Fundamental Physics with SKA

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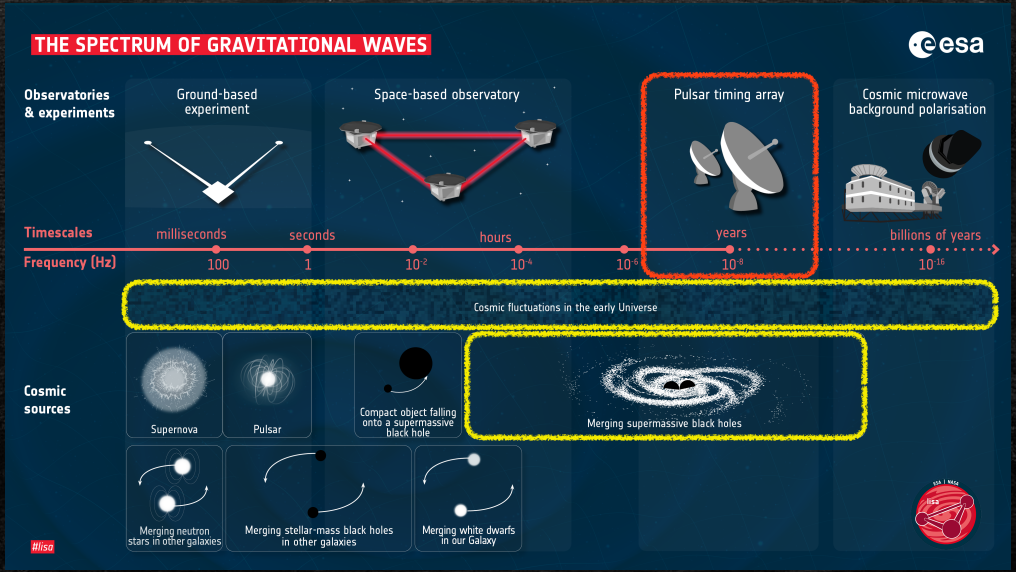
National SKA Science Day Sweden @ AlbaNova (2023/02/02)

Part 1. Gravitational Wave Astronomy & Cosmology

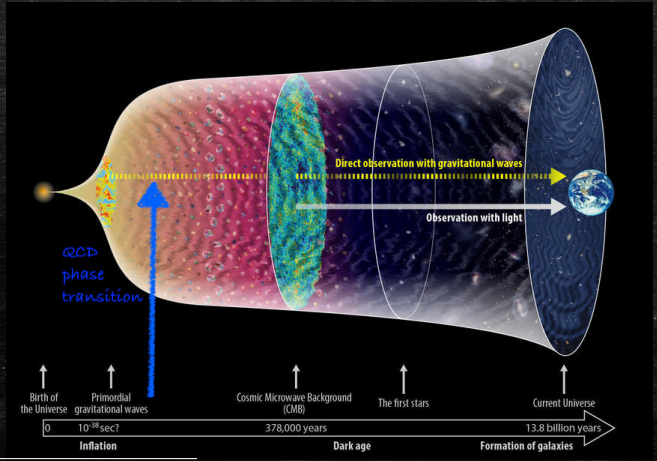
Gravitational Waves (GWs): a vast discovery space



[1] Image credit: ESA 2021.

Gravitational Waves (GWs): from QCD phase transition

- QCD phase transition: condensation of quarks into hadrons.
- Occurred at $T \sim 100\text{MeV} \sim 10^{12}\text{K}, t \sim 10^{-5}\text{s}, z \sim 10^{13}$.
- The only (direct) observable are the relic GWs around 10^{-9} Hz.

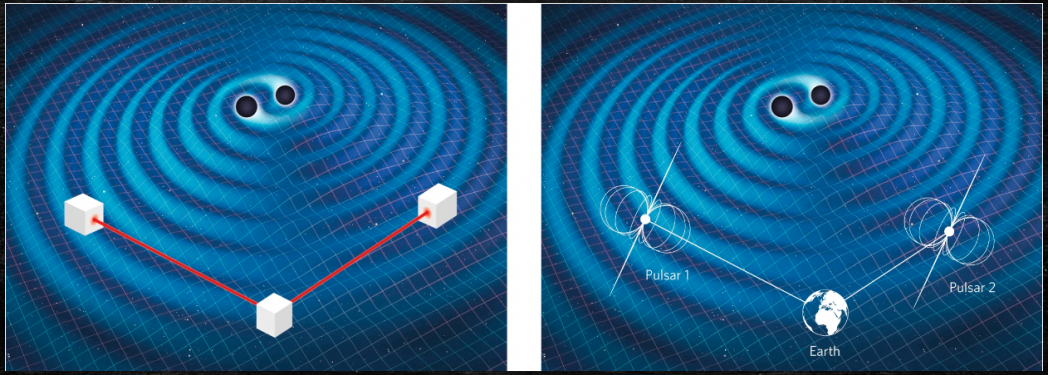


[2] Image credit: NAOJ 2016.

Part 2. Radio telescopes as GW detectors

Pulsar timing arrays (PTAs)

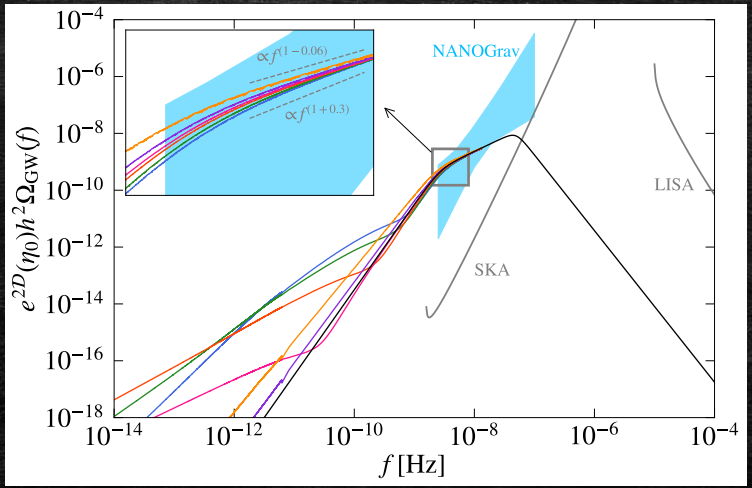
- Stable millisecond pulsars (MSPs) as clocks.
- Radio telescopes measure the time of arrivals of MSP signals.
- Campaign duration of ~ 10 yrs $\Longrightarrow$ sensitive to GWs with $\sim 10^{-9}$ Hz.
- NANOGrav[1], EPTA, PPTA, IPTA... SKA!



[1] North American Nanohertz Observatory for Gravitational Waves.
[3] Image credit: Mark Garlick 2017.

Constraining modified gravity with SKA[2]

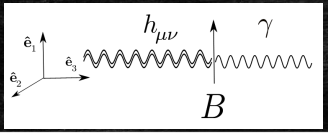
- GWs from the time of QCD phase transition:
  - Spectral slopes near the peak depend on modified gravity parameters.

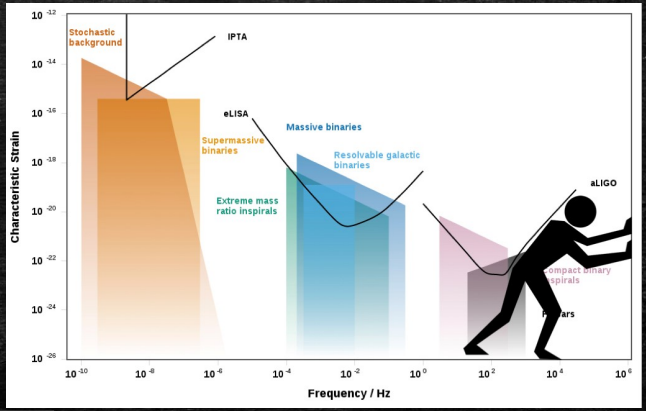


[2]He, Roper Pol, and Brandenburg 2022.

Radio telescopes as detectors of high-frequency GWs

- High-frequency GWs may come from primordial black holes (PBHs).
- GWs convert to electromagnetic (EM) waves in the presence of external magnetic fields, such that $f_{\rm GW} \approx f_{\rm EM}$.
- All EM detectors can be (indirect) GW detectors!





[4] Image credit (left): Domcke and Garcia-Cely 2021.
[4] Image credit (right): The Stephen Hawking Centre for Theoretical Cosmology 2019.

Summary

- Radio telescopes could detect GWs around the nano-Hertz range via PTAs and in the high-frequency regime via GW-EM conversion.
- From QCD turbulence and PBHs to modified gravity, exciting physics awaits discovery in both the low- and high-frequency GWs.
- SKA will significantly improve the detection capabilities of existing PTAs, and can, with other radio telescopes, potentially allow us to study HFGWs.

Thank you for your attention!👽

Backup slide: PTA participating observatories

- NANOGrav 🇺🇸:
  - Green Bank 📡, Arecibo ☠️
- EPTA 🇬🇧 🇳🇱 🇩🇪 🇫🇷 🇮🇹:
  - Lovell 📡, Westerbork 📡, Effelsberg 📡, Nancay 📡, Sardinia 📡.
- PPTA 🇦🇺:
  - Parkes Observatory 📡.
- InPTA 🇮🇳:
  - upgraded Giant Meterwave Radio Telescope 📡.
- IPTA:
  - all of the above...
- Upcoming: SKA!

References I

[1] Valerie Domcke and Camilo Garcia-Cely. "Potential of radio telescopes as high-frequency gravitational wave detectors". In: *Phys. Rev. Lett.* 126.2 (2021), p. 021104. DOI: 10.1103/PhysRevLett.126.021104. arXiv: 2006.01161 [astro-ph.CO].

[2] ESA. *The Spectrum of Gravitational Waves*. [Online; accessed November 17, 2021]. 2021. URL: https://www.esa.int/ESA_Multimedia/Images/2021/09/The_spectrum_of_gravitational_waves.

[3] Yutong He, Alberto Roper Pol, and Axel Brandenburg. "Modified propagation of gravitational waves from the early radiation era". In: (Dec. 2022). arXiv: 2212.06082 [gr-qc].

[4] Mark Garlick. *Figure 2 in "Pulsar timing for gravitational wave detection"*. 2017. URL: https://www.nature.com/articles/s41550-017-0324-9 (visited on 12/01/2017).

[5] NAOJ. *Background gravitational waves from the early Universe*. 2016. URL: https://gwpo.nao.ac.jp/en/gallery/000061.html (visited on 06/2016).

[6] The Stephen Hawking Centre for Theoretical Cosmology. *Ultra-High-Frequency Gravitational Waves*. 2019. URL: https://www.ctc.cam.ac.uk/activities/UHF-GW.php (visited on 10/05/2022).