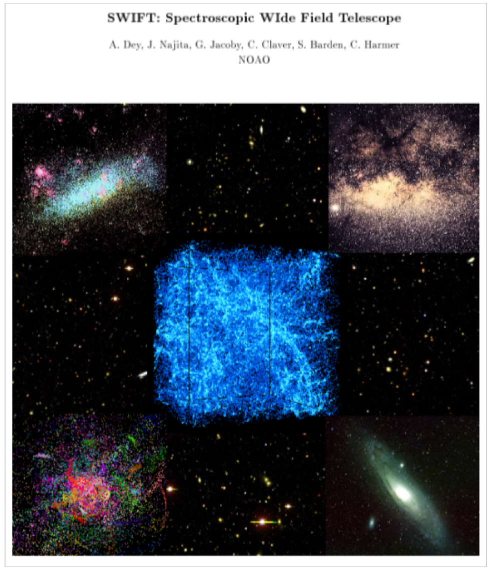
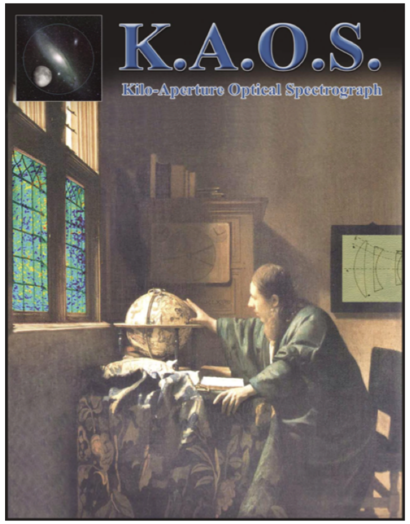
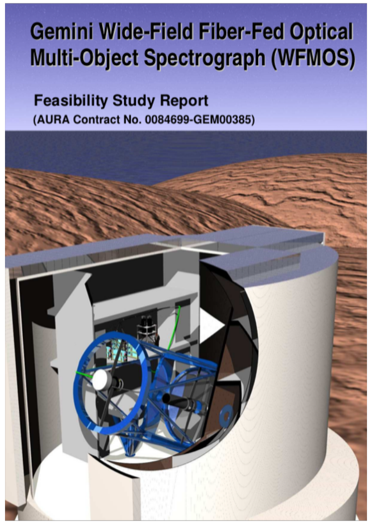
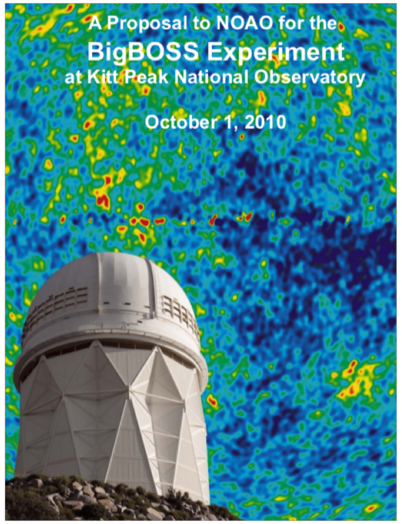








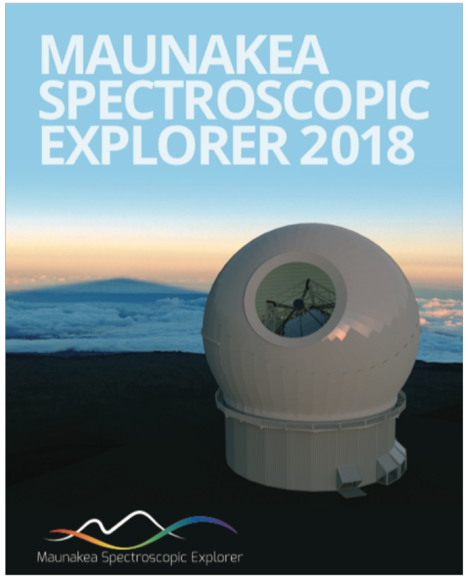
1998

2019

Path to MSE*

Arjun Dey

NOAO AURA NSF



*my version

Outline

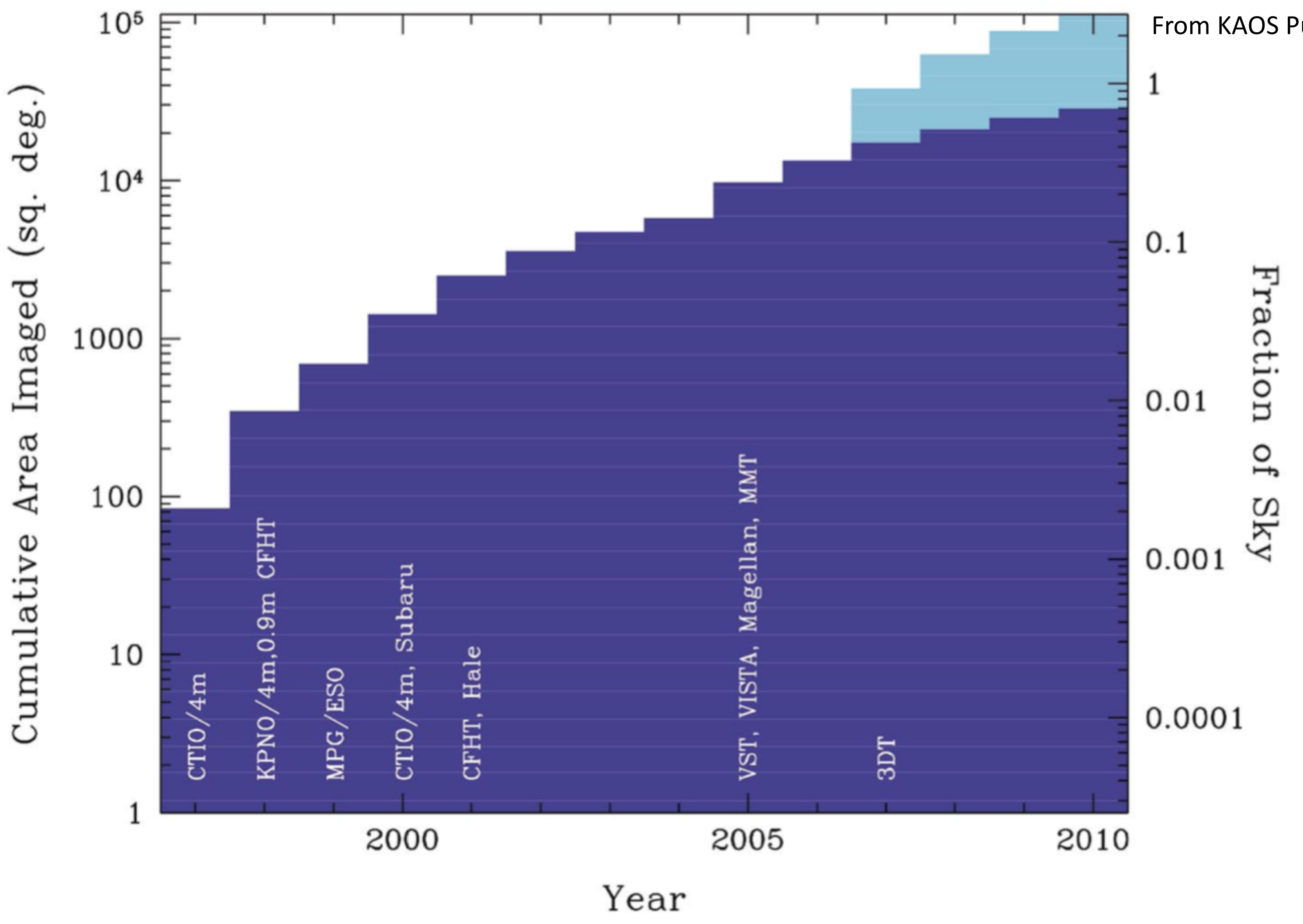
- Some ancient history – and how we got here
- Current landscape for MSE
- Unsolicited advice on how to proceed

MSE: A Highly Multiplexed Wide-Field Spectroscopic Facility

- An old idea whose time is now:
  - Pioneering spectroscopic surveys by CfA, 2dF, SDSS I-IV
  - Spectroscopic Wide-Field Telescope (SWiFT)
  - Kilo-Aperture Optical Spectrograph (KAOS)
  - Gemini Wide-Field Multi-Object Spectrograph (GWFMOS) => Subaru/PFS
  - BigBOSS => DESI

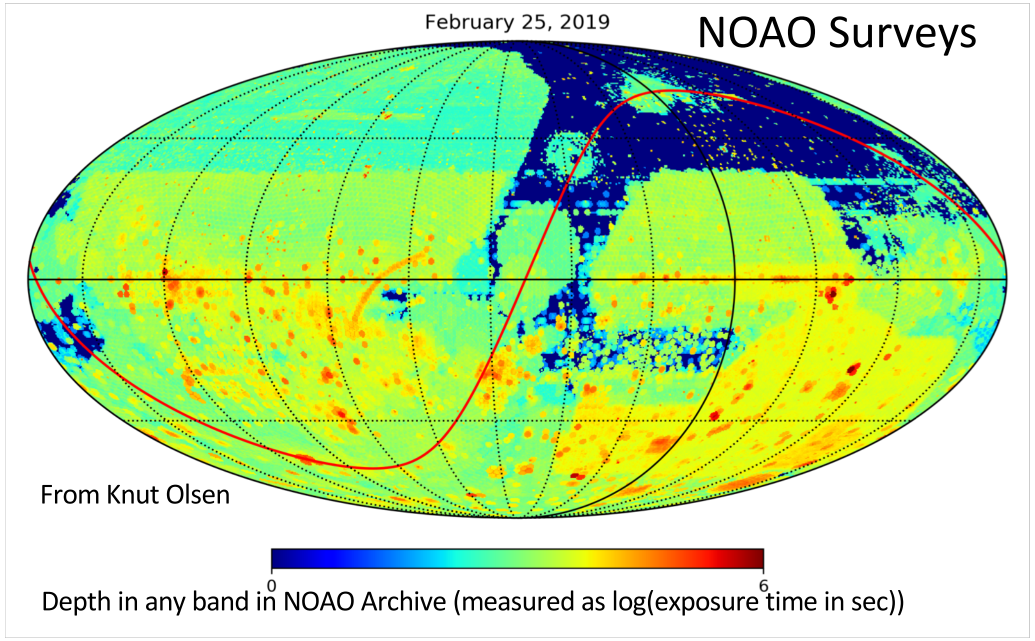
- Won't discuss LAMOST, 4MOST, SDSS-V, BEAST, etc.

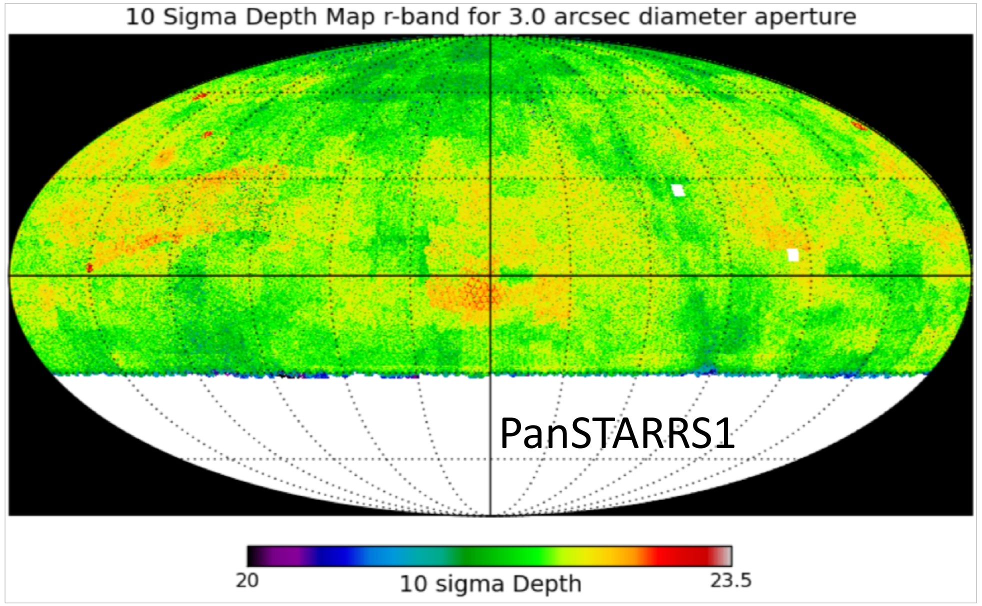
The growth of imaging surveys on >4m telescopes (as imagined 16 years ago):



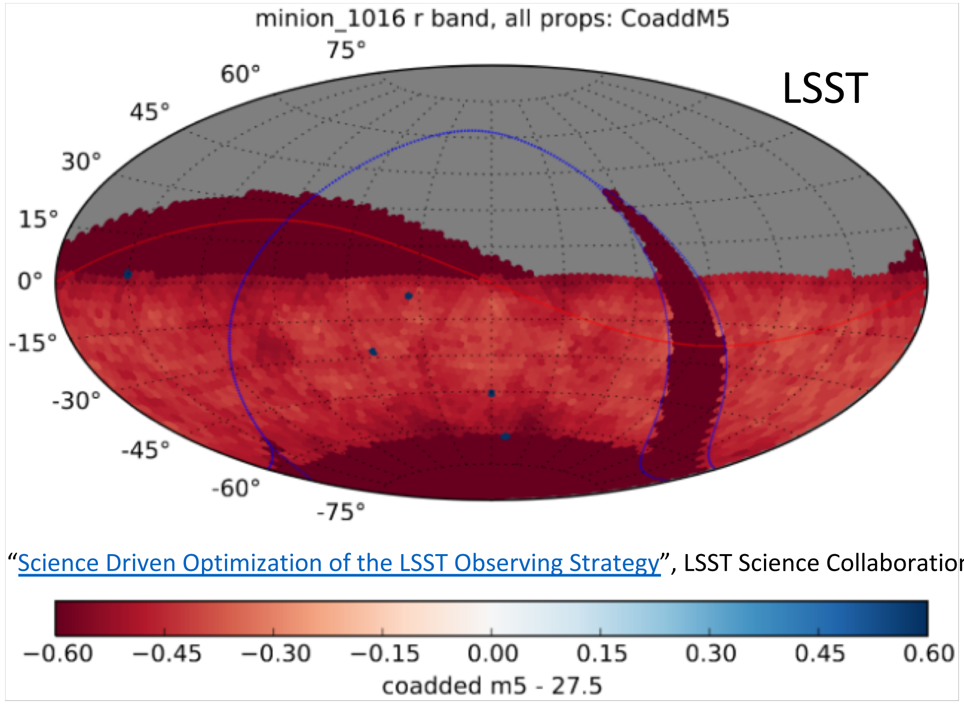
From KAOS Purple Book, 2003

Where we are now





From "PanSTARRS1: Panoramic Survey Telescope and Rapid Response System", N. Metcalfe, 2015



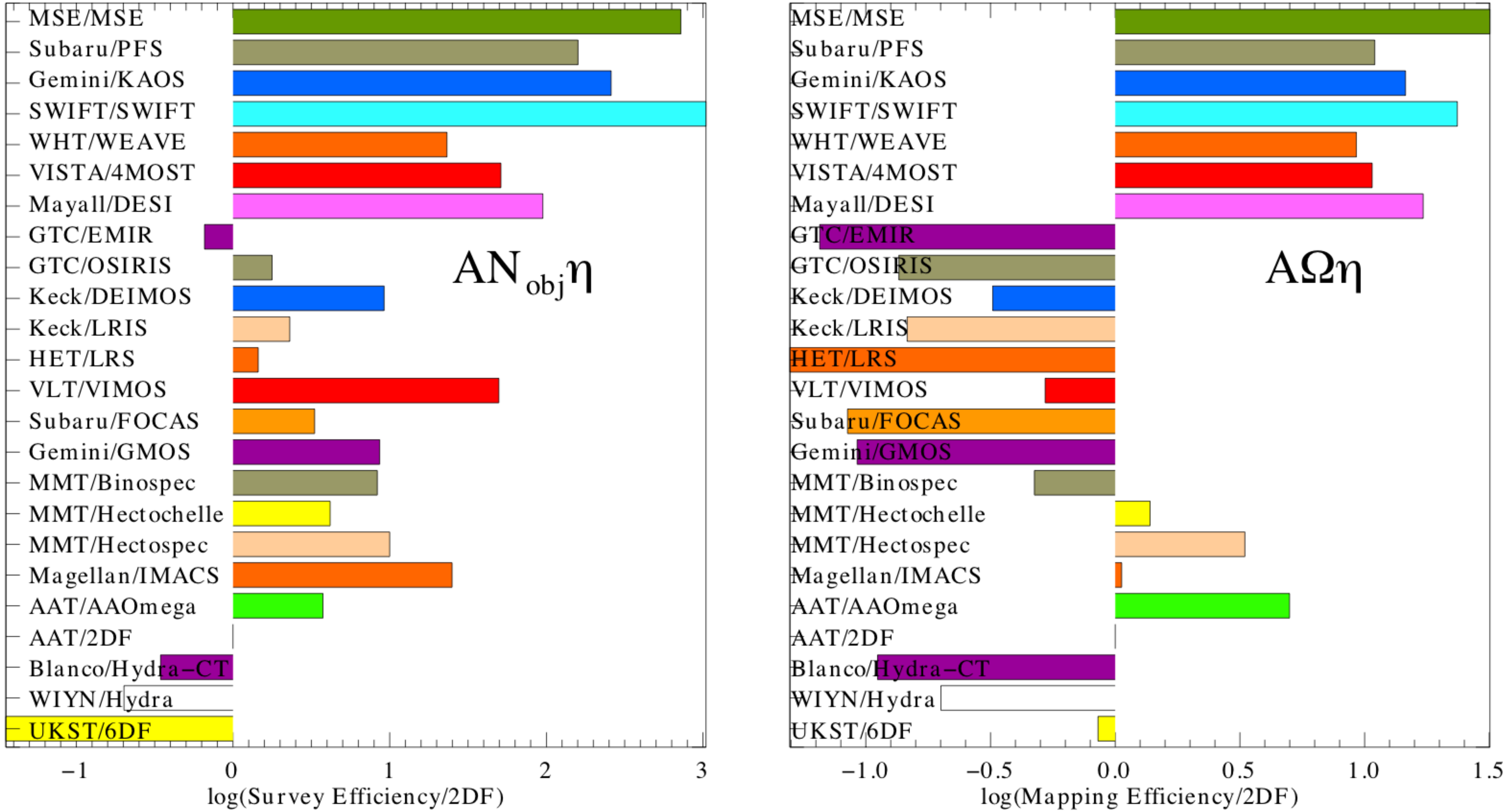
From "Science Driven Optimization of the LSST Observing Strategy", LSST Science Collaboration 2017

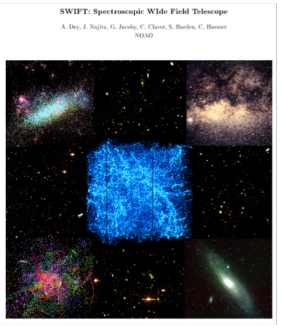
We have ***already completed*** imaging of the entire sky to the spectroscopic depths attainable on 10m class telescopes.

Imaging delivers targets and shapes - spectroscopy delivers understanding and physics

Time to start doing astrophysics …

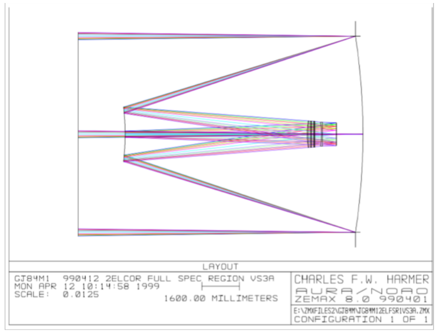
What do we need to map the sky?

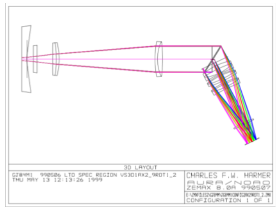




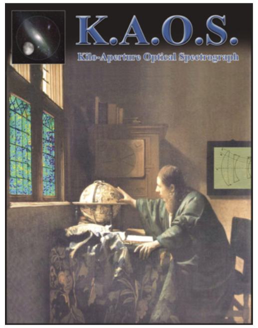
Spectroscopic Wide-Field Telescope 1998/9

- Motivated by remarkable growth of imaging camera real estate and efficiency in the '80s and '90s
- Key science cases:
  - Growth of large-scale structure
  - Formation and evolution of galaxies
  - Formation of the Milky Way and its neighbors

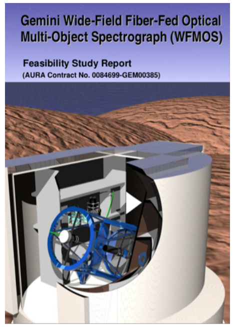




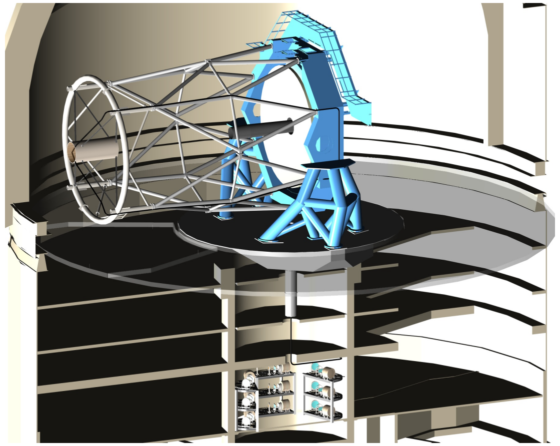
- Designed as 8m class stand-alone dedicated facility for spectroscopy – a single instrument with 8m "front optic"
- Beam-fed spectrograph with 1.5 deg diameter field, slitlets, VPH gratings, R=500/5000/10000
- Estimated WAG cost $109M



KAOS to GWFMOS (to PFS) 2001-2009



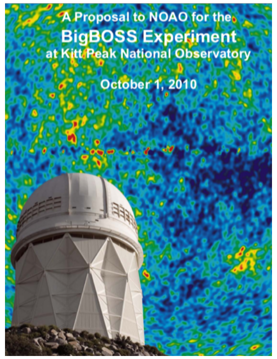
- 2001 – Tucson meeting on "Next Generation Wide-Field Multi-Object Spectroscopy"
  - D. Eisenstein discusses the BAO survey concept
  - J. Huchra and others think that there is no case for a dedicated 8-m class SWIFT
  - Don't build a new telescope, coopt an old one



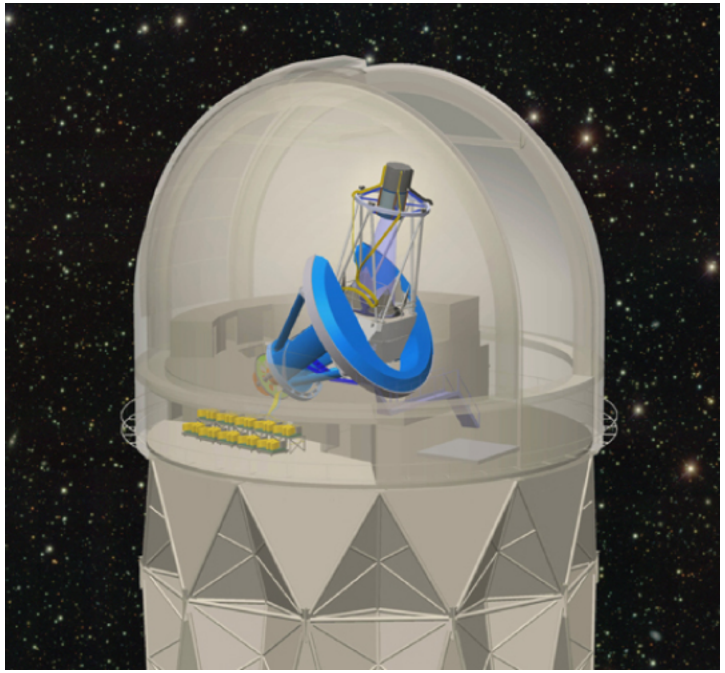
- 2001-2003 - KAOS on Gemini (see "Purple Book")

  Science cases:
  - Dark energy BAO survey
  - Galaxy genesis (Milky Way and M31 structure and formation)
  - Other science (galaxy evolution, star clusters, etc.)

  Design:
  - 1.5 deg diameter field of view, 4000-5000 fibers, R=1000/40000, VPH gratings, etc
- June 2003 – Gemini Instrumentation Workshop in Aspen, resulted in starting a "feasibility study" for a "wide-field fiber fed optical multi-object spectrometer"
- 2005 - GWFMOS Feasibility Study complete; Call goes out for a Conceptual Design Study, two groups selected. Changed in mid-course to design for Subaru behind HSC corrector.
- 2009 - Caltech/JPL team selected, project dissolved. PFS begins from this point, starting from the GWFMOS/Subaru concept.



BigBOSS -> DESI 2009-2019



- Lesson learned: use your own telescope!
- March 6, 2009 – LBNL+NOAO embark on BigBOSS
- Science case: (see Schlegel et al. 2009, 2011)
  - Cosmology survey: BAO (galaxies+Lya forest), RSD, Σm_ν
  - Other science (shared with public access through NOAO)
- Mayall telescope, 3 deg diameter field of view, 5000 fibers, R=3000-4100, and fast operations; telescope structure and optics designed for wide-field
- Similar plan for Blanco ("DECSpec") led by FNAL; Myriad physics & astronomy reviews (DoE/NSF/etc.) => DESI
- March 2019 – First light with DESI Commissioning Instrument (camera)
- September 2019 – DESI instrument commissioning begins
- 2020-2025 – DESI surveys

Main Take-Aways

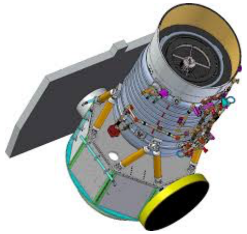
- Long history (20+ years) of significant effort to develop science case and technical capabilities
- Still no *dedicated* spectroscopic survey facility currently functioning - DESI will be the first
- Science case has evolved some, but not that much:
  - Cosmology: dark energy equation of state and variation with redshift
  - Galactic structure and the origin of the Milky Way
  - Galaxy evolution over cosmic time

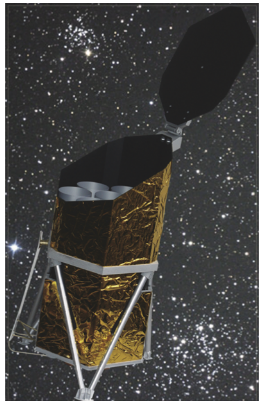
i.e., the scientific need remains!

- Took 10 years to build with an existing telescope
- What has changed?

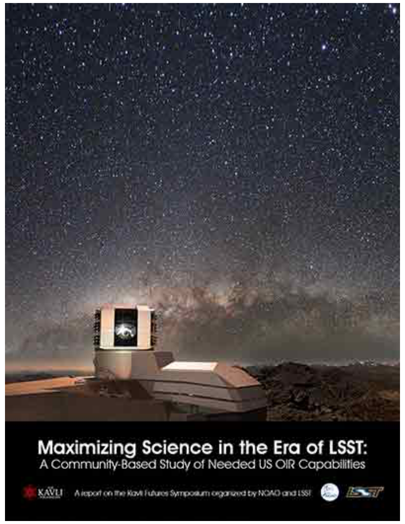
New opportunities

- Gaia astrometry and proper motions
- All-sky* maps at X-ray, UV, optical, near-IR, radio
- LSST imaging is in sight
- High-resolution on large scales will remain untapped





LSST Spectroscopic Needs: Requirements

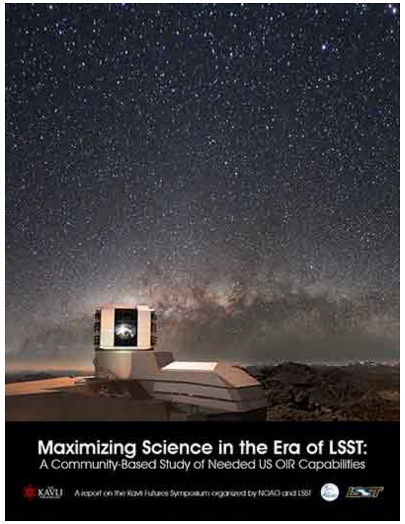


Najita et al. 2016 "[Maximizing Science in the Era of LSST]"

Capability	Telescope Aperture			
	< 3m	3–5m	8–10m	$\gtrsim$25m
Optical Imager (Wide-field)	Solar System **Stars** Transients *Dark Energy*	**Solar System** **Stars** Milky Way Transients *Dark Energy*	**Solar System** **Stars** Transients Galaxy Evolution	Transients *Solar System*
NIR Imager		Transients	Transients *Milky Way*	Transients
AO IFU R ~ 5000			**Galaxy Evolution** Dark Energy	**Galaxy Evolution** Dark Energy
OIR MOS R = 5000 0.35–1.3 micron		**Stars** **Galaxy Evolution** **Dark Energy**	**Stars** **Milky Way** **Galaxy Evolution** **Dark Energy**	**Galaxy Evolution** Dark Energy *Milky Way*
Optical SOS R = 1k–5k 0.35–2.5 micron	Stars	**Solar System** Stars Transients	**Solar System** **Transients** **Galaxy Evolution** Stars *Milky Way* *Dark Energy*	**Transients** Solar System
Optical SOS R > 20,000			Stars *Transients* *Galaxy Evolution*	Stars *Transients* *Galaxy Evolution*
OIR MOS R > 20,000			**Milky Way** **Stars**	**Stars** *Milky Way*

MSE scope

LSST Spectroscopic Needs: Illustrative Demand



Najita et al. 2016 "[Maximizing Science in the Era of LSST](#)"

Capability	Telescope Aperture 3–5 m	8–10 m	> 25 m
Optical Imager (Wide-field)	**~2.5 yrs with Blanco/DECam** for Solar System science case **~ 3 yrs** for Stars science case		
AO IFU R ~ 5000		**~ 1.3 yrs with Gemini/NIFS** for Galaxy Evolution science case	**~ 1.3 yrs with TMT/IRIS** for Galaxy Evolution science case
OIR MOS R = 5000 0.35–1.3 micron		**~ 8 yrs with Subaru/PFS** equivalent for Milky Way, Galaxy Evolution, Dark Energy science cases	**~ 0.7 yrs with TMT/WFOS** for Galaxy Evolution science case
Optical SOS R = 1k–5k 0.35–2.5 micron		**~ 3.5 yrs** for Transients science case **~ 0.4 yrs** for Galaxy Evolution science case	
OIR MOS R > 20,000		**~10 fiber-yrs** for Milky Way science case **~ 550 fiber-yrs** for Stars science case	

MSE scope

New challenges

- Competition has increased:
  - SDSS-V on 2.5m
  - LAMOST, DESI, 4MOST, WEAVE on ~4m
  - PFS on 8m
- Multi-λ imaging has increased, so need continues, but …
- What are the key science cases for the next stage?
  - Galactic structure
  - Cosmology/LSS at z>3 over large areas
  - Spectroscopy for LSST
- There will not be a lack of things to observe, but beware the industrialization of astronomy
  - key science projects will make big gains
  - … but hopefully will greatly impact the "non-key" fields of astrophysics
  - enable / allow small projects (since innovation comes from small groups)
  - share data (since innovation comes from small groups)

Moving forward

- Reiterate the case to Astro2020 highlighting the science impact: they will be focused on the ELTs
- Emphasize cost effectiveness of the science:
  - Cheaper hardware (perhaps?)
  - Cost-effective operations because of limited observing modes
  - relatively easy to archive and pipeline process uniform datasets (compared to multi-purpose observatories)
- Important to understand the landscape - how will the main science cases change with the existence of SDSS-V, DESI and PFS data?
- Important to articulate why new facility is needed (as opposed to just continuing to fund existing capabilities). What is revolutionary about MSE?
  - Power of MSE is in its AΩ + *dedicated* nature - “all-sky” surveys at unprecedented speed.
  - MSE is unique in high-resolution capability at ~10m. How critical is this?
- Allow small-group, small-proposal access – need innovative, disruptive science!
- What about making all the data public immediately?

NOAO as a partner

- Long history of pioneering survey operations and support for survey science
- NOAO’s 4m telescopes are moving toward high-impact instruments dedicated to long-term projects + ease of operation
- Data systems development has focused on providing services for science with big data
  - Datalab
  - Antares
- Coming soon: NCOA = LSST+Gemini+NOAO
  - Can plan strategically across all platforms to support community desires

DESI
Coming soon …

desi.lbl.gov
legacysurvey.org