Ground-based Gravitational-wave detectors: Plans for the coming decade (and a bit beyond)

HEAD 2020

Chicago 20 March 2018

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For the LIGO and Virgo Scientific Collaborations


A
B
C

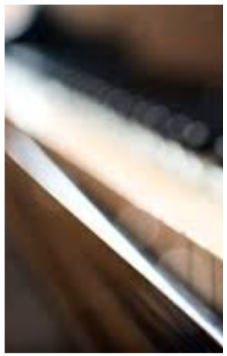


A-23





Realistic 3D Keyboa



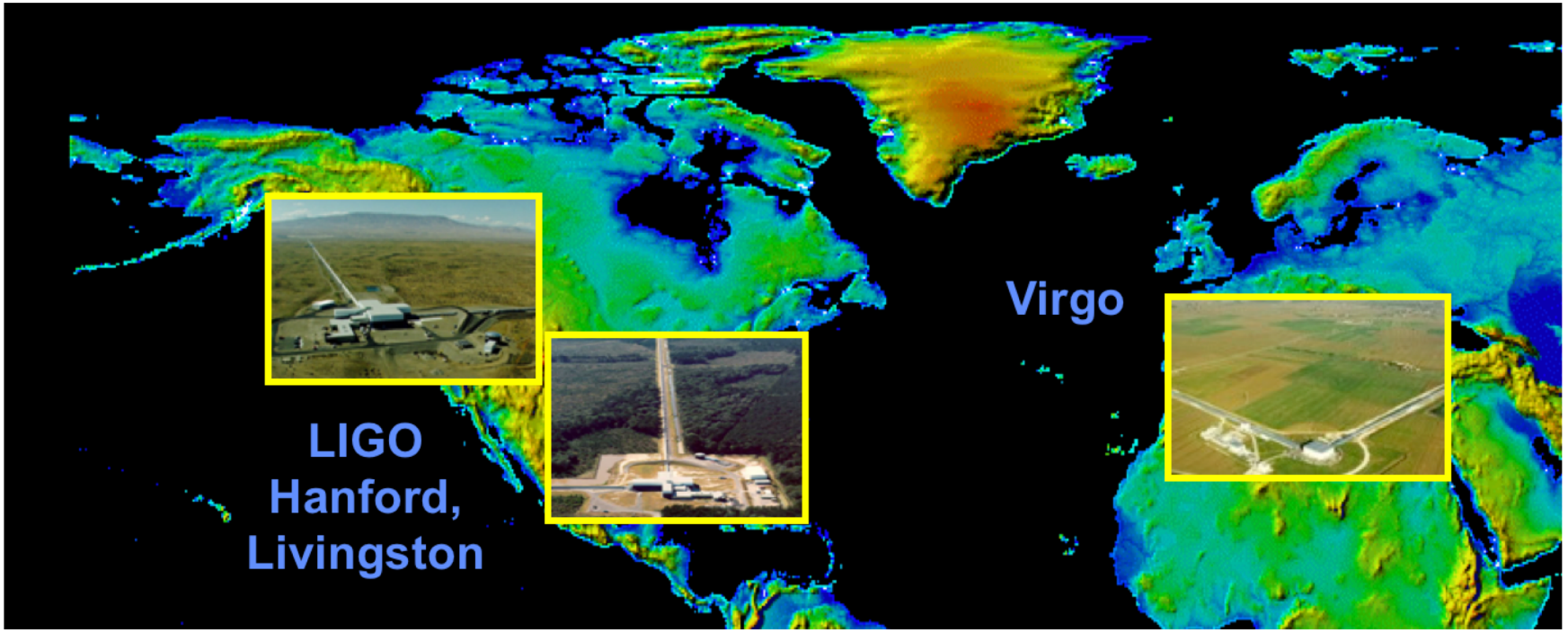








Ground based detectors



- Initial observatories, and instruments, constructed starting in mid-90's
  - » NSF Physics for LIGO; Virgo's support from CNRS and INFN
- Observed, setting upper limits until 2011
- Both Virgo and LIGO undertook a complete rework of the instruments
- Advanced LIGO came on line in 2015 – First discovery 15 Sept 2015
- Advanced Virgo came on line in 2017 – First signal 14 August 2017

….then, on 17 August 2018….

Multimessenger Observations

Approximate timeline:

GW170817 - August 17, 2017 12:41:04 UTC = t_0

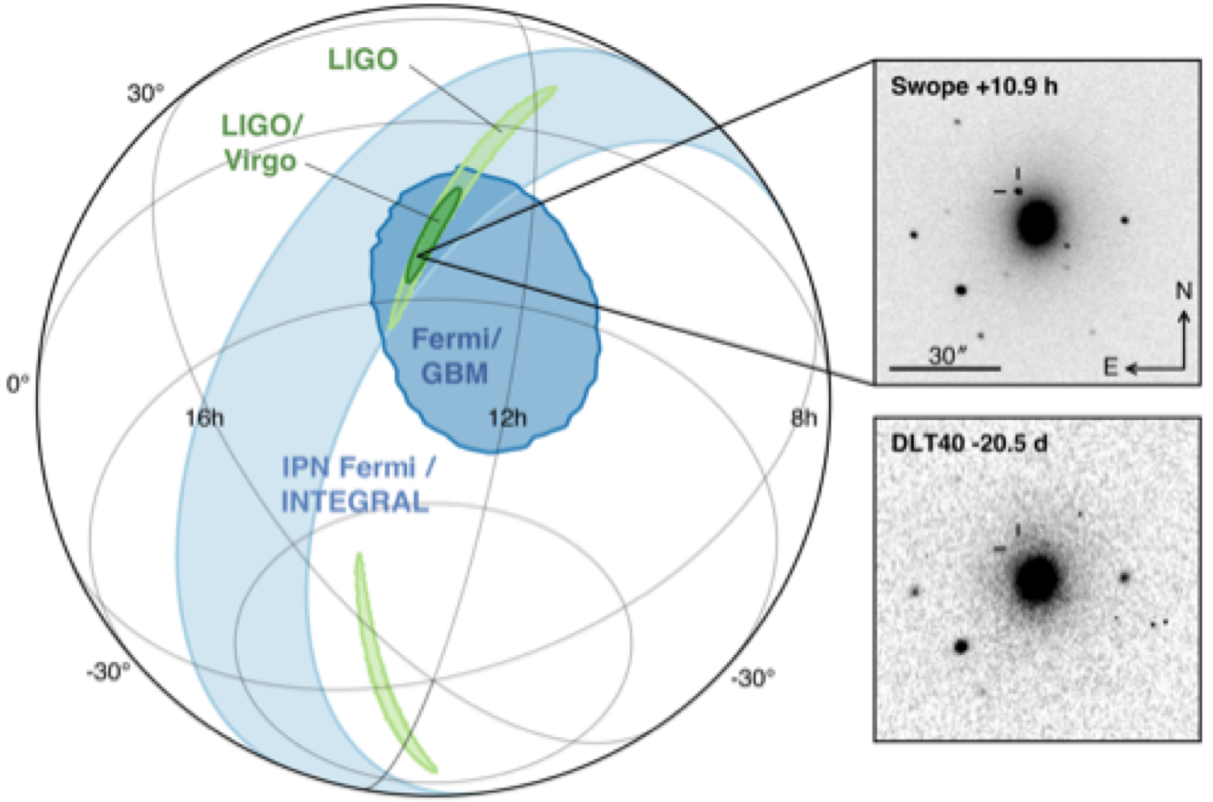
GRB 170817A
t_0 + 2 sec

LIGO signal found
t_0 +6 minutes

LIGO-Virgo GCN reporting BNS signal associated with the time of the GRB
t_0 +41 minutes

SkyMap from LIGO-Virgo
t_0 + 4 hours

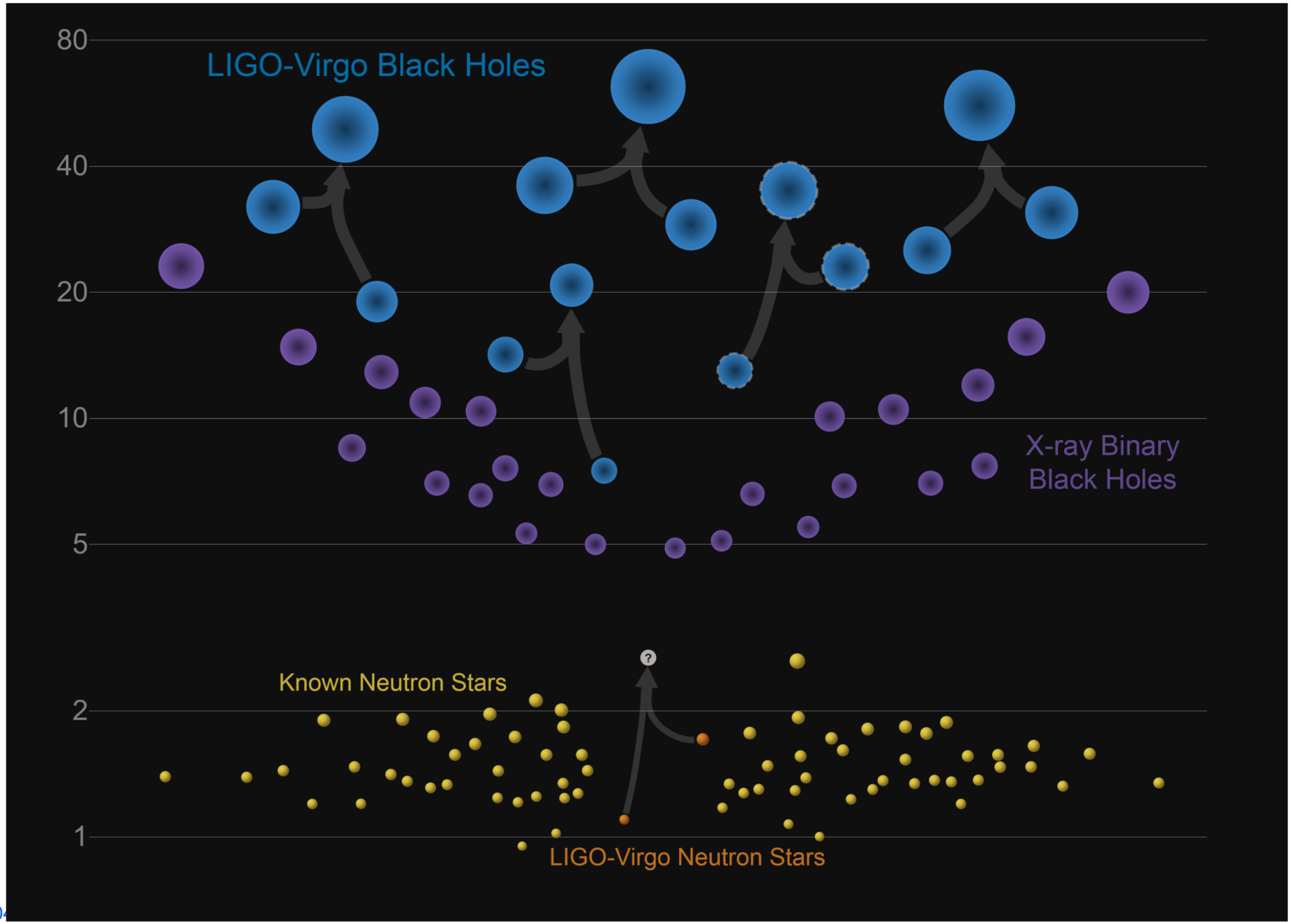
Optical counterpart found
t_0 + 11 hours



- The localisation region became observable to telescopes in Chile 10 hours after the event time (wait for nightfall!)
- Approximately 70 ground- and space- based observatories followed-up on this event

B. P. Abbott, *Multi-messenger Observations of a Binary Neutron Star Merger*, 2017, ApJL in press. doi:10.3847/2041-8213/aa91c9

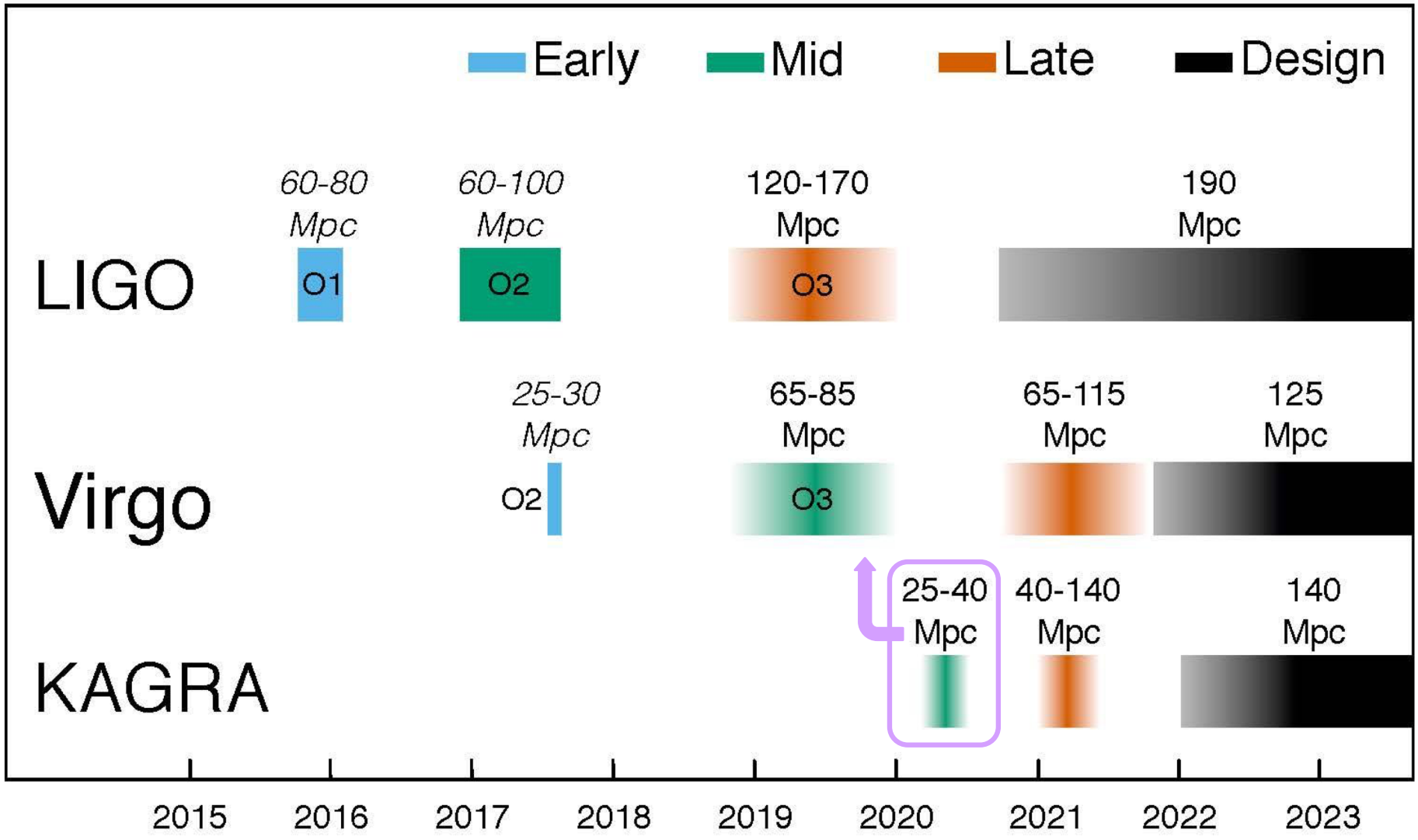
Visual summary of signals to date



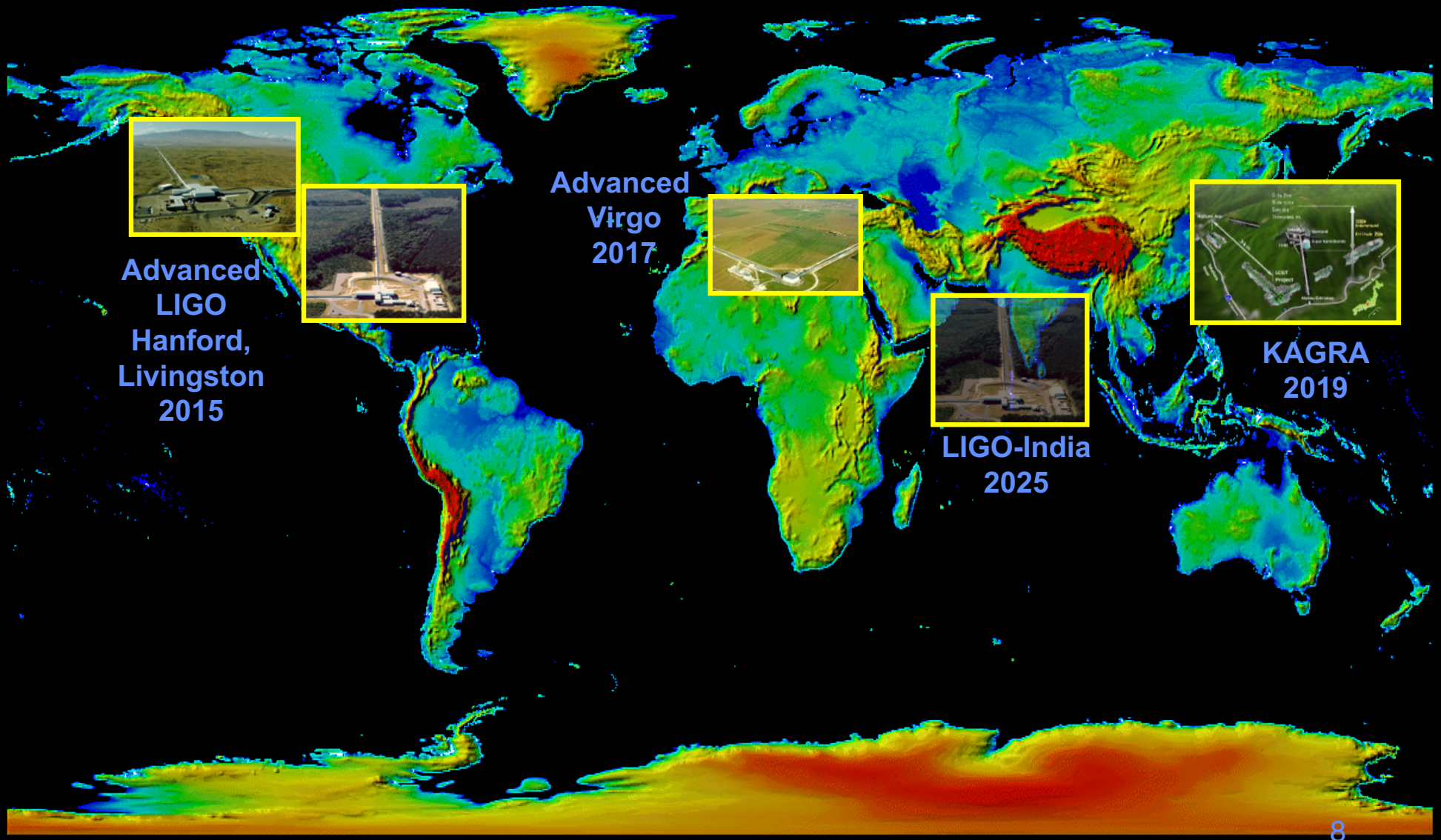
Near Future: 2019-20

- O2 – The Second Advanced detector Observing Run – was undertaken at 1/3-1/2 of the design sensitivity of the LIGO and Virgo instruments
- Currently both LIGO and Virgo improving sensitivity of instruments:
  - » Introduction of higher laser power and use of 'squeezed light' (better high frequency performance)
  - » Changes in Virgo Suspension (better low-frequency performance)
  - » Better baffling/scattered light handling (better stationarity)
  - » (for Advanced LIGO, these are undertaken with LIGO Lab Operating funds, and anticipated as part of the commissioning)
- Next: ~1 year long O3 run
  - » Start in Winter (late 2018/early 2019)
  - » LIGO with a NS-NS 'reach' of ~120 Mpc, Virgo ~65 Mpc
- **What can we expect from O3? Best guesses:**
  - » **BBH: Several per month to several per week**
  - » **BNS: 1 to 10 in the year-long run**
  - » **NSBH: N=0 not ruled out in any scenario, most give ~50% N>0**

5-year plan


Early
Mid
Late
Design
LIGO
60-80 Mpc
O1
60-100 Mpc
O2
120-170 Mpc
O3
190 Mpc
Virgo
25-30 Mpc
O2
65-85 Mpc
O3
65-115 Mpc
125 Mpc
KAGRA
25-40 Mpc
40-140 Mpc
140 Mpc
2015
2016
2017
2018
2019
2020
2021
2022
2023

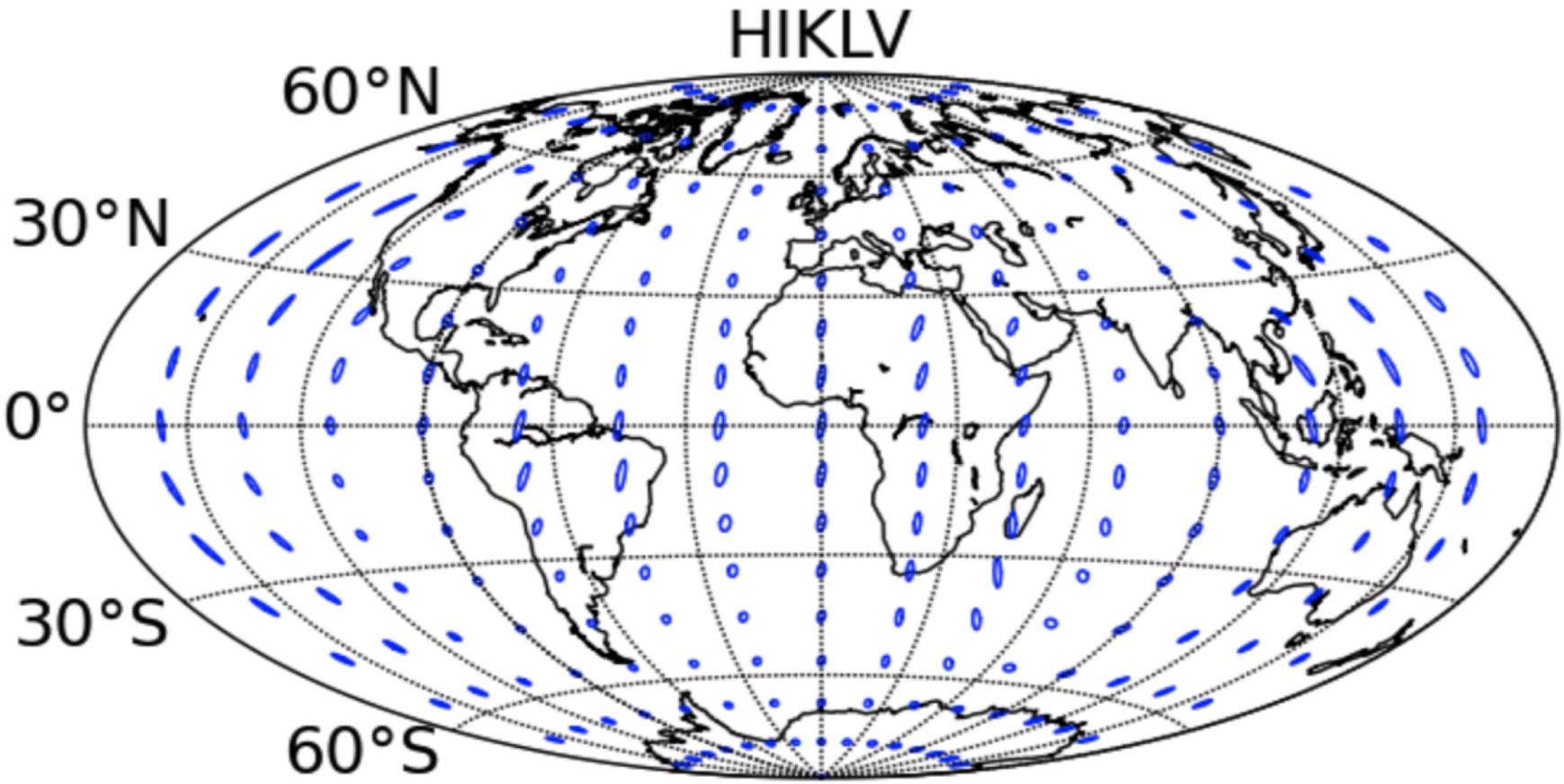
The advanced GW detector network



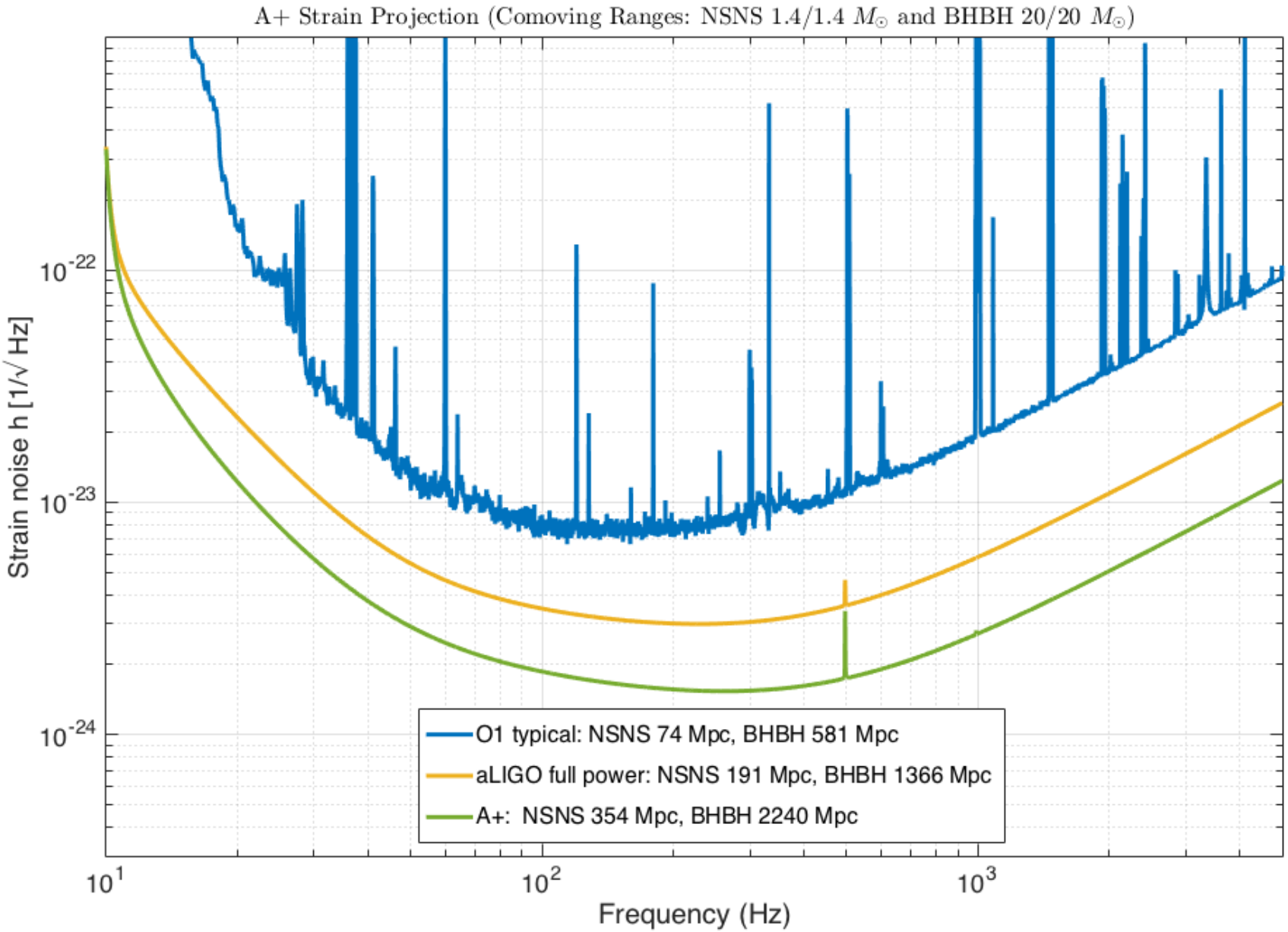
2025 Sensitivity/configuration:

5 detectors (add India and Japan)
far improved source localization

~60% in 10 sq deg



Next LIGO Improvement: A+, ~2024



A+ ‘elevator pitch’

- An incremental upgrade to aLIGO that leverages existing technology and infrastructure, with minimal new investment and moderate risk
  - » Target: factor of 1.7 increase in range over aLIGO
  - ➔ About a factor of 5 greater event rate (goes as the cube of sensitivity)
  - » “Scientific breakeven” within 1/2 year of operation
- Could be observing within 6-7 years
- Incremental cost: *a small fraction of aLIGO* -- NSF Mid-Scale Project
- Requires some technical progress on
  - » High laser power handling
  - » Low optical losses
  - » Lower-mechanical loss optical coatings
    - – (our principal thermal noise source)
- Sensitivity offers e.g., **NSNS rates of 20-200 in a year observation**

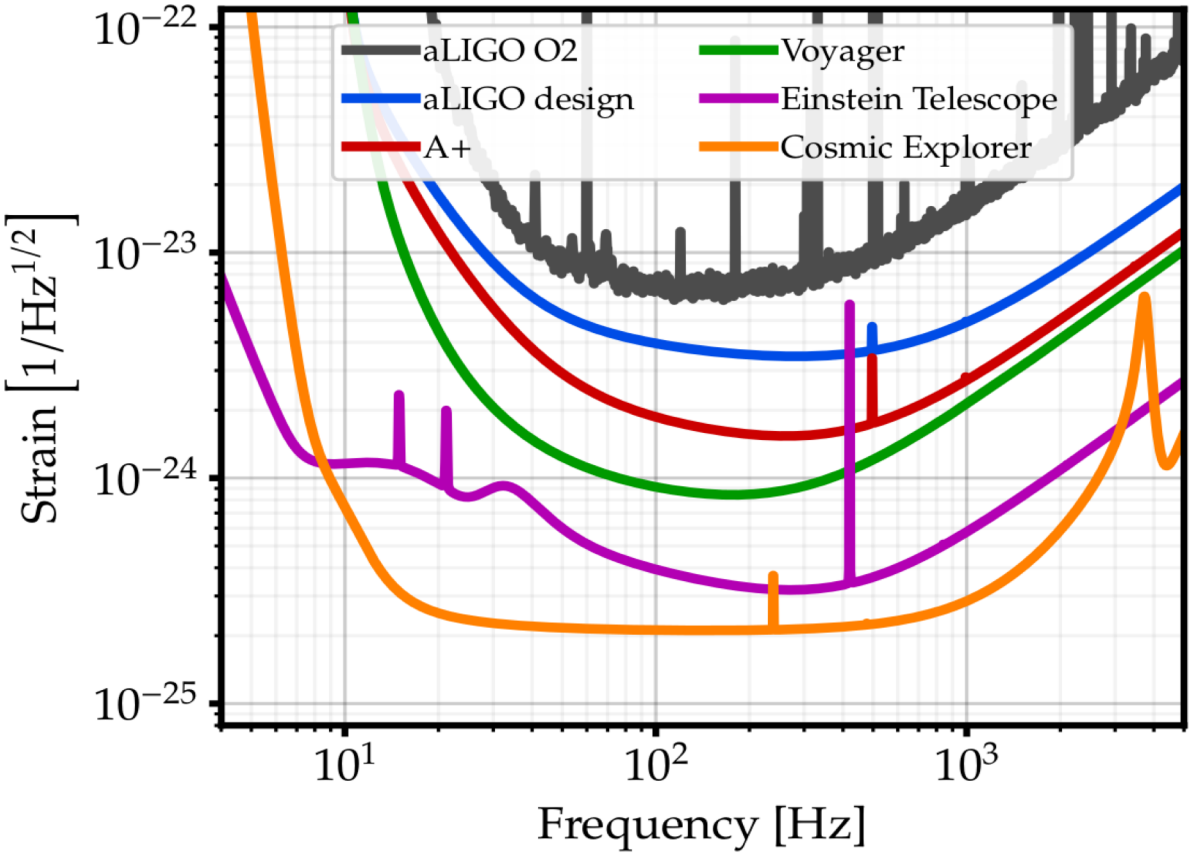
- **Proposal in preparation to NSF Physics** and the UK STFC

Evolution of detectors

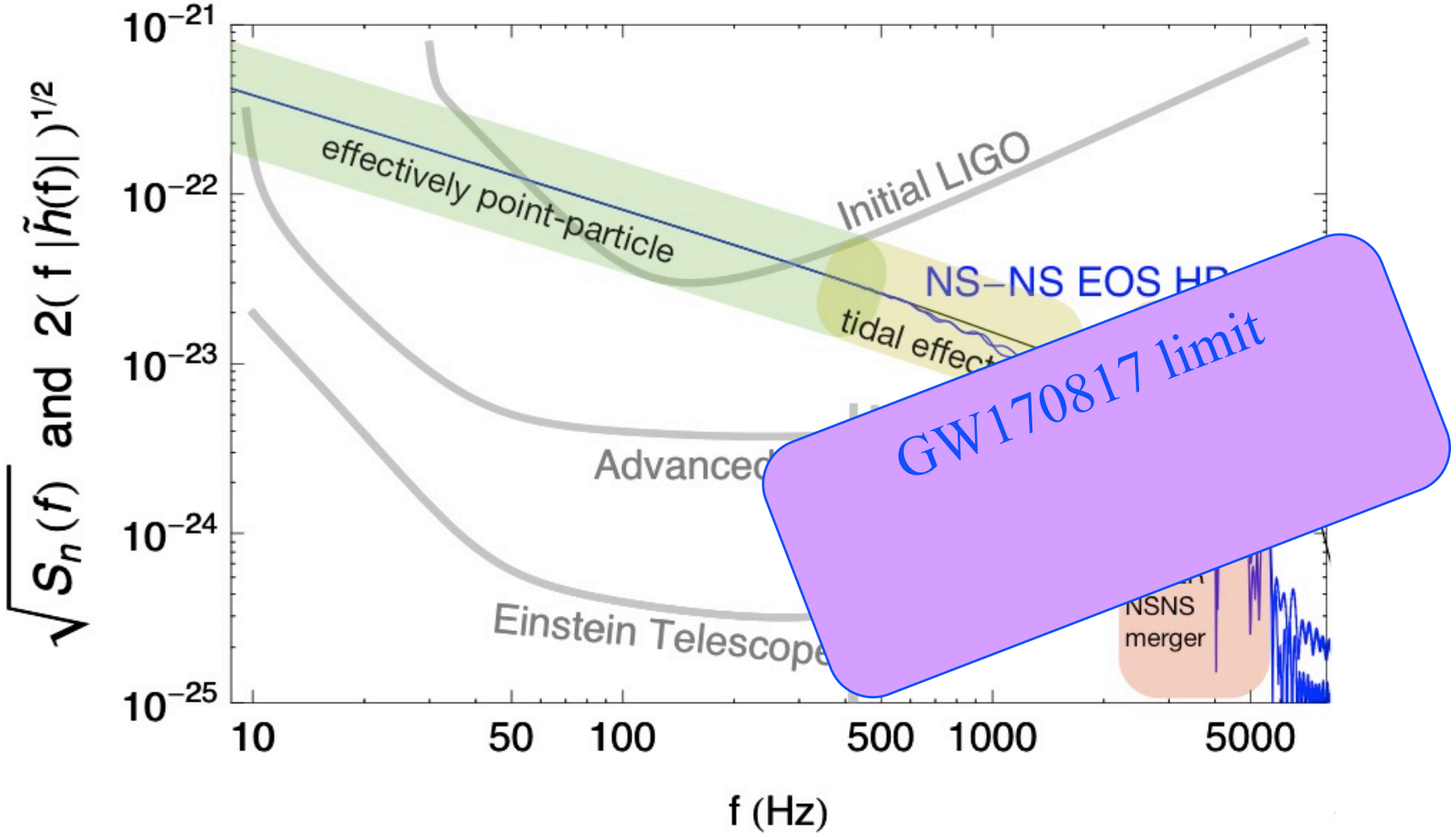
- aLIGO, AdV – commission to full sensitivity by early 2020's
- A+, AdV+ – add squeezing, lower thermal noise coatings; ~2024
- Voyager – cryogenics to reduce thermal noise; ~2028
- ..at that point there is no choice but to seek longer arms

→ Einstein Telescope

→ Cosmic Explorer



Not just about rates: With sensitivity comes new physics



Read, Schmidt, Clark and Lackey, G1700453
Read et al, Phys. Rev. D 88, 044042 (2013)

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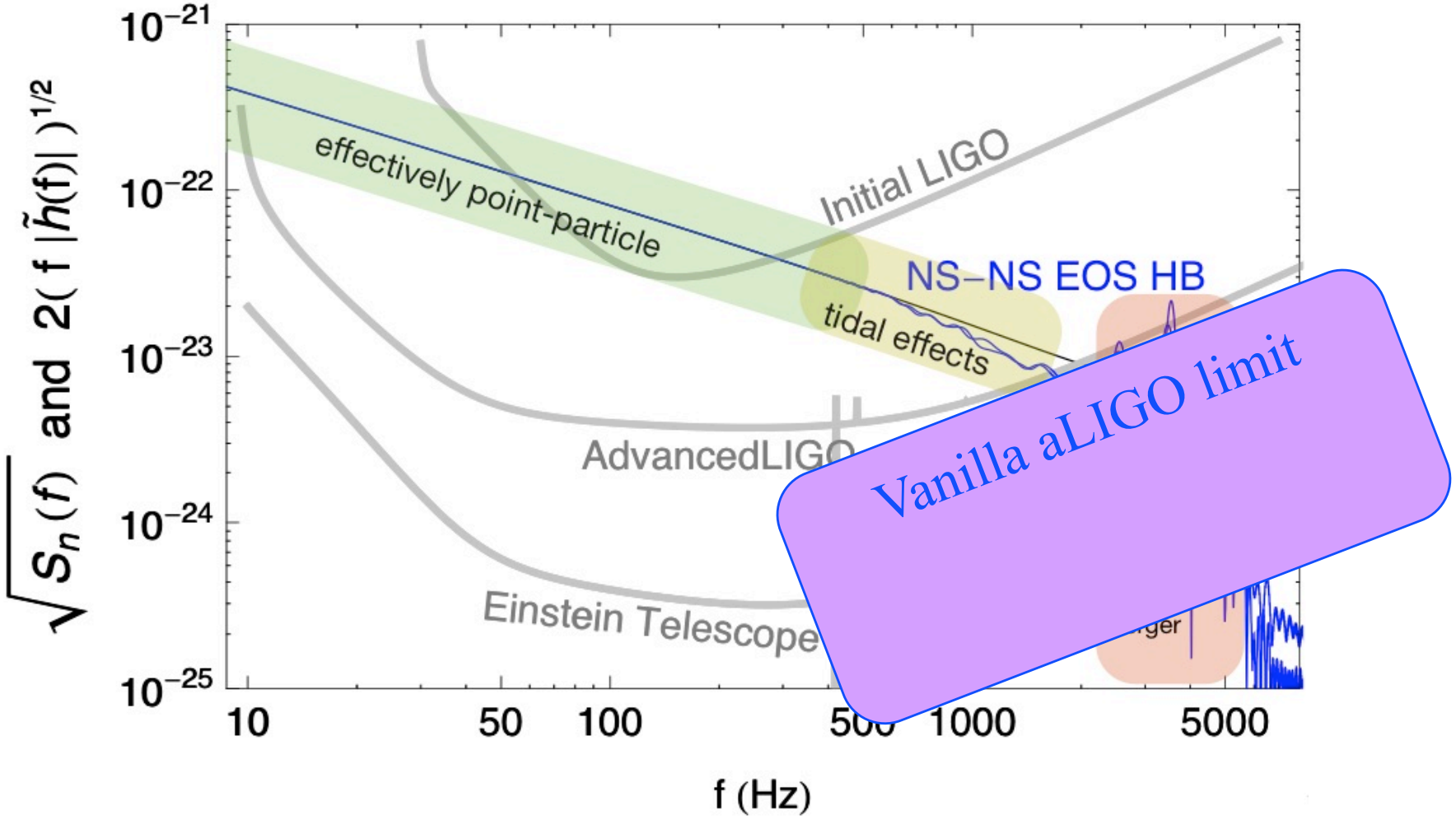

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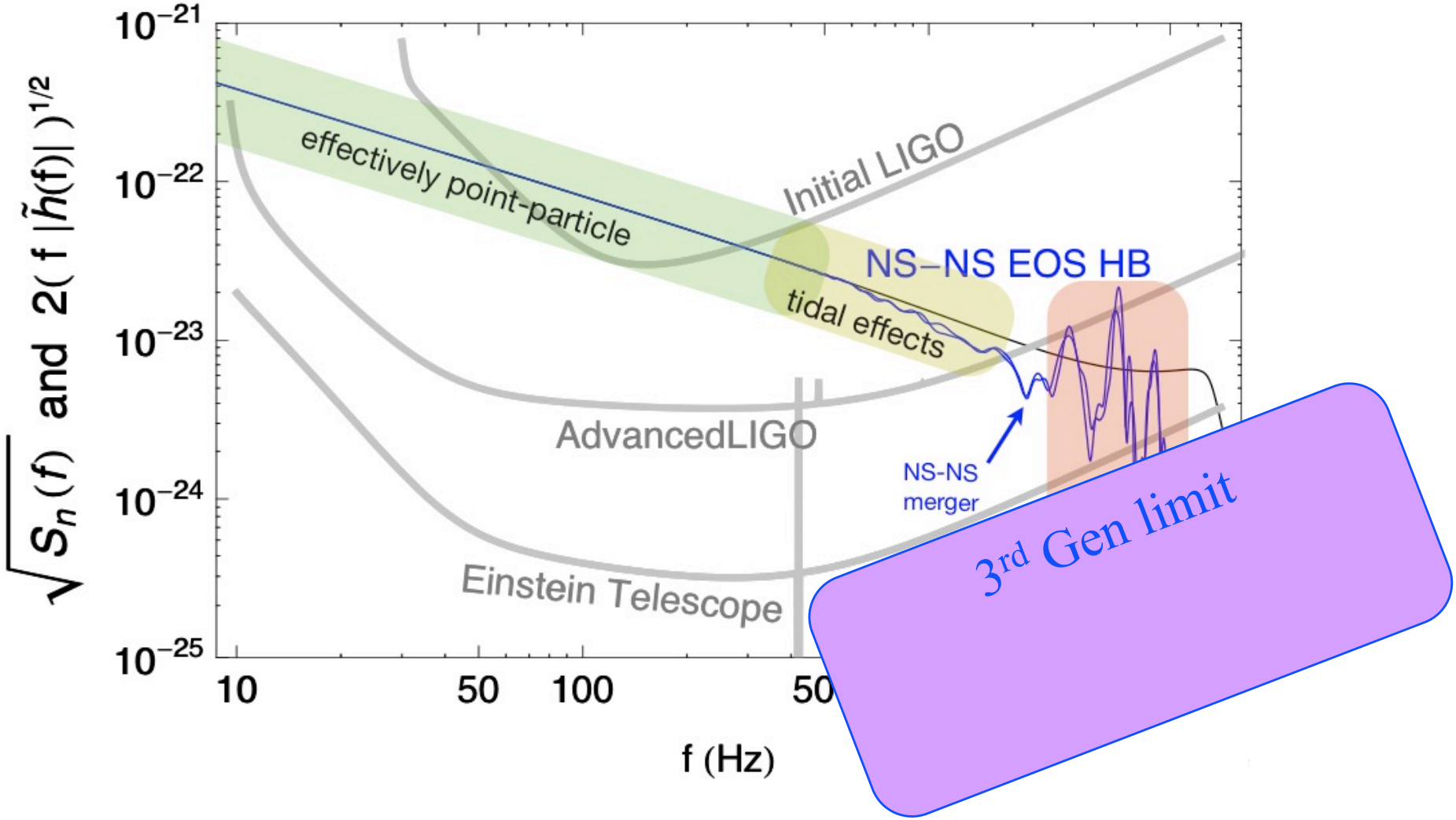

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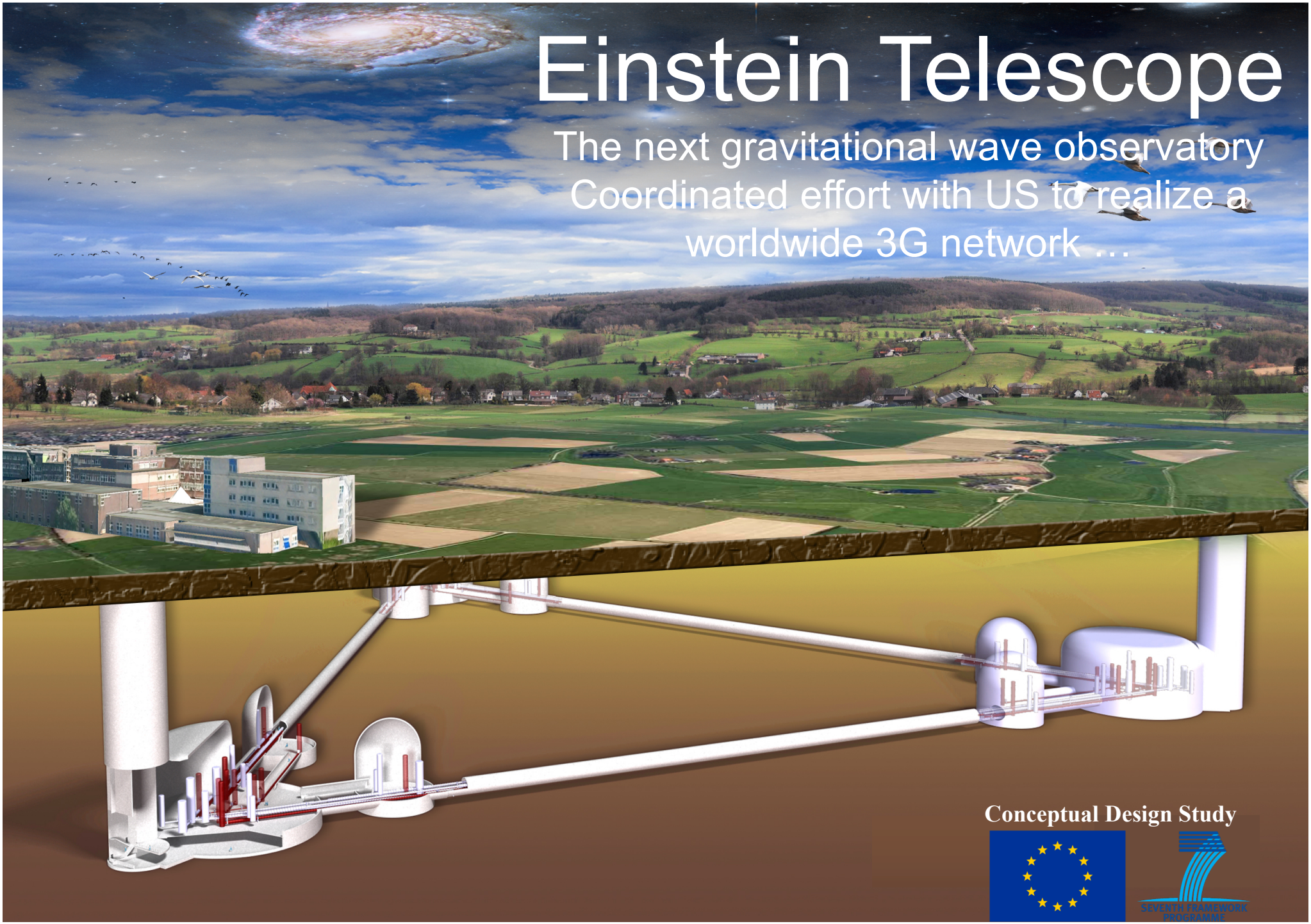
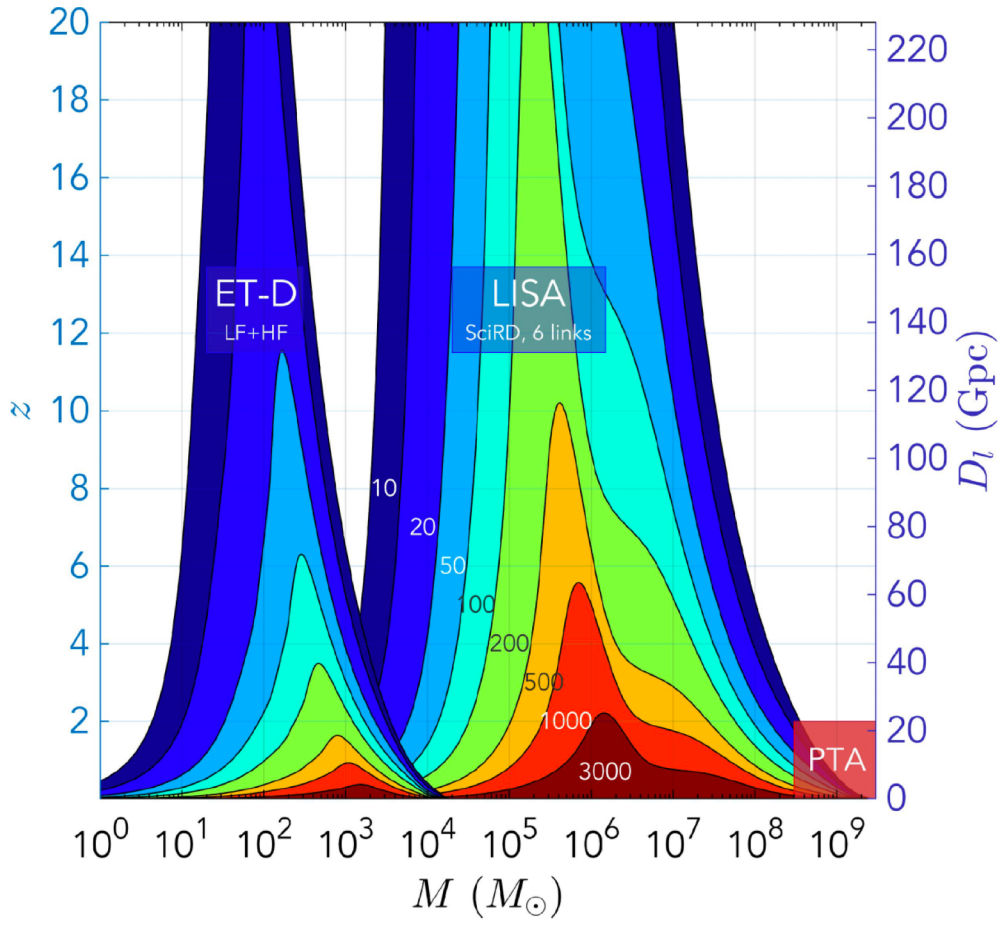

Einstein Telescope
The next gravitational wave observatory
Coordinated effort with US to realize a worldwide 3G network …
Conceptual Design Study
SEVENTH FRAMEWORK PROGRAMME

Another Concept: Make Advanced LIGO 10x longer, 10x more sensitive

Signal grows with length – ***not*** most noise sources

- Thermal noise, radiation pressure, seismic, Newtonian unchanged
- Coating thermal noise improves *faster* than linearly with length
- 40km surface Observatory 'toy' baseline
  - can still find sites, earthmoving feasible; costs another limit…
- Concept offers sensitivity without new measurement challenges; could start at room temperature, modest laser power, etc.



3rd Generation

- When could this new wave of ground instruments come into play?
- Appears 15 years from *t*=0 is a feasible baseline
  - » Initial LIGO: 1989 proposal, and at design sensitivity 2005
  - » Advanced LIGO: 1999 White Paper, GW150914 in 2015
- **Modulo funding, could envision 2030's**
- Should hope – and strive and plan – to have great instruments ready to 'catch' the end phase of binaries seen in LISA (ref. Sesana)
- Worldwide community working together on concepts and the best observatory configuration for the science targets

- **Crucial for all these endeavors: to expand the scientific community planning on exploiting these instruments far beyond the GR/GW enclave**
  - » Costs are like TMT/GMT/ELT – needs a comparable audience
  - » Events like GW170817 help!

Summary on Future planning

- **All ground-based interferometric detectors planning on working together** – LIGO, LIGO-India, Virgo, KAGRA
  - Sharing data, analysis development and execution
  - Sharing instrument science technology development
  - Coordinating on observing and upgrade schedules
- **Will share events via public alerts** (GCN) with low latency to enable effective followup by EM/neutrino observers, Maximizing the joint MMA science
- **Incremental funding enables incremental improvements for the next decade**
- GWIC – the Gravitational Wave International Committee – coordinating development of '3rd Generation' instrument concepts and approaches
  - Explicitly global to ensure the best science, and best use of resources
  - Refinement of the science case currently underway
  - Governance models being explored
  - **Will look for support from the EM/neutrino Observers when seeking funding for major new infrastructures and instruments**

Expect the GW Field to be a growing and reliable partner for EM and neutrino observatories and observers

Just the beginning of a new field – new instruments, new discoveries, new synergies

Milliseconds	Minutes to Hours	Years to Decades	Billions of Years
LIGO/Virgo	LISA	Pulsar Timing Array	Cosmology Probes