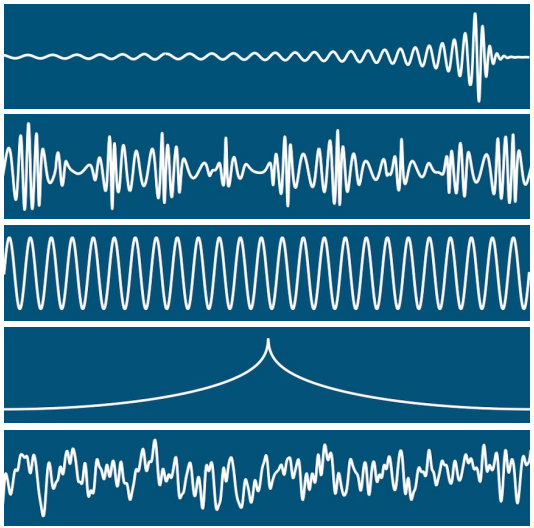
Analysing LDC submissions

Maude Le Jeune (APC), Quentin Baghi (CEA Paris-Saclay)

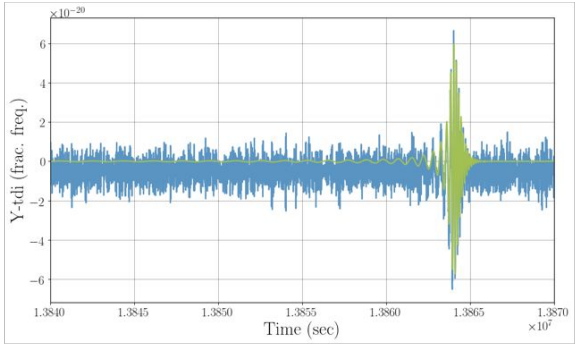


Outline

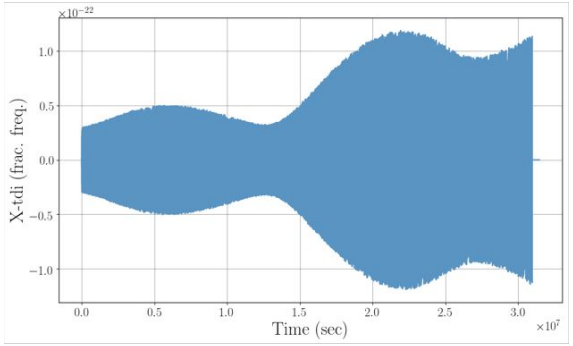
- Past challenges: Radler
- Including artefacts: Spritz
- The first enchilada: Sangria
  - Massive black hole binaries
  - Galactic binaries
  - Noise evaluation
  - Future work

Past challenges: Radler

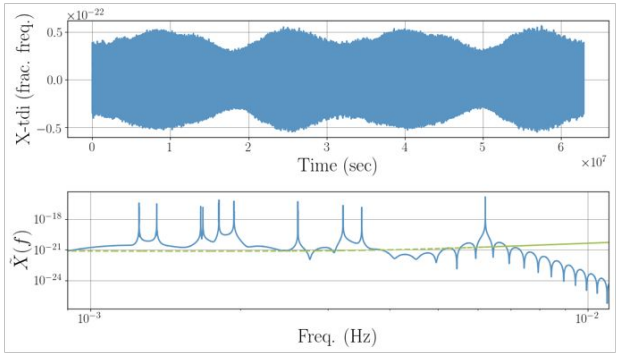
Merging MBHB



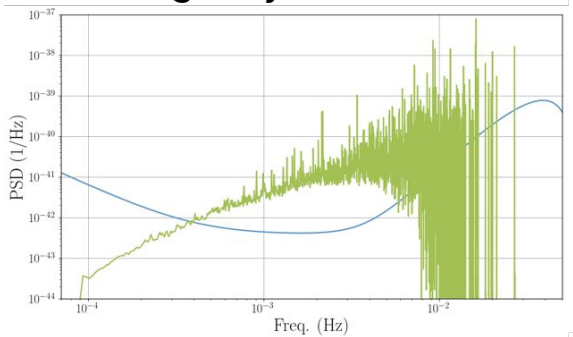
EMRI



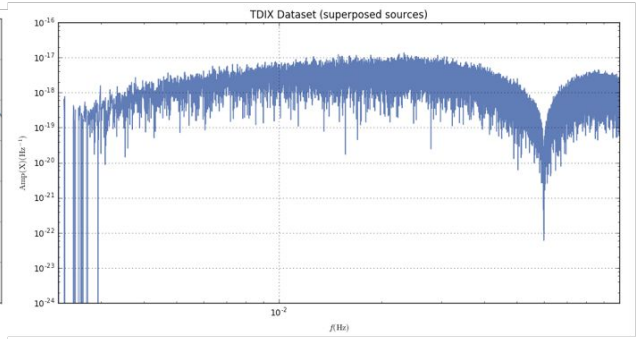
Verification Galactic binaries



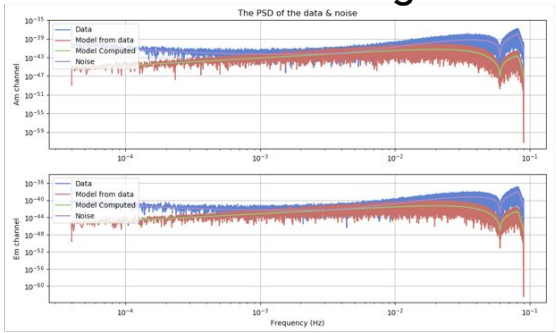
Full galaxy (WD binaries)



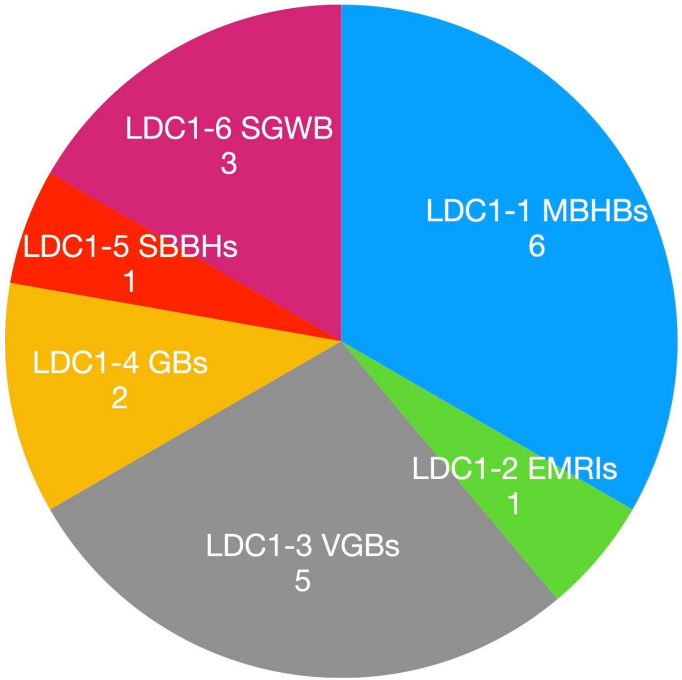
Stellar mass BH binaries



Stochastic GW background



Past challenges: Radler

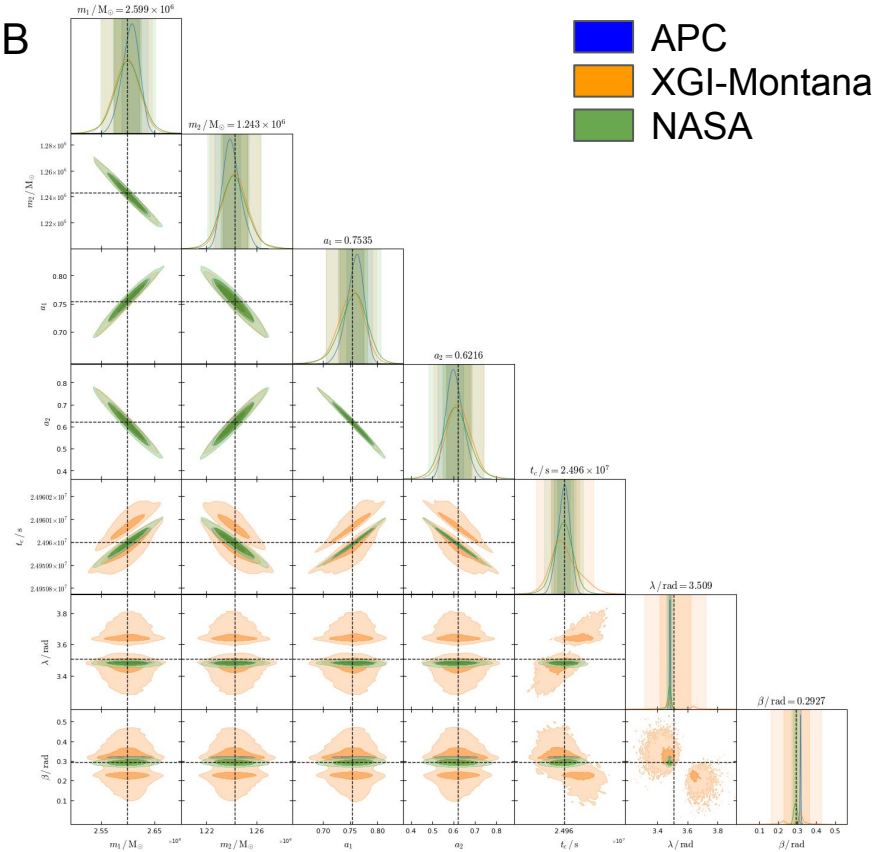


[LISA Data Challenges Living Review, in prep.]

Past challenges: Radler

LDC 1-1: Merging MBHB

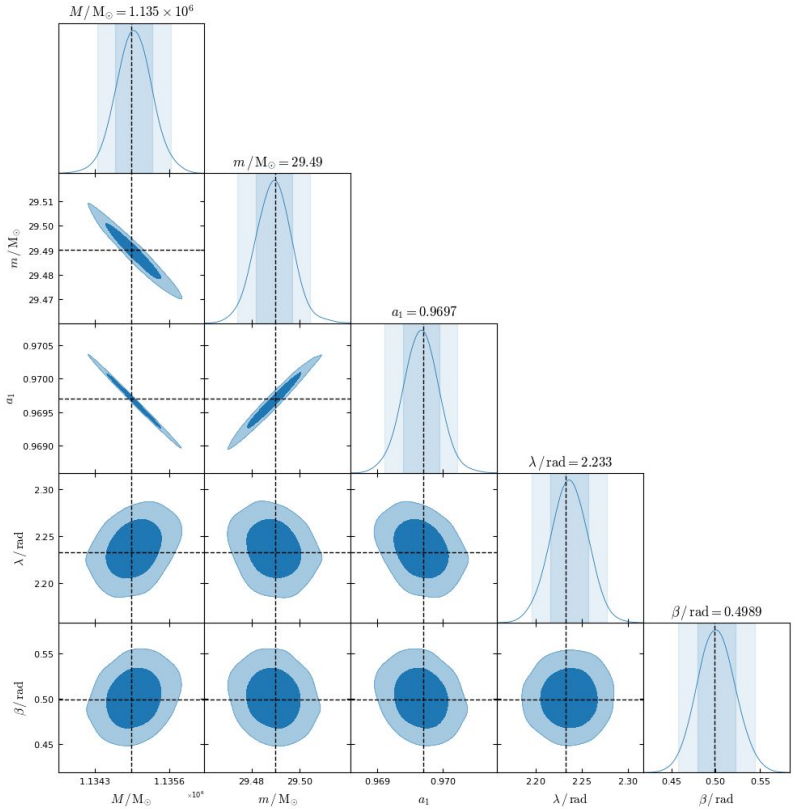
- Short, loud signal
- 6 submissions
- PTMCMC
- Narrow posteriors
- Multimodalities
- Different posterior width, but overall good recovery



Past challenges: Radler

LDC 1-2: EMRI

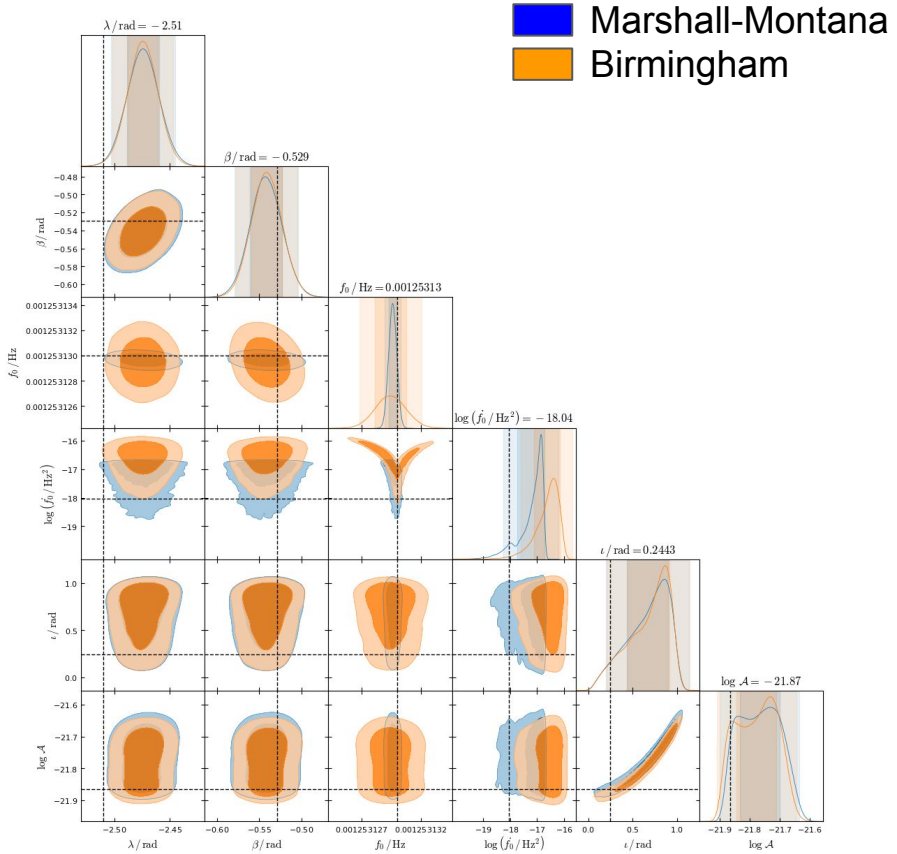
- Augmented analytic kludge waveform
- One submission: Katz & Chua
- GPU accelerated
- Affine-invariant MCMC
- No search phase, start MCMC from injected parameter values
- Excellent agreement with injection



Past challenges: Radler

LDC 1-3: VGBs

- 5 submissions
  - Marshall-Montana: RJMCMC
  - Birmingham: nested sampling
  - Barcelona: PTMCMC
  - CEA: non-parmametric maximum likelihood
  - ETH: parametric maximum likelihood estimate + MCMC
- Different priors used
- No confusion



Past challenges: Radler

LDC 1-4: Galaxy

- 3 submissions
- Marshall-Montana:
  - RJMCMC
  - Demonstration on band 3.98 - 4.12 mHz, split in 3
  - Time-evolving solution 1.5, 3, 6, 12 months
- APC:
  - Band 1.5 - 11.5 mHz
  - Grid search using F-statistics
  - PTMCMC for parameter estimation
- ETH:
  - Band 0.3 - 33.3 mHz
  - Spit in windows of 1μHz
  - MLE + MCMC

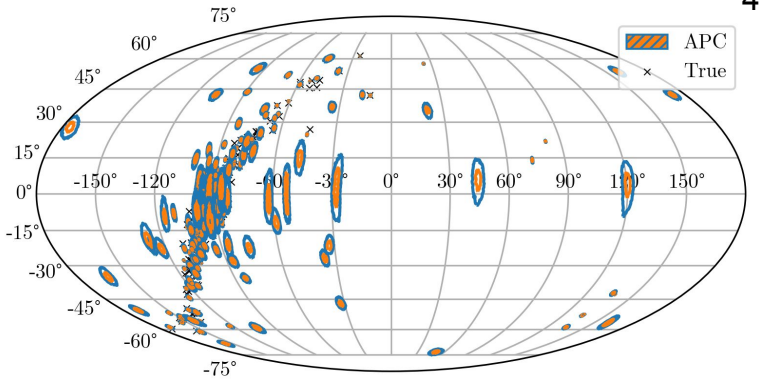
Past challenges: Radler

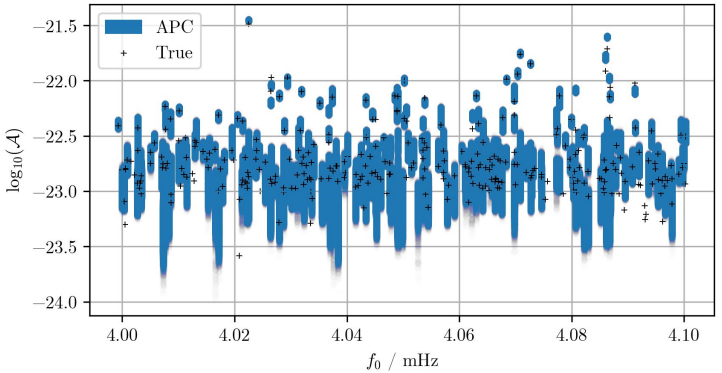
LDC 1-4: Galaxy

Algorithm	T_{obs} [yr]	Injected ($\mathrm{SNR}_{\mathrm{opt}} > 10$)	Submitted	Matched	Match rate
MM	2	57	63	54	0.86
APC	2	246	292	218	0.75
MM	0.5	6813	6145	3818	0.62
ETH	0.5	6813	7995	4489	0.56
MM	1	11 814	10 027	6844	0.68
ETH	1	11 814	13 077	7830	0.60
ETH	2	18 332	18 901	12 491	0.66

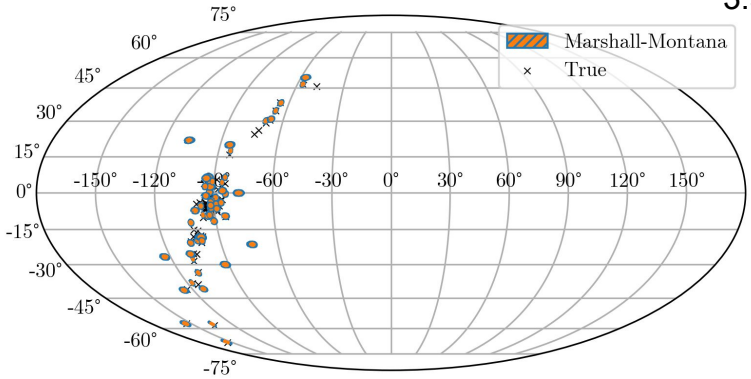
Past challenges: Radler

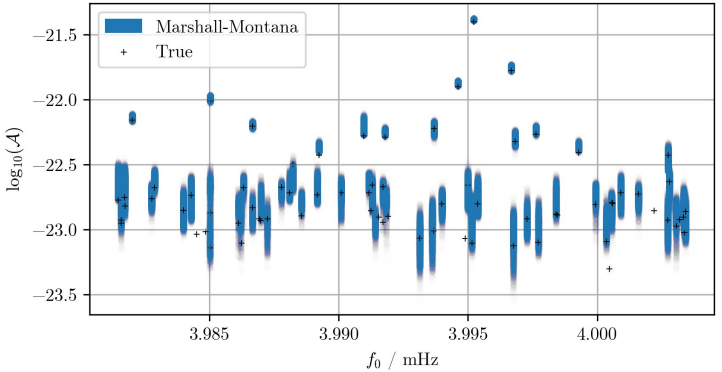
4 – 4.10 mHz



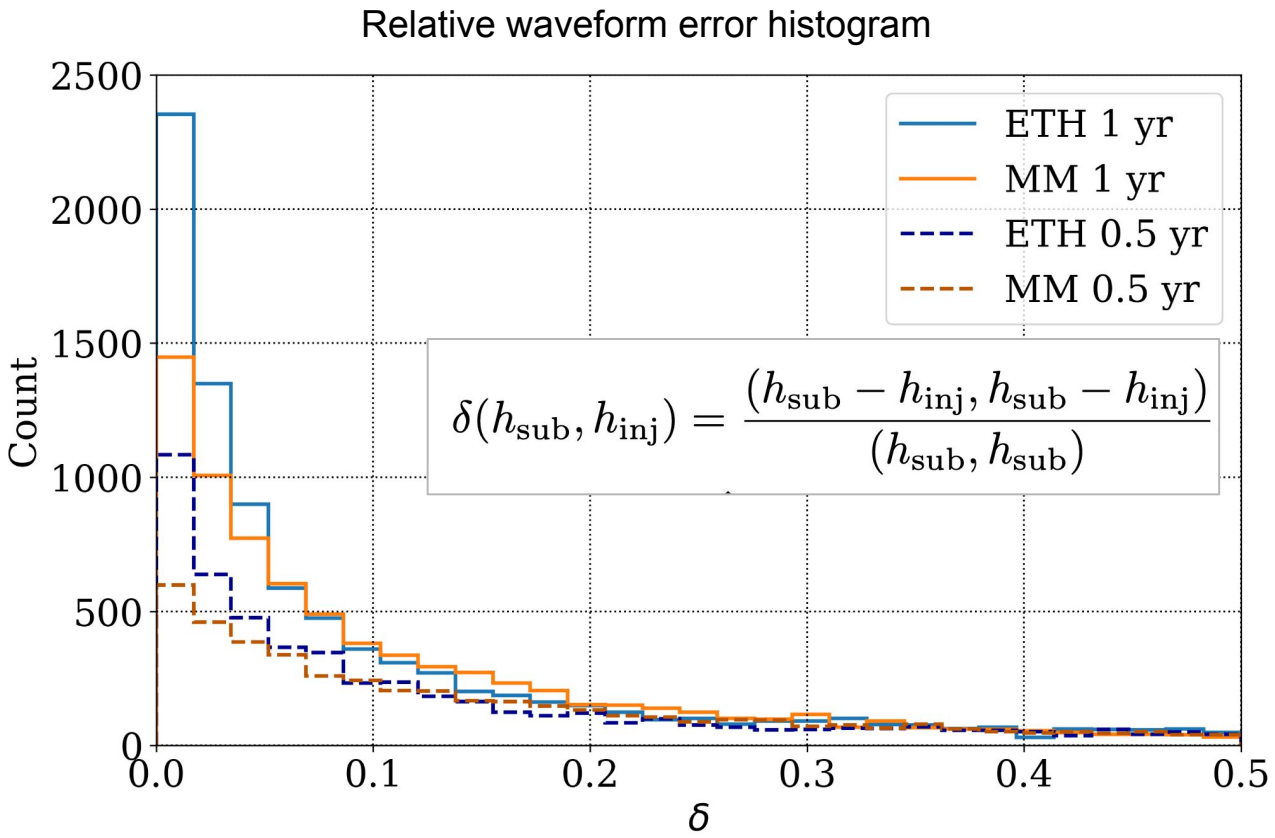


3.98 – 4.12 mHz

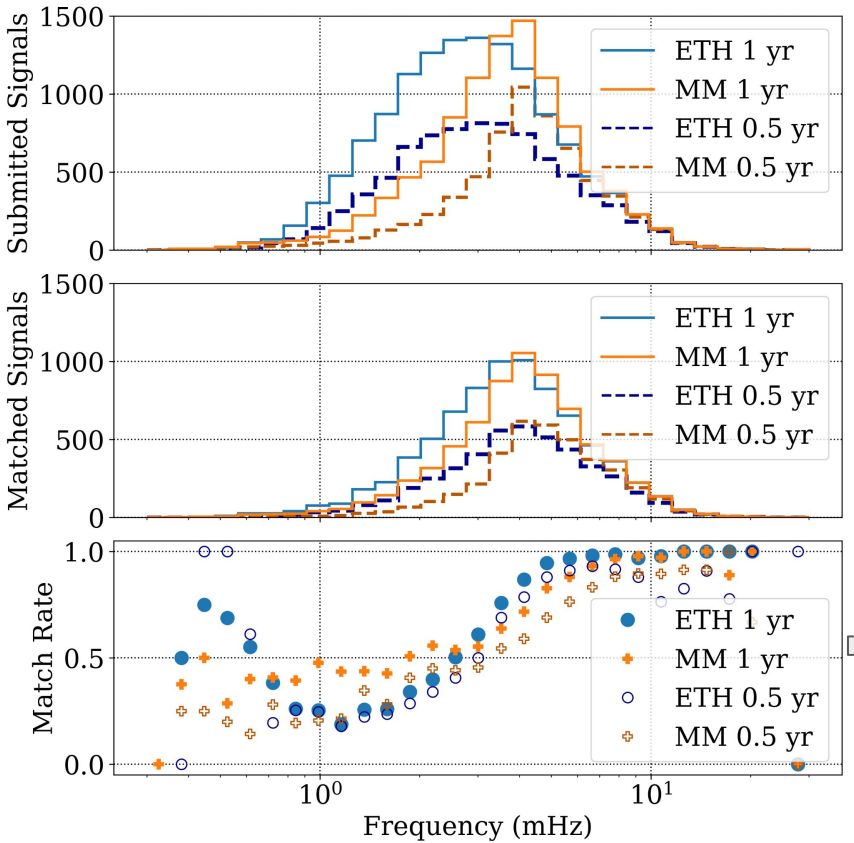




Past challenges: Radler



Past challenges: Radler

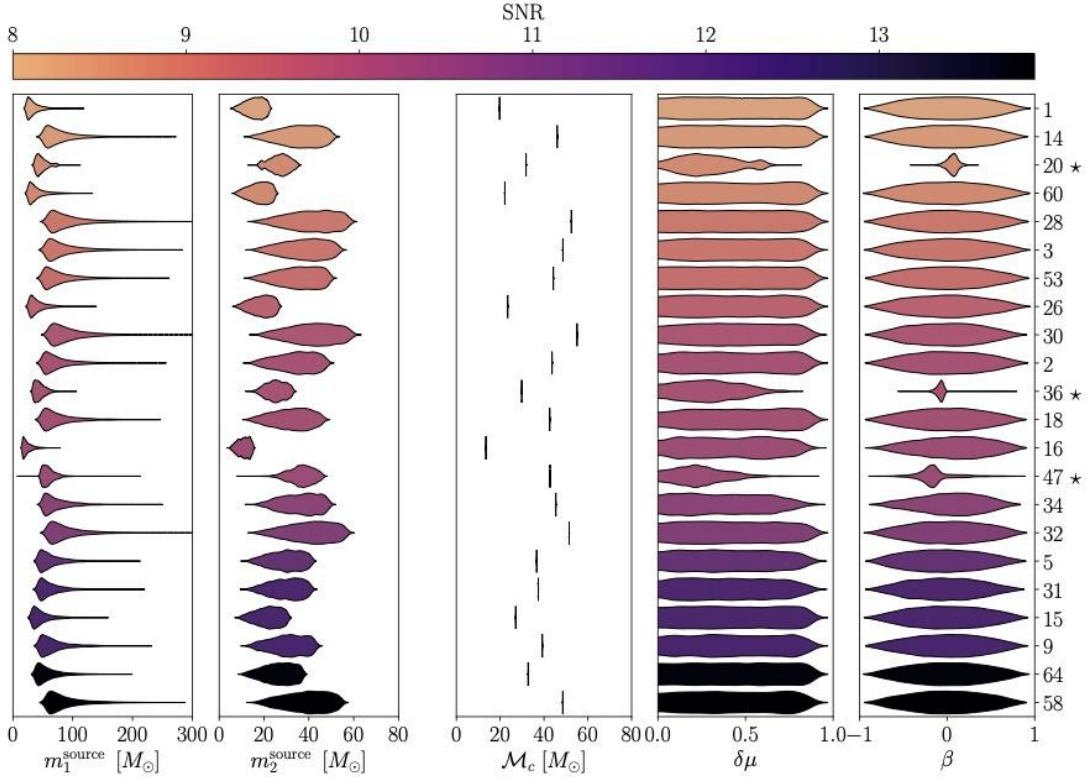


$$\frac{\text{\# Matched signals}}{\text{\# Detected signals}}$$

Past challenges: Radler

LDC 1-5: Stellar-mass BHBs

- 1 submission: Birmingham
- 66 brights SMBHBs
- 22 sources with SNR > 8
- Large parameter space in general!
- Not fully blind: priors assume first detection
- Nested sampling
- TaylorF2 3.5 PN waveform

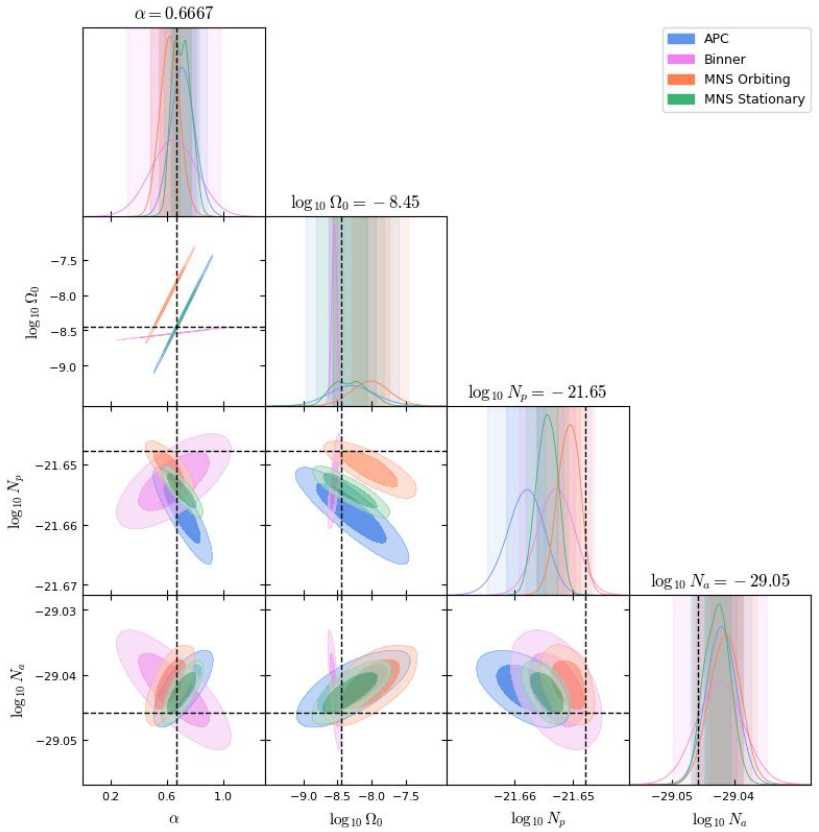


[Buscicchio et al., 2021]

Past challenges: Radler

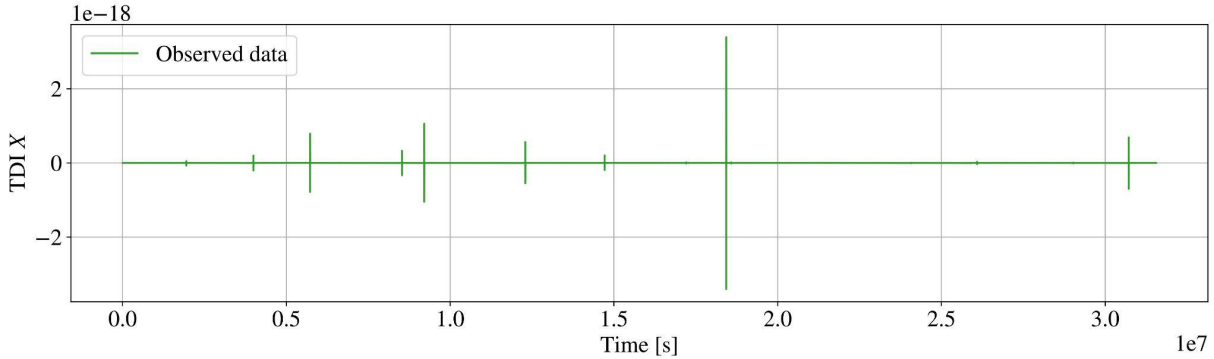
LDC 1-6: Stochastic GW background

- Isotropic, stationary power-law injection
- 3 submissions
- APC (Nikos Karnesis)
  - Welch periodogram averaging
  - Template-based
  - Adaptive MCMC
- SGWBinner (Flauger et al.)
  - Model-independent reconstruction of the signal PSD
  - Parametric noise model
- Minnesota (Banagiri et al.)
  - Nested sampling
  - Template-based

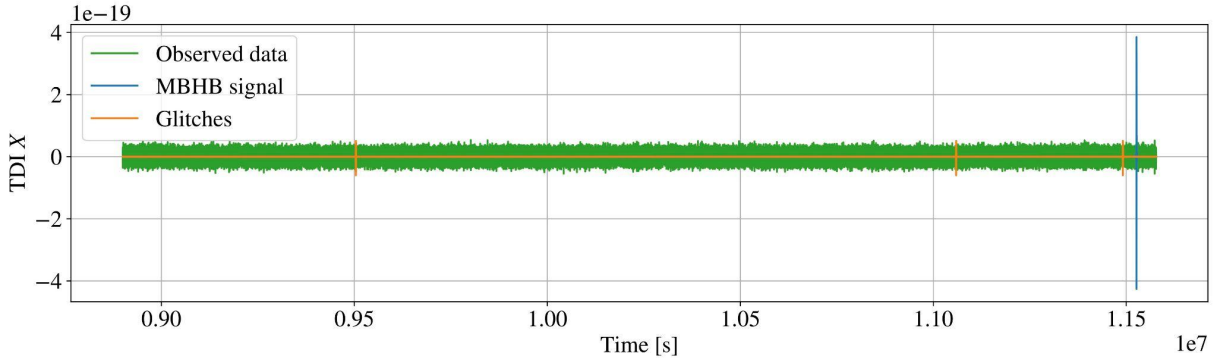


Including artefacts: Spritz

LDC 2b VGBs: LPF-like glitches (4/day) + gaps + 36 verification Galactic binaries



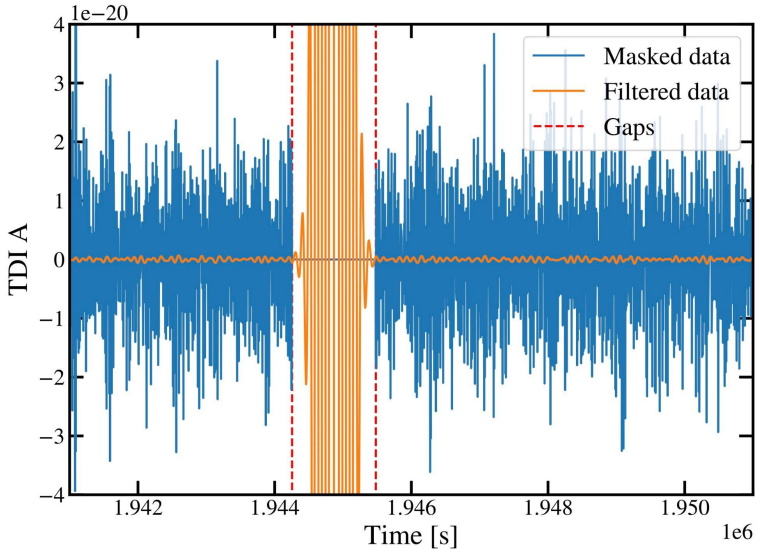
LDC 2b MBHB-1: 3 short loud glitches + gaps + MBHB



Including artefacts: Spritz

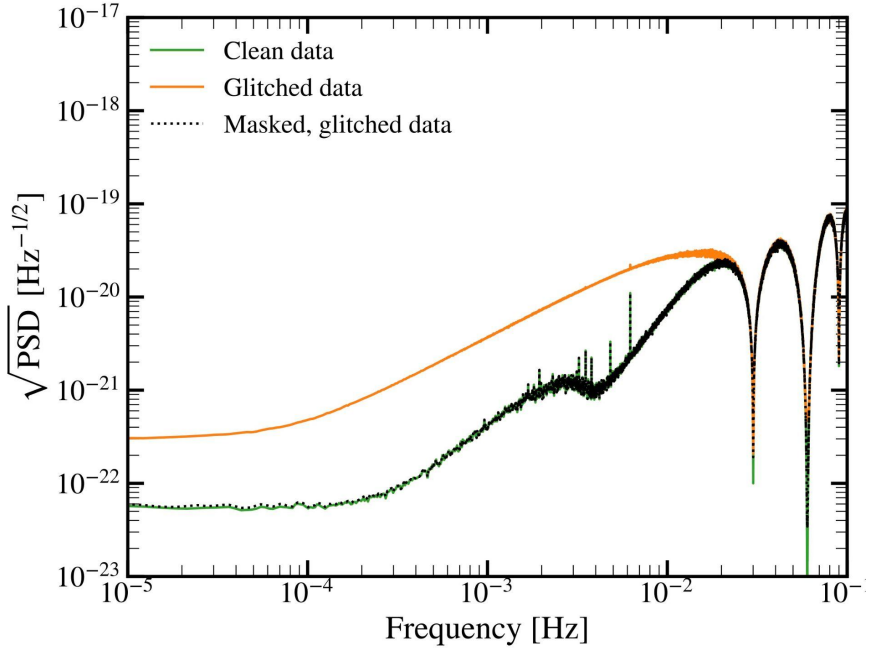
LDC 2b

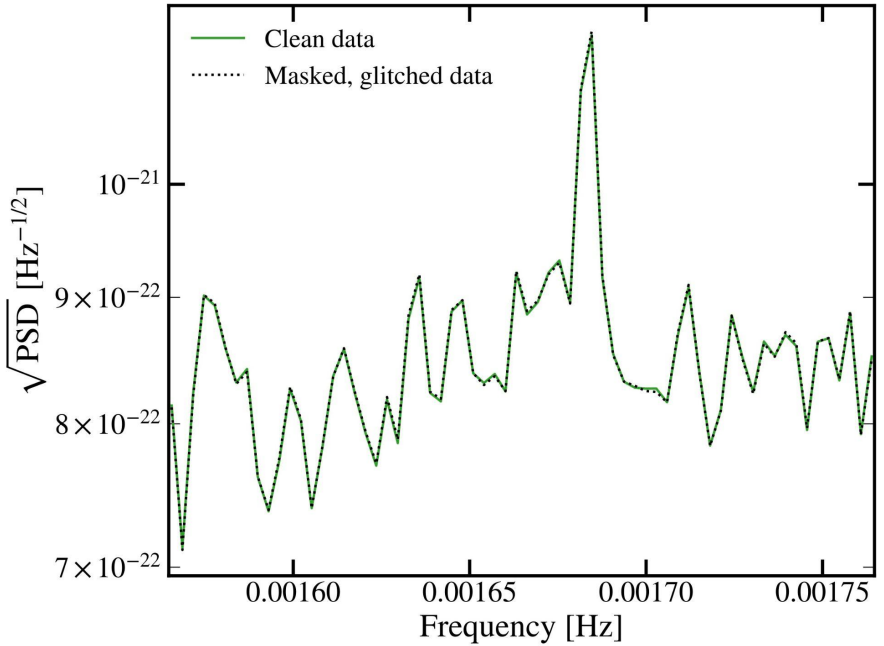
- Analysis as part of FMT tasks
- Three-stage strategy:
  a. Detection of power excesses in filtered TDI data
  b. Construction of a smoothed mask (gapping)
  c. Parameter estimation on Fourier-transformed windowed data
- We distinguish between impact of glitches and gaps



Including artefacts: Spritz

LDC 2b VGBs: impact of glitches

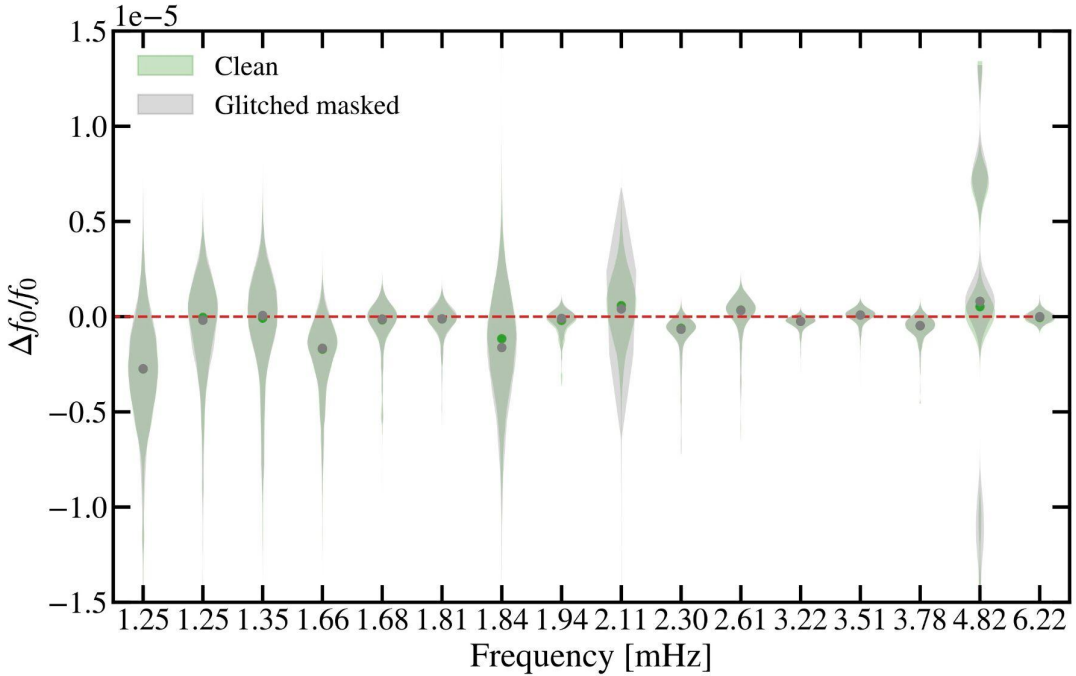




Including artefacts: Spritz

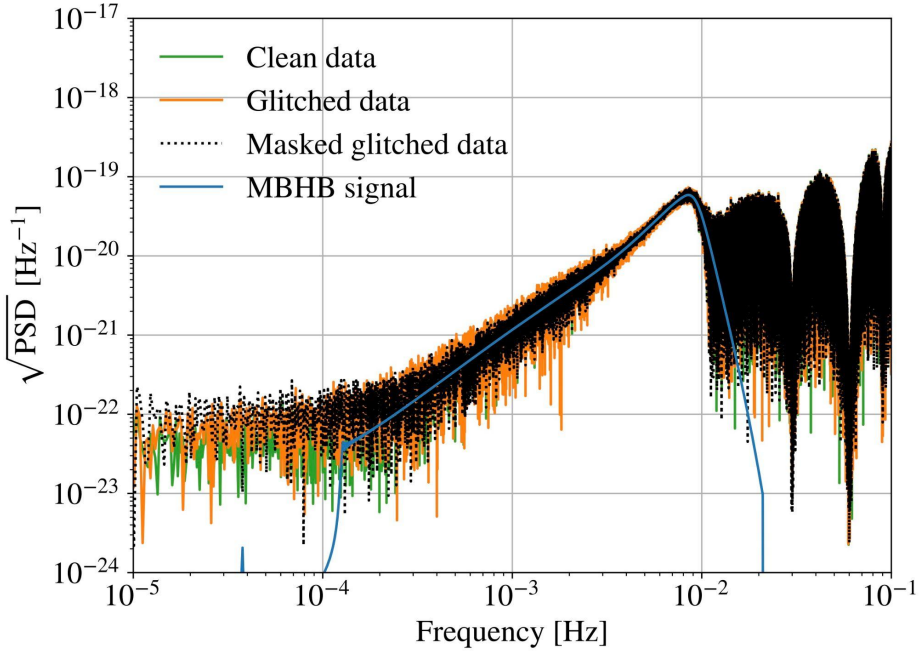
LDC 2b VGBs: impact of glitches

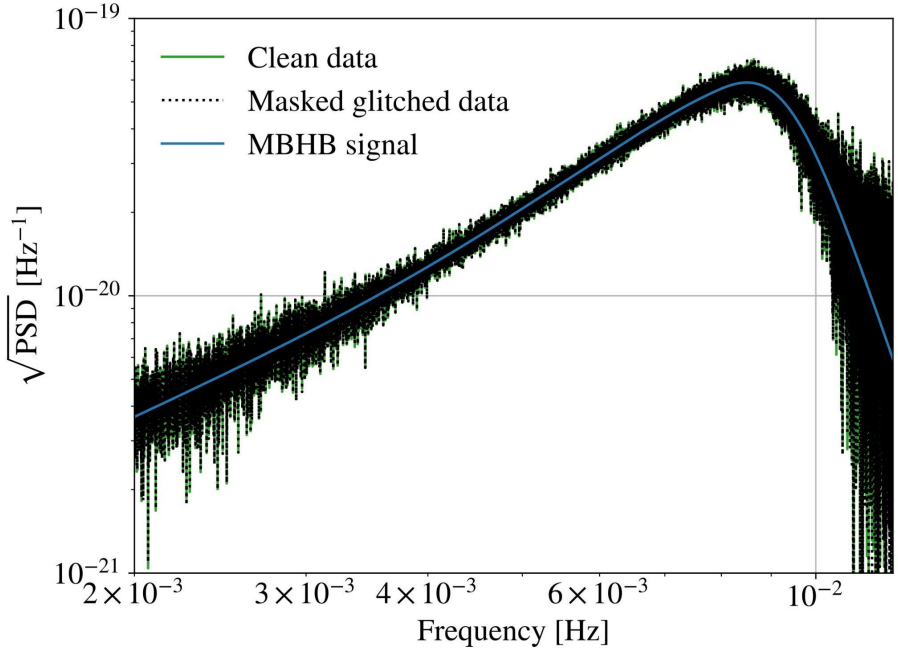
- Impact of glitches on VGB parameter estimation is mild with adapted masking



Including artefacts: Spritz

LDC 2b MBHB-1: impact of glitches

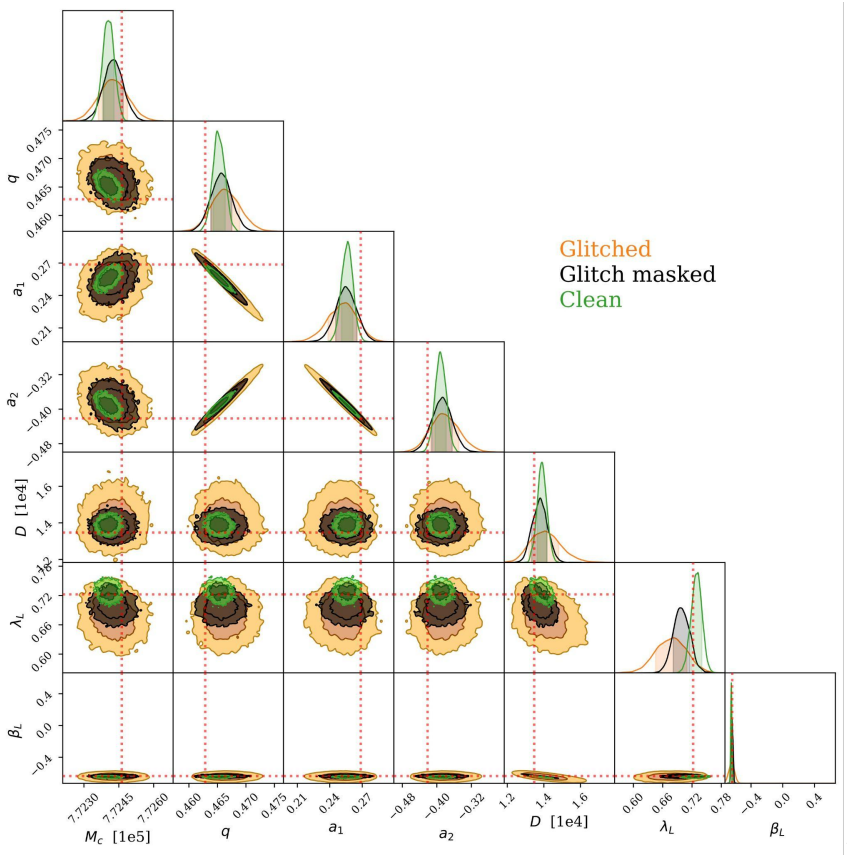




Including artefacts: Spritz

LDC 2b MBHB-1: impact of glitches

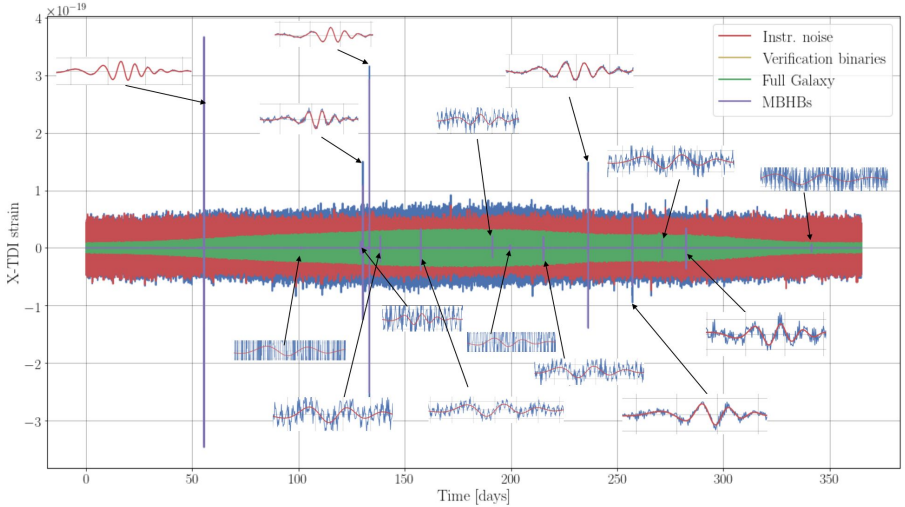
- Glitches affect the parameter estimation
  a. Posterior widening
  b. Parameter biases
- Glitch masking mitigates this impact
- Not at the level of clean data
- Glitch modeling needed for PE refinement

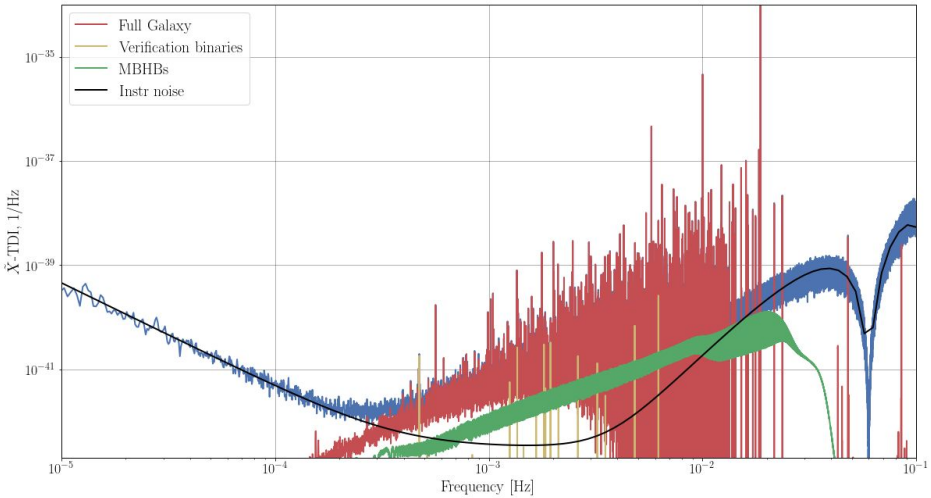


The first enchilada: Sangria

LDC 2a: Sangria

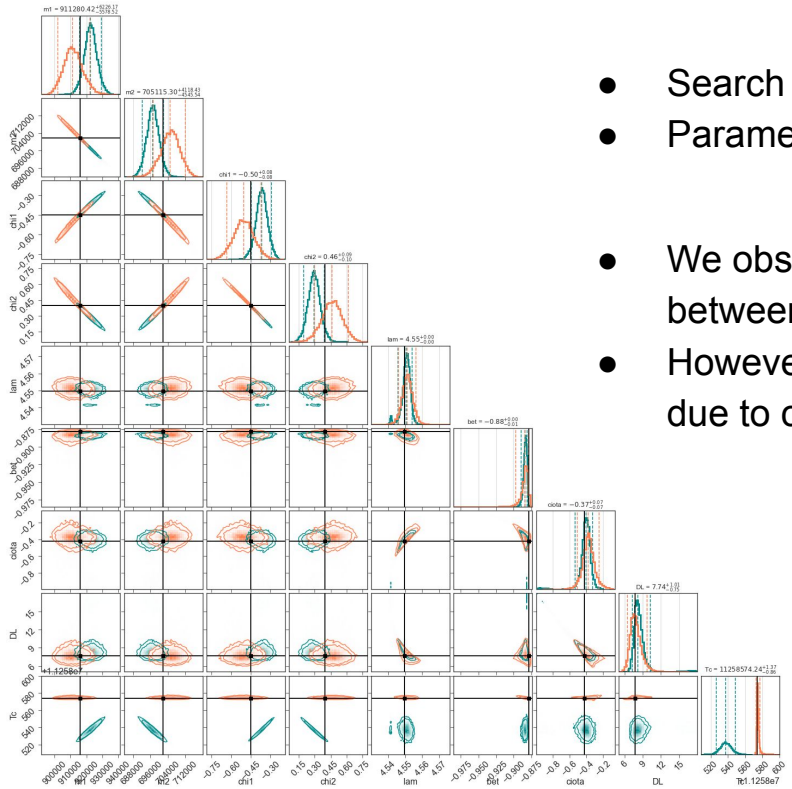
- Mixing of 2 source types:
  - Galaxy: 3 x 10^7 compact binaries
  - MBHBs: 15 mergers drawn from an astrophysical population





The first enchilada: Sangria

LDC 2a: Sangria / MBHBs



- Search phase with maximized likelihood (F-statistics)
- Parameter estimation phase (PTMCMC)

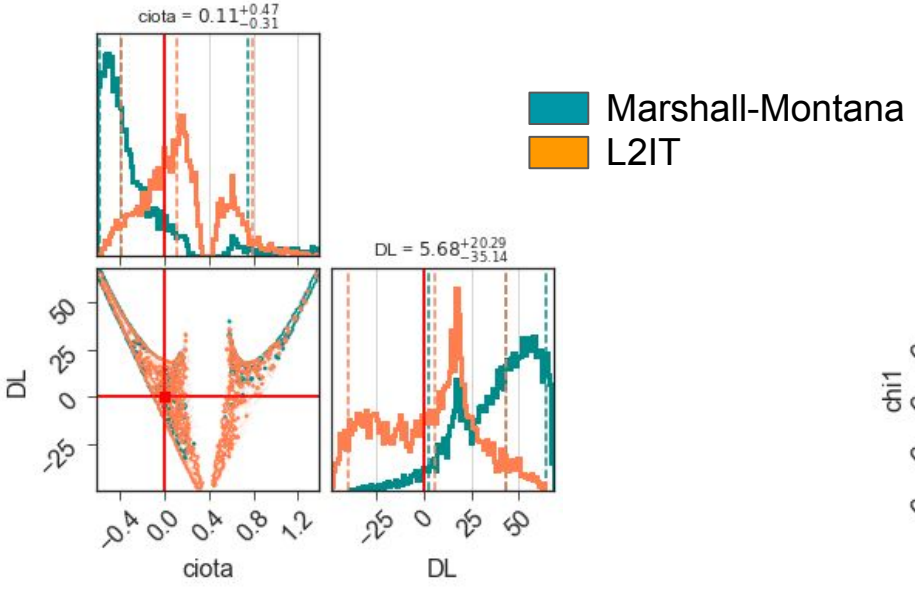
- We observe general consistency between injection and between submissions
- However different distributions for merger time, probably due to convention difference

Marshall-Montana
L2IT

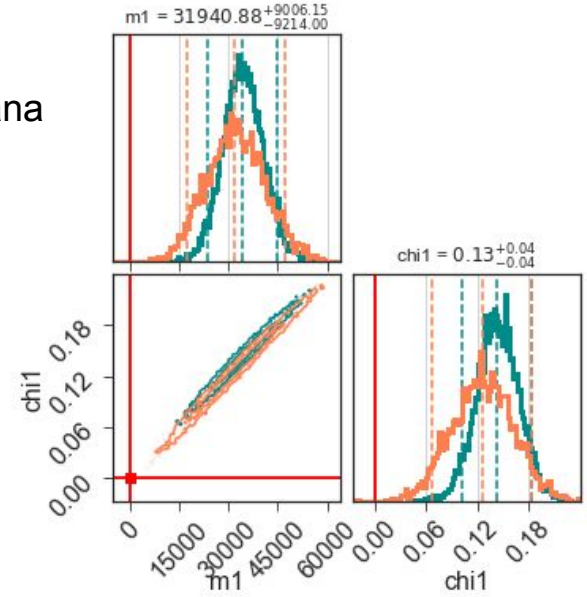
The first enchilada: Sangria

LDC 2a: Sangria / MBHBs

- Observed differences in submitted posteriors: example of inclination - luminosity distance
- Apparent bias observed for one source, common to both submissions



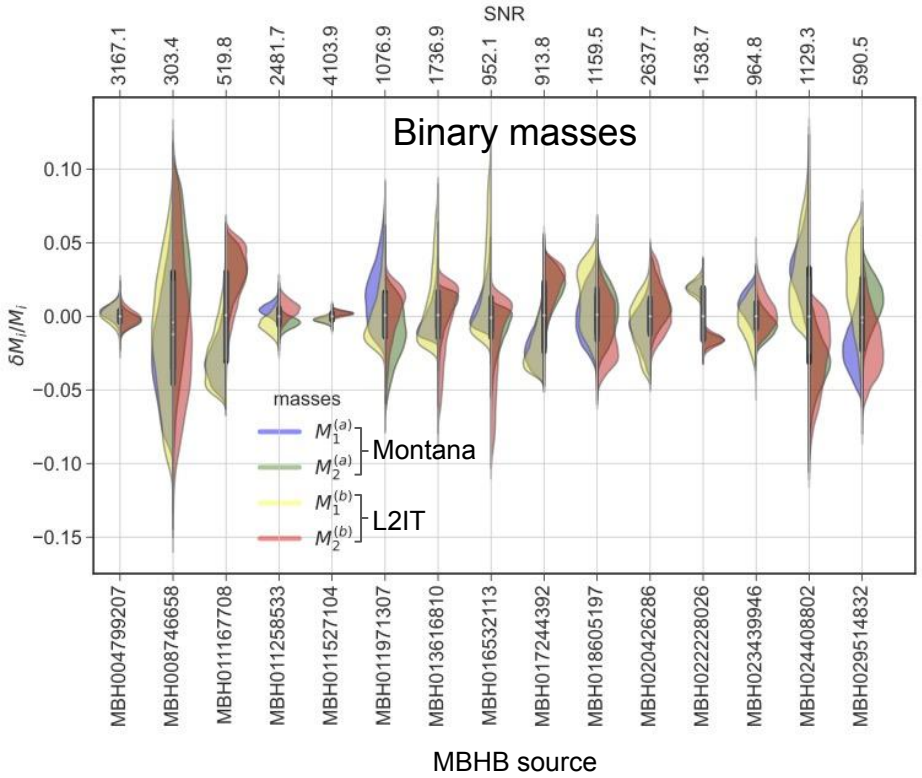
MBH008746626

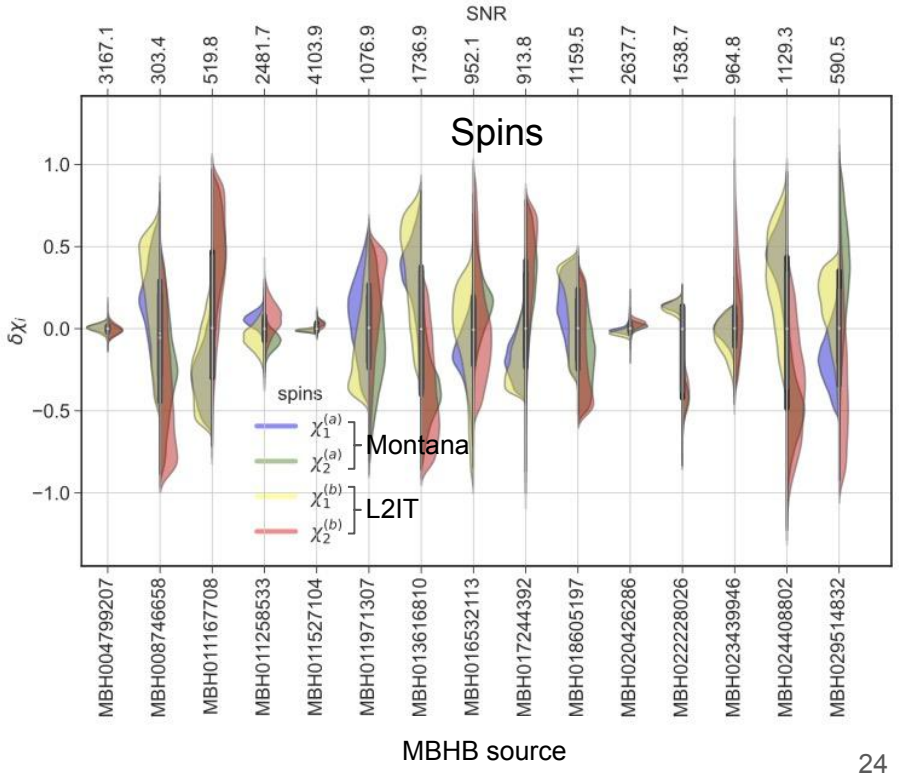


MBH011971300

The first enchilada: Sangria

LDC 2a: Sangria / MBHBs





Analysing LDC submissions part 2

- Galactic binary (GB) evaluation
- Noise evaluation
- Future work

GB submission files

catalog as yml file

```
author: Stefan Strub
challenge: LDC2a
dataset: LDC2_sangria_training_v2
date: 2022/11/2
e-mail: stefan.strub@erdw.ethz.ch
estimates:
- Amplitude: 2.4139956940282333e-21
  EclipticLatitude: -0.5816118460861086
  EclipticLongitude: -3.0398597982332327
  Frequency: 0.30188060419584795
  FrequencyDerivative: -1.876617233921759e-21
  Inclination: 1.9989482053081973
  InitialPhase: 2.0187633871795843
  IntrinsicSNR: 9.42426286925173
  Polarization: 1.228561264749977
- Amplitude: 2.0486561986115623e-21
  EclipticLatitude: -0.852987516590376 3
  EclipticLongitude: 0.7521573347125161
  Frequency: 0.38061513124450075
  FrequencyDerivative: -7.581036996115868e-21
  Inclination: 1.6227758173665354
  InitialPhase: 3.299988284939258
  IntrinsicSNR: 9.686838218322078
  Polarization: 1.5669237767752373
- Amplitude: 1.752610872559127e-21
  EclipticLatitude: -0.23524916700880735
  EclipticLongitude: -3.075656178872085
  Frequency: 0.3872336242617268
  FrequencyDerivative: 2.5054488622650847e-19
  Inclination: 1.834128044674326
  InitialPhase: 3.8896488984230126
  IntrinsicSNR: 10.85837949355127
```

posterior tables : N_{sample} x (N_{param} x N_{source})

	Amplitude_5482	Frequency_5482	FrequencyDerivative_5482	EclipticLatitude_5482	EclipticLongitude_5482
0	-22.487192	4.000346	-5.296830e-16	0.269702	4.794506
1	-22.487192	4.000346	-5.296830e-16	0.269702	4.794506
2	-22.487192	4.000346	-5.296830e-16	0.269702	4.794506
3	-22.433159	4.000357	-1.393717e-15	0.151787	4.845192
4	-22.487192	4.000346	-5.355117e-16	0.269702	4.794506
5	-22.433159	4.000357	-1.393717e-15	0.151787	4.845192
6	-22.487192	4.000346	-5.336256e-16	0.269702	4.794506
7	-22.487192	4.000346	-5.336256e-16	0.269702	4.794506
8	-22.433159	4.000357	-1.393717e-15	0.151787	4.845192
9	-22.487192	4.000346	-5.651451e-16	0.269702	4.794506

GB: best estimate comparisons

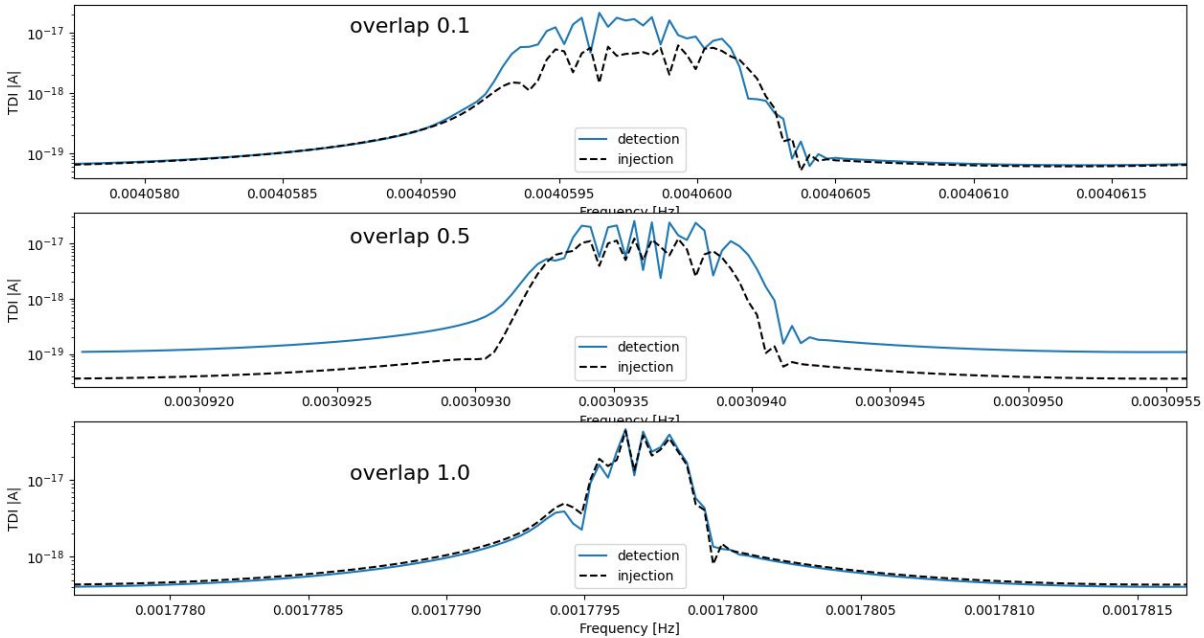
provided that we have

- a fast waveform
- a noise estimate

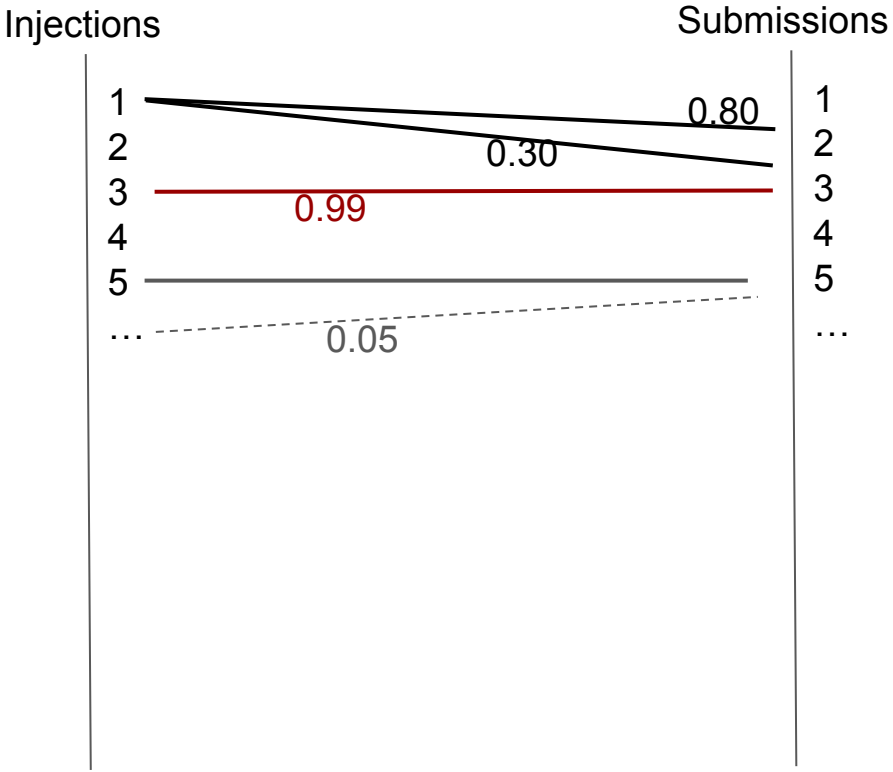
overlap or correlation

$$c = \frac{(h_1|h_2)}{\sqrt{(h_1|h_1)(h_2|h_2)}}$$

$$(d|h) = 4\Re \sum \frac{\tilde{d}(f)\tilde{h}(f)^*}{S_n(f)}$$



Matching GB catalogs



- injections well identified and true positive
  - at least one match with overlap > 0.9
- injections not found and false positive
  - no match with overlap > 0.1
- partial match
  - 0.1 < overlap < 0.9
- multiple match
- low match

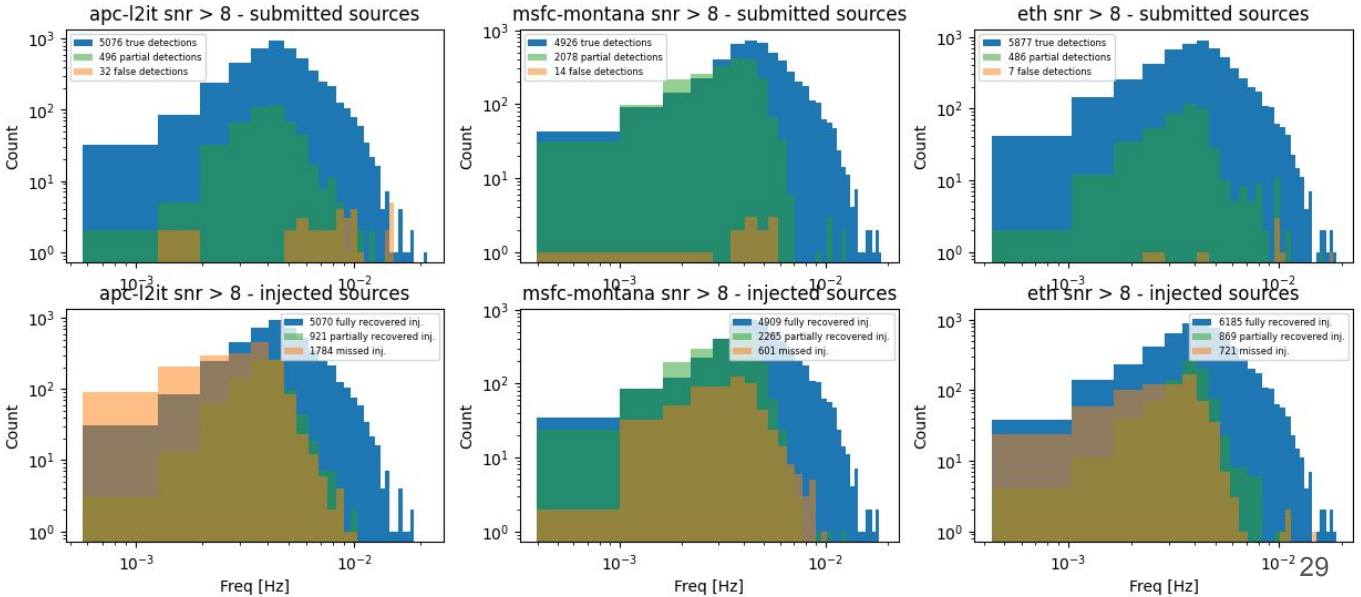
Sangria preliminary counts

- Injections with SNR > 8 : ~7800 (1 year of data)
- Well recovered : 5000 to 6000
- Missed: ~650
- Partially recovered: 1000 to 2000 (**up to 25%**)
- False positive:

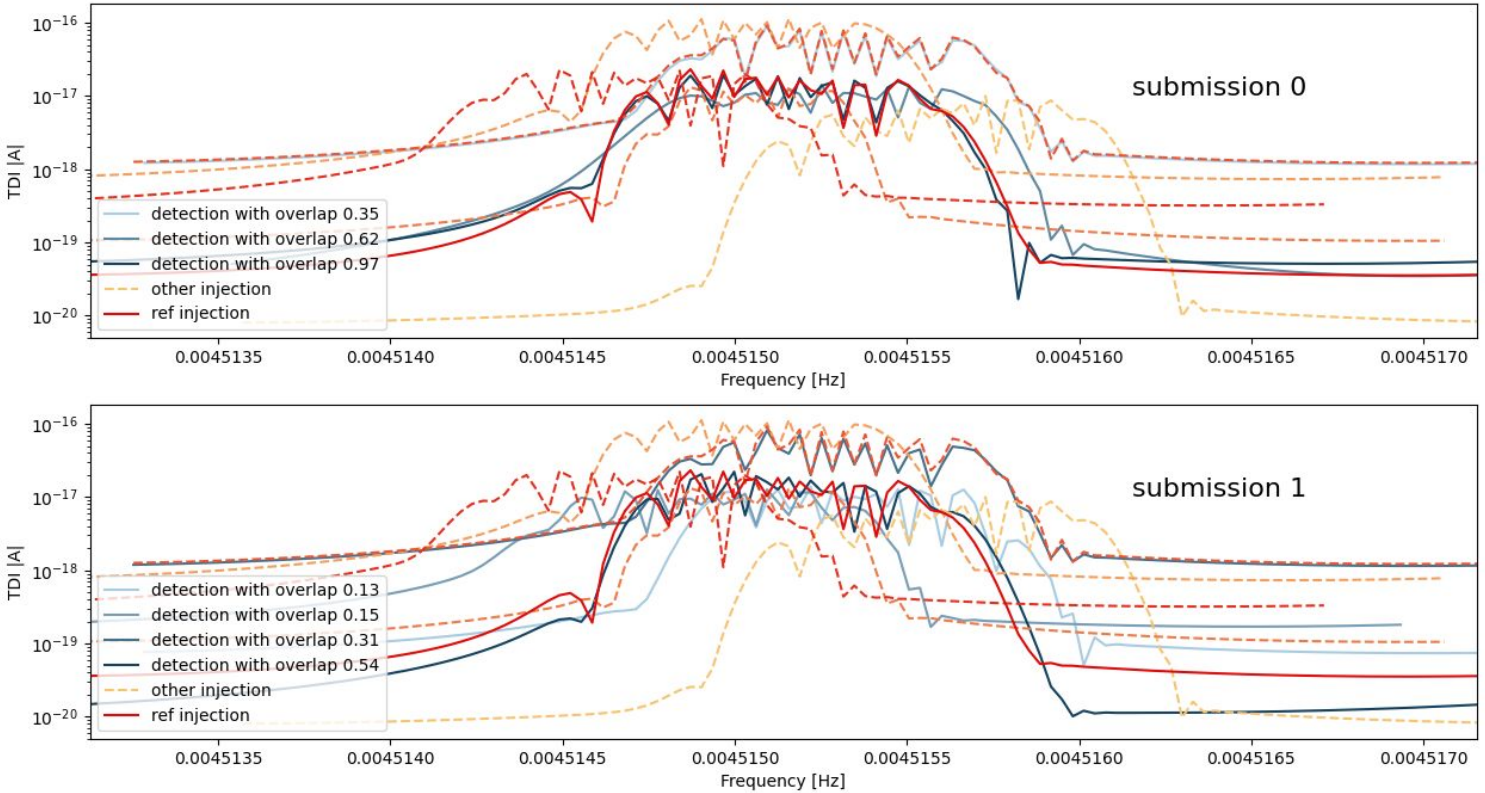
  5 to 30

- Confused region

  1 to 5 mHz

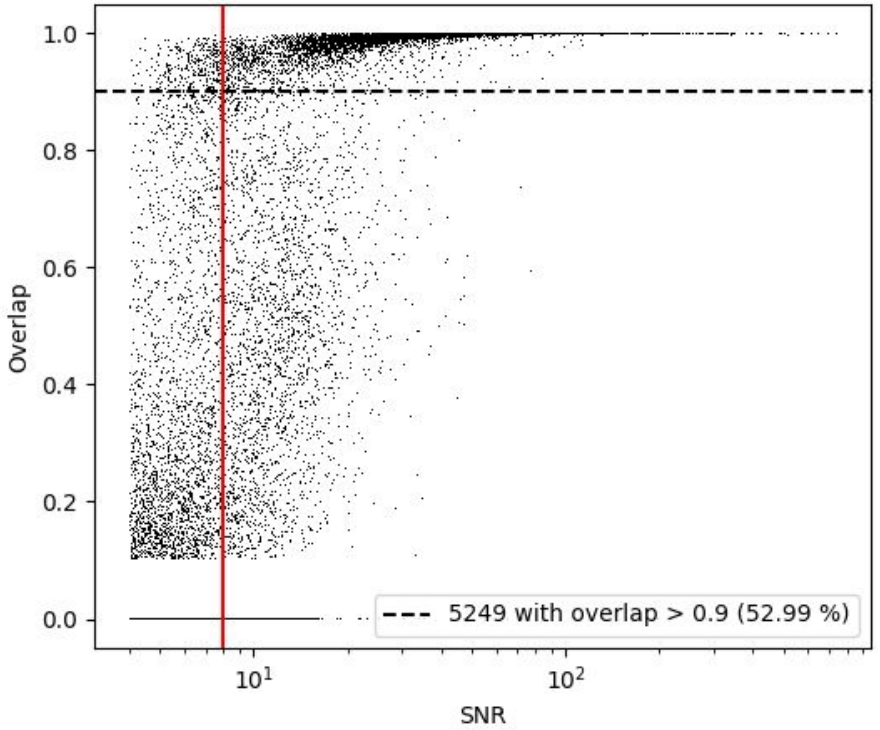


An example of ambiguous match



Tuning the purity a posteriori

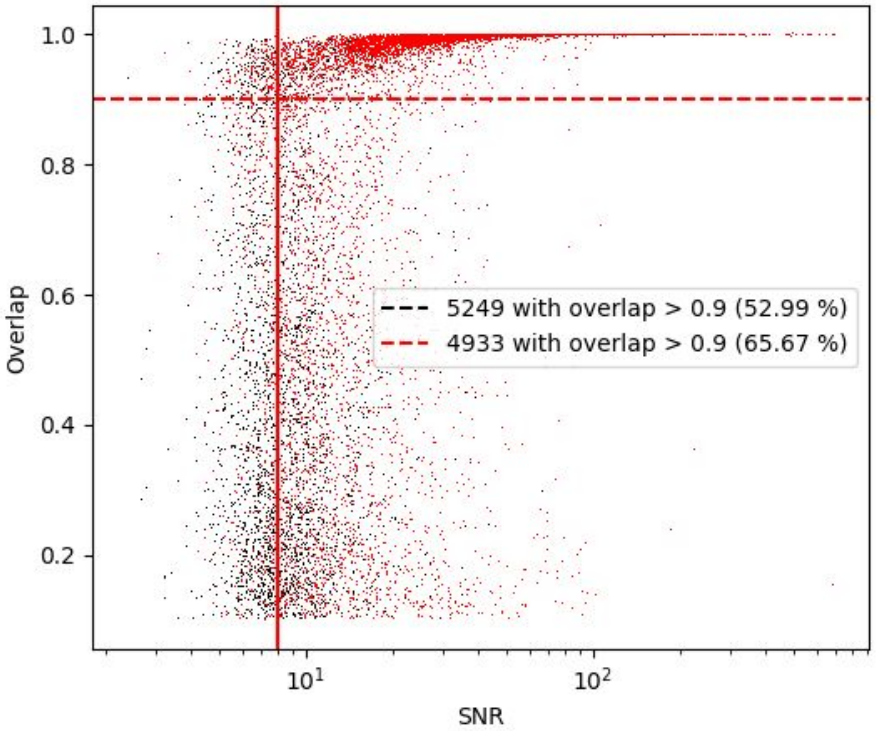
- SNR / parameter uncertainties



Tuning the purity a posteriori

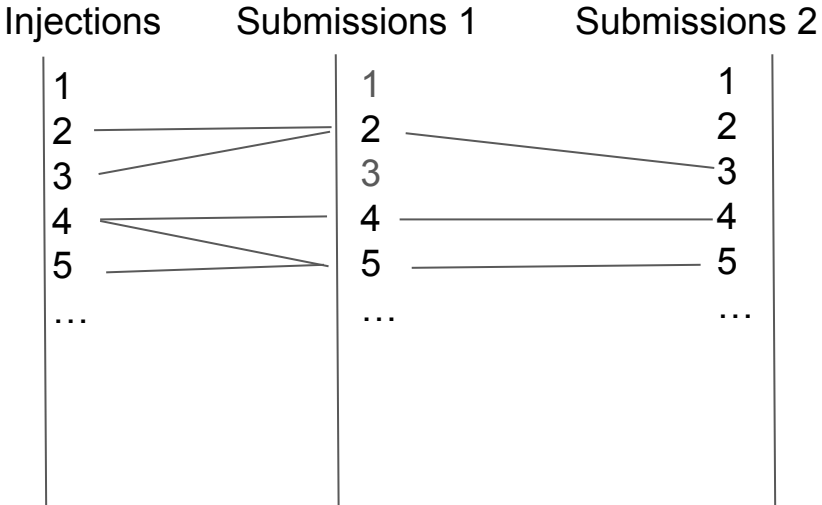
- SNR / parameter uncertainties
- additional information from mode selection

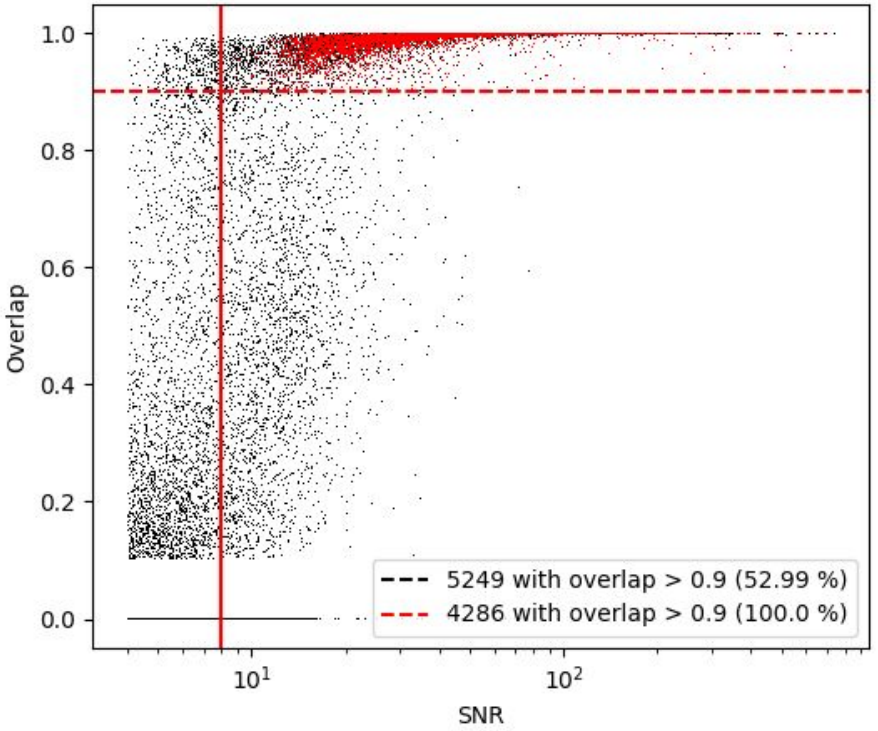
  fraction of samples of a chain which contains the source (z>0.5)



Tuning the purity a posteriori

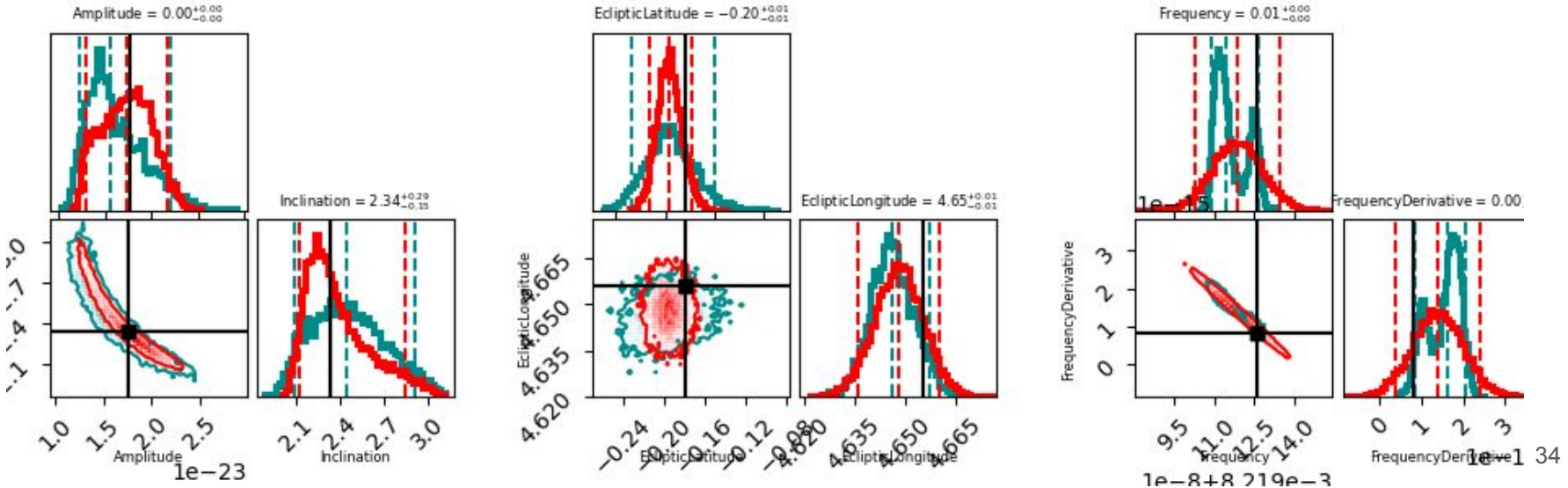
- SNR / parameter uncertainties
- additional information from mode selection
- submission cross match





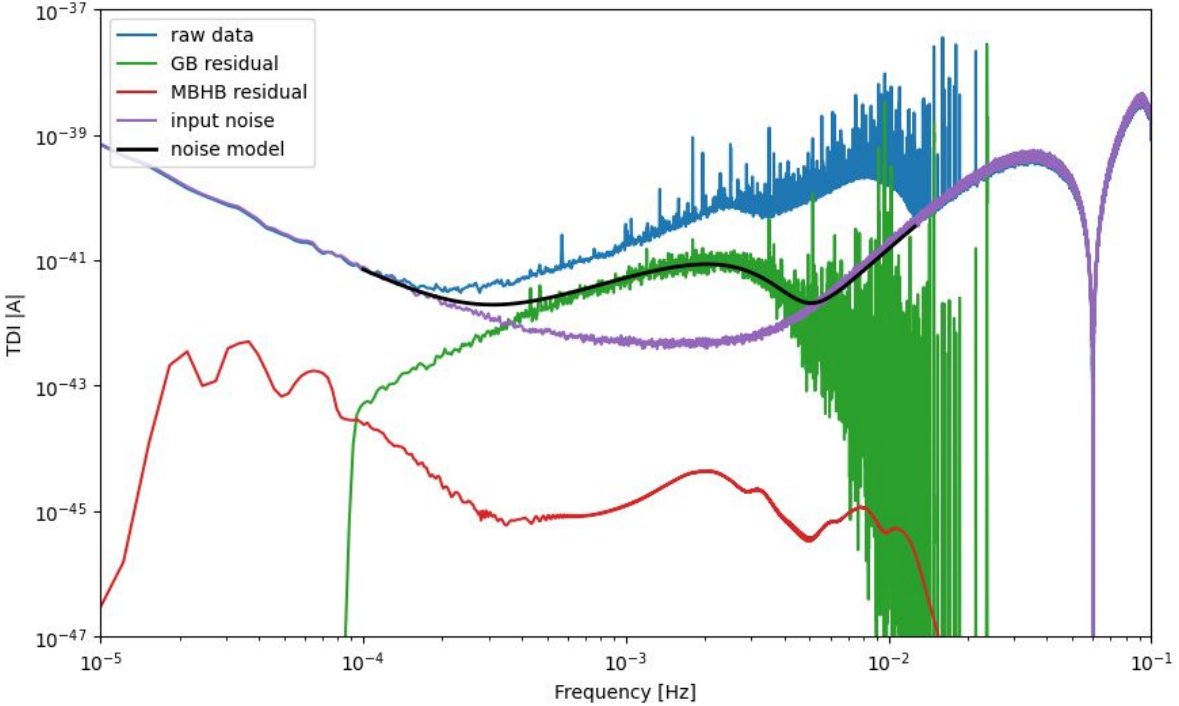
GB: PDF comparison

- 2D submission cross comparisons
- Confidence interval which contains the true value
- Sampling assessment by computing distance with ‘true’ distribution
- To be extended to 8 parameters, then multi-sources



Noise evaluation

- Is the noise compatible with actual residuals



Future work

Most of the evaluation work remains to be done

- A dedicated team of volunteers are starting this job within the LDC WG
- Evaluate the provided uncertainties and posterior distribution functions
- Are the cross correlations well captured ? (MCMC convergence, impact of priors, …)
- Improve on catalog evaluation
- Verification galactic binaries: impact of neighbouring sources and MBHB residuals (wrt existing forecast studies)
- Technical side: provide common evaluation tools within the LDC toolbox