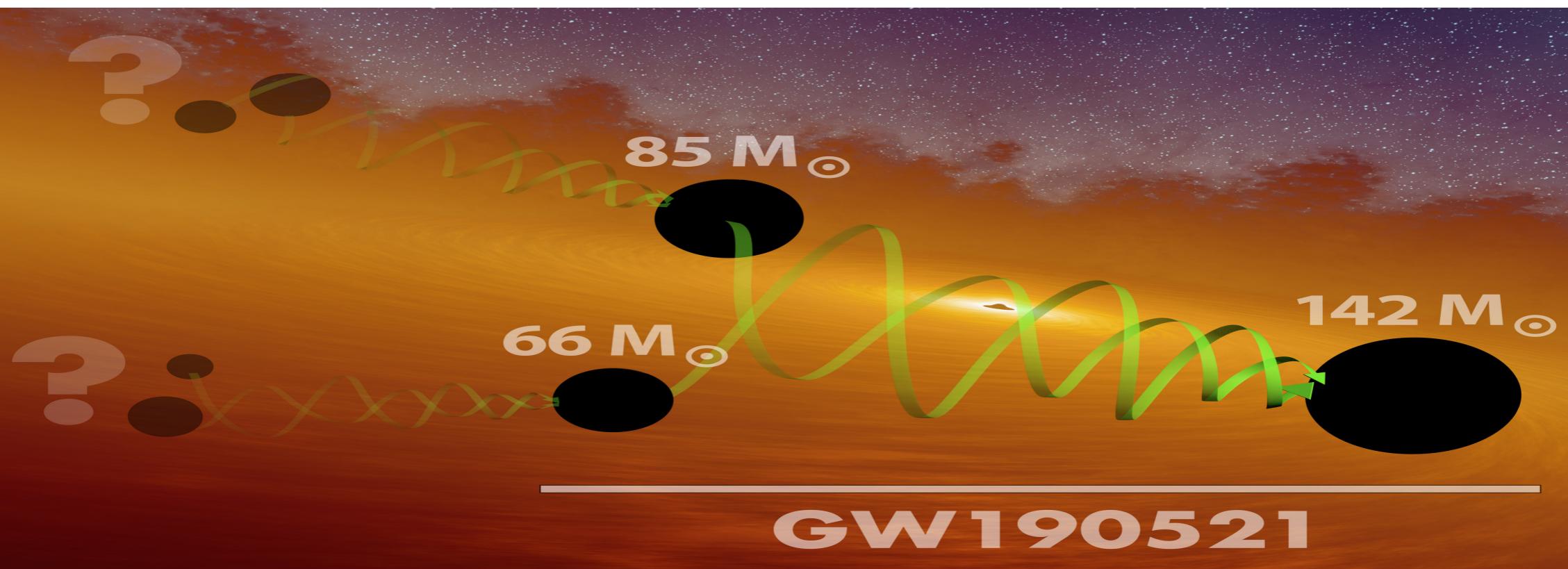


Future plans for the LVK network and for the Einstein Telescope

Ed Porter
Journées PHNE 2021



Outline

* 01 - 03

* Evolution to 04/05

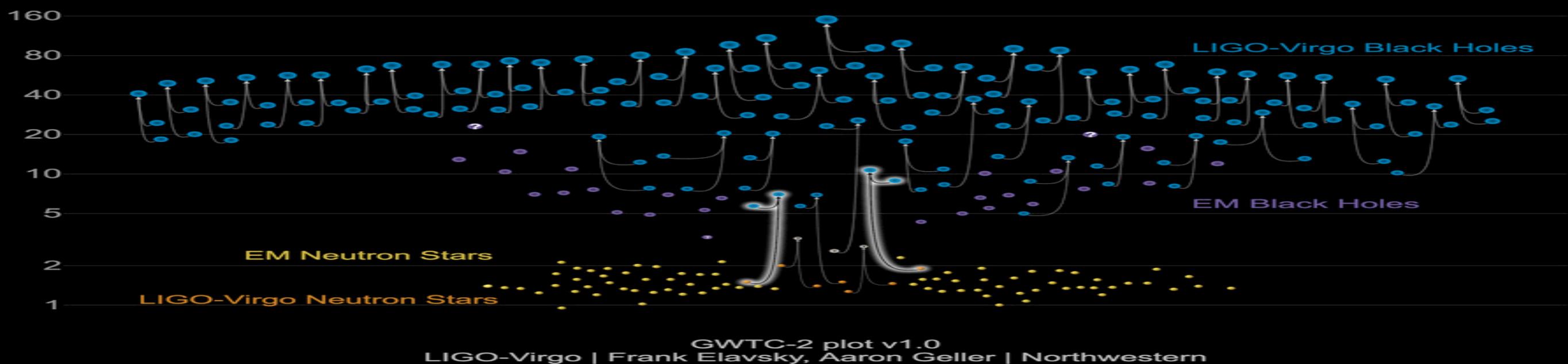
* Post-05

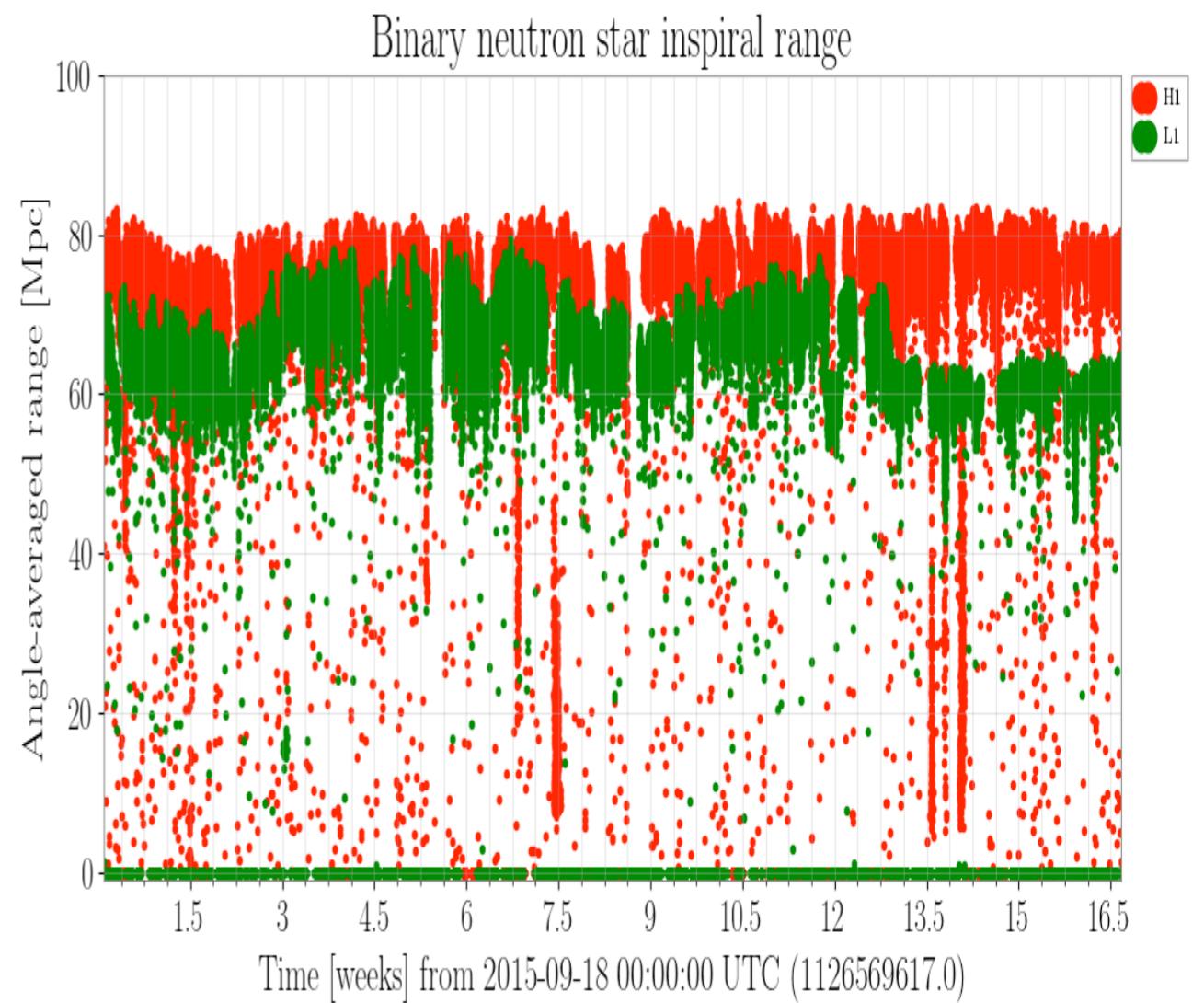
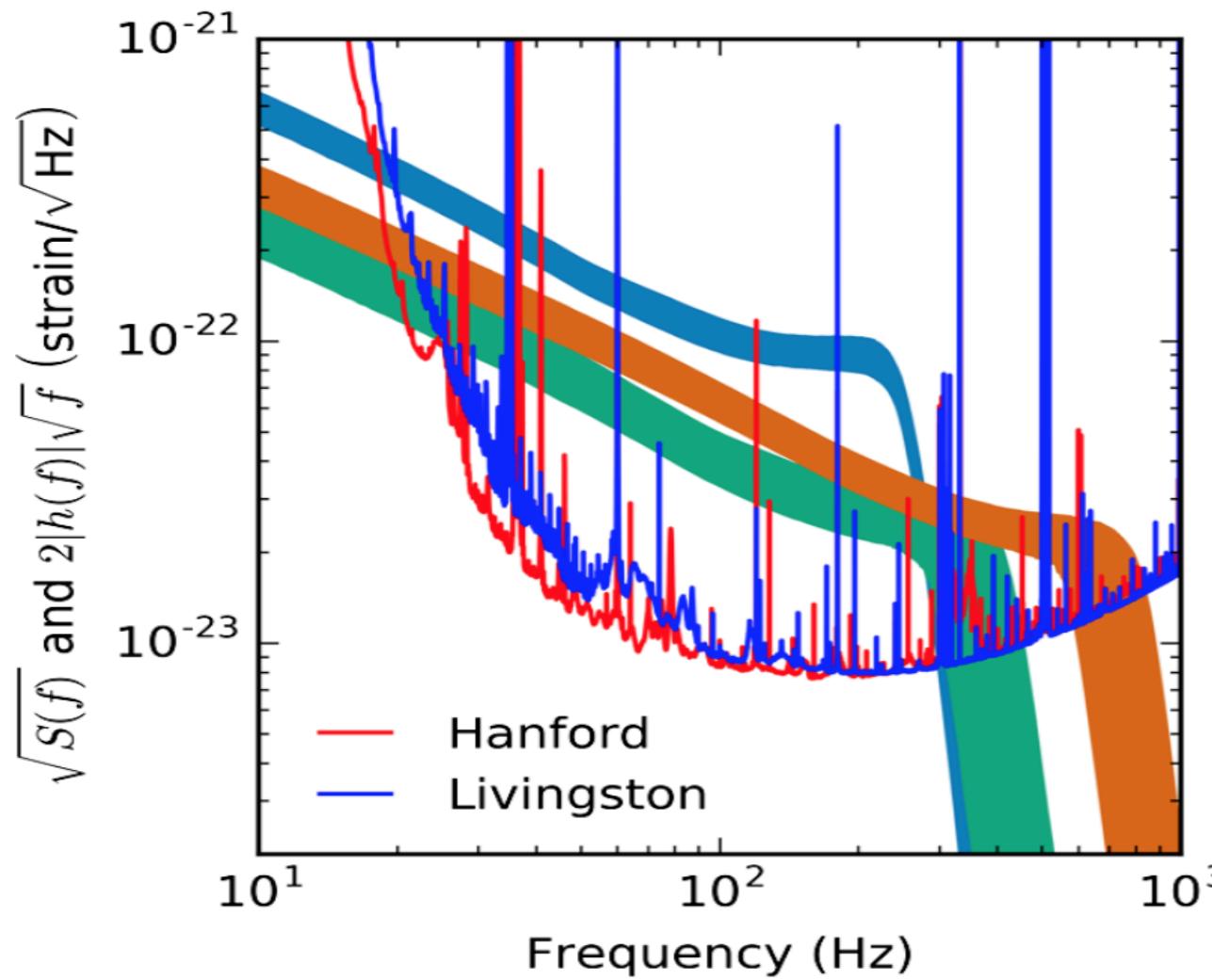
* The Einstein Telescope



01-03

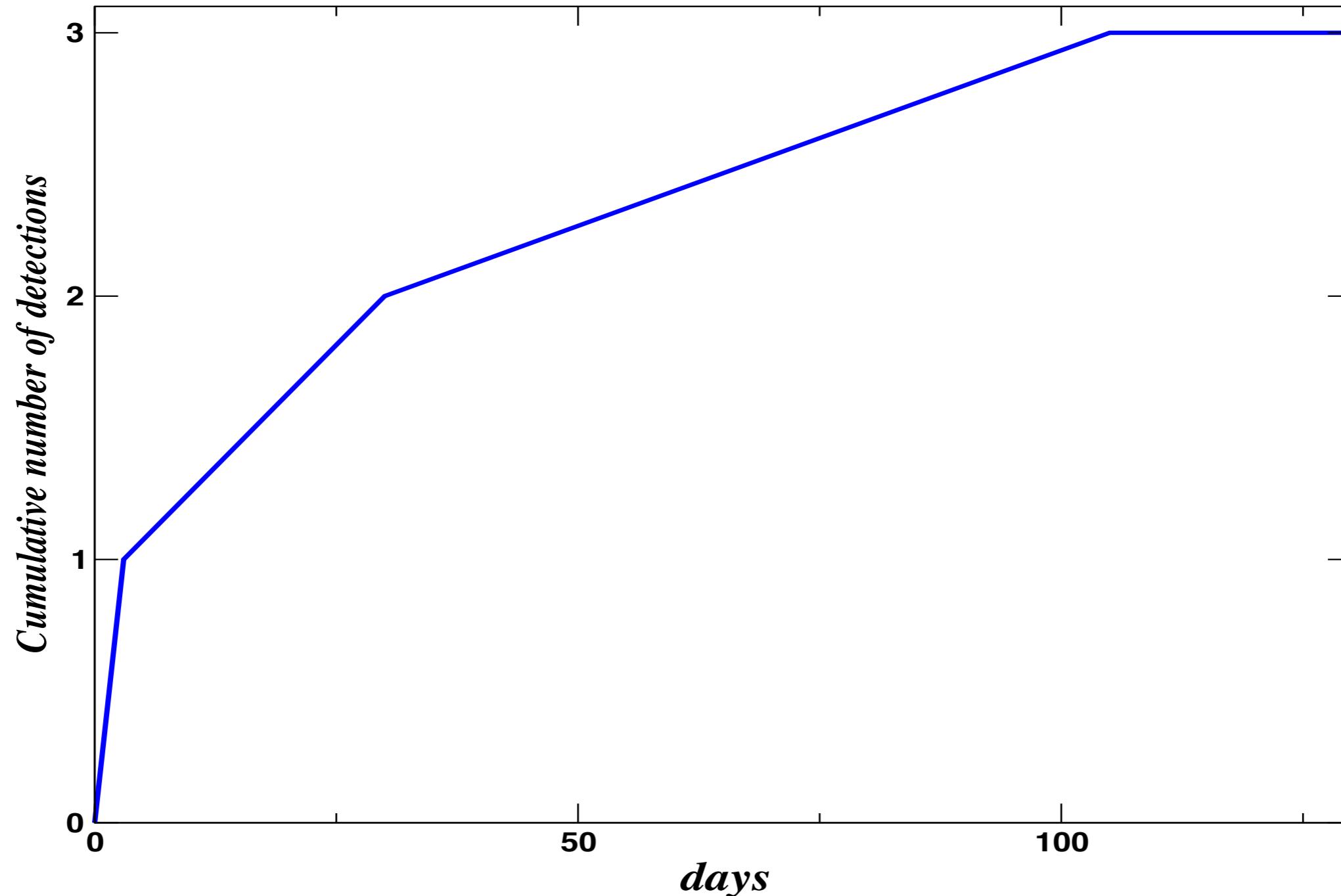
Masses in the Stellar Graveyard *in Solar Masses*



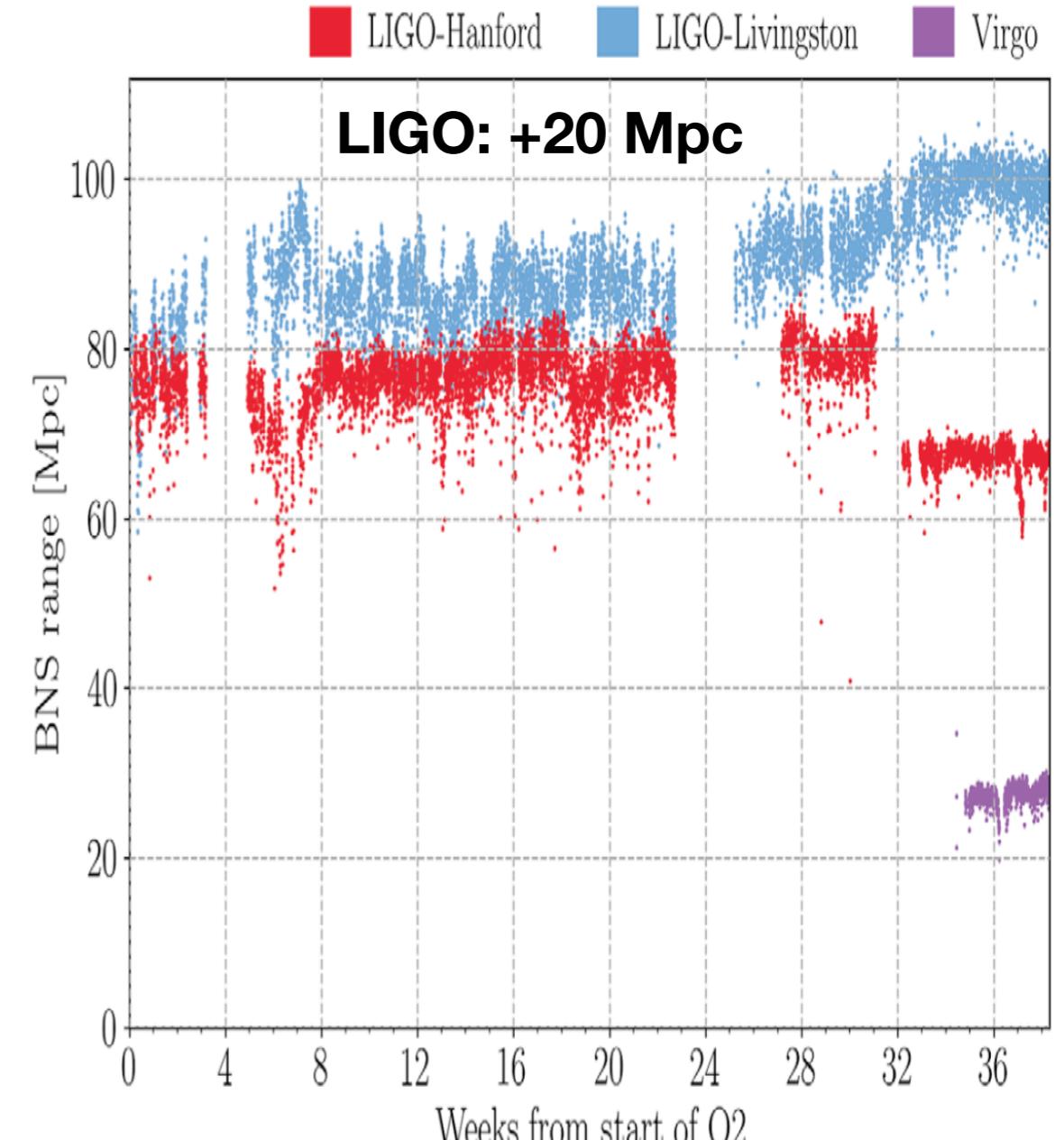
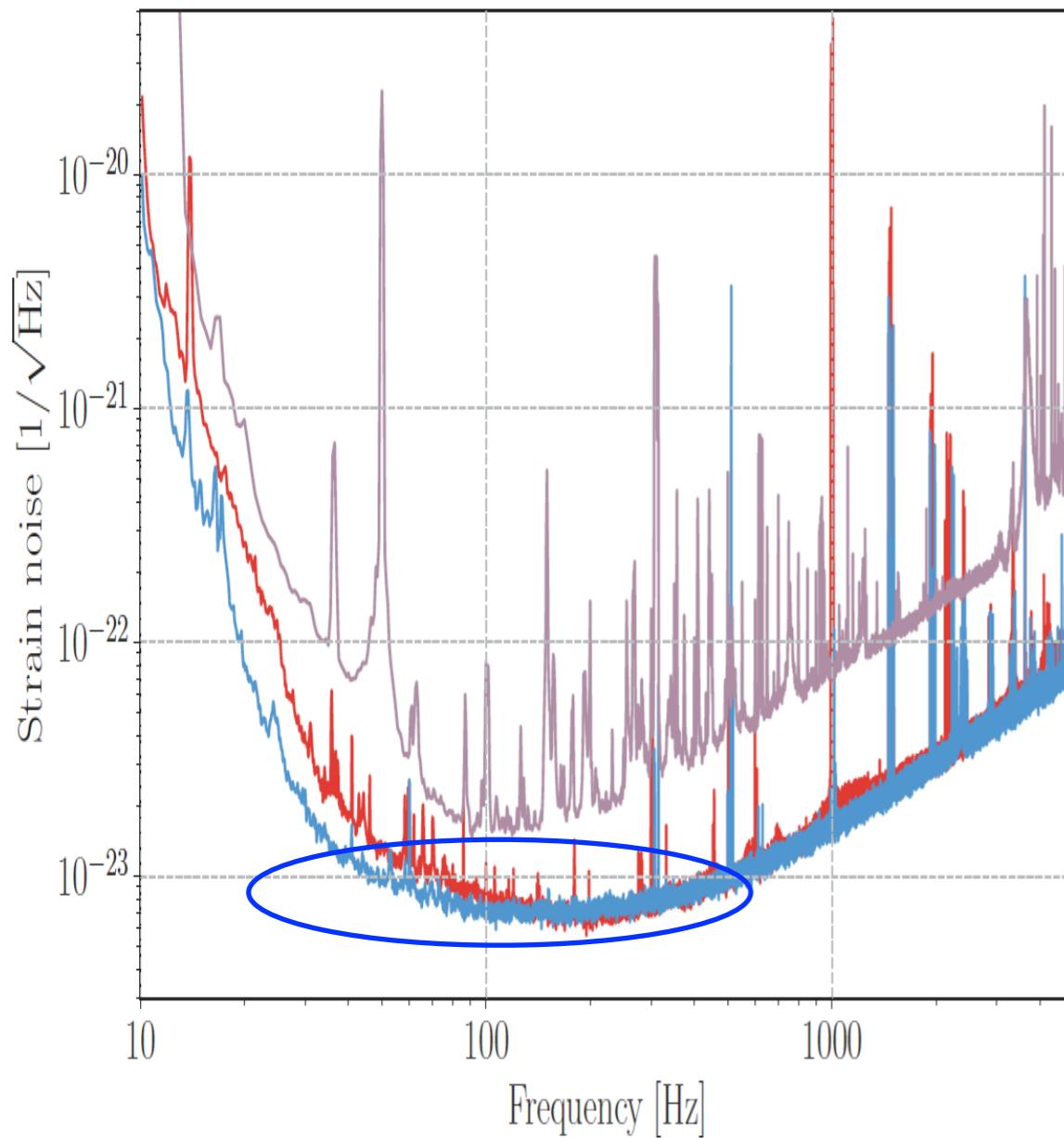


O1

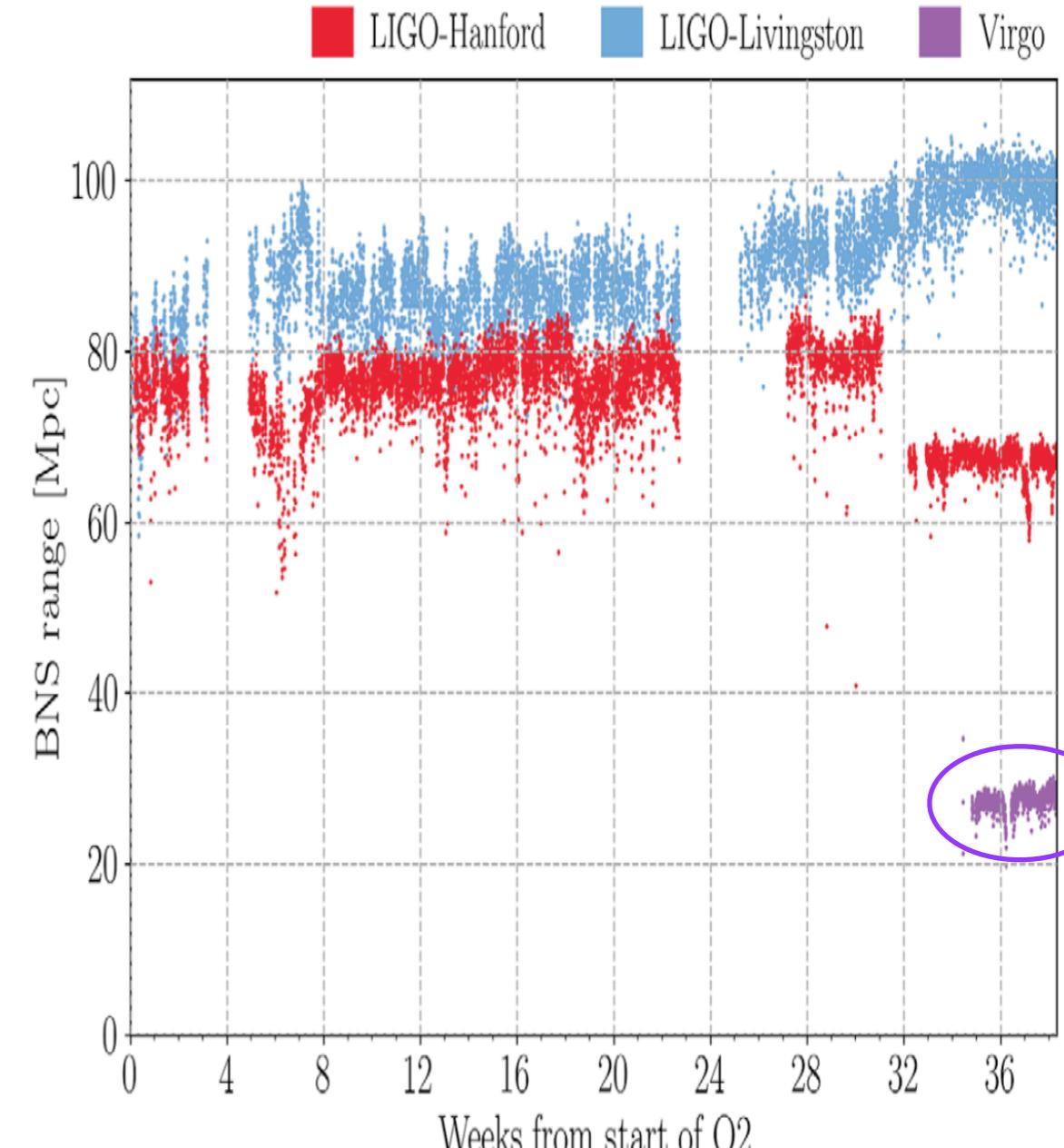
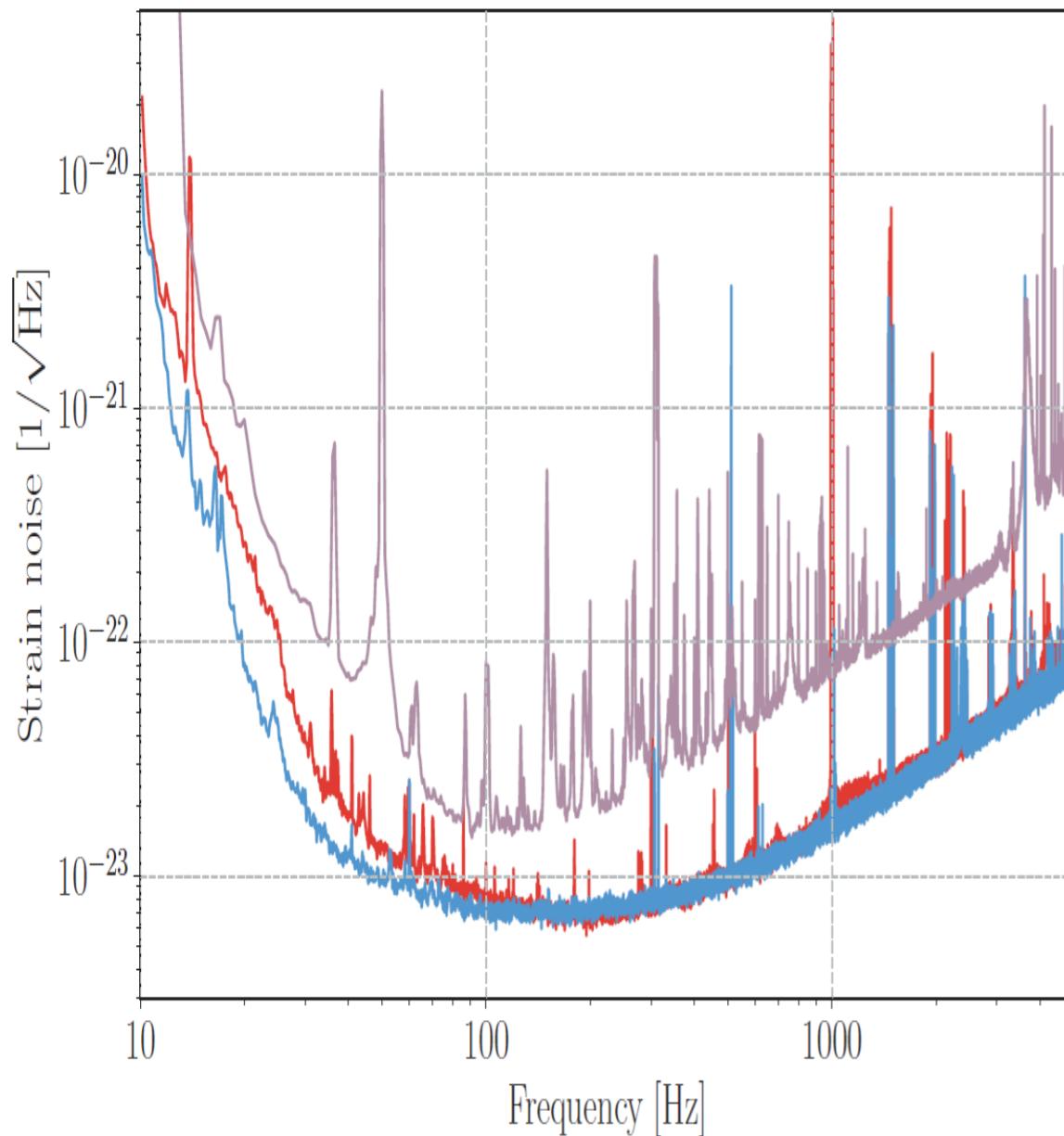
12/09/15 - 19/01/2016 : 129 days



O2

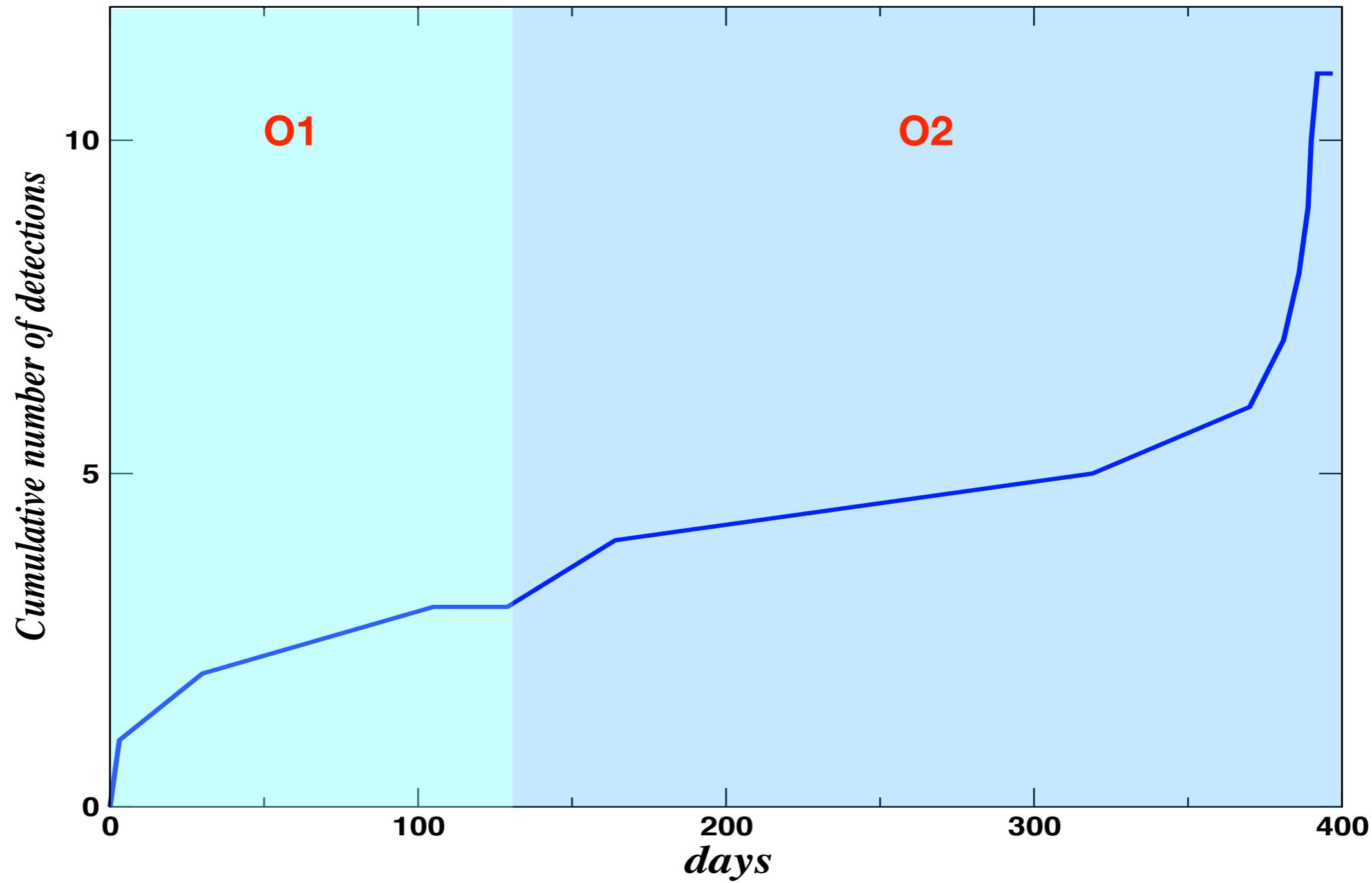


O2



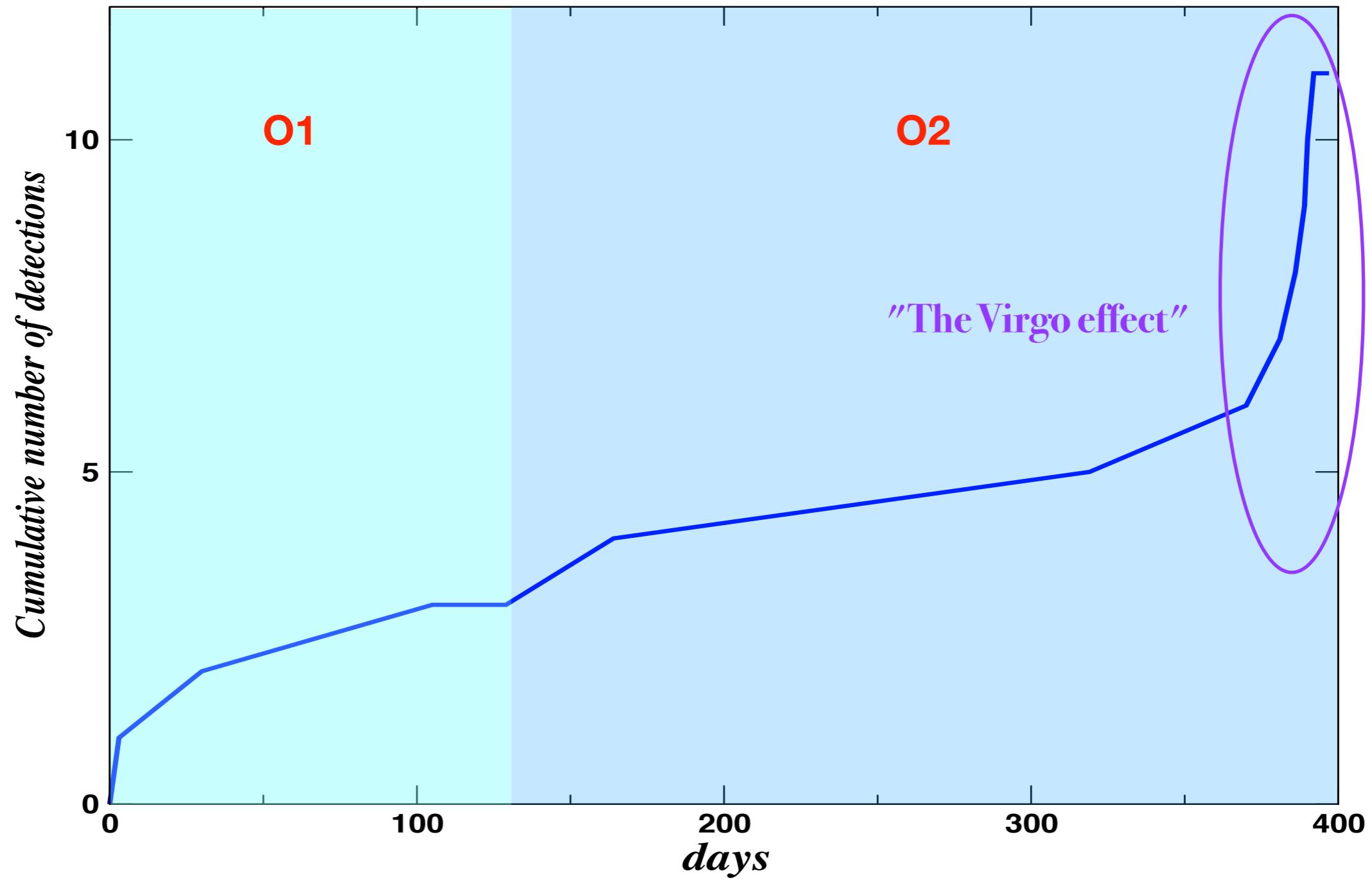
O2

30/11/2016 - 25/08/2017 : 268 days



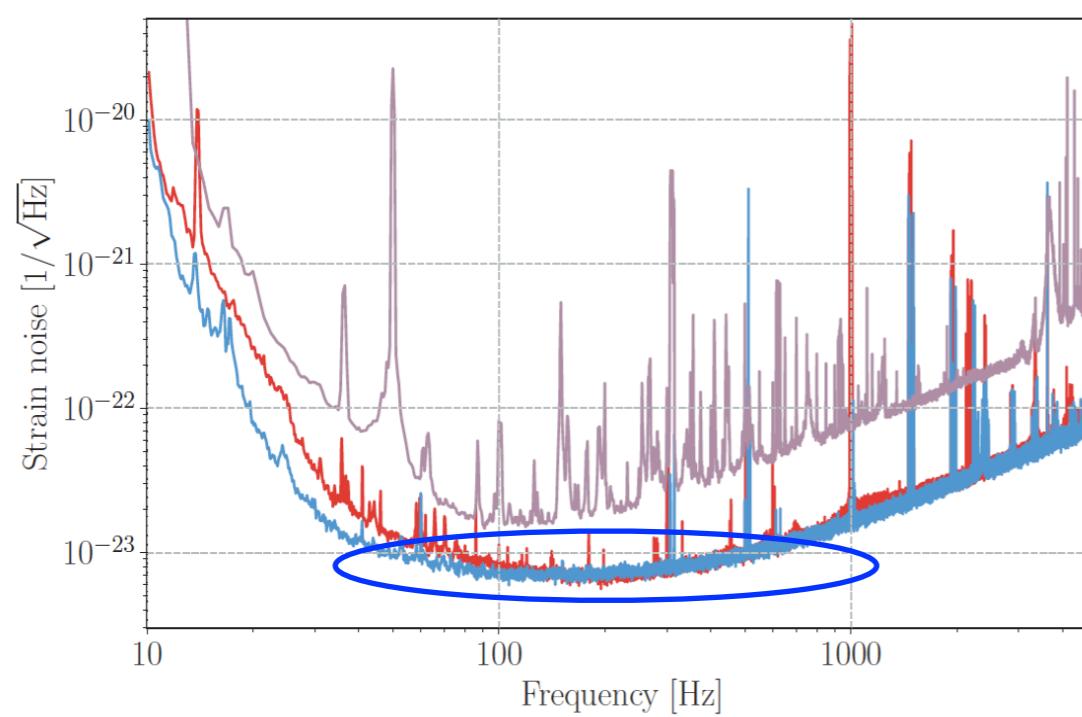
O2

30/11/2016 - 25/08/2017 : 268 days

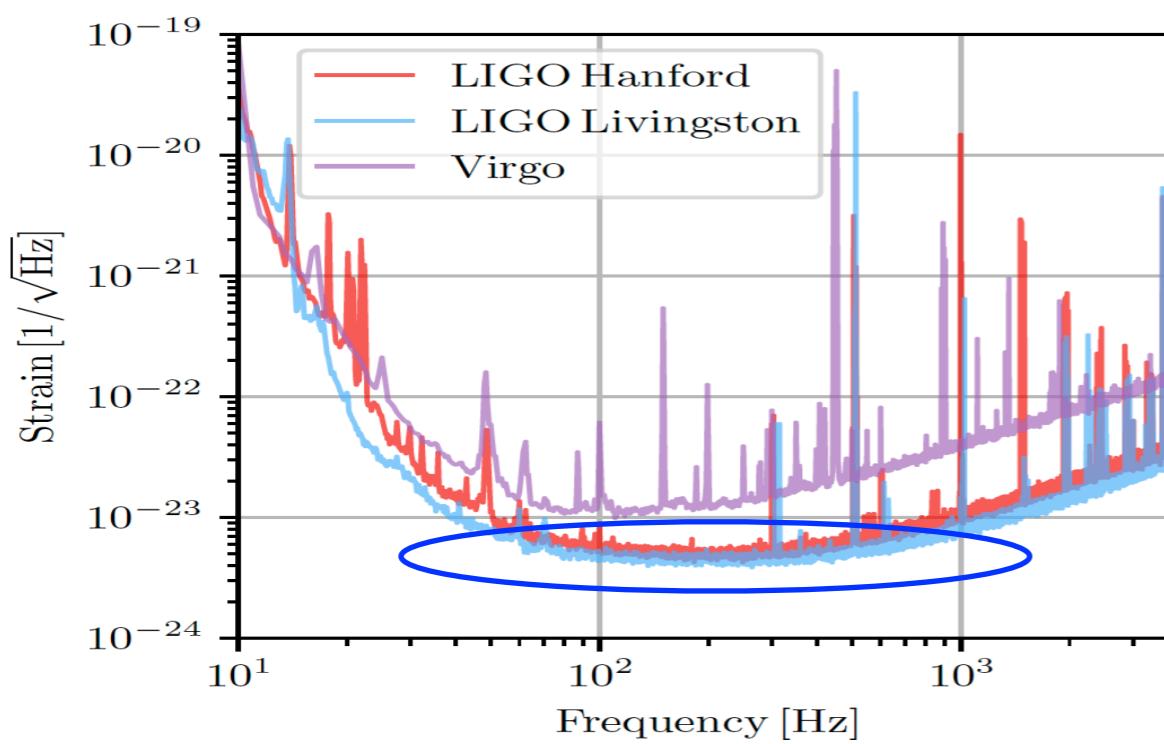


O3a

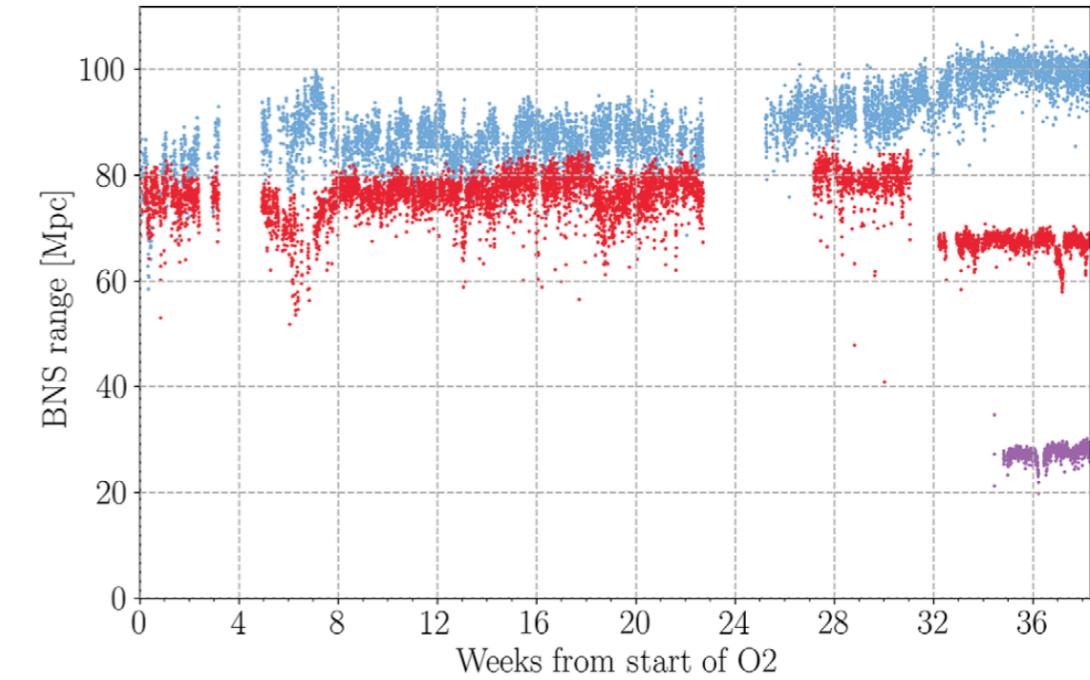
O2



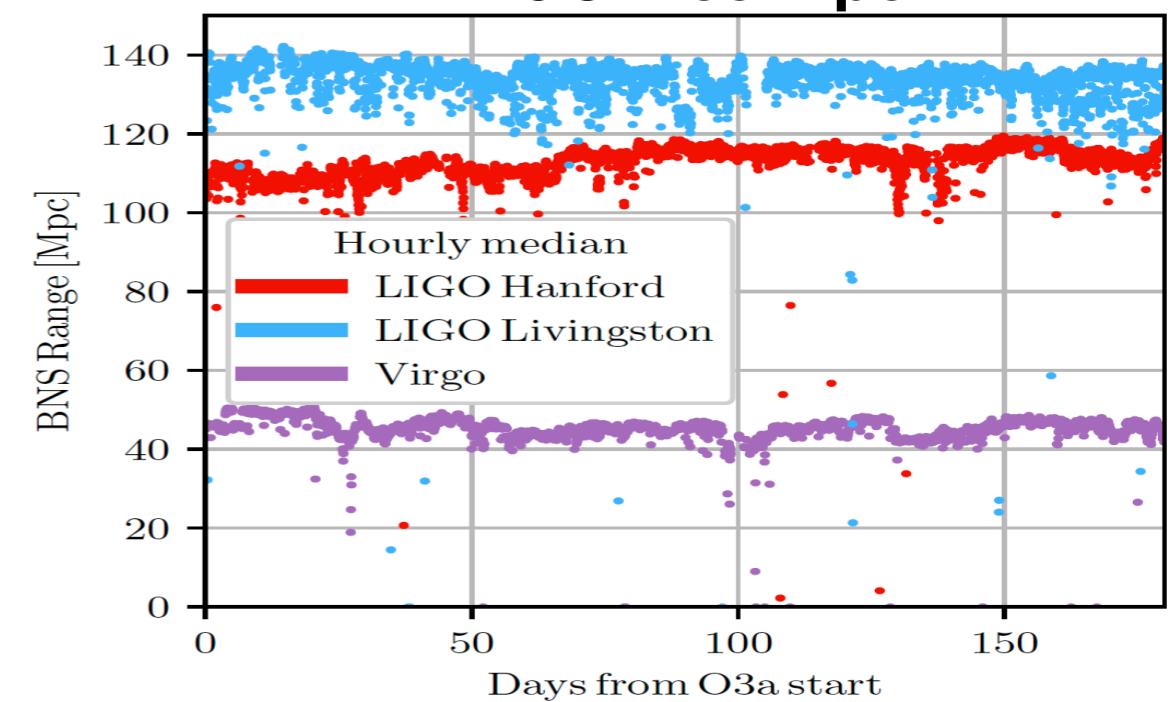
O3a



LIGO-Hanford LIGO-Livingston Virgo

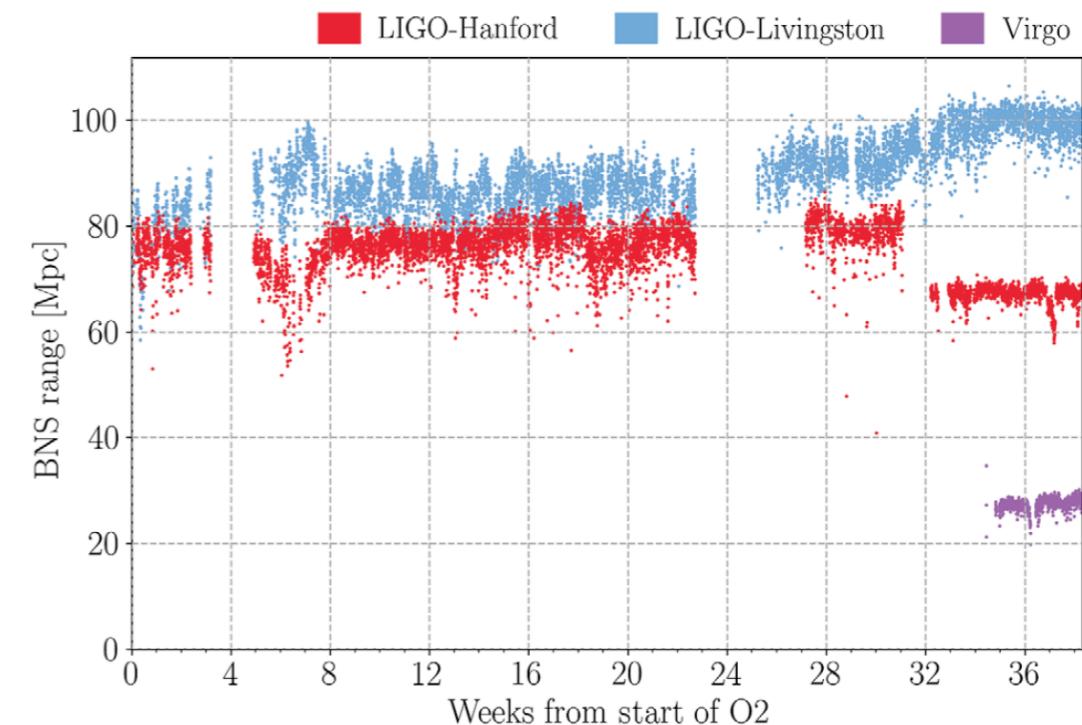
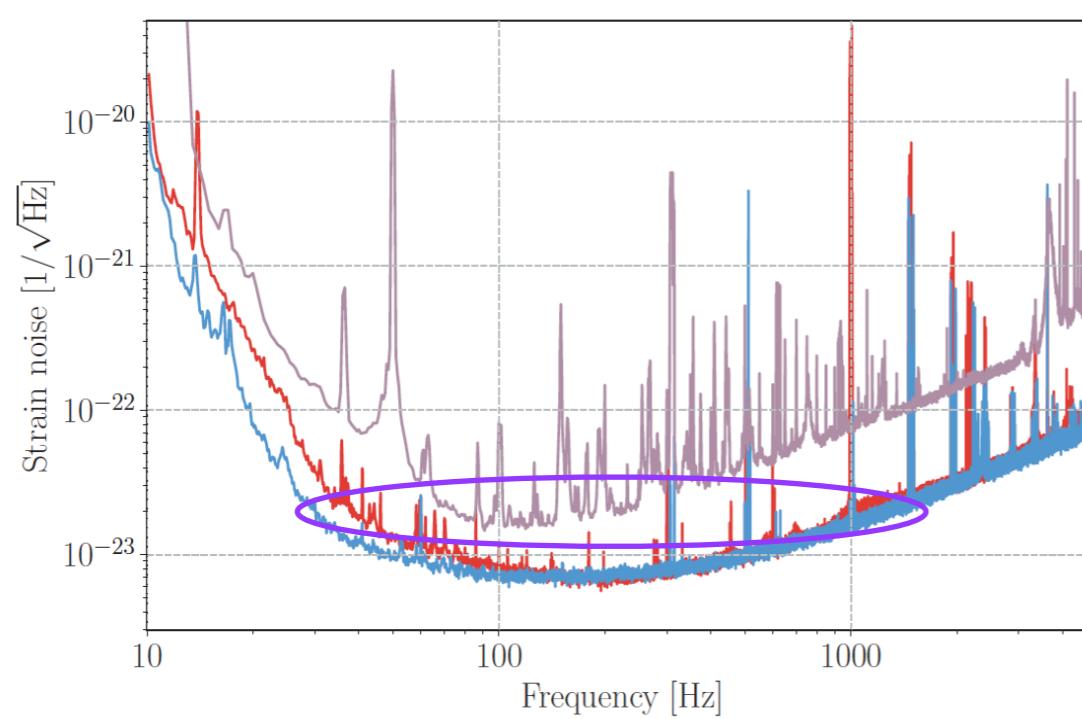


LIGO: +35 Mpc

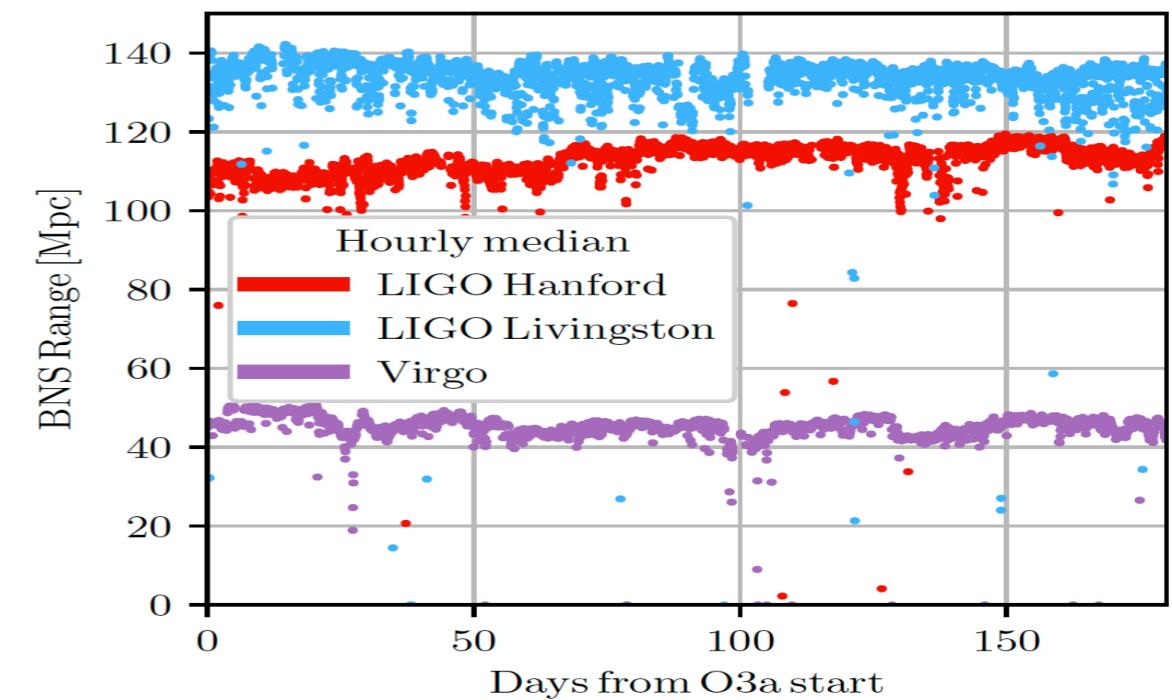
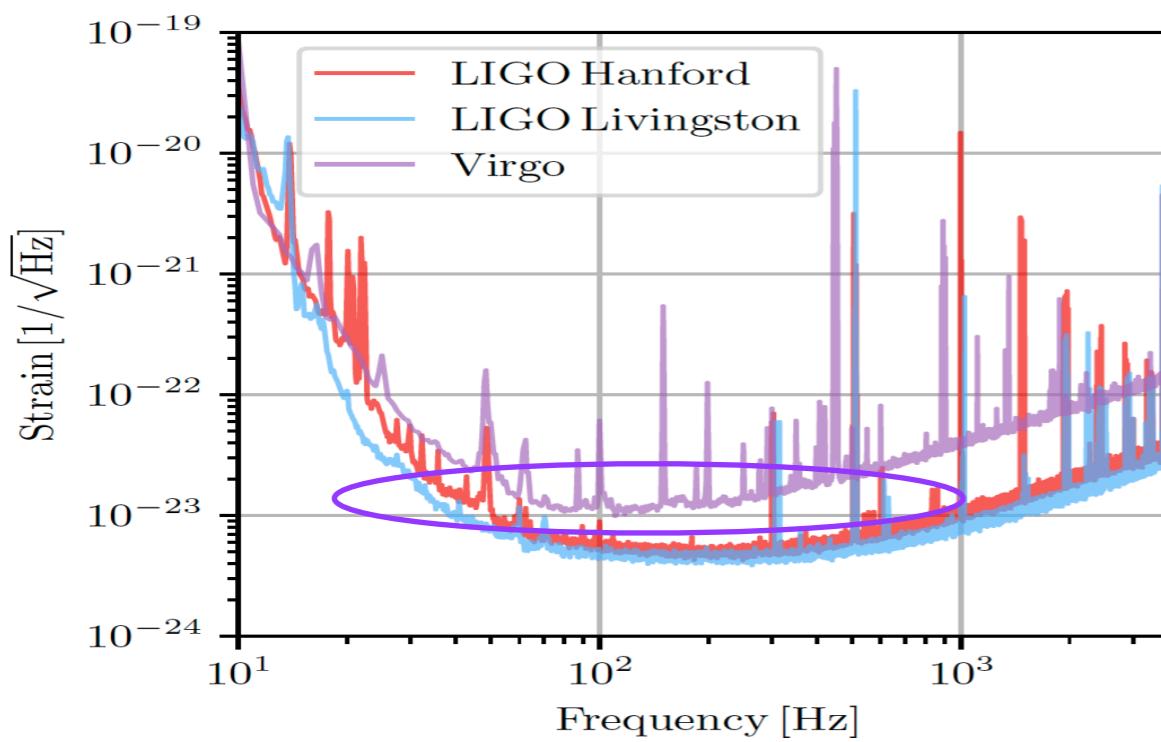


O3a

O2

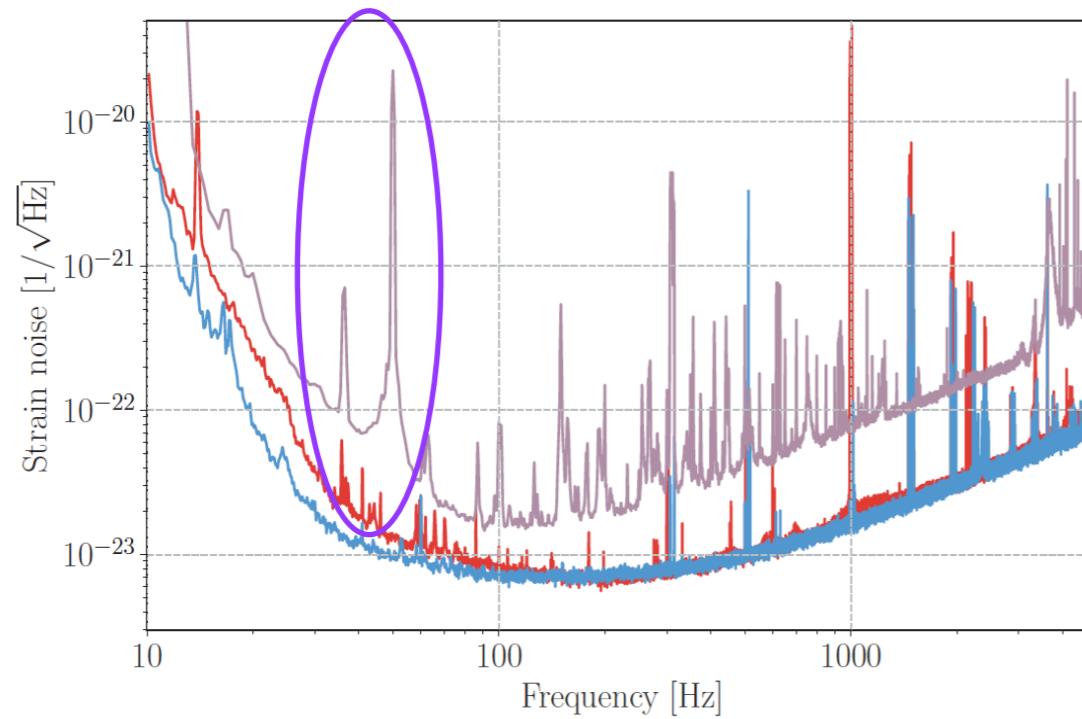


O3a

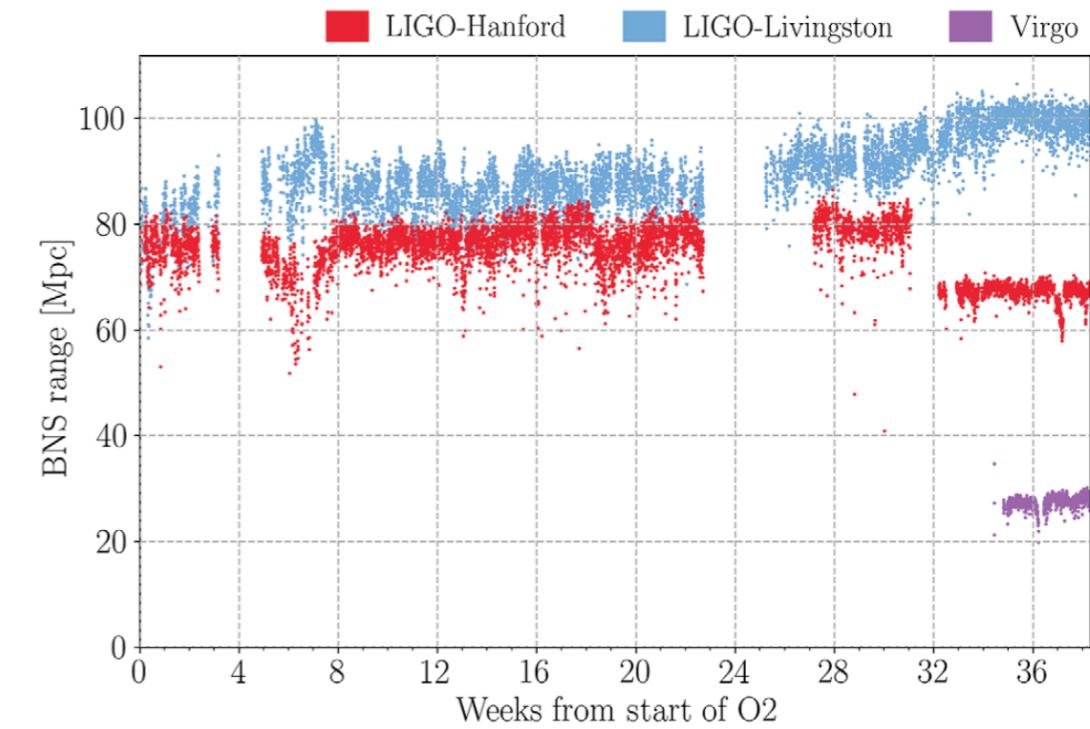
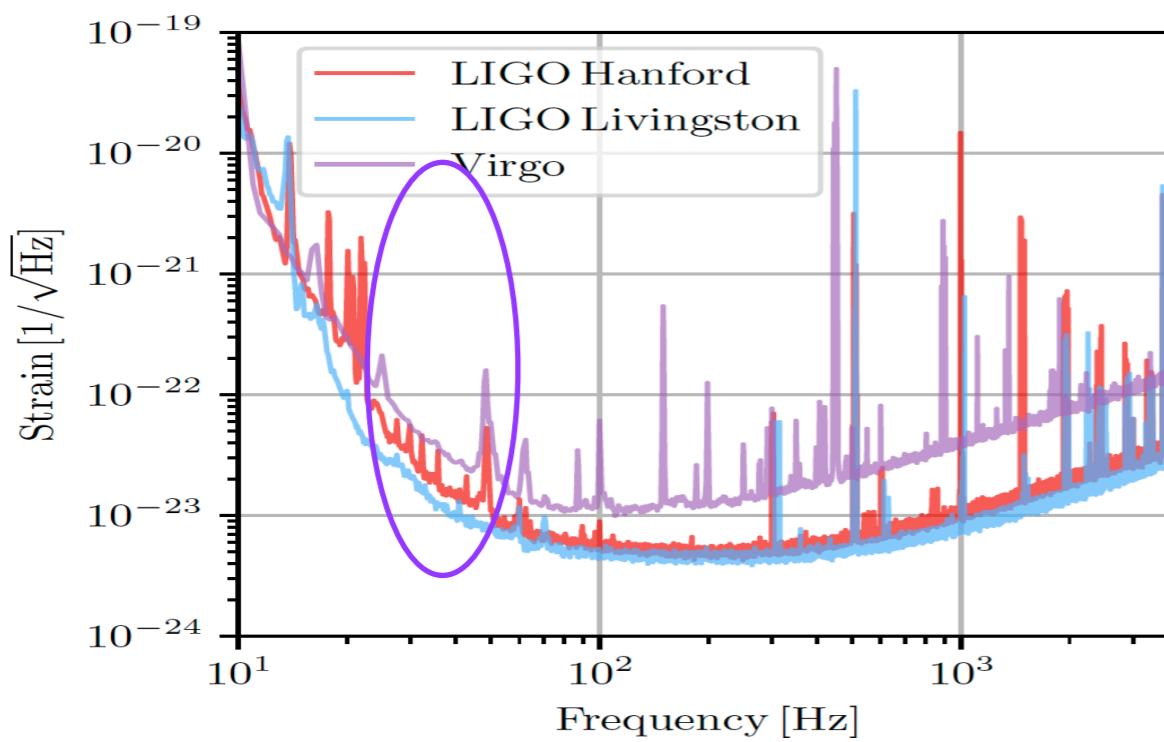


O3a

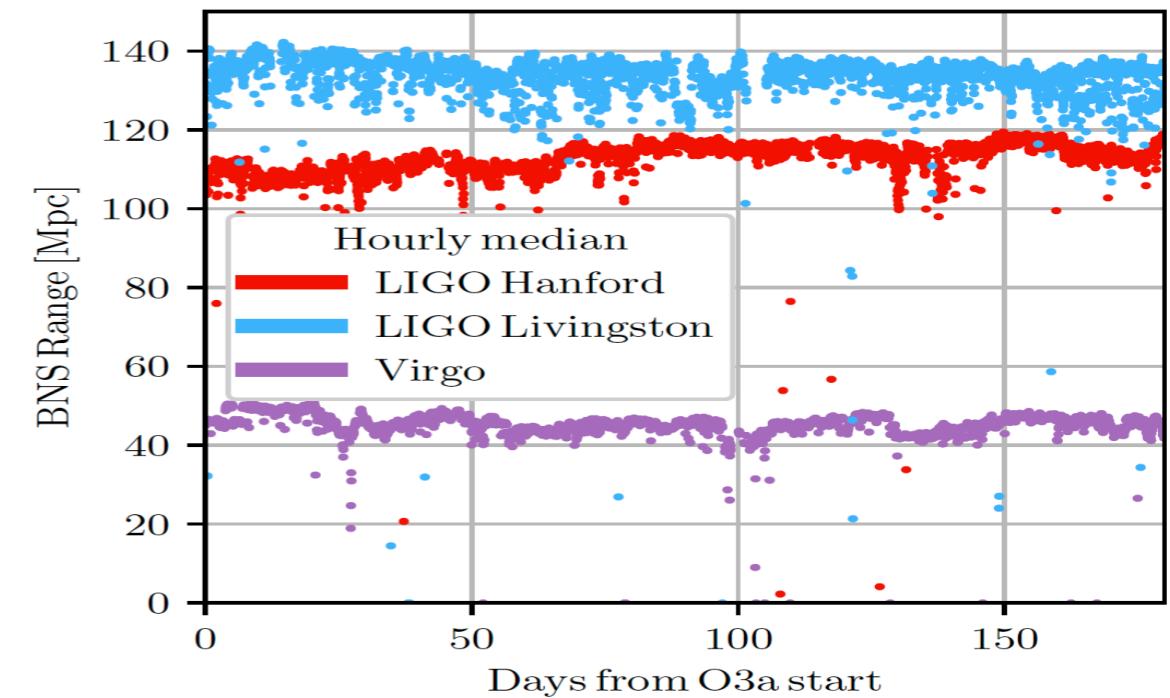
O2



O3a

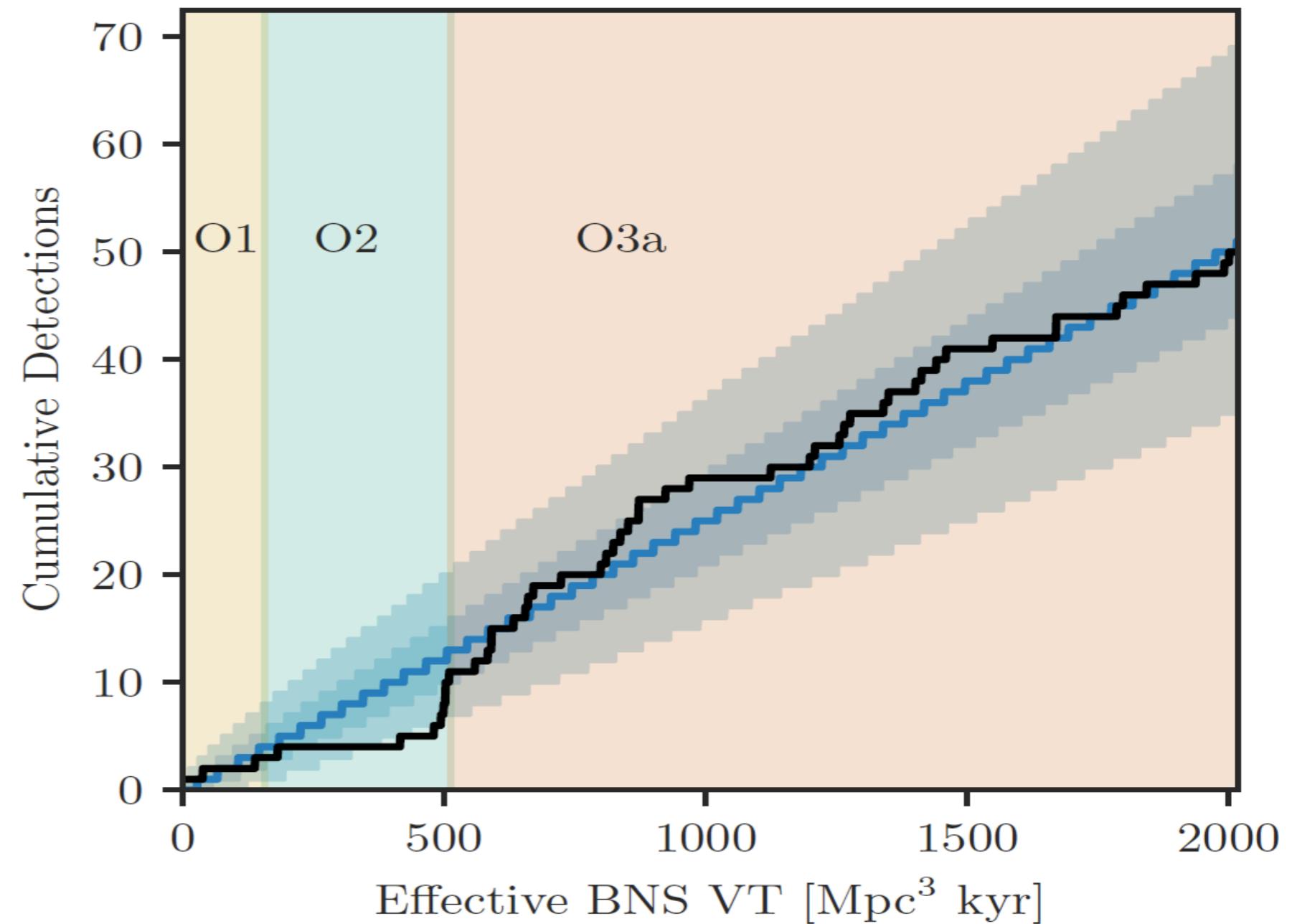


VIRGO: +20 Mpc



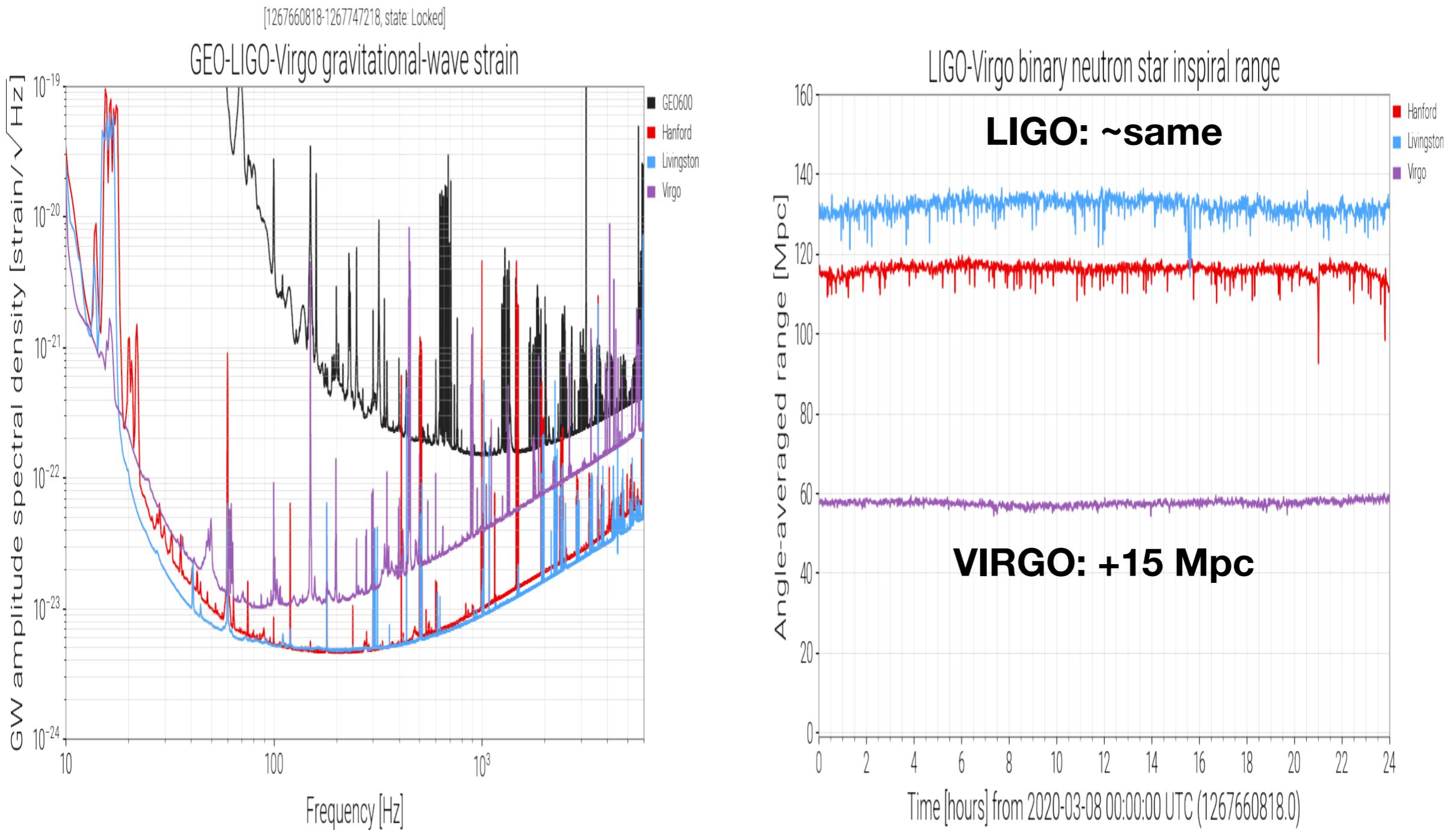
O3a

- April 1 - October 1, 2019
- FAR = 2/yr
- <10% contamination
- 26 Public Alerts
- 13 first announcements

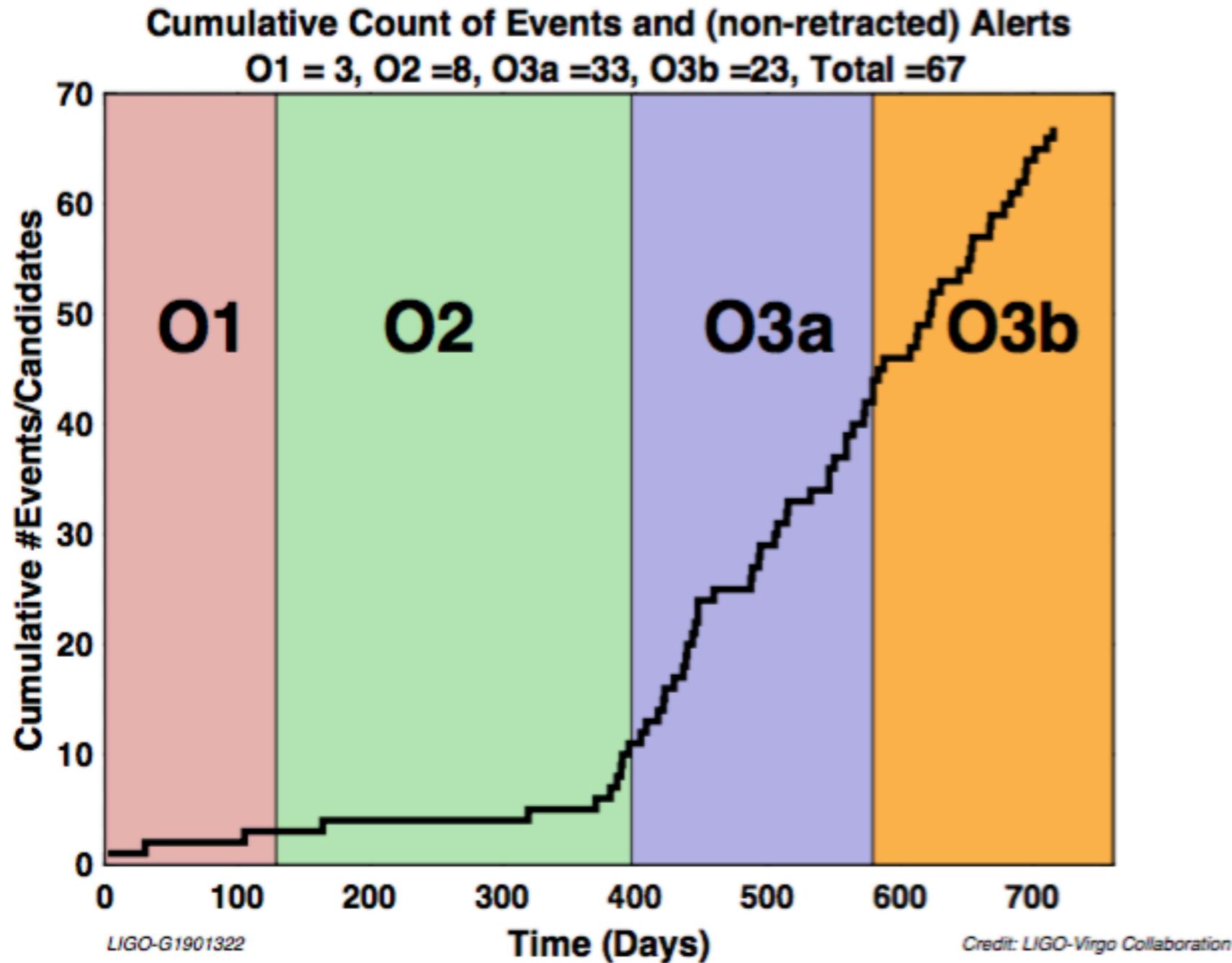


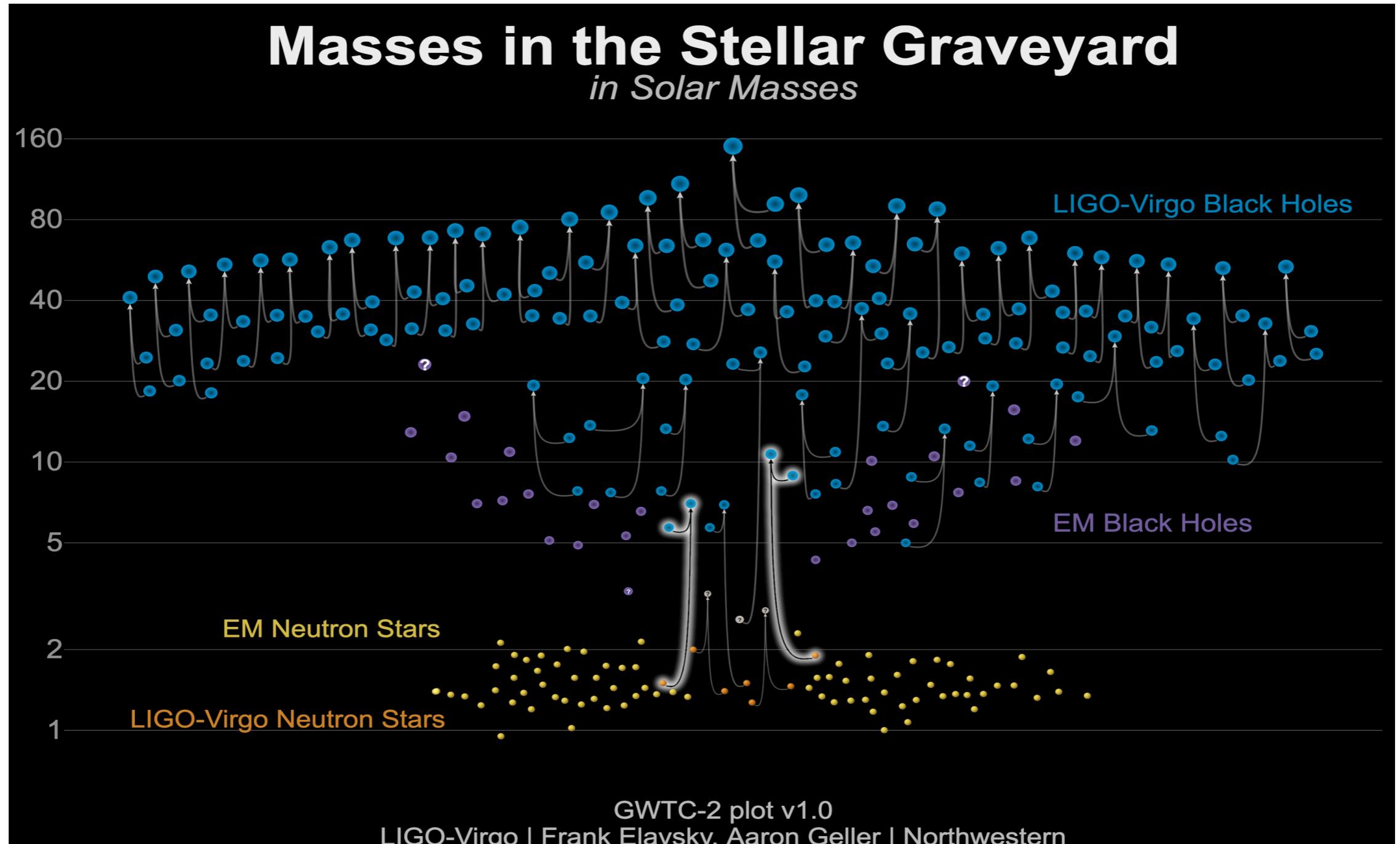
Abbott et al, Phys. Rev. X 11, 021053 (2021)

O3b



O3b



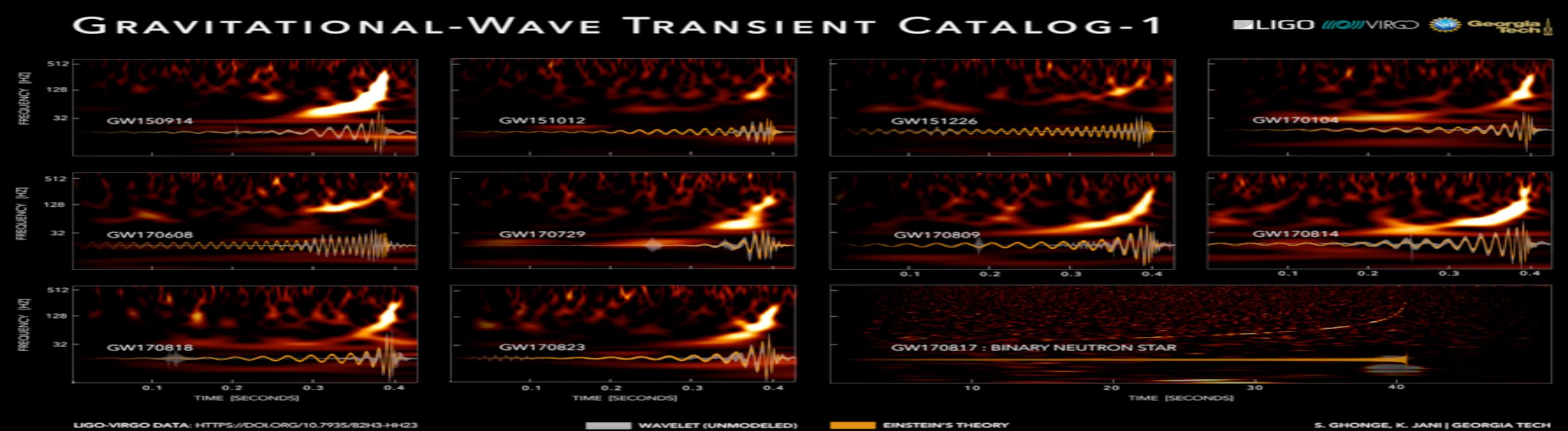


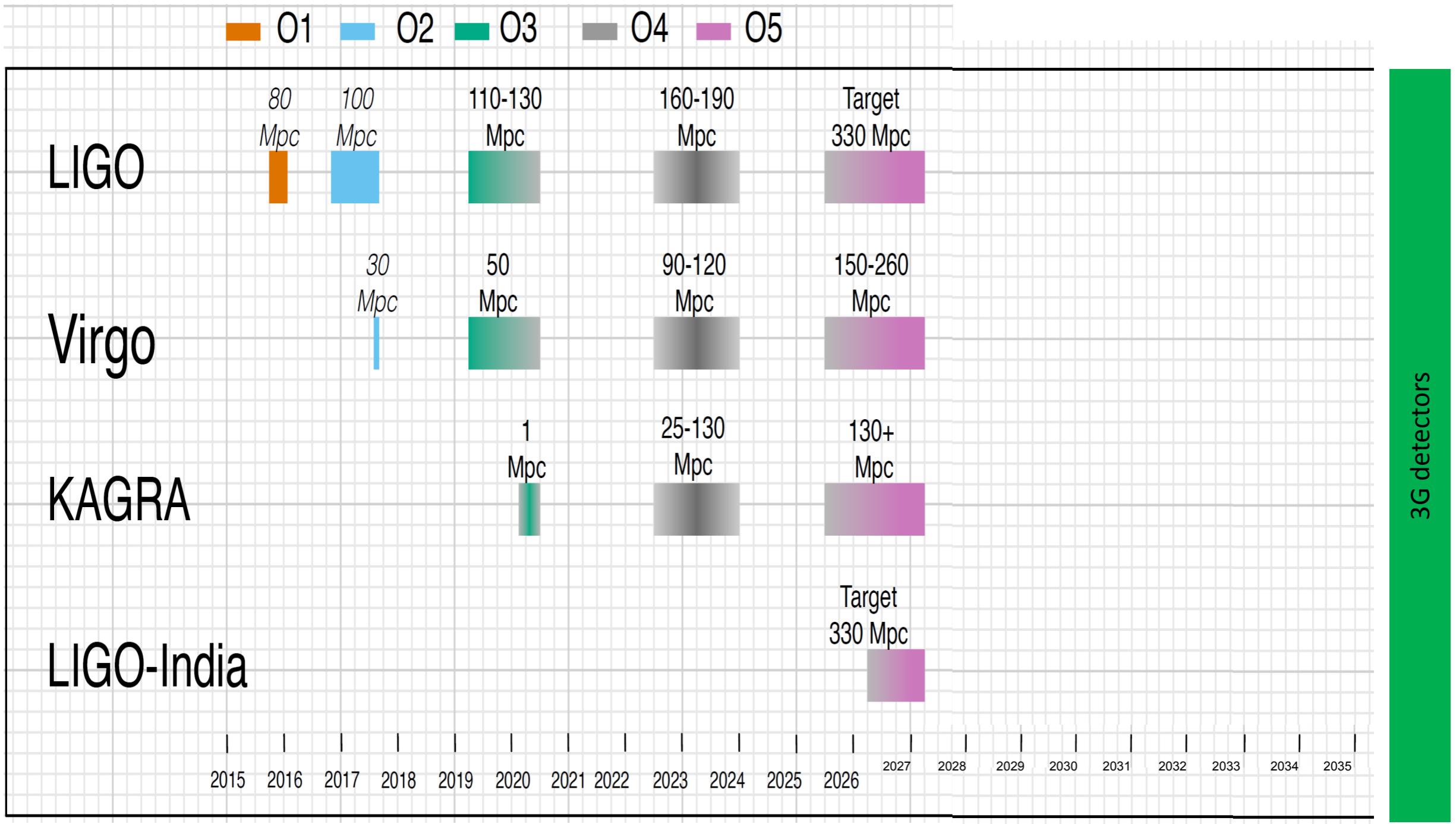
GWTC-2 + NSBHs

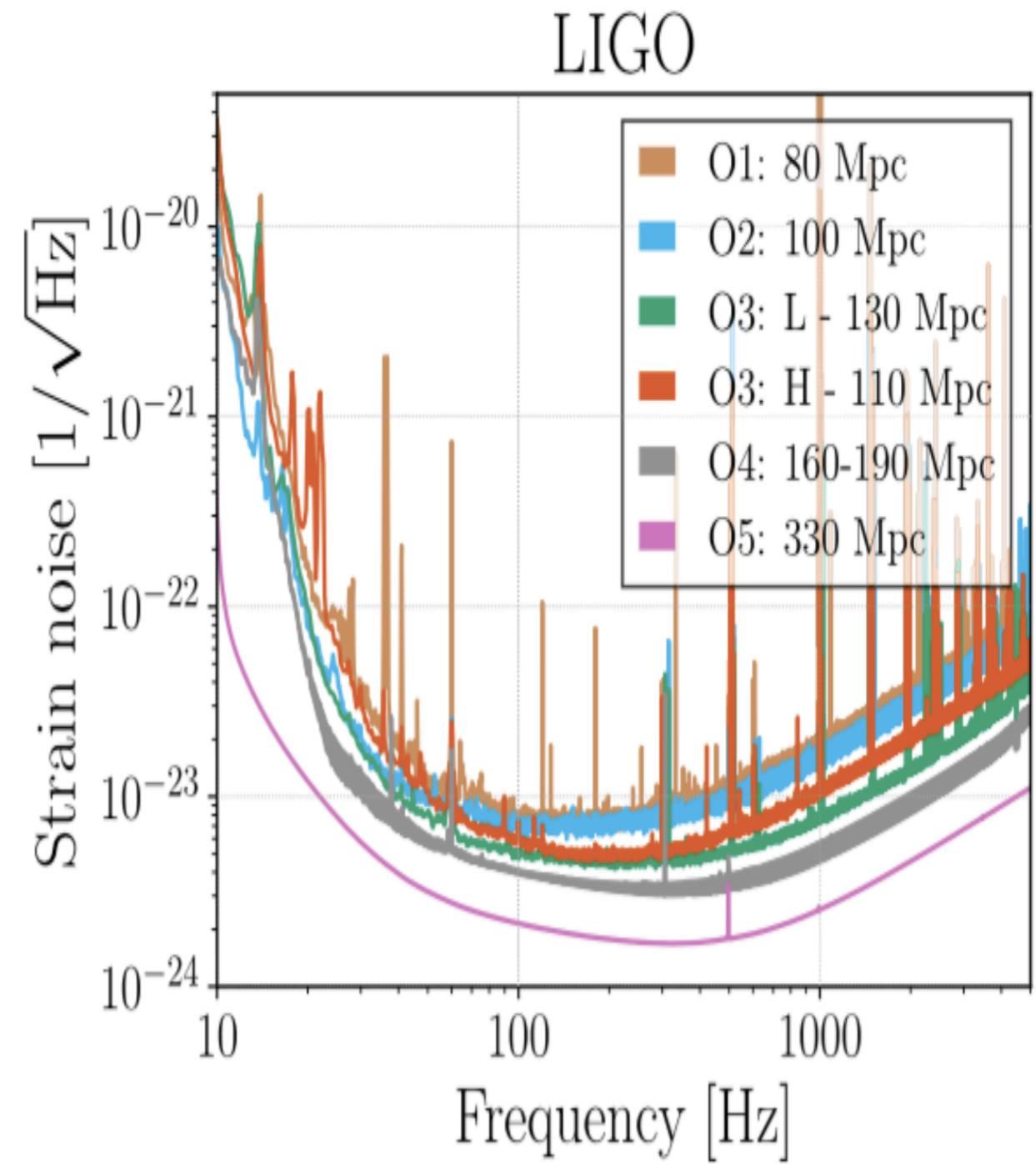
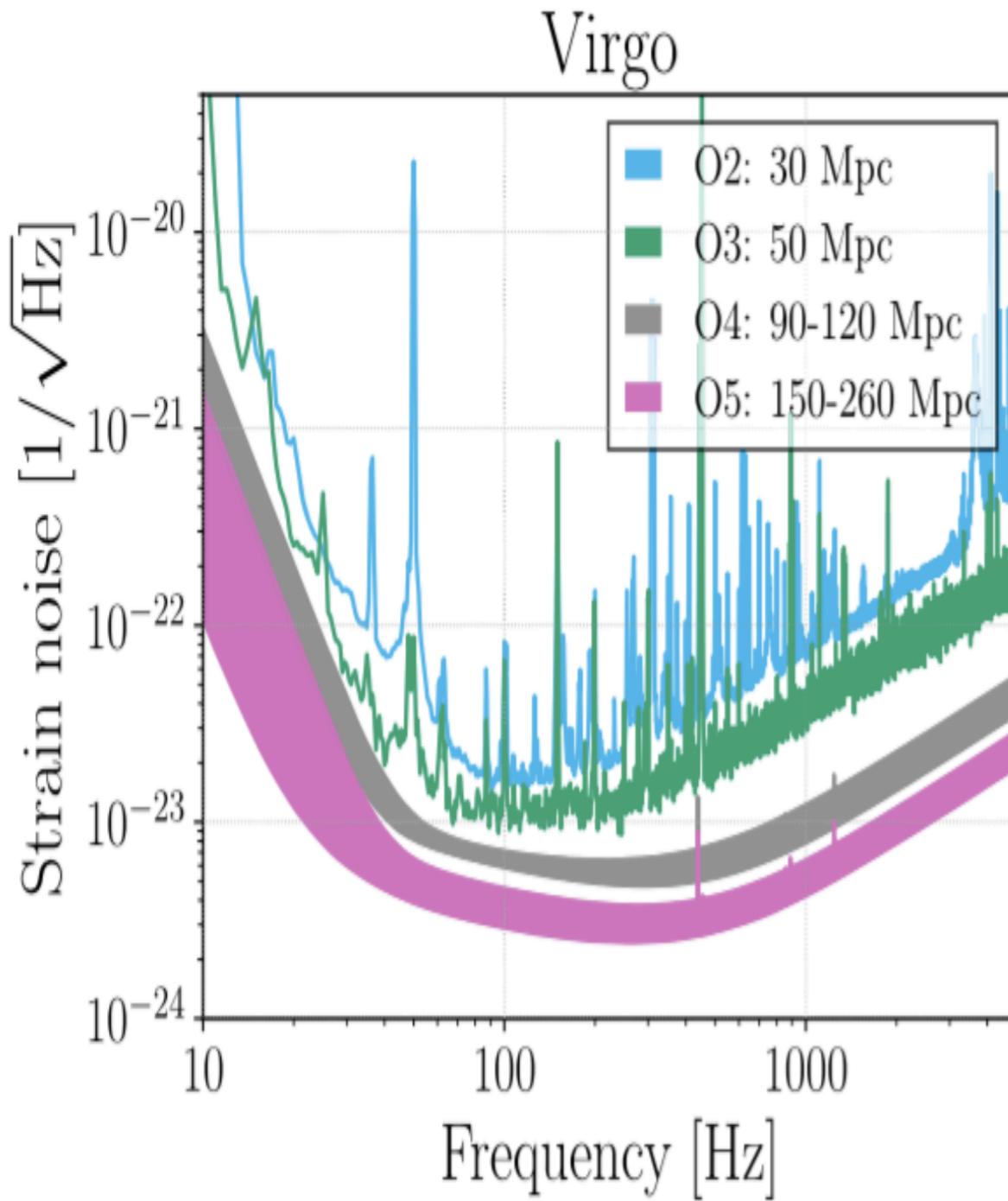
Highlights so far....

- **GW150914:** first detection of GWs from a BBH merger
- **GW170817:** first BNS merger with EM counterpart, beginning of MMA, constraints on speed of GWs and alternative theories of gravity, constraints on NS-EOS, heavy element production.
- **GW190412:** most asymmetric system (m_1, m_2) = $(30, 8) M_{\odot}$. Evidence of higher modes as predicted by GR
- **GW190425:** most massive BNS system? $m = 3.4 M_{\odot}$
- **GW190524:** most massive BBH system (m_1, m_2) = $(85, 66) M_{\odot}$. Primary sits in the pair-instability gap. Remnant has a mass of $142 M_{\odot}$ - first evidence of IMBH formation
- **GW190814:** (m_1, m_2) = $(23, 2.6) M_{\odot}$. Secondary object in lower mass gap. Either heaviest NS or lightest BH detected!

Evolution to 04/05







Advanced Virgo+

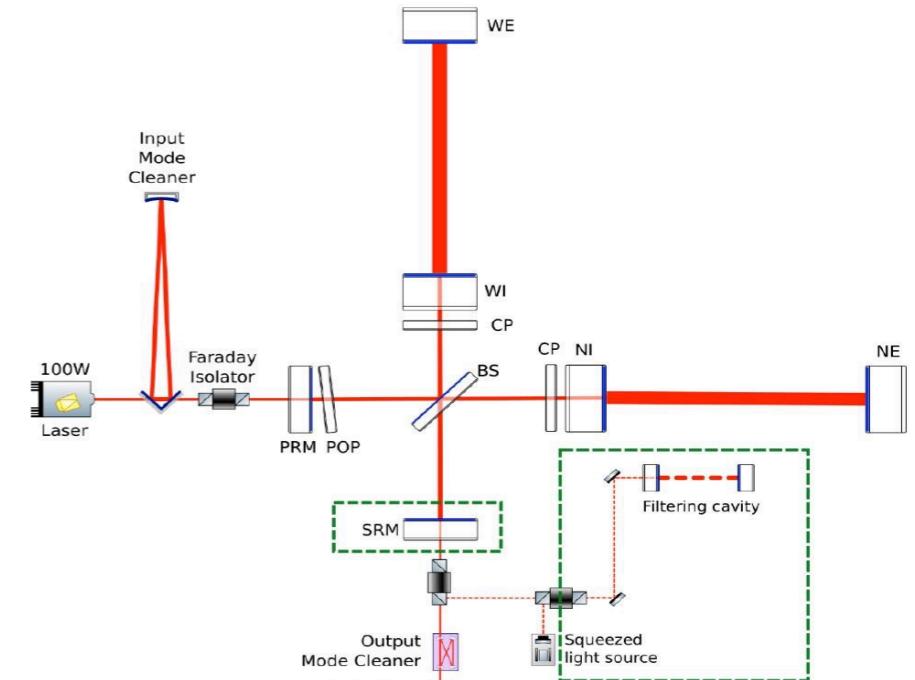
Coordinated strategy with Advanced LIGO

Phase 1:

Use signal recycling (used by Adv LIGO in O3)

Increase laser power from 26W to 40W

Use frequency dependent squeezing



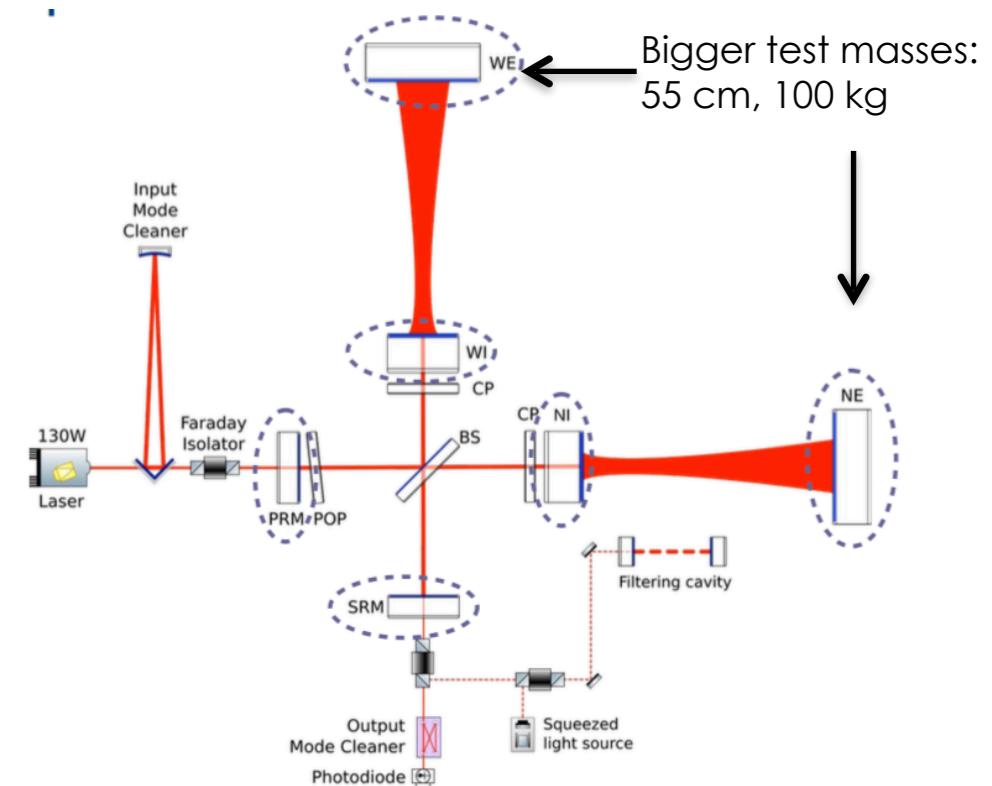
Phase 2:

Increase beam size on end test masses

R&D on coating mechanical / optical properties

Quantum noise reduction

Laser power increase from 40W to 80W



Advanced Virgo+

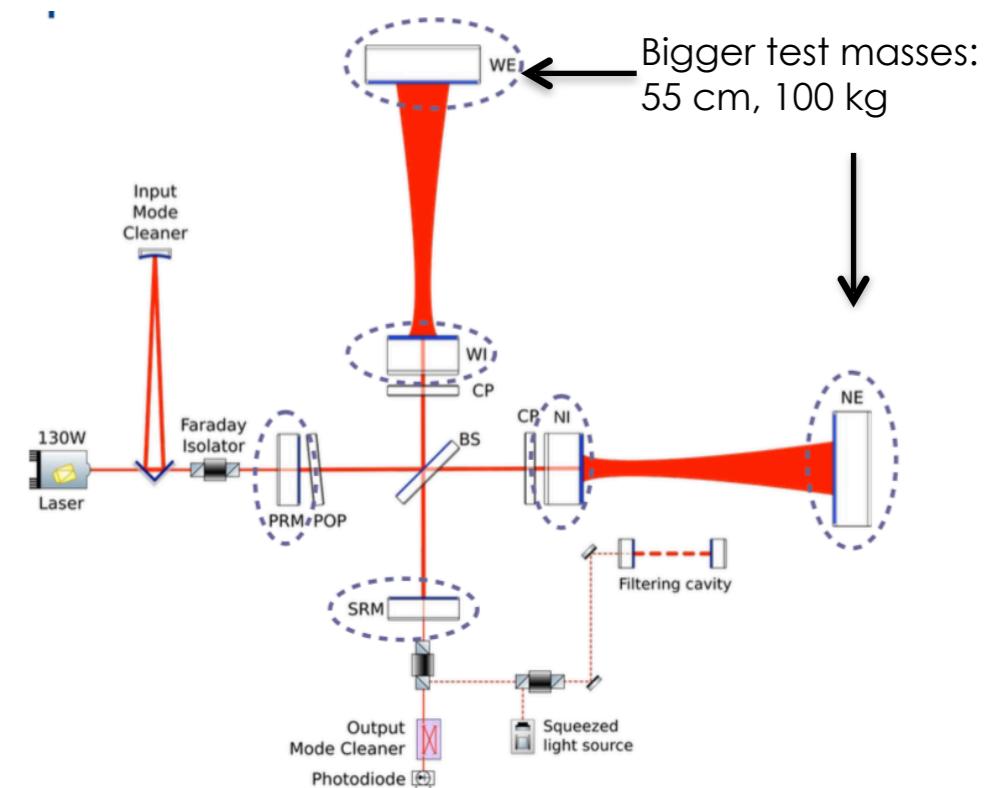
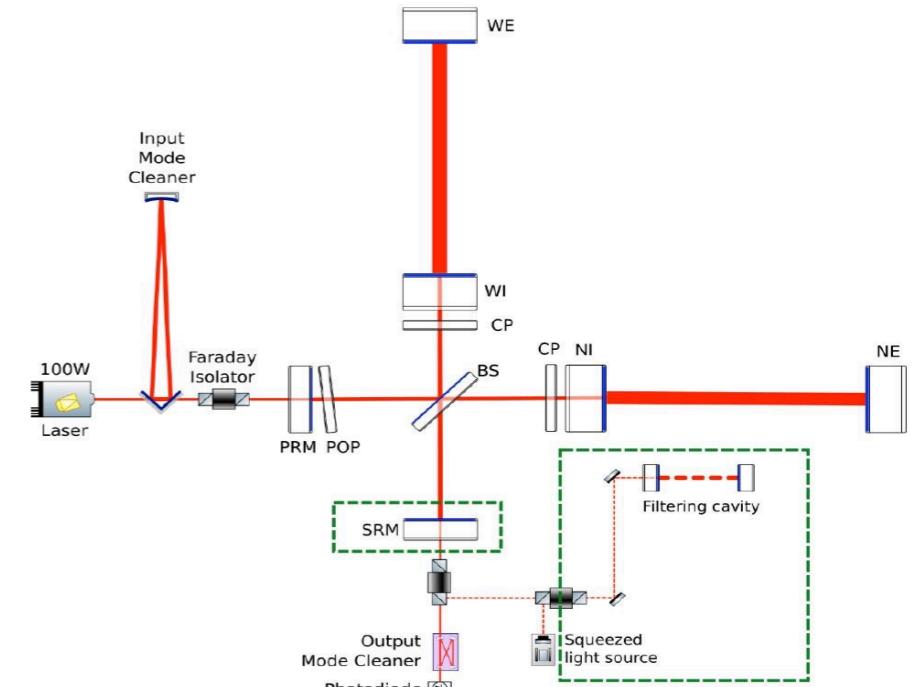
At present:

The IFO and filter cavity has been locked

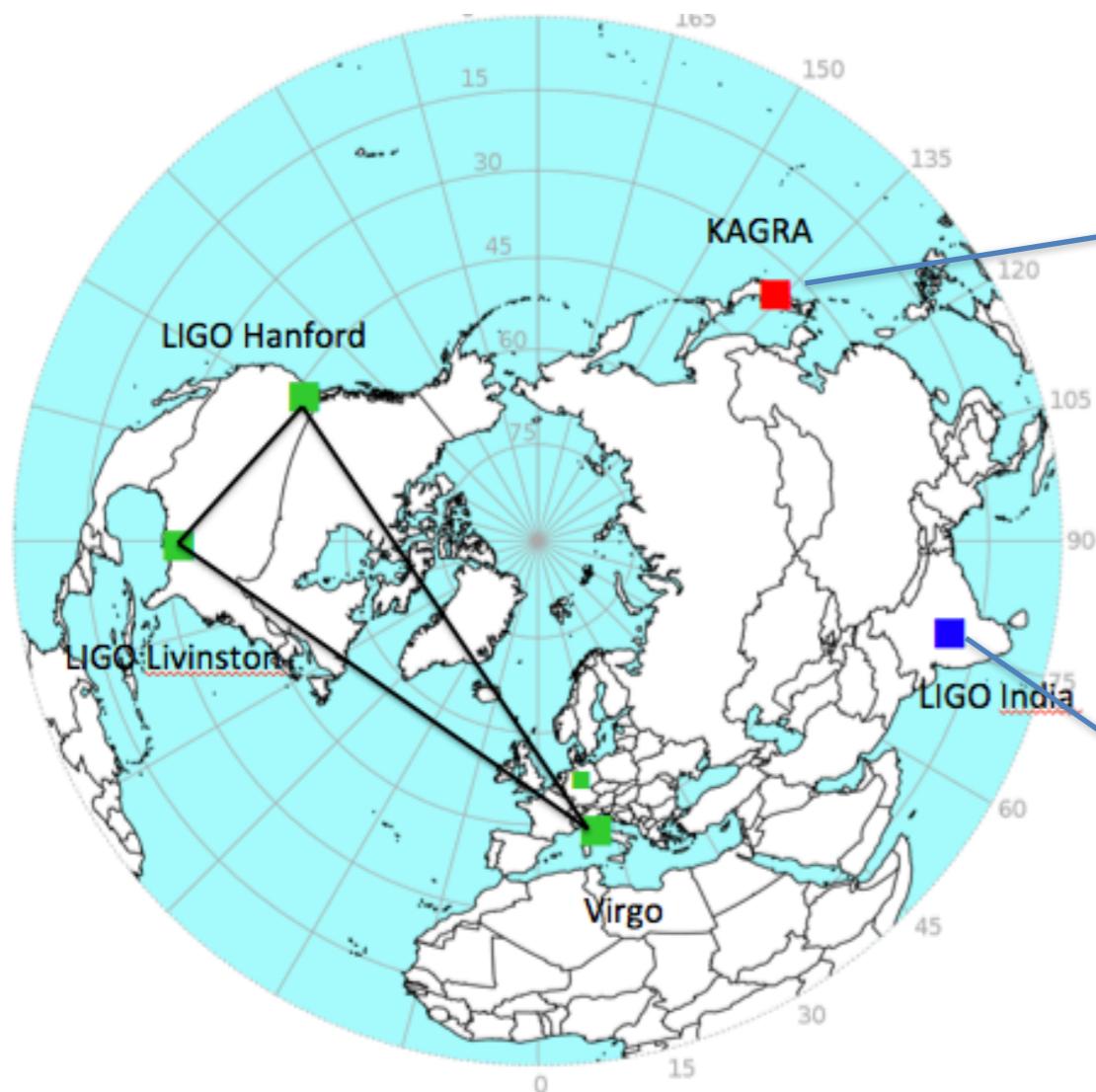
Noise hunting will take place in 1st half of 2022

04 starting date to be announced in Nov.

Most likely, second half of 2022



Kagra & LIGO India



KAGRA

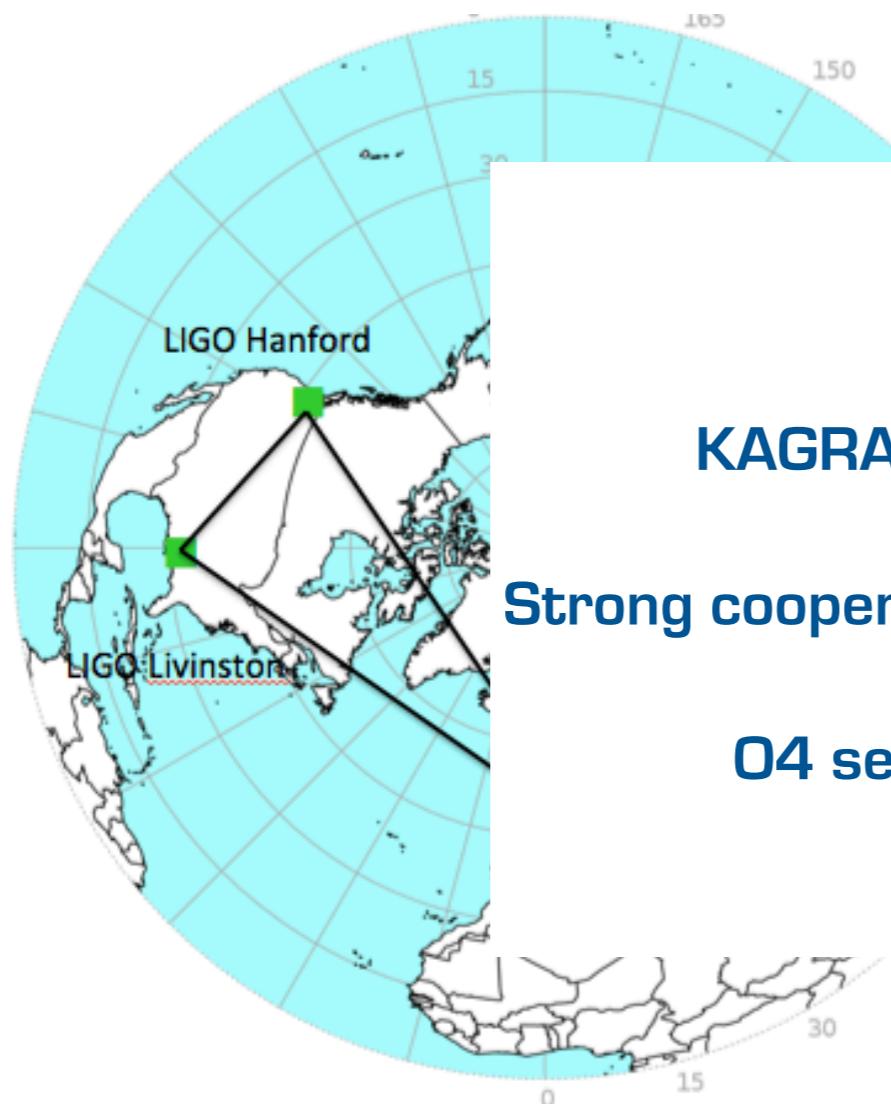


<https://gwcenter.icrr.u-tokyo.ac.jp/en/>



LIGO India

Kagra & LIGO India



KAGRA on track to join O4.

Strong cooperation on data analysis etc.

O4 sensitivity uncertain



KAGRA

inter.icrr.u-tokyo.ac.jp/en/



LIGO India

O4/O5 detection 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) [$E_{\text{GW}} = 10^{-2} M_{\odot} c^2$]	aLIGO	50	60	80–90	110–120	210
	AdV	-	25	35	65–80	100–155
	KAGRA	-	-	5–25	25–95	95+
Burst Range (kpc) [$E_{\text{GW}} = 10^{-9} M_{\odot} c^2$]	aLIGO	15	20	25–30	35–40	70
	AdV	-	10	10	20–25	35–50
	KAGRA	-	-	0–10	10–30	30+

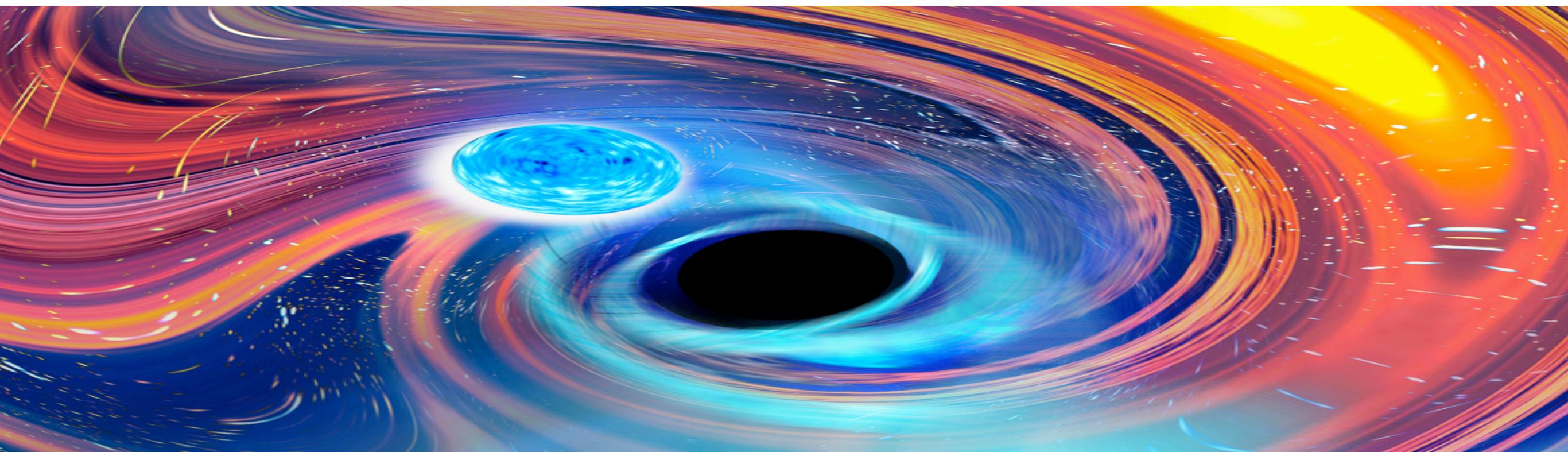
O4 Event number predictions

Observation Run	Network	Expected BNS Detections	Expected NSBH Detections	Expected BBH Detections
O3	HLV	1^{+12}_{-1}	0^{+19}_{-0}	17^{+22}_{-11}
O4	HLVK	10^{+52}_{-10}	1^{+91}_{-1}	79^{+89}_{-44}

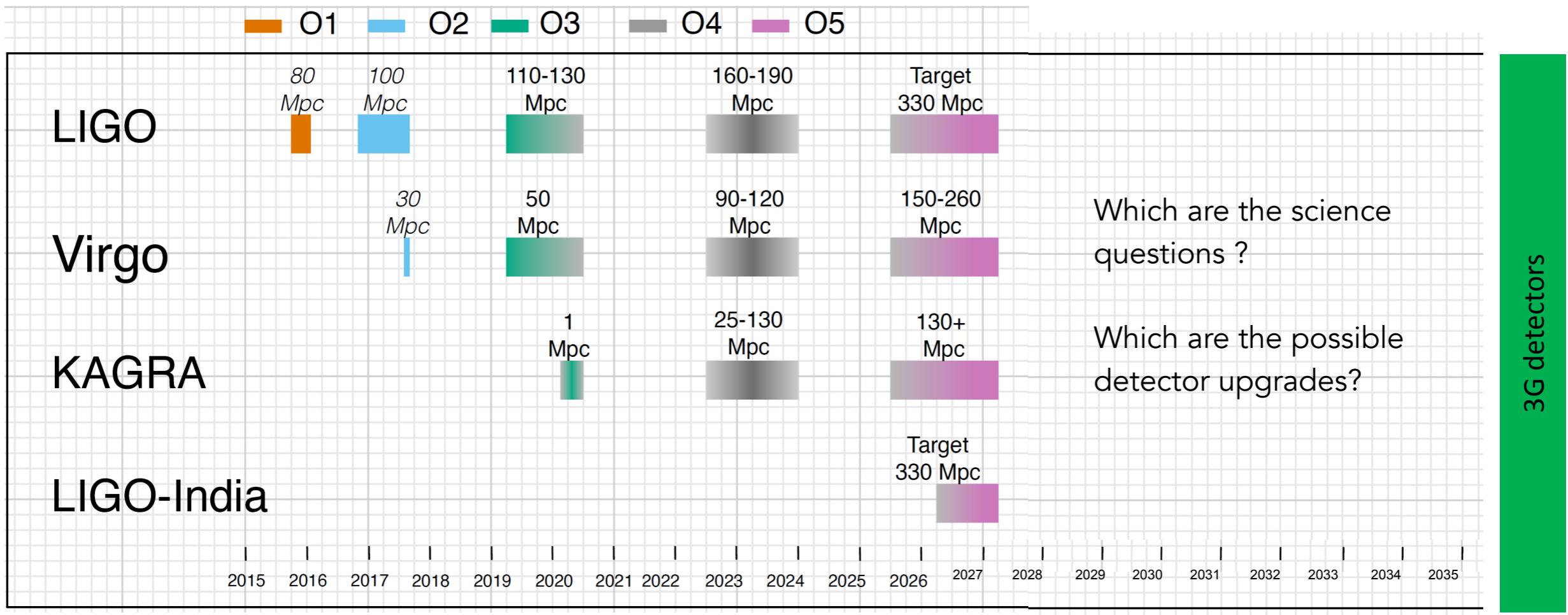
		Area (deg ²) 90% c.r.	Area (deg ²) 90% c.r.	Area (deg ²) 90% c.r.
O3	HLV	270^{+34}_{-20}	330^{+24}_{-31}	280^{+30}_{-23}
O4	HLVK	33^{+5}_{-5}	50^{+8}_{-8}	41^{+7}_{-6}

		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	120^{+19}_{-24}	860^{+150}_{-150}	16000^{+2200}_{-2500}
O4	HLVK	52^{+10}_{-9}	430^{+100}_{-78}	7700^{+1500}_{-920}

Post-05



Post-O5



towards the infrastructure limits

Post-O5

Studies have begun on data taking and detector improvement

Goal is to improve O5 sensitivity by x2

Investigate risk reduction for 3G detectors

Possible shaping of high frequency noise curve for EOS investigations

Possible upgrades:

Higher input power

Improved thermal compensation system

Improved frequency dependent squeezing

New coatings

Larger mirrors/beams on all test masses

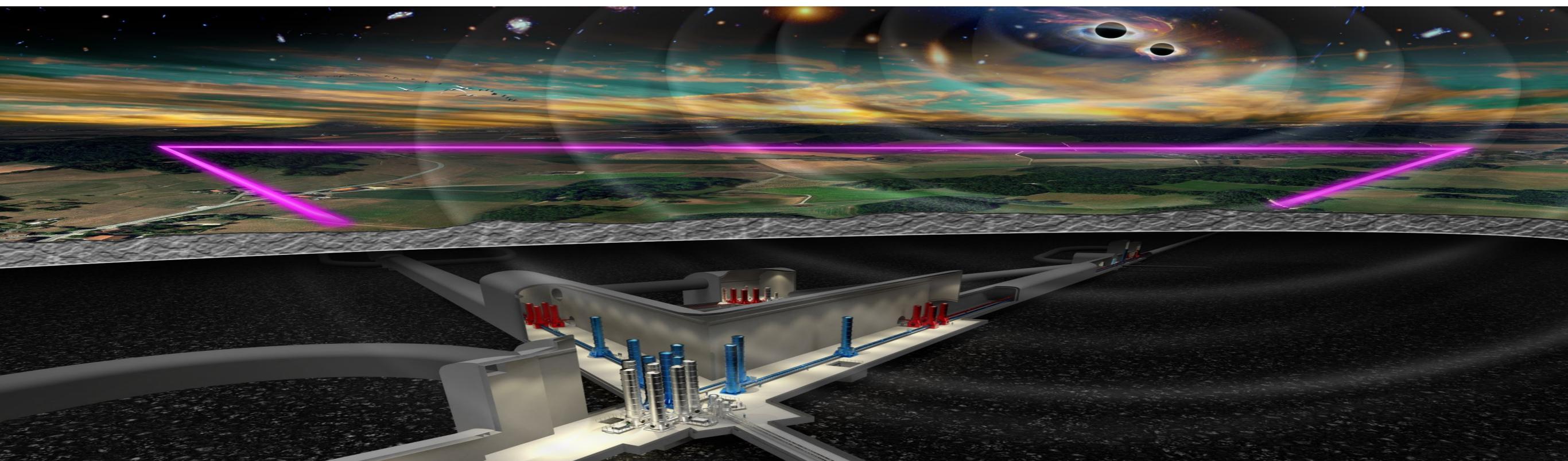
Enhanced Newtonian noise subtraction

Better suspensions

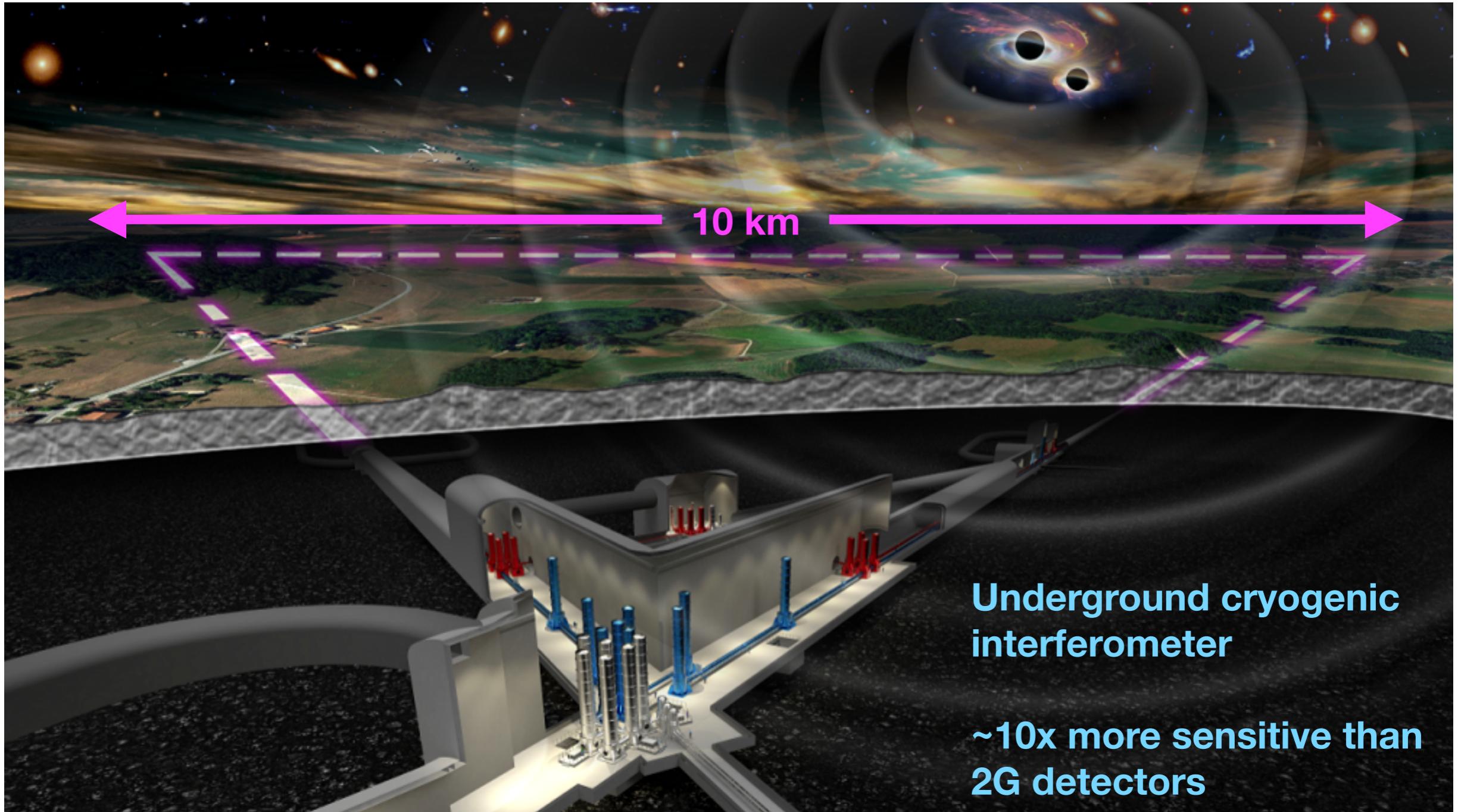
Scattered light mitigation



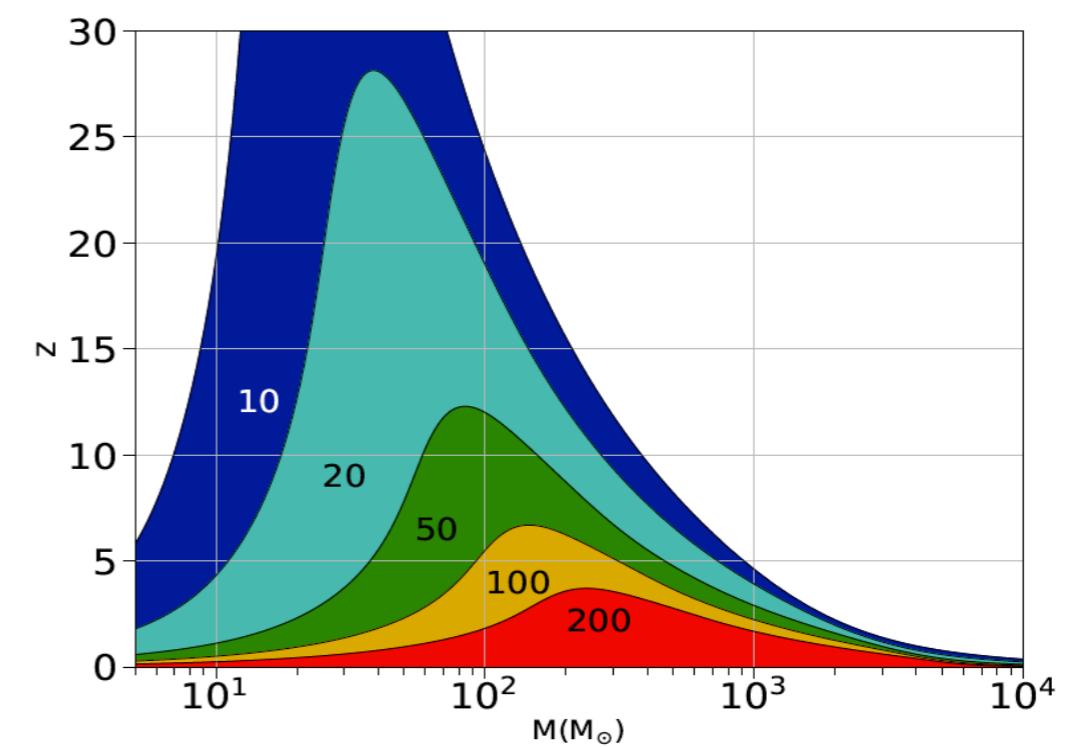
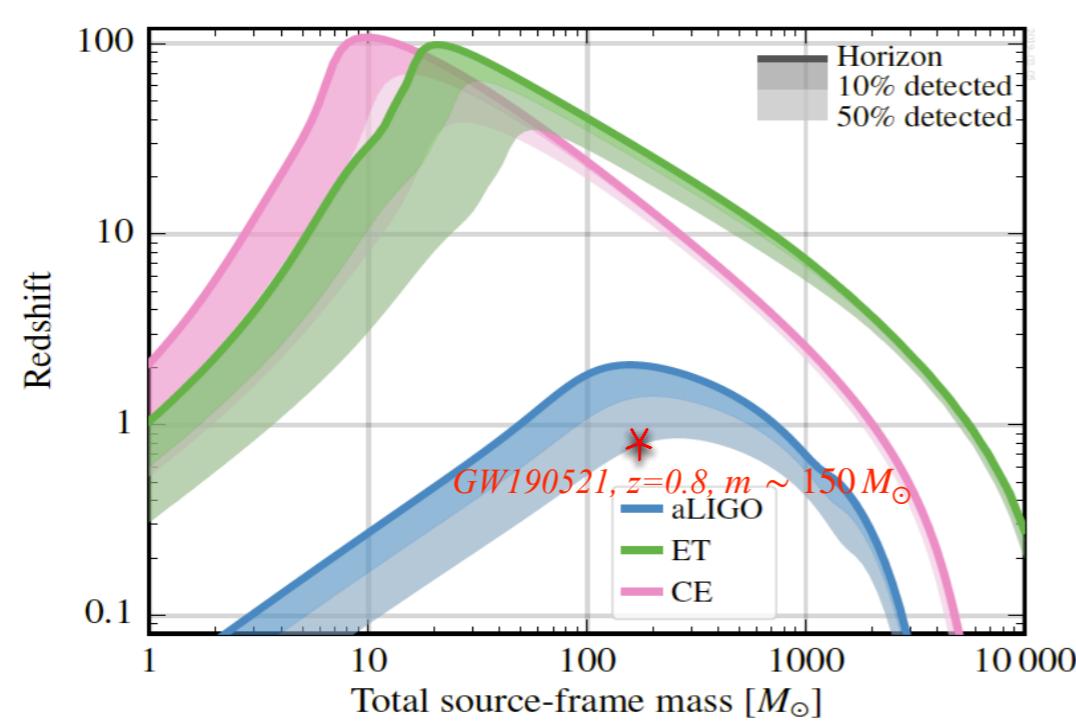
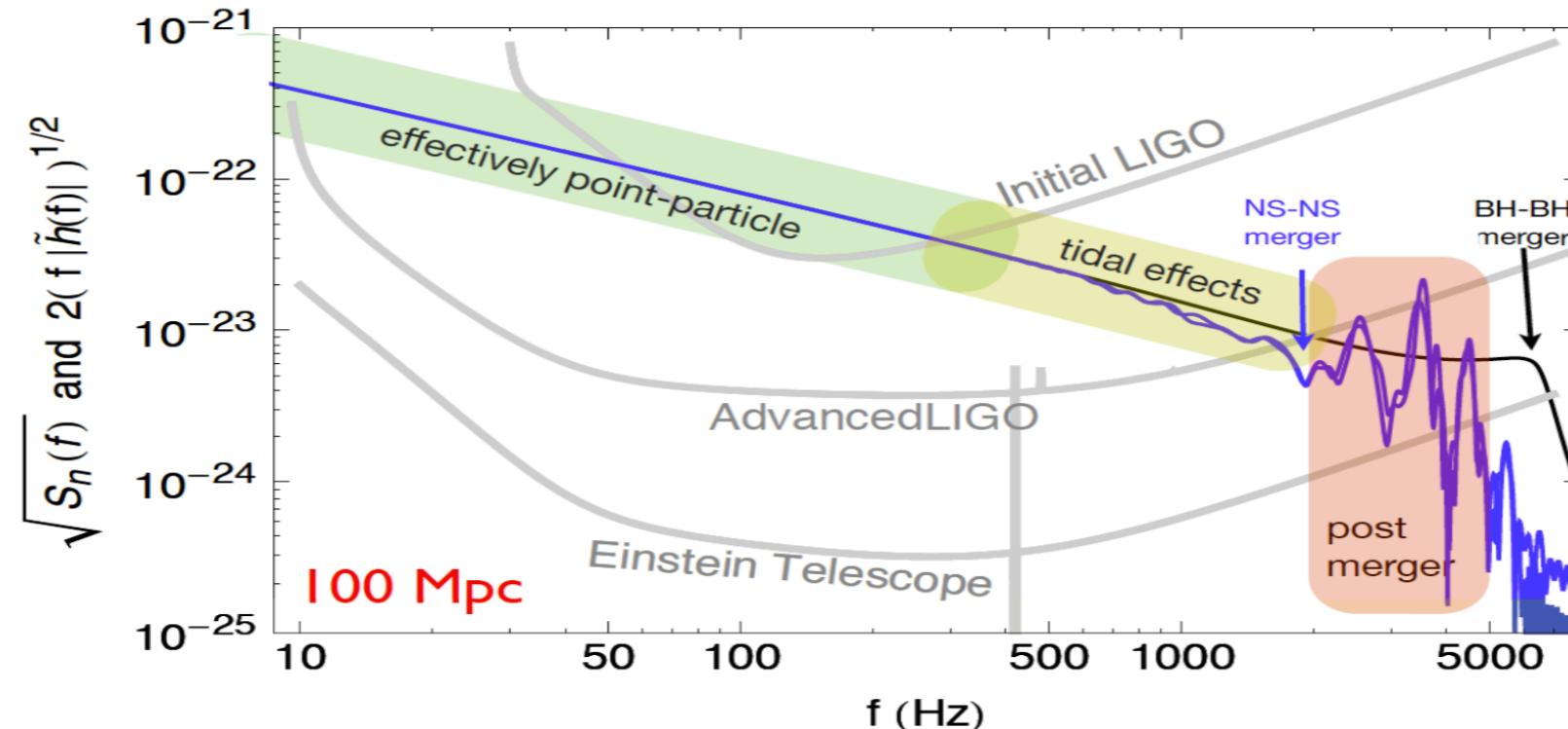
Einstein Telescope



Einstein Telescope

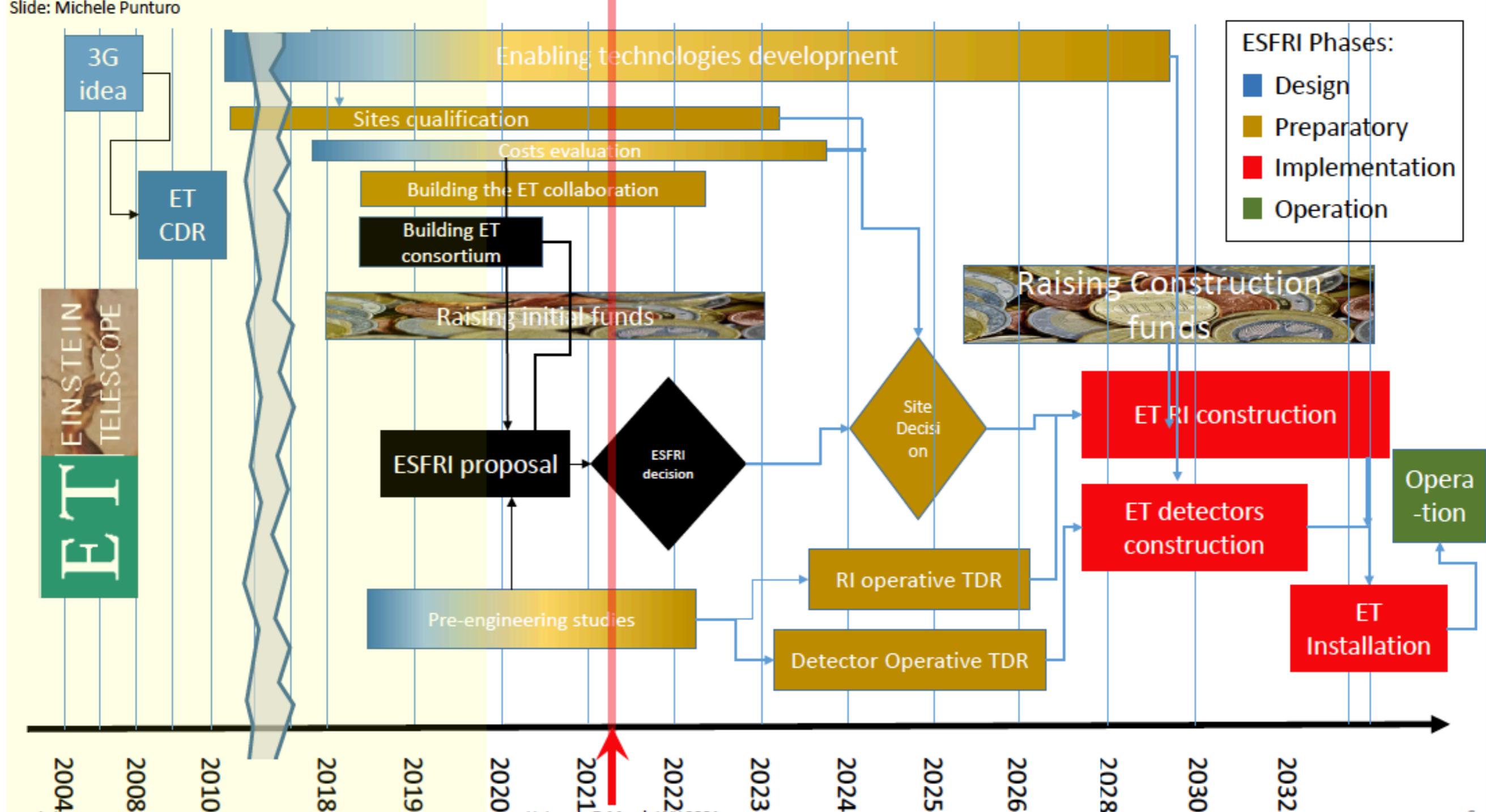


Einstein Telescope



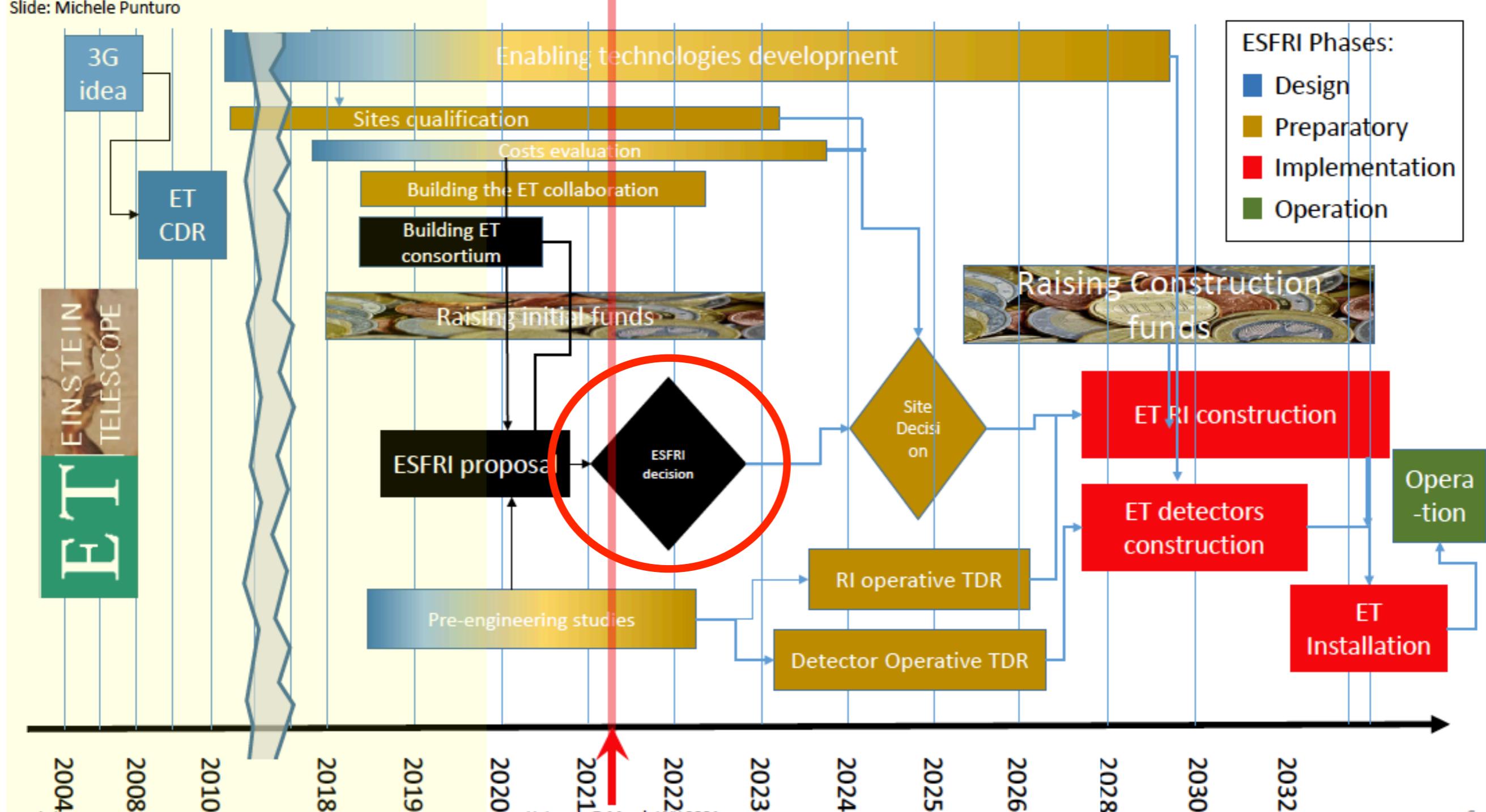
ET Timeline

Slide: Michele Punturo



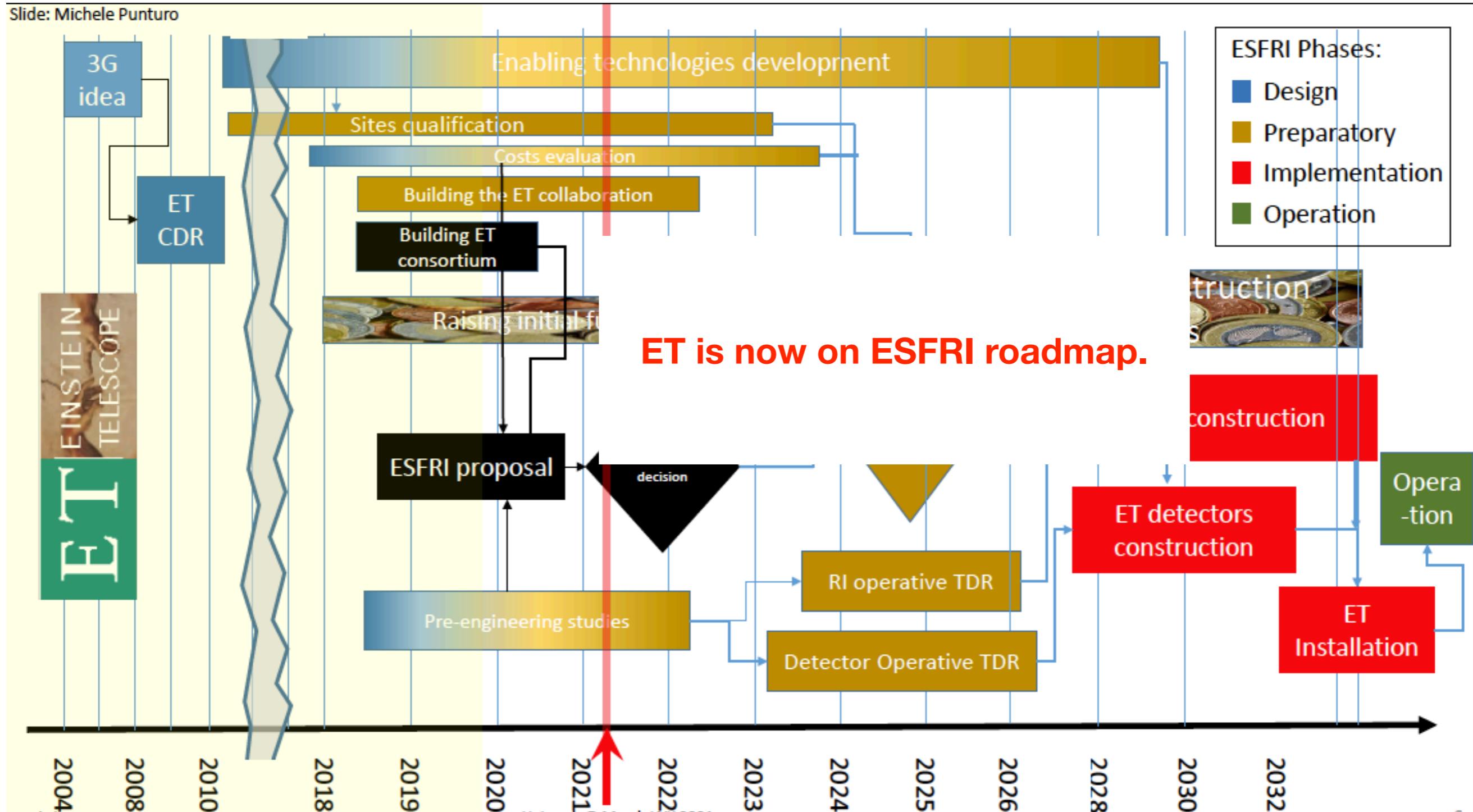
ET Timeline

Slide: Michele Punturo



ET Timeline

Slide: Michele Punturo

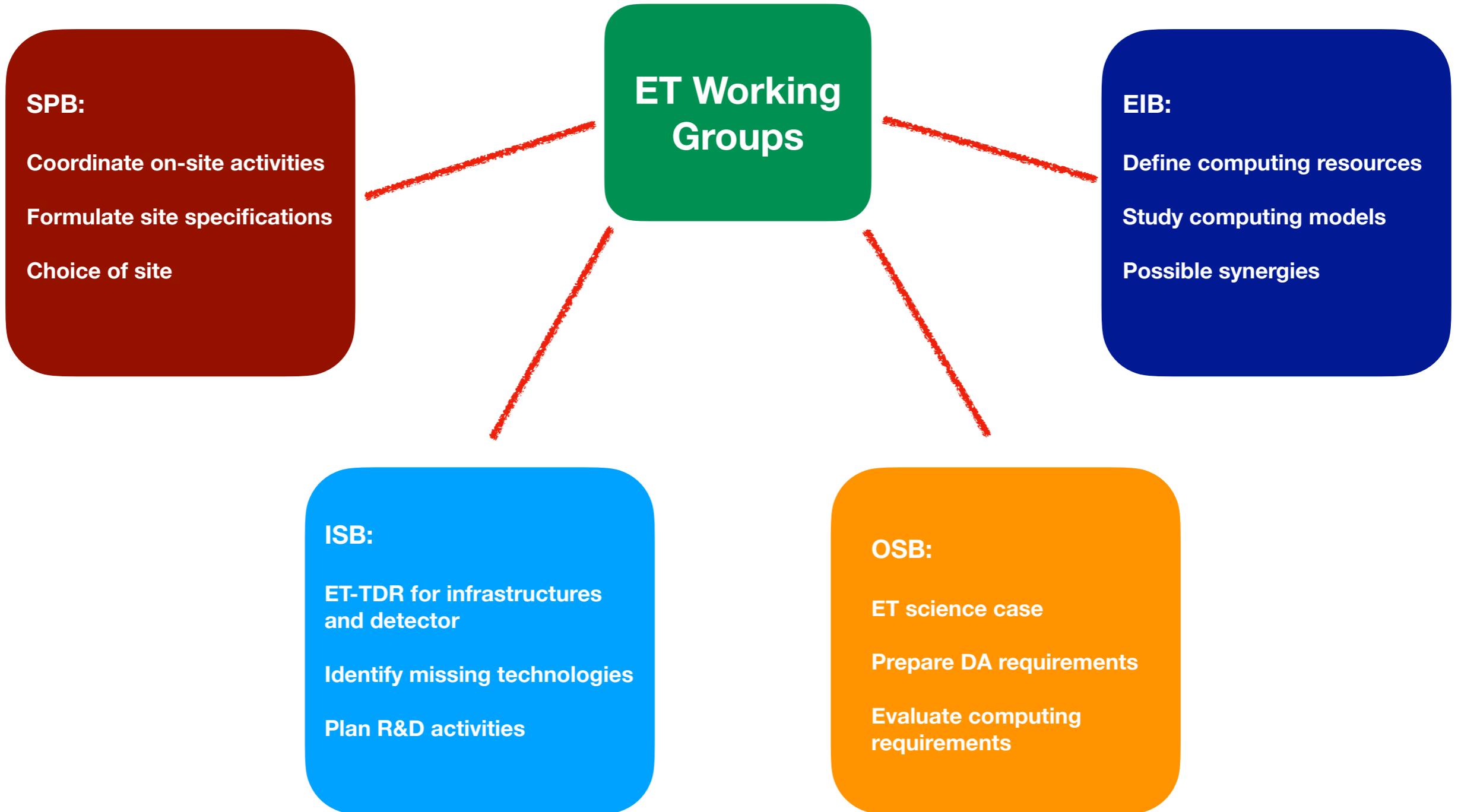


Einstein Telescope

- Currently putting together the collaboration
- A steering committee exists and meets weekly
- Chairs have been assigned to various working groups
- Working groups themselves are currently being organised
- Close collaboration with members of Cosmic Explorer, as well as LIGO, Virgo and KAGRA



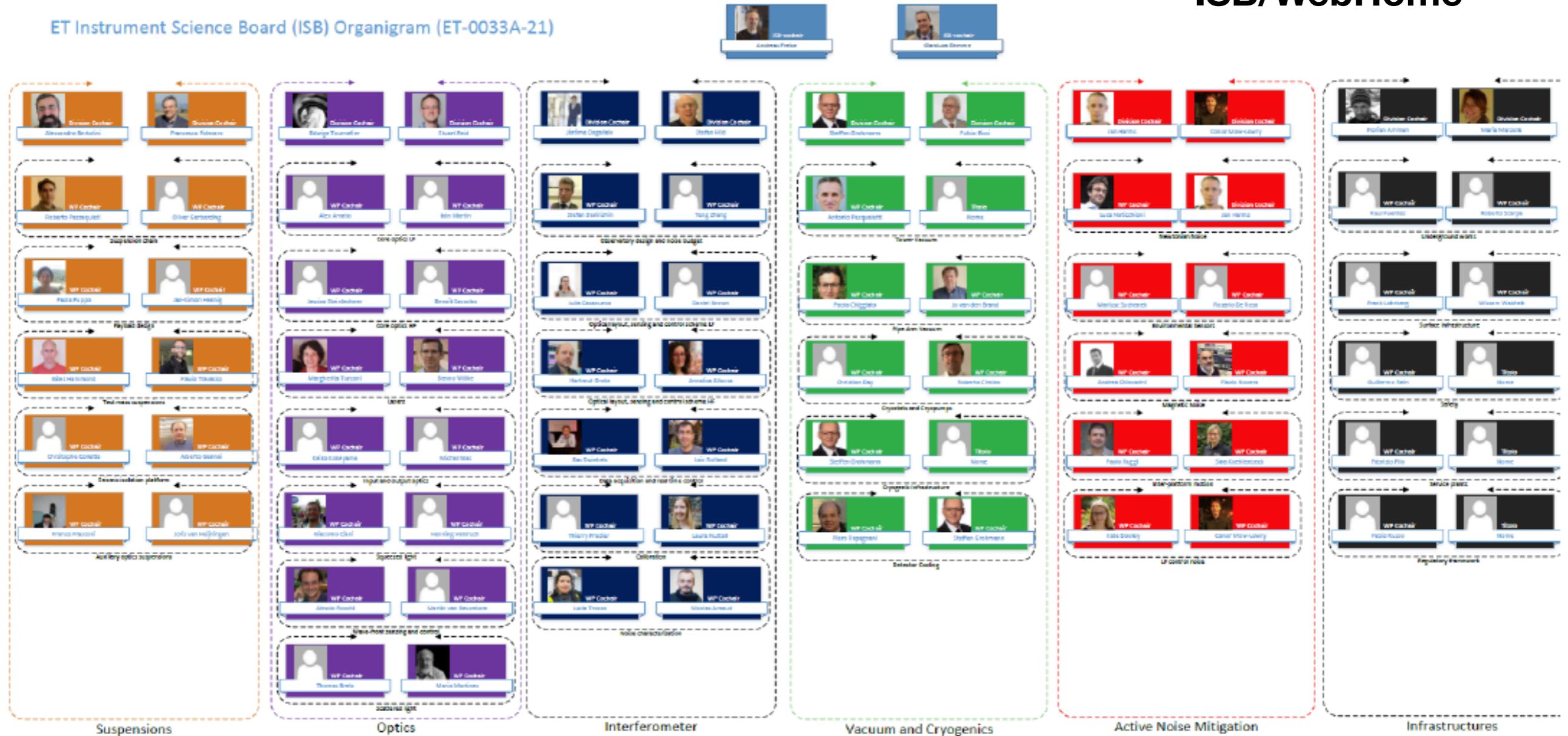
Einstein Telescope



ET-ISB

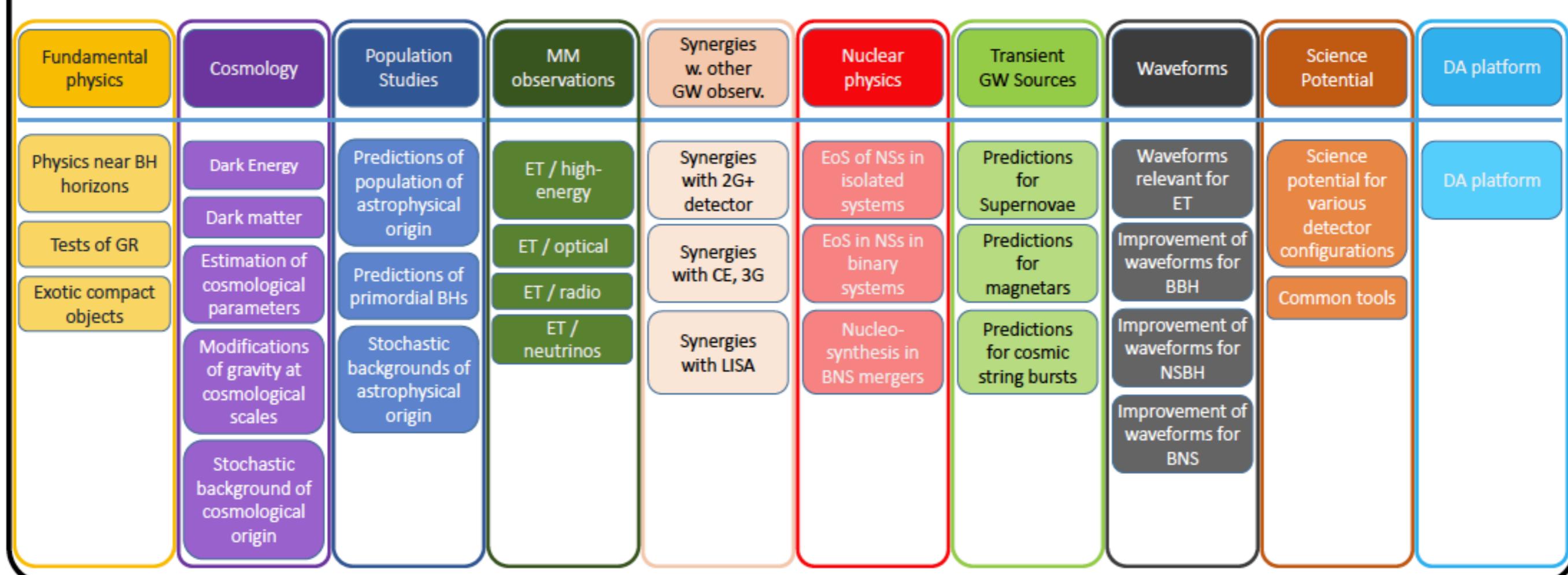
[https://wiki.et-gw.eu/
ISB/WebHome](https://wiki.et-gw.eu/ISB/WebHome)

ET Instrument Science Board (ISB) Organigram (ET-0033A-21)



ET-OSB

Marica Branchesi - Michele Maggiore - Ed Porter



- Investigate the science case for ET, especially for different configurations
- Develop more sophisticated waveform models, incorporating higher order modes, EOS, and possible deviations from GR
- Investigate population models at near and high redshift, and the consequence for stochastic backgrounds
- Develop an infrastructure for MMA, as well as a deep connection with external telescopes/facilities
- Investigate fundamental physics in the vicinity of compact objects, dark energy and dark matter, and the existence of exotic objects such as primordial black holes
- Investigate cosmology at high redshift, including networks of cosmic strings, and precise estimates of Hubble's constant.
- Develop DA tools and analyses for CBCs, and transient events such as SN, cosmic string kinks/cusps etc.
- Develop synergies with other GW observatories, i.e. 2G, Cosmic Explorer, LISA

ET-OSB: Div S

- The goal of Div S is to build a bridge to communicate, coordinate and collaborate with other neutrino and electromagnetic observatories.
- Div S is governed by the OSB chairs, the MMA division chairs, plus a representative from each experiment

High-energy

- SVOM
- Einstein Probe
- GECAM
- eXTP
- Athena
- Mission concept THESEUS
- Mission Concept TAP
- Mission Concept GAMOW Explorer
- HERMES constellation
- AMEGO

UV/Optical/infra-red

- Vera Rubin Observatory
- ULTRASAT
- JWST
- The Nancy Roman Telescope
- ESO : NTT+SOXS
- ESO : VLT (optical and NIR instrumentation)
- ESO : ELT
- ESO: 4MOST
- Euclid (indirect synergy)
- WAVE
- DESI

RADIO

- SKA
- VLBI
- VLA(?)

Very High Energy

- CTA

NEUTRINO EXPERIMENTS

- Hyper-Kamiokande
- KM3NET
- Ice-Cube/GEN 2

+ ESO, ESA, European collaborations such as ENGRAVE, and European infrastructure/networks such as ESCAPE/AHEAD2020 etc.



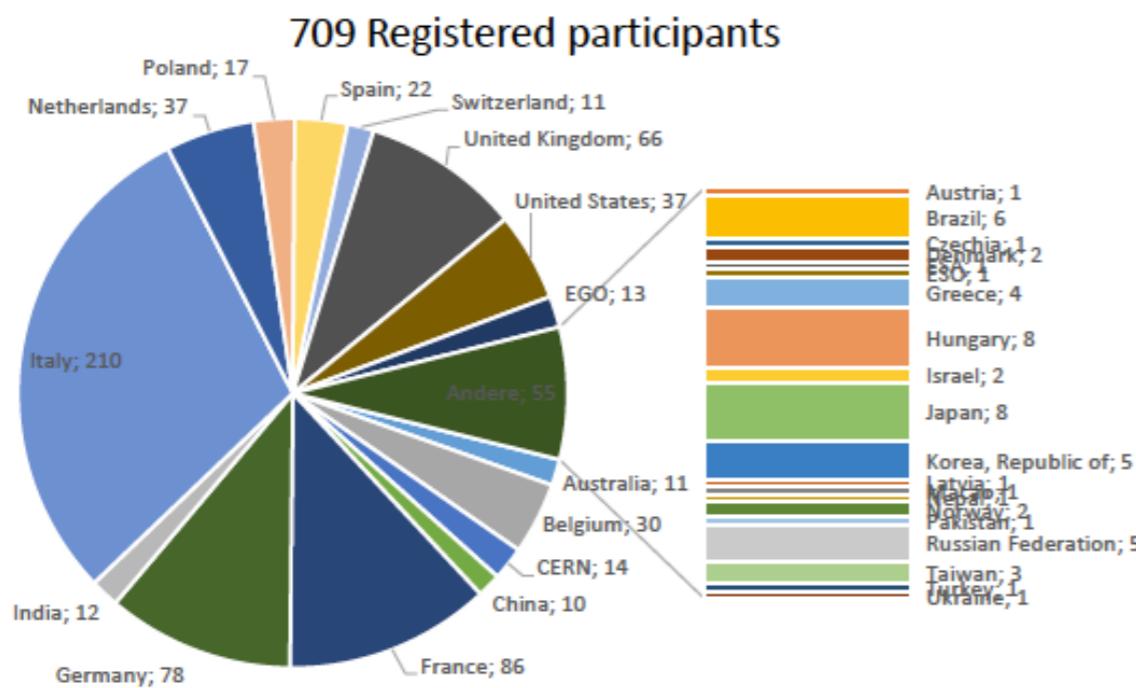
Kick Off Workshop of the Einstein Telescope Observational Science Board



<https://indico.ego-gw.it/event/240/>

Currently 447 participants

Einstein Telescope



Next ET Symposium: Nov 30th - Dec 3rd
<https://indico.in2p3.fr/event/20576/>

Conclusion

- O1 - O3 has been full of surprises, with many unexpected events
- Final analysis of O3 is concluding. O3b data to be released in November
- Preparation currently ongoing for O4
- Investigations have begun for post-O5
- Einstein Telescope is now on the ESFRI roadmap and the community is beginning to form.

