Tests of Gravity with LISA and 3rd Generation Detectors

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Montana State University

Numerical Relativity Beyond GR,

Benasque, Spain

June 8th, 2018

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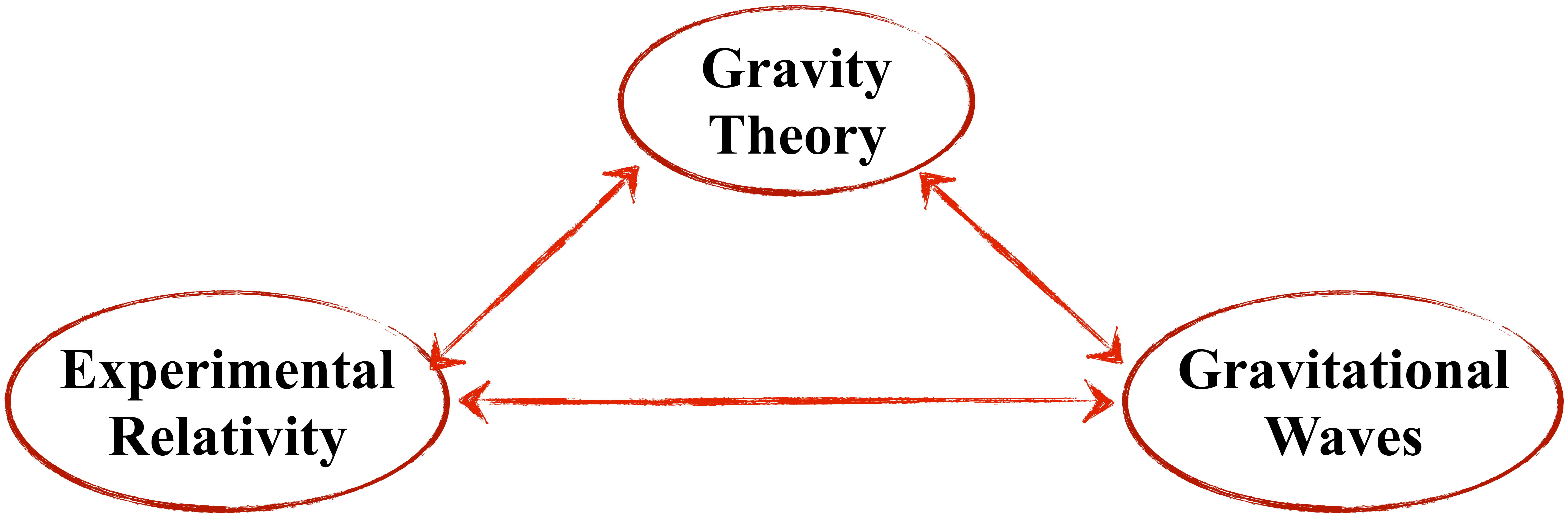
eXtreme Gravity Institute

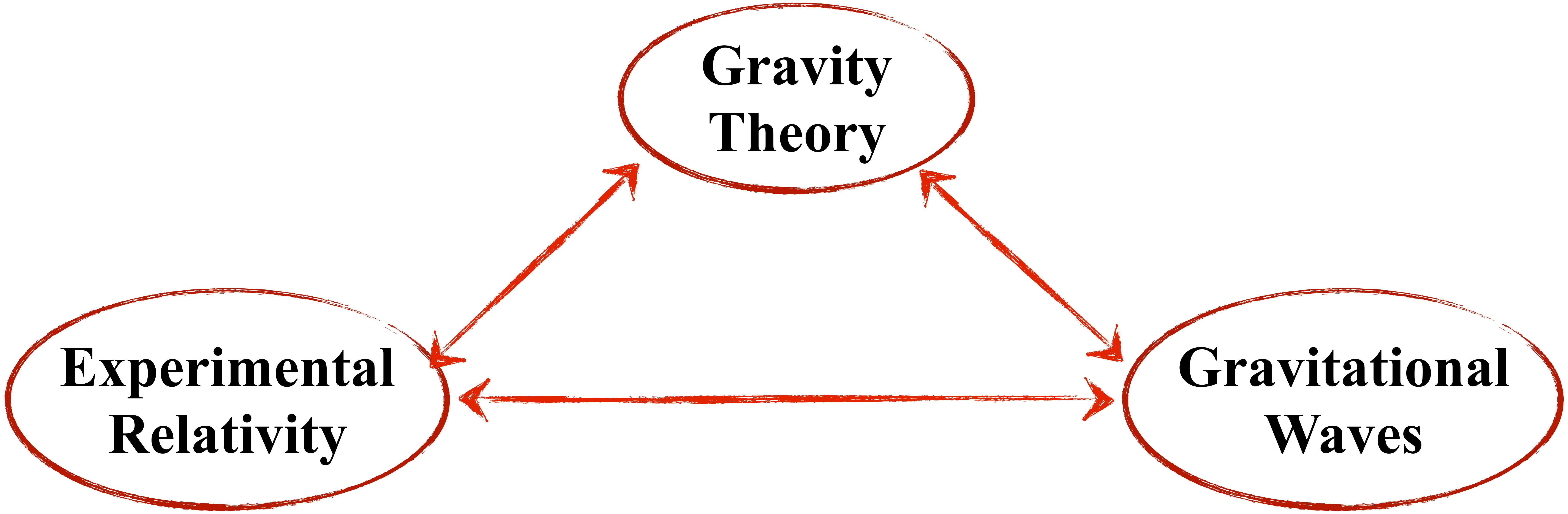
Co-Chair of NASA PCOS GWSIG &

Fundamental Physics in LISA Consortium

Who are you again?



Who are you again?



What can we learn about theoretical physics from future GW observations?

A Fantastical Timeline

2018 2022 2026 2030 2034

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aLIGO

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aLIGO A+

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improved quantum noise
improved thermal coating
increased range to 140% wrt aLIGO

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mild-to-moderate improvement of constraints

Example: Ground-based constraints on Graviton

$$\frac{v_g^2}{c^2} = 1 - \frac{m_g^2 c^4}{E^2}$$

$$\tilde{h}(f) = \tilde{h}_{GR}(f)\,(1 + \alpha f^a)\,e^{i\beta f^b}$$

$$\beta = \pi^2 \frac{D\,\mathcal{M}_z}{1+z} m_g^2$$

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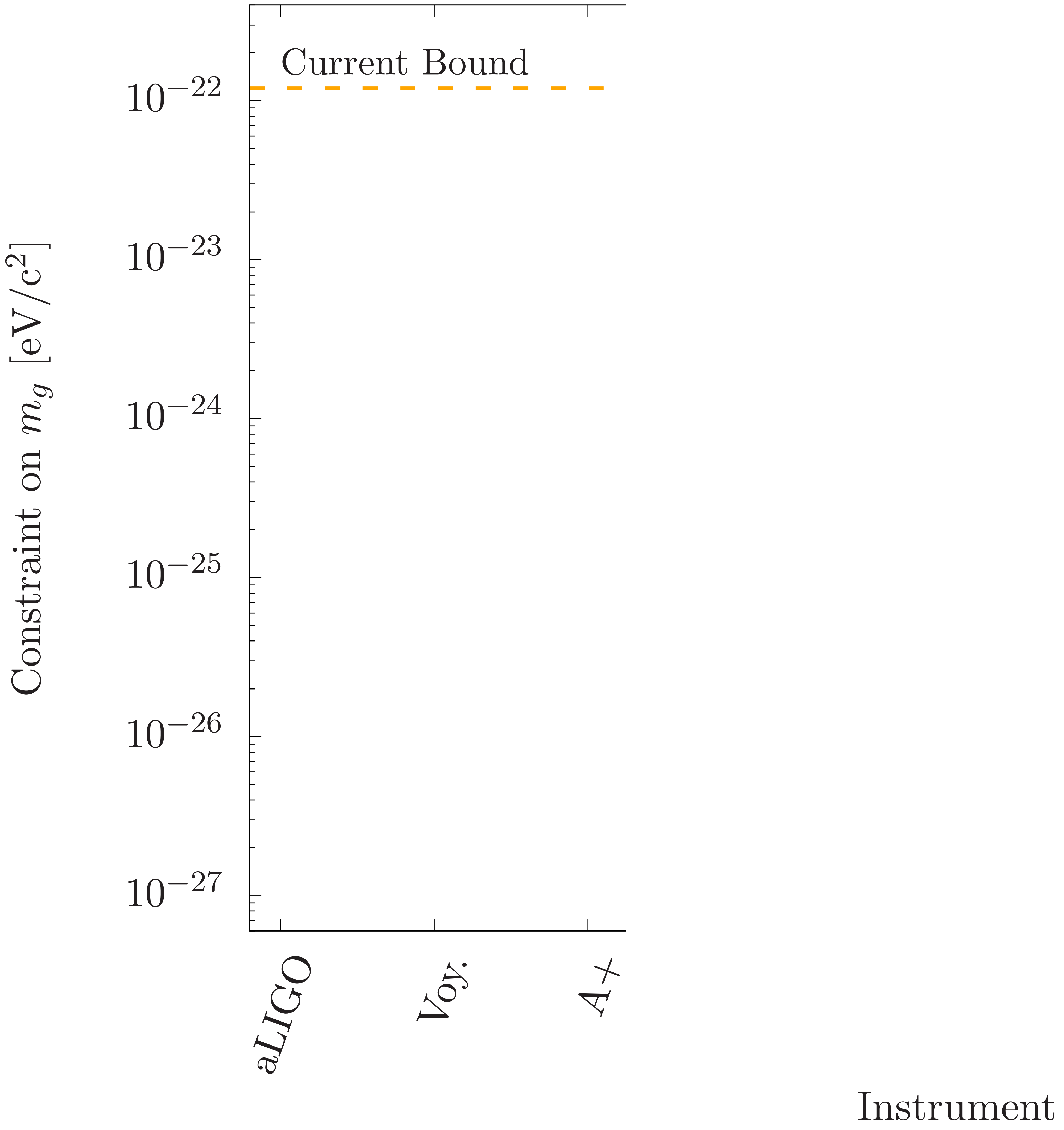

[Chamberlain & Yunes, PRD '17]

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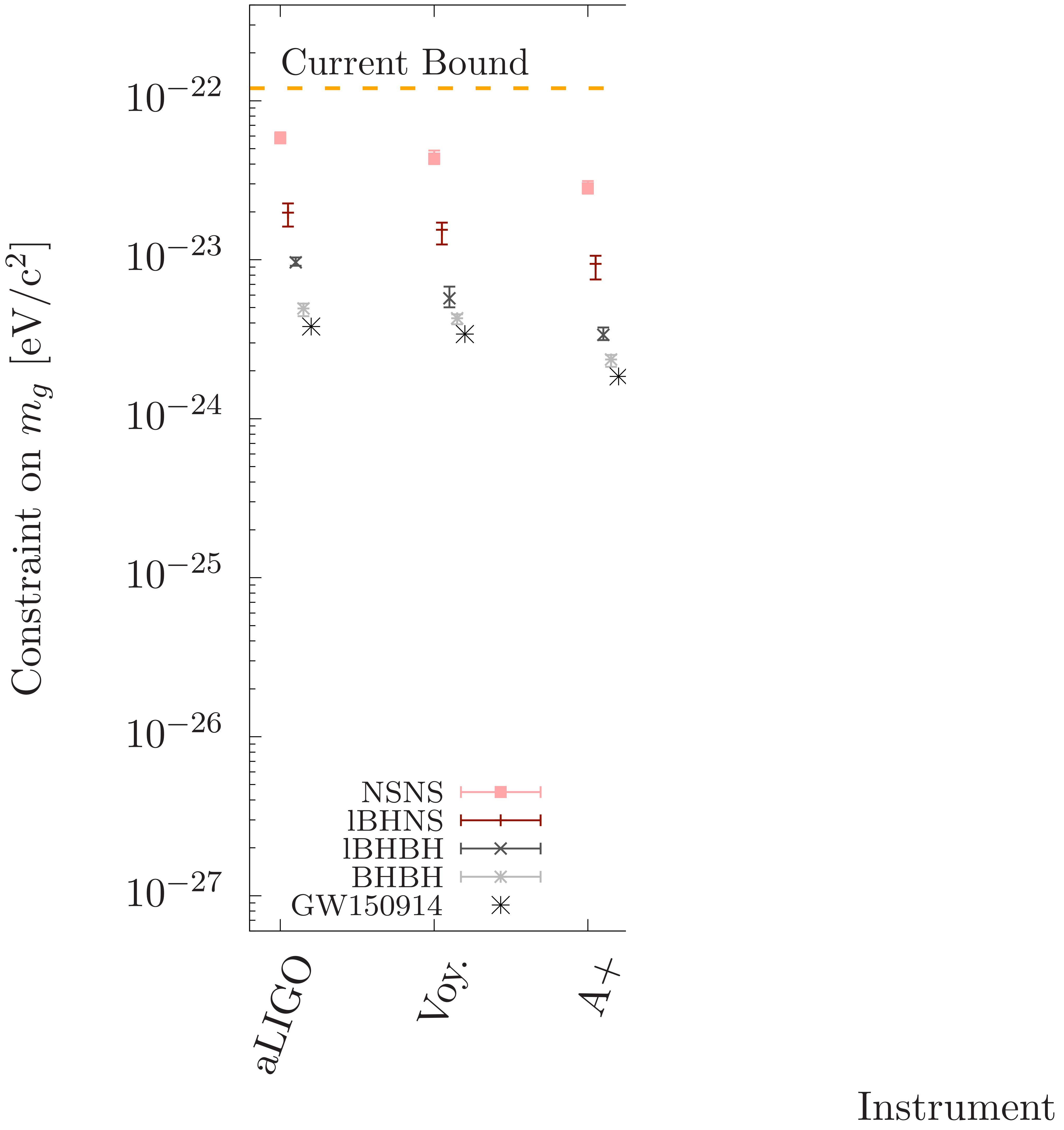

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Cosmic Explorer

fractional improvement of constraints

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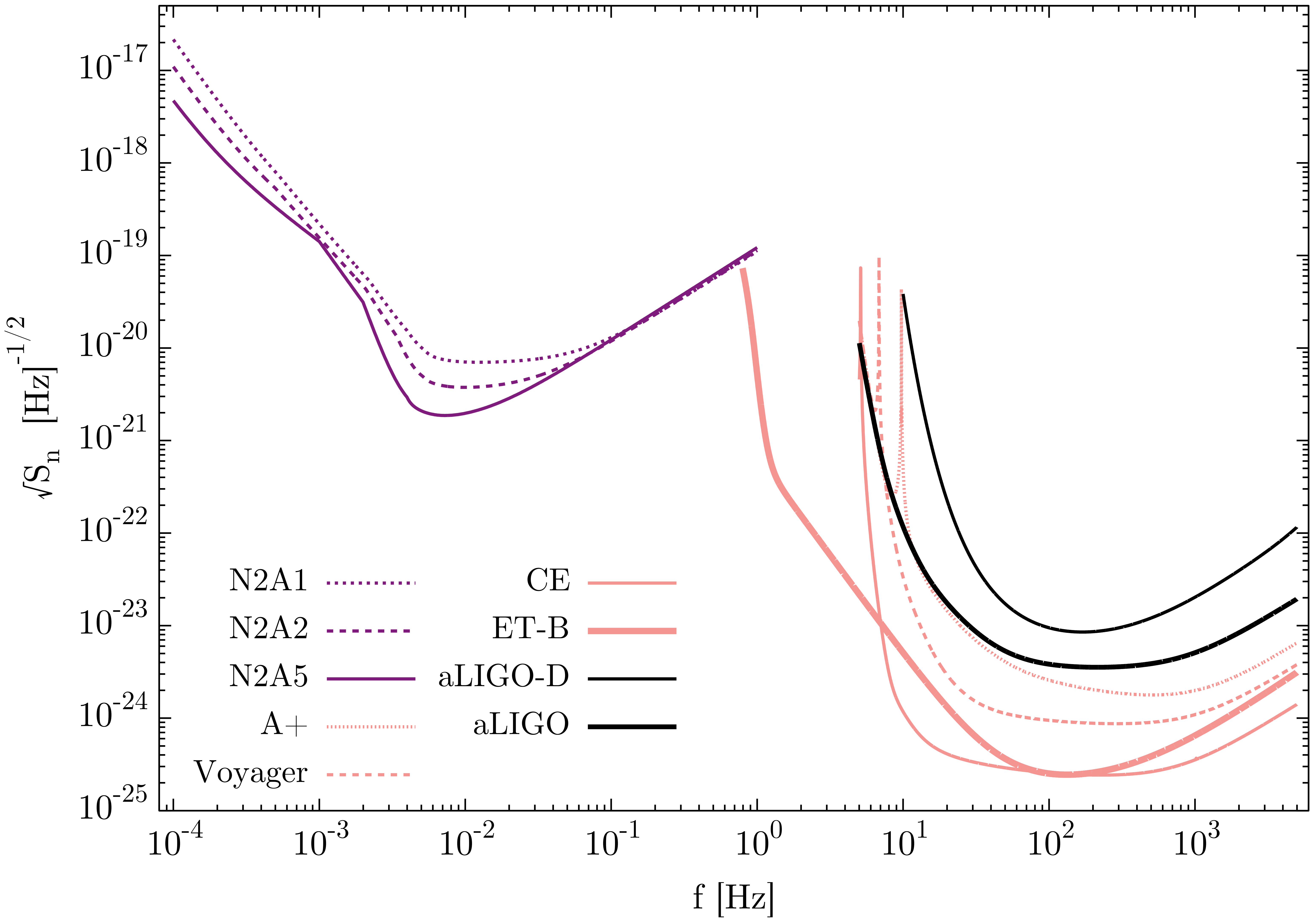
New Tests

New how? Example: Multi-Band Events



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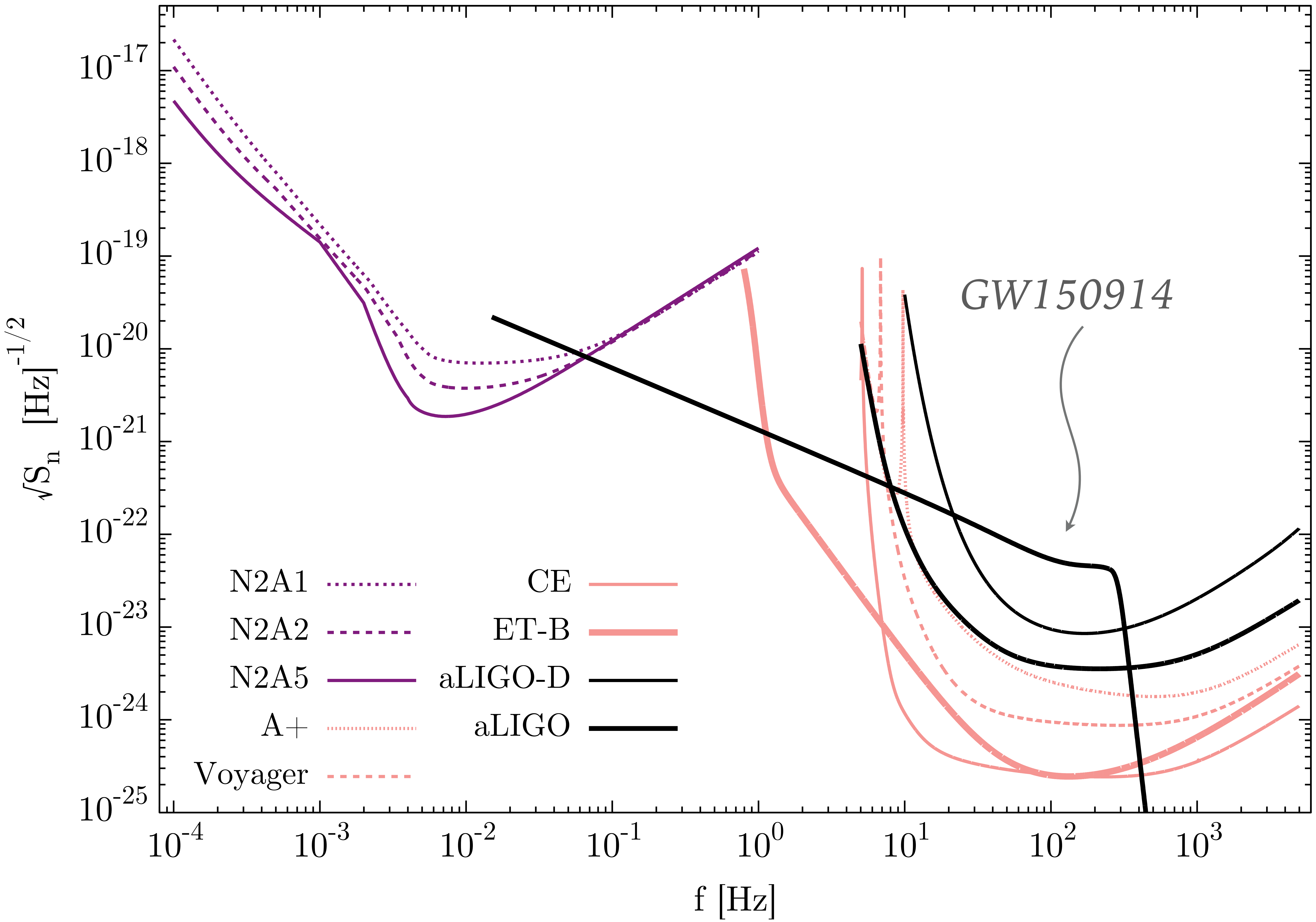

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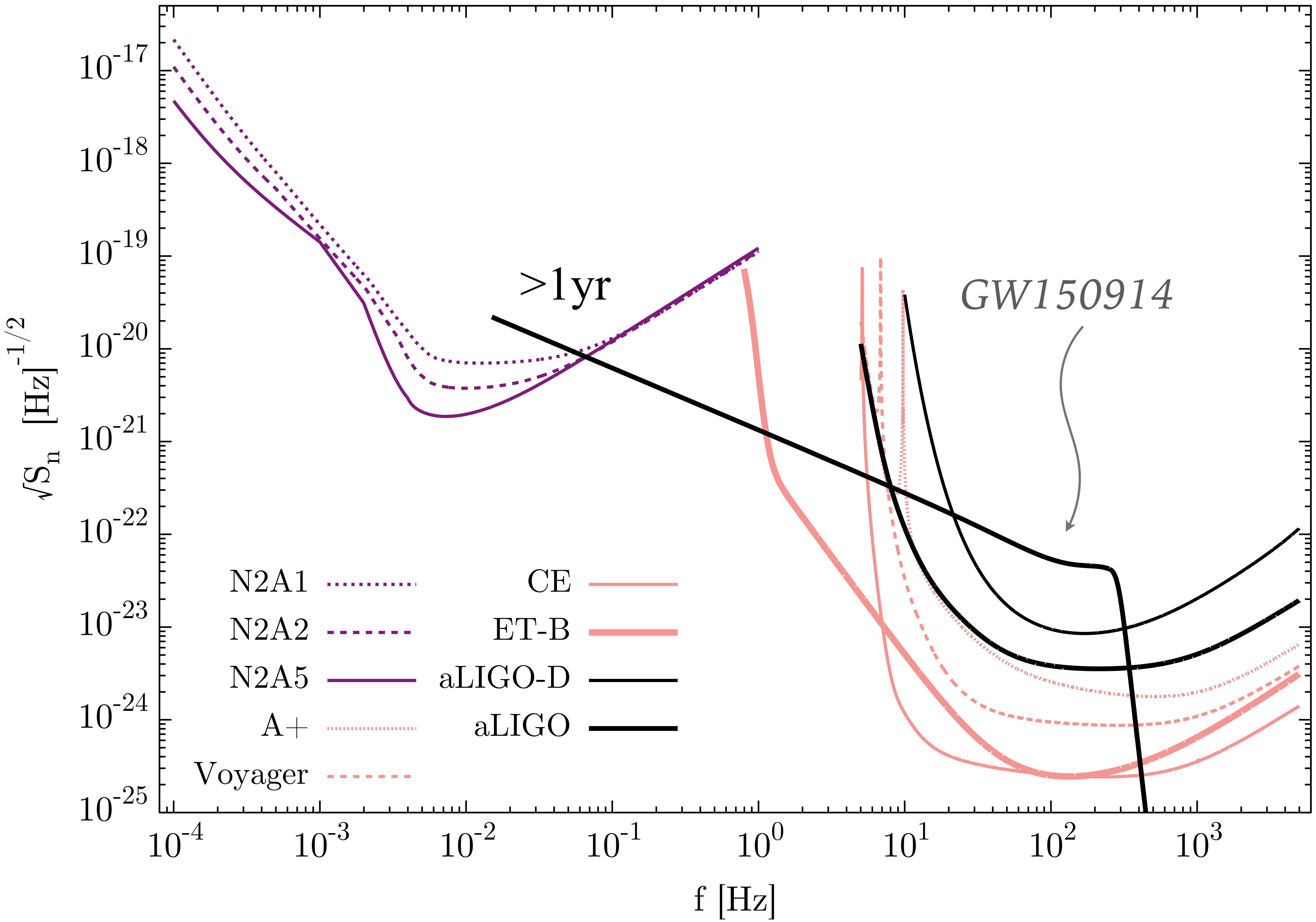

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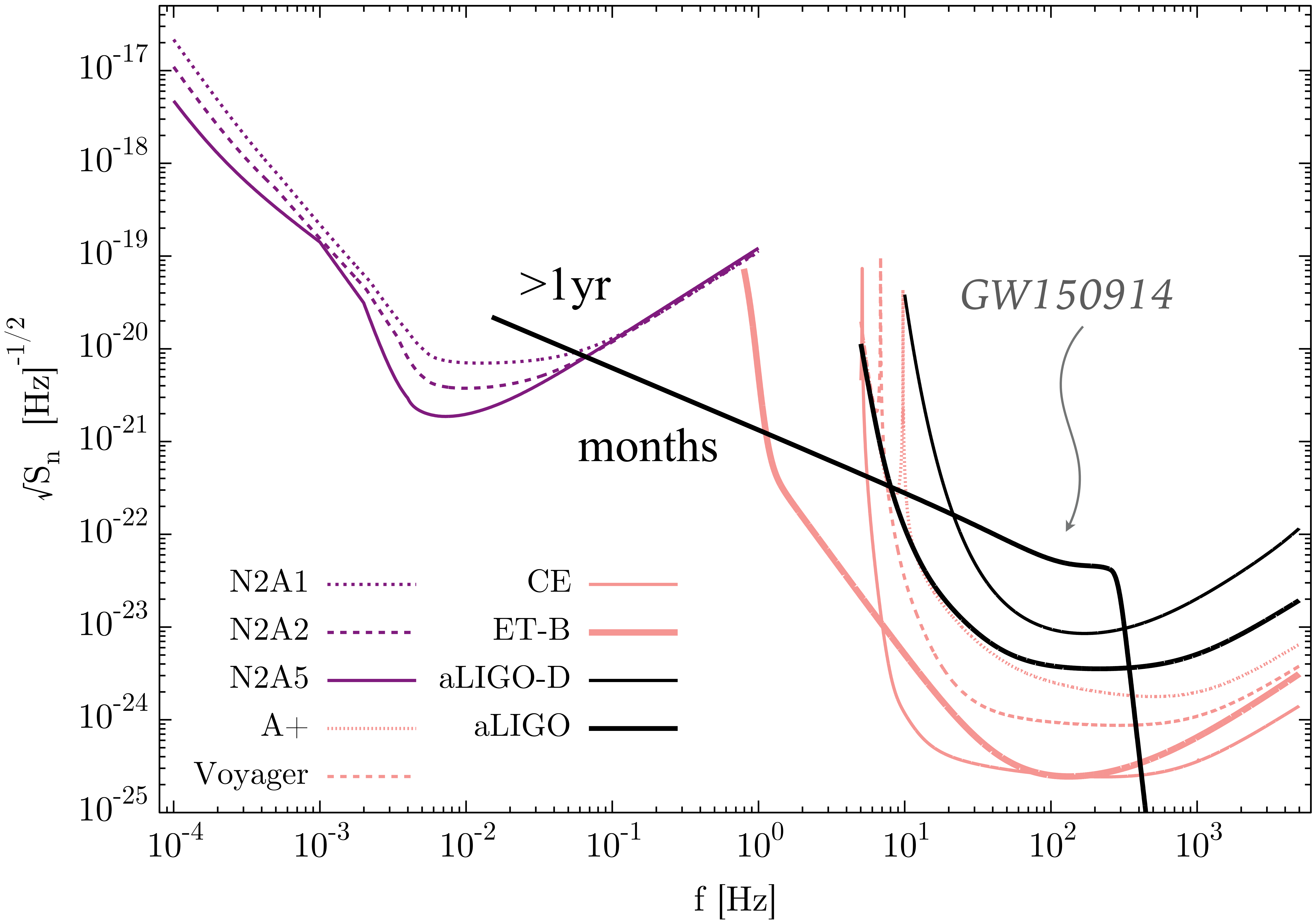

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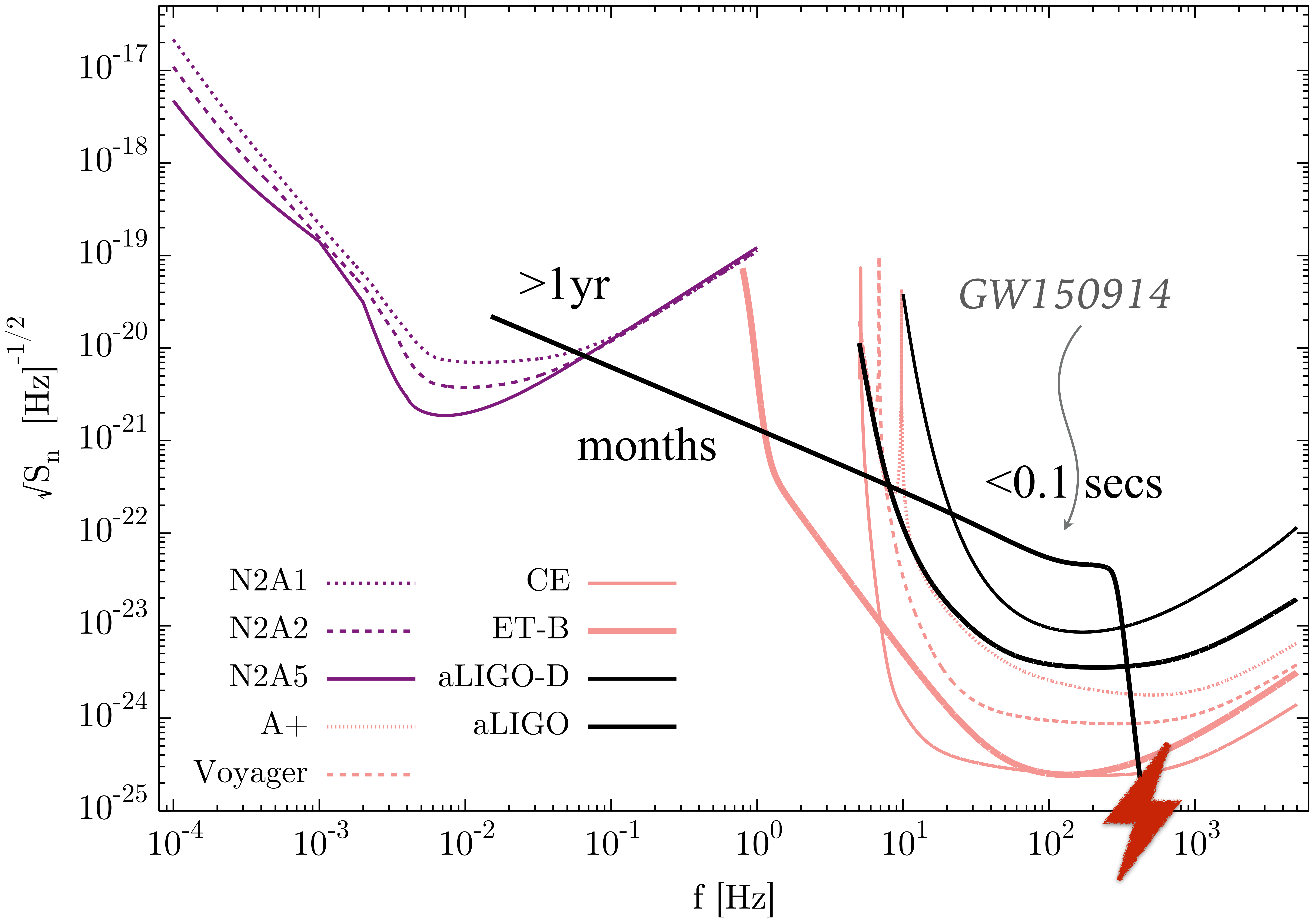

New how? Example: Multi-Band Constraints

Case Study:
Dipole Radiation

$$\dot{E}_{\rm GW} = \dot{E}_{\rm GR}\left[1 + B\left(\frac{Gm}{r_{12}c^2}\right)^{-1}\right]$$

$$\tilde{h}(f) = \tilde{h}_{GR}(f)\,(1+\alpha f^a)\,e^{i\beta f^b}$$

$$\beta = -\frac{3}{224}\eta^{2/5}B$$

[Barausse, Yunes, Chamberlain, PRL ’16]

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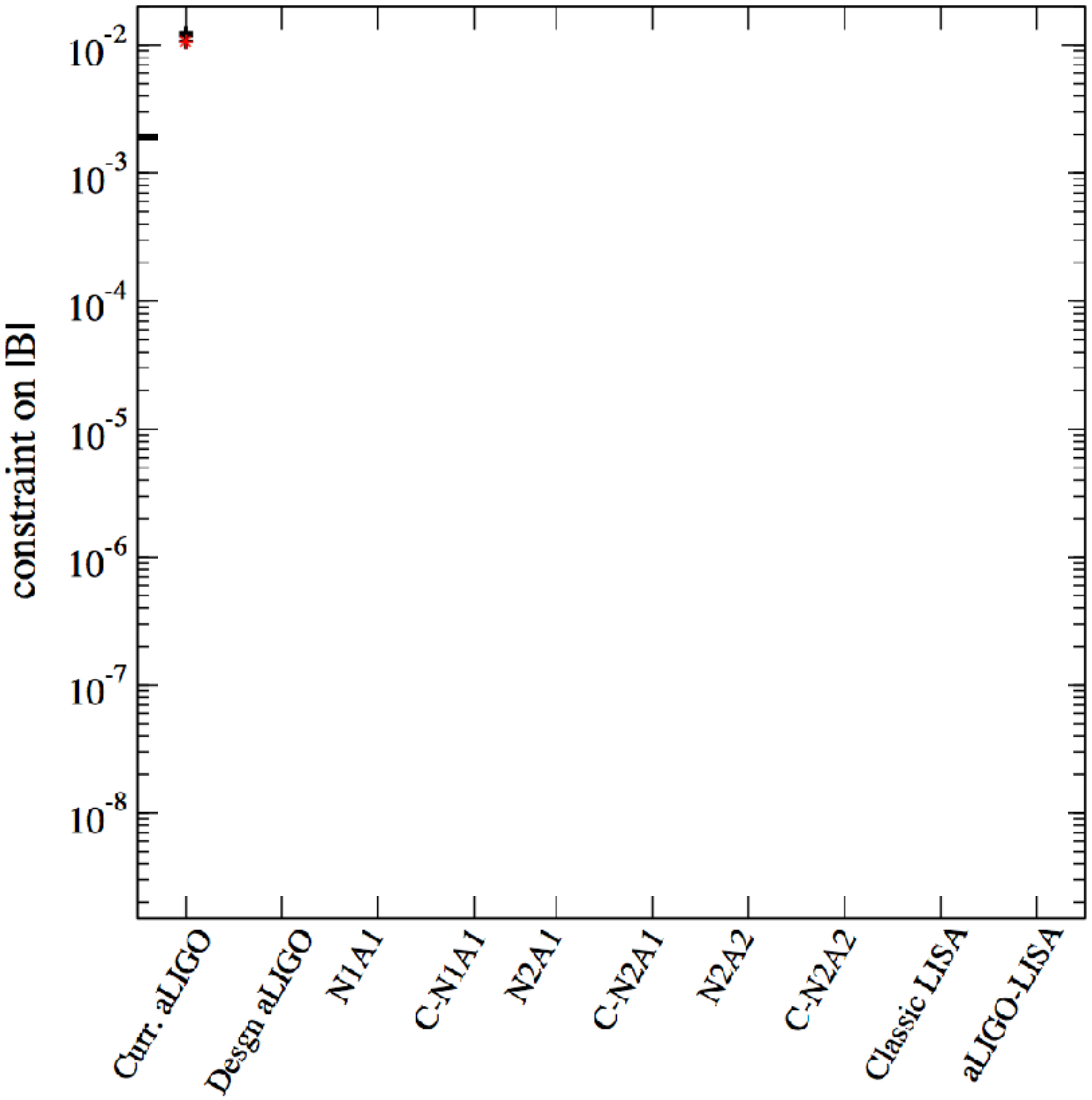

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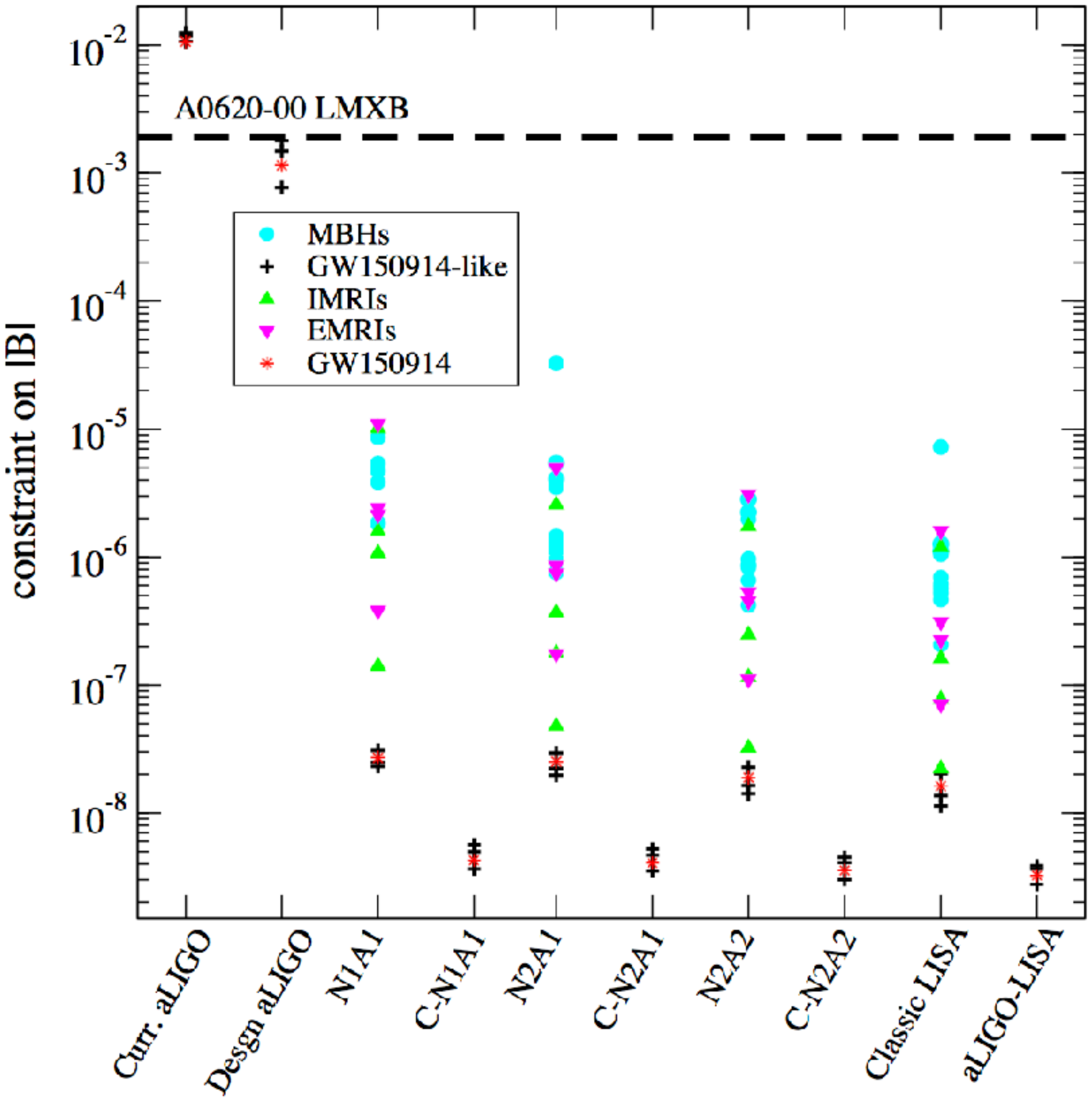

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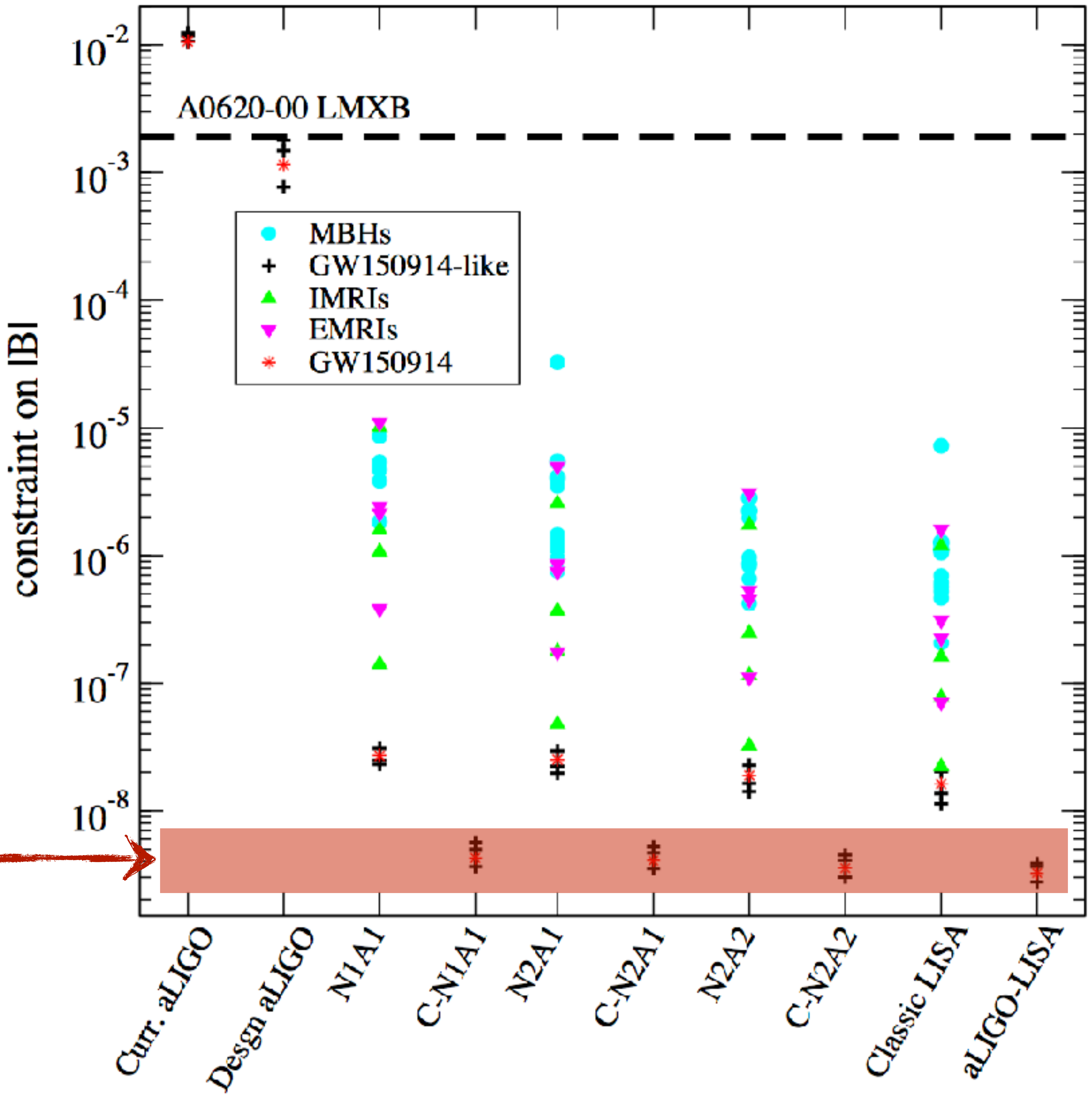
10^6 times better than current bounds!!



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New how? Example: Precision Tests

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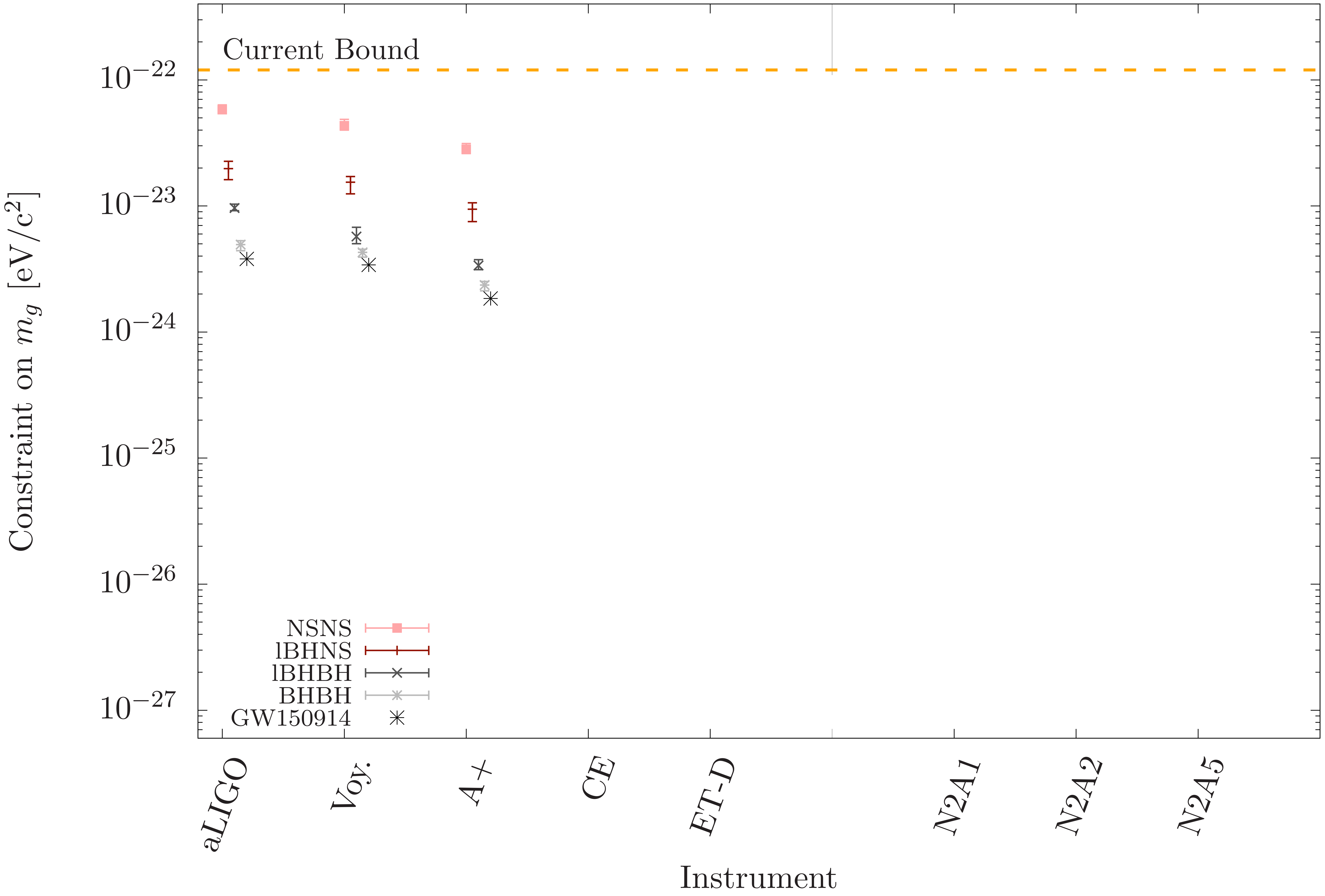

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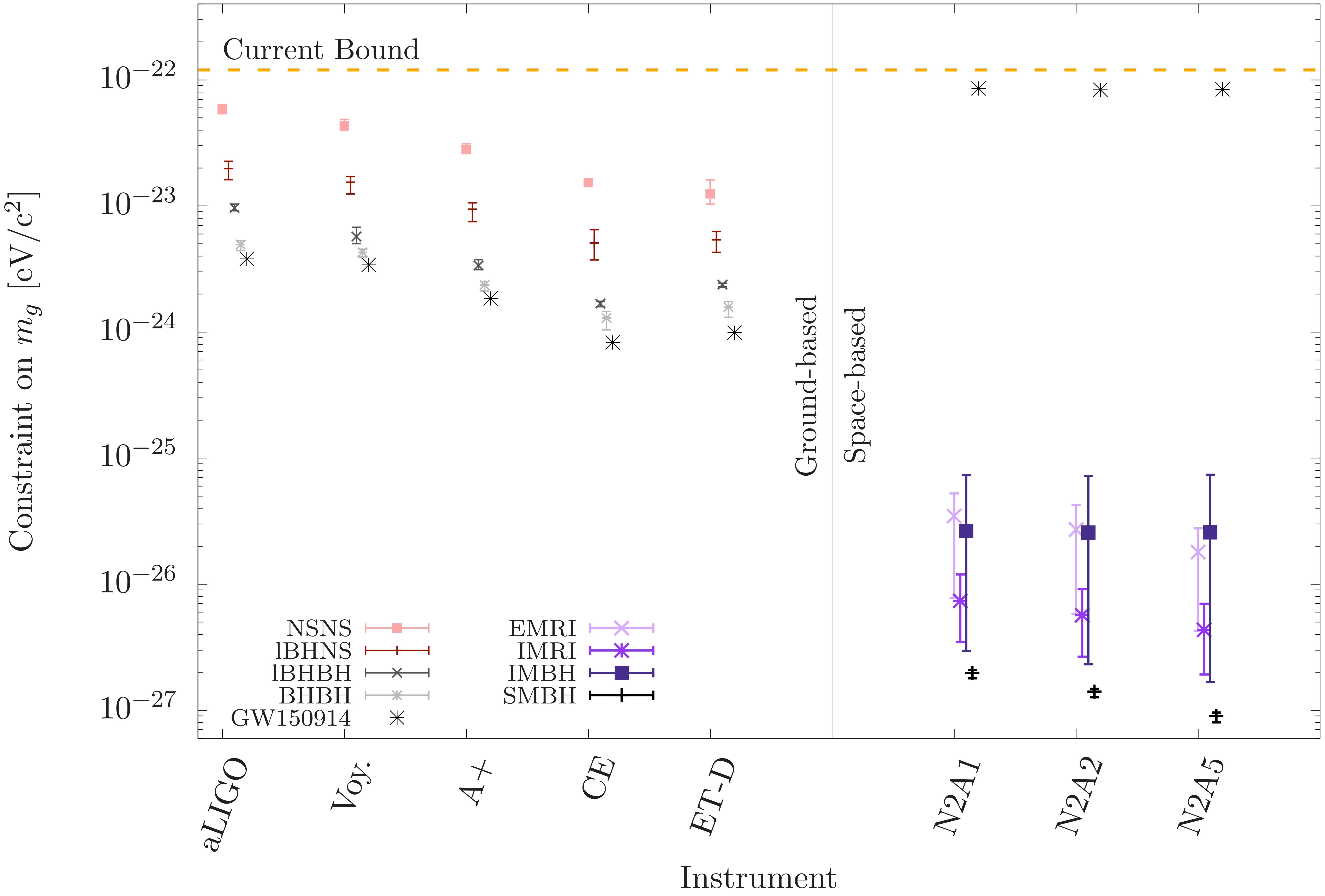

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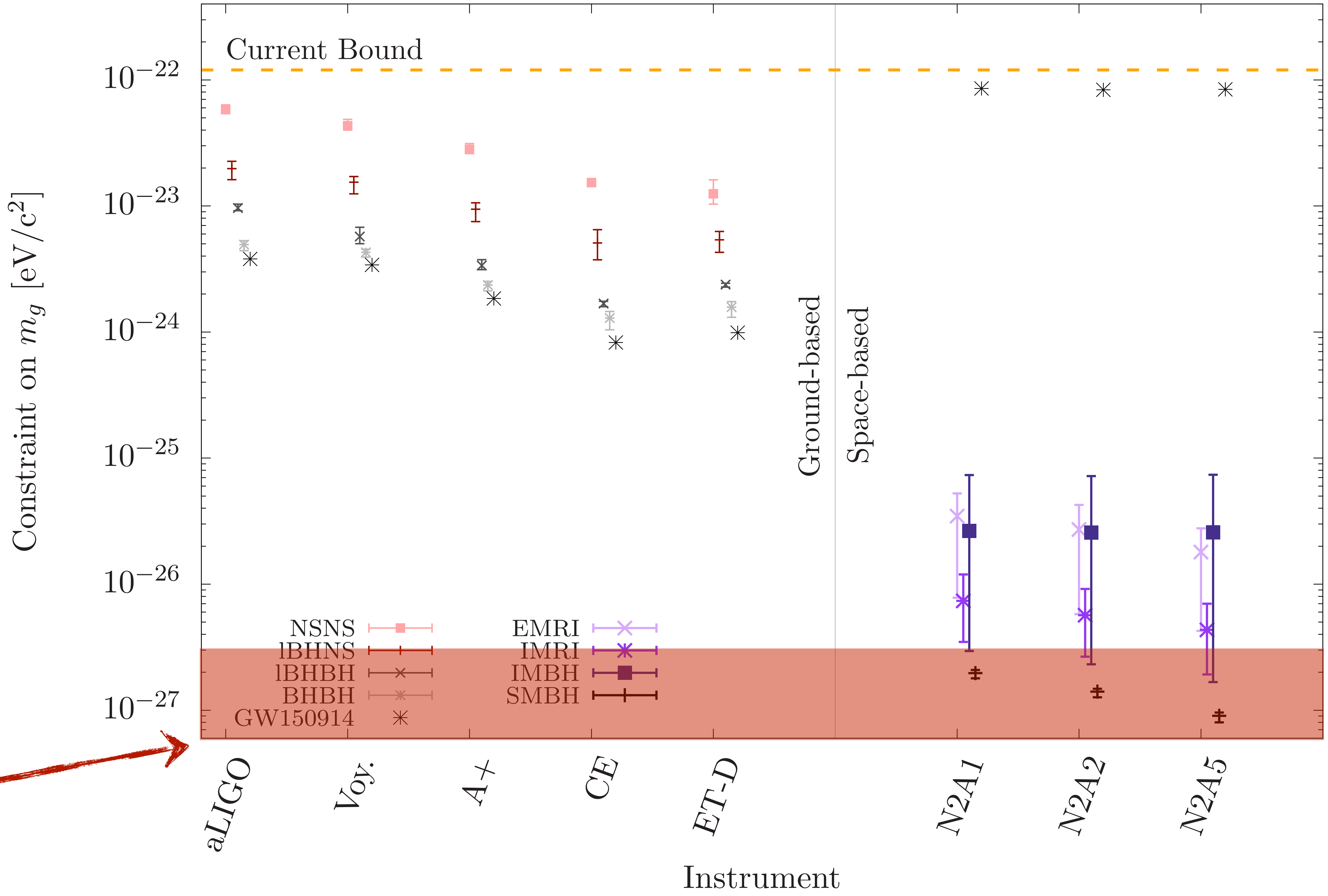

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A Brave New World: A Classification

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New Sources

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SMBH Mergers

Final State Conjecture through QNMs, graviton mass, modified dispersion.

A Brave New World: A Classification

New Sources

SMBH Mergers **Final State Conjecture through QNMs, graviton mass, modified dispersion.**

EMRIs **Kerr Hypothesis via GW geodesy, strong equivalence principle, chaos.**

A Brave New World: A Classification

New Sources

SMBH Mergers	Final State Conjecture through QNMs, graviton mass, modified dispersion.
EMRIs	Kerr Hypothesis via GW geodesy, strong equivalence principle, chaos.
Stochastic Backgrounds	Cosmological modified gravity, cosmic strings ?

A Brave New World: A Classification

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New Data

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New Data

Much Higher SNR — Precision tests of extreme gravity

A Brave New World: A Classification

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Much Higher SNR — **Precision tests of extreme gravity**

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A Brave New World: A Classification

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Multi-Band Sources — **Dipole emission, variability of fundamental constants.**

A Brave New World: A Classification

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Multi-Band Sources — **Dipole emission, variability of fundamental constants.**

Connection to cosmological modified theories?

You ready for this? Necessary Simulations

New Sources

- **BH Mergers**
- **EMRIs**
- **Stochastic Backgrounds**

New Data

- **Much Higher SNR**
- **Much Larger DL**
- **Multi-Band Sources**

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New Sources

BH Mergers

The whole NR enchilada in MG (spin-precessing + eccentric + higher modes)

EMRIs

Stochastic Backgrounds

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Multi-Band Sources

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The whole PN enchilada in MG (spin-precessing + eccentric + intermediate-mass?)

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Multi-Band Sources

Two stage-analysis (PN for early LISA inspiral —> NR for LIGO merger)

What are the NR challenges?

New Sources

SMBH Enchilada

EMRIs

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High SNR/High Precision

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Multi-Band Sources

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New Sources

SMBH Enchilada — Many parameters & some (high spin, high eccentricity) very challenging.

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Multi-Band Sources

Intermediate mass-ratio inspiral modeling…

Conclusions

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3G Detectors Will Allow for New Tests of GR

(precision tests, new sources, new effects)

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Data analysis implementations?
Control over systematic errors in parameter estimation? etc…

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