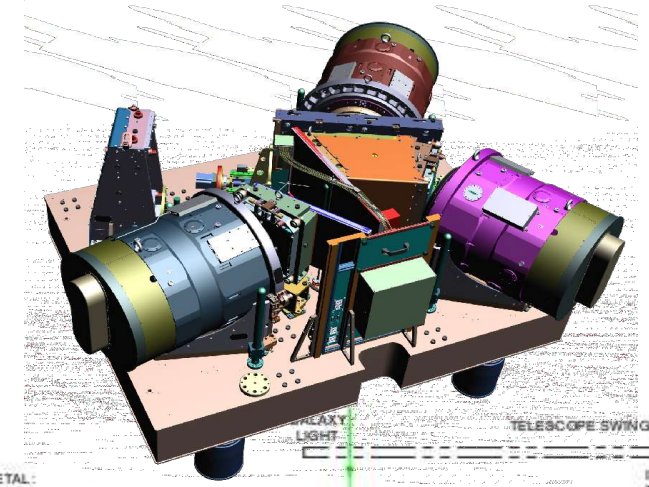
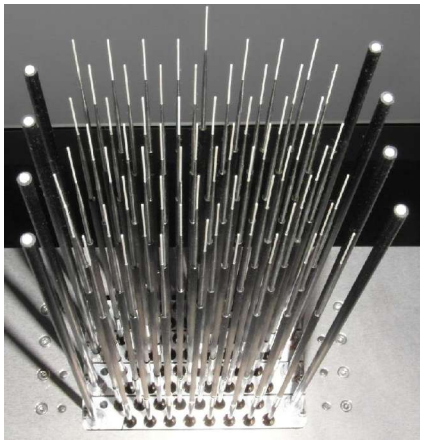
Future Spectroscopic Instruments and Surveys

Stephen Kent, Fermilab Sept. 26, 2016





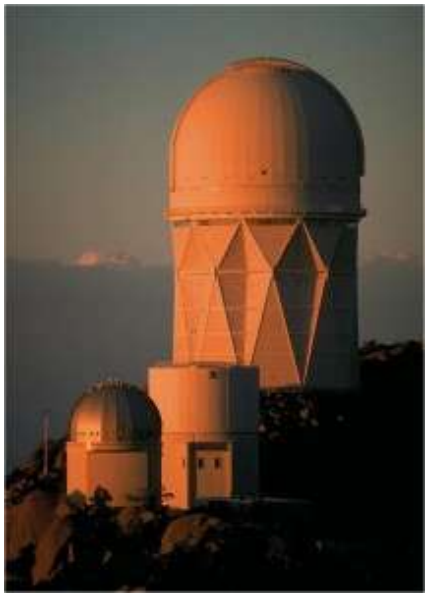
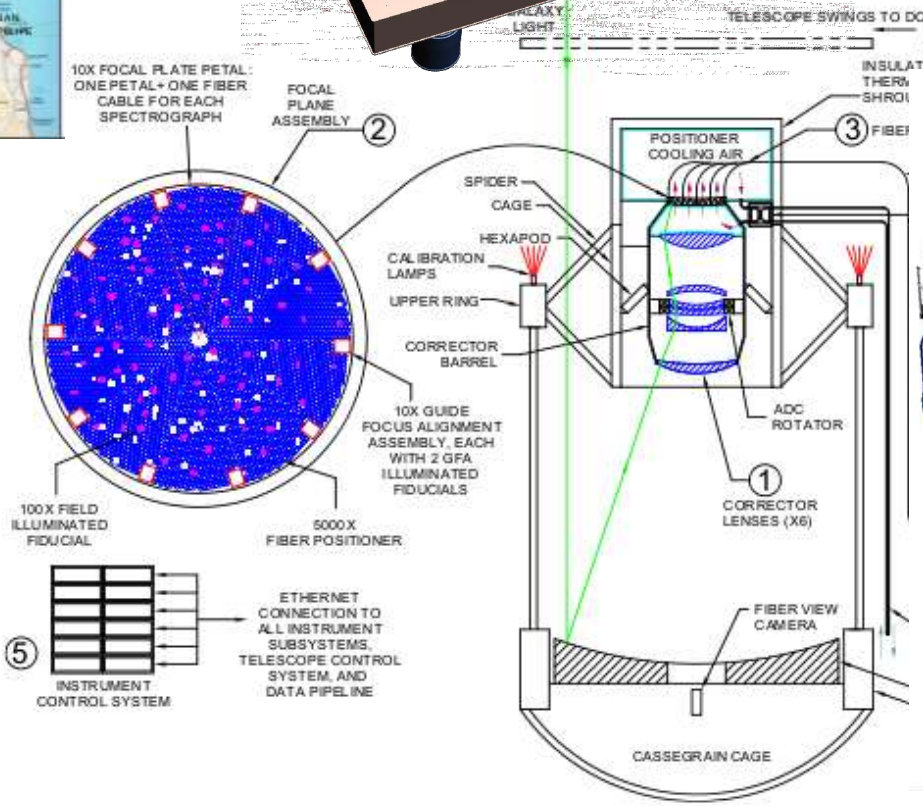
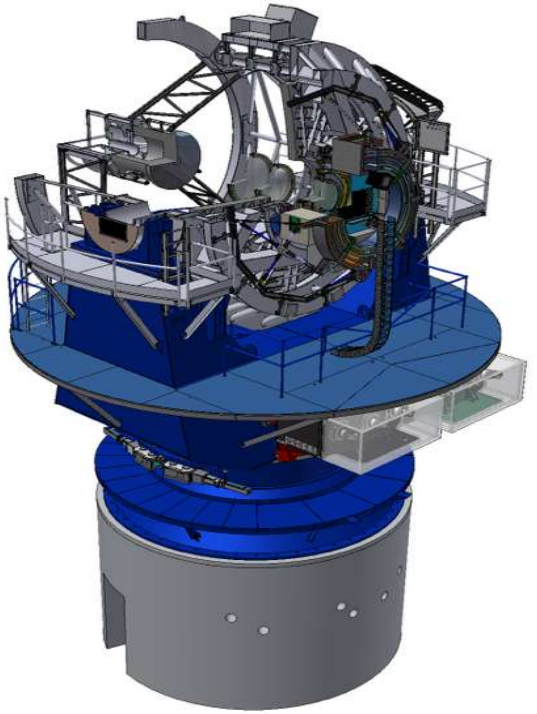


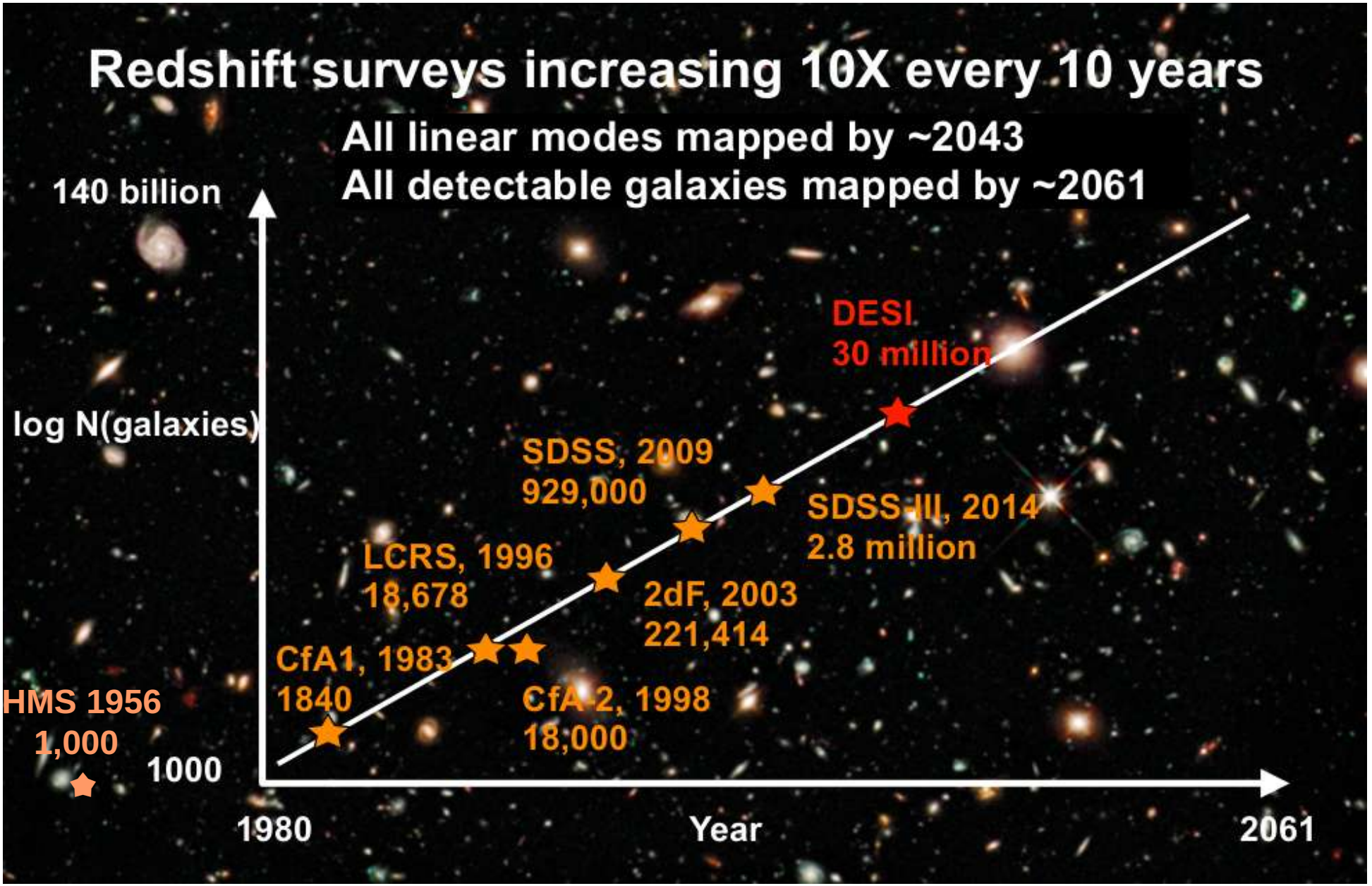
Figure 1.2: DESI block diagram.





Recent Workshops

- **Southern Survey Spectroscpic Initiative**
  - **Aug 22-23, 2016**
  - **Argonne National Lab**
- **Future Cosmic Surveys**
  - **Sep 21-23, 2016**
  - **U. of Chicago**
- **Steering documents**
  - **Cosmic Visions Dark Energy: Science**
  - **NAS Elmegreen Report (LSST followup)**
  - **NOAO/Kavli study (LSST followup)**

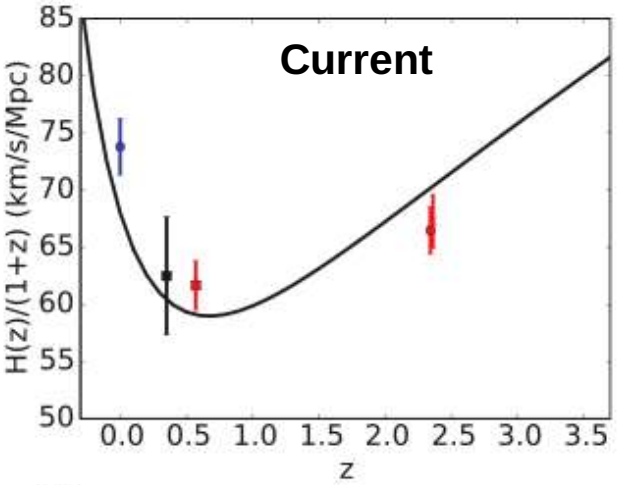

Redshift surveys increasing 10X every 10 years
All linear modes mapped by ~2043
All detectable galaxies mapped by ~2061
140 billion
log N(galaxies)
1000
DESI
30 million
SDSS, 2009
929,000
SDSS-III, 2014
2.8 million
LCRS, 1996
18,678
2dF, 2003
221,414
CfA1, 1983
1840
CfA 2, 1998
18,000
HMS 1956
1,000
1980
Year
2061

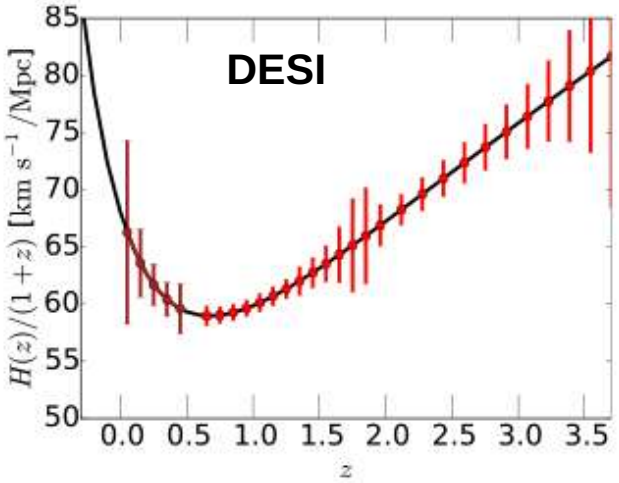
(D. Schlegel)

Science Drivers for Next Generation Surveys

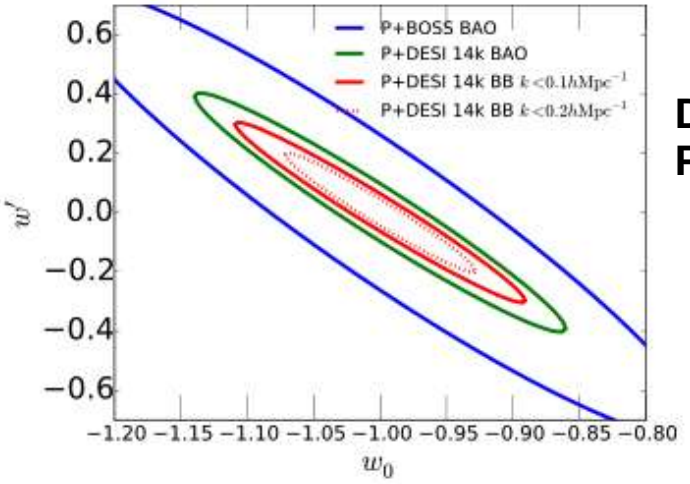
- **Dark Energy, Modified Gravity**
  - **Baryon Acoustic Oscillation**
  - **Redshift Space Distortion**
- **Neutrinos**
  - **Sum of masses**
  - **Number of species**
- **Acillary science**
  - **Photo-Z calibration**
  - **Galaxy cluster velocity data**
  - **Supernovae, MW science, dwarf galaxies**

Baryon Acoustic Oscillations

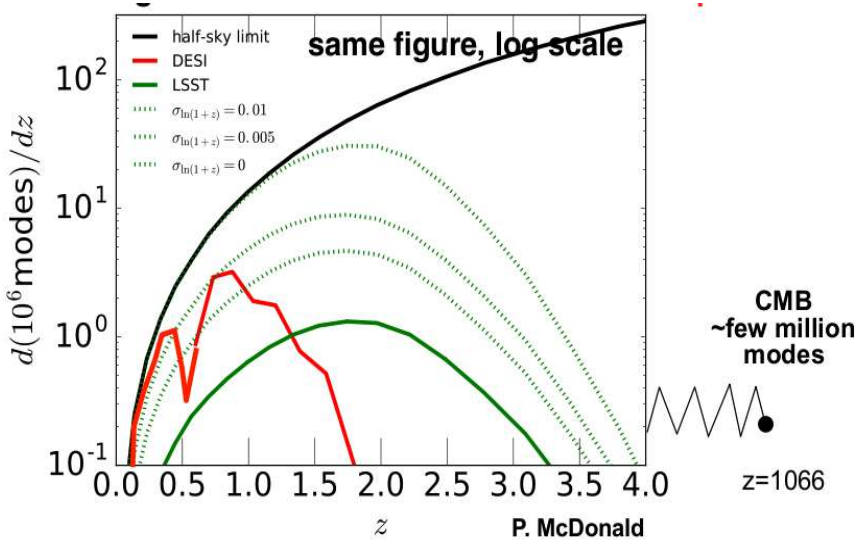




BAO angular scale v. redshift



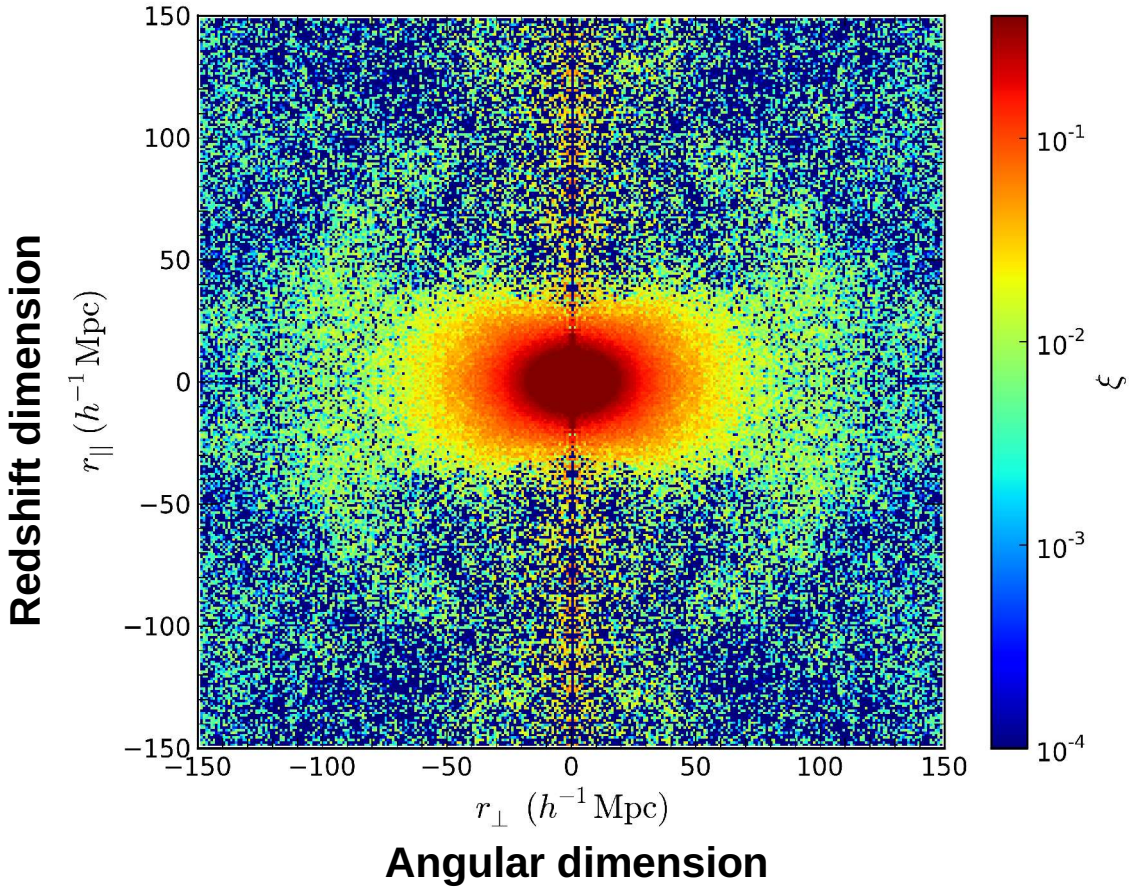
DETF Figure of Merit



Potential reach of future spectroscopic surveys

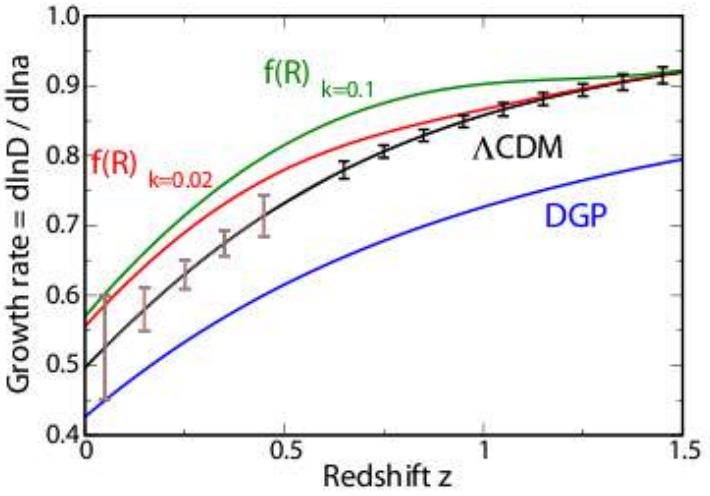
Redshift Space Distortions

3-dimensional correlation function



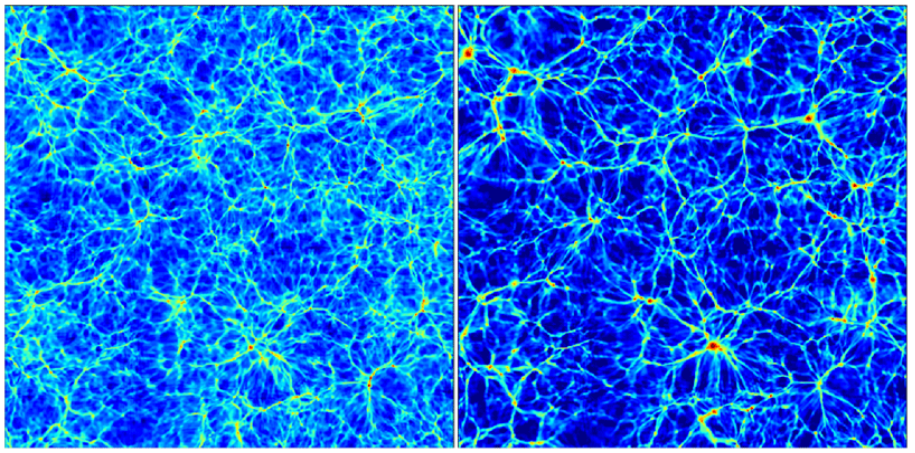
Angular dimension

Anisotropy depends on growth rate of structure



Growth rate due to modified gravity

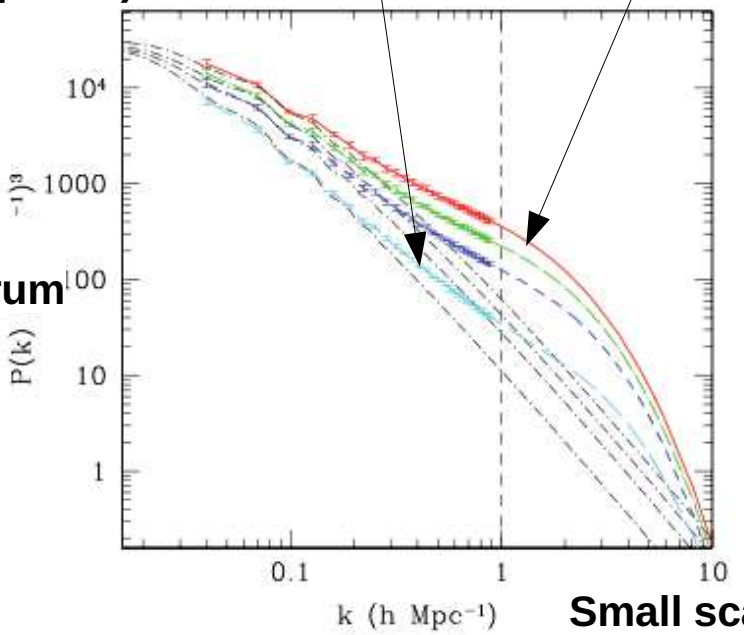
Neutrino Masses and Number



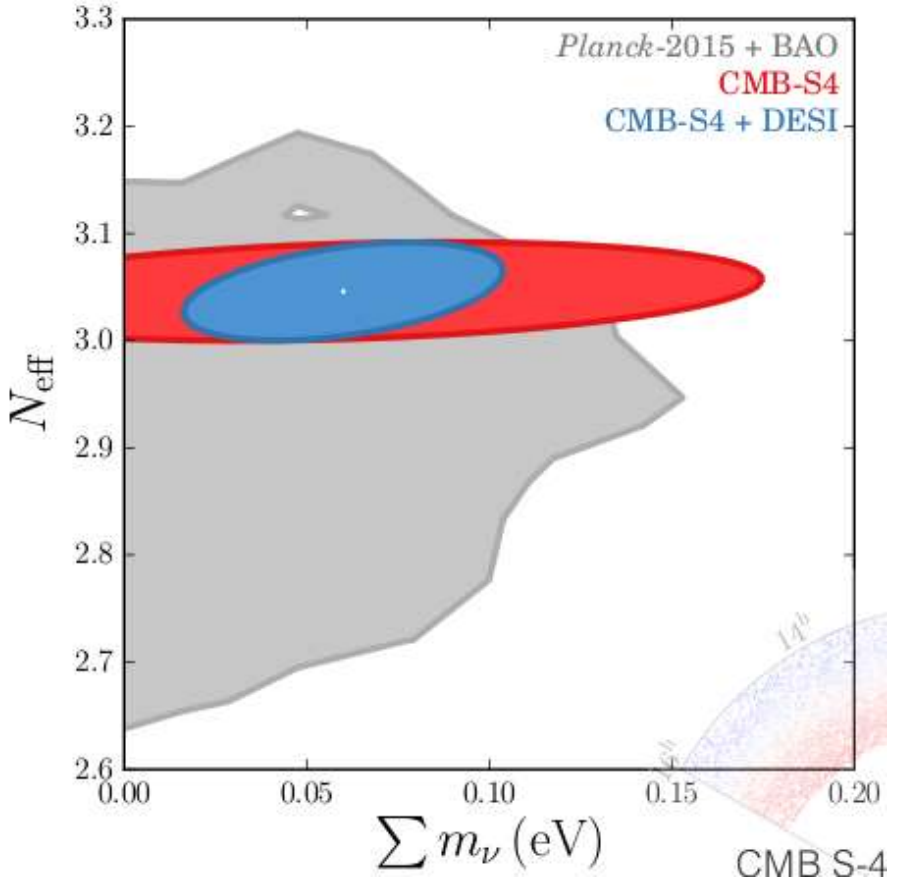
With massive neutrinos (suppress small scale power)

No neutrinos

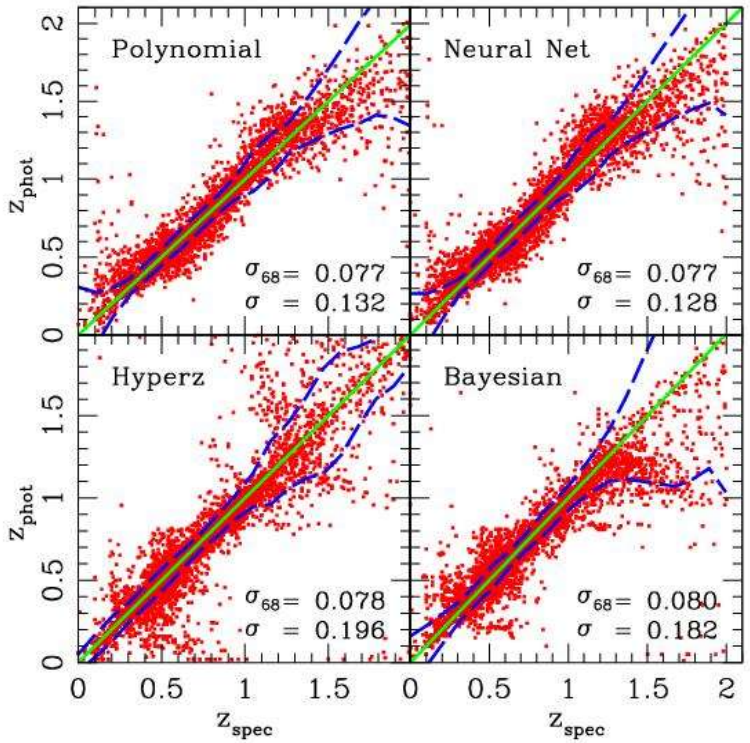
Power Spectrum



Small scales

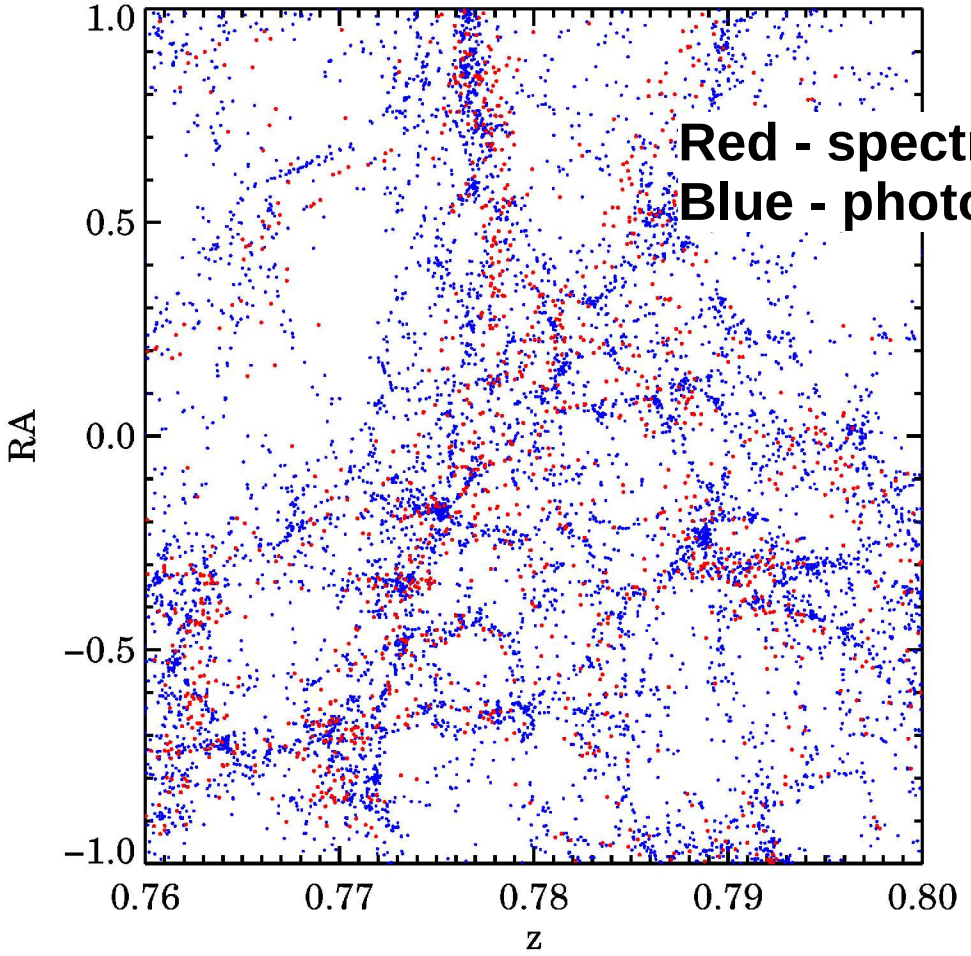


Photometric Redshift Calibration (for LSST)



Multi-color imaging survey - low re spectra and redshifts

Require ~30,000 spectroscopic redshifts for "training"

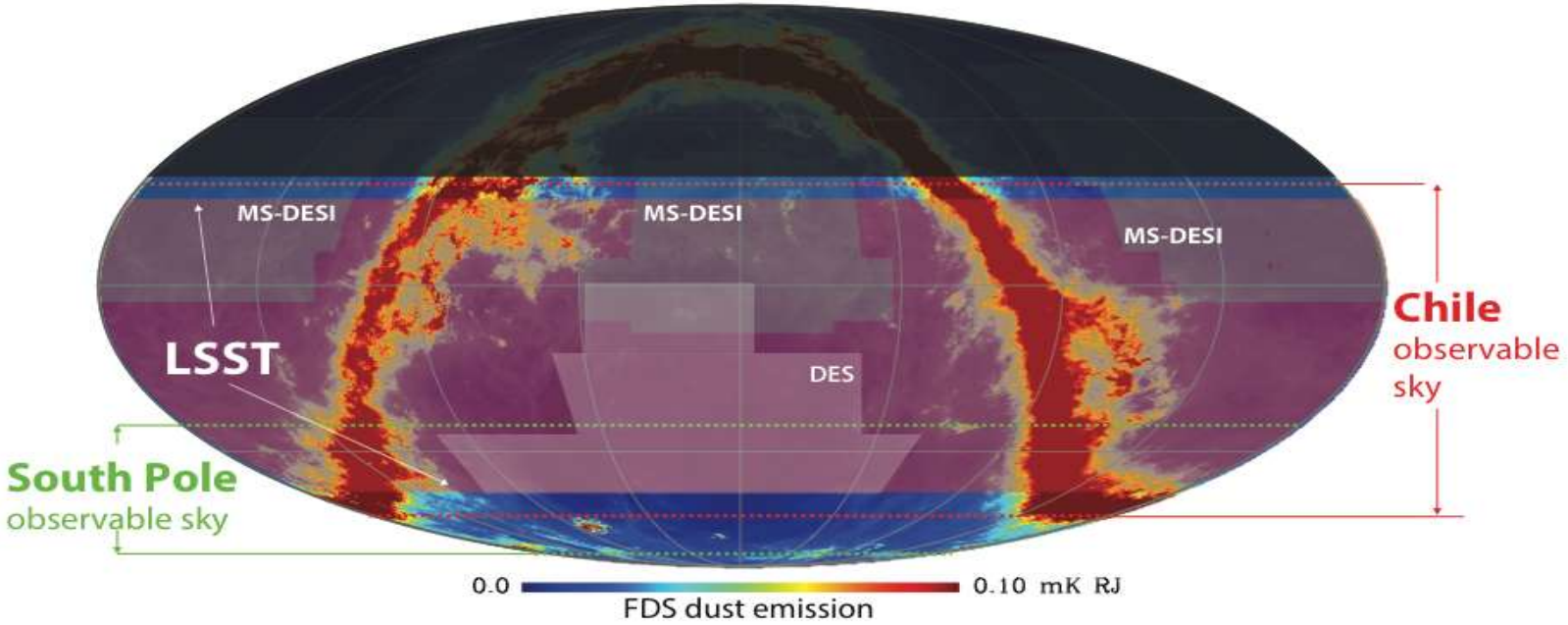


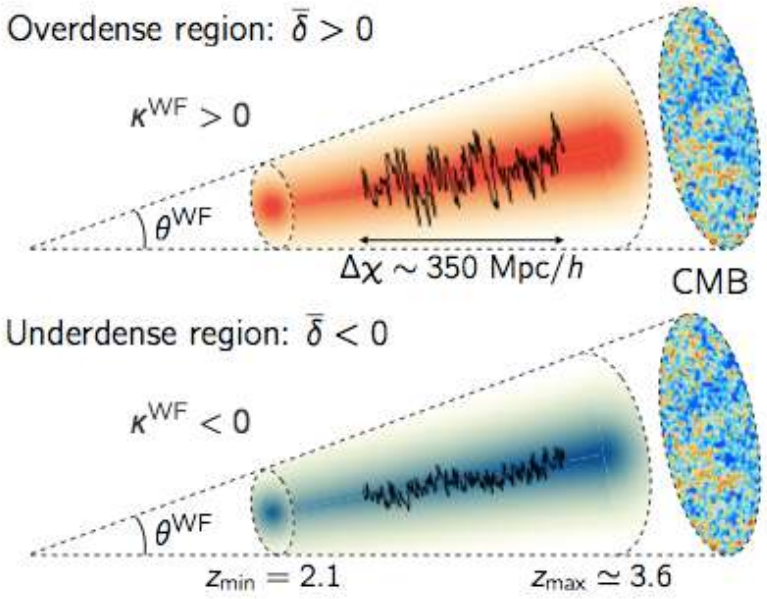
Red - spectro-Z
Blue - photo-Z

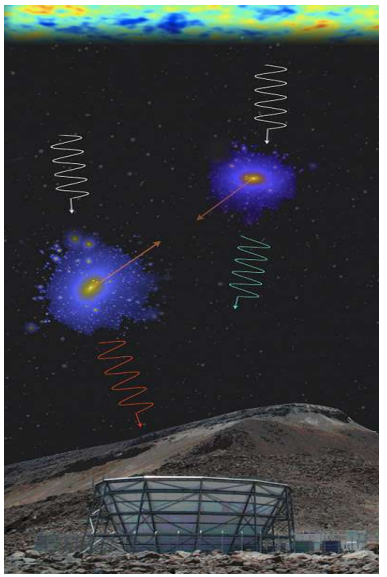
Galaxies cluster - use correlation function to calibrate photo-Z distr. using subset with spectro-Z.

Joint Spectroscopy - CMB-S4

(Bleem)







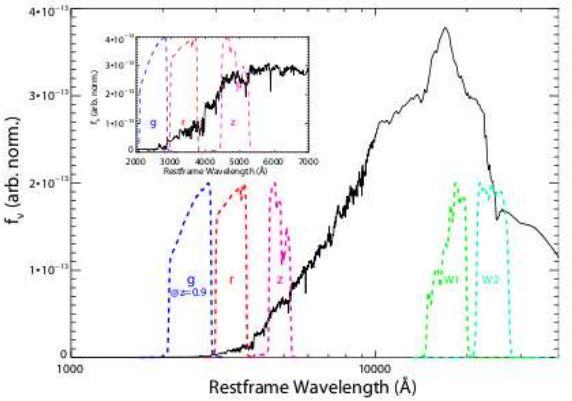
Lyman Alpha forest X CMB-S4

Kinetic S-Z effect

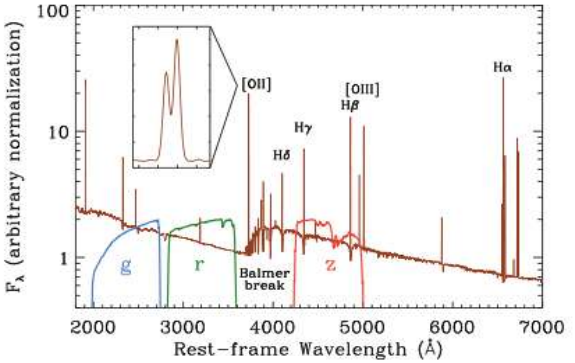
Gravity
Neutrinos
Astrophysics

Galaxy and QSO samples:
Target Selection and Redshift Features

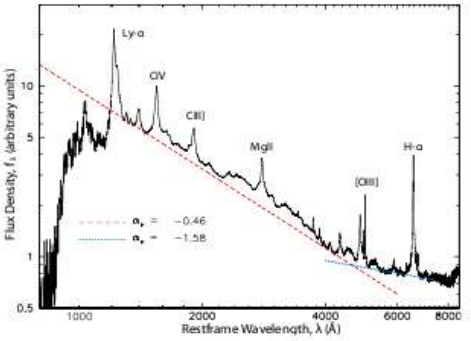
- **Red Galaxies**
  - **H&K break**
  - **WISE photometry**
  - **0.4 < z < 1**

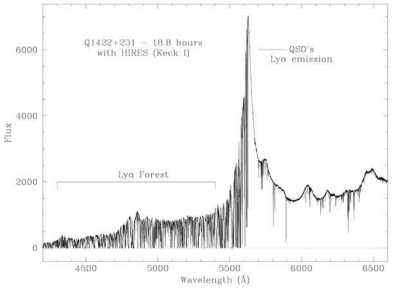


- **Emission Line Galaxies**
  - **[O II] Doublet: 3726/3729 Å**
  - **Hα 6563 Å**
  - **0.6 < z < 1.7**



- **Quasars**
  - **Ly α Forest**
  - **2.1 < z**

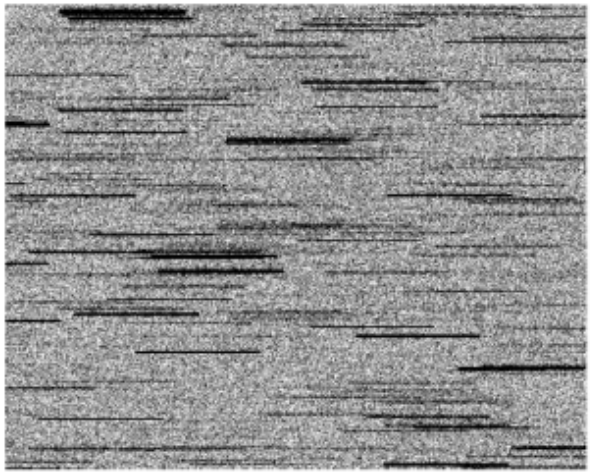




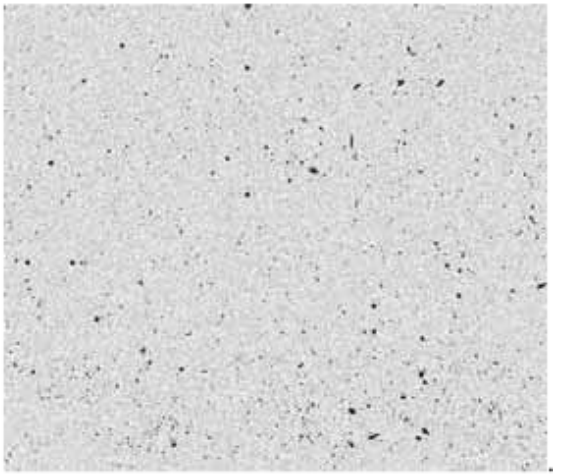
Ground v. Space

- **Ground**
  - **Large number of objects using multifiber spectroscopy (DESI: 25 million objects to z=1.7 [galaxies] and z=3.5 [QSOs])**
  - **Sky background dominated by OH emission - use high resolution**
  - **H2O opacity limits wavelength and redshift range**
    - **[O II] 3726/3729: z < 1.7 (CCD) or z < 2.4 (IR detector)**
- **Space**
  - **Large number of objects using slitless spectroscopy (EUCLID: 50 million galaxies to z=2.0)**
  - **Sky much darker; dominated by zodiacal light**
  - **Hα emission easiest to detect (IR detectors)**

Space Experiments (EUCLID, WFIRST)

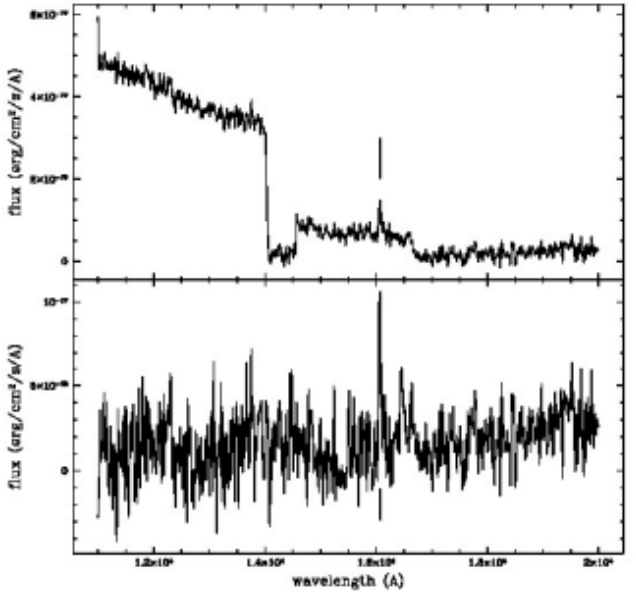


Dispersed image



Direct Image

- Slitless spectroscopy
- GRISM disperser
- 2K x 2K IR detector (EUCLID) or 4K x 4K
- (WFIRST)
- 1 - 2μ (EUCLID) or 1.35-1.95μ (WFIRST)

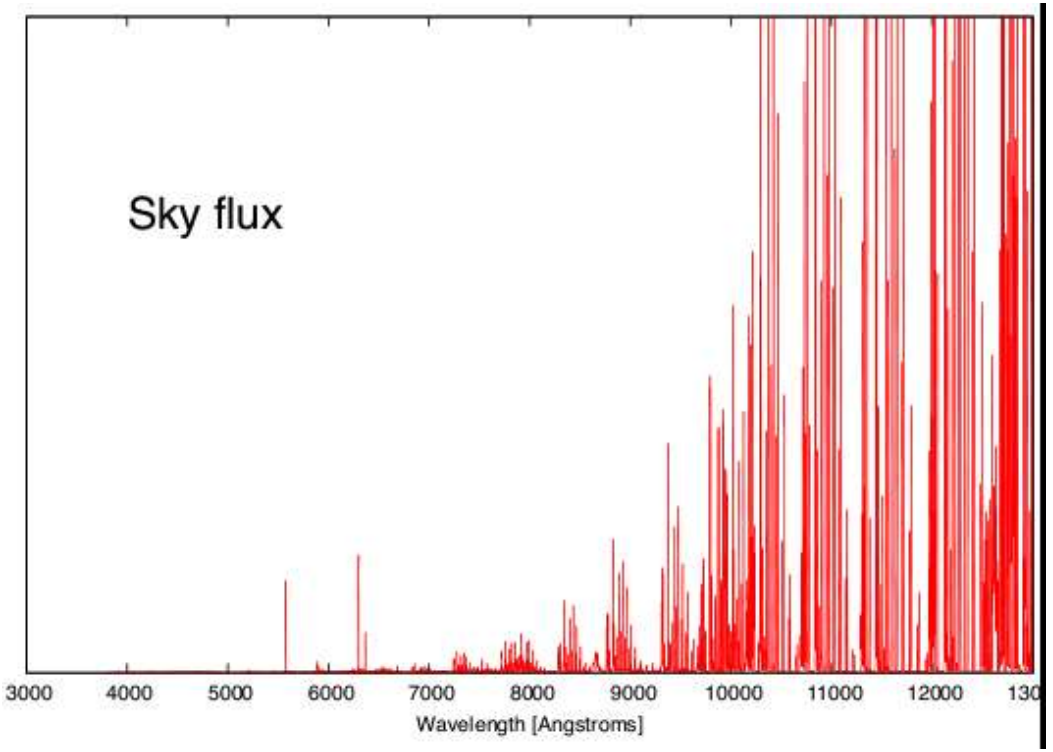


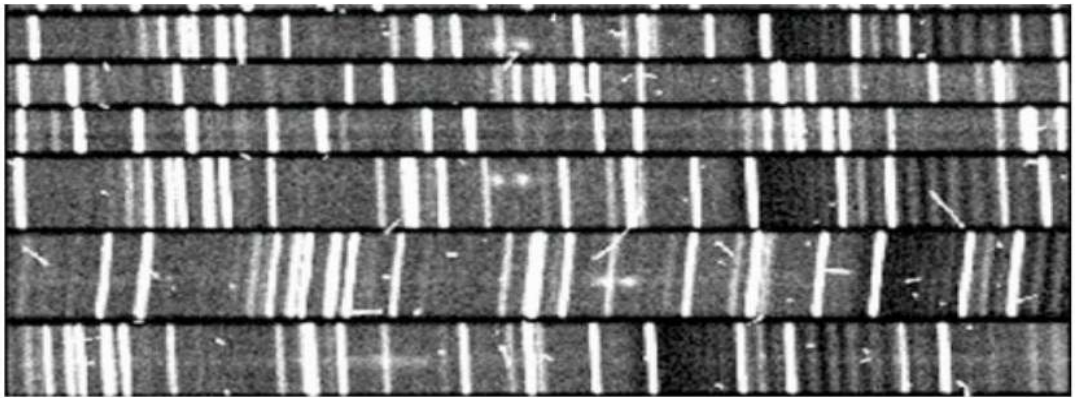
Ground Spectroscopy

- **Telescope - retrofit existing telescope with wide field corrector (DESI - 4m, PFS - 8m).**
- **Fiber positioners**
  - **Plug plate (SDSS)**
    - **Manual labor**
    - **Efficiently tile sky**
  - **Mechanical Positioners (LAMOST)**
    - **Fixed grid - inefficient tiling of sky in presence of large-scale clustering of galaxies**
    - **Metrology camera needed for fiber positioning.**
- **Fiber runs can be up to 100 meters**

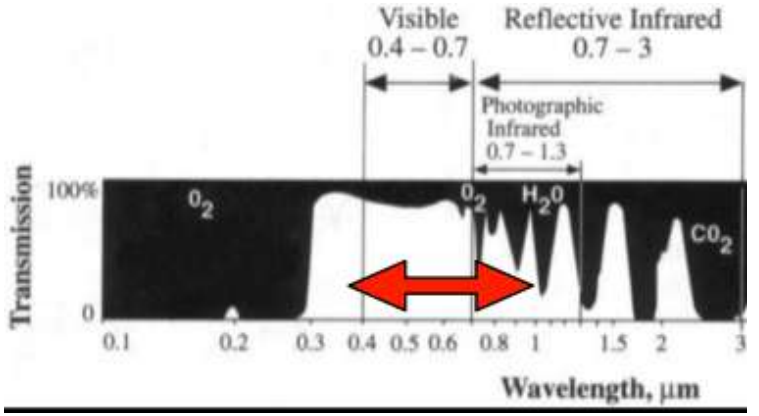
Ground Spectroscopy

- Sky spectrum dominated by OH forest
- Requires high resolution (R ~ 5000) - lines are narrow, gaps between lines are dark.
- Wavelength range depends on detectors:
  - CCDs - 0.98 μ
  - IR detectors - 1.3 μ



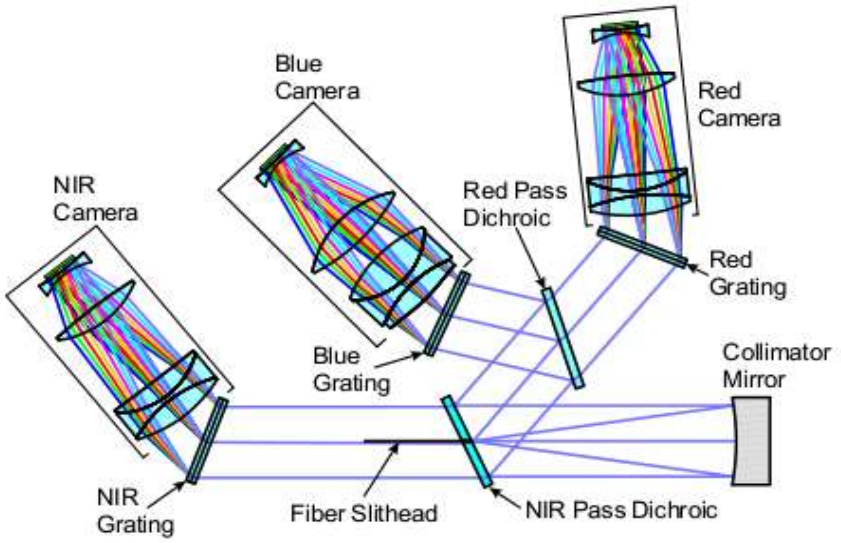


DEEP 2 survey

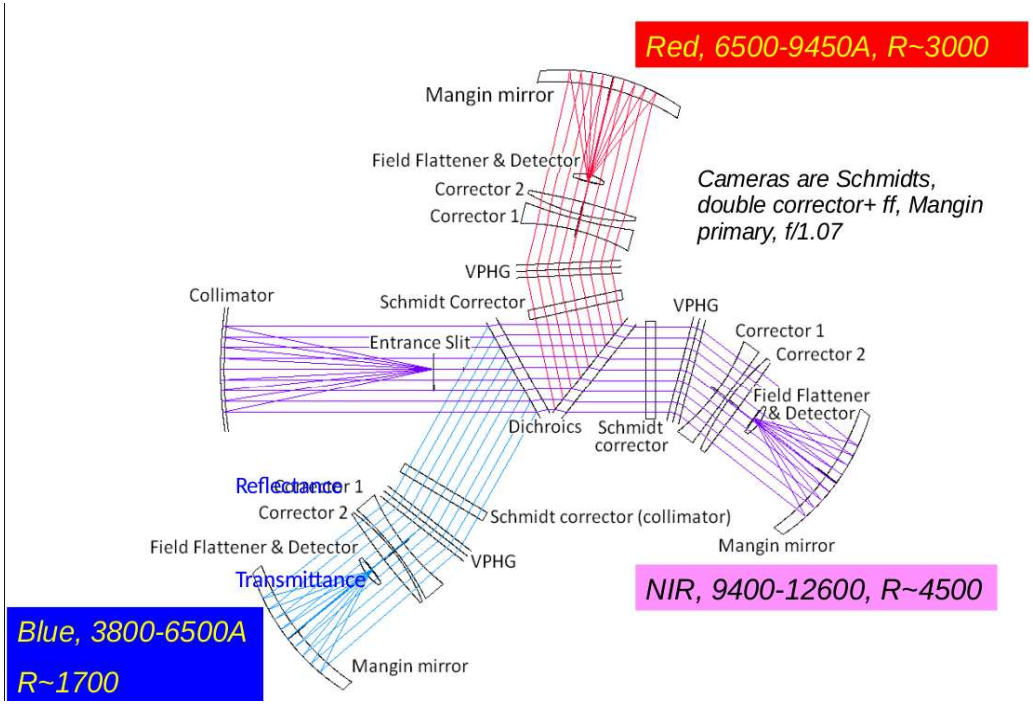


Ground Spectrographs

- **Typically 3-armed spectrographs with dichroics, VPH GRISMs.**

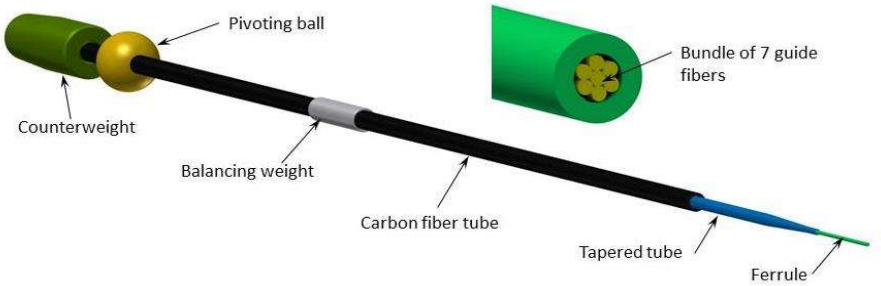


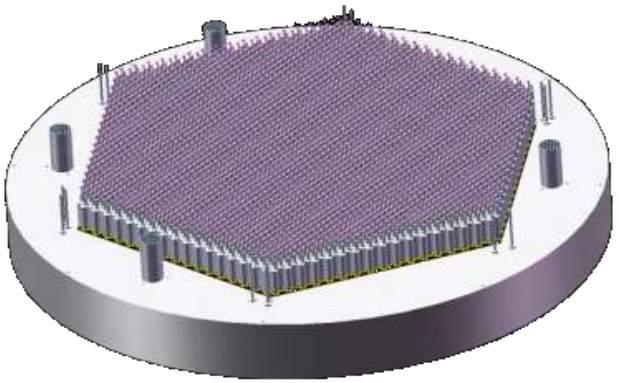
DESI



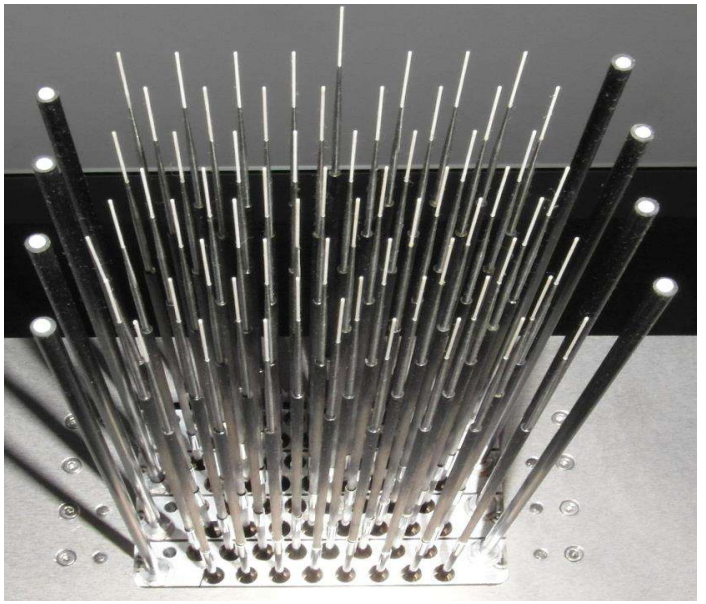
Subaru PFS

Fiber Positioning Systems





“Twirling Posts” - 2-axis positioners (PFS, DESI)



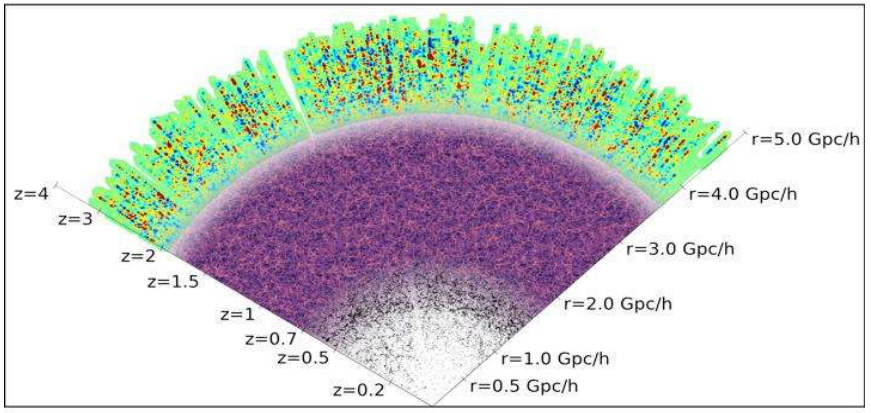
Tilting spines (4MOST)

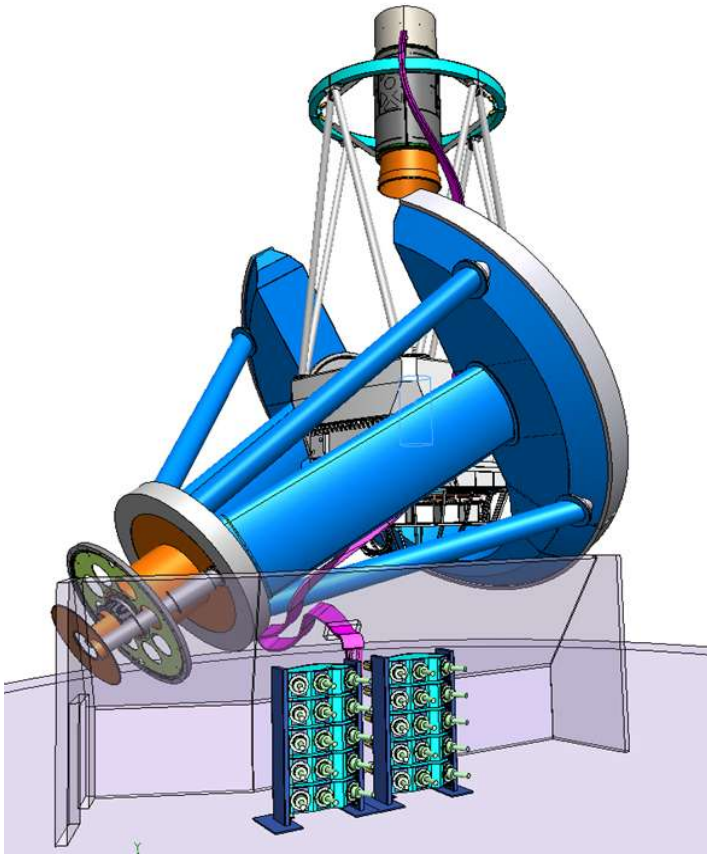
Future Surveys

- **In progress**
  - **DESI (ground)**
  - **4MOST (ground)**
  - **SUMIRE / PFS (ground)**
  - **WEAVE (ground)**
  - **EUCLID (space)**
  - **WFIRST (space)**
- **Concepts**
  - **Keck-FOBOS**
  - **Mauna Kea Spectroscopic Explorer**
  - **Beyond DESI**
  - **Magellan future instrument**
  - **Gemini WFMOS**
  - **Telescopio San Pedro Martir**

DESI (Dark Energy Spectroscopic Instrument)

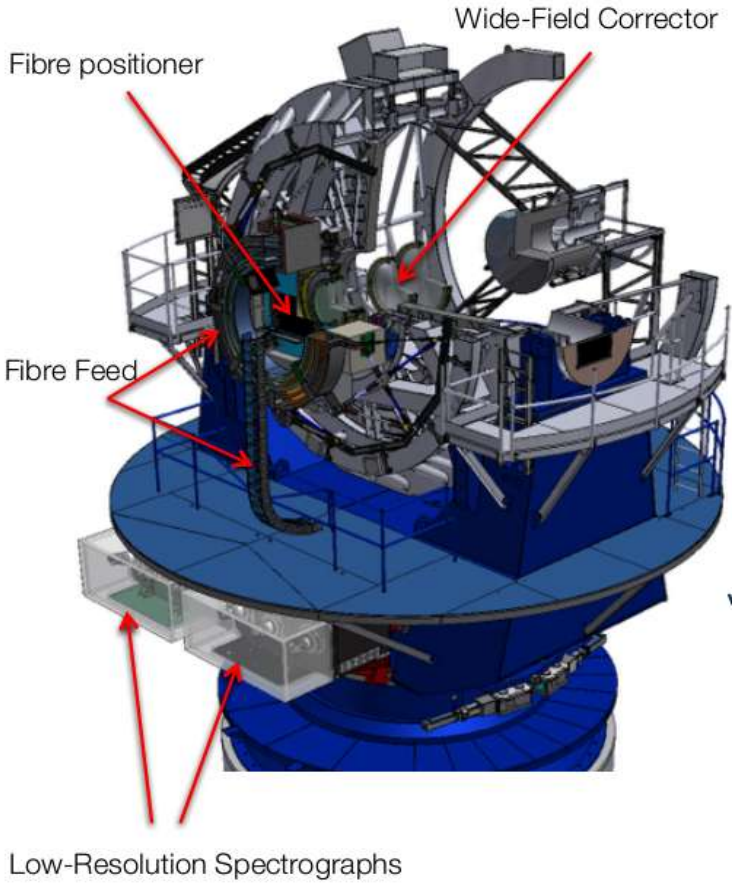
- **Repurpose existing Mayall 4-M telescope, Kitt Peak**
- **5000 fiber positioner**
- **25 million objects to z=3.5**
- **14,000 sq. deg.**
- **5 years**





4MOST- Cosmological Survey

- VISTA telescope, Paranal, Chile
- 1600 fibers for low-res spectrograph
- Low res spectrograph
  - 0.39-0.95μ
  - R = 5000
- 12 million galaxies
- 18,000 sq. deg.
- 5 years

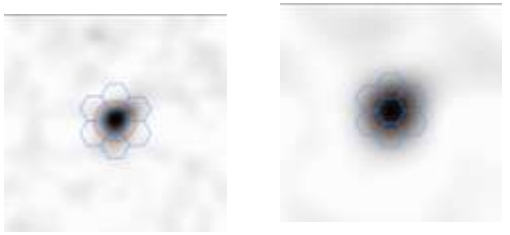


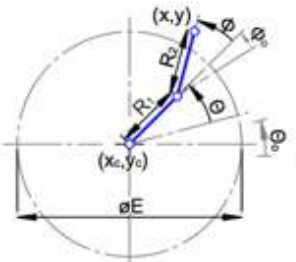
EUCLID - Combined Imaging/Spectroscpy

- 1.2-M diameter mirror
- 65 megapixel IR detectors
- (600 megapixel CCD)
- 15,000 sq. deg.
- $0.5 < z < 2.0$
- 50 million redshifts
- 6 years
- Launch 2020

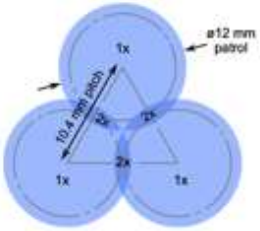
Keck - FOBOS

Replicate DESI hardware with as few changes as possible

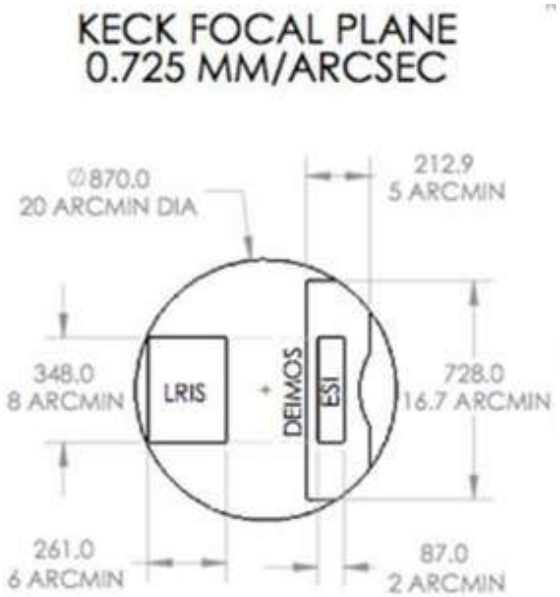


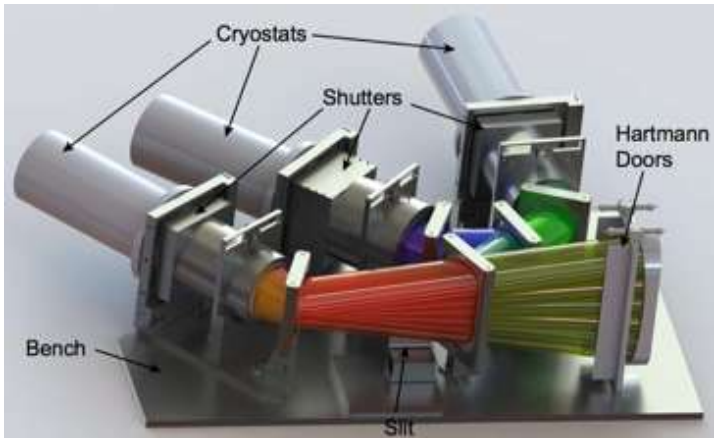


KINEMATICS /
COORDINATES



EXACT COVERAGE
R1 = R2 = 3 mm





Mauna Kea Spectroscopic Explorer

Replace existing CFHT with all-new telescope

11-M

Problem - enlarges existing dome. Need permission of restless natives.