

# **ESA-ESO Working Group on Fundamental Physics**

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on behalf of the WG*

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# Scope

- Fundamental Cosmology (dark energy, dark matter, inflation, ....)
- not: galaxy evolution, SFR, reionization, etc.
- thus, limited range of issues.
- We took Planck for granted.

# What are the BIG questions?

- What generated the baryon asymmetry? Why is there negligible antimatter, and what set the ratio of baryons to photons?
- What is the dark matter? Is it a relic massive supersymmetric particle, or something (even) more exotic?
- What is the dark energy? Is it Einstein's cosmological constant, or is it a dynamical phenomenon with an observable degree of evolution?
- Did inflation happen? Can we find observational relics of an early vacuum-dominated phase?
- Is standard cosmology based on the correct physics? Are features such as dark energy artefacts of a different law of gravity, perhaps associated with extra dimensions? Could fundamental constants actually vary?

# Where can astronomy help?

- Baryogenesis?  
No, instead CP violation in lab.
- Nature of dark matter?  
Partly: interaction cross section, how cold, annihilation signatures  
But: LHC (neutralino), direct underground dark matter searches.
- Nature of dark energy?  
Yes, exclusively in the Universe!
- Inflation?  
Yes, exclusively in the Universe!
- Laws of physics?  
Partly: fine-structure constant time dependent?  $\mu(t) = m_p/m_e$ ?  
Alternative gravities?

# Appropriate methods

- Dark energy, affects expansion rate  $H(z)$ , thus the  $D(z)$  relation and the structure growth  $g(z)$ .
  - Supernovae Hubble diagram;
  - Large-scale structure, including baryonic acoustic oscillations;
  - Clusters of galaxies: abundance( $M, z$ ), LSS, baryon fraction;
  - Weak lensing: cosmic shear, calibration of galaxy bias, distance ratio test

Dark energy too important to rely on a single methods.

- Inflation
  - Gravity waves from inflation:  
directly with LISA++ or B-mode CMB polarization
  - CMB: Planck and beyond
  - primordial power spectrum, tilt, running spectral index  
 $P(k)$  from largest to smallest scales: CMB to Lyman- $\alpha$  forest
- New physics, variation of fundamental constants
  - line ratios at high redshift

# Promises and limitations

We discussed forecasts, systematics, and how to overcome them; e.g.:

- SN Ia: evolution effects, extinction/reddening, selection effects (Malmquist, non-Ia's), photometric accuracy/K-corrections
- LSS: biasing of galaxies, non-linearities
- clusters of galaxies, mainly X-rays: mass-observable relation, e.g.,  $M(T_x)$ ,  $M(L_x)$ : scatter and ( $z$ -dependent) bias; non-relaxed clusters, mergers, effects of central AGN activity
- weak lensing: PSF correction, redshift (distribution) of source galaxies, contamination and clustering, intrinsic alignments, non-linearities (challenge for modellers)
- Lyman- $\alpha$  forest: mean flux level, thermal state of IGM, additional physical processes, metal line absorbers

# What CAN be done until 2020?

Which of these methods appear promising to be realized within Europe, or with strong European participation, over the next  $\sim 15$  years up to a level which superseeds the current accuracy by at least one order of magnitude?

For example, what is unlikely to happen?

- Successor for LISA before LISA has proved the concept and technology
- post-Planck CMB mission, though technology must be developed
- We left SKA out of the discussion, though time-scale perhaps  $\sim 2020$ .

What are specific strengths in Europe?

What is technically feasible?

Where can community support be gained?

## Range of application

Which of these methods has a broad range of applications and a high degree of versatility even outside the field of fundamental cosmology?

Any major advance will be costly; new projects better have many spin-offs, to gain support from wide community.

# Redshift

Nearly all of the methods need redshift information, up to and beyond  $z \sim 1$ :

- LSS and BAO: obviously, need 3-D positions of  $\geq 10^6$  galaxies spread over large sky area
- Clusters: quasi all-sky distribution of  $\sim 10^5$  clusters with eROSITA ( $\sim 10^4$  SZ-clusters from Planck), cannot be individually followed-up by spectroscopy
- Weak lensing: need only approximate but unbiased redshifts of  $\sim 10^9$  galaxies
- CMB-polarization: needs to map 3-D foreground structure to control B-mode polarization from lensing of E-modes.

$\Rightarrow$  Accurate photometric redshifts mandatory, over wide regions of the sky.  
Only for BAO can spectroscopy be done, but not with current ESO facilities (VIMOS has too small f.o.v.)

# LSS & BAO

- Status: low- $z$ : 2dF, SDSS, 6dF;  
high- $z$  pencil surveys: COMBO-17, VVDS, DEEP2, COSMOS, SDSS LRG
- Near-term: wigglez with AAOmega on AAT (done by 2010),  $\sim 6 \times 10^5$  galaxies at  $z \sim 1$   
photo- $z$  surveys: KIDS@VST + VIKING@VISTA (done by 2010),
- Future: WFMOS@Subaru: 2000 fibers over 1.5-degree field  
Dark Energy Survey, PanSTARRS, KIDS/VIKING+, LSST, SNAP/JDEM

# Clusters

- Status: various ROSAT cluster samples, XMM serendipitous samples; optical cluster samples (from 2dF, SDSS)
- Near-term/future: SZ-surveys (APEX, Planck, ACT, SPT),  
X-rays: eROSITA

# Weak lensing

- Status: COMBO-17, CFHTLS, GaBoDS, HST (GEMS, COSMOS, ACS parallel), CTIO, ....
- Near-term: KIDS/VIKING, PanSTARRS, DES, HyperCam
- Future: LSST, SNAP/JDEM, PanSTARRS4

Bottleneck: near-IR photometry

# Supernovae

Same telescopes and instruments as for lensing surveys used for SN-detection and photometry;

needs 10-m class telescopes for spectroscopy, not feasible for DES, LSST, and PanSTARRS4 SN surveys;

SN cosmology from photometry only?

SNAP

## Lyman- $\alpha$ absorption

and

## Variability of physical constants

both need high-resolution and high S/N spectroscopy:

- Status: 10-m class telescopes
- Future: 30-m class telescopes

## Related activities

- Dark Energy Task Force (Kolb et al.), provided detailed quantitative comparison of the four methods: SN, clusters, BAO, weak lensing
- CMB report (Bock et al.), recommended CMBPOL as future mission
- ESA's Cosmic Vision 2015-25, two major recommendations in fundamental cosmology:
  - Wide-field optical/near-IR imager, prime target: weak lensing, plus SN
  - CMB polarization mission

# Recommendations

## 1. **Wide-field optical and near-IR imaging survey.**

- Clearly the highest priority, needed for LSS-BAO, weak lensing, cluster identification and redshifts, SN
- KIDS/VIKING is pathfinder, but VST not competitive after  $\sim 2010$
- ESA and ESO have unique opportunity to collaborate on this
- Essentially all-sky, depth comparable to CFHTLS Wide

- Survey has three major components:
  - Wide-field imager in space, with 1 optical band (for shape measurement) and 2-3 near-IR bands,
  - wide-field optical photometry from the ground for additional 4-5 optical bands,
  - spectroscopy of at least  $10^5$  galaxies down to AB-mag of  $\sim 24.5$  spread sparsely over  $\sim 10^4 \text{ deg}^2$  for calibrating photo-z, integrated with the imaging surveys;
- a project with enormous legacy –  
imagine : 2MASS 7 magnitudes deeper,  
SDSS imaging  $\sim 4$  magnitudes deeper and  $\sim 3$  times wider) –  
and huge range of applications.

**2. Supernova survey, extending current ones at  $0.5 \lesssim z \lesssim 1$  by one order of magnitude.**

- VST can carry out such a survey, if not required for other cosmological surveys
- VLT spectroscopy
- improved local sample also needed for calibration

3. **European ELT will have significant cosmological applications** although main science drivers in other fields of astronomy.

- SN samples at  $z > 1$ , at least to back-up photometric surveys
- Lyman- $\alpha$  absorption spectroscopy, large lever arm for shape of power spectrum (tilt, running spectral index)
- time variation of fundamental constants

#### **4. Plan for next steps in CMB research.**

- Deal with foreground effects from gravitational lensing
- Measure the B-mode polarization signal

A CMB polarization mission should have high priority in ESA's future planning; technological developments should be started

#### **5. We endorse space-borne gravity-wave studies as an essential current and future priority for ESA.**