Galactic Gravitational Waves and Pulsar Timing Arrays

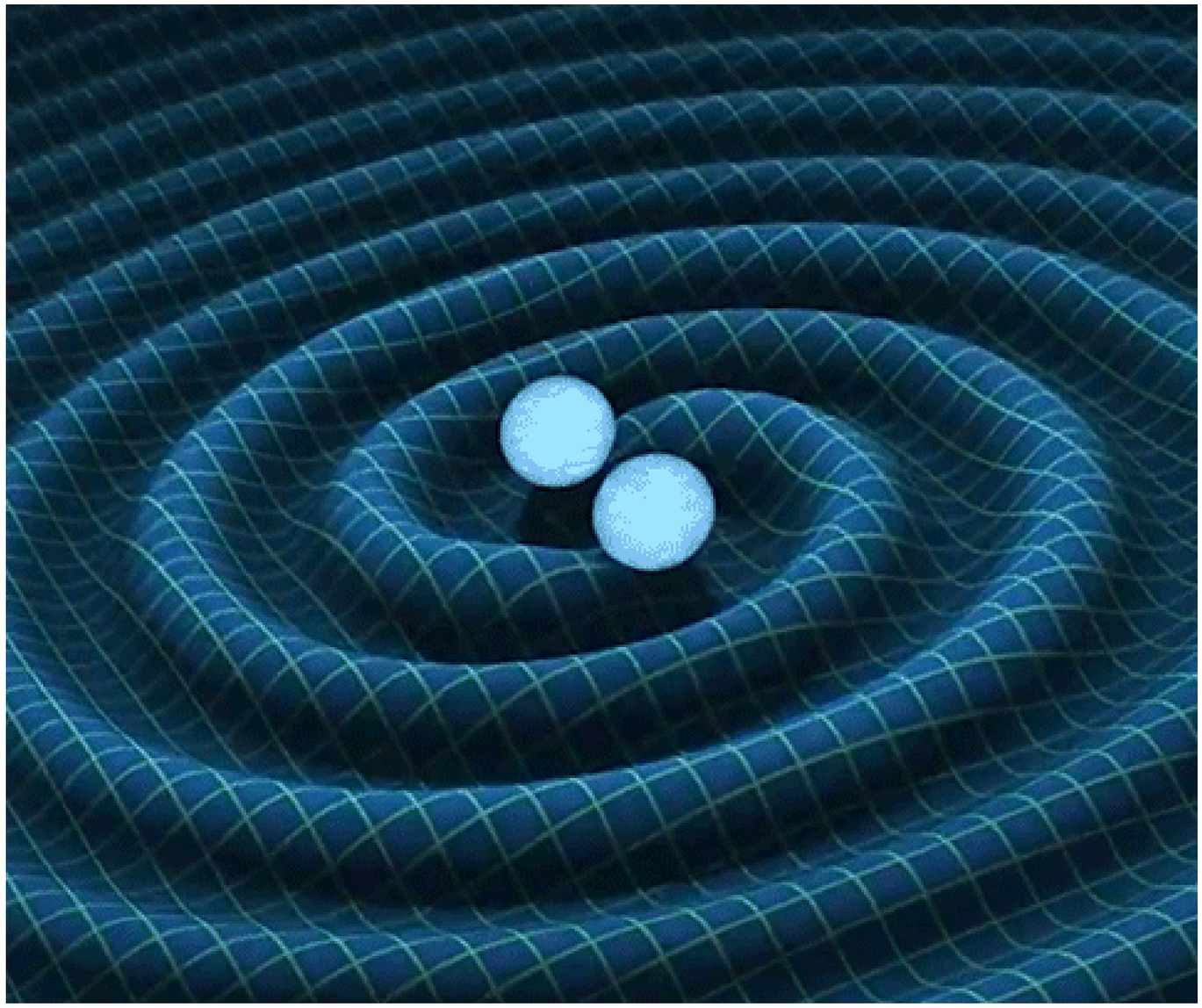
Dusty Madison

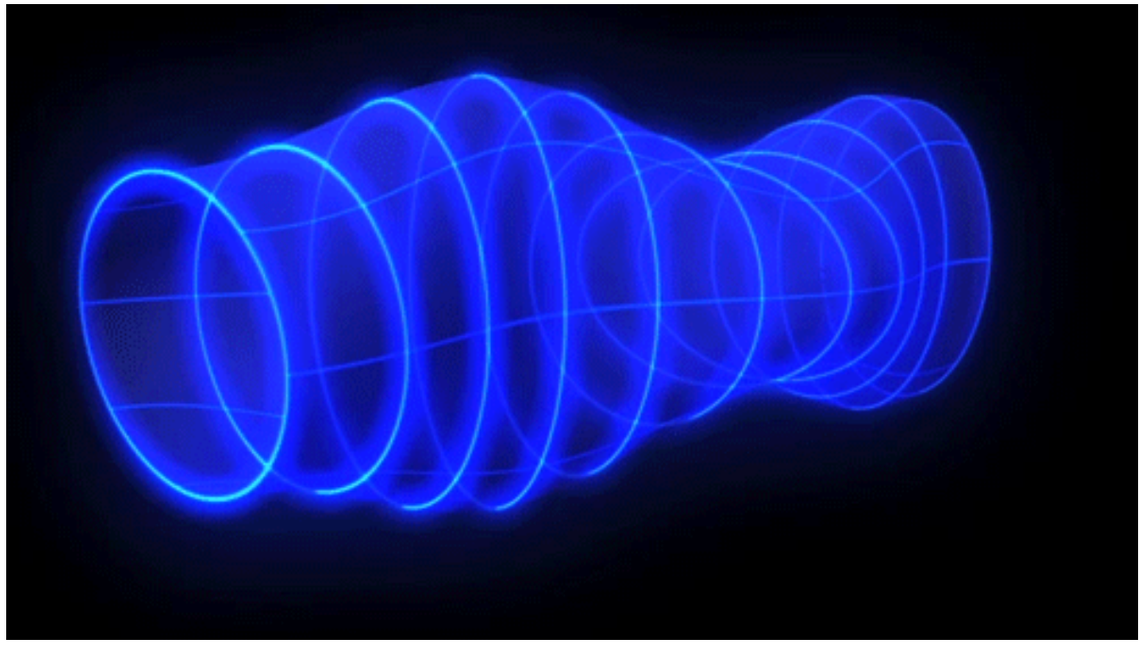
2018 Jansky Symposium
Socorro, NM

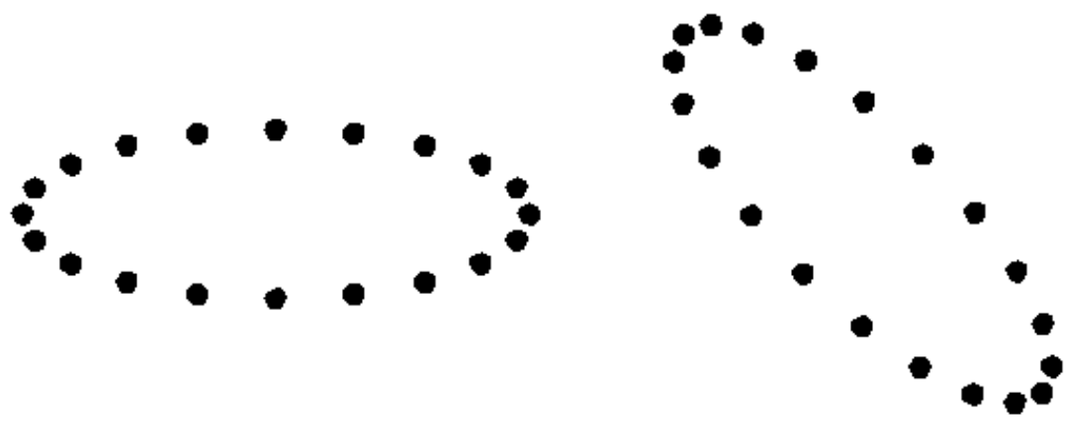
Overview

- **GW searches across the spectrum**
- **Galactic considerations for pulsar timing**
- **GW Bursts with Memory**
- **Possible Galactic Memory sources**
- **The real, non-revisionist story**

Gravitational Waves

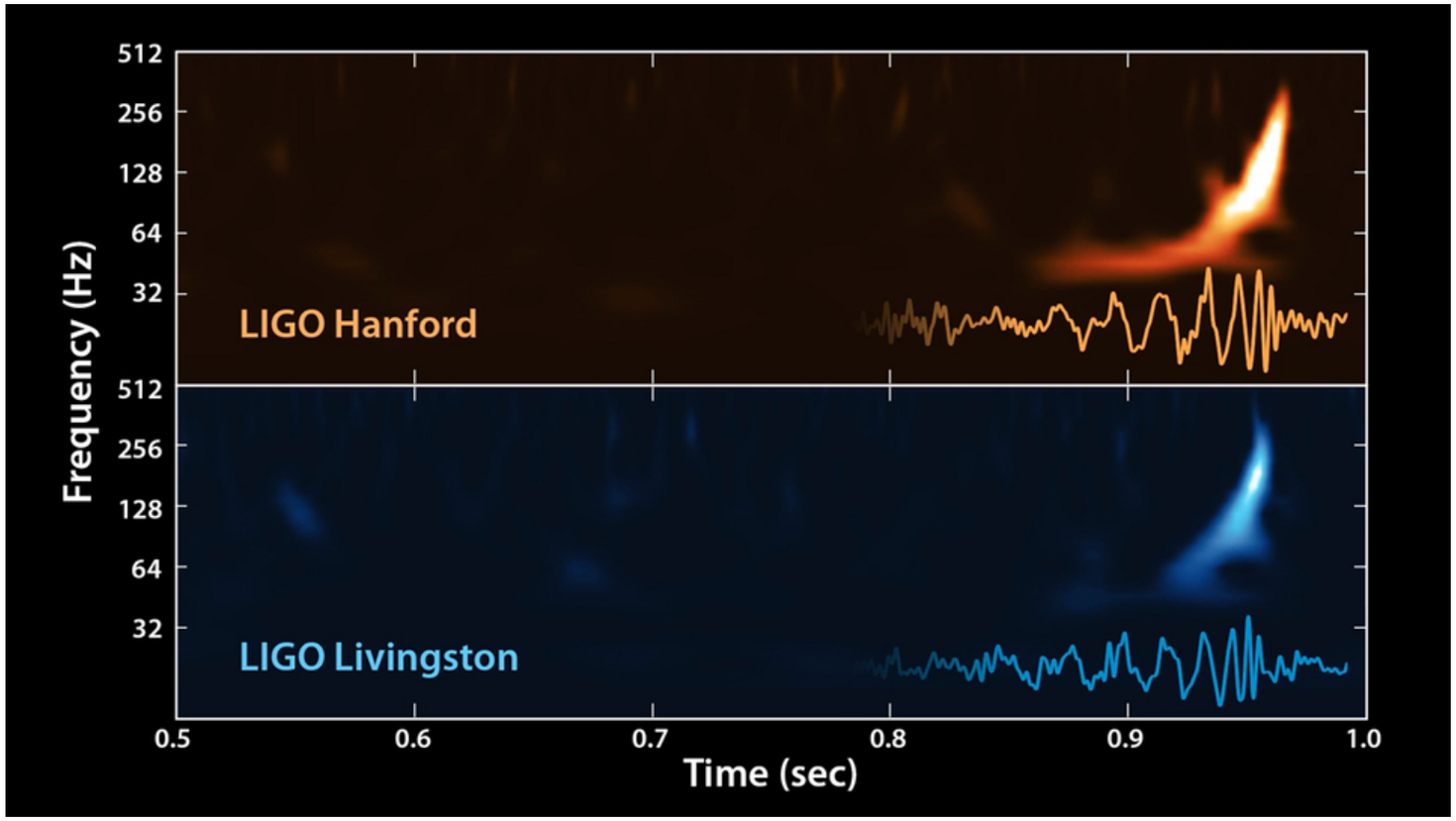




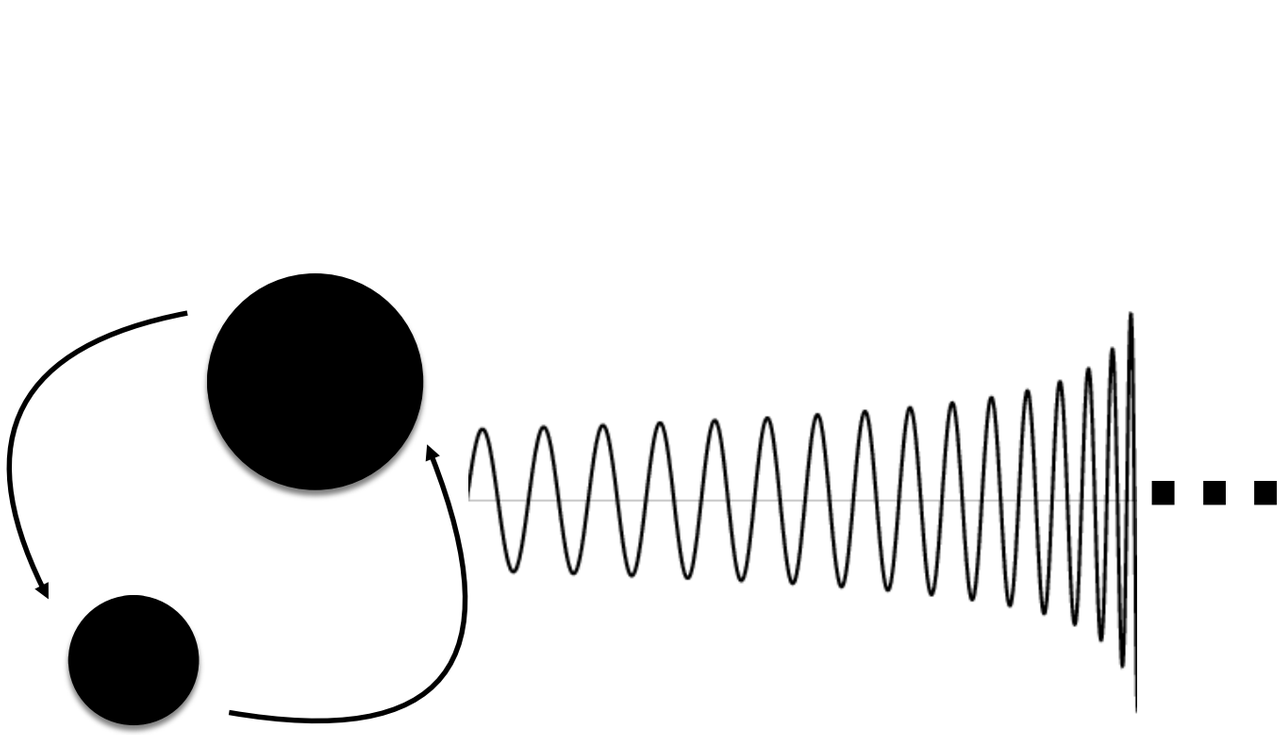


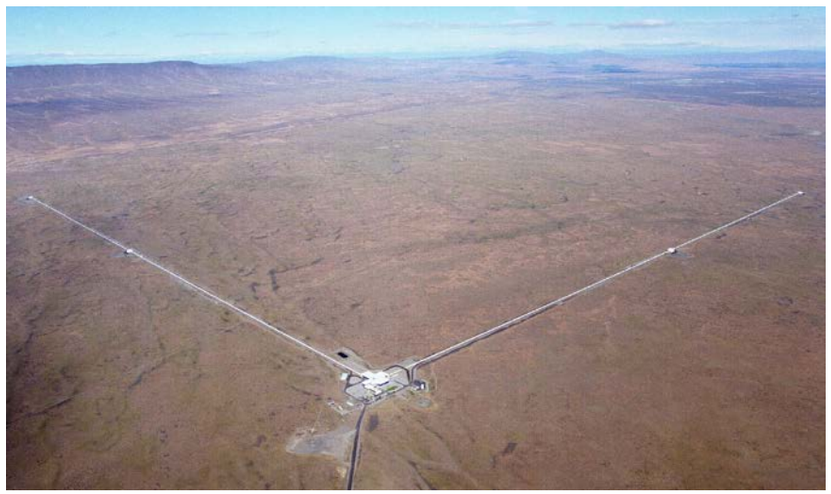
A GW Celebrity

LIGO



A Straightforward Measurement

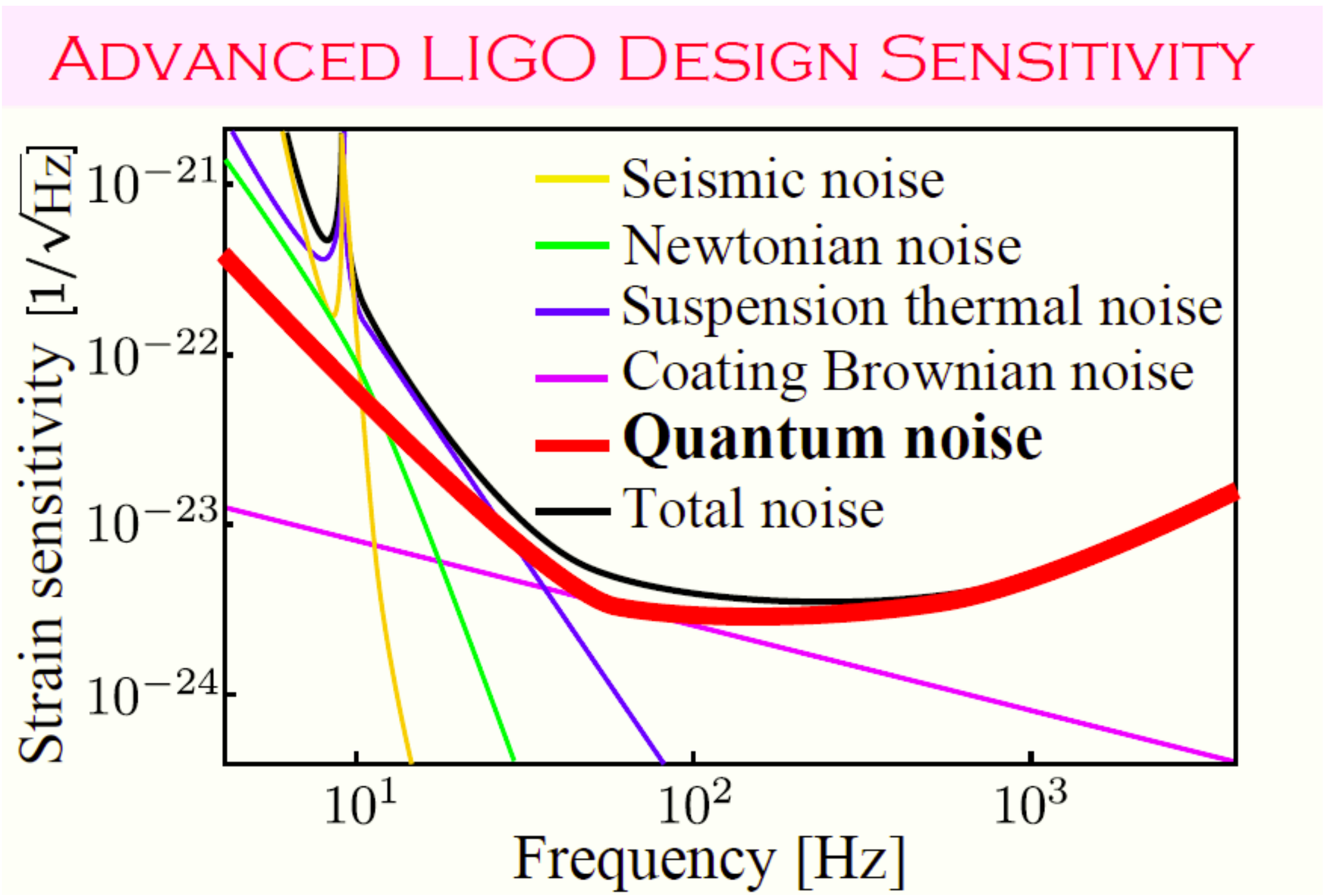




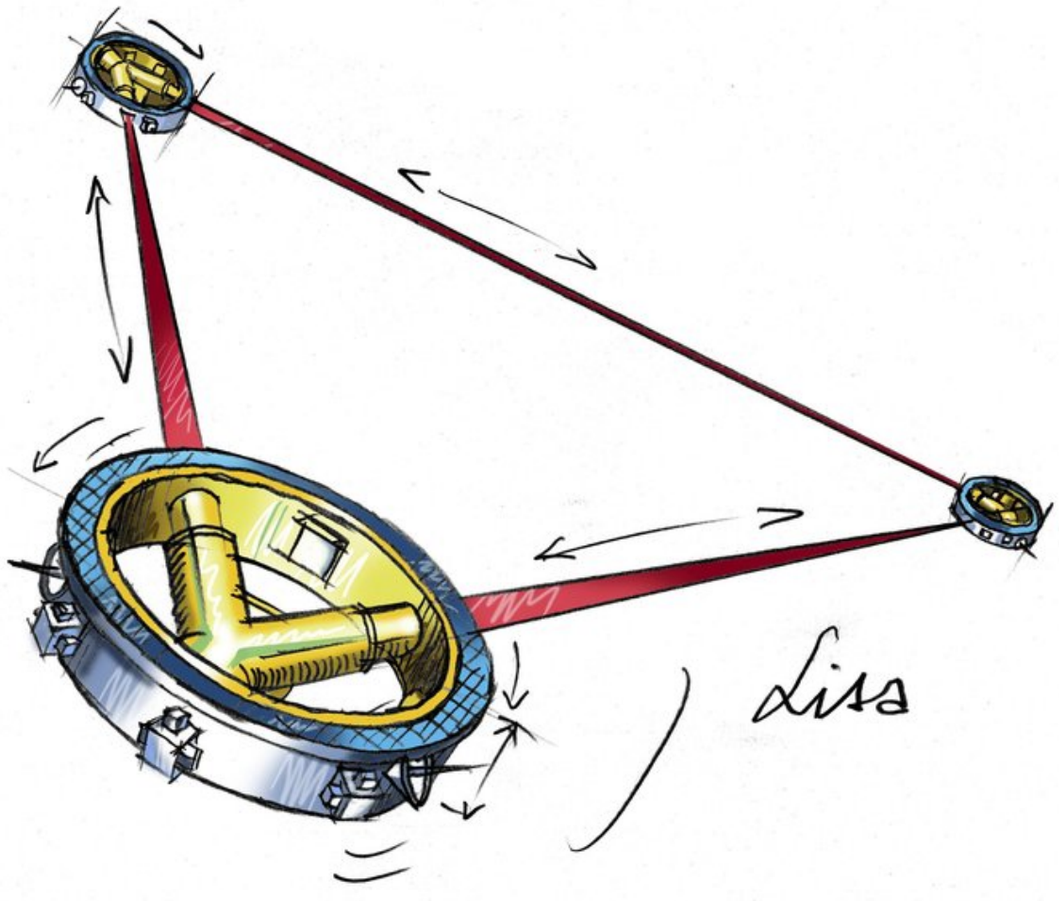
4 km

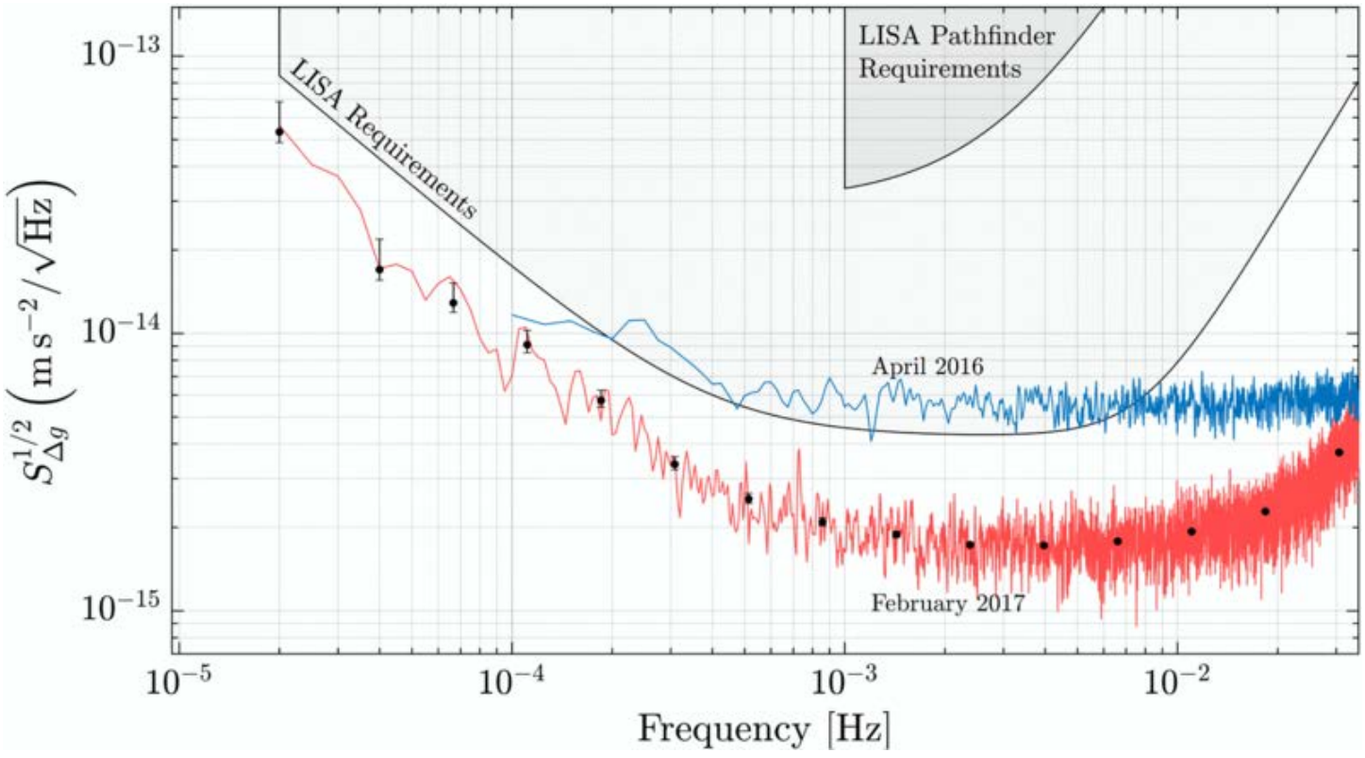
few x 100 Mpc

LIGO's Noise

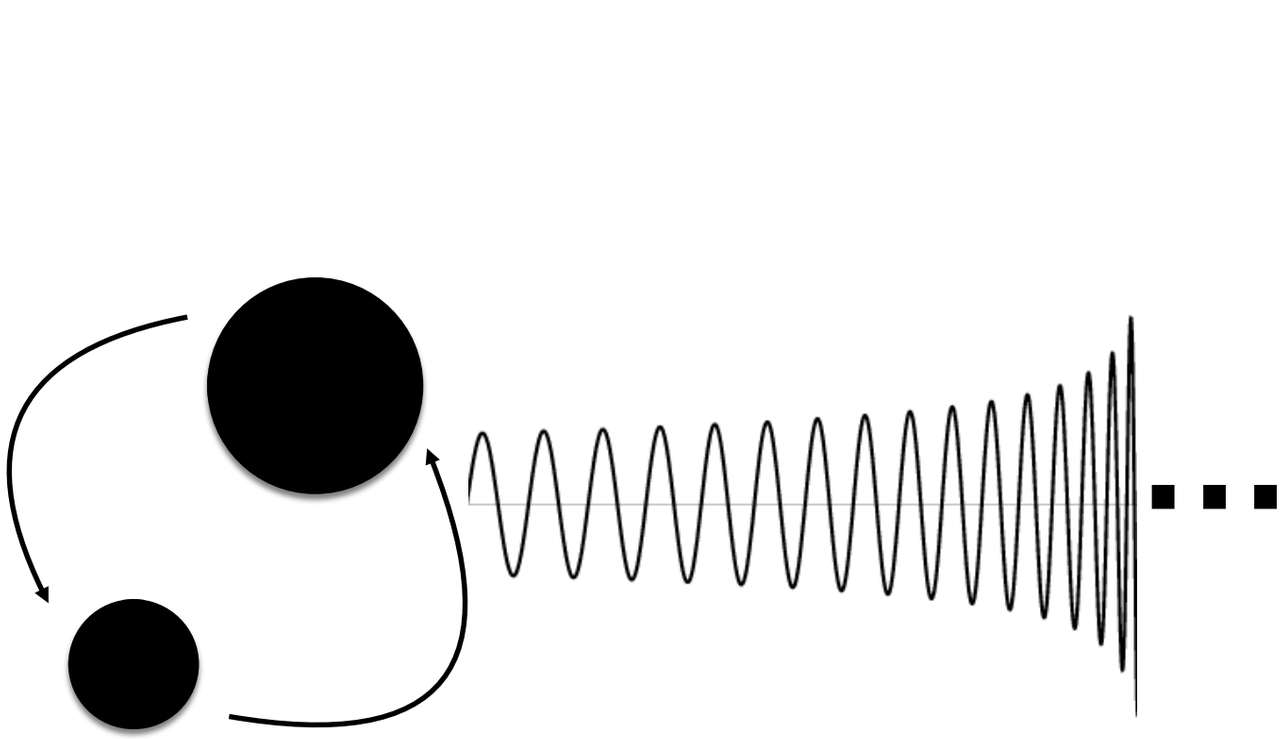

ADVANCED LIGO DESIGN SENSITIVITY
Strain sensitivity [1/√Hz]
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{1}
10^{2}
10^{3}
Frequency [Hz]
Seismic noise
Newtonian noise
Suspension thermal noise
Coating Brownian noise
Quantum noise
Total noise

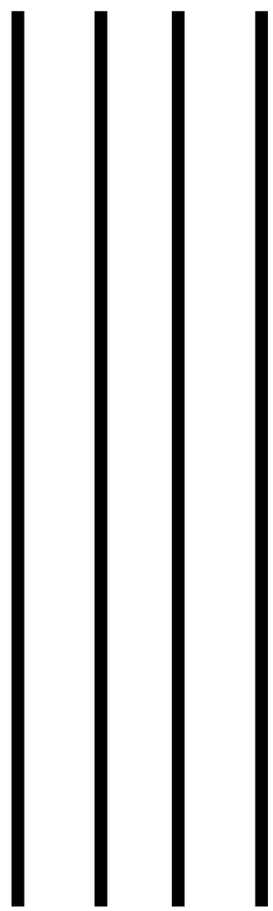
A Space Based Detector

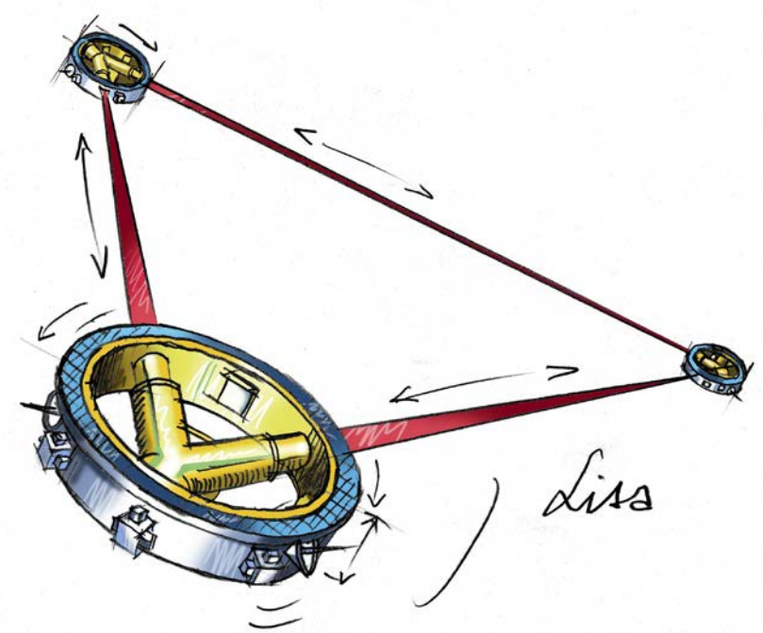




Similar Idea



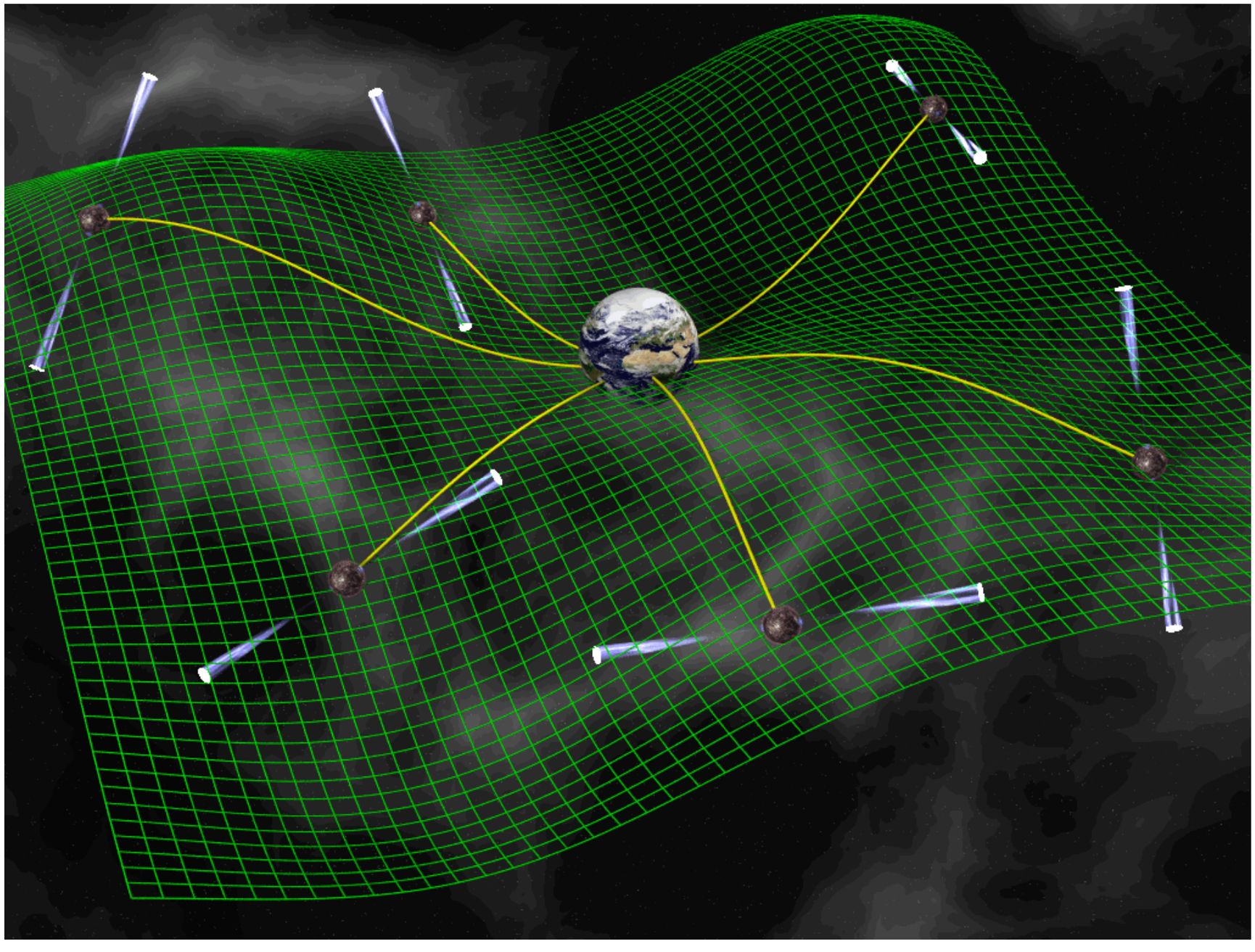




5e6 km

few x 100 pc — few x 100 Mpc

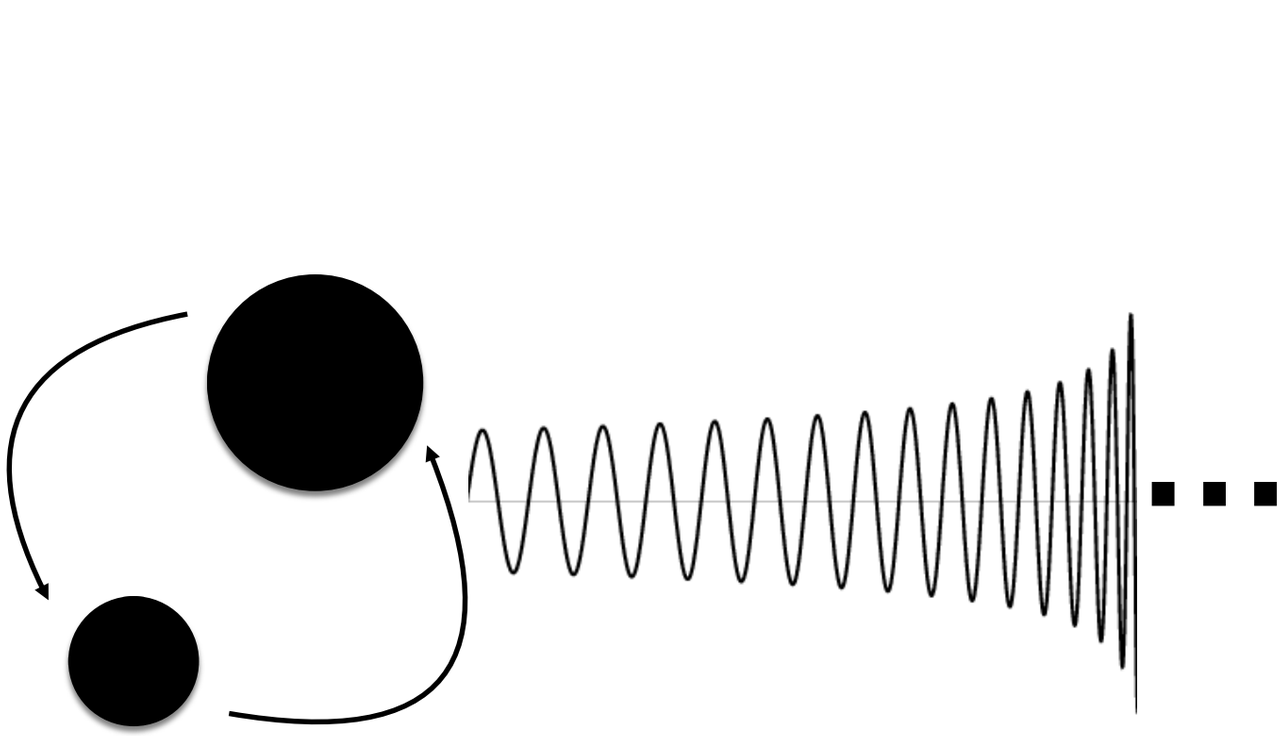
A Pulsar Timing Array

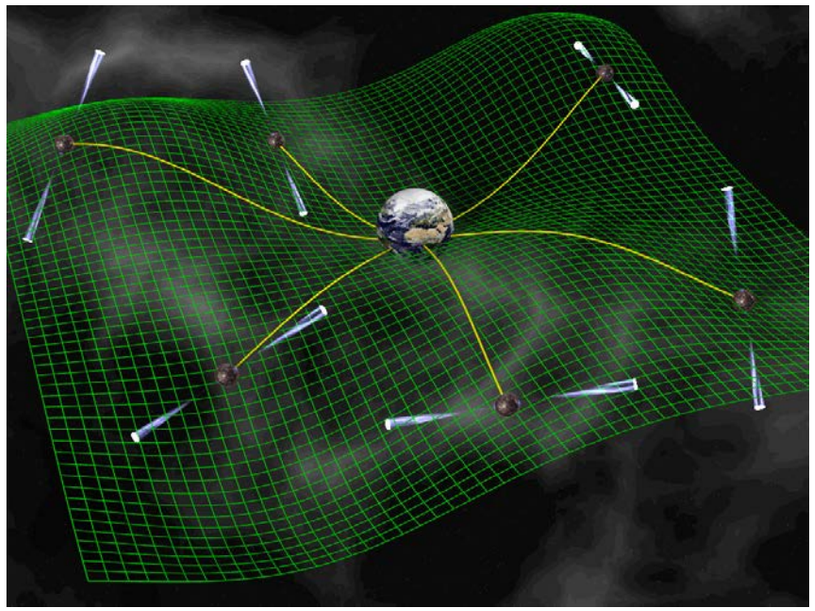


PPTA

NANOGrav

Similar Idea Again

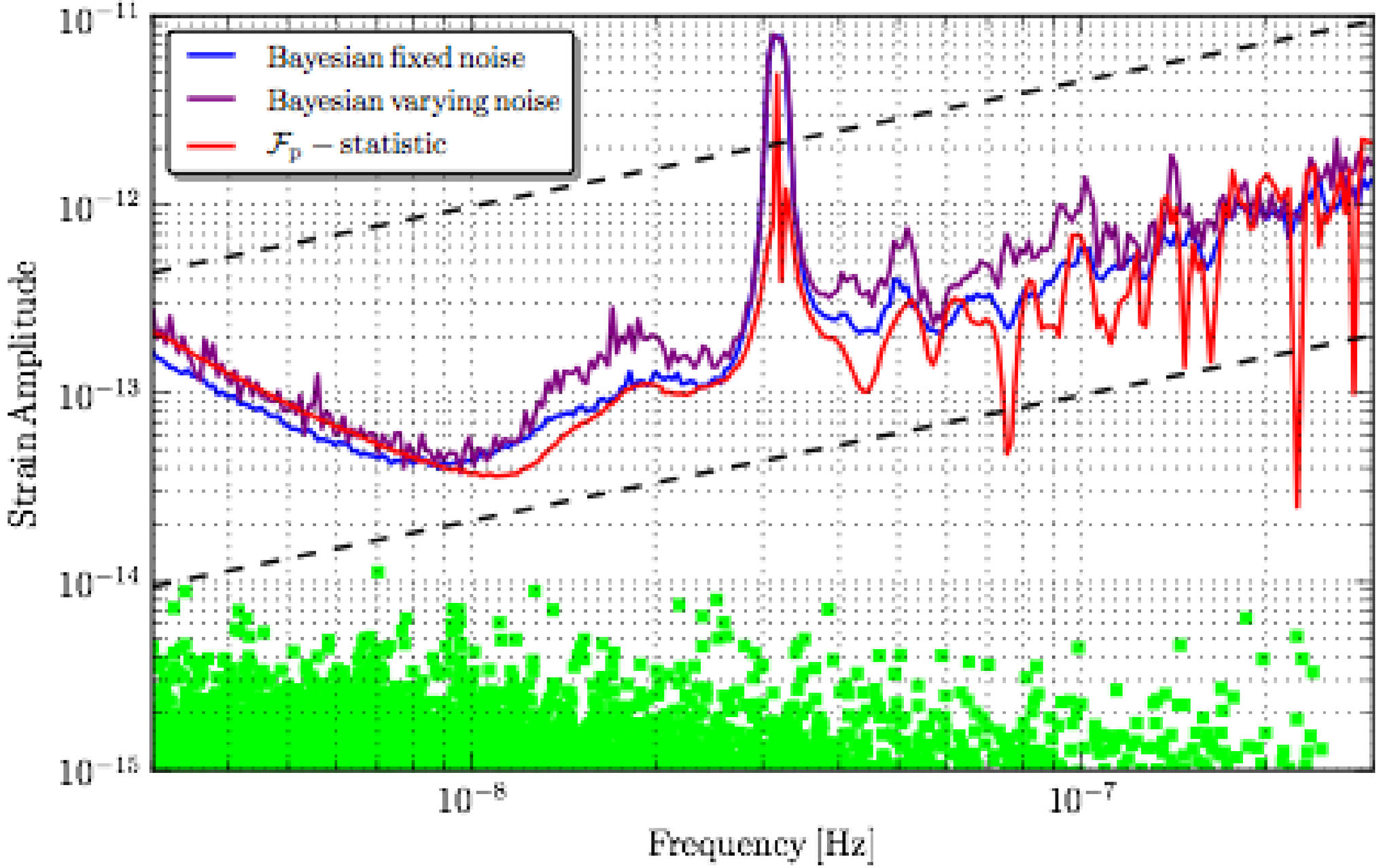




few kpc

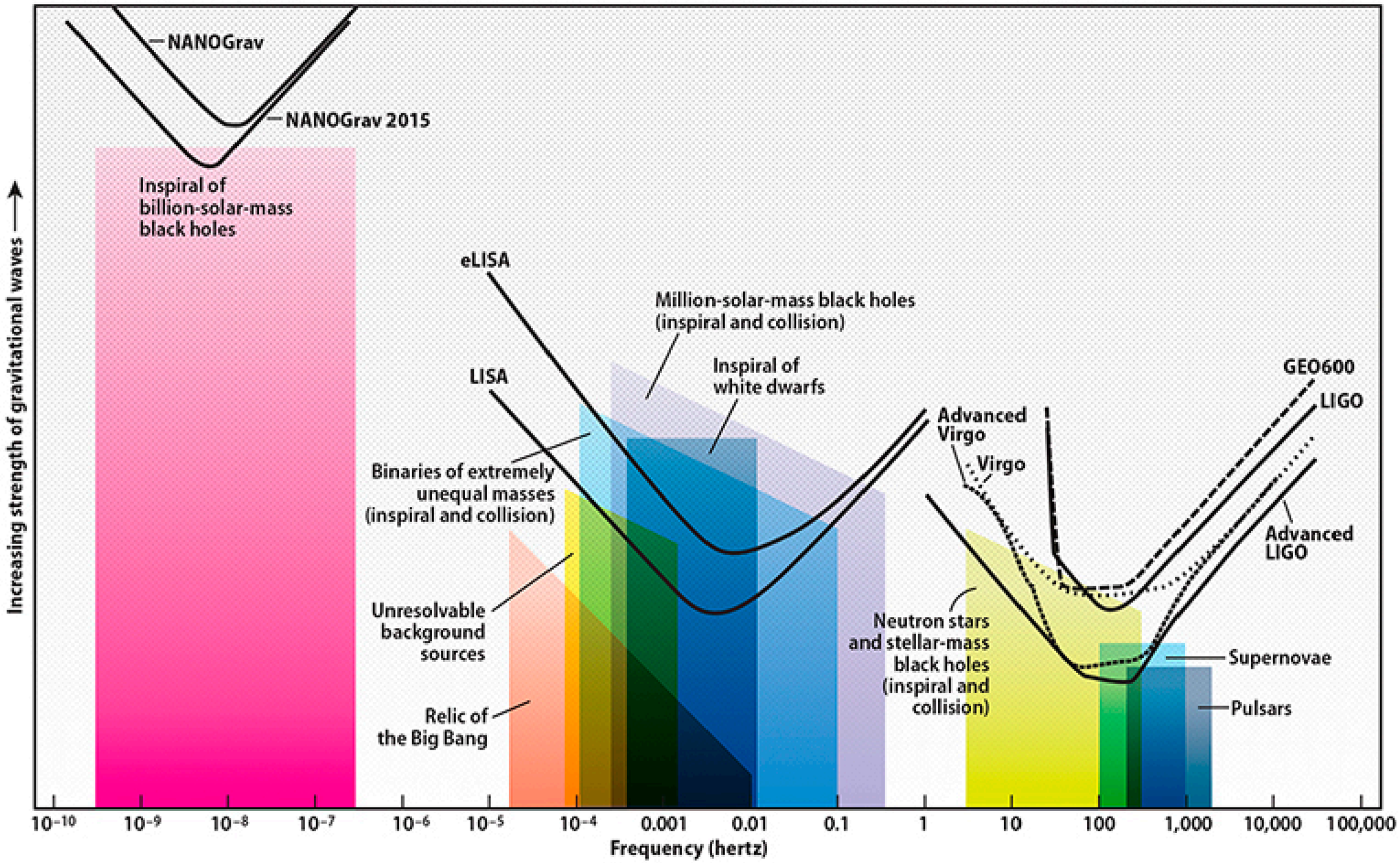
few x 100 Mpc

NANOGrav's Noise

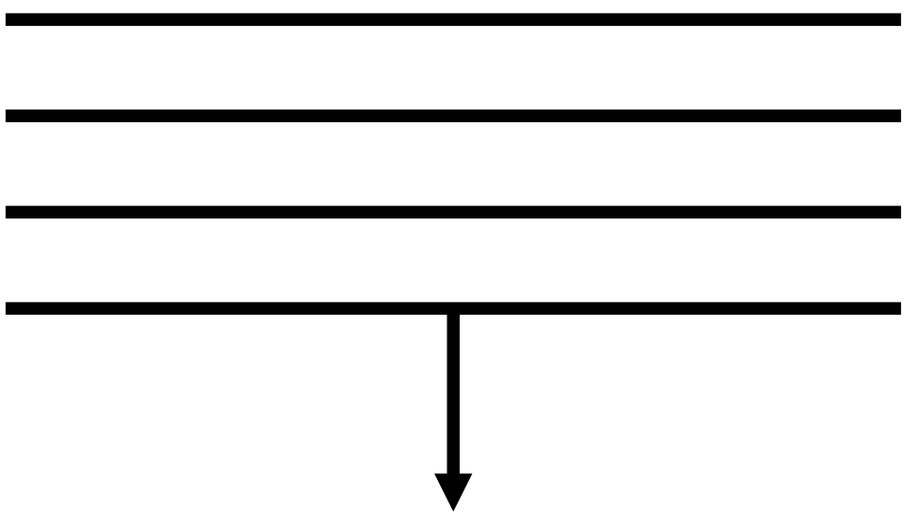


Arzoumanian et al. (2014)

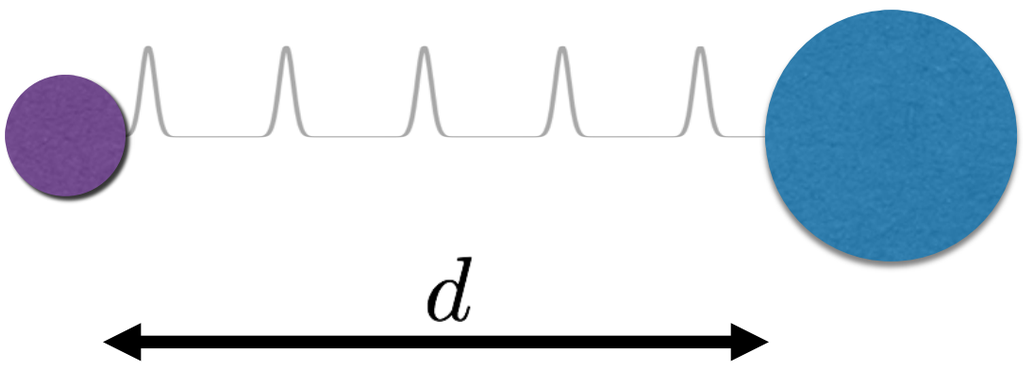
The Full Spectrum



What do we Measure?

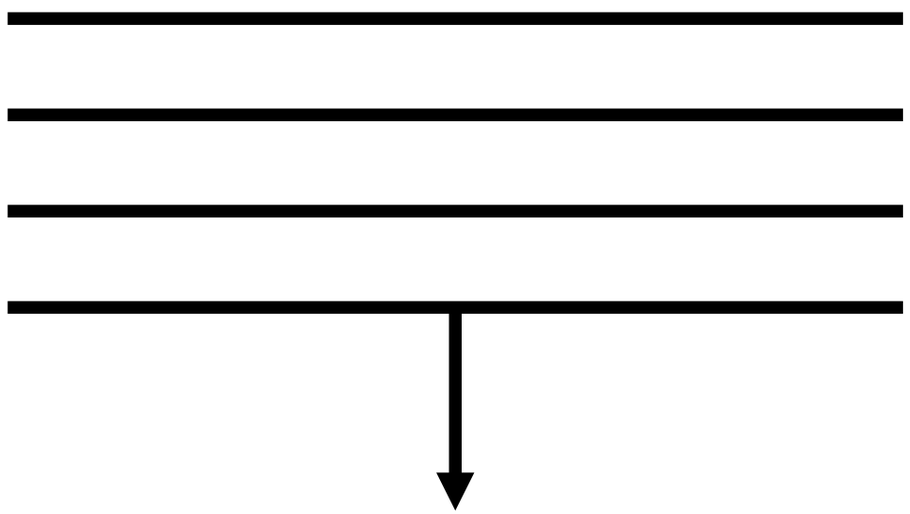


$$h_{ij}(t, \mathbf{r}) = P_{ij} f(t - r/c)$$



$$\Delta(t) = \frac{1}{2} \int_{t-d/c}^{t} \hat{k}^i \hat{k}^j h_{ij}(t', \mathbf{r}(t'))dt'$$

What do we Measure?



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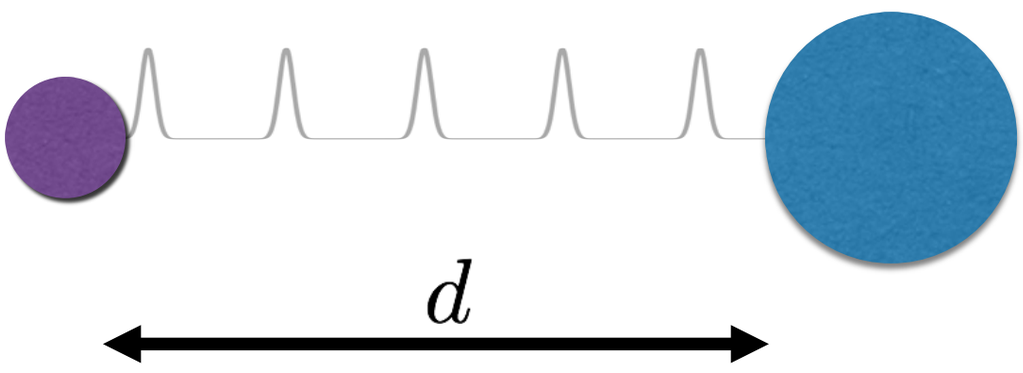


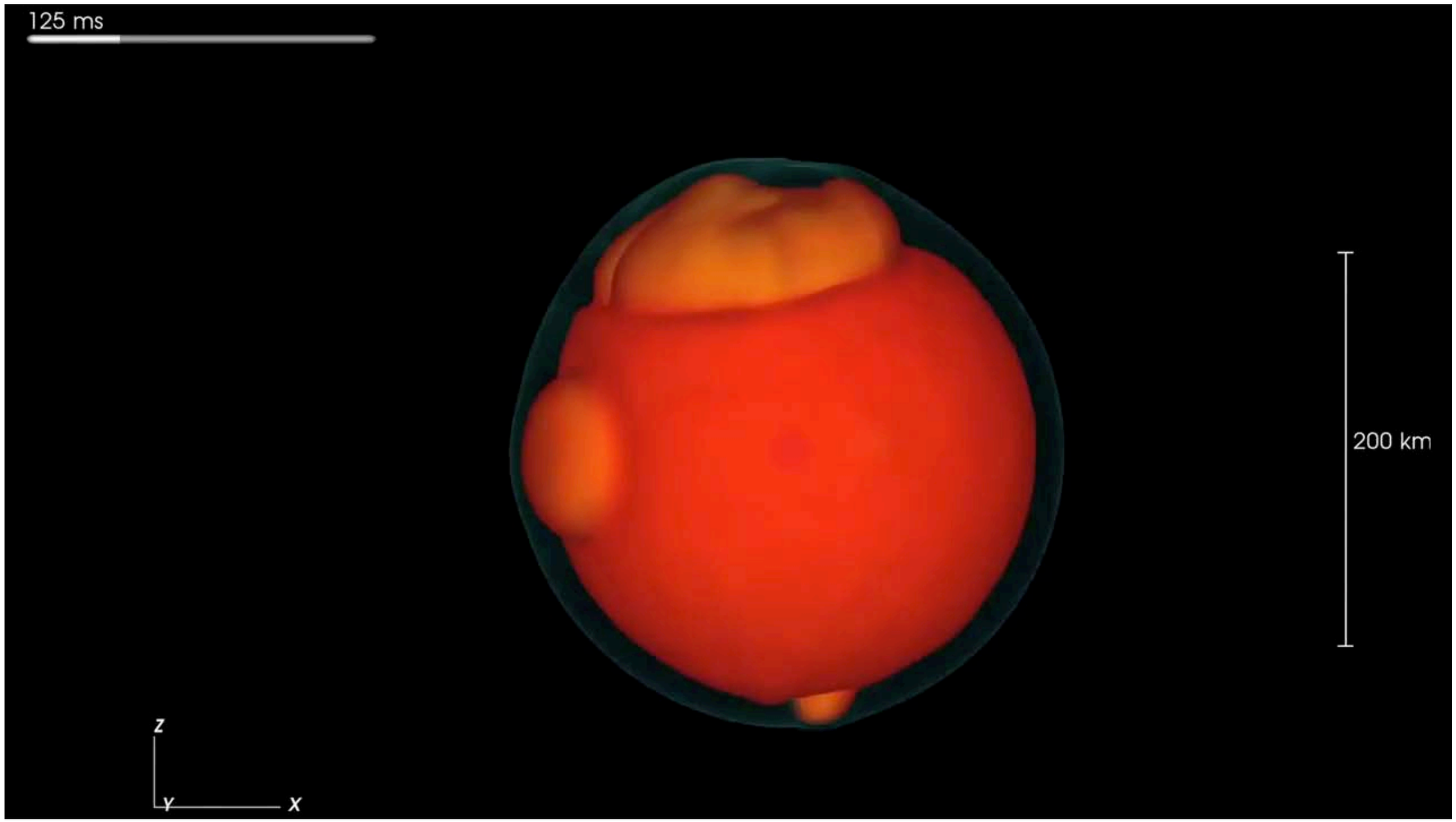
$$\Delta(t) = \frac{1}{2} \int_{t-d/c}^{t} \hat{k}^i \hat{k}^j h_{ij}(t', \mathbf{r}(t'))dt'$$

$$\Delta(t) = A[f(t) - f(t_p)]$$

Earth term

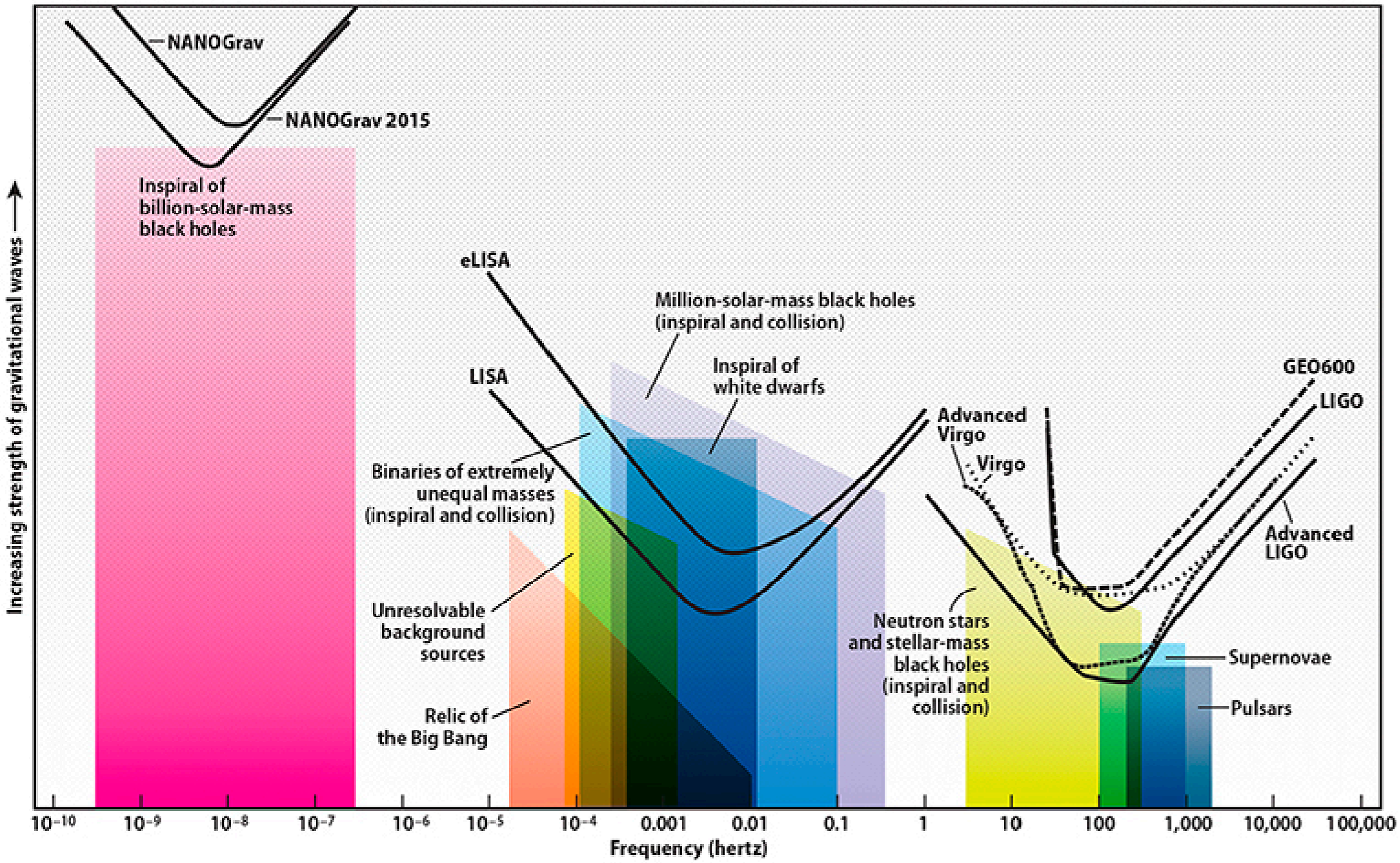
Pulsar term

A Galactic Supernova

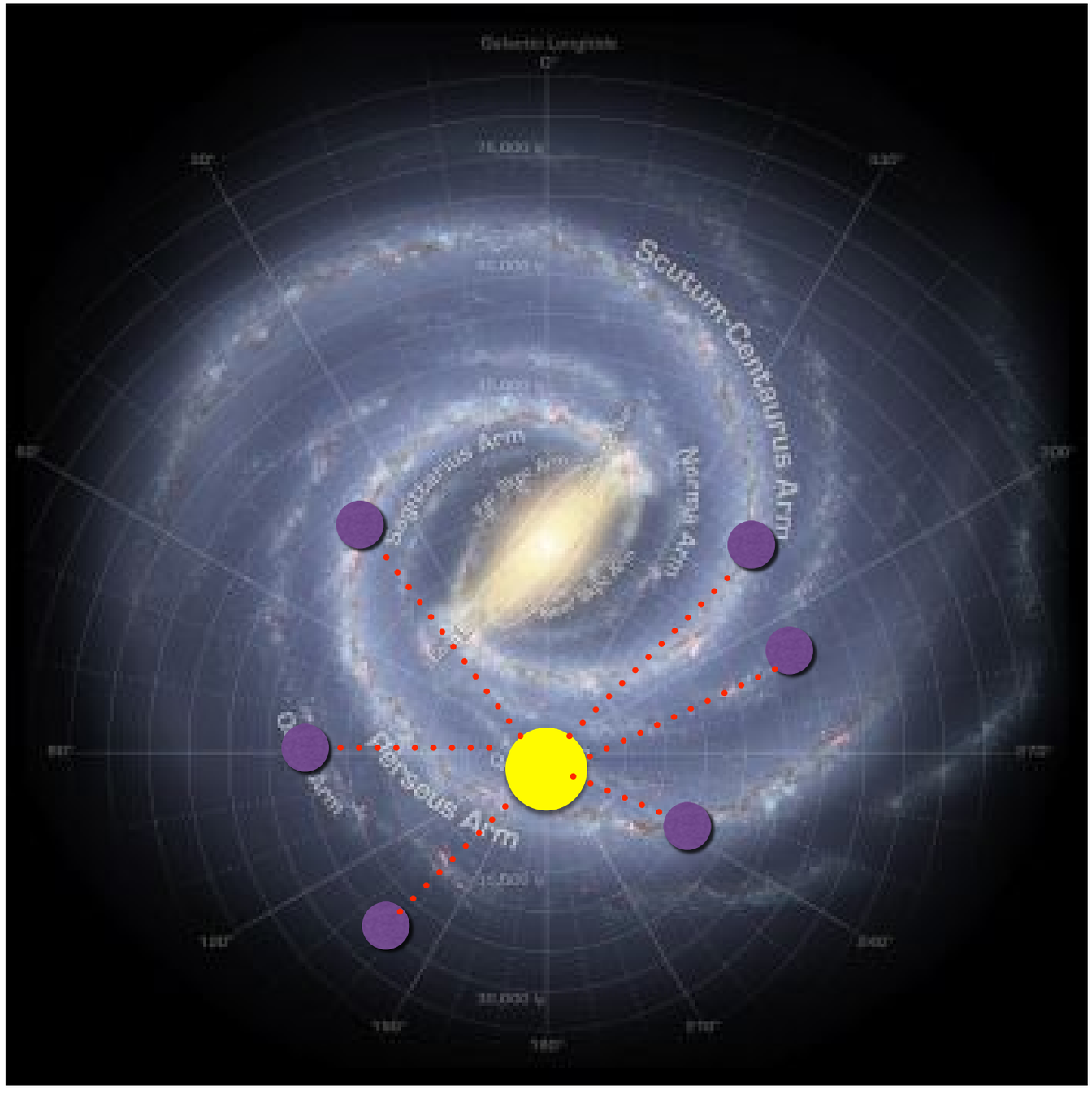


Max Planck Institute, Garching

The Full Spectrum



Our Detector is Big



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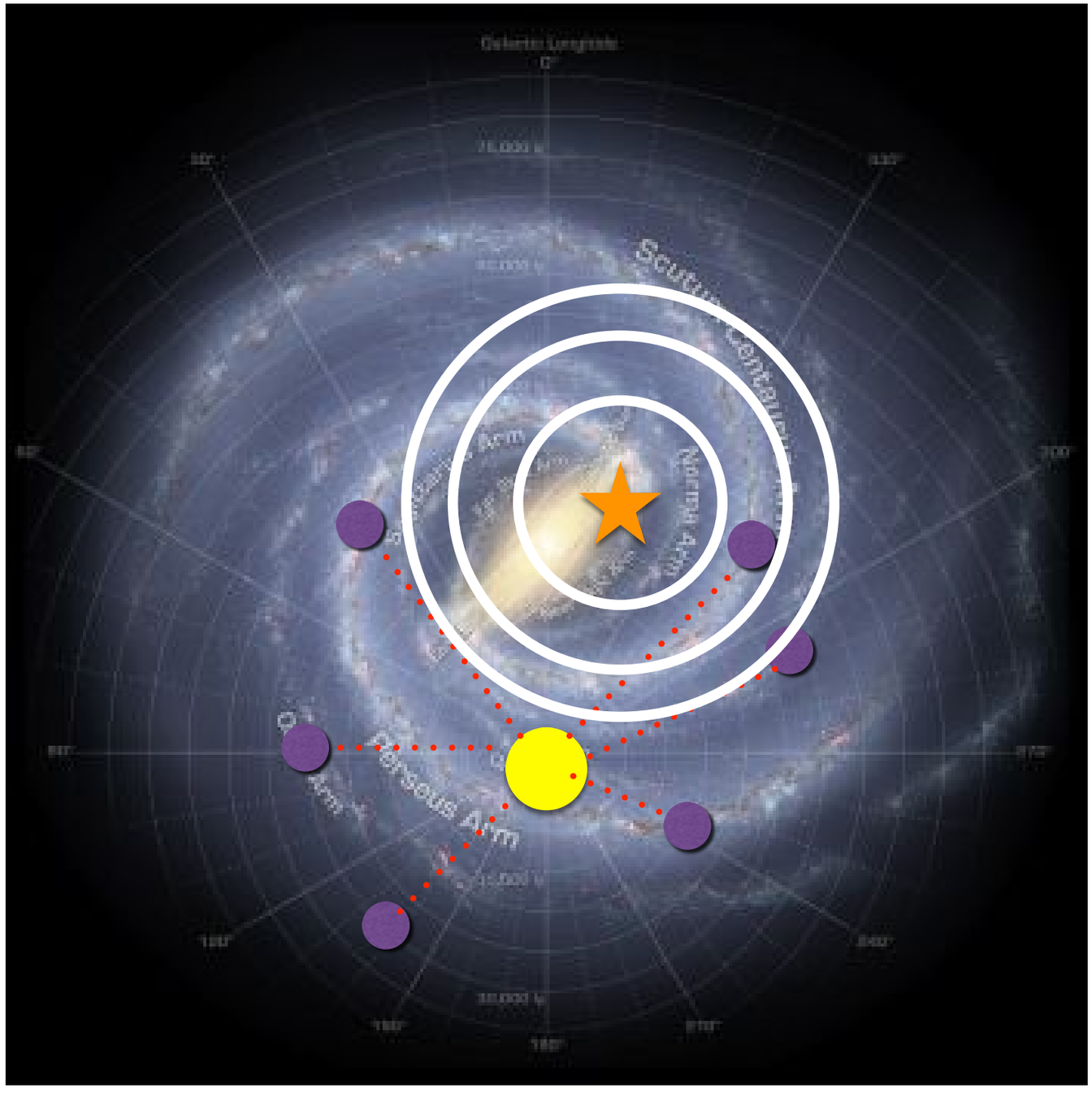
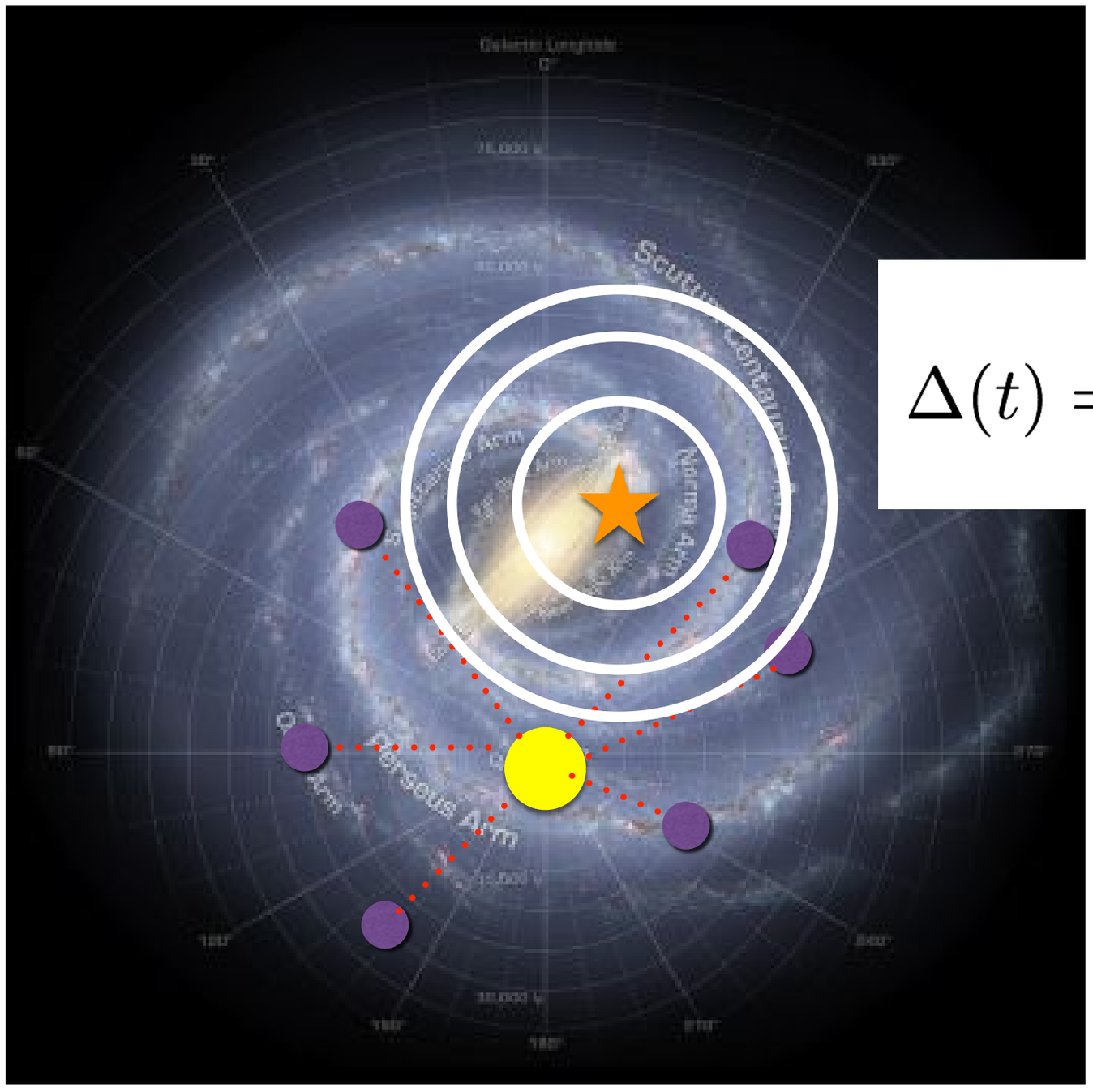


Our Detector is Big



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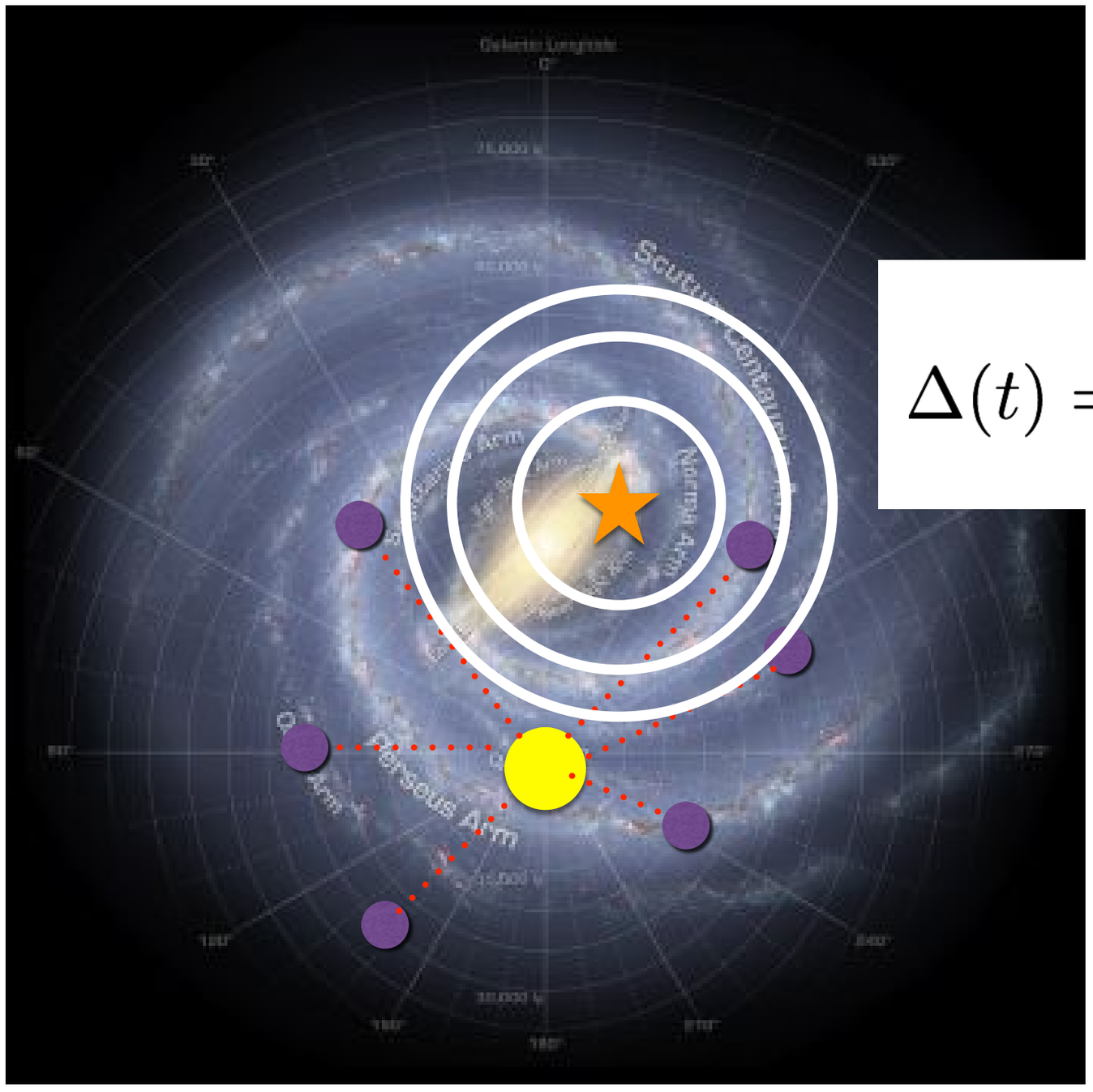
$$\Delta(t) = \frac{1}{2} \int_{t-d/c}^{t} \hat{k}^i \hat{k}^j h_{ij}(t', \mathbf{r}(t'))dt'$$

$$\Delta(t) = A[f(t) - f(t_p)]$$

Our Detector is Big



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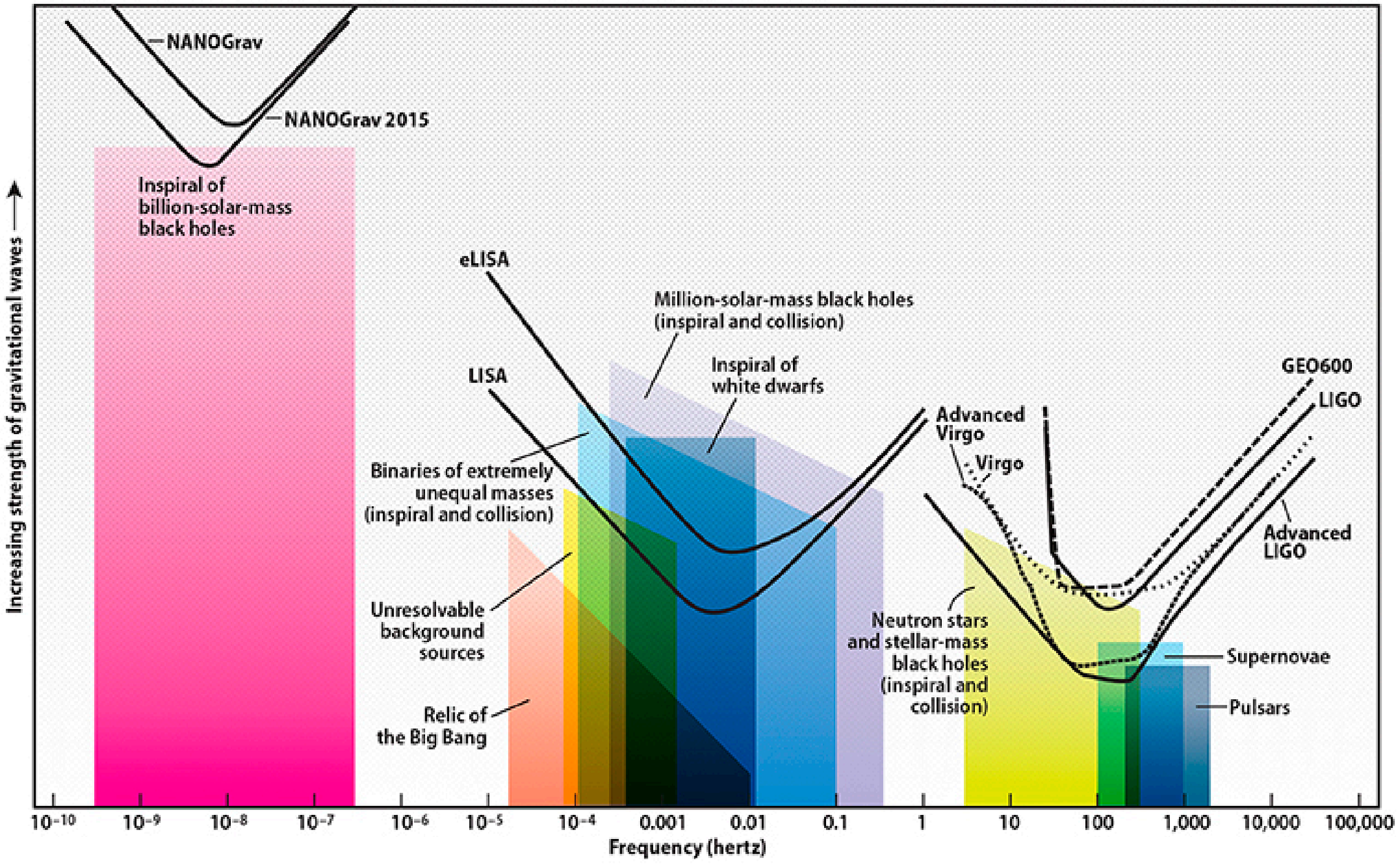
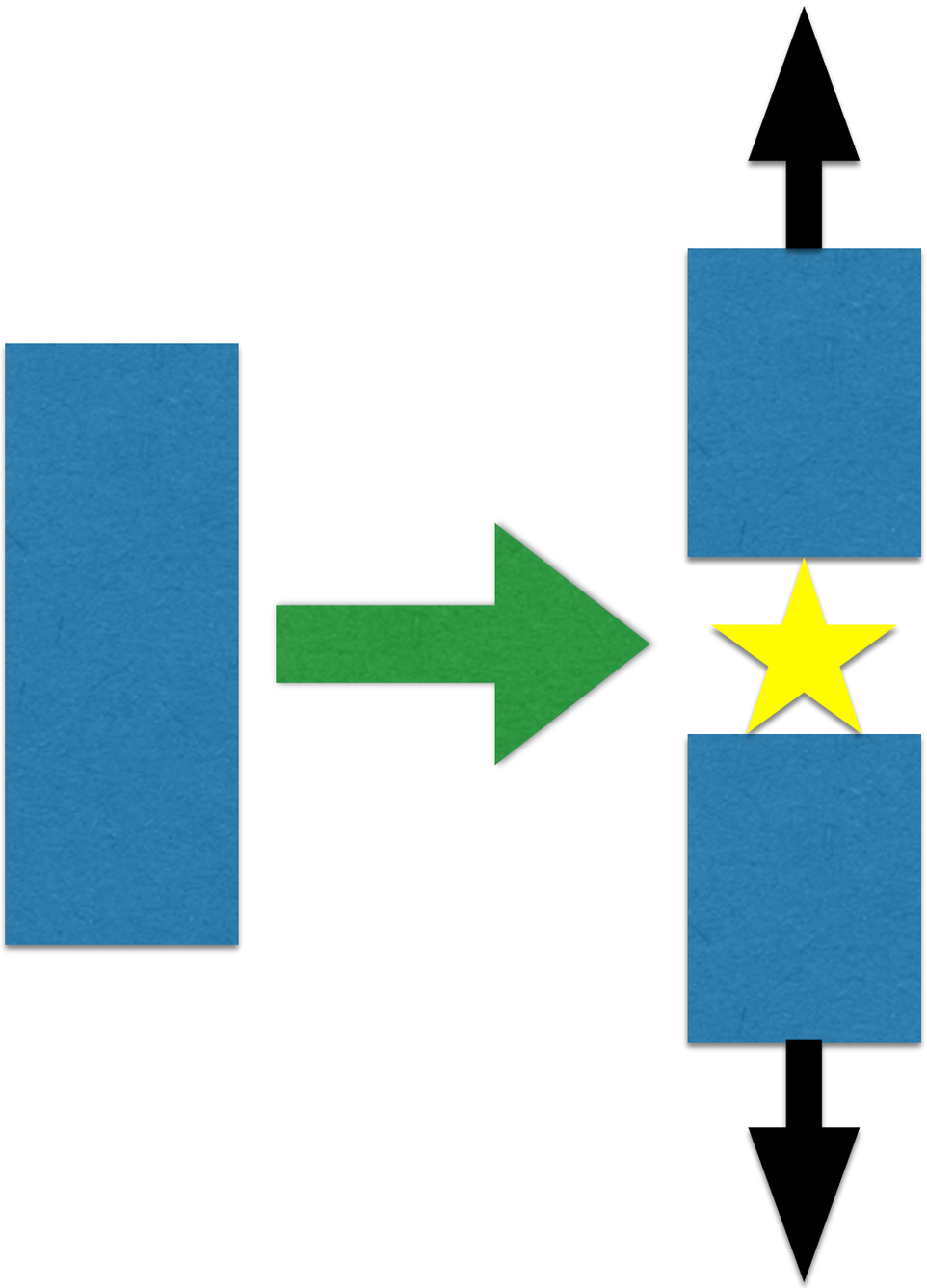
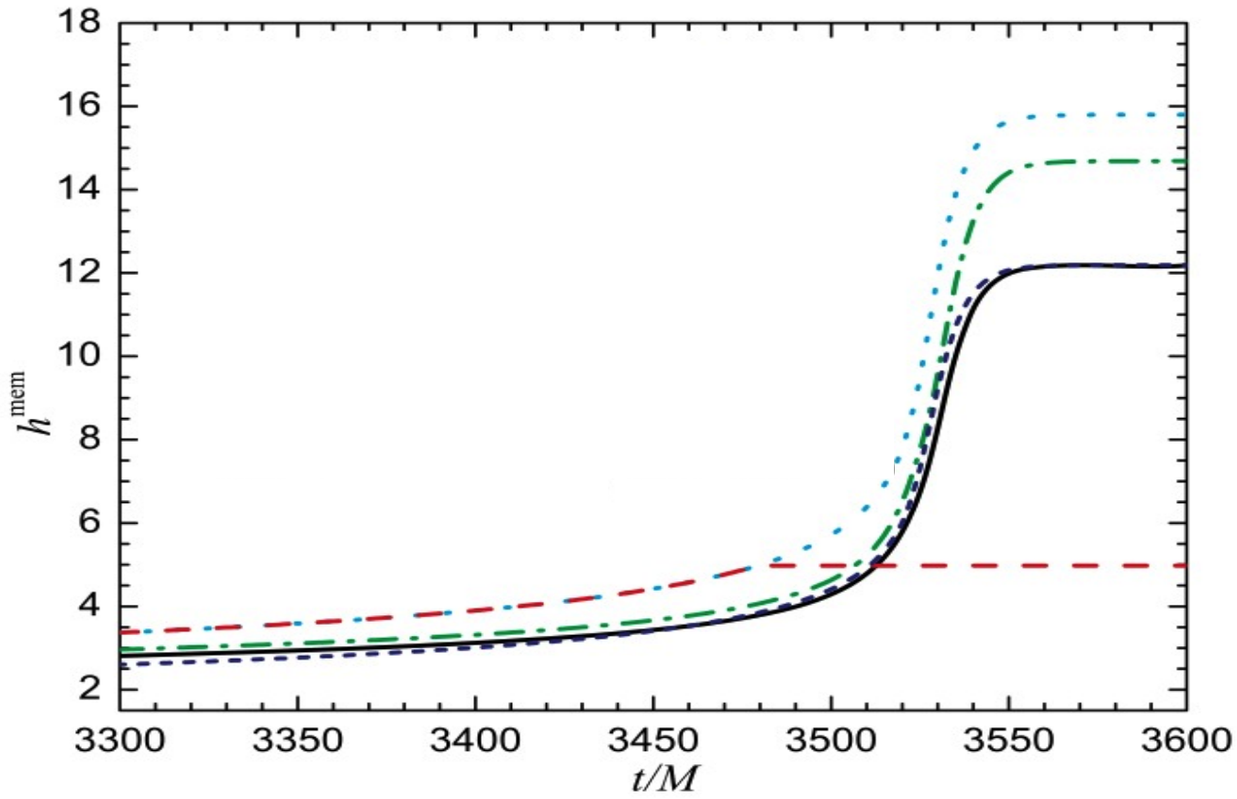
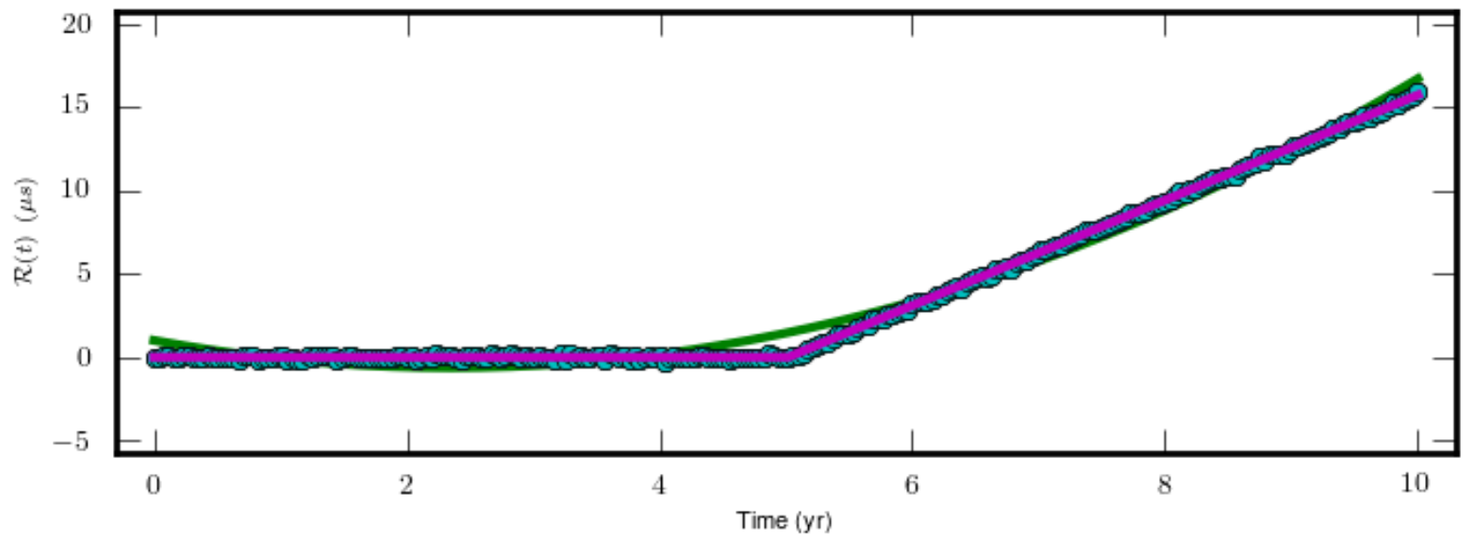
Aren’t SN High Frequency



Enter GW Memory







A Project is Born

PHYSICAL REVIEW D 96, 123016 (2017)

Pulsar timing perturbations from Galactic gravitational wave bursts with memory

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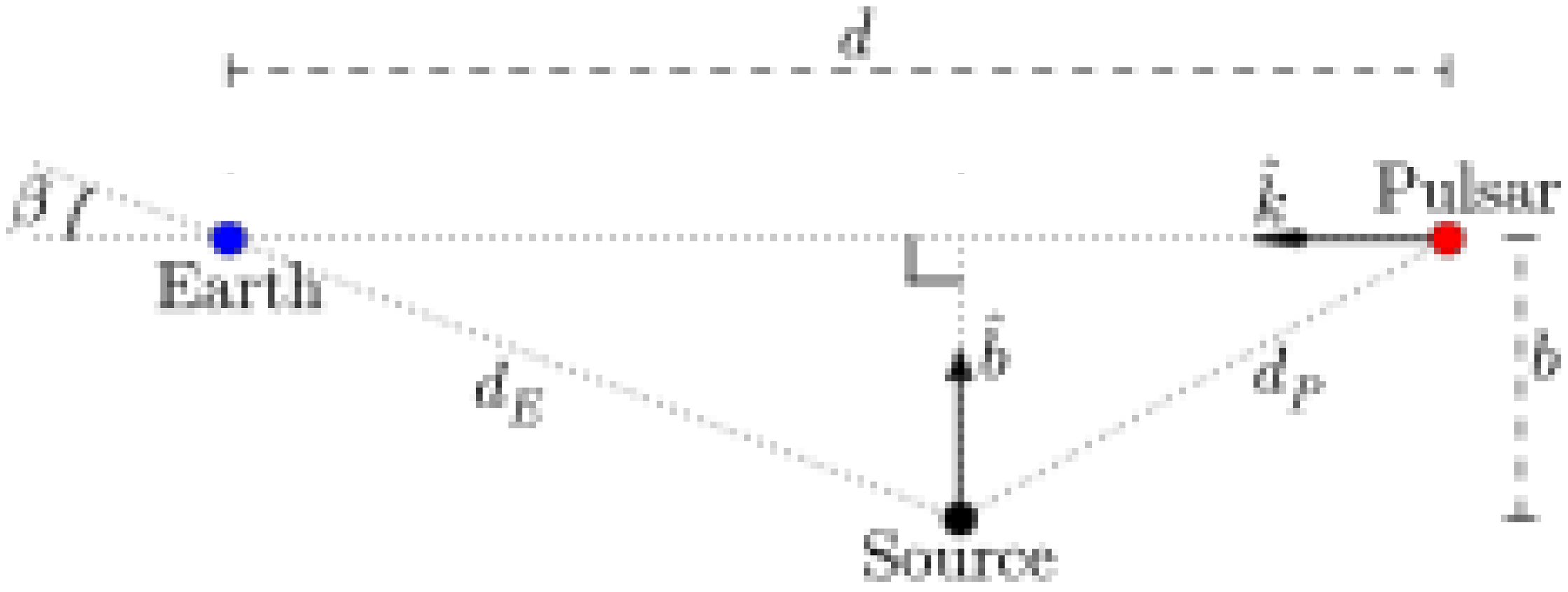
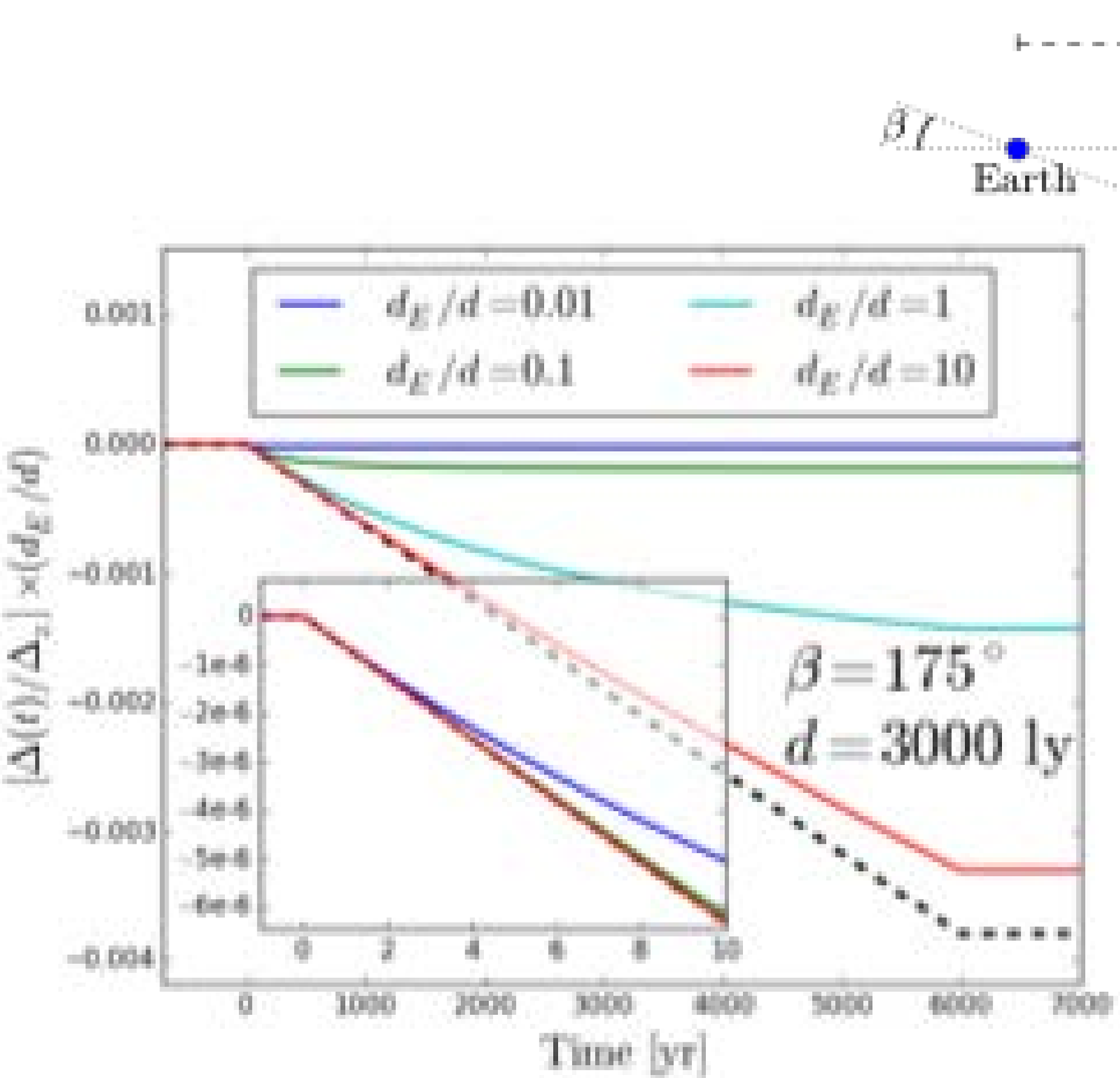
(Received 13 October 2017; published 29 December 2017)

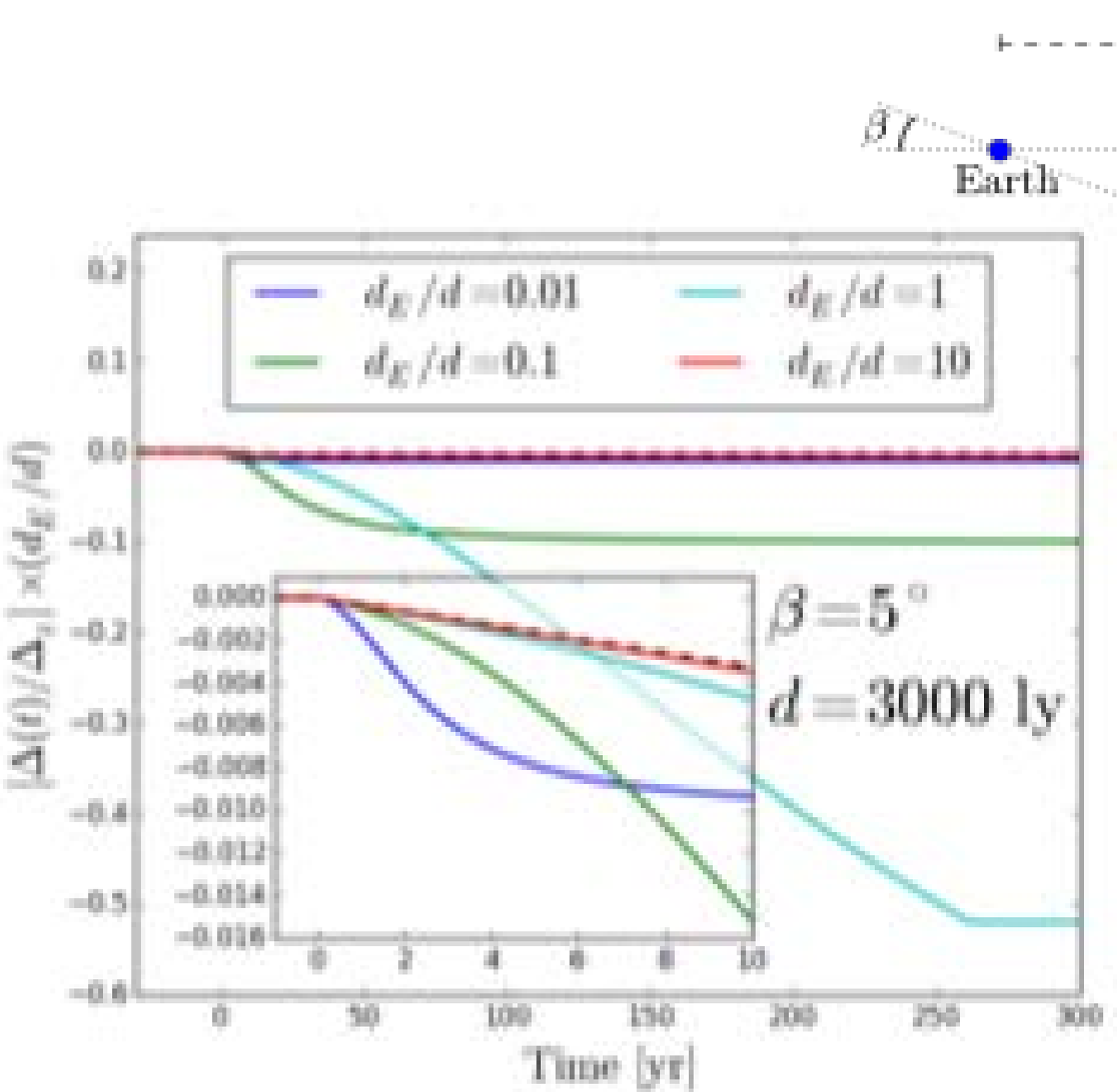
Some Geometry

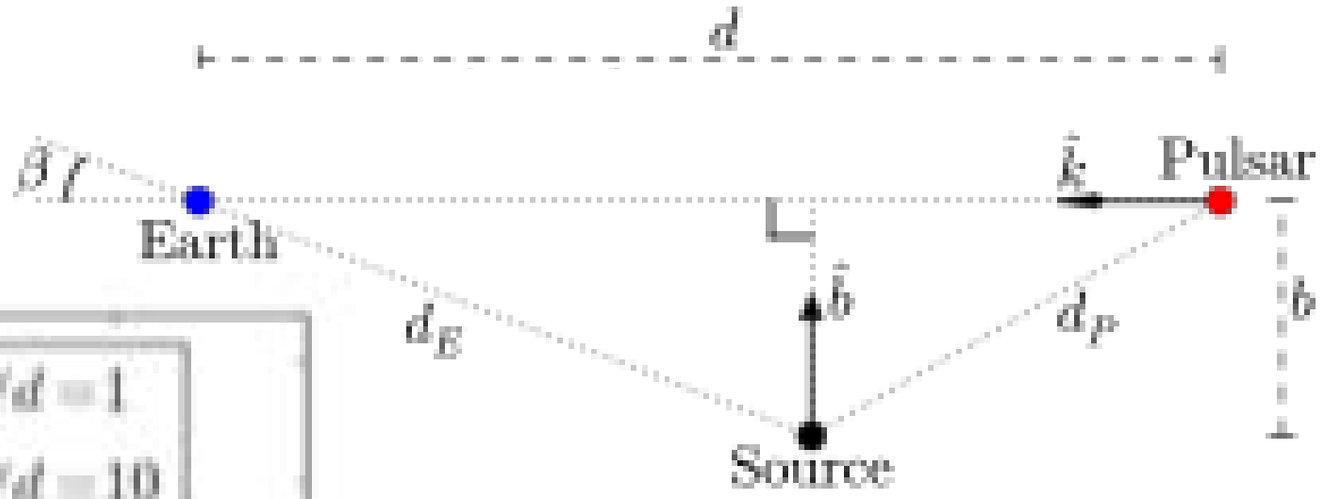


Case One

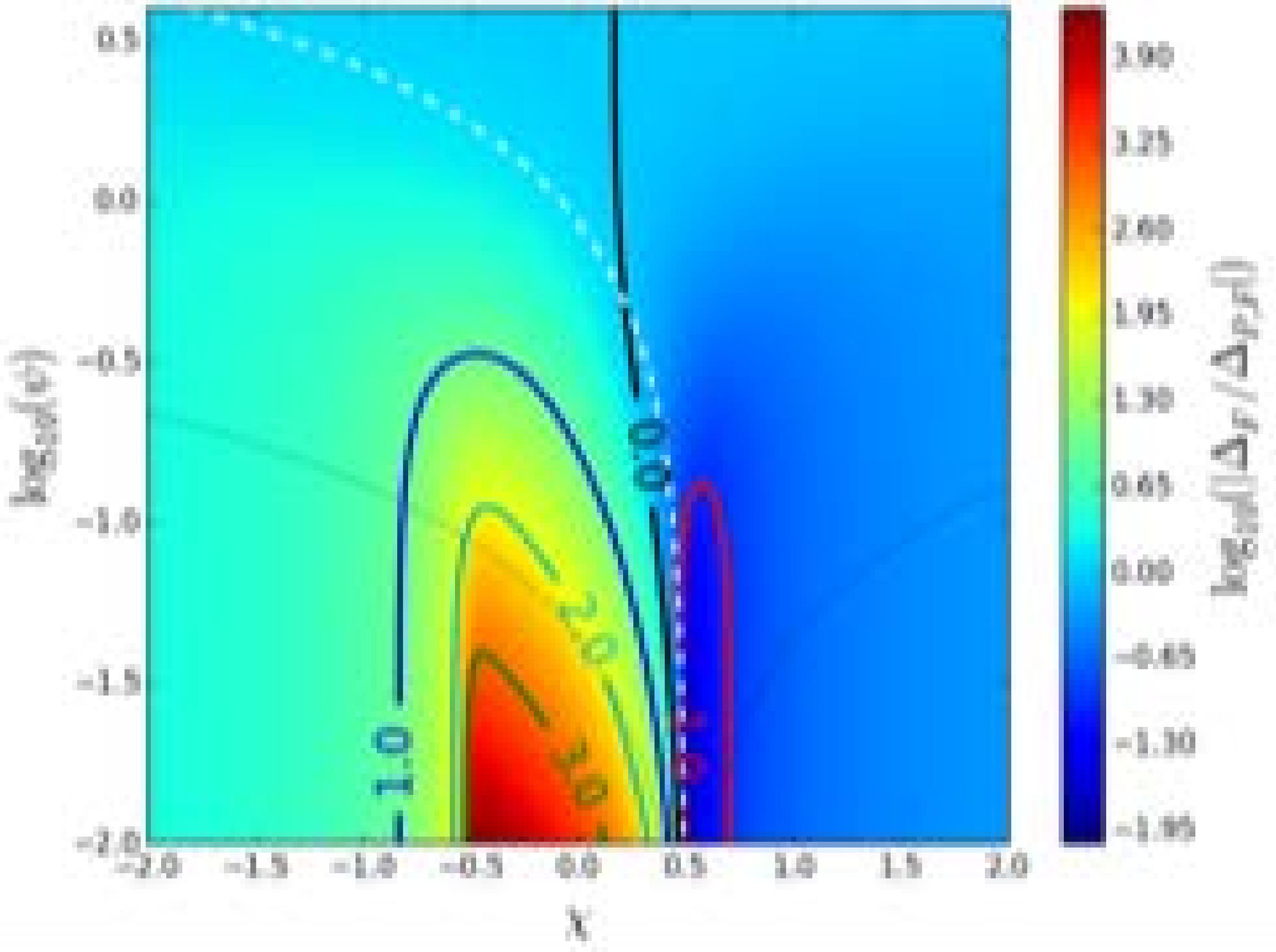

d
$\vec{\beta}_\ell$
Earth
d_E
$\vec{k}$
Pulsar
$\vec{b}$
d_P
b
Source
$d_E/d = 0.01$
$d_E/d = 1$
$d_E/d = 0.1$
$d_E/d = 10$
$\beta = 175^\circ$
$d = 3000$ ly
$|\Delta(z)/\Delta_{\perp}| \times (d_E/d)$
Time [yr]

Case Two


$d_E/d = 0.01$
$d_E/d = 0.1$
$d_E/d = 1$
$d_E/d = 10$
$\beta = 5^\circ$
$d = 3000$ ly
$|\Delta(\epsilon)/A_+| \times (d_E/d)$
Time [yr]

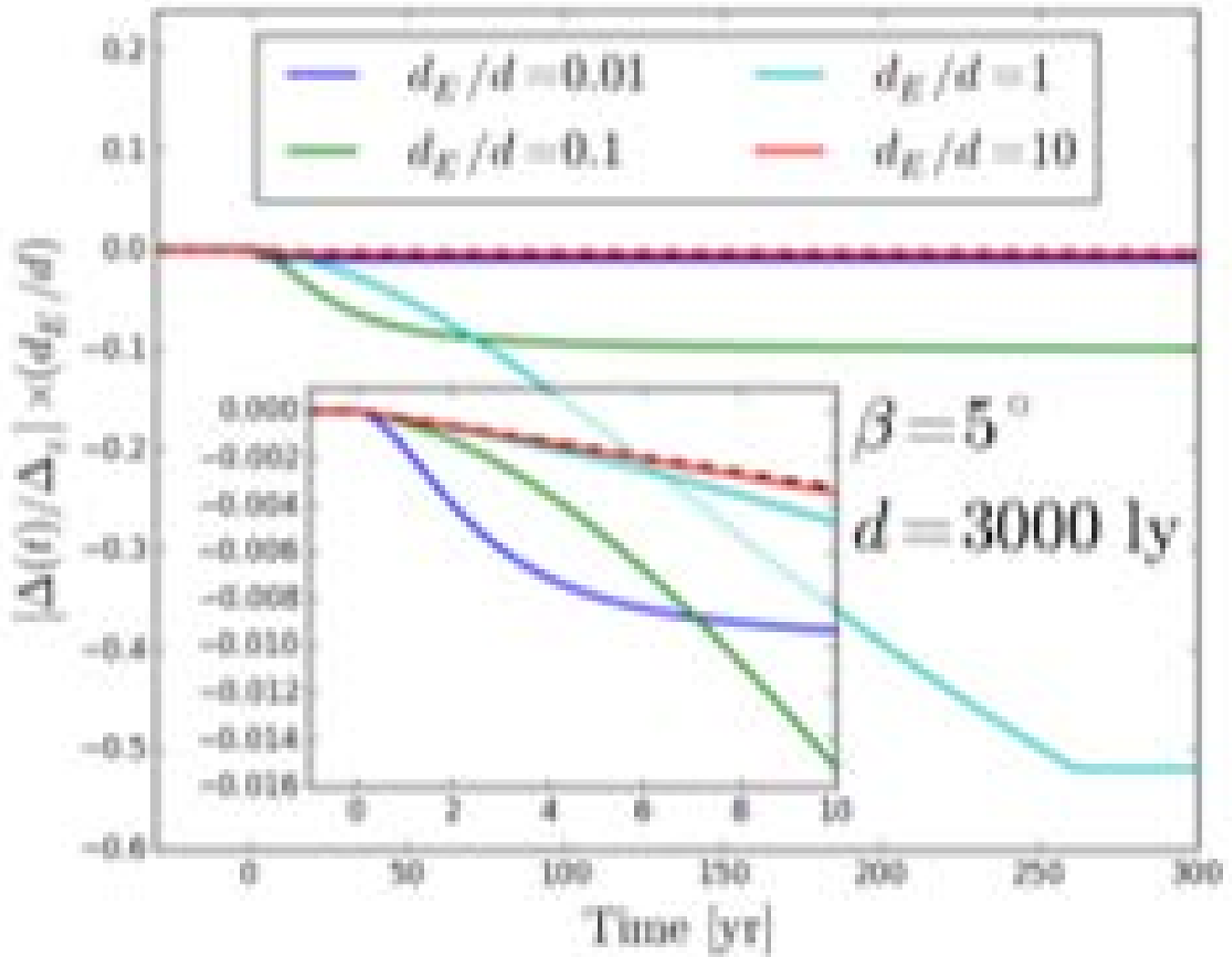

d
$\vec{\beta}_\ell$
Earth
d_E
$\vec{b}$
$\vec{k}$
Pulsar
d_P
b
Source

All the Cases



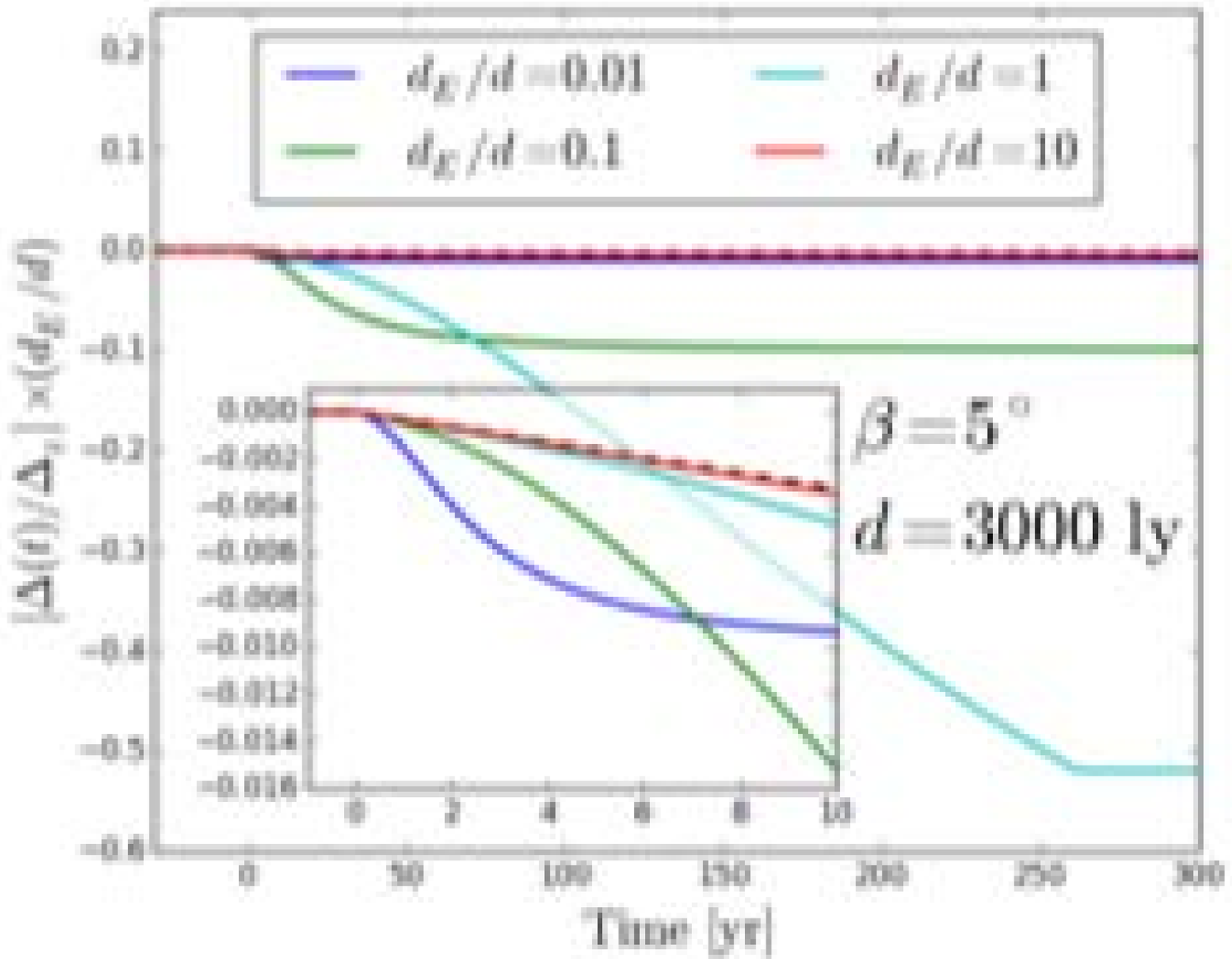
Can we Detect This?

Supernovae: $$\Delta_z \approx 2.7 \text{ ns} \left(\frac{\epsilon_2}{0.01}\right)\left(\frac{b_{00}}{10^{53} \text{ ergs}}\right)$$

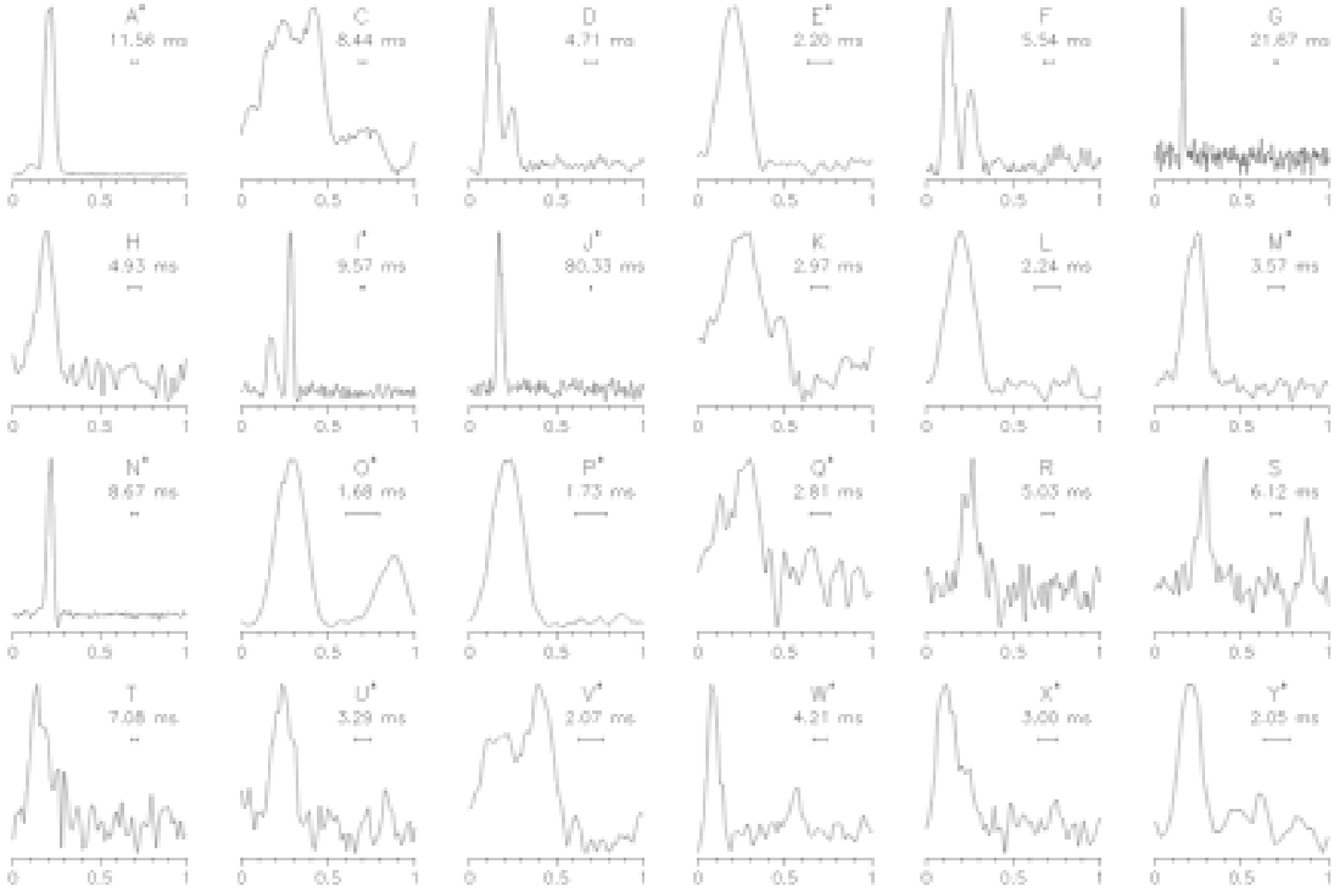


Can we Detect This?

Merger: $\Delta_z \approx 2\ \mu\text{s} \left(\frac{\mu}{10\ M_\odot} \right)$



Pulsars in Clusters



Ransom et al. (2005)

IMBH in Clusters

GRAVITATIONAL WAVES AND INTERMEDIATE MASS BLACK HOLE RETENTION IN GLOBULAR CLUSTERS

GIACOMO FRAGIONE[1], IDAN GINSBURG[2] AND BENCE KOCSIS[3]

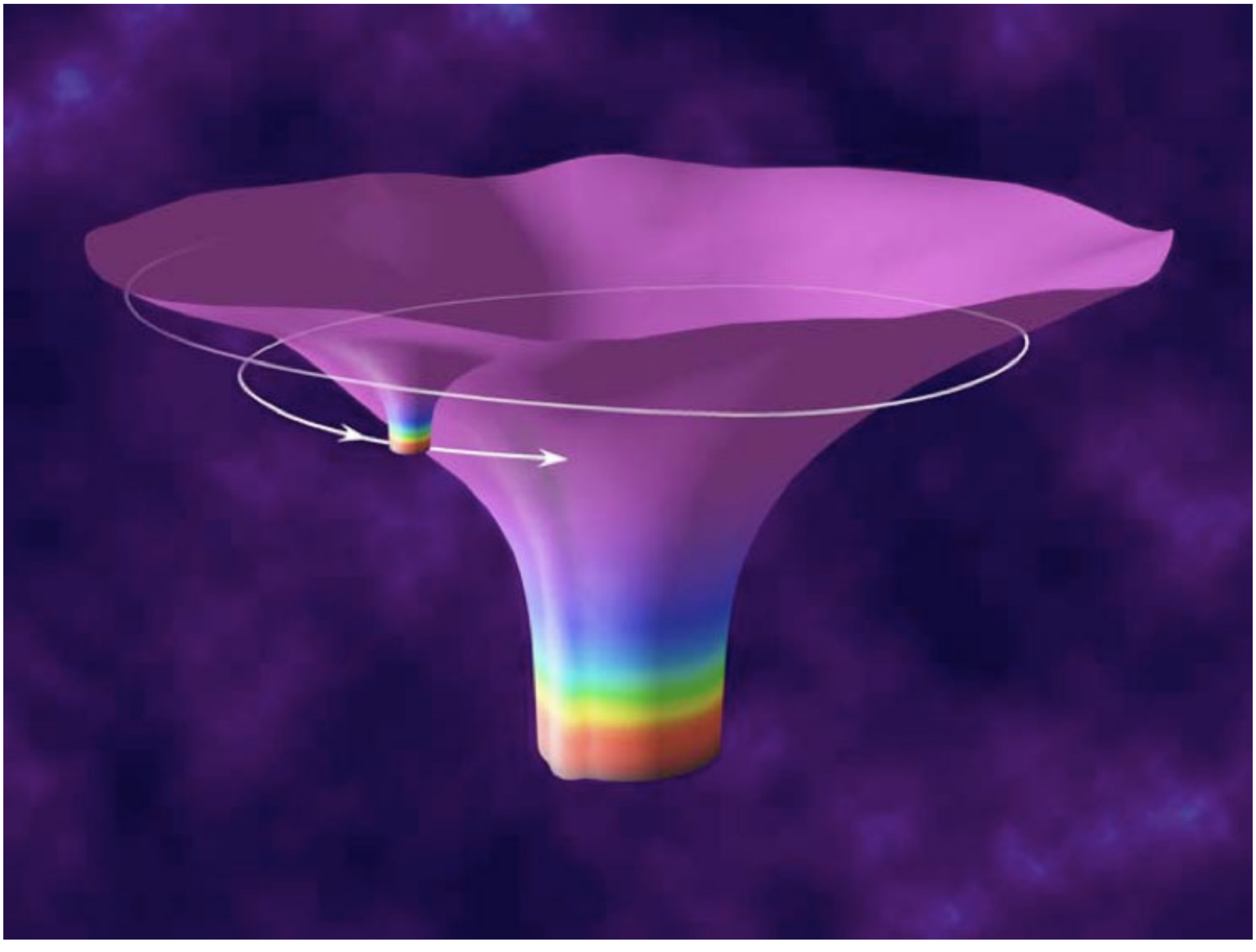
An intermediate-mass black hole in the centre of the globular cluster 47 Tucanae

Bülent Kızıltan[1], Holger Baumgardt[2] & Abraham Loeb[1]

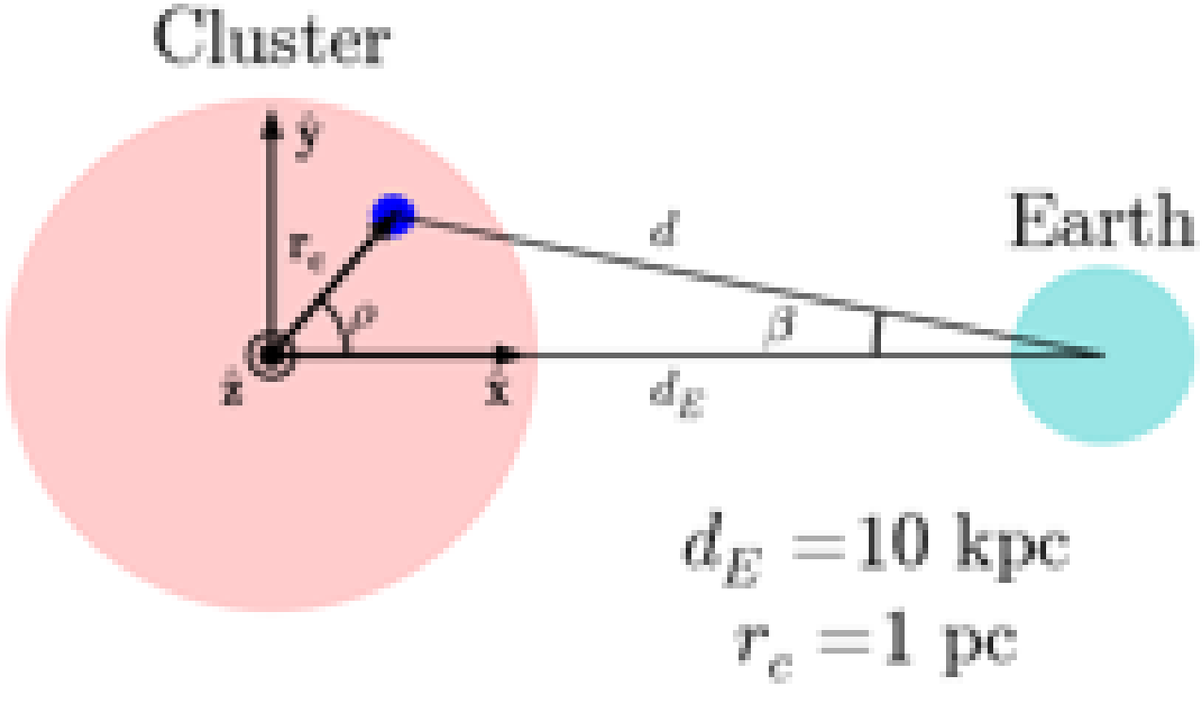
Evidence for an intermediate-mass black hole in the globular cluster NGC 6624

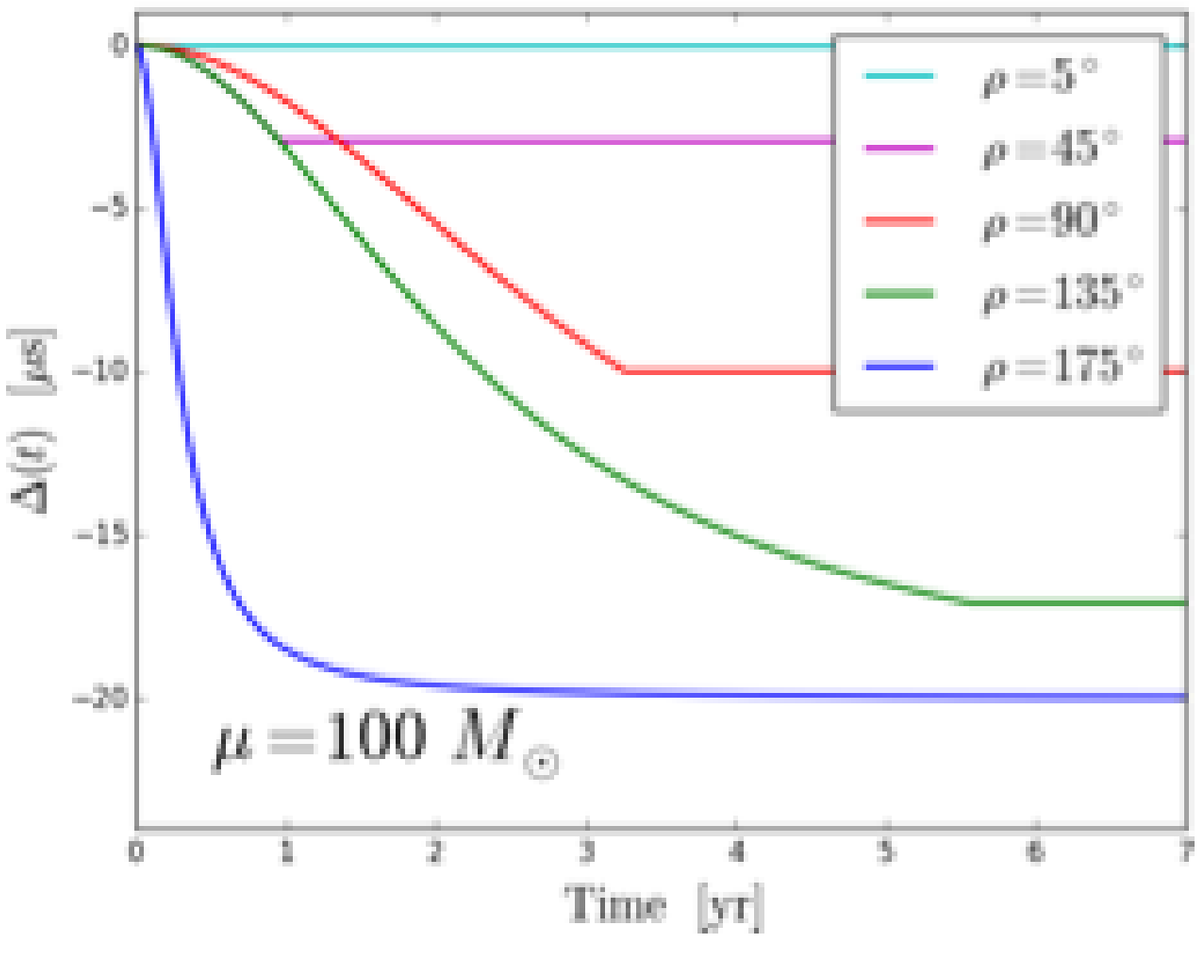
B. B. P. Perera[1], B. W. Stappers[1], A. G. Lyne[1], C. G. Bassa[2], I. Cognard[3,4], L. Guillemot[3,4], M. Kramer[5,1], G. Theureau[3,4,6], G. Desvignes[5]

EMRIs

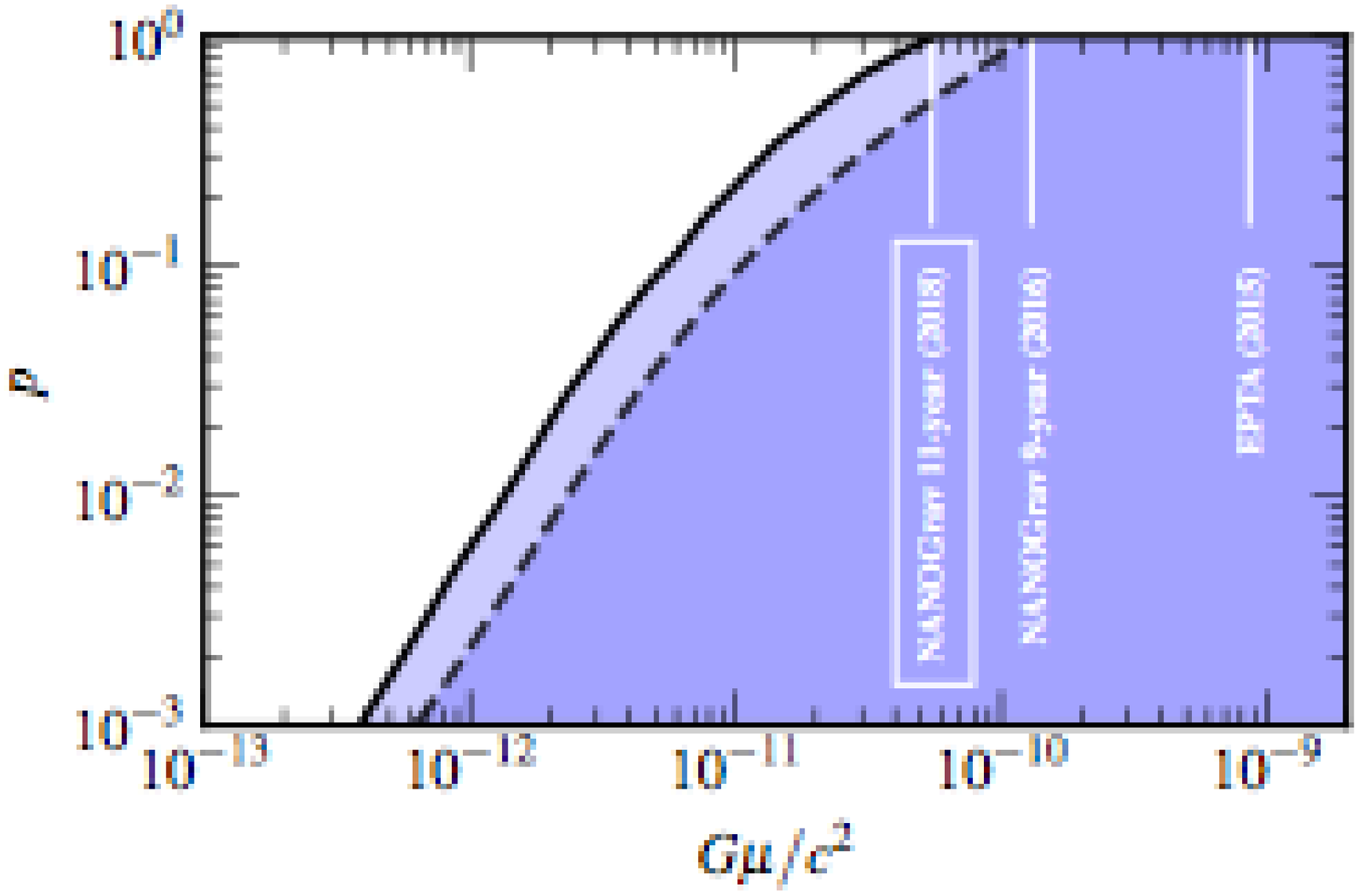


Leveraging Proximity





Okay, here’s how this actually started…

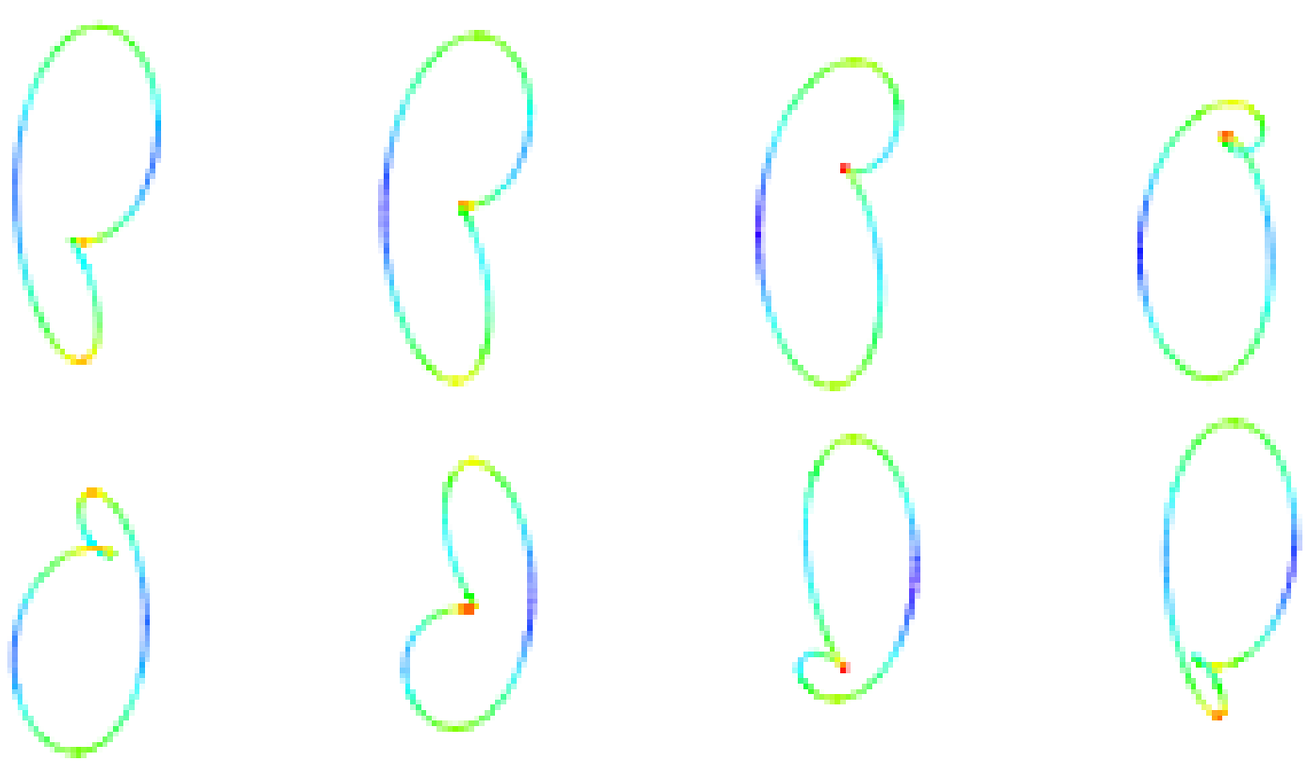


Arzoumanian et al. (2018)

Okay, here's how this actually started…

Clustering of Superstring Loops

David F. Chernoff



Bloomfield & Chernoff (2014)

In Summary

- **Among GW detectors, PTAs respond uniquely to Galactic sources due to their sheer scale.**

- **Memory is a generic feature of GW events and causes PTA signals that grow over time.**

- **Detection of a conventional Galactic BWM is unlikely because of low event rates and the need for fortuitous alignment.**

- **Globular clusters and the GC are good places to look.**

- **This is a useful first step towards considering more exotic forms of Galactic GW sources such as string loops.**