Theory SWG Update

F. Finelli and M. Viel

M. Archidiacono, M. Baldi, D. Bertacca, S. Camera, M. Pietroni, A. Raccanelli

List of WPs and coordinators

Leads: Kunz, Silvestri Co-leads: Finelli, Pettorino (new lead and co-leads replace L. Amendola and M. Viel who resigned)

- WP1/2: Dark energy & Modified Gravity **(Frusciante, Lombriser)**
- WP3: Dark Matter and Particle Cosmology **(Camera, Archidiacono, Clesse)**
- WP4: Initial conditions (inflation, non-gaussianity etc) – **(Akrami, Finelli)**
- WP5: Deviations from homogeneity and isotropy **(Garcia-Bellido, Clarkson, Sapone)**
- WP6: Extended Forecasts **(Casas, Tutusaus)**
- WP7: analytical approaches to non-linearities (incl. baryon physics) **(Pietroni, Vernizzi, Pace)**
- WP9: Relativistic effects in observations **(Bertacca, Lepori)**
- WP10: New observational probes **(Martins, Raccanelli)**
- WP11: Likelihood **(Blanchard, Ilic, Trotta)**
- WP12: Joint WP Simulations - Theory **(Baldi, Koyama)**

more than 1/3 of WP coordinators in Italian institutions

Science

Required accuracy in theoretical predictions

Observations

WPs

- WP1: Dark energy & testing gravity
- WP3: Dark Matter and Particle Cosmology
- WP4: Initial conditions (inflation, non-gaussianity etc)
- WP5: Deviations from homogeneity and isotropy
- WP6: Extended Forecasts
- WP7: Analytical approaches to non-linearities (incl. baryon physics)
- WP9: Relativistic effects in observations
- WP10: New observational probes
- WP11: Likelihood
- WP12: Joint WP Simulations - Theory

Pre-launch KP & SP

- KP-TH-1: Forecasts for beyond-standard models in cosmology and fundamental physics (WP1,3,4,6)

  Coord: Y. Akrami, S. Casas, A. Silvestri

- KP-JC-6: simulations and non-linearities beyond LCDM (WP7,12)

  Coord: M. Baldi & F. Vernizzi -- **joint KP w/ COSIM & IST:NL**

- KP-TH-2: relativistic effects (WP9)

  Coord: D. Bertacca & F. Lepori

- SP: Testing the foundations of the standard model (isotropy & homogeneity) (WP5)
- KP-JC-7: Multi-messenger cosmology: combining Euclid with gravitational waves (WP10)-- **joint KP w/ GC,WL,COSIM**

  C. Carbone, A. Raccanelli, et al.

Summary of KP-TH-1 papers

KP-TH1 - Key Project Papers

KP-TH-P1 - Euclid preparation: xx. Forecast constraints on dark energy and modified gravity (WP1/2)

KP-TH-P2 - Euclid preparation: xx. Forecast constraints on neutrinos ~~beyond-LCDM~~ in LCDM and beyond (WP3)

KP-TH-P3 - No key project papers

KP-TH-P4 - Euclid preparation: xx. Forecast constraints on initial conditions and implications for inflation (WP4)

KP-TH-P6 - Euclid preparation: xx. Impact of nonlinear clustering beyond-LCDM constraints (WP7/12)

https://gitlab.euclid-sgs.uk/PF-TWG/key_projects/-/wikis/home

Names of the leads are TBC

Summary of KP-TH-1 papers

KP-TH1 - Standard Project Papers

KP-TH1-1:

SP-TH-[WP1/2]-P1: Euclid: Constraints on f(R) cosmologies from the spectroscopic and photometric primary probes

SP-TH-[WP1/2]-P2: Euclid: Constraining linearly scale-independent modifications of gravity with the spectroscopic and photometric primary probes

SP-TH-[WP1/2]-P3: Euclid: Constraints on model-independent parametrizations of gravity

KP-TH1-2: no standard papers

KP-TH1-3:

SP-TH-[WP3]-P1: Particle Models of Dark Matter

SP-TH-[WP3]-P2: Primordial Black Holes

SP-TH-[WP3]-P3: Generalized Dark Matter

KP-TH1-4:

SP-TH-[WP3]-P4: Euclid forecasts for early Universe: the search for primordial features

SP-TH-[WP3]-P4: Euclid forecasts for early Universe: Bayesian inference of cosmic initial conditions

KP-TH1-6: no standard papers

https://gitlab.euclid-sgs.uk/PF-TWG/key_projects/-/wikis/hom

Names of the leads are TBC

WP1/2 (coordinators: N. Frusciante, L. Lombriser)

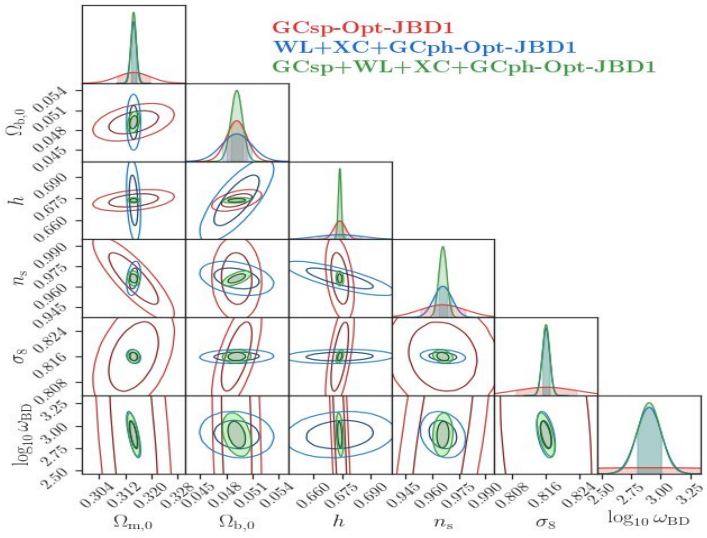
KP-TH-1: Forecasts for beyond-standard models in cosmology and fundamental physics

- **KP Paper 1:** Forecast constraints on dark energy and modified gravity
  [Coordinator: L. Lombriser]

- **SP Paper 1:** Euclid: Constraints on f(R) cosmologies from the spectroscopic and photometric primary probes
  [Lead: S. Casas]
- **SP Paper 2:** Euclid: Constraining linearly scale-independent modifications of gravity with the spectroscopic and photometric primary probes
  [Lead: N. Frusciante, F. Pace]
- **SP Paper 3:** Euclid: Constraints on model-independent parametrizations of gravity
  [Lead: L. Lombriser, A. Silvestri]

SP-TH-[WP1/2]-P2: Constraining linearly scale-independent modifications of gravity with the spectroscopic and photometric primary probes

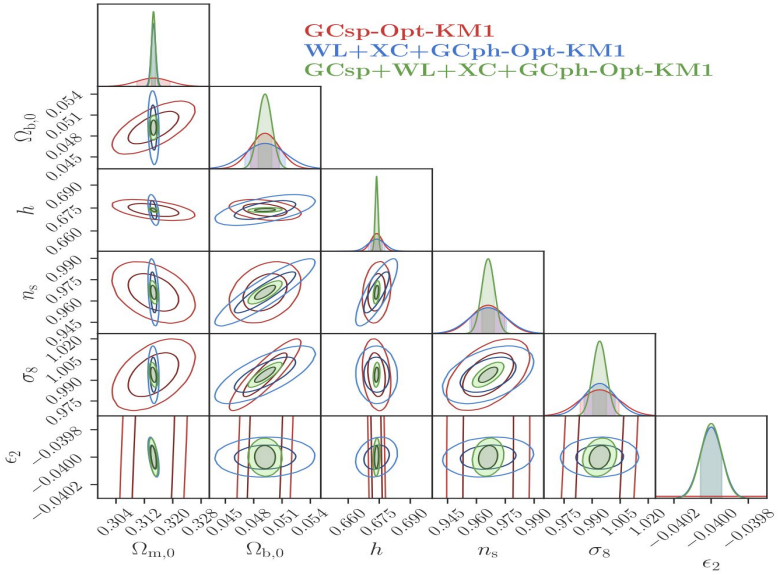
Led by Noemi Frusciante, Francesco Pace



M. Ballardini, E. Bellini, V. Cardone, F. Finelli et al.

Euclid alone will be able to constrain log10(omegaBD) JBD (omegaBD=800):

- at the 35% level with spectroscopic GCsp alone;
- at the 3.6% level combining WL, GCph, and XC;
- at the 3.3% level using the full combination GCsp+WL+GCph+XC.



G. Benevento, N. Bartolo et al.

Euclid alone will be able to constrain K-Mouflage (epsilon2=-0.014):

- at the 5% level with spectroscopic GCsp alone;
- at the 0.15% level combining WL, GCph, and XC;
- at the 0.14% level using the full combination GCsp+WL+GCph+XC.

WP3 (coordinators: M. Archidiacono, S. Camera, & S. Clesse)

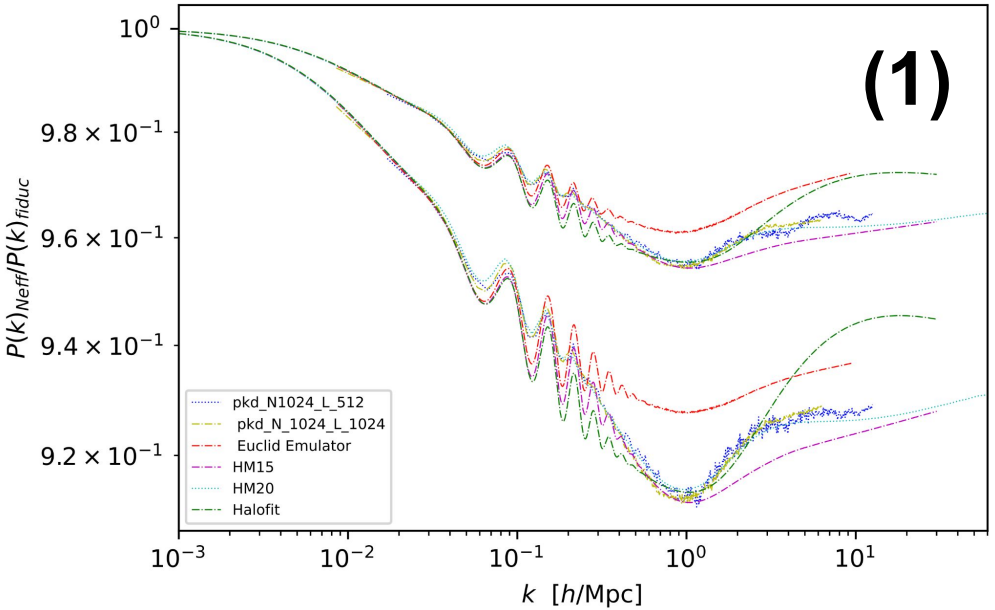
KP-TH-1: Forecasts for beyond-standard models in cosmology and fundamental physics

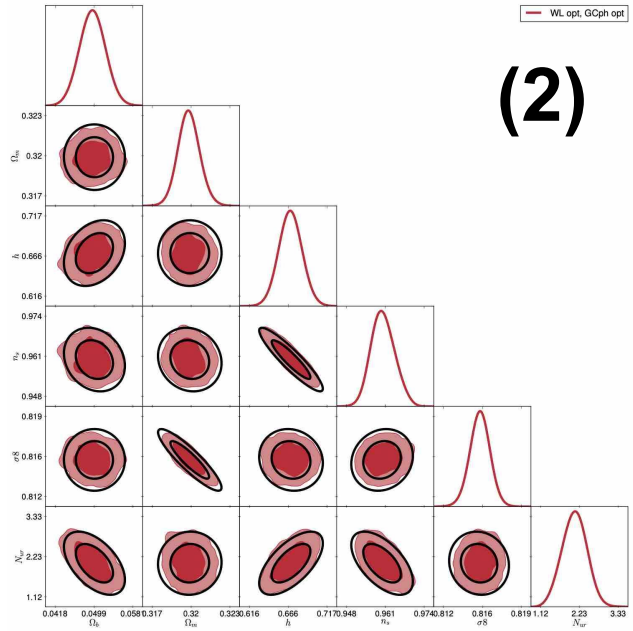
- **KP Paper 2:** Constraints on massive neutrinos ~~beyond LCDM model~~ in LCDM and beyond
  [Coordinators: M. Archidiacono & S. Camera]
  This paper will forecast the capability of Euclid of constraining neutrino masses and their hierarchy, and assessing their degeneracy with modified gravity.
  - Project progressing fast, with analysis set-up in place and the most important tests already performed. There is a draft, currently being populated.

- ~~**KP Paper 3:** Review of dark matter constraints with Euclid~~
  This KPP has been substituted by 3 SPP, a possibility which was initially envisioned
- **SP Paper 1:** Particle dark matter constraints with Euclid
  [Lead: J. Lesgourges]
- **SP Paper 2:** Generalised dark matter constraints with Euclid
  [Lead: Z. Sakr]
- **SP Paper 3:** Primordial black-hole dark matter constraints with Euclid
  [Lead: S. Clesse]

WP3 (coordinators: M. Archidiacono, S. Camera, & S. Clesse)

- **KP-TH-1: Forecasts for beyond-standard models in cosmology and fundamental physics**
  - **KP Paper 2:** Constraints on massive neutrinos ~~beyond LCDM model~~ in LCDM and beyond [Coordinators: M. Archidiacono & S. Camera]
    - Comparison of nonlinear prescriptions vs simulations (Fig. 1: G. Parimbelli, A. Schneider)
    - Validation of Fisher forecasts with different methods (Fig. 2: J. Lesgourges, Z. Sakr, …)





WP4 Initial Conditions (Coordinators: Y. Akrami, F. Finelli)

The activities of WP4 are currently focusing on the development of the following Key and Standard Projects papers within KP-TH-1:

KP-TH-P4: Euclid forecasts for the Early Universe: Constraints on initial conditions and implications for inflation [Coord. F. Finelli, co-led by Y. Akrami]

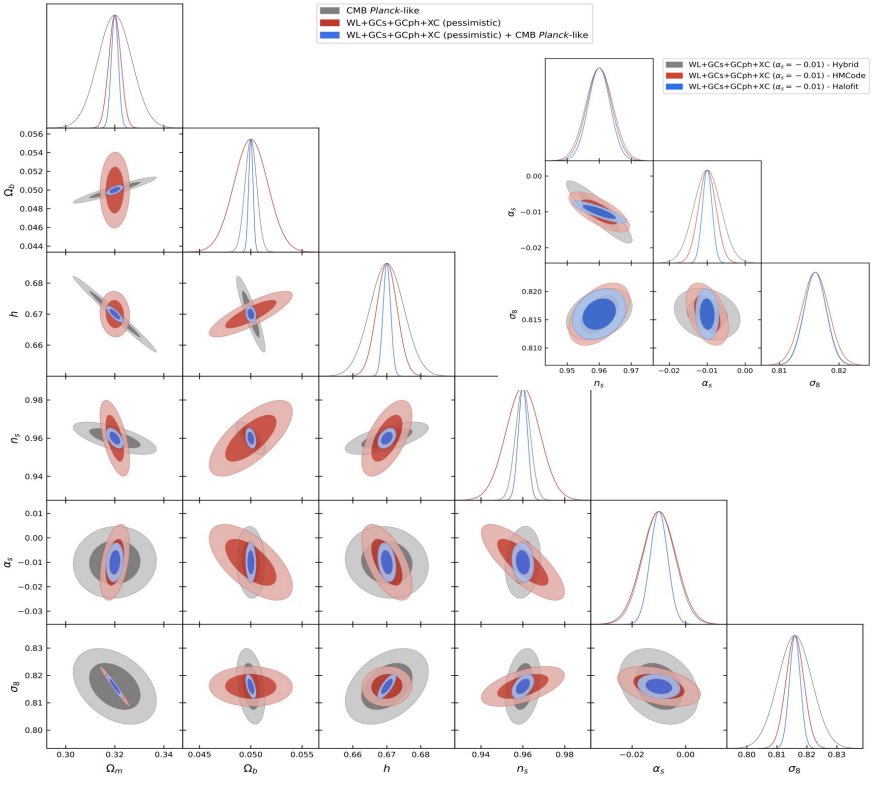
The paper will describe expected constraints on curvature, running of the spectral index, primordial non-Gaussianities, isocurvature perturbations, implications for inflationary models by using Fisher forecasts. It will also contains highlights of the two satellite papers described below. The paper will compare the constraints from the Euclid main probes (following IST:F) with those obtained by Planck (following CMBXC 1) and will present the expected combined results.

SP-TH-P1: Euclid forecasts for the Early Universe: The search for primordial features (led by M. Ballardini)
The paper will describe the expected constraints on primordial features by using Fisher forecasts for different templates by both spectroscopic and photometric surveys. It will also present the constraints on features which can be obtained by the bispectrum alone and in combination with the main probes.

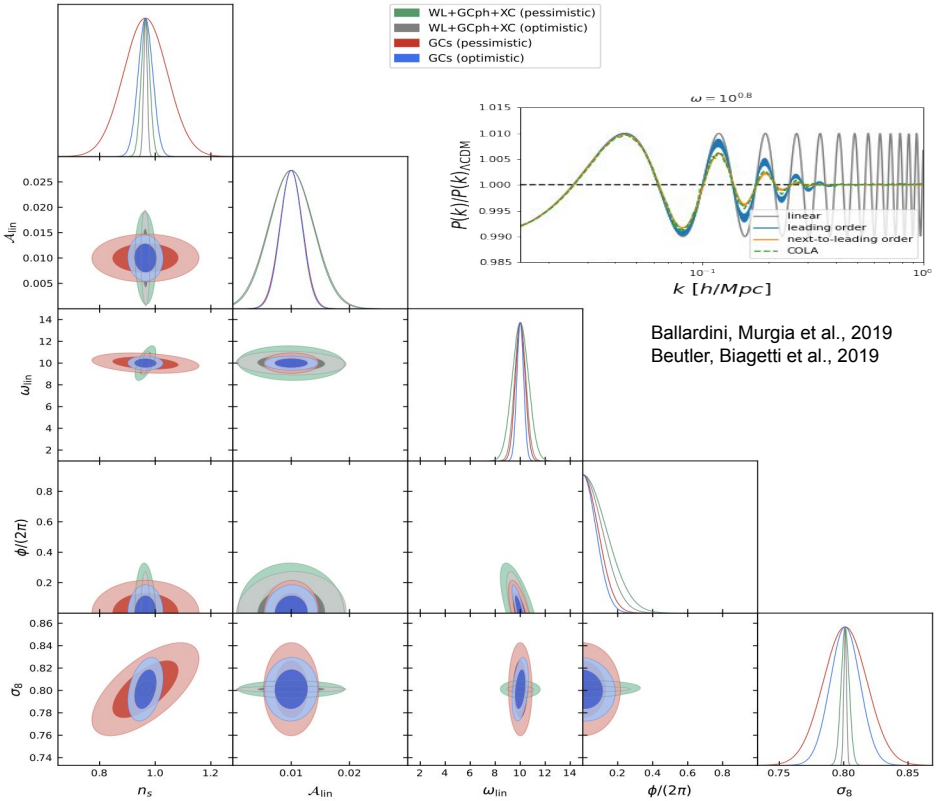
SP-TH-P2: Euclid forecasts for the Early Universe: Bayesian inference of cosmic initial conditions (led by A. Andrews, assisted by J. Jasche, G. Lavaux)
The paper will describe the expected constraints on primordial parameters by using the forward modeling approach by BORG employing the full 3D density fields.

WP4 Initial Conditions (Coordinators: Y. Akrami, F. Finelli)

KPP4:



SPP4:



Ballardini, Murgia et al., 2019
Beutler, Biagetti et al., 2019

M. Ballardini

WP 7 *Analytical approaches to nonlinearities*

(M. Pietroni - UniPR, F. Vernizzi- IPhT Saclay, F. Pace - U. of Torino)

Ongoing activities:

- Development of fast (FFTLog) perturbation theory codes for galaxy clustering in scale-dependent models (massive neutrinos, modified gravity models …);
- Strong interaction with WP12 and IST-NL: cross-validation of available perturbation theory codes (PBJ, PyBird); LCDM null tests on Flagship simulations; Exact time dependence (w0/wa+massive neutrinos)

Involved in the following KP's:

- KP-TH-1, especially Paper 6: "Impact of non-linear clustering on beyond-LCDM constraints", Lead **Ben Bose**
  Methodology paper: *"Assess the robustness with respect to nonlinear effects, implemented in different methods. We will rely on standard perturbation theory extended to beyond-LCDM models"*

- KP-JC-6, especially Paper 3: "Cosmological constraints from non-standard simulations", Lead **G. D'Amico (UniPR)**
  Pipeline paper: *"Extraction of cosmological parameters beyond LCDM from the simulated galaxy mocks, using improved perturbation theory and Markov-Chain Monte-Carlo techniques to scan the power spectrum likelihood over different cosmologies."*

WP9 (coordinators: **D. Bertacca** & F. Lepori) *is strongly involved in*

- ***KP-TH-2:*** **Impact of lensing magnification and wide angle effects on spectroscopic and on photometric sample of Euclid:**

Observations of galaxy clustering are affected by a number of relativistic effects (hereafter, GR effects), which alter the redshift, appearance, and sky position of distant light sources. Among them, lensing magnification (and the related concept of magnification bias) has been found noteworthy at high redshift. The aim of this project is to assess the importance of lensing magnification and other GR effects for Euclid and to determine if they should be included in the modelling of n-point statistics of galaxy clustering.

- **There are 3 KP papers:**

Wide-angle and lensing magnification from simulations

- Paper 1: **The impact of wide-angle, lensing, and the `finger of the observer' effects on the multipoles of two-point statistics for the Euclid spectroscopic sample (**Mohamed Y. Elkhashab, Cristiano Porciani, and Daniele Bertacca)

Fisher forecast: impact of magnification on cosmological analysis

- Paper 2: **The impact of magnification on photometric galaxy clustering (merged with KP-GC-7). Submitted to A&A.**
- Paper 3: **The impact of magnification on spectroscopic galaxy clustering** (Camille Bonvin, Stefano Camera, Francisco Castander, Ruth Durrer, Pablo Fosalba, Goran Jelic-Cizmek, Martin Kunz, Francesca Lepori, Isaac Tutusaus, Cristian Viglione)

- ***Standard Projects.*** **2 papers:**
  - **Relativistic effects: the dipole of the correlation function**
  - **Relativistic effects beyond LCDM** (led by Francesco Pace)

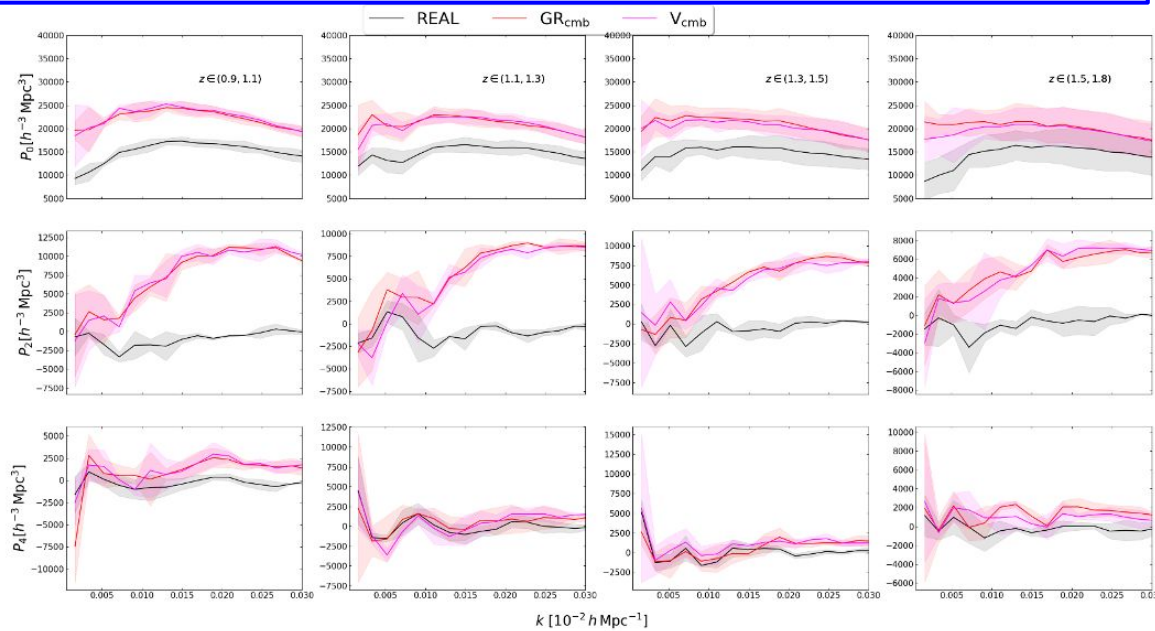
KP-TH-2: paper 1 We use LIGER (LIght cones using GEneral Relativity): Led by **Mohamed Y. Elkhashab**

LIGER is a method to create mock galaxy catalogues in redshift space including general relativistic effects to linear order in the cosmological perturbations [Borzyszkowski, Bertacca & Porciani 2017]. LIGER can be used to forecast the performance of wide-angle surveys and to estimate the covariance matrix of the observables.

With N-Body simulations and LIGER method (Elkhashab, Porciani & Bertacca 2021) we are studying the impact of redshift-space distortions and the lensing magnification on configuration space correlation function, power spectrum and angular power spectrum in the spectroscopic Euclid Survey.

- *Realspace:* REAL
- *With sources peculiar velocity:* V_cmb
- *With all relativistic RSD* (linear order) *without the observer velocity:* GR_cmb
- *With all relativistic RSD with the observer velocity* GR_obs

- **Configuration space correlation function** (we use LE3_GC_TwoPointCOrrelation) *in progress*
- **Power spectrum** *(see very preliminary results)* (we use LE3_GC_PowerSpectrum)
- **Angular Power spectrum**



WP 10 *New Observations* (C. Martins, A. Raccanelli)

Euclid x Gravitational Waves

Theory WP10 – GWxLSS now also a KeyProject!

Note: KeyProject is in collaboration with GC, WL, Sims and will do also other things
(with Bertacca, Camera, Carbone, Cardone, Raccanelli, Ricciardone, et al.)

Theoretical modeling and coding structure for GWxLSS projects
Forecast GWxLSS cosmological tests with EuclidxGW interferometers
Use theoretical modeling to provide tools to the the KP-GW

Currently validating codes for the cross-correlation

I. Cross-correlation Euclid galaxies - resolved compact object mergers

a. Determining the origin of merging binary black holes. The clustering of merger's hosts can provide information on the nature of their progenitors, allowing discrimination between different types of astrophysical and primordial objects.
b. Constraining the distance-redshift relation. The cross-correlation of Euclid galaxies with GW events can provide measurements of ΛCDM parameters, including H0.

II. Cross-correlation Euclid galaxies - stochastic GW background

a. Measurements of the Astrophysical SGWB will be fundamental to disentangle the inflationary SGWB from the observed one and to tests astrophysical models of binary BH formation and mergers

III. Euclid and gravitational wave interferometers for tests of gravity

a. Modifications happening in deviations from GR: (i) Effective luminosity distances of GW sources, (ii) Dynamics of cosmological perturbations, (iii) Dispersion relation of GWs and waveform generation at source

WP12 (Coordinators: M. Baldi & K. Koyama)

The activities of WP12 are currently focusing on the development of the following Key and Standard Projects:

KP-JC-6: Simulations and non-linearities beyond LambdaCDM
(Coordinators M. Baldi & F. Vernizzi)
To **develop, validate, present numerical methods** for cosmological simulations beyond LCDM; To **produce simulations** of selected non-standard models and **distribute them** to the collaboration; To test accuracy, robustness, and performance of **cosmological parameters estimation** using extended perturbations theory

KP 1: Numerical methods and validation (Paper Lead: Julian Adamek)
KP 2: Scientific results from Non-standard cosmological simulations (Paper Lead: Christian Arnold)
KP 3: Cosmological constraints on non-standard cosmologies from simulated Euclid probes (Paper Lead: G. D'Amico)
SP 1: (still TBC) Cosmological constraints on non-standard cosmologies from simulated Weak Lensing Maps (Paper Lead: K. Koyama)

SP: Massive Neutrinos code-comparison project
(Coordinators M. Baldi, K. Koyama, S. Hannestad; Paper Lead: J. Adamek)
To provide a detailed assessment of the **numerical convergence and accuracy** of the several different implementations of **massive neutrinos in cosmological simulations** codes available within Euclid

KP-JC-6: KP Papers status *(M. Baldi & F. Vernizzi)*

Paper 1

Core Team: J. Adamek, M. Baldi, M.-A. Breton, C. Carbone, A. Casalino, C. Giocoli, F. Hassani, C. Hernandez-Aguayo, K. Koyama, B. Li, L. Lombriser, A. Pourtsidou, Z. Sakr

- ➔ Defined general structure of the paper
- ➔ Waiting for Paper 2 to define the final set of simulations to be used: each simulation will have a corresponding presentation of its numerical methods
- ➔ Currently Idle…

Paper 2

Core Team: C. Arnold, B. Li, C. Hernandez-Aguayo, M. Andrès-Breton, B. Fiorini, K.Koyama, A. Casalino, M. Baldi, C. Carbone, A. Le Brun, C. Giocoli

- ➔ Collected available simulations; these include Modified Gravity (f(R), nDGP, EFTofDE, parameterised models), Dark Energy (w0-wa, interacting DE) both w and w/0 massive neutrinos;
- ➔ Currently tailoring the post-processing pipeline: modified the DenHF halo finder to fit the needs of the paper analysis
- ➔ Contacting other KPs and SWGs for possible special requirements on the simulations data products

Paper 3

Core Team: G. D'Amico, M. Pietroni, M. Marinucci, L. Piga, Lucia F. de la Bella, A. Pourtsidou, C. Moretti, K. Koyama, B. Li, C. Hernandez-Aguayo, M. Baldi, C. Carbone, D. Saadeh, B. Bose, A. Le Brun, A. Schneider, L. Lombriser, D. Mota, C. Arnold, M.-A. Breton, Z. Sakr, F. Vernizzi, B. Wright, C. Giocoli

- ➔ Running null tests on Flagship catalogues for: massive neutrinos, scale-independent models (w0-wa, nDGP, Dark Scattering).
  Soon moving to scale-dependent models (f(R) gravity)
- ➔ Implementing theoretical modelling in two main codes: PyBird (D'Amico et al.) and PBJ (Moretti et al.). Cross validation planned.
- ➔ Using halos for non-standard sims until galaxy mocks (produced by KP-CS-2) will be available

Contribution to IST:L

Most of the IST:L comes already from active TH members.

It is time to push extended models into the IST:L capitalizing on the work done and ongoing for the pre-launch forecasts, which included also the study and the selection of non-linear prescriptions.

TH SWG interfaces with IST:L through a mirror of CLOE. Extended models for the linear part will be implemented in CLOE (under coordination of WP11) and these will be merged to the master branch after a review.

TH SWG interfaces with IST:NL for the non-linear part. IST:NL will have a mirror of the linear mirror handled by the TH SWG.

Summary

A wide range of Euclid science and tools developed with 14 KPPs and 11 SPPs planned in 4 different KPs as milestones of the pre-launch activities.

High forecasted number of paper leads in italian institutions (> 7) expected.

Contribution to IST:L for extended models currently reloaded.