Fast Localisation and Galaxy Host Ranking with Bayesian Nonparametrics
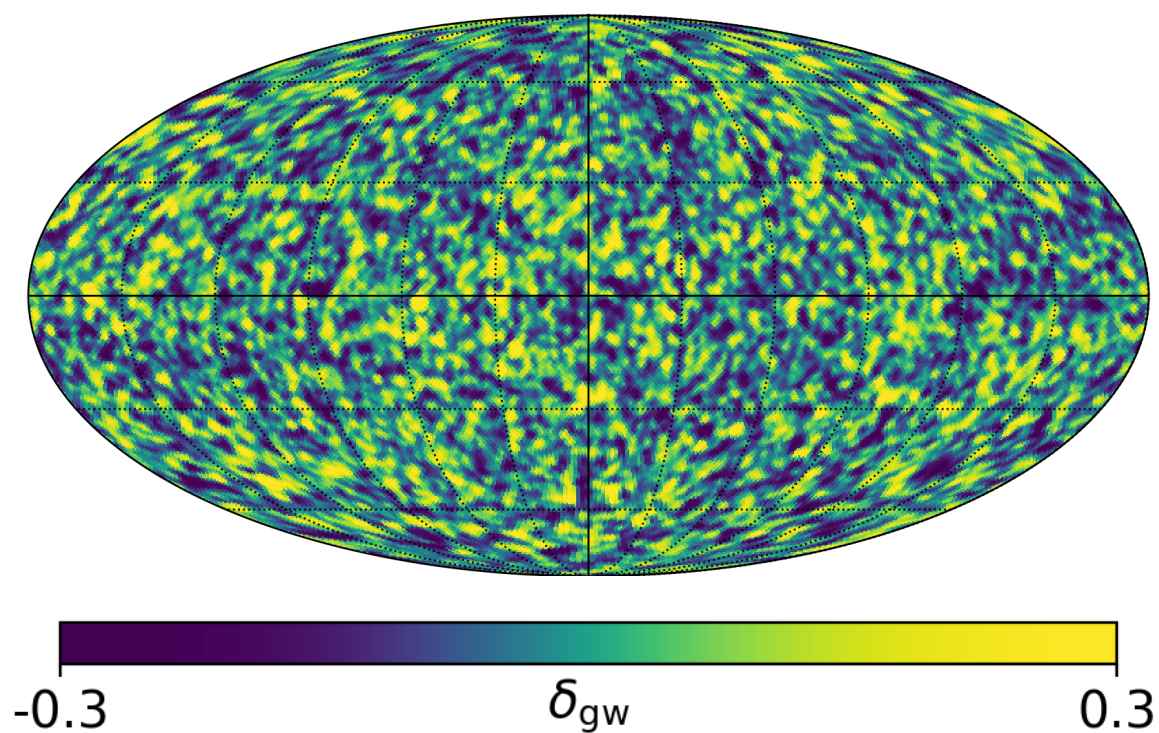
Virgo Pisa Internal Workshop - 23 May 2024

Giulia Capurri
Università di Pisa

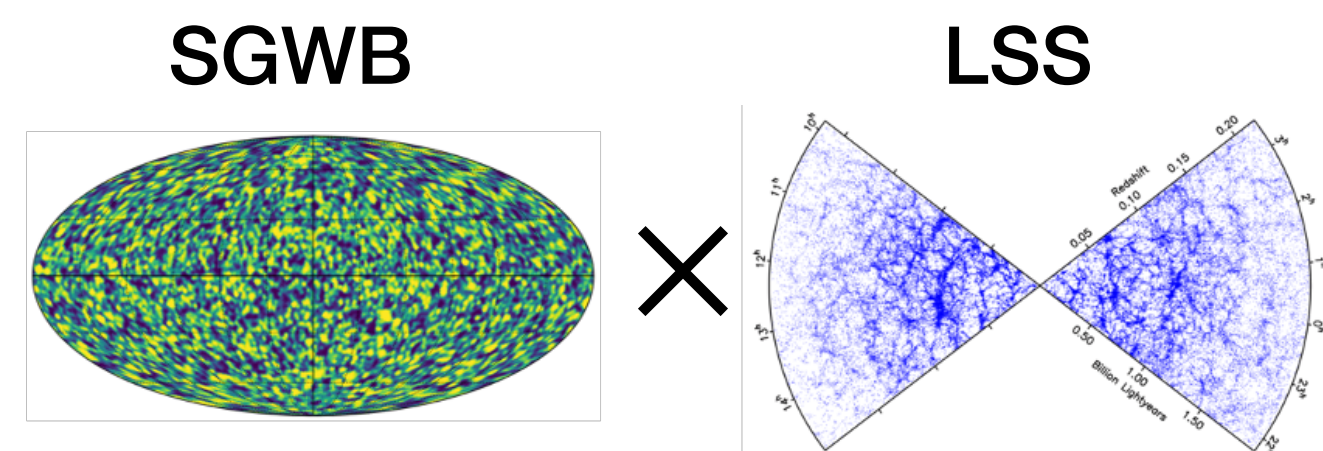# My research interests so far: astrophysics and cosmology with the SGWB from CBCs

Theoretical models for SGWB intensity and anisotropies

Simulated map of the astrophysical SGWB
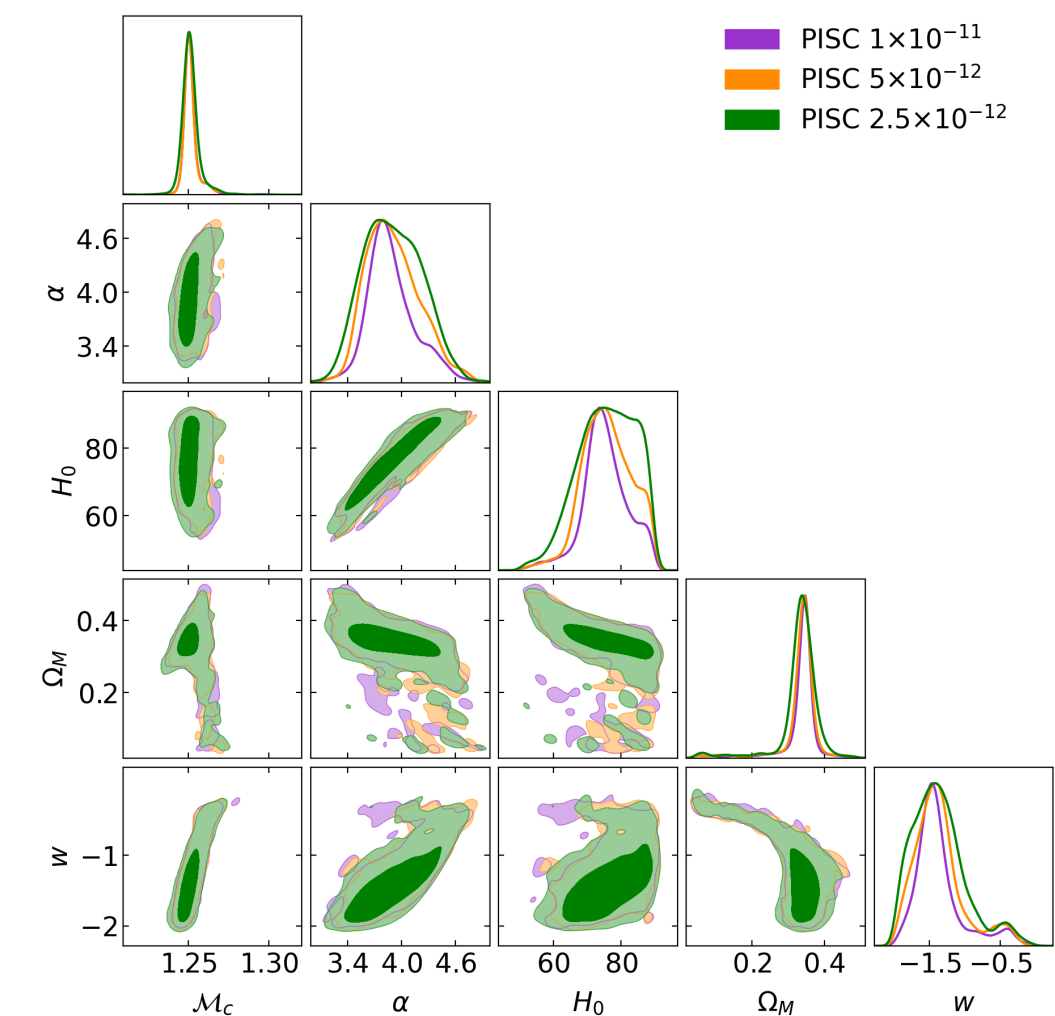

GC+21, JCAP, arXiv:2103.12037

Cross-correlations with EM tracers of the LSS, shot noise and detection prospects

SGWB × **LSS**

GC+22, Universe, arXiv:2111.04757
GC+23, ApJ, arXiv:2212.06162

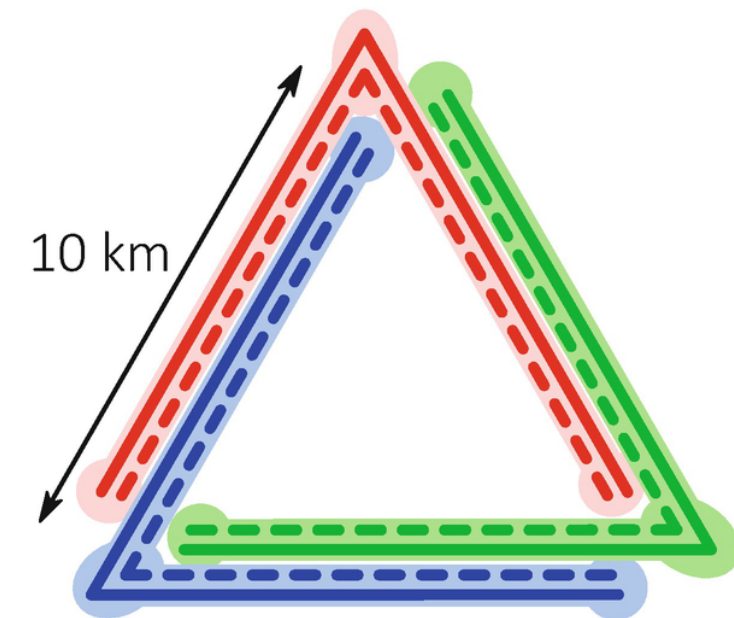Astrophysical and cosmological parameters from the SGWB

GC+24, Phys. Rev. D, arXiv:2310.18394

My current activity here in Pisa

50% ET EINSTEIN TELESCOPE

50% VIRGO

Impact of correlated noise on the detection and characterisation of the SGWB

People involved:

Lorenzo Valbusa Dall'Armi, Ilaria Caporali, Walter Del Pozzo, Angelo Ricciardone
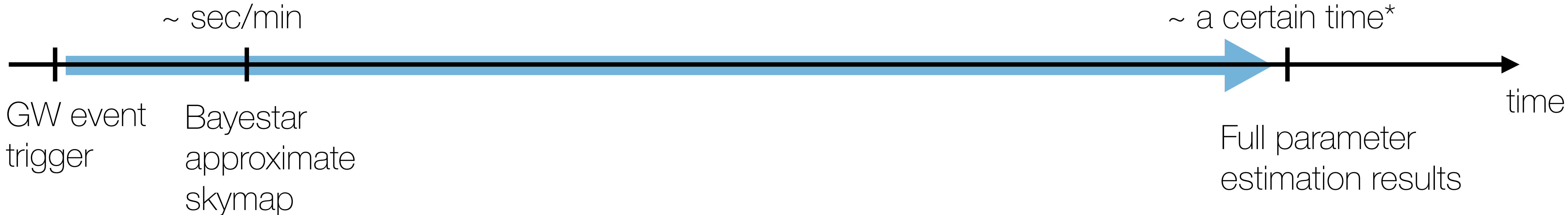
SKYFAST

A tool to speed up the localization of GW events and the ranking of galaxy hosts, enhancing the identification of EM counterparts.
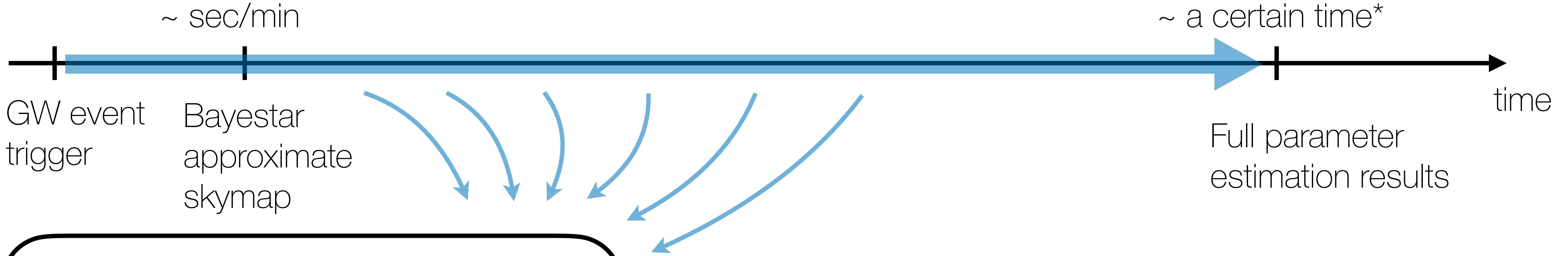
People involved:

Gabriele Demasi, Barbara Patricelli, Angelo Ricciardone, Walter Del Pozzo

10 km

Speeding up GW event localization and galaxy host ranking with bayesian non-parametrics

~ sec/min

~ a certain time*

GW event trigger

Bayestar approximate skymap

Full parameter estimation results

time

Speeding up GW event localization and galaxy host ranking with bayesian non-parametrics

~ sec/min

~ a certain time*

time

GW event
trigger

Bayestar
approximate
skymap

Full parameter
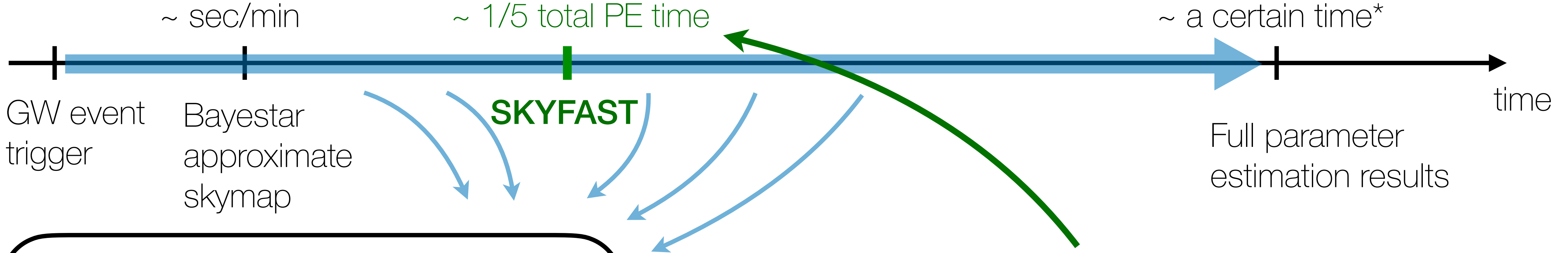estimation results

Adds **samples** and
updates the mixture…

SKYFAST

Dirichlet process gaussian mixture model
FIGARO, *Rinaldi & Del Pozzo 2022*

$$p(\boldsymbol{x}) \sim \sum_{k=1}^{\infty} w_k \, \mathcal{N}(\boldsymbol{x} \,|\, \boldsymbol{\mu}_k, \boldsymbol{\sigma}_k)$$

$$\boldsymbol{x} = \{\alpha, \delta, D_L, \theta_{jn}\}$$

Speeding up GW event localization and galaxy host ranking with bayesian non-parametrics

~ sec/min

~ 1/5 total PE time

~ a certain time*

time

GW event trigger

Bayestar approximate skymap

SKYFAST

Full parameter estimation results
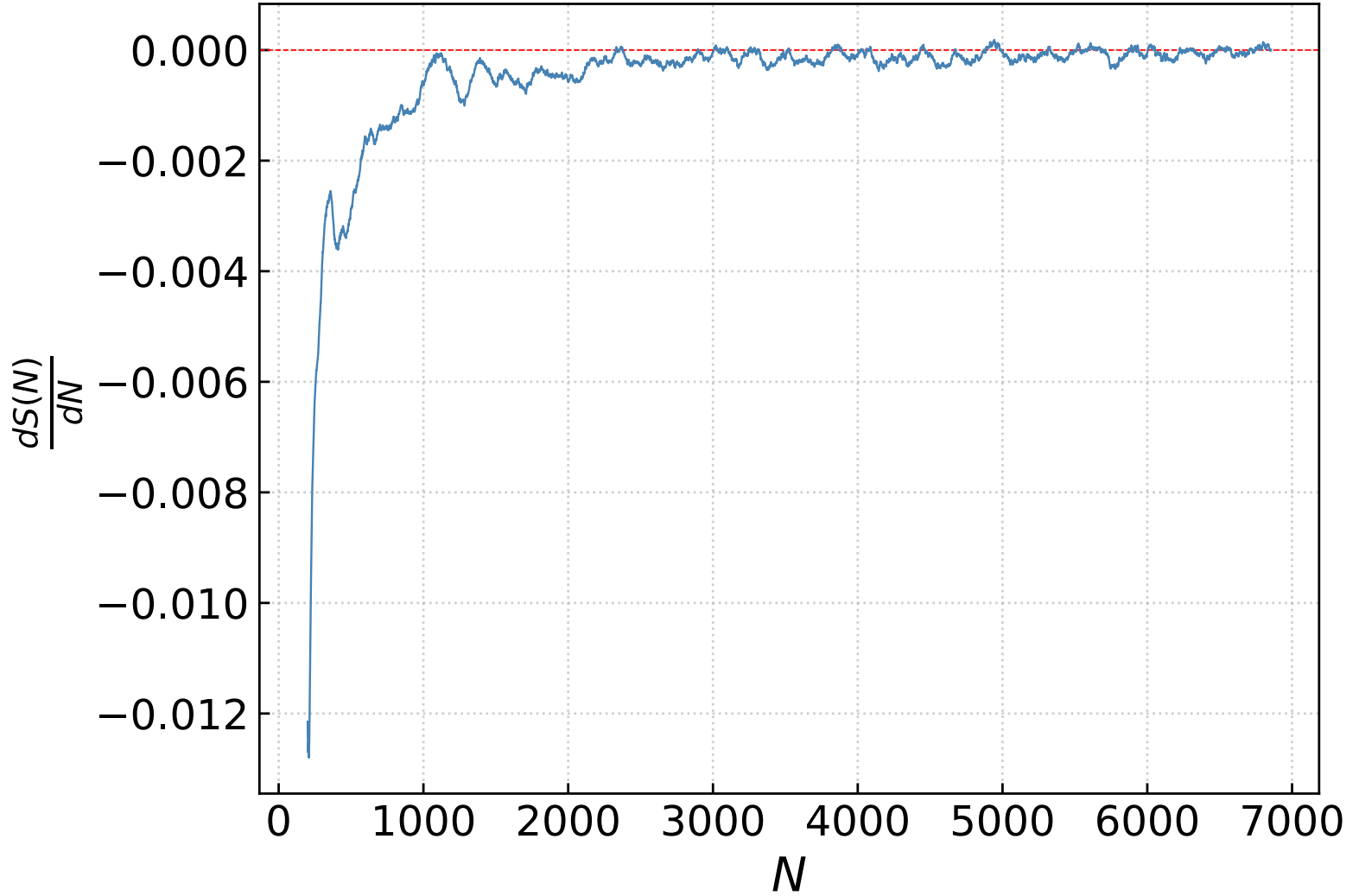
… until the information entropy saturates

SKYFAST

Dirichlet process gaussian mixture model
FIGARO, *Rinaldi & Del Pozzo 2022*

$$p(\boldsymbol{x}) \sim \sum_{k=1}^{\infty} w_k \, \mathcal{N}(\boldsymbol{x} \,|\, \boldsymbol{\mu}_k, \boldsymbol{\sigma}_k)$$

$$\boldsymbol{x} = \{\alpha, \delta, D_L, \theta_{jn}\}$$
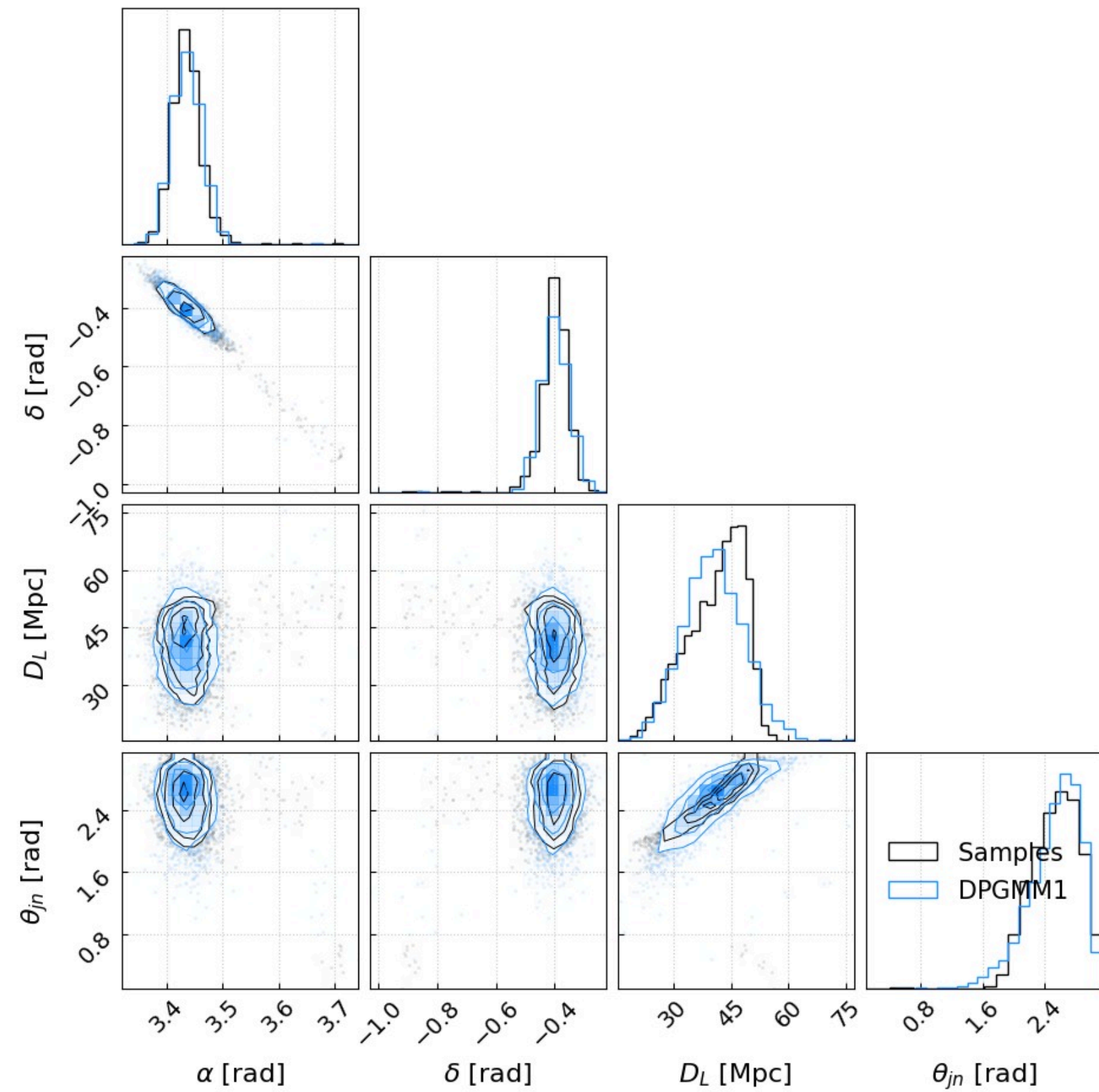
SKYFAST outputs

Main output:

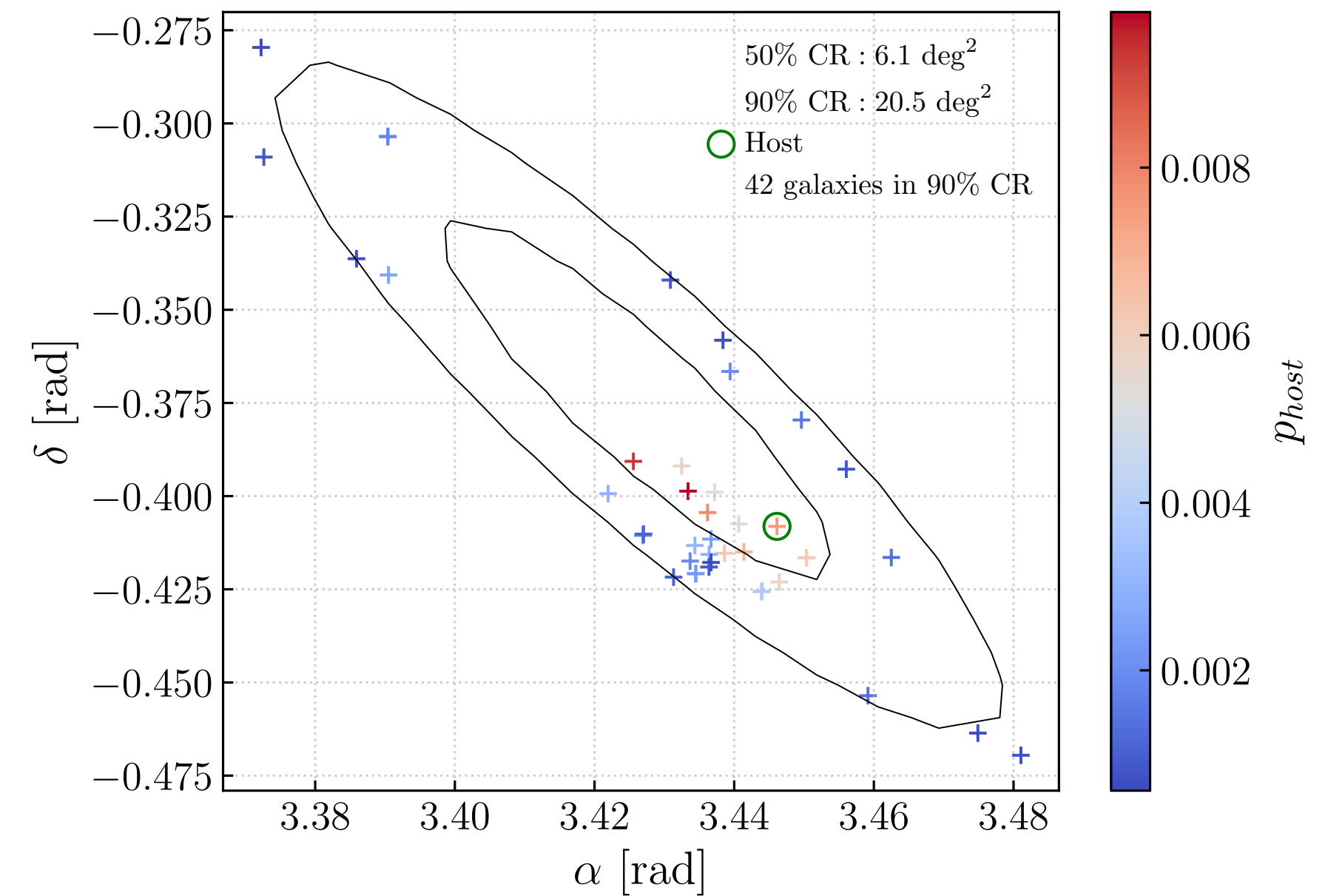Analytical posteriors for $\{\alpha, \delta, D_L, \theta_{jn}\}$

We can use the analytical posteriors to obtain other useful outputs:

- Skymaps and volume maps with the credible regions
- Ranked list of potential galaxy hosts from GLADE+ catalog

Test on GW170817

Galaxy ranking with inclination angle information

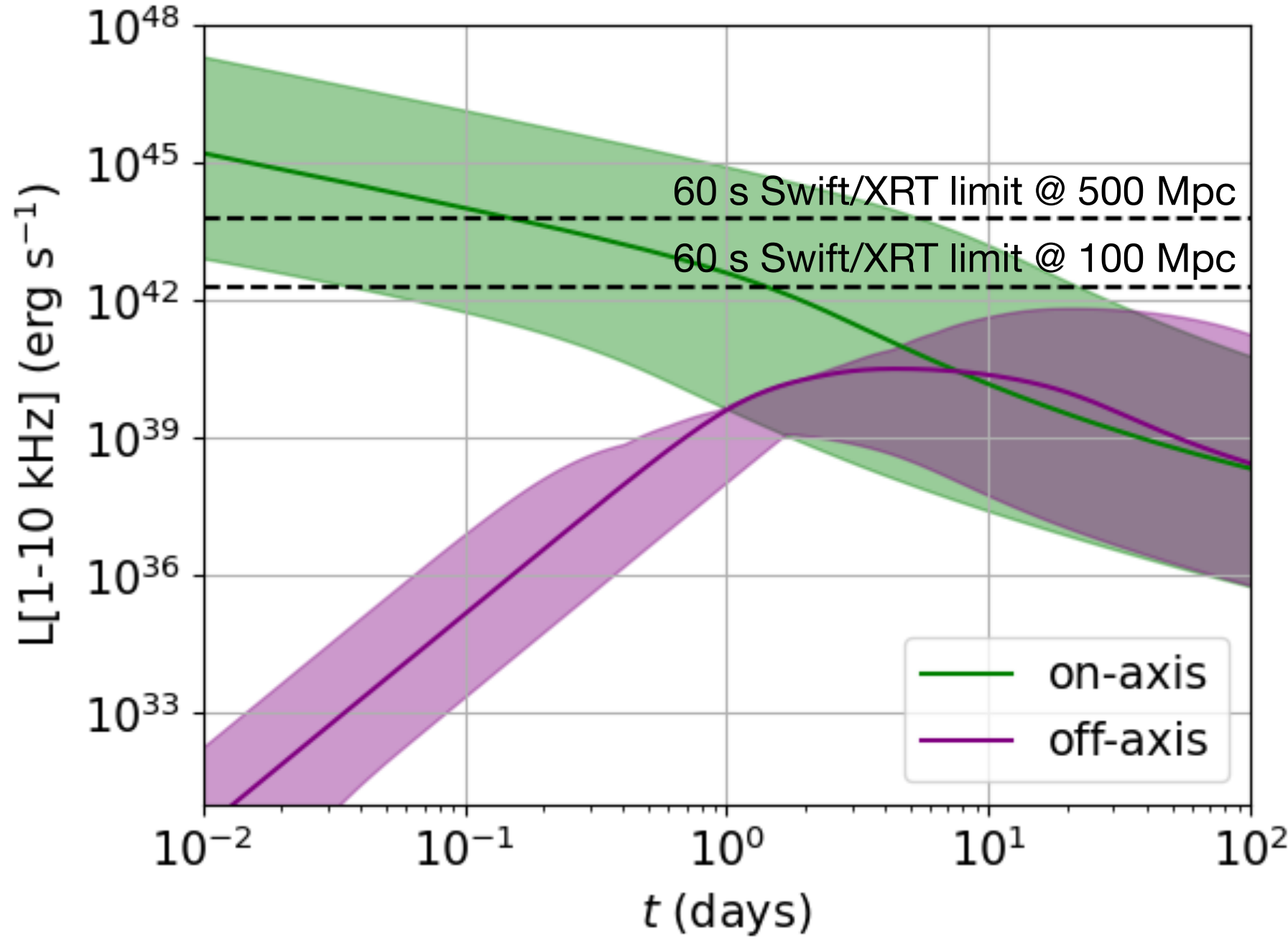| Galaxy N°	α	δ	D_L	logP (position)	logP (position + magnitude)	θ_{jn}
1						
2						
3						
4						
5						
...						

Galaxy ranking with inclination angle information

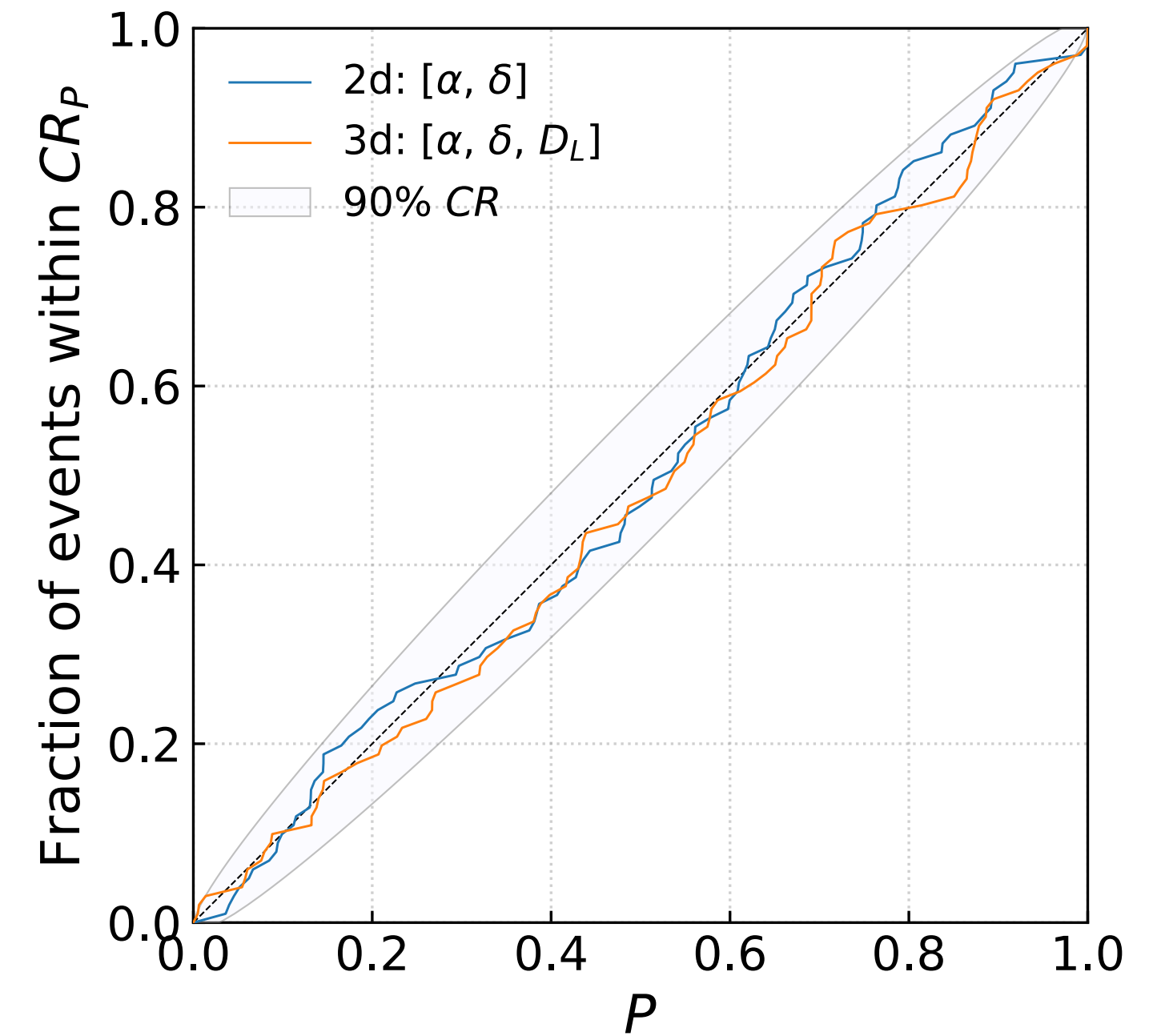| Galaxy N°	α	δ	D_L	logP (position)	logP (position + magnitude)	θ_{jn}
1						
2						
3						
4						
5						
...						

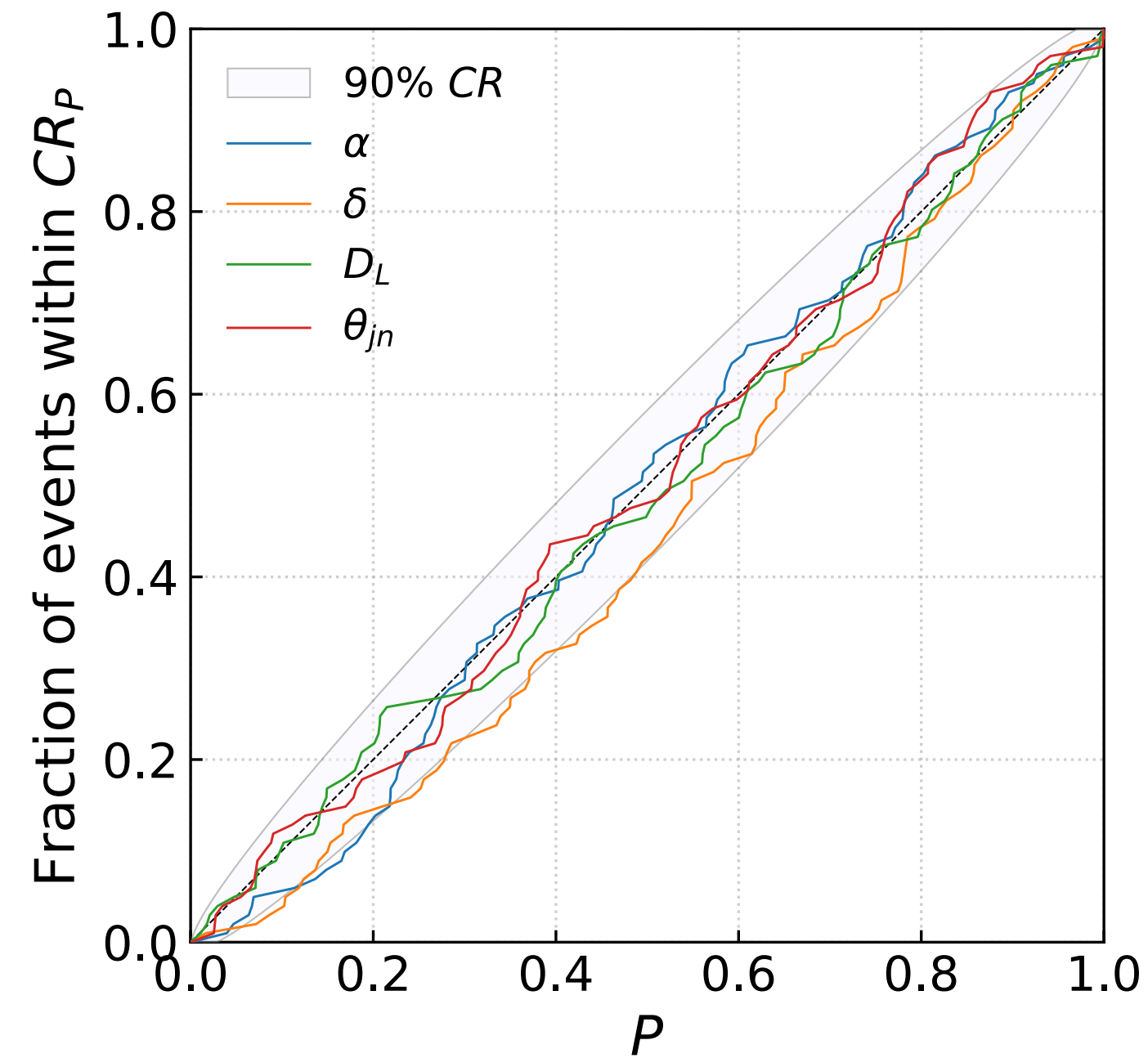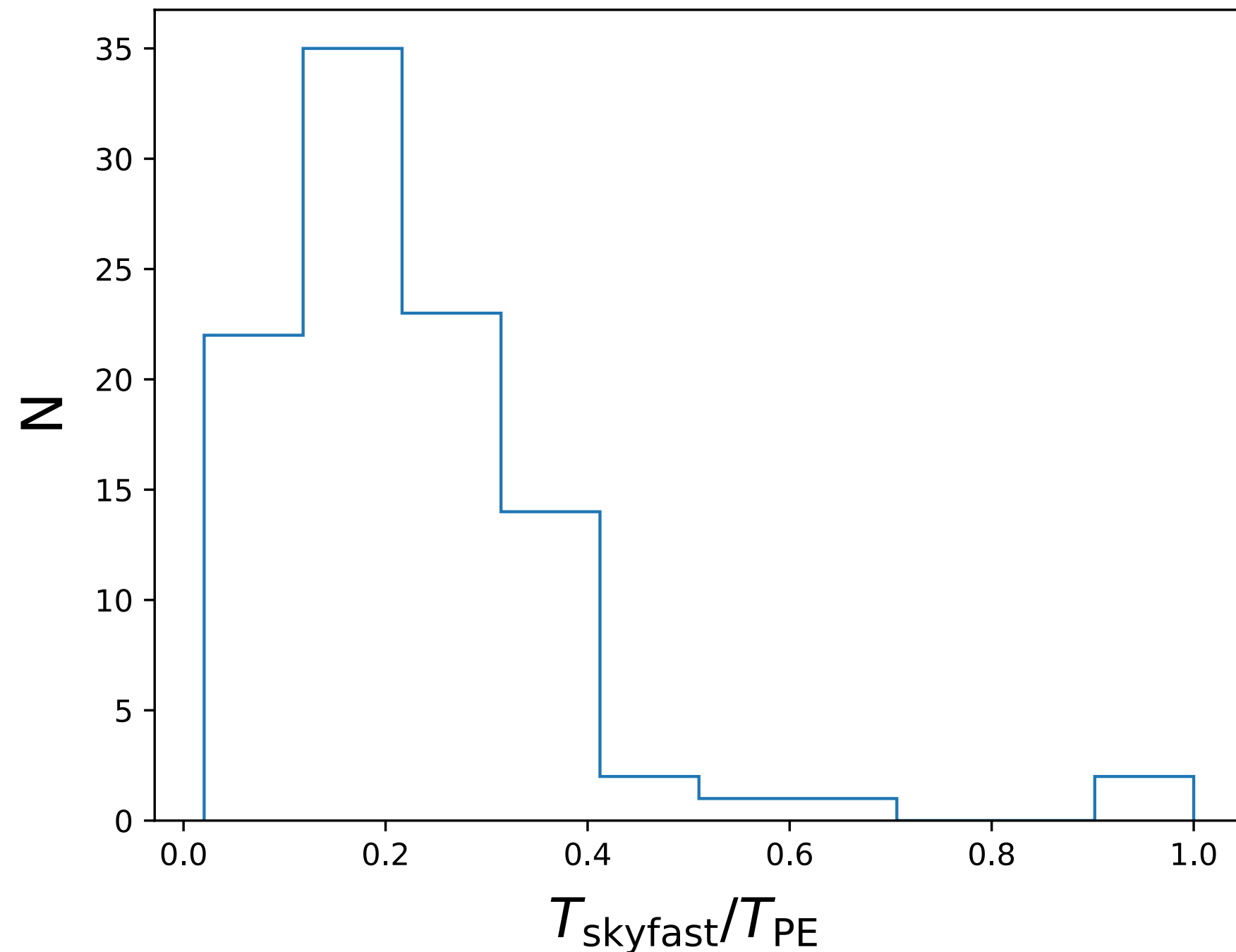Qualitative examples of GRB afterglow light-curve

Computed with **afterglowpy**, _Ryan et al 2020_
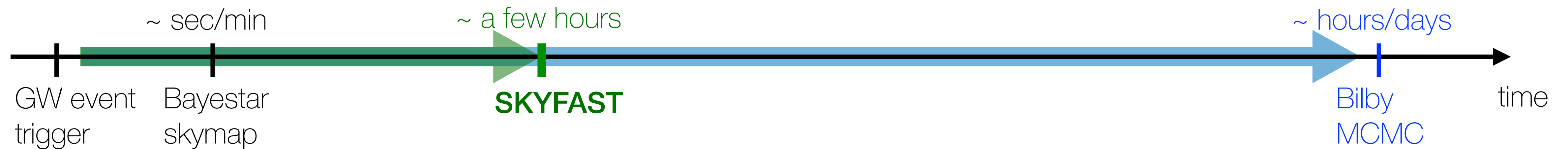
Validation on a population of 100 mock BBH events

We obtain analytical posteriors for $\{\alpha, \delta, D_L, \theta_{jn}\}$ in ~1/5 of the duration of the PE

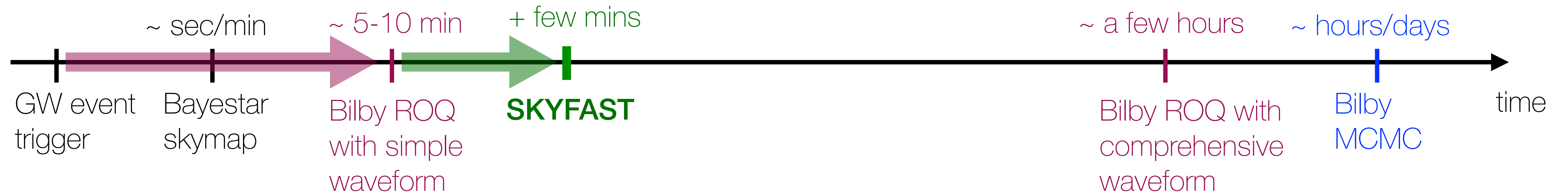The quality of the posteriors is comparable to the results of the full PE, as shown also by the pp-plots

Where does Skyfast come into play?

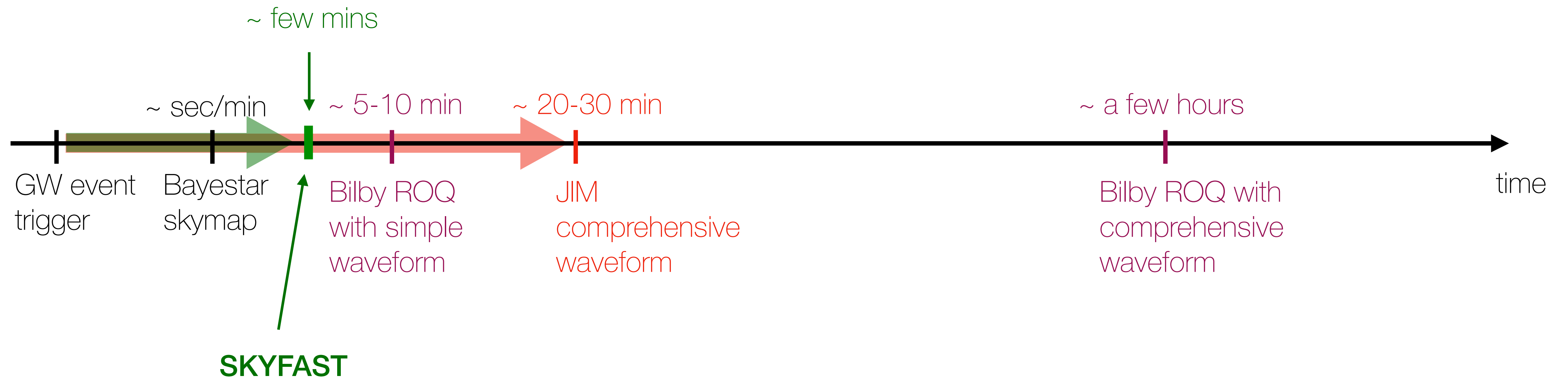- **Bilby** with standard MCMC samplers (*Ashton&Talbot, 2021*), $\sim10^2$ CPUs

Where does Skyfast come into play?

- **Bilby** with standard MCMC samplers *(Ashton&Talbot, 2021)*, ~10^2 CPUs
- **Bilby** with nested sampling and ROQ *(Morisaki et al., 2023)*, ~10^2 CPUs, used in O4

~ sec/min   ~ 5-10 min   + few mins   ~ a few hours   ~ hours/days

GW event   Bayestar   Bilby ROQ   **SKYFAST**   Bilby ROQ with   Bilby   time
trigger   skymap   with simple   comprehensive   MCMC
                              waveform   waveform

Where does Skyfast come into play?

- **Bilby** with standard MCMC samplers *(Ashton&Talbot, 2021)*, ~10^2 CPUs
- **Bilby** with nested sampling and ROQ *(Morisaki et al., 2023)*, ~10^2 CPUs, used in O4
- **JIM** with normalising flow-enhanced MCMC sampler *(Wong et al. 2023; Wouters et al., 2024)*, 1 GPU

Future perspective

Short-term:

- Release SKYFAST and present it to the community

- Refine the interface between SKYFAST and existing PE tools, so that it can be integrated in existing pipelines

Future applications of Skyfast:

- Cross-correlation of GWs with galaxy catalogs (e.g. Euclid)

- Cosmology applications, e.g. H0 constraints

Thank you!

Get in touch:

Office 63, Building C
giulia.capurri@df.unipi.it