Black hole observations with Advanced LIGO: status and future plans for the Advanced detector network

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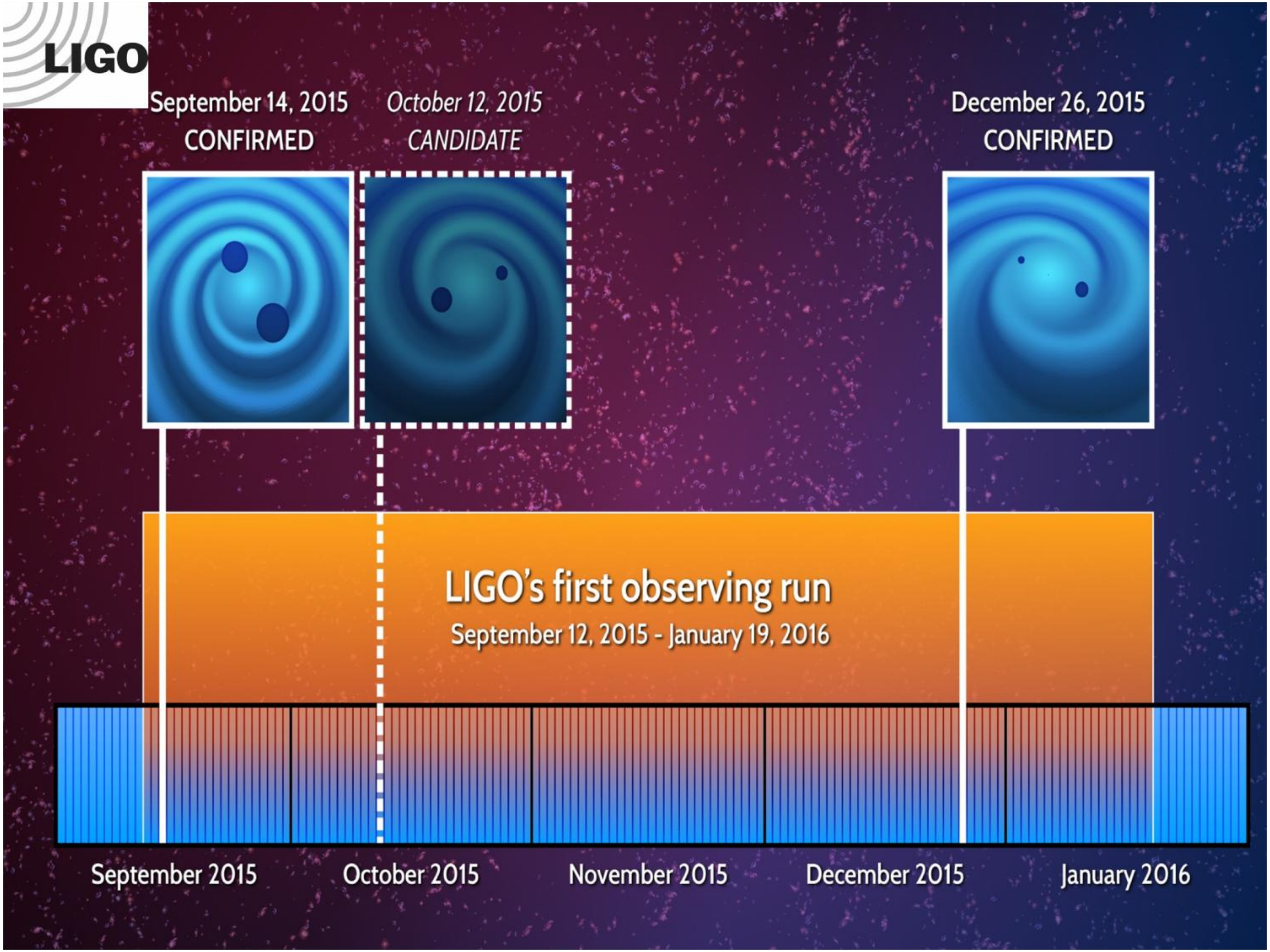
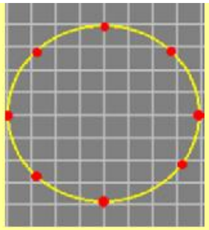
For the LIGO Scientific Collaboration

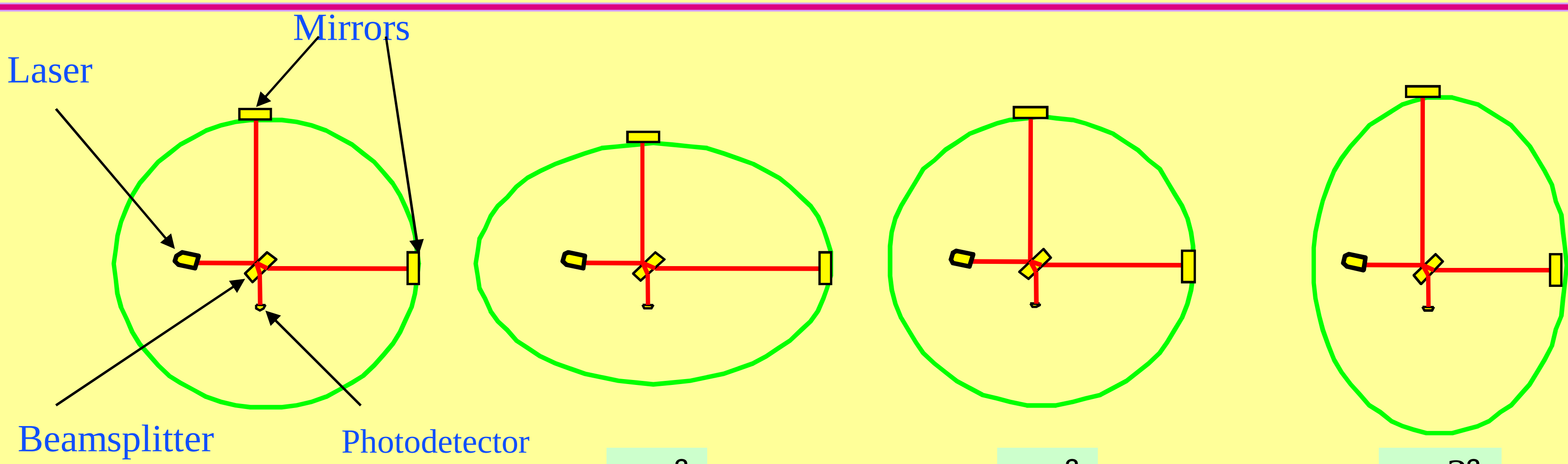
IAU Symposium, Slovenia
Sept 2016

LIGO-G1601934

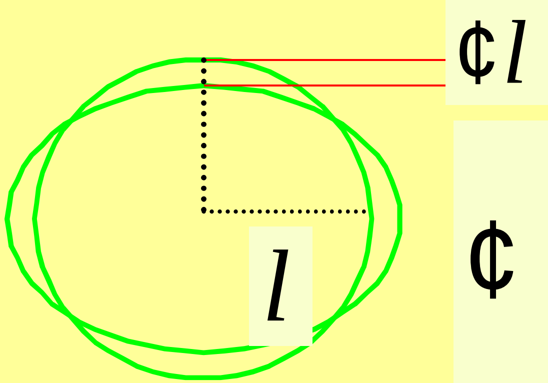

LIGO
September 14, 2015
CONFIRMED
October 12, 2015
CANDIDATE
December 26, 2015
CONFIRMED
LIGO's first observing run
September 12, 2015 - January 19, 2016
September 2015
October 2015
November 2015
December 2015
January 2016



Operation of Interferometric Gravitational Wave Detectors



$t = 0$ $\qquad t = \frac{2}{4}$ $\qquad t = \frac{2}{2}$ $\qquad t = \frac{32}{4}$



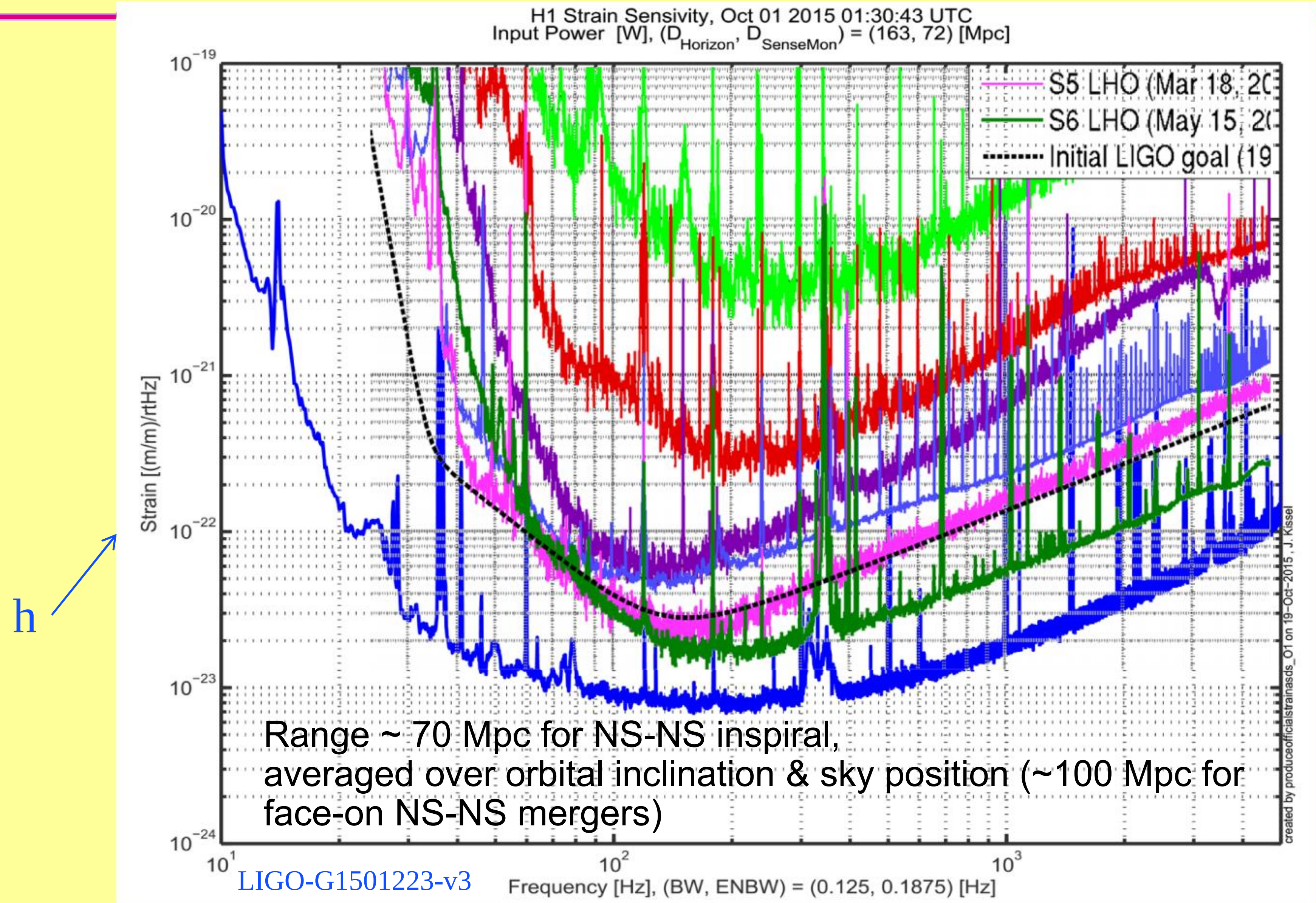
$$¢\, l = \frac{h}{2} l$$

Gravitational wave amplitude

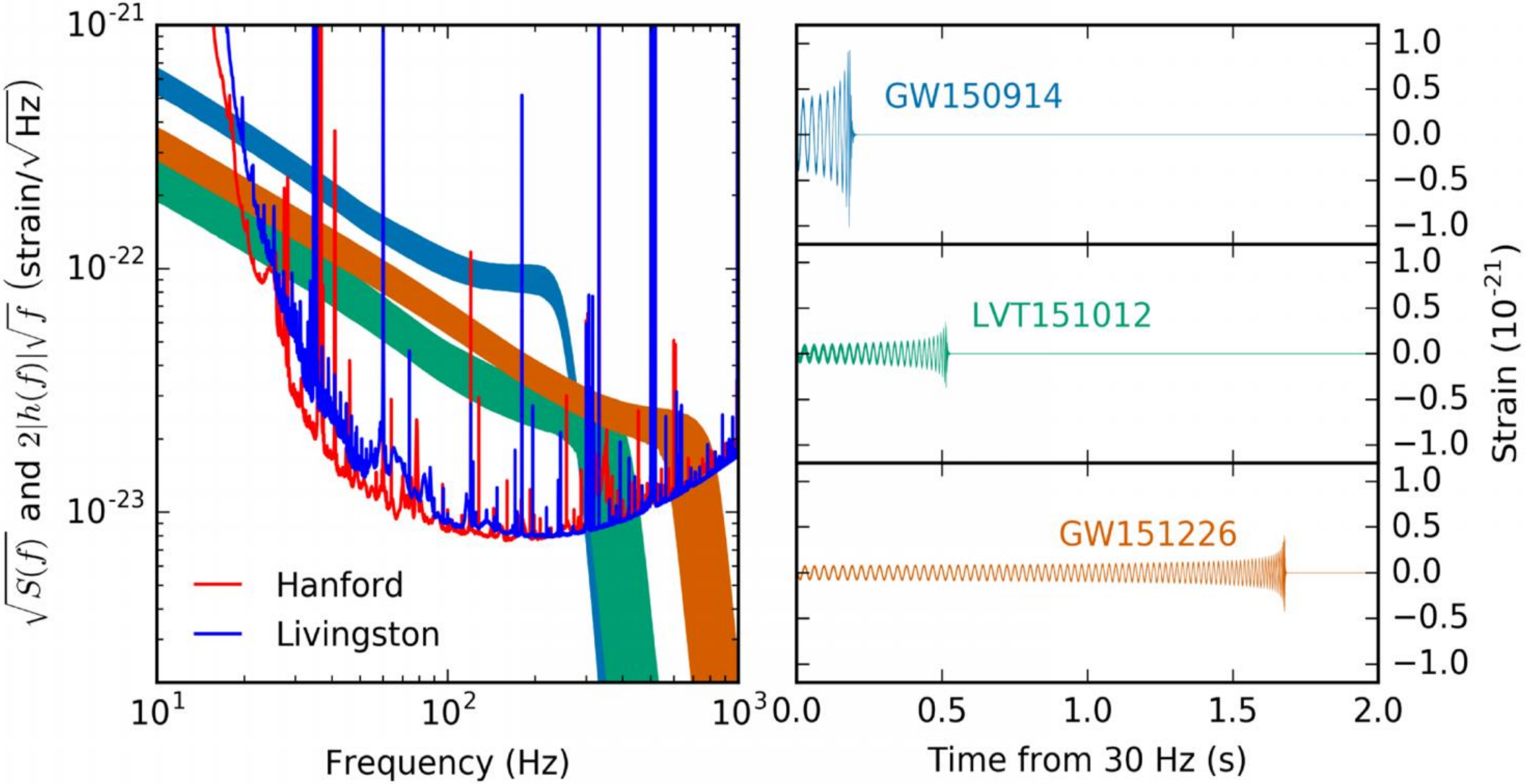
For Typical Astronomical sources

$$h = \frac{2 ¢\, l}{l} \leq 10^{-22}$$

Advanced LIGO sensitivity in 1st Observing run

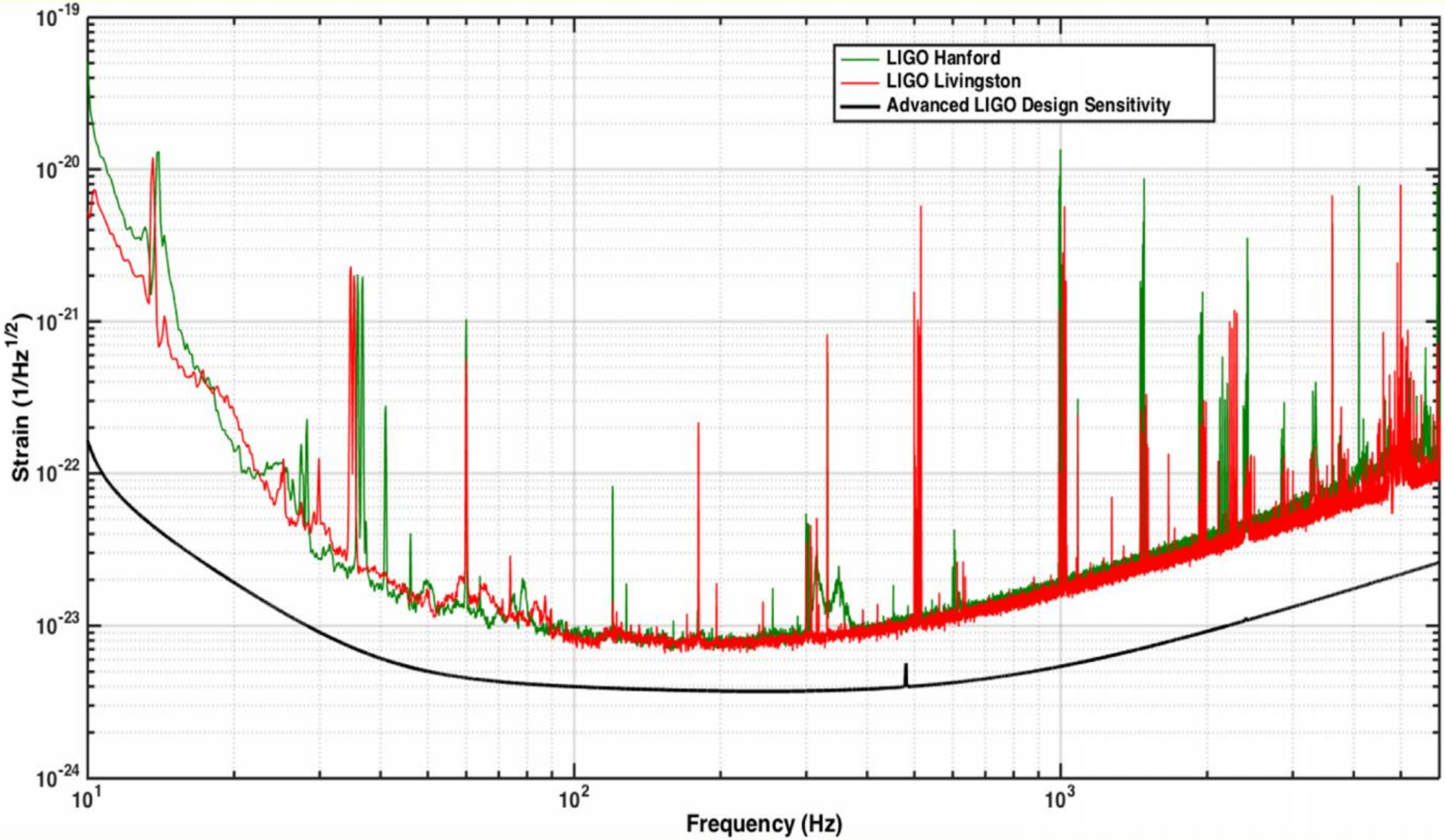


Three events compared



PhysRevLett.116.241103,
arxiv.org/abs/1606.04856 (accepted to PRX)

Advanced LIGO Sensitivity: Observing Run 1 vs design sensitivity



Credit: LIGO Laboratory

Living Rev. Relativity, **19**, (2016), 1
DOI 10.1007/lrr-2016-1

LIVING REVIEWS *in relativity*

Prospects for Observing and Localizing Gravitational-Wave Transients with Advanced LIGO and Advanced Virgo

Abbott, B. P. et al.
The LIGO Scientific Collaboration and the Virgo Collaboration
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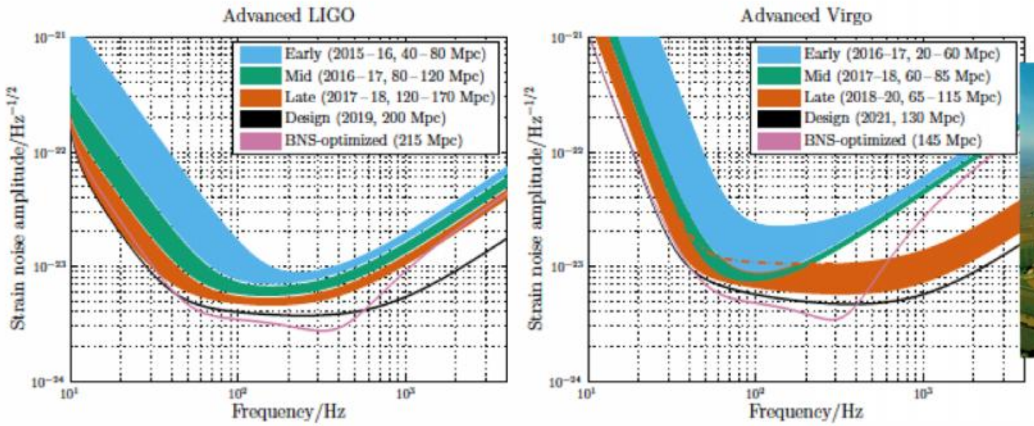


Figure 1: aLIGO (*left*) and AdV (*right*) target strain sensitivity as a function of frequency. The binary neutron-star (BNS) range, the average distance to which these signals could be detected, is given in megaparsec. Current notions of the progression of sensitivity are given for early, mid and late commissioning phases, as well as the final design sensitivity target and the BNS-optimized sensitivity. While both dates and sensitivity curves are subject to change, the overall progression represents our best current estimates.

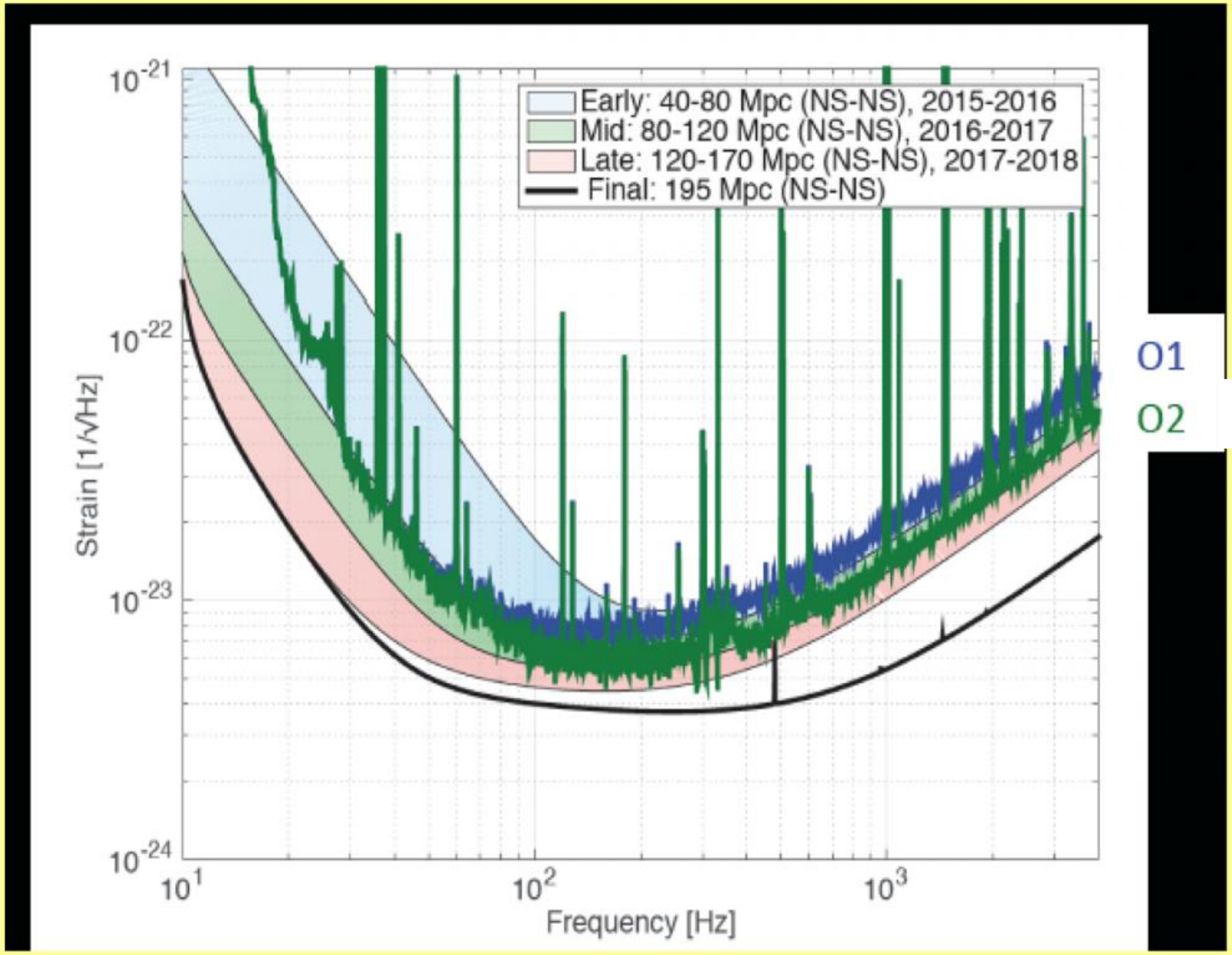
2015 – 2016 (O1) A four-month run (beginning 18 September 2015 and ending 12 January 2016) with the two-detector H1L1 network at early aLIGO sensitivity (40 – 80 Mpc BNS range).

2016 – 2017 (O2) A six-month run with H1L1 at 80 – 120 Mpc and V1 at 20 – 60 Mpc.

2017 – 2018 (O3) A nine-month run with H1L1 at 120 – 170 Mpc and V1 at 60 – 85 Mpc.

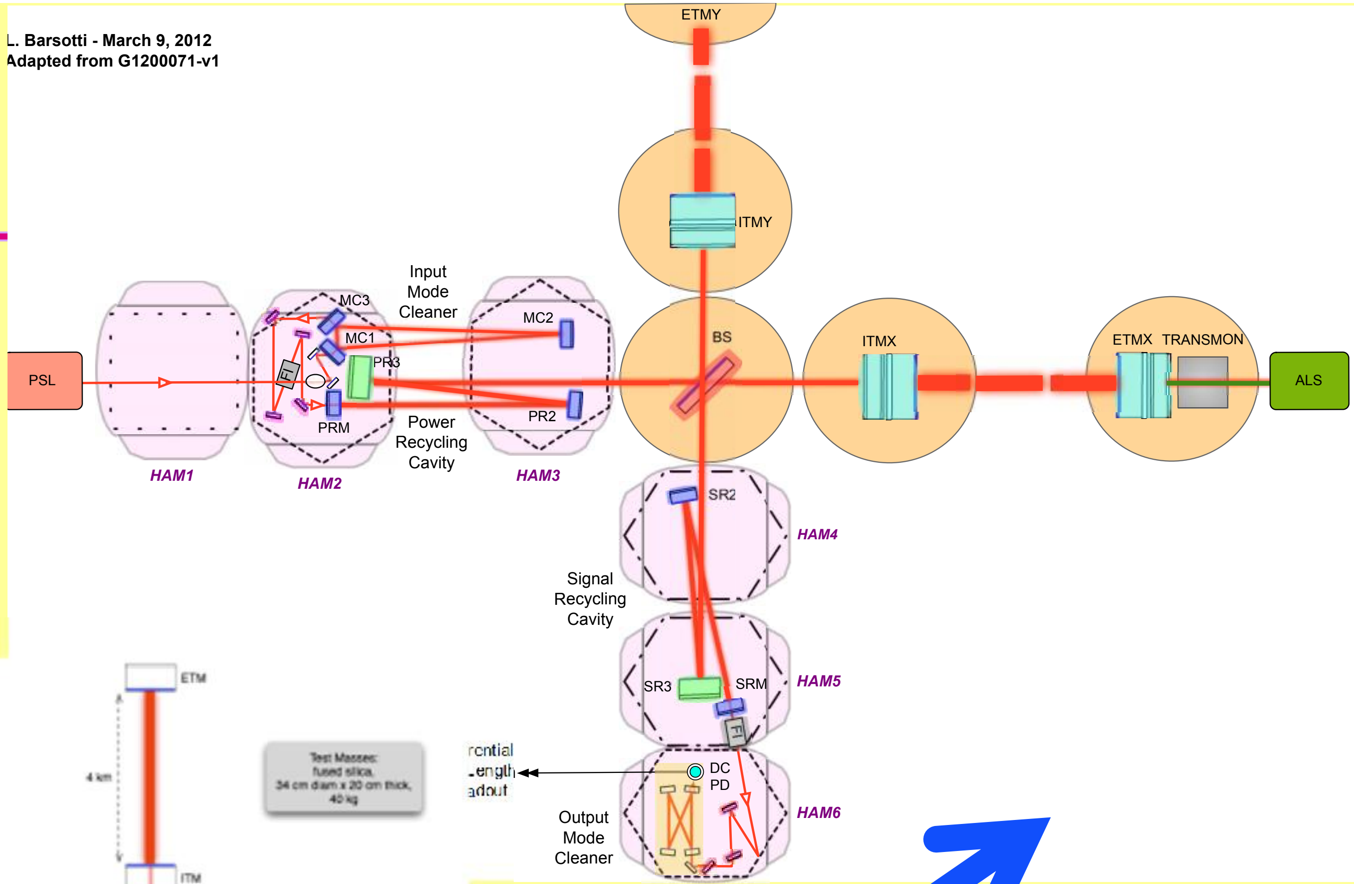
2019+ Three-detector network with H1L1 at full sensitivity of 200 Mpc and V1 at 65 – 115 Mpc.

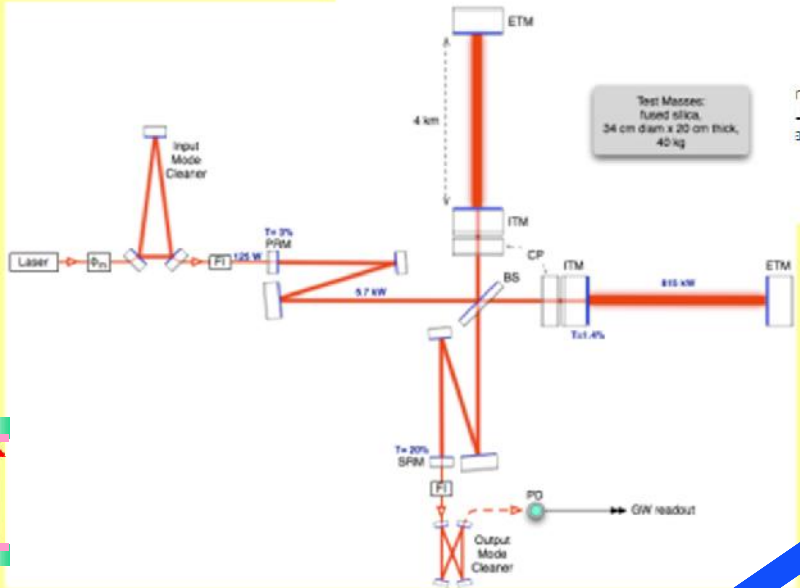
Past and short term future

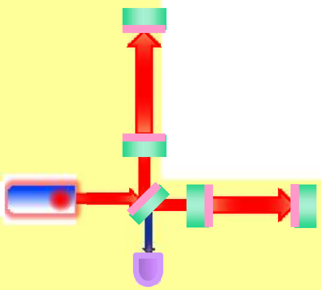


projection

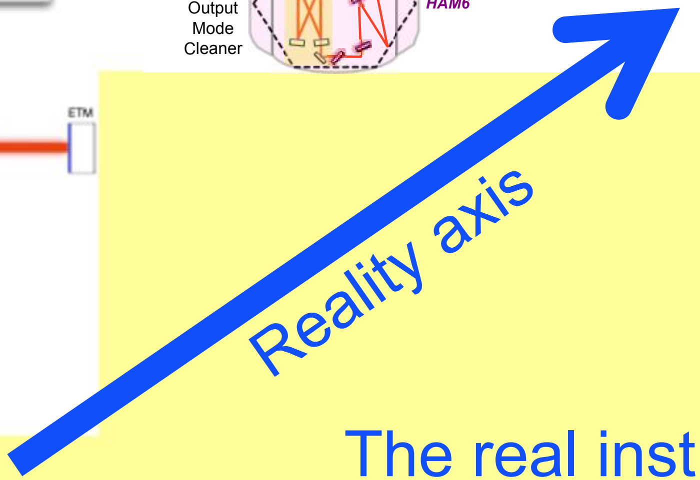
From Gonzalez LIGO- G1601165





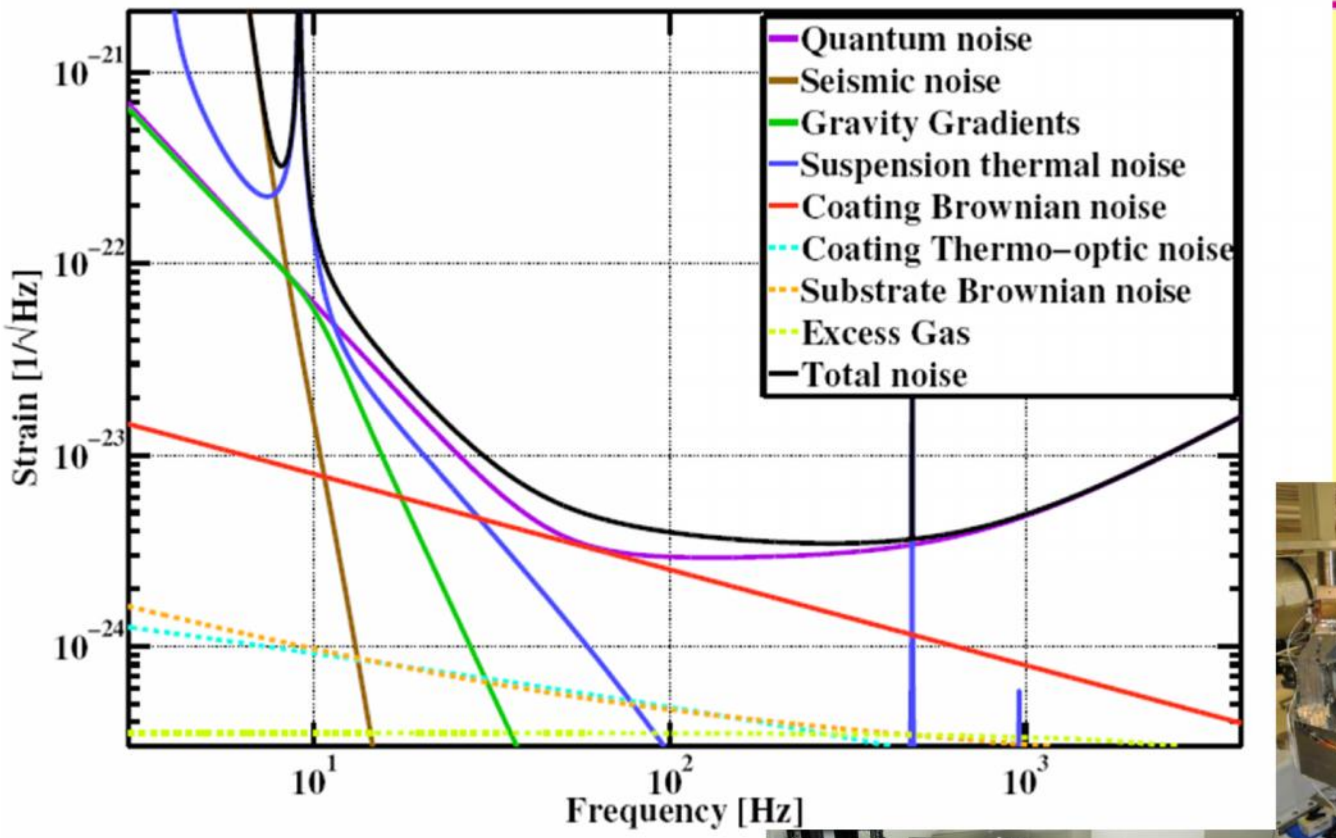


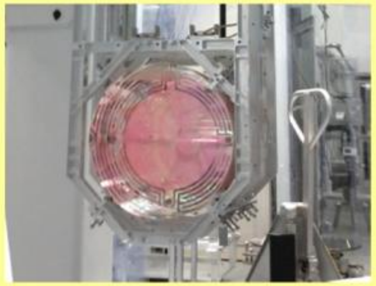
photodiode



The real instrument is far more complex…

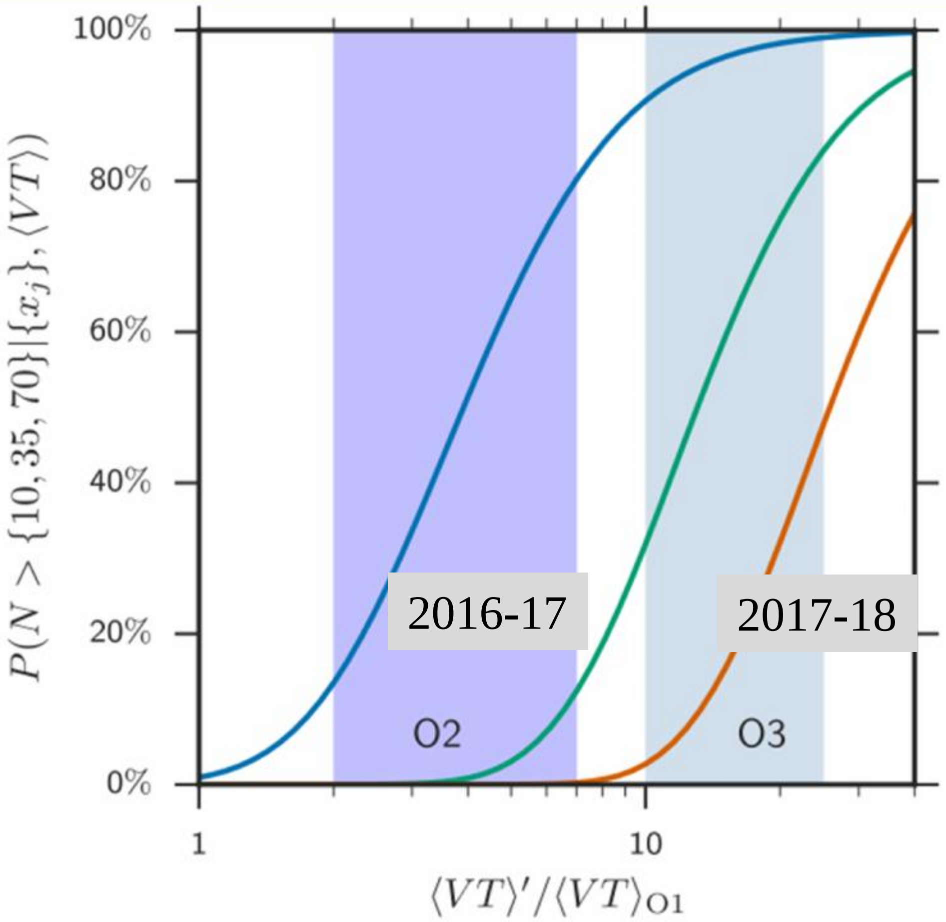
Advanced LIGO Noise Breakdown:





» Commissioning ongoing…..

Future BBH observations



LVC:arxiv:1606.04856v2

FIG. 12. The probability of observing $N > 10$, $N > 35$, and $N > 70$ highly significant events, as a function of surveyed time-volume. The vertical line and bands show, from left to right, the expected sensitive time-volume for the second (O2) and third (O3) advanced detector observing runs.

Improve the sensitivity of the Advanced LIGO detectors and operate for longer

2nd scientific run "O2" starts in next couple of months

Advanced Virgo should join the observing network soon

Multi-detector network needed for localisation

Projected ranges and detection rates for binary neutron star inspirals - (arXiv:1304.0670)

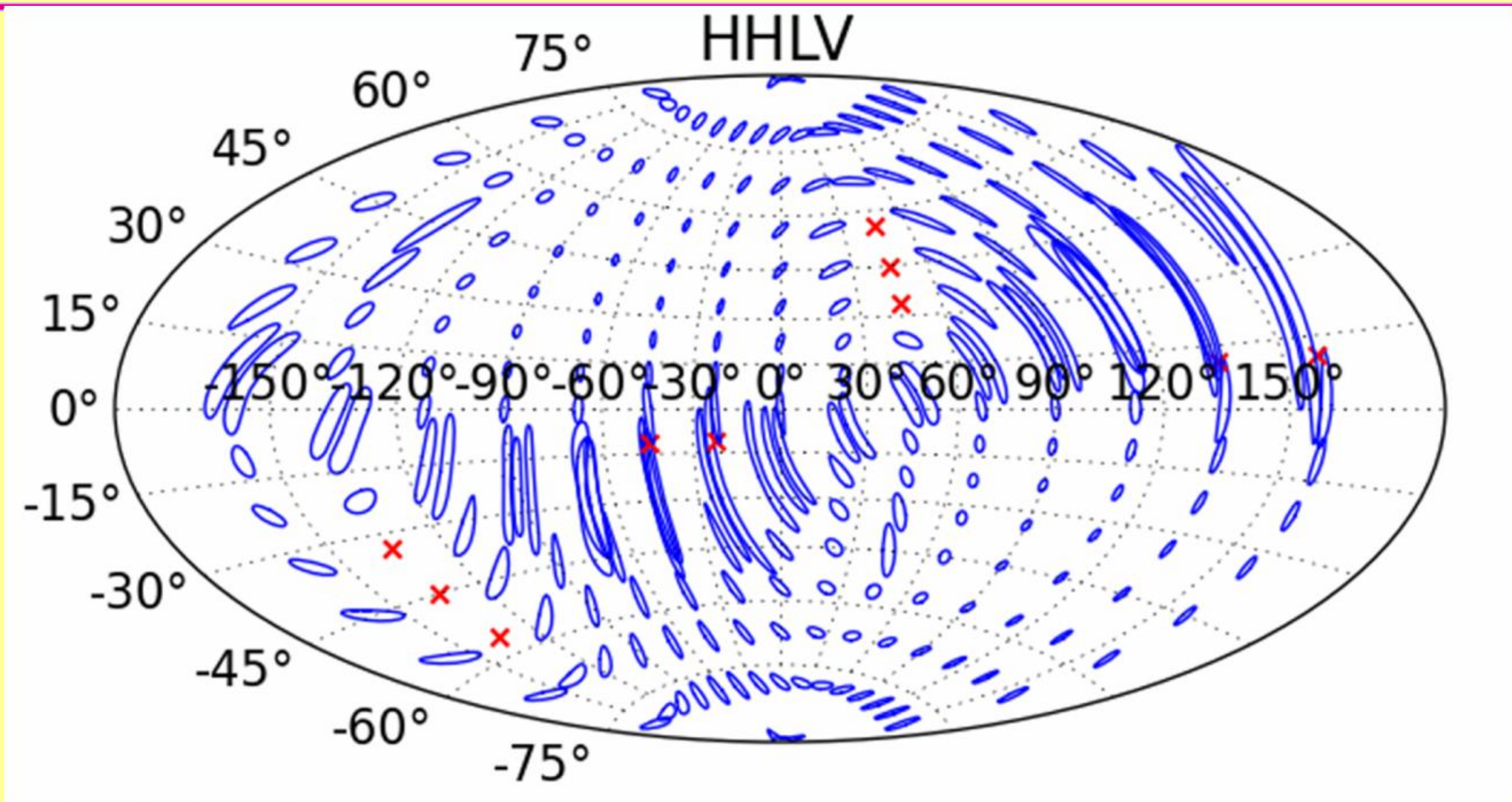
Epoch	Estimated Run Duration	BNS Range (Mpc) LIGO	BNS Range (Mpc) Virgo	Number of BNS Detections	% BNS Localized within 5 deg^2	% BNS Localized within 20 deg^2
2015	3 months	40 – 80	–	0.0004 – 3	–	–
2016–17	6 months	80 – 120	20 – 60	0.006 – 20	2	5 – 12
2017–18	9 months	120 – 170	60 – 85	0.04 – 100	1 – 2	10 – 12
2019+	(per year)	200	65 – 130	0.2 – 200	3 – 8	8 – 28
2022+ (India)	(per year)	200	130	0.4 – 400	17	48

using “low” rate,
worst noise curve

using “high” rate,
best noise curve

Wide range of estimates from observed binary pulsars and population synthesis simulations – begs for observational truth!

Sky localization with 3 sites …



Typical 90% error box areas for Neutron Star-Neutron Star binaries

» median > 20 sq deg

Fairhurst, CQG 28 105021 (2011)

What more do we need soon?

Need a network of detectors for good source location and to improve overall sensitivity

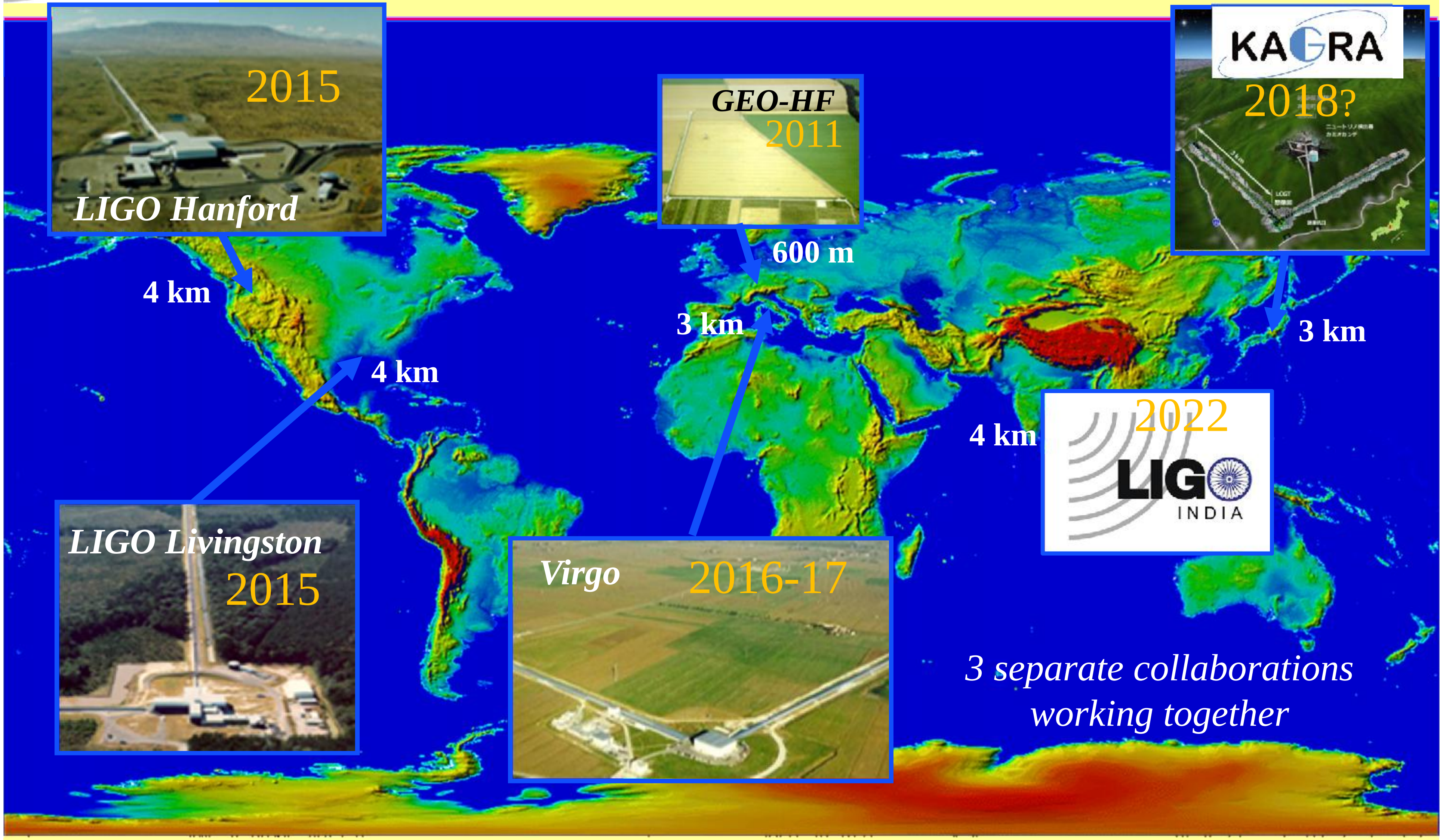
'KAGRA' New 3km detector in Japan (cryogenic, underground interferometer in Kamioka mine)

Installation of a 3rd Advanced LIGO detector India

Thus Second Generation Network is developing:

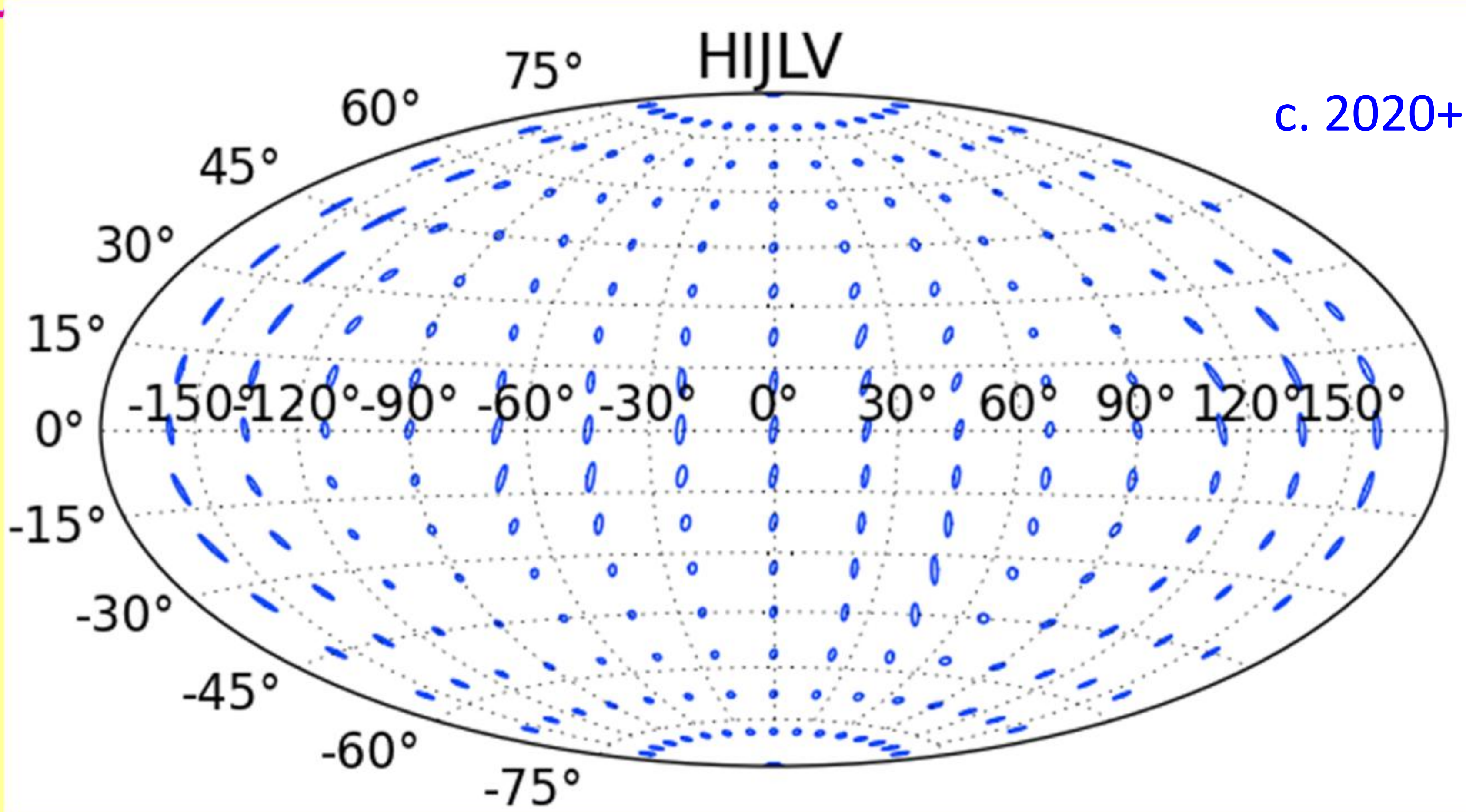
Advanced LIGO/Advanced Virgo/Geo-HF/KAGRA/LIGO India

Advanced GW Detector Network: Under Construction → Operating



The Global Network c. 2020+

… and with 5 sites



c. 2020+

Fairhurst (2011)

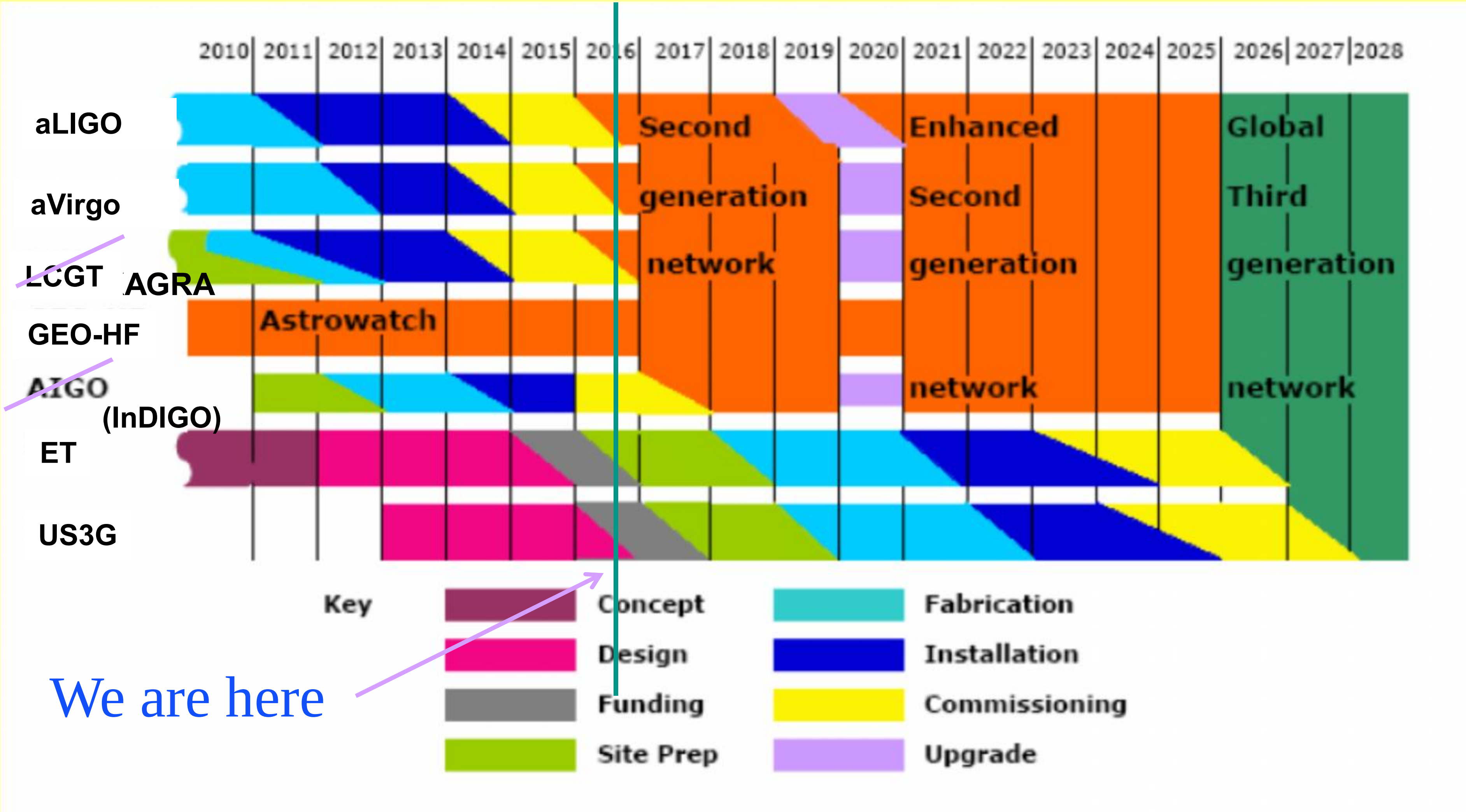
Plans for the era of gravitational wave astronomy

- We expect soon to be making regular detections...
- When we do, it is inevitable we will want to see further into the Universe.....see new sources......with better signal-to-noise .....driven by maximising the astronomy and astrophysics we can do

- Planning has started for the next steps.

GWIC
Gravitational Wave International Committee

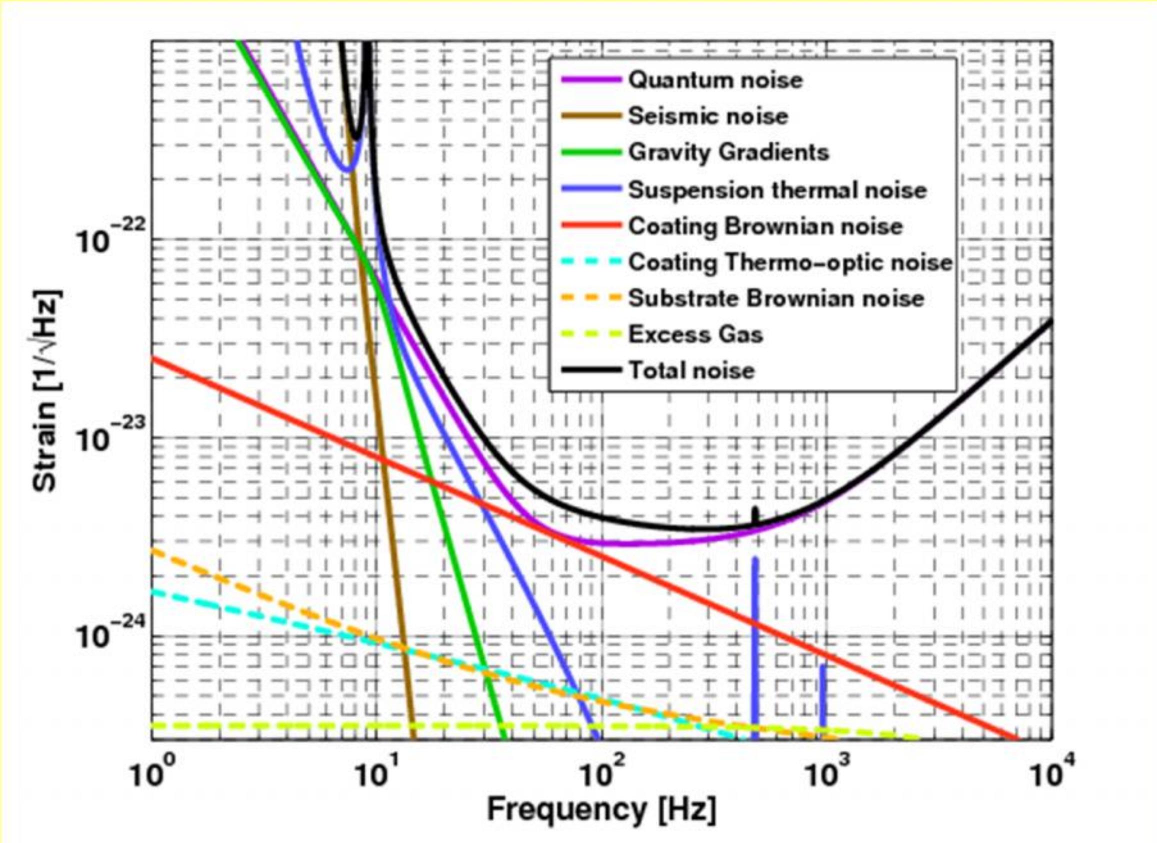
The global Gravitational Waves roadmap



From the Gravitational Wave International Committee (GWIC roadmap - available at: http://gwic.ligo.org/roadmap/)

Maximising the potential of Advanced detectors

Two 'Dawn' meetings in May 2015, Maryland, July 2016, Atlanta – consider in various detection scenarios what directions the field should take.



Considered:

- Likelihood of detecting different sources
- Payoffs of improving sensitivity in different frequency bands
- Technological readiness of instrumentation improvements

(….and of course $$/££)

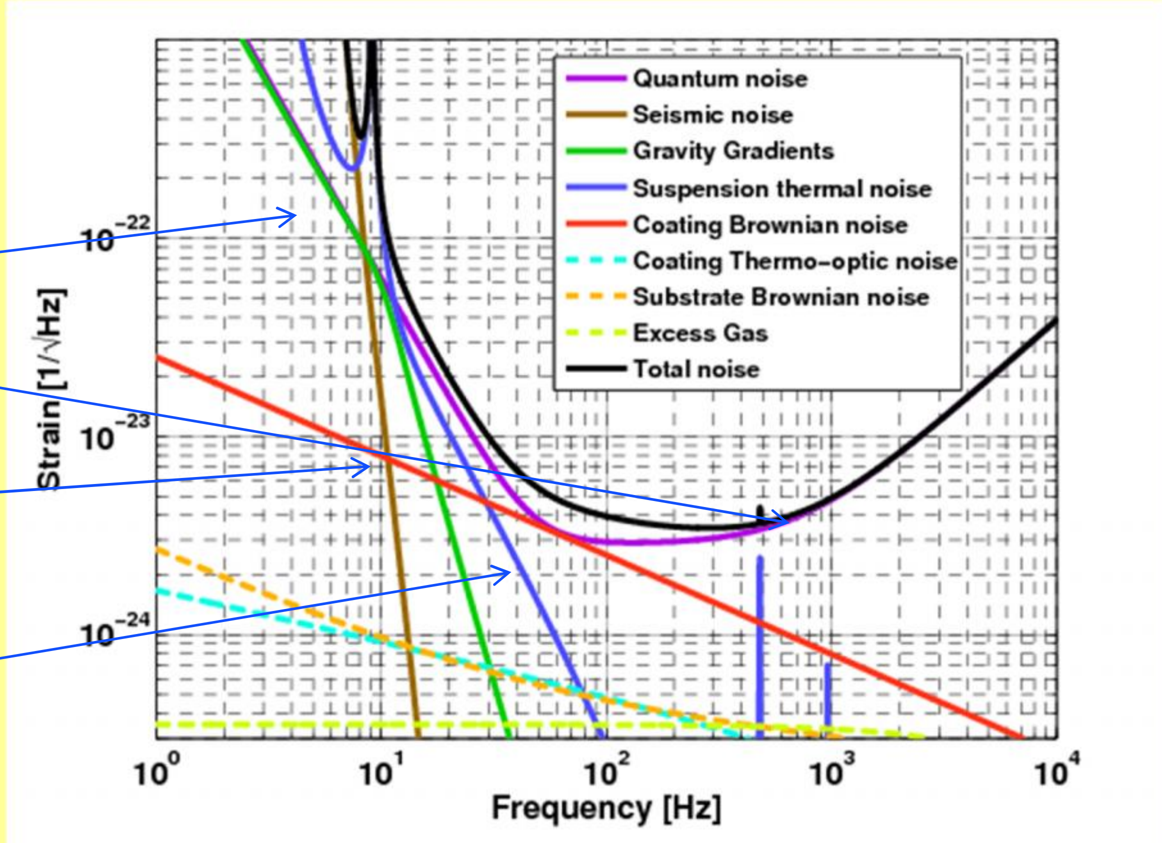
https://dcc.ligo.org/public/0121/P1500147/001/WhatComesNextForLIGO.pdf

Maximising the potential of Advanced detectors

'Immediate' targets:

- Mitigation of Newtonian Noise
- Addition of squeezed light
- Improved coating thermal noise
- (and possible suspension upgrades)

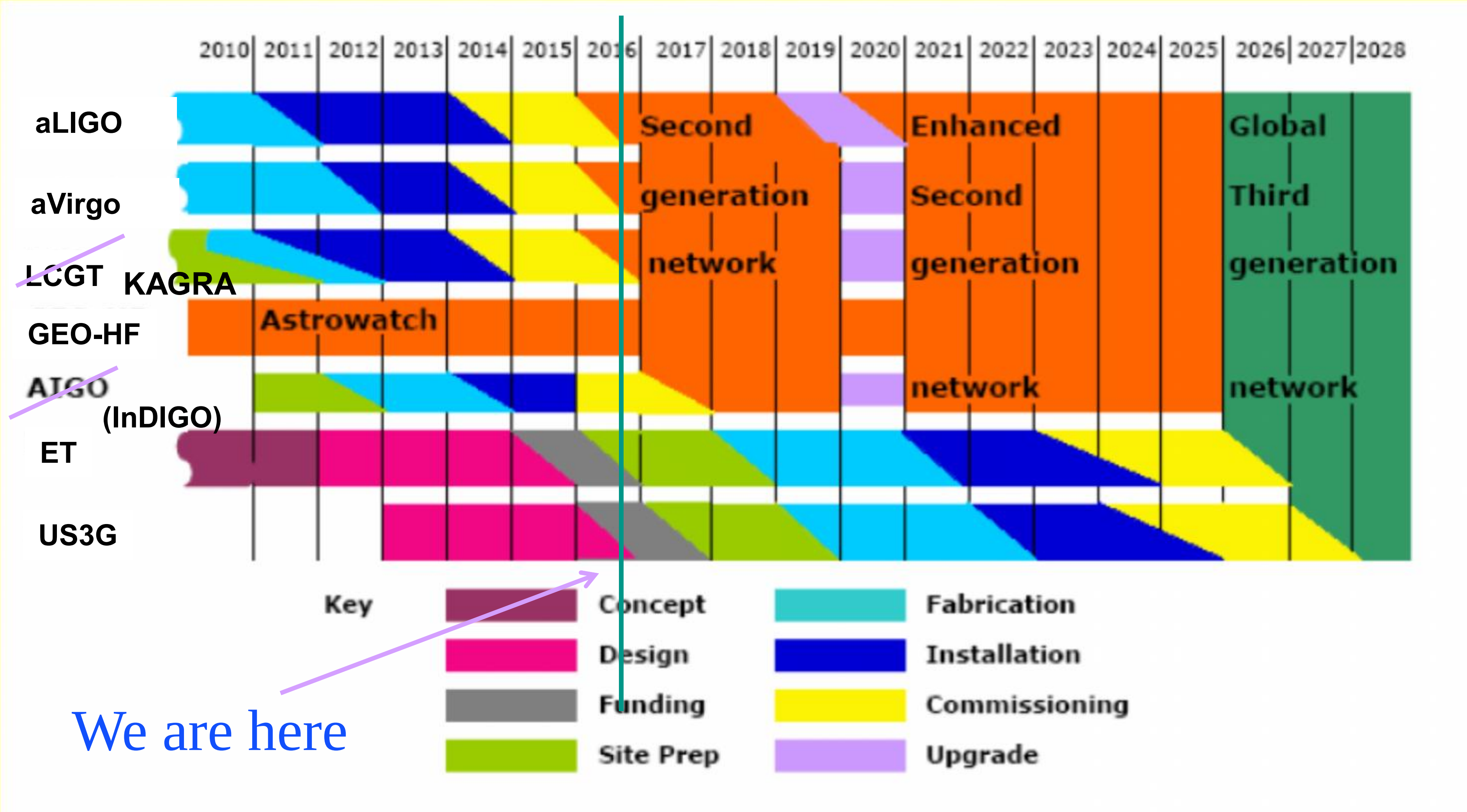
For sensitivity gains of up to ~ 5 in event rate over baseline design.



https://dcc.ligo.org/public/0121/P1500147/001/WhatComesNextForLIGO.pdf

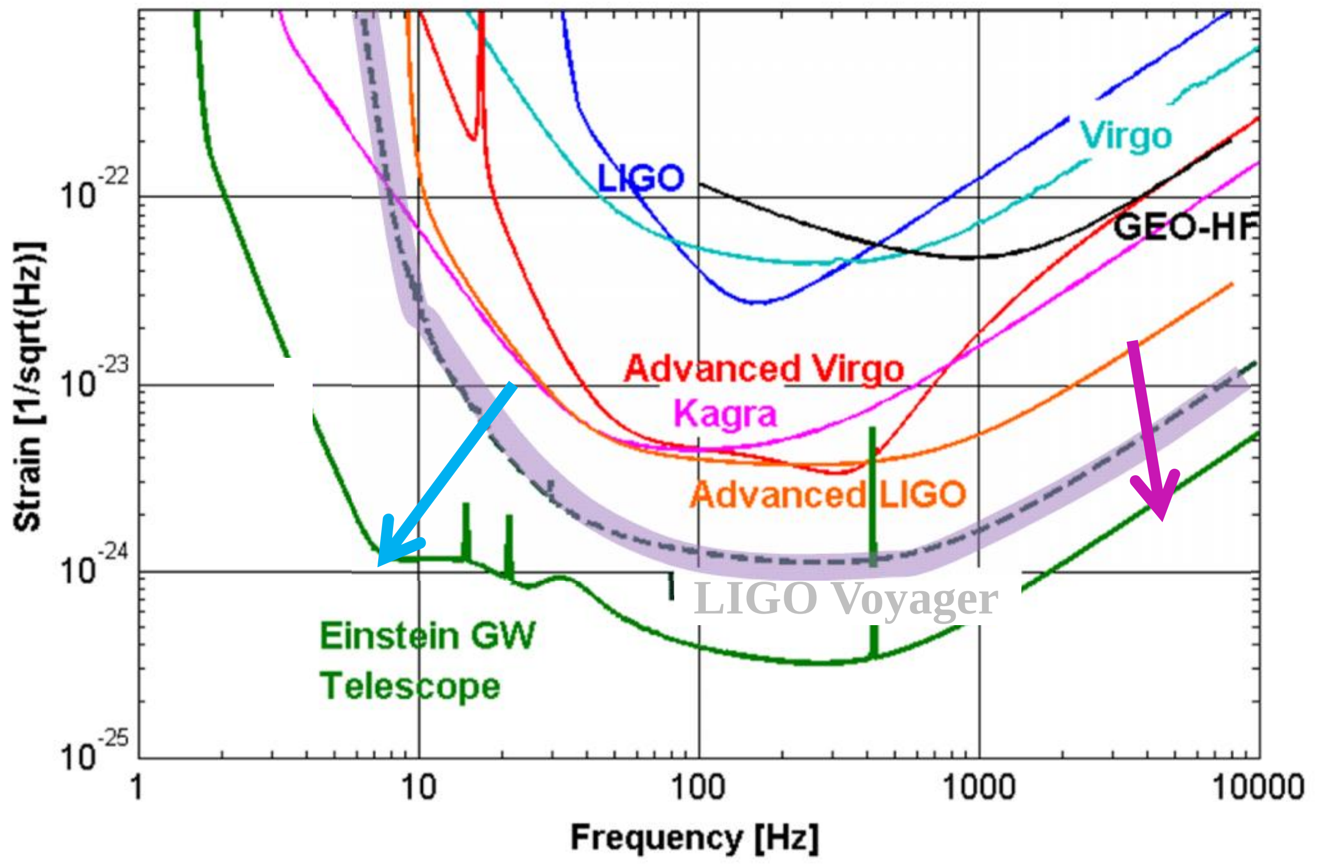
Maximising the potential of the field

GWIC
Gravitational Wave International Committee



From the Gravitational Wave International Committee (GWIC roadmap - available at: http://gwic.ligo.org/roadmap/)

Future detector network evolution



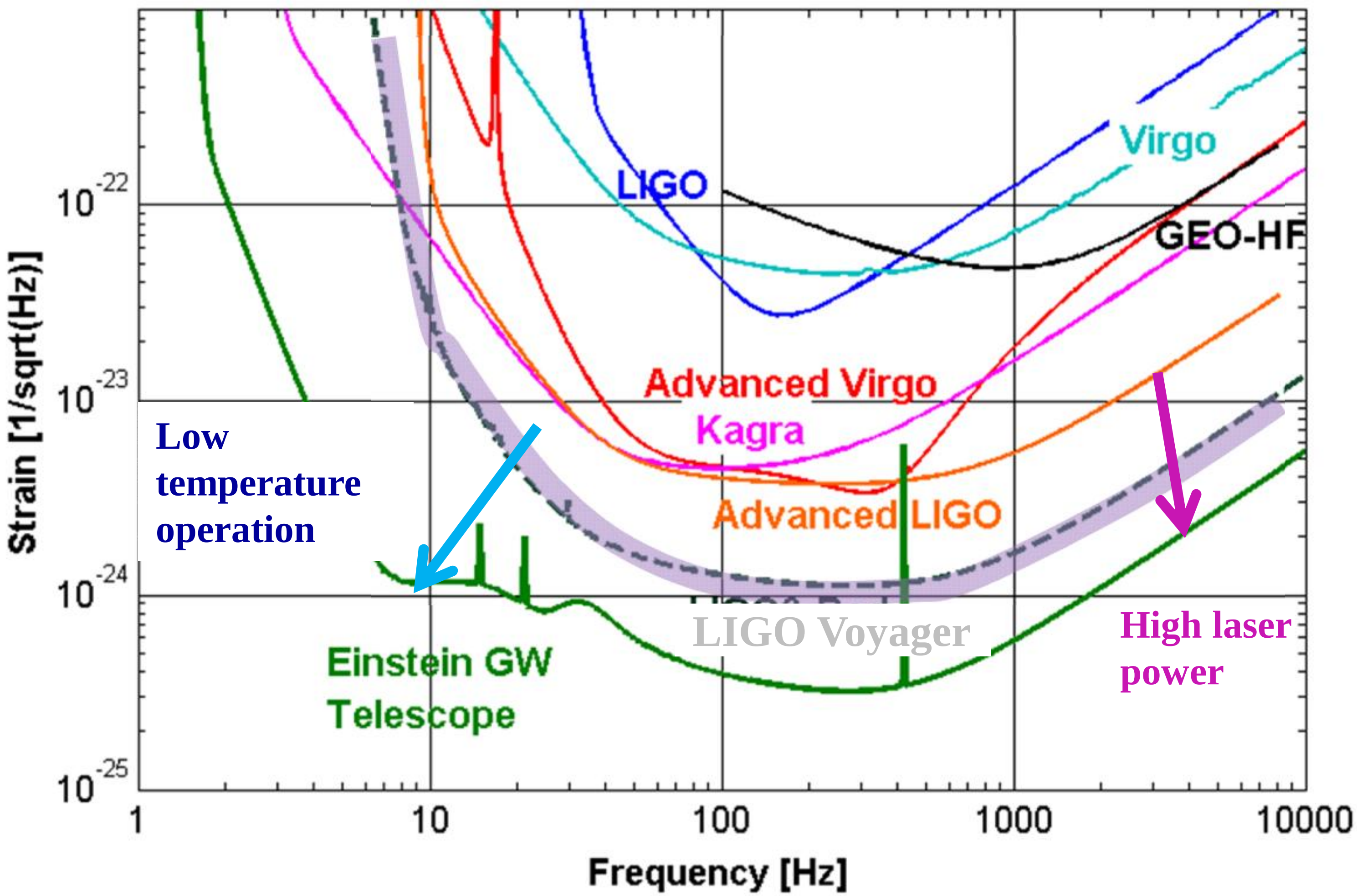
ET should detect of order 10^5 compact binary coalescences per year: neutron star binaries to z~ 2-4, stellar mass black hole binaries to z ~8-20, and intermediate mass black holes (up to 10^4 solar masses) to z~5-15.

http://www.stfc.ac.uk/files/2016-draft-roadmap-for-particle-astrophysics/

ET/Cosmic Explorer will take a census of black holes when the Universe was a mere 650 million years old

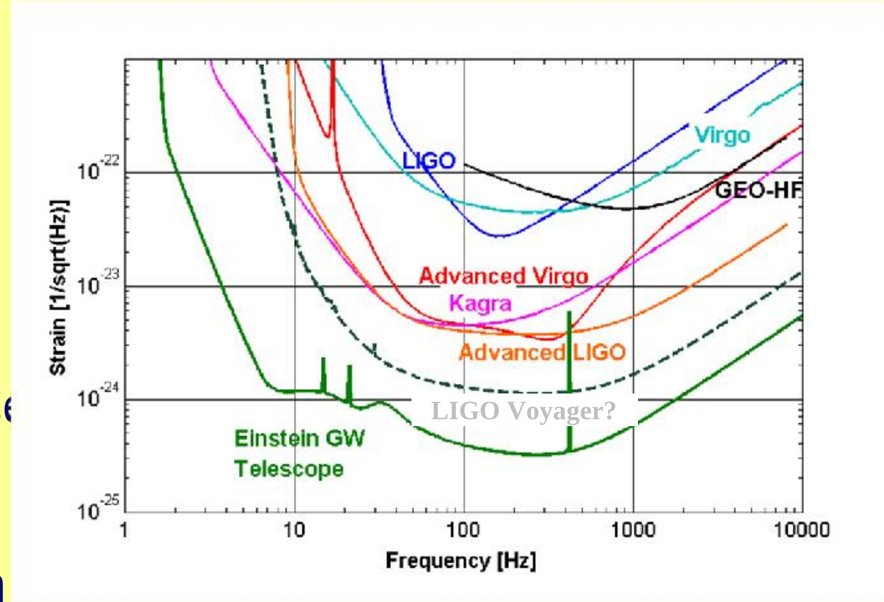
B. Sathyaprakash, GWADW 2016

Future detector network evolution

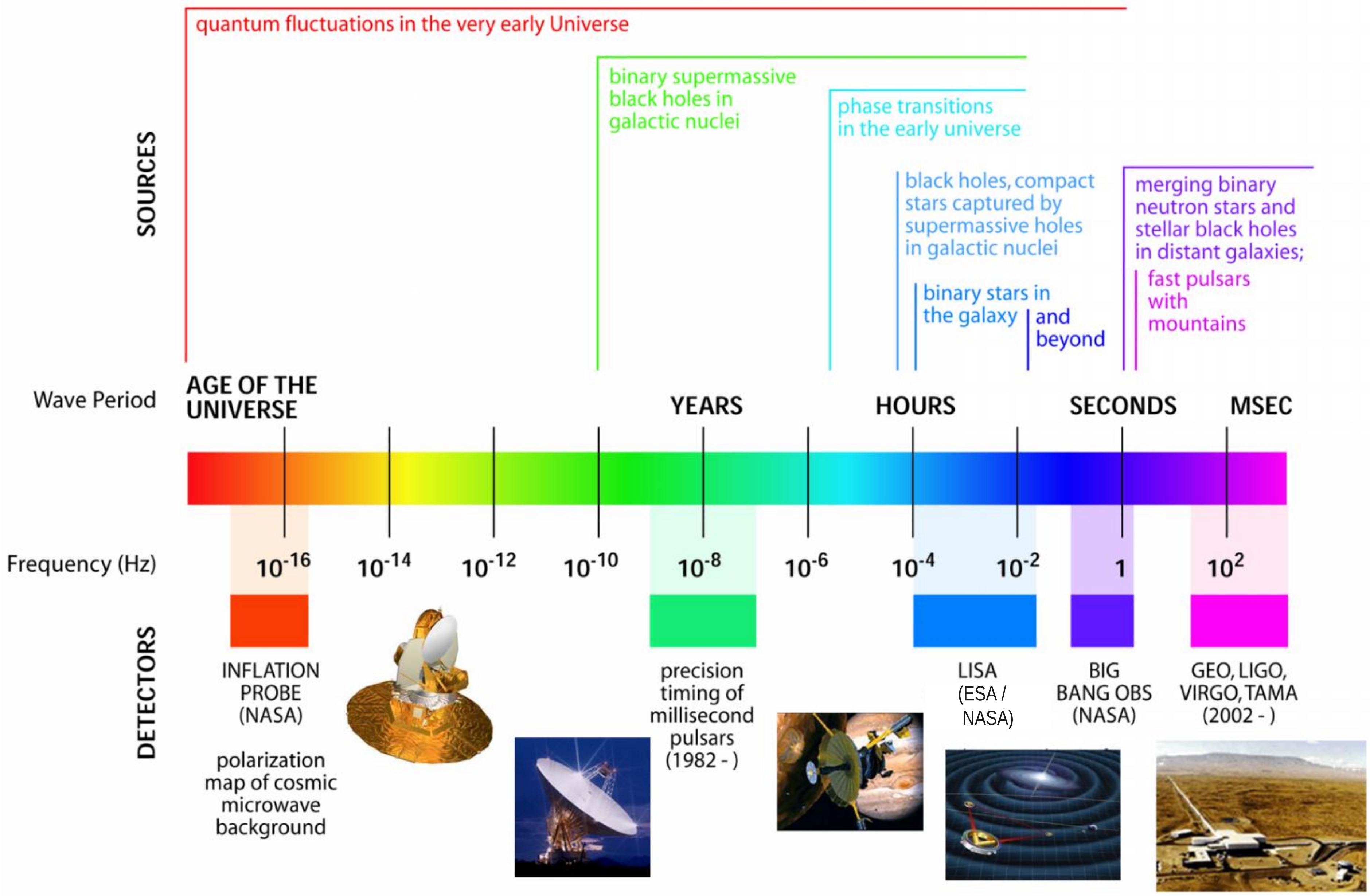


What new technologies are needed?

- Longer arms
- Underground site?
- Higher laser powers
- Cryogenic optics for low thermal noise
- Improved mirror coarings
- Larger, heavier optics; non-Gaussian laser beams;
- Laser wavelength (Silicon:1550nm; fused Silica: 1064nm)
- Frequency dependent 10 dB ‚squeezing'



THE GRAVITATIONAL WAVE SPECTRUM



The future

- The field of gravitational-wave astronomy has begun!
- 100s of black hole observations expected in next 5 years

- 2017: Virgo will improve sky sensitivity
- 2020+: LIGO India, Einstein Telescope, LIGO Voyager
- 2030+: Space-based detectors