Current Status of GW Observations

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KASI
On behalf of KGWG

LIGO-Virgo O3

- Began on April 1, 2019
- Mid-run commissioning break started Oct 1 2019 at 15:00:00 UTC.

  Scattered light mitigation.

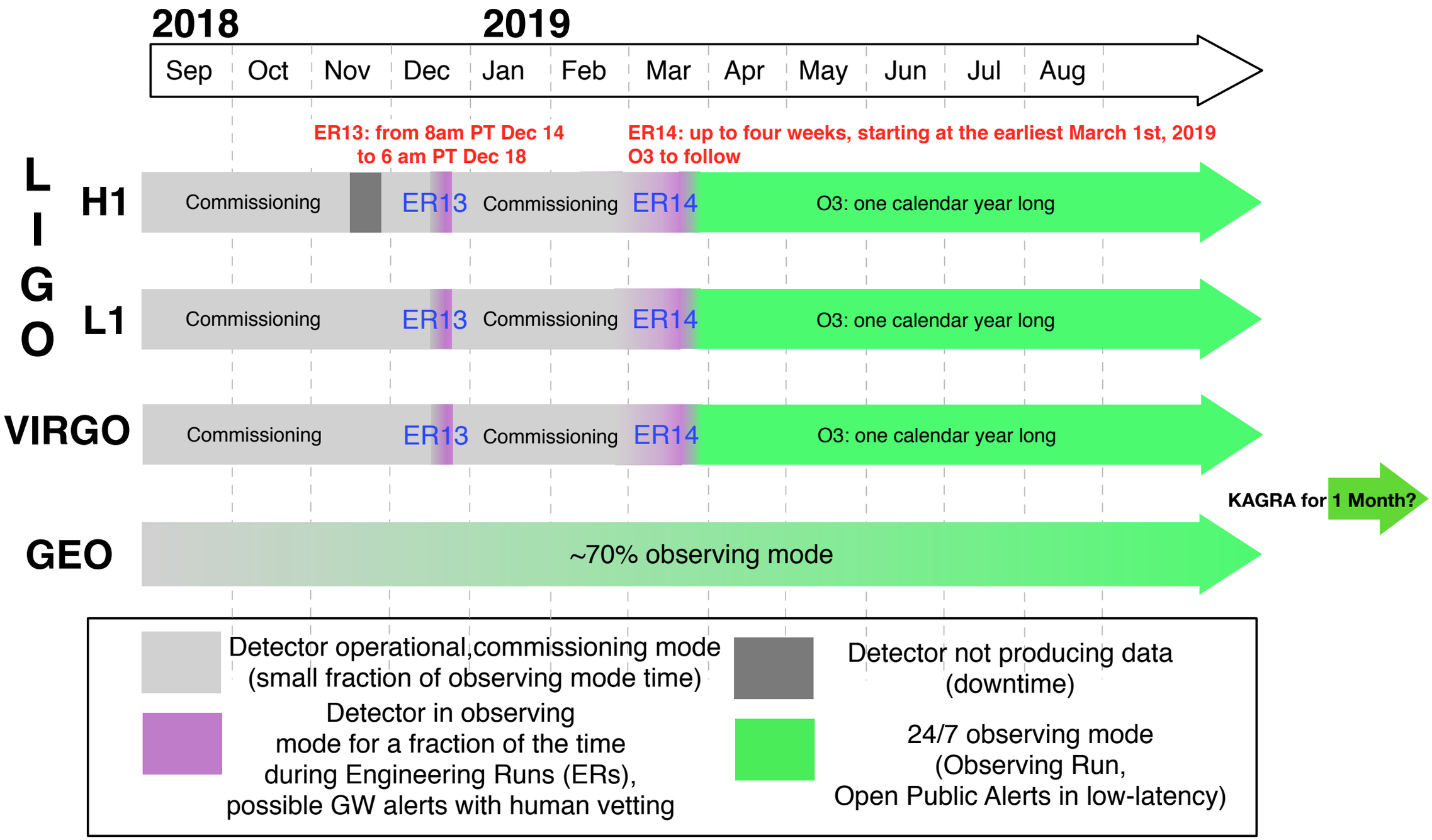
  Hanford squeezing improvements.

  Virgo power increased from 18W to 26W.
- LIGO/Virgo/KAGRA Memorandum of Agreement signed Oct 4.
- O3b began Nov 1 at 15:00:00 UTC.
- Public information/data: https://www.gw-openscience.org/
- O3 Public Alerts: https://gracedb.ligo.org/superevents/public/O3/

LIGO-VIRGO Joint Run Planning Committee

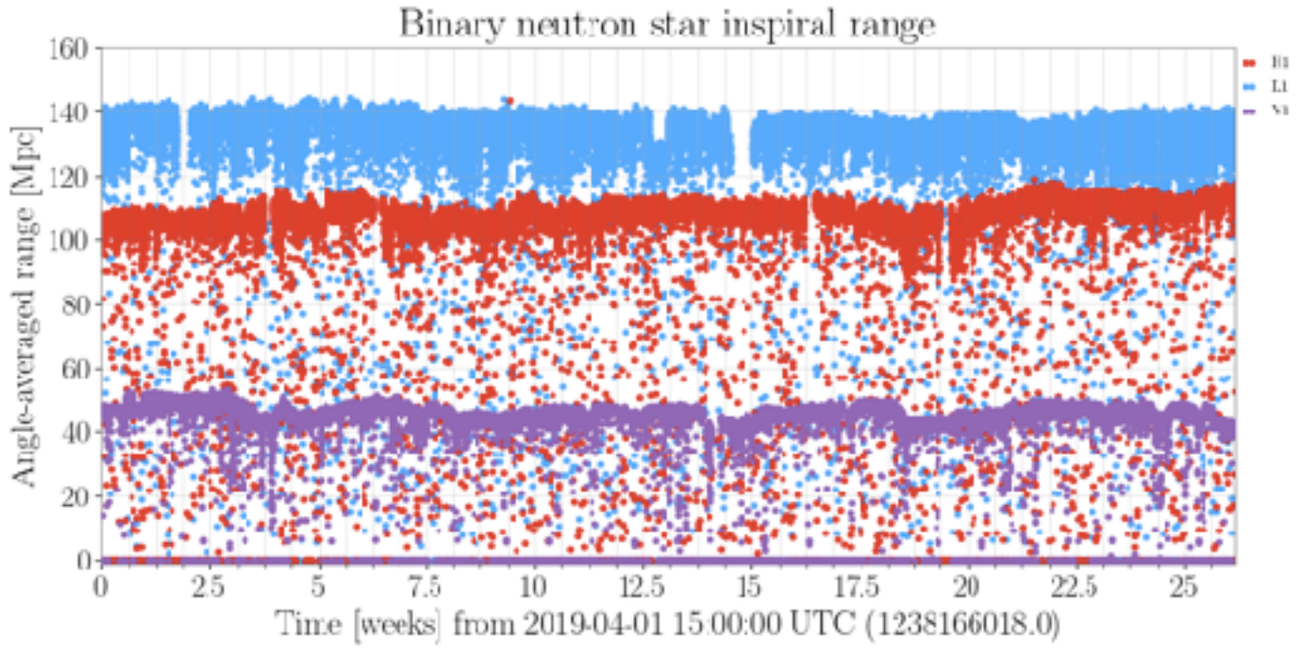
Working schedule for O3

(Public document G1801056-v4, based on G1800889-v7)

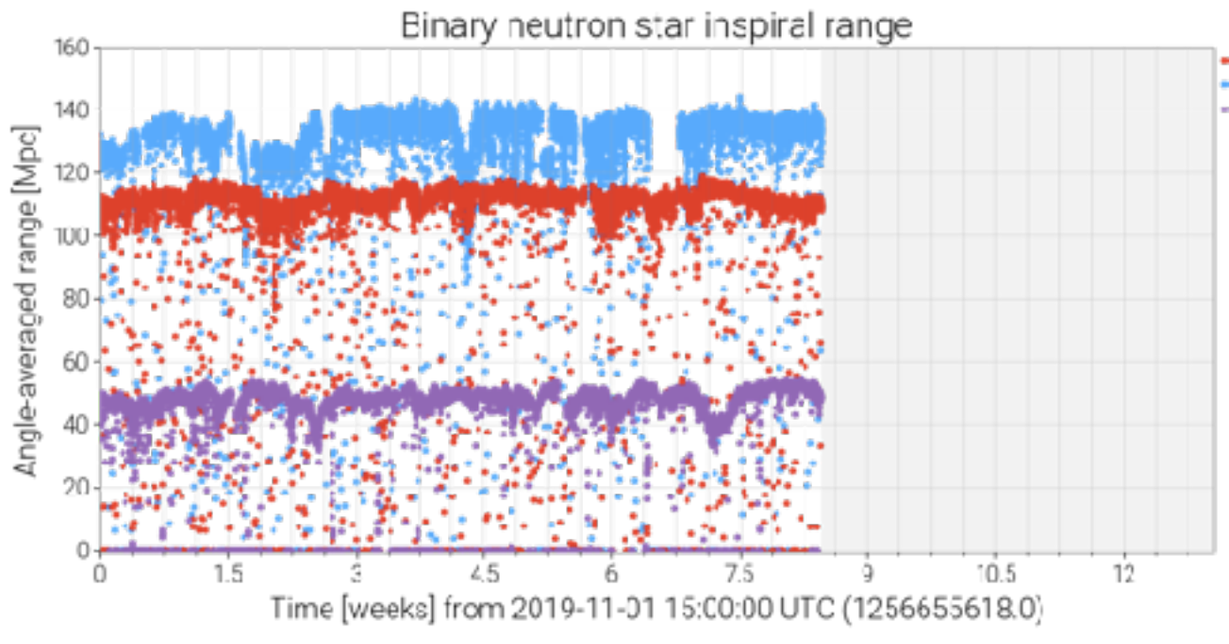


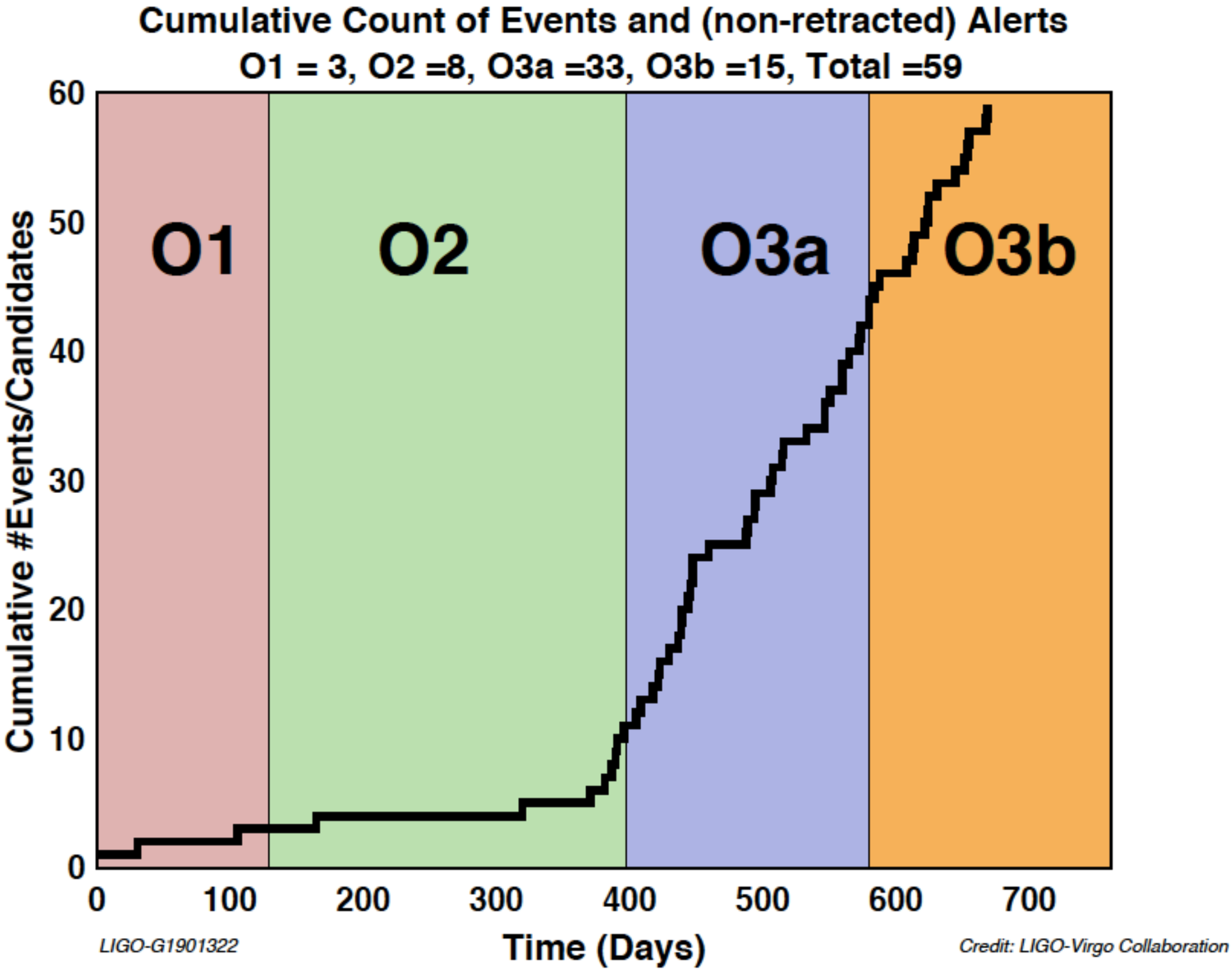
Sensitivities

O3a



O3b



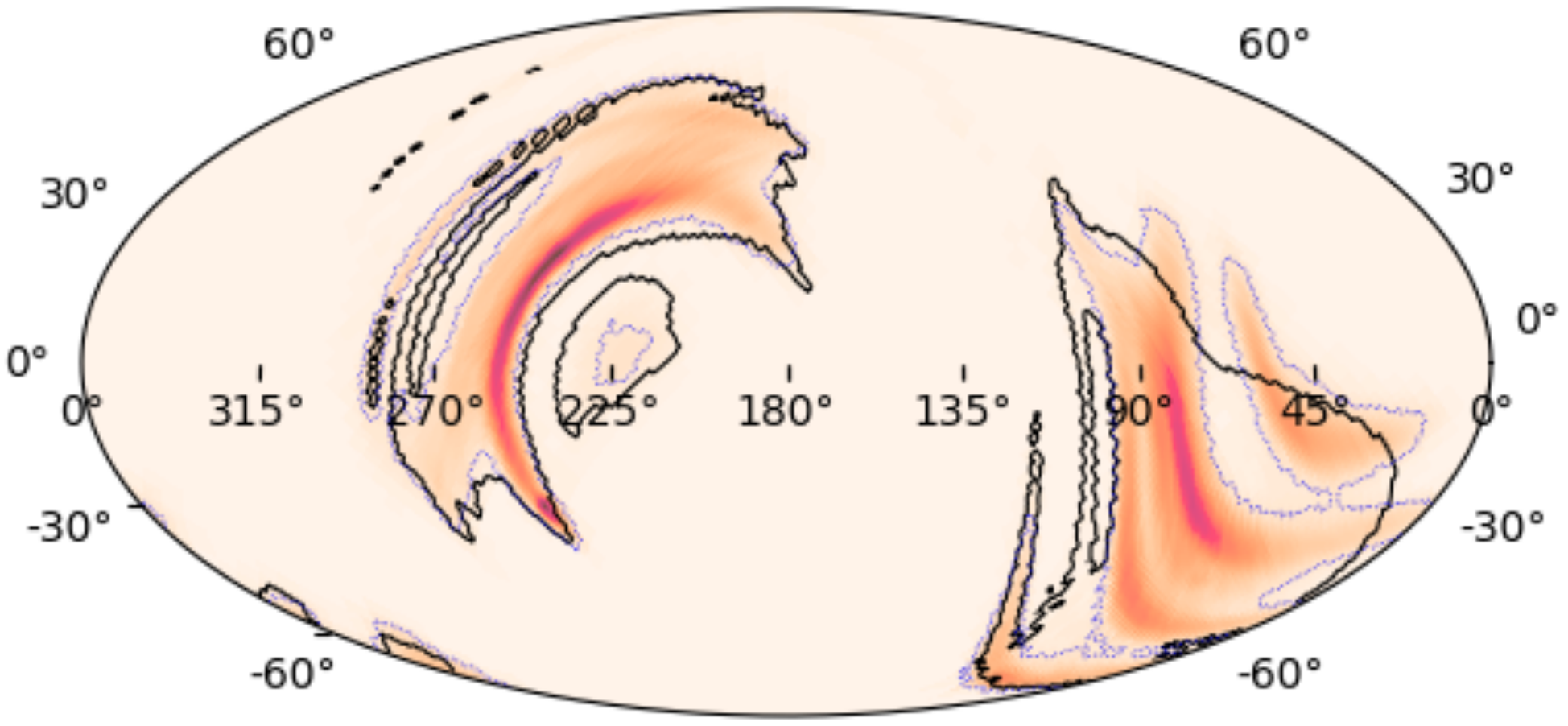


Latest one: January 29, 2020

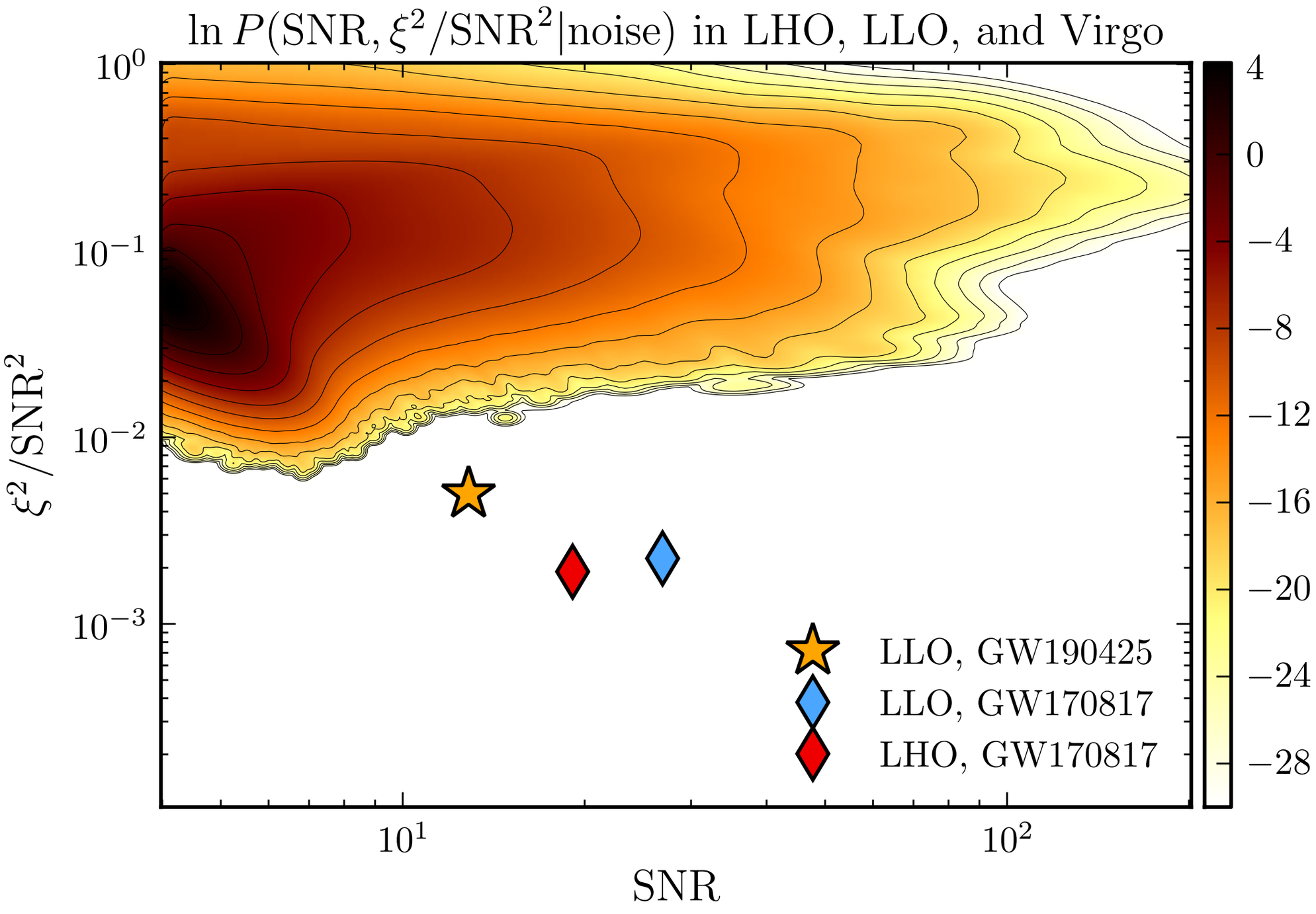
GW 190425: another Binary Neutron Star merger

- Network status:
  - Hanford: Offline
  - Livingstone: Online, BNS Range: 135 Mpc, SNR=12.9
  - Virgo: Online, BNS Range: 48 Mpc, SNR=2.5

Sky localization

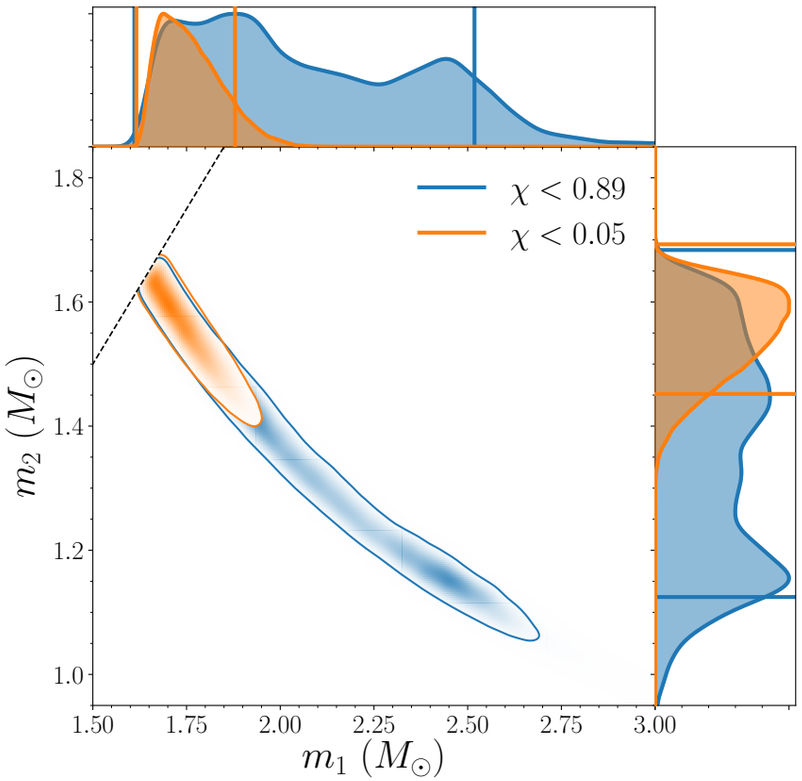


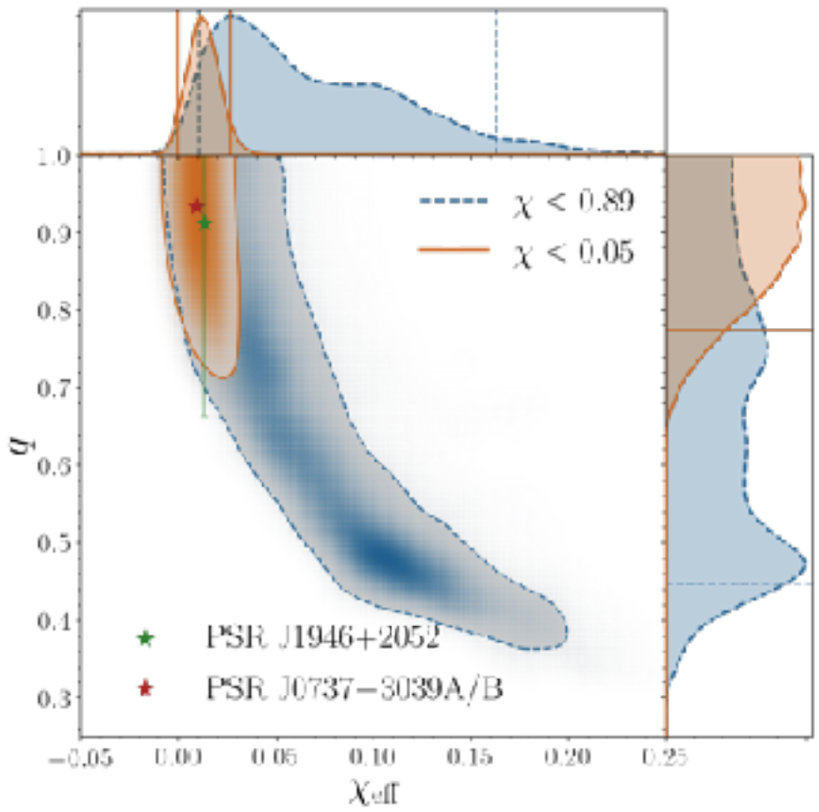
Confidence

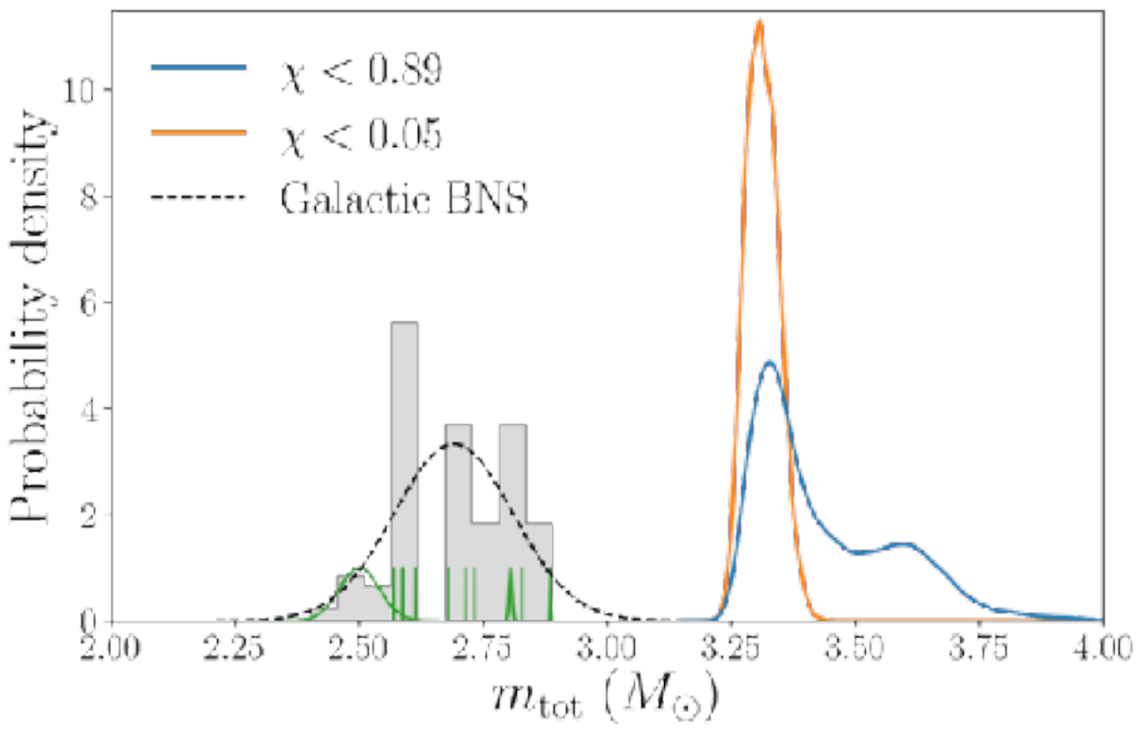


ξ: measure of the signal consistency

Masses, and spin

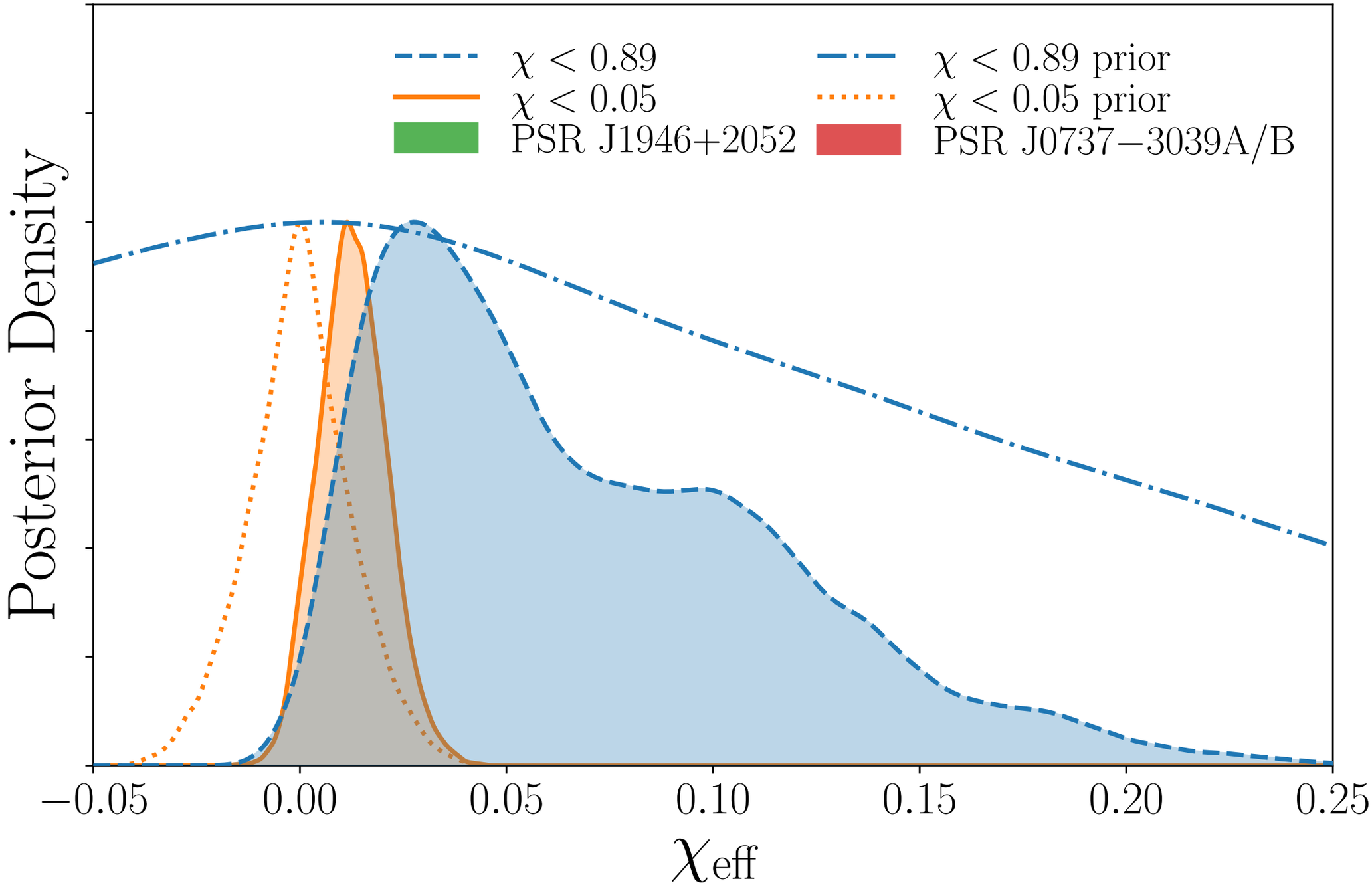




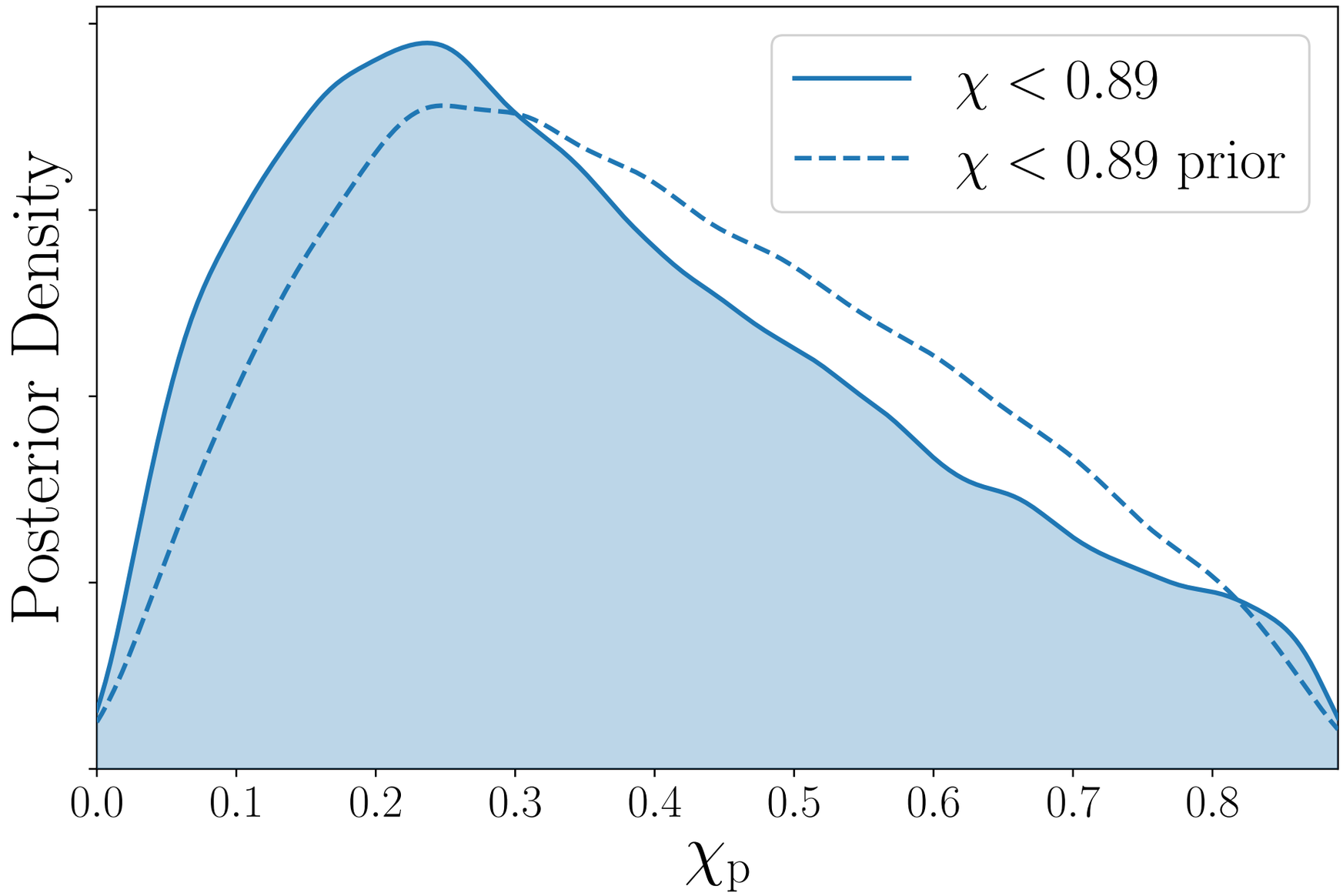


Total mass significantly higher than Galactic BNS

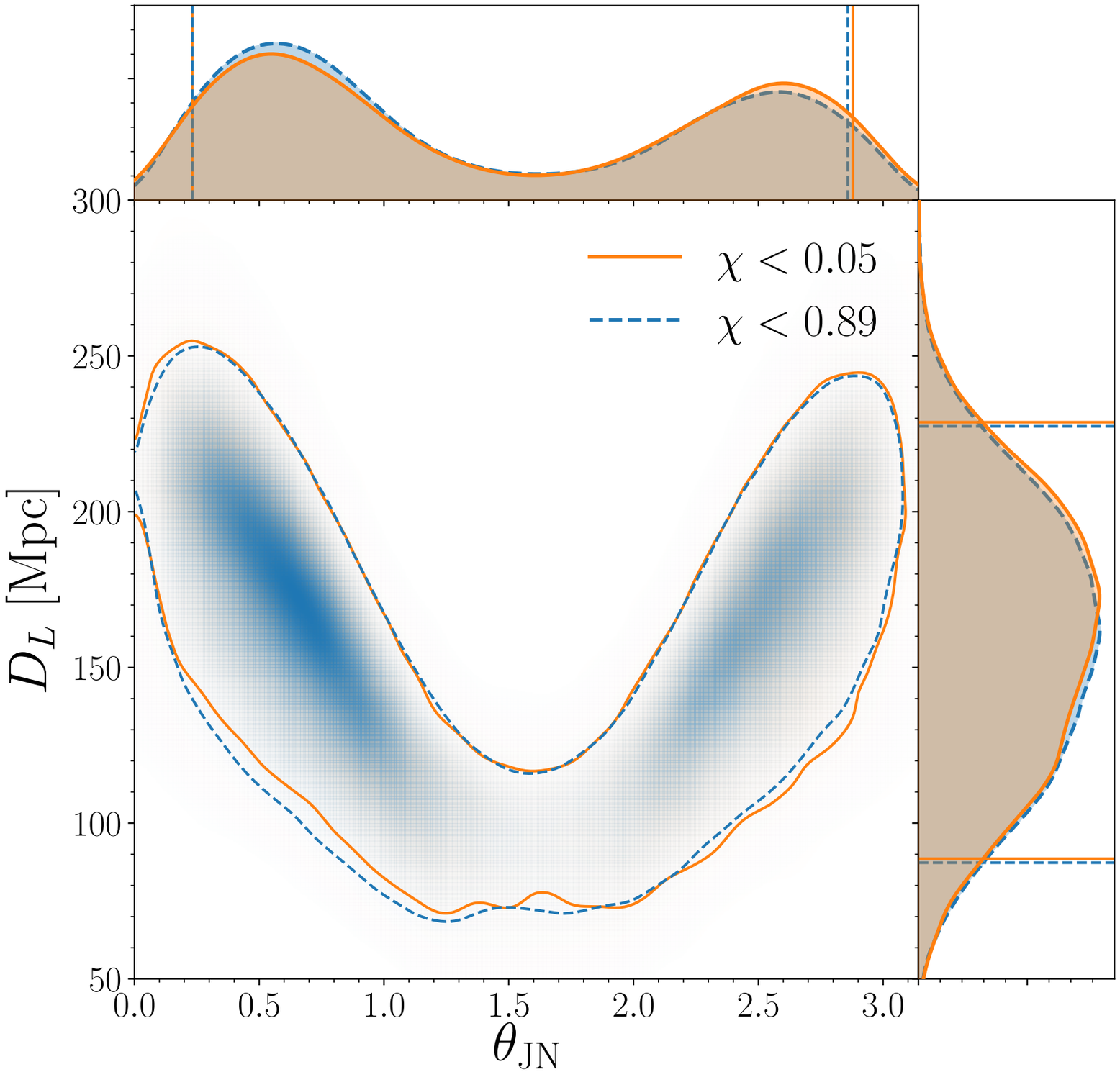
Effective Spin



Spin of the primary



Distance - Inclination



Rate of NS merger in the local universe

- GW170817: $760^{+1740}_{-650}\ \mathrm{Gpc}^{-3}\ \mathrm{yr}^{-1}$
- GW190425: $460^{+1050}_{-390}\ \mathrm{Gpc}^{-3}\ \mathrm{yr}^{-1}$
- Combination of both: $1090^{+1720}_{-800}\ \mathrm{Gpc}^{-3}\ \mathrm{yr}^{-1}$
- With BNS Range of ~140 Mpc, we expect to detect $12^{+20}_{-9}\ \mathrm{yr}^{-1}$ events during the O3.
- Duration of O3: 8 Months by the end of Jan.
- Duty Cycle: 75% individual, 44% Triple, and 80 % Double

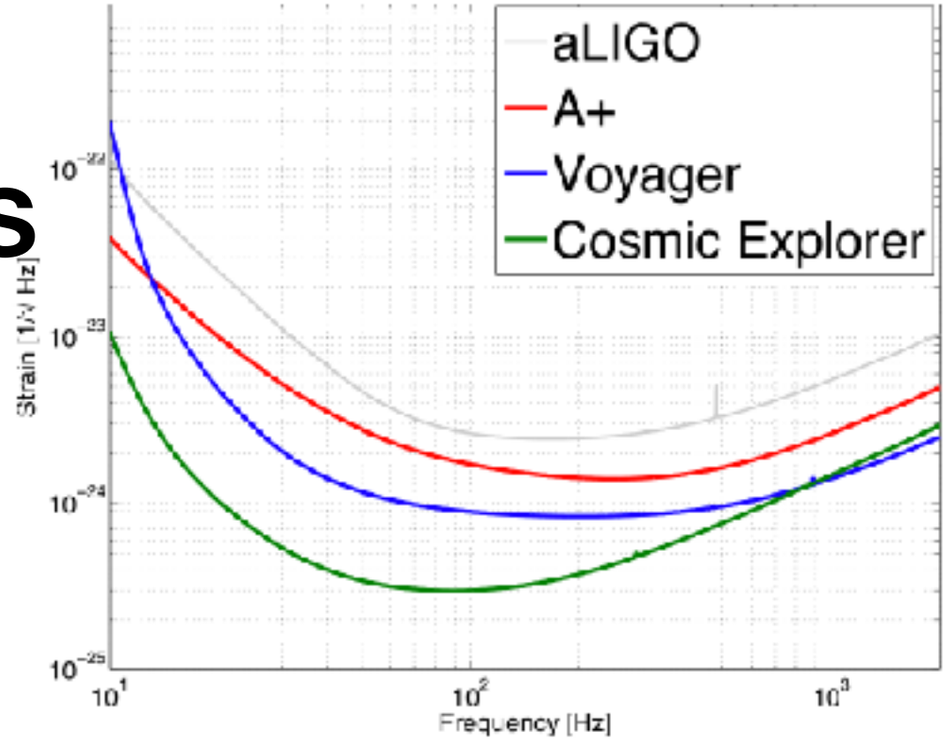
Outstanding Issues

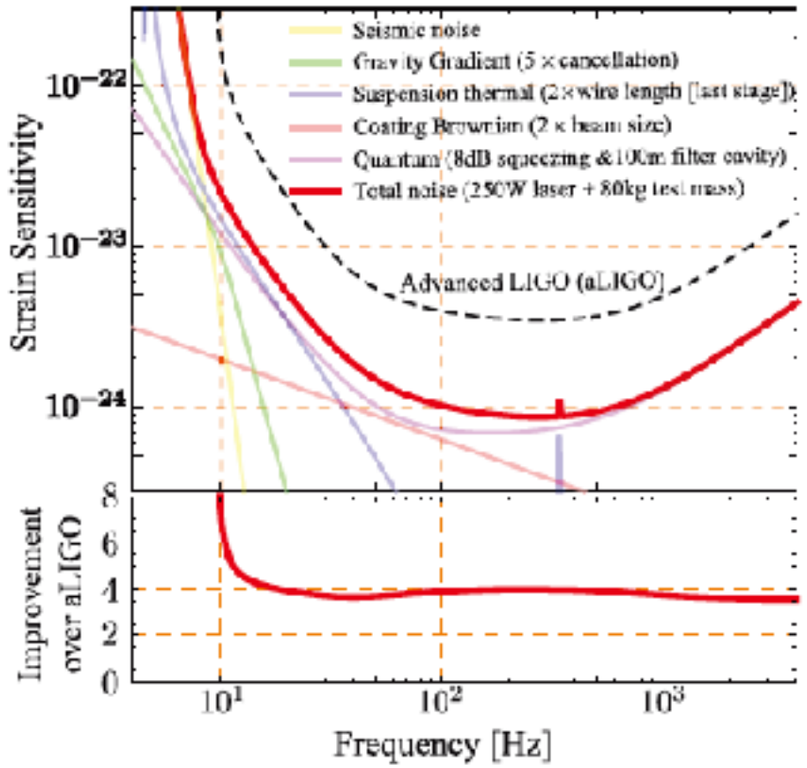
- More BNS (or NSBH) with EM counterpart
  - A few candidates but no EM counterpart yet
- Black Hole in the mass gap above NS (>3 $M_\odot$) but smaller than the lowest BH mass so far (~ 5$M_\odot$)
- Intermediate mass black holes ($m_1 + m_2 > 120\ M_\odot$)
- Individual spin + spin Alignment

LIGO/Virgo Upgrades and near future detectors

- Accuracy of the sky localization could be improved by additional detectors and better sensitivity
- LIGO's upgrade plan
  - A+ (~50%)
  - Voyager (factor of 3)
  - Cosmic Explorer (order of magnitude)
- Additional Detectors
  - KAGRA (~2019), LIGO India (~2020)
  - 8 km detectors in Australia (and possibly in China)
  - Einstein Telescope

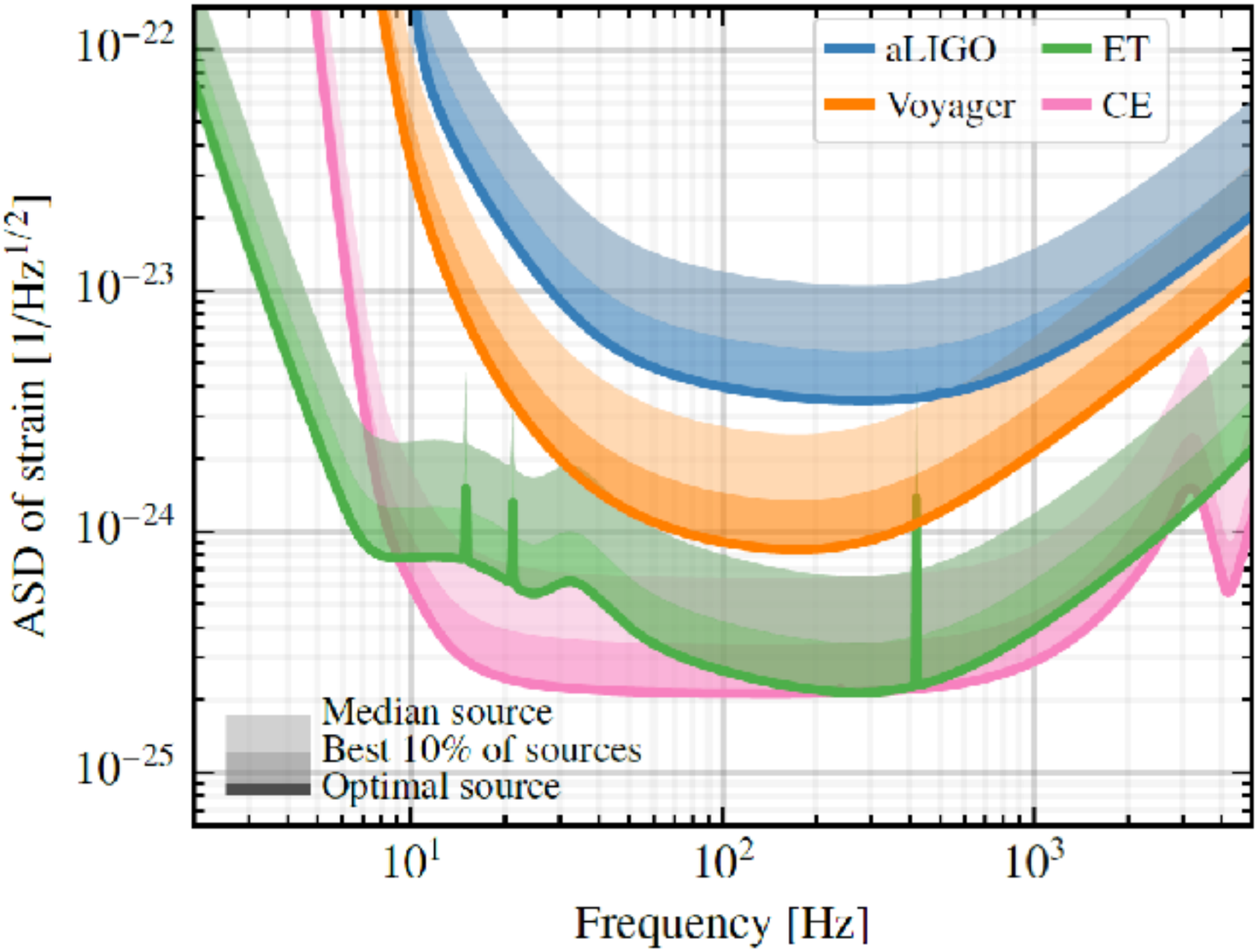
LIGO Upgrade Plan white paper (LIGO-T1400316)





Blair et al. 2015, Science China Physics, Mechanics, and Astronomy, 58, 5747

3G Ground based detectors



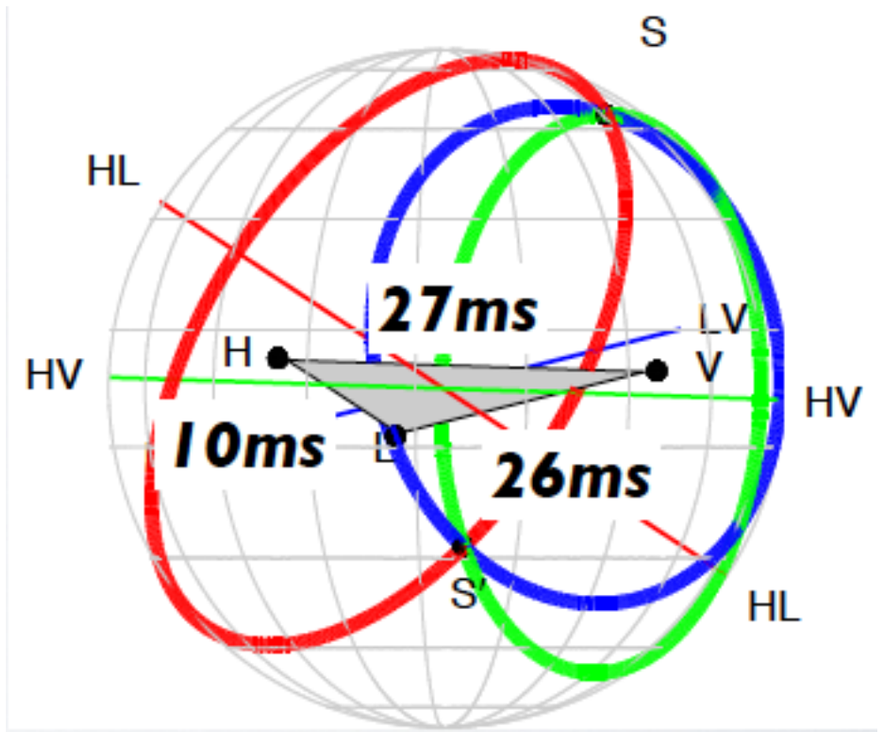
- Laser interferometers similar to LIGO/Virgo covers frequencies higher than 10 Hz (except for ET which will be located underground)

Sensitivity gain and localization

- Detection of more distant sources
- Higher signal-to-noise ratio means better angular resolution

$$\sin\theta d\theta = \frac{\sqrt{\sigma_1^2+\sigma_2^2}}{\Delta t} \qquad \sigma_t = \frac{1}{2\pi\rho\sigma_f}$$

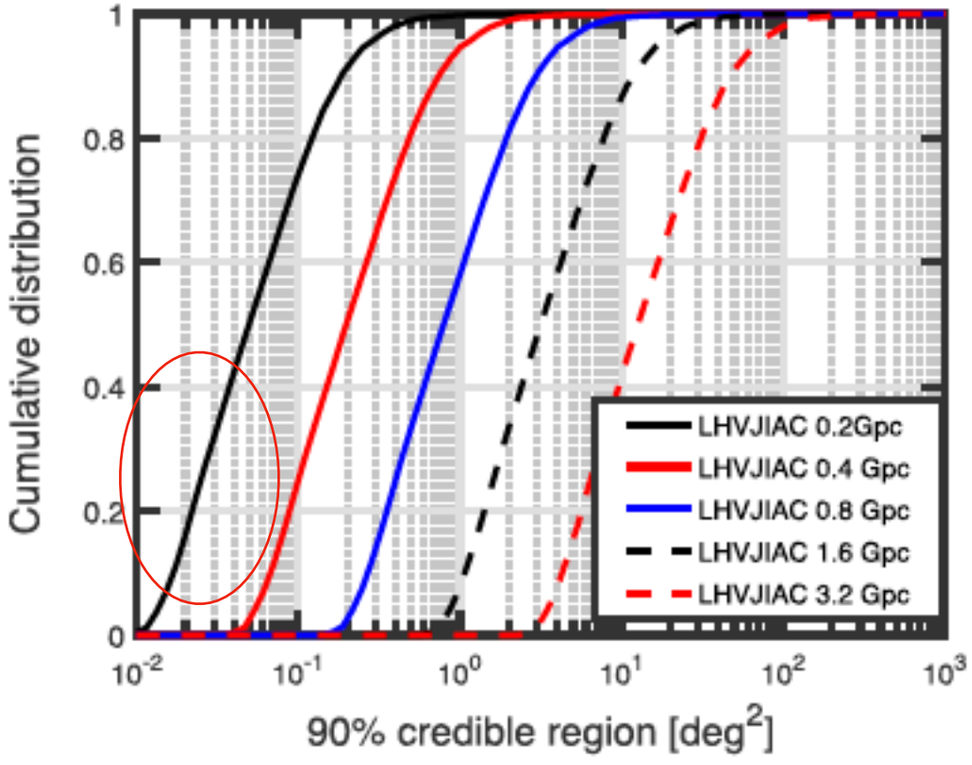
- $d\theta$: width of the ring, Δt: baseline, ρ: signal-to-noise ratio, σ_f: effective bandwidth of the source, (~100 Hz for NS binaries, smaller for BH binaries

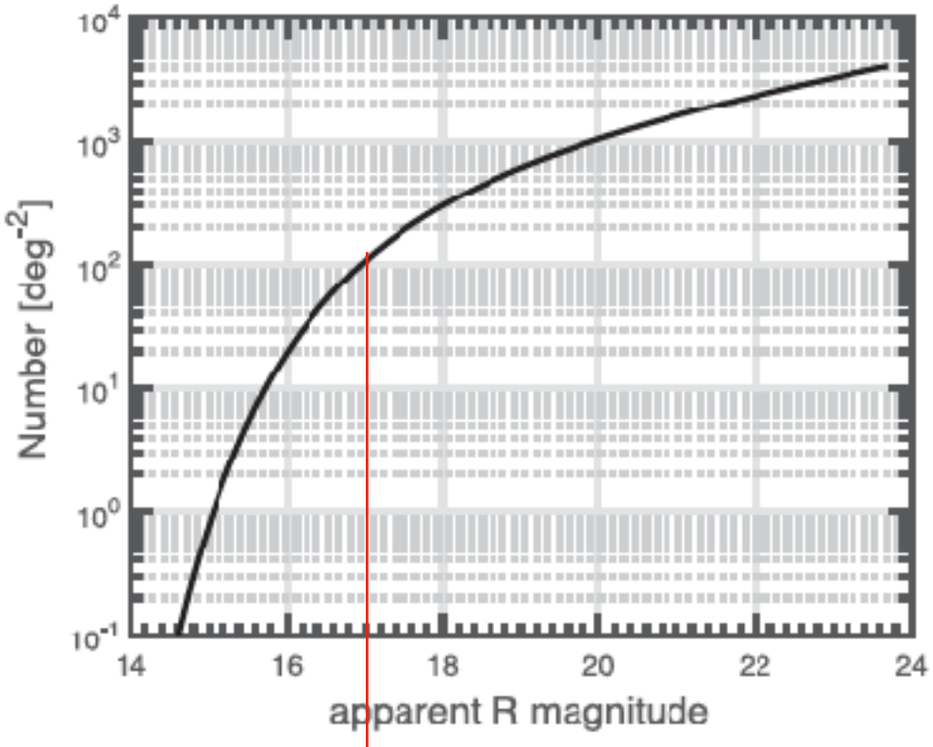


Fairhurst 2011

Can BBH hosts be identified with GW alone?

Howell et al. 2018





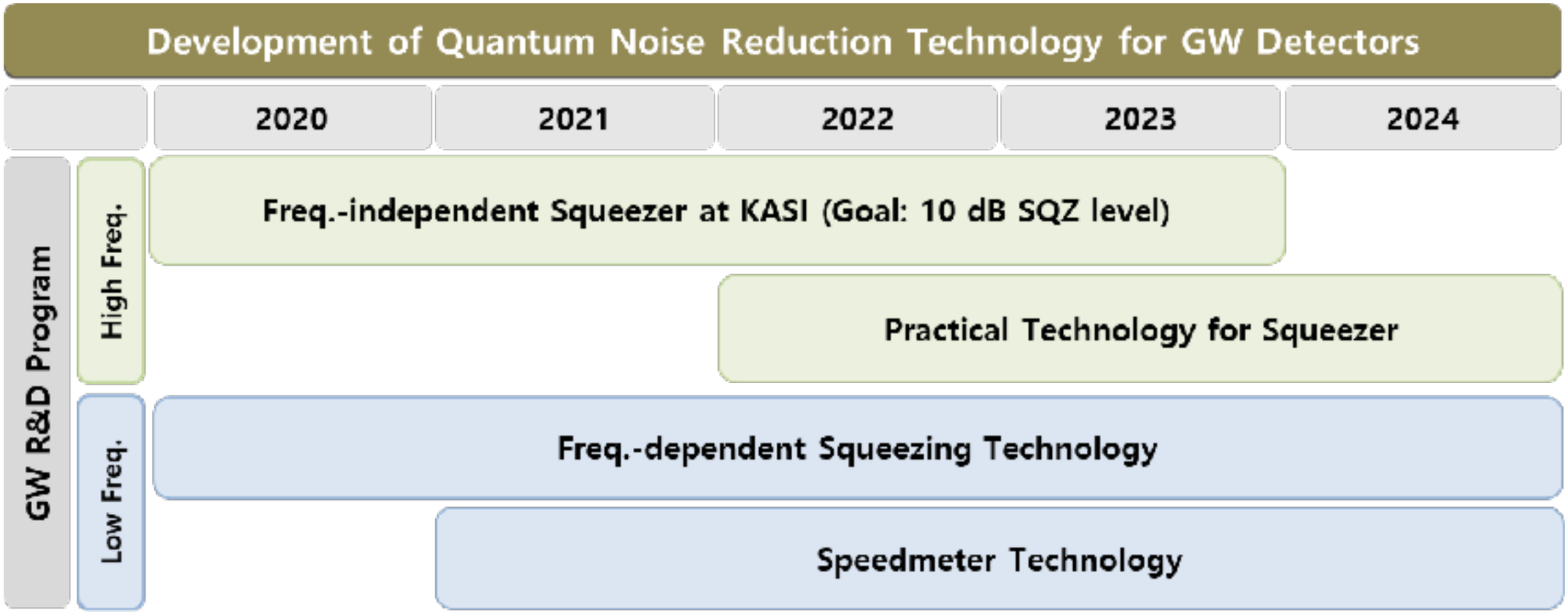
Milky Way Galaxy at 0.4 Gpc

- ~20% of the BBHs at 400 Mpc can be localized with 0.1 sq. deg.
- There could be 10-20 galaxies within the 0.1 sq. deg.

Development of Quantum Noise Reduction at KASI led by Sungho Lee

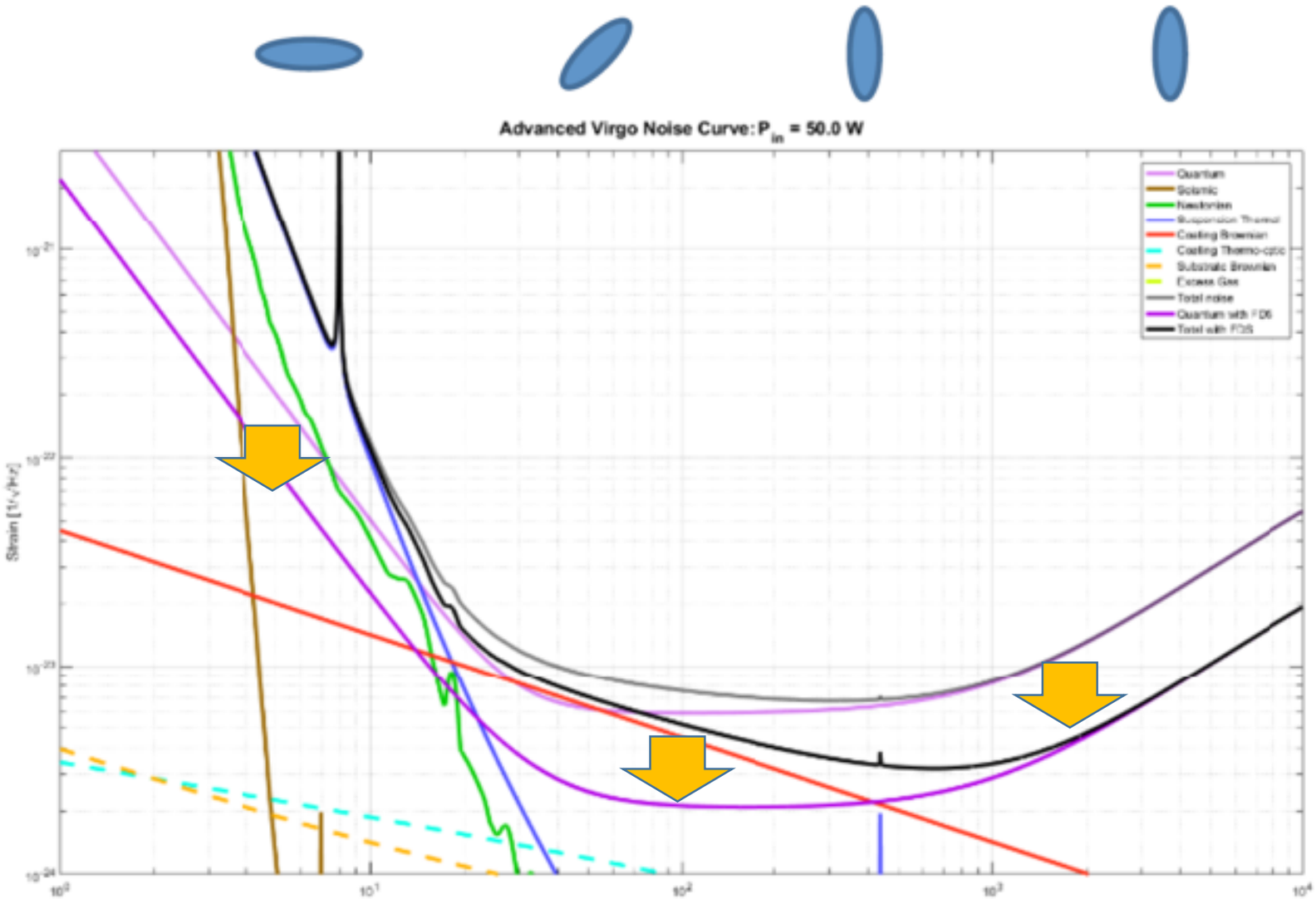
GW R&D Program (from 2020)

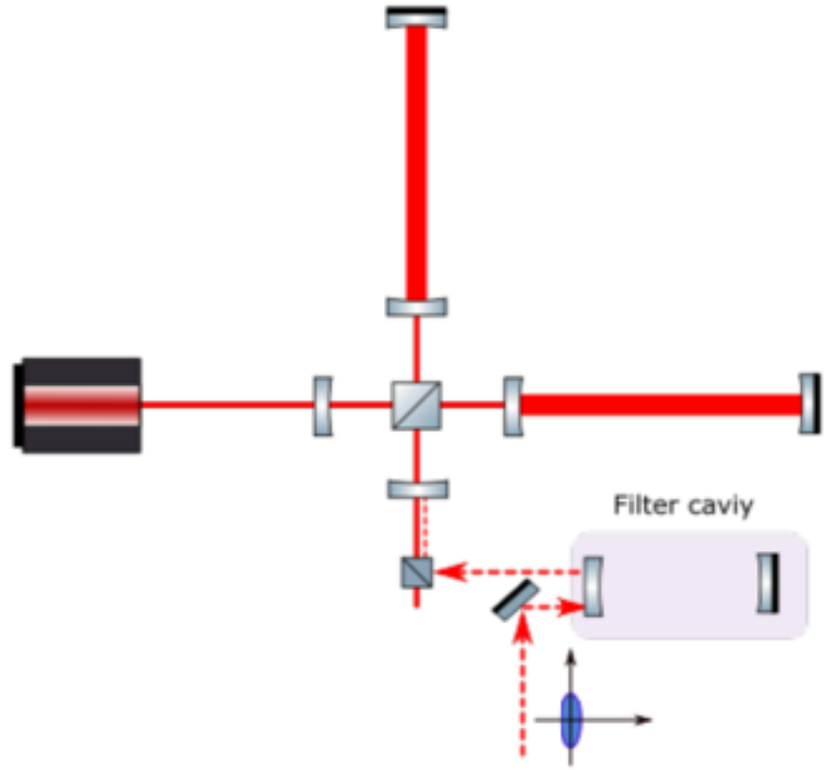
- Periods : 2020 - 2024 (5 years)
- Research Topics
  - Crystal based Squeezer Technology
    - Extending the pilot study carried out in 2019 together with Myungji U. Group
    - Practical technology improvement for squeezer
  - Quantum noise reduction at lower frequencies
    - Frequency dependent squeezing (by international collaborations)
    - Other technologies (Sagnac interferometer, non-demolition measurement)



Quantum Noise Reduction at Lower Freq.

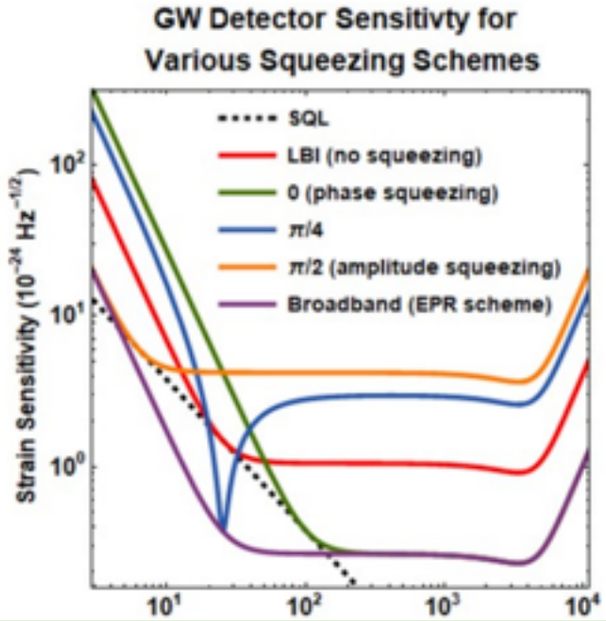
- ❖ Frequency dependent squeezing using filter cavity
  - Collaboration with NAOJ and NTHU for KAGRA upgrade
  - Participation to TAMA 300 experiment from 2020
  - Contribution to development of the KAGRA filter cavity (~60 m) (cavity length control, optical fabrication, etc.)





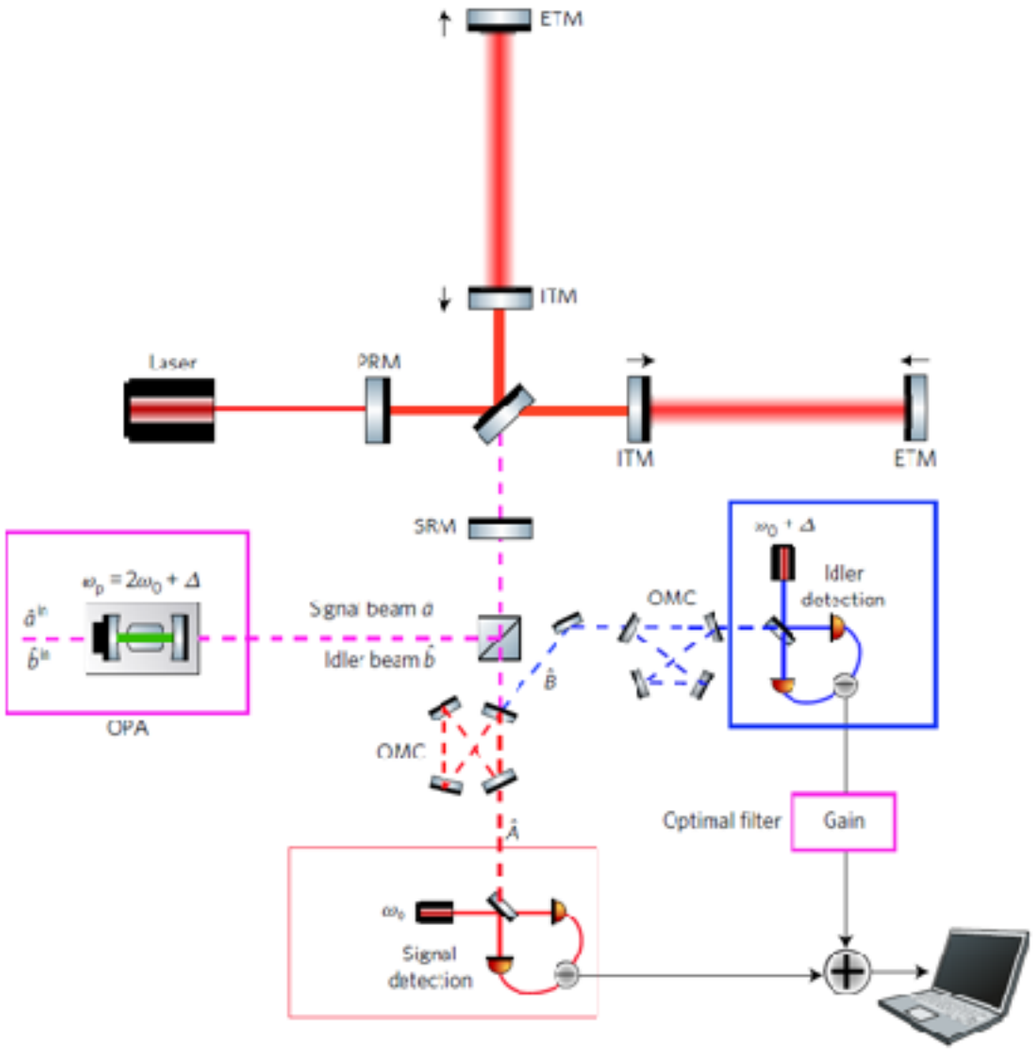
F. Sorrentino – QN reduction in AdV

Quantum Noise Reduction via EPR Entanglement



❖ Development of EPR technology
- Participation to the Virgo/ET R&D

① Table top demonstration
② Implementation on a testbed interferometer
③ Development for AdV+ and ET



Interferometer de-tuned for the idler

Interferometer working like a filter cavity for the idler

Idler freq.-dependent squeezed

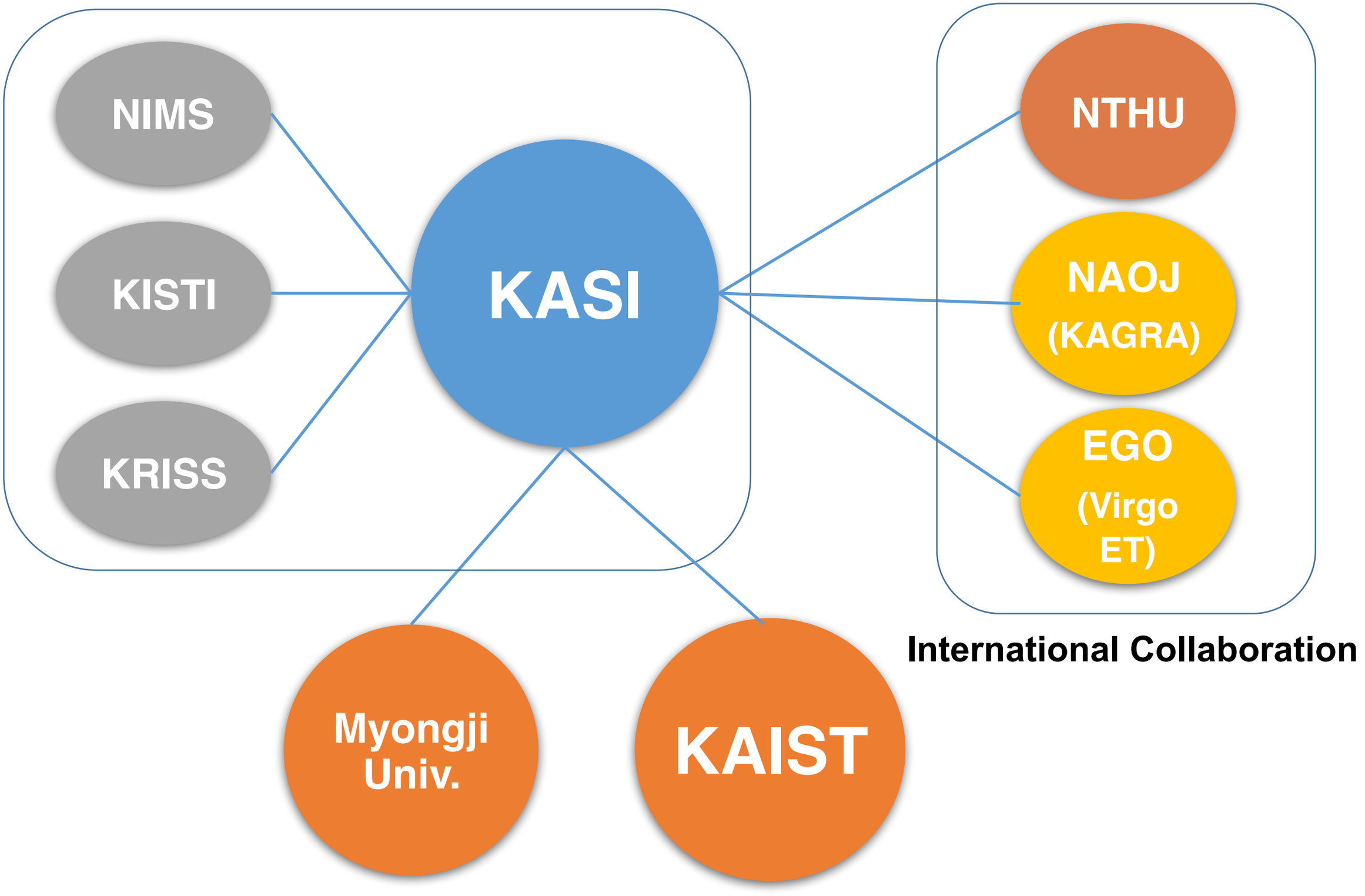
Measurement of an idler fixed quadrature

Signal conditionally squeezed in a freq. dependent way

Y. Ma et al. Nat Phys 13 no. 8, (Aug,2017) 776–780

Collaboration for Squeezing

MoU for GW Technology Development



Summary

- O3 underway, to be completed by the end of April 2020
- ~59 unrestricted triggers, mostly BBH but possible candidates of NS-BH, BNS [e.g., GW190425], IMBH, and mass-gap events so far (end of January)
- Future ground-based laser interferometer detectors include
  - Improvement based on current infrastructure (up to factor of 3)
  - New infrastructure (more than an order of magnitude)
- In Korea, KASI is just launched a project for development of quantum noise reduction