Star shearing season: transient signals from black hole formation

Based on **2408.10296** (EPJC), **25XX.YYYYY**

in collaboration with **J. Jaeckel** (U. Heidelberg), **Y. Garcia del Castillo** (New South Wales U.)

Arturo de Giorgi

PASCOS, 22nd July 2025

Durham University

Where are we?

SM

Where are we?

Dark Energy

Baryogenesis

BSM

New scalars

Cosmological Constant

Flavour puzzle

Hierarchy Puzzle

SM

Neutrino Masses

Higgs Potential

Strong CP

Sterile Neutrinos

<u>Dark Matter</u>

Dark Photons

Axions

....

(Ultra) Light DM & Periodic Signals

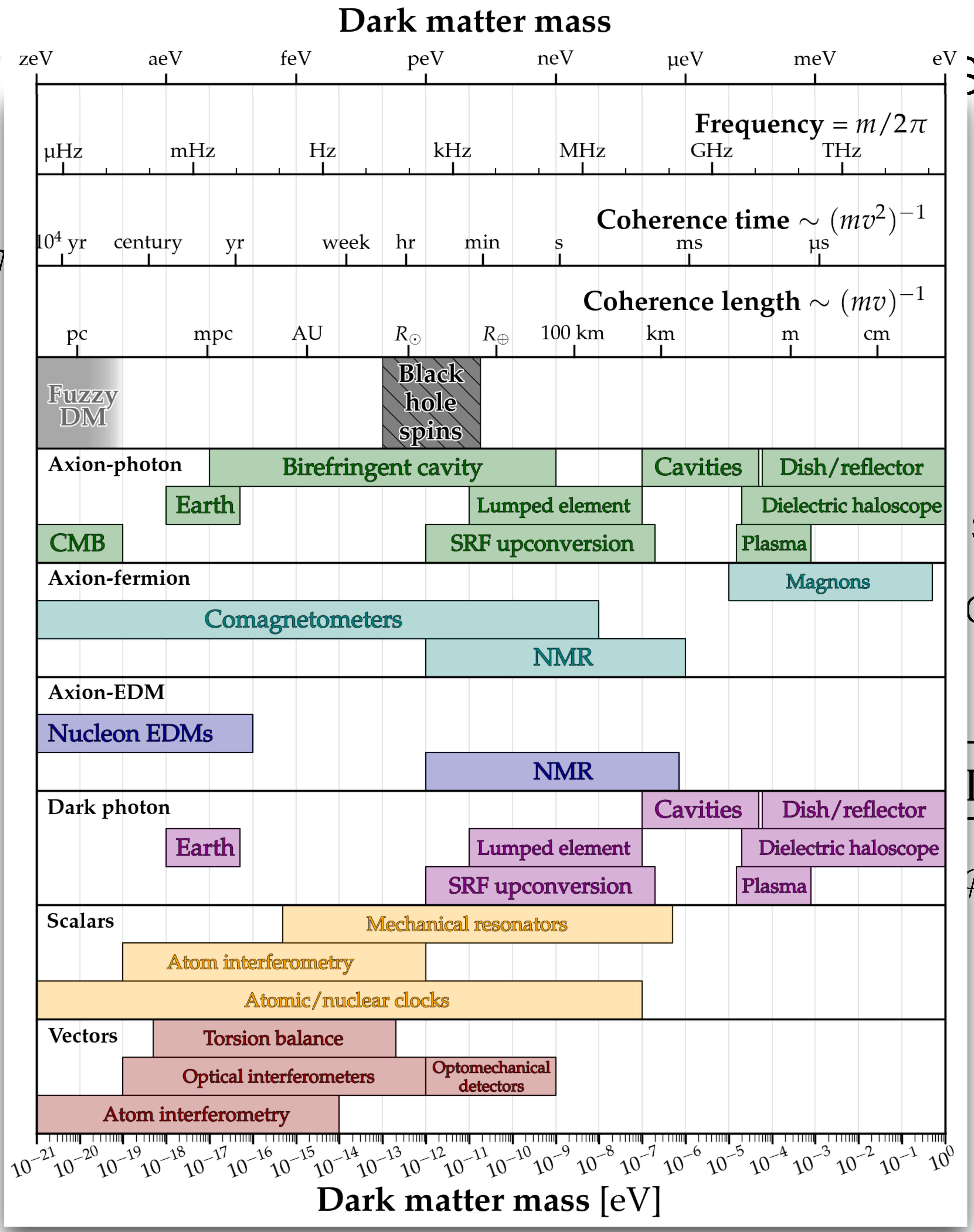
$$N_{\rm dB} \sim \frac{\rho_{\rm DM}}{m}\lambda_{\rm dB}^3 \qquad \lambda_{\rm dB} = \frac{2\pi}{mv} \qquad N_{\rm dB} \sim \left(\frac{34\,{\rm eV}}{m}\right)^4 \left(\frac{250\,{\rm km/s}}{v}\right)^3$$

For $m \lesssim 30\ \mathrm{eV}$ the field has **large occupation number**

⇒ it behaves as a **classical field**

$$\phi(t) = \frac{\sqrt{2\rho_{\rm DM}}}{m_\phi}\cos(m_\phi t)$$

(Ultr… s



N

$$N_{\rm dB} \sim \left(\frac{34\,{\rm eV}}{m}\right)^4 \left(\frac{250\,{\rm km/s}}{v}\right)^3$$

s **large occupation number**

a

Vast research programme!

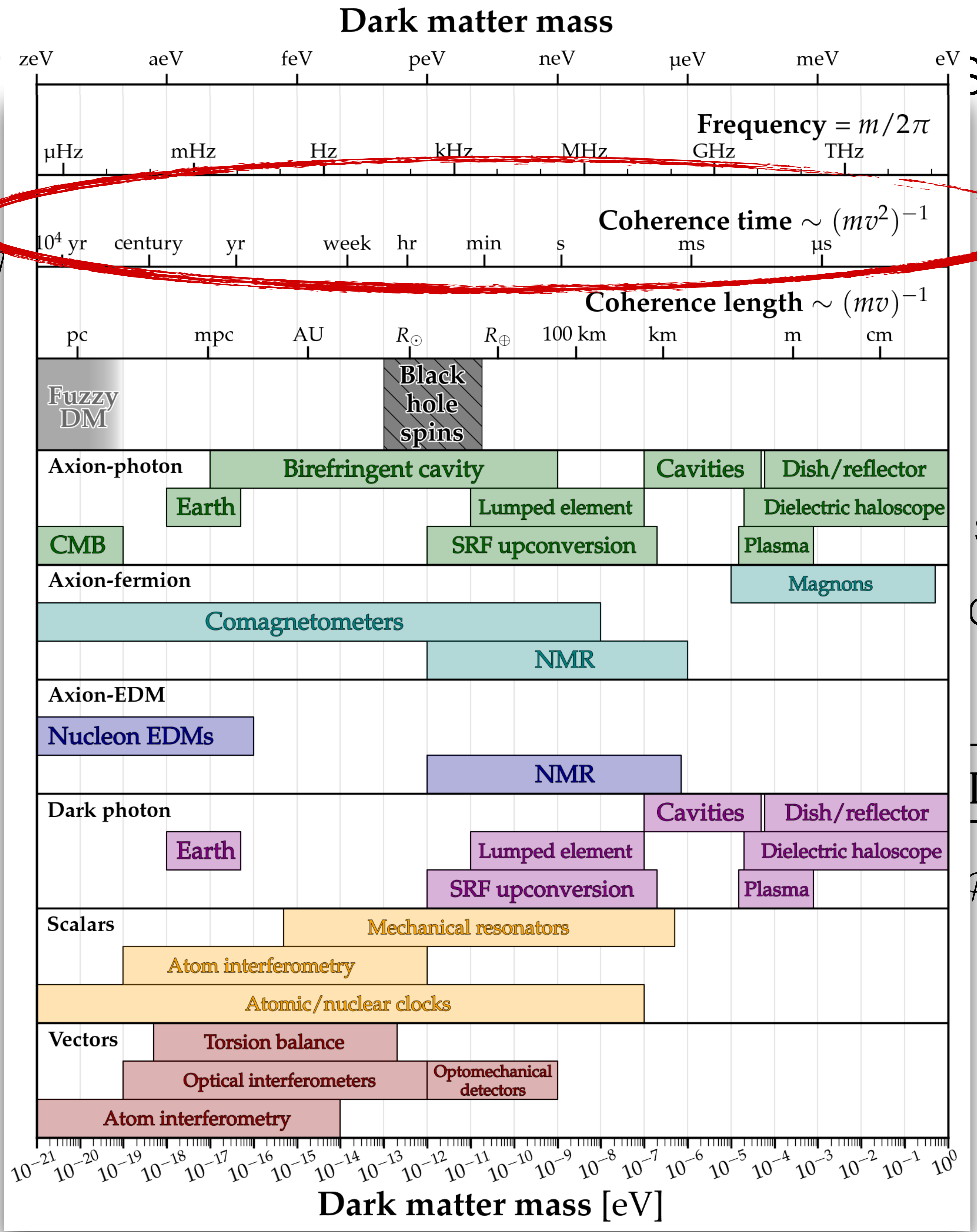
DM

$\cos(m_\phi t)$

ϕ

AxionLimits, C. O'Hare

(Ultr… s



“Human” scale

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a c

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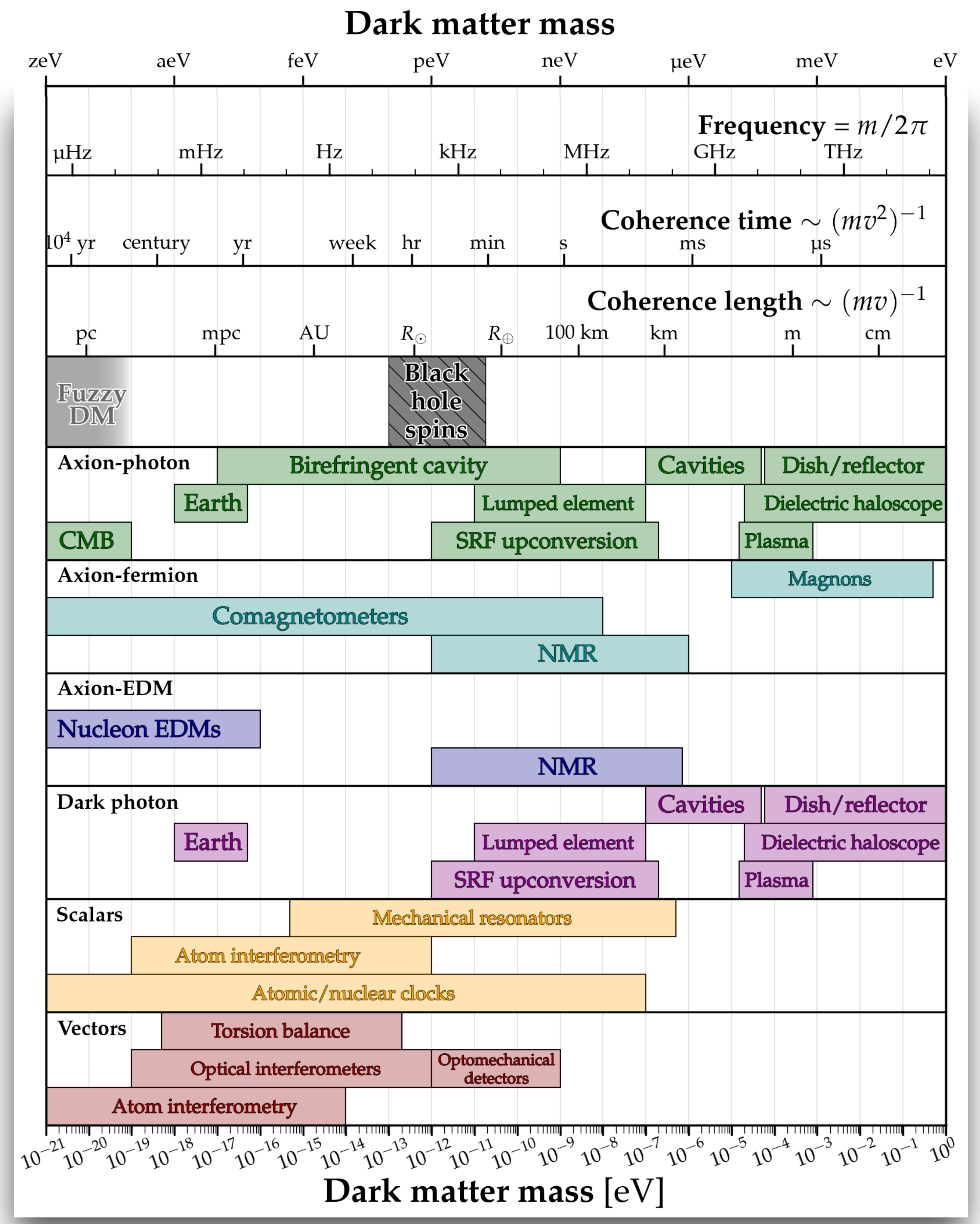
AxionLimits, C. O'Hare

Different signal for New Physics?



What if the **local** DM density is **small**?

Or what if DM is made of **several subcomponents**?

What if an ultra light scalar exists, but it is **not DM**?

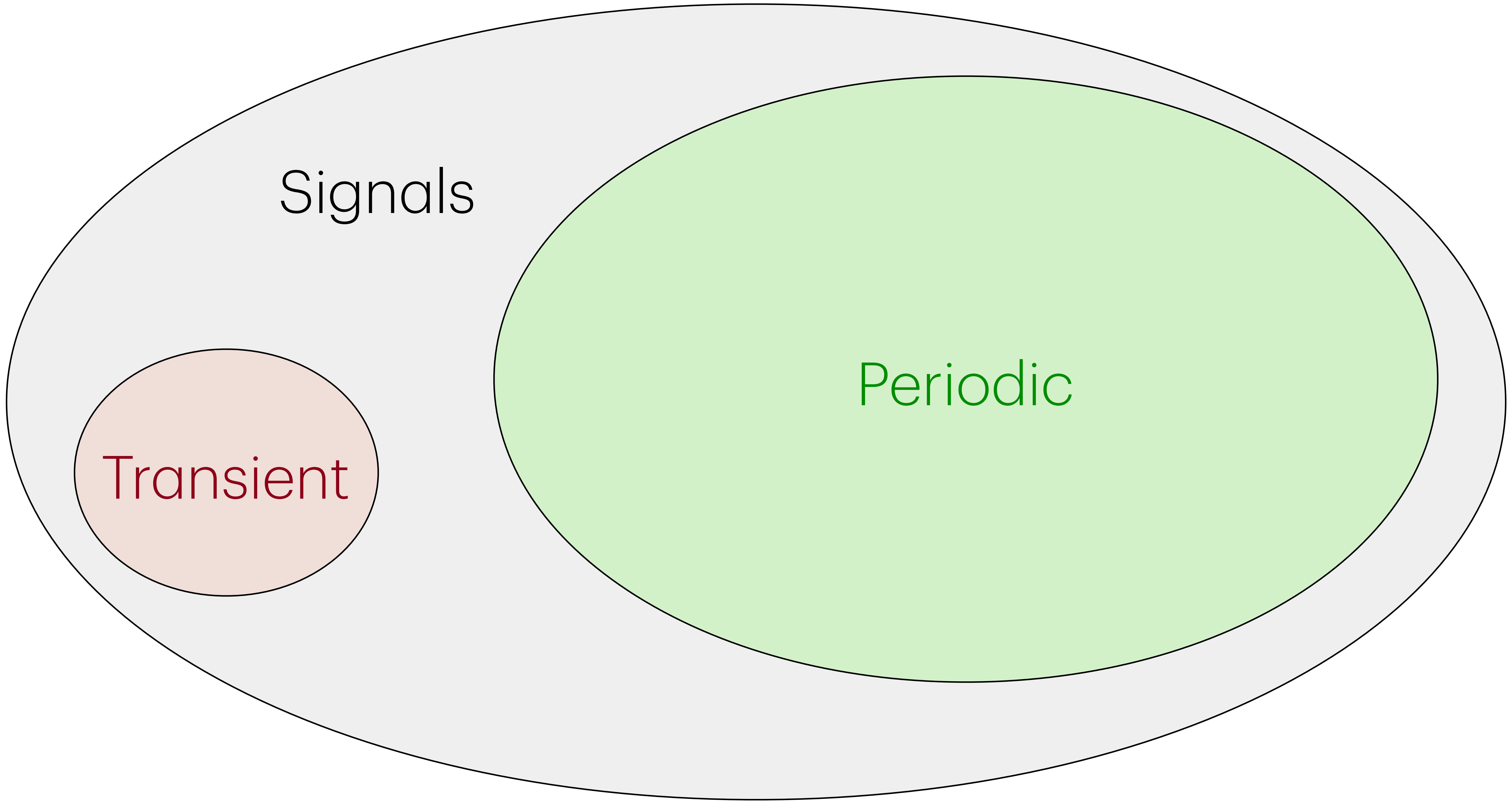
...

The infamous “**why not**”?

AxionLimits, C. O'Hare

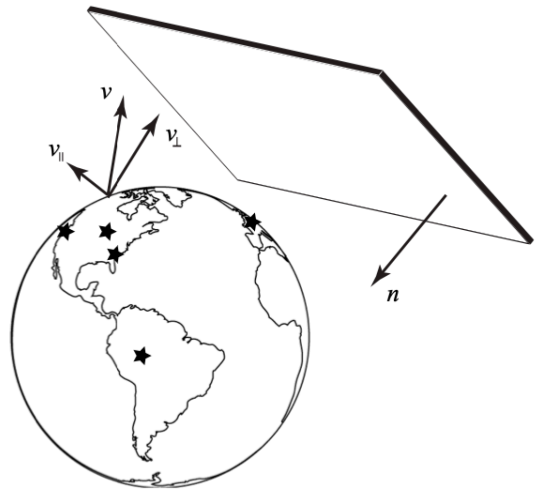
Transient Signals

Some interesting studies in the literature:
(non-exhaustive list)



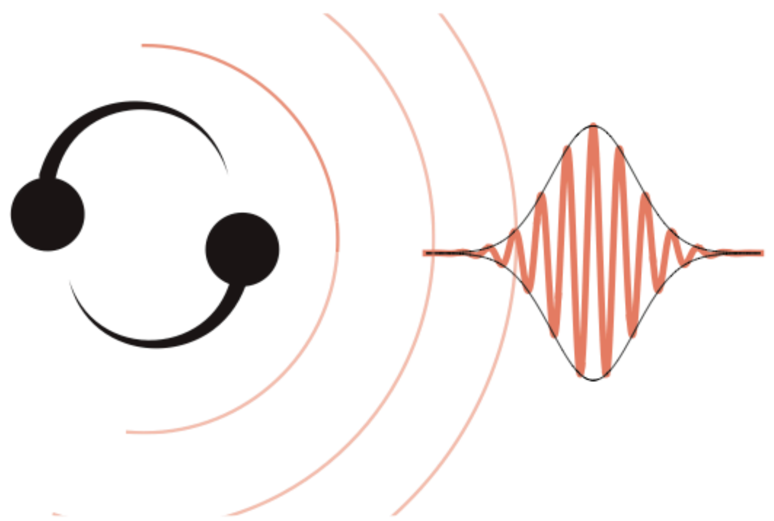
Passage of a domain wall

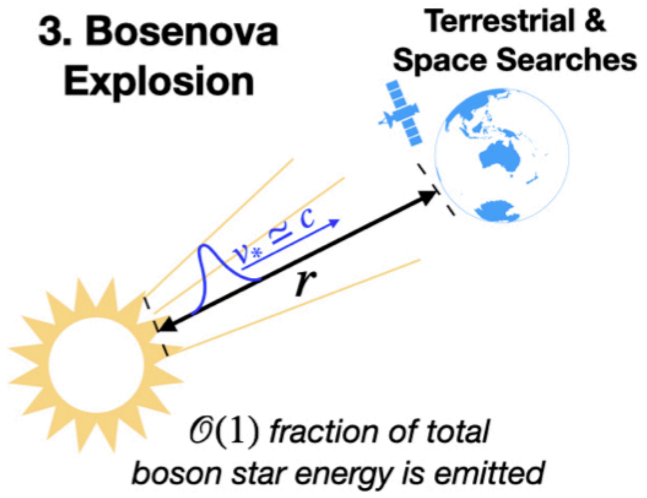
"How do you know if you ran through a wall?"
M. Pospelov et al. (1205.6260)



Binary mergers

"Quantum sensor networks as exotic field telescopes for multi-messenger astronomy"
C. Dailey et al. (2002.04352)





Bosenova

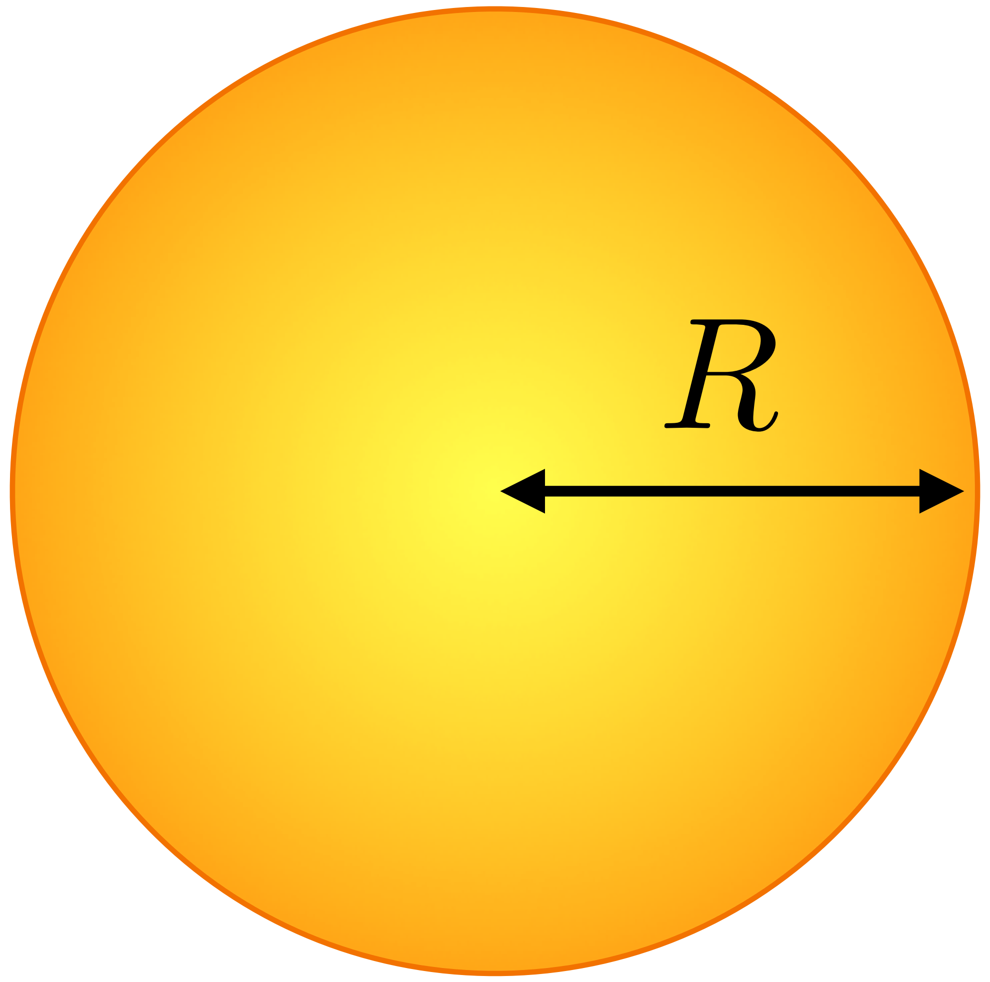
"Detection of Bosenovae with Quantum Sensors on Earth and in Space?"
J. Arakawa, V. Takhistov et al. (2306.16468)

Transient Signal from BH Formation

A. de Giorgi, J. Jaeckel [2408.10296]

New Mechanism

Transient Signal from BH Formation



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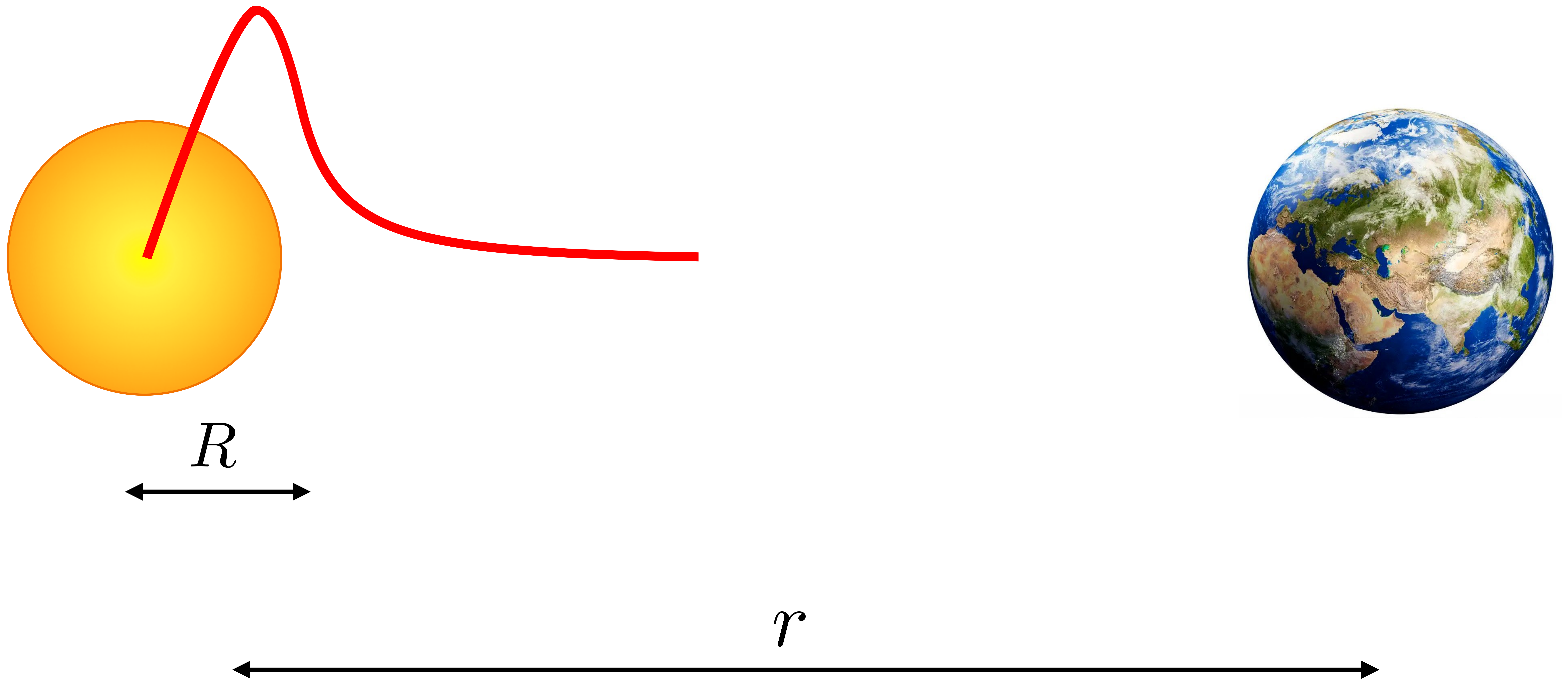

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*not in scale

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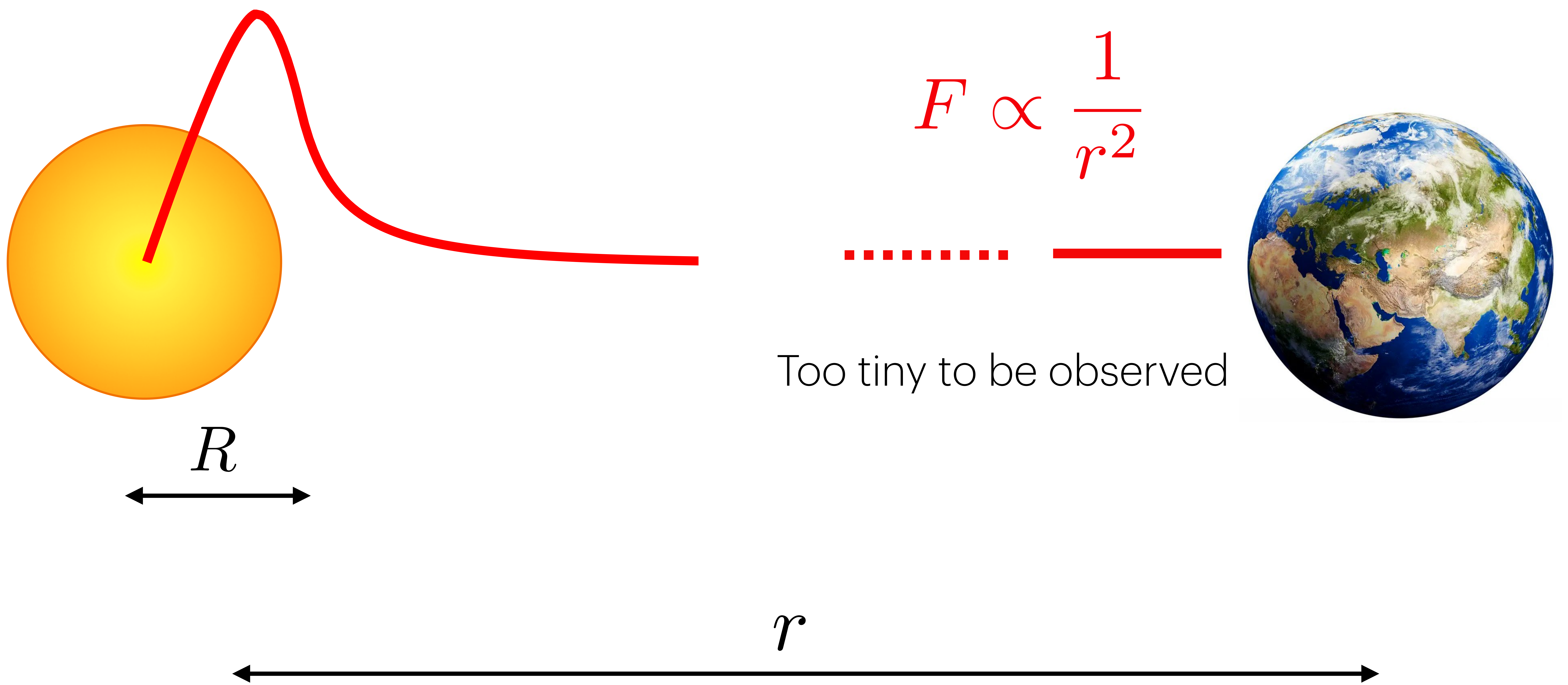

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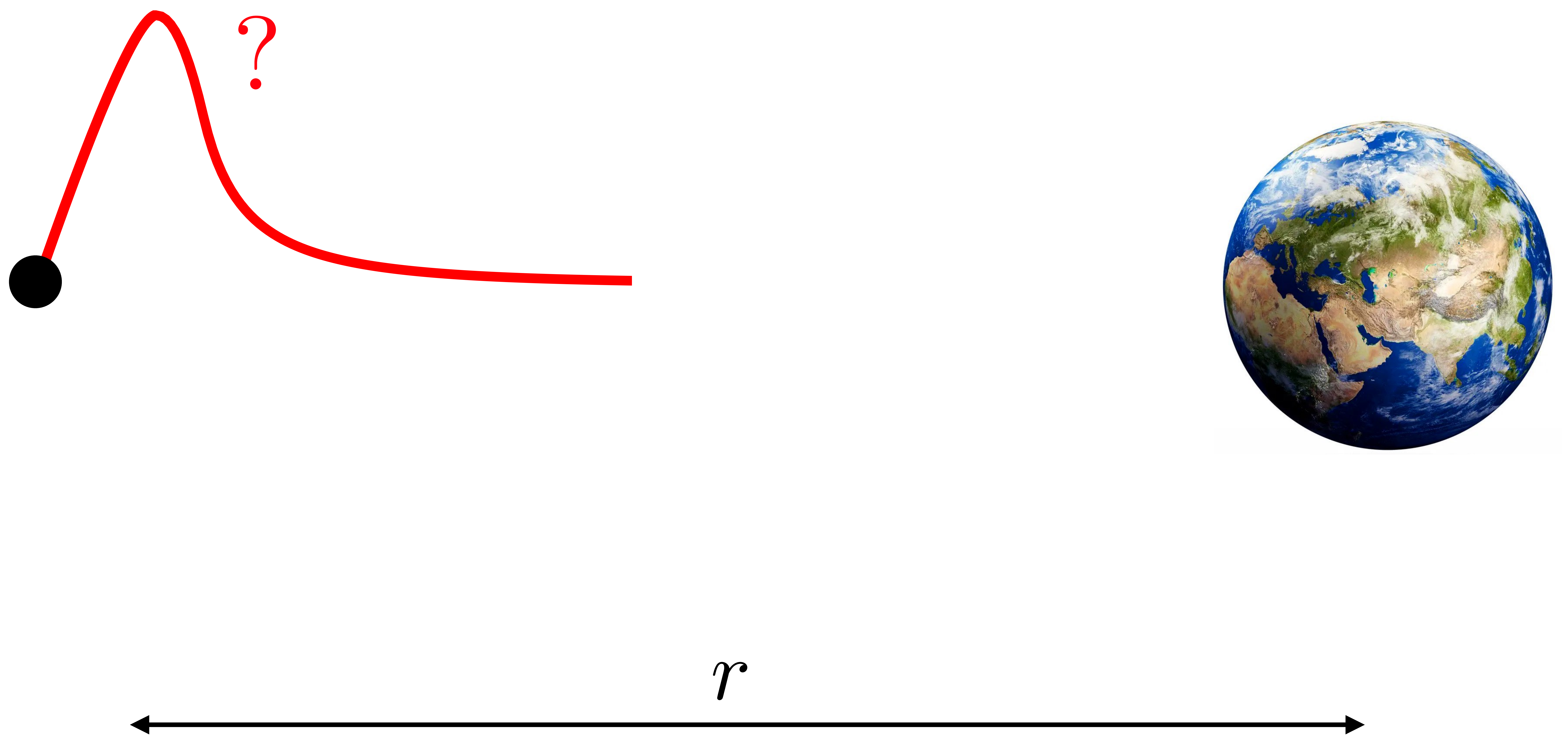

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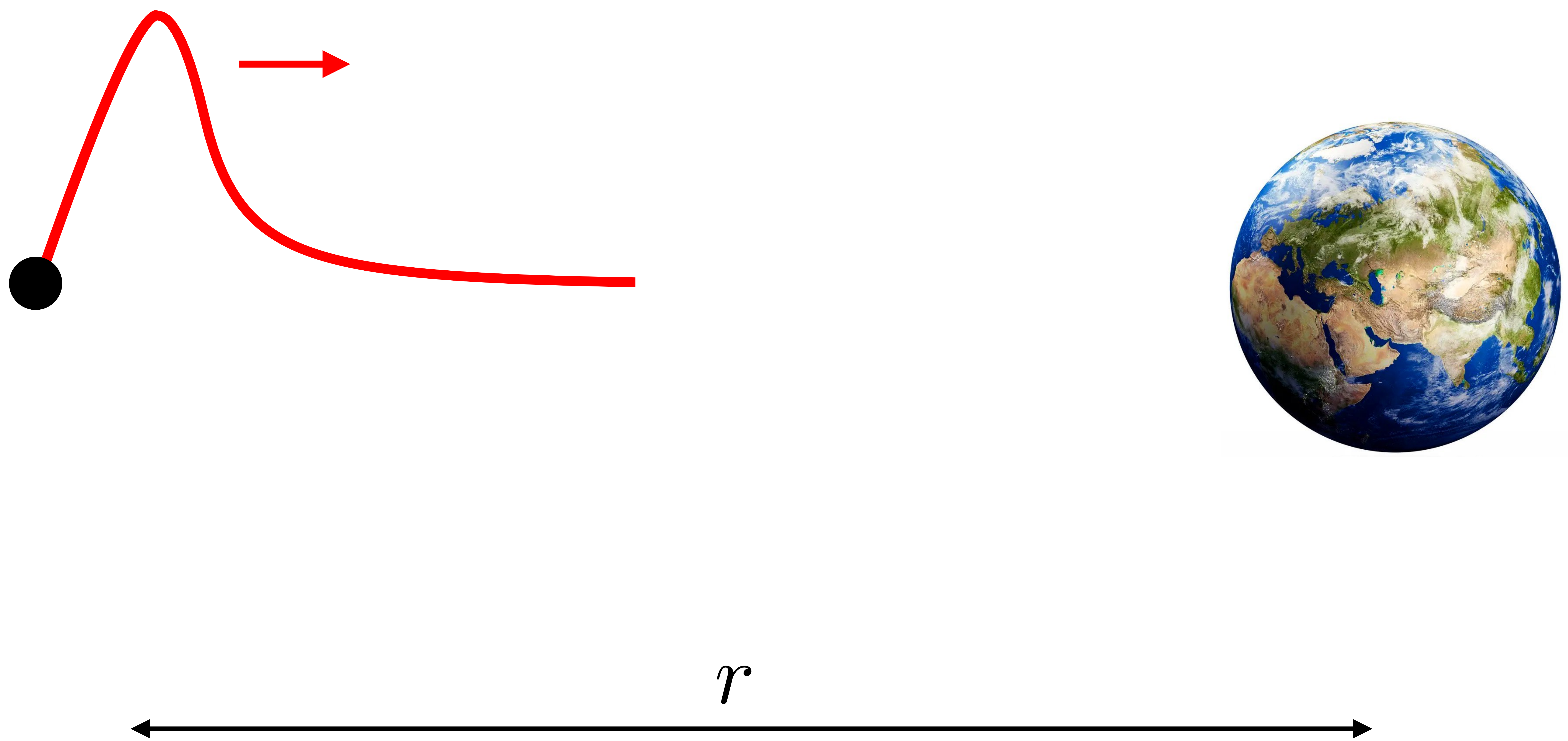

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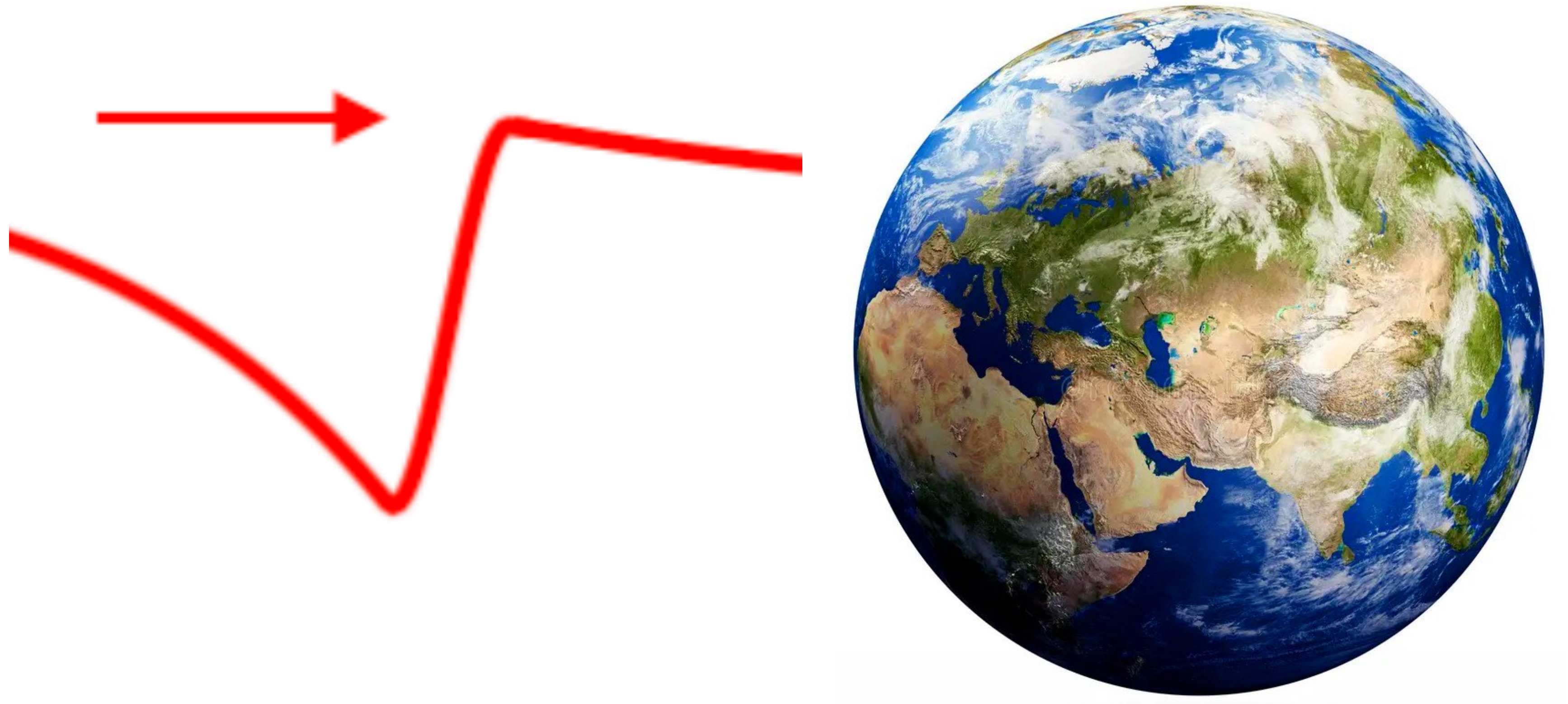
*not in scale

$\mathrm{ly} \sim 10^{13}\ \mathrm{Km}$

Transient Signal from BH Formation

$$F \propto \frac{1}{rR}$$



$\frac{r}{R}$ enhancement!

$m_\phi \lesssim \frac{1}{r}$ avoid signal dilution!

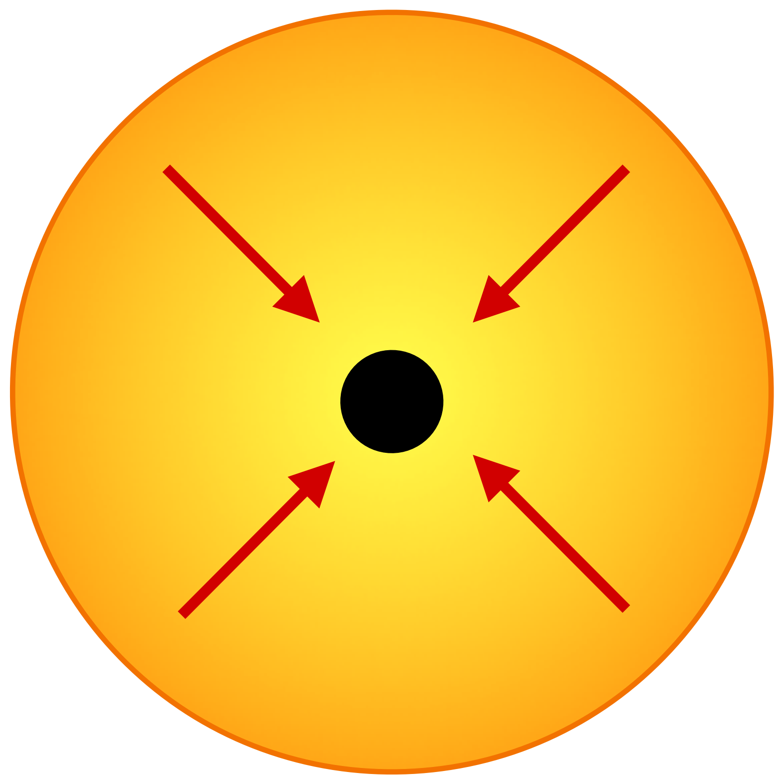
r

A. de Giorgi, J. Jaeckel [2408.10296]

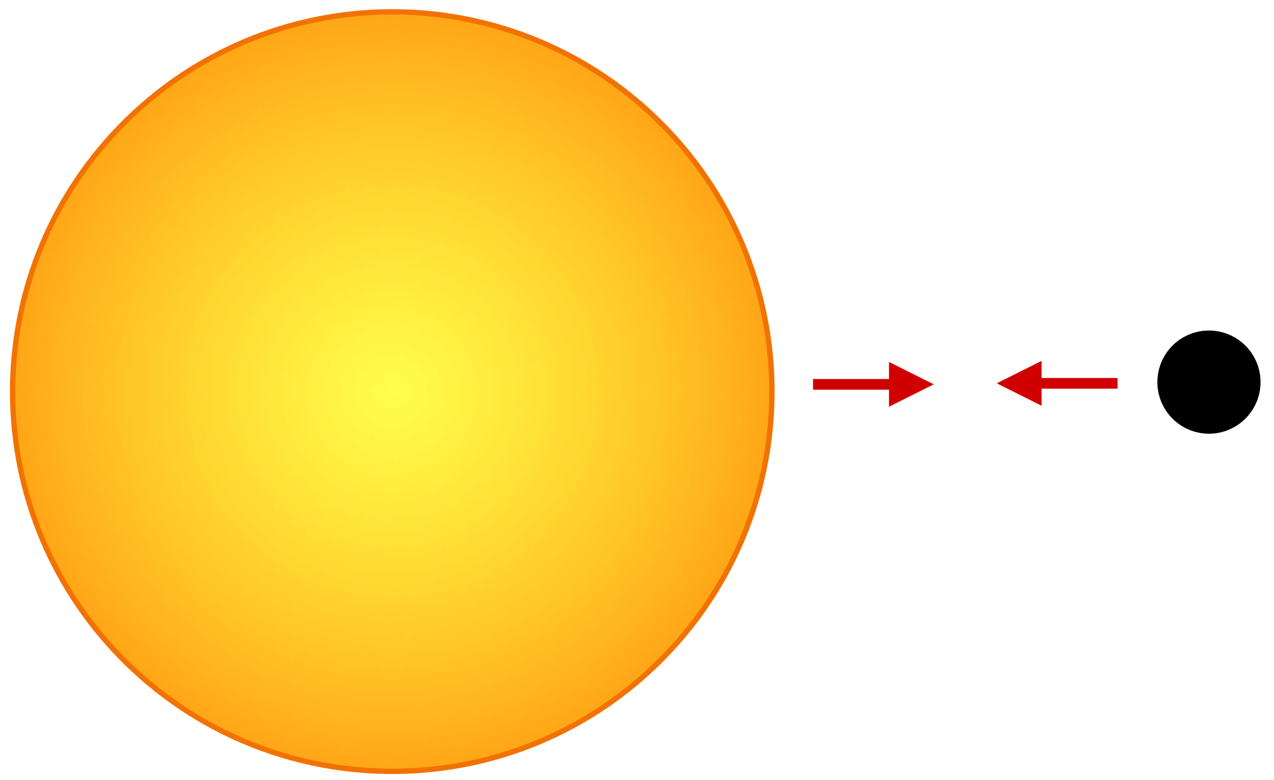
*not in scale

Sources

Accretion



Merger



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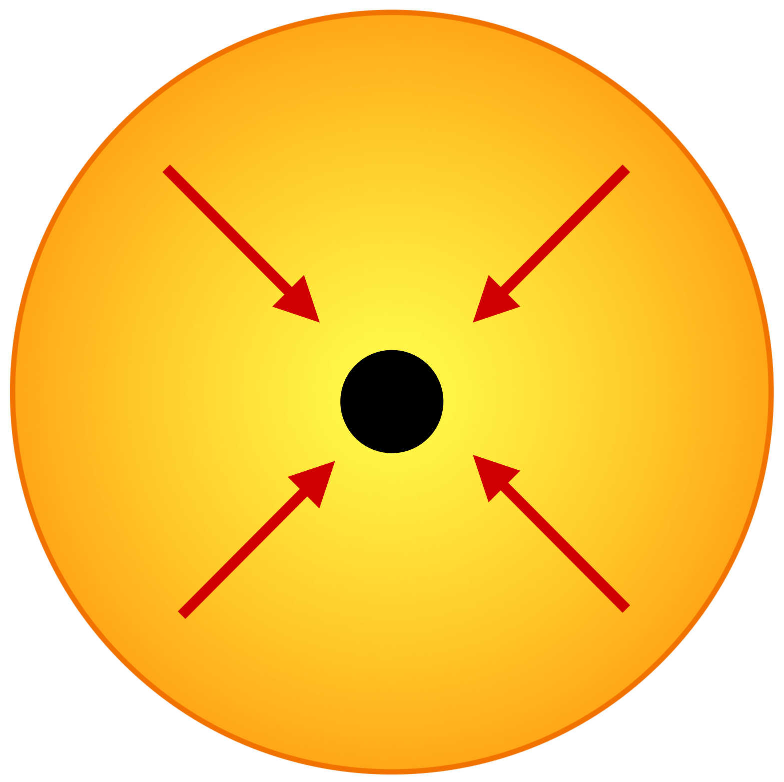

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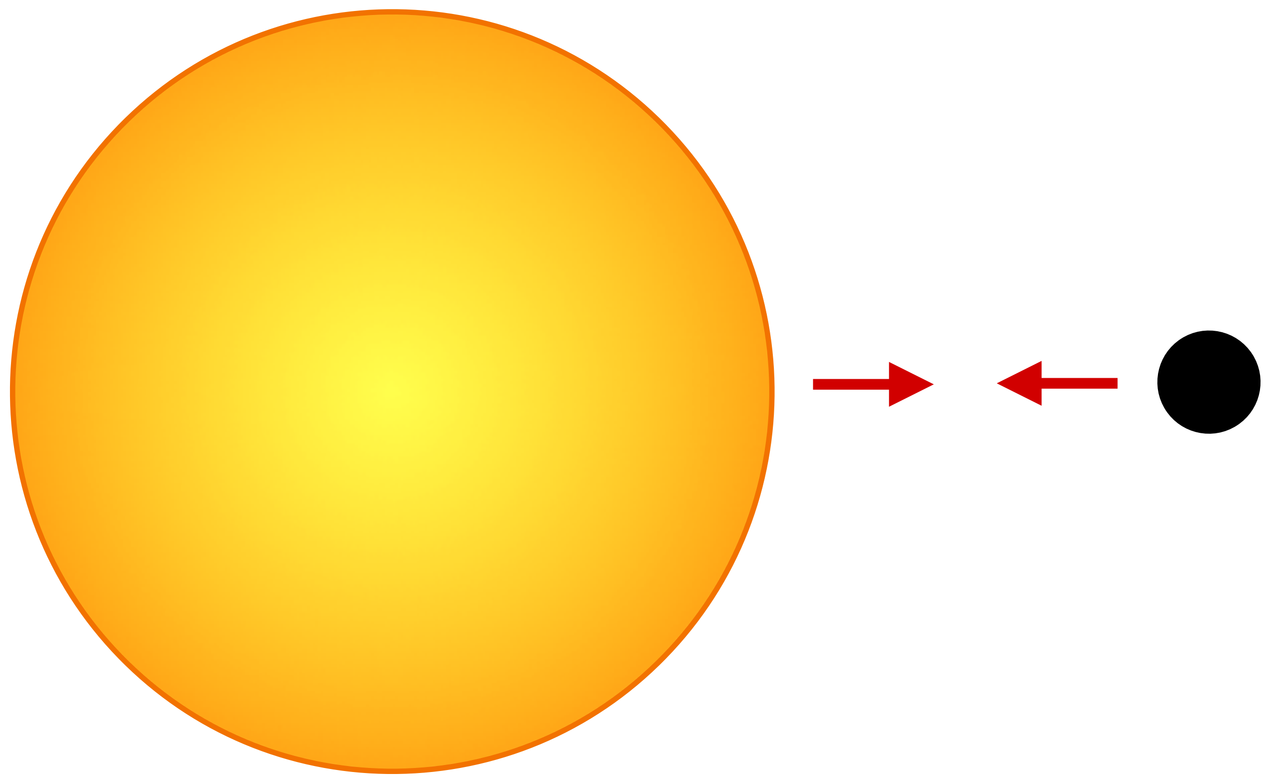

$$f_{\mathrm{SN1987A}} \approx 2 \times 10^{-3}\mathrm{Hz}\,,$$

Most famous supernova

$$f_{\mathrm{Betelgeuse}} \approx 9 \times 10^{-5}\mathrm{Hz}\,,$$

Red-giant, SN candidate

$$f_{\mathrm{NS}} \approx 5 \times 10^{3}\mathrm{Hz}$$

Closest Neutron Star

Name	Type	$M\ [M_\odot]$	r [ly]	R
SN1987A	Supernova	20	170×10^3	$35\,R_\odot \approx 2.4 \times 10^7$ Km
Betelgeuse	Red Giant	18	500	$800\,R_\odot$
RX J1856.5-3754	Neutron Star	0.9	400	10 Km

$$R_s \equiv 2GM \qquad R_s^{\mathrm{sun}} \approx 2.95\ \mathrm{Km}$$

A. de Giorgi, J. Jaeckel [2408.10296]

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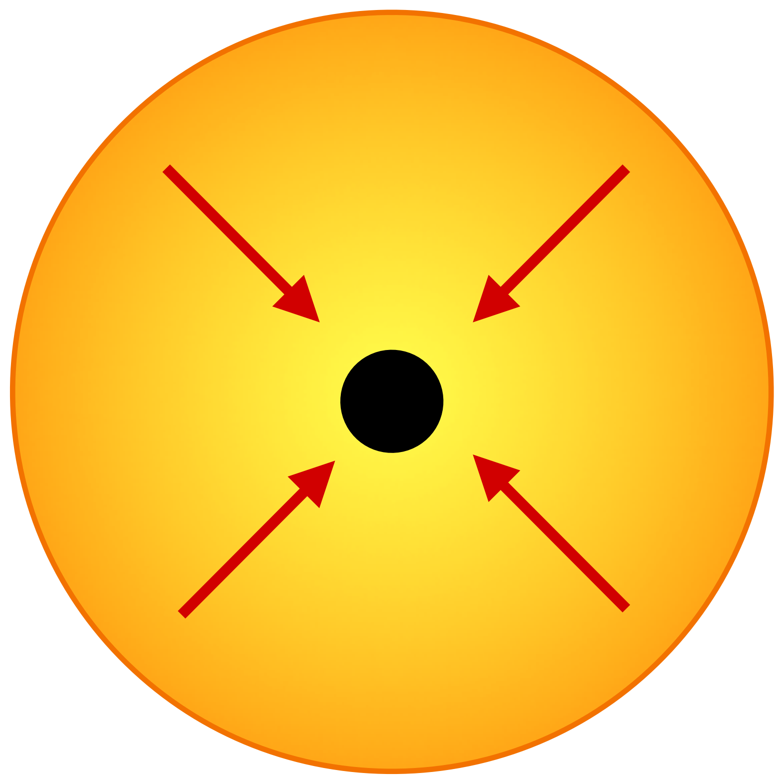

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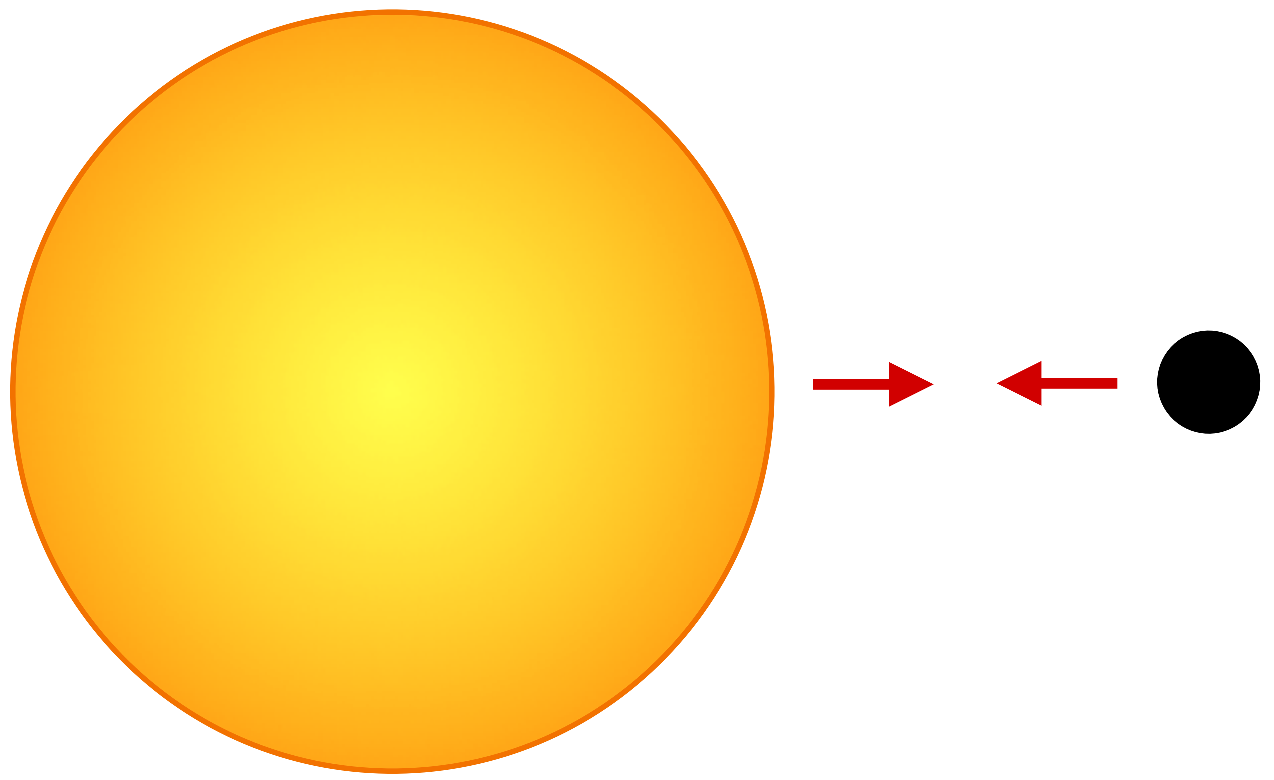

Very different frequencies

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Where to start?

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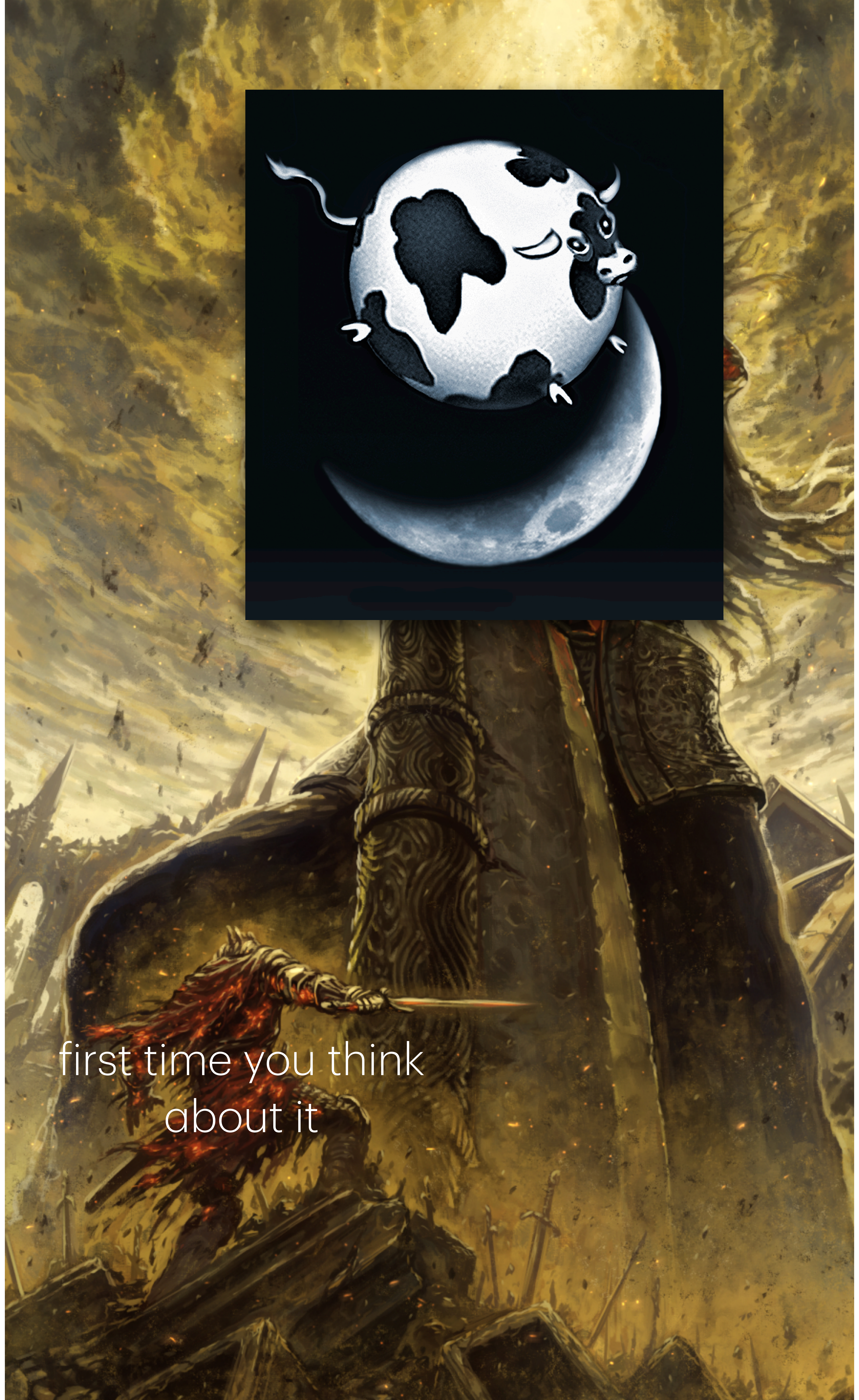

"spherical cow"

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Where to start?

Ultra-simplified approach:

1. BH formation is **instantaneous**
2. **Neglect** BH **remnant** effects

"spherical cow"

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Couplings

$$\mathcal{L} \supset -g_S \phi \overline{N} N + g_S \phi \bar{e} e - g_P \phi \overline{N} i \gamma_5 N - \frac{g_\gamma}{4} \phi F^{\mu\nu} \widetilde{F}_{\mu\nu}$$

We considered some case studies:

Interferometer: LISA Pathfinder
Torsion Pendulum
[2310.06017, 2109.08822]

Optical Magnetometry: GNOME
[2305.01785]

Haloscope: DMRadio-m^3
[2204.13781]

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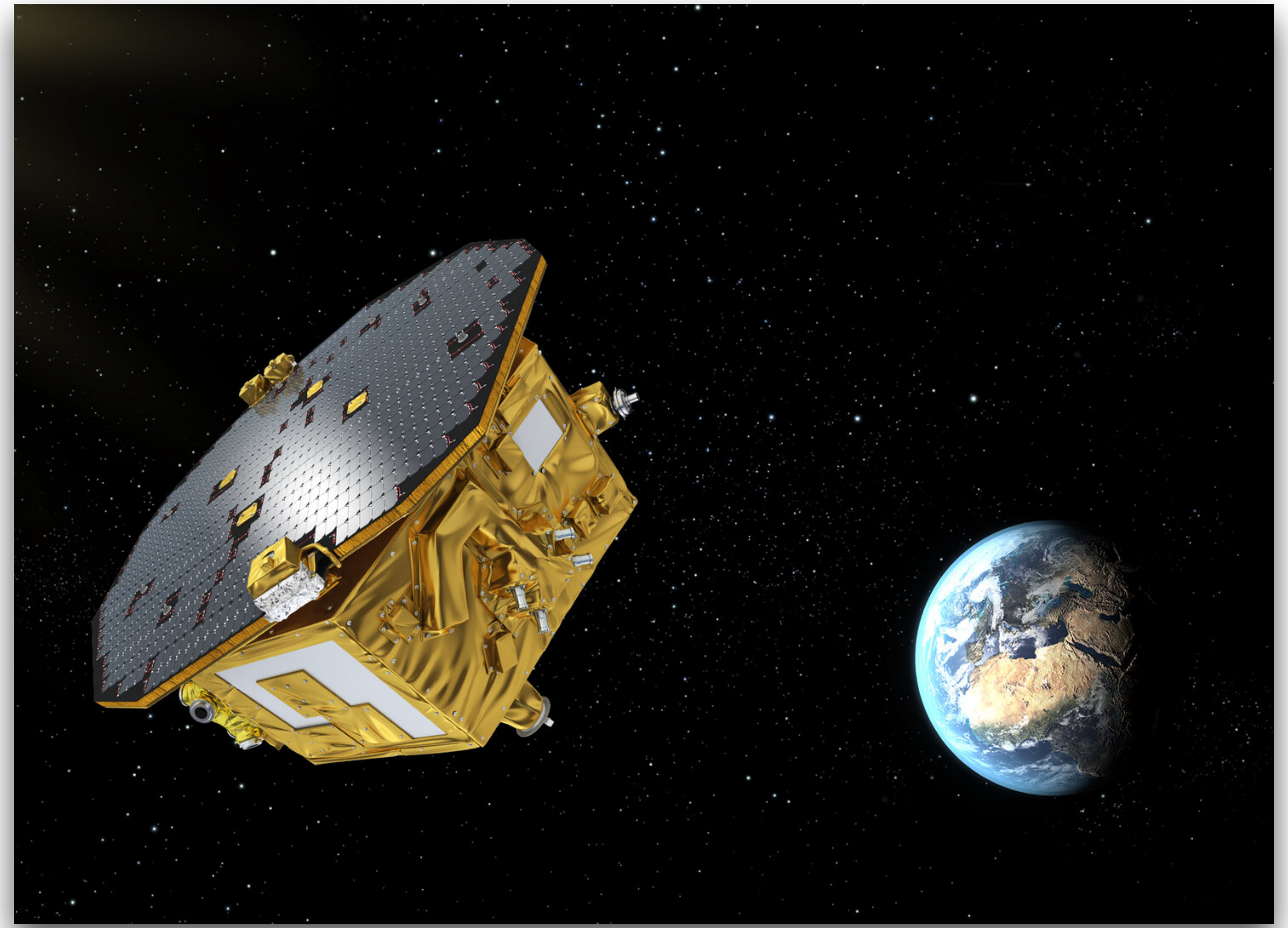

Credit: ESA

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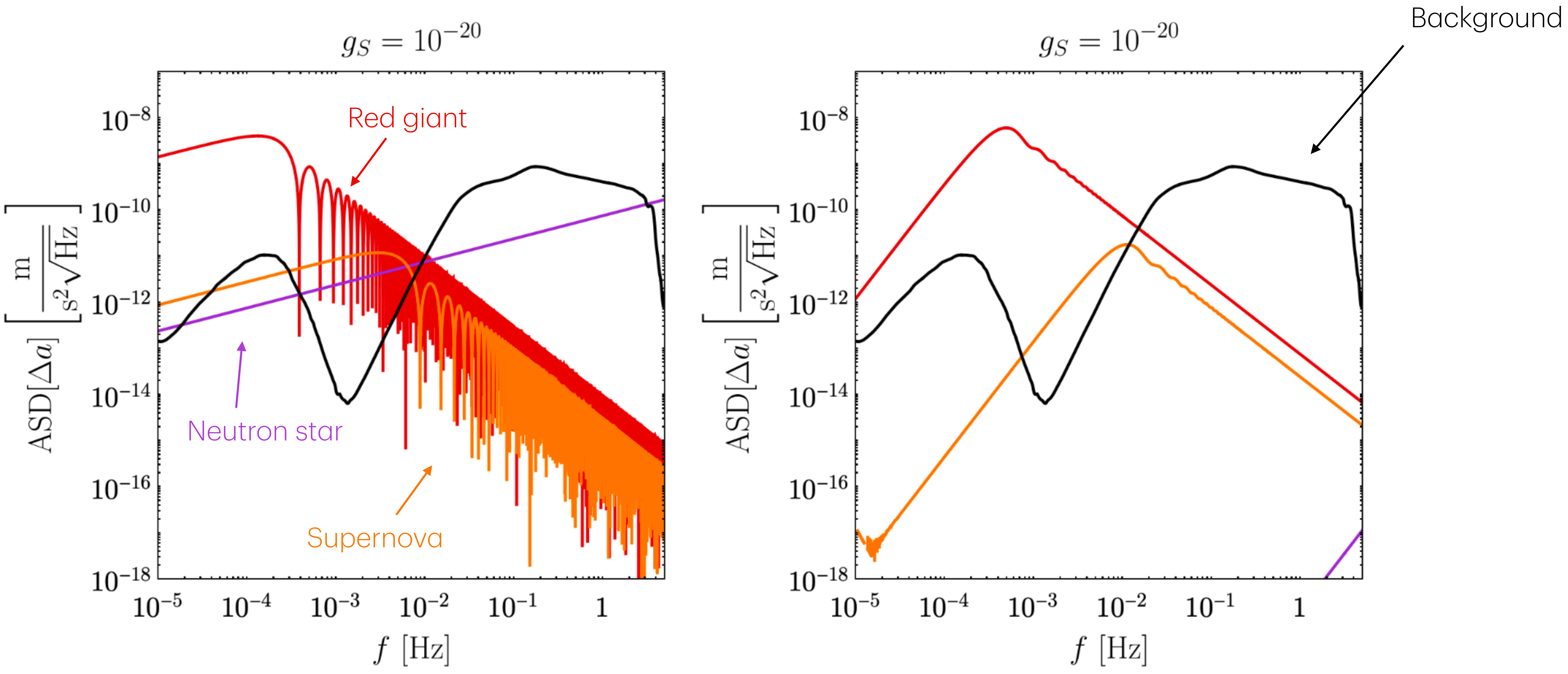
Signal VS Noise

$$\tilde{h}(\omega) \equiv \int_{-\infty}^{\infty} \mathrm{d}t\, h(t) e^{-i\omega t} \qquad \mathrm{ASD}[h](f) \equiv \sqrt{f}|\tilde{h}(f)|$$



(a) Yukawa-like (b) Compact Source

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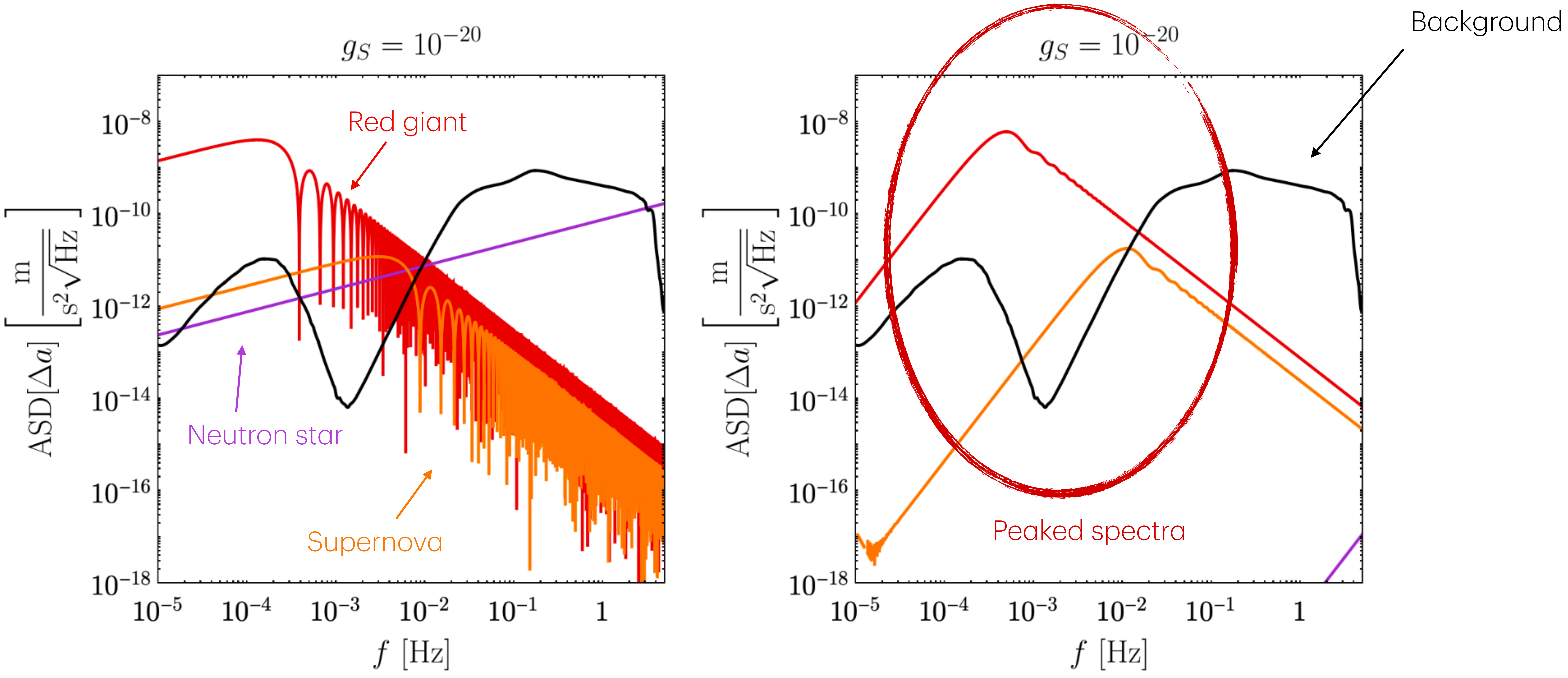

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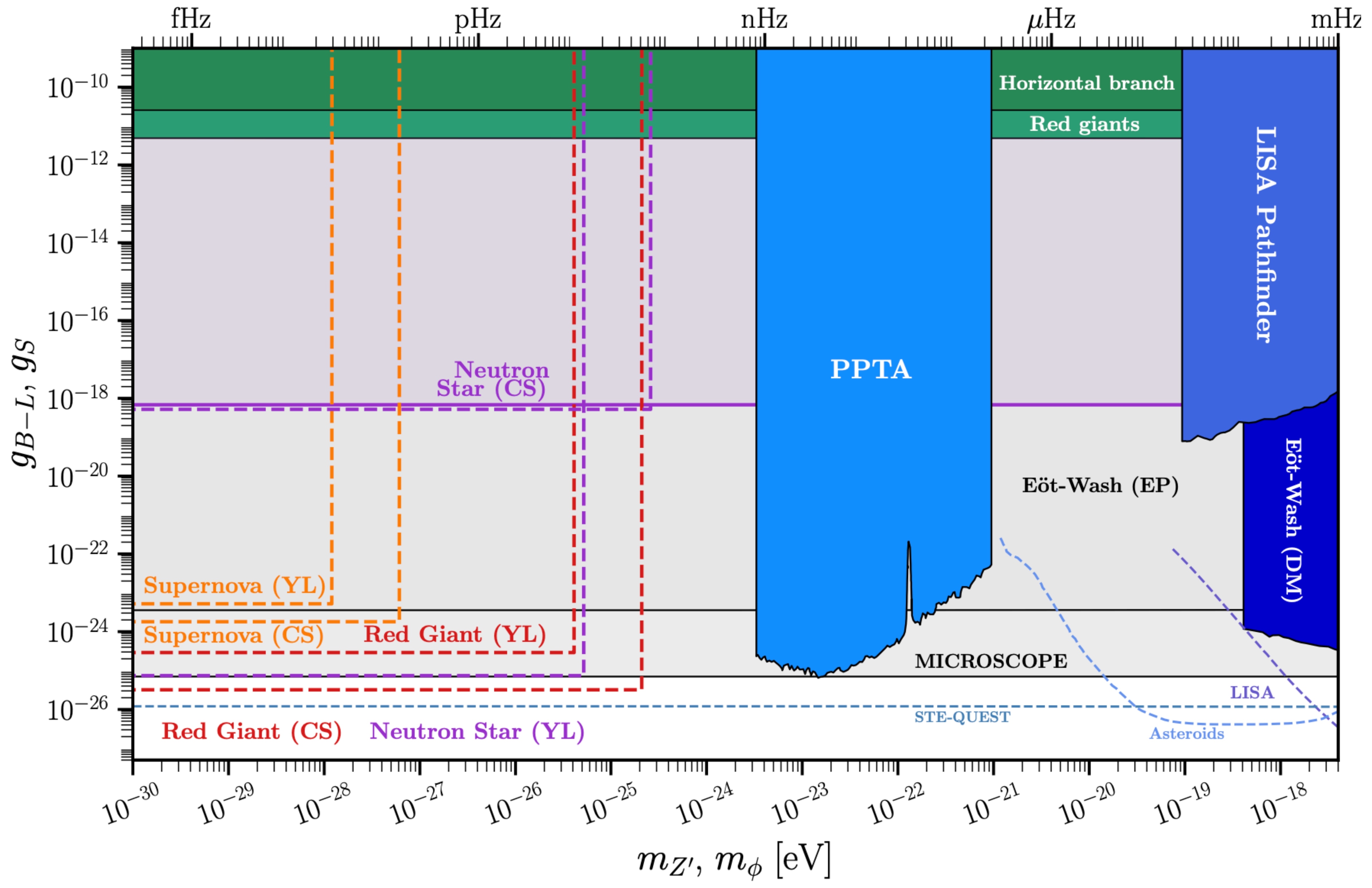
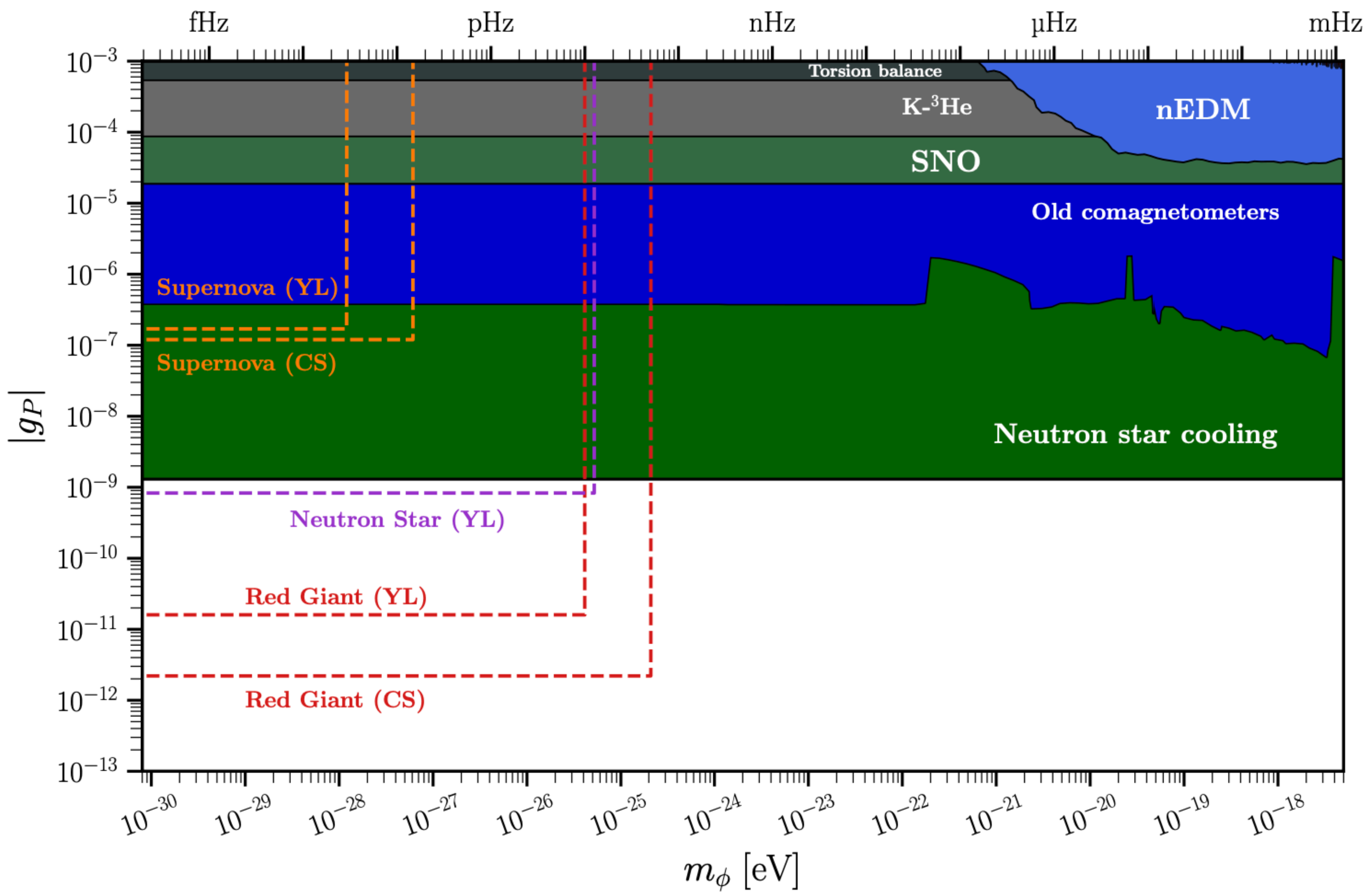
Sensitivities comparable to current bounds

Scalar



Pseudo-scalar



(similarly for photons)

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Summary and future directions

Searches for **periodic** and **transient** signals are **complementary**

$\Rightarrow$ need to characterise **most-likely frequency ranges**

New mechanism: BSM transients from **BH formation**

Frequency^{-1} **~ size of the source** - Neutron Star: **kHz range**

The BH **remnant** will **affect** the signal!

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Work in progress (**25XX.YYYYY**)

with **J. Jaeckel** (U. Heidelberg) and **Y. Garcia del Castillo** (New South Wales U.)

2408.10296 (EPJC)
25XX.YYYYY

Thanks

Durham University

IP3

Arturo de Giorgi 22nd July 2025

Initial Field Configuration

1) **Yukawa-type** source

$$\mathcal{L}_{\mathrm{source}} = \sum_{\psi} g_{\phi\psi\psi}\phi\bar{\psi}\psi \equiv \phi J(x)$$

$$J(x) = g_{\mathrm{YL}}\frac{3}{4\pi R^3}\Theta(-t)\Theta(R-r)$$

$$\phi_{\mathrm{YL}}(r \le R) = \frac{g_{\mathrm{YL}}}{8\pi R}\left(3 - \frac{r^2}{R^2}\right)$$

$$\phi_{\mathrm{YL}}(r \ge R) = \frac{g_{\mathrm{YL}}}{4\pi r}\,.$$

2) What if the field had some tiny **self-interactions**? *"Compact Source"*

$$\phi_{\mathrm{CS}}(x) = \begin{cases} \phi_{\mathrm{CS}}(r) & r \le R\,, \\ 0 & \text{otherwise} \end{cases}$$

Example:

$$\phi_{\mathrm{CS}}(r) = \sqrt{\frac{35|E|R}{6\pi}}\frac{(R-r)^3}{R^4}$$

[fixed energy E]

Mass-Dilution Effect

If **massive**, different Fourier **modes** propagate at a **different speed** $\Rightarrow$ **dilution**

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typical velocity

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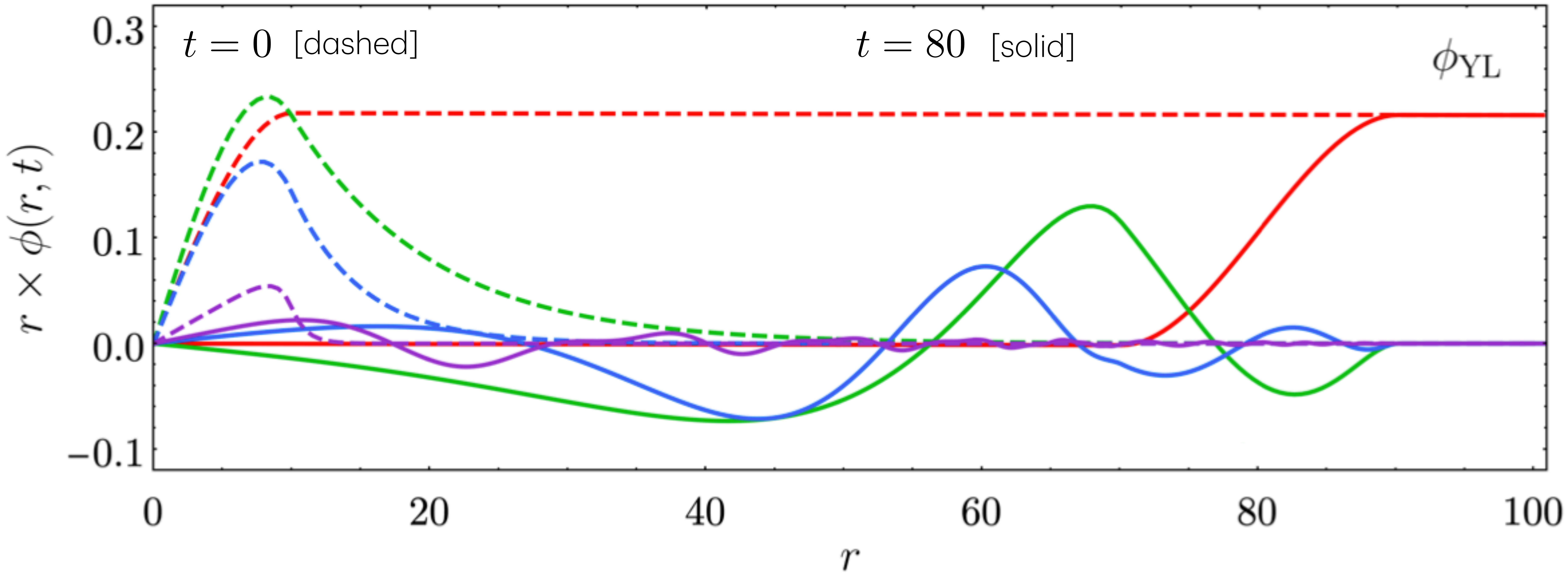


m_ϕ = 0 (**red**)

m_ϕ = 0.1 (**green**)

m_ϕ = 0.2 (**blue**)

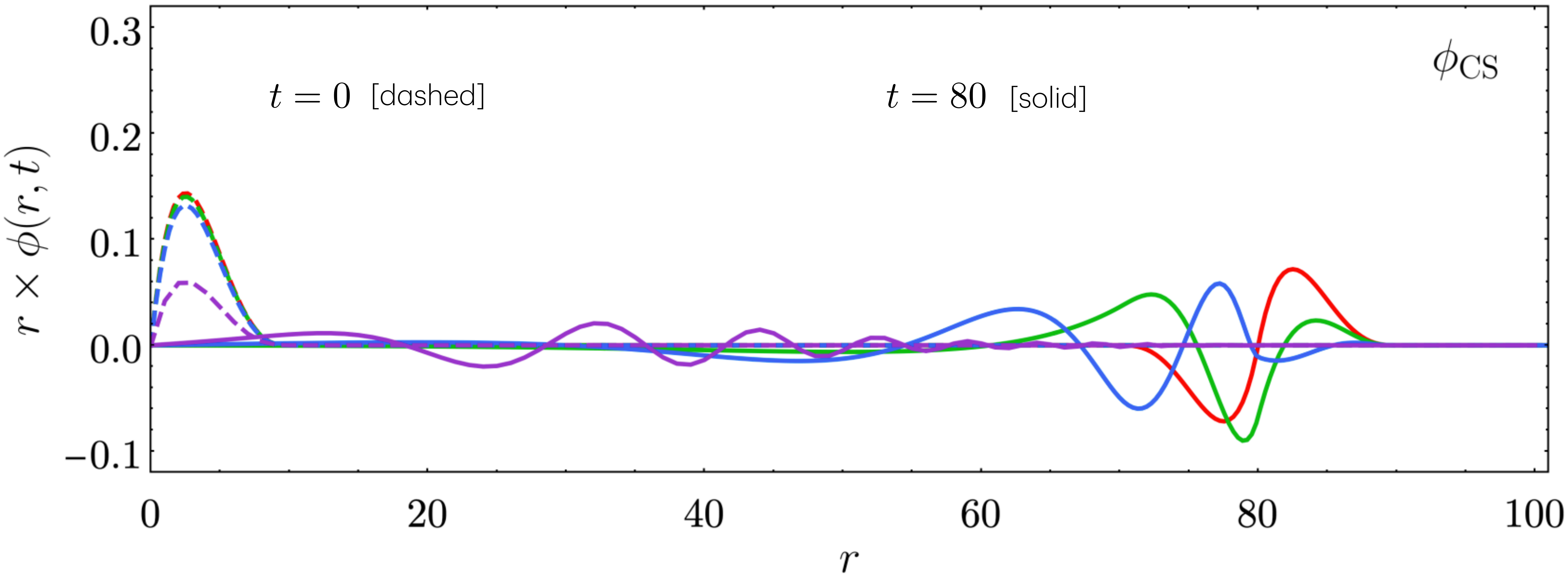
m_ϕ = 1 (**purple**)

$$\phi(r, 0) = \frac{e^{-m_\phi r}}{4\pi r}$$

[natural units]

$c = \hbar = 1$

Compact Field Propagation



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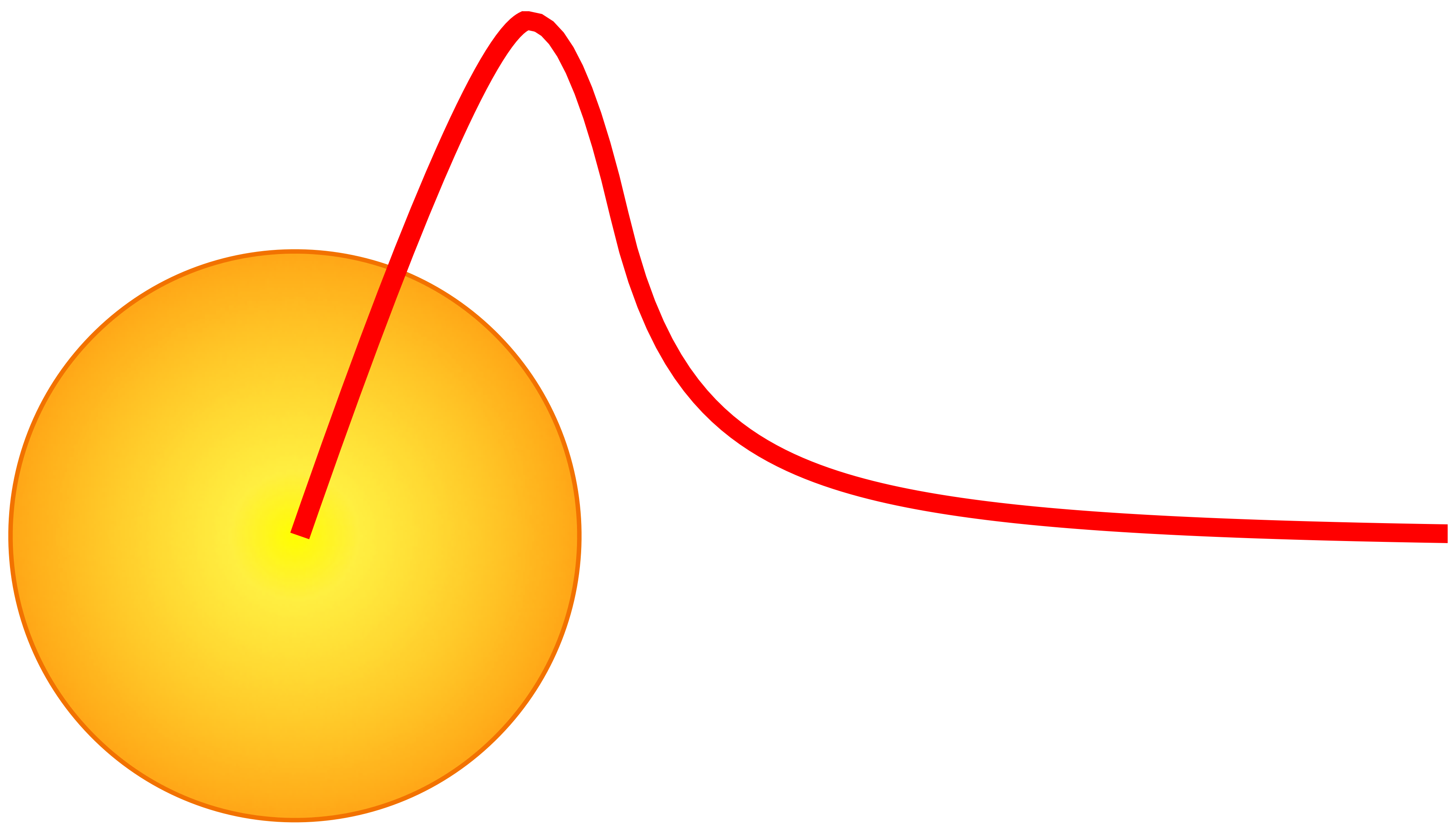
How much energy is left?

Crude estimate:



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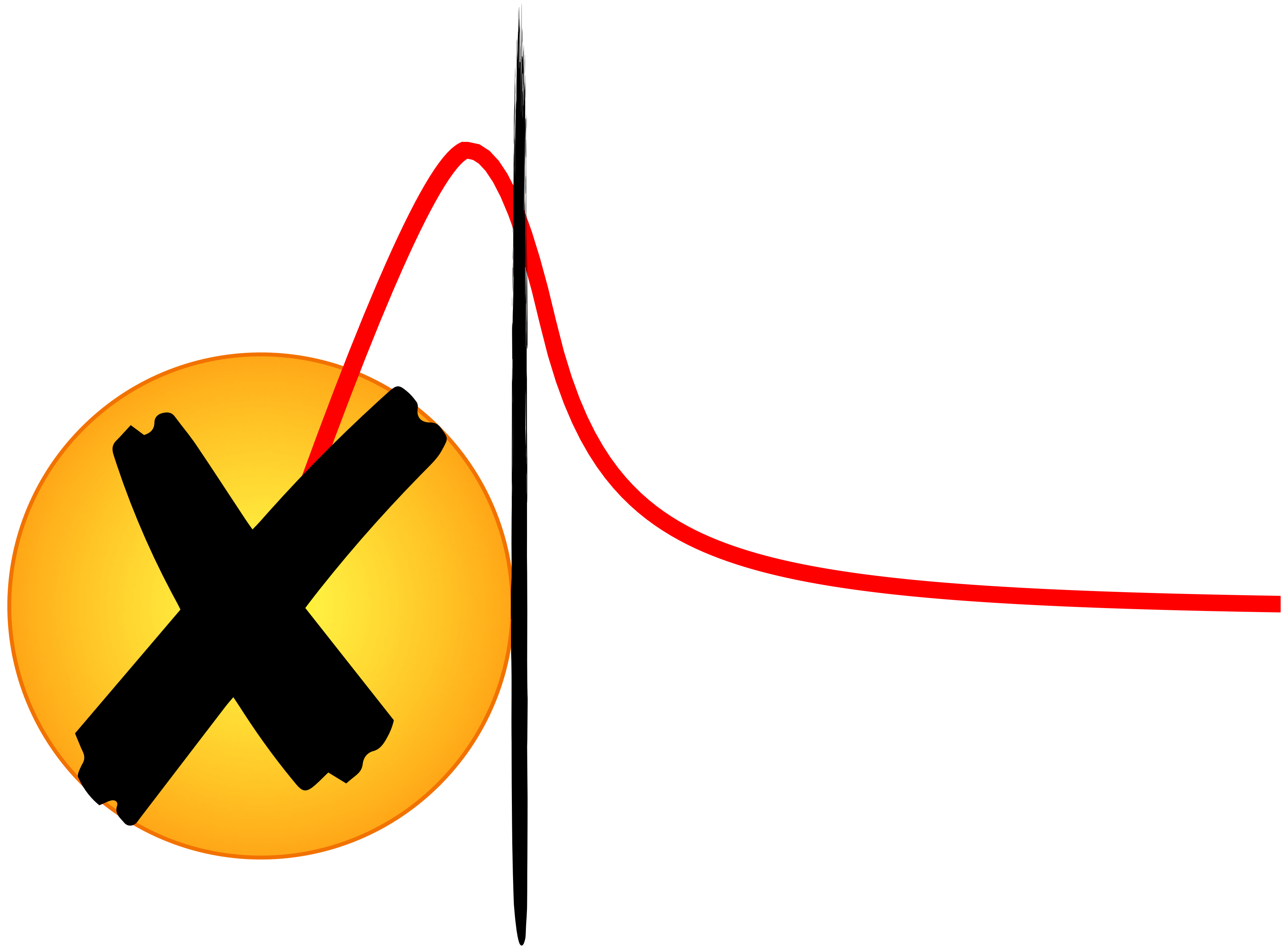

$\times \frac{1}{2}$

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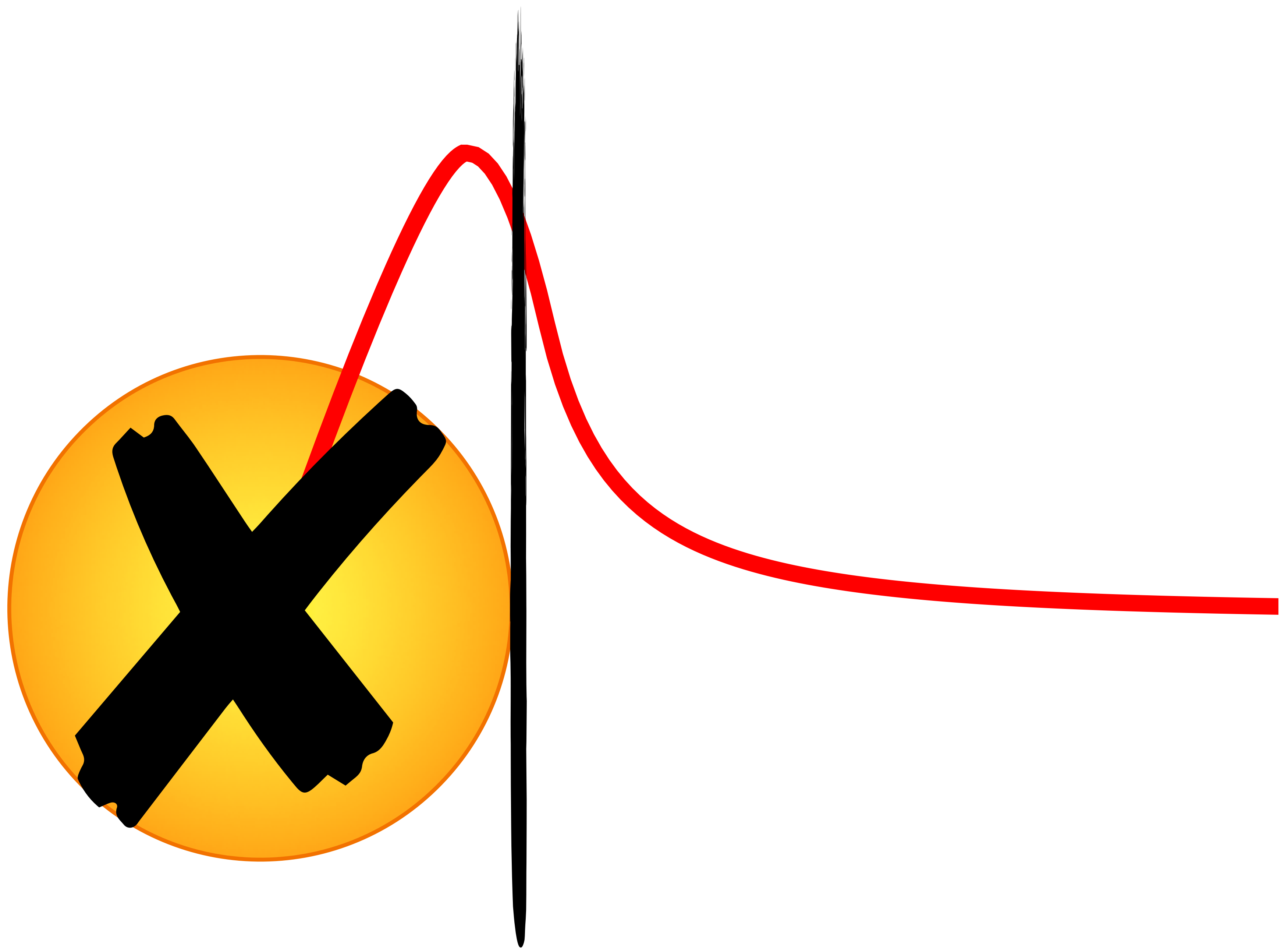

$$\times \frac{1}{2}$$

$$g_{\max} \to g_{\max} \times \sqrt{\frac{12R}{5R_s}} \approx 0.9\, g_{\max} \times \sqrt{\left(\frac{R}{10\,\mathrm{Km}}\right)\left(\frac{10\,M_\odot}{M}\right)}$$

almost *no impact* for *Neutron Stars* - huge impact on larger objects