Searching for New Physics with Cold Atom and Laser Interferometers (and some Magic)

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GOBIERNO DE ESPAÑA

MINISTERIO DE UNIVERSIDADES

MINISTERIO DE CIENCIA E INNOVACIÓN

AGENCIA ESTATAL DE INVESTIGACIÓN

This talk

15’: I will present different ‘new physics’ cases from LISA and AION

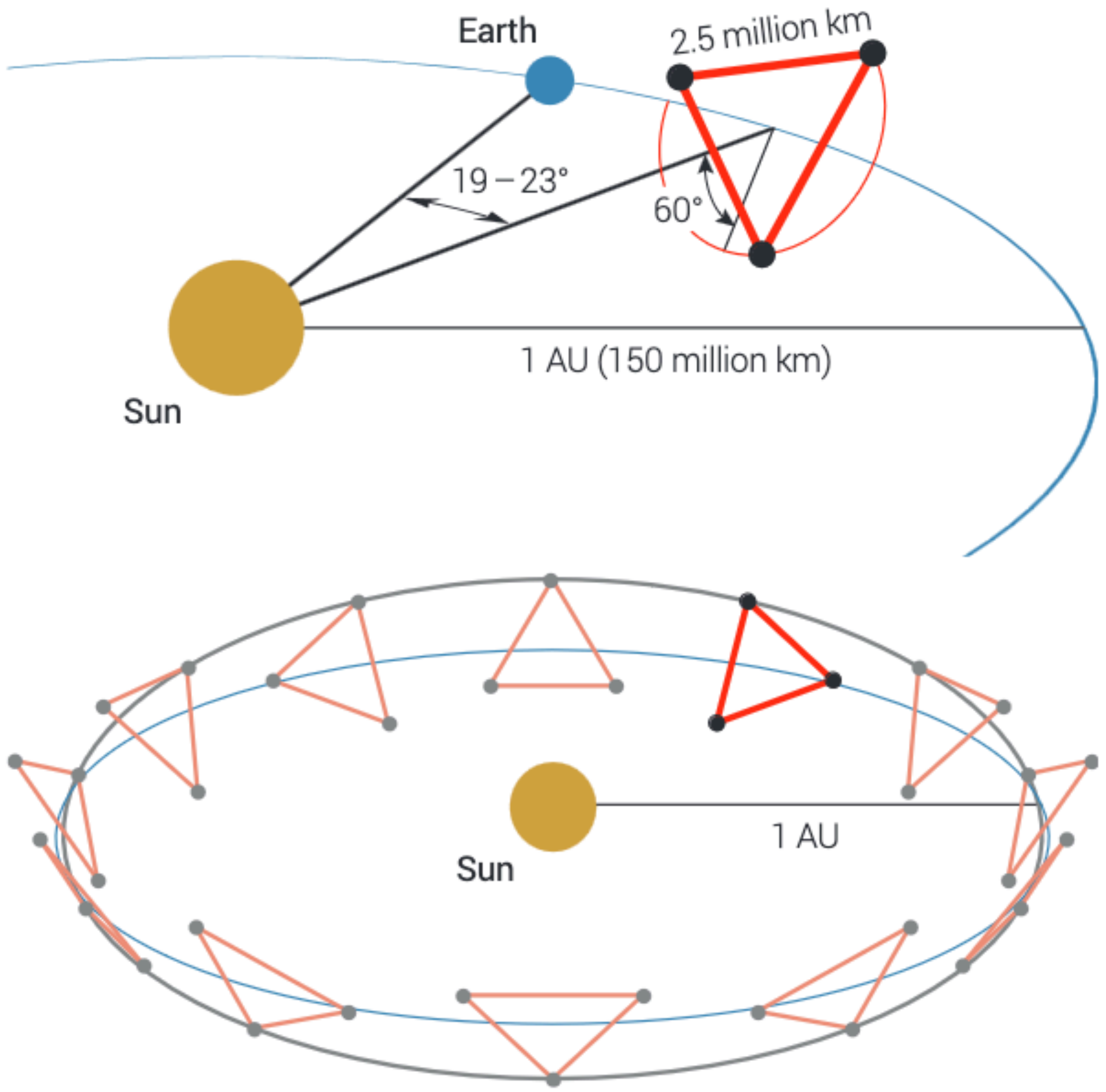
5’: I’ll mention briefly recent progress on UHFGWs
(may be of interest for the atomic physics community + CERN community)

10’: discussion/find synergies

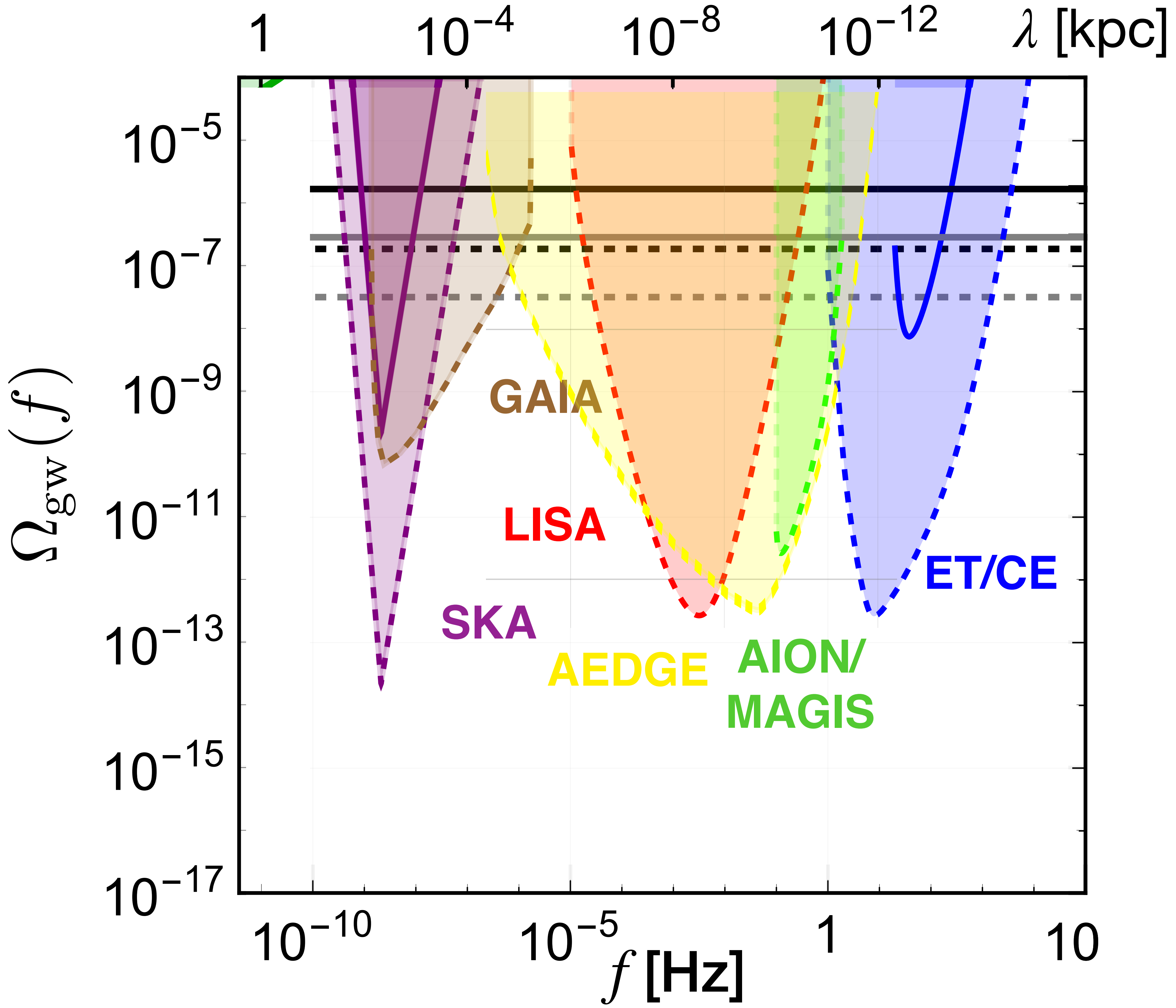
LISA

ESA Mission at “B1” (definition) phase (possible adoption in 2023!)

- Launch ca. 2032
- 2.5 million km arms
- picometer displacement of free falling masses



A fantastic laboratory for GWs!



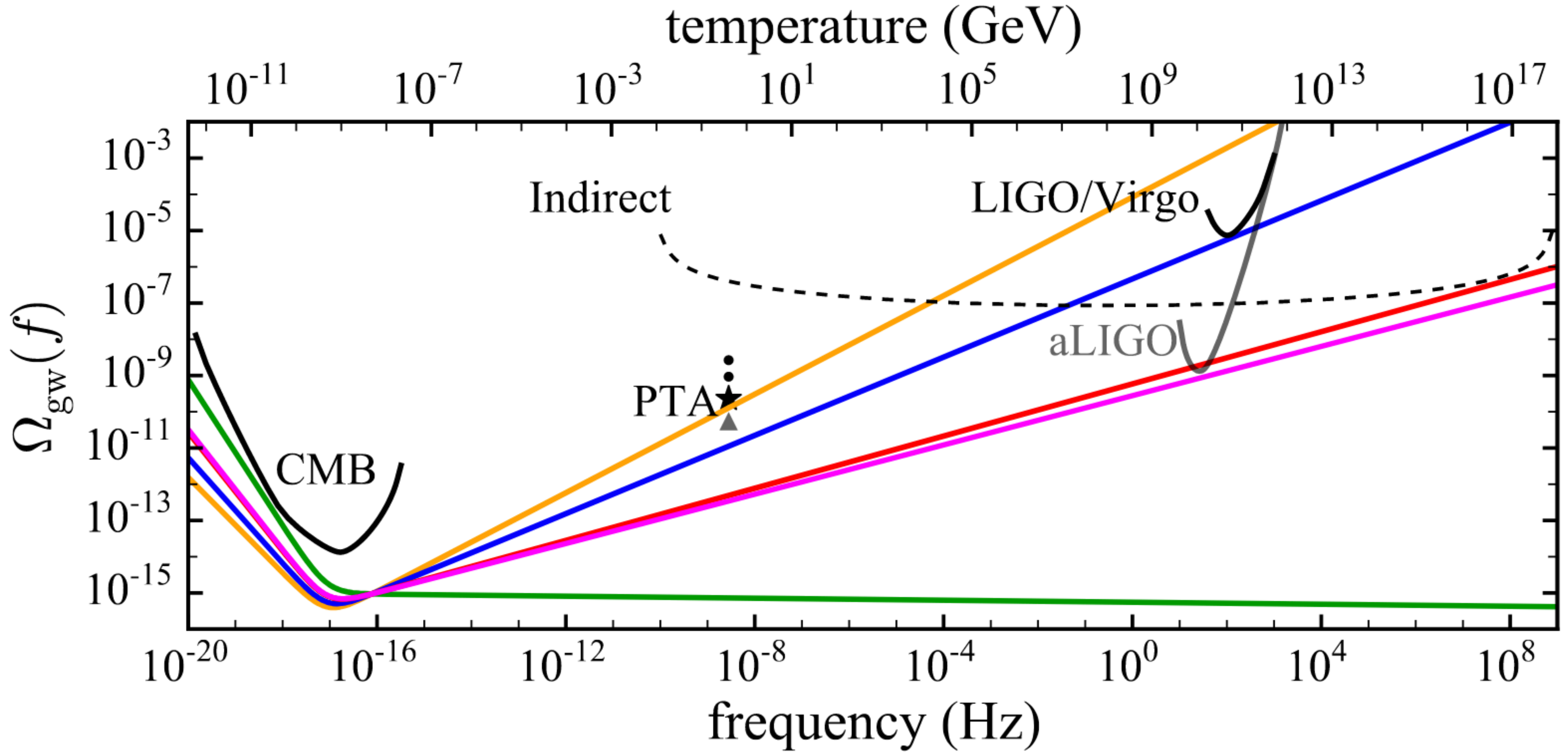
LISA and ‘new’ Physics

LISA and ‘new’ Physics

Stochastic backgrounds of GWs at the LISA band are harbingers of the Physics of the primordial Universe

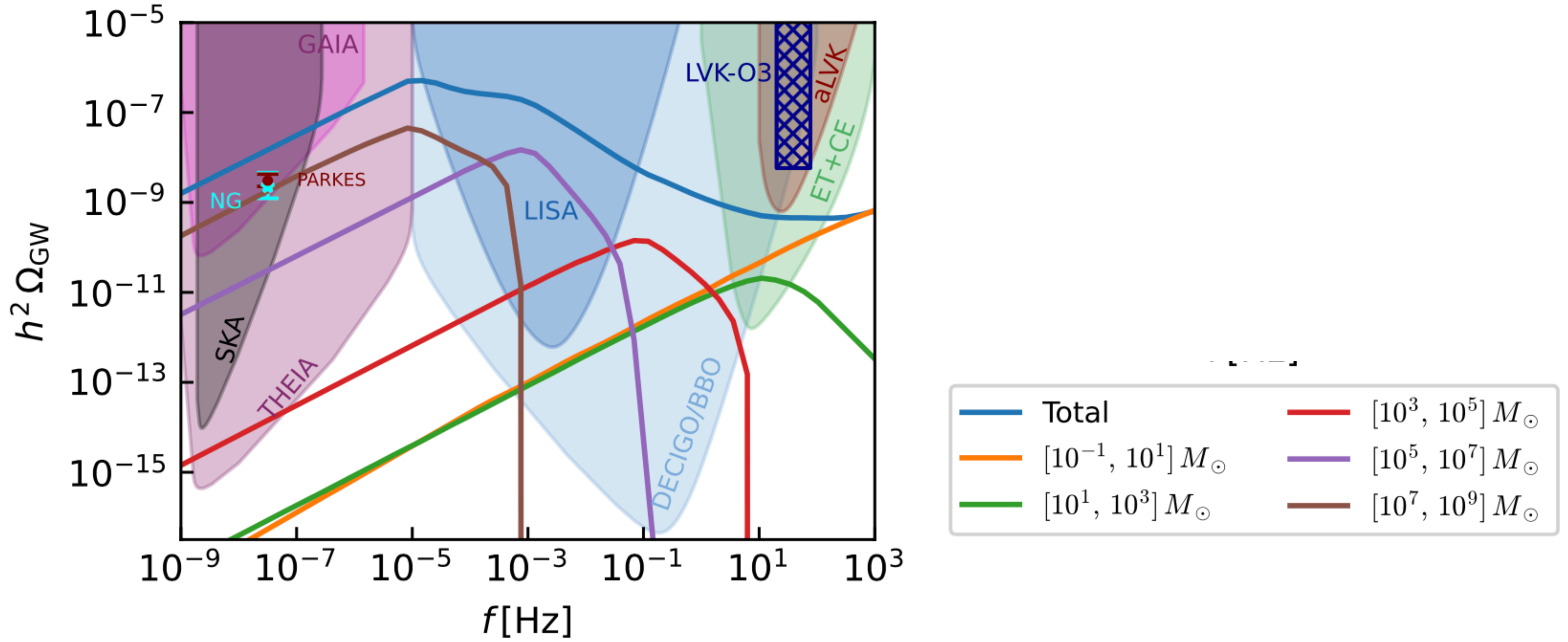
Inflation

Lasky et al PRX 6, 011035



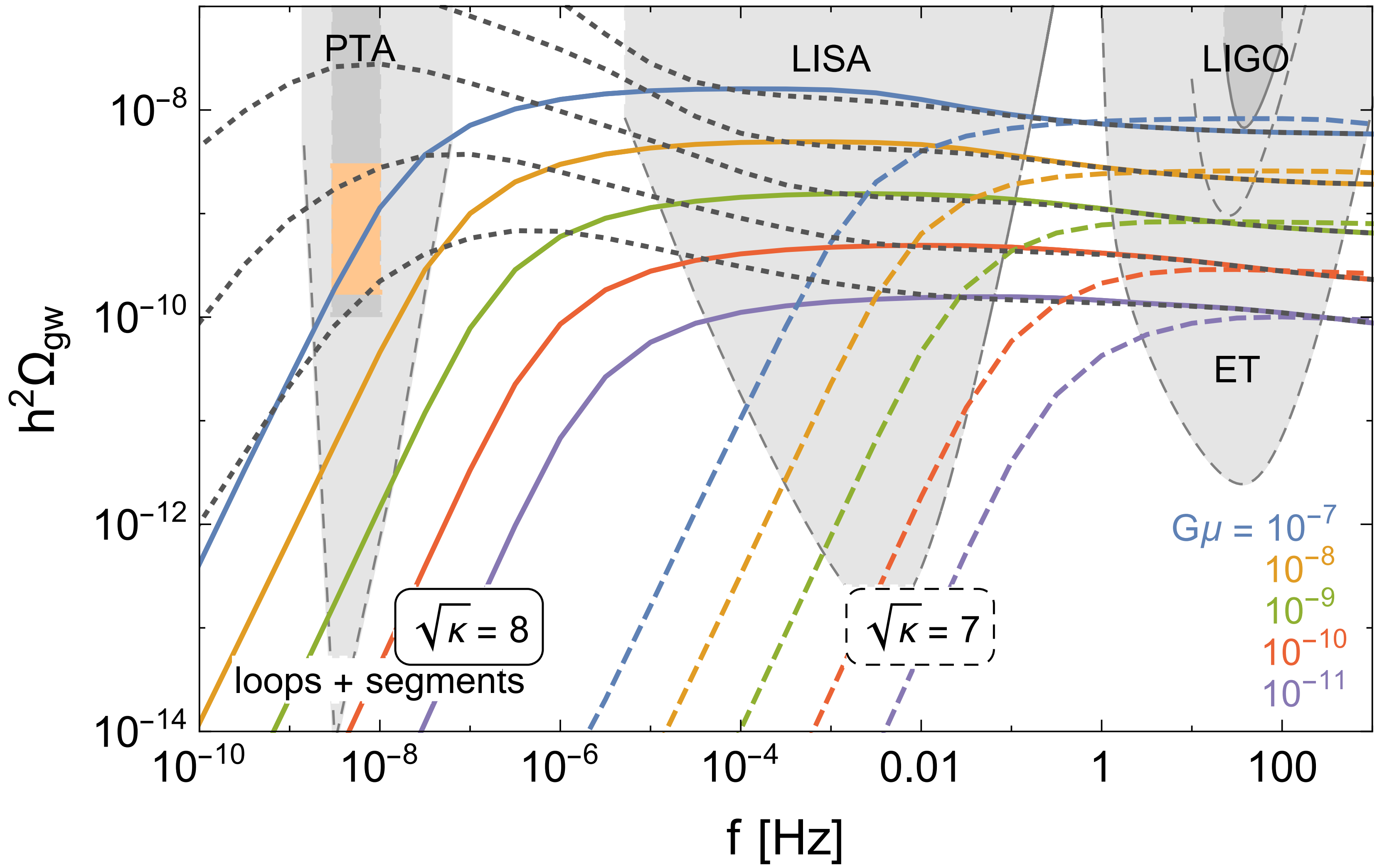
Primordial BHs

Braglia et al. JCAP 12 (2021)



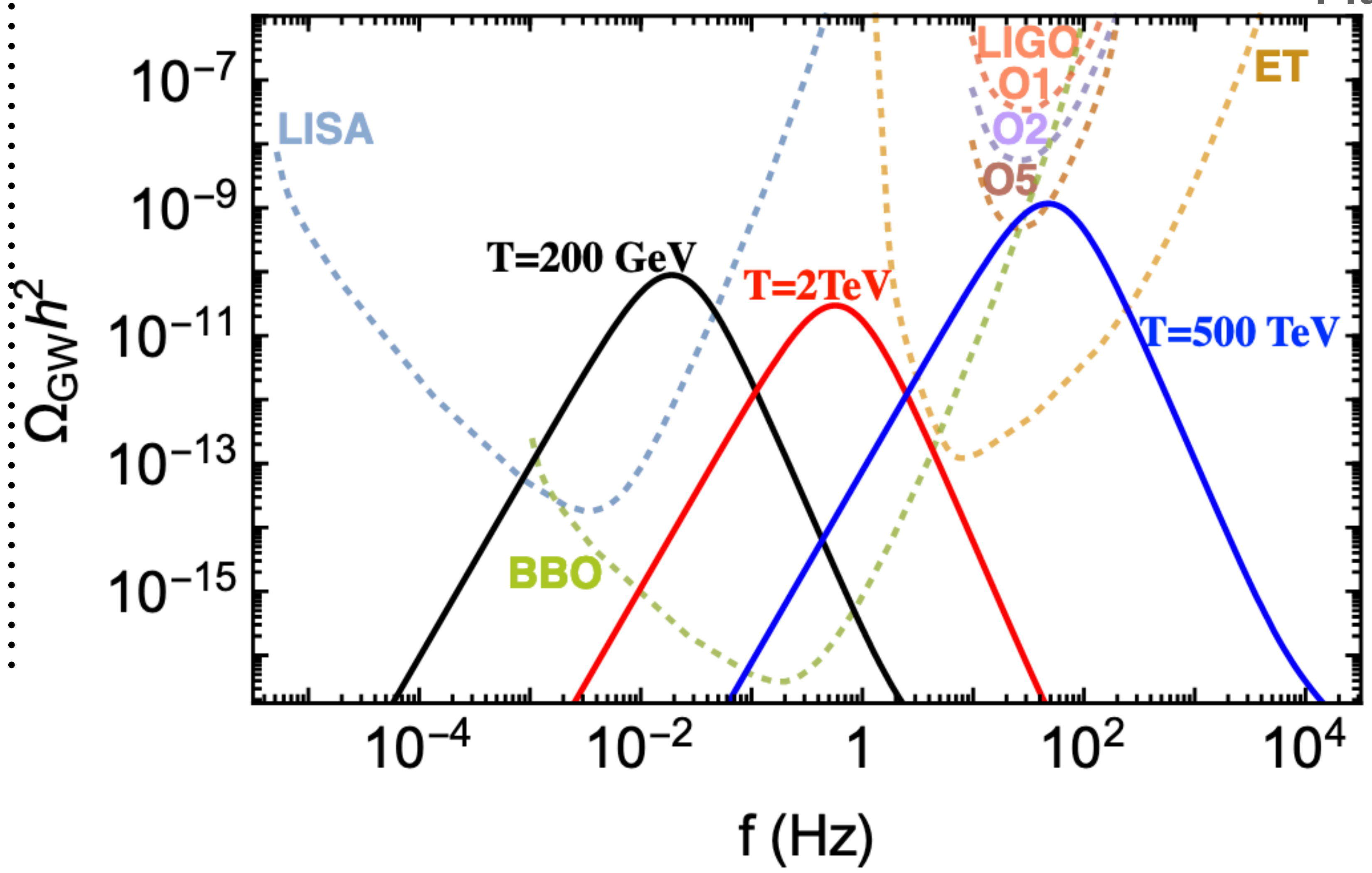
Cosmic strings

Buchmuller et al. 2107.04578



First order phase transitions

Hall et al JHEP 04 (2020) 042



also effects on propagation of GWs

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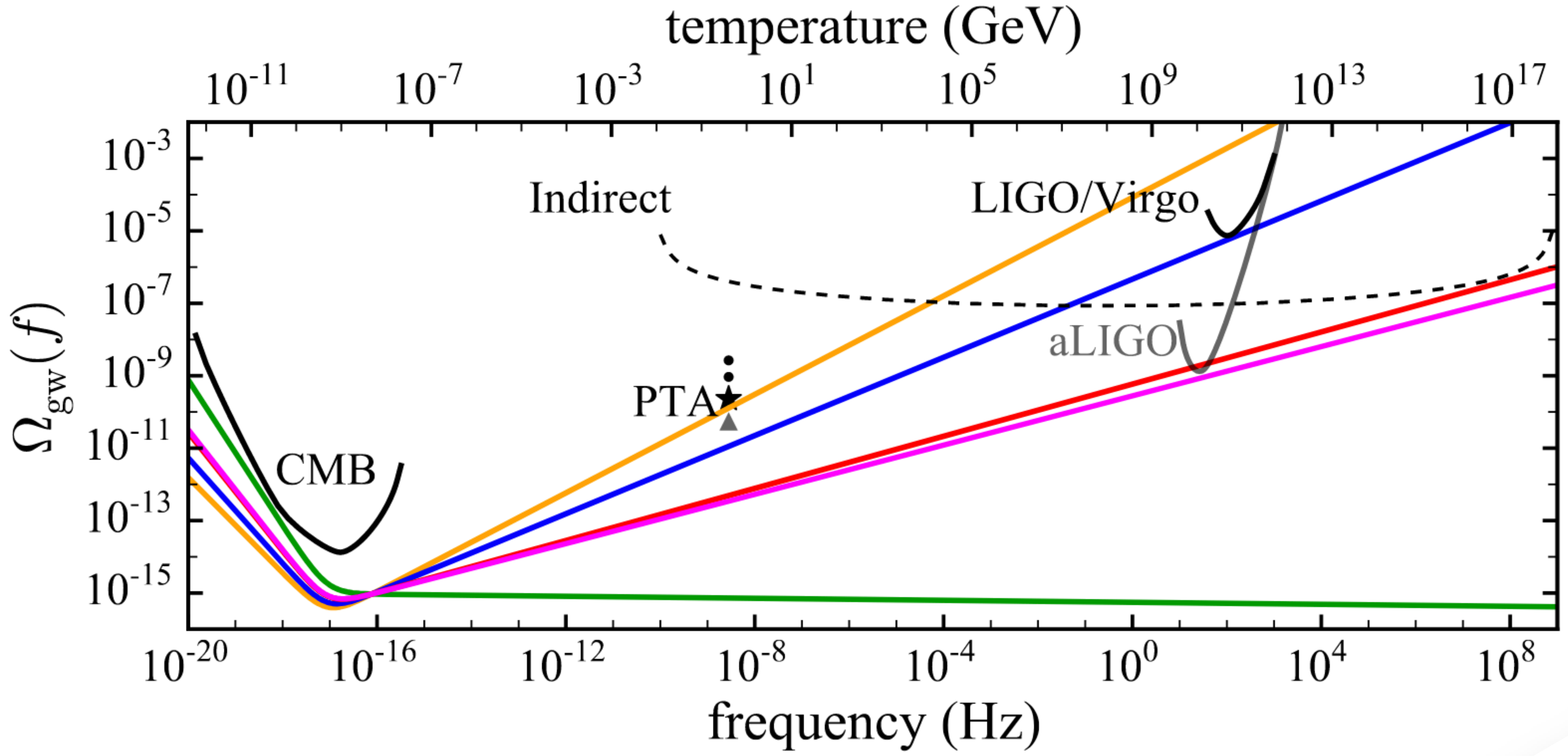

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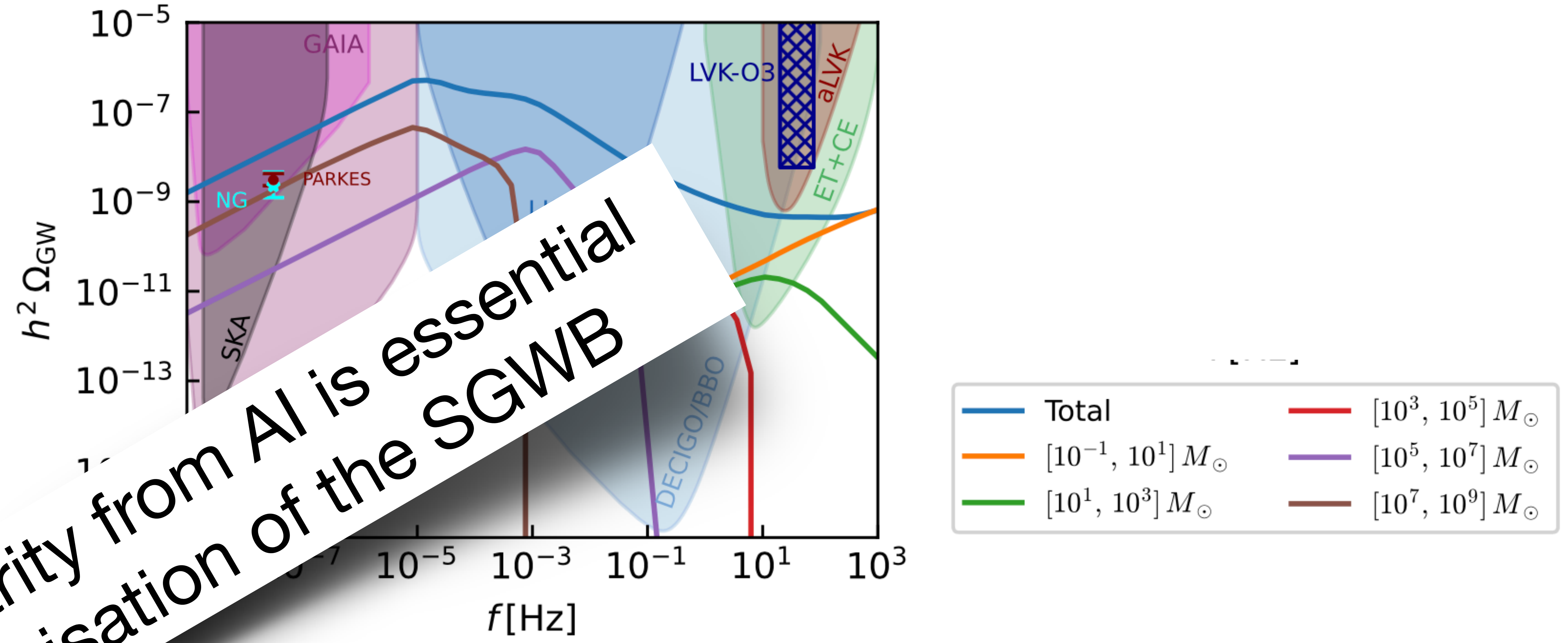

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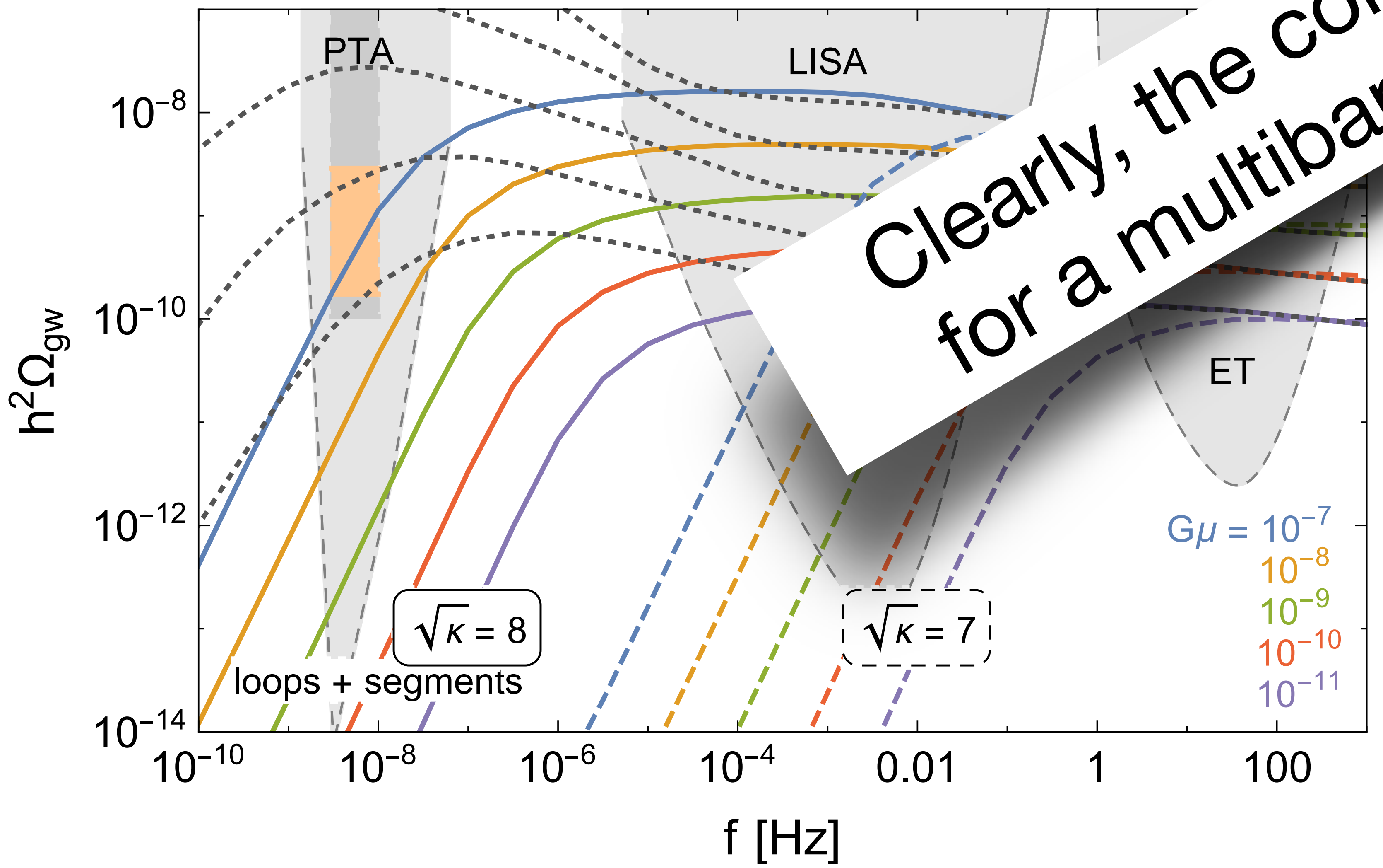
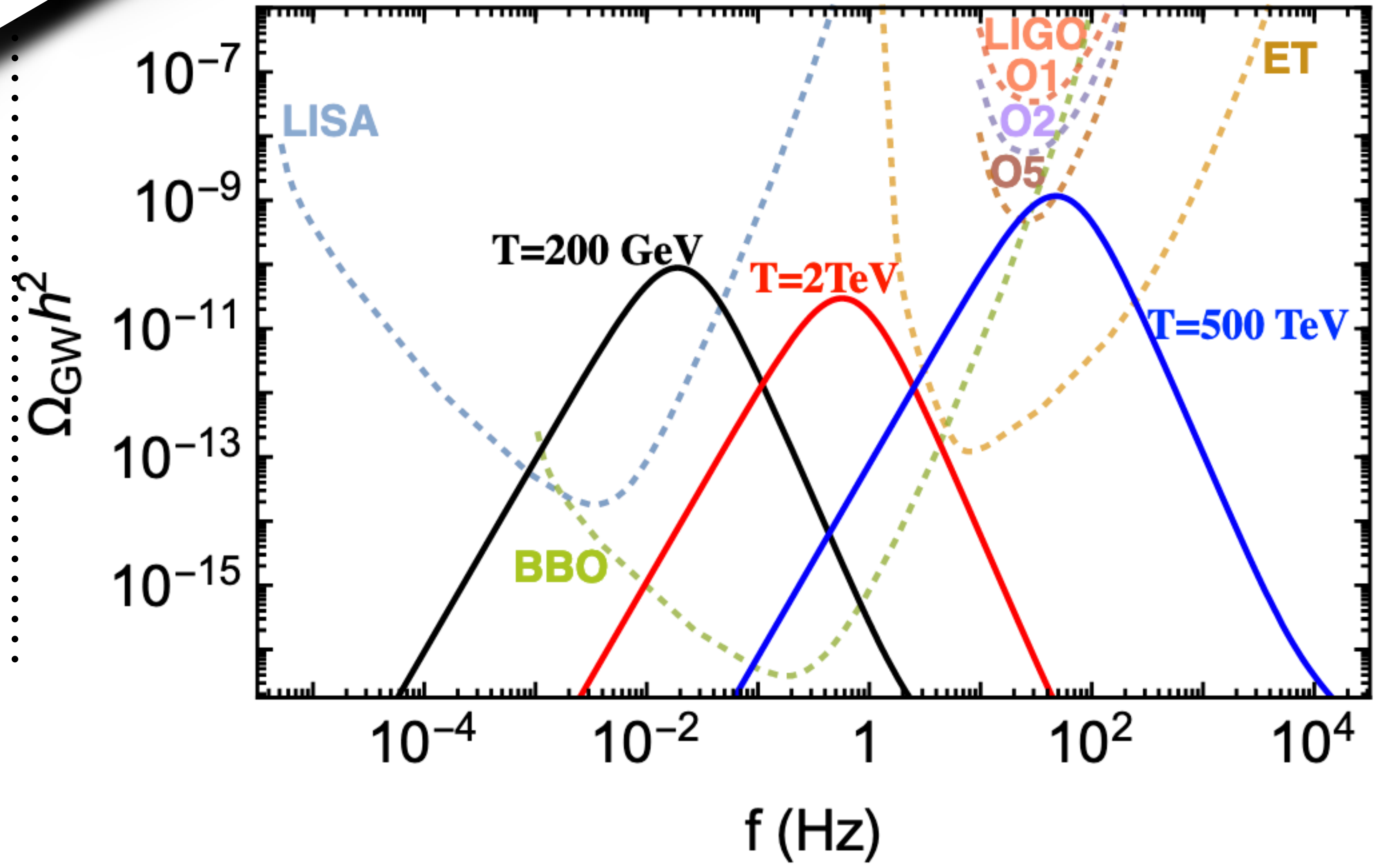


Clearly, the complementarity from AI is essential for a multiband characterisation of the SGWB

First order phase transitions

Hall et al JHEP 04 (2020) 042



also effects on propagation of GWs

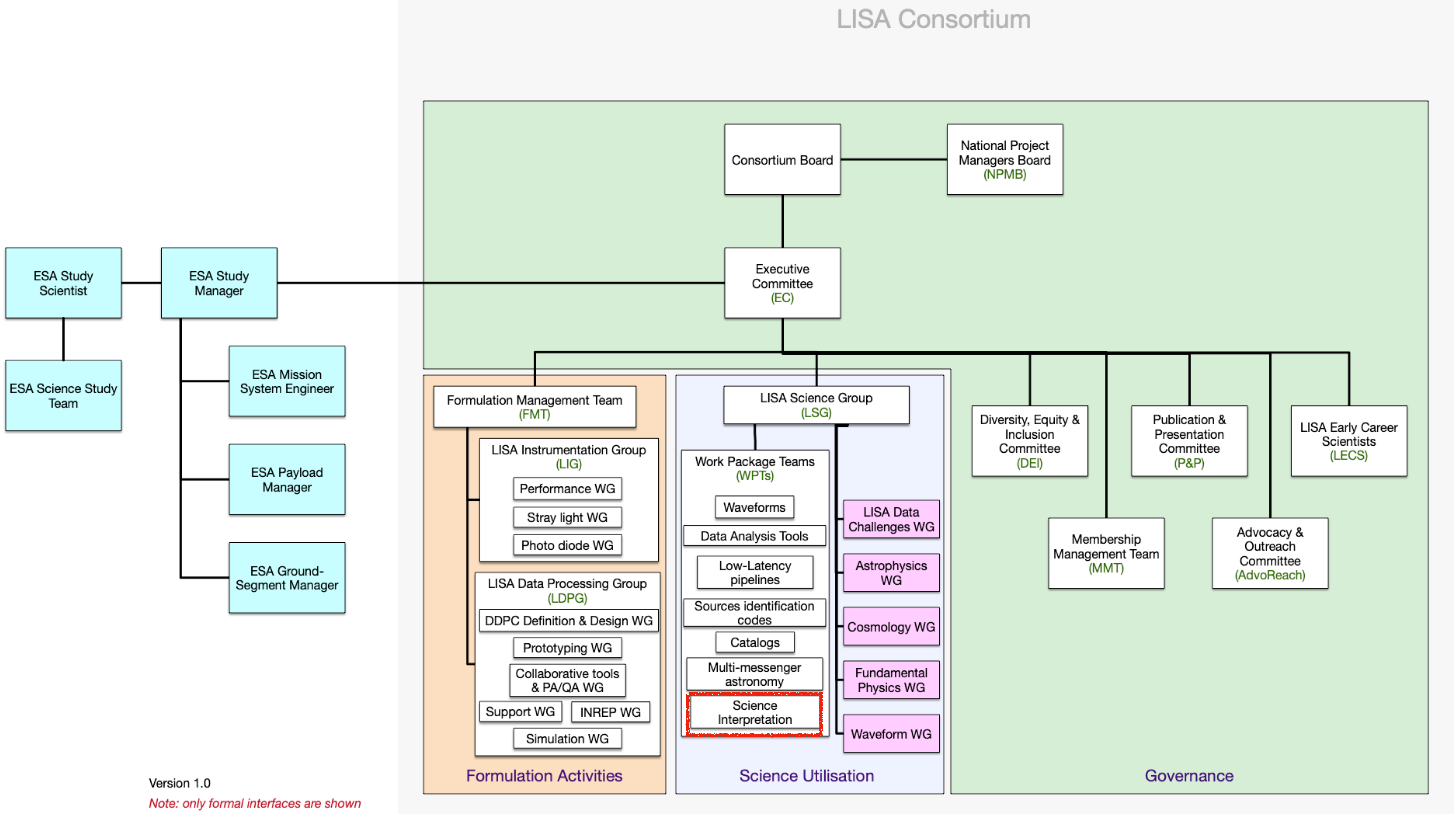
LISA and ‘other new’ Physics

* The LISA Science Group has Working groups focusing on (inspiration for atomic inter?)

i) Dark matter (led by D. Blas)

ii) Tests of black holes (led by P. Pani)

iii) Tests of general relativity (led by K. Yagi and T. Baker)


LISA Consortium
Consortium Board
National Project Managers Board (NPMB)
Executive Committee (EC)
ESA Study Scientist
ESA Study Manager
ESA Science Study Team
ESA Mission System Engineer
ESA Payload Manager
ESA Ground-Segment Manager
Formulation Management Team (FMT)
LISA Instrumentation Group (LIG)
Performance WG
Stray light WG
Photo diode WG
LISA Data Processing Group (LDPG)
DDPC Definition & Design WG
Prototyping WG
Collaborative tools & PA/QA WG
Support WG
INREP WG
Simulation WG
LISA Science Group (LSG)
Work Package Teams (WPTs)
Waveforms
Data Analysis Tools
Low-Latency pipelines
Sources identification codes
Catalogs
Multi-messenger astronomy
Science Interpretation
LISA Data Challenges WG
Astrophysics WG
Cosmology WG
Fundamental Physics WG
Waveform WG
Diversity, Equity & Inclusion Committee (DEI)
Publication & Presentation Committee (P&P)
LISA Early Career Scientists (LECS)
Membership Management Team (MMT)
Advocacy & Outreach Committee (AdvoReach)
Formulation Activities
Science Utilisation
Governance
Version 1.0
Note: only formal interfaces are shown

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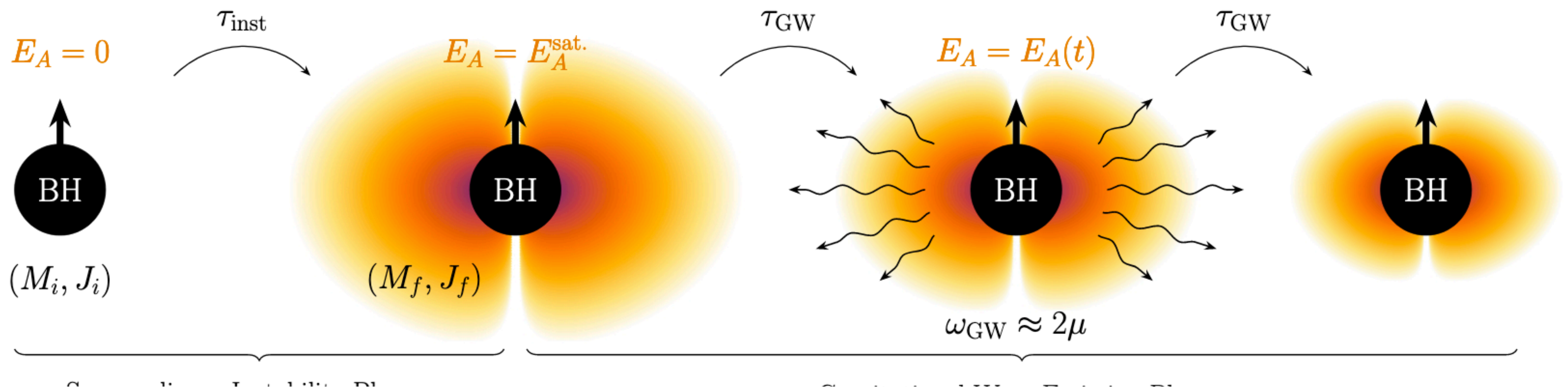
Two main directions under scrutiny

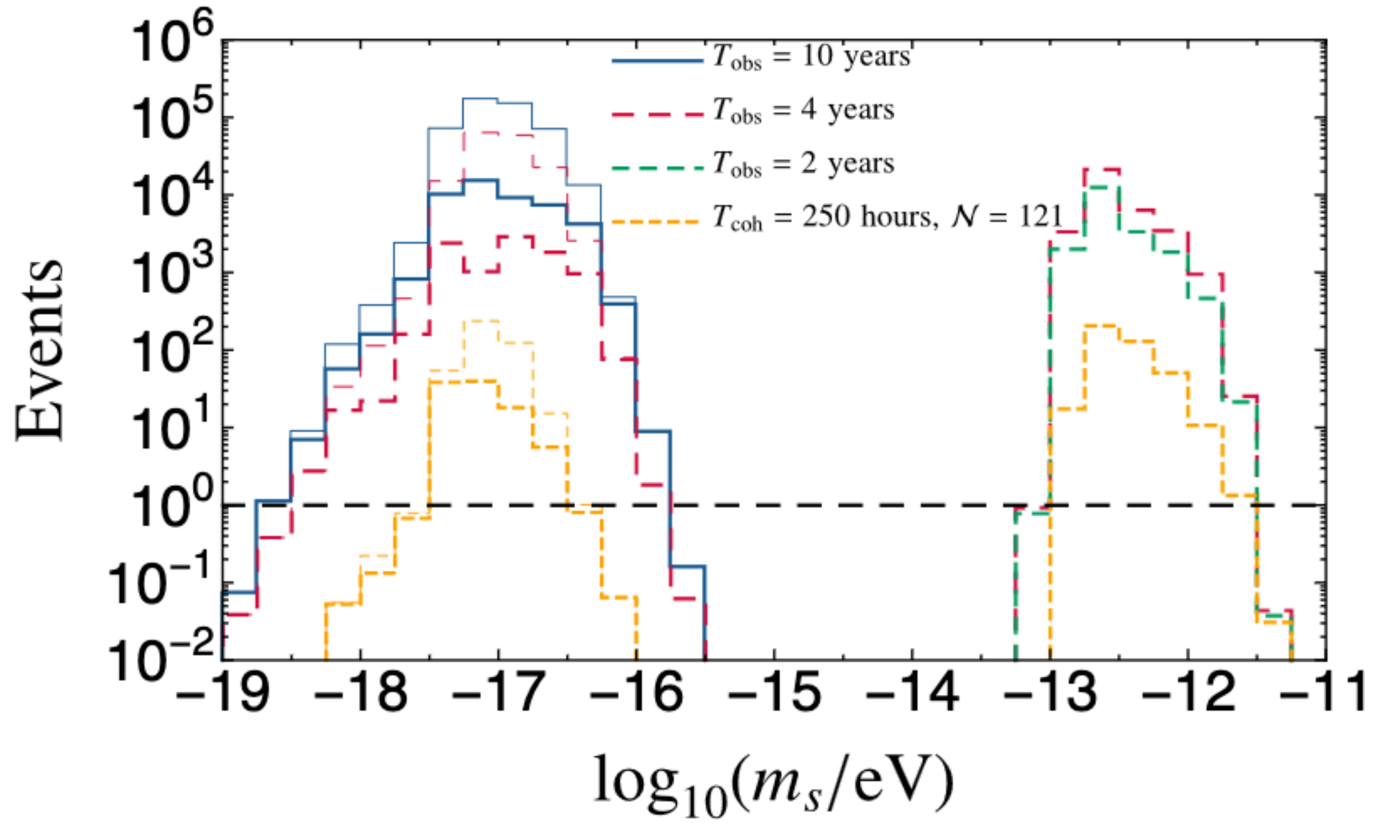
GWs from ultralight dark matter

$$m_b M \sim \frac{m_b}{10^{-10}\,\mathrm{eV}} \frac{M}{M_\odot} \sim O(1)$$

Tsukada et al (2021)



Brito et al 1706.06311



optimistic prospect

also SGWB

Effects on GWs from ambient dark matter

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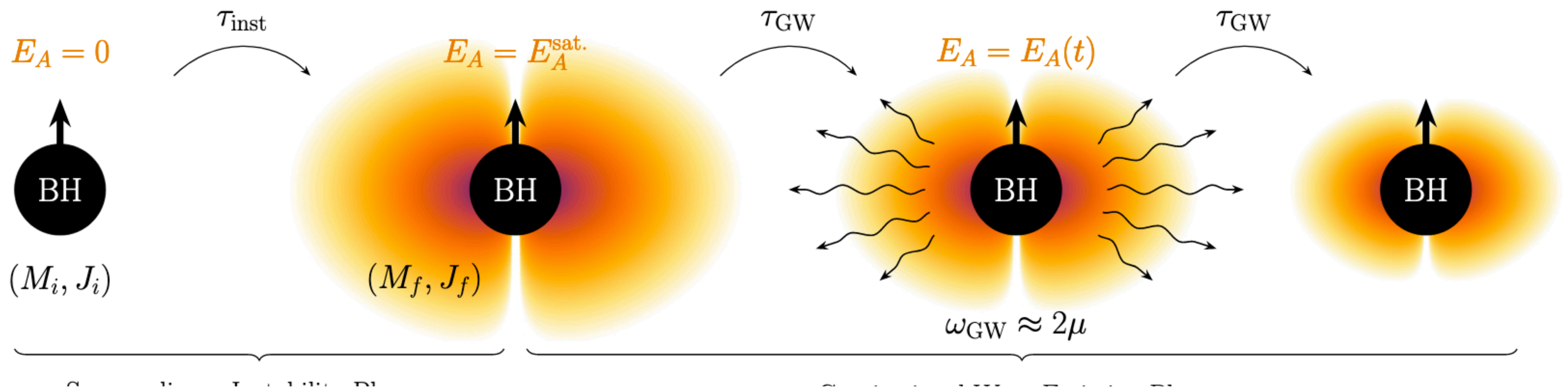
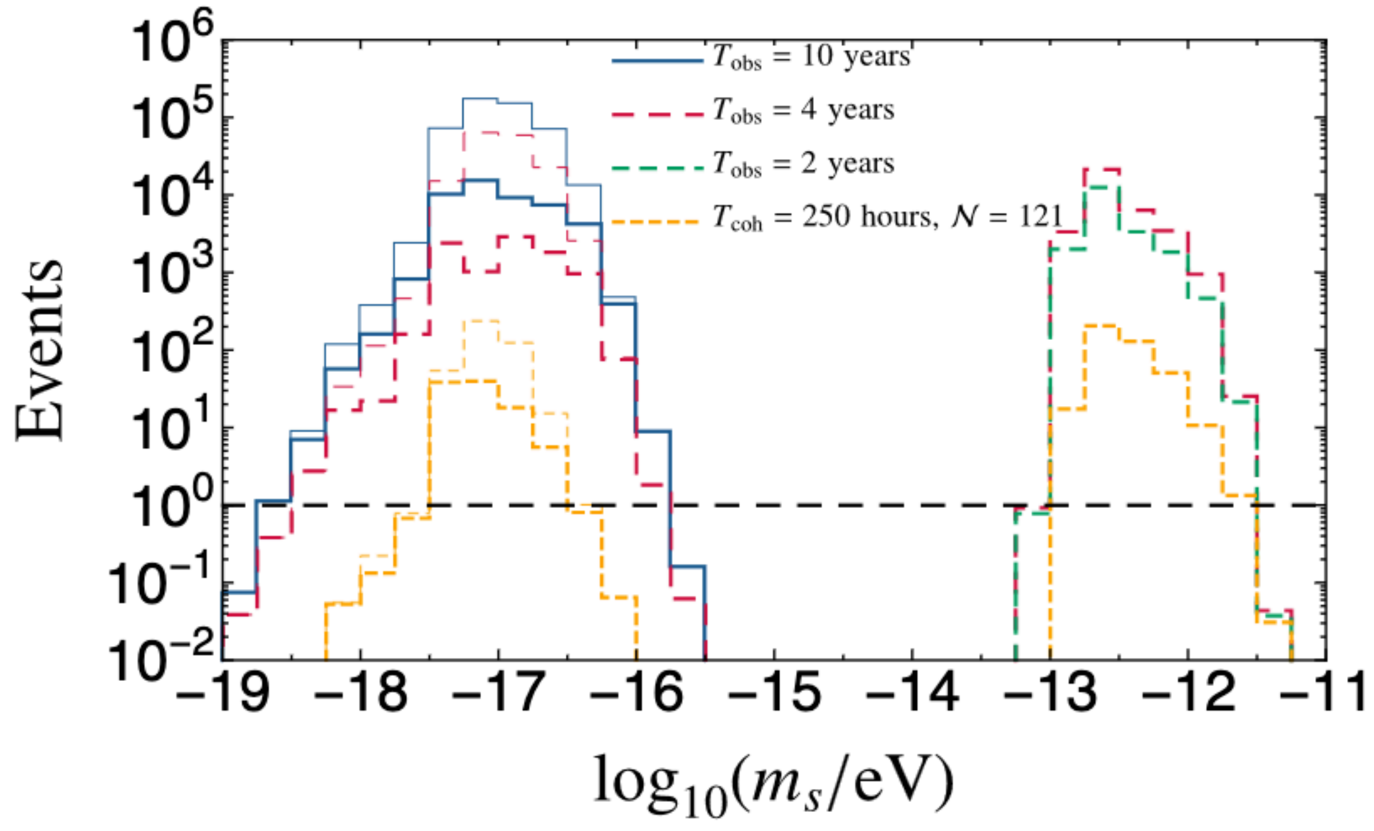


Brito et al 1706.06311



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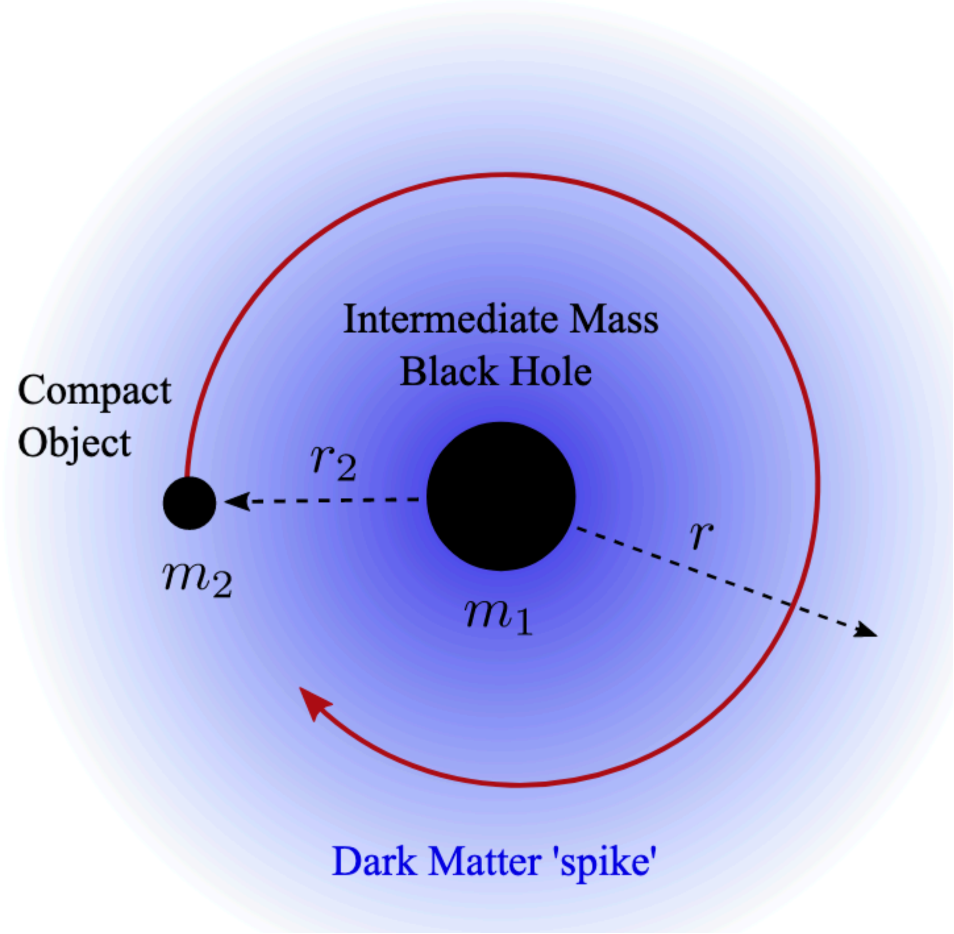
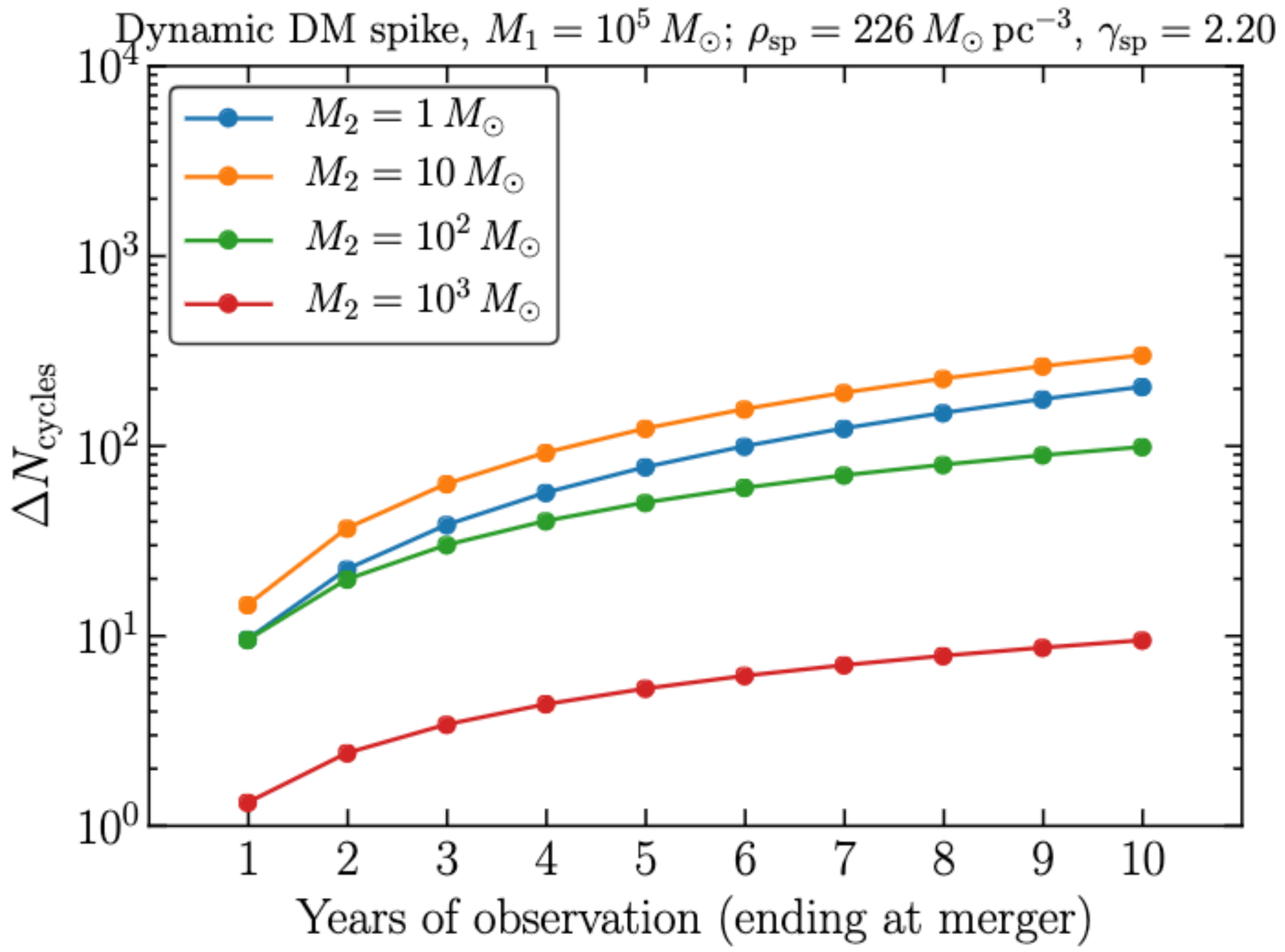


Cardoso & Maselli 1909.05870

Coogan et al. 2108.04154 [gr-qc]

Amaro Seoane et al 2107.09665



LISA and ‘other new’ Physics

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ii) Tests of black holes (led by P. Pani)

Exotic compact objects

BHs in non-vacuum GR (e.g SR)

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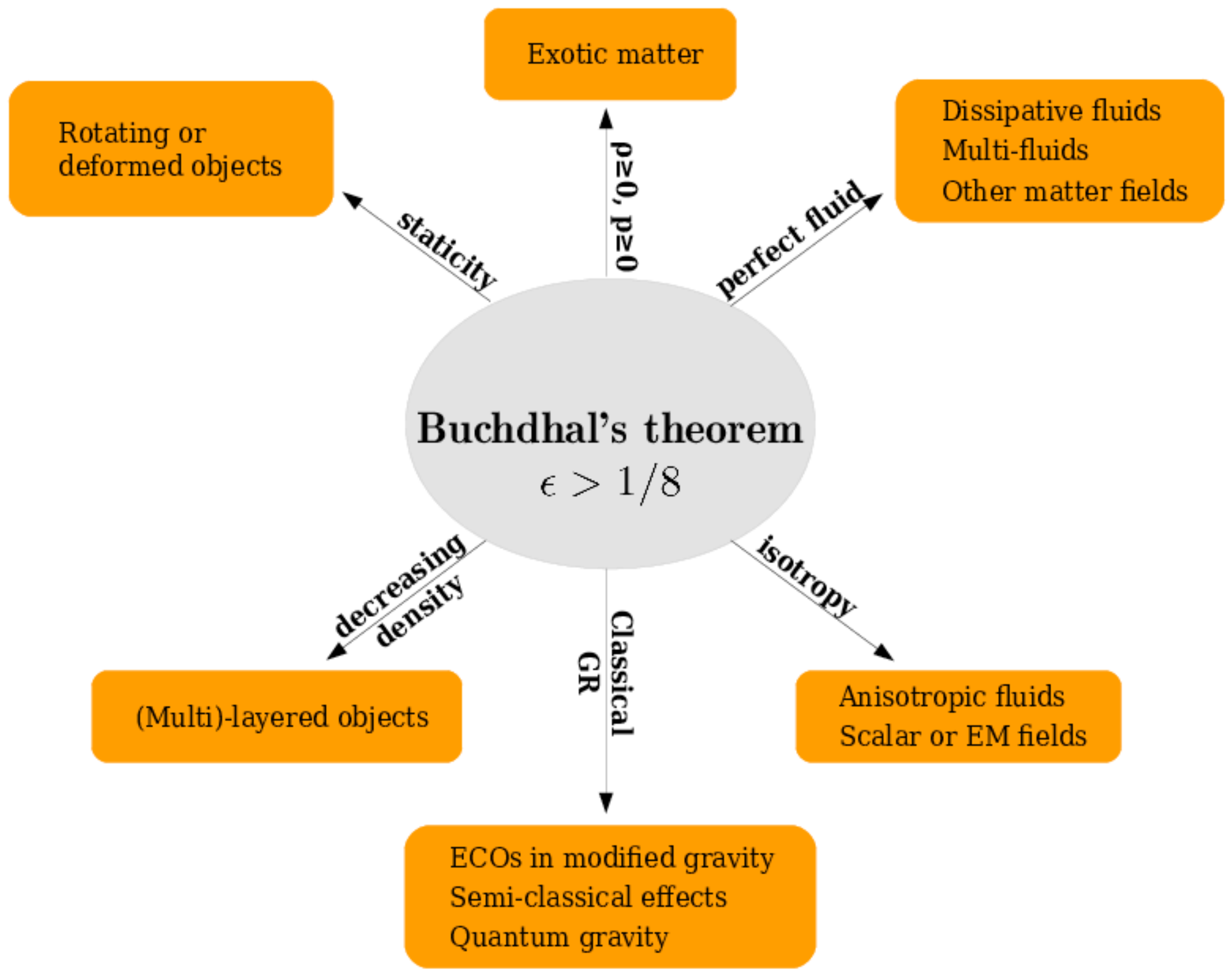
Objects almost as compact as BHs from 'new' Physics

Cardoso & Pani arXiv:1904.05363



Tests:

i) new channels of emission

ii) Multipolar structure & Kerr bound

$$\mathcal{M}_\ell^{\mathrm{BH}} + \mathrm{i}\mathcal{S}_\ell^{\mathrm{BH}} = \mathcal{M}^{\ell+1}(\mathrm{i}\chi)^\ell$$

iii) Tidal heating/Tidal deformations

iv) QNM

v) Echos

Arun et al 2205.01597

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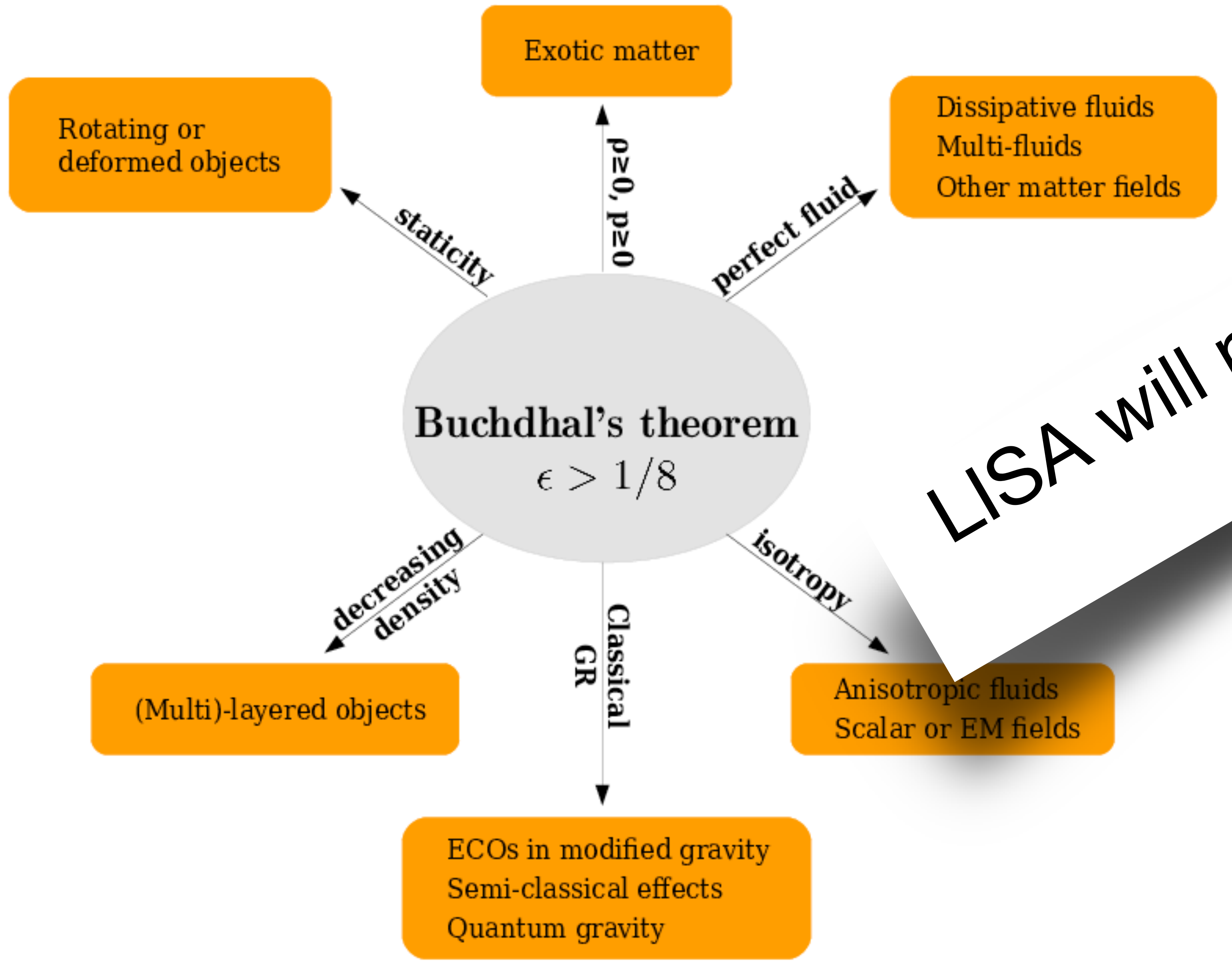

BHs in n-vacuum GR (e.g SR)

Te

ew channels of emission

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$$\mathcal{M}_\ell^{\rm BH} + {\rm i}\mathcal{S}_\ell^{\rm BH} = \mathcal{M}^{\ell+1}({\rm i}\chi)^\ell$$

iii) Tidal heating/Tidal deformations

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v) Echos

LISA will measure all this with unprecedented precision!

Arun et al 2205.01597

LISA and ‘other new’ Physics

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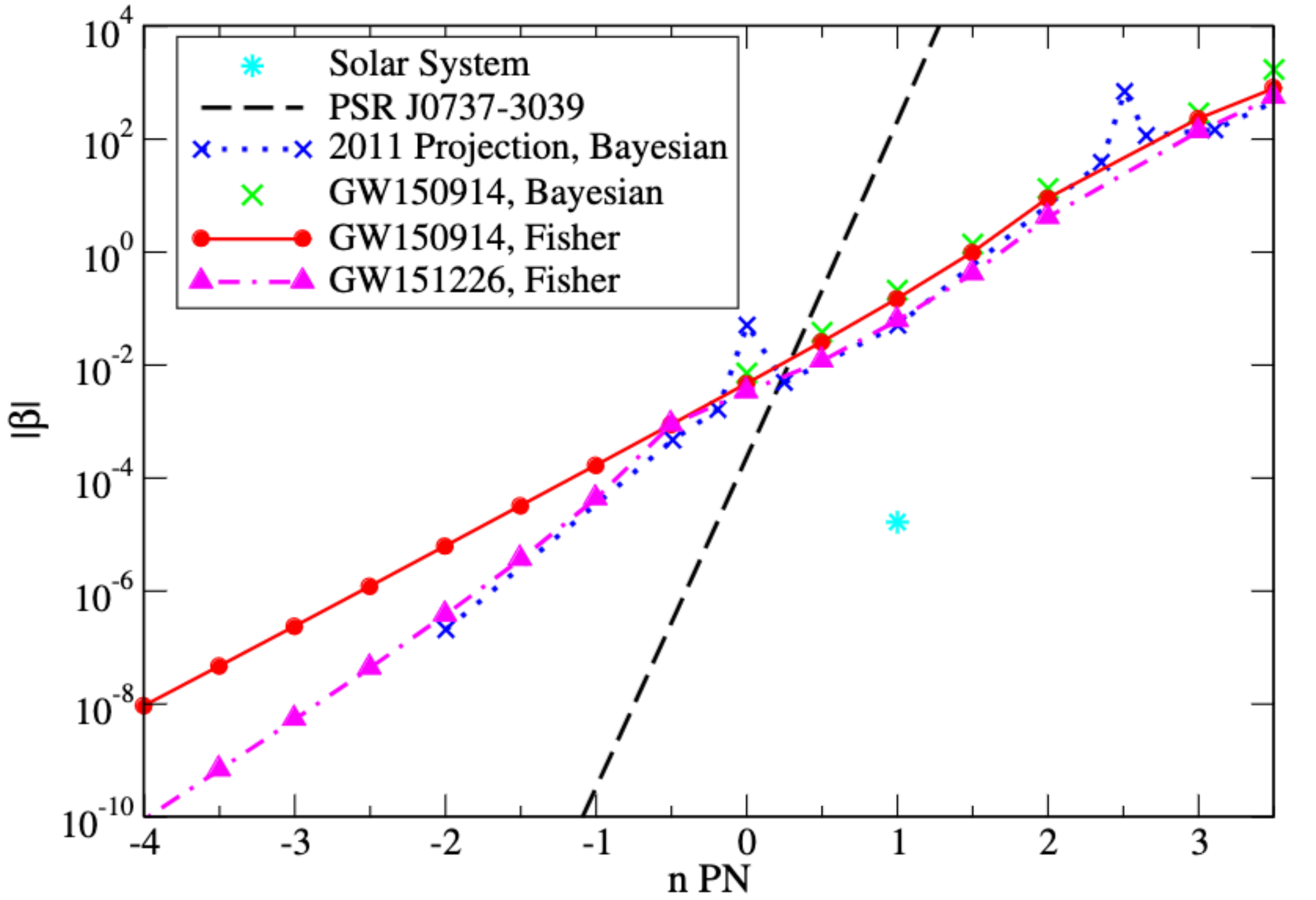
iii) Tests of general relativity (led by K. Yagi and T. Baker)

Non-GR corrections to the inspiral part of the waveform

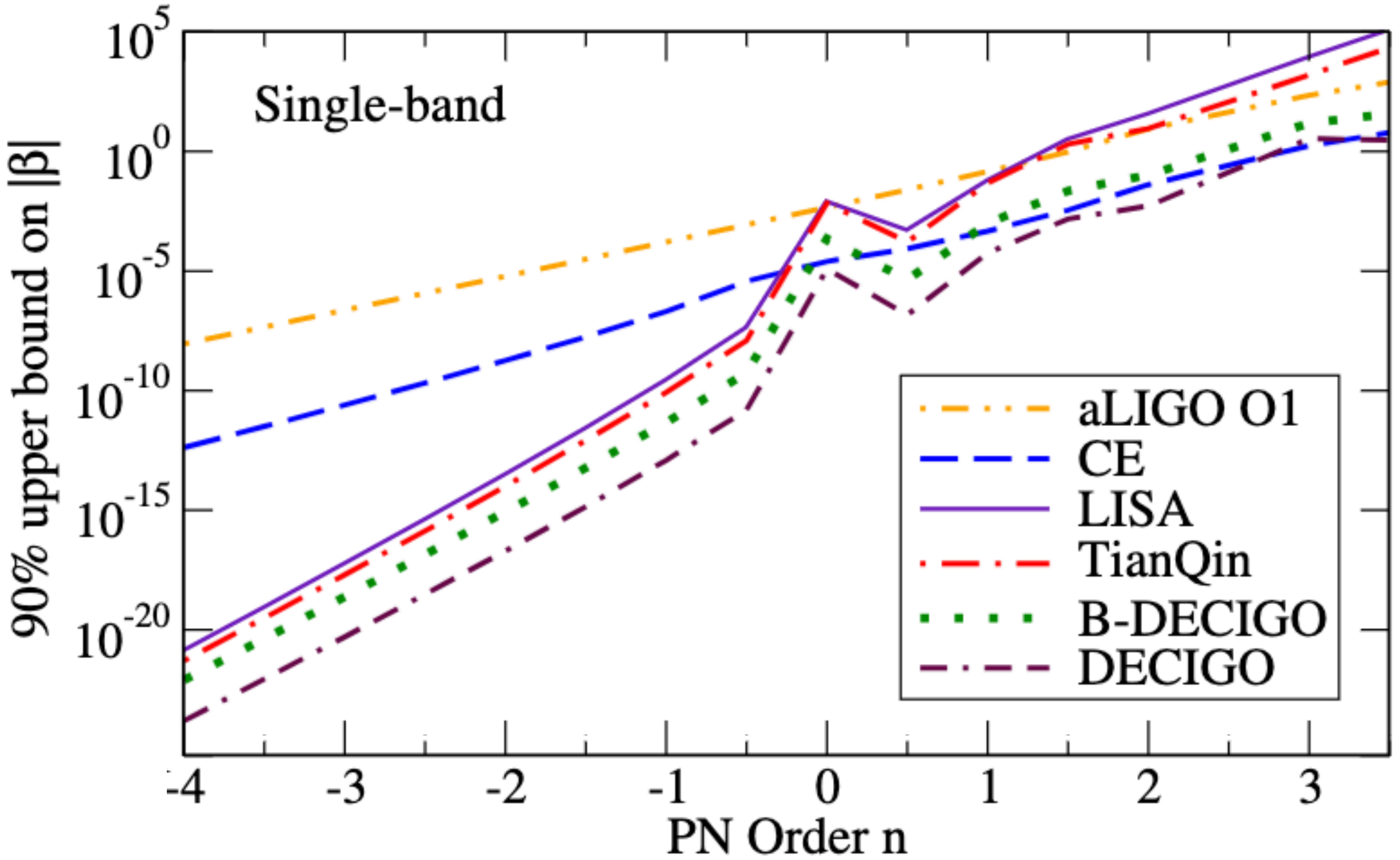
$$\Psi = \Psi_{\rm GR} + \beta(\pi \mathcal{M} f)^{2n-5}$$

LVK

Yunes et al 1603.08955

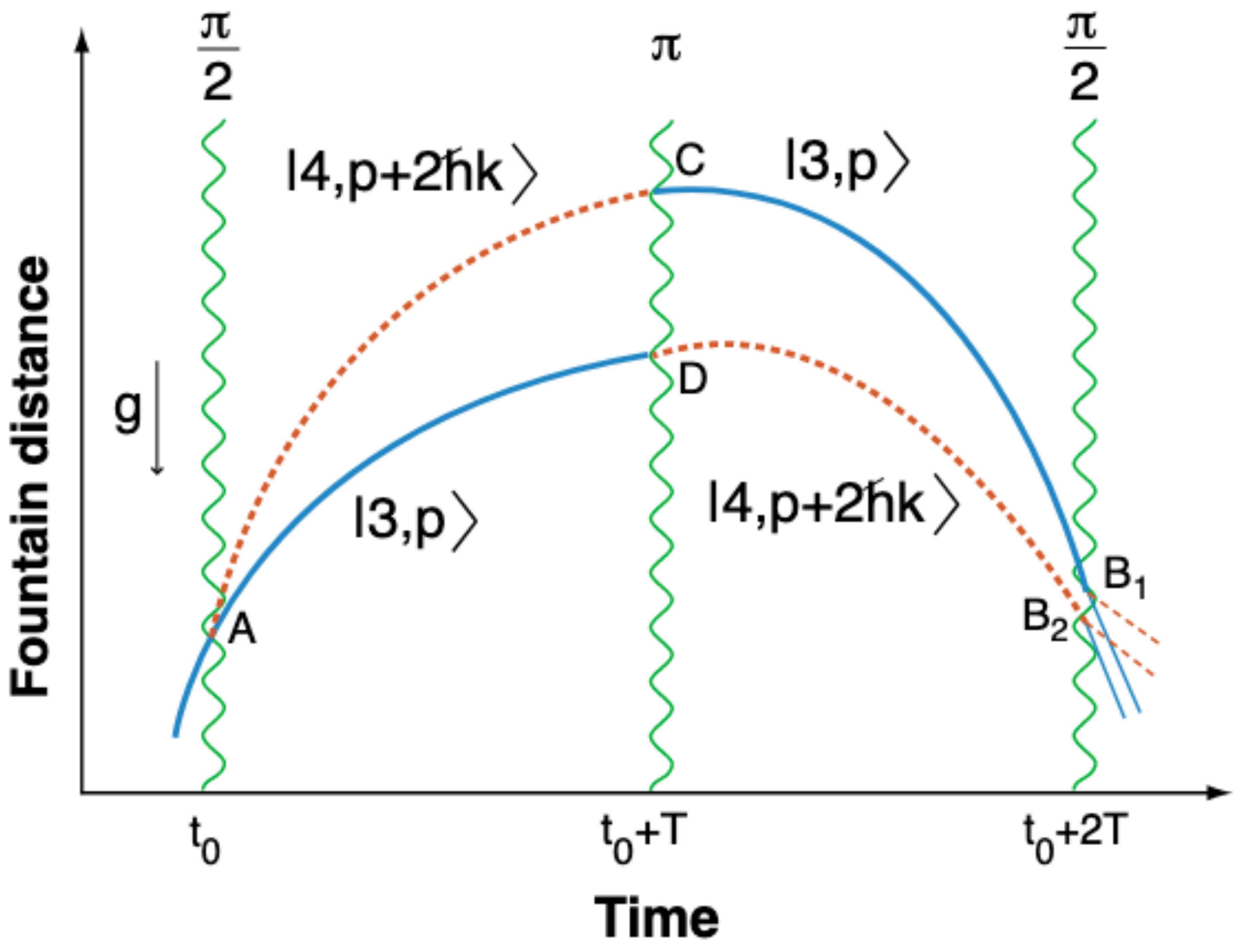


Carson and Yagi 2011.02938



Atomic interferometry and ‘other new’ Physics

You have already heard that atomic interferometers are great detectors for GWs and ultra-light dark matter



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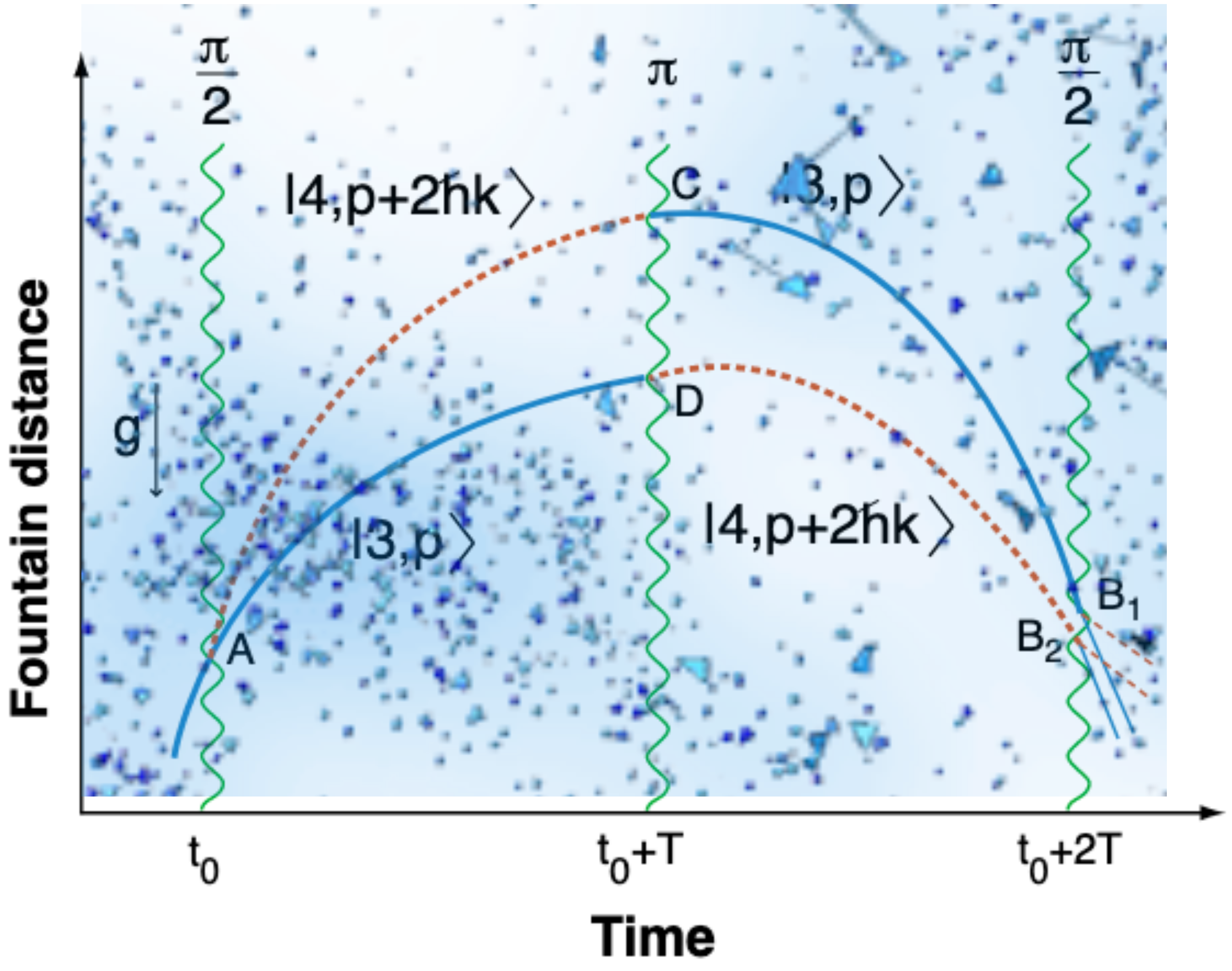


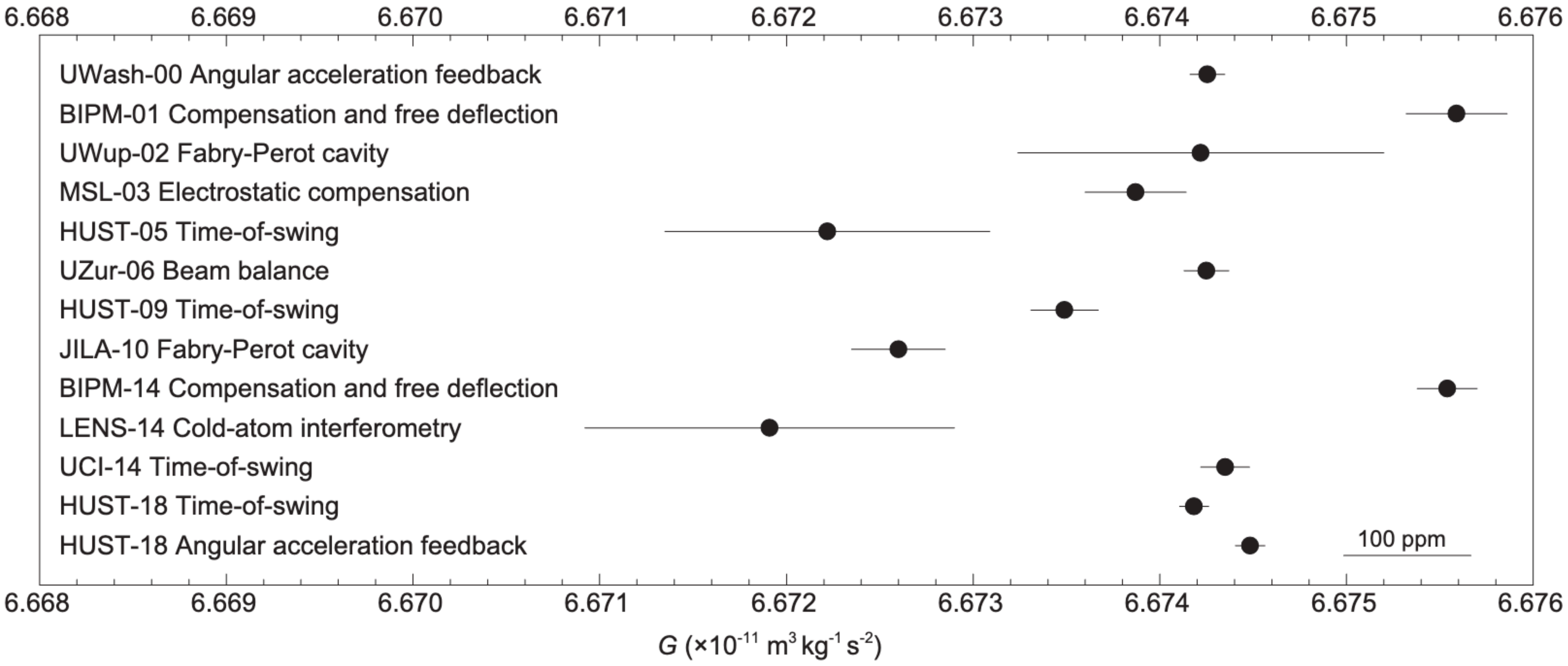
i) Would they ever sense the scattering from heavier DM candidates?

see Alonso, Blas, Wolf for co-magnetometers and AC 1810.00889 [hep-ph], And Du et al. arXiv:2205.13546 for AI

To be explored!

Atomic interferometry and ‘other new’ Physics

ii) Measuring *G:* We all know that *G rules gravitational interactions*



CODATA $6.67430(15) \cdot 10^{-11}\ \mathrm{m}^3\ \mathrm{kg}^{-1}\ \mathrm{s}^{-2}$

Precision measurement of the Newtonian gravitational constant
Chao Xue, Jian-Ping Liu, Qing Li, Jun-Fei Wu, Shan-Qing Yang ...
National Science Review, Volume 7, Issue 12, December 2020, Pages 1803–1817, https://doi.org/10.1093/nsr/nwaa165

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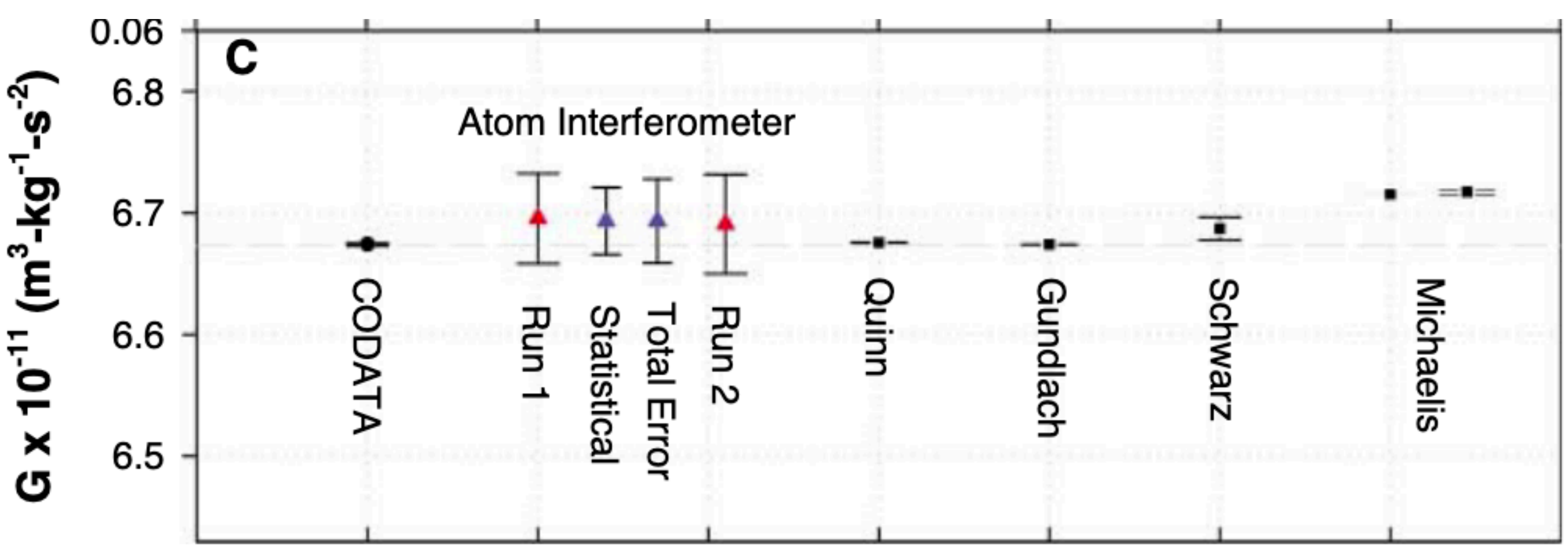
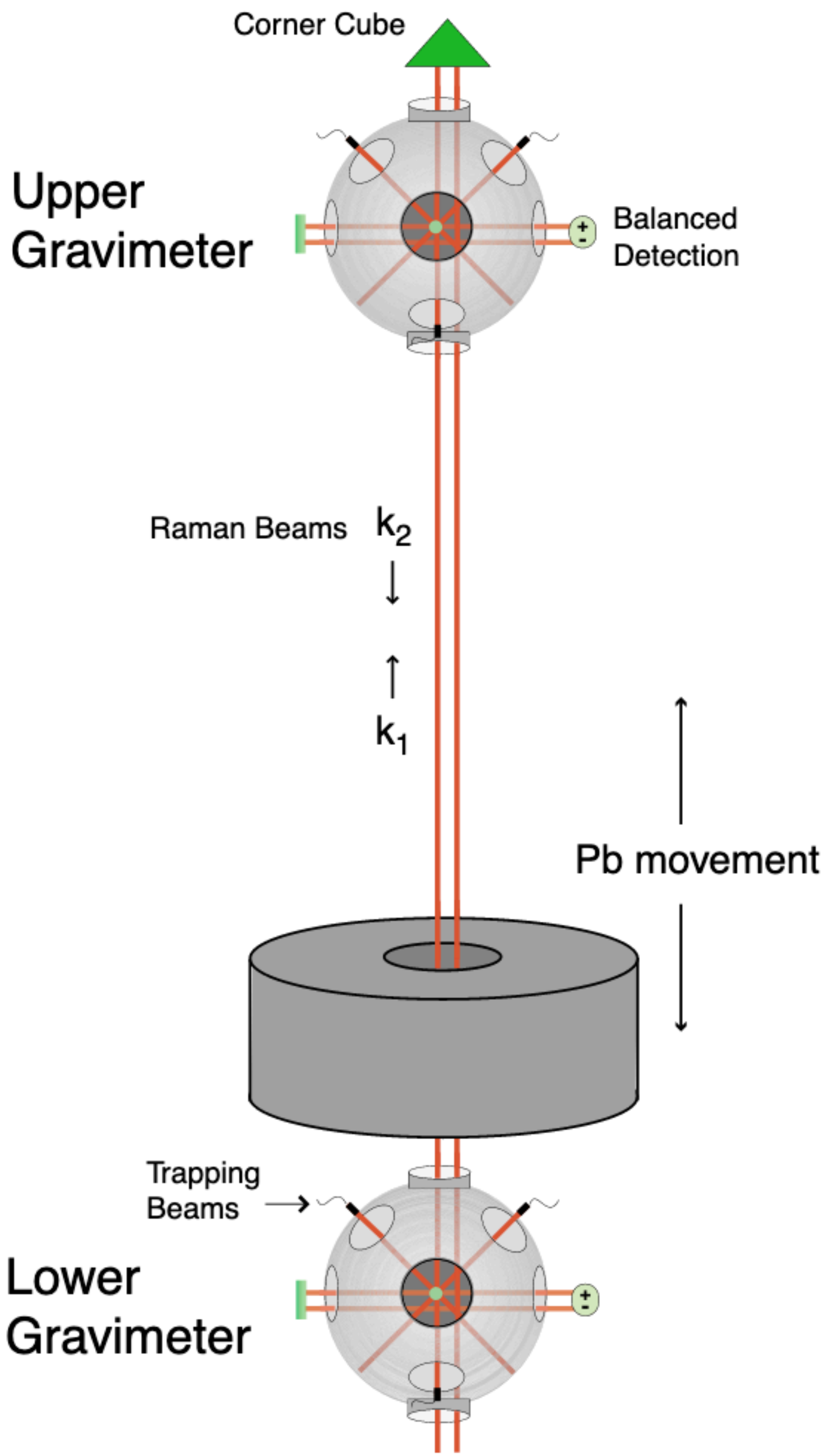
REPORT

Atom Interferometer Measurement of the Newtonian Constant of Gravity

J. B. Fixler[1], G. T. Foster[2], J. M. McGuirk[3], M. A. Kasevich[1,*]
+ See all authors and affiliations



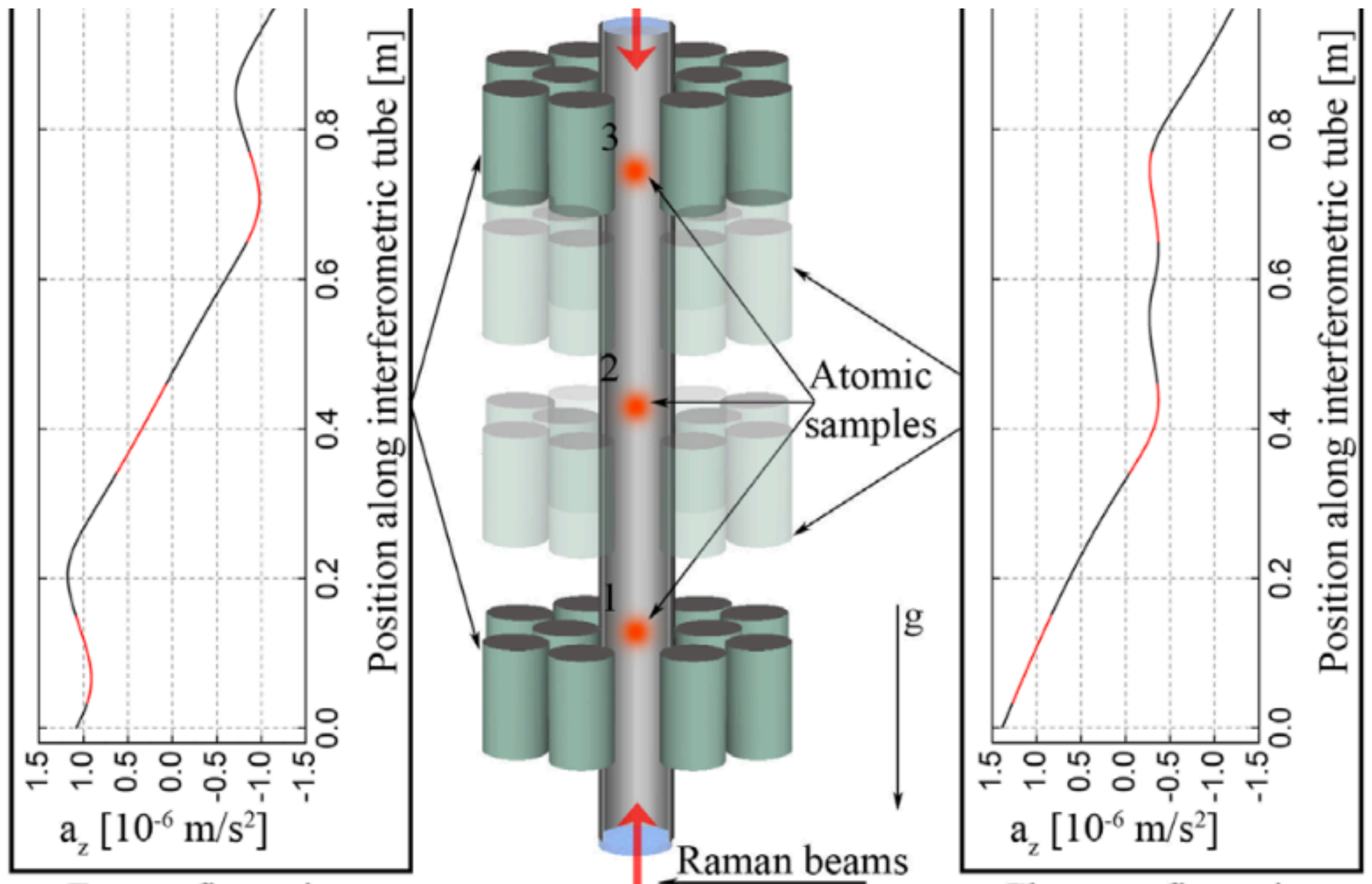


PRL 119, 253201 (2017) PHYSICAL REVIEW LETTERS week ending 22 DECEMBER 2017

Canceling the Gravity Gradient Phase Shift in Atom Interferometry

G. D'Amico,[1] G. Rosi,[1] S. Zhan,[1,*] L. Cacciapuoti,[2] M. Fattori,[1] and G. M. Tino[1,†]
[1]*Dipartimento di Fisica e Astronomia and LENS, Università di Firenze, INFN Sezione di Firenze, via Sansone 1, I-50019 Sesto Fiorentino (FI), Italy*
[2]*European Space Agency, Keplerlaan 1, 2200 AG Noordwijk, Netherlands*

(Received 23 May 2017; revised manuscript received 22 July 2017; published 19 December 2017)



Problems

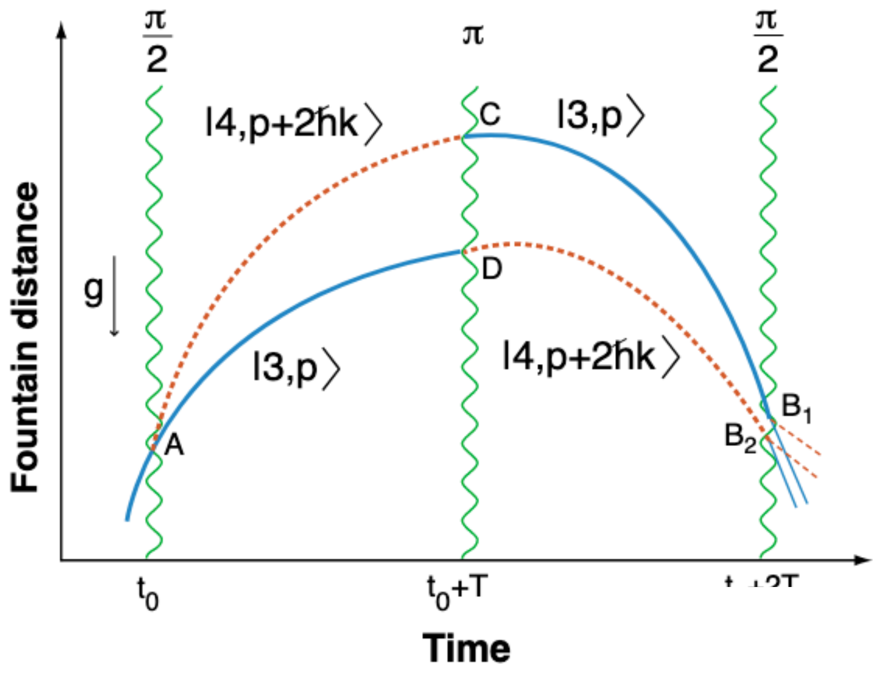
Laser noise

Velocity/position of cloud

Gravity gradient…

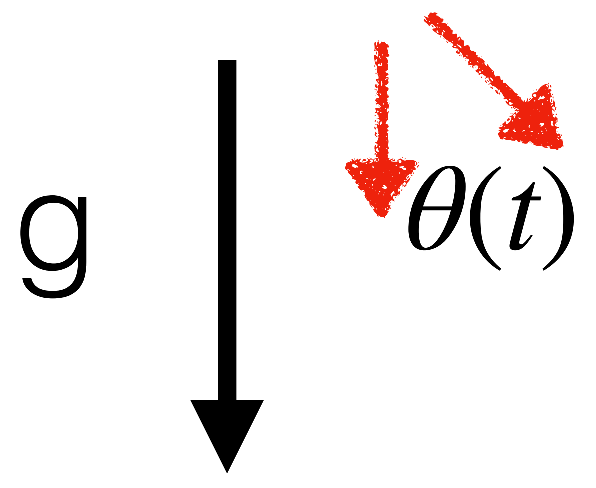
Can AIs improvements help here?
(to reach 10 ppm)

Atomic interferometry and ‘other new’ Physics

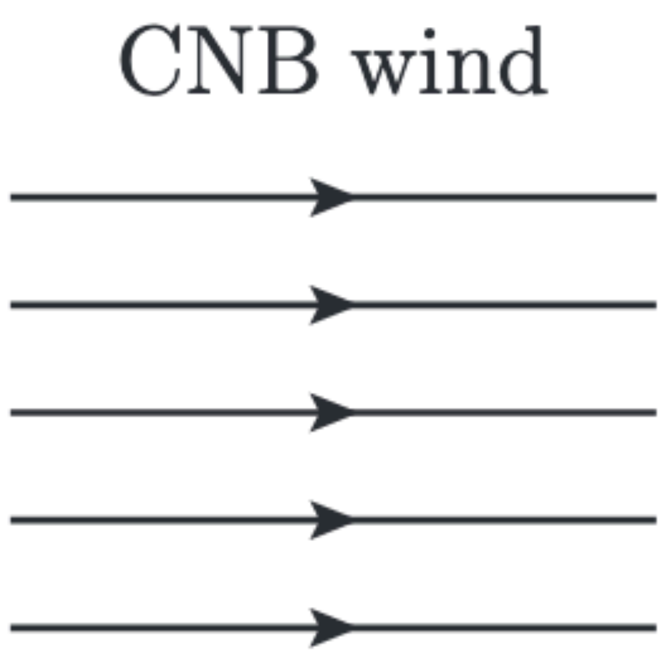


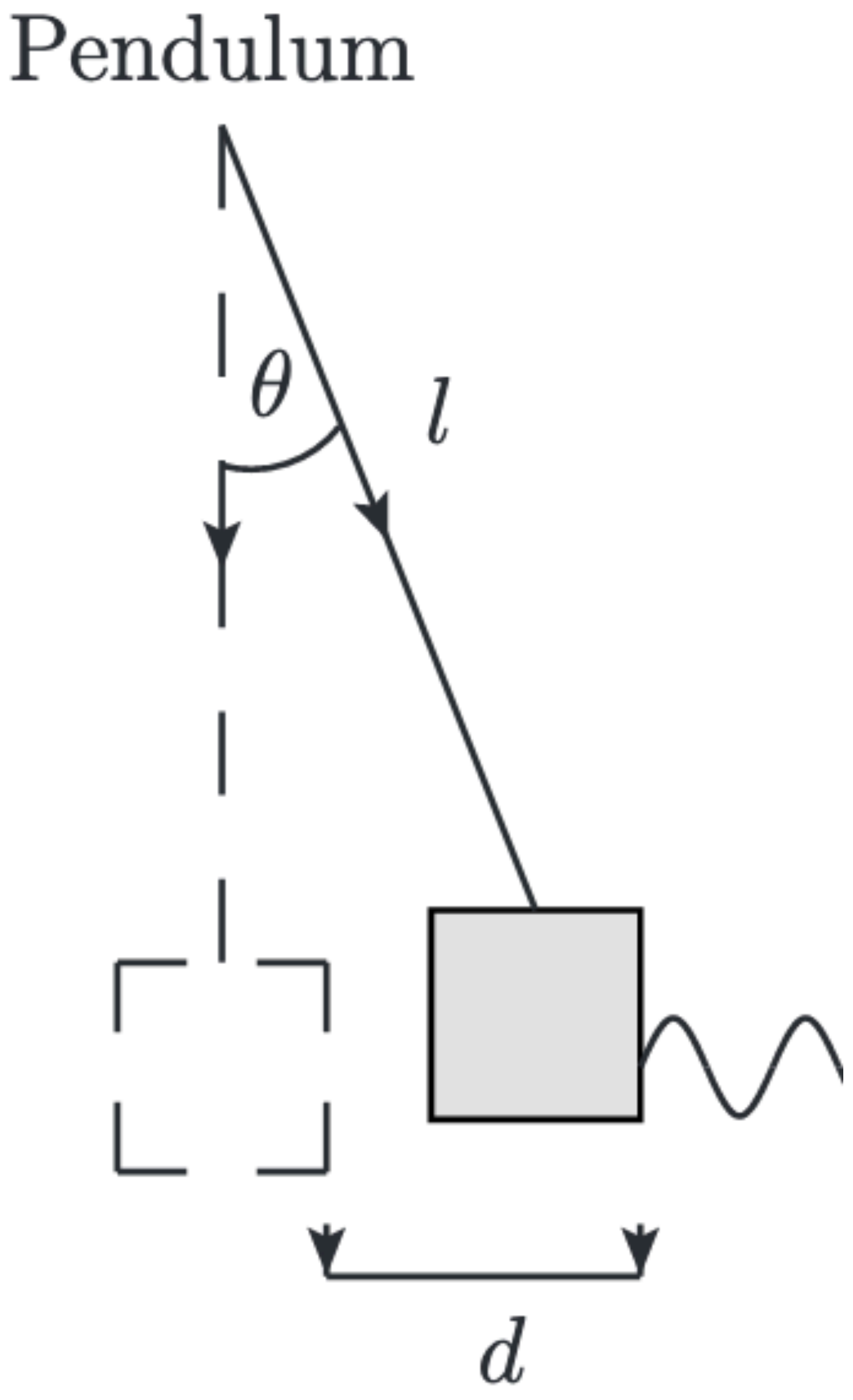
AIs/LISA are very good accelerometers.
iii) Can we feel the ‘force’ from cosmic relics?

Given the DM/neutrino wind, if it scatters with an atom it will also transfer momentum (accelerate)



DM wind





Domcke, Spinrath 1703.08629

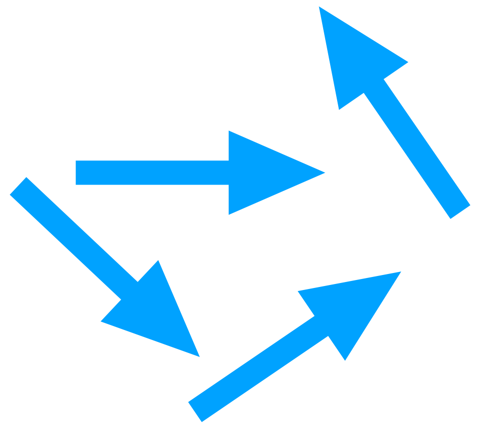
$$a_{G_F^2} \approx 10^{-18}\ \mathrm{cm/s^2}\,, \quad m_X = 10\ \mathrm{GeV}\,, \quad \sigma_{X-N} = 3\cdot 10^{-34}\ \mathrm{cm}^2\,,$$
$$a_{G_F^2} \approx 10^{-20}\ \mathrm{cm/s^2}\,, \quad m_X = 0.1\ \mathrm{GeV}\,, \quad \sigma_{X-N} = 3\cdot 10^{-36}\ \mathrm{cm}^2\,,$$
$$a_{G_F^2} \approx 10^{-22}\ \mathrm{cm/s^2}\,, \quad m_X = 1\ \mathrm{MeV}\,, \quad \sigma_{X-N} = 1\cdot 10^{-40}\ \mathrm{cm}^2\,.$$

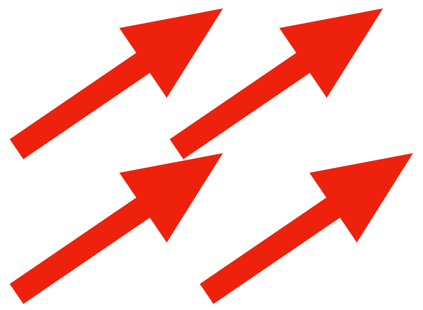
Atomic interferometry and ‘other new’ Physics

Axions couple to:

i) atoms in AIs/LISA

$\nabla a \cdot \vec{S}$ harder to test w/ EP tests

a)  if unpolarised: effects cancels

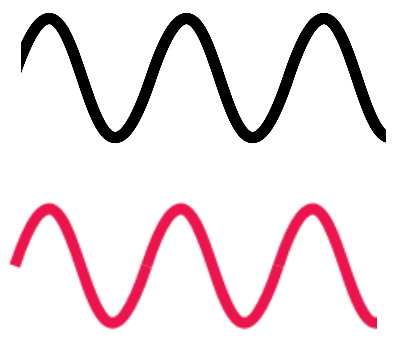
b)  if polarised time dep. Zeeman

may be challenging

$\mu \vec{B} \cdot \vec{S}$

ii) light in AIs/LISA

$g_{a\gamma\gamma}\, a\vec{B} \cdot \vec{E}$ generates birrefringence

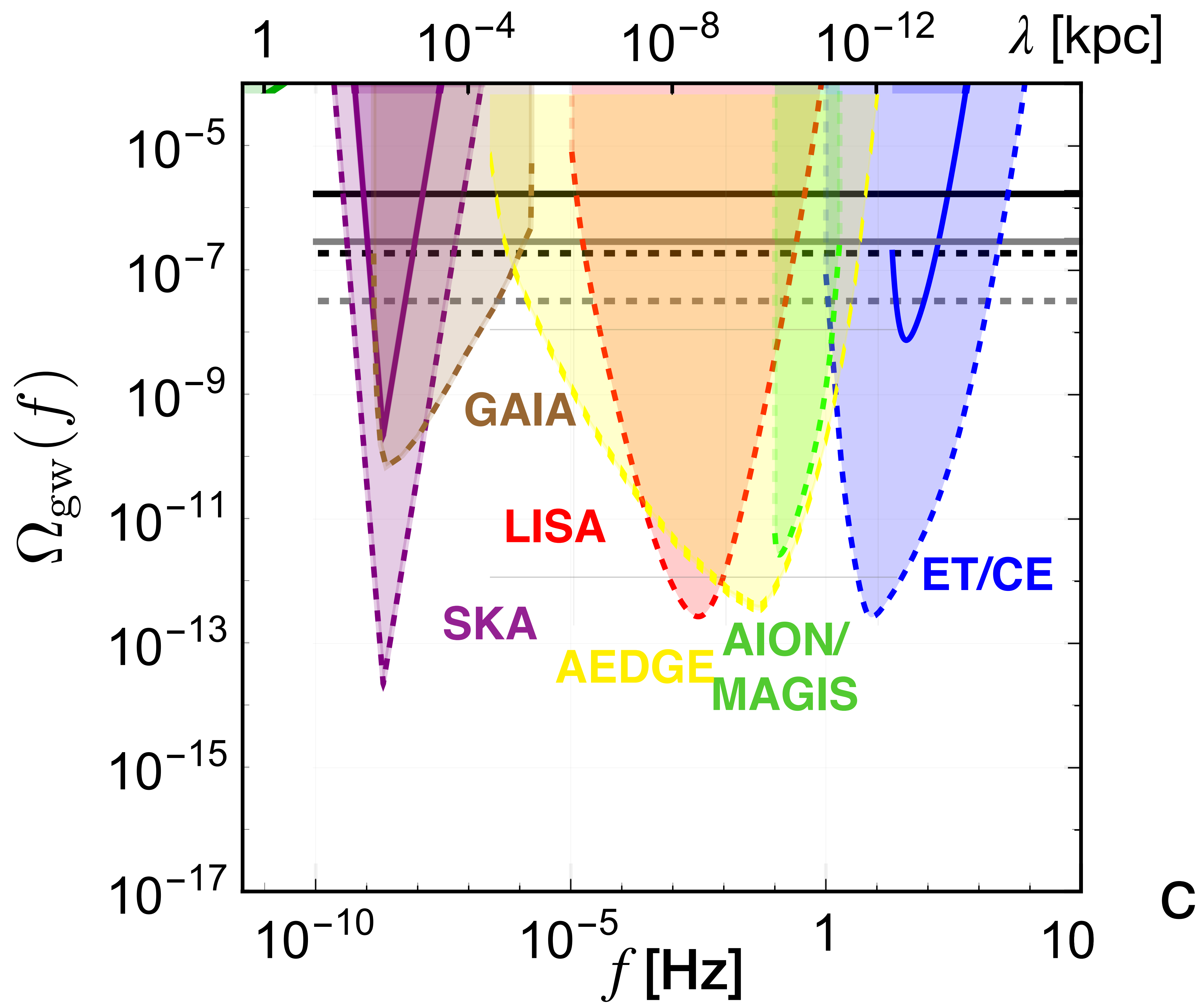


± polarisations travel with different phase velocities

is this detectable?

And now some Magic…

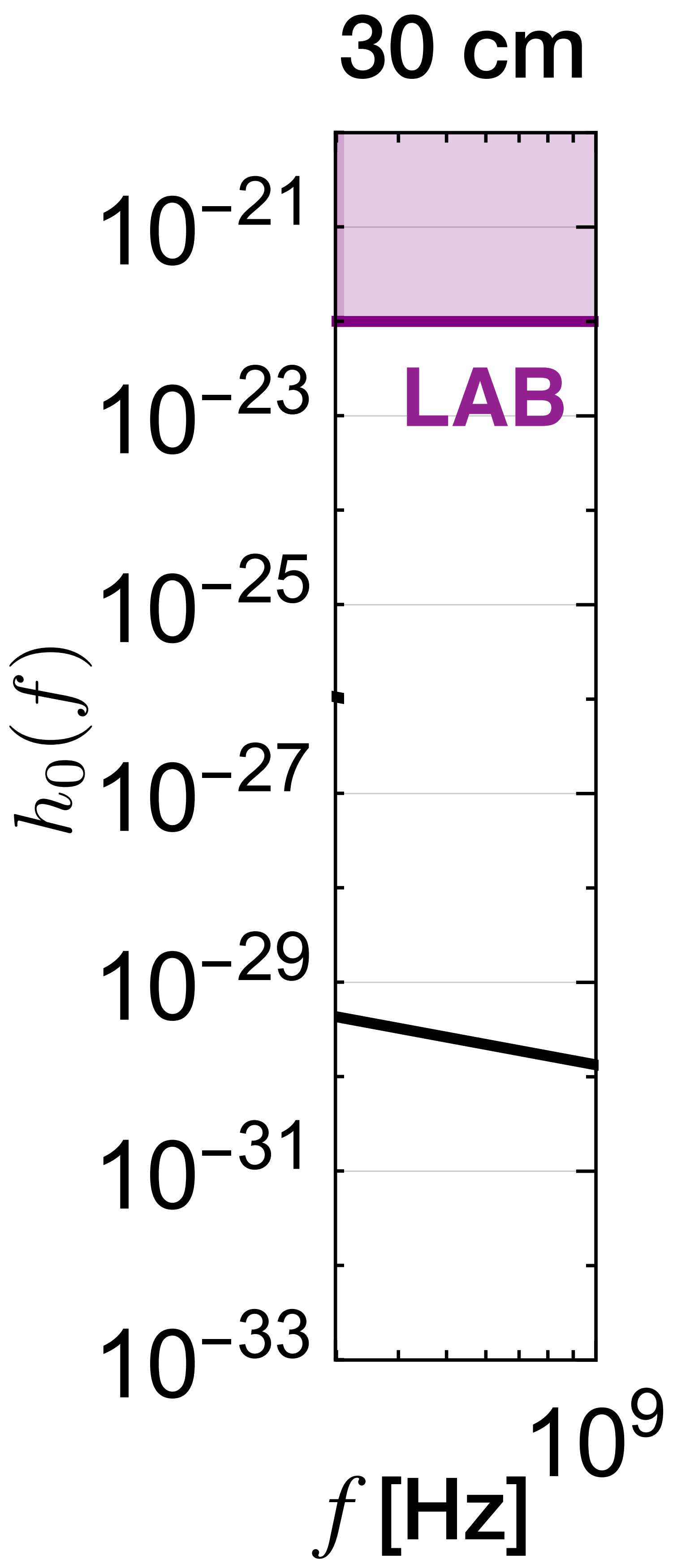
As compared to the EM spectrum, GWs are searched for at very small frequencies



What happens at 'laboratory' sizes?

MIND THE GAP

challenge i) sources?
challenge ii) how to detect them?



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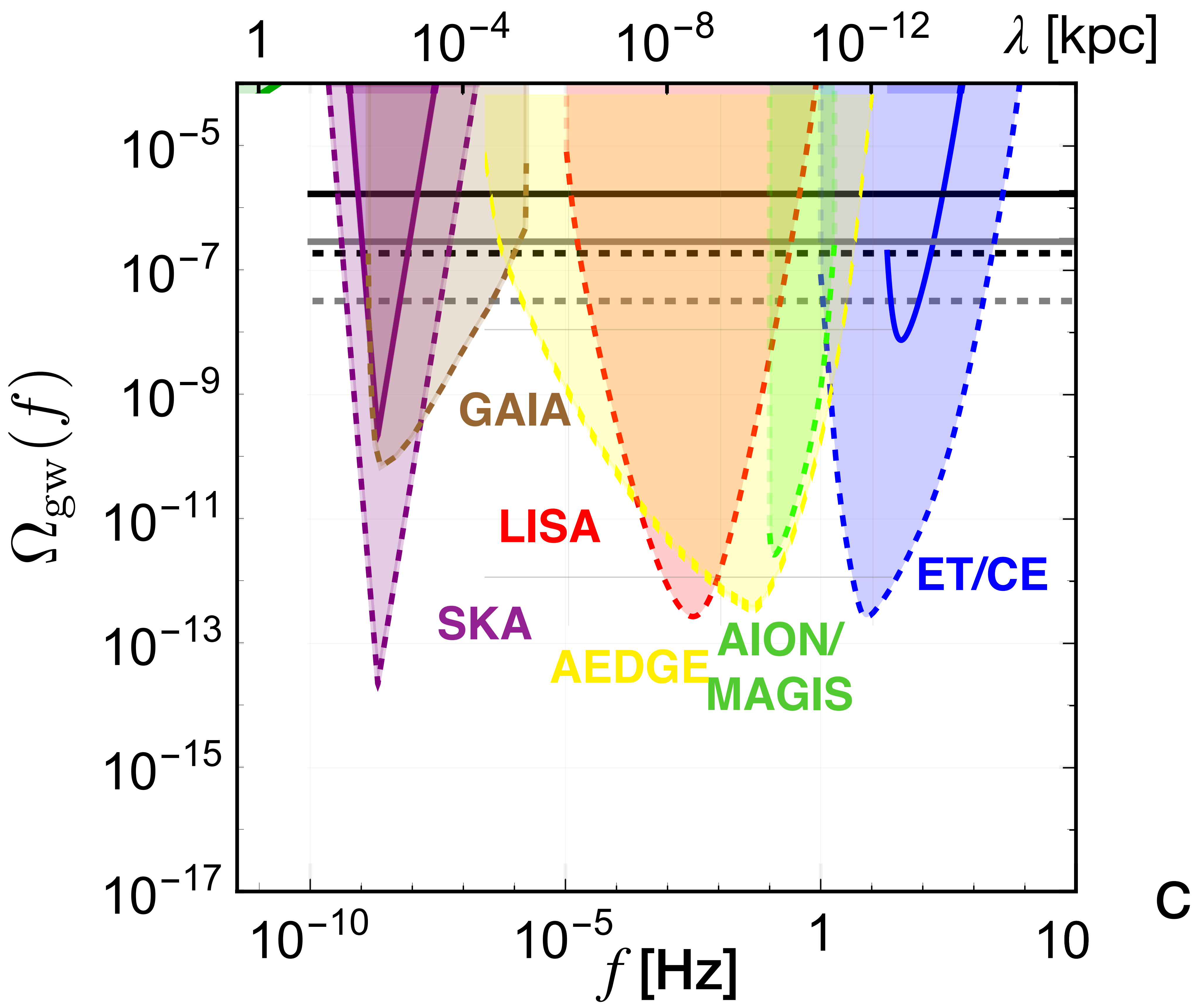

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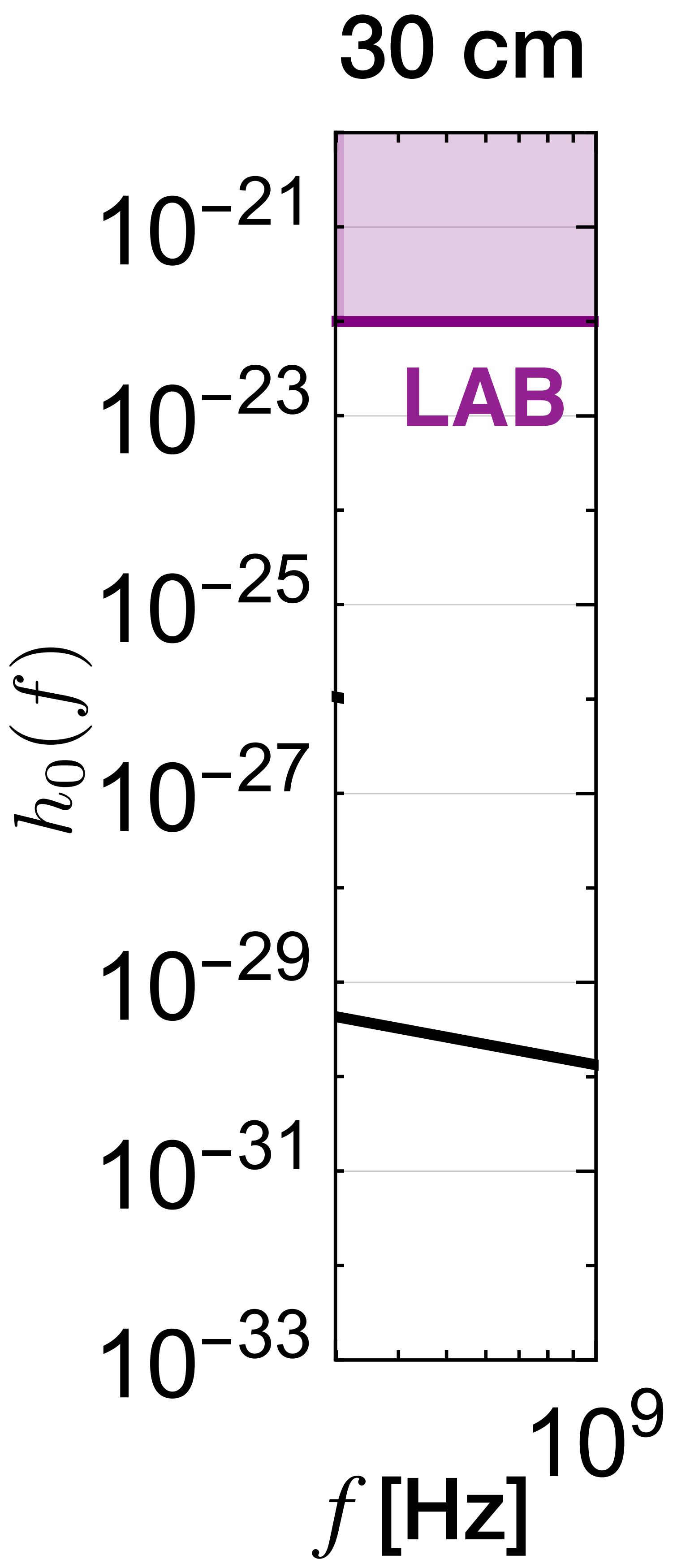
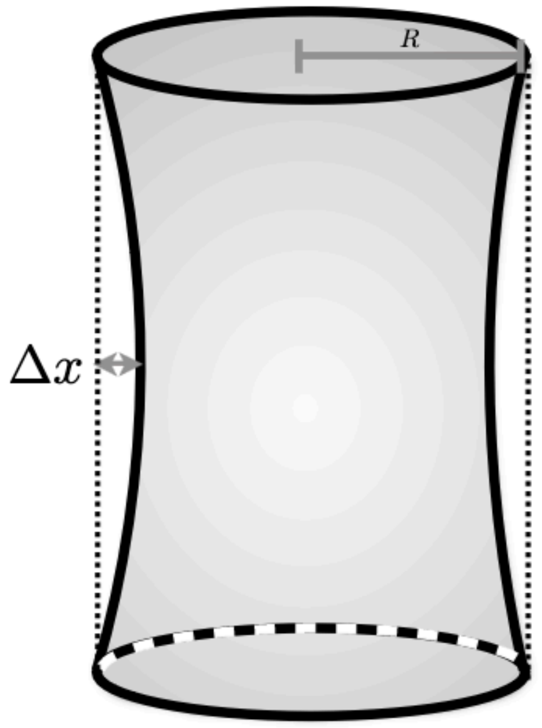
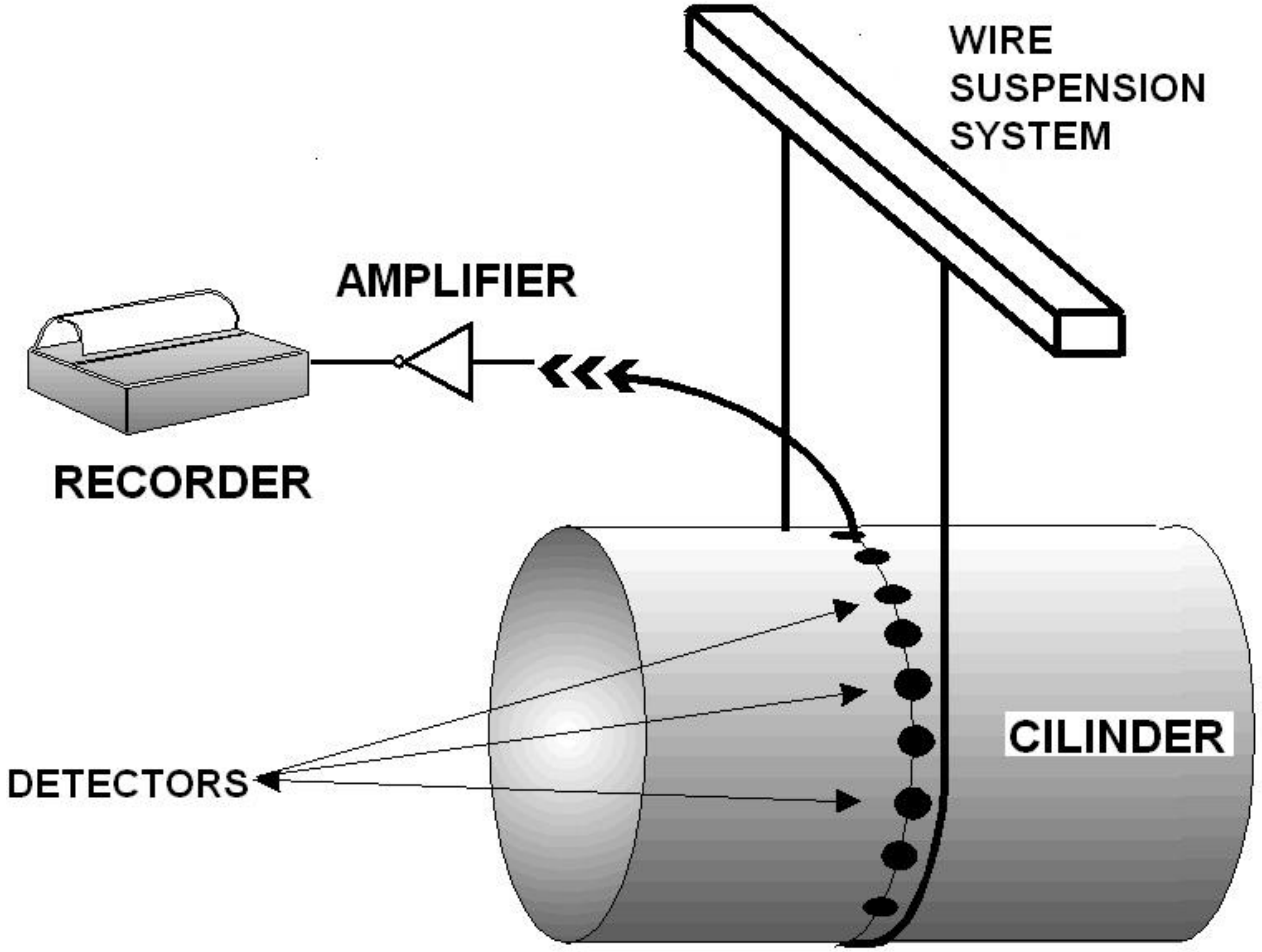


GWs exciting solids



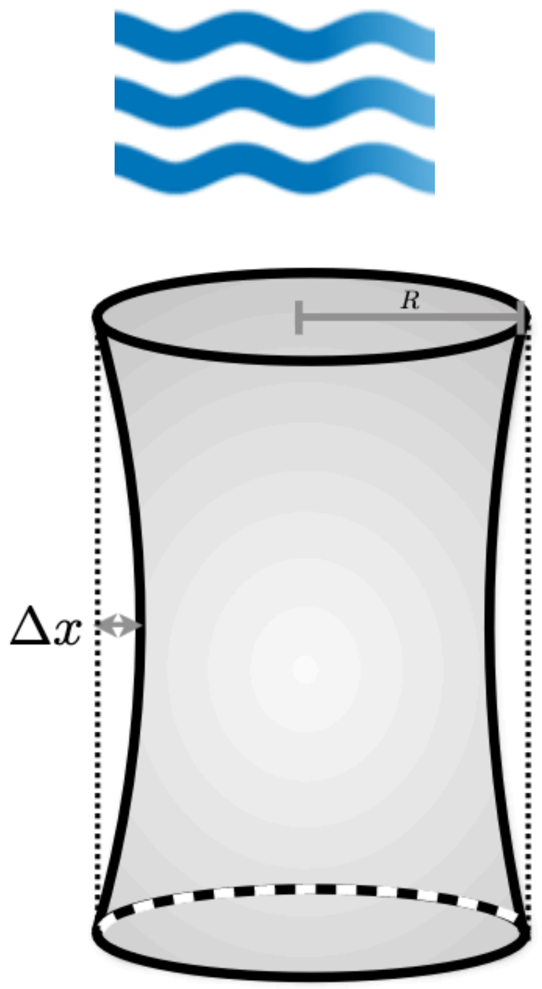
The passage of a GW deforms solids (principle of Weber bars)



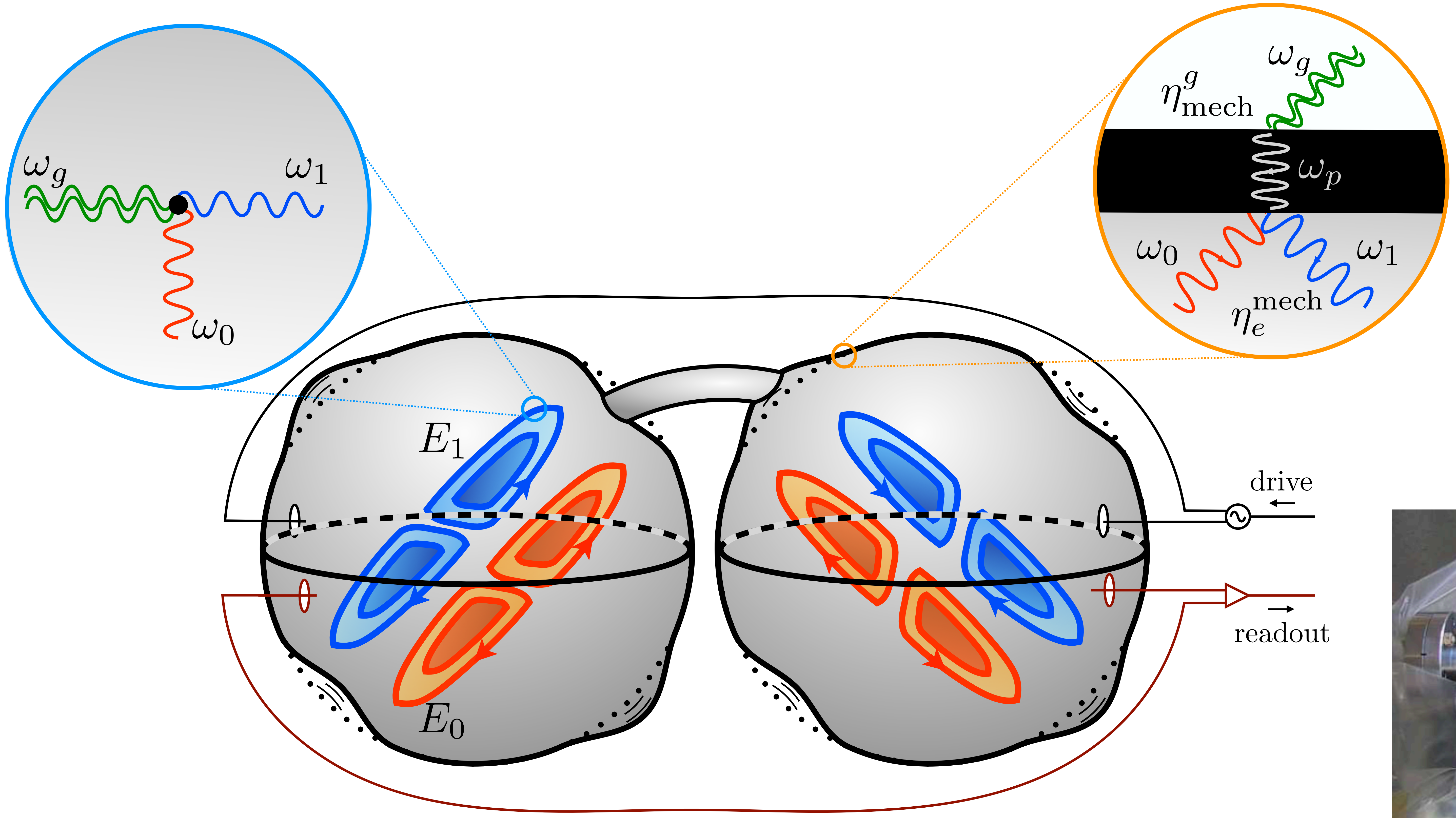
MAGO set-up

(Microwave Apparatus for Gravitational Waves Observation)

Ballantini et al arXiv:gr-qc/0502054.

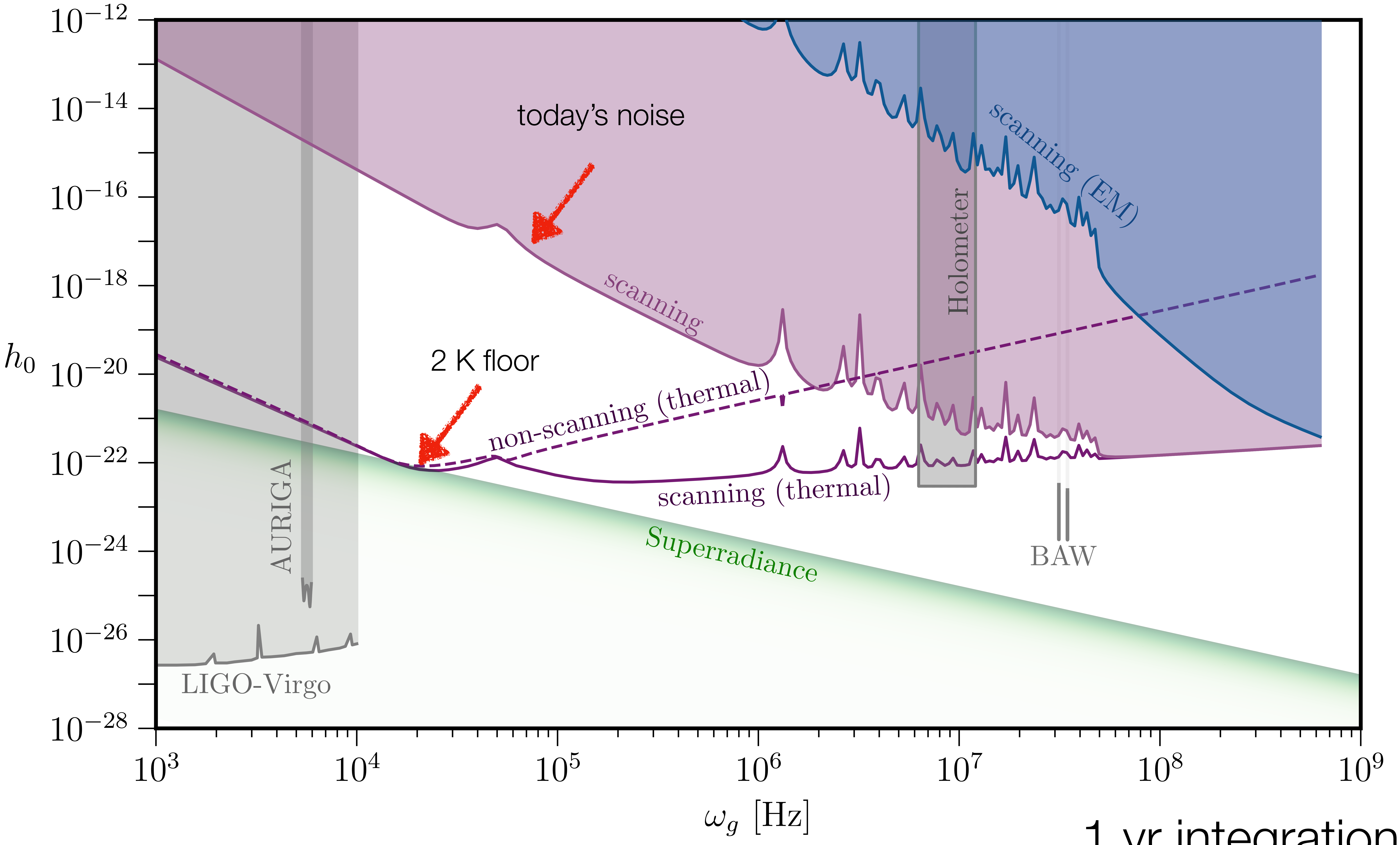


Principle: an eigenmode is no longer an eigenmode when the cavity is deformed: mode-mixing!



Estimates

A. Berlin, DB, R. T. D'Agnolo, S. Ellis, R. Harnik, Y. Kahn, J. Schütte-Engel, 2303.01518



1 yr integration in band!

Conclusions

1. A clear synergy LISA/AI is already been exploited with SGWBs

2. Both LISA-like missions and AIs: great potential for other new physics (and complementarity)

   DM in GW searches from ULDM clouds or ambient DM

   Tests of nature of BHs (several smoking guns)

   Tests of gravitation (measurements of PN parameters)

   Measurements of *G*

   Effects of pressure/noise from scattering with DM/CNB

   Birrefringent effects from axions in the propagation of lasers

3. Other opportunities may be awaiting for Atomic Physics for UHFGWs