

# Optimizing the extraction of cosmological information from Large Scale Structure analysis

in view of the next large spectroscopic surveys

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## **PRIN2022**

This meeting is organized in the context of the grant PRIN-MUR 2022 2022NY2ZRS 001 "Optimizing the extraction of cosmological information from Large Scale Structure analysis in view of the next large spectroscopic surveys" supported by Next Generation EU

#### Components:

- Michele Moresco (PI, University of Bologna)
- Benjamin Granett (co-I, INAF OABrera)
- Robert Benton Metcalf (co-I, University of Bologna)
- Massimo Guidi (University of Bologna)
- Ilaria Risso (INAF OABrera)











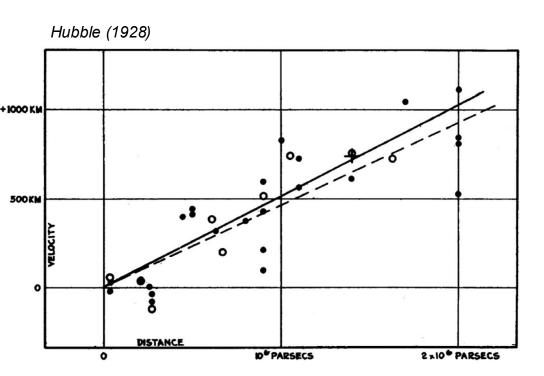








## Scientific context



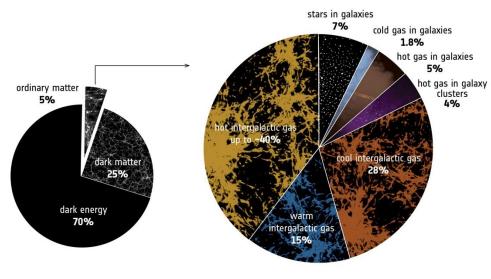


Image credit: ESA

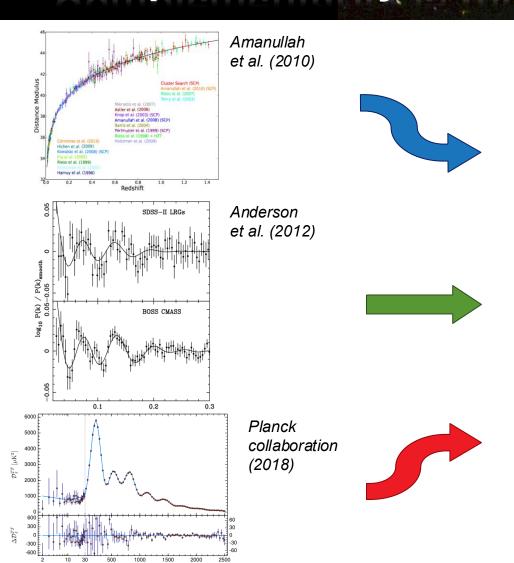








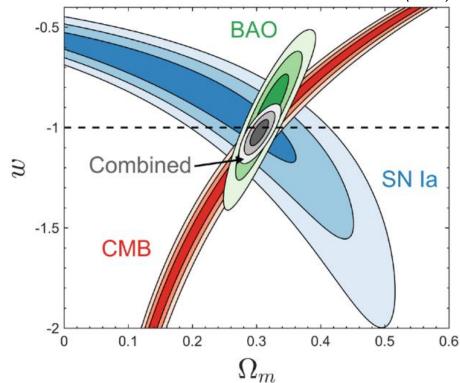
# Complementarity is the key



Different probes, different cosmic times, different sensitivity to parameters, different systematics

## Synergy between differences

Huterer & Shafer (2018)



as done in the past, moving beyond in crucial



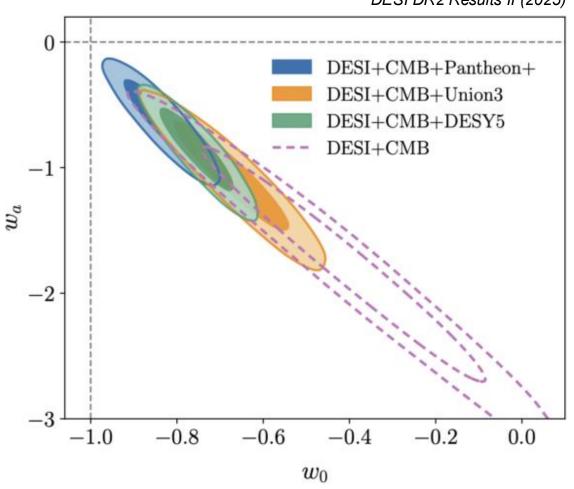






# New tensions and frontiers in cosmology





What is the **nature of dark energy**? Is it a cosmological constant or is it (and if, how) evolving with redshift?

What is the **nature of dark matter**?

What **physics** drives the **cosmic expansion** and the large-scale evolution of the universe?

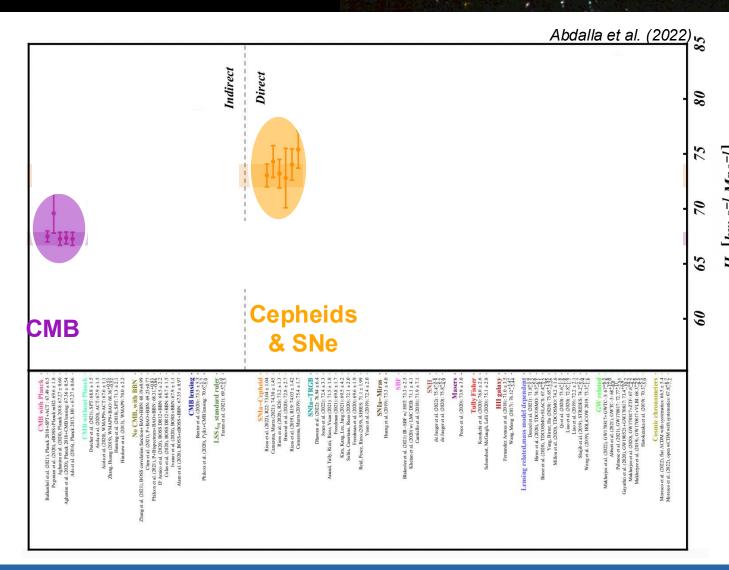








# New tensions and frontiers in cosmology



Is the observed H<sub>0</sub> tension due to systematics in one (or both) measurements?

Does it point toward **new physics**?

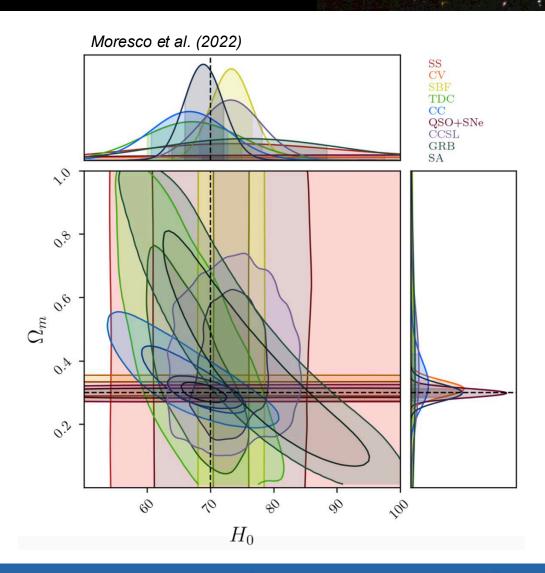
How to make a step forward?







# New tensions and frontiers in cosmology



Several **new cosmological probes and indicators** are quickly improving, and will play a significant roles in the future:

- Higher-order correlation function
- New statistics
- Alternative cosmological probes

The more independent cosmological probes, the more we can improve our constraints and keep systematics under control, maximizing the scientific return

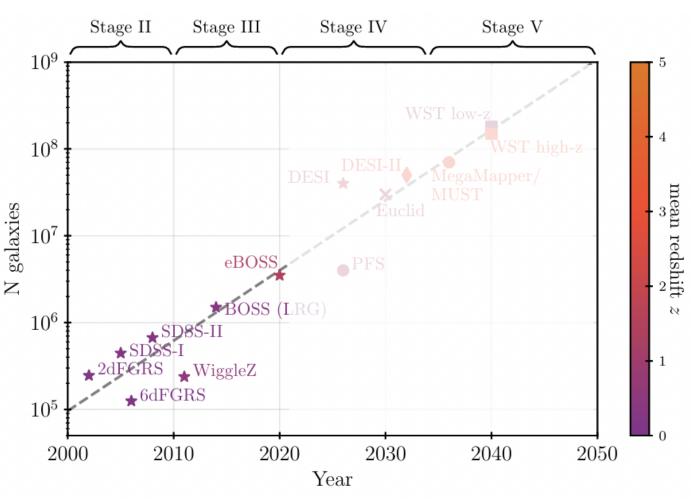






## A bright future ahead







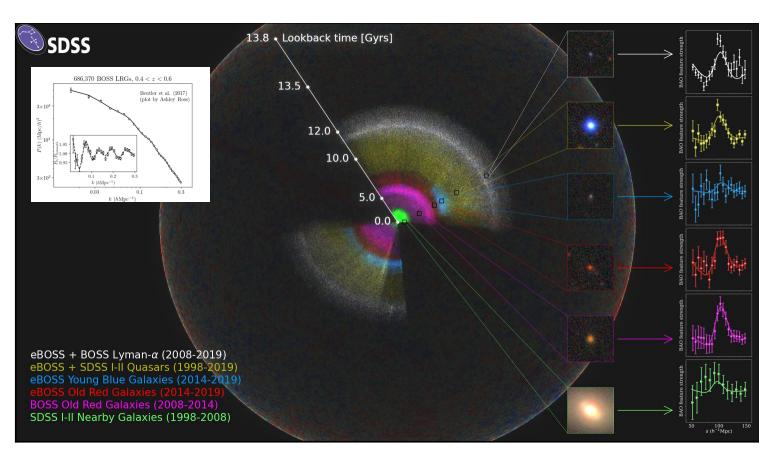






## The need to go further

BAO detected in 2-point statistics extensively, but few detections with higher-orders (and mostly in Fourier space, apart from Gaztanaga et al., 2009, Slepian et al. 2017, Moresco et al. 2021).



#### Bottlenecks:

- demanding in CPU time
- Difficulty in modeling
- 2PCF+3PCF never attempted
- Covariance: heavy to measure, not easy to derive theoretically

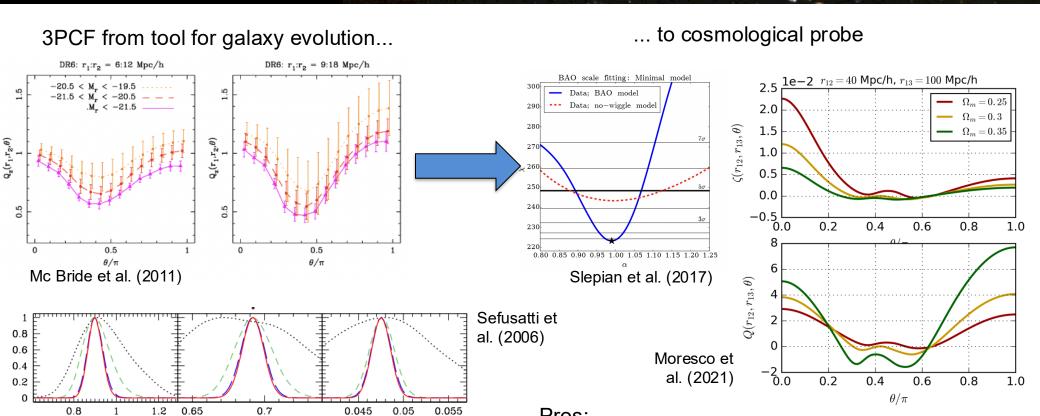








## State of the art



#### Pros:

- Increased constraining power
- Breaking degeneracies
- Sensitivity to different effects (shape vs scale)



1.2

-0.1

0.8 0.6

8.0

b,



2

bLRG

0.1

2.5

 $\Omega_{\mathbf{b}}$ 

CMB+P+B+P<sub>LRC</sub>  $M.S. k_{max} = 0.3 h/Mpc$ 

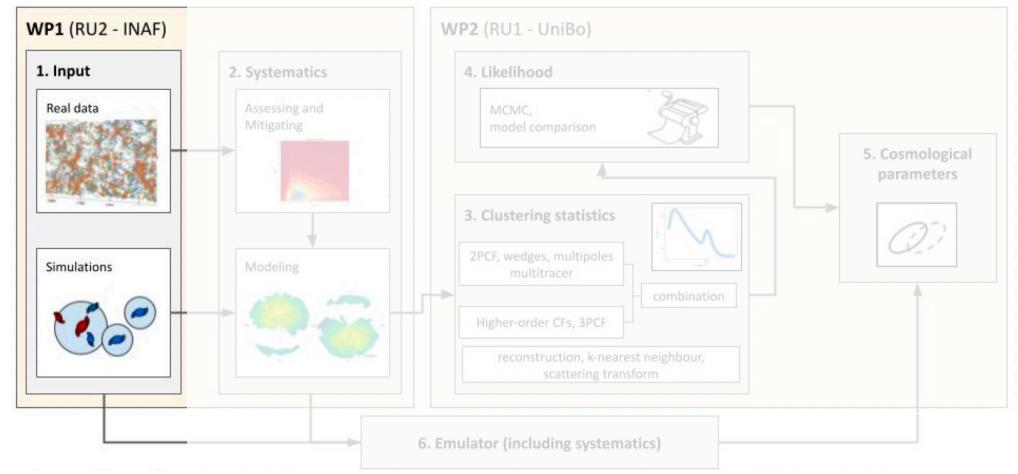
LRG k<sub>max</sub>=0.2 h/Mpc





# The Project

PRIN 2022 "Optimizing the extraction of cosmological information from Large Scale Structure analysis in view of the next large spectroscopic surveys" (2022NY2ZRS 001)











# WP1 (RU2 - INAF)



## Assessing and modelling systematic effects from data and imprinting on simulations

<u>Main contributors</u>: Benjamin Granett, Ilaria Risso (INAF - OABrera) + Michele Moresco (Univ. Bologna), with the contribution of A. Farina

#### Papers and activities:

- development of a forward-modelling code to imprint realistic systematic effects on simulations, and provide quick and robust forecasts for future surveys (Granett et al. 2025, in prep)
  - $\rightarrow$  see talk by B. Granett
- assessment of the impact of redshift interlopers on correlation functions for future spectroscopic surveys, and development of mitigation strategies
  - Two-point correlation function (Risso et al. 2025, arXiv:2505.04688)
    - → see talk by I. Risso
  - Three-point correlation function (Principi, Veropalumbo, Moresco et al. 2025, in prep)
    - $\rightarrow$  see talk by M. Moresco
- Euclid Quick Data Release (Q1). Characteristics and limitations of the spectroscopic measurements (Le Brun, Bethermin, Moresco et al. 2025, arXiv:2503.15308)







# WP1 (RU2 - Unibo)



Measuring and modelling 3PCF, and maximizing the scientific return using the 3PCF for cosmological analysis in simulated and real data

**Main contributors**: Massimo Guidi, Michele Moresco, Nicola Principi, Kristers Nagainis, Andrea Labate (Univ. Bologna), with the contribution of A. Veropalumbo, A. Farina

#### Papers and activities:

- A) 3PCF measurement and modelling
- development of the 3PCF algortihm and code for the Euclid survey (Veropalumbo, Moresco et al. 2025, in prep)
- modeling and measuring the anisotropic halo 3-point correlation function (Farina, Veropalumbo, Branchini, Guidi 2025, arXiv:2408.03036)
- development of new emulator for the anisotropic 3PCF and cosmological implications (Nagainis, Guidi, Moresco et al. 2025, in prep)
  - → see talk by K. Nagainis
- B) 3PCF cosmological constraints
- first cosmological constraints for the Euclid survey from the full-shape analysis of the 3PCF, and 2PCF+3PCF analysis (Guidi, Veropalumbo, Pugno, Moresco et al. 2025, arXiv:2506.22257)
  - $\rightarrow$  see talk by M. Guidi
- first cosmological constraints for the BOSS survey from the full-shape analysis of the 3PCF, and 2PCF+3PCF analysis (Guidi, Moresco, Veropalumbo et al. 2025, in prep)
- 3PCF as a tool to constrain neutrino masses (Labate, Moresco, Guidi 2025, in prep)
  - → see talk by M. Moresco









## **Alternative methods**





#### Alternative methods and cosmological probes

#### Papers and activities:

- Modelling higher-order velocity-density-density correlation function (Guidi et al. 2025, in prep)
- ages of the oldest objects as cosmological probes: globular clusters and lensed GC (Tomasetti, Moresco et al. 2025a, arXiv:2410.22466,Tomasetti, Moresco et al. 2025a, arXiv:2412.06903), oldest stars in GAIA (Tomasetti, Chiappini, Nepal, Moresco et al. 2025, in prep)
- cosmic chronometers (Moresco et al. 2022, arXiv:2201.07241, Moresco 2023, arXiv:2307.09501, Moresco 2024, arXiv:2412.01994)
- Gravitational waves as standard sirens: accelerating the method with GPU (Tagliazucchi, Moresco et al. 2025, in prep) and including the impact of catalog incompleteness in the Bayesian framework (Borghi, Moresco et al. 2025, in prep)

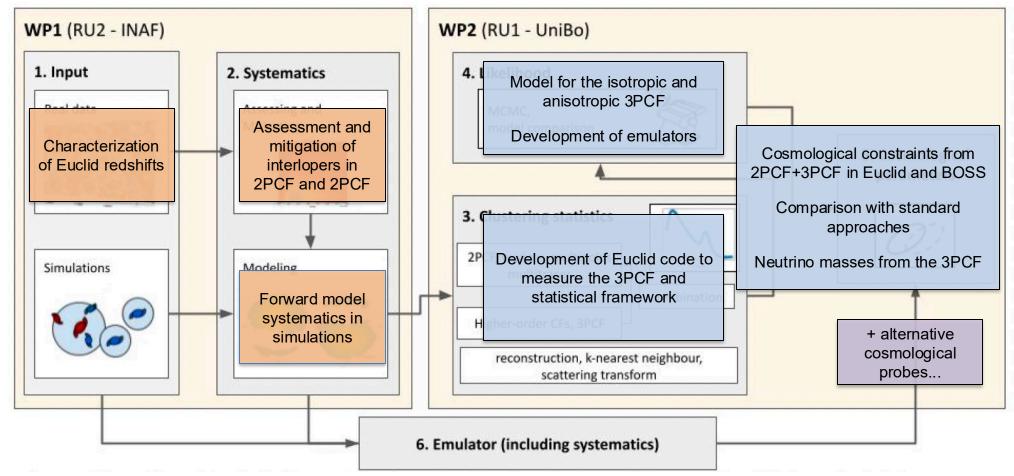






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## Scientific highlights

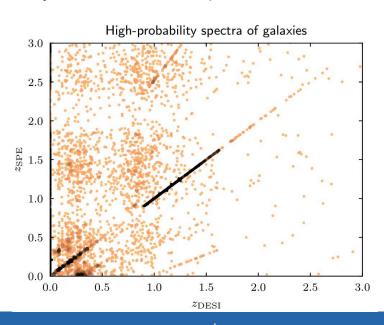
Euclid Quick Data Release (Q1) ©ESO2025 Characteristics and limitations of the

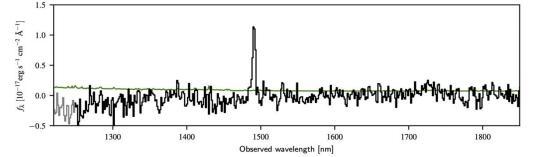
spectroscopic measurements

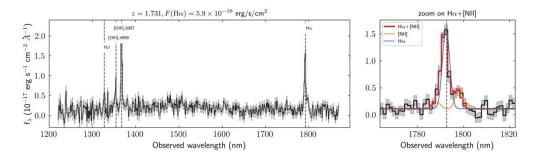
V. Le Brun, M. Bethermin, M. Moresco et al (2025)

 development of the spectroscopic pipeline to measure redshift and spectral features

 issue to address: in many cases there is only one line in the spectrum







 Validation with DESI demonstrate the capability to identify a reliable sample









## Scientific highlights

### Modelling higher-order velocity-density-density correlation function

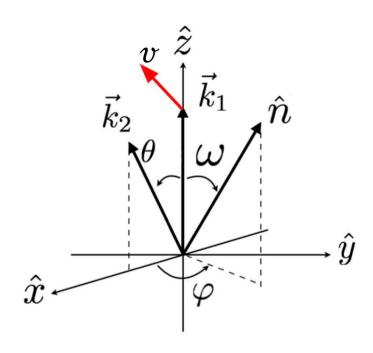
M. Guidi, A. Nusser, A. Farina, E. Branchini

Goal: providing an analytical modelling of correlation of the peculiar velocity density density correlation function

Why: adding constraining power by extraction of cosmological information. Secondary: potential source for relativistic effect/parity violation

How: multipoles expansion approach, radial part + angular mixing matrix, assumption of vanishing curl of the divergence of the velocity field

Status: in prep, analytical modelling (done), pipeline (in advanced status, both Fourier space and configuration space), planned future application to simulated and real dataset



Visual representation of a peculiar velocity, density, density triplet







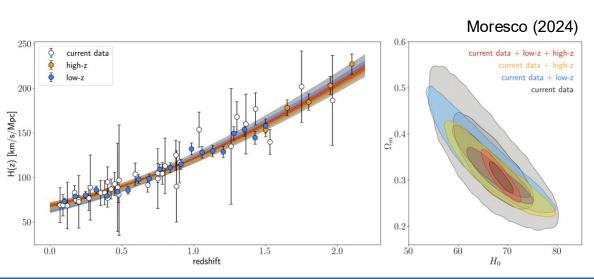


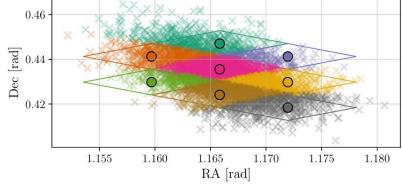
## Scientific highlights

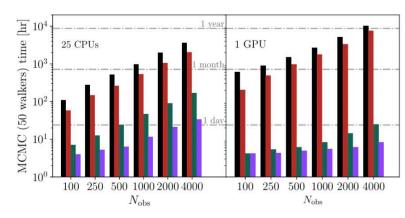
#### Stellar ages and gravitational waves as cosmlogical probes

M. Moresco, E. Tomasetti, M. Tagliazucchi, N. Borghi

- cross-correlation of GW and galaxy catalogs to provide contraints on cosmological parameter and modified gravity propagation
- Ages of old galaxies, GC and star can provide independent constraints on the expansion history of the Universe







Tagliazucchi, Moresco et al. (2025)







