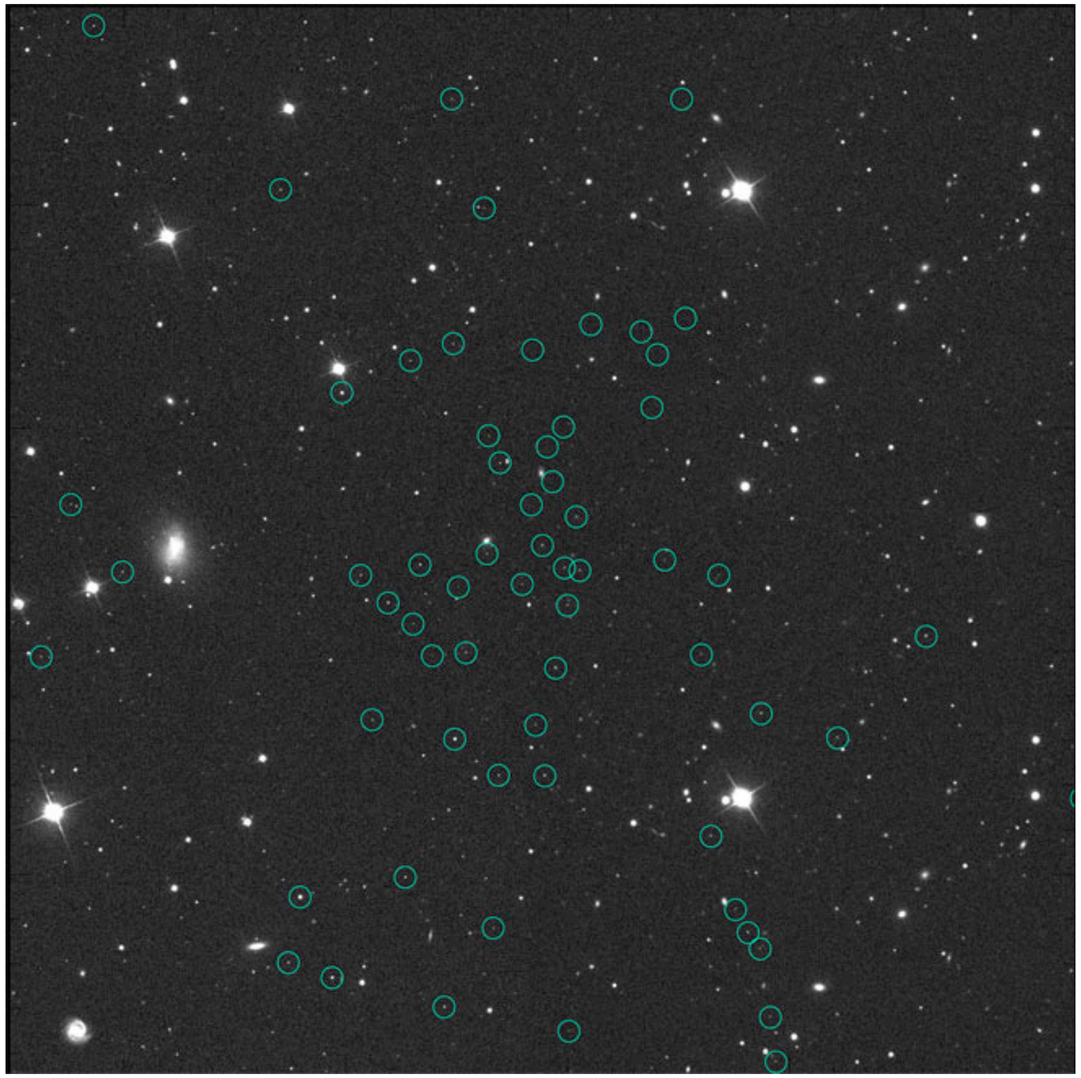
Springel et al. 1999

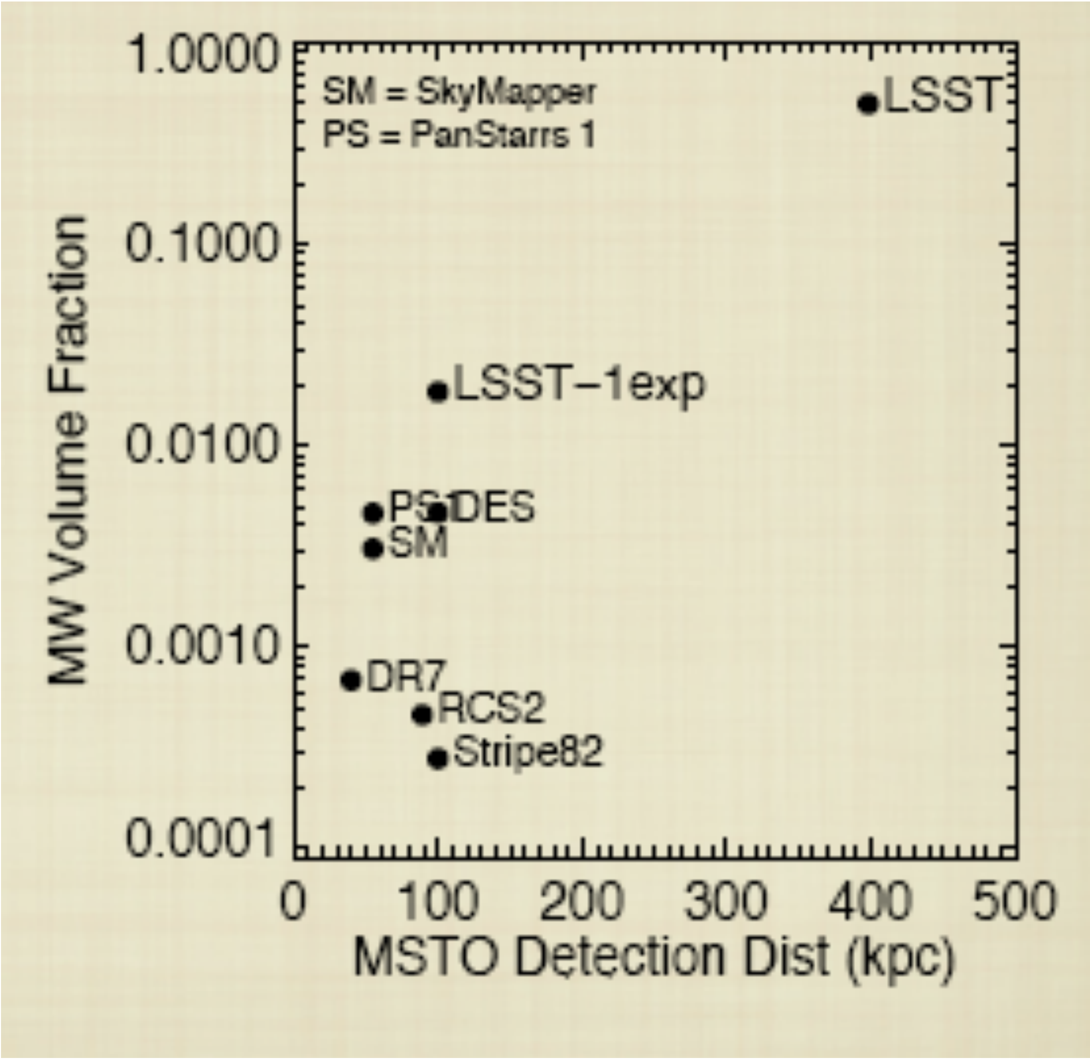




- Steep halo mass function at sub-galactic mass scales is a strong prediction of CDM
- We see far fewer Milky Way satellites than are predicted - why?

Finding Milky Way Satellites

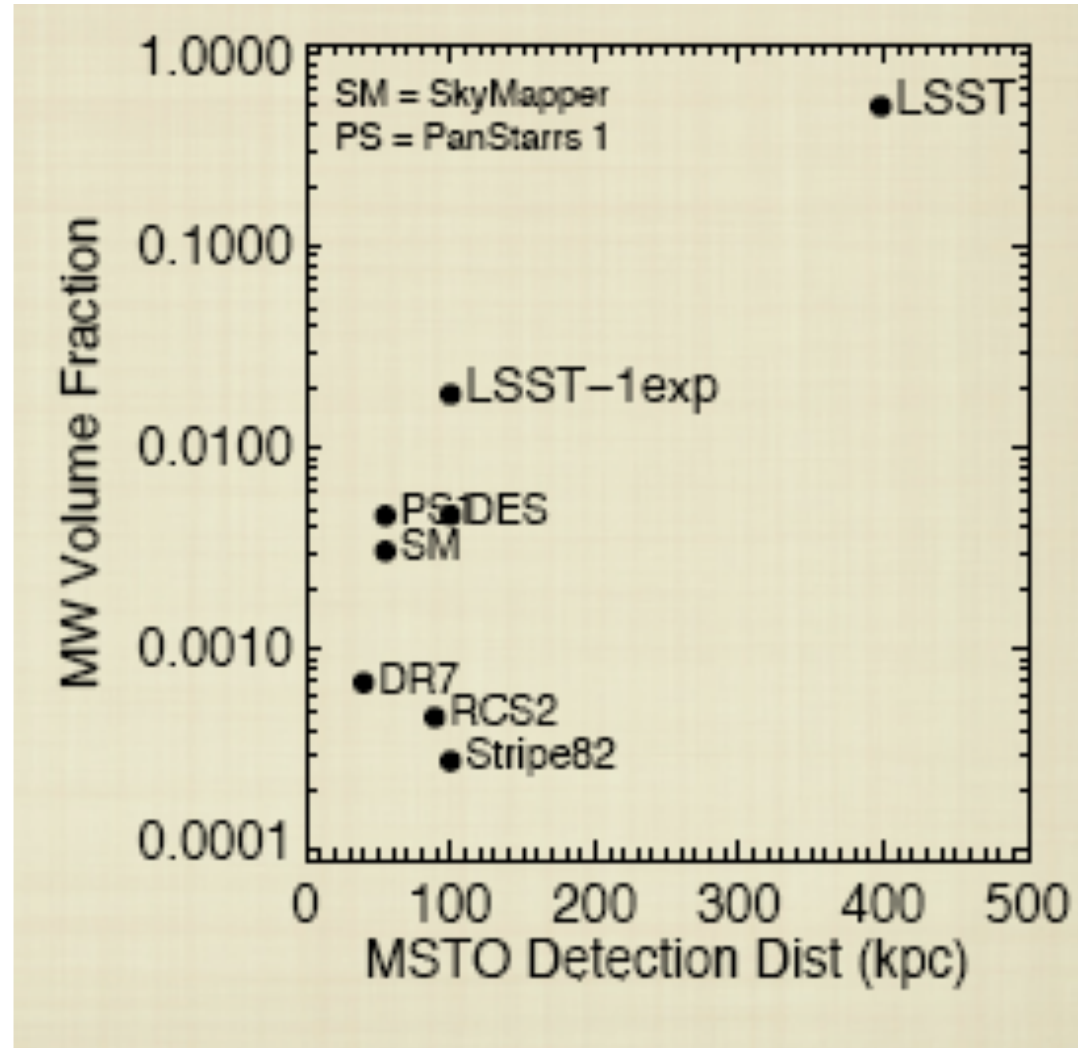




Figures from Beth Willman

- Ultra-faint dwarf galaxies detectable as overdensities of stars on a background of faint galaxies
- LSST should find **hundreds of new MW satellites** as it reaches 10 times further out than SDSS

Finding Milky Way Satellites



Figures from Beth Willman

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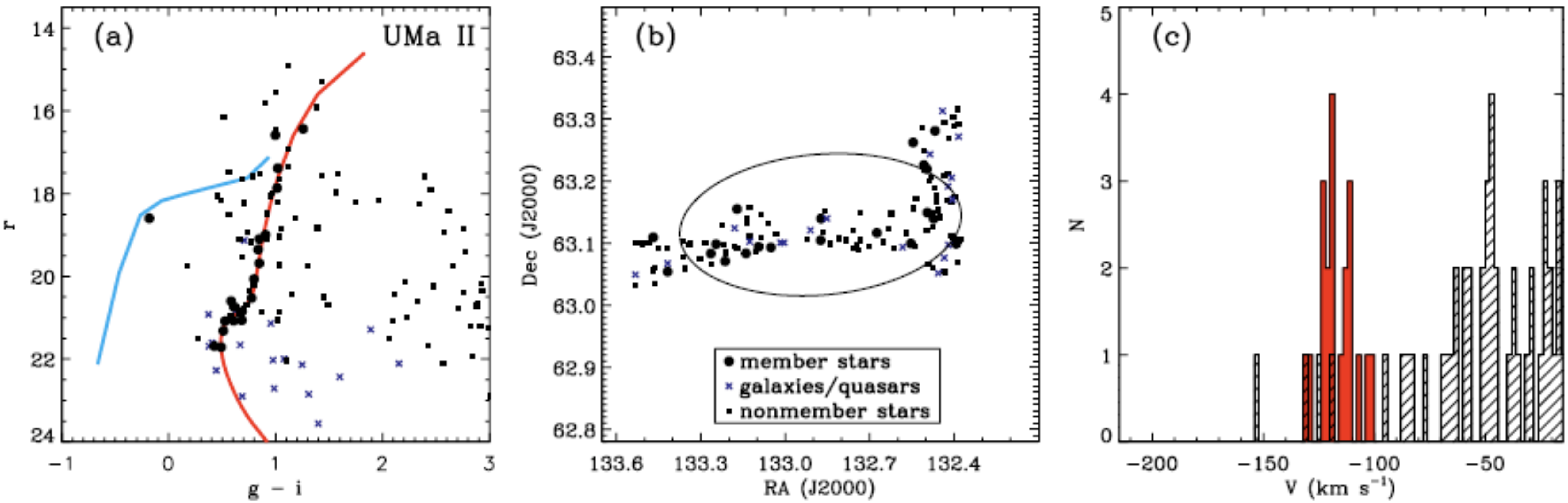
Weighing subhalos with ELTs (1)



Simon & Geha (2007) observed 8 targets with Keck DEIMOS:
200 stars (~20th mag), 10% confirmed members, σ = 5 km/s (20%)

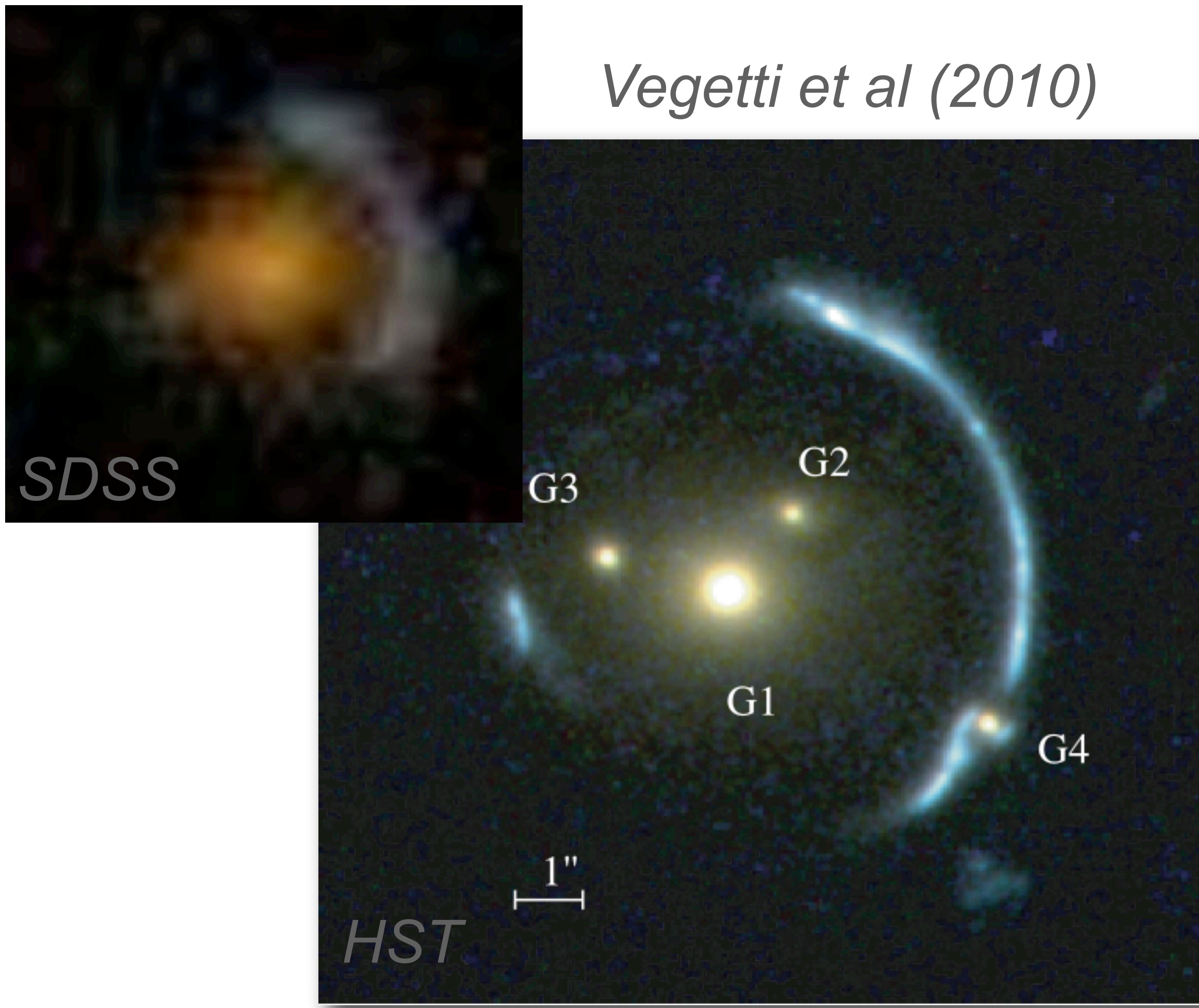
ELT follow-up stellar spectroscopy will be required to:

- **test whether the detections are galaxies** with dark matter halos
- and then **measure how much mass they contain**;

10-m class telescopes cannot reach beyond the inner 100 kpc already searched - the tracer stars are too faint.

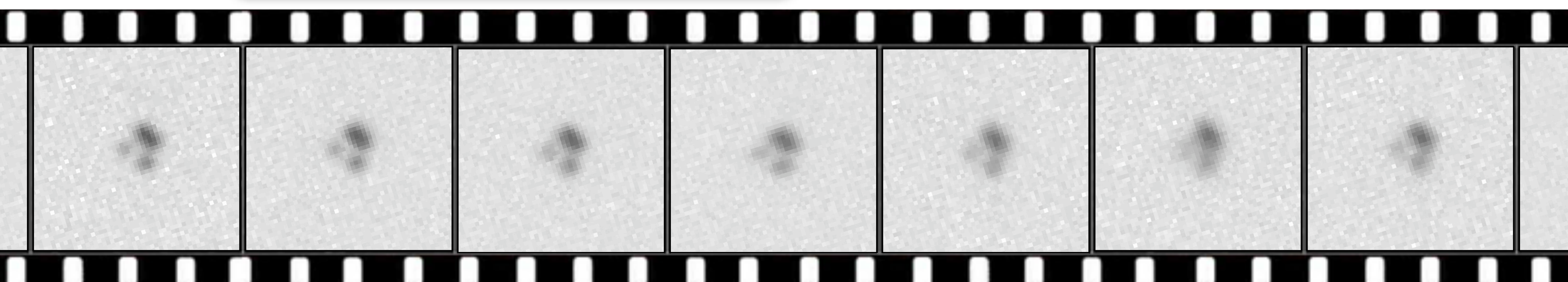
Strong Gravitational Lensing

Vegetti et al (2010)



LSST survey will contain 10^4 strong lenses:

- Lensed AGN and SNe fluxes and lensed galaxy arcs are *sensitive to perturbation by CDM subhalos*
- Extragalactic complement to MW satellite studies

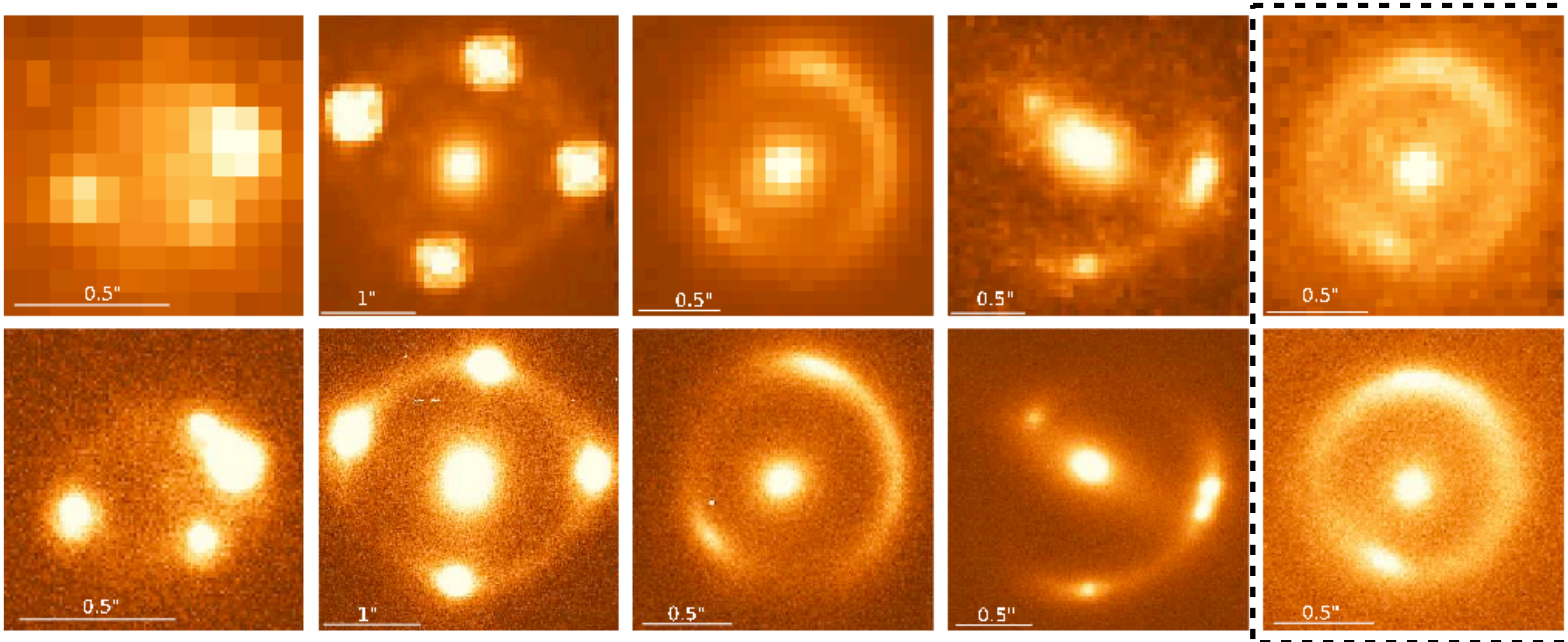


High precision image astrometry

Large Synoptic Survey Telescope

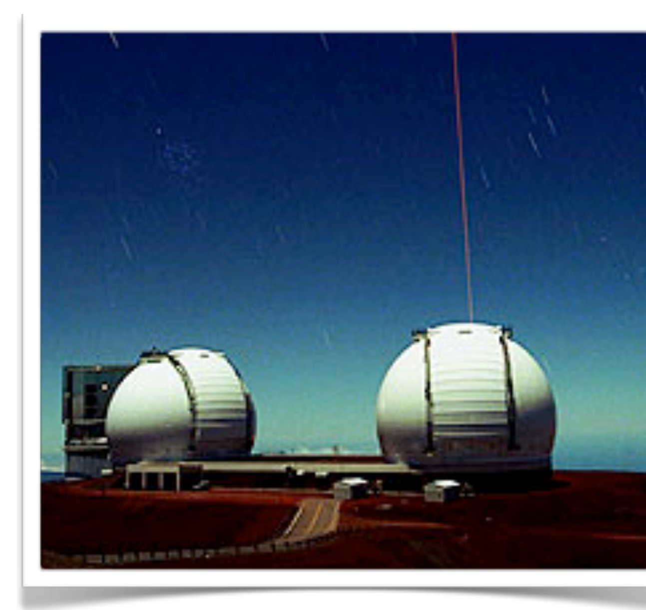
HST

AO



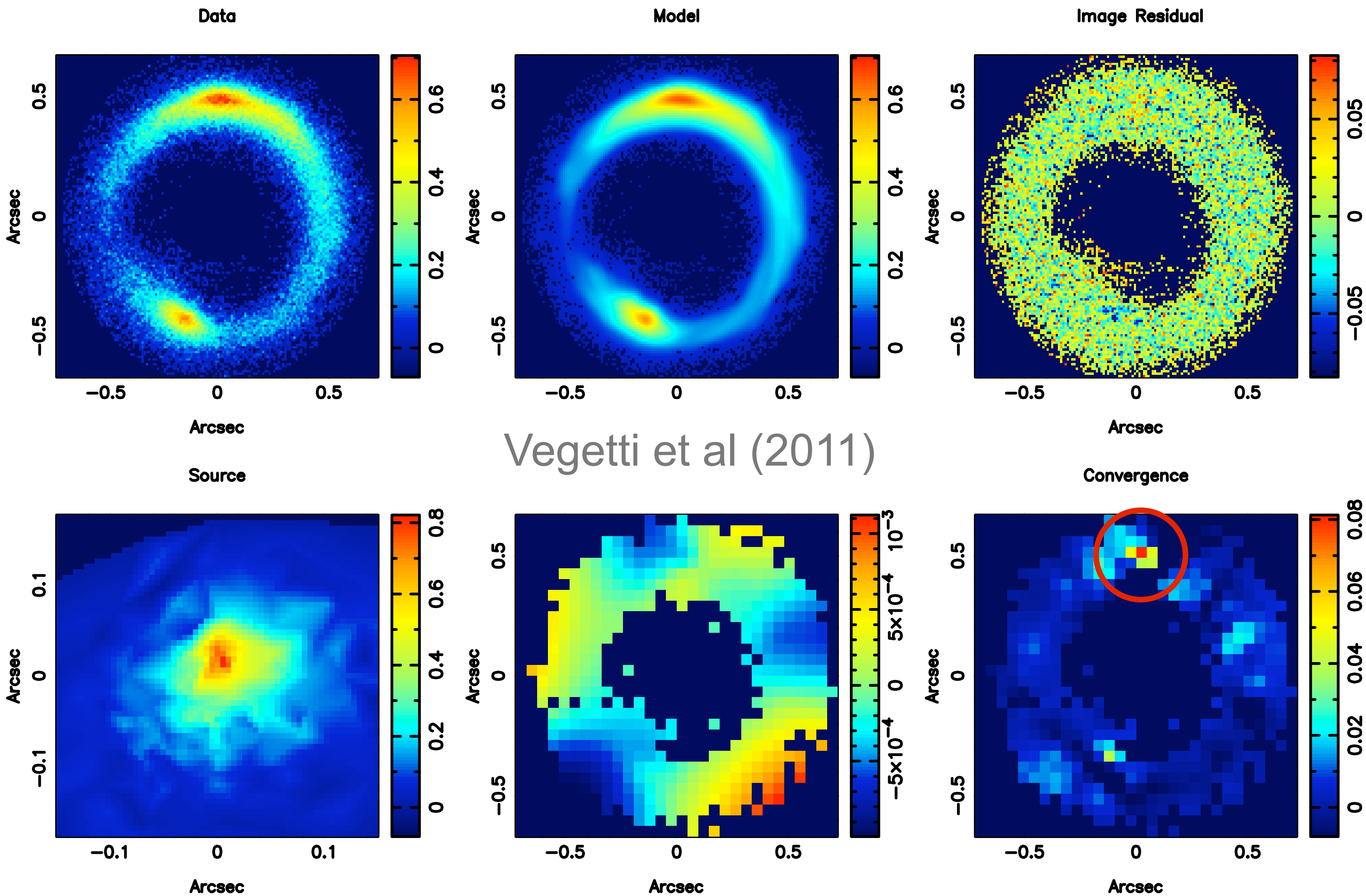
Montage from Leon Koopmans

Fassnacht et al (in prep) are observing galaxy-scale lenses with Keck LGSAO: higher resolution than HST enables more sensitive "gravitational imaging"



LSST will provide *highly informative lenses* - **both extended and pointlike images, time delays, high magnification configurations**

Weighing subhalos with ELTs (2)



Vegetti et al (2011)

ELTs:

- **detection of large numbers of $10^{7\text{-}8}$ M$_o$ dark matter subhalos**

- **IFU** to **reject foreground light,** focus on **emission lines,** use source **velocity field** etc etc

Several hundred high S/N lenses will constrain the subhalo mass fraction and mass function slope, testing CDM theory

LSST: Feeding the Giants

Large Synoptic Survey Telescope

LSST will provide an absolute feast for the Giants - the challenge will be *deciding which things to eat!*

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If all goes to plan, LSST should be surveying the sky throughout the next decade: time to book a table at the banquet for sometime between 2020 and 2030!

Questions