A visualization of the cosmic web, showing a complex network of dark matter filaments and galaxy clusters. The filaments are depicted as thin, interconnected lines of orange and red, set against a dark blue background. The overall structure is highly irregular and fractal-like, representing the large-scale structure of the universe.

COSMOLOGY

CURRENT SURVEYS AND INSTRUMENTATION

MATTHEW COLLESS

MULTI-OBJECT SPECTROSCOPY IN THE NEXT DECADE

SANTA CRUZ DE LA PALMA

2-6 MARCH 2015

WHY SURVEYS? WHY MOS?

- ASTRONOMY IS AN OBSERVATIONAL SCIENCE DEALING WITH LARGE POPULATIONS OF COMPLEX OBJECTS THAT FORM STRUCTURES IN SPACE AND EVOLVE IN TIME
- SURVEYS ALLOW US TO STUDY LARGE POPULATIONS, TO MAP STRUCTURES, AND TO TRACK EVOLUTION
- “A PICTURE IS WORTH A THOUSAND WORDS”,
BUT, TO AN ASTRONOMER,
“A SPECTRUM IS WORTH A THOUSAND IMAGES”
- MULTI-OBJECT SPECTROSCOPY (MOS) IS THE MOST EFFICIENT WAY TO GATHER ASTROPHYSICAL INFORMATION FOR LARGE POPULATIONS SCATTERED OVER TIME AND SPACE
- SO...IN THE LAST FEW DECADES MOS SURVEYS HAVE TRANSFORMED OBSERVATIONAL COSMOLOGY

COSMOLOGY SURVEYS TIMELINE

1980s

1990s

2000s

2010s

CfA, 0, 4.0

LCRS, 2.0, 4.4

PSCz, 0, 4.2

DEEP, ~2, 4.0

2dFGRS, 2.6, 5.3

SDSS, 2.8, 5.9

6dFGS, 2.2, 5.1

WiggleZ, 2.6, 5.5

BOSS, 3.0, 6.2

non-MOS

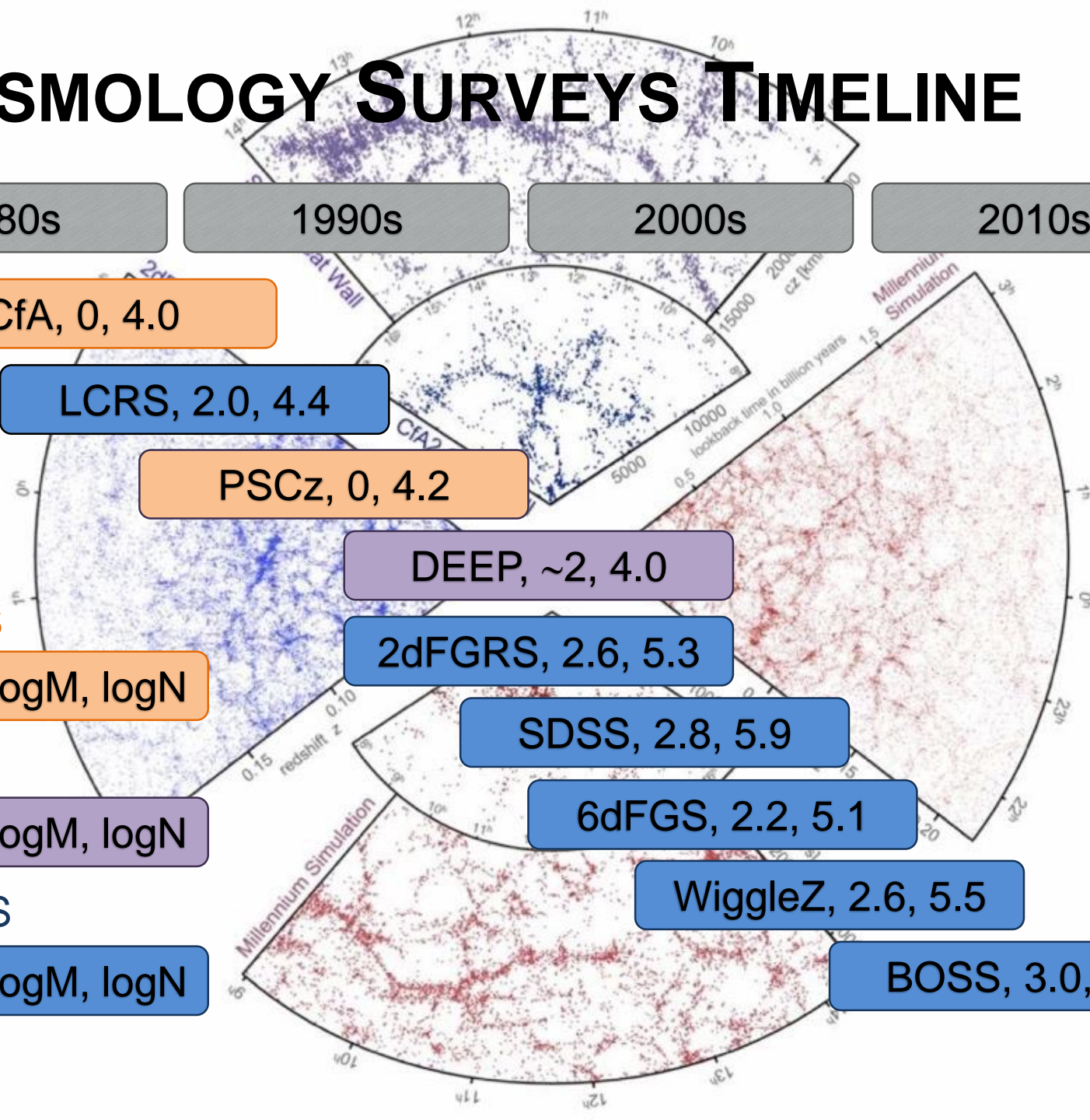
Survey, logM, logN

slit MOS

Survey, logM, logN

fibre MOS

Survey, logM, logN



MOS INSTRUMENTS FOR COSMOLOGY

□ 1D (MULTI-FIBRES)

- LAS CAMPANAS FIBRE SYSTEM (LCRS)
- 2DF (2DFGRS, 2QZ) → AAΩ (WIGGLEZ, GAMA, OzDES)
- 6DF (6DFGS) → TAIPAN (TAIPAN)
- SDSS (SDSS-I, SDSS-II) → BOSS (BOSS, eBOSS)

□ 2D (MULTI-SLITS)

- DEIMOS (DEEP, DEEP-2)

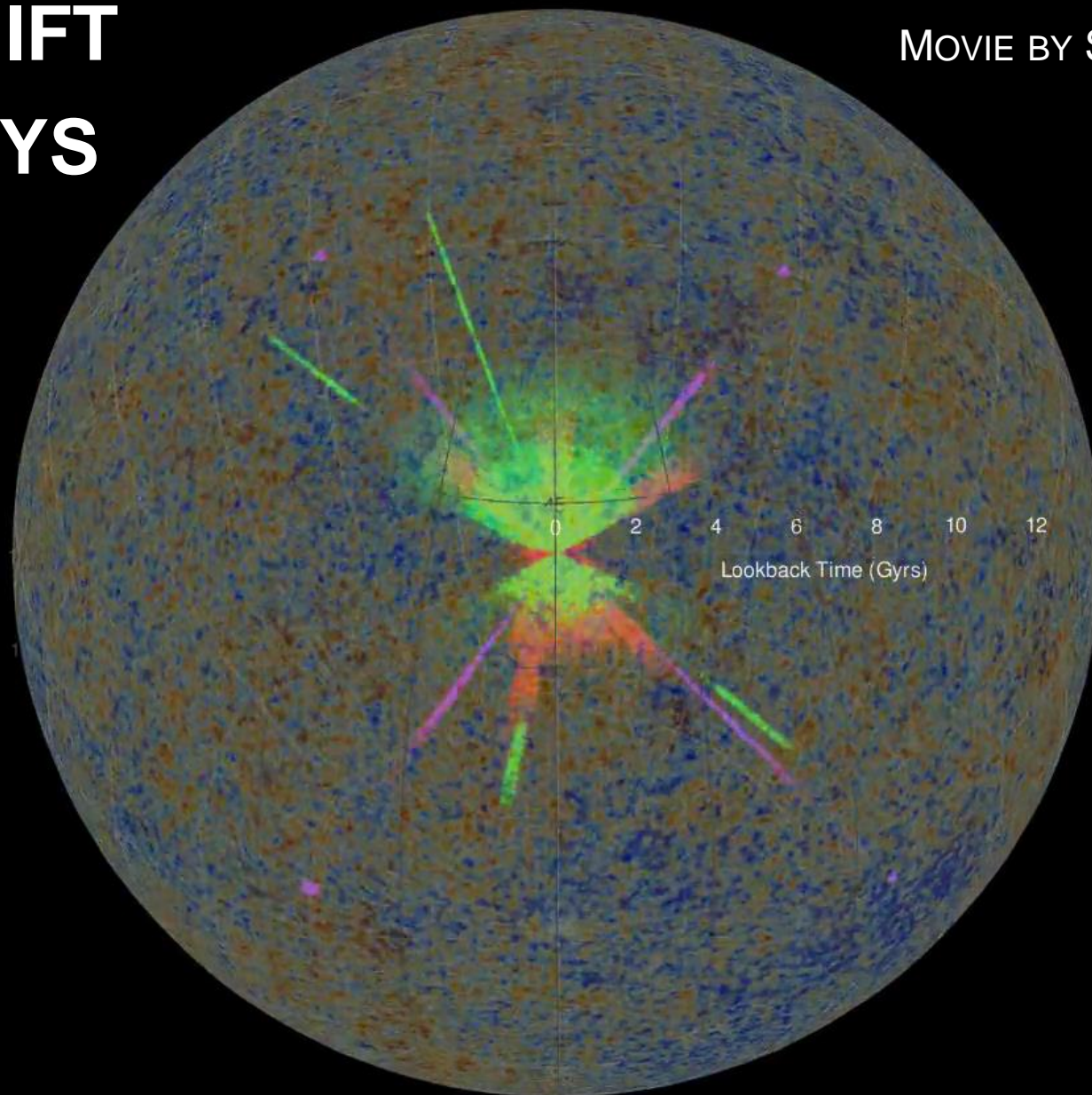
□ 3D (MULTI-IFUs)

- MUSE(?)
- HET/VIRUS (HETDEX)

FIBRES DOMINATE MOS
COSMOLOGY SURVEYS
BECAUSE SCIENCE DRIVERS
ARE MULTIPLEX AND AREA

REDSHIFT SURVEYS

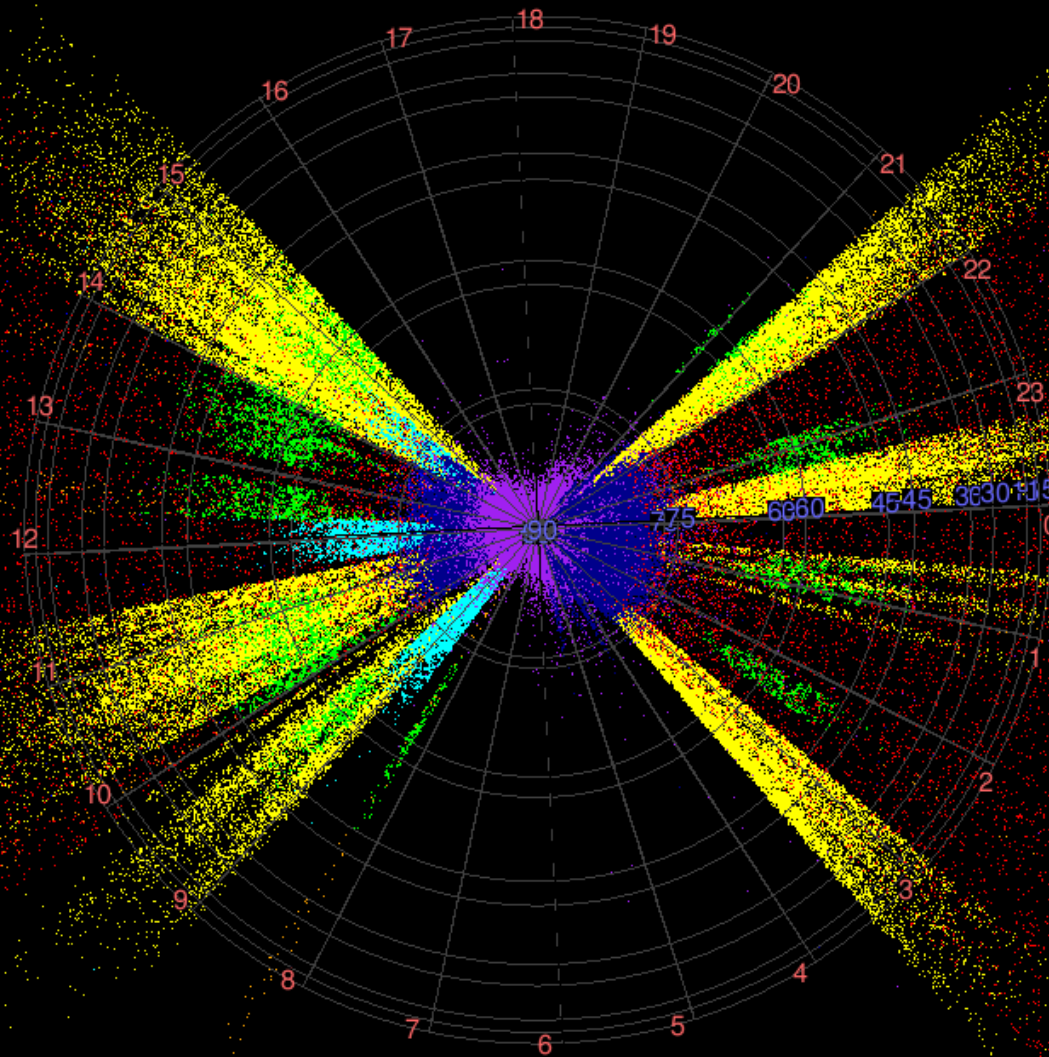
MOVIE BY SIMON DRIVER



REDSHIFT SURVEYS: **US SURVEYS**, **EUROPEAN SURVEYS**,
AUSTRALIAN SURVEYS; CELESTIAL SPHERE IS AT CMB

AAO Z-SURVEYS

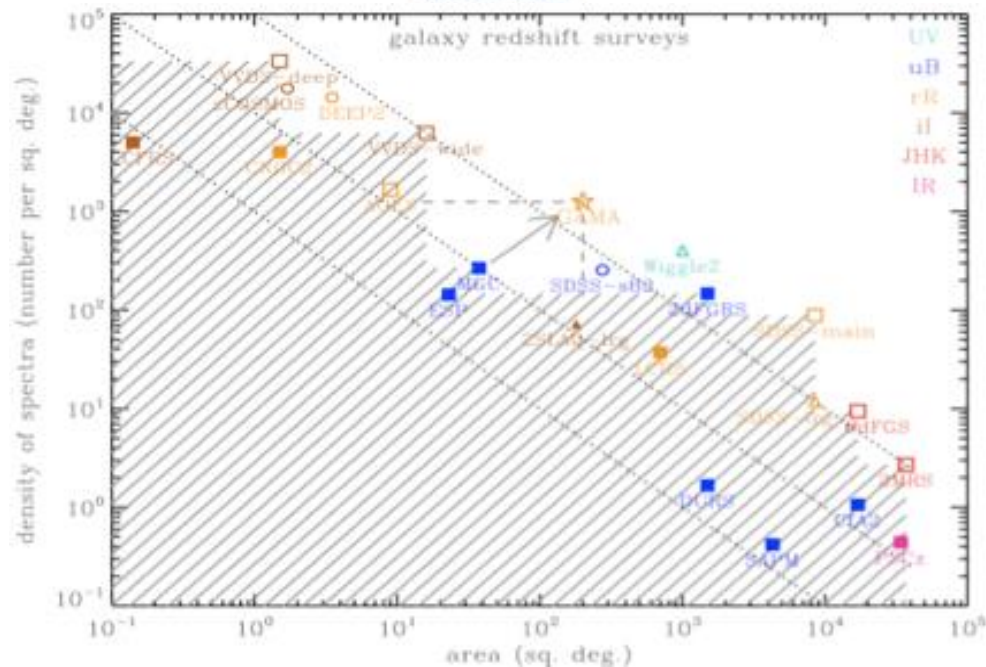
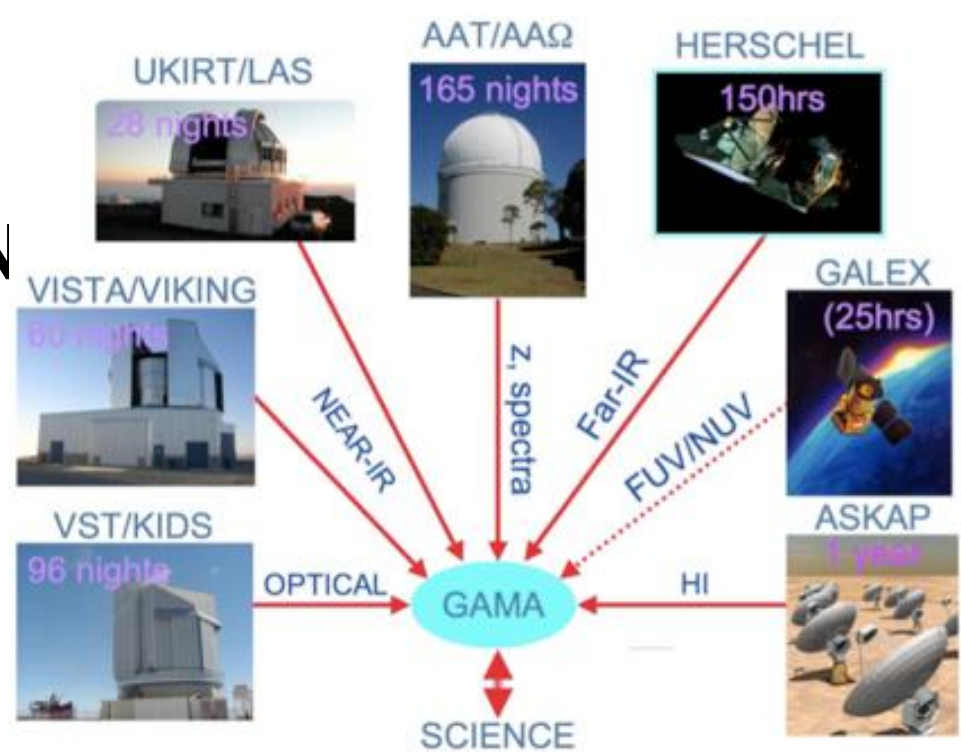
MOVIE BY SIMON DRIVER



2DFGRS, 2QZ, 2SLAQ-LRG, 2SLAQ-QSO,
6DFGS, GAMA, WIGGLEZ; CELESTIAL SPHERE AT $z=1$

GAMA: THE VERY MODEL OF A MODERN REDSHIFT SURVEY

- GALAXY AND MASS ASSEMBLY SURVEY
- FEDERATIVE, MULTI- λ , AND MULTI-FACILITY
 - GALAXY SEDs FROM UV TO RADIO USING EXISTING SURVEYS & NEW OBSERVATIONS
 - ALSO MULTI-Z WHEN ASKAP PROVIDES HI REDSHIFTS



...COMPLEX INFORMATION STRUCTURES

GAMA Galaxy And Mass Assembly

Home | GAMA Team | Publications | Data Access | ...

Galaxy And Mass Assembly

Project Overview

GAMA is a project to exploit the latest generation of ground-based and space galaxy formation and evolution.

At the heart of this project lies the GAMA spectroscopic survey of ~340,000 galaxies carried out using the *AAT* multi-object spectrograph on the *2dF* project has so far been awarded 152 nights over 4 years (2009–2011) and is on, and is augmented by previous spectroscopic surveys such as the *SDSS*, *Reid* Survey (*IRF*), and the *Millennium* Galaxy Catalogue (*MGC*).

On the imaging side, GAMA uses public data as well as conducting its own coordinated survey regions and negotiated data sharing agreements with a number of other surveys.

Public surveys:

- United Kingdom Infrared Telescope (UKIRT)
- Galaxy Evolution Explorer (GALEX)
- Giant Metrigalactic Telescope (GMT)
- VLT Survey Telescope (VST)
- Visible and Infrared Survey Telescope for Canada (France/Hawaii Telescope (CFHT))
- Herschel Space Observatory
- The Australian Square Kilometre Array
- X-ray Multi-Mission Mission (XMM-Newton)
- Wide field Infrared Survey Explorer (WISE)

The main objective of GAMA is to study structure on scales of 1 kpc to 1 Mpc (clusters and filaments). It is on these scales where baryons play a critical role in the structure in the Universe breaks down.

Our primary goal is to test the Λ CDM paradigm of structure formation, in particular:

- To test modified theories of gravity by measuring the growth rate of structure formation efficiency in groups.
- To measure the connection between star formation, stellar mass, and galaxy evolution.
- To uncover the detailed mechanisms that governs the build-up of the structure.
- To directly measure the recent galaxy merger rate as a function of mass.

To address these goals, GAMA is creating an extraordinary multi-wavelength photometric and spectroscopic dataset with outstanding value to both the large-scale galaxy evolution communities. By virtue of its unrivalled combination of area, spectroscopic depth, high spatial resolution and broad wavelength coverage the GAMA is uniquely capable of advancing low- and intermediate-redshift galaxy studies.

More details on GAMA and its science case can be found in our proposals ([G097](#), [G099](#)) and in [this article](#).

Contact | **Surveys** | **Data Access** | **Links**

Email us | GAMA Team | KIB | VIKING | MGC | UKIDSS | Herschel-ATLAS | GALEX/GAMA | DRINGO

Data Access synopsis | Data release 1 | SQL access | Data inspection tools - Public access | GAMA on ADS | Data inspection tools - GAMA team access | Active Robotics Camera | Variance calculator

WEB

Wiki
Galaxy And Mass Assembly

Navigation

- GAMA Wiki
- Science
- Data Management
- Meetings
- GAMA Australia
- Extra

Search

Toolbox

- Recent changes
- Backlinks
- Update Profile
- Logout

WIKI

GAMA Wiki

Show pagesource | Old revisions

Welcome to the GAMA Wiki, a collection of editable pages and resources for the GAMA Project. This wiki is maintained by [Joe Liske](#) (contact person) and [Lee Kelvin](#).

DATABASE

GAMA Galaxy And Mass Assembly

Database | Schema browser | Query | Data | Tools | Internal | Public site

Query | Query Builder | Example queries

Galaxy And Mass Assembly

Team database > Query > SQL query builder

SQL Query Builder

The query builder allows you to construct SQL queries by point and click. This is helpful if you have trouble remembering the SQL syntax, or when constructing complicated queries.

Begin by selecting the table(s) that you wish to query by clicking the "Tables" button. If you select more than one table then the query builder will by default attempt to join them together in a meaningful way. However, you probably want to edit the way the tables are joined by hitting the "Join" button.

Next, for each of the tables you selected above, you need to select the columns that you want your query to return by clicking the "Columns" button.

Finally, in the bottom panel you can set the constraints that determine which rows of the above table(s) will be returned by your query. Leaving this empty will simply return all rows.

The query builder is a pretty powerful tool, and it should be able to construct most of the queries that anyone is likely to ever want to execute. However, there will be some queries that the query builder will not be able to construct in full. Note that in these cases you can still use the query builder to construct your query in part. You can then display the partially constructed query by clicking the "Show SQL" button, cut and paste it to the standard query form, finish editing it, and then submit it.

Tables to query and columns to return:

Constraints:

Format of results file: CSV ASCII FITS

Submit query | Show SQL | Reset

MOS SURVEYS/INSTRUMENTS HERE

TELESCOPE : INSTRUMENT	SURVEY(S)
AAT : AAQ, HERMES, SAMI	WIGGLEZ, GAMA, GALAH, SAMI
UKST : 6dF, TAIPAN	RAVE, 6dFGS, TAIPAN
SDSS 2.5M : SDSS, BOSS, MANGA	SDSS, BOSS, EBOSS, MANGA
WHT : ISIS, WEAVE	WEAVE
GTC : OSIRIS, EMIR, MEGARA	
VLT : VIMOS, KMOS, MUSE, MICRONS	VANDELS, VIPERS, LEGA-C,...
VISTA : MOST	4MOST, WAVES
LAMOST	LEGUE
CALAR ALTO : CALIFA	CALIFA
MAGELLAN : PRIMUS	PRIMUS
SUBARU : FMOS, PFS	FACTS AND
HET : VIRUS	HETDEX
GAIA	GAIA
KPNO 4M : DESI	DESI
EUCLID	EUCLID
LSST:MOS / MSE / WFIRST	...

**MANY TELESCOPES,
MANY INSTRUMENTS,
MANY SURVEYS,
AN INDUSTRY, NOT A NICHE!**

IMPACT OF MOS SURVEYS - 1

- LITERATURE ANALYSIS BY TRIMBLE & CEJA (2008)
LOOKED AT 11,831 PAPERS PUBLISHED IN 2001-3
(DATED, BUT RESULTS STILL APPLICABLE)
- THE MOST-CITED OPTICAL/INFRARED FACILITIES...

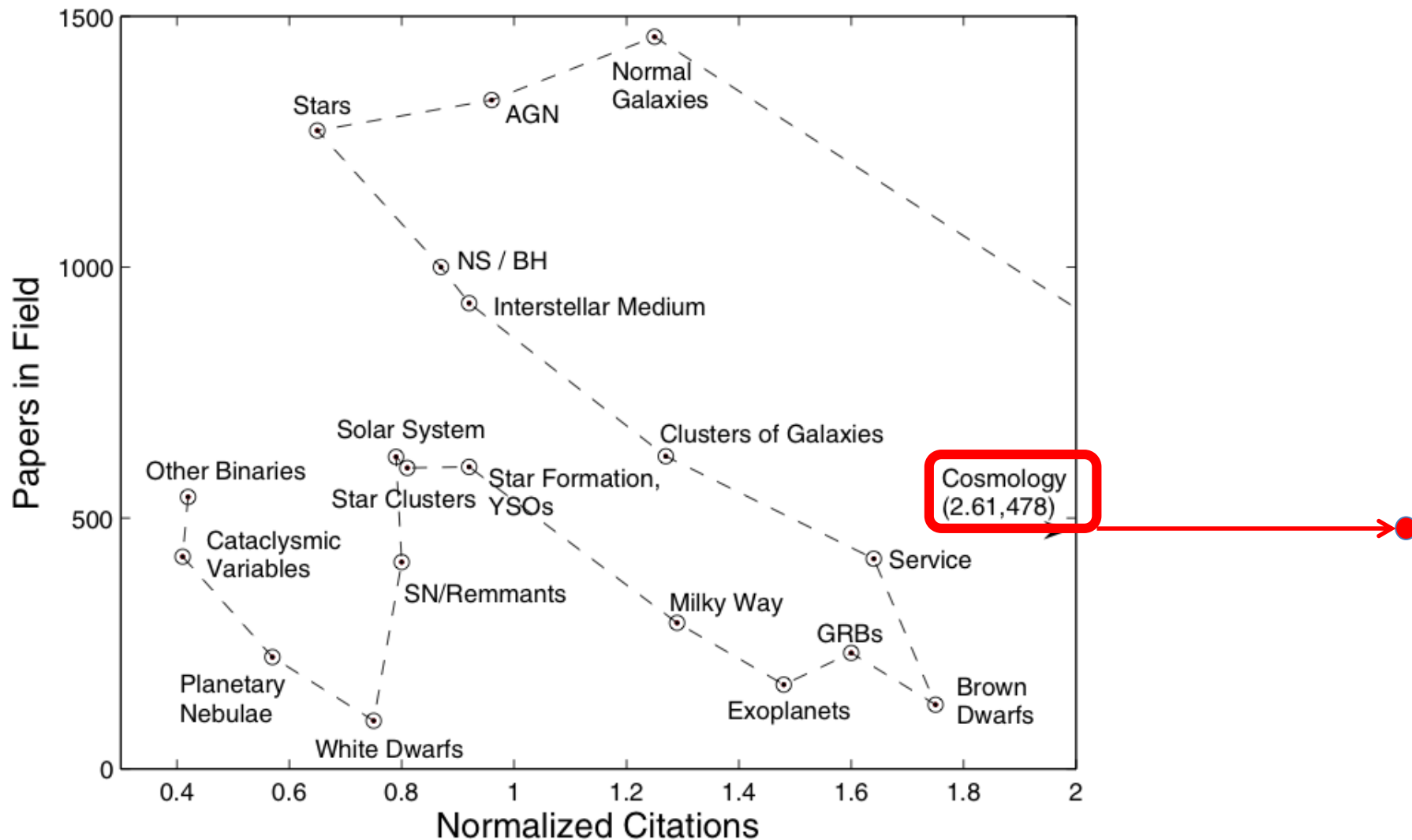
FACILITY	CITATIONS	PAPERS
HST	15390	1063.1
Keck	8122	365.6
SDSS	7235	161
VLT	5696	345.5
AAT	4592	170.2
Schmidts	3430	247.8
2MASS	2937	182.9

IMPACT OF MOS SURVEYS - 2

	Citations	Journal	Subject	Facilities
20 MOST-CITED PAPERS 2001-3	2770	ApJS	Cosmology	WMAP, ACBAR, CBI, AAT, HST, other optical
	1301	ApJS	Cosmology	WMAP, optical & X-Ray unidentified
	632	ApJ	Cosmology	HST
	466	ApJS	Cosmology	WMAP
	450	MNRAS	Galaxies	JKT, Siding Spring 2.3m, SDSS, IUE
	397	ApJ	Cosmology	CFHT, CTIO-4, Keck II & I, CTIO-1.5, VLT, UKIRT, UHi 2.2, Vatican, WIYN, HST, SDSS
	383	ApJS	Cosmology	WMAP, CBI, ACBAR, AAT, other optical
	380	A&A	Service	XMM
	375	AJ	Service	SDSS
	370	A&A	Service	XMM
	313	AJ	Service	SDSS
	309	Nature	GRB	VLT 1 & 2
	306	A&A	Service	XMM
	298	ApJLett	GRBs	VLA, Keck, Palomar 5-m
	281	ApJS	Cosmology	WMAP
	281	ApJLett	GRBs	MMT, Magellan, Whipple-1.5
	279	MNRAS	Galaxies	AAT
	277	AJ	Service	Schmidt surveys (USNO catalogue)
275	ApJ	Cosmology	Boomerang	
258	ApJ	Cosmology	HST, Keck, WIYN, ESO-3.6, CFHT, INT, ESO-NTT, CTIO-4	

TRIMBLE & CEJA (2008)

SURVEY IMPACT BY FIELD



PHYSICS FROM LARGE-SCALE STRUCTURE

**RICH INFORMATION
ENCODED IN LSS**

Information from geometry

- Galaxy clustering as a standard ruler
- BAO or full power spectrum
- Alcock-Paczynski effect

Information from power spectrum shape

- Matter density
- Baryon Acoustic Oscillations
- Neutrino mass
- Inflation fluctuation spectrum

Information from large scale bias

- f_{NL}

$$P_{gg}^s(k, \mu, z) = k^n T^2(k) G^2(z) [b(z, k) + f(z)\mu^2]^2$$

Information from structure growth

- amplitude of power spectrum
- Redshift-Space Distortions

k = comoving wavenumber
 μ = $\cos(\text{angle to line-of-sight})$
 a = cosmological scale factor
 b = galaxy bias factor
 G = linear growth rate
 f = $d\ln G/d\ln a$

SIDEBAR: SPECTRO-Z'S vs PHOTO-Z'S

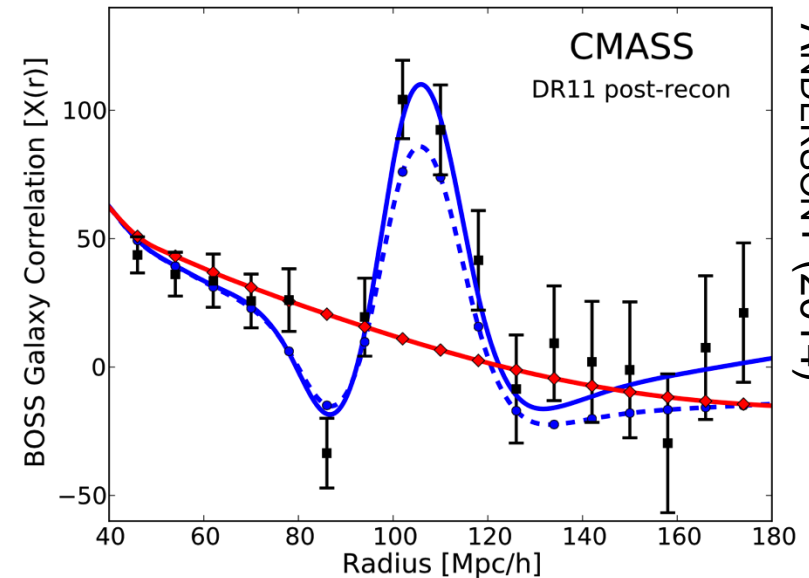
- PHOTO-Z'S ARE POTENTIALLY A CHEAP WAY TO MEASURE MANY GALAXY REDSHIFTS AND HENCE THE BAO PEAK
- PROBLEM IS LARGE ERRORS - FOR Z-ERRORS >1000 KM/S, BAO PEAK IS SMEARED OUT & $H(z)$ CANNOT BE MEASURED; FULL INFORMATION REQUIRES Z-ERRORS <300 KM/S
- TO MEASURE $D_A(z)$, A PRECISION OF $\sigma_z/(1+z) \lesssim 4\%$ IS REQUIRED; WORSE PRECISION CAUSES CATASTROPHIC CANCELLATION OF BAO SIGNAL OVER WIDTH OF Z-SHELL
- HOWEVER 3-4% PRECISION YIELDS POOR CONSTRAINTS ON THE BAO PER UNIT VOLUME; A PHOTO-Z SURVEY NEEDS ~ 10 X MORE VOLUME THAN A SPECTRO-Z SURVEY
- BETTER PRECISION HELPS, BUT AT $z < 0.7$, SPECTRO-Z SURVEYS ARE ALREADY COVERING LARGE FRACTION OF SKY, SO PHOTO-Z SURVEYS ONLY COMPETITIVE AT HIGHER Z'S
- PHOTO-Z SURVEYS REQUIRE STRINGENT CALIBRATION AND MORE EXTENSIVE MODELING THAN SPECTRO-Z SURVEYS

COSMOLOGY FROM 2DFGRS

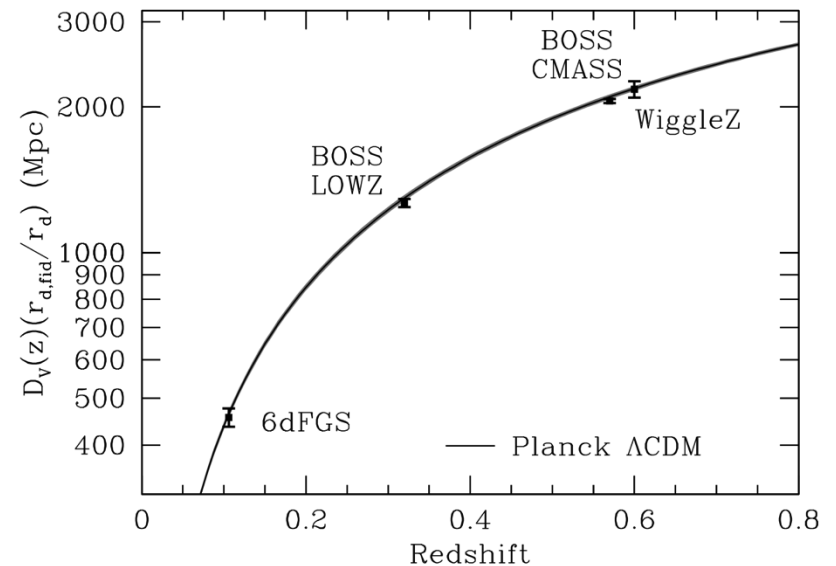
- 2DFGRS MEASURED 221,000 Z'S OVER 2000 DEG²
- LARGE-SCALE STRUCTURE OF THE GALAXY DISTRIBUTION PRECISELY MAPPED ON SCALES OF 10⁶–10⁹ LIGHT-YEARS
- THE FORM OF LARGE-SCALE STRUCTURE IS CONSISTENT WITH GROWTH BY GRAVITATIONAL INSTABILITY ⇒ QUANTUM FLUCTUATIONS FROM THE BIG BANG ARE AMPLIFIED BY GRAVITY TO BECOME GALAXIES, CLUSTERS & SUPERCLUSTERS
- THE TOTAL DENSITY OF ALL TYPES OF MATTER IS $\Omega_M = 0.23$ ⇒ THERE IS ONLY 23% OF THE MATTER NEEDED TO MAKE A CRITICAL-DENSITY (I.E. FLAT = ZERO-CURVATURE) UNIVERSE
- THE TOTAL DENSITY IN ORDINARY MATTER IS $\Omega_B = 0.04$ ⇒ BARYONS ARE 17% & CDM 83% OF THE TOTAL MATTER
- NEUTRINOS MAKE UP LESS THAN 13% OF ALL MATTER ⇒ TOTAL MASS OF 3 NEUTRINO SPECIES IS LESS THAN 0.7 eV
- BARYON ACOUSTIC OSCILLATIONS DETECTED AT 2.5 σ

COSMOLOGY FROM MOS – BAO

- **BARYON ACOUSTIC OSCILLATIONS (BAO) PROVIDE STANDARD RULER**
- BAO RESULT FROM PRESSURE WAVES IN PRE-RECOMBINATION PHOTON-BARYON FLUID IMPRINTING THE SOUND HORIZON SCALE ON THE MATTER DISTRIBUTION
- GALAXY REDSHIFT SURVEYS YIELD ANGULAR DIAMETER DISTANCES $D_A(z)$ & EXPANSION RATES $H(z)$
- BAO MAP EXPANSION HISTORY BOTH ALONG AND ACROSS THE LINE OF SIGHT, PROBING BOTH DARK ENERGY AND GRAVITY
- A WELL-UNDERSTOOD, PRECISE TOOL; MAIN LIMITATION IS THE SCALE OF THE SURVEYS REQUIRED



ANDERSON+ (2014)

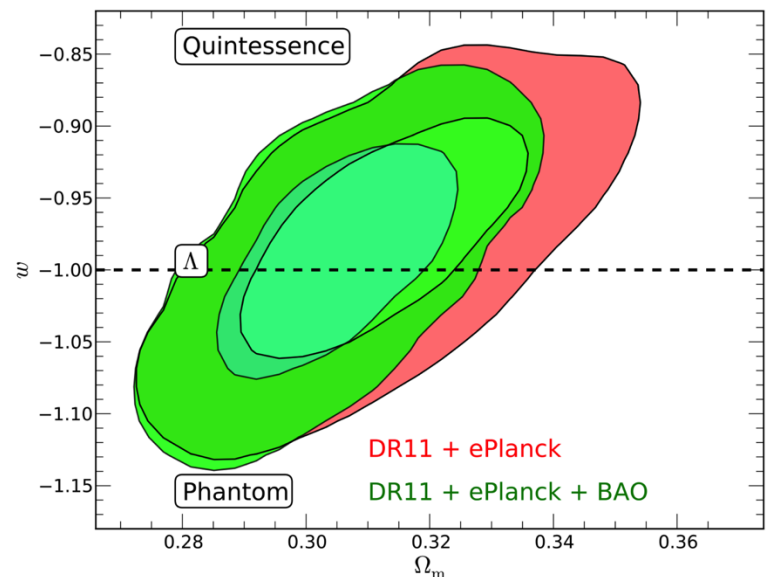
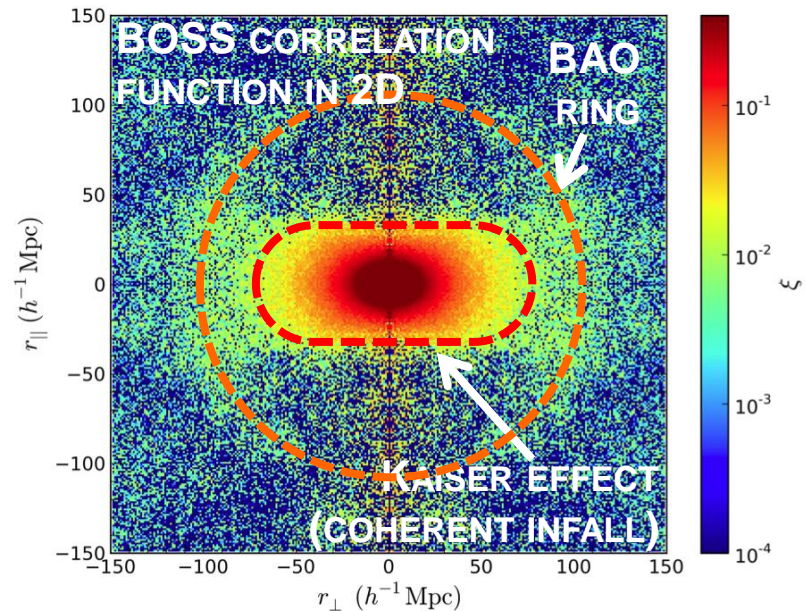


BAO SURVEYS

- BAO FIRST DETECTED IN GALAXY DISTRIBUTION (AT 2.5σ) BY 2DFGRS AND SDSS (COLE+ 2005, EISENSTEIN+ 2005)
- THE WIGGLEZ SURVEY OBSERVED 2×10^5 EMISSION-LINE GALAXIES OVER 800 DEG² AND MEASURED BAO AT $0.5 < z < 1$ WITH 3.8% PRECISION AT $z=0.6$ (BLAKE+ 2011)
- BEUTLER+ (2011) USED 6DFGS TO MAKE A LOW-REDSHIFT ($z < 0.1$) BAO DISTANCE MEASUREMENT WITH 4.5% PRECISION
- KAZIN+ (2010) USED THE FULL LRG SAMPLE FROM DR7 TO MEASURE THE GALAXY CORRELATION FUNCTION AND OBTAIN A 3.5% MEASUREMENT OF THE BAO SCALE AT $z = 0.35$
- PERCIVAL+ (2010) USED 900,000 GALAXIES OVER 9100 DEG² FROM THE COMBINED 2DFGRS, SDSS DR7/LRG SAMPLES TO OBTAIN THE BAO SCALE AT $z=0.27$ WITH 2.7% PRECISION
- PADMANABHAN+ (2012) SHOWED THAT DENSITY FIELD RECONSTRUCTION COULD IMPROVE THESE BAO MEASURES BY ABOUT A FACTOR OF 2

COSMOLOGY FROM MOS - RSD

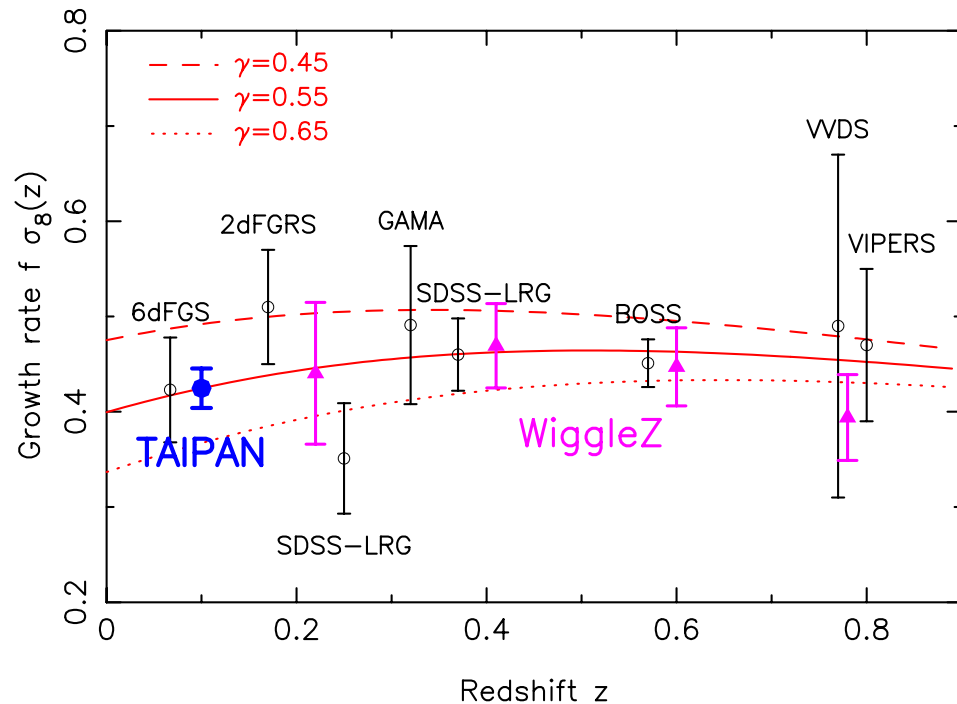
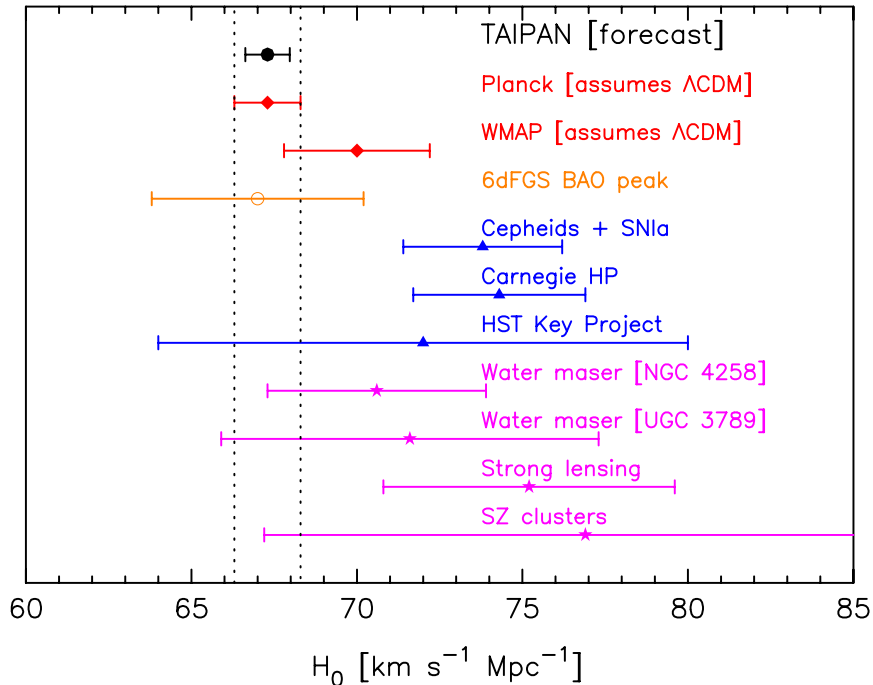
- REDSHIFT-SPACE DISTORTIONS RESULT FROM PECULIAR MOTIONS DUE TO GRAVITY AND MEASURE THE GROWTH OF STRUCTURE
- RSD MEASURE THE COMBINATION $f(z)\sigma_8(z)$ WHERE $f(z)=\Omega_M(z)^{\gamma}$ AND σ_8 IS FLUCTUATION IN 8 MPC/h SPHERE
- RSD CONSTRAINTS COME FOR FREE WITH ANY LARGE GALAXY z-SURVEY
- MAIN UNCERTAINTY IS THEORETICAL MODELING OF THE NON-LINEAR GRAVITATIONAL EVOLUTION AND NON-LINEAR BIAS; CURRENTLY THIS LIMITS APPLICATION OF RSD METHOD TO CO-MOVING SEPARATIONS $r > 10$ MPC/h (OR $k < 0.2$ h/Mpc)



SAMUSHIA+ (2014)

LOW-Z COSMOLOGY SURVEYS

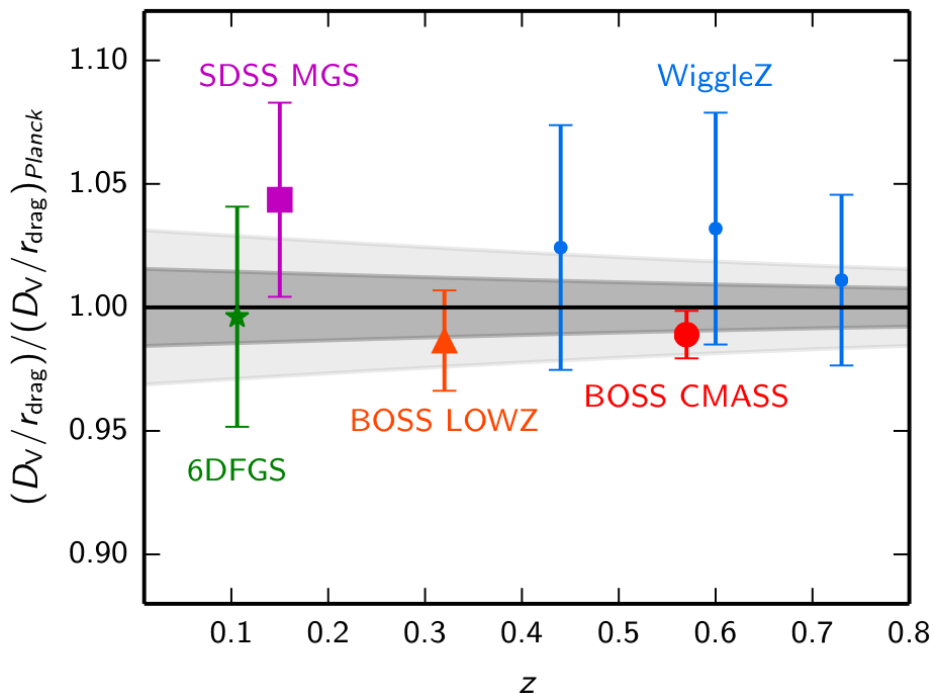
- 6DFGS, THOUGH SMALLER THAN 2DFGRS & SDSS, GIVES VALUABLE CONSTRAINTS ON COSMOLOGY AT LOW Z, NOTABLY A DIRECT MEASURE OF H_0 AND GROWTH OF STRUCTURE
- THE TAIPAN SURVEY (HOPKINS TALK) WILL HAVE 4X THE SAMPLE SIZE & VOLUME OF 6DFGS AND GIVE H_0 WITH $\sim 1\%$ PRECISION AND GROWTH OF STRUCTURE TO 5% AT $\langle z \rangle \approx 0.1$
- DARK ENERGY IS A LATE-TIME (LOW-REDSHIFT) PHENOMENON!



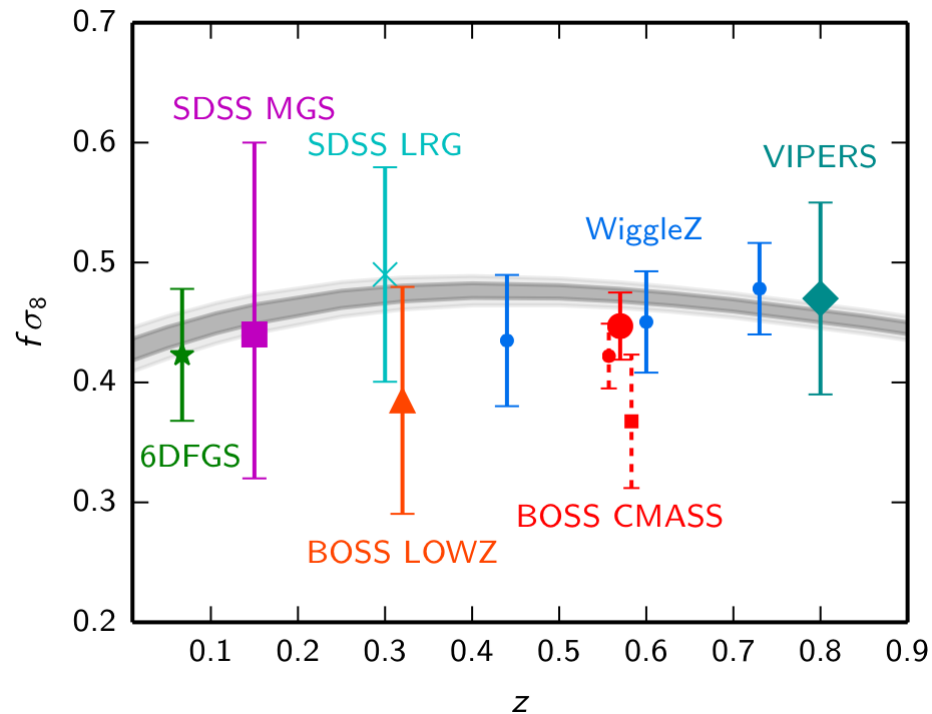
HIGH-Z COSMOLOGY SURVEYS

- REDSHIFT SURVEYS COVERING A RANGE OF EPOCHS (WIGGLEZ, BOSS...) CONSTRAIN THE EVOLUTION OF THE GEOMETRY OF THE UNIVERSE AND THE GROWTH OF STRUCTURE OVER COSMIC TIME

BAO: DEVIATIONS FROM Λ CDM GEOMETRY

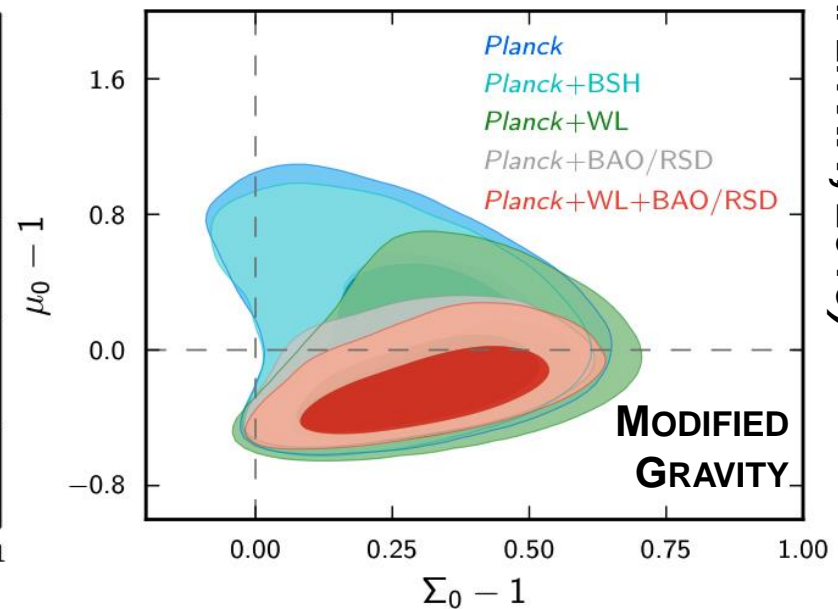
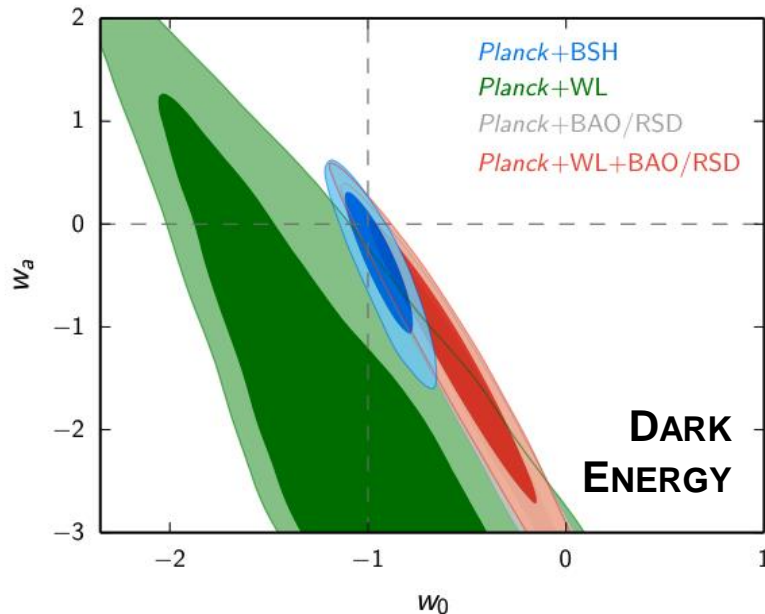
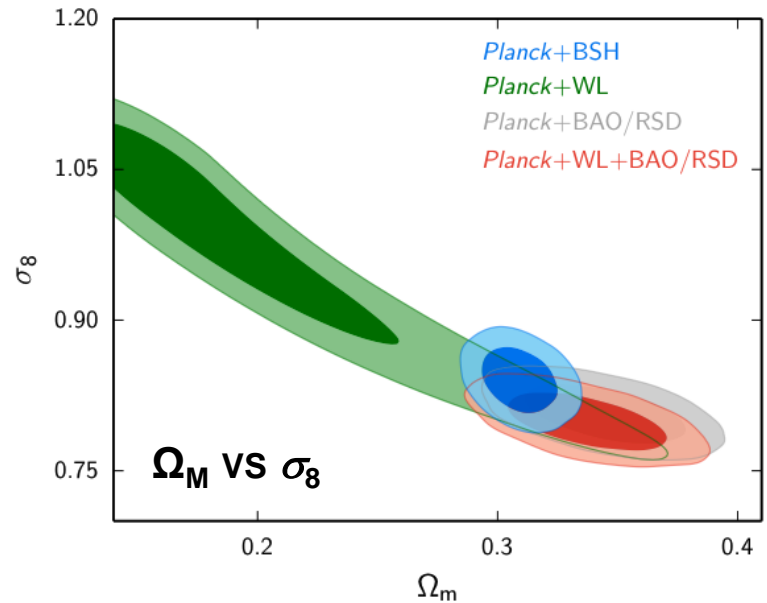


RSD: GROWTH RATE OF STRUCTURE



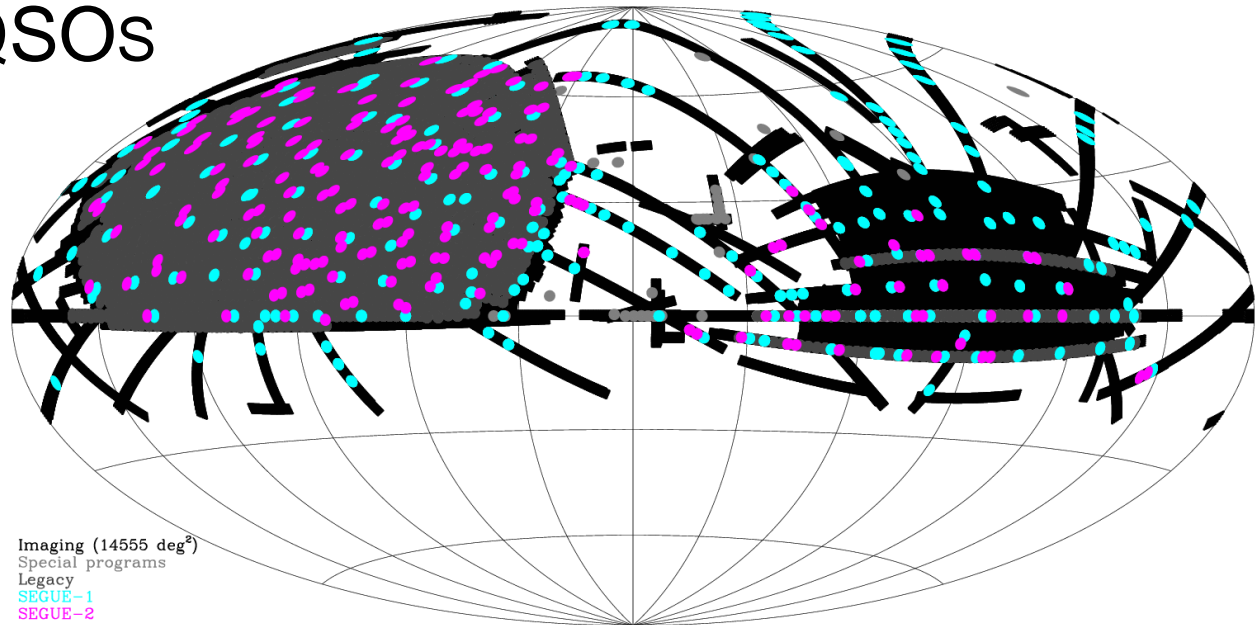
COSMOLOGICAL POWER OF MOS

- THE ADDED INFORMATION GIVEN BY MOS SURVEYS IS QUANTIFIED BY THE TIGHTER CONSTRAINTS ON DARK ENERGY AND MODIFIED GRAVITY RELATIVE TO THOSE FROM THE CMB ALONE

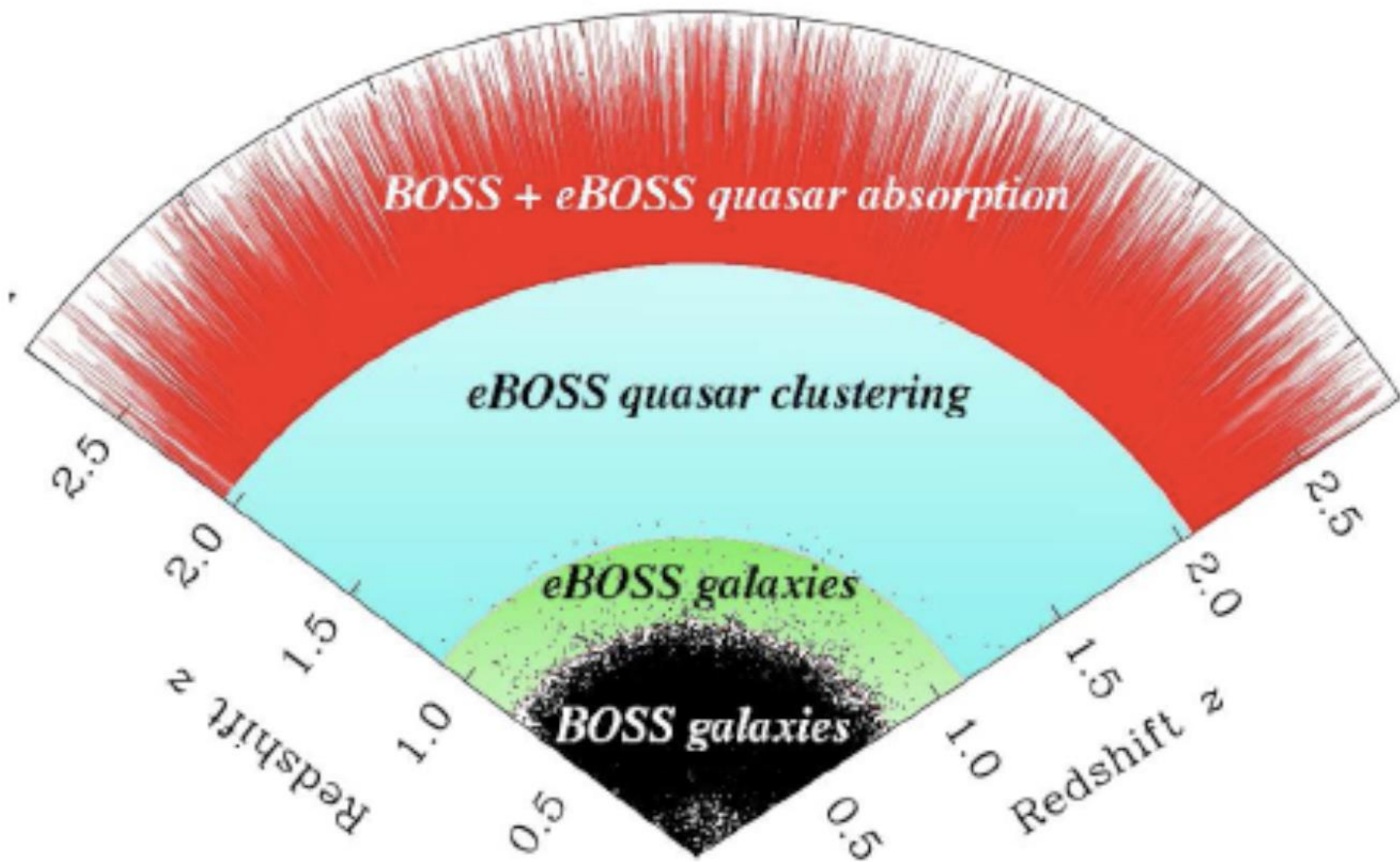


BOSS: THE STATE OF THE ART

- GOAL: MEASURE BAO OVER LARGER VOLUME AND Z-RANGE THAN ALL PREVIOUS Z-SURVEYS
- FINAL DATASET IS SDSS DR12 (TO JULY 2014)
- GALAXIES: 1.4×10^6 AT $z < 0.7$ ($i < 19.9$) OVER 10^4 DEG²
 - FORECAST: D_A TO 1.0% AND $H(z)$ TO 1.8% AND 1.7% AT $z=0.3$ AND $z=0.57$
- Ly α : 1.6×10^5 QSOs WITH $g < 22$ AT $2.15 < z < 3.5$
 - FORECAST: OVERALL DILATION FACTOR TO 1.9% AT $z < 2.5$



BOSS AND eBOSS

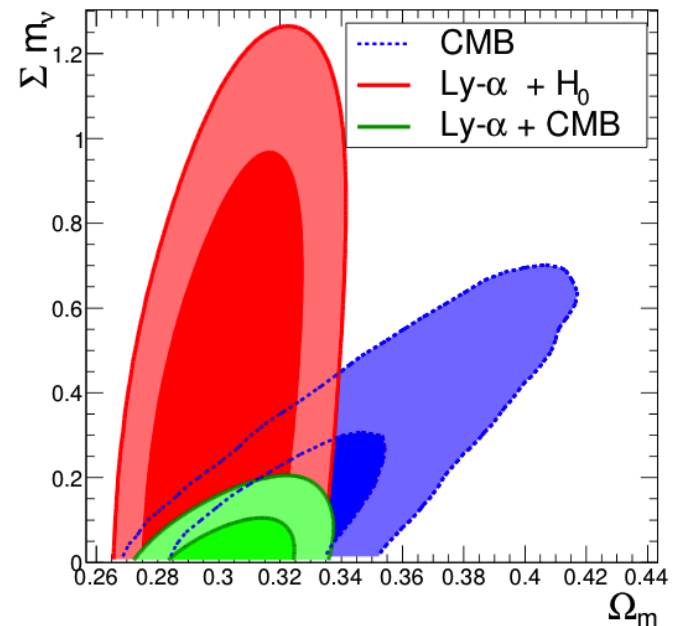
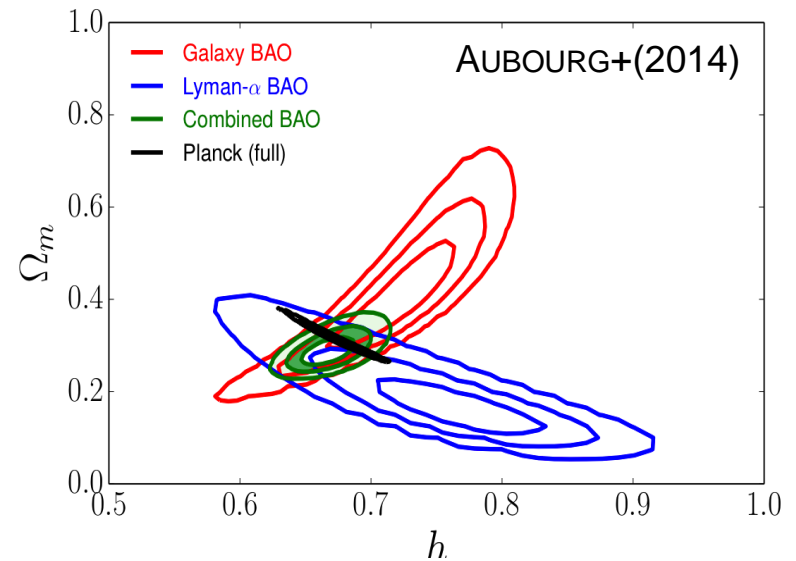


BOSS: THE STATE OF THE ART

- BOSS DETECTS BAO FEATURE AT 7σ IN GALAXIES AND 5σ IN Ly α FOREST
- BAO ALONE YIELD A HIGH CONFIDENCE DETECTION OF DARK ENERGY AND, WITH THE CMB ACOUSTIC SCALE, BAO IMPLY A NEARLY FLAT UNIVERSE
- BAO+CMB+SN DATA JOINTLY GIVE $H_0 = 67.3 \pm 1.1$ KM/S/MPC (1.7%) ROBUST TO ASSUMPTIONS ABOUT DARK ENERGY OR SPACE CURVATURE
- FOR CONSTANT DARK ENERGY (Λ), BAO+CMB+SN YIELDS

$$\Omega_M = 0.301 \pm 0.008 \text{ (2.7\%)}$$

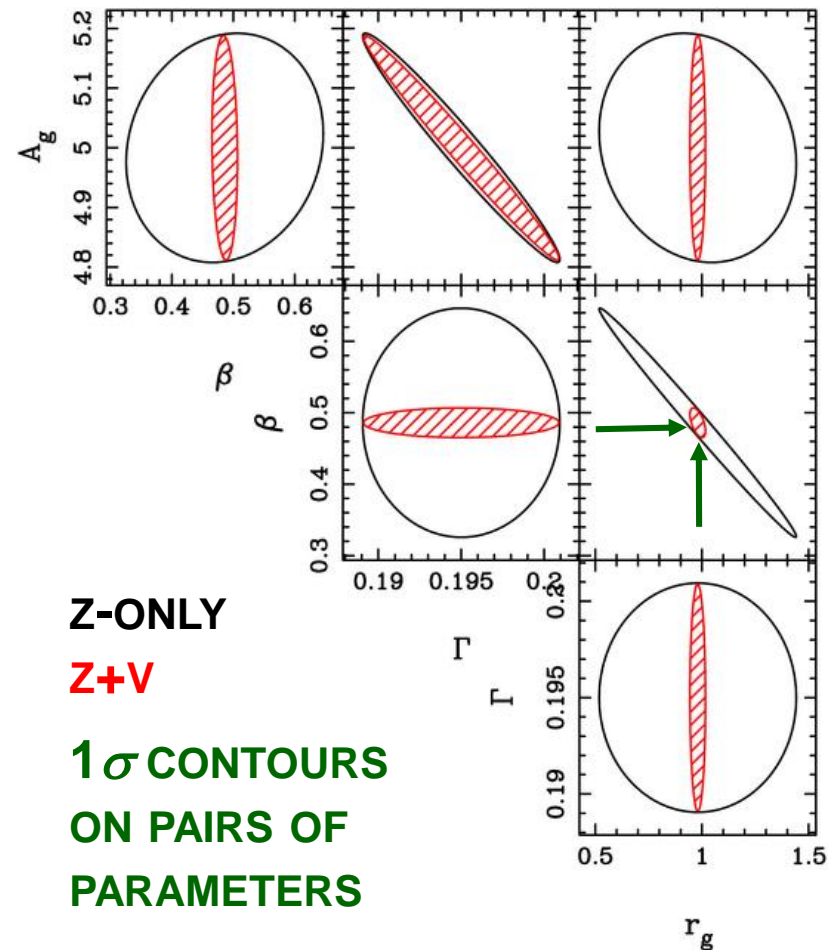
$$\Omega_K = -0.003 \pm 0.003$$
- FOR EVOLVING FORMS DARK ENERGY, BAO+CMB+SN DATA ARE ALWAYS CONSISTENT WITH FLAT Λ CDM AT $\sim 1\sigma$
- BAO+PLANCK-WL GIVES A SUMMED MASS OF NEUTRINOS $\Sigma m_\nu < 0.25$ eV



PALANQUE-DELABROUILLE+ (2014)

COSMOLOGY - PECULIAR VELOCITIES

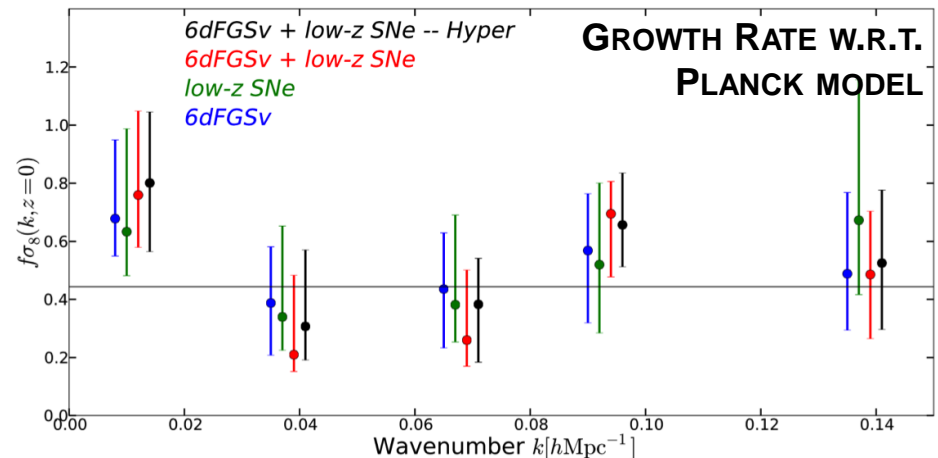
- MOS COSMOLOGY IS NOT JUST ABOUT REDSHIFTS!
- PECULIAR VELOCITY SURVEYS (V-SURVEYS) CAN PROVIDE ADDITIONAL INFORMATION REMOVING SOME DEGENERACIES INTRINSIC TO Z-SURVEYS (E.G. BETWEEN β AND r_g)
- V-SURVEYS ARE NECESSARILY LOW-REDSHIFT DUE TO FIXED FRACTIONAL DISTANCE ERRORS
- DISTANCE ERRORS ARE TYPICALLY SIGNIFICANT (E.G. 20-25% FOR TF AND FP, BUT 5-8% FOR SNE)
- 6DFGRS IS THE CURRENT STATE-OF-THE-ART Z+V-SURVEY:
 - 125,000 REDSHIFTS AND 9000 PECULIAR VELOCITIES (USING FUNDAMENTAL PLANE DISTANCES FOR EARLY-TYPE GALAXIES)
 - V-SURVEY COVERS 17000 DEG² TO DEPTH OF ~ 16000 KM/S



V-SURVEY COSMOLOGY

- JOHNSON+ (2014) USE THE POWER SPECTRUM OF THE 6DFGS PECULIAR VELOCITIES TO OBTAIN FIRST SCALE-DEPENDENT MEASUREMENTS OF THE GROWTH RATE OF STRUCTURE $f\sigma_8$ (IN COMBINATION WITH $z < 0.07$ SNE)

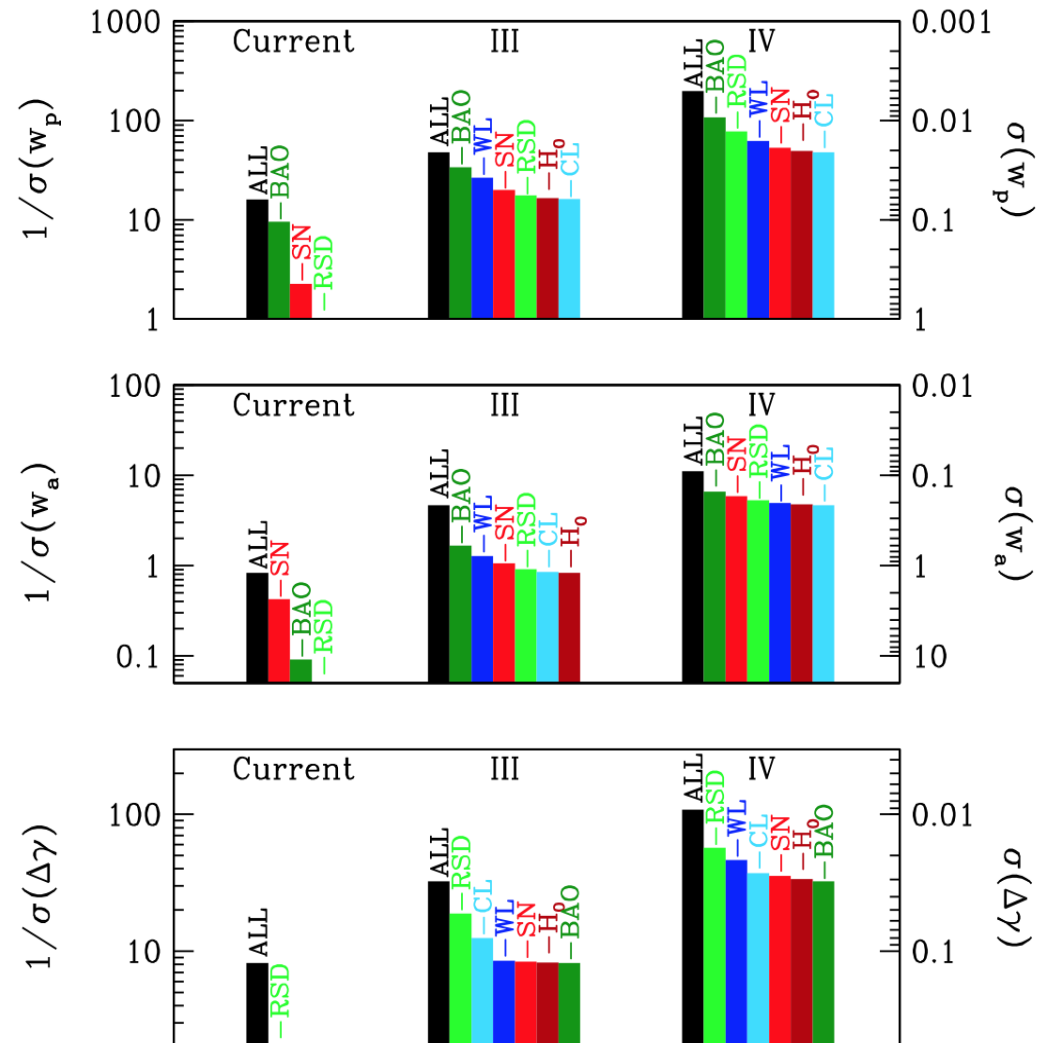
- MEASURED THE GROWTH RATE IN $\Delta k = 0.03$ h/MPC BINS TO $\sim 35\%$ PRECISION, INCL. A MEASUREMENT ON SCALES > 300 h/MPC, THE LARGEST-SCALE MEASUREMENT OF THE GROWTH RATE TO DATE



- NO EVIDENCE FOR A SCALE DEPENDENCE IN GROWTH RATE OR VARIATION FROM PREDICTIONS OF PLANCK Λ CDM MODEL
- COMBINING ALL SCALES, THE GROWTH RATE AT $z=0$ IS MEASURED WITH $\sim 15\%$ PRECISION, INDEPENDENT OF GALAXY BIAS & IN GOOD AGREEMENT WITH RSD GROWTH RATE MEASUREMENTS FROM 6DFGS Z-SURVEY
- FUTURE PECULIAR VELOCITY SURVEYS WILL ALLOW US TO UNDERSTAND IN DETAIL THE GROWTH OF STRUCTURE IN THE LOW-REDSHIFT UNIVERSE, PROVIDING STRONG CONSTRAINTS ON THE NATURE OF DARK ENERGY

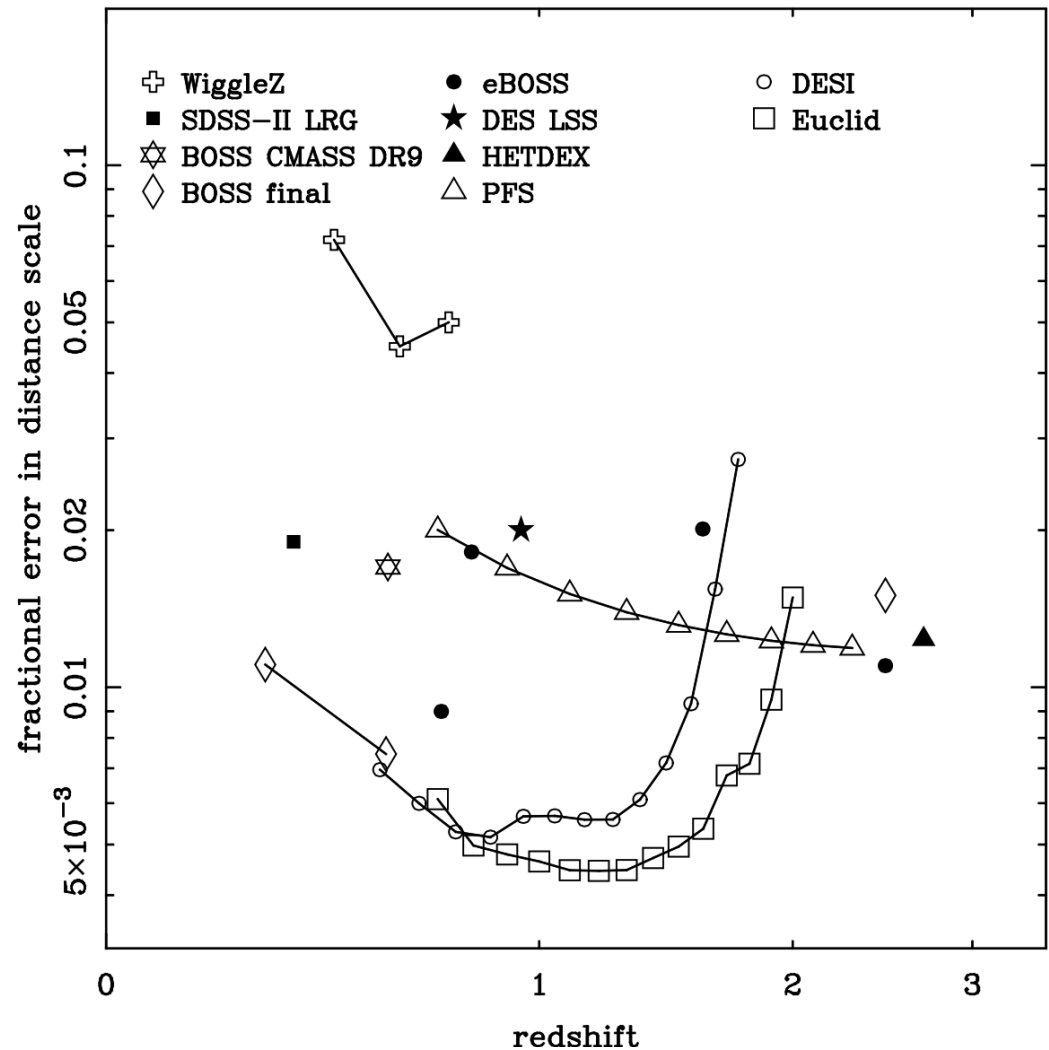
DARK ENERGY – FUTURE PROGRESS

- ALL OBSERVATIONS TO DATE OF THE COSMIC EXPANSION HISTORY AND THE GROWTH OF STRUCTURE ARE CONSISTENT WITH A FLAT Λ CDM + GR MODEL WITH $\Omega_M \approx 0.3$ AND $\Omega_\Lambda \approx 0.7$
- Z-SURVEY METHODS (BAO, RSD) ARE EXPECTED IN FUTURE TO PROVIDE 10X BETTER CONSTRAINTS ON THE DARK ENERGY EQUATION OF STATE



CONSTRAINTS FROM MOS SURVEYS

- FISHER MATRIX PREDICTIONS FOR PRECISION OF BAO DISTANCE SCALE MEASUREMENTS AS A FUNCTION OF REDSHIFT
- THE BOSS SURVEY ACHIEVES $\sim 2\%$ FOR $z < 1$ AND AT $z \sim 2.5$
- THE DESI & EUCLID SURVEYS WILL ACHIEVE 0.5-1% OUT TO $z=2$



MOS COSMOLOGY IN 2025

□ WHAT WILL MOS COSMOLOGY LOOK LIKE IN 2025? SOME SAFE PREDICTIONS...

1. REDSHIFT SURVEYS EXIST TOTALING A FEW $\times 10^7$ GALAXIES OUT TO $z \sim 1.7$ AND A FEW $\times 10^6$ GALAXIES/QSOS OUT TO $z \sim 3$
2. PECULIAR VELOCITY SURVEYS (OPTICAL AND HI) EXIST TOTALING $>10^5$ GALAXIES IN THE NEARBY UNIVERSE
3. LSST PROVIDES ULTIMATE TARGET LIST FOR MOS SURVEYS; HOW CAN WE FULLY EXPLOIT THIS? NEED DEDICATED 8M MOS!
4. A COMMON FEDERATED DATABASE SYSTEM HAS EMERGED FROM A HETEROGENEOUS SET OF SURVEYS AND SOFTWARE
5. MANY MORE PAPERS ARE BASED ON ARCHIVAL MOS SPECTRA AND DATABASES THAN ON FRESH OBSERVATIONS
6. 'DATA SCIENTISTS' OUTNUMBER 'OBSERVERS' (AND HAVE MORE KUDOS AND BETTER CAREER PROSPECTS)
7. TEAM LEADERS ARE STILL COMPLAINING THAT SCIENCE OUTPUTS FROM THEIR SURVEYS ARE PERSON-/BRAIN-POWER-LIMITED

FUTURE MOS INSTRUMENTS

- EVERY SELF-RESPECTING GENERAL-PURPOSE 4M OR 8M-CLASS TELESCOPE NEEDS MOS CAPABILITY
- MOS IS EXPANDING IN NEW DIRECTIONS: NOT JUST HIGH-MULTIPLEX BUT ALSO HIGH-RESOLUTION AND MULTI-IFUS (& EVENTUALLY MOAO MULTI-IFUS)
- IN THE ELT ERA, MOST 8M-CLASS TELESCOPES WILL HAVE A MOS INSTRUMENT OF SOME VARIETY AS THEIR CUTTING-EDGE FACILITY
- GMT TO HAVE HIGHLY VERSATILE MOS/MULTI-IFU CAPABILITY PROVIDED BY THE MANIFEST FACILITY
 - COUPLED TO LARGE OPTICAL/NIR SPECTROGRAPHS (BOTH MEDIUM AND HIGH RESOLUTION)
 - $A\Omega = 25\text{M APERTURE} \times 20 \text{ ARCMIN DIAMETER FIELD}$
 - OPERATING IN NATURAL SEEING AND GLAO MODES

IN MEMORIAM

THIS TALK IS DEDICATED TO
PROFESSOR PETER MCGREGOR



A FINE ASTRONOMER, A SUPERB INSTRUMENTALIST
AND A WONDERFUL COLLEAGUE
AT THE AUSTRALIAN NATIONAL UNIVERSITY
WHO PASSED AWAY 5 MARCH 2015