NOAO Wide-Field Surveys

David Silva

Dark Energy Survey

The Ground-Based Stage IV BAO Experiment

BigBOSS

LSST

Large Synoptic Survey Telescope

NOAO Survey Program: The starting point

NOAO Survey Program
First steps, not all wide field

- Definition
  - Must address novel, well-focused scientific goals
  - Must enable large, statistically complete, homogeneous datasets
  - Must enables extensive archival research
  - Must be significant enhancement over existing surveys

- Survey time available on all NOAO & Gemini facilities
- Up to 20% of total time available per telescope class
  - For 4-m class, up to 175 nights per year
  - For Gemini USA time, up to 40 nights per year

NOAO Survey Program
29 programs since 1999

- 24 completed
- 5 in progress
- 411 papers, 18725 citations
- No papers yet for surveys started in 2009 or later
- First Gemini survey started in 2010

Surveys produce twice as many papers per night
as regular programs (and more high impact papers)

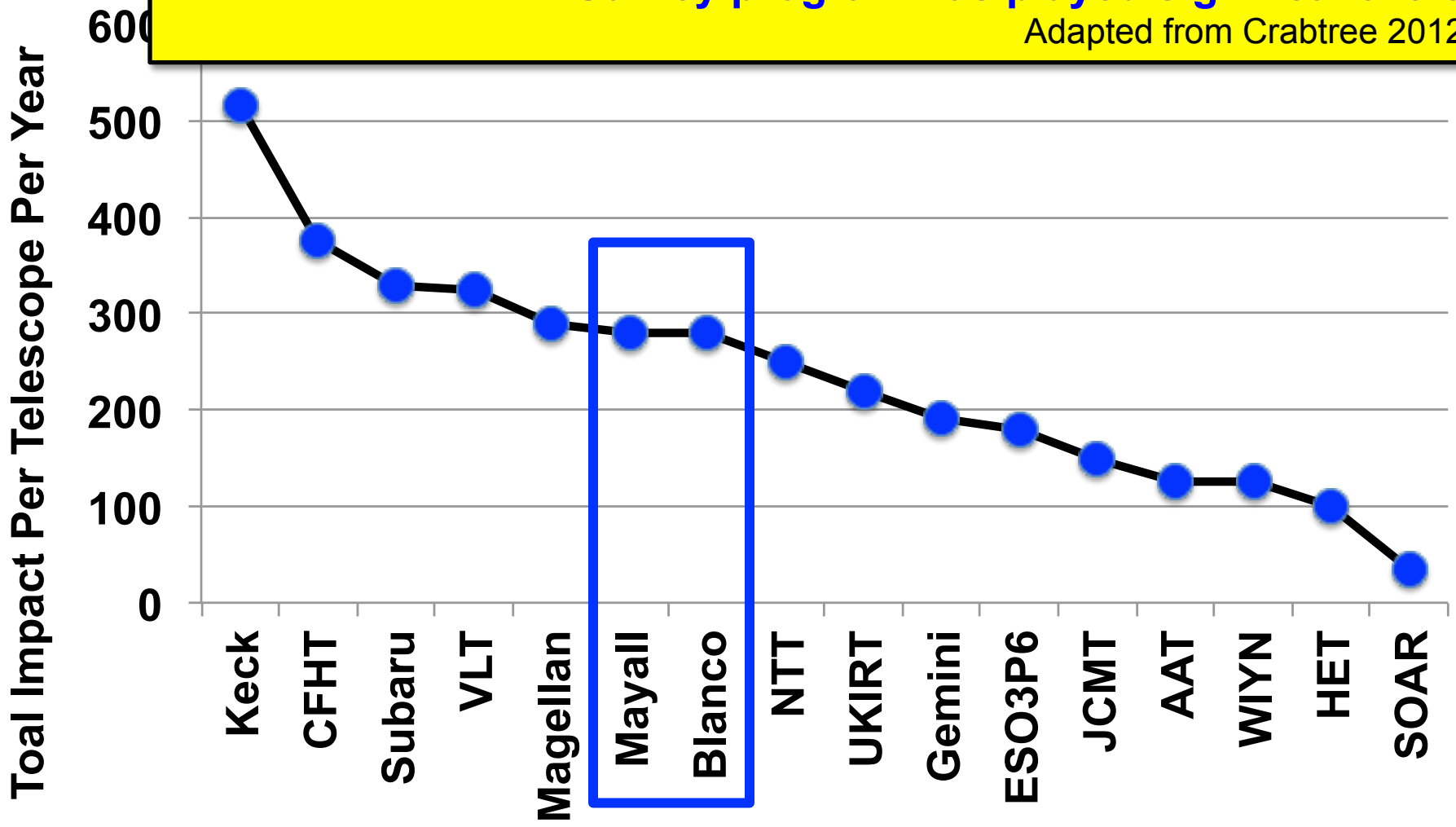
Median Impact Per Telescope Per Year (2006 – 2010)

Impact = number of papers x median normalized citation rate

Impact independent of aperture size

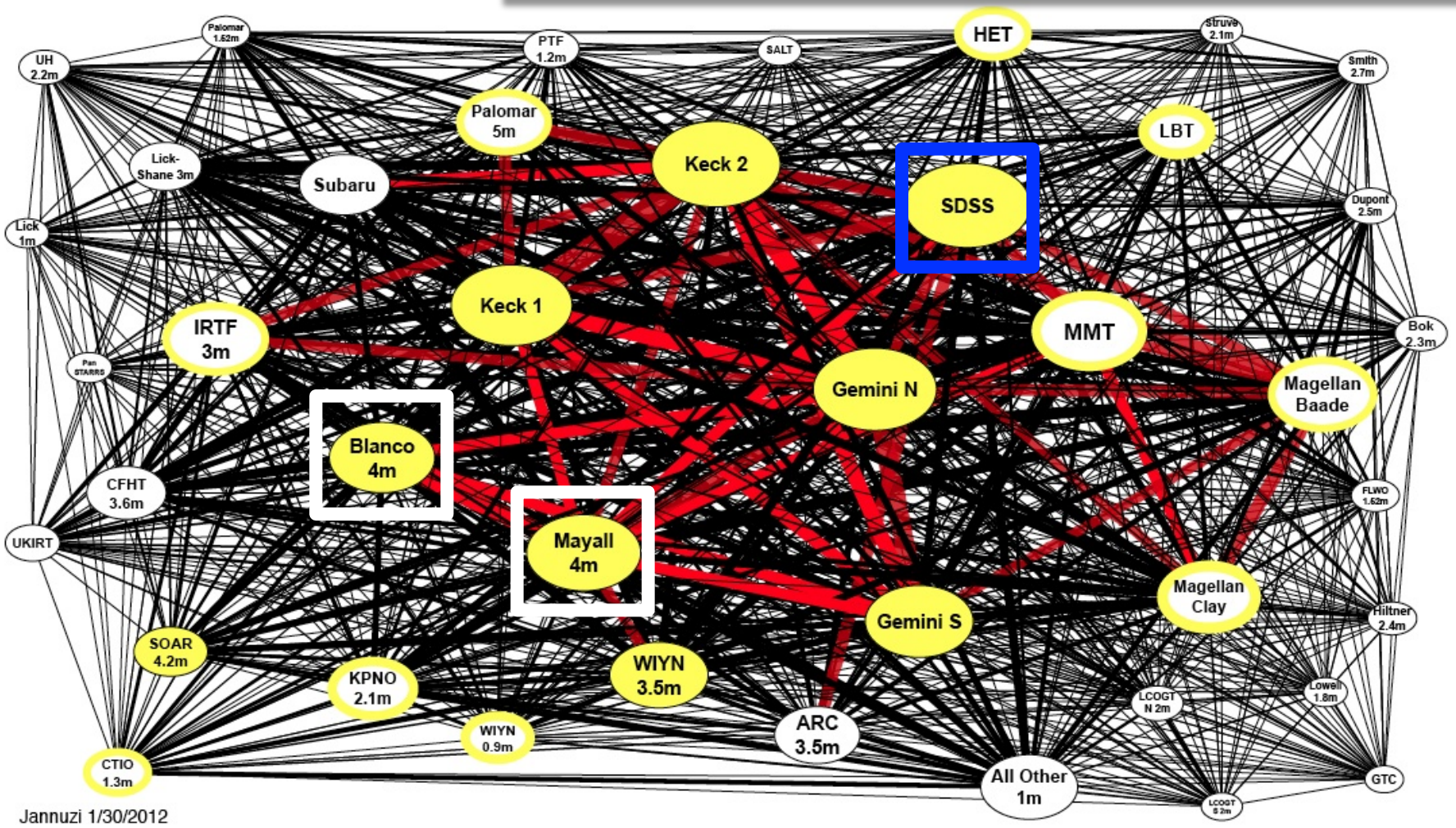
Survey program has played significant role

Adapted from Crabtree 2012



Highly interconnected

Key result from System Roadmap Survey (N = 1178)
Bubble size = relative number of users in last 3 years
Lines = users of multiple facilities
Red lines = most frequent connections
Yellow (solid) = NSF investment, ≥ $1M/year
Yellow (border) = NSF investment, less



Jannuzi 1/30/2012

NOAO Survey Program
Examples – I

- The NOAO Deep Wide-Field Survey
  - Leaders: Jannuzi & Dey (NOAO)
  - KPNO Mayall 4-m 57 nights, CTIO Blanco 4-m 25 nights
  - KPNO 2.1m 139 nights,
  - 126 papers, 5295 citations (52 archive papers, 1732 citations)
  - http://www.noao.edu/noao/noaodeep/

  - 2 x 9.2 deg sq.
  - Optical depth: ~ 26 (AB, 5 sigma)
  - Near-IR depth: ~ 21 (AB, 5 sigma)

NDWFS
High-impact results

- Evolution of the red galaxy population from z~1 to present in the context of large scale structure
  - Brown et al. 2007 & 2008 (196 & 96 cites)
  - White et al. 2007 (81 cites)

- Discovery of very dust-obscured galaxies (DOGs) at high redshift
  - Dey et al. 2008 (130 cites)

- Enabled discoveries of several high-z galaxy clusters
  - *NDWFS + IRAC Shallow Survey*
  - Eisenhardt et al. 2008 (106 candidates, z > 1) (90 cites)
  - Stanford et al. 2012 (z = 1.75)
  - Zeimann et al. 2012 (z = 1.89)

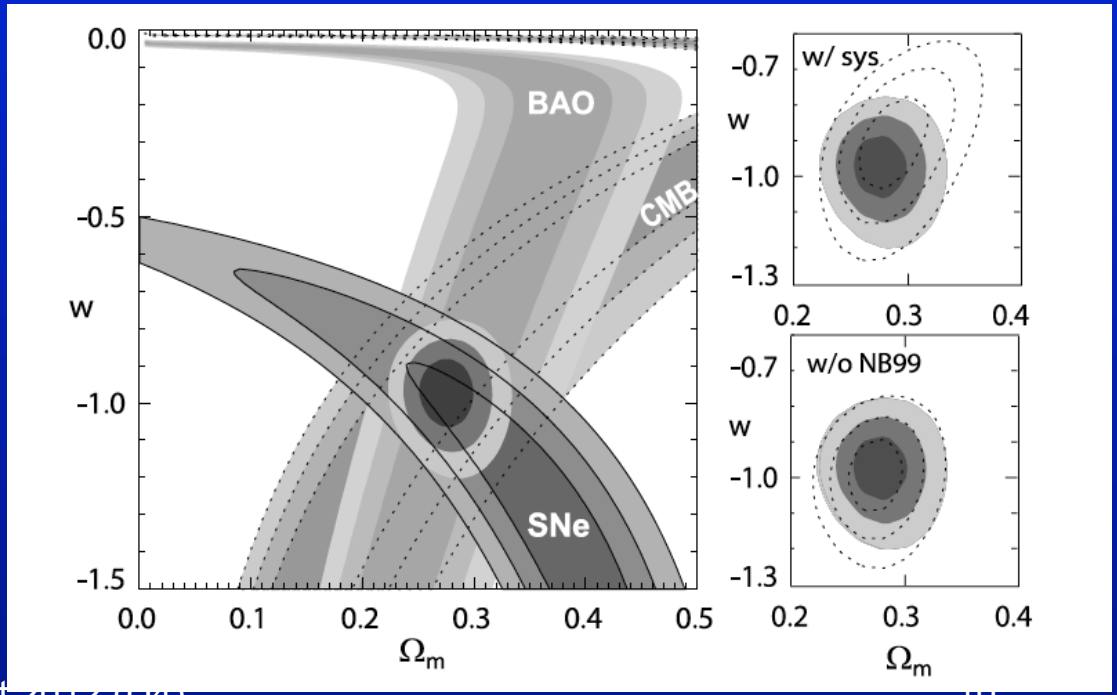
NOAO Survey Program
Examples – II

- ESSENCE: Measuring Equation of State of the Universe
  - PI: Nick Suntzeff (TAMU)
  - KPNO WIYN 3.5-m 20 nights, CTIO Blanco 4-m 90.5 nights
  - CTIO 1.5m 12 nights, 0.9m 67.5 nights
  - 21 papers, 7559 citations (7 archive papers, 5273 citations)
  - http://www.ctio.noao.edu/wproject/

  - High-z SN Ia program → Hubble diagram
  - NOAO survey provided "discovery" images and light curves
  - Many other facilities contributed spectroscopic followup

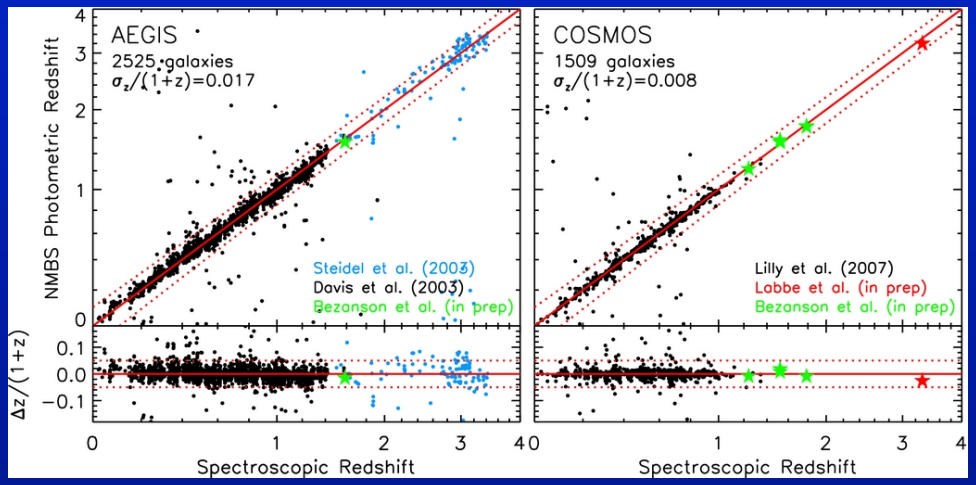
ESSENCE
High-impact results

- Observational Constraints on the Nature of Dark Energy
  - Wood-Vasey et al. (2007) (624 cites)
- Scrutinizing Exotic Cosmological Models…
  - Davis et al. (2007) (381 cites)
- Improved Cosmological Constraints…
  - *The Union SN set*
  - Kowalski et al. 2008 (724 cites)



NOAO Survey Program
Examples – III

- The NEWFIRM medium-band survey (NMBS): accurate redshifts for 40,000 K-selected galaxies
  - PI: van Dokkum (Yale)
  - KPNO Mayall 4-m 75 nights
  - 13 papers, 383 citations (1 archive paper, 3 citations)
  - http://www.astro.yale.edu/nmbs/Overview.html
  - 2 x 0.21 deg sq fields, JHK ~ 24.5 (5 sigma)



Redshift accuracy goals achieved (Whitaker et al. 2011)

Massive Galaxy Growth since z = 2

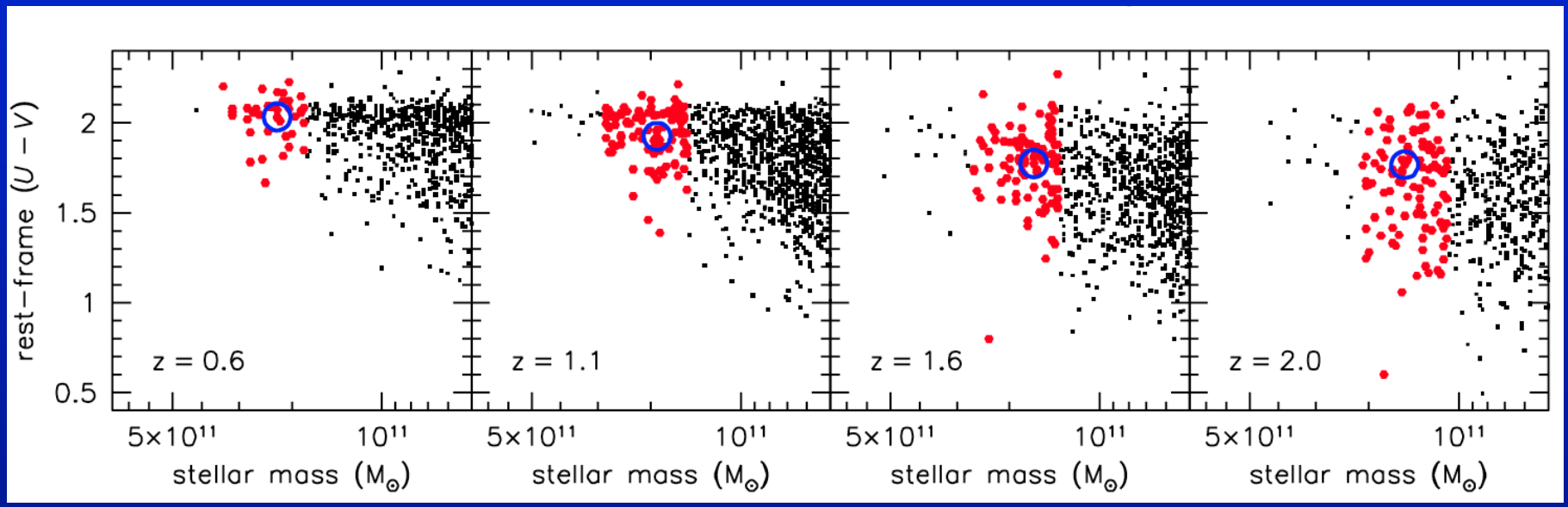
Van Dokkum et al. 2010, ApJ, 709, 1018

Most cited (136) "NOAO data dominant" paper from 2010

Deep near-IR imaging
User-designed filters
NEWFIRM near-IR imager
KPNO Mayall 4-m

Time allocated through
NOAO Survey Program

- Stellar mass of massive galaxies has increased by 2 since z = 2
- Growth has occurred in outer parts
- Favors "inside-out" growth models dominated by mergers



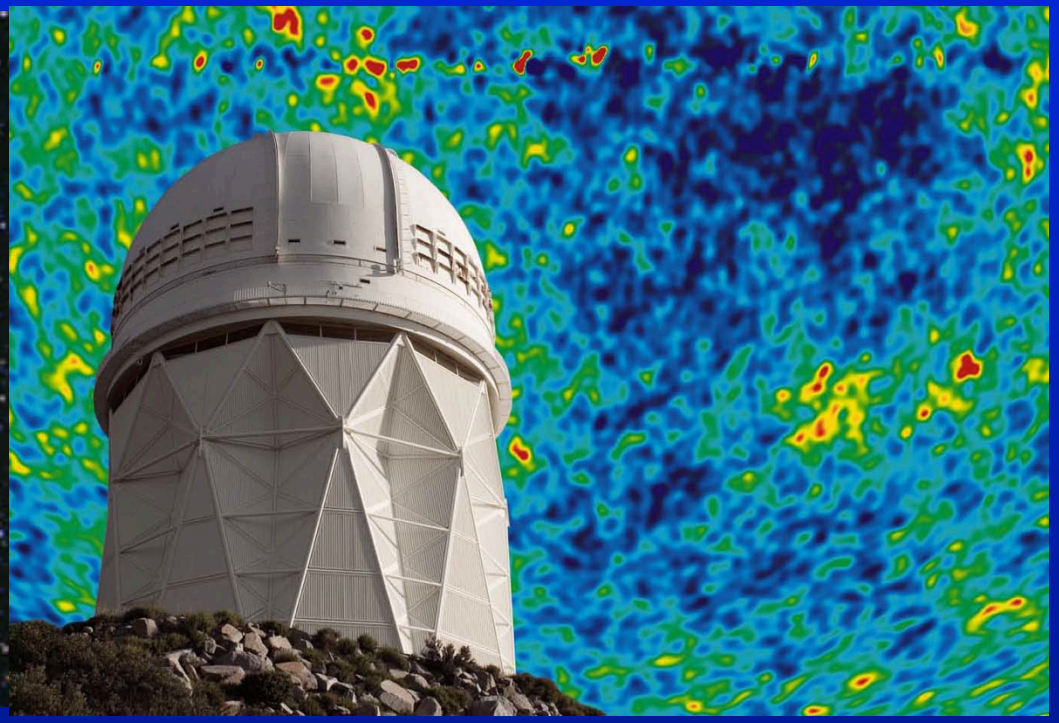
Large Science Programs @ NOAO

Large Science Programs @ NOAO
Dark Energy Survey (DES), BigBOSS (BB)

Dark energy characterization = core challenge

A 2010 Decadal Survey Science Frontier

Premier dark energy missions of this decade



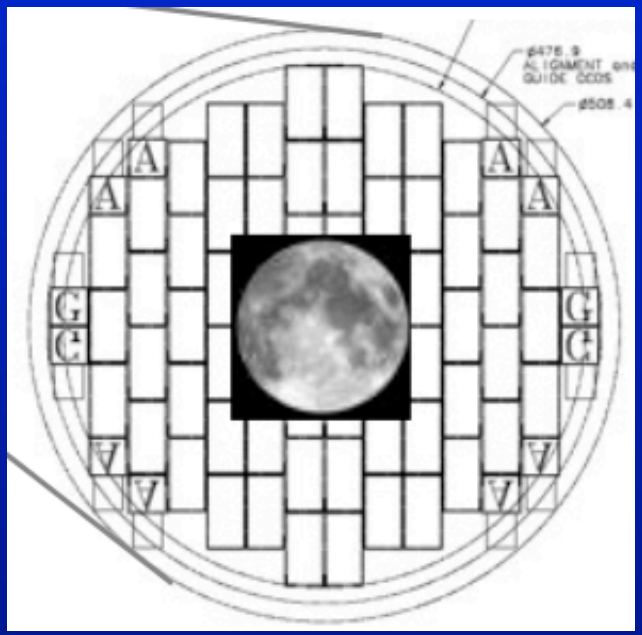
~ $60M project
35/25 DOE/NSF

Dark Energy Survey (DES)

www.darkenergysurvey.org

- Dark Energy Survey (DES)
  - Stage III dark energy experiment
  - 5000 sq deg, 300 million objects to z = 1.3
  - 5-band (optical) + 3-band (NIR) photometric redshifts
  - Survey plan: 2012 – 2017, 525 nights
- Dark Energy Camera (DECam)
  - Builder: consortium led by DOE Fermilab
  - Located @ Blanco 4-m
  - 2.2-degree, 500 Mpix camera
  - Pipeline (NSF funding)
  - DES archive / data products
- Status: will start December 2012

DES+VHS (10σ)			
g	24.6	J	20.3
r	24.1	H	19.4
i	24.0	Ks	18.3
z	23.8		
Y	21.6		



What are we measuring?

Cosmic expansion rate as function of redshift, H(z)

$$H(z) = H_0 \times [\ \Omega_M (1+z)^3 + \Omega_R (1+z)^4 + \Omega_{DE} (1+z)^3 (1+w)\ ]^{0.5}$$

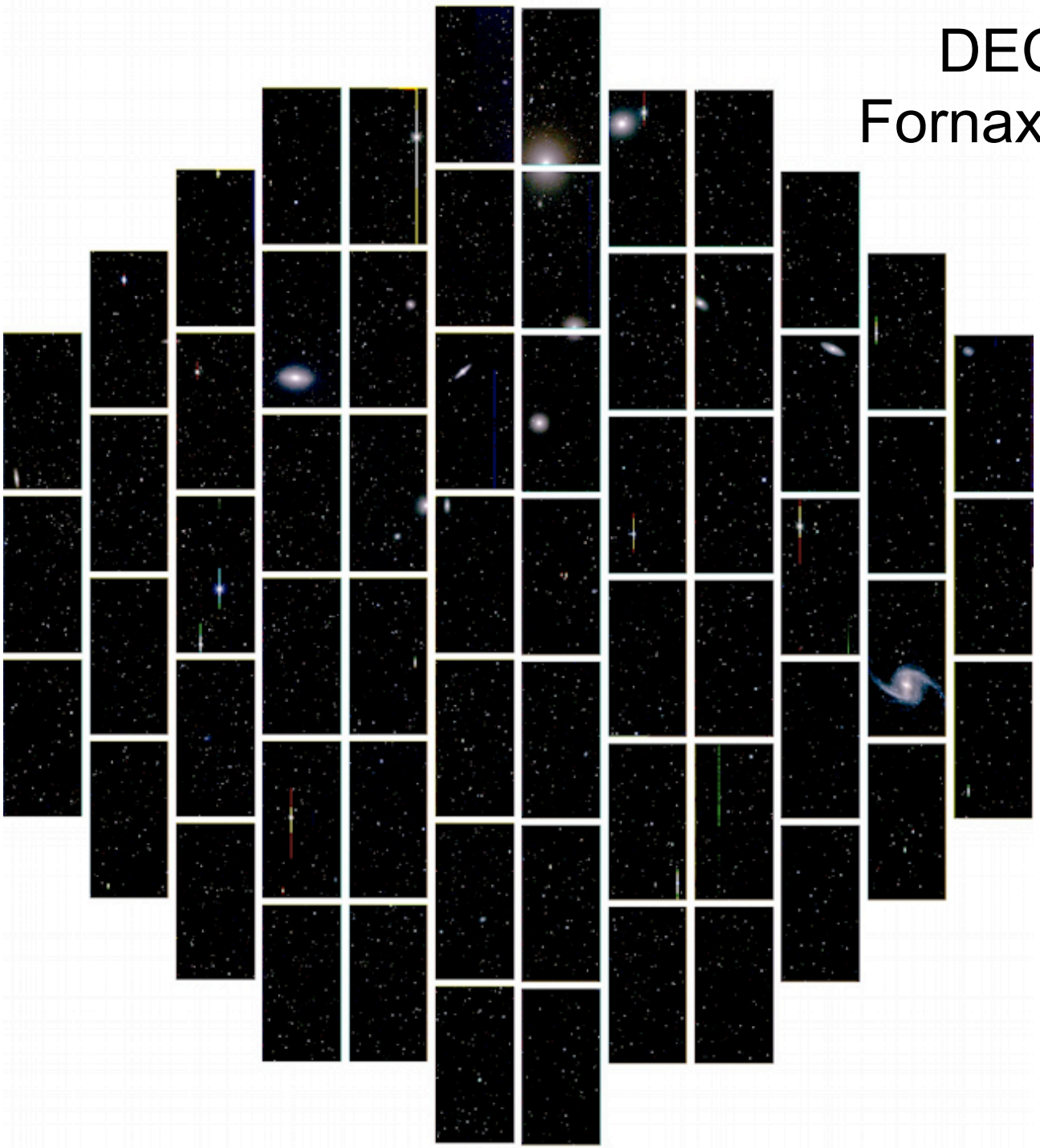
matter radiation dark energy

- Evolution of luminosity vs. redshift ("geometry")
  - Standard candle
  - Example: Hubble diagrams using SN Ia
- Evolution of angular separation vs. redshift ("geometry")
  - Standard ruler (angular separation or size)
  - Example: BAO "wavelength" at recombination vs. now (or any t)
- Evolution of structure vs. redshift ("structure")
  - Interplay of cosmic expansion and gravitational interaction
  - Example: density perturbation spectrum at recombination compared to observed structure (presumably dominated by dark matter halos and filaments) vs. redshift

Dark Energy Survey
Four probes of dark energy, f(z)

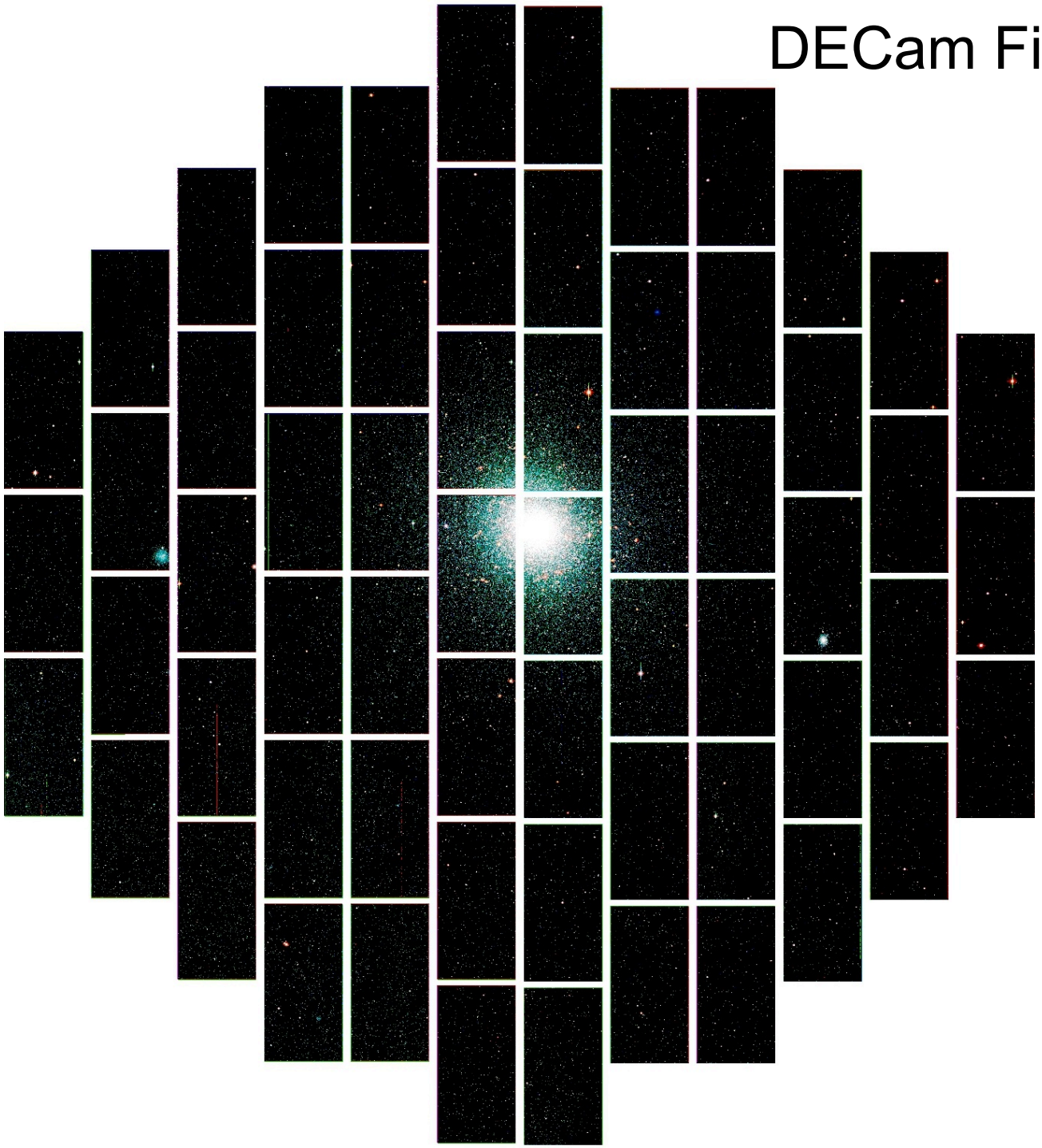
Combined DES DE Figure-of-Merit ~ 260

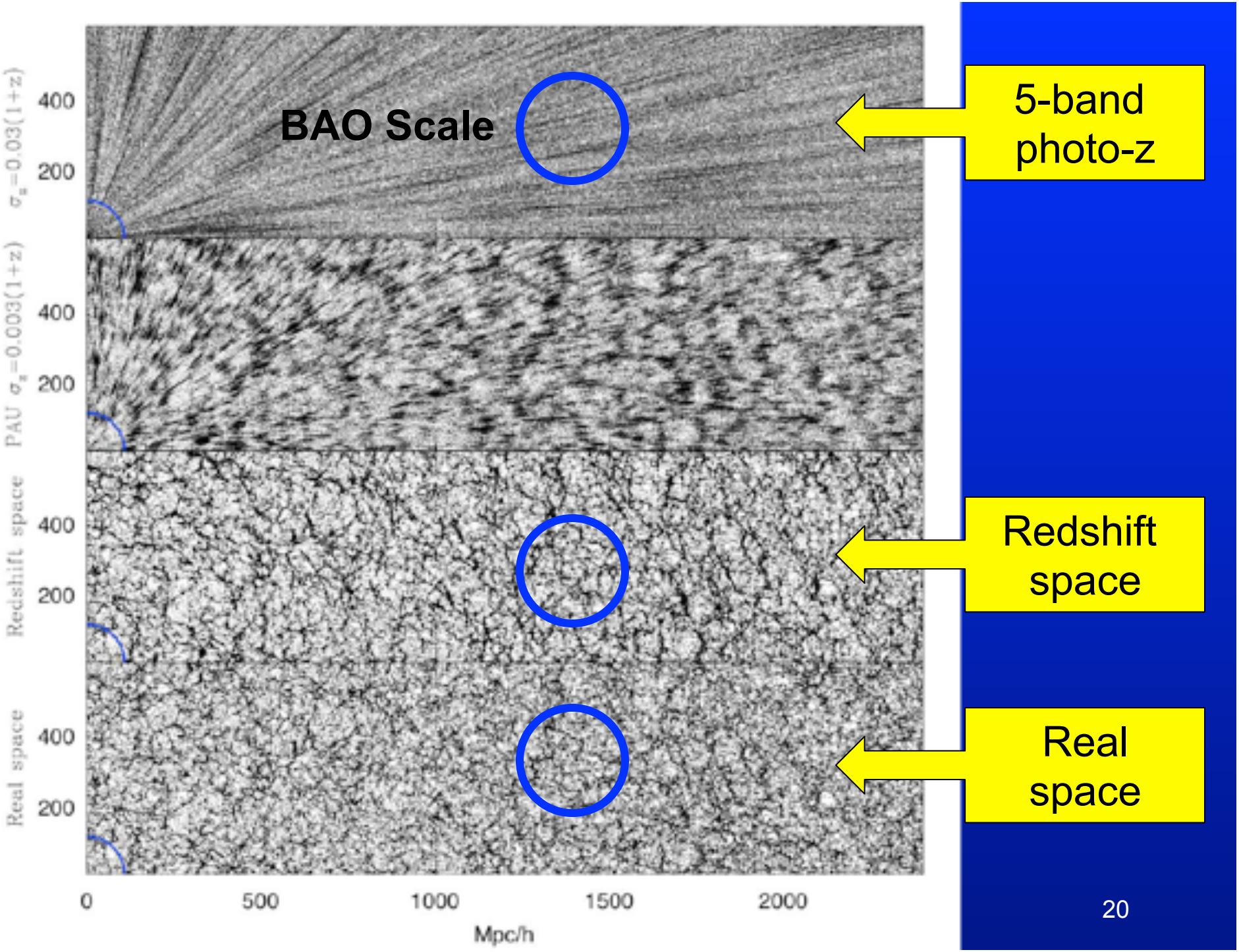
- Galaxy clusters
  - Circa 100 000 clusters to z = 1 and beyond
  - Synergy: South Pole Tele (SPT), VISTA Hemisphere Survey (VHS)
  - *Angular power spectrum → geometry*
  - *Mass function = N(z) vs. mass → structure*
- Weak lensing
  - Shape measurements of 300 million galaxies
  - *Line of sight mass distribution vs. redshift → geometry, structure*
- Baryon Acoustic Oscillations (BAO)
  - Circa 300 million galaxies to z = 1 and beyond
  - *Metric angular separation vs. redshift → geometry*
- Supernovae
  - 30 square degree time-domain survey
  - ~ 4000 well-sampled SNe Ia to z ~1
  - *Hubble diagram → geometry*



DECam First Light
Fornax galaxy cluster

2.2-degree
(diameter)

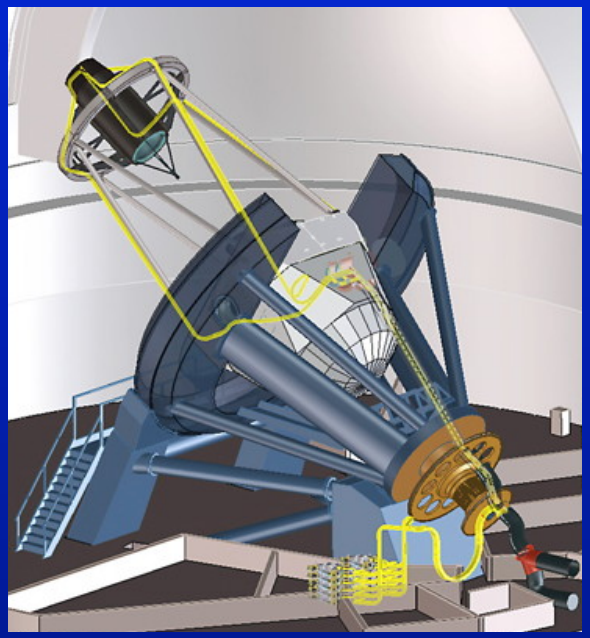

DECam First Light
47 Tuc


BAO Scale
5-band photo-z
Redshift space
Real space
Real space
Redshift space
PAU σ_z=0.003(1+z)
σ_z=0.03(1+z)
400
200
400
200
400
200
400
200
0
500
1000
1500
2000
Mpc/h

~ $90M project
70/20 DOE/NSF

BigBOSS
bigboss.lbl.gov

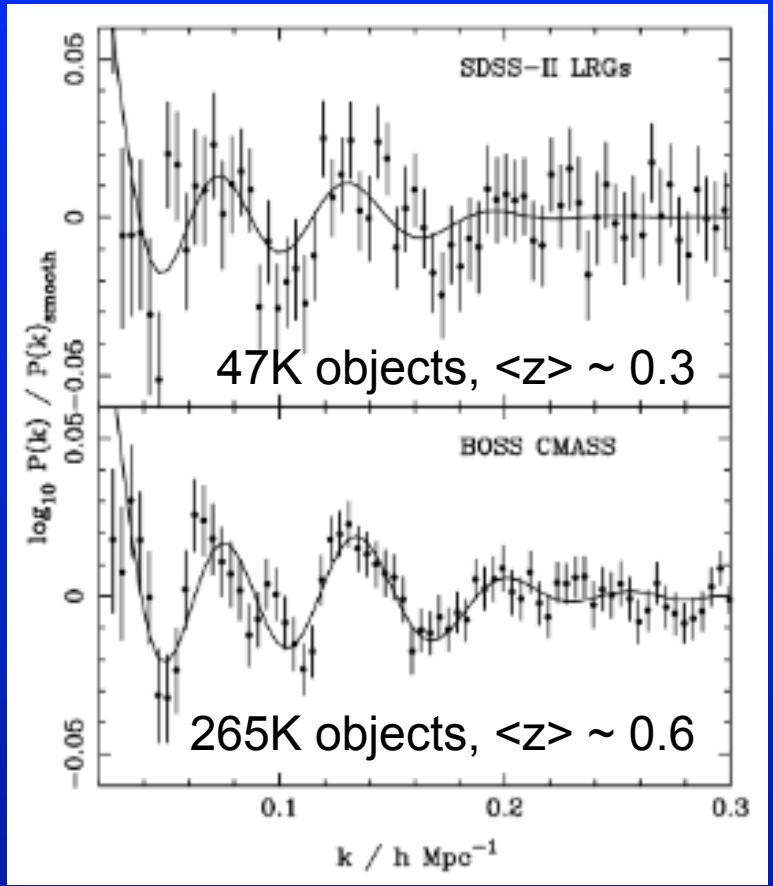
- Big Baryonic Oscillation Spectroscopic Survey
  - BOSS underway using Sloan 2.5-m telescope
  - Leader: DOE LBNL
  - Stage IV dark energy experiment
  - 14,000 sq deg spectroscopic survey
  - 20 million objects to redshift = 1.7
  - Survey plan: 2018 – 2022, 495 nights
- Instrument
  - 3-degree, 5000-fiber spectrometer
    - λ = 0.34 – 1.13 μm, *R* ~ 4000
- Status: under development



Combined BB DE Figure-of-Merit ~ 600

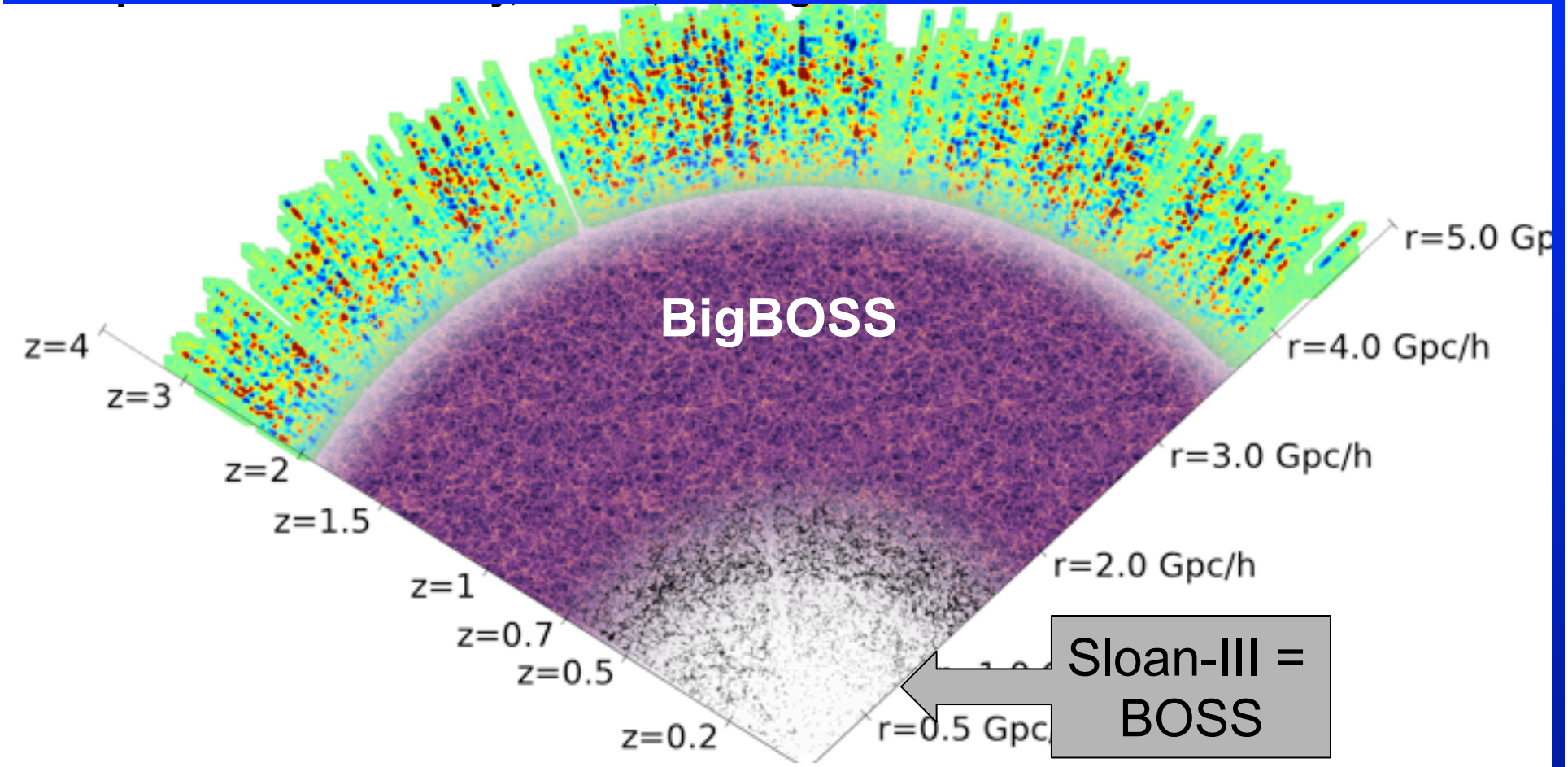
BigBOSS
Key measurements

- Baryonic Acoustic Oscillations (BAO)
  - *Sensitive to geometry vs. redshift*
  - Angular diameter distance
  - Line-of-sight (Hubble constant)
- Redshift space distortions (RSD)
  - *Gravitational growth vs. redshift*
  - Correction to BAO "smearing"
- Estimates of total neutrino mass



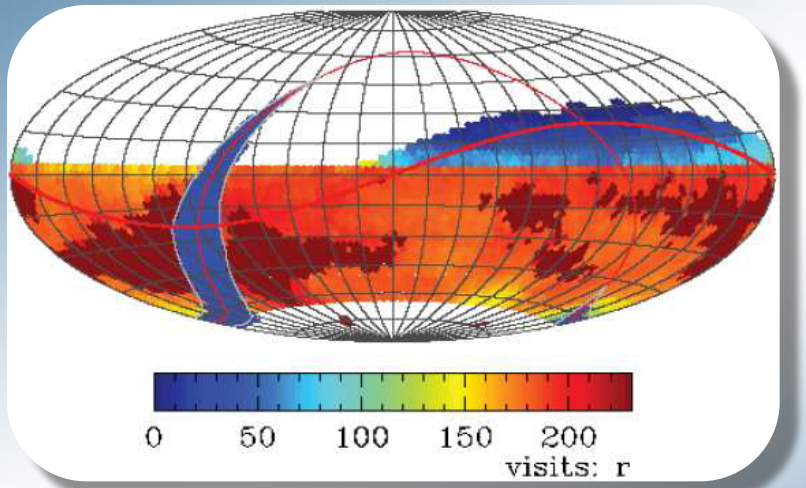
Anderson et al. 2012
BB ➔ 2000K objects, <z> ~ 1

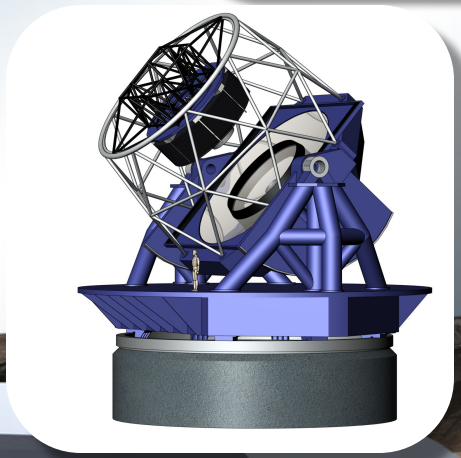
BigBOSS
Increased "grasp"



NOAO and Large Synoptic Survey Telescope

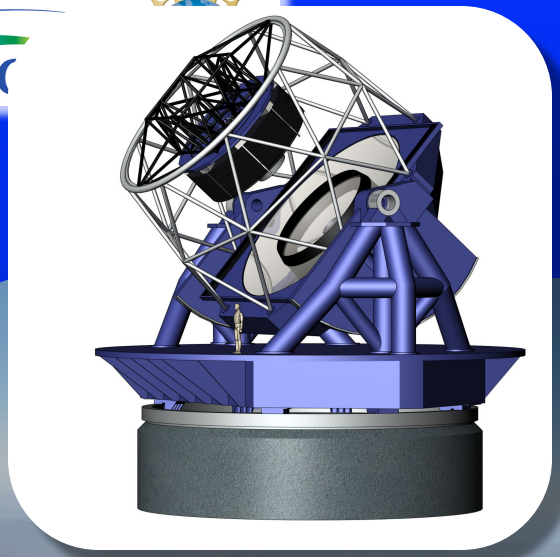
- Dark matter, dark energy
- Solar system census
- Time domain
- Galactic structure
- And more!





NOAO and LSST

NOAO deeply engaged in LSST



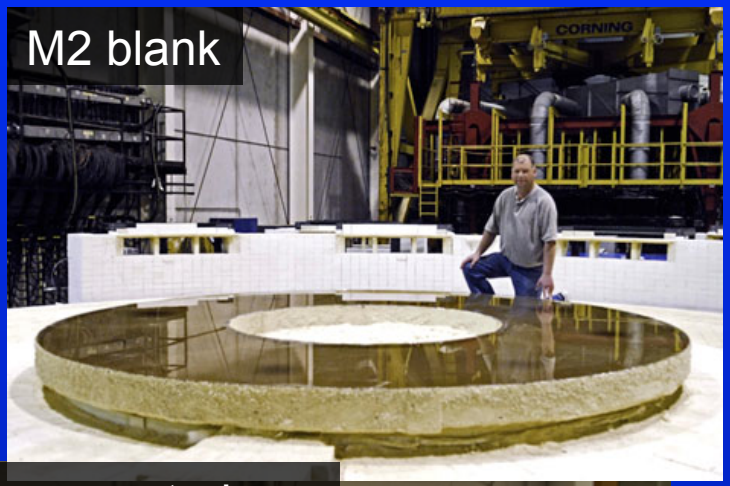
NOAO Lead Institution, Telescope/Site

- NOAO one of four Founding Partners
- LSST operations in Chile for collaboration (planned)
- NOAO / LSST Community Science Center (proposed)
- Current NOAO facilities needed for follow up research

NOAO and LSST
Actual progress

Site preparation in Chile

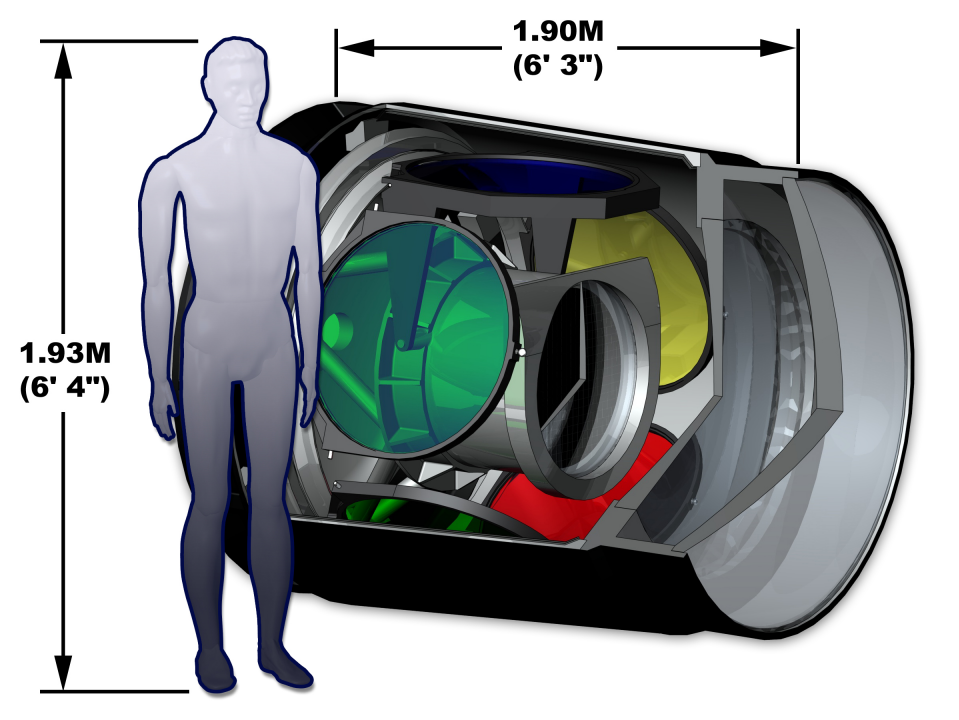
M2 blank



M1M3 being generated
at Steward Obs. Mirror Lab

LSST camera

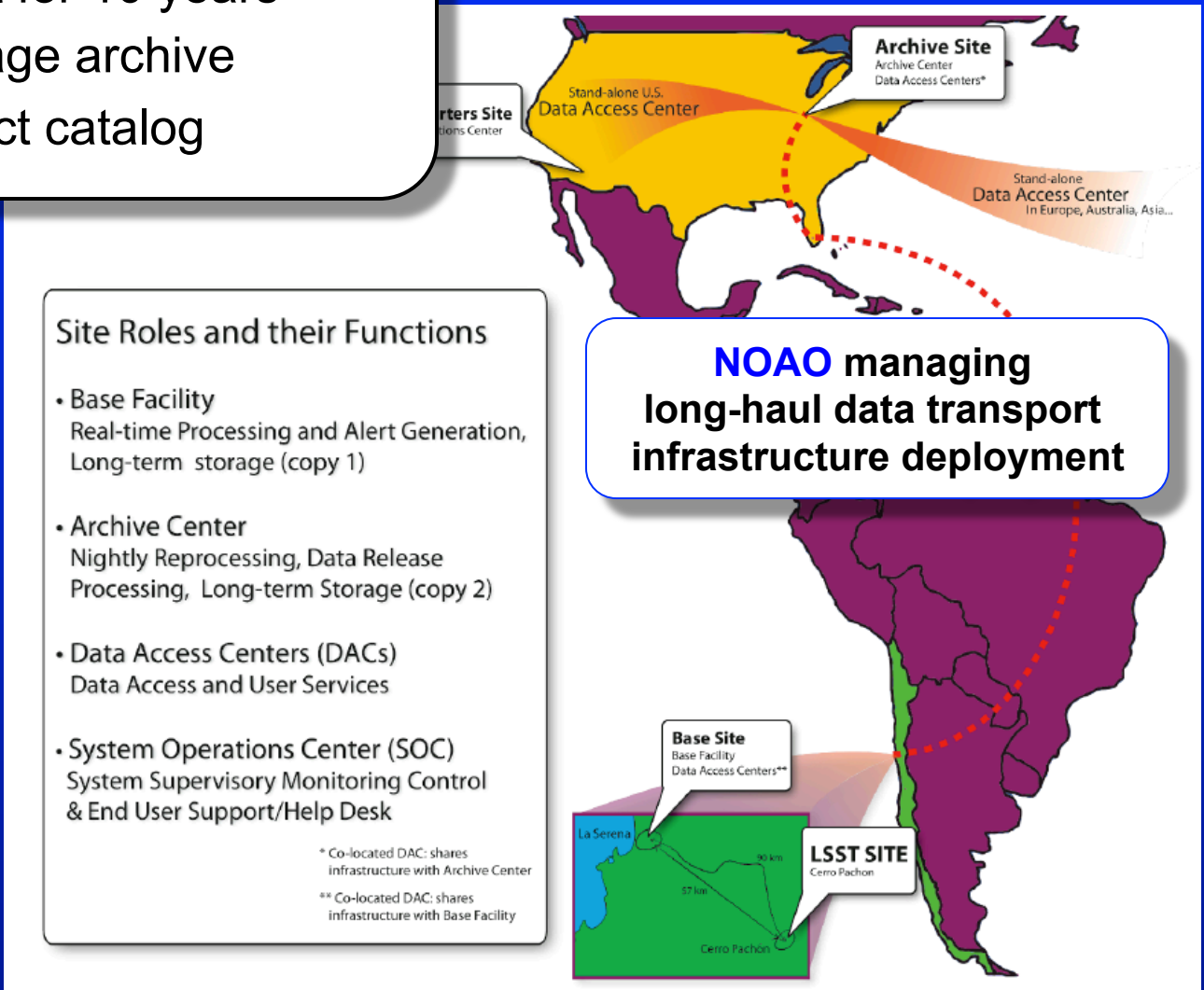
189 4096 x 4096 CCDs
3200 mega-pixels
9.6 deg^2 field-of-view
634 mm diameter (inscribed)



NATIONAL ACCELERATOR LABORATORY

LSST
Data management

- One 6-GB image every 17 seconds
- 30 TB every night for 10 years
- Final: 200 PB image archive
- Final: 20 PB object catalog



Summary

- NOAO Survey program has maintained high scence impact of our existing wide-field 4-m telescopes
- New, more powerful survey instruments will extent high science impact beyond 2020
- LSST era is coming!
- Massive spectroscopic surveys remain the frontier…

Backup slides

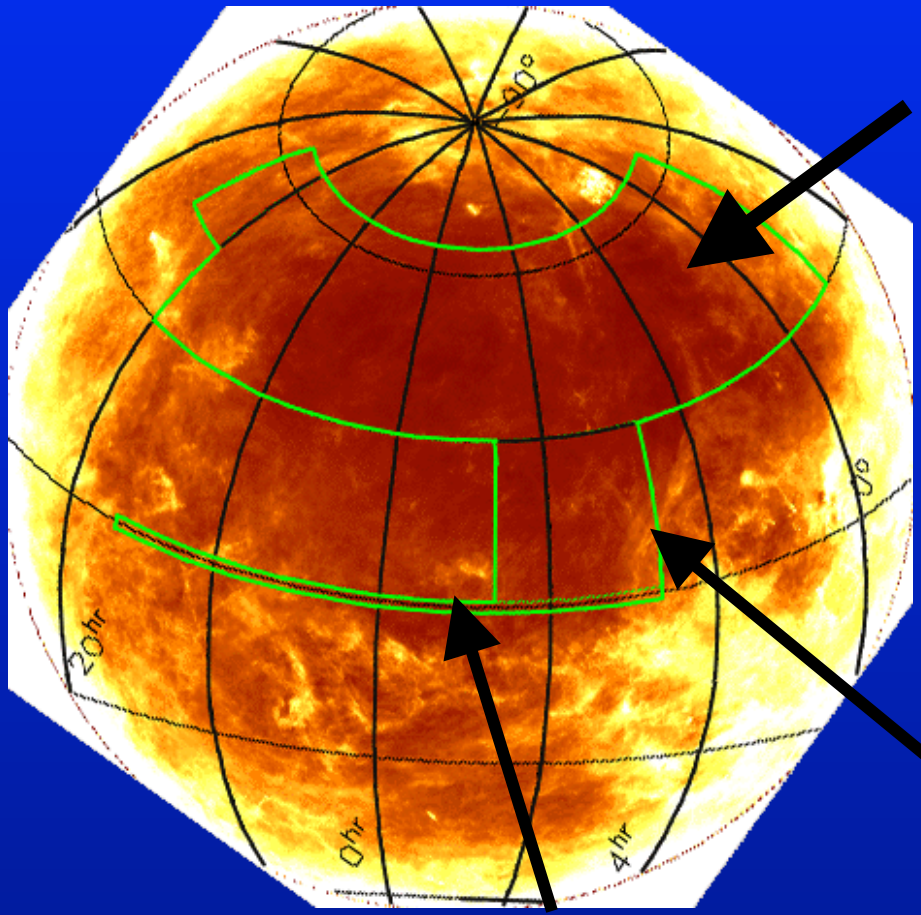
Dark Energy Survey Spectroscopic follow up

- Campaigns being planned with existing facilities but…
- Redshift survey of circa 5 – 10 million galaxies over ~5000 sq deg could be done with 4-m class wide-field telescope(s)
- Such a massive survey would provide…
  - Improved photo-z calibration
  - Cluster velocity dispersions (dynamical mass estimates)
  - BAO measurements: *H(z)*
  - Redshift Space Distortion (RSD) measurements: *δ(z)*
    - RSD + DES WL = powerful test of gravity
- Concepts emerging…
  - 4MOST @ VISTA (see de Jong talk)
  - DESpec @ Blanco (see http://arxiv.org/abs/1209.2451)

DES Survey Area

Builds on previous NSF funded surveys

Sloan Digital Sky Survey, South Pole Telescope



Overlap with NSF South Pole Telescope Survey (4000 sq deg)

Connector region (800 sq deg)

Overlap with Sloan Digital Sky Survey equatorial Stripe 82 (200 sq deg)

LSST
Data products

Application Layer -
Generates open, accessible data products with fully documented quality

Processing Cadence	Image Category (files)	Catalog Category (database)	Alert Category (database)
Nightly	Raw science image Calibrated science image Subtracted science image Noise image Sky image Data quality analysis	Source catalog (from difference images) Object catalog (from difference images) Orbit catalog Data quality analysis	Transient alert Moving object alert Data quality analysis
Data Release (Annual)	Stacked science image Template image Calibration image RGB JPEG Images Data quality analysis	Source catalog (from calibrated science images) Object catalog (optimally measured properties) Data quality analysis	Alert statistics & summaries Data quality analysis

NOAO and LSST
Telescope/Site