NEW DIRECTIONS:

NICOLA BARTOLO, Dip. Di Fisica e Atronomia ``G.Galilei'', Univ. di Padova
INFN, sezione di Padova

Conveners: Nicola BARTOLO, Paolo de BERNARDIS, Alessandro MELCHIORRI

Thanks to the contributions of: C. Baccigaluppi, S. Borgani, E. Branchini, L. Conti, F. Finelli, M. Liguori, S. Matarrese, M. Viel

NEW DIRECTIONS:

- **CMB and Inflation**
- **Large Scale Structure (LSS) and Dark Energy, synergies between CMB and LSS**
- **Cosmological constraints on neutrinos**

WHAT WE HAVE DONE: HIGHLIGHTS

- We have tried to stimulate the discussion in a transverse /interdisciplinary way, keeping contact with some of the people who sent some ideas/proposals for the Angelicum April 2014 and who kept interest in What Next

- Theory/interface with observations-data analysis: N. Bartolo & A. Melchiorri; Experiments: P. de Bernardis

- http://wiki.ge.infn.it/wn-newdirections/index.php/Main_Page

23 idee/proposte iniziali ad Aprile 2014, di cui 18 in ambito cosmologico

Microsoft Excel - risposte2.xls

	A	B	C	D	E	F	G	H
1	Informazioni	Nome	Cognome	Indirizzo e-mail	Istituto di	Tipo di	inquadrame	Contributo
2		Carlo	Baccigalupi	via e-mail				CMB-LSS Cross Correlation for Dark Energy and Modified Gravity
3		Marco	Baldi	via e-mail				Simulation of non.standard cosmologies
4	3/7/2014 9:25:08	walter	Bonivento	walter.bonivento	INFN Cagliari	CSN2	attività futura	http://ship.web.cern.ch/ship/
5	3/9/2014 17:36:49	Fabio	Bossi	fabio.bossi@lnf.i	lnf	CSN1	attività già in	dark photons searches at colliders
6		Enzo	Branchini	via e-mail				The Large Scale Structure of the Universe as a probe to Dark Energy and Gravity
7		Livia	Conti	via e-mail				CMB in a non-equilibrium universe
8	4/6/2014 7:58:42	Paolo	de Bernardis	paolo.debernardi	Dipartimento	CSN2	attività futura	Studio sperimentale della polarizzazione del fondo cosmico di microonde allo
9	4/3/2014 12:36:00	Eleonora	Di Valentino	eleonora.divalenti	Roma	CSN4	attività già in	Studio delle non gaussianità del CMB dovute ad interazione tra lensing ed effetto
10	3/14/2014 11:22:59	Angela D.	Di Virgilio	angela.divirgilio@	INFN-Pisa	CSN2	attività già in	G-GranSasso-RD è un R&D di GruppoII che ha lo scopo di costruire GINGER, un
11	3/24/2014 17:24:16	Antonaldo	Diaferio	diaferio@ph.unito	Universita' di	CSN4	attività già in	La strategia che InDark-Torino intende perseguire con le sue competenze e'
12	3/14/2014 17:02:16	Daniele	Fargion	daniele.fargion@r	Phys Depart	CSN2	attività futura	"Horizontal Upward Airshower by Plane and Balloons:
13	3/14/2014 17:14:12	Daniele	Fargion	daniele.fargion@r	Dipt Fisica	CSN4	attività già in	1) Oscillazioni:
14		Fabio	Finelli	via e-mail				Implication of BICEP2, inflation, and new physics
15	3/26/2014 15:49:02	Nicolao	Fornengo	fornengo@to.infn.	Universita' di	CSN4	attività futura	Volevo segnalarvi un tipo di studio per la ricerca di DM che può mettere in
16	4/3/2014 12:33:57	Martina	Gerbino	martina.gerbino	Roma	CSN4	attività già in	Vincoli a modelli inflazionari tramite misure di radiazione di fondo cosmico
17		Michele	Liguori	via e-mail				new pathways to primordial non-Gaussianity and inflationary models
18	4/3/2014 13:46:27	Andrea	Marchini	andreaAbout Get	Sapienza -	CSN5	attività già in	Alternative theories of Gravity -- Marchini, A., & Salvatelli, V. (2013). Updated
19	4/3/2014 12:31:59	Alessandro	Melchiorri	alessandro.melc	Roma	CSN4	attività già in	Mi propongo di vincolare la fisica del neutrino e di particelle leggere come assioni
20		Edoardo	Milotti	via e-mail				Gamma-gamma scattering
21		Lauro	Moscardini	via e-mail				CMB-LSS Cross Correlation for Dark Energy and Modified Gravity and Extreme
22		Paolo	Natoli	via e-mail				CMB as a laboratory for new physics
23		Anna	Nobili	via e-mail				GG & GGG fondamenti della relatività generale - principio equivalenza
24		Massimo	Pietroni	via e-mail				Understanding the Large Scale Structure of the Universe
25		Nicola	Poli	via e-mail				Interferometri e orologi atomici con atomi ultrafreddi per tests di fisica
26		Antonino	Pullia	via e-mail				Geyser - tecnica nuova di ricerca DIRETTA e TERRESTRE di Materia Oscura
27	4/3/2014 20:24:37	Najla	Said	najlasd@gmail.c	università di	CSN4	attività già in	dark energy properties
28	4/3/2014 14:26:38	Valentina	Salvatelli	vale.salvatelli@g	La Sapienza,	CSN4	attività già in	Dark matter- dark energy interactions
29		Matteo	Viel	via e-mail				Probing the Universe at mildly non-linear scales
30								
31								
32								

Risposte del modulo

WHAT WE HAVE DONE: HIGHLIGHTS

- Participation to workshops that have been organized within What Next or that have been strongly connected to it

  e.g. Multiple Messengers and Challenges in Astroparticle Physics Gran Sasso Science Institute, from October 6 to 17, 2014

- Informal meetings/discussions between focused/restricted teams of people

- Some of these ideas/proposal have taken a concrete form (see discussion of opportunities and some examples later in this talk)

WHAT HAPPENED IN THE LAST YEAR?

- 2nd *Planck* data release in Februray 2015
  (full mission temperature data+a first release of polarization data)

- BICEP2/Keck and *Planck* joint analysis

- SDSSIII/BOSS collaboration final release

- SKA Telescope (decision on the headquarter will be taken soon; Padova is a candidate).

CMB and INFLATION

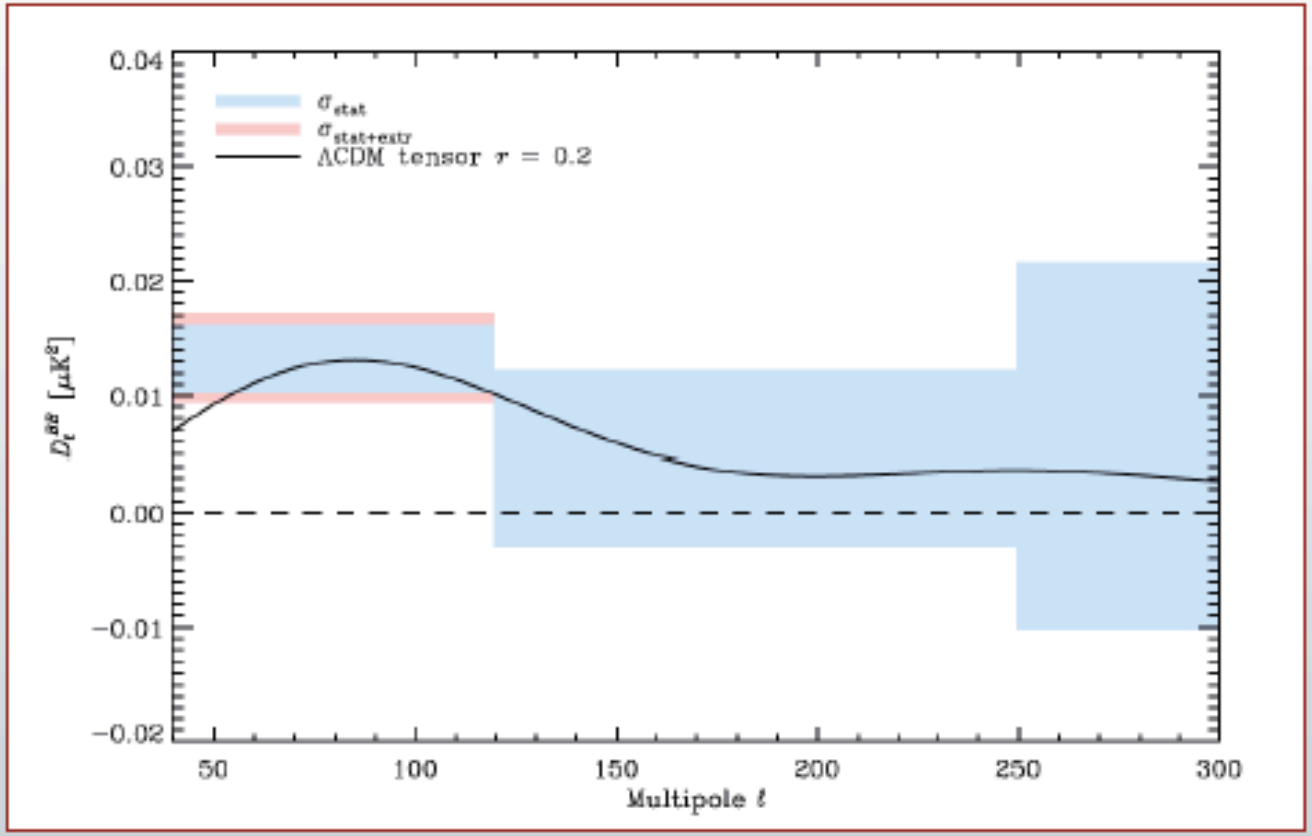
BICEP2/Keck & *Planck* joint analysis

These results show:

- *Planck measurements of the polarization from dust have been crucial to properly interpret the signal measured by BICEP2*

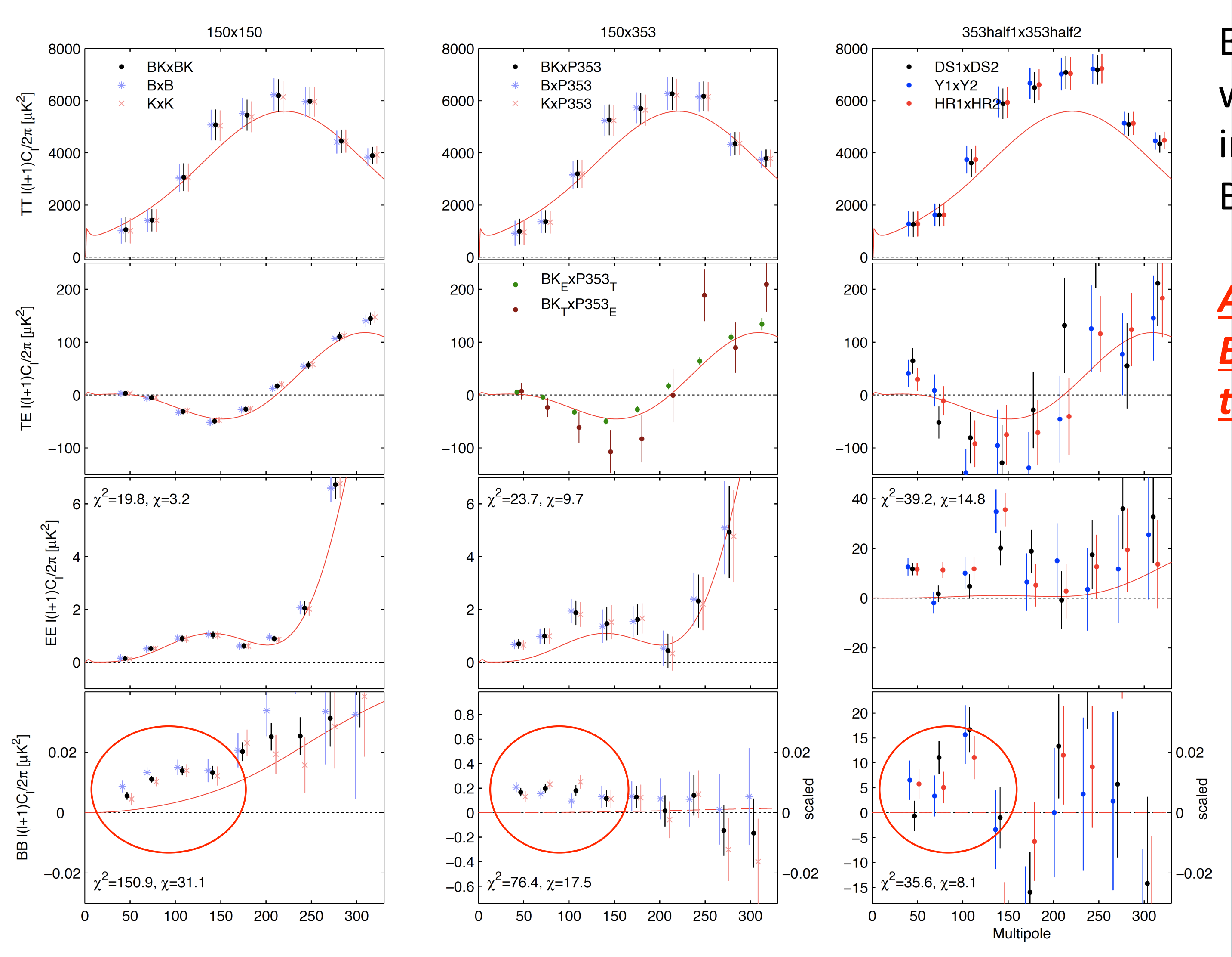
- *the understanding and handling/removal of foregrounds is crucial for the search of a primordial signal in the B-modes*

Planck analysis of polarized dust



Planck 353 GHz D^{BB} angular power spectrum extrapolated to 150 GHz (box centres). The shaded boxes represent the 1 sigma uncertainties: blue for the statistical uncertainties from noise; and red adding in quadrature the uncertainty from extrapolation to 150 GHz. The *Planck* 2013 best-fit CDM D_{BB} CMB model based on temperature anisotropies, with a tensor amplitude fixed at r = 0.2, is overplotted as a black line.

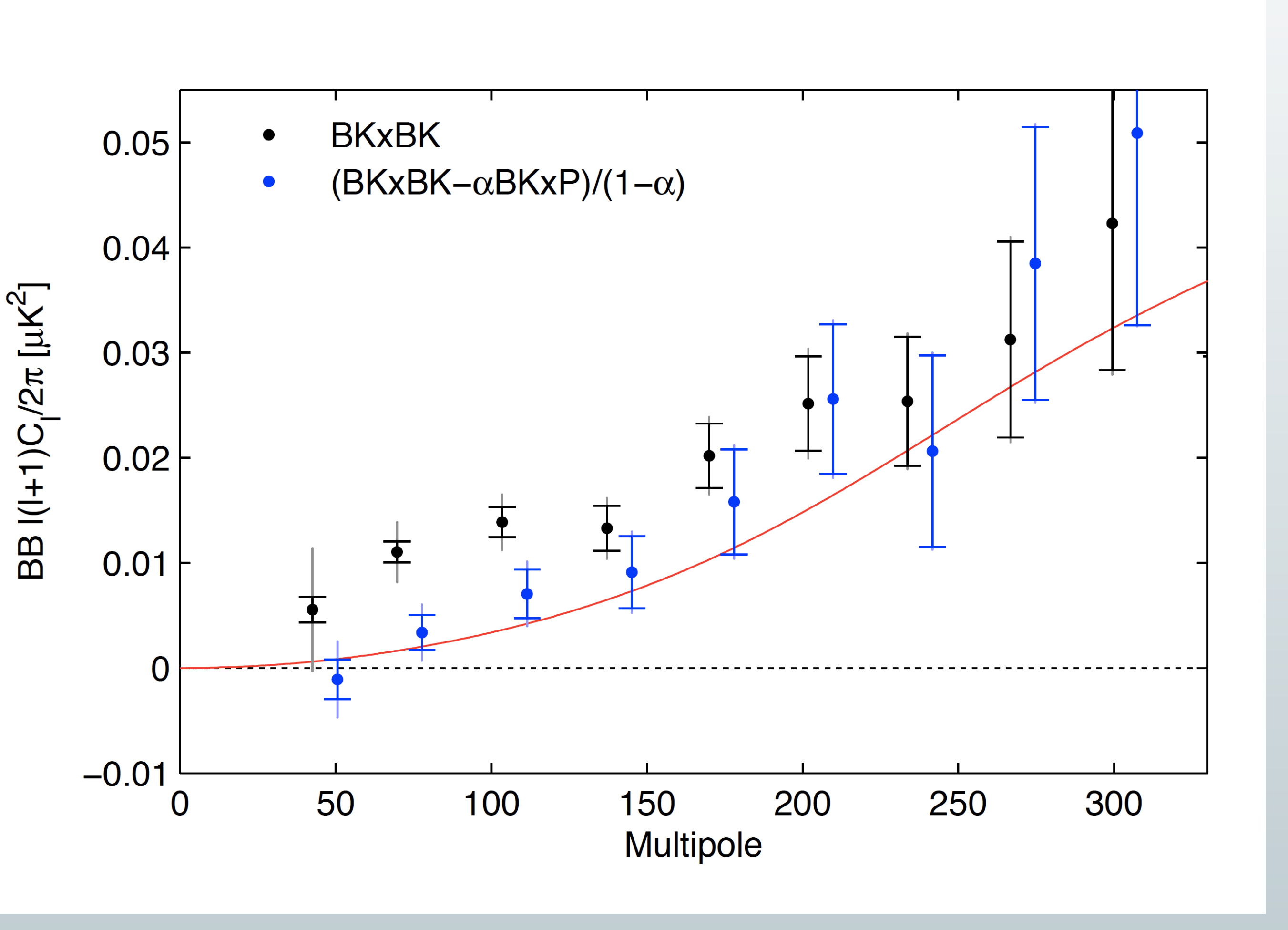
BICEP2/Keck & *Planck* joint analysis



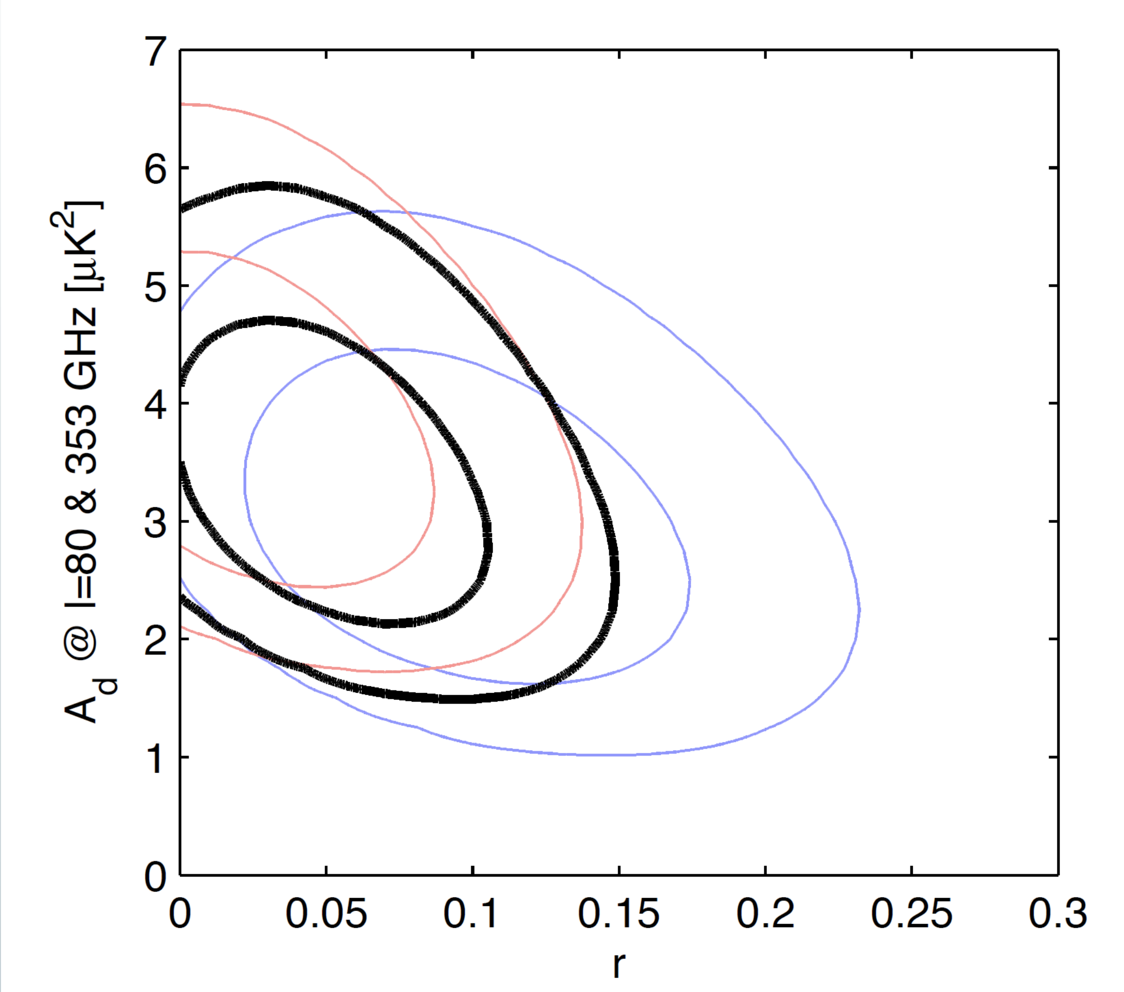
B-modes detected with high significance in the BK150 GHz × P353 GHz.

A substantial amount of BK150 × BK150 appears to be due to dust

BICEP2/Keck & *Planck* joint analysis



BICEP2/Keck & *Planck* joint analysis

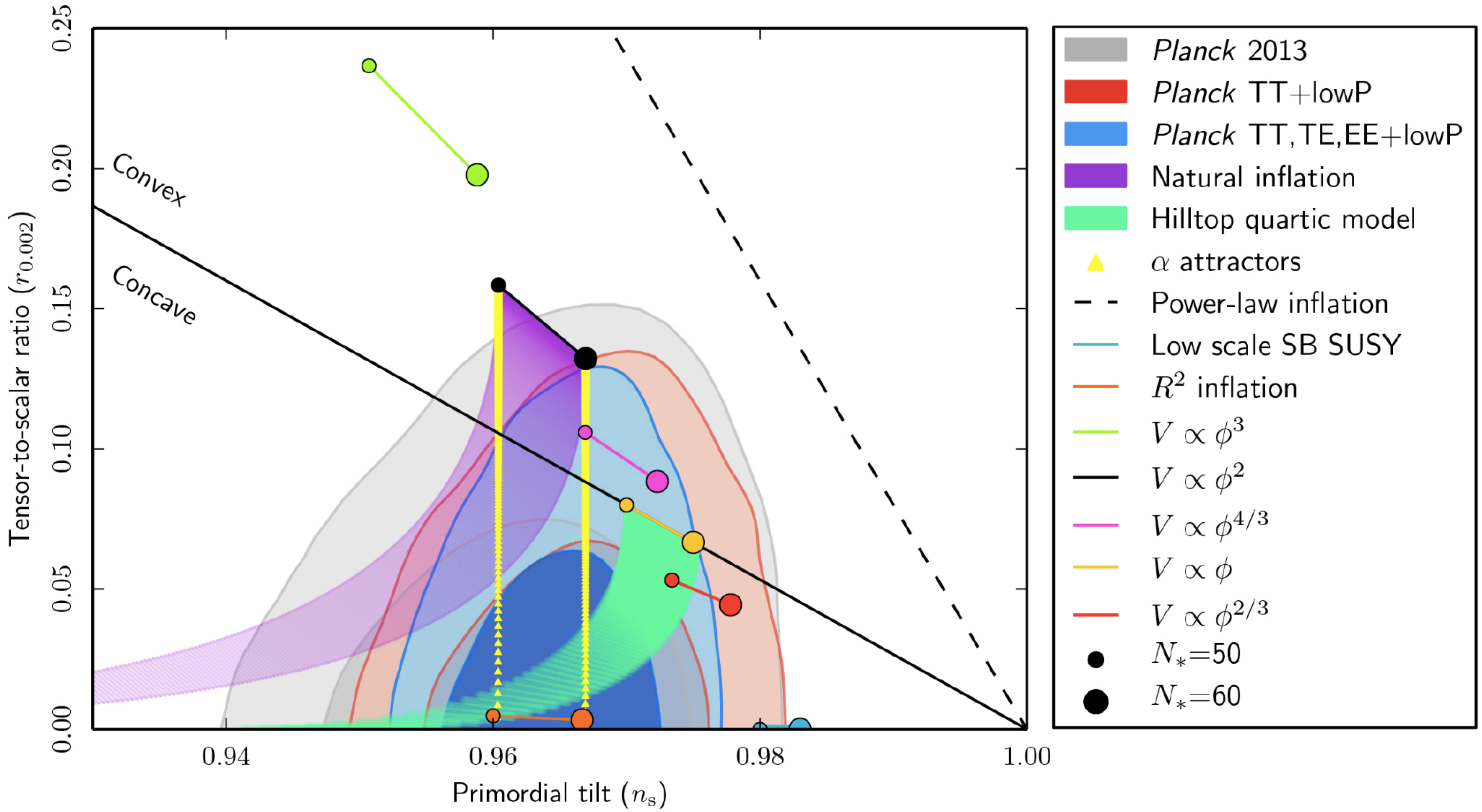


r<0.12 @95% CL

Planck constraints on inflation

Model	Parameter	*Planck* TT+lowP	*Planck* TT+lowP+lensing	*Planck* TT+lowP+BAO	*Planck* TT,TE,EE+lowP
ΛCDM+r	n_s	0.9666 ± 0.0062	0.9688 ± 0.0061	0.9680 ± 0.0045	0.9652 ± 0.0047
	$r_{0.002}$	< 0.103	< 0.114	< 0.113	< 0.099
	$-2\Delta \ln \mathcal{L}_{max}$	0	0	0	0
ΛCDM+r +$dn_s/d\ln k$	n_s	0.9667 ± 0.0066	0.9690 ± 0.0063	0.9673 ± 0.0043	0.9644 ± 0.0049
	$r_{0.002}$	< 0.180	< 0.186	< 0.176	< 0.152
	r	< 0.168	< 0.176	< 0.166	< 0.149
	$dn_s/d\ln k$	$-0.0126^{+0.0098}_{-0.0087}$	$-0.0076^{+0.0092}_{-0.0080}$	-0.0125 ± 0.0091	-0.0085 ± 0.0076
	$-2\Delta \ln \mathcal{L}_{max}$	-0.81	-0.08	-0.87	-0.38

Planck constraints on inflation



$$V^{1/4} = 1.94 \times 10^{16} \left(\frac{r}{0.12}\right)^{1/4} \mathrm{GeV}$$

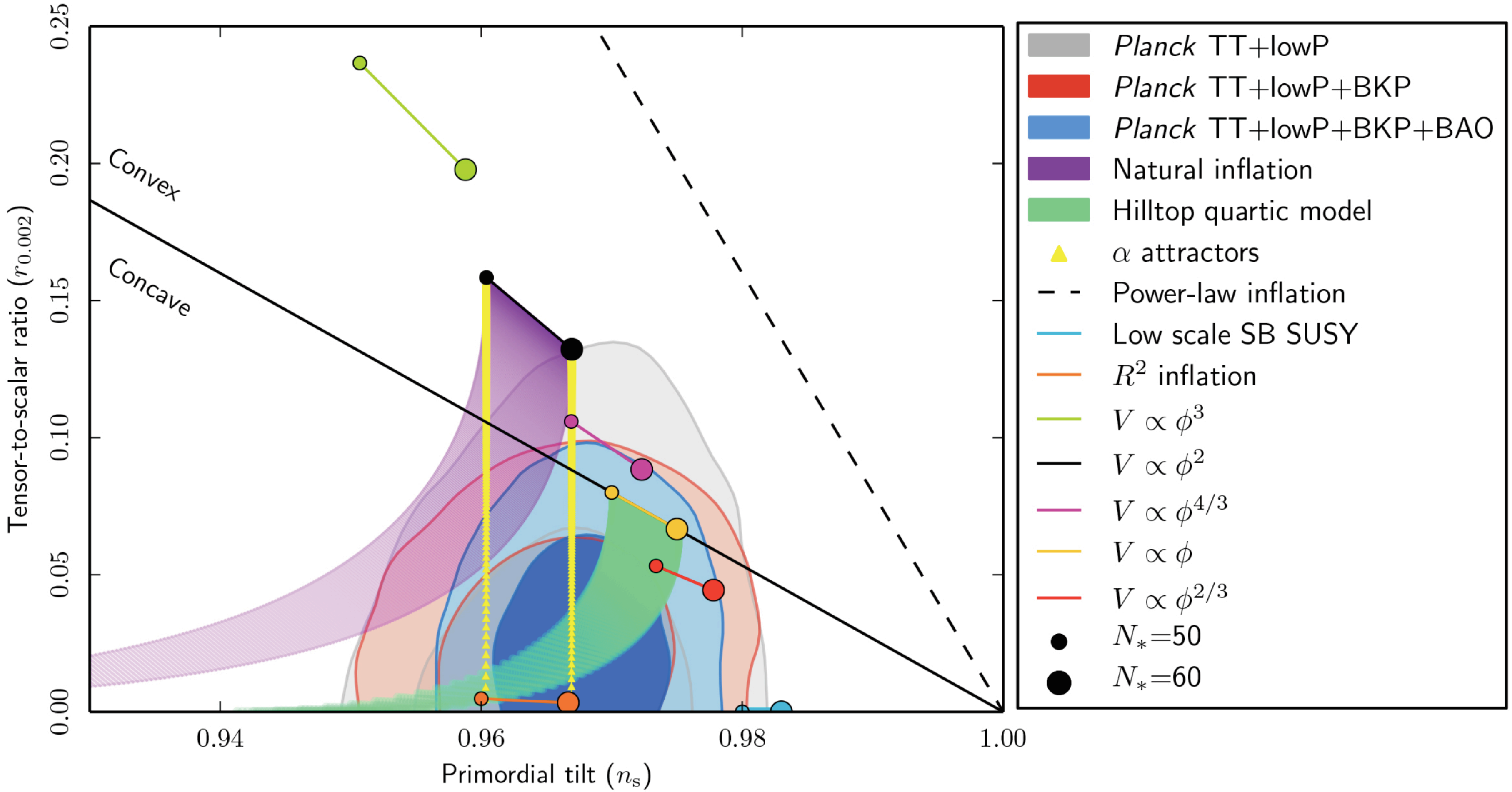
Results consistent with *Planck* 2013;

$r_{0.002}$<0.11 @95% CL consistent with Bicep2/Keck & *Planck* joint

Increased precision

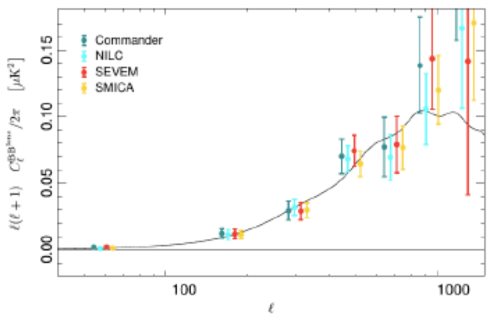
V(ϕ) ~ ϕ^2 disfavored wr.t. Starobinski model R+R^2

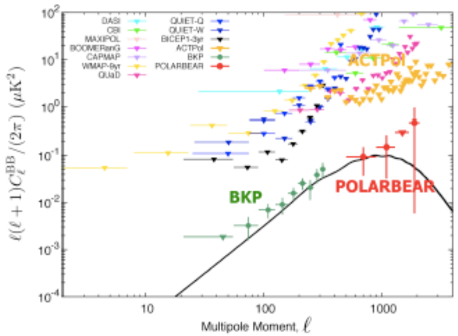
BICEP2/Keck & *Planck joint constraints*



CMB B modes

- 2014: technological breakthrough for ongoing experiments
- Lensing B modes detected by Planck, PolarBear, SPT at arcminute scales
- Contamination to B modes from primordial gravitational waves caused by Galactic foregrounds assessed by BICEP2/Keck, Planck
- Several experiments optimizing technology to achieve foreground cleaning, better accuracy, satellite/combination proposals for EU, NASA, JAXA
- Areas of impact: extreme early Universe (GWs), DE/MG (lensing)





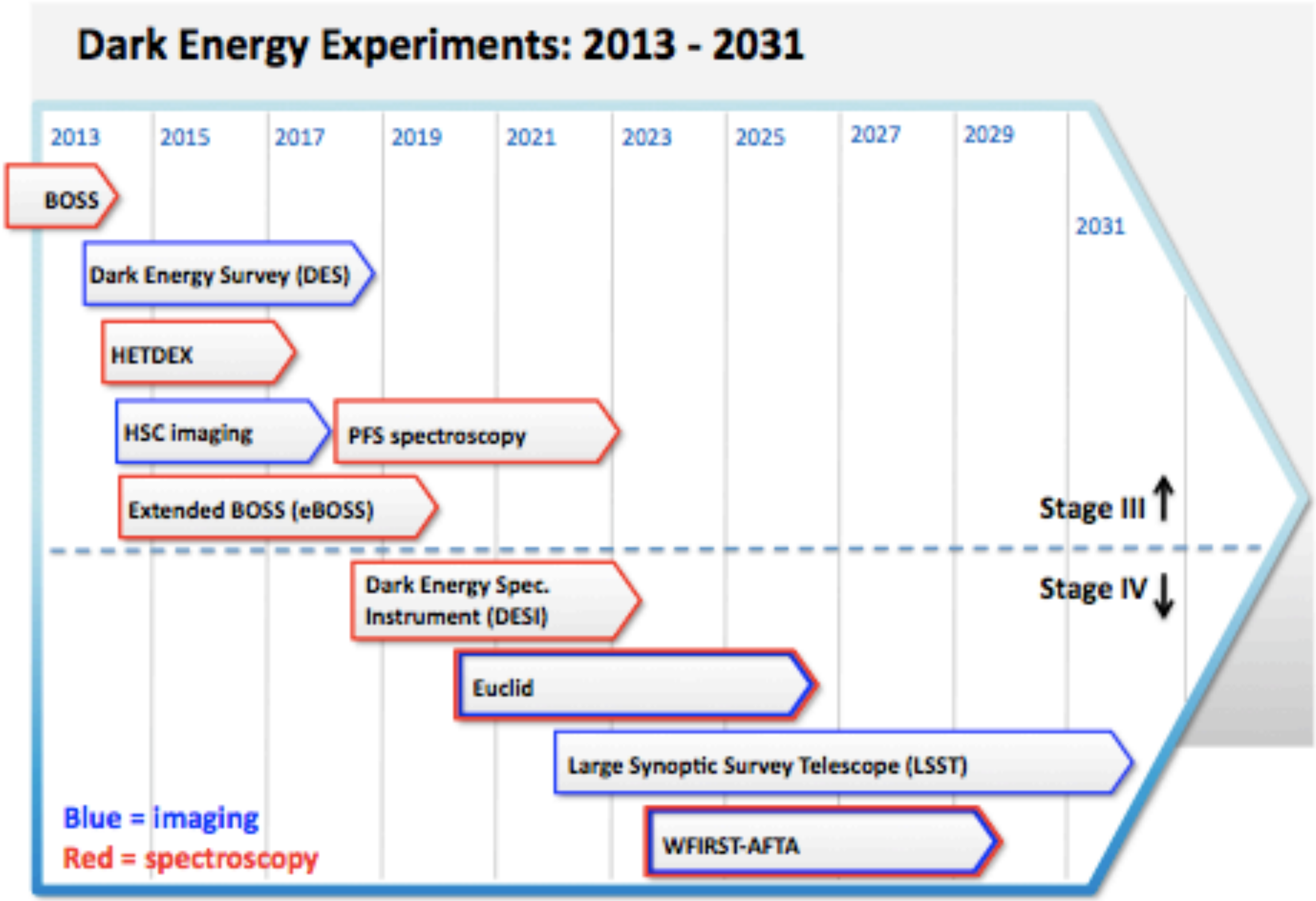
Planck 2015 (top), other B mode probes (bottom)

There are a lot of CMB polarization experiments already under way or very far along

- ACT
- KECK
- CLASS
- EBEX
- PIPER
- PIXIE
- POLARBEAR
- SPTpol
- SPIDER
- LSPE
- .....

Forecasted sensitivities around
$r \sim 10^{-2} – 10^{-3}$
Fluid situation

LARGE-SCALE-STRUCTURE SURVEYS AND DARK ENERGY



Over the next 10 years or so study of galaxy clustering will be a major focus for Cosmology that will involve a significant fraction of the community worldwide and **will trigger major theoretical and technical advances** towards a better understanding of the Dark Energy, Dark Matter and Non-standard gravity issues, **inevitably involving theoretical and particle Physics**.

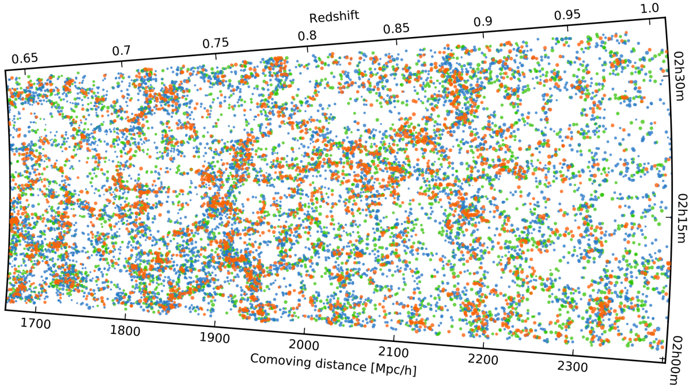
Cosmology with large galaxy surveys

$$ds^2 = -a^2(\tau)\left[(1+2\Psi)\,d\tau^2 - (1-2\Phi)\,d\vec{x}^2\right]$$

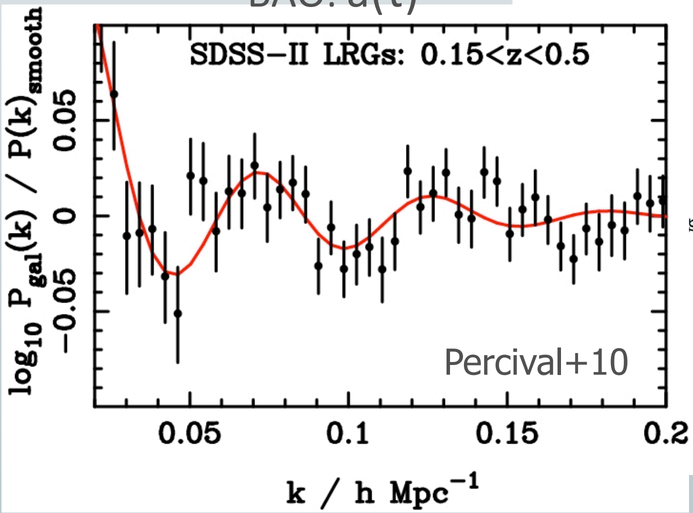
Ψ : governs motion of matter

Φ : governs motion of light

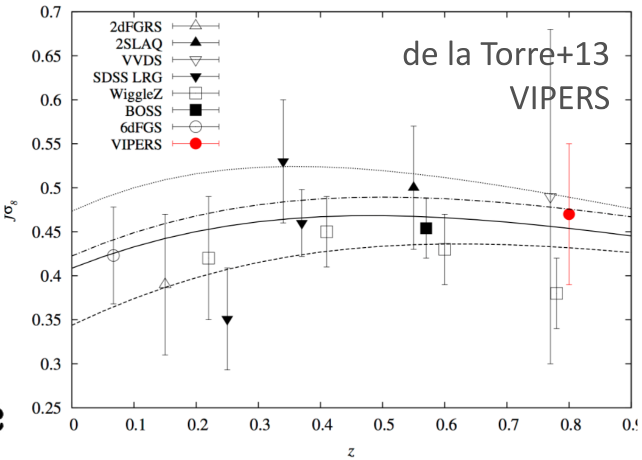
$\Phi = \Psi$ for GR



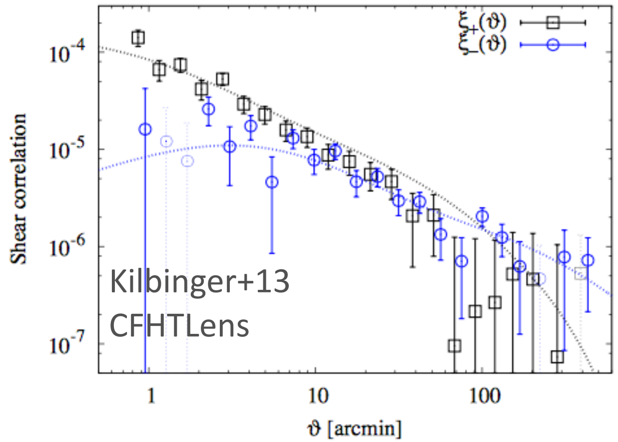
BAO: a(τ)



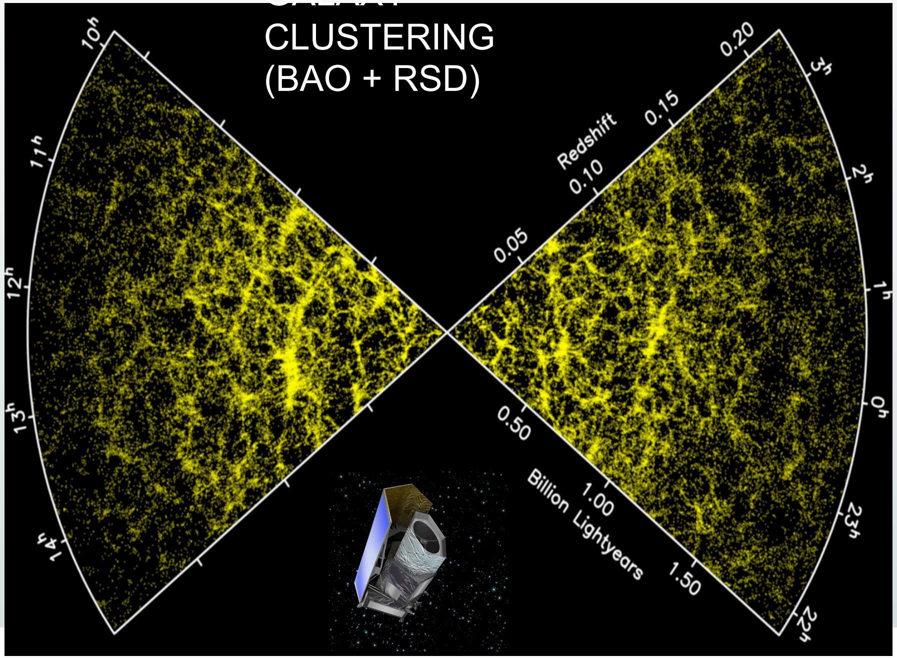
RSD: Ψ

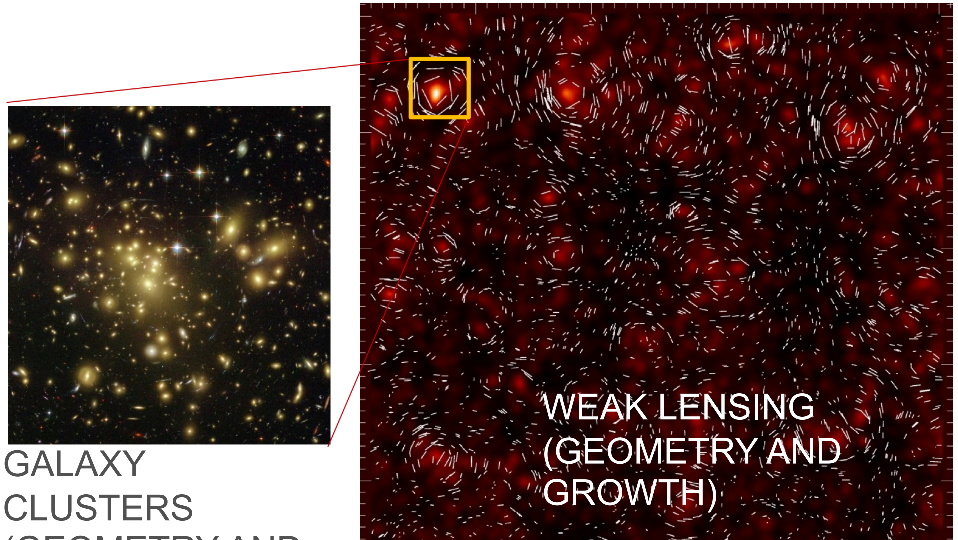


Cosmic shear: $\Phi + \Psi$



Euclid – THE cosmology experiment





GALAXY CLUSTERS (GEOMETRY AND GROWTH)

- Visible imaging (1 band)
- Infrared imaging (Y,J,H)
- Infrared slitless spectroscopy
- Approved 2011; Launch 2020

- 15,000 deg^2 survey
- Images for $2x10^9$ galaxies
- Spectra for ~5 x 10^7 galaxies (0.9<z<1.8)

Objectives:
- Build a map of dark and luminous matter over 1/3 of the sky and to z~2
- Unveil the nature of dark matter
- Trace the origin of cosmic acceleration
- Use multiple probes → max control over systematic errors

Euclid – expected results

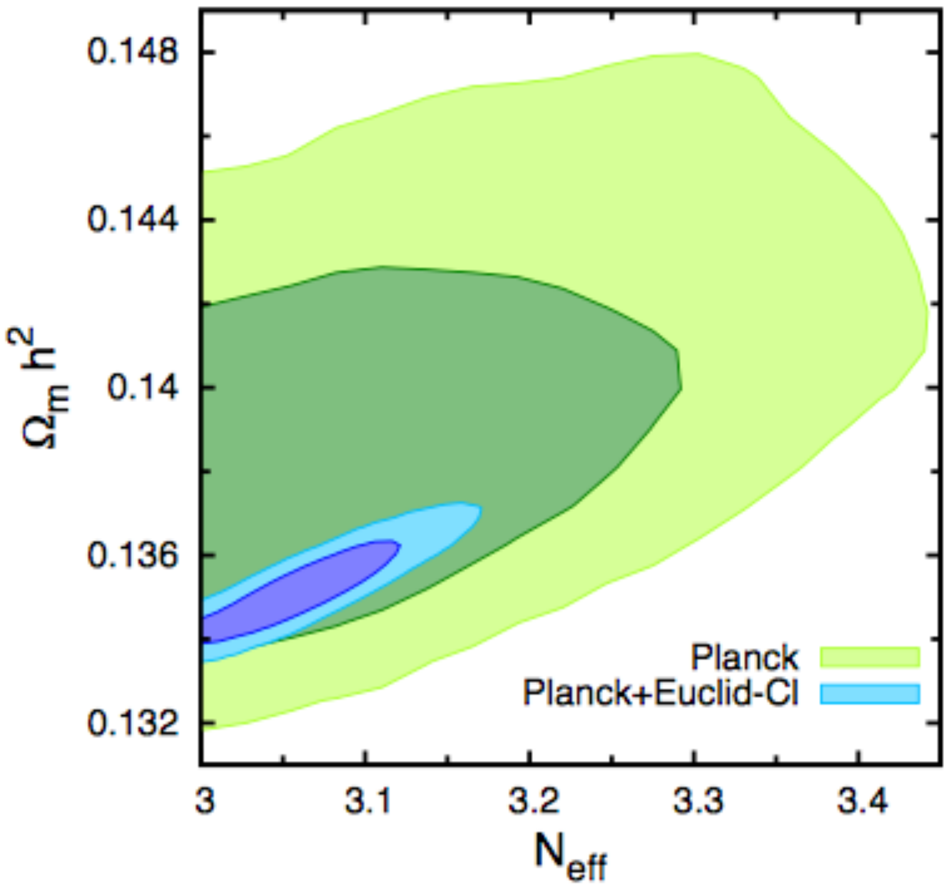
	Modified Gravity	Dark Matter	Initial Conditions	Dark Energy		
Parameter	γ	m_ν /eV	f_{NL}	w_p	w_a	*FoM*
Euclid primary (WL+GC)	0.010	0.027	5.5	0.015	0.150	430
Euclid All	0.009	0.020	2.0	0.013	0.048	1540
Euclid+Planck	0.007	0.019	2.0	0.007	0.035	4020
Current (2009)	0.200	0.580	100	0.100	1.500	~10
Improvement Factor	**30**	**30**	**50**	**>10**	**>40**	**>400**

Ref: Euclid RB arXiv:1110.3193

Assume systematic errors are under control

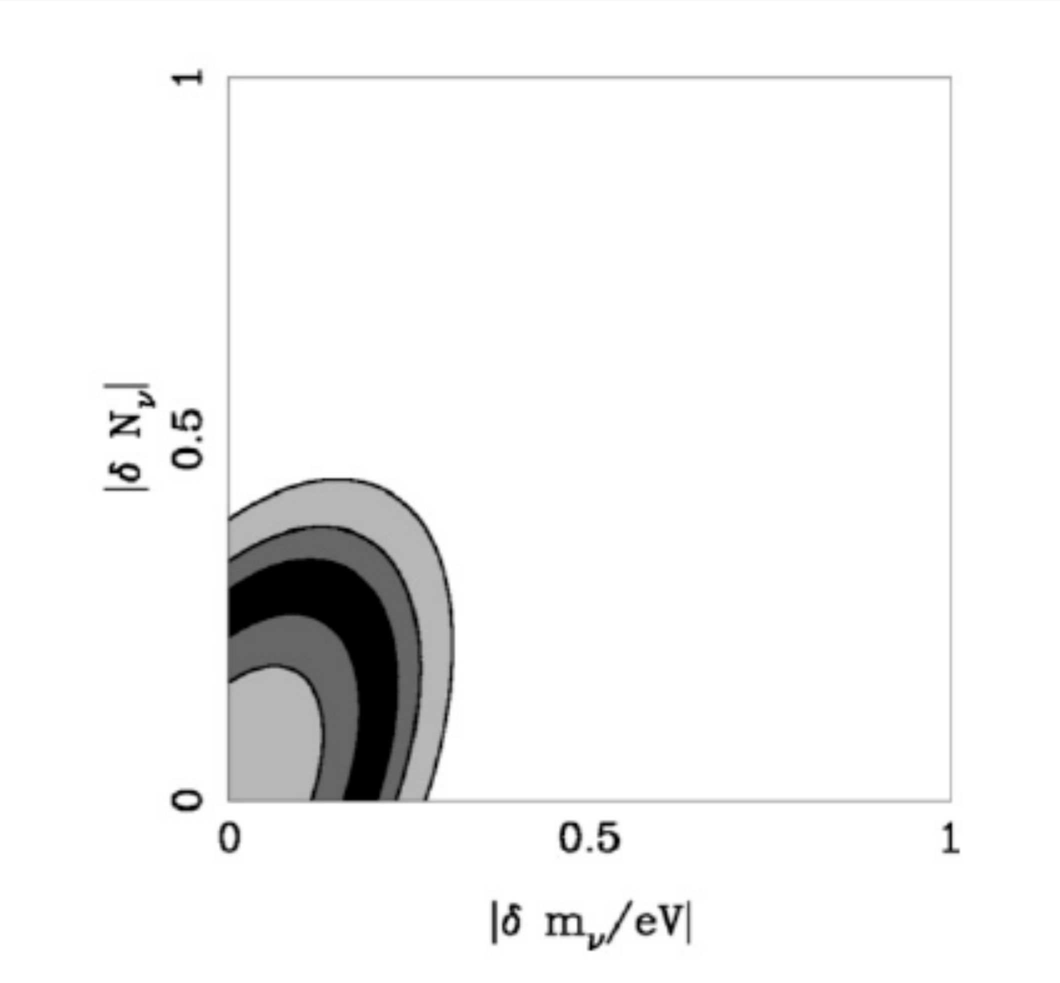
Example: Euclid survey of galaxy clusters

Costanzi (2013) JCAP 06 020



A. Biviano, S. Borgani, M. Costanzi, B. Sartoris, M. Viel

Example: Euclid and neutrino physics



Planck+Euclid
(Kitching et al.2008)

Δm_ν~0.03 eV & ΔN_ν~0.08

The Square Kilometer Array

https://www.skatelescope.org/

New re-baselining (as of March 2015)

SKA1-Mid

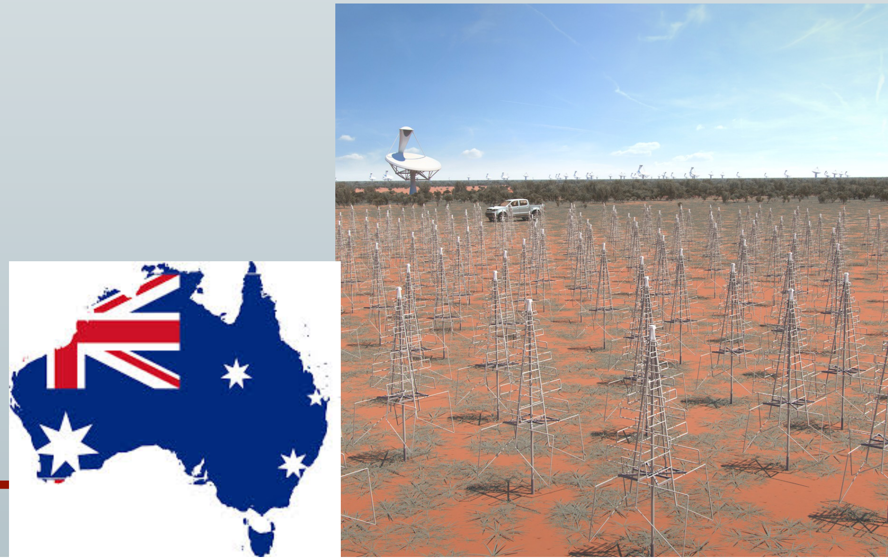
➔ Freq. range: 300 MHz - 15 GHz

➔ 130 15m dishes in South Africa

SKA1-Low

➔ Freq. range: 50-350 MHz

➔ ~ 130.000 low-frequency dipoles in Australia



2018-2023: Construction of SKA1;
2020+ SKA1 Early Science

SKA – Surveys for Cosmology

1. **HI Intensity Mapping** [BAO, super-horizon, etc.]
   All-sky (3π sr); **low-resolution >30'**; 0<z<3

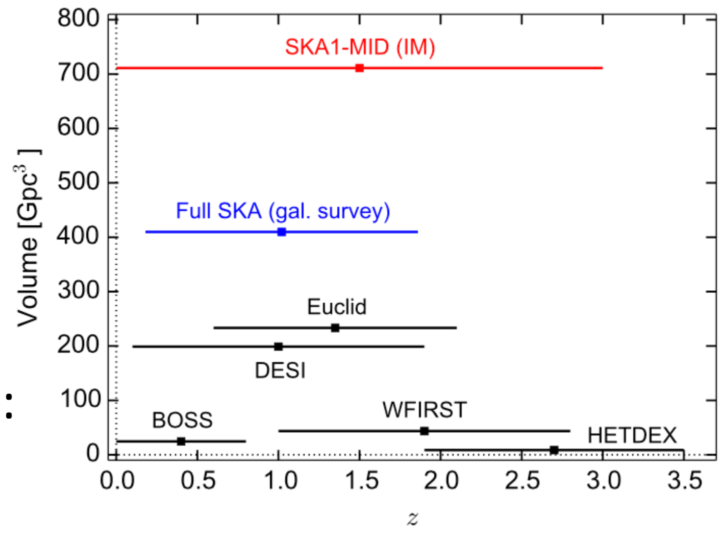
2. **HI Threshold:** galaxy redshift survey [BAO, RSD]
   SKA1: 5 10^6 gals @ z<0.5
   SKA2: ~10^9 gals @ z<2

3. **Continuum** [weak lensing, angular clustering, ISW]:
   - ➔ All-Sky Survey (~ 1-2" res.)
   - ➔ Weak Lensing Survey (0.5" res.):

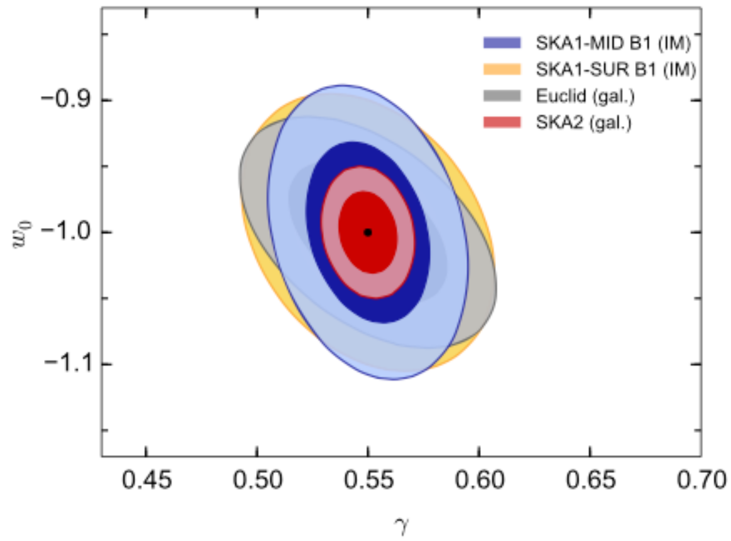
   NB: Commensality with HI/Continuum surveys for galaxy evolution

Euclid + SKA: huge synergies
→ Scientific: smaller volume higher res. vs large volume low-res, complementary constraints, multi-tracers, etc.
→ Programmatics: e.g. simulations, likelihood definitions and coding, etc.

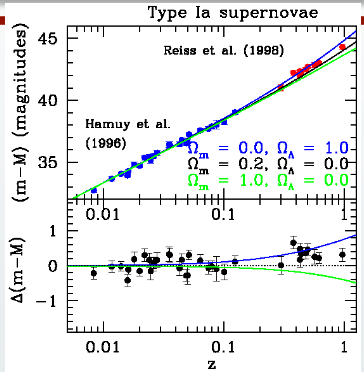
Maartens+15



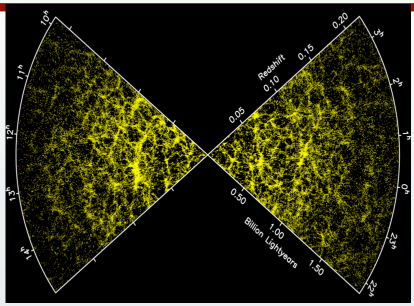
Raccanelli+14



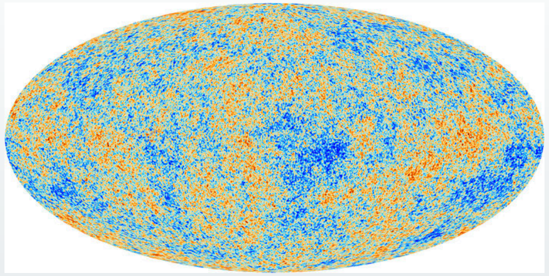
SN-Ia + CMB + surveys: a single experiment



+

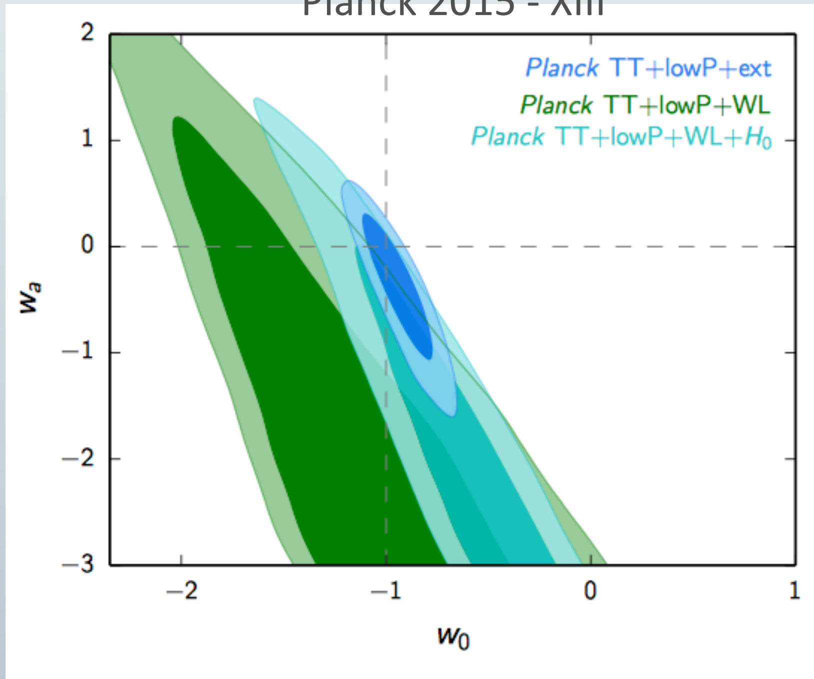


+

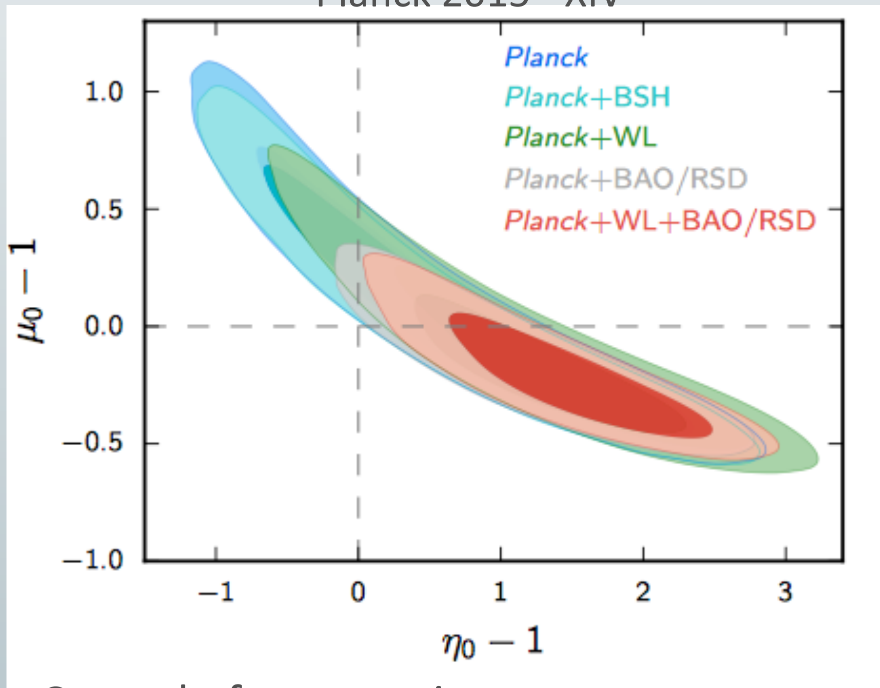


The combination is much more than the sum of the parts

Planck 2015 - XIII



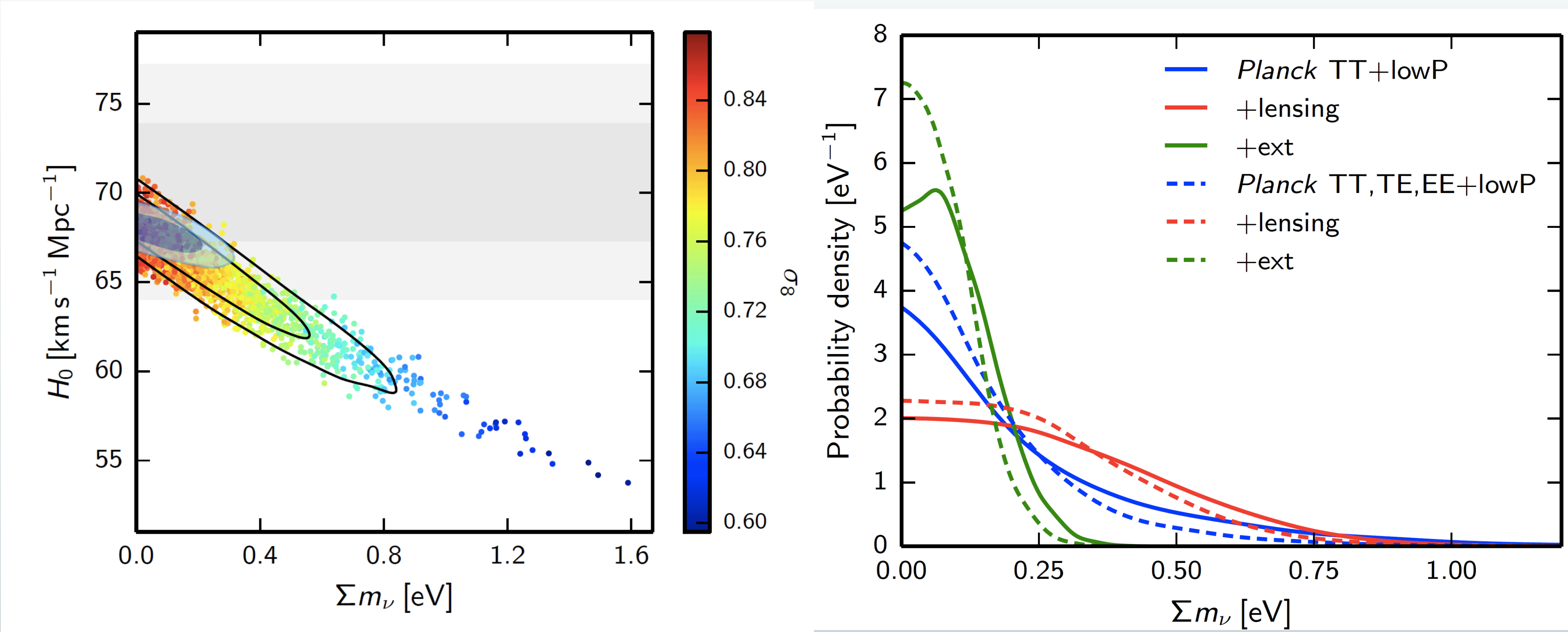
Planck 2015 - XIV



Signatures of new physics → Control of systematics

COSMOLOGICAL CONSTRAINTS ON NEUTRINOS

Planck constraints on neutrino masses

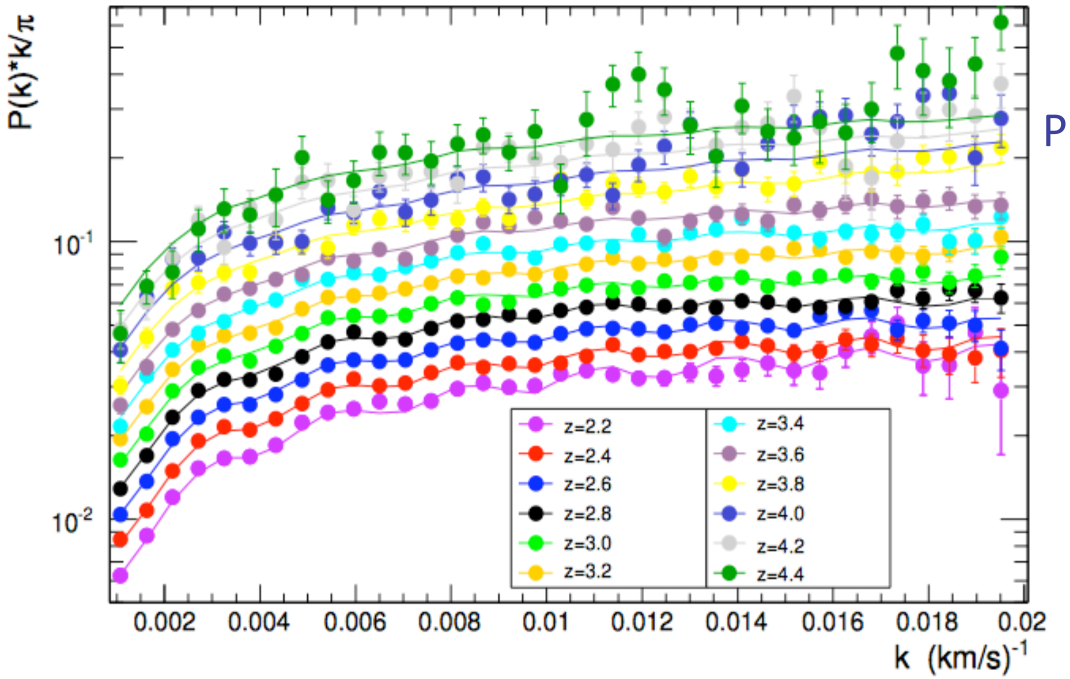


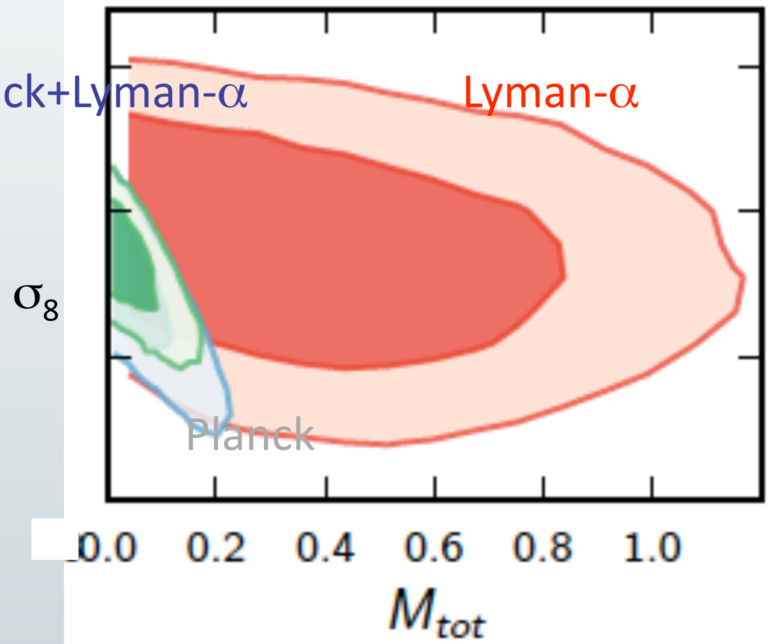
$\Sigma m_\nu < 0.23$ eV (95% CL)

$N_{eff} = 3.15 \pm 0.23$

Tightest constraints on neutrino total mass

IGM Lyman-α flux power spectrum

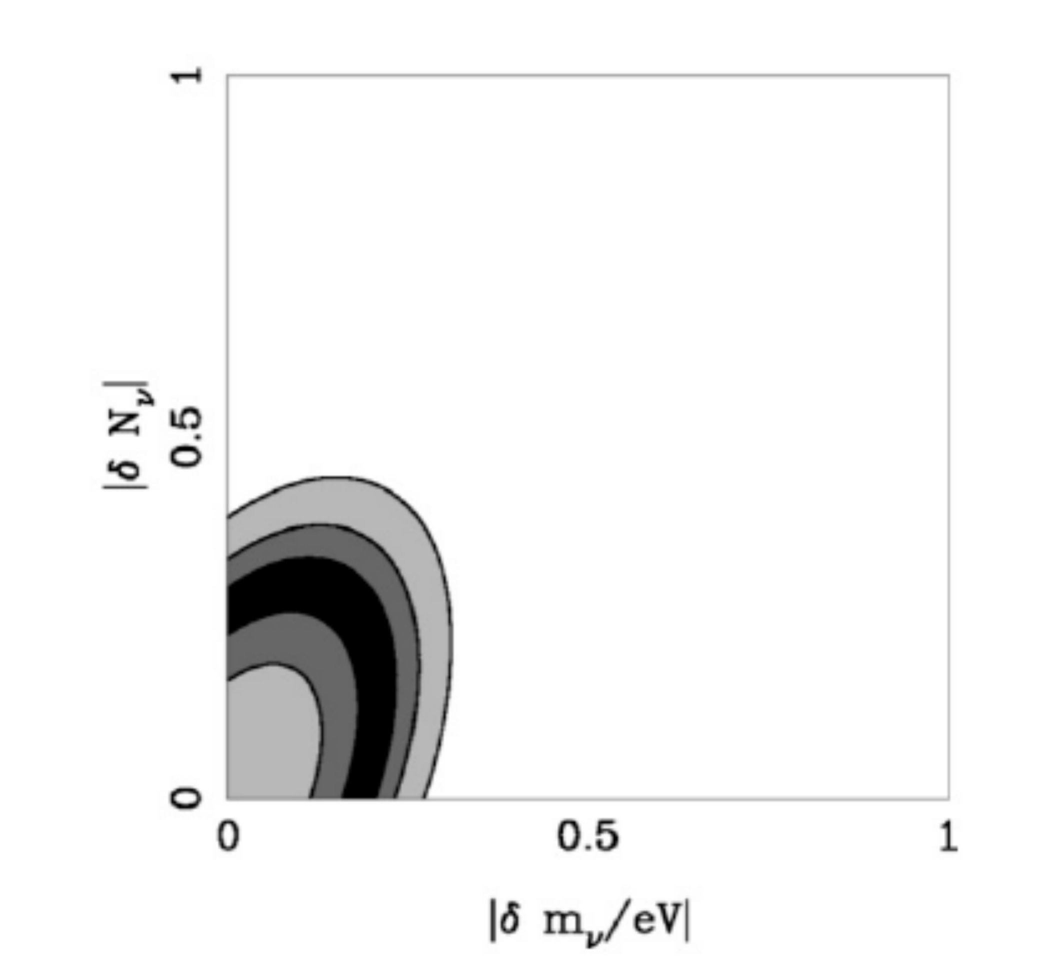




$\Sigma\, m_{\nu} < 0.14$ eV (C.L)

from SDSS-III/BOSS collaboration Palanque-Delabrouille et al. 14

Example: Euclid and neutrino physics



Planck+Euclid
(Kitching et al.2008)

Δm_ν~0.03 eV & ΔN_ν~0.08

OPPORTUNITIES

INFN E EUCLID

- Finita la fase esplorativa per entrare in Euclid: due gruppi INFN PD e BO hanno iniziato attivita` mirate alla parte strumentale con un adeguato finanziamento

- Partecipazione all'integrazione hardware/software di moduli del NISP, con schedule 2015-2017

- Risposta positiva dall' INAF e dall'Euclid Consortium

- Interessante esempio/esperimento di collaborazione tra enti di ricerca (comunita` scientifiche) con know-how diversificati.
  Sono gia` molte le competenze in questo ambito di ricerca presenti all'interno dell'INFN attraverso alcune IS astroparticellari.

OPPORTUNITIES

INFN e EUCLID

Individuate alcune aree per un possibile contributo INFN nell' ambito delle responsabilità italiane in Euclid

– integrazione SW di bordo nell'HW delle unità di qualifica e di volo per Data Processing Unit (DPU) e per Instrument Control Unit (ICU) del Near Infrared Spectro-Photometer (NISP)

– integrazione e test delle unità di warm electronics di NISP con qualifica funzionale e verifica delle performance presso laboratori INFN

– contributo alle attività di sviluppo del SW di bordo

– attività di system engineering della warm electronics del NISP

OPPORTUNITIES

INFN E *Planck*

- Interesse dell'INFN per coinvolgimento con *Planck*
- Valutazione di possibile attività sinergica con *Planck* per acquisire know-how and expertise in data analysis
- Sono già state individuate delle tematiche di lavoro (primordial non-Gaussianity; limiti sulle ,masse dei neutrini;likelihood)
- Positivi riscontri da parte della Collaborazione *Planck.* Possibilita' che l'INFN partecipi alla release finale dei dati di PLANCK (nov. 2015)

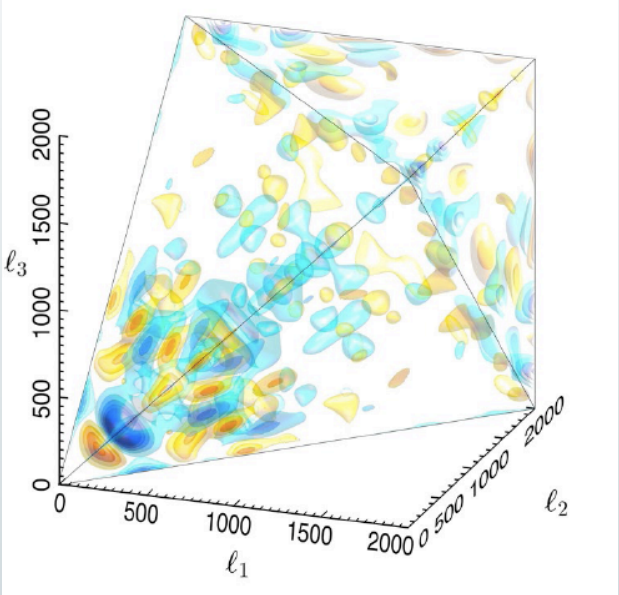
OTHER EXAMPLES OF CONCRETE PROJECTS

- Primordial NG
- Measuring the cosmic expansion (the Sandage effect)
- NEPhUS (effetti di non-equilibrio termodinamico nella radiazione cosmica di fondo)

NEW PATHWAYS TO (PRIMORDIAL) NON-GAUSIANITY

N.B,Michele Liguori , Sabino Matarrese, Padova

The CMB bispectrum as seen by Planck



Planck 2013 results. XXIV. Constraints on primordial non-Gaussianity

$$f_{NL}(local) = 2.5 \pm 5.7$$
$$f_{NL}(equilateral) = -16 \pm 70$$
$$f_{NL}(orthogonal) = -34 \pm 33$$

- **Primordial non-Gaussianity (NG) is a crucial observable to test the Physics of inflation. It tests interaction terms in the inflaton Lagrangian.**
- Best constraints to date come from observations of CMB anisotropies (*Planck*).
- But a lot of information can be extracted from LSS data. Euclid will be able to achieve a sensitivity to f_{NL}=2.

A *crucial* prediction of Standard Single Field Inflation: f_{NL}~ 0.01 ~O(ε,η)

Acquaviva et al 2002; Maldacena 2002.

(PRIMORDIAL) NON-GAUSSIANITY: MANY OPEN QUESTIONS

1. **Can we in the future achieve the sensitivity to test f_{NL}(local) ~ 0.01?**
   IT WOULD BE ANOTHER FUDAMENTAL TEST OF STANDARD MODELS OF INFLATION.

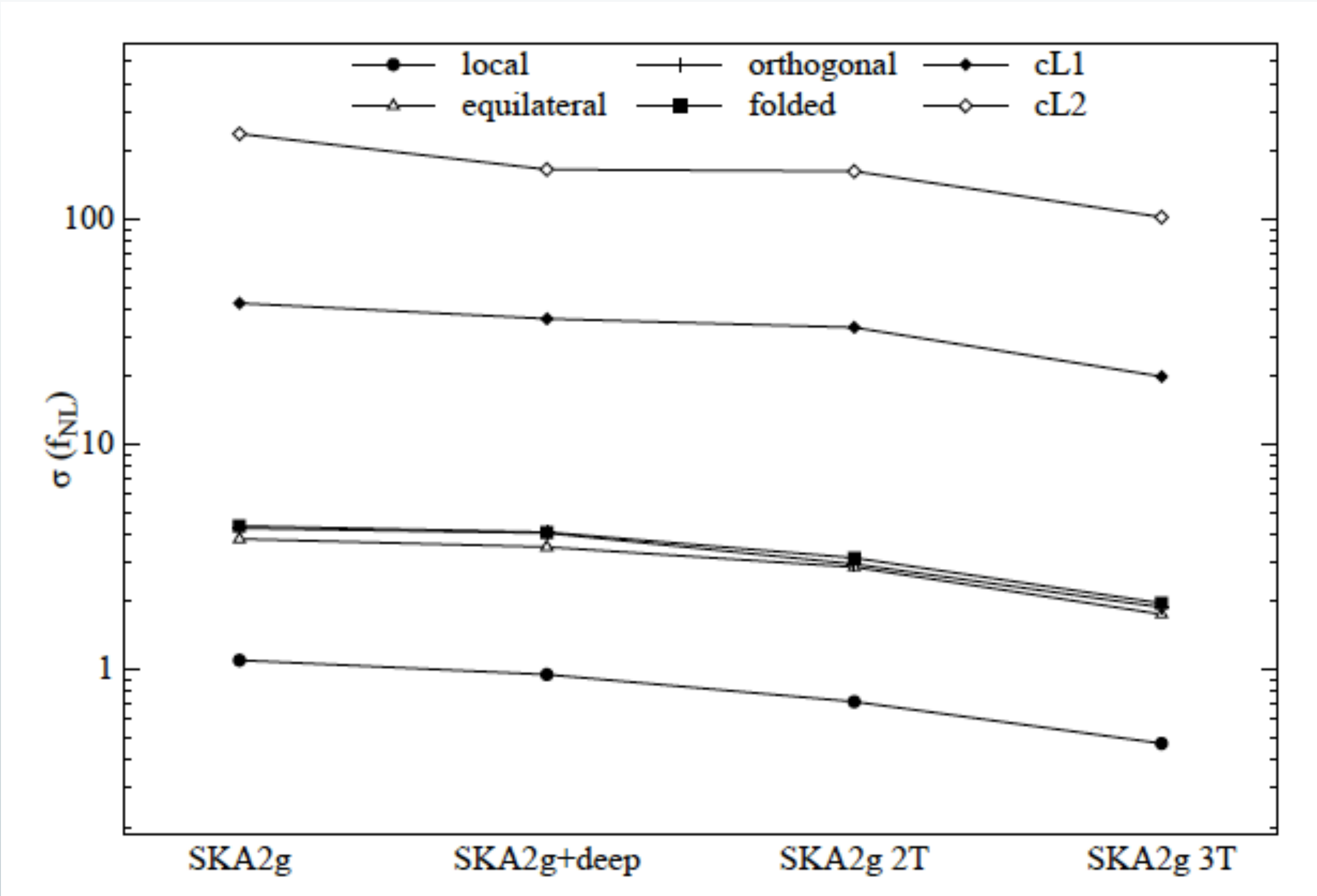
   - LSS: scale dependent halo bias+bispectrum
   - CMB: spectral distortions
   - 21 cm: Physics under control

2. **Are there missing shapes/parameters to test in current and forthcoming polarization CMB datasets? Yes!**
   e.g. Very little work so far on Trispectrum (g_{NL},τ_{NL})

3. **Can we use NG to test gravity? What about 3-point function of tensor perturbations?**

N.B, Michele Liguori , Sabino Matarrese, Padova

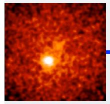
NEW PATHWAYS TO (PRIMORDIAL) NON-GAUSIANITY: AN EXAMPLE WITH SKA

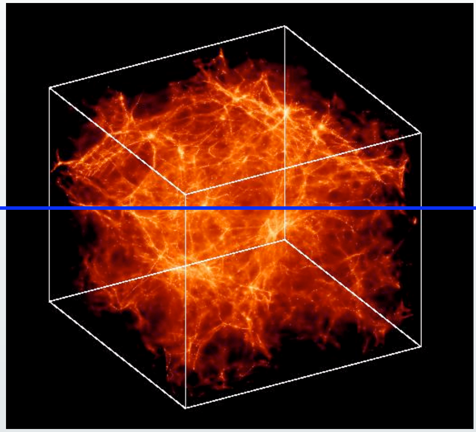


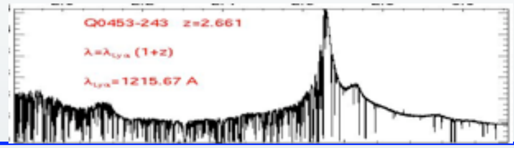
In collaboration with Raccanelli, M Shiraishi, D. Bertacca, S. Matarrese

NOW: σ(f_NL equilateral)~70 from *Planck*→ σ(f_NL equilateral)~3 with a SKA like survey

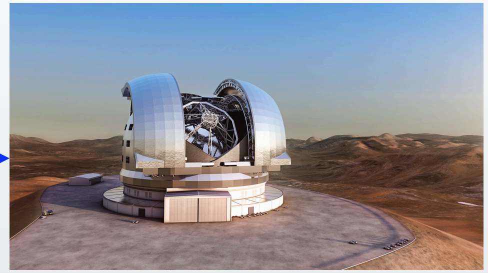
Measuring cosmic expansion with HIRES@E-ELT







Lyman-alpha forest

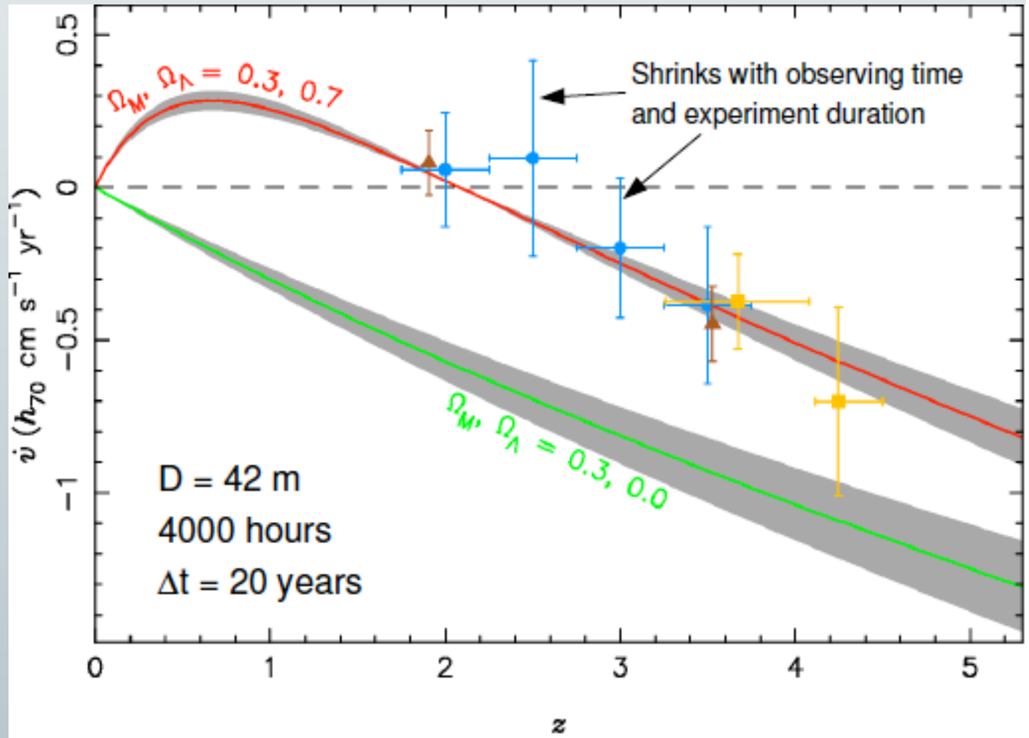


3 different observing strategies:
Best constraints on Ω_{Λ}, smallest σ_v, largest signal

Cosmic expansion measured in real time by comparing spectra of QSO taken >10 years apart and by looking at shifting of Lyman-alpha forest lines: *unique and model independent probe* of the universe global dynamical state i.e. measure of a(t)

$$\dot{z} = (1+z)H_0 - H(z)$$

$$\dot{v} = \dot{z}c/(1+z)$$



Sandage 1962, Loeb 1998, Liske+ 08

NEPhUS: Non Equilibrium Physics and the Universe Sciences

``The ultimate goal of NEPhUS is to enrich research on non-equilibrium (NE) phenomena, by providing new fields of application, experimental results, numerical models and theoretical reasoning. NE research has not yet led to a general theory but already finds countless applications in modern science and technology.
Physical systems which are not at thermodynamic equilibrium show peculiar effects which are absent at equilibrium: one such phenomenon is the NE enhancement of fluctuations.
Differently from present understanding, NEPhUS argues its presence even in two fields of the Universe Sciences which are scarcely investigated by research on NE systems: the Cosmic Microwave Background (CMB) and the Gravitational Wave (GW) detectors ''

Livia Conti in collaborazione con dr Carlo Burigana dell'INAF di Bologna
prof Lamberto Rondoni (Politecnico di Torino) e dr Marco Baiesi (Univ. Padova)

CONCLUSIONS

S and O of SWOT

- **Exciting physics to dig out**

- **Exciting LSS surveys are coming in the future**

- **CMB: need high quality CMB polarization data: Planck , balloons + ground based, post Planck**

Critical points:

- **Need expertise, in particular phenomenological, data analysis and interpretation. Benefit from Planck experience/legacy: the expertise acquired within Planck can also exploited for LSS analysis of data (e.g. 3-point correlation functions)**

- **Within INFN there are already the necessary expertise inside various IS**