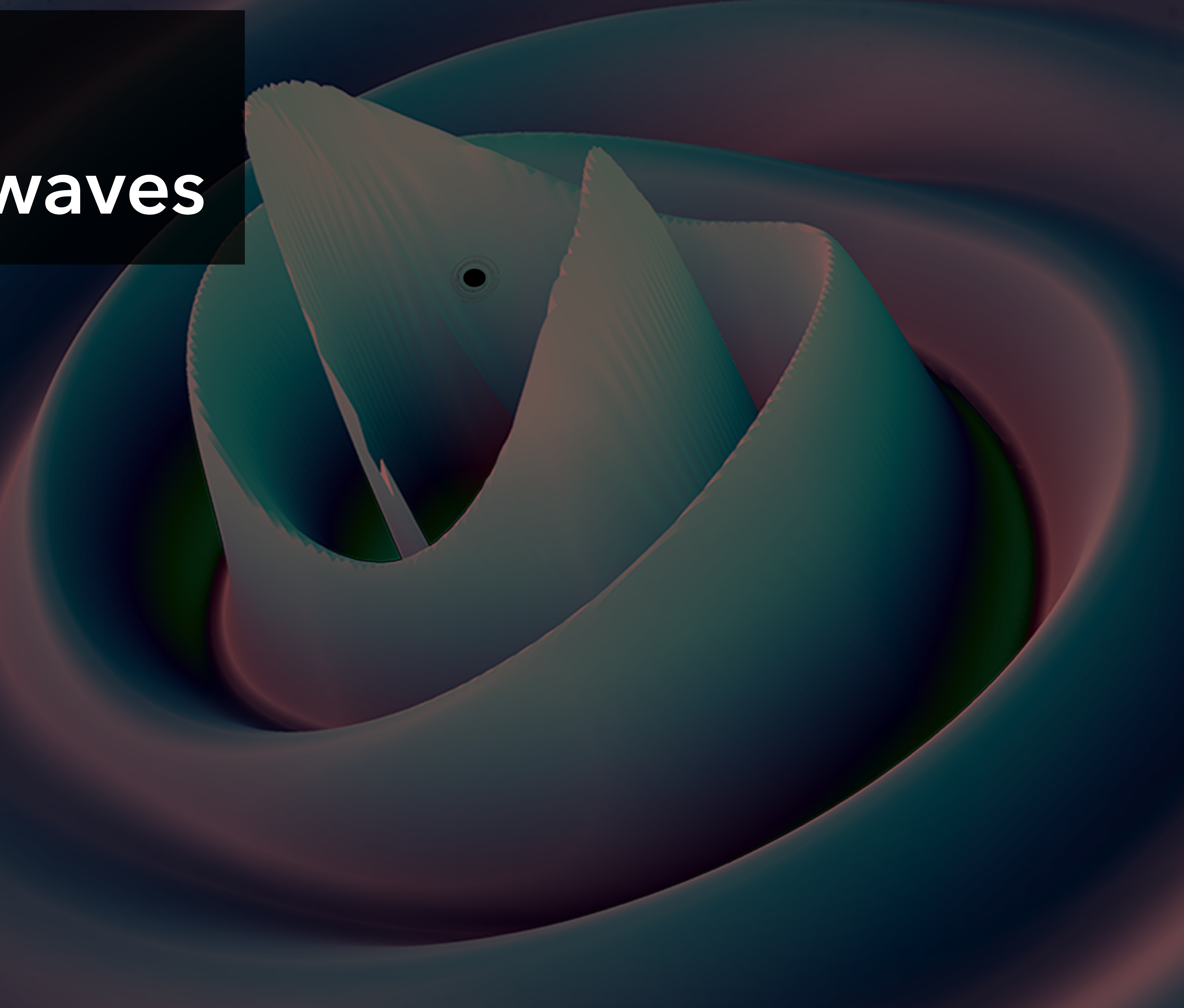
# deci-Hertz:
## The missing link of gravitational waves

**Karan Jani**
Vanderbilt University
@astrokpj



**1st International Workshop for Gravitational-Wave Detection on Moon**
European Gravitational Observatory, Italy
October 14, 2021

Image: Deborah Ferguson, KPJ+

# **LIGO-Virgo Epoch**: Revolution from 10~$10^2$ Hz of GWs


2015 (O1) — 2017 (O2) — 2019 (O3a)

*"Every black hole is unique, every black hole has a story to tell."*

Image: Sudarshan Ghonge, KPJ

# Complete Gravitational-Wave Spectrum (Almost!)

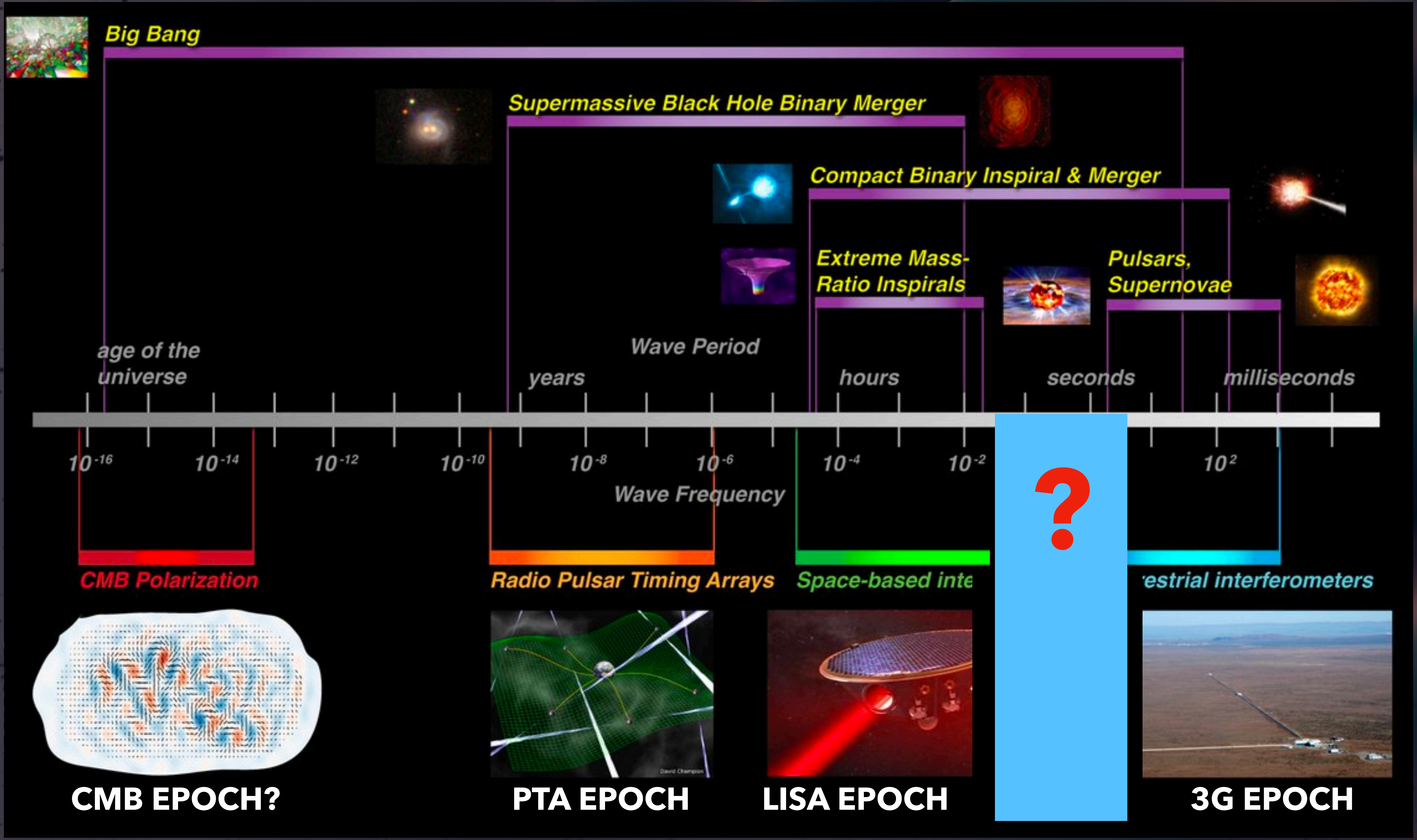
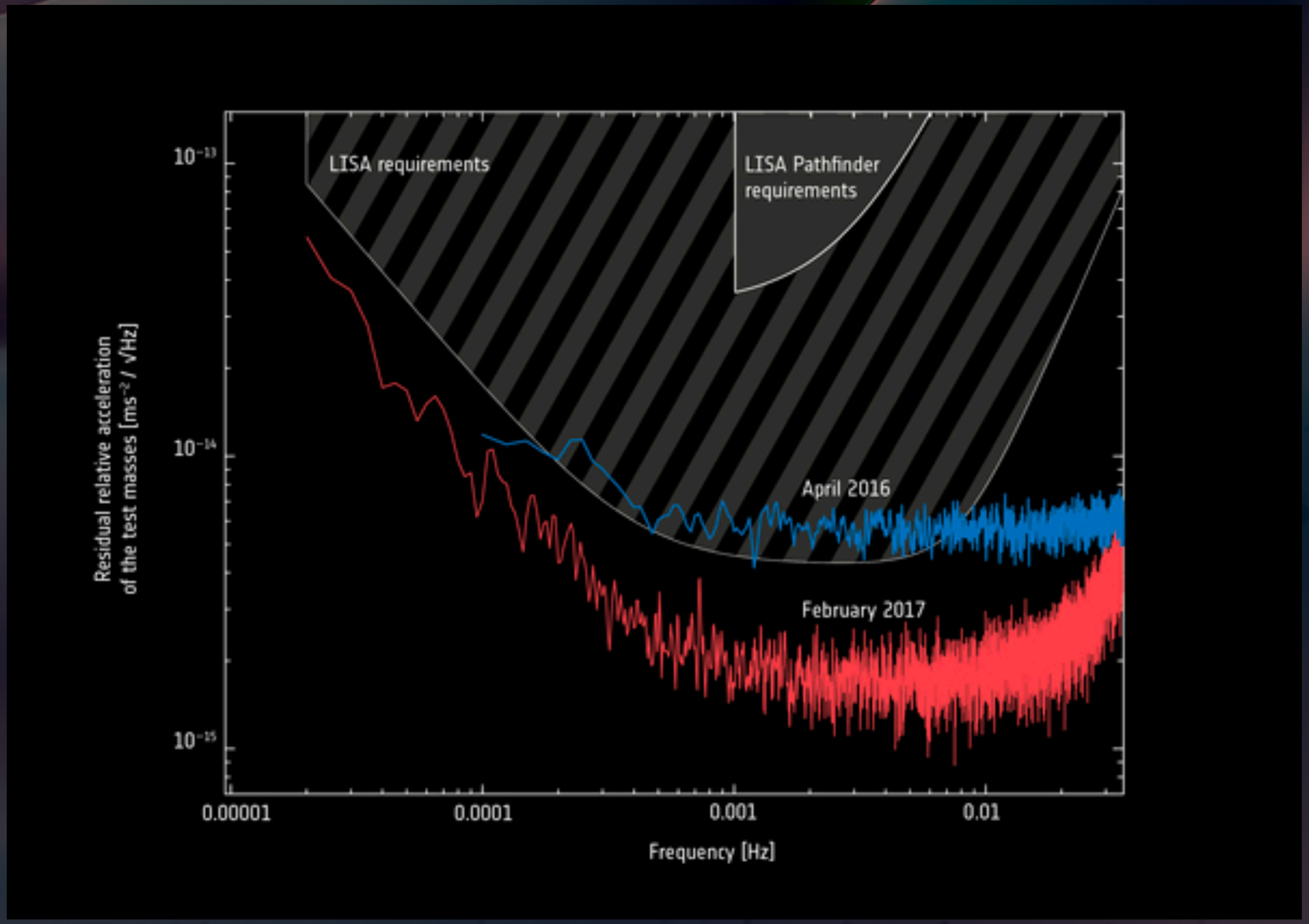



Image: GSFC

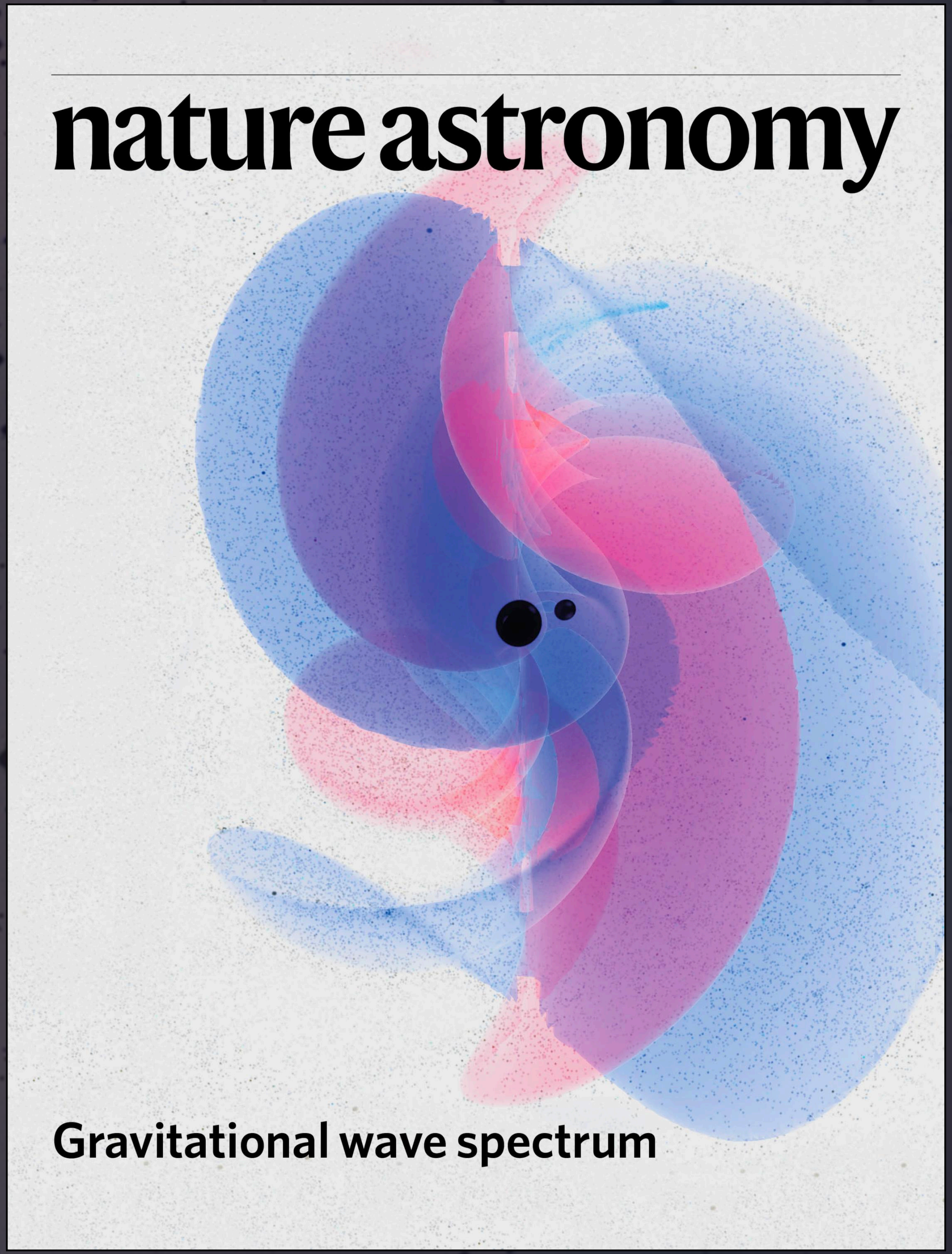
# Fundamental challenges near **0.1-1 Hz**

- For any ground-based laser interferometric setup (LIGO, Virgo, ET), it is challenging to go below 1 Hz limit due to earth's seismic noise.
    - Lowest frequency with detection sensitivity for Einstein Telescope is expected to be ~5 Hz

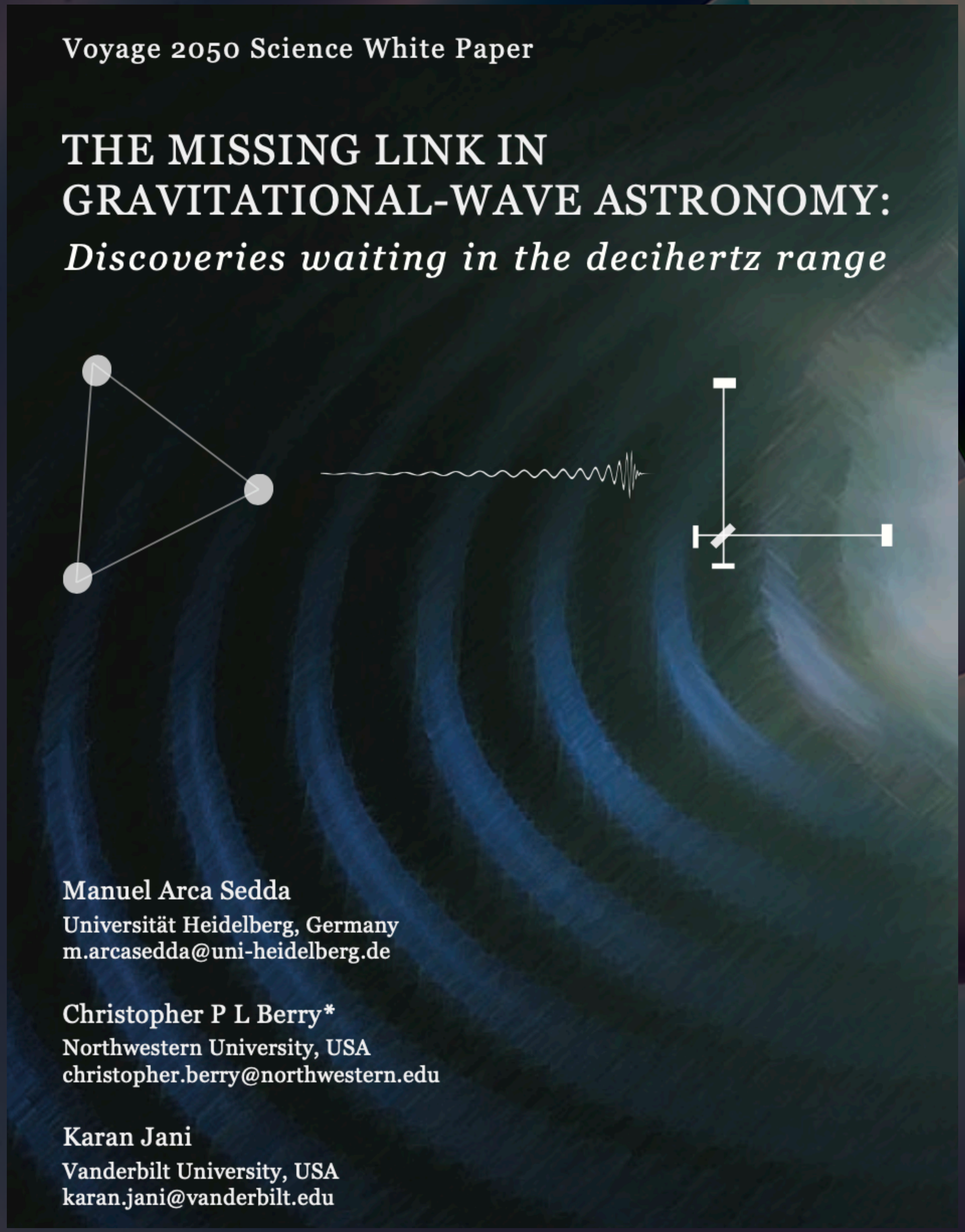
- For space-based laser interferometers, the high frequency sensitivity is fundamentally limited by the laser shot noise.
    - Highest frequency with detection sensitivity for LISA is expected to be ~0.1 Hz



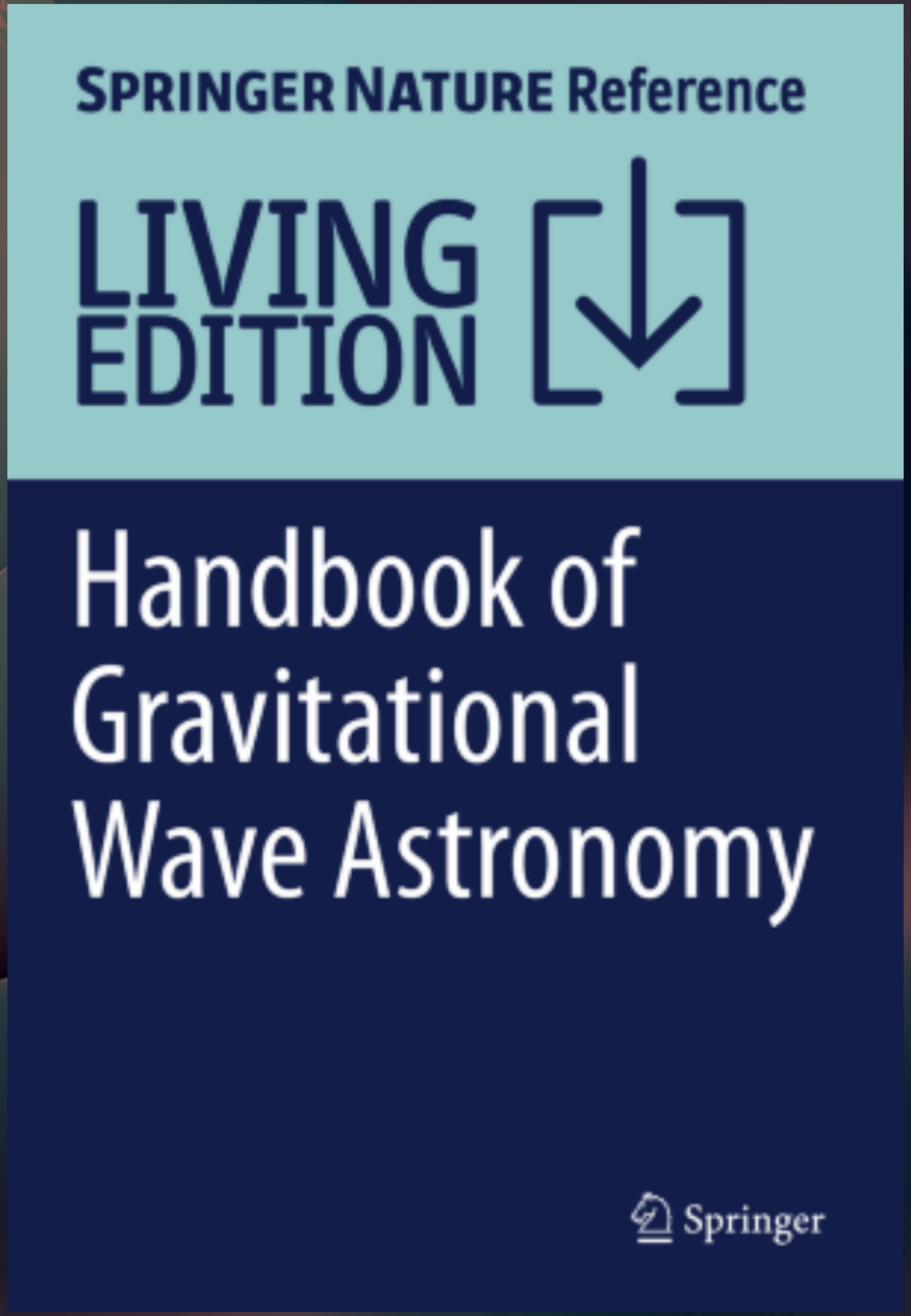
# Intermediate-Mass Black Holes & Science Case for Deci-Hertz




**KPJ**, Shoemaker, Cutler
(Nature Astronomy, 2020)

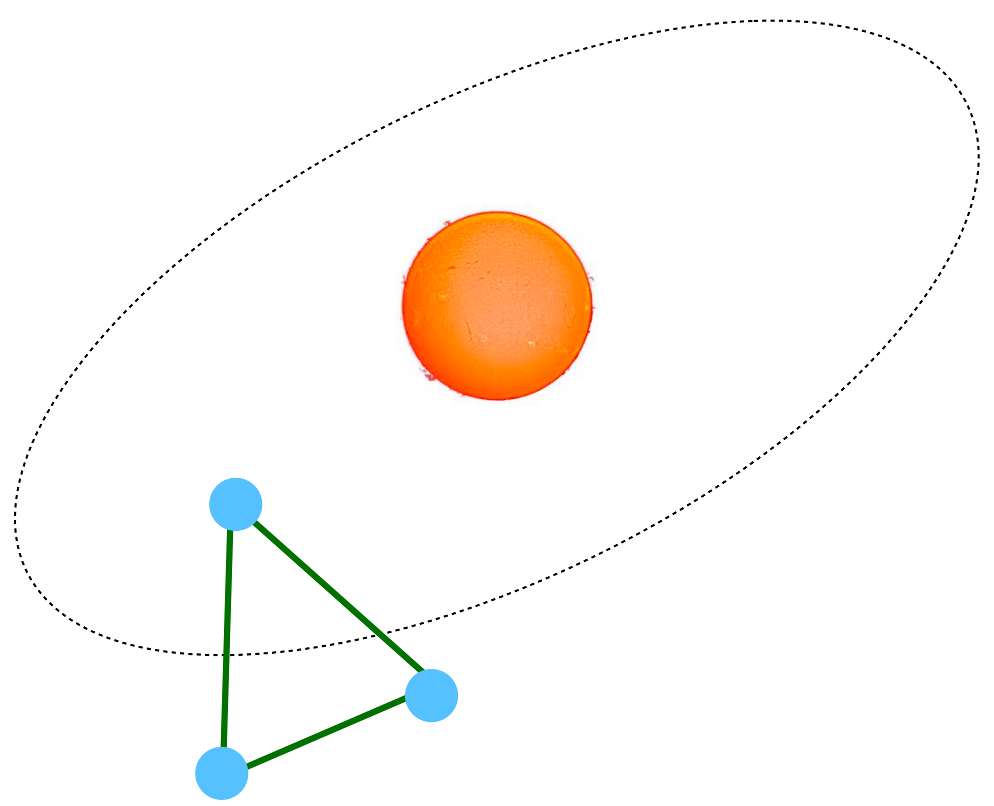
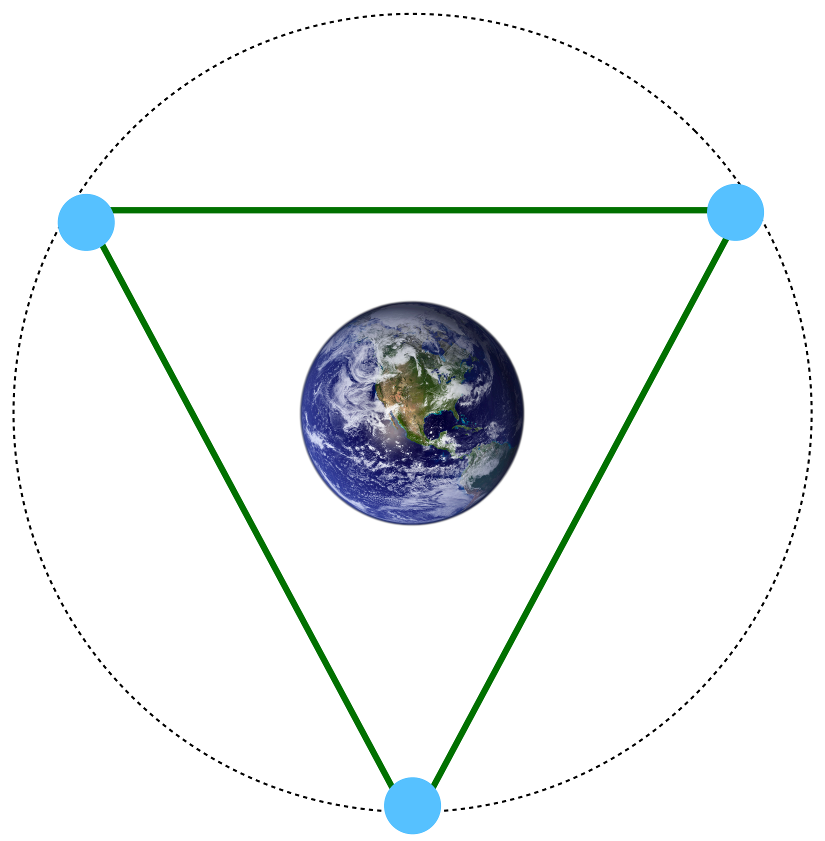
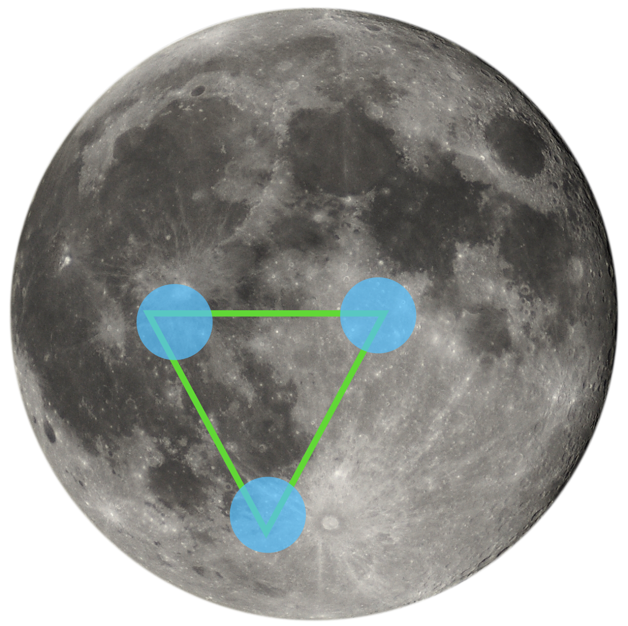
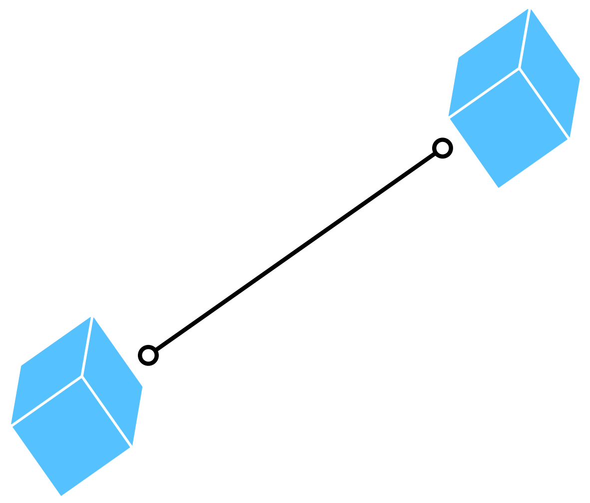



Arca Sedda, Berry, **KPJ** +
(Classical & Quantum Gravity, 2020)



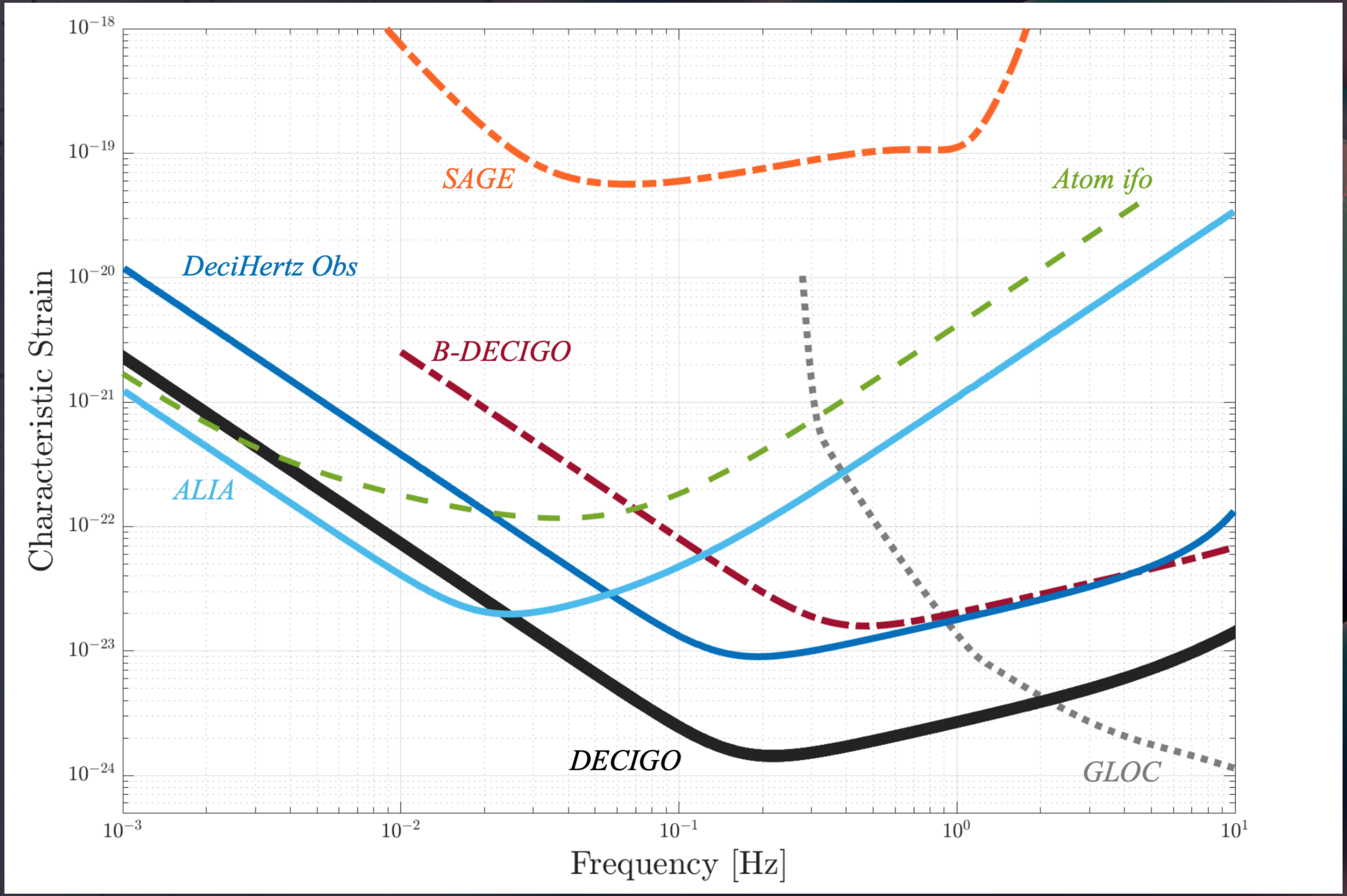

Izumi & **KPJ**
(2021)

# The deci-Hz epoch?

| Large Space Missions (Heliocentric) | Small Space Missions (Geocentric) | Lunar-based Experiments | Atom Interferometry |
| --- | --- | --- | --- |
|  |  |  |  |
| ***Decihertz Observatory*** Arca Sedda, Berry, **KJ**+ (CQG 2020); Submitted to ESA's Voyage 2050 | ***SAGE*** Lacour+ (with **KJ**) (CQG 2019) | ***LSGA*** Katsanevas et al. | ***MAGIS*** Graham+ (2017) |
| ***DECIGO*** Kawamura S et al. (CQG 2011) | | ***GLOC*** **KJ** & Loeb (JCAP 2021) | ***AEDGE*** El-Neaj+(2020) |
| | | ***LGWA*** Harms et al. (ApJ 2021) | |

Izumi & **KPJ,** *"Detection Landscape in the Deci-Hertz Gravitational-Wave Spectrum"*
*Invited chapter for "Handbook of Gravitational Wave Astronomy"* (Eds. C. Bambi, S. Katsanevas & K. Kokkotas; Springer 2021)

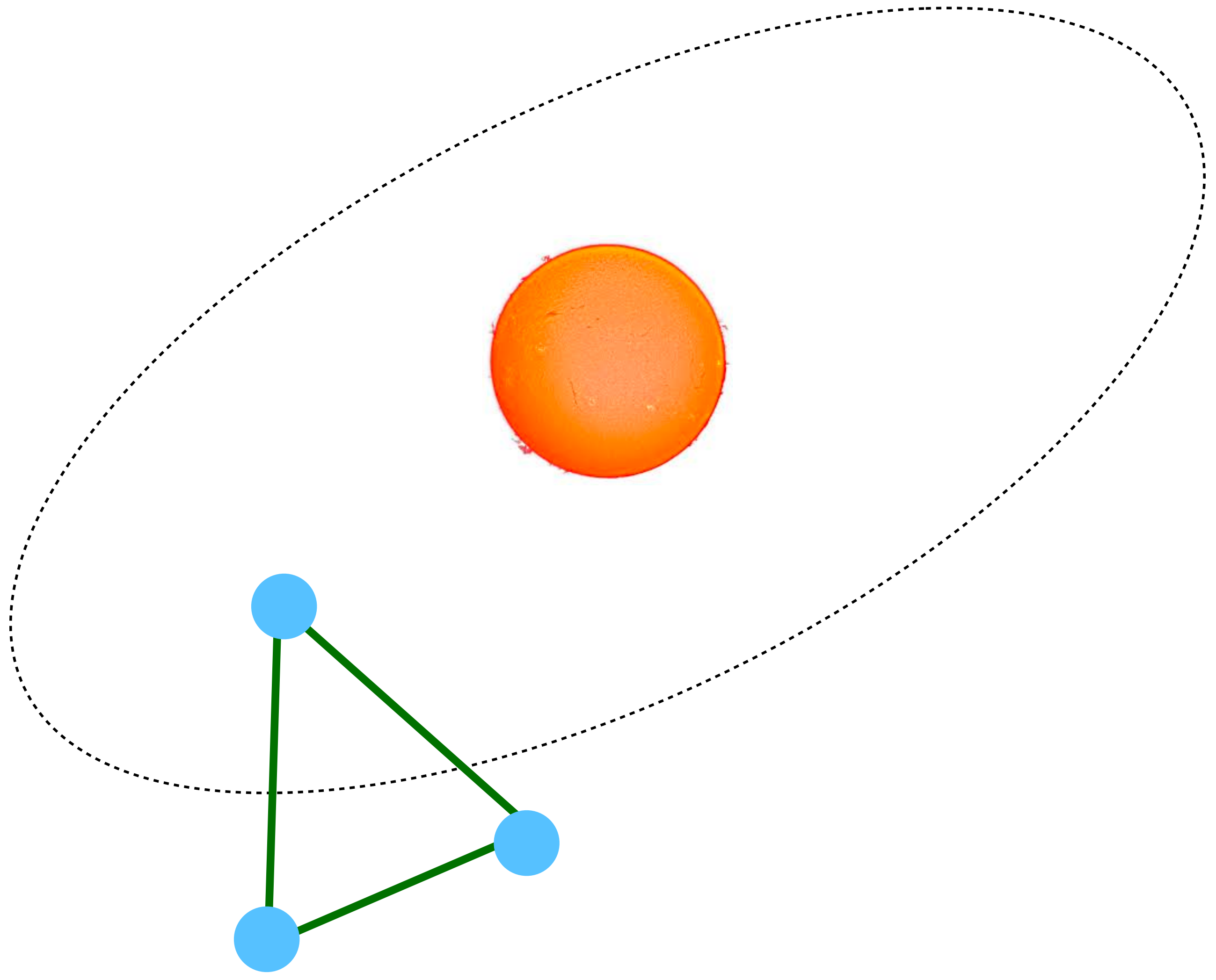
# The deci-Hz epoch?




Izumi & **KPJ,** *"Detection Landscape in the Deci-Hertz Gravitational-Wave Spectrum"*
*Invited chapter for "Handbook of Gravitational Wave Astronomy"* (Eds. C. Bambi, S. Katsanevas & K. Kokkotas; Springer 2021)

# deci-Hz for ESA Voyage 2050

Large Space Missions
(Heliocentric)



***Decihertz Observatory***
Arca Sedda, Berry, **KJ**+ (CQG 2020);
Submitted to ESA's Voyage 2050

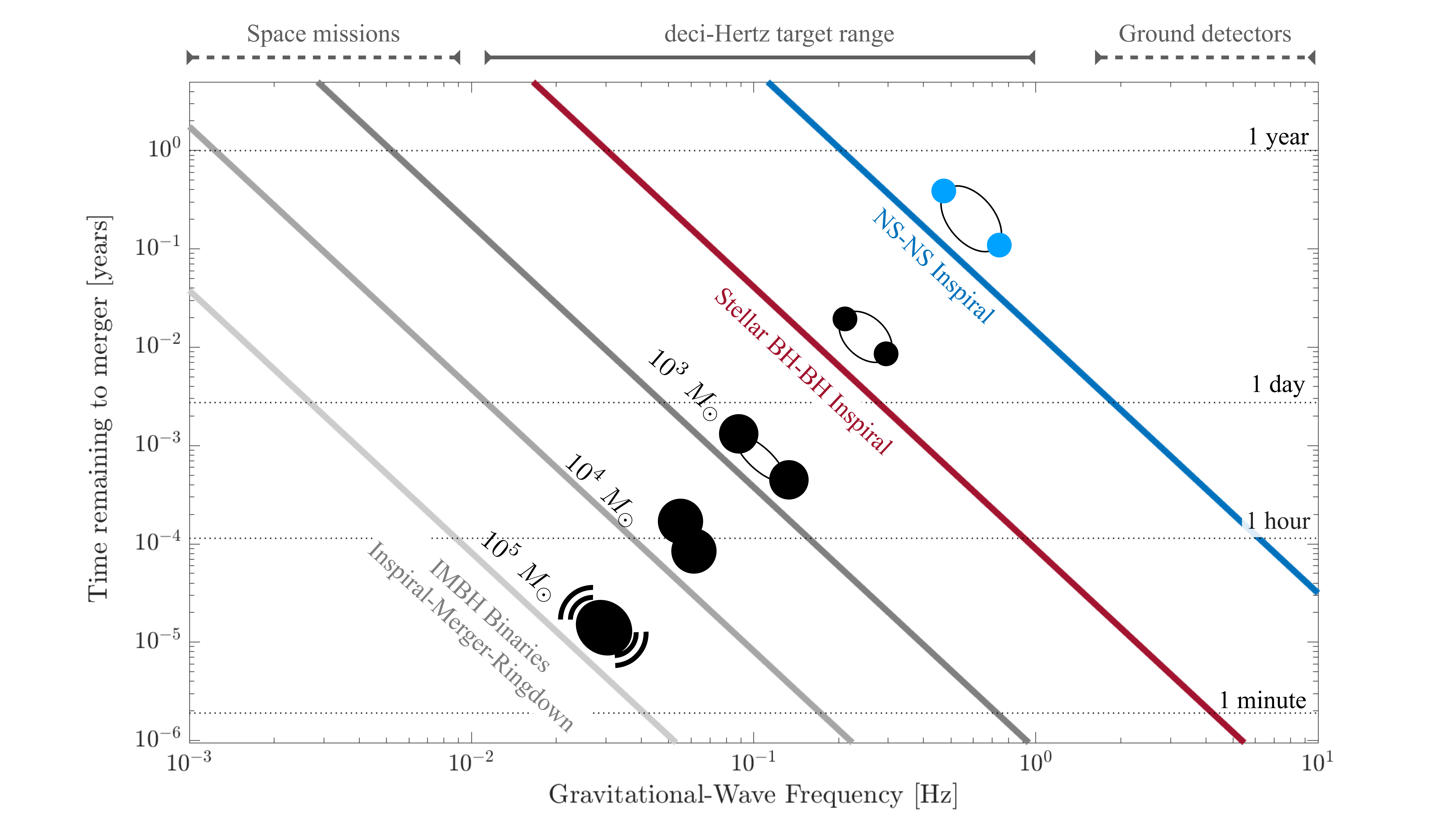
- **Deci-Hertz Observatory:**
  potential successor to LISA technology

- Assumes a factor of 100 improvement in acceleration noise

- Wavelength to 532 nm, laser power 10 W
  (1064 nm and 2W used in LISA)
  Diameter of the telescope: 1 m

- Baseline 25x shorter than for LISA
  - Shorter arms in a heliocentric orbit - reduced Doppler shifts between spacecraft. Reduces the timing requirements by a 25x.

# Science Case-1: The Elusive Intermediate-Mass Black Holes (IMBHs)

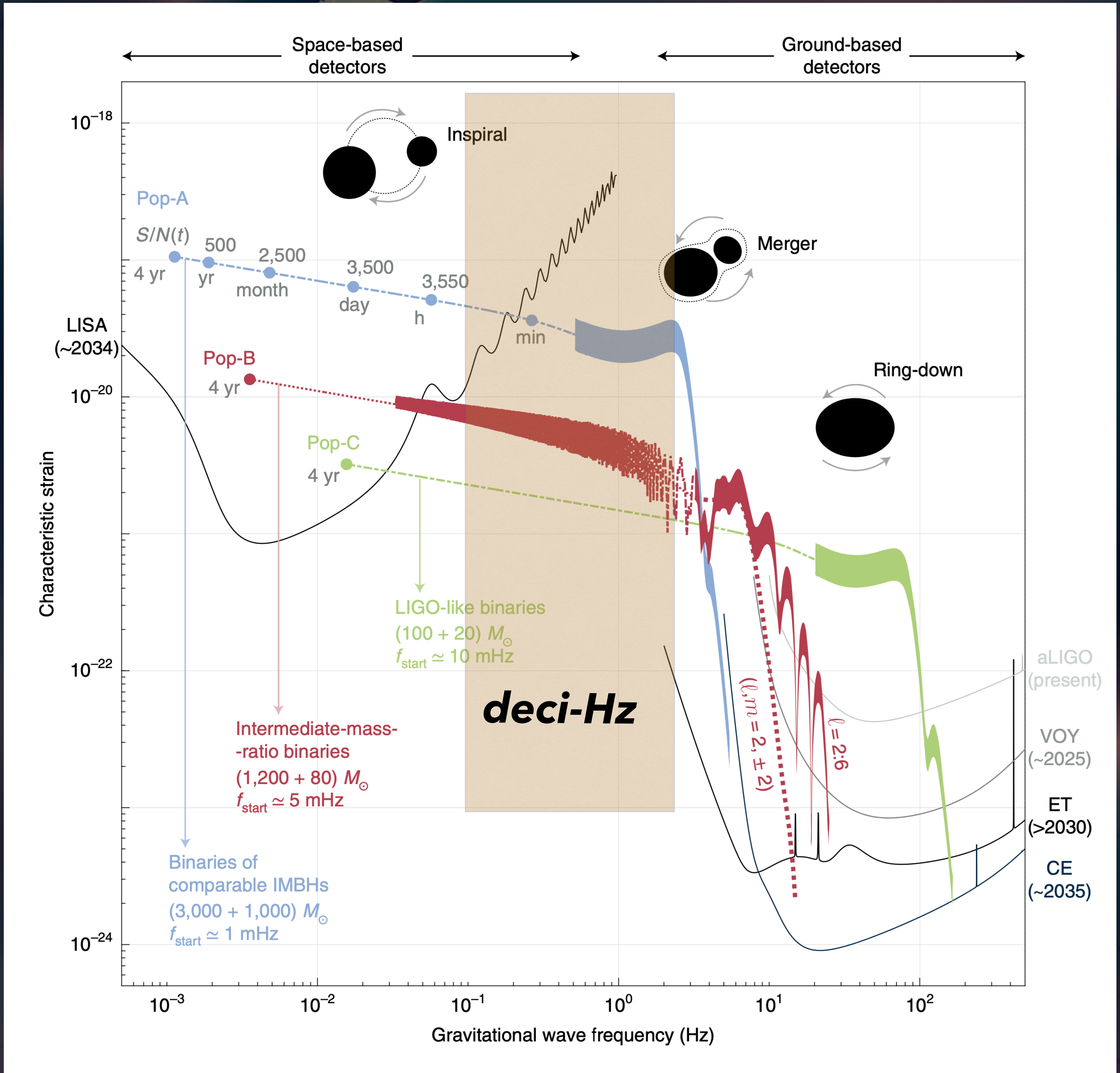



Izumi & **KPJ,** *"Detection Landscape in the Deci-Hertz Gravitational-Wave Spectrum"*
*Invited chapter for "Handbook of Gravitational Wave Astronomy"* (Eds. C. Bambi, S. Katsanevas & K. Kokkotas; Springer 2021)

# Science Case-2: Multi-Wavelength GW Astronomy

- **<u>Every</u>** <u>compact binaries</u> seen by ground-based detectors (LIGO, Virgo, ET), will be measured in dec-Hertz detector for months to years in advance. **<u>Not true for LISA</u>**
- Opens new regime to test General Relativity
- Direct information of astrophysical environment

Sesana (Phys Rev. Let. 2016),
Vitale (Phys Rev. Let. 2016),
KPJ+ (Nature Astro. 2020) and many others



# Science Case-3: Multi-Messenger Astrophysics

- **Joint electromagnetic + gravitational wave** observations can potentially lead to the discovery of thousands of tidal disruptions
- Example: white dwarf inspiraling around an IMBH will be tidally disrupted before it is swallowed.
- Gravitational wave signal will be accompanied by bright electromagnetic flare at much beyond Eddington luminosity during the tidal disruption and accretion.

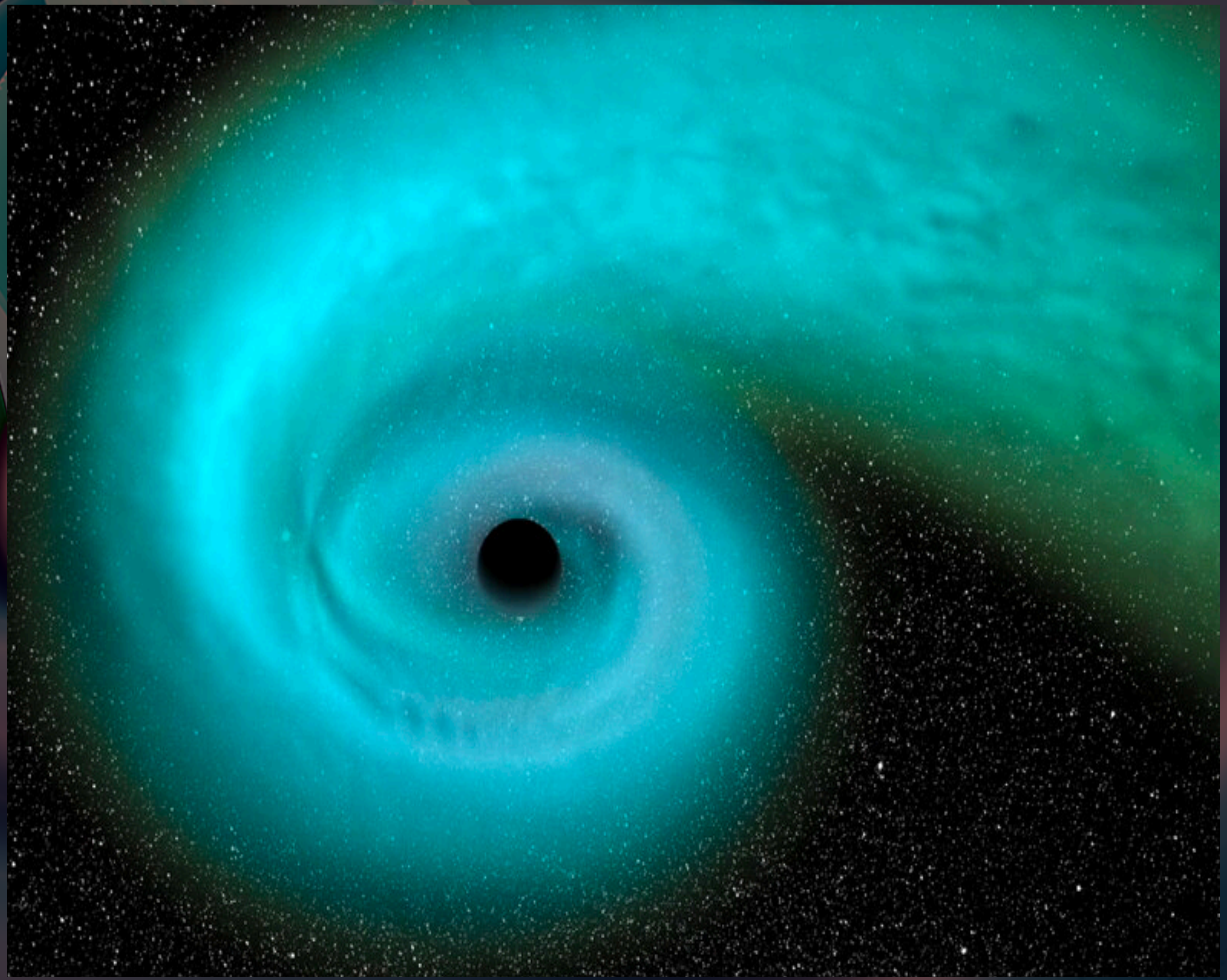
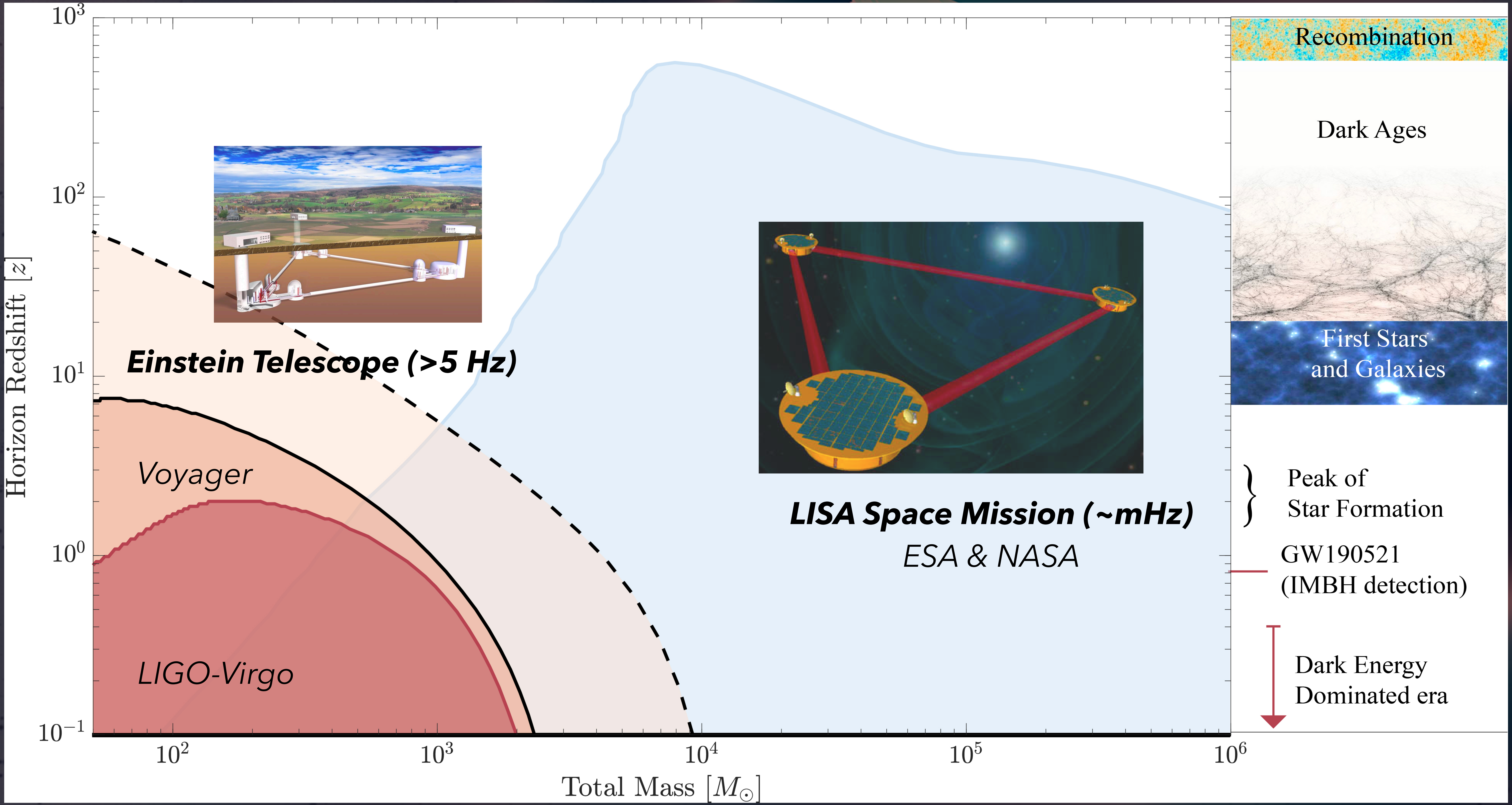


Image: Deborah Ferguson +

Arca Sedda, Berry, **KPJ** + (CQG, 2020) and references within

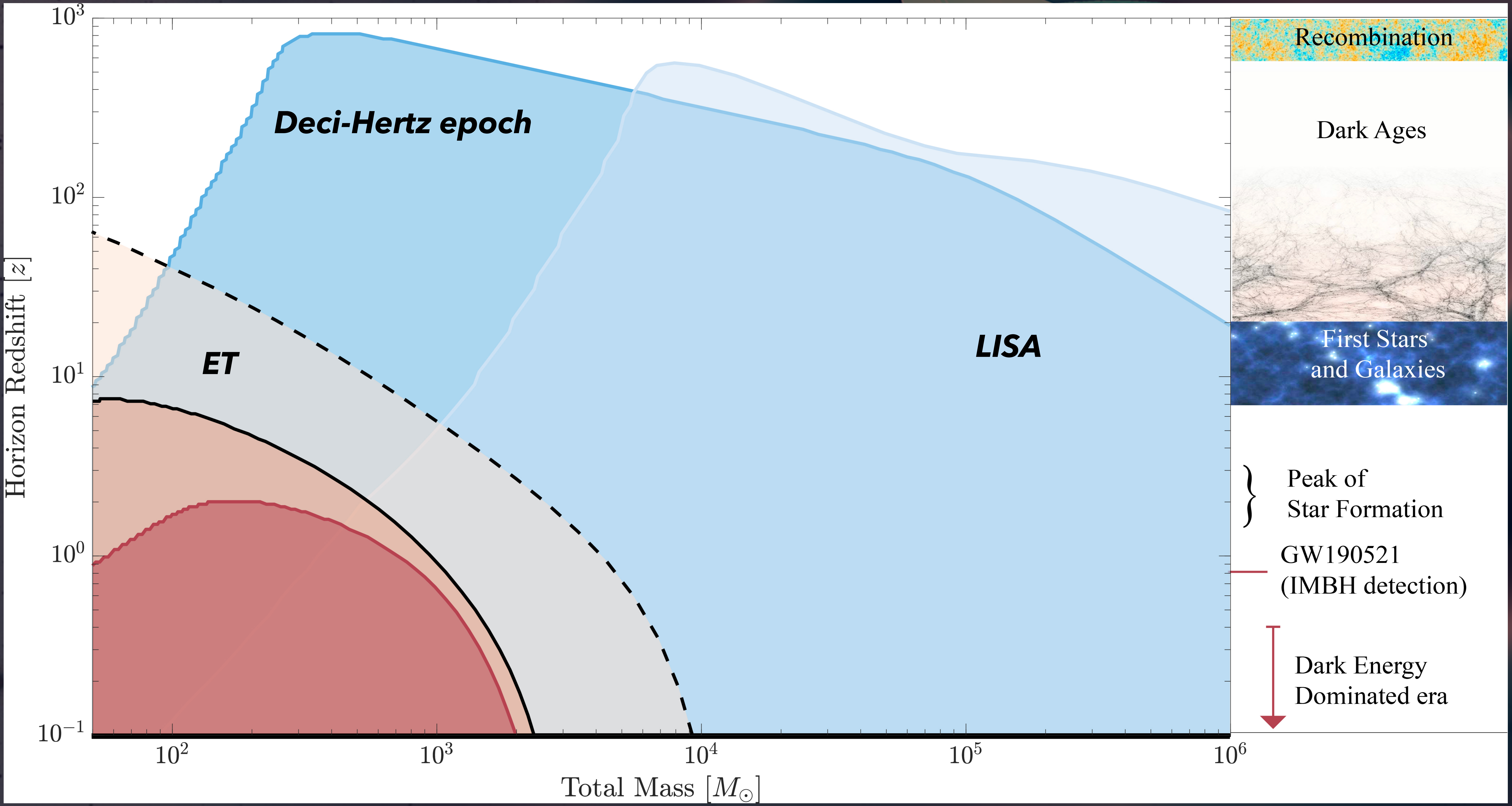
# Science Case-4: Largest survey of black holes in the universe




KPJ, Shoemaker & Cutler (Nature Astronomy, 2020)

# Science Case-4: Largest survey of black holes in the universe

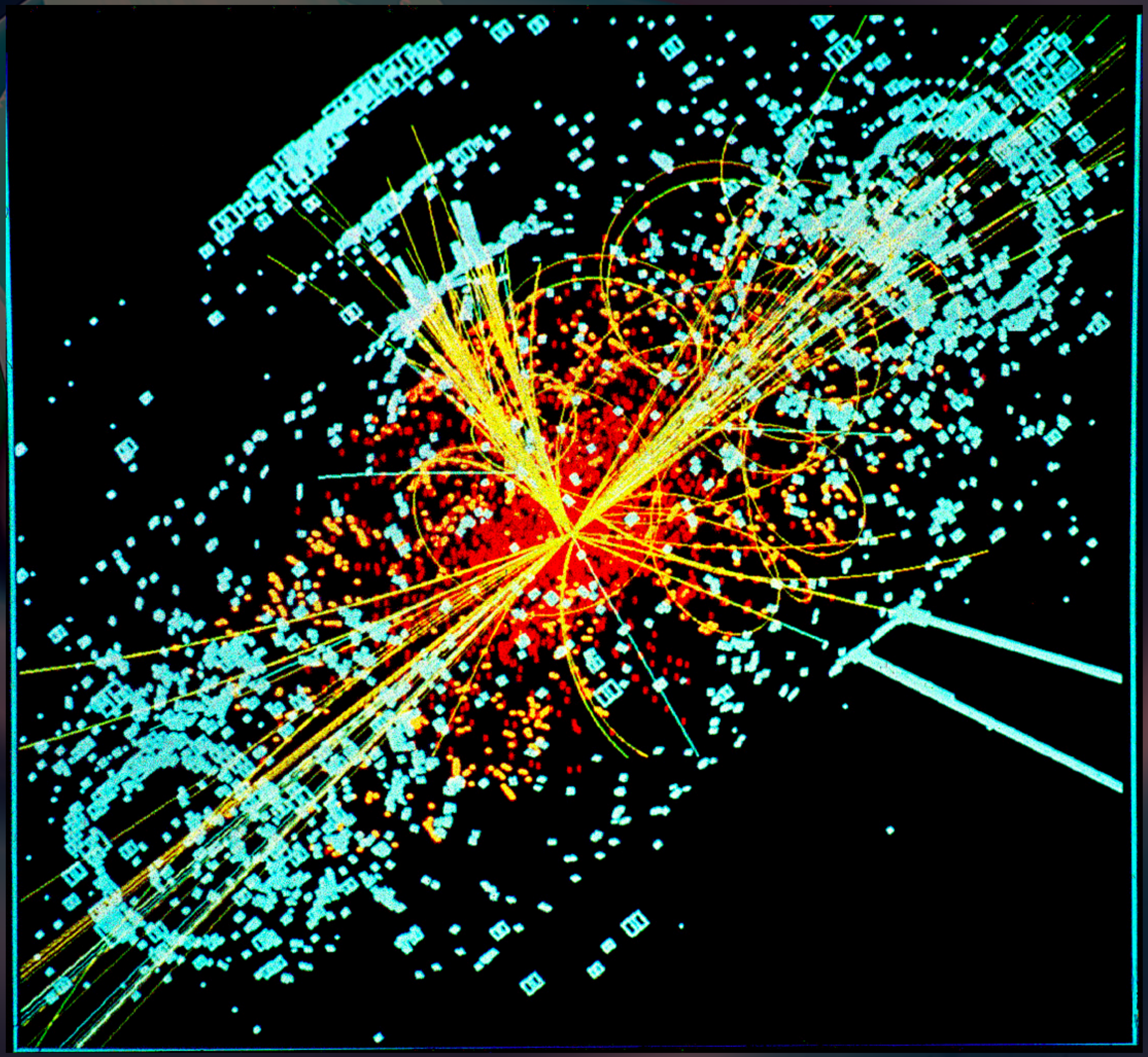
***(And continuing the LISA science)***




Arca Sedda, Berry, **KPJ** + (Classical & Quantum Gravity, 2020)

# Science Case-5: Physics Beyond the Standard Model

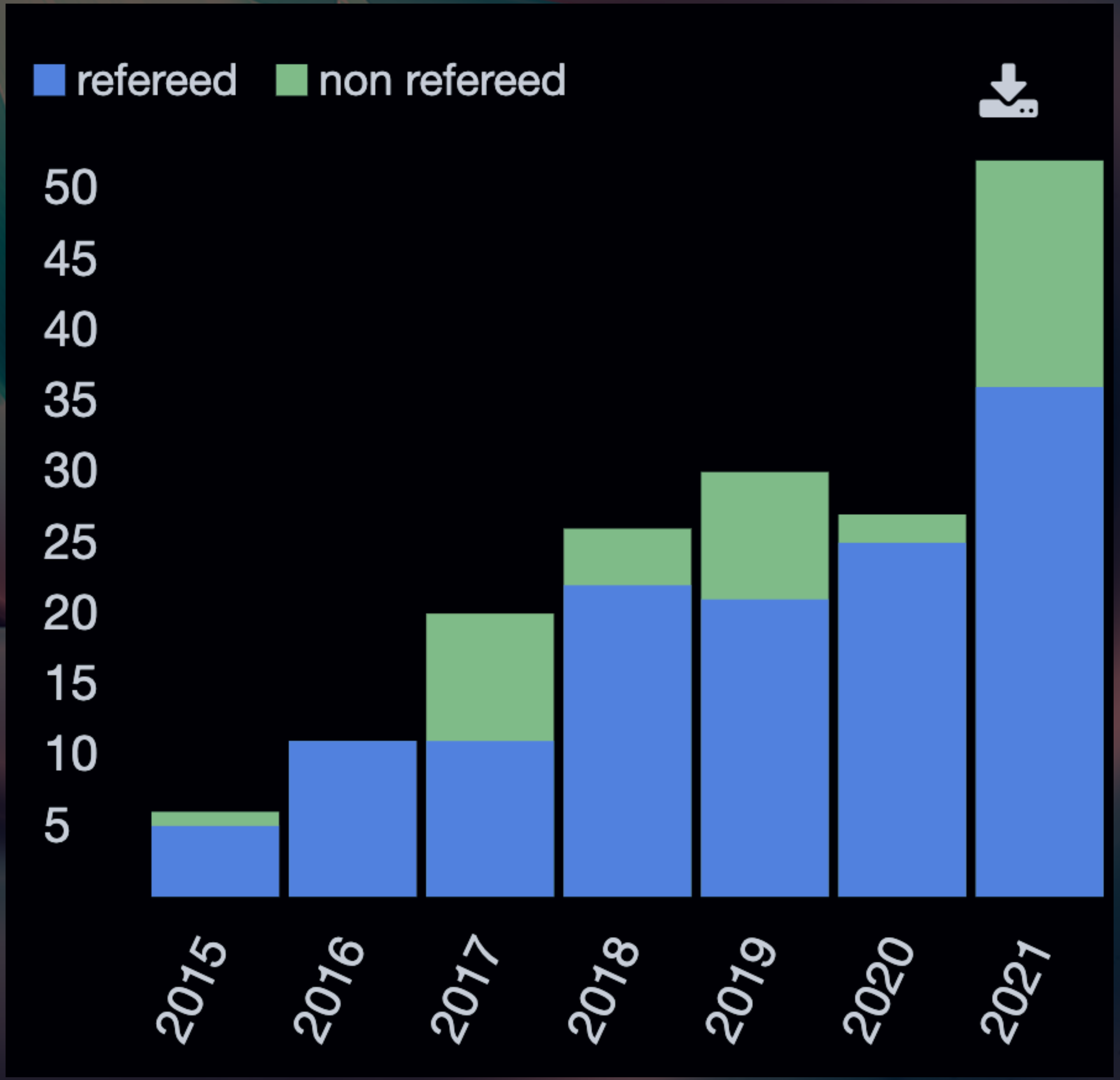
- Sub-solar mass dark matter search to cosmological scale
- Low frequency bosonic fields scattering off rotating IMBHs are super-radiantly amplified - can probe beyond-standard model particles from dark matter candidates
- Sensitivity to discover stochastic GW background (strongest constraints on merger rate to remove astrophysical background); constraining cosmic string tension with other band



Arca Sedda, Berry, **KPJ** + (CQG, 2020) and references within

# In conclusion

- Observing gravitational waves in ~**<u>0.1-1 Hz</u>** range presents huge opportunities for advancing our understanding of both **<u>astrophysics</u>** and **<u>fundamental physics</u>**
- **Strong synergy** of deci-Hertz science-case with ground-based (>10 Hz) and space-based (~mHz) gravitational-wave spectrum
- Many promising detector concepts for bridging the **missing link**
- Potential timescale of technology demonstration **remains unknown**




*Publications on deci-Hertz since GW150914*