DETECTOR OVERVIEW

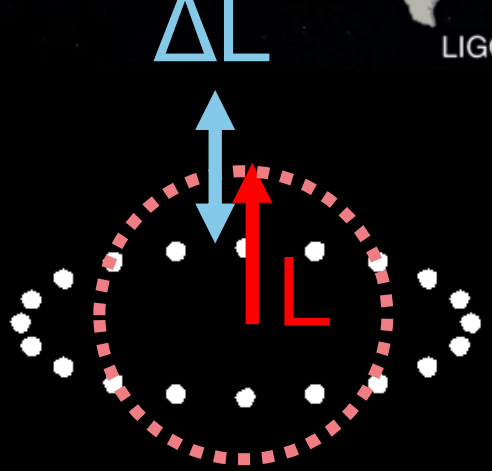
VICTORIA XU, LIGO-MIT

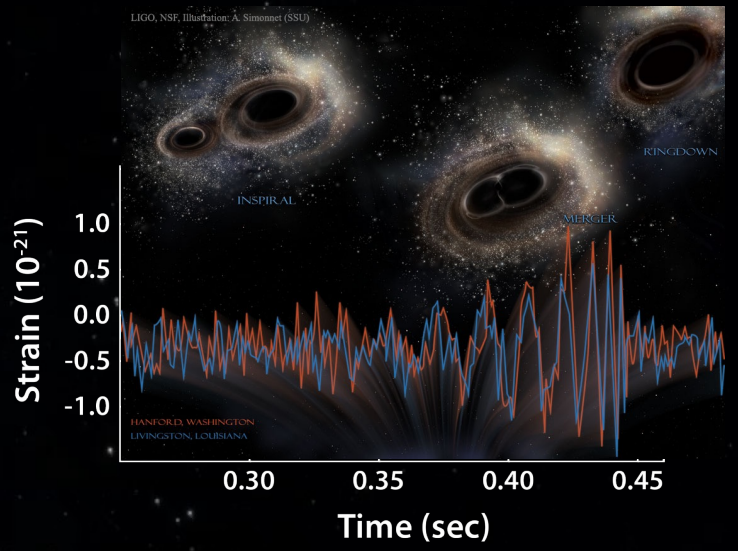
GW OPEN DATA WORKSHOP, MAY 15, 2023

Credits: R. Hurt - Caltech / JPL

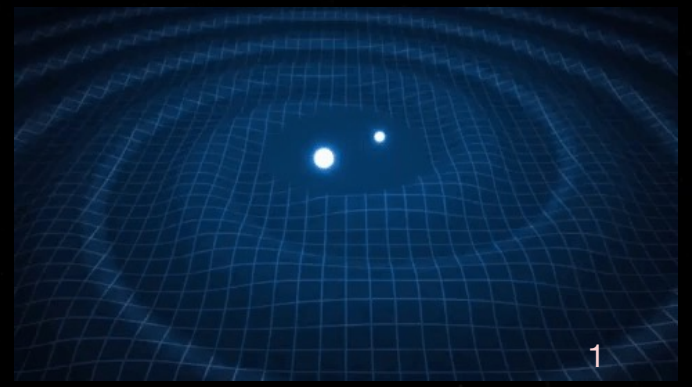
GRAVITATIONAL WAVES

LIGO





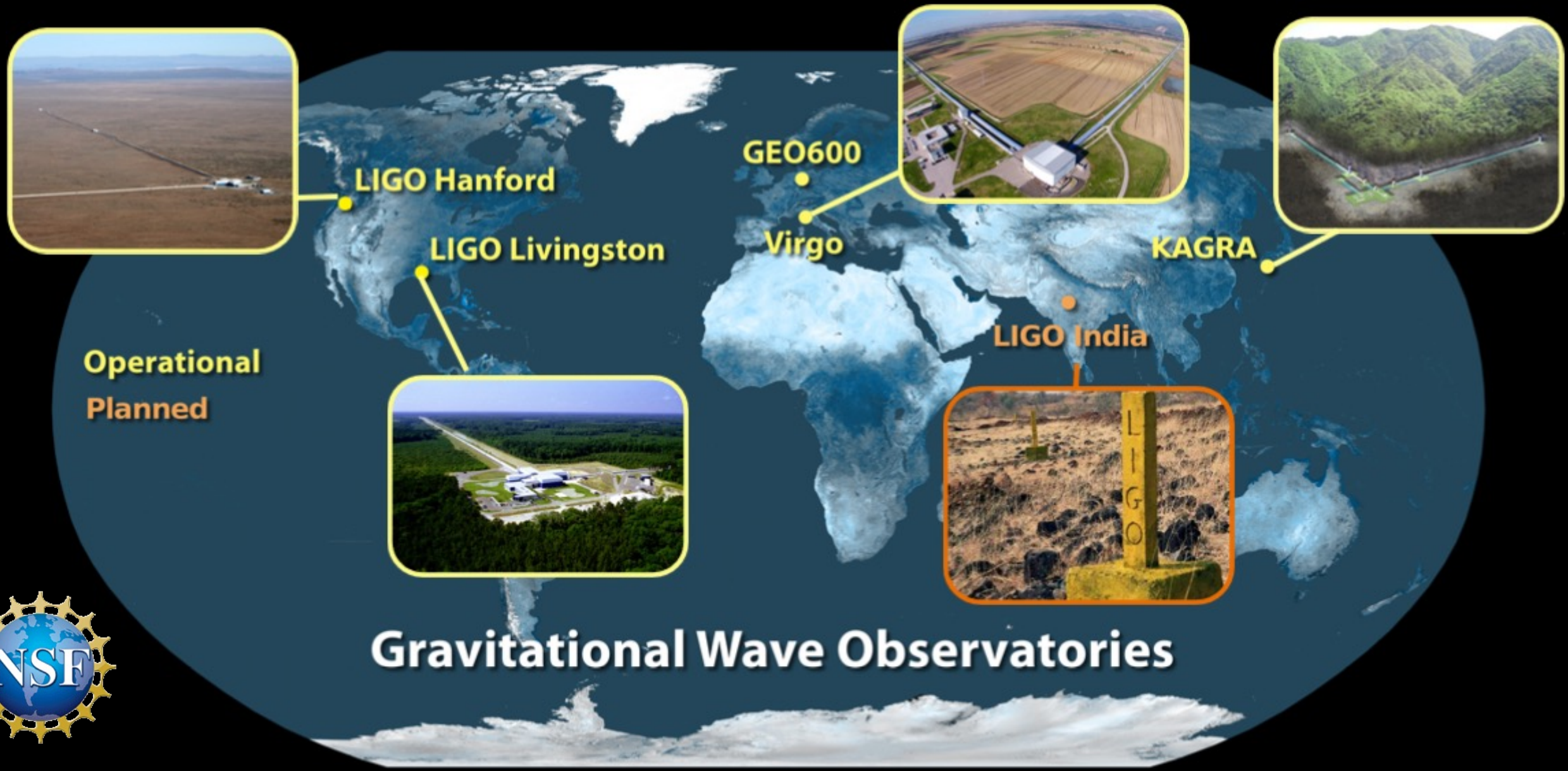
$$\text{Strain } h = \frac{\Delta L \sim 10^{-18}\ \text{m}}{L \sim 4\ \text{km}}$$



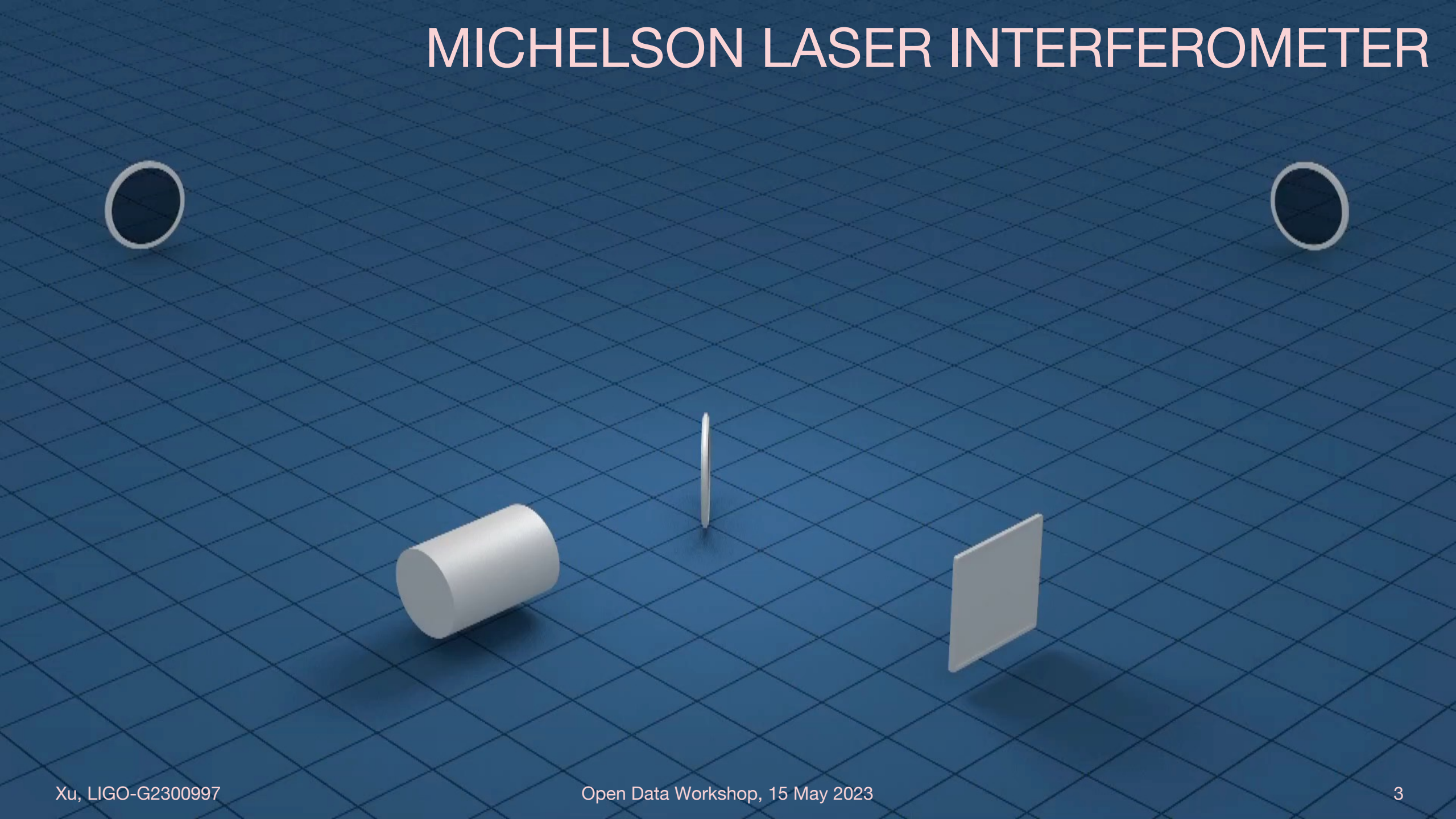
Scale of Effect Vastly Exaggerated

Xu, LIGO-G2300997 Credit: LIGO/R. Hurt

A WORLDWIDE EFFORT



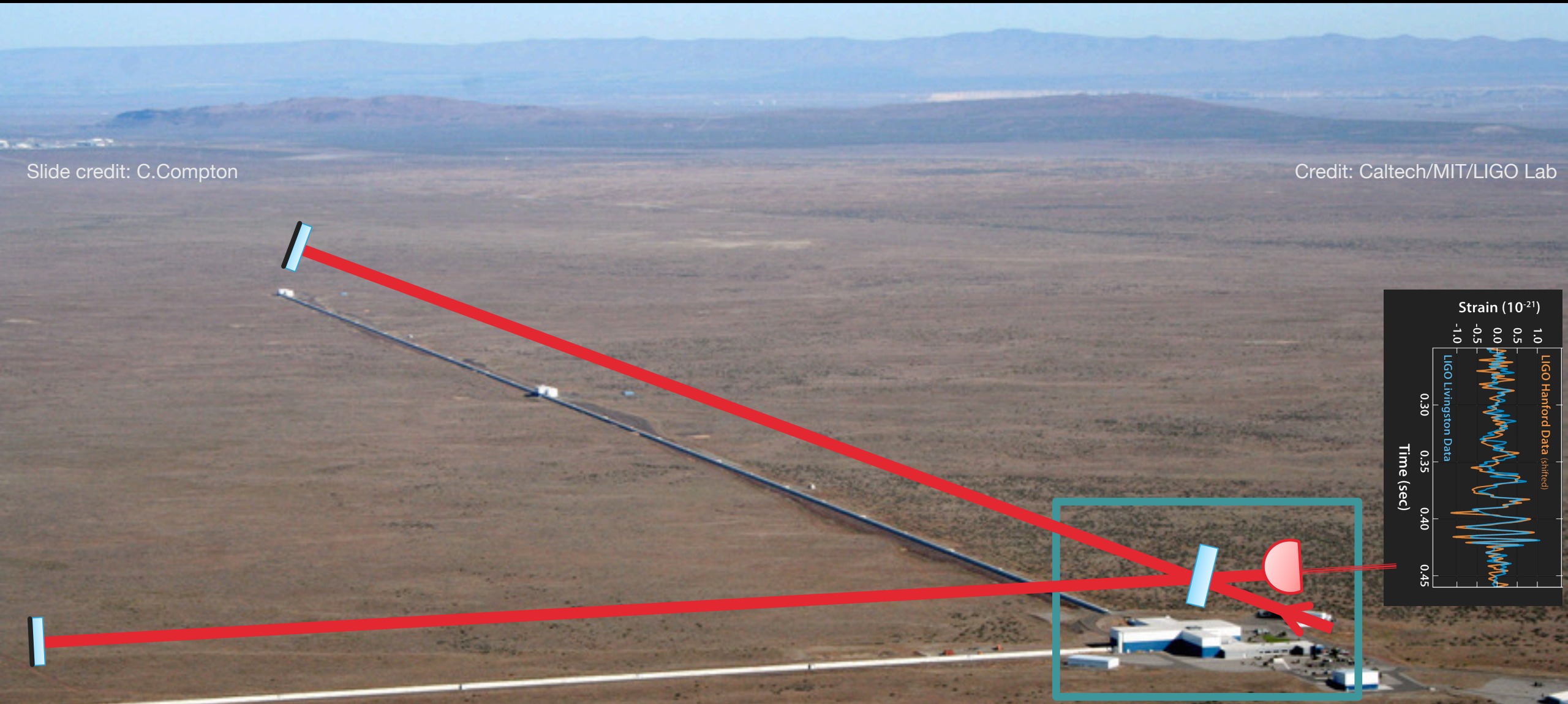
MICHELSON LASER INTERFEROMETER



DETECTOR OVERVIEW

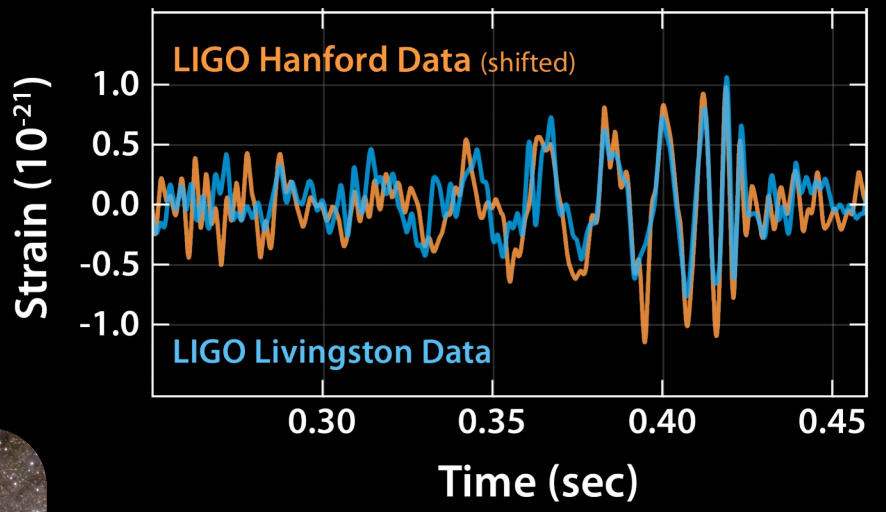
Slide credit: C.Compton

Credit: Caltech/MIT/LIGO Lab



DETECTOR OVERVIEW

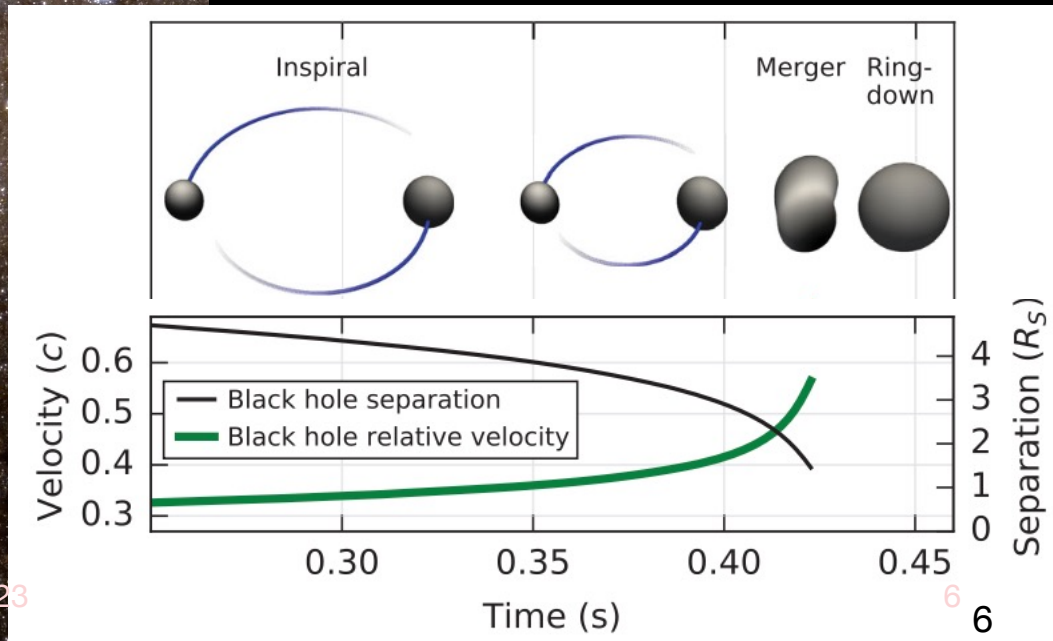
The dawn of gravitational wave astrophysics



1.3 Billion Years Ago…. GW150914
2 black holes merged into 1 September 14, 2015

$M \approx 29$ & $36\ M_{sun}$
$D \approx 1.3$ billion l.y. (410 Mpc)
$\Delta E \approx 3\ M_{sun}$

PRL 116, 061102 (2016)



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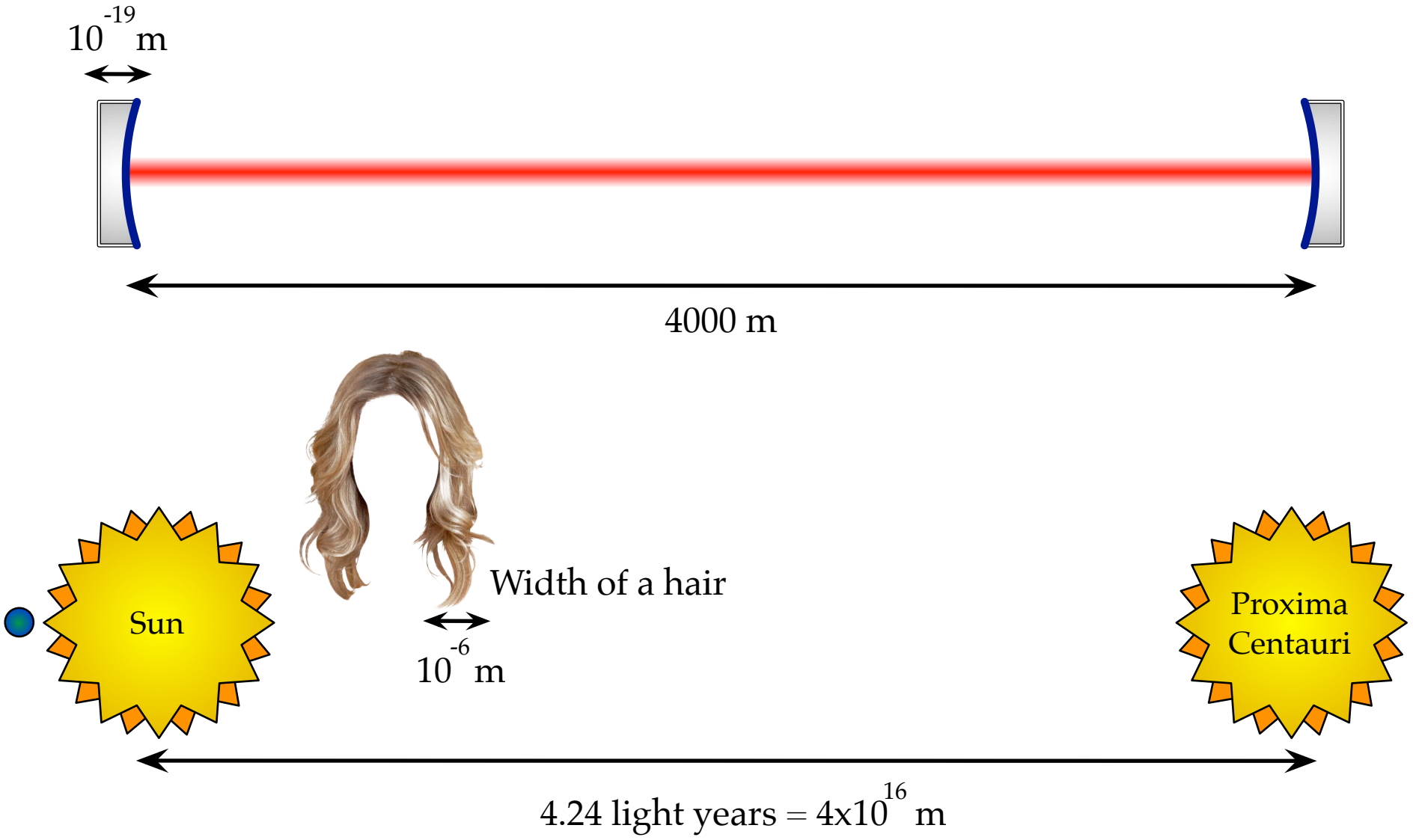
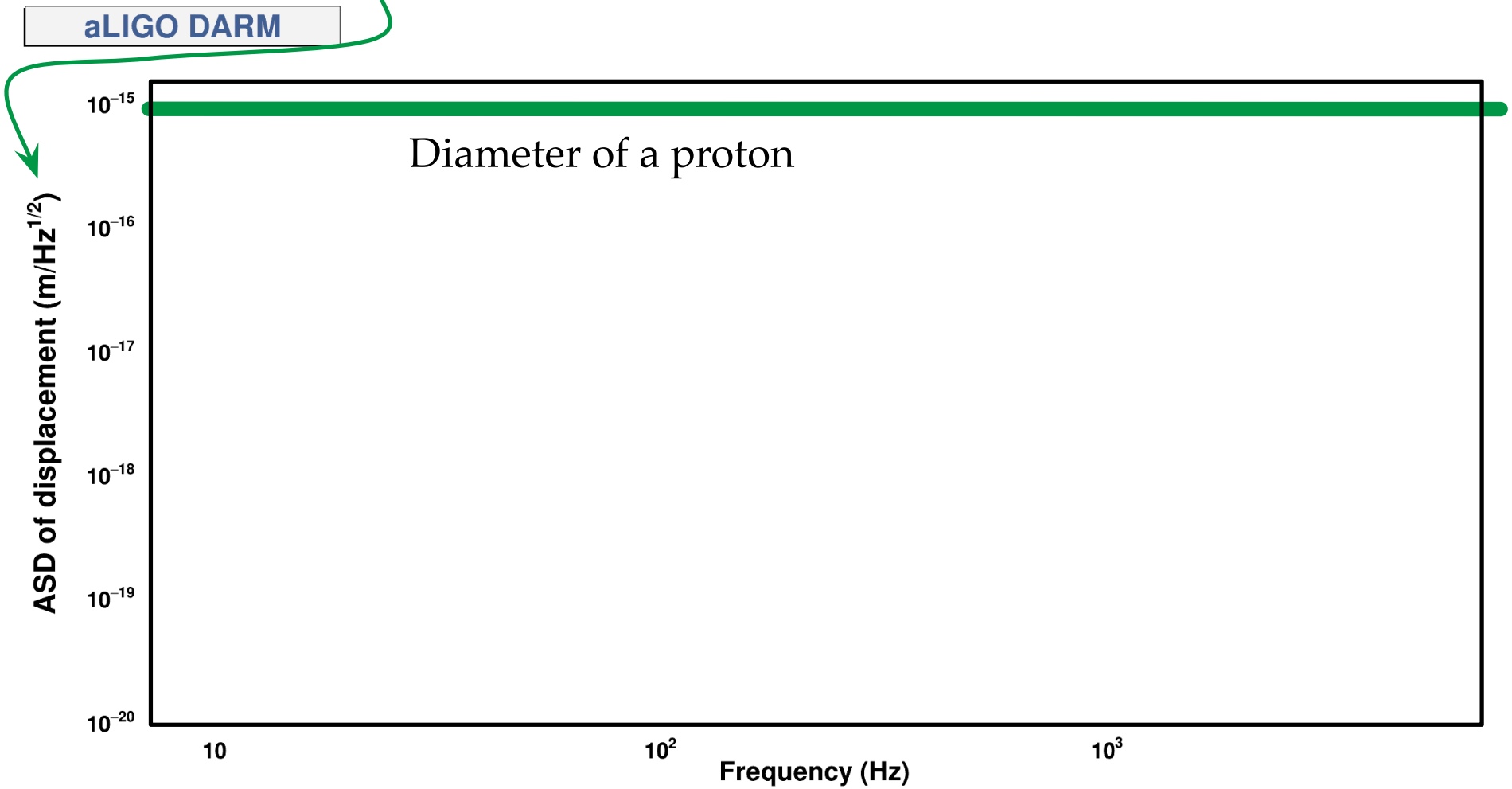
VERY PRECISE



Slide credit: J.Driggers

SENSITIVITY

How much are the mirrors moving?



Slide credit: J.Driggers

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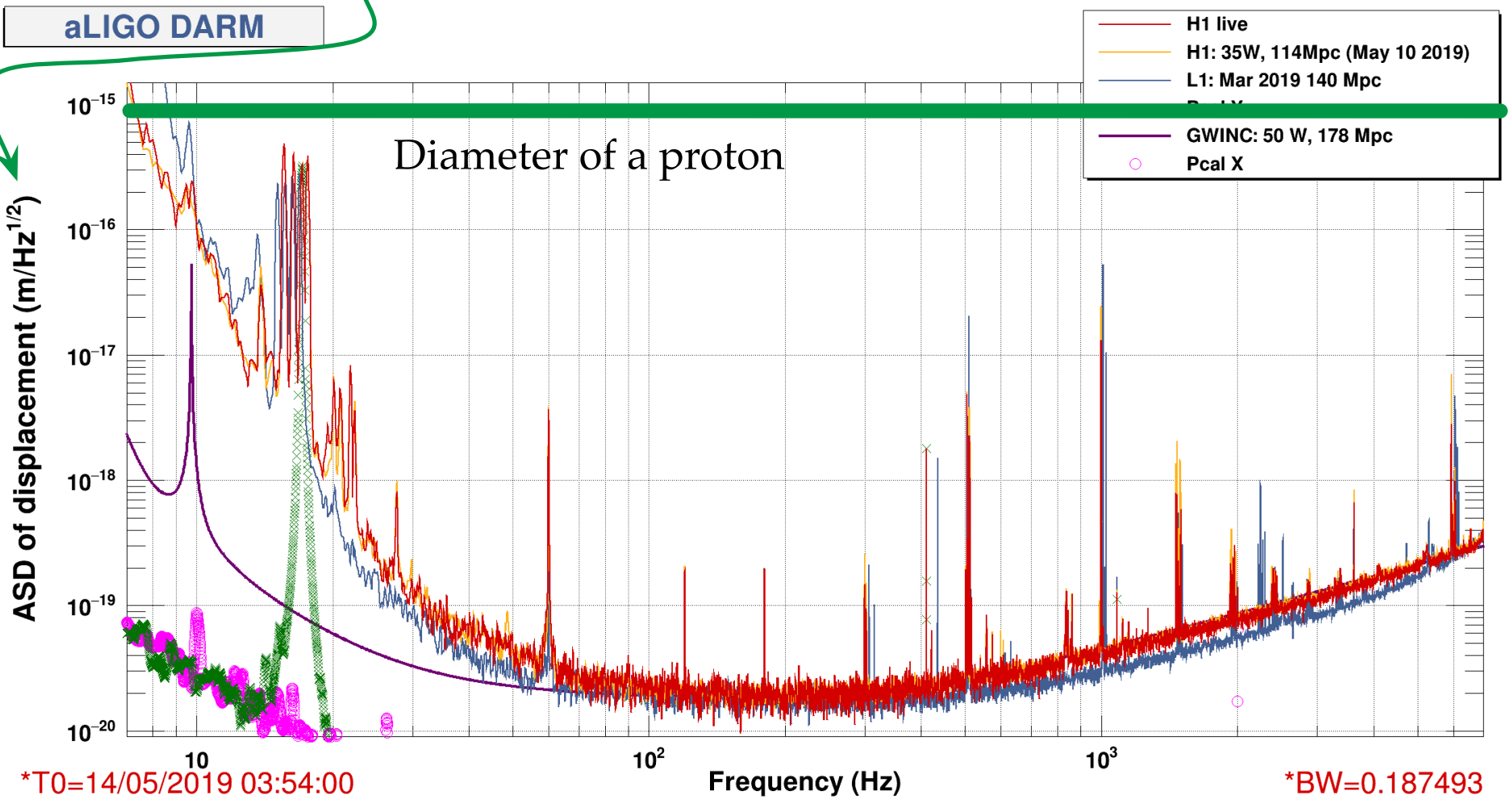
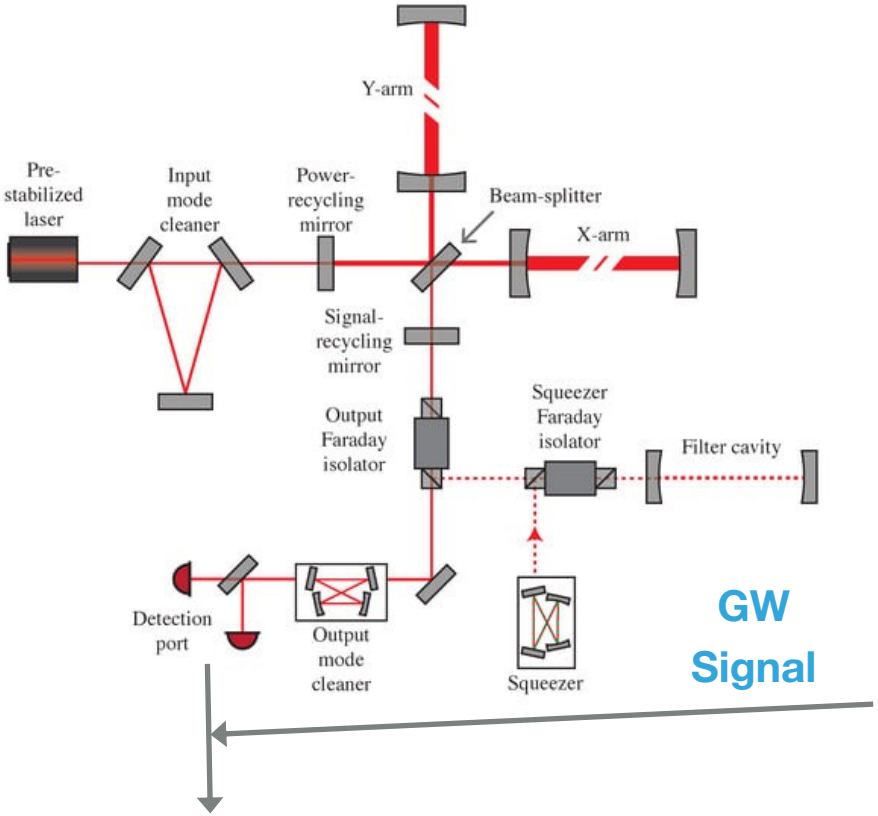


Slide credit: J.Driggers

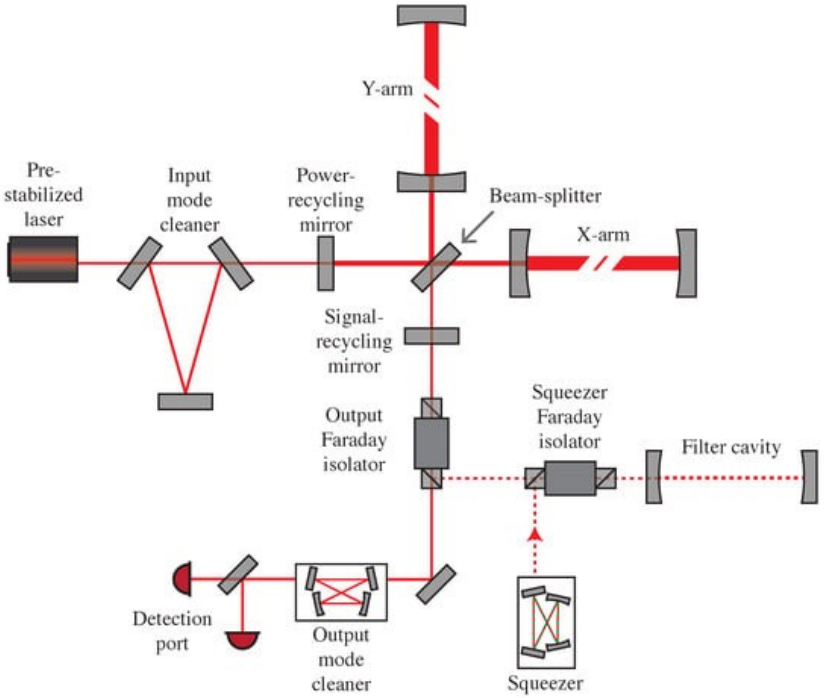
Advanced LIGO signal-to-noise



How do we reach such sensitive detectors?

→ Understand the signal & the noise

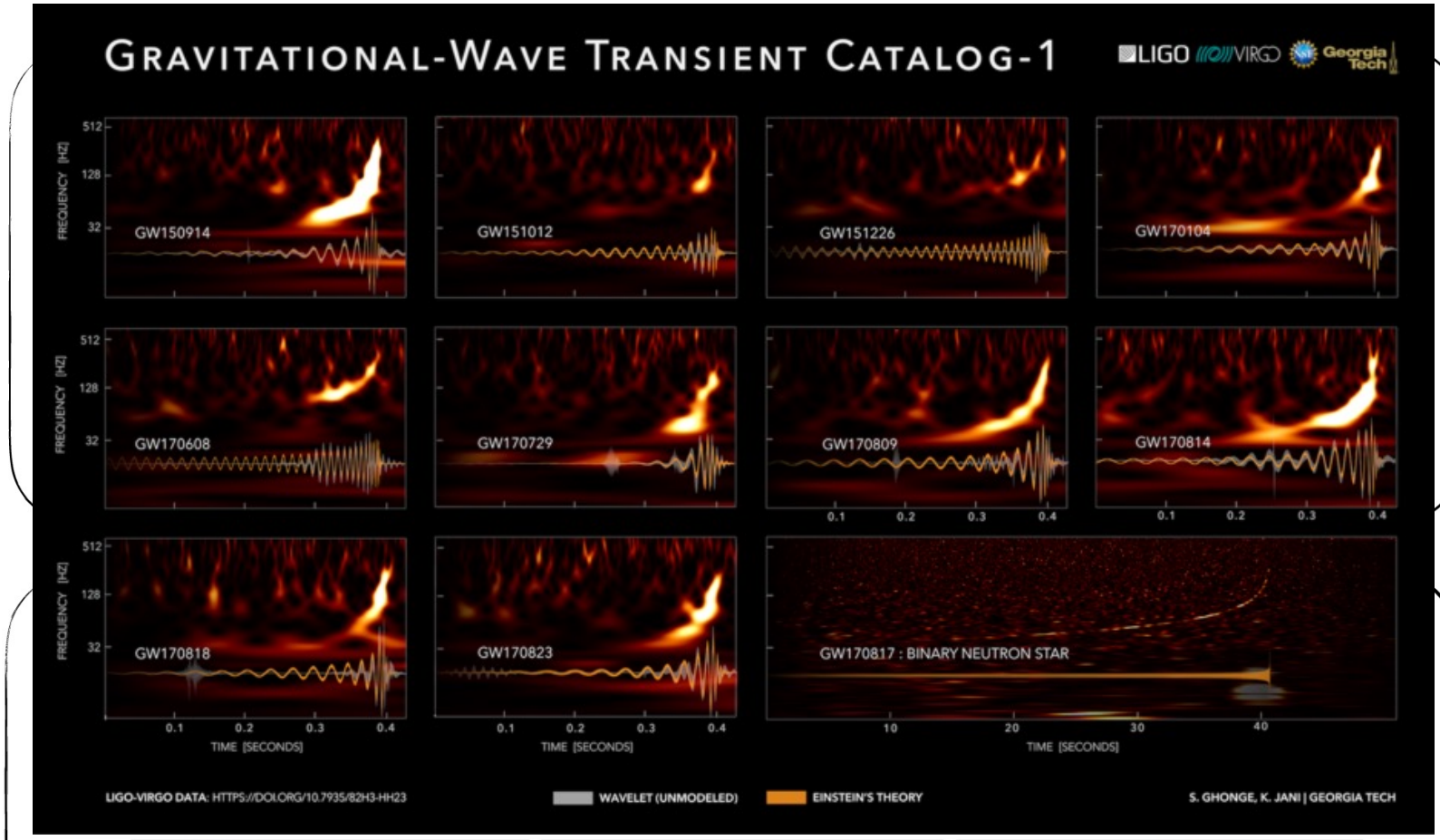
Advanced LIGO **signal**-to-noise

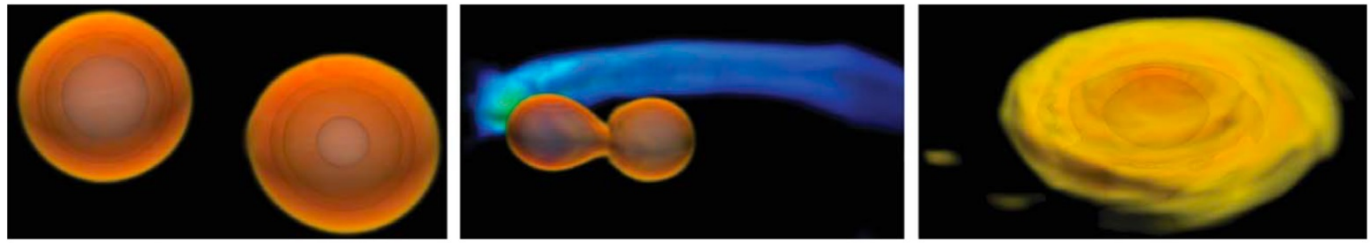


Astrophysical GW signals

Black hole mergers

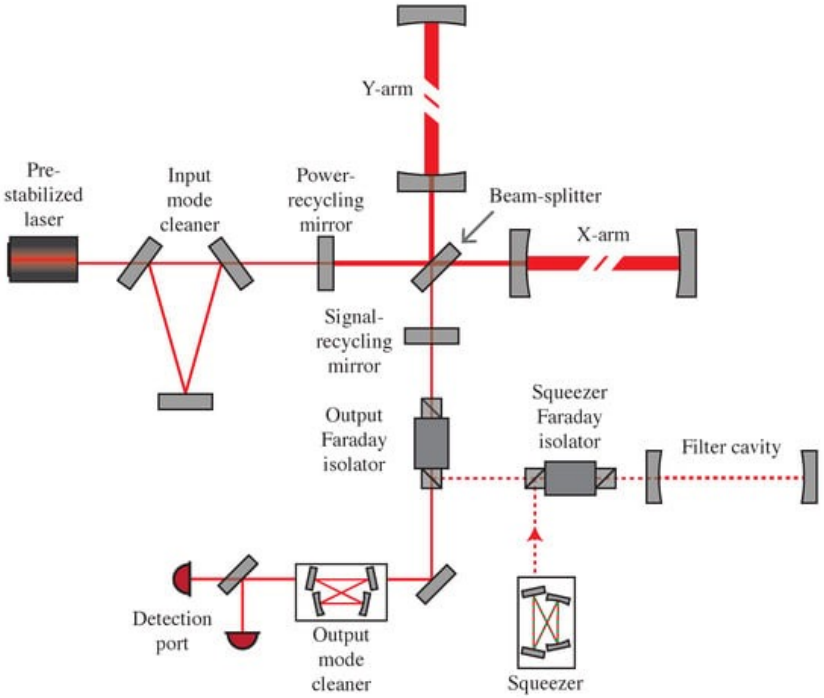
Neutron star mergers



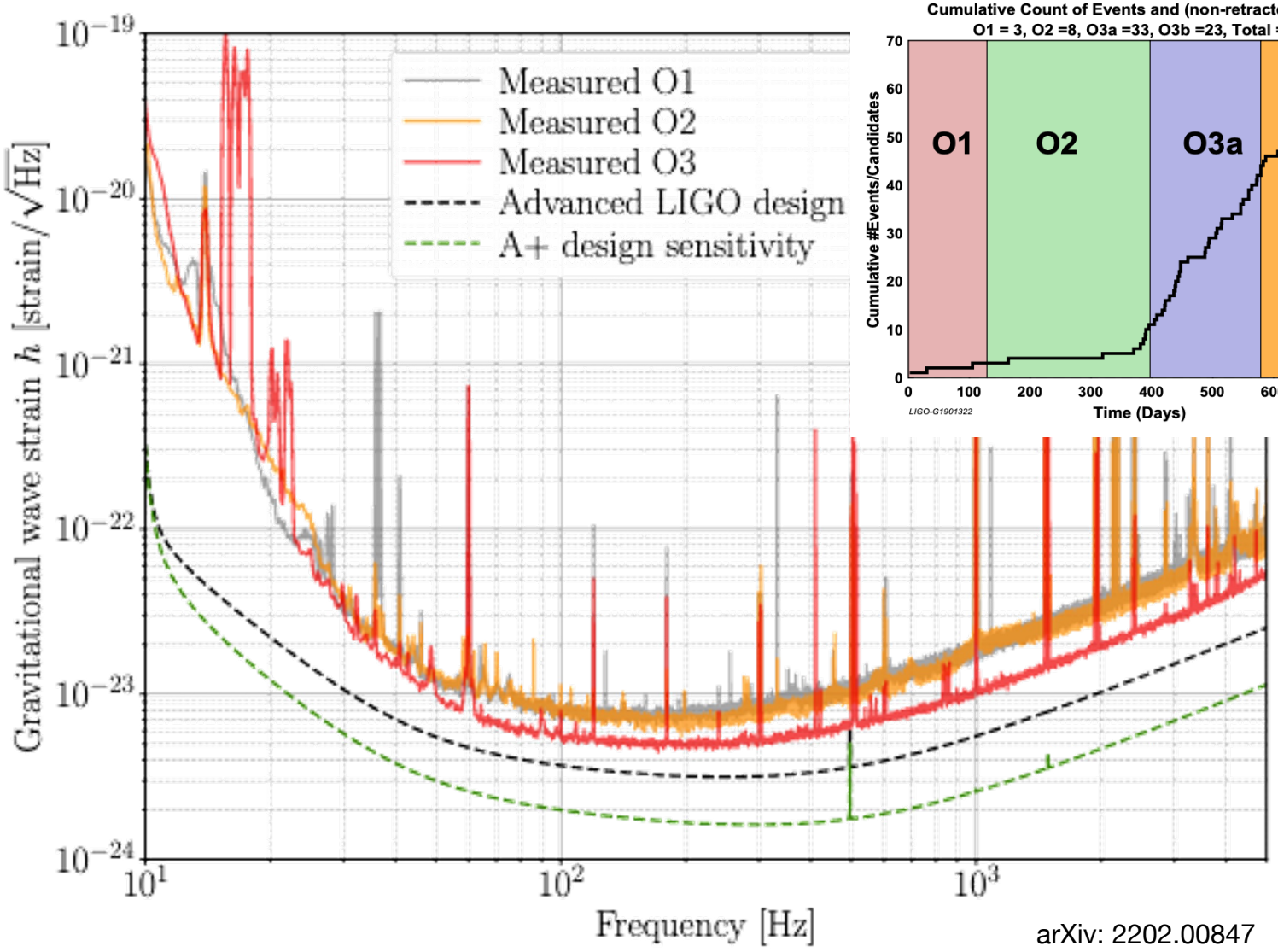


Late inspiral | Merger | Post merger

Advanced LIGO signal-to-**noise**

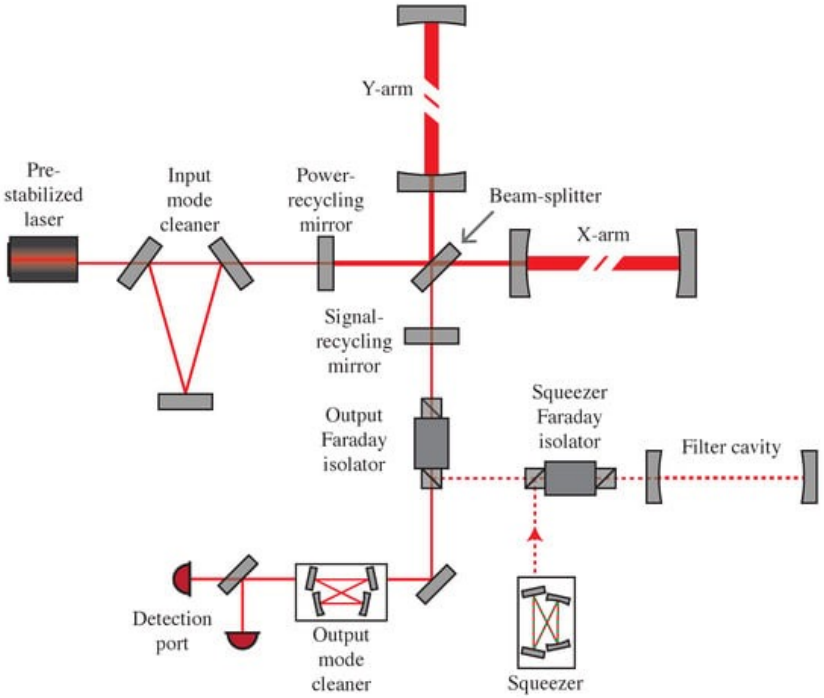


Detector noise

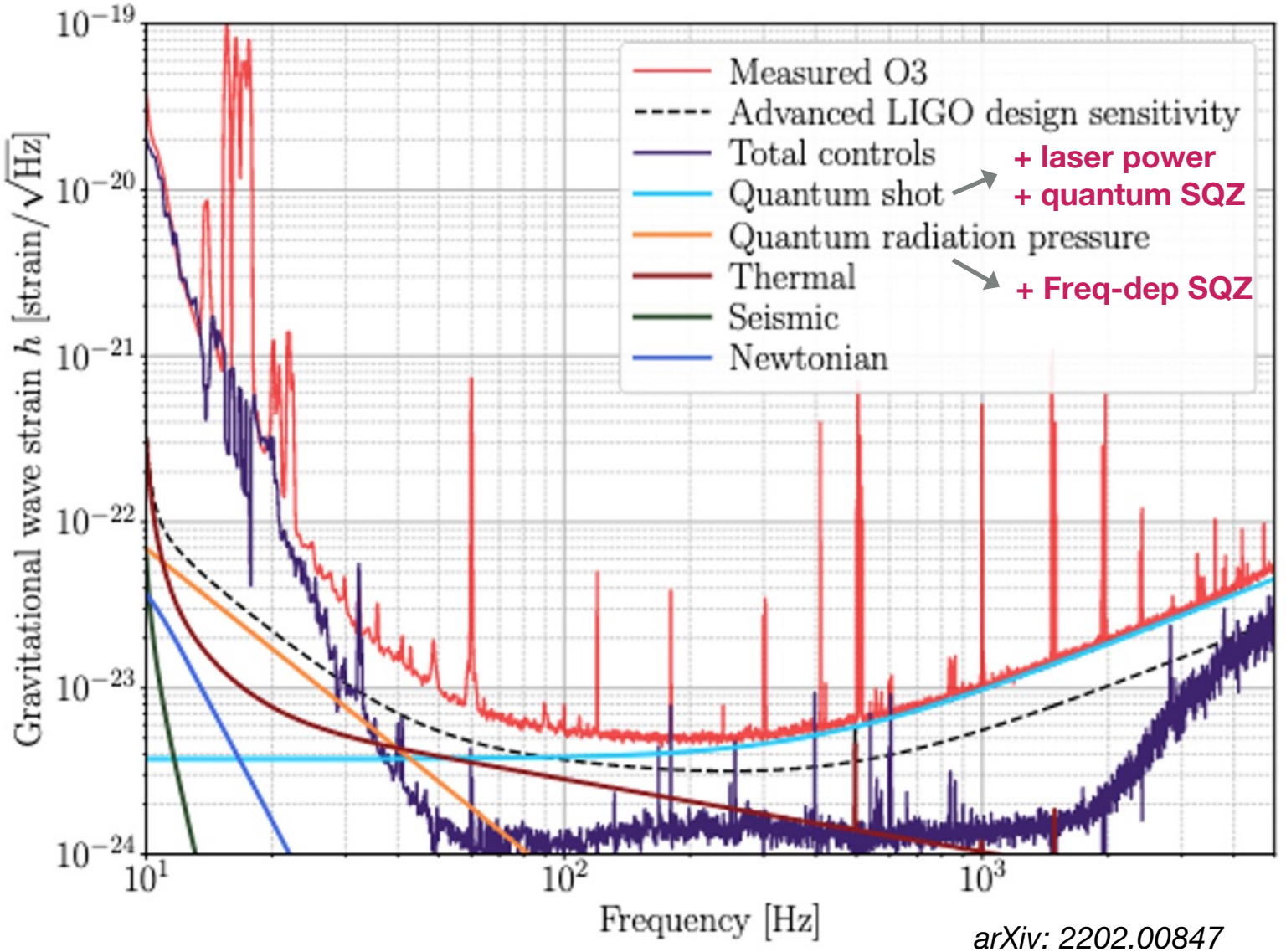


arXiv: 2202.00847

Advanced LIGO signal-to-**noise**



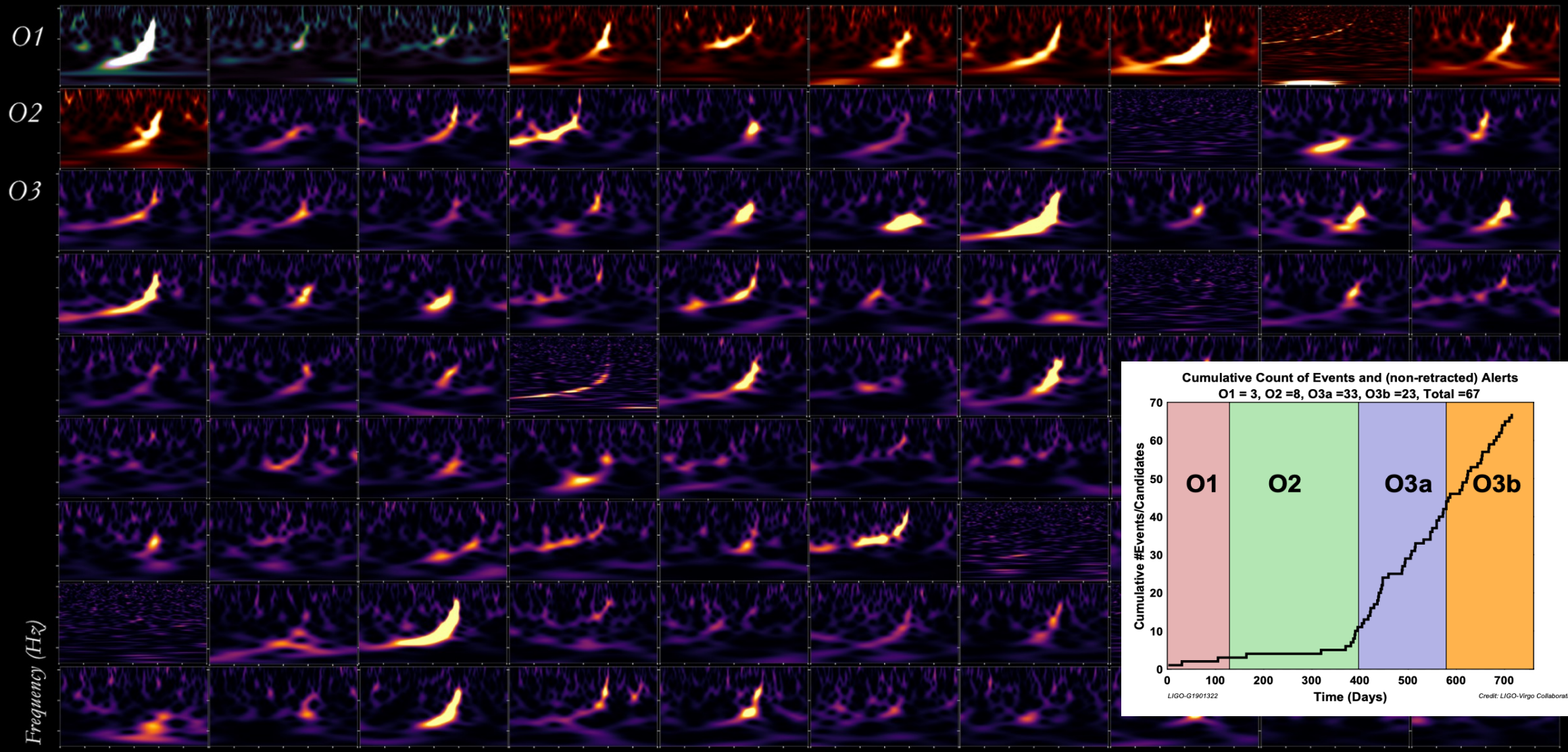
Detector noise



arXiv: 2202.00847
Galaxies 2022, *10(1)*, 36

Gravitational-Wave Transient Catalog

Detections from 2015-2020 of compact binaries with black holes & neutron stars



Sudarshan Ghonge | Karan Jani

SQUEEZING QUANTUM NOISE

Squeeze quantum noise at the interferometer's output port.

Heisenberg uncertainty – quantum noise comes in two forms: $\Delta x\,\Delta p \geq \frac{\hbar}{2}$

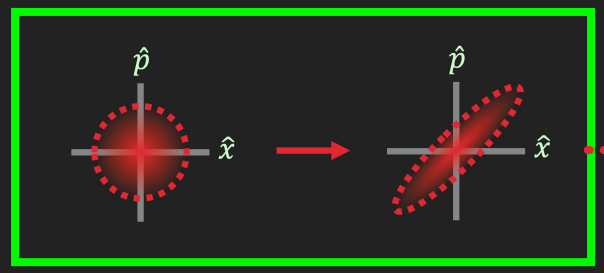
1) Δx, Photon shot noise (high frequency, vacuum **phase** noise) — O3 ✓

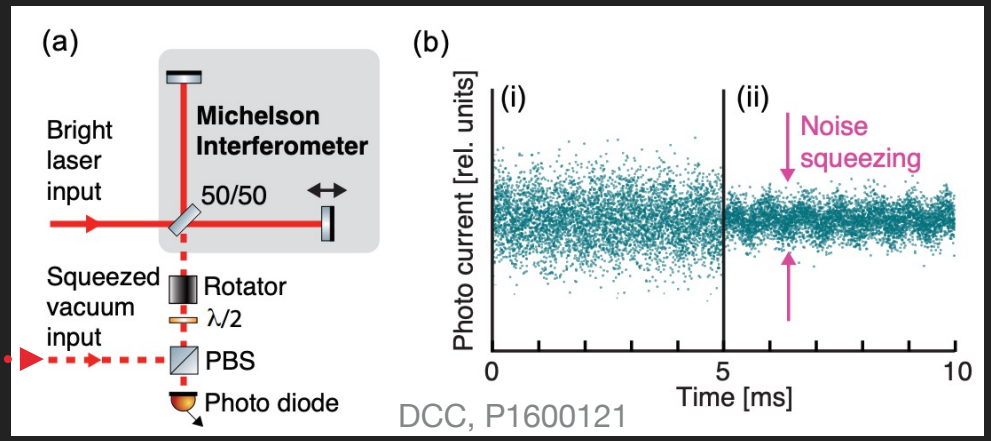
2) Δp, Quantum radiation pressure noise (low frequency, vacuum **amplitude** noise) — O4 ✓

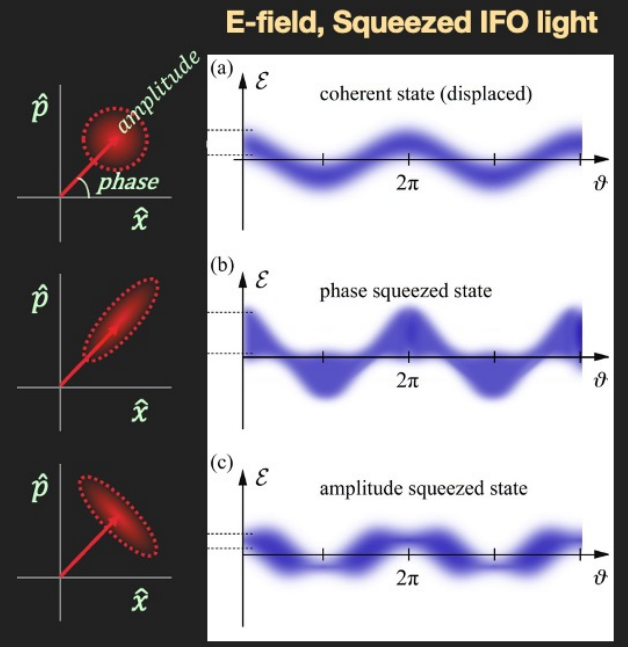
**** SQZ reduces one at the expense of the other ****

✓ O4 – reduce both!!

Squeezer







Credit: Wikipedia, R.Schnabel

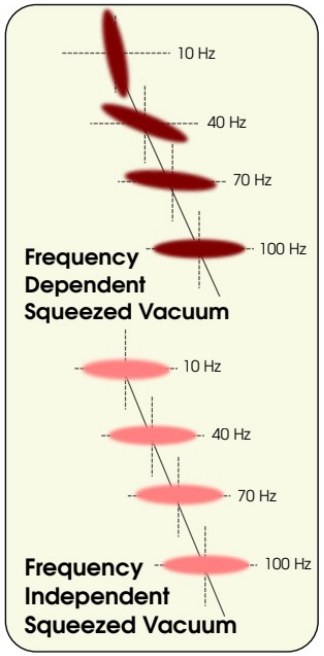
O4: Frequency-*dependent* squeezing

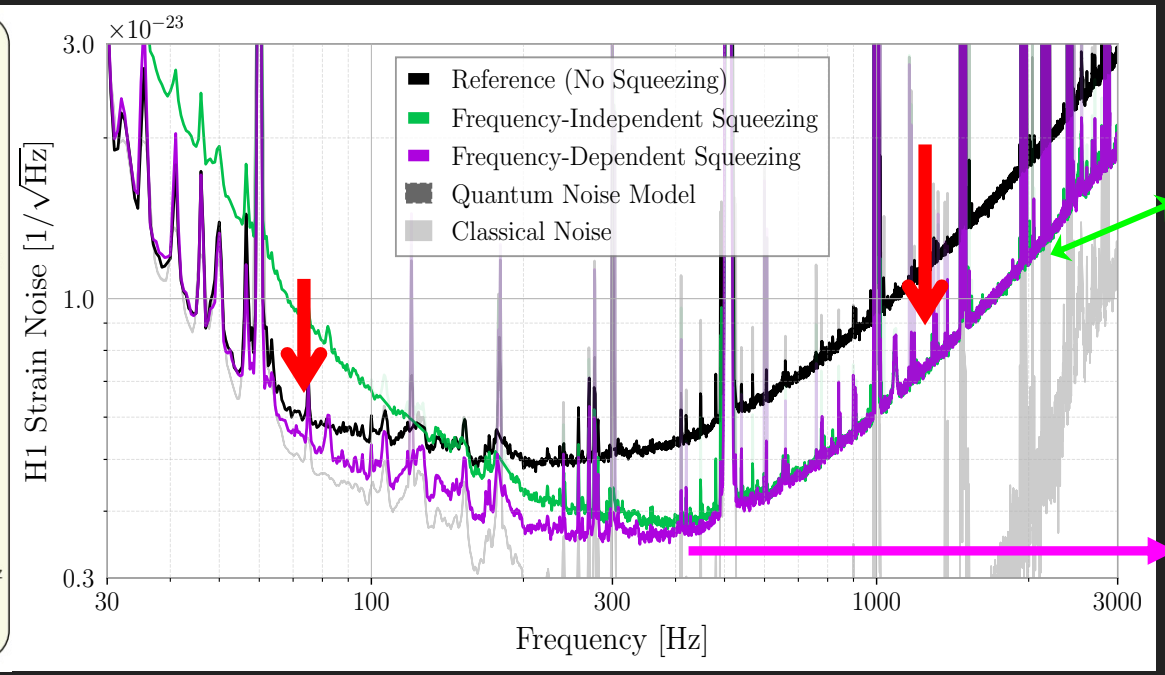
Low-freq amplitude SQZ (reduce QRPN) | High-freq phase SQZ (reduce shot noise)

→ **O4 REDUCES BOTH**, using a new **filter cavity** for FDS

LESS QRPN

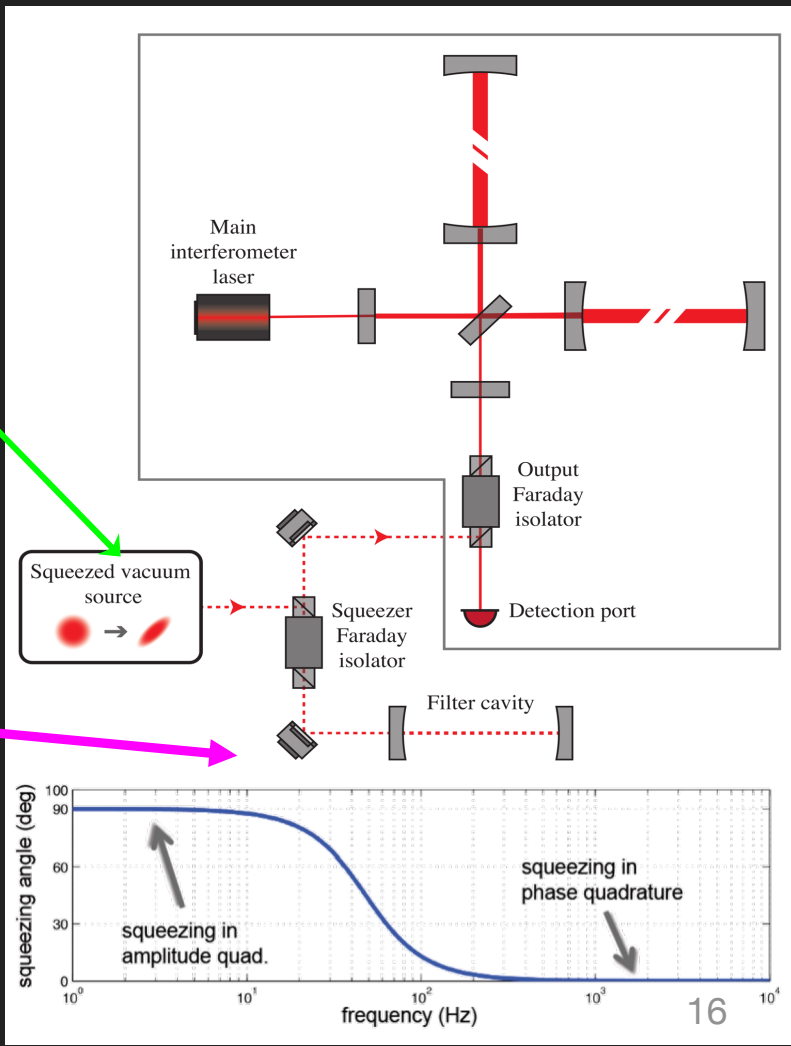
Less shot noise





O3

O4



D.Ganapathy et al, *in prep* (2023)

Xu, LIGO-G2300997

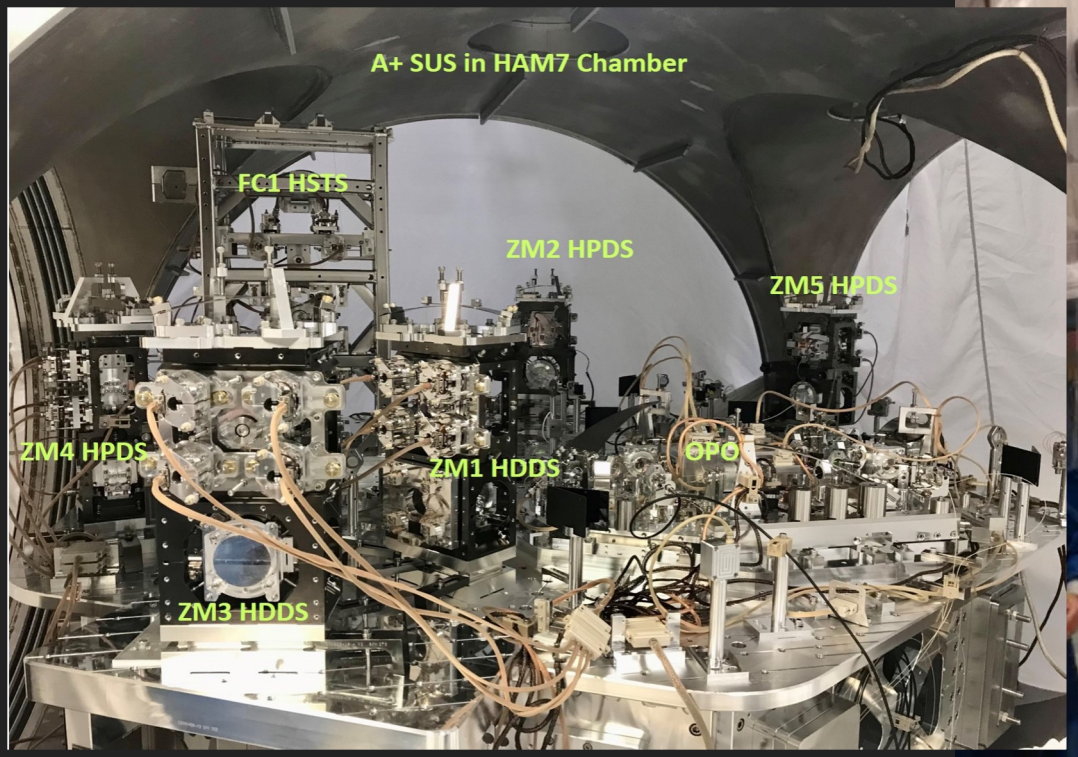
Open Data Workshop, 15 May 2023

ON-SITE SQZ INSTALLS

LATE-2021

LHO:60854, LLO:57774, 57911, 58012

ALL CREDIT TO ON-SITE CREWS



Epic video of HAM7-ISI install @ LLO:5777


October 2021, LHO
(alog 60149)
January 2022, LLO
(alog 57505)
HAM shack
p/c Timothy Nelson, LLO
February 2022, LHO
(alog 61631)
HAM shack!
p/c Bubba Gately, LHO
NSF

300-m Filter cavity install @ LHO, LLO

TJ O'Hanlon alog61193

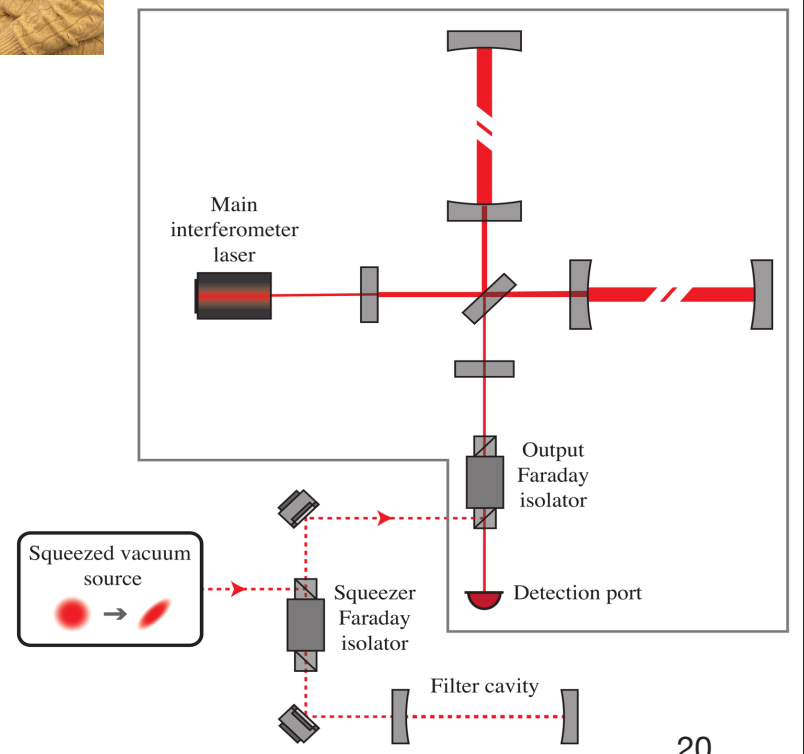
First lights + locks

Dec. 12, 2022:
LHO first FDS!!

→ Reflect SQZ off a **detuned filter cavity** for frequency-dependent squeezing

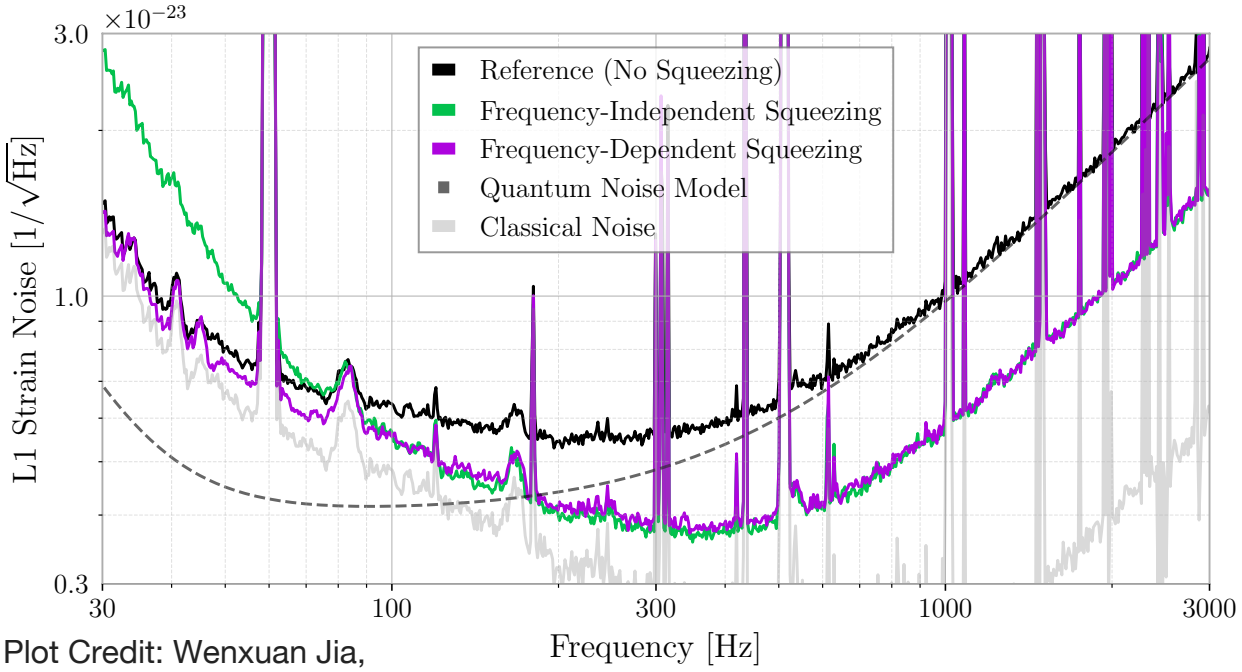
Nov. 18, 2022:

first light + locks at BOTH observatories!!!



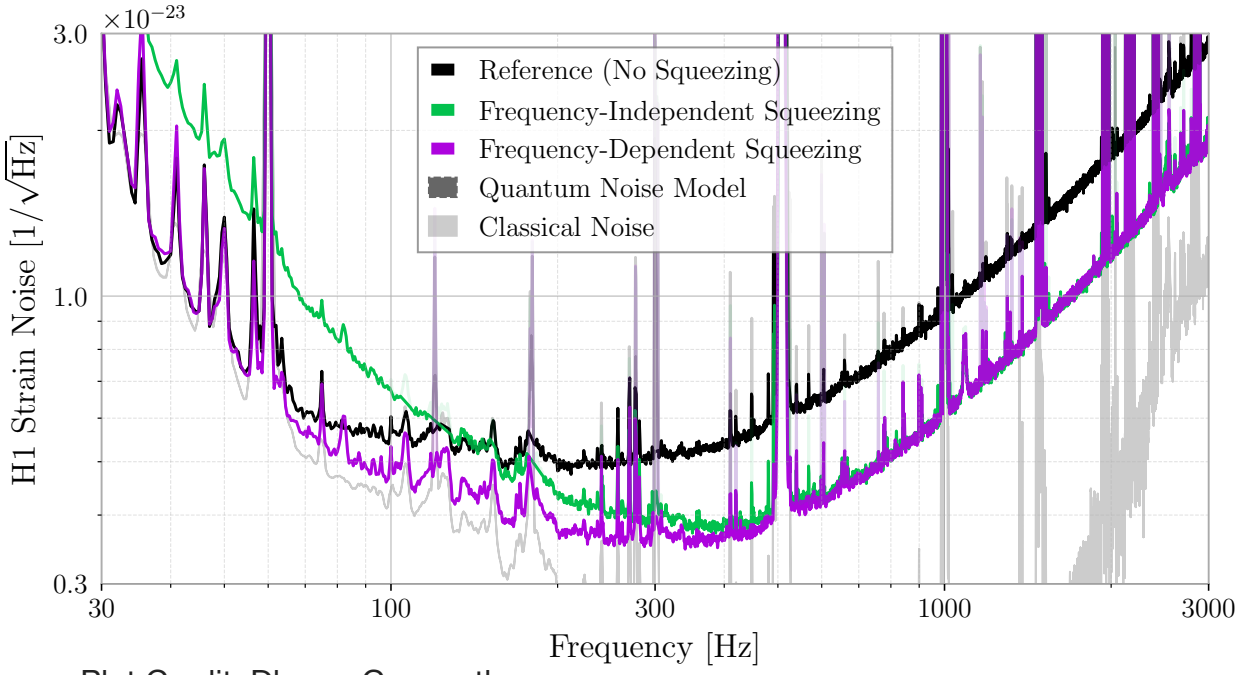
SPRING 2023, both sites have seen 4.5 dB FDS

LLO

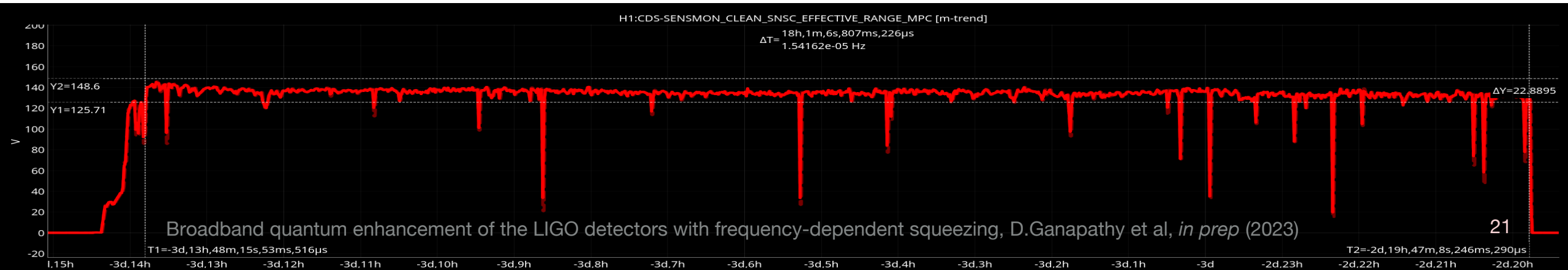


Plot Credit: Wenxuan Jia, Masayuki Nakano

LHO



Plot Credit: Dhruva Ganapathy

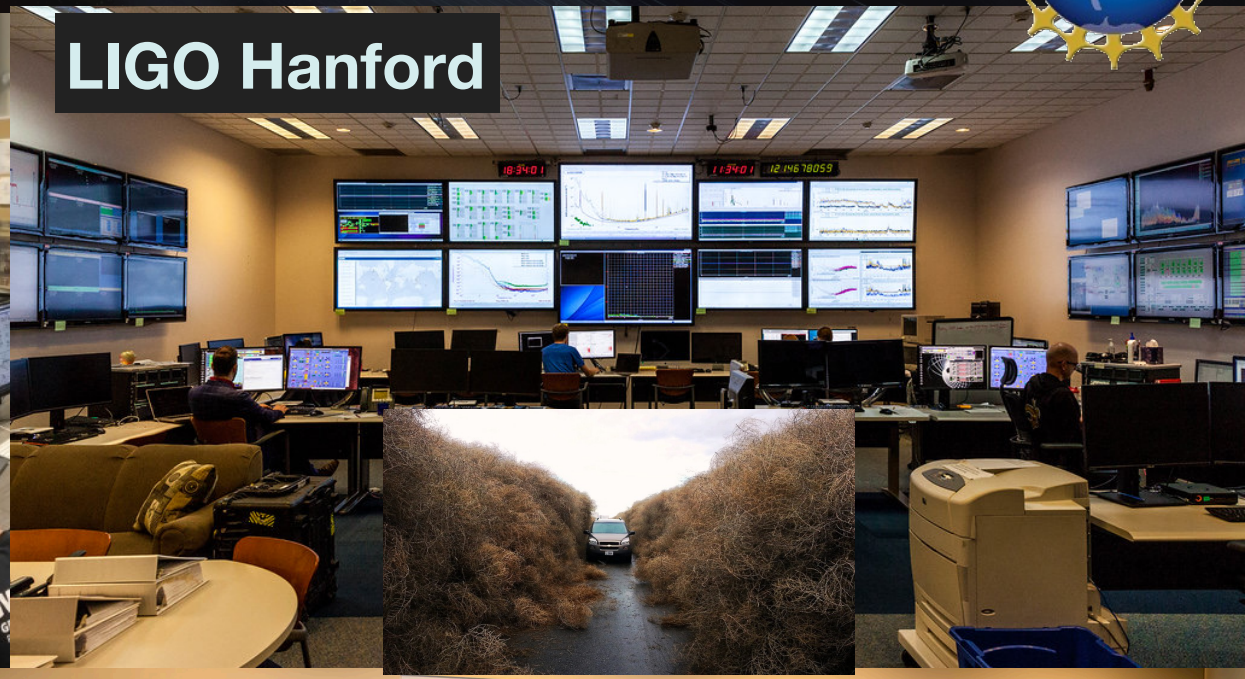


Broadband quantum enhancement of the LIGO detectors with frequency-dependent squeezing, D.Ganapathy et al, *in prep* (2023)

LIGO LIVINGSTON, HANFORD, MIT, CALTECH

LIGO Livingston

LIGO Hanford



LIGO-MIT

LIGO Scientific Collaboration

>1200 members, >100 institutions, 18 countries

The material presented here is based upon work supported by NSF's LIGO Laboratory, which is a major facility fully funded by the National Science Foundation.

LIGO VIRGO KAGRA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NSF
Thank you!