LIGO, LISA, & 3G
Status & Prospects for Gravitational Wave Detection

Opinions by Brian Lantz, Science by the LSC, ET-consortium, and LISA team
Discussion for the SLACmass group, Feb 27. 2020. LIGO-G2000297

Now: Advanced LIGO/VIRGO network is making lots of detections.
2026-2028: A+ presents clear, funded plans to improve performance (now to ~2028)
2026 to ~2040: Maximize science from the current facilities
- LIGO India and KAGRA will be running (2 more 2G facilities)
- potential for low-temperature operation of LIGO - Voyager

2034: LISA launch scheduled
2035-2040: working to bring 2 new next generation detectors in new facilities online
- Einstein Telescope (ET) in Europe, Cosmic Explorer (CE) in the US.

Brian thinks - DOE involvement with 3G detectors might be a good move

1. DOE has experience & management structures in place to deal with large facilities and large on-going scientific staffing for those facilities.
2. 3G detectors need lots of very good engineering to enable the GW science
3. in general - GWs present exciting new astronomy, astrophysics, and cosmology.
4. in particular - GWs are an excellent window into extreme energy-density physics.

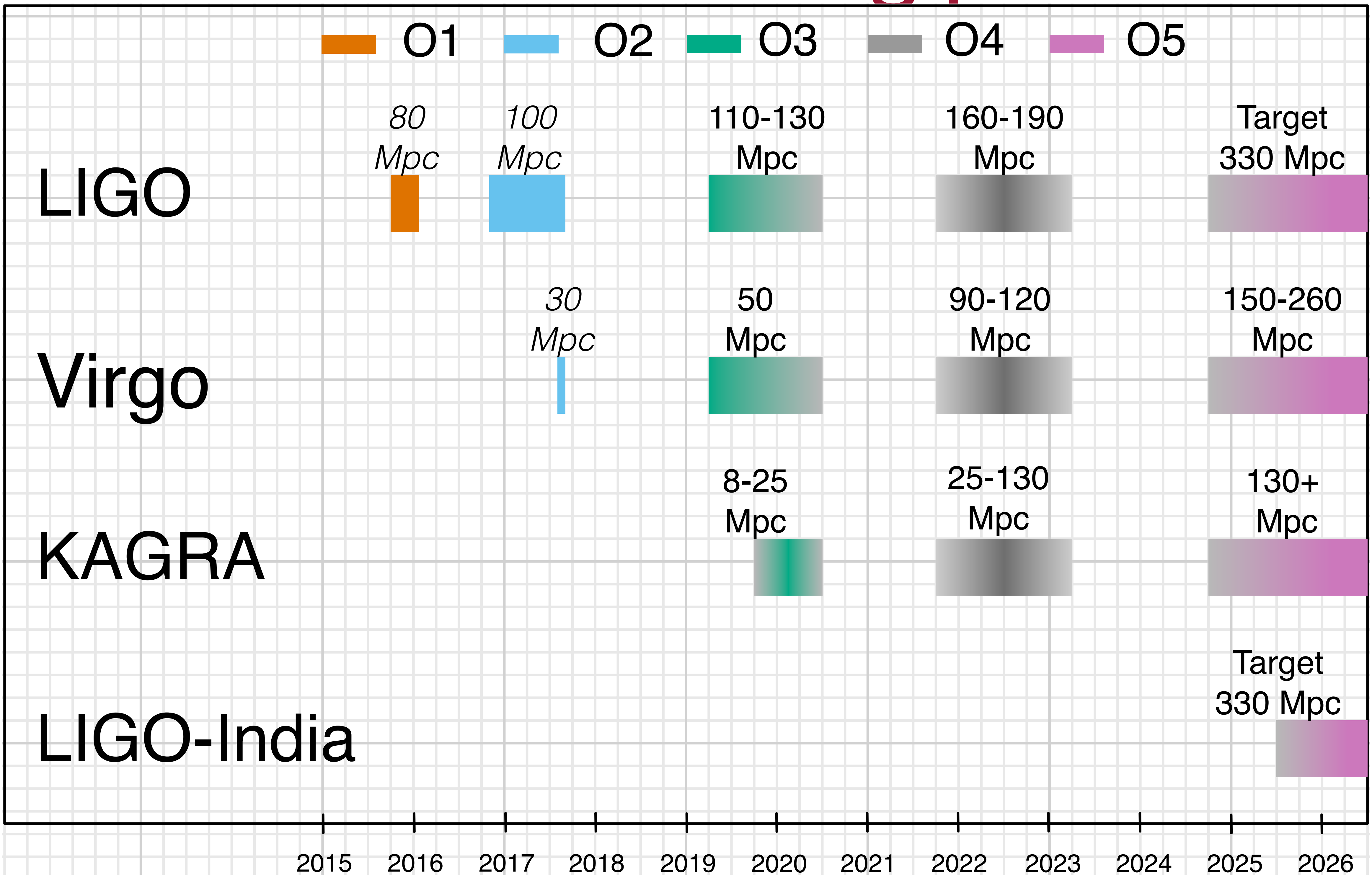
But

1. The cultures are different. SLAC should not try to run LIGO.
2. How can we keep the golden goose, but scale it to bigger teams, bigger facilities and ~continuous detections?

International Network

map from http://www.nationsonline.org/maps/political_world_map3000.jpg

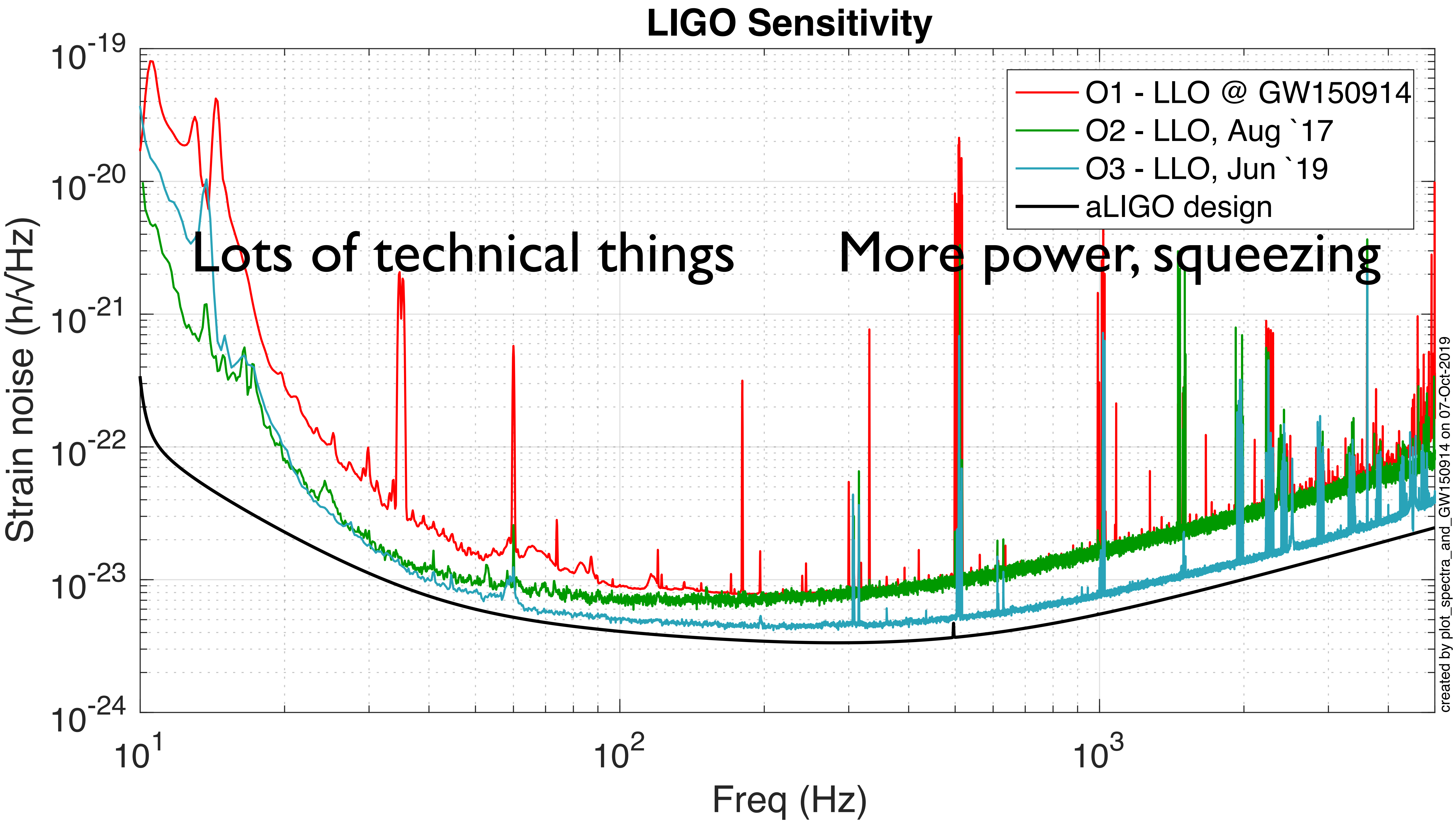
LIGO observing plans



Timeline from: Prospects for observing and localizing gravitational-wave transients with Advanced LIGO, Advanced Virgo and KAGRA

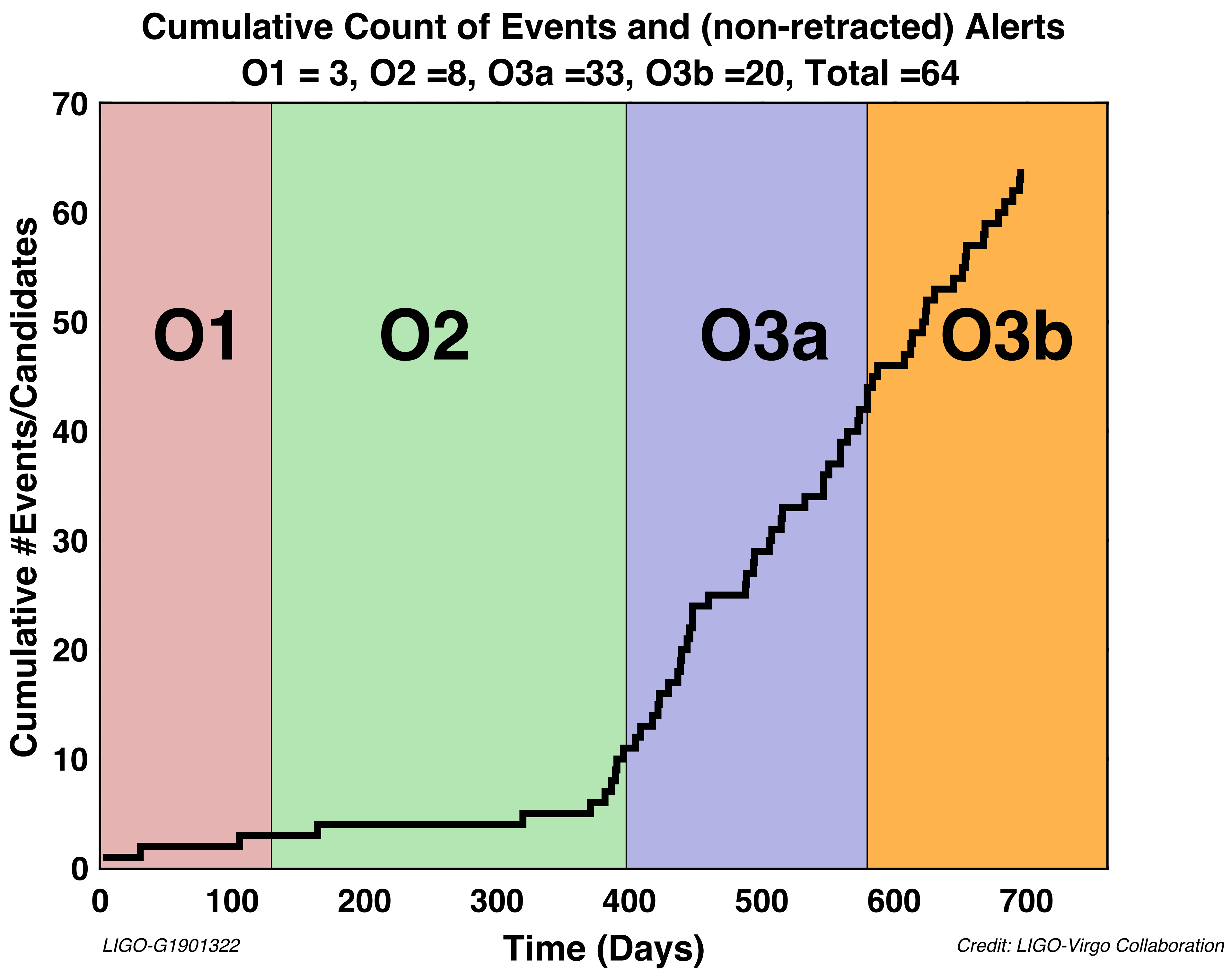
https://doi.org/10.1007/s41114-018-0012-9

Performance Evolution O1-O3



There's a factor of 2-3 in noise - comes from lots of work, leads to lots of discoveries

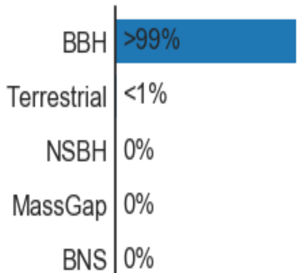
Signal/ Alert Rate



These detectors are now Observatories.

O3a triggers as of Sept, 2019

BBH	BNS	NSBH	Terrestrial



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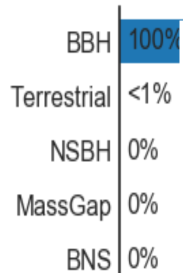
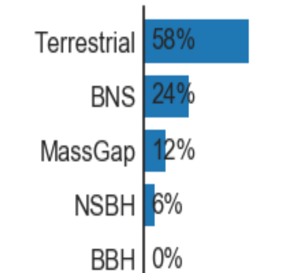


S19041

lbv



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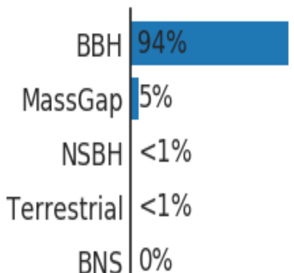

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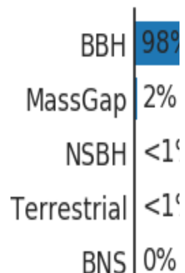

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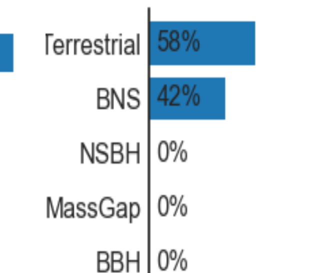
10d



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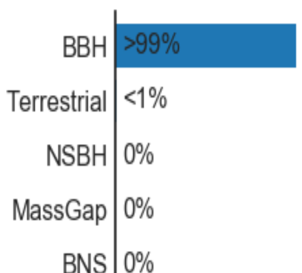

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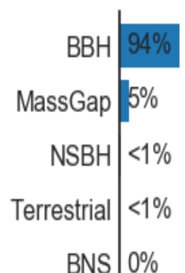

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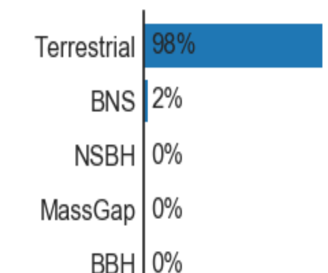
23y



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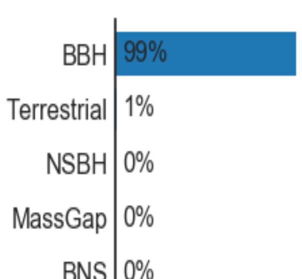

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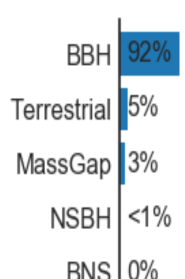

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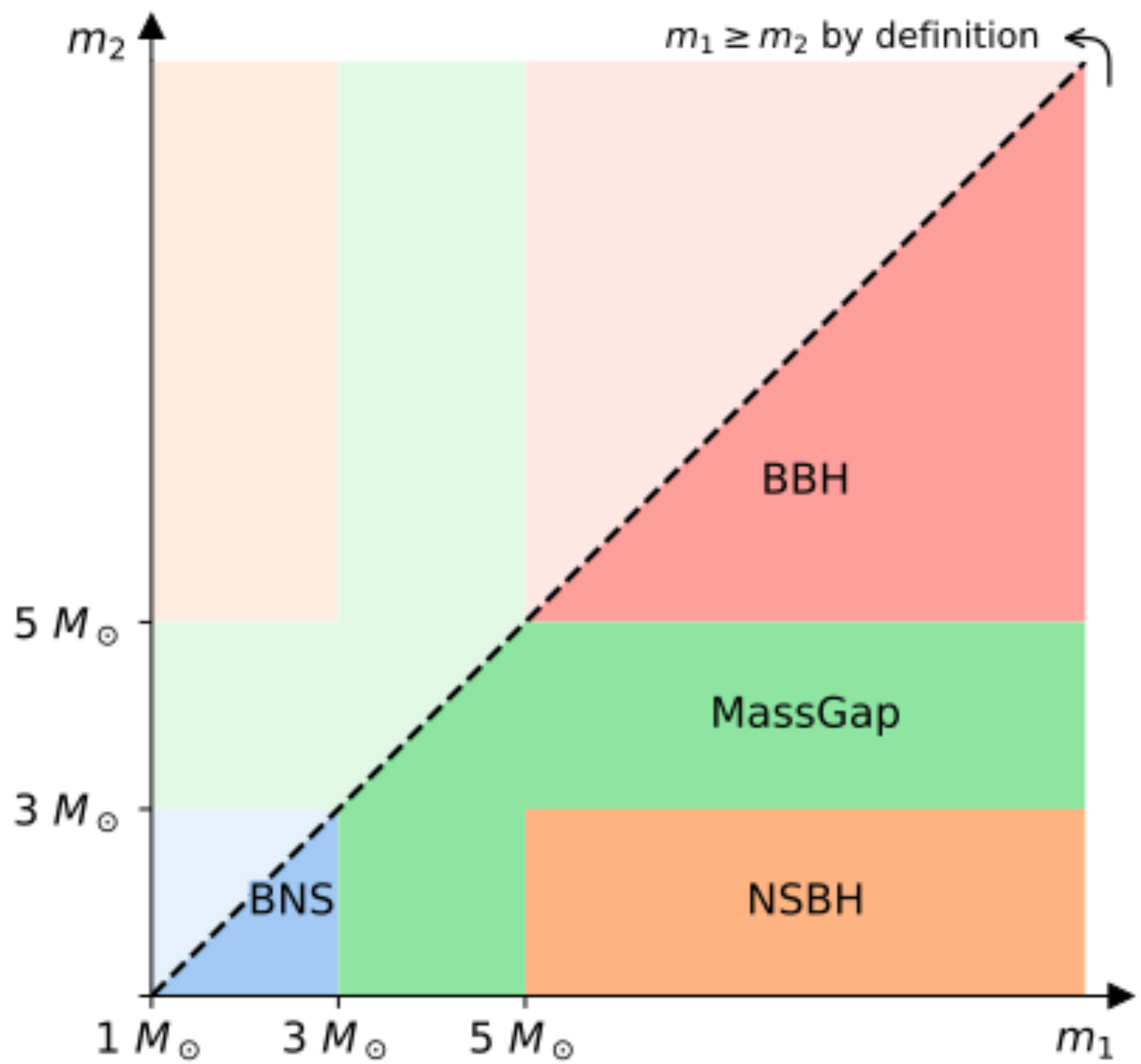

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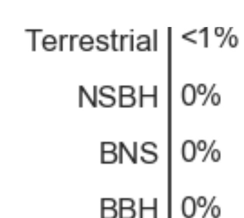
Gap

5

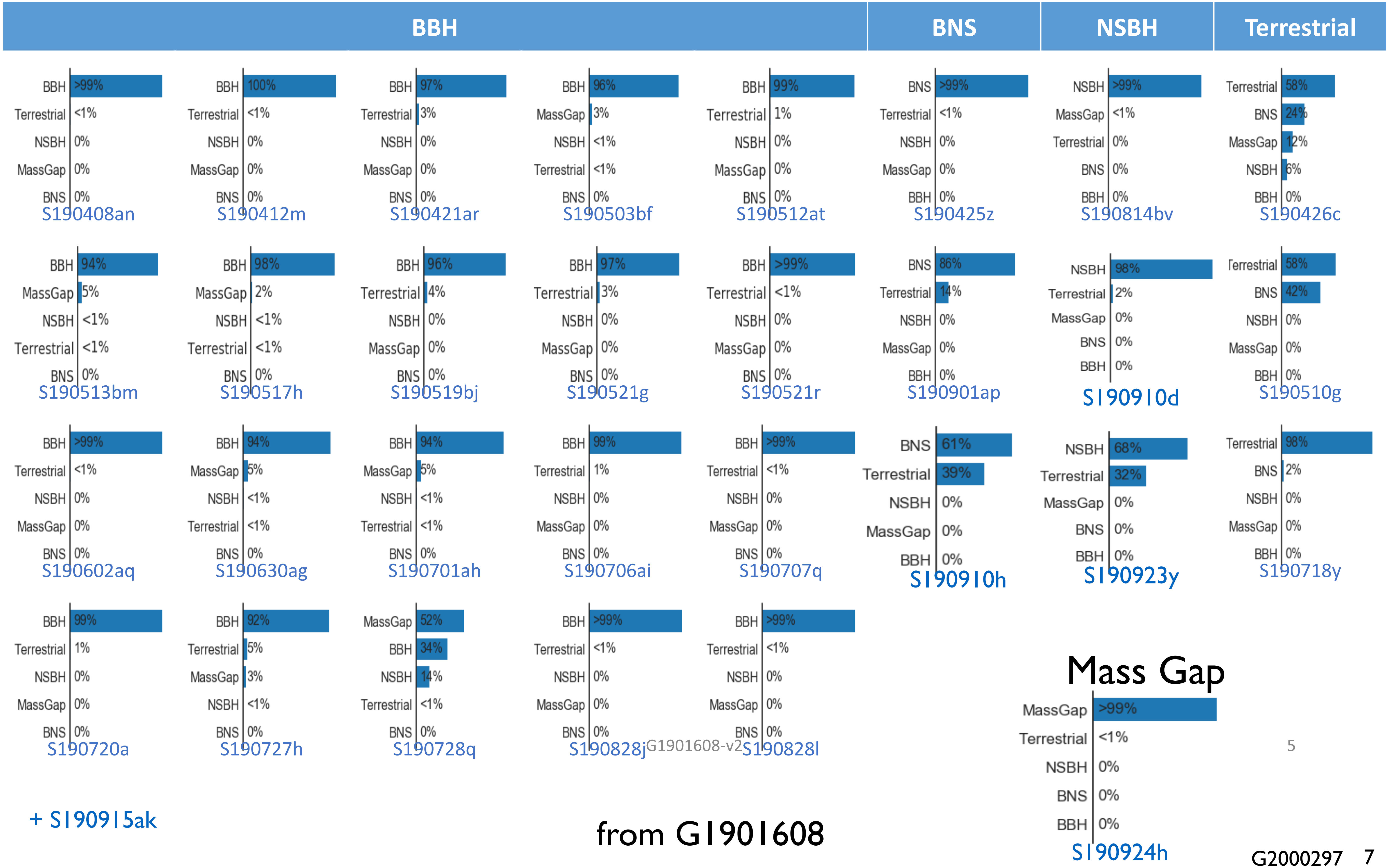


S190924h

+ S190915ak

from G1901608

O3a triggers as of Sept, 2019



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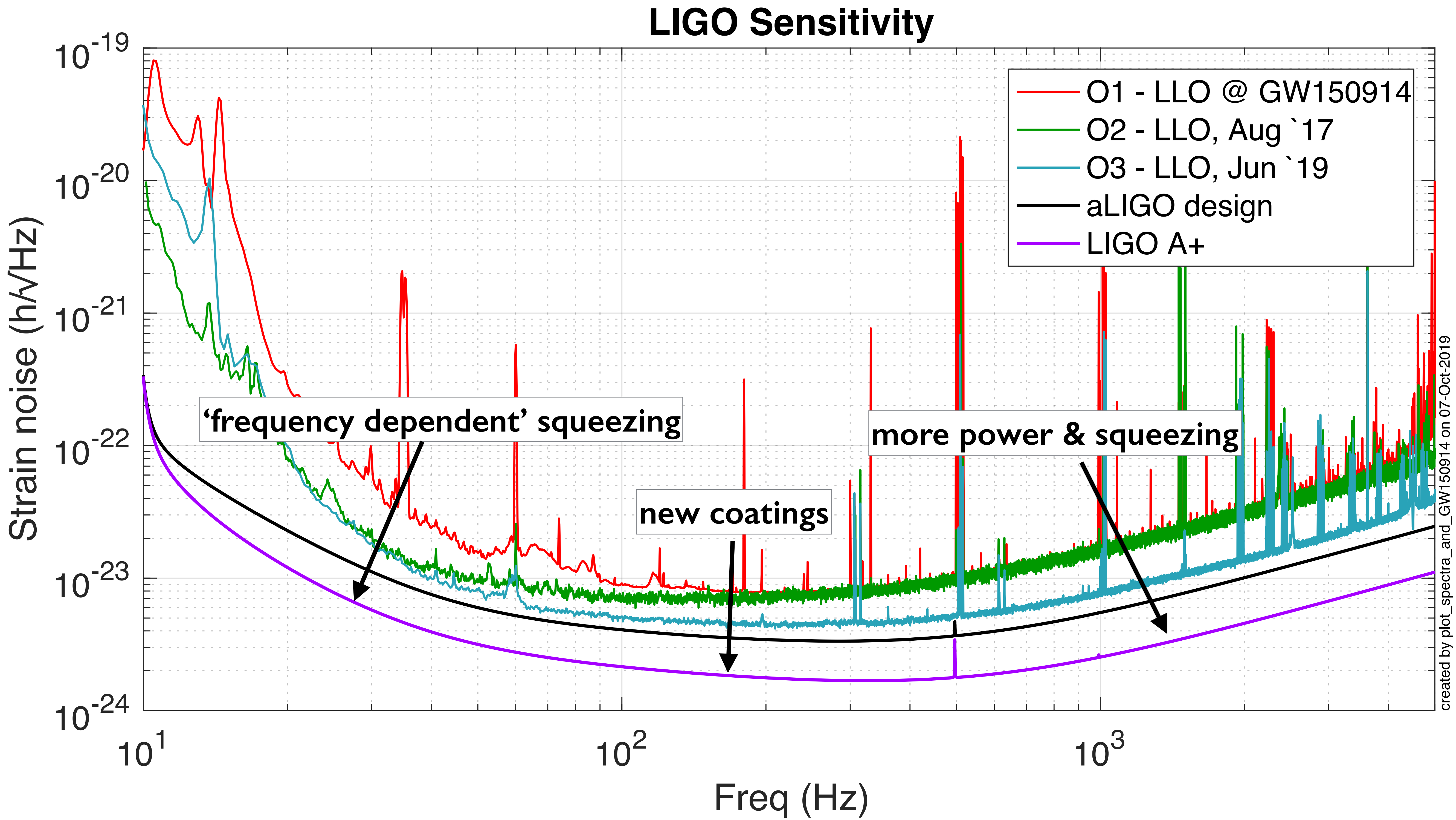
from G1901608

Performance Evolution to A+



Range

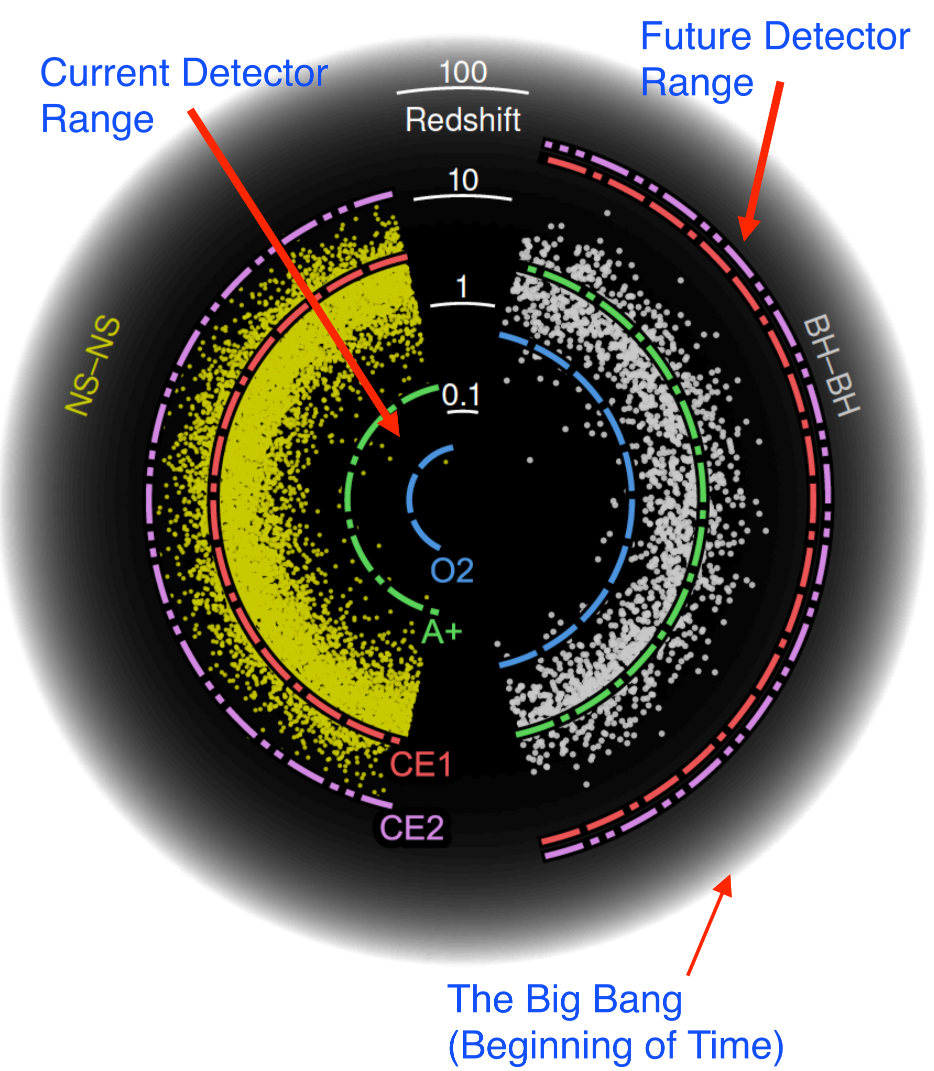
		O1	O2	O3	O4	O5
BNS Range (Mpc)	aLIGO	80	100	110 – 130	160 – 190	330
	AdV	-	30	50	90 – 120	150 – 260
	KAGRA	-	-	8 – 25	25 – 130	130+
BBH Range (Mpc)	aLIGO	740	910	990 – 1200	1400 – 1600	2500
	AdV	-	270	500	860 – 1100	1300 – 2100
	KAGRA	-	-	80 – 260	260 – 1200	1200+
NSBH Range (Mpc)	aLIGO	140	180	190 – 240	300 – 330	590
	AdV	-	50	90	170 – 220	270 – 480
	KAGRA	-	-	15 – 45	45 – 290	290+
Burst Range (Mpc) $[E_{GW} = 10^{-2} M_\odot c^2]$	aLIGO	50	60	80 – 90	110 – 120	210
	AdV	-	25	35	65 – 80	100 – 155
	KAGRA	-	-	5 – 25	25 – 95	95+
Burst Range (kpc) $[E_{GW} = 10^{-9} M_\odot c^2]$	aLIGO	15	20	25 – 30	35 – 40	70
	AdV	-	10	10	20 – 25	35 – 50
	KAGRA	-	-	0 – 10	10 – 30	30+

Prospects for observing and localizing gravitational-wave transients with Advanced LIGO, Advanced Virgo and KAGRA
https://doi.org/10.1007/s41114-018-0012-9

Motivation & Rationale for Future GW Detectors

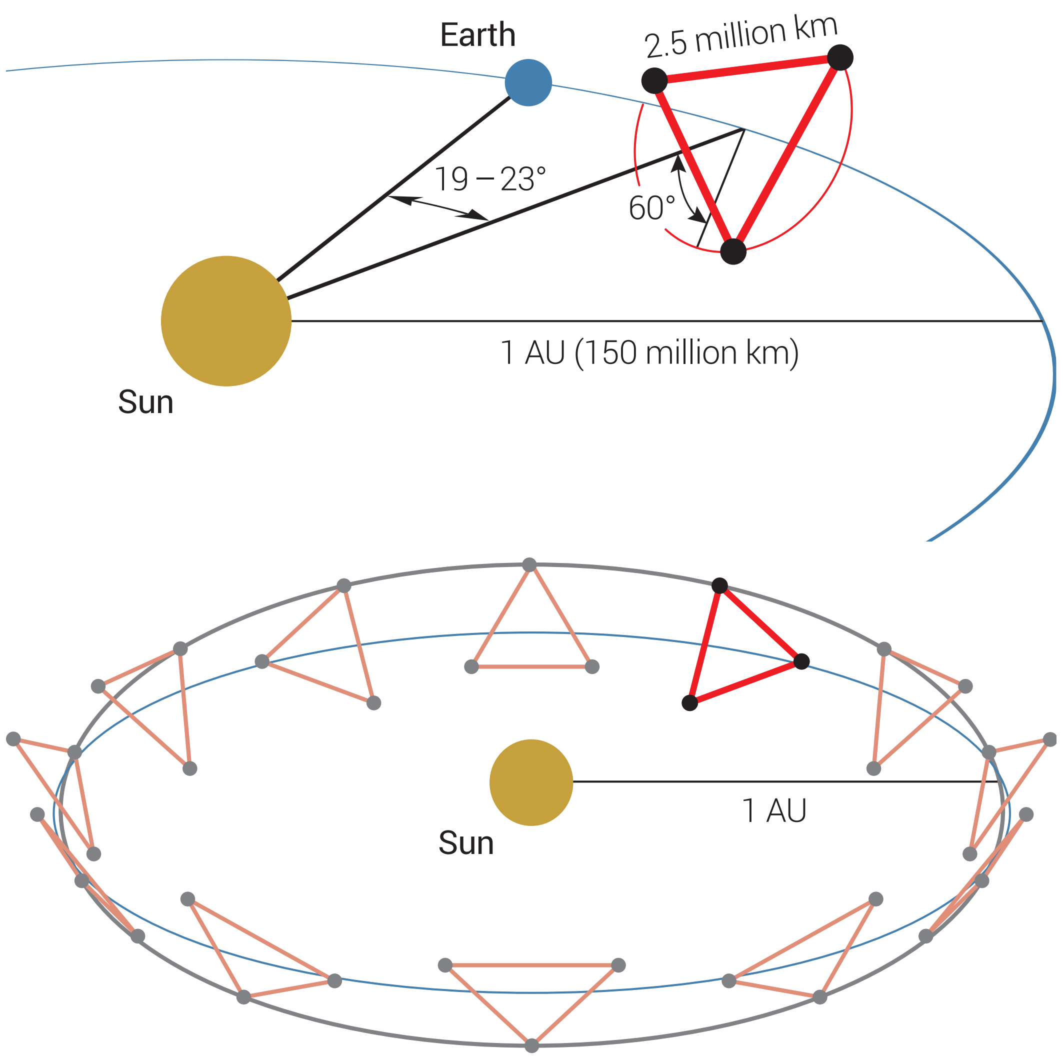
- Current GW detectors can 'see' limited distances with limited SNRs and rates
  - » Advanced LIGO binary neutron star maximum ('horizon') distance: **~ 380 Mpc**
  - » Advanced LIGO binary black hole maximum distance: **3.6 Gpc**
  - » O(100) detections per year, *however:*
    - – Rare coincident GW-gamma ray events
    - – Rare post-merger binary neutron star ringdowns
    - – Very limited range (10 kpc) to supernovae events
- Future GW detectors could see:
  - » High redshift detections
    - – Remnants of Population III stars merging at z ≲ 10
  - » Large number of detections:
    - – O(100,000) detections per year, some rare and exotic events, population studies
  - » High-fidelity (precision waveform) detections:
    - – Events with SNR >1000 for precision tests of relativity and neutron star physics

'No Black Hole Left Behind'



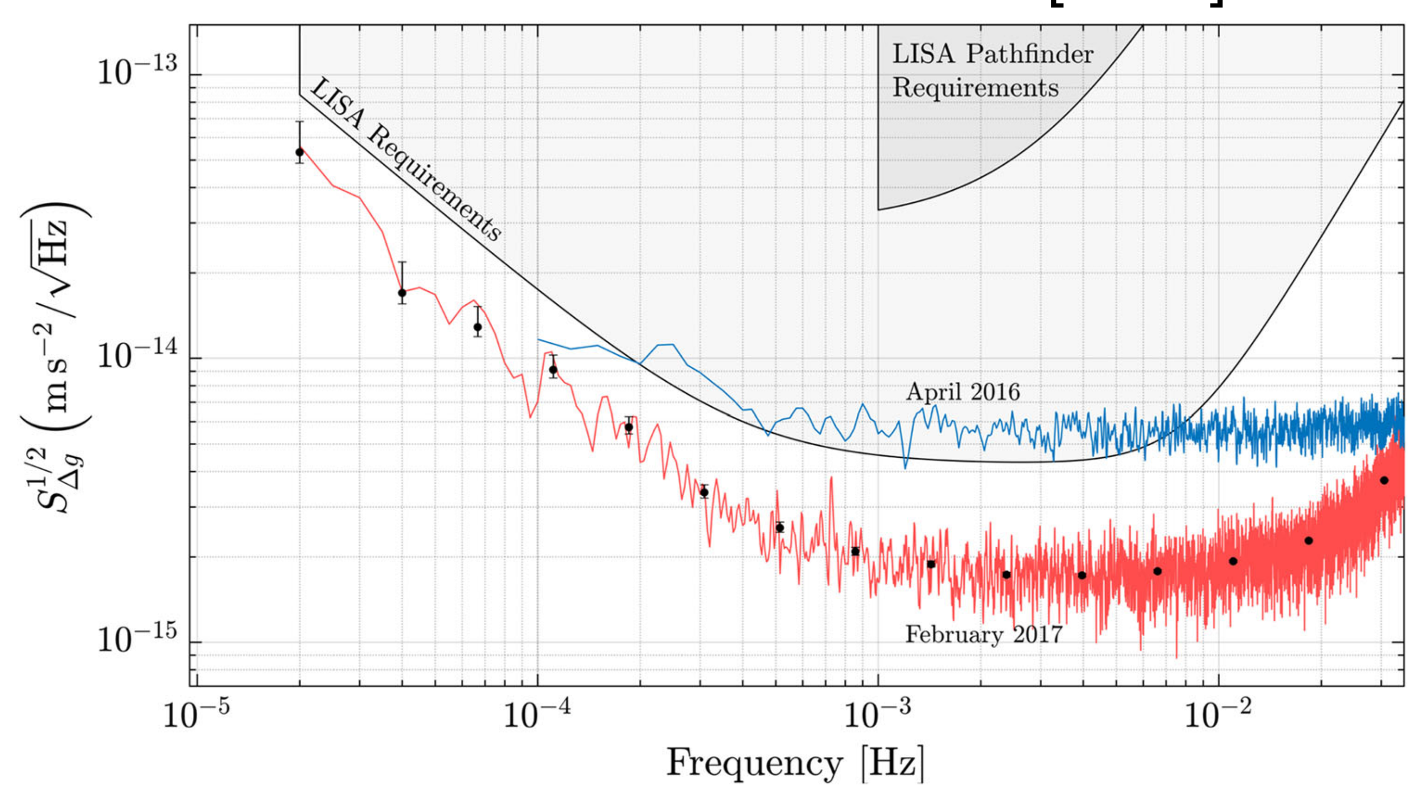
LISA Status

- Current LISA project plan is 3 spacecraft separated by 2.5 million km. [1]
- LISA selected by ESA as "L3" (3rd Large) mission, expected launch date of 2034 [2]
- LISA Pathfinder very successful demonstration of acceleration noise in orbit [3]



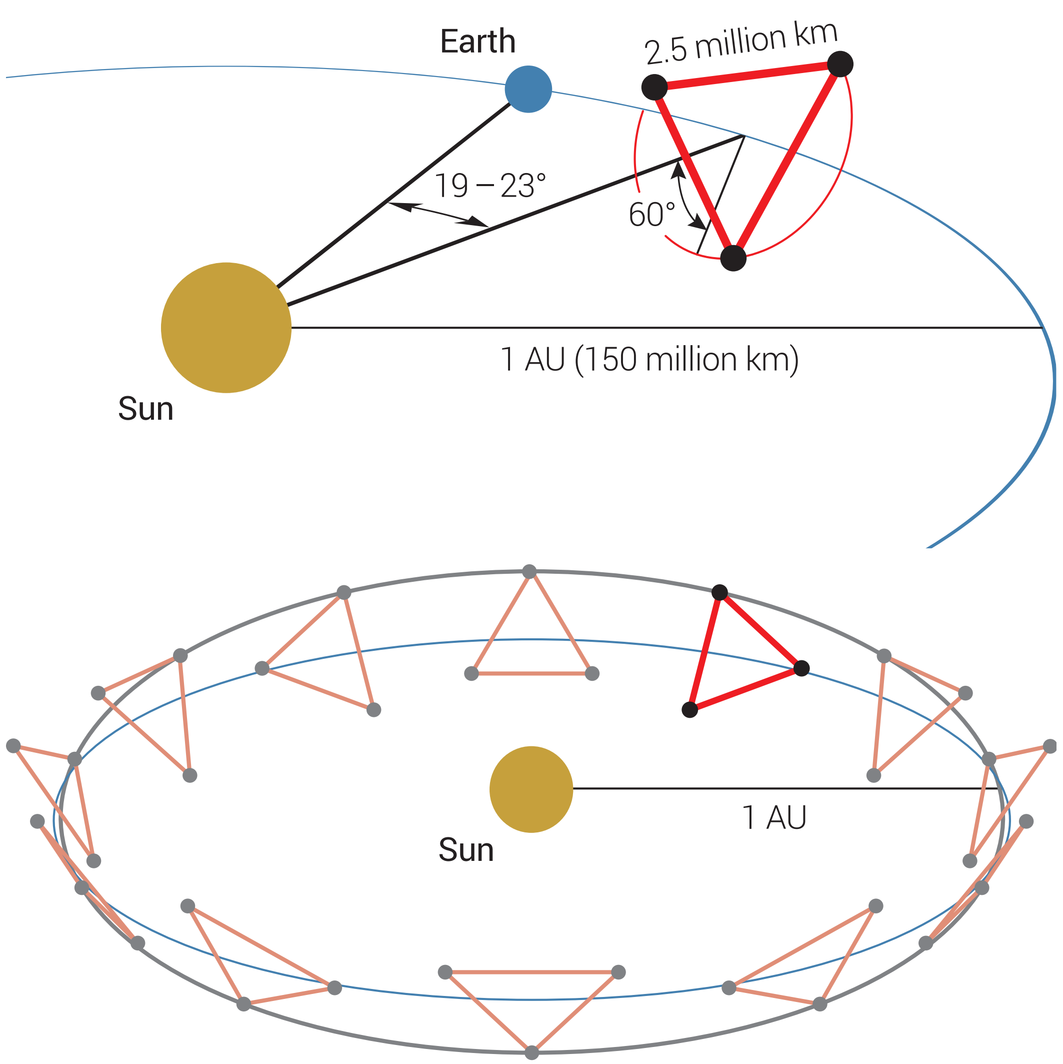
Depiction of the LISA orbit, from [3]

ASD of parasitic differential acceleration of LISA Pathfinder test masses [from 3].



[1] Amaro-Seoane et. al. 2017, see https://arxiv.org/abs/1702.00786
[2]: https://www.aei.mpg.de/2068798/lisaselection
[3]: Amaro et. al. PRL, 2018, see https://link.aps.org/doi/10.1103/PhysRevLett.120.061101

LISA Status



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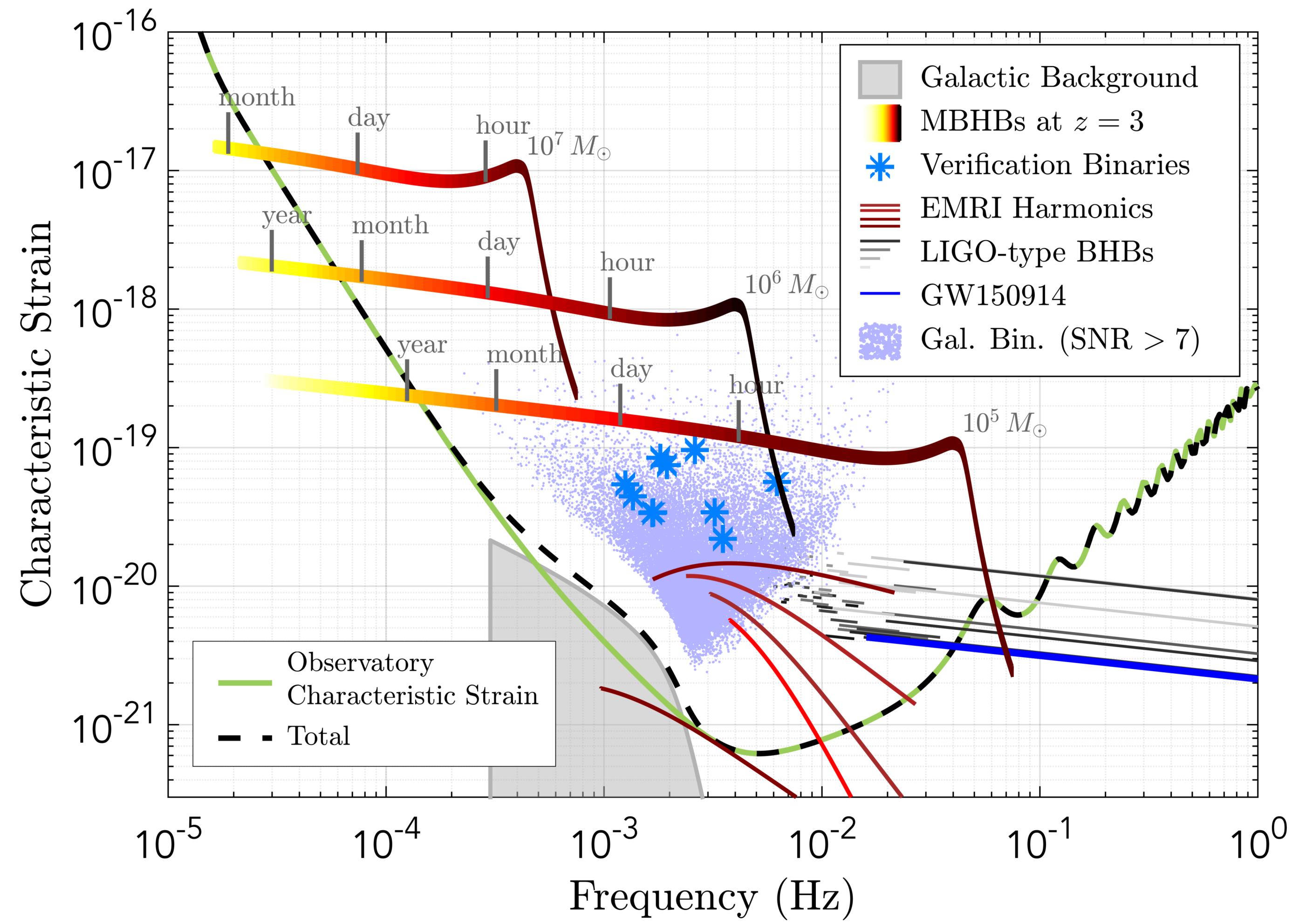
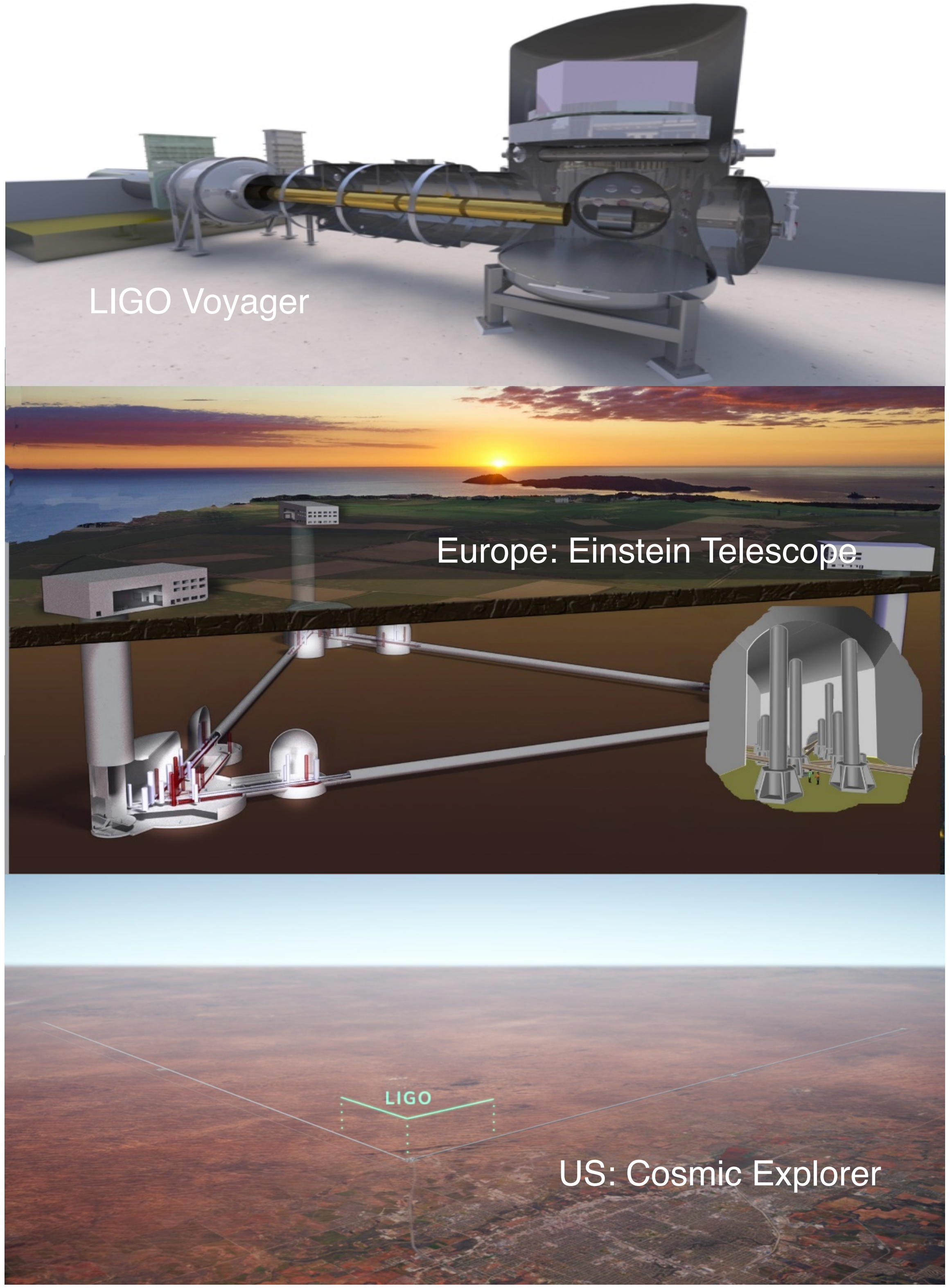


Figure 1: Examples of GW sources in the frequency range of LISA, compared with its sensitivity for a 3-arm configuration. The data are plot-

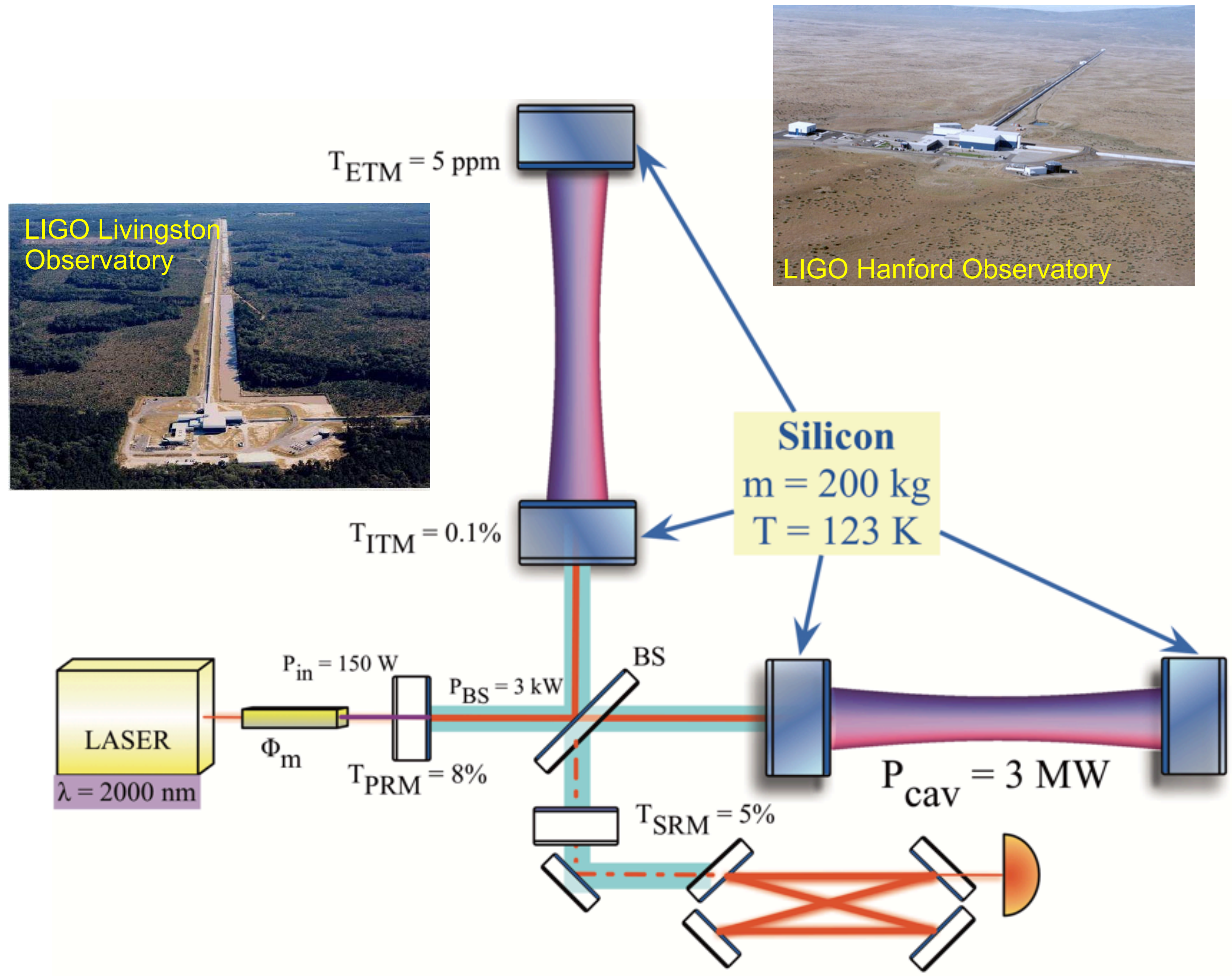
Future LIGO-style Detector Concepts

1. LIGO Voyager – the ultimate upgrade of the existing LIGO Observatories
   » Designed to reach the strain sensitivity limit imposed by the LIGO facilities – seismic/Newtonian noise below 25 Hz, residual gas noise at higher frequencies
2. Einstein Telescope (ET) – a new underground GW observatory located in Europe
   » Triangular configuration, 10 km arm lengths
3. Cosmic Explorer (CE) – a new above ground facility in the US
   » L-shaped configuration, 40 km arm lengths



LIGO Voyager

- A (quasi)cryogenically silicon test mass detector
  - » An upgrade of one or both of the existing US LIGO Observatories
- New lasers (2 μm), crystalline silicon optics, MCT photodetectors, cryogenic suspensions
  - » And modifications to the existing seismic isolation systems
- Target binary neutron star range: 1100 Mpc
  - » Up to z ~ 5 for binary black holes
- Earliest operation in early 2030s



Cosmic Explorer

- A new 40 km L-shaped facility on the Earth's surface
- Effectively '10 x LIGO'
  - » Sensitivity improvement from increased arm length
  - » ***Will 'see' the entire high frequency gravitational-wave universe***
- Two phase approach to building Cosmic Explorer
  - » Models successful two-stage approach of the current LIGO detectors
- Phase 1 (2030s): room-temperature glass detector
  - » Low risk: uses existing Advanced LIGO technology
- Phase 2 (2040s): (quasi)cryogenic silicon detector

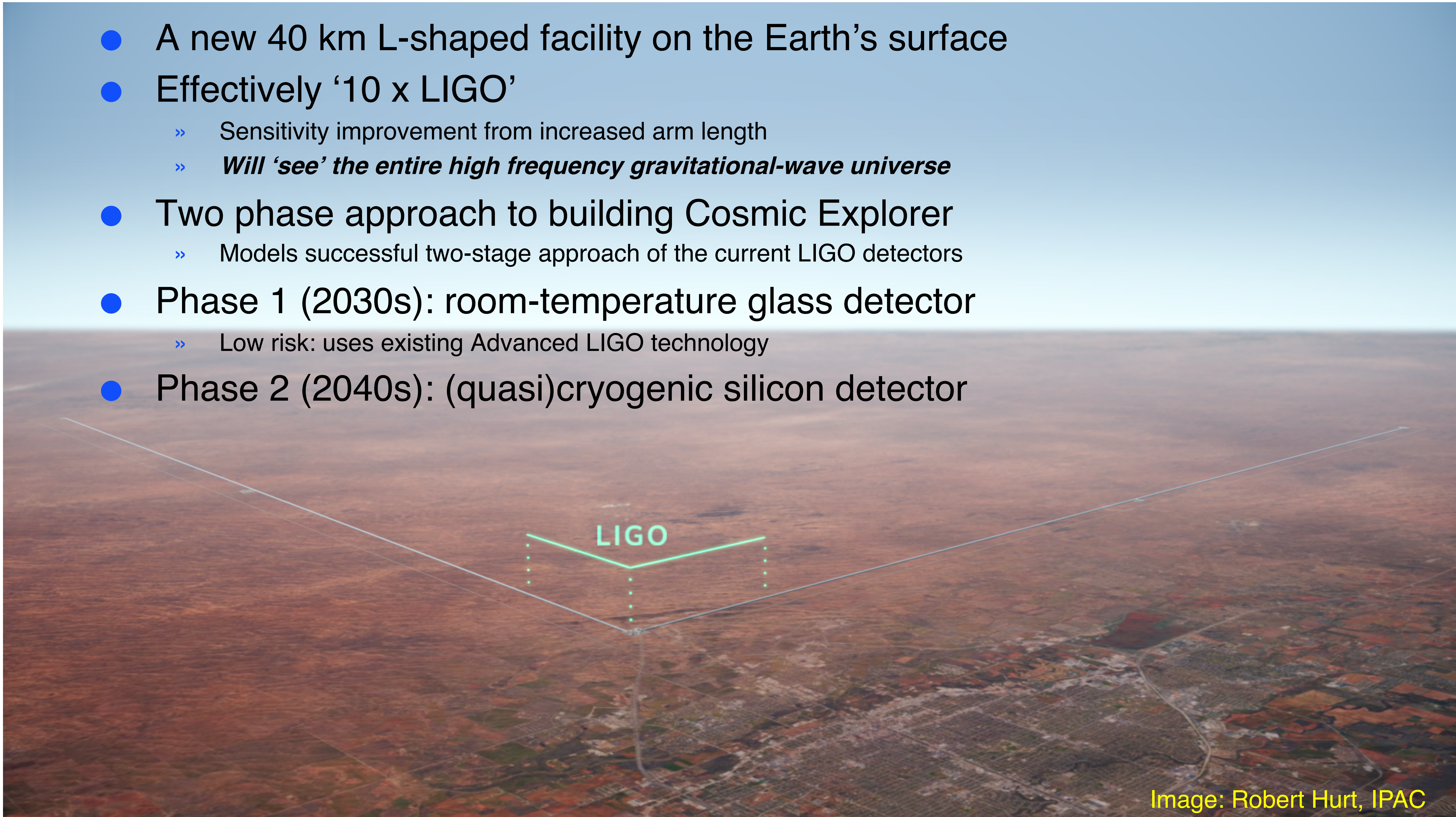
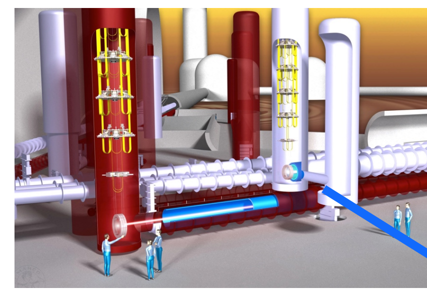
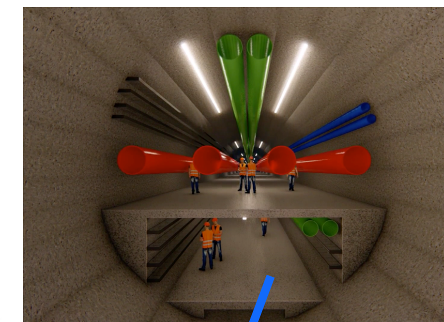


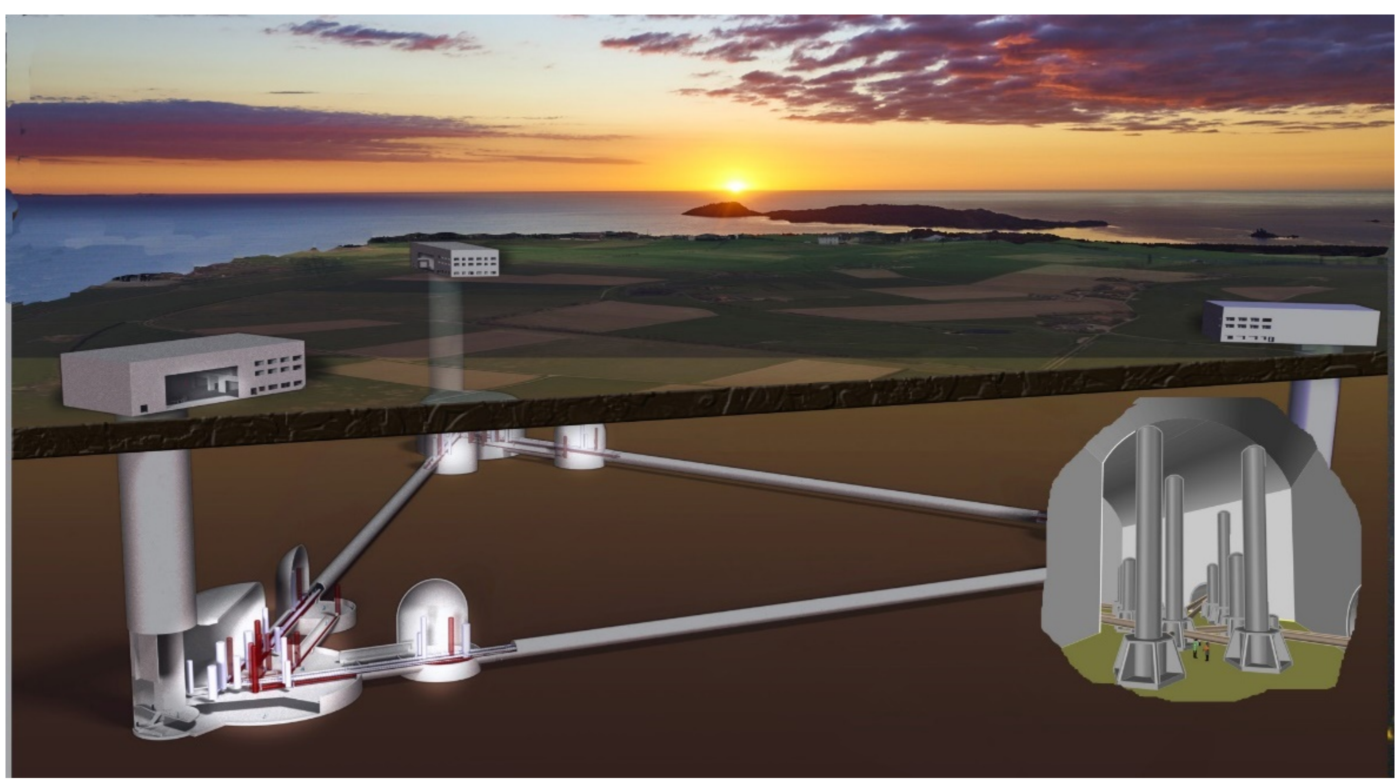
Image: Robert Hurt, IPAC

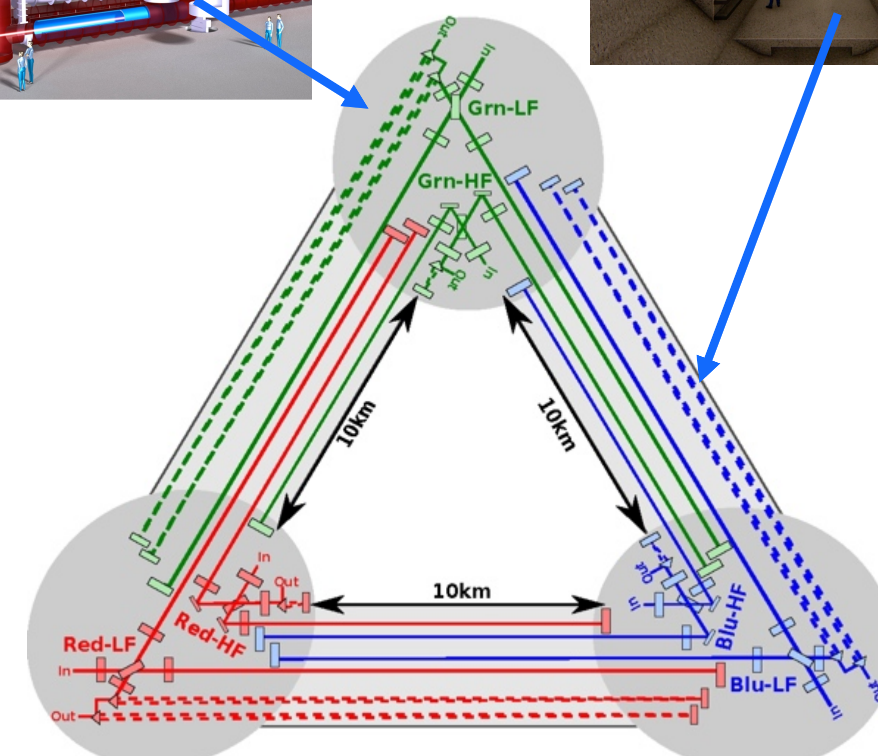
Einstein Telescope

- A new 10 km long triangular underground detector
  - Can resolve GW polarizations!
  - ***Will 'see' the entire high frequency gravitational-wave universe***
- 6 interferometers (3 high frequency, 3 low frequency)
  - Low frequency: silicon test masses @ 10K
  - High frequency: room temperature fused silica test masses
- Likely to be sited either in Sardinia or on Netherlands/Belgium/German border



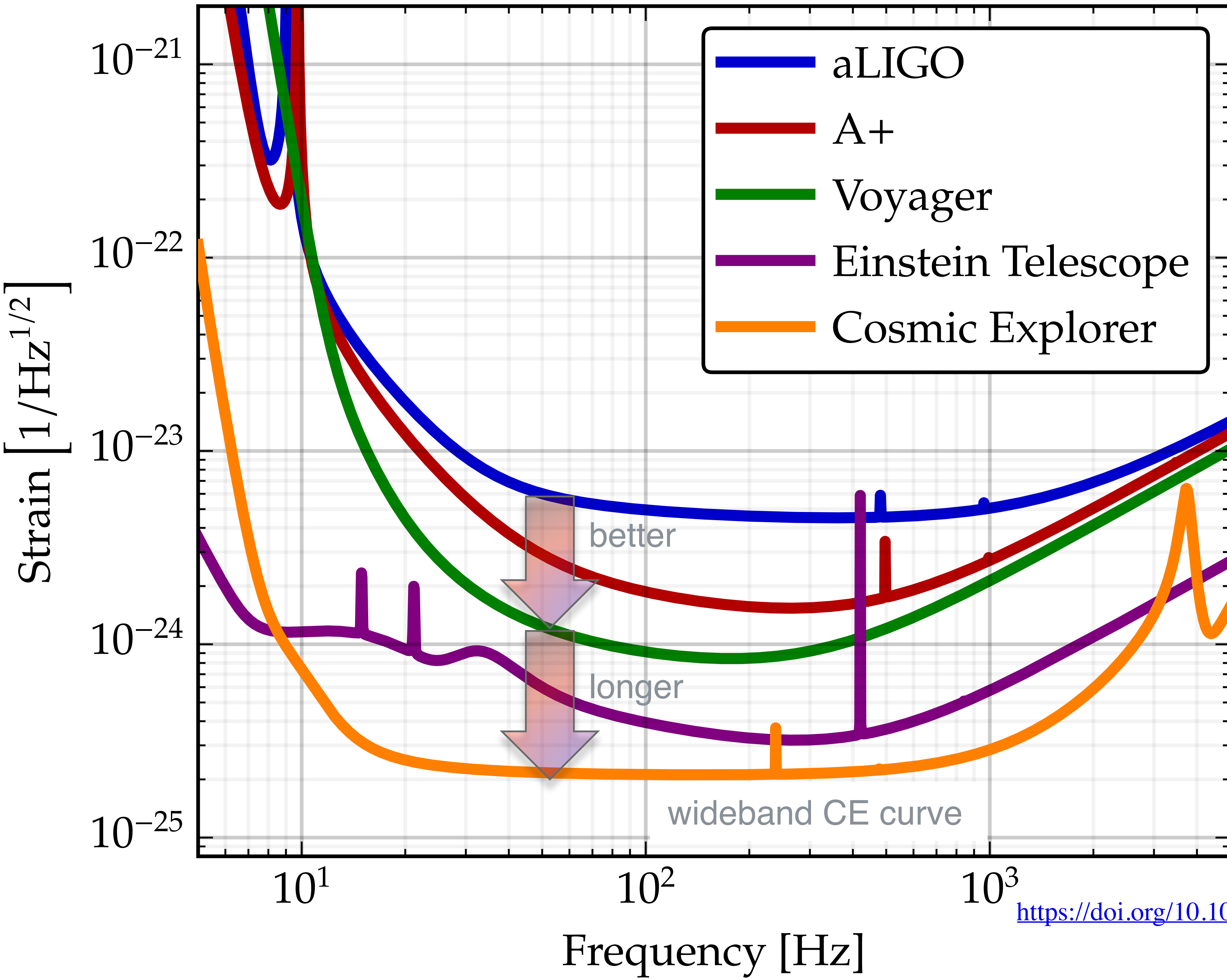






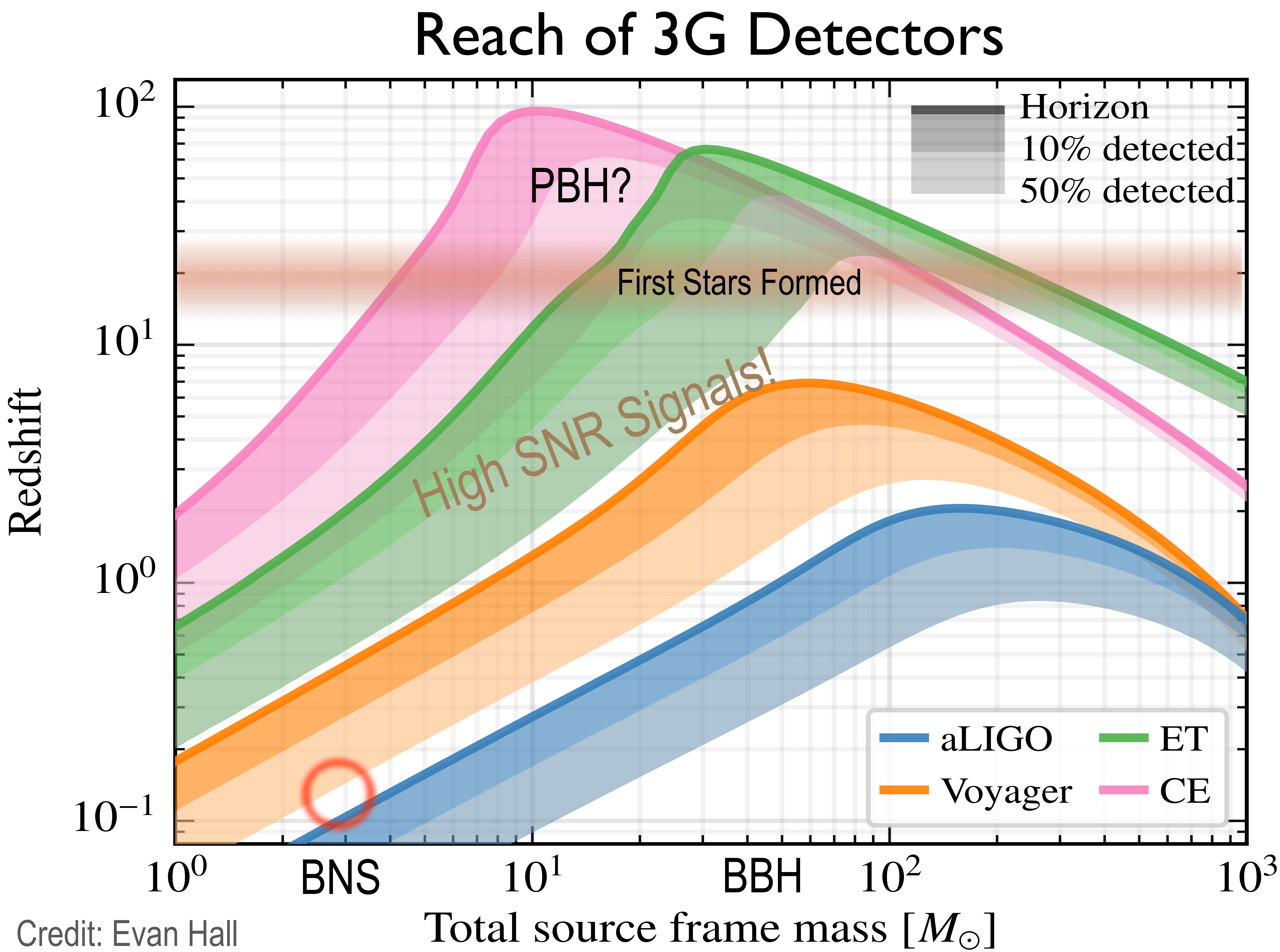
slide courtesy of D. Reitze

3G detectors



https://doi.org/10.1088/1361-6382/aa51f4

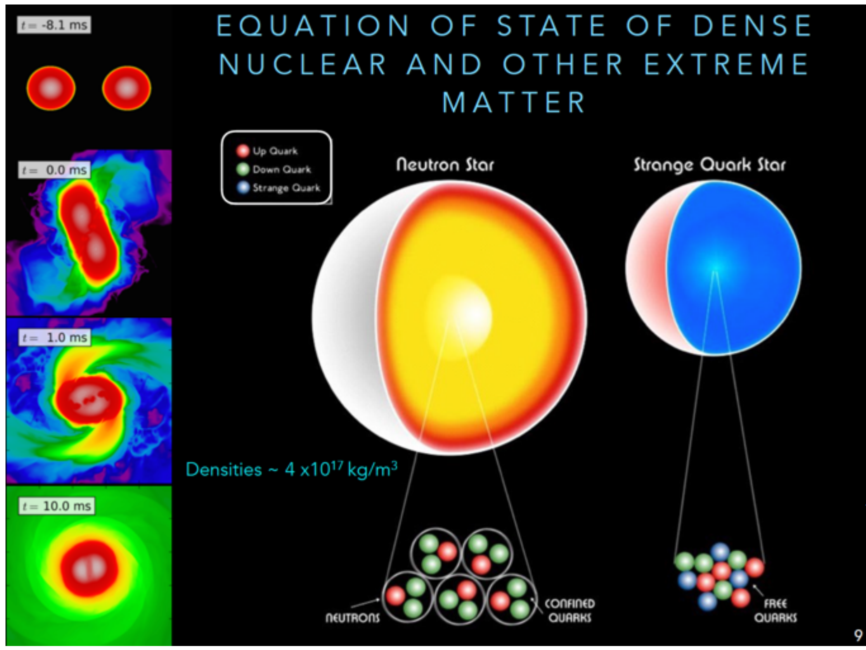
How much could we see?

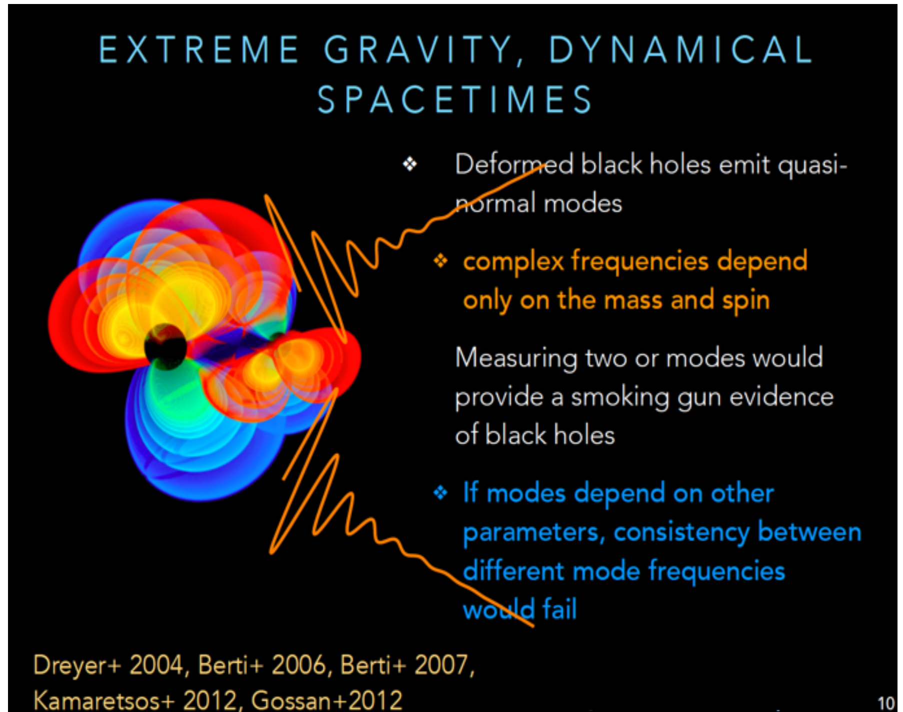


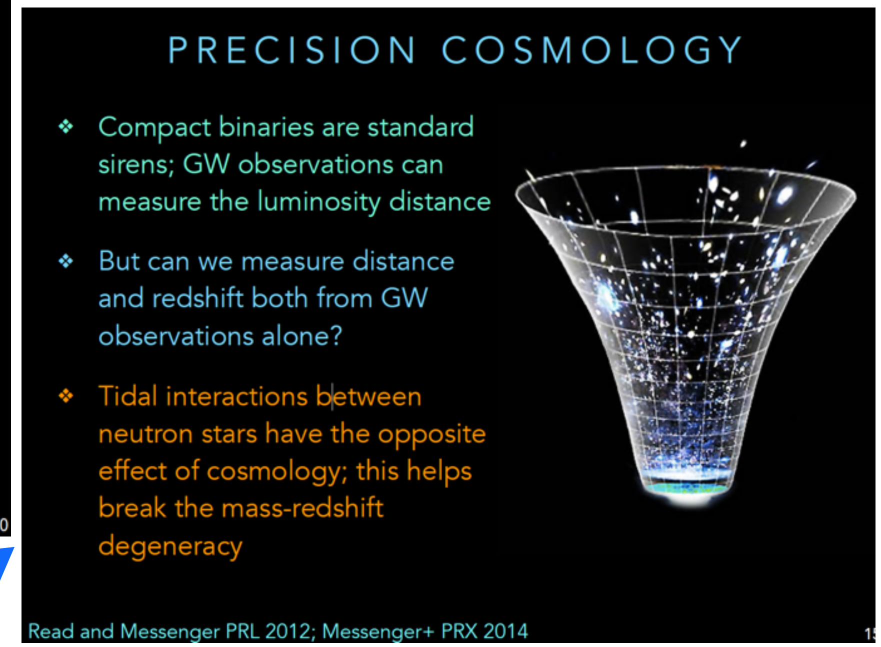
Credit: Evan Hall

New GW Observatories: An Abundance of Science

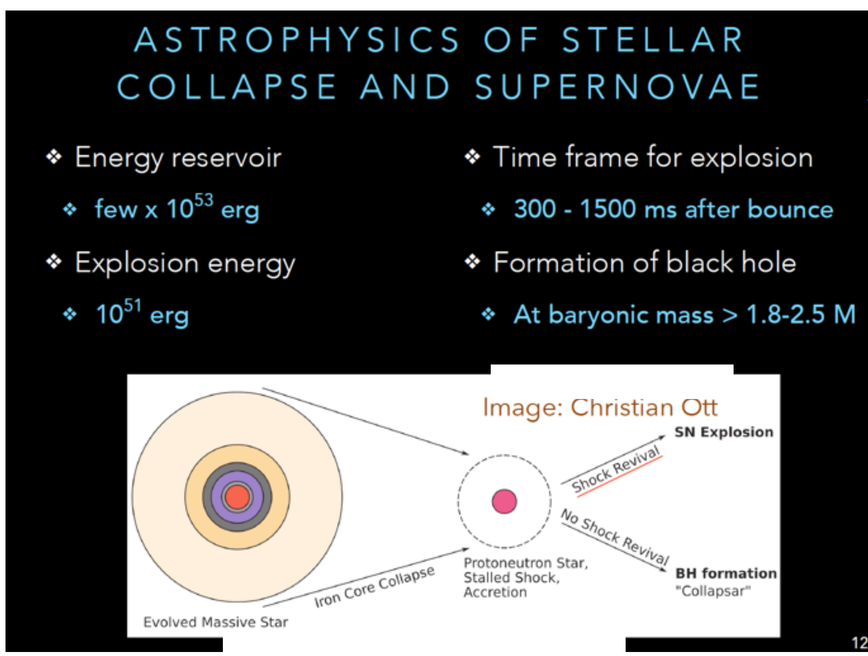
Science Case:
The Next-Generation Global Gravitational-Wave Observatory New Astrophysics with the Farthest, Oldest, and Most Violent Events in the Universe
GWIC 3G Subcommittee White Paper

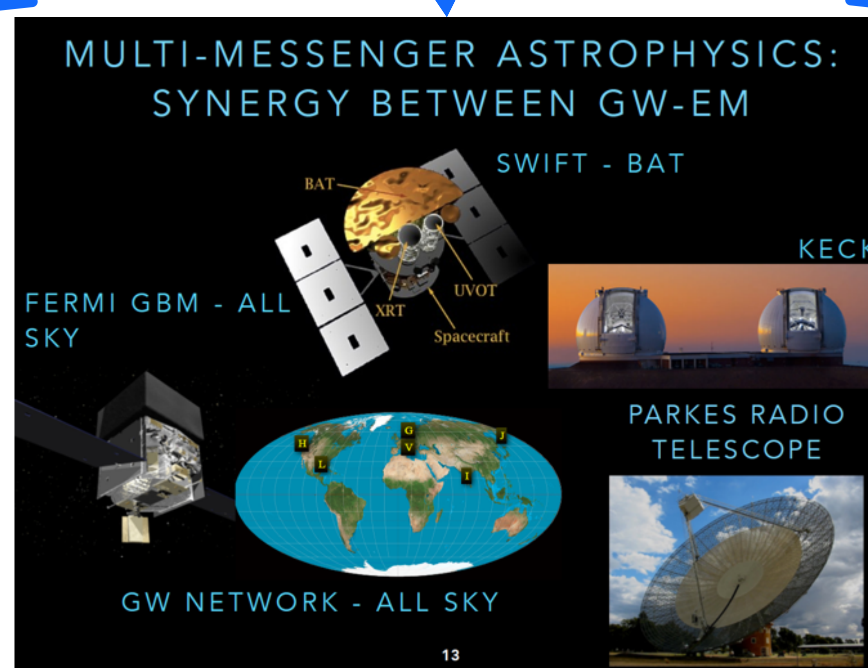


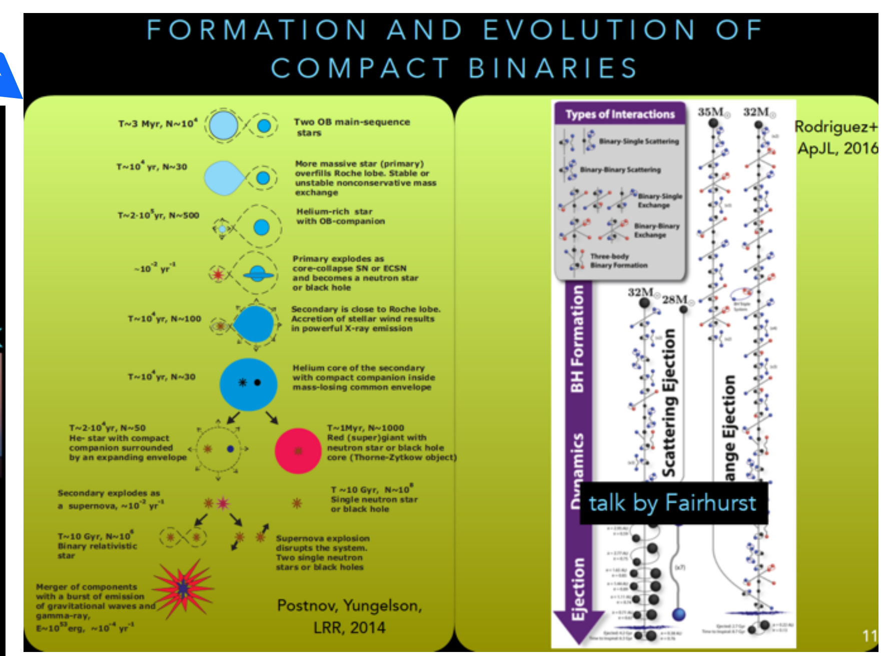




The 3G Gravitational Wave Ground-based Network







resources listed by the

Gravitational Wave International Committee (GWIC)

3G Subcommittee Reports (July 2019)

- The Next-Generation Global Gravitational-Wave Observatory: New Astrophysics with the Farthest, Oldest, and Most Violent Events in the Universe
- 3G R&D: Research and Development for the Next Generation of Ground-based Gravitational-wave Detectors
- Community Engagement: Scientific Constituencies Relevant to a Future 3G Detector Network Array
- Gravitational-Wave Data Analysis Computing Challenges in the 3G Era
- GWIC Governance Subcommitee Recommendations to Full 3G Committee

European Particle Physics Strategy Update 2018-2020 White Papers

- Gravitational Waves in the European Strategy for Particle Physics

US Astro2020 Decadal Survey Science White Papers

- Deeper, Wider, Sharper: Next-Generation Ground-Based Gravitational-Wave Observations of Binary Black Holes
- The Yet-Unobserved GW Universe
- Cosmology and the Early Universe
- Extreme Gravity and Fundamental Physics
- Multimessenger Universe with Gravitational Waves from Binaries
- Gravitational Wave Astronomy with LIGO and Similar Detectors in the Next Decade
- Gravitational-Wave Astronomy in the 2020s and Beyond: A View Across the Gravitational Wave Spectrum
- The US Program in Ground-Cased Gravitational-Wave Science: Contribution from the LIGO Laboratory

US Astro2020 Decadal Survey Activity/Project White Paper

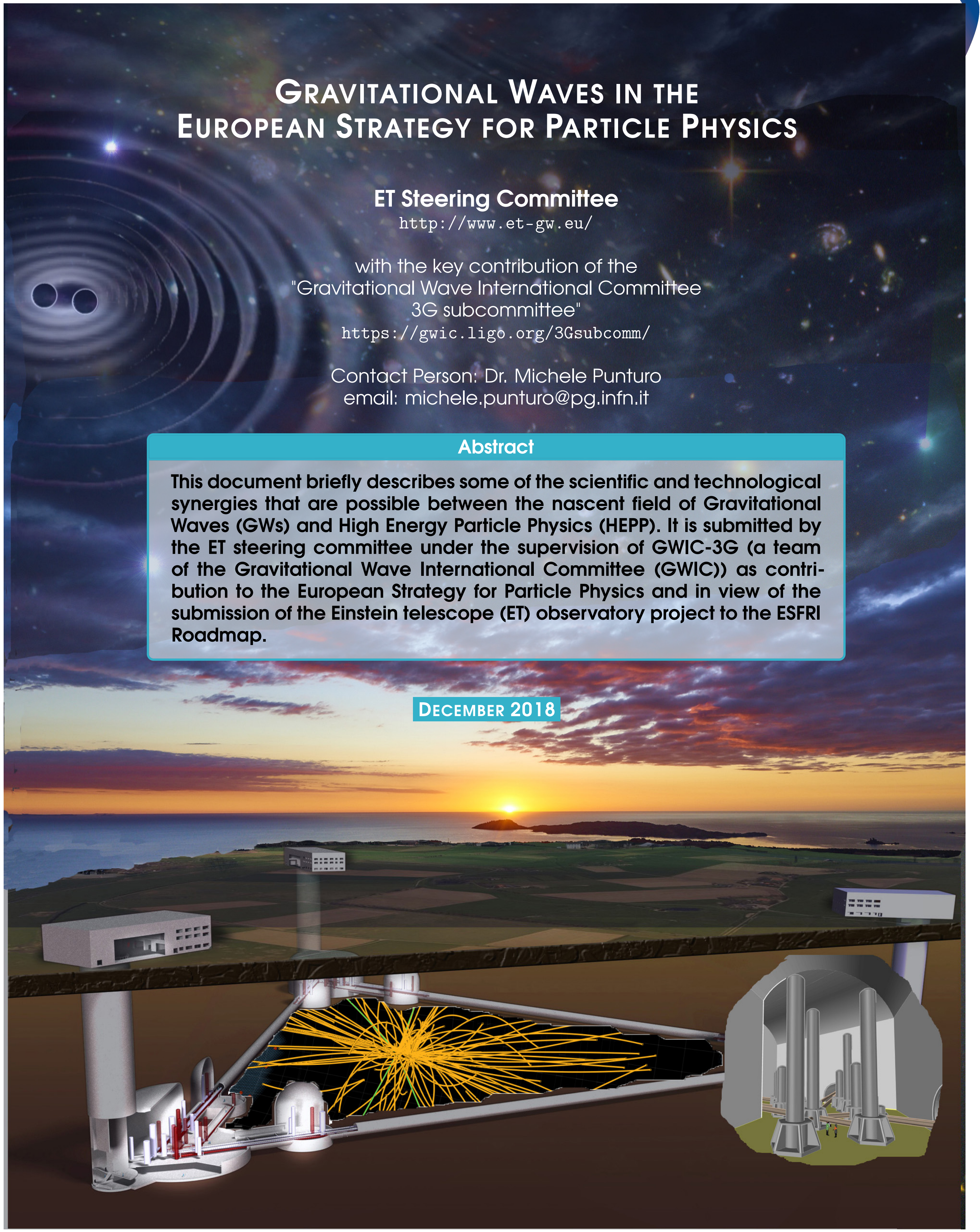
- Cosmic Explorer: The U.S. Contribution to Gravitational-Wave Astronomy beyond LIGO

Report of the Dawn IV Workshop, held in Amsterdam, Netherlands, August 30-31, 2018

- Global strategies for gravitational wave astronomy

ET & Particle physics

3G collaboration in Europe is actively pursuing collaborations with high energy physics.
(probably necessary to secure ESFRI support)
"the European Strategy Forum on Research Infrastructures is a strategic instrument to develop the scientific integration of Europe…"



https://indico.cern.ch/event/765096/contributions/3295673/attachments/1785200/2906171/GW3G-ET.pdf

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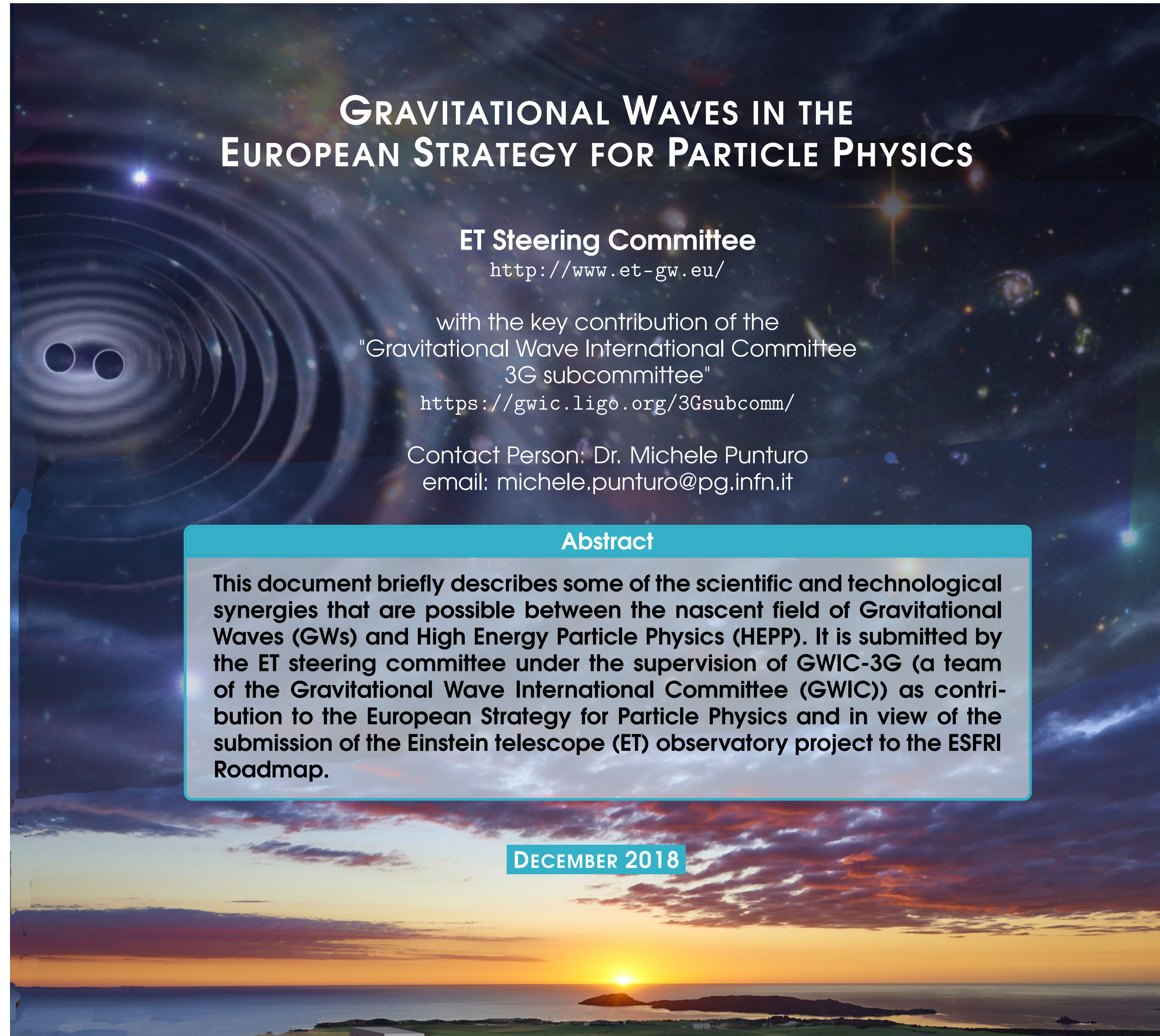

GRAVITATIONAL WAVES IN THE EUROPEAN STRATEGY FOR PARTICLE PHYSICS

ET Steering Committee
http://www.et-gw.eu/

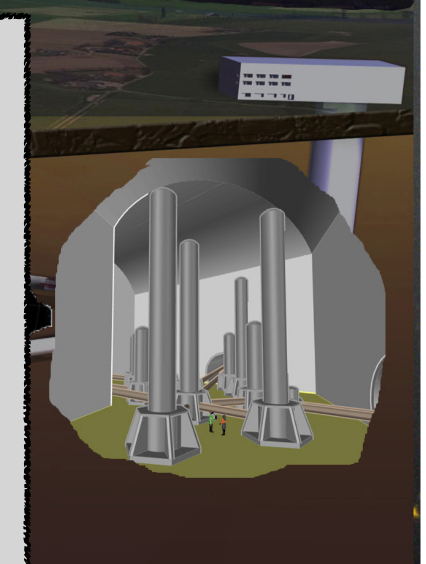
with the key contribution of the "Gravitational Wave International Committee 3G subcommittee"
https://gwic.ligo.org/3Gsubcomm/

Contact Person: Dr. Michele Punturo
email: michele.punturo@pg.infn.it

Abstract

This document briefly describes some of the scientific and technological synergies that are possible between the nascent field of Gravitational Waves (GWs) and High Energy Particle Physics (HEPP). It is submitted by the ET steering committee under the supervision of GWIC-3G (a team of the Gravitational Wave International Committee (GWIC)) as contribution to the European Strategy for Particle Physics and in view of the submission of the Einstein telescope (ET) observatory project to the ESFRI Roadmap.

DECEMBER 2018



Recommendations

- We recommend that the **existing and potential synergies between high-energy particle physics and the gravitational wave** community in regard to science and common technologies be analysed, promoted and developed, and exploited for the mutual benefit of both communities.
- The gravitational wave community encourages a **strong participation** of Europe’s leading particle physics institutions in future gravitational wave observatories, in particular in the fields of **engineering and computer science**.
- We recommend to **jointly develop governance schemes** for the installation and operation of a global network of third-generation gravitational wave detectors.

https://indico.cern.ch/event/765096/contributions/3295673/attachments/1785200/2906171/GW3G-ET.pdf

Thoughts…

The ground based detectors are now Observatories,
and we are on track for continued progress over the next decade.

LISA is also on track to significantly enhance the science reach of GW detectors.
(and so is the International Pulsar Timing Array)

We have clear methods to extend the reach to cosmological distance,
but this will require scientific R&D, engineering, and money to get there.

for discussion

Brian thinks - DOE involvement with 3G detectors might be a good move

1. DOE has experience & management structures in place to deal with large facilities and large on-going scientific staffing for those facilities.
2. 3G detectors need lots of very good engineering to enable the GW science
3. in general - GWs present exciting new astronomy, astrophysics, and cosmology.
4. in particular - GWs are an excellent window into extreme energy-density physics.

But

1. The cultures are different. SLAC should not try to run LIGO.
2. How can we keep the golden goose, but scale it to bigger teams, bigger facilities and ~continuous detections?