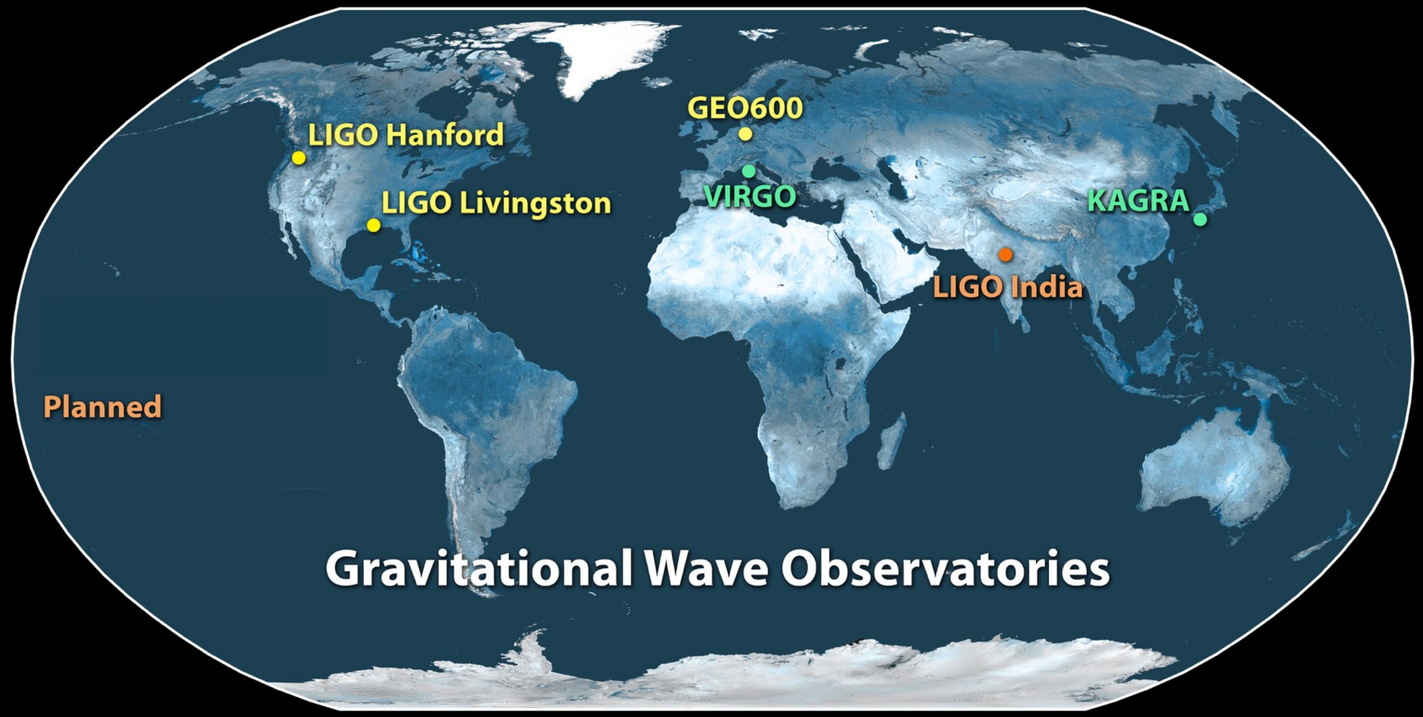
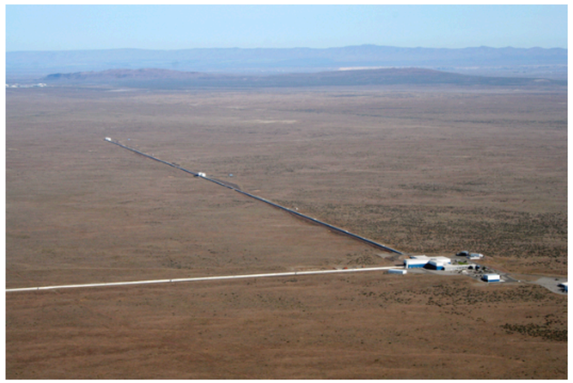
Current & Future Ground-Based GW Detectors

Laura Cadonati, Georgia Tech
Jo van den Brand, Nikhef

Transients 2020, Cape Town, February 5, 2020

IGWN = International Gravitational Wave observatory Network

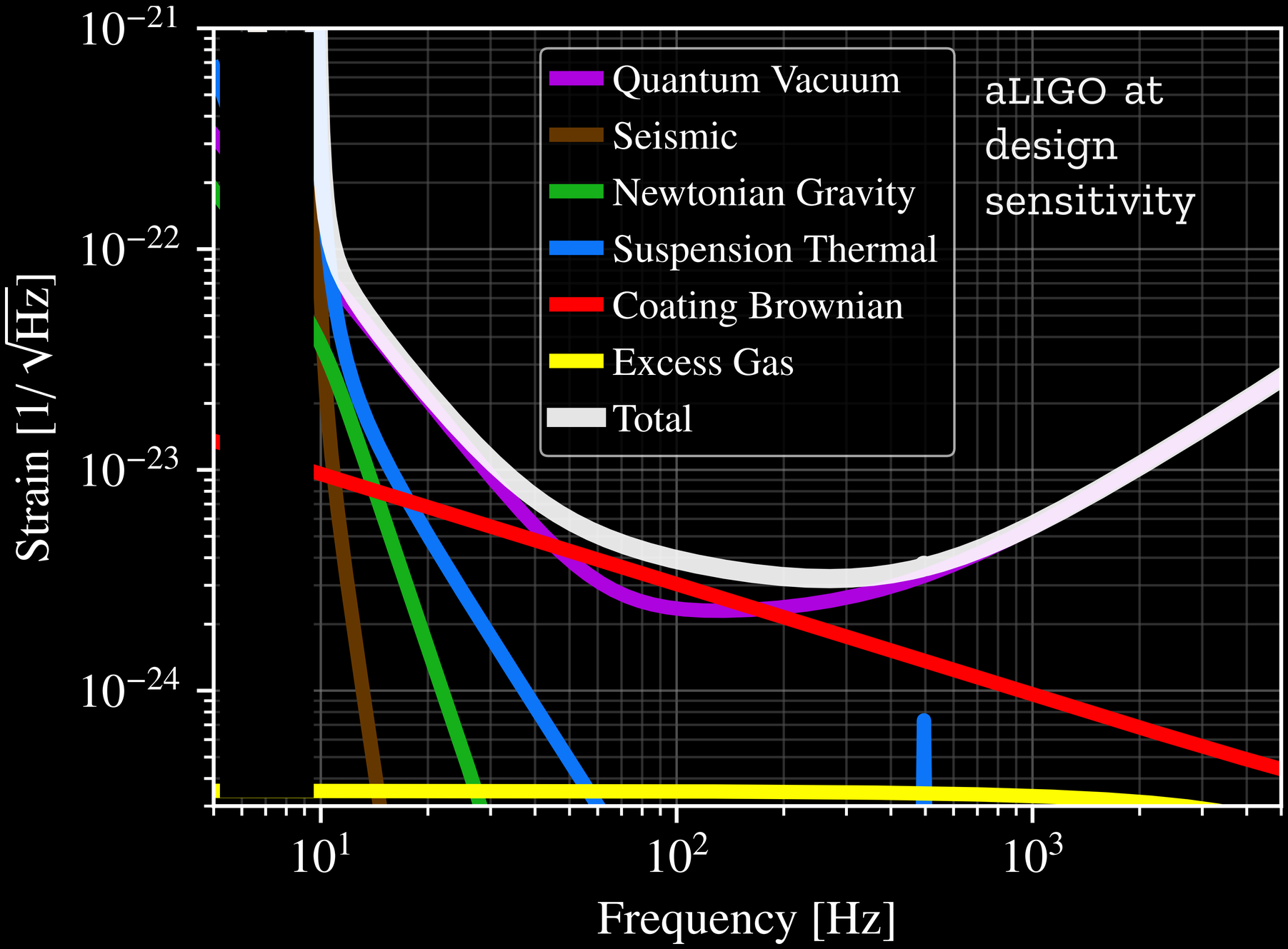



LIGO Hanford

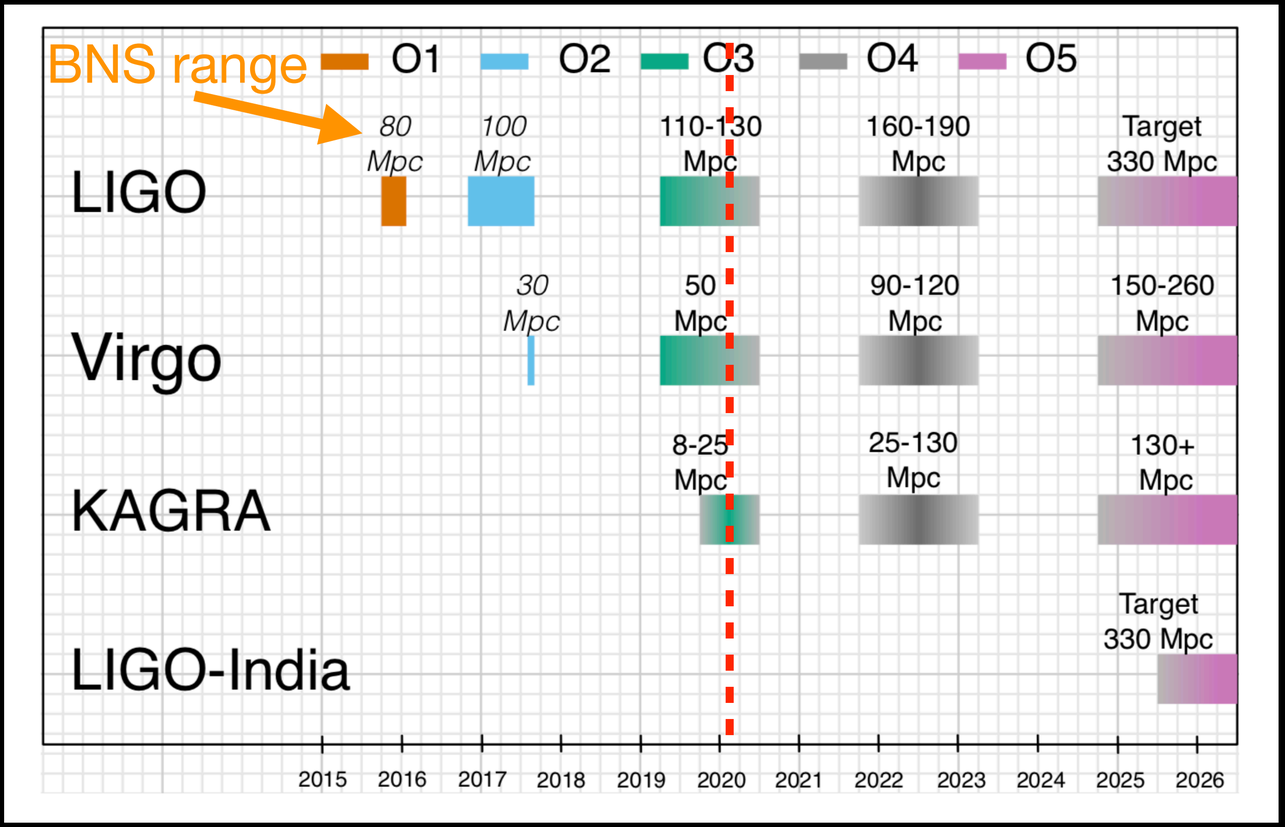

LIGO Livingston

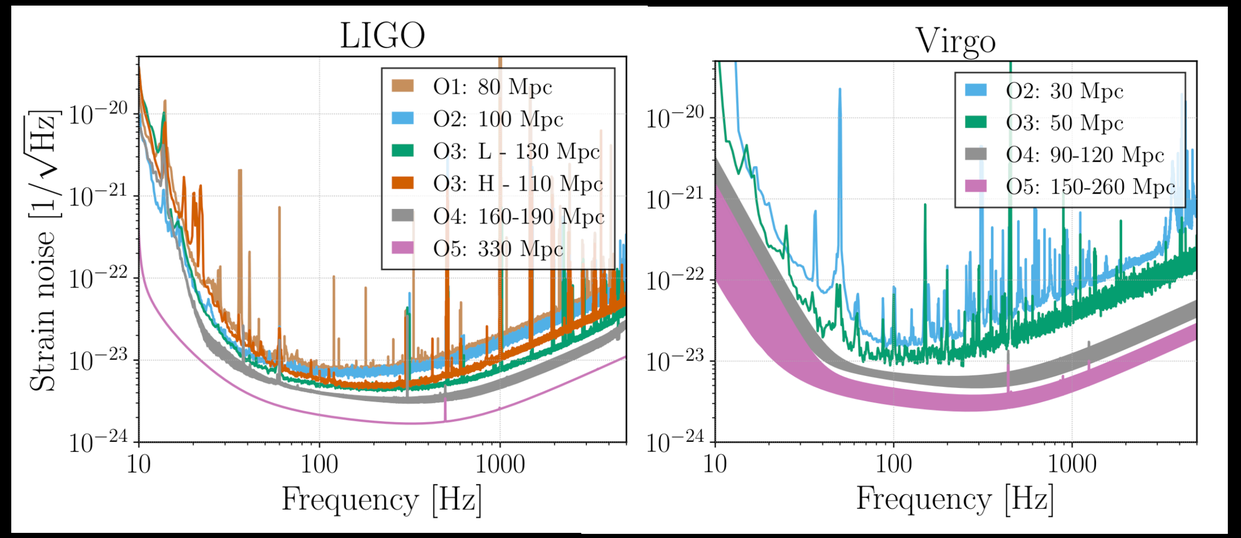

Virgo

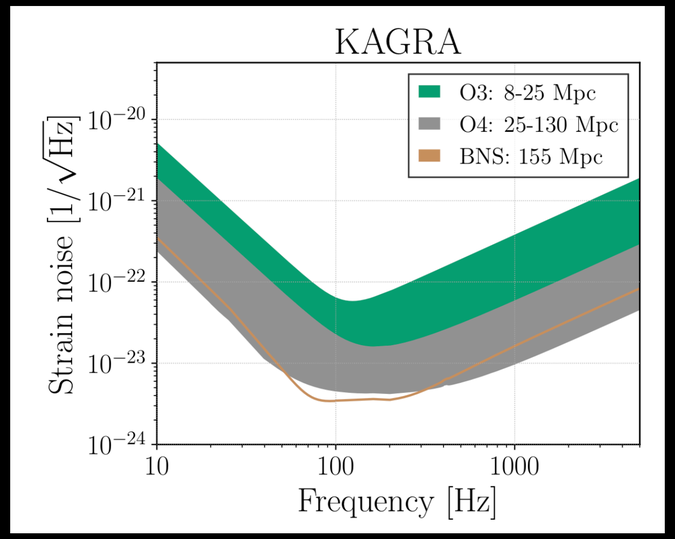

GEO600


Quantum Vacuum
Seismic
Newtonian Gravity
Suspension Thermal
Coating Brownian
Excess Gas
Total
aLIGO at design sensitivity
Strain [1/√Hz]
Frequency [Hz]
10^-21
10^-22
10^-23
10^-24
10^1
10^2
10^3

Observing Scenarios







See also:

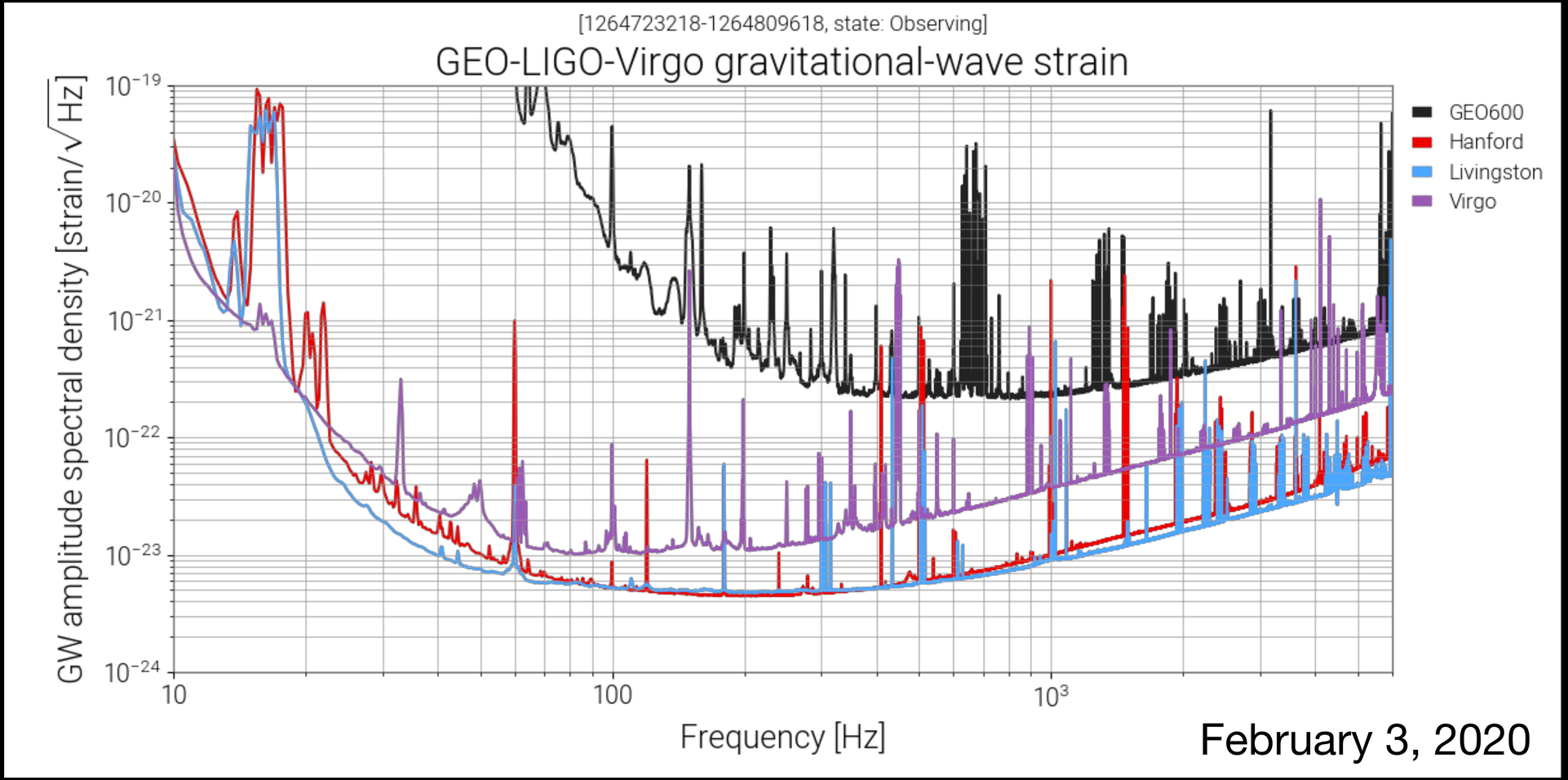
https://www.ligo.org/scientists/GWEMalerts.php

Prospects for Observing and Localizing Gravitational-Wave Transients with Advanced LIGO and Advanced Virgo and KAGRA — **arxiv.org:1304.0670**

The Present

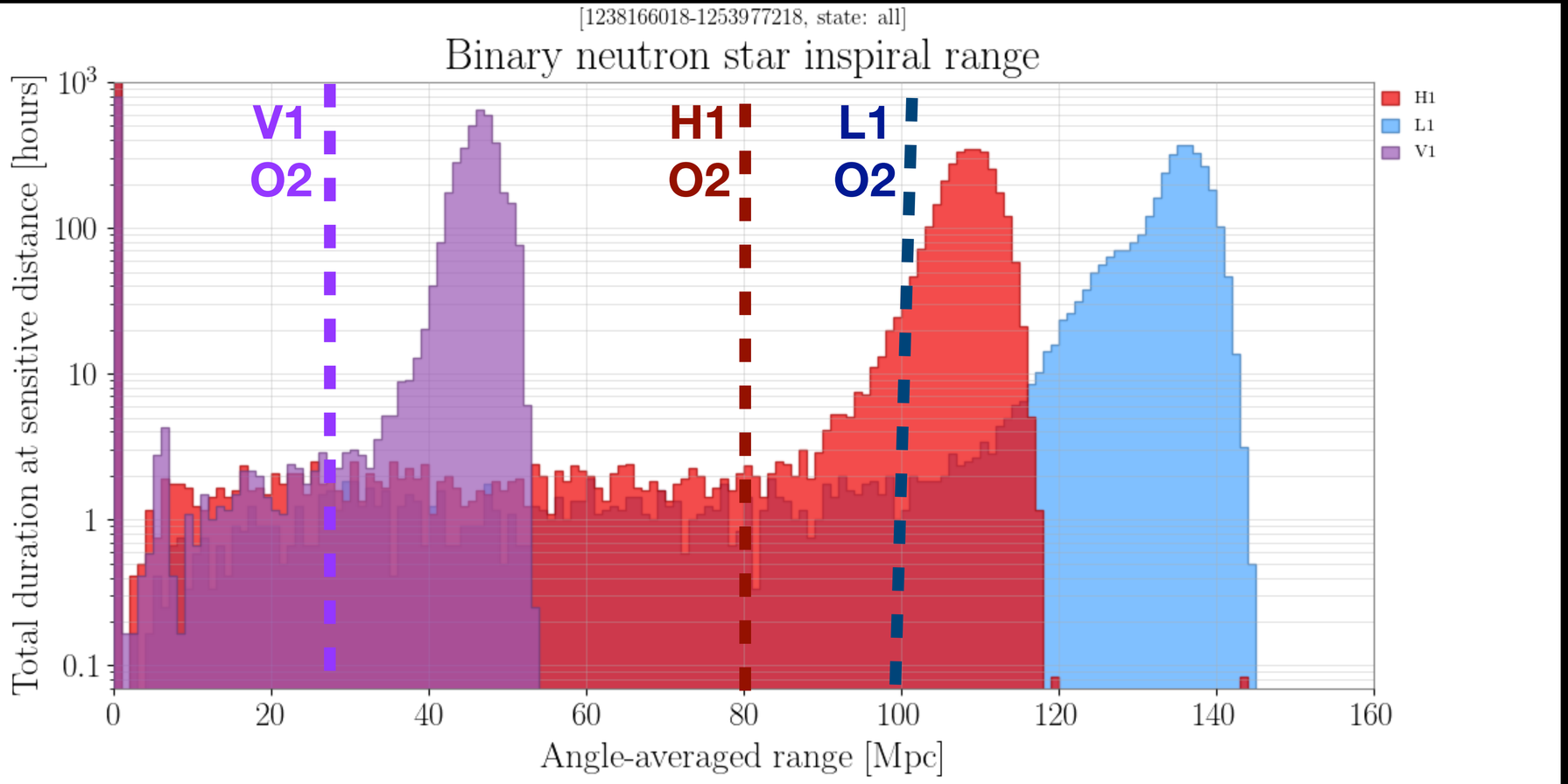
The Present: LIGO, Virgo, GEO

O3 run: April 1, 2019 - April 30, 2020

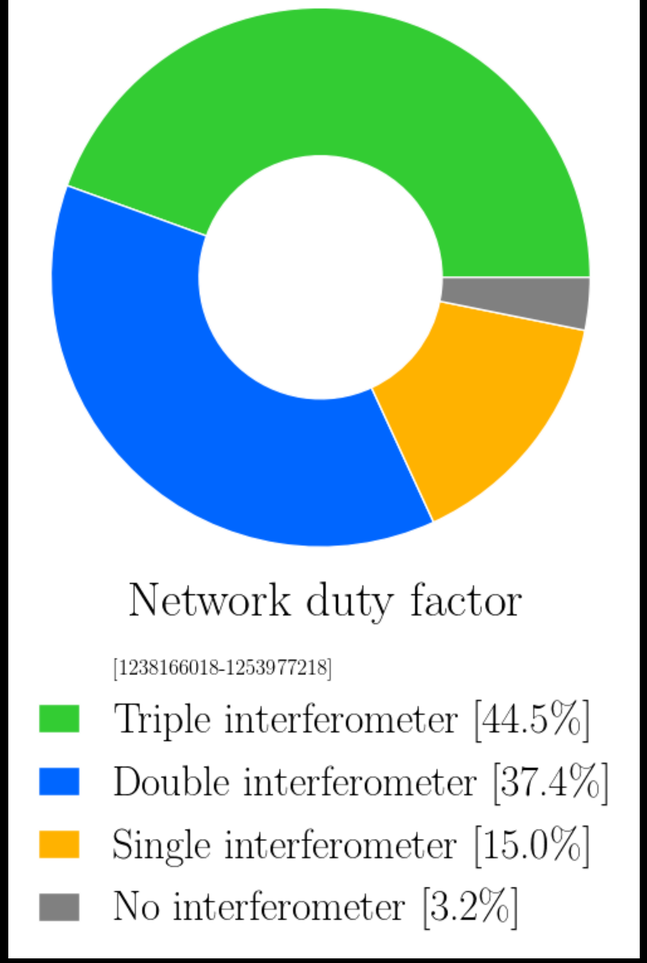


https://www.gw-openscience.org/detector_status/day/20200203/

The Present: LIGO, Virgo
Performance in the first 6 months (O3a)



This plot uses all available data, regardless of observatory operational state



April 2019

S	M	T	W	T	F	S
	1	2	3	4	5	6
7		9	10	11		13
14	15	16	17	18	19	20
	22	23	24			27
28	29	30				

May 2019

S	M	T	W	T	F	S
			1	2		4
5	6	7	8	9		11
		14	15	16		18
	20		22	23	24	25
26	27	28	29	30	31	

June 2019

S	M	T	W	T	F	S
						1
	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29

July 2019

S	M	T	W	T	F	S
		2	3	4	5	
	8	9	10	11	12	13
14	15	16	17		19	
21	22	23	24	25	26	
	29	30	31			

August 2019

S	M	T	W	T	F	S
				1	2	3
4	5	6	7		9	10
11	12	13		15		17
18	19	20	21	22	23	24
25	26	27		29	30	31

September 2019

S	M	T	W	T	F	S
	2	3	4	5	6	7
8	9		11	12	13	14
	16	17	18	19	20	21
22			25	26	27	
29						

October 2019

S	M	T	W	T	F	S
		1	2			5
6	7	8				12
13					18	19
20				24	25	26
27		29	30	31		

Commissioning Break

November 2019

S	M	T	W	T	F	S
					1	2
3	4		6	7	8	
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28		30

December 2019

S	M	T	W	T	F	S
1	2	3			6	7
8	9	10	11	12		14
		17	18	19	20	21
	23	24		26	27	28
29	30	31				

January 2020

S	M	T	W	T	F	S
			1	2	3	4
		7		9	10	11
	13			16	17	18
19	20	21	22	23	24	25
26	27			30	31	

February 2020

S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29

March 2020

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

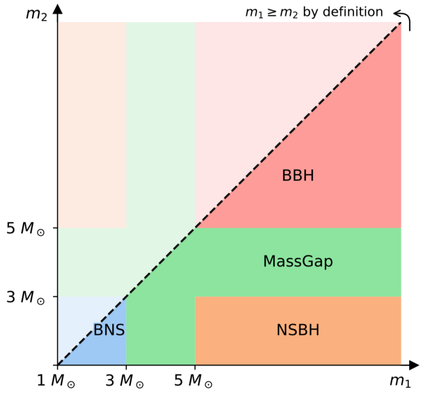
April 2020

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

as of 02-02-20:

70 alerts, 48 detection candidates, with preliminary (online) classification

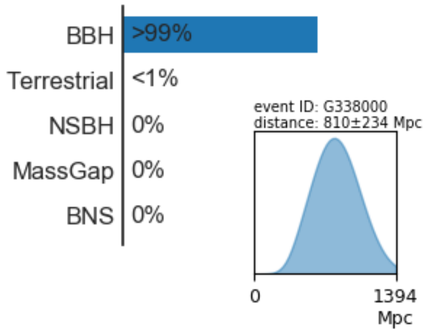
- BBH (32)
- BNS (7)
- NSBH (6)
- MassGap (3)
- Retracted (22)

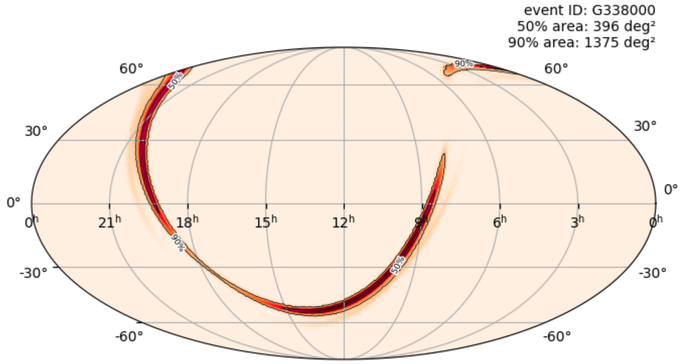


https://gracedb.ligo.org/superevents/public/O3/

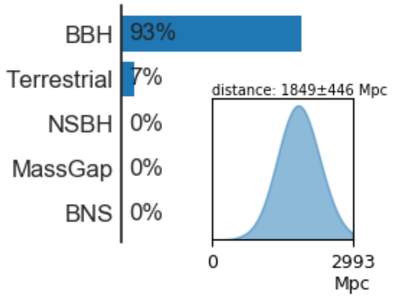
Some examples

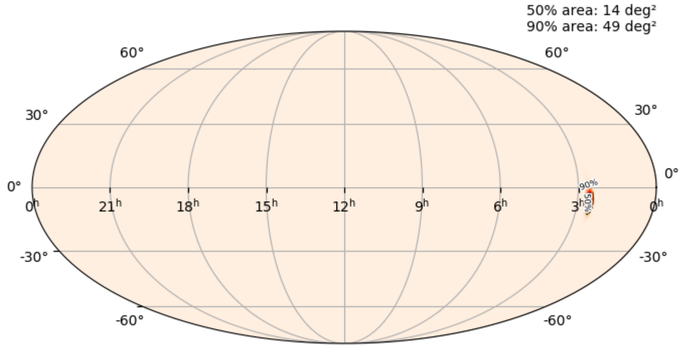
- **S190707q**
- FAR 5e-12 or 1/6019 years
- H1, L1



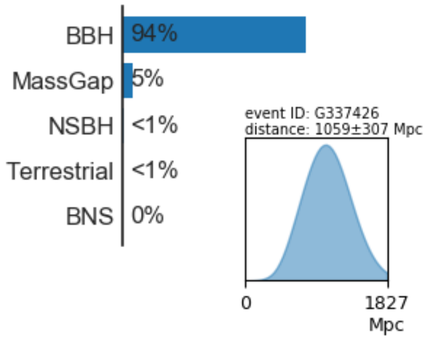


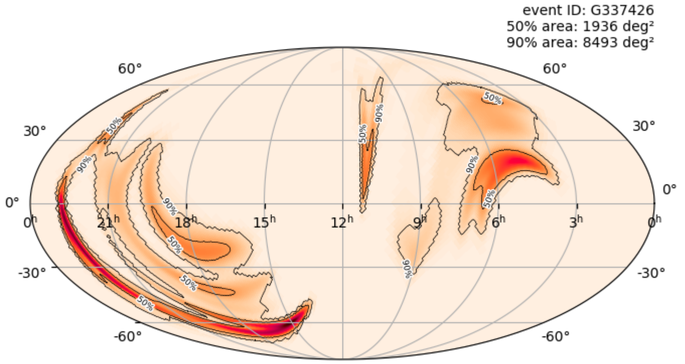
- **S190701ah**
- FAR 2e-8 or 1/1.6 years
- H1, L1, V1





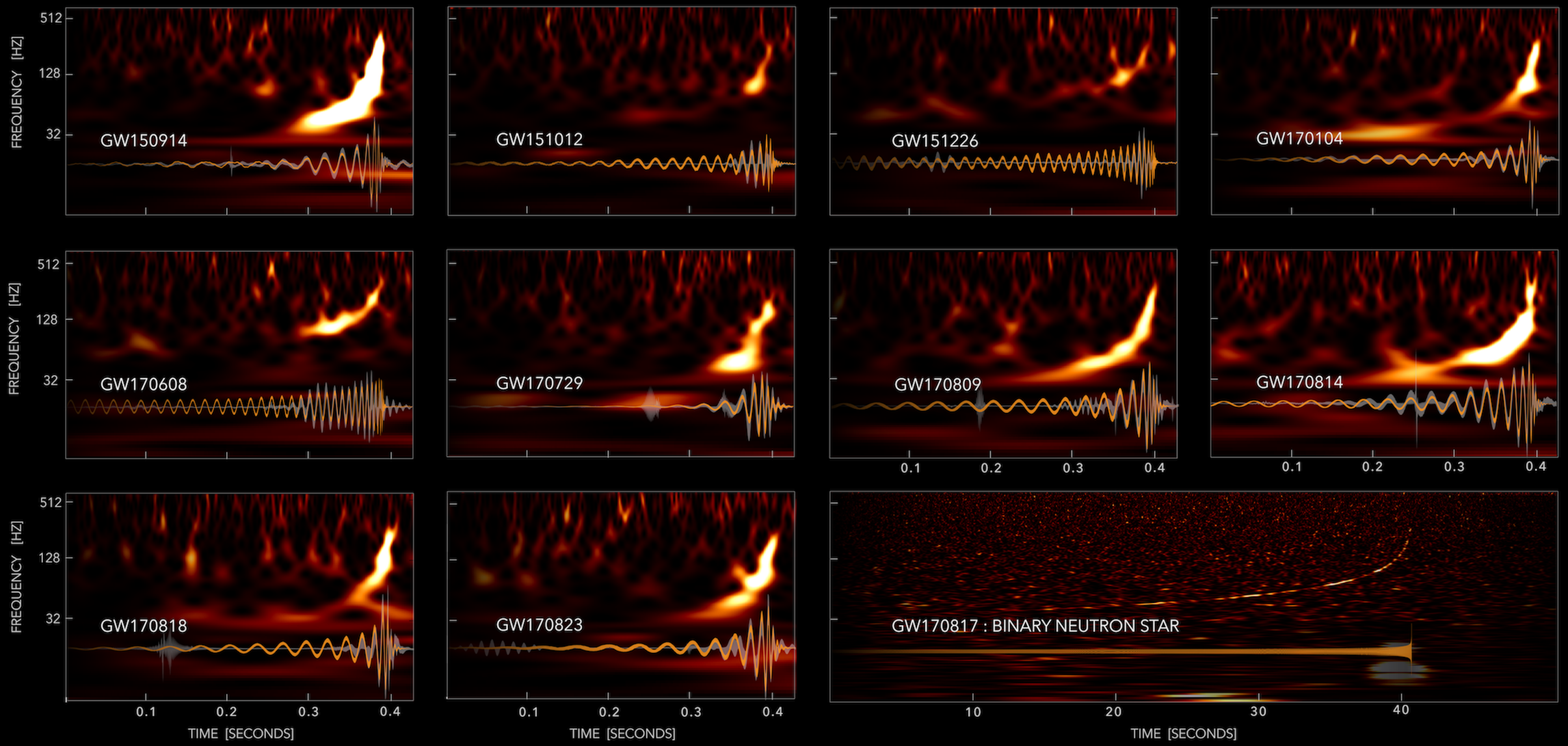
- **S190630ag**
- FAR 1e-13 or 1/22,077 years
- L1, V1





https://gracedb.ligo.org/superevents/public/O3/

GRAVITATIONAL-WAVE TRANSIENT CATALOG-1



LIGO-VIRGO DATA: HTTPS://DOI.ORG/10.7935/82H3-HH23

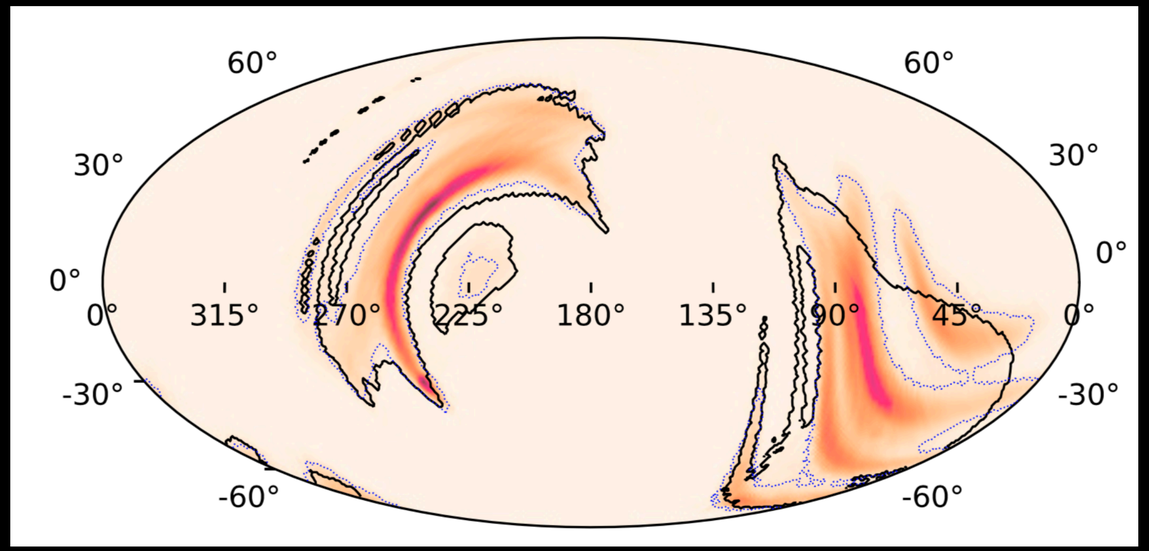
WAVELET (UNMODELED)

EINSTEIN'S THEORY

S. GHONGE, K. JANI | GEORGIA TECH

GW190425: Observation of a compact binary coalescence with total mass ~3.4 $M_\odot$

arxiv:2001.01761



Initial Alert (solid line)

43 minute latency

BNS w/ >99% probability

90% region: **10,200 deg²**

Distance: **110 – 200 Mpc**

Final (dotted line)

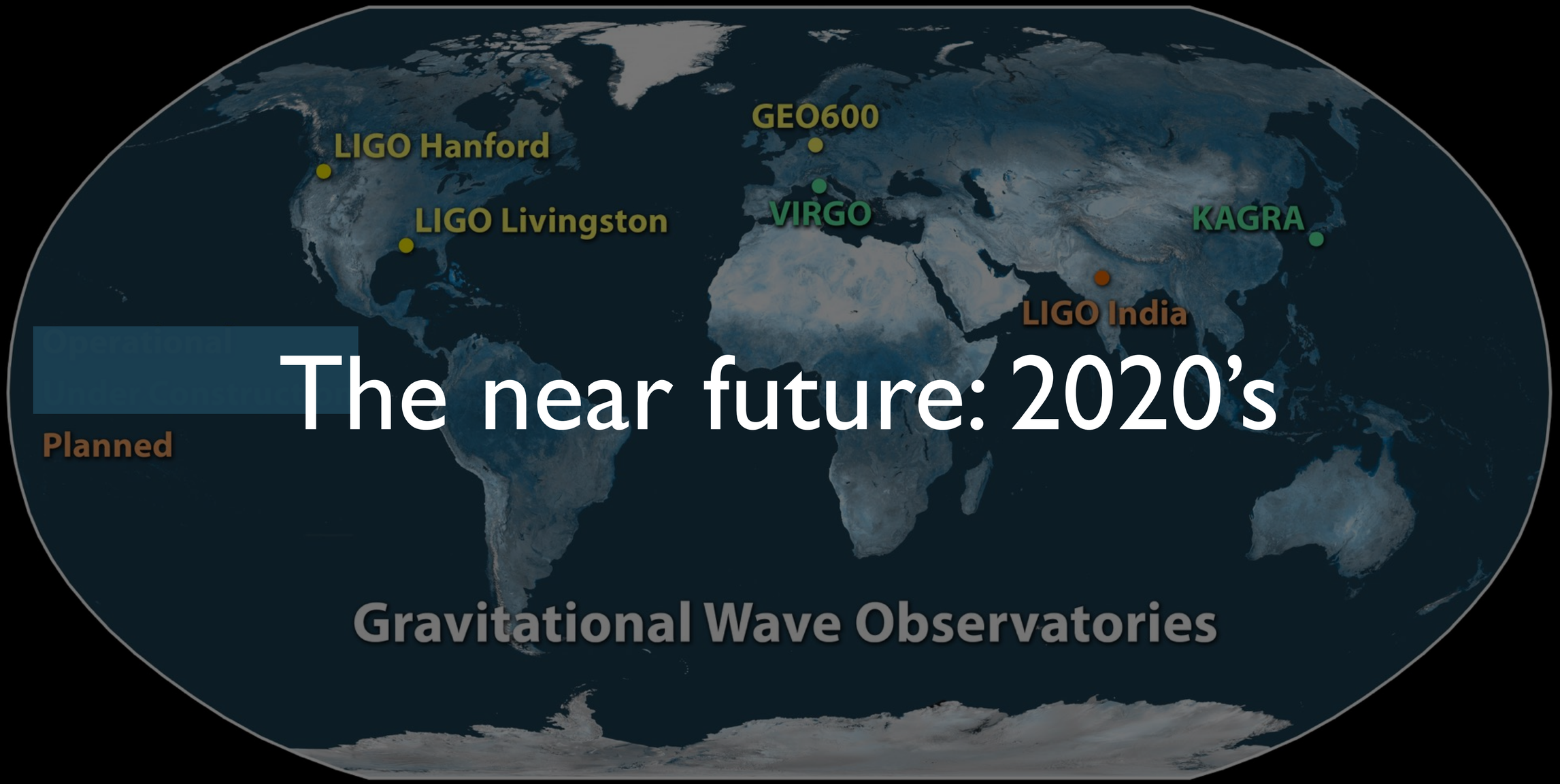
90% region: **8,284 deg²**

Distance: **88 – 228 Mpc**

GW190425:

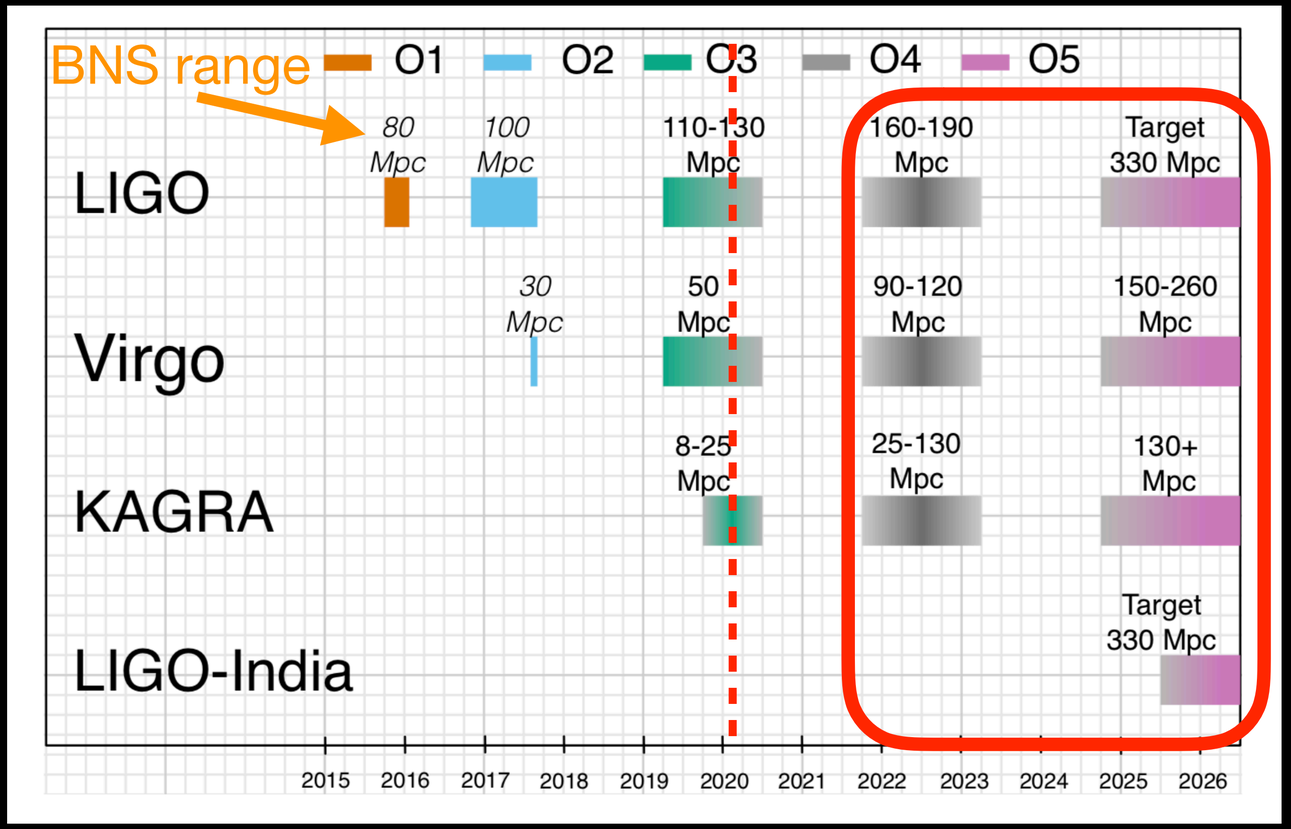
1. the first demonstration of single-detector detection
2. likely the second BNS detection with gravitational waves
3. an outlier of observed galactic BNS population

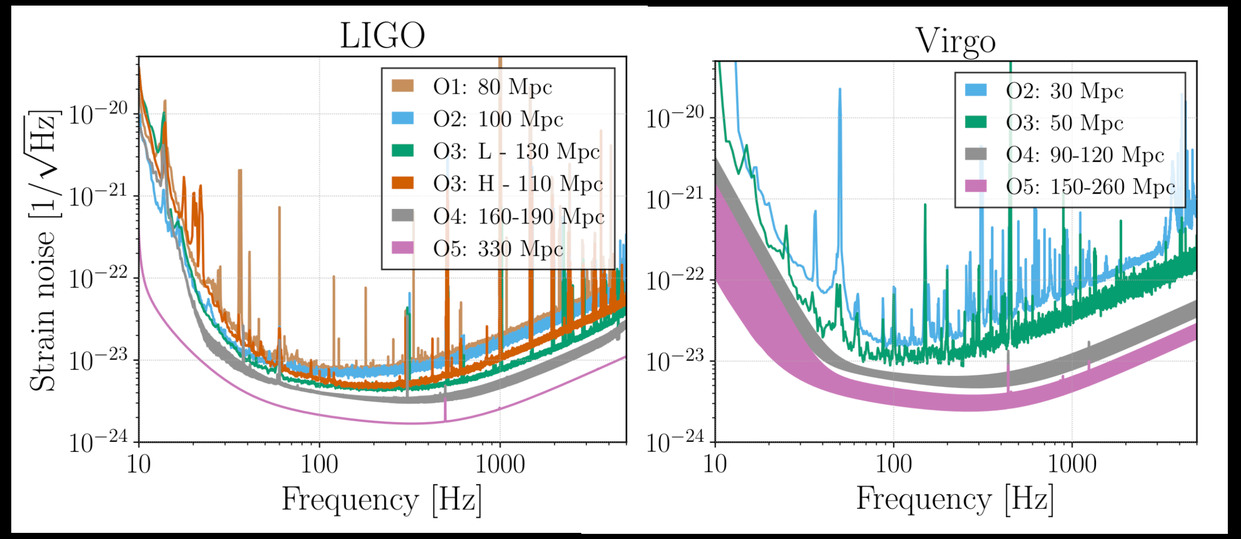
Using L1 and V1

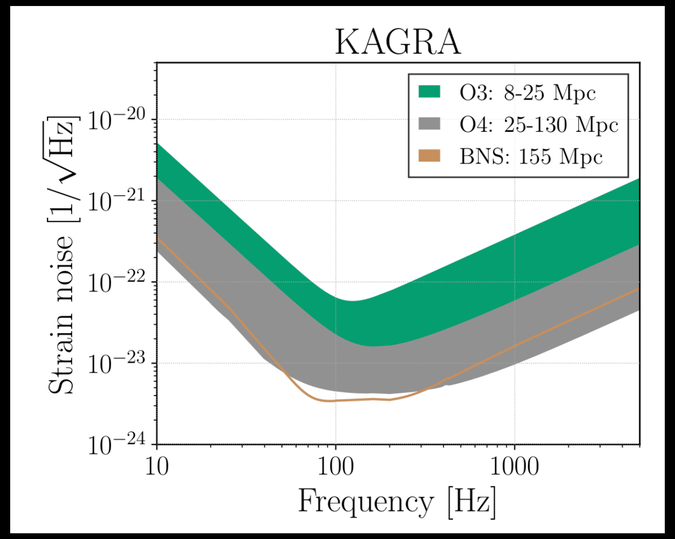


The near future: 2020's

Observing Scenarios







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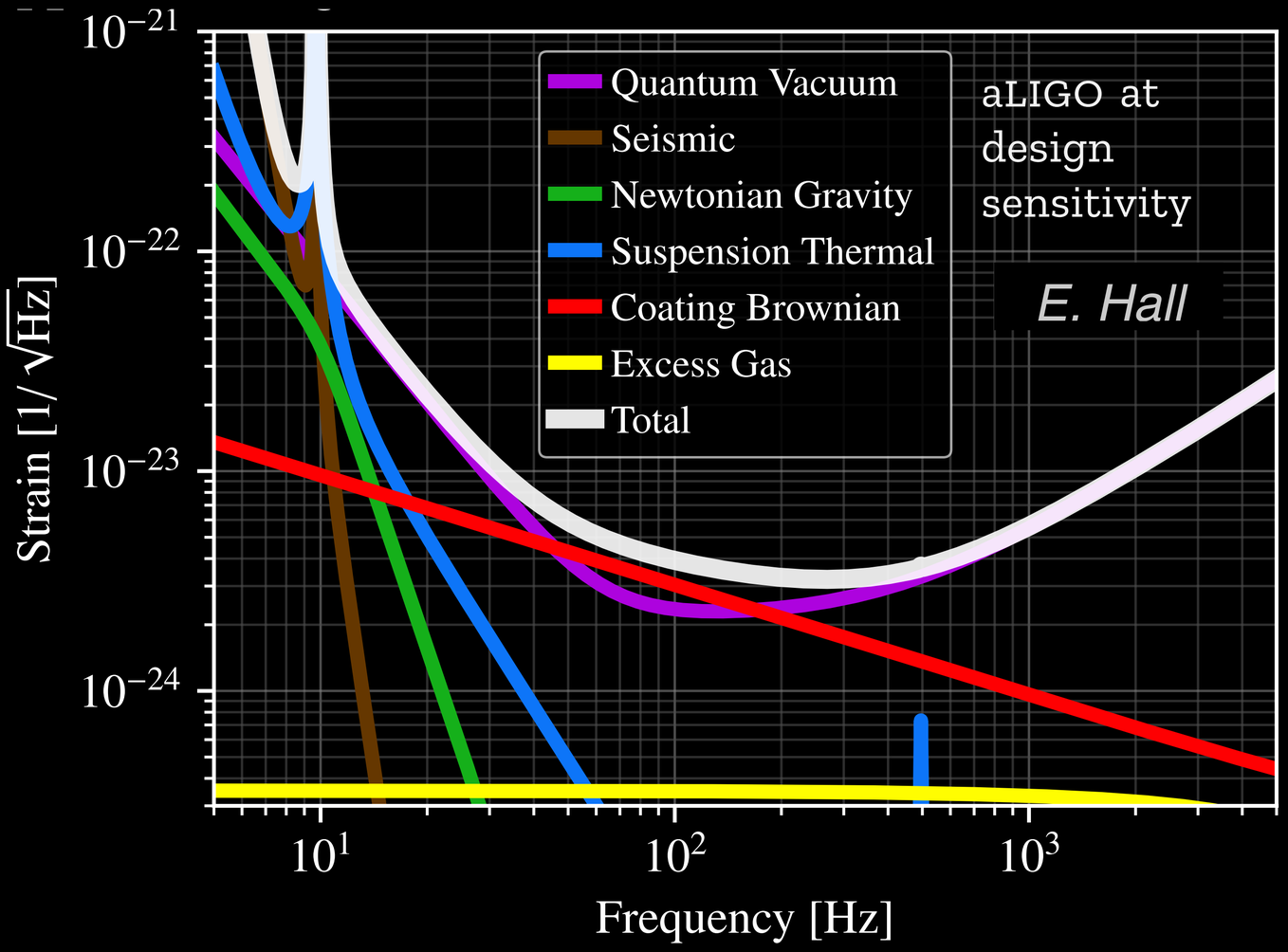
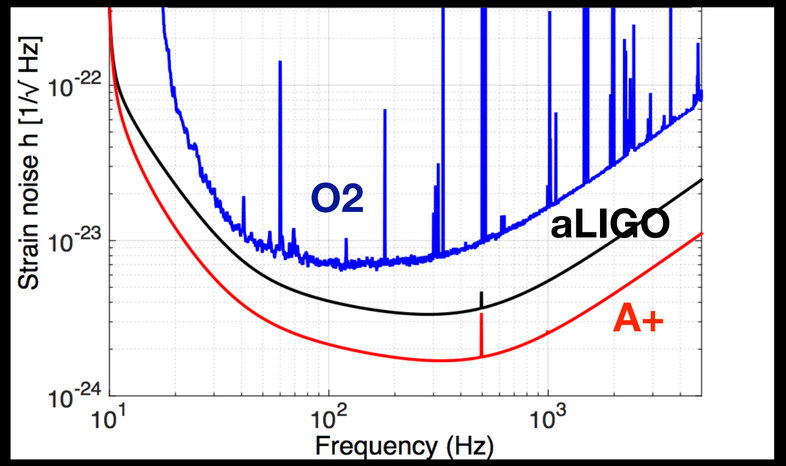
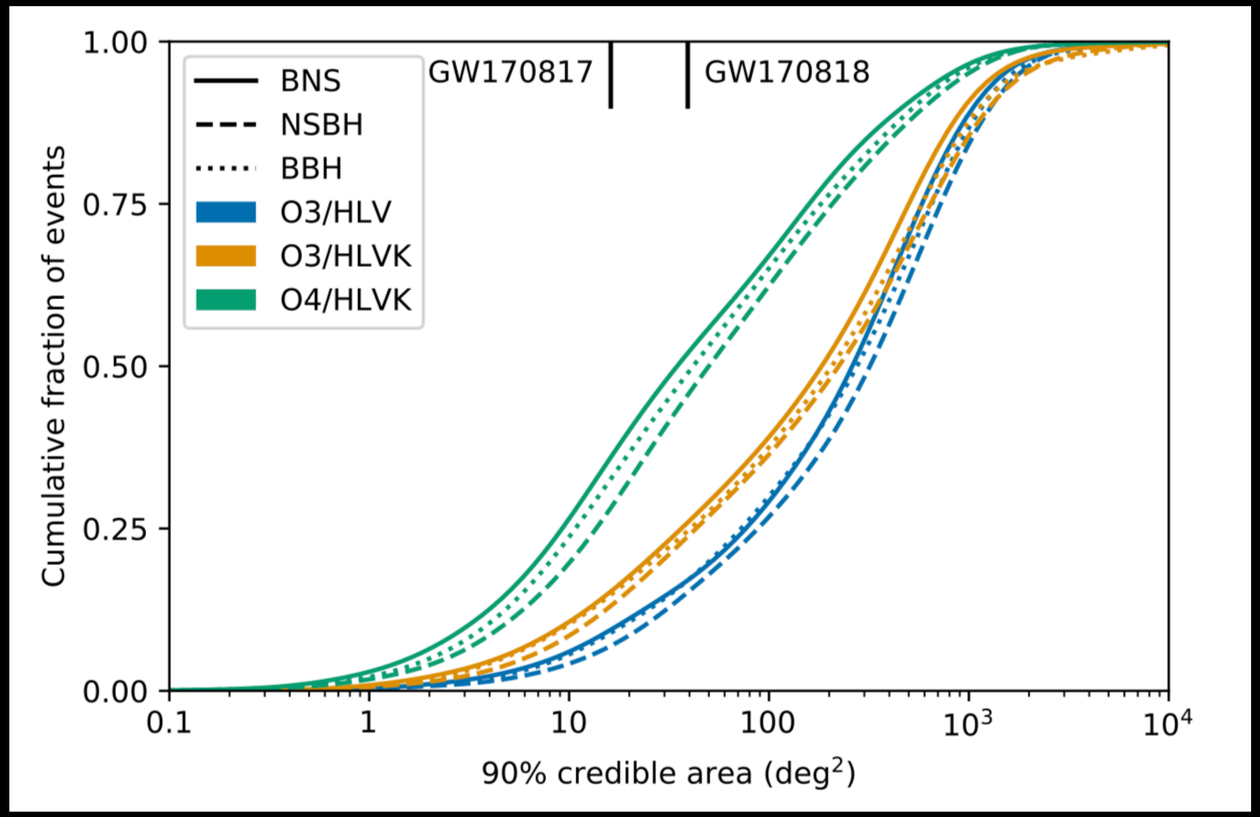
O4: 2G @ Design Sensitivity (~2022)

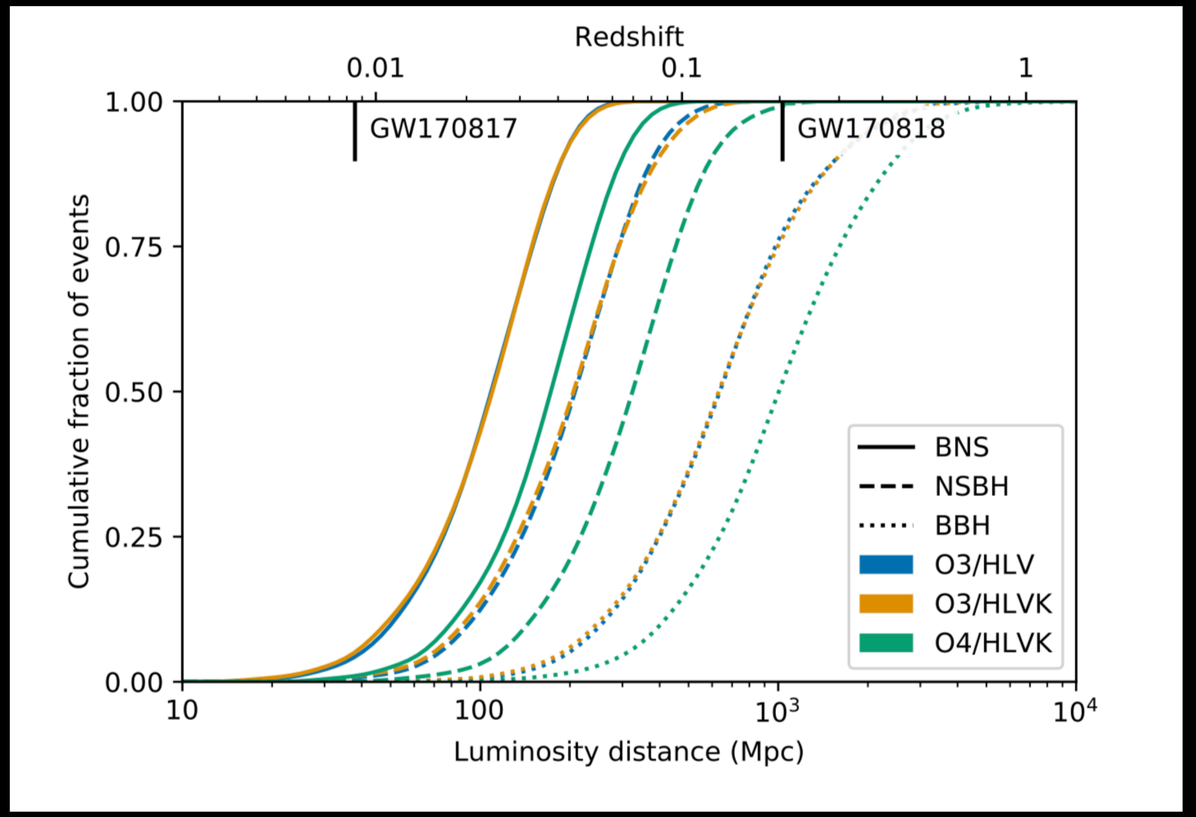




after additional commissioning
Reach: ~ 2x O2
~100 BBH/year ($z \lesssim 2$)
~1-2 NS-BH/year
~20-30 BNS/year ($z \lesssim 0.1$)

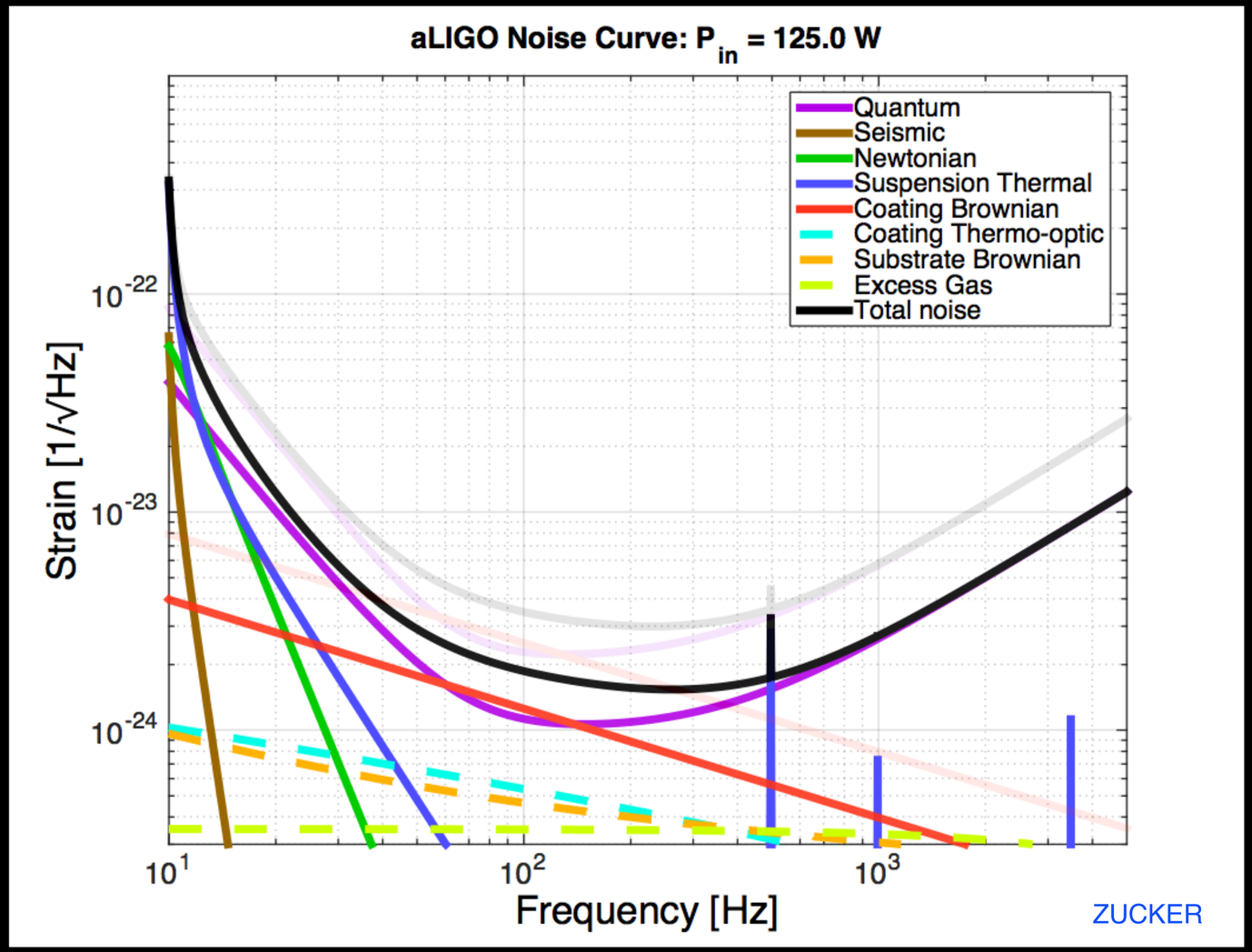
Prospects for Localization

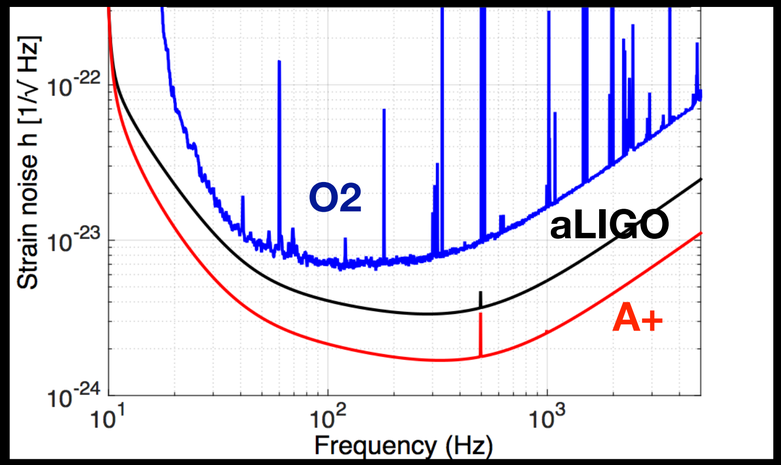




Prospects for Observing and Localizing Gravitational-Wave Transients with Advanced LIGO and Advanced Virgo and KAGRA — **arxiv.org:1304.0670**

O5: A+ (circa 2025)





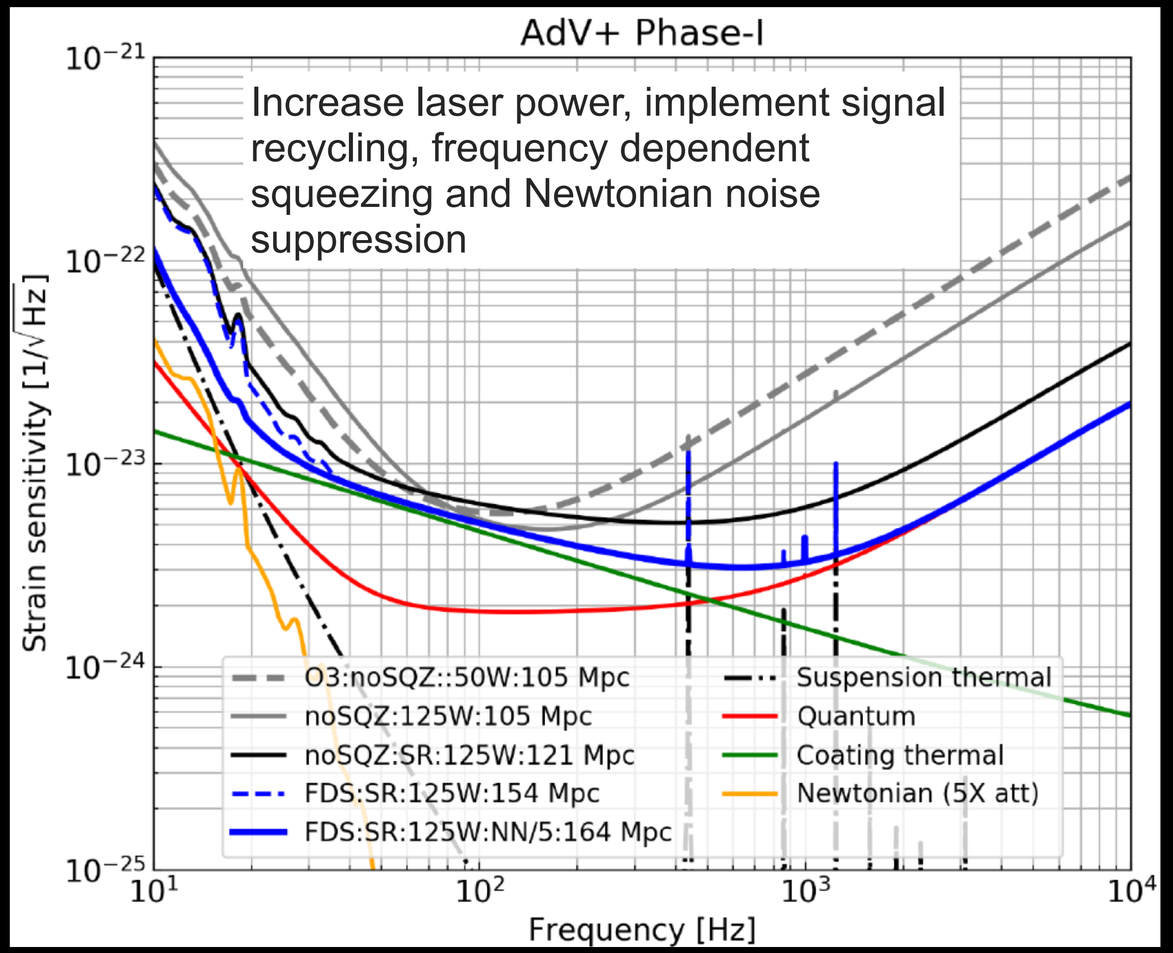
Modest upgrades to aLIGO and AdVirgo
- Frequency-dependent squeezing
- lower optical coating thermal noise

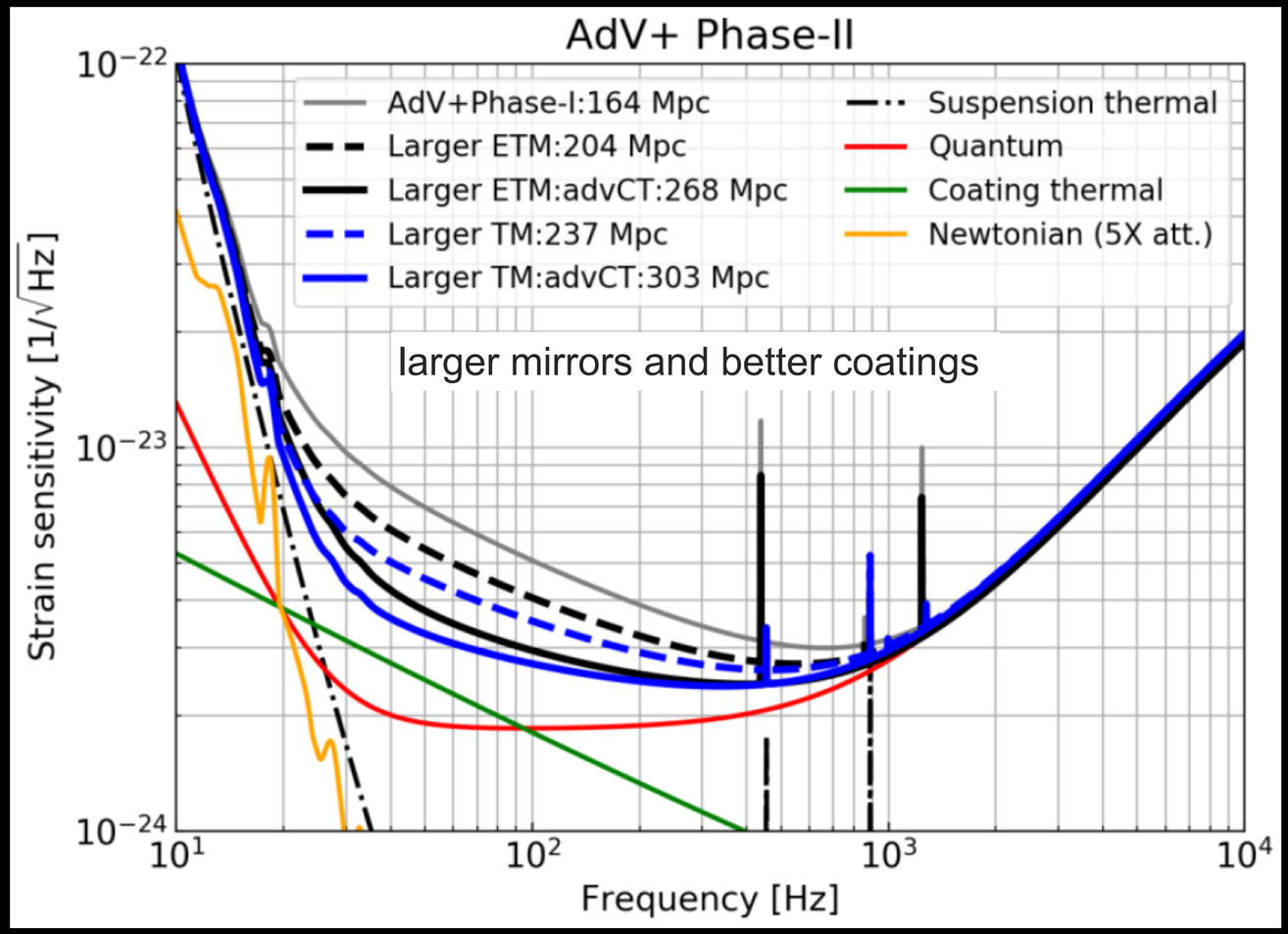
Reach: ~ 3x O2
~500-1000 BBH/year
~10 NS-BH/year
~200-300 BNS/year

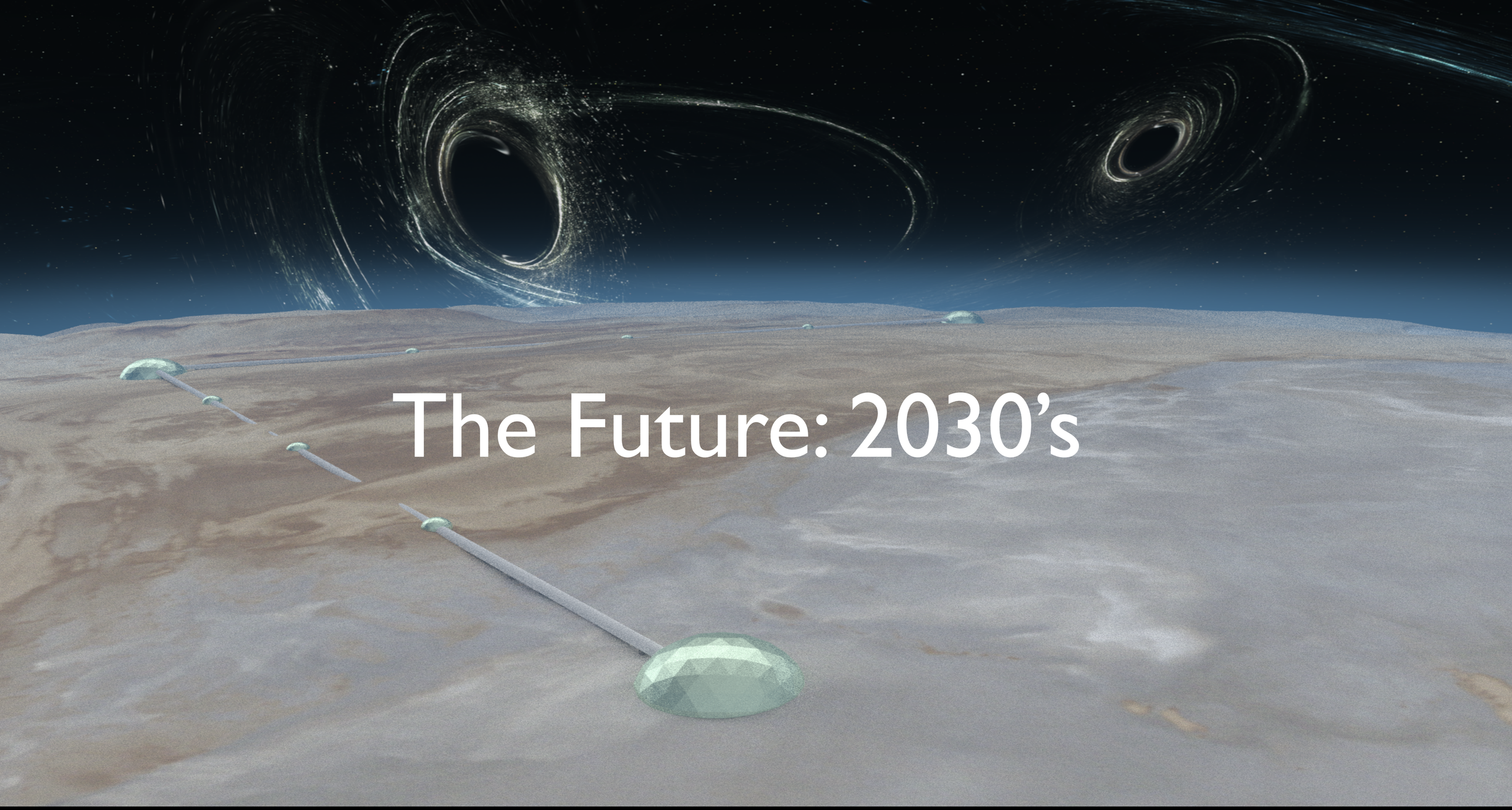
O5: AdV+ (circa 2025)

- Tuned signal recycling and HPL: 120 Mpc
- Frequency dependent squeezing: 150 Mpc
- Newtonian noise cancellation: 160 Mpc

- Larger mirrors (105 kg): 200-230 Mpc
- Improved coatings: 260-300 Mpc

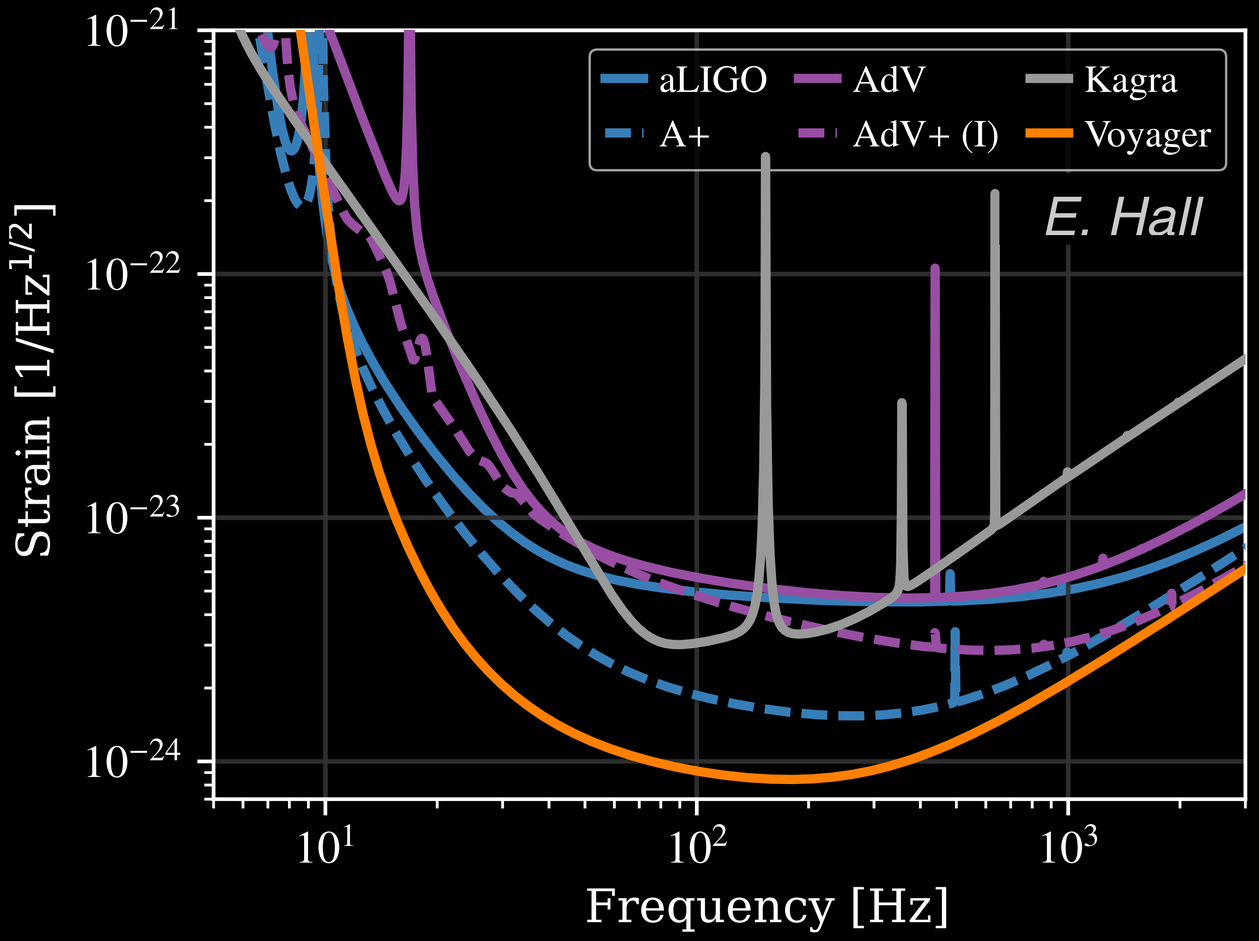




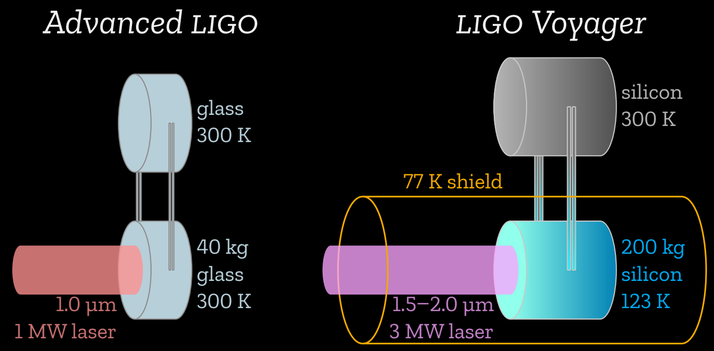


The Future: 2030's

Long-term Future for current facilities: Voyager



A concept under study for incremental performance improvement in the late 2020s



N. Smith and R. Adhkiari, *Cold voyage*, tech. rep. G1500312 (LIGO, 2015)

aLIGO with:
Si optics, > 100 kg;
Si or AlGaAs coatings;
'mildly' Cryogenic;
λ~2 μm, 300 W

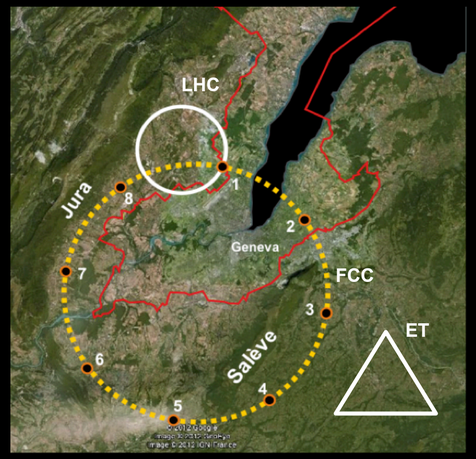
BNS reach: ~10x O2
BBH reach: z~5
~10^4 binary coalescences per year

The 3rd Generation

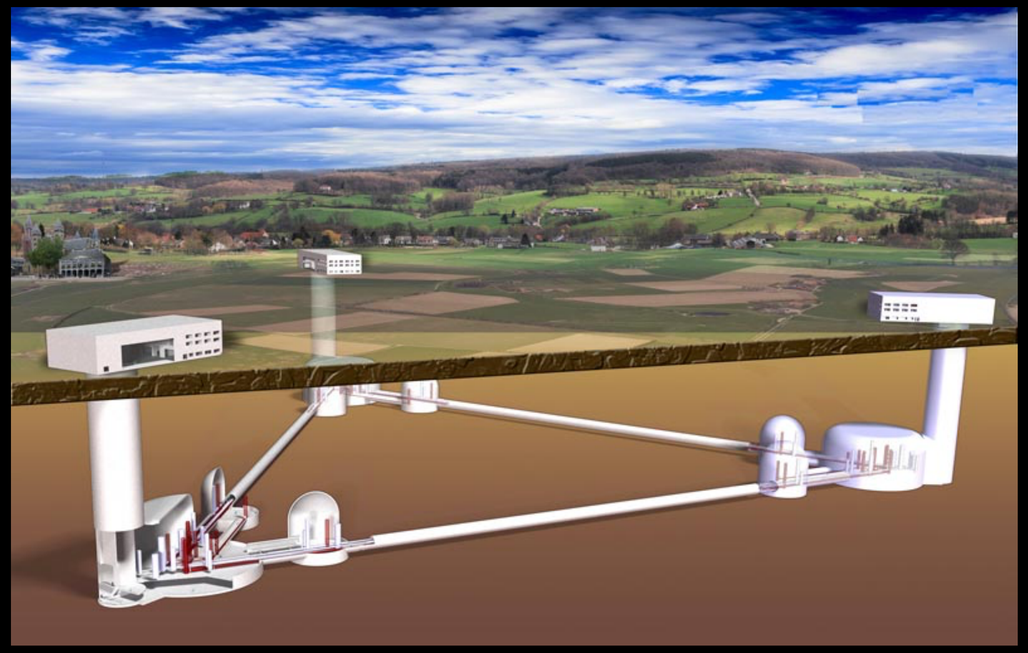
~10^5 binary coalescences per year (circa 2035)

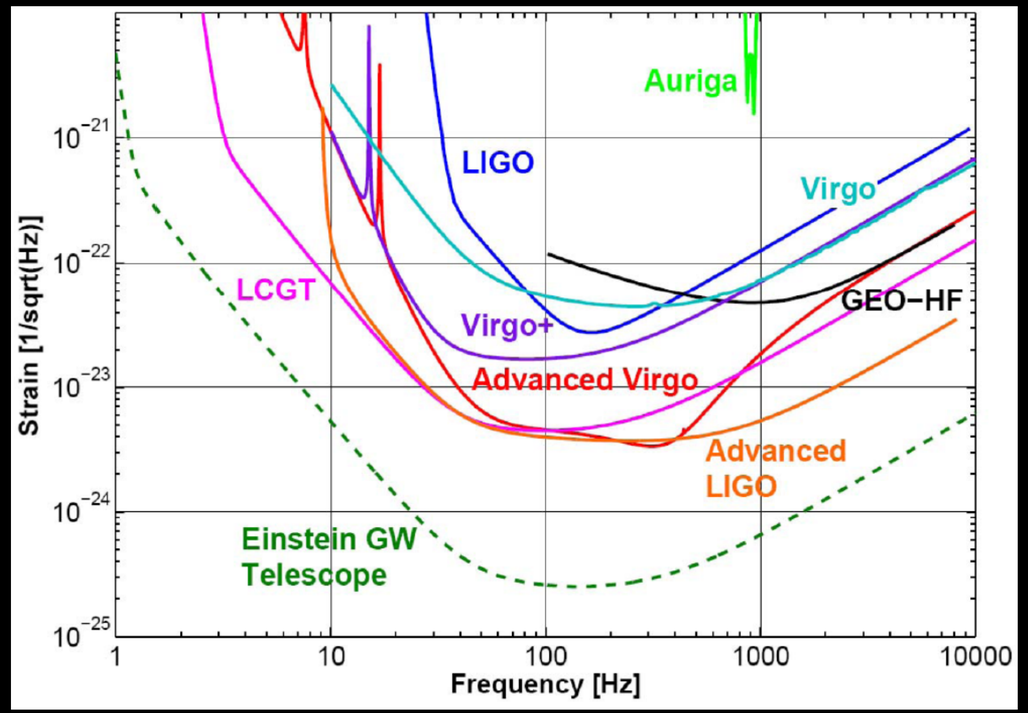
Einstein Telescope

- European conceptual design study
- Multiple instruments in xylophone configuration
- underground to reduce newtonian background
- 10 km arm length, in triangle.
- Assumes 10-15 year technology development
- Site selection ~2023



SEVENTH FRAMEWORK PROGRAMME



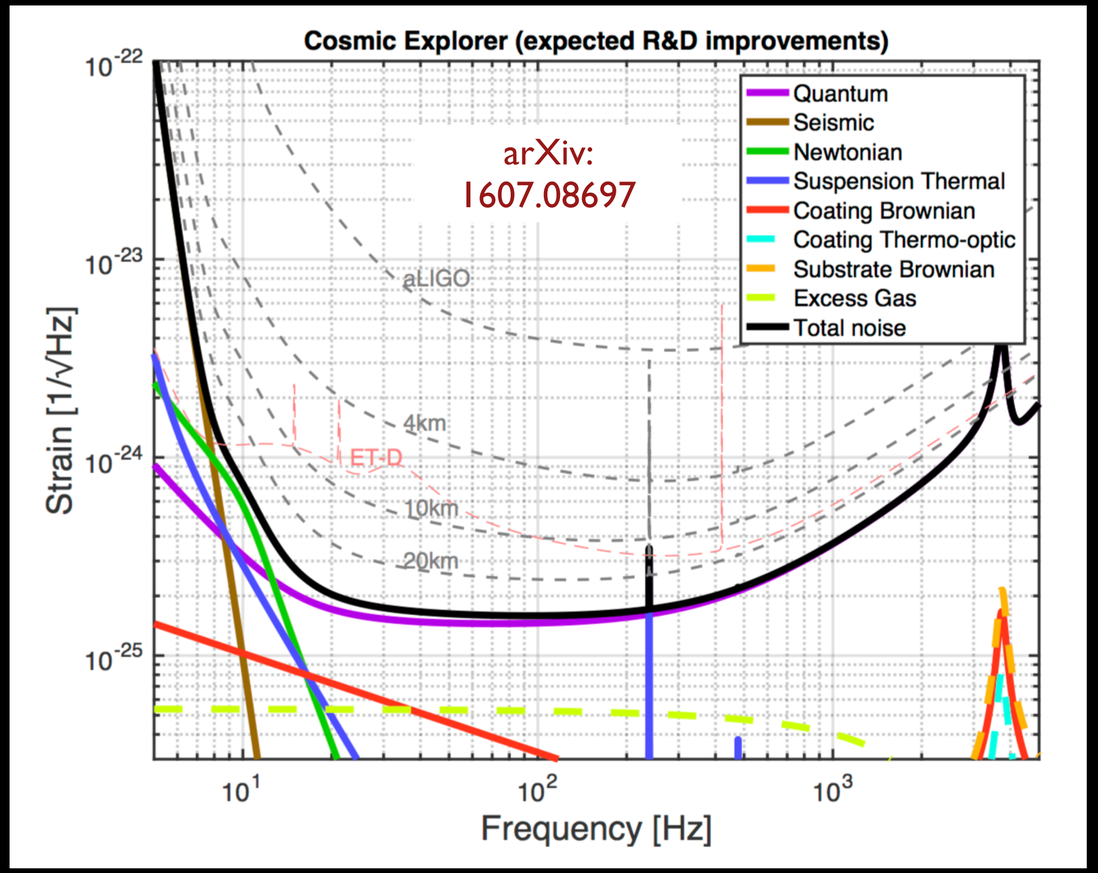


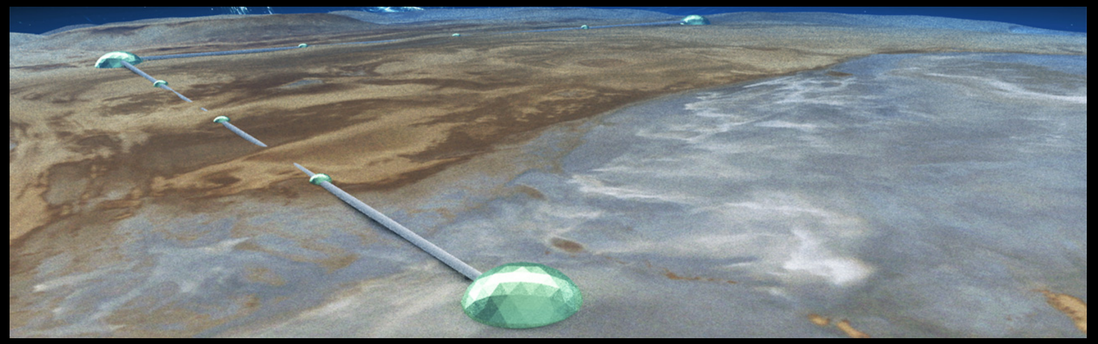
The 3rd Generation

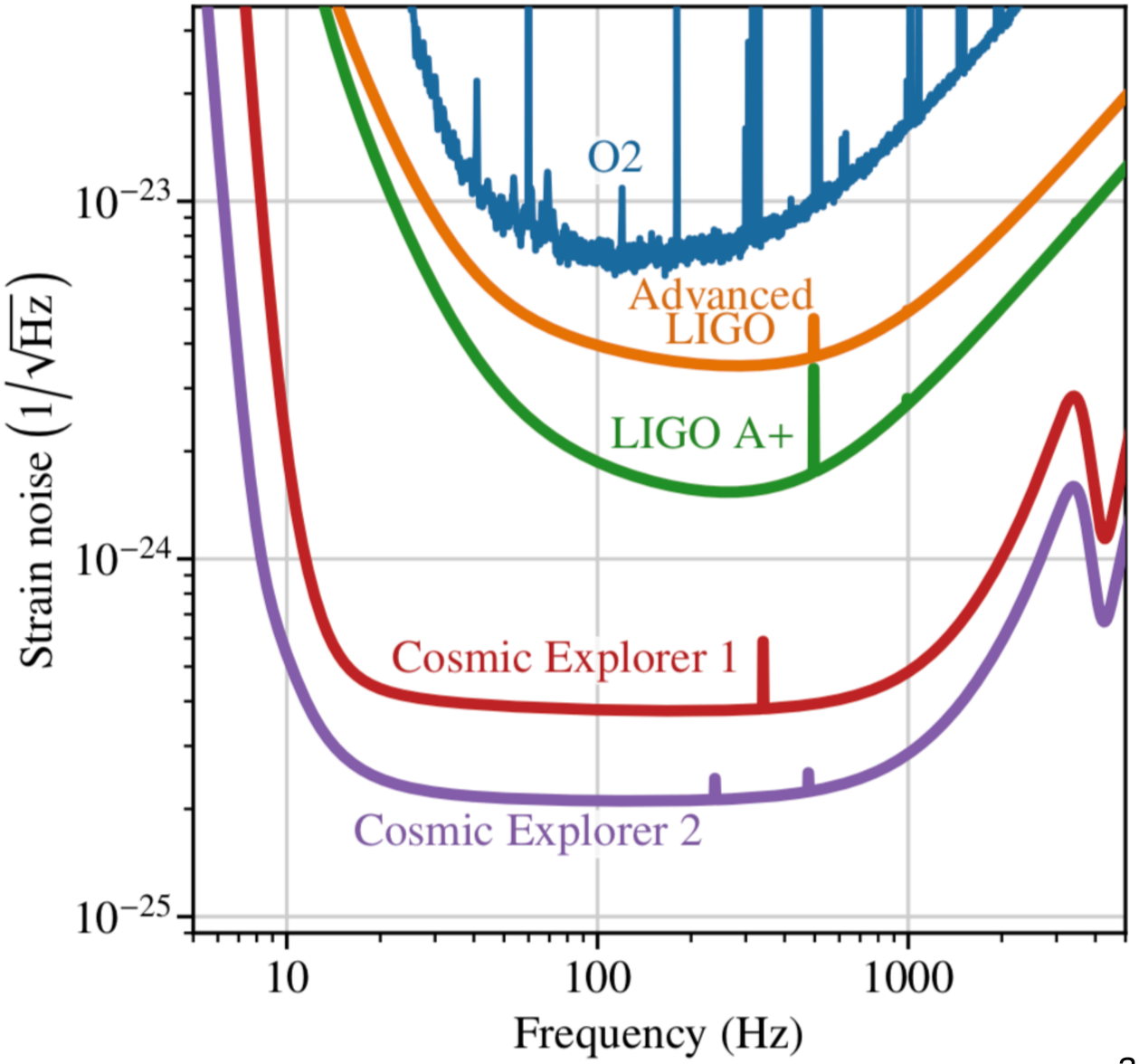
~10^5 binary coalescences per year (circa 2035)

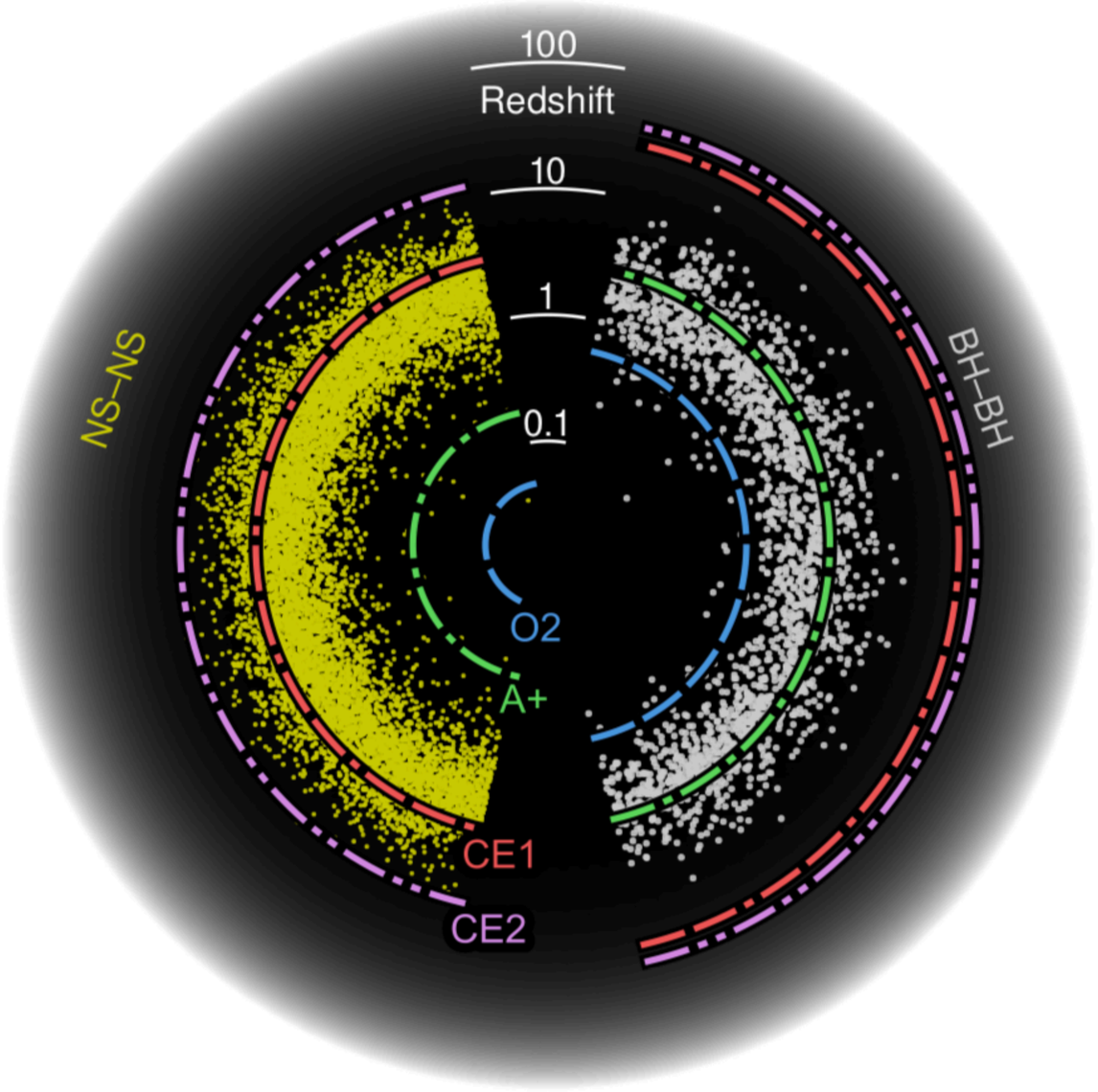
Cosmic Explorer

- NSF-funded US conceptual design study starting now
- 40km surface Observatory baseline
- Signal grows with length – not most noise sources
- Thermal noise, radiation pressure, seismic, Newtonian unchanged; coating thermal noise improves faster than linearly with length
- Stage 1(~2035) Extension of A+ technologies
- Stage 2 (~2045) Cryogenics, new material for test masses and coatings









arXiv:1903.04615

The Future for MMA

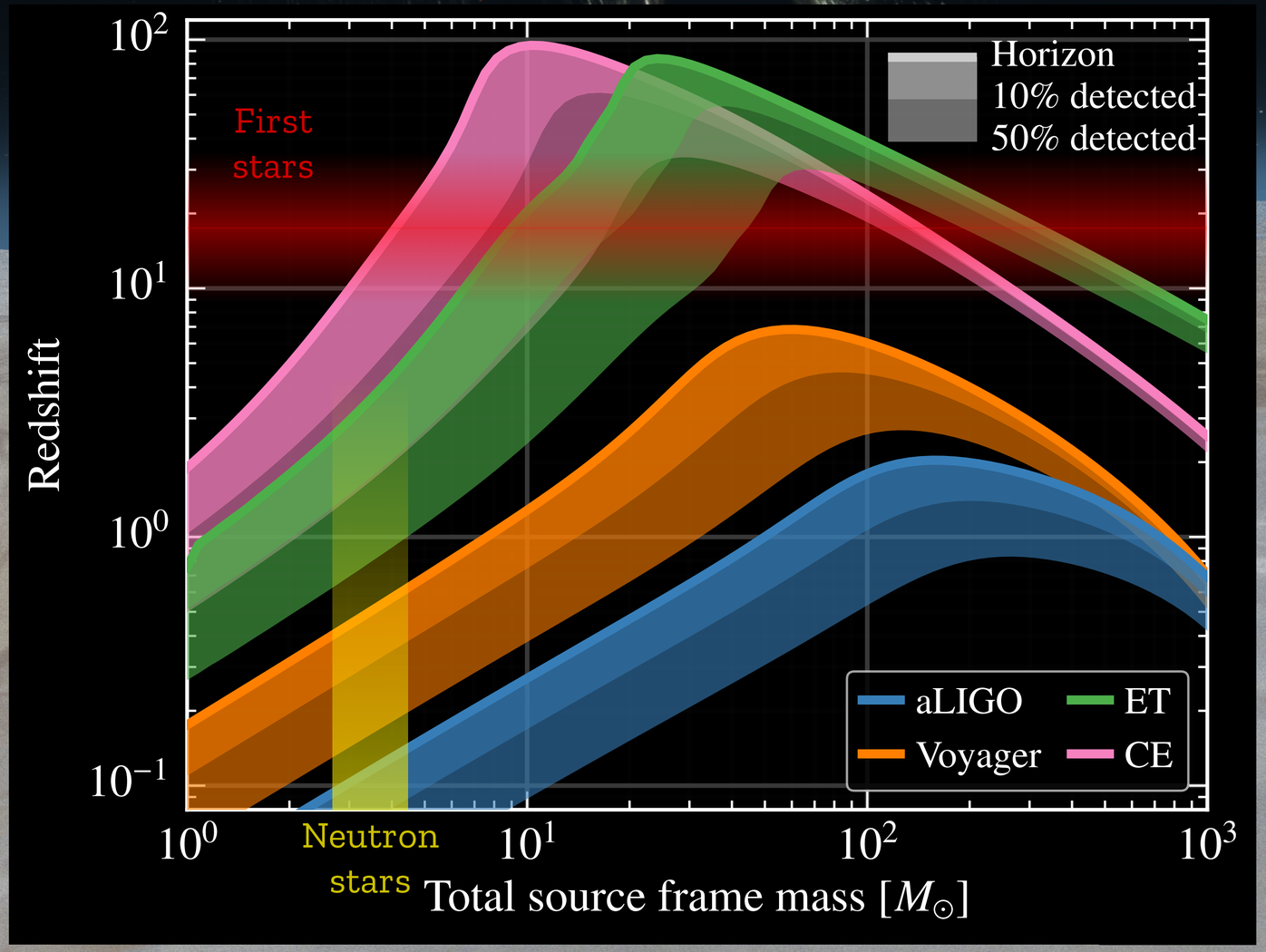


Table 1: Expected detections per year (N), number detected with a resolution of < 1, < 10 and < 100 sq. deg. (N_1, N_{10} and N_{100}, respectively) and median localization error (M in sq. deg.), in a network consisting of LIGO-Hanford, LIGO-Livingston and Virgo (HLV), HLV plus KAGRA and LIGO-India (HLVKI) and 1 Einstein Telescope and 2 Cosmic Explorer detectors (1ET+2CE).

Network	N	N_1	N_{10}	N_{100}	M
HLV	48	0	16	48	19
HLVKI	48	0	48	48	7
1ET+2CE	990k	14k	410k	970k	12

arXiv:1903.09277