FUTURE COSMOLOGY SURVEYS

MATTHEW COLLESS

JENAM, 21 APRIL 2009

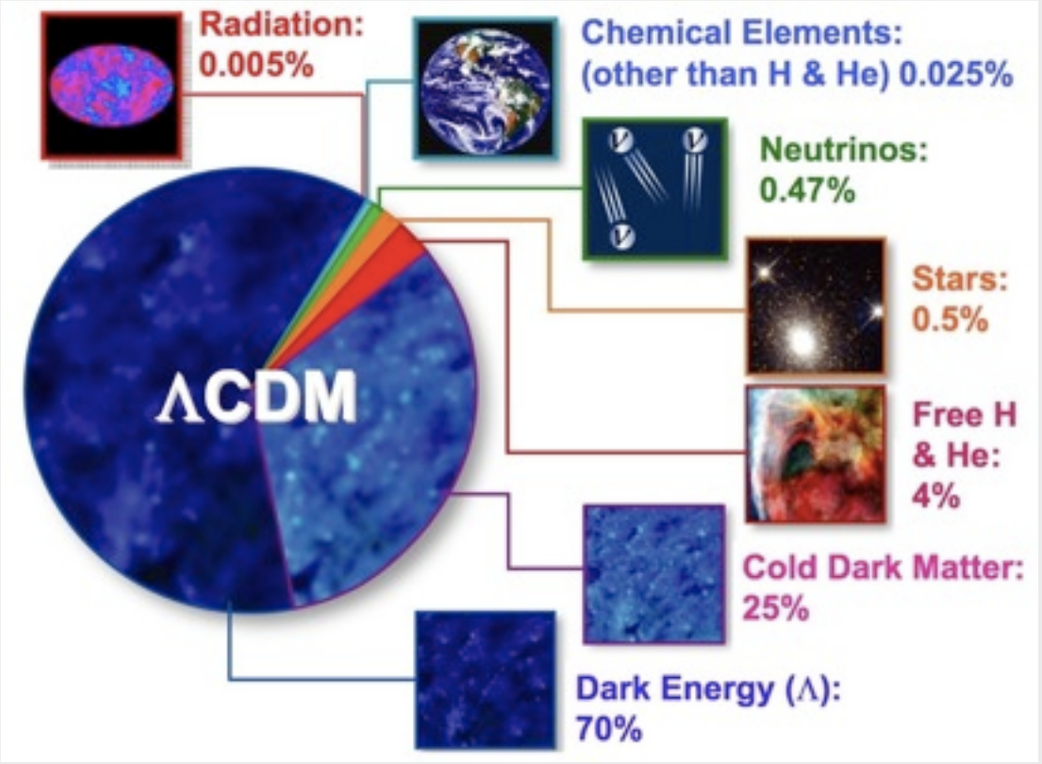
SO MUCH UNIVERSE, SO LITTLE TIME

- A PERSONAL VIEW OF THE SURVEYS THAT ARE LIKELY TO MAKE AN IMPACT ON COSMOLOGY IN THE COMING DECADE

- A CLOSER LOOK AT SOME OF THE DARK ENERGY SURVEYS, INCLUDING A BRIEF UPDATE ON THE WIGGLEZ BAO SURVEY

TYPES OF COSMOLOGY SURVEYS

- ☐ DARK ENERGY SURVEYS
  - ☐ BARYON ACOUSTIC OSCILLATIONS (BAO)
  - ☐ SUPERNOVAE (SNE)
  - ☐ WEAK LENSING (WL)
  - ☐ GROWTH OF STRUCTURE (CL, ISW)



- ☐ STRUCTURE FORMATION AND ASSEMBLY SURVEYS
  - ☐ FORMATION OF FIRST GALAXIES AT HIGH REDSHIFT
  - ☐ SURVEYS OF MATTER PHASES AND CYCLING
  - ☐ DISTRIBUTION OF MASS (DM) AND LIGHT (GALAXIES)
  - ☐ GALACTIC ARCHAEOLOGY (GA) SURVEYS

TOP(?) TEN COSMOLOGY SURVEYS

- COSMIC MICROWAVE BACKGROUND
  1. PLANCK - ULTIMATE CMB SURVEY, LAUNCHING 6 MAY!
- DARK ENERGY SURVEYS - SPECTROSCOPY (BAO)
  2. WIGGLEZ - FIRST Z>0.5 BAO SURVEY FOR EVOLVING W
  3. BOSS - MASSIVE BAO DARK ENERGY SURVEY AT Z~0.5
  4. WFMOS - BAO DARK ENERGY SURVEYS AT Z~1 & Z~3
- DARK ENERGY SURVEYS - IMAGING (BAO/SNE/WL/CL)
  5. DES/PAN-STARRS1 - OPTICAL IMAGING; SNE/WL/CL/BAO
  6. VISTA - NIR COMPLEMENT TO DES/PS1 (SEDS, PHOTO-Z)
  7. SPT - SZE CLUSTERS TO Z~2; DE VIA CLUSTER GROWTH
- FORMATION AND ASSEMBLY OF GALAXIES
  8. GAMA - DETAILED Z~0 LSS, RELATION OF MASS & LIGHT
  9. RAVE/APOGEE/HERMES/WFMOS/GAIA - ASSEMBLY OF THE MILKY WAY AND LOCAL GROUP GALAXIES
  10. JWST - ASSEMBLY OF EARLIEST GALAXIES

BEYOND THE 10-YEAR HORIZON

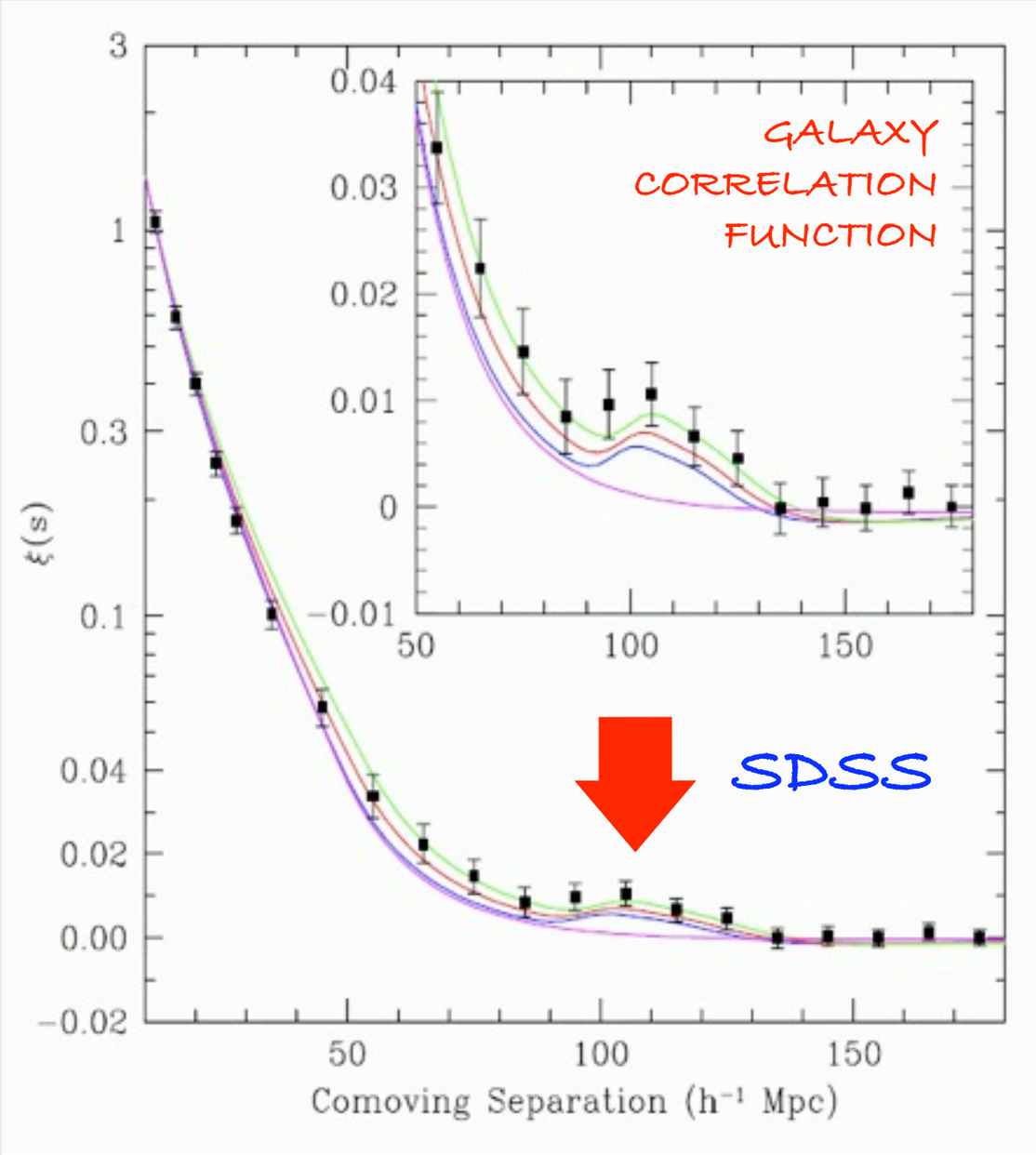
SOME OF THE BIGGEST ADVANCES IN CAPABILITY FOR COSMOLOGY SURVEYS WILL COME ON-LINE JUST OUTSIDE THE DECADAL HORIZON...

- ☐ LSST - ULTIMATE GROUND-BASED IMAGING SURVEY
- ☐ JDEM/EUCLID/??? - ULTIMATE DARK ENERGY SURVEYS
- ☐ GMT/TMT/E-ELT - FIRST STARS AND GALAXIES
- ☐ SKA - HI/AGN/BH THROUGHOUT THE UNIVERSE

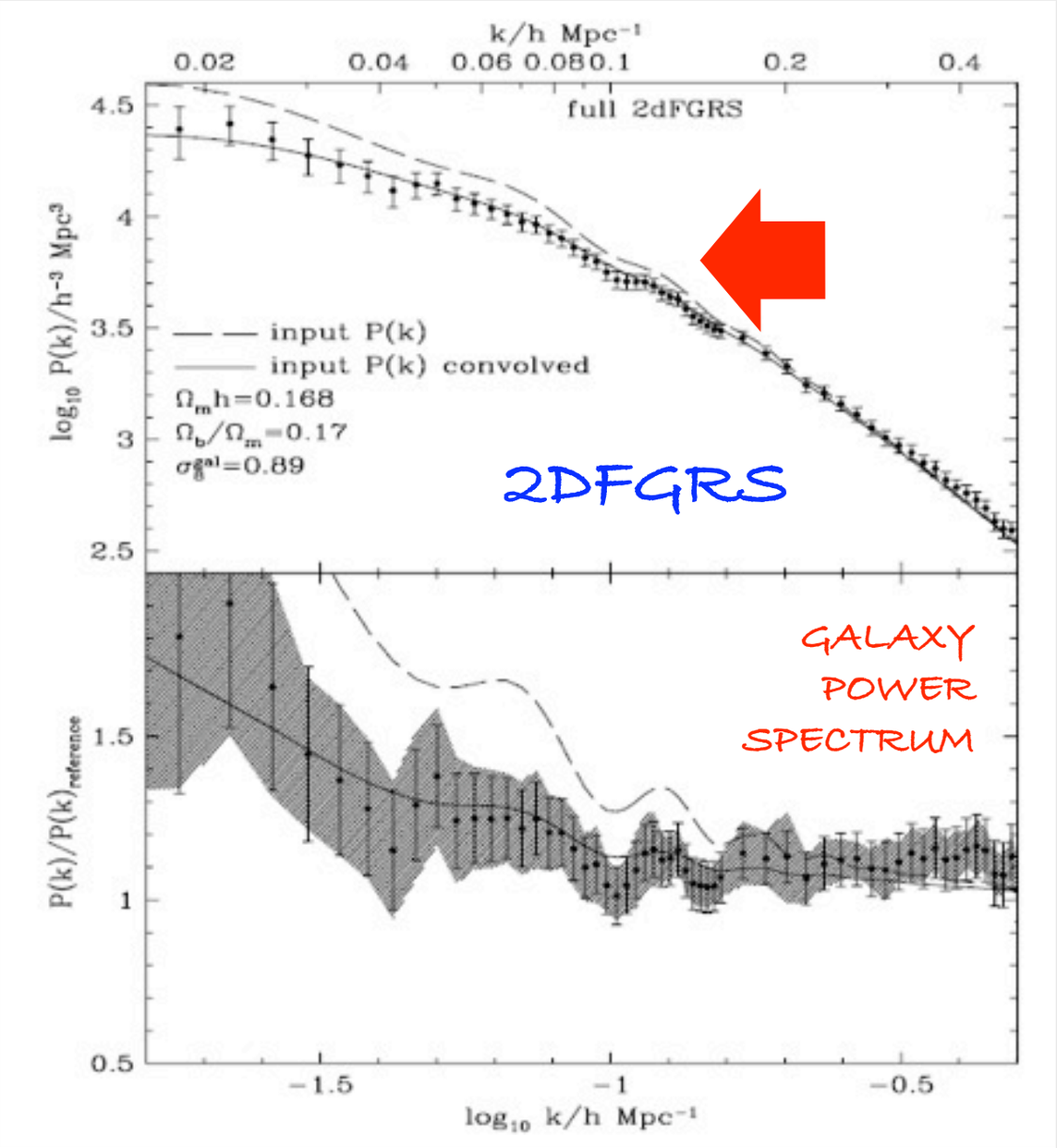
MEASURING BAO FROM LSS

THE BAO IN THE GALAXY DISTRIBUTION AT Z~0 WERE FIRST DETECTED IN THE 2DFGRS AND SDSS GALAXY REDSHIFT SURVEYS...

SDSS: EISENSTEIN ET AL. (2005)

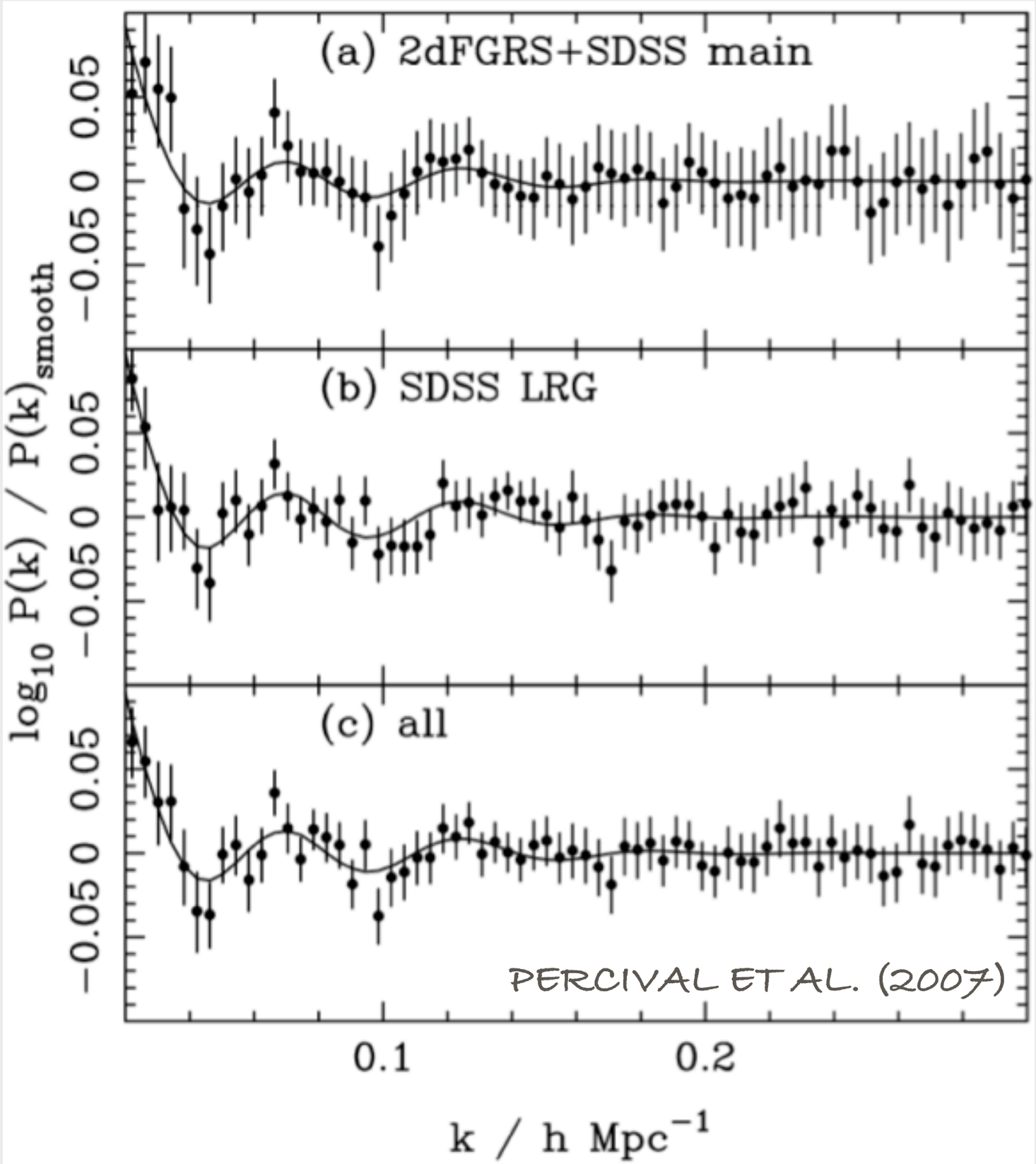


2DFGRS: COLE ET AL. (2005)



CURRENT STATE OF THE ART

- BAO DETECTED AT SIGNIFICANCE >3σ IN COMBINED SAMPLE USING ALL OF 2DFGRS + SDSS MAIN + SDSS LRGS



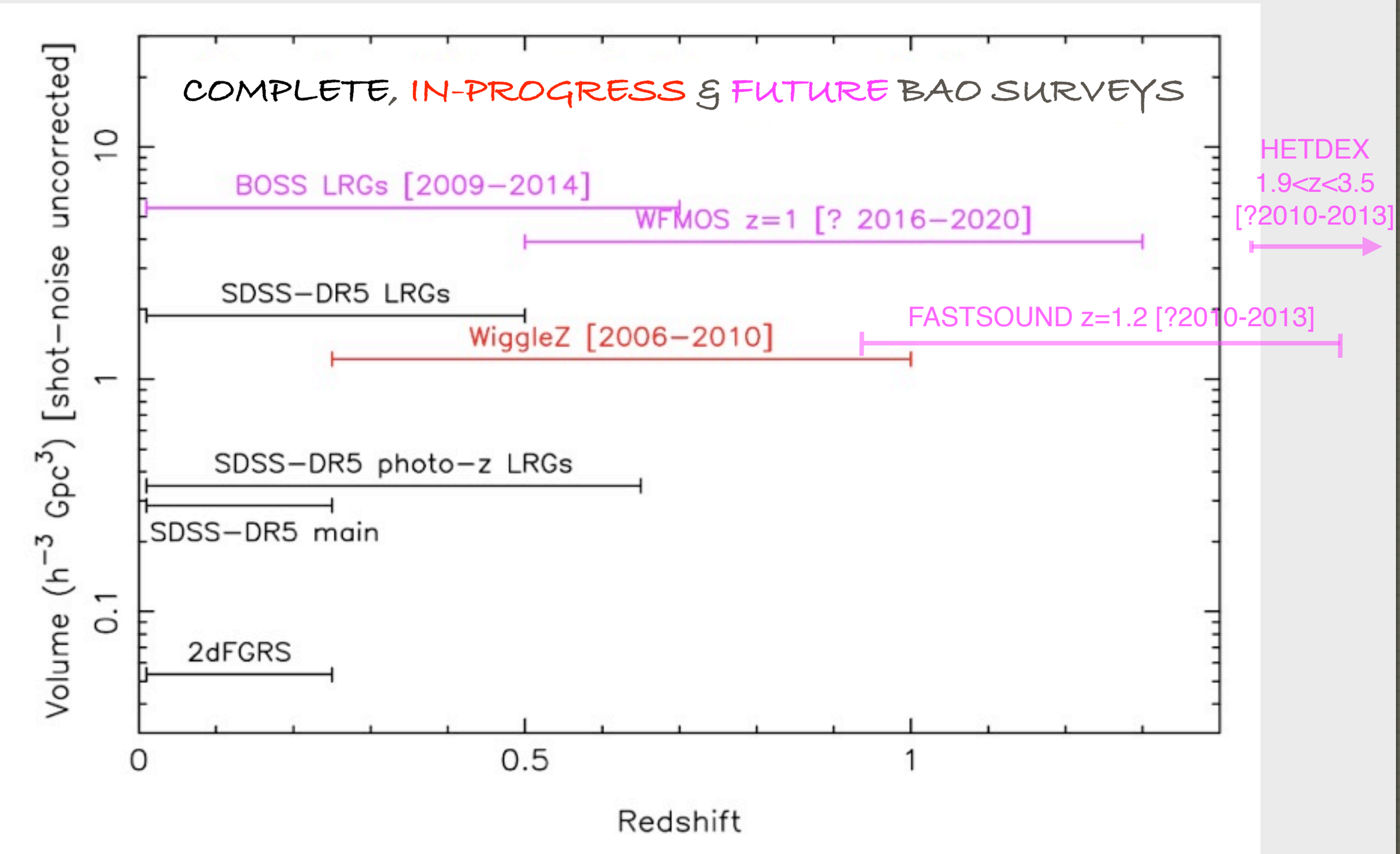
ADVANTAGES OF BAO SURVEYS

- BAO - ABSOLUTE STANDARD ROD CALIBRATED BY CMB
  - LINEAR PHYSICS; DEPENDS ONLY ON Ω_M AND Ω_B
  - CMB CALIBRATION GIVES ABSOLUTE SCALE AT Z=1100
- IN PRINCIPLE GET ~1% DISTANCES OVER A WIDE RANGE OF REDSHIFTS, SO A POTENT PROBE OF DARK ENERGY
  - CAN MEASURE H(Z) RADIALLY AND $D_A(Z)$ TANGENTIALLY
  - REQUIRES LARGE SAMPLES: ~10^6 GALAXIES OVER ~1 GPC^3
- COMPLEMENTARY TO OTHER DARK ENERGY PROBES
  - MEASURES DIFFERENT COSMOLOGICAL PROPERTIES
  - DIFFERENT PHYSICAL BASIS AND SYSTEMATICS
    - NON-LINEAR CLUSTERING ON SMALL SCALES
    - Z-SPACE DISTORTIONS OF THE CLUSTERING PATTERN
    - SCALE-DEPENDENT BIAS OF GALAXIES

ONGOING/FUTURE BAO SURVEYS

SURVEY	TELESCOPE / INSTRUMENT	N(Z) / 10^6	DATES	STATUS
WIGGLEZ	AAT/AAΩ	0.2	2007-2010	IN PROGRESS
FASTSOUND	SUBARU/FMOS	0.6	2010-2013	PROPOSAL
BOSS	SDSS	1.5	2009-2013	STARTING
HETDEX	HET/VIRUS	1.0	2010-2013	PART FUNDED
LAMOST-DE	LAMOST	T.B.D.	2010-201?	PROPOSAL
WFMOS-DE	SUBARU/WFMOS	>2	2013-2016	FUNDING?
JDEM	NASA/JDEM	>100	2012+	STATUS?
SKA	SKA	>100	2020+	FUTURE

BAO SURVEY COMPARISON



THE WIGGLEZ SURVEY

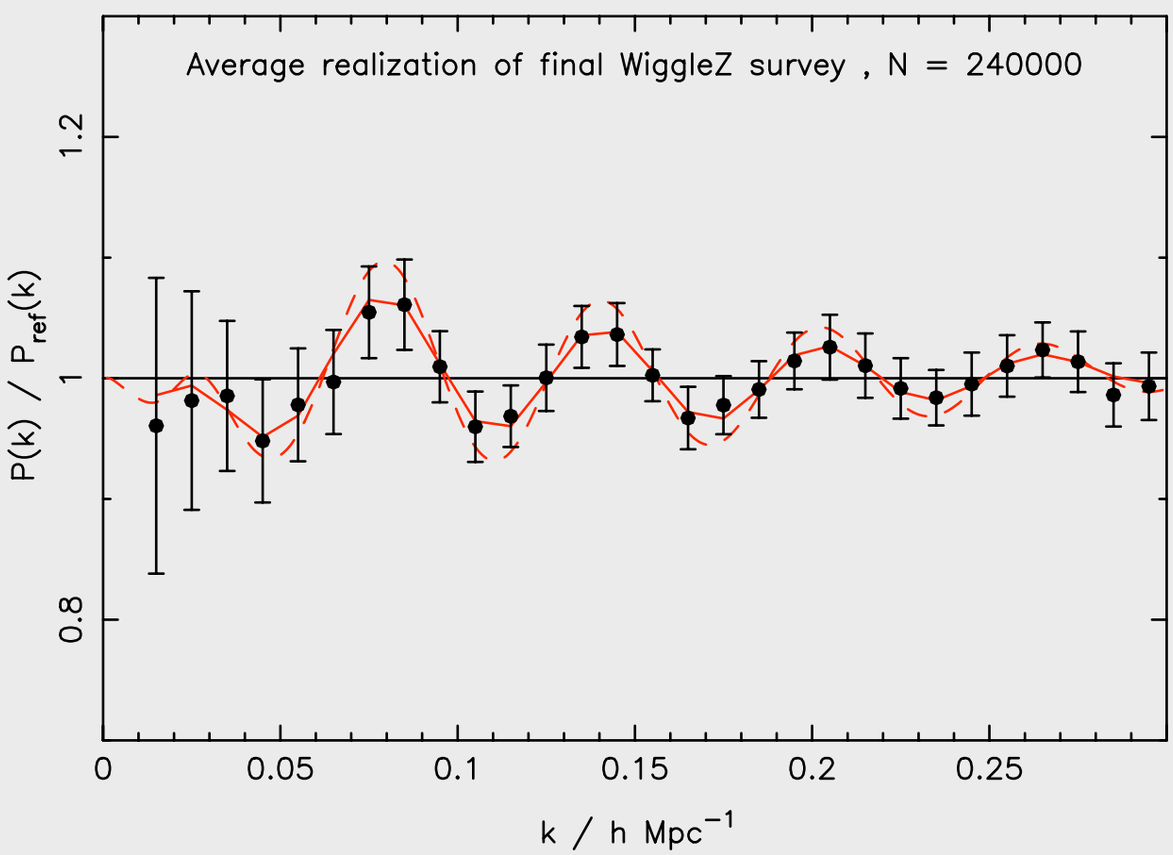
- PROJECT GOALS:
  - THE FIRST 'HIGH' REDSHIFT ($Z>0.5$) BAO SURVEY
  - SURVEY 240,000 GALAXIES WITH MEDIAN $Z \sim 0.6$
  - BAO SCALE TO 2% AND TEST $W_0=-1$ OVER $Z\sim0.25$-1.0
- SURVEY OBSERVATIONS AND SAMPLE:
  - STAR-FORMING GALAXIES FROM GALEX & SDSS/RCS2
  - FUV-NUV-OPT COLOURS SELECT 'LYMAN-BREAK' GALAXIES AT $Z>0.5$
  - COVERS ~1000 DEG^2 ON SKY & A VOLUME OF ~1 GPC^3
  - AAOMEGA GIVES REDSHIFTS TO $Z\sim1$ IN 1 HOUR
- STATUS AND RESULTS:
  - ABOUT TWO-THIRDS COMPLETE; FINISH BY JULY 2010
  - PRELIMINARY RESULTS & FORECAST CONSTRAINTS

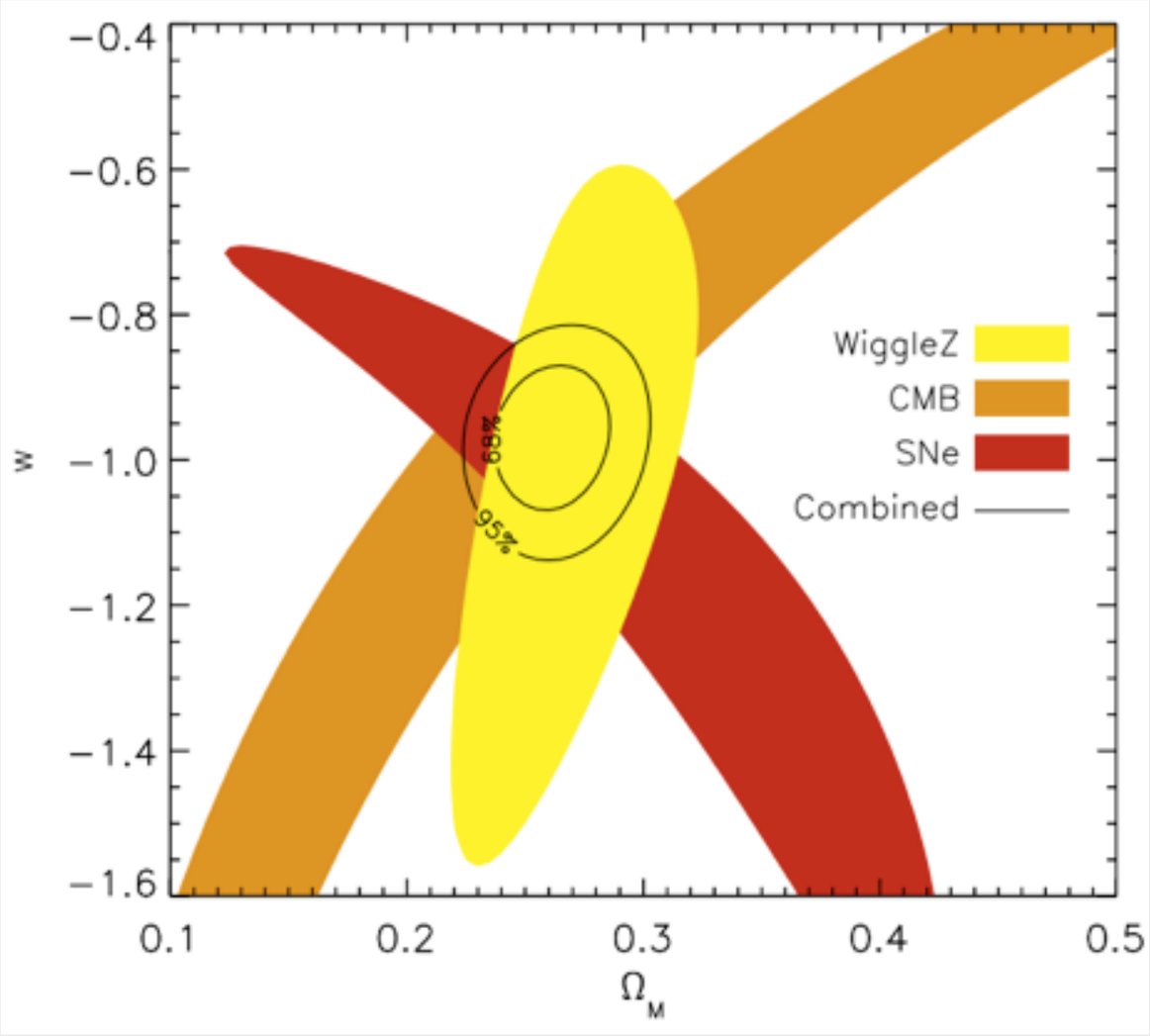
WIGGLEZ VITAL STATISTICS

SURVEY PARAMETER	SURVEY PLAN	MARCH 2009	SURVEY END
SKY COVERAGE	1000 DEG^2	675 DEG^2	1000 DEG^2
NUMBER OF NIGHTS	220	157	240
GOOD WEATHER FRACTION	75%	66%	66%
NUMBER OF WIGGLEZ SPECTRA	340,000	266,000	410,000
NUMBER OF WIGGLEZ GOOD Z'S	240,000	139,000	215,000
WIGGLEZ Z-COMPLETENESS	70%	70%	70%
NUMBER OF AAT POINTINGS	1200	807	1235
NUMBER OF GALEX ORBITS	1250	1142	1250
DURATION OF SURVEY	AUGUST 2006 – JULY 2010		

WIGGLEZ SURVEY FORECASTS

- PREDICTED UNCERTAINTIES BASED ON CURRENT RESULTS AND MONTE CARLO SIMULATIONS OF THE EXPECTED FINAL DATASET:
  - ~2.7% IN TANGENTIAL SCALE AND ~4.3% IN RADIAL SCALE
  - < 2% PRECISION ON MEASUREMENT OF OVERALL BAO SCALE
  - ~5% PRECISION IN 3 REDSHIFT INTERVALS OVER Z=0.25-1.0

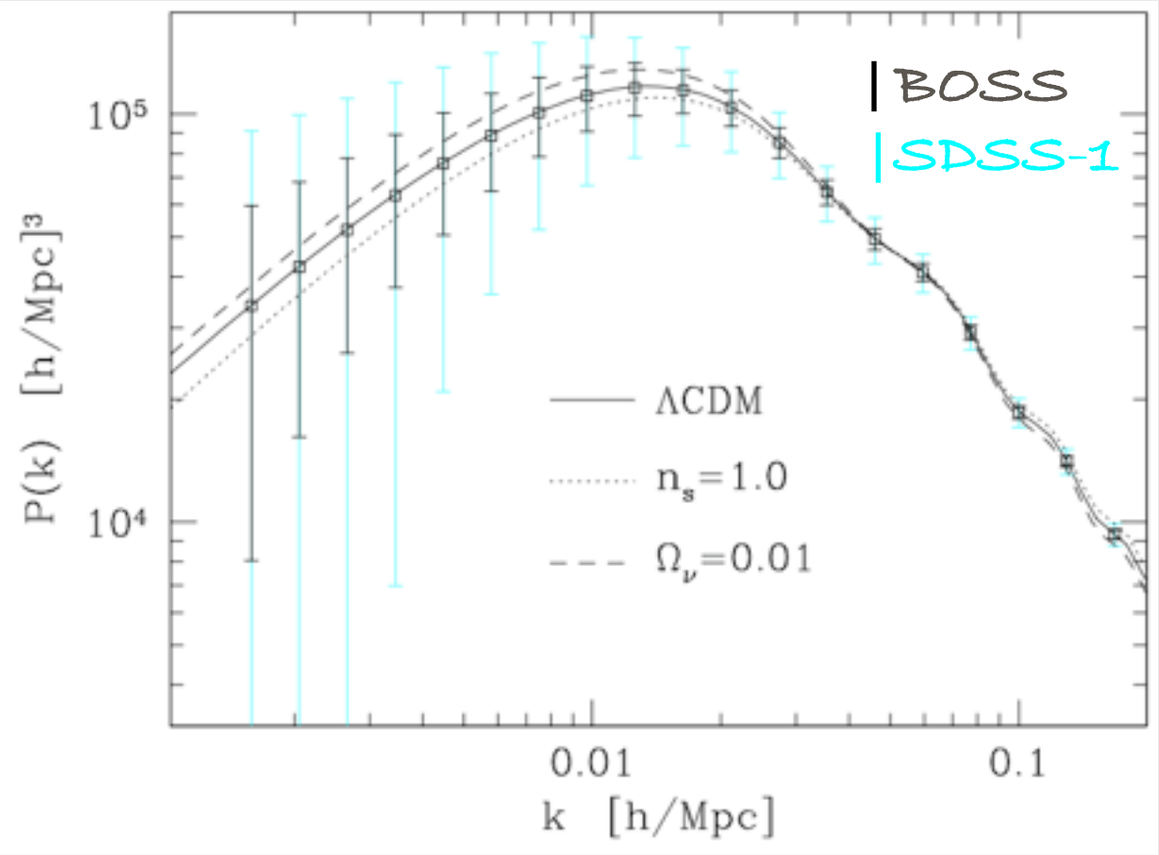


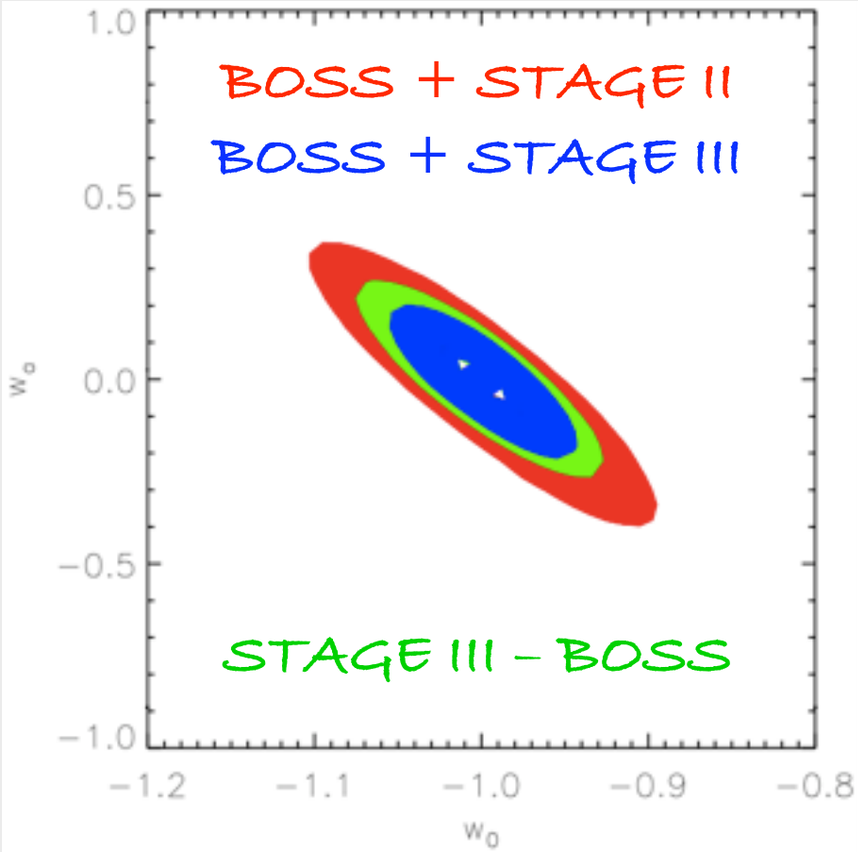


$\Rightarrow \sigma(\Omega_M)=0.02,\ \sigma(w_0)=0.07$

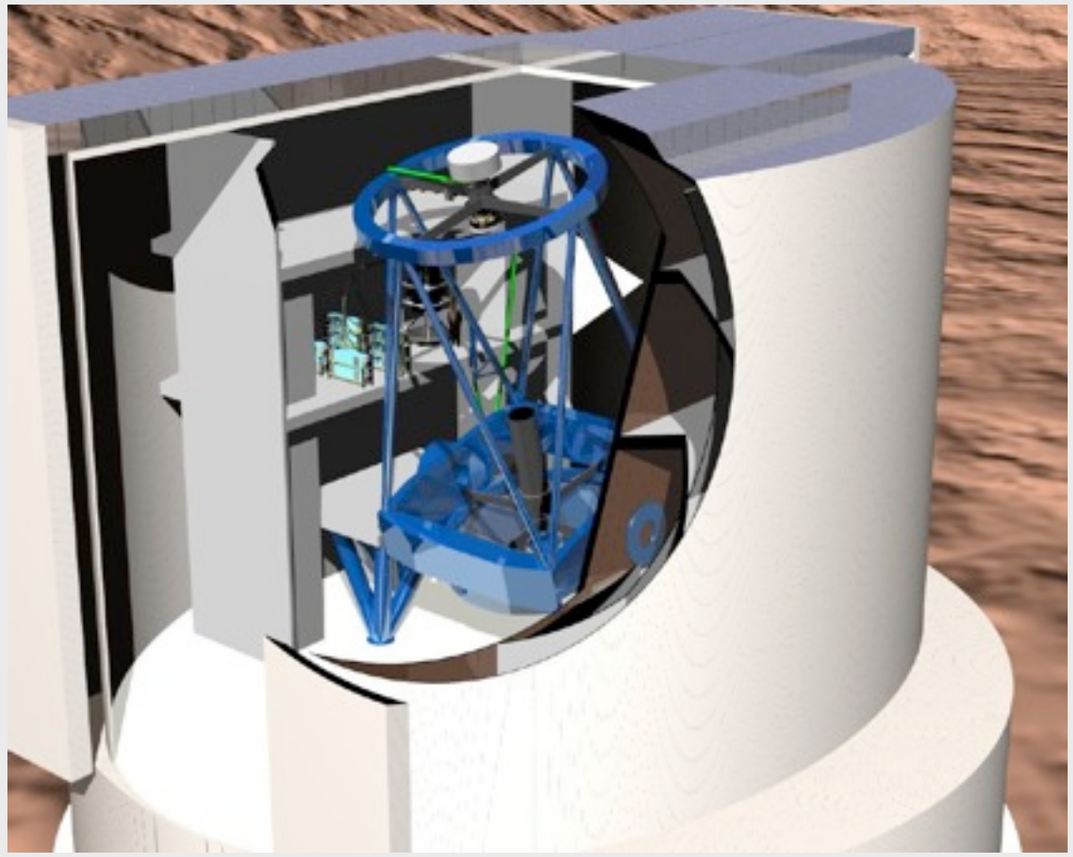
BOSS - SDSS-III BAO SURVEY

- BARYON OSCILLATION SPECTROSCOPIC SURVEY
- DARK TIME OBSERVATIONS FALL 2009-SPRING 2014
- 1000-FIBRE SPECTROGRAPH; 360-1000NM AT R~2000
- 1.5×10^6 LUMINOUS RED GALAXIES: 10^4 DEG^2, $Z<0.7$
- 1.6×10^5 QSOS: LY-α FOREST SPECTRA, $2.2<Z<3.0$
- $D_A(Z)$ TO 1% AT $Z = 0.3, 0.6$ & 1.5% AT $Z = 2.5$; $H(Z)$ TO 2%





WFMOS BAO SURVEY



- WIDE-FIELD MULTI-OBJECT SPECTROGRAPH ON SUBARU
- 4000-FIBRE SPECTROGRAPH; 400-1000NM AT R~2000
- INSTRUMENT TO BE BUILT (FUNDING? SURVEY IN 2013?)
- STRATEGY DEPENDS ON BOSS/HETDEX HI-Z SUCCESS:
  - LO-Z ONLY: 8.8×10^6 ELGS OVER 6150 DEG^2 AT $\langle z\rangle\sim1.2$
    - ⇒ $D_A(z)$ TO 0.48%, $H(z)$ TO 0.75%
    - ⇒ DETF F.O.M. = 78
  - LO-Z+HI-Z: 5.8×10^6 ELGS OVER 3450 DEG^2 AT $\langle z\rangle\sim0.4$
    - ⇒ $D_A(z)$ TO 0.75%, $H(z)$ TO 1.2%

    PLUS 4.5×10^5 ELGS OVER 2700 DEG^2 AT $\langle z\rangle\sim2.5$
    - ⇒ $D_A(z)$ TO 1.1%, $H(z)$ TO 1.8%
    - ⇒ COMBINED DETF F.O.M. = 21

WIGGLEZ vs BOSS vs WFMOS

- SURVEY COMPARISON USING DETF FIGURE OF MERIT (INVERSE AREA OF 1σ ERROR ELLIPSE IN W_0-W_A PLANE)

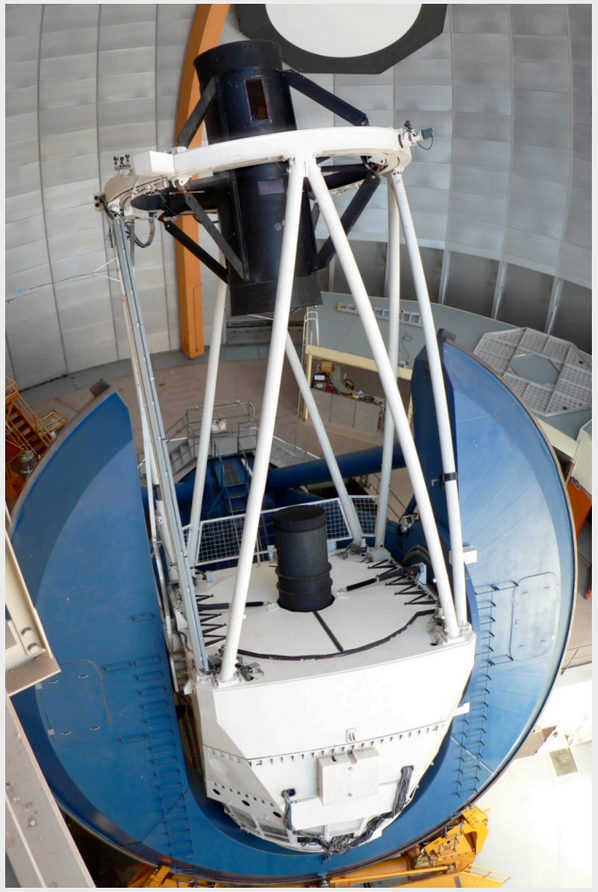
	NO CURVATURE			WITH CURVATURE		
SURVEY	FOM	$\sigma(W_0)$	$\sigma(W_A)$	FOM	$\sigma(W_0)$	$\sigma(W_A)$
WIGGLEZ	5.5	0.58	1.59	1.1	1.11	4.25
BOSS (NO QSO)	36	0.20	0.59	6.6	0.47	1.98
BOSS (+ QSO)	40	0.19	0.53	21	0.21	0.71
WFMOS	60	0.13	0.41	21	0.20	0.73
STAGE III SNE	39	0.21	0.65	3.7	0.46	2.51
COMBINED	99	0.10	0.33	78	0.12	0.38

IMAGING DARK ENERGY SURVEYS

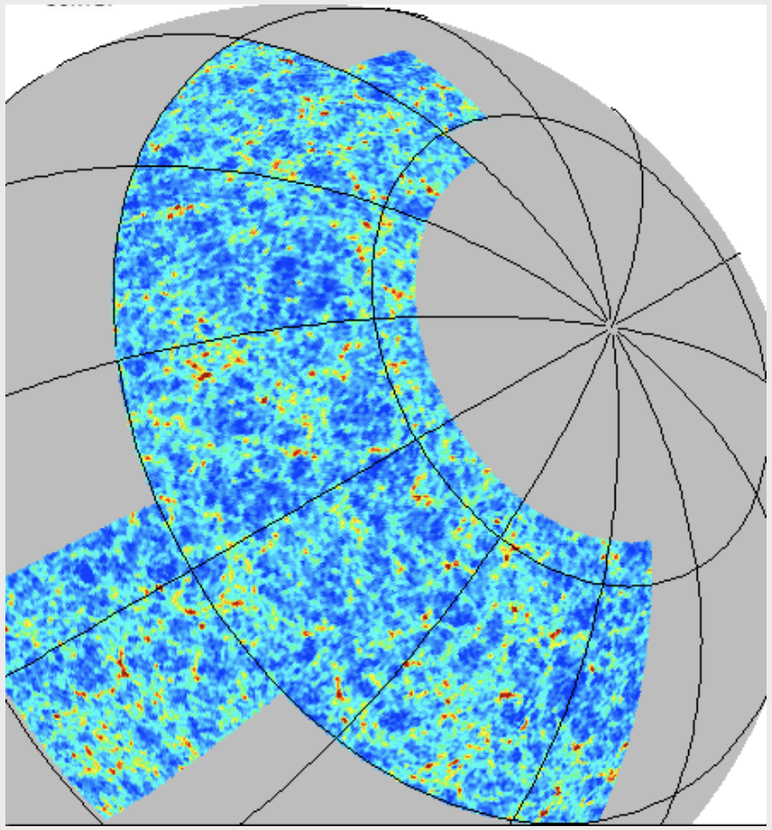
Survey	Depth (mag or redshift)	Area (sq deg)	Imaging Filters/ Spectra Resolution	Schedule
KIDS(+Viking)	r′ < 24.4	1500	ugri ZYH	2008-2013
DES(+VHS)	r < 24	5000	grizYJHK	2011-2016
Pan-STARRS1	r < 24	15000	grizY	2008-2012
Pan-STARRS4	r < 25.6	30000	grizY	2012-2017
Hyper-Suprime	r < 25	2000	BVRiz	2011-2016
Skymapper	g < 22.9	15000	Uvgriz	2008-2011
PAU	i < 23	8000	50 narrow bands	2010-2015
LSST	g< 26	30000	Ugriz	2014-2014
SNAP	*R<28.3*	*4000*	*9 visible and IR*	*2015-2021*
Euclid-Photometric	***(RIZ)<24.5***	***20000***	***(RIZ)+YJH***	***2017-2020***

- IMAGING SURVEYS ARE ABLE TO UTILIZE MULTIPLE METHODS OF MEASURING THE DE EQUATION OF STATE:
  - WEAK LENSING - A VERY POWERFUL METHOD, BUT REQUIRES EXCELLENT IMAGE QUALITY
  - GROWTH OF STRUCTURE - CLUSTERS, ISW EFFECT
  - SUPERNOVAE - REQUIRES REPEAT OBSVNS TO DETECT
  - BAO - VIA PHOTO-Z'S, BUT ALSO REQUIRES SPECTRO-Z'S

DARK ENERGY SURVEY



- DES IS 5000 DEG^2 SURVEY OF SGP TO MEASURE DARK ENERGY VIA BAO (PHOTO-Z'S), WEAK LENSING, SNE, AND CLUSTER COUNTS
- USE BLANCO 4M AT CTIO WITH A NEW 520 MEGAPIXEL CAMERA AT PRIME FOCUS HAVING A 2.2° FIELD
- PLAN - CONSTRUCTION 2008-2011, THEN 525 NIGHTS 2011-2016
- SURVEY AREA OVERLAPS WITH SPT SZE AND VISTA VHS SURVEYS
- 12 INSTITUTIONS, >100 PEOPLE



DARK ENERGY SURVEY

- 5000 DEG^2 IN GRIZY TO R=24 PLUS 40 DEG^2 REPEATED
- 3X10^8 PHOTO-Z'S IN VOLUME OF 23(GPC/H)^3 TO Z=2 (NEED 10^6 SPECTRO-Z'S TO CALIBRATE)

FOUR PROBES OF DARK ENERGY

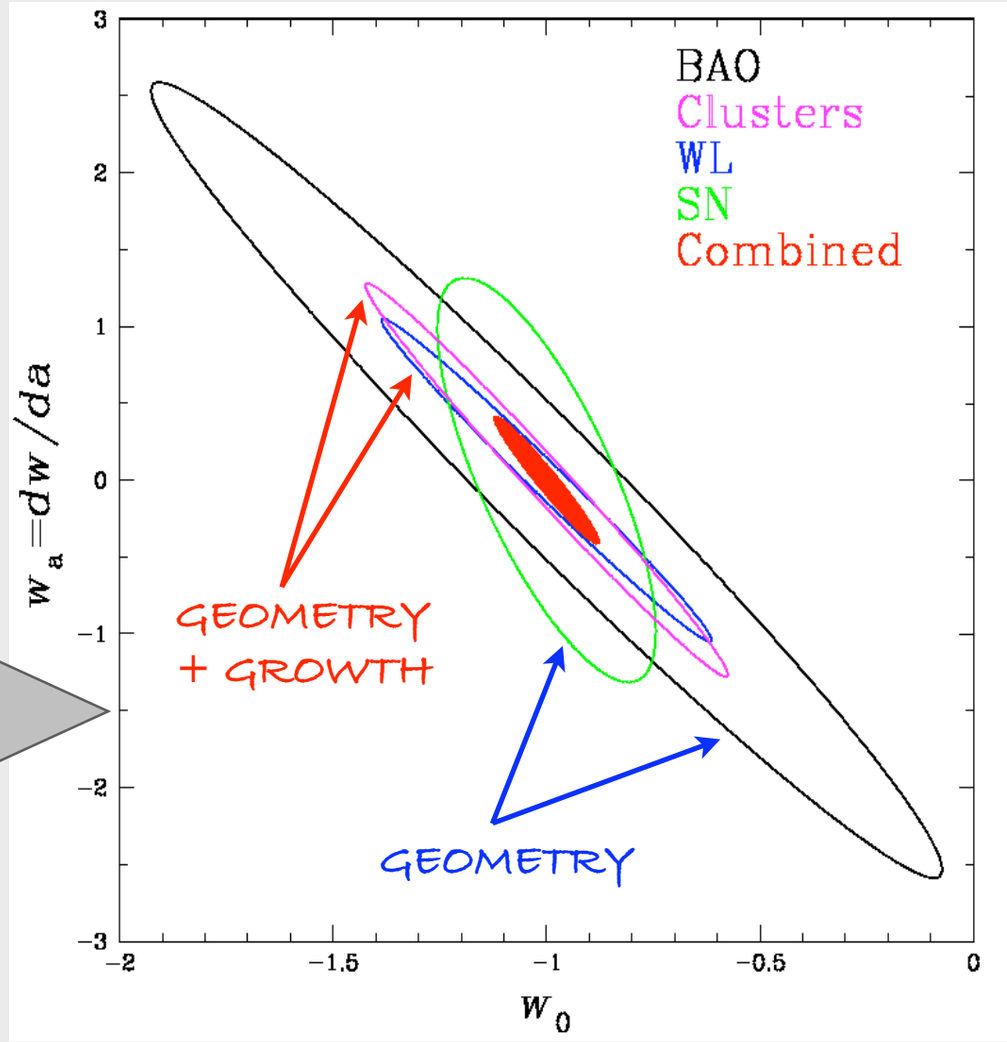
- GALAXY CLUSTERS
  - Z'S & MASSES FOR 10^5 CLUSTERS TO Z>1
  - 10^4 CLUSTERS WILL HAVE SZE FROM SPT
- WEAK LENSING
  - SHAPES FOR 3X10^8 GALAXIES
- BARYON ACOUSTIC OSCILLATIONS
  - 3X10^8 GALAXIES WITH PHOTO-Z'S TO Z>1
- SUPERNOVAE
  - >9 DEG^2 SURVEY, ~10^3 SN IA TO Z~1

SENSITIVE TO GROWTH OF STRUCTURE & GEOMETRY

SENSITIVE TO GEOMETRY

DARK ENERGY SURVEY

- MULTIPLE METHODS GIVE TIGHTER CONSTRAINTS AND CROSS- CHECKS ON SYSTEMATICS
- PLANCK CMB PRIOR, CURVATURE AND GALAXY BIAS MARGINALISED
- DETF F.O.M. GAIN OF A FACTOR OF 4.6 RELATIVE TO STAGE II



Method	$\sigma(\Omega_{DE})$	$\sigma(w_0)$	$\sigma(w_a)$	z_p	$\sigma(w_p)$	DETF FoM
BAO	0.010	0.097	0.408	0.29	0.034	72.8
Clusters	0.006	0.083	0.287	0.38	0.023	152.4
Weak Lensing	0.007	0.077	0.252	0.40	0.025	155.8
Supernovae	0.008	0.094	0.401	0.29	0.023	107.5
Combined DES	0.004	0.061	0.217	0.37	0.018	263.7
DETF Stage II Combined	0.012	0.112	0.498	0.27	0.035	57.9

Table 1: 68% CL marginalized forecast errorbars for the 4 DES probes on the dark energy density and equation of state parameters, in each case including Planck priors *and* the DETF Stage II constraints. The last column is the DETF FoM; z_p is the pivot redshift. Stage II constraints used here agree with those in the DETF report to better than 10%.

PAN-STARRS1

- 1.8M TELESCOPE WITH 7 DEG^2 FIELD AND 1.4 GIGAPIXEL CAMERA
- R~24 IN 30S, 7000 DEG^2/NIGHT
- ALL-SKY (3 STERADIANS) SURVEY TO R~26; WEAK LENSING, CLUSTER ABUNDANCES, PHOTO-Z BAO
- MEDIUM/DEEP-FIELD SURVEYS WITH MULTI-EPOCH REPEATS FOR SN IA

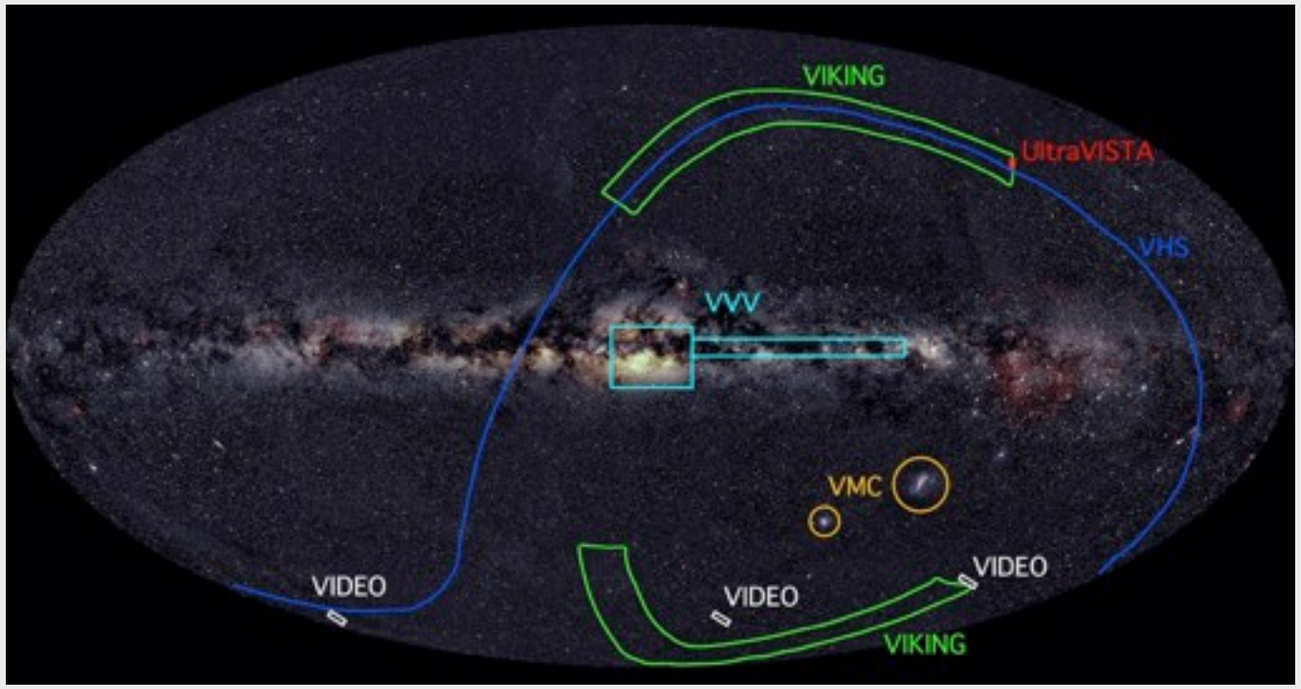
PS1 Surveys	Filters	Percent time
3 π Steradian Survey	g, r, i, z, y	56
Calibration Fields	g, r, i, z, y	2
Medium Deep Survey	g, r, i, z, y	25
Solar System "Sweet Spot" Survey	r	5
Stellar Transit Survey -"PanPlanets"	i	4
Microlensing in M31 "Pandromeda" Survey	g, r, i, z, y	2
Principal Investigator Discretionary Time		6

VISTA SURVEYS

- VISTA: 4M WIDE-FIELD (1.65° FOV) SURVEY TELESCOPE AT PARANAL WITH NEAR-IR (ZYJHK$_S$), 67 MEGAPIXEL CAMERA HAVING EFFECTIVE AREA 0.6 DEG^2
- TWO VISTA PUBLIC SURVEYS ARE RELEVANT TO DE...

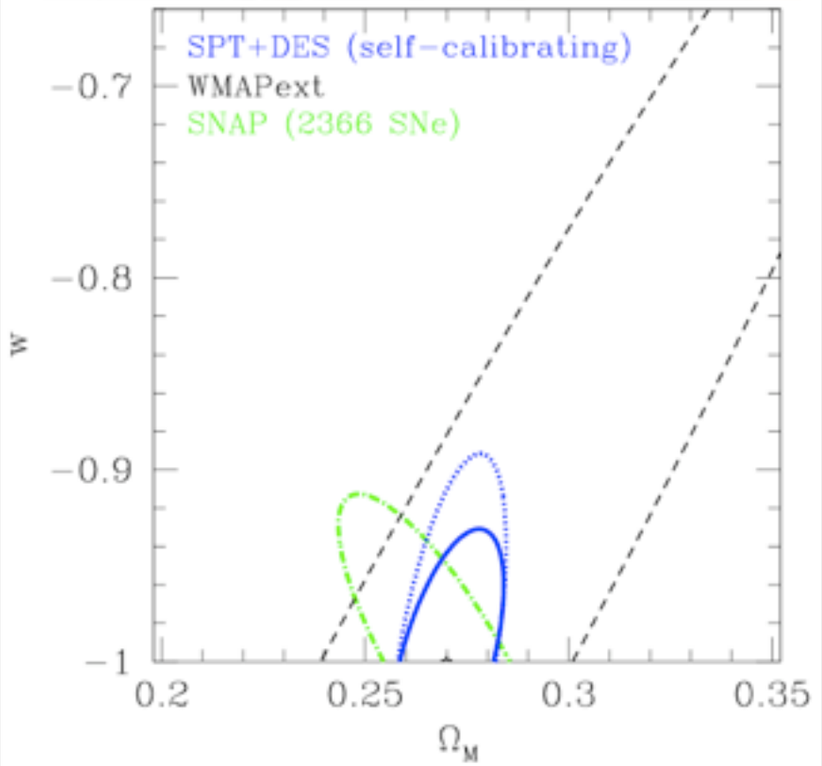
SURVEY	AREA	LIMITING MAGNITUDES (5σ)
VHS	20,000	Y=21.2 J=21.2 H=20.6 K$_S$=20.0
VIKING	1,500	Z=23.1 Y=22.3 J=22.1 H=21.5 K$_S$=21.2

- VIKING & DES HAVE 5000 DEG^2 OVERLAP; IMPROVES PHOTO-Z'S BY 2x FOR Z>1;
- VHS WILL YIELD DE VIA LATE-TIME INTEGRATED SACHS-WOLFE EFFECT



SOUTH POLE SPT TELESCOPE

- SPT IS 10M MM/SUBMM TELESCOPE AT SOUTH POLE WITH A 960-ELEMENT TES BOLOMETER AT 95, 159, 225, 270GHZ
- SURVEY OF 4000 DEG^2 TO DETECT 2×10^4 CLUSTERS WITH MASS $>2\times10^{14}$ M_{SOL} USING THE SUNYAEV-ZEL'DOVICH EFFECT (N.B. SZE IS Z-INDEPENDENT)
- DARK ENERGY CONSTRAINTS FROM CLUSTER NUMBER DENSITY EVOL^N
- WITH CLUSTER Z'S CAN MEASURE W_0 TO 5% PRECISION (DES WILL PROVIDE PHOTO-Z'S FOR CLUSTERS)
- SYSTEMATICS ARE PRIMARY ISSUE



CONCLUSIONS

- A VERY RICH FUTURE FOR COSMOLOGICAL SURVEYS!
- BOTH IMAGING & SPECTROSCOPY OFFER POWERFUL ROUTES TO THE DARK ENERGY EQUATION OF STATE
- THESE SURVEYS ALSO PROVIDE VALUABLE DATA FOR A WIDE RANGE OF OTHER SCIENCE - BUT IT IS A FINE BALANCE OF FIT-FOR-PURPOSE & OVERLY-SPECIALISED
- GOAL: REDUCE NUMBER OF DARK ENERGY CANDIDATES!

  tracker quintessence, single exp quintessence, double exp quintessence, axion-photon coupling, holographic dark energy, pseudo-Nambu-Goldstone boson quintessence, cosmic strings, cosmic domain walls, phantom dark energy, Cardassian model, brane cosmology (extra-dimensions), Van Der Waals quintessence, dilaton, generalized Chaplygin gas, quintessential inflation, unified dark matter and dark energy, superhorizon perturbations, ndulant universe, general oscillatory models, Milne-Born-Infeld model, k-essence, chameleon, k-chameleon, f(R) gravity, quiessence, perfect fluid dark energy, adiabatic matter creation, varying G, scalar-tensor gravity, double scalar field, scalar+spinor, quintom model, SO(1,1) scalar field, five-dimensional Ricci flat bouncing cosmology, scaling dark energy, radion, DGP gravity, Gauss-Bonnet gravity, tachyons, power-law expansion, phantom k-essence, vector dark energy, dilatonic ghost condensate dark energy, quintessential Maldacena-Maoz dark energy, superquintessence, vacuum-driven metamorphosis, wet dark fluid...