The status of standard cosmology and the future with Euclid and SKA

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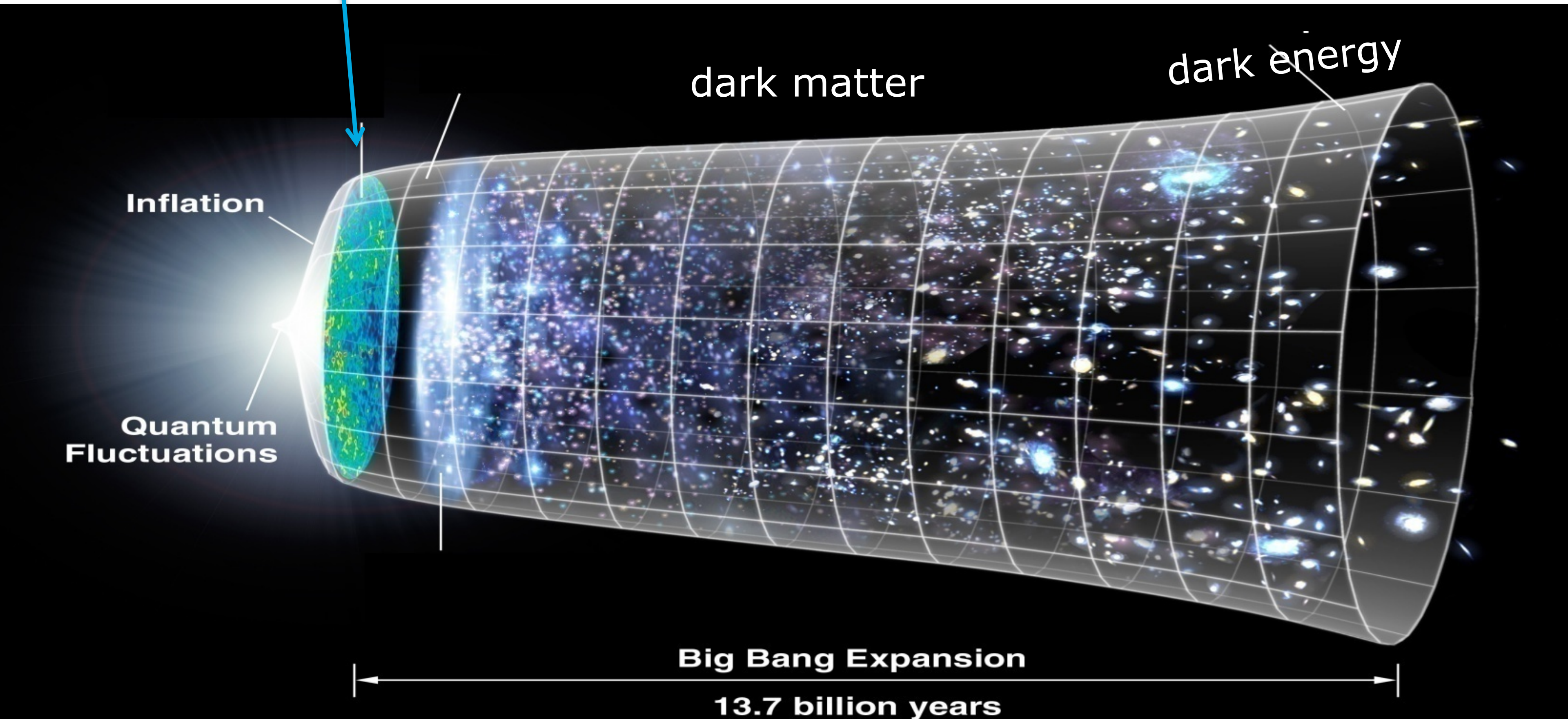
outline

- Super-brief intro
- Planck + galaxy survey / WL data
    - does LCDM fit the data?
    - do the data sets agree with each other? (in LCDM)
    - what are the values of the cosmological parameters?
- Brief overview of upcoming cosmological surveys
- Euclid
- SKA
- Conclusions

cosmological overview

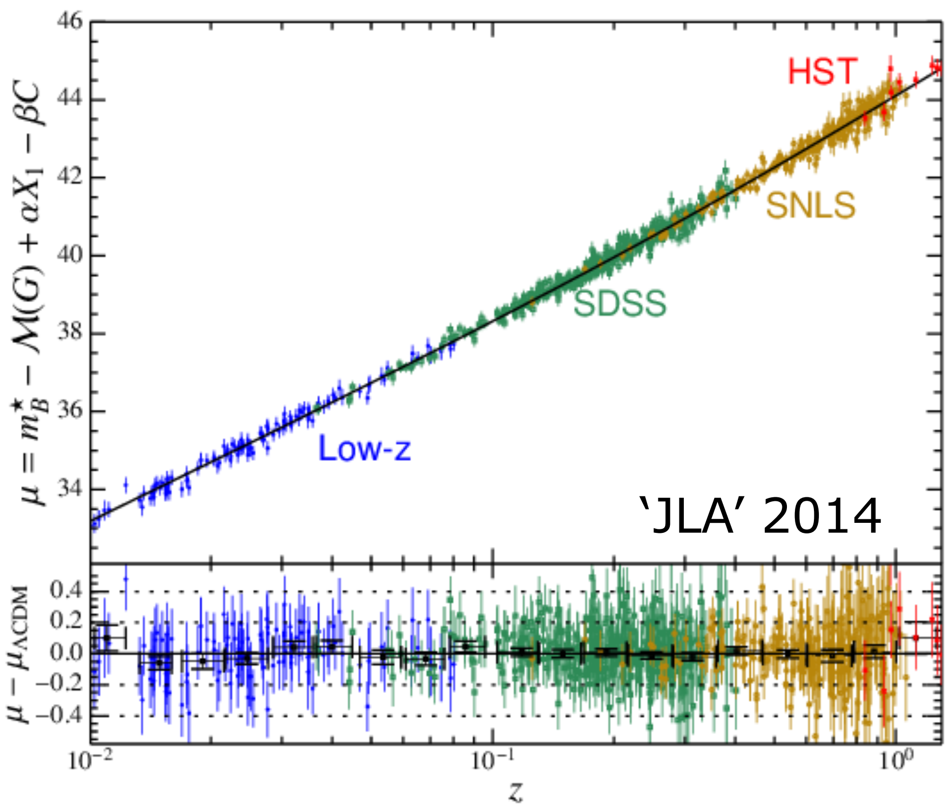
cosmic microwave background (CMB)

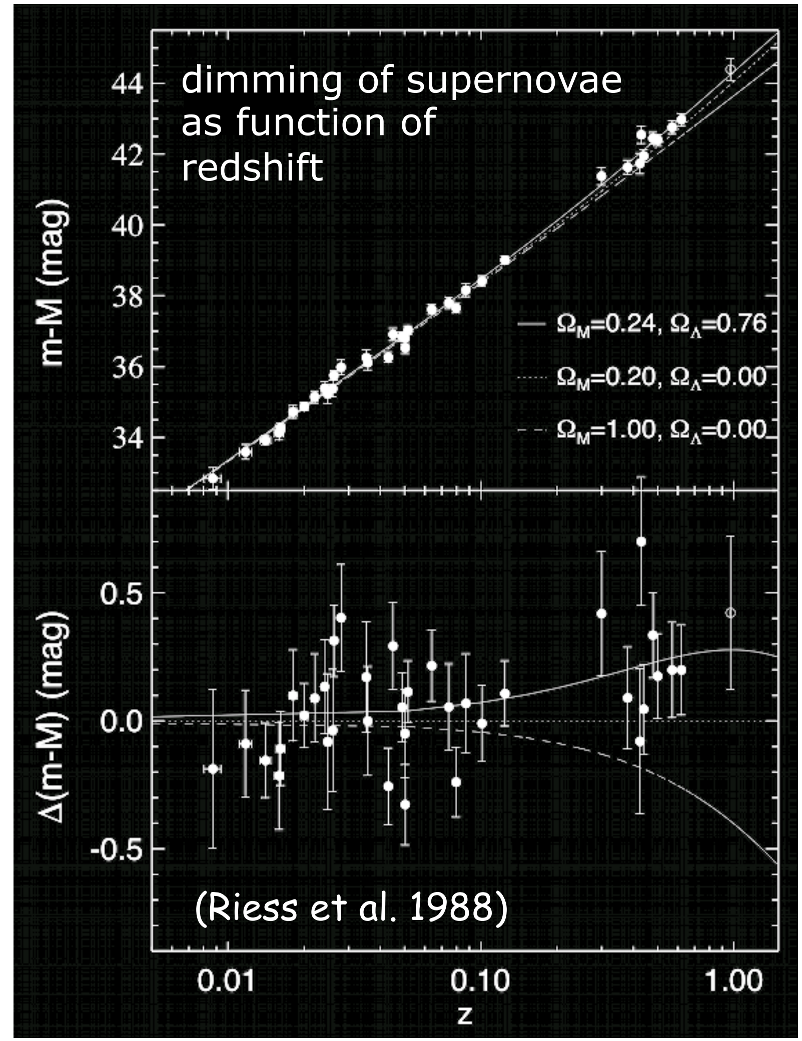
Euclid & SKA



The Nobel Prize 2011

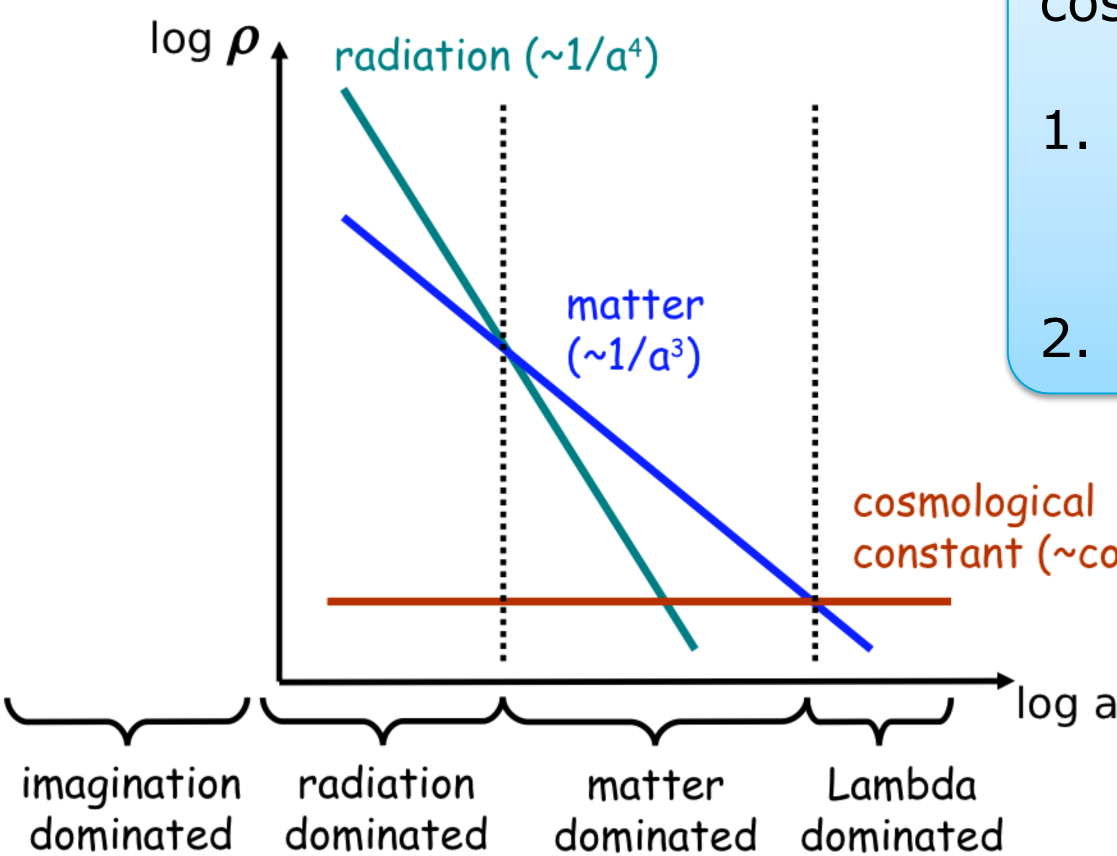
The Universe is now officially accelerating, thanks to the prize given to Saul Perlmutter, Brian P. Schmidt and Adam G. Riess, and we need to understand the reason!





What's the problem with Λ?

Evolution of the Universe:



Classical problems of the cosmological constant:

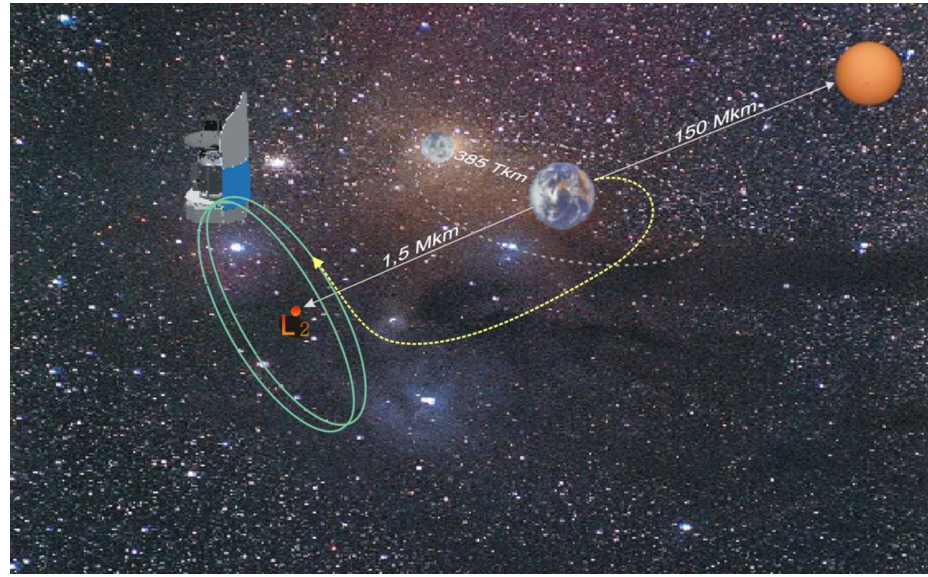
1. Value: why so small? Natural?
   (but is 0 more natural?)
2. Coincidence: Why now?

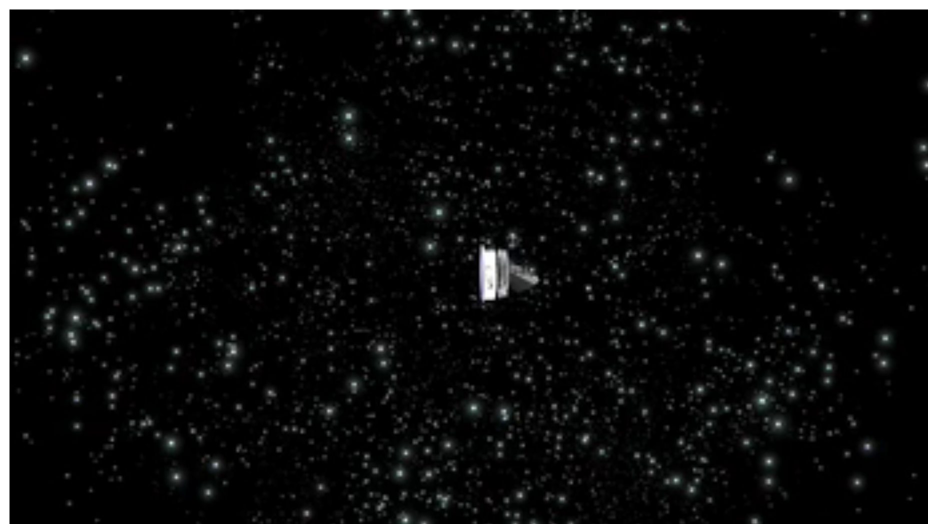
Are we sure that the data is right?

The scientific results that we present today are a product of the Planck Collaboration, including individuals from more than 100 scientific institutes in Europe, the USA and Canada

Planck is a project of the European Space Agency, with instruments provided by two scientific Consortia funded by ESA member states (in particular the lead countries: France and Italy) with contributions from NASA (USA), and telescope reflectors provided in a collaboration between ESA and a scientific Consortium led and funded by Denmark.

the Planck mission

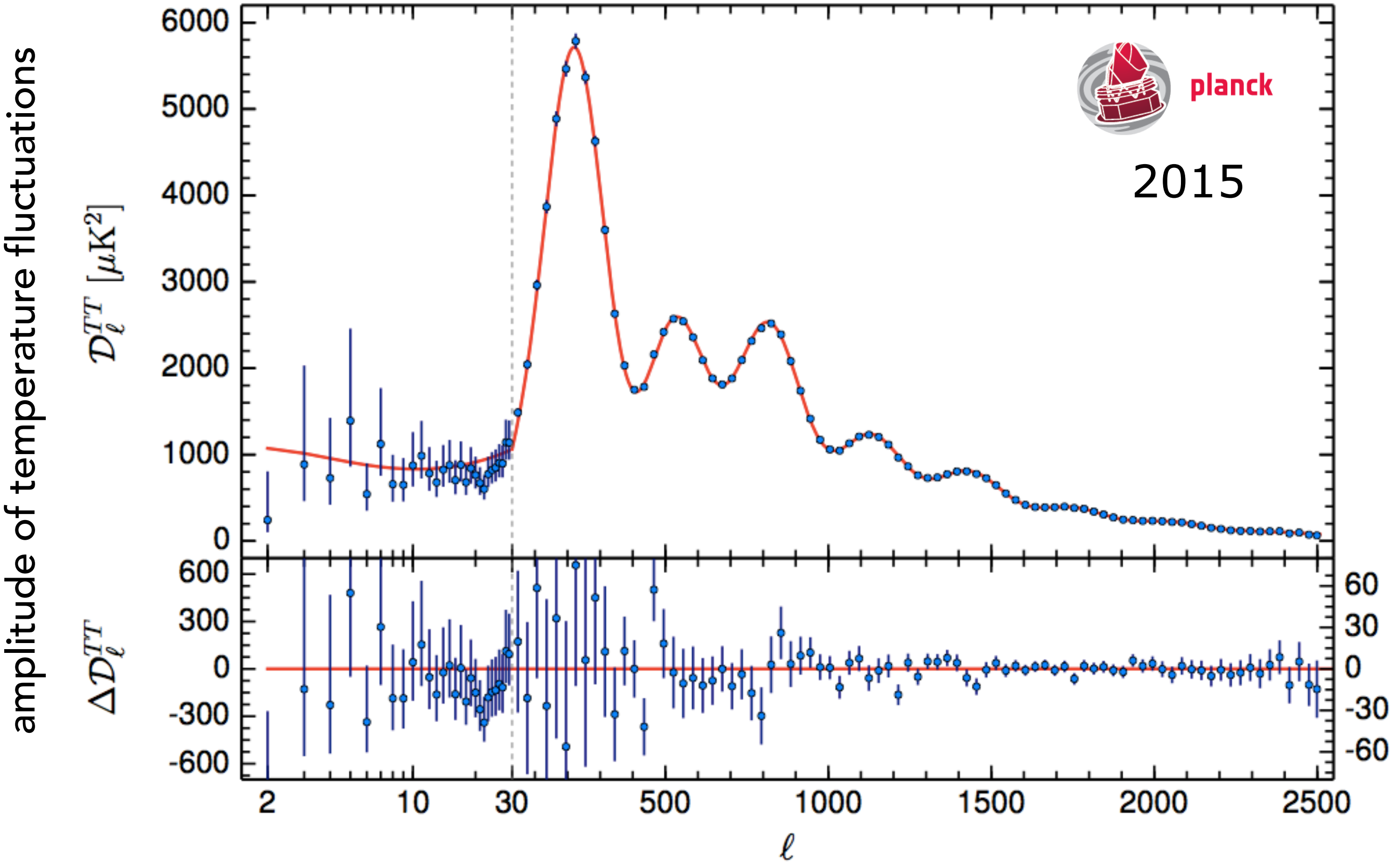




Agency

the cosmic microwave background

planck



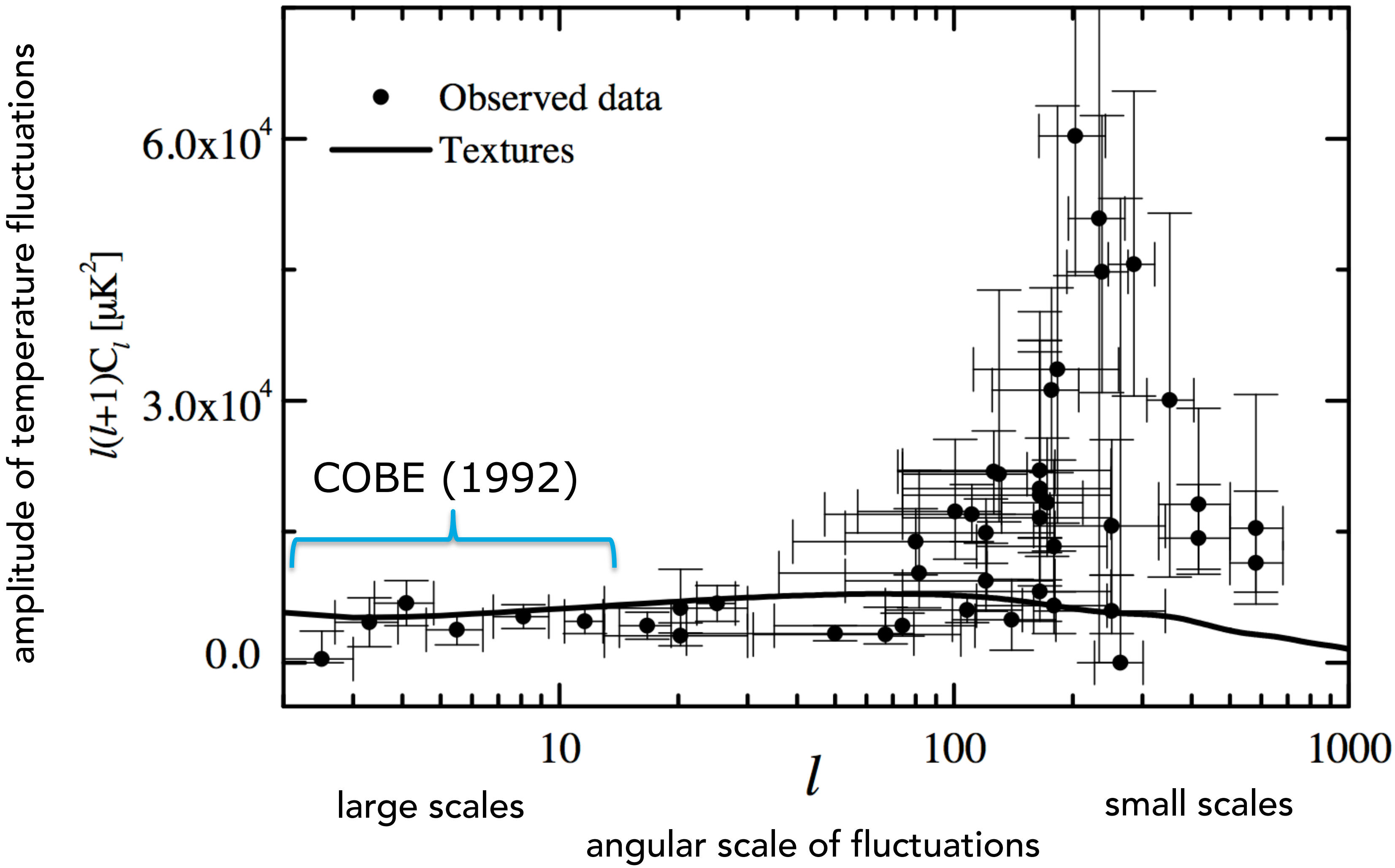
esa

European Space Agency

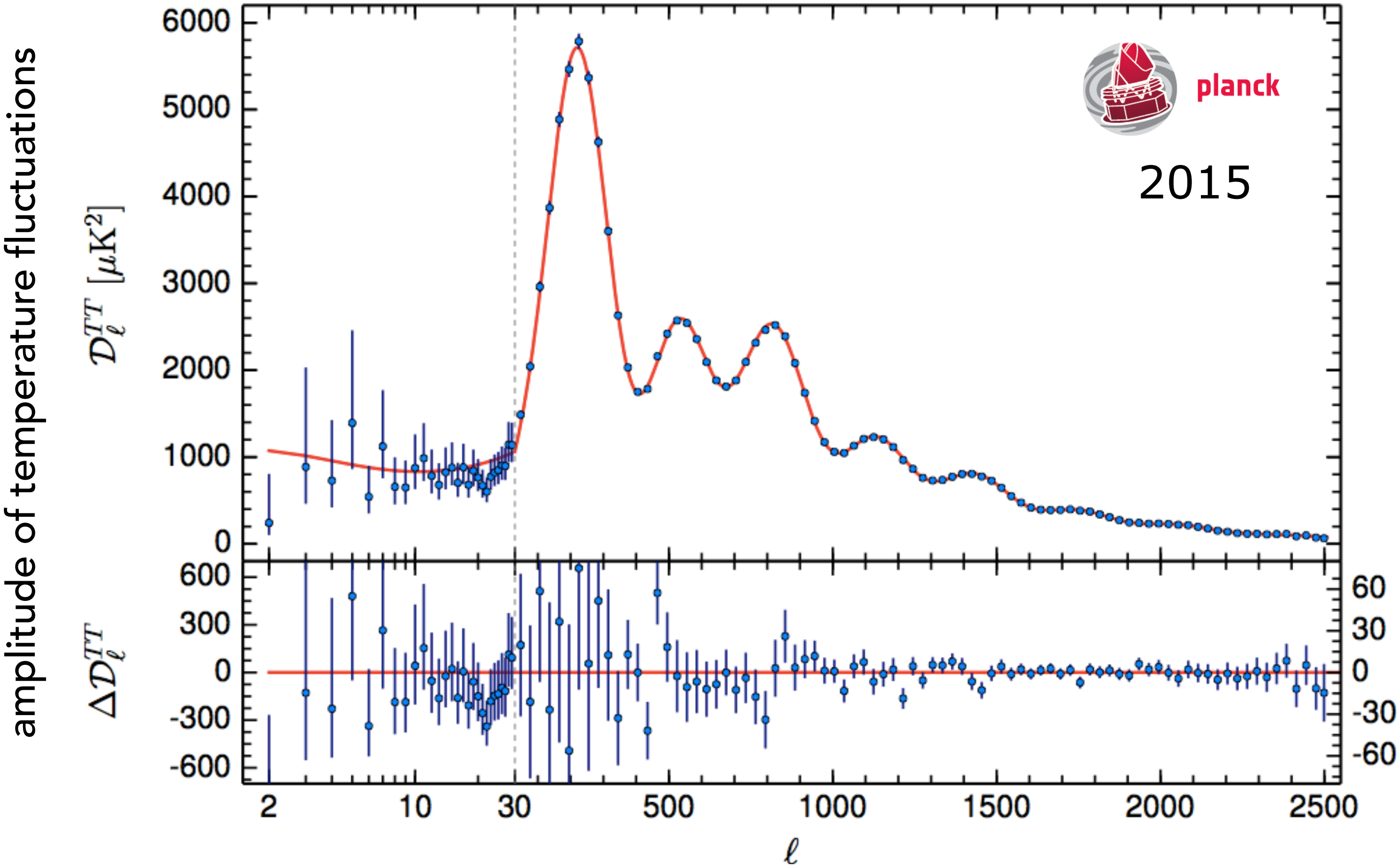
the cosmic microwave background

planck

angular fluctuation spectrum in CMB ca **1998**:



Planck vs LCDM

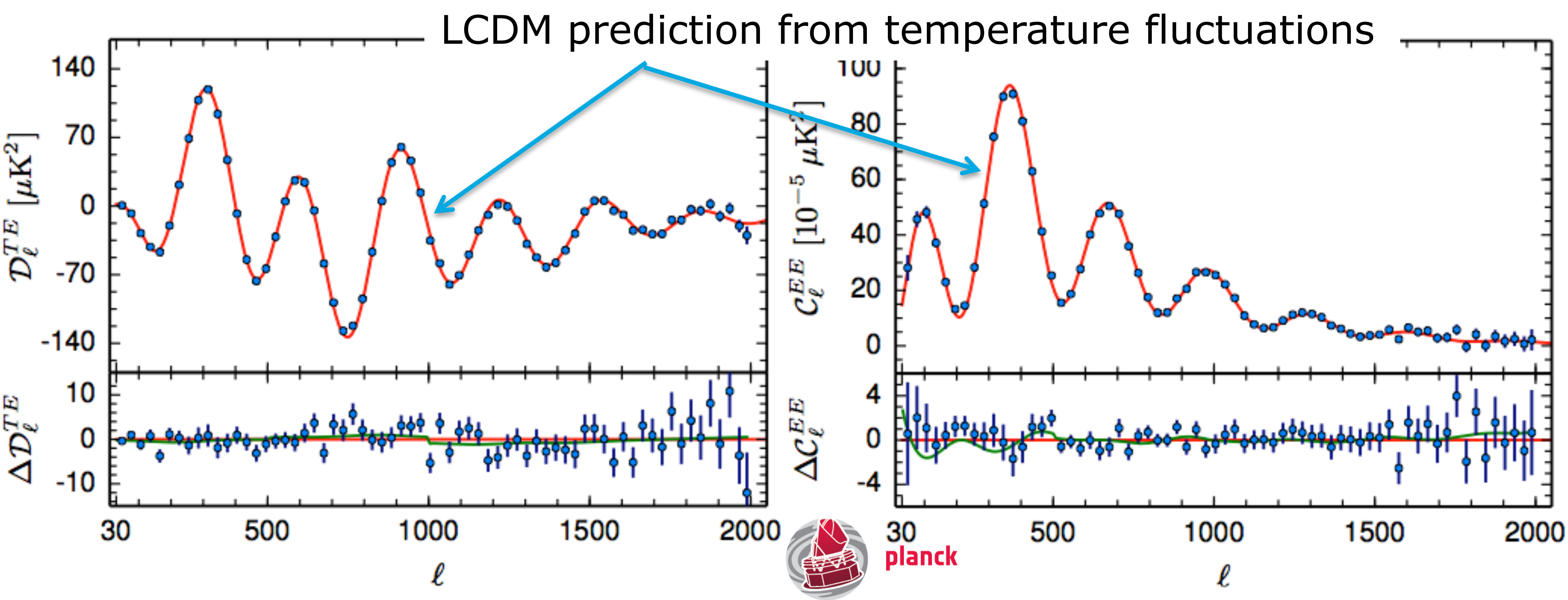


red curve:
best fit 6-parameter ΛCDM ('standard') model
→ fits thousands of C_l / millions of pixels

Planck 2015 TT combined:
ell range 30 – 2508
$X^2 = 2546.67$; $N_{dof} = 2479$
probability 16.8%

2015 polar power spectrum

- scattering of photons off electrons depends on polarisation
- polarisation decomposed into
  - E: gradient type
  - B: vector / rotation type
- for density / scalar perturbations alone, TT predicts TE and EE (and no B-type polarisation)
- CMB lensing, other constituents (e.g. grav. waves) and foregrounds create B-type polarisation



flat LCDM parameters

arXiv:1605.02985

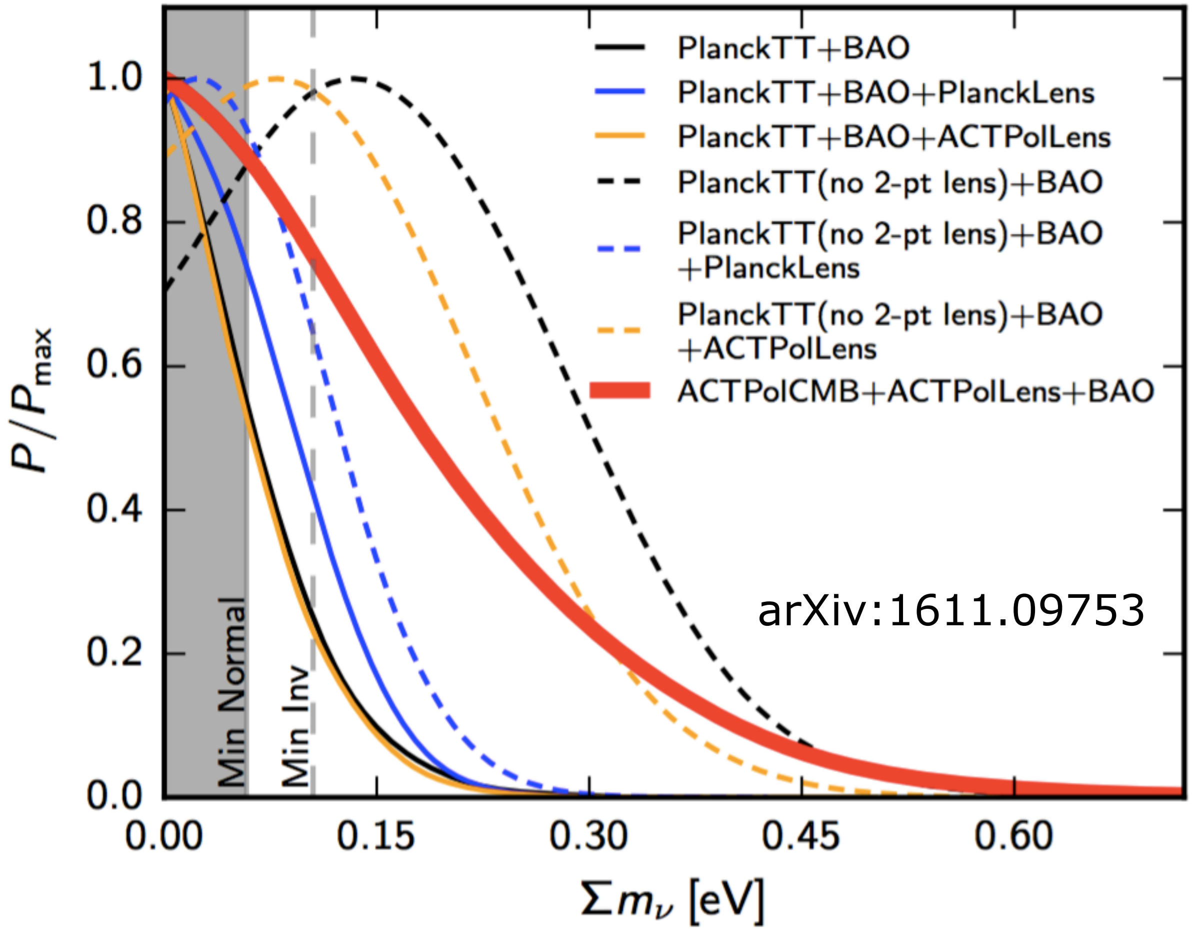
Parameter	PlanckTT+lowP 68 % limits	PlanckTT+SIMlow 68 % limits	PlanckTTTEEE+lowP 68 % limits	PlanckTTTEEE+SIMlow 68 % limits	
$\Omega_b h^2$	0.02222 ± 0.00023	0.02214 ± 0.00022	0.02225 ± 0.00016	0.02218 ± 0.00015	
$\Omega_c h^2$	0.1197 ± 0.0022	0.1207 ± 0.0021	0.1198 ± 0.0015	0.1205 ± 0.0014	
$100\theta_{MC}$	1.04085 ± 0.00047	1.04075 ± 0.00047	1.04077 ± 0.00032	1.04069 ± 0.00031	$<0.03\%$
τ . . . . (WMAP9 reionisation: $\tau = 0.089\pm0.014$)	0.078 ± 0.019	0.0581 ± 0.0094	0.079 ± 0.017	0.0596 ± 0.0089	
$\ln(10^{10} A_s)$	3.089 ± 0.036	3.053 ± 0.019	3.094 ± 0.034	3.056 ± 0.018	
n_s	0.9655 ± 0.0062	0.9624 ± 0.0057	0.9645 ± 0.0049	0.9619 ± 0.0045	$>8\sigma$
H_0	67.31 ± 0.96	66.88 ± 0.91	67.27 ± 0.66	66.93 ± 0.62	
Ω_m	0.315 ± 0.013	0.321 ± 0.013	0.3156 ± 0.0091	0.3202 ± 0.0087	
σ_8	0.829 ± 0.014	0.8167 ± 0.0095	0.831 ± 0.013	0.8174 ± 0.0081	
$\sigma_8 \Omega_m^{0.5}$	0.466 ± 0.013	0.463 ± 0.013	0.4668 ± 0.0098	0.4625 ± 0.0091	
$\sigma_8 \Omega_m^{0.25}$	0.621 ± 0.013	0.615 ± 0.012	0.623 ± 0.011	0.6148 ± 0.0086	
z_{re}	$9.89^{1.8}_{-1.6}$	8.11 ± 0.93	$10.0^{1.7}_{-1.5}$	8.24 ± 0.88	
$10^9 A_s e^{-2\tau}$	1.880 ± 0.014	1.885 ± 0.014	1.882 ± 0.012	1.886 ± 0.012	
Age/Gyr	13.813 ± 0.038	13.829 ± 0.036	13.813 ± 0.026	13.826 ± 0.025	25 Myr!

percent-level constraints – but most of this is model dependent!

Planck-only fLCDM extensions

arXiv:1605.02985

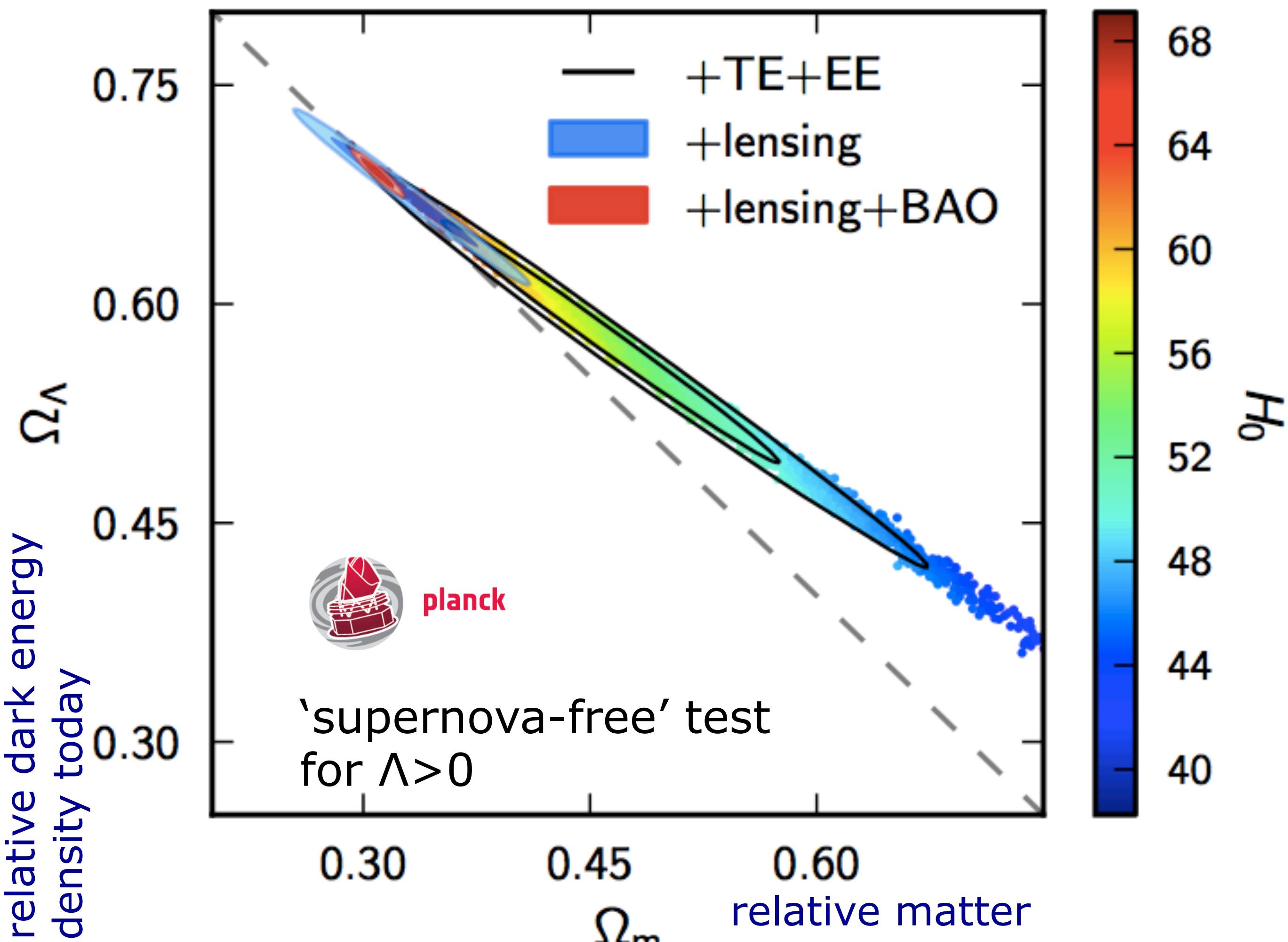
Parameter	PlanckTT+lowP 95 % limits
Ω_K	$-0.052^{+0.049}_{-0.055}$
Σm_ν [eV]	< 0.715
$N_{\rm eff}$	$3.13^{+0.64}_{-0.63}$
$Y_{\rm P}$	$0.252^{+0.041}_{-0.042}$
$dn_s/d\ln k$	$-0.008^{+0.016}_{-0.016}$
$r_{0.002}$	< 0.103
w	$-1.54^{+0.62}_{-0.50}$
$A_{\rm L}$	$1.22^{+0.21}_{-0.20}$



- No significant deviat
  - except maybe A_L?
  - w is artificial parameter space issue, see later
- We can do much better by combining probes

basic cosmological results

spatial curvature: Ω_k=0.000±0.005 (95%)

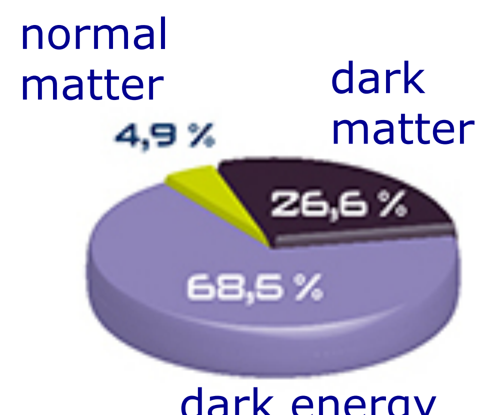


relative dark energy density today

relative matter density today

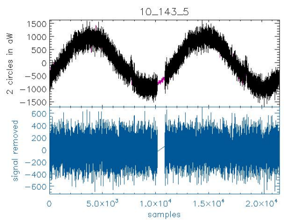
Different data sets point to a dark energy independently

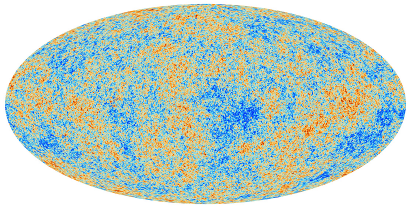
Multiple probes are much more powerful, but need more care

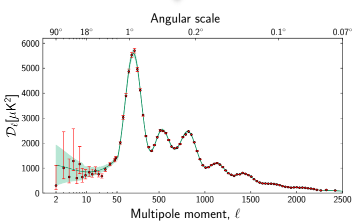


extreme compression!

planck







$\{\Omega_b, \Omega_\Lambda, H_0, A_s, n_s, \tau\}$

1. science samples: 530’632’594’653 (991’929’524’565 for full mission), a few terabytes
2. maps: ca 50 mega-pixels, compression 10’000:1
3. power spectrum: ca 2500 values, compression 20’000:1
4. model: 6 parameters, compression 3000:1

total compression ca 10^{11}:1 !

(nearly 10^7:1 from map)

why go beyond Λ?

- because we can
- because we have to test the model (of course also isotropy/ homogeneity, Gaussianity, initial conditions, nature of DM, … cf eg Euclid science case)
- and maybe because $n_s \neq 1$

- Scalar field inflaton: $1 + w = -\frac{2}{3}\frac{\dot{H}}{H^2} = \frac{2}{3}\epsilon_H$ and $r = T/S \sim 24\,(1+w)$
- Link to dw/da: $\frac{d\ln(1+w)}{dN} = 2(\eta_H - \epsilon_H)$ $\quad 2\eta_H = (n_s - 1) + 4\epsilon_H$

$n_s \neq 1 \Rightarrow \varepsilon \neq 0$ or $\eta \neq 0$
=> $w \neq -1$ and/or w not constant
=> not a cosmological constant!

(Ilic, MK, Liddle & Frieman, 2010)

(current limit: $r < 0.1$)

→ **inflation was not an (even effective) cosmological constant!**
→ inflation is one measurement ahead of dark energy research!

what is the “consensus” 2015?

beyond ΛCDM
Oslo 2015

	RD	PL	JM	BR	GS	LV	AH	Beyond LCDM
Dimensions	3+1	3+1	2 in UV	4	4	e^(4-x) x>=4	3+1	3+1
FRW	y	y	n	y	n	y	y	n
Inflation?	y or n	y	n	y	maybe	y	y	y
Dark Matter	CDM	CDM+	none	CDM+	Strange	CDM-like	IDM	Split
Gravity Theory	MG	GRish	Not GR	GR	nearly GR	GR++	GR++	Split
Acceleration: Λ/DE/MG/BR	MG	DE	MG	DE	Λ	Degenerate w/ Λ	Λ	MG
Anomalies =New Physics	n	y	y	n	y	not yet	n	Split

DE/MG constraints w/ current data

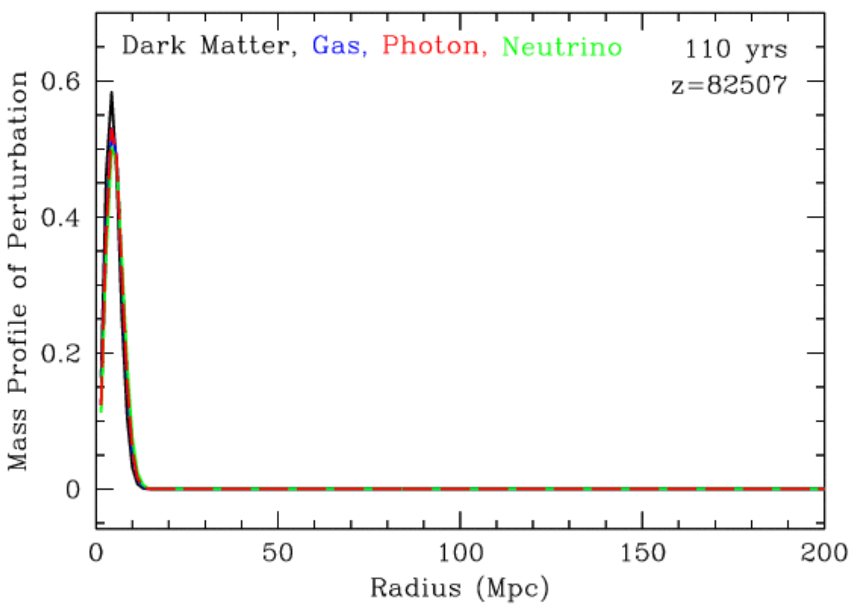
(mostly based on Planck 2015 paper XIV)

- **Planck CMB data** (temperature + polarization)
- **'background'** (BSH): constrain **H(z) ↔ w(z)**
  - supernovae: JLA
  - Baryon acoustic oscillations (BAO): SDSS, BOSS LOWZ & CMASS, 6dFGS
  - H_0: (70.6 ± 3.3) km/s/Mpc [Efstathiou 2014]
- **redshift space distortions** (BAO/RSD)
  - sensitive to velocities from gravitational infall
  - acceleration of test-particles (galaxies) come from **grad ψ**
  - usually given as limit on $f\sigma_8$ (continuity eq.)
  - we use BOSS CMASS
- **gravitational lensing** (WL and CMB lensing)
  - deflection of light governed by **φ+ψ**
  - galaxy weak lensing: CFHTLenS with 'ultraconservative cut'
  - CMB lensing: lensing of Planck CMB map
    - extracted from map trispectrum
    - power spectrum is also lensed!

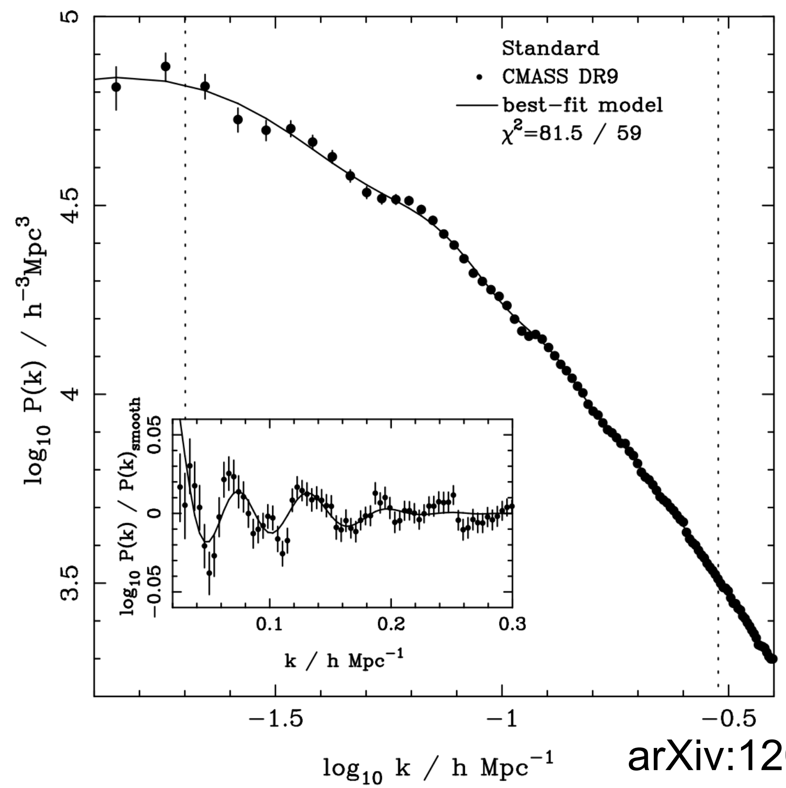
standard rulers: BAO

- On sub-horizon scales, the baryon-photon fluid oscillates until t_{dec}
- After t_{dec}, the photons free-stream away, and the baryons fall into the potential wells of the cold dark matter
- But the CDM also falls a bit into the baryon potential wells
- This imprints the oscillations also into the matter power spectrum

-> Baryonic Acoustic Oscillations feature -> **standard ruler!**



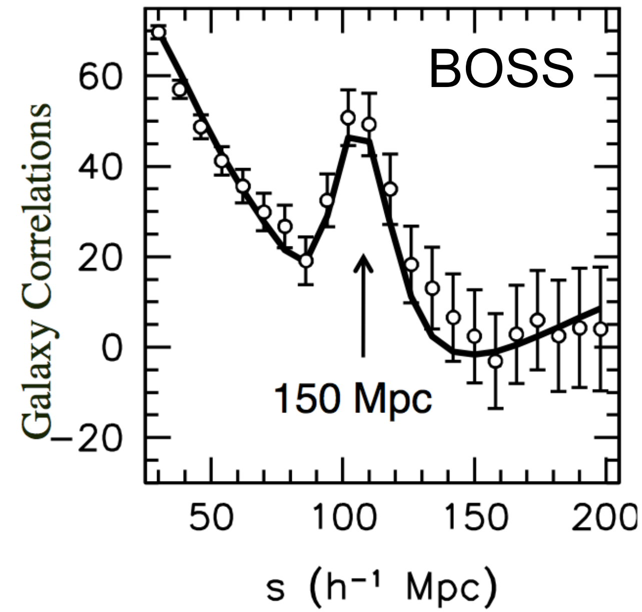
animation by Eisenstein, uses cmbfast



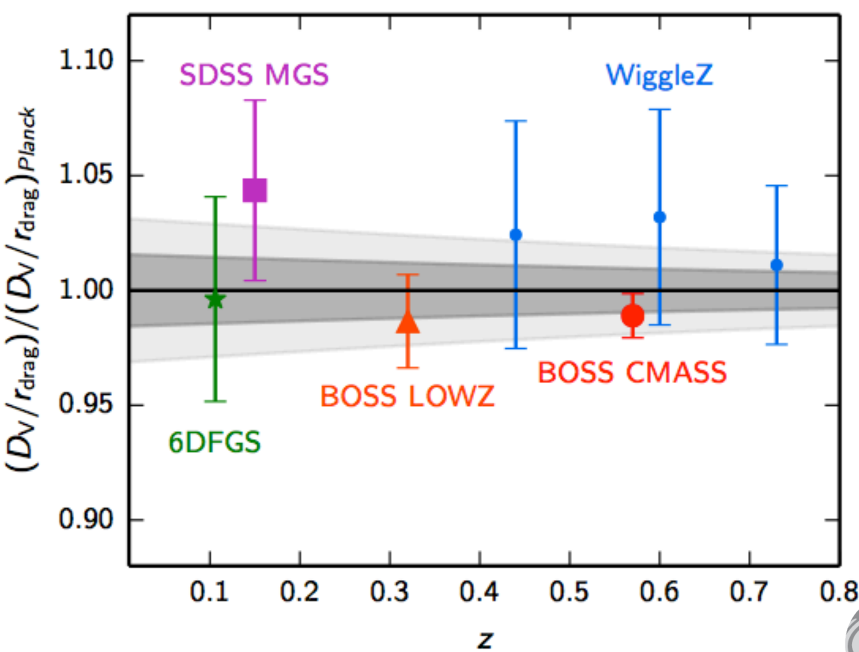
arXiv:1203.6594

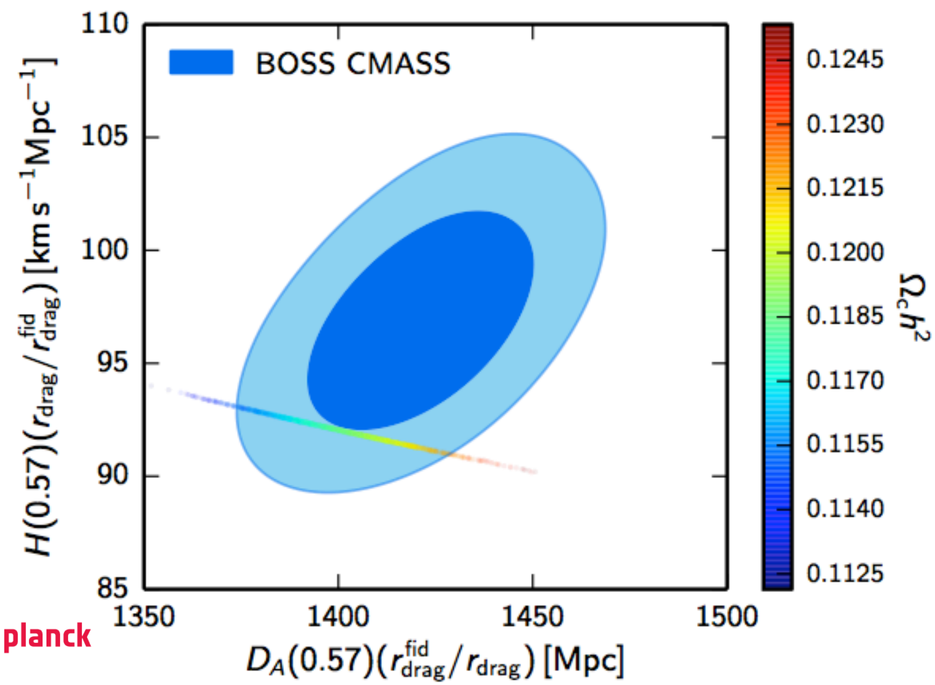
BAO distances

a standard ruler of ~150 comoving Mpc gives us an angular diameter distance (linked to same scale as CMB peak position!)



Planck 2015

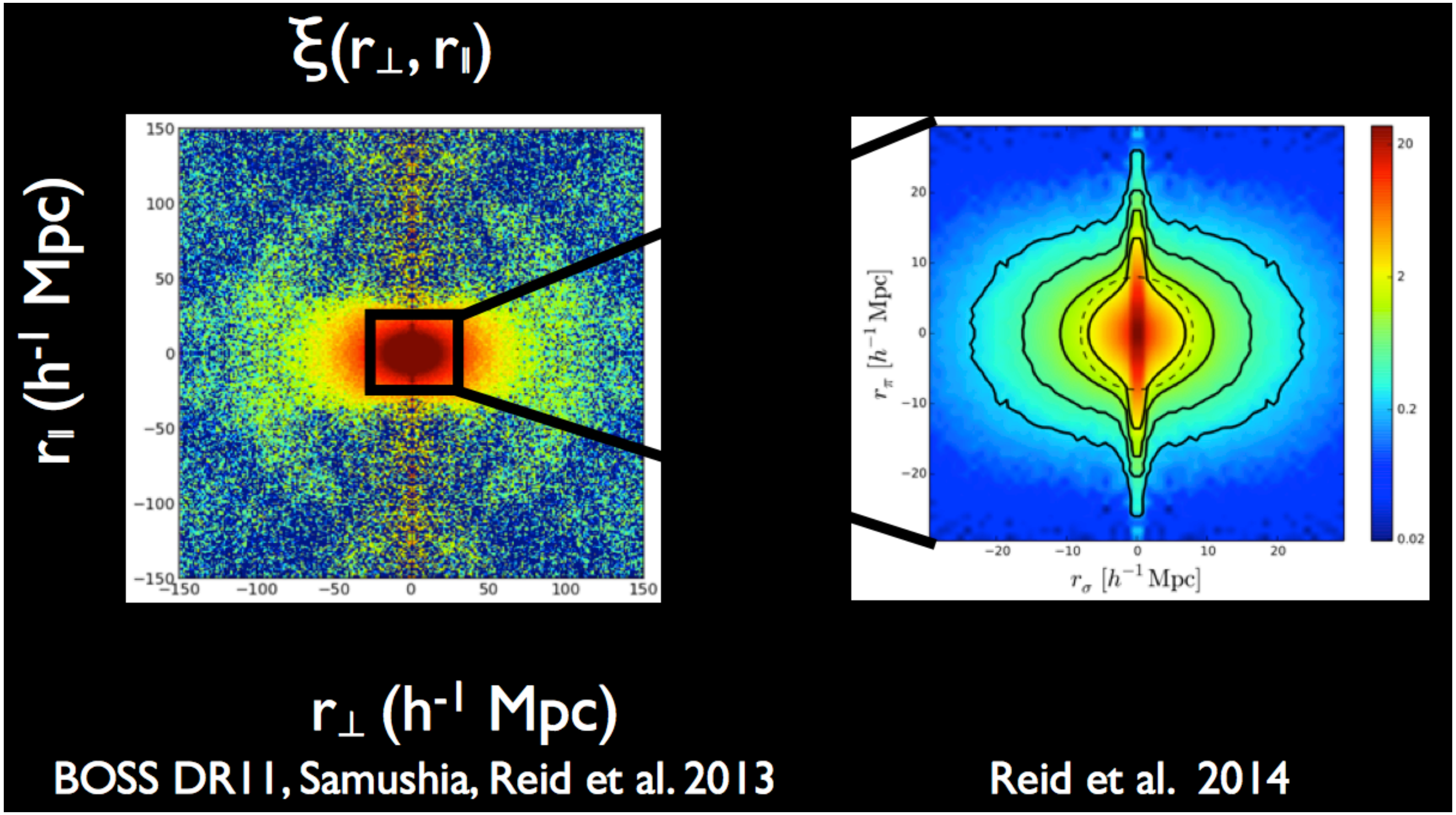




redshift space distortions

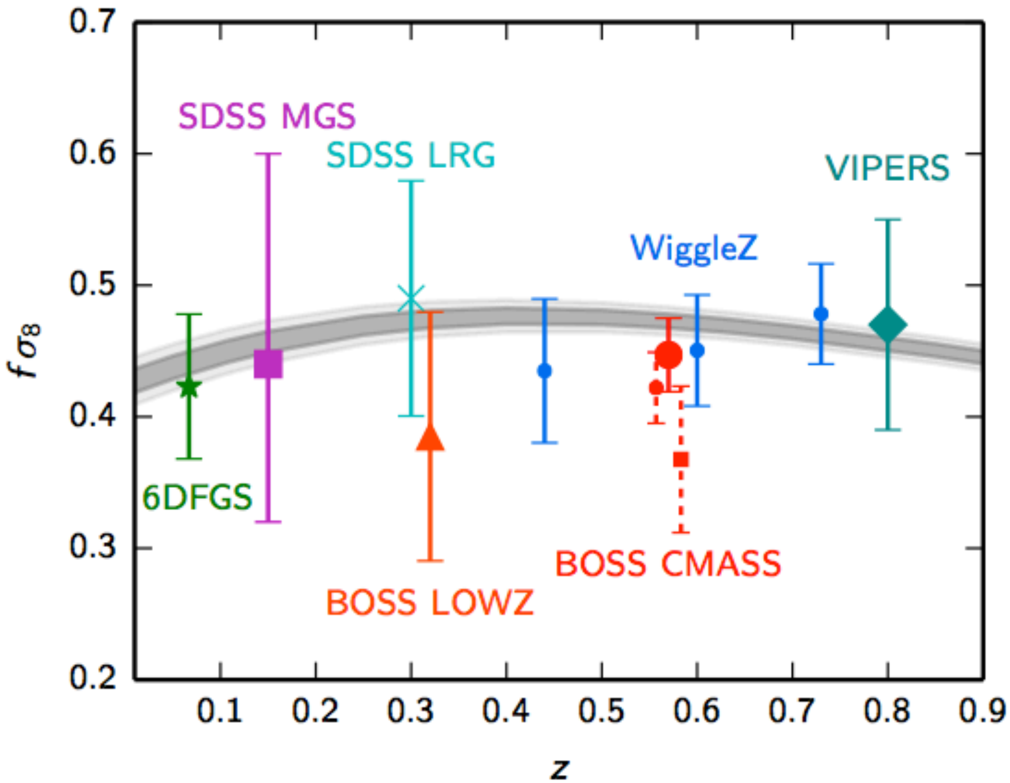
We observe galaxies in redshift space, not real space

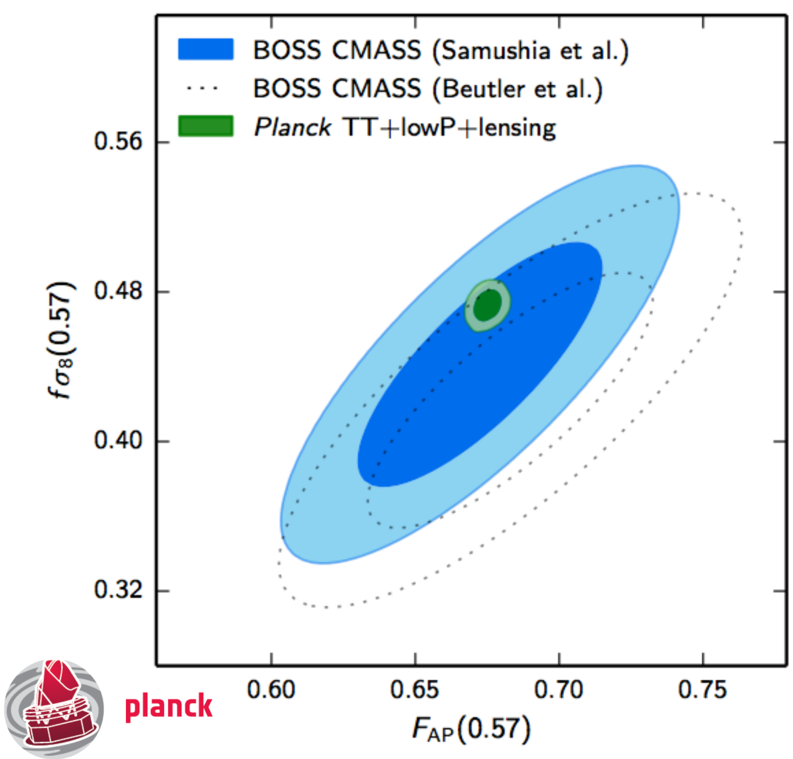
- large scales: coherent infall → squashing
- small scales random motion → elongation (`finger of god')



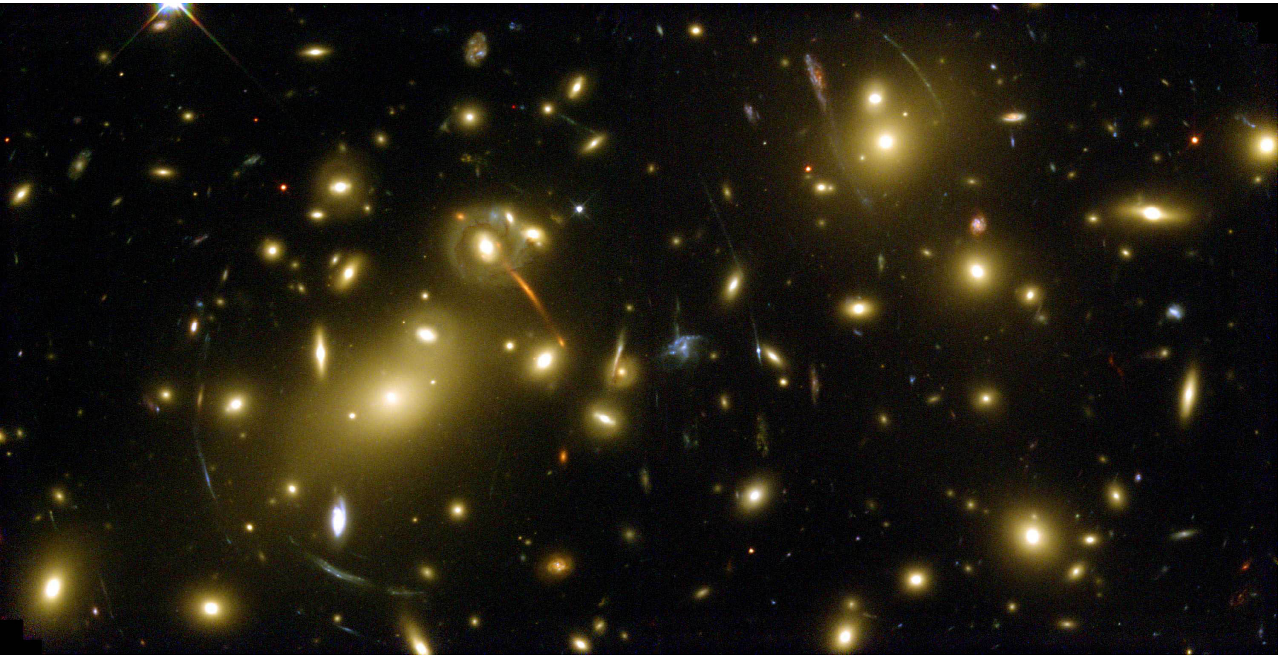
redshift space distortions

- particle conservation: velocities → growth
  → RSD measure combination $f\sigma_8$, $f = d\ln D/d\ln a$
- particle acceleration ~ grad Ψ



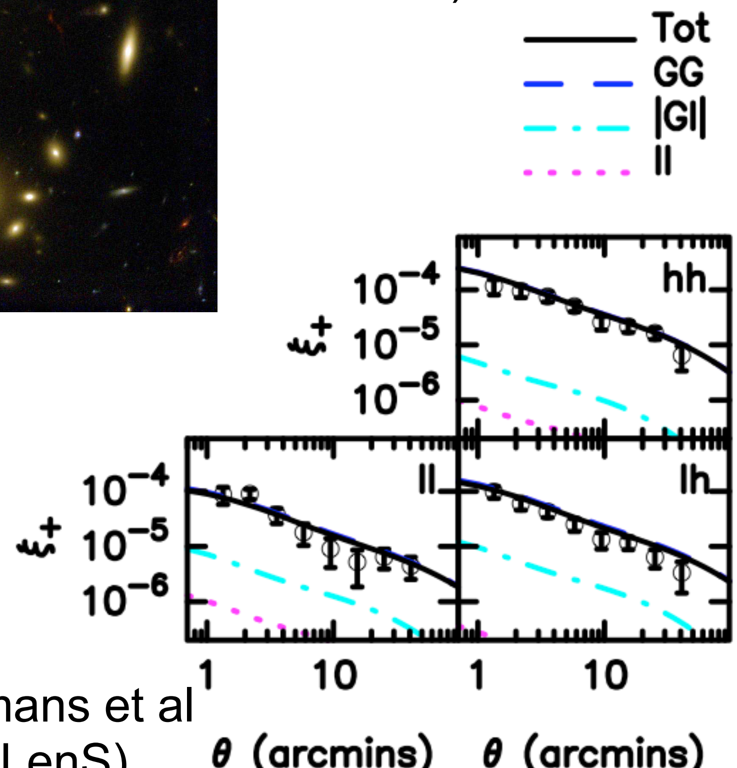


gravitational lensing



mass deflects light
this distorts galaxy
shapes a tiny bit

(lensing potential
~ $\Phi+\Psi$)

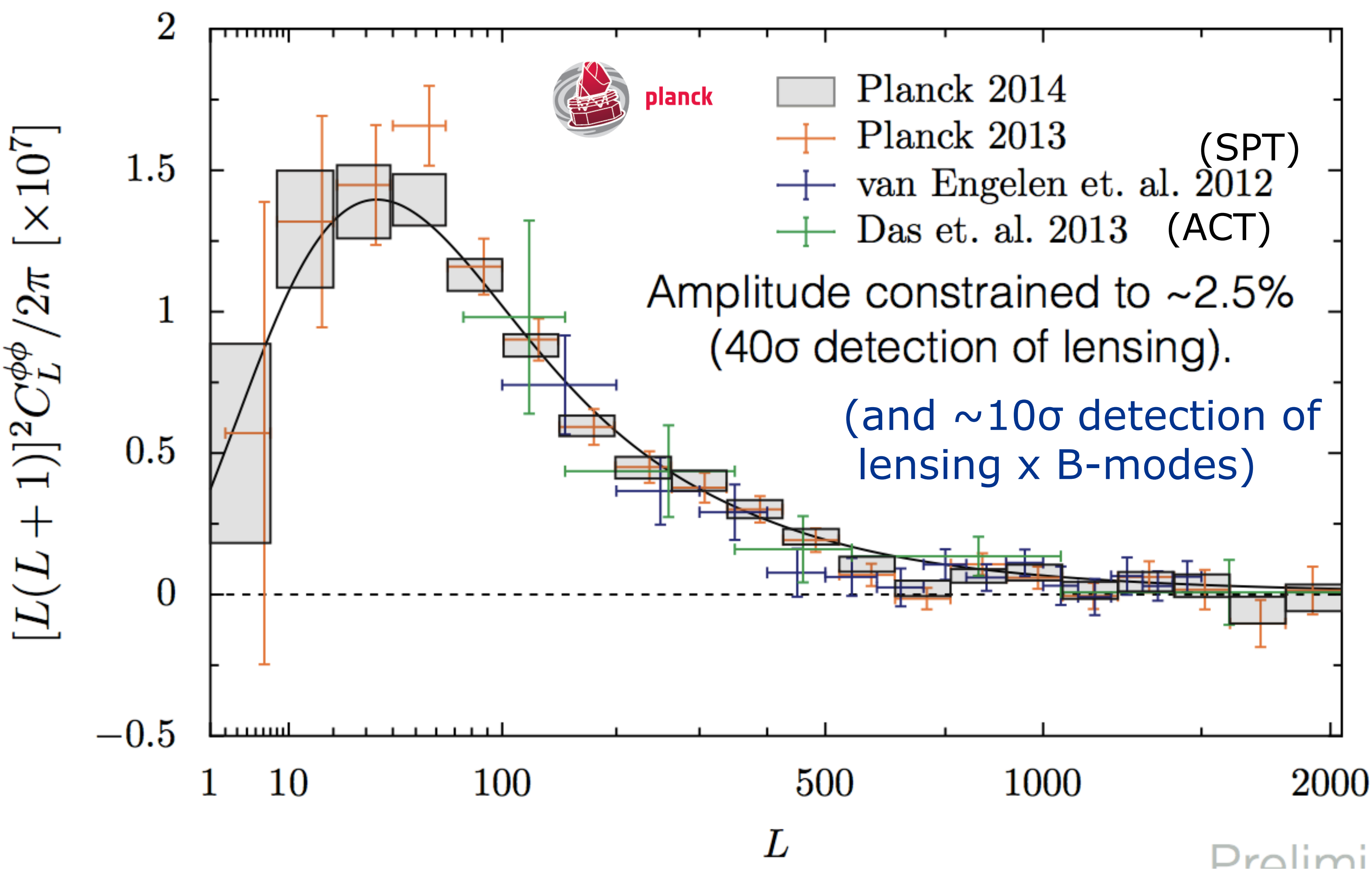


(Heymans et al
CFHTLenS)

seen as a future key probe,
but difficult:

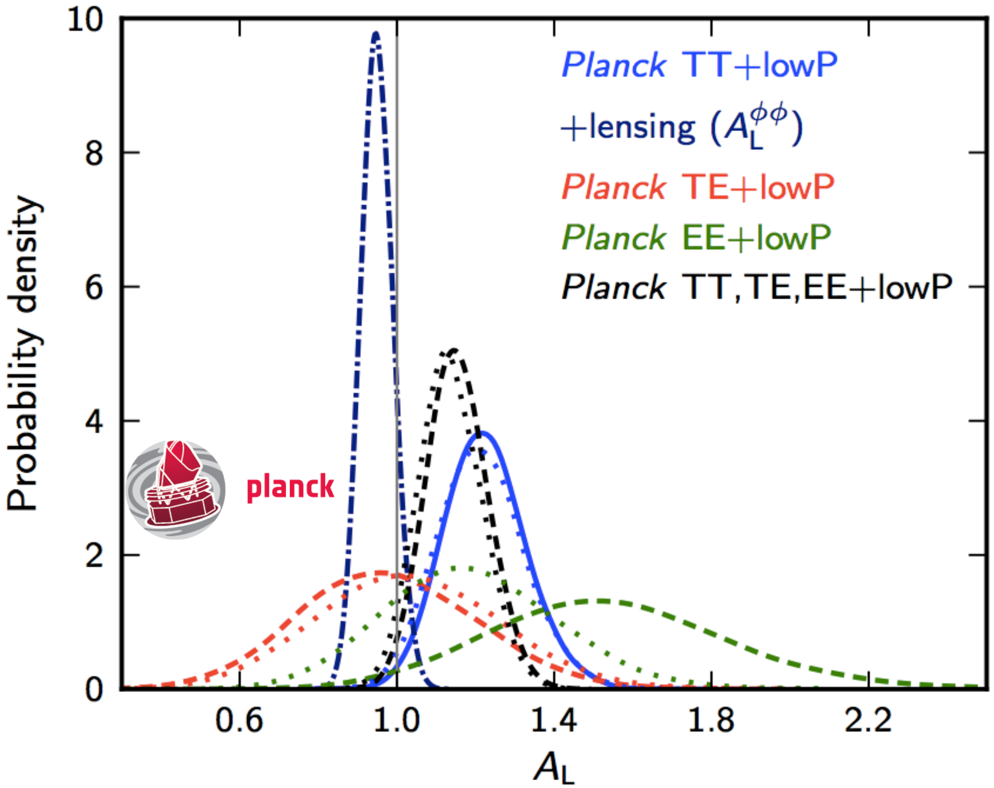
- **non-linear scales**
- **baryons**
- **intrinsic alignments**
- **photo-z**

CMB lensing

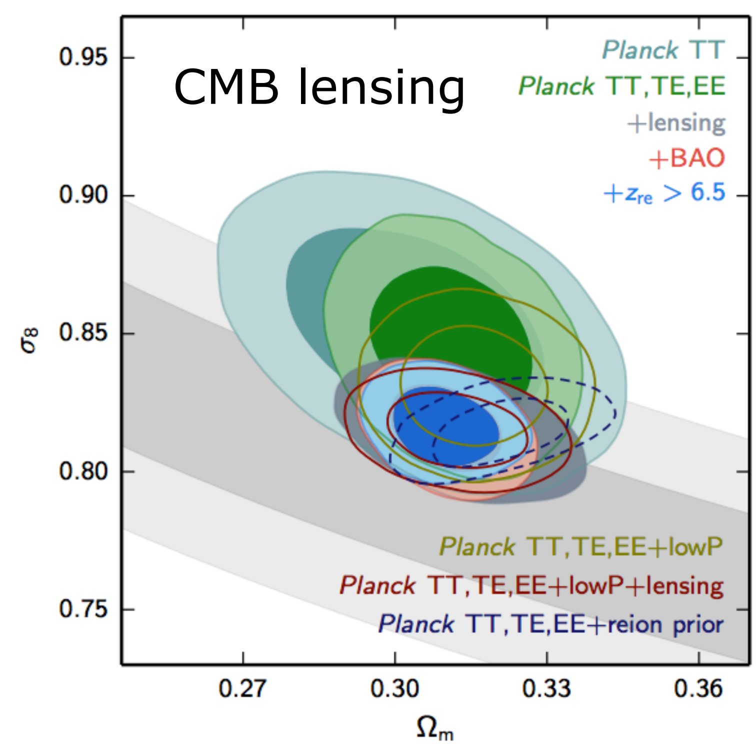


planck
Planck 2014
Planck 2013
van Engelen et. al. 2012
Das et. al. 2013
(SPT)
(ACT)
Amplitude constrained to ~2.5%
(40σ detection of lensing).
(and ~10σ detection of
lensing x B-modes)
$[L(L+1)]^2 C_L^{\phi\phi}/2\pi \ [\times 10^7]$
2
1.5
1
0.5
0
−0.5
1
10
100
500
1000
2000
L
Prelimi

comparison with lensing data



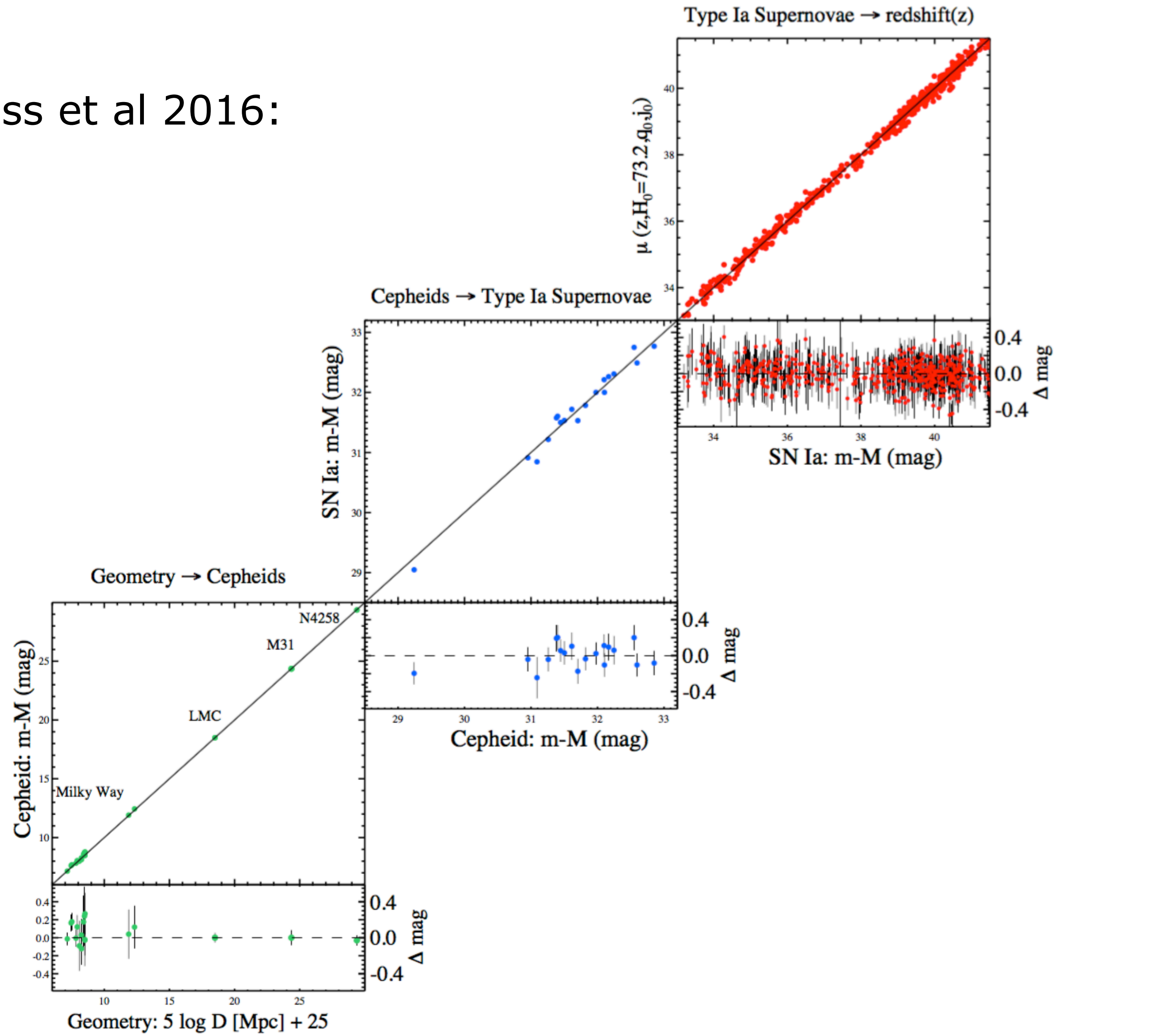
- WL still young technique
- CFHTLenS analyses marginally compatible with each other
- region ~Planck needs high H_0
- we use 'ultraconservative' cut



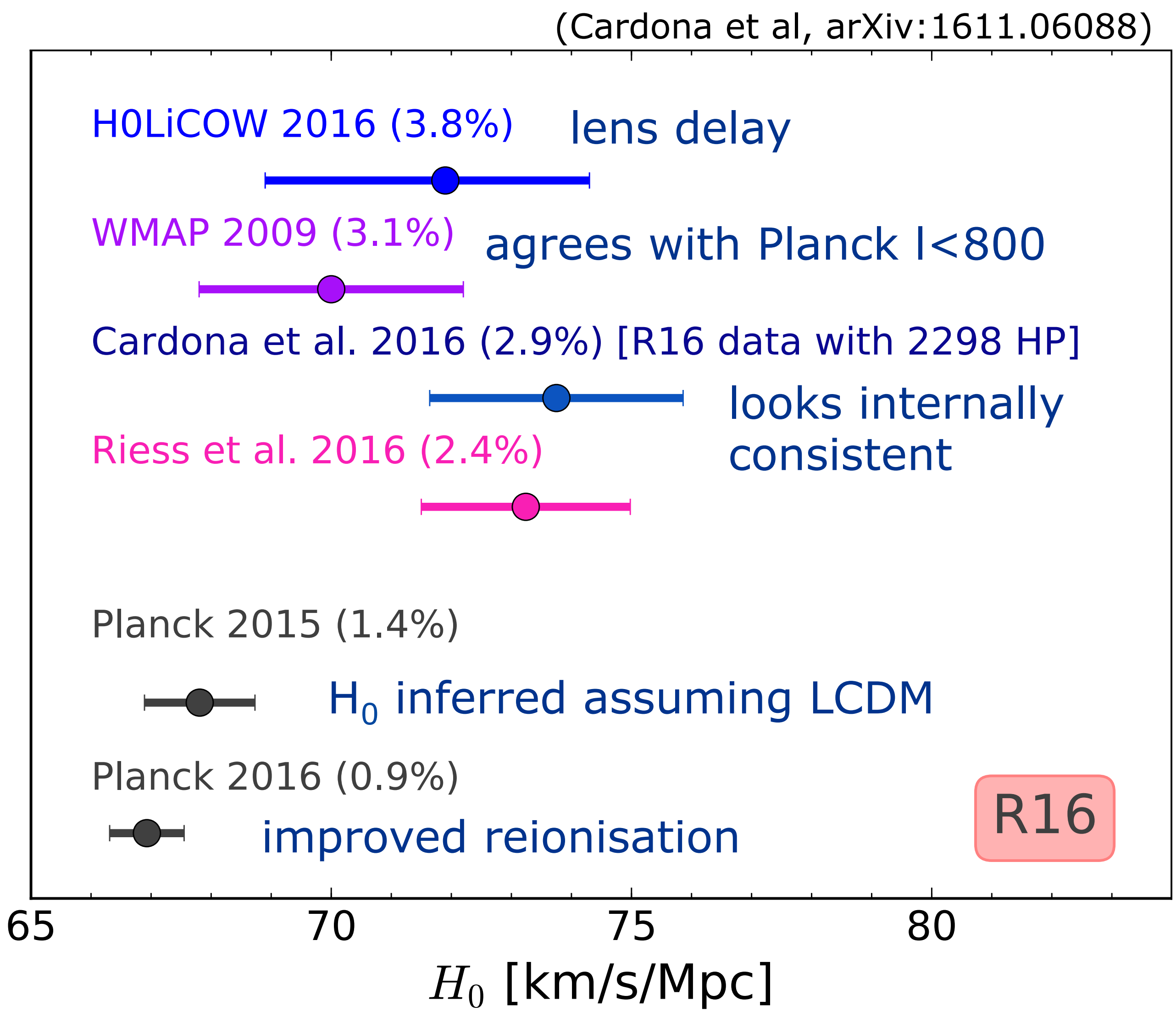
- CMB lensing now quite mature
- relatively good agreement with primary CMB
- (still a slight 'lensing excess' in power spectrum)

status of the Hubble constant H_0

Riess et al 2016:



status of the Hubble constant H_0

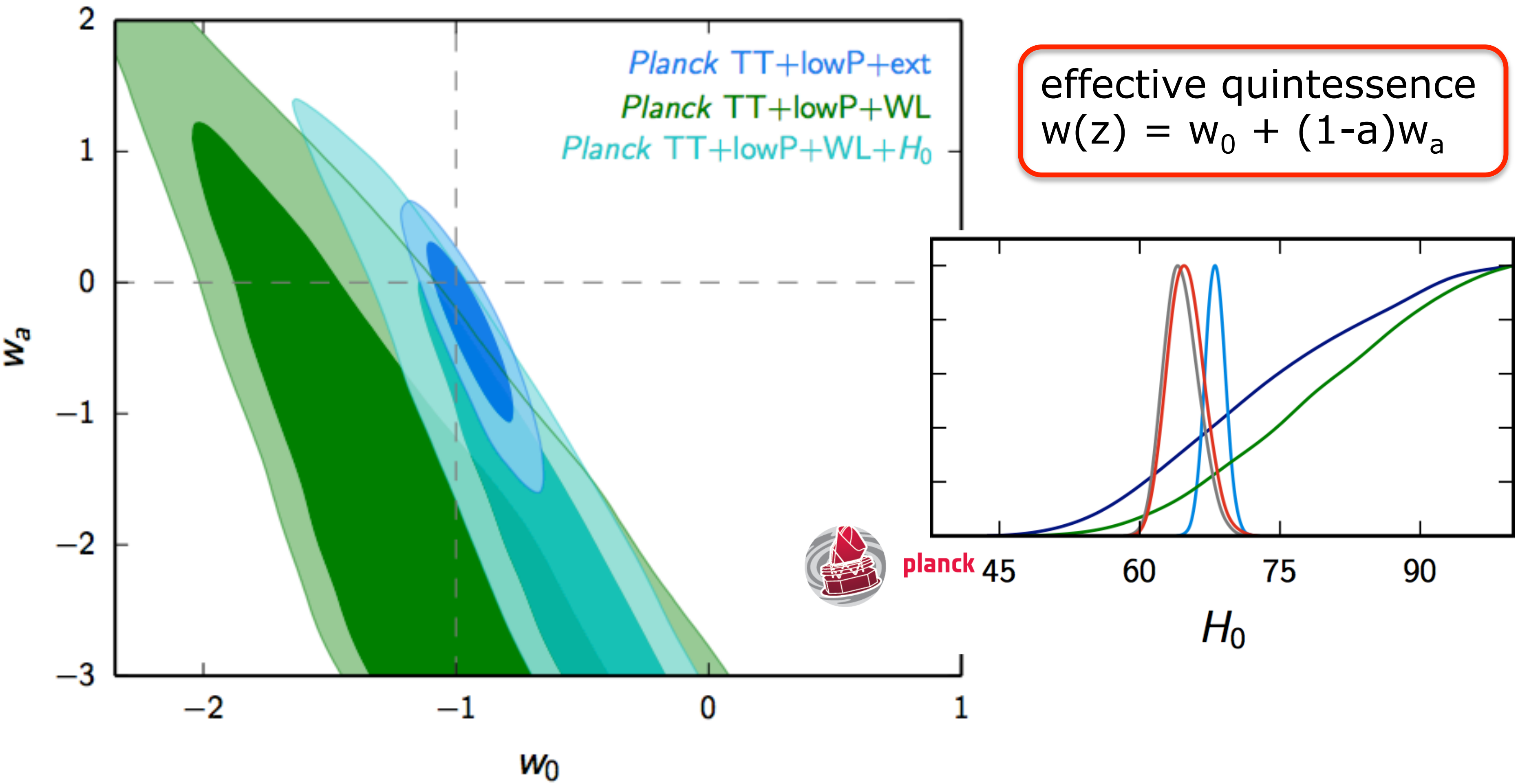


Reason for difference is unclear, but also not so easy to explain with new physics … maybe local bubble or w<-1?

(I would bet on systematics, but don't know where.)

Gaia Cepheids may shed some light in the coming years.

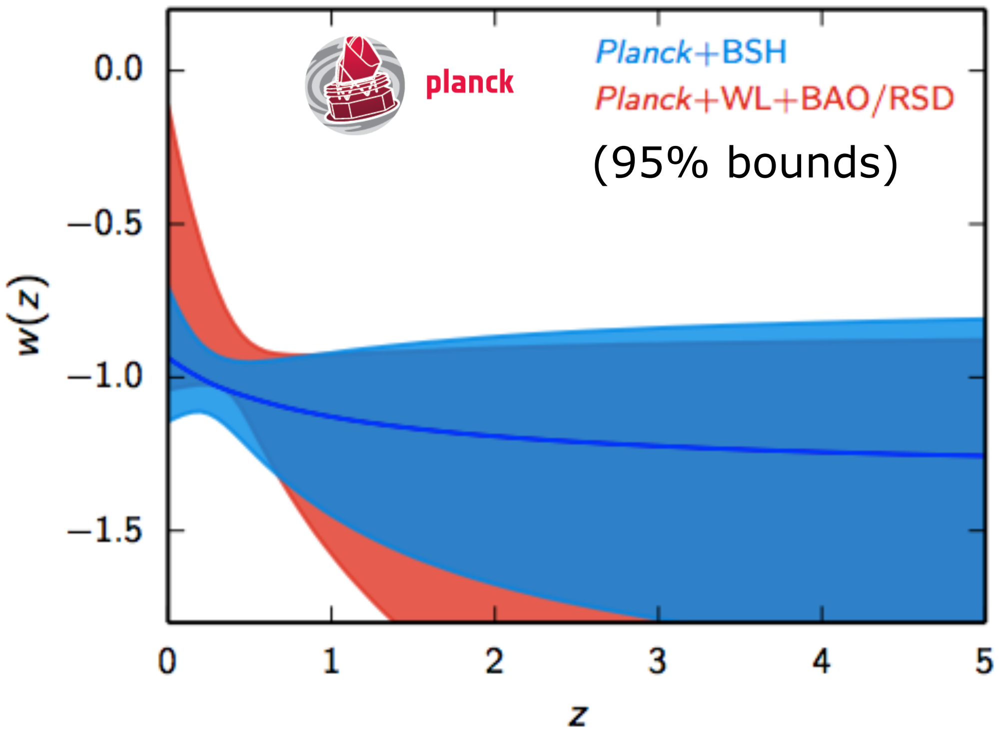
dark energy



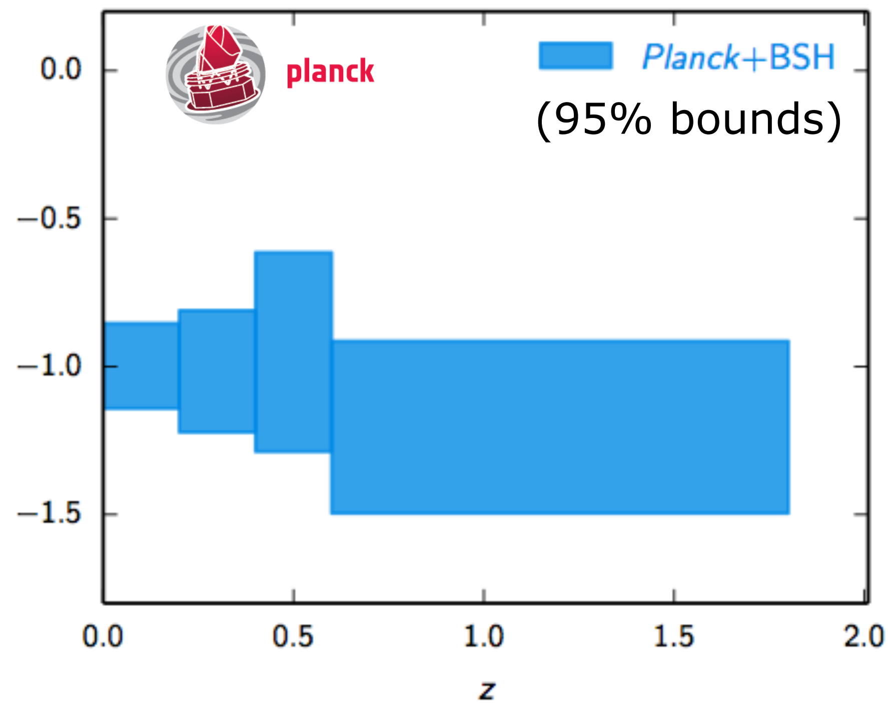
effective quintessence
$w(z) = w_0 + (1\text{-}a)w_a$

- Planck and WL prefer high H_0 and the 'phantom domain'
- no deviation from LCDM when adding BAO+JLA+H0
- **const w: w=-1.02±0.04** (TT,TE,EE+lowP+lensing+ext)

w(z) reconstruction



from ensemble of
$w_0+(1-a)w_a$ curves
(we also tried cubic in a)



PCA
(we also tried more bins)

no deviation from w=-1

deviations from GR?

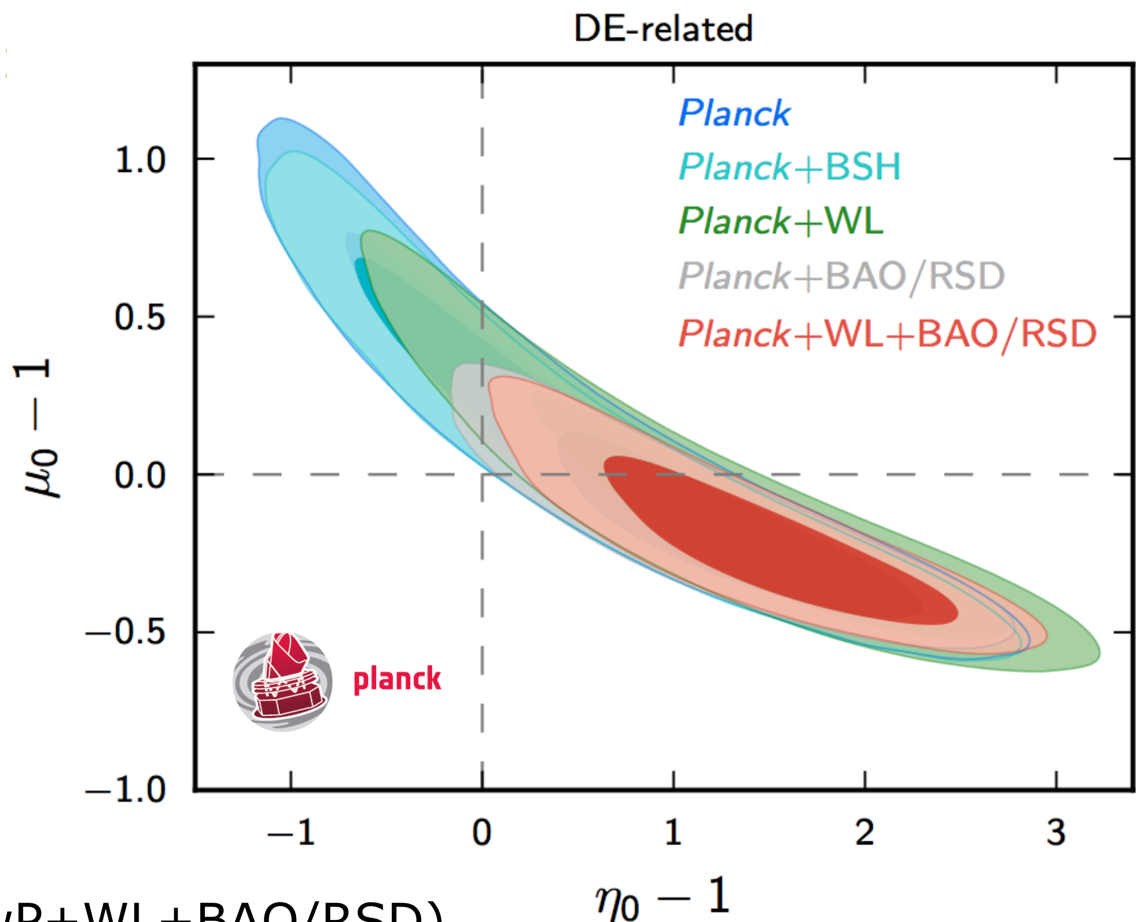
parameterisation of
late-time perturbations:

$$-k^2\Psi \equiv 4\pi G a^2 \mu(a,\boldsymbol{k})\rho\Delta$$

$$\eta(a,\boldsymbol{k}) \equiv \Phi/\Psi$$

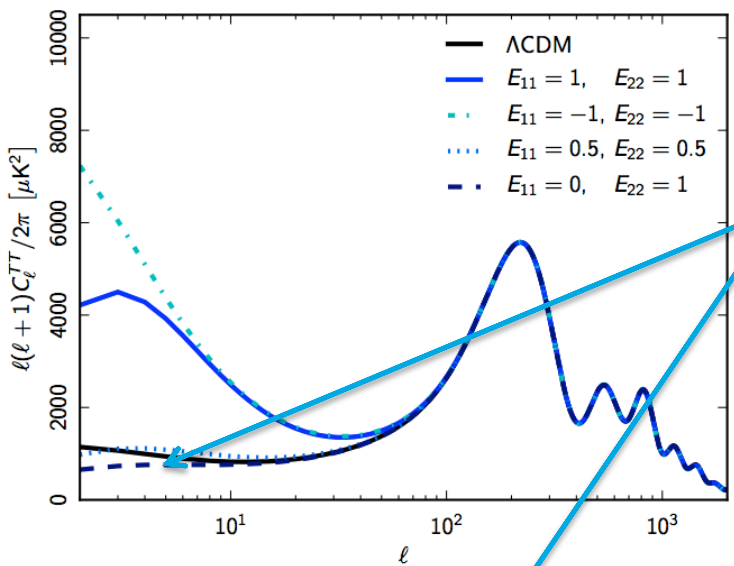
functions ~ $\Omega_{DE}(a)$
ΛCDM background

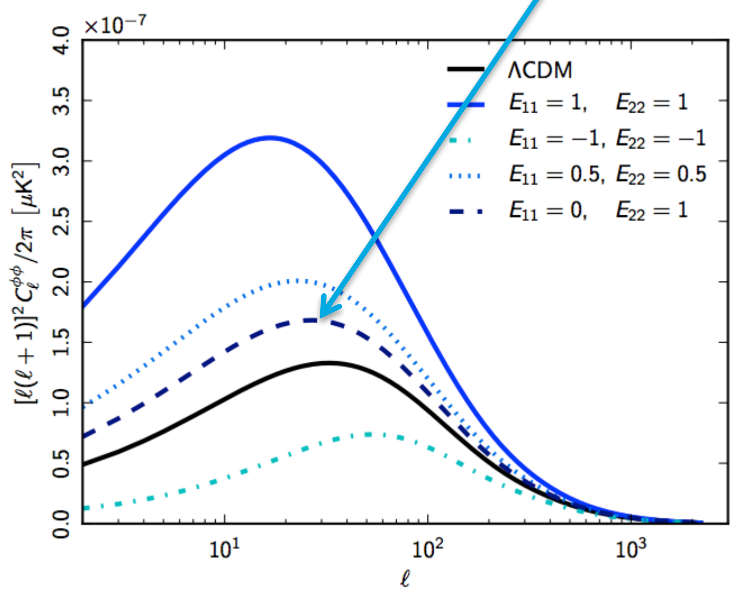
- no scale dependence detected
- deviation driven by CMB and WL



$\Delta\chi^2$ = -10.8 (Planck TT+lowP+WL+BAO/RSD)

MG impact on observables



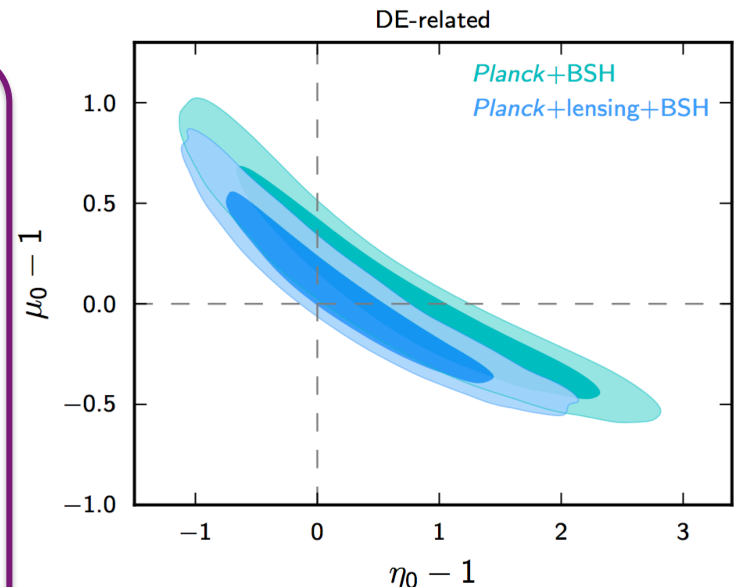


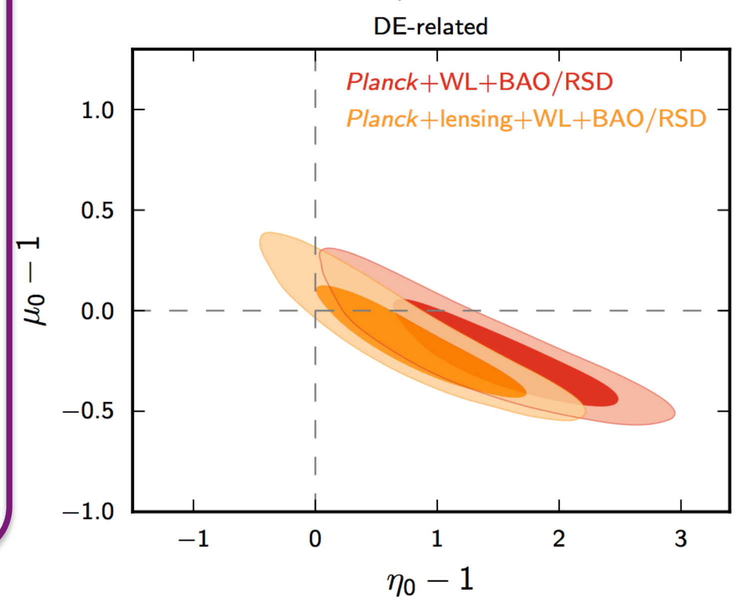
best-fit model is similar to -- model

CMB data prefers lower low-l value and higher lensing in TT

BUT NOT in the 4-point lensing → CMB lensing prefers LCDM!

→ doesn't look very significant after all?



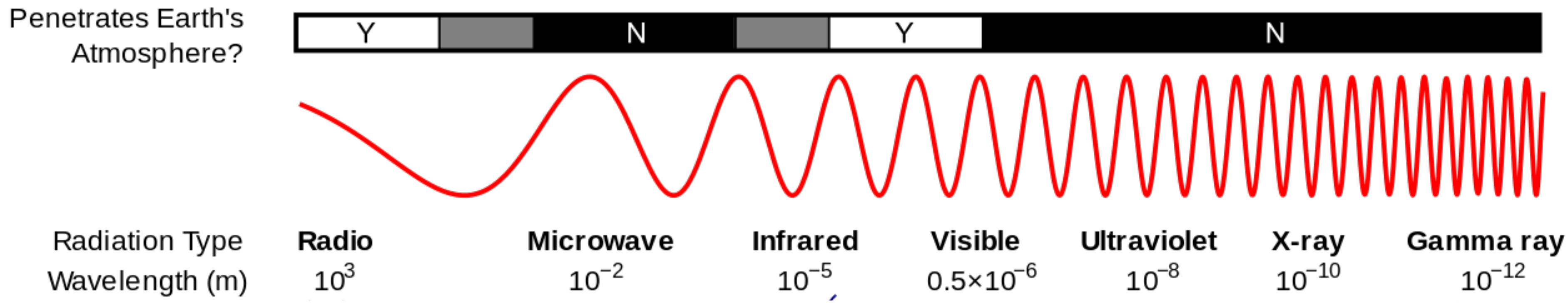


intermediate summary

- We seem to live in the maximally boring, minimal-information-content universe…
- 95% is composed of apparently two very simple components – while the other 5% are composed of an amazing collection of SM particles and fields?!

- Maybe the reason for acceleration is dynamical, but it may be too close to Λ to ever know?
- There are some hints of anomalies, but nothing very convincing yet – need more data.
- Of course we have to test all aspects of the model … so what will the future bring?

cosmological surveys



ground (SKA) | space/gr. (CMB) | space (far IR, NIR) | ground/space (optical)

- galaxy surveys BAO, P(k), RSD, mag., nG
- weak lensing
- strong lensing
- CMB T+P & spectral distortions
- CMB weak lensing
- CMB SZ clusters (+ velocity field)
- intensity mapping
- CIB
- SN-Ia (+ perturbations?)
- neutrinos
- gamma rays
- gravitational waves

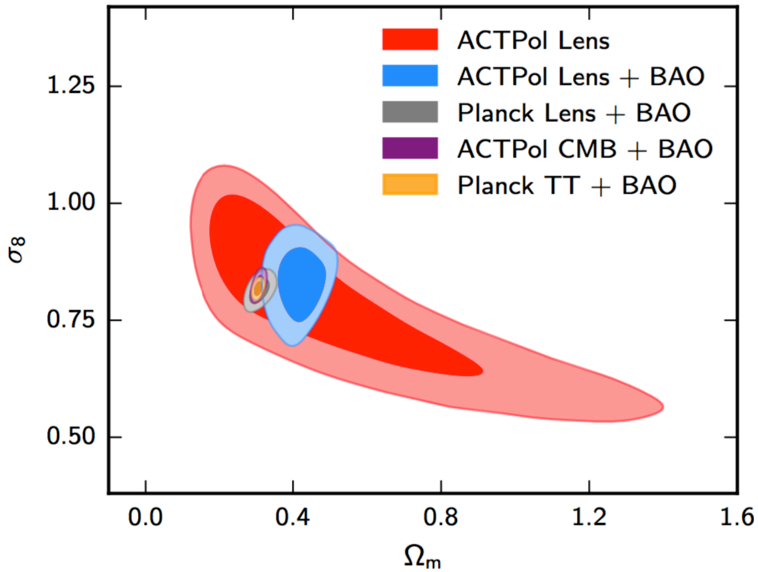
not to forget:

- photo-z vs spec-z
- cross-correlations
- relativistic effects
- multi-tracer
- other new/creative uses!

future surveys (near-term)

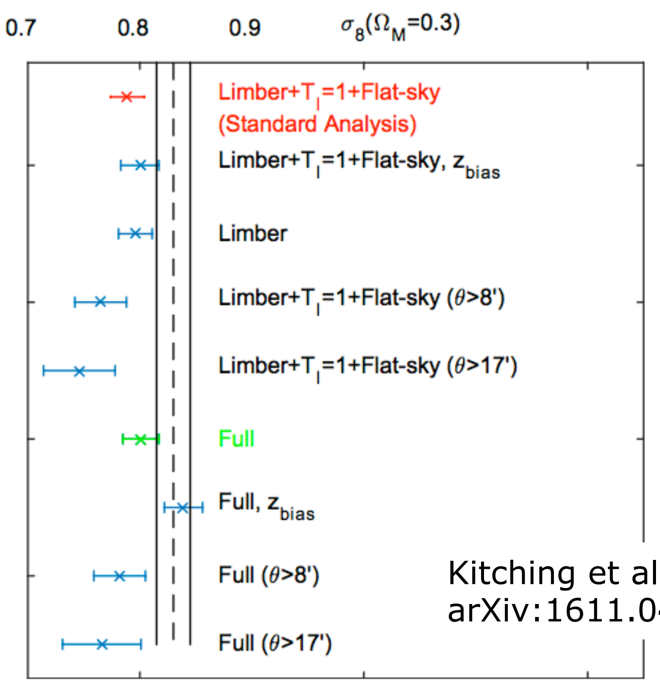
- **DES**
  - wide-field camera on 4m telescope, 2013-2018
  - 5000 deg2, optical (griz), goal 3×10^8 galaxies
  - probes: LSS/BAO, WL, SNe, clusters
  - photo-z's
- **eBOSS/SDSS-IV**
  - Sloan telescope (2.5m)
  - 1500 deg2 (10^6 ELG) + 7500 deg2 60k quasars, LRG's
  - 2014 – 2020
- **other LSS**: Pan-STARRS (2x 1.8m, 5 filters, Hawaii), VST-VISTA (ESO Paranal, VST 2.6m, VISTA 4.1m, surveys KiDS, VHS), SkyMapper (1.35m, southern sky, 6 filters), PAU/JPAS (Spain, many filters, 'near-spec' redshifts)
- **CMB**: several suborbital experiments with 1000's of detectors, for polarisation (E & B), lensing, CIB
  [latest ACTpol data in good agreement with Planck, arXiv:1610.02360]

another look at lensing

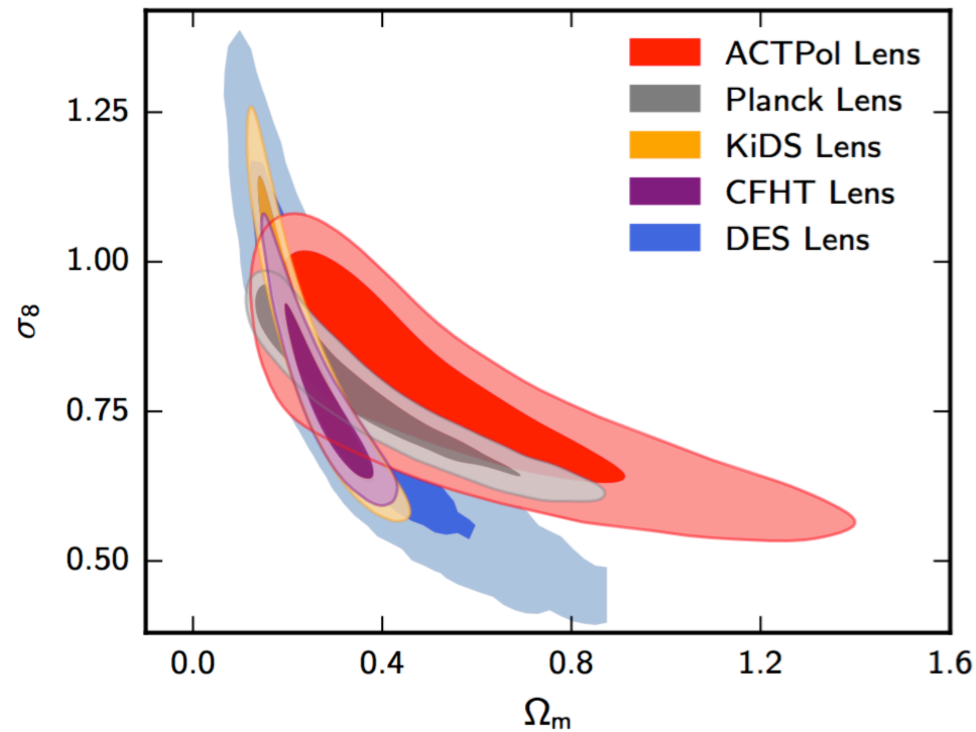


ACTpol, arXiv:1611.09753

ACTpol and Planck
are very consistent
in this parameter plane



Kitching et al
arXiv:1611.04954

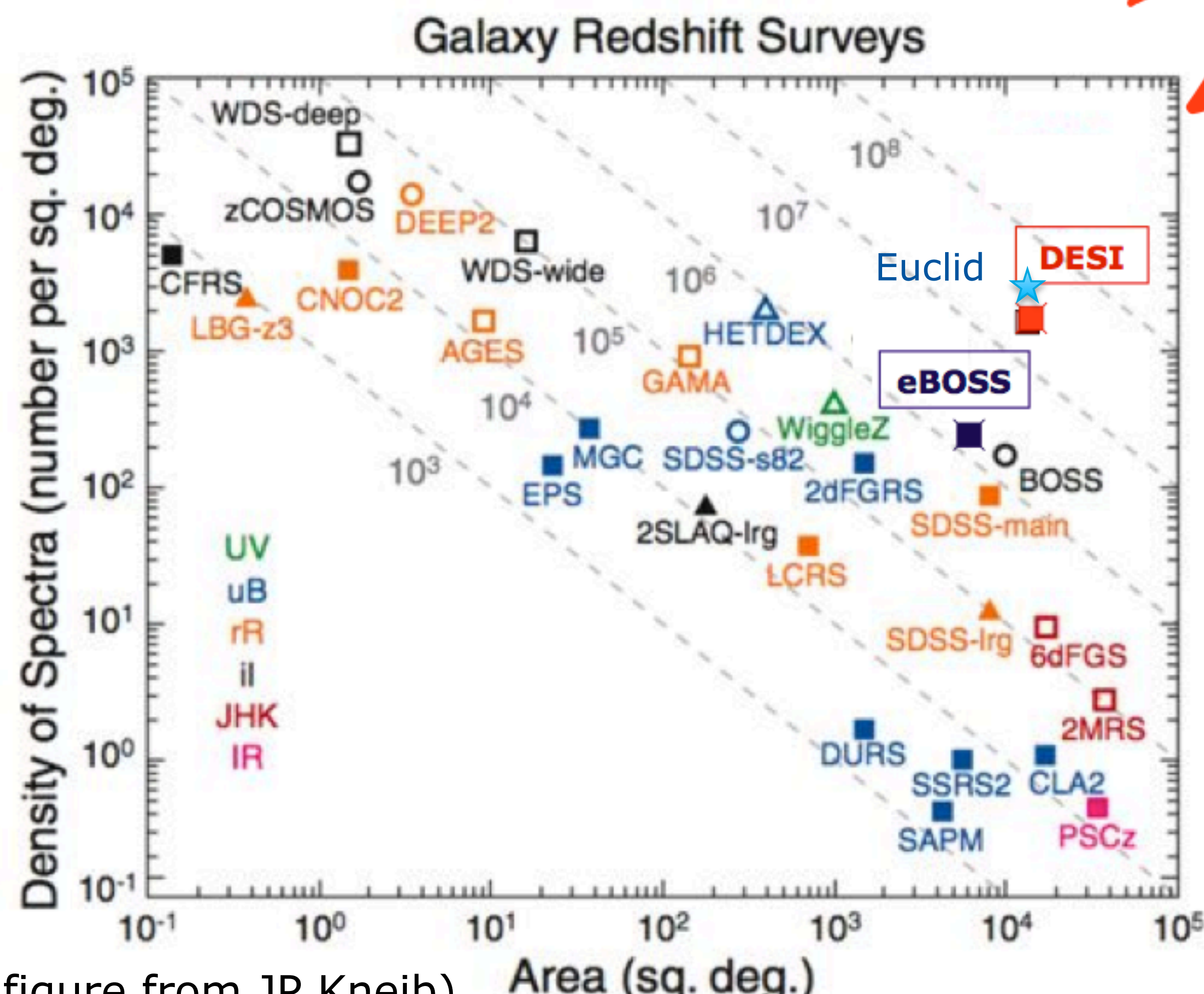


future surveys (medium term)

- **Multi-object spectrographs** on 4m class telescopes
  - 5000 to 14000 deg2, ca 4x10^7 spec gal, 5x10^5 quasars, cosmic variance limited to z~1.4
  - DESI (BigBOSS+DESpec), 2019 start
  - WEAVE (2018 start), 4MOST (2020 start?)
- **MOS** on 10 class telescopes
  - HETDEX (Hobby Eberle) 420 deg2, 800'000 gal $1.9<z<3.5$
  - PFS (Subaru) 1400 deg2 ELGs, 3x10^6 gals, $0.6<z<2.4$
- **imaging** surveys
  - LSST: 8.4m telescope, rolling survey, WL & photo-z, 2021 – 2030
- **space missions**
  - Euclid (30M spec gal, 10^9 WL gal, $0.9<z<1.8$), launch 2020
  - SPHEREx: 20cm telescope, launch 2020+ (?)
  - WFIRST: launch 202X(?)
  - CMB: (LiteBIRD, PIXIE, CORE) / GW: LISA / …
- **radio**
  - CHIME/HIRAX: intensity mapping, 2016+
  - SKA1 / SKA2: lots, 2020+
- and many more that I forgot… (adv LIGO/VIRGO, icecube, etc, …)

Galaxy redshift survey “history”

1986	CfA	3500
1996	LCRS	23000



(figure from JP Kneib)

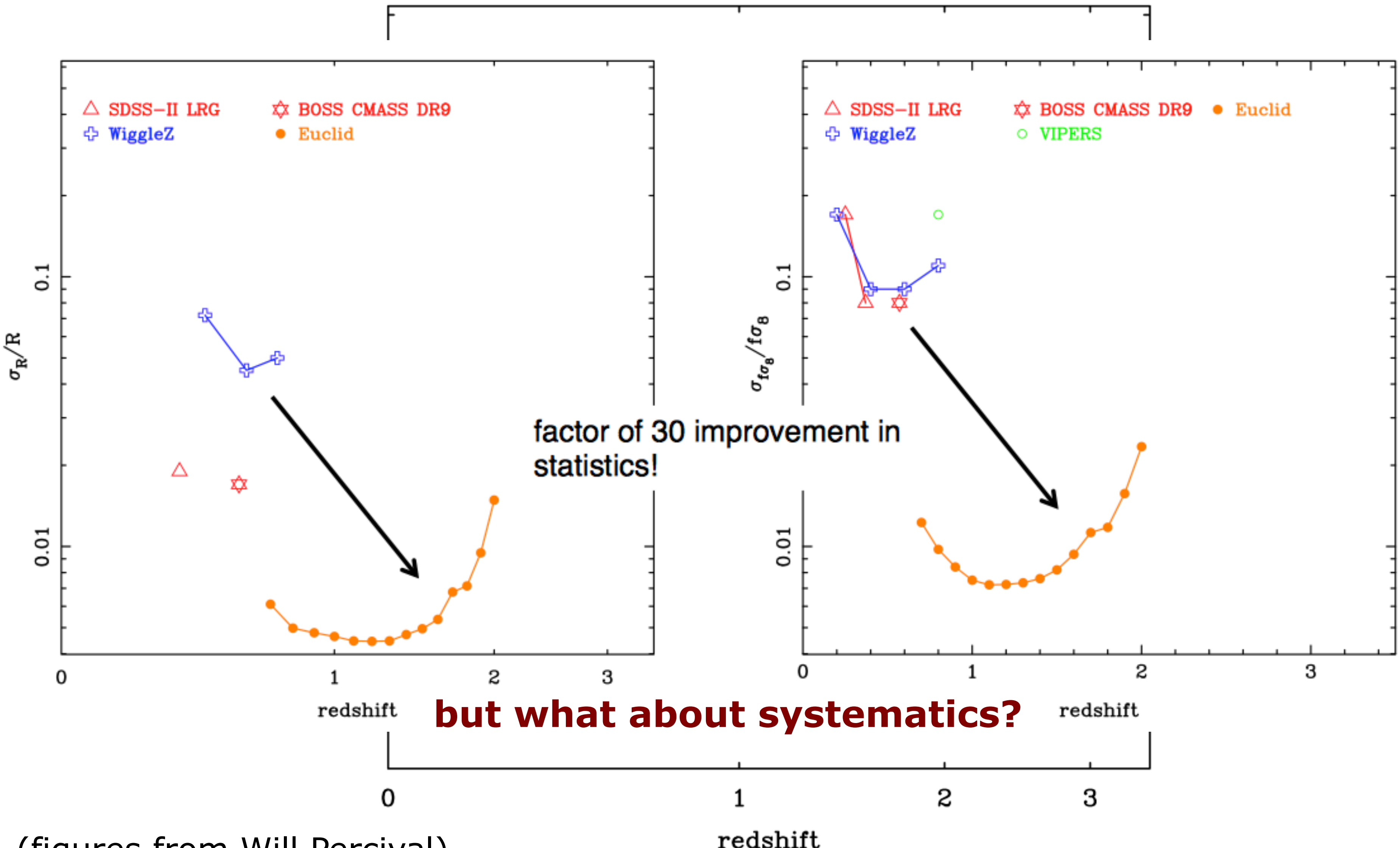
Fractional error in the amplitude of the fluctuation spectrum

1970	x100
1990	x2
1995	±0.4
1998	±0.2
1999	±0.1
2002	±0.05
2003	±0.03
2009	±0.01
2012	±0.002

Driven by the development of instrumentation

(slide from Will Percival)

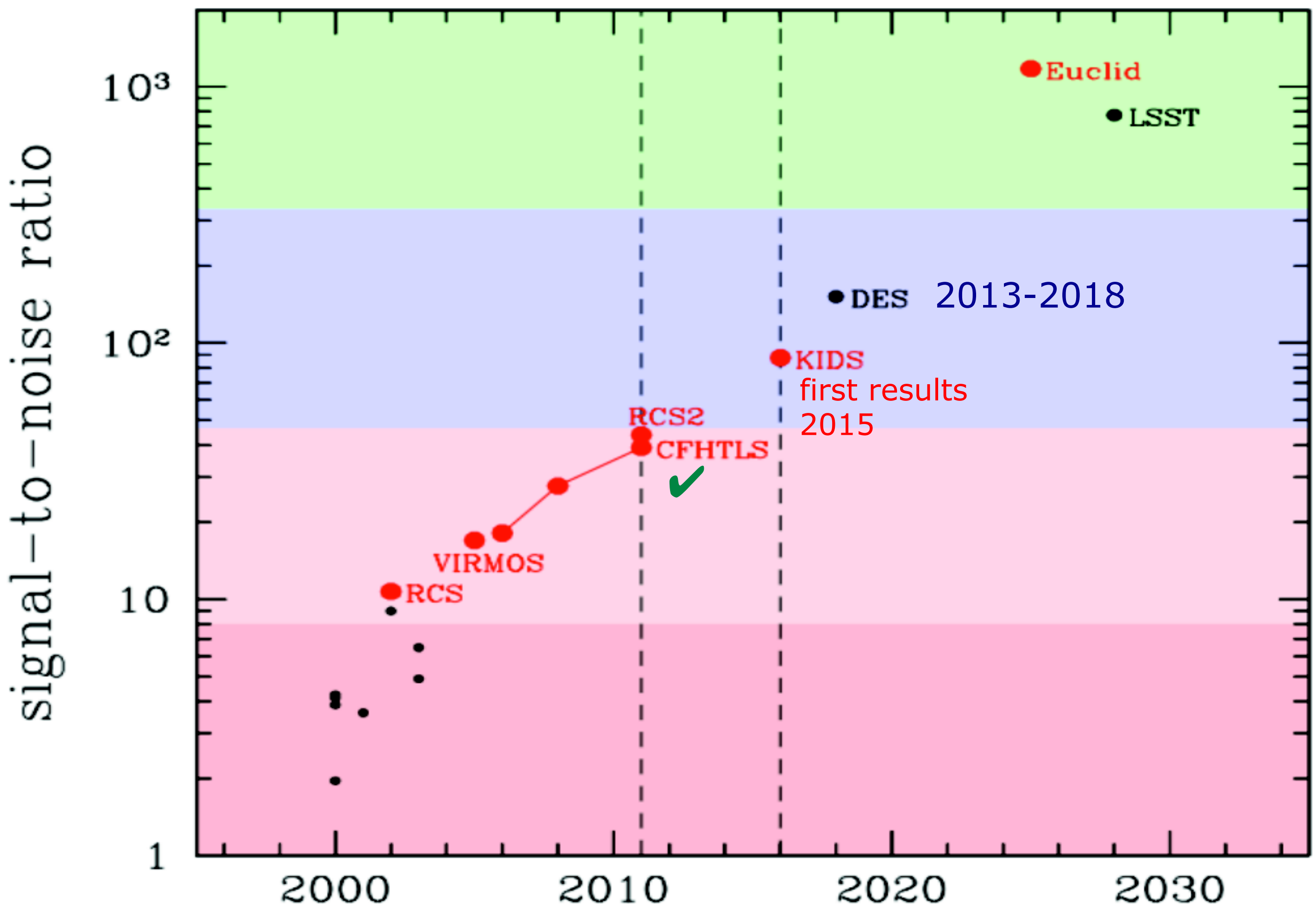
BAO's from future surveys



(figures from Will Percival)

using the code of Seo & Eisenstein 2007, arXiv:0701079

weak lensing surveys (wide-field cosmic shear)

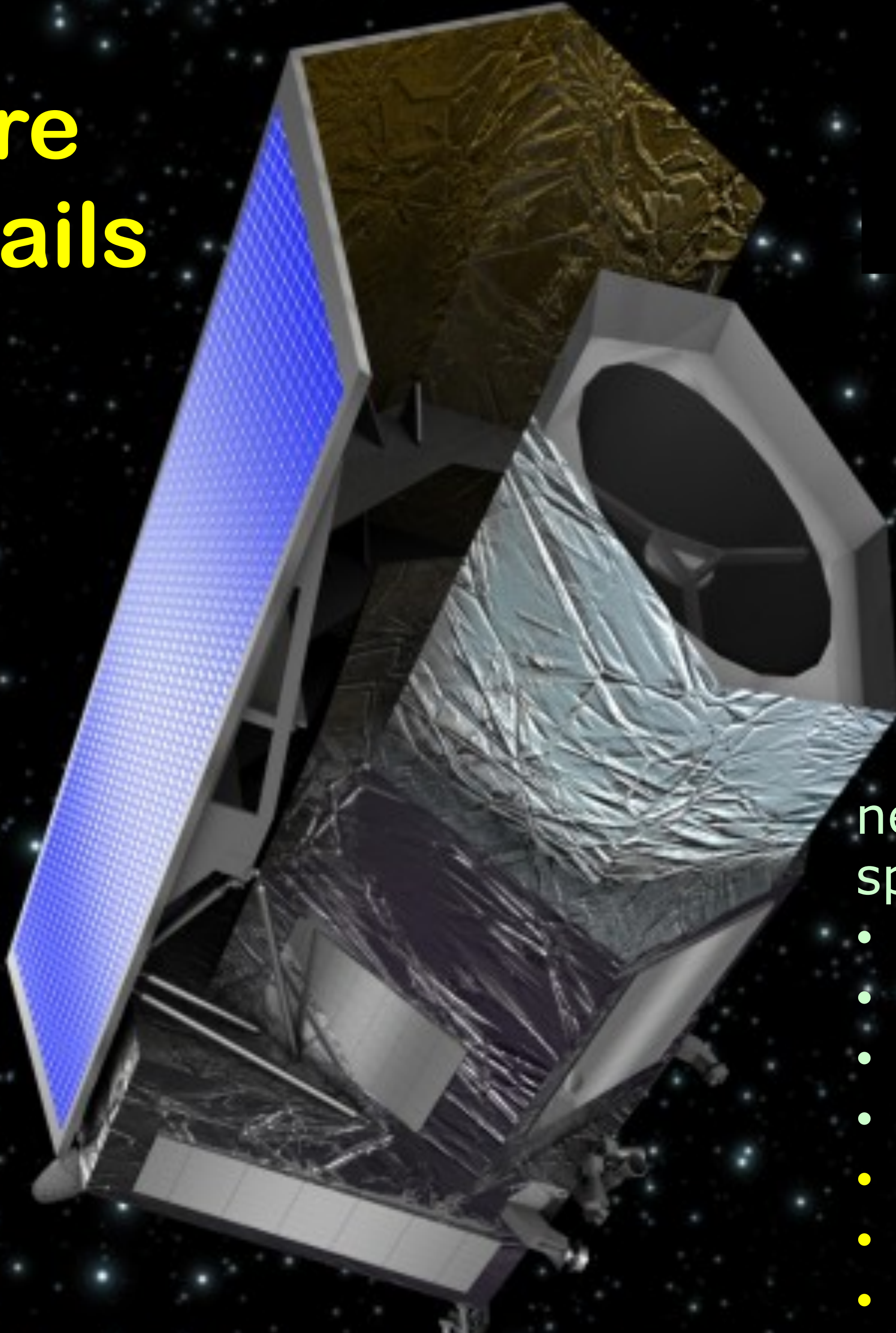


CFHTLS: www.cfhtlens.org, KiDS: kids.strw.leidenuniv.nl, DES: www.darkenergysurvey.org

more details on:

Euclid

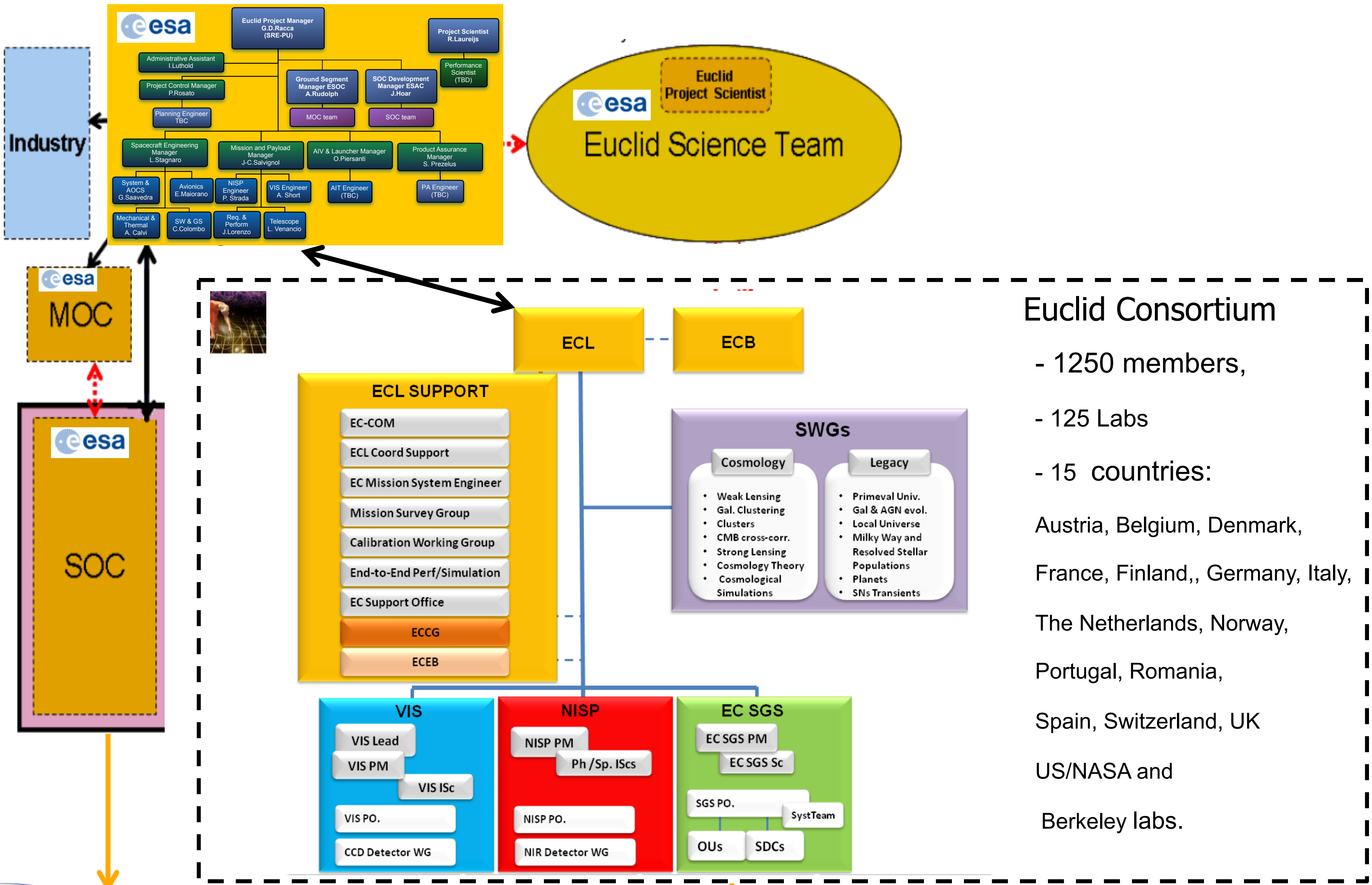
ca 2020



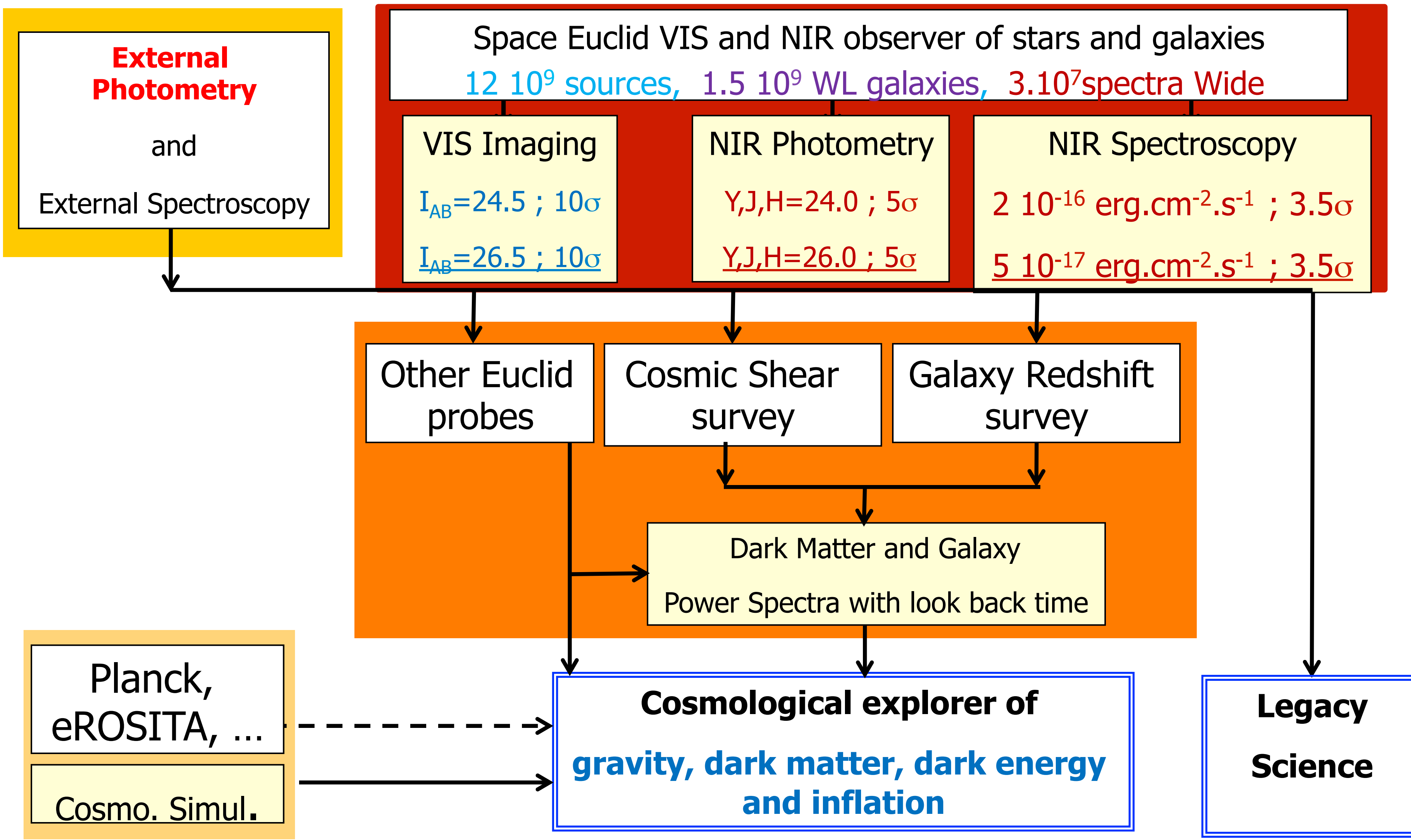
near-infrared and optical space telescope

- 15’000 square degrees
- 1 million+ images
- data rate ~1Tb/day
- ~100 Pb data (inc grnd)
- 12 billion sources
- 1.5 billion shapes
- 30 million redshifts

Euclid Collaboration/Consortium



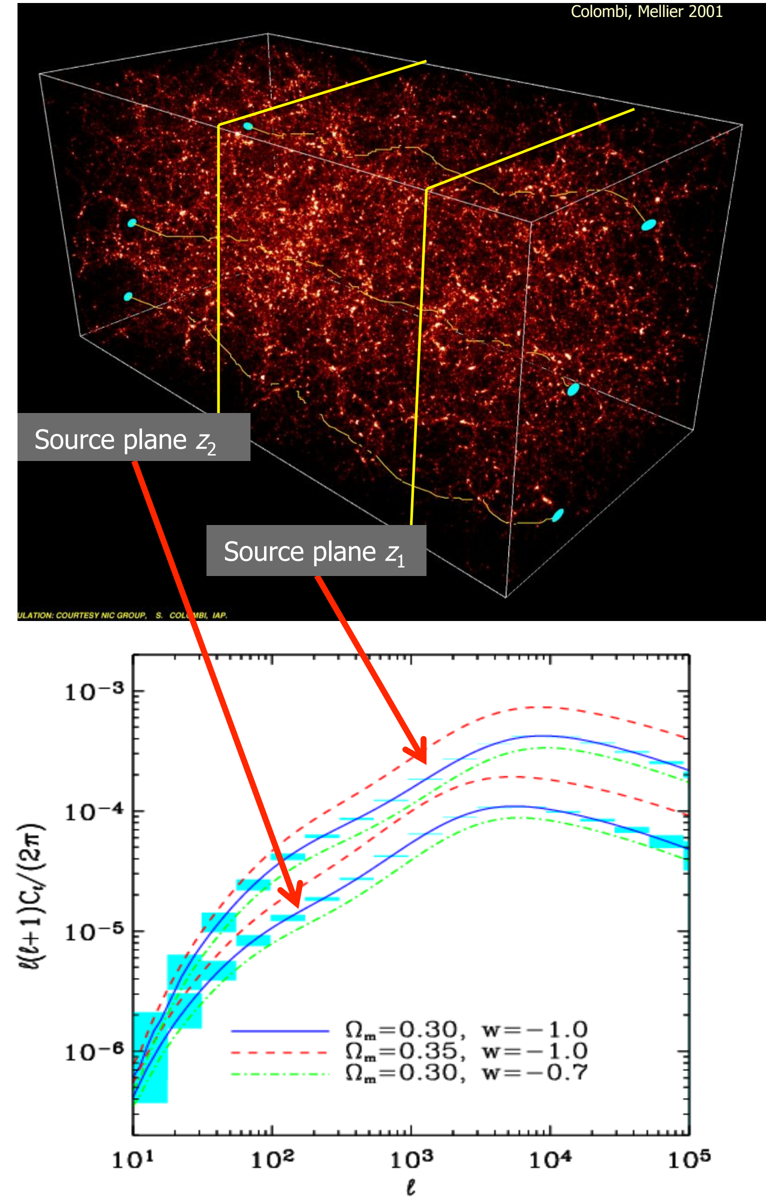
Euclid Survey Machine: 15,000 deg^2 + 40 deg^2 deep



primary probe 1: Euclid Weak Lensing Survey

Cosmic shear over 0<z<2

$$\kappa_{eff} = \frac{3H_0^2\Omega_0}{2c^2}\int_0^{\omega}\frac{f_K(\omega-\omega')\,f_K(\omega')}{f_K(\omega)}\frac{\delta\left[f_K(\omega')\boldsymbol{\theta};\omega'\right]}{a(\omega')}d\omega'$$



- Probes distribution of matter (Dark +Luminous): expansion history, lensing potential φ+ψ.

→ Shapes+distance of galaxies: shear amplitude, and bin the Universe into slices.

→ "Photometric redshifts" sufficient for distances: optical+NIR data.

Euclid:

WL with 1.5 billion galaxies

over 15,000 $\deg^2$

VIS performance:imaging

A 4kx4k view of the Euclid sky

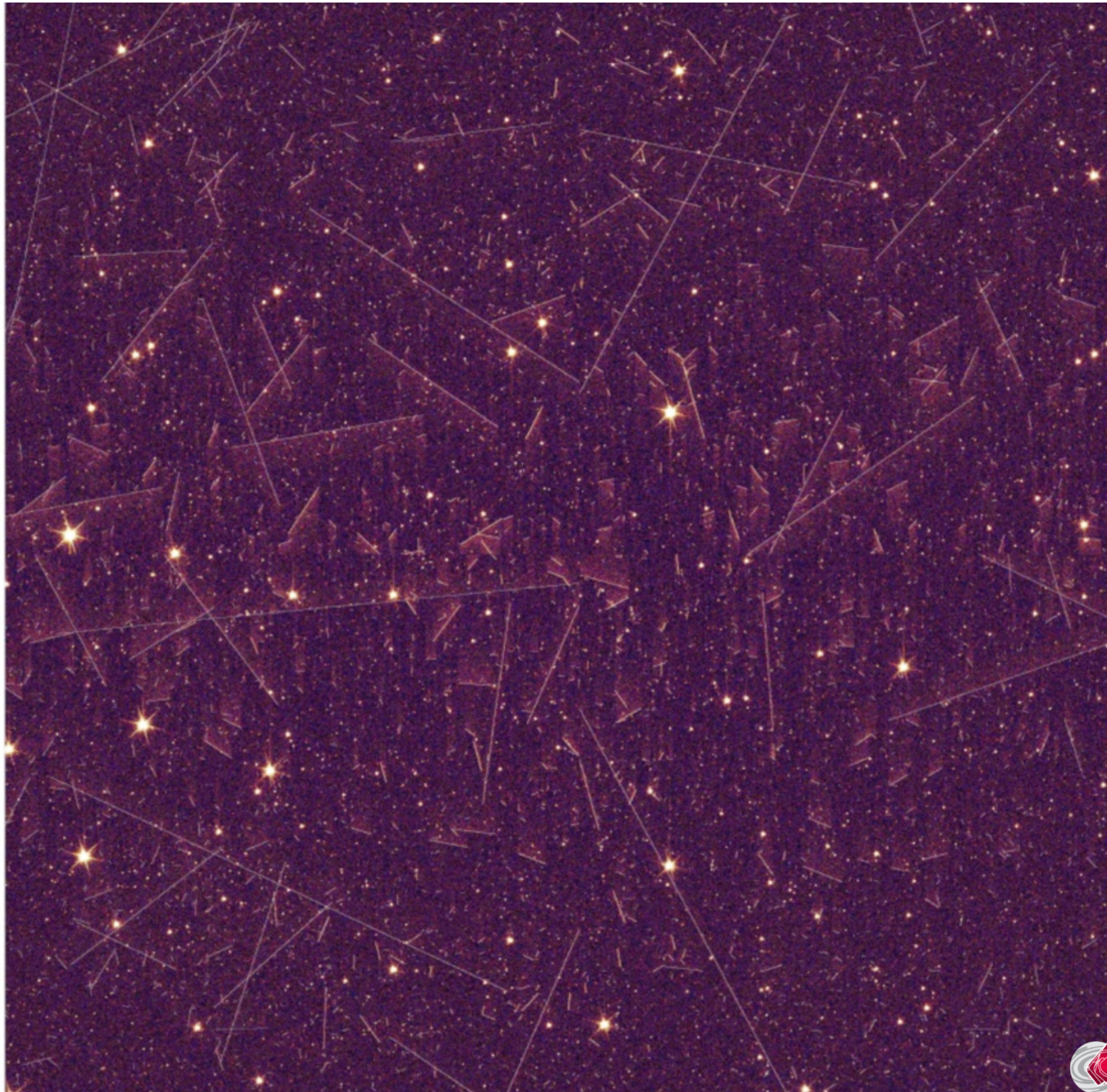
VIS image: cuts made to highlight artefacts

goal: measure shapes to high accuracy

GREATxx challenges

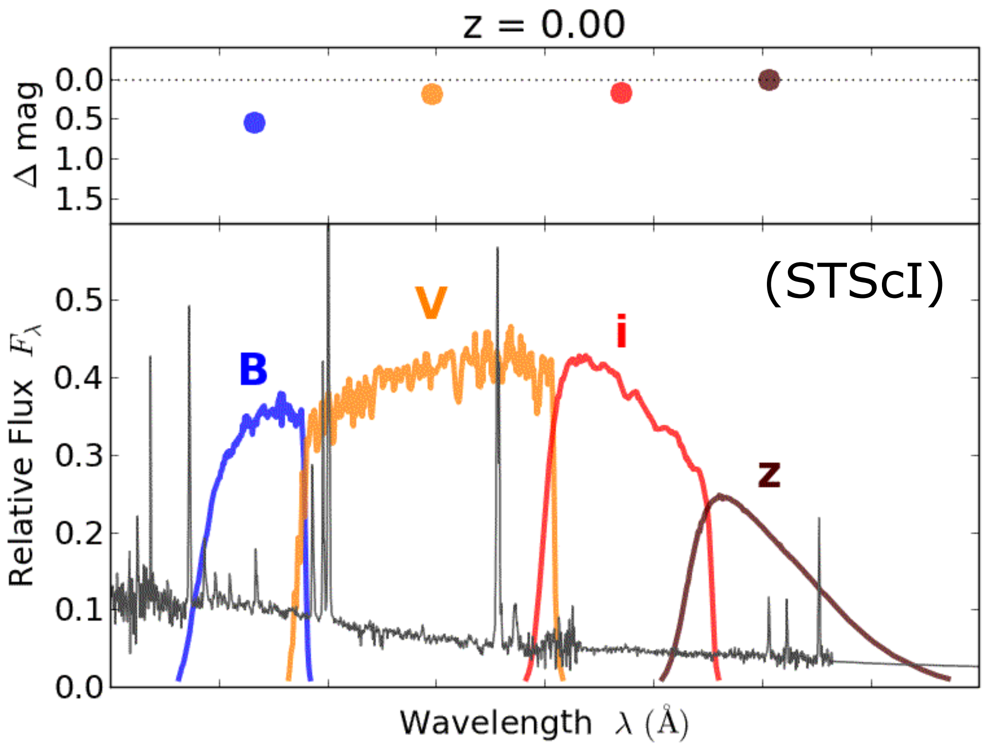
Courtesy Mark Cropper,

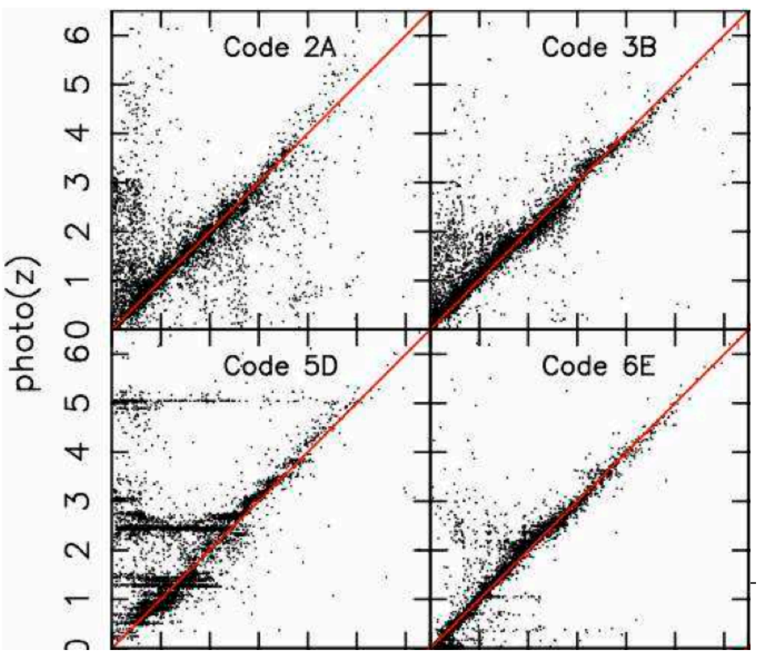
Sami M. Niemi



photometric redshifts

- For majority of objects we only have 'colours', no spectra
- But we need to have 'rough' redshift → photo-z
- Nice statistical challenge





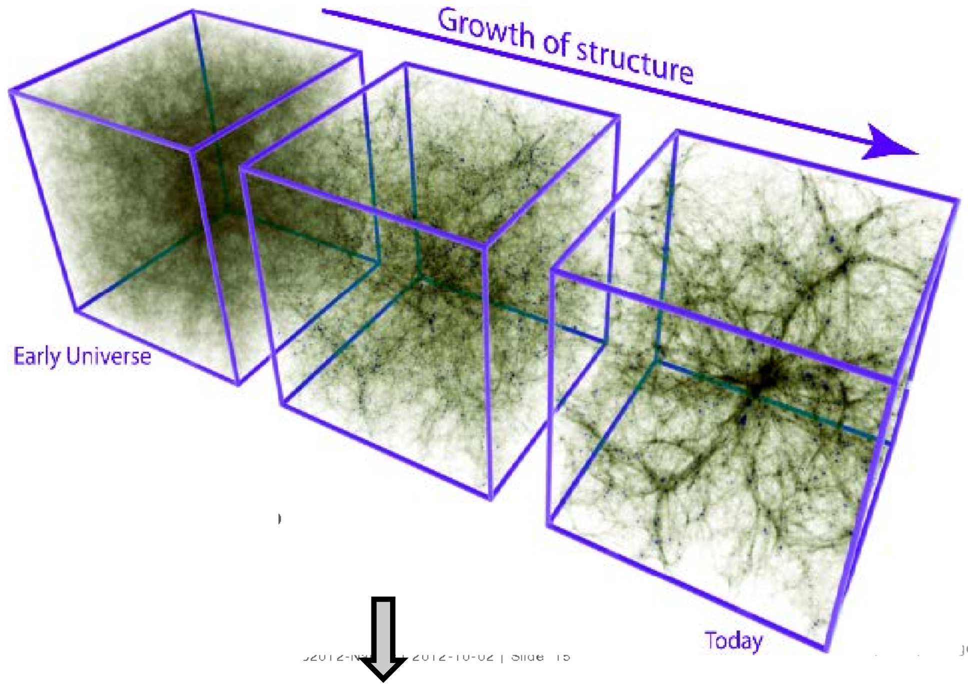
some approaches:

- template fitting
- neural networks / other ML
- linear and other regression
- Bayesian parameterized models
- meta methods (combine several)

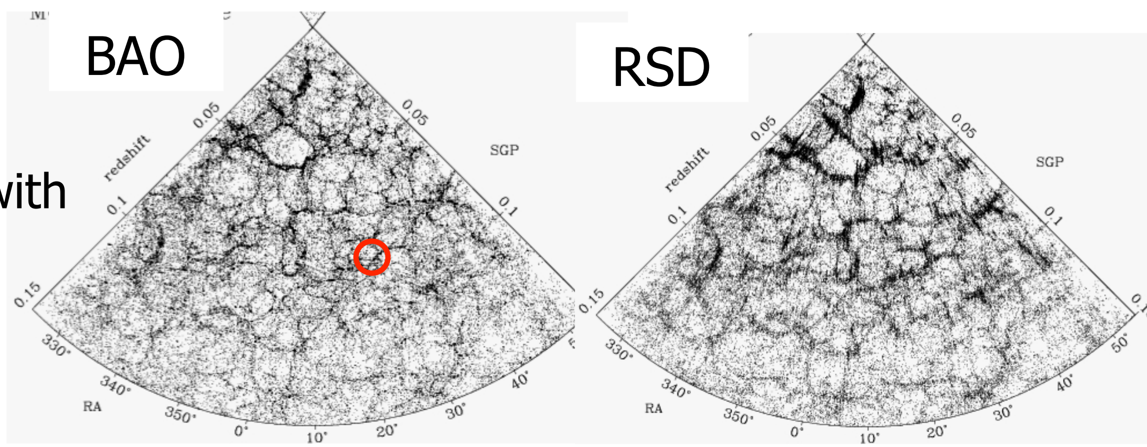
primary probe 2: Galaxy Clustering: BAO + RSD

3-D position measurements of galaxies over $0.7<z<1.8$

- Probes expansion rate of the Universe (BAO) and clustering history of galaxies induced by gravity (RSD); ψ, $H(z)$.



- Need high precision 3-D distribution of galaxies with spectroscopic redshifts.



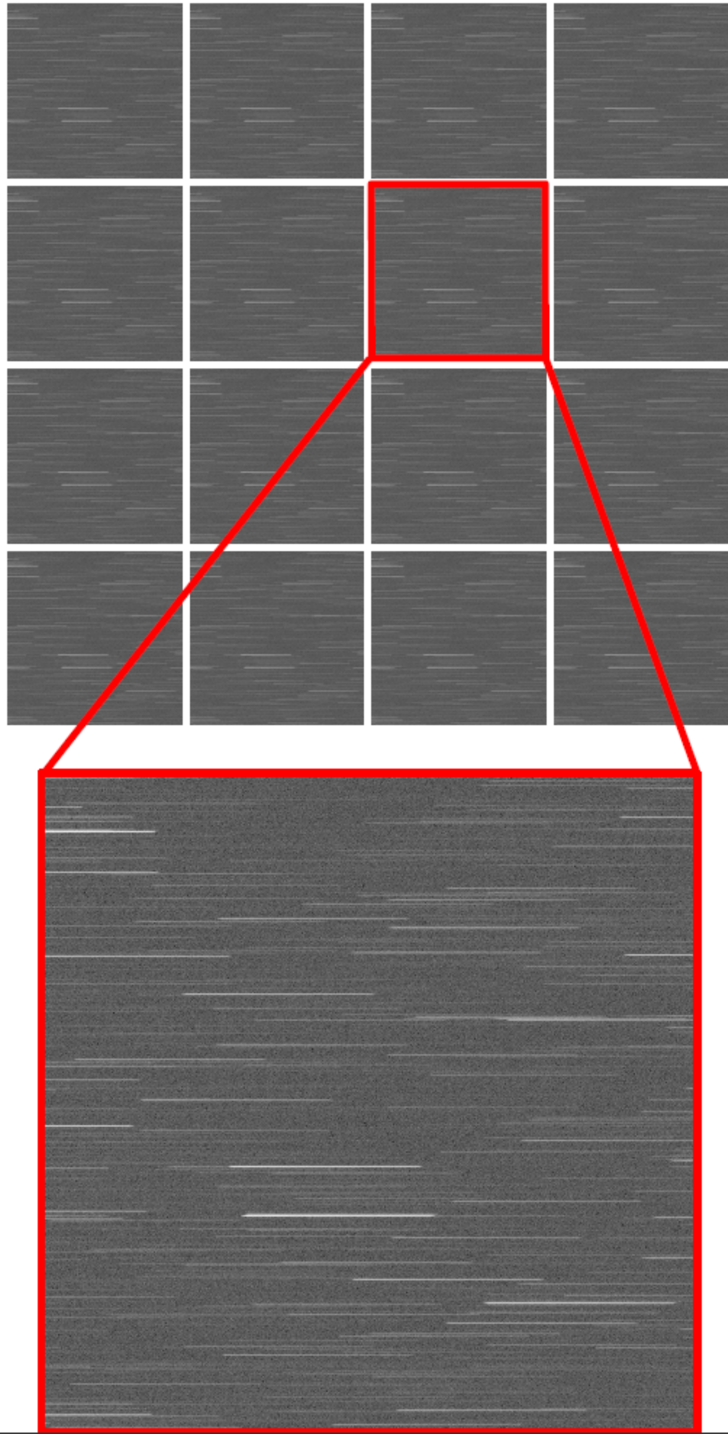
Euclid:

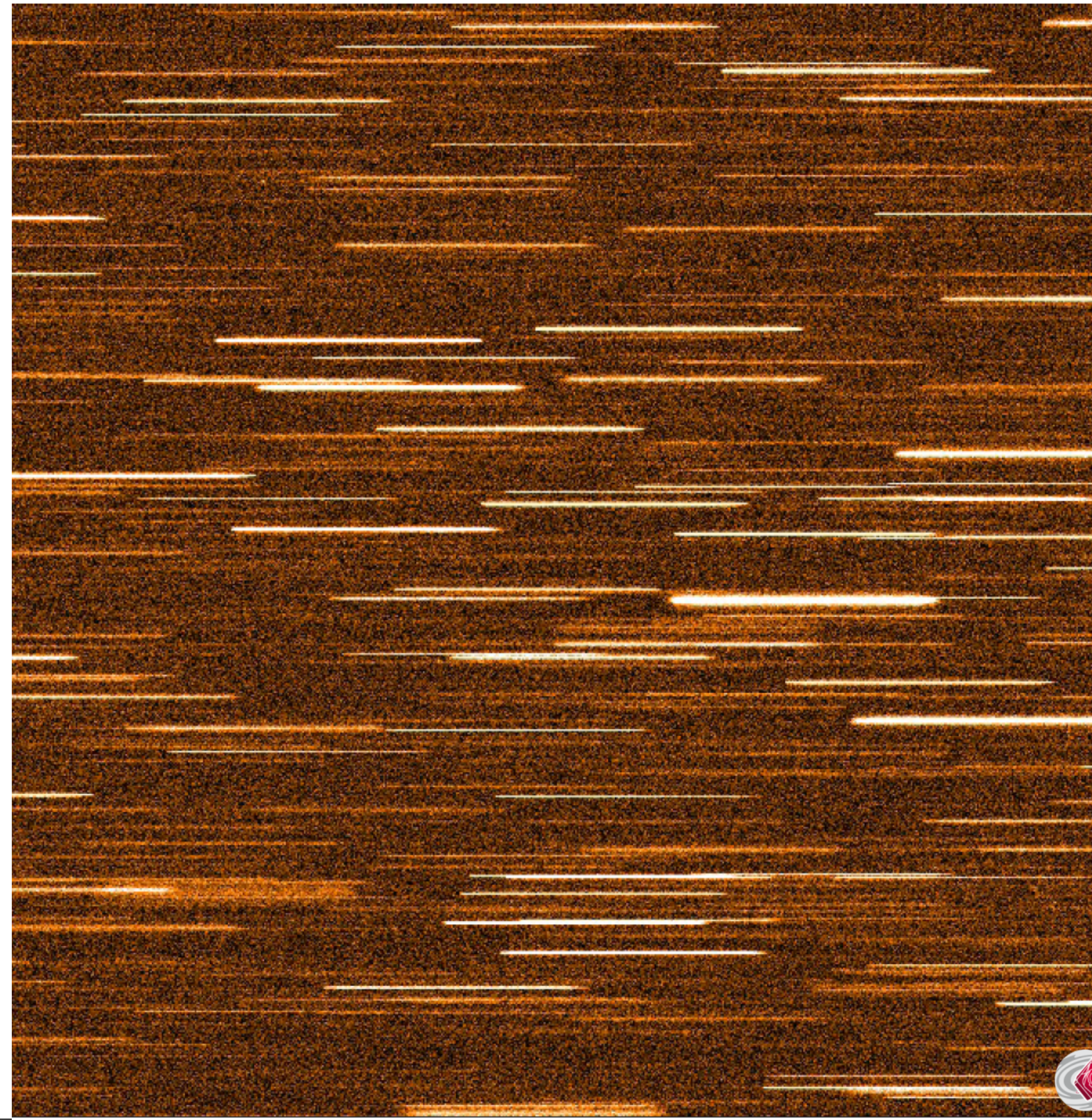
30 million spectroscopic redshifts with 0.001 (1+z) accuracy over 15,000 deg^2

NISP-spectroscopy (2015 simulations)

goal: galaxy spectra and redshifts

From P. Franzetti, B. Garilli, A. Ealet, N. Fourmanoit & J. zoubian





Simulation of M51 with VIS

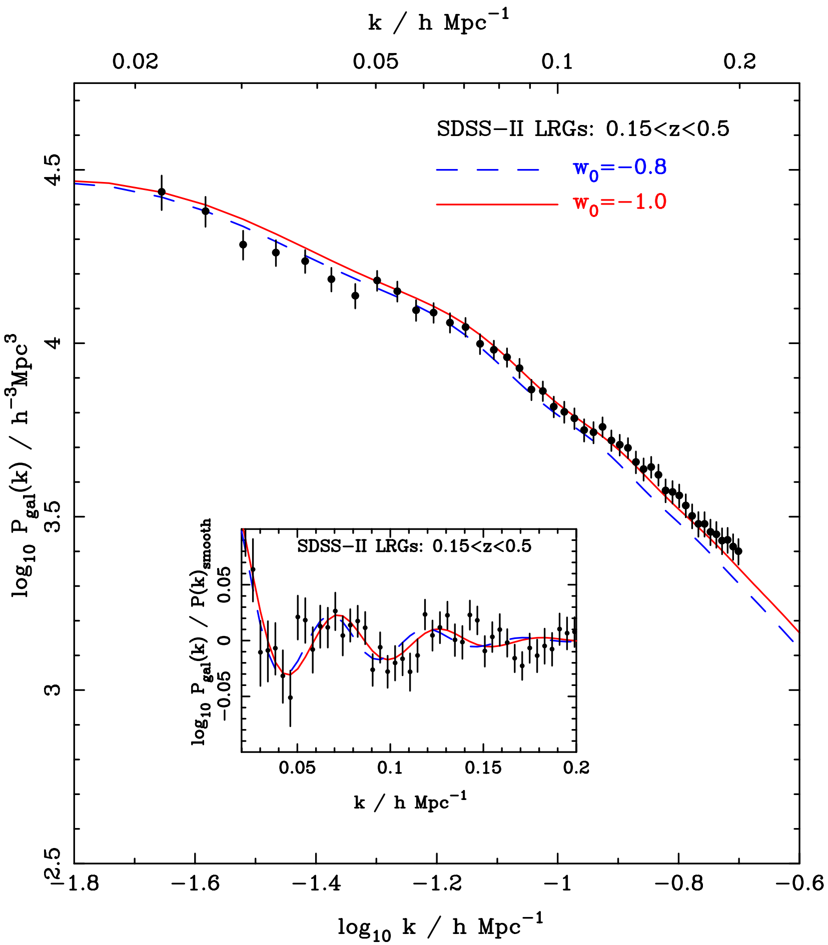
(Courtesy J. Brinchmann and S. Warren)

Messier 51 galaxy at z~0.1 and 0.7:

Euclid will get the resolution of Sloan Digital Sky Survey but at z=1 instead of z=0.05.

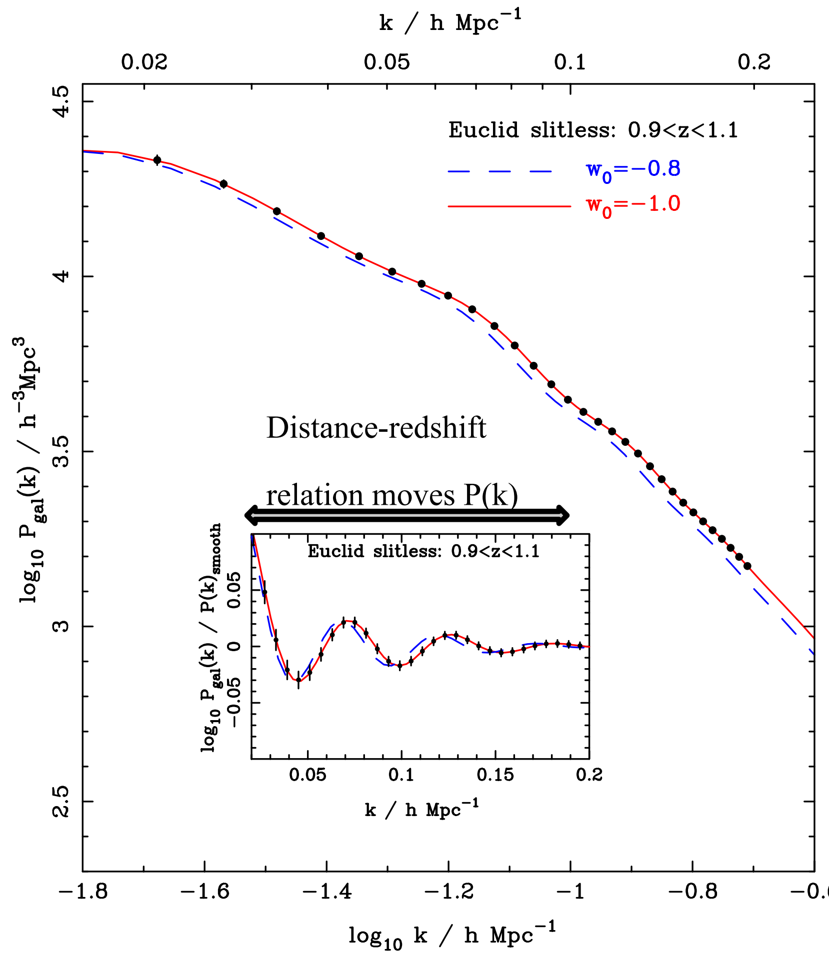
Euclid will be 3 magnitudes deeper → Euclid Legacy = Super-Sloan Survey

BAO : SDSS vs Euclid



SDSS today

0.15<z<0.5

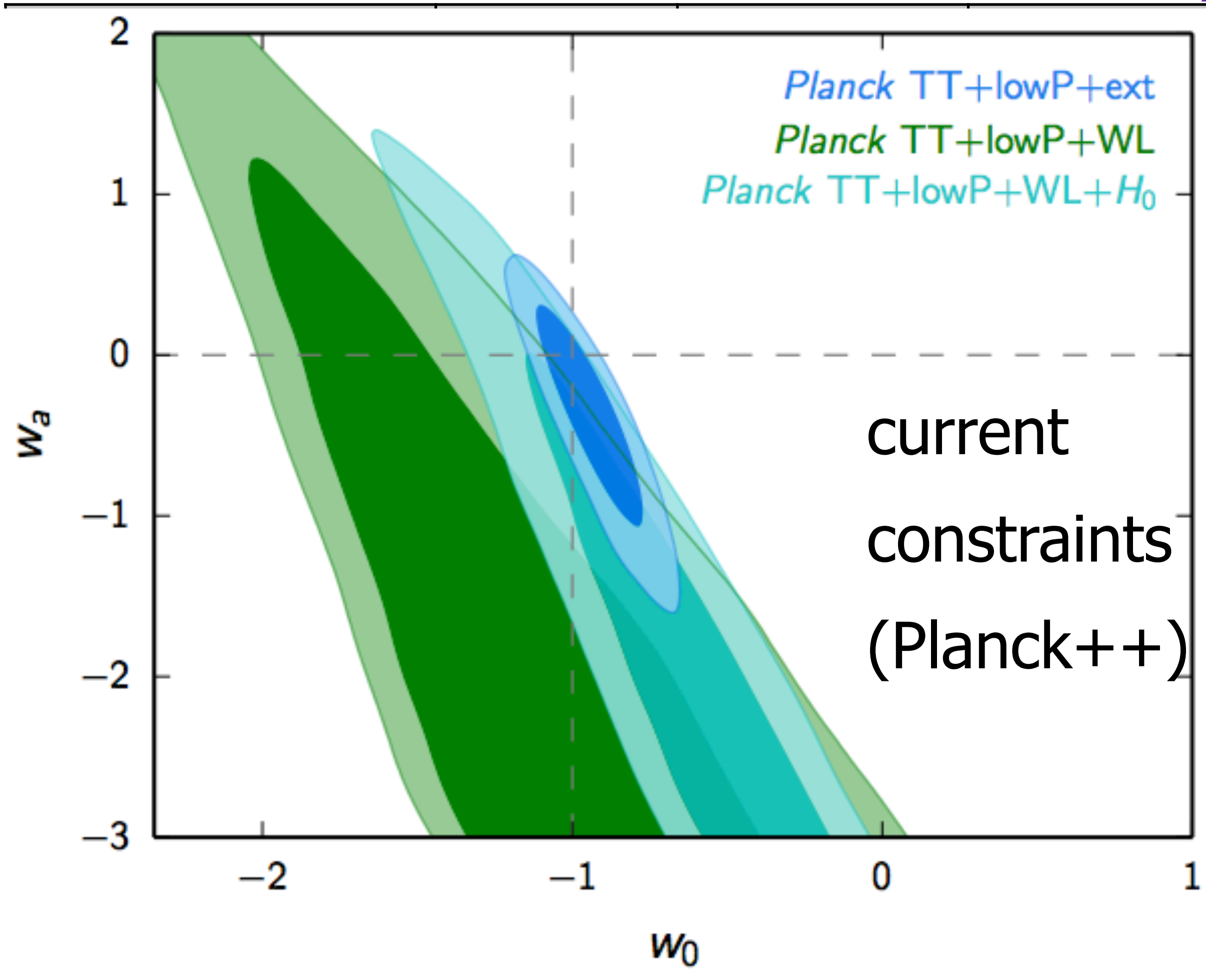


EUCLID expected

0.7<z<2.0

Euclid Post-Planck Forecast for the Primary Program

Assume systematic errors are under control



	Dark Energy		
	w_p	w_a	FoM $= 1/(\Delta w_0 \times \Delta w_a)$
	0.015	0.150	430
	0.013	**0.048**	**1540**
	0.007	0.035	**6000**
	0.100	**1.500**	**~10**
	>10	**>40**	**>400**

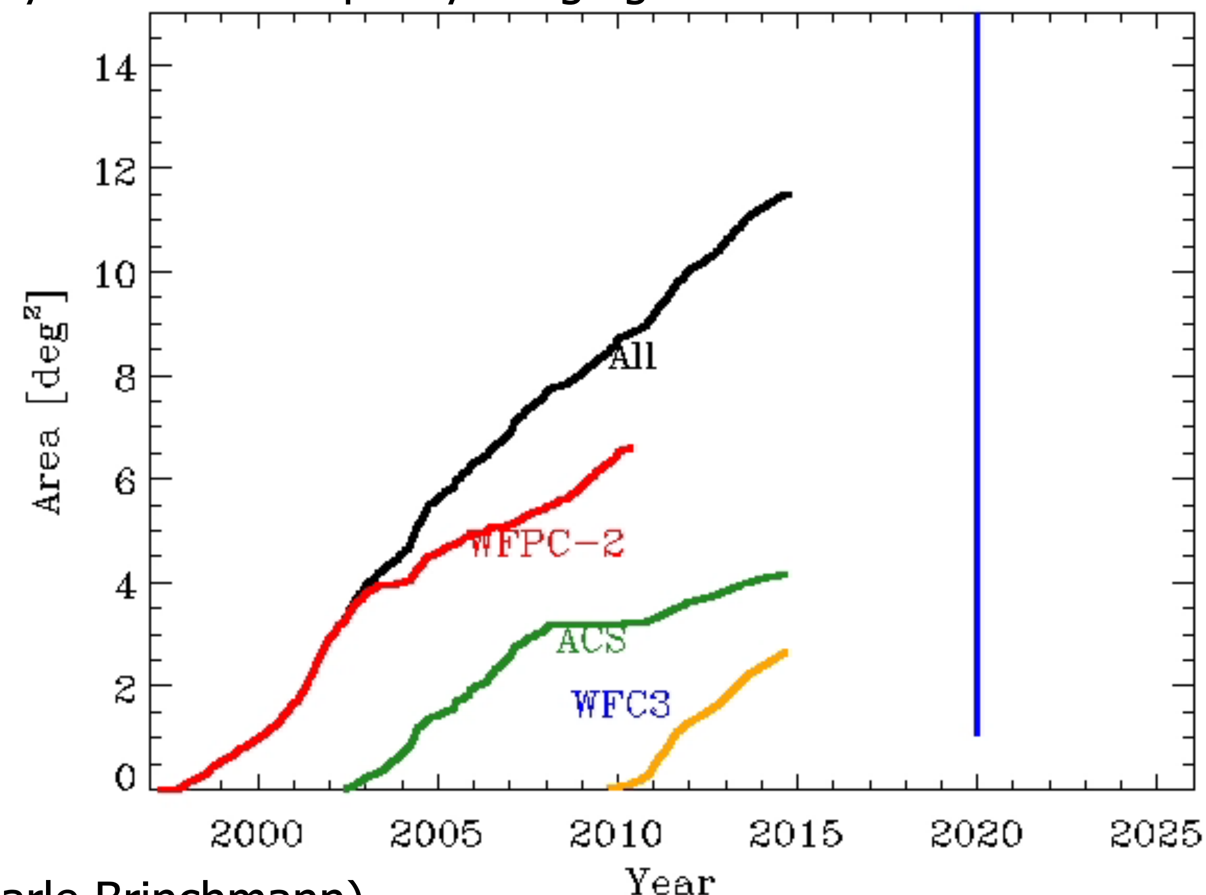
$w_a(a_p-a)$

- From Euclid data alone, get FoM=$1/(\Delta w_a \times \Delta w_p)$ > 400→ ~1% precision on w's.
- **Notice neutrino constraints -> minimal mass possible ~ 0.05 eV!**

Euclid VIS+NISP Legacy

- 12 billion sources, 3-σ

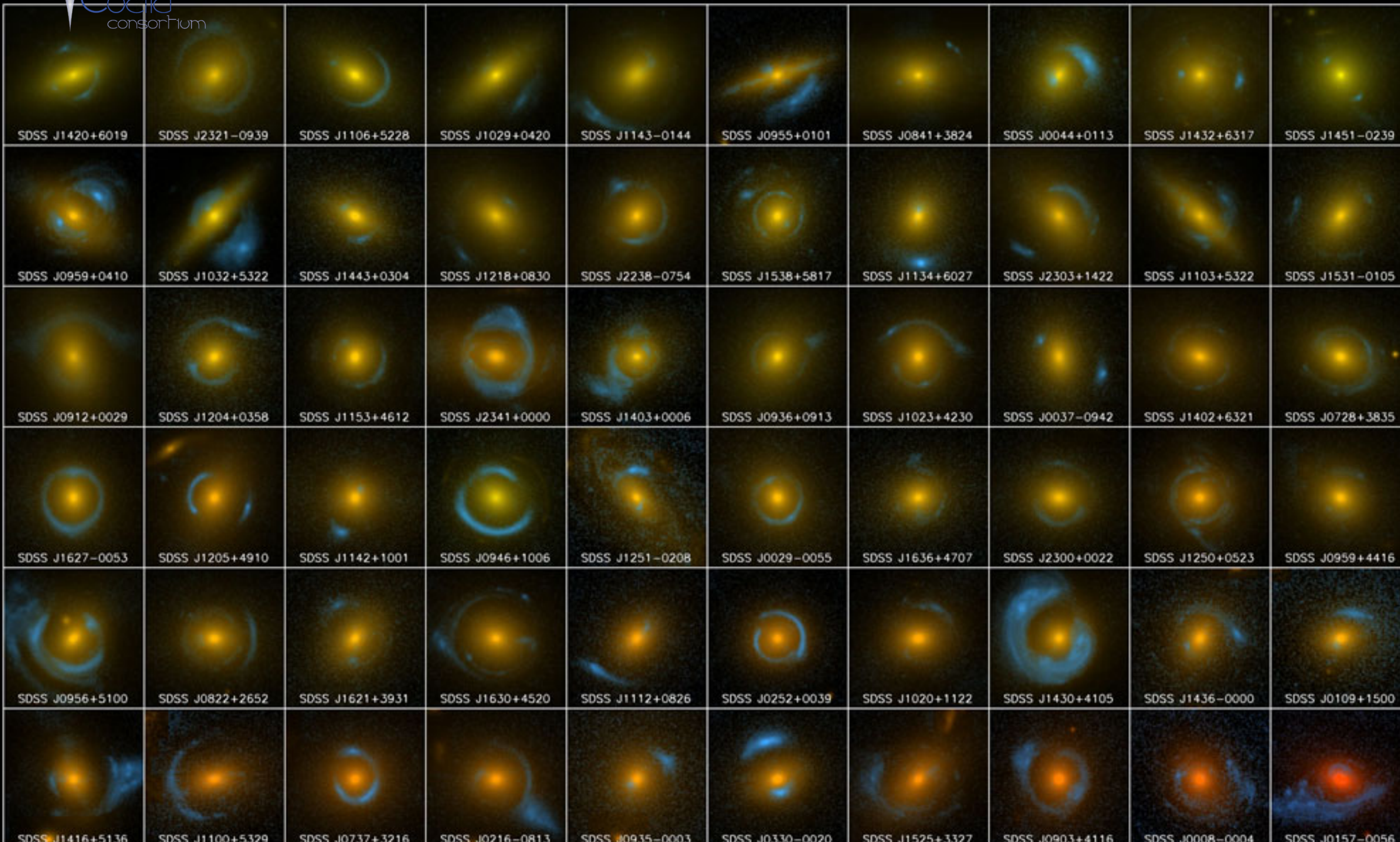
sky area of HST quality imaging



(Jarle Brinchmann)

Objects	Euclid	Before Euclid
	$\sim 2\text{x}10^8$	$\sim 5\text{x}10^6$
	Few hundreds	Few tenss
	$\sim 4\text{x}10^7/10^4$	$\sim 10^4/\sim 10^2$?
	$\sim 2\text{x}10^4$	$\sim 10^3$?
	$\sim 10^4$	$<10^3$
	$\sim 10^5$	
	~few 10^2	<10
	~300,000	~10-100
	~30	None

SLACS (~2010 - HST)



SLACS: The Sloan Lens ACS Survey

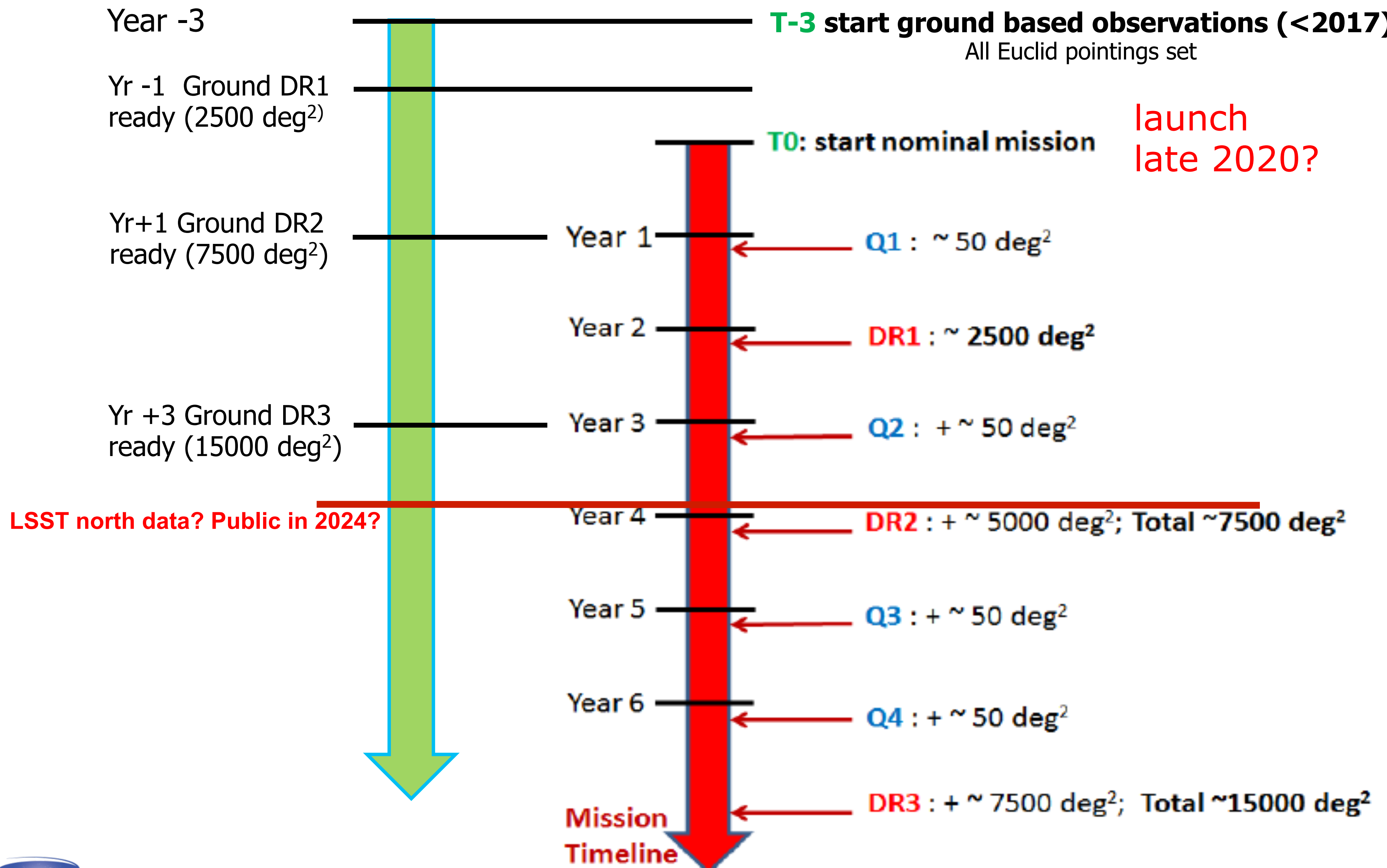
www.SLACS.org

A. Bolton (U. Hawai'i IfA), L. Koopmans (Kapteyn), T. Treu (UCSB), R. Gavazzi (IAP Paris), L. Moustakas (JPL/Caltech), S. Burles (MIT)

Image credit: A. Bolton, for the SLACS team and NASA/ESA


SLACS
Euclid VIS Legacy : after 2 months
(66 months planned)

Euclid data release



Square Kilometre Array

SKA is a huge radio telescope, composed of many small telescopes with interferometry

- ~200 dishes in South Africa
- ~130'000 antennae in Australia

Phase 1 to start ~ 2023, several precursors already/soon in operation

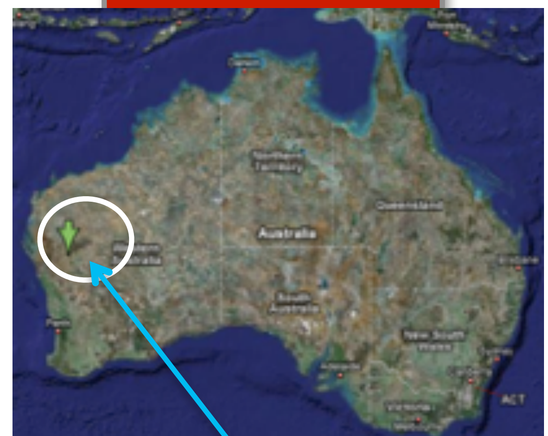
Computing power and data management will be a major challenge

SKA Phase 1 (SKA1)
Cost: €650M, construction start 2017

Southern Africa

SKA1_MID
254 Dishes including:
64 x MeerKAT dishes
190 x SKA dishes

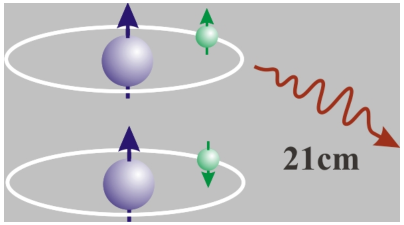
Australia



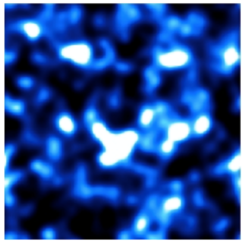
SKA1_LOW
Low Frequency Aperture Array Stations

SKA cosmological surveys

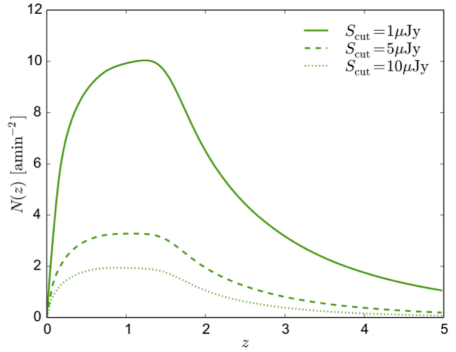
- ***HI galaxy redshift survey***
  - ‘21cm’ radiation from neutral hydrogen spin flip
  - individual galaxies detected
  - precise redshift, radio analogue of optical spectroscopic survey
  - no foregrounds, but needs very high sensitivity



- ***HI intensity mapping survey (IM)***
  - individual galaxies not detected, only integrated emission
  - good for large-scale structure mapping
  - a bit like CMB but with multiple redshifts, can also extract lensing information (similar to CMB)
  - many narrow redshift bins possible
  - foreground a big problem, not yet fully proven technique

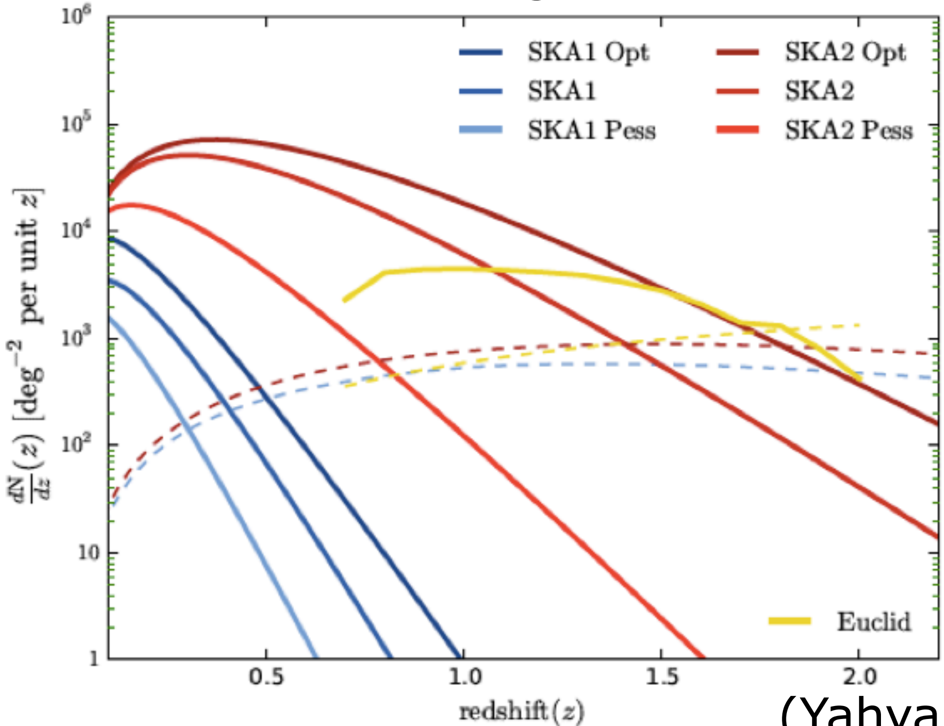


- ***Radio continuum survey***
  - total radio emission from galaxies
  - many galaxies at high redshift, but no redshifts
  - can do weak lensing, needs HI redshift information

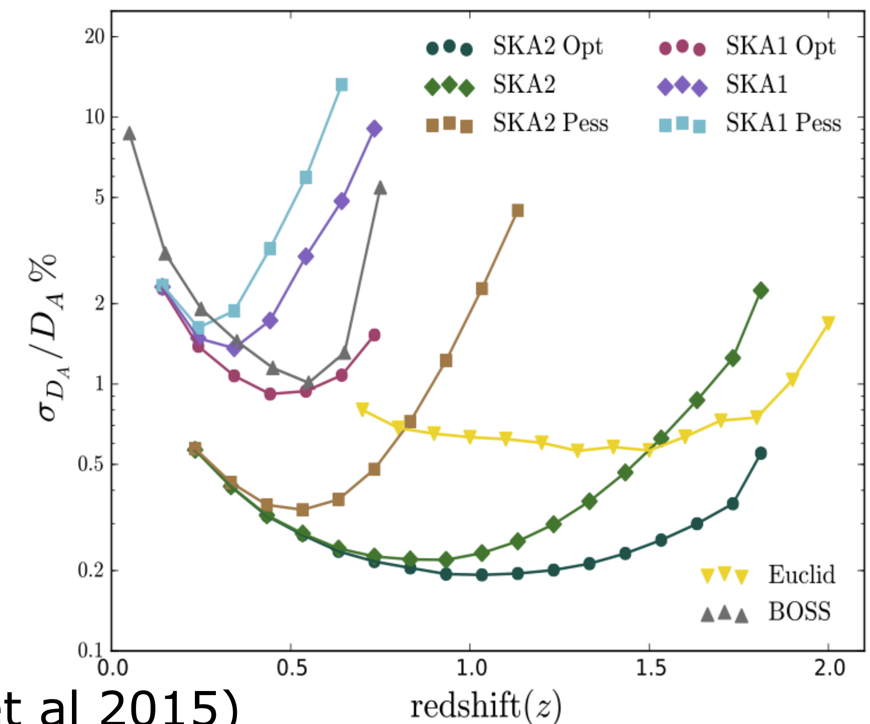


SKA HI galaxy redshift surveys

number of galaxies



precision of distance measurement

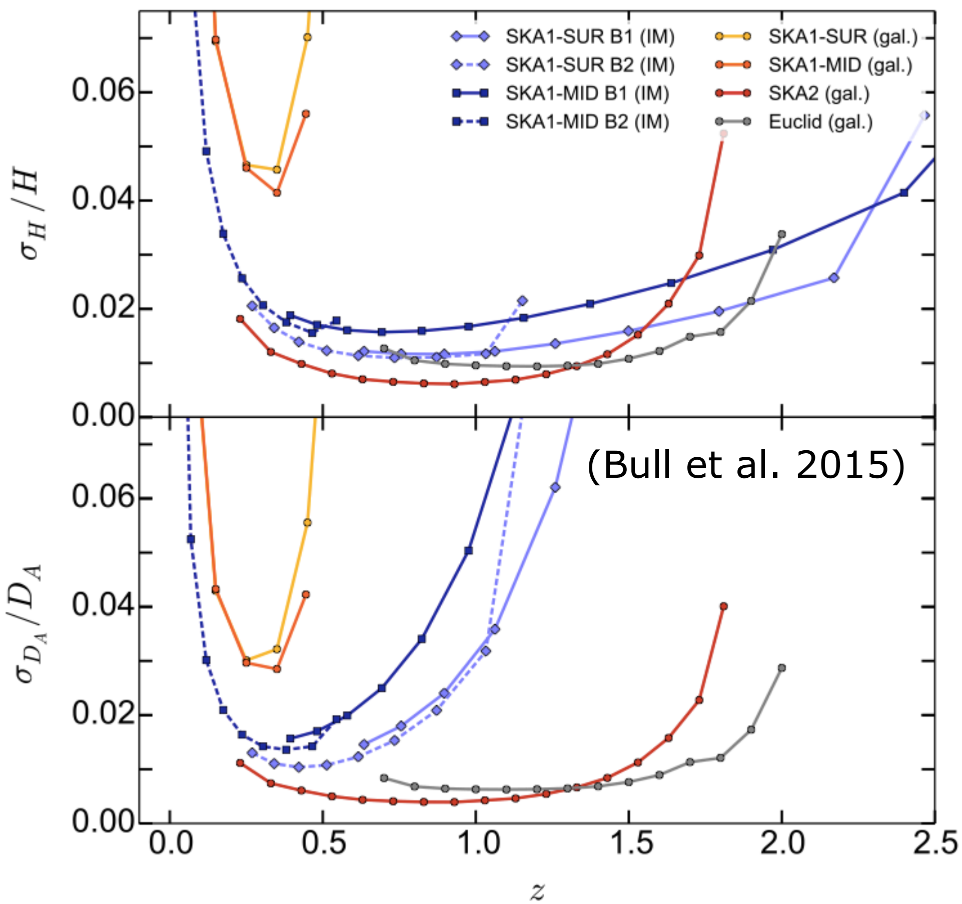


(Yahya et al 2015)

- SKA1: 10 million galaxies, 5000 deg2, z<0.6
- SKA2: 1 billion galaxies, 30000 deg2, z<2

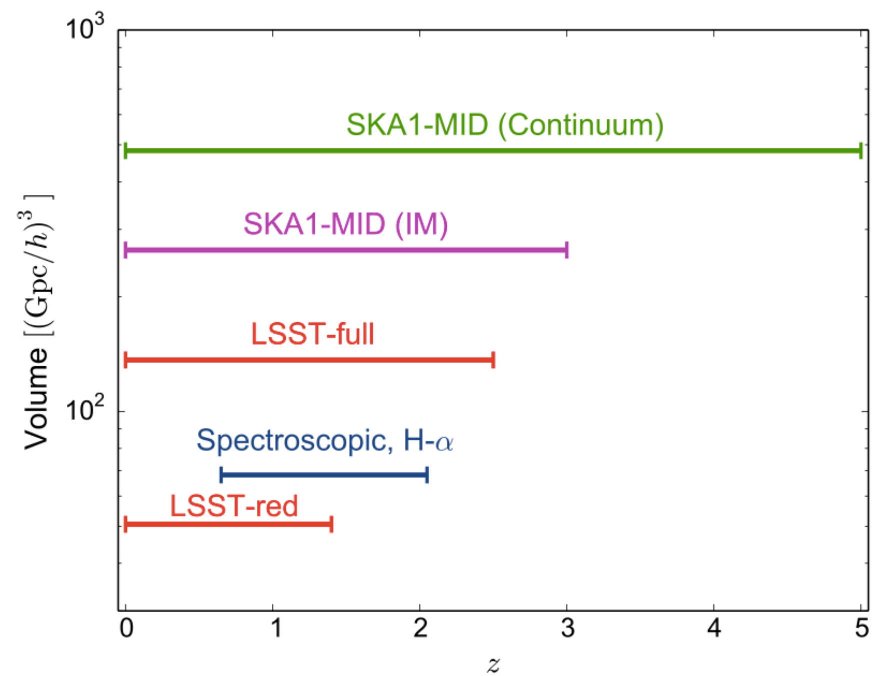
- *SKA1 not a game changer, but complementary to optical surveys*
- *SKA2 will be a game changer*

SKA1 intensity mapping



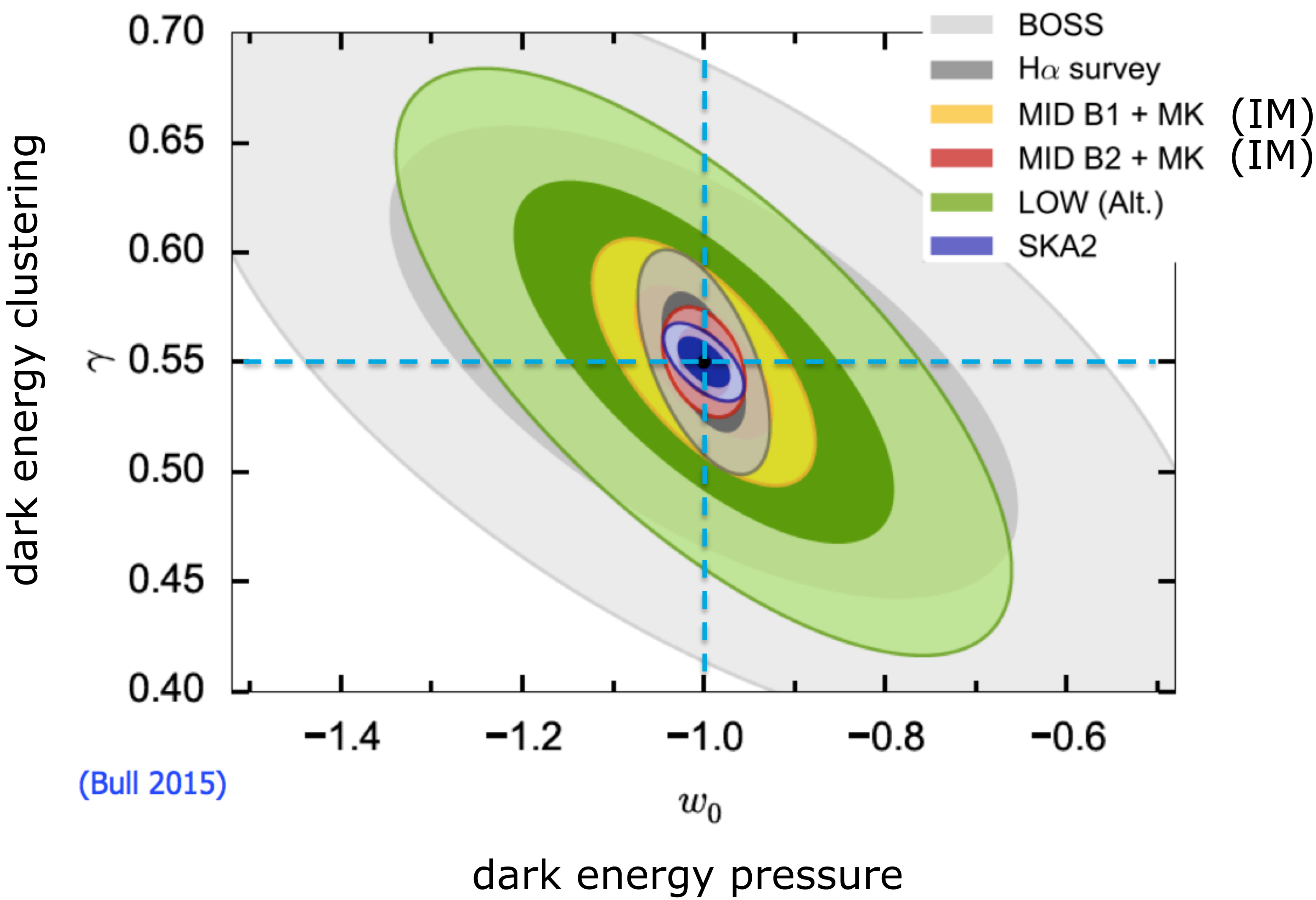
Intensity mapping:

- good redshift precision
- large volume
- but need to control systematic effects



errors on expansion rate H(z) and distance D(z): Intensity mapping with SKA1 performs very well

testing the nature of dark energy



(Bull 2015)

testing isotropy on large scales

Does the matter dipole agree with the CMB dipole?

- current data (NVSS) shows a difference in velocity (? cf Planck kSZ)

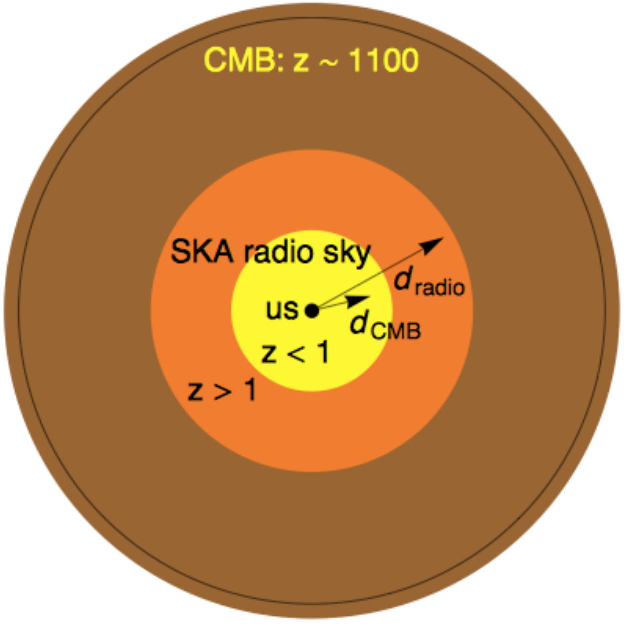
SKA continuum surveys:

- SKA1 will locate dipole within 5°
- SKA2 will locate dipole within 1°

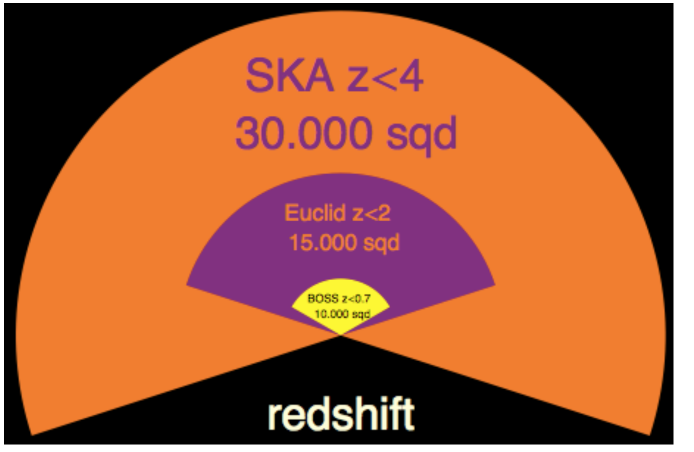
- IM survey can test Copernican Principle to a few per cent

- These are fundamental tests on which all the other cosmological analyses rely!

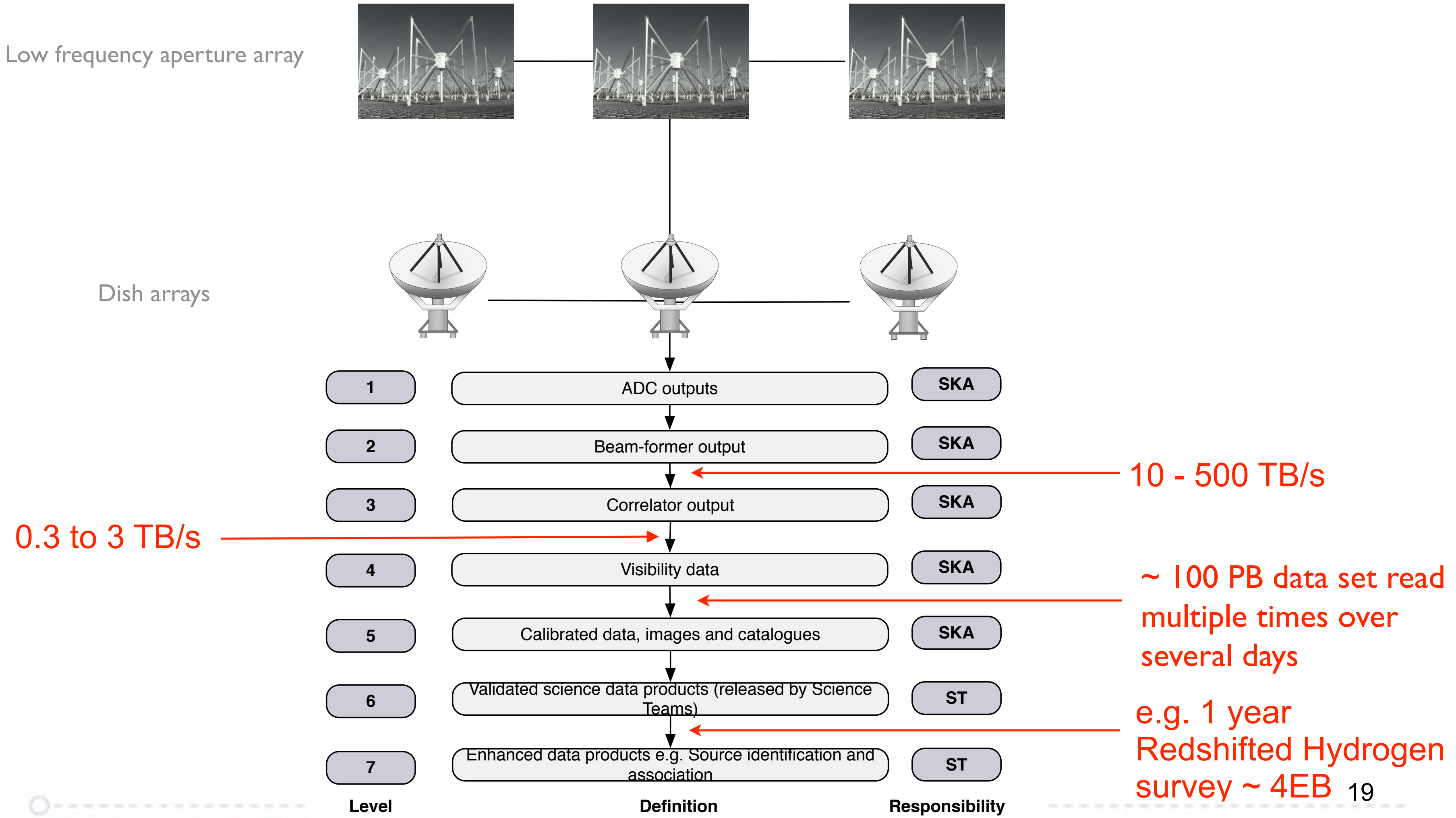
- Surveys probing ultra-large scales are also the best (the only?) hope for testing the Planck large scale anomalies.



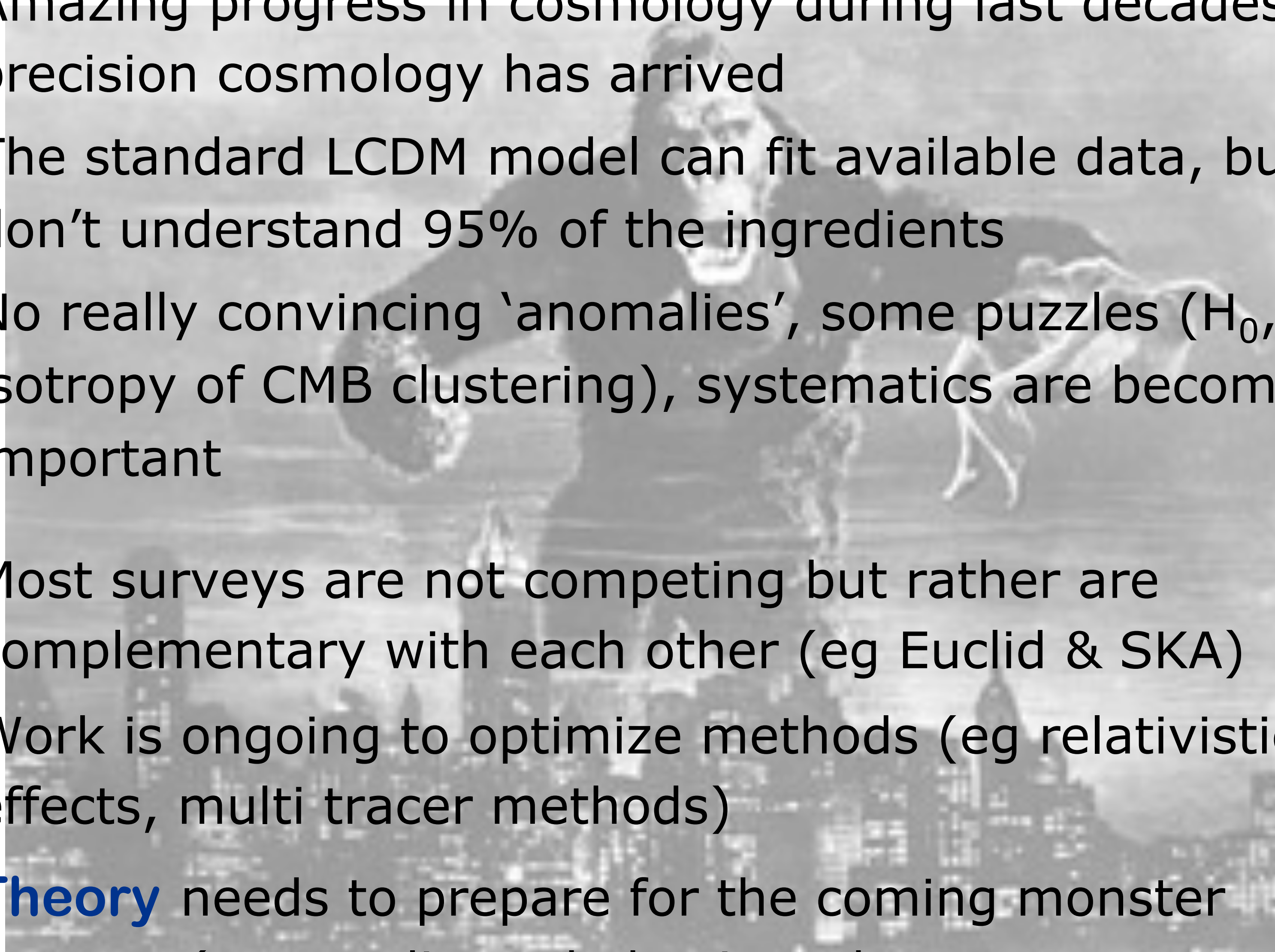
Schwarz et al, 2015



SKA1 data product sizes



Summary



- Amazing progress in cosmology during last decades, precision cosmology has arrived
- The standard LCDM model can fit available data, but we don’t understand 95% of the ingredients
- No really convincing ‘anomalies’, some puzzles (H_0, isotropy of CMB clustering), systematics are becoming important

- Most surveys are not competing but rather are complementary with each other (eg Euclid & SKA)
- Work is ongoing to optimize methods (eg relativistic effects, multi tracer methods)
- **Theory** needs to prepare for the coming monster surveys (eg non-linear behaviour, baryons, stats, …)!


Thank you
X, Ferrara, Dec 2014