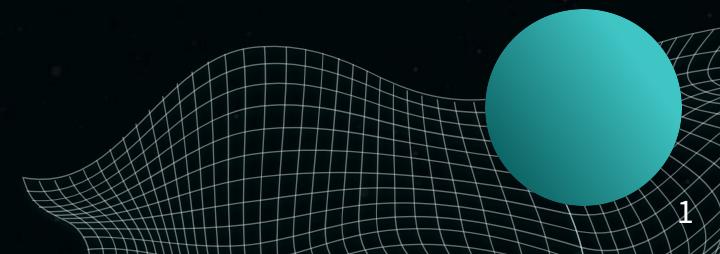




Designing an All-Sky Search on Einstein@Home

Brian McGloughlin

The 2024 BNU Continuous Gravitational Waves Workshop





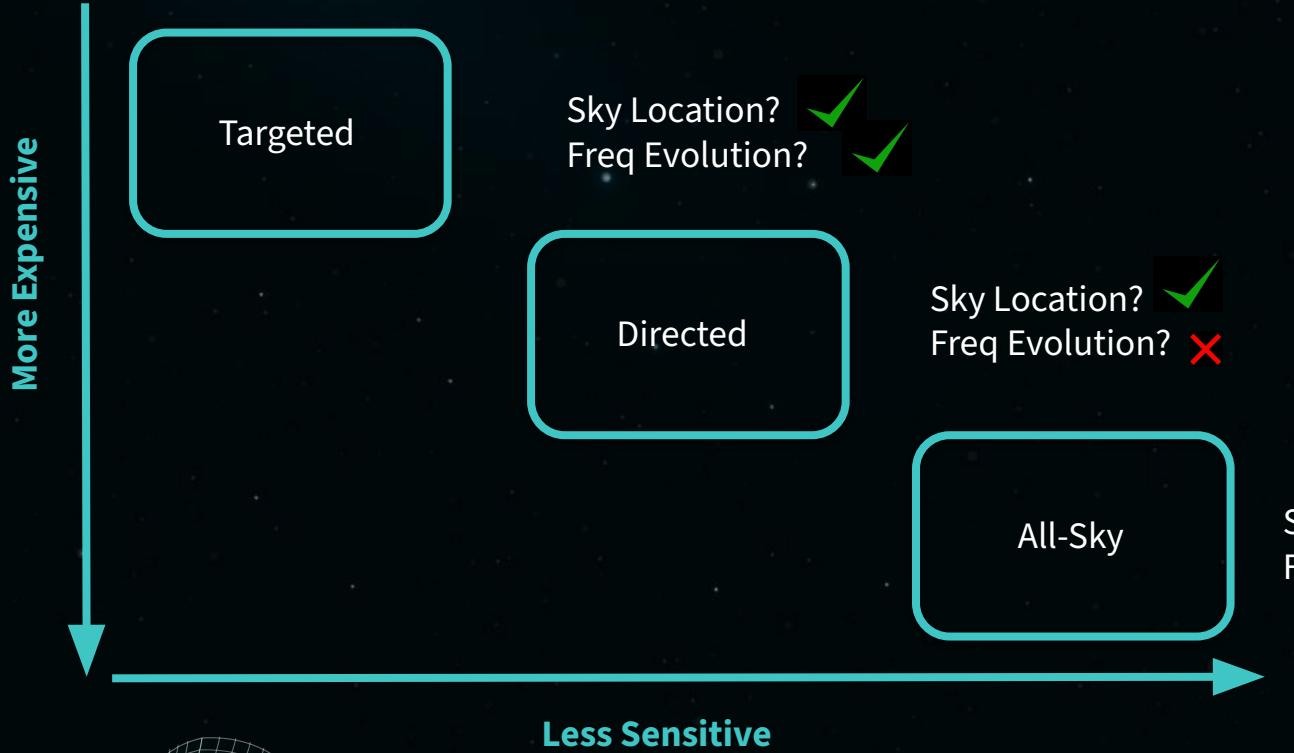
17	Suzhou	Jiangsu	5,892,892
18	Jinan*	Shandong	5,648,162
19	Changsha*	Hunan	5,630,256
20	Kunming*	Yunnan	5,273,144
21	Harbin*	Heilongjiang	5,242,897
22	Shijiazhuang*	Hebei	5,090,440
23	Hefei*	Anhui	5,055,978
24	Dalian~	Liaoning	4,913,879
25	Xiamen†	Fujian	4,617,251



Outline

- Introduction
- Timing Einstein@Home Searches
- Choosing a Search Setup
- Sensitivity Estimates
- Outlook

Types of Searches



The Signal at Detector

8 Parameters

Amplitude

- GW amplitude: h_0
- Inclination angle: ι
- Polarization angle: ψ
- Initial phase: Φ_0

Phase Evolution

- Freq evolution: f $f^{(k)}$
- Sky position: α δ

$$h(t; \mathcal{A}, \lambda) = \sum_{\mu=1}^4 \mathcal{A}^\mu h_\mu(t; \lambda)$$

$$h(t) = F_+(\alpha, \delta, \psi; t)h_+(t) + F_X(\alpha, \delta, \psi; t)h_X(t)$$

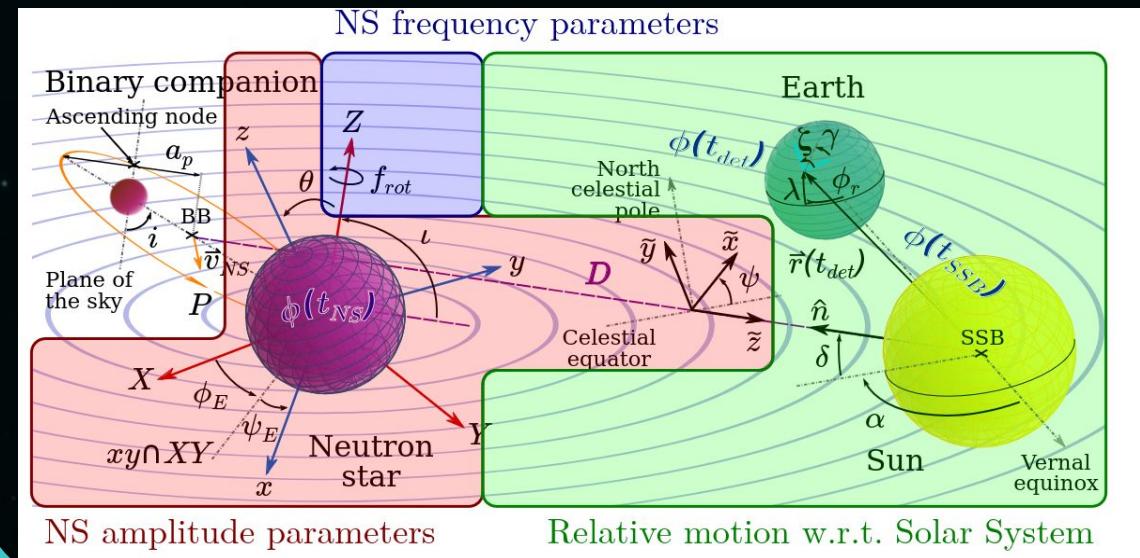
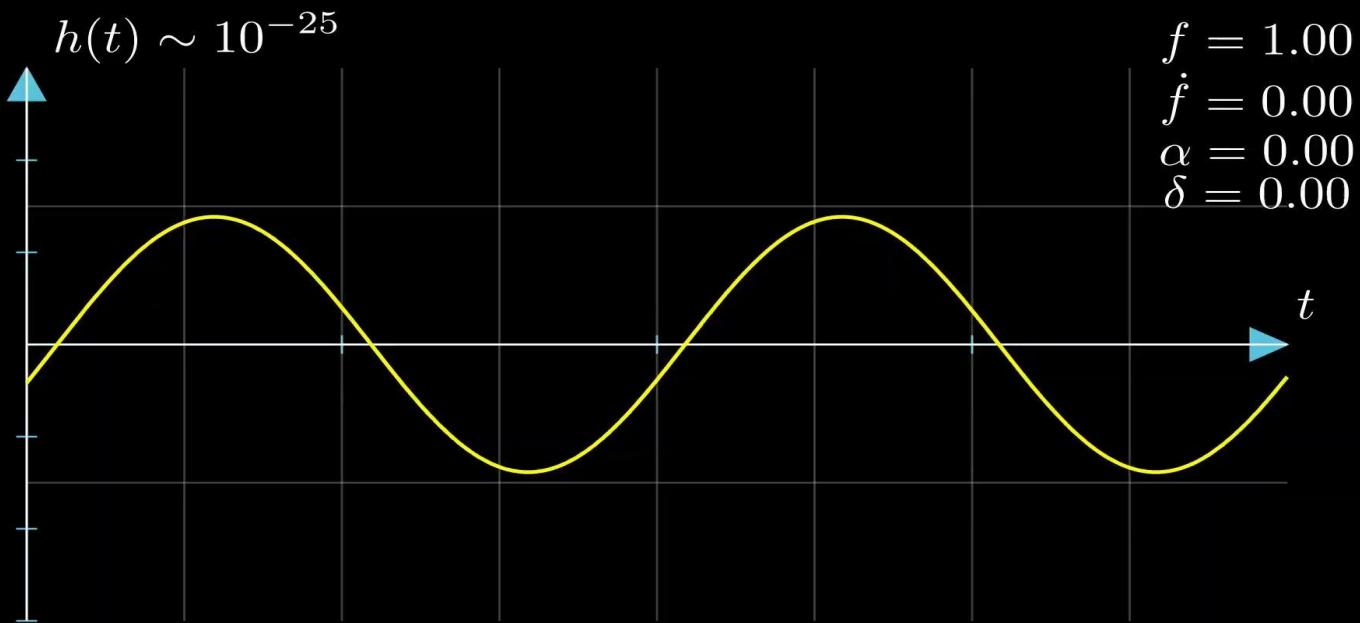


Image credits: K. Wette, Astroparticle Physics 153, 102880 (2023)

Example: Signal at Hanford



$$h(t) = F_+(\alpha, \delta, \psi; t)h_+(t) + F_\times(\alpha, \delta, \psi; t)h_\times(t)$$

Detection Statistic

$$\Lambda = \frac{P(x(t)|h(t))}{P(x(t)|0)}$$

$$\mathcal{F} \equiv \log \Lambda|_{MLE}$$

Data

Is the data more similar to ...

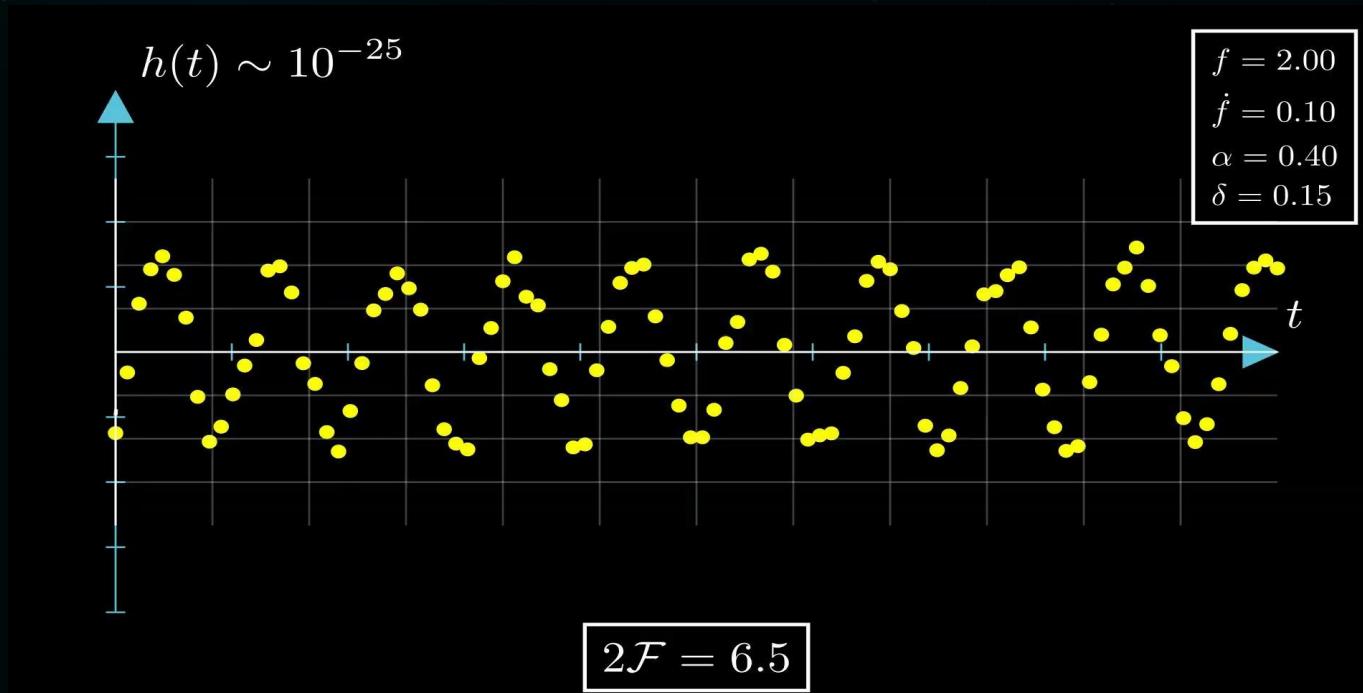
Gaussian Noise?

2F Lower

Gaussian Noise + Signal
with $(\alpha, \delta, f, \dot{f})$?

2F Higher

Detection Statistic

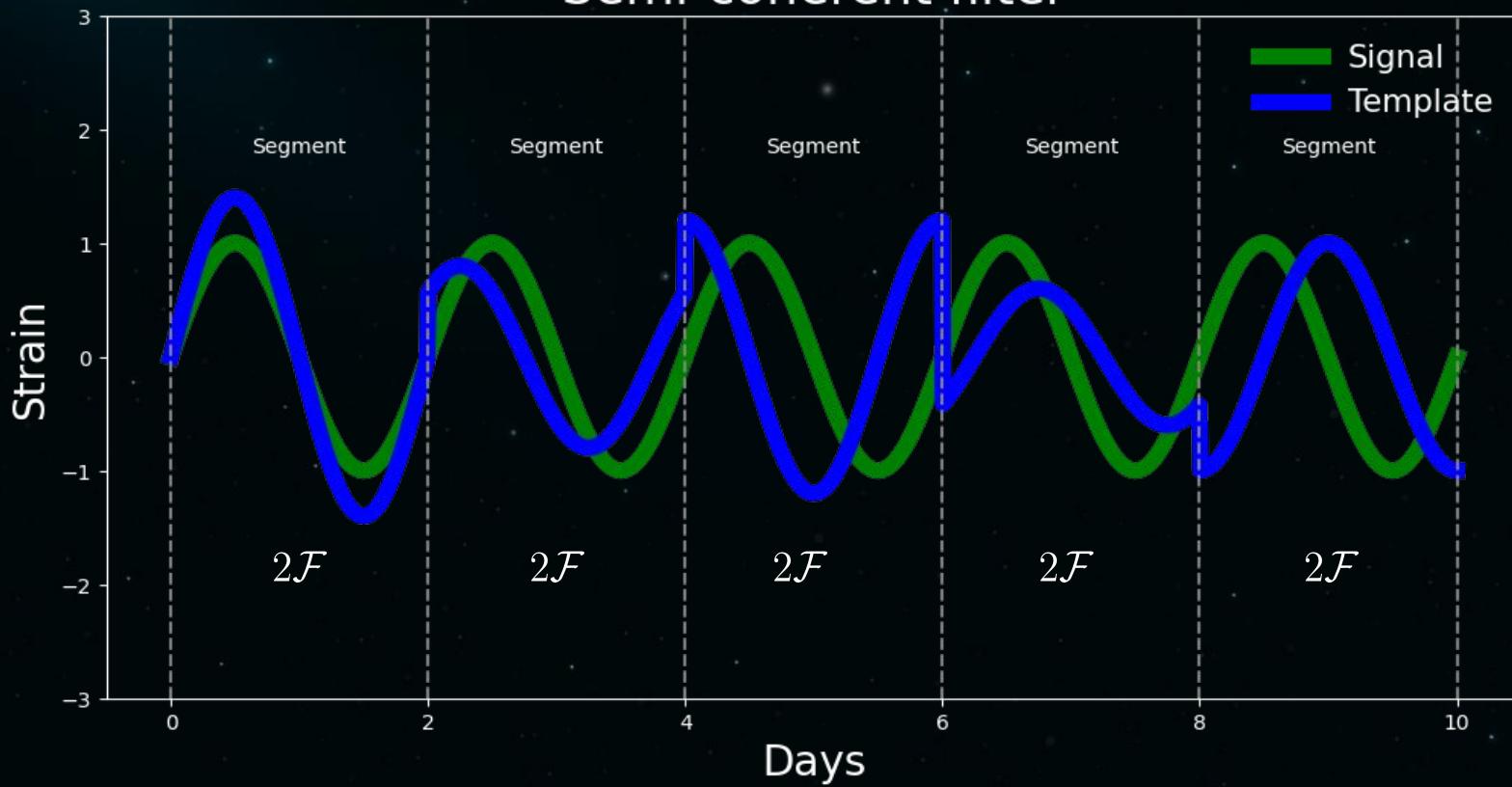


Mismatch

$$\frac{2\mathcal{F}^{PM} - 2\mathcal{F}^{MM}}{2\mathcal{F}^{PM} - 4}$$

Denser grid \Rightarrow
Lower Mismatch \Rightarrow
Higher Runtime

Semi-coherent filter



Computational Cost

Cost of search \propto # of templates * log likelihood calc time

Example: Previous all sky search on O3a data on E@H:

Coherent

Freq ~ 32 billion choices
Sky ~ 9.9 trillion choices
f1 ~ 670 thousand choices

~ 728 octillion templates

~ 2.14×10^{14} years
~ Age of universe * 15000

Semi-Coherent

Freq ~ 2.5 million choices
Sky ~ 547 million choices
f1 ~ 5 thousand choices

~ 6.8 quintillion templates

~ 2000 years of compute time

Fully coherent

- Sensitivity $\propto T_{obs}^{\frac{1}{2}}$
- Cost $\propto T_{obs}^m$

Semi Coherent

- Sensitivity $\propto N_{seg}^{\frac{1}{4}} T_{seg}^{\frac{1}{2}}$
- Cost $\propto N_{seg}^n T_{seg}^m$ ($n \ll m$)

Deep Einstein@Home all-sky search for continuous gravitational waves in LIGO 03 public data

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ABSTRACT

We present the results of an all-sky search for continuous gravitational waves in the public LIGO O3 data. The search covers signal frequencies $20.0\text{ Hz} \leq f \leq 800\text{ Hz}$ and a spin-down range down to $-2.6 \times 10^{-9}\text{ Hz s}^{-1}$, motivated by detectability studies on synthetic populations of Galactic neutron stars (Pagliaro et al. 2023). This search is the most sensitive all-sky search to date in this frequency/spin-down region. The initial search was performed using the first half of the public LIGO

ATLAS and Einstein@Home



Credit: M. Fiorito/Max Planck Institute for Gravitational Physics

Einstein@Home

The screenshot shows the Einstein@Home website homepage. At the top, there is a navigation bar with links for HOME, NEWS, SCIENCE, COMMUNITY, and HELP. To the right of the navigation bar are LOGIN and SEARCH buttons. The main content area features a large image of a galaxy or nebula. On the left, a section titled "What is Einstein@Home?" explains the project's purpose: searching for weak astrophysical signals from spinning neutron stars using data from various detectors. Below this text is a blue "JOIN NOW" button. On the right, there are two news cards. The first card, titled "Einstein@Home Progress (Credits per day)", shows a line graph of fluctuating blue bars representing credit generation over time. The second card, titled "New Improved Gravitational Wave App & Happy New Year 2024 Special", discusses the GPU accelerated GW app and its reduced memory usage. It includes a "MORE | DISCUSS 49" link. The third card, titled "A New Fermi Gamma Ray Pulsar Catalog Has Just Been Published!", announces the publication of a catalog of gamma-ray pulsars discovered by NASA's Fermi Gamma-ray Space Telescope. It includes a "MORE | DISCUSS 27" link. At the bottom, there are sections for "User of the day" (LISYAMORD), "Over 500,000 volunteers and counting." (with links for WINDOWS, MAC, and LINUX), and footer links for FAQ, Moderation, Source Code License, Imprint, and Privacy Policy. The footer also includes APPLICATIONS, SERVER STATUS, Language selection, and a RSS feed icon.

einstein
home

HOME NEWS SCIENCE COMMUNITY HELP

LOGIN | SEARCH

What is Einstein@Home?

Einstein@Home uses your computer's idle time to search for weak astrophysical signals from spinning neutron stars (often called pulsars) using data from the LIGO gravitational-wave detectors, the MeerKAT radio telescope, the Fermi gamma-ray satellite, as well as archival data from the Arecibo radio telescope.

[Learn more](#)

[JOIN NOW](#)

User of the day
LISYAMORD

Over 500,000 volunteers and counting.
WINDOWS MAC LINUX

Einstein@Home Progress
(Credits per day)

New Improved Gravitational Wave App & Happy New Year 2024 Special
January 16, 2024
Dear crunchers!
We would like to share with you two things:
a) the GPU accelerated GW app is now much less memory hungry...
[MORE | DISCUSS 49](#)

A New Fermi Gamma Ray Pulsar Catalog Has Just Been Published!
November 28, 2023
The latest catalog of gamma-ray pulsars discovered in data from NASA's Fermi Gamma-ray Space Telescope has just been published in the ...
[MORE | DISCUSS 27](#)

FAQ / Moderation / Source Code License / Imprint / Privacy Policy

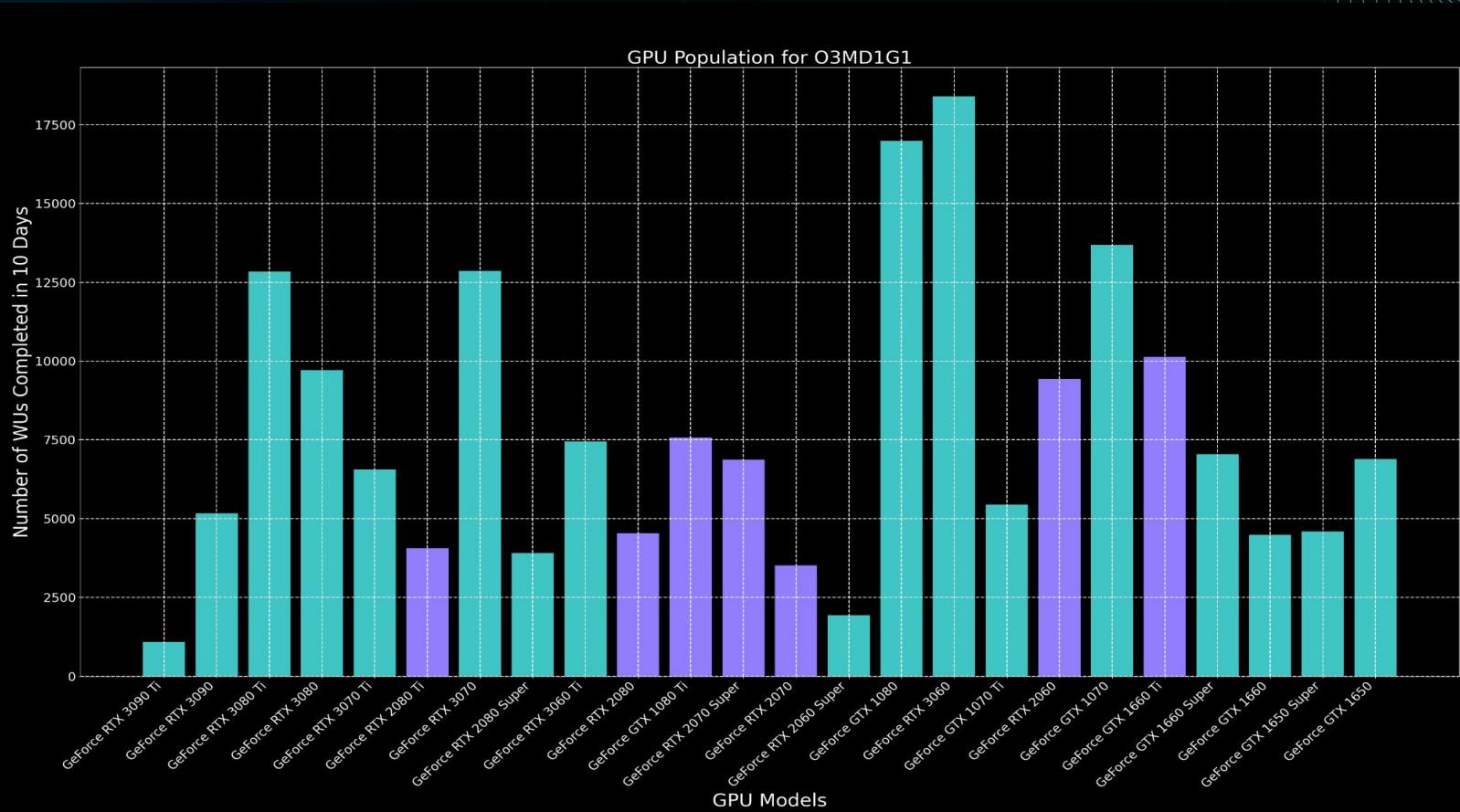
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APPLICATIONS | SERVER STATUS

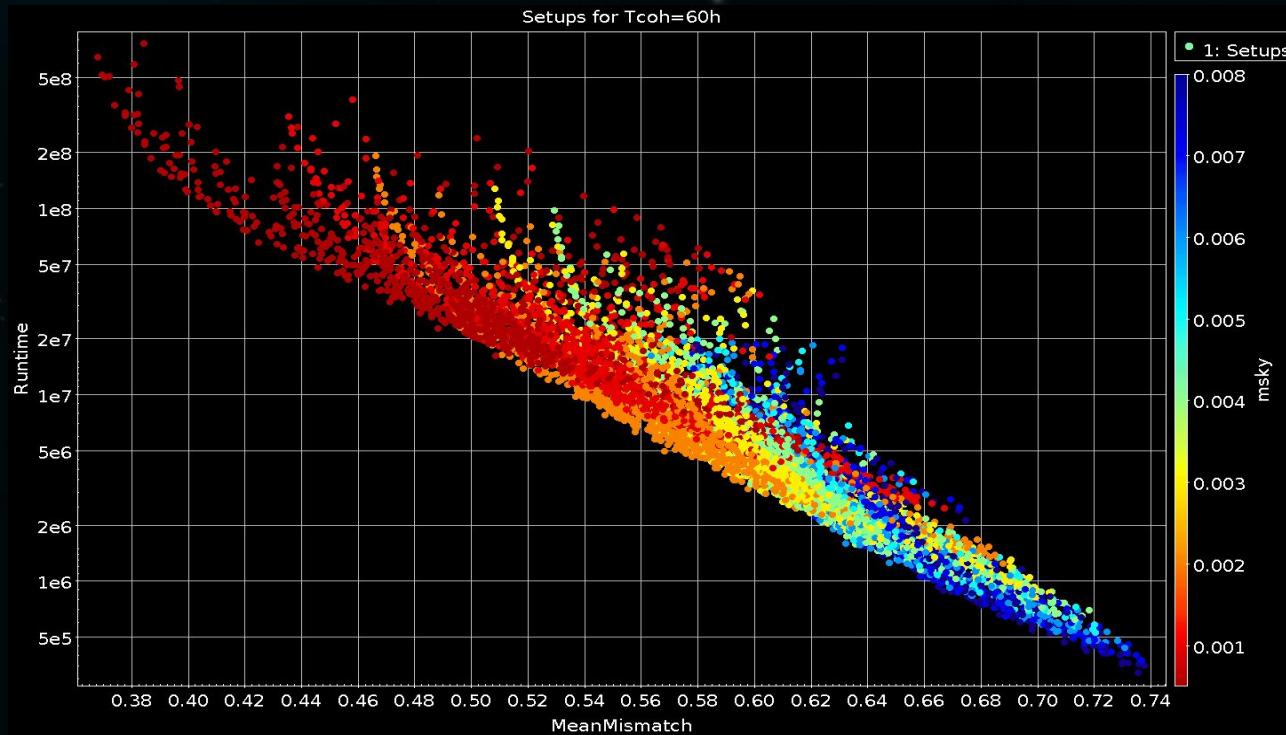
Language

Einstein@Home

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Mismatch V Computational Cost



Sensitivity Estimates

What does it mean to “recover” a signal?

- Choose the loudest candidate per x number of templates
- Would this candidate be louder than a signal with strength ρ ?
- If not then the signal is recovered, else not.



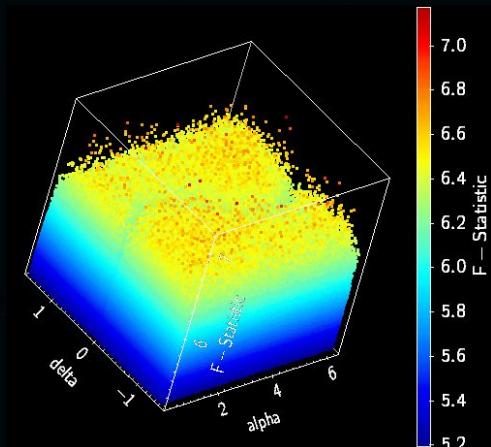
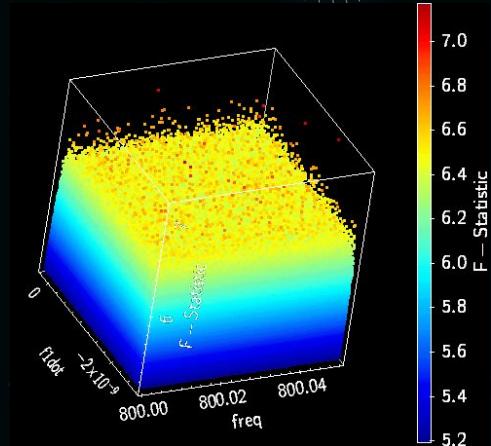
Do injection search and recovery multiple times? - EXPENSIVE \times

Instead: Our Method

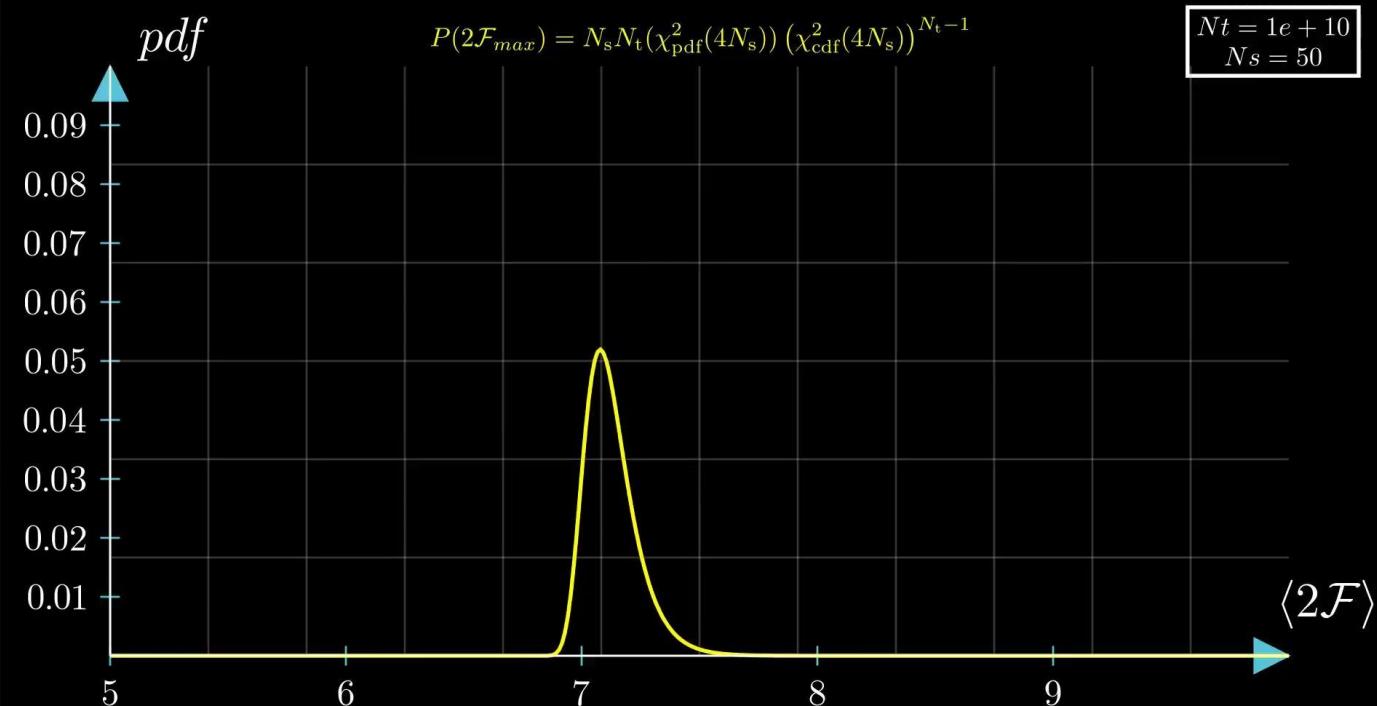
$$2\mathcal{F}_{Noise}^{max} \sim \text{Known}$$

- No MC simulations required!
- “Semi-Analytical”

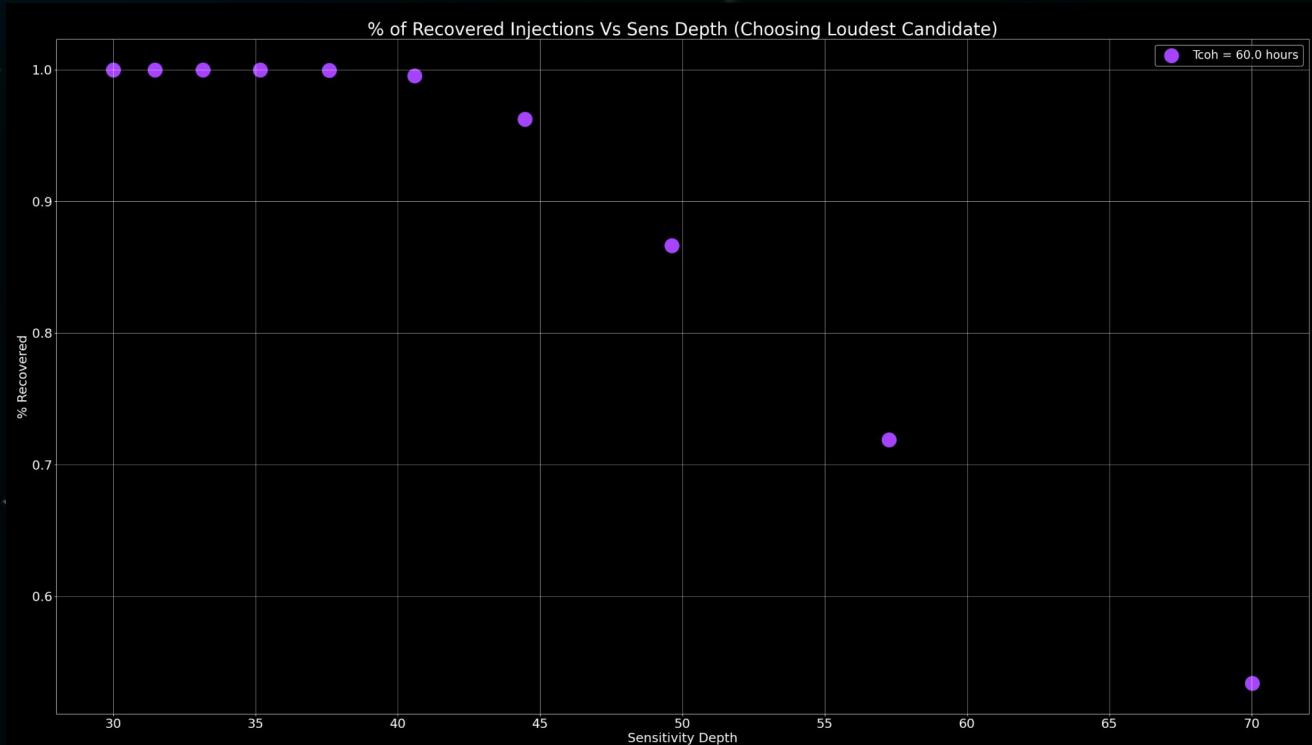
$$2\mathcal{F}_{sig} \sim \chi^2(4N_s, \rho^2)$$



Semi Analytic Sensitivity

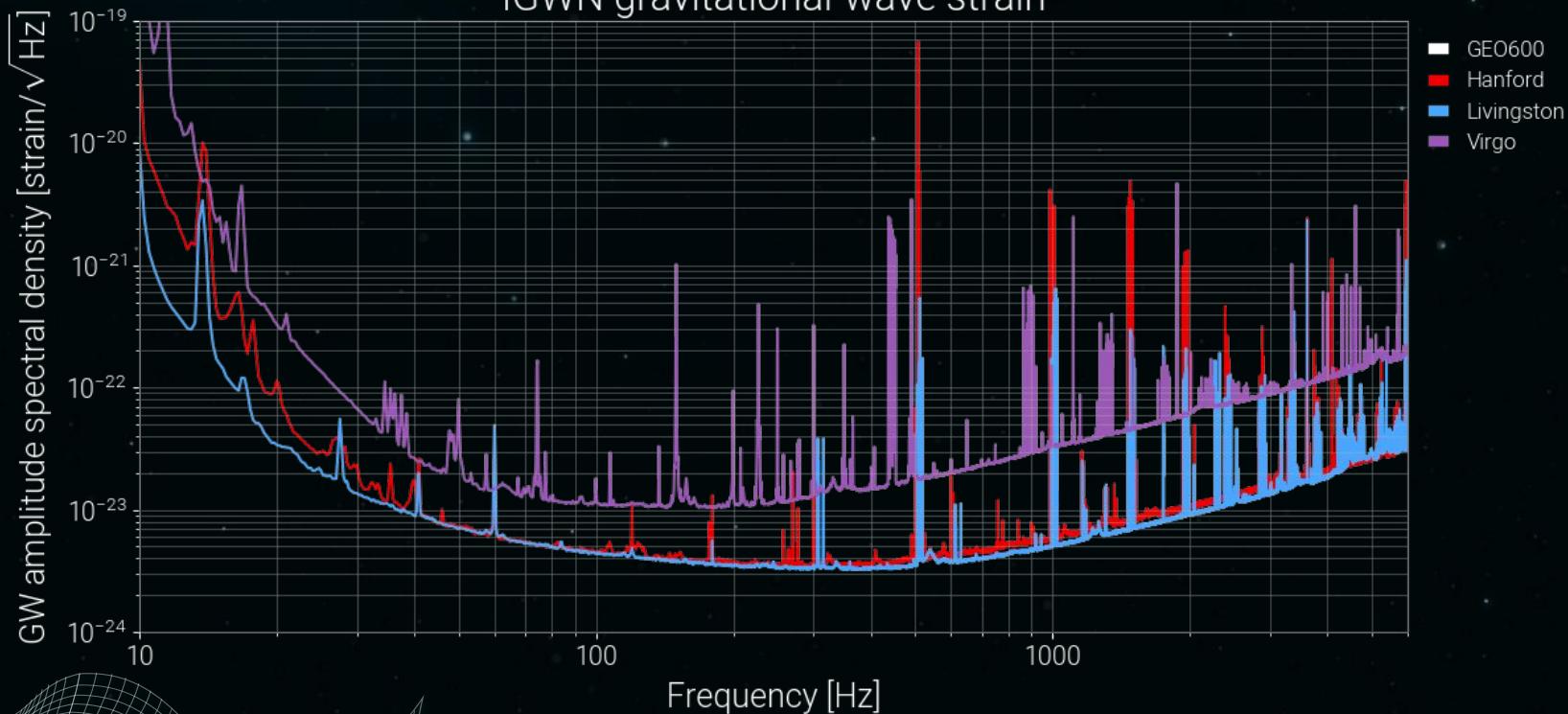


Detection Probability



Outlook - O4

[1403222418-1403308818, state: Observing]
IGWN gravitational-wave strain



Thank you!