Observations for Cosmology and Structure Formation - Part 3

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Contents

- **Goal:**

Understand how to obtain scientific results from observational data (redshift survey)

- **Part 1:**
  - **Extragalactic Distance Indicators**
  - **Optical Spectroscopy**
  - **Redshift Space Distortion**

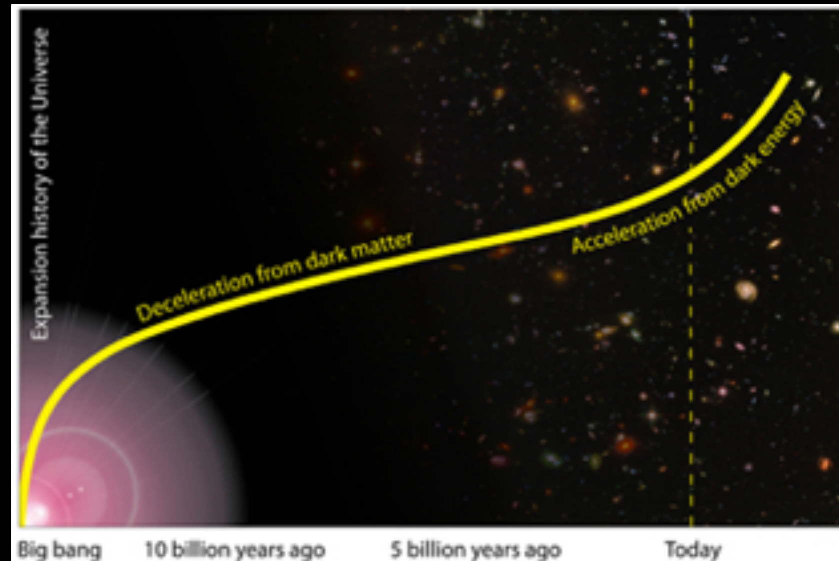
- **Part 2:**
  - **Voids**
  - **Photometric Redshifts (K-correction)**
  - **Cosmology with High-z Objects**
  - **Peculiar Velocity (Large-Scale Structure Near Local Group)**

- **Part 3:**
  - **Current/Future Redshift Surveys**

Current/Future Redshift Surveys

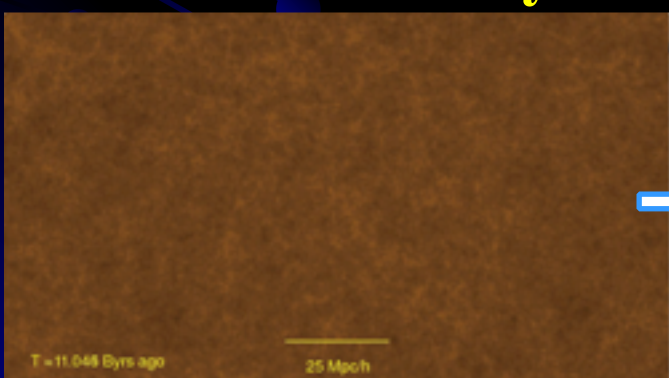
Study of Universe: Effects of Dark Matter/Energy

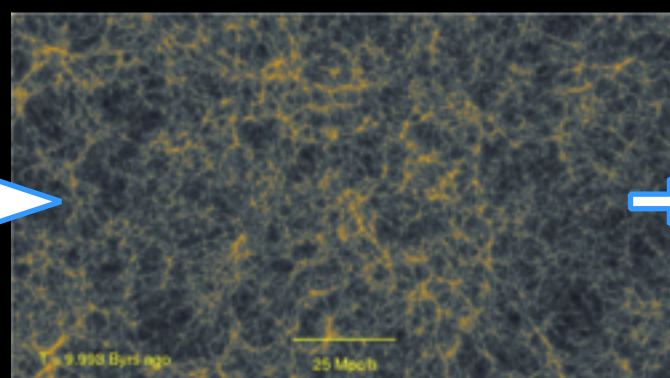
➢ **Expansion History of the Universe**

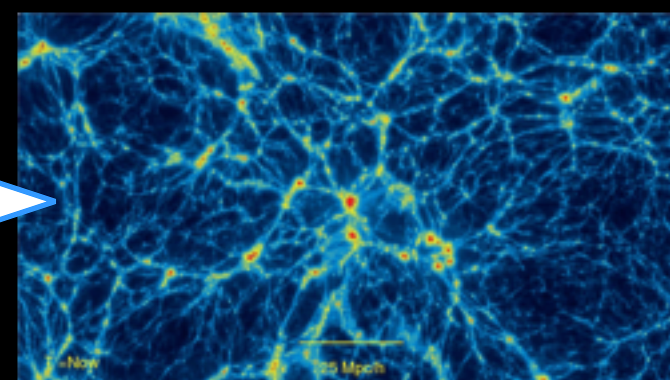


Euclid

➢ **Growth History of Structures**

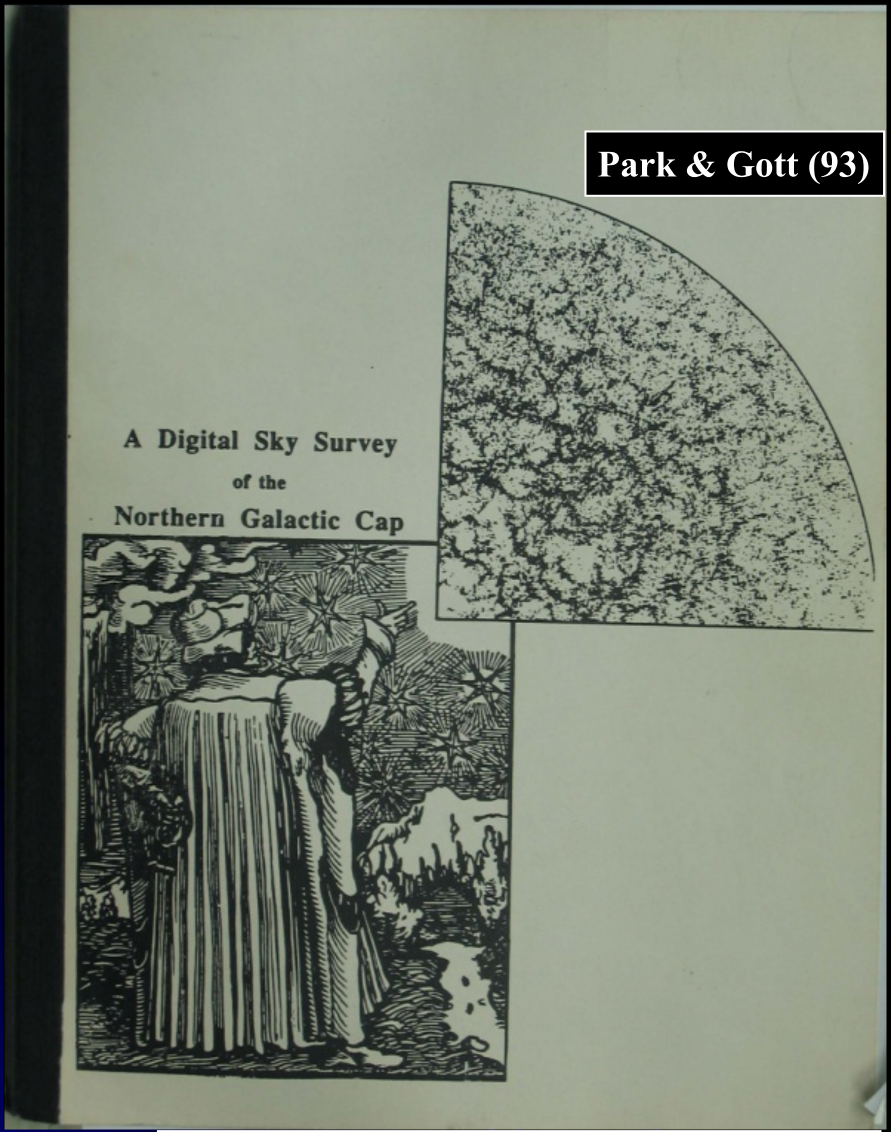




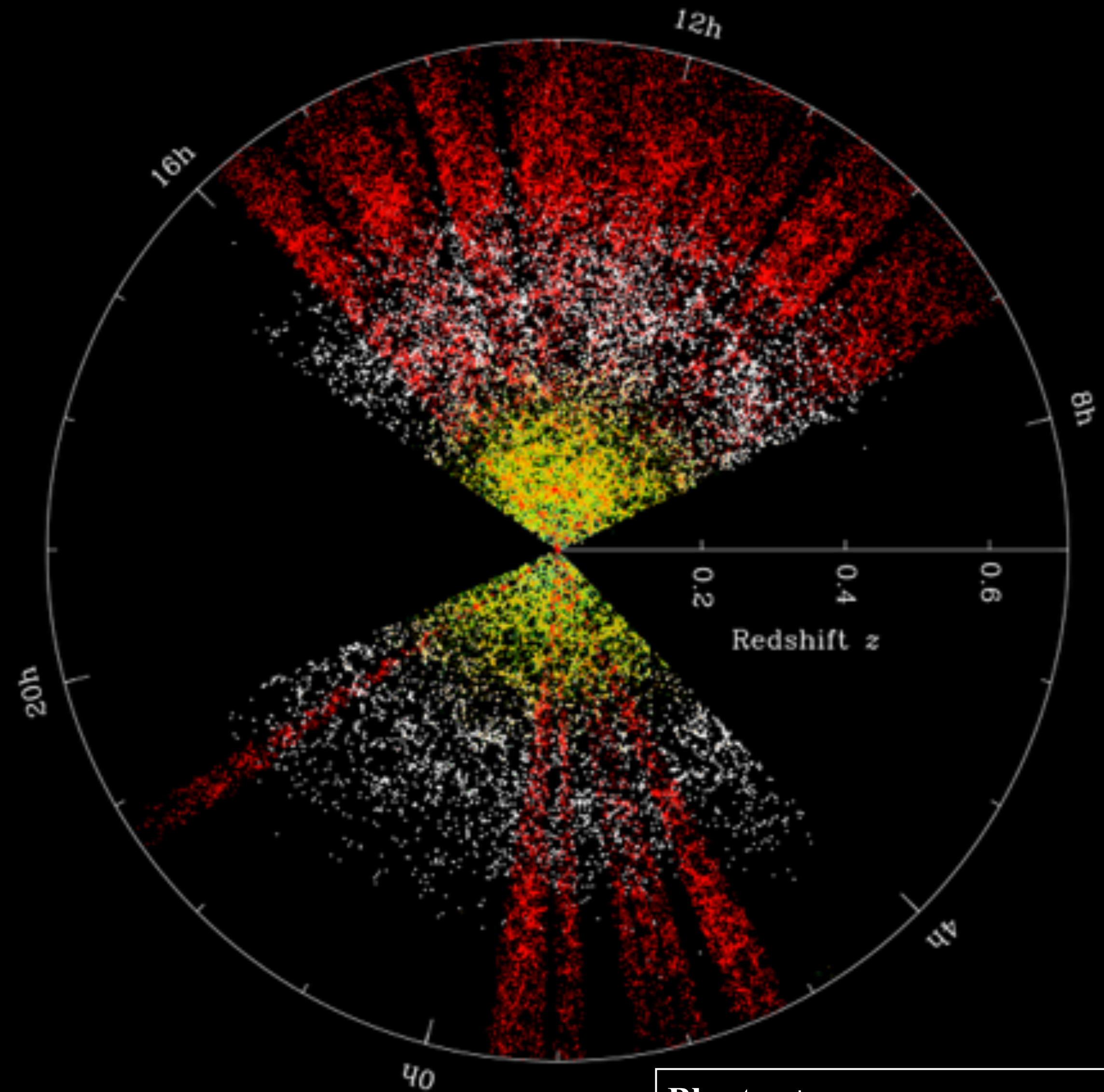


Kim & Park

Redshift Surveys: Sloan Digital Sky Survey



The Grey Book (SDSS Proposal to the NSF)



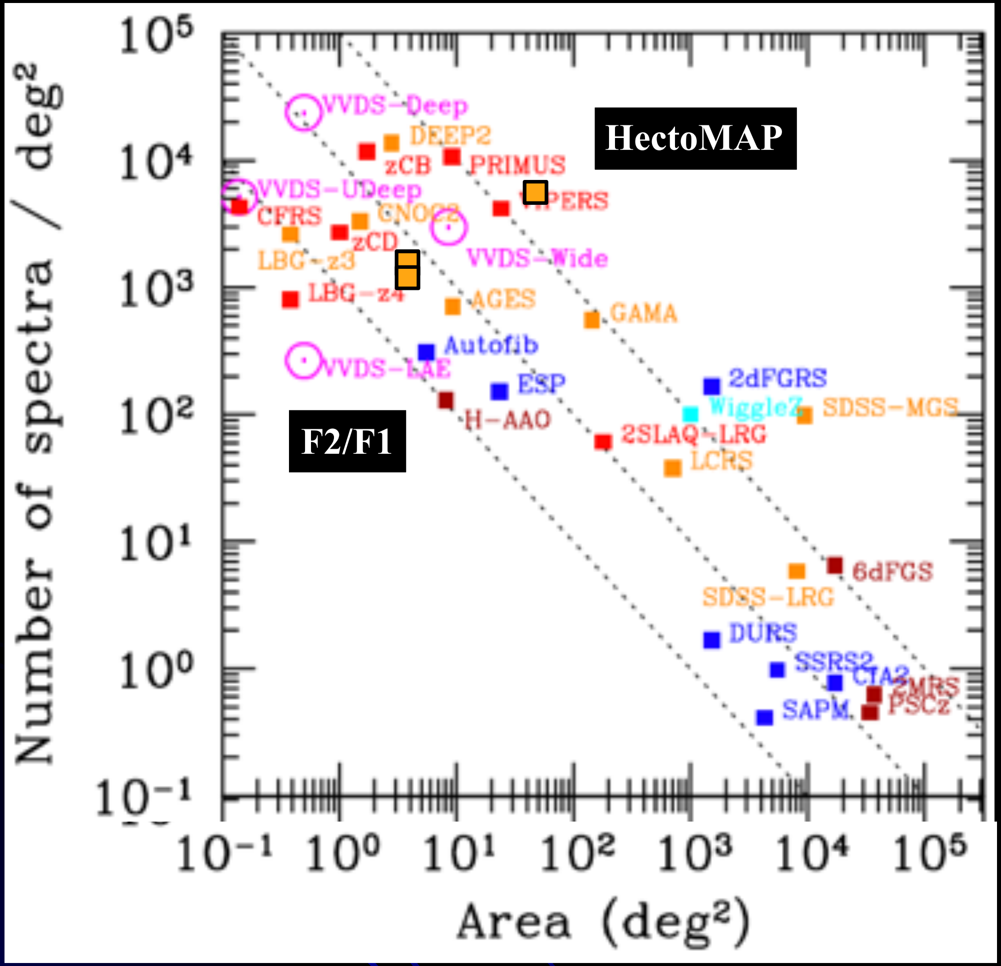
Blanton+
red: BOSS galaxies
white: LRGs
yellow: Main SDSS galaxies

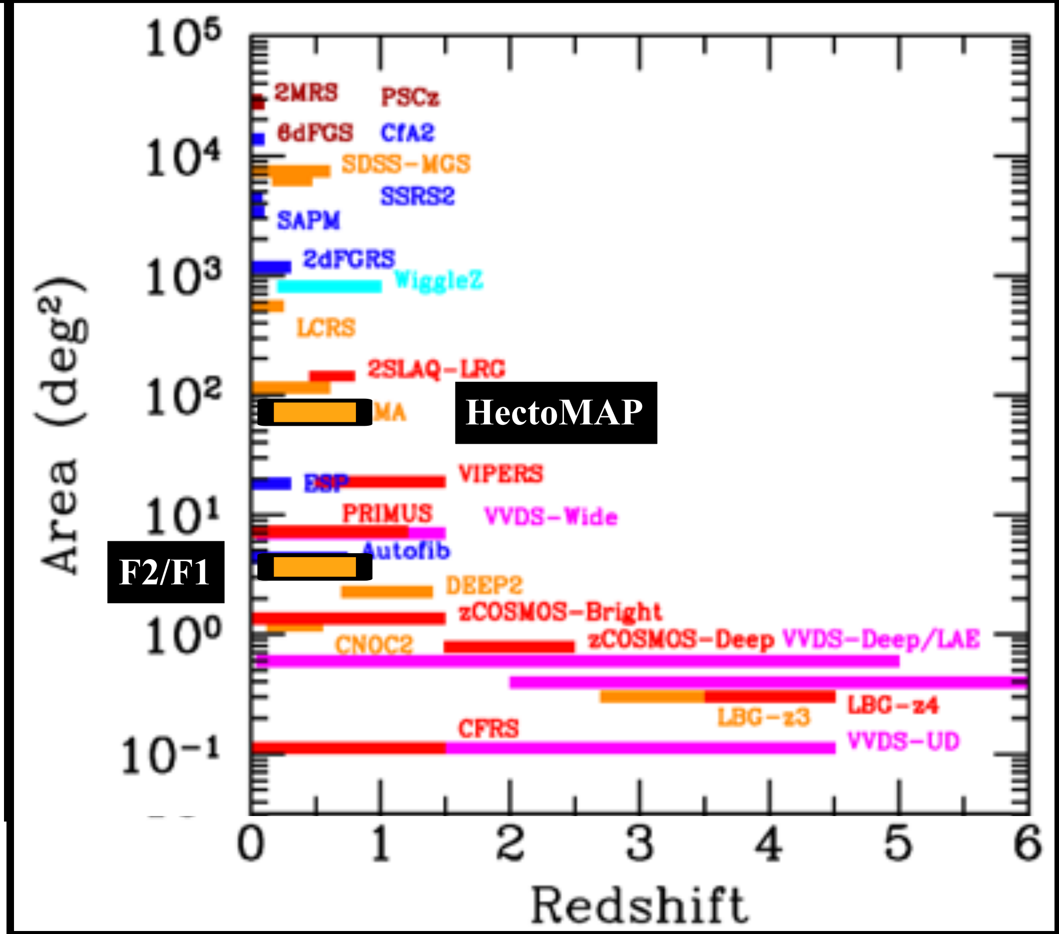
Redshift Surveys

Survey	Area	Depth i_{AB}[a]	N_{obj}	z_{range}	z_{mean}	Selection	Reference
SSRS2	5500	14.5	5369	0.0–0.08	0.03	$B < 15.5$	da Costa et al. (1998)
PSCz	34 000	15.0	15 411	0.0–0.1	0.03	$60\,\mu_{AB} < 9.5$	Saunders et al. (2000)
2MRS	37 000	15.2	23 200	0.0–0.08	0.03	$K < 15.2$	Erdoğdu et al. (2006)
SAPM	4300	15.7	1769	0.0–0.1	0.034	$BJ < 17.1$	Loveday et al. (1992)
6dFGS	17 000	15.7	110 256	0.0–0.1	0.05	$K < 12.7$	Jones et al. (2009)
CfA2	17 000	14.5	13 000	0.0–0.1	0.05	$B < 15.5$	Falco et al. (1999)
DURS	1500	15.6	2500	0.0–0.2	0.07	$BJ < 17.0$	Ratcliffe et al. (1996)
LCRS	700	17.5	26 418	0.0–0.25	0.1	$R < 17.5$	Shectman et al. (1996)
2dFGRS	1500	18.0	250 000	0.0–0.3	0.11	$BJ < 19.4$	Colless et al. (2001)
H-AAO	8.2	18.0	1056	0.0–0.55	0.14	$KAB < 16.8$	Huang et al. (2003)
ESP	23.3	18.0	3500	0.0–0.3	0.15	$BJ < 19.4$	Vettolani et al. (1997)
AGES	9.3	19.8	6500	0.0–0.5	0.2	$R < 20 B_W < 20.5$	Watson et al. (2009)
GAMA	144	19.8	79 599	0.0–0.6	0.25	$r < 19.8, z < 18.2, K_{AB} < 17.6$	Baldry et al. (2010)
CNOC2	1.5	21.3	5000	0.12–0.55	0.3	$R < 21.5$	Yee et al. (2000)
Autofib	5.5	20.5	1700	0.0–0.75	0.3	$B_J < 22$	Ellis et al. (1996)
SDSS-LRG	8000	19.5	46 748	0.16–0.47	0.3	$r < 19.5+$ CS[b]	Eisenstein et al. (2005)
SDSS-MGS	9380	17.8	935 000	0.0–0.6	0.3	$r < 17.8$, DR7	Abazajian et al. (2009)
2SLAQ-LRG	180	20.3	11 000	0.45–0.8	0.5	$i < 19.8$ + CS	Cannon et al. (2006)
CFRS	0.14	22.5	600	0–1.5	0.55	$I_{AB} \leq 22.5$	Lilly et al. (1995)
zCosmos-Bright	1.7	22.5	20 000	0–1.5	0.55	$17.5 \leq i_{AB} \leq 22.5$	Lilly et al. (2007)
VVDS-Wide[c]	8.7	22.5	26 178	0–1.5	0.55	$17.5 \leq I_{AB} \leq 22.5$	Garilli et al. (2008)
PRIMUS	9.1	23.5	96 599	0.0–1.2	0.6	$i_{AB} \leq 23$	Coil et al. (2011)
WiggleZ	1000	21.0	100 000	0.2–1.0	0.6	$NUV < 22.8$ + CS	Blake et al. (2011)
VVDS-Deep	0.74	24.00	11 601	0–5	0.92	$17.5 \leq I_{AB} \leq 24.0$	Le Fèvre et al. (2005a), this paper
DEEP2	2.8	23.4	38 000	0.7–1.4	1.0	$RAB < 24.1$ + CS	Newman et al. (2013)
VIPERS	24	22.5	100 000	0.5–1.5	1.0	$17.5 \leq i_{AB} \leq 22.5$ + CS	Guzzo et al. (2013)
VVDS-UDeep	0.14	24.75	941	0–4.5	1.38	$23.0 \leq i_{AB} \leq 24.75$	This paper
zCosmos-Deep	1	23.75	2728	1.5–2.5	2.1	$B_{AB} \leq 25$ + CS	Lilly et al. (2007)
LBG-z3	0.38	24.8	1000	2.7–3.5	3.2	$R_{AB} < 25.5$ + CS	Steidel et al. (2003)
VUDS	1	25	10 000	2–6.7	3.7	$i_{AB} < 25$ + photo-z	Le Fèvre et al. (in prep.)
LBG-z4	0.38	25.0	300	3.5–4.5	4.0	$I_{AB} < 25$ +CS	Steidel et al. (1999)
VVDS-All[d]	8.7	24.75	35 016	0–5	1.2	Combined VVDS	This paper

Le Fevre+13

Redshift Surveys: Density vs. Area

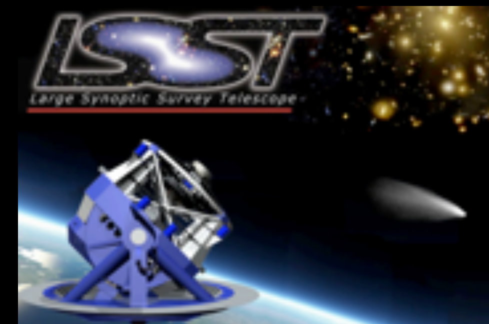


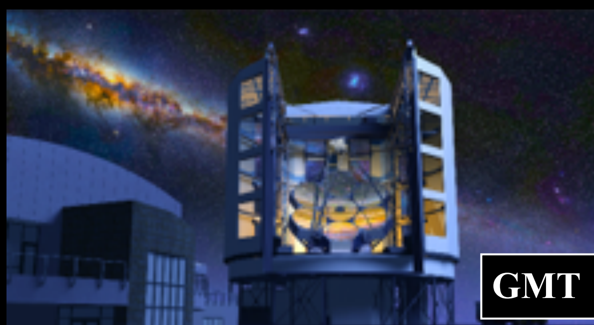


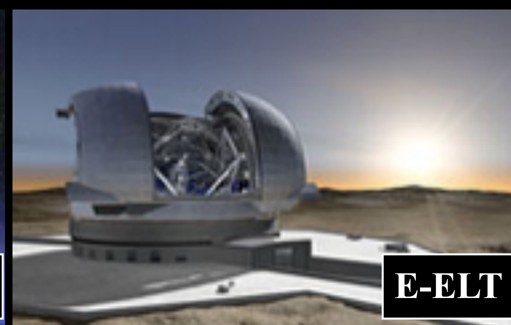
Le Fevre+13

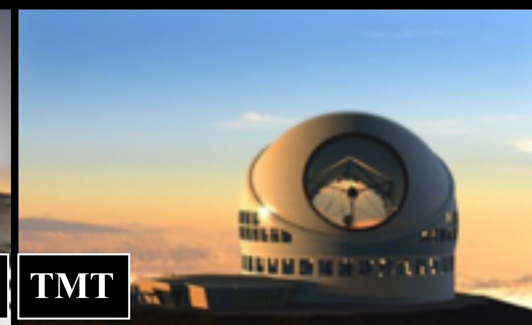
Current/Future Surveys for Cosmology/Structure Formation

➢ Ground Based Surveys

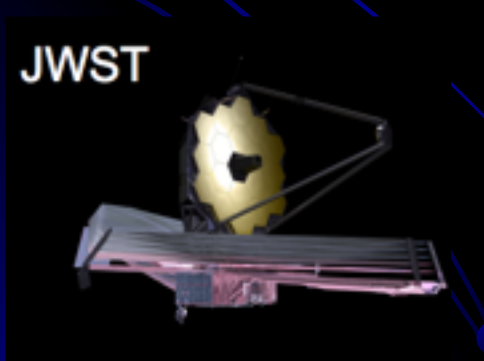


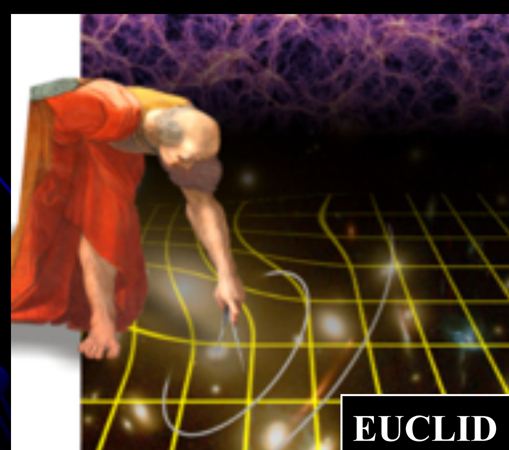






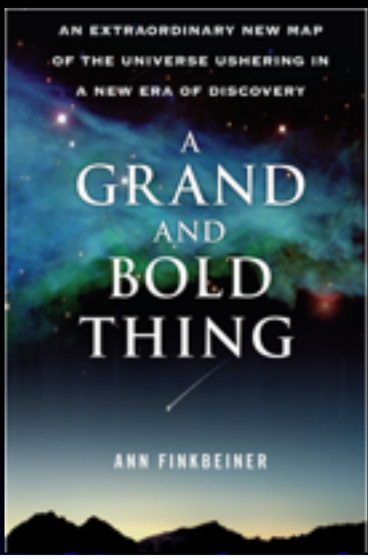
➢ Surveys in Space





Current: Low Redshift - SDSS

- SDSS-I: 2000 - 2005
- SDSS-II: 2005 - 2008
- SDSS-III: 2008 - 2014
- SDSS-IV: 2014 - 2020



SDSS-IV: Project Members

Full Institutional Members (24):

- Carnegie Institution for Science
- Carnegie Mellon University
- CU Boulder
- Kavli IPMU / U. Tokyo
- Instituto de Astrofísica de Canarias
- Johns Hopkins University
- Lawrence Berkeley National Labs
- Max-Planck-Institut fuer Astrophysik (MPA Garching)
- Max-Planck-Institut fuer Extraterrestrische Physik (MPE)
- Max-Planck-Institut fuer Astronomie (MPIA Heidelberg)
- National Astronomical Observatory of China
- New Mexico State University
- New York University
- The Ohio State University
- Observatório Nacional
- Penn State University
- Shanghai Astronomical Observatory
- Shanghai Jiao Tong University
- Universidad Nacional Autónoma de México
- University of Arizona
- University of Portsmouth
- University of Utah
- University of Wisconsin
- Yale University

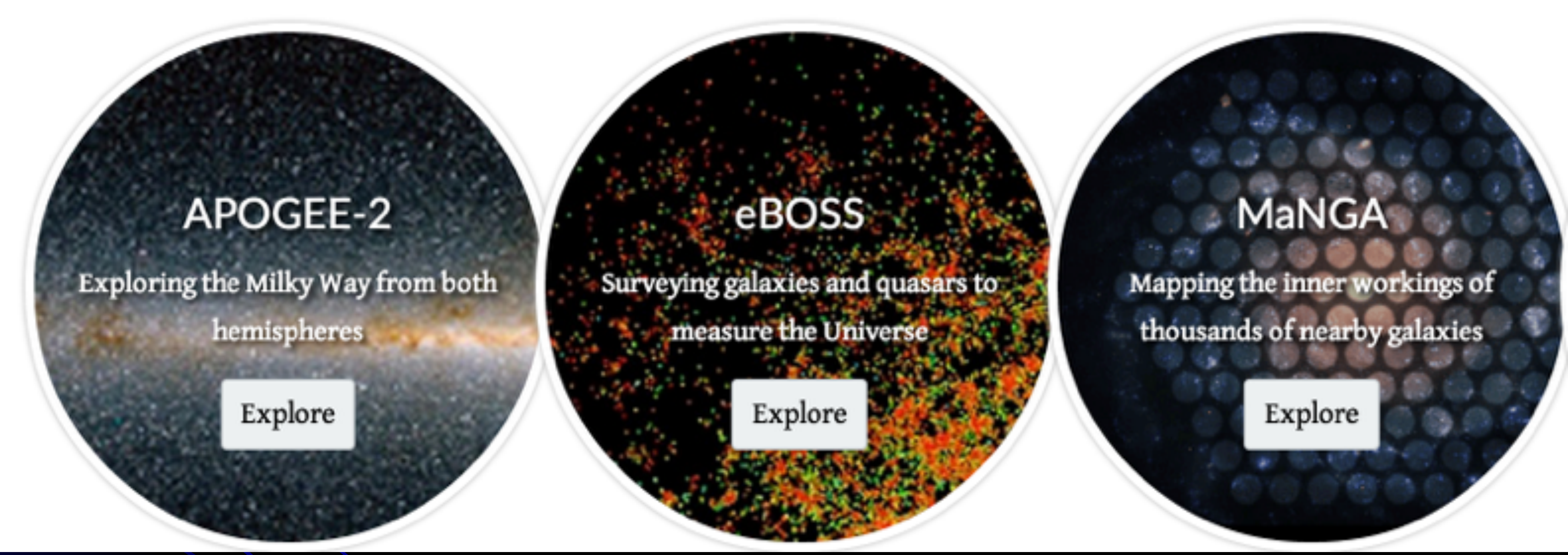
Participation Groups (4, comprising 9 institutions):

- Harvard-Smithsonian Center for Astrophysics (AC)
- Israel Center Of Research Excellence (I-CORE)
  - Tel Aviv University
- Korean Participation Group
  - Korea Institute for Advanced Study
  - Korea Astronomy and Space Science Institute
- United Kingdom Participation Group (AC)
  - Liverpool John Moores University
  - University of Cambridge
  - University of Nottingham
  - University of Oxford

Associate Institutional Members (21):

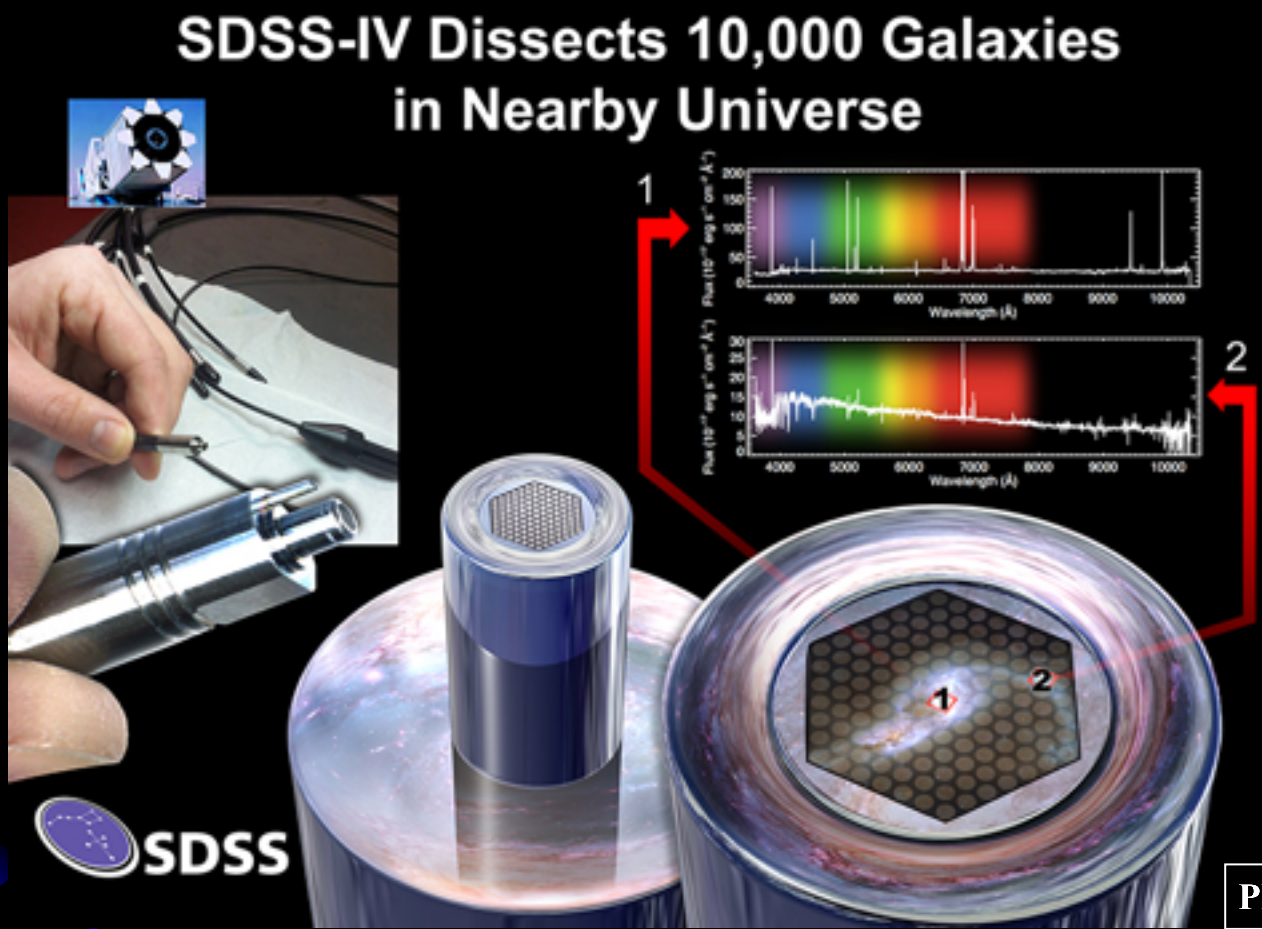
- Academia Sinica Institute of Astronomy and Astrophysics (ASIAA)
- Brookhaven National Labs
- École Polytechnique Fédérale de Lausanne
- Leibniz Institut fur Astrophysik Potsdam (AIP) (AC)
- Nanjing University
- Princeton University
- Sejong University
- Texas Christian University
- Tsinghua Center for Astrophysics
- University of Alabama, Tuscaloosa
- University of California Irvine
- University of Edinburgh
- University of Iowa
- University of Kentucky
- University of Notre Dame (AC)
- University of Pennsylvania
- University of Pittsburgh
- University of Toronto
- University of Washington (AC)
- University of Wyoming
- Vanderbilt University (AC)

SDSS-IV: Programs



MaNGA

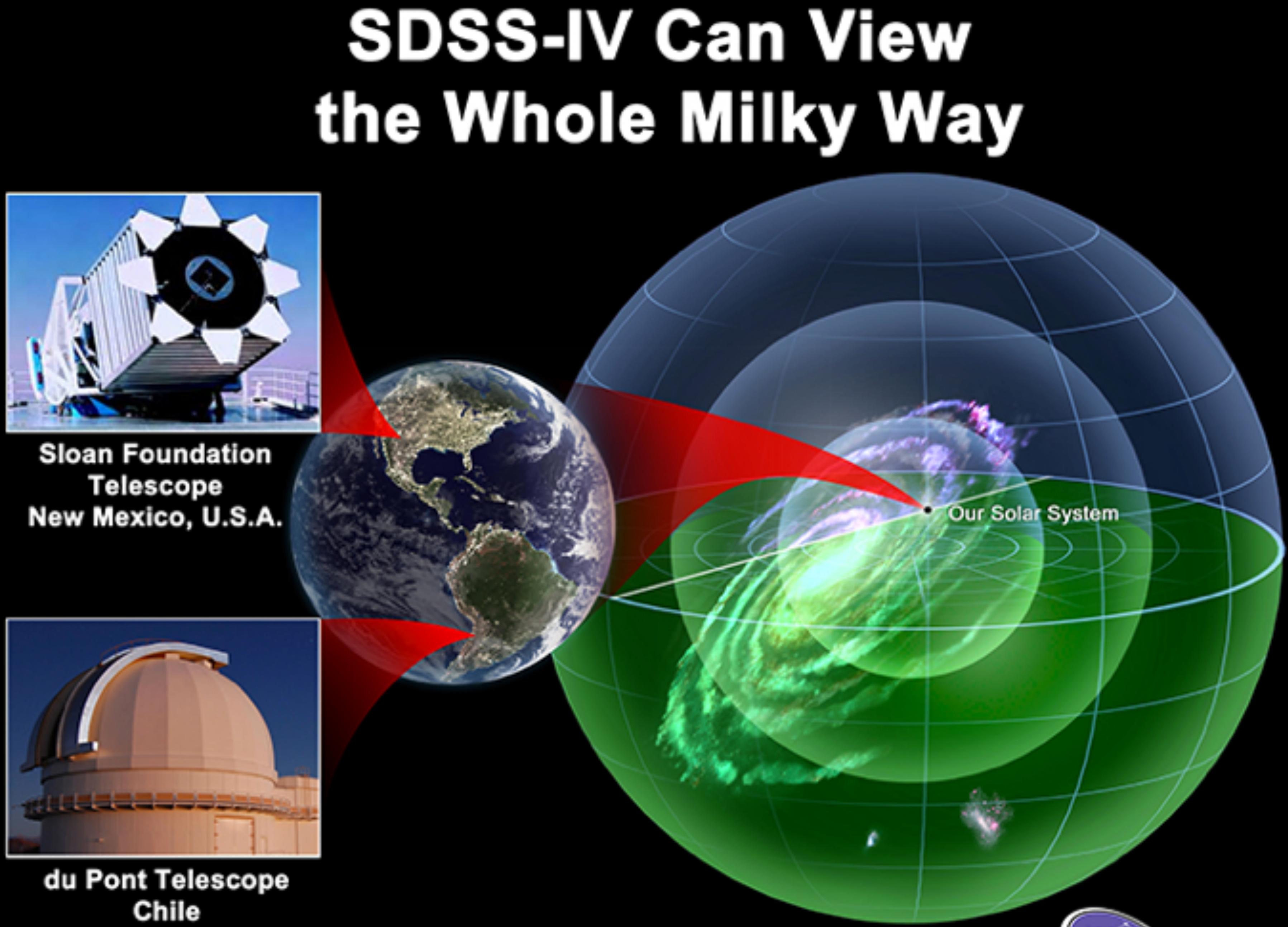
MaNGA (Mapping Nearby Galaxies at APO)



PI: Kevin Bundy (Kavli IPMU)

UCG 5124 | Gas Intensity | Gas Velocity | Stellar age | Stellar velocity

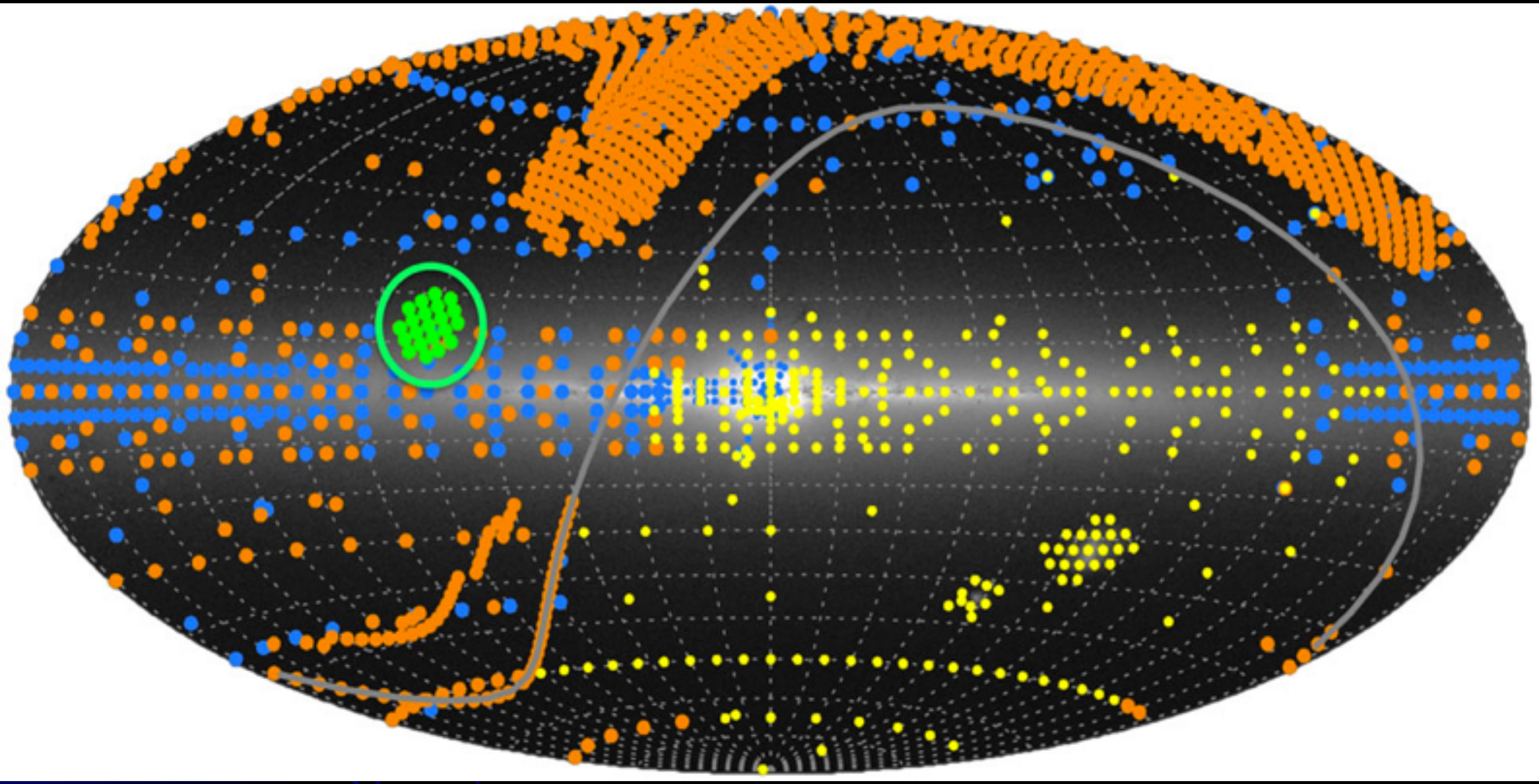
APOGEE-2: APO Galactic Evolution Experiment 2



PI: Steve Majewski (EPFL)

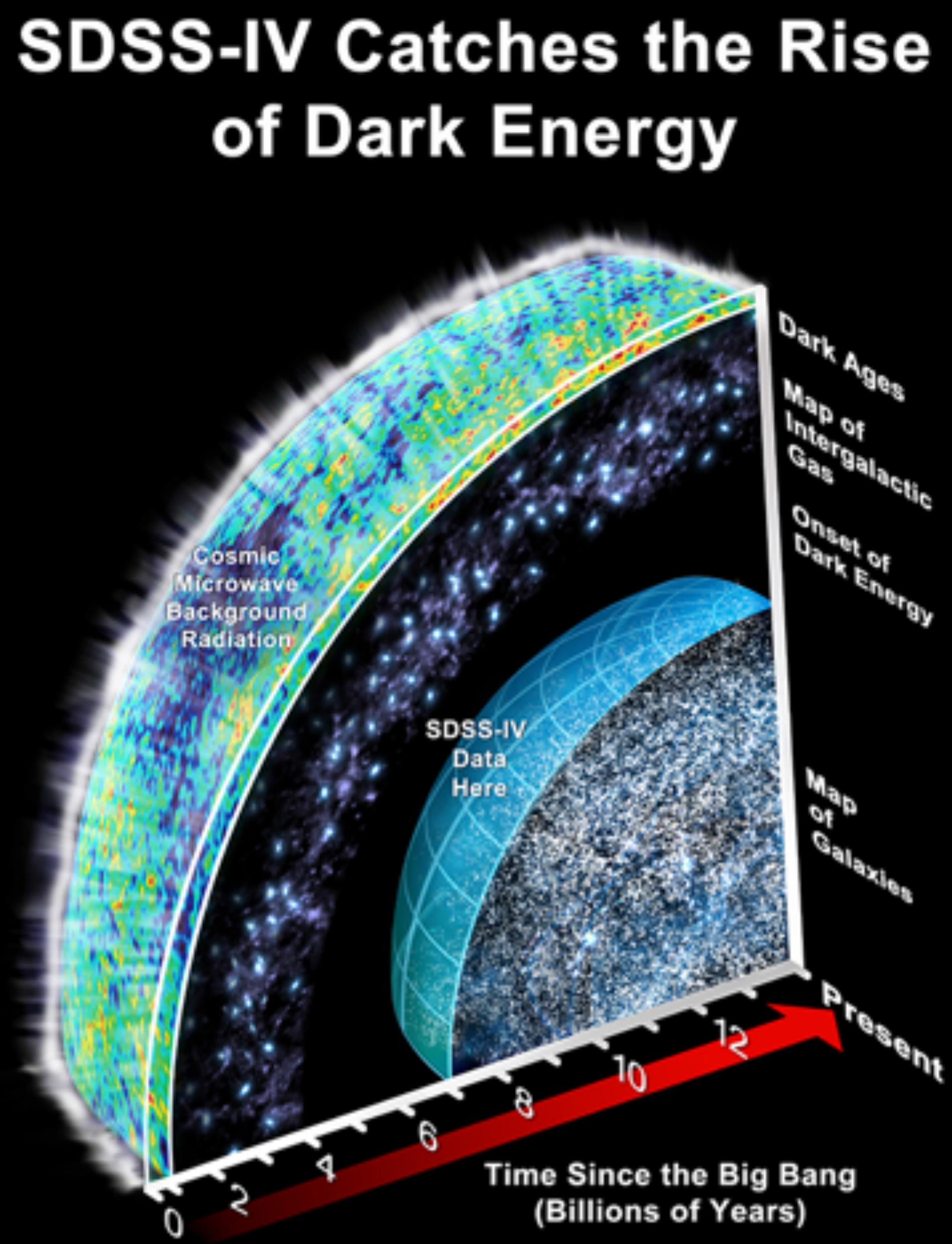
SDSS

APOGEE-2: Technical Details



APOGEE-1, APOGEE-2 (orange and green (Kepler) for APO, yellow for LCO) (SDSS WP)

eBOSS (Extended Baryon Oscillation Spectroscopic Survey)



PI: Jean-Paul Kneib (EPFL)

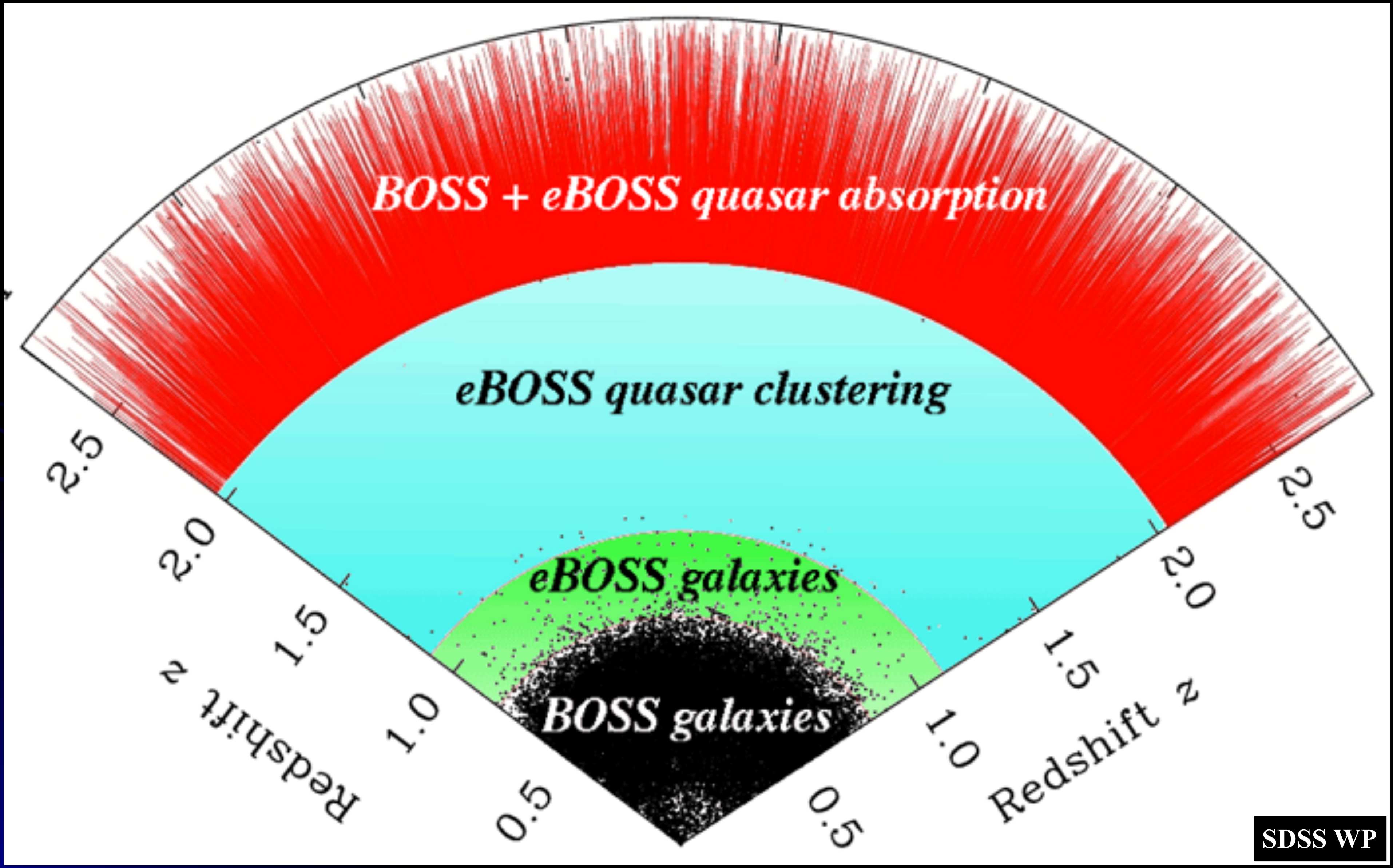
SDSS

eBOSS: Technical Details

- Dark-time observations
- Fall 2014 – Spring 2020
- 1000 fibers per 7 deg^2 plate
- Wavelength: 360-1000 nm, R~2000

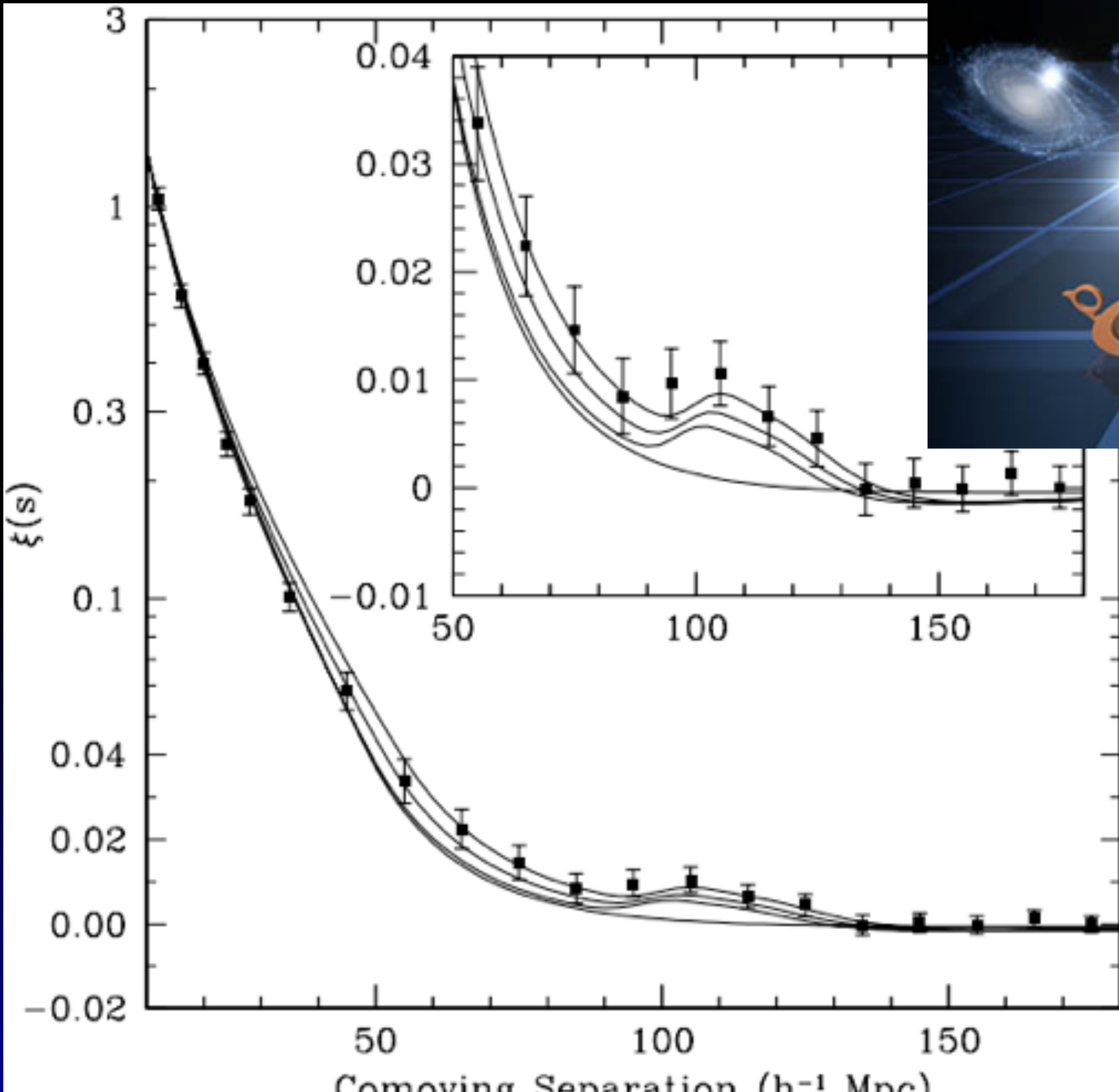
eBOSS: Technical Details

- 375,000 luminous red galaxies over 7500 deg^2, $0.6 < z < 0.8$
- 260,000 emission line galaxies over 1500 deg^2, $0.6 < z < 1.0$
- 740,000 quasars over 7500 deg^2, $0.9 < z < 3.5$



eBOSS: Science Goals

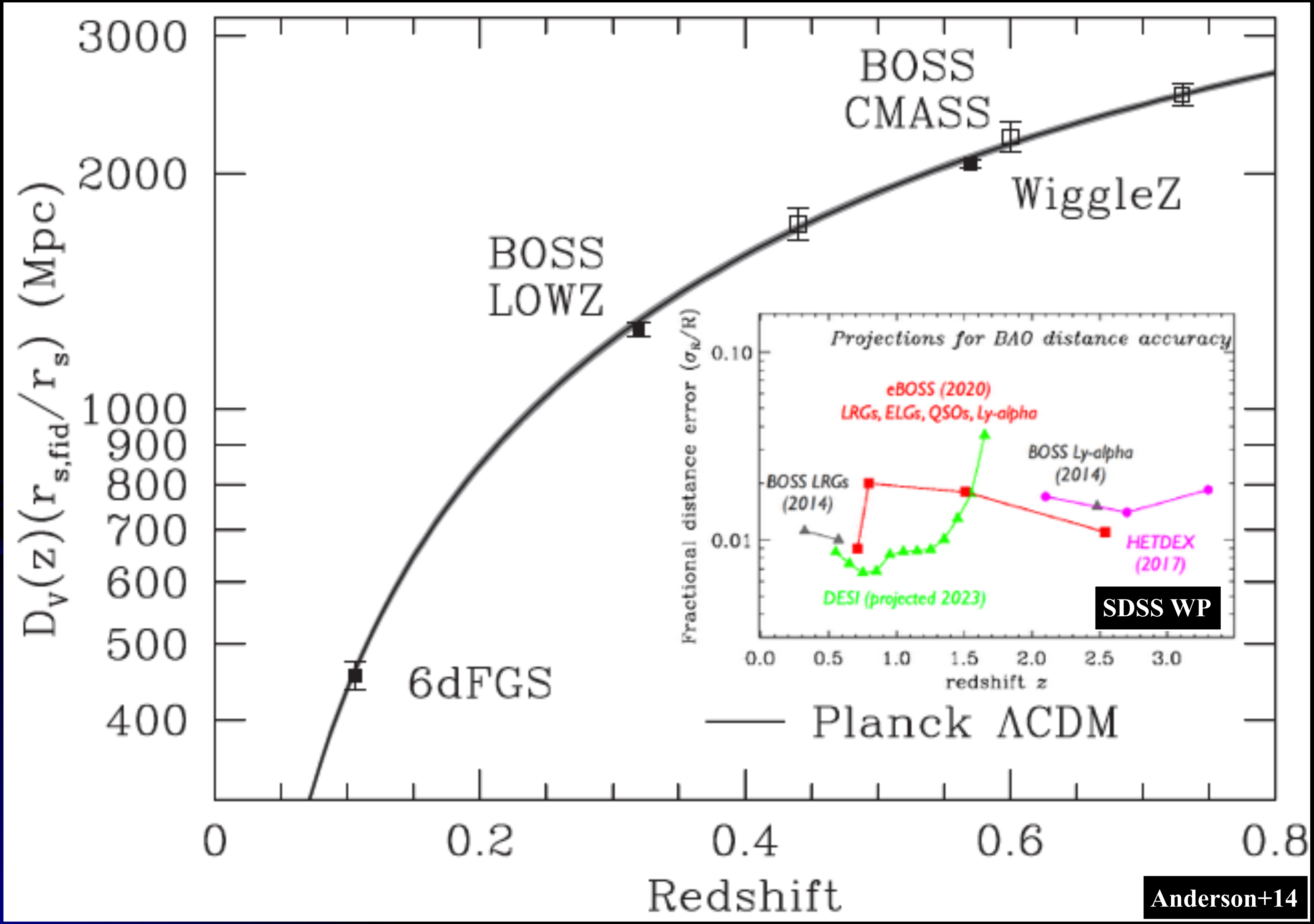
➢BAO: Baryon Acoustic Oscillations



Eisenstein+05

eBOSS: Science Goals

➢BAO: the effects of dark energy on the expansion history



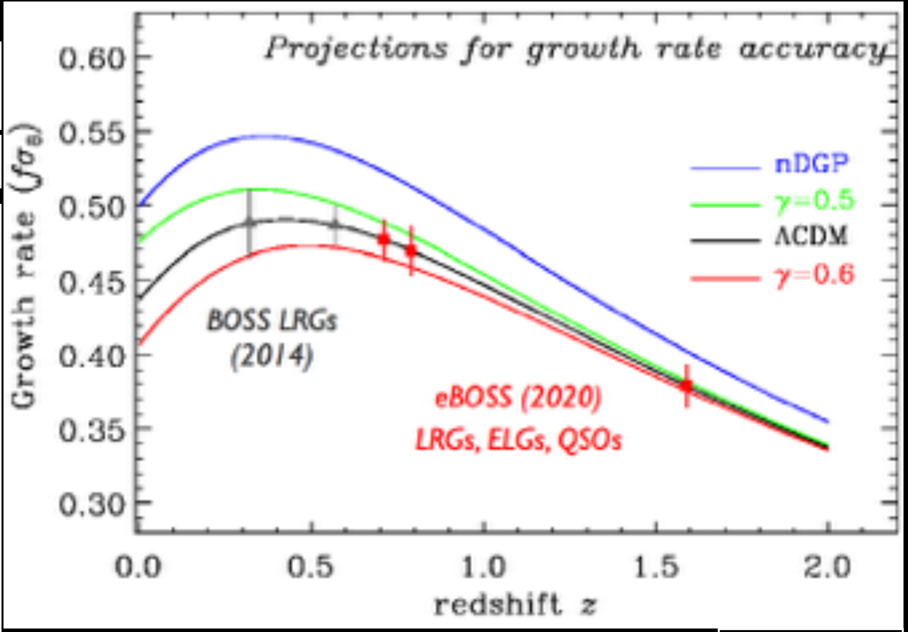
eBOSS: Science Goals

➢ **Redshift-Space Distortion (RSD): Growth of Structure**

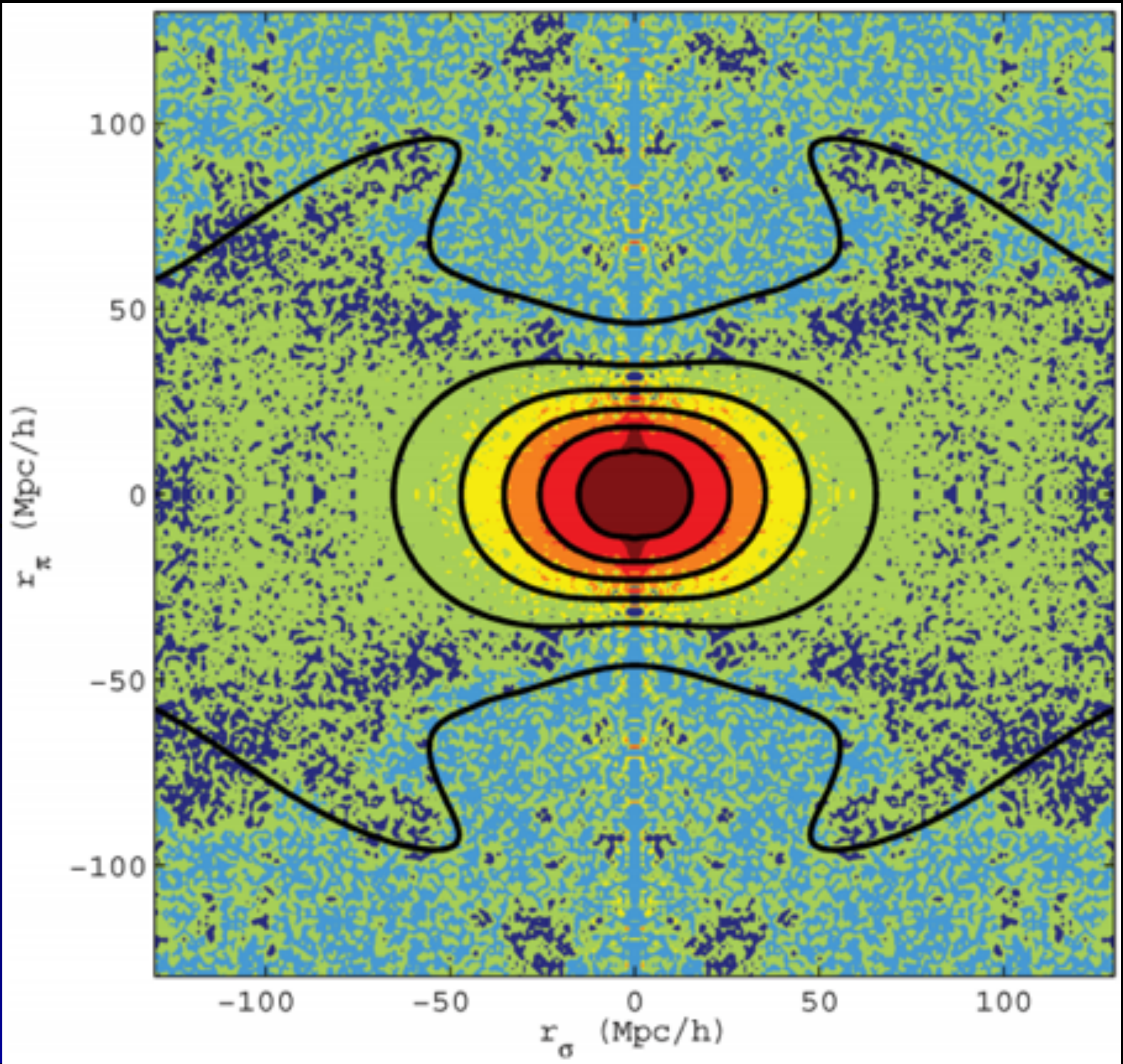
→ **Test of General Relativity**

$$f = \frac{d\ln D(a)}{d\ln a}$$

$$f \simeq \Omega_m(z)^\gamma$$



SDSS WP



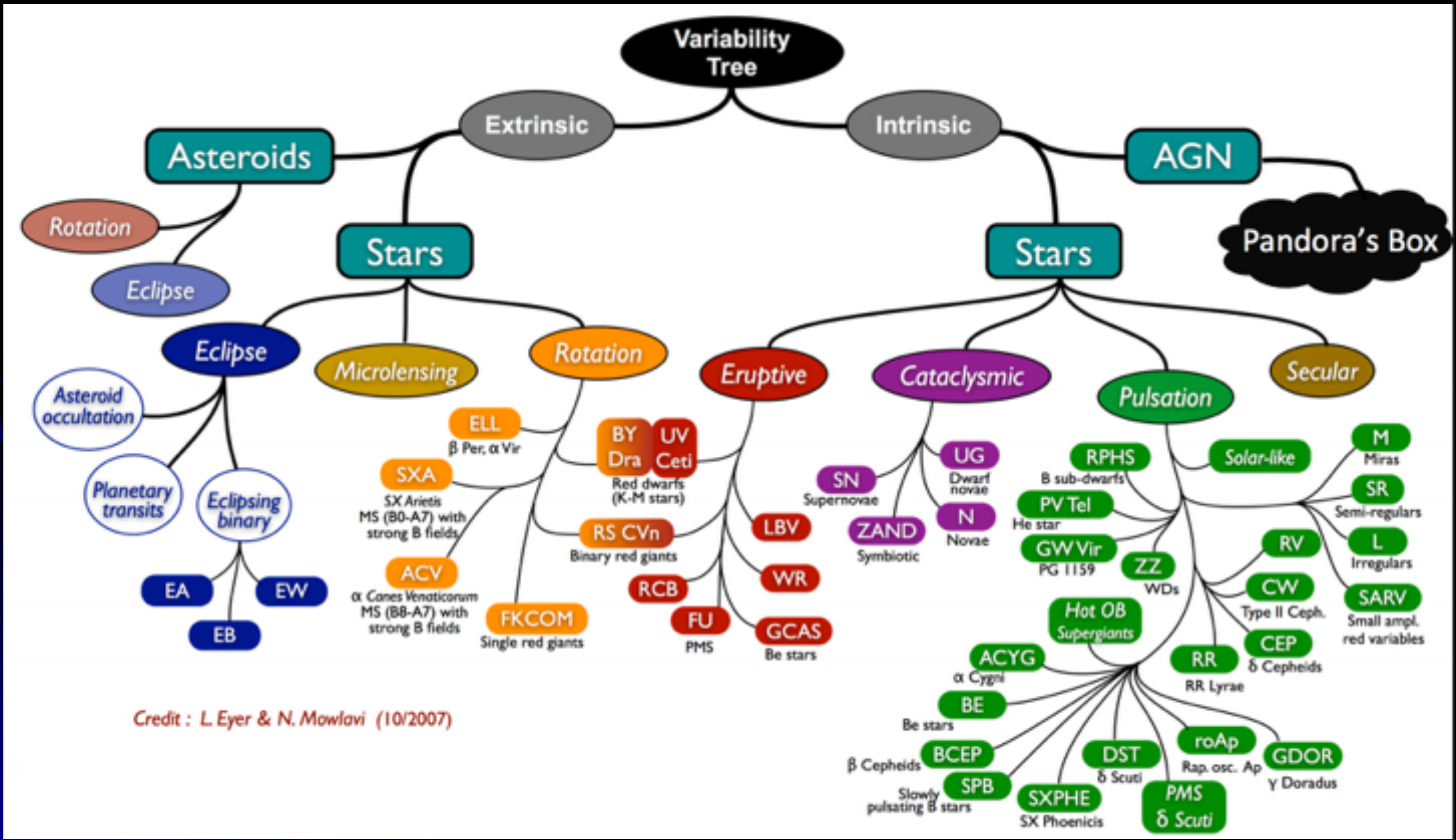
2D correlation function of DR9 CMASS (Reid+12)

eBOSS: Science Goals

- Cosmology Beyond Dark Energy
  - Test of non-Gaussianity in the primordial density field
  - Test of inflation
  - Measure of the sum of the neutrino masses
- More info : SDSS-IV White Paper
  at https://www.sdss3.org/future/sdss4.pdf

eBOSS: Sub-Programs (~5% each)

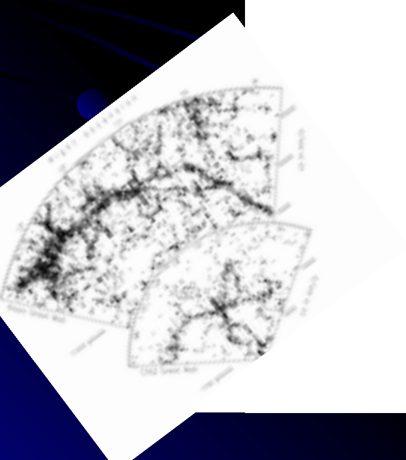
- ➢ TDSS (Time-Domain Spectroscopic Survey)
  - ➢ ~10^5 PanSTARRS-1 photometric variables at i≲21
  - ➢ No preselection based on colors or light curves
  - ➢ PI: Paul Green (SAO) & Scott Anderson (UW)



eBOSS: Sub-Programs (~5% each)

- SPIDERS (Spectroscopic Identification of eROSITA Sources)
  - ~10^5 eROSITA sources (AGN & Galaxy Clusters)
  - eROSITA (extended ROentgen Survey with an Imaging Telescope Array)
    - all-sky survey at 0.2 - 8 keV
    - to be launched early 2017
  - PI: Andrea Merloni & Kirpal Nandra (MPE)

Current: Intermediate Redshift - HectoMAP



HectoMAP (Geller, Hwang+)

HSC survey parameters (tentative)

	g	r	i	z	y	
wide	26.2	25.9	26.2	25	24	
deep	22.7	27.4	27.0	25.7	24.5	+3 narrow bands
ultra-deep	28.3	28.0	28.0	27.1	25.8	+6 narrow bands

5-sigma for 2" aperture, ABmag

● Deep: 28 sq. degree
- XMM-LSS
- E-COSMOS
- ELAIS-N1
- VIMOS-4

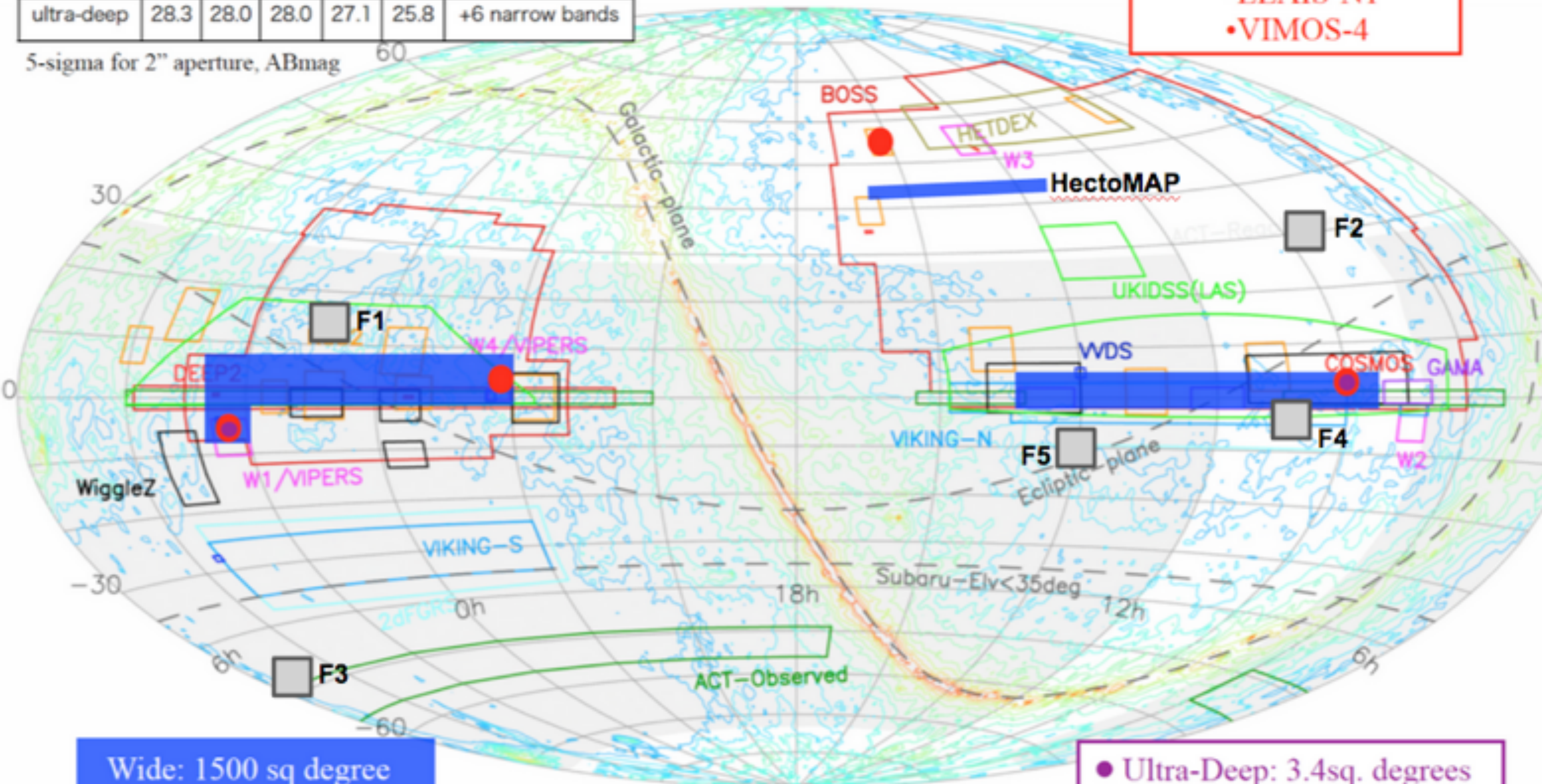


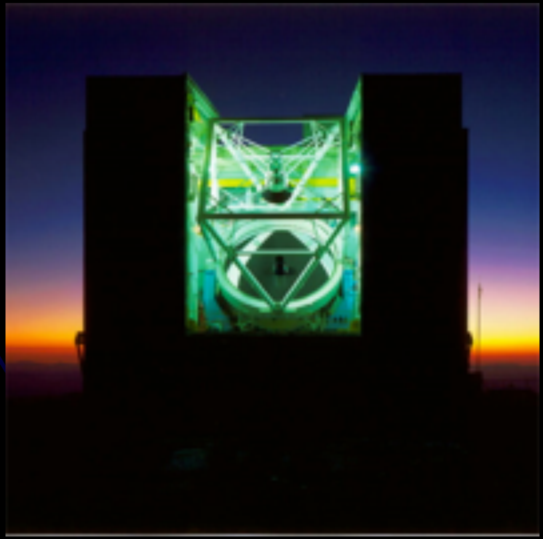
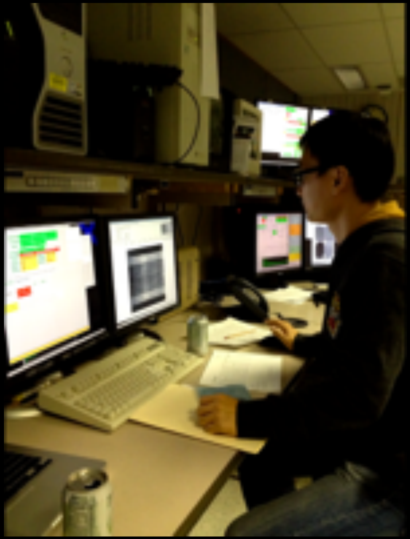
Figure Courtesy of A. Nishizawa

Wide: 1500 sq degree
- 3 fields

● Ultra-Deep: 3.4sq. degrees
- SXDS/UKIDSS-UDS
- COSMOS-ultra VISTA

HectoMAP: Technical Details

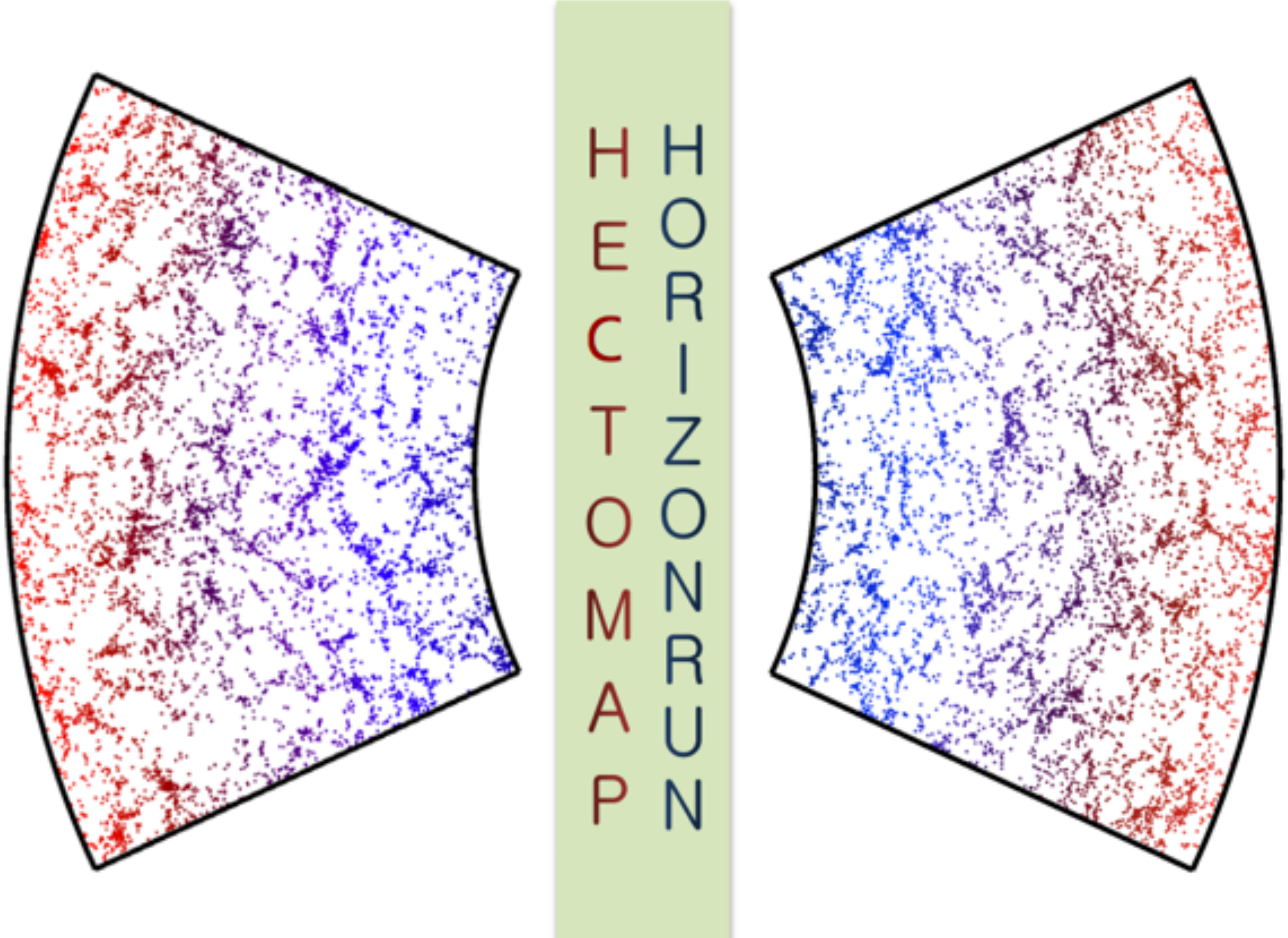
- 80,000 redshifts with $z_{med}=0.4$ in 50 deg^2 (200°<R.A.<250° & 42.5°<Decl.<44°)
- Spring 2010 – Spring 2016 (Bright/Gray/Dark-time)
- Targets: red galaxies with r<21.3 & g-r>1 & r-i>0.5
- Wavelength: 350-1000 nm, R~1000 (~30 km s^{-1})
- MMT/Hectospec: 300 fibers with 1 deg diameter FOV


M. Geller

S. Miyazaki

A. Diaferio



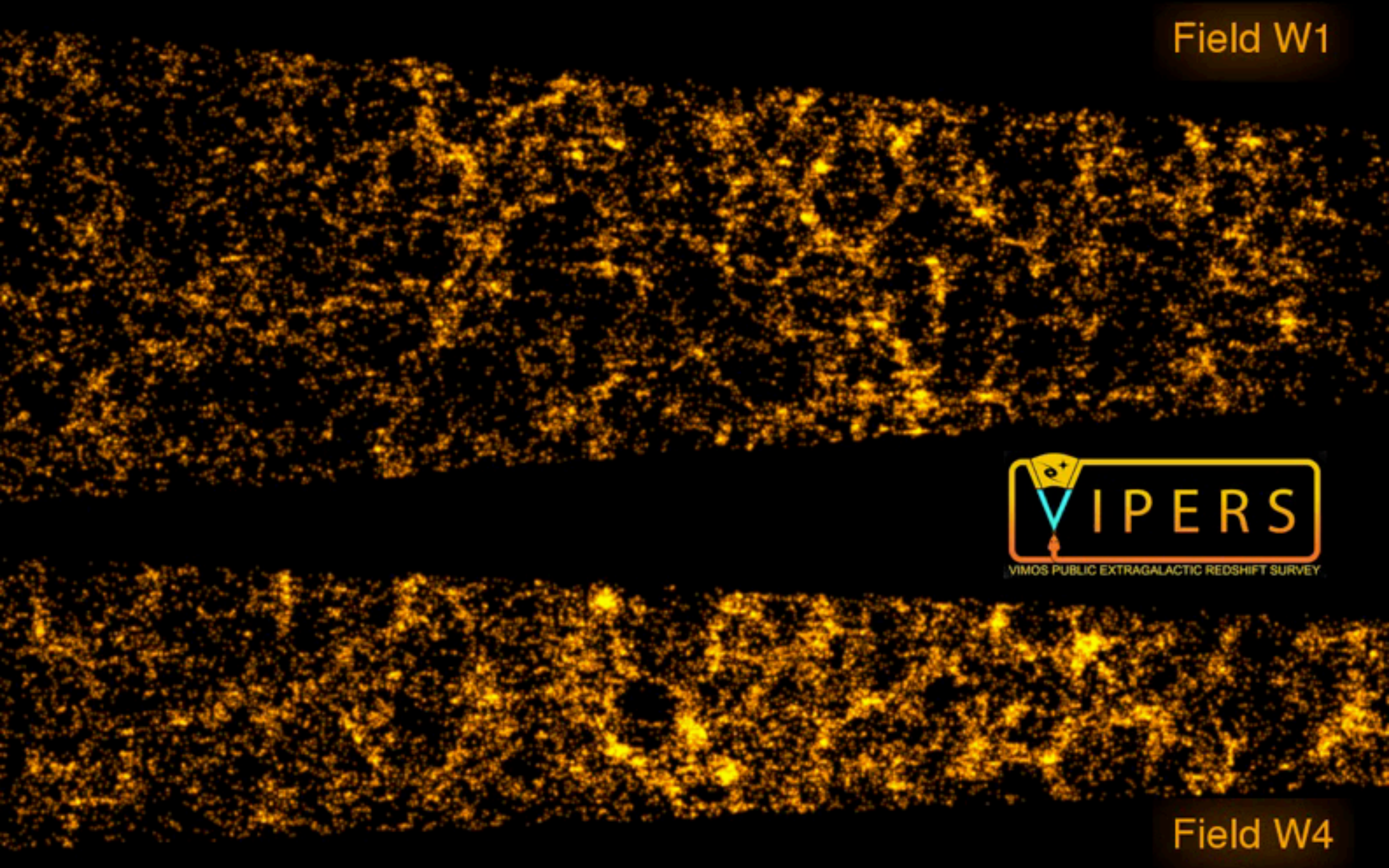
C. Park
H.S. Hwang

J. Kim

HectoMAP: Science Goals

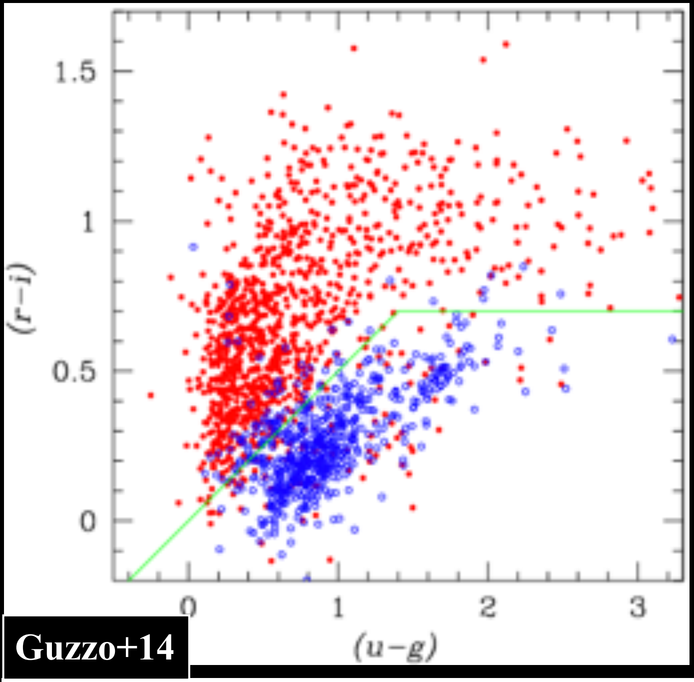
- Comparison of the projected mass density with the Subaru HSC weak lensing map
- A direct measure of the mass accretion rate of clusters of galaxies
- Exploration of the largest structures including the detailed relationship between massive clusters and the surrounding large-scale structure
- Evolution of voids

Current: High Redshift - VIPERS

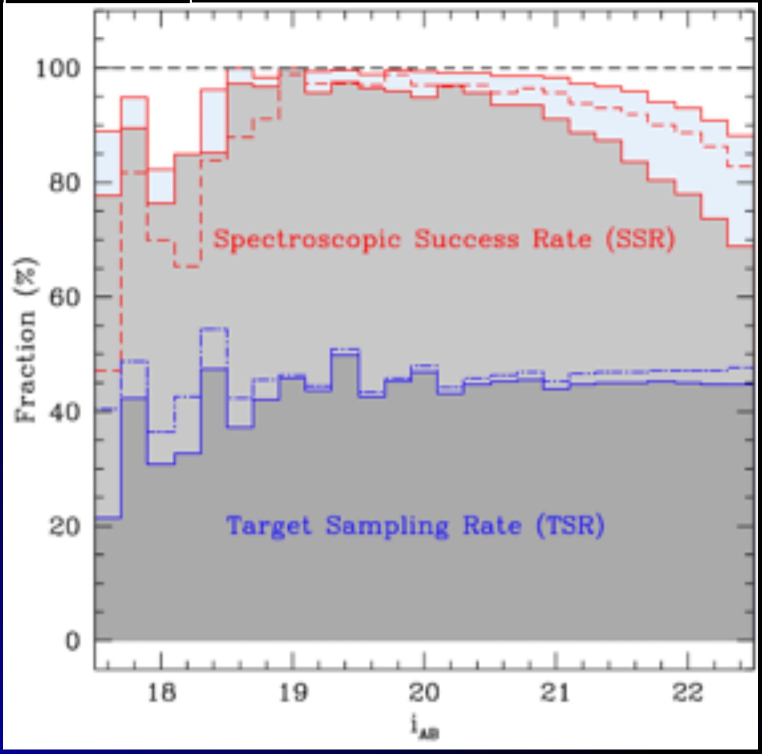


Guzzo+14

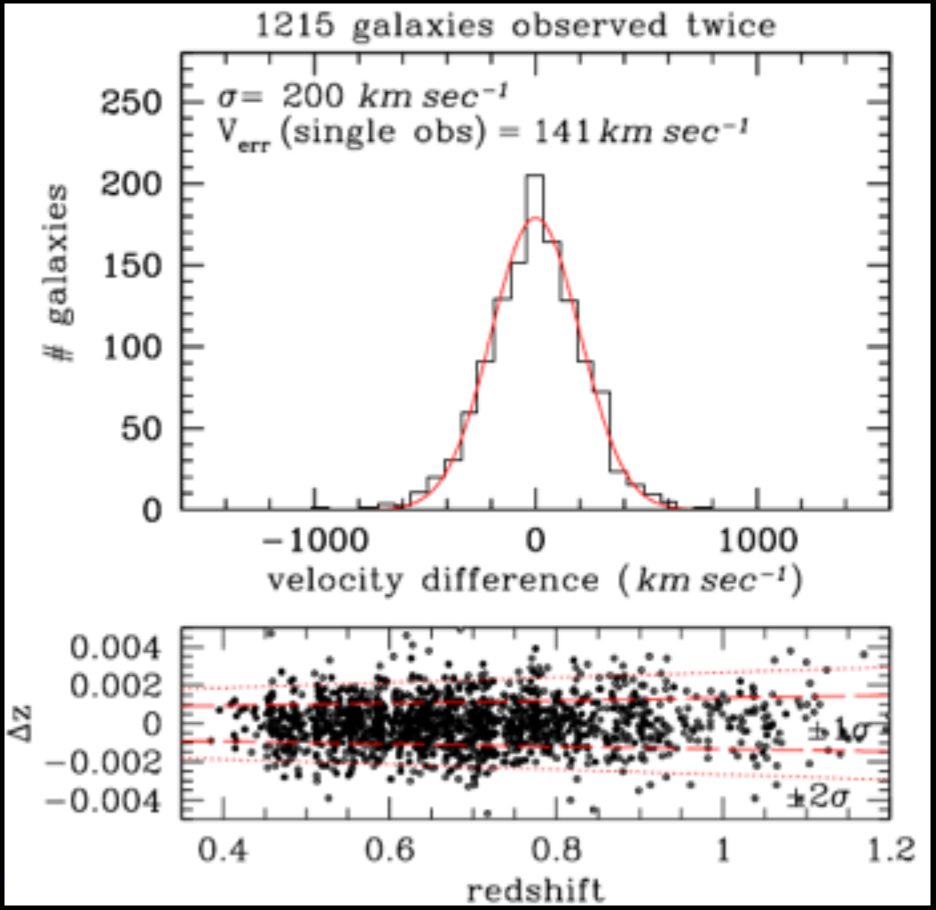
Current: High Redshift - VIPERS



Guzzo+14



- ~10^5 galaxies with i_{AB}<22.5 and 0.5<z<1.5 (color selection for z)
- ~24 deg^2 within the CFHTLS-Wide W1/W4 fields
- PDR-1 with 57,204 redshifts



HSC survey parameters (tentative)

	g	r	i	z	y	
wide	26.2	25.9	26.2	25	24	
deep	22.7	27.4	27.0	25.7	24.5	+3 narrow bands
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5-sigma for 2" aperture, ABmag

● Deep: 28 sq. degree
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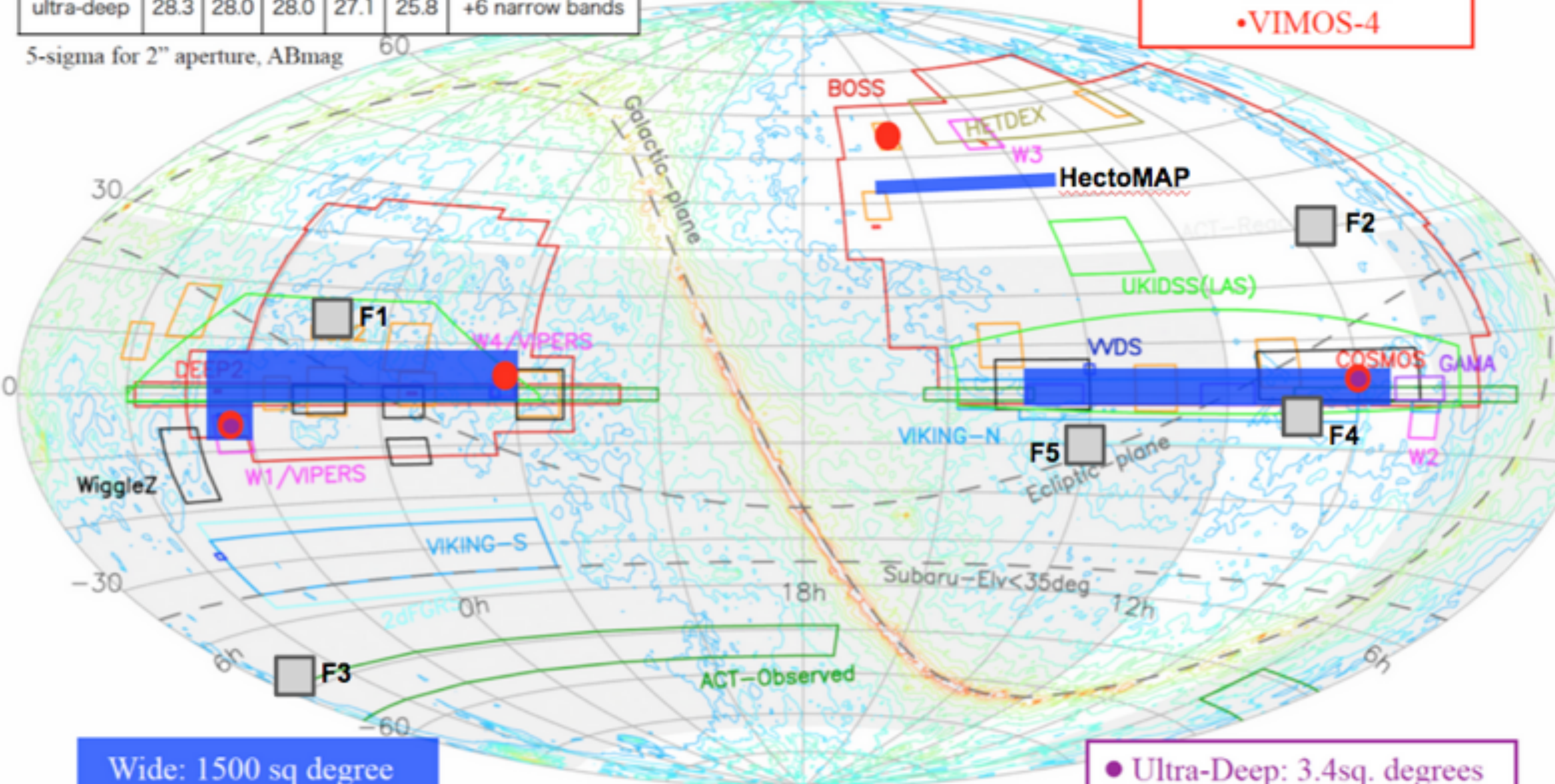
- E-COSMOS
- ELAIS-N1
- VIMOS-4

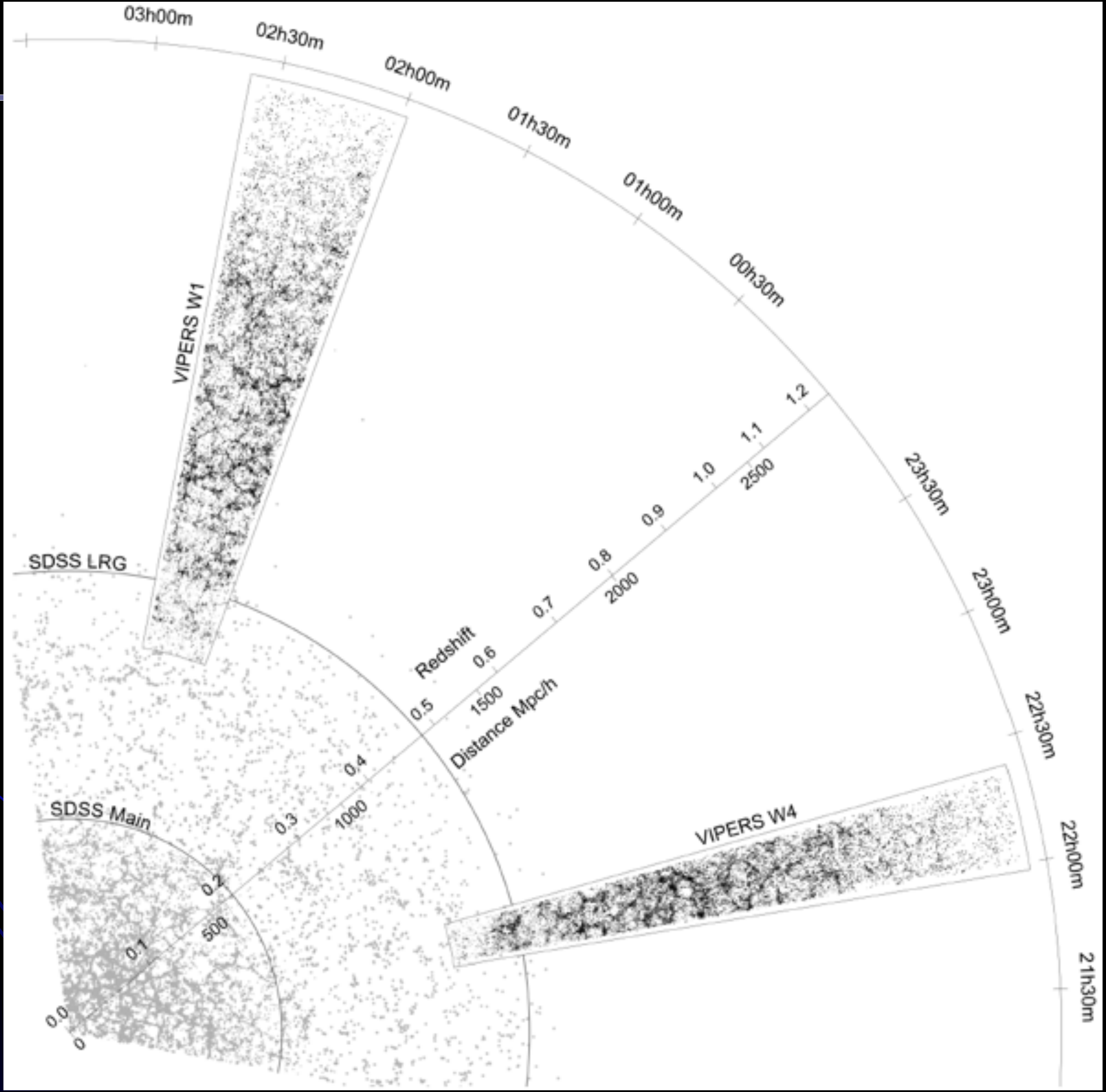


Wide: 1500 sq degree
- 3 fields

Figure Courtesy of A. Nishizawa

● Ultra-Deep: 3.4sq. degrees
- SXDS/UKIDSS-UDS
- COSMOS-ultra VISTA

VIPERS



Guzzo+14

VIPERS: Science Goals

At $0.5<z<1.2$

➢ Measure the growth of structure

➢ Study the clustering of galaxies depending on luminosity and stellar mass

➢ Measure the Power spectrum → Cosmological parameters

➢ Determine the Luminosity snd Stellar Mass functions

Growth Rate

Schneider+

Continuity eq.

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho\, \boldsymbol{v}) = 0$$

Momentum eq.

$$\frac{\partial \boldsymbol{v}}{\partial t} + (\boldsymbol{v} \cdot \nabla)\, \boldsymbol{v} = -\frac{\nabla P}{\rho} - \nabla \Phi$$

Poisson eq.

$$\nabla^2 \Phi = 4\pi G \rho$$

$$\boldsymbol{r} = a(t)\, \boldsymbol{x}$$

$$\boldsymbol{v}(\boldsymbol{r}, t) = \frac{\dot{a}}{a}\boldsymbol{r} + \boldsymbol{u}\left(\frac{\boldsymbol{r}}{a}, t\right)$$

$$\frac{\partial \boldsymbol{u}}{\partial t} + \frac{\boldsymbol{u} \cdot \nabla}{a}\boldsymbol{u} + \frac{\dot{a}}{a}\boldsymbol{u} = -\frac{1}{\overline{\rho}\, a}\nabla P - \frac{1}{a}\nabla \phi$$

Using the Continuity eq., $\rho = \overline{\rho}(1+\delta)$ **& Linearization**

$$\frac{\partial^2 \delta}{\partial t^2} + \frac{2\dot{a}}{a}\frac{\partial \delta}{\partial t} = 4\pi G \overline{\rho} \delta$$

$$\delta(\boldsymbol{x}, t) = D(t)\, \tilde{\delta}(\boldsymbol{x})$$

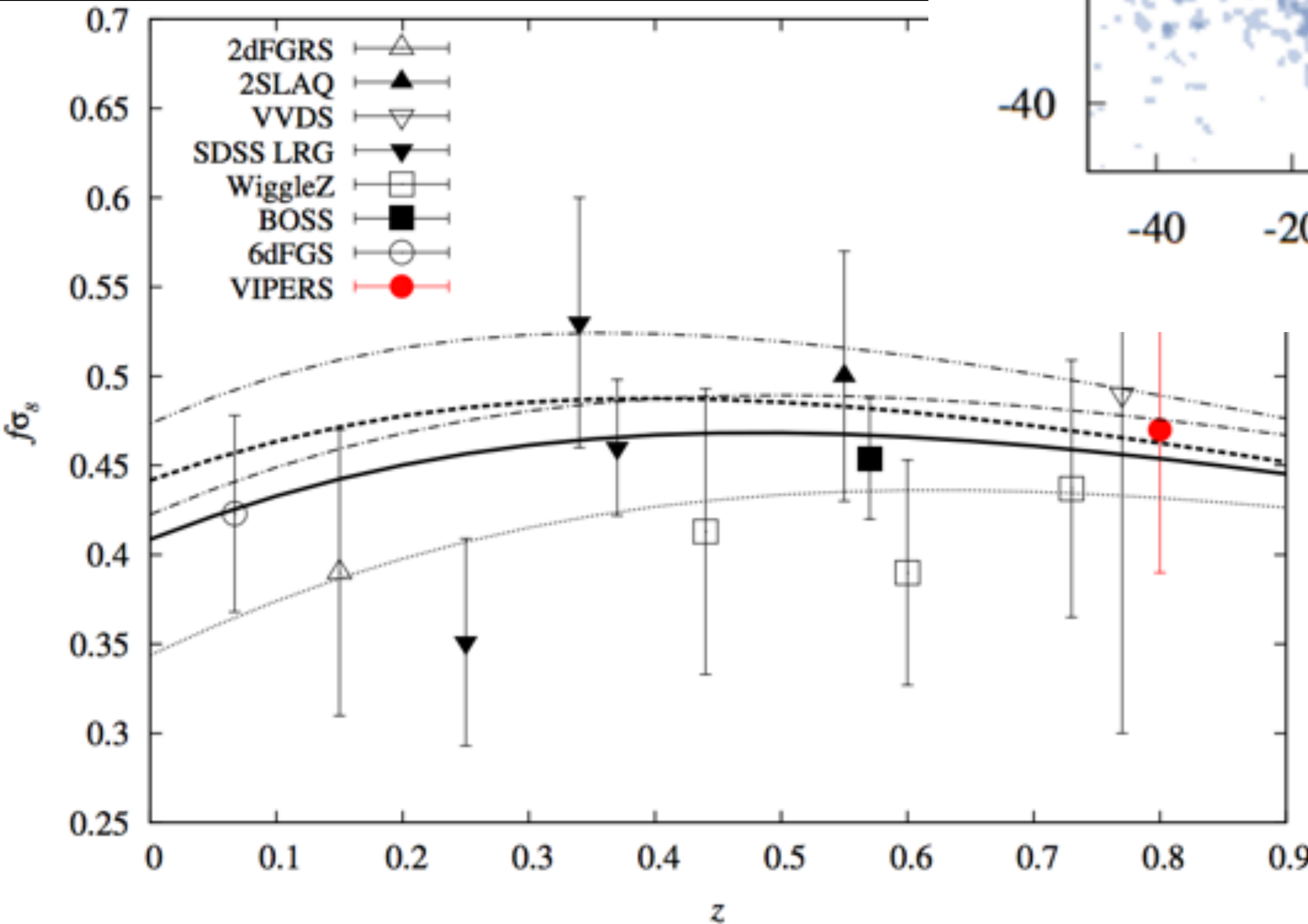
$$\ddot{D} + \frac{2\dot{a}}{a}\dot{D} - 4\pi G \overline{\rho}(t)\, D = 0$$

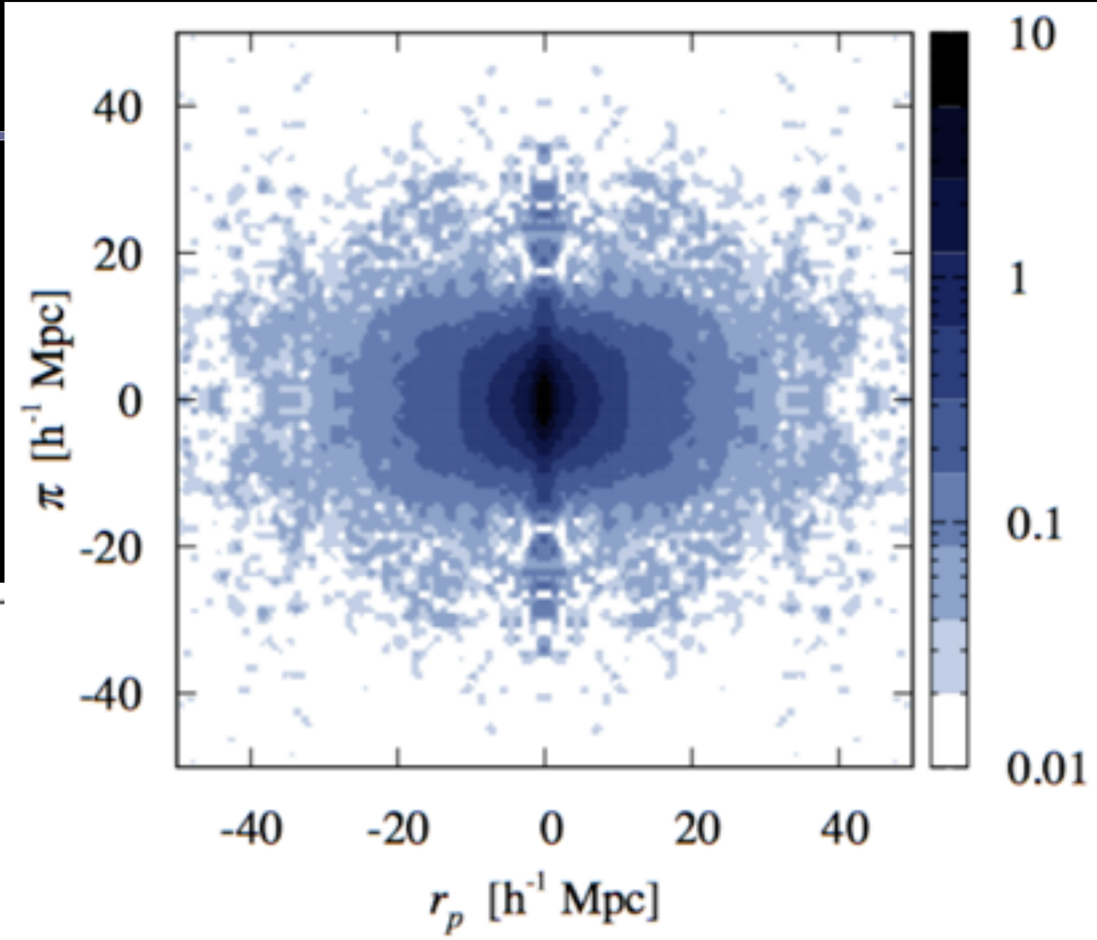
$$f = \frac{d \ln D(a)}{d \ln a}$$

VIPERS: Growth Rate

$$f\sigma_8(a) = d\sigma_8(a)/d\ln a$$

$$\sigma_8(a) = \sigma_8 D(a)$$

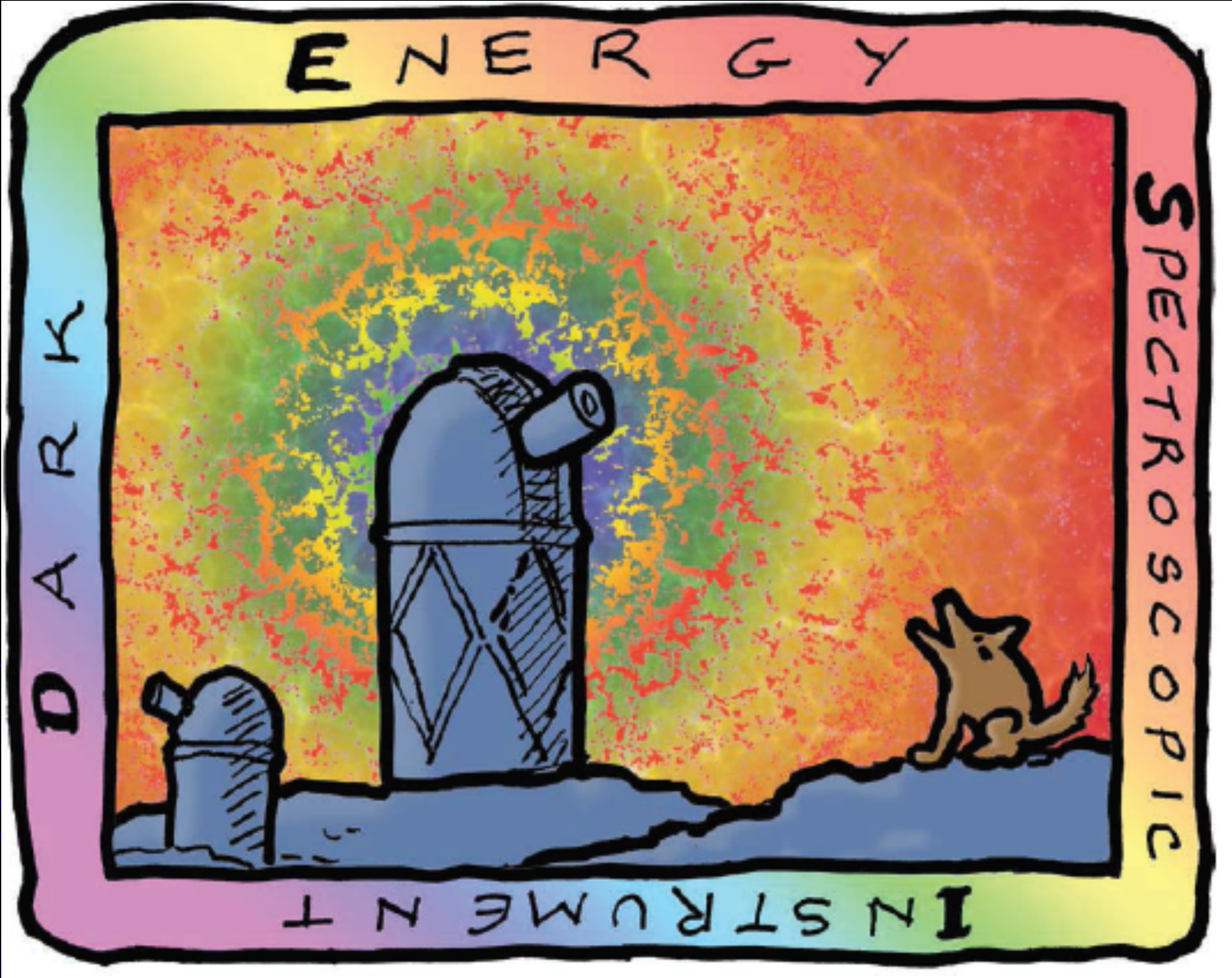




de la Torre+13

DESI (Dark Energy Spectroscopic Instrument)

- Formally BigBOSS
- (Imaging &) Spectroscopic Survey with 4m Mayall telescope
- 2018 - 2022

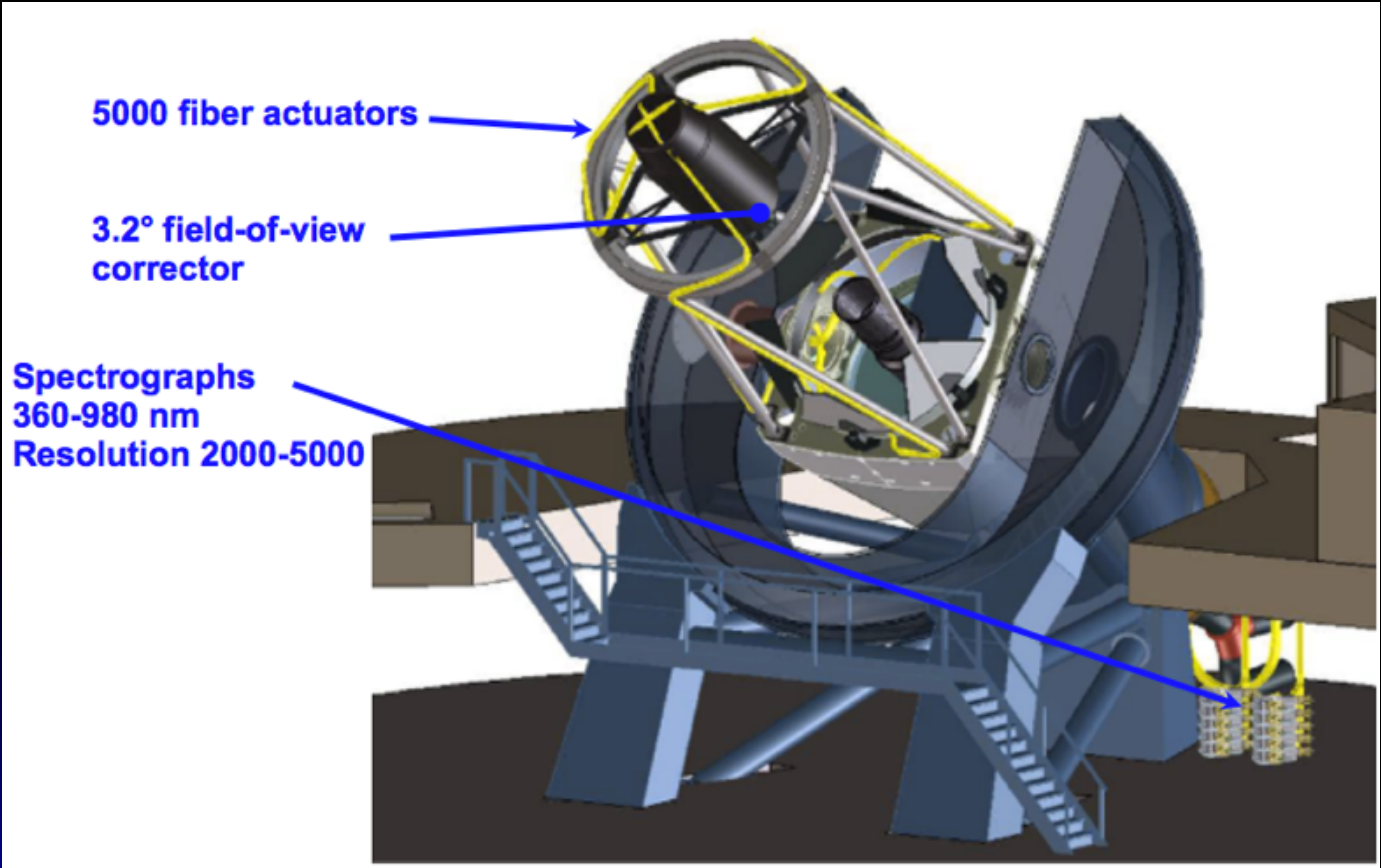


DESI: Project Members

Interim Institutional Board

- University of the Andes, Columbia - Jaime Forero-Romero
- University of Arizona and Steward Observatory - Buell Jannuzi
- Anglo-Australian Observatory - Andrew Sheinis
- Argonne National Lab - Salman Habib
- University of Barcelona - Francisco Castander
- University of California, Berkeley - Jerry Edelstein
- Observatorio Nacional, Brazil - Luiz Nicolaci da Costa
- Brookhaven National Lab - Anze Slosar
- CEA-Saclay - Christophe Yeche
- Carnegie Mellon University - Shirley Ho
- Laboratoire d'Astrophysique de Marseille - Jean-Gabriel Cuby
- Le Centre de Physique des Particules de Marseille - Anne Ealet
- Cornell University - Rachel Bean
- Durham University - Jeremy Allington-Smith
- University of Edinburgh - John Peacock
- Ecole Polytechnique Federale de Lausanne EPFL - Jean-Paul Kneib
- ETH Zurich - Alexandre Refregier
- Fermi National Accelerator Laboratory - Brenna Flaugher
- Harvard University - Daniel Eisenstein
- University of California, Irvine - David Kirkby
- University of Kansas - Gregory Rudnick
- Kansas State University - Bharat Ratra
- Korea Astronomy and Space Science Institute - Yong-Seon Song
- Korea Institute for Advanced Study - Changbom Park
- Lawrence Berkeley National Lab - David Schlegel
- Universidad Nacional Autonoma de Mexico - Axel de la Macorra
- University of Michigan - Gregory Tarle
- National Optical Astronomy Observatory - Robert Blum
- New York University - Michael Blanton
- University of Pittsburgh - Jeffrey Newman
- University of Portsmouth - Will Percival
- Ohio State University - Klaus Honscheid
- University of California, Santa Cruz - Constance Rockosi
- University of Science & Technology - Zhai Chao
- Shanghai Astronomical Observatory - Cheng Li
- Siena College - John Moustakas
- Shanghai Jiao Tong University - Pengjie Zhang
- Southern Methodist University - Robert Kehoe
- Stanford National Accelerator Lab - Aaron Roodman
- University of Madrid - Francisco Prada
- Universidad Autonoma de Madrid-HCTLab Guillermo Gonzalez-de-Rivera
- Texas A&M University - Darren Depoy
- University of Toronto - Ray Carlberg
- University of London - Ofer Lahav
- University of Utah - Adam Bolton
- Washington University at St. Louis - Jim Buckley
- University of Wyoming - Adam Myers
- Yale University - Charlie Baltay

DESI: Instrument

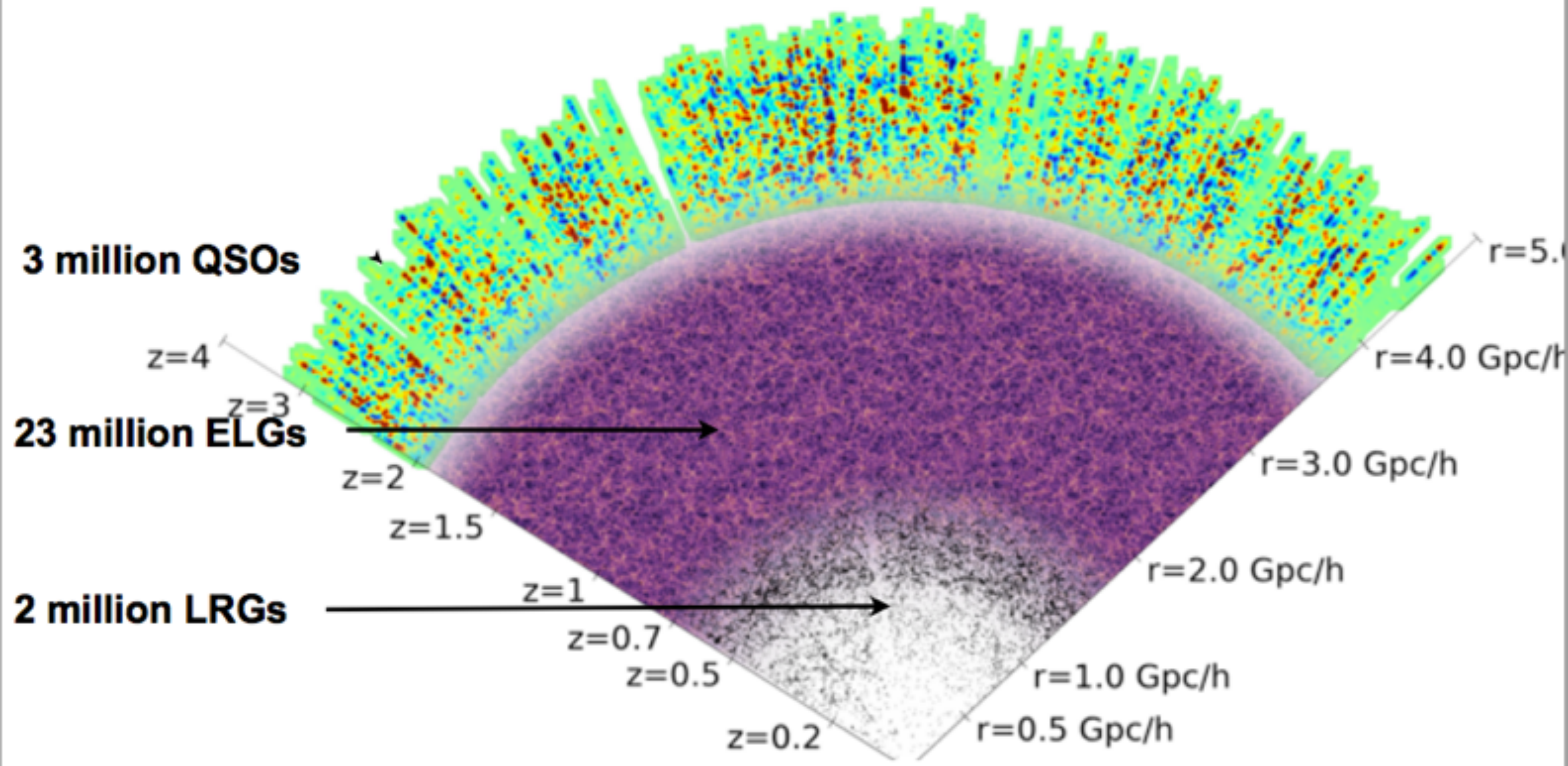


Mayall 4-meter telescope at KPNO (Schlegel+)

DESI: Sample Selection

The largest spectroscopic survey for dark energy

SDSS ~$2h^{-3}$Gpc^3 ⇨ BOSS ~$6h^{-3}$Gpc^3 ⇨ DESI $50h^{-3}$Gpc^3



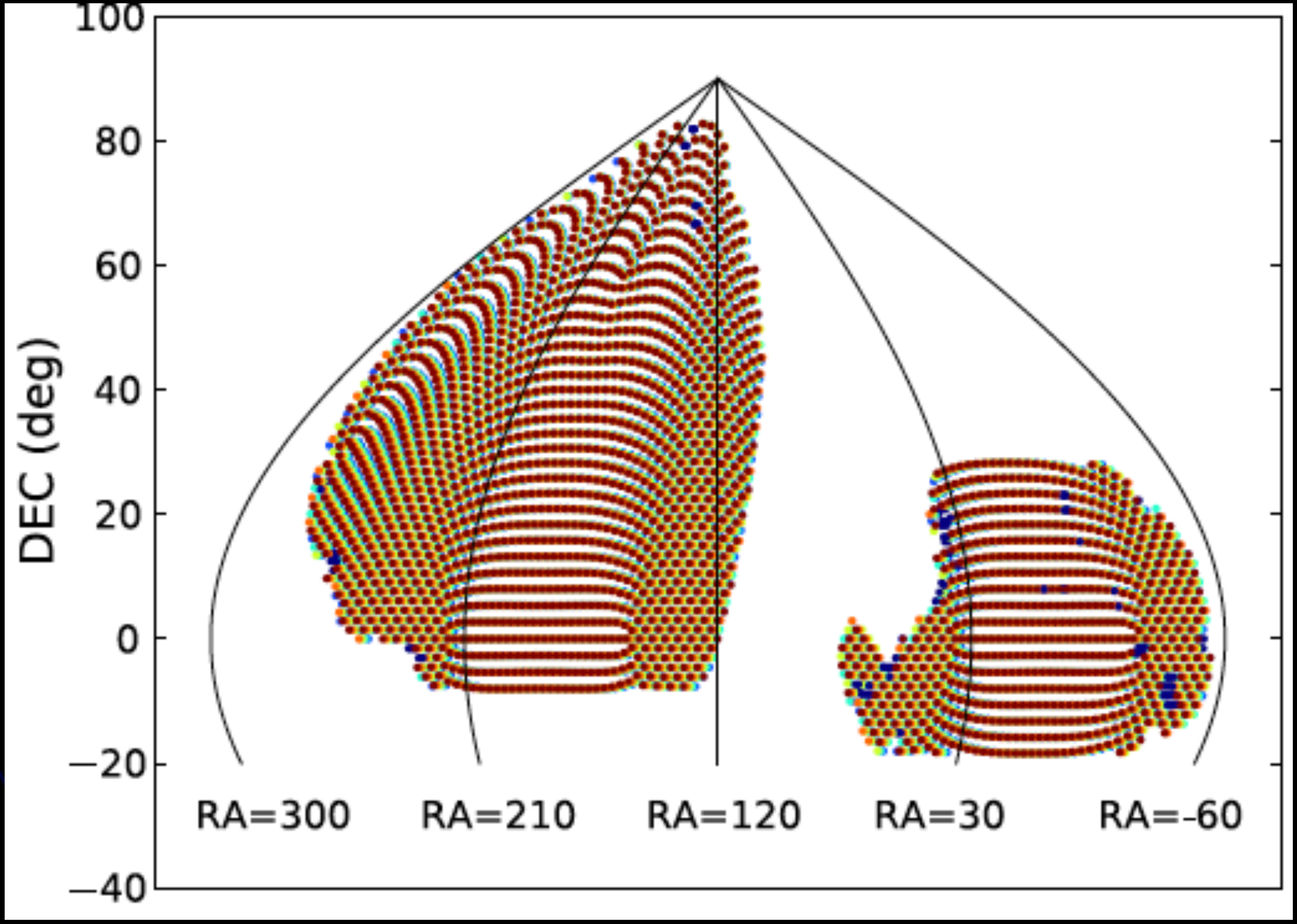
Schlegel+

DESI: Sample Selection

Telescope	Bands	Area deg^2	Location
Blanco DECam	g,r,z	9k	NGC+SGC equatorial (Dec< +30 deg)
Bok 90Prime	g,r	5k	NGC (Dec> +30 deg)
Bok z-band dewar	z	5k	NGC (Dec> +30 deg)
WISE-W1	3.4 μm	all sky	all-sky
WISE-W2	4.6 μm	all sky	all-sky

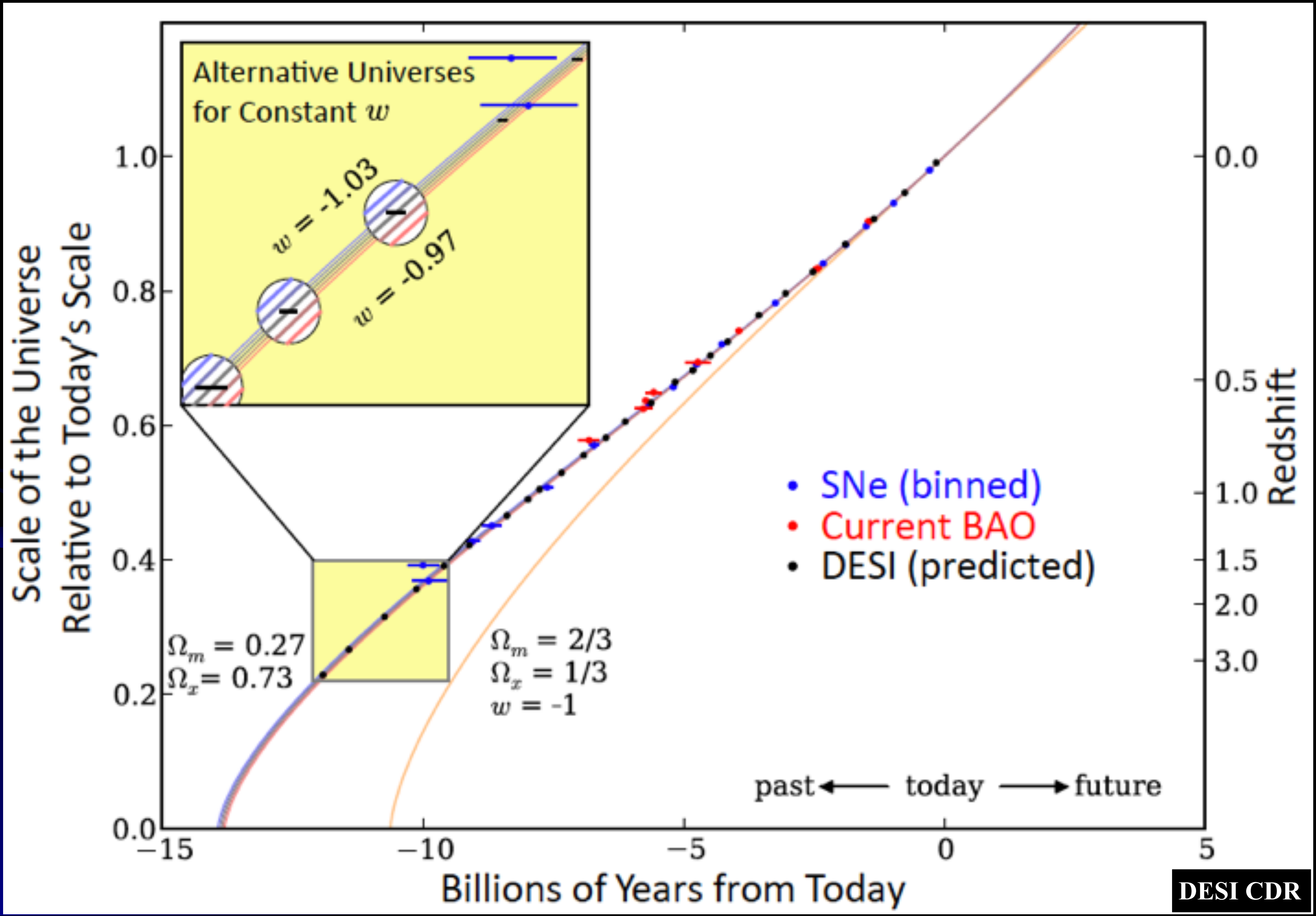
DESI CDR

- g=24.0
- r=23.6
- z=23.0



DESI: Science Goals

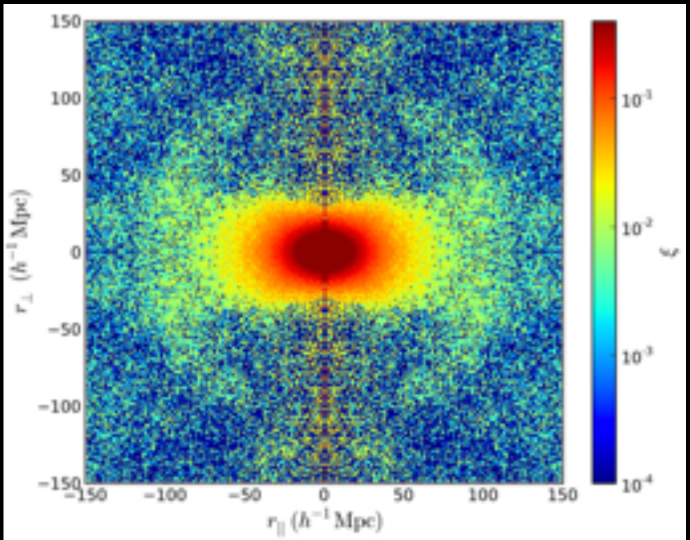
➢ **BAO: the effects of dark energy on the expansion history**



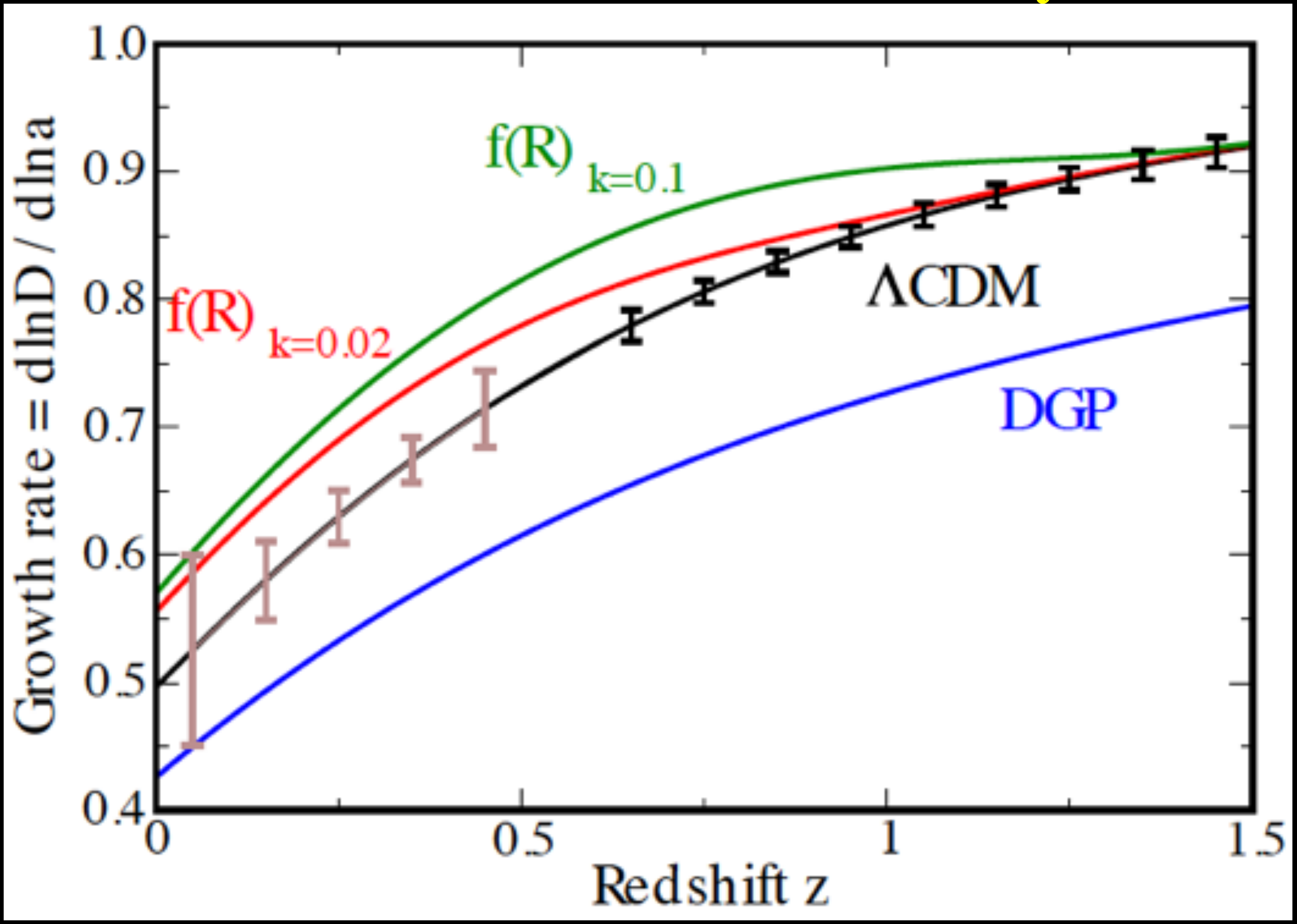
DESI CDR

DESI: Science Goals

➢RSD: Growth of Structure → Test of General Relativity



Samushia+14



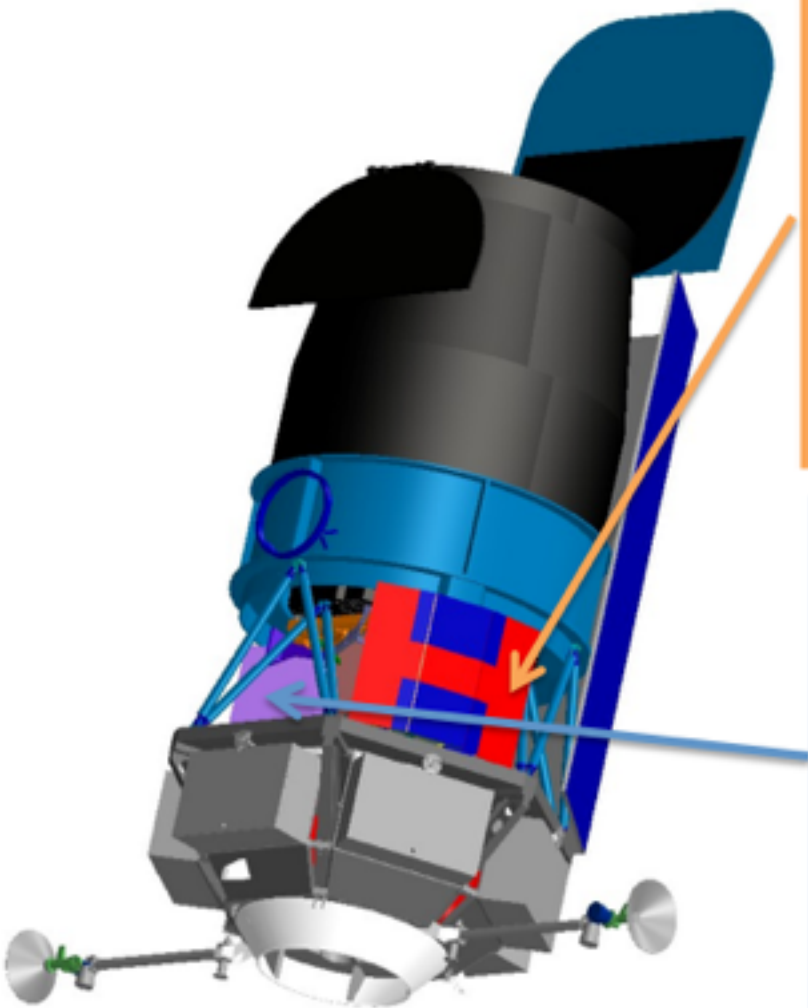
Huterer+13

DESI: Science Goals

- Cosmology Beyond Dark Energy
  - Test of non-Gaussianity in the primordial density field
  - Test of inflation
  - Measure of the sum of the neutrino masses

- More info : Conceptual Design Report at http://desi.lbl.gov/

Future: WFIRST-AFTA



Wide-Field Instrument

- *Imaging & spectroscopy over 1000s of sq. deg.*
- *Monitoring of SN and microlensing fields*
- 0.7 – 2.0 micron bandpass
- 0.28 deg^2 FoV (100x JWST FoV)
- 18 4kx4k H4RG HgCdTe detectors
- 6 filter imaging, grism + IFU spectroscopy

Coronagraph

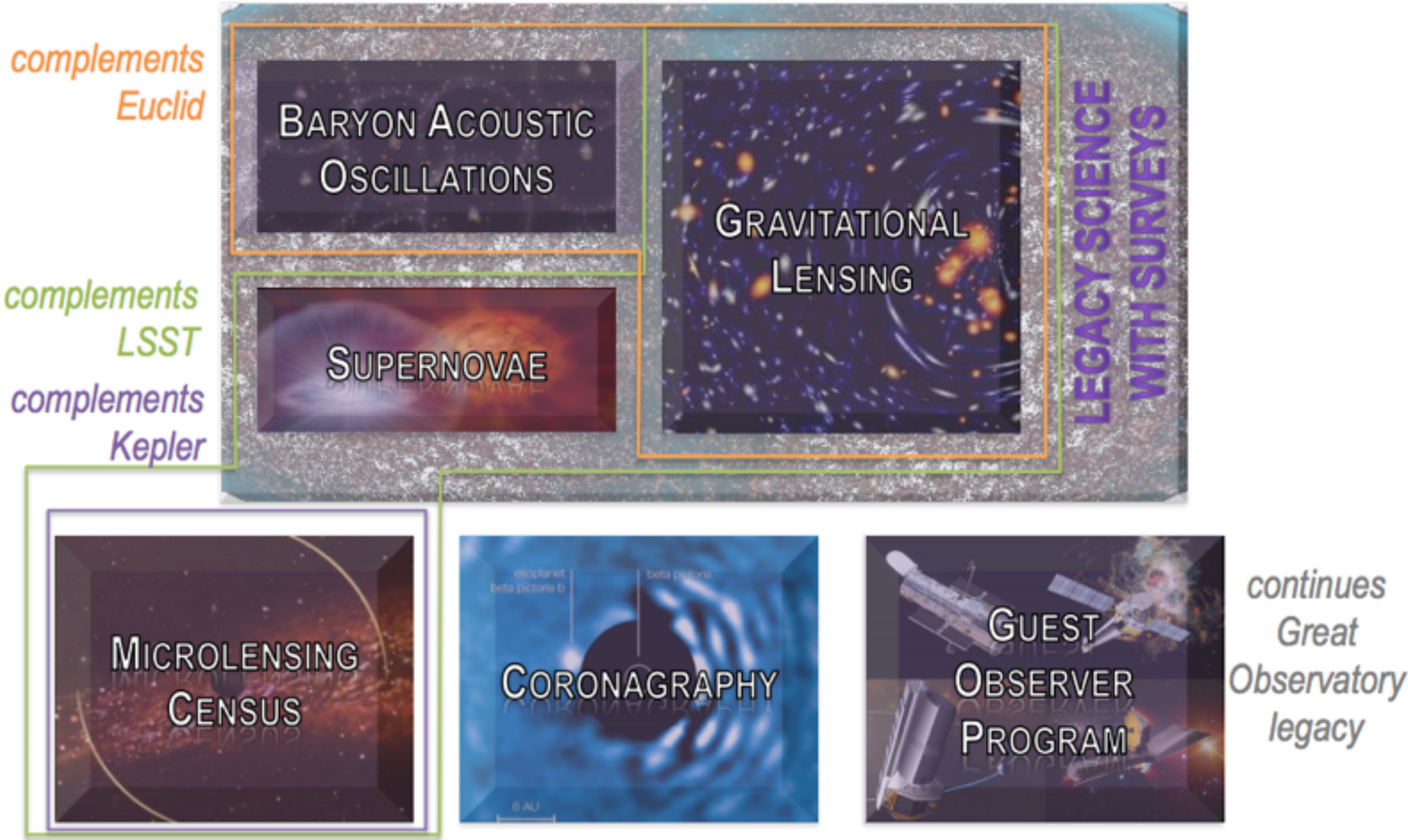
- *Imaging of ice & gas giant exoplanets*
- *Imaging of debris disks*
- 400 – 1000 nm bandpass
- d10^{-9} contrast (after post-processing)
- 100 milliarcsec inner working angle at 400 nm

➢ **More info : 2015 Report (Spergel+15, arXiv: 1503.03757)**

➢ **Launch: before 2024**

Borrowed from WFIRST-AFTA team

Future: WFIRST-AFTA

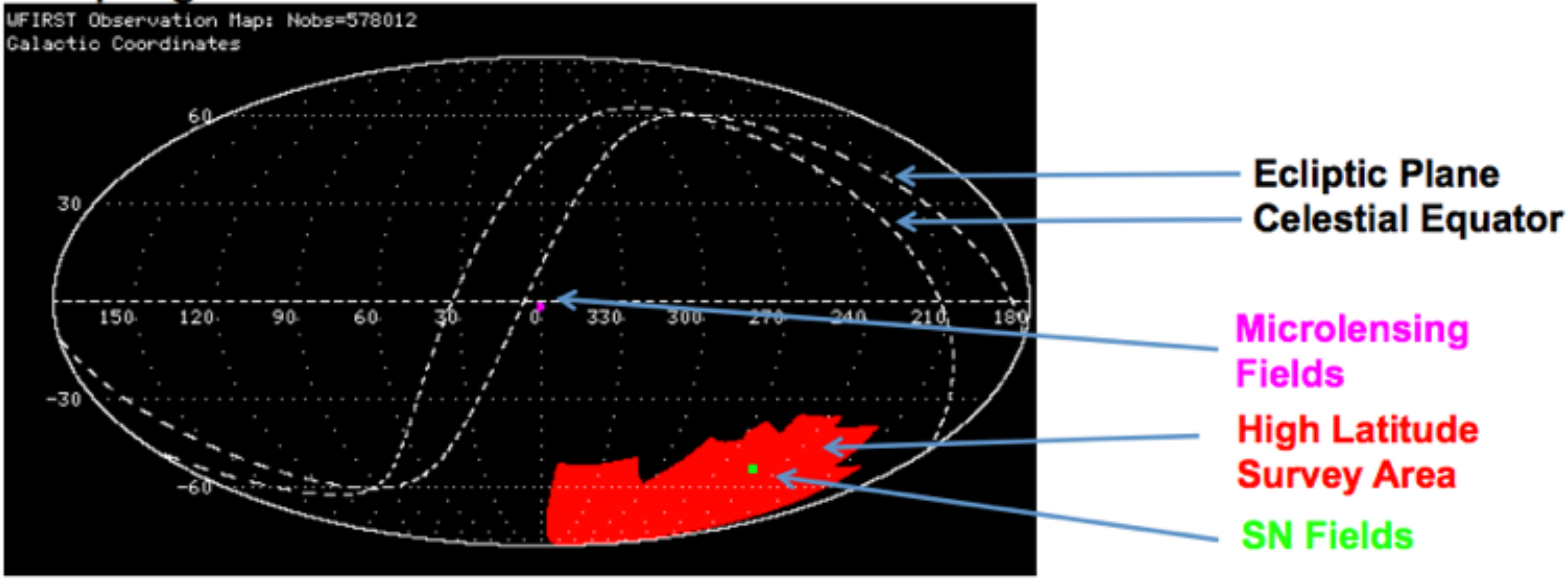


SDSS in space!

Borrowed from WFIRST-AFTA team

Future: WFIRST-AFTA

- High latitude survey (HLS: imaging + spectroscopy): 1.96 years
  - **2400 deg^2** @ ≥3 exposures in all filters (2440 deg^2 bounding box)
- 6 microlensing seasons (0.98 years, after lunar cutouts)
- SN survey in 0.62 years, field embedded in HLS footprint
- 1 year for the coronagraph, interspersed throughout the mission
- GO program is **25%** of the mission



Borrowed from WFIRST-AFTA team

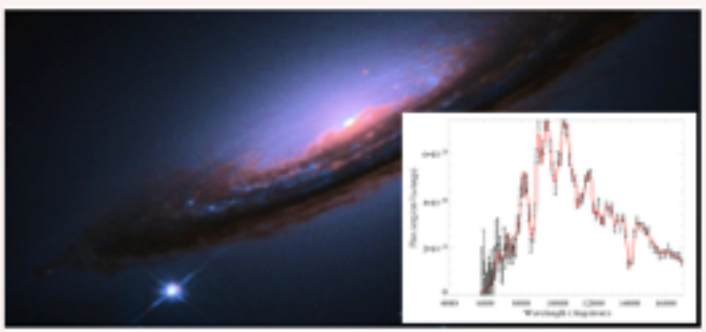
Future: WFIRST-AFTA - Dark Energy Roadmap

Supernova Survey

wide, medium, & deep imaging
+
IFU spectroscopy

2700 type Ia supernovae
z = 0.1–1.7

standard candle distances
z < 1 to 0.20% and z > 1 to 0.34%



High Latitude Survey

spectroscopic: galaxy redshifts

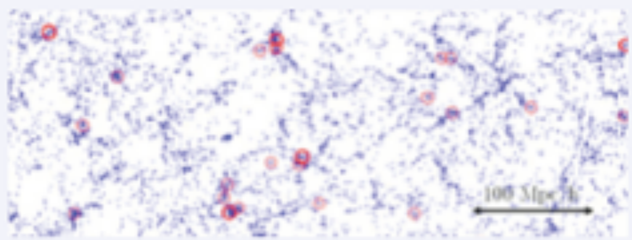
16 million Hα galaxies, z = 1–2
1.4 million [OIII] galaxies, z = 2–3

imaging: weak lensing shapes

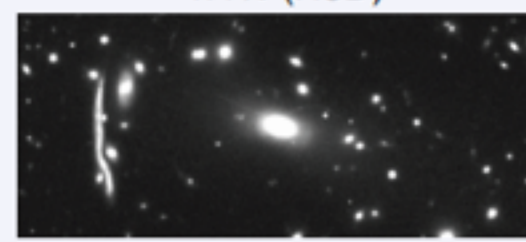
380 million lensed galaxies
40,000 massive clusters

standard ruler

distances	expansion rate
z = 1–2 to 0.5%	z = 1–2 to 0.9%
z = 2–3 to 1.3%	z = 2–3 to 2.1%

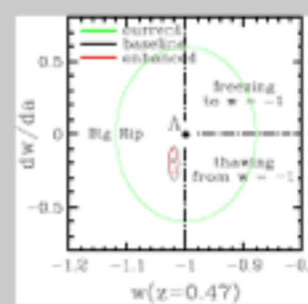


dark matter clustering
z < 1 to 0.21% (WL); 0.24% (CL)
z > 1 to 0.78% (WL); 0.88% (CL)
1.1% (RSD)



history of dark energy
+
deviations from GR

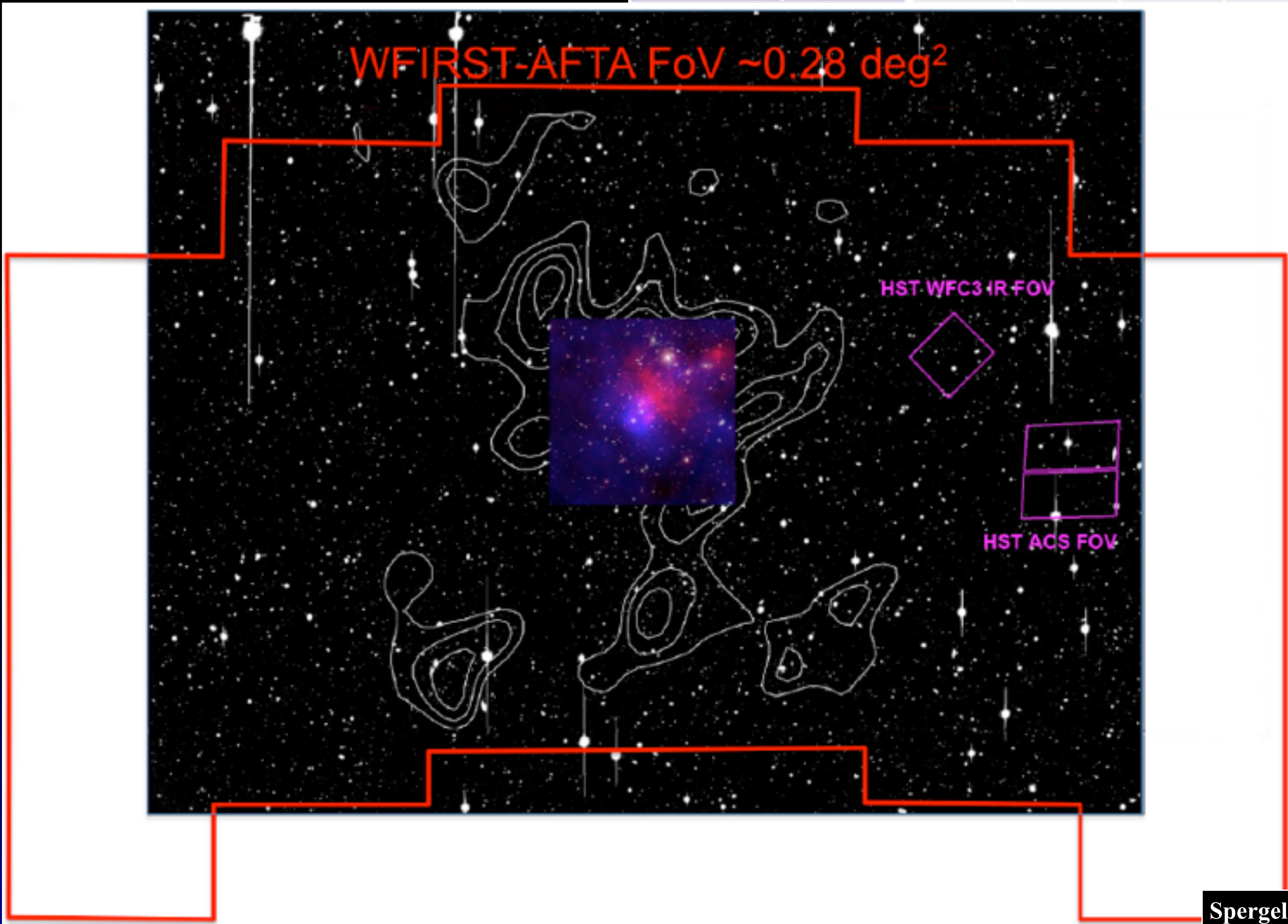
w(z), ΔG(z), Φ_{REL}/Φ_{NREL}



Spergel+15

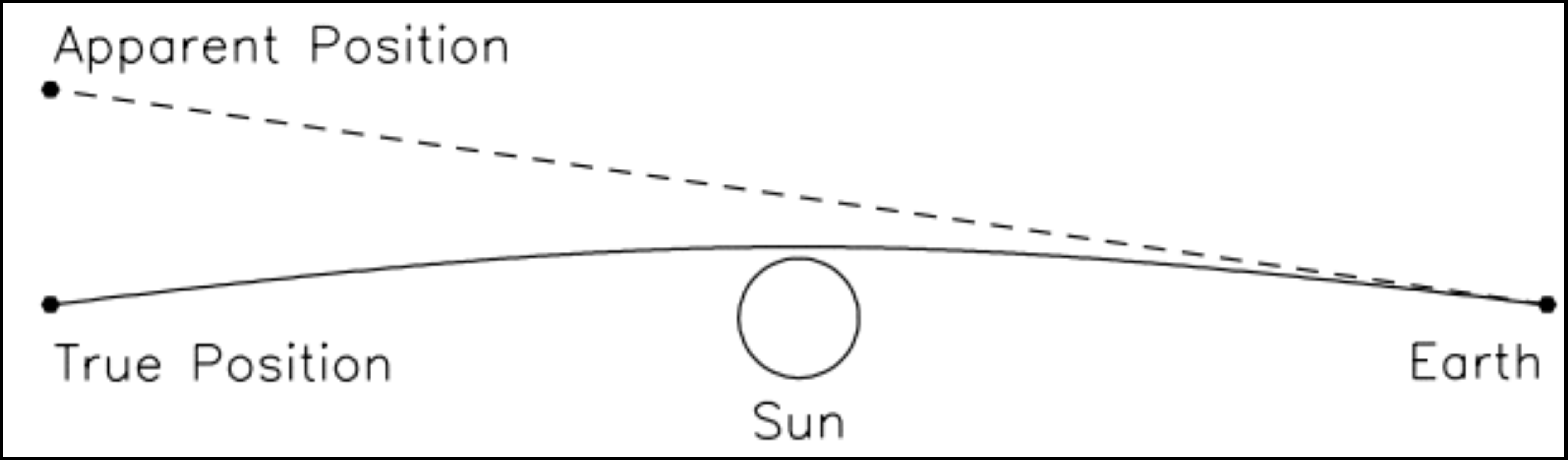
Future: WFIRST-AFTA

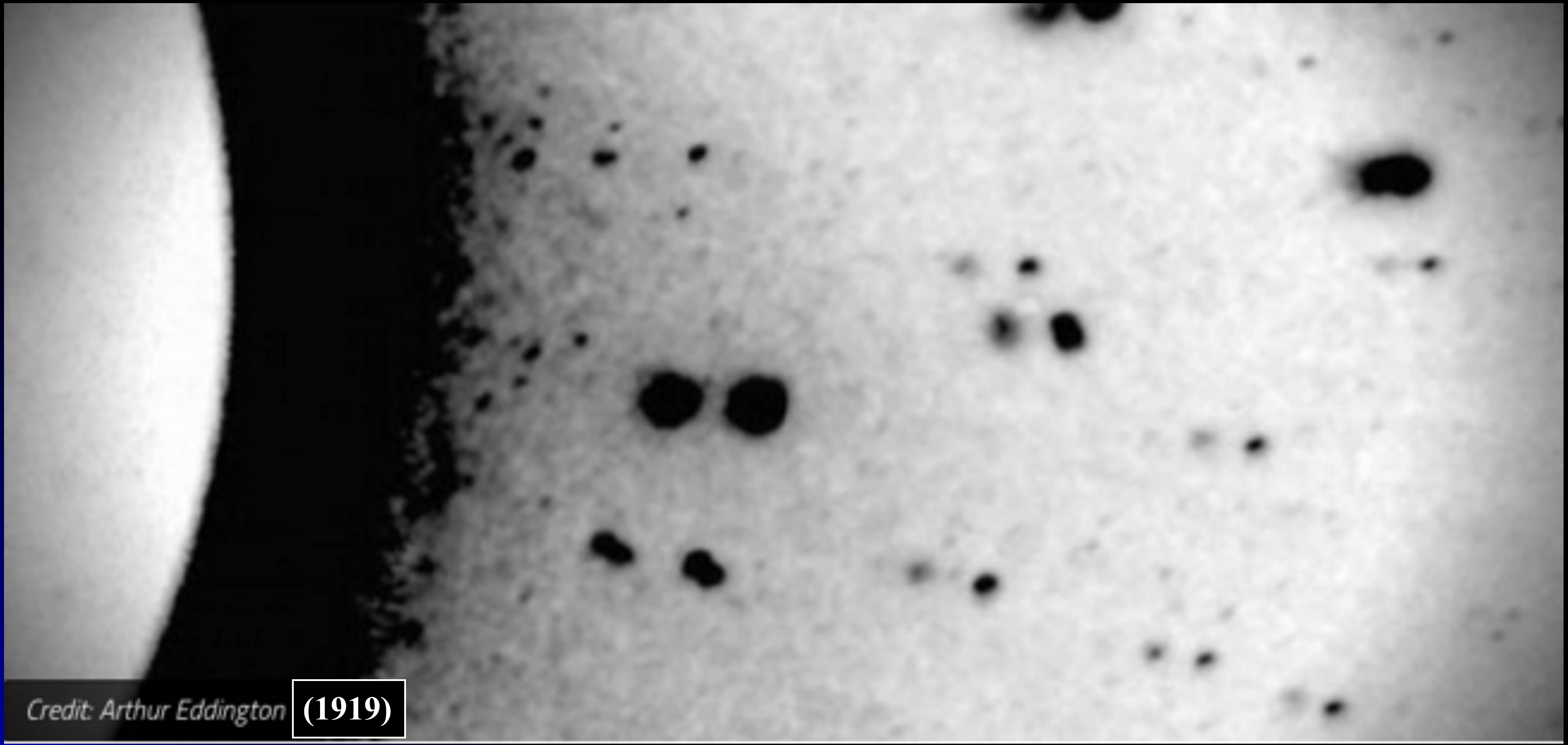
Characteristic	Y	J	H	F184
λ_{min} (μm)	0.927	1.131	1.380	1.683



Spergel+15

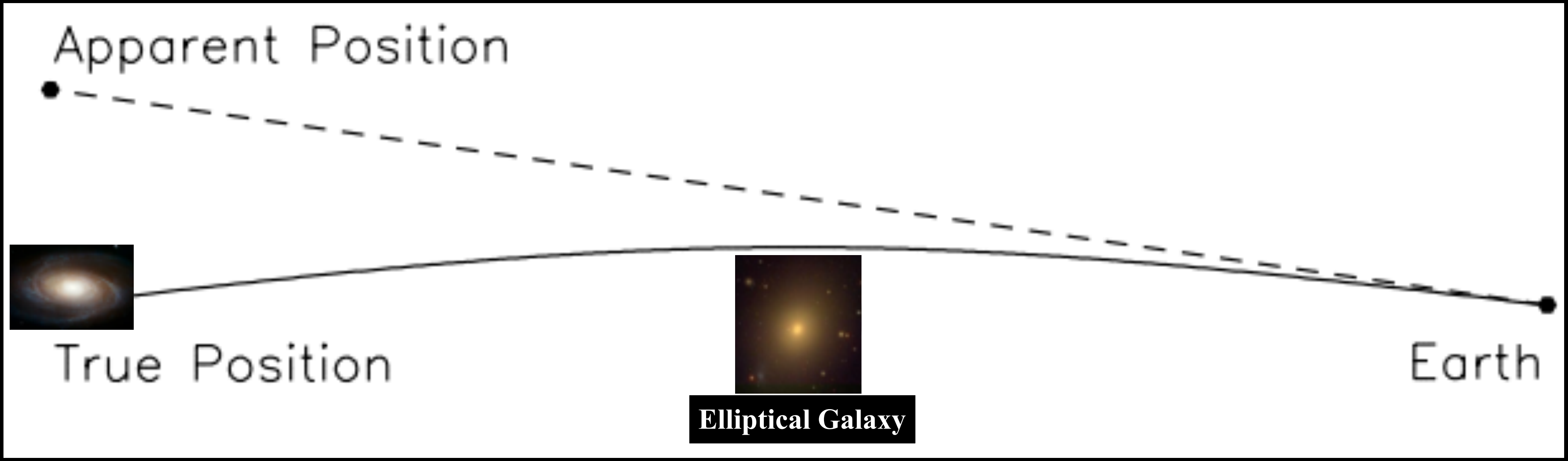
Gravitational Lensing

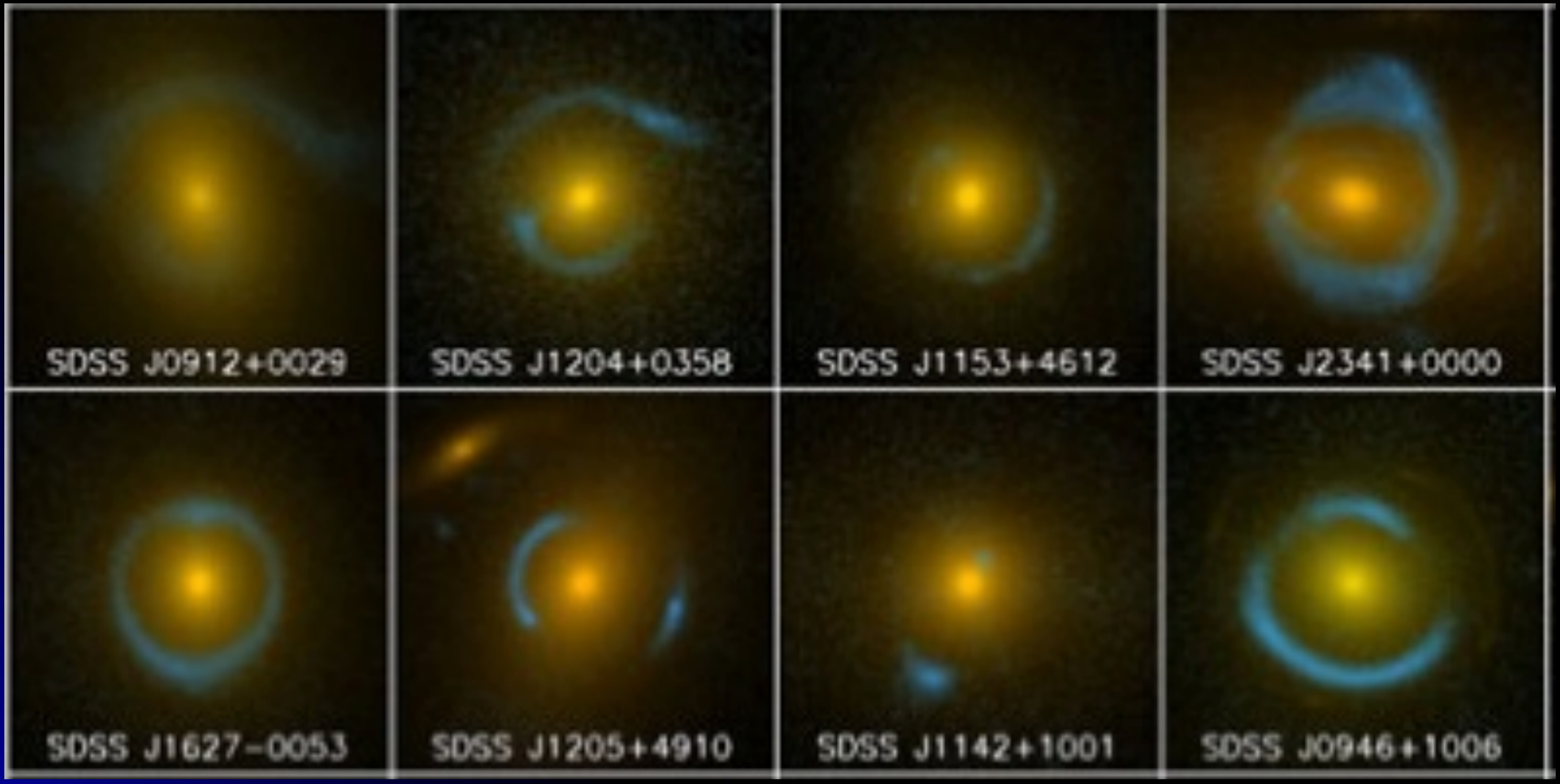




Narayan & Bartelmann (2008)

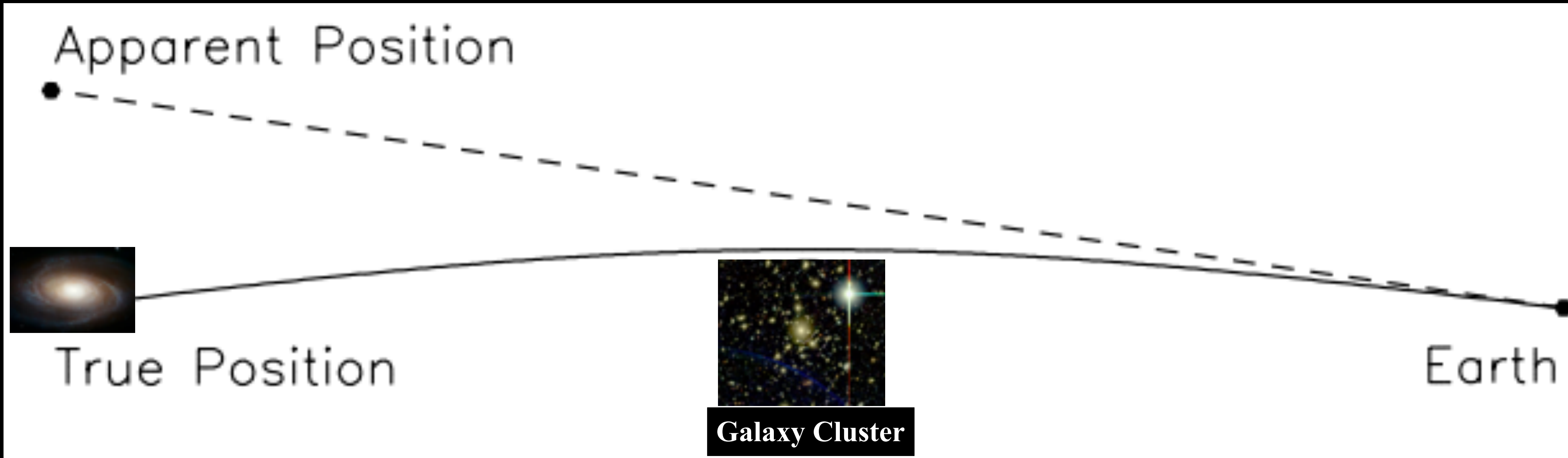
Gravitational Lensing





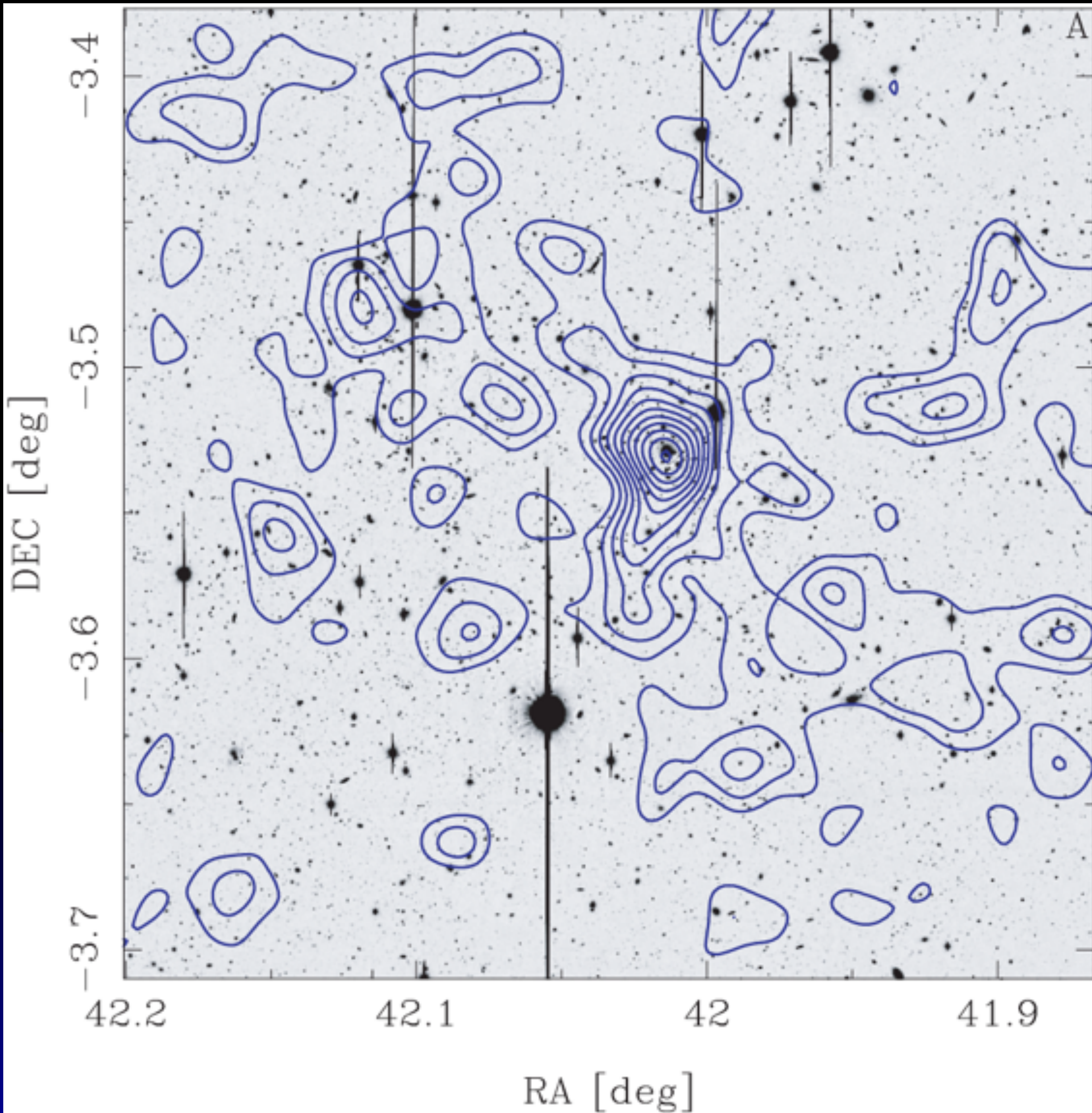
SLACS (Bolton+)

Gravitational Lensing

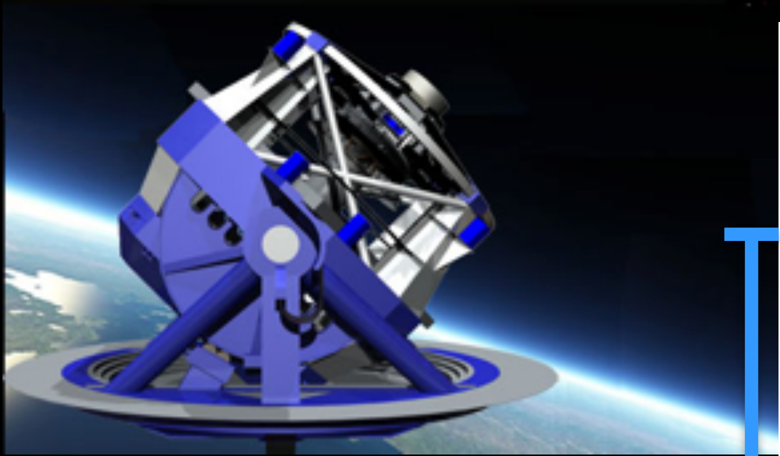


Coe+

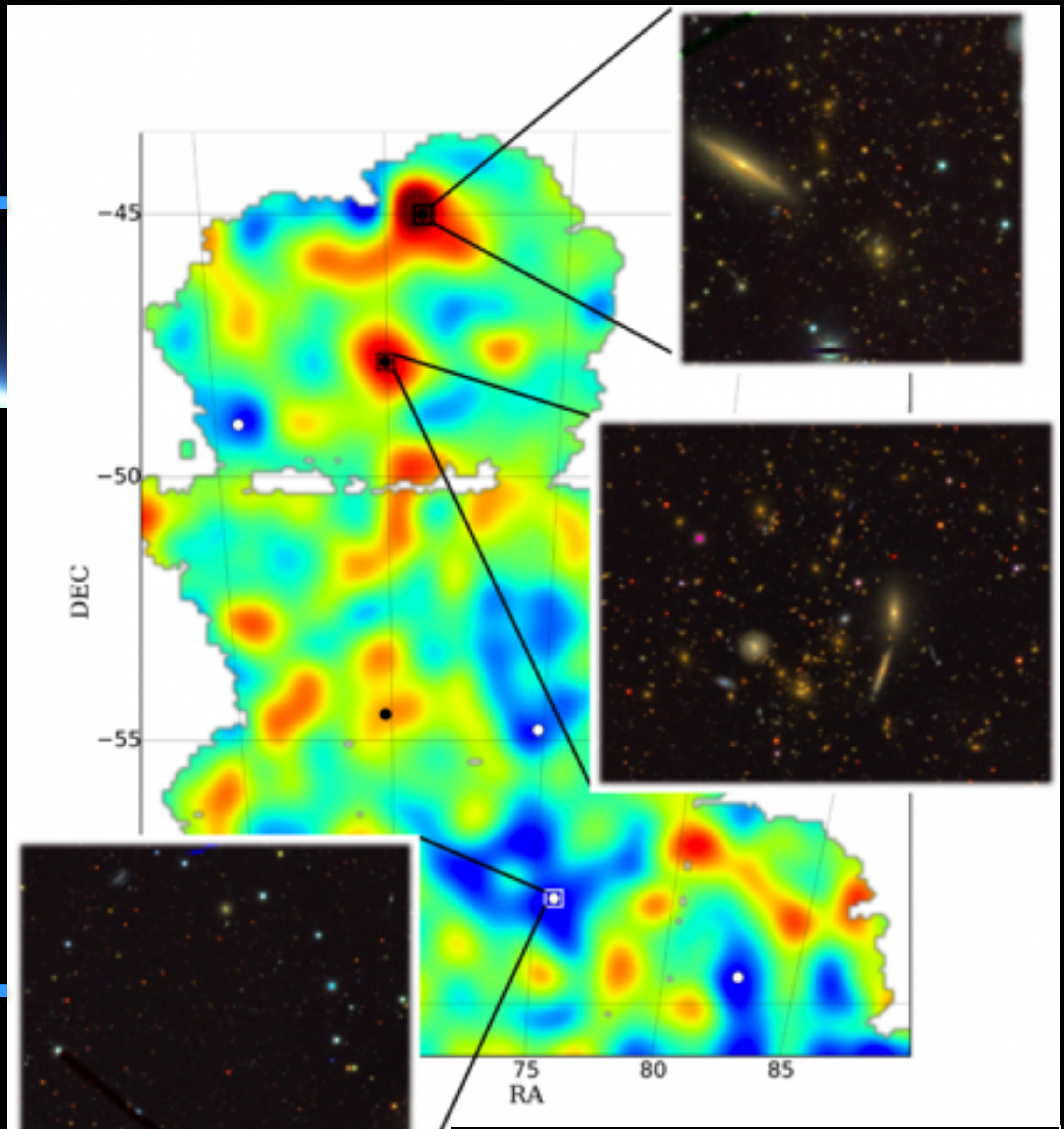
A383 (Coe+)



A383 (Okabe+10)

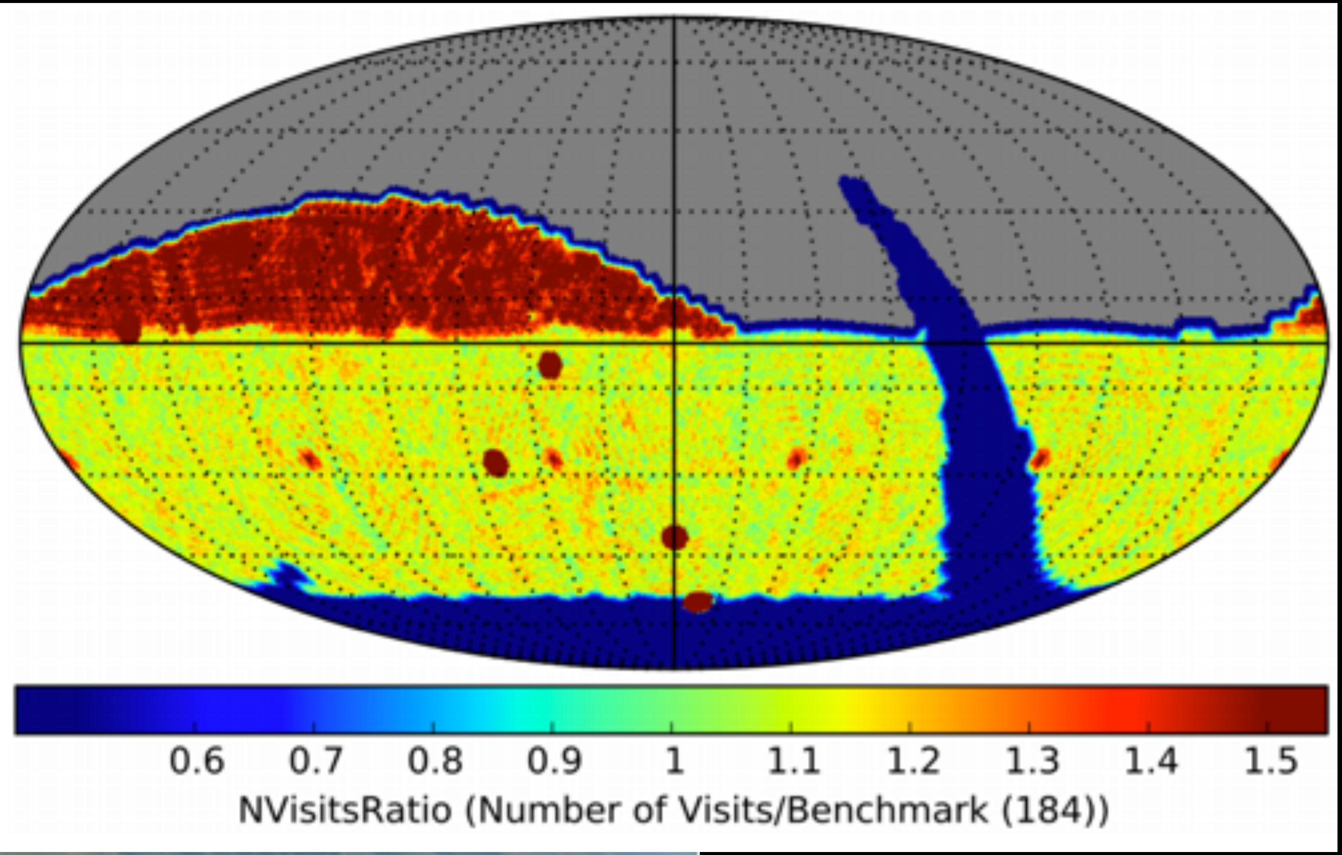


~1.5 Gly (~450 Mpc)
at distance of galaxies at z~0.3

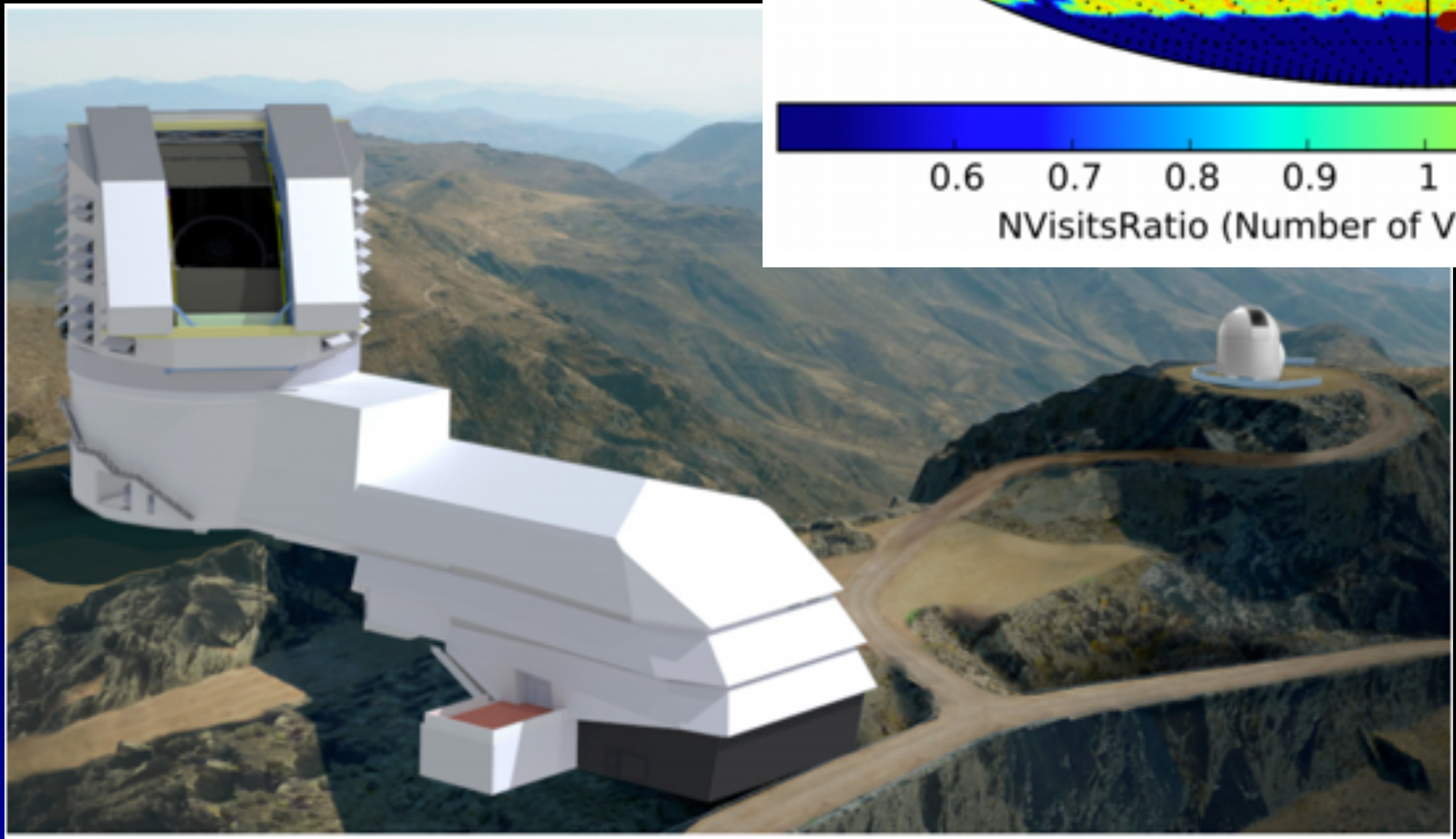


Mass map (Dark Energy Survey @ APS 2015)

Future: LSST

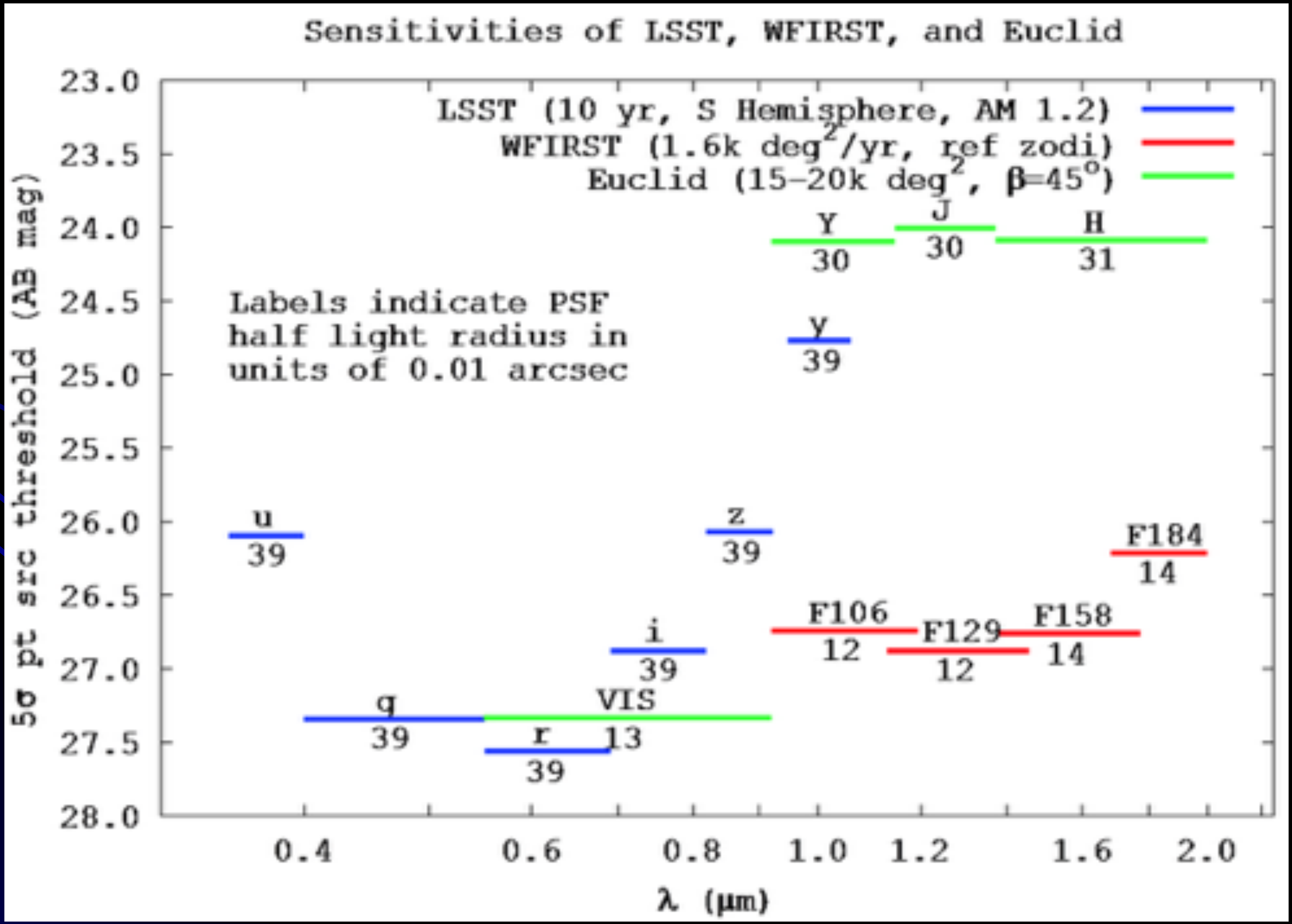


0.6 0.7 0.8 0.9 1 1.1 1.2 1.3 1.4 1.5
NVisitsRatio (Number of Visits/Benchmark (184))

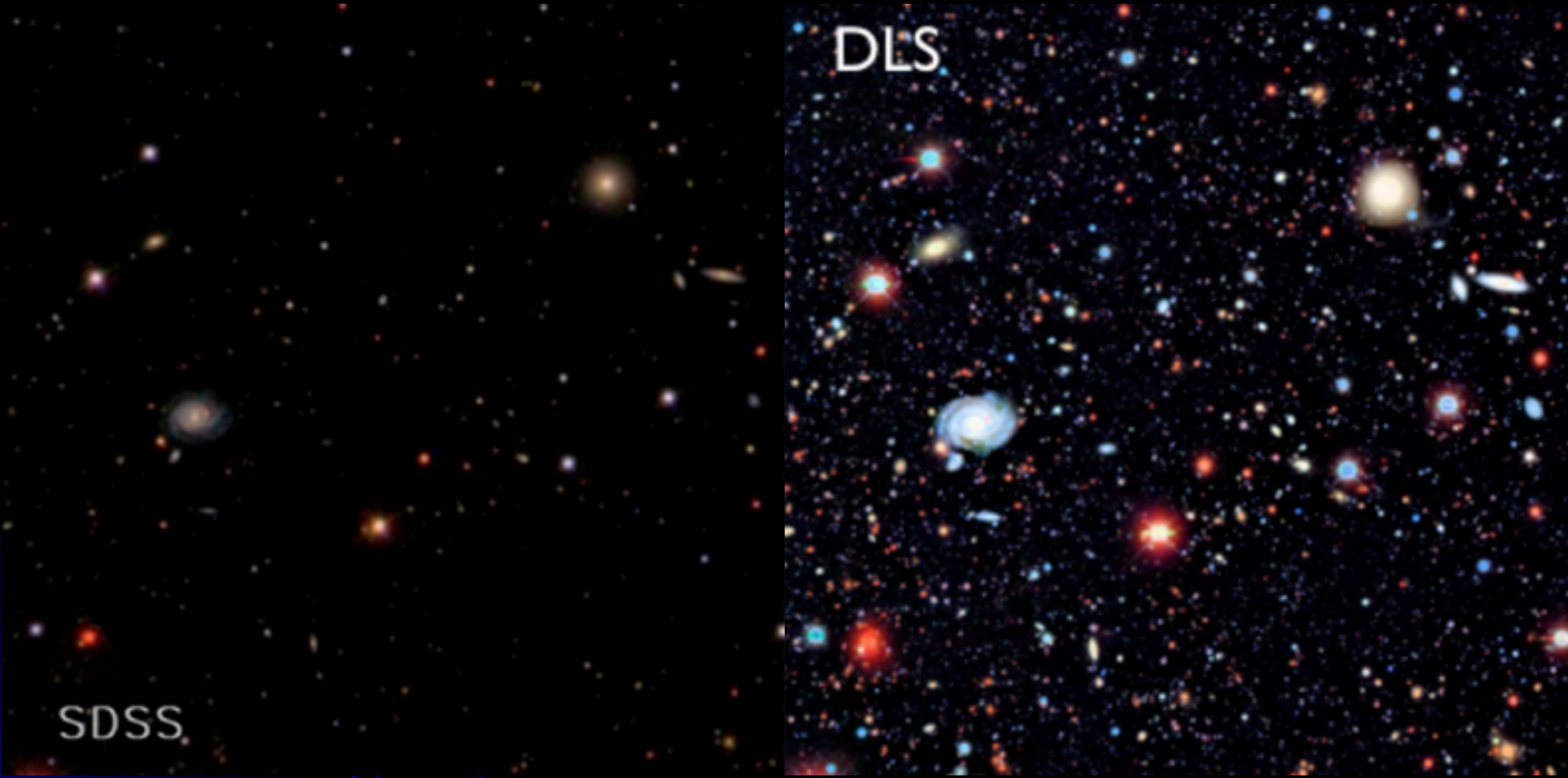


LSST: Technical Details

- 8.4m Telescope with 3.5 deg FOV (diameter)
- From 2020 (normal operation from 2023) for 10 years
- Wavelength: 320-1050 nm, ugrizy



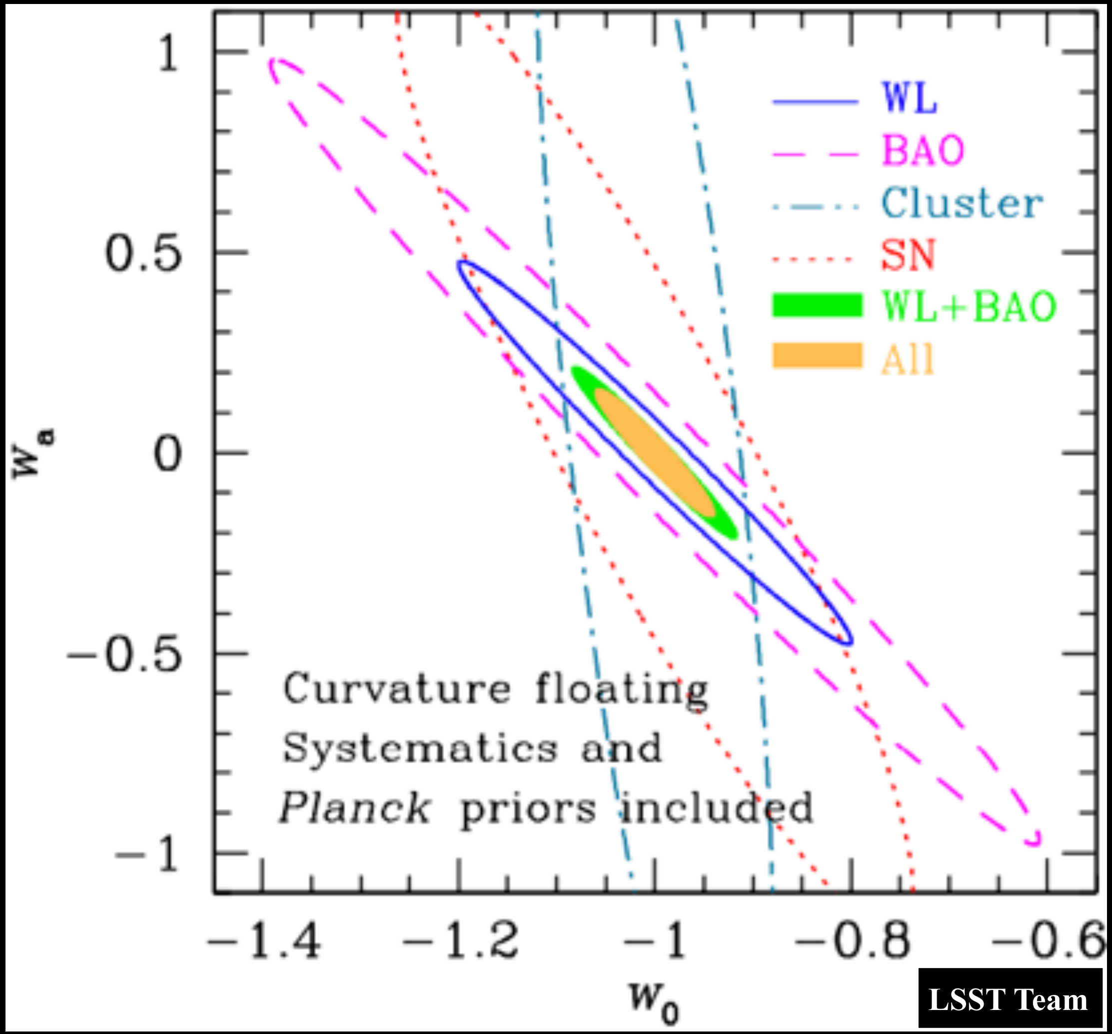
LSST: Science Goals



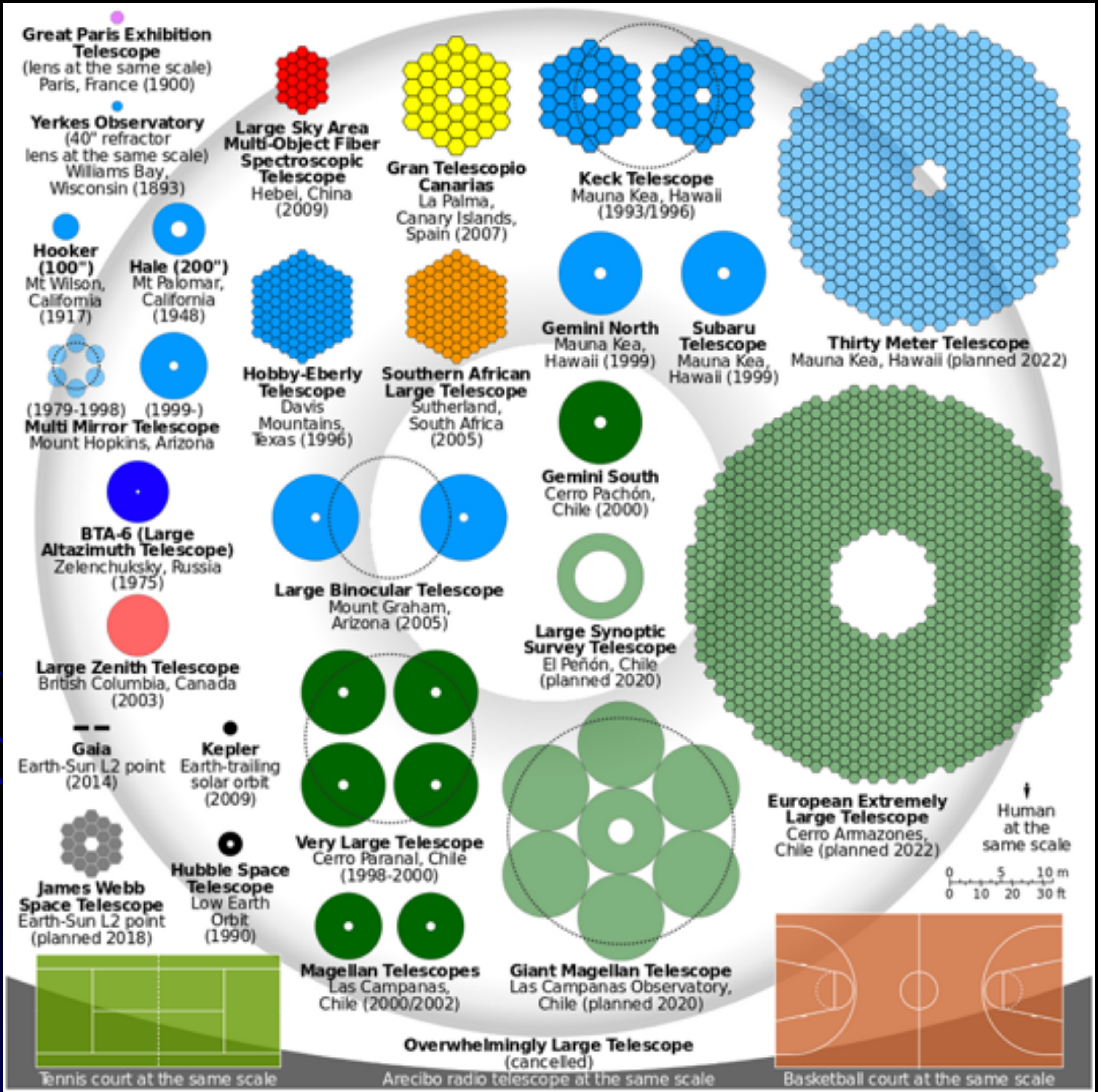
LSST Team

LSST: Science Goals

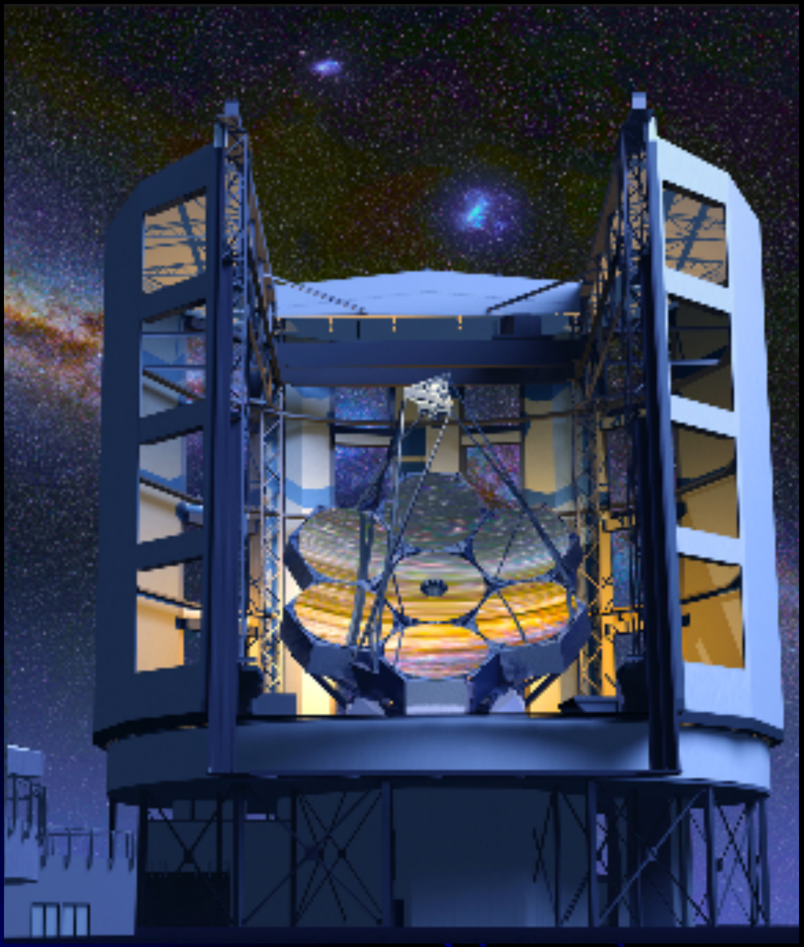
- Probing Dark Energy and Dark Matter
  - Weak Lensing, BAO with photo-z, Supernovae
- Taking an Inventory of the Solar System
- Exploring the Transient Optical Sky
- Mapping the Milky Way



Future: Telescope Opportunity



Future: Giant Magellan Telescope



- Seven 8.4 m primary segments (25m in diameter)
- Field of view: ~20 arcmin
- Site: Las Campanas Peak, Chile
- 2020: First Light/ Early Operation with 4 mirrors
- 10% of telescope time for Korea

Future: Giant Magellan Telescope

Future: Giant Magellan Telescope

G-CLEF	GMACS
Optical high-resolution (R=20k-100k) fiber-fed spectrograph, with high precision radial velocity capacity.	Wide field, multi-object, moderate-resolution (R~2k), optical spectrograph.

G-CLEF Design Parameters

Passband	3500Å-9500Å*
Resolution	25k ~ 120k**
MOS	a single-object (with 1~2 sky fibers)

* Simultaneous coverage using separate red & blue channels

**Depending on fiber feed selection

GMACS Design Parameters

Passband	4000Å-9000Å*
Resolution	~2000
FOV	4.5'x9'**
MOS	multi-slits***

Future: Giant Magellan Telescope

Future: Giant Magellan Telescope

Redshift Surveys of Field Galaxies at $0.8<z<2$

적색이동 사막 구간의 고밀도 적색이동 탐사

김주한,[1] 박창범,[1] 황호성,[1] 황정선,[2] Benjamin L'Huillier,[1]
Cristiano Sabiu,[1] 박현배[3]
고등과학원,[1] 경희대학교,[2] Univ. of Texas, Austin[3]

심우주의 고밀도 은하 탐사

김주한,[1] 양유진,[2] 박창범,[1] 황호성,[3] Benjamin L'Huillier,[1]
Cristiano Sabiu,[1] 박현배[4]
고등과학원,[1] Universität Bonn,[2] Harvard Smithsonian Center for Astrophysics,[3]
Univ. of Texas, Austin[4]

Large-Scale Structure Survey at $0.8<z<2.5$

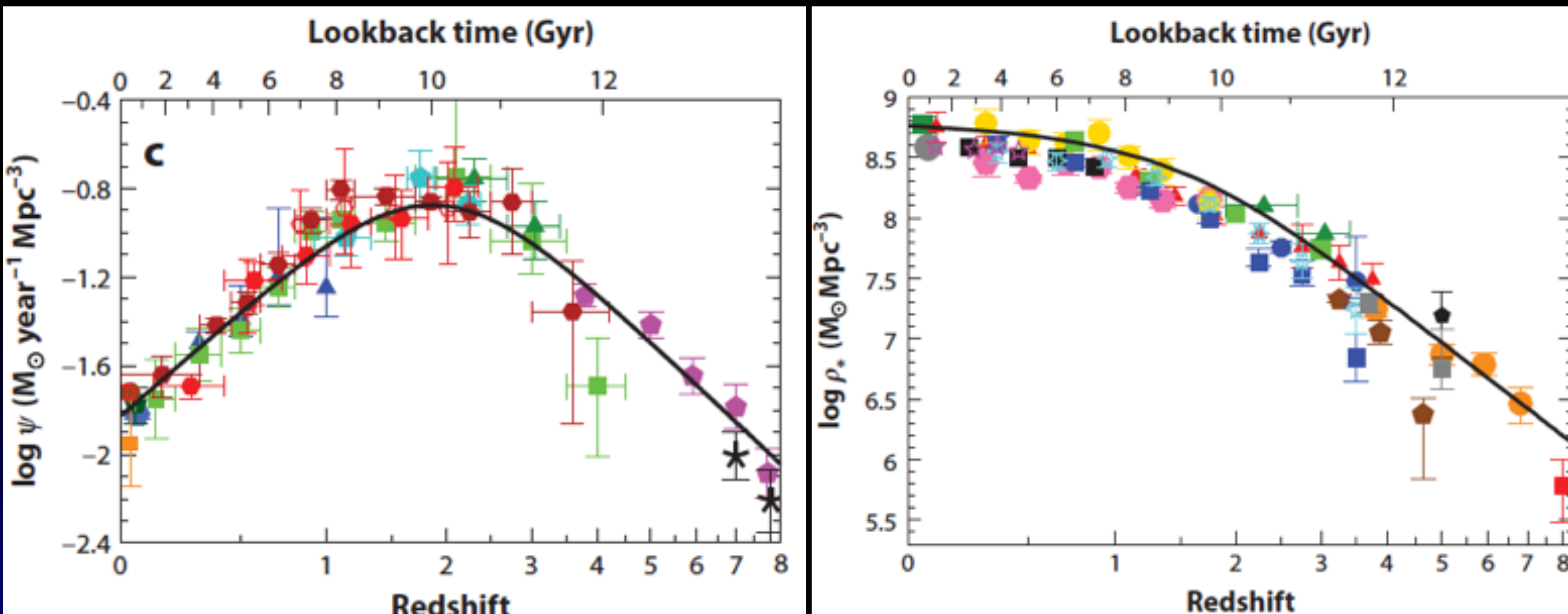
- Propose to survey galaxies with $i \lesssim 24.5$ in the redshift-desert
  - Simple unbiased flux-limited
    (~ the VIMOS VLT Deep Survey Ultra-Deep: $i<24.75$)
  - Dense (no random sampling: VVDS-UDeep has
    Target Sampling Rate~0.065)
  - Faint (M_B~-20 at $z=1.5$)
  - Wide? (~1 deg^2)

- Science Goals
  - Formation & evolution of LSS
  - Unbiased study of evolution of various galaxy classes
  - Environmental effects on galaxy properties
  - Galaxy-galaxy interactions & satellite galaxy systems

From CBP

Why at 0.8<z<2.5?

➢ **Galaxies underwent active mergers and star formation that resulted in a rapid evolution with strong environmental effects.**

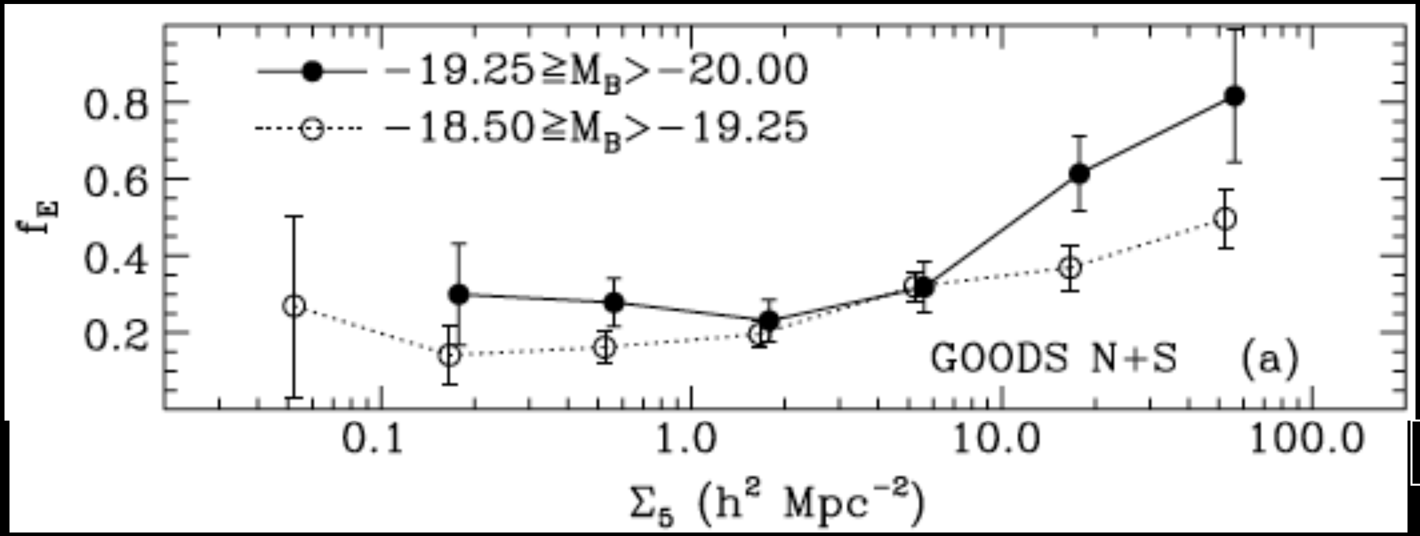


Madau & Dickinson (14)

From CBP

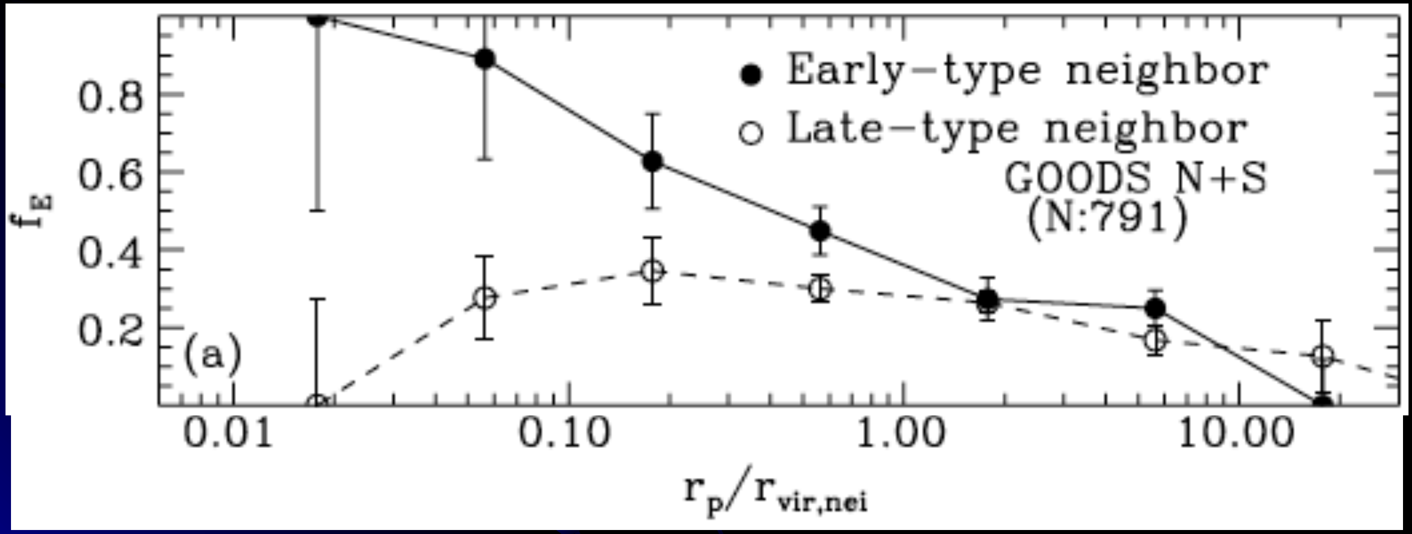
Why at 0.8<z<2.5?

- Most fundamental galaxy properties and environmental connection already set up at z<1.0



Hwang & Park (09)

- Morphology - M_{abs}
- Morphology - Σ_5



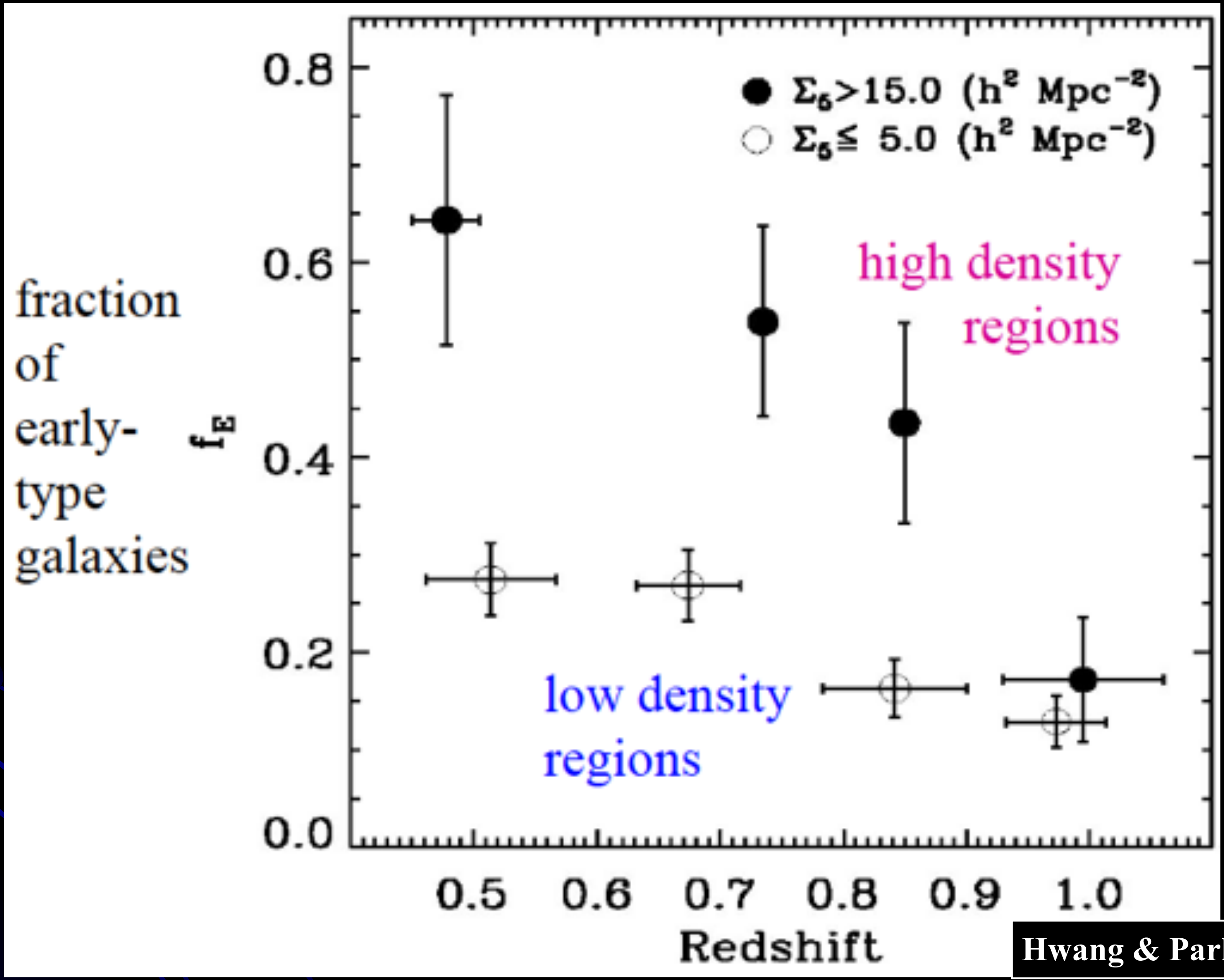
- Morphology - r_p

- Morphology conformity already exists at z≲1.0

From CBP

Why at 0.8<z<2.5?

➢ **Background-density Dependence of evolution of galaxy morphology**



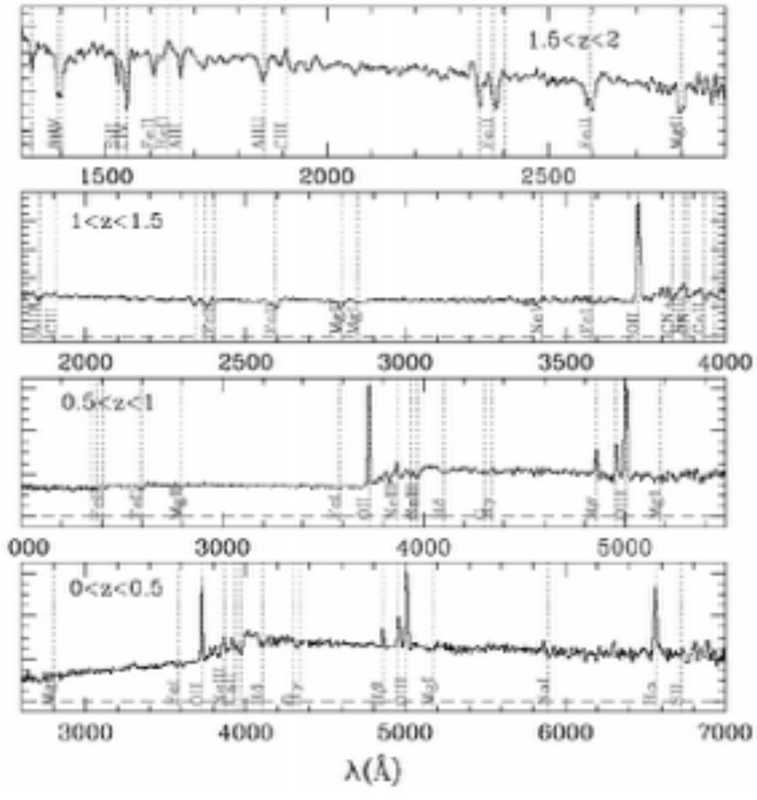
Hwang & Park (09)

➢ **In high-density regions,**
morphological transformation to early types is faster!

From CBP

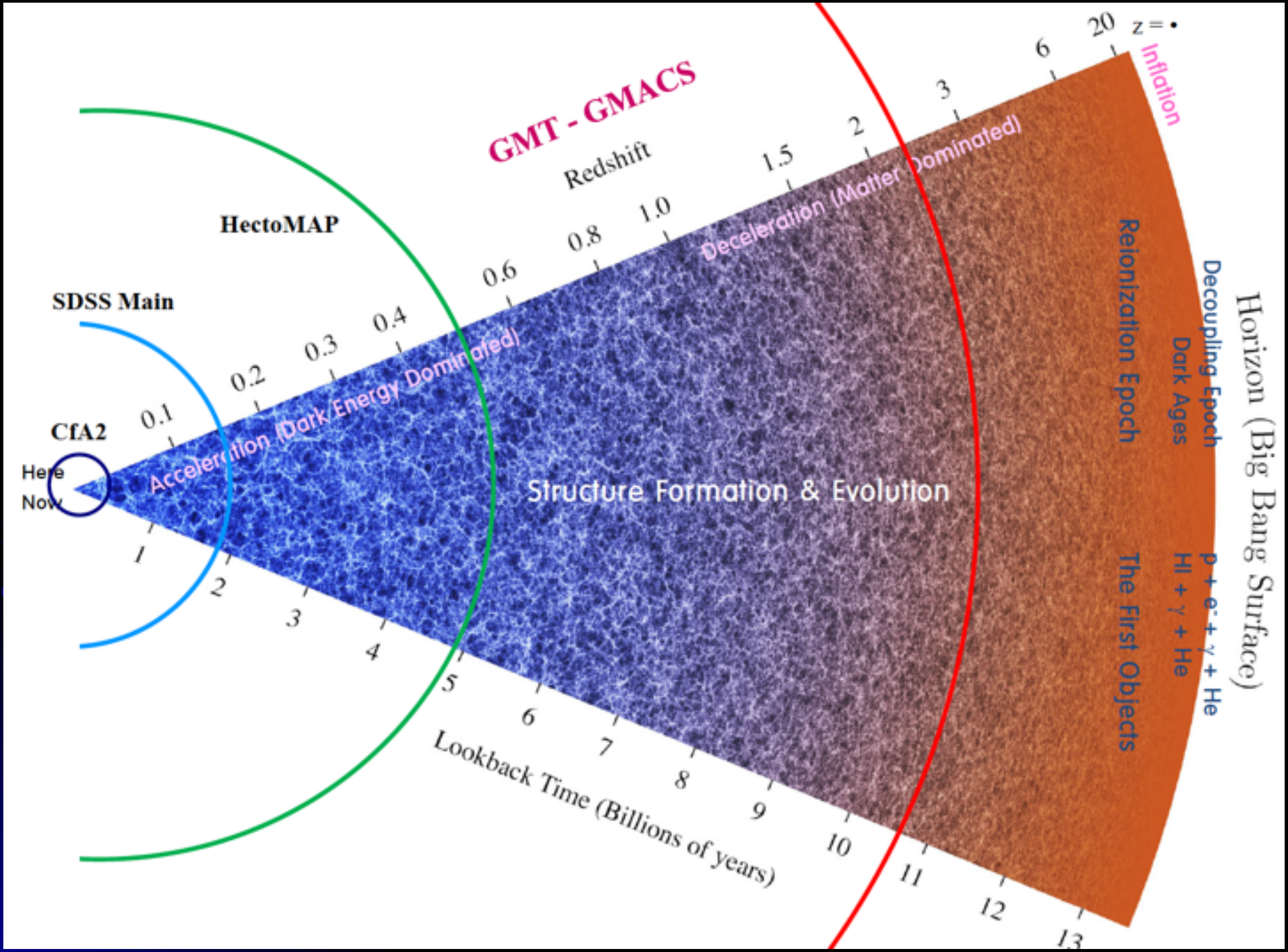
Survey Strategy

- Survey field
  - ~1 deg^2 (1 deg = ~50 h^{-1} Mpc at z=1.5) from existing deep redshift survey regions (zCOSMOS, VVDS, etc.)
- Survey : ~1000 galaxies down to i=24.5 per 30 sam FOV
  - ~10 pointings per field if 100 slits
  - costs ~1 day per field for t_{exp}=1 h per mask
  - 1 deg^2=120 fields requires 120 days
  - returning ~5×10^4 redshifts



Average spectrum of galaxies [Le Fevre+13]

Future: Giant Magellan Telescope



Redshift Surveys of Galaxy Clusters at $0.8<z<2$

고적색이동 은하단들의 고밀도 분광 탐사

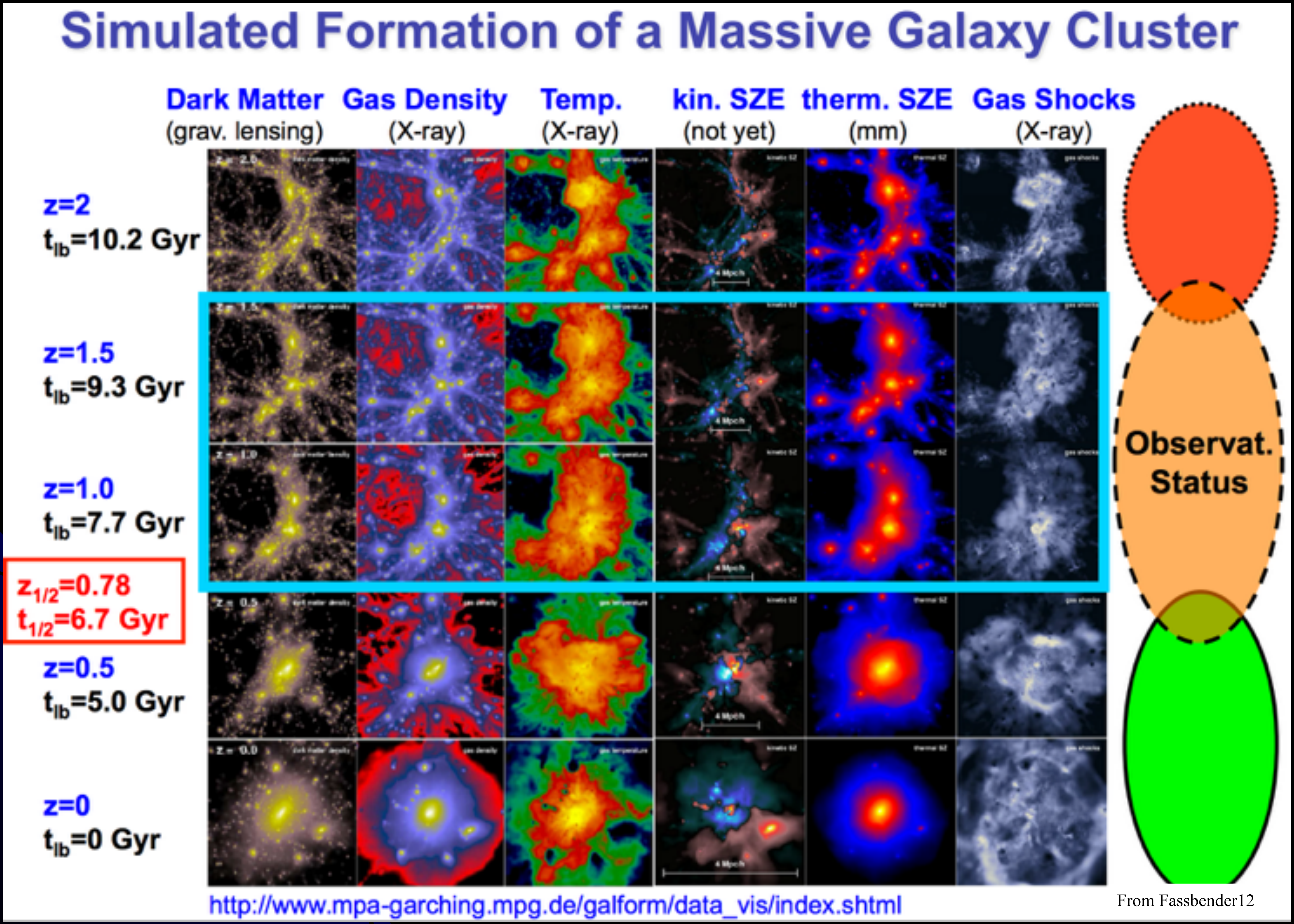
황호성,[1] 이성국,[2] Raphael Gobat,[1] Veronica Strazzullo,[3] 박창범,[1] 이종철,[4] 고종완,[4] 임명신,[2] 김재우,[2] 황정선,[5] Benjamin L'Huillier,[1] 이광호,[2] 손주비,[2] 현민희[2]

고등과학원,[1] 서울대학교,[2] Ludwig-Maximilians-University,[3] 한국천문연구원,[4] 경희대학교[5]

GMT/GMACS를 이용한 원시 은하단 분광 탐사

이종철 (천문연), 김재우 (서울대), 황호성, Raphael Gobat (고등과학원), Veronica Strazullo (LMU), 박창범, Benjamin LHuillier (고등과학원), 심현진 (경북대), 고종완 (천문연), 임명신, 이성국, 이광호, 손주비, 현민희 (서울대)

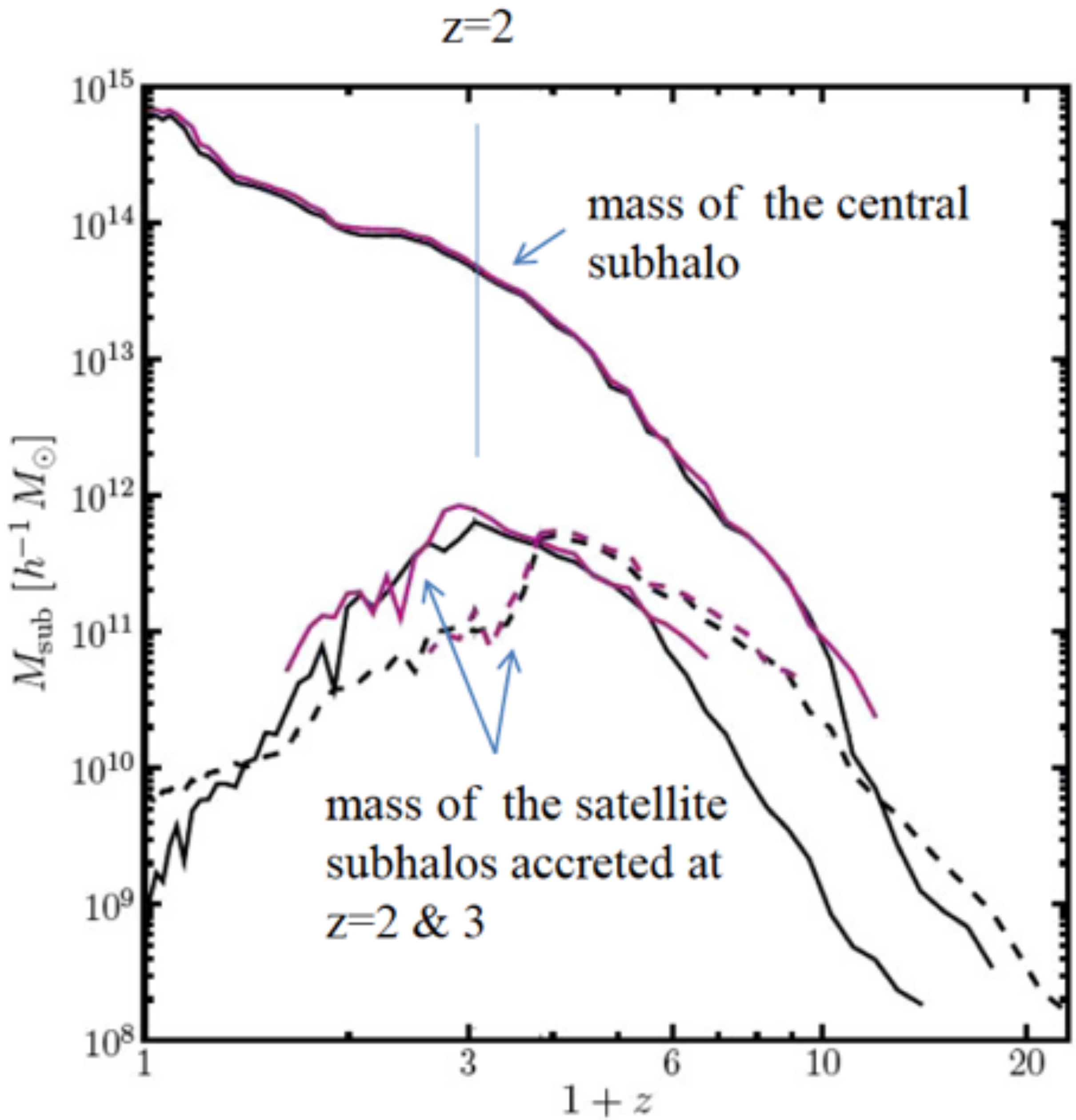
Why Clusters at 1.0<z<2.0



Why Clusters at 1.0<z<2.0

Central halo mass has increased by an order of magnitude since z=2.

Satellite halo mass has decreased by orders of magnitude since z=2.



From CBP (Boylan-Kolchin+09)

Science Goals

- Obtain a large, homogenous sample of galaxy clusters at 1<z<2
- Determine the dynamical mass and its profile
  - Compare with other mass proxies (e.g. SZ, X-ray)
- Determine the cluster-scale M/L → Ω_m
- Properties of brightest cluster galaxy
  - Important hint of their formation and the connection to their host clusters
- Environmental effects on galaxy properties

→ By combining with local & intermediate-z clusters,
we can study the evolution of clusters and their galaxies

Survey Strategy

- ➢ **Cluster targets : 20 at $1<z<2$ (10 at $z<1.5$ &10 at $z>1.5$)**
  - ➢ **From multiwavelength data: (e.g. eROSITA, CCAT)**
  - ➢ **Deep Imaging survey for target galaxies (e.g. Subaru HSC)**

The Top-10 Most Distant Clusters known

spectroscopically confirmed + X-ray signature

#	z	Name	Sel.	$L_{X,500,bol}$ 10^{44}erg/s	M_{200} $10^{14}M_{sun}$	References
1	2.07	CL J1449+0856	MIR	0.9	0.7	Gobat+11
2	1.75	XMMU J1053+5723	Xray	0.5	0.6	Henry+10
3	1.75	IDCS J1426-3508	MIR	16	4.1	Stanford+12, Brodwin+12
4	1.62	XCL J0218-0510	MIR	0.4	0.7	Tanaka+10, Pierre+11, Papovich+10
5	1.58	**XDCP J0044.0-2033**	**Xray**	**6.1**	**3.0**	Santos+11
6	1.56	**XDCP J1007.3+1237**	**Xray**	**2.1**	**1.7**	Fassbender+11
7	1.49	**XDCP J0338.8+0021**	**Xray**	**1.1**	**1.2**	Nastasi+11
8	1.49	ISCS J1432.4+3250	MIR	3.5	2.5	Brodwin+10
9	1.46	**XCS J2215.9-1738**	**Xray**	**2.2**	**2.0**	Hilton+10, Stanford+06, Bielby+10
10	1.41	ISCS J1438.1+3414	MIR	2.2	2.2	Brodwin+10, Stanford+05
11	1.39	XDCP J2235.3-2557	Xray	10.0	6.6	Rosati+09, Jee+09, Mullis+05

From Fassbender(12)

Survey Strategy

- ➢ **Cluster targets : 20 at 1<z<2 (10 at z<1.5 &10 at z>1.5)**
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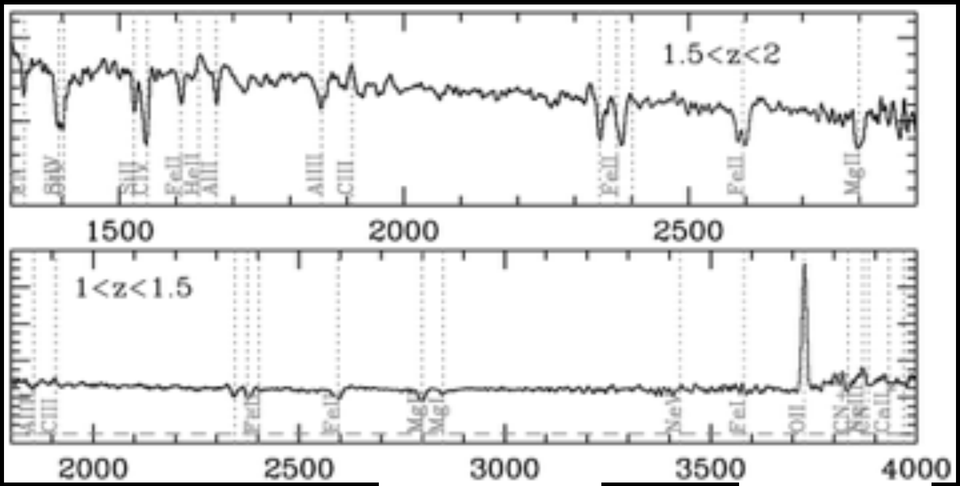
이름	EDisCS	ISCS	GCLASS	MaDCoWS
적색이동구간	0.5<z<1.0	1.0<z<1.5	0.8<z<1.3	0.7<z<1.3
은하단 개수	10	16	10	19
한 은하단당 관측 은하 개수	~45	~30	~130	~30
한 은하단당 구성원 은하 개수	~20	~20	~45	~10
관측 은하 등급 범위	19.5<I<23.0	15<3.6μm<18.5	15<3.6μm<21	19.0<z<22.5
망원경 기기/ 분해능 (R)	VLT FORS2/ R~1000	KECK LRIS/R~900 HST WFC3/R~130	Gemini-N and S GMOS/R~440	KECK DEIMOS/R~2000 Gemini-N GMOS/R~1900
참고문헌	White 등 (2005)	Eisenhardt 등 (2008); Brodwin 등 (2013)	Muzzin 등 (2012)	Stanford 등 (2014)

표 1. 기존의 체계적인 고적색이동 은하단 분광 탐사

Survey Strategy

- **For a given cluster, our goal is to get >100 member galaxies at $R_{cl}<1\text{-}3r_{vir,cl}$ (e.g. Rines+13):**
  - **>250 spectra per cluster** (assuming member selection rate ~ 40%; Muzzin+12)
  - **3-5 masks per cluster** (assuming 50-120 slits per mask)
  - **$S/N_{pixel,continuum}$>10 for galaxies at 23<V<25 (redshifts, EW,..)**
    - >1 hour per mask with GMACS ETC (4 mirrors & elliptical galaxies)
  - **Redshift measurement:** spectrum template fitting with main spectral features of
    - [O II] 3727 and/or Ca II H&K for z<~1.5
    - UV Fe II and Mg II lines for z>~1.5



λ_{rest} (angstrom)   Le Fevre+13

- **Technical Requirements**
  - **Spectral coverage: longer (λ_{max}>1000nm if possible) & wider is better!**
  - **Velocity precision: <100 km/s (smaller than σ_{cl}) ➔ Spectral resolution>~1500**
  - **FOV: >15 arcmin ($R_{cl(proj,comov)}$~5 h^{-1}Mpc = 3 $r_{vir,cl}$ at z=1)**

Contents

- **Goal:**

Understand how to obtain scientific results from observational data (redshift survey)

- **Part 1:**
  - **Extragalactic Distance Indicators**
  - **Optical Spectroscopy**
  - **Redshift Space Distortion**

- **Part 2:**
  - **Voids**
  - **Photometric Redshifts (K-correction)**
  - **Cosmology with High-z Objects**
  - **Peculiar Velocity (Large-Scale Structure Near Local Group)**

- **Part 3:**
  - **Current/Future Redshift Surveys**

Please Enjoy Observing the Universe