Capabilities of Future Gravitational-Wave Detectors

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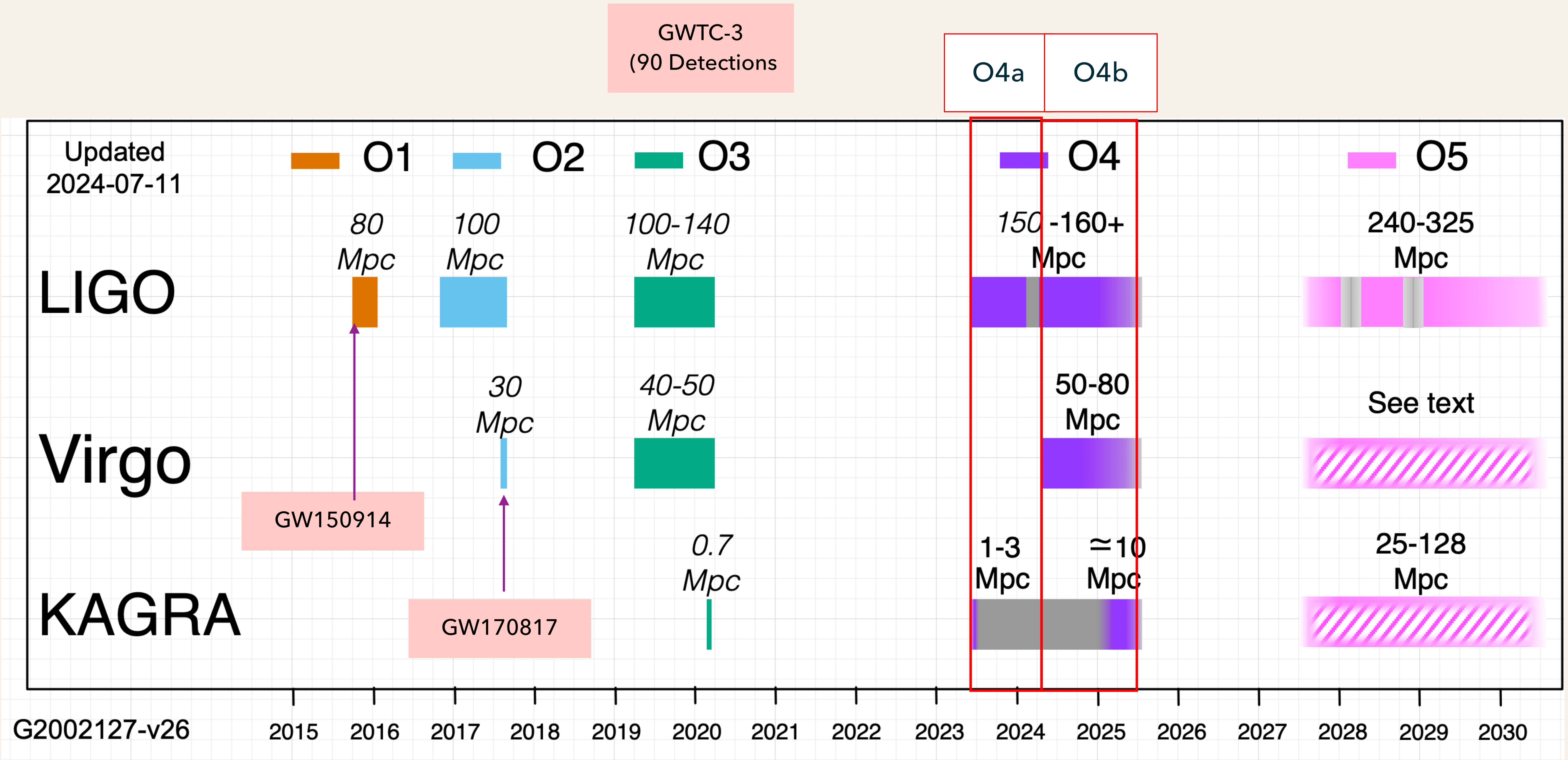
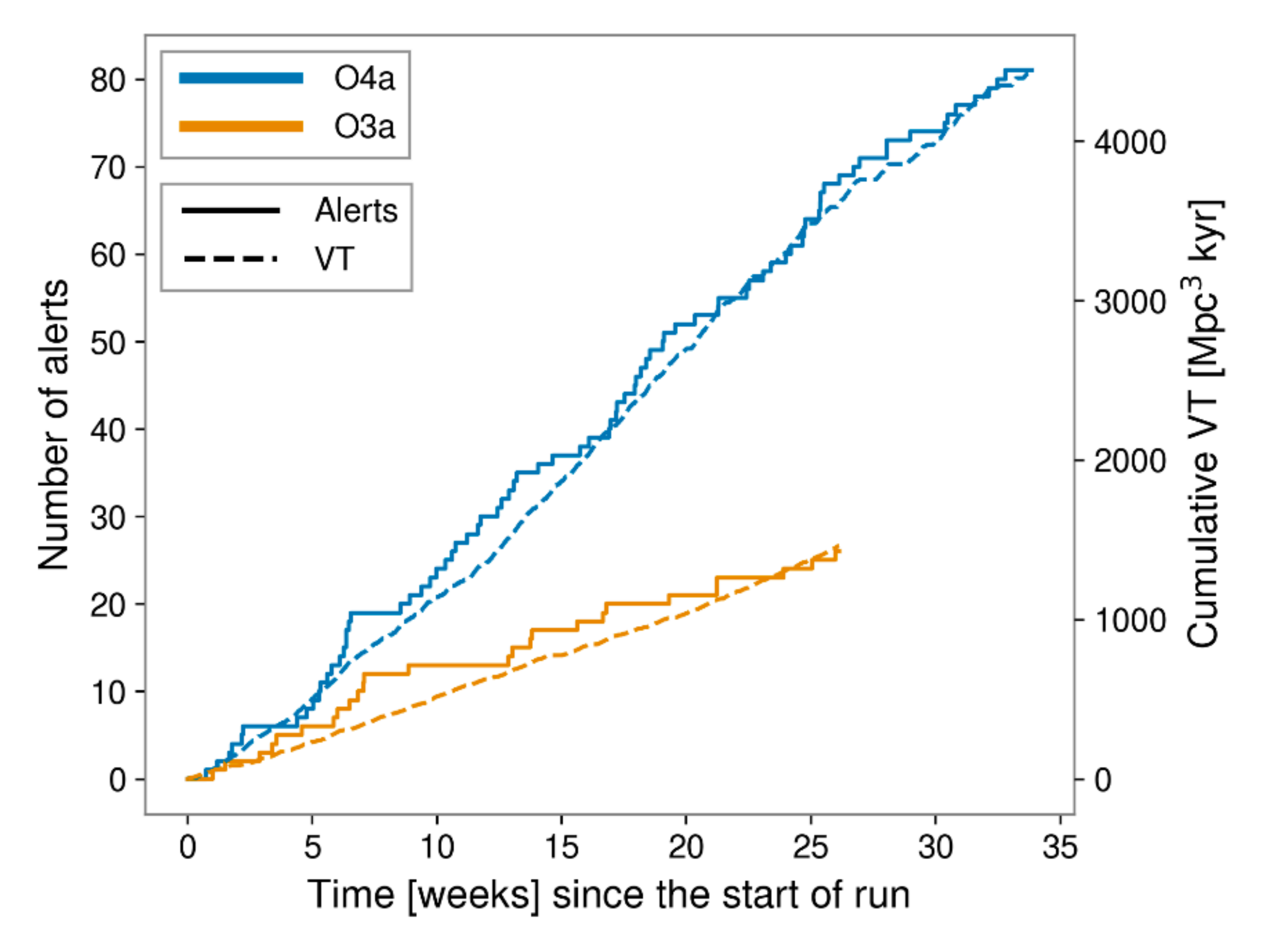
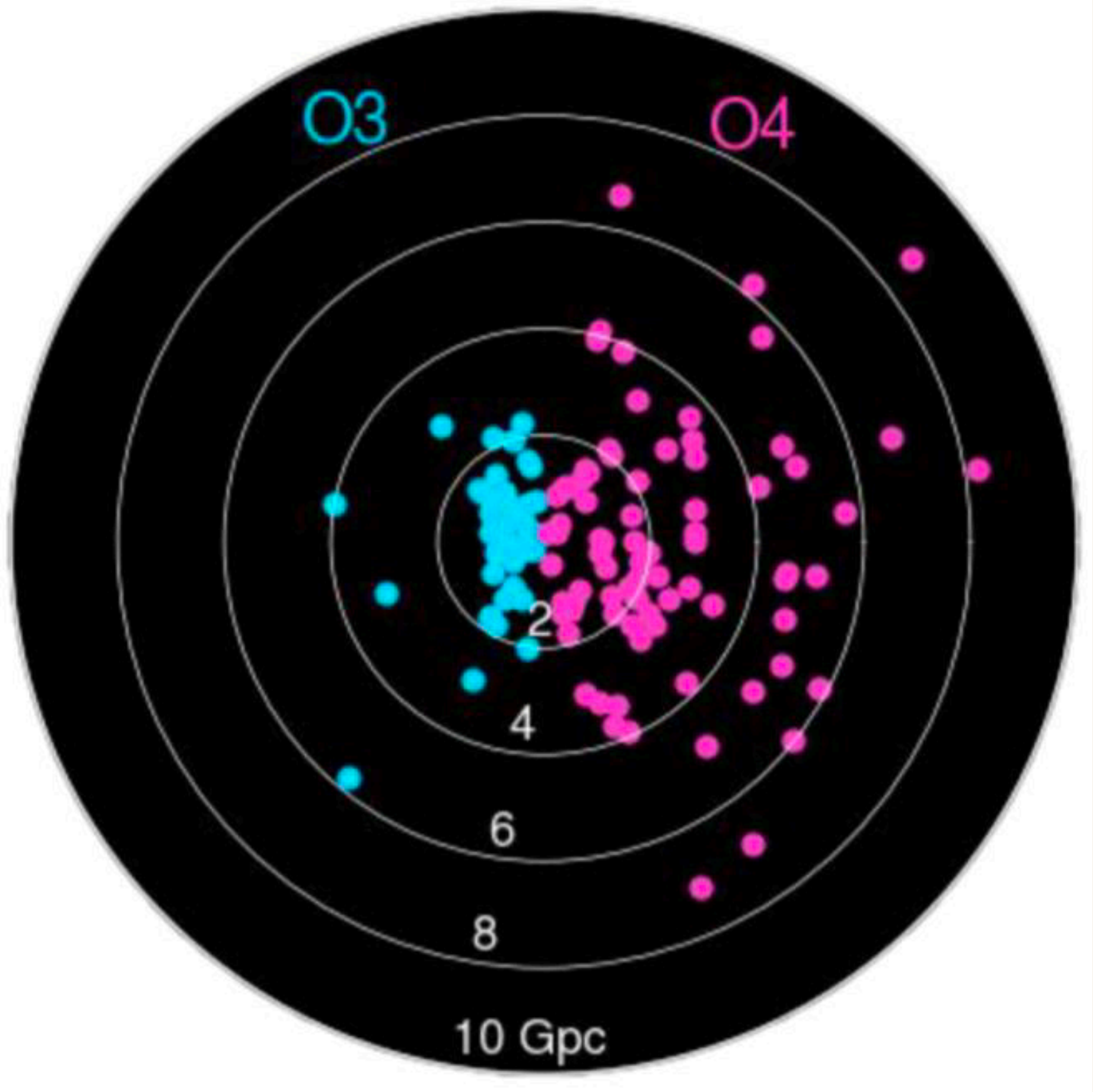
Current Detectors: LIGO/Virgo/KAGRA (2G)



O3 versus O4

- Better sensitivity → More detections, further distances
- Lower retraction



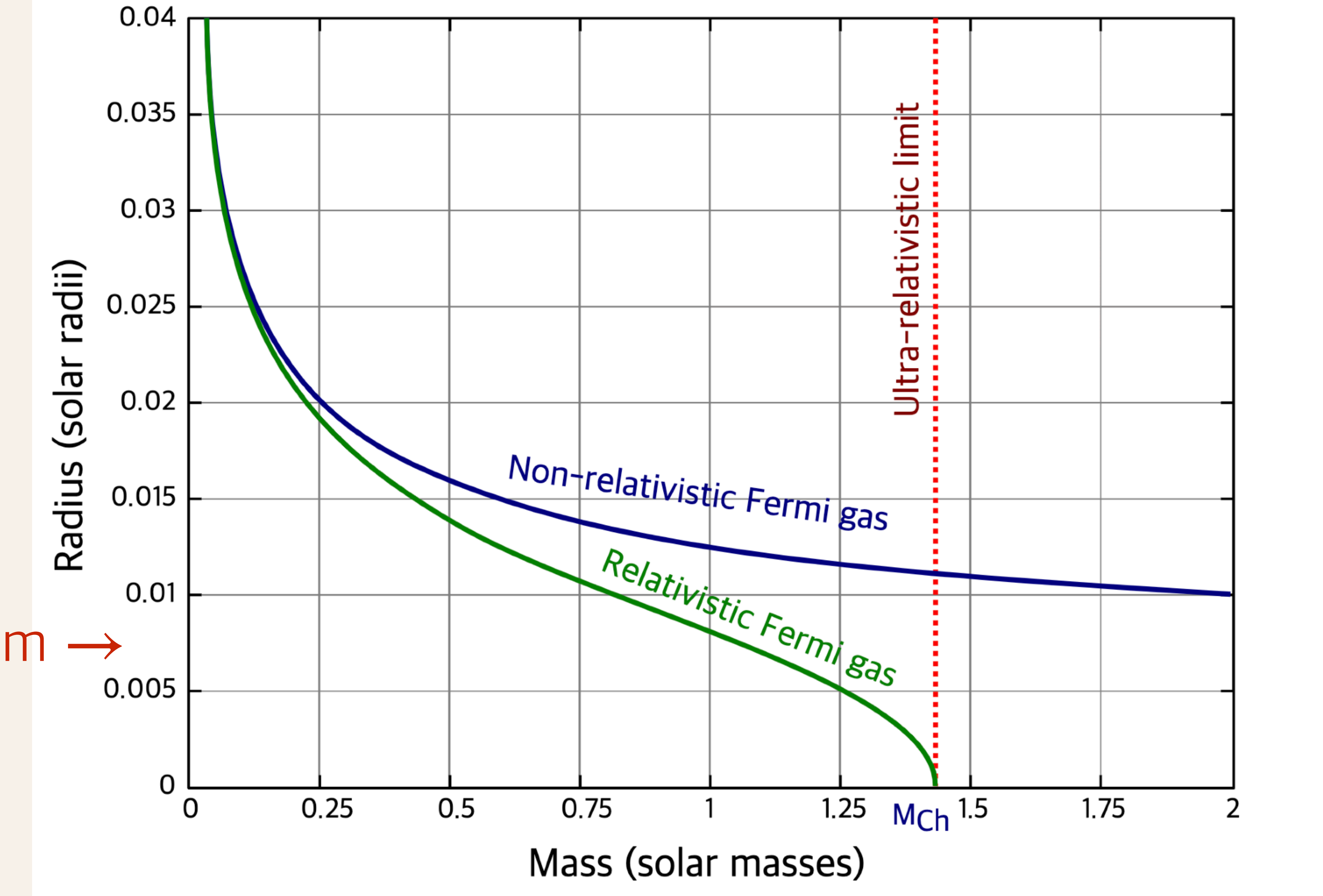


Compact Objects in the Universe

- White Dwarfs:
  - $M \lesssim 1.4\ \mathrm{M}_\odot$
- Neutron stars:
  - $1\ \mathrm{M}_\odot \lesssim \mathrm{M} \lesssim 2.5\ \mathrm{M}_\odot$, R~ 20 km
- Black holes:
  - Stellar Mass Black holes:
    - $5\ \mathrm{M}_\odot \lesssim \mathrm{M} \lesssim 70\ \mathrm{M}_\odot$
  - Supermassive Black Holes
    - $M \gtrsim 10^6\ \mathrm{M}_\odot$
  - Intermediate Mass Black Holes
    - $100\ \mathrm{M}_\odot \lesssim \mathrm{M} \lesssim 10^4\ \mathrm{M}_\odot$
  - Primordial Black Holes
    - Any mass

via stellar evolution

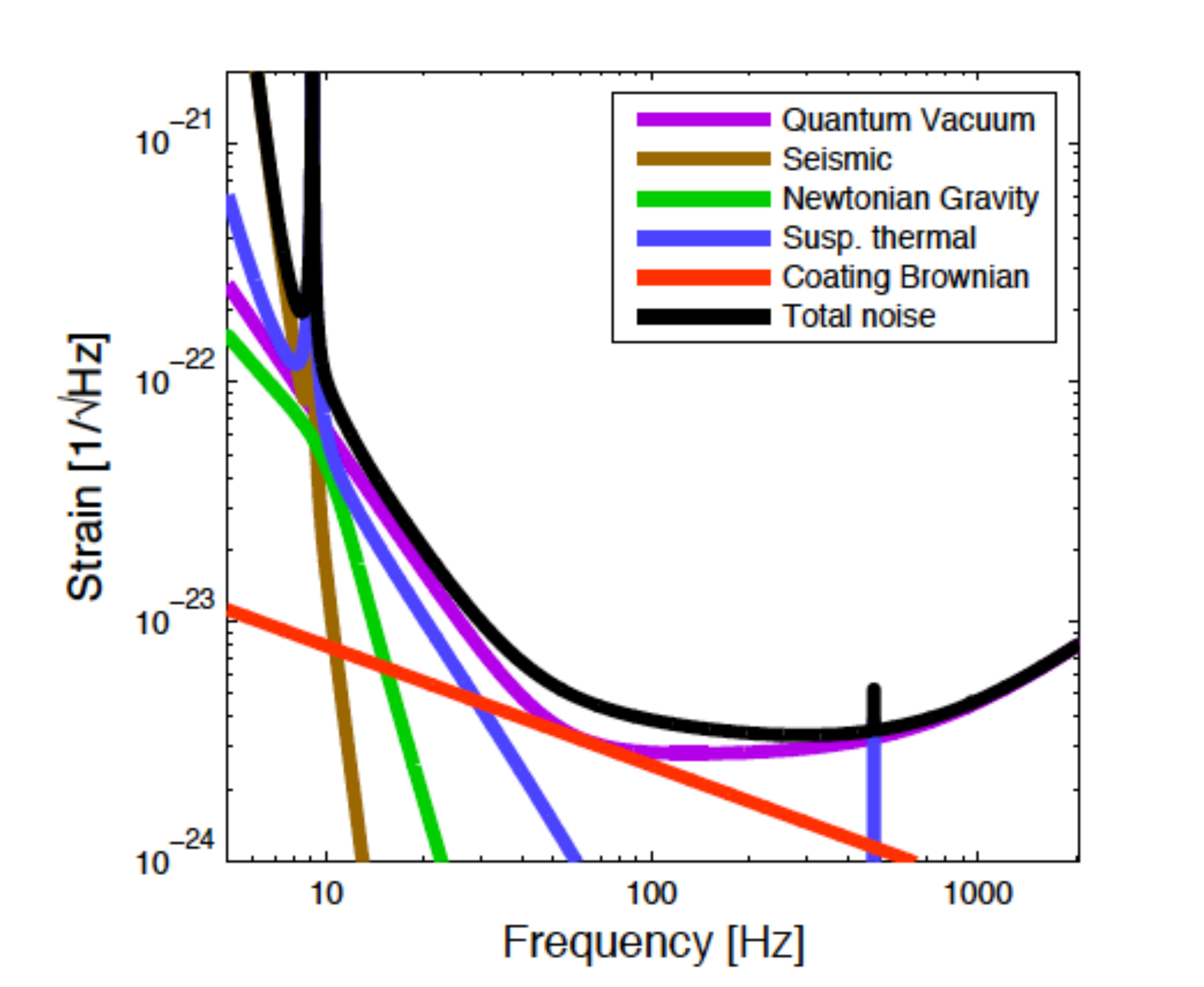
5000 km →



Mass-radius relationship for degenerate gas

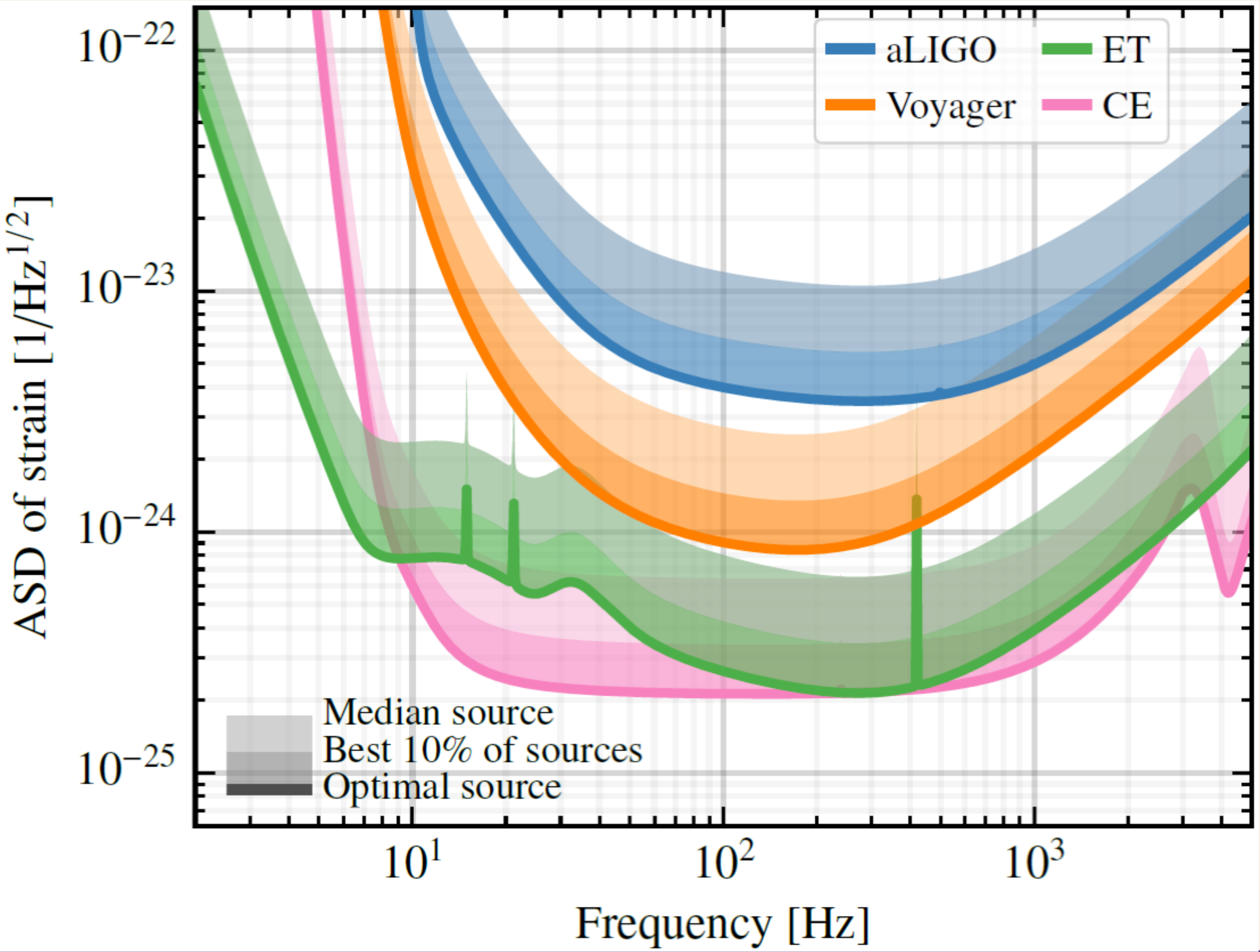
Future GW Detectors: Ground Based

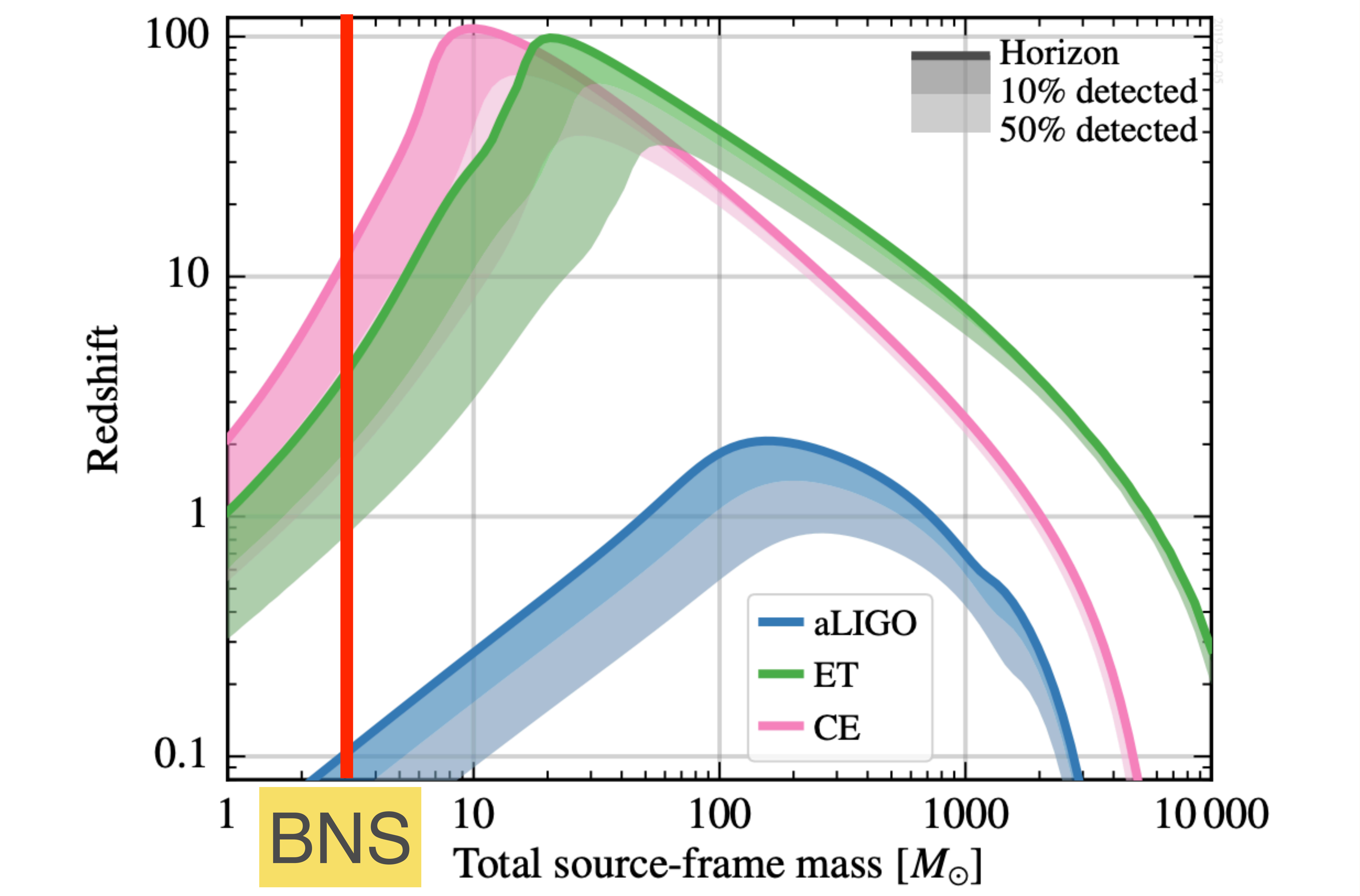
- Currently, the detection frequency is limited by the seismic and gravity noises of the ground-based detectors i.e, $f_{GW} \gtrsim 30\ \mathrm{Hz}$.
  - LIGO is planning to upgrade to achieve x1.5 (A+) and x3 (Voyage) sensitivity
- Future Detectors
  - Larger scale ground based detectors for higher sensitivity (3G Detectors)
    - Einstein Telescope (ET)
    - Cosmic Explorer (CE)



Sensitivities of 3G Detectors

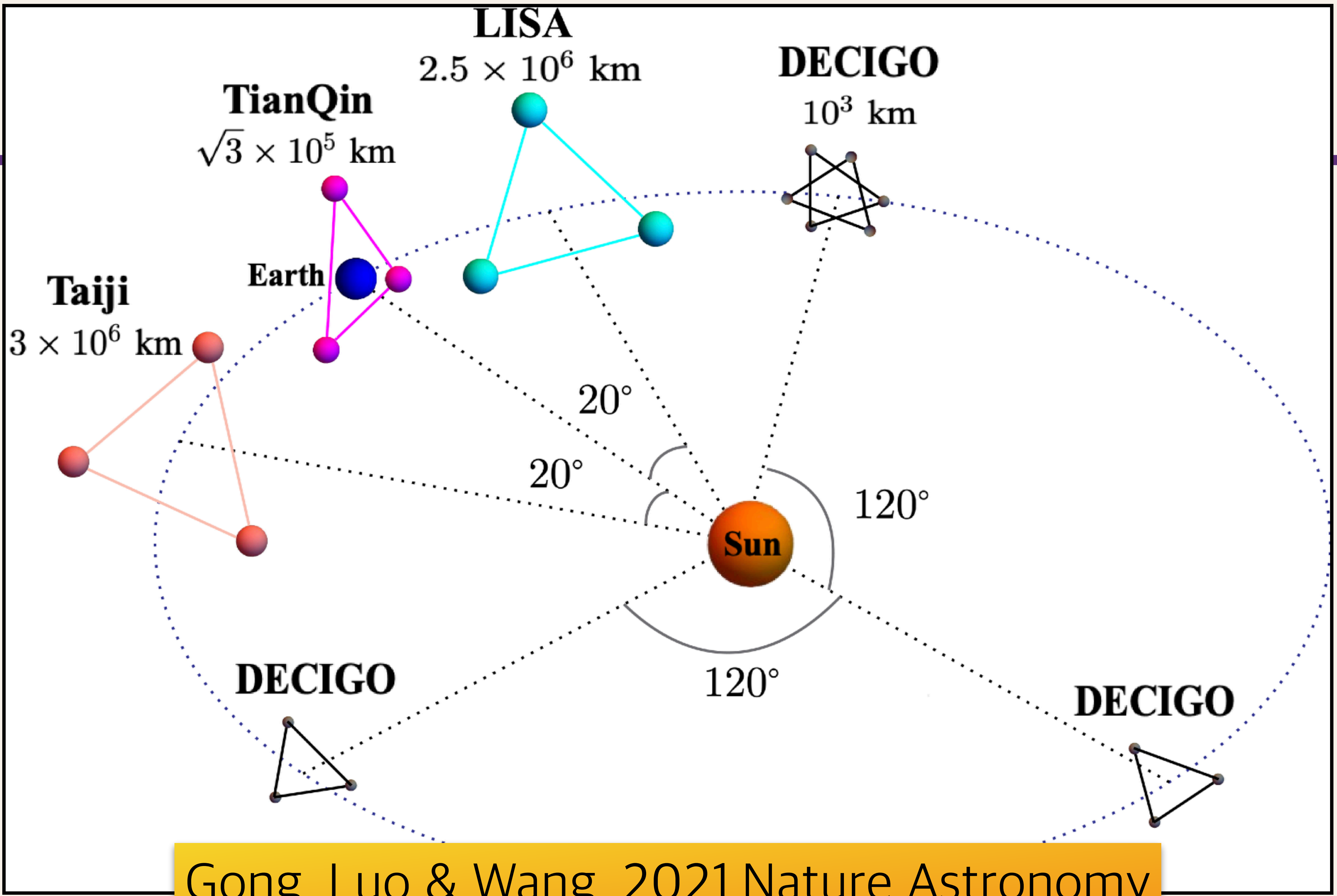
Laser interferometers similar to LIGO/Virgo covers frequencies higher than 10 Hz (except for ET which will be located underground)



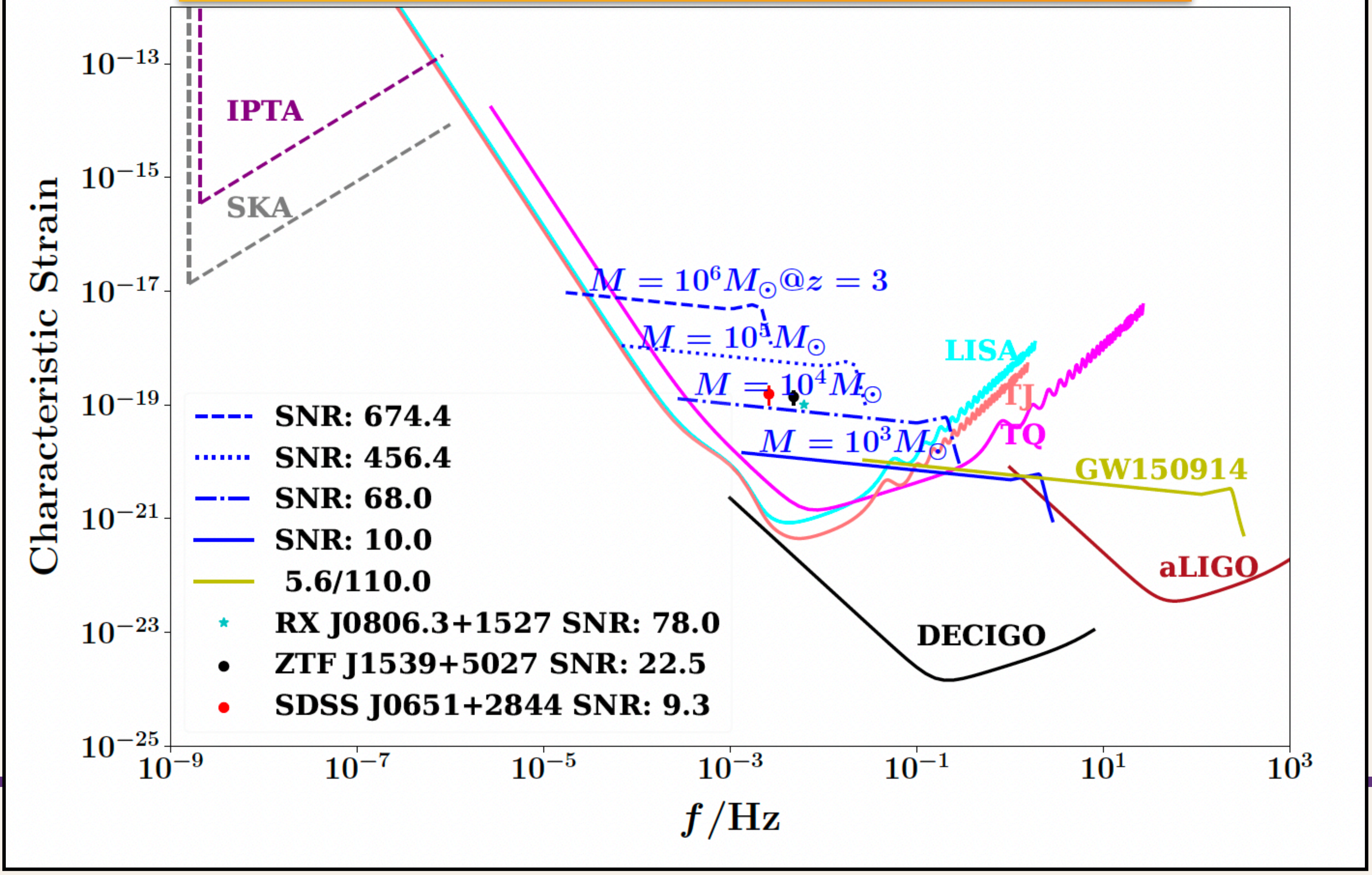


Space based detectors

- LISA: Trailing Heliocentric
  - Composed of 3 spacecrafts with 5×10^6 km separation each
  - Sensitive at frequency range of $10^{-4} \sim 10^{-1}$ Hz
  - Targets are massive binaries composed of $10^3 \sim 10^6$ $M_\odot$ black holes
  - Scheduled to be launched in 2037
- TianQin (天琴): Geocentric
- Taiji (太極): Prevailing Heliocentric
- DECIGO: Geocentric

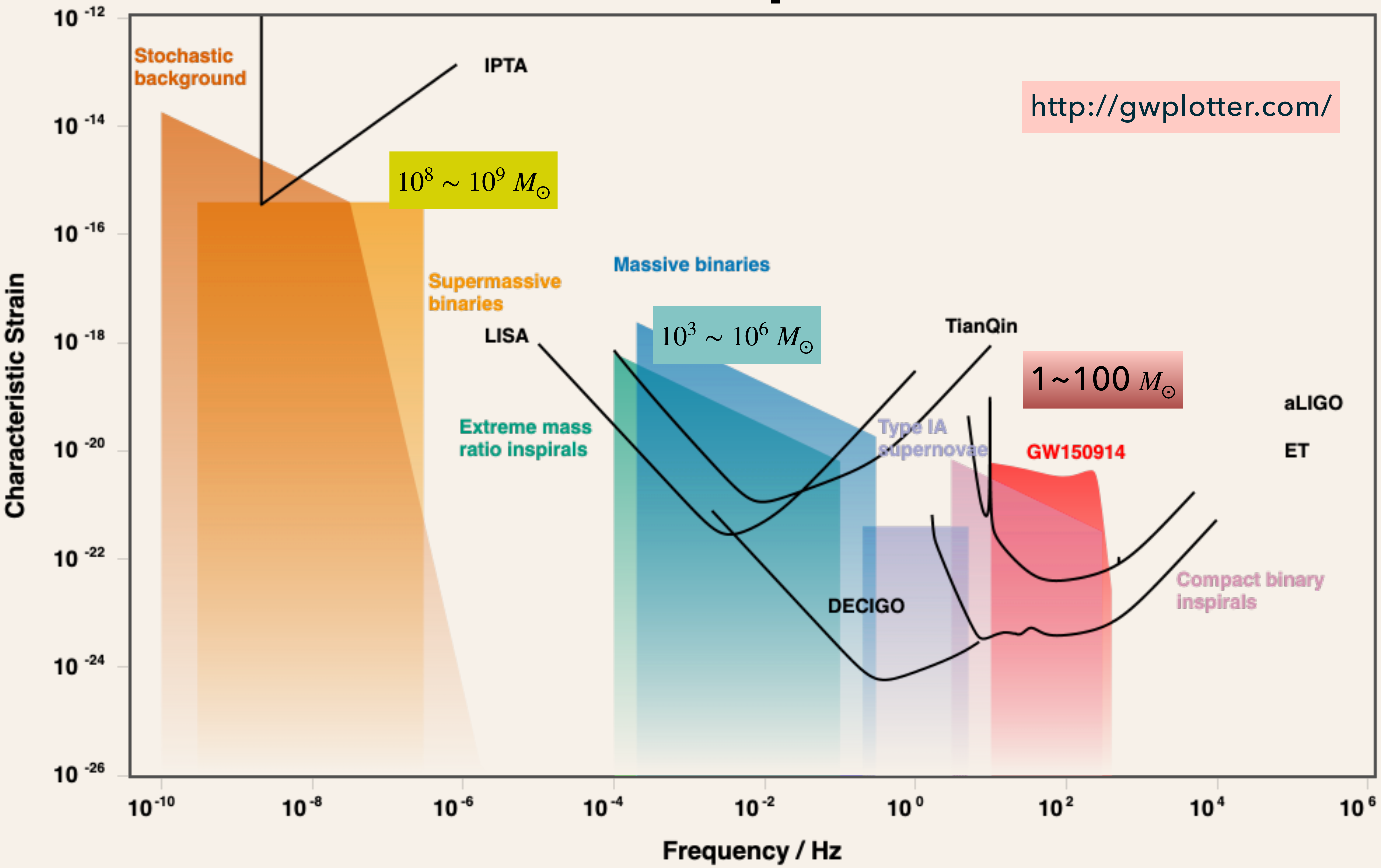


Gong, Luo & Wang, 2021,Nature Astronomy



Current and Future Detecors at All Frequencies

- We expect many different types of gravitational sources at various frequencies
- Future detectors will be able to observe gravitational waves at lower frequencies
  - LISA
  - DECIGO



International GW Observatory Network (IGWN)

- History
  - Currently, LIGO, Virgo, and KAGRA are working together based on the MOU that expires soon
  - The GW community decided to form an organization that encompasses all ground-based detectors
- Missions:

The IGWN is a self-governing consortium using gravitational-wave detectors to explore the fundamental physics of gravity and observe the universe. The IGWN works toward this goal through development, commissioning and operation of the IGWN ground-based interferometric gravitational-wave detectors; through the development and deployment of techniques for gravitational-wave observation; and through interpretretation of gravitational-wave data.

VIRGO
LIGO
KAGRA

International Gravitational-Wave Observatory Network (IGWN)

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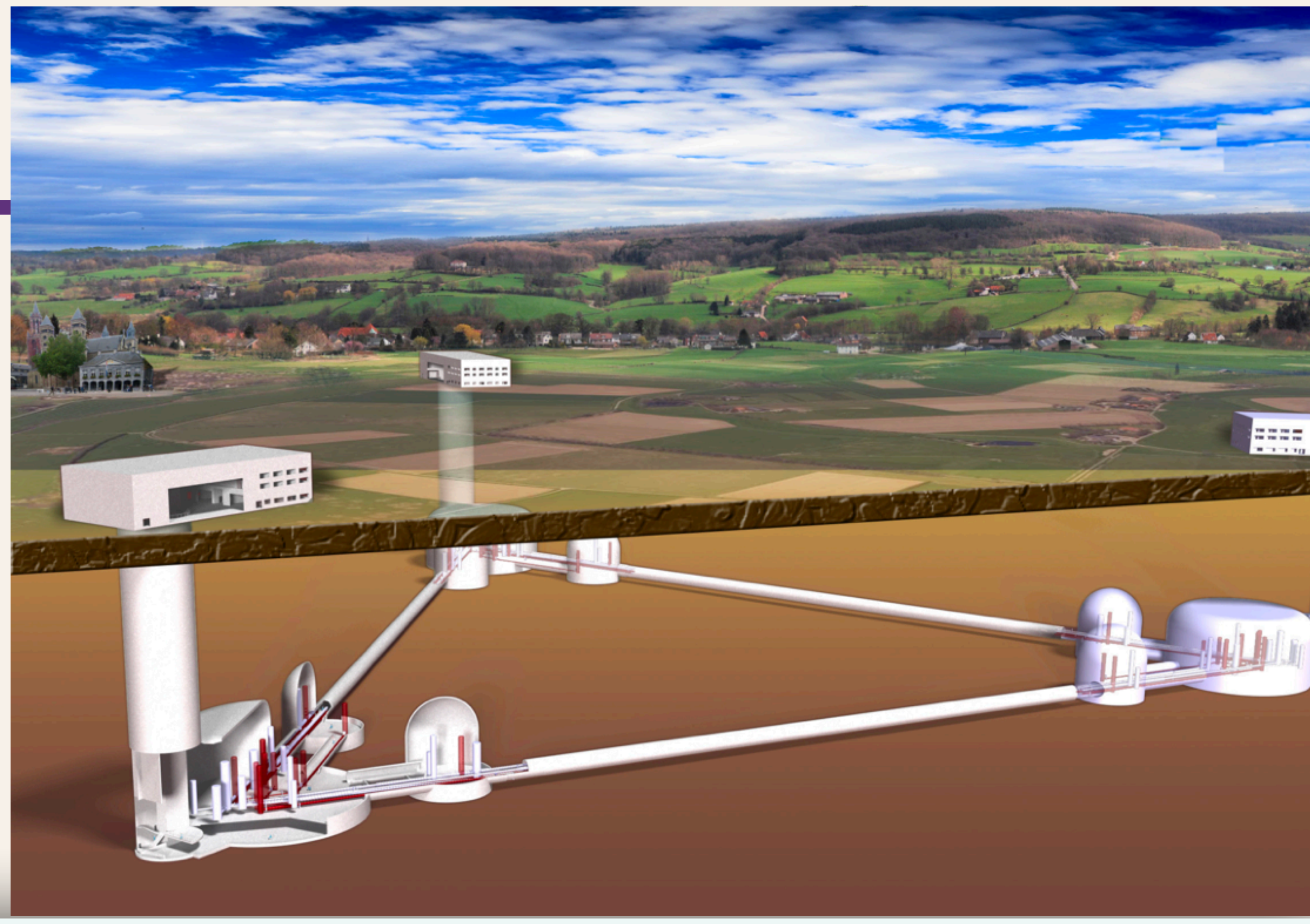
Korean GW Community

- Korean GW Group (KGWG) was founded in Nov. 2003 as a voluntary study group and has grown to a ~100 member group
- KGWG members are taking part in LIGO, KAGRA, ET projects.
    - But each group is small.
- Experimental Groups
    - Characterization and search for coating material (LIGO) [성균관대]
    - Squeezing of light source to overcome quantum limit (KAGRA, ET) [KASI, KAIST]
    - Multi-messenger Astronomy (KMTNet, 7DT)
    - Micro-gravity experiment (NIMS)
- Science Interests
    - Black Holes in various mass scale
    - Application of GWs to astrophysics and cosmology

ET Collaboration & Korean Research Unit

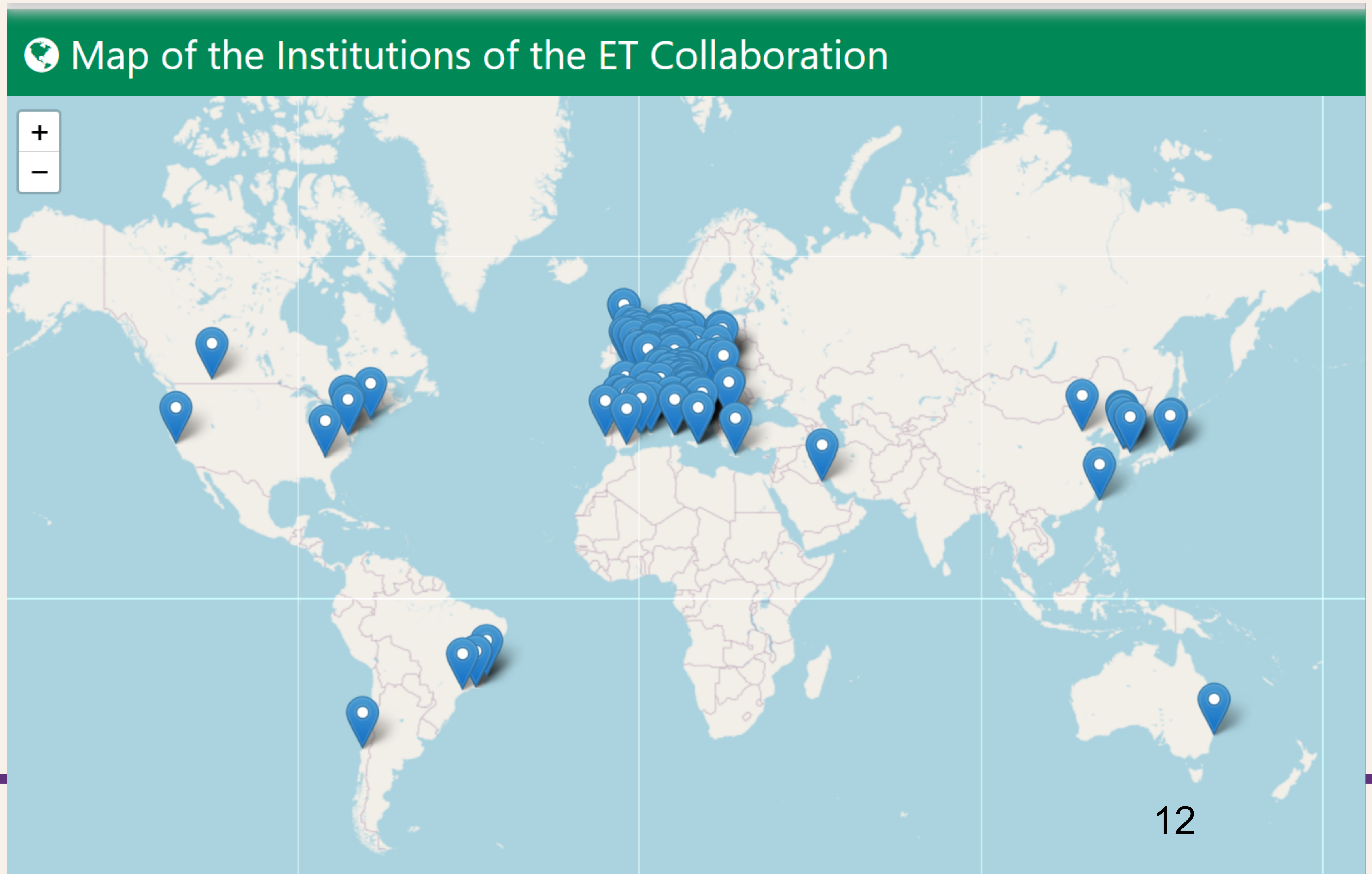


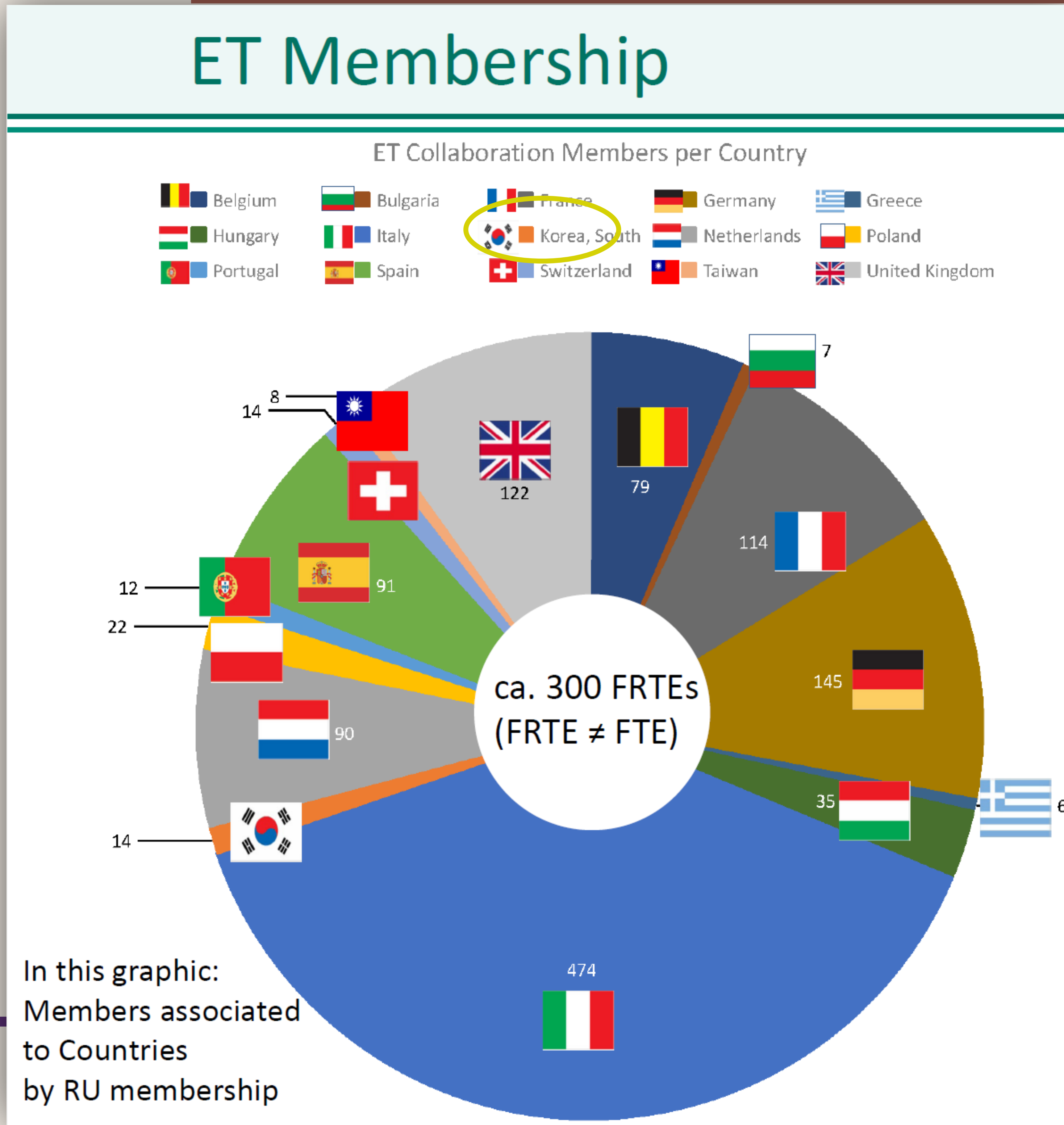
ET Collaboration

- ✓ Officially launched in June 2022
- ✓ 25 countries, 87 Research Units, 1,611 members

Korean Research Unit

- ✓ 19 members @ 7 institutions (KASI, KAIST, KHU, UNIST, EWU, SKKU, Yonsei U.)
- ✓ Research Unit leader: Sungho Lee (KASI) → ET Collaboration Board member
- ✓ National Representative: Chunglee Kim (EWU) → ET Forum of National Representative



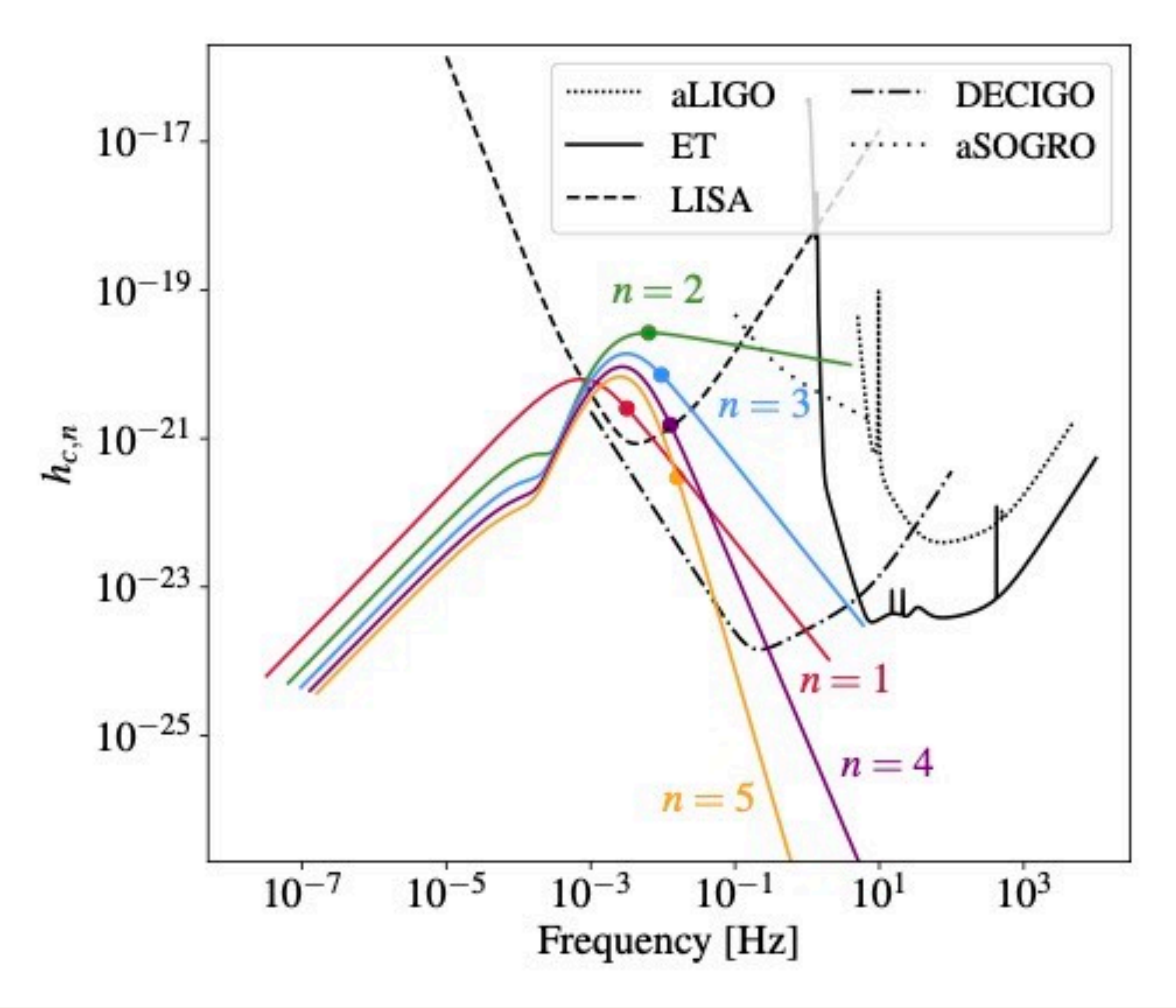


Directions

- Independent development of detector?
  - Our community is small and expertise is limited
  - It may be also desirable to develop a pathfinder project for new type of detectors (e.g., SOGRO)
- Collaboration on large scale experiments
  - ET: Consortium was already formed, and Korean members are Already in place with ~20 members (and growing)
  - CE: CE is not a funded project yet. We may be invited in the future.
  - LISA is moving forward
  - DECIGO
  - LGWA: Together with lunar lander program?

Intermediate mass black holes (IMBH)

- There is a gap between stellar mass (~10 $M_\odot$) and supermassive BH ($> 10^6 M_\odot$)
  - Observational bias or real?
- The most likely place for IMBH is center of star clusters
  - $M_{BH} \sim 10^{-3} M_{host}$ star cluster mass
  - For M_{host} in the range of $10^5 \sim 10^7$ $M_\odot$, $M_{BH} = 10^2 \sim 10^4$ $M_\odot$.
- In star clusters, we also expect to have large number of stellar mass black holes
  - Binaries can form between IMBH and Stellar mass BH through dynamical processes
  - Initial eccentricity is extremely high, and even remain as eccentric binary until final merger.
  - The best frequency range for detection of such binary is $10^{-3} \sim 1$ Hz. SOGRO can make a discovery, if Newtonian noise can be mitigated.

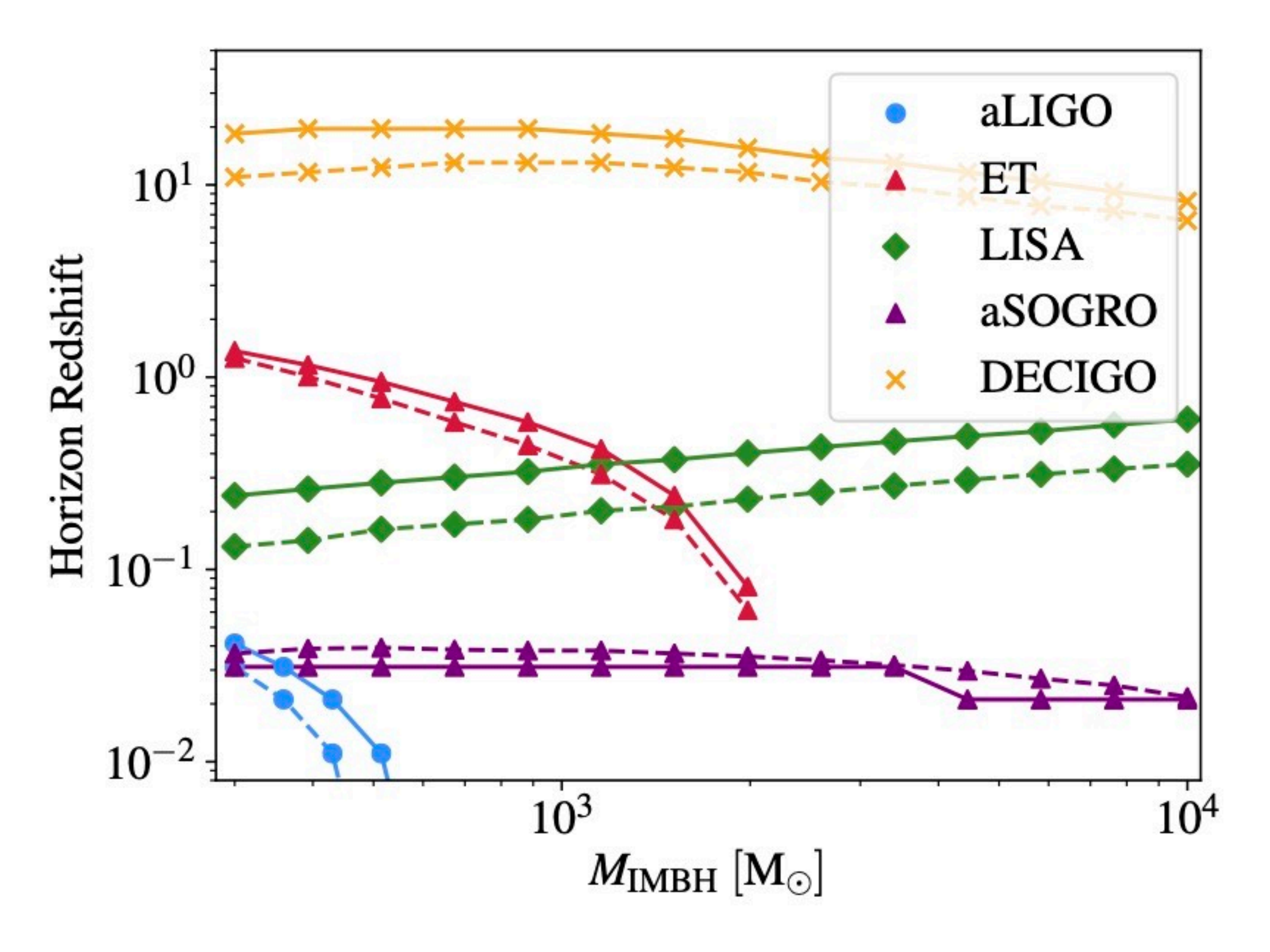


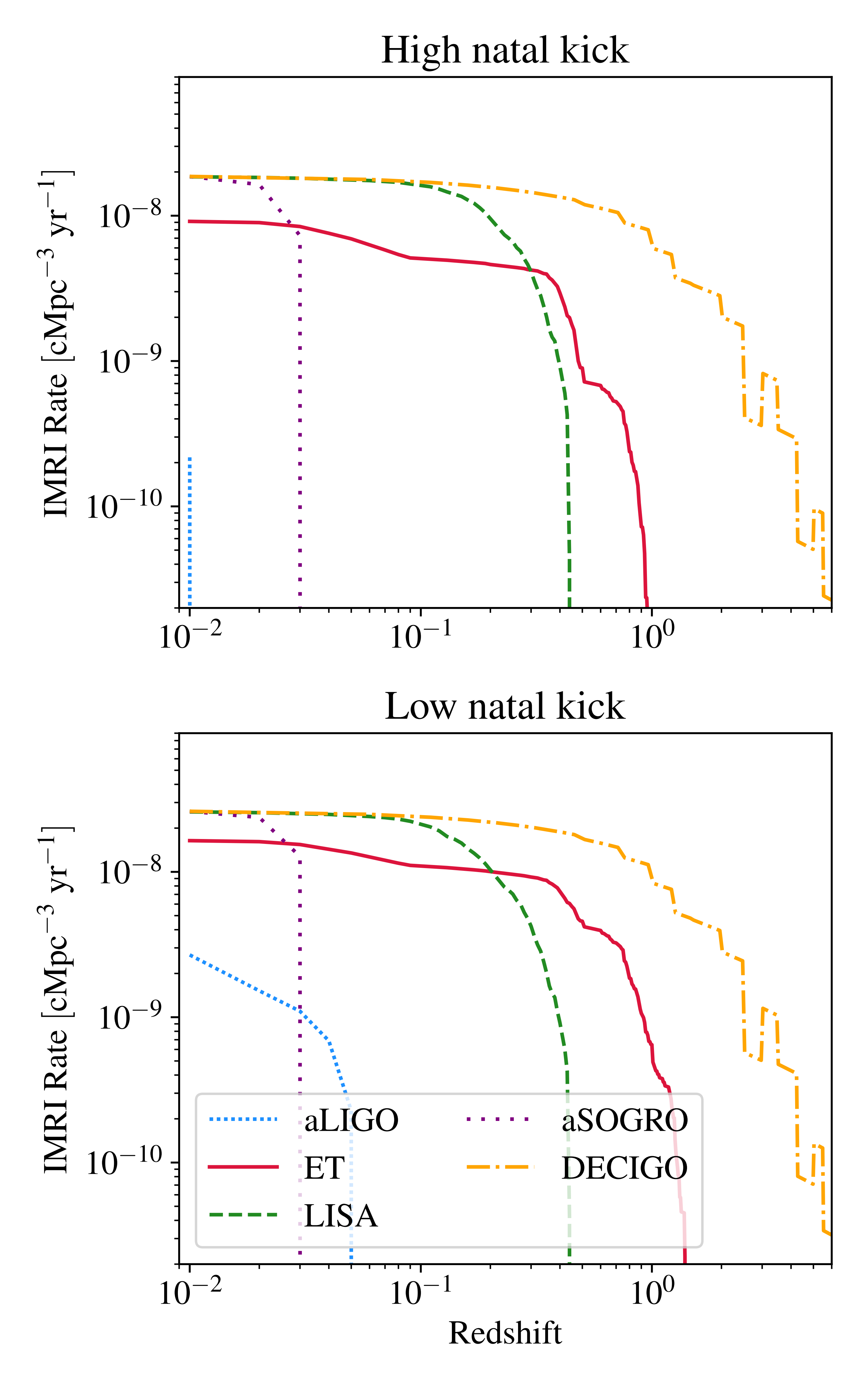
1000 $M_\odot$ - 40 $M_\odot$ pair at 500 Mac, with initial $e = 0.9999$, $a = 10$ AU (Lee et al. submitted)

IMBH with various detectors

- $\Gamma \sim 0.00\mathrm{yr}^{-1}$(aLIGO)
- $\Gamma \sim 0.1\mathrm{yr}^{-1}$ (aSOGRO)
- $\Gamma \sim 100\mathrm{yr}^{-1}$ (LISA)
- $\Gamma \sim 300\mathrm{yr}^{-1}$ (ET)
- $\Gamma \sim 5000\mathrm{yr}^{-1}$ (DECIGO)

Lee et al. 2025, Submitted





Hubble Diagram with GW Observations

- Sensitive GW detectors allow us to accurately constrain $z - d_L$ relation within z<0.5