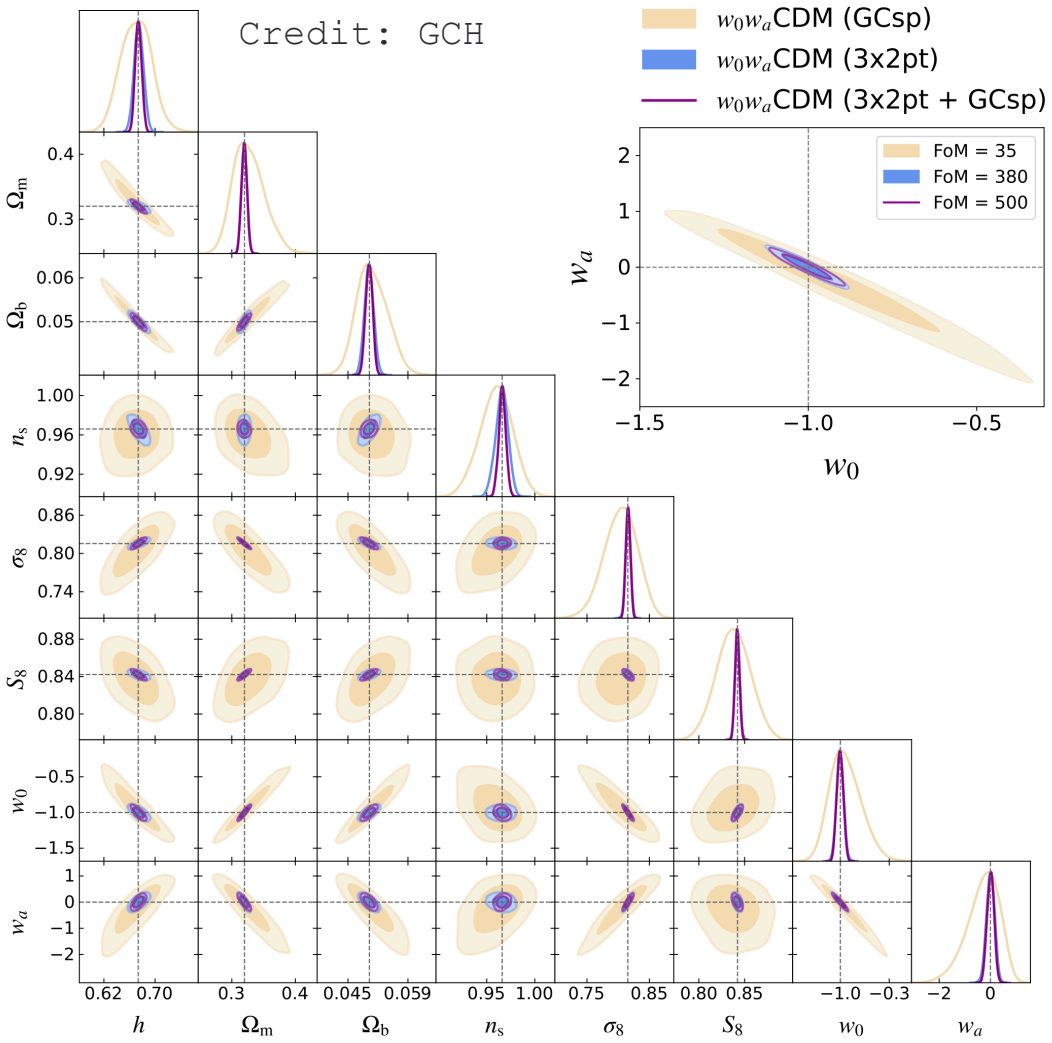
cloe-org maintainers: M. Bonici, G. Cañas-Herrera, S. Casas, P. Carrilho, C. Moretti, A. Pezzotta

open scientific software for cosmological modeling & statistical inference for galaxy surveys

G. Cañas-Herrera, 23rd July 2026

github.com/cloe-org

Stage IV cosmology: new challenges



- ***Obtain dark energy cosmological constraints for Stage IV galaxy surveys at the end of operations is computationally expensive.***
- ***Very expensive.*** Doing a Euclid-like end-of-operations analysis without AI-support (emulators) takes weeks.
- It will only get worse by combining data sets or galaxy surveys.
- This is a new challenge: we knew it would be hard, but we did not foresee how harder. We are talking about sampling a parameter space +100 dimensions.

CLOE: the story of a successful failure

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The Euclid Consortium started developing in 2019 the “Cosmology Likelihood for Observables in Euclid” (CLOE).

- ***Born as the standard statistical framework of the Euclid Consortium to explore posterior distributions.***
- ***It was delivered.*** And it runs. And has produced several (very!) highly robust scientific papers.
- Taught solid software engineering principles to many (naive!!) students
- Created a very solid and safe network among early careers developing the code who have grown into experts in the field.

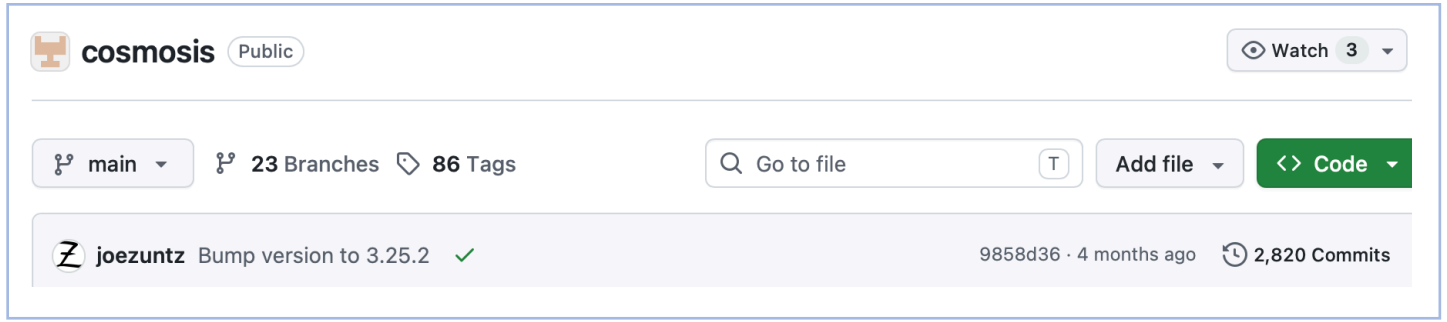
- ***Very high technical debt.*** We have coded a black box that only developers could use.
- Heavily dependent on external codes in a very complicated way
- Euclid is an observation-dominated community. We designed a tool to do theory easily. We never understood that comes later.
- **Strong(er) competitors out there in the market. We never analyzed why people were really using them.**

Currently available software in the community

CCL

continuous-integration no status | coverage 97% | docs passing | DOI 10.3847/1538-4365/ab1658

The Core Cosmology Library (CCL) is a public standardized library of routines to calculate basic observables used in cosmology. It will be the standard theoretical prediction package used by the LSST Dark Energy Science Collaboration (DESC), although we hope it will have broader applicability.



desilike

tests passing | docs rate limited by upstream service | coverage 19% | license BSD-3-Clause

`desilike` is the cosmological inference framework used by the Dark Energy Spectroscopic Instrument (DESI) collaboration. It enables writing likelihoods for the analysis of baryon acoustic oscillations (BAOs) and redshift-space distortions (RSDs) and to import them in commonly used cosmological inference codes (`Cobaya`, `CosmoSIS`, `MontePython`). Additionally, `desilike` provides support for Bayesian samplers and profile-likelihood analysis out of the box.

Why a new ecosystem

Evaluated in detail, one-per-one, no cosmological statistical framework is up for the challenge of Stage IV cosmology beyond their first data releases

HOW DO WE PERFORM THE STATISTICAL ANALYSIS SUCCESSFULLY?

BY ENCOURAGING OPEN SCIENCE DEVELOPMENT OF INFERENCE PIPELINES FOLLOWING FAIR PRINCIPLES AND ADOPTING XXI TECHNIQUES

Why a new ecosystem

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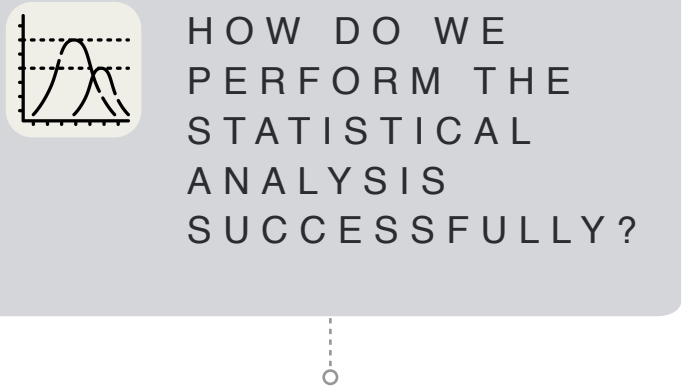


What we need, as community

- Easy to use, easy to modify pipelines
- Minimum maintenance, minimum training
- Fast and (eventually) faster computations
- Prepared to adopt newly developed pipelines
- Not enforcing, naturally adopted

A shared language for cosmological scientific software

Philosophy behind: Why one single software that builds interfaces with others, when we can benefit from a common brand?

Repository Name	Description
cloelib	Computation of the theoretical predictions for Euclid primary observables
cloelike	Euclid likelihood module for photometric and spectroscopic primary observables
playground	Tutorials, examples and DEMO notebooks
blindspot	Generation of blinding shifts for cosmological analyses
darkflipper	Computation of statistical estimators such as p-values, Figures of Merit and Figures of Bias

A shared language for cosmological scientific software

Philosophy behind: Why one single software that builds interfaces with others, when we can benefit from a common brand?

cosmology

large-scale structure, observables, inference

`cloelib` `cloelike`

Supporting tools

modular libraries, reproducible pipelines

`darkflipper` `blindspot`

community

open source, learning material

`playground`

`cloelib`, the joy of cloe-org

Philosophy behind: I want to compute large-scale structure summary statistics predictions in less than 3 minutes

- **Intuitive & User-Friendly** – Fast generation of **Euclid-like** observables (e.g., power spectra, window functions, and tracer statistics).
- **Automatic Differentiation** – Supporting `JAX` for gradient-based computations.
- **Modular & Extensible** – Easily interface with external Boltzmann solvers or emulators via Python `Protocols` following the cosmology.API. The core structure enables defining Background & Perturbation models, choosing observables via Tracer or SpectroPower protocols, and computing final summary statistics such as angular power spectra or Legendre multipoles. Check the guide to learn more about its architecture.

`cloelib`, the joy of cloe-org

Philosophy behind: I want to compute large-scale structure summary statistics predictions in less than 3 minutes

Cosmological probes	Systematic nuisance modelling	Spaces
Photometric galaxy surveys (cosmic shear, 3x2pt), spectroscopic galaxy surveys (BAO, full shape), cross-correlations with CMB lensing (for photometric probes)	Everything needed for a Stage IV analysis (almost!)	Configuration and harmonic space (Limber and beyond Limber)

Simple, but powerful

Designed with a clear user baseline in mind: the incoming generation of cosmologists that will supervise those students doing the ultimate galaxy surveys cosmological analyses

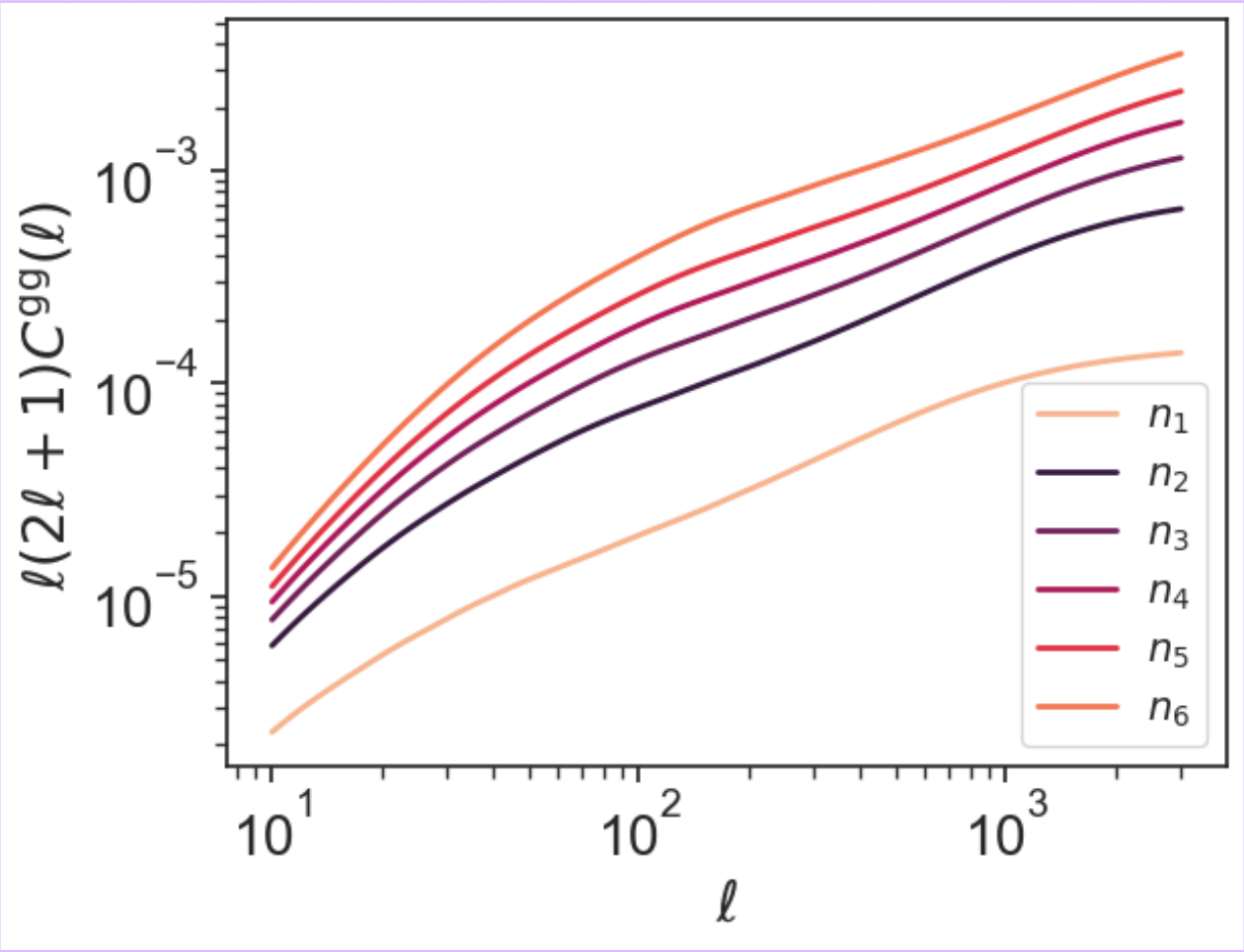
```
import numpy as np
from cloelib.observables.photo import ShearTracer, PositionsTracer
from cloelib.summary_statistics.angular_two_point import AngularTwoPoint

shear = ShearTracer(perturbations, dndz_shear, z, shear_nuisance)
galaxies = PositionsTracer( perturbations, dndz_galaxies, z, "poly", galaxy_nuisance )

ells = np.arange(2, 3000)

Cls = {**AngularTwoPoint(shear, shear).get_Cl(ells, nl=0, ks=ks), **AngularTwoPoint(galaxies,
shear).get_Cl(ells, nl=0, ks=ks), **AngularTwoPoint(galaxies, galaxies).get_Cl(ells, nl=0,
ks=ks)}
```

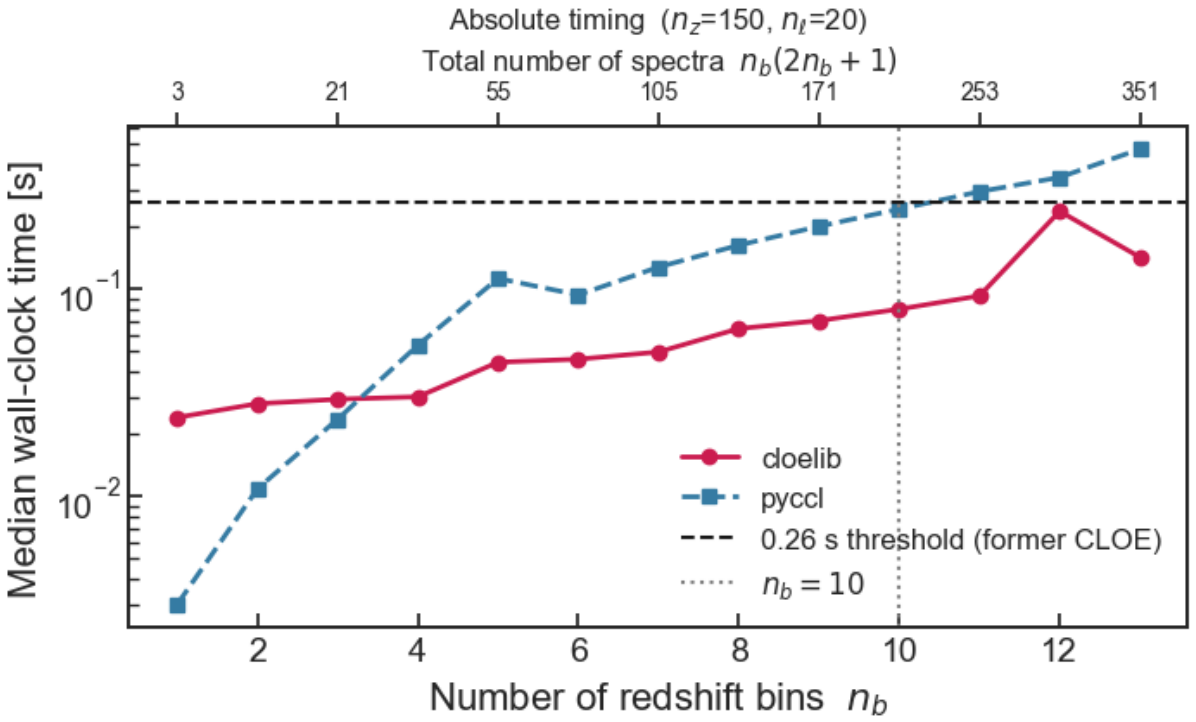
Simple, but powerful

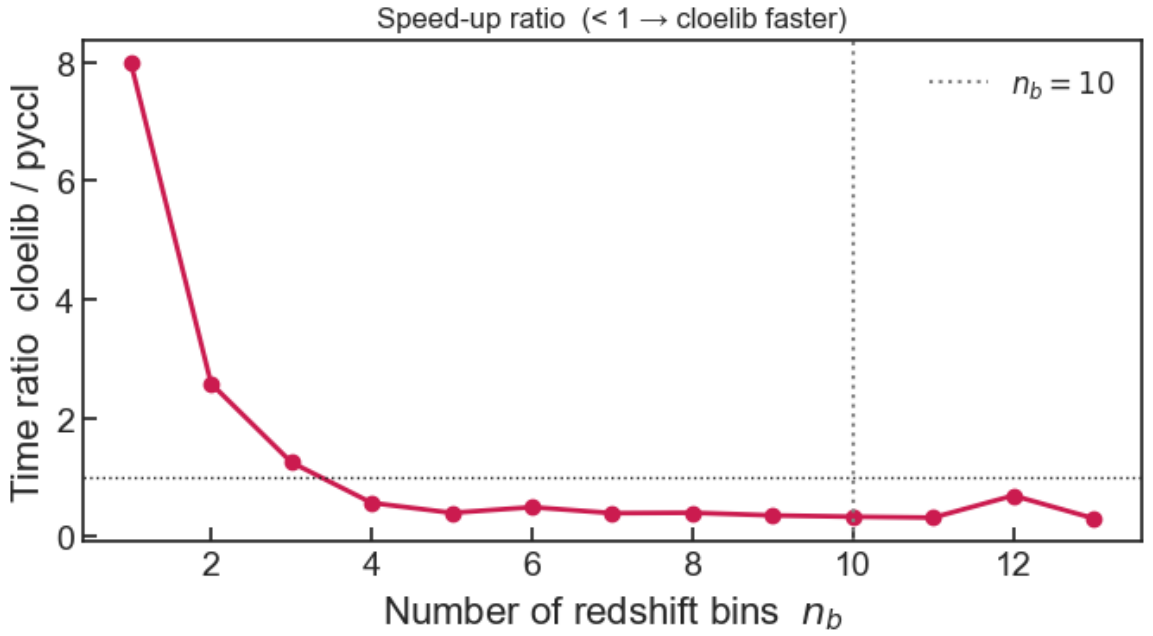


`cloelib`, and its direct competitors

Lightweight, yet the faster in the current cosmo market, for realistic large-scale structure galaxy survey specifications

SPV3 n(z) — 3x2pt, harmonic space, n_z=150, n_ℓ=20 (3 runs, median)

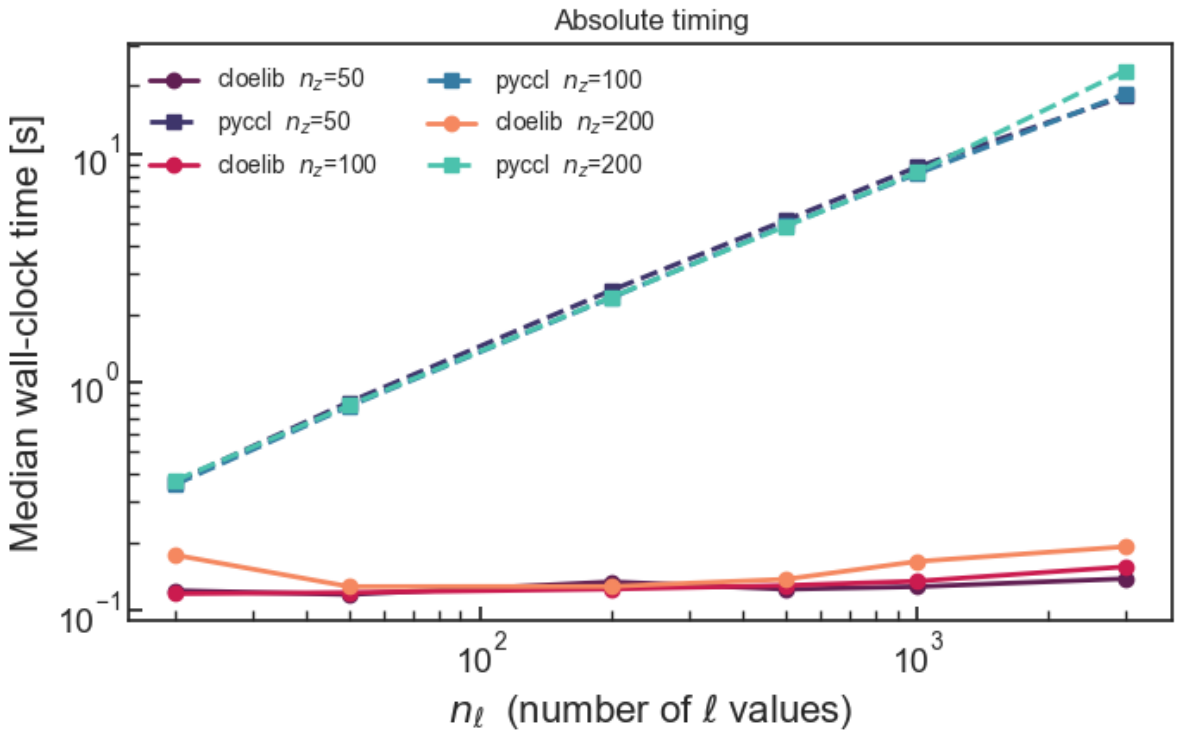


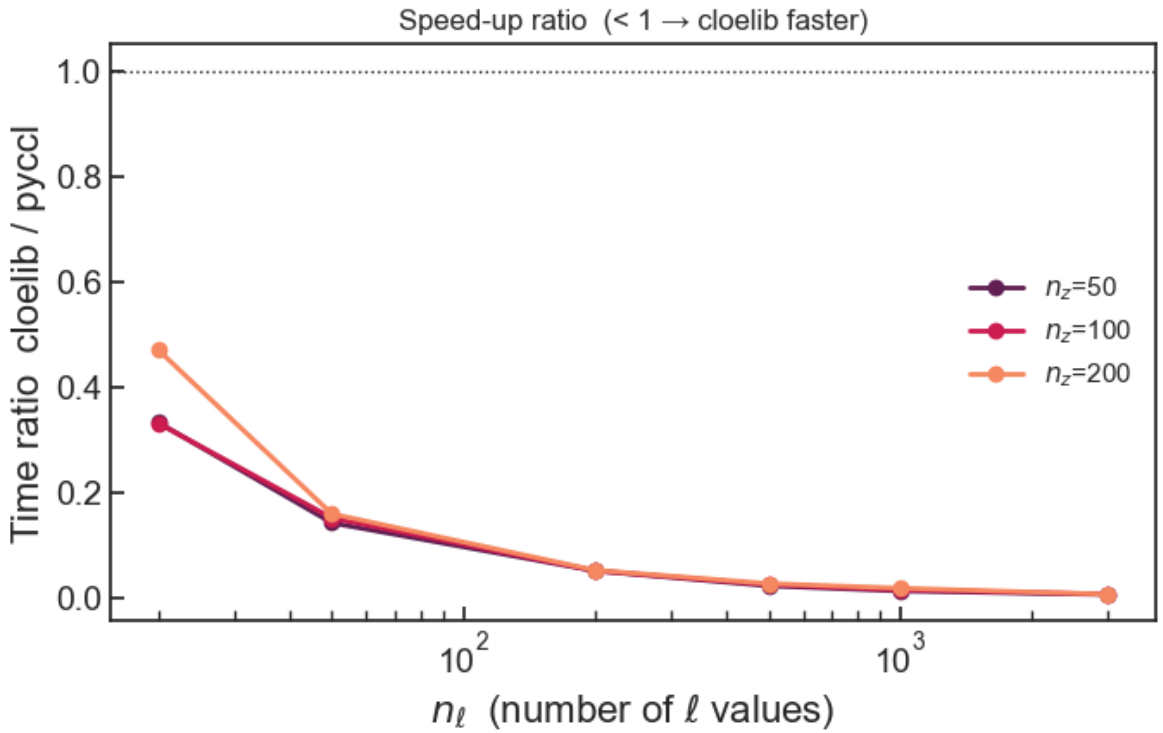


`cloelib`, and its direct competitors

Lightweight, yet the faster in the current cosmo market, for realistic large-scale structure galaxy survey specifications

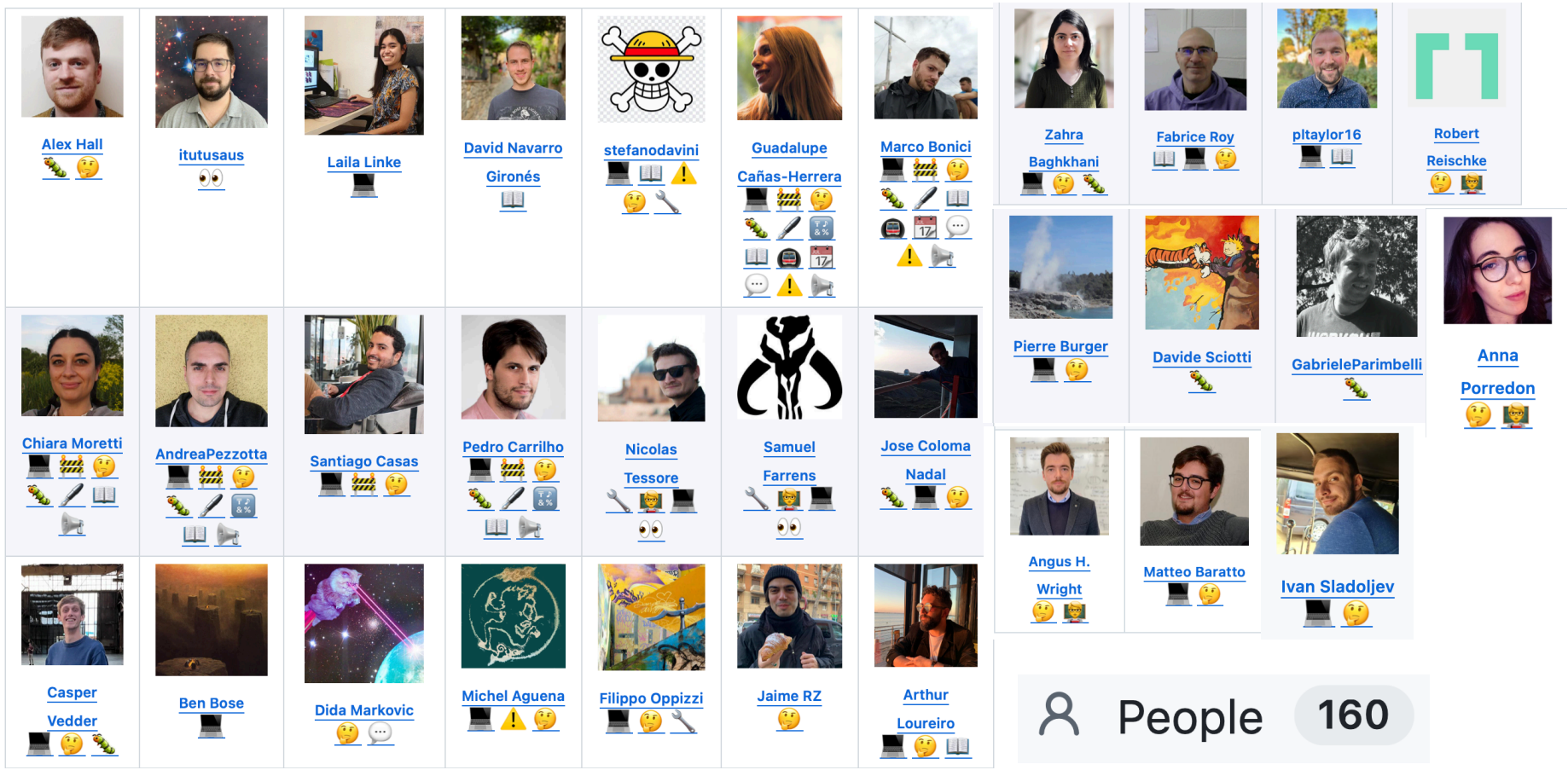
SPV3 n(z) — 13 bins, 3x2pt (3 runs, median)





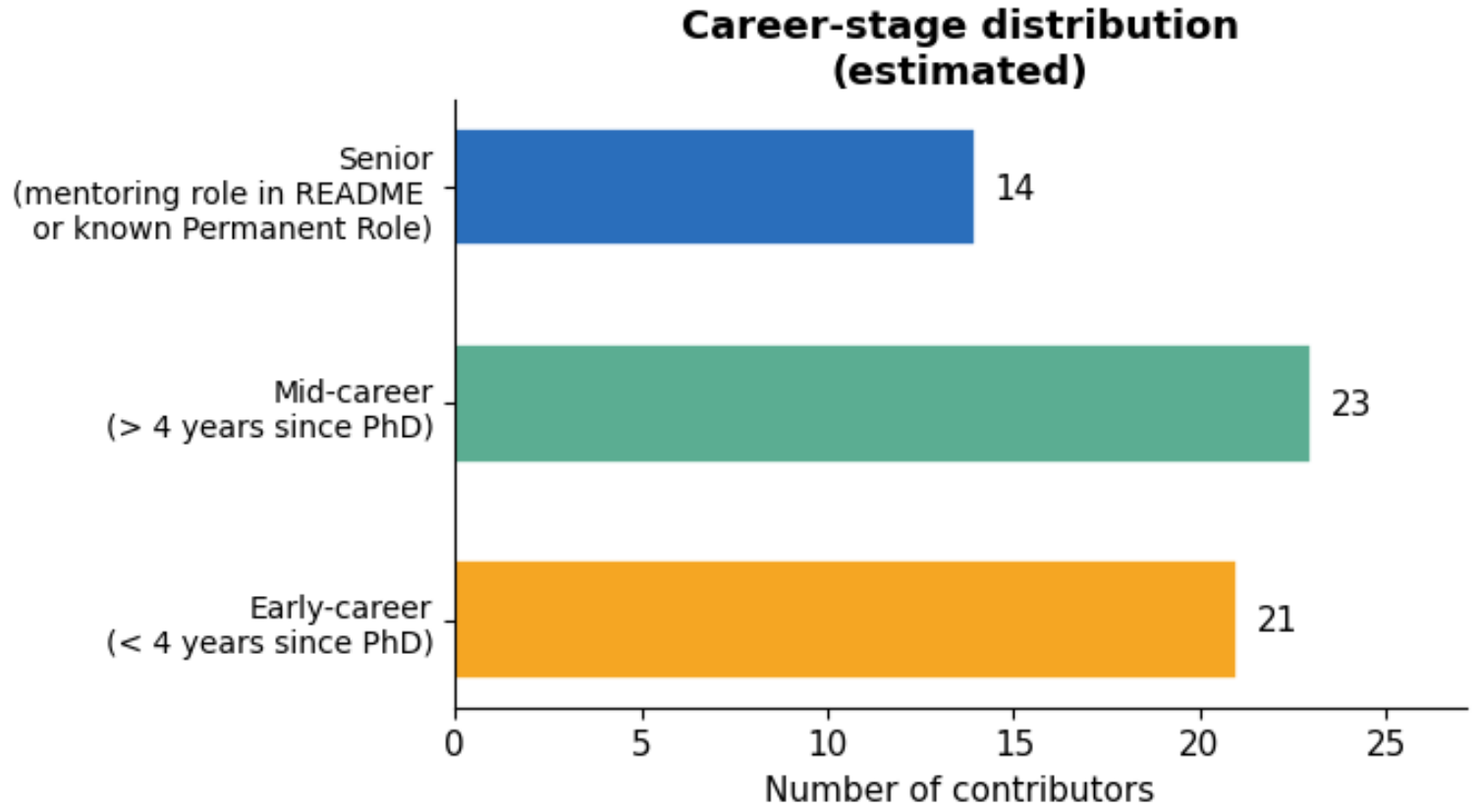
`cloelib`, honest reviews

Designed with a clear user baseline in mind: the incoming generation of cosmologists that will train their students to do the ultimate cosmological analyses of Stage IV multi-probe analyses



A community powered by diversity

The success of the project so far has come from having a team of daily contributors centered into mid-career postdoctoral researchers and senior scientists who mentor early careers



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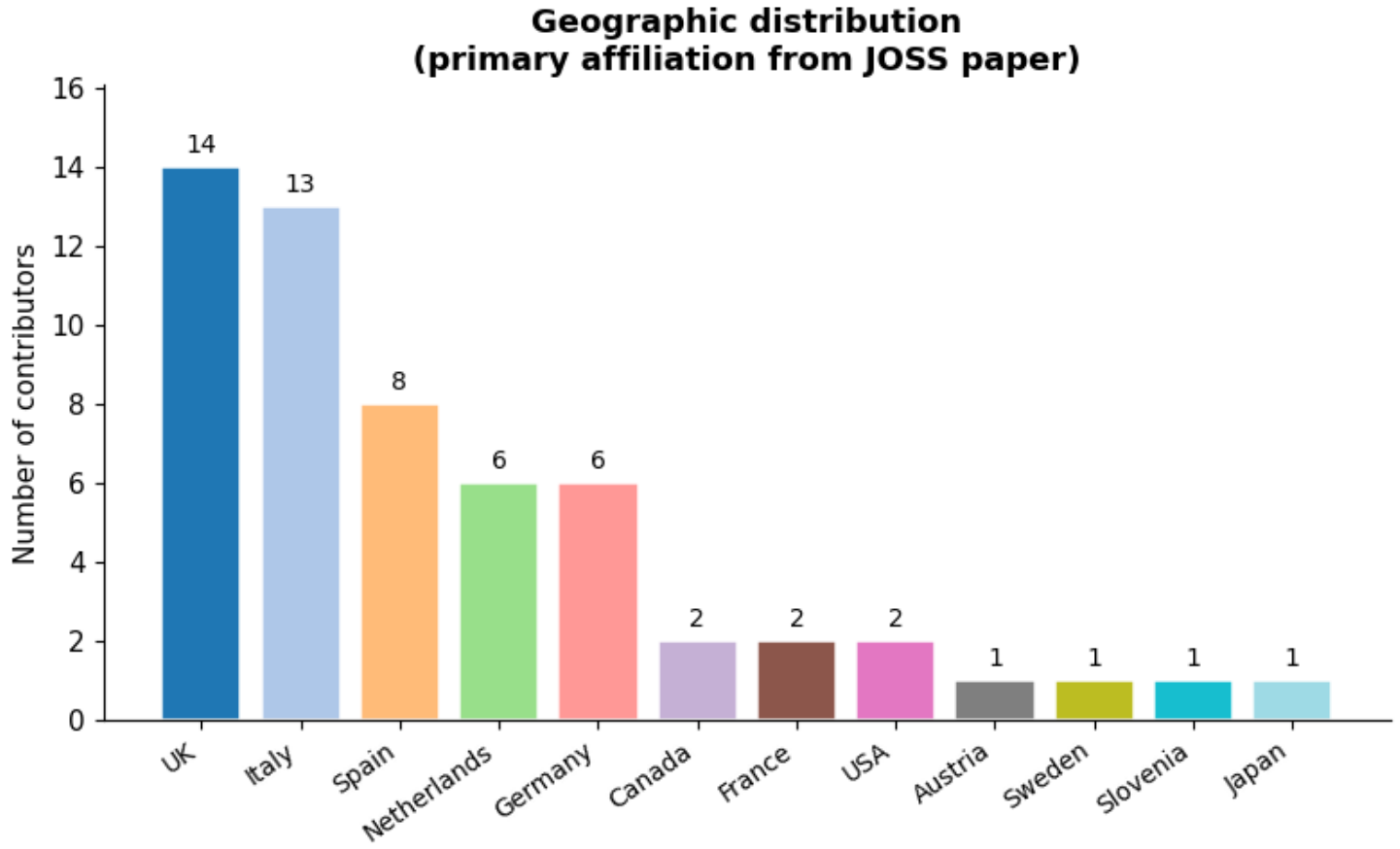

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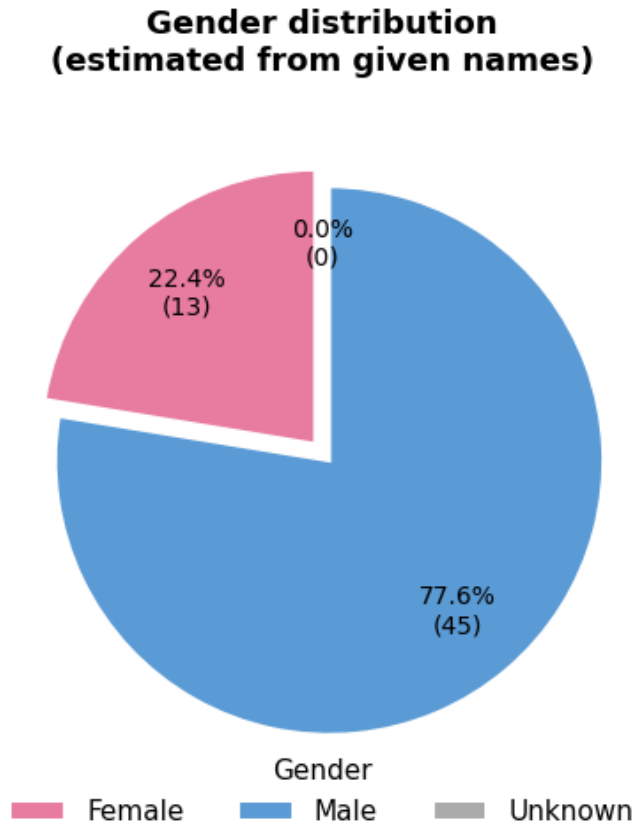


- ***Gender bias*** still present
- Direct consequence of the gender bias already present in the Euclid collaboration
- Still, we are almost 4 points* above the overall representation of female researchers in the Euclid Consortium
- Ideas (and external contributors welcome!)

`cloelike`, the statistics mate

Philosophy behind: let me evaluate the Euclid likelihood with the official products and cloelib in less than 3 minutes

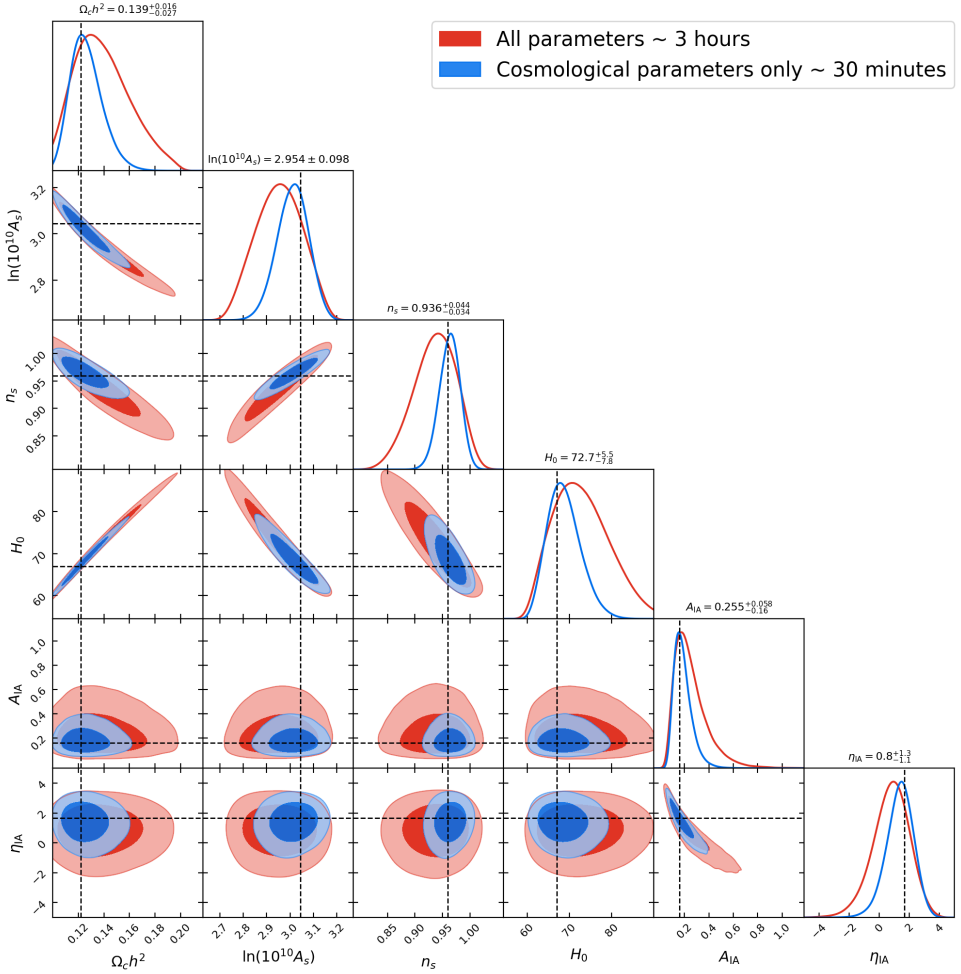
✨ Features

🔷 **Intuitive & User-Friendly** – General description of the likelihood options by classes

🔷 **loglike calculation for Euclid primary probes** – currently supporting 3x2pt and spectroscopic galaxy clustering full-shape

`cloelib + cloelike`, the fastest couple

Run Euclid official joint cosmological analysis in less than 1 day



With cloe-org, we can now achieve cosmological contours for a Euclid analysis in a matter of hours.

Former time scale was *days*.

Embracing Open Science

European Space Agency missions have struggled to adopt Open Science for their pipelines early on in development, it is time to change the rules of the game

`cloelib`: A Flexible Python Library for Computing Cosmological Observables in the Euclid Era ☑ arXiv: 2605.23839

`cloelike`: A Python Library for Cosmological Likelihood Inference in the Euclid Era ☑ arXiv: 2605.23841

Embracing Open Science

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💥 Since following Open Science approaches, we constantly get feedback (+3 issues per week…)

🐞 Yet in 5 years of internal development of CLOE in the Euclid Consortium:

0 bugs reported

🫠 Conclusion: silence is not always golden

🚨 Open Science ≠ public code dump

it's about visibility, accountability, and *actual* collaboration

Take home message

Play with the immediate future, *now*

cloe-org is prepared to be able to adopt the “mega-analysis” of combined data sets from Stage IV galaxy surveys

Big *small* wins in less than two years of active development

Many achievements the Nobel Committee will never notice: homogenization of data structure of heterogenous Euclid science ground segment products, getting students trained in a matter of a running a notebook, easy adoption by the Euclid community…

software with a purpose

Less pipeline, more cosmology. A tool ceases to be useful when it becomes an obstacle—too cumbersome for scientists to use freely when exploring new questions.

open scientific software for cosmological modeling & statistical inference for galaxy surveys

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Adopted within the Euclid Consortium and scientifically coordinated by I. Tutusaus, M. Crocce and M. Carbone