GWADW | May 22, 2019

an overview of (some) high frequency GW sources

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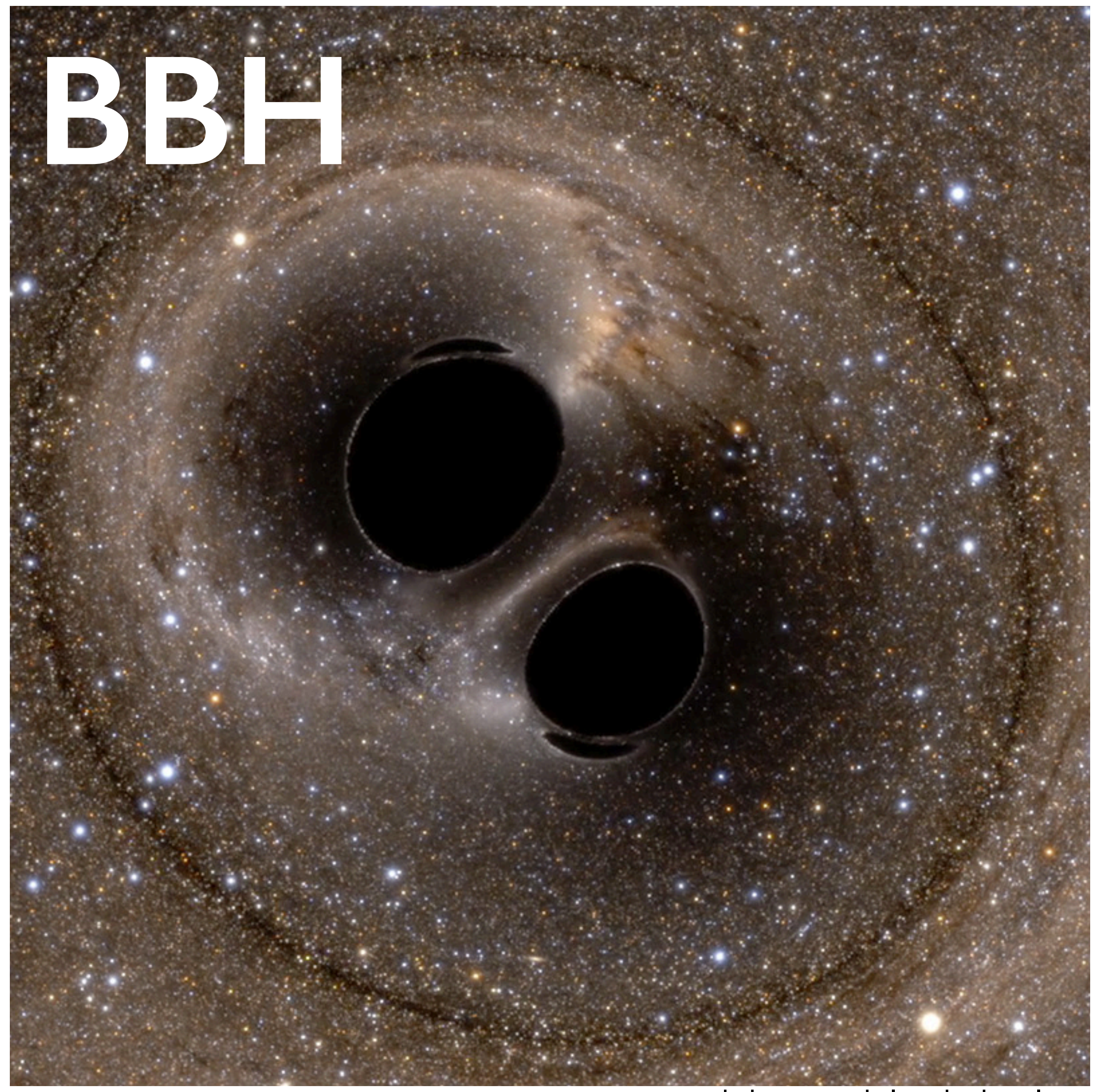
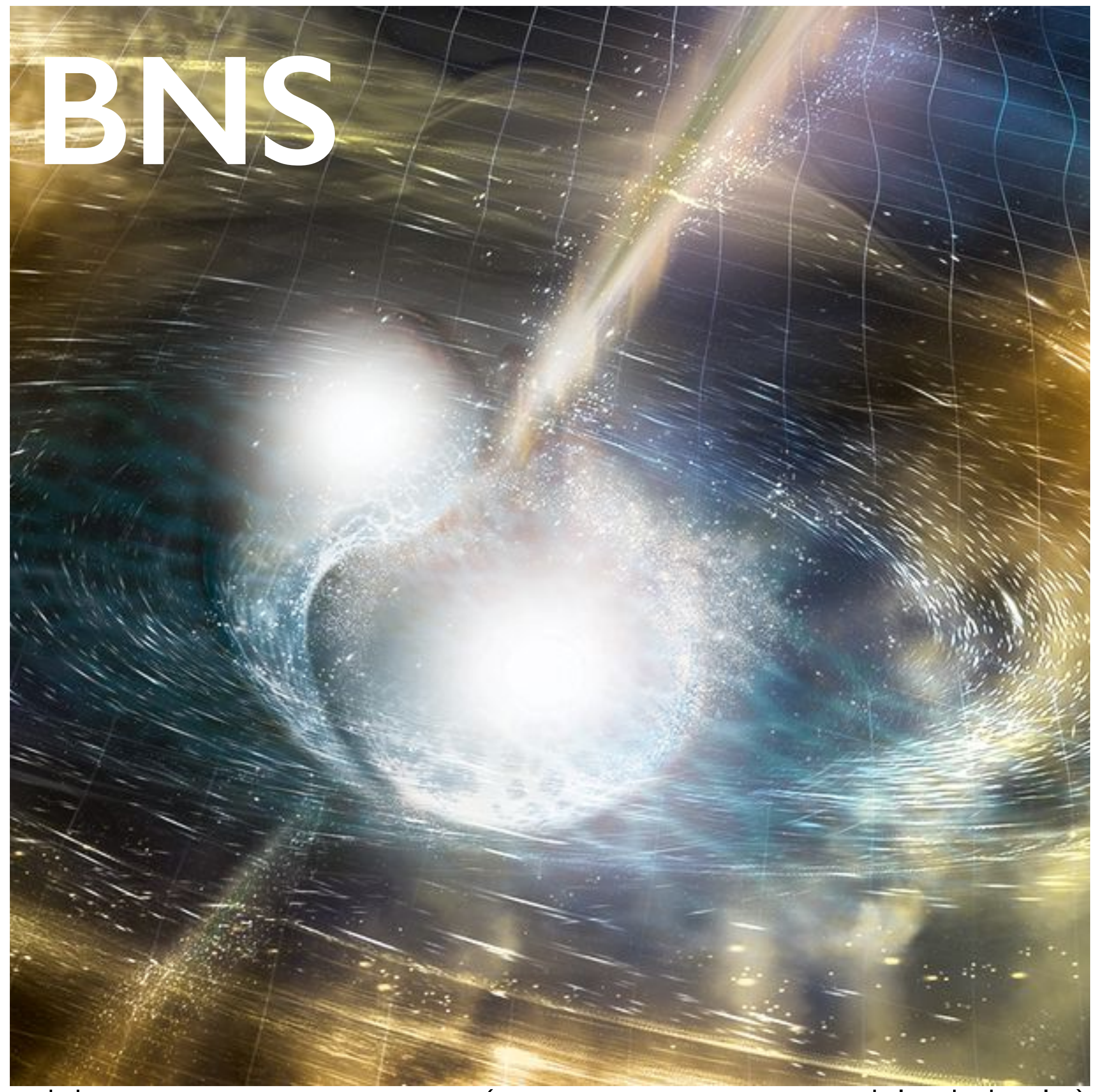
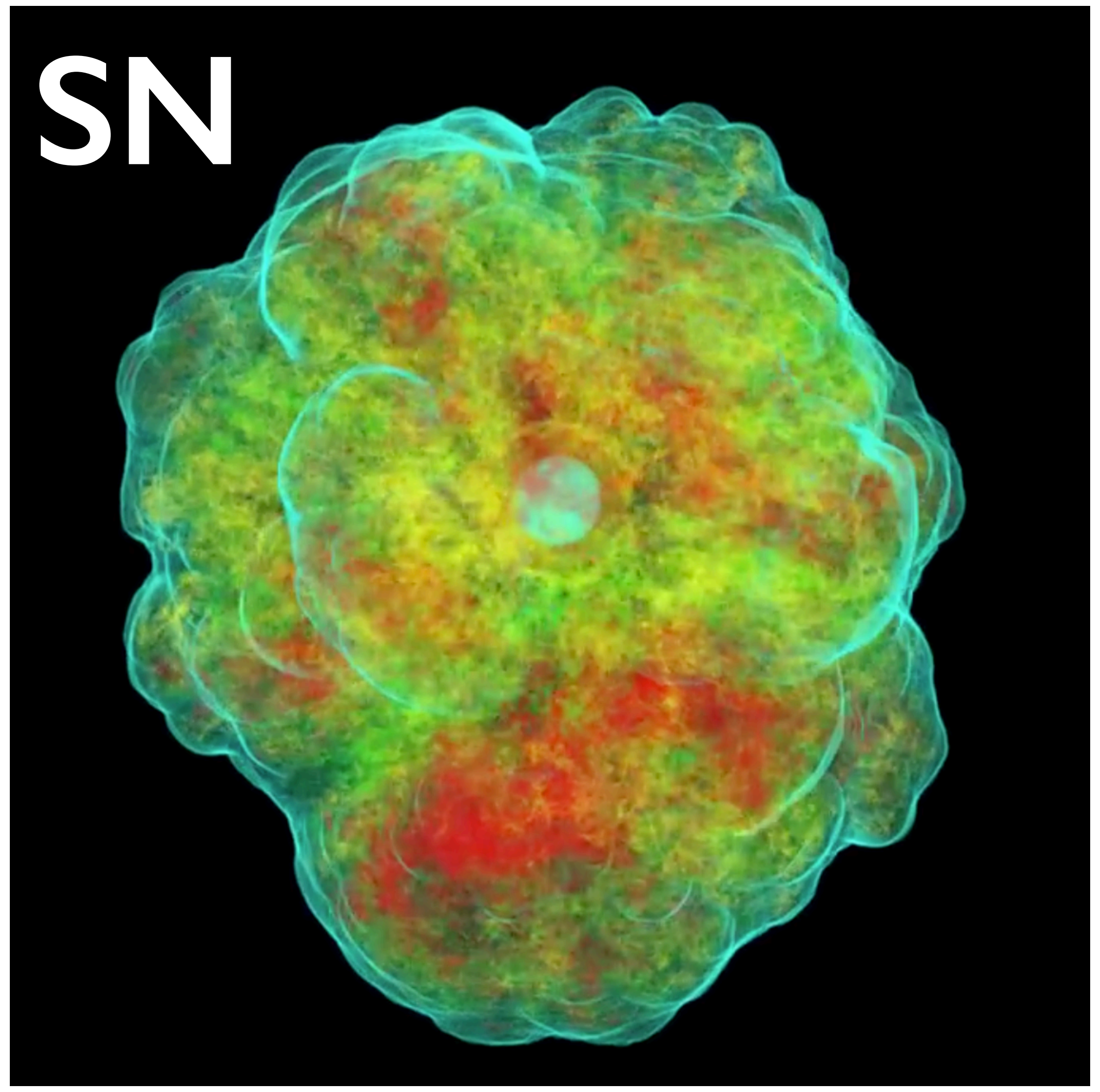
sources



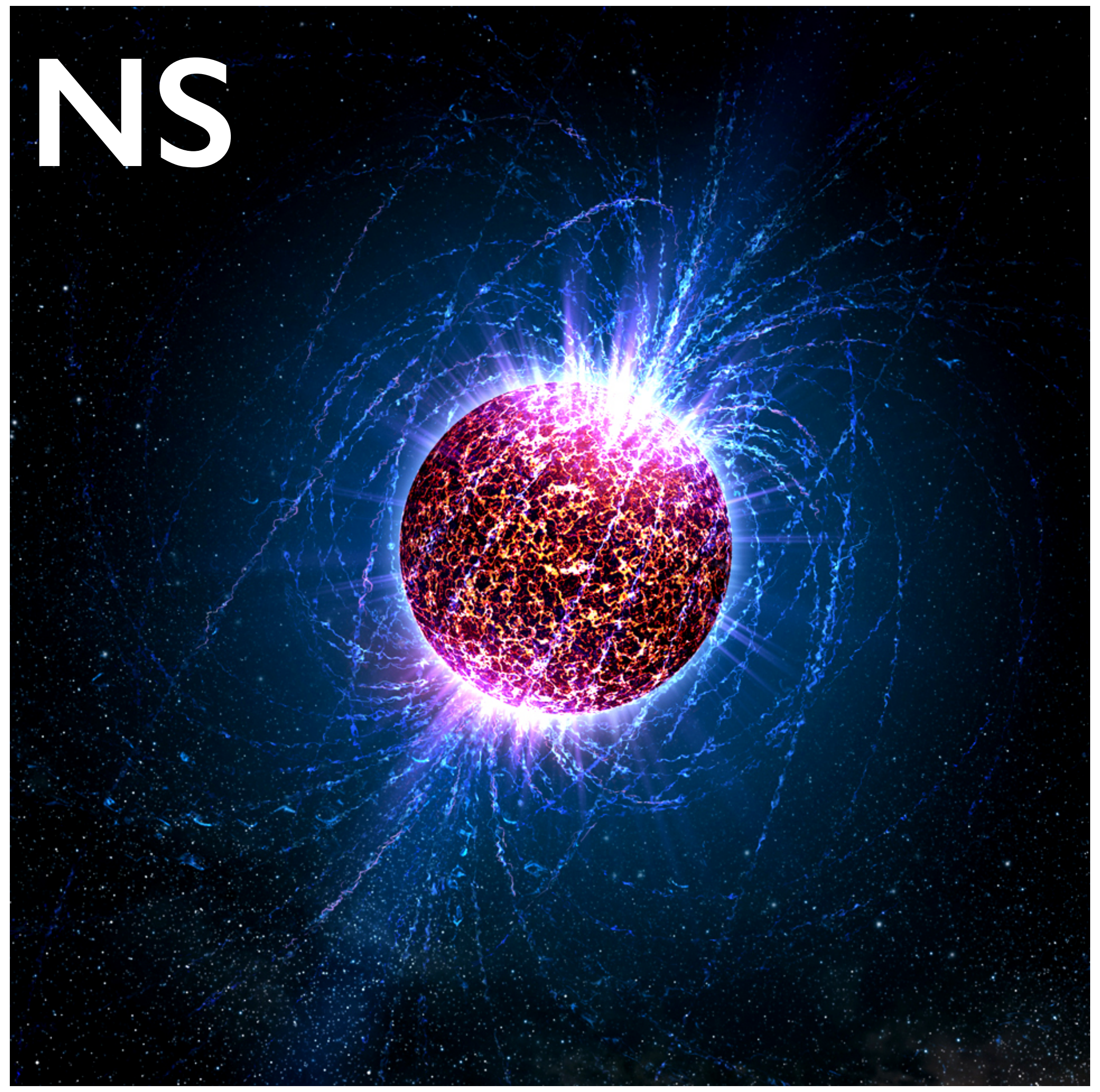
binary black holes



binary neutron stars (or neutron star + black hole)

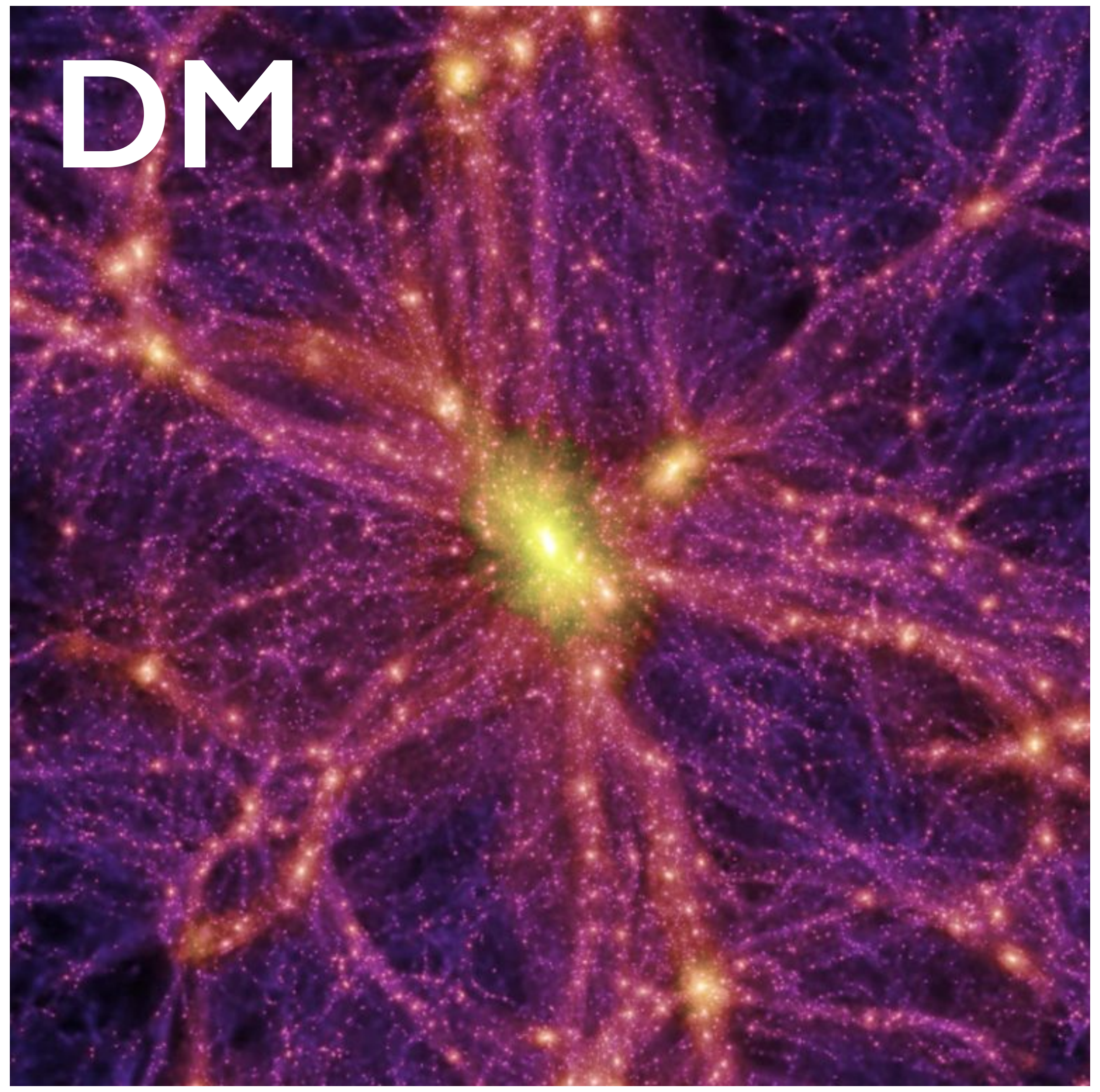


supernovae



neutron stars

stochastic background



dark matter & exotica

Image credit (left-right, top-bottom): SXS | LIGO, A. Simonnet | C. Ott || C. Reed | OzGrav | V. Springel

sources

see talks by

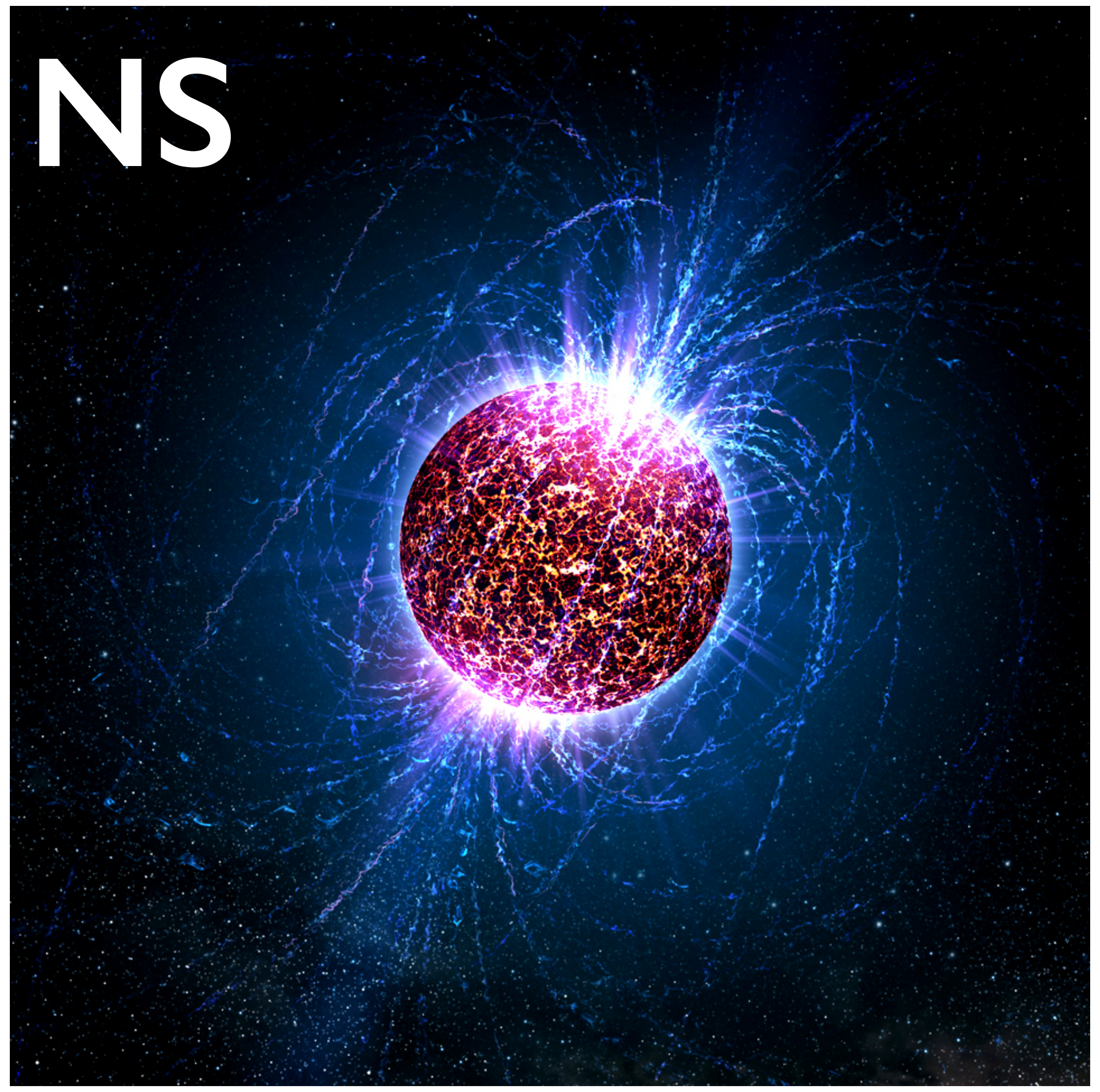
Michael Coughlin, Masaru Shibata, Huan Yang

Mon11:25am Wed06:00pm Wed06:30pm

binary black holes

binary neutron stars (or neutron star + black hole)

supernovae



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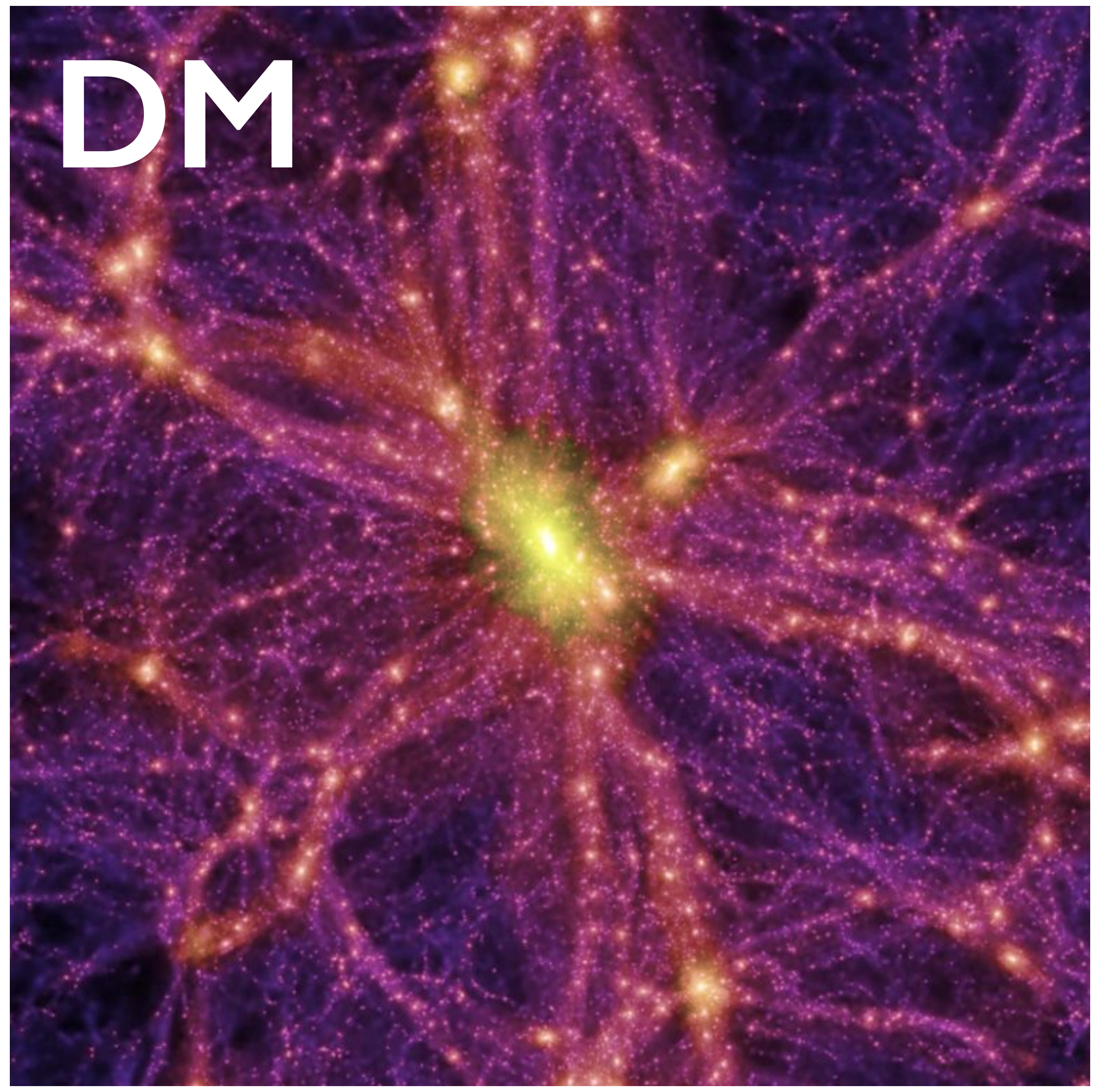

dark matter & exotica

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neutron stars

could emit GWs through multiple mechanisms

continuous wave due to non-axisymetry

simplest mechanism, $f_{\mathrm{GW}} = 2f_{\mathrm{rot}}$

very weak! $h_0 \approx 10^{-24} \left(\frac{I_{zz}}{I_0}\right) \left(\frac{f_{\mathrm{GW}}}{1\,\mathrm{kHz}}\right)^2 \left(\frac{\mathrm{kpc}}{r}\right) \left(\frac{\epsilon}{10^{-6}}\right)$

I_{zz}: moment of inertia along z-axis | $I_0 = 10^{38}\,\mathrm{kg\,m^2}$: canonical moment of inertia | $\epsilon = (I_{xx} - I_{yy})/I_{zz}$: ellipticity

what's the highest f_{GW} we could get?

$$F_{\mathrm{cent}} = F_{\mathrm{grav}} \implies f_{\mathrm{GW}} \approx 3\,\mathrm{kHz} \left(\frac{R}{12\,\mathrm{km}}\right)^{-3/2} \left(\frac{M}{1.4\,M_\odot}\right)^{1/2}$$

other mechanisms: *r*-modes and *f*-modes

CWs would teach us about nuclear physics!

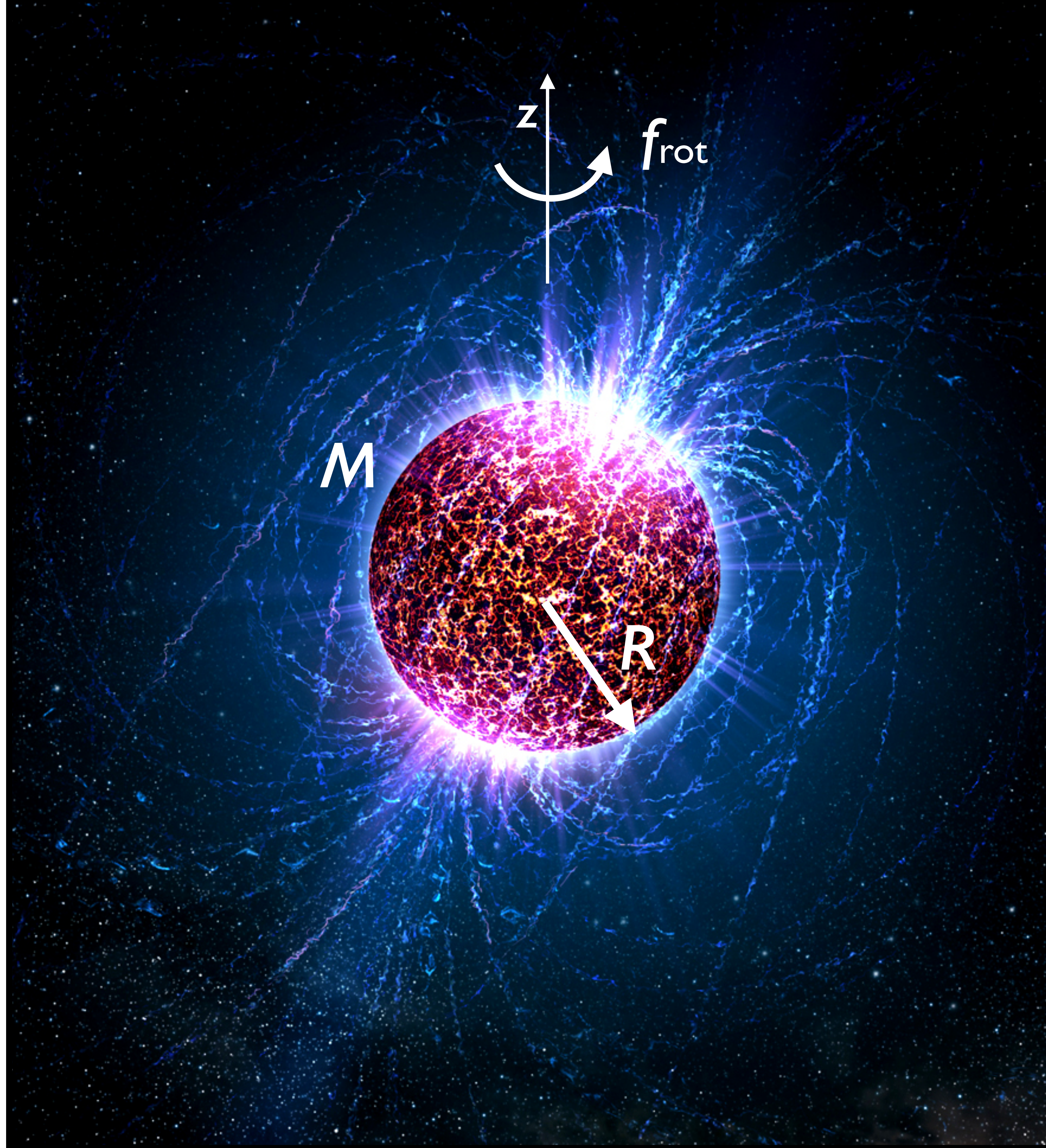


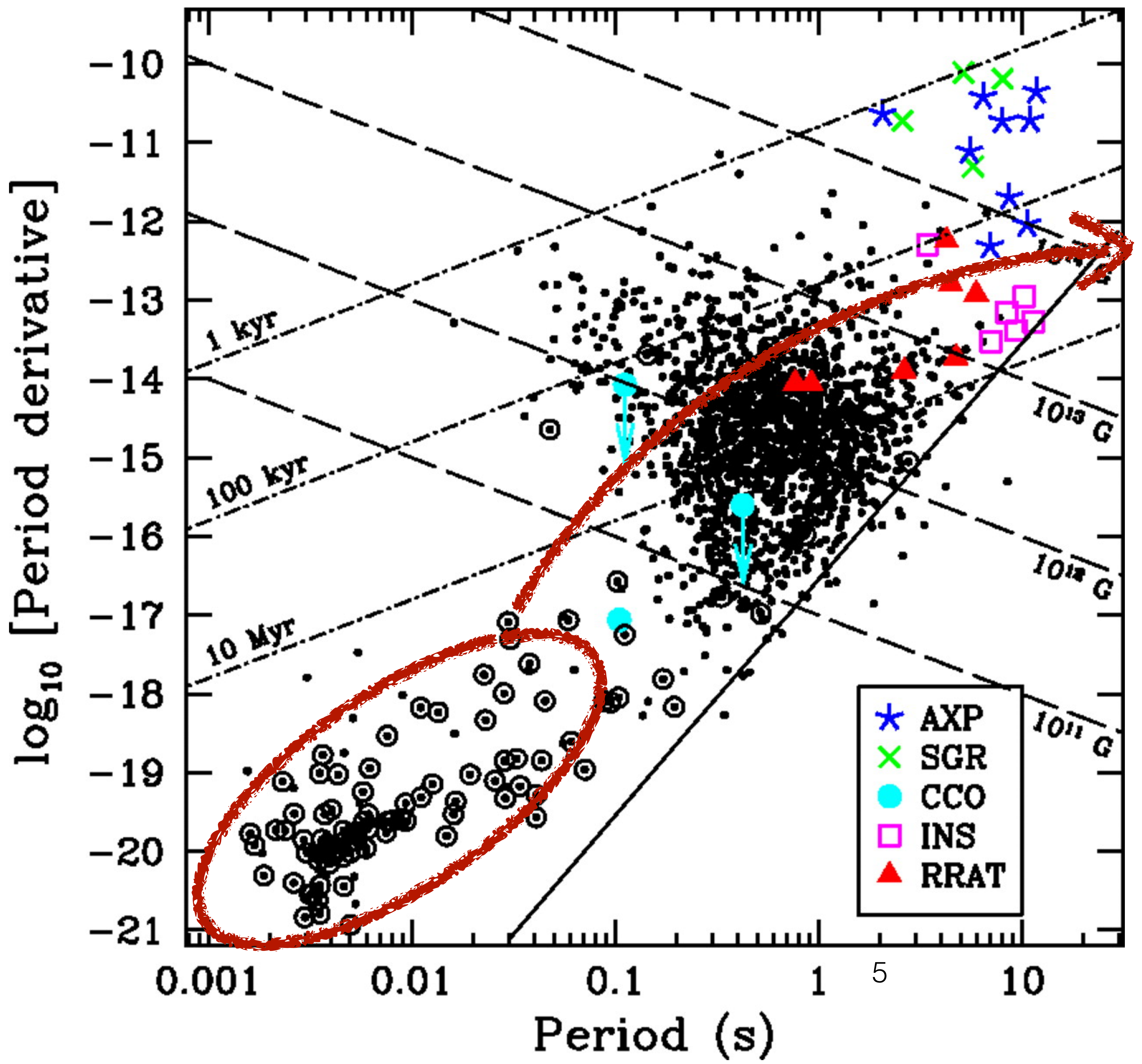
Image credit: C. Reed

neutron stars

abundant in our galaxy ($10^{8\text{-}9}$ expected)

~2500 detected (most as pulsars)

found isolated and in binaries



· rotation-powered pulsar

⊙ pulsar in binary

~200 ms pulsars

most in binaries

fast, old, low B-fields

fastest f_{rot} = 716Hz

(PSR J1748-2446ad)

AXP : anomalous X-ray pulsar

SGR : soft gamma-ray repeater

CCO : central compact object

INS : isolated neutron stars

RRAT : rotating radio transients

Source: V. M. Kaspi PNAS 2010;107:7147-7152

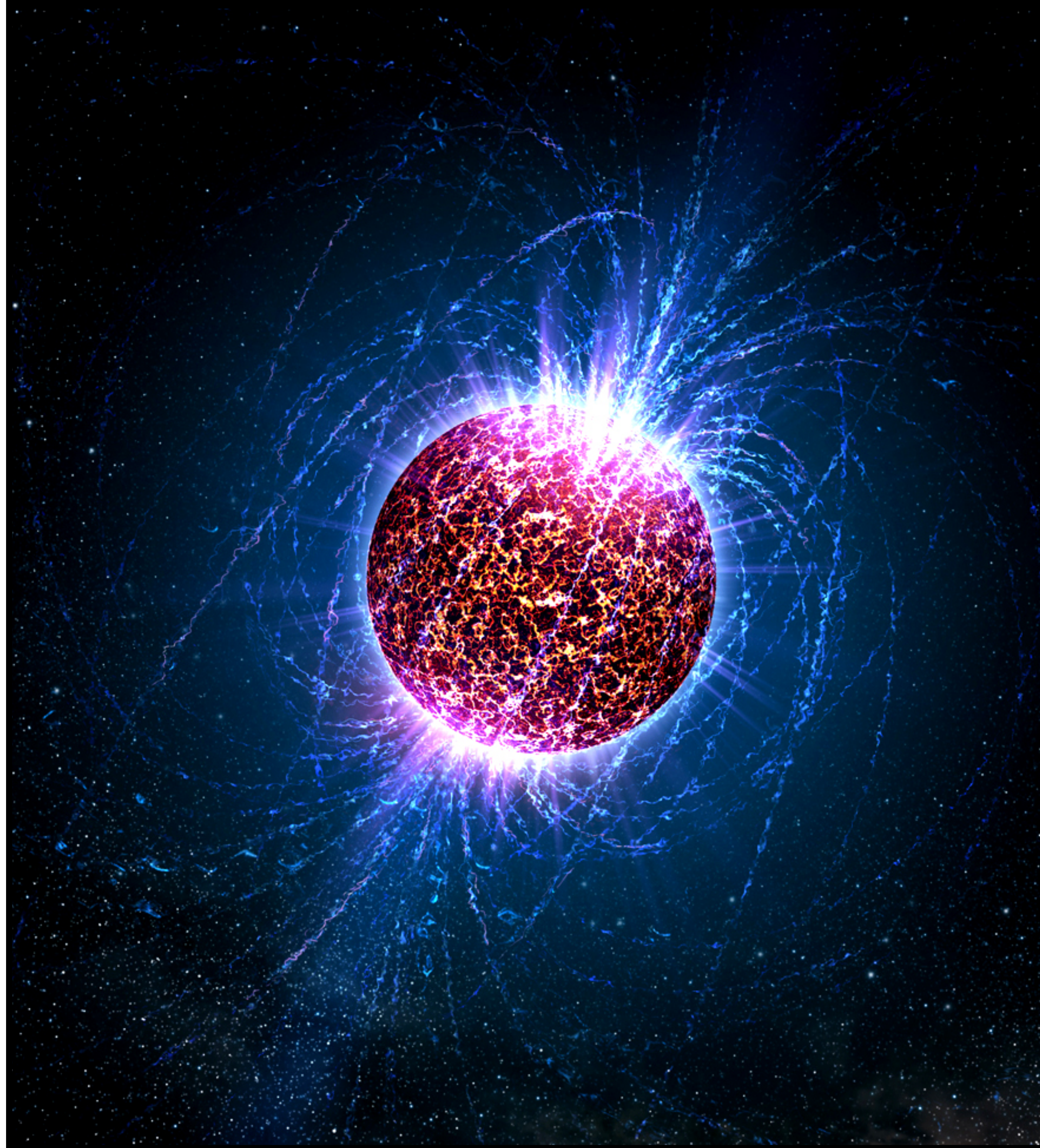


Image credit: C. Reed

searches

to dig out the weak signal,
must observe for long periods of time
this is computationally expensive

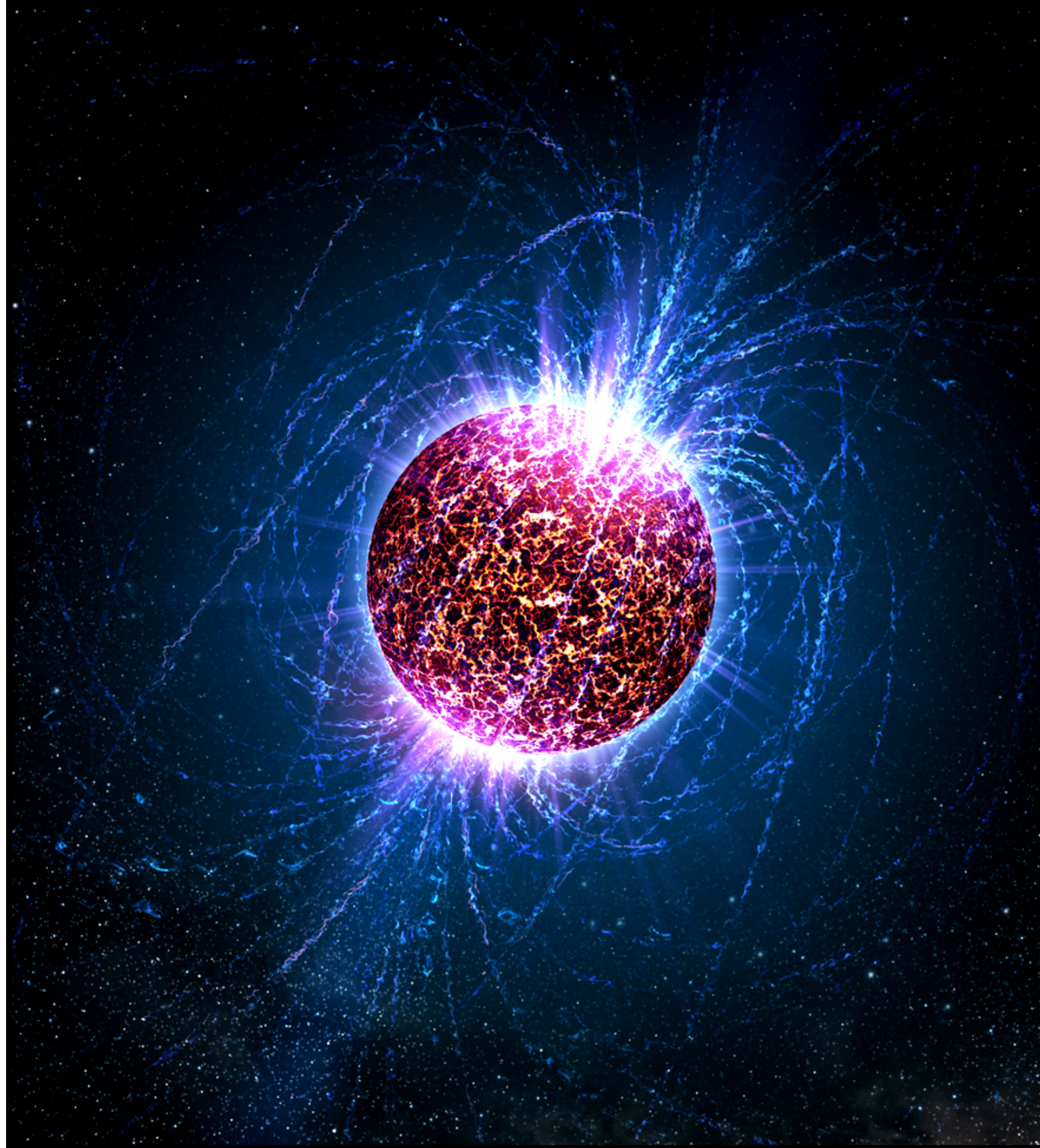
three broad kinds of searches:

targeted (i.e. we know everything; it's CPU cheap)
use timing from EM astronomers to track phase

directed (i.e. we know something; it's CPU manageable)
use location information, but do not track phase

all-sky (i.e. we know nothing; it's CPU expensive)
search over all sky locations and phase evolutions

see review by K. Riles (2018) [arXiv:1712.05897]



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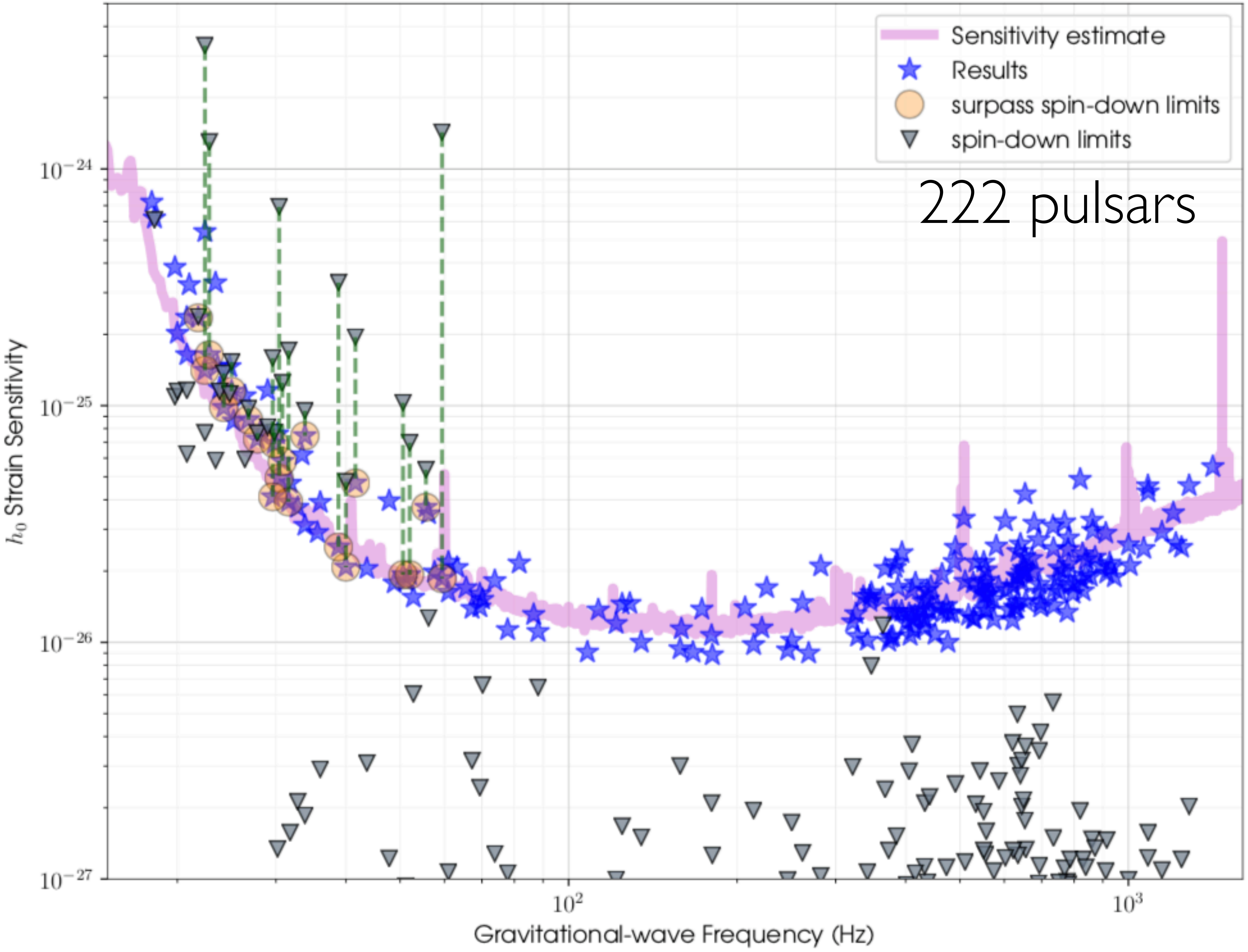
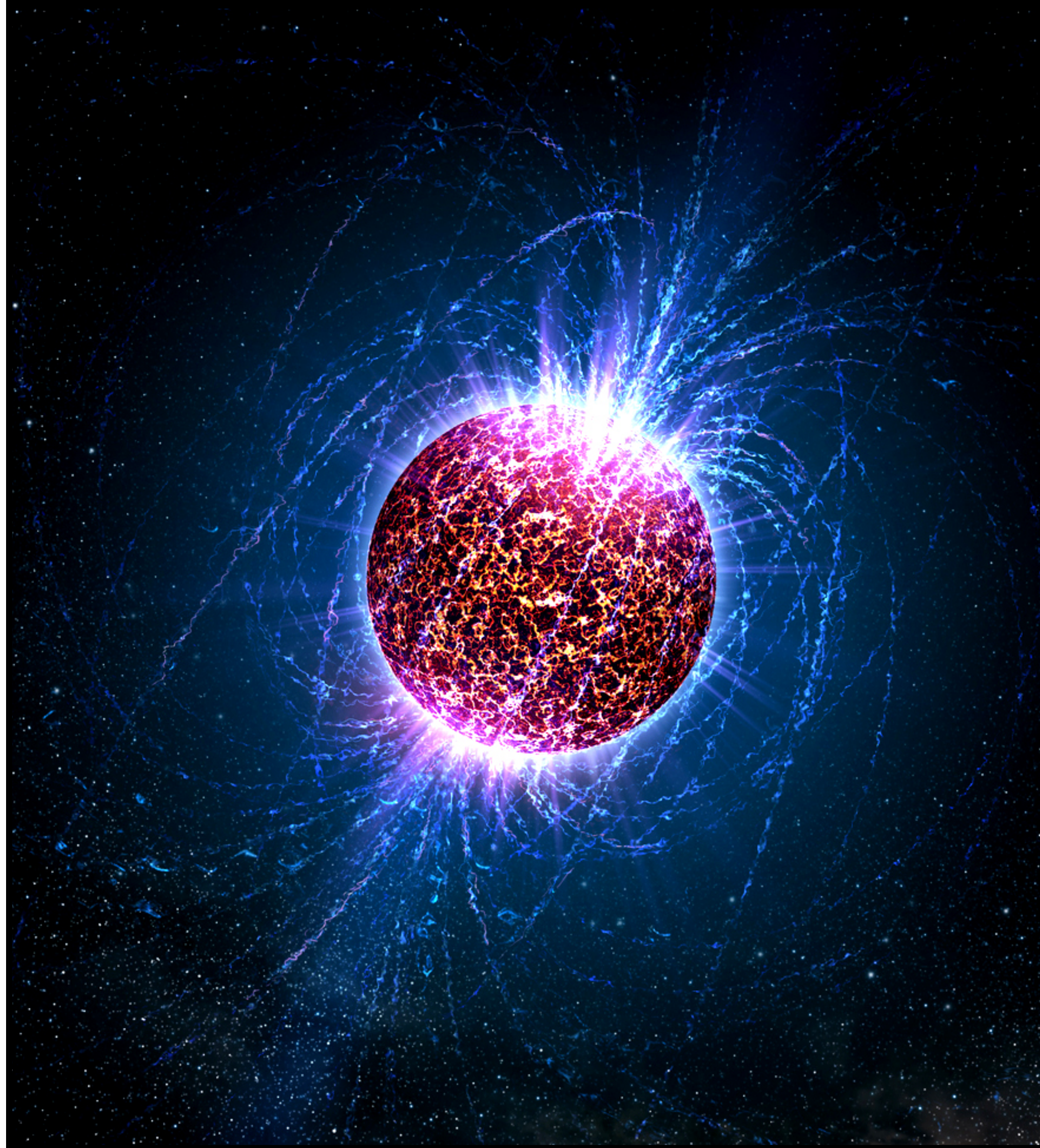
O1-O2 results

Abbott et al. (2019) [arXiv:1902.08507]





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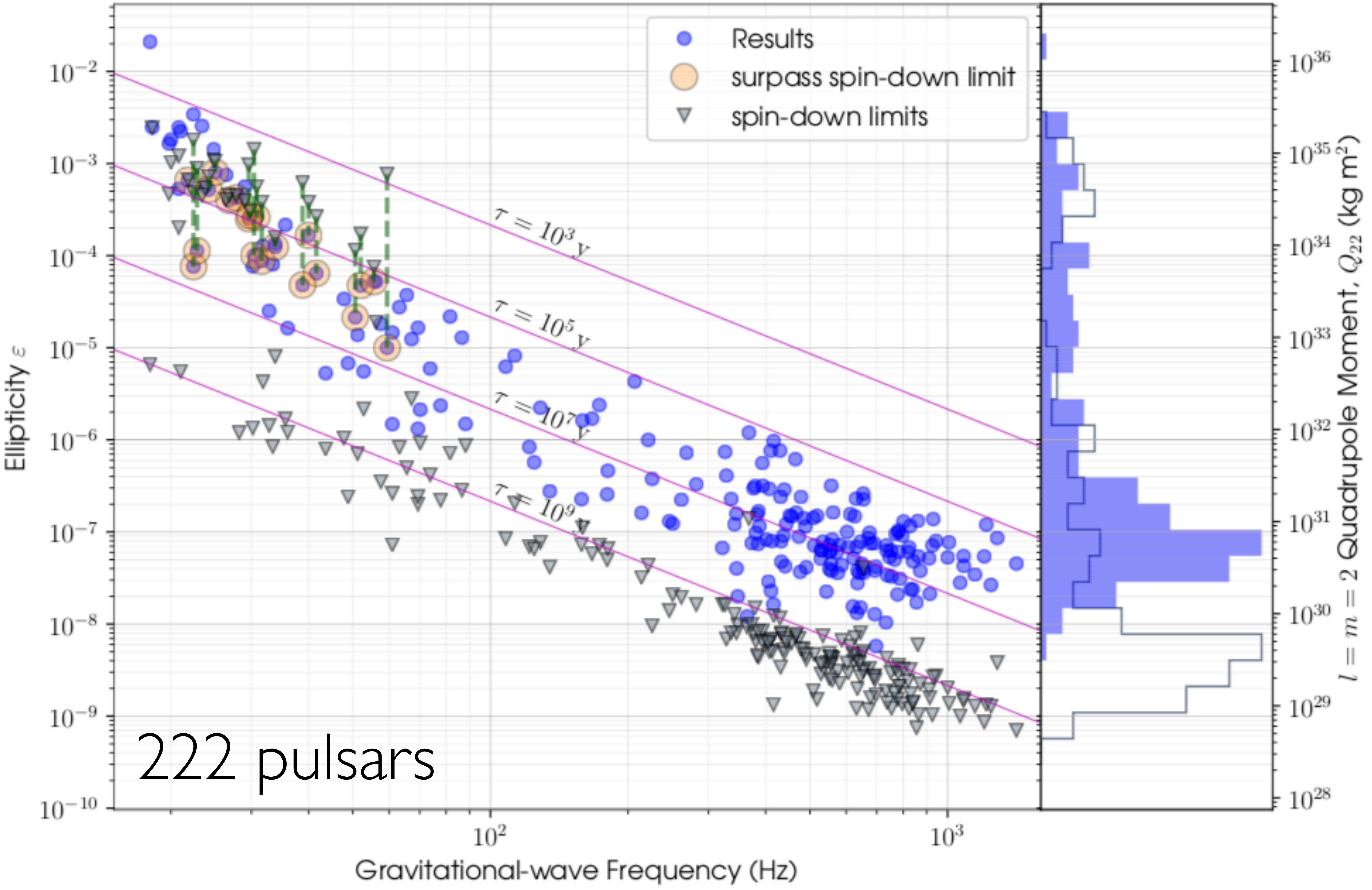


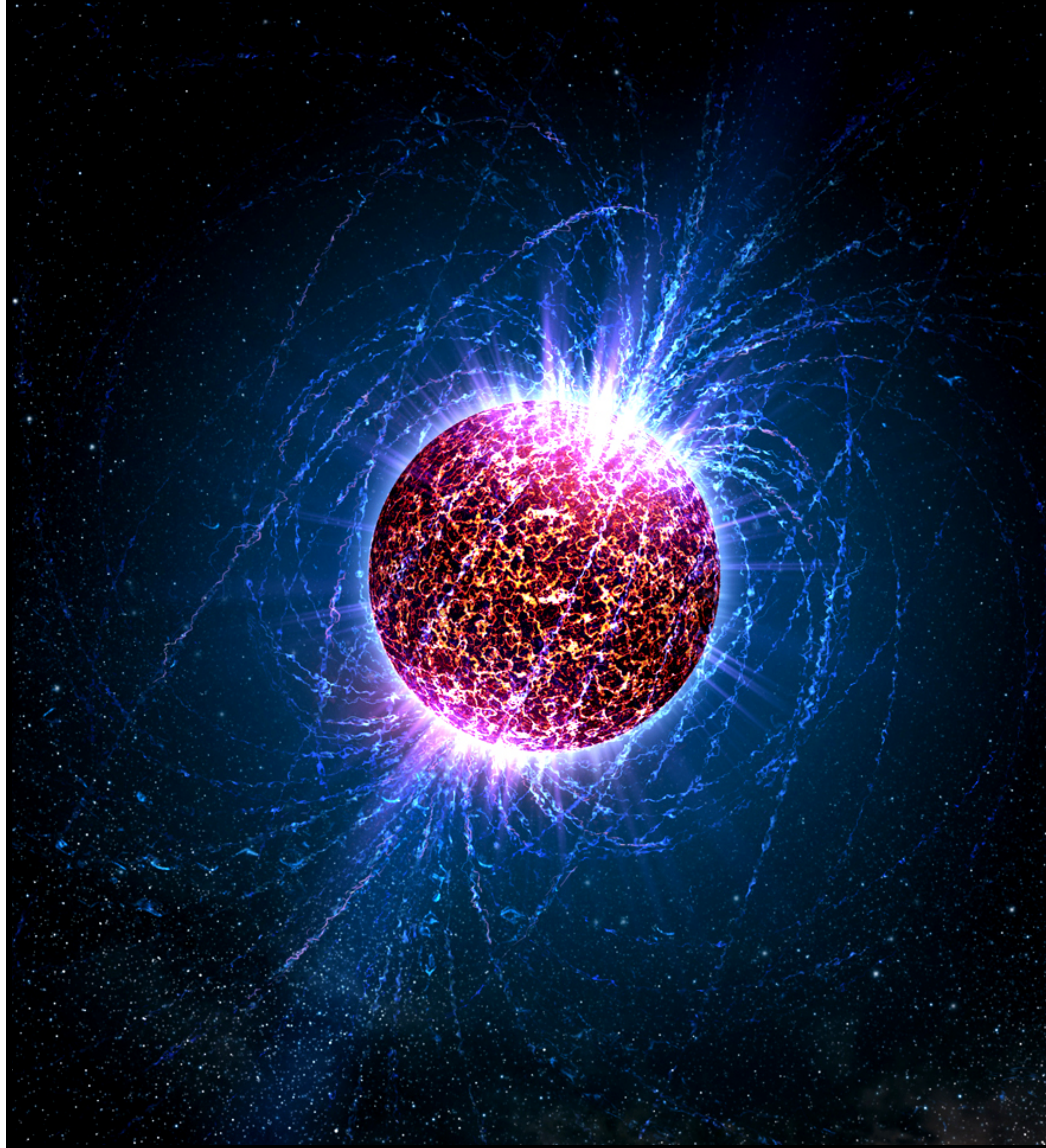


Image credit: C. Reed

stochastic background

incoherent, broadband, all-sky

astrophysical

superposition of *many* individual but unresolvable sources, most notably compact binaries

cosmological (aka, primordial)

signal produced during or shortly after inflation, e.g. due to vacuum fluctuations or phase transitions

besides these two, there could also be more exotic sources, like cosmic strings (topological defects)

SB would teach us about cosmology!

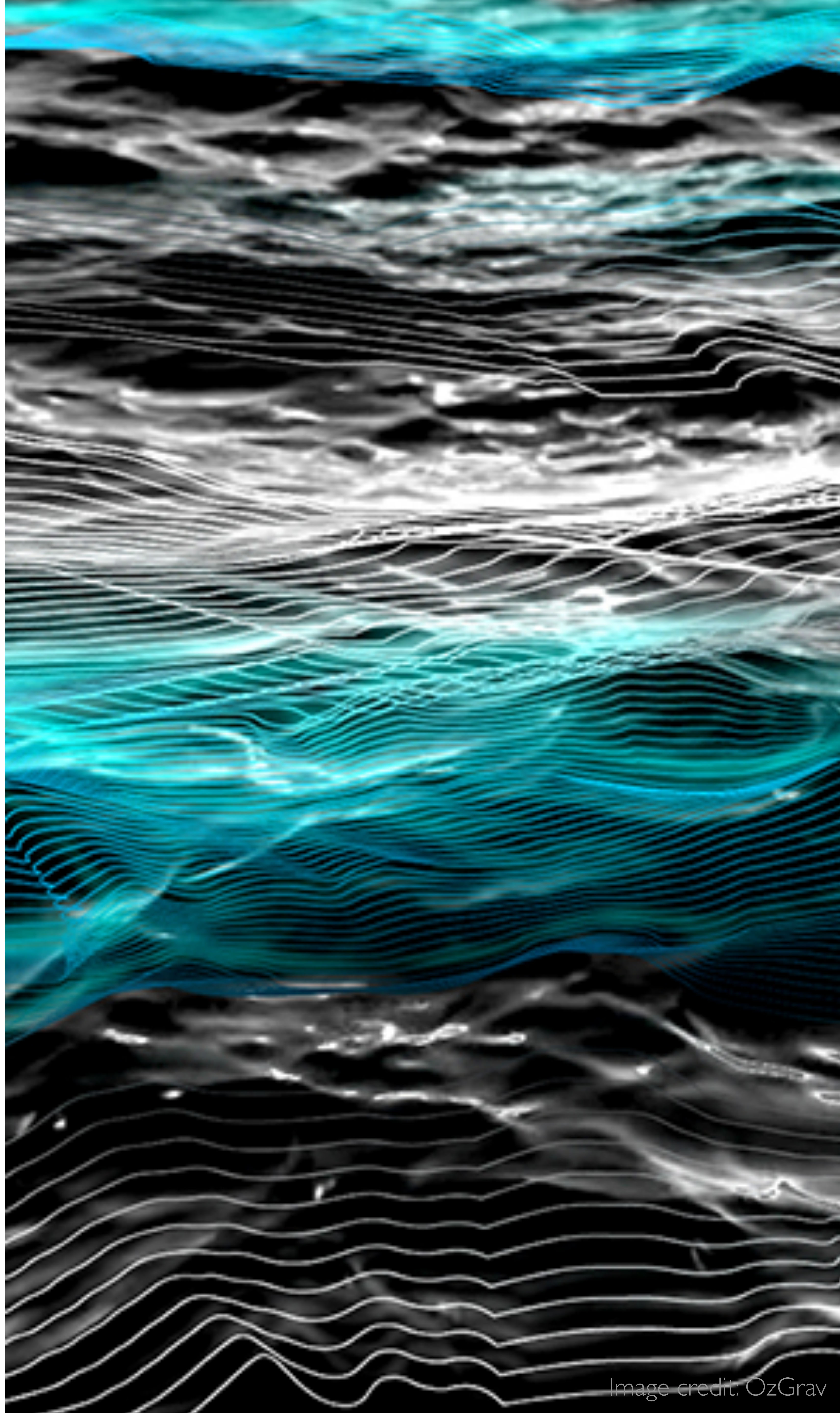


Image credit: OzGrav

stochastic background

interested in the *fractional energy density spectrum*

$$\Omega(f) \equiv \frac{1}{\rho_c} \frac{d\rho}{d\ln f},$$

ρ, GW energy density; $\rho_c = 3c^2 H_0^2 / 8\pi G$, critical density to close universe.

measure this through the **cross-correlation** of detector outputs

$$\left\langle \tilde{h}_1^*(f) \tilde{h}_2^*(f') \right\rangle = \frac{3H_0^2}{20\pi^2} \delta(f - f') |f|^{-3} \Omega(f) \gamma(f)$$

where γ is the **overlap reduction function**

(folds in antenna patterns and time delay between detectors)

see review by Romano & Cornish [arXiv:1608.06889]

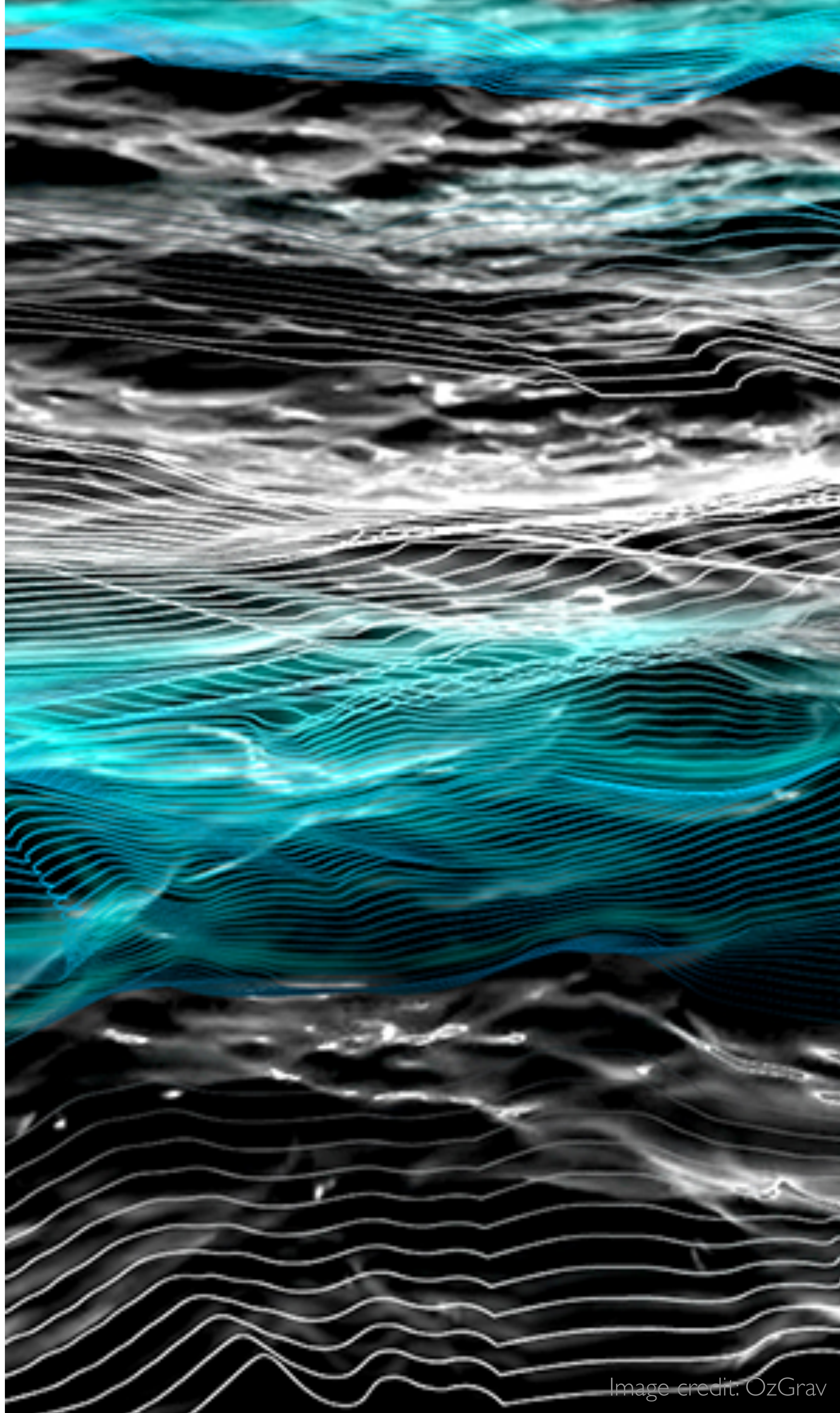
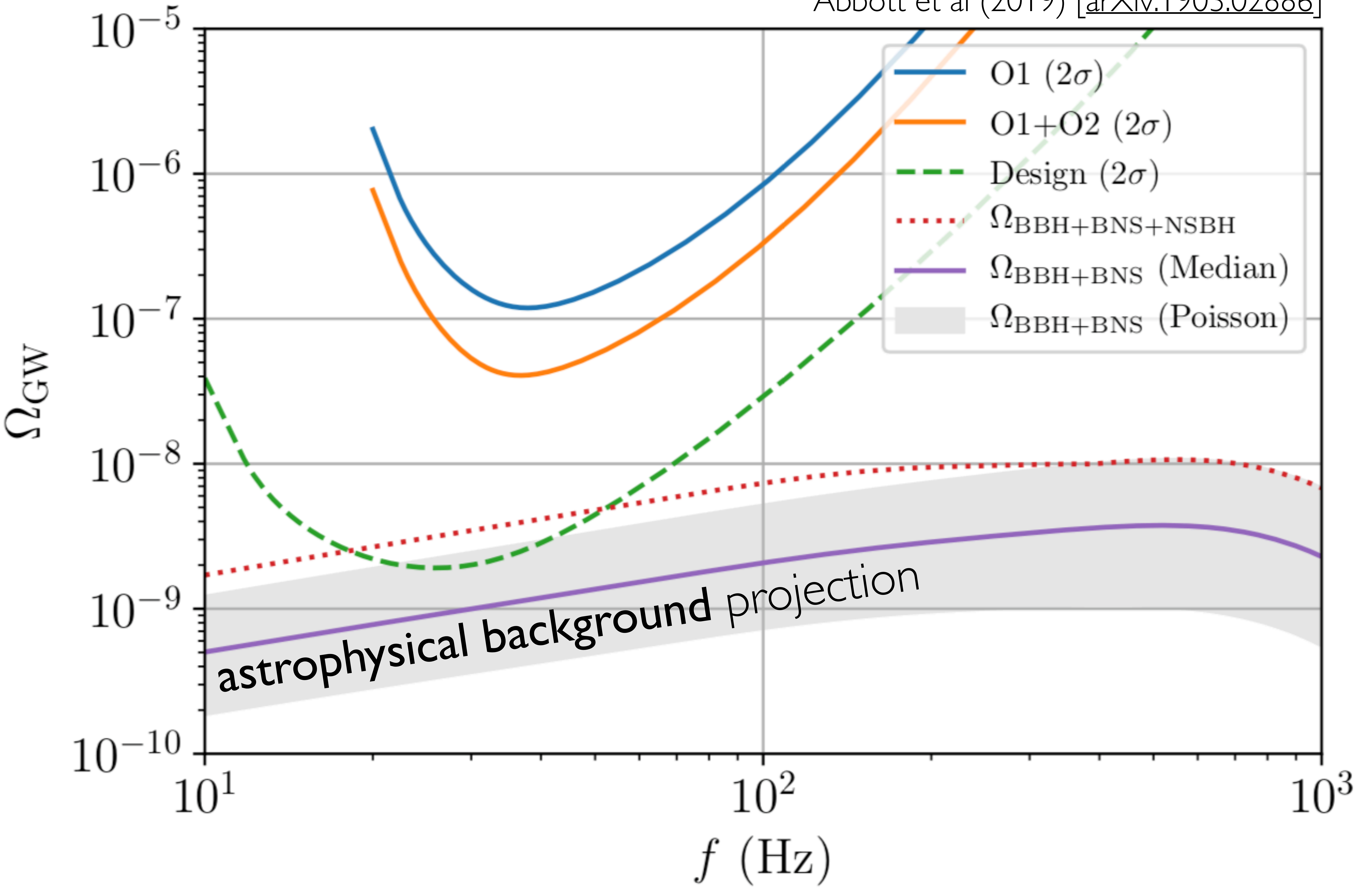
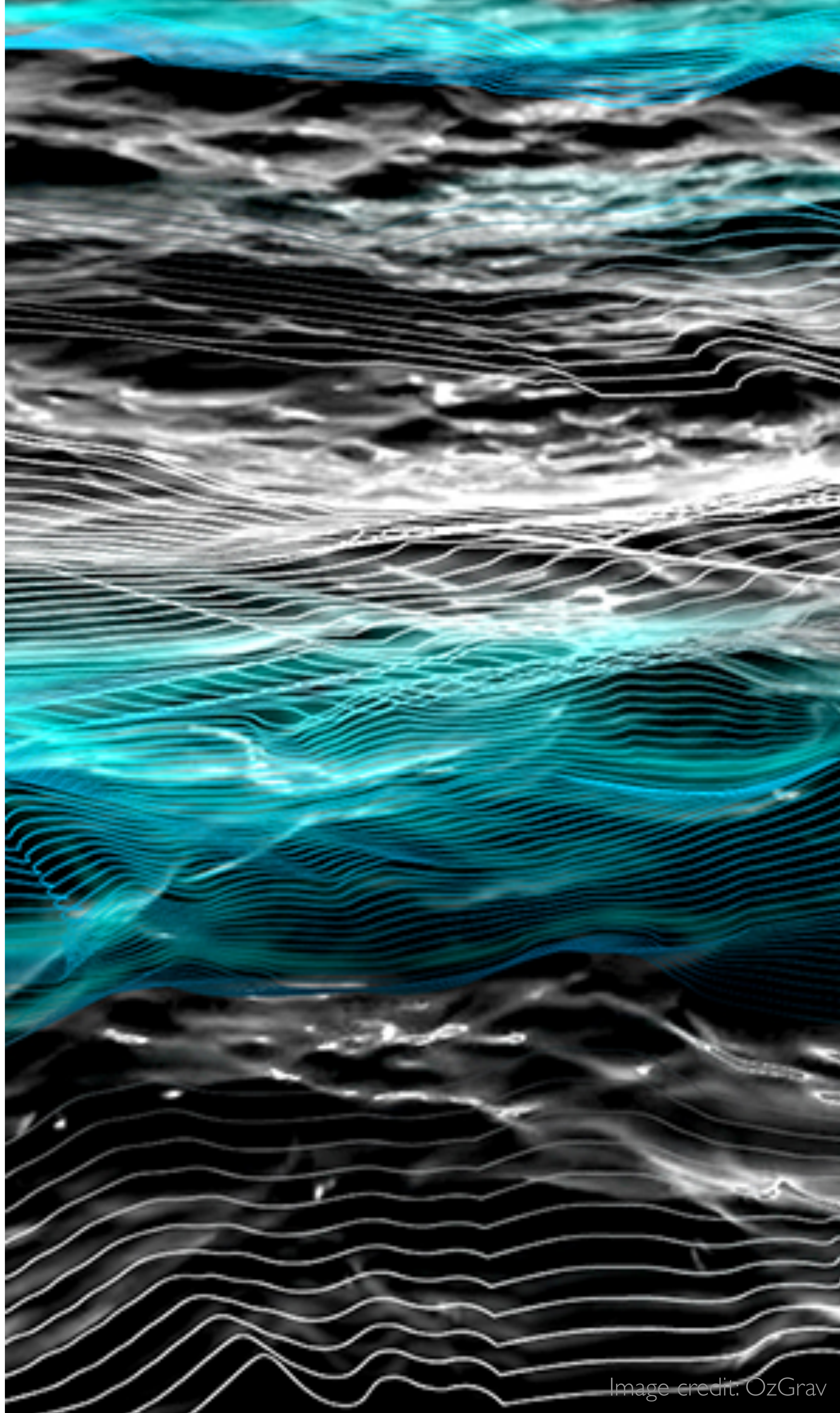


Image credit: OzGrav

O2 results

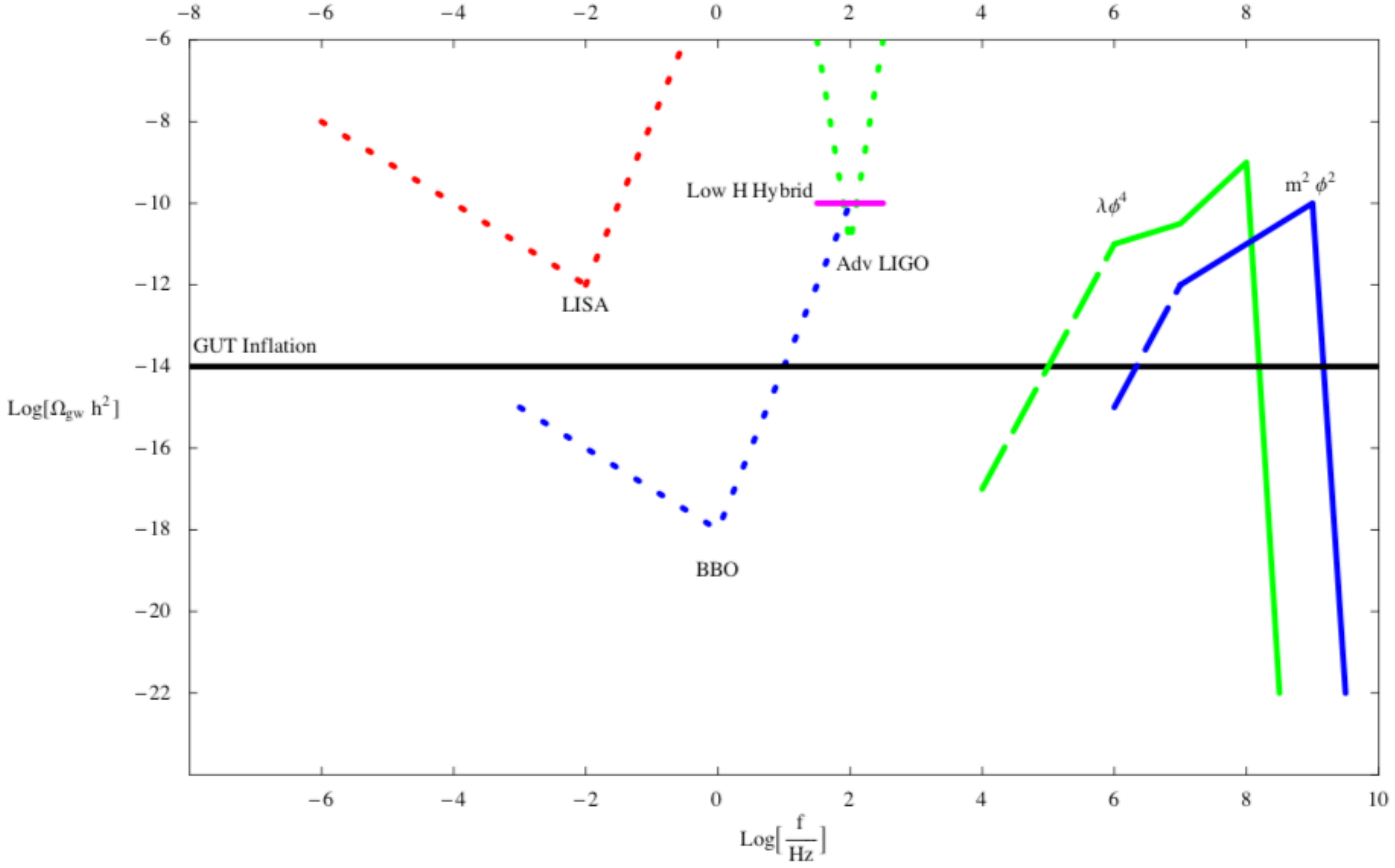
Abbott et al (2019) [arXiv:1903.02886]





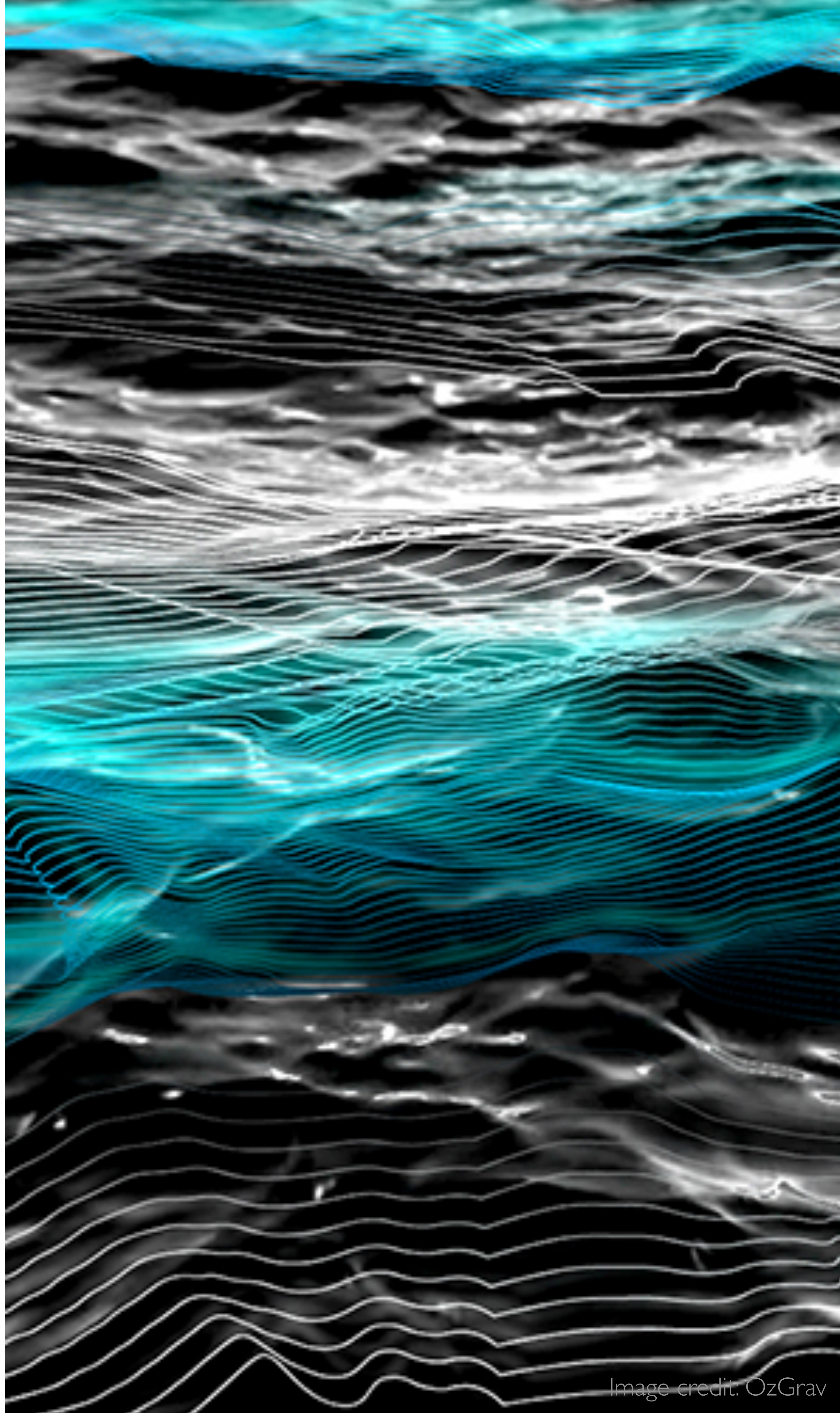
stochastic background

cosmological background projection



h = 0.6704 (cosmological parameter)

Easther and Lim (2006) [arXiv:astro-ph/0601617]



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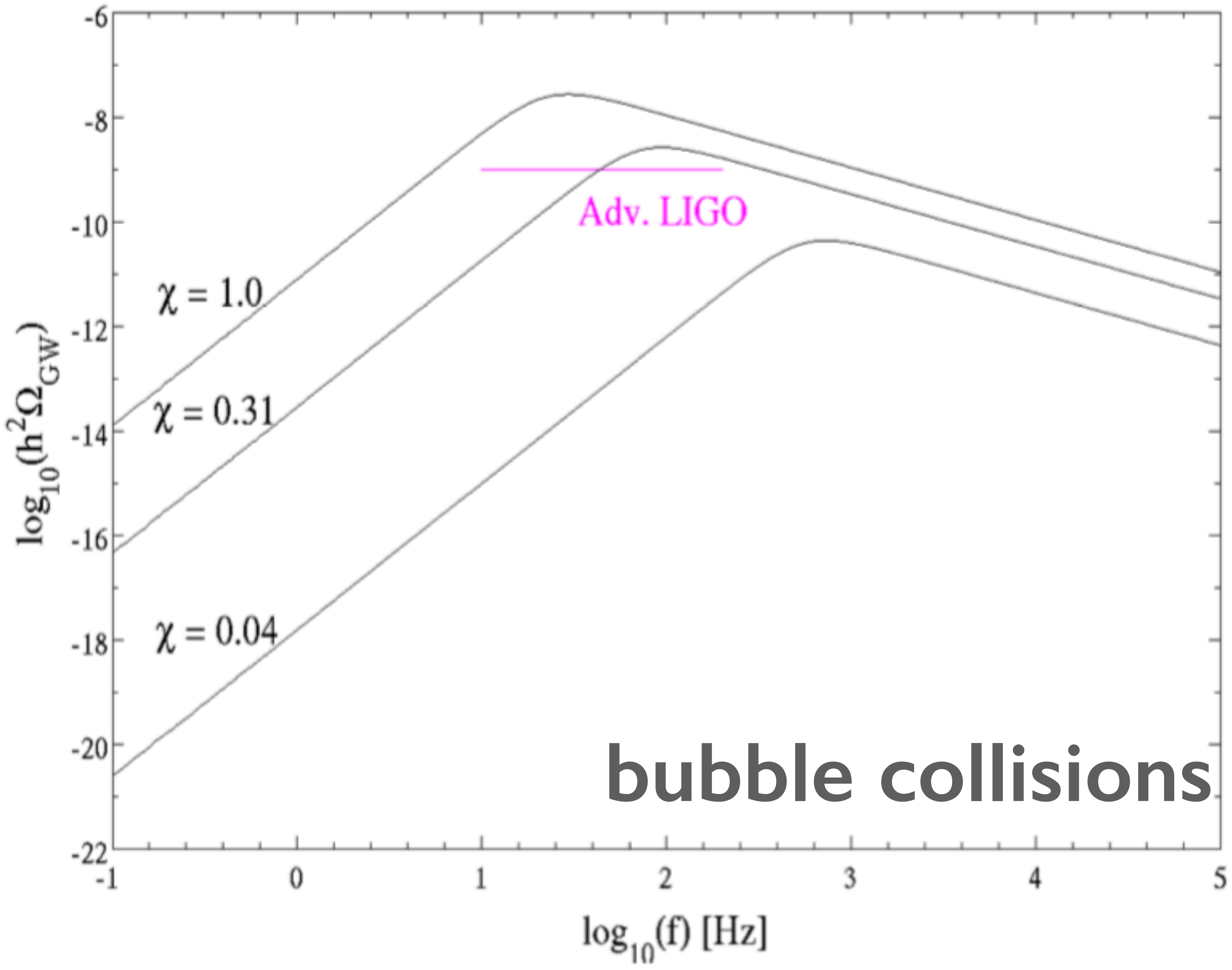

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Lopez and Freeze (2013) [arXiv:1305.5855]

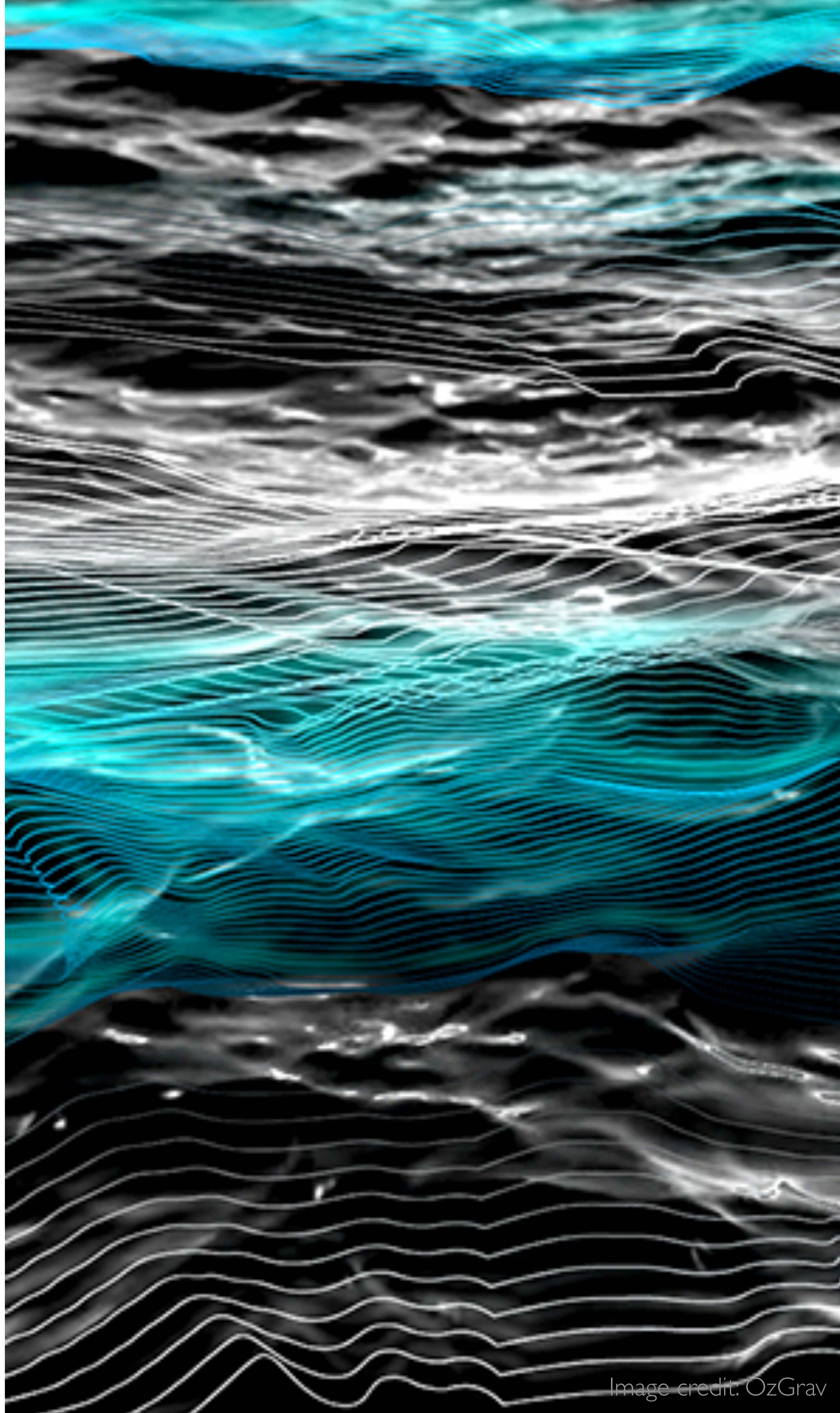
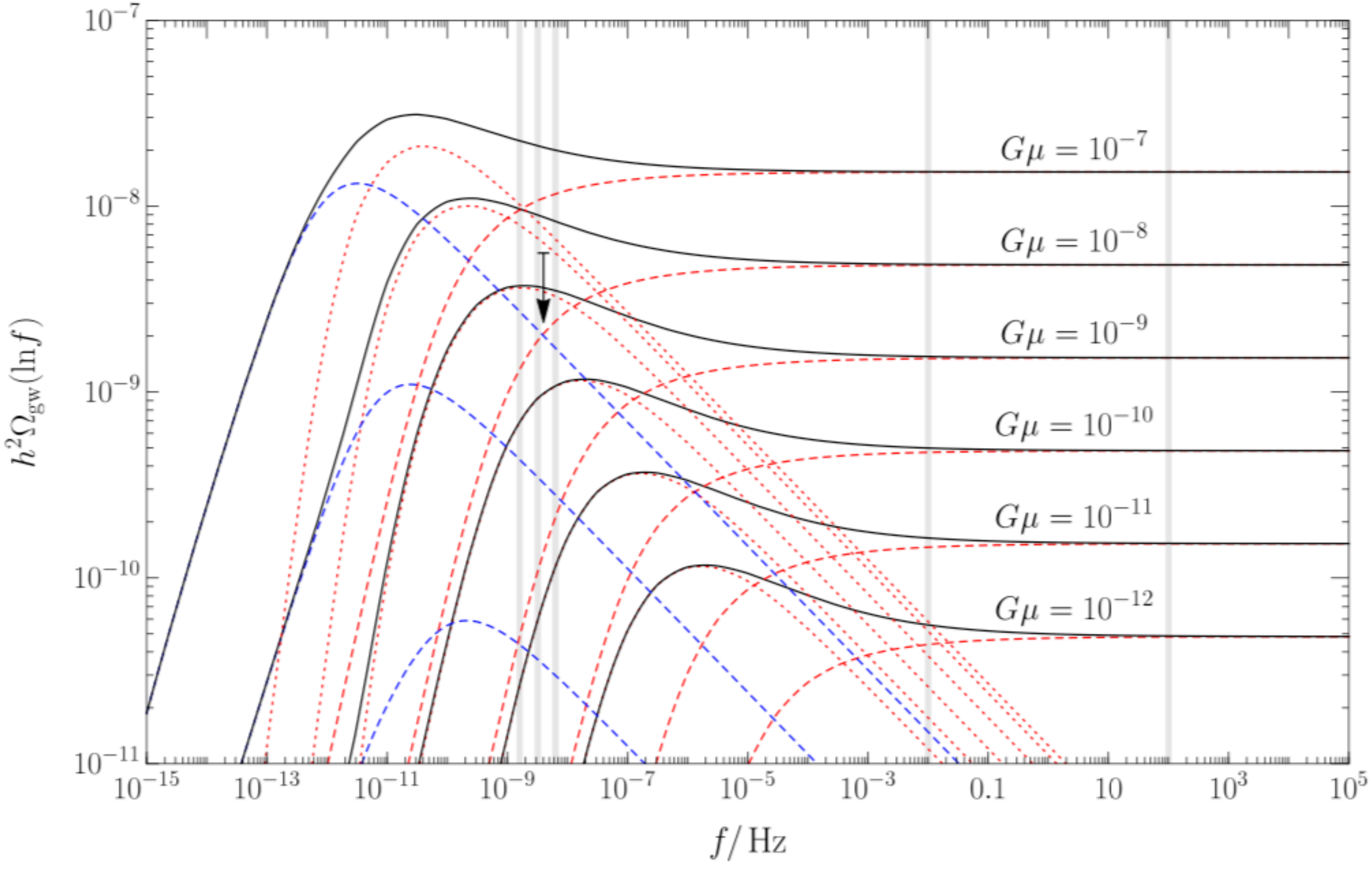


Image credit: OzGrav

stochastic background

cosmic strings projection



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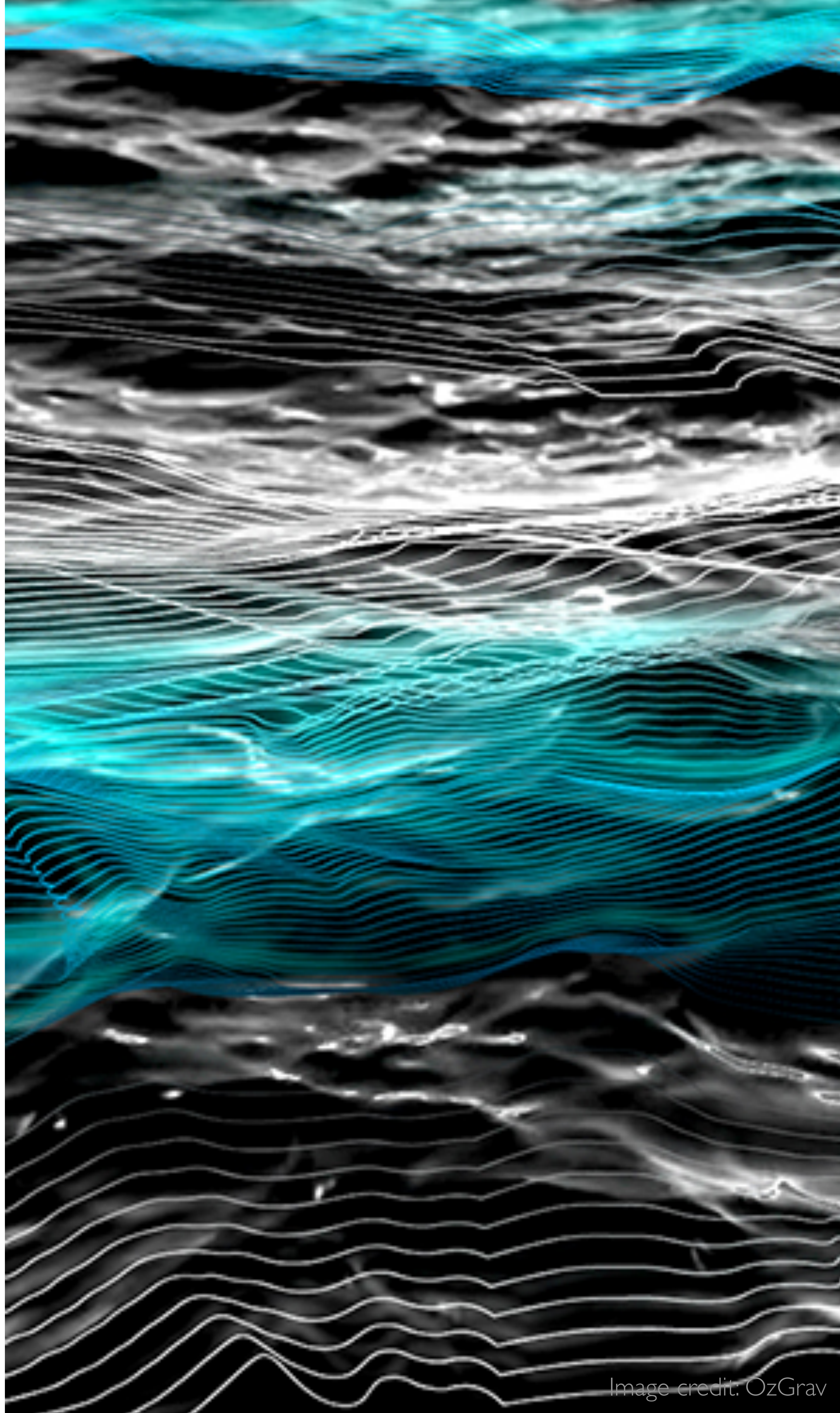
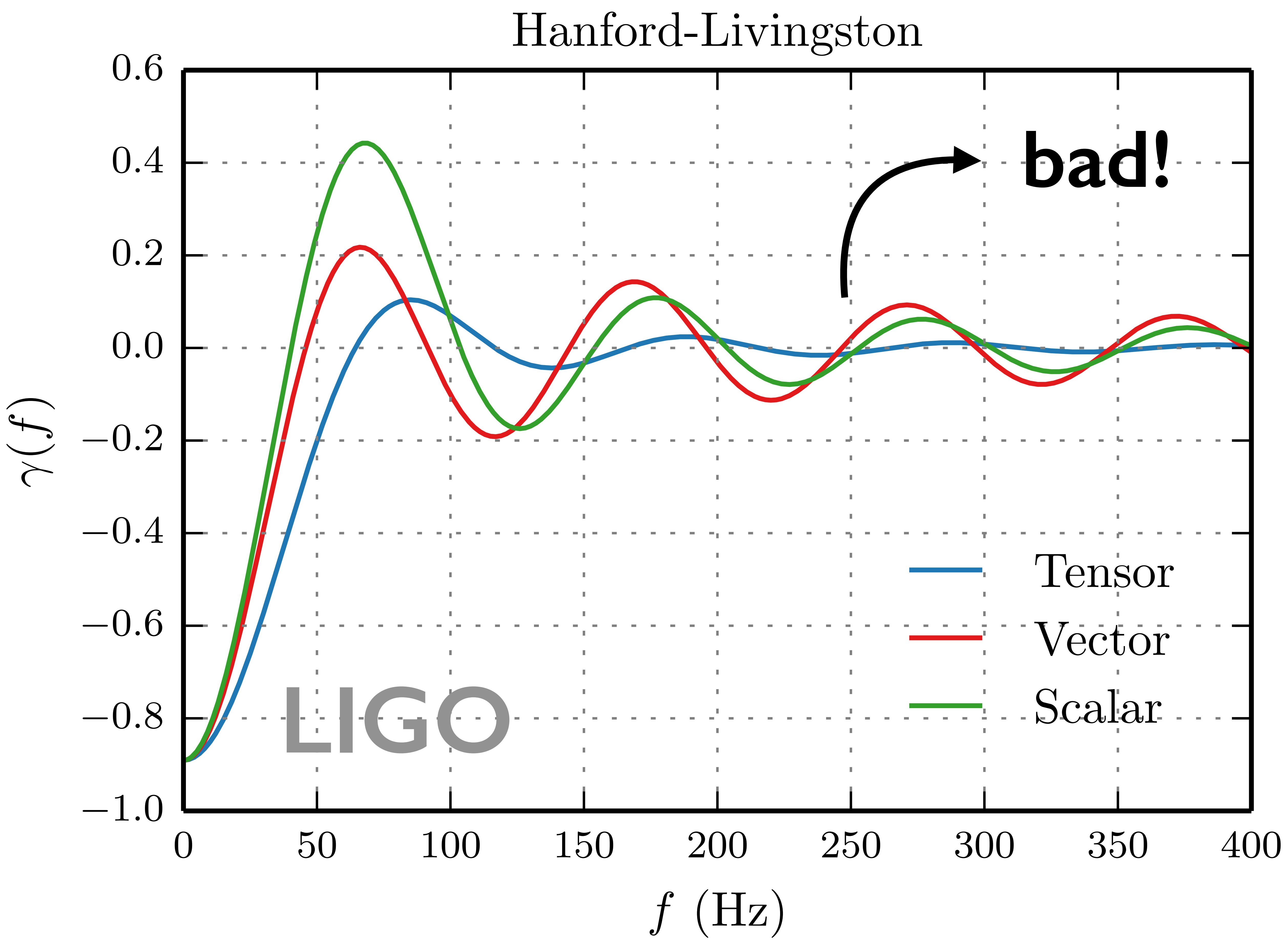
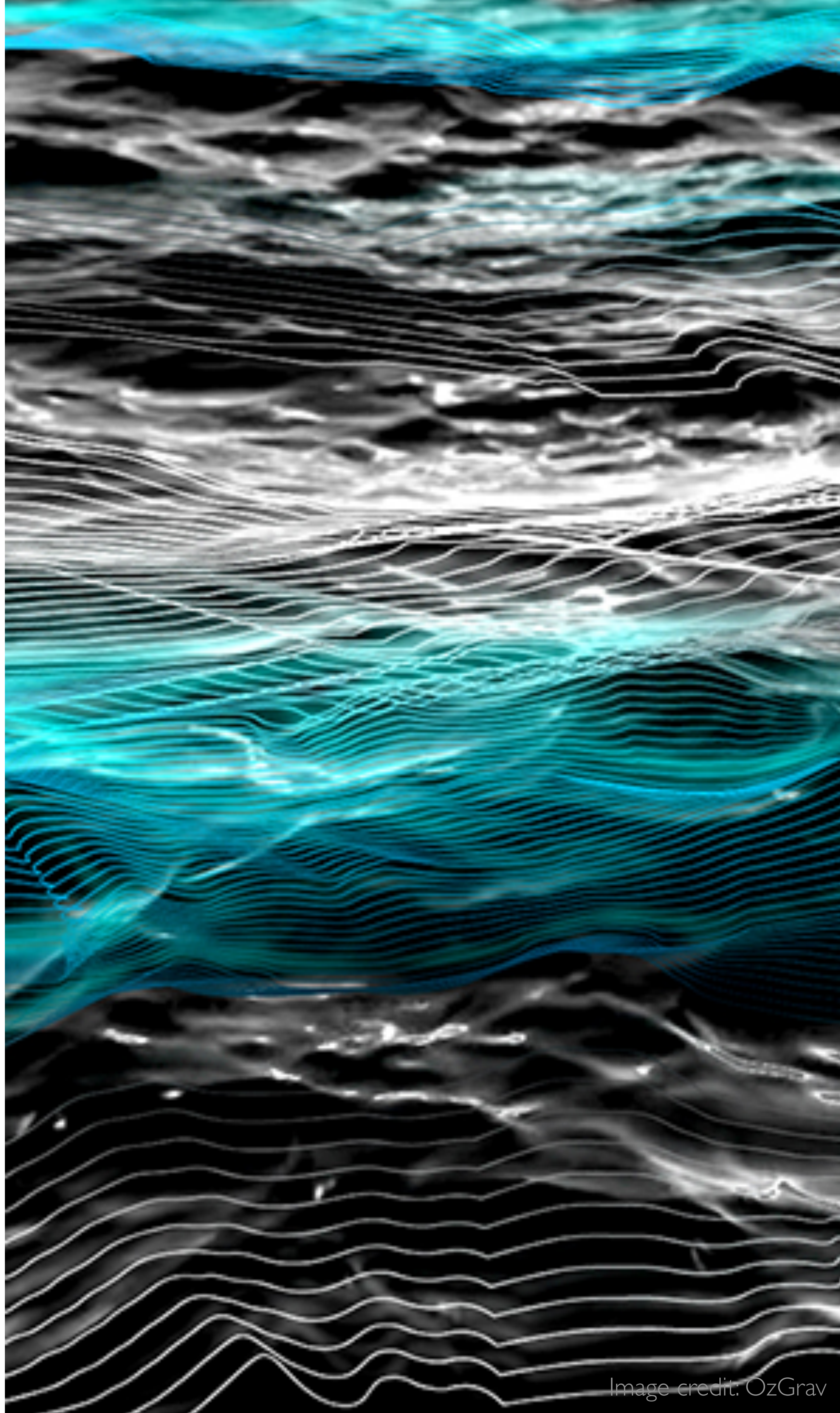
https://arxiv.org/abs/1309.6637



overlap reduction function

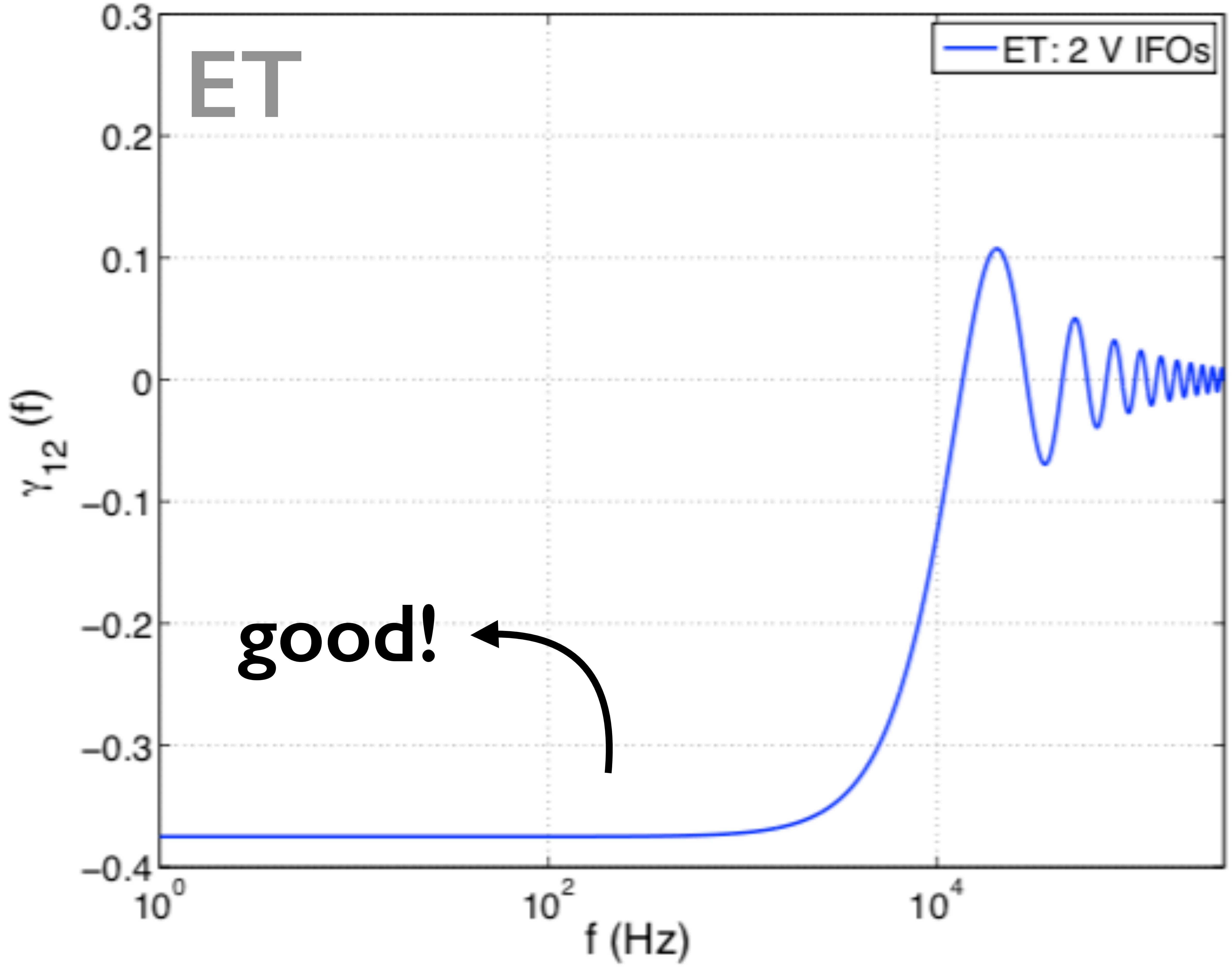


Callister et al. (2017) [arXiv:1704.08373]

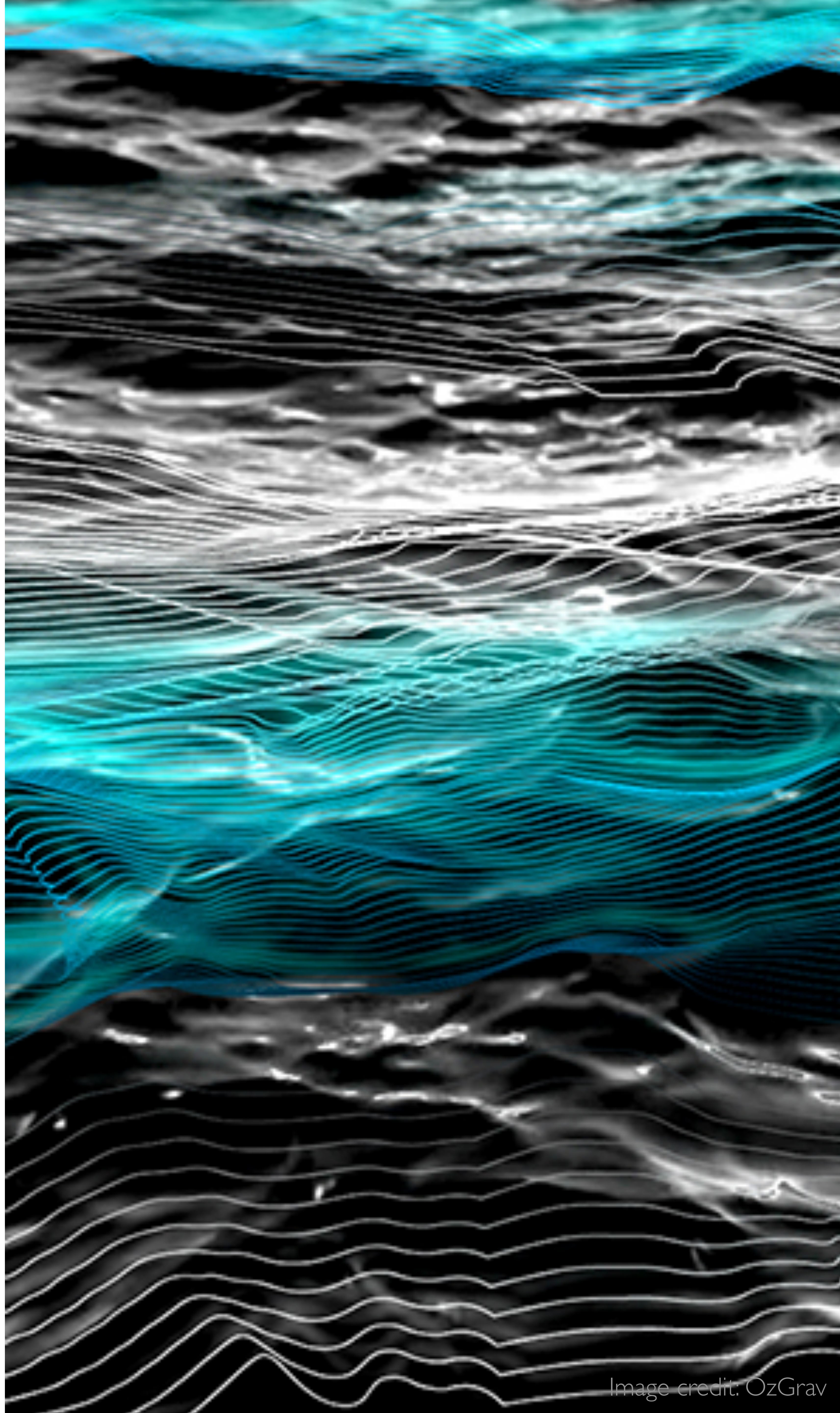


overlap reduction function

want co-located detectors!



Regimbau et al. (2012) [arXiv:1201.3563]



dark matter & exotica

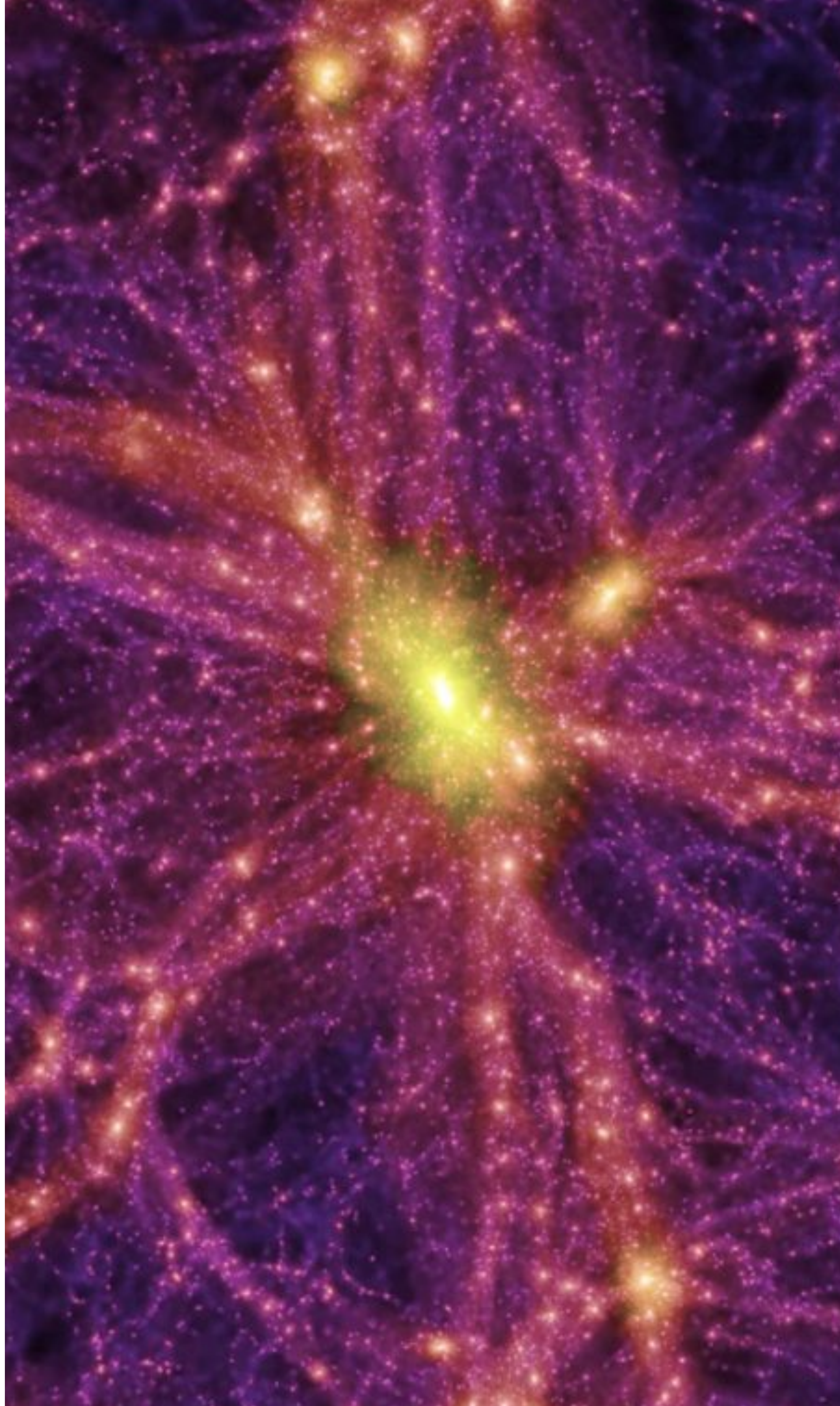
DM (or other new particles) could produce GW signals or interact with detectors directly

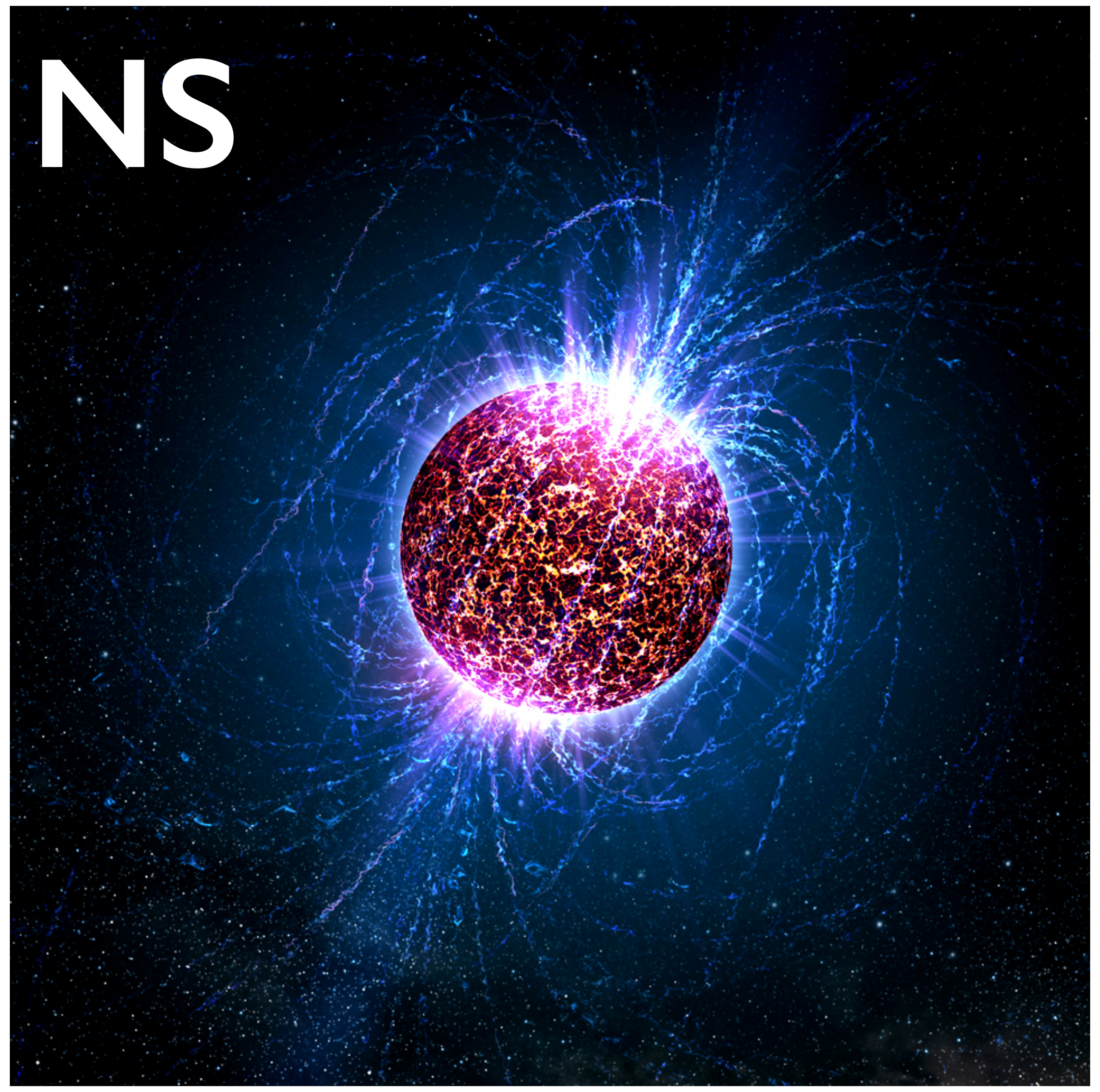
ultralight bosons (e.g. axion)
would produce macroscopic clouds around fast-spinning black holes, this would emit CWs; could produce high-freq signals if BH is light

[arXiv:1706.06311] [arXiv:1810.03812] [arXiv:1812.09622]

direct coupling (e.g. dark photons)
particle could act on test masses, resulting in displacements with a characteristic frequency set by the particle mass $f \sim (m/10^{-12}\text{eV})$ 241 Hz

[arXiv:1801.10161] [arXiv:1905.04316]





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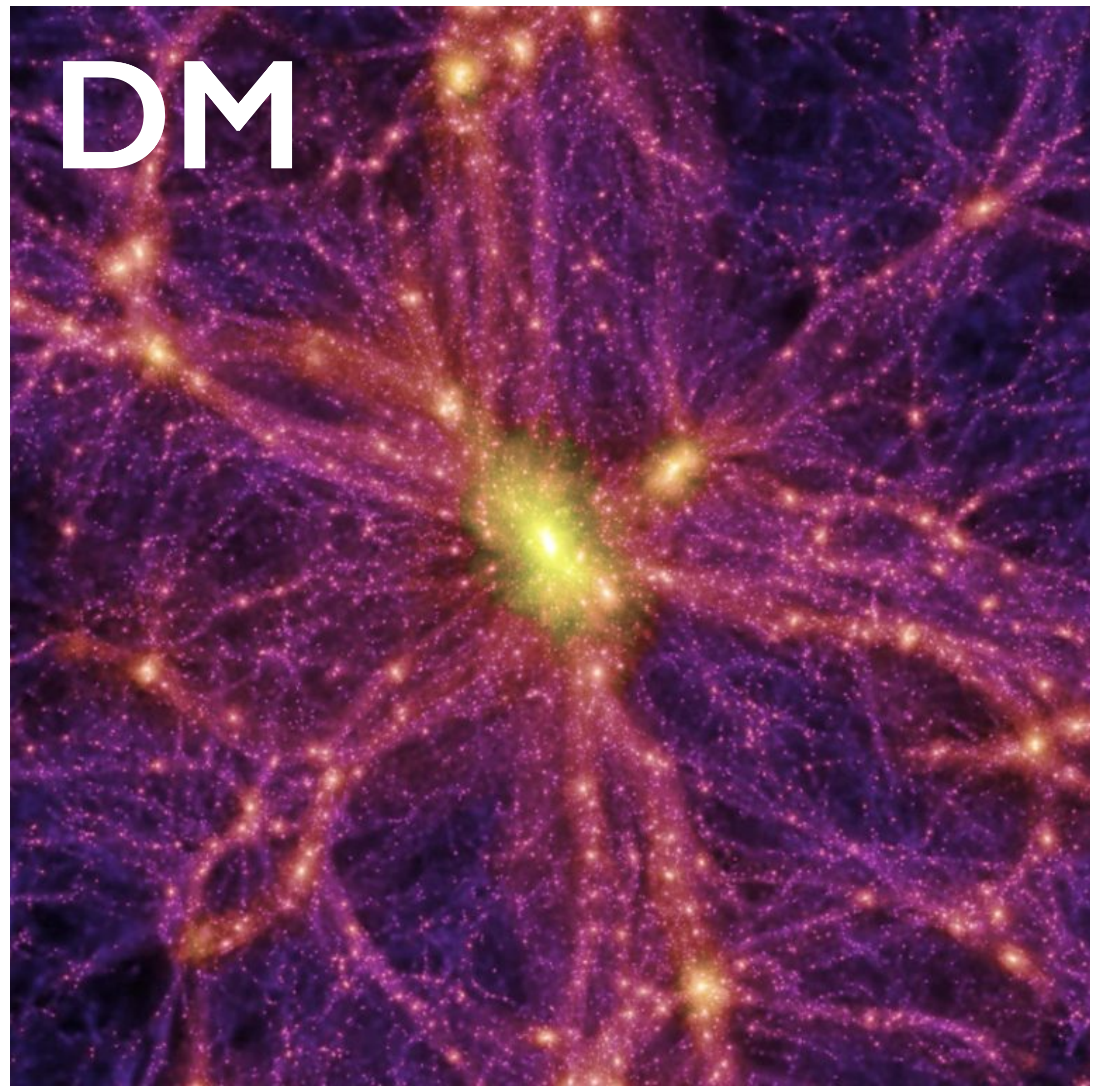

dark matter & exotica

thank you!