Closing Remarks

Developing the Physics Case

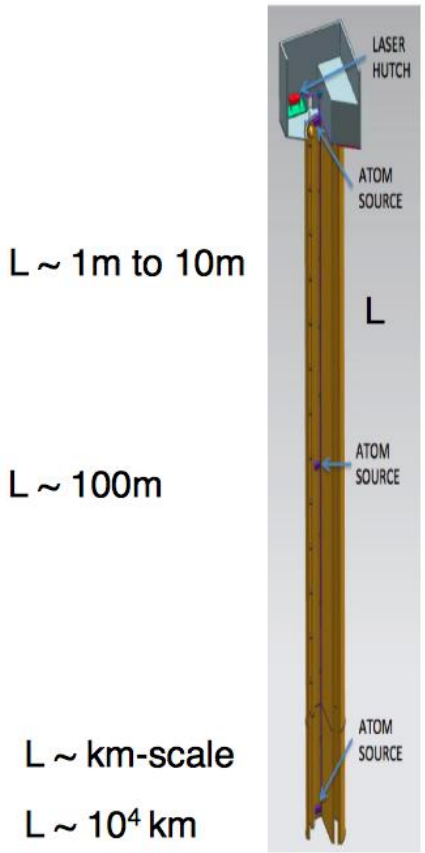
AION Workshop @ Imperial

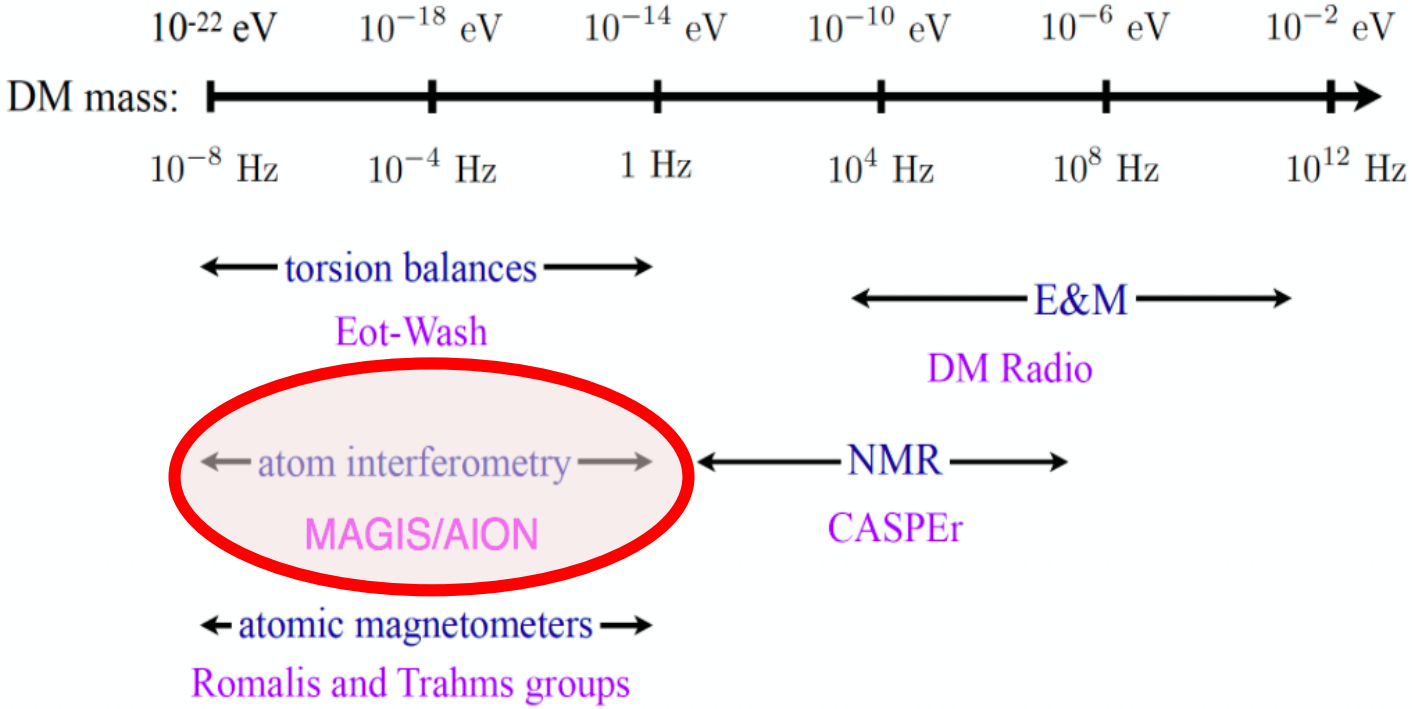
March 25/26, 2019

John Ellis (King's College London)

Searches for Light Dark Matter

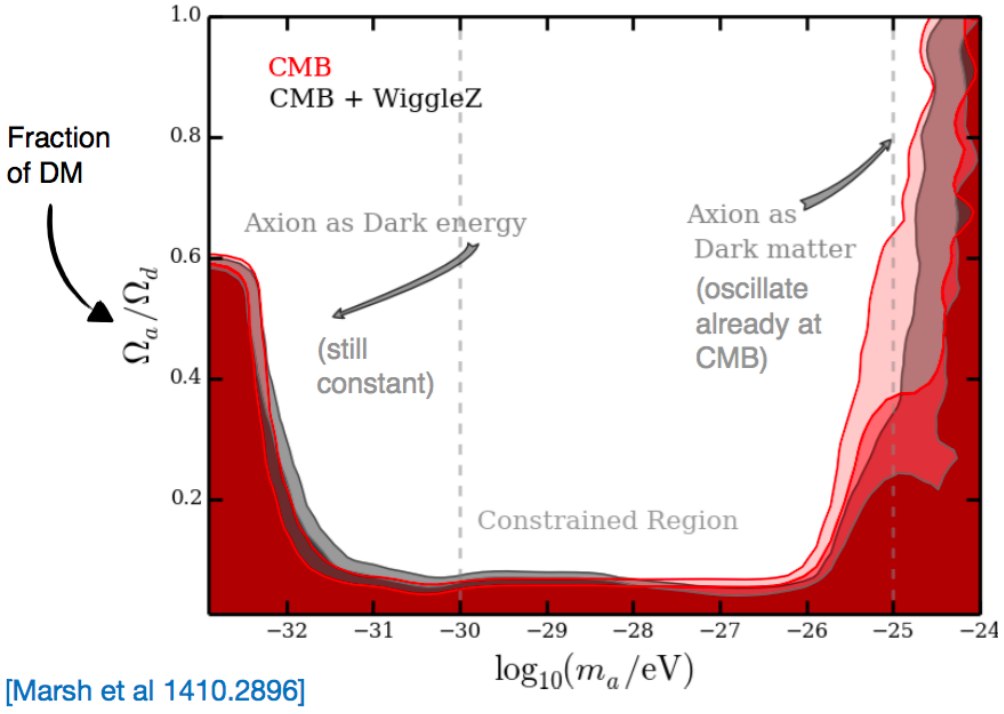
- Dark matter could be coherent waves of light bosons
  - Many detection techniques, **e.g. atom interferometers**





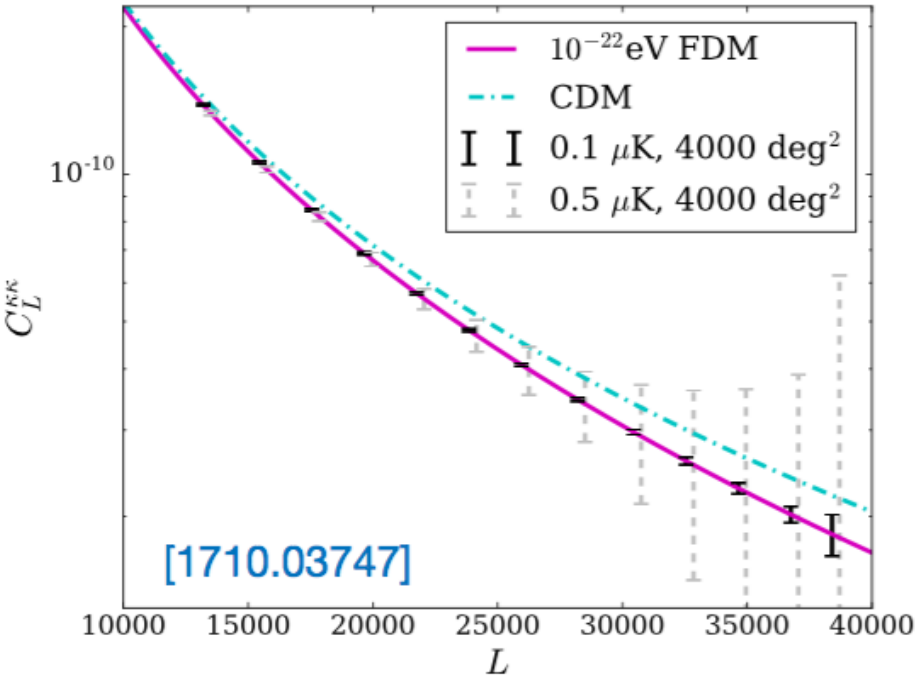
also interesting for gravitational waves

Constraints on Light Bosonic DM & Preferred (?) Mass



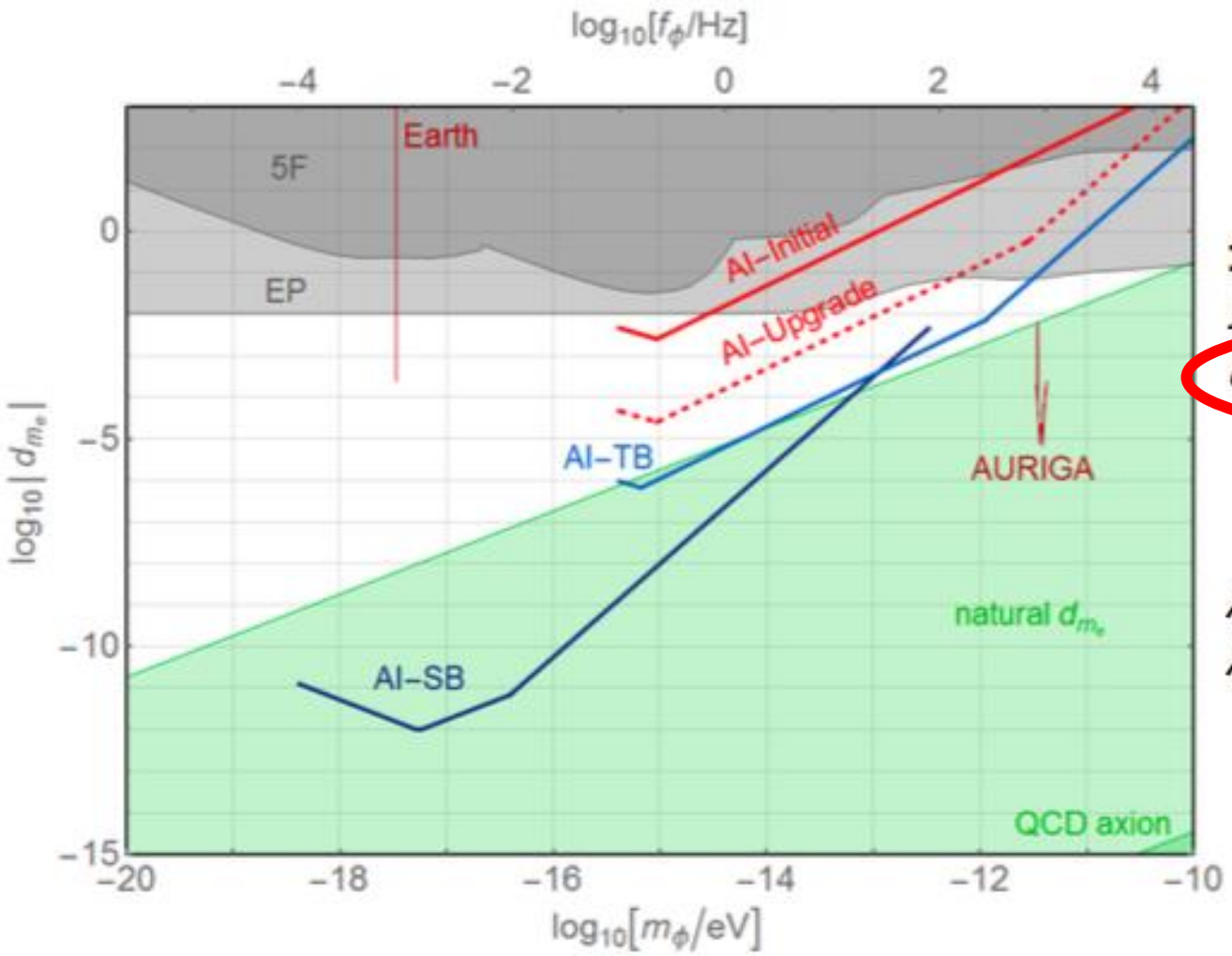
[Marsh et al 1410.2896]

Could be all DM if mass > 10^{-24} eV



Small-scale structure likes mass ~ 10^{-22} eV

Searches for Light Scalar DM



100-meter detector:

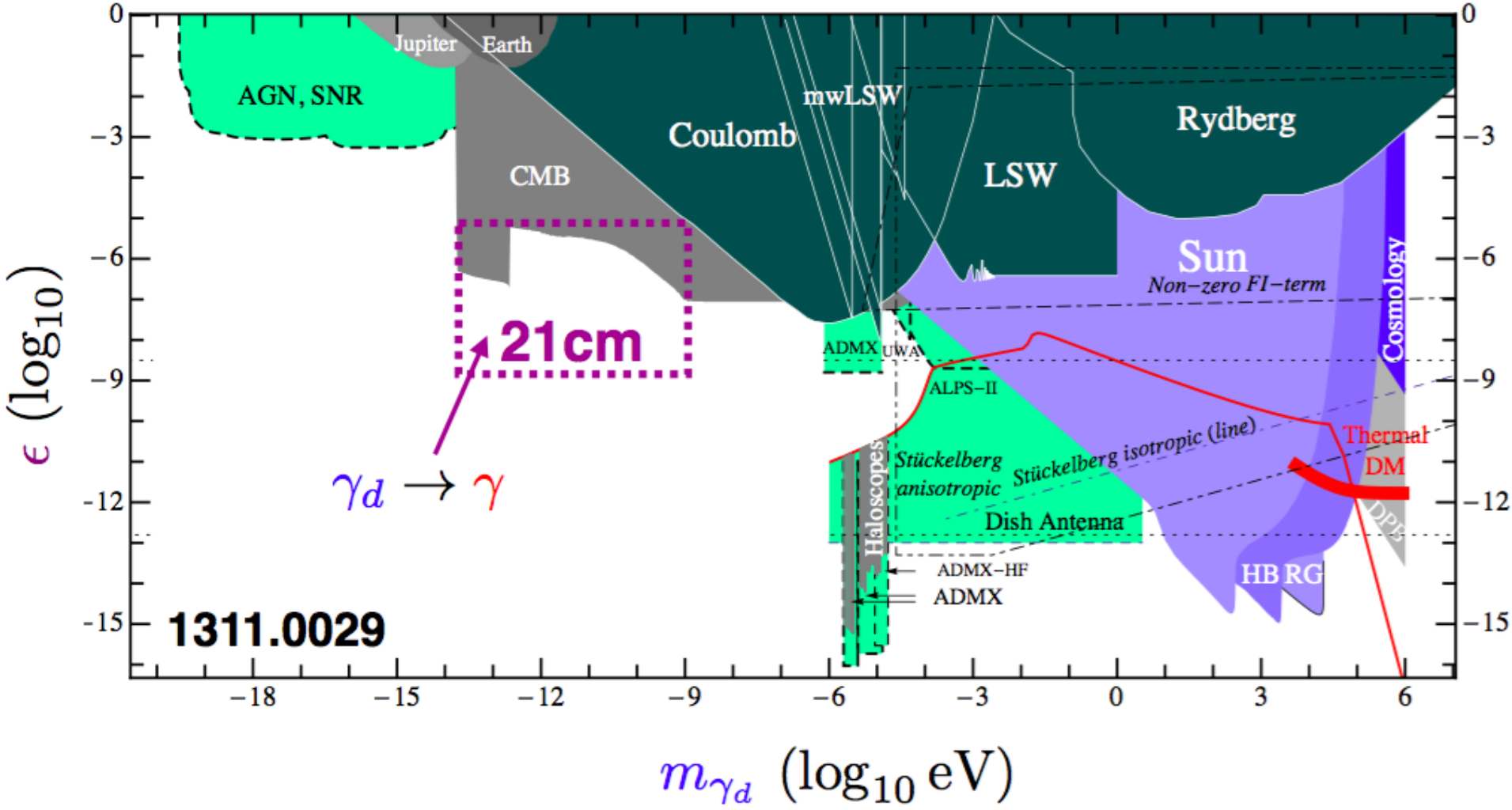
Initial: 100 ħk, 1e6/s flux

Upgrade: 1000 ħk, 1e8/s flux

AI-TB: km baseline

AI-SB: Space GW detector

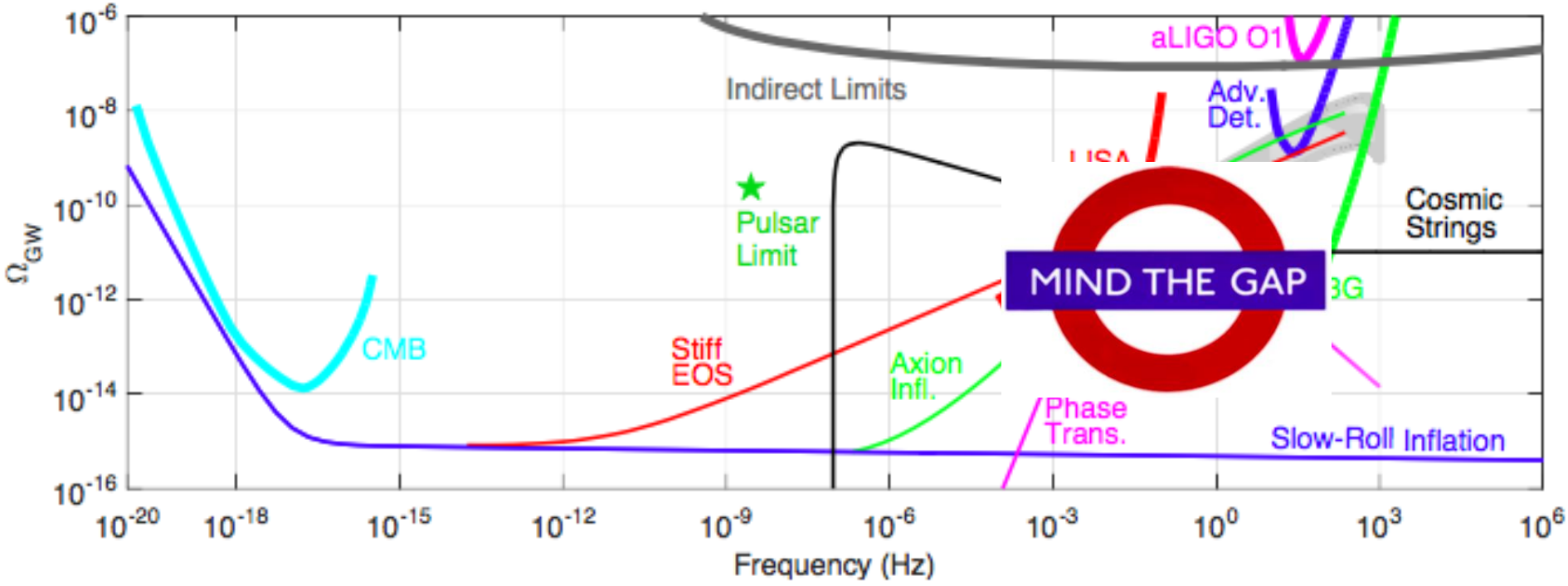
Searches for a Dark Photon



Possible DM Theory Tasks

- Understanding the synergies between dark matter searches in this mass range and other astrophysical and cosmological observations.
- Exploring the synergies between AION and other laboratory probes of ultra-light bosonic dark matter.
- Showing how to identify unambiguously dark matter as the origin of a signal in AION, rather than a signal from, e.g., time-varying physical parameters or GWs, and extract the dark matter properties from the signal.

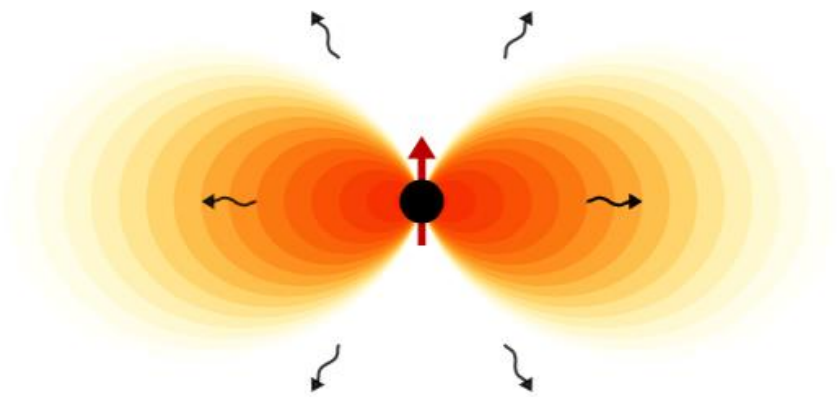
Gravitational Wave Spectrum



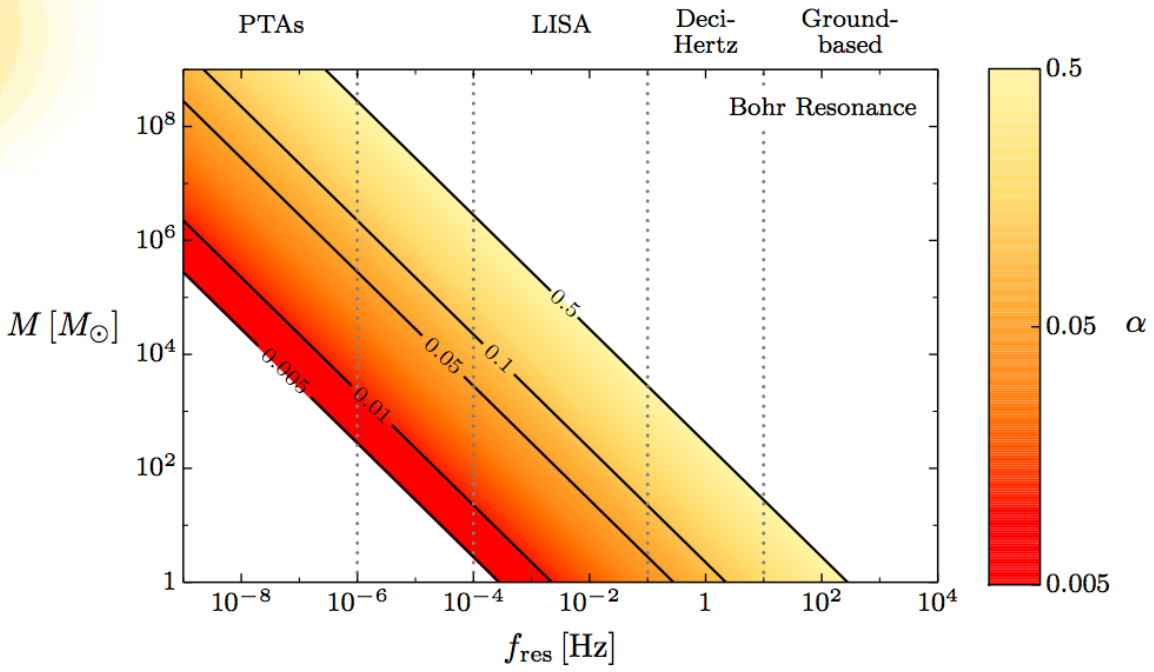
- Gap between ground-based optical interferometers @ LISA
- Electroweak phase transition? Cosmic strings?

Gravitational Radiation from Scalar Cloud around Black Hole

Horng Sheng Chia



$$\alpha \equiv M\mu = \frac{\text{Gravitational radius}}{\text{Compton wavelength}}$$



Observe radiation from Sagittarius A*?

$$h_c \simeq 2 \times 10^{-26} \left(\frac{M}{3M_\odot}\right) \left(\frac{M_c(\alpha)/M}{0.1}\right) \left(\frac{\alpha}{0.07}\right)^6 \left(\frac{10\,\text{kpc}}{d}\right)$$

Gravitational Waves from Phase Transition

Marek Lewicki

Signals are produced by three main mechanisms:

- collisions of bubble walls: $\Omega_{\rm col} \propto \left(\frac{\kappa_{\rm col}\alpha}{\alpha+1}\right)^2 (HR_*)^2$

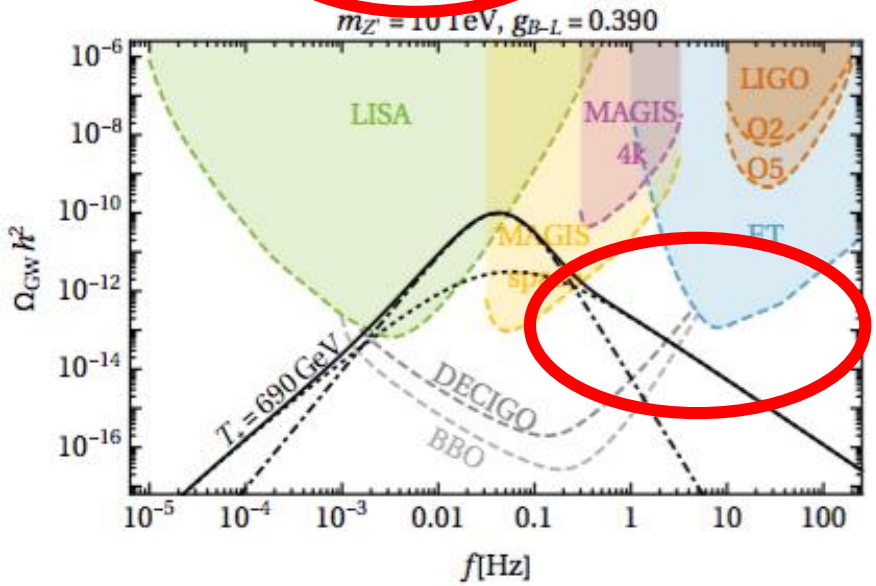
  Kamionkowski '93, Huber '08, Hindmarsh '18,

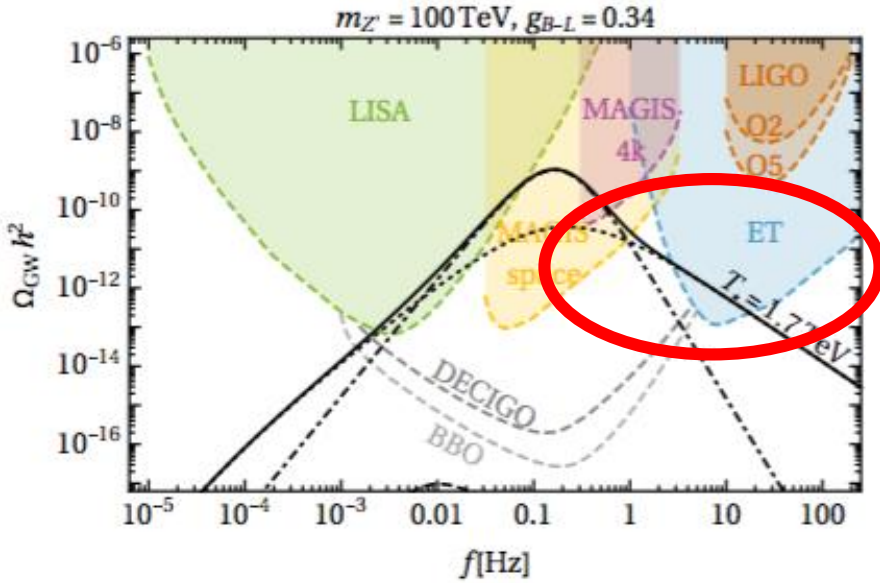
- sound waves: $\Omega_{\rm sw} \propto \left(\frac{\kappa_{\rm sw}\alpha}{\alpha+1}\right)^2 HR_* \frac{HR_*}{U_f}$

  Hindmarsh '13 '15 '17 Ellis 18'

- turbulence $\Omega_{\rm turb} \propto \left(\frac{\kappa_{\rm turb}\alpha}{\alpha+1}\right)^{\frac{3}{2}} HR_*$

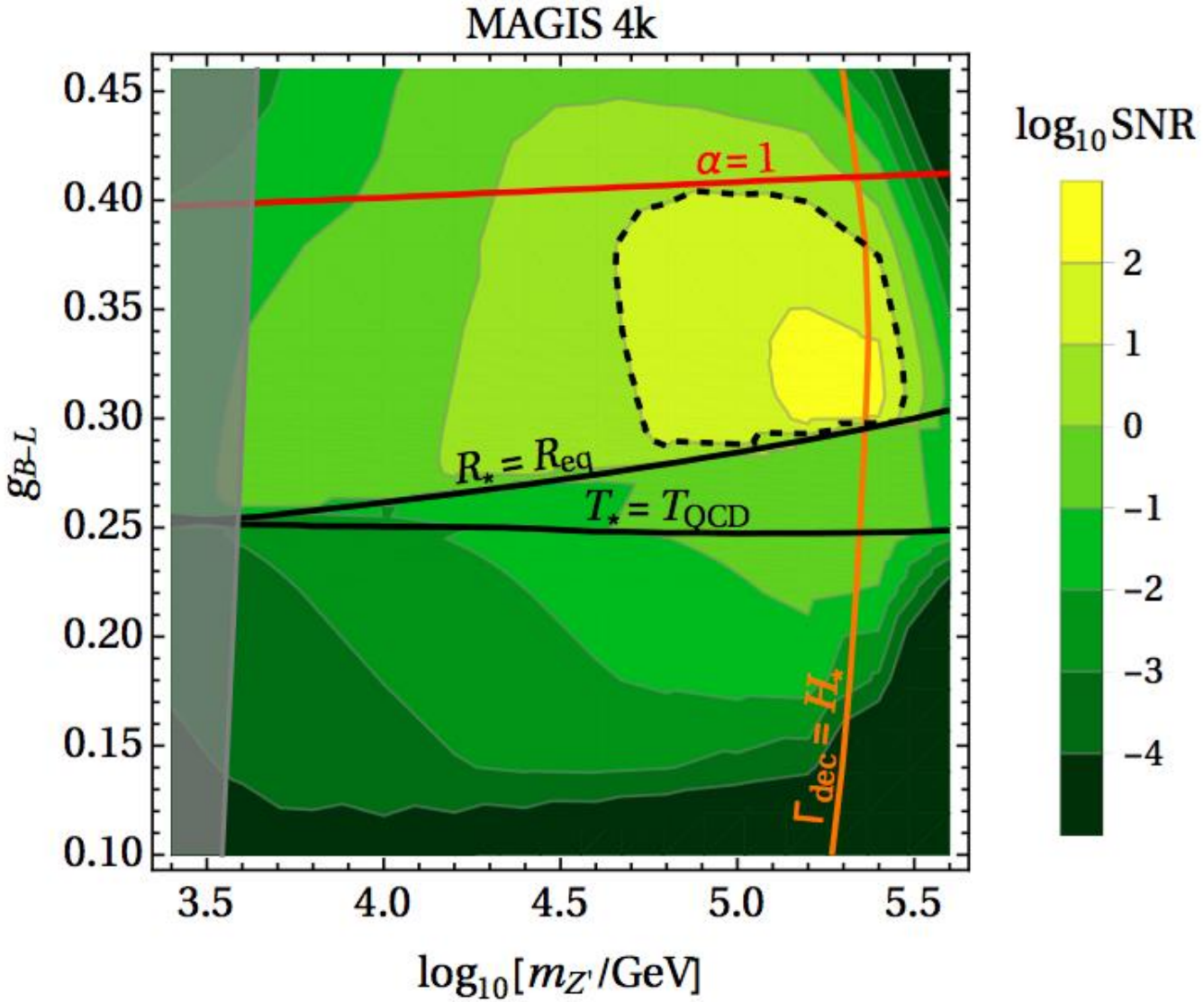
  Caprini '09





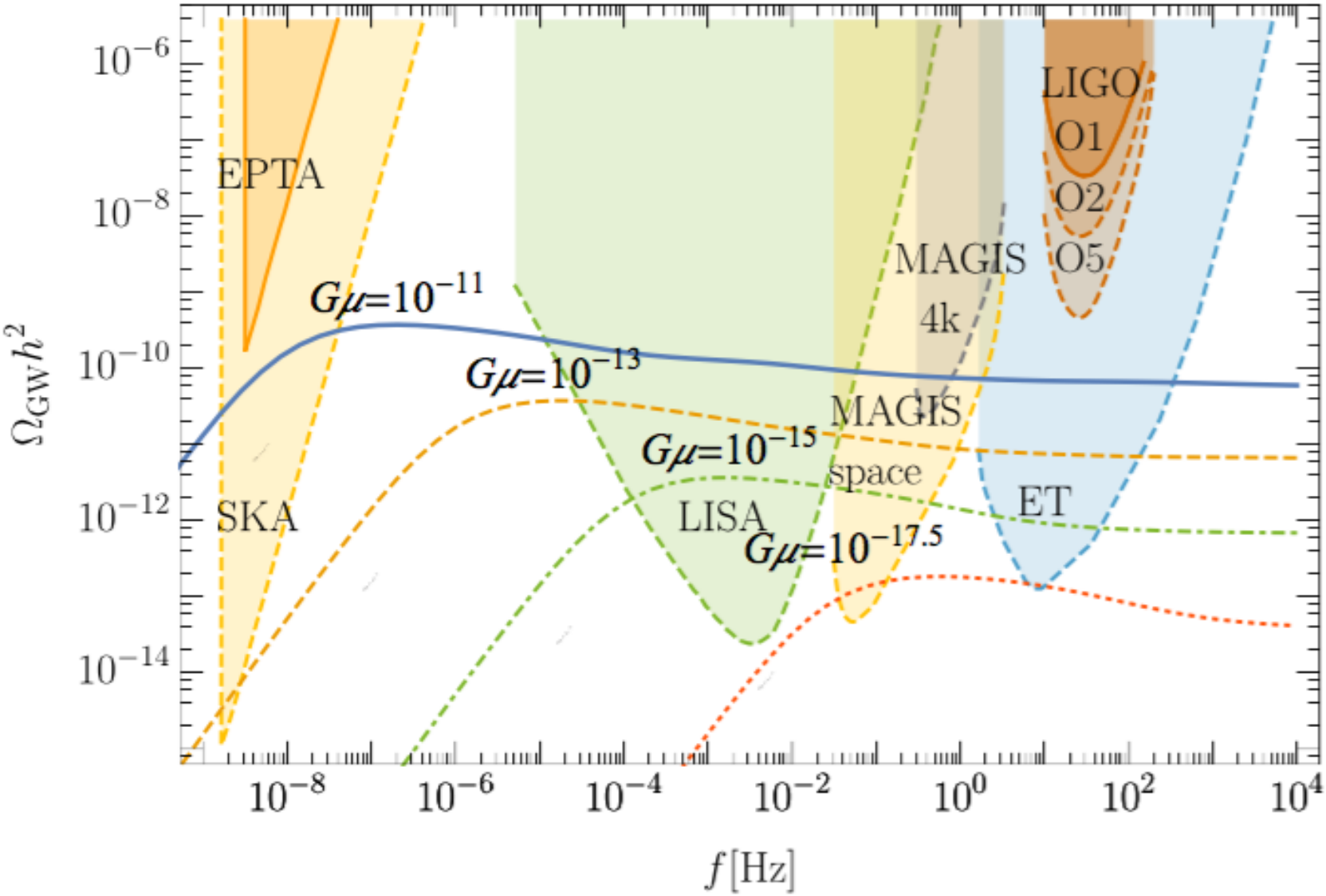
Gravitational Waves from Phase Transition

Marek Lewicki



Marek Lewicki

Gravitational Waves from Cosmic Strings



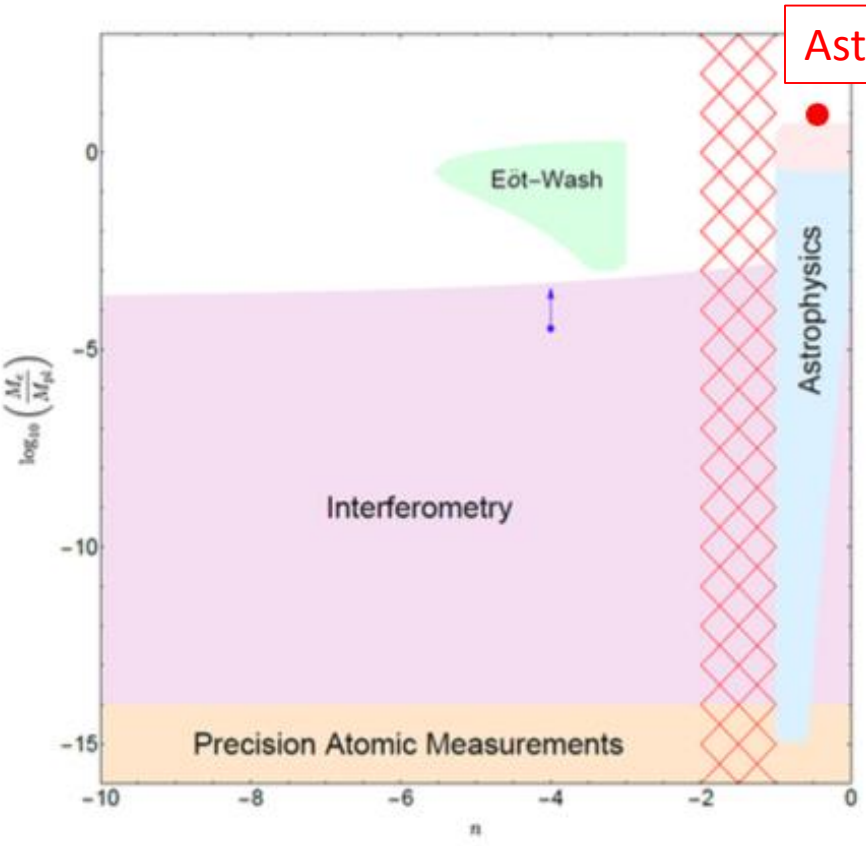
Possible GW Theory Tasks

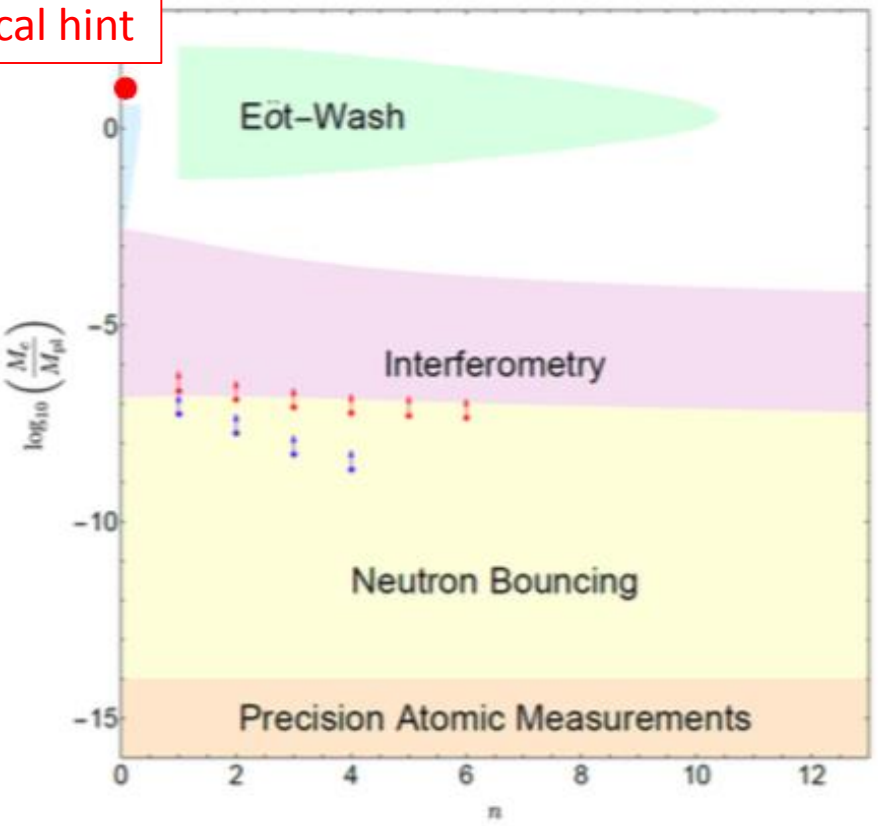
- Calculating mid-frequency GW signatures of cosmological phase transitions, e.g., at the electroweak scale, and relating them to collider signatures of possible extensions of the Standard Model.
- Sensitivity to cosmic strings.
- Understanding synergies of multiband GW astronomy combining GW searches in this frequency range with LISA, LIGO/Virgo/KAGRA & other astrophysical observations, e.g., for predicting timing, directions & distances of future merger events.
- Novel tests of the strong-gravity regime via, e.g., accurate timing of the GW phase evolution, that are not accessible with ground-based interferometers and LISA alone.
- Modelling astrophysical sources whose GWs peak in mid-frequency range, e.g., intermediate-mass BHs (seeds for supermassive BHs observed today), providing insight into their evolution and their host galaxies.

Interferometry & Chameleons?

$$V(\phi) = \frac{\Lambda^{n+4}}{\phi^n}$$

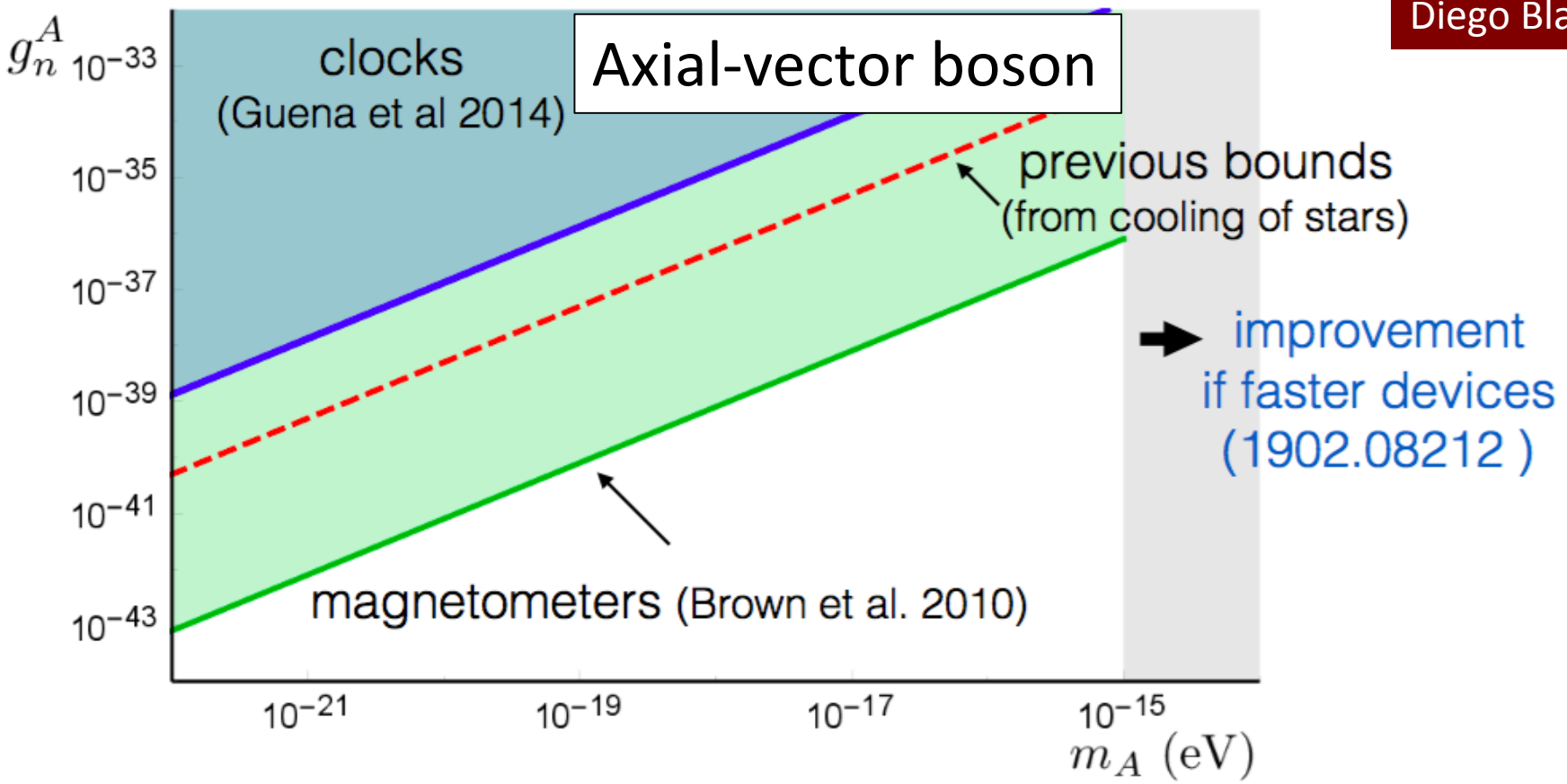
$$\Lambda = \Lambda_{\rm DE} = 2.4 \text{ meV}$$





Quantum Clocks & Co-Magnetometers

Diego Blas



Towards systematic comparisons:

to-do list

- Other couplings and other interferometers (AION)

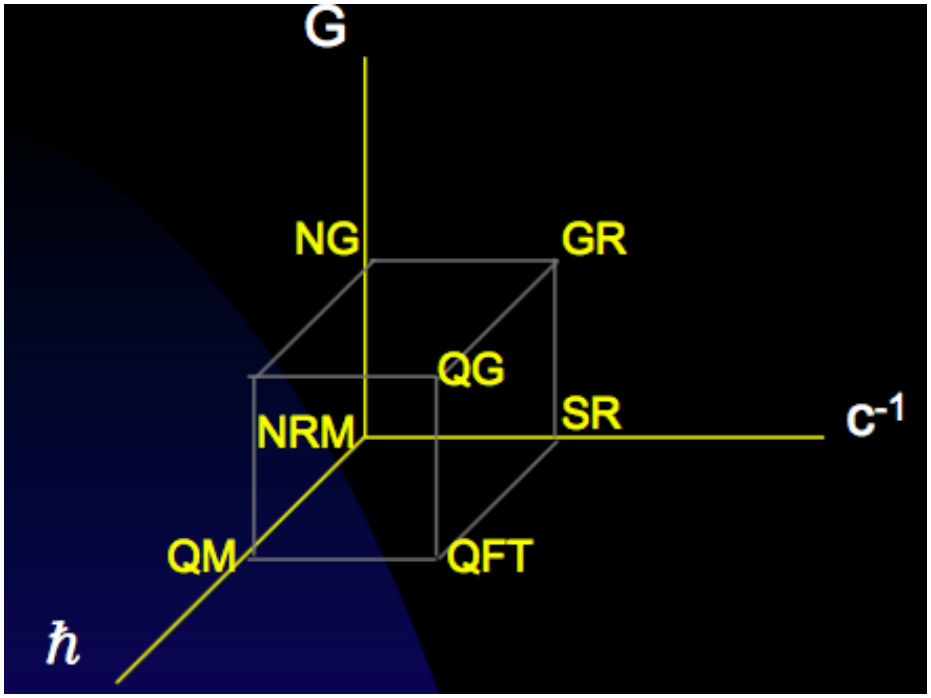
$$\bar{f}(0)_1 - \bar{f}(0)_2 \neq 0$$

populations of different momentum (interfering rotating states?)

- TBD: map of EFT operators to devices! (relatively complete for dimensions 5 operators, axions/dilatons)

Varying Fundamental "Constants"?

Grand cube or hypercube?
How many dimensions?
Variable geometry?



Effective action in string theory depends on moduli/dilaton fields

$$S = \int d^4x\sqrt{-\gamma}\left[B_g(\phi)\mathcal{R} - B_\phi(\phi)(\nabla\phi)^2 - \frac{1}{4}B_F(\phi)F^2 + \cdots\right]$$

Varying "constants" related to varying moduli/dilaton

Beyond Dark Matter & GWs

- Probing fundamental “constants”, chameleons, dark energy
- Detecting the astrophysical neutrinos that traverse the Earth with high flux though very small cross-section and tiny momentum
- Precise interferometry may also be relevant for understanding long-range fifth forces
- Fundamental (≠ environmental) decoherence

Gravitational Decoherence?

- Quantum nonlocality, expressed in the Bell inequality, which has been verified to high accuracy
- Microscopic quantum decoherence could provide a dynamical mechanism of quantum-to-classical transition.
- Origin in quantum gravity?

  [JE, Hagelin, Nanopoulos & Srednicki (1984),
  JE + Mavromatos + Nanopoulos (1992), Penrose (1996)].
- Constrained by kaon physics, neutrons, …
- Could the unprecedented macroscopic quantum superpositions achieved by AION provide a test of gravitational decoherence?

Future Planning

- AION-Physics also includes atomic physics, data analysis
- Particle theory/phenomenology still in fledgling state
  - Continue brainstorming new ideas
  - Refine/correct/add to topics proposed in previous slides
- After call for proposals, will have 3 months
  - When the time comes, there will be little time
- Prepare to write White Paper?
- Two conveners each for DM, GW, other topics:
  - Martin B/Chris McC(?) Marek L/? Clare B/Diego B