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Centro Nazionale di Ricerca in HPC,
Big Data and Quantum Computing

BAO extraction in the Euclid Era

Elena Sarpa, Chiara Moretti, Matteo Viel

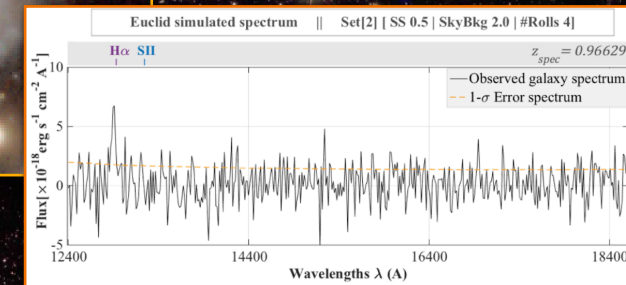
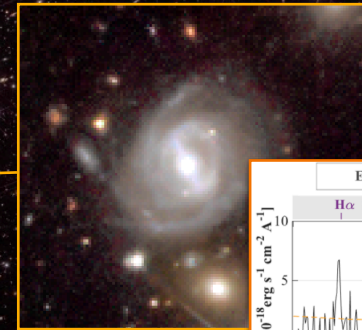
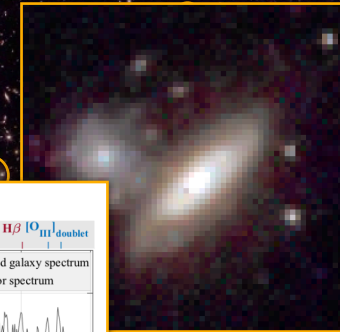
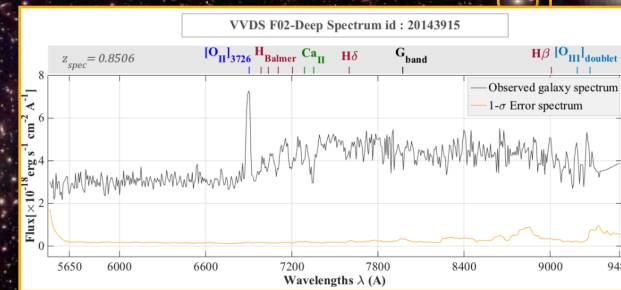
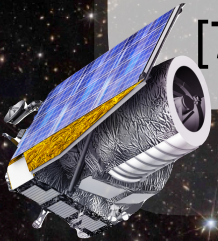
Spoke 3 II Technical Workshop, Bologna Dec 17 -19, 2024

Scientific Rationale: The Euclid Survey

Exploring the past Universe to solve GR

Observation Plan

- Space-based telescope
- 1/3 full-sky
- 1.5×10^9 galaxy's images
- 30×10^6 galaxy's spectra
- Look-back time [7.4-10.3 Gyrs]



Scientific Rationale: Why BAO

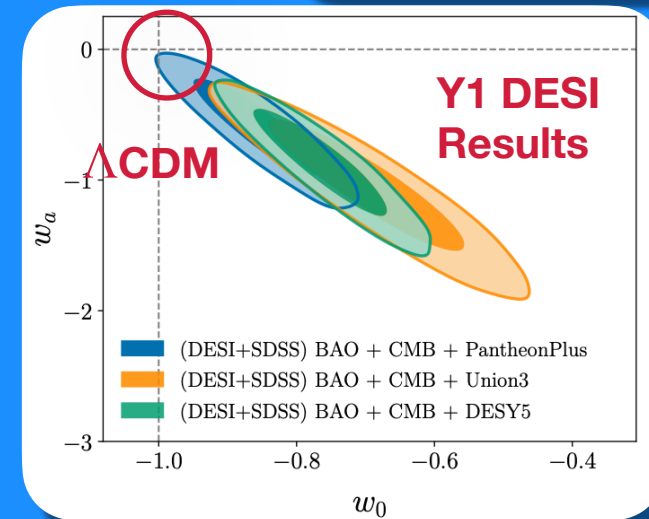
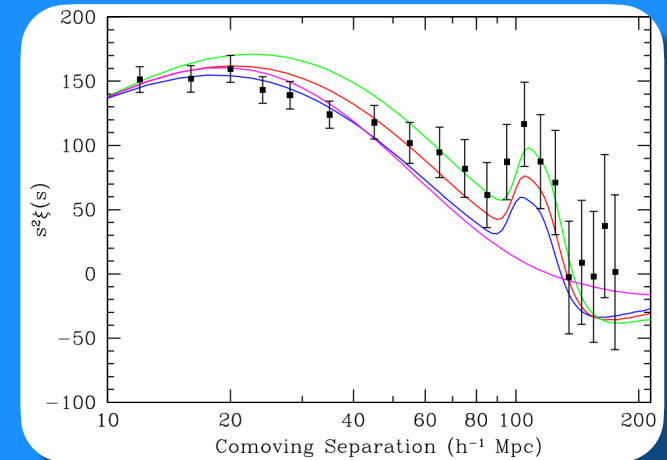
Baryon Acoustic Oscillation:

- Constrain the Universe's expansion across cosmic time by comparing measured and model-dependent BAO scales

Scientific responsibility

- BAO analysis of DESI DR1 (April 2024), has shown a tension with Λ CDM
- Euclid has to confirm or question these results

Eisenstein et al 2005

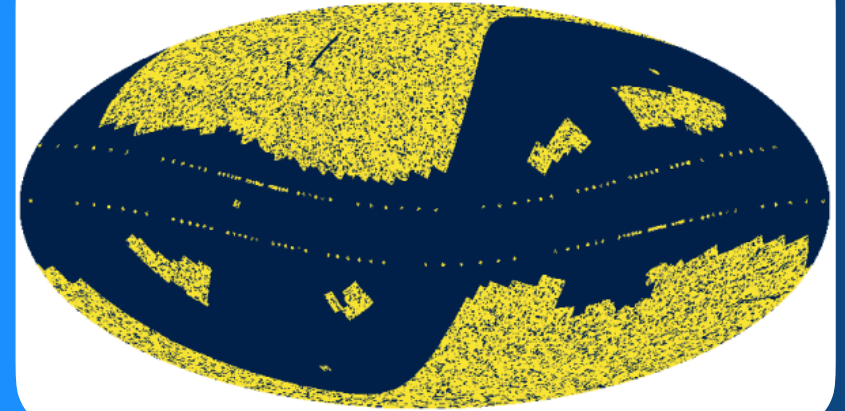


DESI collaboration 2024

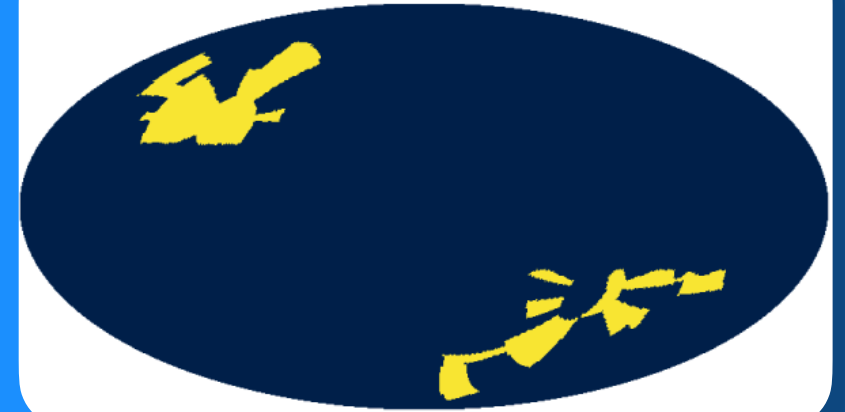
Challenges

- Accurate **analytical & numerical models** accounting for **non-linear** effects
- Multipole ($\sim 10^3$) **high-fidelity mocks** reproducing instrument systematics
- **Fast likelihood samplers** handling huge datasets

Full Euclid-like



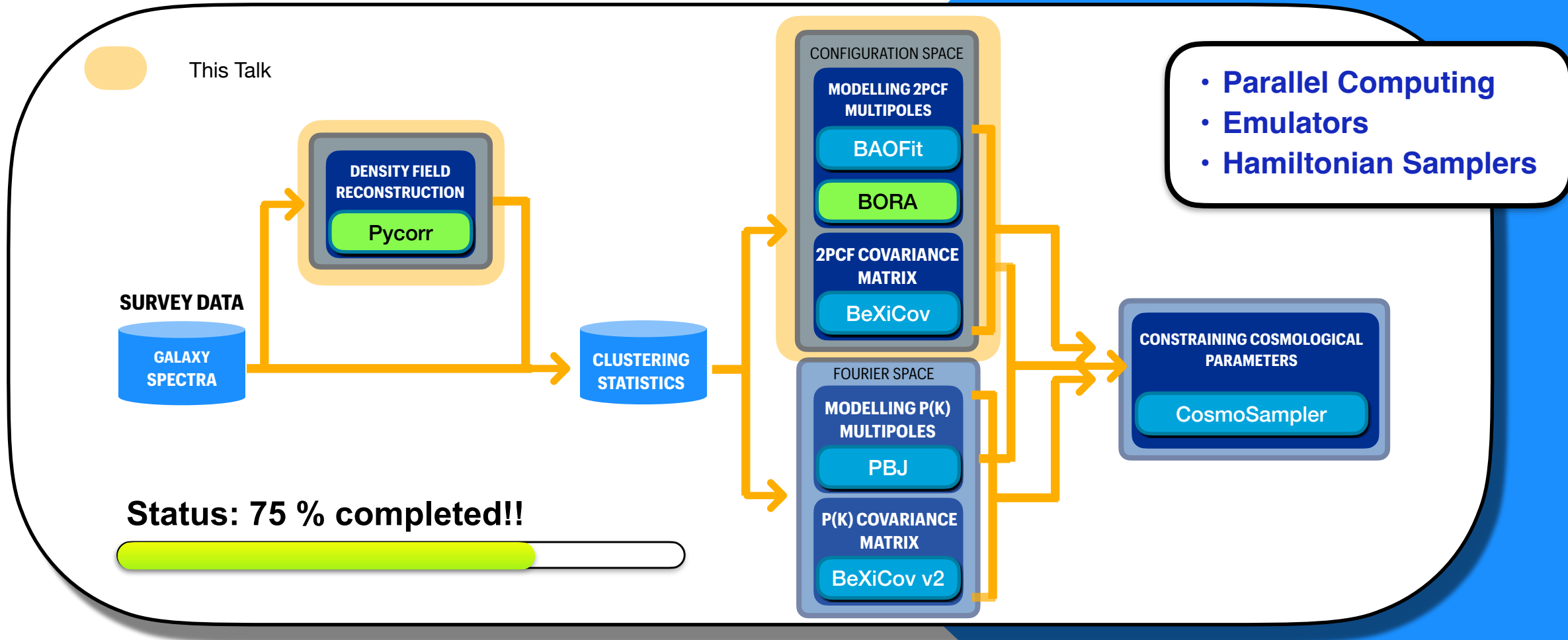
Euclid DR1-like



Upham et al 2022

Methodologies: pipeline flowchart

HPC Solutions



BAO reconstruction: overview

Key idea

- **Numerically** remove non-linear effects by moving galaxies backwards in time

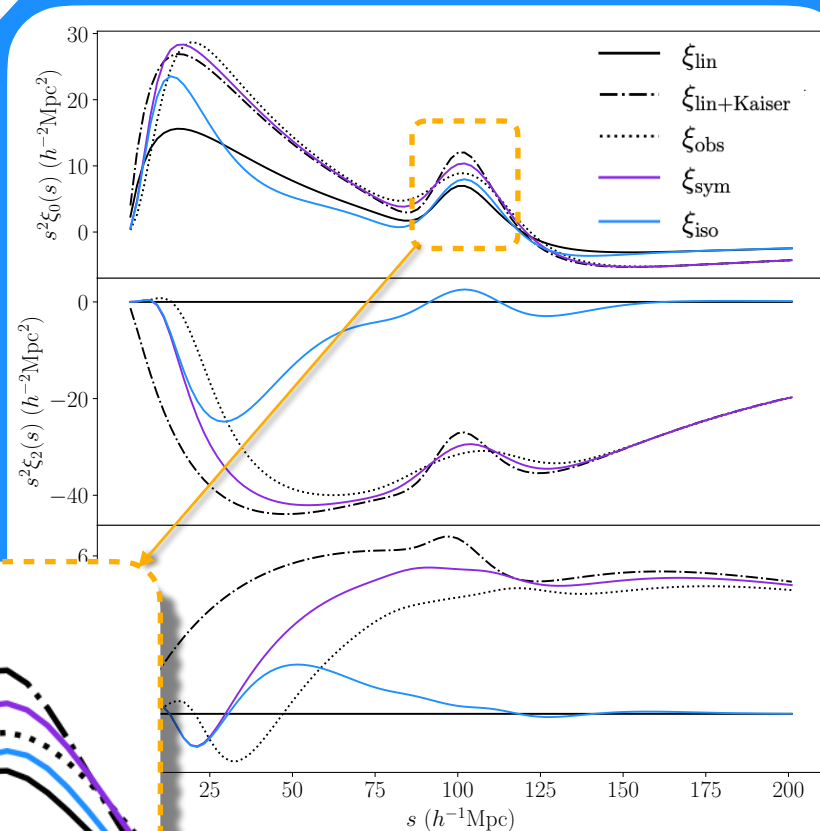
Goal

- Obtain a **sharper BAO peak**
- **Ease the modeling** of the clustering signal

100 % completed!!



2PCF multipoles



Sarpa et al in prep.

BAO reconstruction: methods

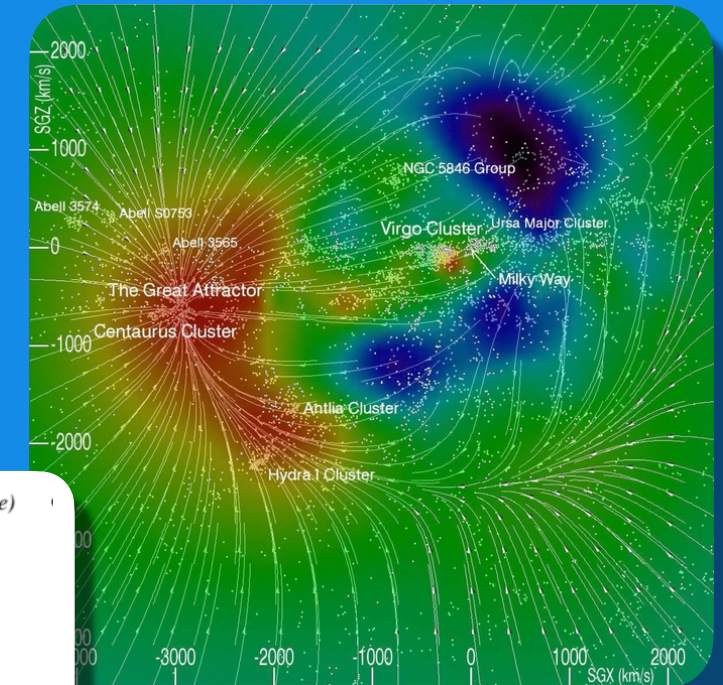
Algorithm

- Solve the dynamics (Poisson equation) on a multiple grids layering
- Displace galaxies back to their earlier position

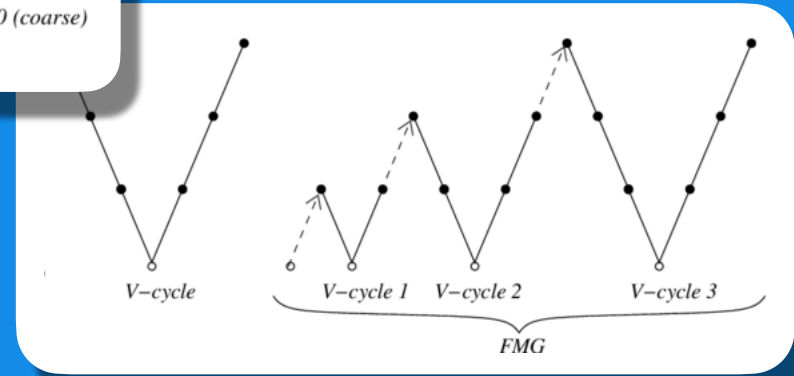
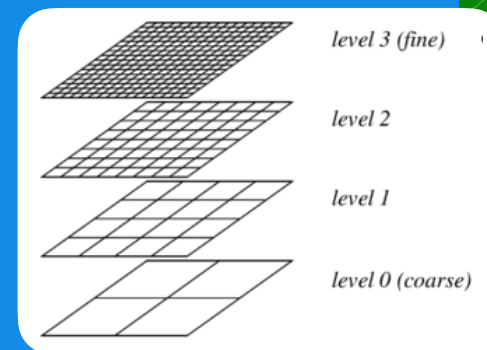
Strengths

- Optimized for **parallel computing**: 1 CPUs for 10^6 objects
- **Adaptive resolution**: Robust with respect to the grid choice
- **noise reduction**

Reconstructed Displacement field

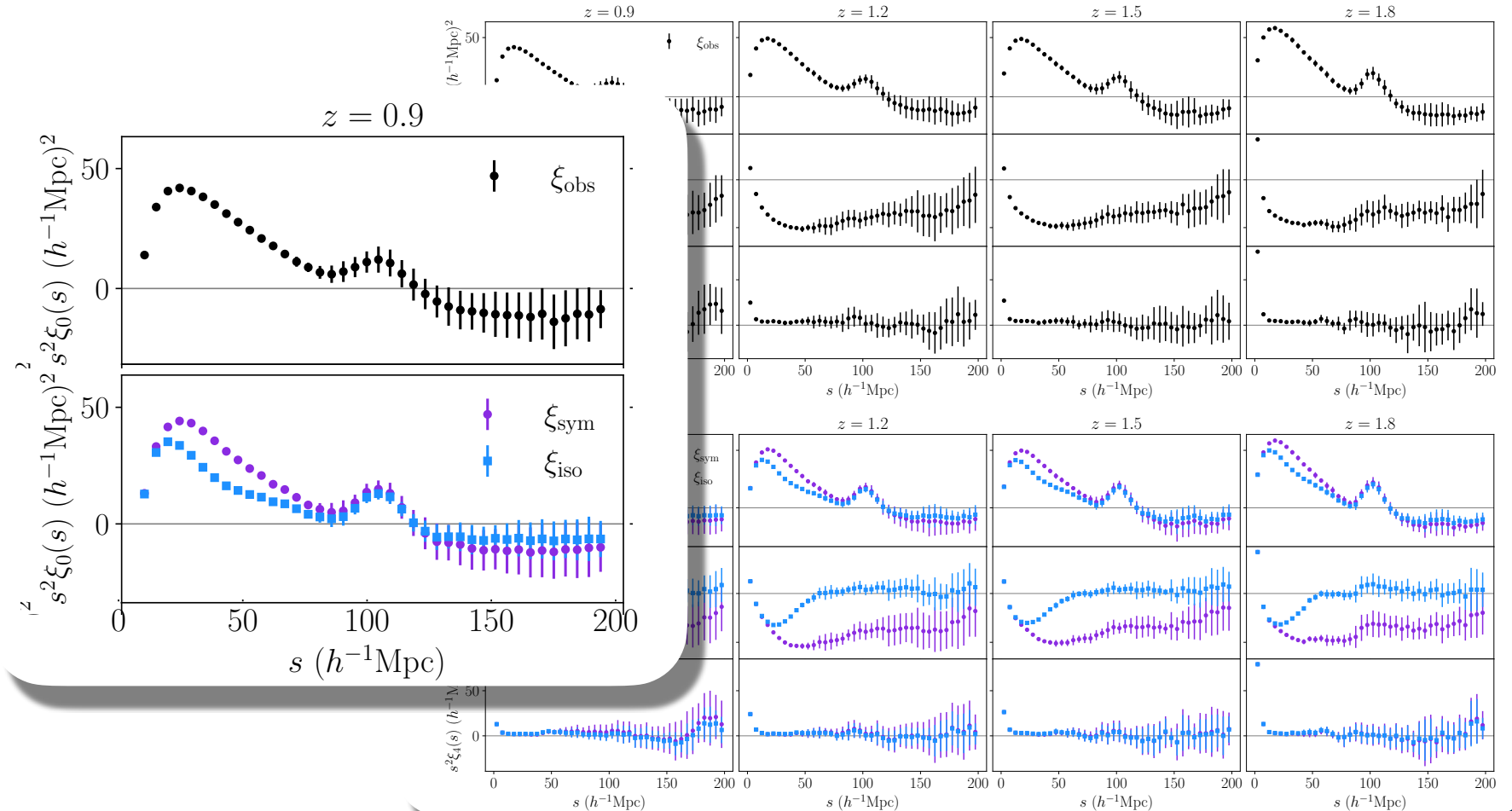


V-Cycle Multigrid



BAO reconstruction: main results

- Test on **Euclid realistic mocks**
- **BAO peak sharper** in each redshift range targeted by Euclid
- **Successful** in the **strong non-linear & low number density regimes**



Signal modeling: overview

Models

- **Physical description** of the signal including linear prediction + non-linear corrections
- Parametric modeling of **systematic effects**

Samplers

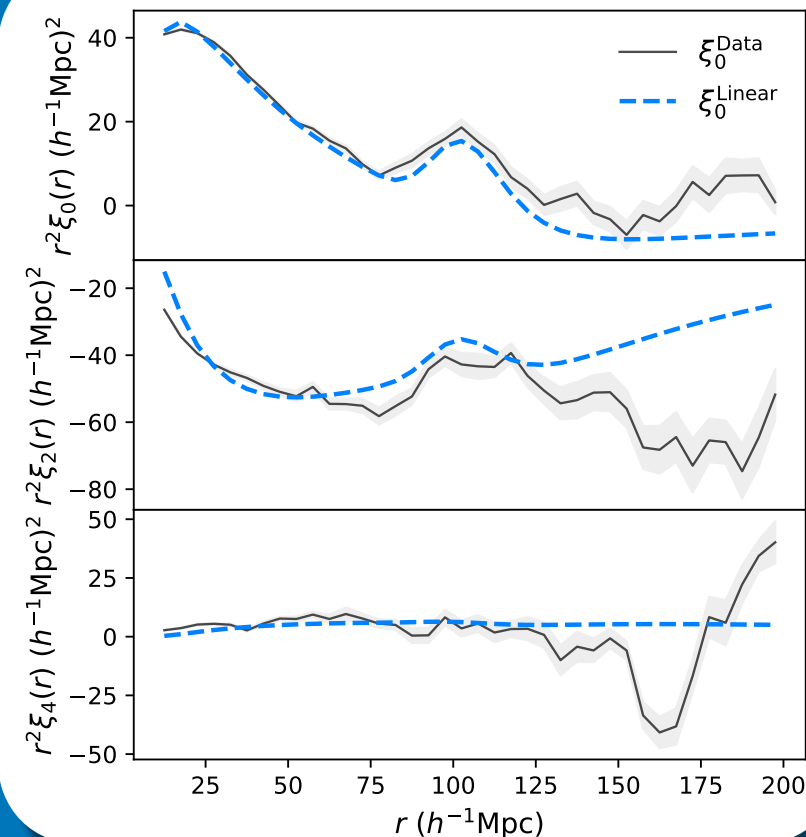
- **BAOFitter** <https://gitlab.com/esarpa1/> direct model evaluation + emcee
- **BORA.jl** (By M.Bonici): **ML Emulator** for 2PCF models, Hamiltonian Montecarlo Sampler
- **PBJ** (By C.Moretti): Direct **power spectrum estimate**, Analytical Marginalization, **Nested sampling**

Status

80 % completed!! P(k) testing ongoing



2PCF Multipoles



Sarpa et al in prep.

Signal modeling: performances

Training

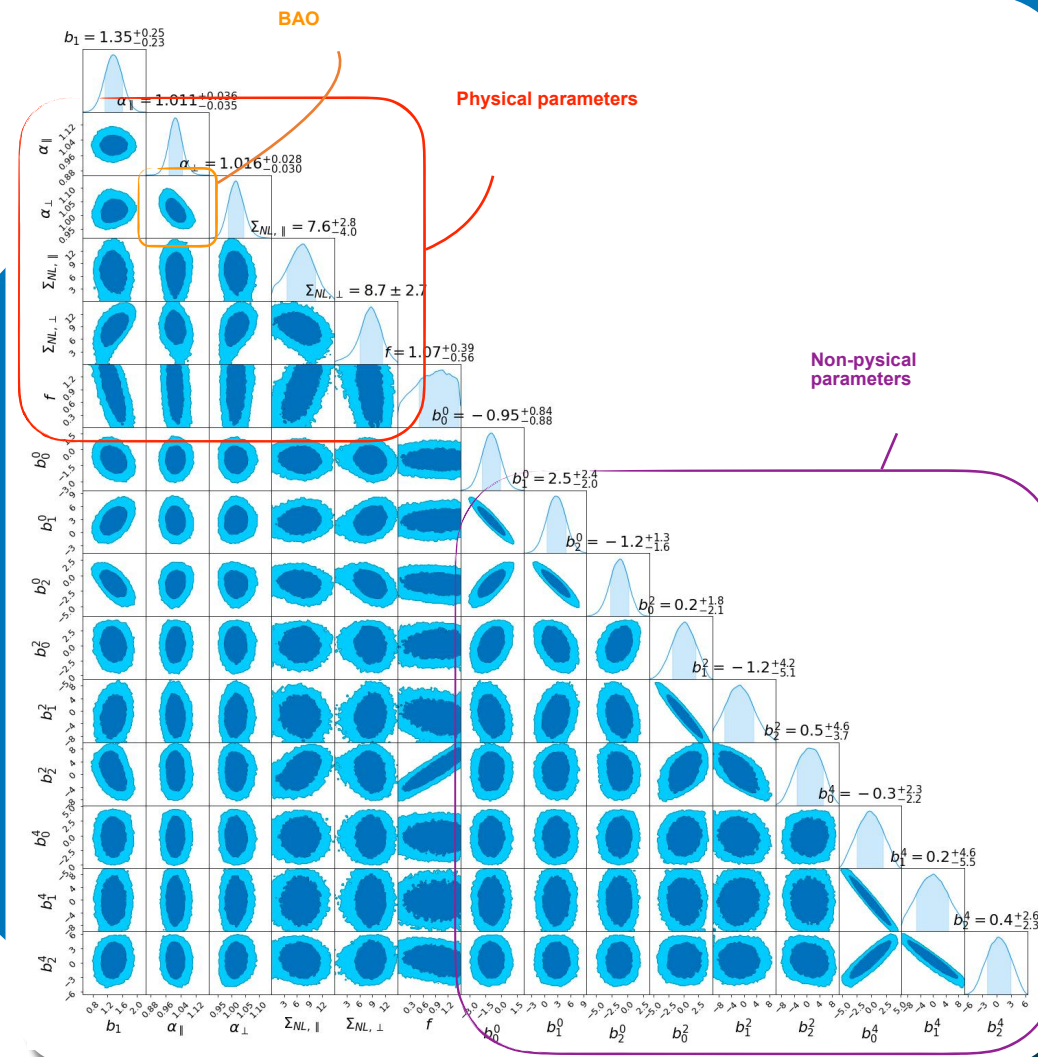
- 10k model evaluations
- 300 epochs
- **Adam minimizer** with Loss = RMS
- **CPU time: 15 minutes**

Sampling

- 8 walkers, 6k steps
- **CPU time: 3 minutes**

Advantages

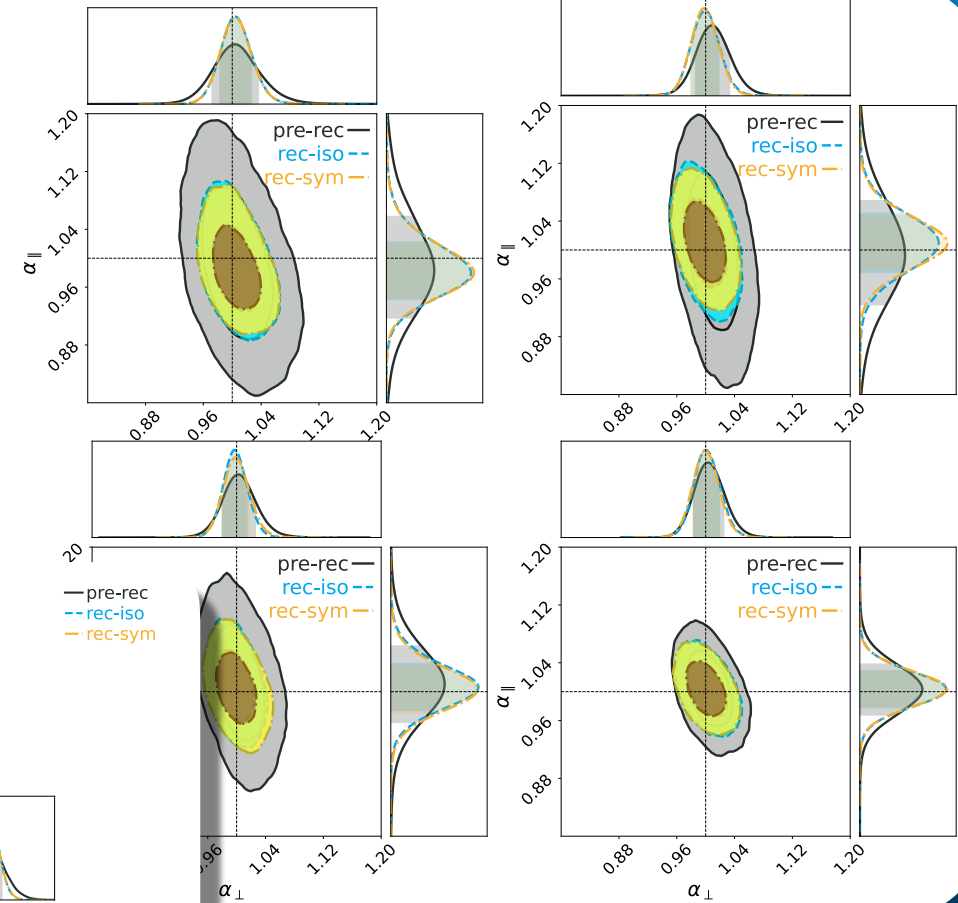
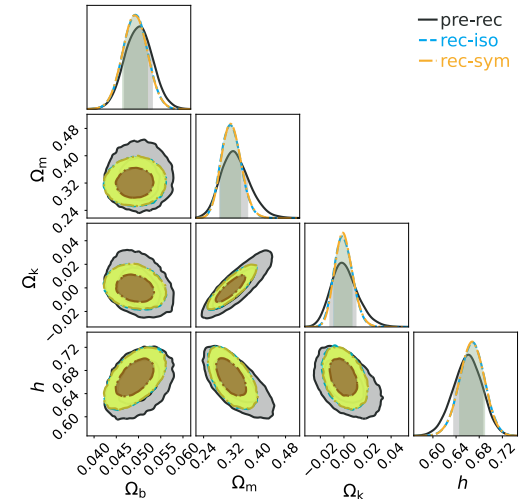
- Shorter chains: Reduce the correlation between consecutive steps
- **Faster convergence: 1/300 steps than emcee**



Final Results: (mock) Euclid BAO

Training

- Extract the BAO scale at the 4 nominal bins of Euclid light-cone
- **170% improvement** over non reconstructed measurements



Sarpa et al in prep.

Sarpa et al in prep.

Progress overview & Final steps

- BAO reconstruction routine
- Signal modeling Correlation Function
- Covariances Matrixes
- BAO to Cosmological constraints
- Signal modeling Power spectrum: test phase
- Euclid publication



Final steps: Ready for the Euclid Universe

- Inclusion of survey systematic effects
- **First Euclid Analysis**

Overall Status: 75%





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Thank you!

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