Title: Challenges in gravitational wave astronomy

Speakers: Jess McIver

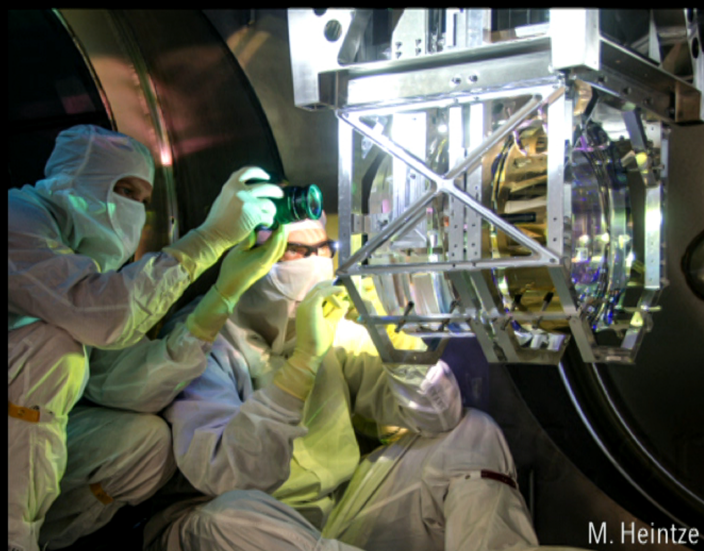
Series: Strong Gravity

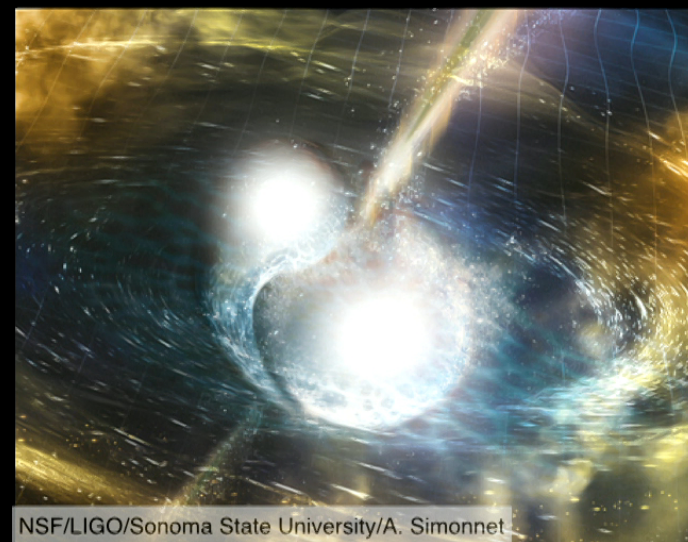
Date: October 03, 2019 - 1:00 PM

URL: http://pirsa.org/19100057

Abstract: Advanced LIGO and Advanced Virgo are currently in the middle of their third observing run, and releasing open public event alerts for the first time. The LIGO-Virgo collaboration has issued 29 un-retracted candidate event alerts as of September 20th, 2019, potentially adding dozens more known compact binary object mergers to the eleven confident LIGO-Virgo detections from the first two Advanced-era observing runs. Iâ€™ll review novel LIGO-Virgo results to date, and discuss the challenges of extracting interesting new physics from noisy detector data. Finally, I'll summarize future prospects for astrophysics, cosmology, and tests of general relativity with gravitational waves, and the roadmap to future gravitational wave detectors on Earth and in space.

# Challenges in gravitational wave astronomy

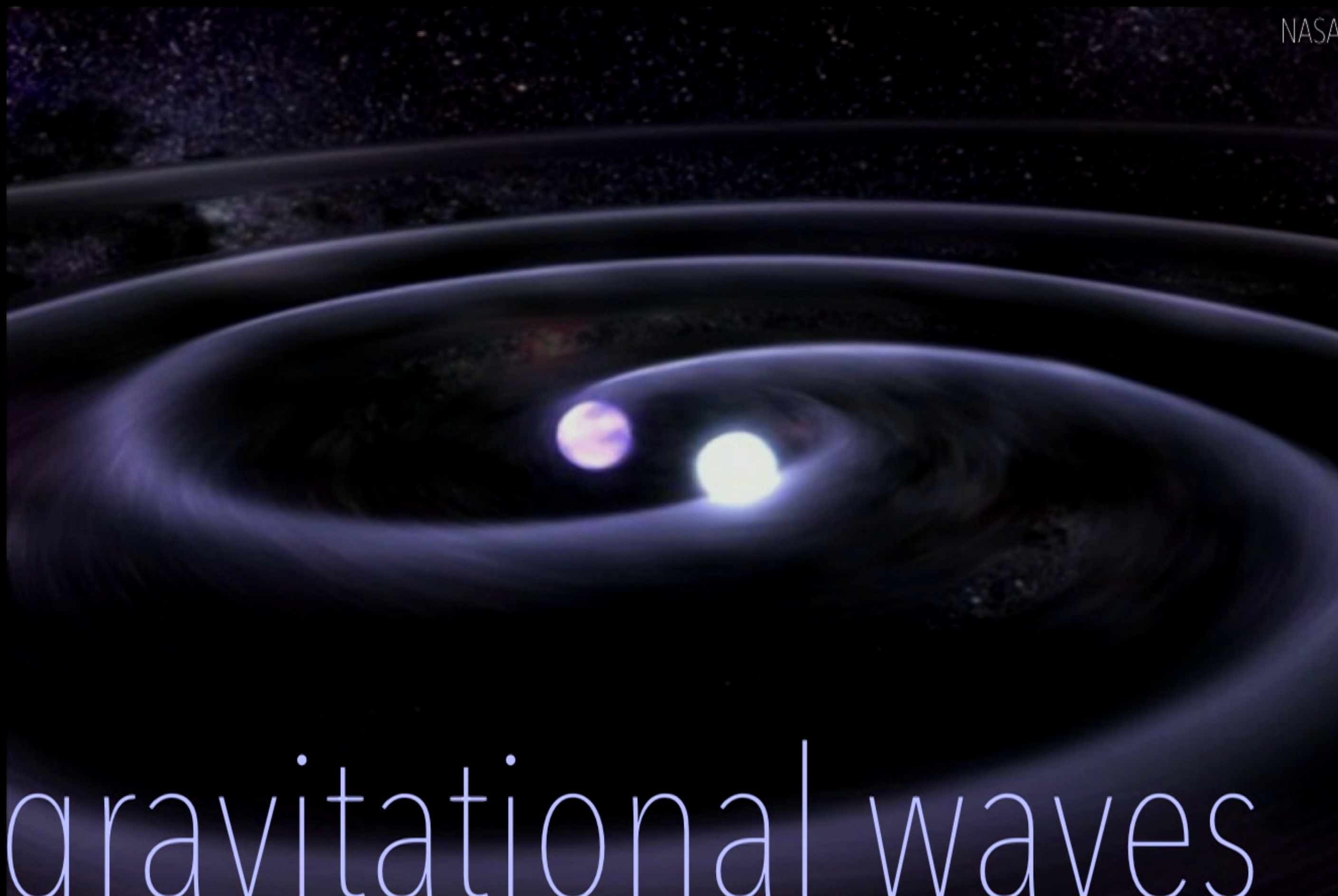



LSC

Jess McIver
**Perimeter Institute**
October 3rd, 2019

UBC



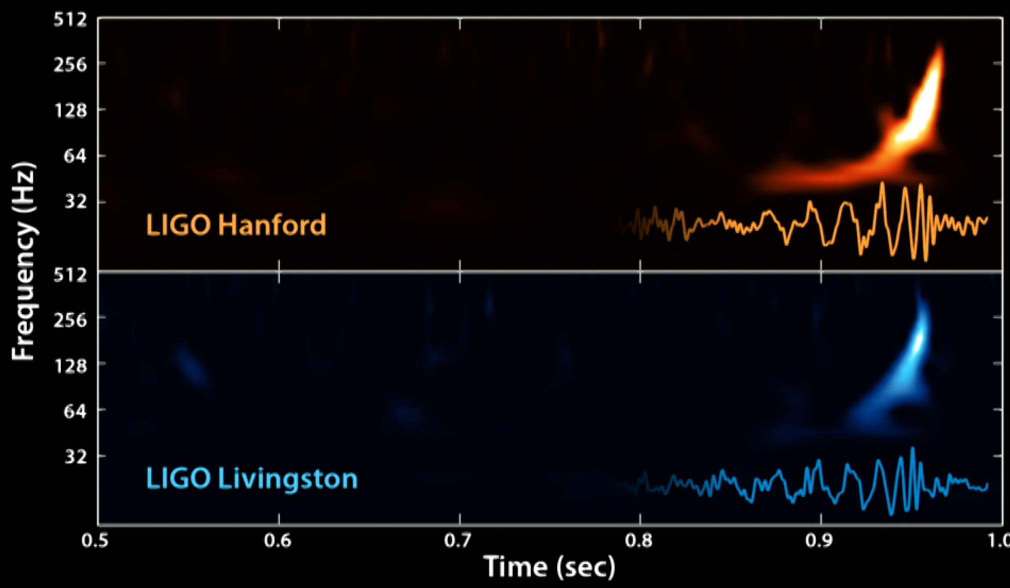

# gravitational waves

## a new view of the universe

2

# The beginning of a new era of astronomy

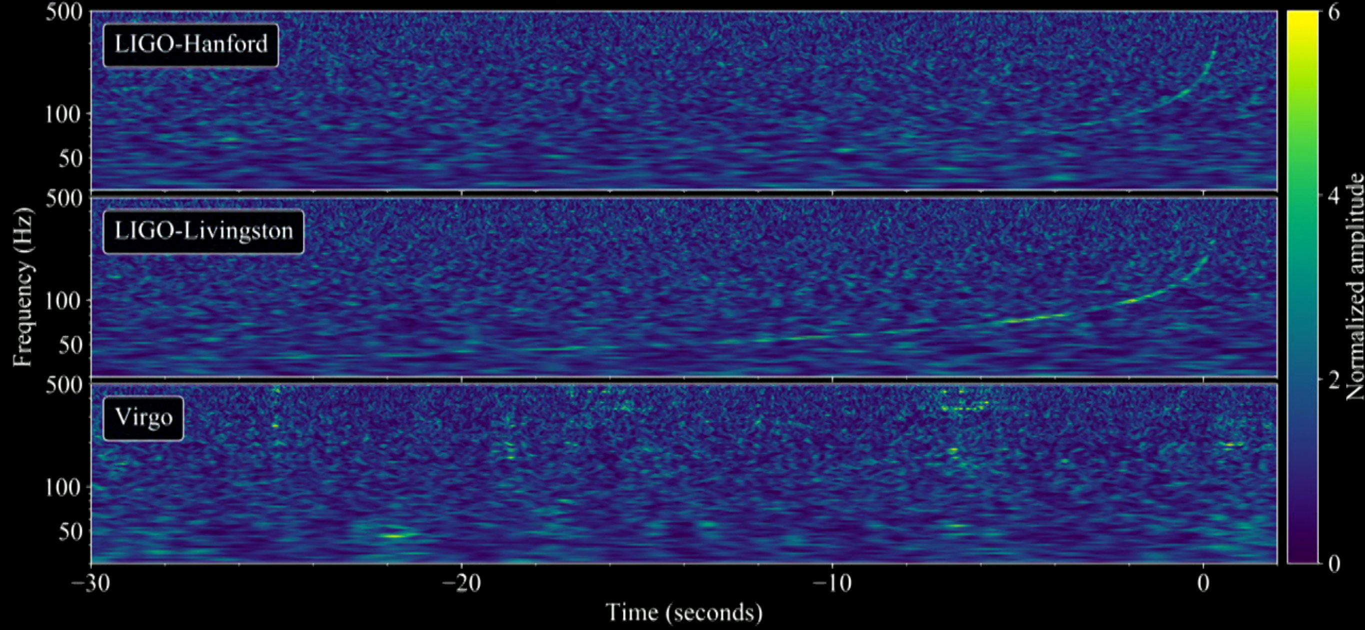
September 14, 2015




LIGO/Virgo

# GW170817: gravitational waves from a binary neutron star merger

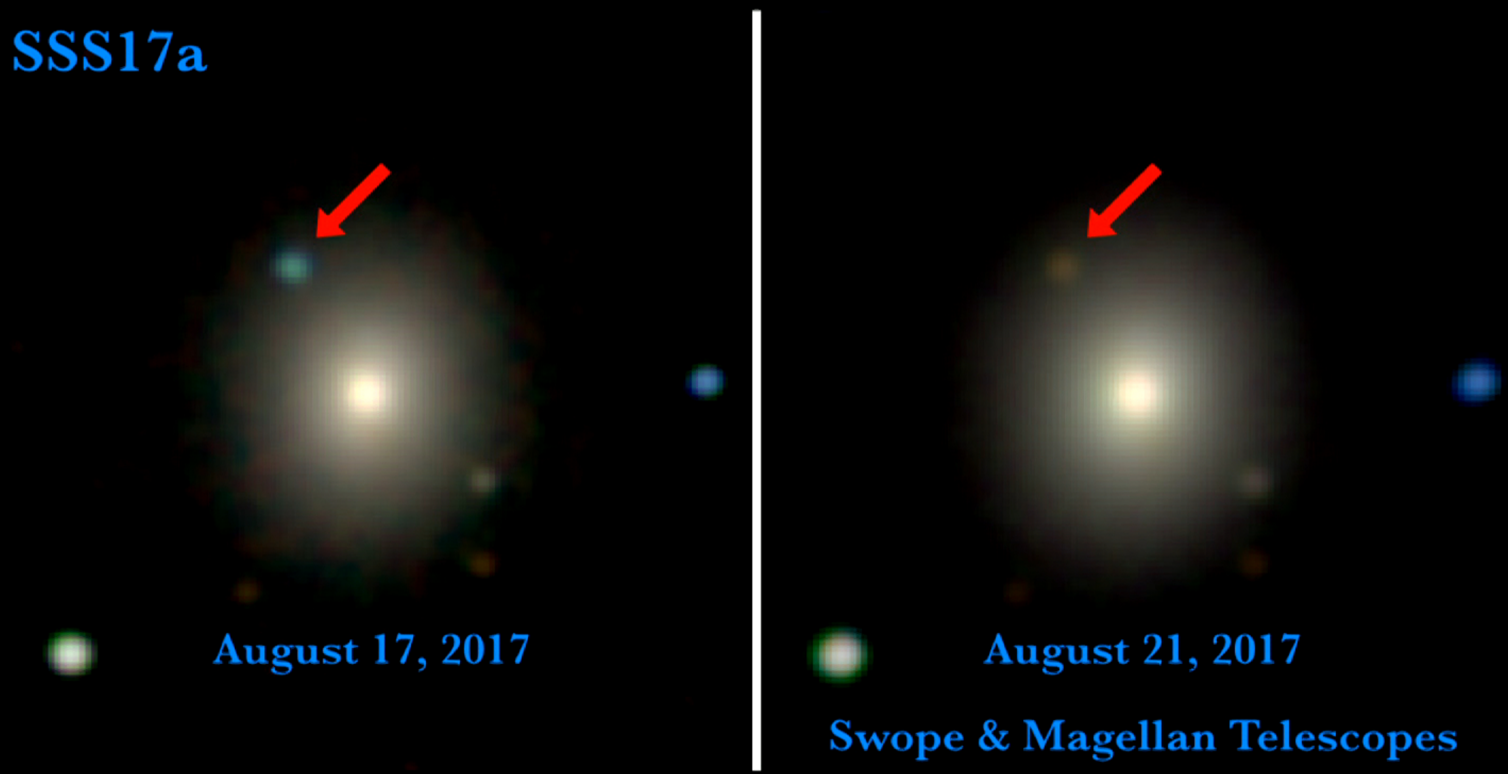
August 17, 2017




LIGO/Virgo/Lovelace, Brown, Macleod, McIver, Nitz

4

# Discovery of an optical counterpart

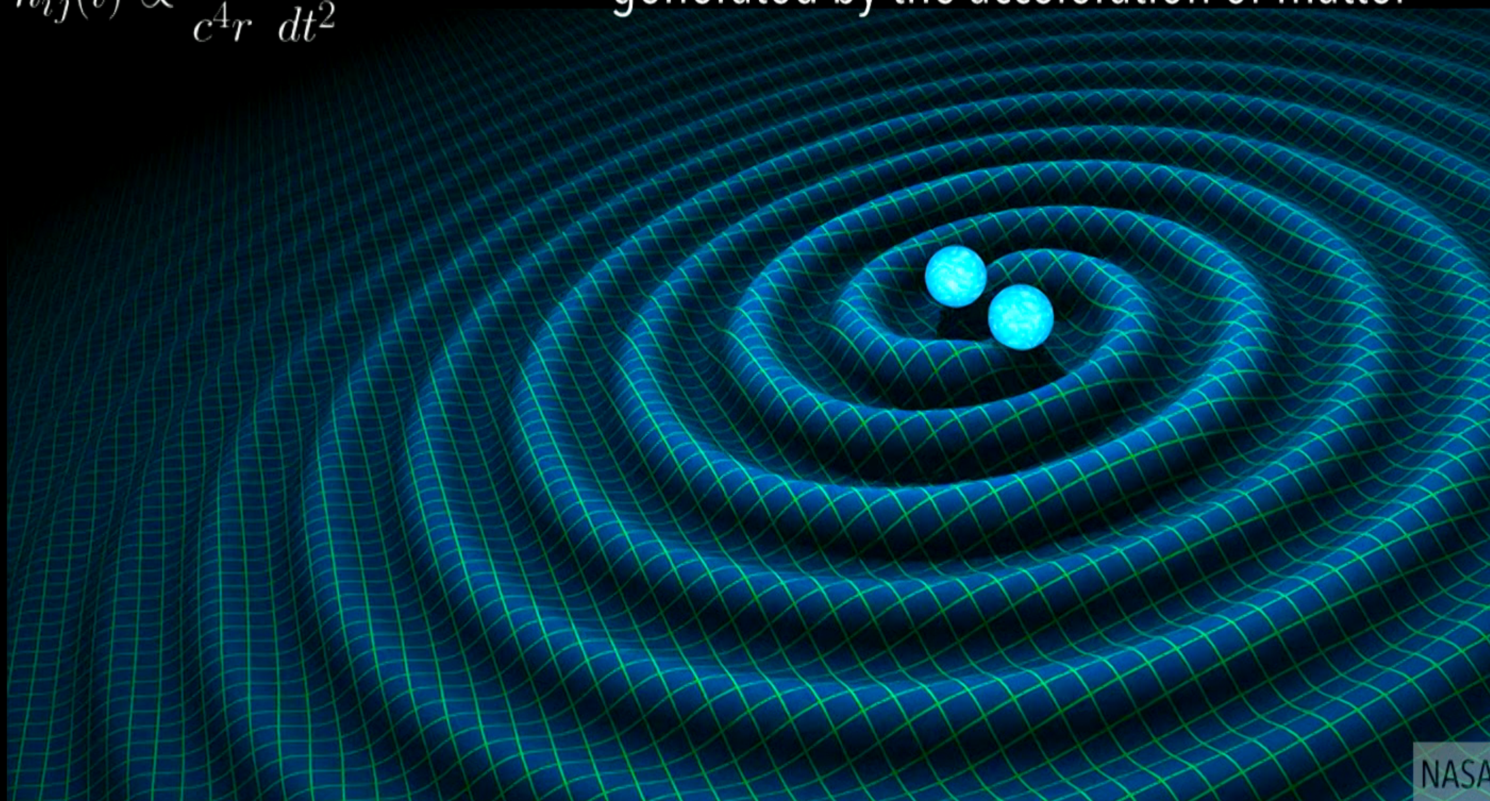



D. Coulter et al. 2017 arXiv 1710.05452
Image: 1M2H/UC Santa Cruz and Carnegie Observatories/Ryan Foley

# Gravitational waves

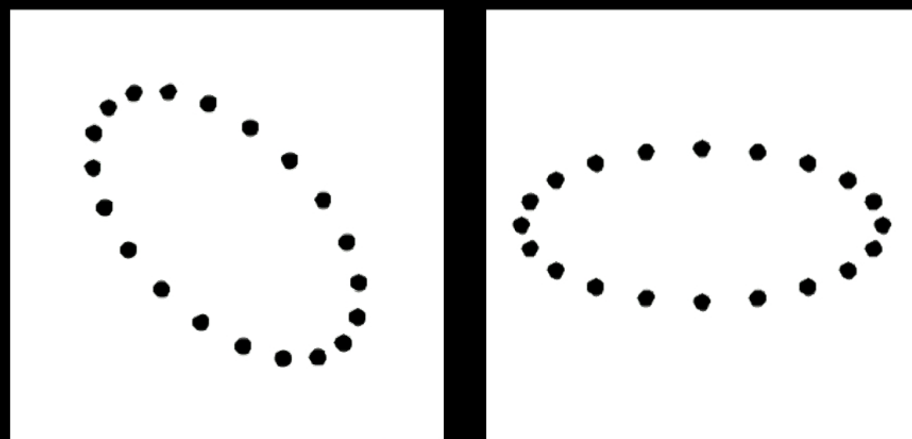
$$h_{ij}(t) \propto \frac{G}{c^4 r}\frac{d^2 I_{ij}}{dt^2}$$

Ripples in the fabric of spacetime
generated by the acceleration of matter



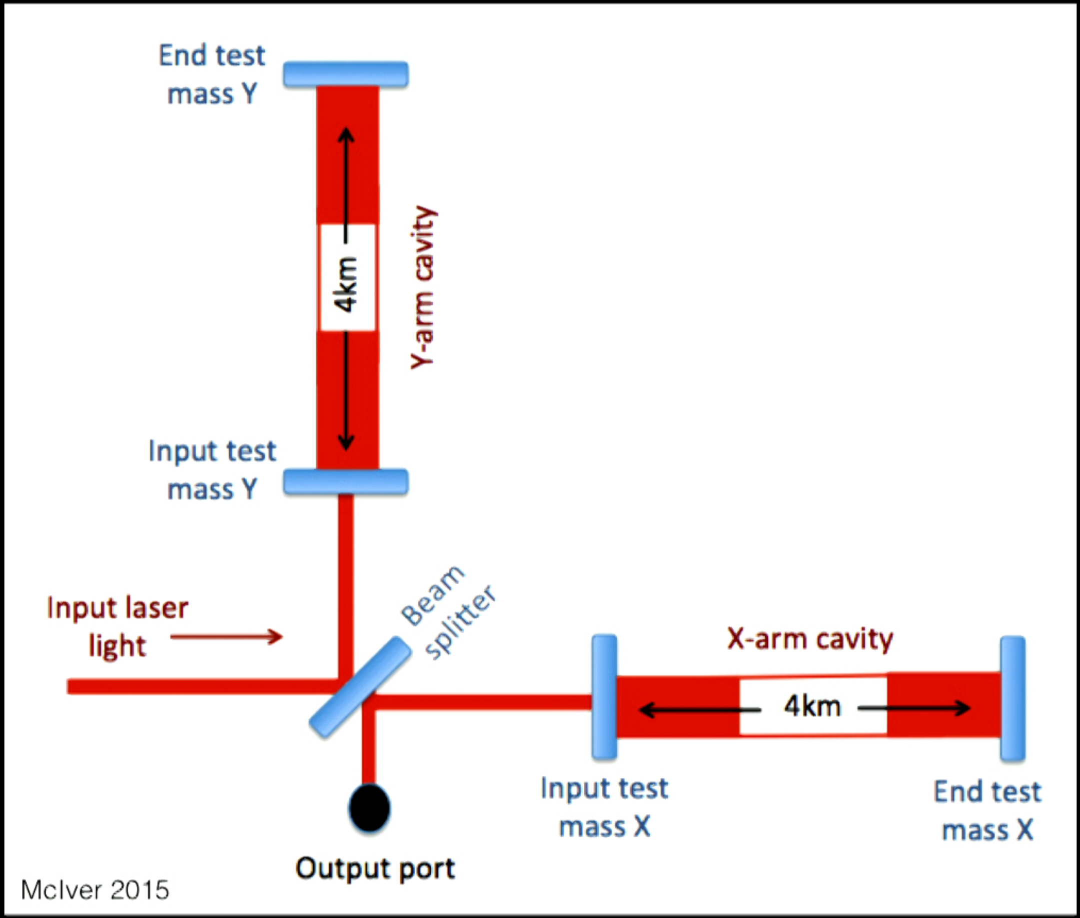
# Gravitational wave propagation

Spacetime strain h(t) measured as $\frac{\Delta L}{L}$

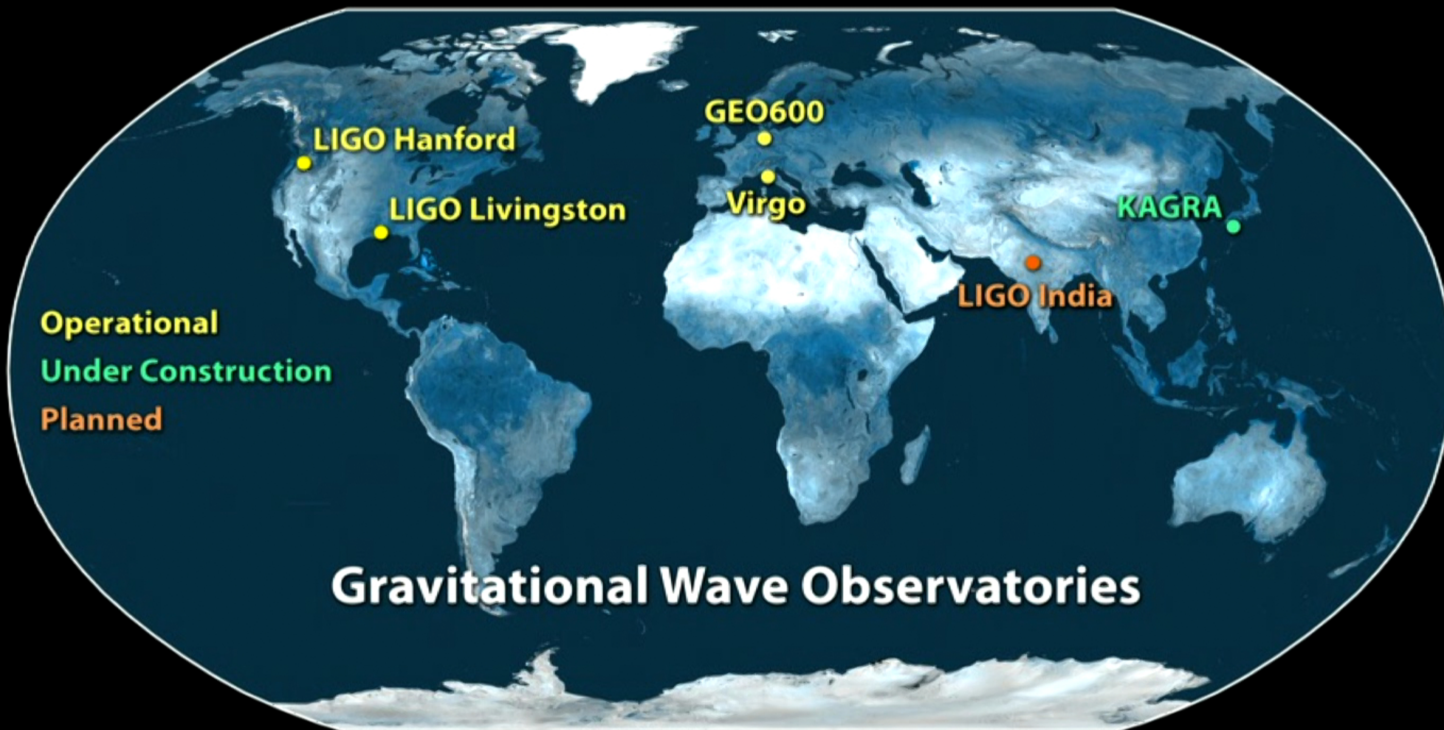


7

# Observing GWs with interferometry



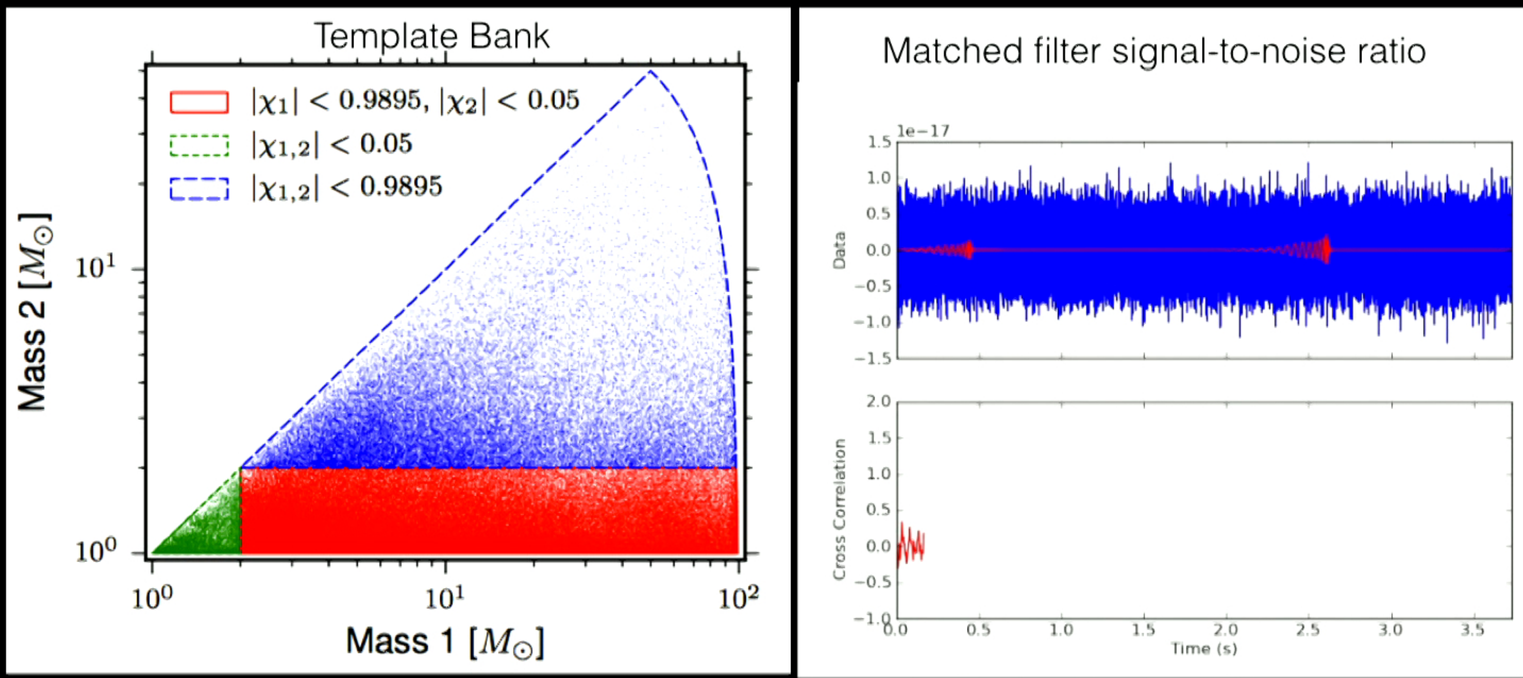
# The global network of current gen interferometers




LIGO/Caltech

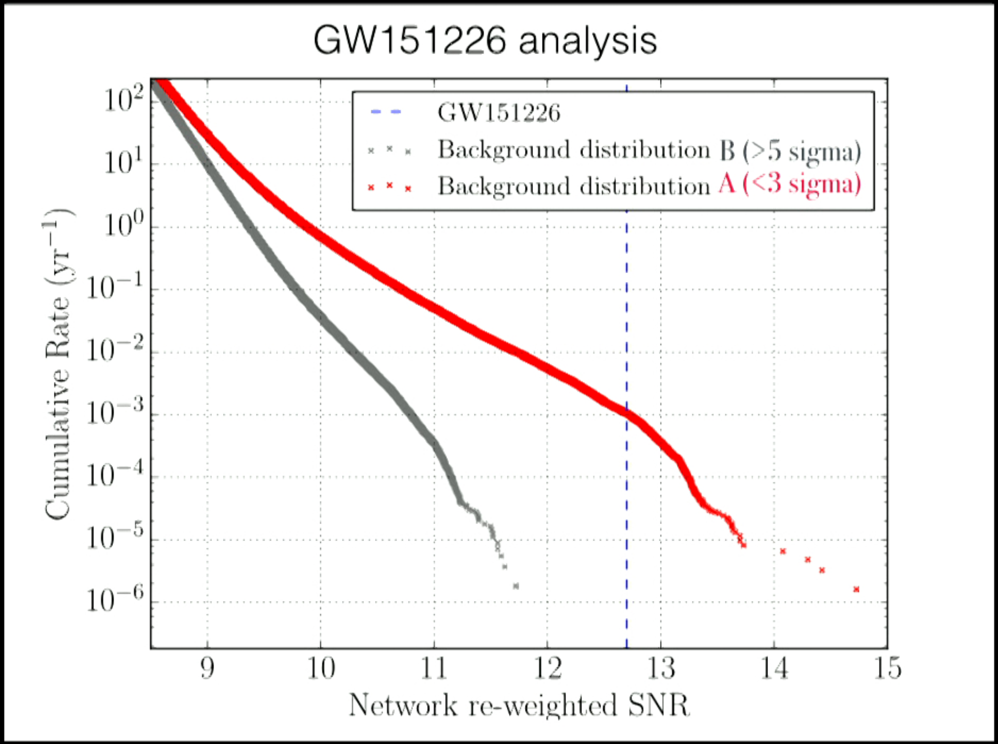
# Searching for signals with matched filtering

Slide adapted from S. Caudill



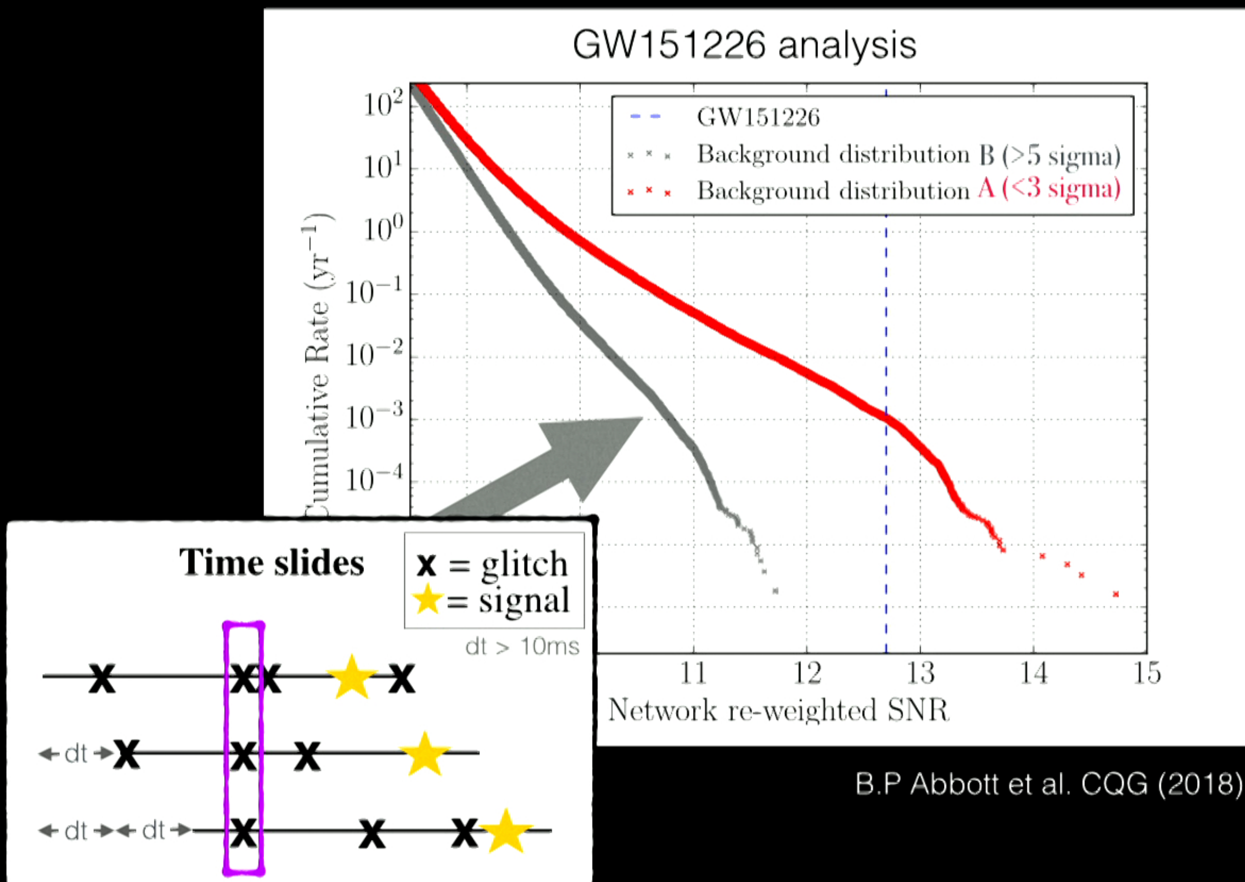

B. P. Abbott et al. Phys. Rev. X (2016)

# The significance of a detected event



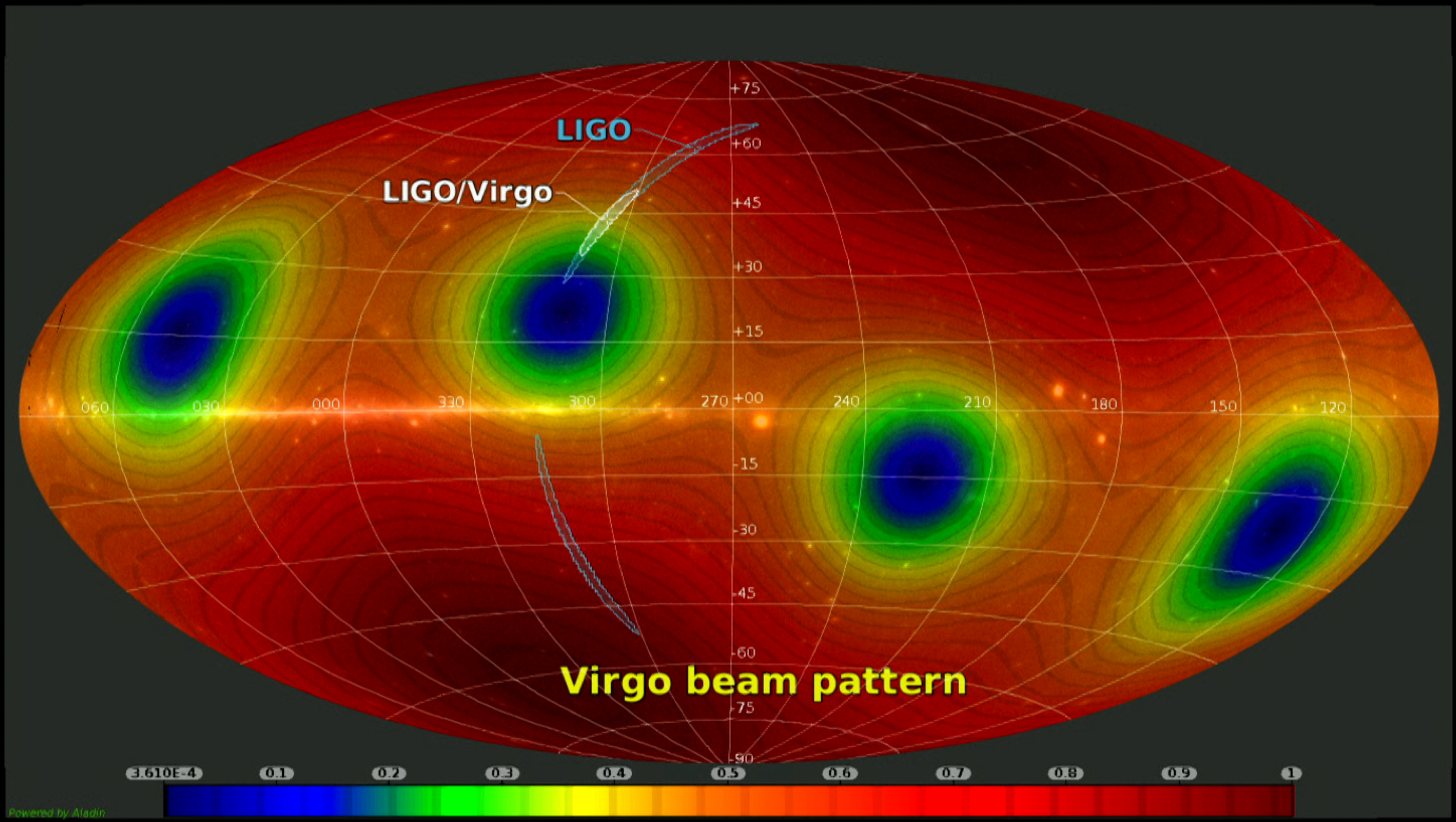

B.P Abbott et al. CQG (2018)

# The significance of a detected event



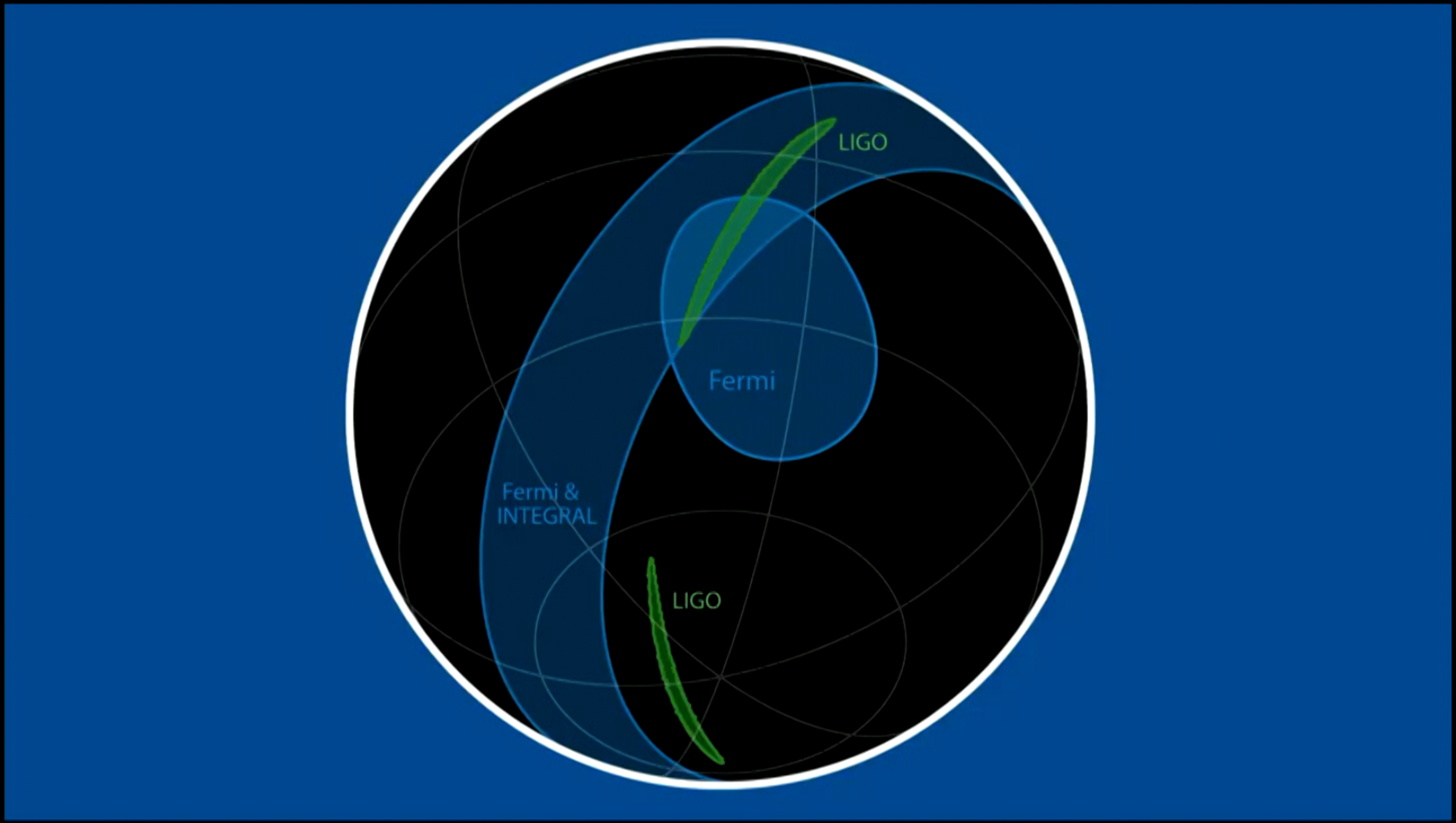

B.P Abbott et al. CQG (2018)

# Inferring sky location from antenna pattern

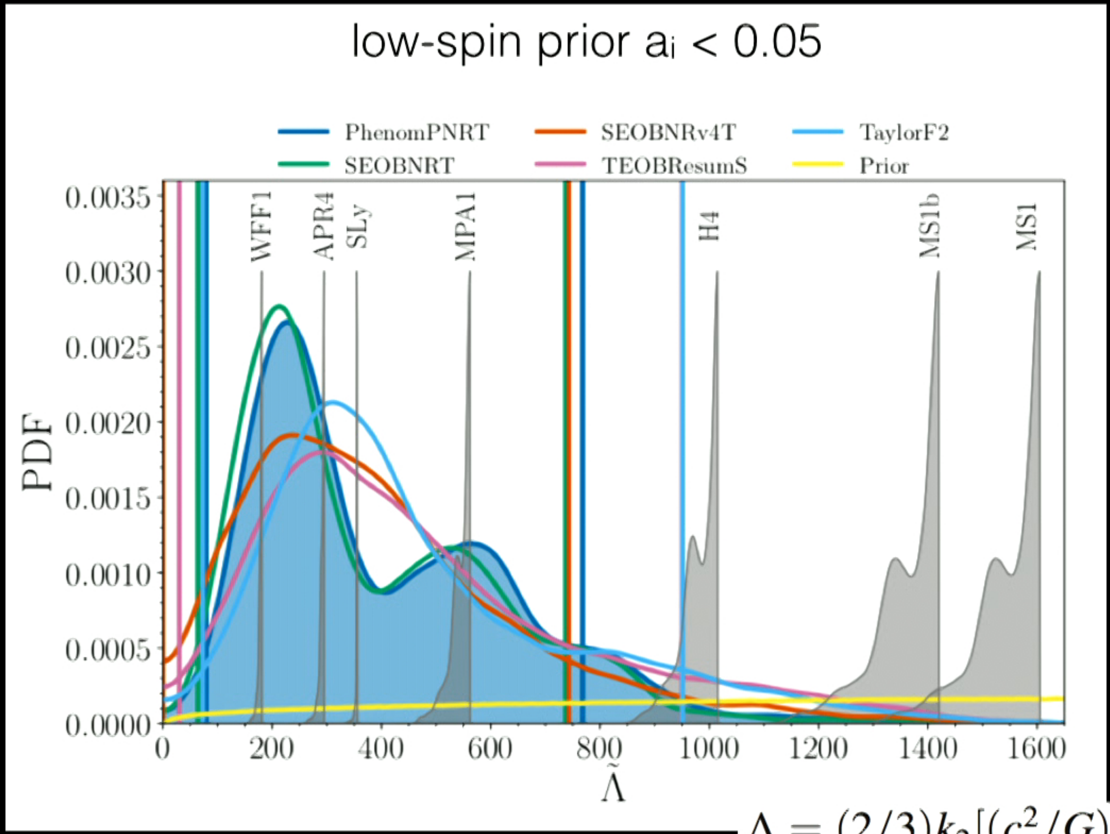



LIGO-Virgo/Greco, Arnaud, Vicerè

# Sky localization with GWs and gamma rays



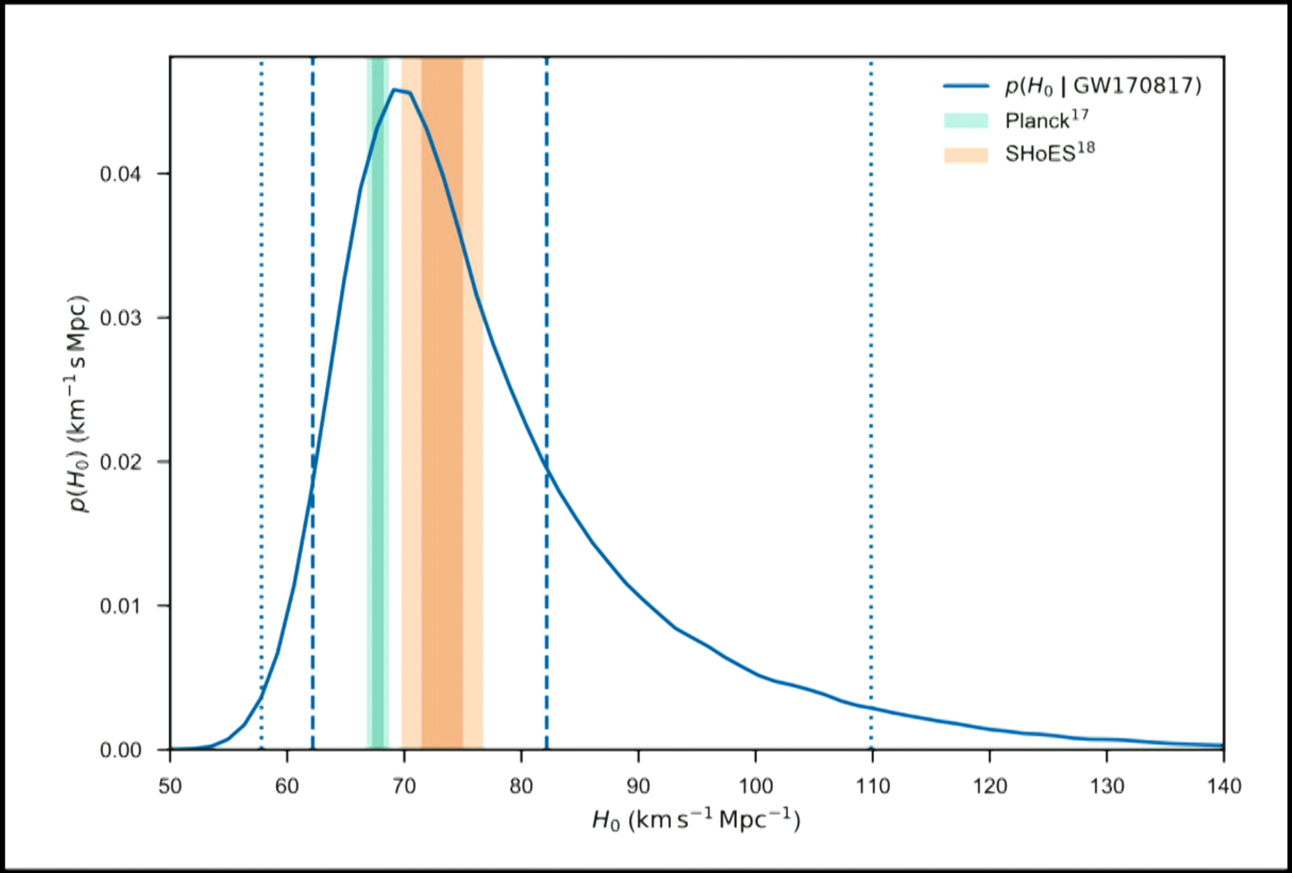
# From GWs: constraining NS EoS




$$\Lambda = (2/3)k_2[(c^2/G)(R/m)]^5$$

B.P. Abbott et al. arXiv 1811.12907 (2018)

# Independent measurement of the Hubble constant




B.P. Abbott et al. Nature (2017)

18

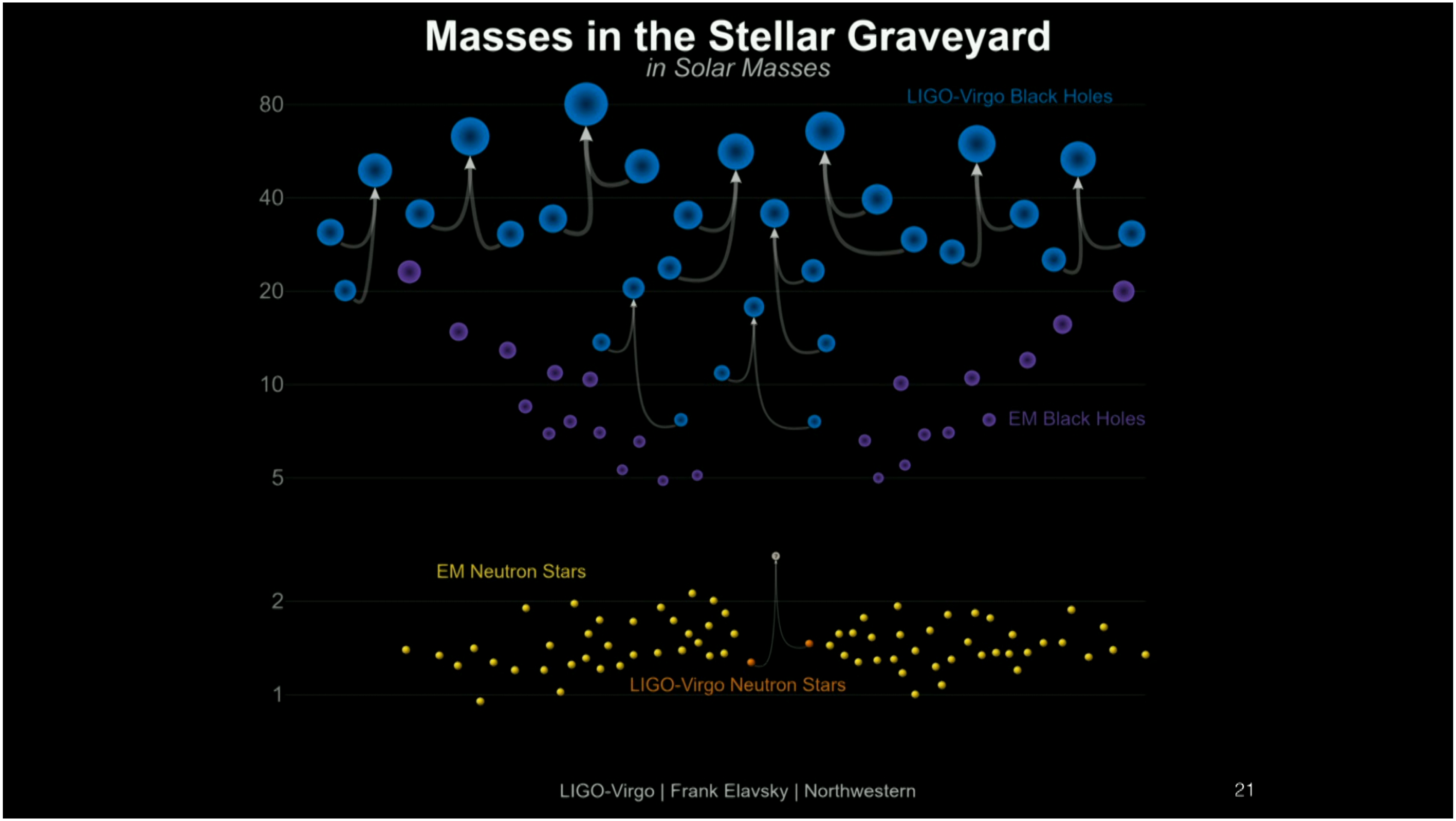
# Other claimed GW detections

From Advanced LIGO and Advanced Virgo's second observing run:

TABLE II: New events with astrophysical probability > 50% in all of the BBH banks.

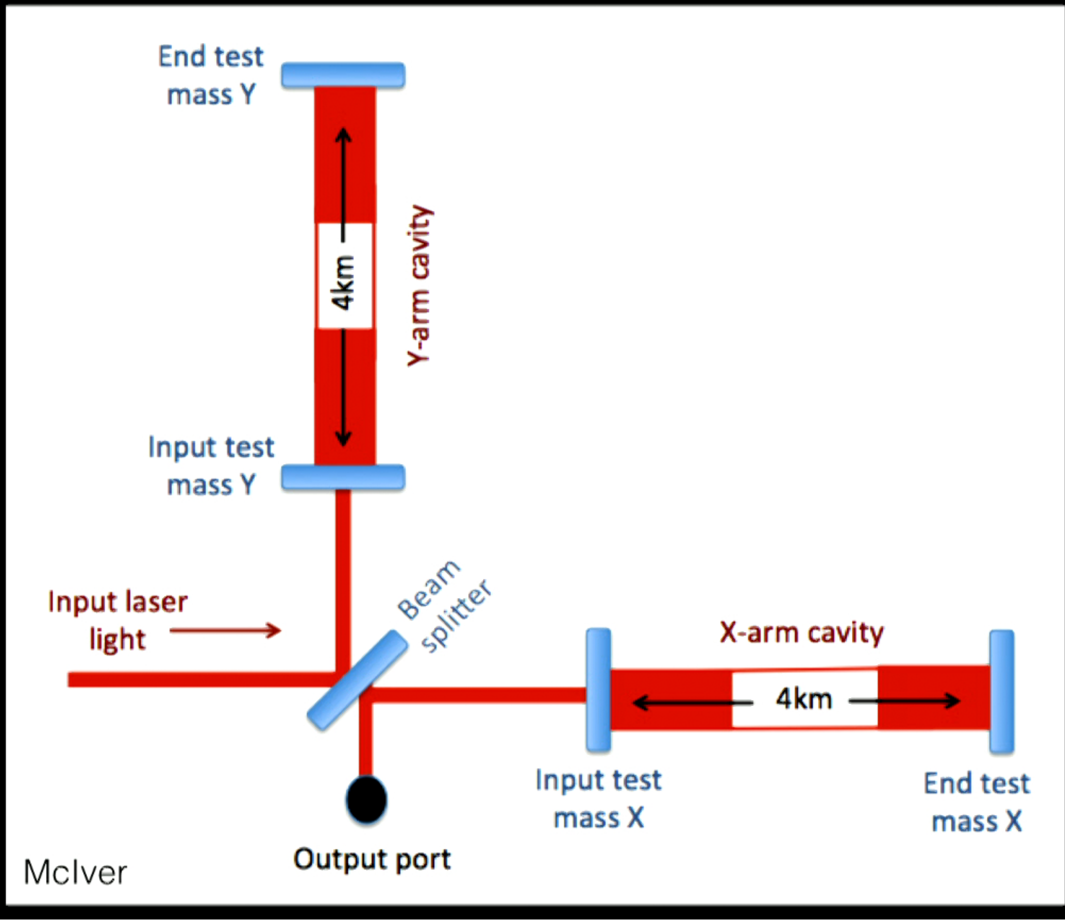
| Name | Bank | $\mathcal{M}^{\rm det}(\rm M_\odot)$ | $\chi_{\rm eff}$ | $z$ | GPS time[a] | $\rho^2_{\rm H}$ | $\rho^2_{\rm L}$ | $\rm FAR^{-1}(O2)^b$ | $\frac{W(\rm event)}{\mathcal{R}(\rm event \mid \mathcal{N})}$ (O2) | $p_{\rm astro}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| GW170121 | BBH (3,0) | $29^{+4}_{-3}$ | $-0.3^{+0.3}_{-0.3}$ | $0.24^{+0.14}_{-0.13}$ | 1169069154.565 | 29.4 | 89.7 | $2.8 \times 10^3$ | $> 30$ | $> 0.99$ |
| GW170304 | BBH (4,0) | $47^{+8}_{-7}$ | $0.2^{+0.3}_{-0.3}$ | $0.5^{+0.2}_{-0.2}$ | 1172680691.356 | 24.9 | 55.9 | 377 | 13.6 | 0.985 |
| GW170727 | BBH (4,0) | $42^{+6}_{-6}$ | $-0.1^{+0.3}_{-0.3}$ | $0.43^{+0.18}_{-0.17}$ | 1185152688.019 | 25.4 | 53.5 | 370 | 11.8 | 0.98 |
| GW170425 | BBH (4,0) | $47^{+26}_{-10}$ | $0.0^{+0.4}_{-0.5}$ | $0.5^{+0.4}_{-0.3}$ | 1177134832.178 | 28.6 | 37.5 | 15 | 0.65 | 0.77 |
| GW170202 | BBH (3,0) | $21.6^{+4.2}_{-1.4}$ | $-0.2^{+0.4}_{-0.3}$ | $0.27^{+0.13}_{-0.12}$ | 1170079035.715 | 26.5 | 41.7 | 6.3 | 0.25 | 0.68 |
| GW170403 | BBH (4,1) | $48^{+9}_{-7}$ | $-0.7^{+0.5}_{-0.3}$ | $0.45^{+0.22}_{-0.19}$ | 1175295989.221 | 31.3 | 31.0 | 4.7 | 0.23 | 0.56 |

T. Venumadhav, et al. arXiv 1904.07214 (2019)



Masses in the Stellar Graveyard
in Solar Masses
80
40
20
10
5
2
1
LIGO-Virgo Black Holes
EM Black Holes
EM Neutron Stars
LIGO-Virgo Neutron Stars
LIGO-Virgo | Frank Elavsky | Northwestern
21

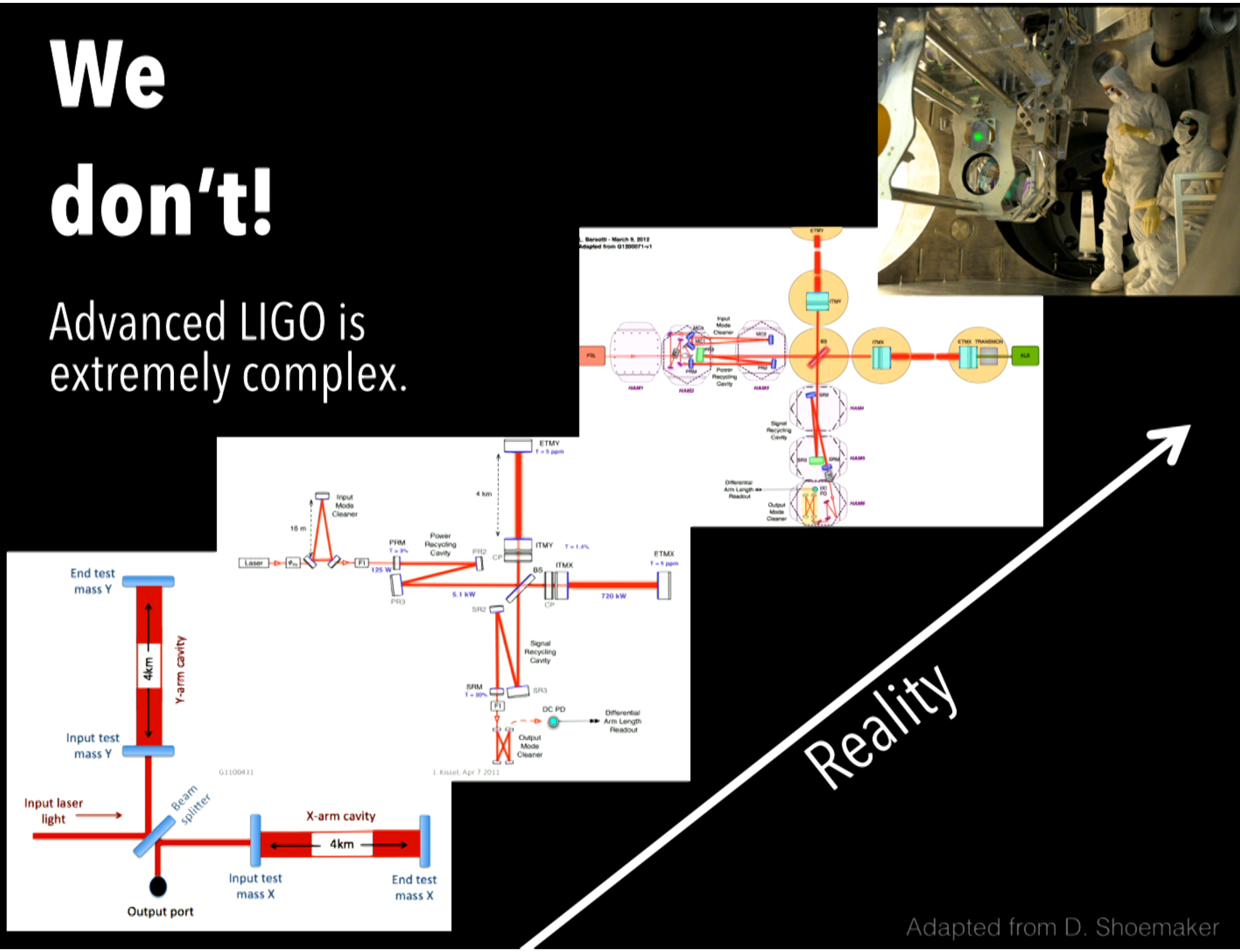
How do we achieve the precision measurements needed to enable these breakthrough results with such a simple measurement scheme?



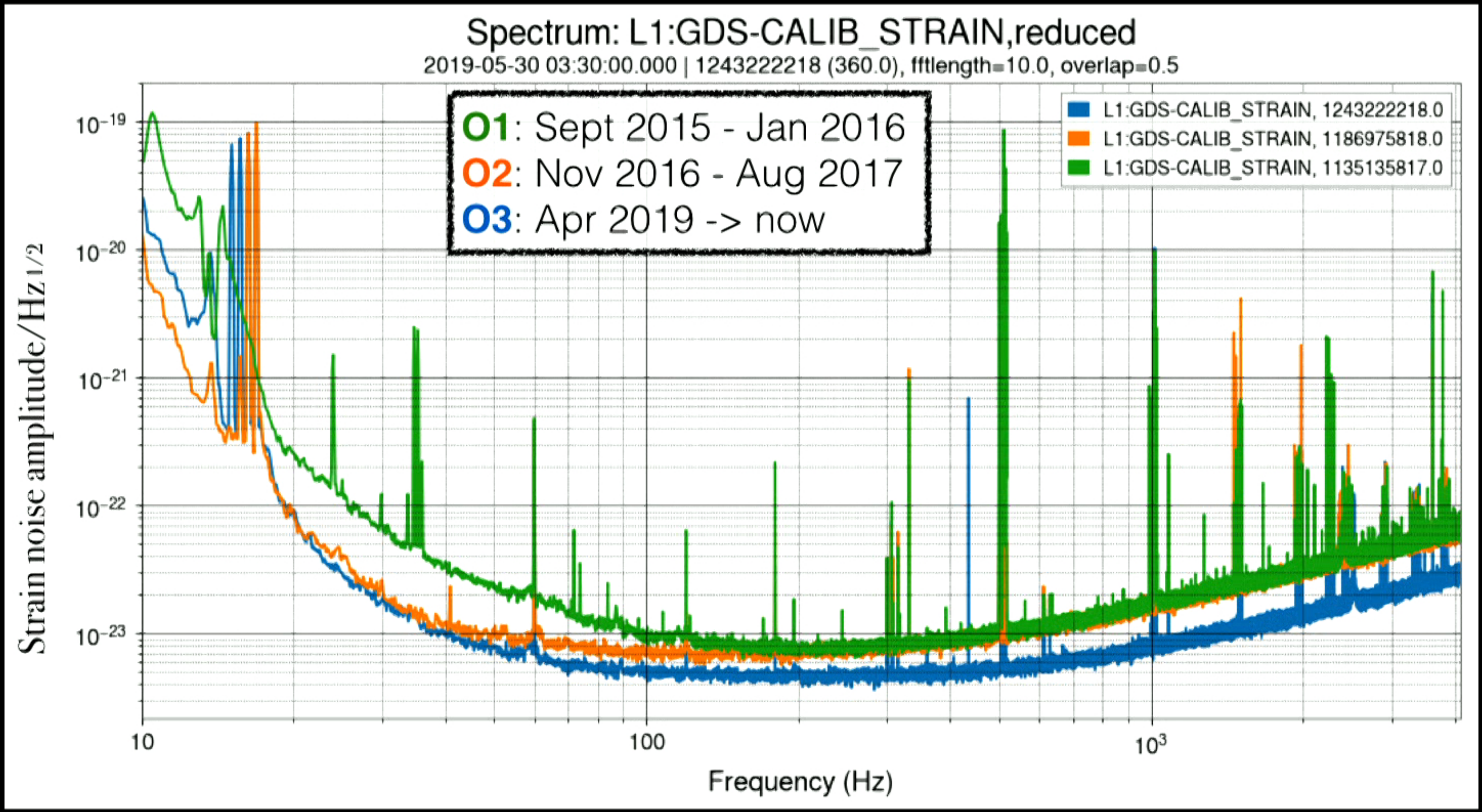

22

# We don't!

Advanced LIGO is extremely complex.



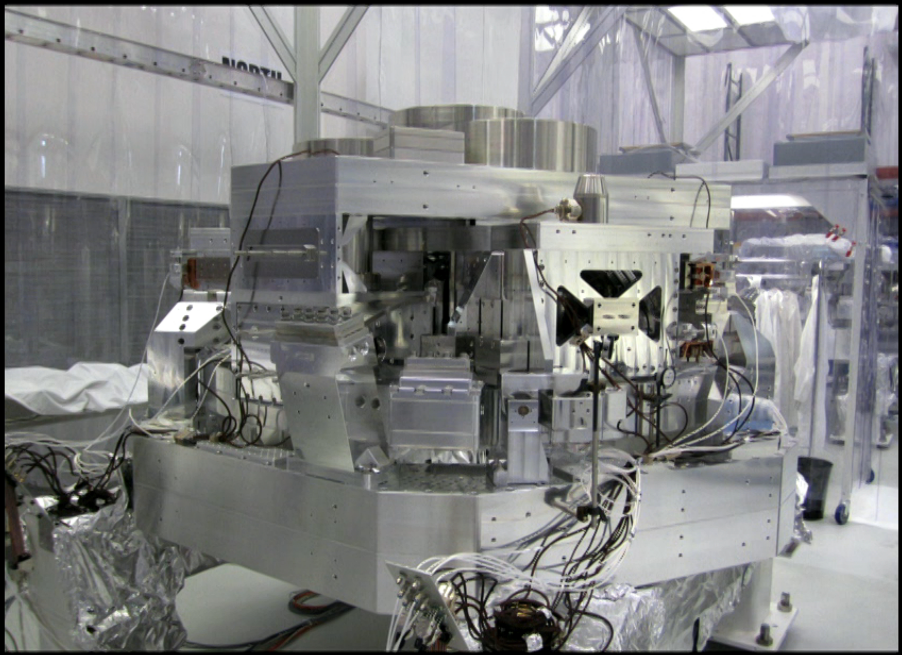
# Advanced LIGO noise




Made with ligoDV web: https://ldvw.ligo.caltech.edu/ldvw/view

# Seismic isolation: active isolation

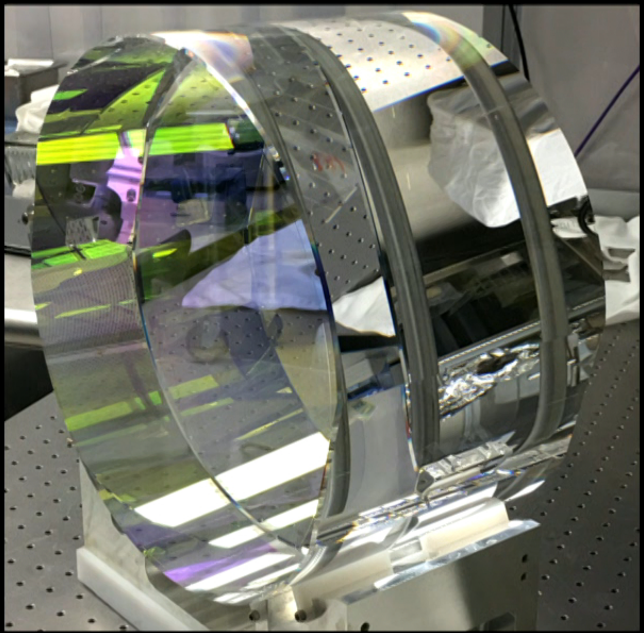

LIGO/Caltech



26

# Advanced LIGO optics

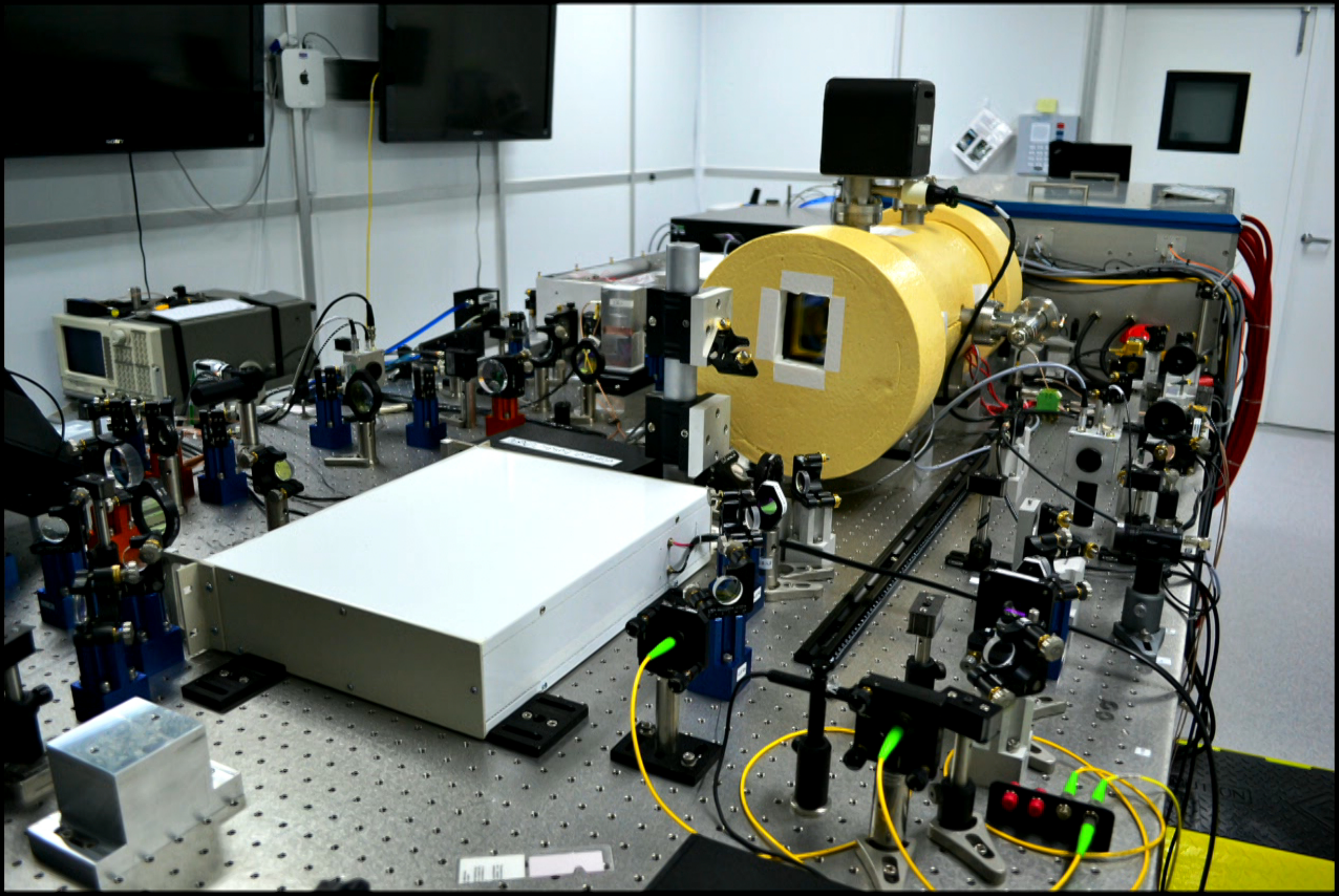
M. Heintze



K. Toland

27

# The Advanced LIGO input laser



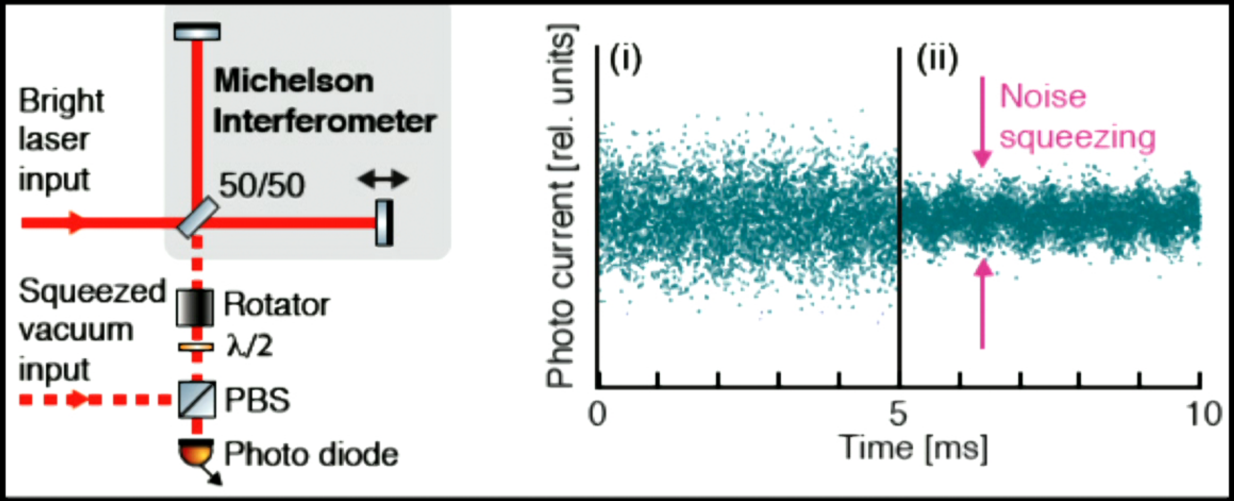
AEI-Max Planck/LZH

# Light squeezing for aLIGO

Quantum noise can be reduced by changing the statistical properties of vacuum optical field entering dark port

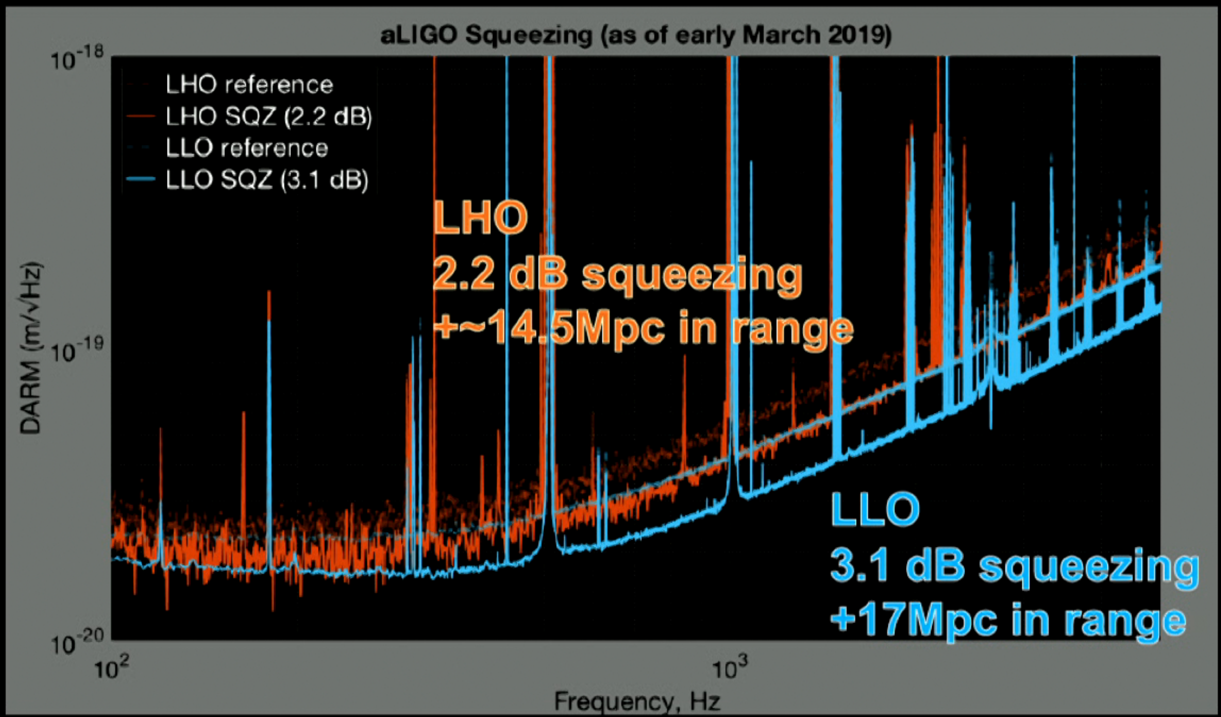
**classical (coherent) states of light:**
- no photon correlations
- equal phase and amplitude fluctuations

**squeezed states of light:**
- photon correlations
- reduced phase fluctuations, increased amplitude fluctuations (or vice versa)



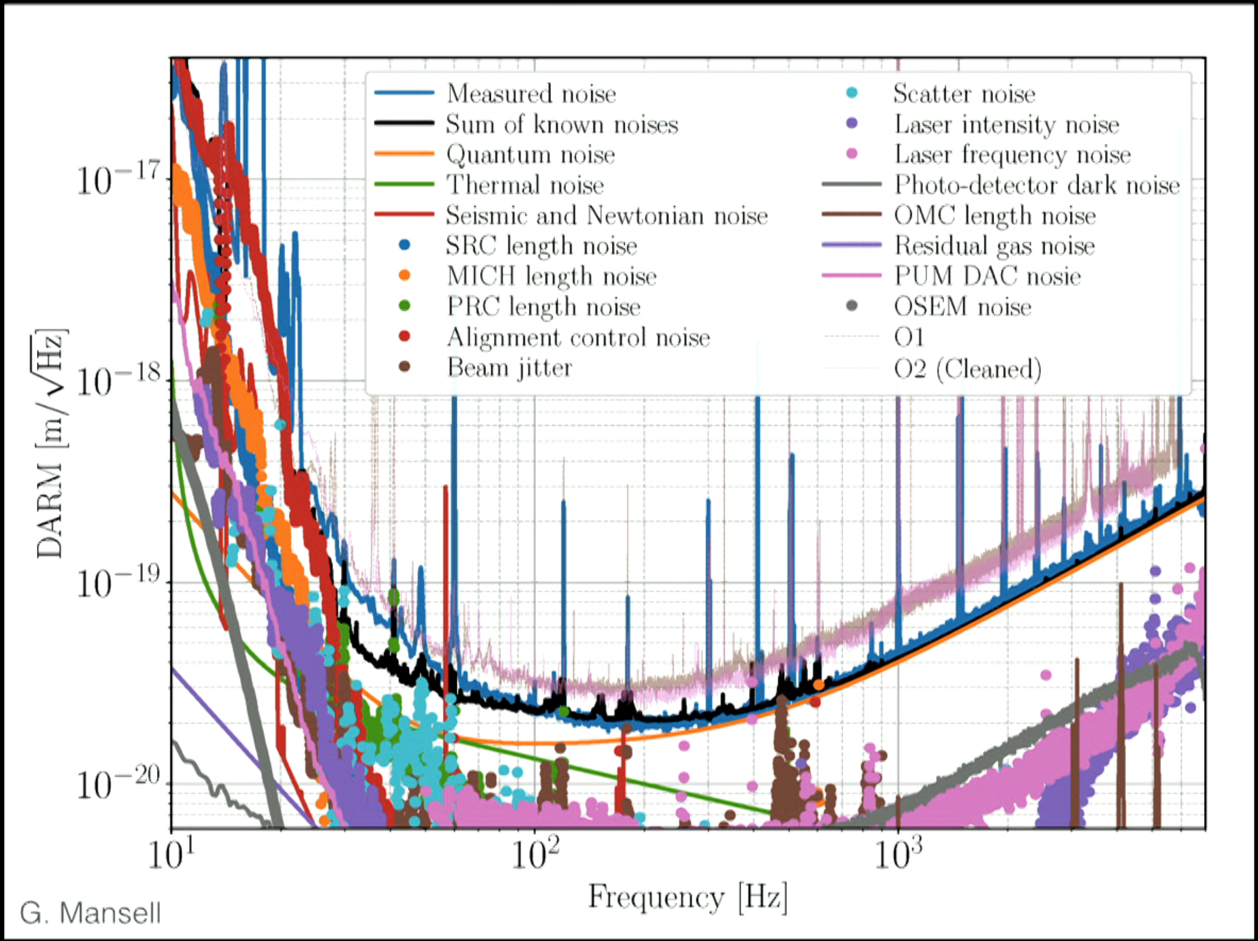

F. Sorrentino, H. Yu

# Current aLIGO squeezing performance



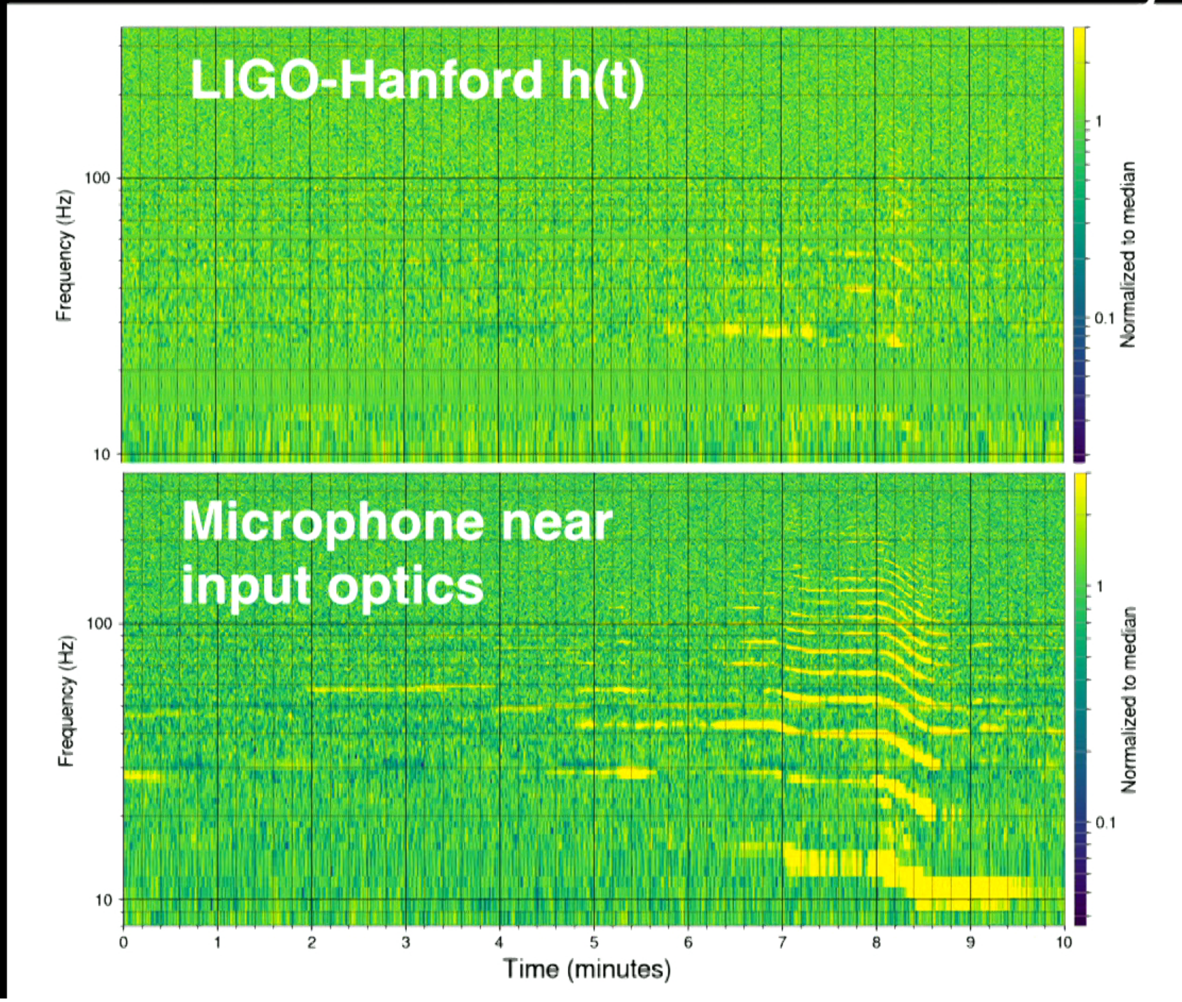

F. Sorrentino, H. Yu

# O3 noise budget: LIGO-Hanford




32

# Detector noise is non-stationary

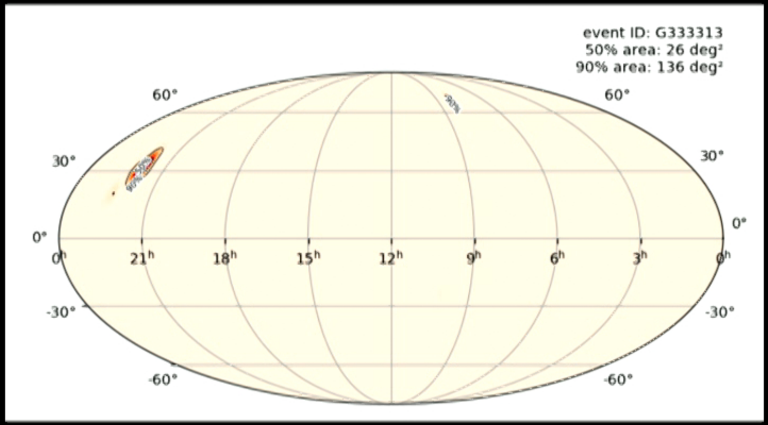


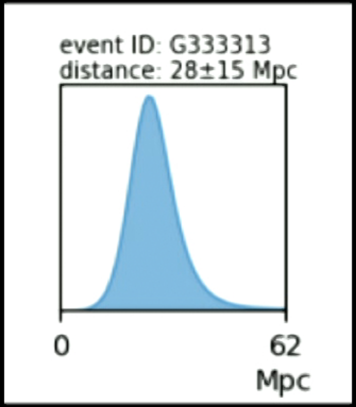

34

# Challenge: S190518bb case study

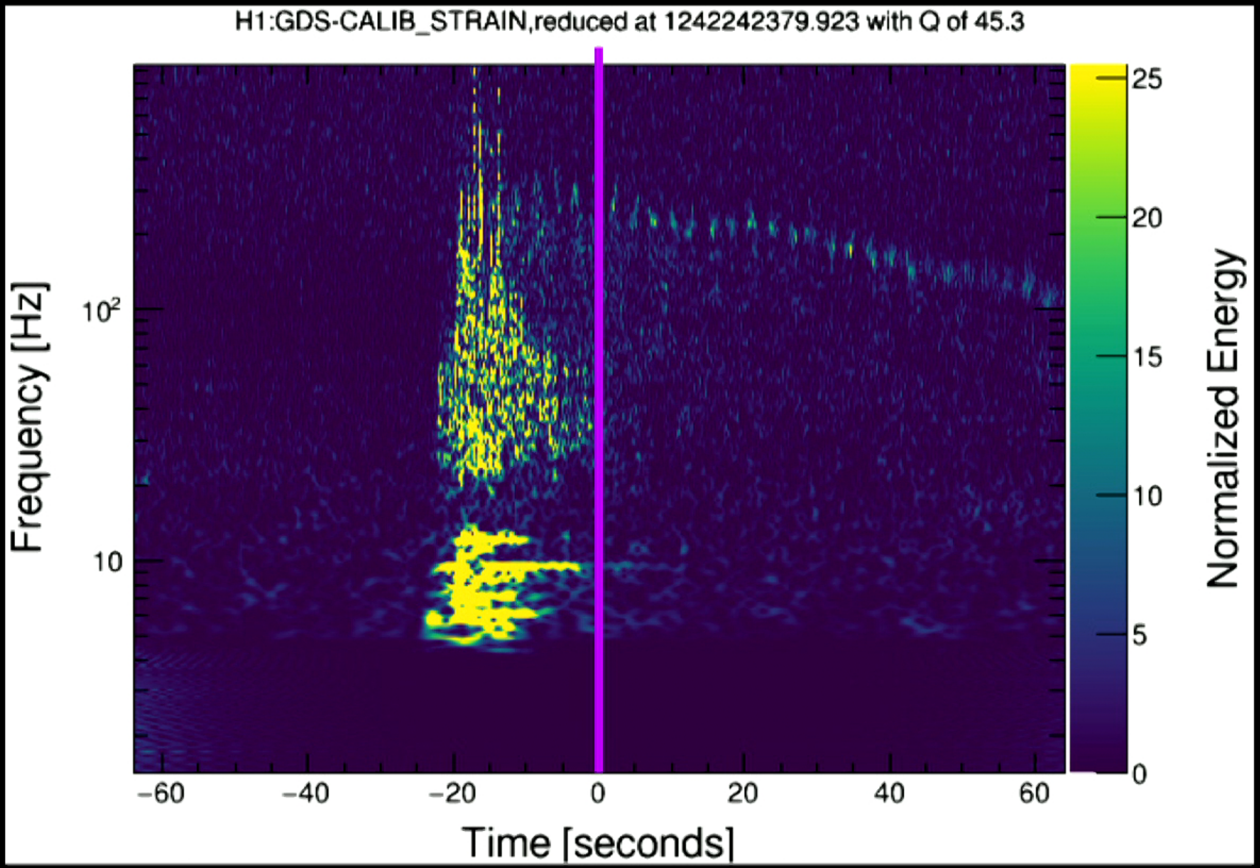
Automatic Preliminary Notice sent ~6 minutes after the event:

*FAR: 1.004e-08 [Hz] (one per ~3 years)*
*PROB_NS: 1.00 [range is 0.0-1.0]*
*PROB_REMNANT: 1.00 [range is 0.0-1.0]*
*PROB_BNS: 0.75 [range is 0.0-1.0]*
*PROB_TERRES: 0.24 [range is 0.0-1.0]*



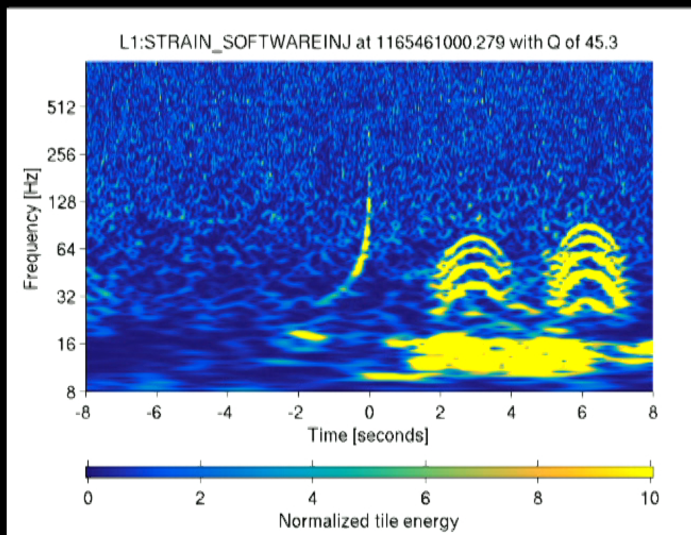



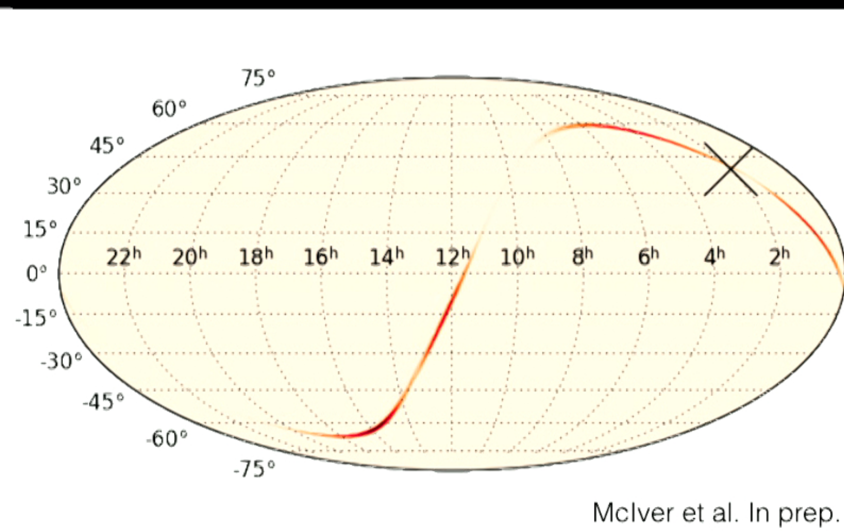
# Challenge: S190518bb case study




LIGO DCC G1900994

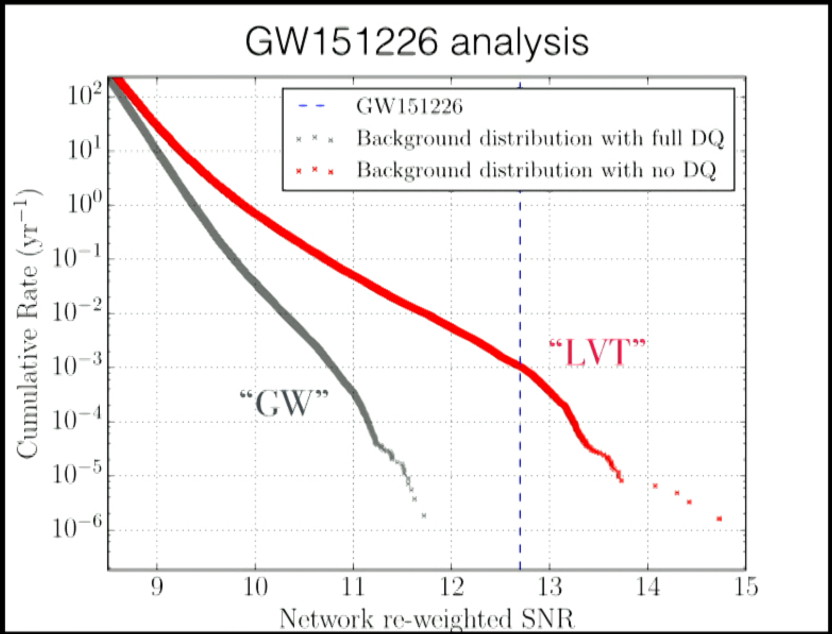
# Impact of light scattering on sky localization




Parameter estimation
produced with the lalinference
pipeline: arXiv 1409.7215

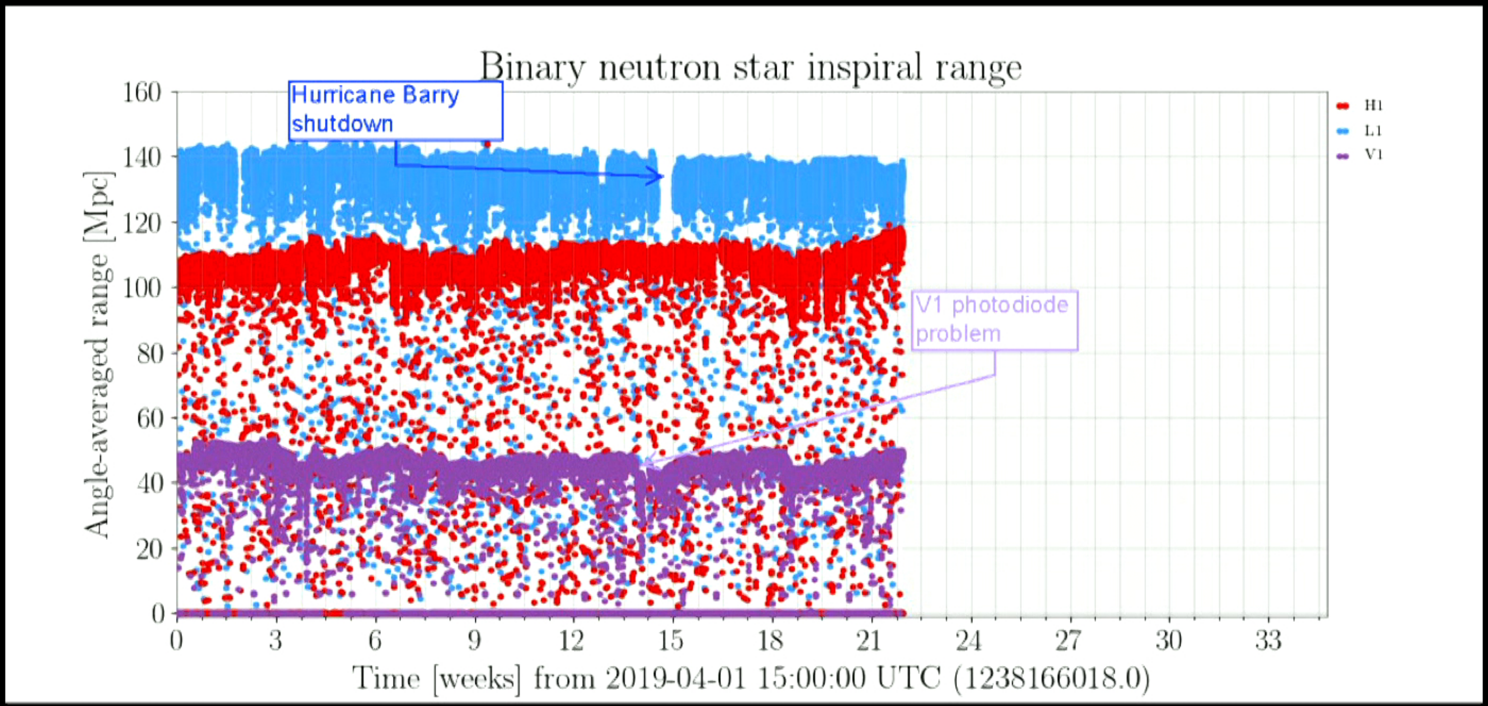
# The impact of detector characterization




B.P Abbott et al. CQG (2018)

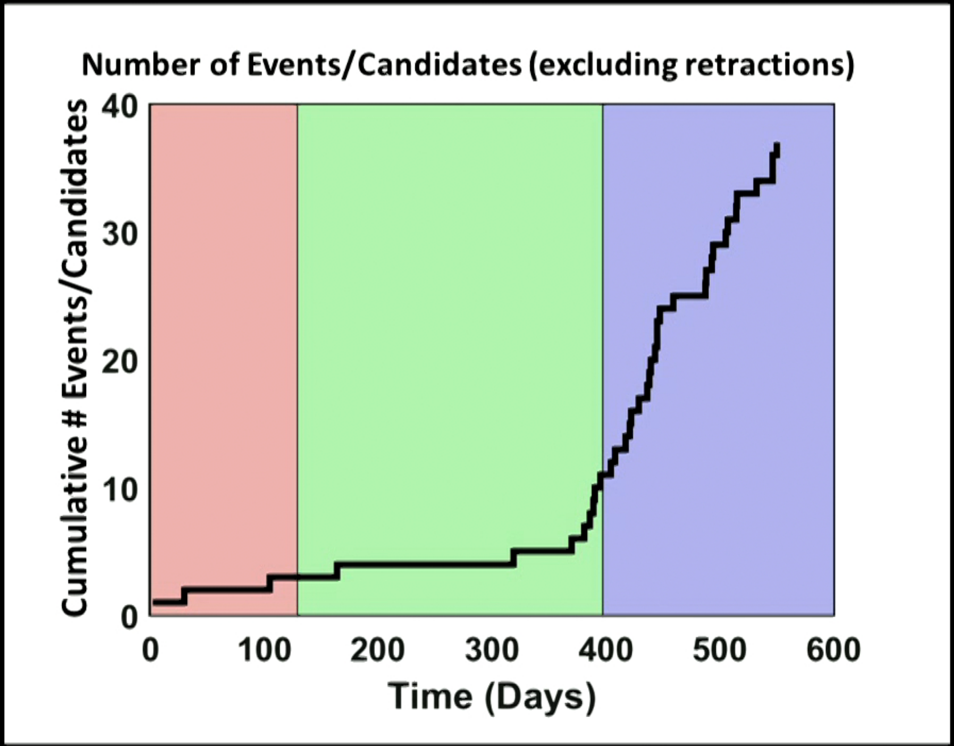
The false alarm rate of GW151226 **improves by a factor of >500**, from 1 in 320 years to 1 in 183,000 years, **with interferometer data quality information!**

# The third observing run (O3) thus far




F. Marion and J. Romie LIGO DCC G1901608

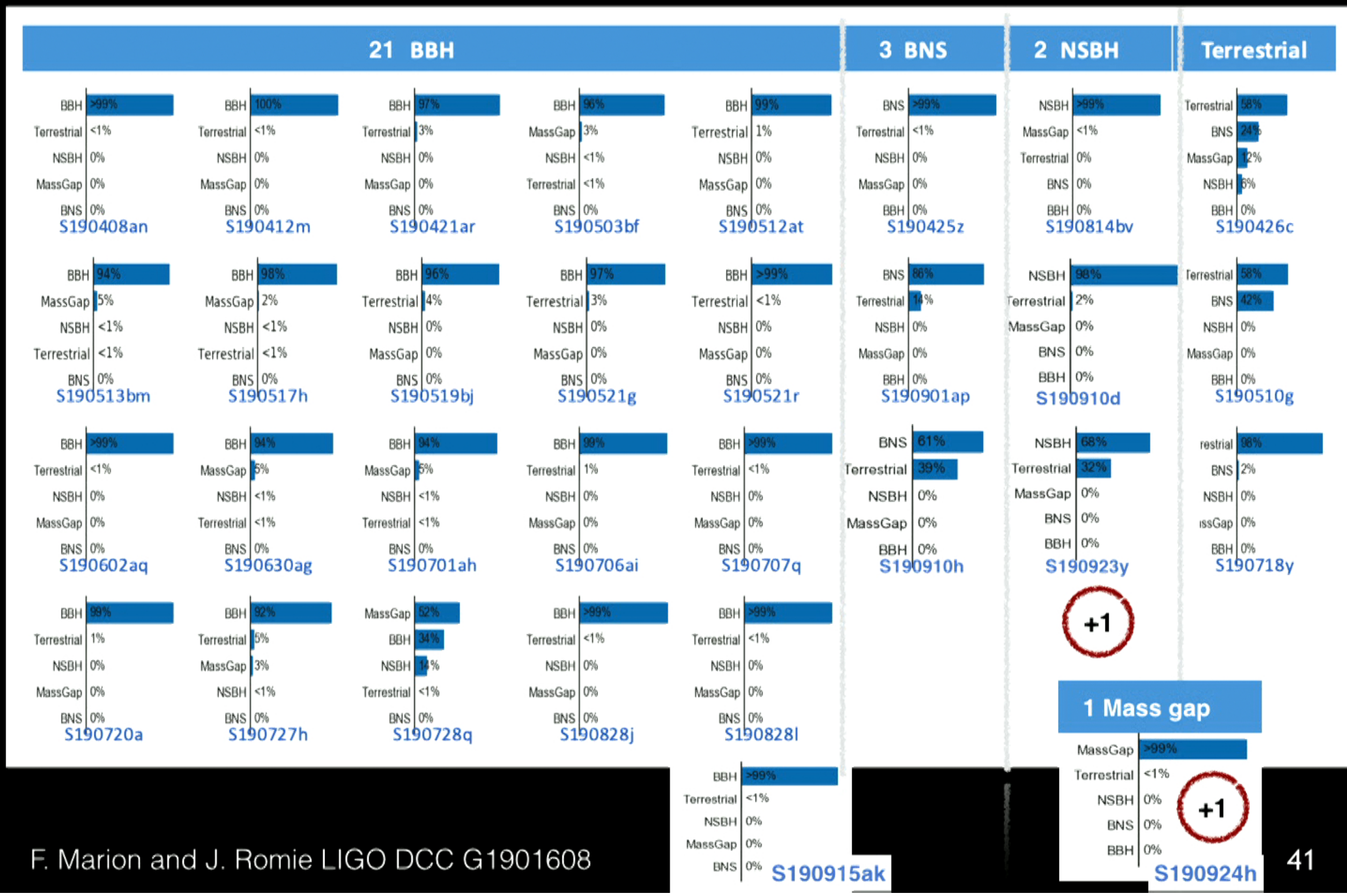
# The third observing run (O3) thus far




F. Marion and J. Romie LIGO DCC G1901608

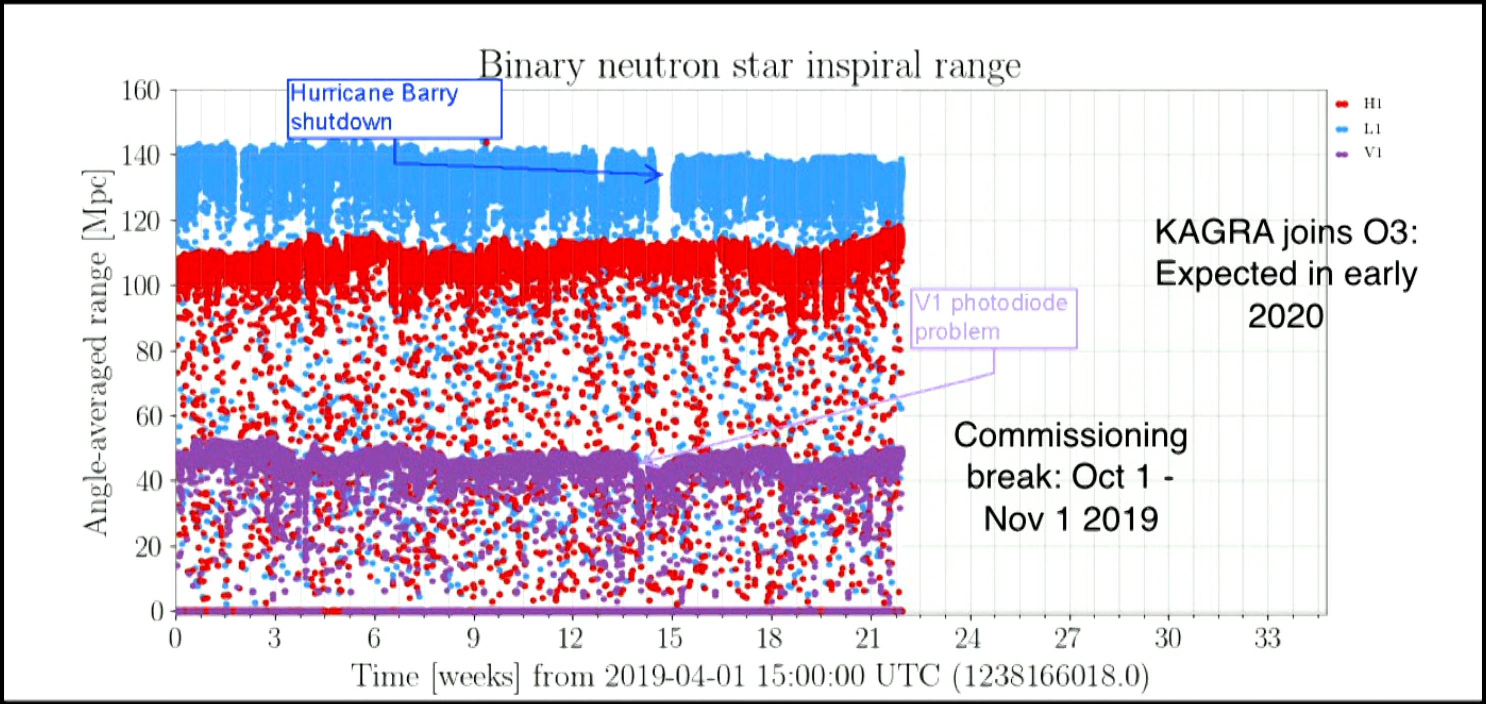
40

# Un-retracted O3 public candidate events thus far



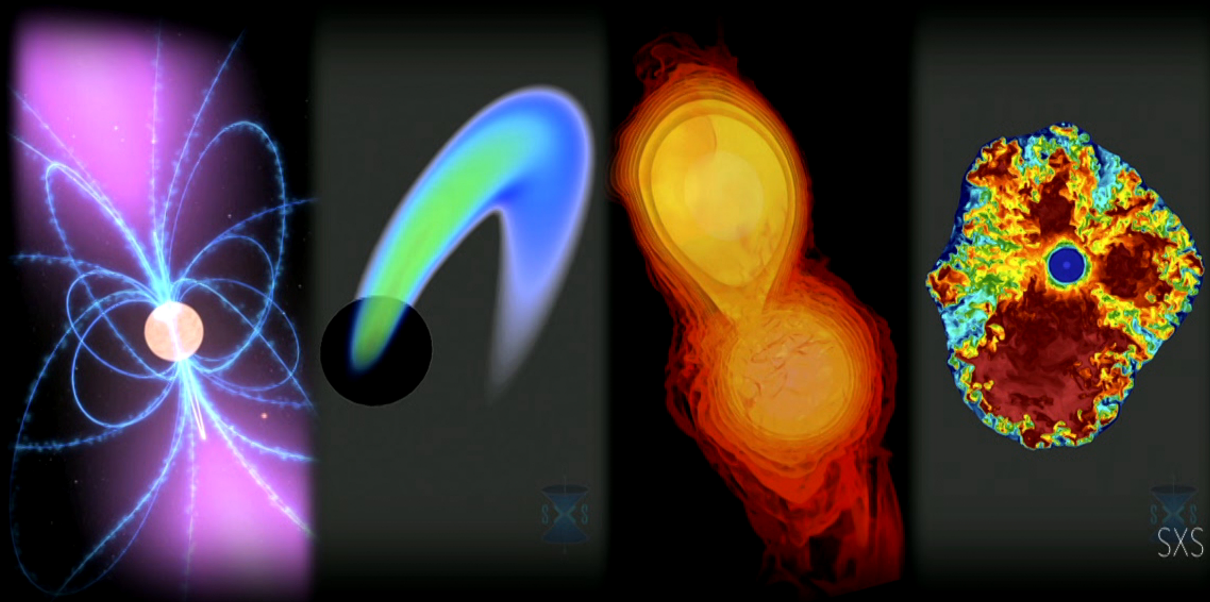

F. Marion and J. Romie LIGO DCC G1901608

# The third observing run (O3) thus far




F. Marion and J. Romie LIGO DCC G1901608

# The future of gravitational wave astronomy




43