

A night sky filled with stars and the Milky Way galaxy. In the foreground, three large astronomical observatories with domes are visible. The central one is a tall, cylindrical structure with a metallic dome. The other two are shorter, box-like structures with domes. The sky is dark with a dense field of stars and the bright, hazy band of the Milky Way stretching across it.

THE DARK ENERGY SURVEY

EMMANUEL BERTIN

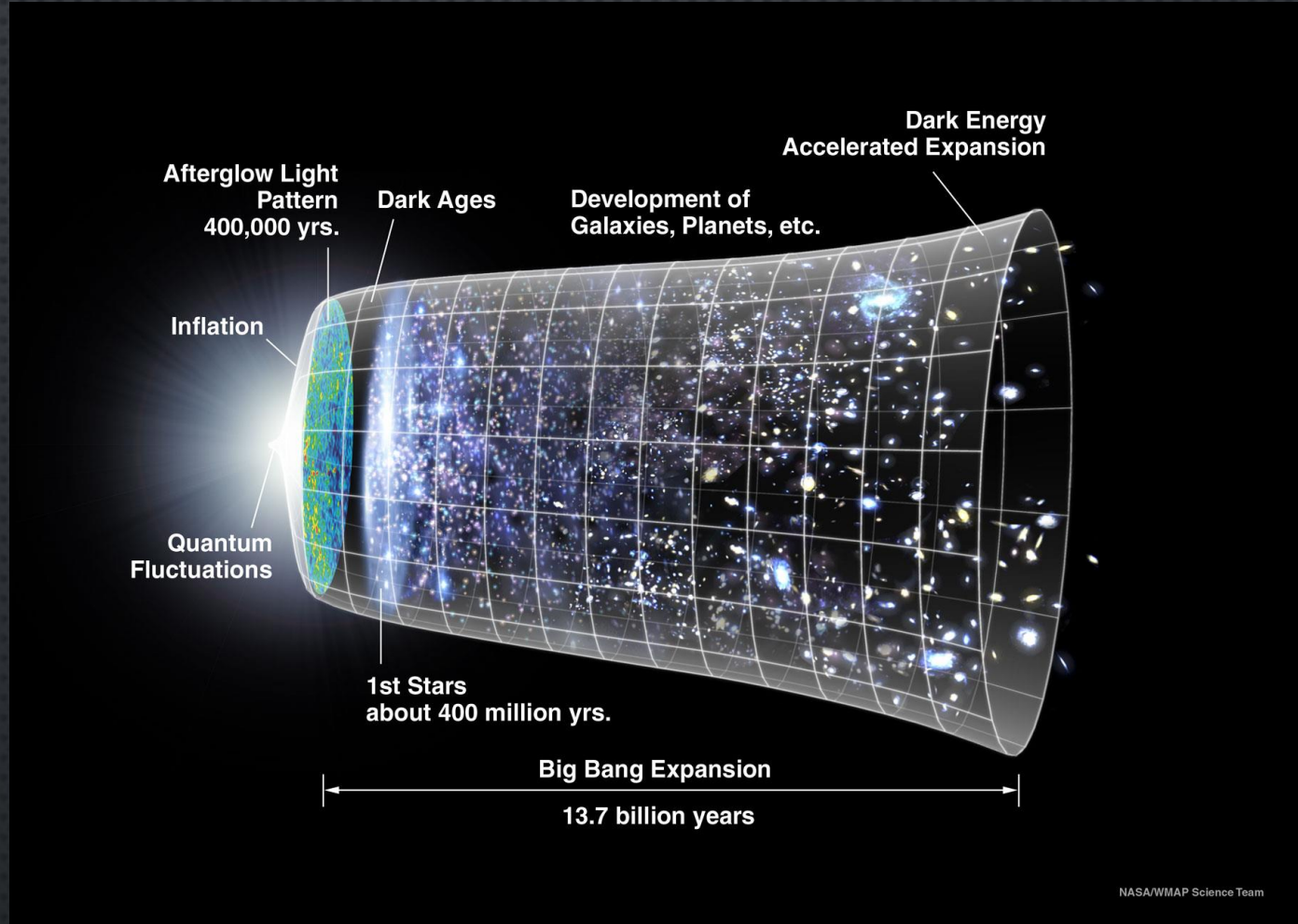
FOR THE DES COLLABORATION



**DARK ENERGY
SURVEY**

DARK ENERGY

- WHAT DRIVES THE UNIVERSE'S ACCELERATED EXPANSION AT PRESENT TIMES?
- GR: DESCRIBE DARK ENERGY AS A FLUID WITH EQUATION OF STATE PARAMETER $w = \frac{p}{\rho}$



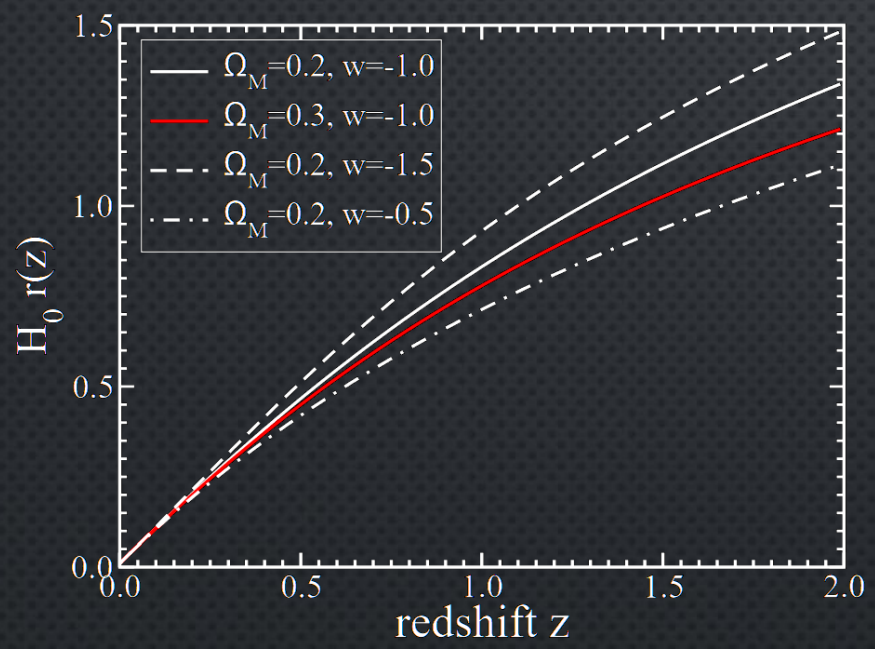


DARK ENERGY IN THE w CDM SCENARIO

w

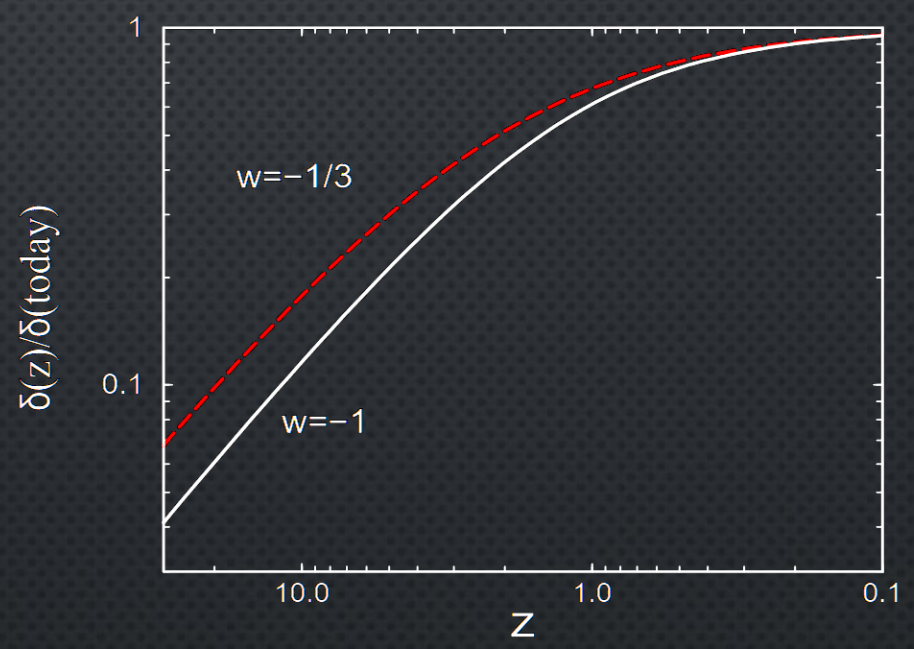


Geometry



Growth

Frieman+ 2008



$$\frac{\ddot{a}}{a} = -\frac{1}{2}H^2(2\Omega_{z,R} + \Omega_{z,M} + (1 + 3w)\Omega_{z,DE})$$

$$\delta_k'' + 2H\delta_k' - 4\pi G\rho_M\delta_k = 0$$



4 CLASSICAL DARK ENERGY PROBES AT INTERMEDIATE REDSHIFTS

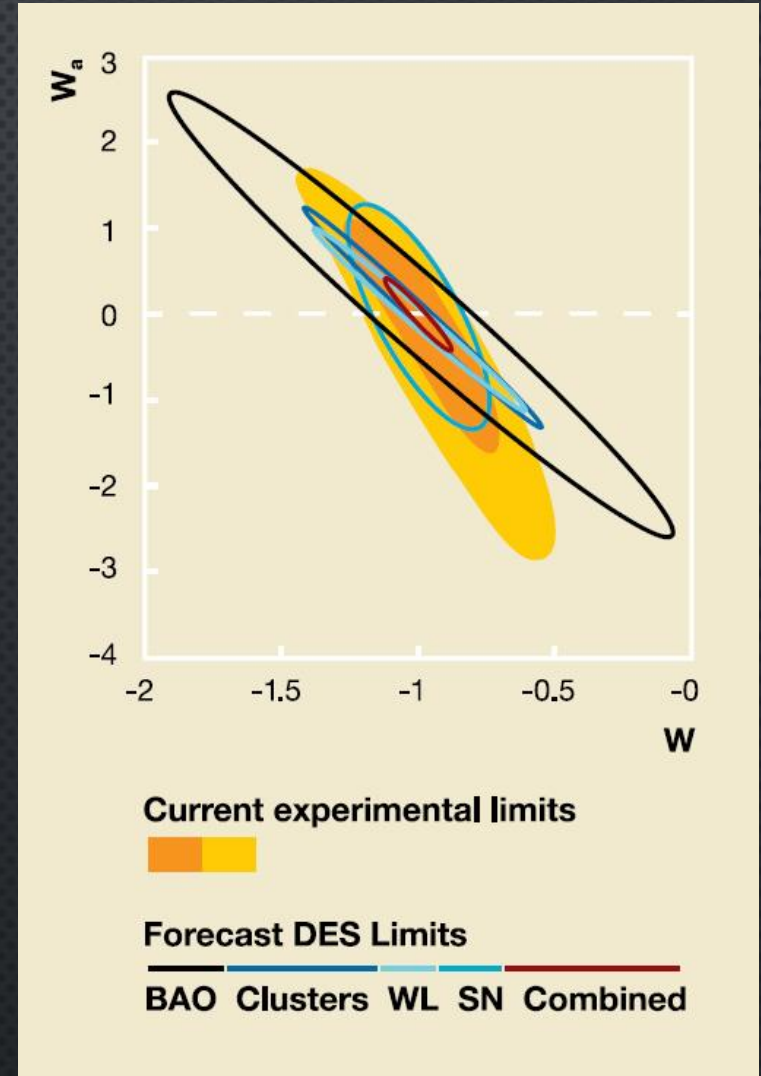
Method	Probe type		Main Issues (systematics)
Angular galaxy clustering (including BAOs)	Geometry	$\frac{s}{(1+z)d_A(z)}$	Bias prescription errors non-linear growth large-scale photometric biases
Weak Lensing	Geometry	$\frac{r^2(z)}{H(z)} W_i(z) W_j(z)$	Shape measurement biases Photo-z biases
	Growth	$P\left(k = \frac{l}{r(z)}\right)$	
Type Ia supernovae	Geometry	$H_0 d_L(z)$	Evolution with redshift Dust Photometric errors
Galaxy Clusters	Geometry	$\frac{dV}{dz}$	Sample selection Mass-observable relation
	Growth	$\frac{dn}{dM}$	

Frieman+ 2008, Ruiz & Huterer 2015



OVERVIEW

- 5000 SQ.DEGREE PHOTOMETRIC SURVEY OF THE SOUTHERN HEMISPHERE IN 5 BANDS (G,R,I,Z,Y) DOWN TO 24TH MAG (GALAXIES, 10σ)
 - 525 NIGHTS OVER 5 YEARS DURING 5-MONTH SEASONS
 - INCLUDES THE 2500 SQ.DEGREE SOUTH POLE TELESCOPE SPT-SZ SURVEY FOOTPRINT
 - 30 SQ.DEGREE REPEATED ~WEEKLY IN G,R,I,Z (SN FIELDS)
- SURVEY STARTED AUG 31, 2013.
- MAIN ORIGINAL SCIENCE DRIVERS: 4 COSMOLOGICAL PROBES BASED ON DISTANCE, GEOMETRY AND STRUCTURE GROWTH:
 - BARYON ACOUSTIC OSCILLATIONS FROM 300 MILLIONS GALAXIES TO $z \geq 1$
 - GRAVITATIONAL LENSING (STRONG AND WEAK) FROM 200 MILLION GALAXIES
 - GALAXY CLUSTER COUNTS ($\sim 100,000$) TO $z \sim 1$
 - 4000 SUPERNOVA Ia LIGHT CURVES WITH $0.1 < z < 1.1$





DARK ENERGY
SURVEY

THE COLLABORATION

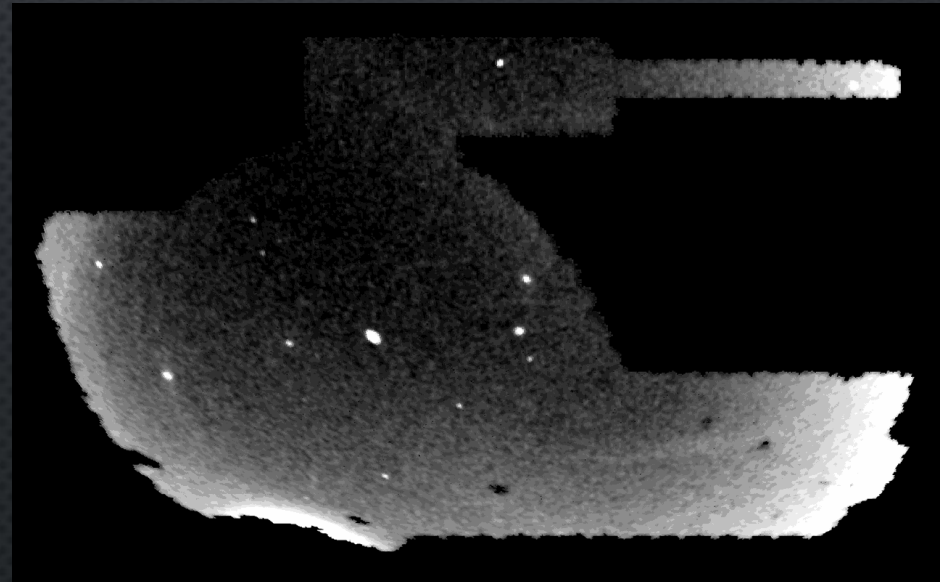
- RICHARD KRON, DIRECTOR
- PROJECT INITIATED IN 2004
- 28 INSTITUTIONS, ~400 PARTICIPANTS
- FUNDING: DOE, NSF, DFG, CSIC, CNPQ, FAPERJ, FINEP + INSTITUTIONS
- NO FRENCH INSTITUTION INVOLVED
 - BUT A FEW FRENCH INDIVIDUALS INVOLVED AS PHDS, POST-DOCS OR EXTERNAL COLLABORATORS
 - POSSIBILITY TO SUBMIT EXTERNAL COLLABORATOR PROPOSALS



MORE THAN DARK ENERGY (HIGHLIGHTS)

- SOLAR SYSTEM BODIES: TROJANS, CENTAURS, TNOs (71 DISCOVERED TO DATE)
- STELLAR STRUCTURE IN THE LMC
- MW SATELLITES (18 DISCOVERED TO DATE)
- STELLAR STREAMS (11 DISCOVERED TO DATE)
- STRONG LENSES DISCOVERY
- MULTIPLY-IMAGED QUASARS
- RAPIDLY EVOLVING TRANSIENTS (72 DISCOVERED TO DATE)
- OPTICAL COUNTERPARTS TO GW EVENTS (E.G. GW170817)
- SACHS-WOLFE SIGNAL FROM SUPERVOIDS
- DETECTION OF THE KINEMATIC SUNYAEV-ZEL'DOVICH EFFECT

Shipp+ 2016

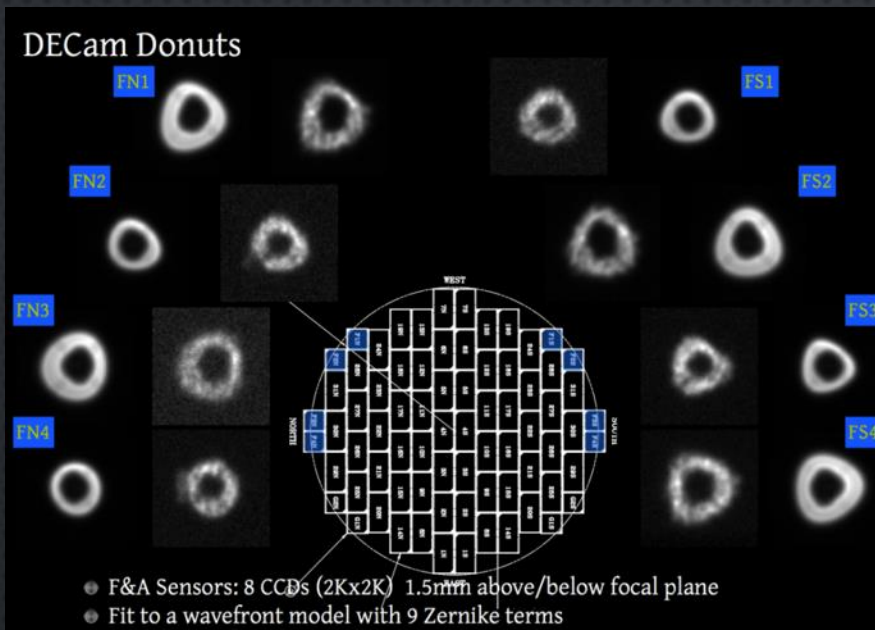




**DARK ENERGY
SURVEY**

THE INSTRUMENT: DECam

- INSTALLED ON THE BLANCO 4M TELESCOPE AT CTIO. SEEING (I BAND) $\sim 0.9''$
- 3-SQ. DEGREE FIELD OF VIEW (2 DEGREE DIAMETER).
- HEXAPOD COMPENSATES FLEXURES BASED ON OUT-OF-FOCUS IMAGES

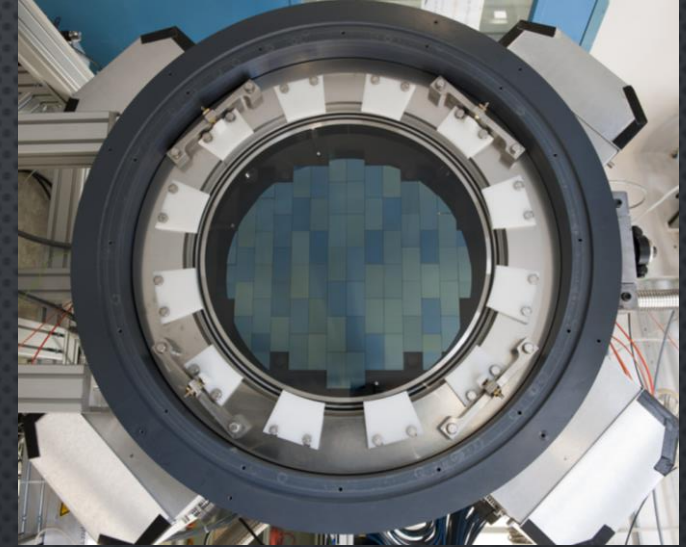




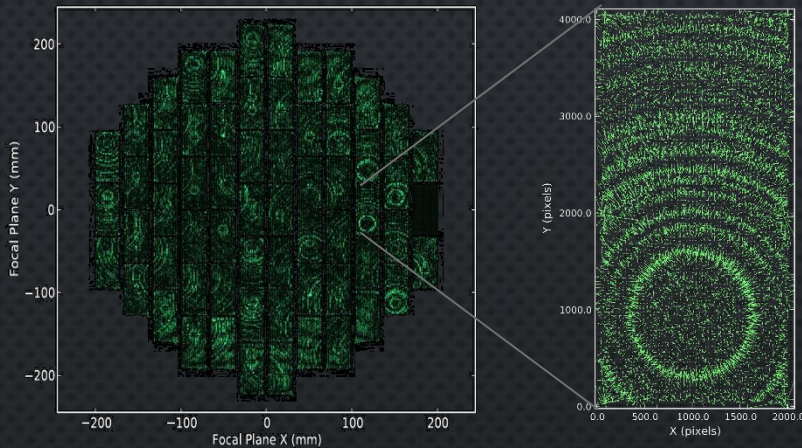
DARK ENERGY SURVEY

DECAM DETECTORS

- 62×8 MPIXEL MOSAIC ARRAY
- THICK, FULLY-DEPLETED CCDs
 - VERY HIGH Q.E IN THE RED
 - VERY LITTLE FRINGING IN I AND Z
 - CARE SHOULD BE TAKEN WITH STRONG LIGHTING (SUPER-SATURATION)
 - SIGNIFICANT DISTORTION OF THE PIXEL GRID DUE TO LATERAL ELECTRIC FIELD VARIATIONS
 - STATIC: RESISTIVITY VARIATIONS (“TREE-RINGS”)
 - DYNAMIC: “BRIGHTER-FATTER” EFFECT

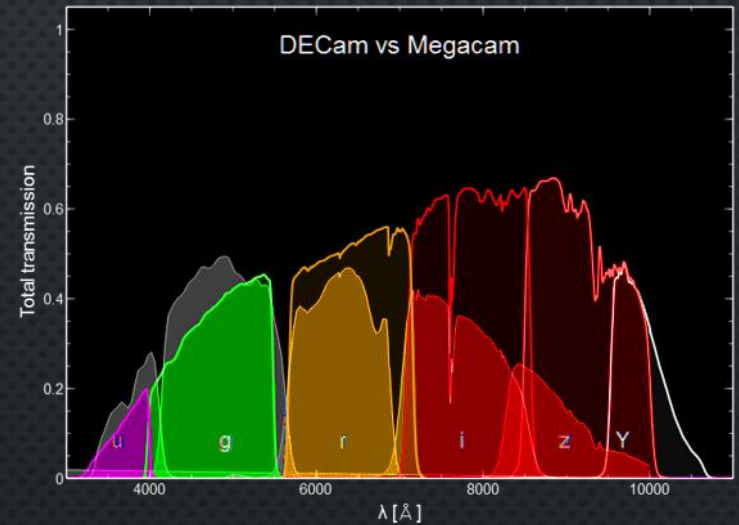


0.056 pixels (15 mas) DES astrometric residuals per CCD
All exposures, all filters.



0.056 pixels (15 mas)

Plazas+ 2014





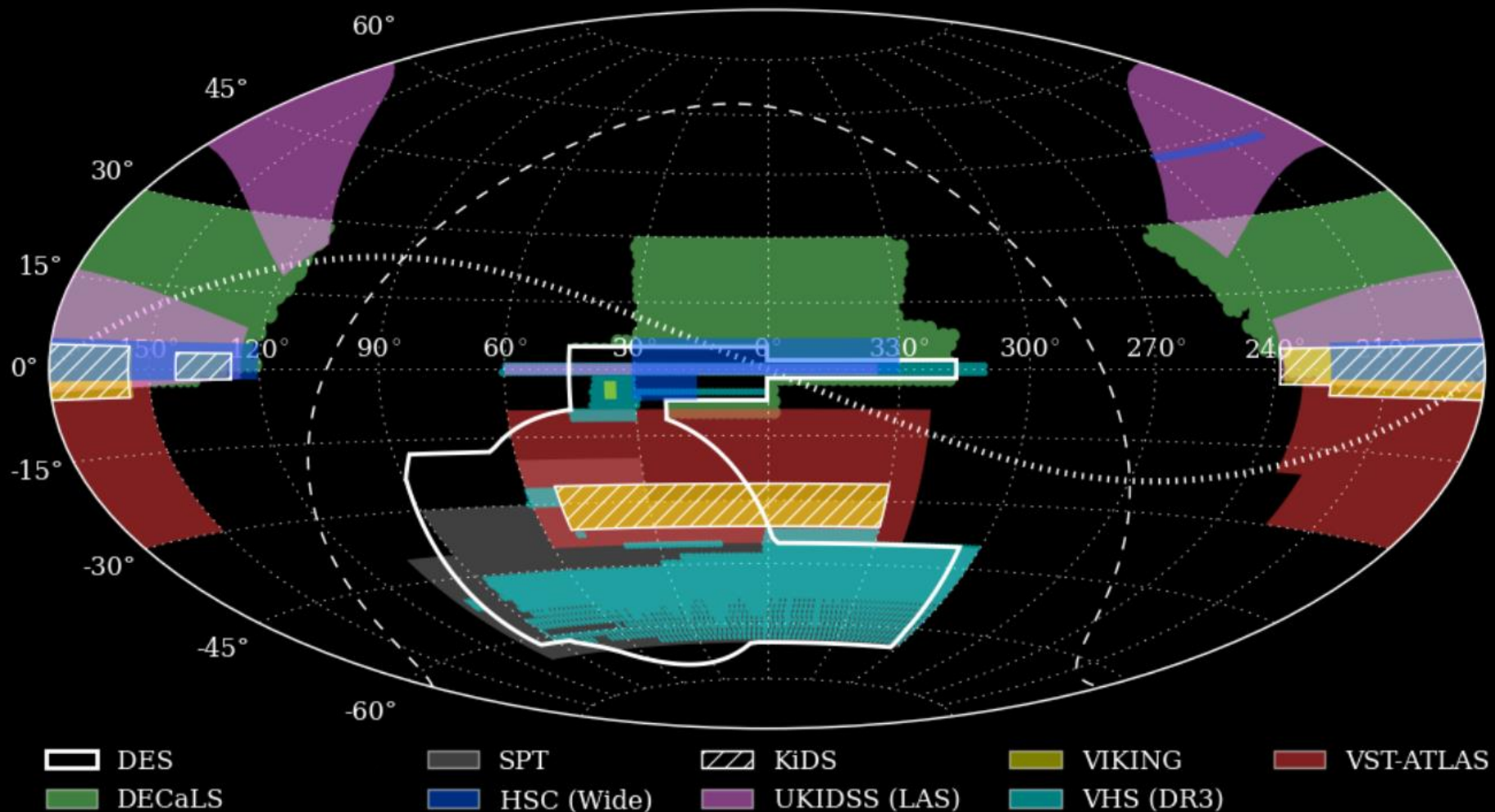
DARK ENERGY
SURVEY

A DECAM EXPOSURE



THE SURVEY

Lahav+ 2016

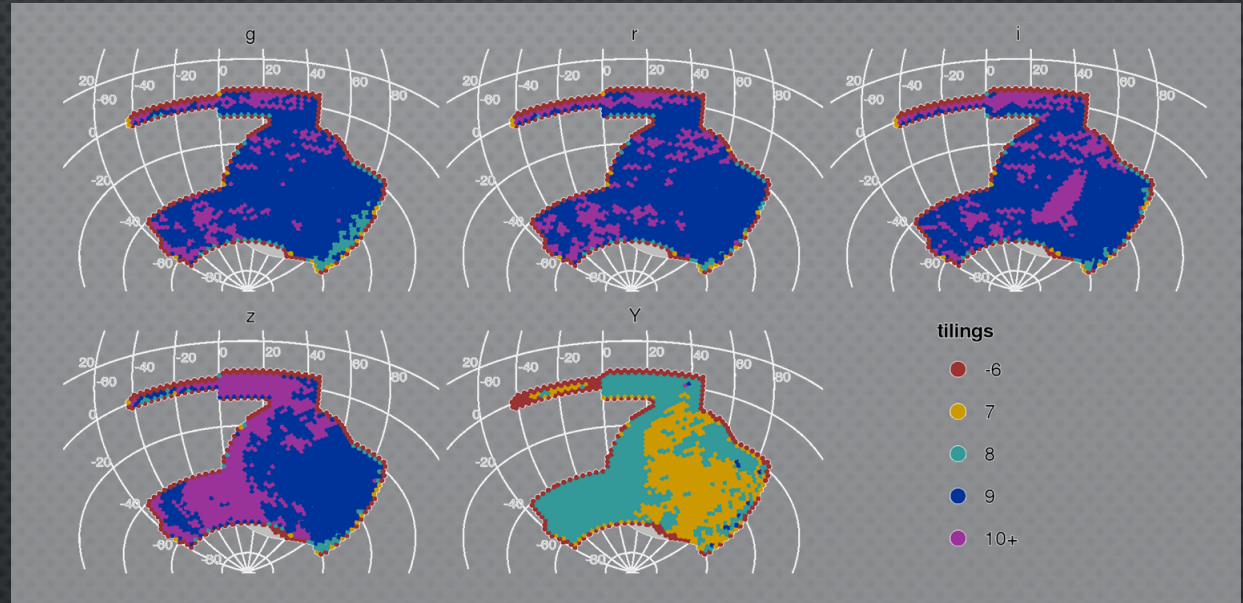




**DARK ENERGY
SURVEY**

SURVEY AND OBSERVATION STRATEGY

- OBSERVATIONS ARE CARRIED OUT BY DES MEMBERS FROM AUGUST TO FEB
- G,R,I,Z,Y FILTERS
- ~ 90S EXPOSURES
- 12 EPOCHS, ~2 PER SEASON IN EACH BAND
- SWITCH TO SN FIELDS DEPENDING ON OBSERVING CONDITIONS
- VERY LARGE DITHERS (UP TO 1 DEG)
 - MULTI-EPOCH MEASUREMENTS

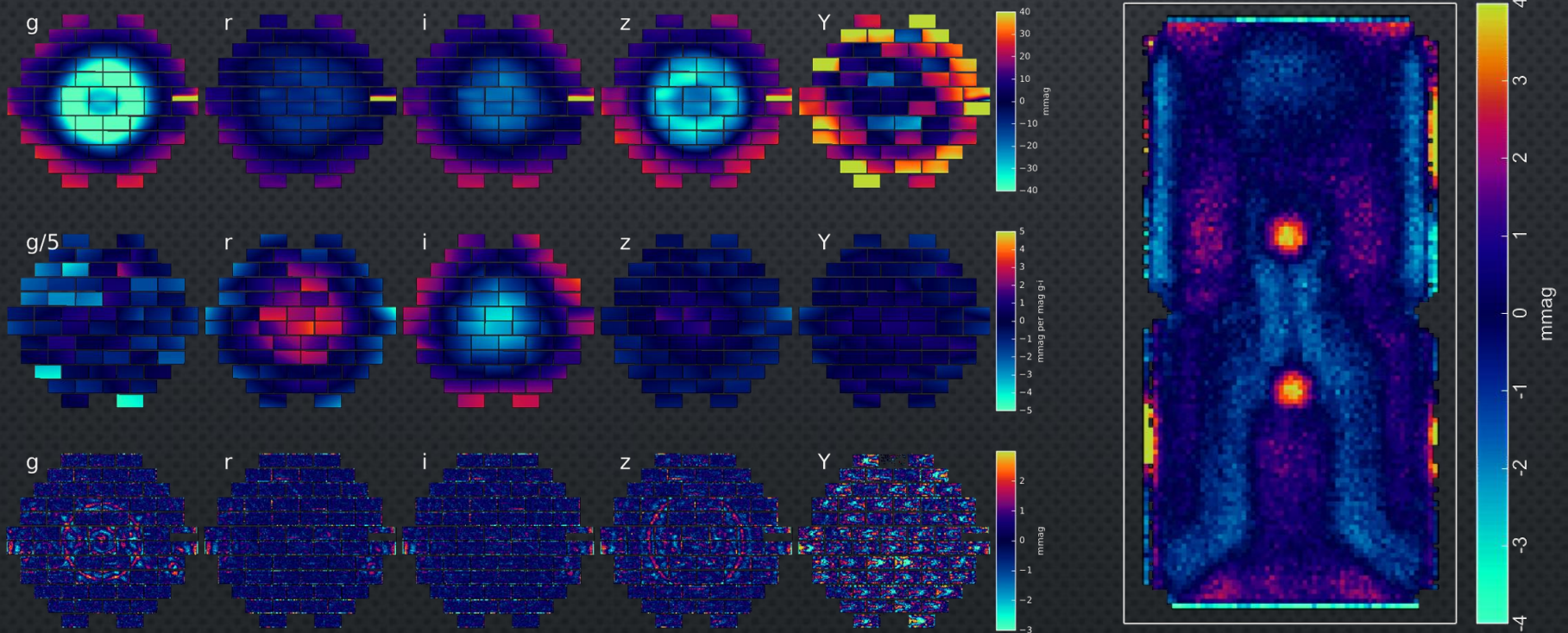


Nielsen (2018)



INSTRUMENTAL CALIBRATION

- PHOTOMETRIC RESPONSE MODELLED AT THE MILLIMAG LEVEL (PHOTOMETRIC HOMOGENEITY REQUIREMENT: <20 MILLIMAG)
- ASTROMETRIC RESPONSE MODELLED AT THE MAS LEVEL (RELATIVE ASTROMETRY REQUIREMENT: <15 MAS)



Bernstein+ 2018



DATA

- SCIENCE DATA THROUGHPUT $\sim 400\text{GB}$ PER CLEAR NIGHT
- DATA PROCESSED AT NCSA (U. OF ILLINOIS) THROUGH THE DESDM (DATA MANAGEMENT) SYSTEM
 - DECam COMMUNITY PIPELINE OPERATED BY NOAO
 - DES DATA PRODUCTS READILY AVAILABLE TO THE DES COMMUNITY THROUGH THE DES ARCHIVE AT NCSA
- YEARLY / BI-YEARLY INTERNAL DATA RELEASES TO THE COLLABORATION
- RAW DATA PROPRIETARY PERIOD IS 12 MONTHS (NOAO STANDARD: 18 MONTHS)
 - CAN BE ACCESSED THROUGH THE NOAO NVO PORTAL





DATA RELEASES

	2012	2013	2014	2015	2016	2017	2018	2019	2020					
Observations	↔ SV		↔ Y1		↔ Y2		↔ Y3		↔ Y4		↔ Y5		↔ Y6	
DESDM Releases		SVA1		Y1A1	Y2Q1		Y3A1	Y3A2		Y5A1		Y6A1		
Science Releases		SV Gold 1.0	SV Gold 1.0.2	SV Gold 1.0.4	Y1 Gold 1.0.1	Y1 Gold 1.0.3		Y3 Gold 1.0		Y3 Gold 2.0	Y3 Gold 2.2			
Public Releases					SV Gold					DR1	Y1 Gold DR1 incremental		Y3 Gold	DR2 ₄

preliminary

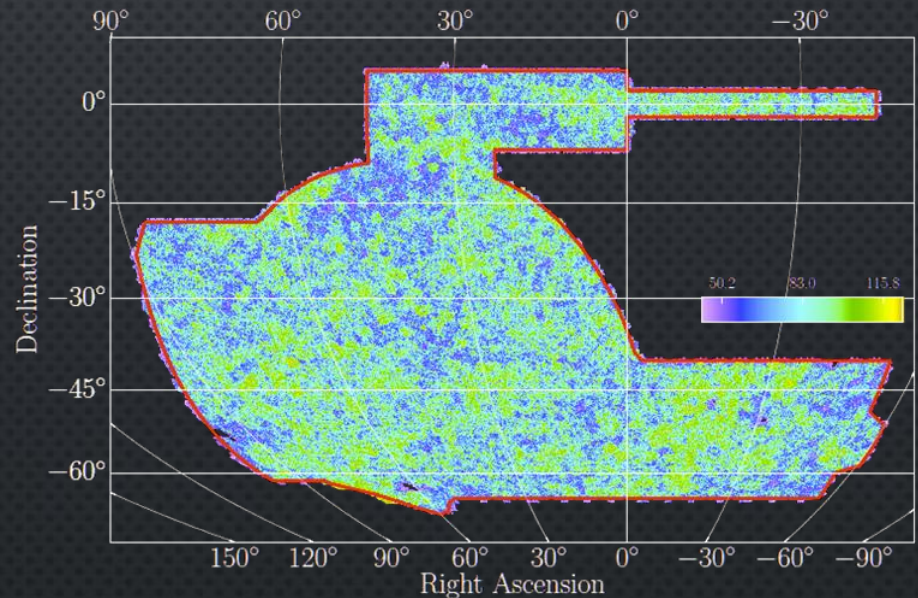
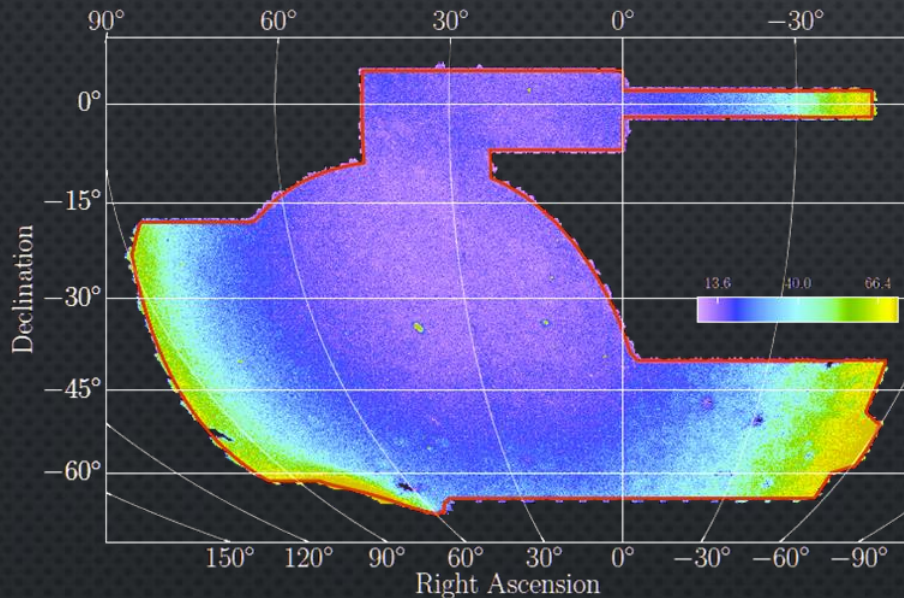
Courtesy of M. Carrasco-Kind



**DARK ENERGY
SURVEY**

YEAR-1 STAR AND GALAXY CATALOGS

- ~5000 SQ. DEG DOWN TO $i = 23.3$ ($2''$, 10σ)
- 310 MILLION GALAXIES
- 80 MILLION STARS
- FORWARD GLOBAL CALIBRATION METHOD (BURKE ET AL. 2018): ~6 MMAG RMS ZERO-POINT RESIDUALS



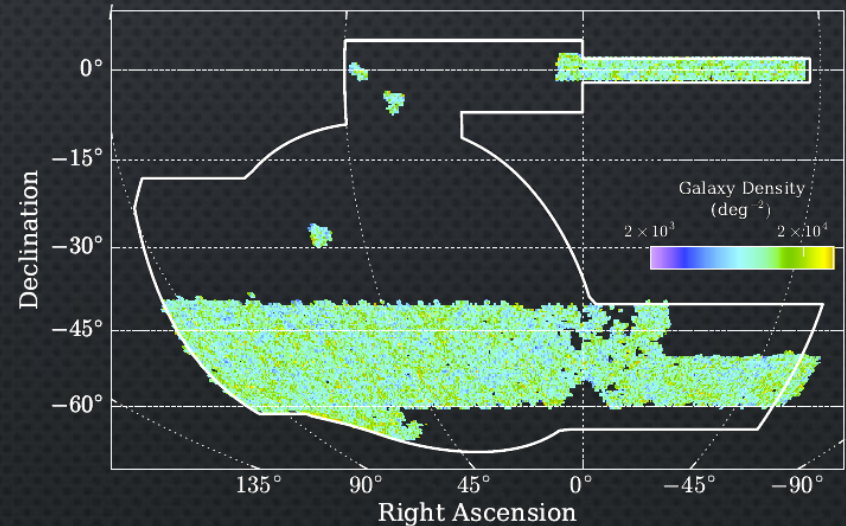
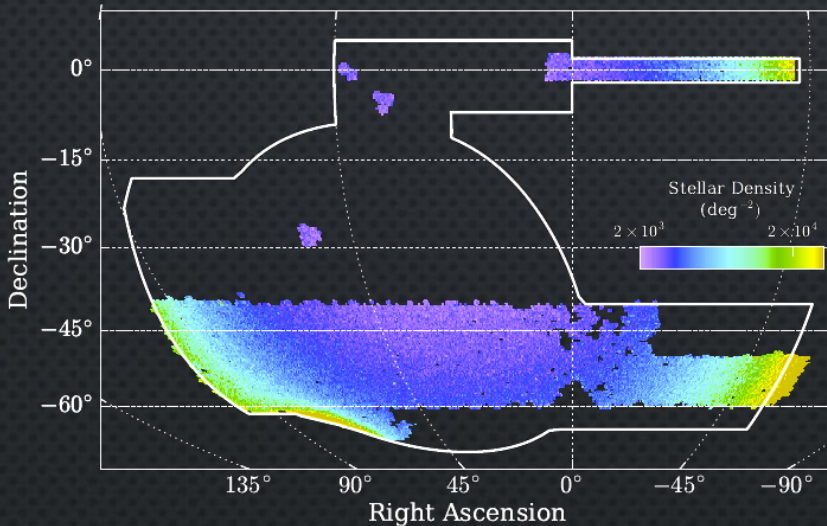
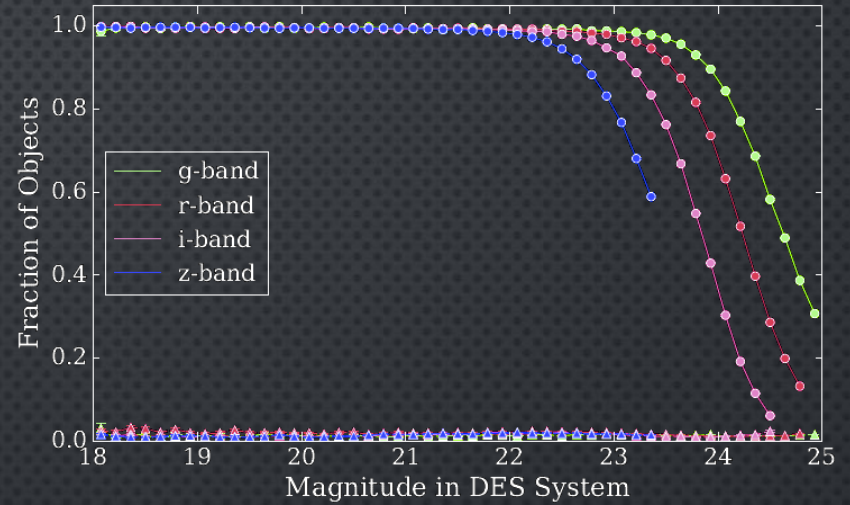
Abbott+ 2018



DARK ENERGY SURVEY

YEAR-1 "GOLD" COSMOLOGY DATASET

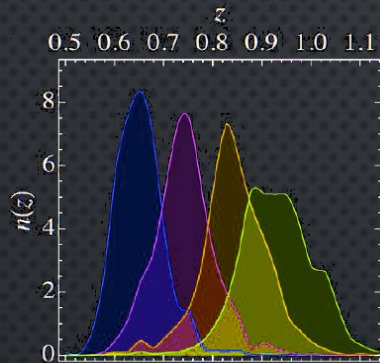
- YEAR-1 ~1800 SQ. DEG. SUBSET IN SPT+STRIPE82 AREAS
- 137 MILLION SOURCES
- CALIBRATION ADJUSTMENT
 - ZERO-POINT REPRODUCIBILITY~3MMAG
- ARTIFACT REMOVAL AND ANCILLARY MAPS
- PHOTOMETRIC REDSHIFTS
- MULTI-FRAME, MULTI-BAND, MULTI-OBJECT MODEL-FITTING TO SOURCES (SHELDON 2014) FOR 35 MILLION GALAXIES



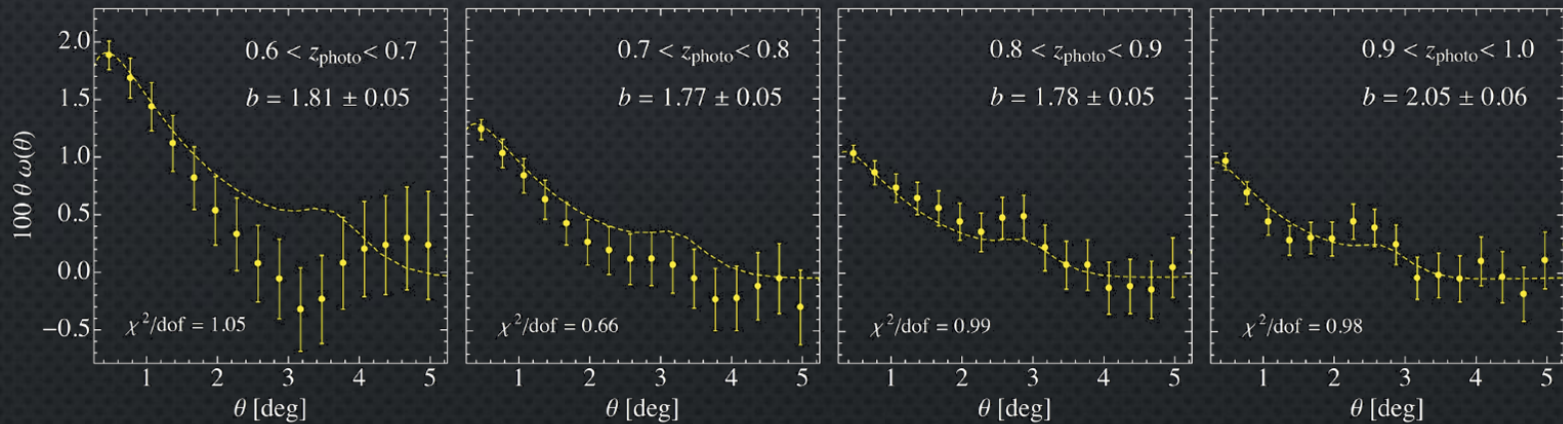
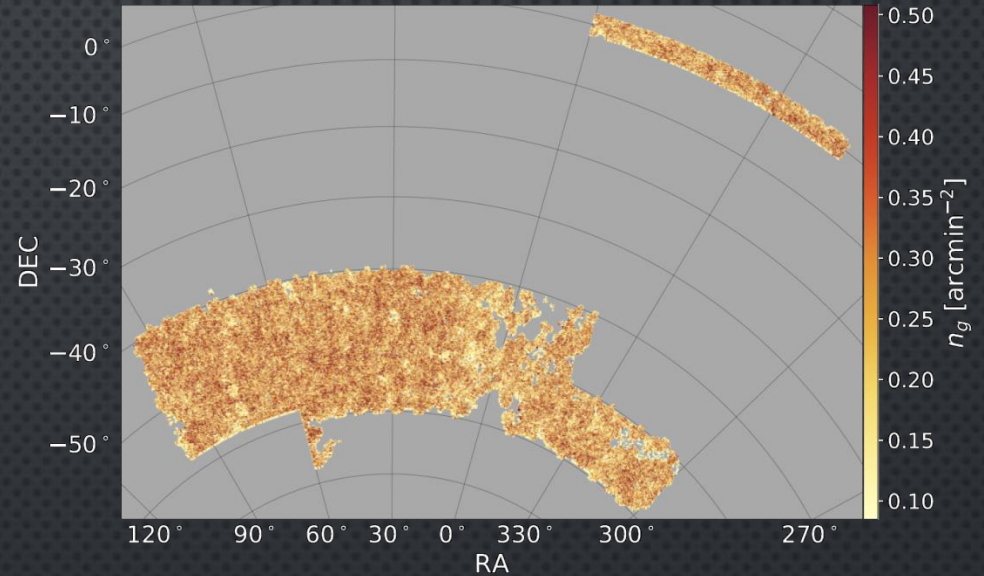
Drlica-Wagner+ 2018

YEAR-1 DENSITY FIELD AND CLUSTERING

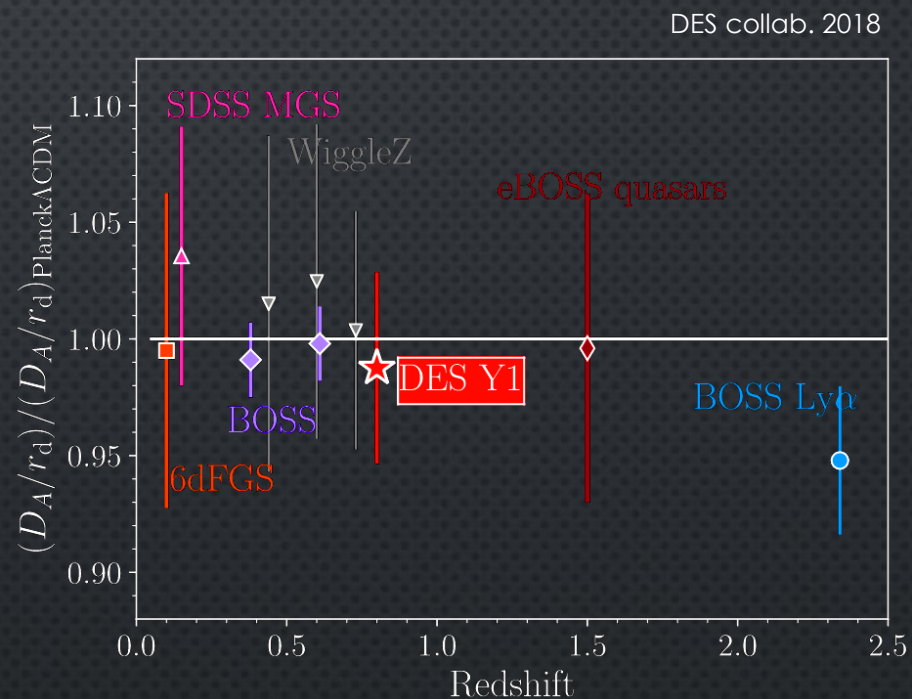
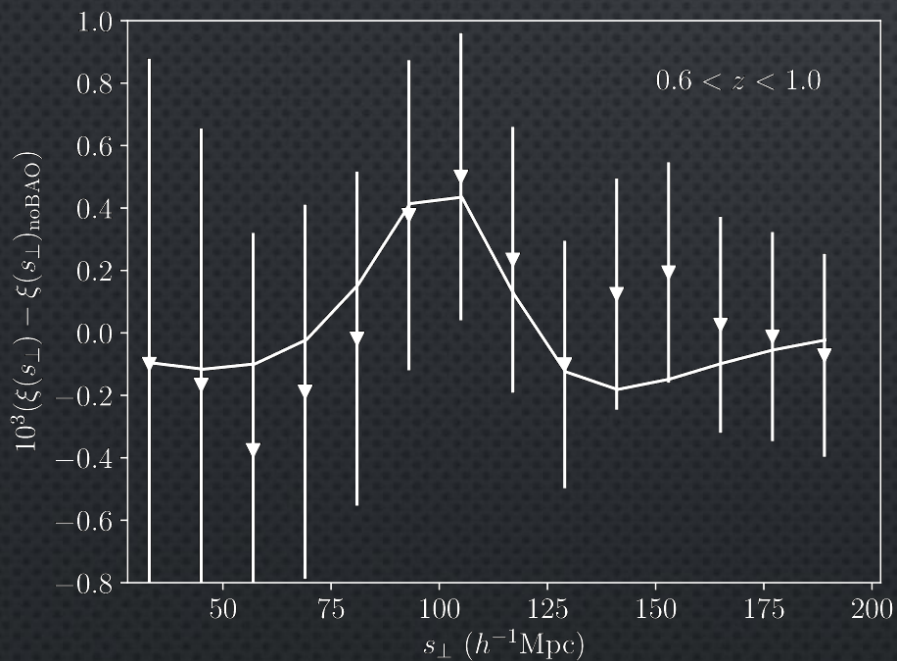
- RED GALAXY CATALOG: 1.3 MILLION GALAXIES WITH $i < 22$
- $0.6 < \text{PHOTO-Z} < 1.0$ WITH $\sigma_{68} \sim 0.02$



Crocce+ 2018



YEAR-1 BAOs

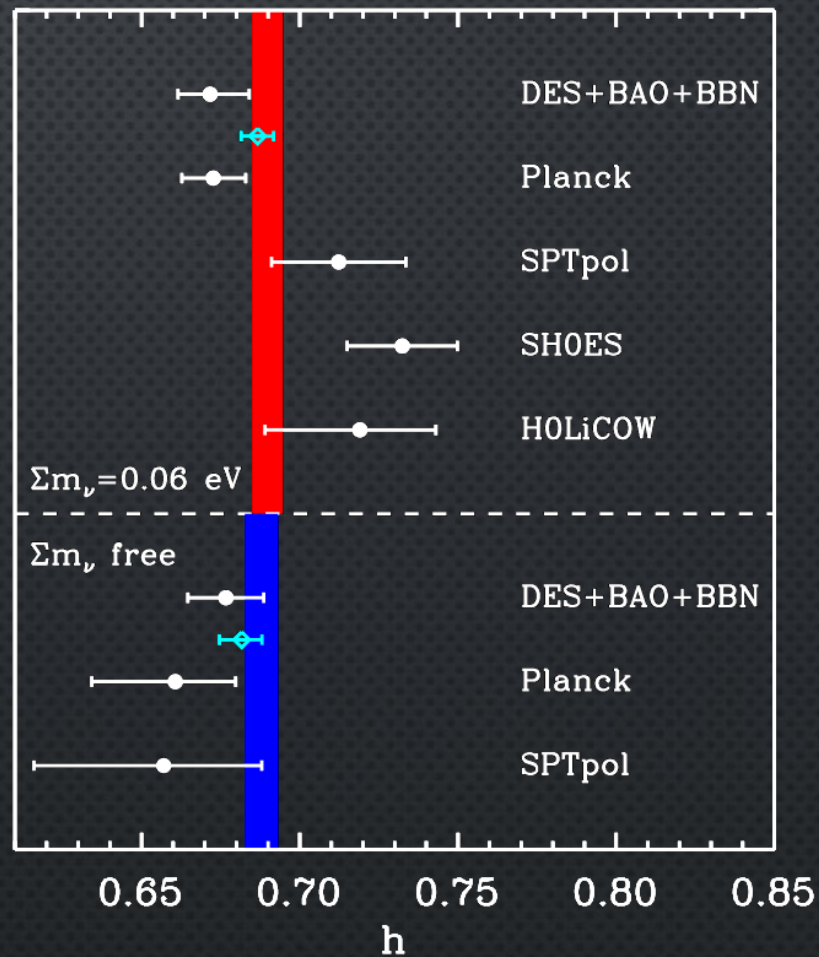
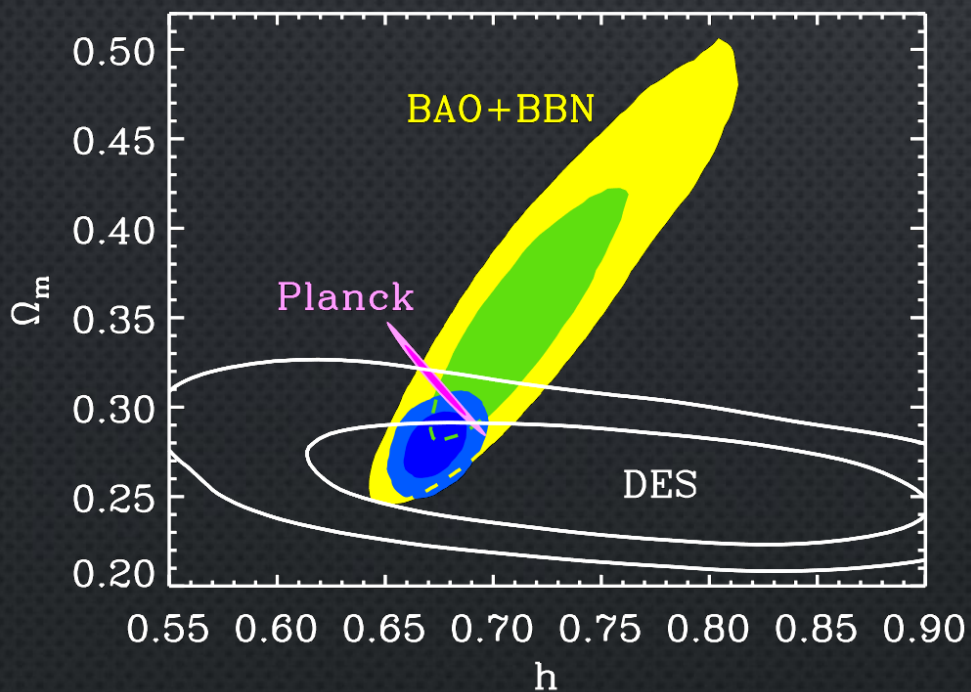


YEAR-1 BAOs

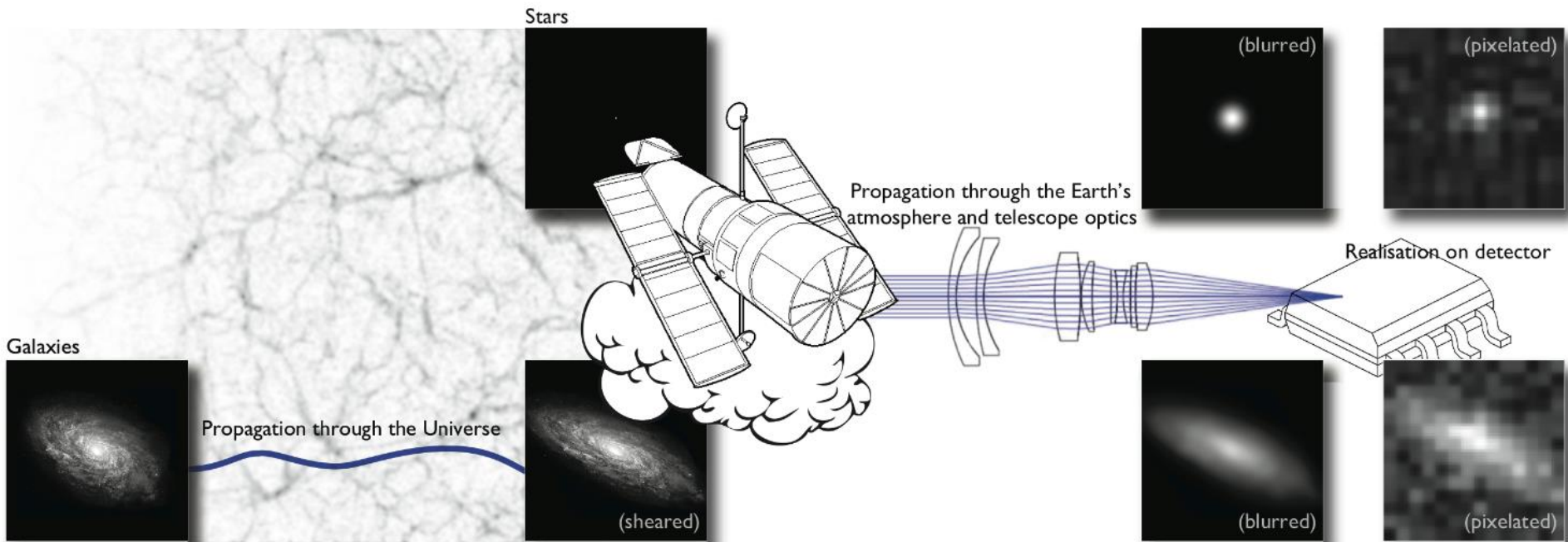
- EXTERNAL BAO+BBN CONSTRAINTS:

$$H_0 = 67.2 \pm 1 \text{ km.s}^{-1}$$

DES collab. 2018



SHEAR MEASUREMENTS



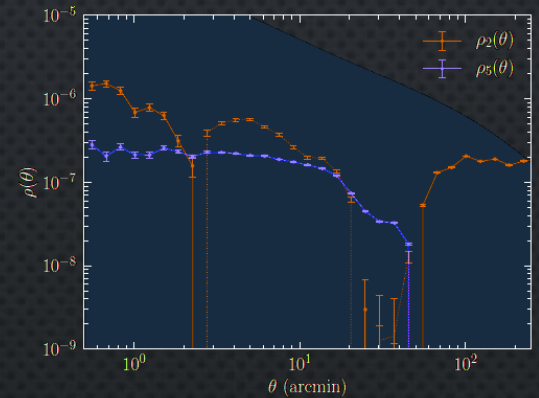
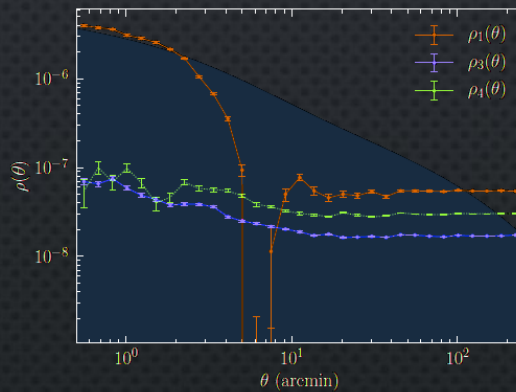
Kitching+ 2010

SHEAR PIPELINE AND MEASUREMENTS

- PSF MODELS: PSFEX, TO BE REPLACED WITH PIFF
- MEASUREMENTS: NGMIX + METACALIBRATION AND IM3SHAPE



Zuntz+ 2018





DARK ENERGY SURVEY

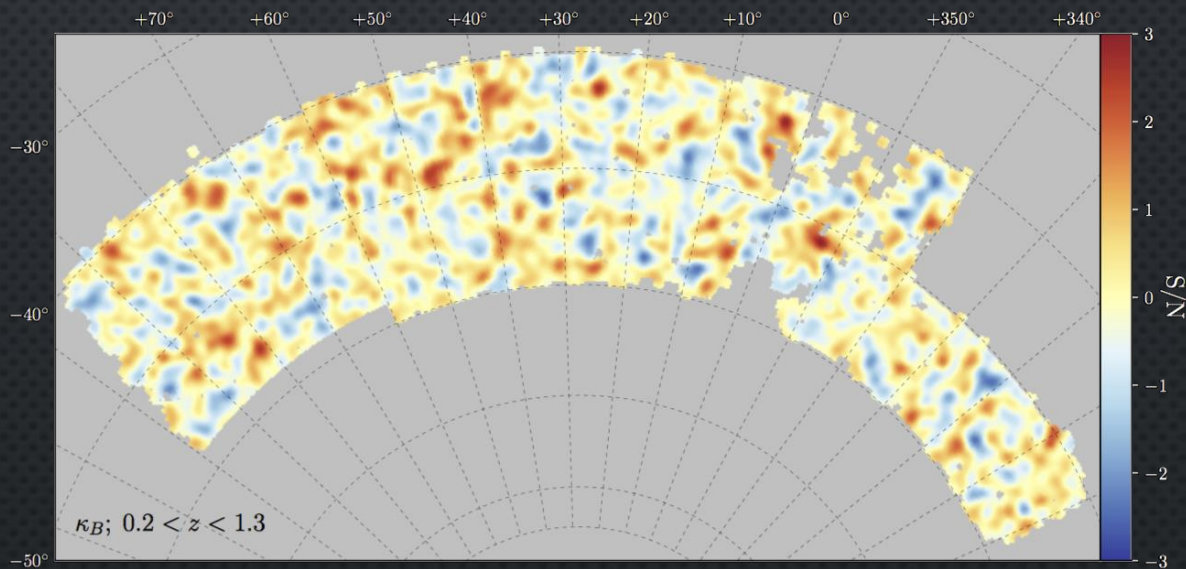
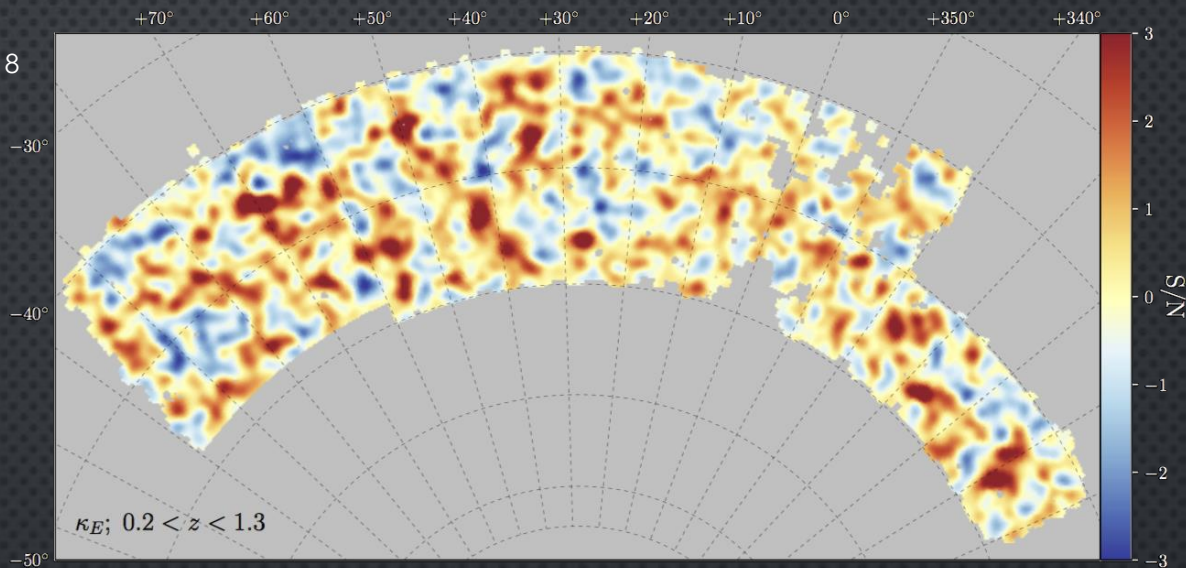
YEAR-1 WEAK LENSING CATALOGS

Chang+ 2018

"E" mode

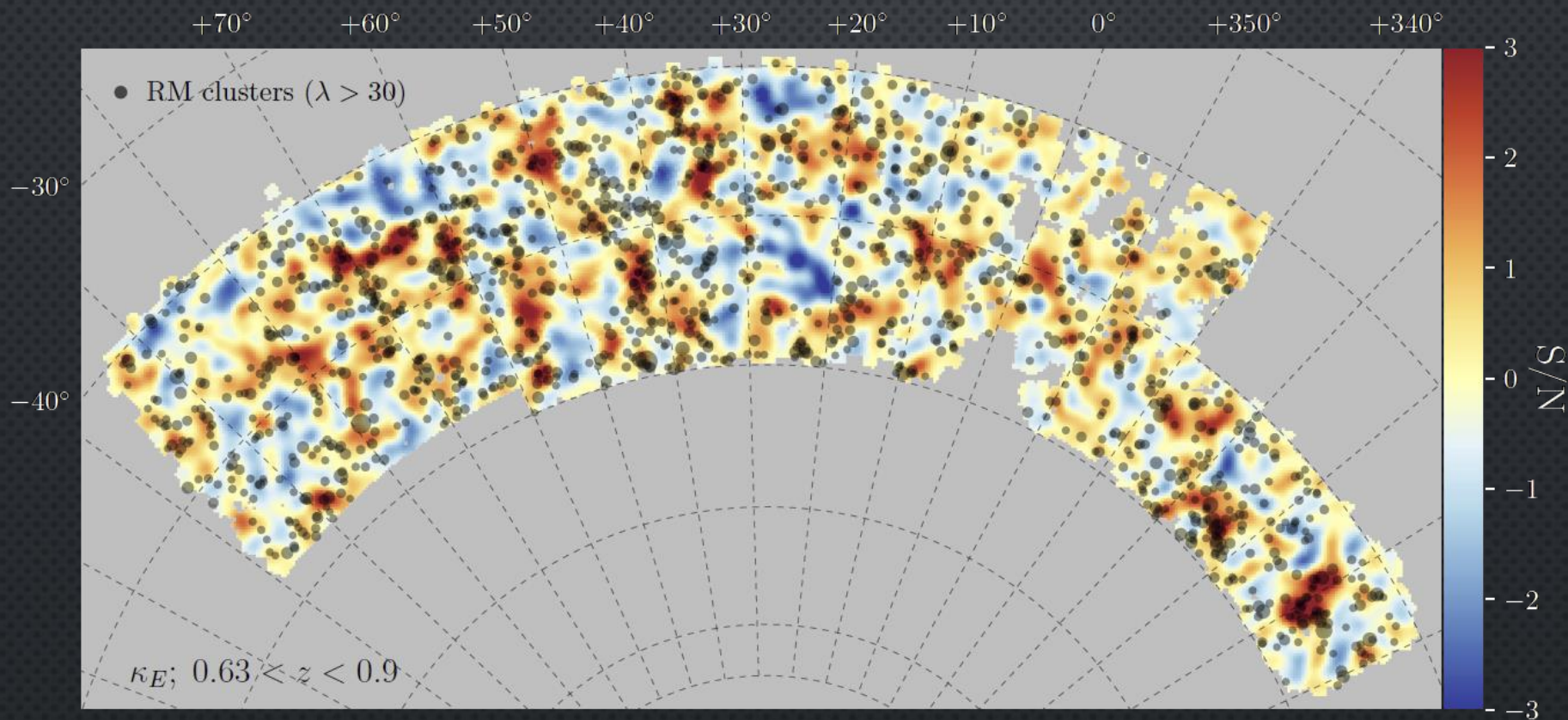


"B" mode



YEAR-1 WEAK LENSING CATALOGS (CONT.)

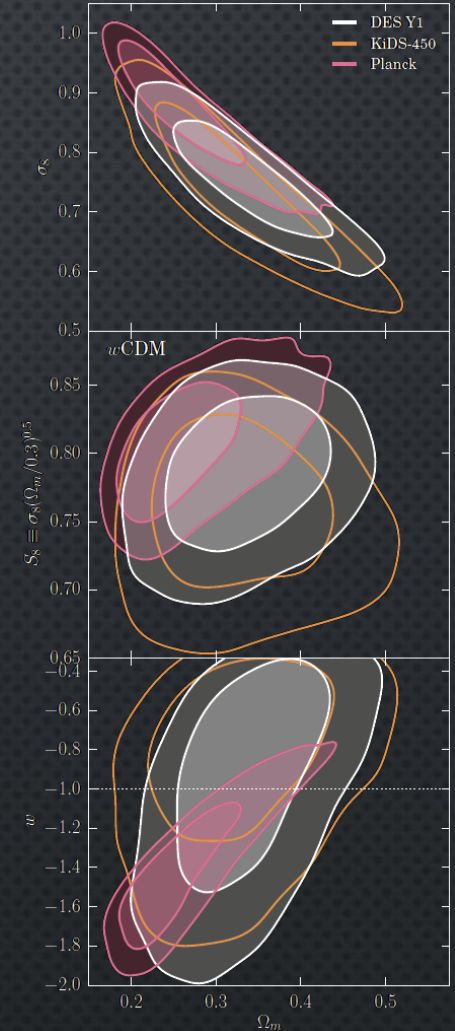
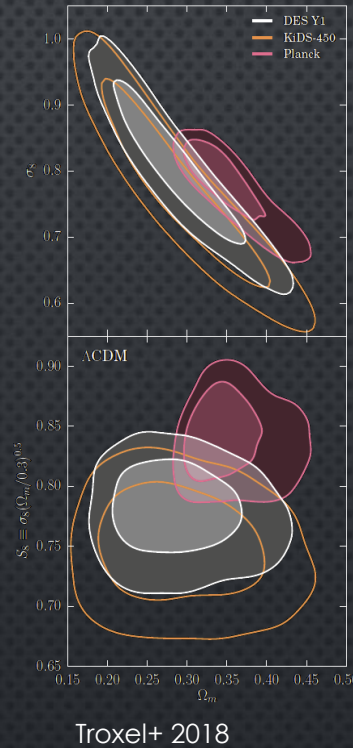
- HIGH CONVERGENCE PEAKS COINCIDE WITH MASSIVE CLUSTERS AT INTERMEDIARY REDSHIFTS



Chang+ 2018

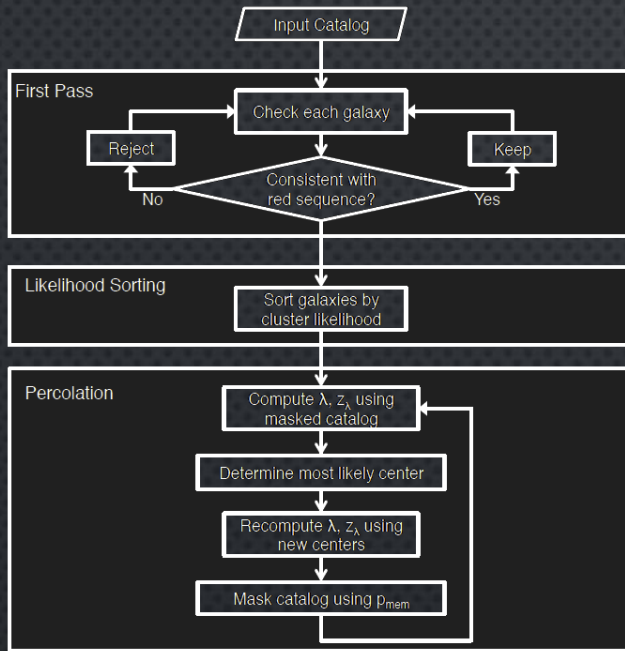
YEAR-1 COSMOLOGICAL ANALYSIS FROM COSMIC SHEAR

- BOTH SHEAR PIPELINES PRODUCE CONSISTENT RESULTS
- $S_8 = 0.782^{+0.027}_{-0.027}$ (Λ CDM)
- $S_8 = 0.777^{+0.036}_{-0.038}$ (w CDM)
- $w = -0.95^{+0.33}_{-0.39}$
- CONSISTENT WITH KIDS-450 AND DES SVA

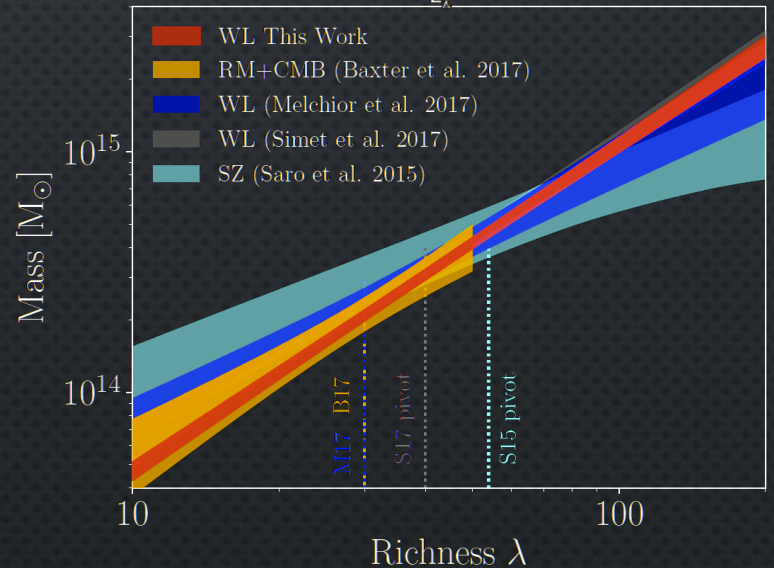
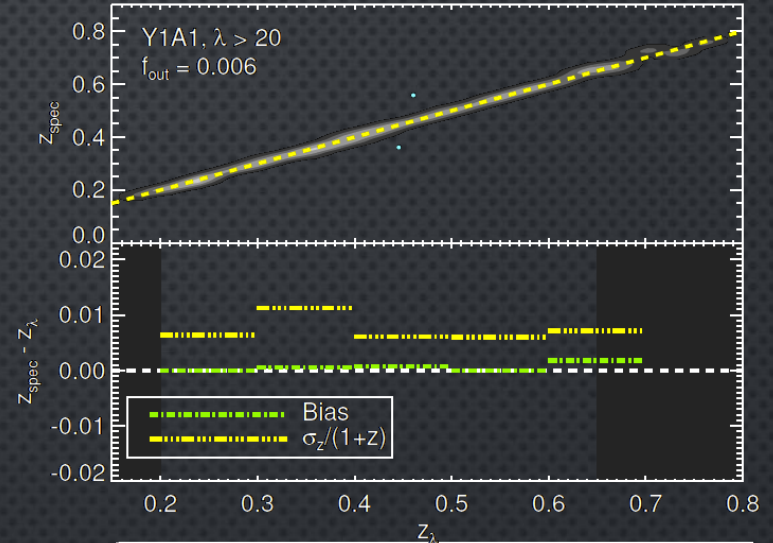


YEAR-1: GALAXY CLUSTERS

- CLUSTERS ARE DETECTED USING REDMAPPER (RYKOFF+ 2014)

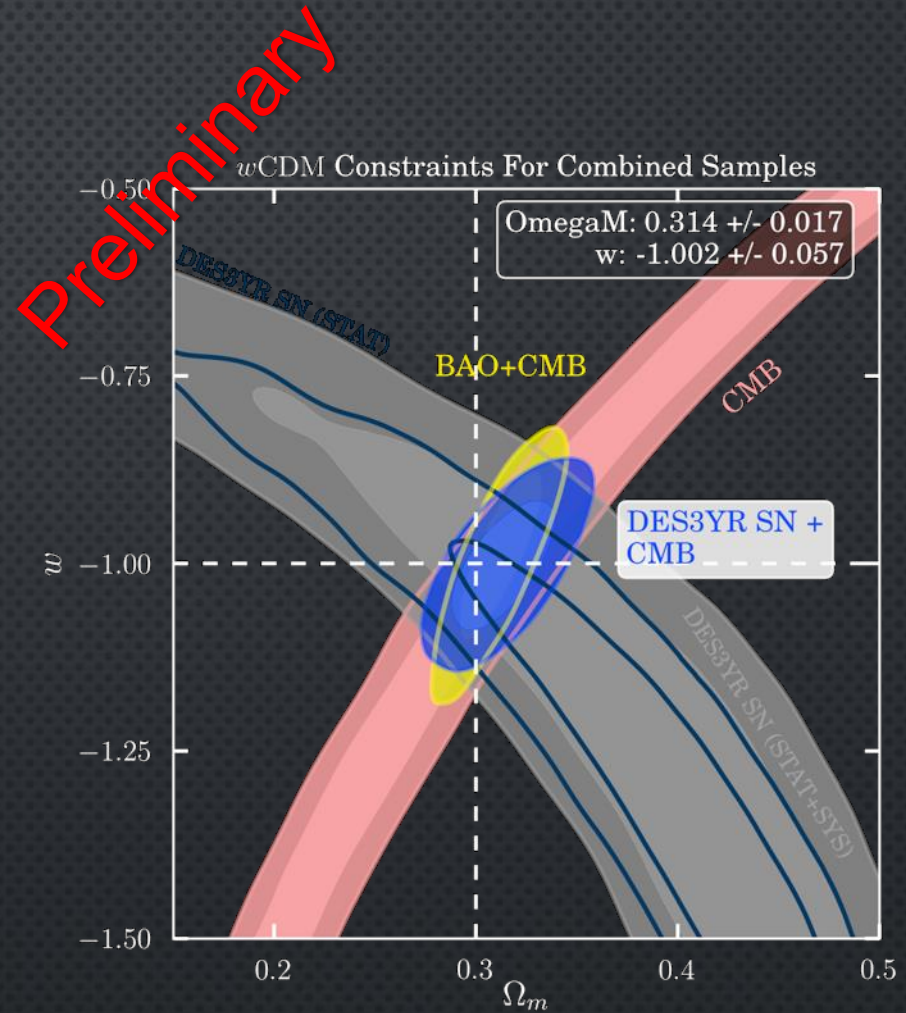
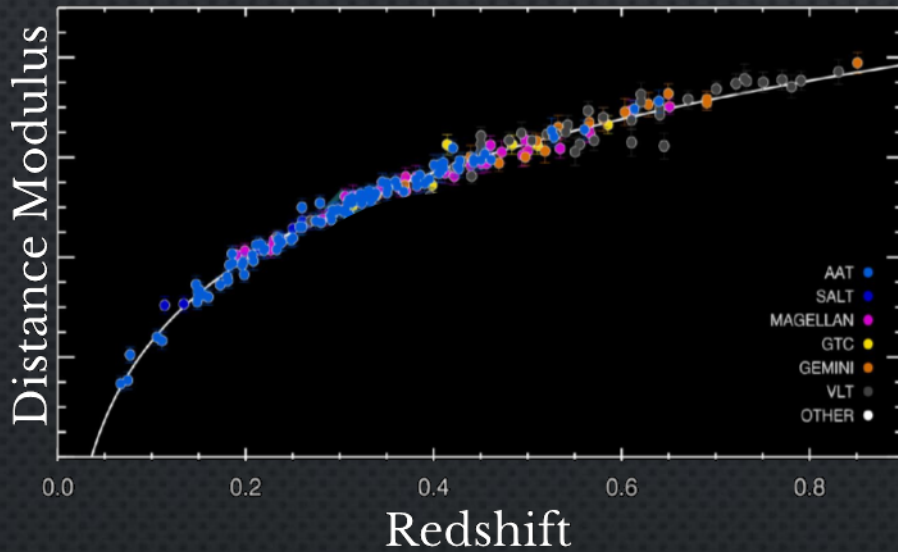


- REDMAGIC (ROZO+ 2016) USES A SIMILAR RED SEQUENCE FITTING SCHEME TO FIND LRGs



SUPERNOVAE

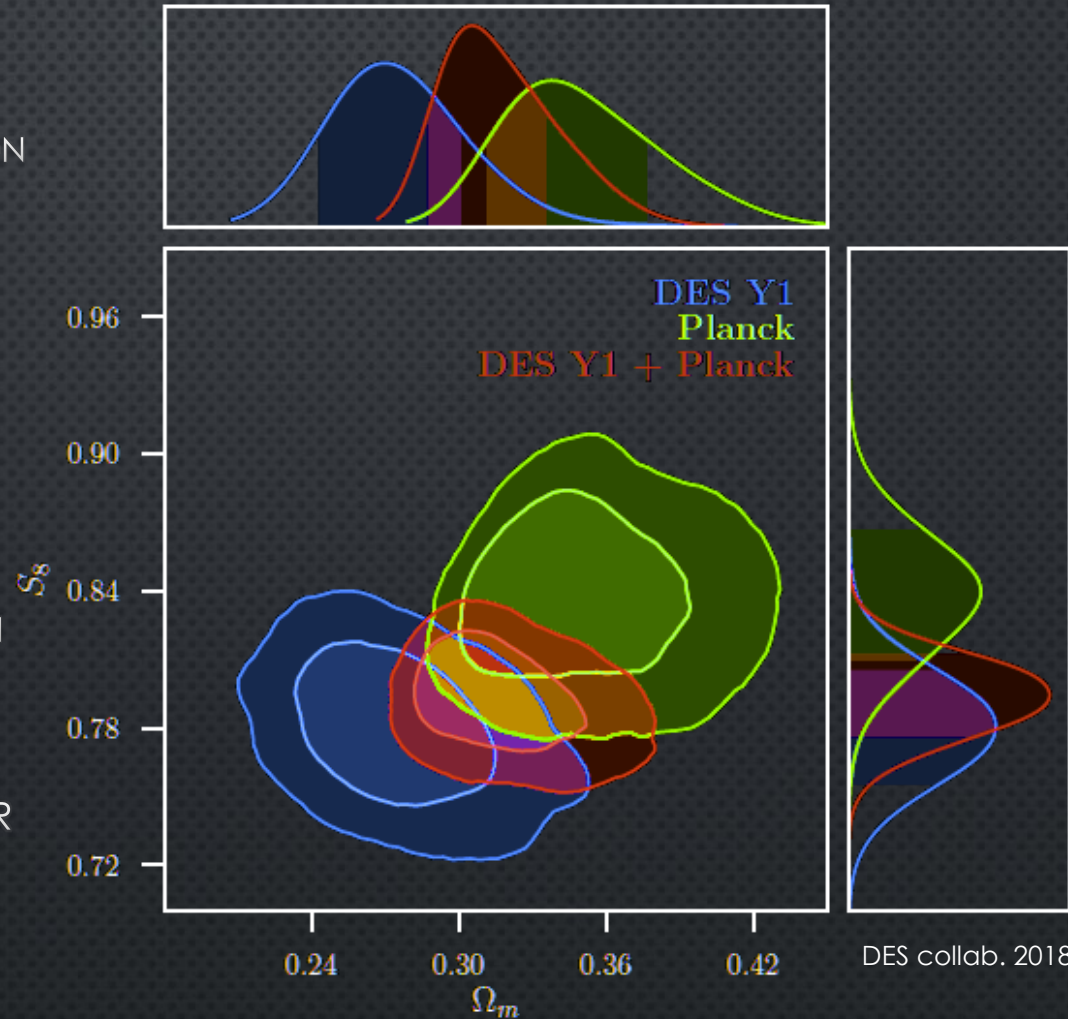
- 3-YEAR DATA *PRELIMINARY*
- 206 NEW SNIa WITH $0.02 < z < 0.85$
- 128 EXTERNAL LOW-Z SNe
- 4% PRECISION ON DISTANCE



Brout+ 2018

YEAR-1: COMBINED PROBES IN Λ CDM

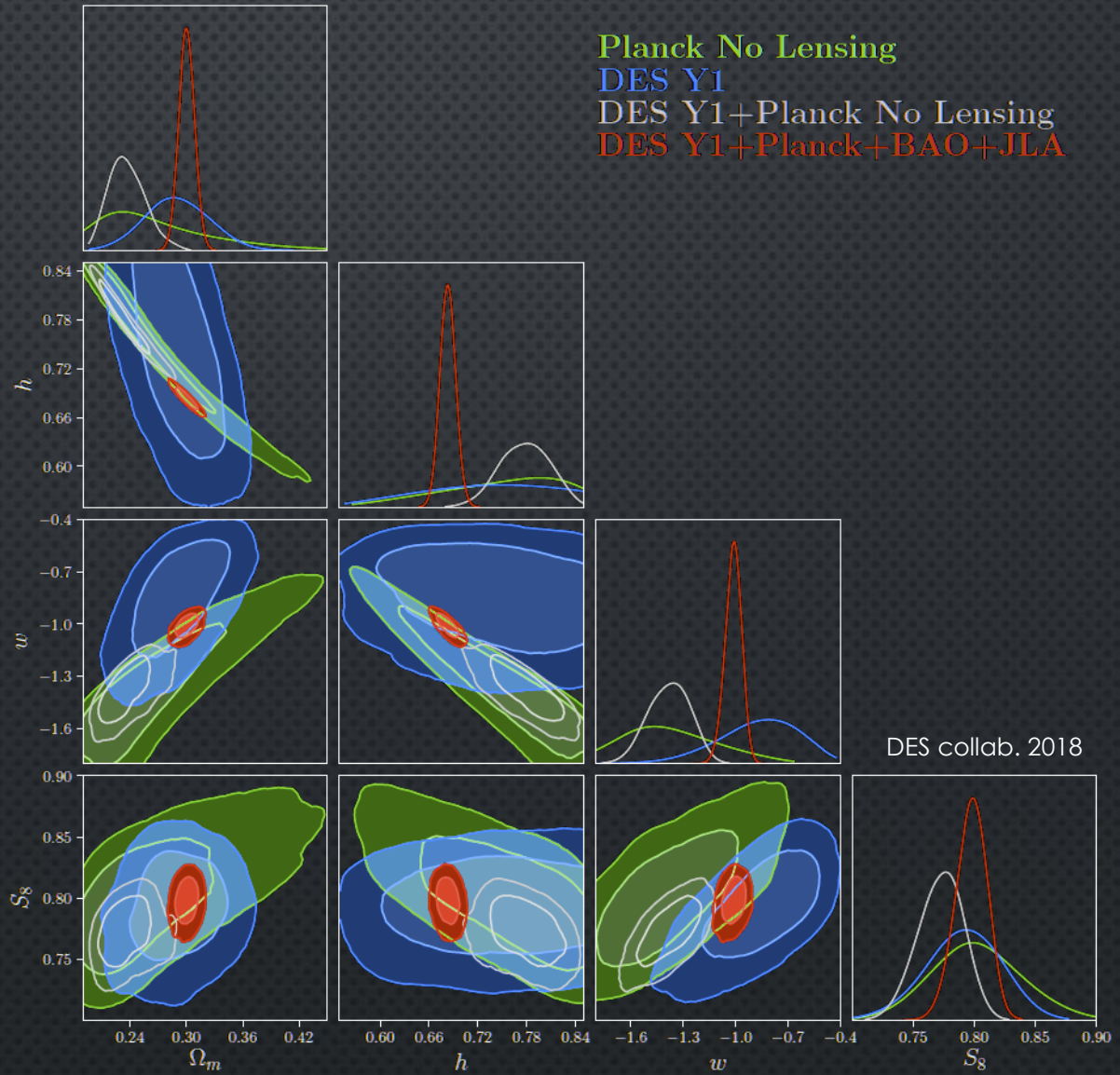
- YEAR-1 INGREDIENTS:
 - GALAXY ANGULAR AUTOCORRELATION FUNCTION
 - 650,000 LRGs
 - 5 REDSHIFT BINS
 - COSMIC SHEAR CORRELATION FUNCTIONS
 - 26 MILLION SOURCES
 - 4 REDSHIFT BINS
 - GALAXY-SHEAR CROSS-CORRELATION OF LRG POSITIONS AND SOURCE GALAXY SHEARS
- BAYES FACTOR $\frac{P(D|w\text{CDM})}{P(D|\Lambda\text{CDM})} = 0.36$ FOR YEAR-1 DATA.





YEAR-1: COMBINED PROBES IN w CDM

- $S_8 = 0.794^{+0.014}_{-0.009}$ (Λ CDM)
- $\Omega_M = 0.301^{+0.006}_{-0.008}$ (Λ CDM)
- $w = -1.00^{+0.04}_{-0.05}$
- LOW ($z = 0.5$) AND HIGH ($z = 1100$) REDSHIFT Λ CDM PARAMETERS HIGHLY CONSISTENT
- EXTENDED MODELS: SEE TALK BY AGNÈS FERTE TOMORROW





SUMMARY AND PERSPECTIVES

- CONSTRAINTS ON COSMOLOGY FROM THE FIRST YEAR OF OBSERVING ALREADY SIGNIFICANT
- TENSION ON s_8 WITH RESPECT TO PLANCK IS SMALL
- COMBINING ALL PROBES (INCLUDING PLANCK) ONE FINDS $w = -1.00^{+0.04}_{-0.05}$
 - BORINGLY CONSISTENT WITH Λ CDM SO FAR
- YEAR-3 RESULTS COMING SOON: ~ 3500 SQ.DEG., 100 MILLION GALAXIES
- YEAR-5: ~ 5000 SQ.DEG., 300 MILLION GALAXIES