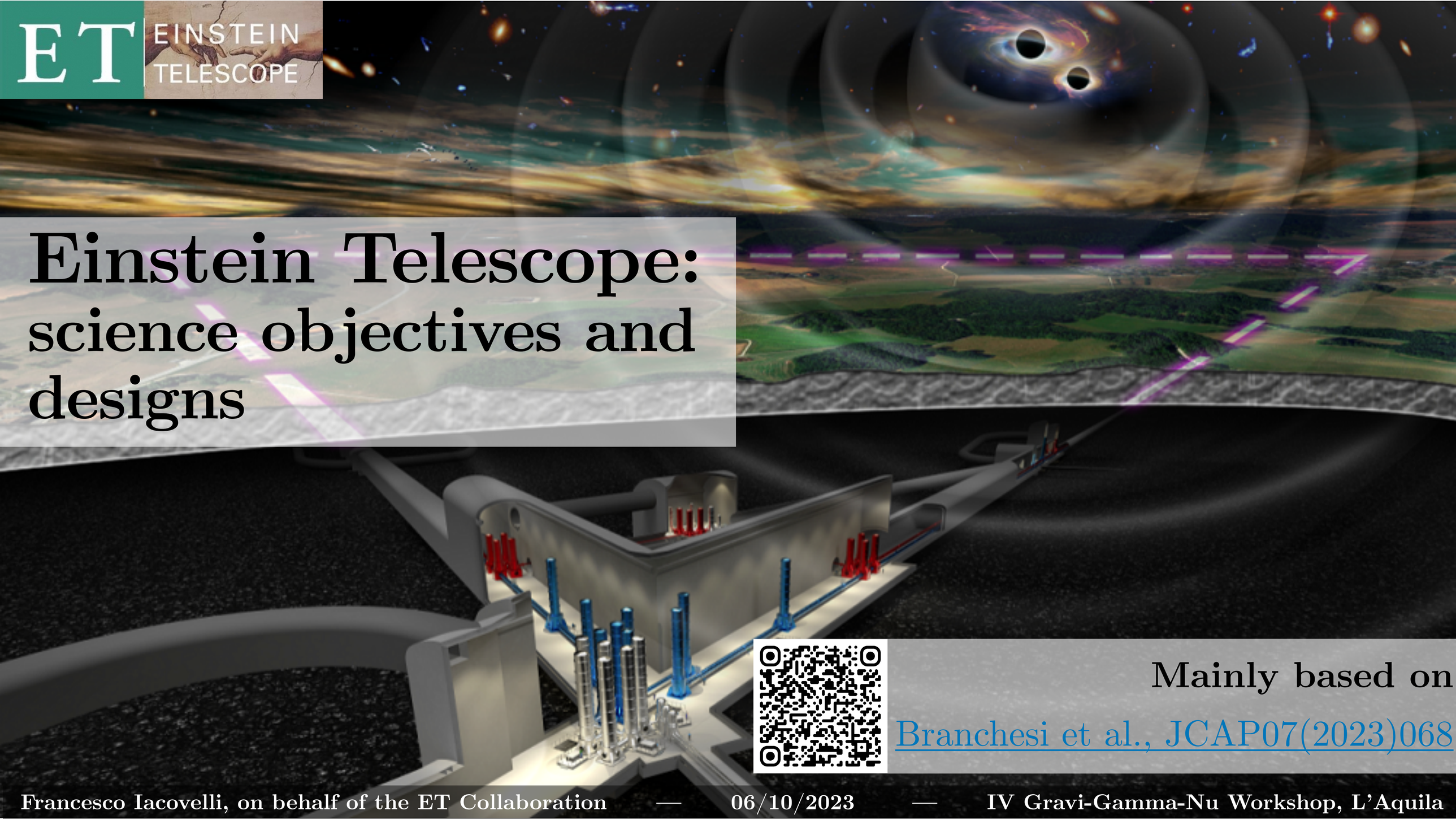
ET EINSTEIN TELESCOPE

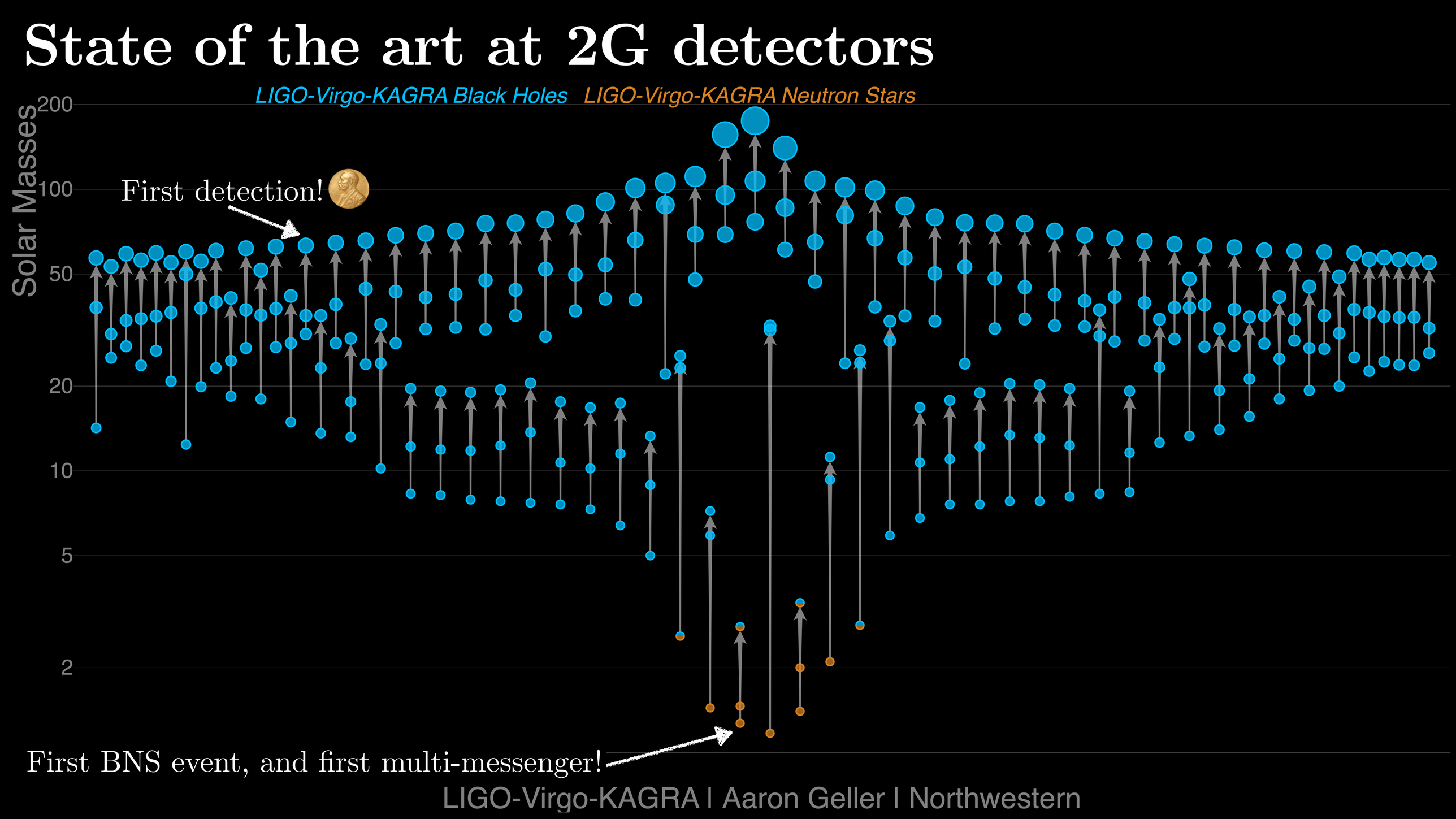
Einstein Telescope: science objectives and designs



Mainly based on

Branchesi et al., JCAP07(2023)068

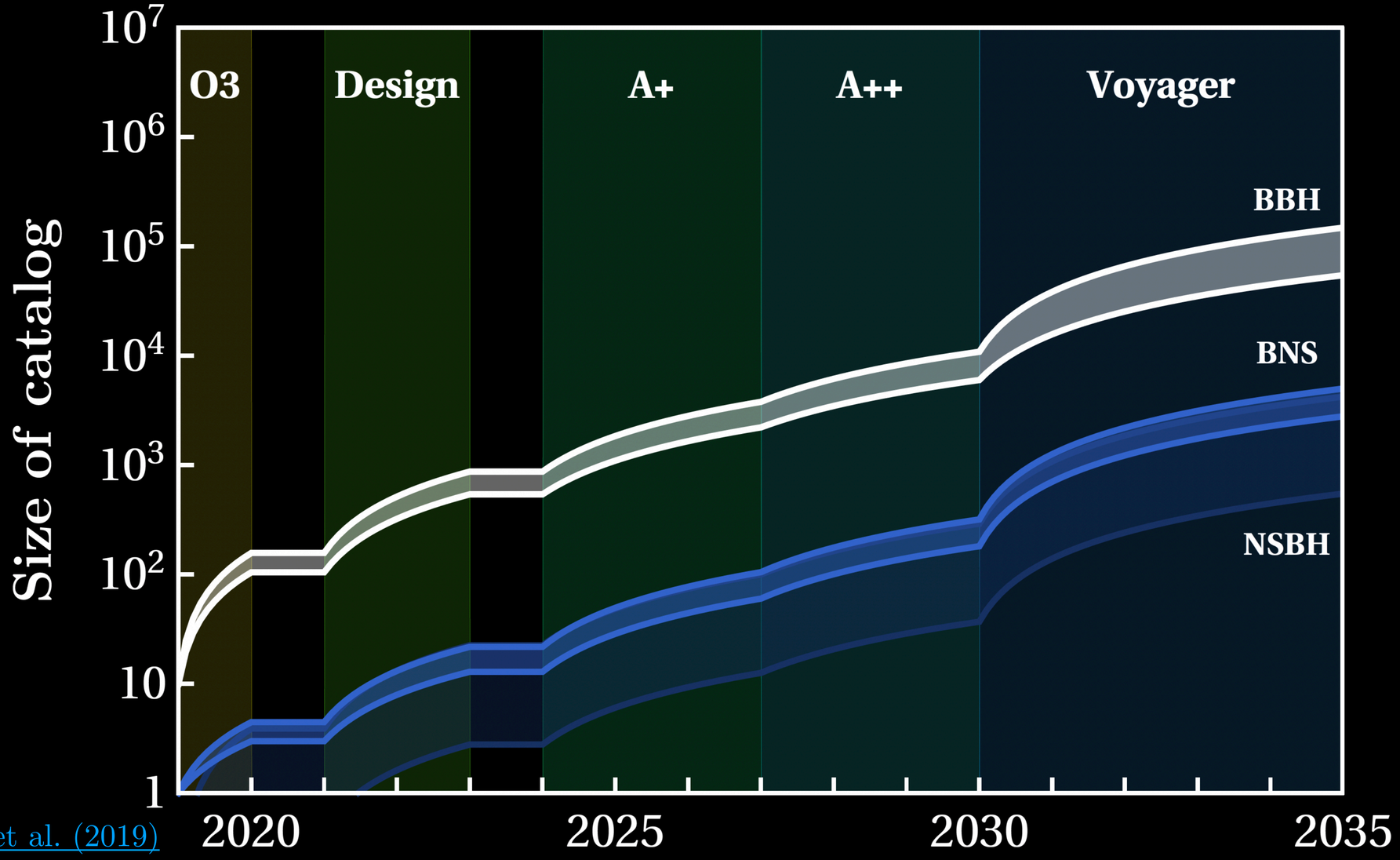
State of the art at 2G detectors



LIGO-Virgo-KAGRA | Aaron Geller | Northwestern

Prospects at 2G detectors

Already at 2G detectors, thanks to future advancements, in the coming years the number of detections is expected to quickly raise

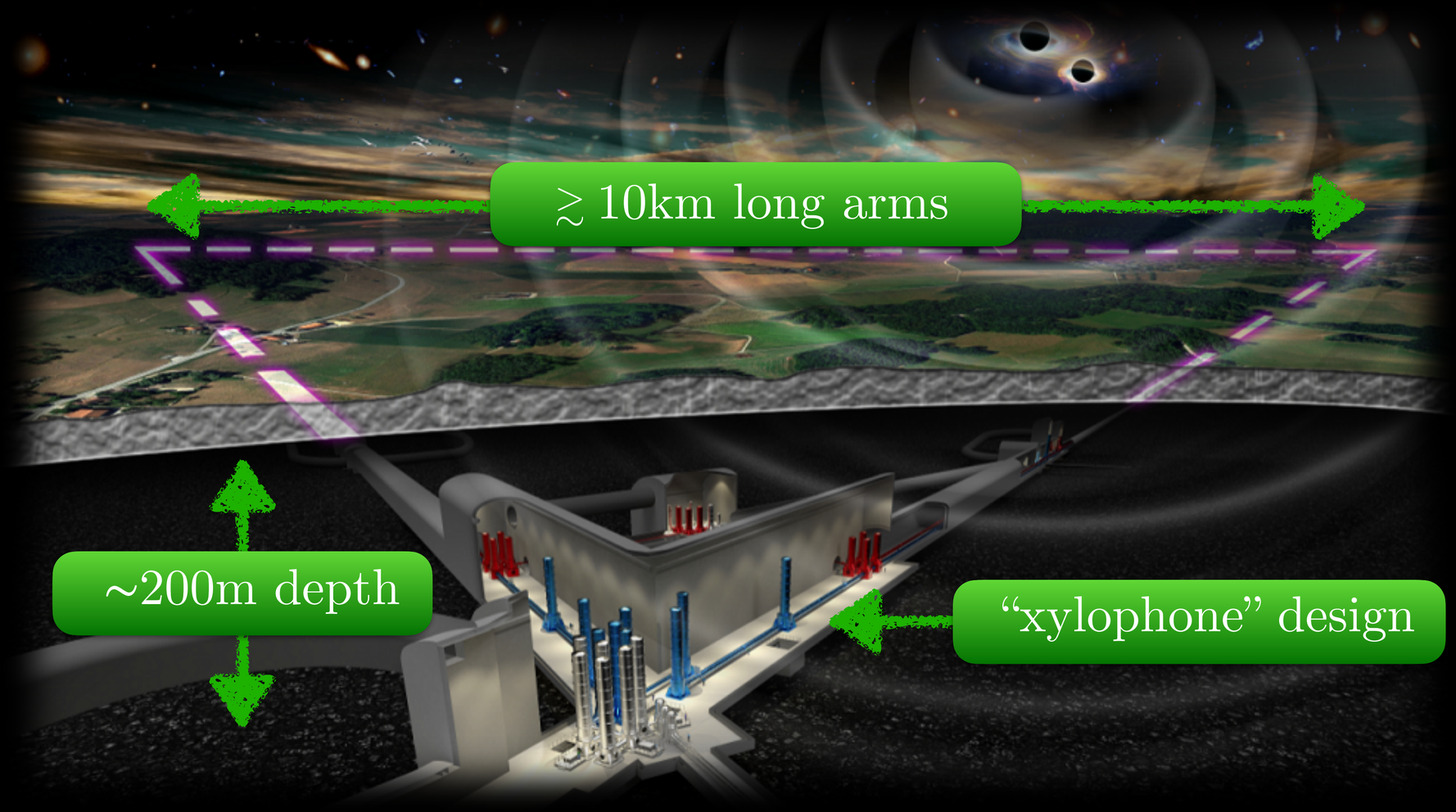


Baibhav et al. (2019)

3G detectors overview: ET

ET pioneered the idea of 3G GW observatory:

- new infrastructure capable to host future upgrades
- large improvement in sensitivity
- greatly extended frequency range, especially below 10Hz
- ...



Proposed more than 10 years ago (Punturo et al. (2010)) and included in ESFRI roadmap in 2021. Science case in Maggiore et al. (2020)

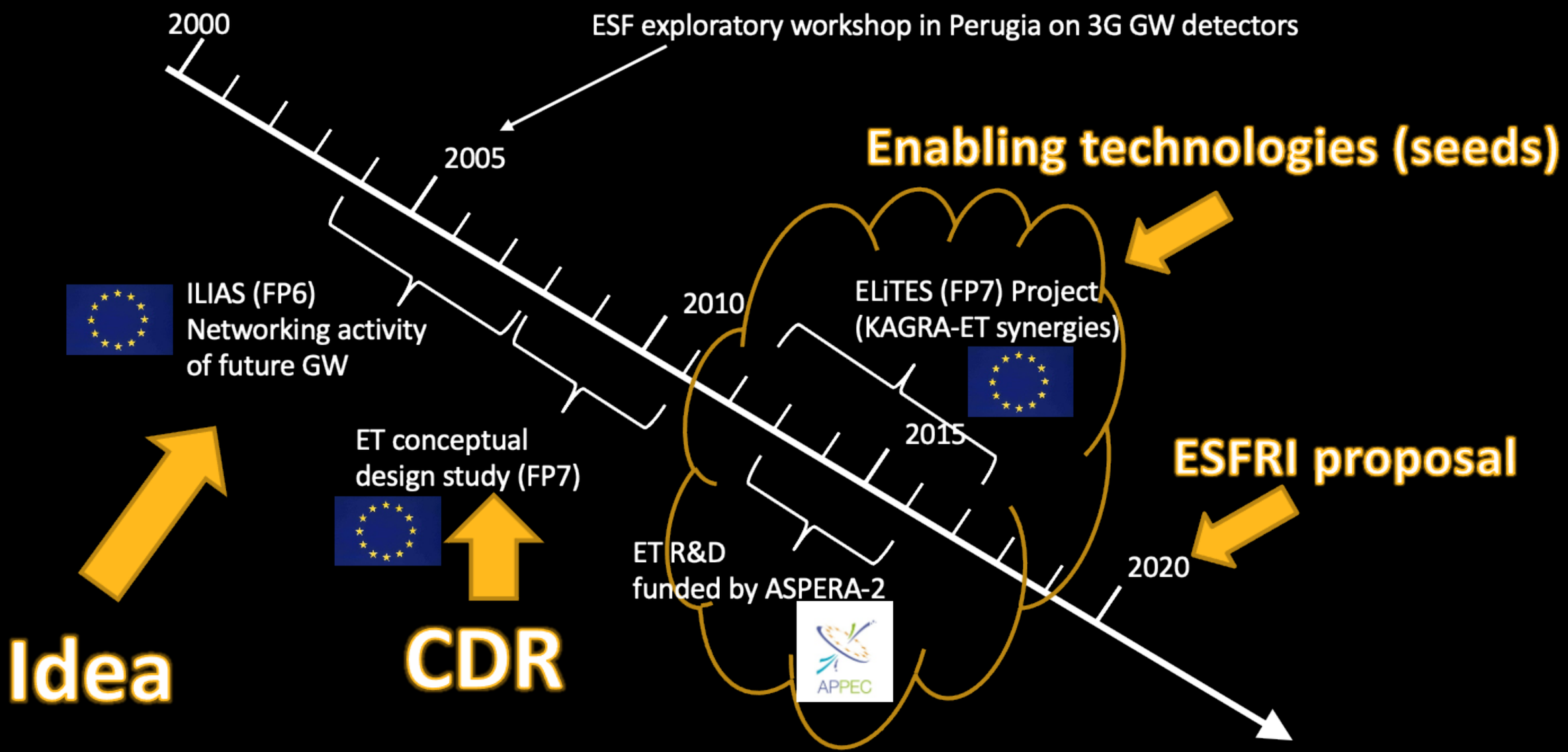
3G detectors overview: CE

CE is the proposed U.S. 3G detector:

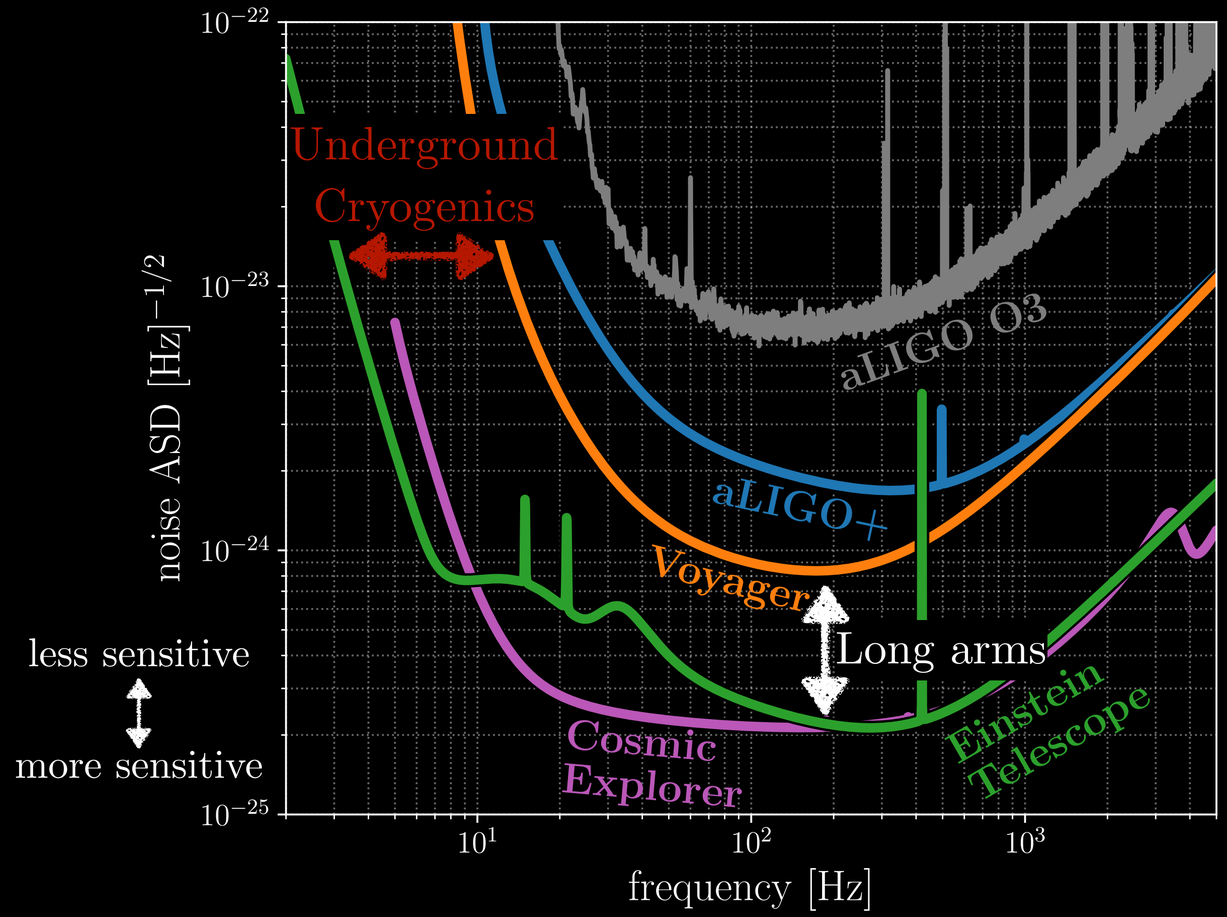
- 2 L-shaped surface instruments, one 40km-long and one 20km-long;
- large improvement in sensitivity
- tunable design
- global network with ET
- ...

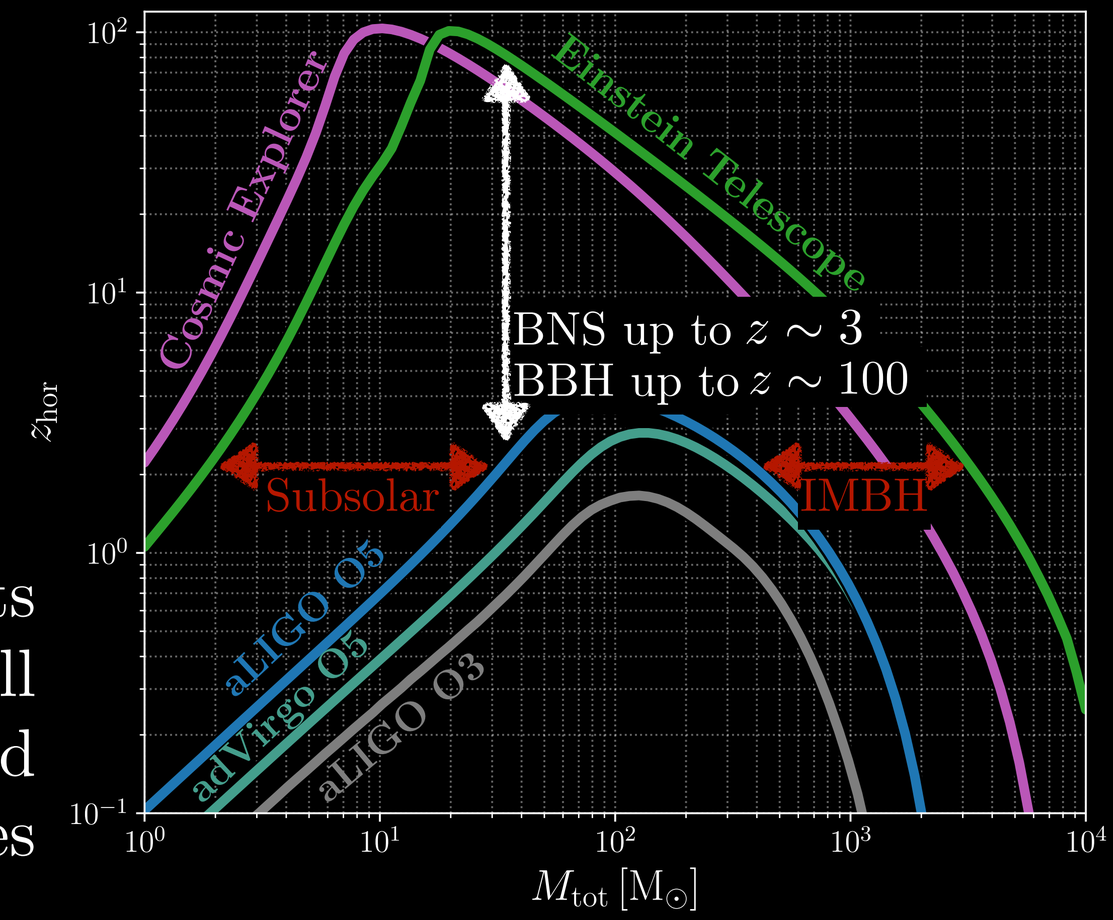
CE white paper in 2019 (Reitze et al. (2021)) and CE Horizon Study document recently published (Evans et al. (2021))

3G detectors overview: ET history



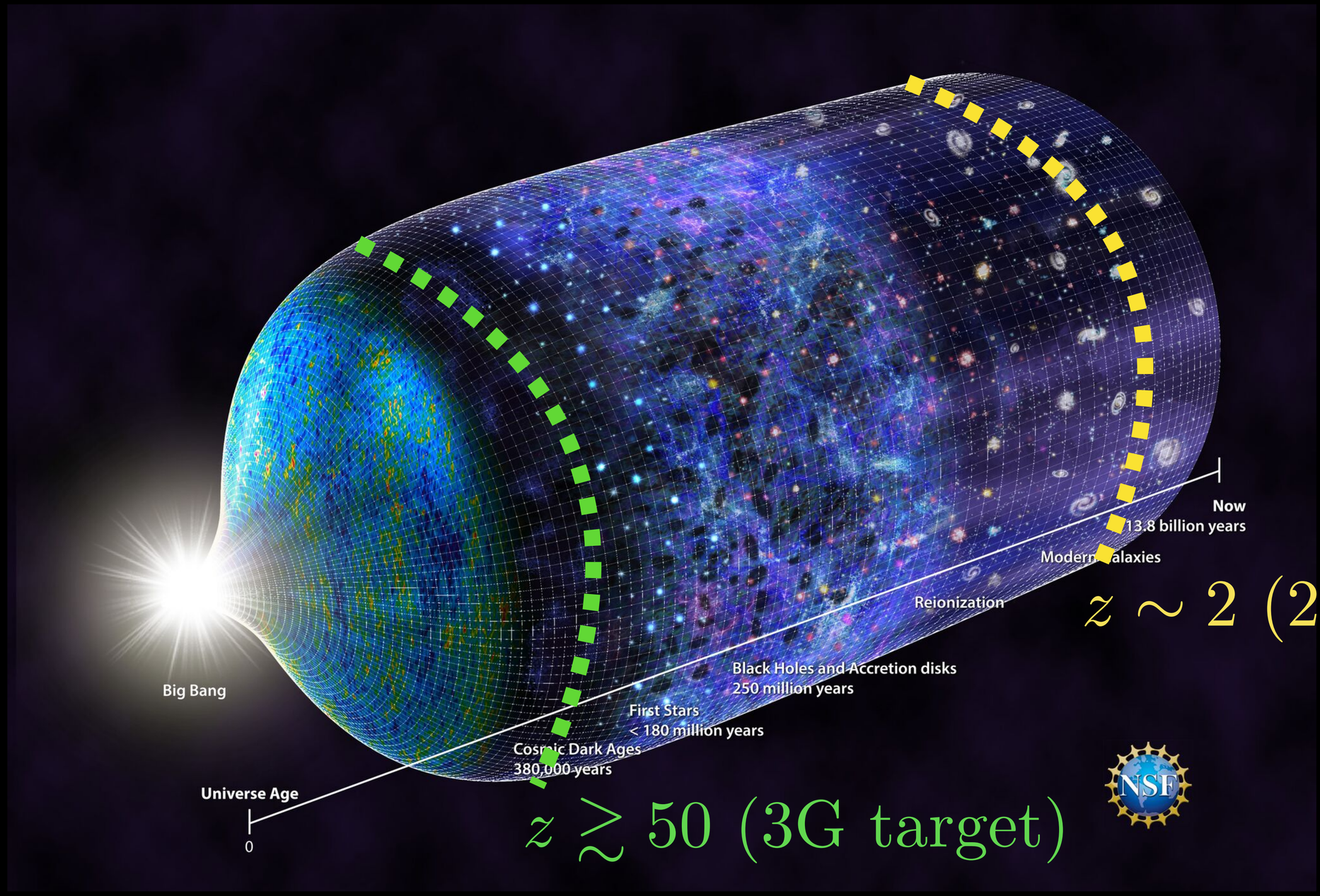
Jump to 3G detectors: how much do we gain?





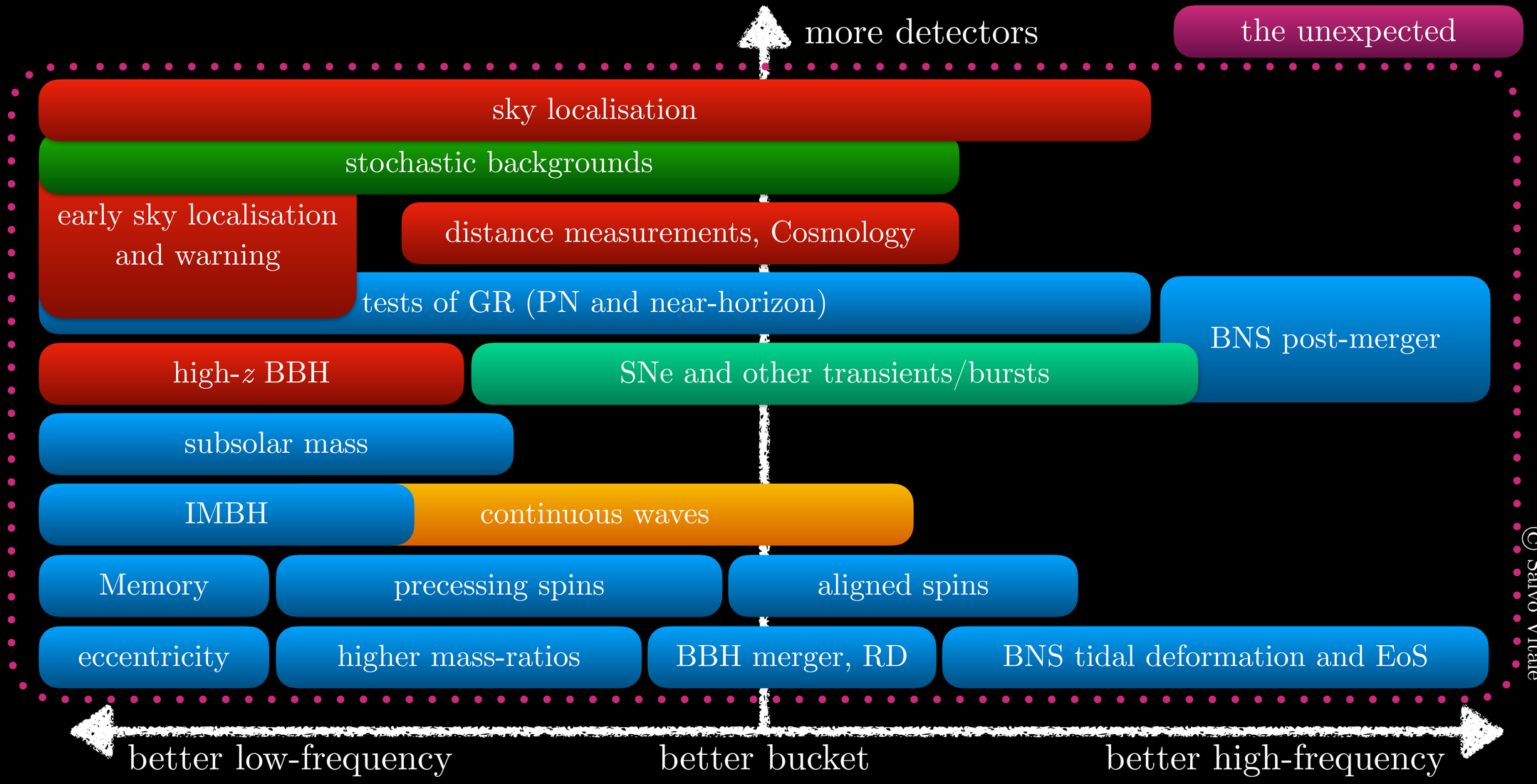
Thanks to their technological advancements and the bigger facilities, ET and CE will have a broader frequency range and sensitivities improved more than 10 times compared to LVK!

Jump to 3G detectors: why do we need it?



Jump to 3G detectors: why do we need it?

GW sources produce signals in different GW ranges: the larger the frequency band and the more sensitive the detector, the higher the scientific output!



ET science case

ASTROPHYSICS

- **Black hole properties**
  - origin (stellar vs. primordial)
  - evolution, demography
- **Neutron star properties**
  - interior structure (QCD at ultra-high densities, exotic states of matter)
  - demography
- **Multi-band and -messenger astronomy**
  - joint GW/EM observations (GRB, kilonova,...)
  - multiband GW detection (LISA)
  - neutrinos
- **Detection of new astrophysical sources**
  - core collapse supernovae
  - isolated neutron stars
  - stochastic background of astrophysical origin

FUNDAMENTAL PHYSICS AND COSMOLOGY

- **Tests of General Relativity and nature of compact objects**
  - post-Newtonian expansion
  - near-horizon physics
  - tests of no-hair theorem
  - exotic compact objects
- **Dark matter**
  - primordial BHs
  - axion clouds, dark matter accreting on compact objects
- **Dark energy and modifications of gravity on cosmological scales**
  - dark energy equation of state
  - modified GW propagation
- **Stochastic backgrounds of cosmological origin**
  - inflation, phase transitions, cosmic strings

ET science case

ASTROPHYSICS

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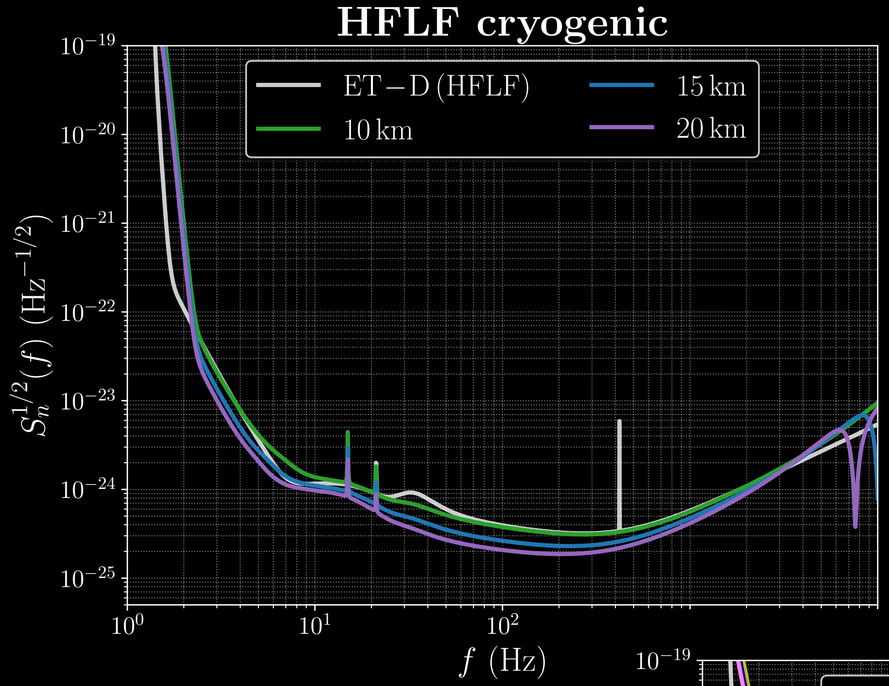
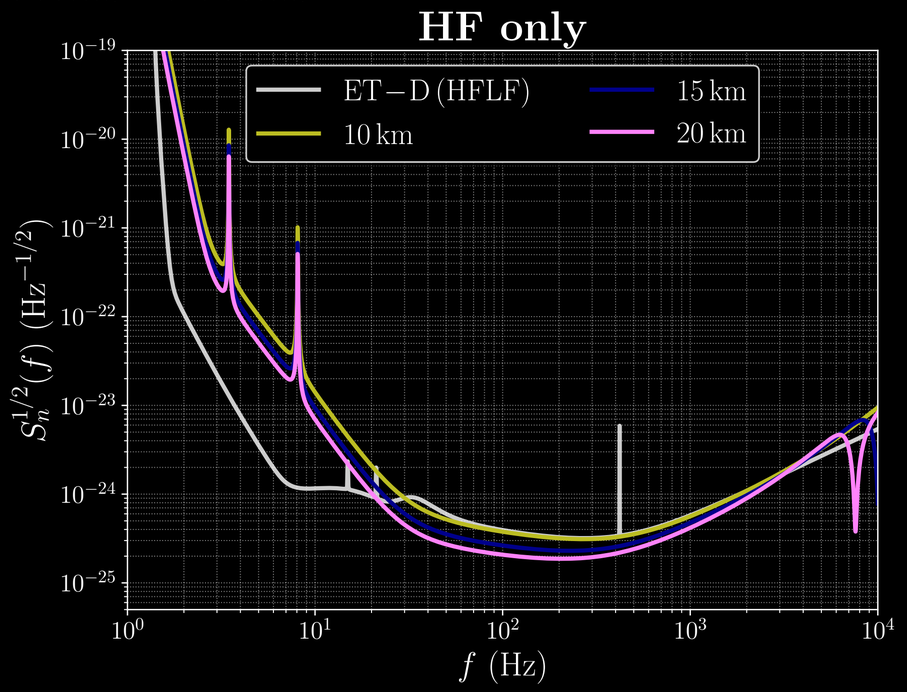
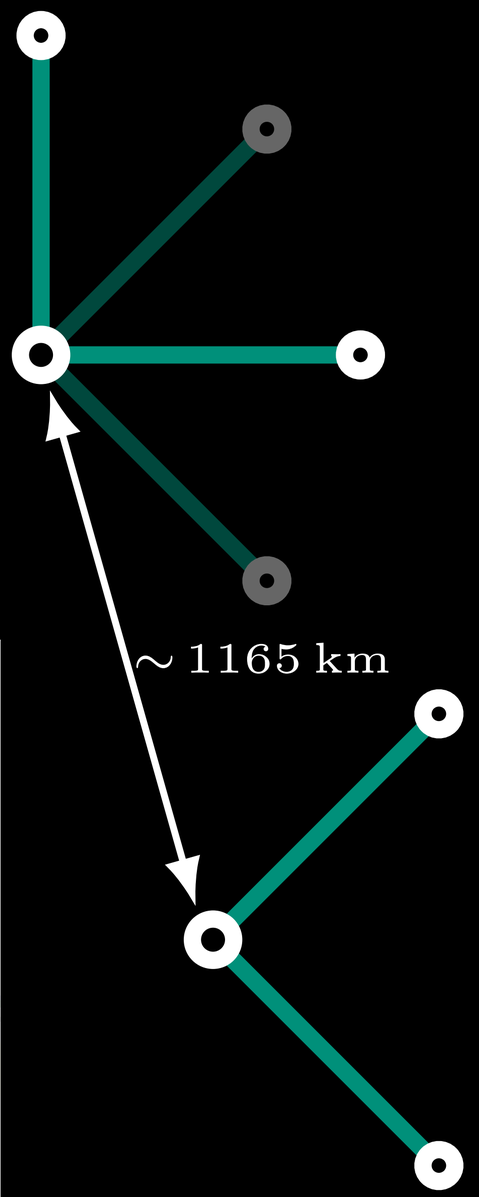
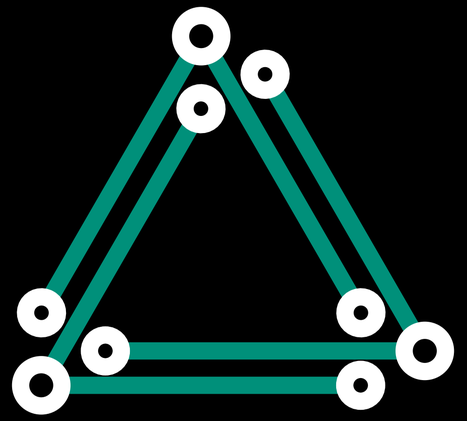
ET will be a "discovery machine": expect the unexpected!

Variation of the design: which ones?









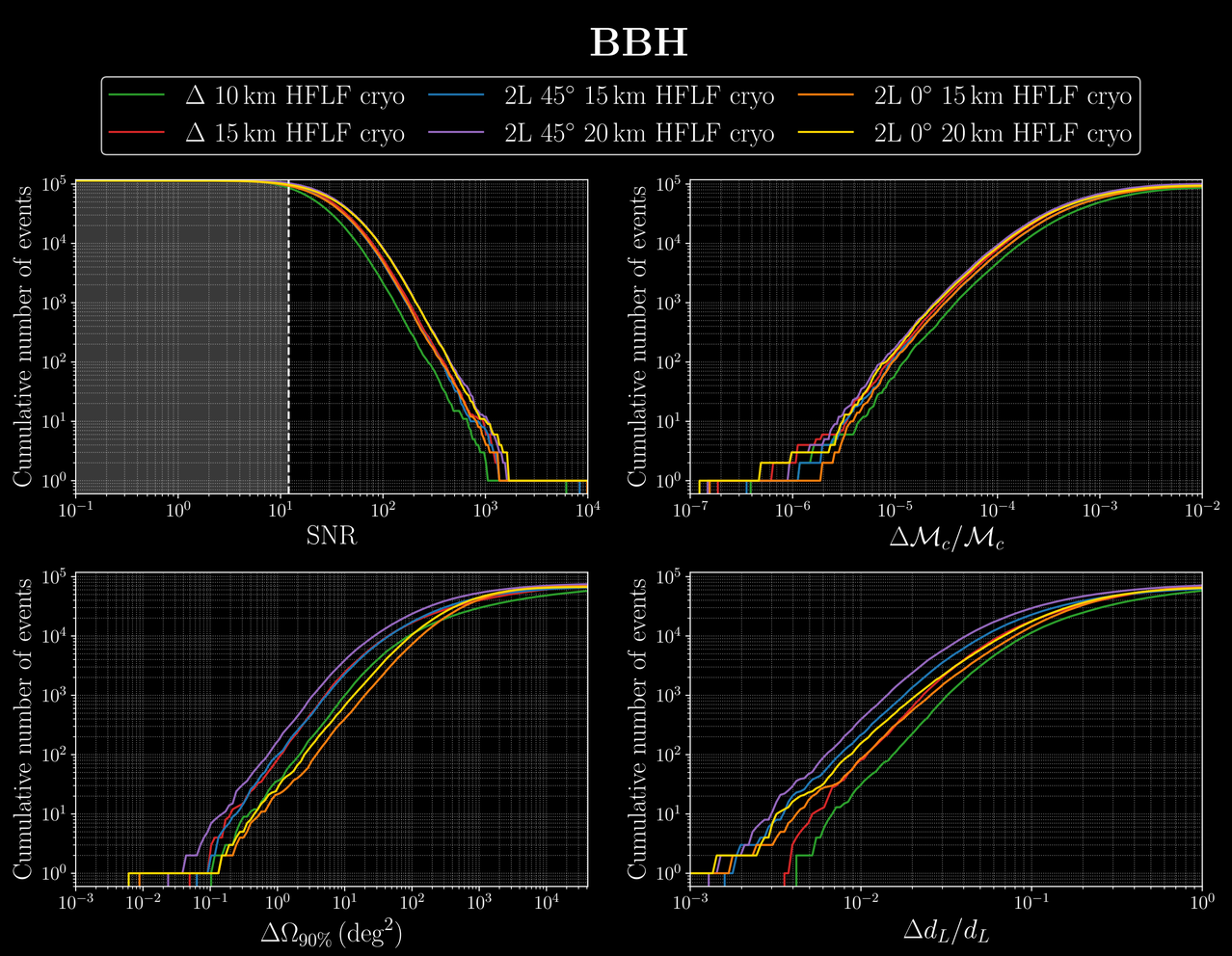
Variation of the design: a lot of work from a lot of people

Science with the Einstein Telescope: a comparison of different designs

Marica Branchesi,[1,2,*] Michele Maggiore,[3,4,*] David Alonso,[5] Charles Badger,[6] Biswajit Banerjee,[1,2] Freija Beirnaert,[7] Enis Belgacem,[3,4] Swetha Bhagwat,[8,9] Guillaume Boileau,[10,11] Ssohrab Borhanian,[12] Daniel David Brown,[13] Man Leong Chan,[14] Giulia Cusin,[15,3,4] Stefan L. Danilishin,[16,17] Jerome Degallaix,[18] Valerio De Luca,[19] Arnab Dhani,[20] Tim Dietrich,[21,22] Ulyana Dupletsa,[1,2] Stefano Foffa,[3,4] Gabriele Franciolini,[8] Andreas Freise,[23,16] Gianluca Gemme,[24] Boris Goncharov,[1,2] Archisman Ghosh,[7] Francesca Gulminelli,[25] Ish Gupta,[20] Pawan Kumar Gupta,[16,26] Jan Harms,[1,2] Nandini Hazra,[1,2,27] Stefan Hild,[16,17] Tanja Hinderer,[28] Ik Siong Heng,[29] Francesco Iacovelli,[3,4] Justin Janquart,[16,26] Kamiel Janssens,[10,11] Alexander C. Jenkins,[30] Chinmay Kalaghatgi,[16,26,31] Xhesika Koroveshi,[32,33] Tjonnie G.F. Li,[34,35] Yufeng Li,[36] Eleonora Loffredo,[1,2] Elisa Maggio,[22] Michele Mancarella,[3,4,37,38] Michela Mapelli,[39,40,41] Katarina Martinovic,[6] Andrea Maselli,[1,2] Patrick Meyers,[42] Andrew L. Miller,[43,16,26] Chiranjib Mondal,[25] Niccolò Muttoni,[3,4] Harsh Narola,[16,26] Micaela Oertel,[44] Gor Oganesyan,[1,2] Costantino Pacilio,[8,37,38] Cristiano Palomba,[45] Paolo Pani,[8] Antonio Pasqualetti,[46] Albino Perego,[47,48] Carole Périgois,[39,40,41] Mauro Pieroni,[49,50] Ornella Juliana Piccinni,[51] Anna Puecher,[16,26] Paola Puppo,[45] Angelo Ricciardone,[52,39,40] Antonio Riotto,[3,4] Samuele Ronchini,[1,2] Mairi Sakellariadou,[6] Anuradha Samajdar,[21] Filippo Santoliquido,[39,40,41] B.S. Sathyaprakash,[20,53,54] Jessica Steinlechner,[16,17] Sebastian Steinlechner,[16,17] Andrei Utina,[16,17] Chris Van Den Broeck[16,26] and Teng Zhang[9,17]

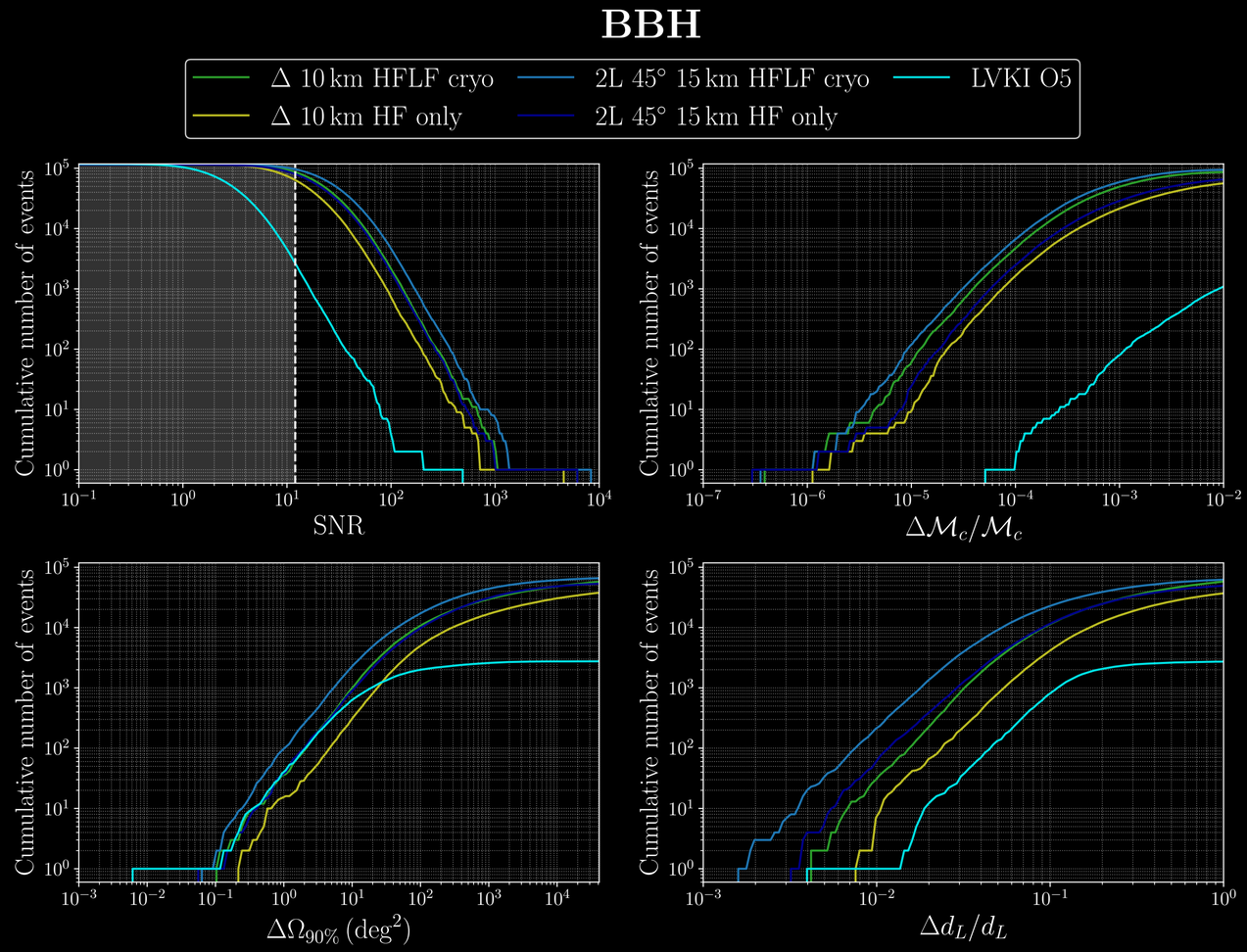
Contents

Variation of the design: PE at ET

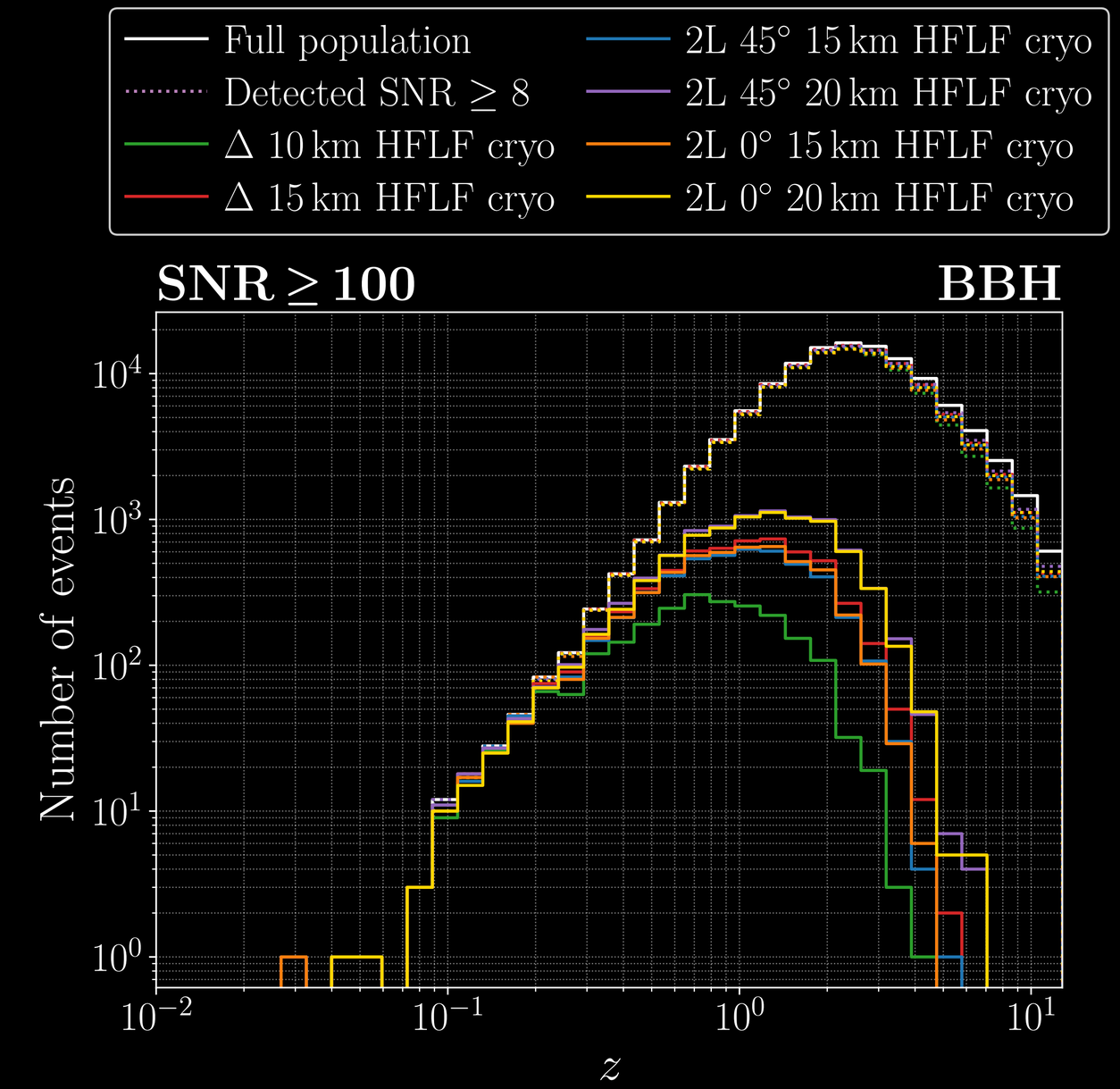


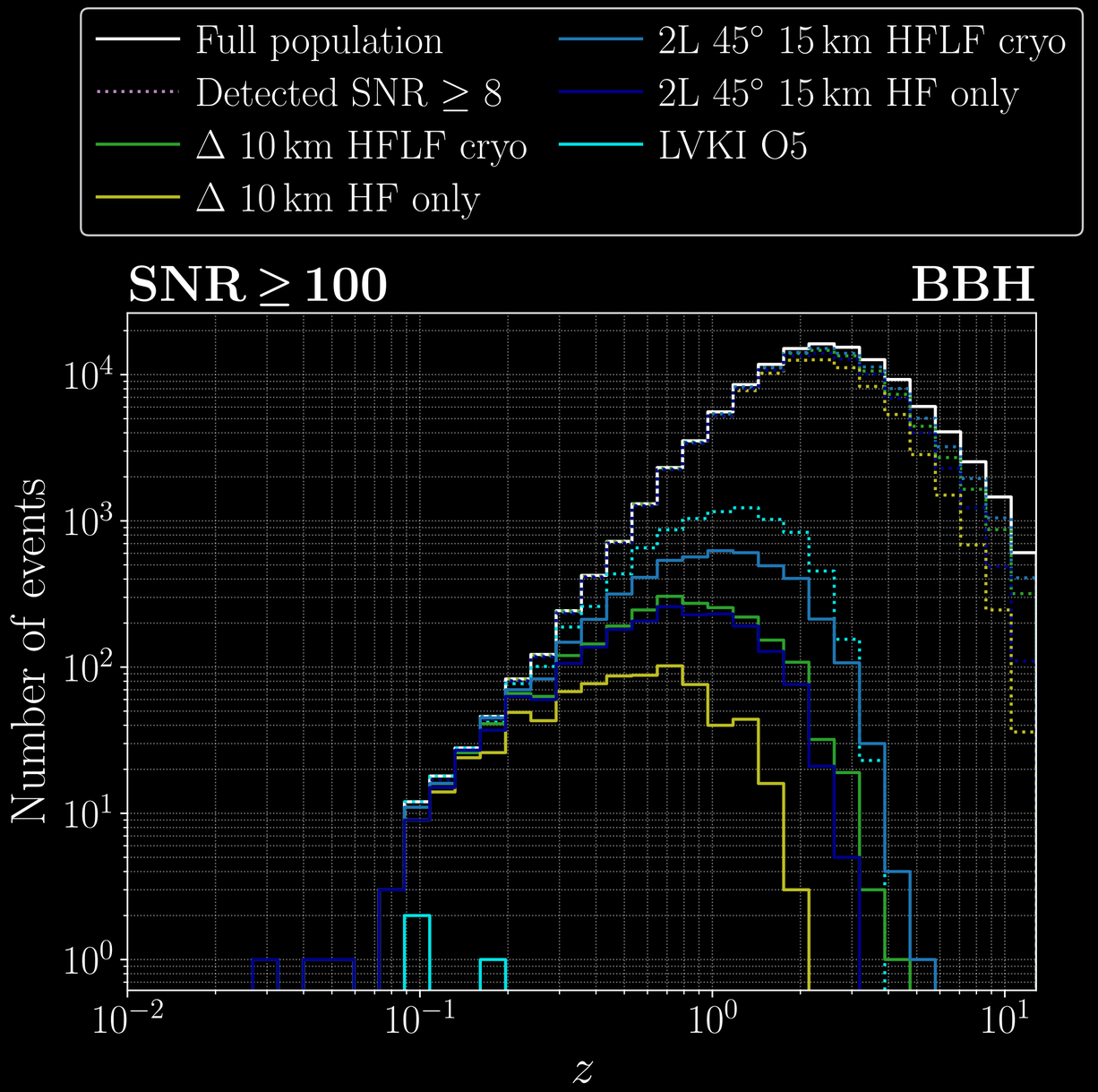
The performance remains however outstanding!

Both the geometry and the technologies can impact the number of detections and the parameter reconstruction

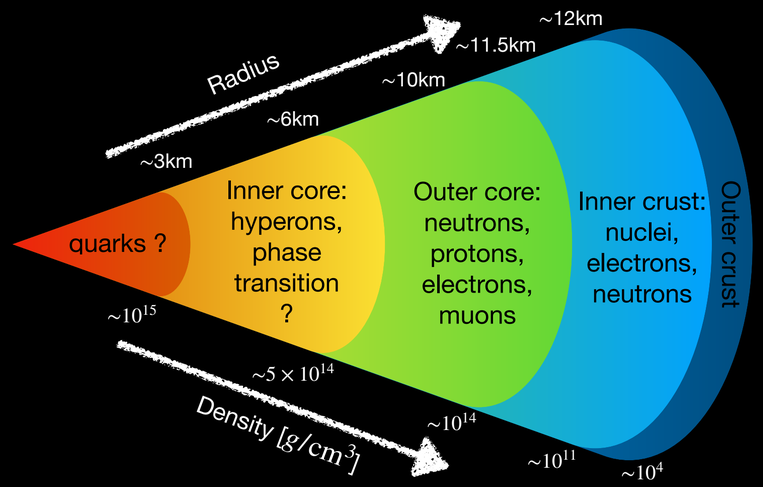


Variation of the design: golden events at ET

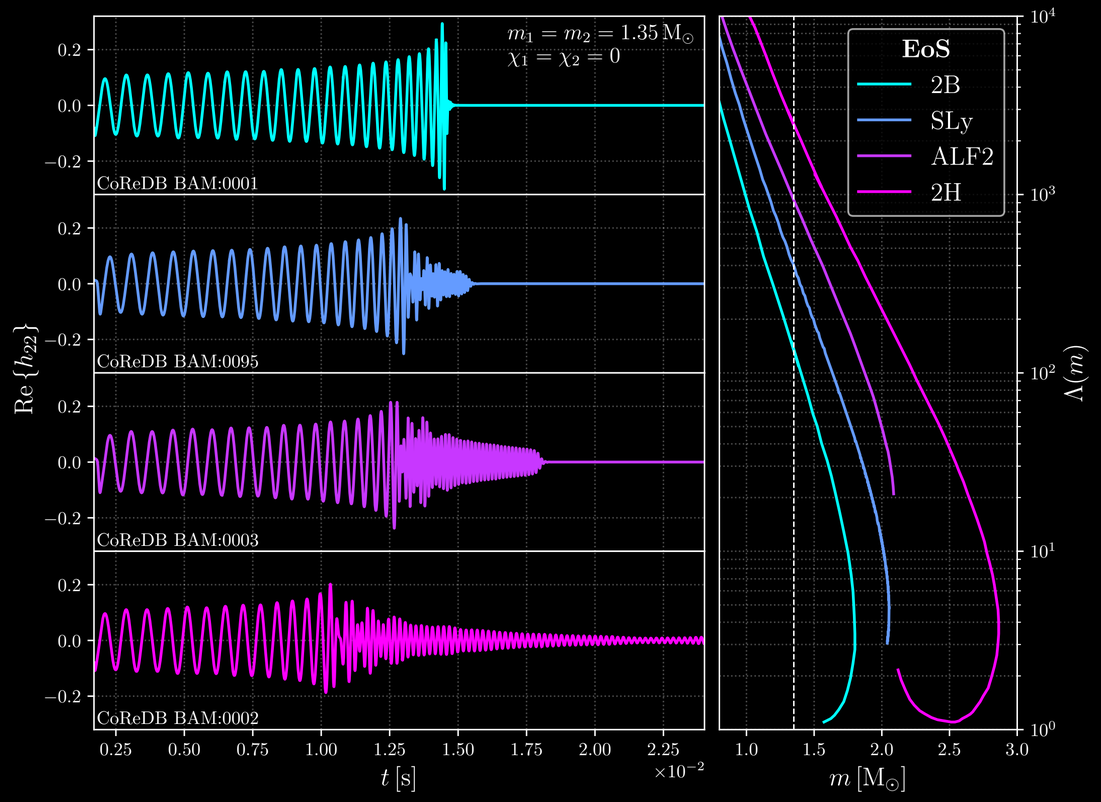


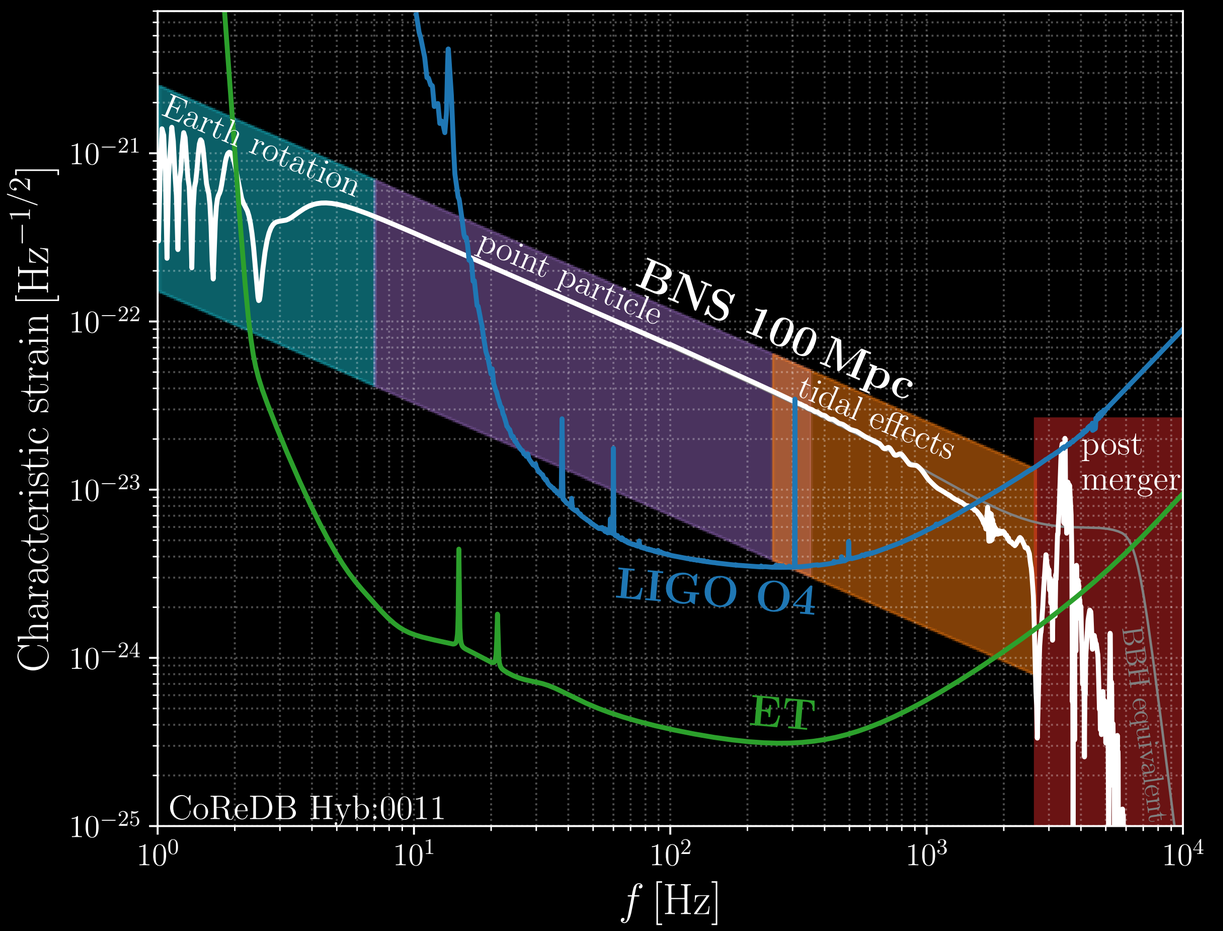


Neutron star structure and properties



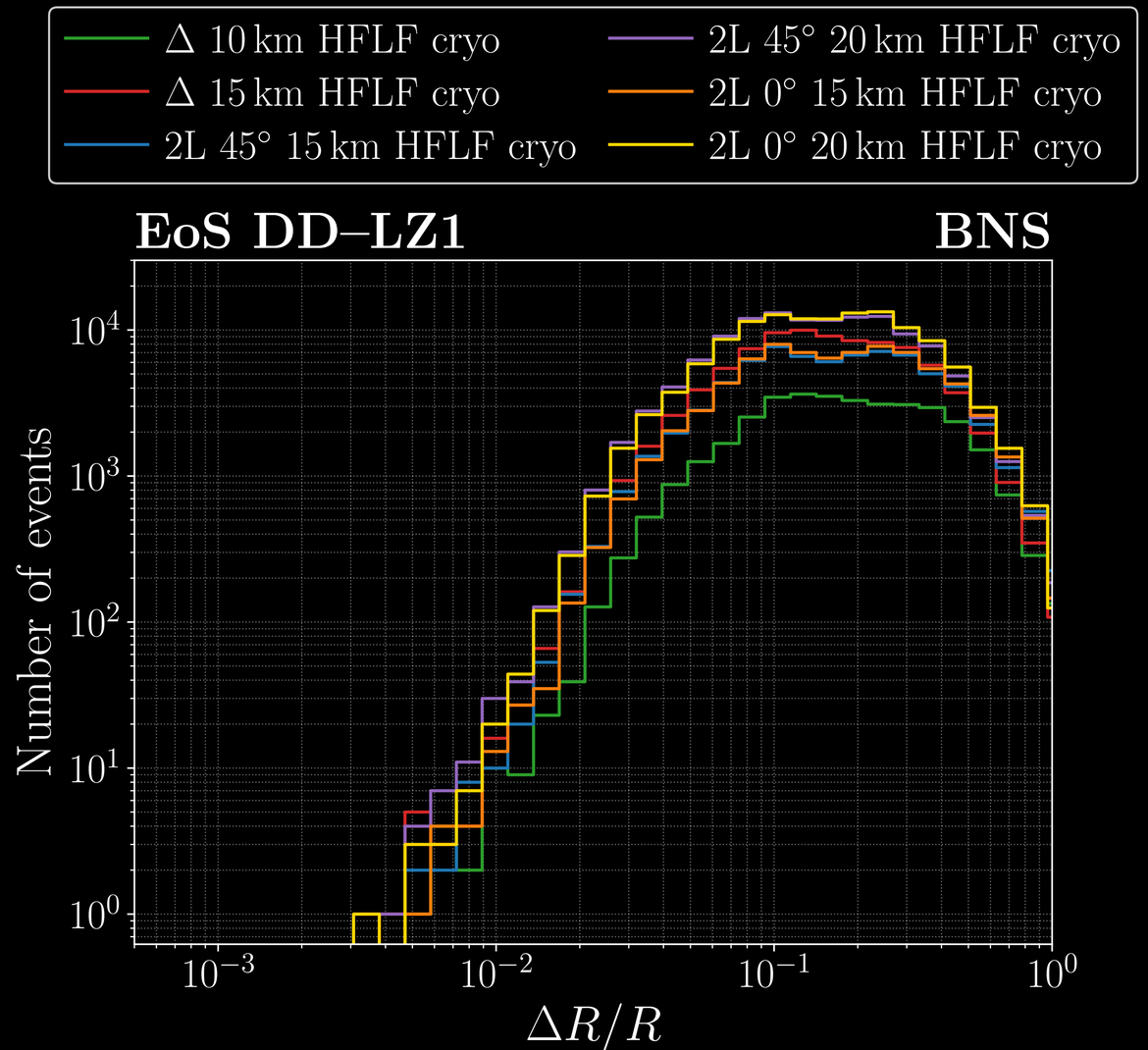
The largely improved sensitivity at high frequencies will allow to look deeply into the PM phase of BNS mergers, that can provide extremely valuable information on the NS structure

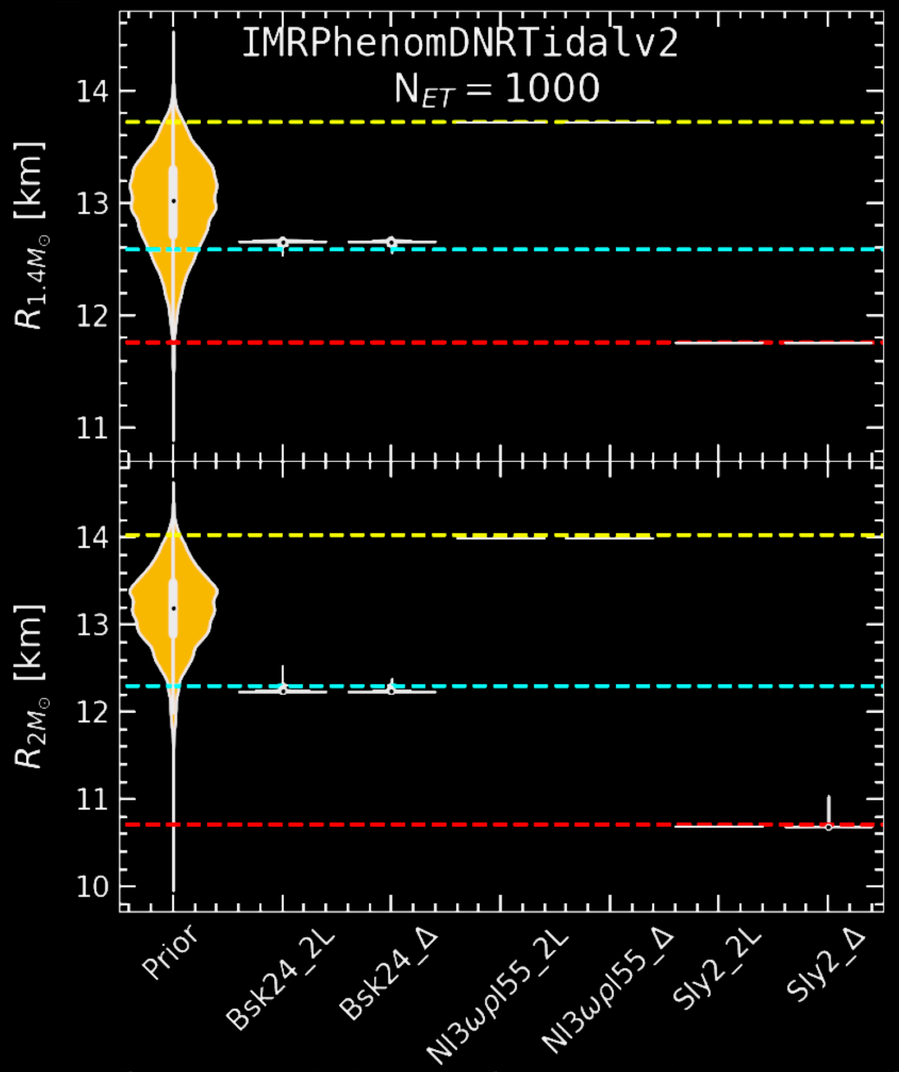




Neutron star structure and properties

The tidal deformability reconstruction is not strongly affected by the geometry and the LF sensitivity



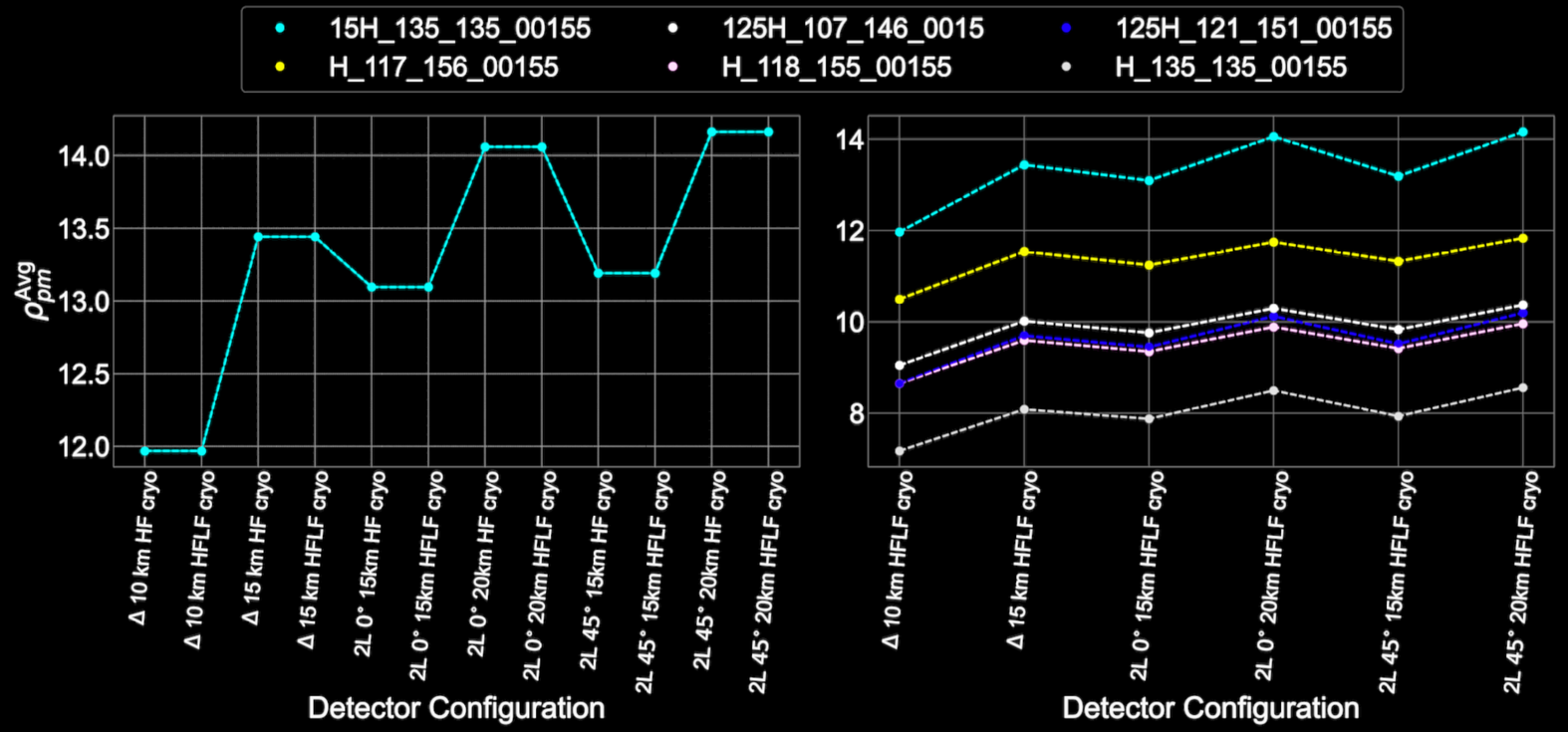


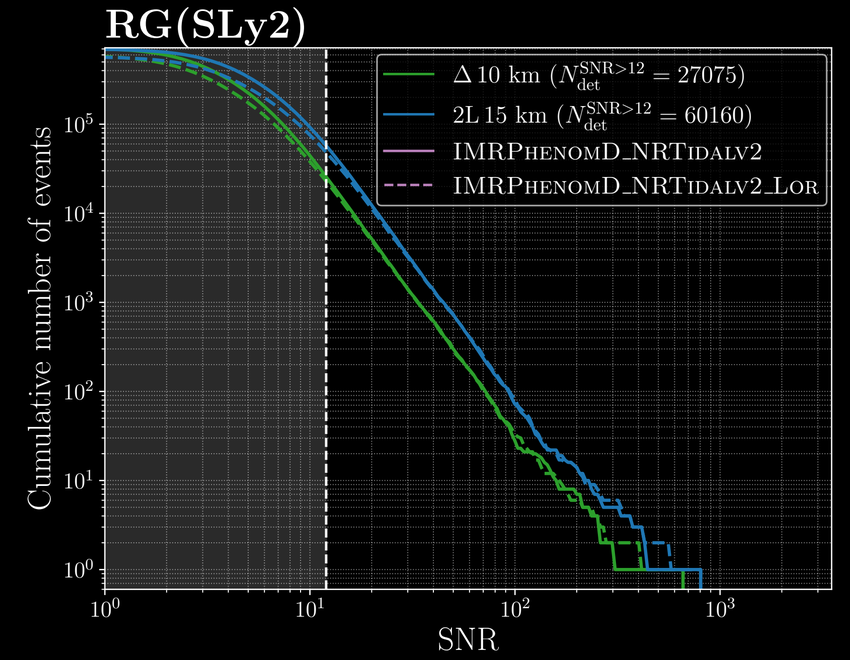
Already with ~ 1000 detections the reconstruction of the NS properties is extremely precise

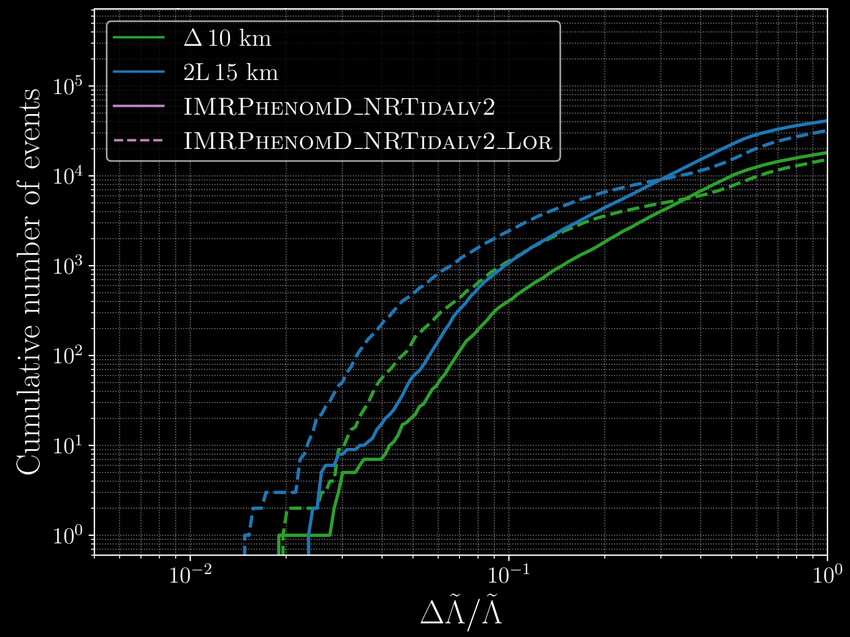
FI et al., (2023)

Neutron star structure and properties

Also the post-merger observation is affected only marginally by the design, but its inclusion can improve on the parameter reconstruction at the population level!

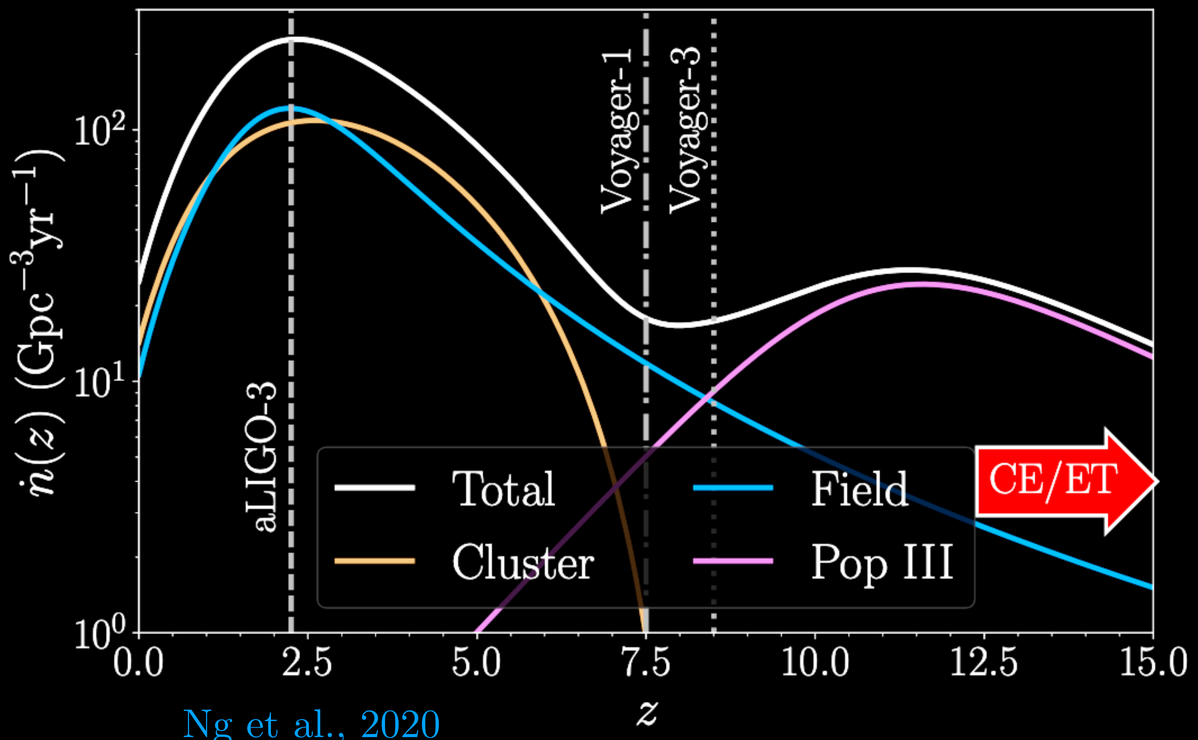




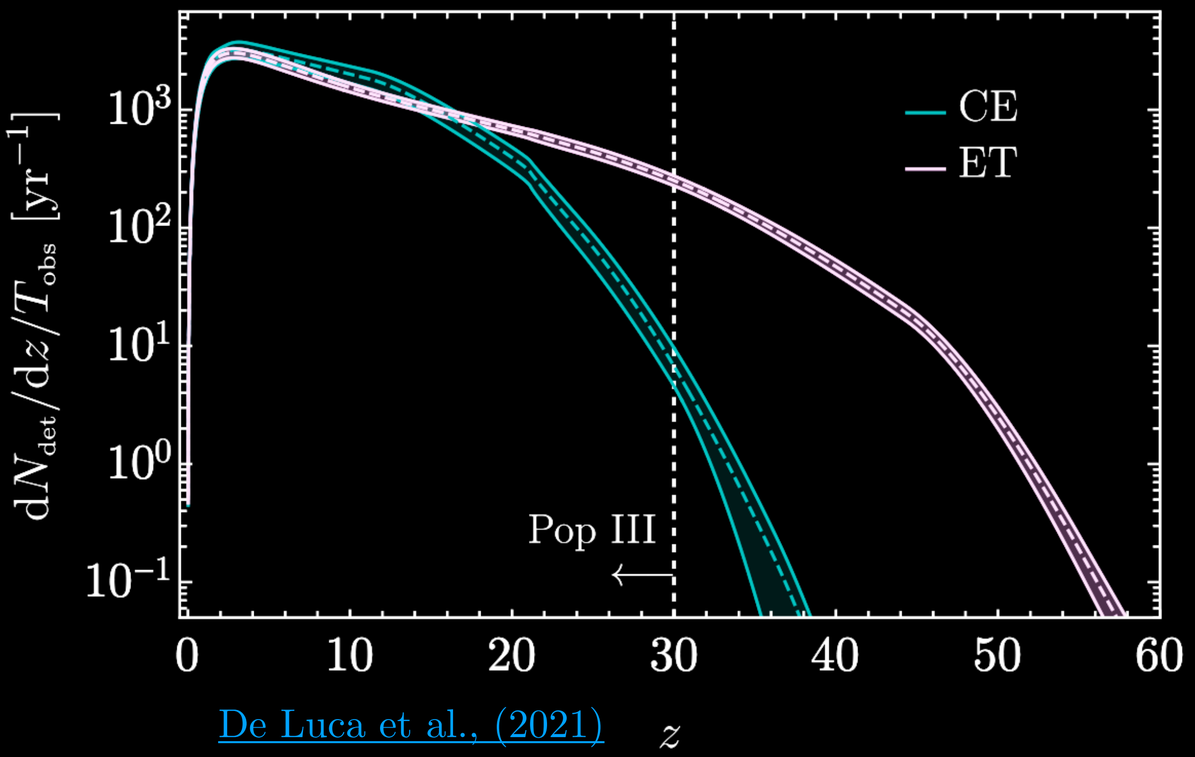


Primordial black holes

PBHs can form from the collapse of inhomogeneities in the radiation-dominated era. PBHs could explain at least a fraction of the dark matter in our universe, be the seed of SMBHs at high z, and could give rise to CBC events



Ng et al., 2020

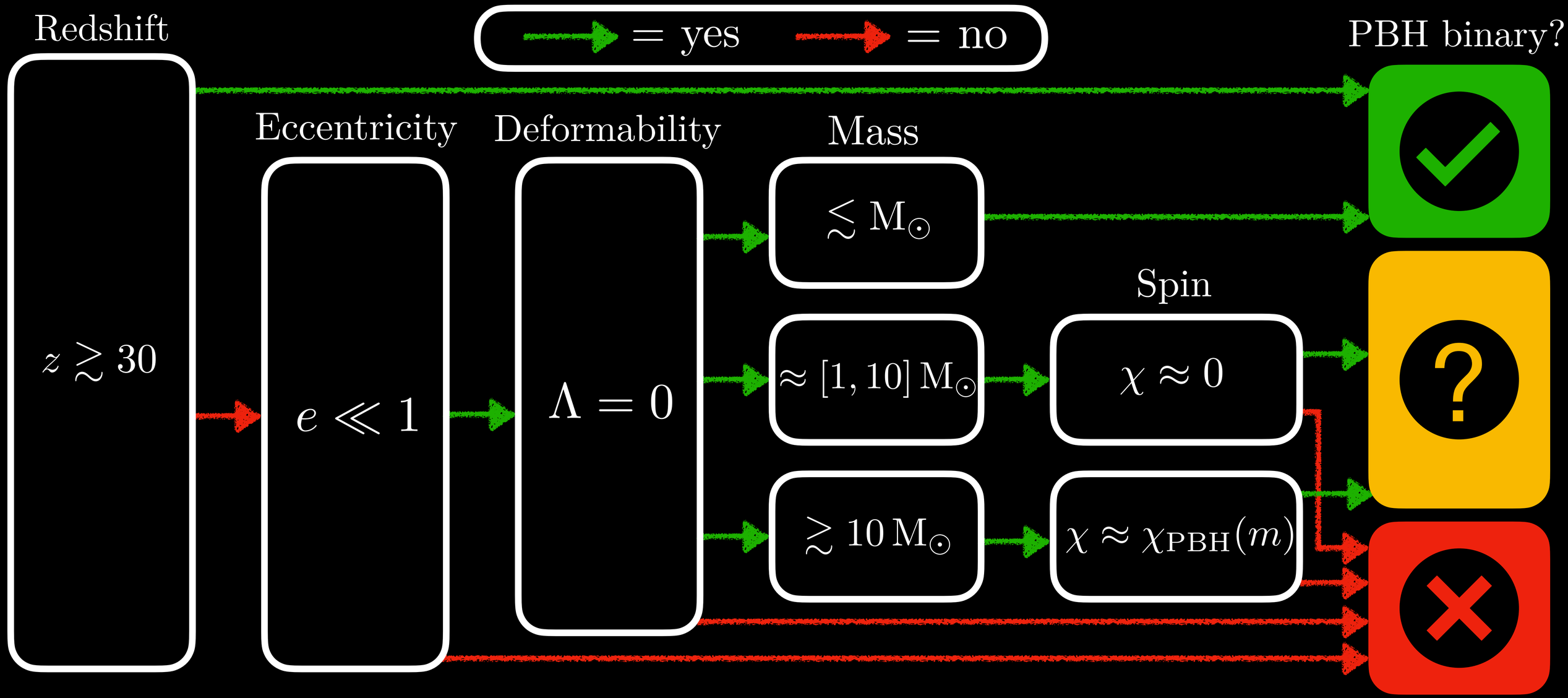


De Luca et al., (2021)

Detecting BBH beyond $z \gtrsim 30$ is a strong indication of PBH, ET can get to $z \gtrsim 100$!
Also the subsolar window is extremely promising, and the LF are crucial

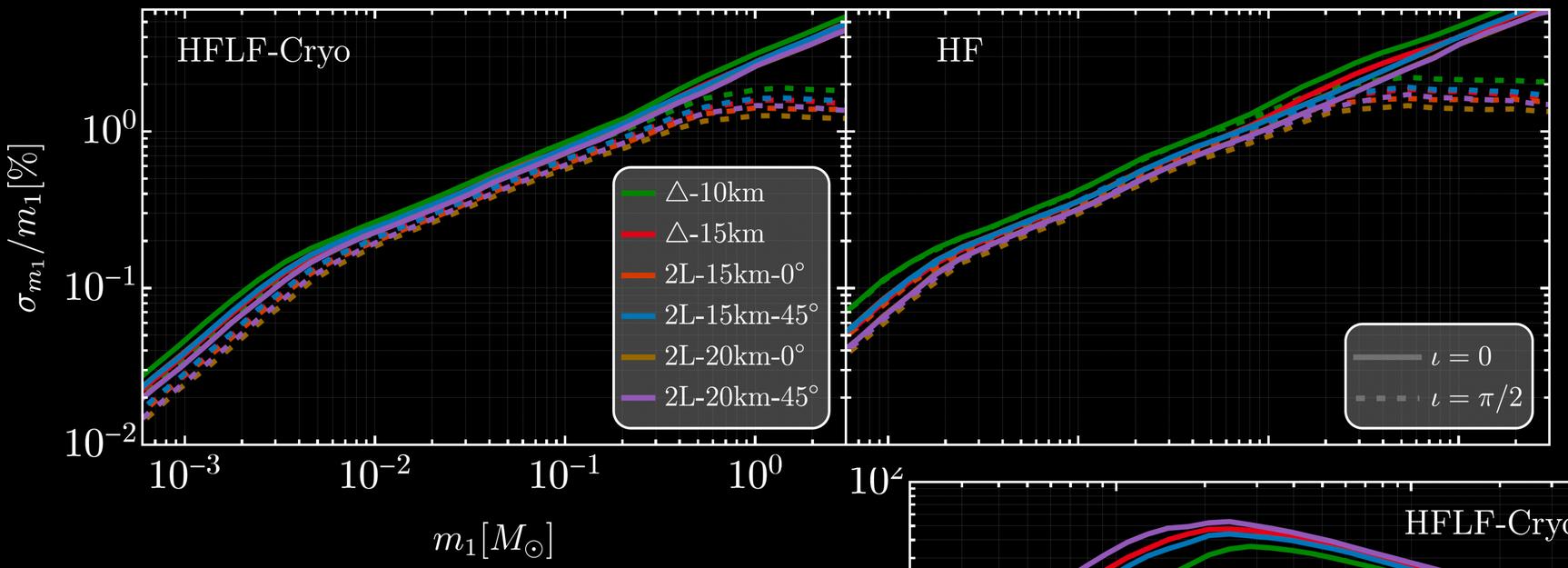
Primordial black holes

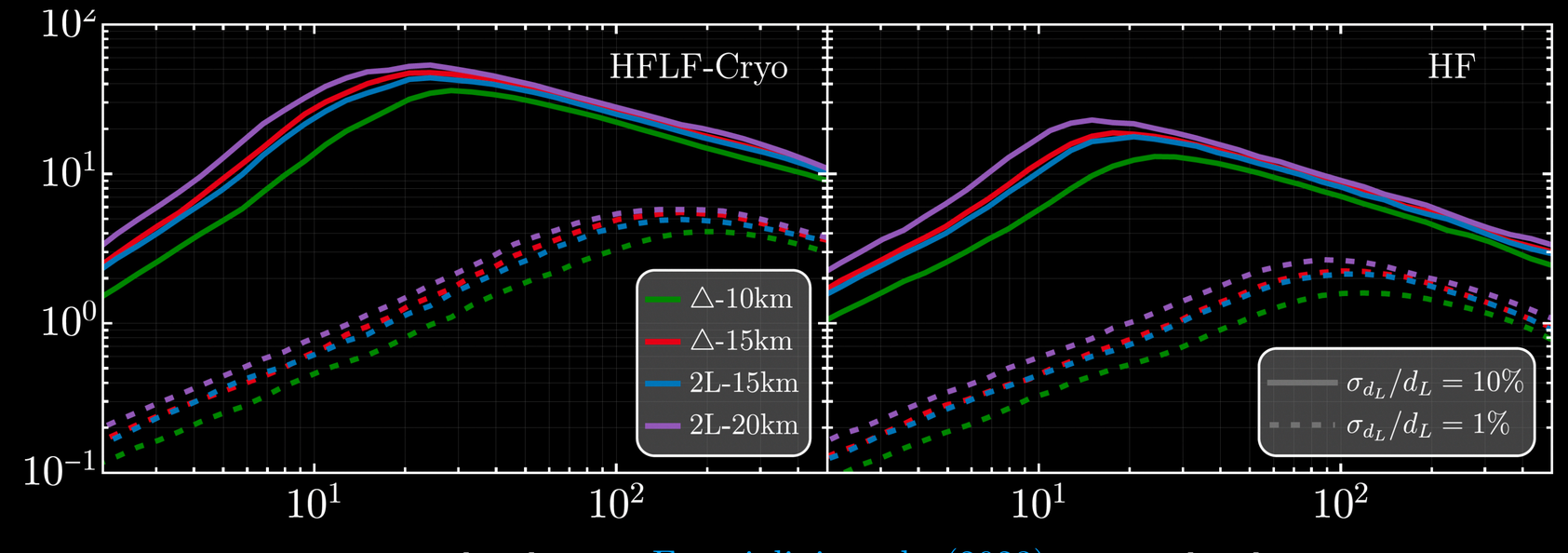
Some key signatures can help disentangling ABH and PBH binaries [Franciolini et al., (2021)]



Primordial black holes

ET could reach an outstanding accuracy in the reconstruction of some relevant source parameters, such as mass, but some others are tricky





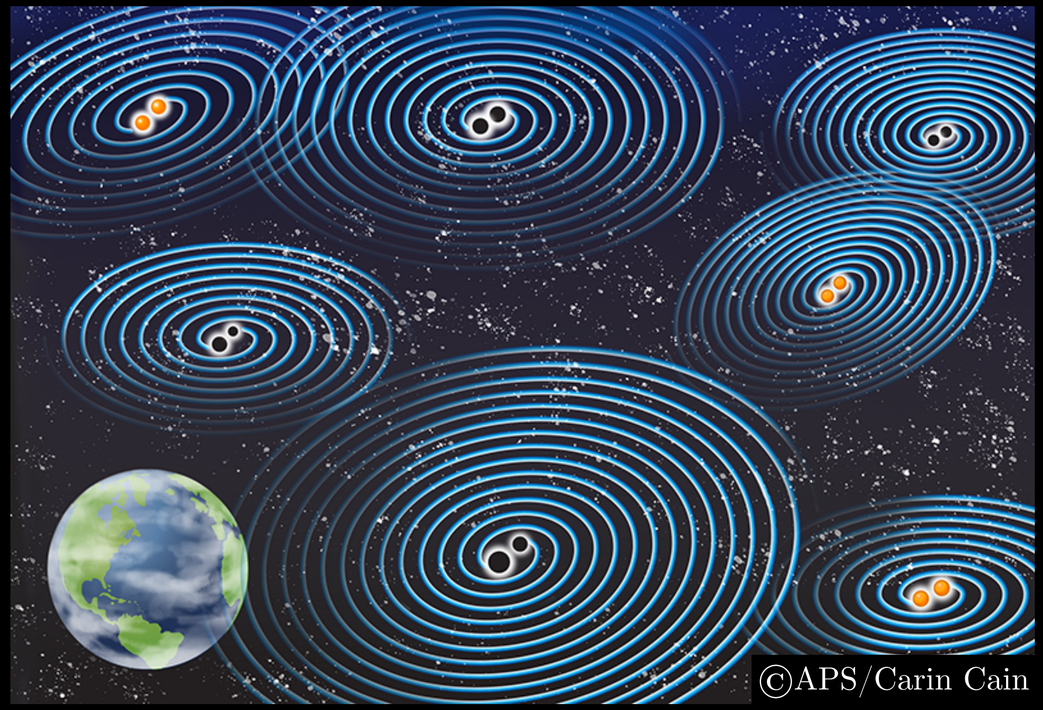
Franciolini et al., (2023)

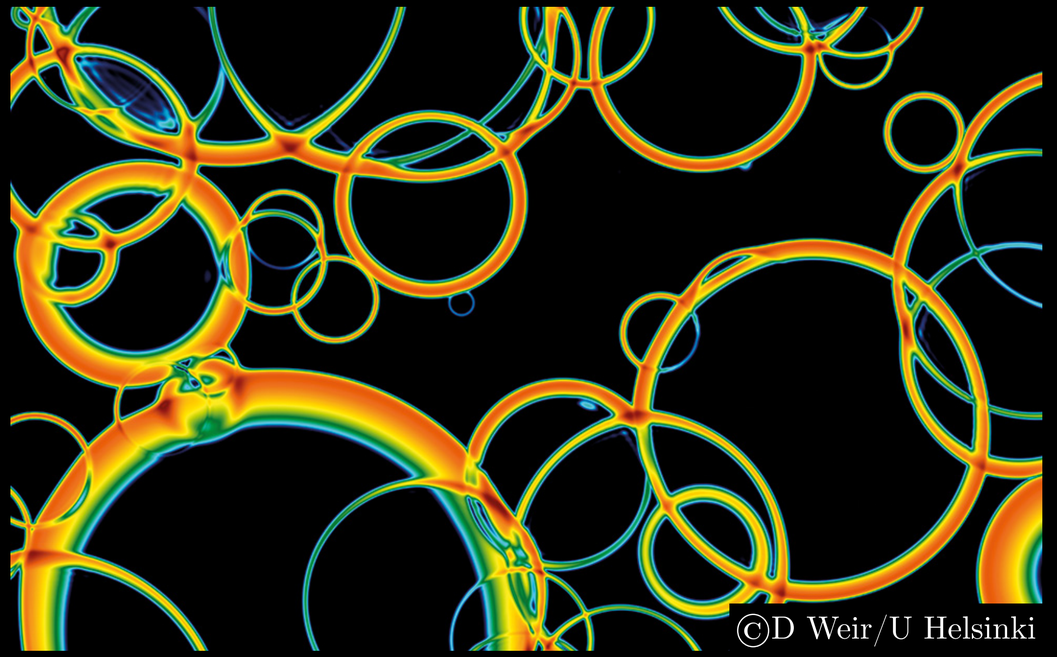
Stochastic GW background

The stochastic GW background is formed by the incoherent superposition of signals emitted by different GW sources in our Universe:

- the **AGWB** is made of the superposition of all GWs emitted by different populations of astrophysical sources, from the onset of stellar activity until the present epoch

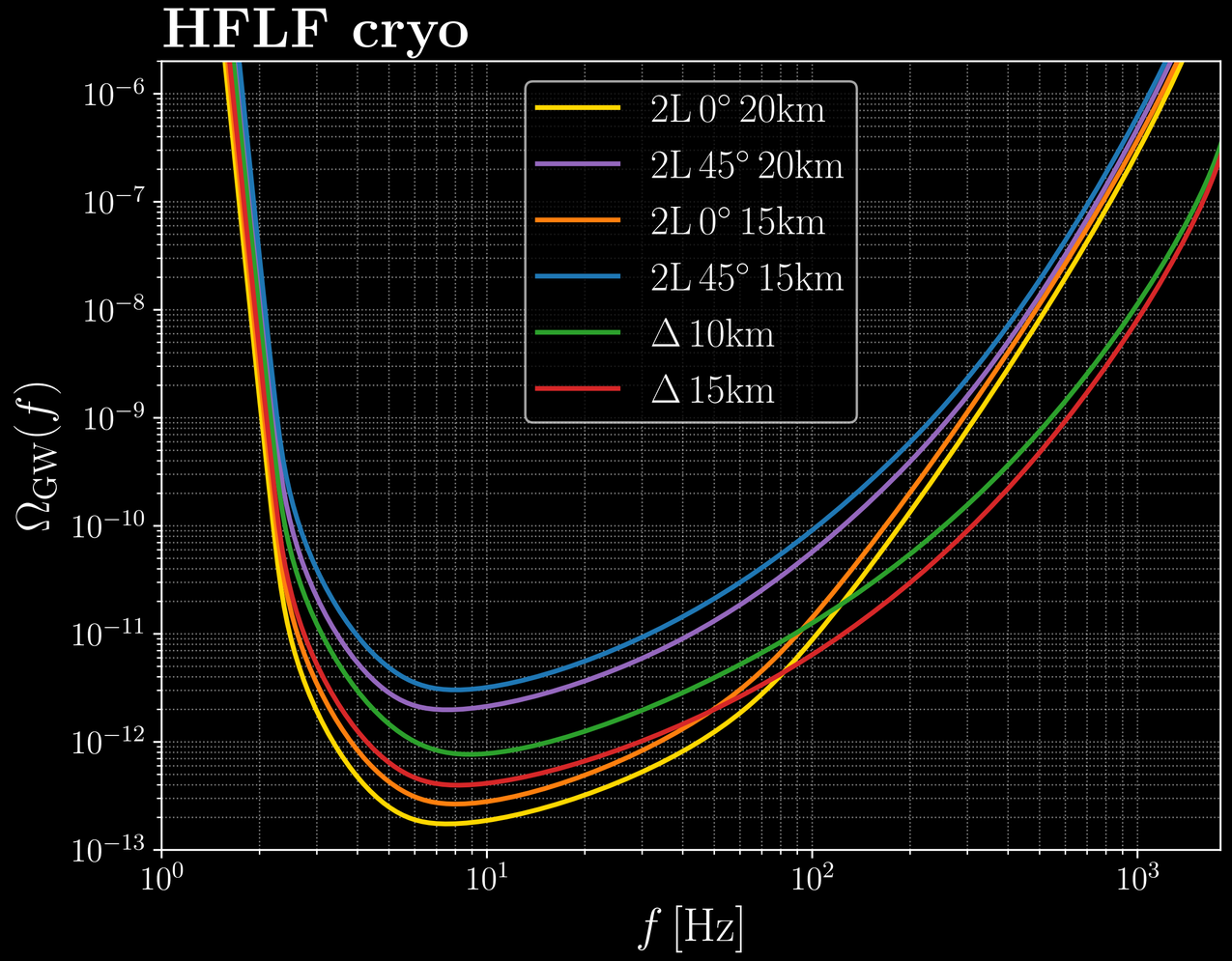
- The **CGWB** are tensor modes produced by different processes in the early universe such as inflation, reheating, phase transitions, cosmic strings, or primordial black holes

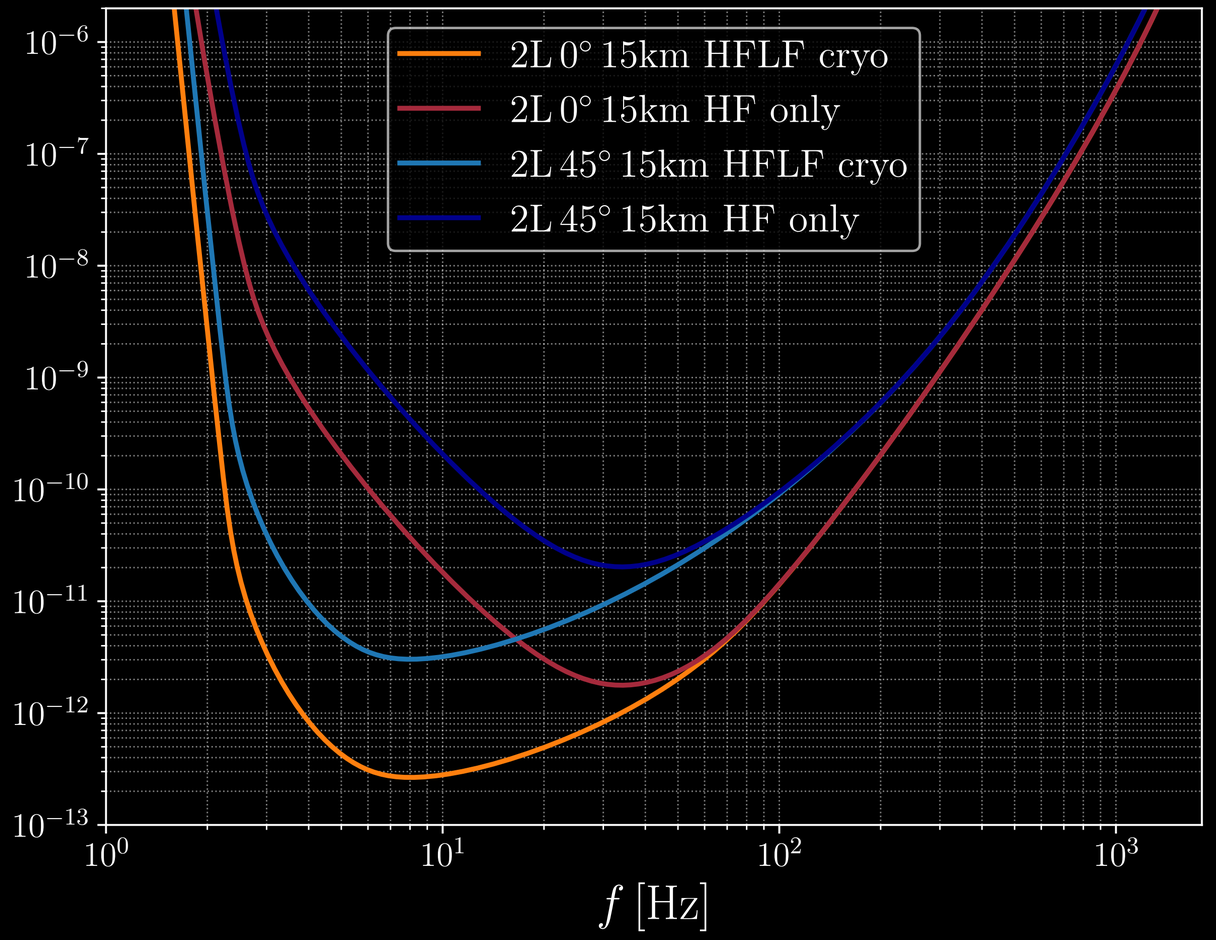




Stochastic GW background

The power-law integrated sensitivity curve is built so that any line tangent to it represent a SGWB that would be detected in a given observational time (1yr) with the chosen SNR (1)





Summary

- Whatever the design, ET is a superb detector with a vast science case: the combination of distances and masses explored, sheer number of detections, and high SNR will provide a wealth of data that have the potential of triggering revolutions in astrophysics, cosmology and fundamental physics

- Studying different designs allows to understand how different elements contribute to the scientific output and to suggest changes to maximise it

- From the scientific point of view, the 15km 2L with arms at 45° is superior on basically all the considered metrics with respect to the 10km triangle, with the exception of the nominal sensitivity to stochastic backgrounds, and offers a better possibility to proceed in steps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Thanks for your attention... questions?