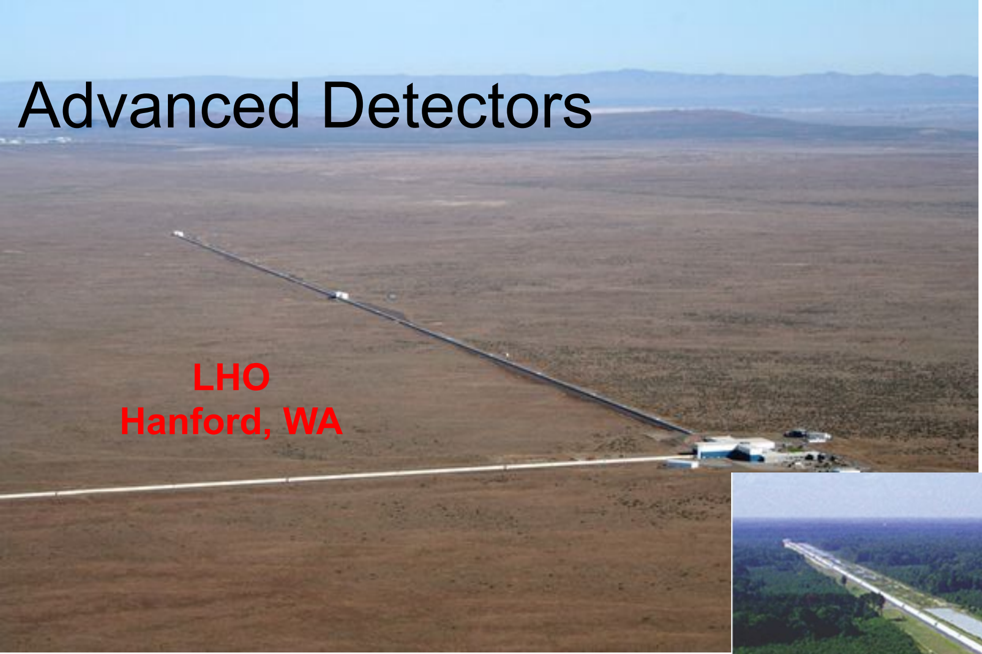
Gravitational Waves Over the Next 40 Years

Reed Clasey Essick
KICP

23 November 2019
Compton Lectures
University of Chicago

https://github.com/reedessick/compton-lectures-2019

Advanced Detectors



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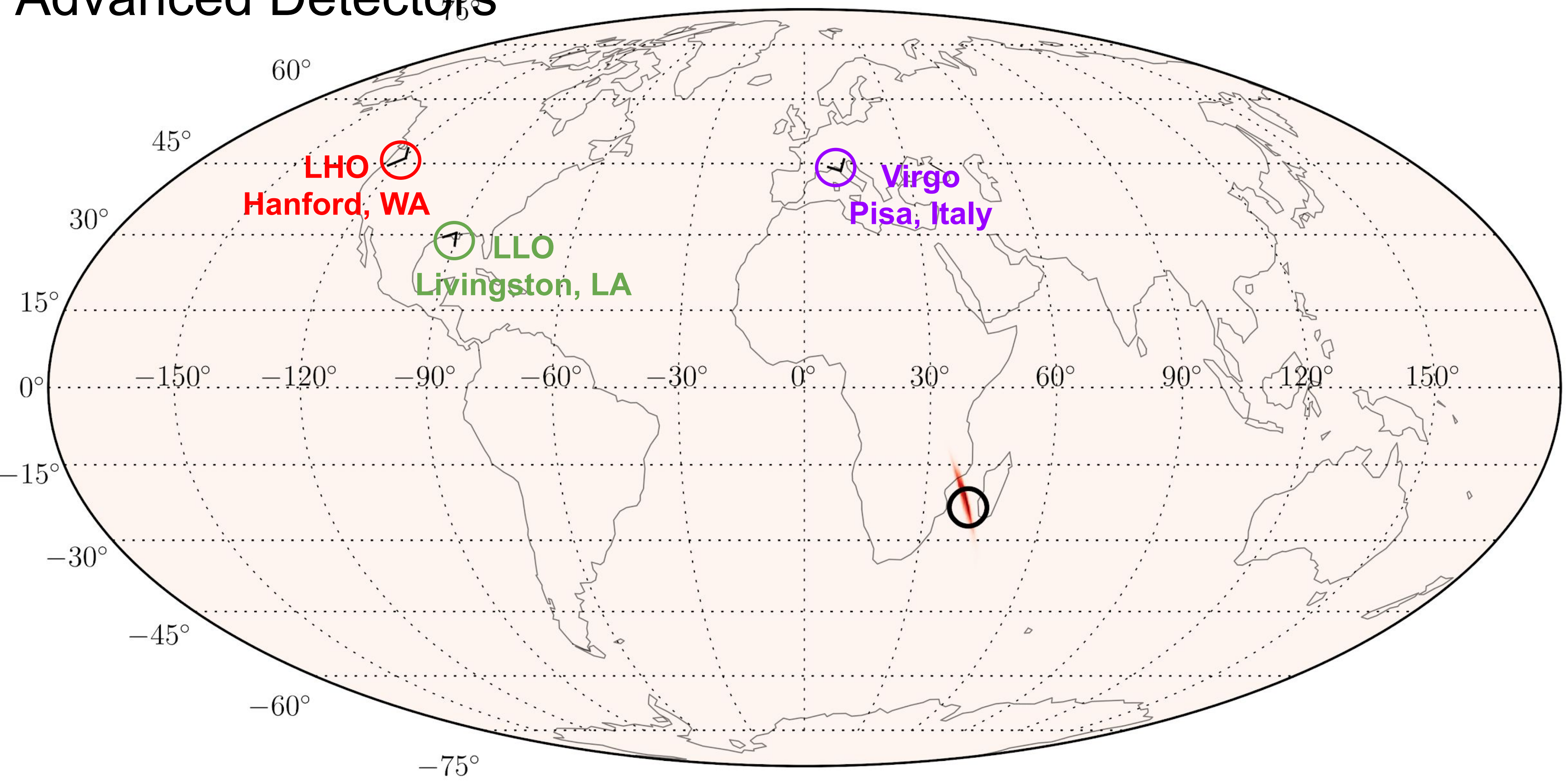

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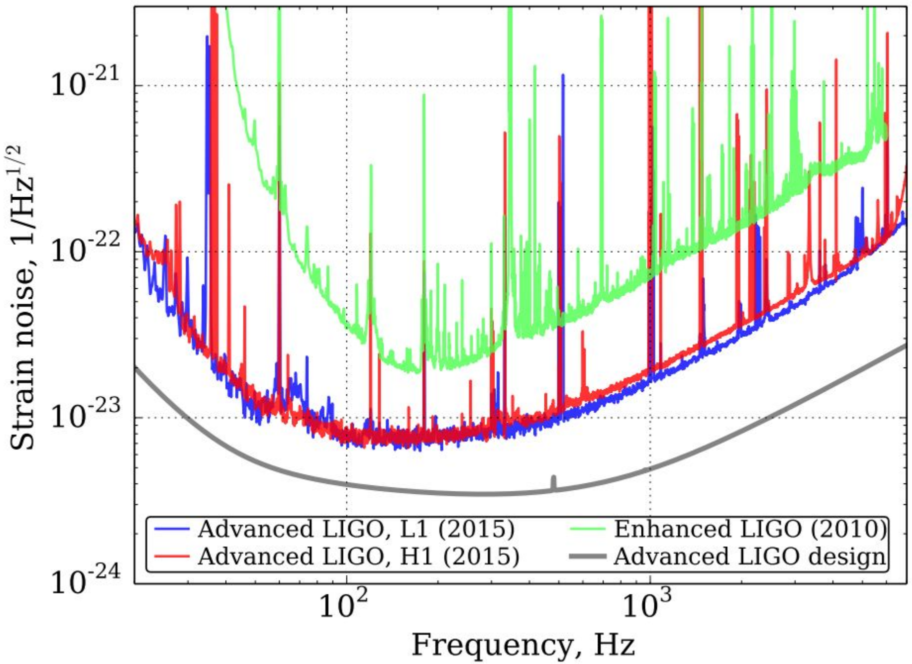

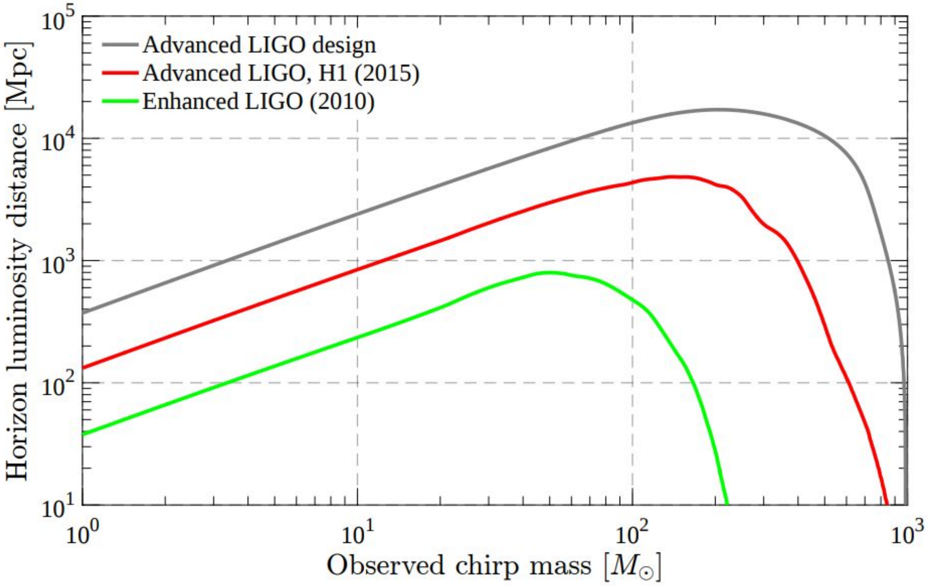

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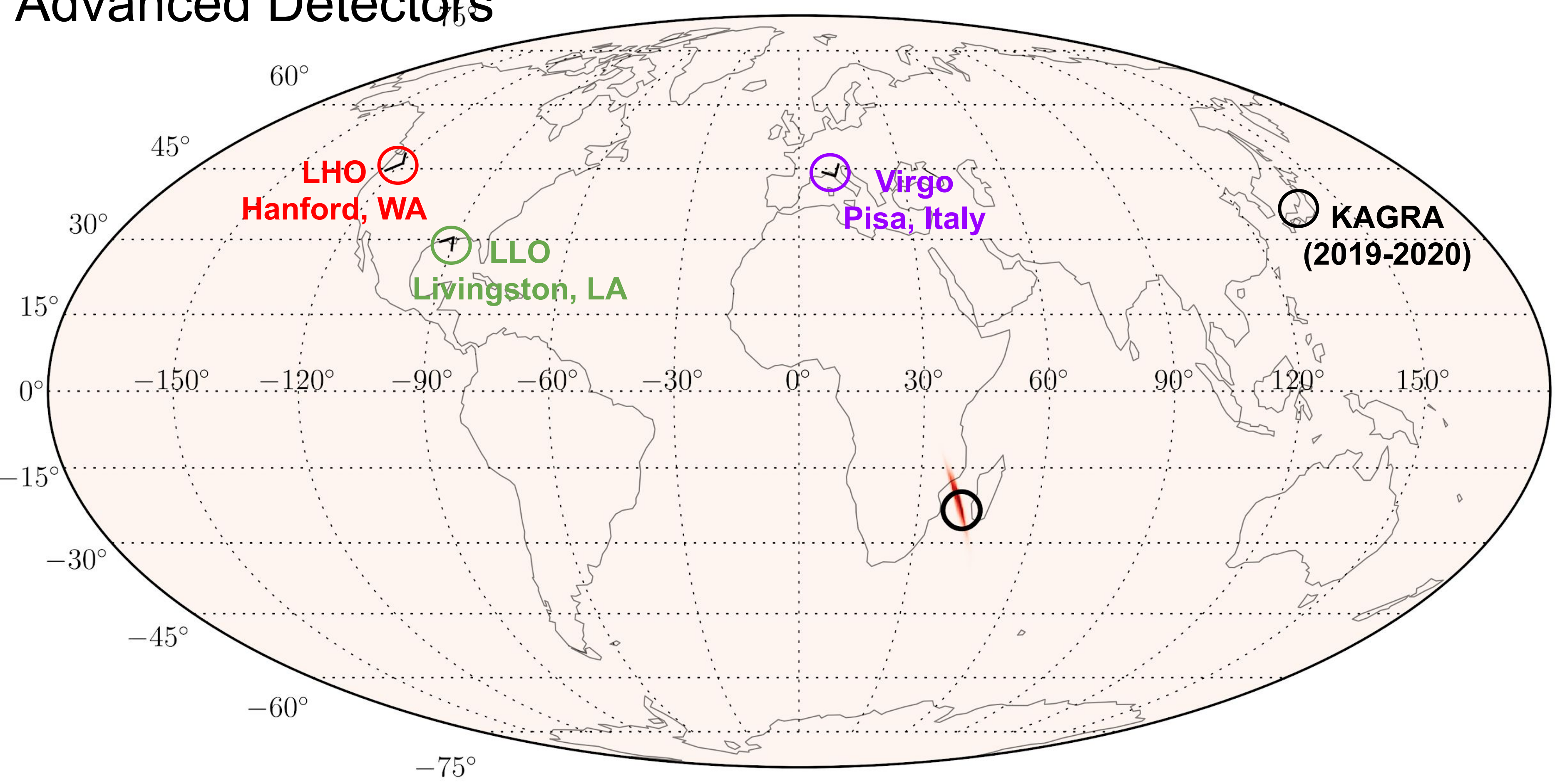

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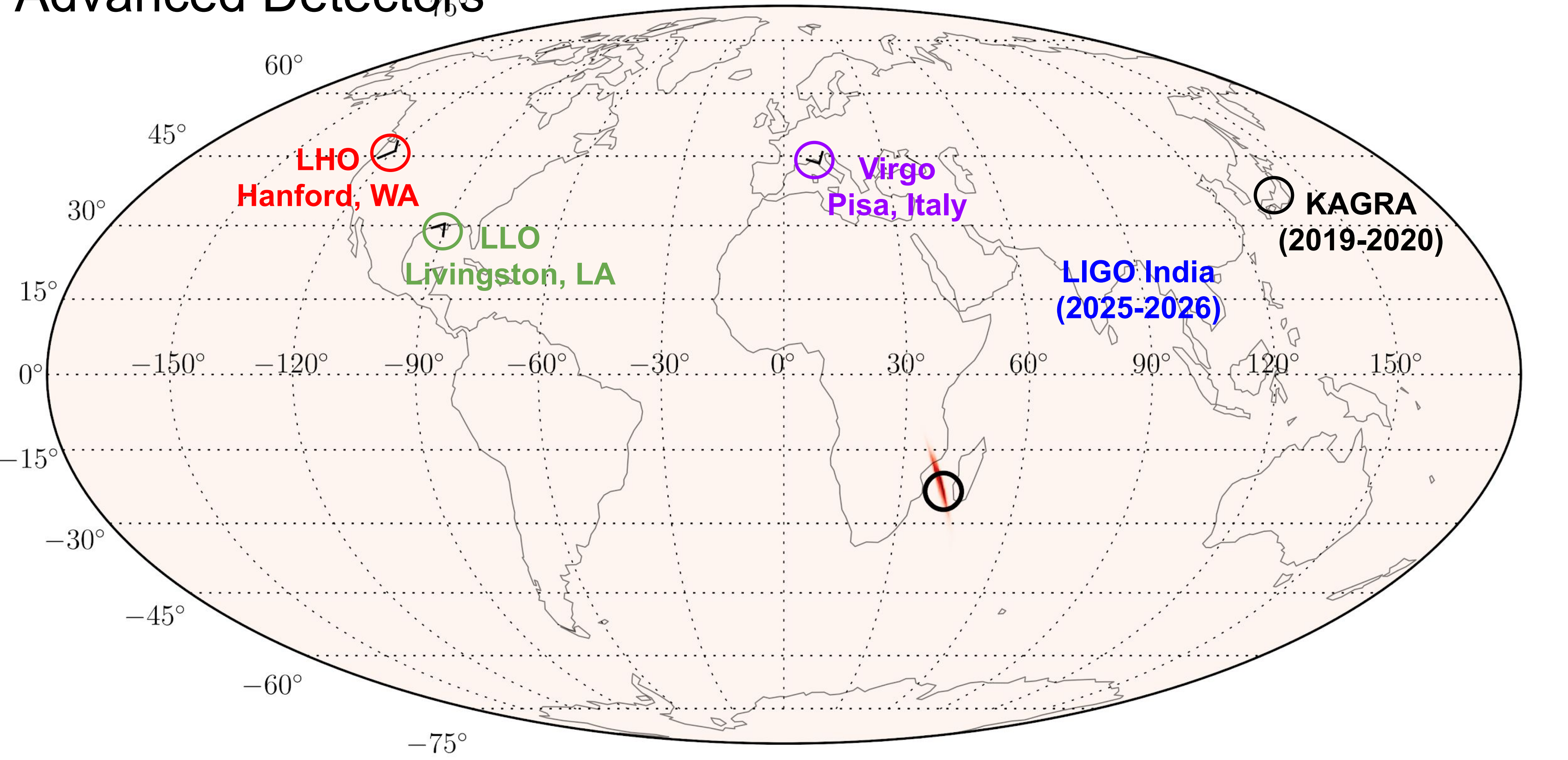

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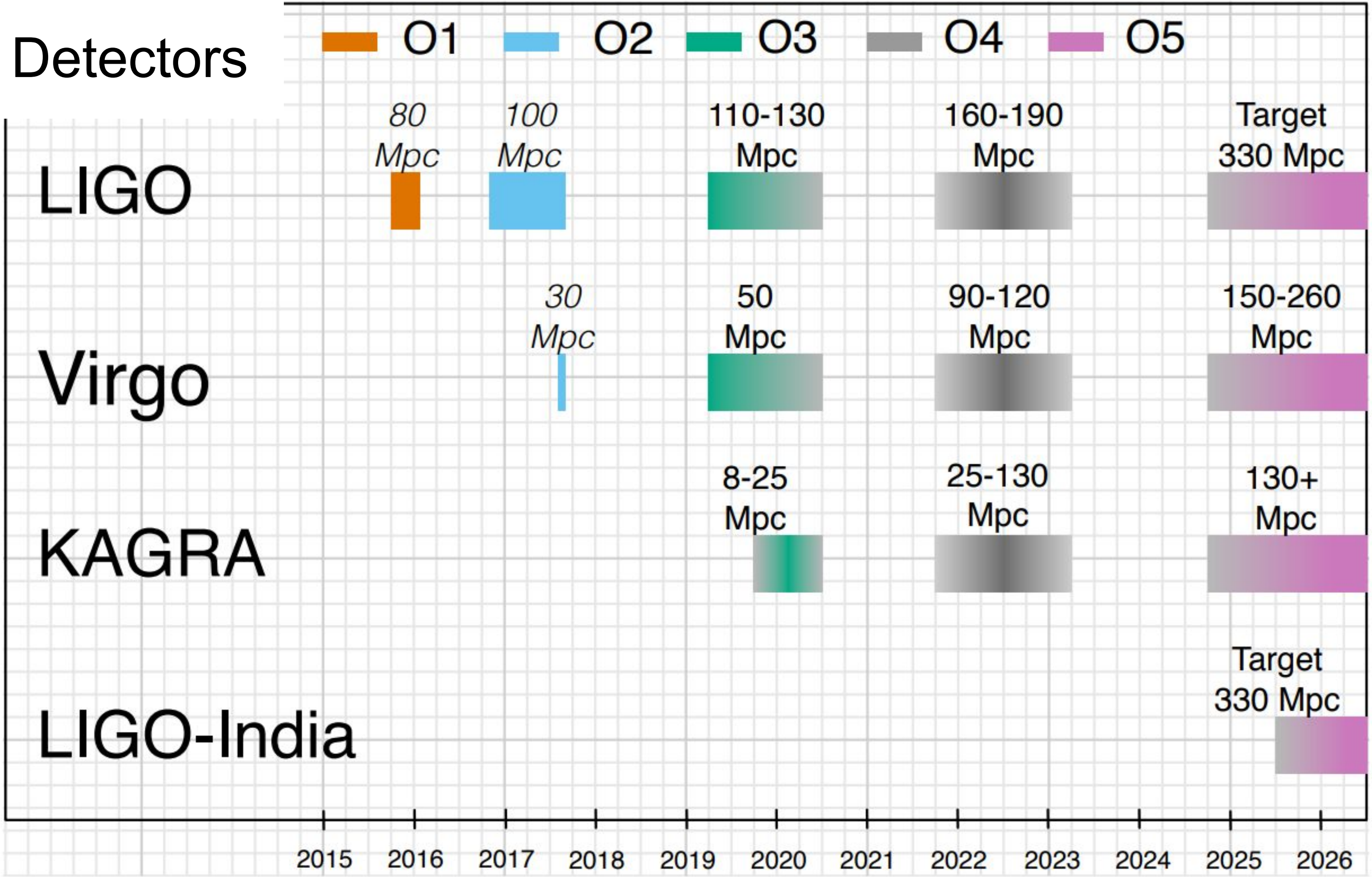

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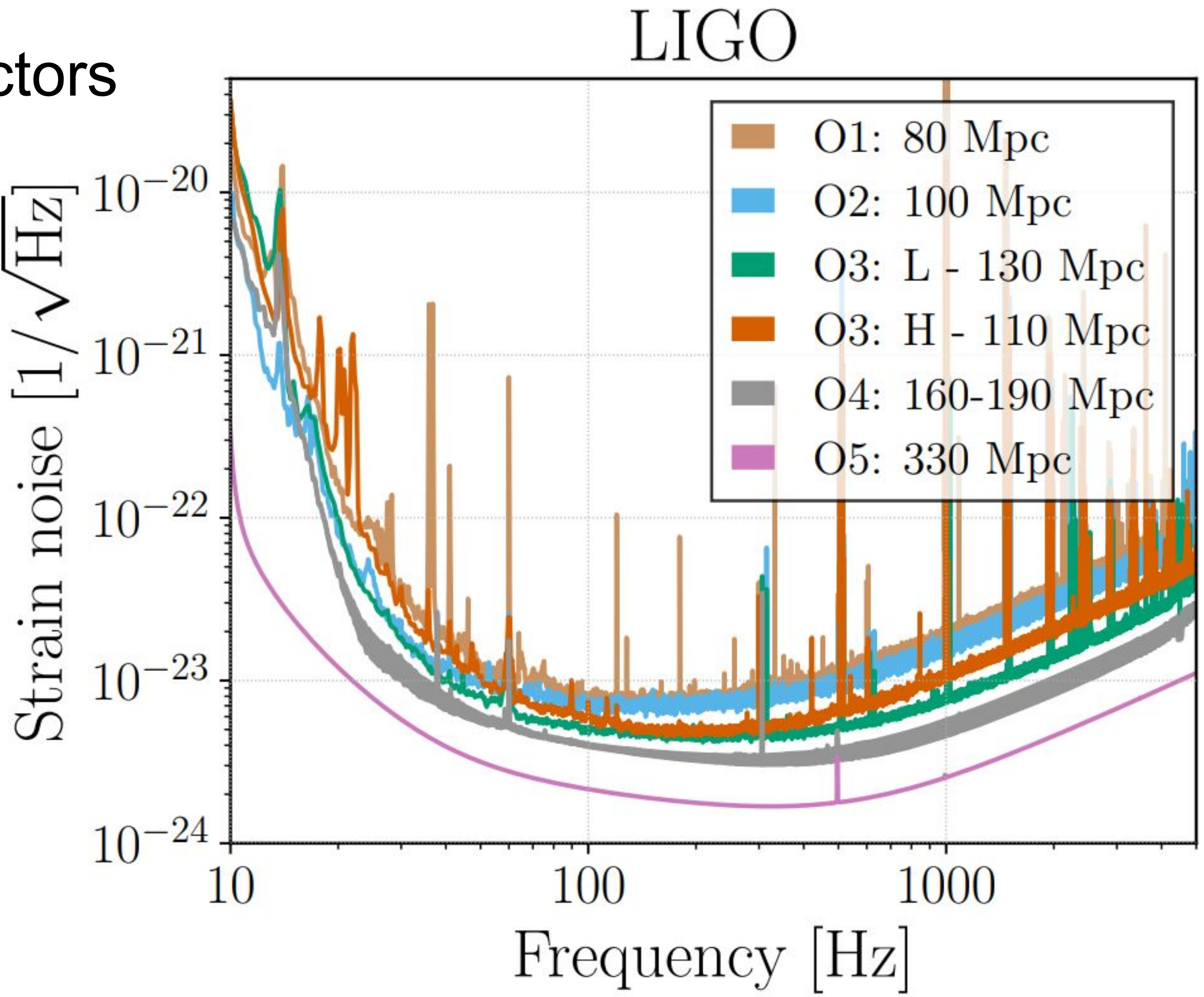

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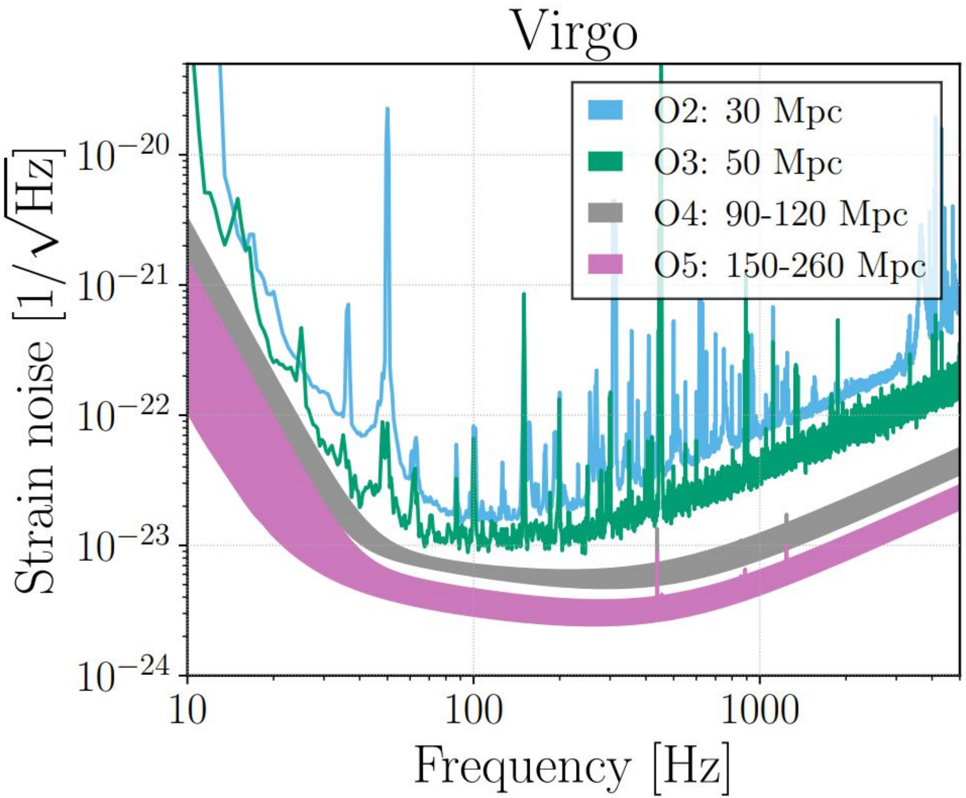

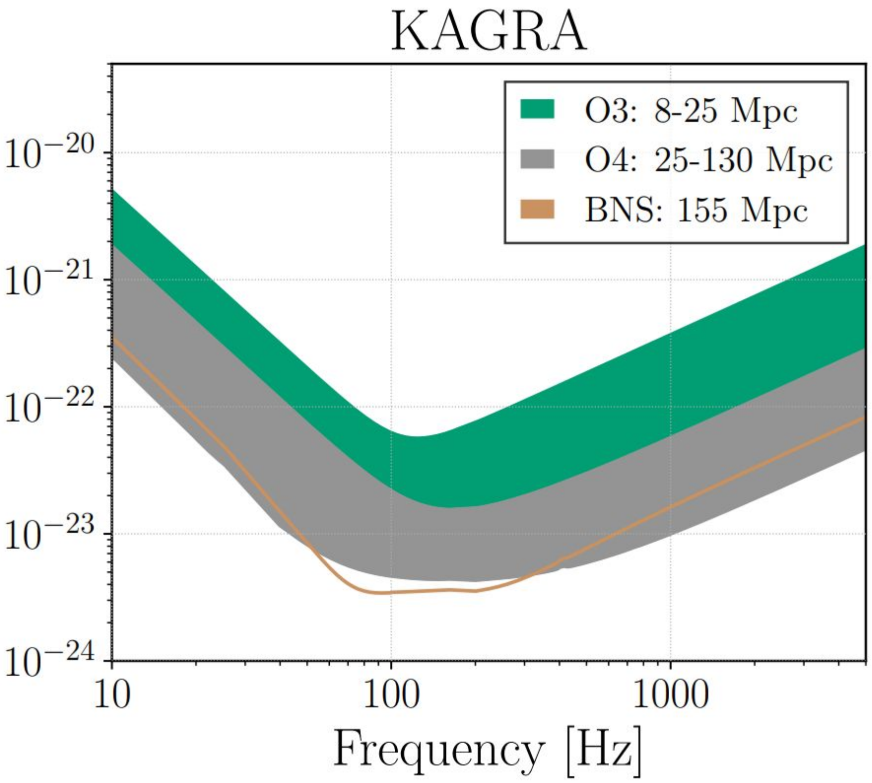

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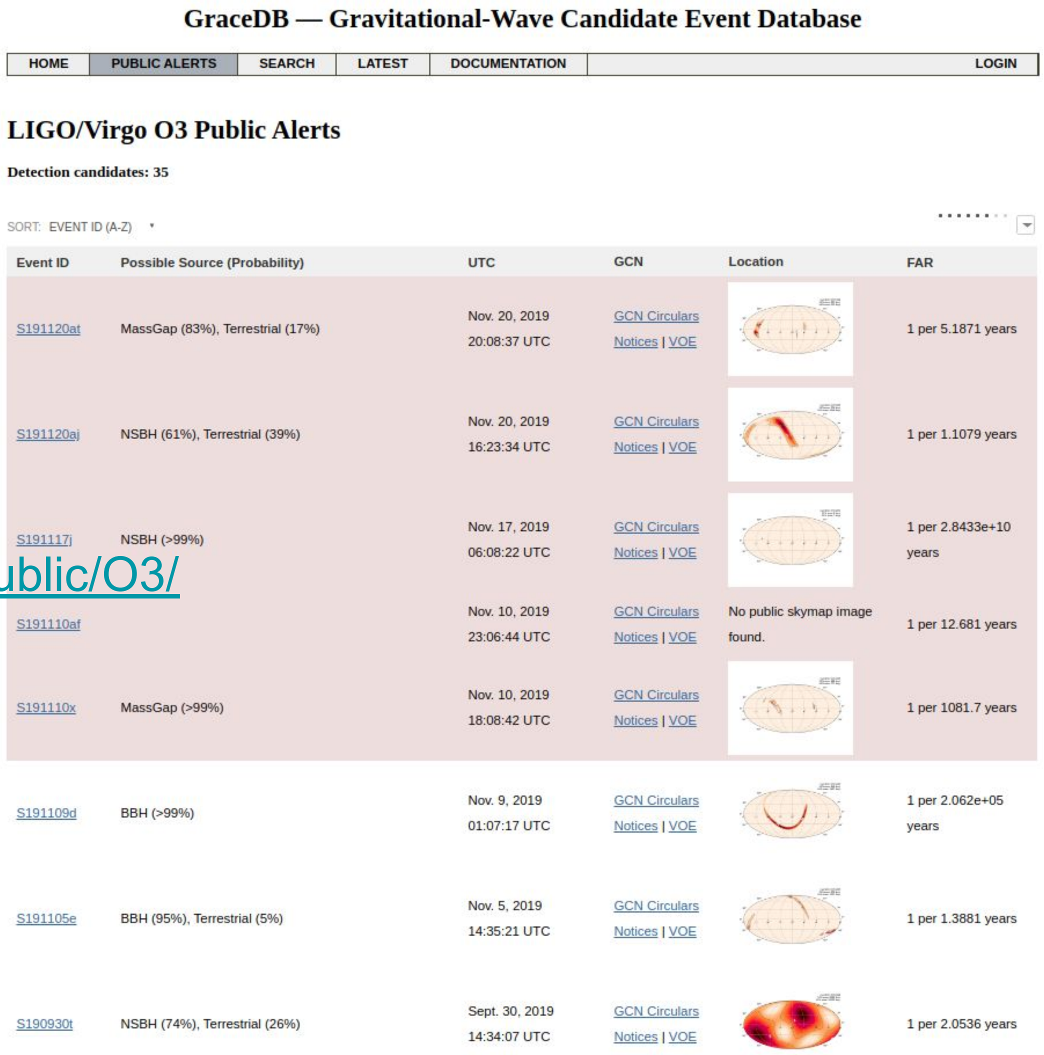


GraceDB — Gravitational-Wave Candidate Event Database

HOME | PUBLIC ALERTS | SEARCH | LATEST | DOCUMENTATION | LOGIN

LIGO/Virgo O3 Public Alerts

Detection candidates: 35

SORT: EVENT ID (A-Z)

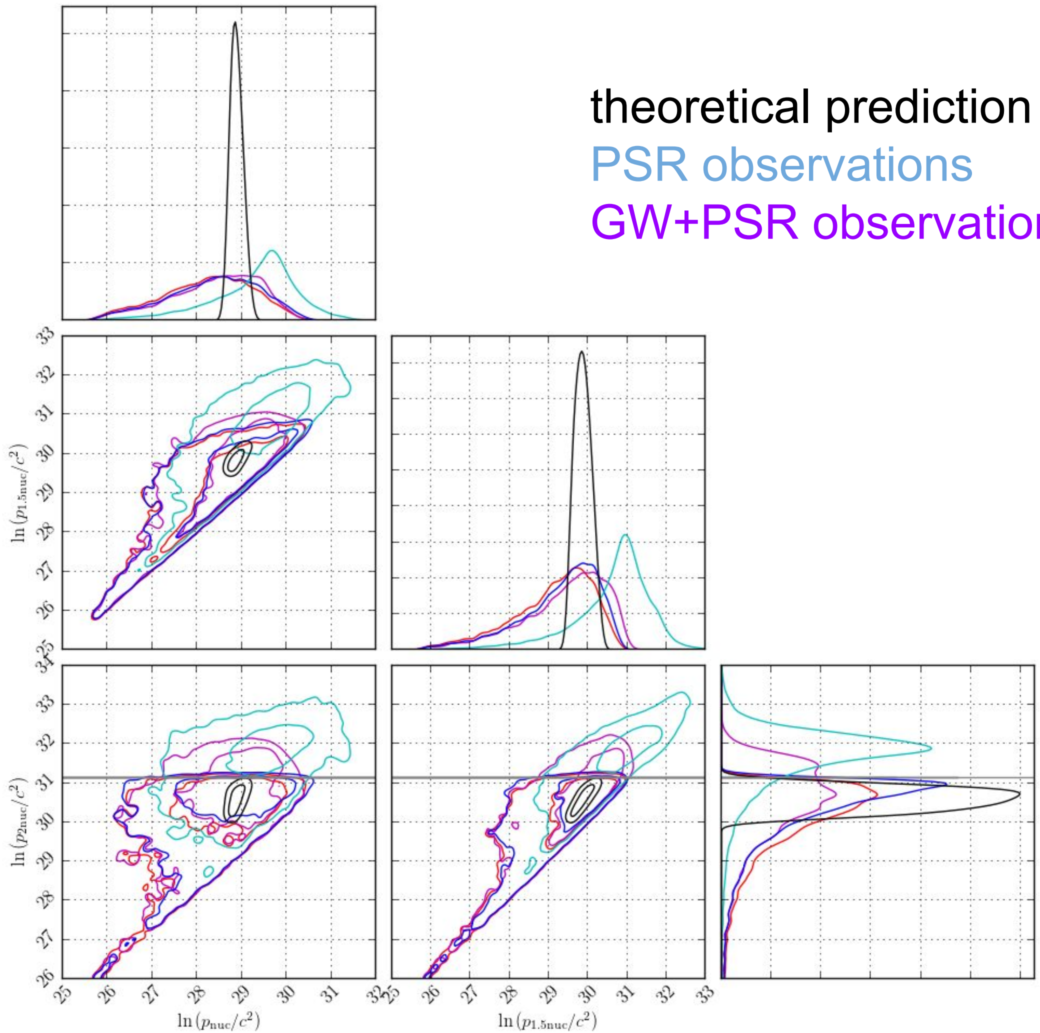
Event ID	Possible Source (Probability)	UTC	GCN	Location	FAR
S191120at	MassGap (83%), Terrestrial (17%)	Nov. 20, 2019 20:08:37 UTC	GCN Circulars Notices | VOE		1 per 5.1871 years
S191120aj	NSBH (61%), Terrestrial (39%)	Nov. 20, 2019 16:23:34 UTC	GCN Circulars Notices | VOE		1 per 1.1079 years
S191117j	NSBH (>99%)	Nov. 17, 2019 06:08:22 UTC	GCN Circulars Notices | VOE		1 per 2.8433e+10 years
S191110af		Nov. 10, 2019 23:06:44 UTC	GCN Circulars Notices | VOE	No public skymap image found.	1 per 12.681 years
S191110x	MassGap (>99%)	Nov. 10, 2019 18:08:42 UTC	GCN Circulars Notices | VOE		1 per 1081.7 years
S191109d	BBH (>99%)	Nov. 9, 2019 01:07:17 UTC	GCN Circulars Notices | VOE		1 per 2.062e+05 years
S191105e	BBH (95%), Terrestrial (5%)	Nov. 5, 2019 14:35:21 UTC	GCN Circulars Notices | VOE		1 per 1.3881 years
S190930t	NSBH (74%), Terrestrial (26%)	Sept. 30, 2019 14:34:07 UTC	GCN Circulars Notices | VOE		1 per 2.0536 years

public alerts!

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

Observation Run	Network	Expected BNS Detections	Expected NSBH Detections	Expected BBH Detections
O3	HLV	2^{+8}_{-2}	0^{+19}_{-0}	15^{+19}_{-10}
O4	HLVK	8^{+42}_{-7}	2^{+94}_{-2}	68^{+81}_{-38}
		Area (deg^2) 90% c.r.	Area (deg^2) 90% c.r.	Area (deg^2) 90% c.r.
O3	HLV	250 – 310	310 – 390	250 – 340
O4	HLVK	29 – 48	48 – 69	33 – 47
		Comoving Volume (10^3 Mpc^3) 90% c.r.	Comoving Volume (10^3 Mpc^3) 90% c.r.	Comoving Volume (10^3 Mpc^3) 90% c.r.
O3	HLV	90 – 130	590 – 1000	11000 – 19000
O4	HLVK	43 – 71	400 – 560	6400 – 10000

Advanced Detectors

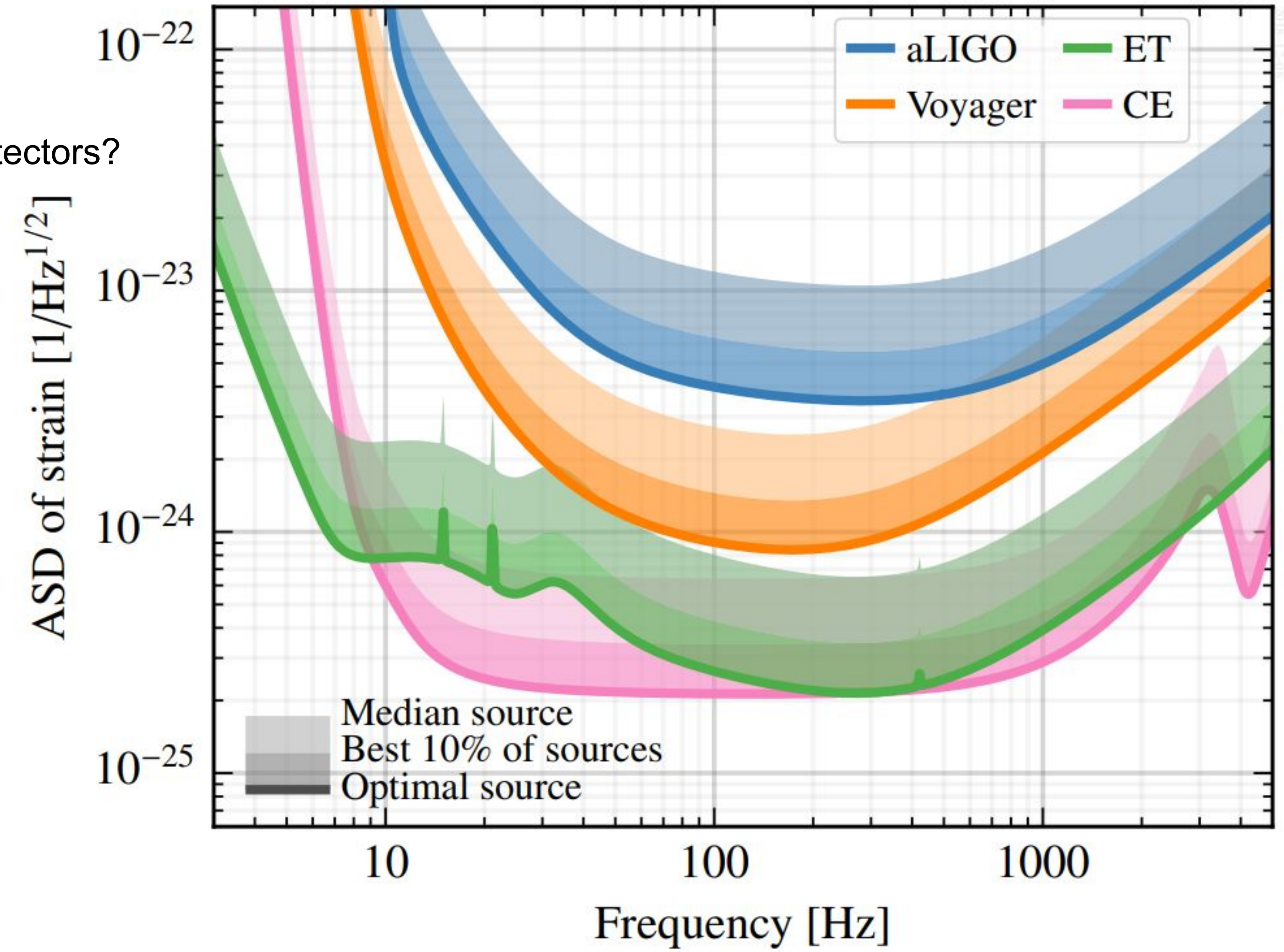


theoretical prediction
PSR observations
GW+PSR observations

3G Detectors

Why do we need bigger detectors?

- Better signal-to-noise
- broader bandwidth



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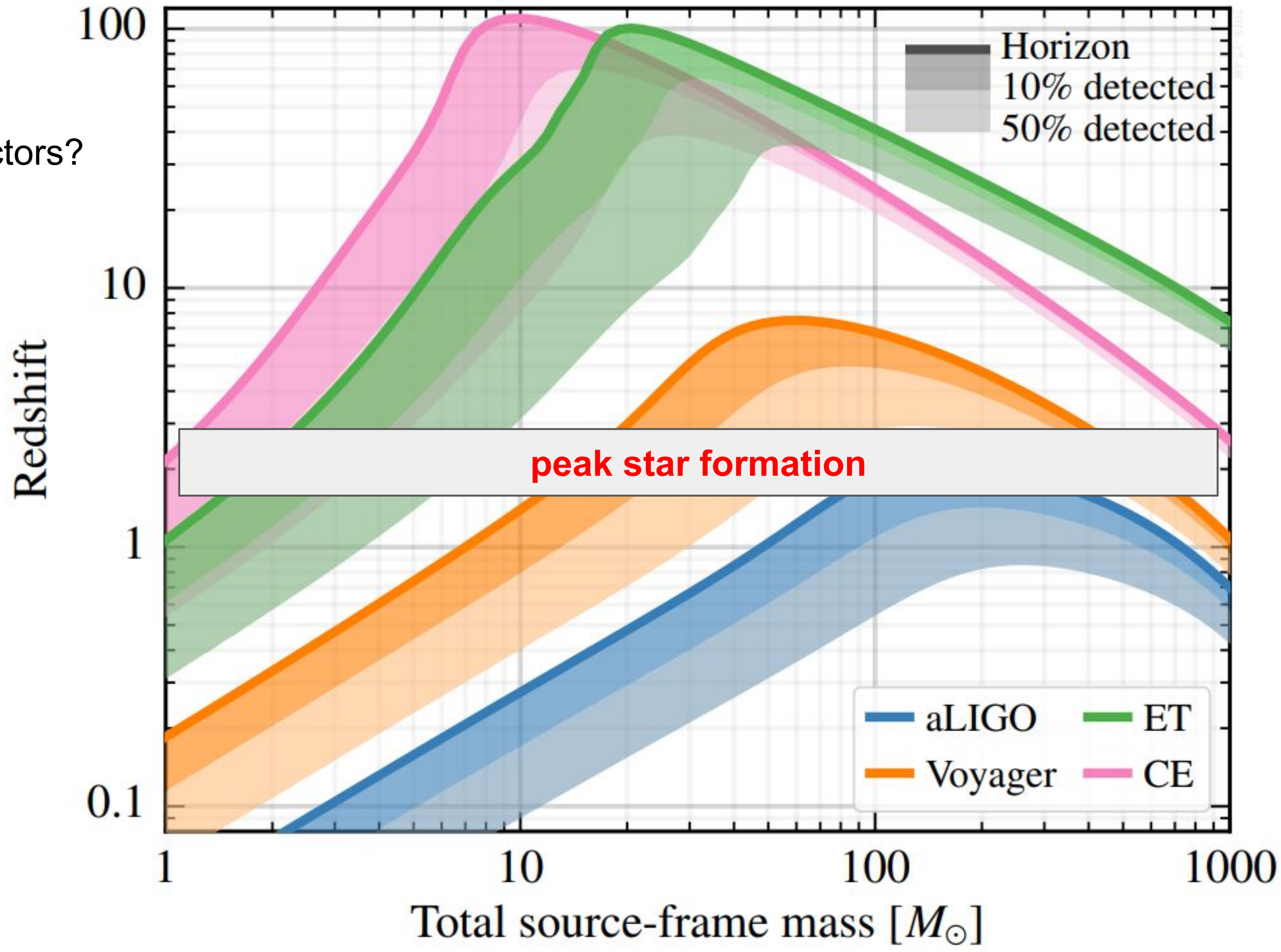
We could see every binary there ever was!



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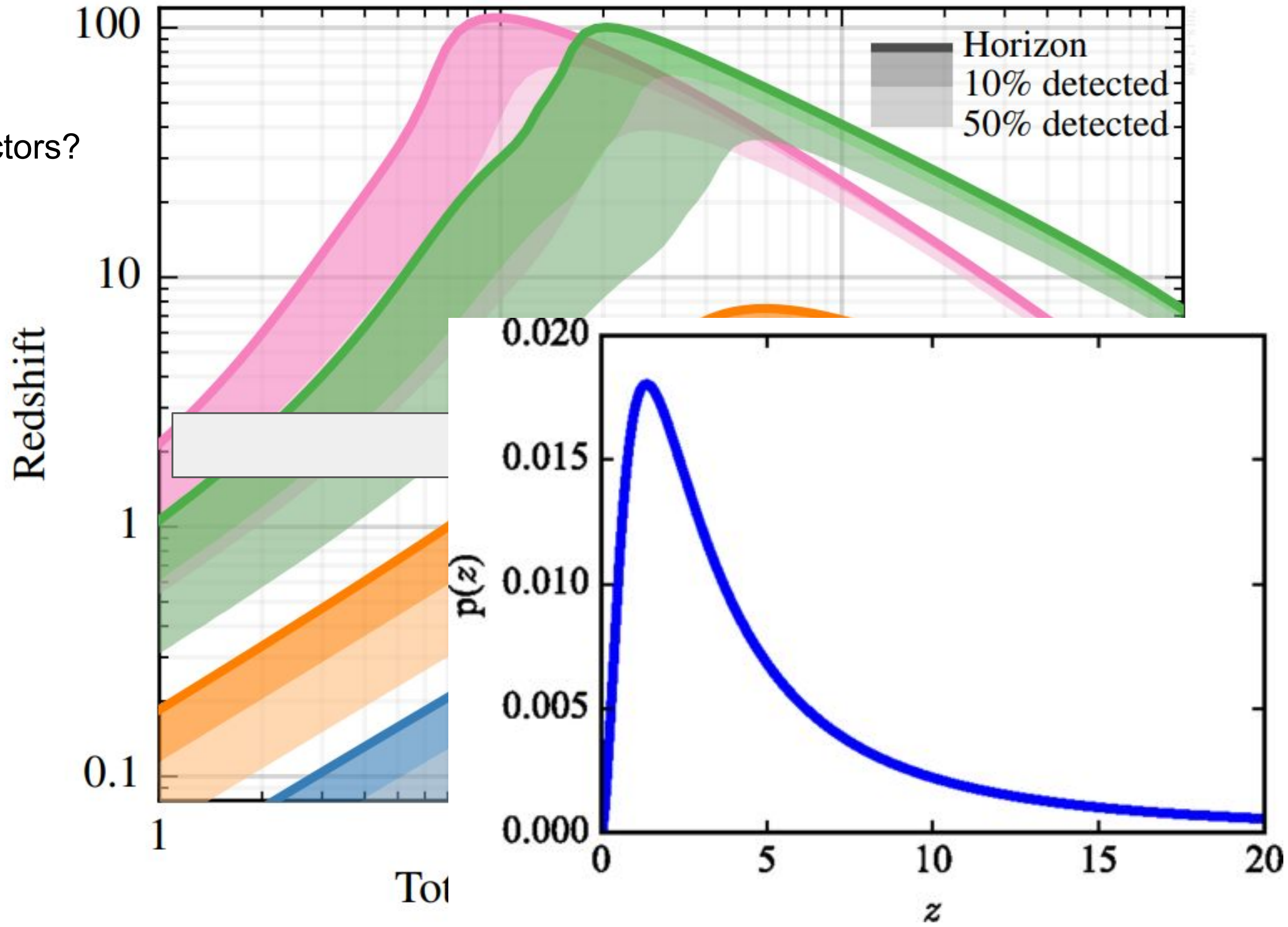
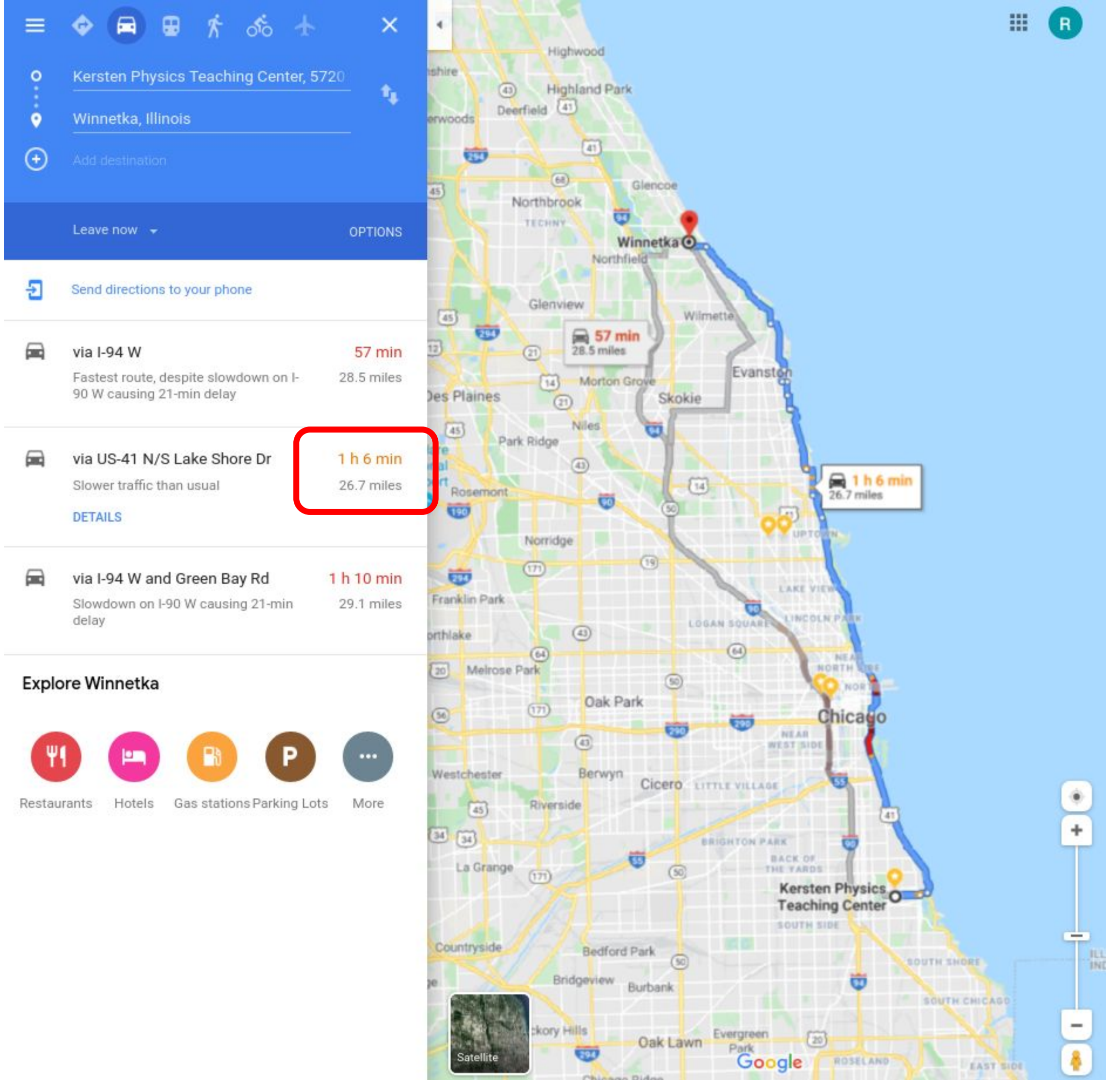


3G Detectors

Cosmic Explorer

- Proven technologies
- Bigger detectors



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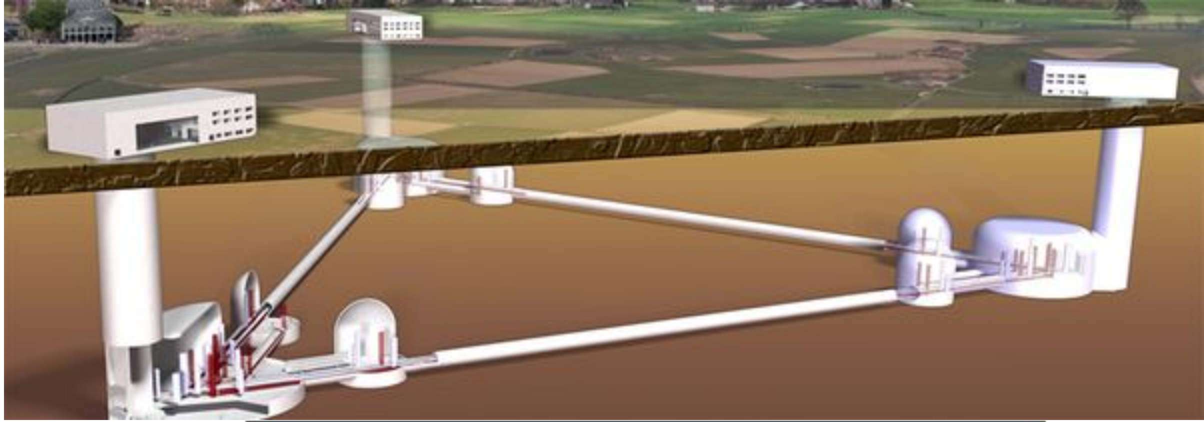
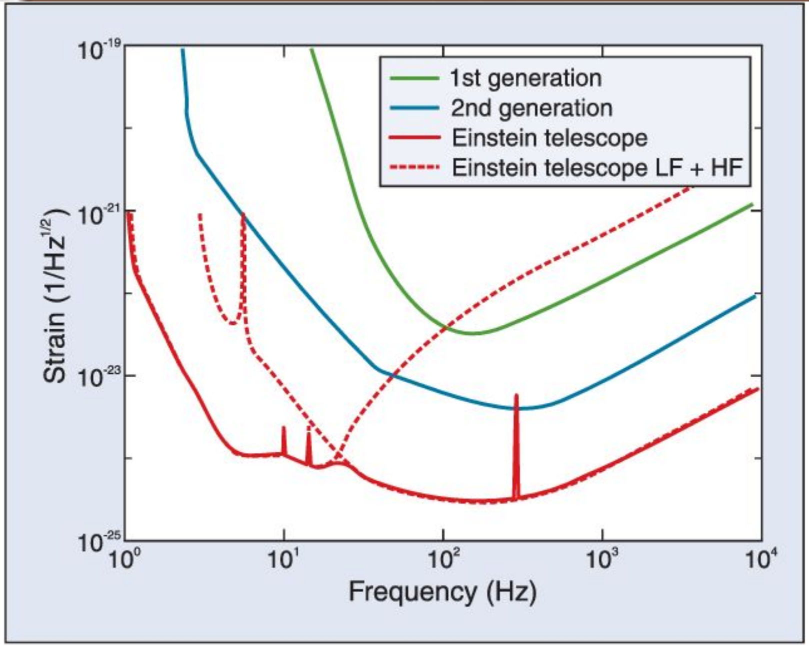


Cosmic Explorer

- Proven technologies
- Bigger detectors

Einstein Telescope

- Separate low-frequency and high-frequency instruments
- Triangular orientation



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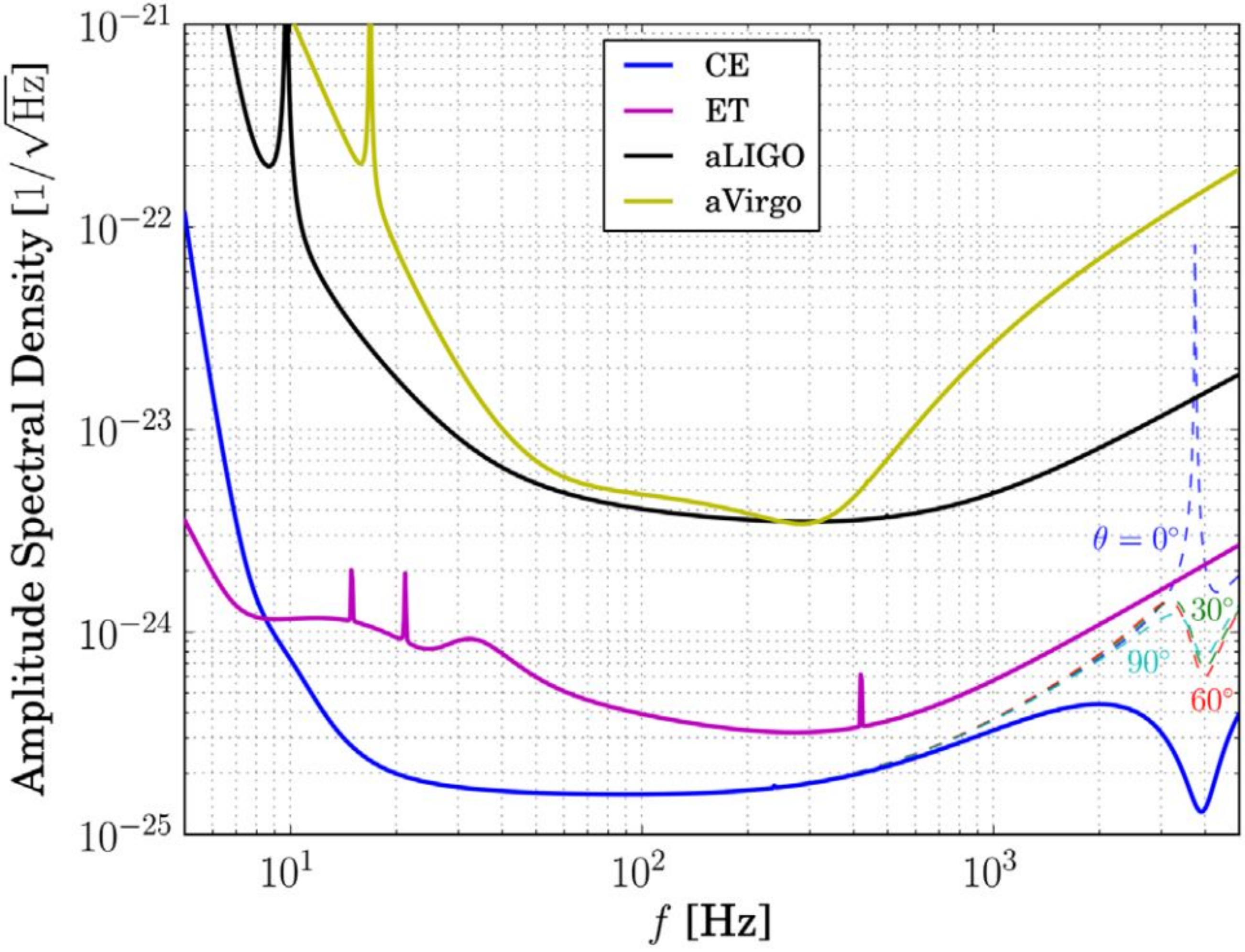

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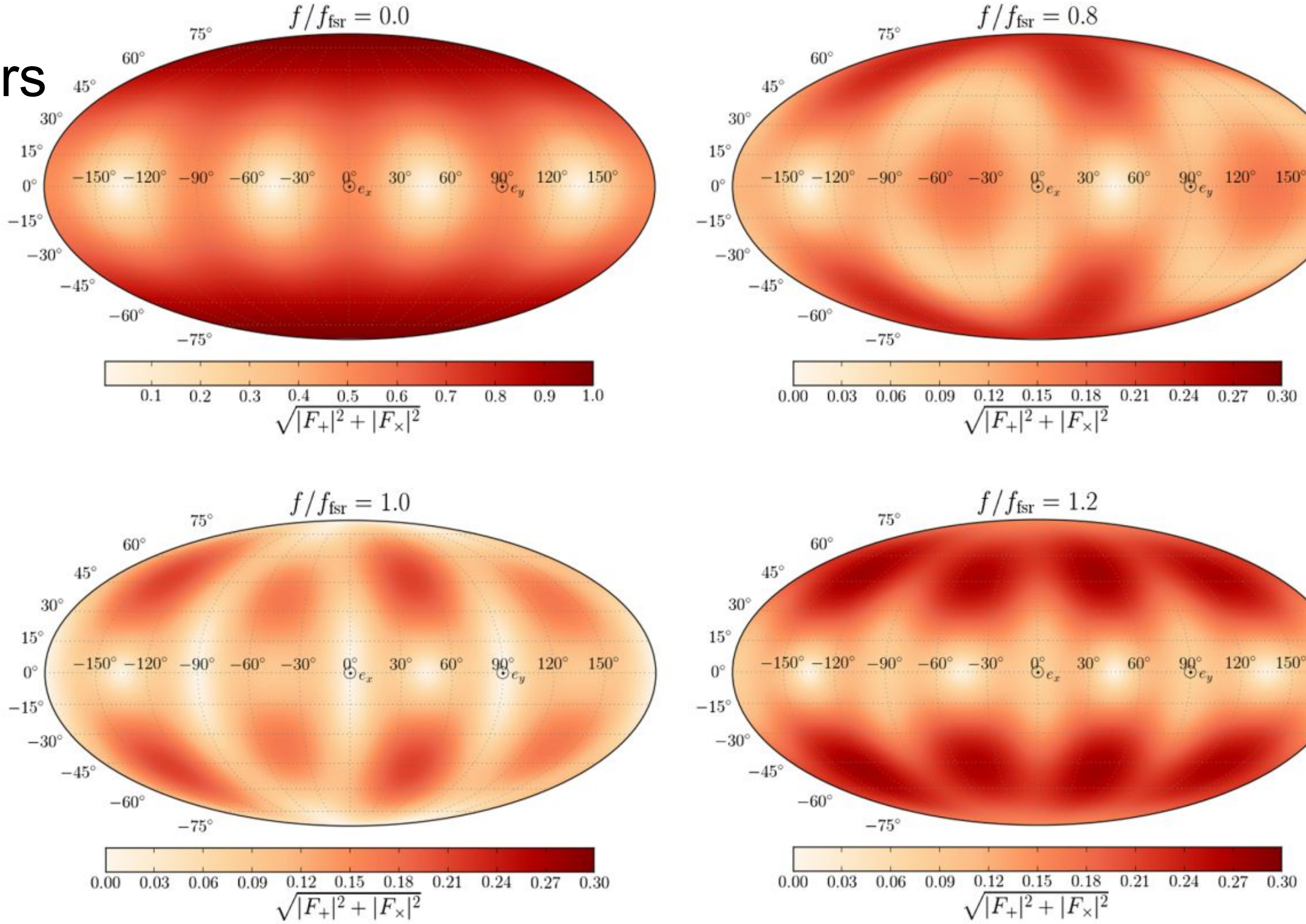

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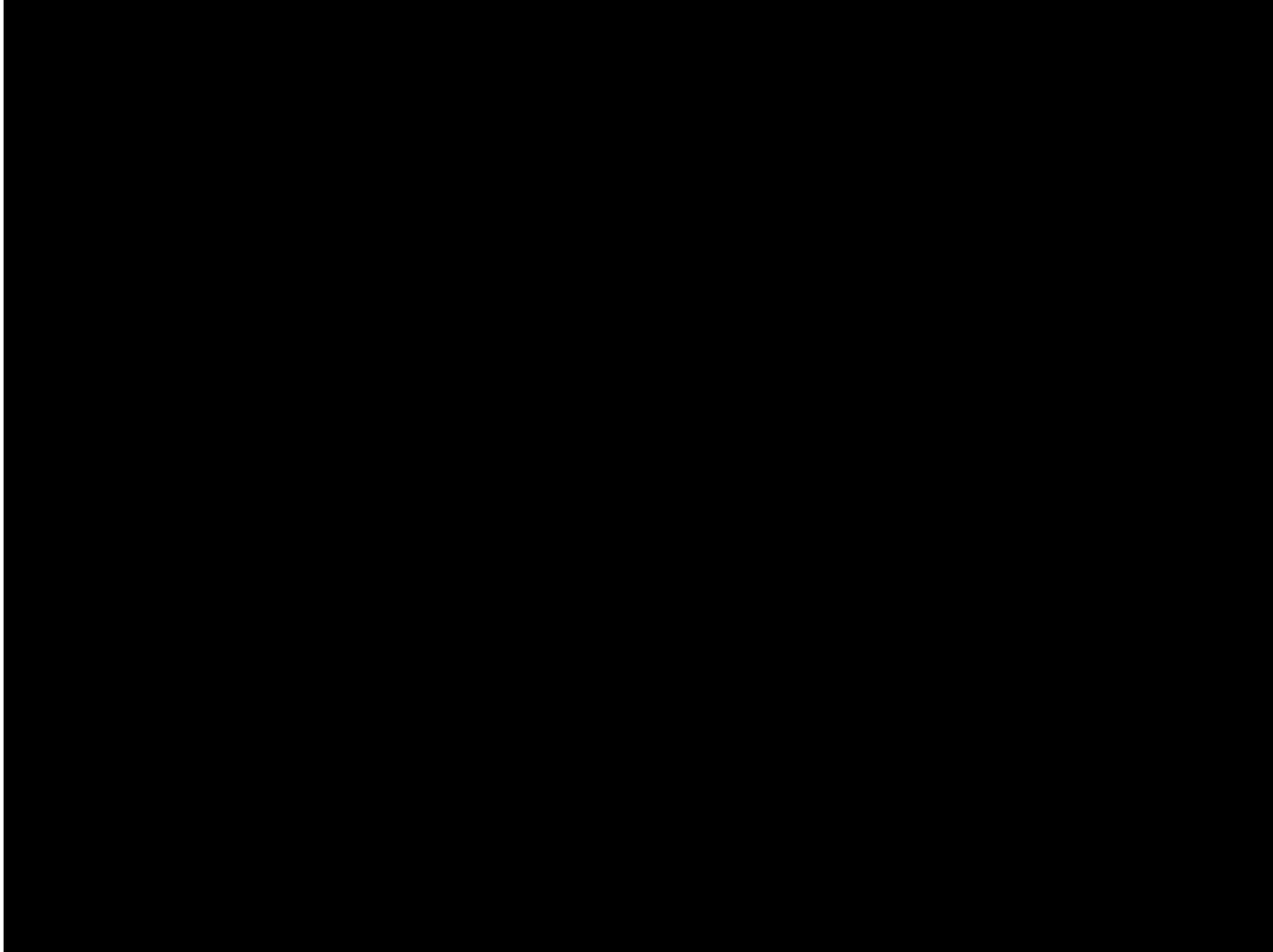
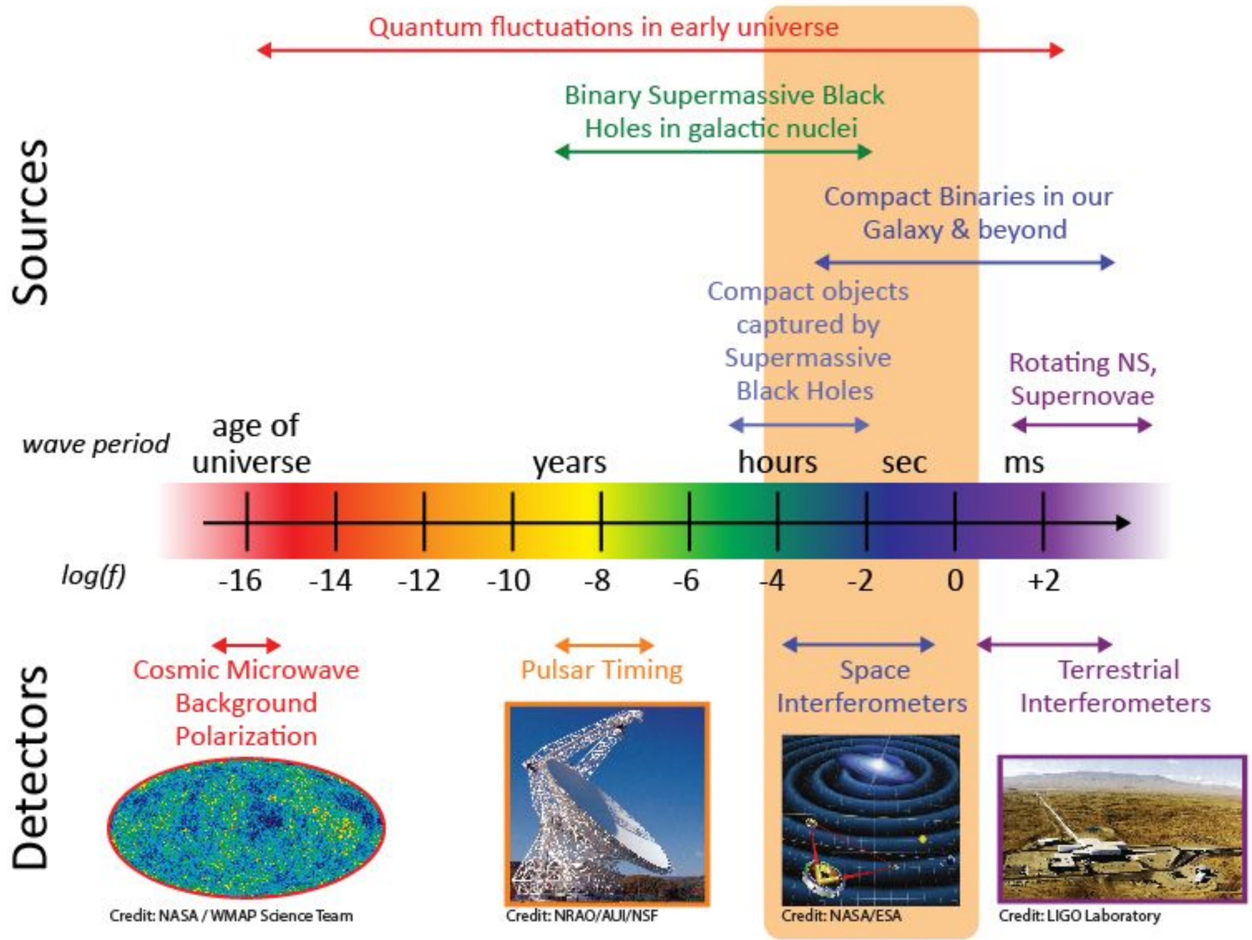
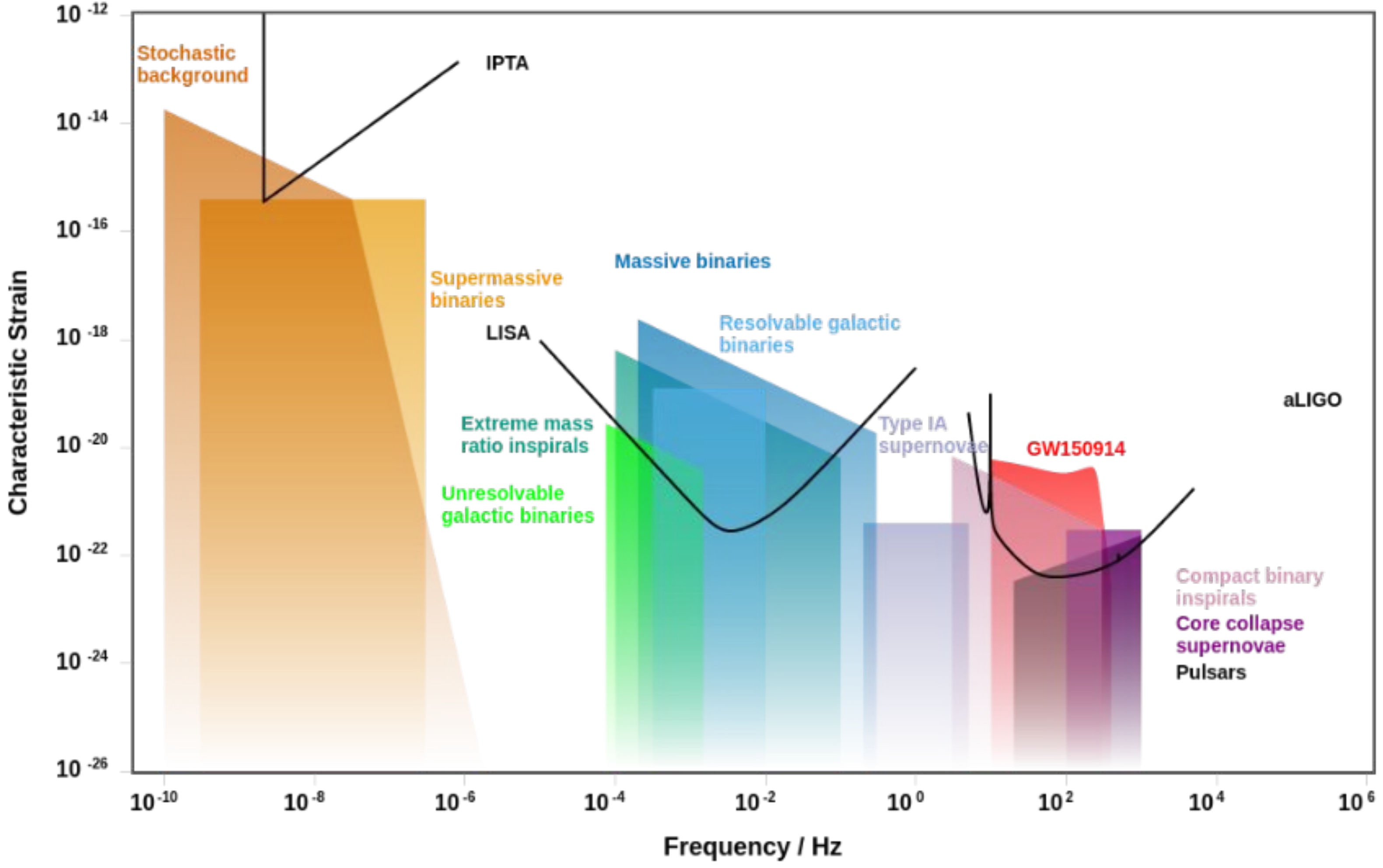


The Gravitational Wave Spectrum





Stochastic background
IPTA
Supermassive binaries
Massive binaries
Resolvable galactic binaries
LISA
Extreme mass ratio inspirals
Unresolvable galactic binaries
Type IA supernovae
GW150914
aLIGO
Compact binary inspirals
Core collapse supernovae
Pulsars
Characteristic Strain
Frequency / Hz
10^{-12}
10^{-14}
10^{-16}
10^{-18}
10^{-20}
10^{-22}
10^{-24}
10^{-26}
10^{-10}
10^{-8}
10^{-6}
10^{-4}
10^{-2}
10^{0}
10^{2}
10^{4}
10^{6}

Laser Interferometer Space Antenna (LISA)

What sort of sources will LISA see?

Laser Interferometer Space Antenna (LISA)

What sort of sources will LISA see?

Dimensional analysis:

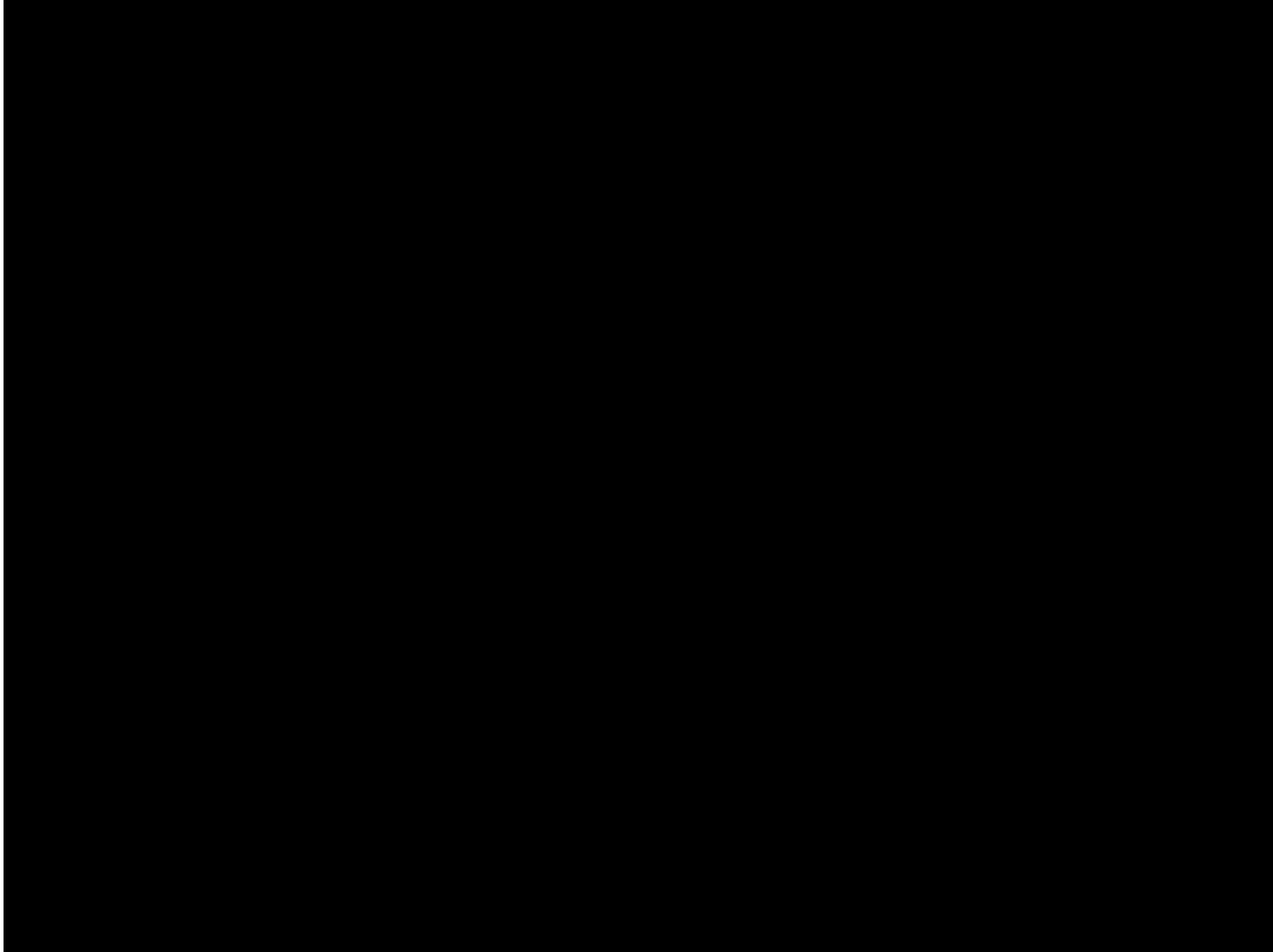
$$h \sim \frac{G}{c^2}\left(\frac{m}{D}\right)\left(\frac{v}{c}\right)^n$$
$$\sim 5\times 10^{-22}\left(\frac{m}{M_\odot}\right)\left(\frac{100\ \mathrm{Mpc}}{D}\right)\left(\frac{v}{c}\right)^n$$

Why do they need to be compact?

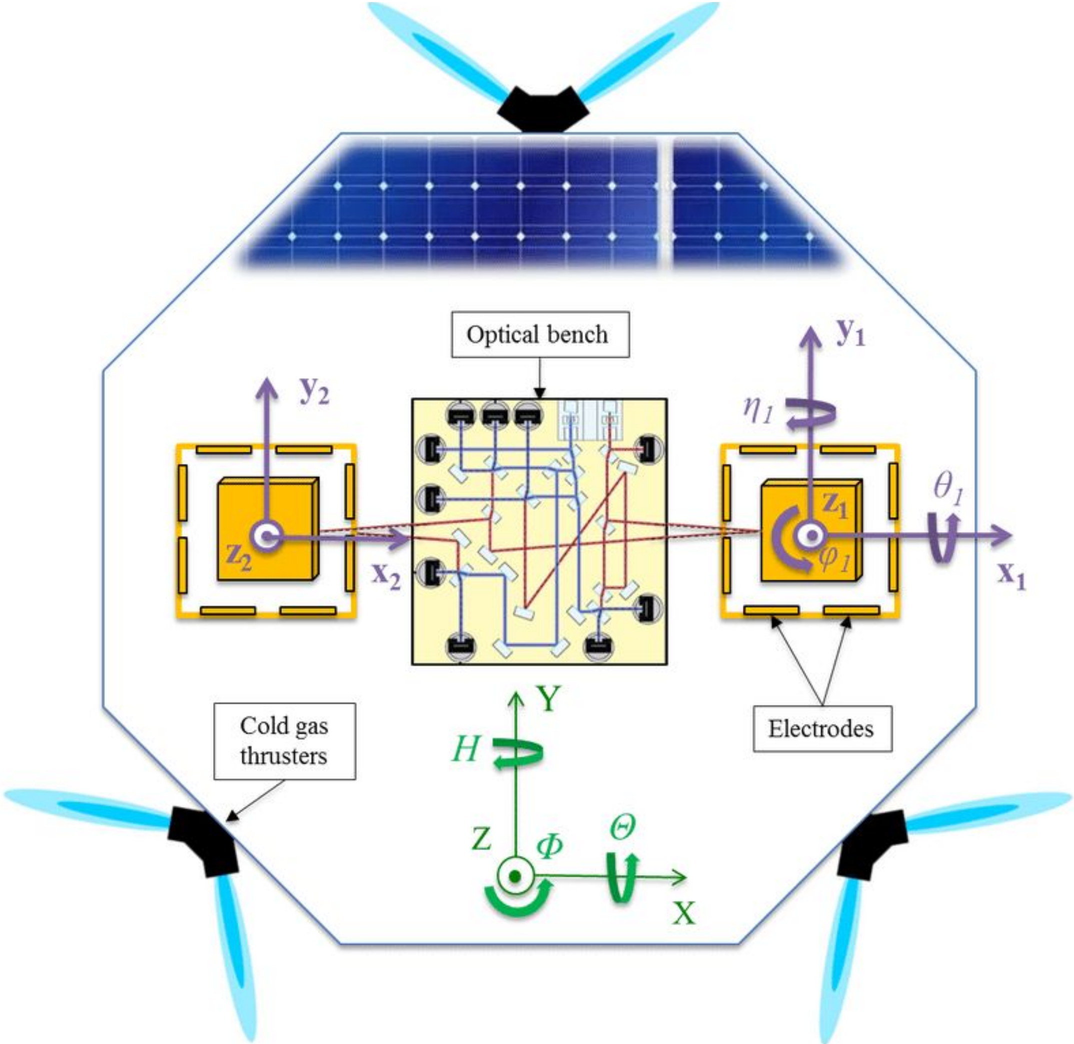
- *Most stars and stellar remnants touch before they are moving at interesting speeds!*

$$\left(\frac{v}{c}\right)^2 \sim \frac{Gm}{c^2 R}$$

LISA



LISA pathfinder



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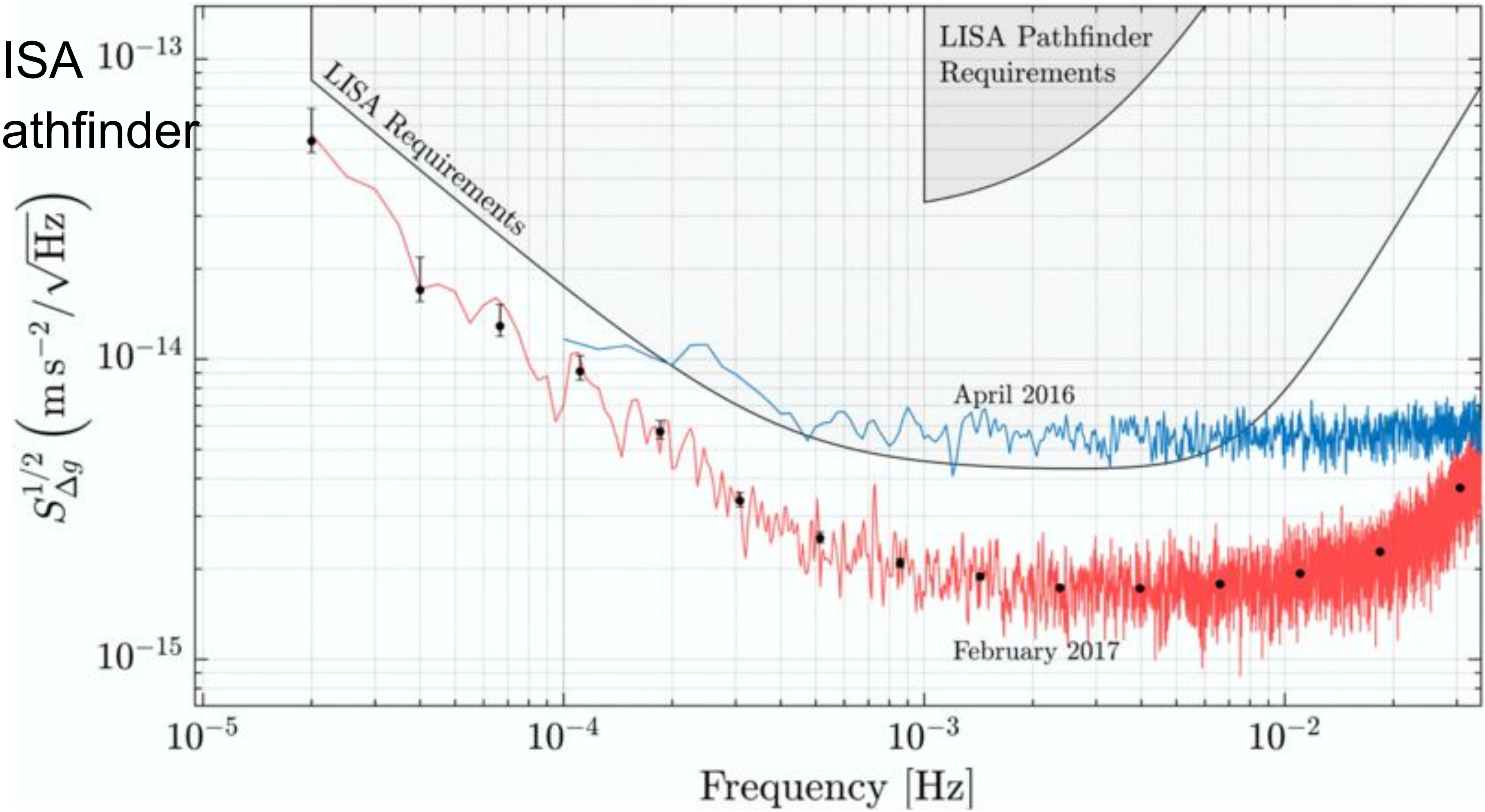
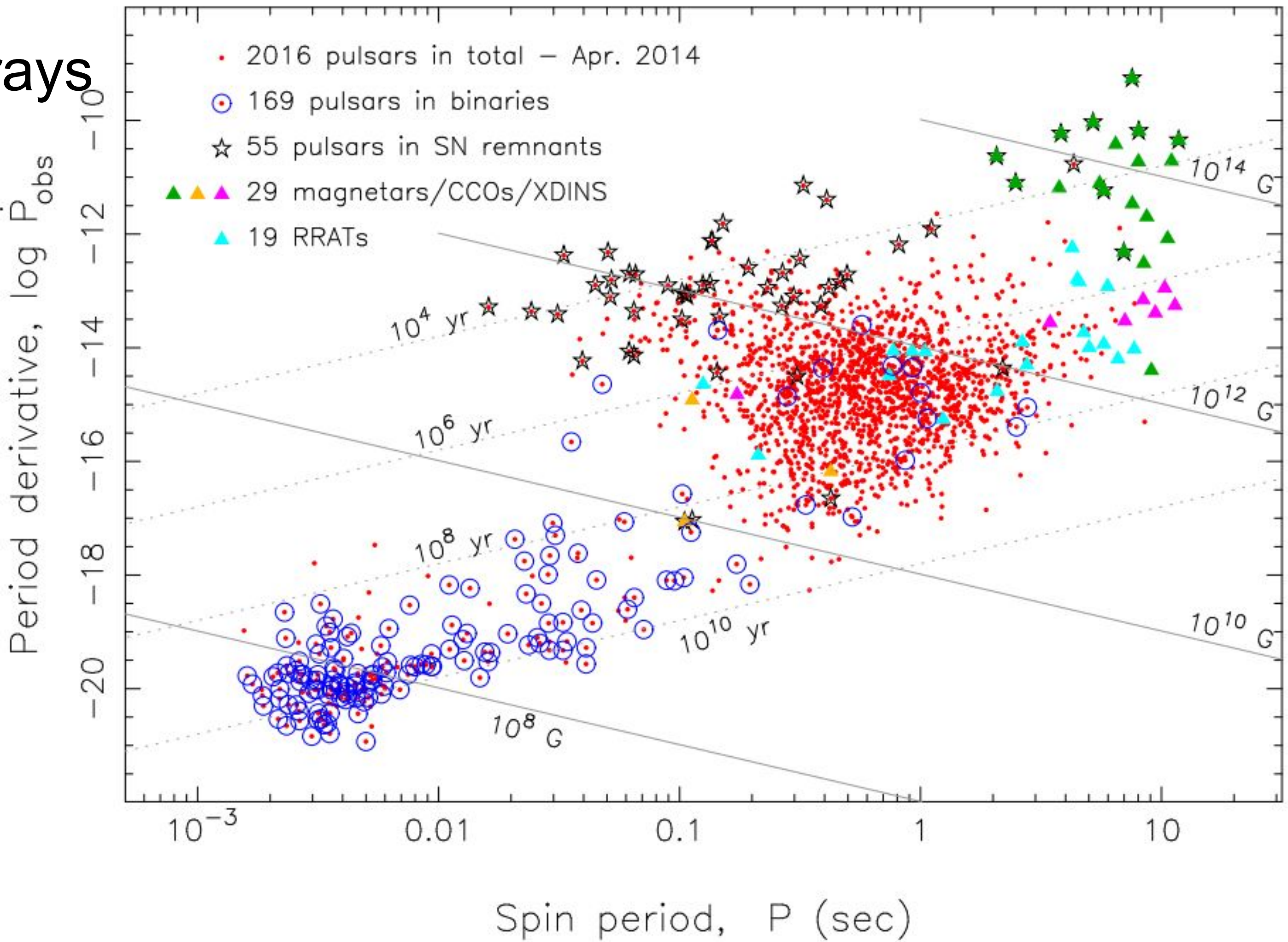


Pulsar Timing Arrays



Next time (hopefully before 40 years pass…)

Lunch!

Suggested Reading

Cosmic Explorer	https://cosmicexplorer.org
Einstein Telescope	http://www.et-gw.eu/
LISA	https://lisa.nasa.gov
Pulsar Timing Arrays	http://nanograv.org