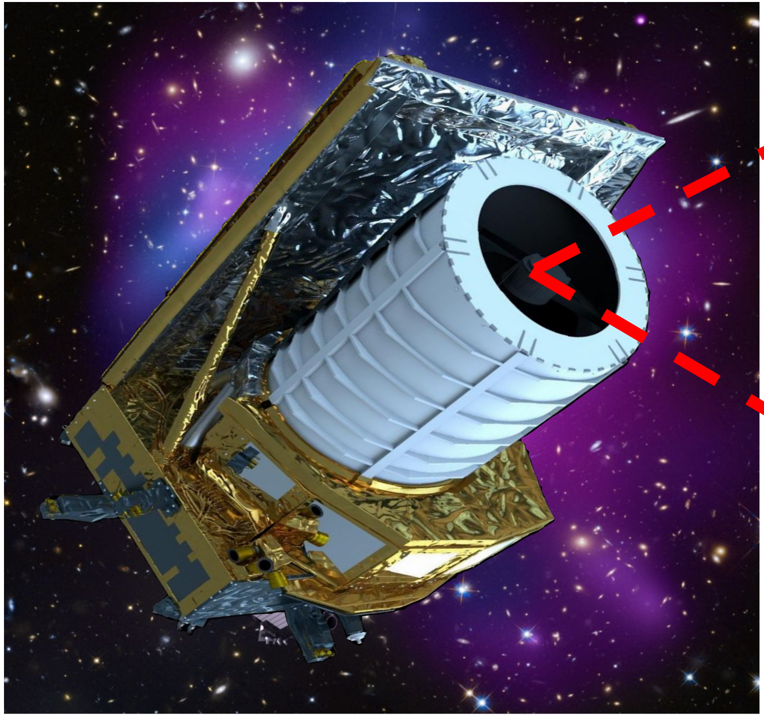
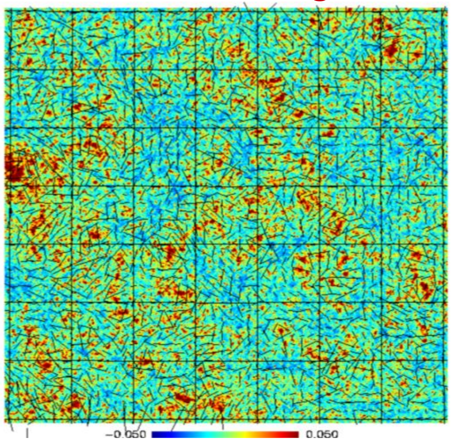
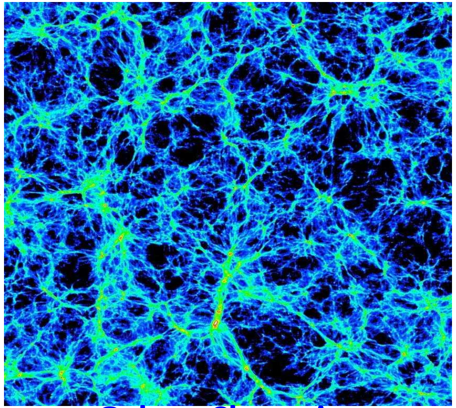
The Euclid *primary probes*: Galaxy Clustering & Weak Lensing



An artist view of the Euclid Satellite – © ESA

Weak lensing





Galaxy Clustering

Carmelita Carbone, INAF - IASF Milano

VI Euclid-IT meeting, Jan 20th, ASI, Rome

The ESA Euclid Science Requirements

Sector	Euclid Targets
Dark Energy	· Measure the cosmic expansion history to better than 10% in redshift bins $0.9 < z < 1.8$. · Look for deviations from $w = -1$, indicating dynamical Dark energy. · Euclid ***primary probes*** to give **FoM$_{DE}$ ≥ 400** (1-sigma errors on w_p & w_a of 0.02 and 0.1 respectively)
Test Gravity	· Measure the growth index, γ, with a precision better than 0.02 · Measure the growth rate to better than 0.02 in redshift bins between $0.9 < z < 1.8$ · Separately constrain the two relativistic potentials. ψ and φ · Test the cosmological principle
Dark Matter	· Detect Dark matter halos on a mass scale between 10^8 and 10^{15} M_{Sun} · Measure the Dark matter mass profiles on cluster and galactic scales · Measure the sum of neutrino masses with an accuracy of 0.03 eV
Initial Conditions	· Measure the matter power spectrum on a large range of scales in order to extract values for the parameters σ_8 and n to a 1-sigma accuracy of 0.01. · For extended models, improve constraints on spectral indices n and α wrt to Planck alone by a factor 2. · Measure a non-Gaussianity parameter : f_{NL} for local-type models with an error < +/-2.

- *DE equation of state: $P/\rho = w$ with $w(a) = w_p + w_a(a_p - a)$*
- *Growth rate of structure formation: $f \sim \Omega^\gamma$;*
- *FoM=$1/(\Delta w_a \times \Delta w_p) > 400$ ~2% precision on w_p*

Euclid Redbook

Measuring the background expansion with GC & WL

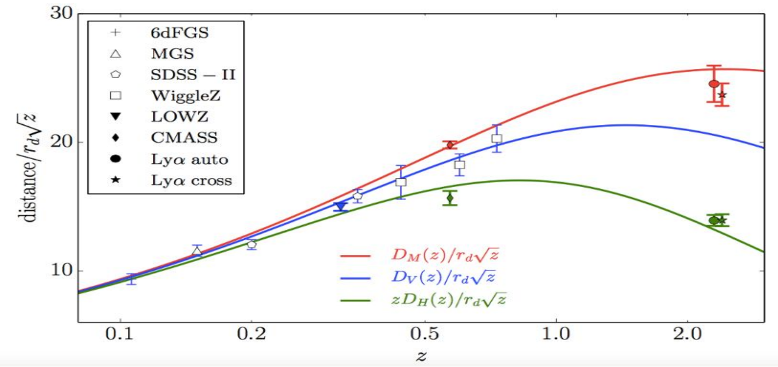
1. Measure ***the expansion history H(z)*** to high accuracy, as to detect percent variations of DE *equation of state* w(z) with robust control of systematics.

Achieve this through **two probes**:

A. Using the scale of Baryon Acoustic Oscillations (BAO) in the clustering pattern of galaxies as a standard ruler

B. Using galaxy shape distortions induced by Weak Gravitational Lensing

Aubourg etal 2015



$$D_M(z) = (1+z)D_A(z) \qquad D_A(z) = \frac{c}{1+z}\int_0^z \frac{dz}{H(z)}$$

$$D_H(z) = c/H(z) \qquad D_V(z) = \left[czD_M^2(z)/H(z)\right]^{1/3}$$

$$H(z) = h\sqrt{\Omega_m(1+z)^3 + \Omega_X \exp\left[3\int_0^z \frac{1+w(z)}{1+z}dz\right]}$$

Spectroscopic galaxy clustering: BAO

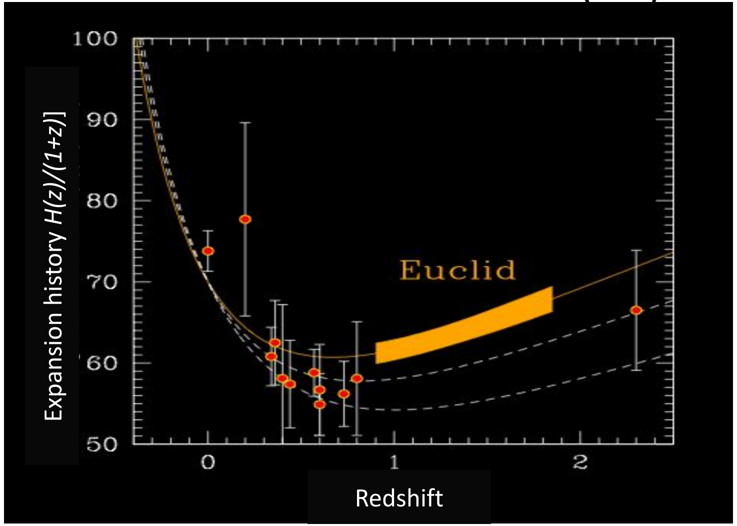
- **Baryon acoustic oscillations (BAO)** as a standard ruler
- Sensitive to the expansion history ***H(z)*** and angular diameter distance relation $\boldsymbol{d_A(z)}$

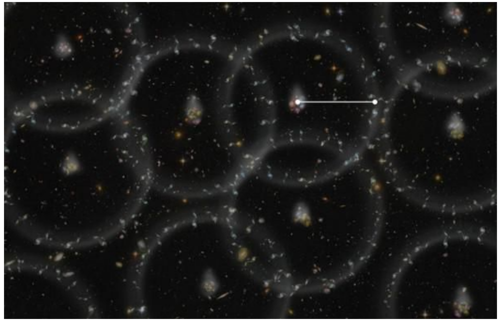
$$r_{\parallel} = \frac{c\Delta z}{H(z)}$$

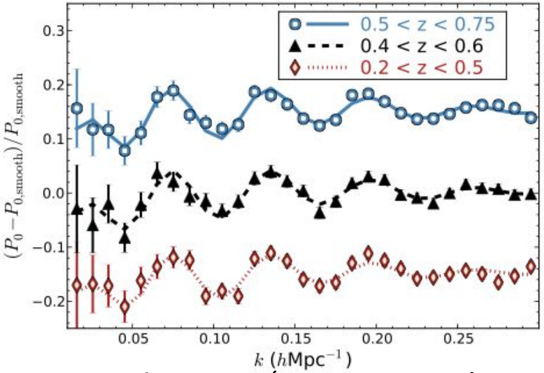
$$r_{\perp} = (1+z)D_A(z)\Delta\theta$$

- Test "beyond Λ" scenario, i.e. an evolving equation of state

Guzzo & GC-SWG (2015)







Alam+16 (SDSSIII BOSS)

Measuring the structure growth with GC & WL

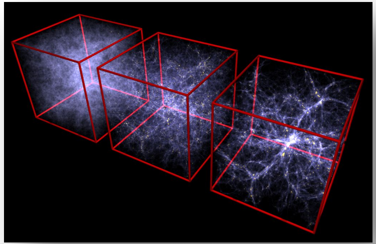
1. Measure expansion history H(z) to high accuracy, as to detect percent variations of DE *equation of state* w(z) with robust control of systematics.

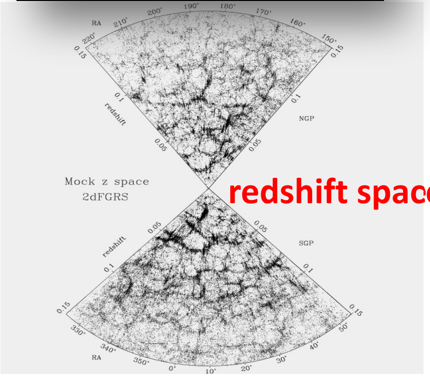
2. Measure at the same time ***the growth rate of structure*** from the same **two probes**, to detect modifications of gravity:

   A. Weak Lensing (WL) Tomography

   B. Clustering redshift-space distortions (RSD)

   A & B are differently sensitive to the Ψ and Φ potentials of the perturbed metric, i.e. to deformation of time and space





Eke & 2dFGRS 2003

Spectroscopic galaxy clustering: RSD

- **Redshift-space distortions (RSD)** probe the growth rate of structure

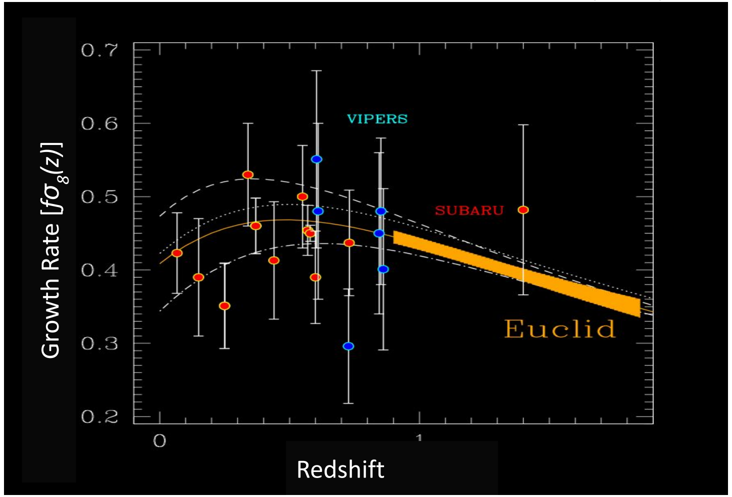
$$z_{\rm obs} = z_{\rm c} + \frac{v_\parallel}{c}(1+z_{\rm c})$$

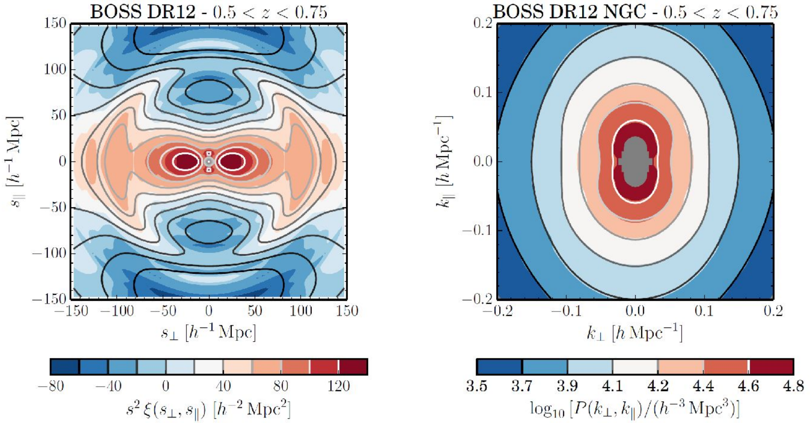
$$\frac{\xi(s)}{\xi(r)} \overset{\text{linear limit}}{=} 1 + \frac{2\beta}{3} + \frac{\beta^2}{5}$$

$$\beta \;=\; f(z)/b(z) \;\simeq\; \Omega_{\rm m}(z)^\gamma/b(z)$$

- **Test "beyond Einstein" scenario, as alternative to GR**

Guzzo & GC-SWG (2015)



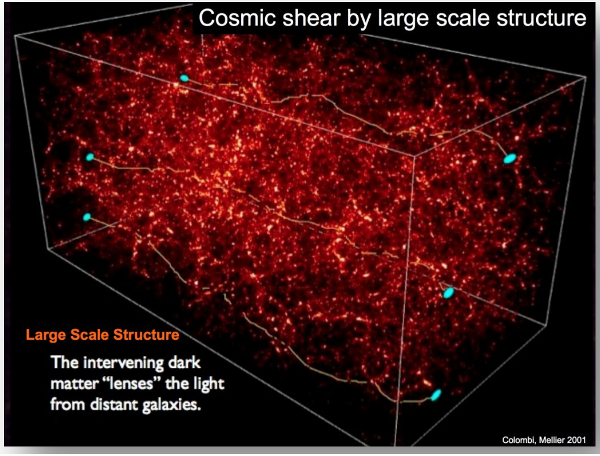


Alam et al 2016 (BOSS/SDSS-III)

AP+RSD

Weak Gravitational Lensing

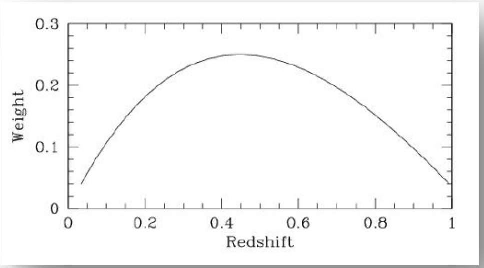
- The lensing kernel is most sensitive to structure halfway between the observer and the source. But the kernel is broad: we do not need precise redshifts for the sources: photometric redshifts are fine
- Since the kernel is broad the tomographic bins are very correlated
- To achieve the science goals we need to measure the matter distribution as a function of redshift: weak lensing tomography requires redshifts for the sources.



Geometry   Large Scale Structure

$$C_{ij}(\ell) = \int_0^{r_H} \mathrm{d}r\, W_{ij}^{\mathrm{GG}}(r) P_{\delta\delta}\left(\frac{\ell}{S_k(r)}; r\right)$$

Lensing Power Spectrum



Measures a combination of geometry (Hz) and growth

The GC_{sp}+3x2pt Euclid **primary probes**

(GC_{sp}+WL+GC_{ph}+WLxGC_{ph})

Modelling used for Fisher forecasts (IST:F) arXiv:1910.09273 **(now improved by GC-WP:NL & IST:NL)**

$$P_{\rm obs}(k_{\rm ref},\mu_{\rm ref};z) = \frac{1}{q_\perp^2 q_\parallel}\left\{\frac{\left[b\sigma_8(z)+f\sigma_8(z)\mu^2\right]^2}{1+[f(z)k\mu\sigma_{\rm p}(z)]^2}\right\}\frac{P_{\rm dw}(k,\mu;z)}{\sigma_8^2(z)}F_z(k,\mu;z)+P_{\rm s}(z)$$

GC_{sp}

$$C_{ij}^{\rm LL}(\ell) = \int_{z_{\rm min}}^{z_{\rm max}} \frac{dz}{H(z)r^2(z)}\mathcal{W}_i^{\rm L}(z)\mathcal{W}_j^{\rm L}(z)P_{\delta\delta}\left(\frac{\ell+1/2}{r(z)},z\right)$$

WL

$$C_{ij}^{\rm GL}(\ell) = \int \frac{dz}{H(z)r^2(z)}\mathcal{W}_i^{\rm G}(z)\mathcal{W}_j^{\rm L}(z)P_{\delta\delta}\left(\frac{\ell+1/2}{r(z)},z\right)$$

WLxGC_{ph}

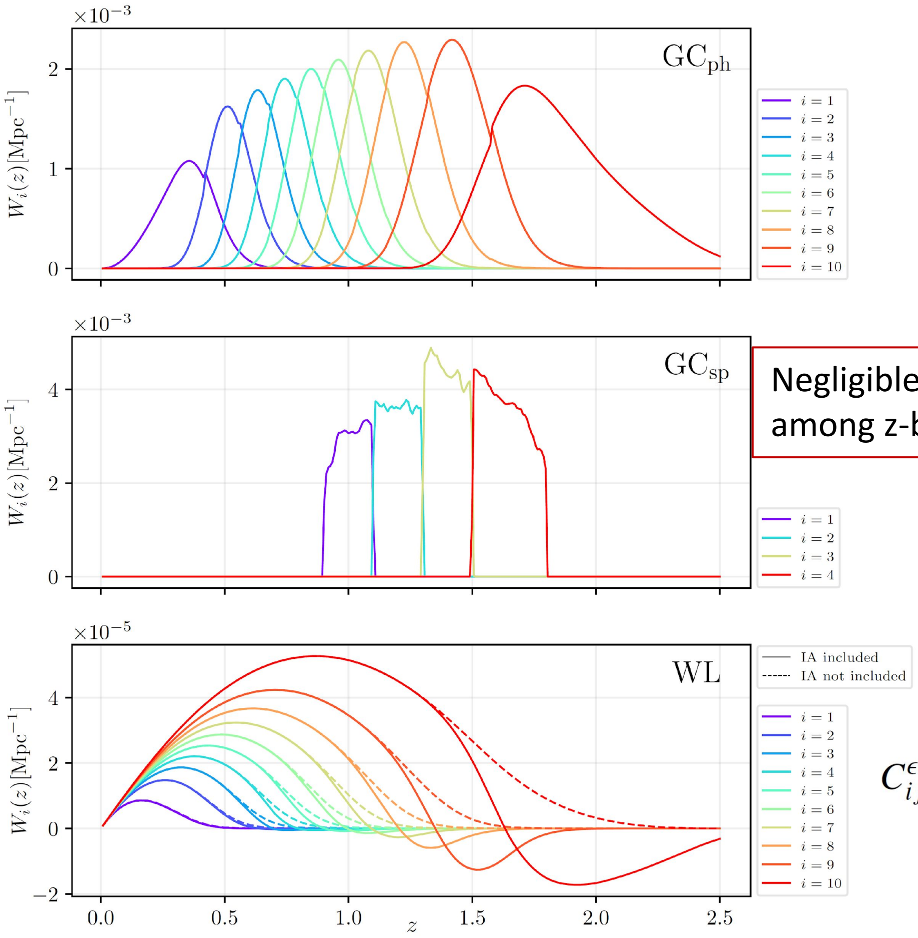
$$C_{ij}^{\rm GG}(\ell) = \int \frac{dz}{H(z)r^2(z)}\mathcal{W}_i^{\rm G}(z)\mathcal{W}_j^{\rm G}(z)P_{\delta\delta}\left(\frac{\ell+1/2}{r(z)},z\right)$$

GC_{ph}

$$\mathcal{W}_i^{\rm L} = W_i^{\gamma}(z) - \frac{\mathcal{A}_{\rm IA}\mathcal{C}_{\rm IA}\Omega_{\rm m}\mathcal{F}_{\rm IA}(z)}{D(z)}W_i^{\rm IA}(z)$$

3x2pt=WL+GC_{ph}+WLxGC_{ph}

Weight functions for GC_{ph}, GC_{sp} & WL

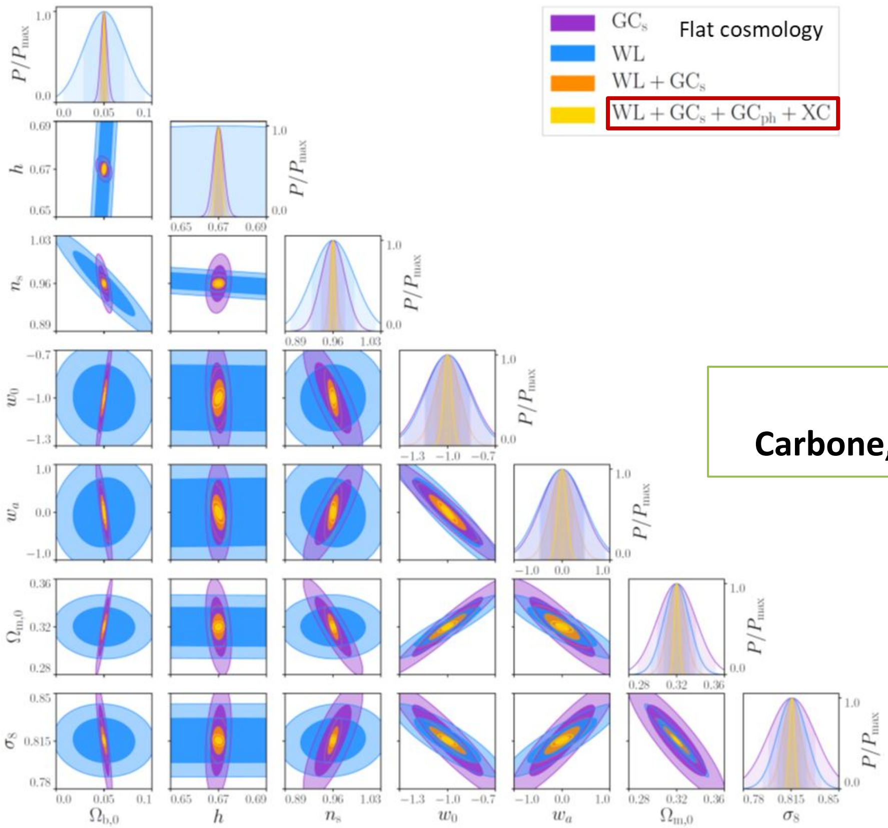


Negligible correlations among z-bins

$$C_{ij}^{\epsilon\epsilon}(\ell) = C_{ij}^{\gamma\gamma}(\ell) + C_{ij}^{\rm II}(\ell) + C_{ij}^{\rm I\gamma}(\ell) + N_{ij}^{\epsilon}(\ell)$$

Forecasts of Euclid scientific performance

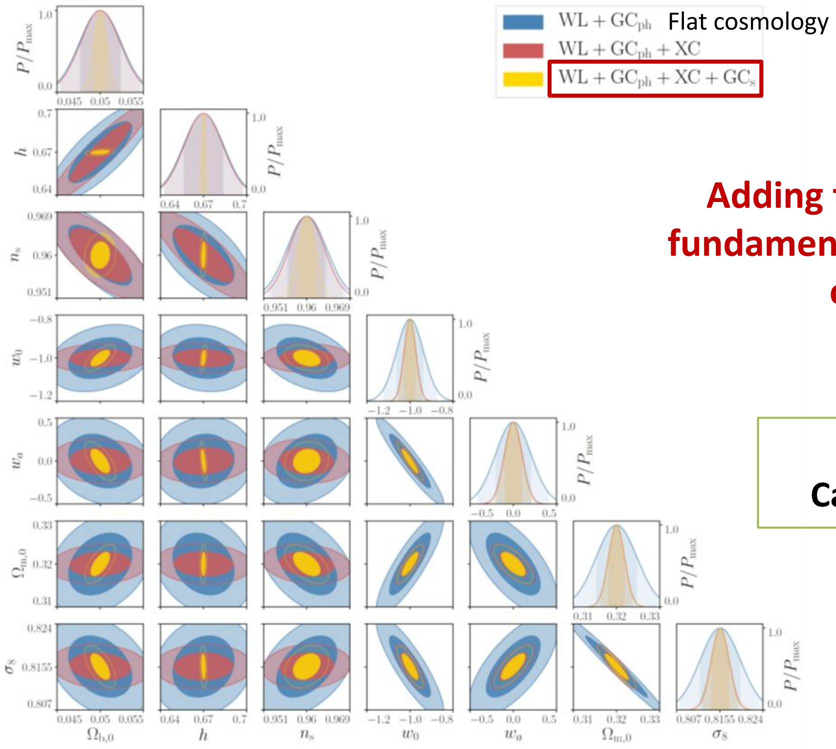
REFERENCE PAPER: Euclid Consortium, arXiv:1910.09273



IT contributors:
Carbone, Cardone, Camera, Martinelli

Probe combination is key to high precision and accuracy

REFERENCE PAPER: Euclid Consortium, arXiv:1910.09273



Adding the WL-GC$_{ph}$ cross-correlation is fundamental to fullfill the ESA requirements of Dark Energy FoM=400

IT contributors:
Cardone, Camera, Martinelli

SWG Work Packages and ISTs in place

GALAXY CLUSTERING WPs

Observational Systematics: Claudia Scarlata & Pierluigi Monaco Italy

End-to-end: Sylvain de la Torre, Ben Granett & Michele Moresco Italy

Likelihood Fitting: Julien Bel & Carmelita Carbone Italy

Non-linear effects: Martin Crocce, Elena Sarpa & Alfonso Veropalumbo Italy

Higher-order stats: Cris Porciani & Emiliano Sefusatti Italy

Additional GC probes: Florent Leclercq & Cora Uhlemann

Photo-z clustering: Isaac Tutusaus & Stefano Camera Italy

Cosmic Voids: Nico Hamaus, Seshadri Nadathur & Alice Pisani

WEAK LENSING WPs

Shape Measurement & PSF: Lance Miller

Photo Redshifts: Ranga-Ram Chary & Hendrik Hildebrandt

Estimators: Alex Hall & Michael Brown

Mass Mapping: Sandrine Pires & Nicolas Martinet

Higher Order Stats: Ismael Tereno & Vincenzo Cardone Italy

Likelihood: Elena Sellentin & Vincenzo Cardone Italy

Galaxy-Galaxy Lensing: Eric Jullo & Mike Hudson

Intrinsic alignment: Benjamin Joachimi & Bjoern Malte Schaefer

Magnification: Chris Duncan & Dipak Munshi

Cosmological Sims: Joachim Harnois-Déraps & Carlo Giocoli Italy

Forward modelling: Peter Taylor & Dipak Munshi

Instra Science working group Task forces

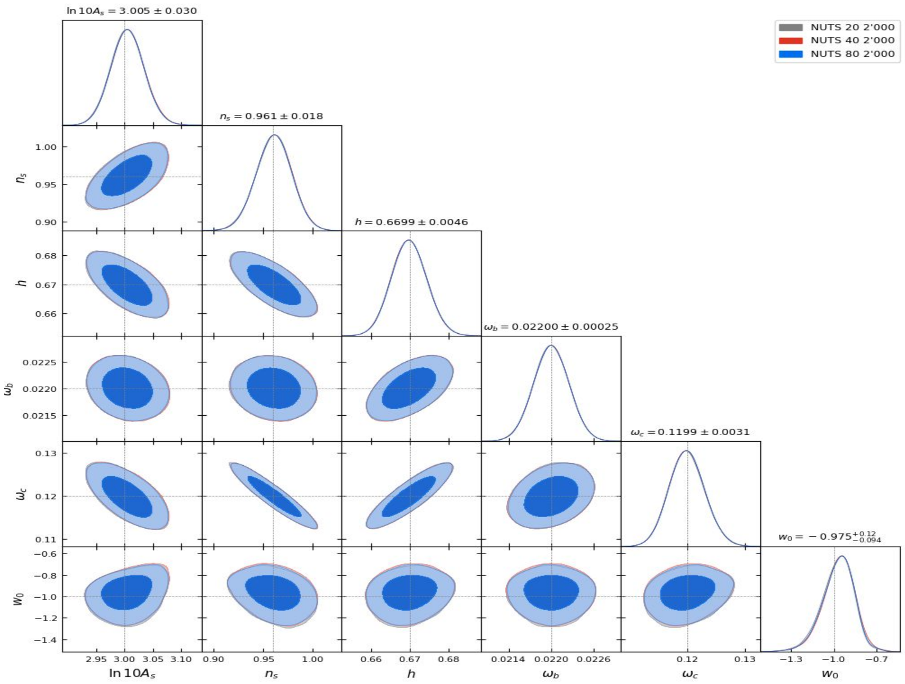
IST:Likelihood: Shahab Joudaki, Valeria Pettorino & Vincenzo Cardone Italy

IST:Non-Linear: Martin Crocce, Alkistis Pourtsidou & Carlo Giocoli Italy

From optimistic Fisher forecasts to realistic cosmological parameter inference
(showing only IT contributors)

1. **IST:NL**: Adding super sample covariance (SSC) (Sciotti, Lacasa, Bonici, Cardone)
2. **GC-WP:Photo**: Optimising the WL&GC_{ph} n(z) choices (Camera, Cardone)
3. **GC-SWG&PC-TT**: Including purity effects and systematics (Carbone, Cardone, Granett, Monaco, Moresco, Risso, Parimbelli)
4. **IST:NL&GC-WP:NL**: GC_{sp} nonlinear modelling and emulators (Moretti, Bonici, Carbone, D'Amico, Sefusatti, Pardede, Biagetti, Veropalumbo, Guidi, Moresco, Rizzo, Piga)
5. **IST:NL&CoS-SWG**: WL&GC_{ph} nonlinear modelling and emulators (Camera, Giocoli, Bonici)
6. **GC-OULE3&GC-SWG**: Estimator validation & testing (Marulli, Moresco, Veropalumbo, Salvalaggio, Pardede, Rizzo, Parimbelli, Tavagnacco, Bardelli, Monaco, Sefusatti, Castorina, D'Amico)
7. **IST:NL&GC-WP:NL**: Analytic covariance matrices for GC_{sp} (Salvalaggio, Pardede, Biagetti, Rizzo, Veropalumbo, Monaco, Sefusatti)
8. **IST:NL&GC-WP:NL**: Analytic covariance matrices for WL&GC_{ph} (Sciotti, Bonici)
9. **GC-OULE3&CoS-SWG&GC-SWG**: Mocks & numerical covariance matrices (Monaco, Parimbelli, Veropalumbo, Giocoli, Carbone, Baldi, Carella)
10. **IST:L&GC-WP:Like**: Full likelihood via standard and deep learning solutions (Bonici, Camera, Cardone, Carbone, Davini, Di Domizio, Sciotti, Martinelli)
11. **GC-WP:NL**: Improving BAO measurements via reconstruction (Veropalumbo)

Deep learning example:
Speeding up cosmological parameters inference with 2pt-emulators and differentiable likelihoods



GC$_{sp}$ likelihood:

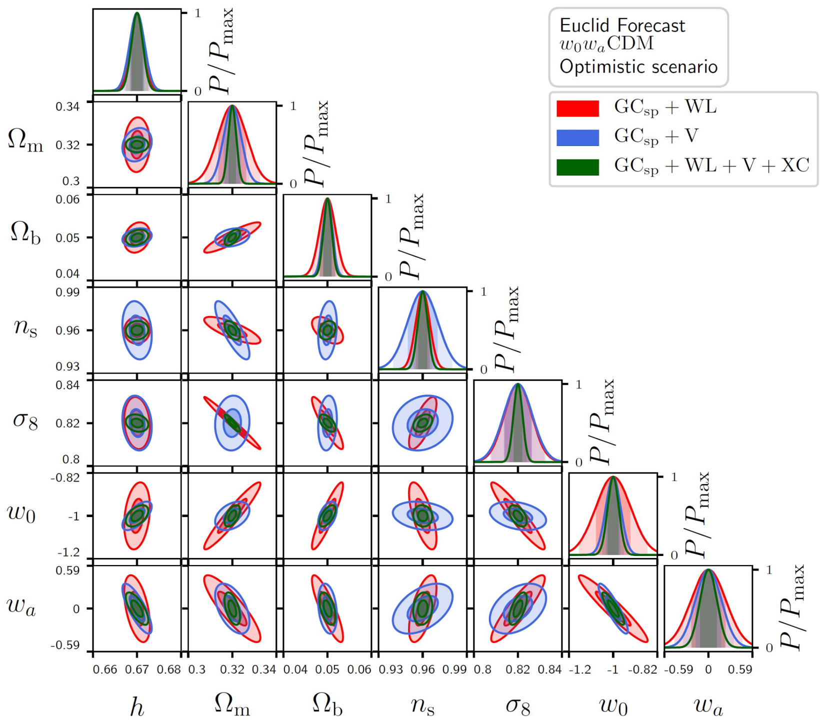
- Trained emulators to mimic PyBird predictions for GC$_{sp}$ power spectra at all Euclid **spectro redshifts**
- Improved performance, the **likelihood computation** when considering 4 spectroscopic bins and 3 multipoles requires **0.5 milliseconds**
- For the full GCsp-sample the **chains run** in about **1 hour** and have shown a optimal **convergence** and **stability** using Hamiltonian MCMC.
- Possible merging and benchmark for CLOE

Bonici, Carbone, D’Amico & Euclid Consortium, in prep.

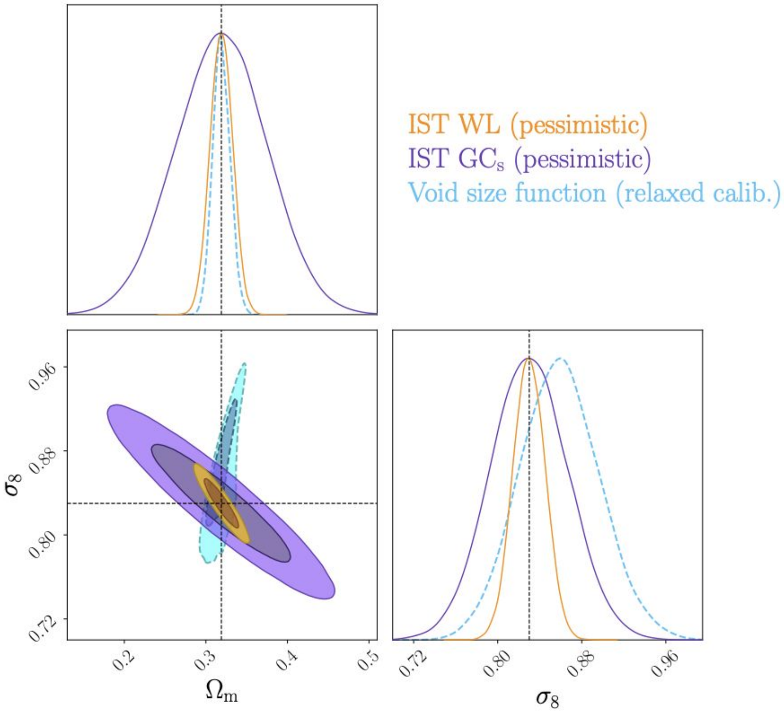
Italy

Euclid Pre-launch Key Project GC-6 paper-3 under GC-SWG WP:Likelihood (led by Carbone and Bel)

Don't forget cosmic voids!
Parameter inference from photo&spectro voids



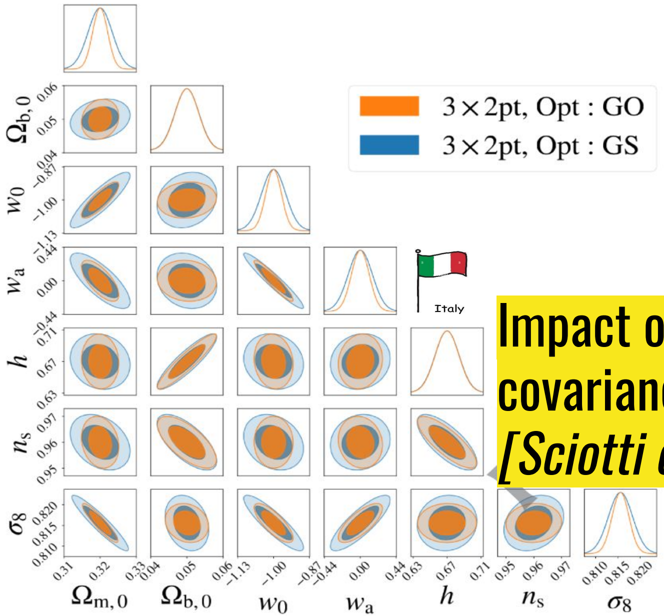
Bonici, Carbone & Euclid Consortium, 2022



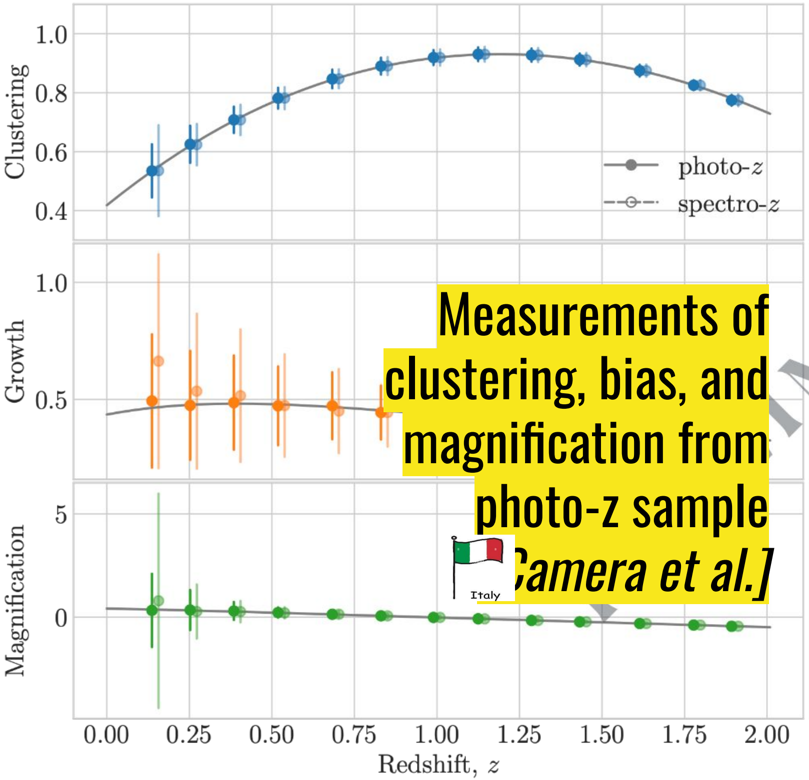
Contarini, Verza & Euclid Consortium, 2021

‘Photo-z clustering’ WP

- **Leads:** *Stefano Camera* & *Isaac Tutusaus* (*https://euclid.roe.ac.uk/projects/gcswg/wiki/Photo-z_clustering*)
- Contribution to the GCph recipe in IST:L, IST:NL, and SPV3
- Involvement in the ‘Visibility Mask’ Tiger Team (lead by B. Joachimi)
- 13 KP Papers (4 Italy):



Impact of super-sample covariance on 3x2pt *[Sciotti et al.]* (Italy)



Measurements of clustering, bias, and magnification from photo-z sample *[Camera et al.]* (Italy)

‘Photo-z clustering’ WP + KP-GC-7

- **Leads:** *Stefano Camera* & *Isaac Tutusaus* (*https://euclid.roe.ac.uk/projects/gcswg/wiki/Photo-z_clustering*)
- 13 KP Papers
  - 3 already published:
    1. Magnification and other relativistic effects [https://arxiv.org/abs/2110.05435]
    2. GCph sample optimization [https://arxiv.org/abs/2104.05698]
    3. Ensemble photo-*z*’s (KP –> SP Paper upon the authors’ request) [https://arxiv.org/abs/2109.07303] Italy
  - 3 ready/submitted to ECEB:
    4. RSDs in Limber approximation
    5. Impact of super-sample covariance on photometric clustering and 3x2pt Italy
    6. Forecast measurements of clustering, growth, and magnification via the spectro- and photo-*z* samples Italy
  - others work in progress, amongst which:
    7. Measurements of BAOs in harmonic space with the photometric sample Italy
- Contribution to the GCph recipe in IST:L, IST:NL, and SPV3

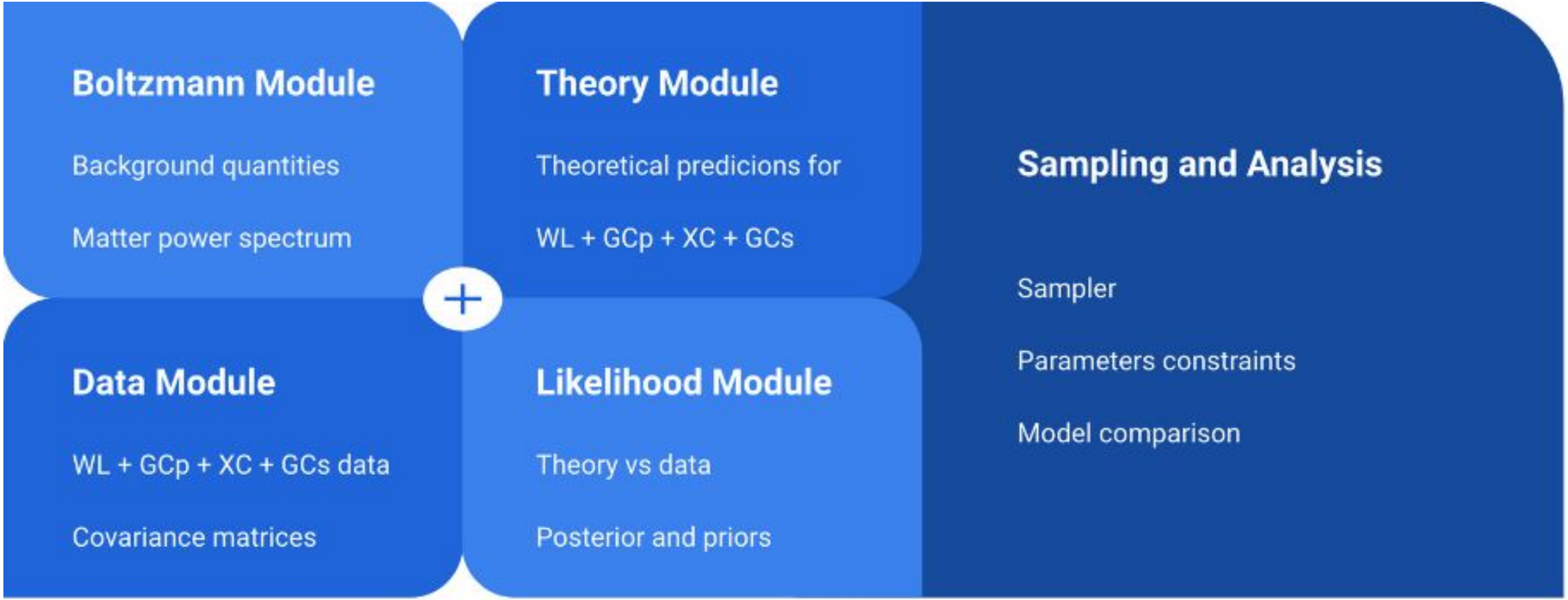
5 + 1 (Known and Unknown) Facts about CLOE

Vincenzo F. Cardone - Osservatorio Astronomico di Roma

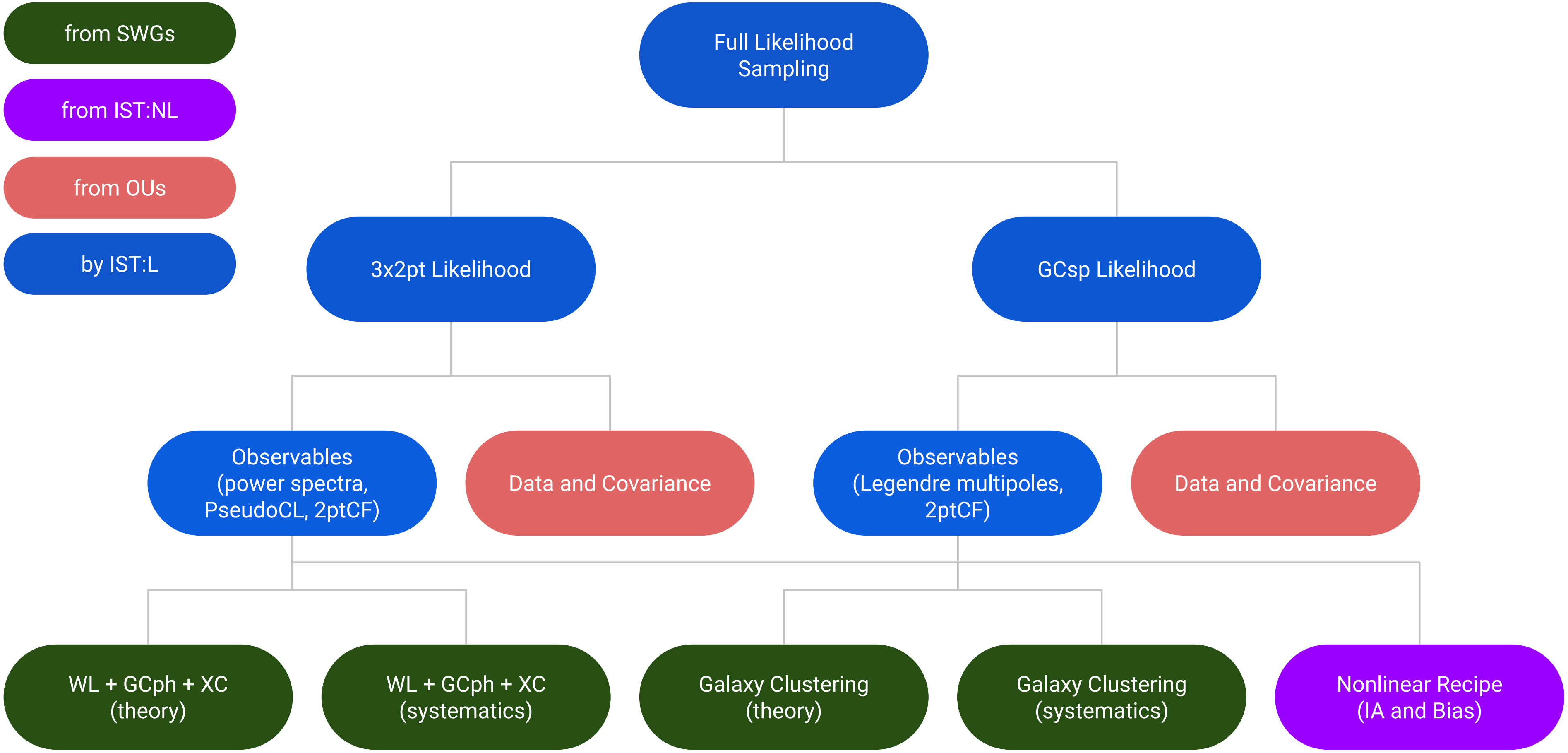
VI Euclid Italia Meeting - 20/01/2023

Fact no.1: What is CLOE (Cosmology Likelihood of Observables in Euclid)

- *Official Euclid Likelihood code for primary probes:* photometric (3x2pt) and spectroscopic (clustering)
- *A joint community effort to get the cosmological results:* input from SWGs + OUs + IST:NL to IST:L
- *More than the likelihood alone:* compute theory, include systematics, compare to data, sample parameters



Fact no.1: What is CLOE (Cosmology Likelihood of Observables in Euclid)



Fact no.2: What is in CLOE v2 and where are we now

90%

- 3x2pt recipe implemented
- GCsp recipe implemented
- nonlinear models for 3x2pt and GCsp
- parameterized modified gravity

- allow for non flat models
- include magnification and (linear) RSD
- merging done for 3x2pt, ongoing for GCsp
- Linder gamma and phenomenological MG

85%

- 3x2pt observables and systematics
- GCsp observables and systematics
- impact of the mask in 3x2pt
- BNT for improving scale cuts

- power spectra, 2pt CFs, and Pseudo Cl
- Legendre multipoles and 2pt CF
- shear multiplicative bias and photo - z shift
- purity (constant or varying with z)

70%

- interface with data
- user interface (at different levels)
- graphical user interface (GUI)
- training for Euclid community

- need to be connected to SAS
- overlayer and scripts to run MCMC
- help non expert users to play with CLOE
- how to use CLOE for your project

10%

- Validation

- compare with external benchmark
- optimize if needed
- validation plan ready
- benchmark codes available

10%

- MCMC forecasts

- defined the cases of interest
- prepared scripts for running
- found computing resources (volunteer)
- install CLOE on available resources

Fact no.3: CLOE vs SPV3 vs DR1/DR3 from the 3x2pt Point of View

SPV3 Forecasts

CLOE v2

- realistic n(z)
- number of bins
- type of bins
- priors on
  - shear bias
  - photo - z
  - mag bias
  - gal bias
- baryons
  - recipe
  - priors
- scale cuts
- BNT transform

SPV3 Pre Launch

CLOE v2.1

- n(z) for WL and GCph
- requirements on n(z)
  - mean
  - variance (?)
  - bin shape (?)
- recipe verification
  - measure Cij
  - comparison
- data interface
  - from SAS
  - survey mask
- redshift cuts (if any)
- full SSC covariance

DR1 Data Analysis

CLOE v3

- high order effects
  - reduced shear
  - shear mag
  - clustering
- advanced IA models
  - TATT
  - halo model
- systematics
  - scale dep bias
  - PSF errors
  - covariance
- nonlinear bias
- beyond Limber

DR3 Data Analysis

CLOE v3.1 (?)

- unknown …
  - …….
  - …….
  - …….
- leftovers
  - speed
  - usefulness
- systematics
  - …..
  - ……
- covariance
  - mock
  - ….

Fact no.4: CLOE vs SPV3 vs DR1/DR3 from the GCsp Point of View

SPV3 Forecasts

CLOE v2

- realistic n(z)
- which observable
  - multipole
  - 2ptCF
- modeling
  - 1 loop PT
  - simplified
  - scale cut
- priors on
  - gal bias
  - 1 loop params
  - purity
- covariance

SPV3 Pre Launch

CLOE v2.1

- realistic n(z)
- purity
  - dependent on z
  - interlopers (?)
- modeling
  - full recipe
  - scale cut
- priors
  - gal bias
  - PT params
  - purity
- convolution with WF
- covariance with WF

DR1 Data Analysis

CLOE v3

- systematics
  - signal
  - covariance
- alternative recipes
  - SWG approved
  - worthy
  - suitable for MG
- covariance
  - DR1 mocks
  - analytic
- (3x2pt) x GCsp
  - signal
  - covariance

DR3 Data Analysis

CLOE v3.1 (?)

- unknown …
  - …….
  - …….
  - …….
- leftovers
  - speed
  - usefulness
- systematics
  - …..
  - ……
- covariance
  - DR3 mocks
  - ….

Fact no.5: CLOE vs the Medusa approach to Blinding

DR1 KPs

CLOE & Euclid

- who runs MCMC?
- non IST:L versions

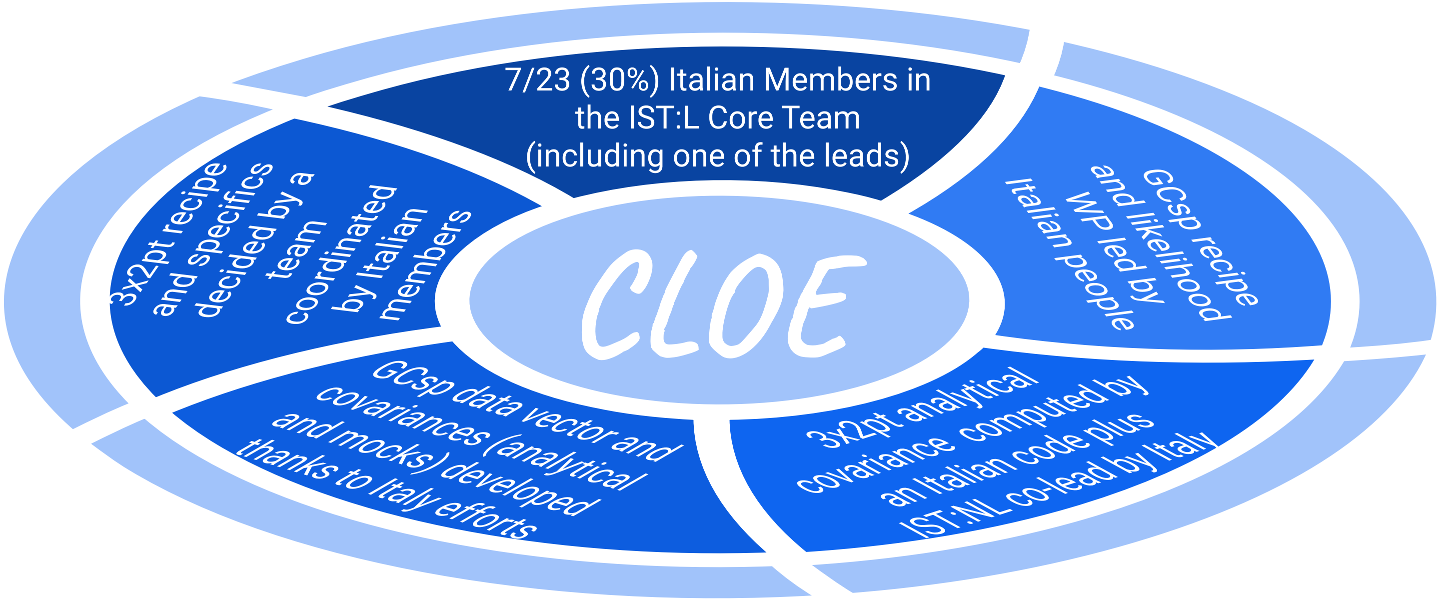
CLOE vs the World

- no public release?

Freezing CLOE

- *when:* after v3?
- *what:* theory recipes only?
- *how:* no modifications?
- *what if:* new systematics?
- *what if:* speed up methods?

Fact no.5 + 1: CLOE and the Italian Scientific Community



Italy in IST:L

- V.F. Cardone (lead)
- S. Camera and M. Martinelli (scrum masters)
- M. Bonici, S. Davini, S. Di Domizio, D. Sciotti (developers)

Italy in SWGs/OUs related to IST:L

- M. Carbone (GCSWG Likelihood WP lead)
- V.F. Cardone (WLSWG Likelihood WP lead)
- C. Giocoli (IST:NL lead & WLSWG CosmoSim lead)
- M. Bonici, D. Sciotti (3x2pt covariance taskforce in IST:NL)
- P. Monaco, E. Sefusatti et al. (GCsp related OUs)

- ***An Italy driven product at all levels: theory + nonlinearity + data + covariance + implementation***
- ***Beware of not wasting the efforts! Non staff people moving to other Euclid countries just when data come***

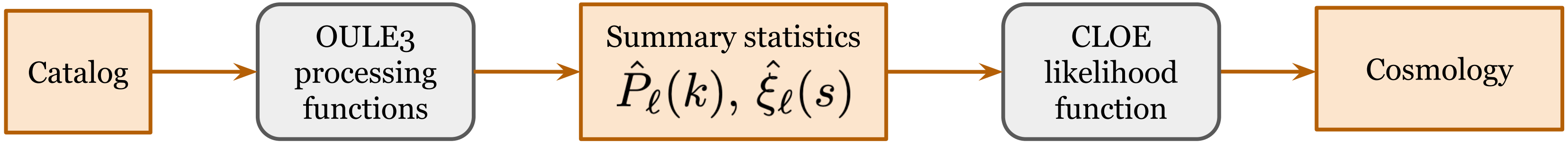
Galaxy Clustering
from the spectroscopic catalog to cosmology

Euclid Italia 2023
Roma - ASI

INAF ISTITUTO NAZIONALE DI ASTROFISICA
Emiliano Sefusatti
Osservatorio Astronomico di Trieste

Galaxy Clustering

from the spectroscopic catalog to cosmology



Emiliano Sefusatti
Osservatorio Astronomico di Trieste

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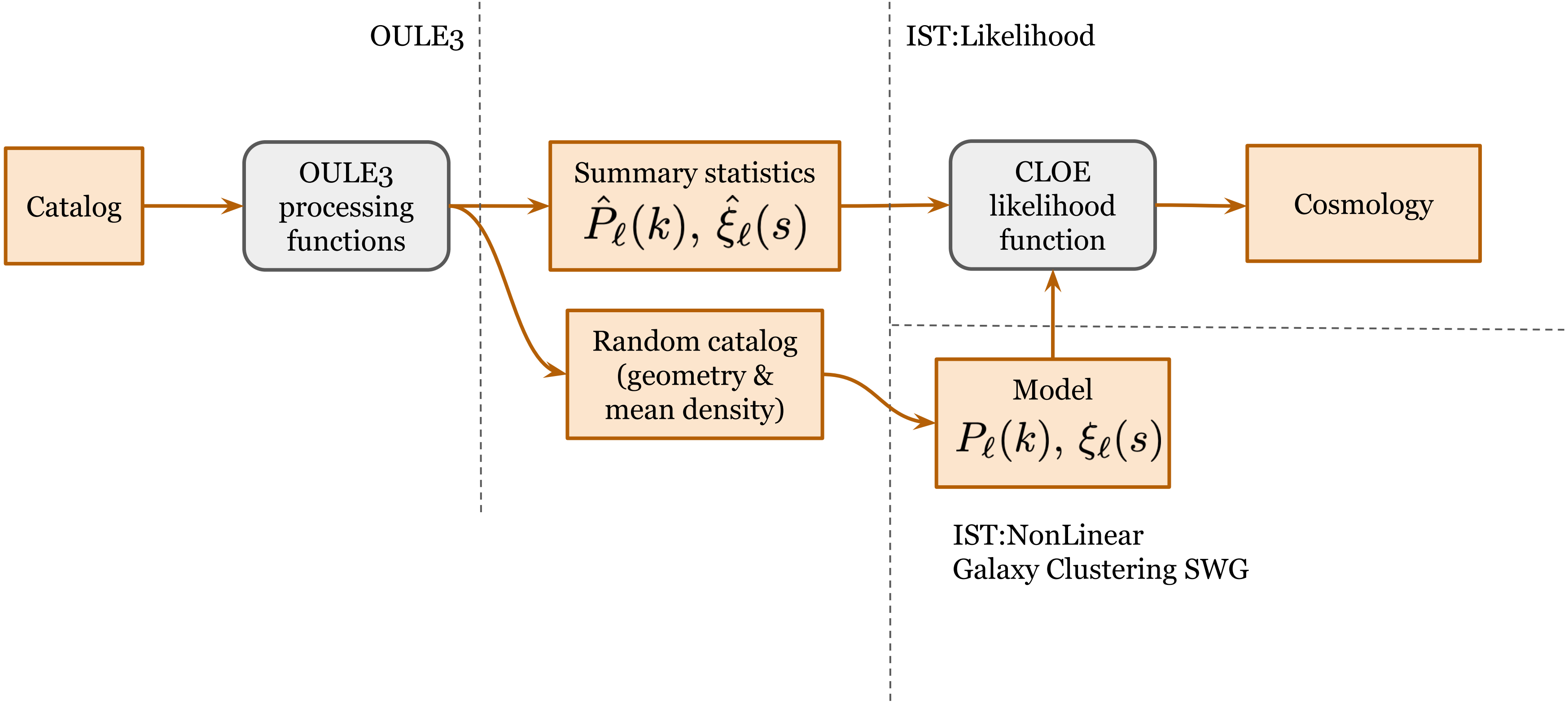
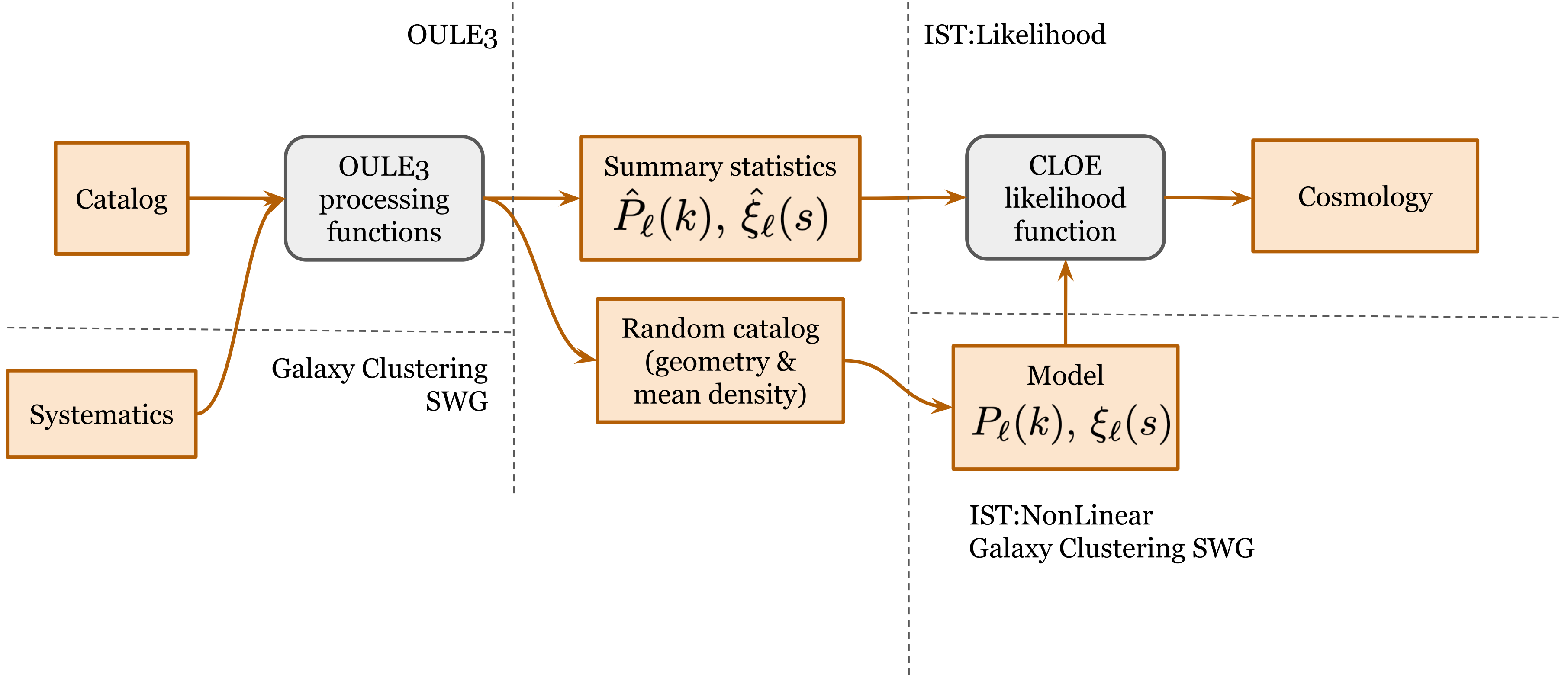


Galaxy Clustering
from the spectroscopic catalog to cosmology



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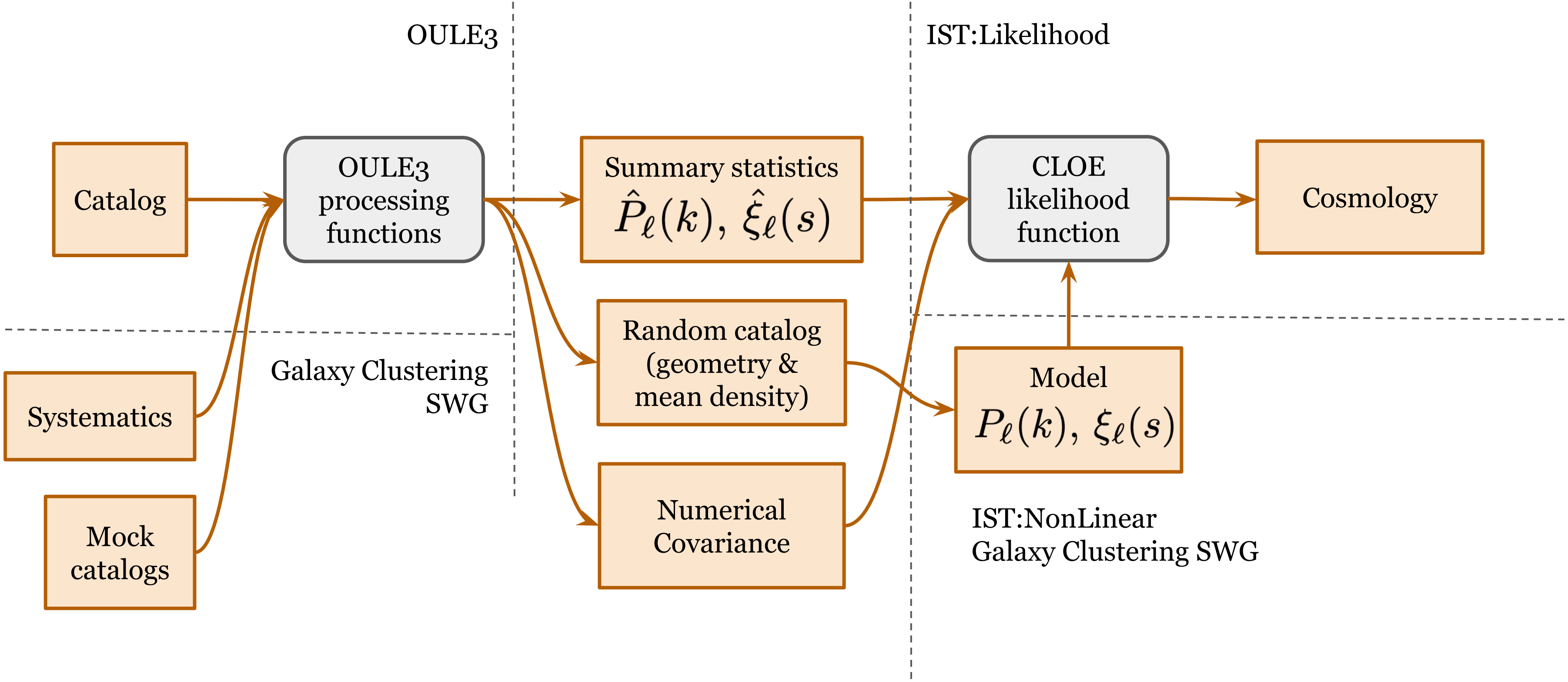

Galaxy Clustering

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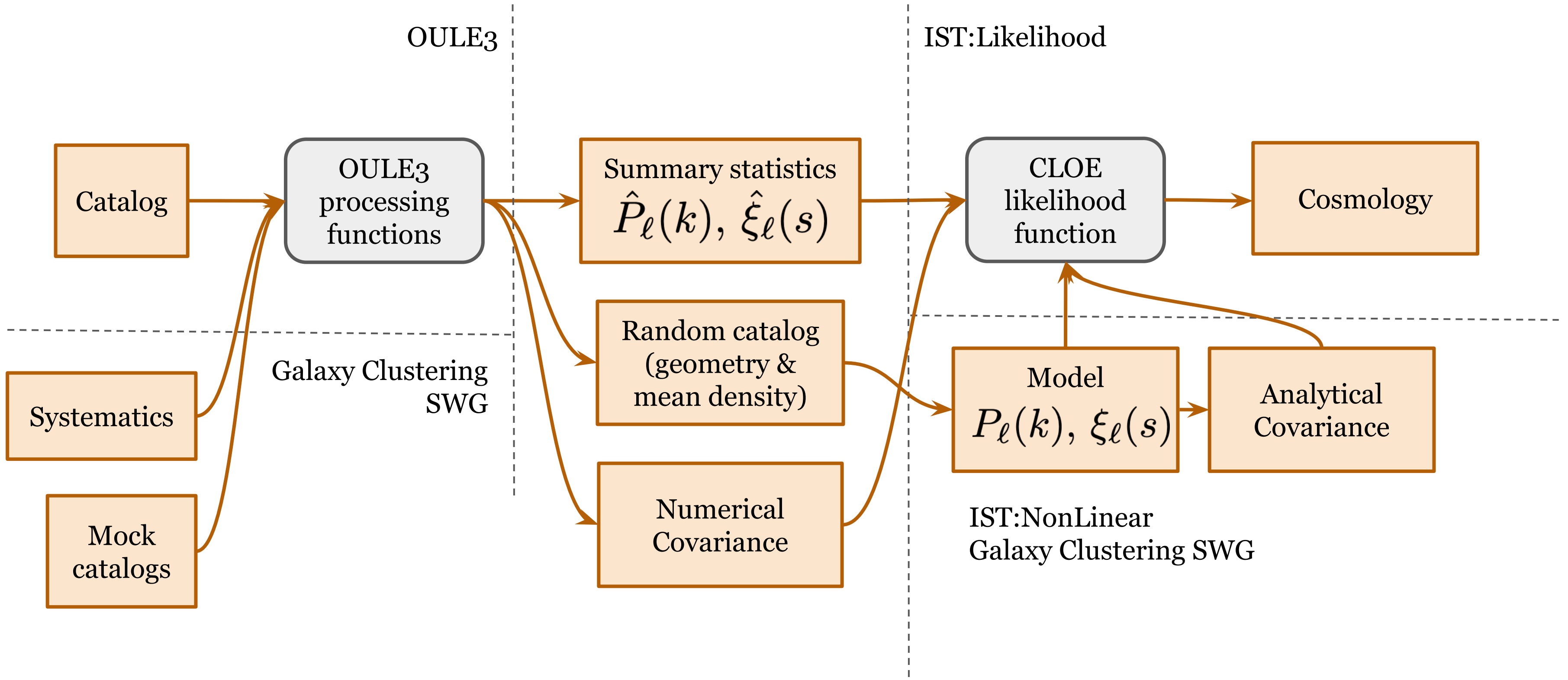


Estimators

OULE3

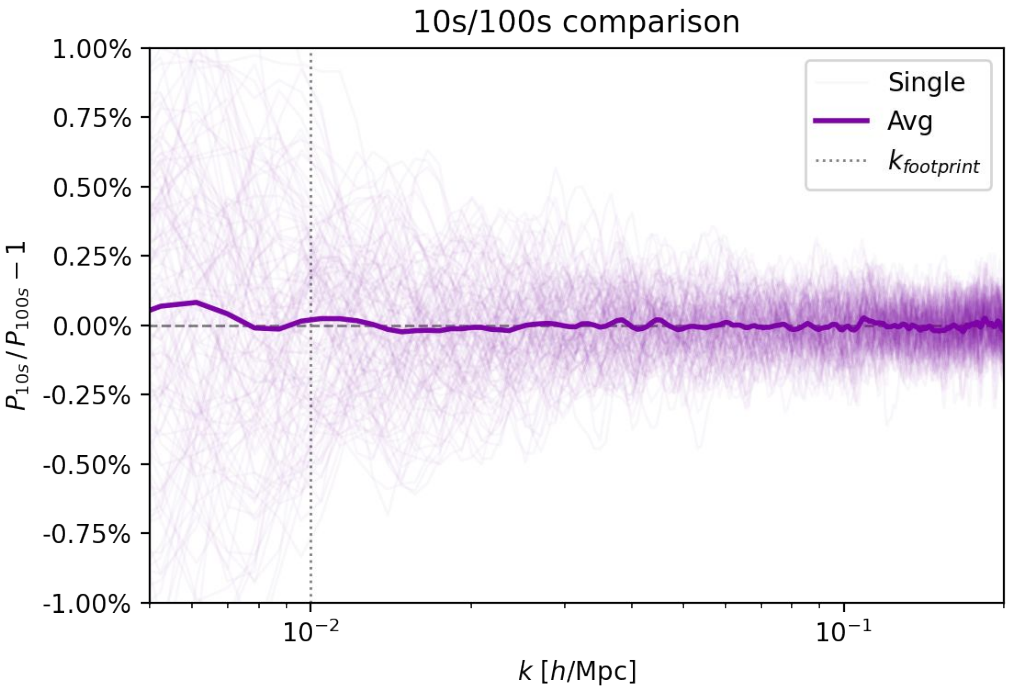
Make sure that all products have potential **systematic errors under control:** ***the target is well below 1%!***

- Galaxy density estimation
- Random density
- Box effects
- Etc …

All processing functions are developed and tested in Italy

A lot more needs to be done to determine the optimal use of these tool

Crucial topic but very limited workforce!



Mock catalogs
OULE3 / GC-SWG

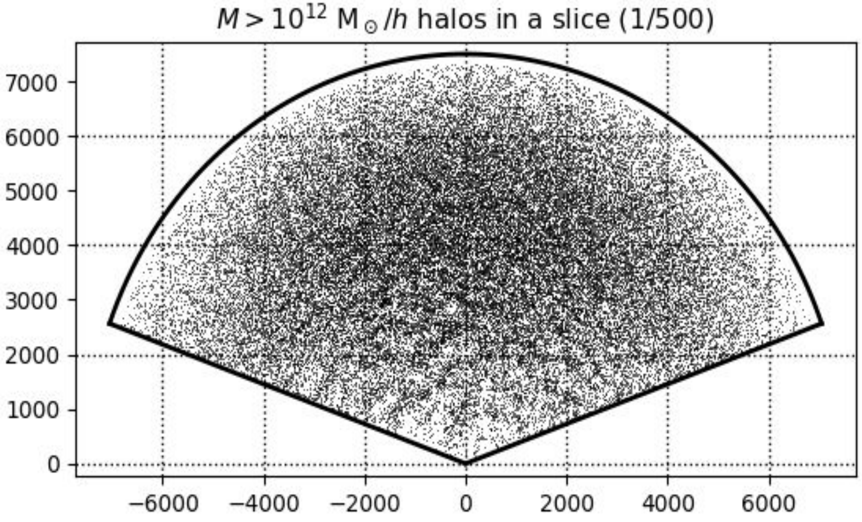
Mocks are essential to estimate statistical errors and quantify systematic errors

A proposal to focus our efforts on two geometries:

- DR1-size mocks
- Flagship simulation light-cones

All realistic mocks of the spectroscopic samples ar[e] based on the Pinocchio code and run in Trieste

They are still relatively small: not accounting for al[l] possible finite-volume effects and .... *all probes!*



Interactions with CLOE

OULE3 / GC-SWG / IST:Nonlinear / IST:Likelihood

Several pieces of the full pipeline are still missing:

- Data model
- **Window function** (*and more …*)

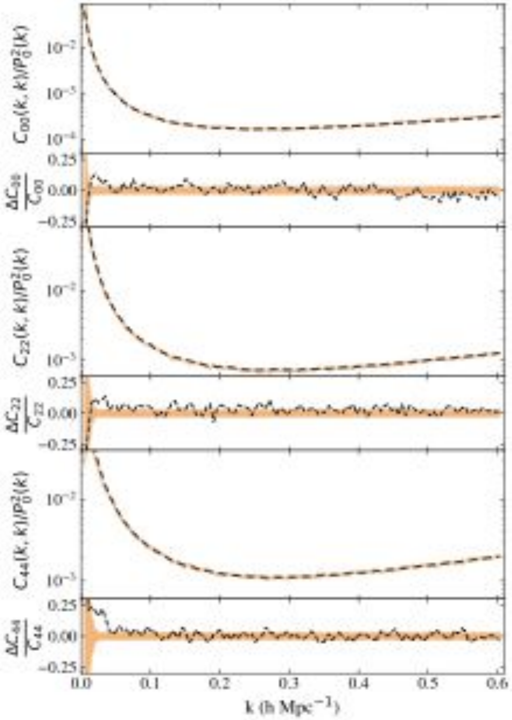
$$\widetilde{P}_{\ell}^{\rm obs}(k) = M_{\ell\ell'}(k,k')P_{\ell'}^{\rm theory} - {\rm IC}(k)$$

- **Analytical covariance**

These algorithms require *extensive* testing

Again: *a lot of work and very small workforce*

Italian participation is substantial
(but too much based on students!)



Errors can be predicted in PT to high accuracy

Wadekar & Scoccimarro (2020)

Euclid Italia 2023
Roma - ASI

Modelling challenge
GC-SWG / IST:Nonlinear

A test of the models and
of likelihood analysis choices

Full shape & BAOs fitting of $P(k)$, $\boldsymbol{\xi}(s)$ and
higher-order correlation functions

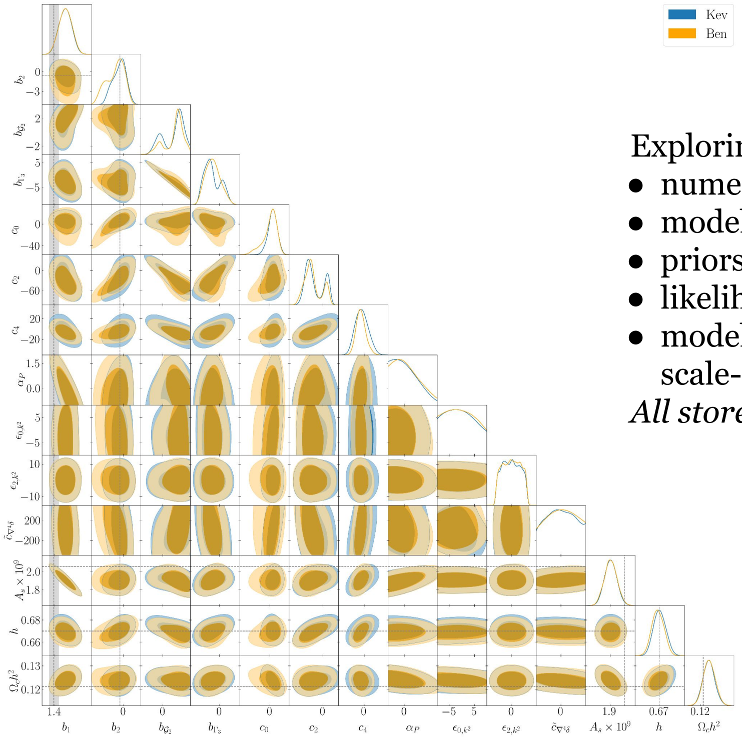
Five different codes:

- Comet
- PBJ
- PyBird
- Code by A. Moradinezhad
- Bacco

Benchmarks for CLOE

2023: first full light-cone analysis from Falgship simulation

- WPs NL & Higher Order Stats with Italian leads
- PBJ & PyBird are mainly developed in Italy



Exploring:

- numerical evaluation
- model assumptions
- priors
- likelihood choices
- model validity range & scale-cuts

All stored!

Observational Systematics

GC-SWG /OULE3

Observational systematics from:

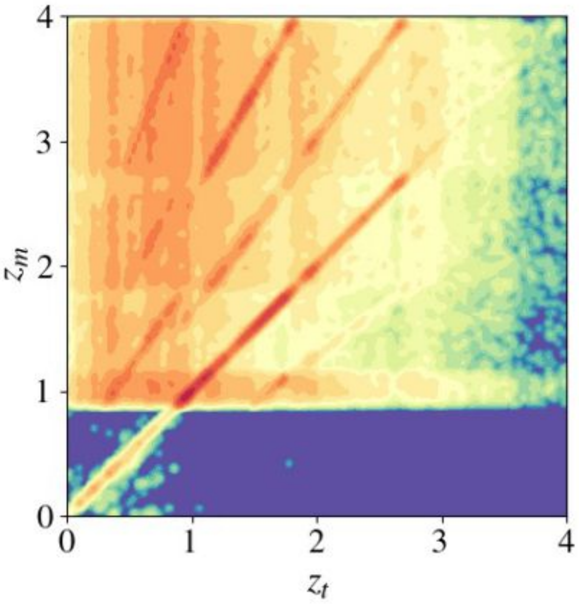
- modulations of the flux limit
- line interlopers (ELGs with misidentified line)
- noise interlopers (sources acquiring a line due to noise)

The main tool to mitigate observational systematics is **the random catalog**, a forward model of completeness and purity.

Uncertainty in the mitigation of systematics will be propagated to cosmological parameters by computing **the numerical covariance of a set of mocks with added systematics** - an operation to be performed by the SWG outside the pipeline

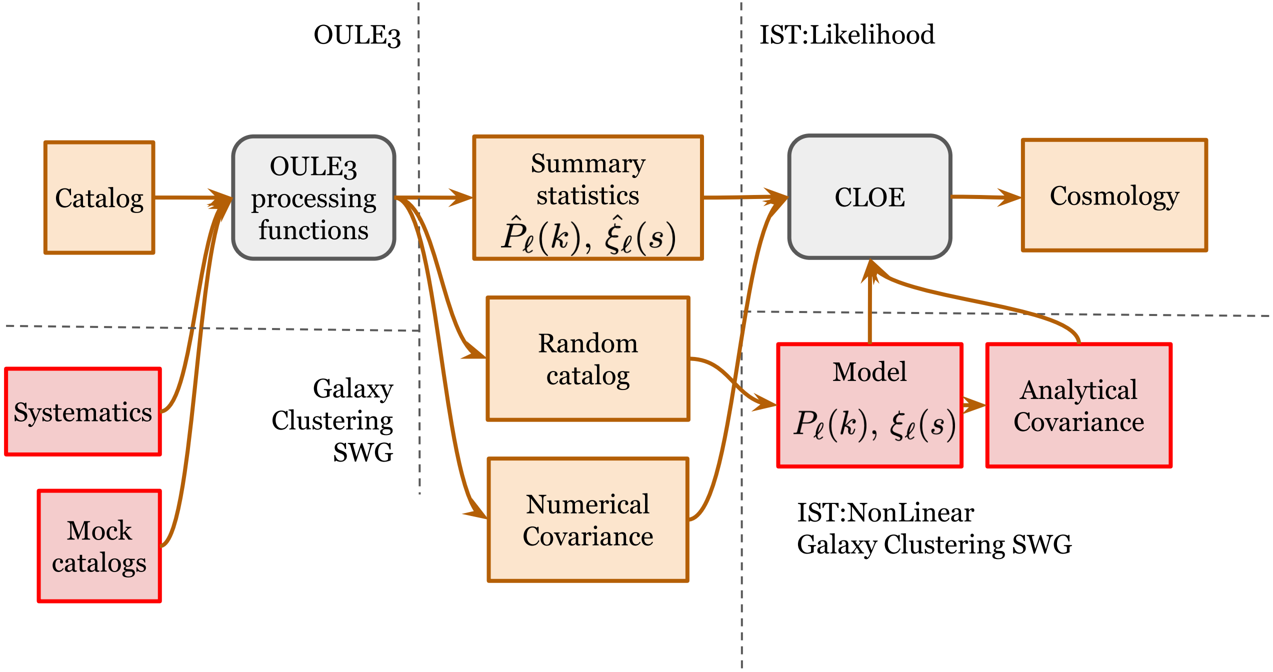
Strong Italian contribution:
leadership of ObsSys (Monaco) and E2E (Granett, Moresco) WPs.

This is a topic where we should consolidate our leadership

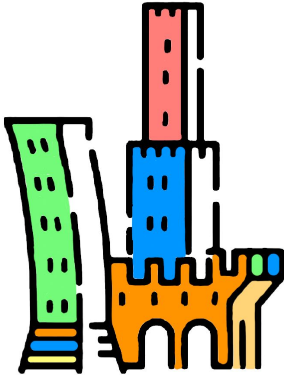


Galaxy Clustering

the status



- several *critical and crucial* open issues
- but a well defined roadmap
- significant (*but relative!*) Italian contribution
- still a lot of opportunities (*maybe not for too long!*)



Euclid Meeting Italia 2023 - ASI Roma

IST:NL & Simulations

going beyond linear scales in cosmological analyses

MAXIMIZING THE SCIENTIFIC RETURN OF THE EUCLID MISSION

Carlo Giocoli – INAF OAS Bologna

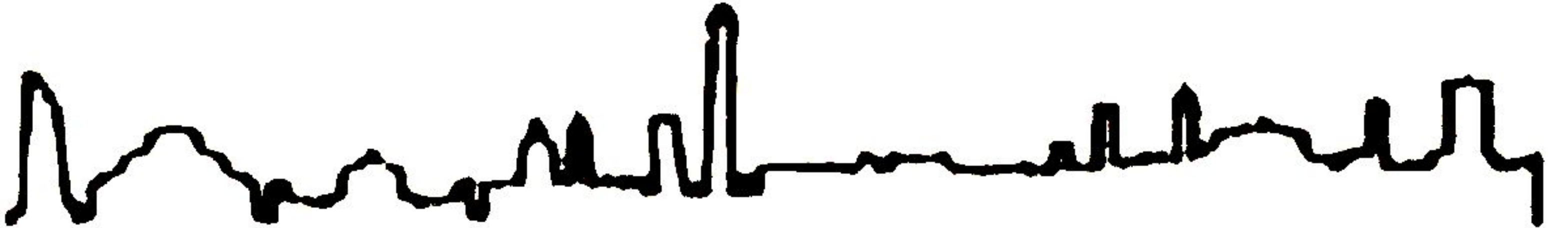
ISTITUTO NAZIONALE DI ASTROFISICA INAF

INFN

ASI Agenzia Spaziale Italiana

esa euclid

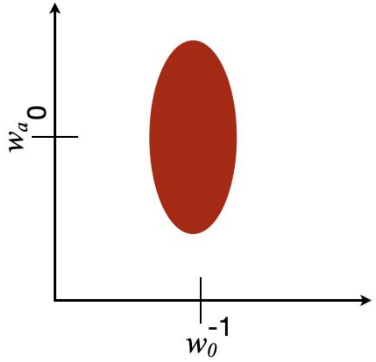
Talking on behalf of IST:NL leads GIOCOLI, CROCCE and POURTSIDOU and many other contributors to the developments

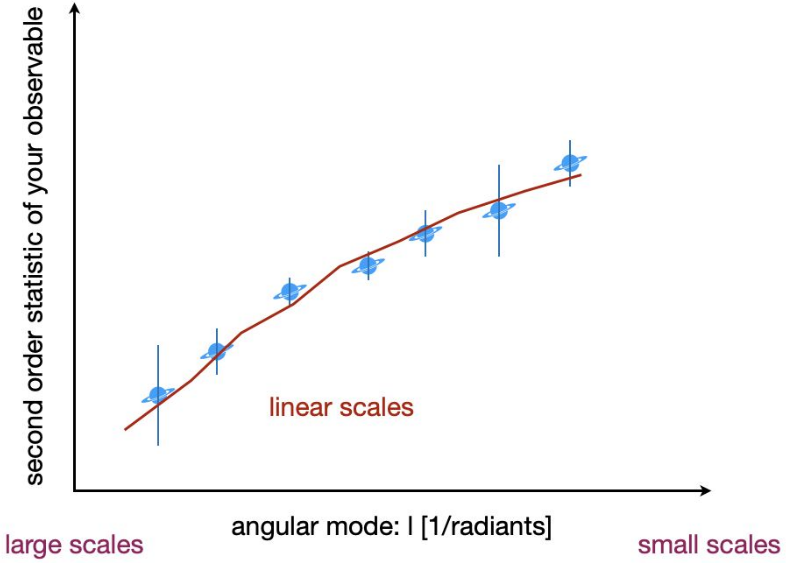


Constraining Cosmological Parameters

$w(a) = w_0 + w_a(1-a)$

$$FoM = 1/(\Delta w_0 \times \Delta w_a)$$





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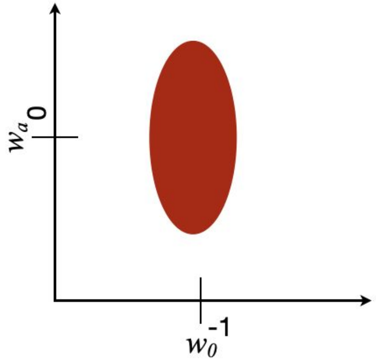

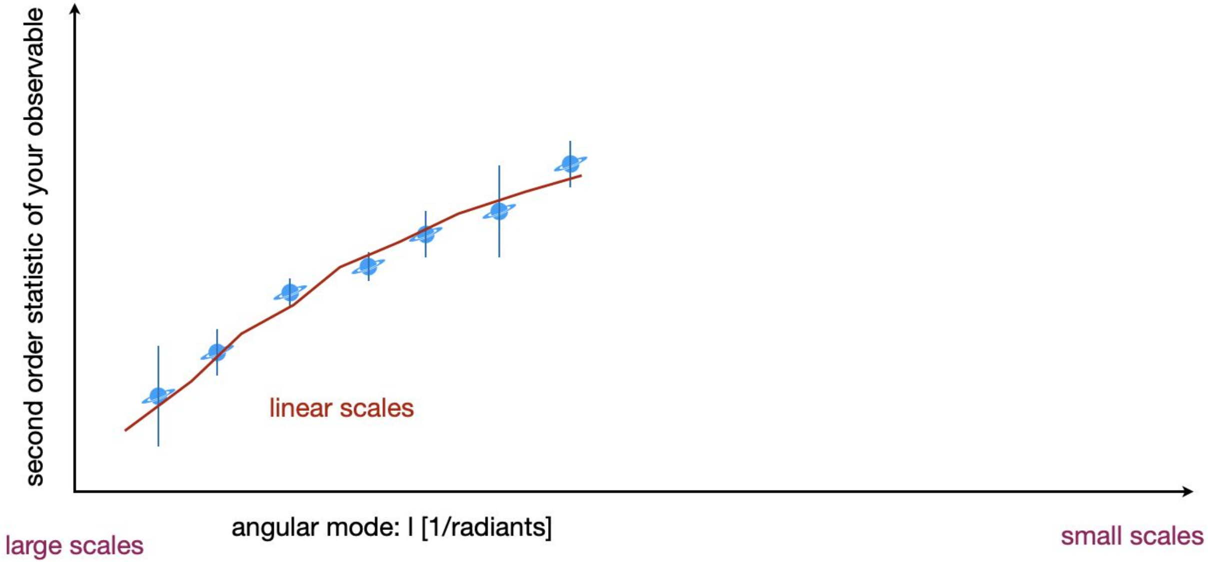

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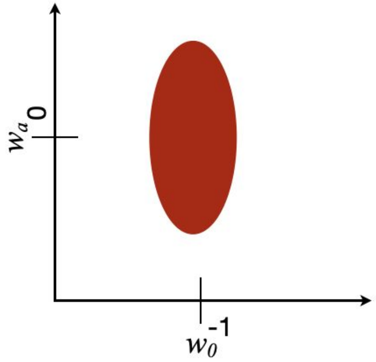
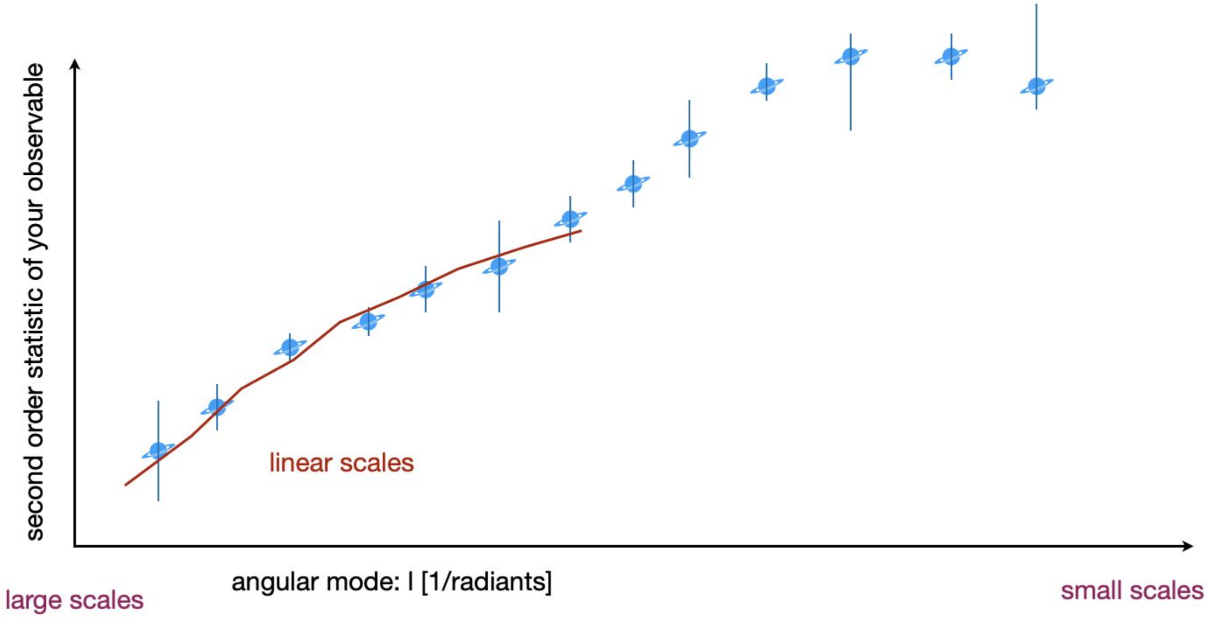


the use of small scales data points will give us the possibility to enhance the *FoM*: **increase the precision**



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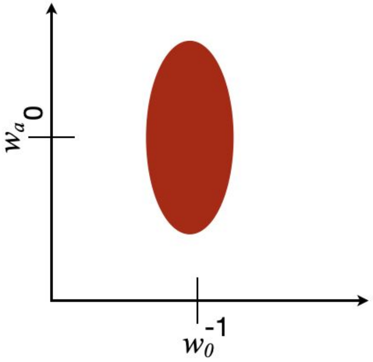

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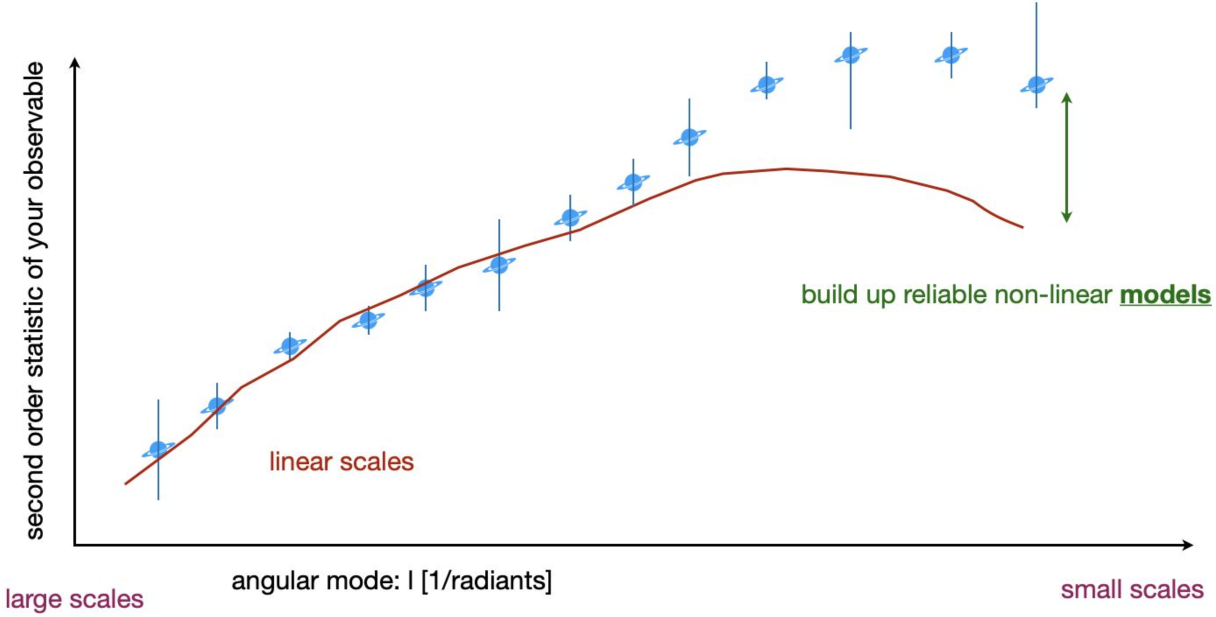
what about **accuracy**?



Second Order Statistics

PHOTOMETRIC OBSERVABLES

$$C_\ell^{AB} = \int \mathrm{d}z \, \frac{\chi'(z)}{\chi^2(z)} \, \omega^A(\chi) \, \omega^B(\chi) \, P\left(\frac{\ell}{\chi(z)}, z\right)$$

χ radial distance

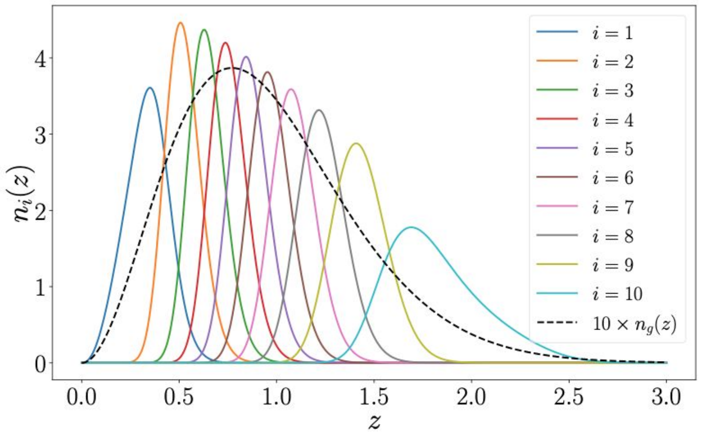
$\omega^A(\chi)$ kernel of a given observable: photometric clustering or lensing

$P\left(\frac{\ell}{\chi(z)}, z\right)$ matter power spectrum at $k = \frac{\ell}{\chi(z)}$ and redshift z

Second Order Statistics

PHOTOMETRIC OBSERVABLES

expected photometric redshift distributions for 10 intervals



$$W_i^{\mathrm{A}}(z) = b^{\mathrm{A}}(z) \frac{H(z)}{c} n_i^{\mathrm{A}}(z)$$

Clustering

$$W_i^{\gamma}(z) = \frac{3}{2} \left(\frac{H_0}{c} \right)^2 \Omega_{\mathrm{m}} (1+z) \chi(z) \int_z^{z_{\max}} \mathrm{d}z' \, n_i^{\mathrm{ph}}(z') \left[1 - \frac{\chi(z)}{\chi(z')} \right]$$

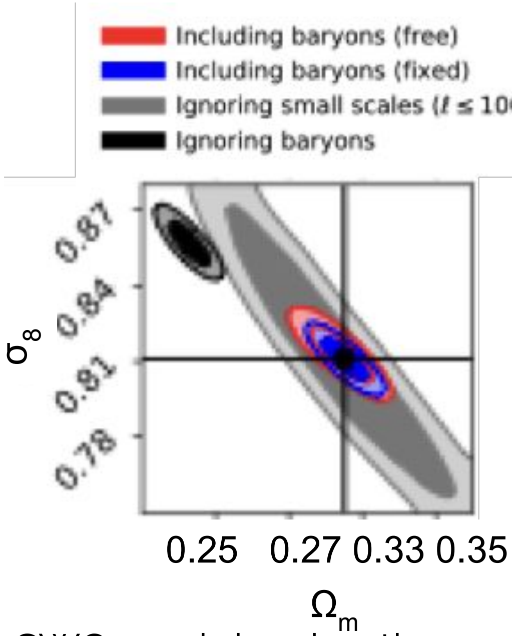
Weak Lensing *(+IA components)*

Build up reliable models for the matter power spectrum as a function of redshift

EFFORTS AND WORKS ON COSMOLOGICAL SIMULATIONS

$P\left(\frac{\ell}{\chi(z)}, z\right)$ matter power spectrum at $k = \frac{\ell}{\chi(z)}$ and redshift z

Motivation



Schneider et al. 2020

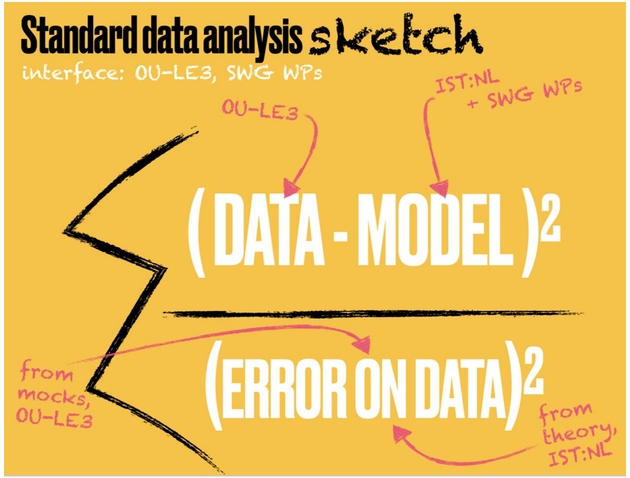
- Euclid science relies on the ability to model observed (and simulated) datasets and extract cosmological information exploiting nonlinear scales
- Wrong and/or incomplete models may bias cosmological results
- Those could affect both main probes: Galaxy Clustering and Weak Gravitational Lensing

- The idea is to collect and join together expertise from the different SWGs and develop the models, the code, and validate them with *challenges*
- IST-Nonlinear has the charge of coordinating those
- Combine common tools for cosmological exploitation: GC, WL + CG with the help of dedicated simulations (CosmoSim)

STRONG SYNERGY AND COMMUNICATION WITH ALL SWGs and WITH THE IST-Likelihood

Likelihood and Cosmology

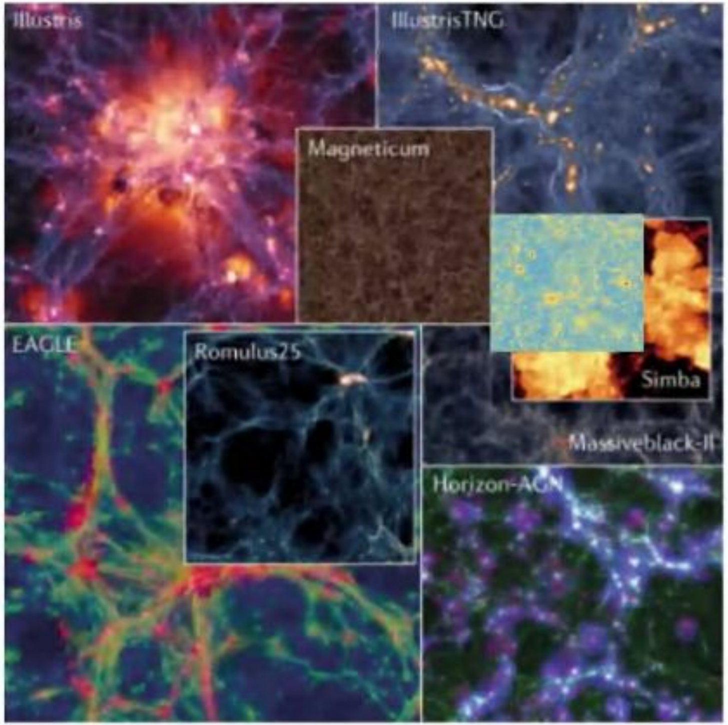
- Develop a consistent model and code for main Euclid observables — to be used by IST:Likelihood: redshift space clustering, bias, photo-*z* clustering, shear-shear, galaxy-shear, Intrinsic Alignments, BAO in reconstructed field, that can reach “smaller” scales; also define reliable scale cuts
- Come up with a validation procedure for the above model and code
- Make sure we have an analytical covariance beyond the gaussian approximation & study non-linear impact on covariance

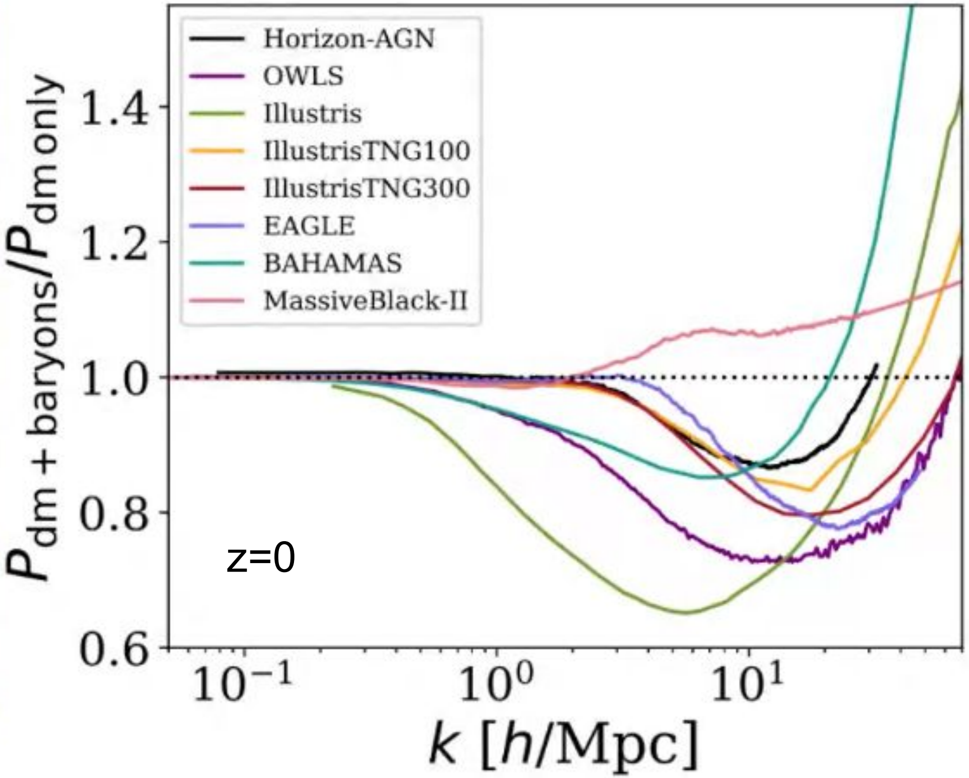


Dida Markovic

STRONG INTERFACE WITH THE IST:L CODE DEVELOPMENTS AND DEVELOPERS

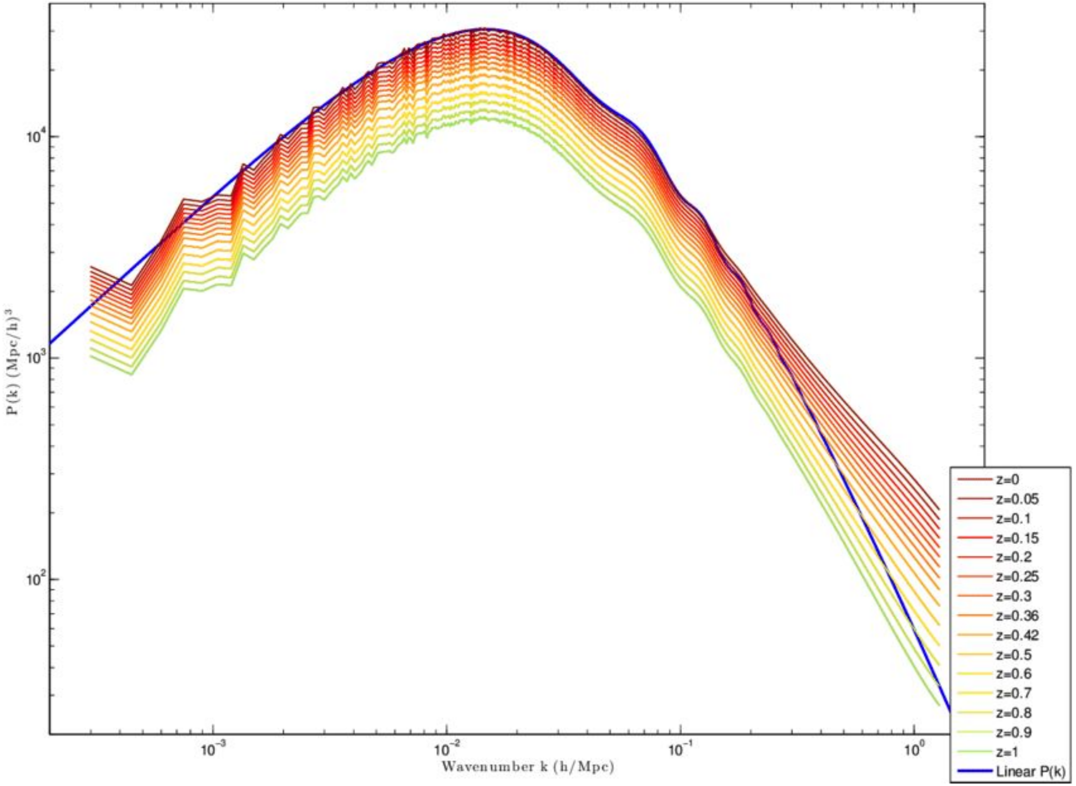
Challenges on small scales





Chisari et al. 2019, Martinet et al. 2020

Challenges on small scales



$$C_\ell^{AB} = \int \mathrm{d}z \, \frac{\chi'(z)}{\chi^2(z)} \, \omega^A(\chi) \, \omega^B(\chi) \, P\left(\frac{\ell}{\chi(z)}, z\right)$$

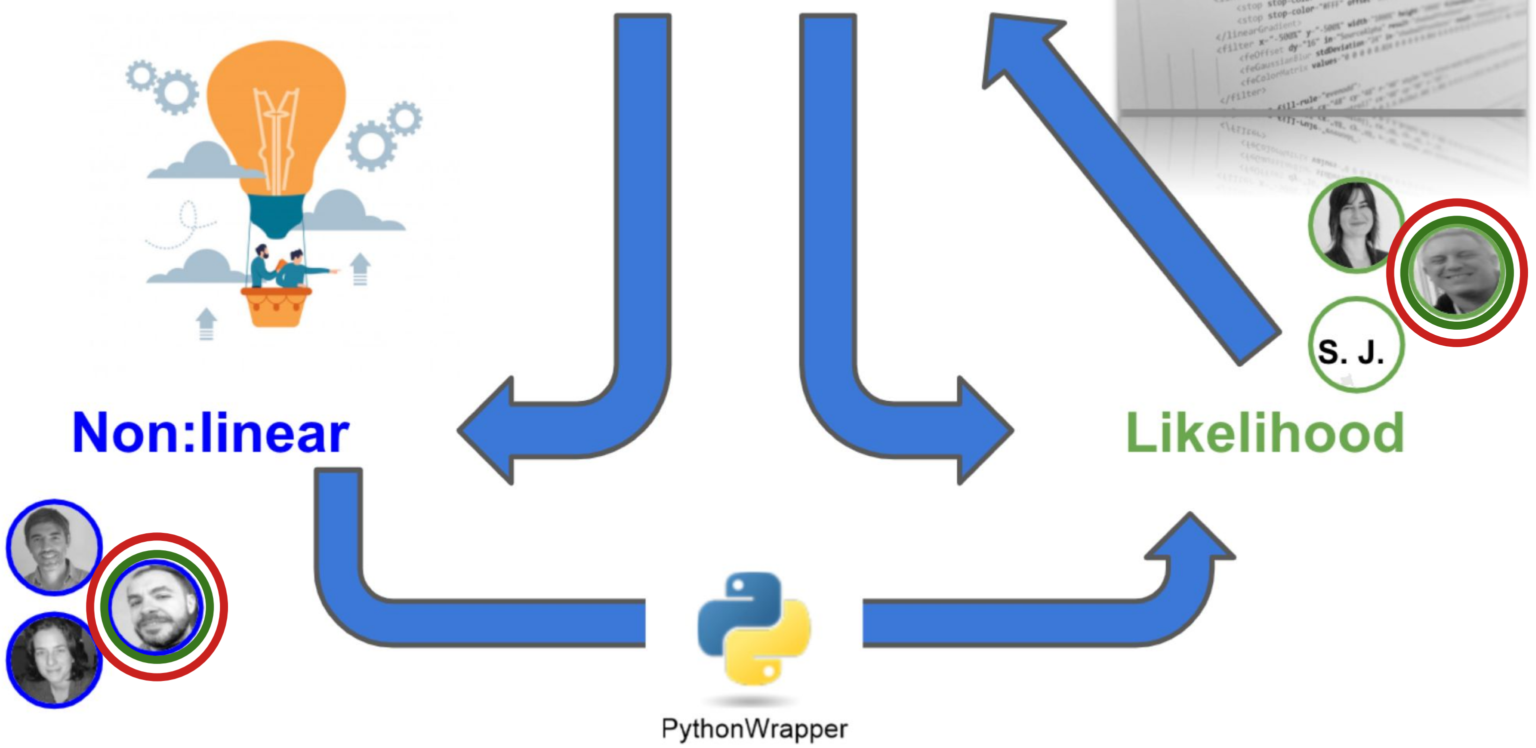
↓

probing the growth of structures filling the gap between low and high redshift (~CMB) cosmological probes!

Rasera et al. 2013

CLOE

Code for Cosmological Analyses



IST:NL model library: current status

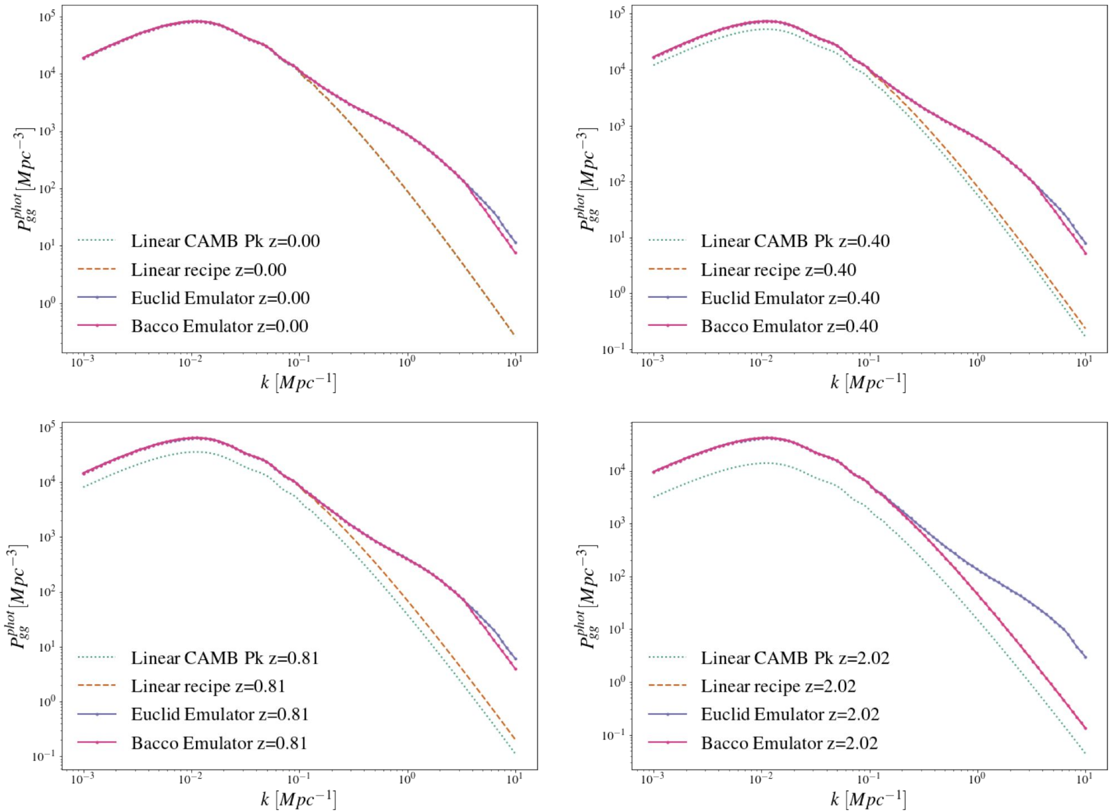
List of our implemented models/tools

- Linear theory from camb/class (default in Cobaya/CLOE)
- BACCO linear theory emulator
- Halofit : darkmatter
- Euclid Emulator 2 (EE2) : dark matter
- HMcode : dark matter and baryons
- BACCO nonlinear emulators : dark matter and baryons
- BCemu emulator: baryons
- Spectroscopic galaxy clustering (one-loop with counterterms, Ivanov et al. model), with FAST-PT
- PySSC & PyCCL : 3x2pt covariance, including super-sample covariance

IST:NL

Examples

Implementing and benchmarking non-linear models:
ISTNL_modelling DEMO
(Jupiter notebook)



P. Carrilho, G. Canas, M. Martinelli et al.

IST:NL

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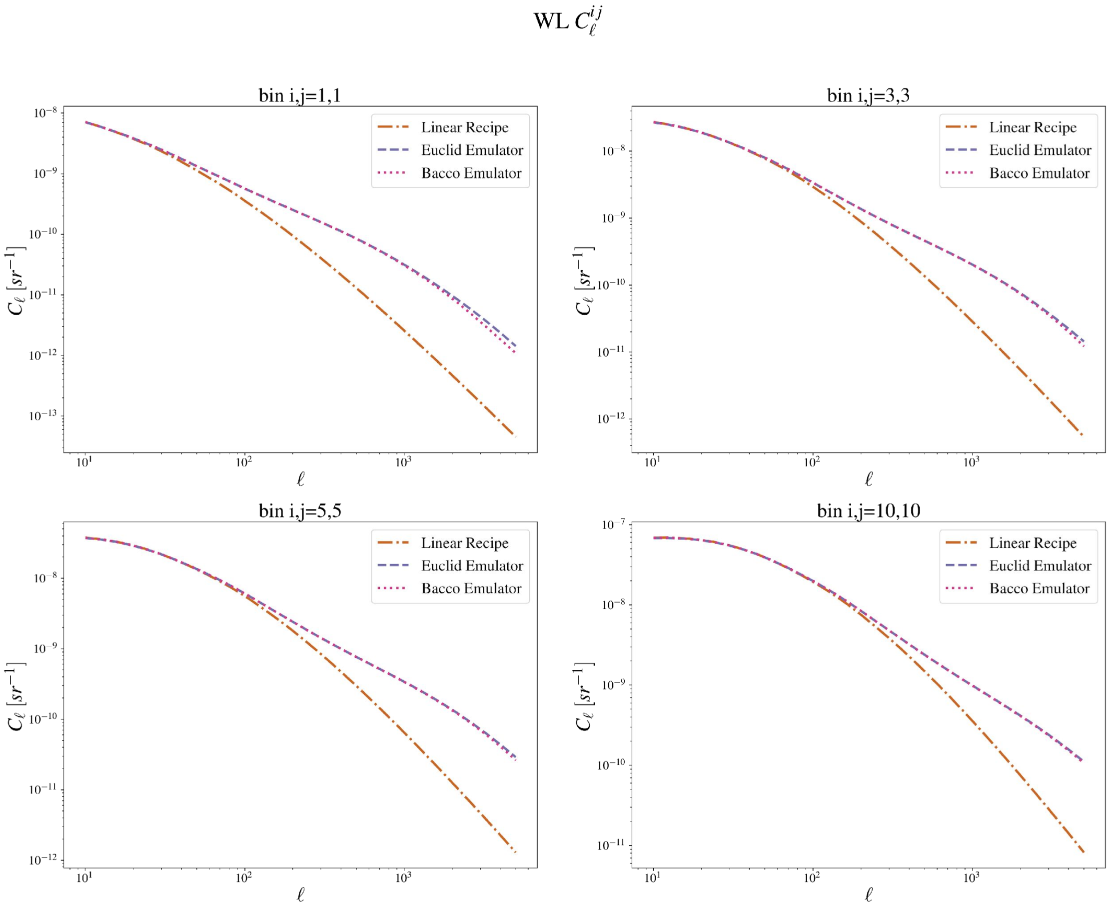

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IST:NL

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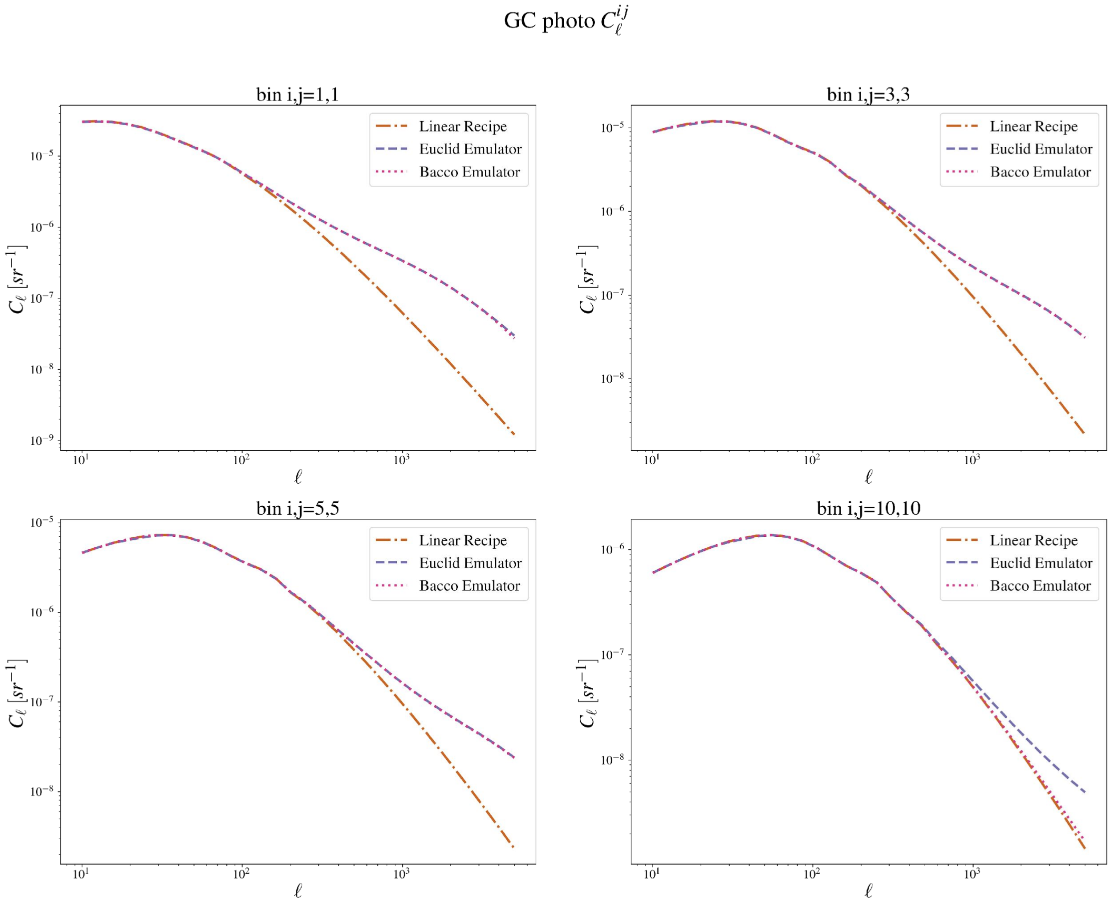


P. Carrilho, G. Canas, M. Martinelli et al.

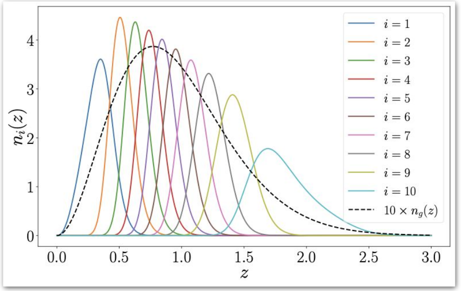
IST:NL Analytical recipes

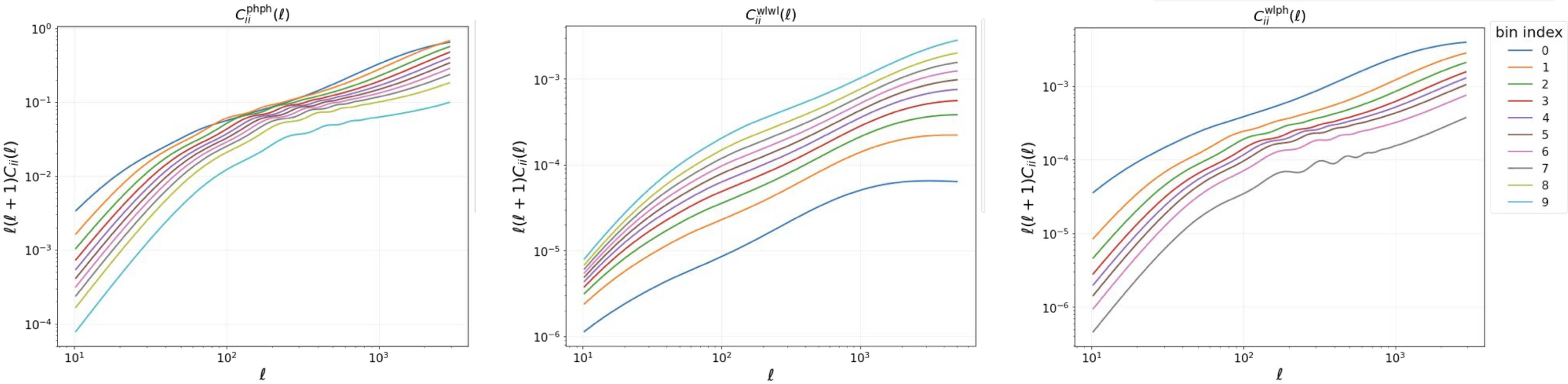
3x2pt Covariance Taskforce

M. Bonici, D. Sciotti, F. Lacasa, K. Benabed, S. Camera, V. Cardone, M. Martinelli et al.

Write down the analytical recipes for the 3x2pt covariance in term of the Angular Fourier Space modes C(l)

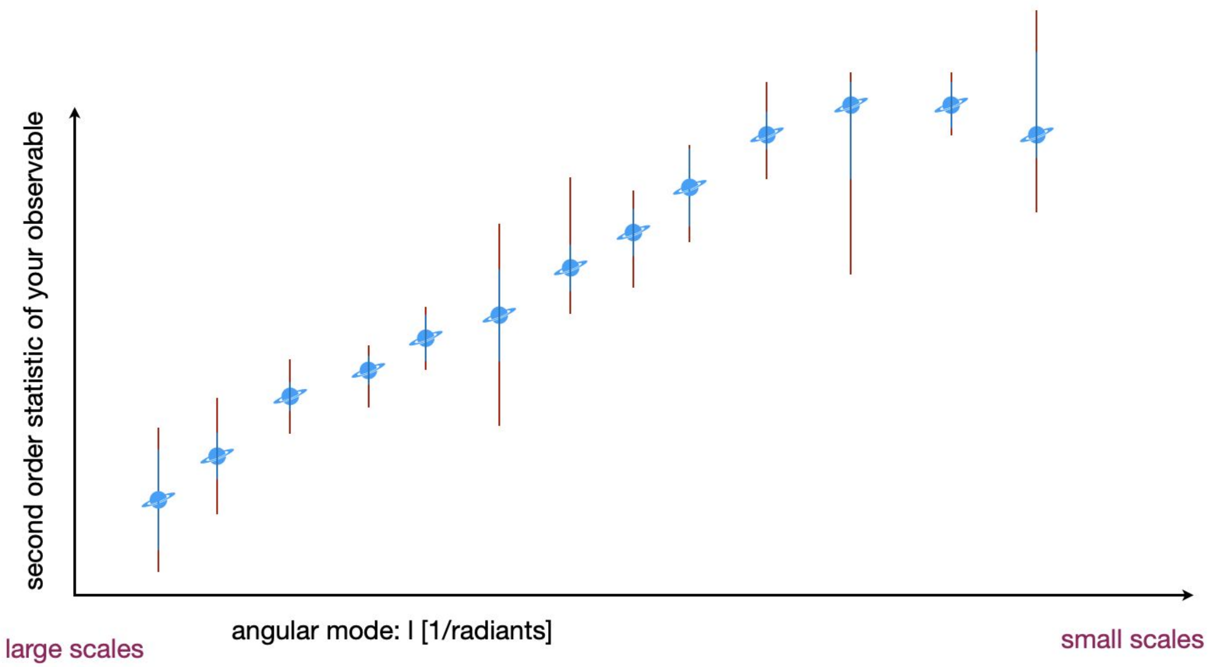
Necessary to go beyond IST:forecast
and run MCMC analyses
Leading the cosmological analysis in SPV3





Expected errors on the data: covariances

IS THERE ANY POSSIBILITY TO LOOK AT NEW PHYSICS?



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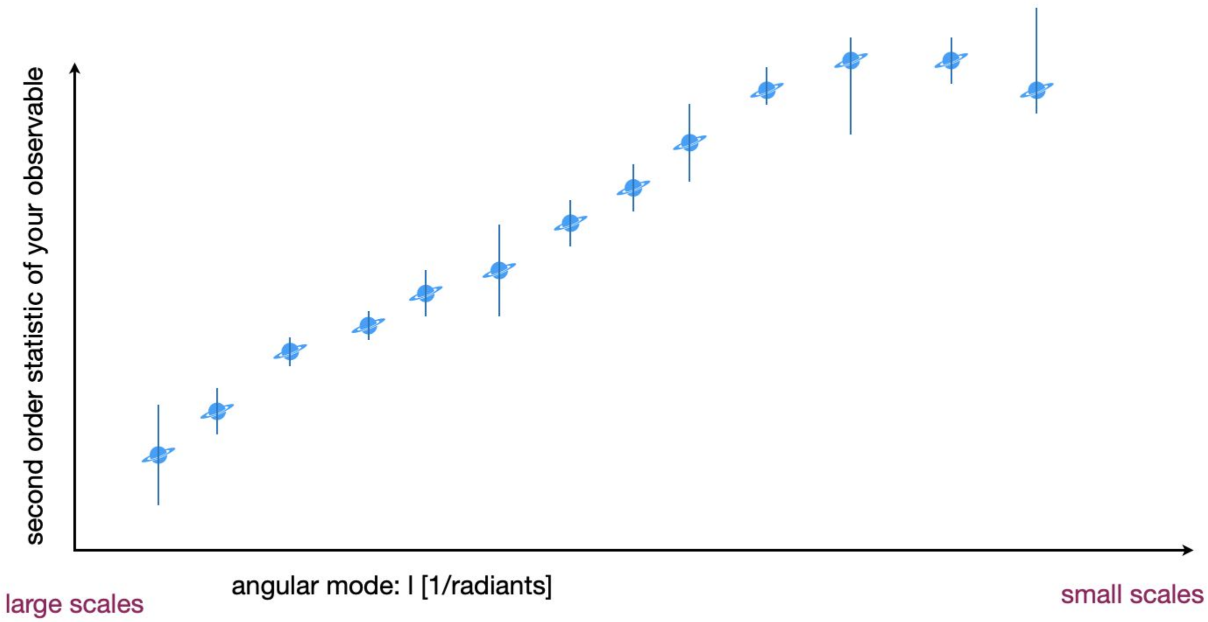


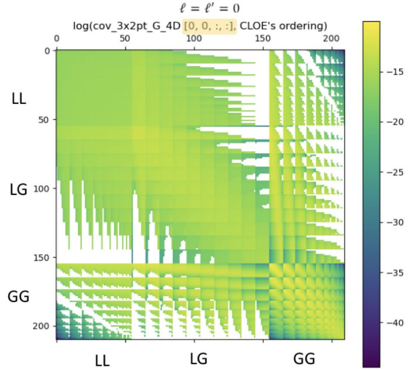
IST:NL covariances

Analytical

3x2pt Covariance Taskforce

Frozen the covariance for SPV-3: Gaussian plus **Super Sample Term** consistently accounting for **non-linear effects**. Interfaced with **PySSC**.

Building a much more direct interface with **CLOE**



D. Sciotti & M. Bonici

- The Covariance Calculation will remain external to CLOE -

- additional computation method via use of AngPow
- massively parallelised
- computation in flat sky (small circular survey, an approx often used in previous literature)
- computation for **partial sky coverage** (masks…)

→ **Strong interface with the PySSC developers**

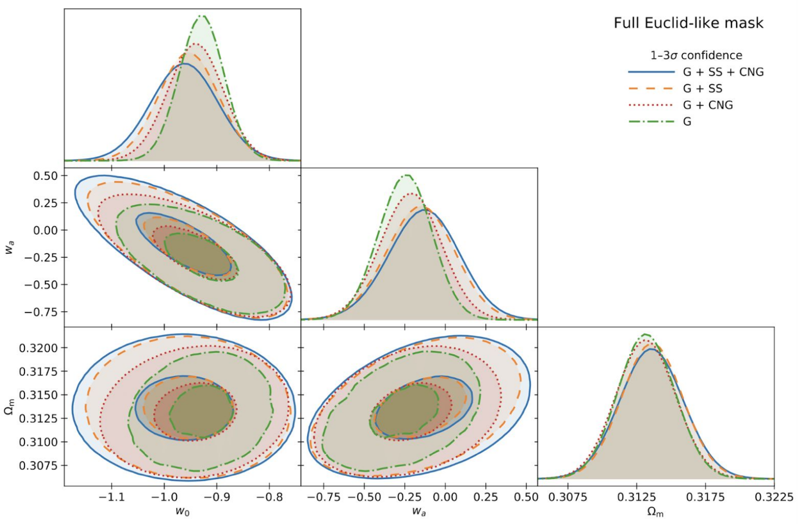
IST:NL covariances & simulations

Numerical

3x2pt Covariance Taskforce

At some point we need to think about the CNG to the 3x2pt covariance

… studying how to fully include it studying Rubin-LSST (PYCCL), DES (Cosmo-like) & KiDS (Halo Model based covariance)



Upham et al. 2022

Howls project: M. Baldi, C. Carbone, V. Cardone, C. Giocoli et al.

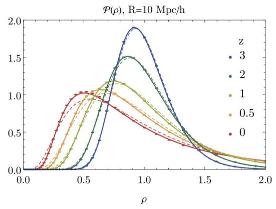
Weak lensing cosmological simulations

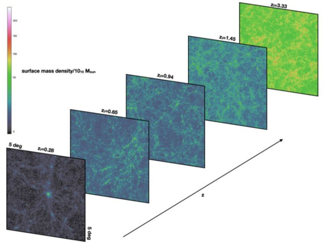
No KP associated to this yet.
WP work:

- Make mock data for HOWLS Key Paper 1, 2, 3
- Make mock data to construct numerical covariance matrix for 3x2pts
- Develop suite of lensing mocks with baryons & IA to enable modelling of key systematics

The above currently use the DUSTGRAIN-*pathfinder*, SLICS & cosmo-SLICS simulations
We are in the process of upgrading with the BACCO simulations for key paper 3.
Dedicated moks using the DEMNUni_cov: 50 runs, 1 Gpc/h by side and 3200 light-cones 10 deg by side.

Gough and Uhlemann 2022





MapSim: Giocoli et al. 2013

J. Harnois-Deraps & C. Giocoli

Constraining Cosmological Parameters

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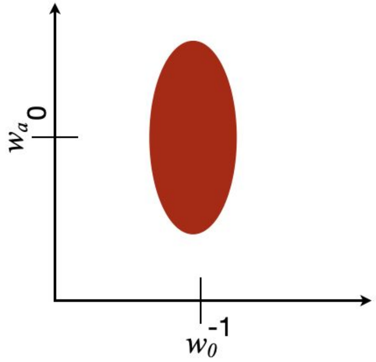
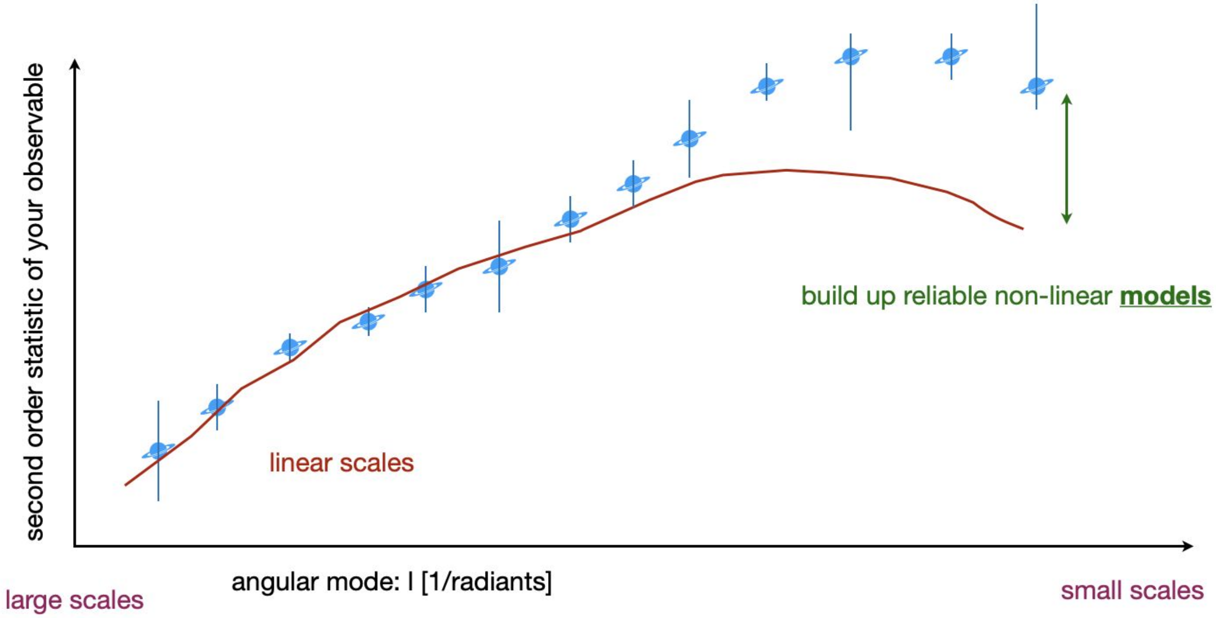


the use of small scales data points will give us the possibility to enhance the *FoM*: **increase the precision**

what about **accuracy**?



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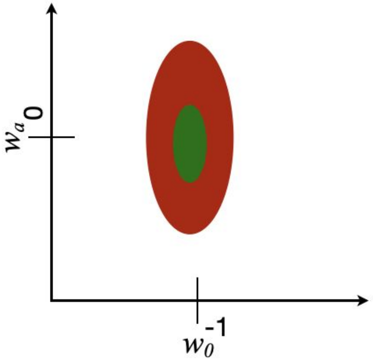

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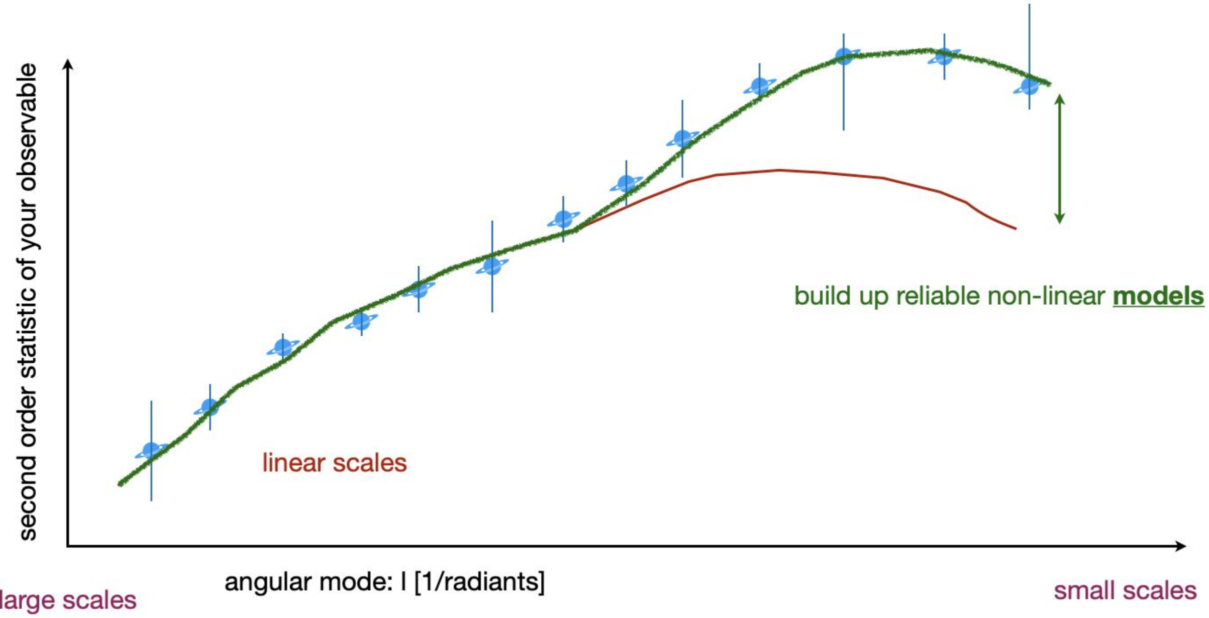
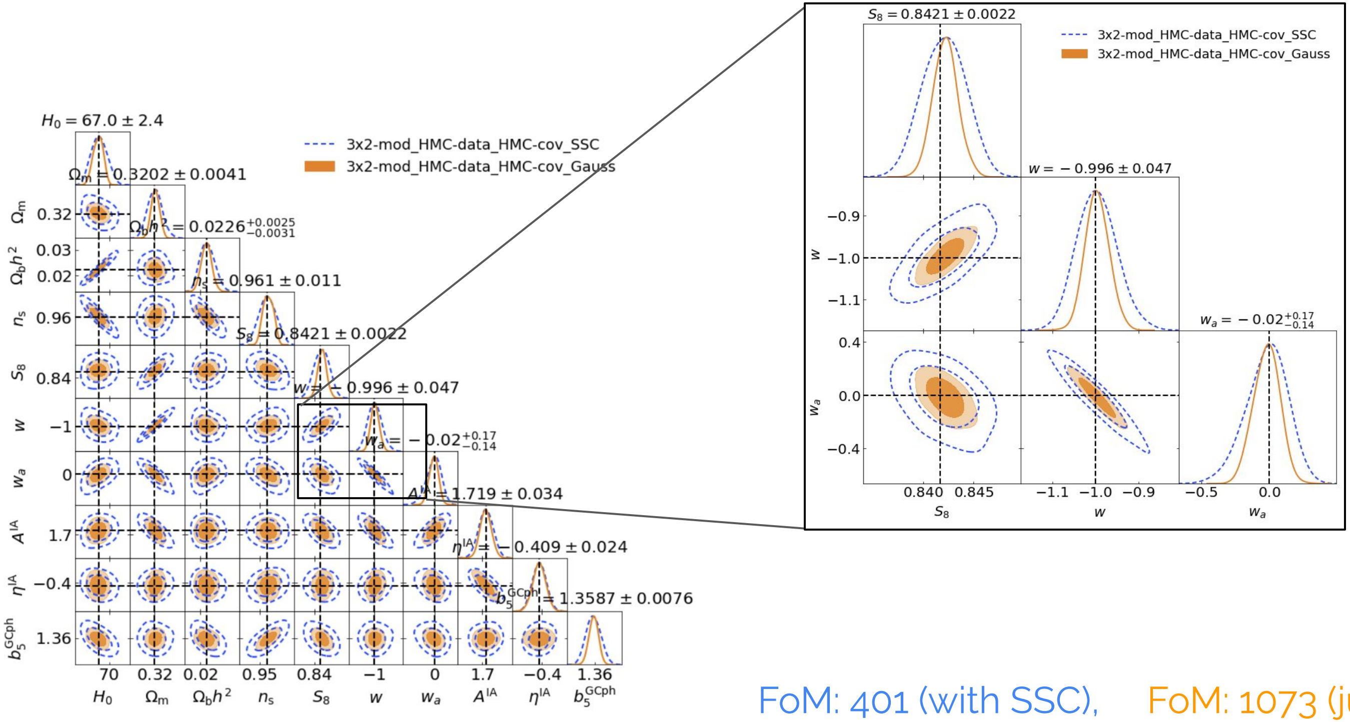


we need to marginalise over a series of nuisance parameters when modelling non-linear scales…

MCMC analyses in flat ΛCDM cosmology

Impact of SSC on parameter constraints



3x2pt photometric data: HMCode
model: HMCode
covariance: HMCode

- **Blue dashed** lines: SSC+Gaussian covariance
- **Orange** solid: Gaussian covariance.

FoM: 401 (with SSC), FoM: 1073 (just Gauss)