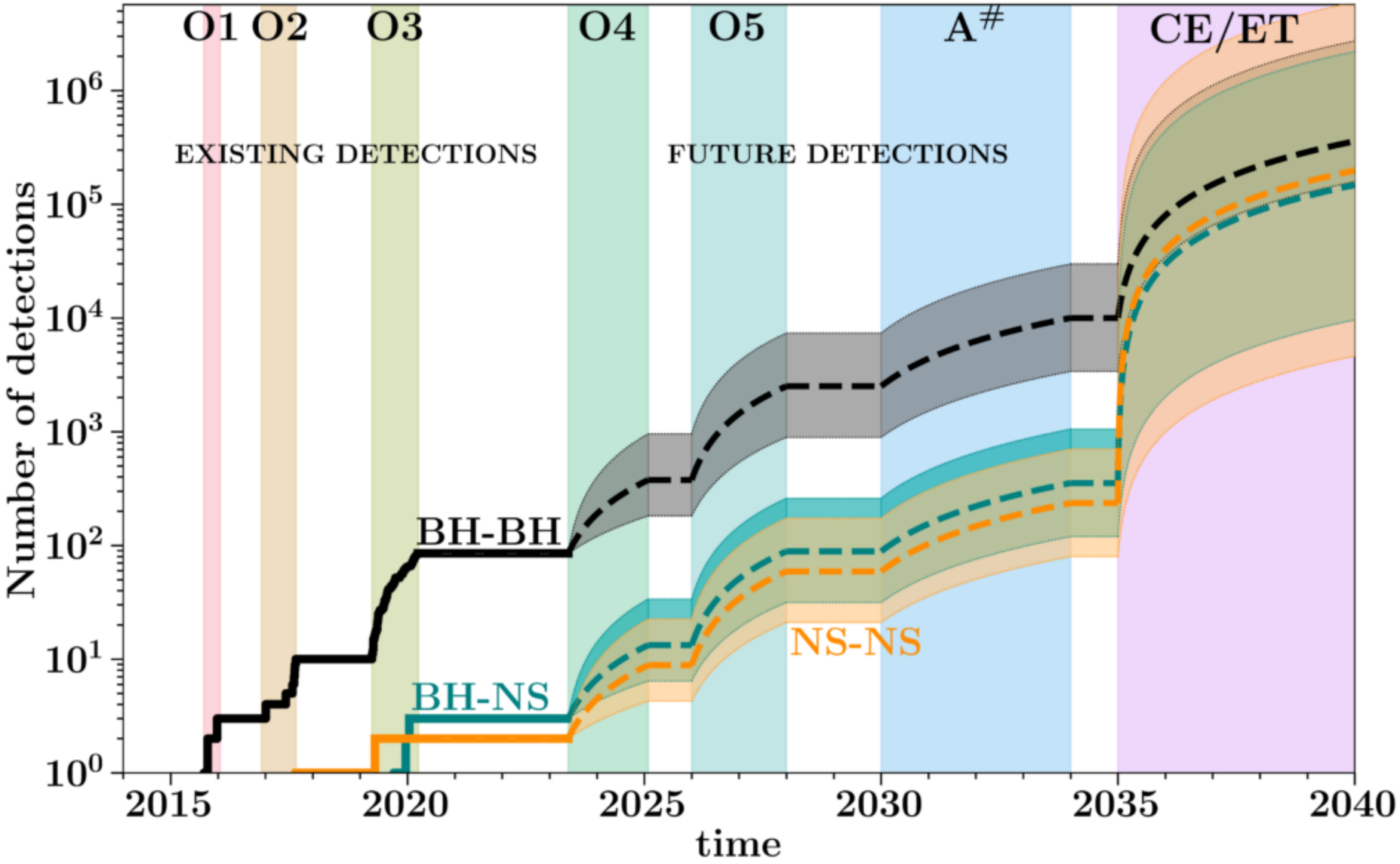
Too Many, Too Long, Too Loud

CBC Data Analysis Challenges in XG era

Koustav Chandra

2nd July 2025 | PAX X

PennState



Next-Gen hopes

BNS: 30s*

> 2800 BNS signals/day

BHNS: 45s*

> 1900 BH signals/day

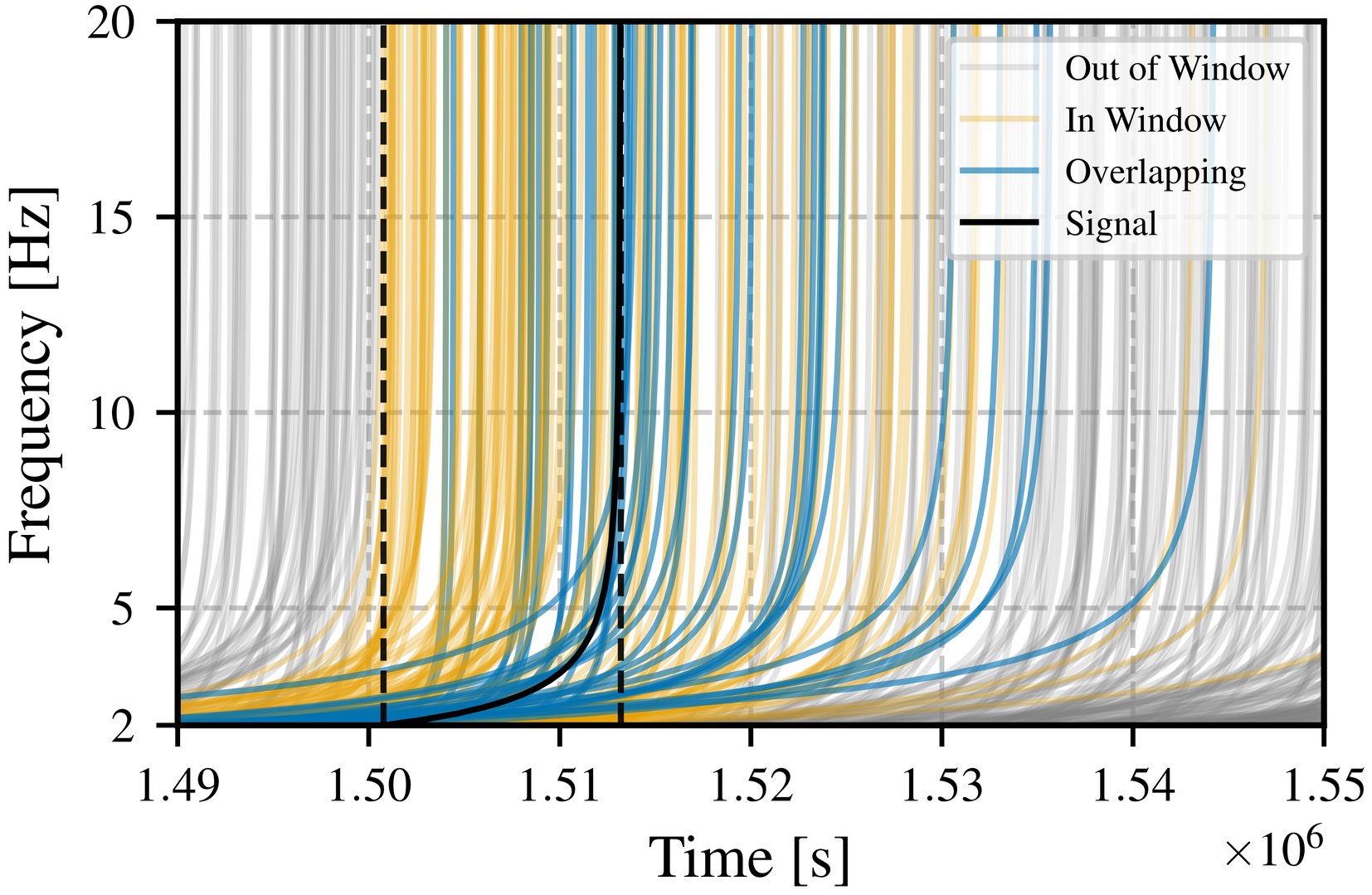
BBH: 6min*

> 200 BBH signals/day

*exact number depending on uncertainties in the binary merger rate and distribution function

Broekgaarden et al. (2023)

Foreground noise

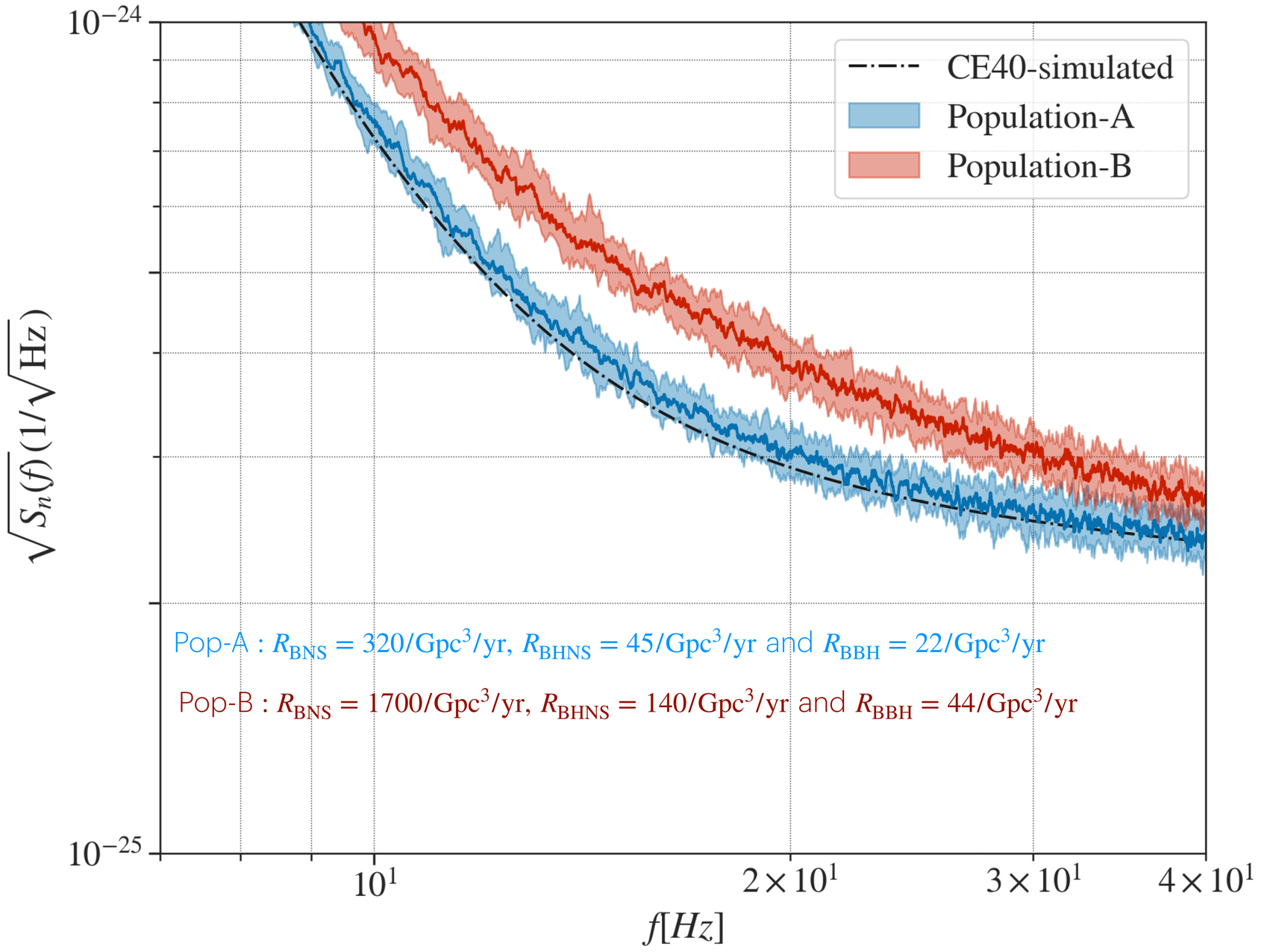


- **Long-lived and frequent signals → Overlapping in-band signals**

  At any given time, multiple signals may overlap in the detector band, introducing non-stationary features in the data.

- Low-frequency signal strain ≠ wide-sense stationary Gaussian noise
- This impacts accurate estimation of the data power spectrum
- **But how bad it is?**

A Johnson et al (2023)



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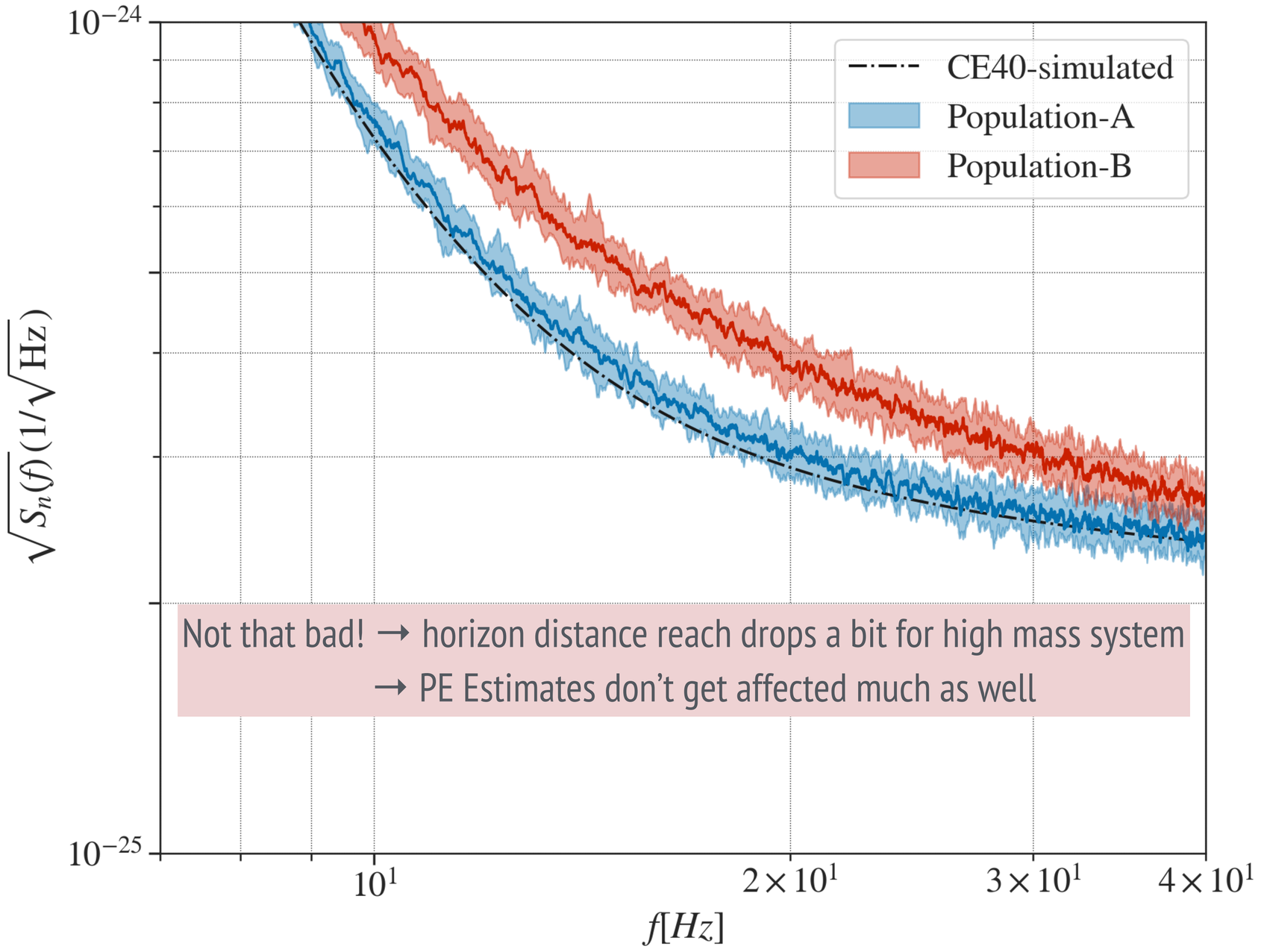
Ish Gupta, Koustav Chandra and B. Sathyaprakash (2024)



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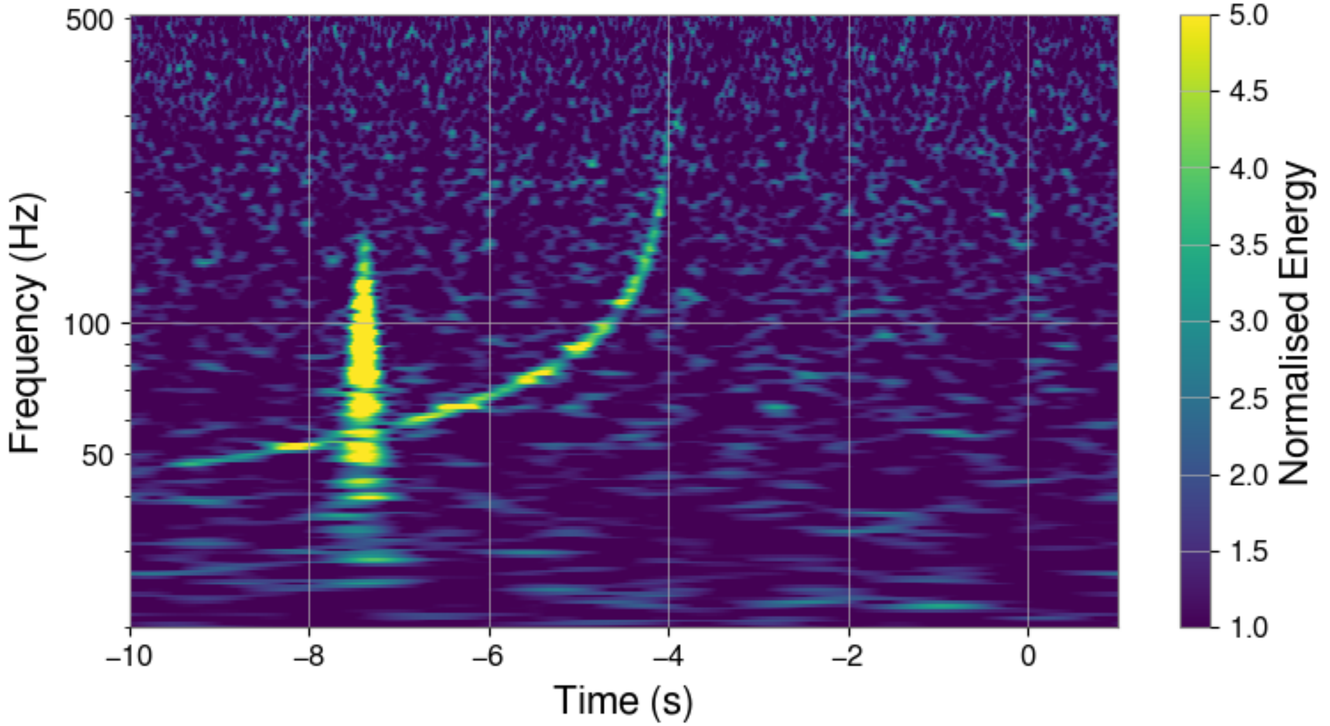
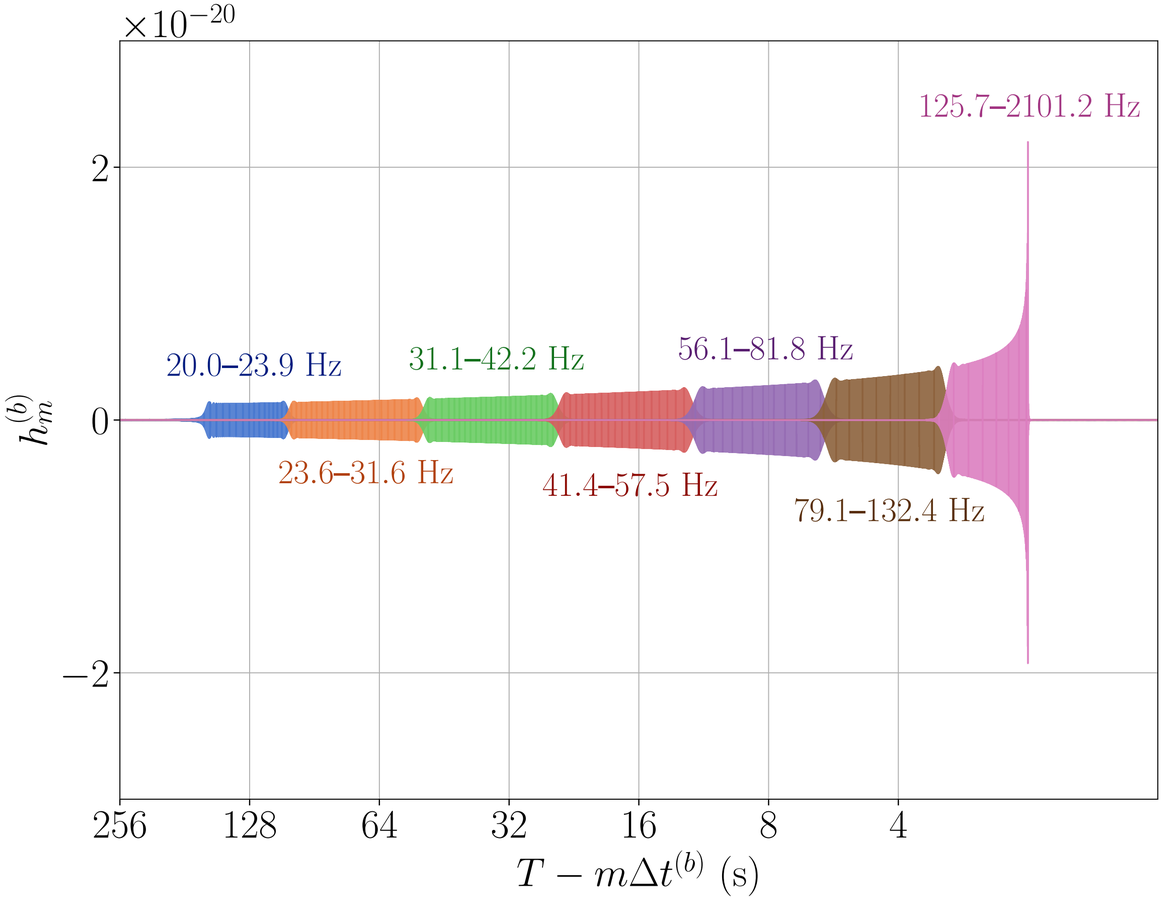
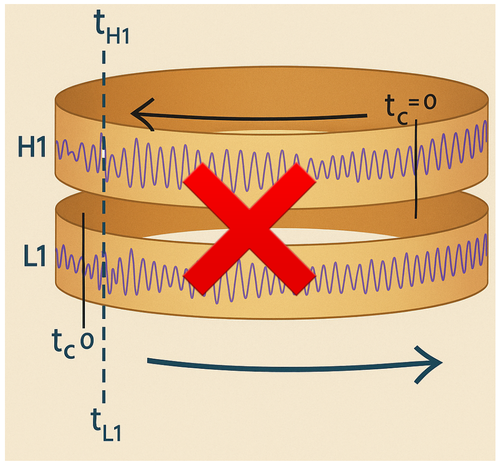
☠️ Overlapping signals with glitches ☠️

- **Long-lived and frequent signals**
- **XG detectors** will be **more sensitive → more glitches**
  - **No idea how bad they will be!**
  - Glitches already occurred >1 per minute in O4
  - Detected signals required glitch mitigation
- **Glitch characterization & subtraction must be automated**
  - Manual interventions (e.g., GW170817) not scalable
- Use non-Gaussian proof PE methods
  - Score-based likelihood (**Legin et al 2024**)
  - Simulation-based inference (**Dax et al 2024**, **Bhardwaj et al 2023**, Marx .)



Nirban Bose, Archana Pai, Koustav Chandra et al (2020)





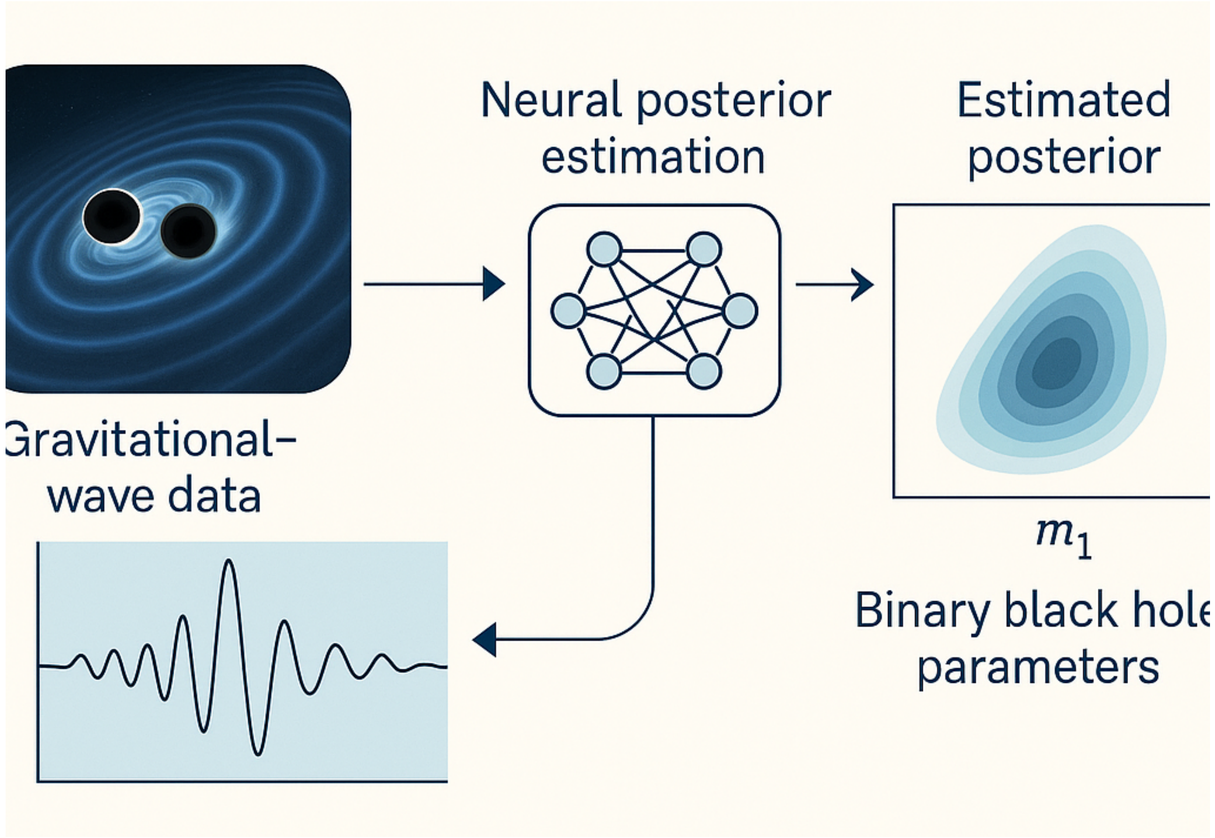
Sheer number and length of signals

Matched-Filter Searches:

- **Longer Signals → Larger Banks → Size Reduction via SVD** (already used by GstLAL)
- **Overlapping Signals → not an issue** as MF is a linear filter
- **Accelerating the Search**
  - **Multi-banding:** Slashes computation (already used by MBTA)
  - **GPU Acceleration** (Nitz 2015, Chu et al 2020, Huang et al 2024)
- **Glitches:** Use (semi-)coherent methods instead of coincident + Better vetoes (?)
- **Background Estimation Limits: Time-slide techniques will break** down in signal-rich data

Unmodelled Searches: can detect overlapping signals, but identify them as a single event rather than separating them (Relton et al 2022)

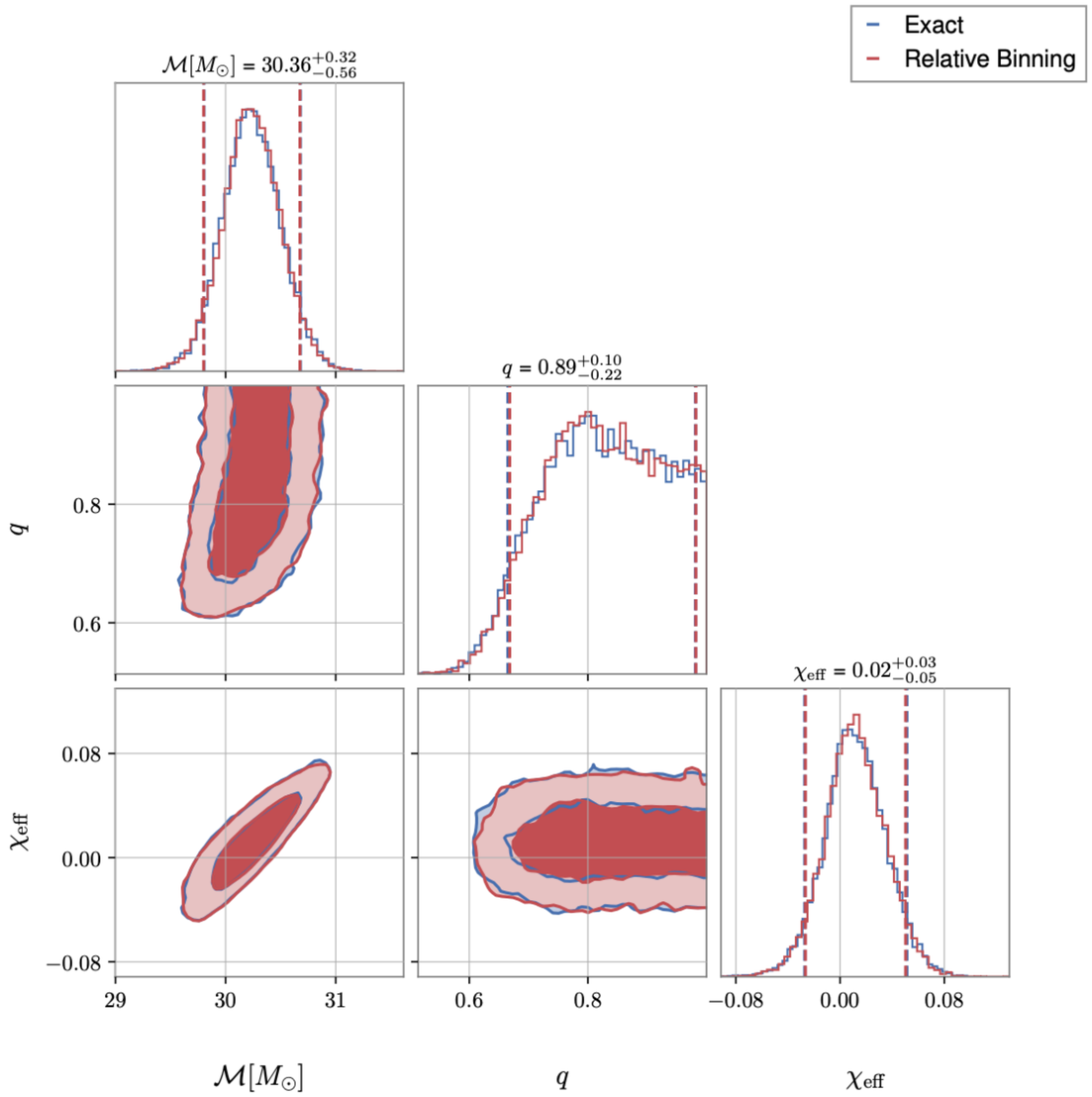
Sheer number and length of signals



Parameter Estimation

- **Simulation-based inference**
  - Neural networks / amortization [Dax et al 2024, Bhardwaj et al 2023]
- Less of a need for faster waveforms

Sheer number and length of signals



Parameter Estimation

- **Simulation-based inference**
  - Neural networks / amortization [Dax et al 2024, Bhardwaj et al 2023]
- **Faster likelihoods**
  - faster waveforms → probably frequency domain surrogate models
  - multi-banding, heterodyning, ROQ, etc.
- **Efficient sampling**
  - Hamiltonian MCMC (DeepMCMC [Perret & Porter 2025])
  - GAMES [Nitz 2024]
  - ML-enhanced samplers (nessai [Williams et al 2023])

- **Fixed sky location assumption** works for 2G signals
- **BNS inspirals in XG detectors** can last >1000s → **Slow amplitude & phase modulation as IFO response time-dependent**

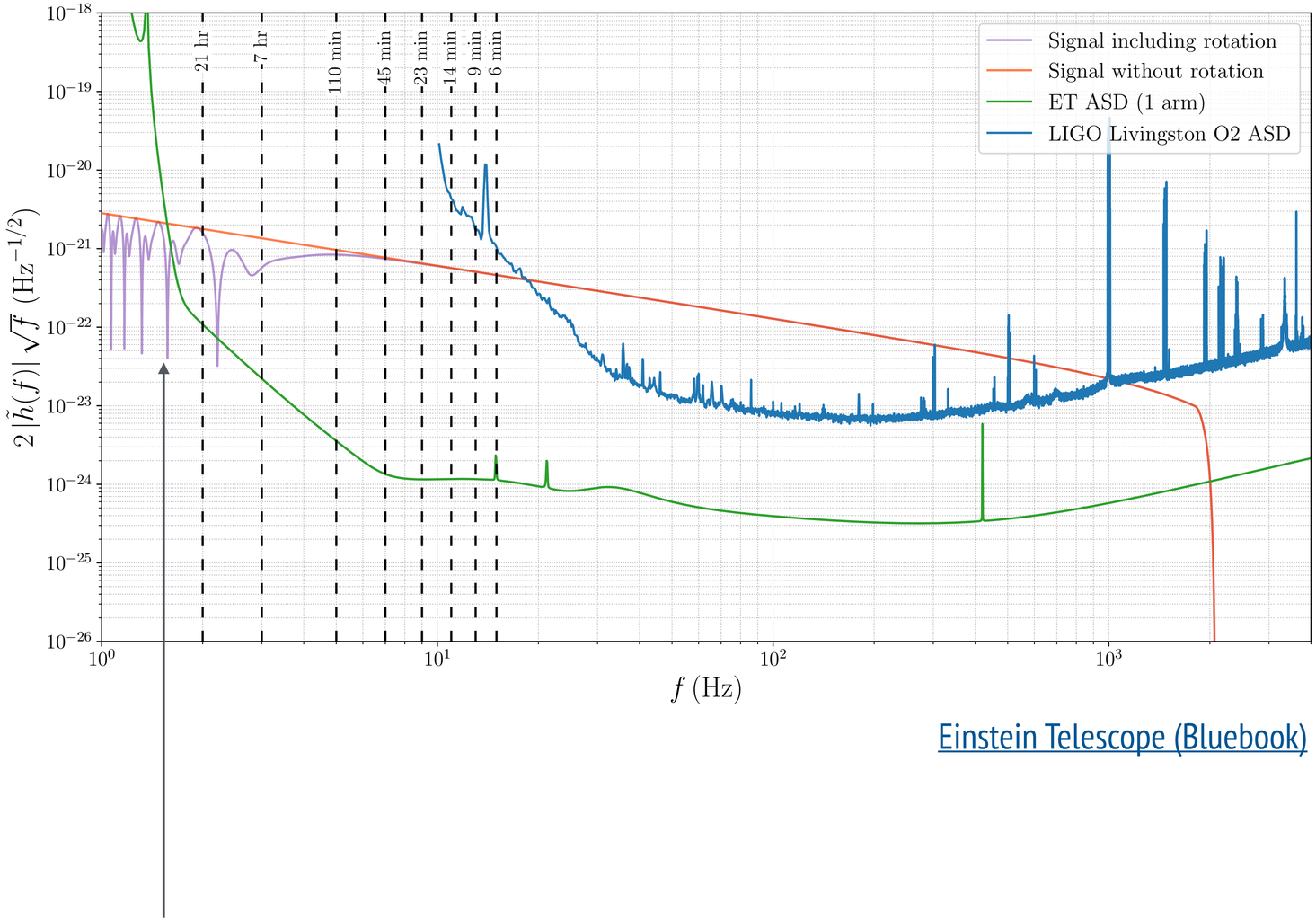
Searches

- **Solution**: Use template banks covering **sky location + intrinsic parameters**
- **No need** → SNR loss negligible (χ_r^2 slightly large) for most detections [Meacher et al 2015]

PE

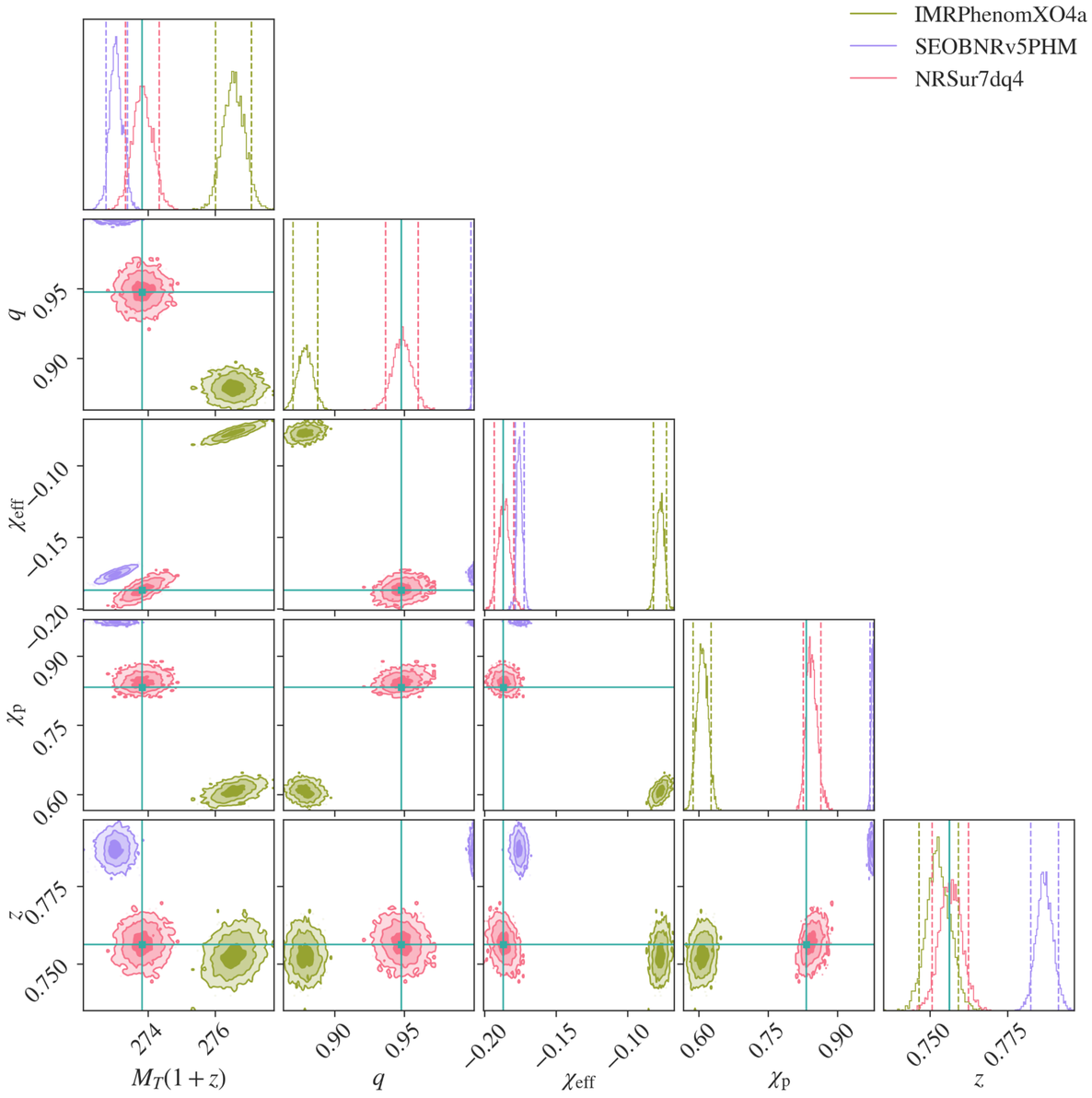
- Frequency-dependent antenna-response codes exists [Biwer et al (2018), Baral et al (2025)]

Comparison of Amplitude modulation



Einstein Telescope (Bluebook)

GW370817 (with and without accounting for Earth's rotation)



🤕List of my headaches (Should be yours too)

- **Noise Modelling & Glitches**
  Now with bonus jump scares!
- **Too Many Waveforms, PE Methods, Searches**
  "Lost in parameter space 🧭🌀 — Send help (and maybe a flowchart)."
- **Waveform Systematics**
  "Still haunting us like a ghost ex 😬👻 — Sorry Rossella, don't 🔪 me!"
- **Calibration Uncertainty**
  "What even is the true strain? 🤷📉 — If I don't know, it's definitely a problem!" & we want no human intervention (even if to do just astrophysics)
- **Computational Resources**
  "WE NEED MORE CLUSTER!!! 🖥️💥 — and by that, I mean 💰💰💰

What’s your headache?