JGW-G2315417
November 26, 2023
Joint RIKEN/N3AS Workshop on Multi-Messenger Astrophysics
(Hilton Waikoloa Village, Hawaii)

KAGRA : The Key to Multi-Messenger Astrophysics

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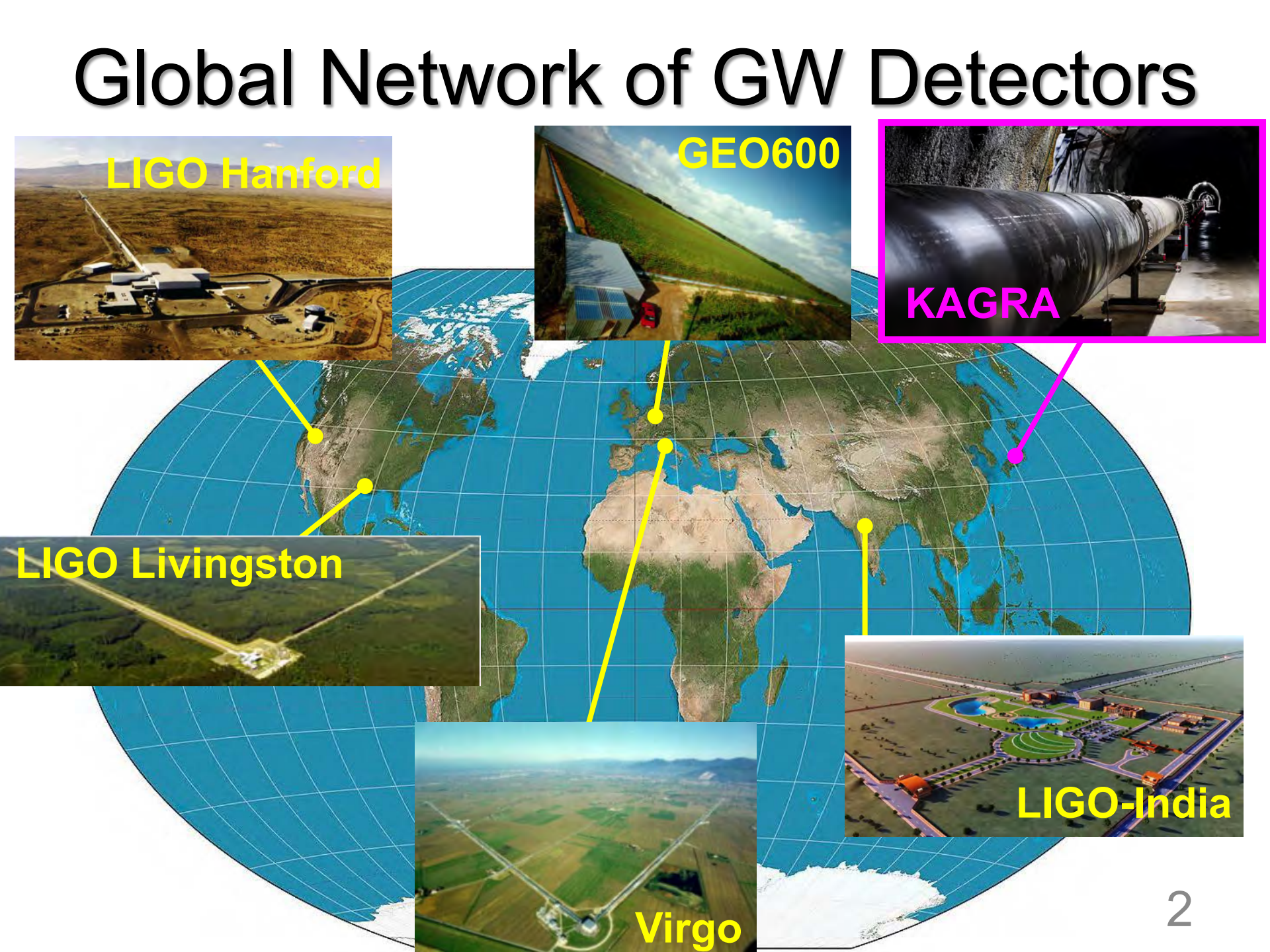
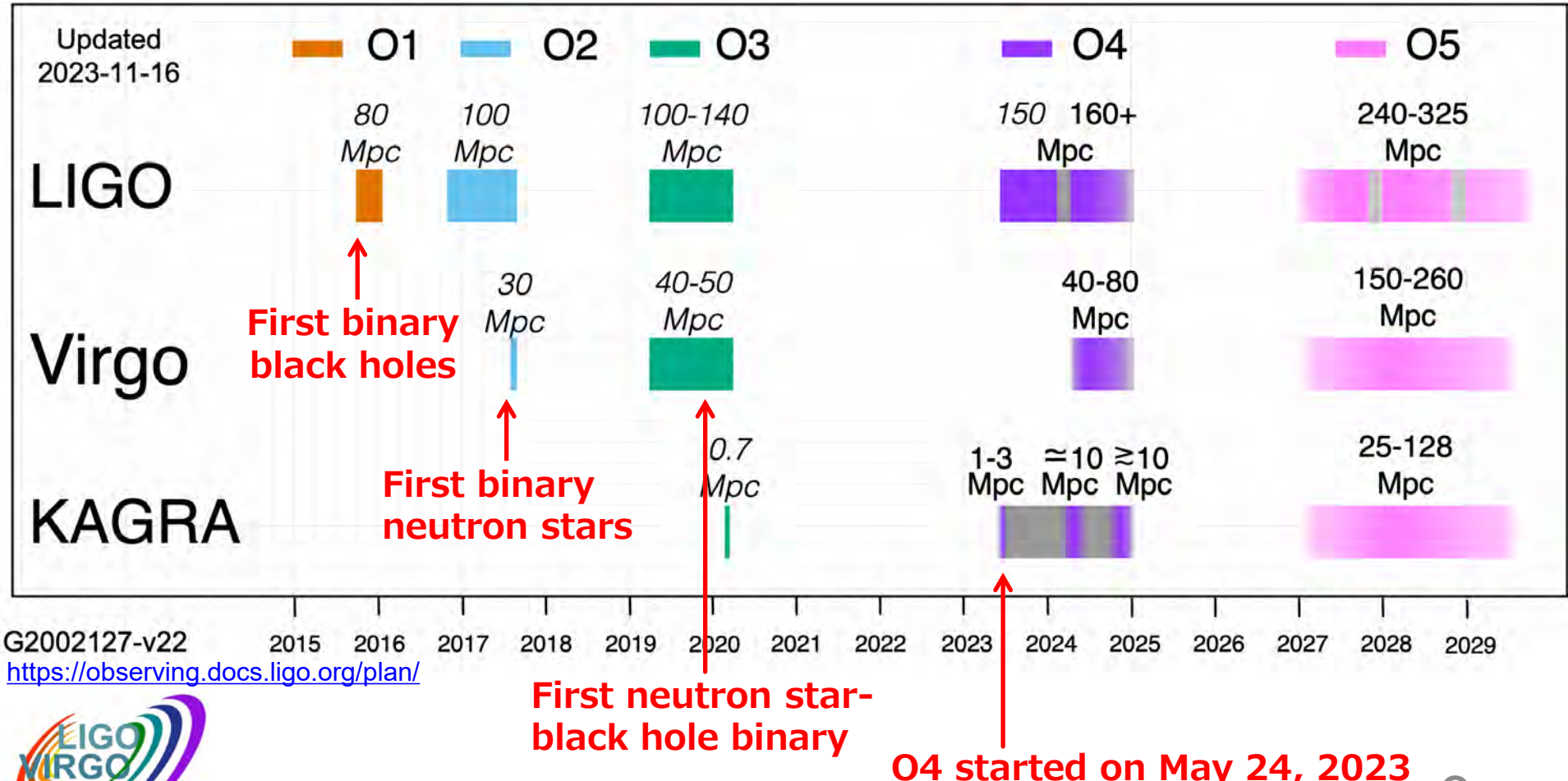
for the KAGRA Collaboration

Global Network of GW Detectors



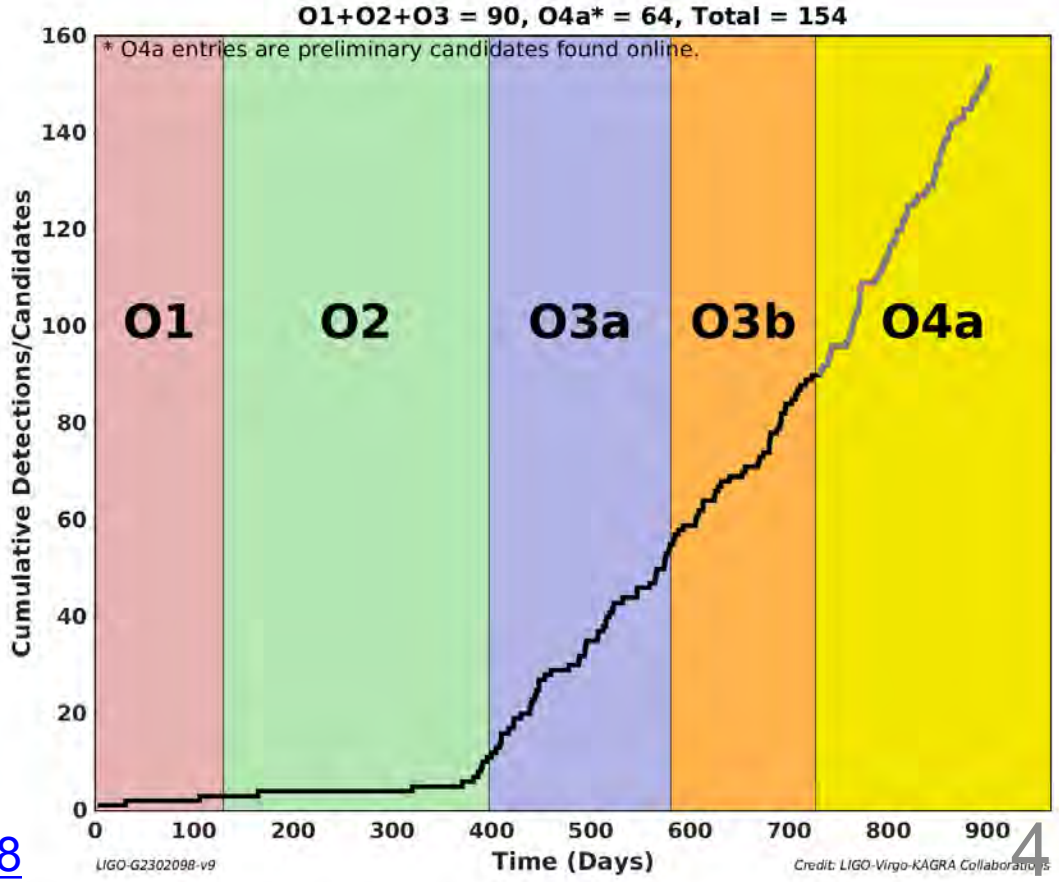
LIGO-Virgo-KAGRA Observing Plan

- Coordinated runs to detect GW signals by multiple detectors



LIGO-Virgo-KAGRA O4 Run Status

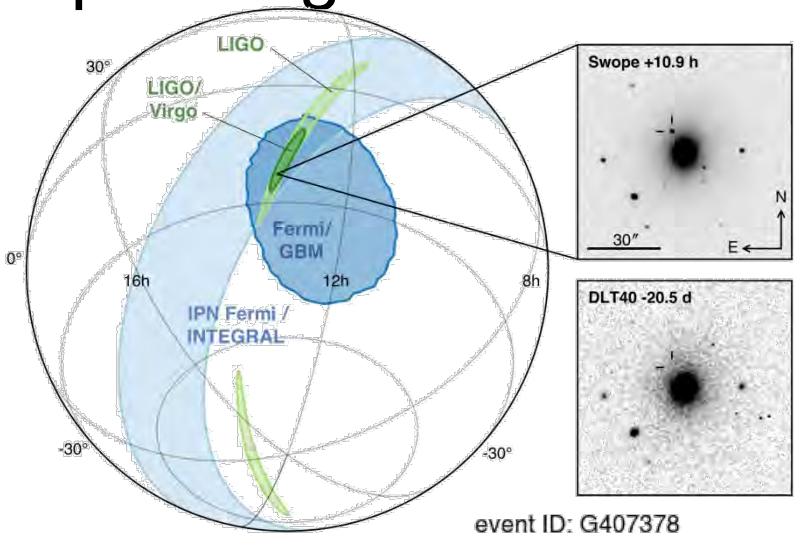
- 69 detections so far, by LIGO Hanford & Livingston
- Virgo to be joined in March 2024
- KAGRA briefly joined O4, but currently in planned commissioning, to be joined again in Spring 2024
- O4a interrupts on January 16, O4b starts two months later (commissioning break)

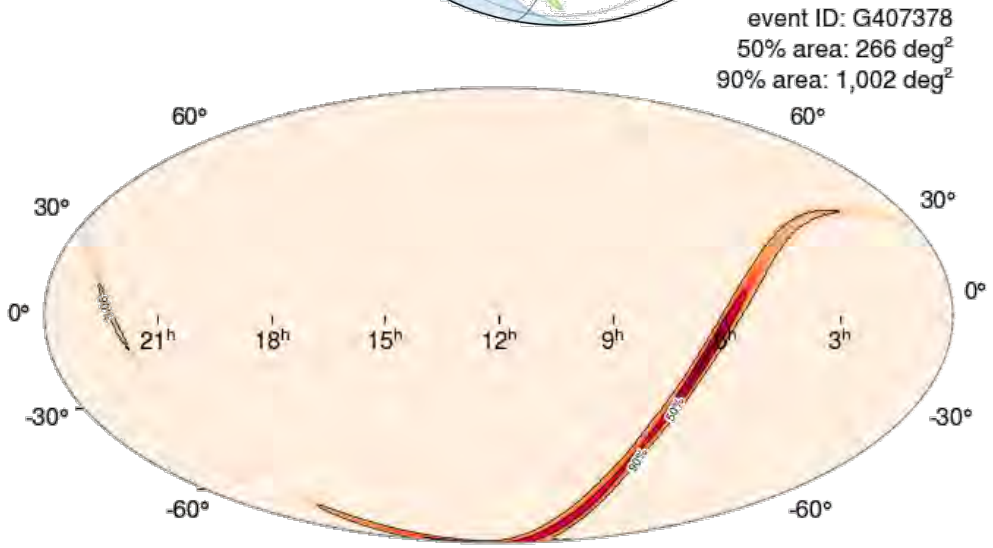


LIGO-G2302098

No Multi-Messenger Event Yet!

- Only Hanford and Livingston operating
- O(100) deg^2 localization
  e.g. GW170817 was
  31 deg^2 with Virgo
- 3 or more detectors are necessary for triangulation
- More detectors for
  - Sky localization
  - Sky coverage
  - 3+ detector duty factor





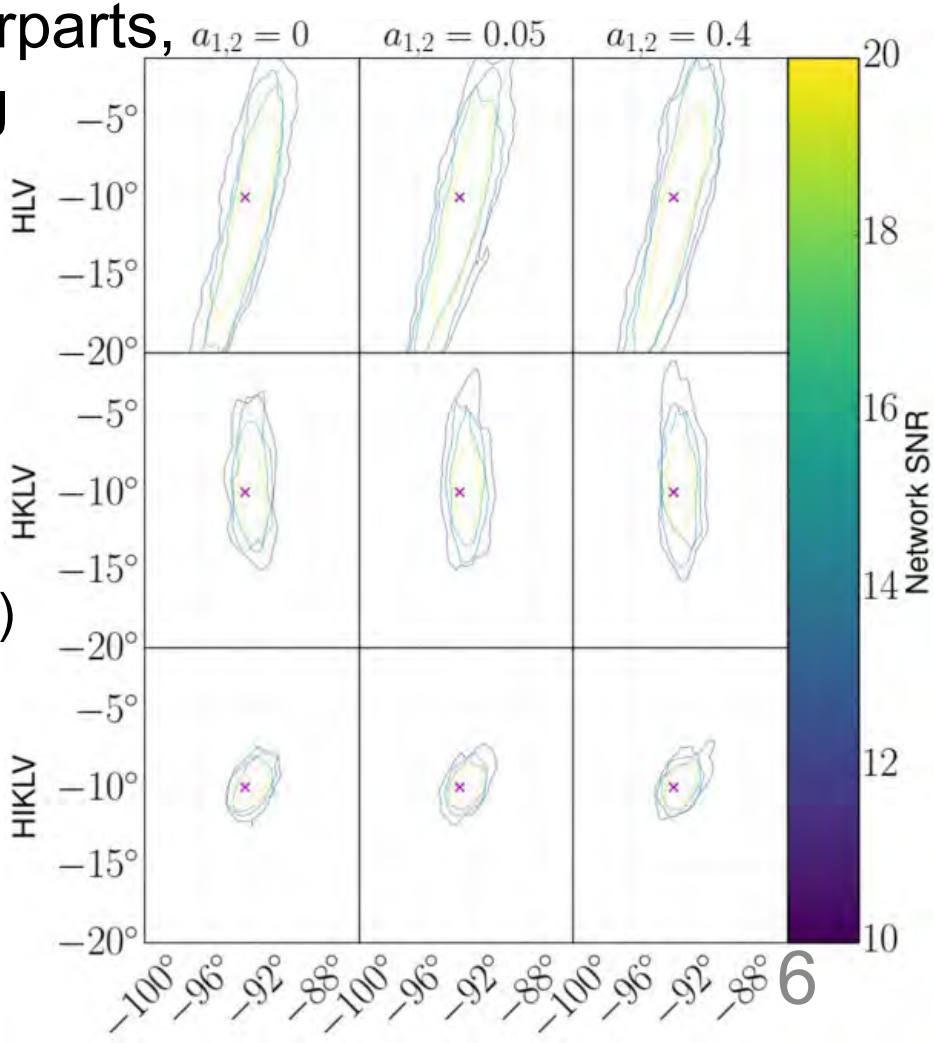
S230518h (NSBH 86%)

When KAGRA Joins

- BNS sky localization < O(10) deg^2

  Also reduces time to identify EM/neutrino counterparts, enabling prompt data taking

C. Pankow+, ApJL **854**, L25 (2018)



- Enables better GW polarization measurements
  - Hubble constant

(by a few precent by resolving distance & inclination degeneracy)

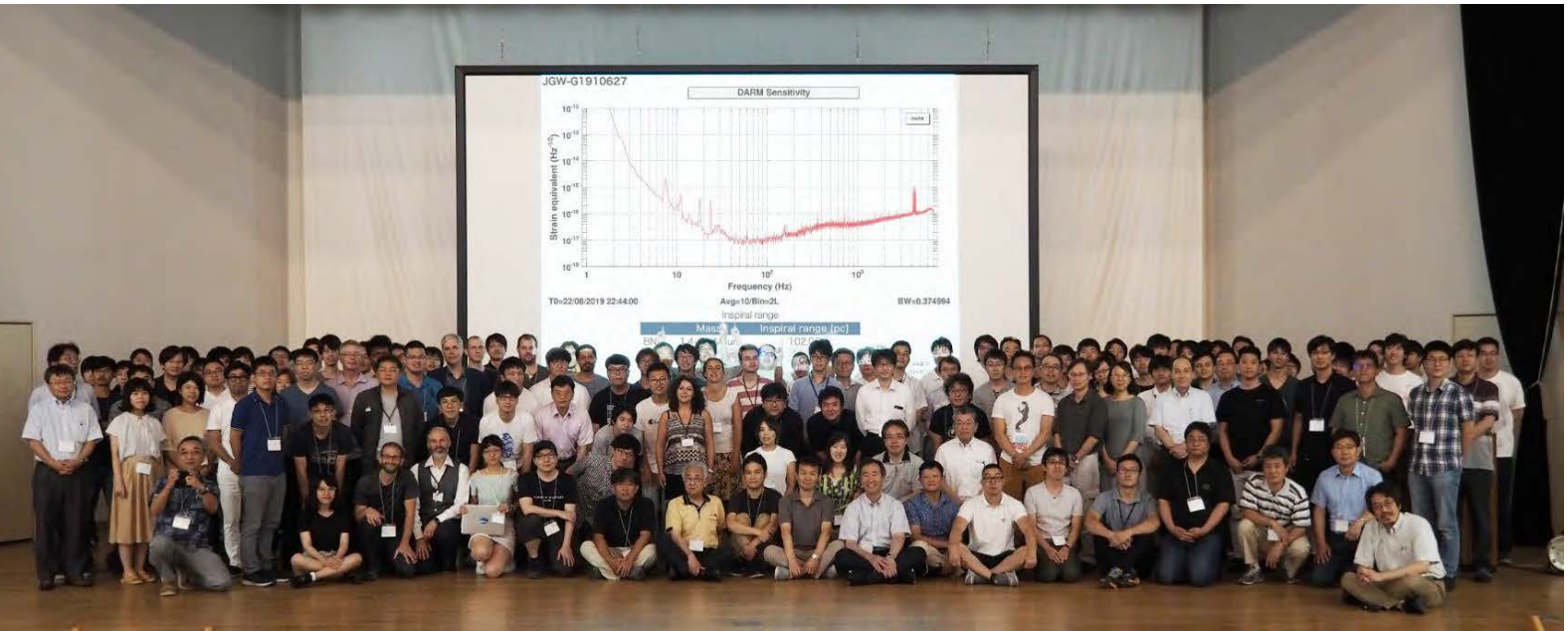
  - Tests of GR

(measure scalar & vector polarizations; # of detectors is # of pols. resolved)

H. Takeda+, PRD **98**, 022008 (2018)

KAGRA Project

- Project started in 2010
- Construction completed and signed MoA with LIGO/Virgo in 2019
- 13 countries, 120+ institutes, 400+ collaborators (155 authors)
- Underground and cryogenic



Aug 2019
F2F meeting
@ Toyama

KAGRA Location

- Kamioka, Gifu prefecture, Japan

Mt. Ikenoyama

KamLAND

CLIO

Super-Kamiokande

3 km

3 km

Office
Control room

KAGRA Tunnel
entrance

Google

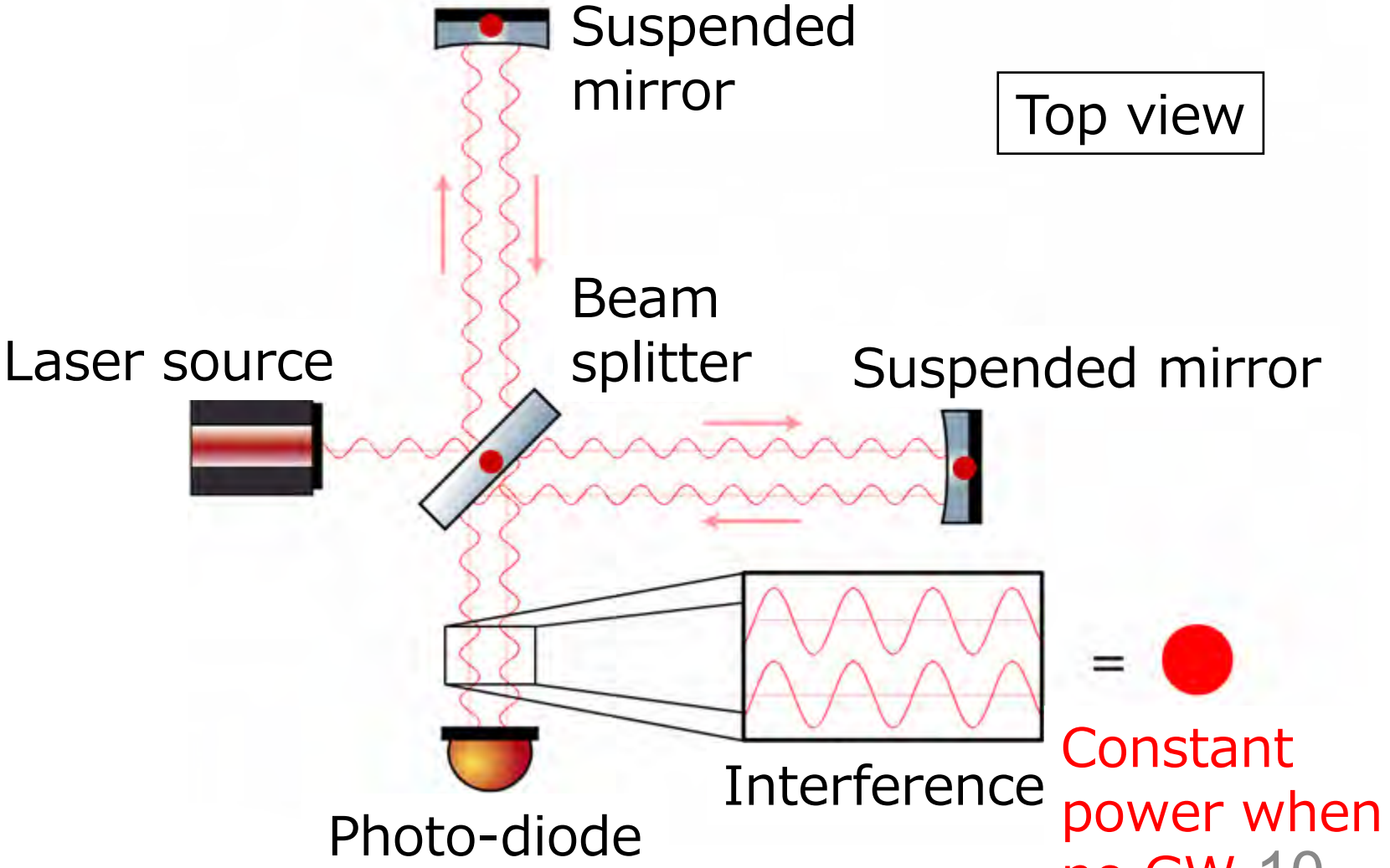
KAGRA Tunnel

- Laser beam goes back and forth inside two 3 km vacuum tubes

Entrance (2016.2.8)

Laser Interferometric GW Detector

- Measures differential arm length change from GW



Laser Interferometric GW Detector

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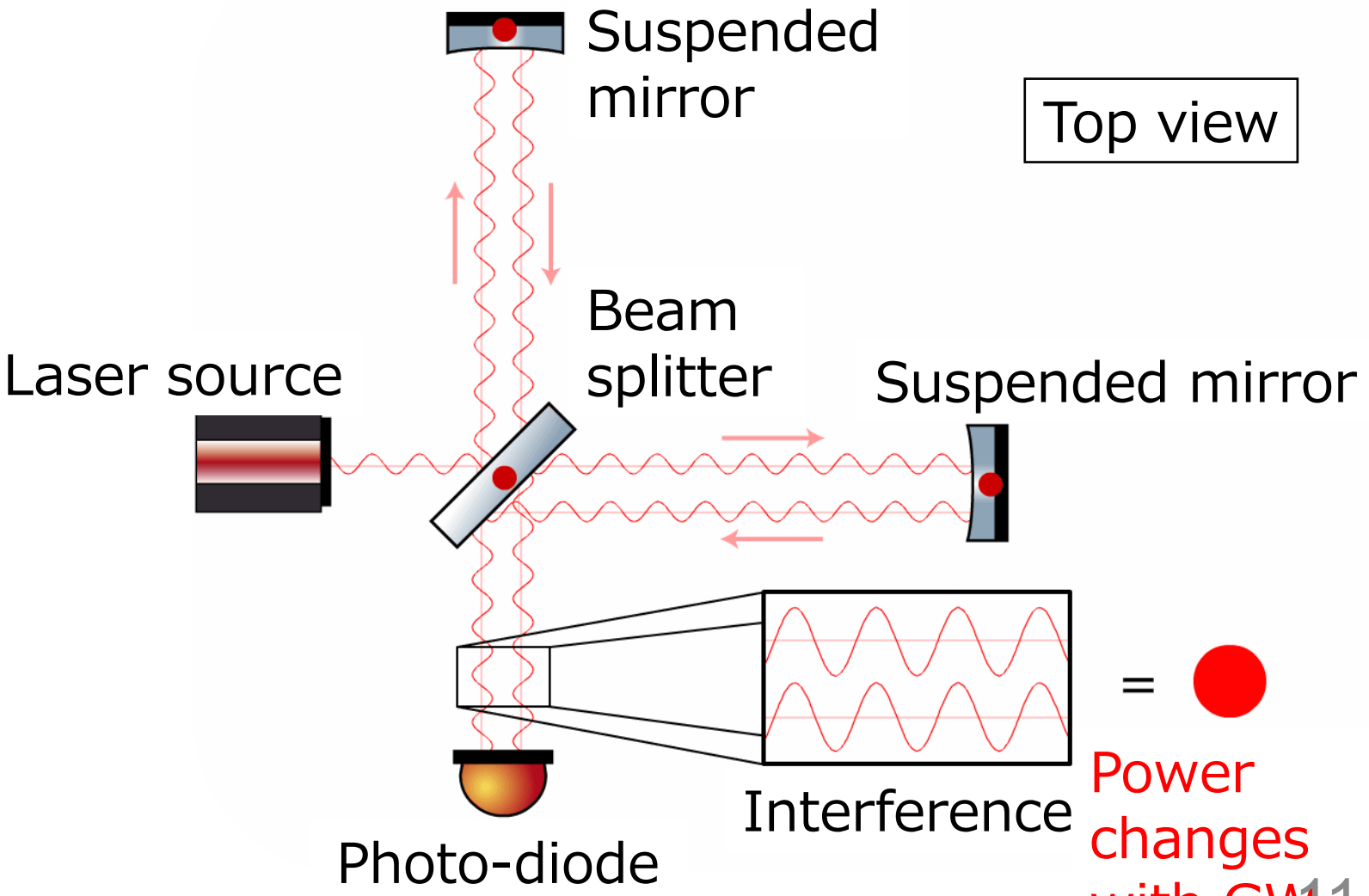
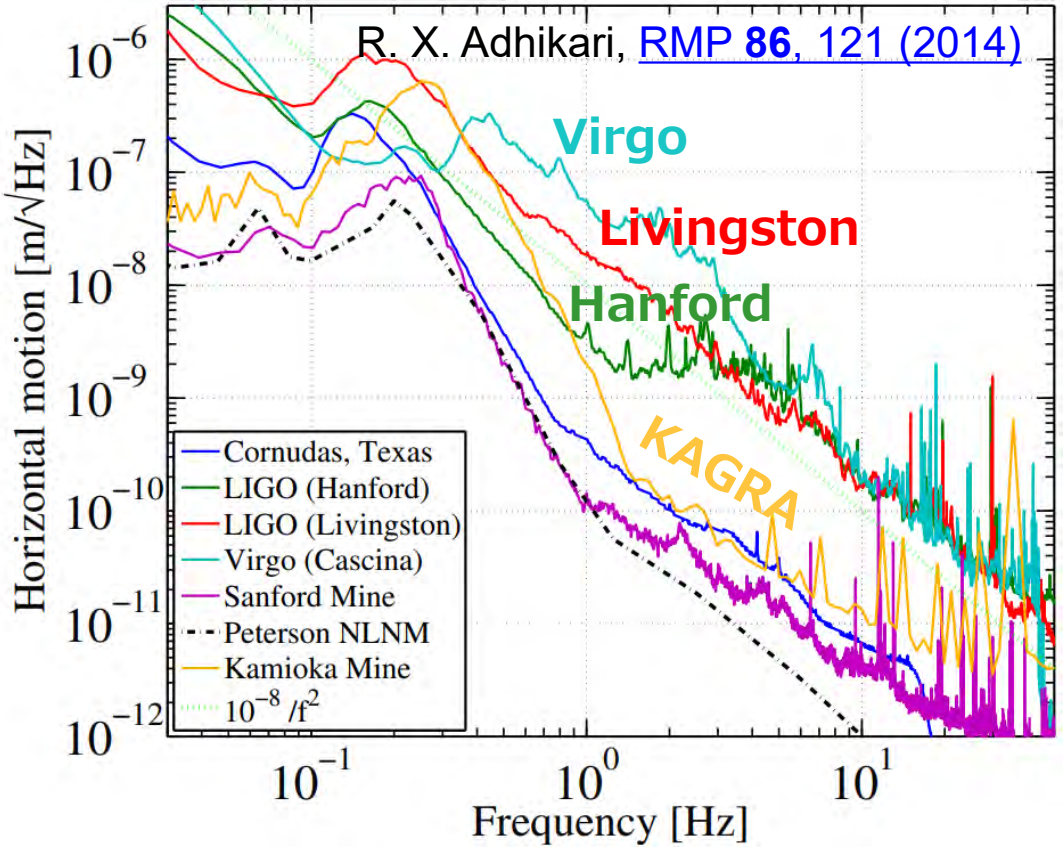
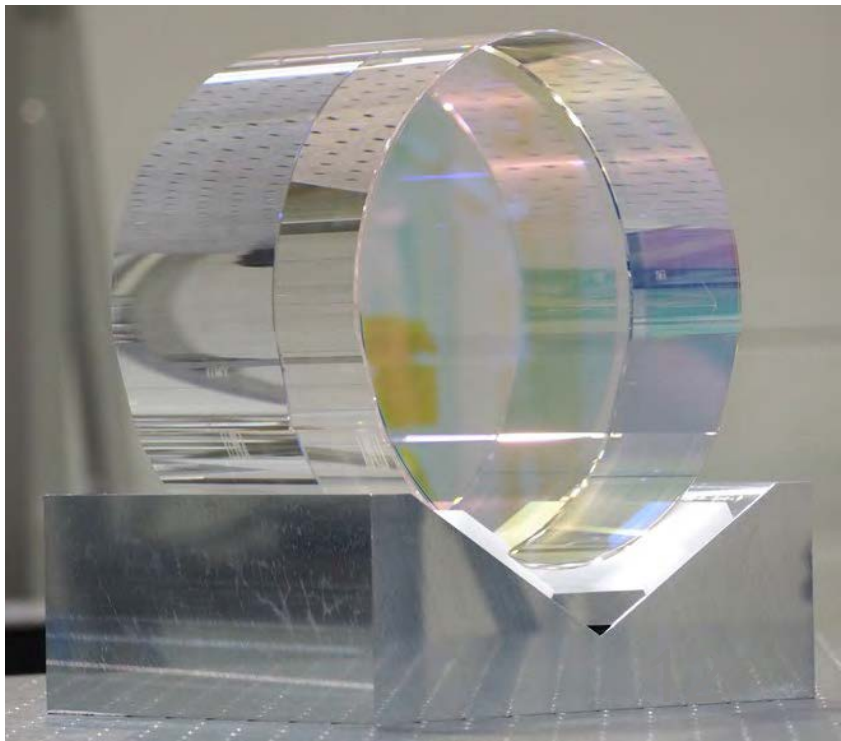


Technologies for Future Detectors

- Underground construction to reduce seismic noise and gravity gradient noise
- Cooling sapphire test masses to ~20 K to reduce thermal noises



φ22 cm, t 15 cm, 22.8 kg

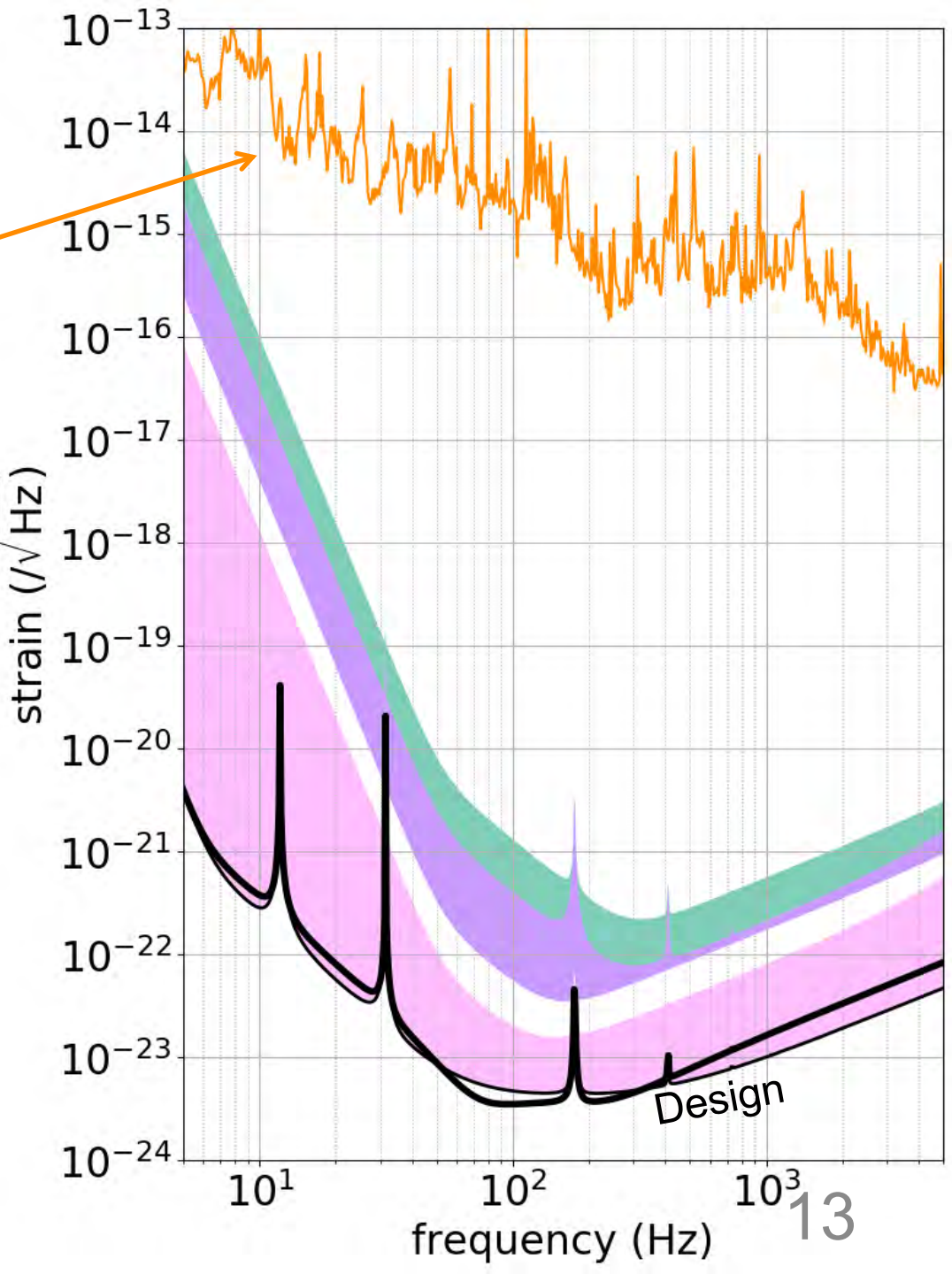


KAGRA Sensitivity

iKAGRA (2016)

- First test run
- 1+2 weeks
- Room temperature
- Michelson interferometer

PTEP **2018**, 013F01 (2018)

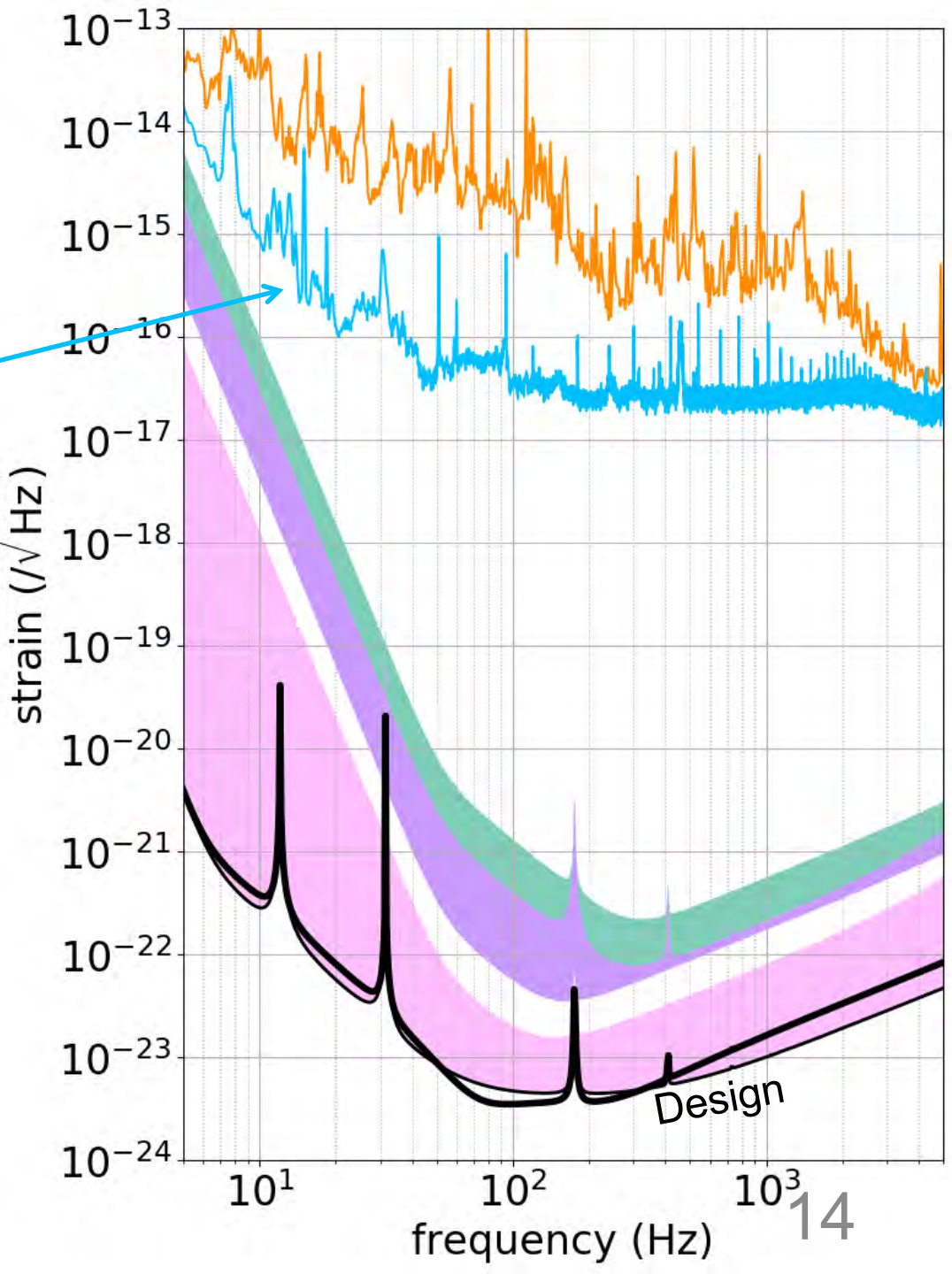


KAGRA Sensitivity

bKAGRA Phase 1 (2018)

- First test run with < 20 K test mass
- 10 days
- Michelson interferometer

CQG **36**, 165008 (2019)



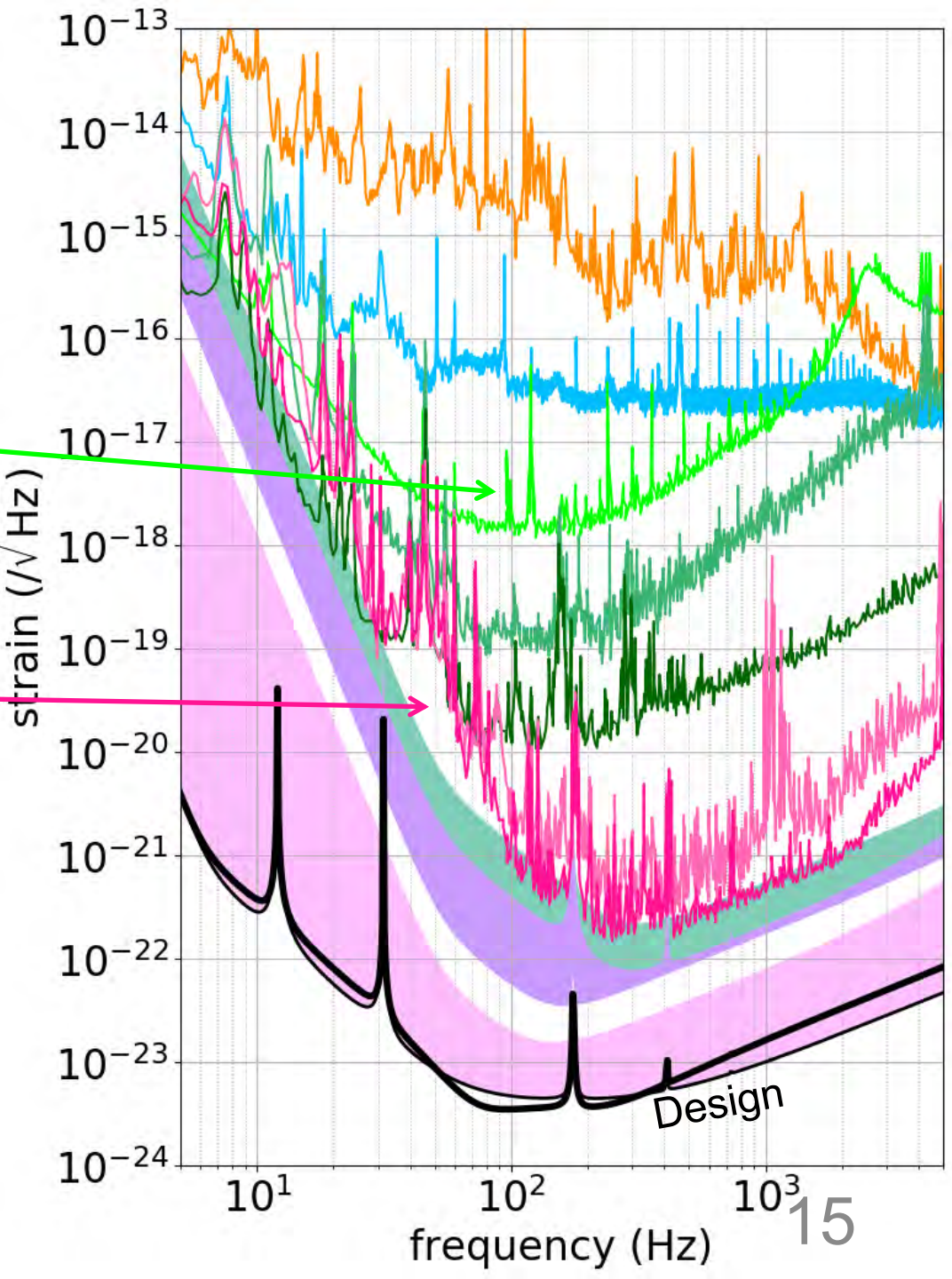
KAGRA Sensitivity

First FPMI lock (Aug 2019)

O3GK (2020)

- First observing run with GEO600
- Feb-Apr 2020
- ~250 K
- Power-recycled Fabry-Perot Michelson interferometer

PTEP **2021**, 05A101 (2021)



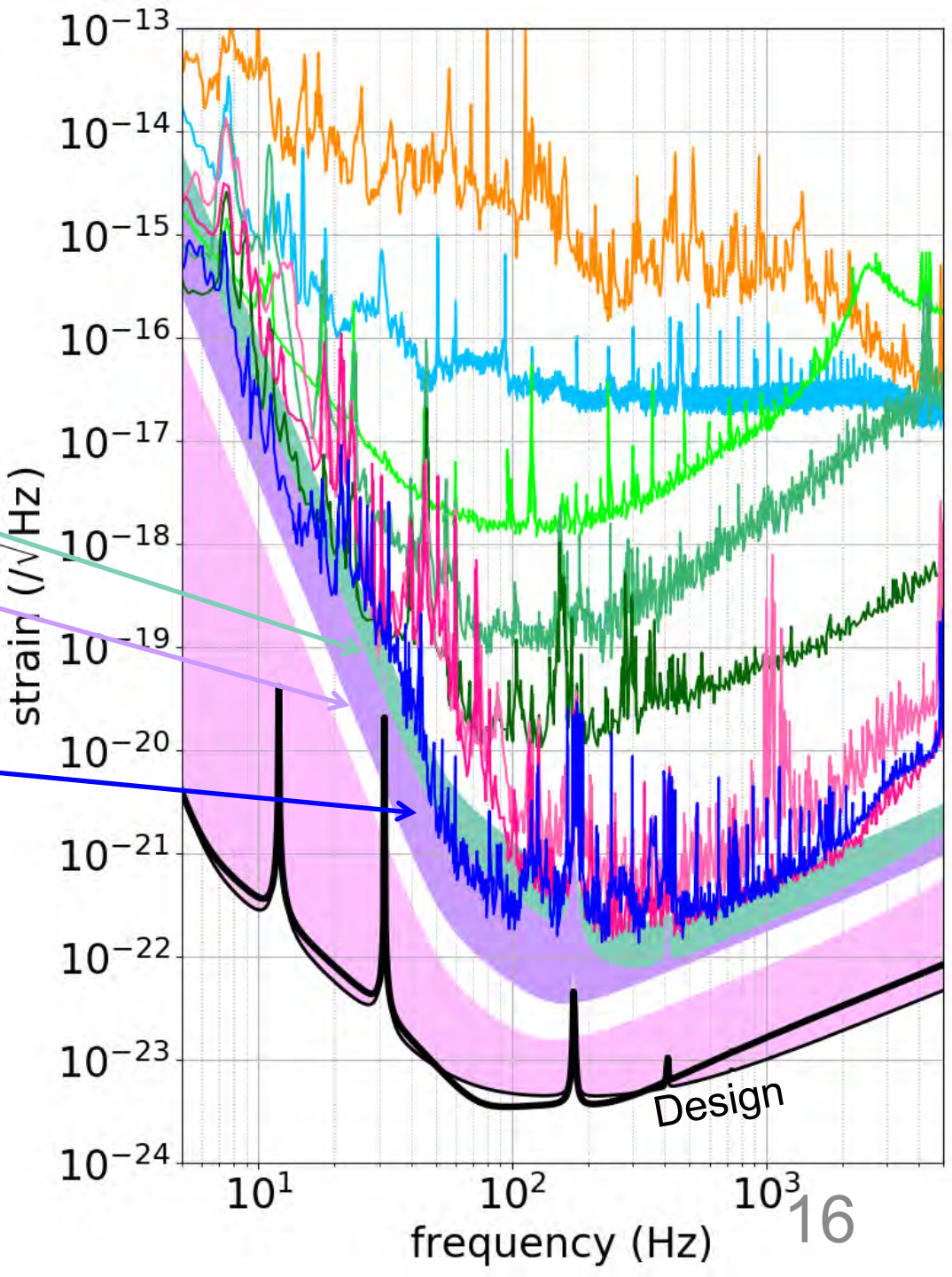
KAGRA Sensitivity

O4a target (1-3 Mpc)

O4b target (3-10 Mpc)

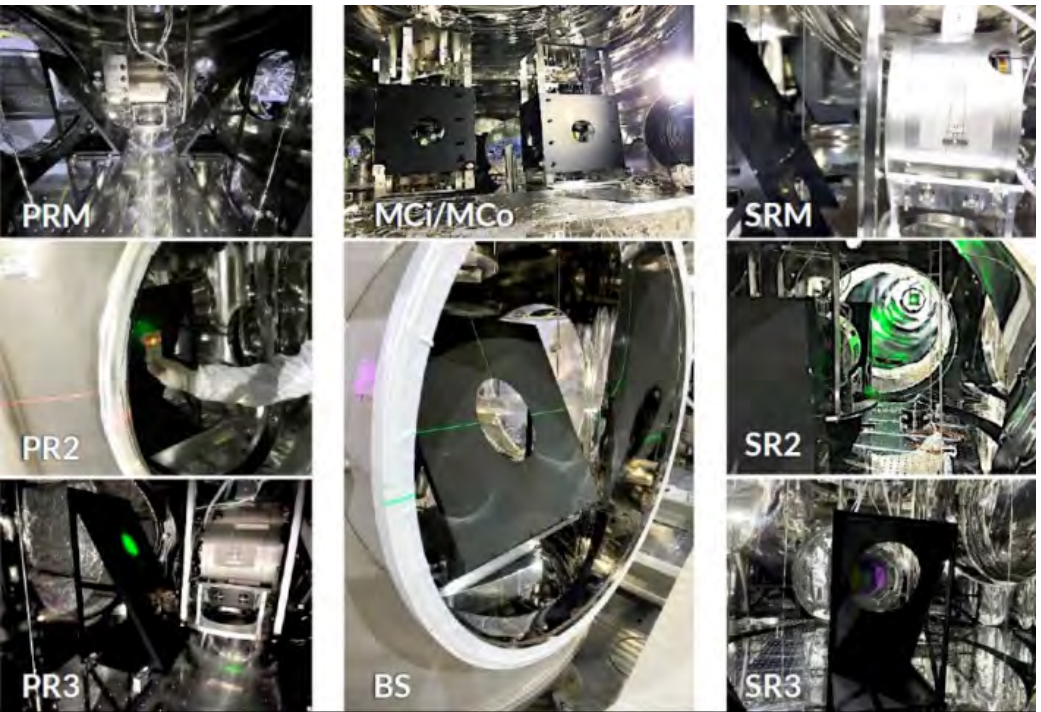
O4a (May 2023)

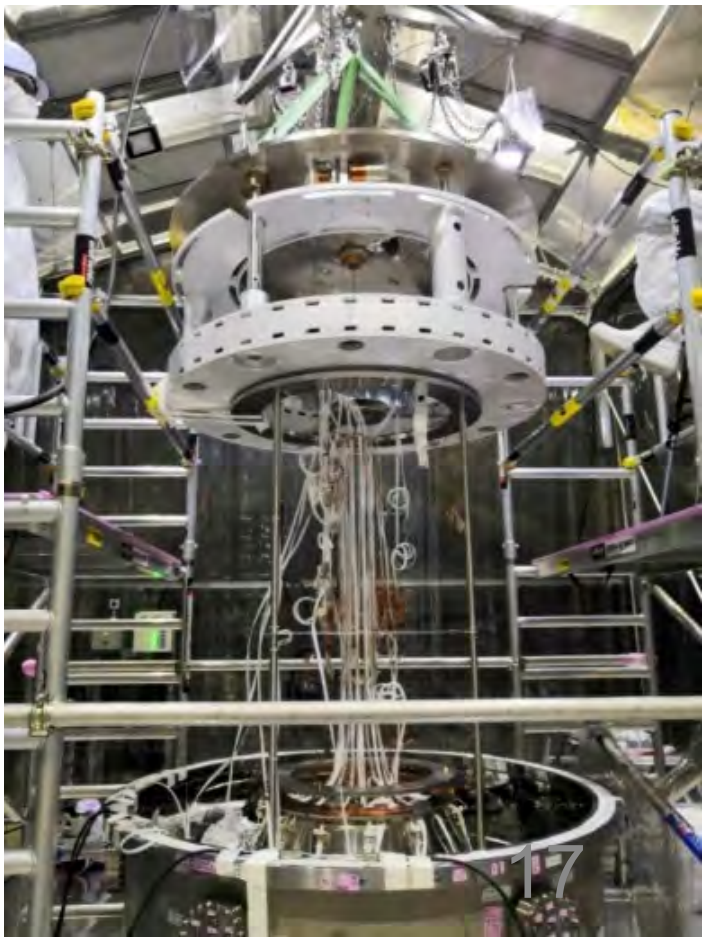
- Started with LIGO
- May-Jun 2020
- ~250 K
- Power-recycled Fabry-Perot Michelson interferometer



Commissioning Toward O4a

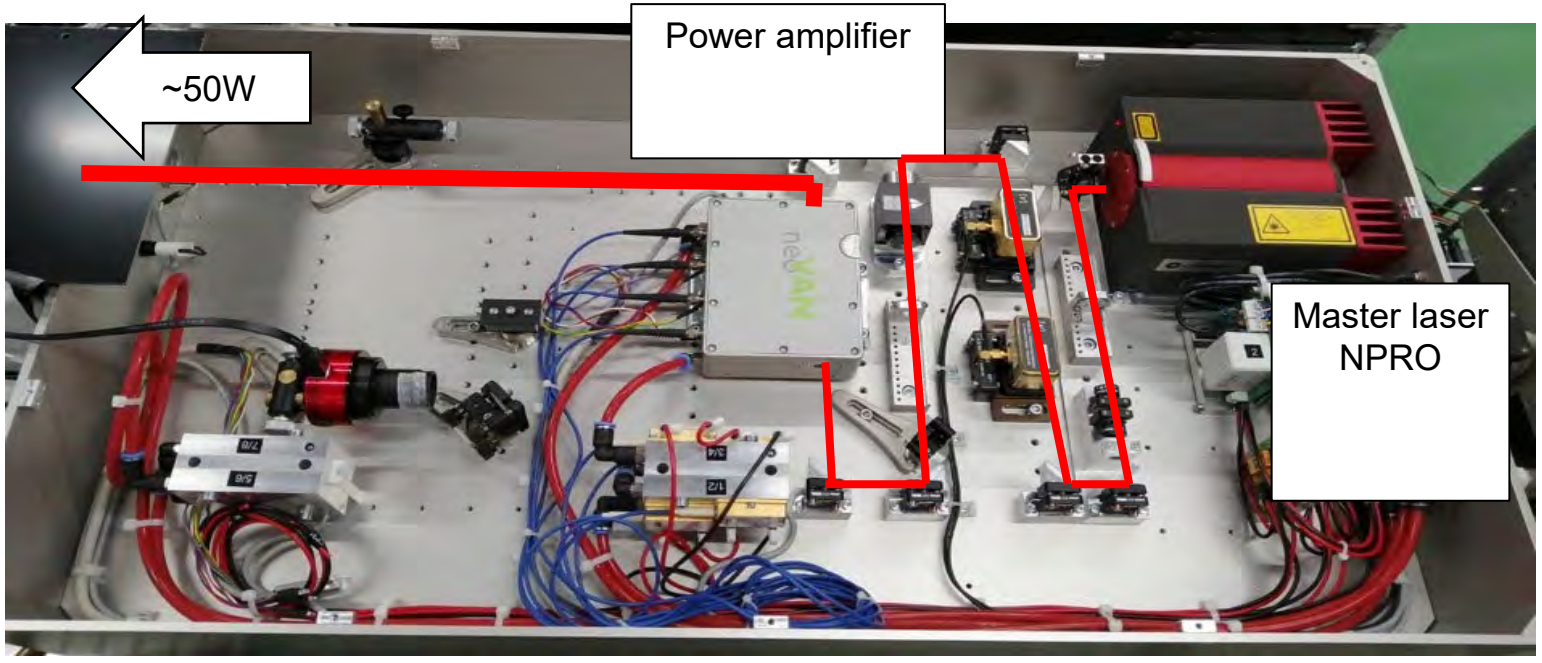
- Test mass vibration isolation system upgrades
  - fixed mechanical failures
  - improved sensors and actuation
- Scattered light noise mitigation
  - Additional baffles and beam dumps





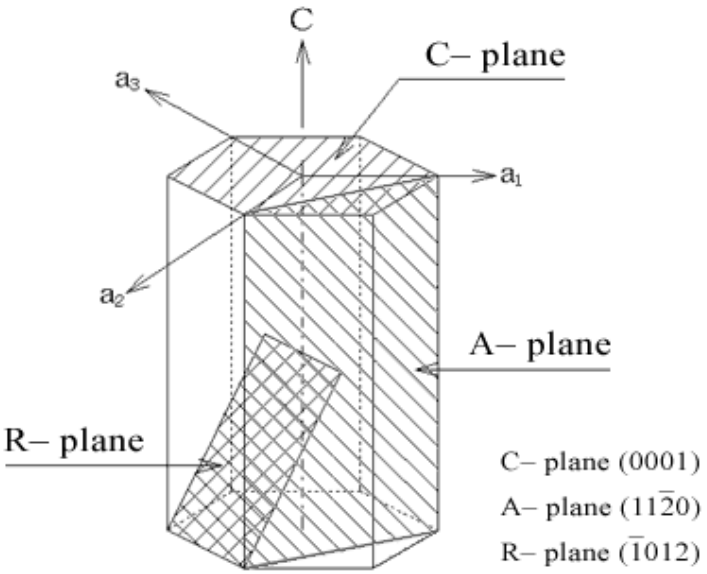
Commissioning Toward O4b

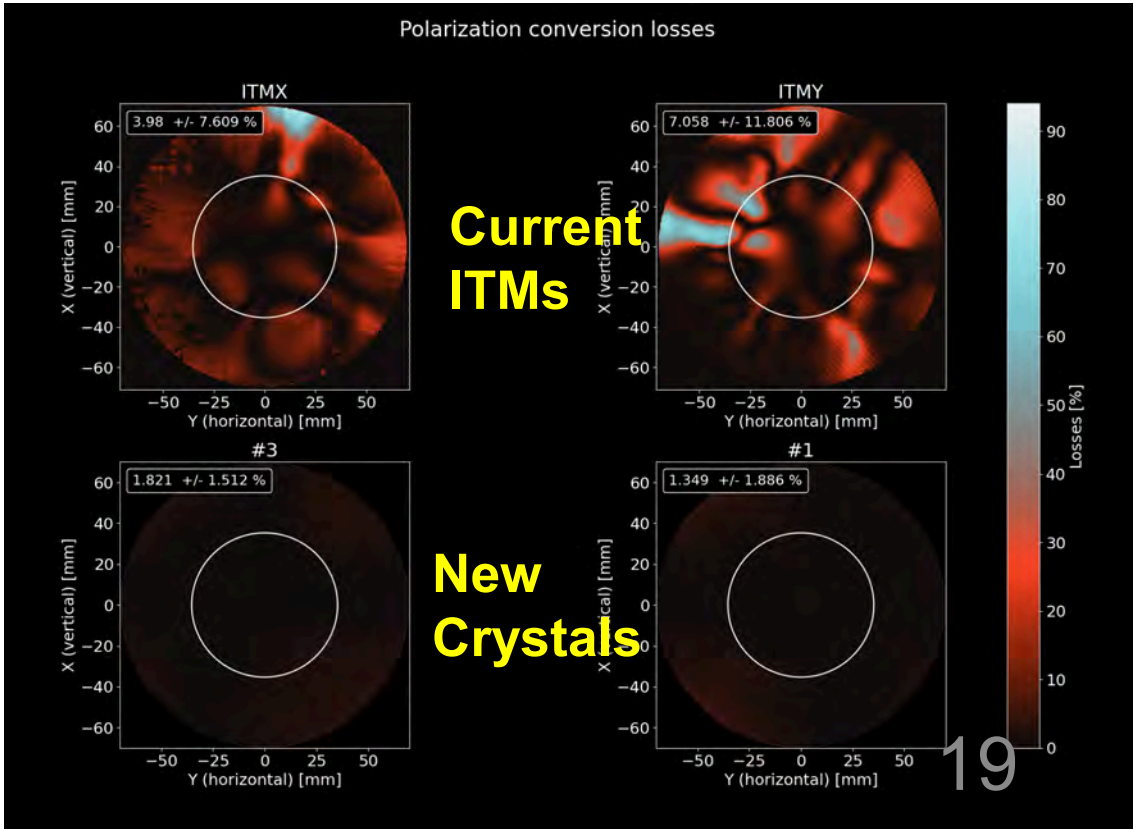
- Alignment sensing and control improvements
  - Wavefront sensing technique
- All the test masses are being cooled down
  - At least below 100 K to reduce thermoelastic noise
  - Takes about a month to cool down
- Higher power laser



Developments Toward O5

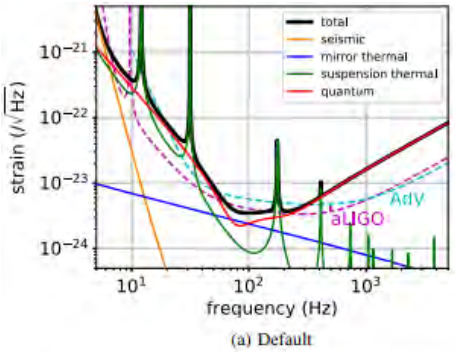
- Birefringence of sapphire was found to be larger than expected
  - c-axis and beam axis not well aligned
  - inhomogeneity
- Polishing crystals with lower birefringence



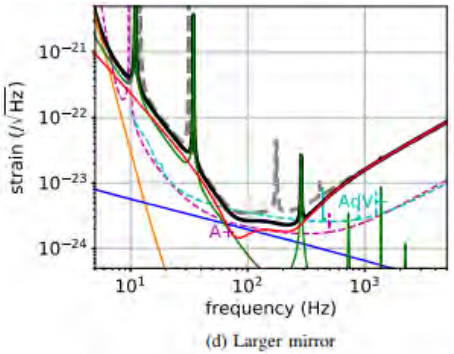


KAGRA Upgrade

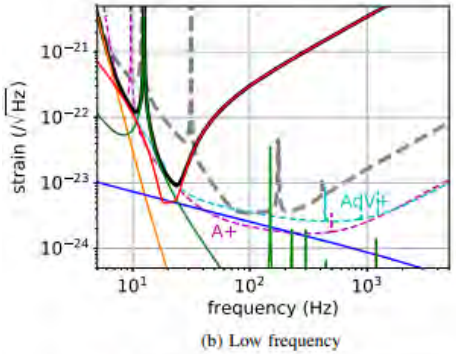
- Various upgrade plans are being considered
- Active R&D ongoing for the upgrade
  - Coating
  - Gravity gradient noise subtraction
  - Frequency-dependent squeezing etc…



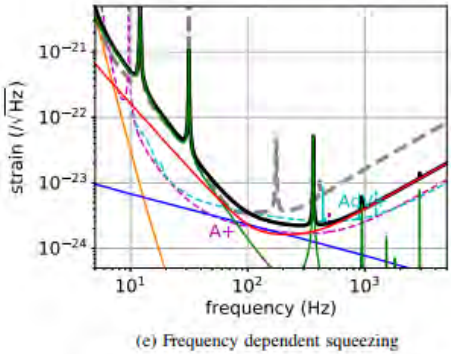
(a) Default



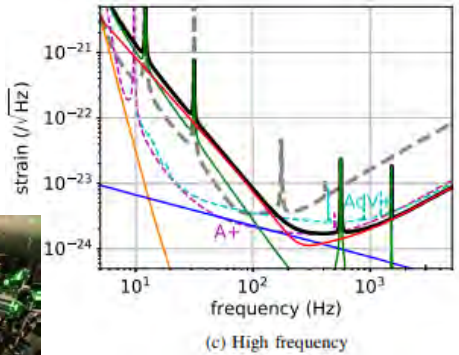
(d) Larger mirror



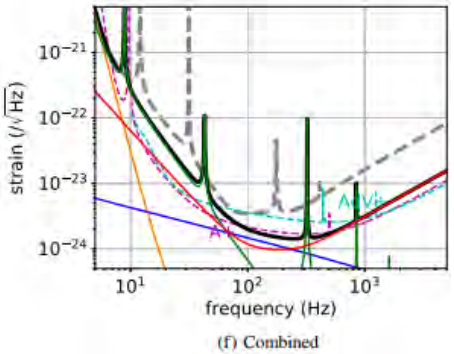
(b) Low frequency



(e) Frequency dependent squeezing



(c) High frequency



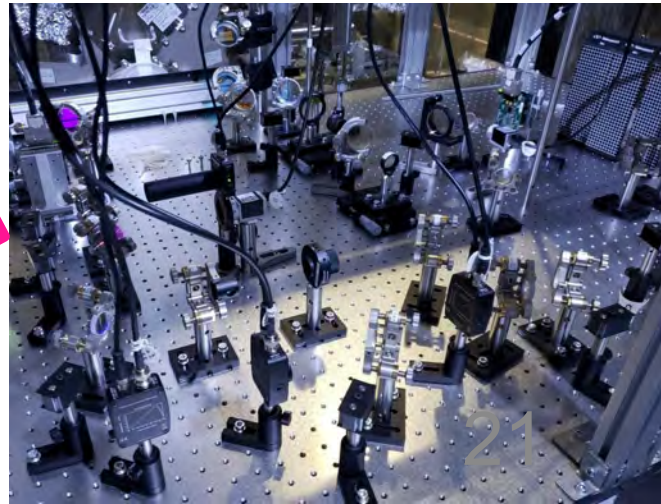
(f) Combined

YM+, PRD **102**, 022008 (2020)
Y. Zhao+, PRL **124**, 171101 (2020)

Ultralight Dark Matter Searches

- Interferometric GW detectors are also sensitive to
  - Scalar dark matter
    through changes in thickness of mirrors
    V. M. Vermeulen+, Nature **600**, 424 (2021)
  - Vector dark matter
    through non-standard forces acting on mirrors
    YM+, PRD **102**, 102001 (2020) LIGO-Virgo-KAGRA, PRD **105**, 063030 (2022)
  - Axion dark matter
    through polarization changes of light
    K. Nagano, T. Fujita, YM, I. Obata, PRL **123**, 111301 (2019)
- KAGRA searches
  - Vector DM with O3 data
    to be released soon
  - Axion DM will be
    possible from O4

See, also, my talk
Dec 1st morning



Summary

- KAGRA is one of the keys to multi-messenger astrophysics
- KAGRA also plays a key role in demonstrating underground and cryogenic technologies for future GW detectors
- KAGRA is now in commissioning mode
  - Will rejoin O4 in Spring 2024
    at BNS range of around 10 Mpc