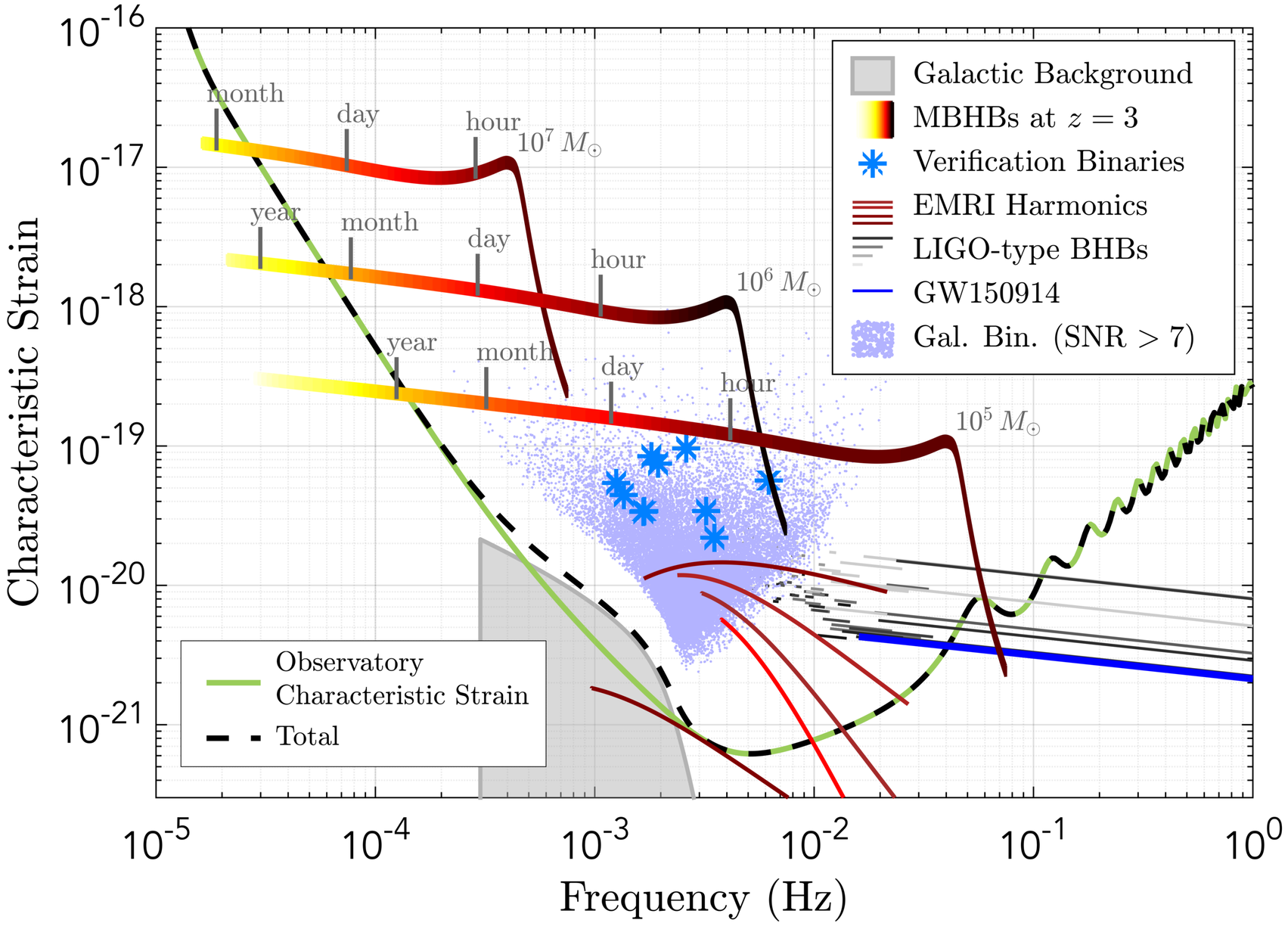
LISA Data Challenges

N Karnesis

For the LISA Data Challenges Group

LISA Canada Workshop - 28 April 2021


Characteristic Strain
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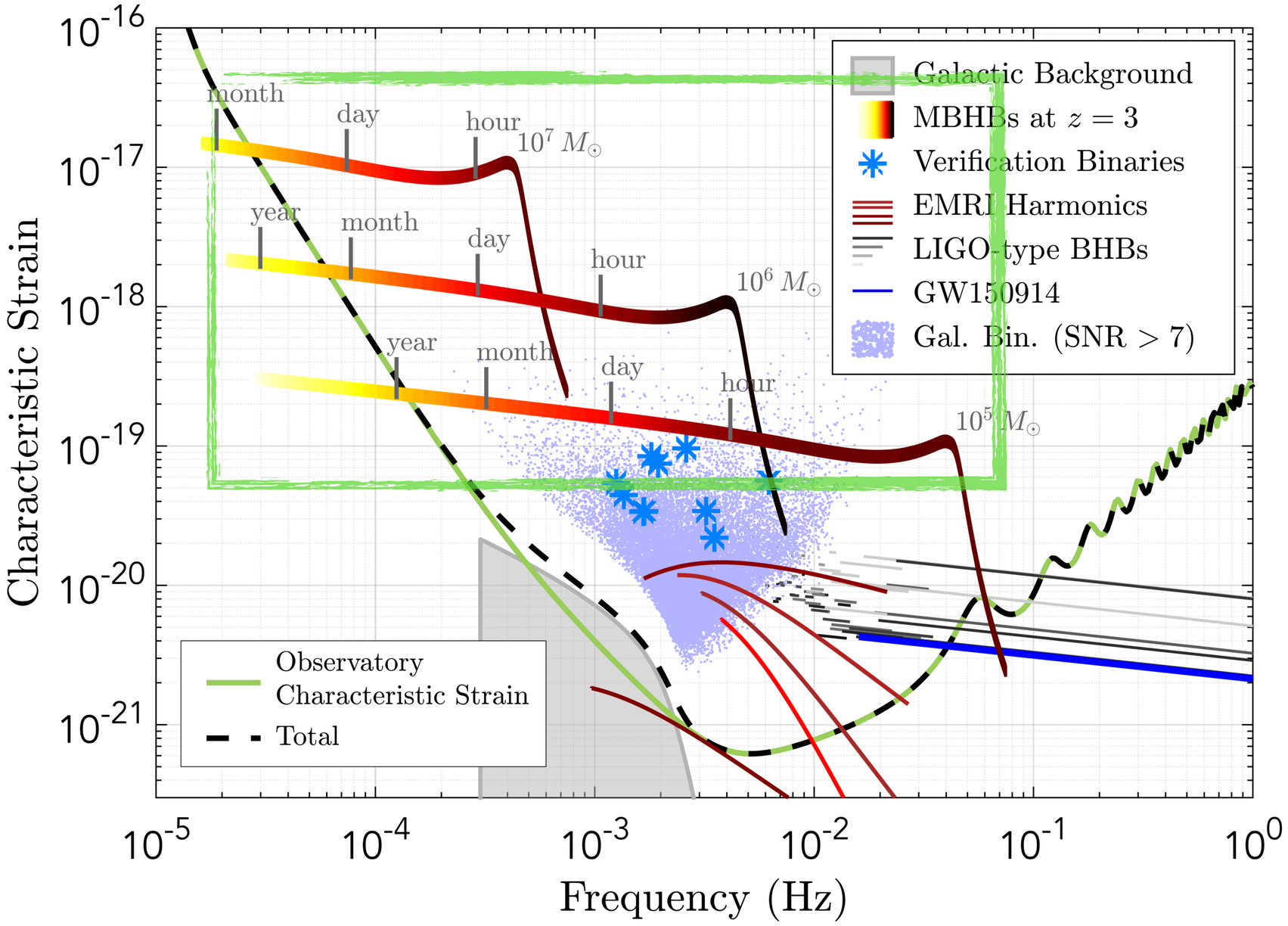
Galactic Background
MBHBs at $z = 3$
Verification Binaries
EMRI Harmonics
LIGO-type BHBs
GW150914
Gal. Bin. (SNR > 7)
Observatory Characteristic Strain
Total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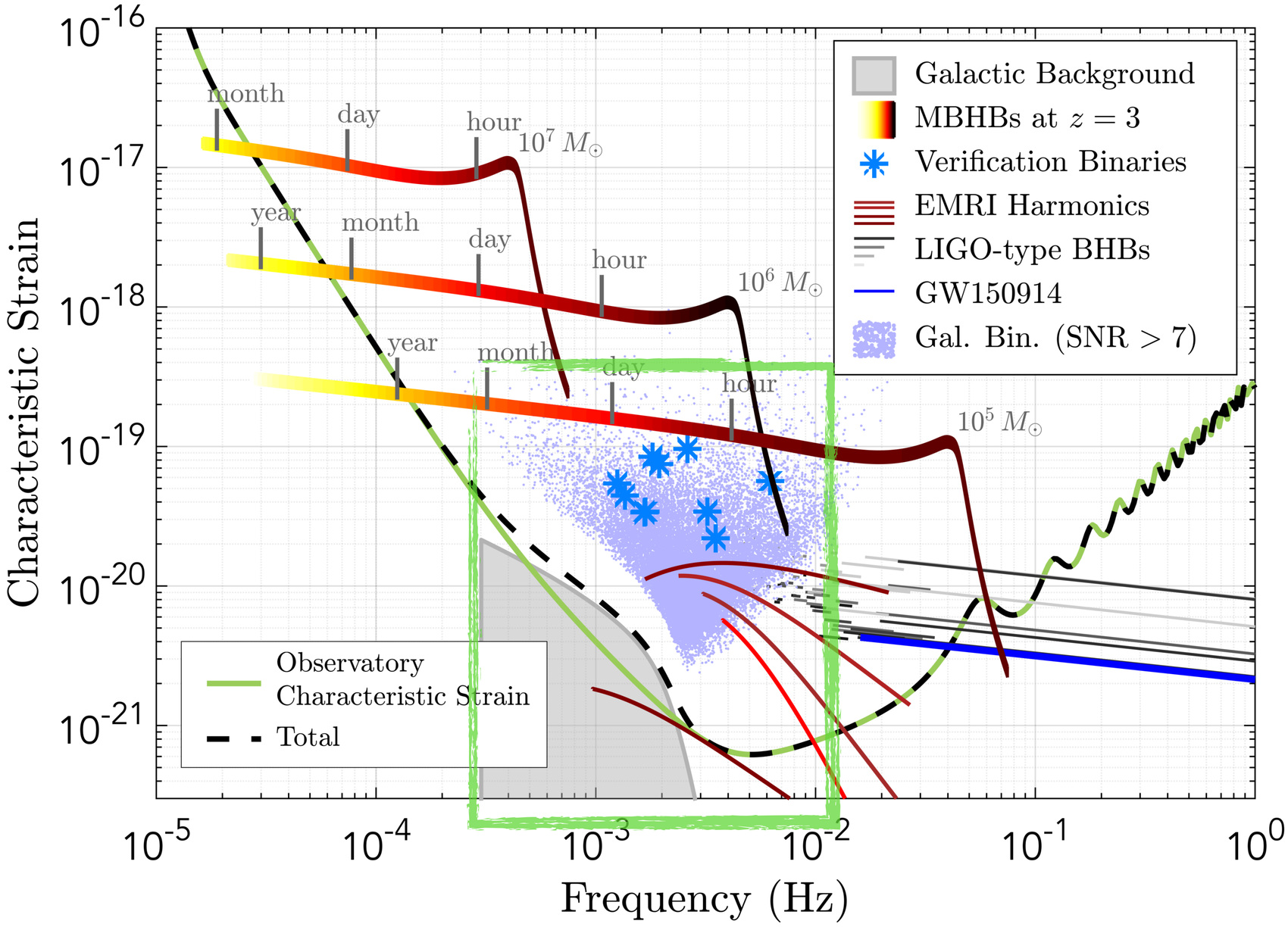
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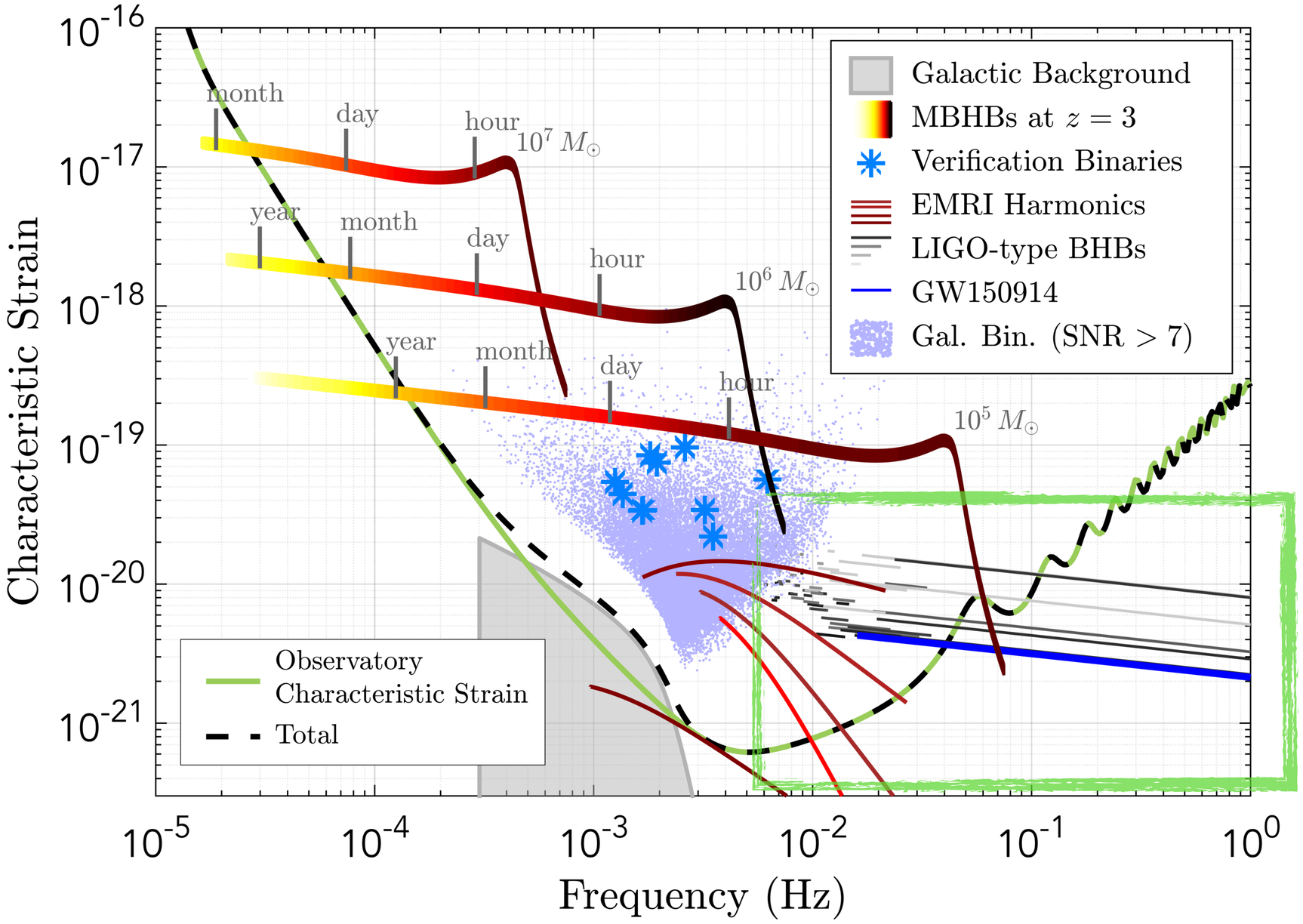
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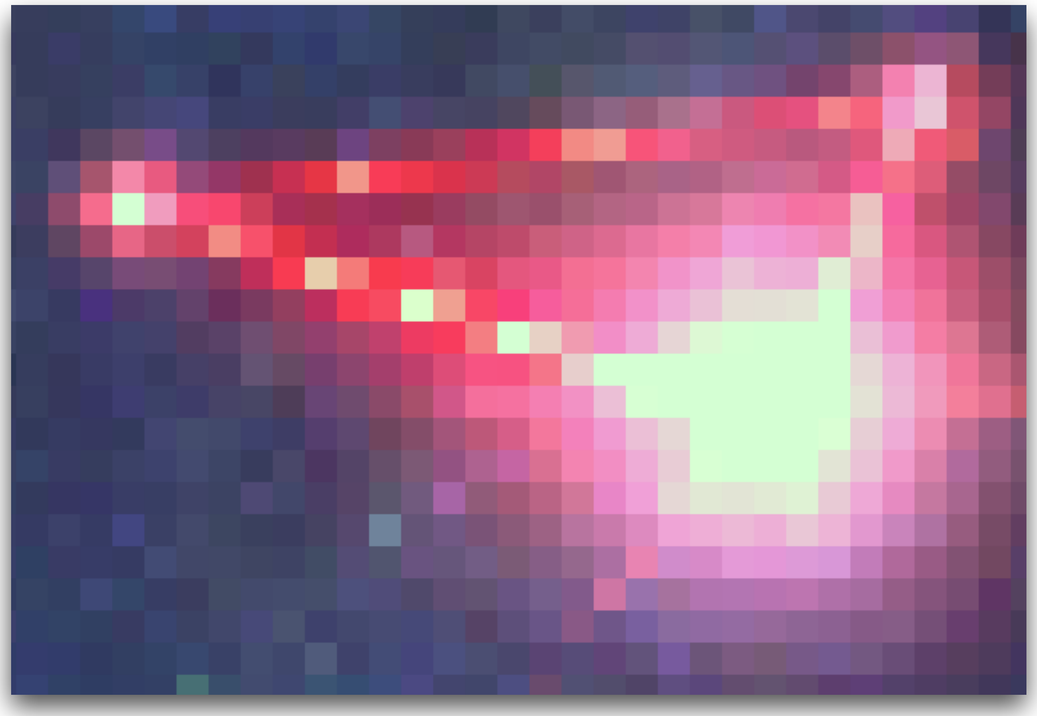
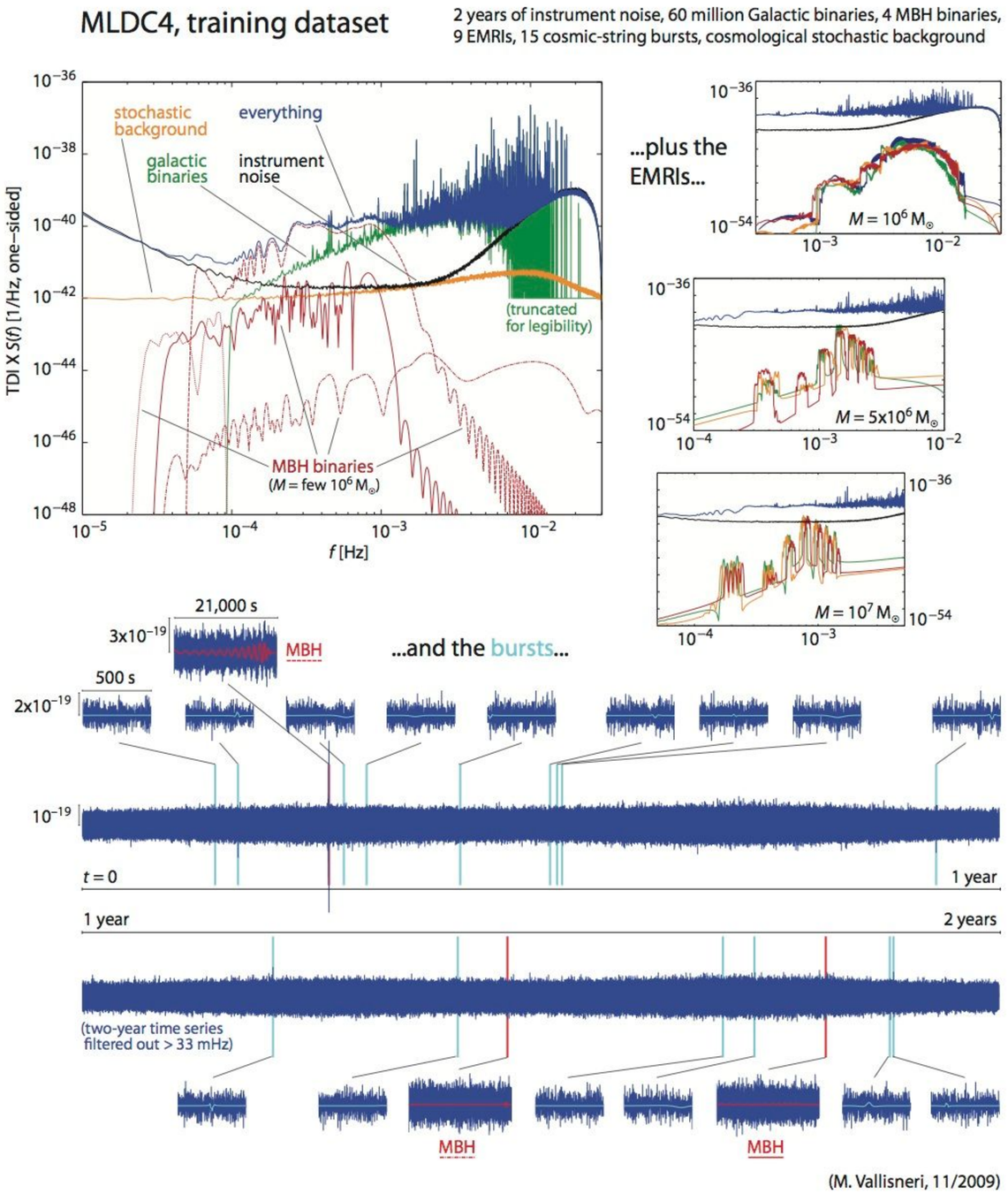
- Introduce software-development standards
- Establish a common playground to evaluate algorithms
- Foster data-analysis research and community involvement
- Address science requirements in project-oriented challenges with realistic assumptions
- Prototype and develop end-to-end data-analysis pipelines

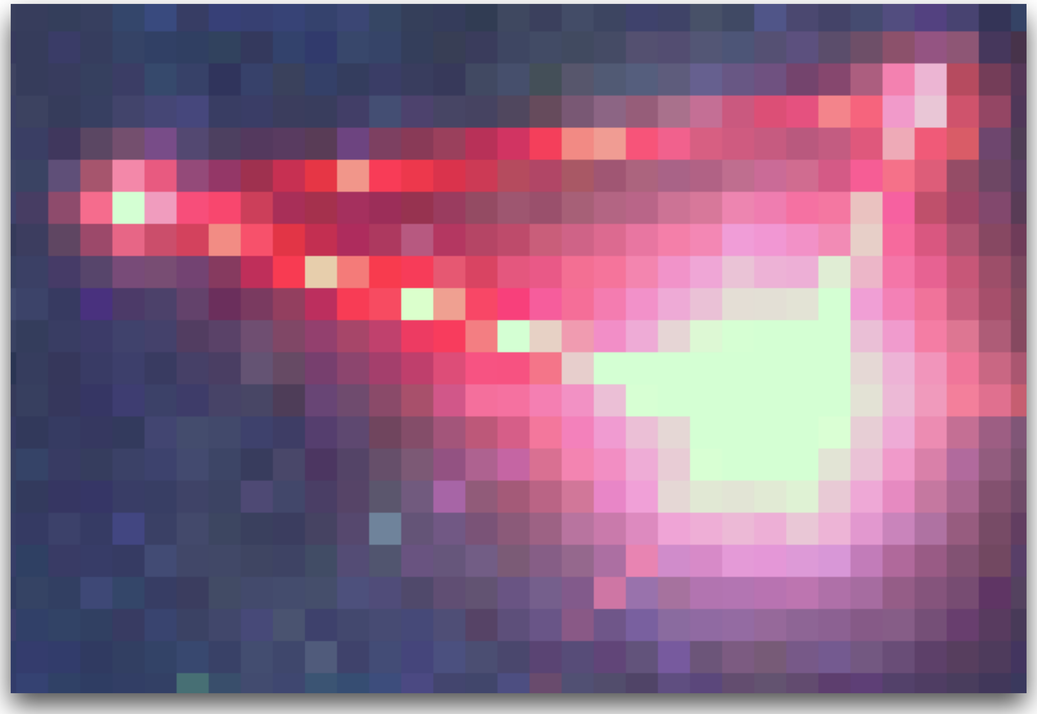


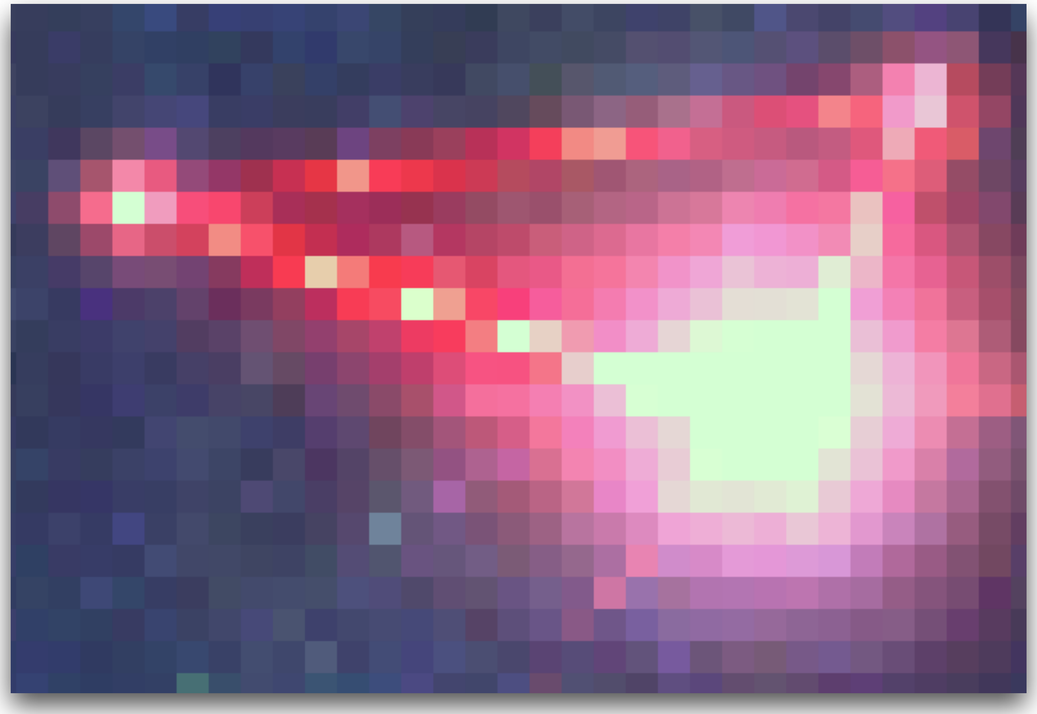
- **Some history first:**
- Five challenges completed
- 70 participants, 25 institutions, 30+ publications
- Chairs: A. Vecchio, M. Vallisneri
- Demonstrated the detection and parameter estimation of all major LISA source classes, using a great variety of methods
- Provided methods for ground-based parameter estimation



LDCs now

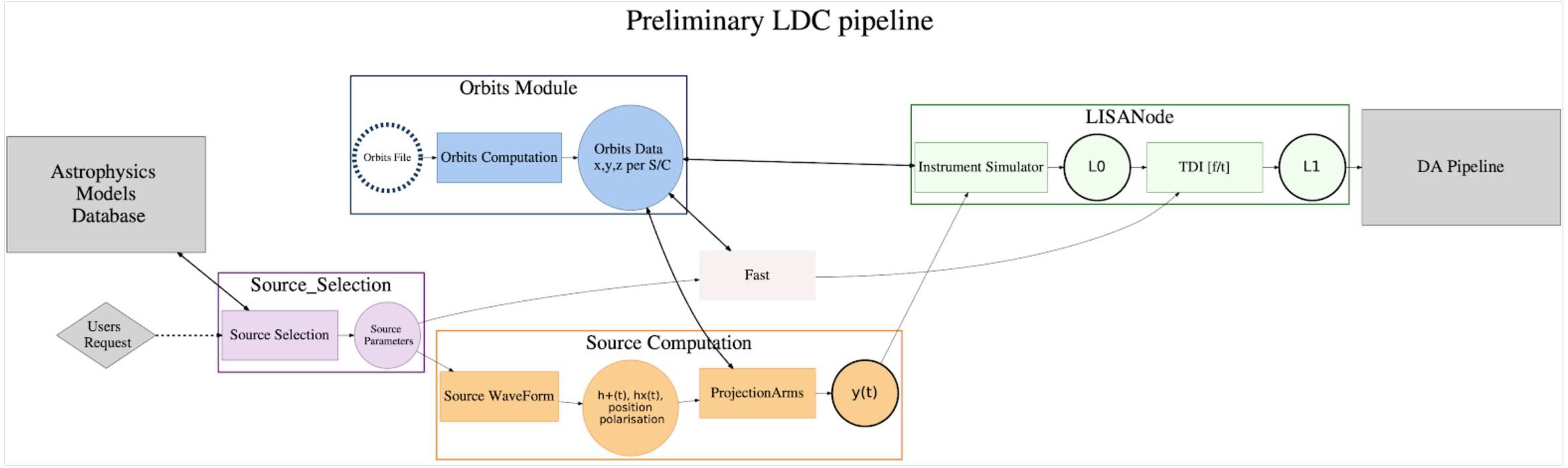
- Who?
  - Chartered by LISA Consortium
  - ~150 members (+ “friends”)
  - Co-chairs:
    - Michele Vallisneri (JPL/Caltech)
    - Stas Babak (APC Paris)
- Working closely with LISA Science Group, LISA Simulation WG, LDPG
- Input from AstroWG (catalogues of sources), WaveformWG (GW models)





- URL: lisa-ldc.lal.in2p3.fr
- Wiki: gitlab.in2p3.fr/LISA/LDC
- Calls: Fridays,16:15 - 17:15 CET

- How to join? signup.lisamission.org


Preliminary LDC pipeline
Orbits Module
Orbits File
Orbits Computation
Orbits Data
x,y,z per S/C
LISANode
Instrument Simulator
L0
TDI [f/t]
L1
DA Pipeline
Astrophysics
Models
Database
Source_Selection
Users
Request
Source Selection
Source
Parameters
Fast
Source Computation
Source WaveForm
h+(t), hx(t),
position
polarisation
ProjectionArms
y(t)

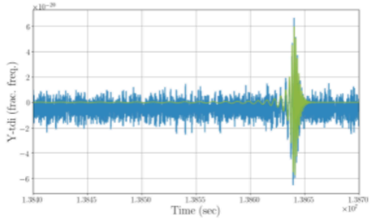
LDC-1: *Radler*

- Tackle main LISA sources separately under idealized instrument noise.
- Introduce new researchers to LISA data analysis
- Rehabilitate (old) MLDC analysis codes
- Establish LDC process, standards, infrastructure

LDC-1: *Radler*

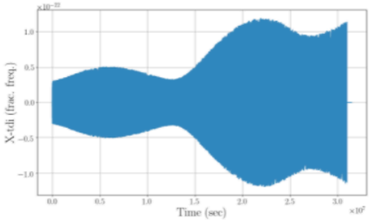
LDC1-1. A single GW signal from a merging massive-black-hole binary.

LIGO and Virgo have done it, so let's get LISA on the right path! MBHBs are represented with a frequency-domain inspiral–merger–ringdown phenomenological model (IMRPhenomD). The black holes are spinning, with spin vectors parallel to the orbital angular momentum. The release includes datasets for two methods (frequency- and time-domain) of applying the LISA response to the GWs.



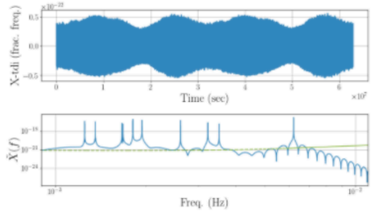
LDC1-2. A single GW signal from an extreme-mass-ratio inspiral.

EMRIs are modeled with the "classic" *Analytic Kludge* waveforms, which will be updated in future challenges, so make your code flexible! The signal is produced in the time domain and the response is applied using LISACode. The signal is of moderate strength, but the source parameters are drawn from relatively wide priors. This should make for a good challenge!



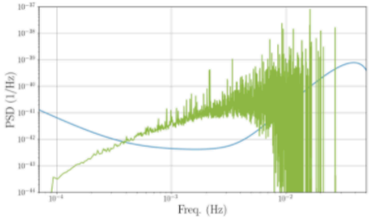
LDC1-3. Superimposed GW signals from several verification Galactic white-dwarf binaries.

We assume circular orbits and purely gravitational interactions. The phase of the signal includes frequency and first derivative. This one should be easy!



LDC1-4. A GW signal from a population of Galactic white-dwarf binaries.

Here's the classic cocktail-party problem: 26 million signals, produced with a "fast response" code. Parameters of all binaries are available in a large HDF5 file.

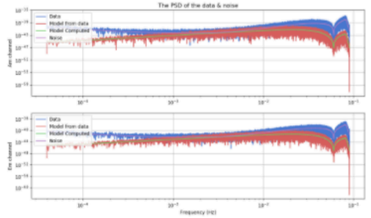


LDC1-5. A GW signal from a population of stellar-origin (stellar-mass) black-hole binaries.

LIGO and Virgo's gift to LISA. The population follows Salpeter's mass function, with an overall rate based on recent LIGO–VIRGO estimates. Waveform and LISA response are computed in the frequency domain.

LDC1-6. An isotropic stochastic GW signal of primordial origin.

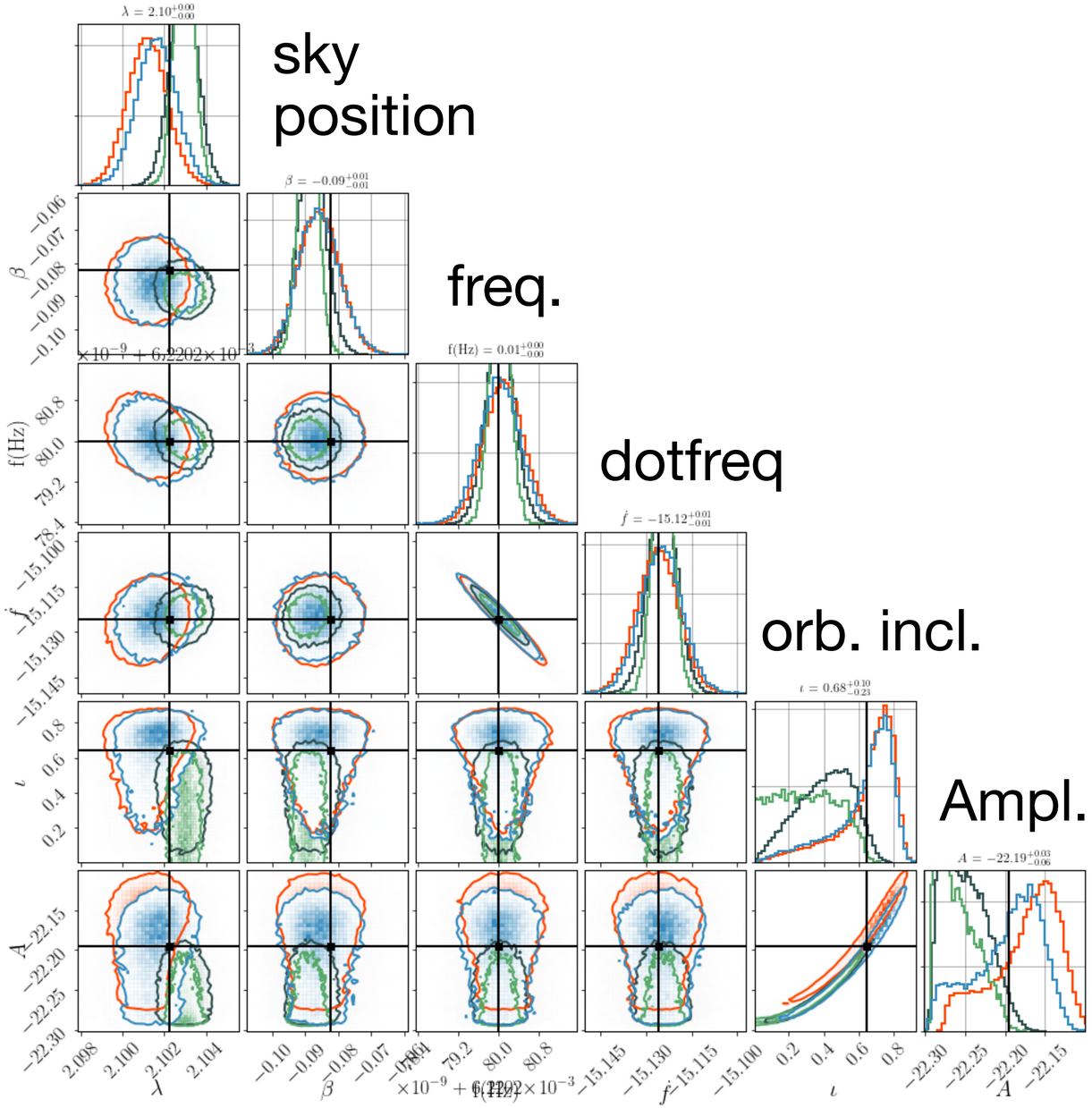
Statistics are Gaussian, but the spectral shape is shrouded in mystery, with parameters chosen for us by the LISA Consortium Cosmology Working Group. The signal is generated using LISACode as a choir of elementary sources uniformly distributed across the sky. To make things easier for you, instrumental noise is Gaussian, uncorrelated, and of the same level in each LISA link.



LDC-1: *Radler* - 15 submissions

- Birmingham University
- Marshall (NASA)
- Montana Uni
- Barcelona (ICE, CSIC, IEEC)
- CEA/IRFU (France)
- Goddard (NASA)
- APC (France)
- University of Trieste
- IISER (India)
- University of Minnesota
- Imperial College London.

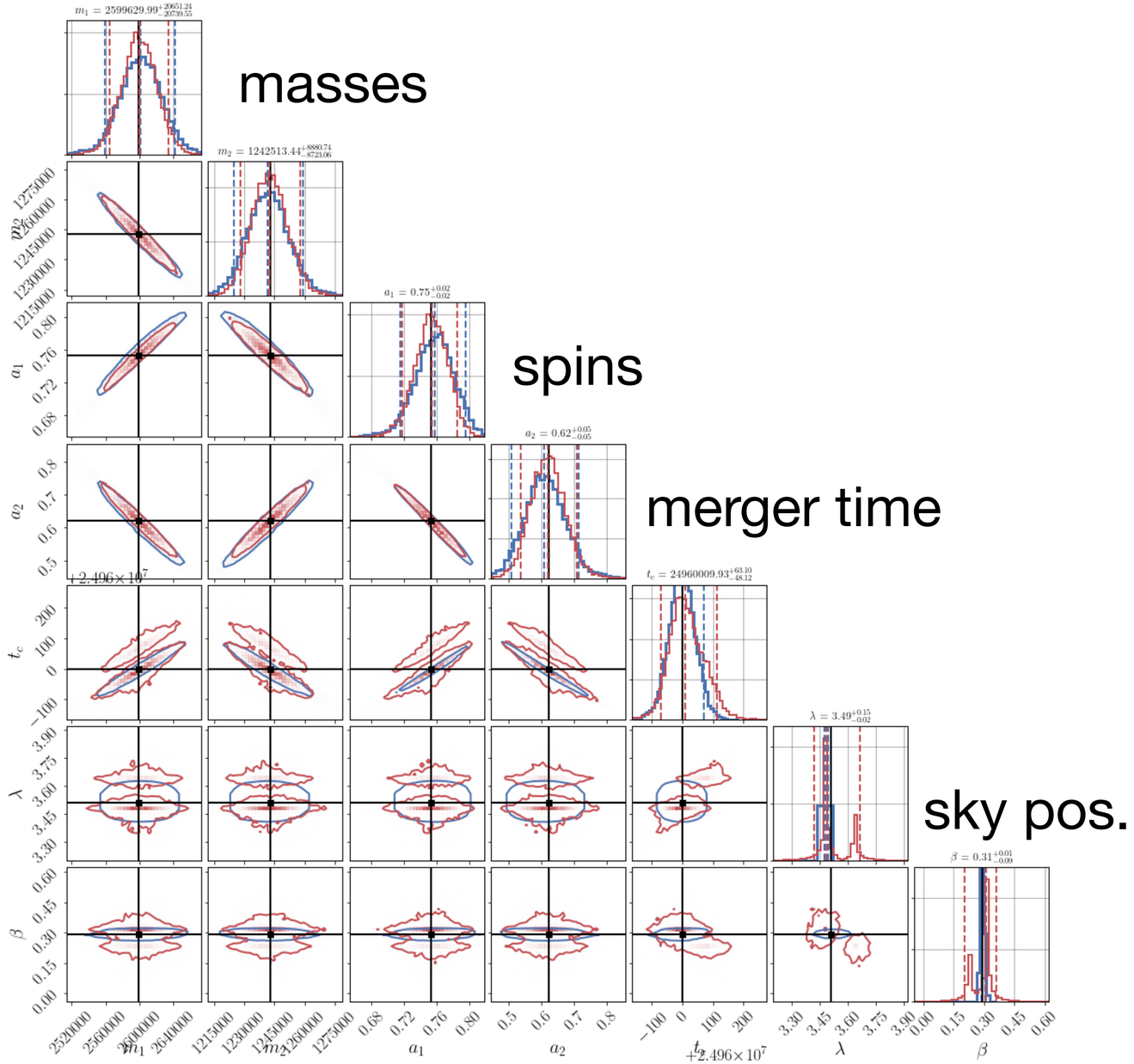
LDC-1: *Radler* - VBs



- Different waveforms
- Different Samplers
- Different priors

[Busciccio+ PRD, 2019]
[Littenberg+ PRD, 2020]

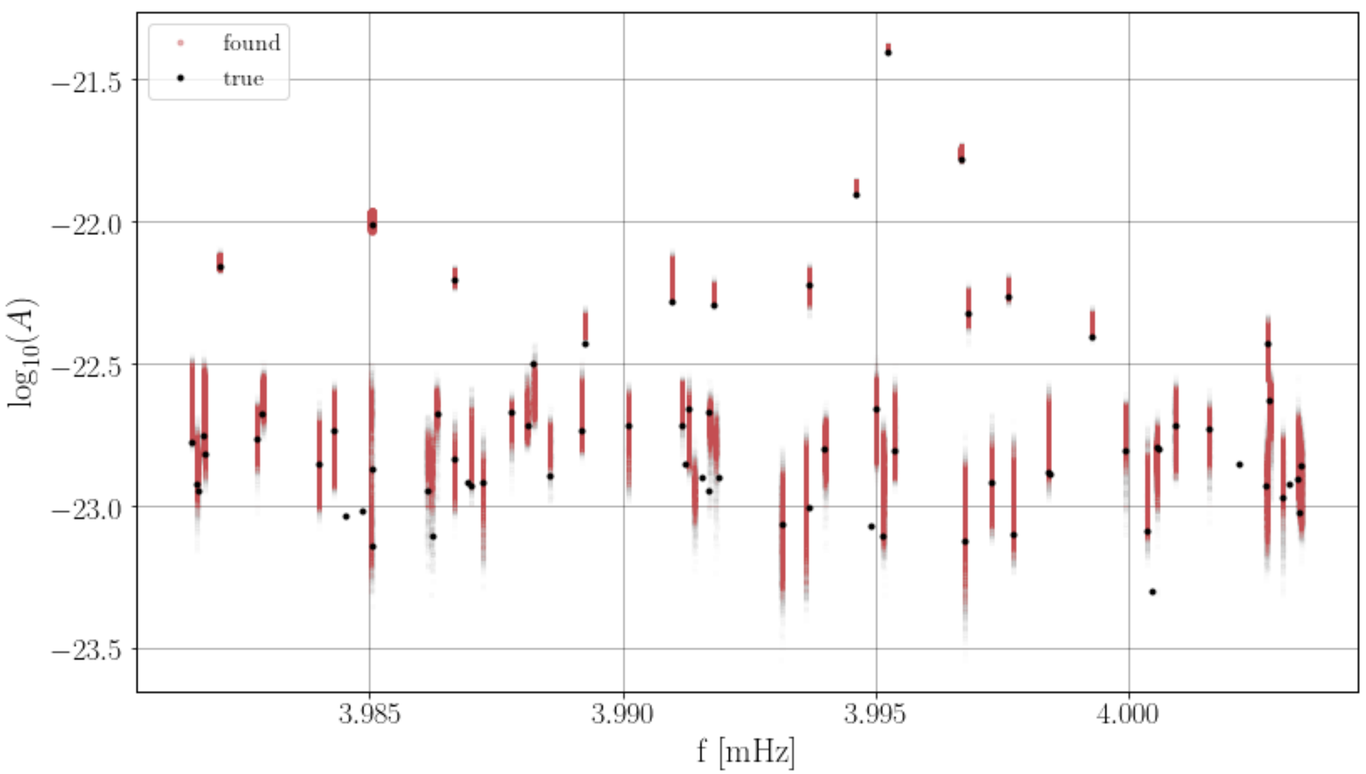
LDC-1: *Radler* - MBHBs



- SNR ~ 400
- PhenomD: Dominant mode, no precession.
- Again, different submissions, different samplers, …

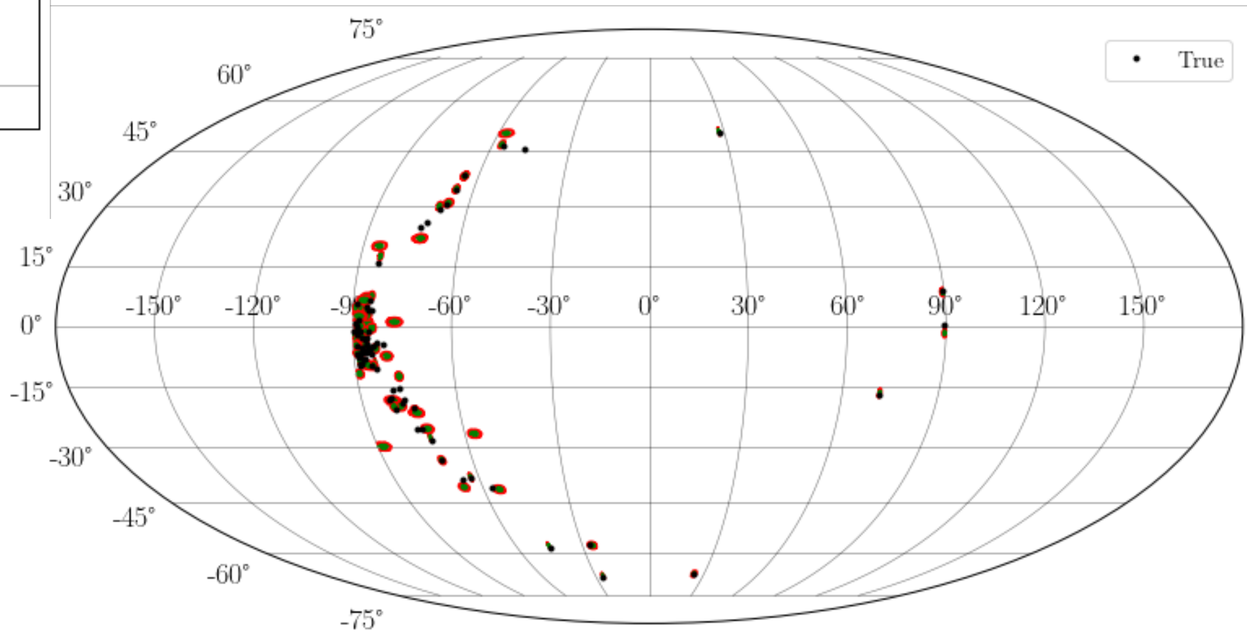
[Cornish & Shuman PRD (2020)]
[Katz+ PRD (2020)]

LDC-1: *Radler* - CGBs

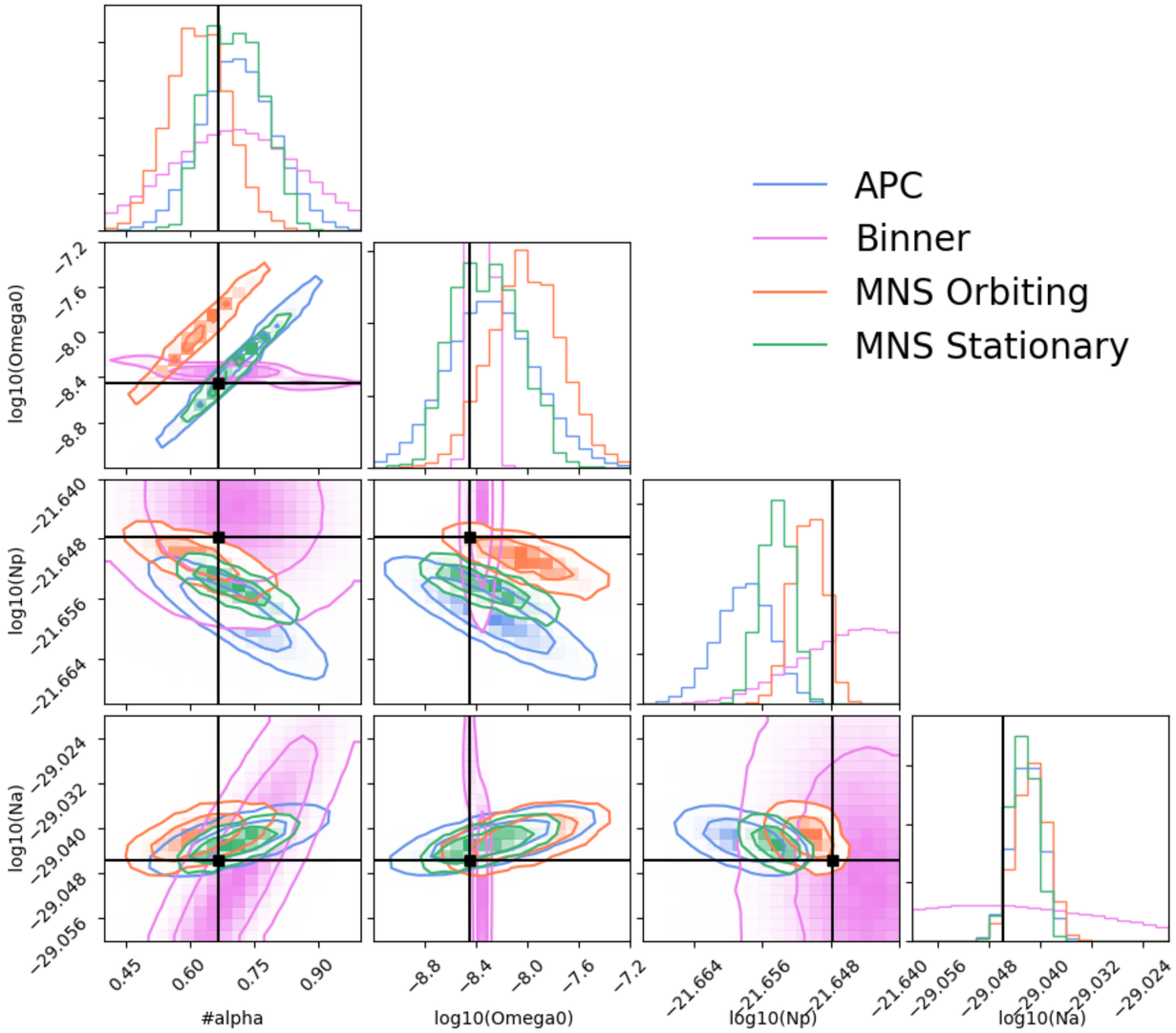


[Littenberg+ PRD, 2020]

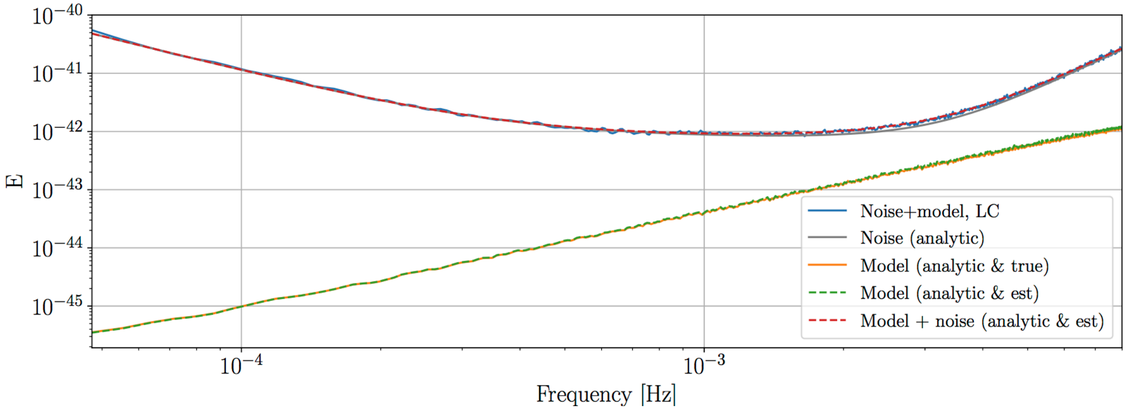
- Analysis in small frequency bands
- Model selection
- ~10000s resolvable



LDC-1: *Radler* - Stochastic



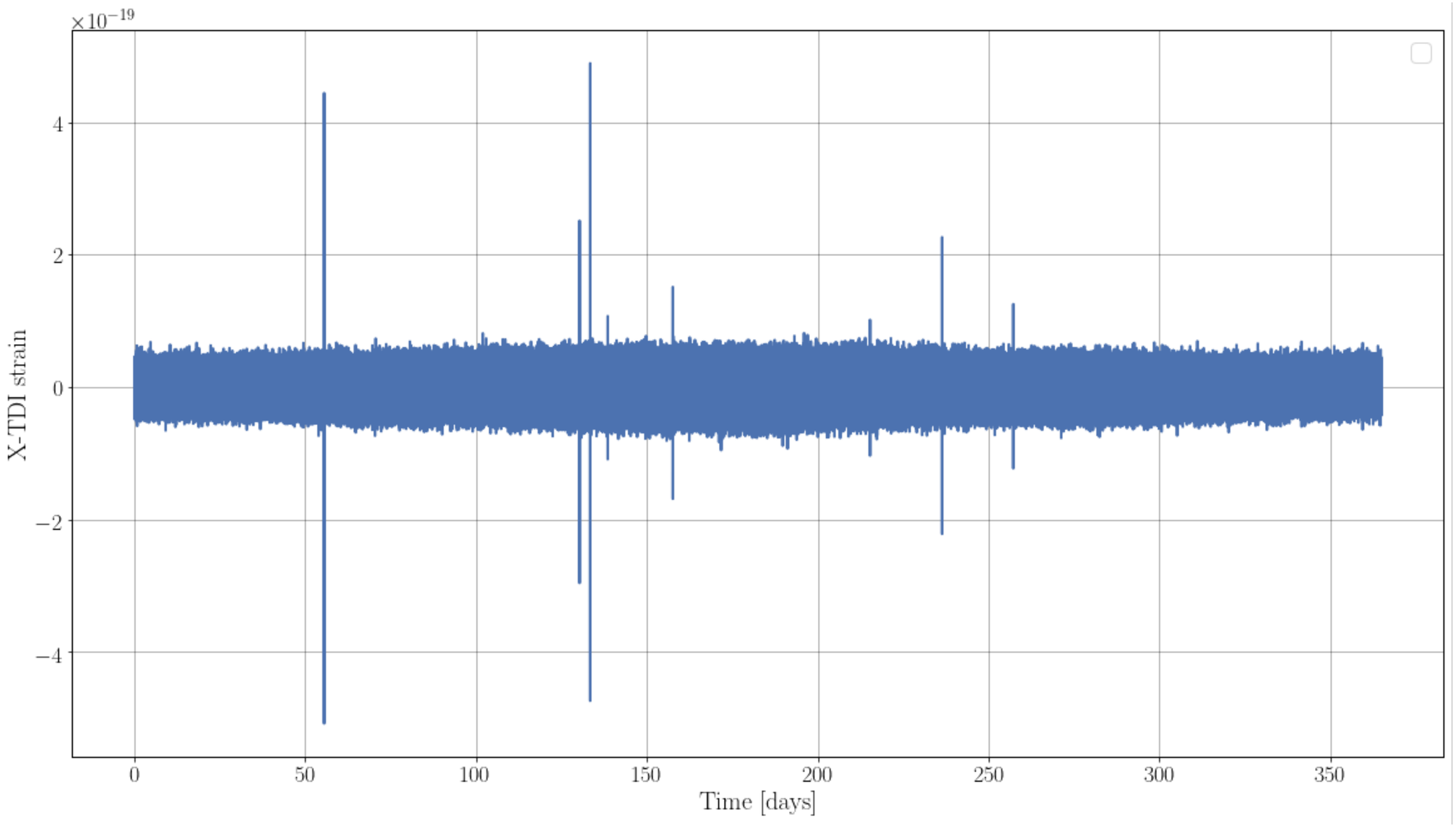
- Power law
- Different priors & samplers
- The ‘Binner’ collaboration was using a different approach.



LDC-2: *Sangria*

- Mild “enchilada” data challenge: mixture of sources + unknow level of instrumental noise
- Galactic WD binaries, plus unknown number of MBHBs:
  - Training data challenge + Blind challenge
  - Noise is not stationary (cyclo-stationary) due to stochastic foreground confusion noise
  - Beta-version of the data is available https://lisa-ldc.lal.in2p3.fr/ldc

LDC-2: *Sangria*



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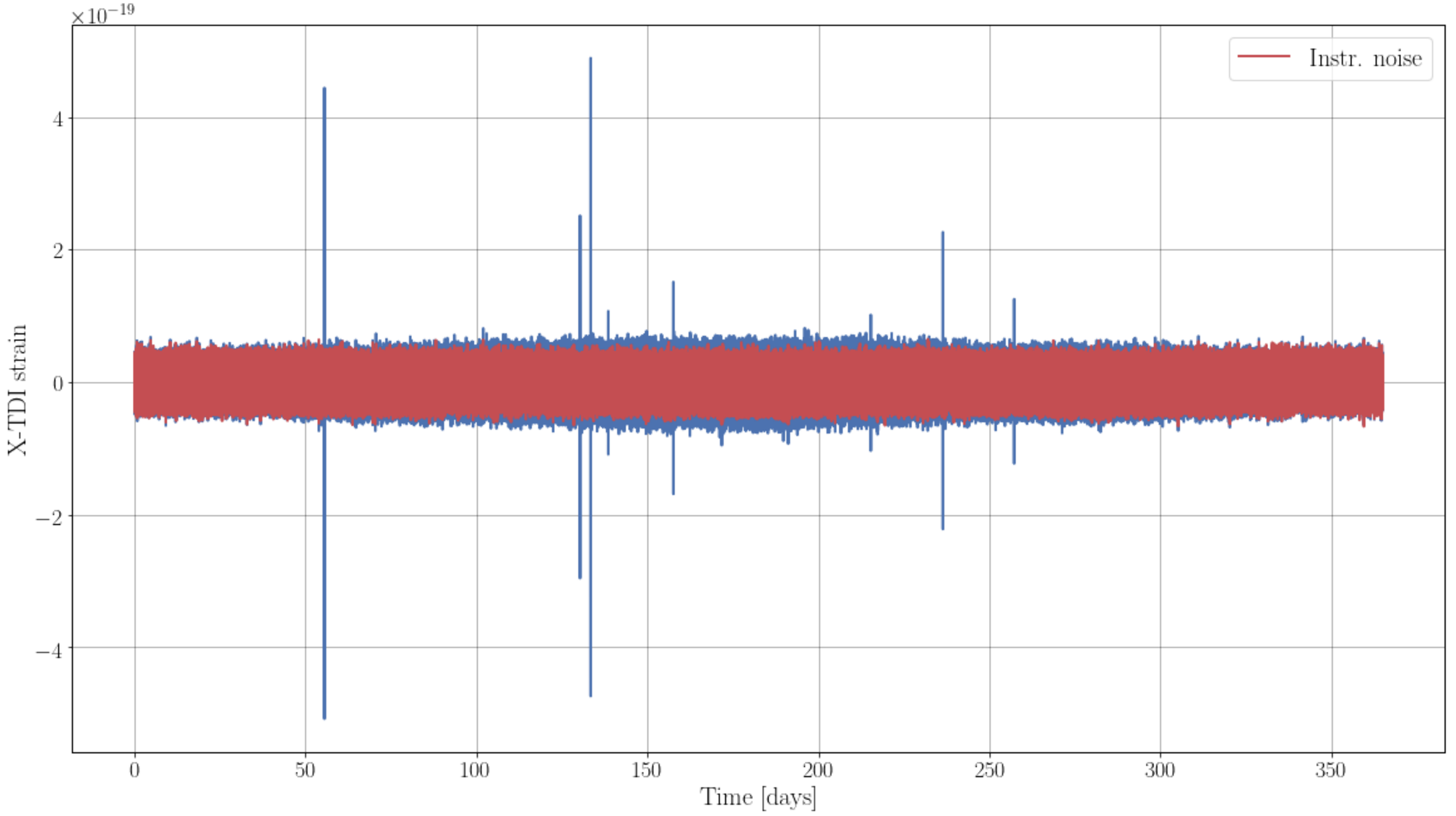

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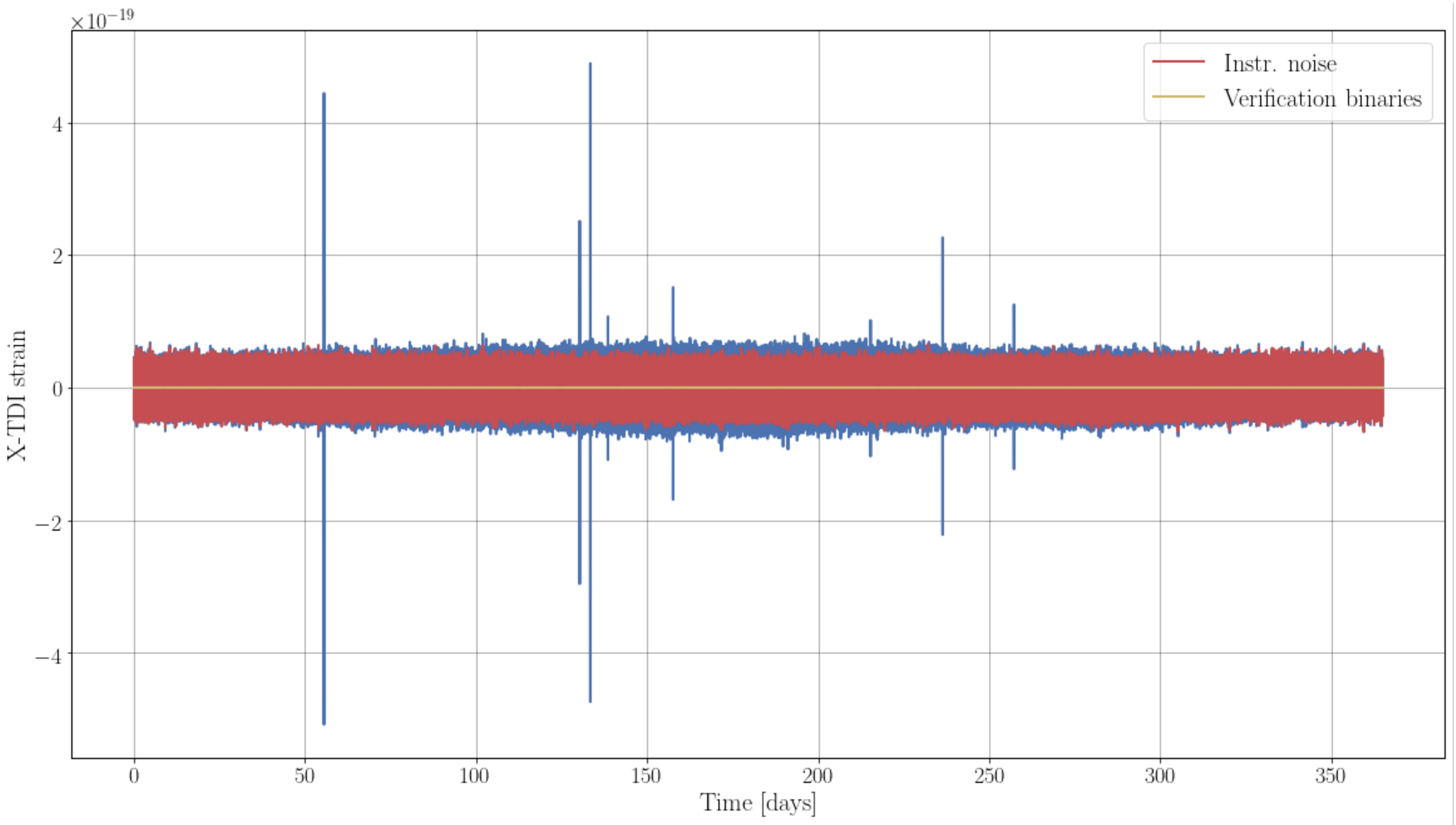

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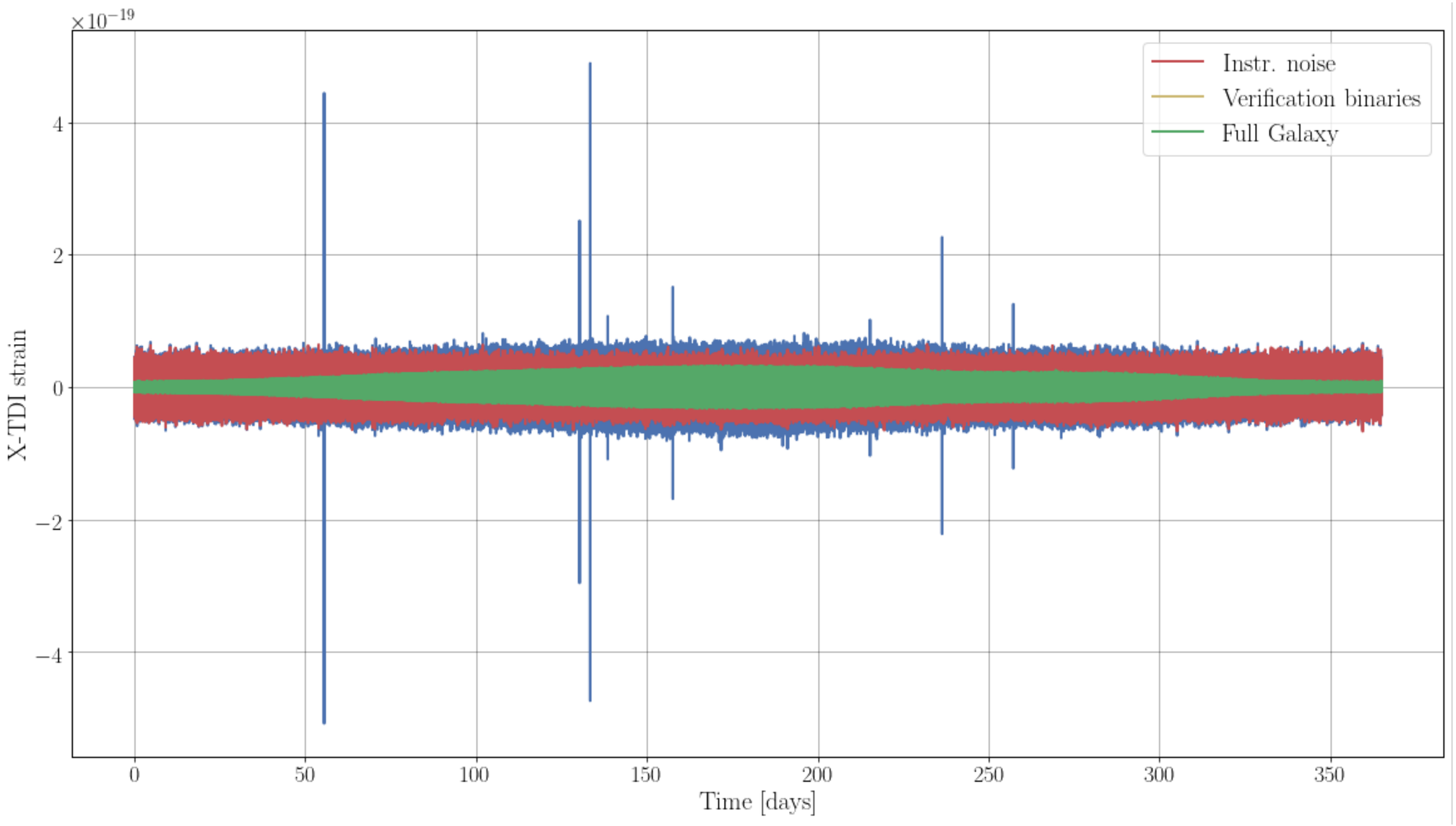

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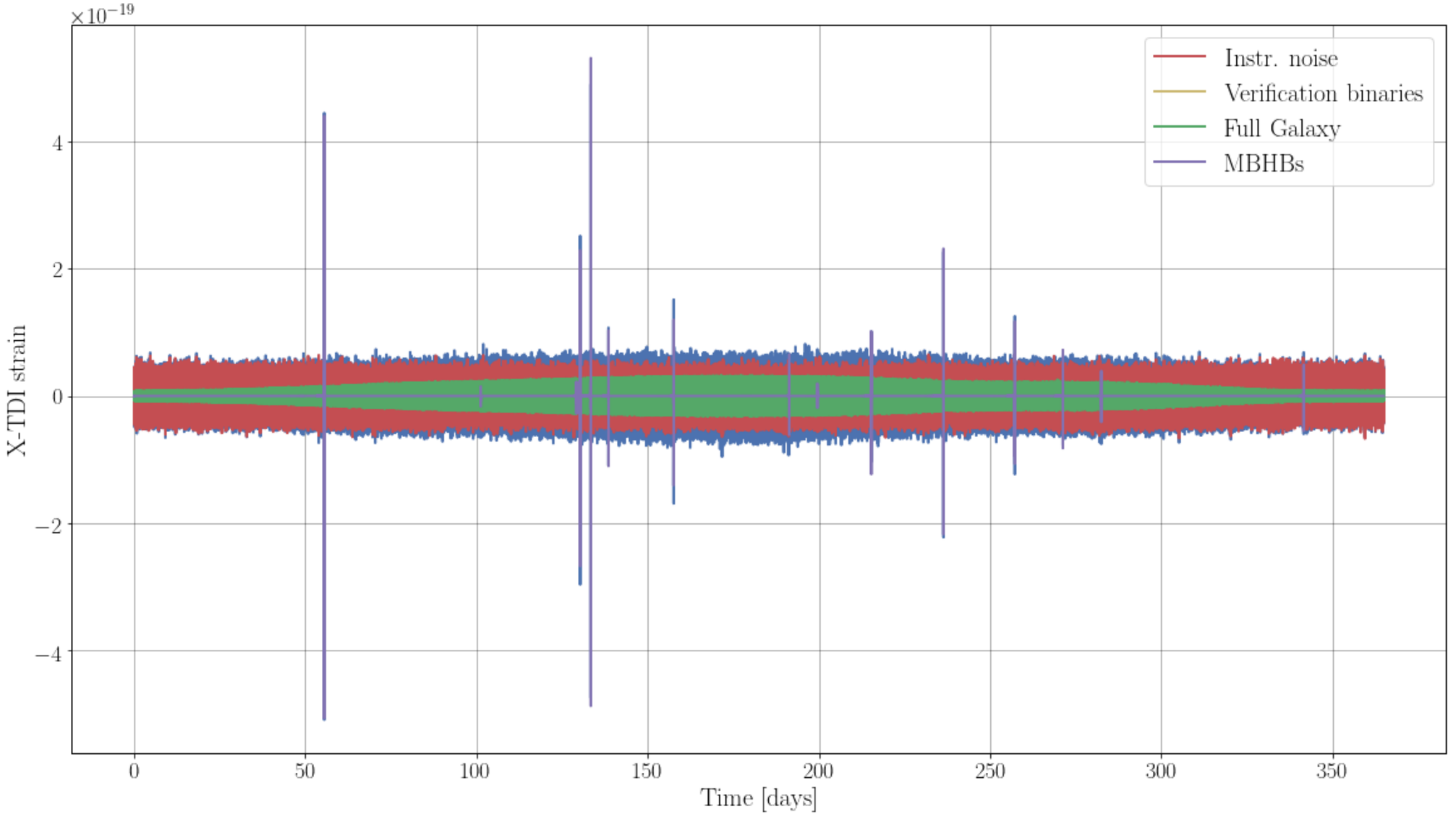

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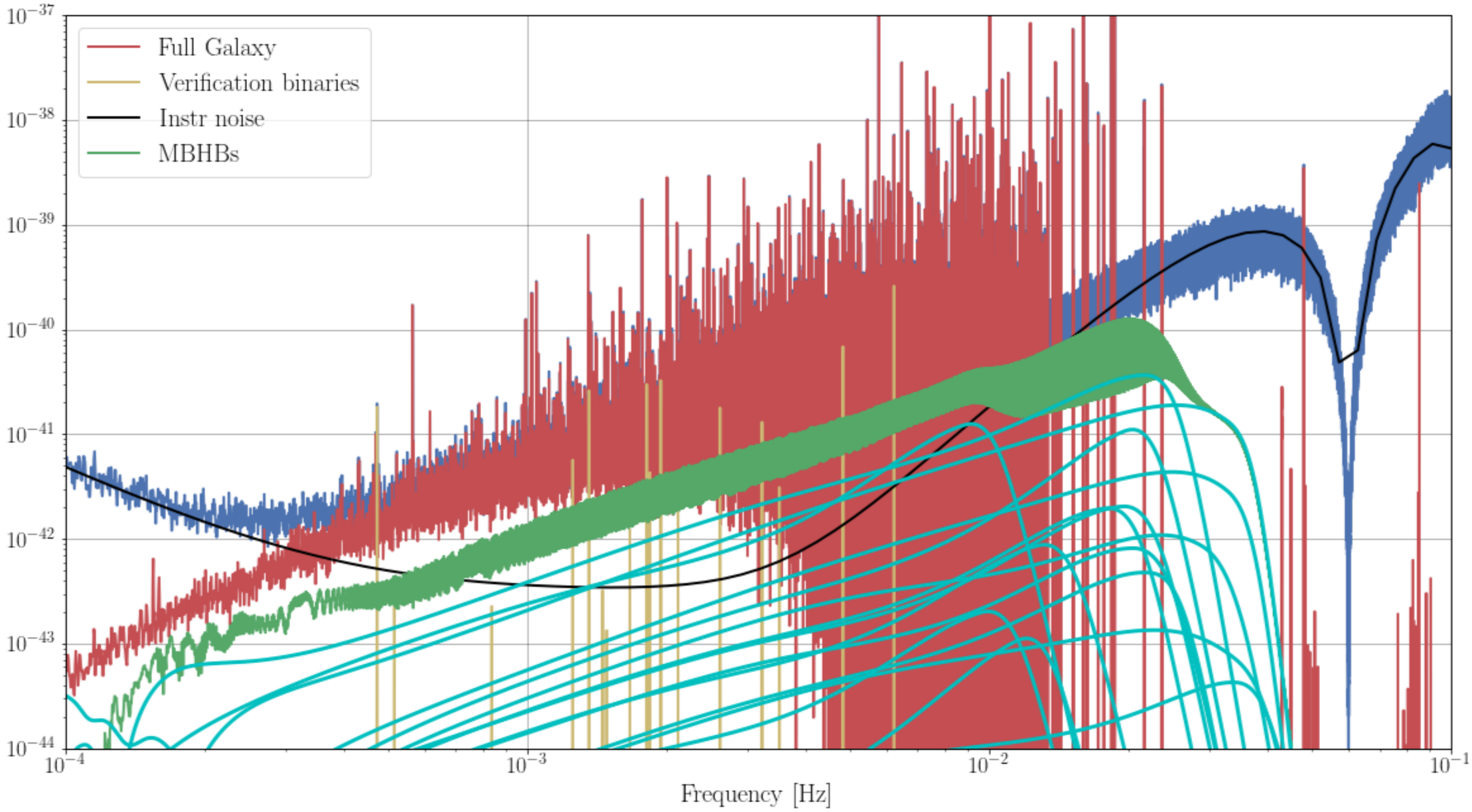

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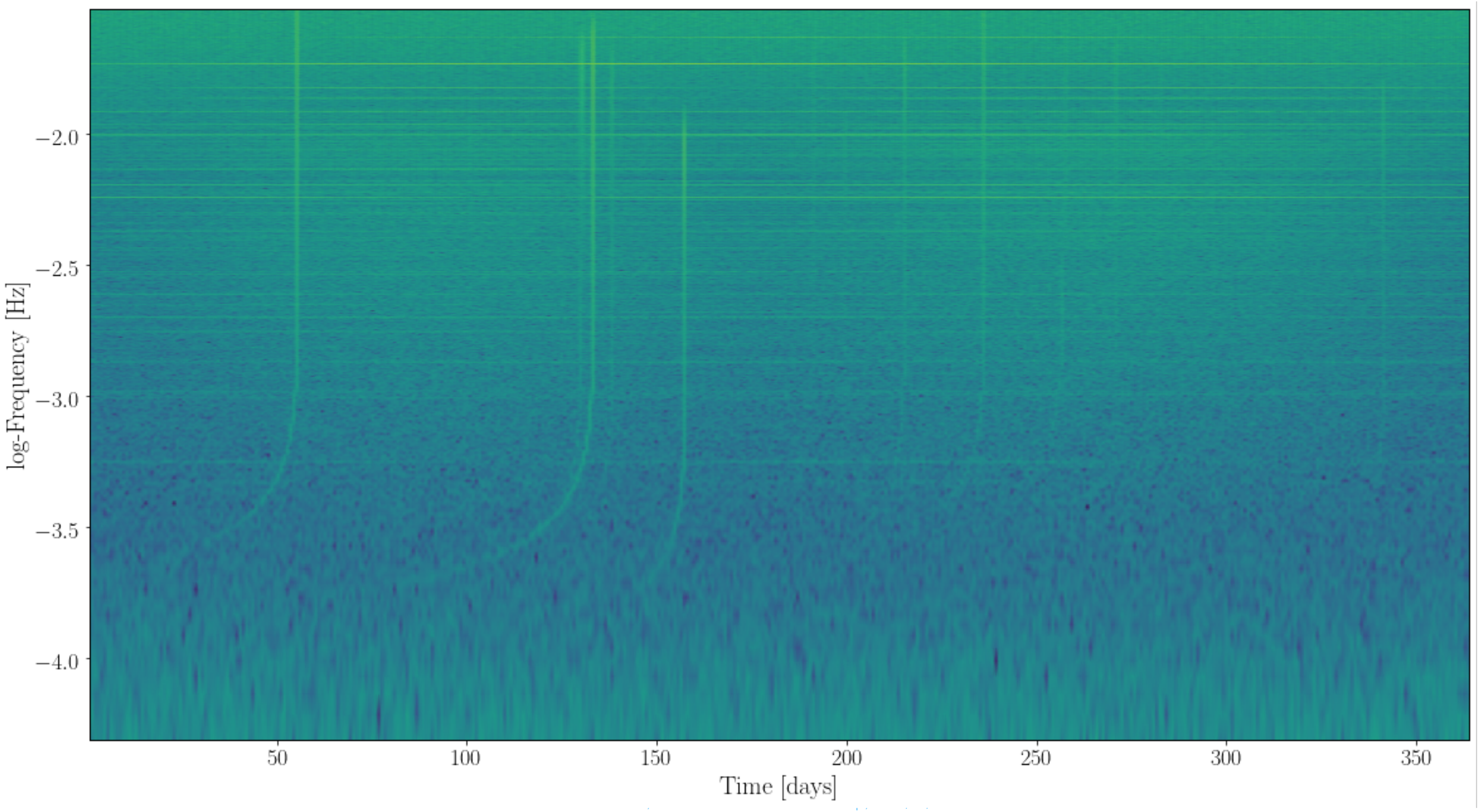
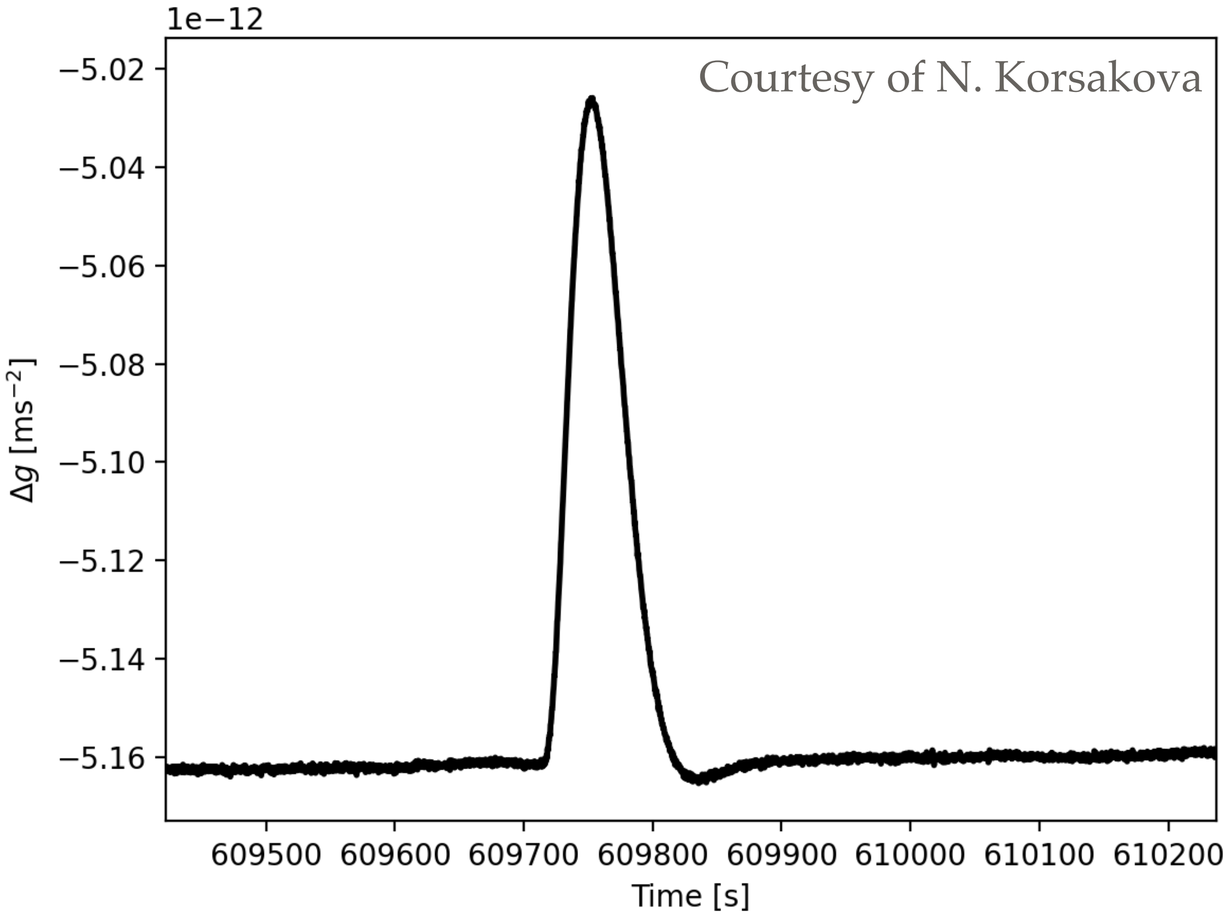


LDC-2b: *Spritz*

- LDC-2b is coming next.
- Non-stationary instrumental noise (gaps, glitch, and more)
- Light astrophysical content
- To address robustness of algorithms used in Radler for non-stationary noise
- To help setting requirements on the instrument design/operation



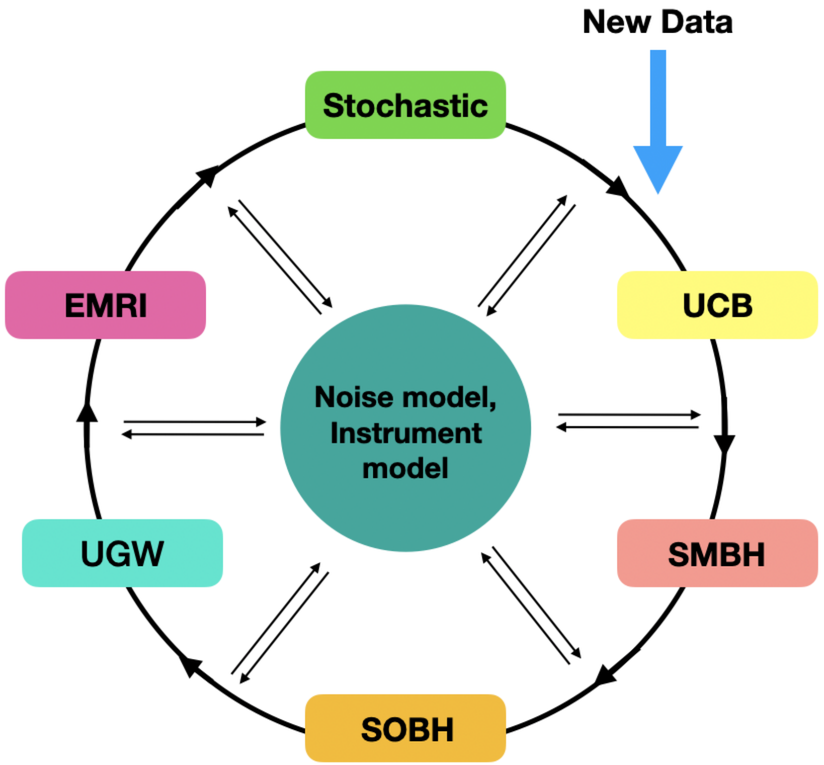
LDC-1b: *Yorsh*

- SBBH: 2 data sets 2 years long each at 5 sec cadence:
  - Gaussian instrumental noise (known level) + 1 SBBH of SNR 25, measurable evolution in frequency (can take one of LVC events)
  - Gaussian instrument noise (known level) + 1 SBBH of SNR 10.

- EMRI: 2 data sets with “realistic” EMRI signal of SNR ~40
  - 1 EMRI (typical, taken from catalogue), Augmented analytic kludge, Gaussian instrumental noise. 2 years
  - 1 EMRI (non-rotating BH), fully relativistic model, Gaussian instrumental noise, 2 years

Active projects

- Code infrastructure/data generation/ pipelines
- LISA noise/orbit/instrument modeling
- Catalogs
- Waveforms
- Search/PE codes/PE tutorials
- Website/communications
- **Global Fit**
- Evaluations of LDC results
- […]



[Littenberg+ PRD, 2020]

The future

- Move step-by-step to more realistic data scenarios
- Both in science and instrument
- Address set of questions before adoption (source mixing, data irregularities, etc).
- **Testing Global Fit solutions**

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