FRONTIERE DELL'ASTROFISICA ITALIANA:

come ottimizzare il ritorno scientifico dalle grandi infrastrutture internazionali

18 - 19 Marzo 2015

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
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COSMOLOGY

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OUTLINE

PART 1 – Science overview (≈1/2 h)

1.1 High level scientific questions

1.2 How to address them

PART 2 – Introducing the discussion (≈1/2 h)

2.1 DM with CTA: the role of INAF

2.2 CMB experiments INAF

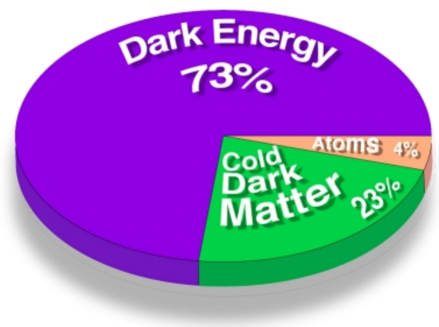
2.3 A INAF strategy for cosmological surveys

- Euclid
- SKA

2.4 The need for computing infrastrucures

PART 3 – Discussion (≈1 h)

High-level questions



- Nature of Dark Matter ?
- Nature of Dark Energy ?
- Behaviour of gravity at the largest scales ?
- Physics of the initial conditions (inflation) ?
- How constant are fundamental constants ?

Implications for the physics beyond

➔ the Standard ΛCDM Cosmological Model

➔ the Standard Model of particle physics

Lots of astrophysics to learn in the process!!

DM nature & cosmic structure formation

Breakthrough: unveiling DM nature (pressureless? condensate? self-interacting? etc.)

➔ candidates: SUSY/WIMPS, axions or axion-like, gravitinos, sterile neutrinos, etc.

Signatures:

➔ free streaming scale

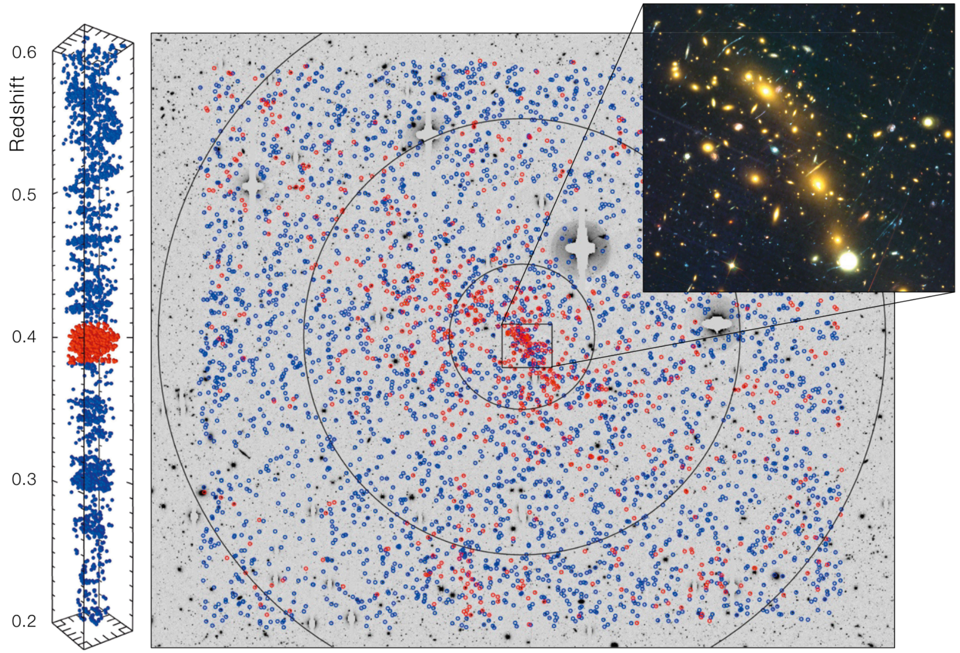
➔ effect on expansion history

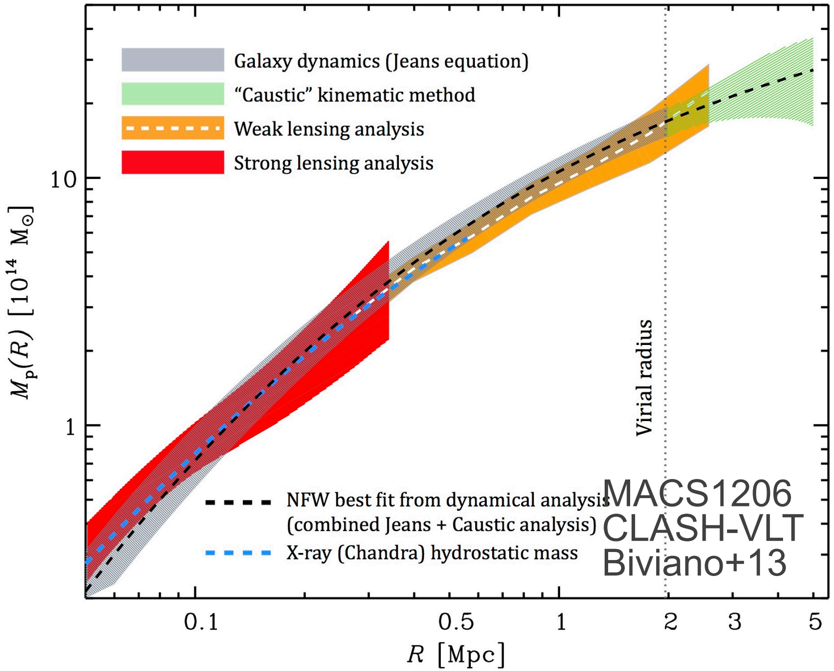
How to probe DM nature?

➔ Small-scale (<1 Mpc) observables:

- Dynamics of dwarf galaxies (e.g. **GAIA**) and groups/clusters (e.g. **CLASH**)
- Strong lensing in clusters and galaxies: **CLASH**, JWST, **Euclid**, LSST, WFIRST

➔ Medium scales (10-100 Mpc): galaxy clustering, weak lensing and IGM (**Euclid**, DESI, LSST, **SKA,** WFIRST)





DM nature & cosmic structure formation

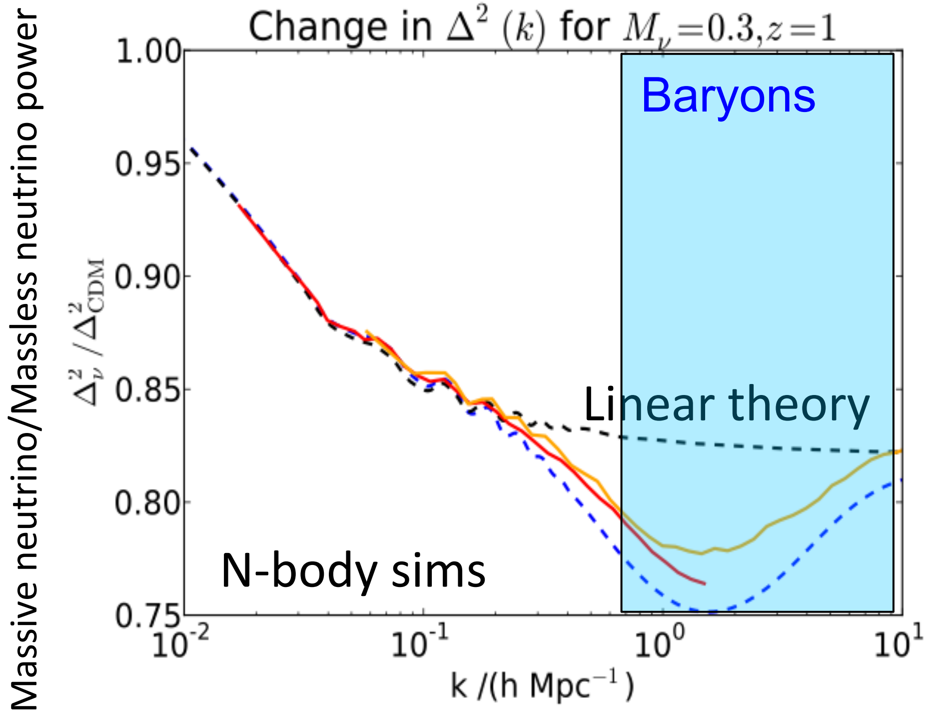
Neutrino masses: constrained by cosmology to a precision higher than particle physics experiments:

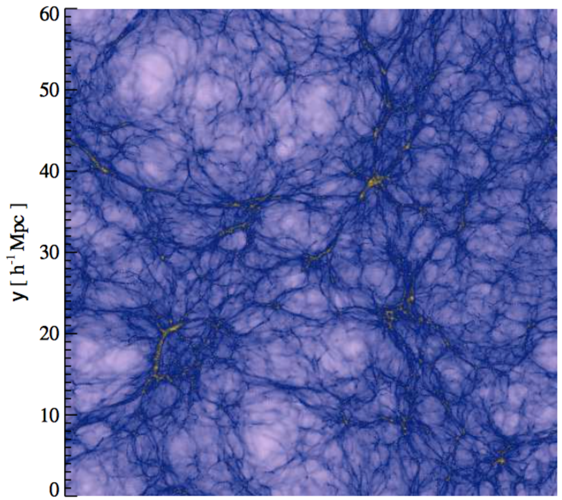
Particle physics: 0.06 eV < m_ν <6 eV
Cosmology: m_ν<0.3 eV

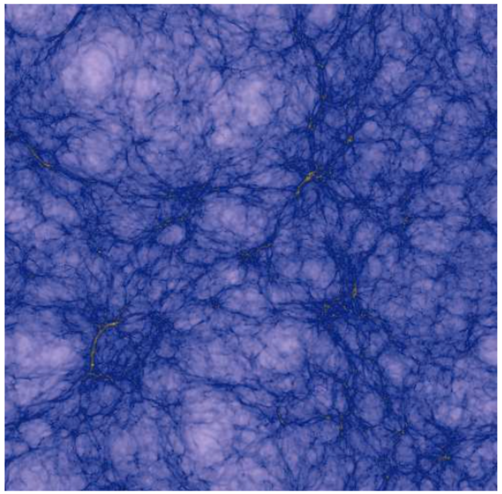
From dynamical probes (galaxy/IGM) + CMB

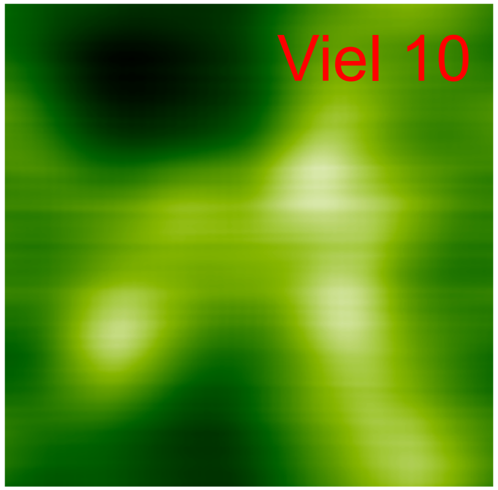
➔ Medium-large scales: low res. investigations with lots of statistics (i.e. SDSS, **Euclid, SKA,** WFIRST)

➔ Small scales: high res. investigations (i.e. **HIRES**, strong lensing **Euclid, GAIA,** WFIRST)









DM indirect detection in γ- and X-rays

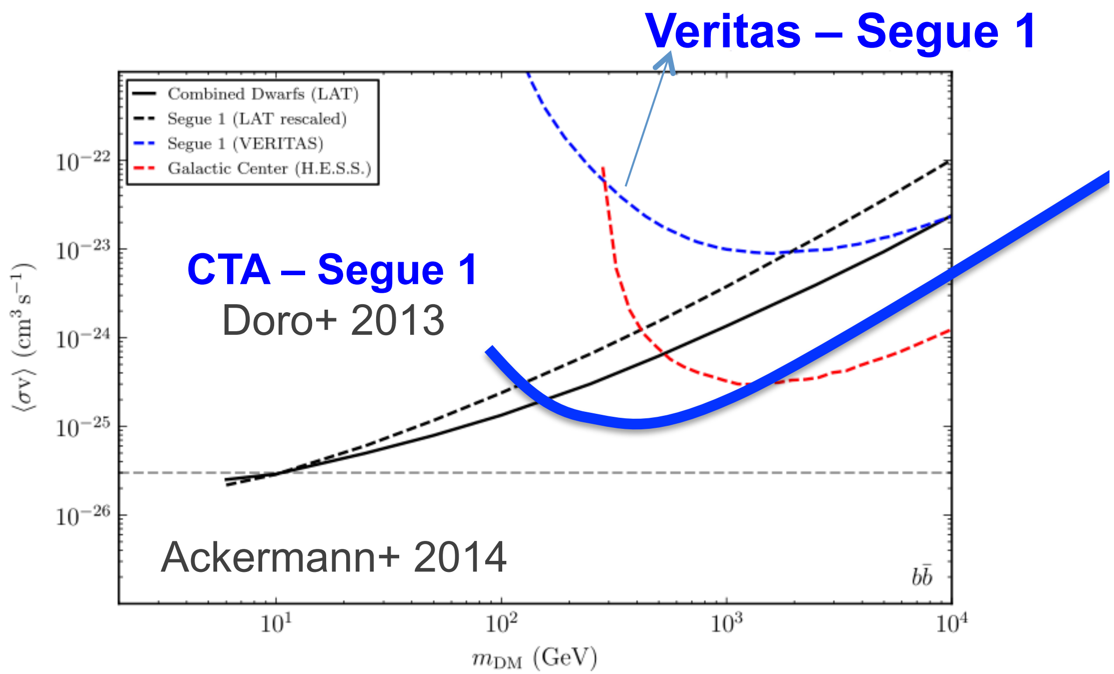
γ-ray range as the "golden channel" for ID

➔ Huge scientific success of Fermi, able to set DM strong constraints:

- **The energy spectrum of the diffuse gamma-ray background (see plot)**
- Gamma-ray flux from
  - Milky Way satellites
  - galaxy clusters
- Anisotropies in the diffuse gamma-ray background and extragalactic sources
- "Fermi excess" from the Galactic Center

➔ These constraints apply to DM candidates lighter than ~ 1TeV.

➔ CTA to push this limit to higher masses



Soft X-rays: detection of a decaying DM particle (e.g. sterile neutrinos at ~3.5 keV) ➔Spectral resolution and coll. area of Athena ideal for this DM search

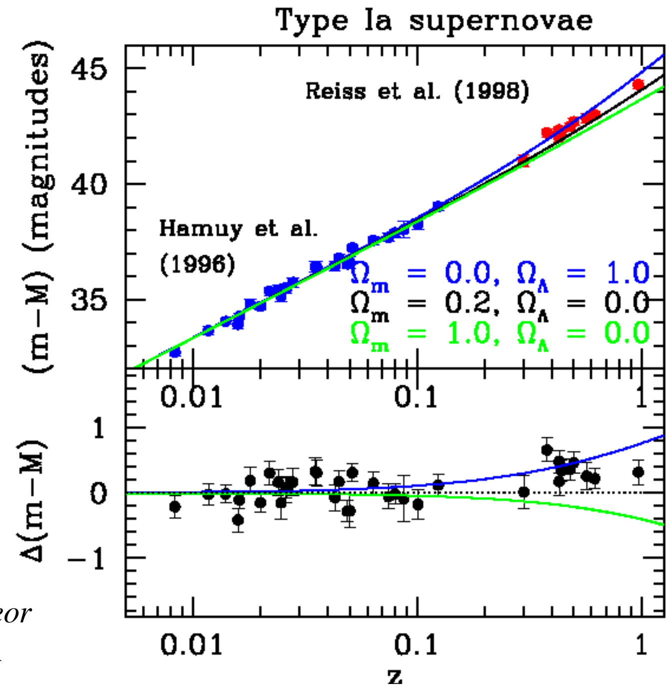
Hard X-rays: next generation optics for improved sensitivity and resolution up to 300 keV

Dark Energy

Why?
To explain accelerated expansion

$$\frac{\ddot{a}}{a} = -\frac{4\pi G}{3}\left(\rho + \frac{3p}{c^2}\right) \qquad p = w\rho c^2 \ ; \quad w < -1/3$$

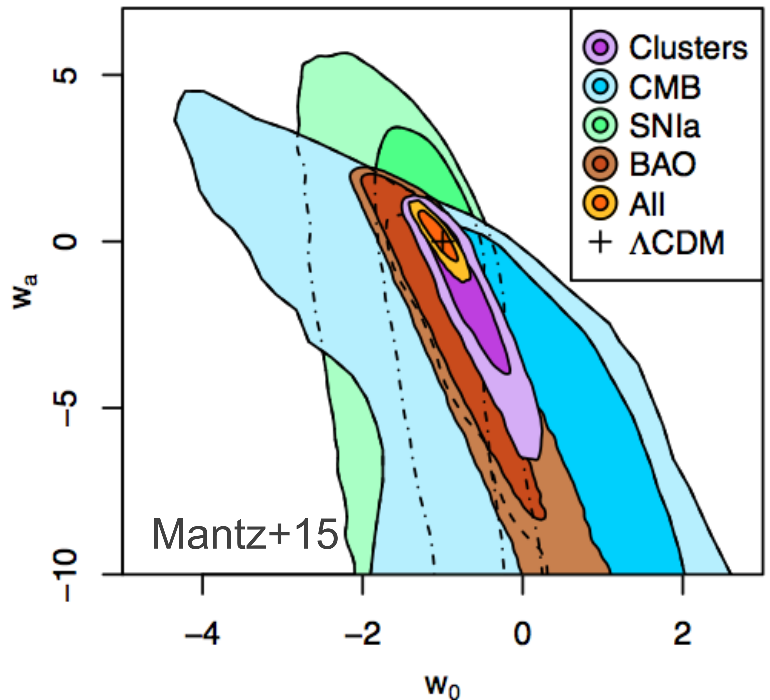
$w = -1$: Cosmological constant
Agrees with all data



Which physics?
Don't know, but should explain why $\rho_\Lambda^{oss} \simeq 10^{-120}\,\rho_\Lambda^{teor}$
$w(z) \neq -1$ as a signature of this physics

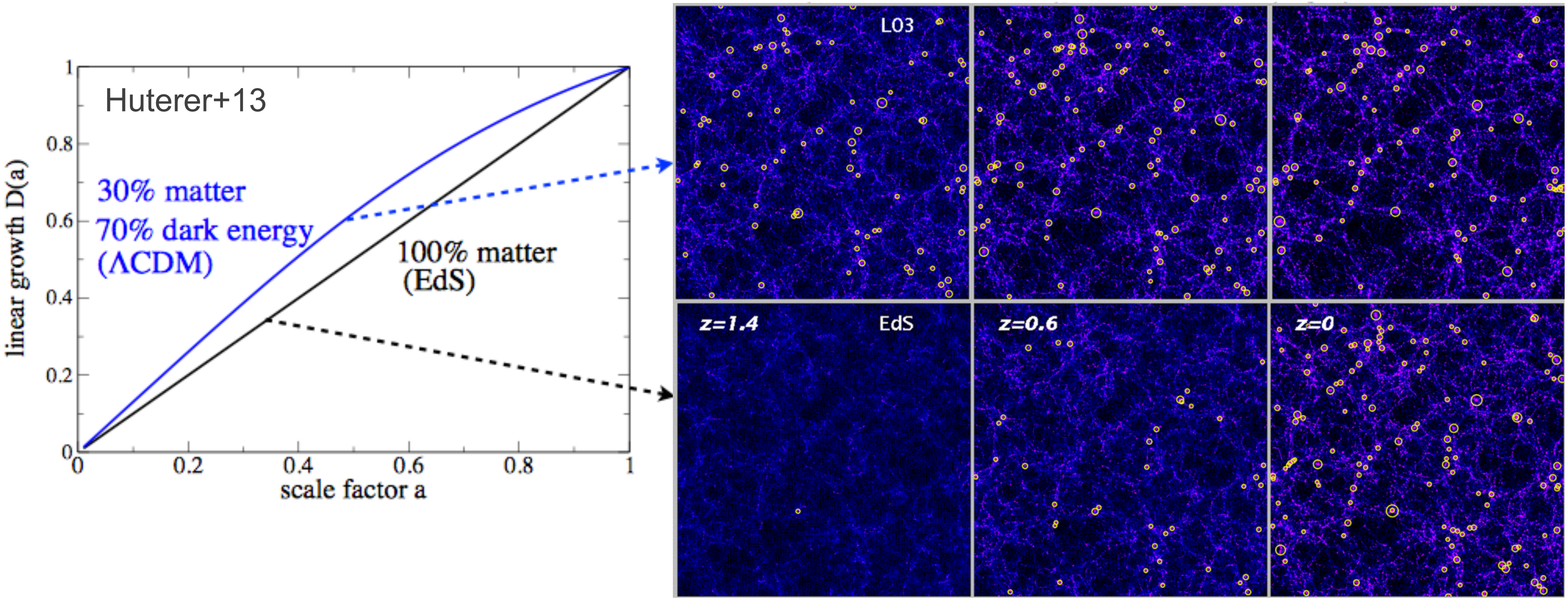
Signatures:
- expansion rate: SN-Ia, BAO, CMB
- evolution of density inhomogeneities: RSD, cosmic shear, galaxy clusters, ISW, ...

Key science driver of all ongoing and future surveys: DES, eROSITA, DESI, LSST, **Euclid**, **SKA**, WFIRST



Expansion and Growth

➔ One-to-one relationship between expansion and growth

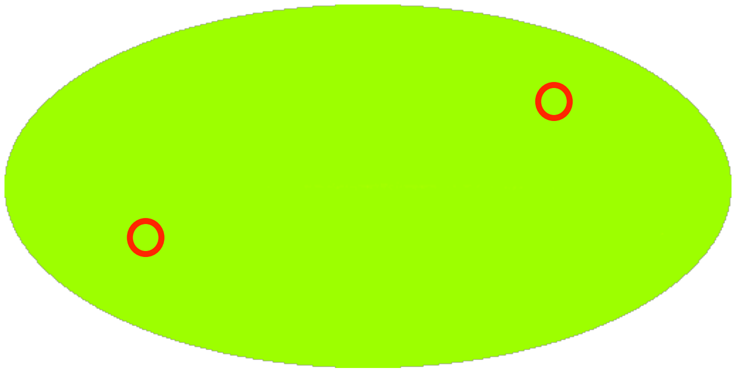


Inconsistencies between expansion and growth

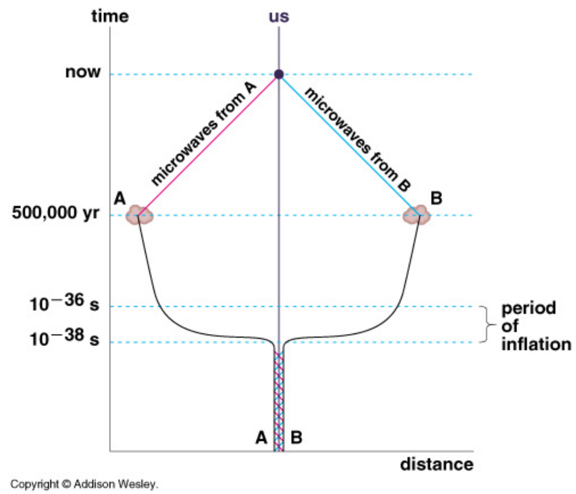
➔ Signature for new physics

Initial conditions: inflation

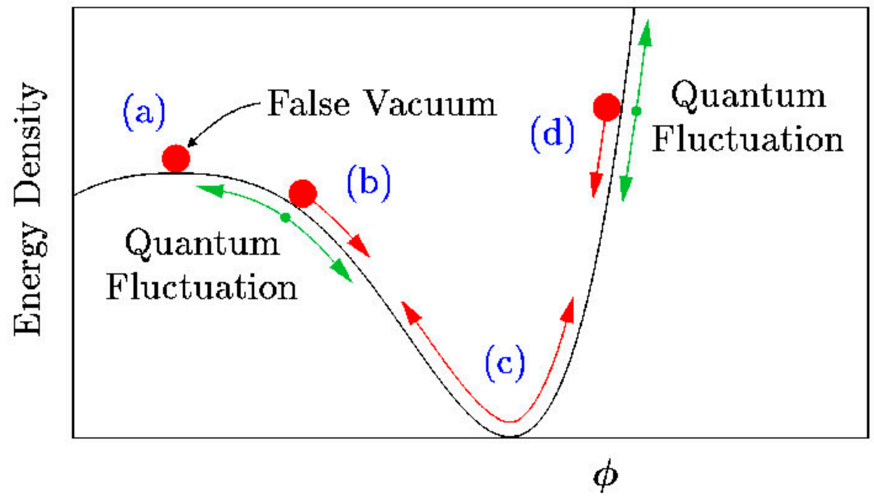
Why? To solve the "horizon problem"



How? Phase of accelerated expansion



Which physics? Expansion dominated by "false vacuum" energy in the potential of a scalar field, slowly rolling to the "true vacuum"



Features and predictions:

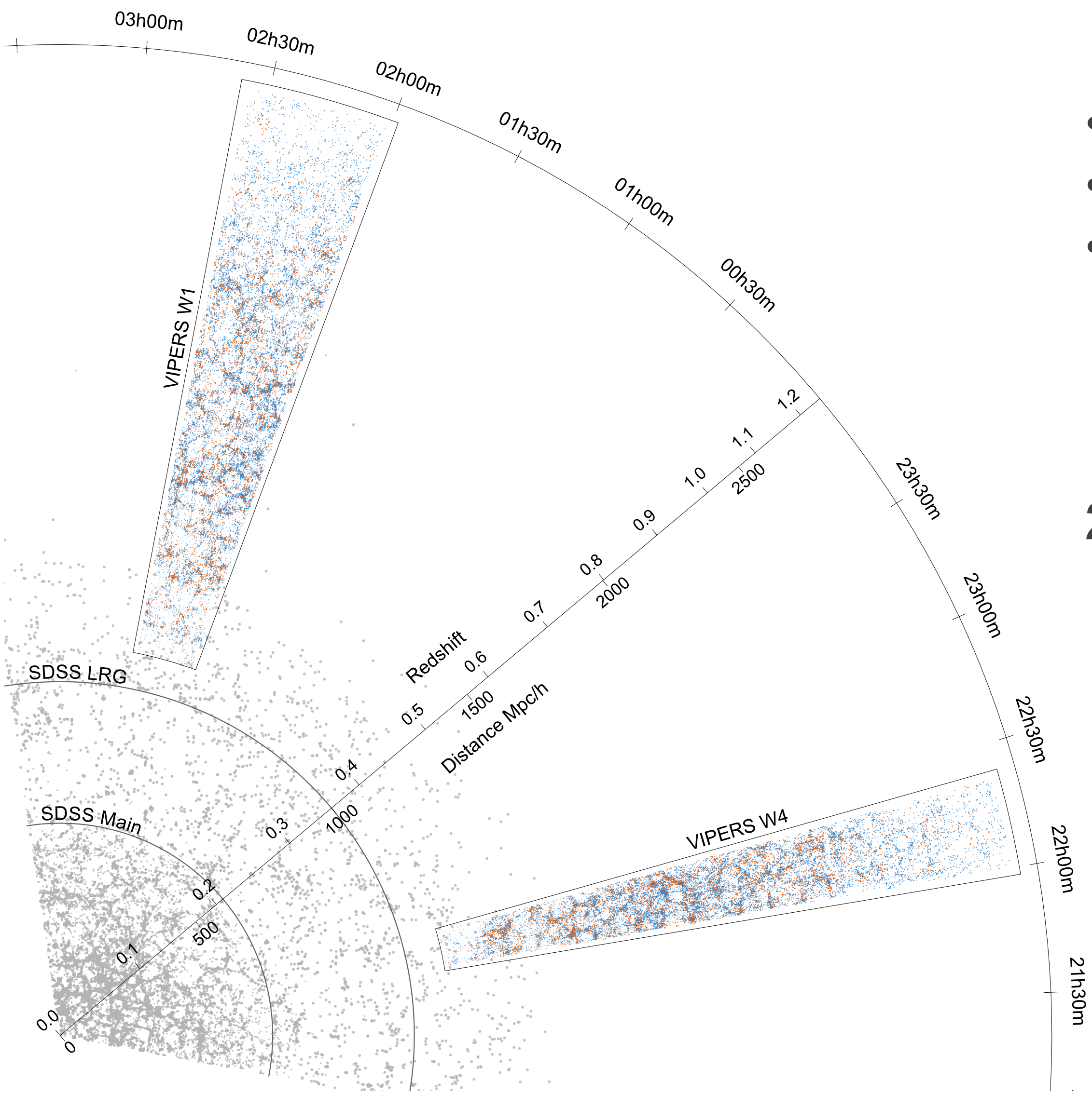
- ➔ No topological defects within the horizon
- ➔ ~ flatness $\Omega_k \sim 0$
- ➔ ~ Gaussian density perturbations $f_{NL} \sim 0$
- ➔ Spectrum of density perturbations: $P(k) \sim k^n$; $n \sim 1$, $dn_s/dk \sim 0$
- ➔ Spectrum of tensor perturbations (GW): B-modes in the CMB polarization

- Agreement with all CMB and LSS data
- Precise measurement as a probe of physics of inflation

Large-scale multi-band imaging surveys

- **CFHTLS** (F): completed, 140 deg^2 in 5 bands, (e.g. CFHT-Lens project and weak-lensing shear results – basis for VIPERS)
- **Dark Energy Survey** (DES: US/UK/E + Munich LMU, ETH Zurich): started, 5000 deg^2 in 5 bands
- **VST-KIDS + VISTA-VIKING** (NL, I, D, …): started, 1500 deg^2 in 9 bands (from U to K)
- **LSST** (US-led consortium): dedicated 8m telescope, 20000 deg^2 (southern sky), in 6 bands (0.3-1.1 m), with time information
- **SUMIRE-PFS** (Japan + others): Subaru 8m prime focus, both imaging and spectroscopy, being defined
- [**Pan-STARRS**? (US, UK, D, …)]: started, but unclear future developments

Redshift surveys: different strategies



1. **Cosmology-focused: maximise volume, sparse tracers: e.g. SDSS-LRG, BOSS, WIGGLE-Z**

- Detect BAO
- Trace redshift-space distortions
- Large-scale violation of ΛCDM (non-Gaussianity, GR modifications)

2. **Higher sampling/smaller volume: Magnitude-limited: 2DFGRS (z<0.2), SDSS, VIPERS (z~1), MOONS@VLT(z~1-2)**

<n> ~20-100 times BOSS

- Detailed studies of non-linear structures (groups, voids)
- Connection between galaxy formation and large-scale structure

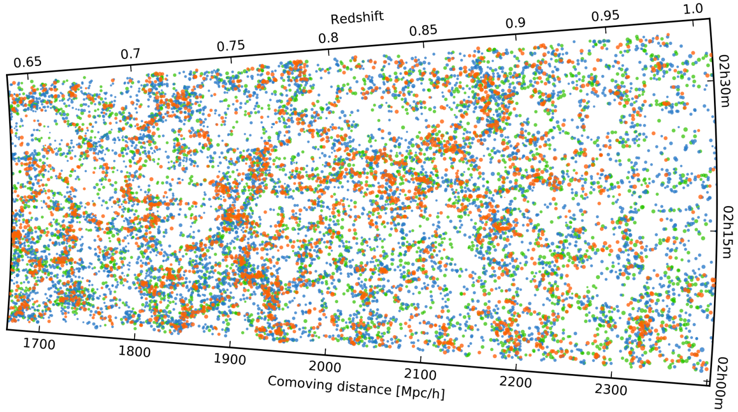
Combining imaging & spectroscopy

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

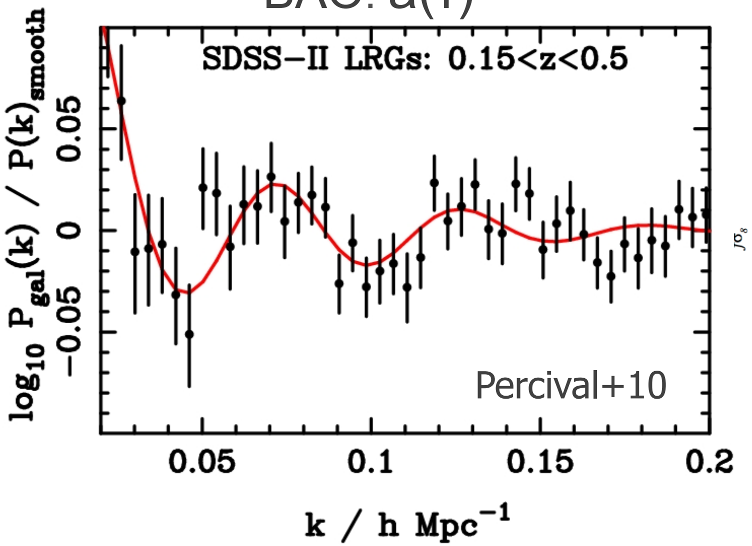
Ψ : governs motion of matter

Φ : governs motion of light

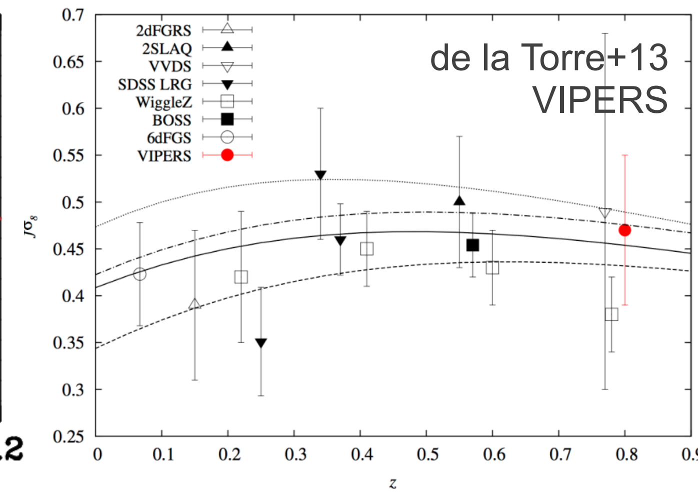
$\Phi = \Psi$ for GR



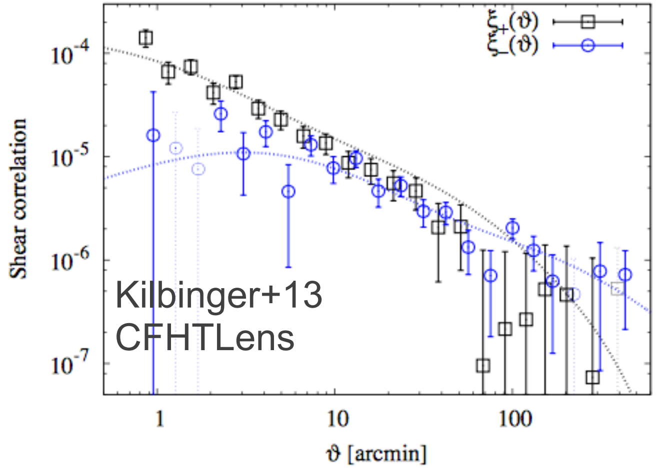
BAO: a(τ)



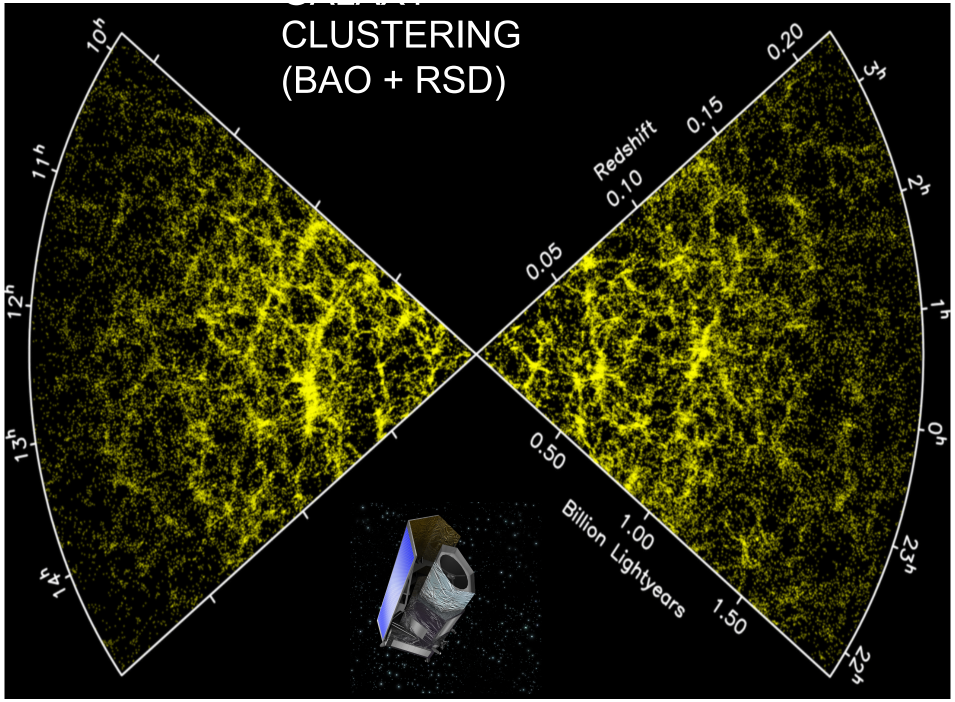
RSD: Ψ



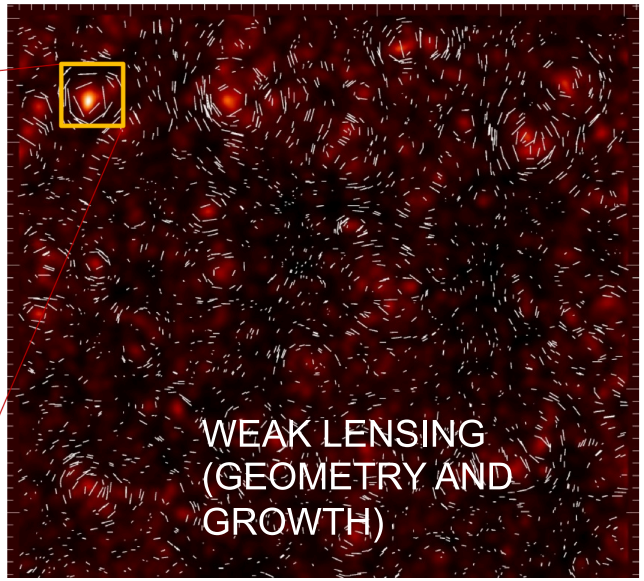
Cosmic shear: $\Phi + \Psi$



Euclid – THE cosmology experiment




GALAXY CLUSTERS (GEOMETRY AND GROWTH)



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

- 15,000 deg^2 survey
- Images for $2x10^9$ galaxies
- Spectra for ~5×10^7 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

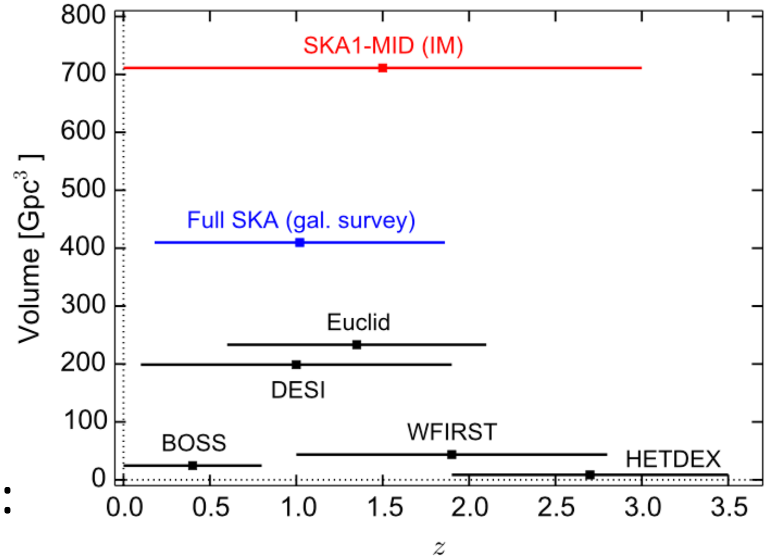
SKA – Surveys for Cosmology

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

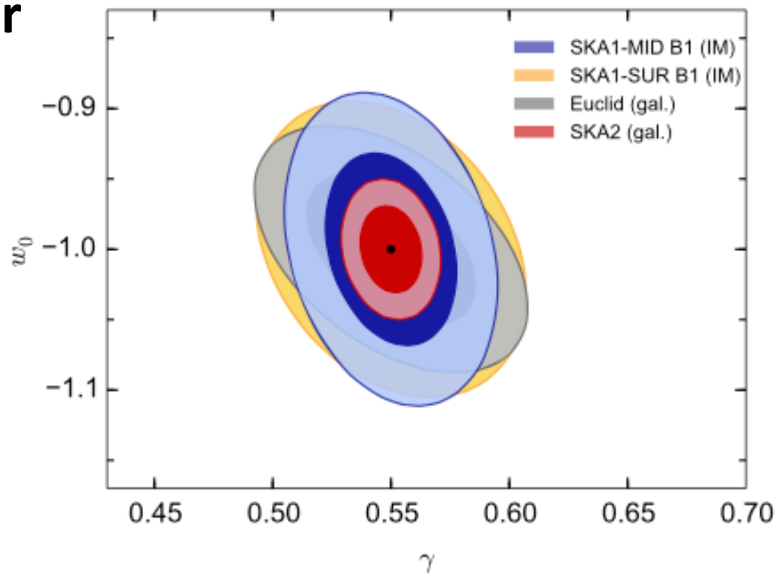
2. **HI Threshold:** galaxy redshift survey [BAO, RSD]
   SKA1: 5 10^6 gals @ z<0.5
   SKA2: ~10^9 gals @ z<2

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

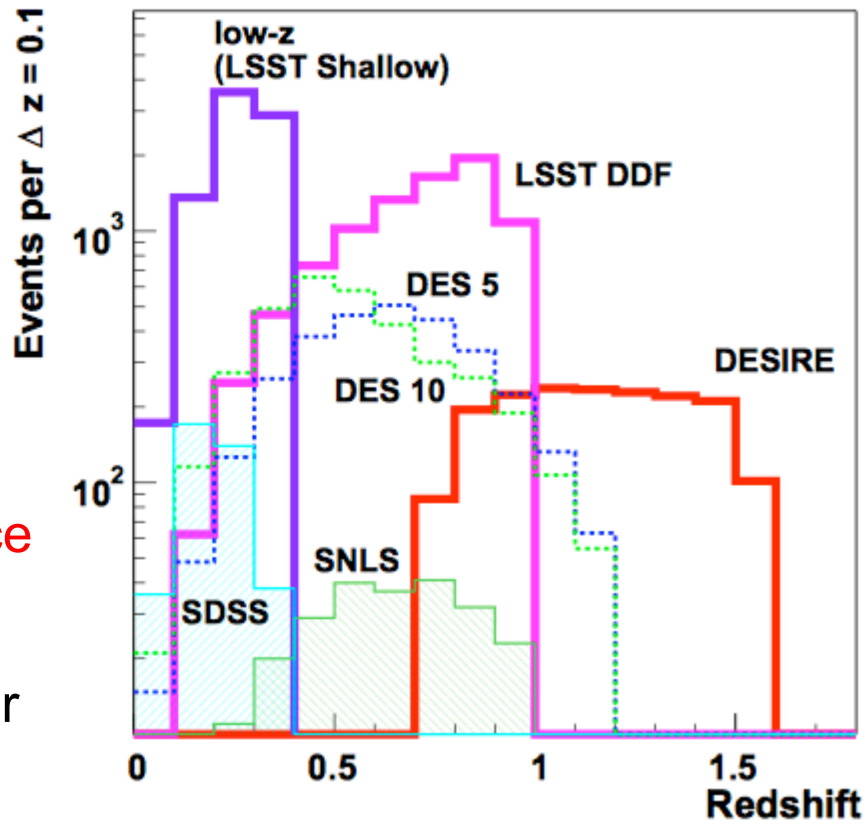


Euclid + SKA: huge synergies
→ Scientific: smaller volume higher res. vs large volume low-res, complementary constraints, multi-tracers, etc.
→ Programmatics: e.g. simulations, likelihood definitions and coding, etc.



Distance indicators and expansion tests

See also talk by F. Palla



Cosmology with Sne-Ia

DES will increase statistics by 10

LSST will increase statistic by 100
100.000 SNIa in the range 0<z<1
Spectroscopic follow-up is the bottle-neck

High-redshift SNIa, z>1 need near-IR from space

Euclid: proposal for a high-z SN search (DESIRE; Astier et al 2014); Not a top priority for the mission

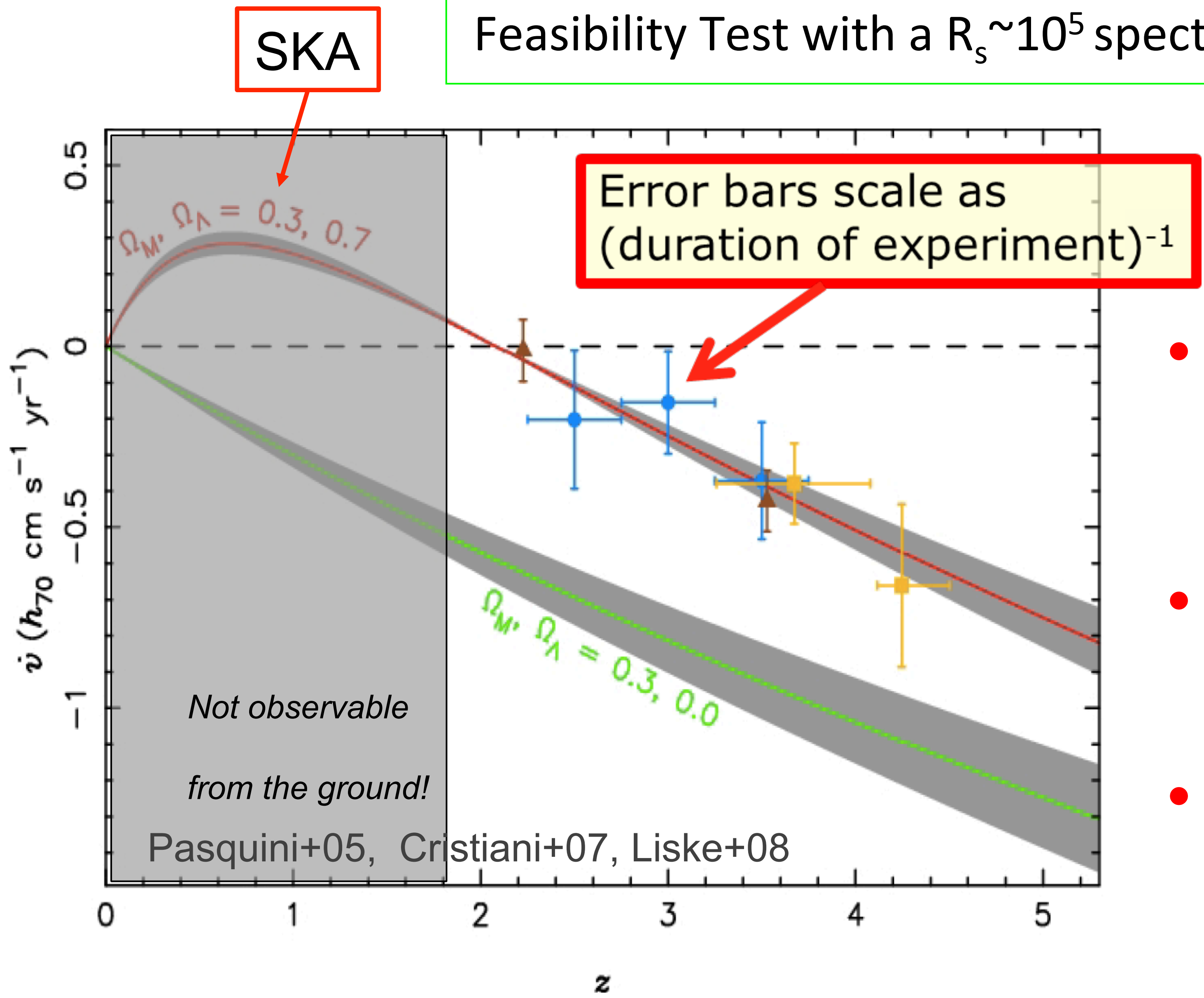
WFIRST : High-z SN search is a major component (180d of observing time)

To date marginal European involvement

➔ Follow-up of a nearby sample is still very much needed for:
- anchoring the Hubble diagram, standardization of SNIa luminosity
- requires accurate (within few %) spectrophotometric calibration

Sandage Test of Cosmic Expansion

Feasibility Test with a R_s~10^5 spectrograph at the E-ELT



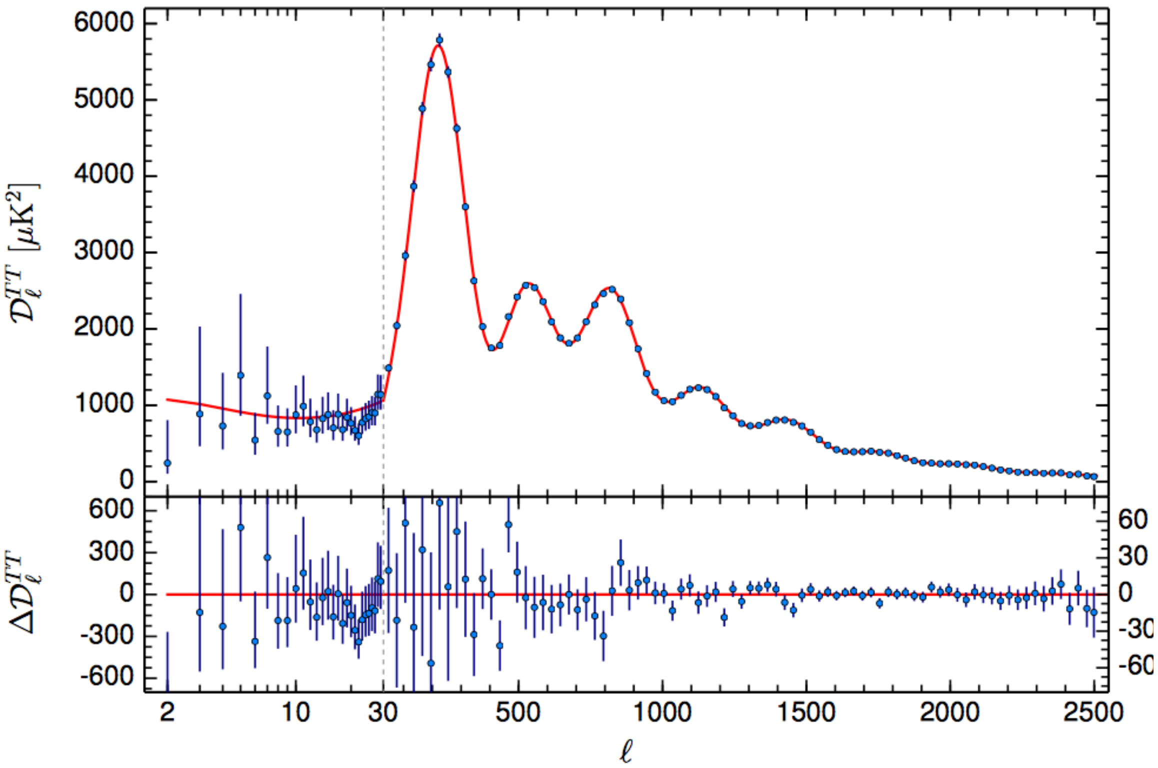
- Different coloured points reflect different targeting strategies
- 4000 hrs on 39-m E-ELT over 21.5 years, *or*
- 1200 hrs on 39-m E-ELT over 40 years

The lesson of the CMB

Difficult measurement, BUT: ➔ Everything is linear: $\Delta T/T \sim 10^{-5}$
➔ Physics is well understood

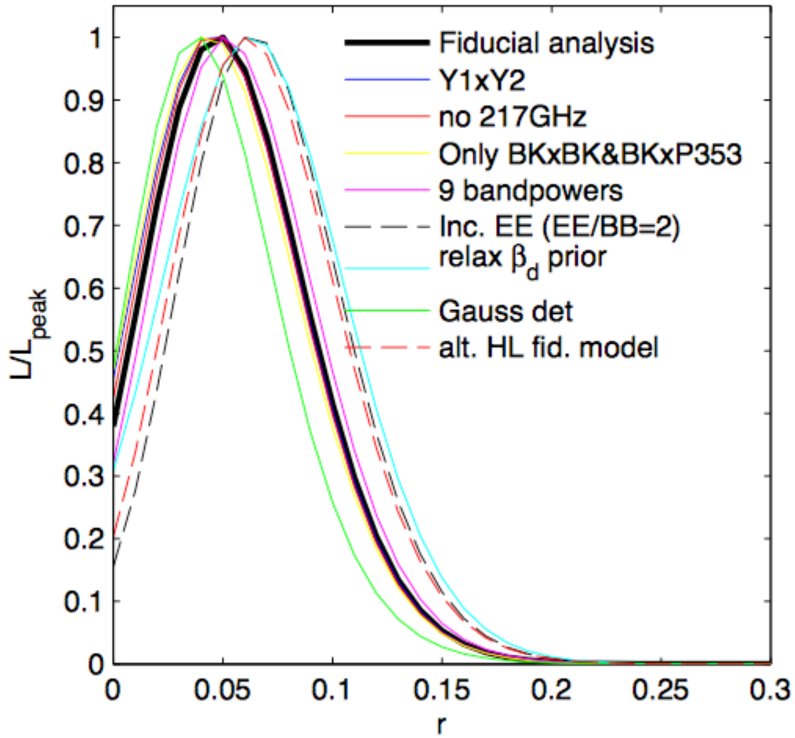
➔ Undergoing transition from precise T measurements to precise polarization measurements

Planck 2015 – XIII: TT spectrum compared to base ΛCDM



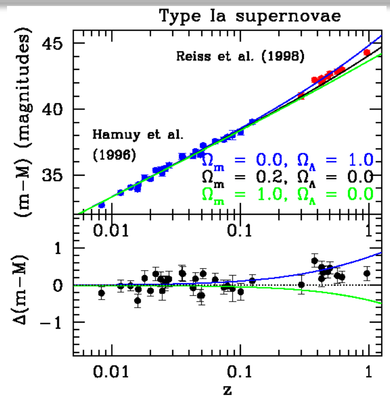
Multipole order

BICEP2/Keck+Planck joint analysis of B-mode polar.



Tensor-to-scalar ratio

SN-Ia + CMB + surveys: a single experiment



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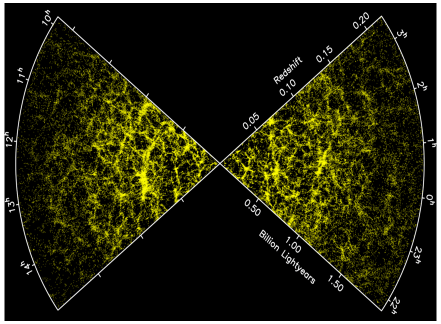

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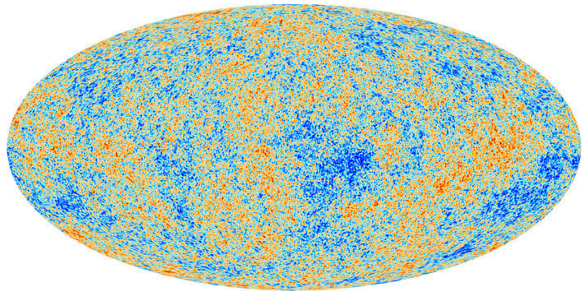
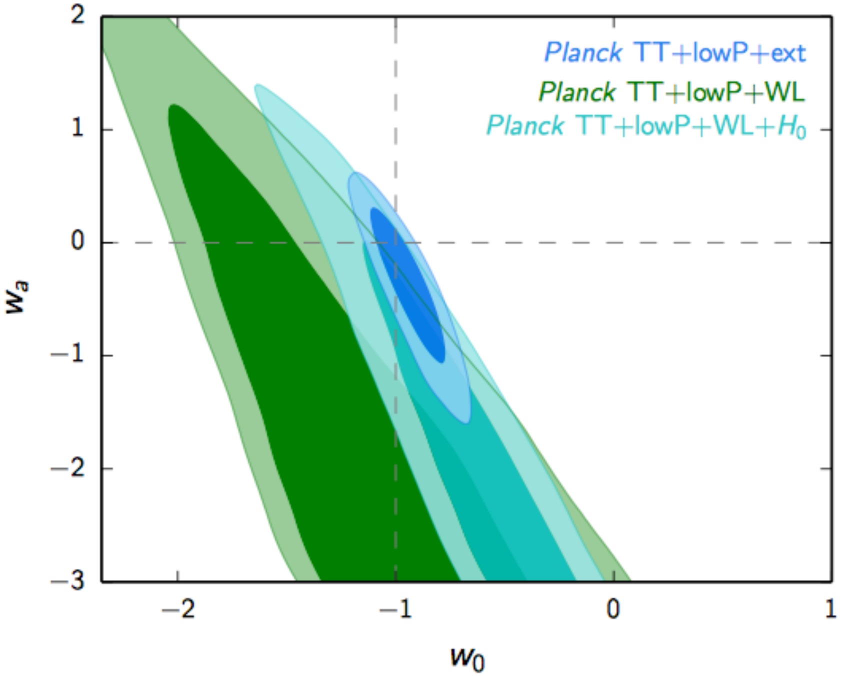
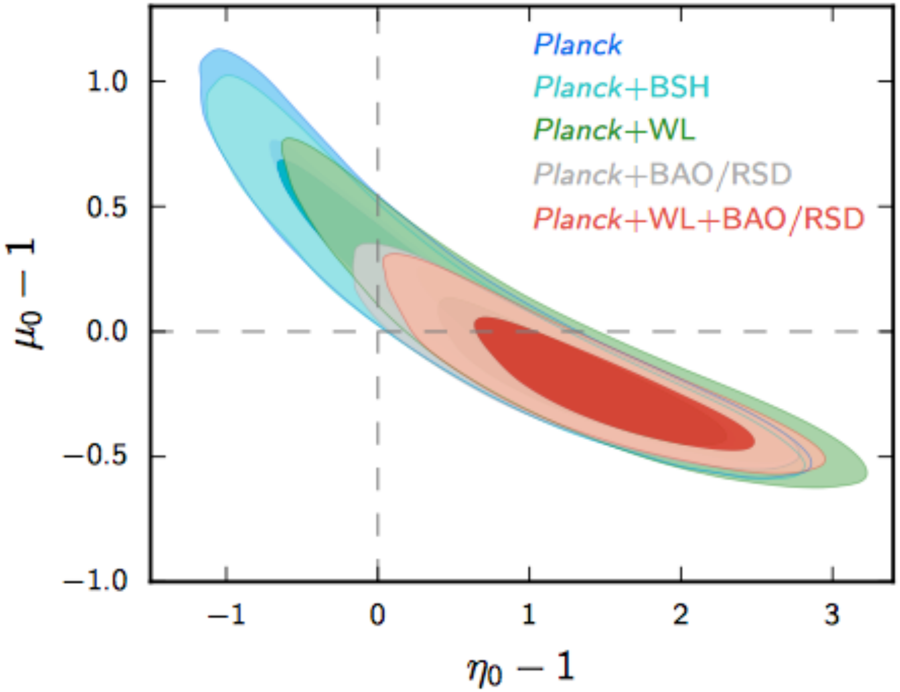


The combination is much more than the sum of the parts

Planck 2015 - XIII



Planck 2015 - XIV

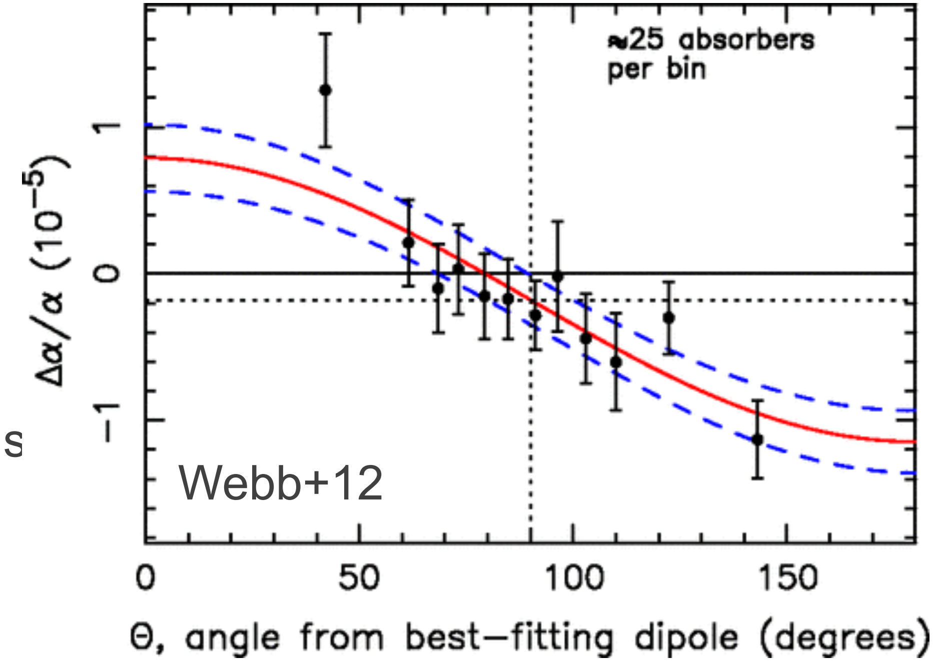


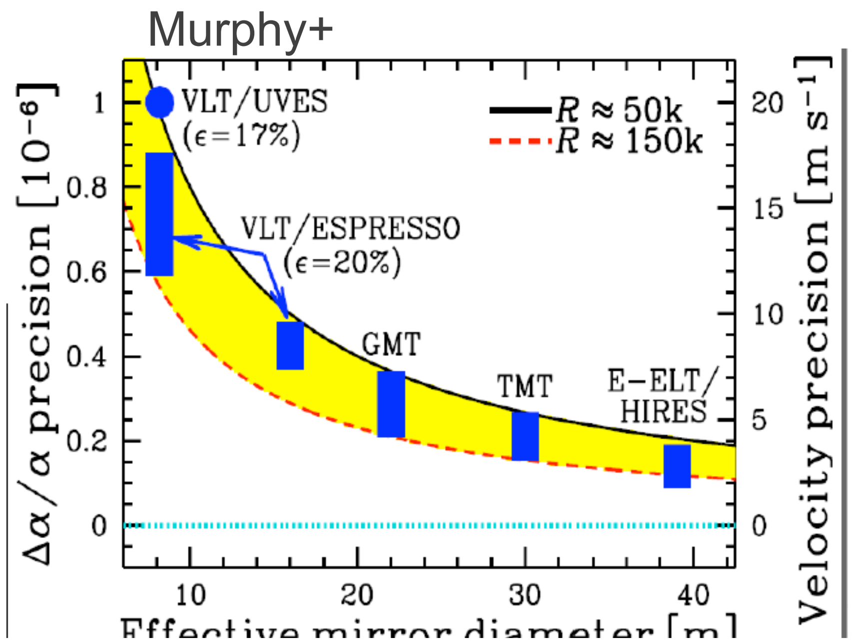
Signatures of new physics ➔ Control of systematics

How constant are fundamental constants?

High-risk/high gain: worth a bet!

- E.g. due to coupling of a scalar field to matter
- How to probe?
  - Alkaline-doublets: changes in frequency of atomic (incl. 21cm) and molecular transitions
  - QSO-absorption systems of atomic or molecular gas
- Status
  - no variation of α with time ~ 5 ppm
  - consistent with spatial variation (at 4.1 σ)
  - but systematics…
- Precision achievable with future facilities:
  - ESPRESSO@VLT first HR spectrograph designed for this science
  - HIRES ~ one order of mag gain in sensitivity
- Role of Italian community?
  - Thanks to ESPRESSO could play a leading role in the next years





A schematic summary

	Euclid (LSST)	SKA	E-ELT	CTA	Athena
Nature of Dark Matter	Highly relevant	Highly relevant	Possibly interesting	Highly relevant	Possibly interesting
Nature of Dark Energy	Highly relevant	Highly relevant	Possibly interesting	Not relevant	Possibly interesting
Gravity on large scales	Highly relevant	Highly relevant	Not relevant	Not relevant	Possibly interesting
Physics of initial conditions	Highly relevant	Highly relevant	Not relevant	Not relevant	Not relevant
Fundam. constants	Not relevant	Highly relevant	Highly relevant	Not relevant	Not relevant

Highly relevant

Possibly interesting

Not relevant