Ground-based Gravitational-wave Detectors: Prospects for the Future

David Reitze
Executive Director
LIGO Laboratory
For the LIGO Scientific Collaboration and Virgo Collaboration

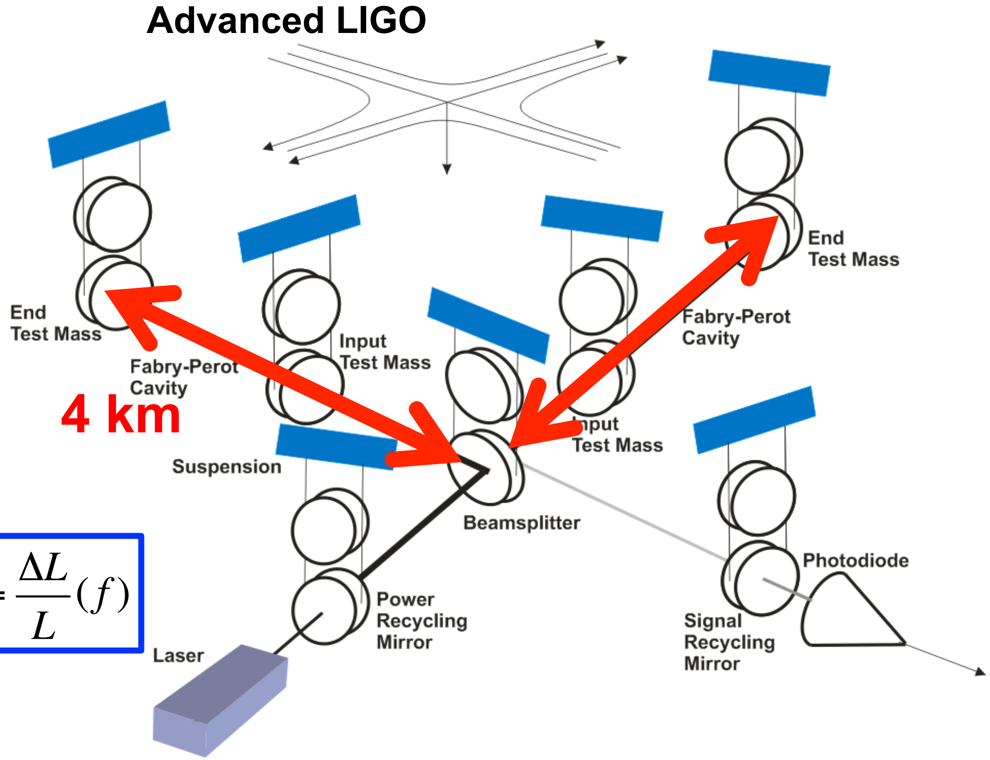
Image Credit: Aurore Simmonet, Sonoma State

The Next Hour

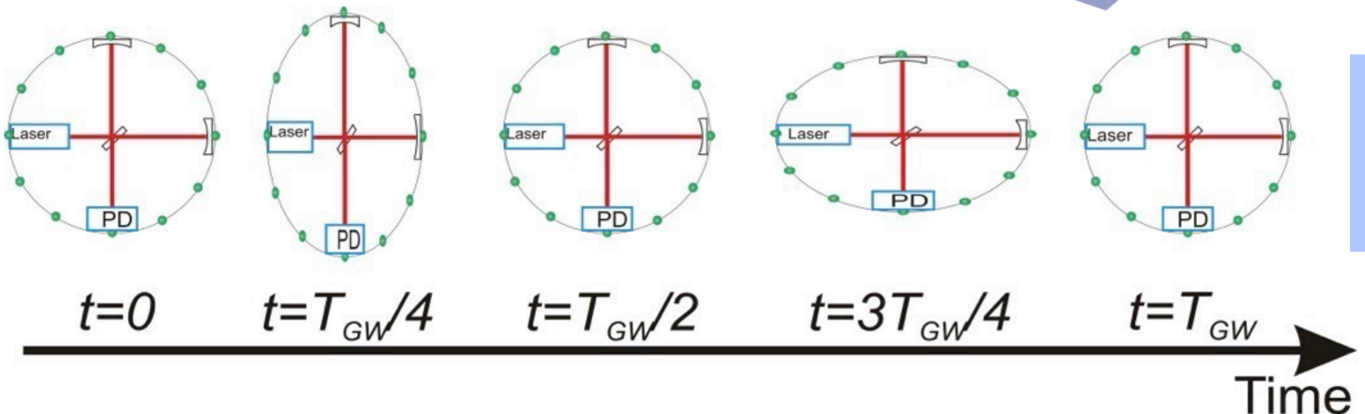
- *Primer on Gravitational-wave Detectors*
- *Advanced LIGO: Current Status*
- *Advanced LIGO: Near Term Prospects*
- *Beyond Advanced LIGO: The 'A+' Upgrade*
- *Probing the Horizons of the Gravitational-wave Universe: Voyager & Cosmic Explorer*

The Advanced LIGO Interferometer

- Advanced LIGO uses enhanced Michelson interferometry
  - suspended (‘freely falling’) mirrors
- Passing GWs stretch and compress the distance between the end test mass and the beamsplitter
- The interferometer acts as a transducer, turning GWs into photocurrent
  - A coherent detector

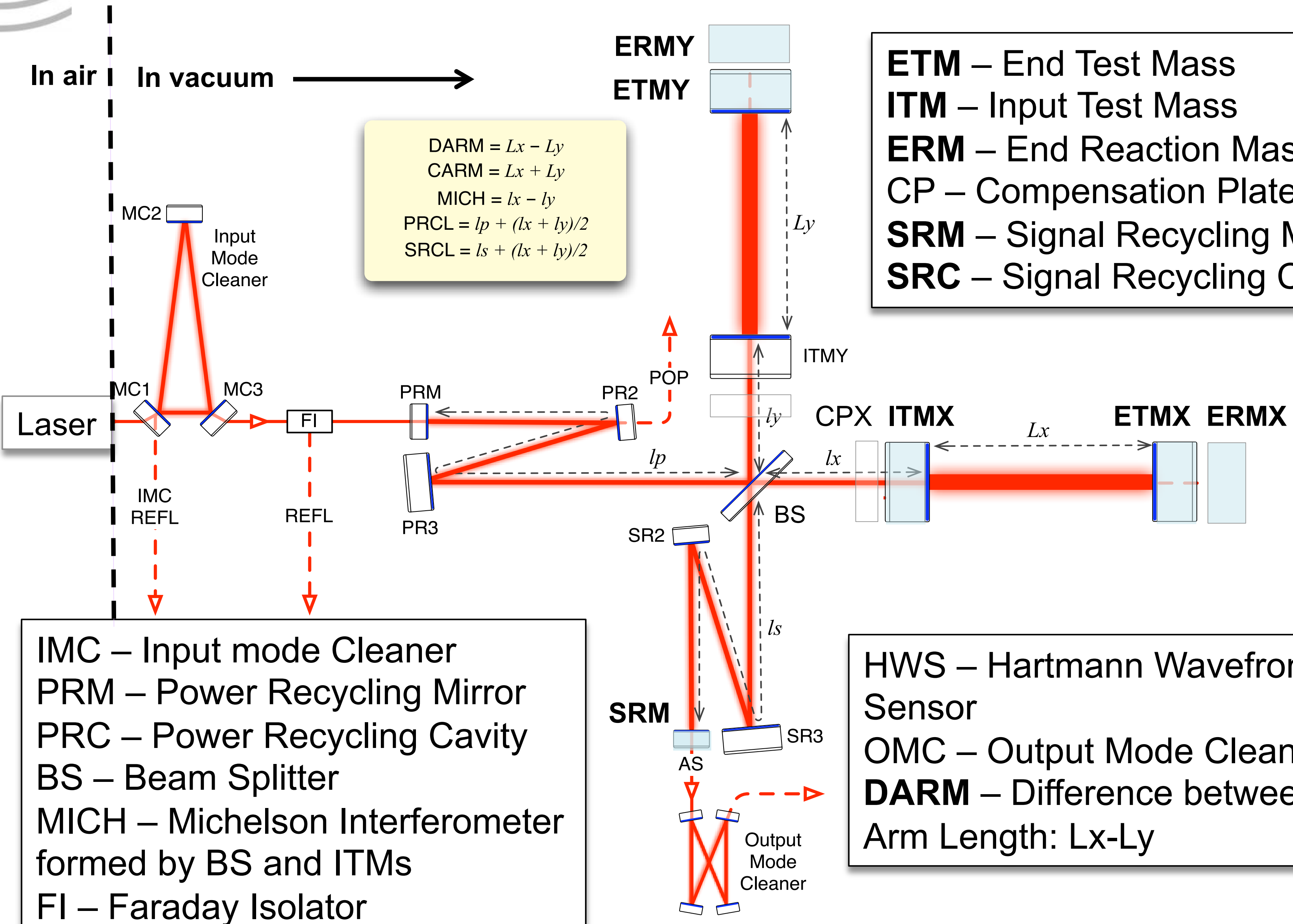


$$\boxed{h(f)=\frac{\Delta L}{L}(f)}$$



J. Aasi et al., (LIGO Scientific Collaboration and Virgo Collaboration), “Advanced LIGO” Classical Quantum Gravity 32, 074001 (2015).

Layout and Nomenclature



DARM = $Lx - Ly$
CARM = $Lx + Ly$
MICH = $lx - ly$
PRCL = $lp + (lx + ly)/2$
SRCL = $ls + (lx + ly)/2$

ETM – End Test Mass
ITM – Input Test Mass
ERM – End Reaction Mass
CP – Compensation Plate
SRM – Signal Recycling Mirror
SRC – Signal Recycling Cavity

IMC – Input mode Cleaner
PRM – Power Recycling Mirror
PRC – Power Recycling Cavity
BS – Beam Splitter
MICH – Michelson Interferometer formed by BS and ITMs
FI – Faraday Isolator

HWS – Hartmann Wavefront Sensor
OMC – Output Mode Cleaner
DARM – Difference between Arm Length: Lx-Ly

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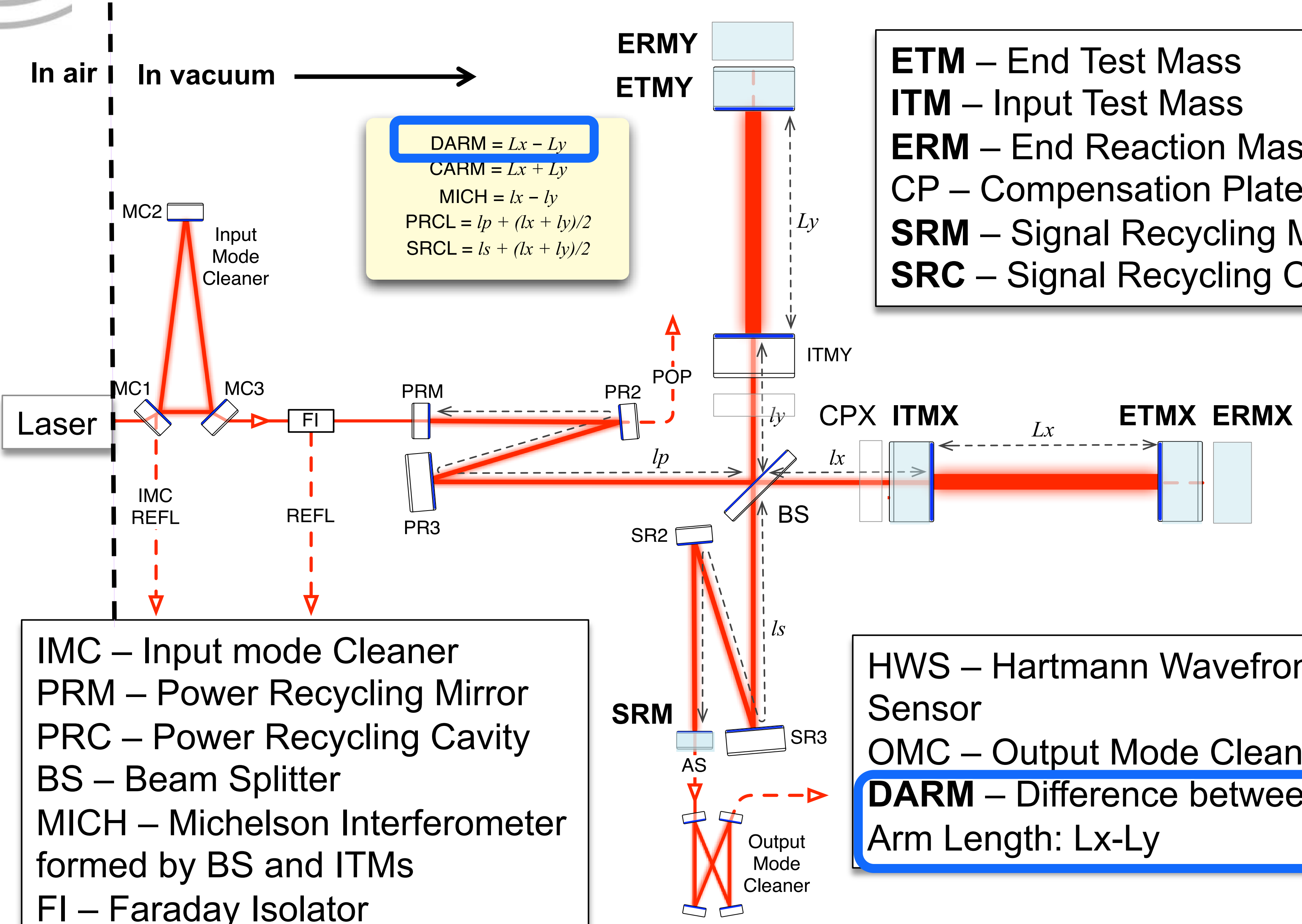

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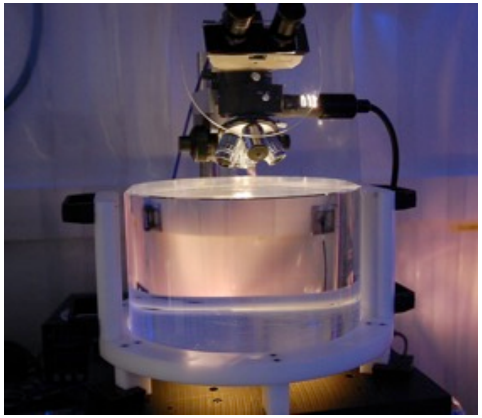
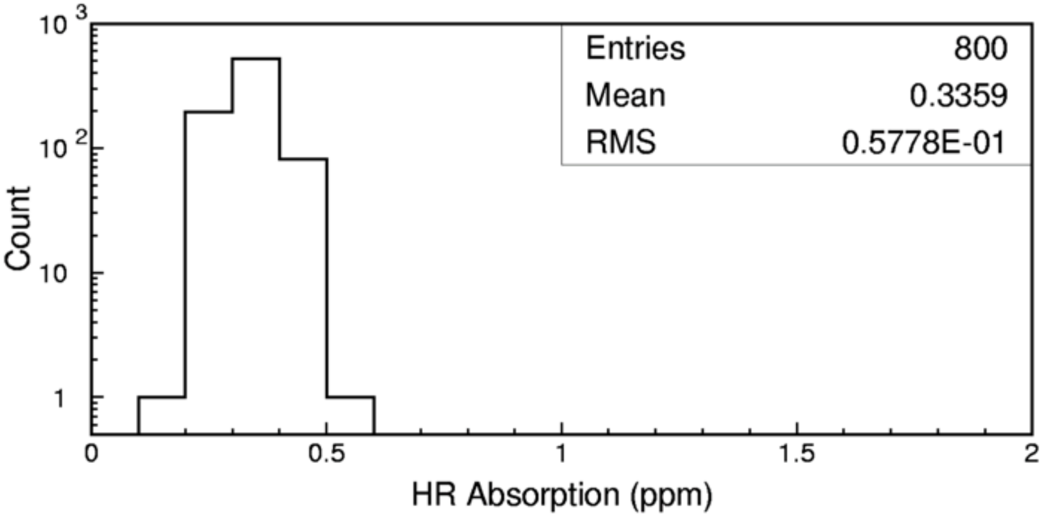
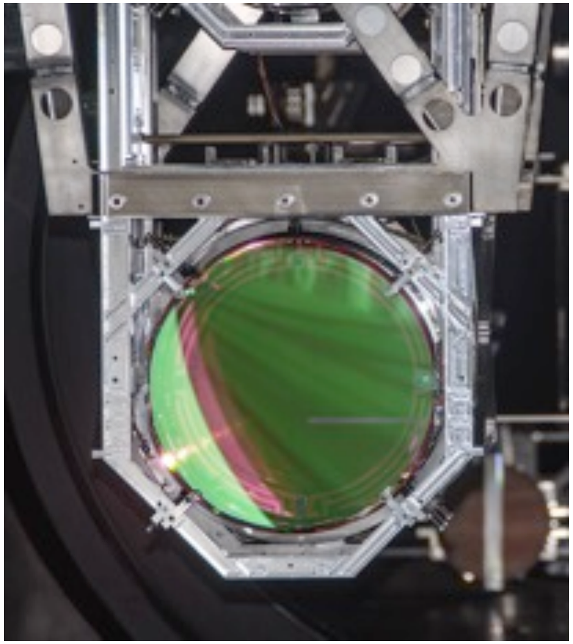
LIGO

Advanced LIGO 'Test Mass' Mirrors

- ***<u>Truly the 'crown jewels' of the detector</u>***
- Physical specifications:
  - Ultra-pure, ultra-homogeneous fused silica
  - 340 mm diameter, 200 mm thick, 40 kg mass
- Surface figure: super-polish followed by ion beam 'spot' polish
  - ***< 0.15 nm RMS deviation from sphere***
- Coatings: TiO_2-doped Ta_2O_5/SiO_2
  - Reflectivity depends upon type of mirror
  - Ultralow absorption (< 0.5 ppm)

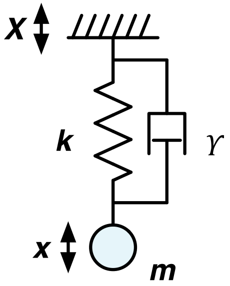






Advanced LIGO Suspensions: A Tour-de-Force in Engineering

Concept:



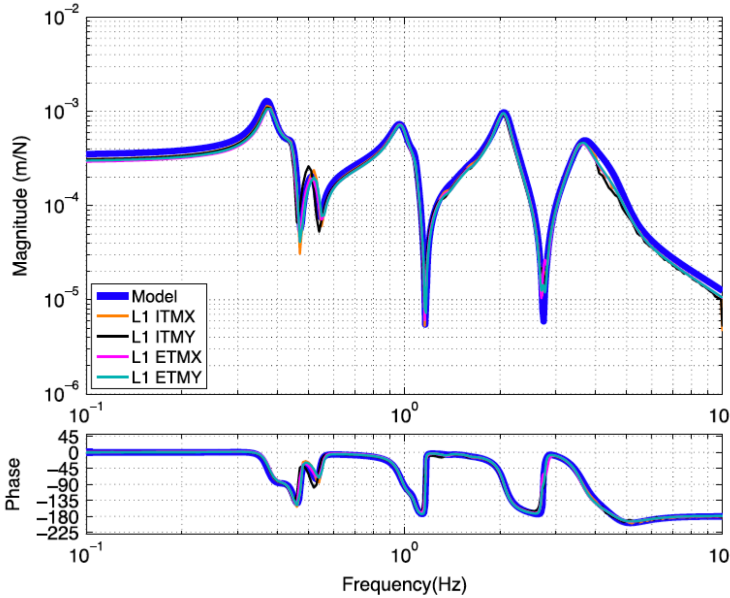
$$m\ddot{x} = -k(x-X) - \gamma(\dot{x}-\dot{X})$$

$$\left(\omega_0^2 + i\frac{\gamma}{m}\omega - \omega^2\right)\tilde{x} = \left(\omega_0^2 + i\frac{\gamma}{m}\omega\right)\tilde{X}$$

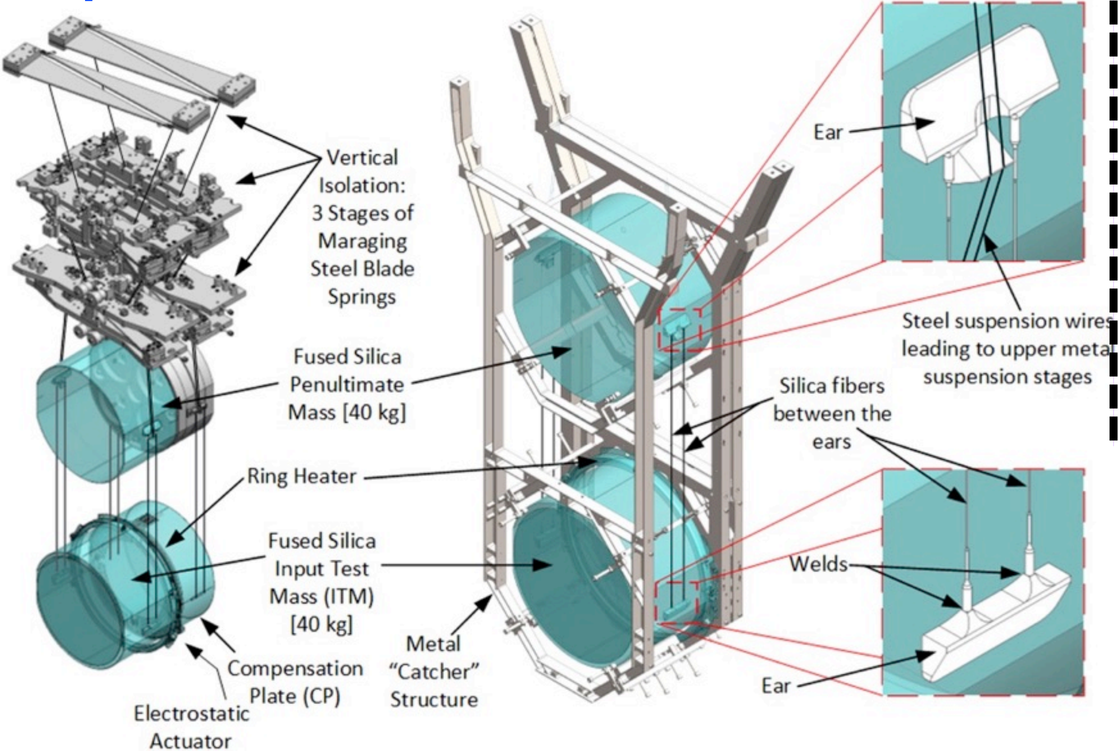
$$\frac{\tilde{x}}{\tilde{X}} = \frac{\omega_0^2 + i\frac{\gamma}{m}\omega}{\omega_0^2 + i\frac{\gamma}{m}\omega - \omega^2}$$

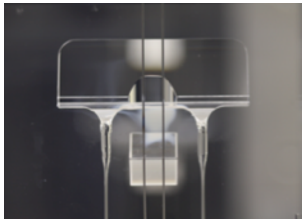
Force → Displacement Transfer Function

Model vs. Measured



Implementation:



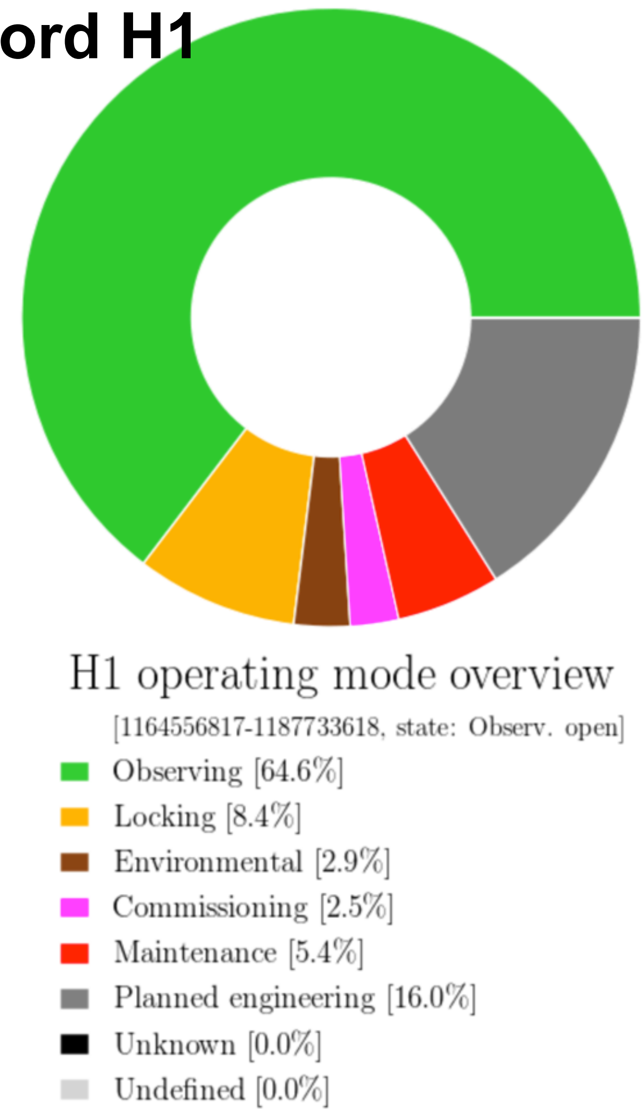


Upper 'ear' **Lower 'ear'**

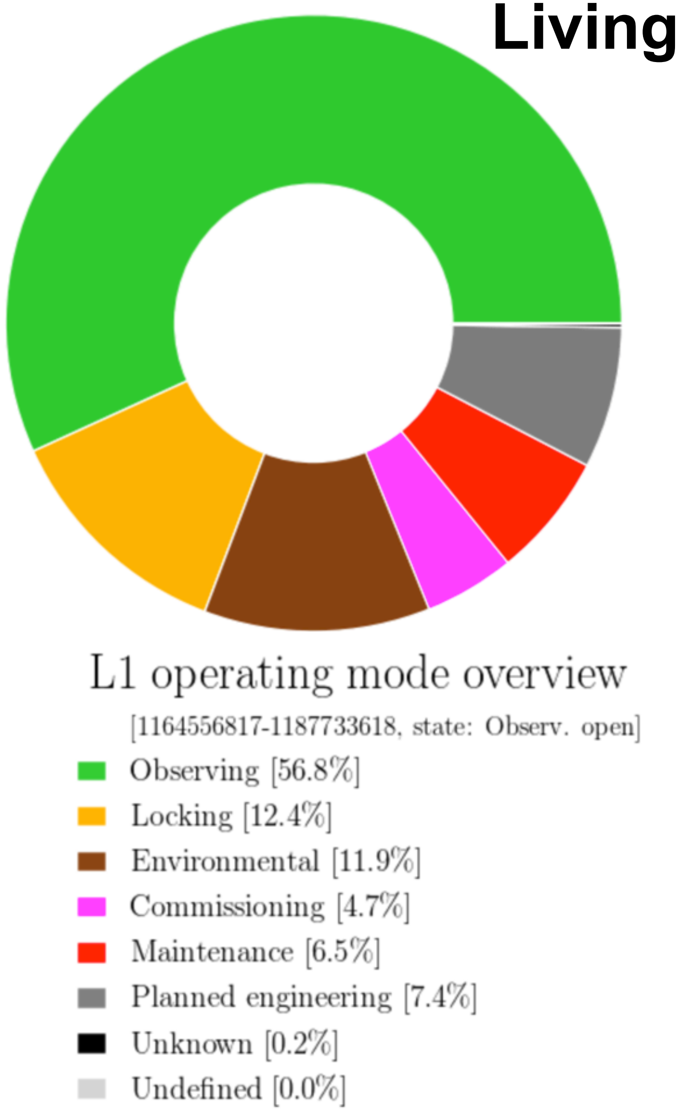
Advanced LIGO:
Current Status

H1, L1 Uptime Dashboard

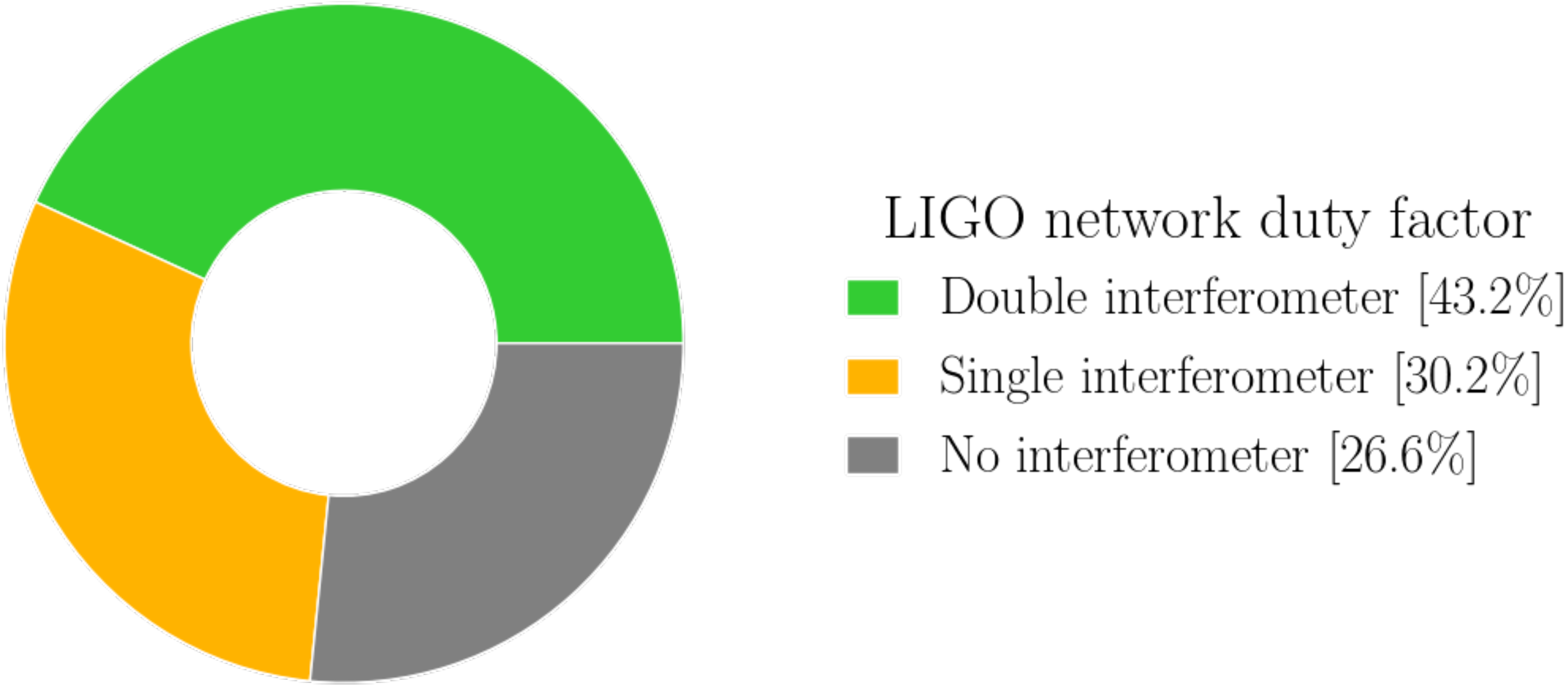
Hanford H1



Livingston L1

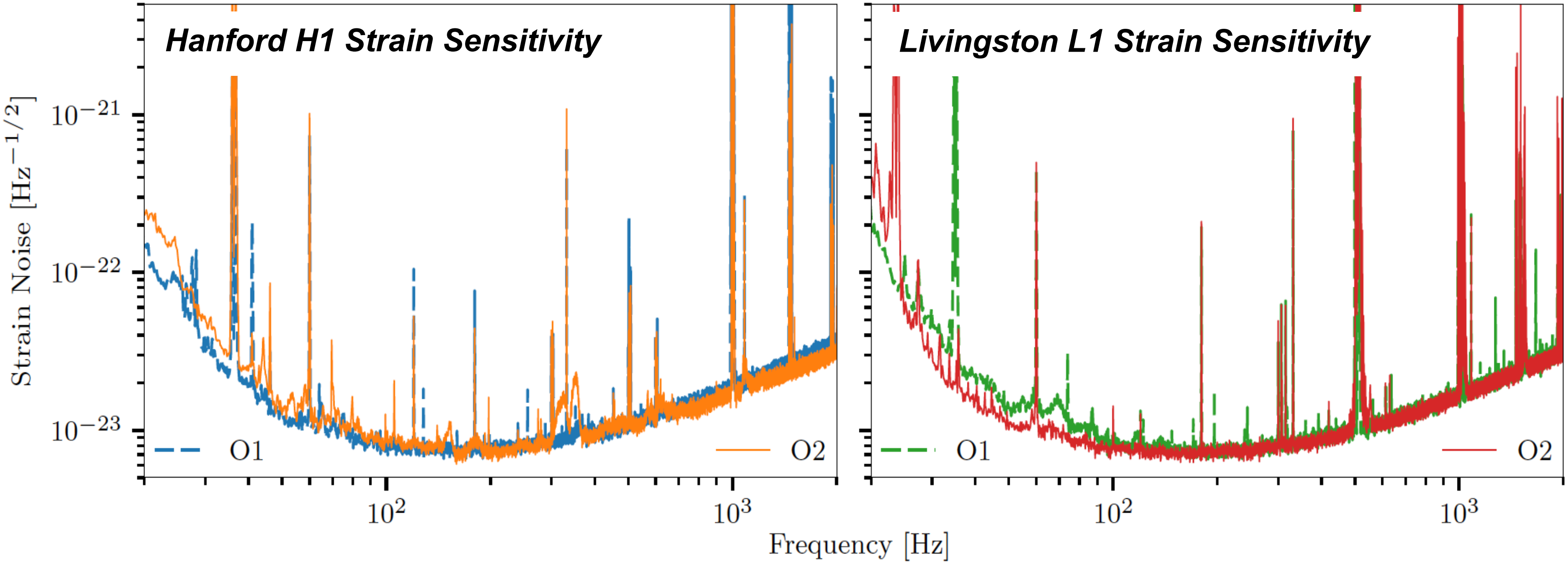


LIGO Network Duty Factor



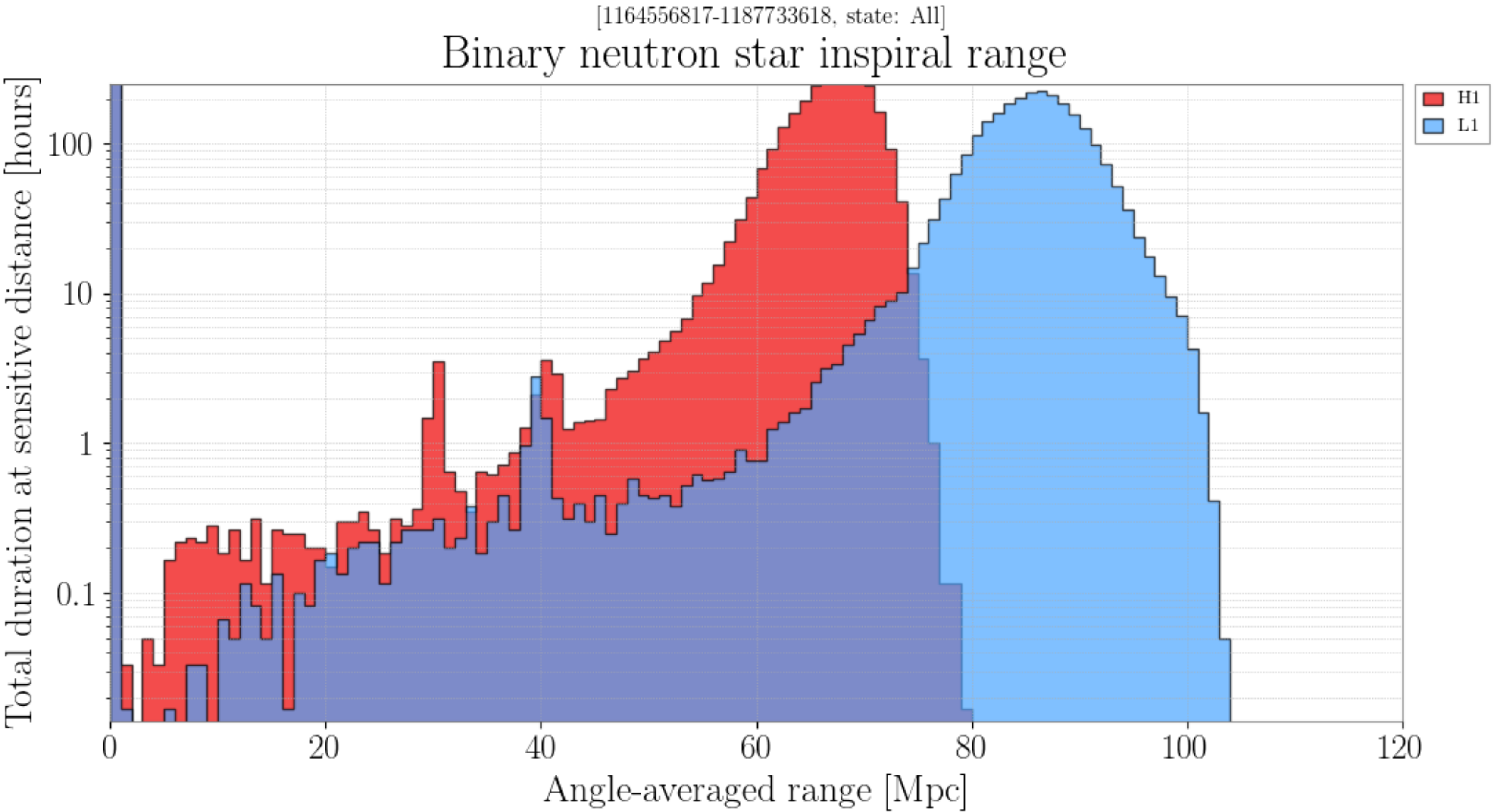
Comparison of Strain Sensitivity: O1 vs. O2

- L1 detector is 30 – 40% more sensitive than in O1
  - 25 W laser power into the interferometer
    - Limited by high power amplifier stage failure at LLO prior to O1
- H1 is slightly ~ 5 – 10% less sensitive
  - 30 W laser power; noise penalty at higher power related to input beam jitter



Binary Neutron Star Inspiral Range

- Goal for O2: > 80 MPc BNS range for H1 and L1



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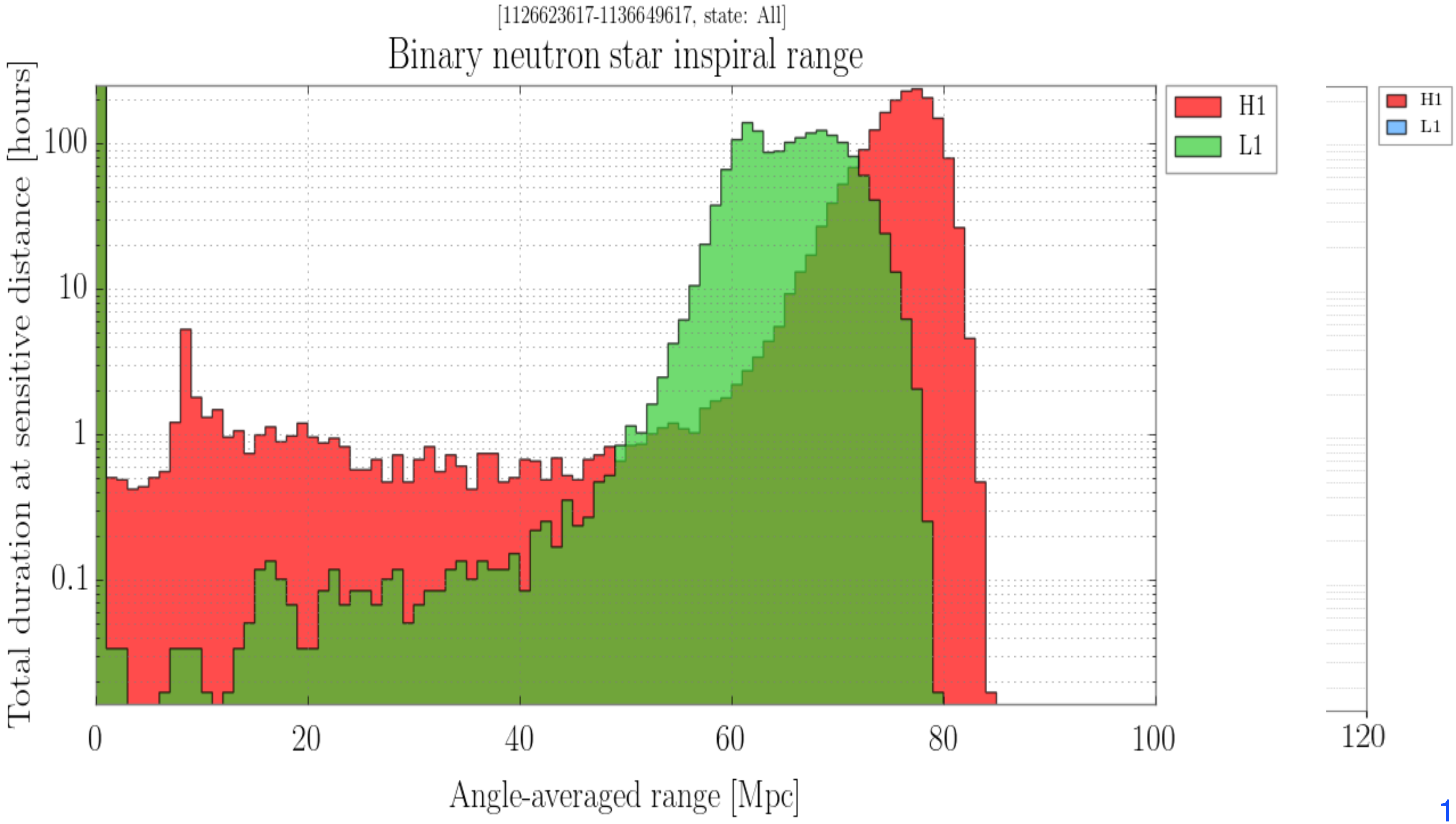
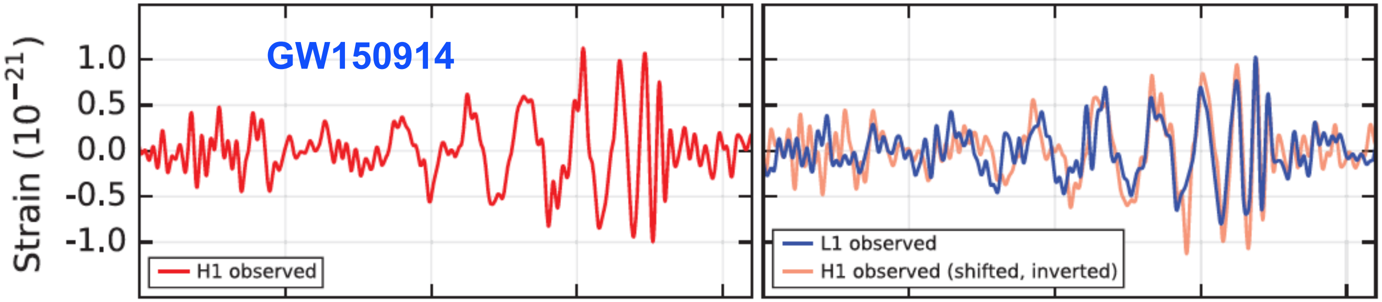


Nonetheless, LIGO is an Observatory!



Selected for a Viewpoint in *Physics*
PRL **116,** 061102 (2016) PHYSICAL REVIEW LETTERS week ending 12 FEBRUARY 2016

Observation of Gravitational Waves from a Binary Black Hole Merger

B. P. Abbott *et al.**
(LIGO Scientific Collaboration and Virgo Collaboration)
(Received 21 January 2016; published 11 February 2016)

PRL **116,** 241103 (2016) PHYSICAL REVIEW LETTERS week ending 17 JUNE 2016

GW151226: Observation of Gravitational Waves from a 22-Solar-Mass Binary Black Hole Coalescence

B. P. Abbott *et al.**
(LIGO Scientific Collaboration and Virgo Collaboration)
(Received 31 May 2016; published 15 June 2016)

PRL **118,** 221101 (2017) PHYSICAL REVIEW LETTERS week ending 2 JUNE 2017

GW170104: Observation of a 50-Solar-Mass Binary Black Hole Coalescence at Redshift 0.2

B. P. Abbott *et al.**
(LIGO Scientific and Virgo Collaboration)
(Received 9 May 2017; published 1 June 2017)

NEW RESULT!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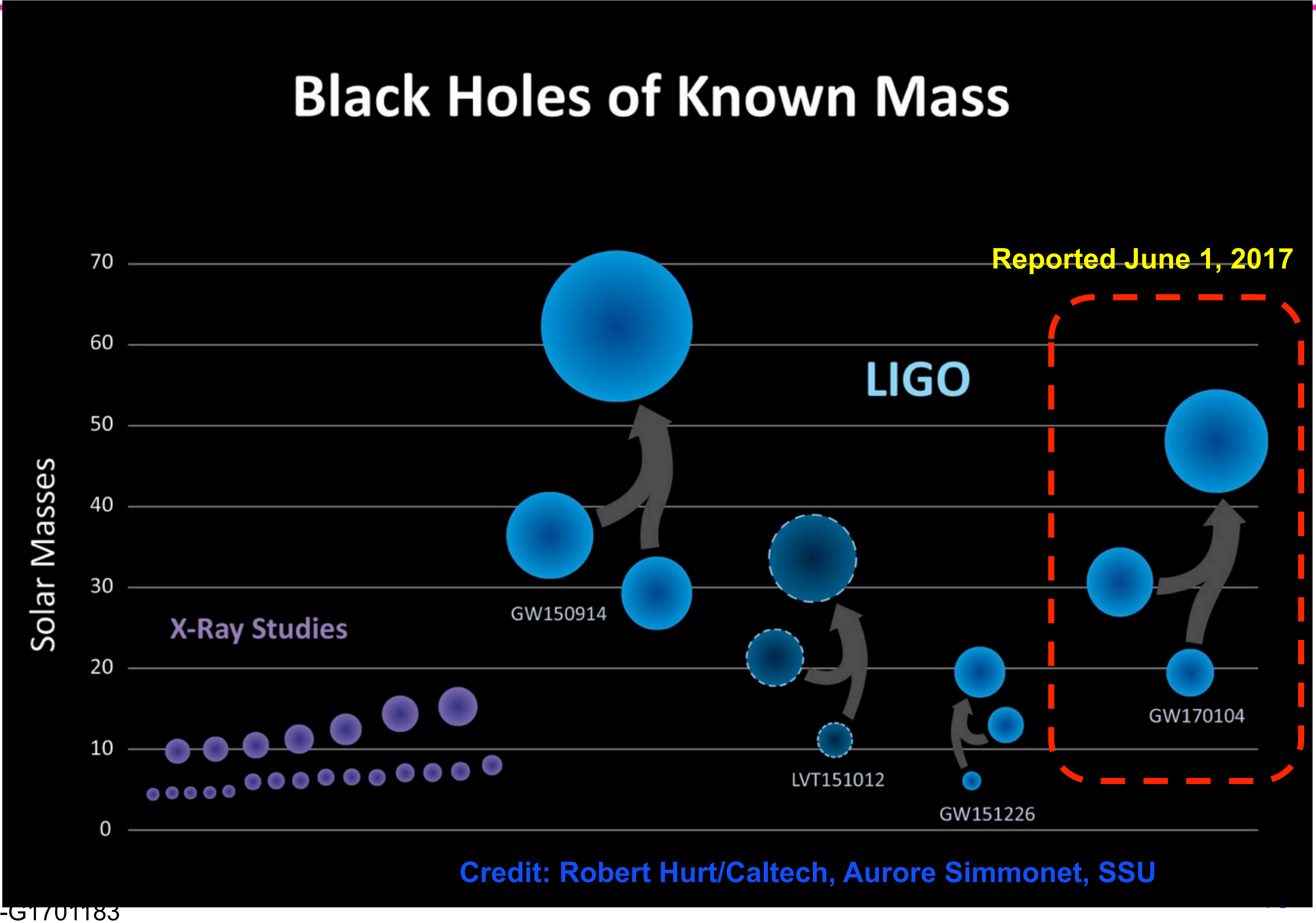
Volume 116, Number 6

The Newest Black Hole Merger



Reported June 1, 2017

Credit: Robert Hurt/Caltech, Aurore Simmonet, SSU

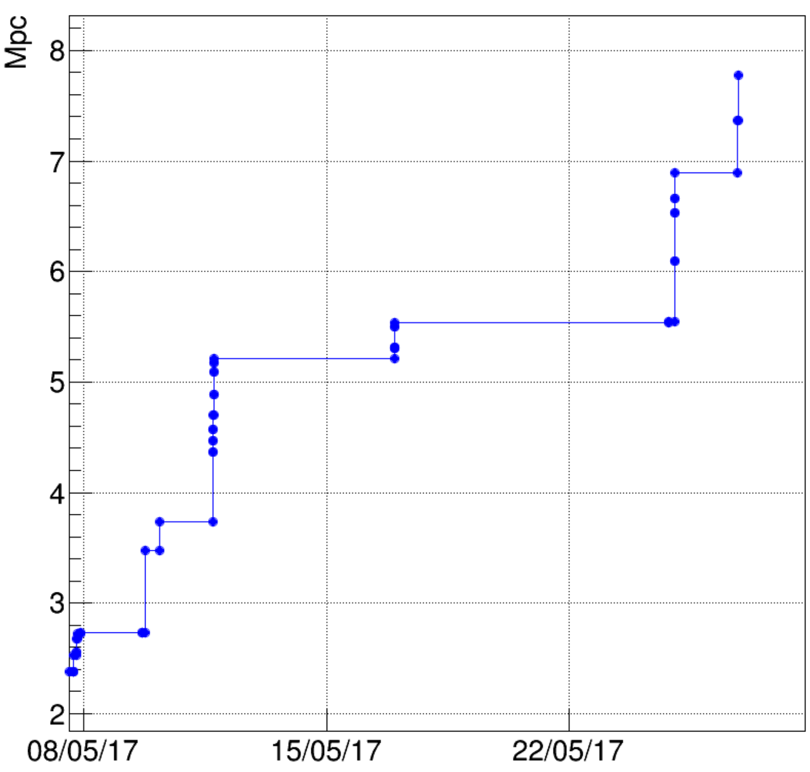
ADVANCED VIRGO

6 EU countries
20 labs, ~250 authors

- APC Paris
- ARTEMIS Nice
- EGO Cascina
- INFN Firenze-Urbino
- INFN Genova
- INFN Napoli
- INFN Perugia
- INFN Pisa
- INFN Roma La Sapienza
- INFN Roma Tor Vergata
- INFN Trento-Padova
- LAL Orsay – ESPCI Paris
- LAPP Annecy
- LKB Paris
- LMA Lyon
- NIKHEF Amsterdam
- POLGRAW(Poland)
- RADBOUD Uni. Nijmegen
- RMKI Budapest
- *University of Valencia*

Virgo pathway to O2

- Path to join O2 includes:
  - Improve power recycling cavity (PRC) stability with thermal compensation (TCS)
  - Suspend the detection bench (includes output photodiodes)
  - Employ low noise actuation
  - Make use of noise subtraction techniques
  - Initiate weekend engineering/ science runs
  - Increase interferometer input power from 13W to 25W
  - Noise hunting!

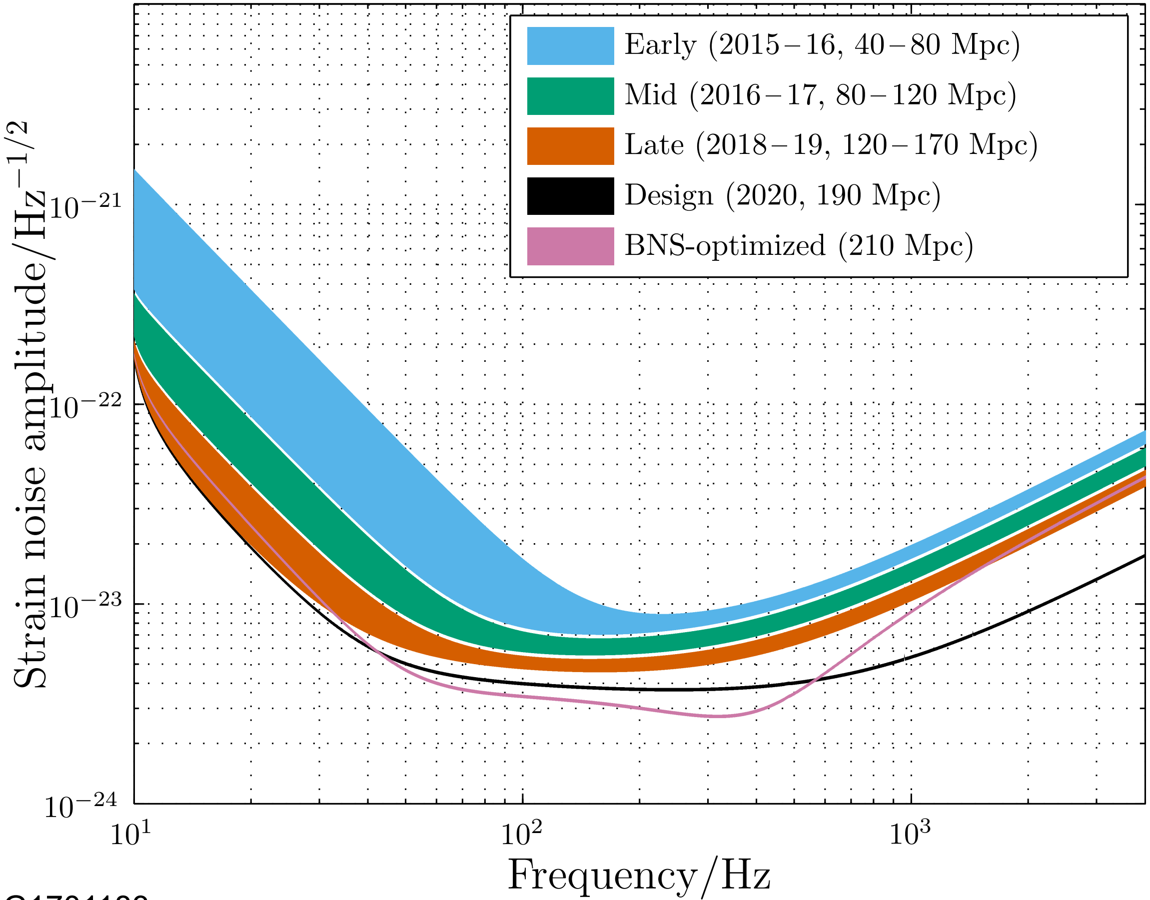


AdV best BNS range (from May 7 to May 27)

Advanced LIGO:
Near Term Prospects

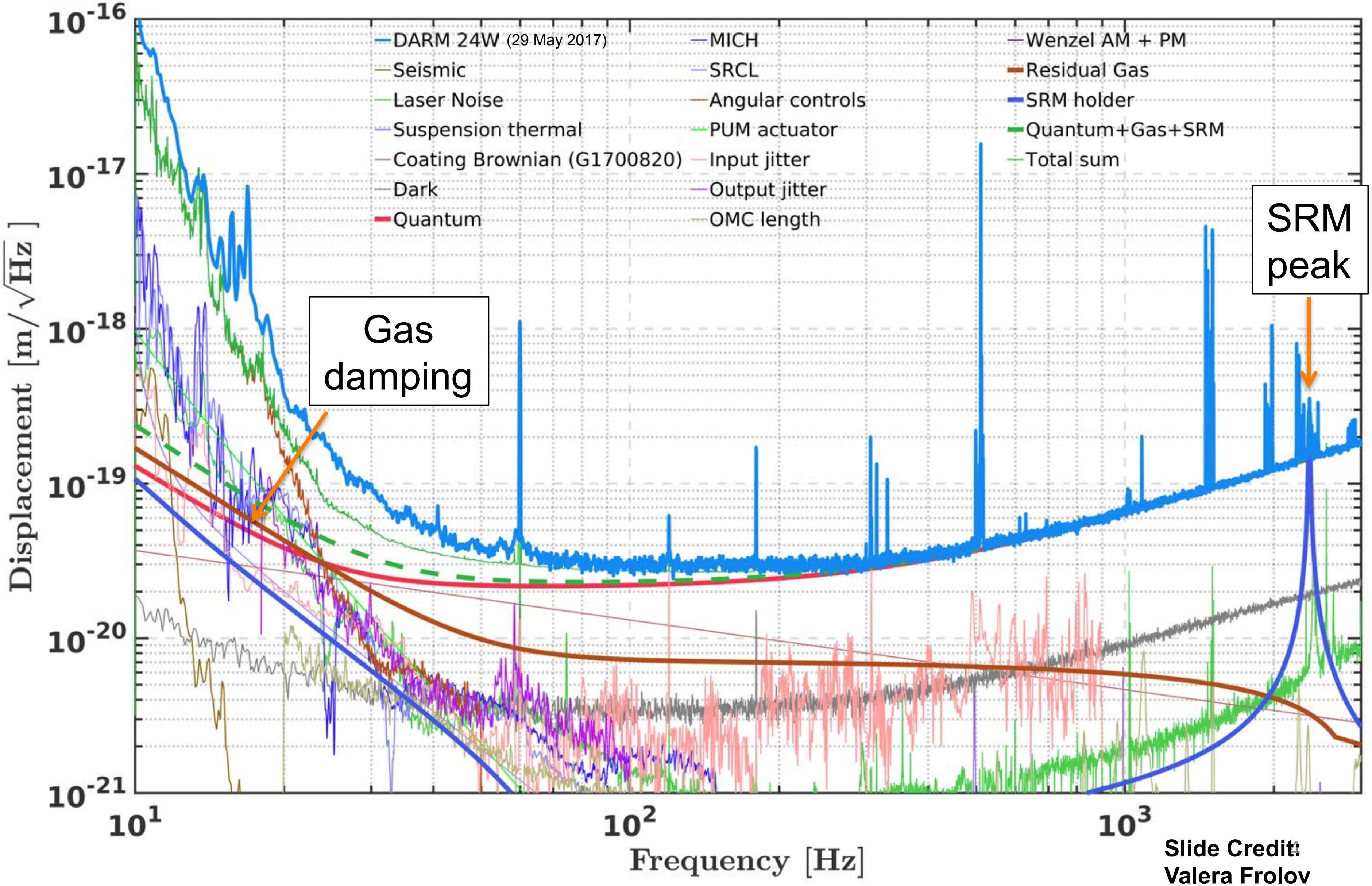
Roadmap to Design Sensitivity for Advanced LIGO

- Roadmap developed in 2013 by the LIGO Scientific Collaboration
  - Based on collective knowledge of LIGO’s Detector Science and Engineering Team ***at that time***



B. E. Abbott, et al., “Prospects for Observing and Localizing Gravitational-Wave Transients with Advanced LIGO and Advanced Virgo”, *Living Reviews in Relativity,* **https://link.springer.com/article/10.1007/lrr-2016-1**

L1 Noise Budget

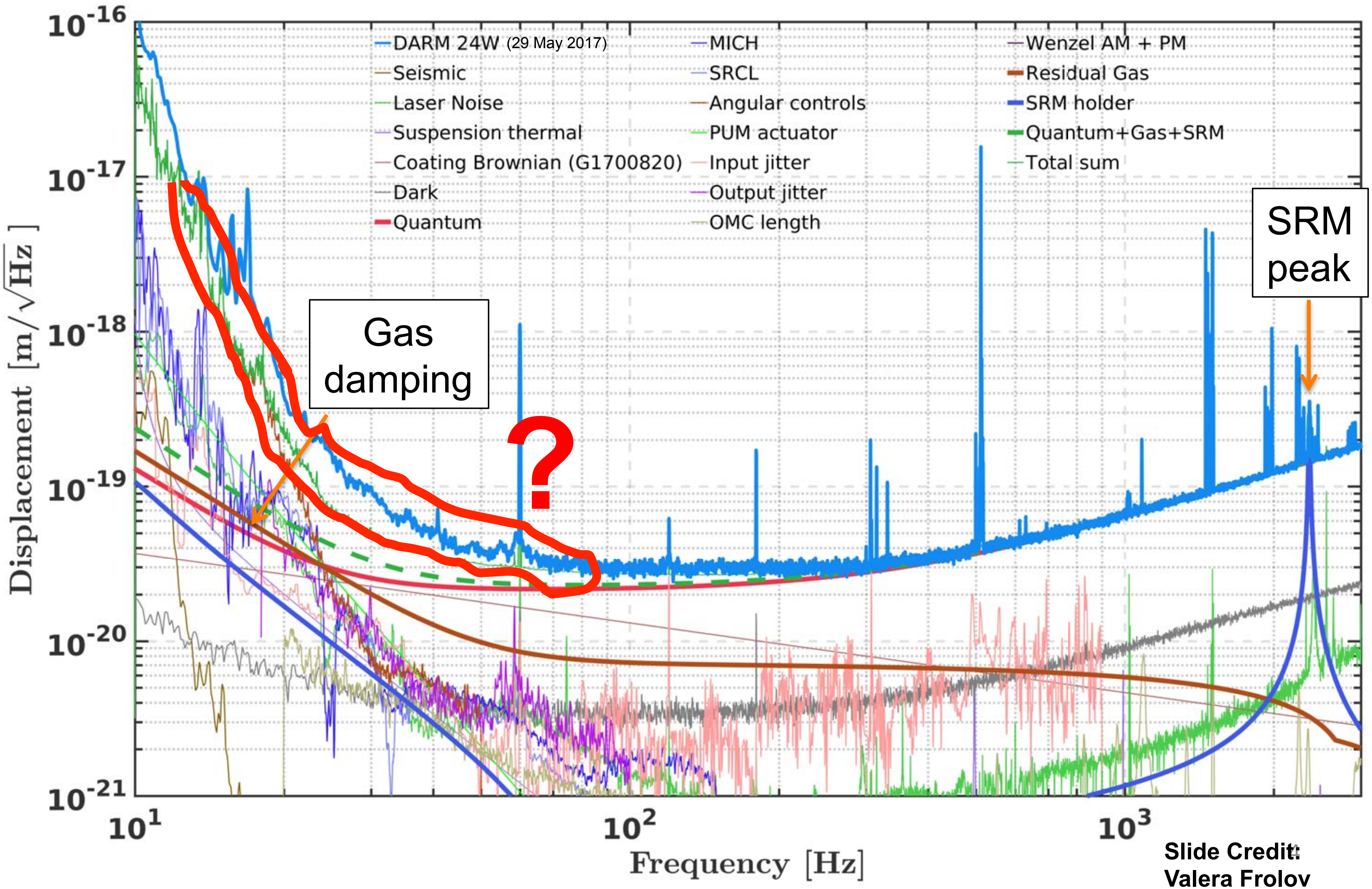


Gas damping

SRM peak

Slide Credit: Valera Frolov

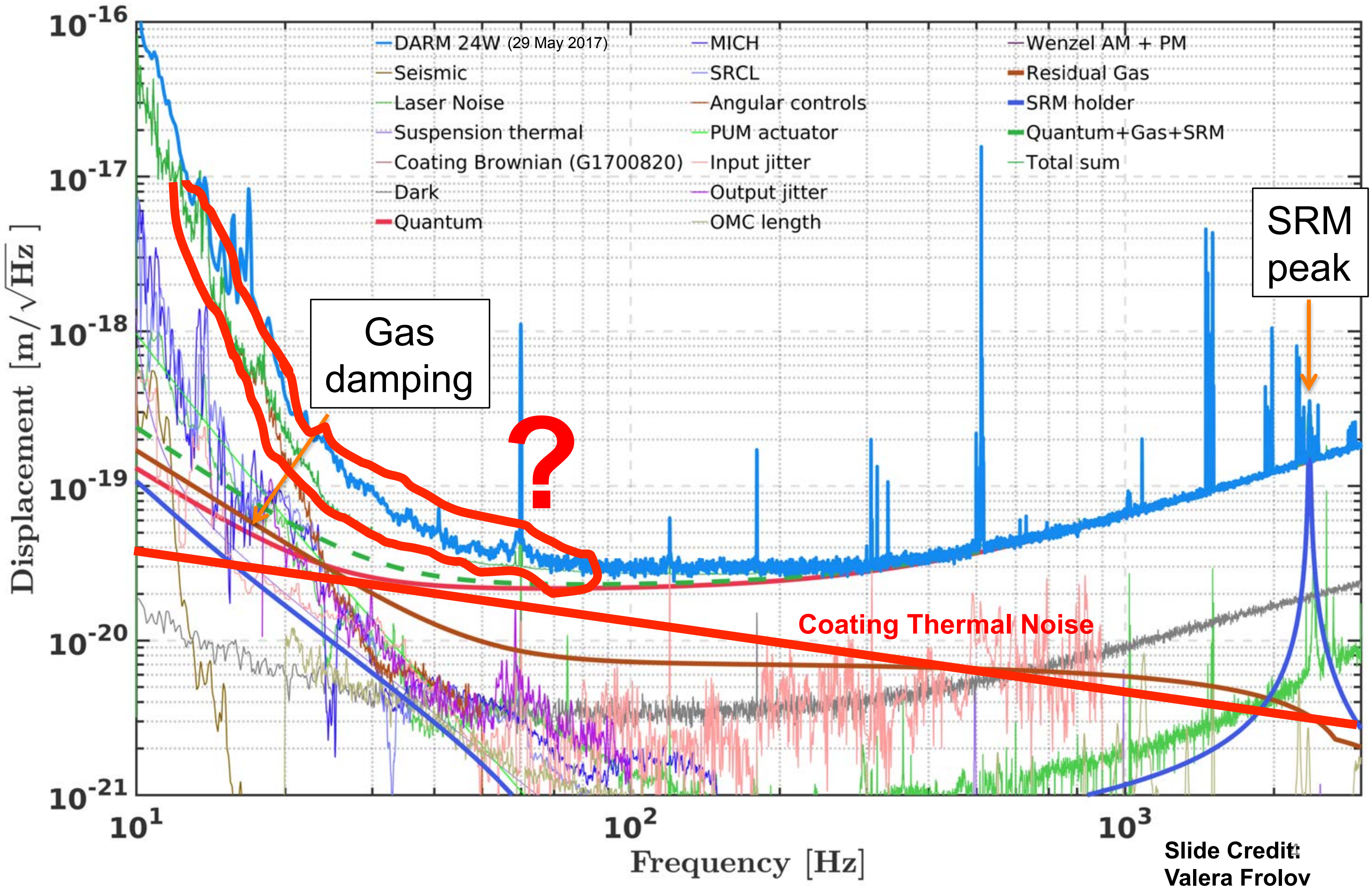
L1 Noise Budget



Slide Credit: Valera Frolov

LIGO

L1 Noise Budget



Gas damping

SRM peak

Coating Thermal Noise

Slide Credit:
Valera Frolov

‘Rogues Gallery’ of Possible Noises

- Bi-Linear coupling of length control system auxiliary loops to DARM
- Bi-Linear coupling of angular sensing and control system noise (> 10 Hz)
- Radiation pressure anomaly?
- Laser frequency noise (~bilinear)
- Laser amplitude noise (~bilinear)
- Audio RAM from electro-optic modulators
- Gas damping (between ERM and ETM)
- Penultimate mass coil driver electronics
- Correlated noise in output mode cleaner photodiodes
- Magnetic fields (~RF and baseband)
- Electric fields in main vacuum chambers
- Audio band vacuum chamber motion
- Downconversion of f > 100 kHz laser noise
- ‘Crackling’ mechanical noise in the blades of the test mass suspensions
- Excess thermal noise in the suspension monolithic stage (ears/fibers)
- Auxiliary optics coating noise
- Scattering from auxiliary vacuum chambers
- Backscatter from the arm beamtubes
- PUM coil driver electronics
- Backscatter from the end stations
- Upconversion of low frequency seismic motion
- Pointing/Intensity noise of TCS lasers

LIGO

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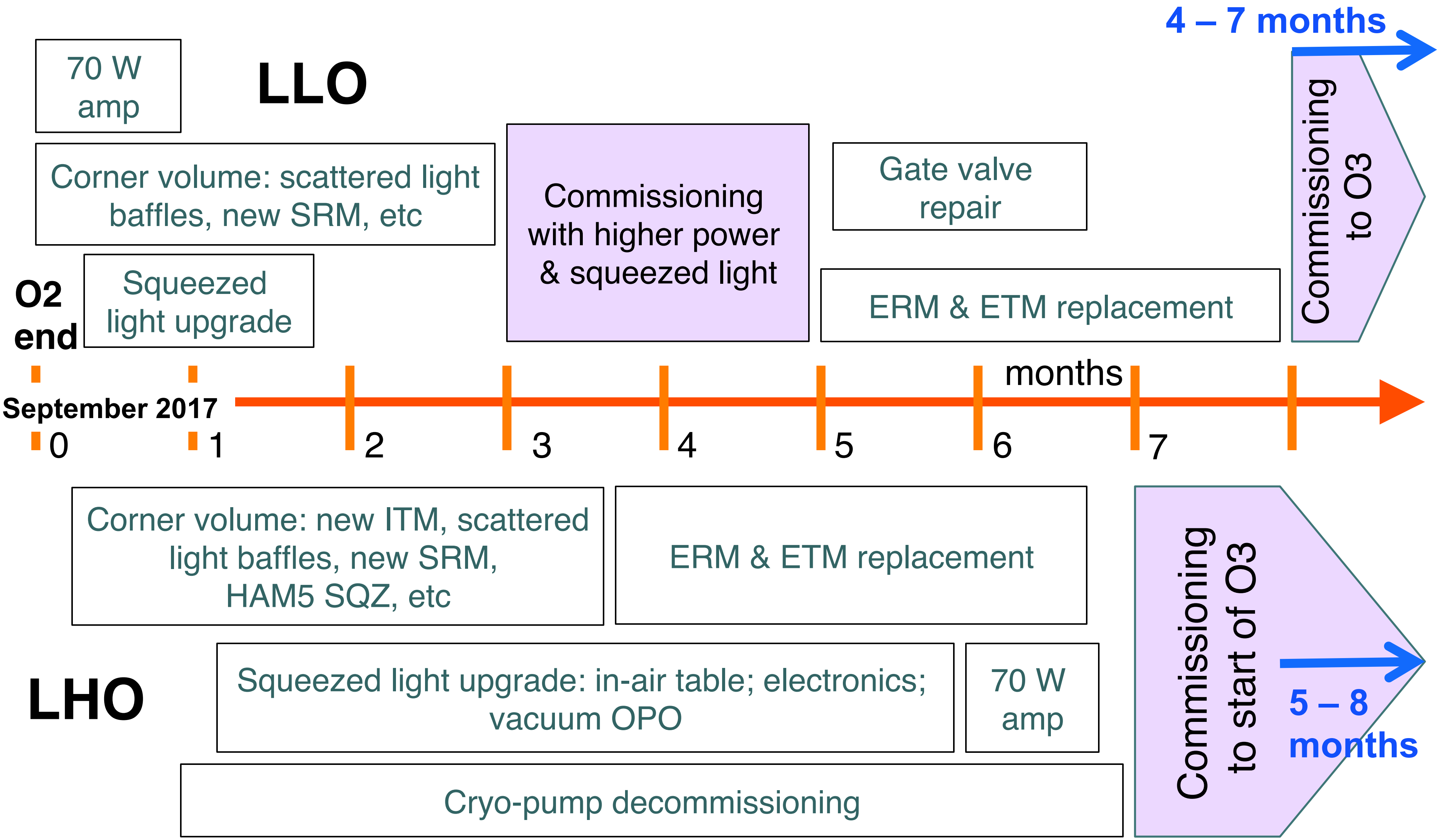
Major H1, L1 Work Planned for post-O2

- **Replace H1's ITMX** (excess absorption)
- **Squeezed Light injection at LLO**
  - Target is 3 dB of effective squeezing: equivalent to doubling the laser power
  - LHO will get the hardware as well; install & commissioning TBD
- **Scattered Light Control improvements & additions**
- **70 W laser amplifier stage**
  - LLO: allows doubling of O2 laser power
  - LHO: plan to move from the HPO to a 70 W amplifier as well
- **Replace End Reaction Masses w/ Annular versions**
  - Squeezed film damping; possibly electro-static charge
  - May also replace End Test Masses
- **Monolithic Signal Recycling Mirrors**
  - Remove several kHz peak in DARM; lower frequency impact?

The Road to O3 'Late aLIGO'



4 – 7 months

LLO

70 W amp

Corner volume: scattered light baffles, new SRM, etc

Squeezed light upgrade

Commissioning with higher power & squeezed light

Gate valve repair

ERM & ETM replacement

Commissioning to O3

O2 end

September 2017

months

0 1 2 3 4 5 6 7

Corner volume: new ITM, scattered light baffles, new SRM, HAM5 SQZ, etc

ERM & ETM replacement

LHO

Squeezed light upgrade: in-air table; electronics; vacuum OPO

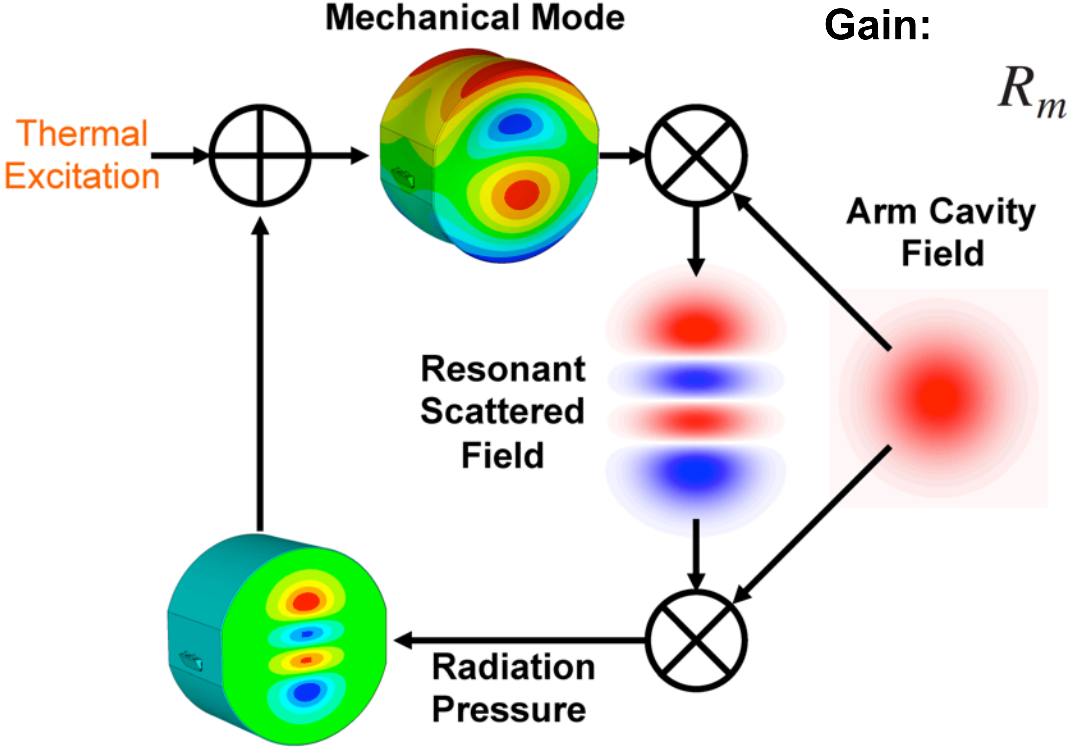
70 W amp

Cryo-pump decommissioning

Commissioning to start of O3

5 – 8 months

Problems with High Laser Power: Parametric Instability



Parametric Gain:

$$R_m = \frac{8\pi Q_m P_{\text{arm}}}{M\omega_m^2 c\lambda}\sum_{n=0}^{\infty}\mathrm{Re}[G_n]B_{m,n}^2$$

mechanical mode Q-factor

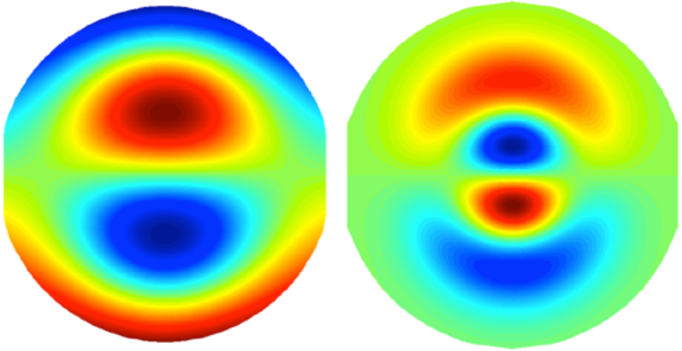
power in the arm cavity

spatial overlap Optical-mechanical mode

Mirror mass

Acoustic mode frequency

optical mode gain



Acoustic mode f_m = 15,539 Hz

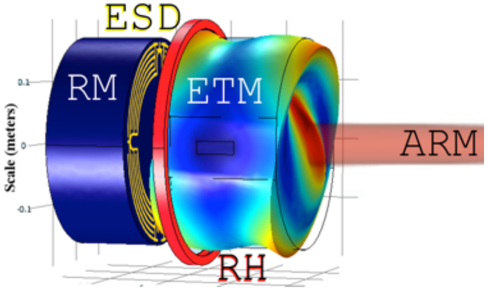
Optical mode

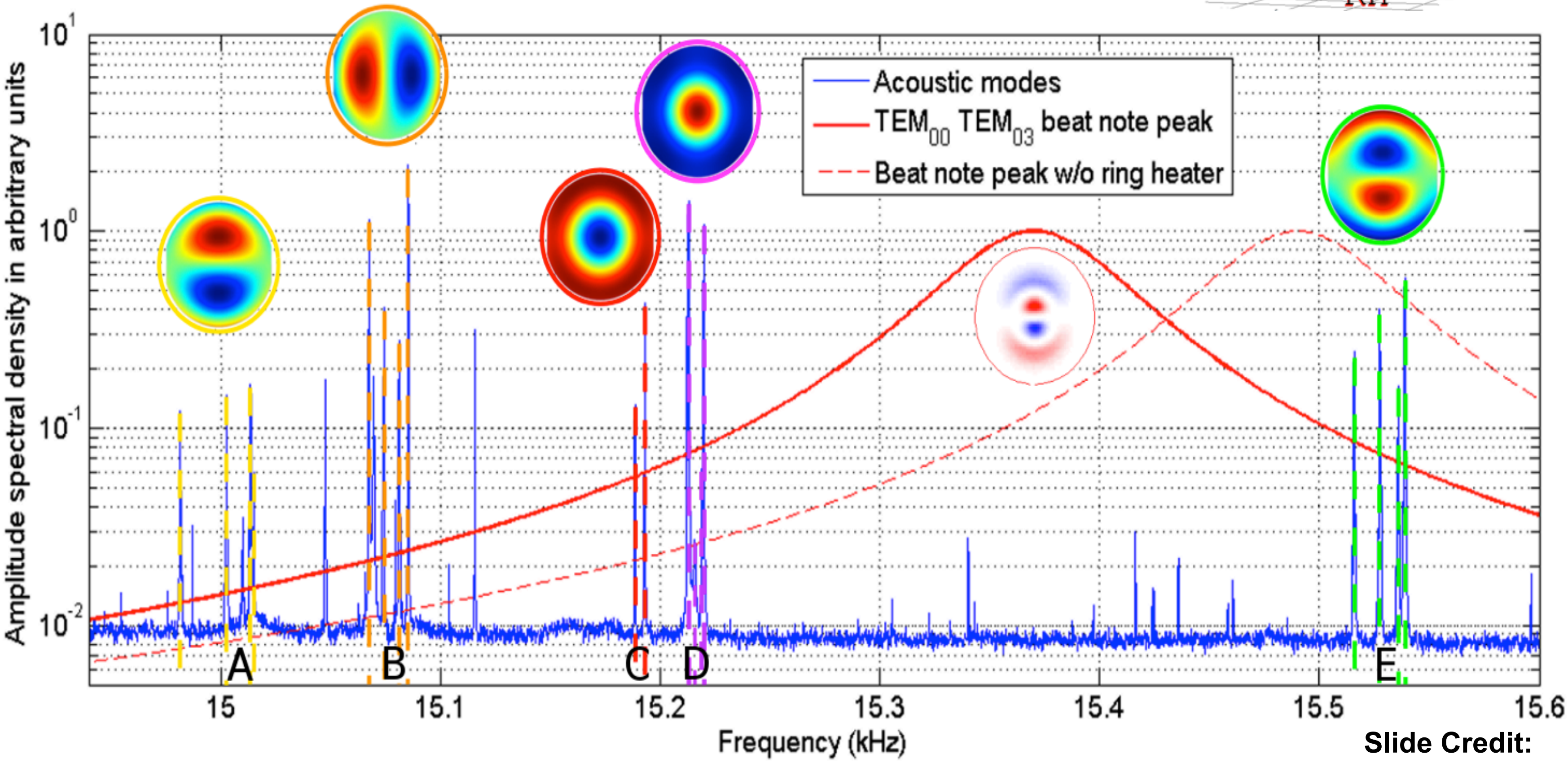
Theory: V. B. Braginsky, S. E. Strigin, and S. P. Vyatchanin, Phys. Lett. A **305**, 111 (2002)
Experiment: C. Zhao, L. Ju, J. Degallaix, S. Gras, and D. G. Blair,
Phys. Rev. Lett. 94, 121102 (2005); M. Evans, et al., “Observation of Parametric Instability in Advanced LIGO”, Phys. Rev. Lett. **114**, 161102 (2015).

Passive Damping of Parametric Instabilities

Thermal tuning of the Test Mass Radii of Curvature

LLO: ring heaters tuned to ‘sweet spot’ (low PI mode density)

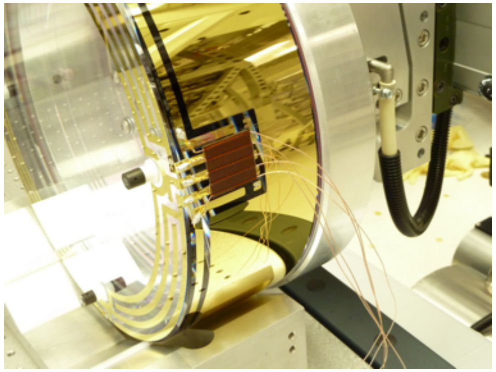




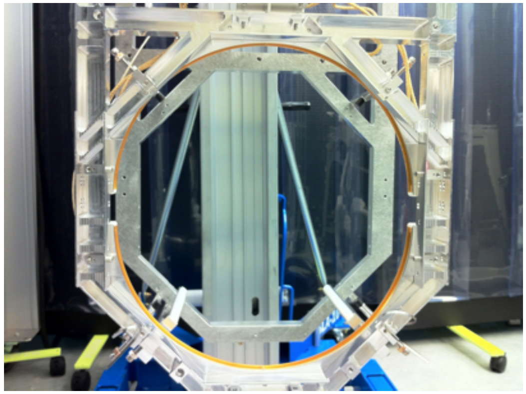
Slide Credit: **Terra Hardwick**

Active Damping of Parametric Instabilities

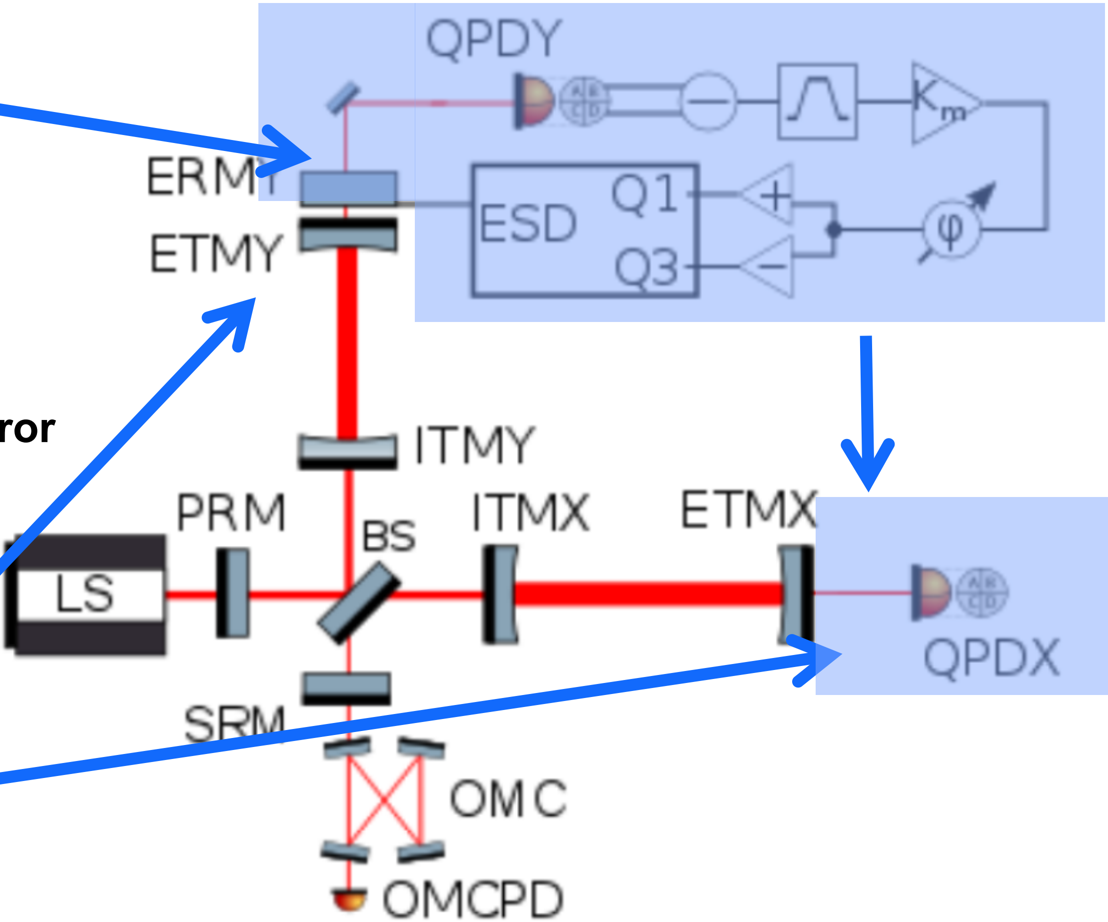
End Reaction Mass (X, Y arms)



Passive Thermal Tuning of the Mirror Radii of curvature via Ring Heater



Active Electrostatic Damping of PI modes

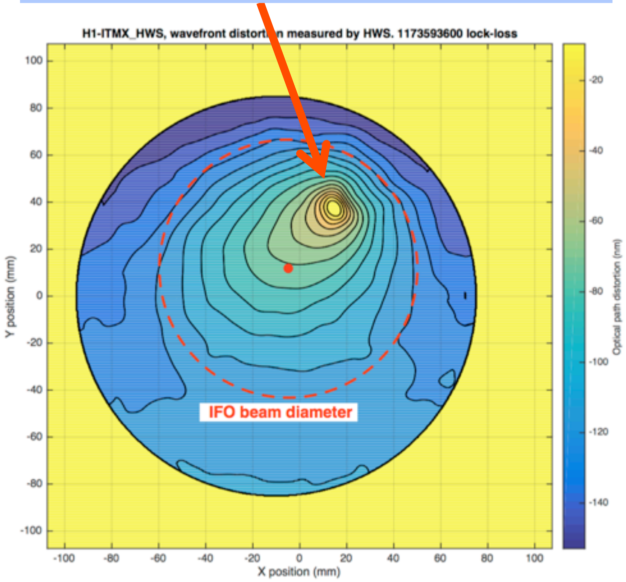


In O2, 4 modes are actively damped (130 kW in the arm cavities)
At 50 W, 10 modes are actively damped (200 kW in the arm cavities)
Challenge: Going beyond 200 kW will require new methods (passive acoustic mass dampers)

H1's ITM-X: Excess Absorption

March 2017: discovered small absorber on H1's ITM-X high reflecting surface

60 nm distortion over 20 mm



Hartman wavefront sensor image

Small absorber, ~ 15 mW absorbed (out of 130 kW arm power)

Results in phase front distortion negatively impacting:

- RF sideband build-up
- Alignment sensing
- Noise couplings
- Higher-order mode jitter

Vented in May 2017 to **inspect** and **clean**

Absorber remained, so ITMX replacement is being planned for post-O2

Slide Credit: Peter Fritschel

Quantum Engineering 'Squeezed' Light for O3

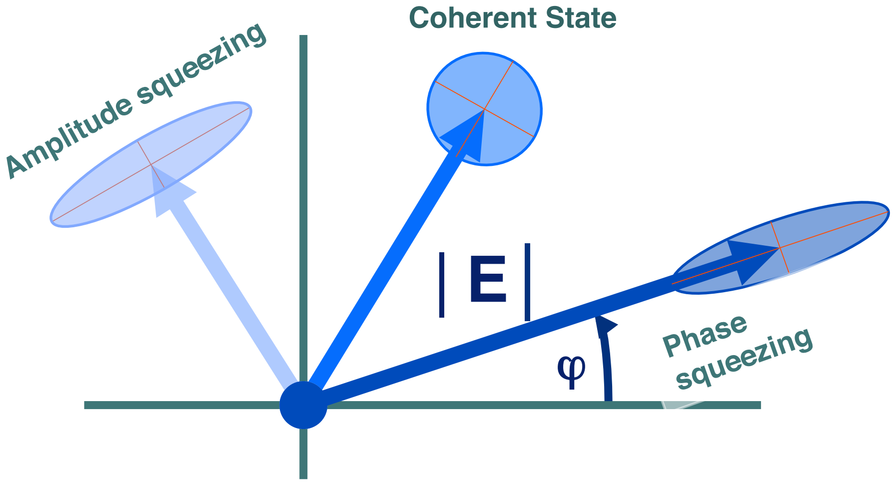
- **Electromagnetic fields are quantized:**

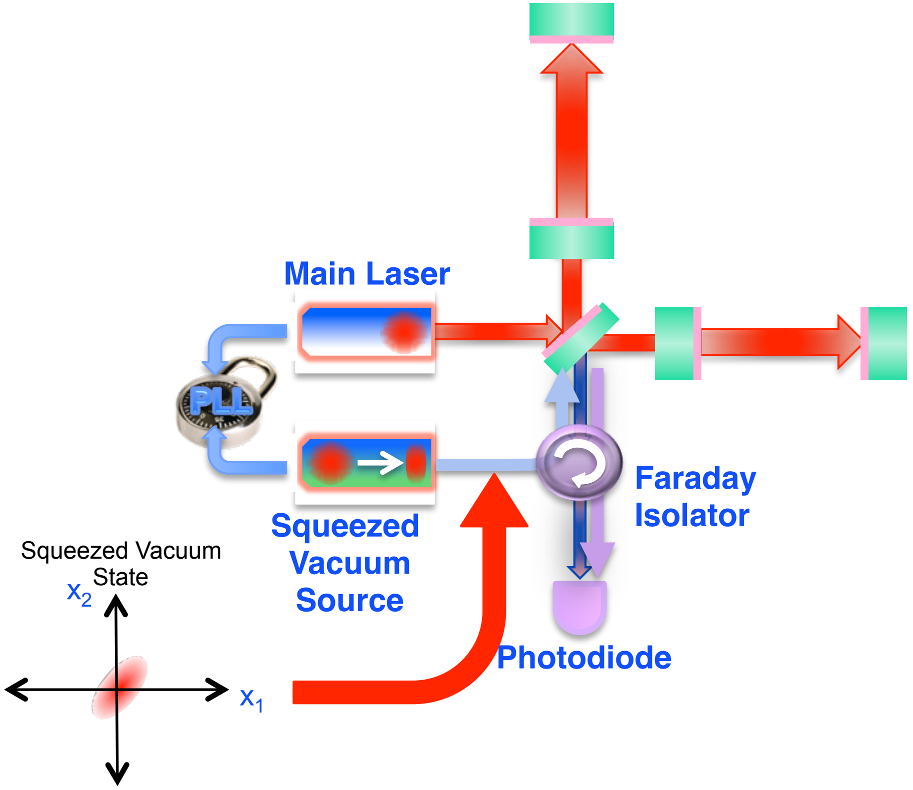
$$\hat{E} = \hat{X}_1 \cos\omega t + i\hat{X}_2 \sin\omega t$$

- **Quantum fluctuations exist in the vacuum state:**

$$\langle(\Delta\hat{X}_1)^2\rangle\,\langle(\Delta\hat{X}_2)^2\rangle \geq 1$$

H. P. Yuen, Phys. Rev. A**13**, 2226 (1976)
C. M. Caves, Phys. Rev. D**26**, 1817 (1982)
Wu, Kimble, Hall, Wu, PRL (1986)





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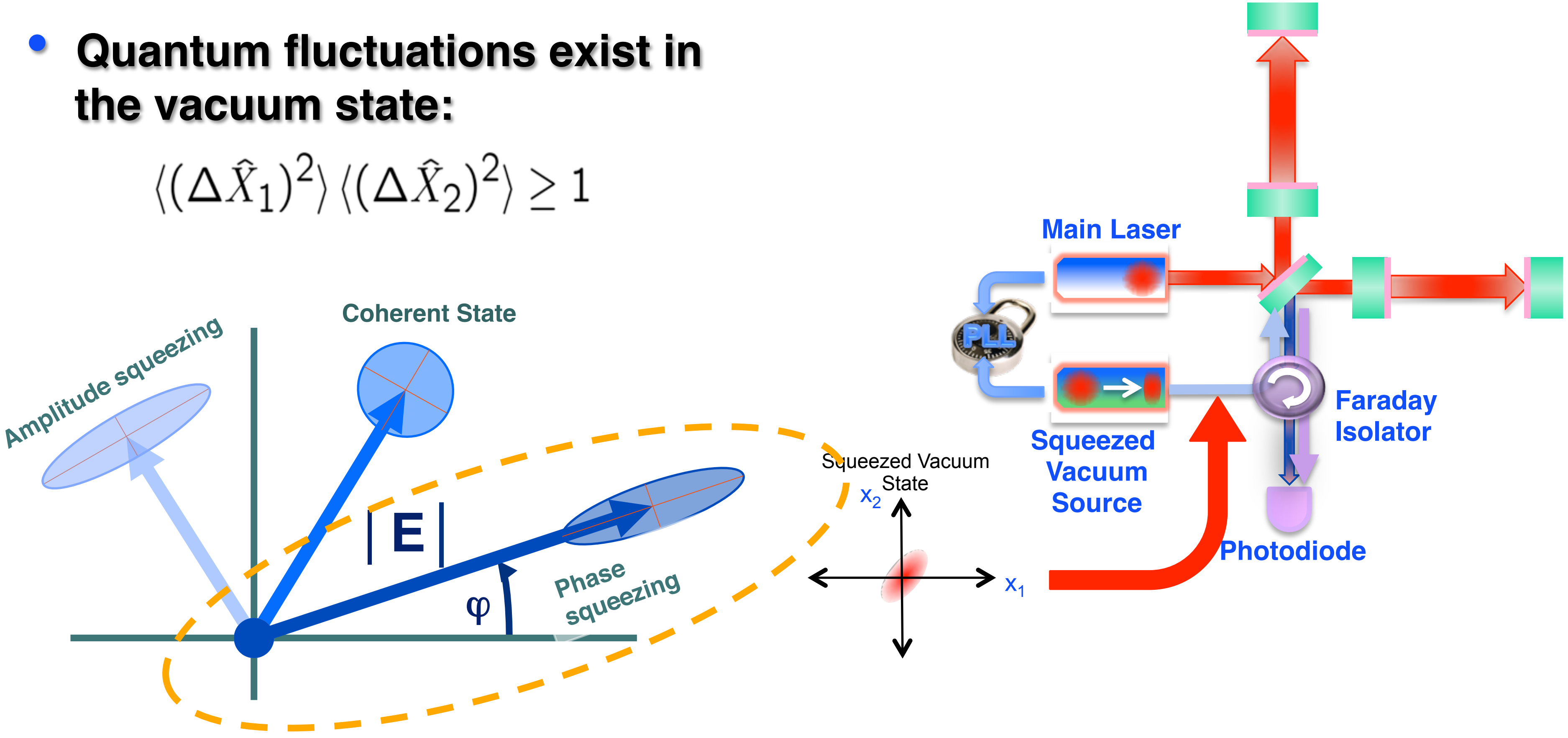

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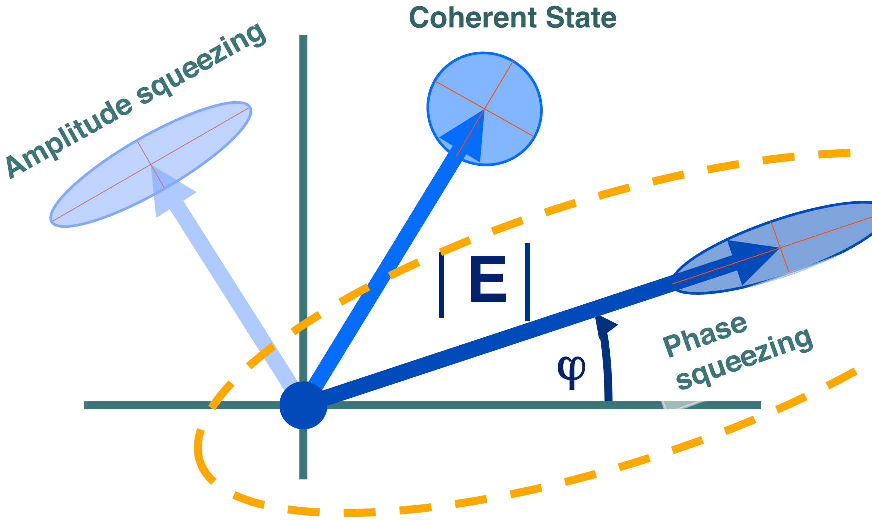
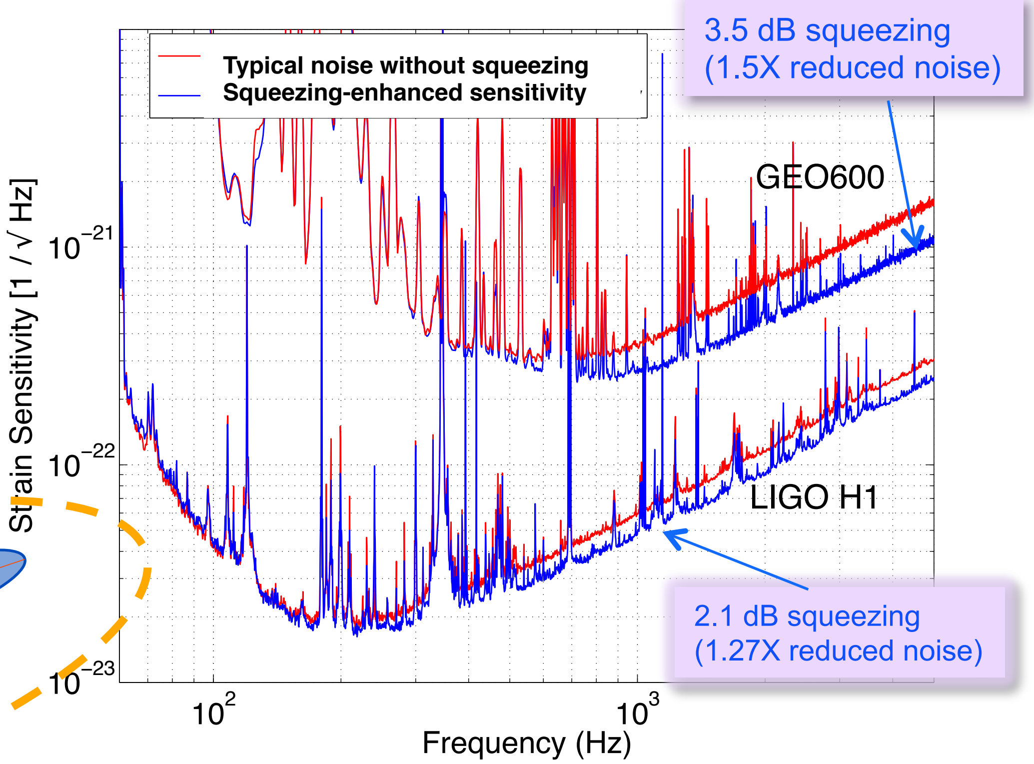
Wu, Kimble, Hall, Wu, PRL (1986)



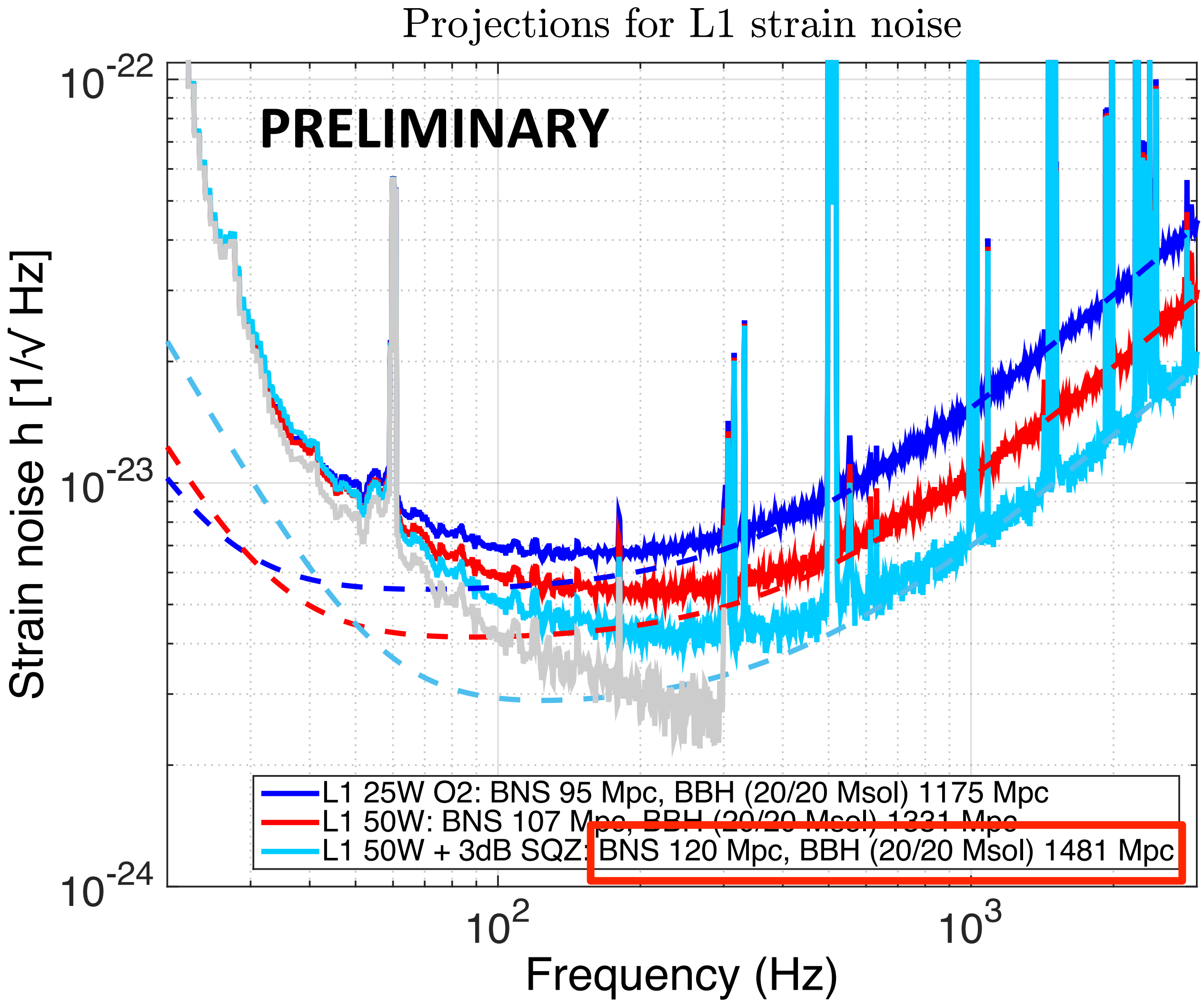


3.5 dB squeezing (1.5X reduced noise)

2.1 dB squeezing (1.27X reduced noise)

Aasi, et al., (LIGO Scientific Collaboration), Nature Physics, **7**, 962 (2011); Nature Photonics **7** 613 (2013).

Squeezed Light Sensitivity Improvement



x2 Higher power
or
3 dB squeezing

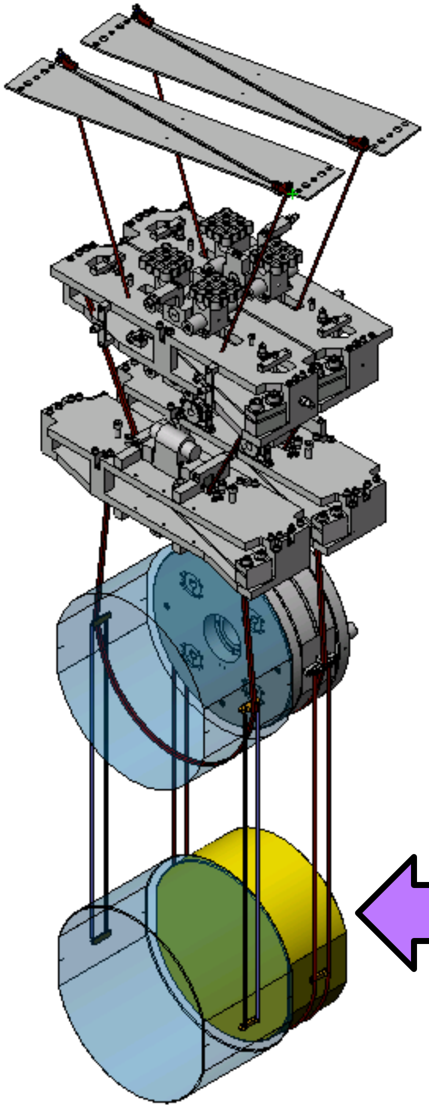
x2 Higher power
+ squeezing

No further reduction of low frequency noise assumed in this plot

Slide Credit:
Peter Fritschel

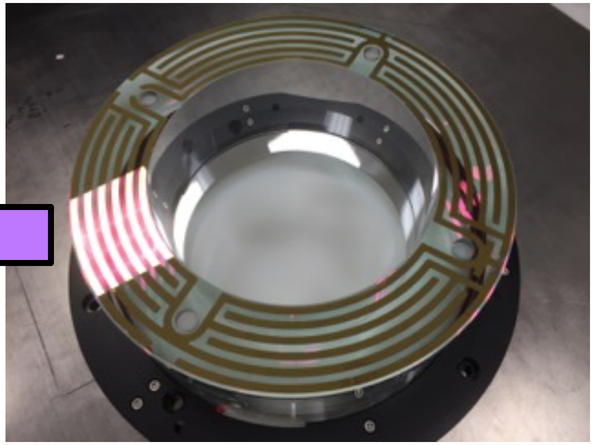
Annular End Reaction Masses

- The current end reaction masses are solid cylinders
    - Gap spaced 5 mm from the end test mass
- 'Squeezed film' gas damping is non-negligible
    - Will be a limit assuming existing tank pressure; but could be a limiting noise source now



Same electro-static force as current ERM

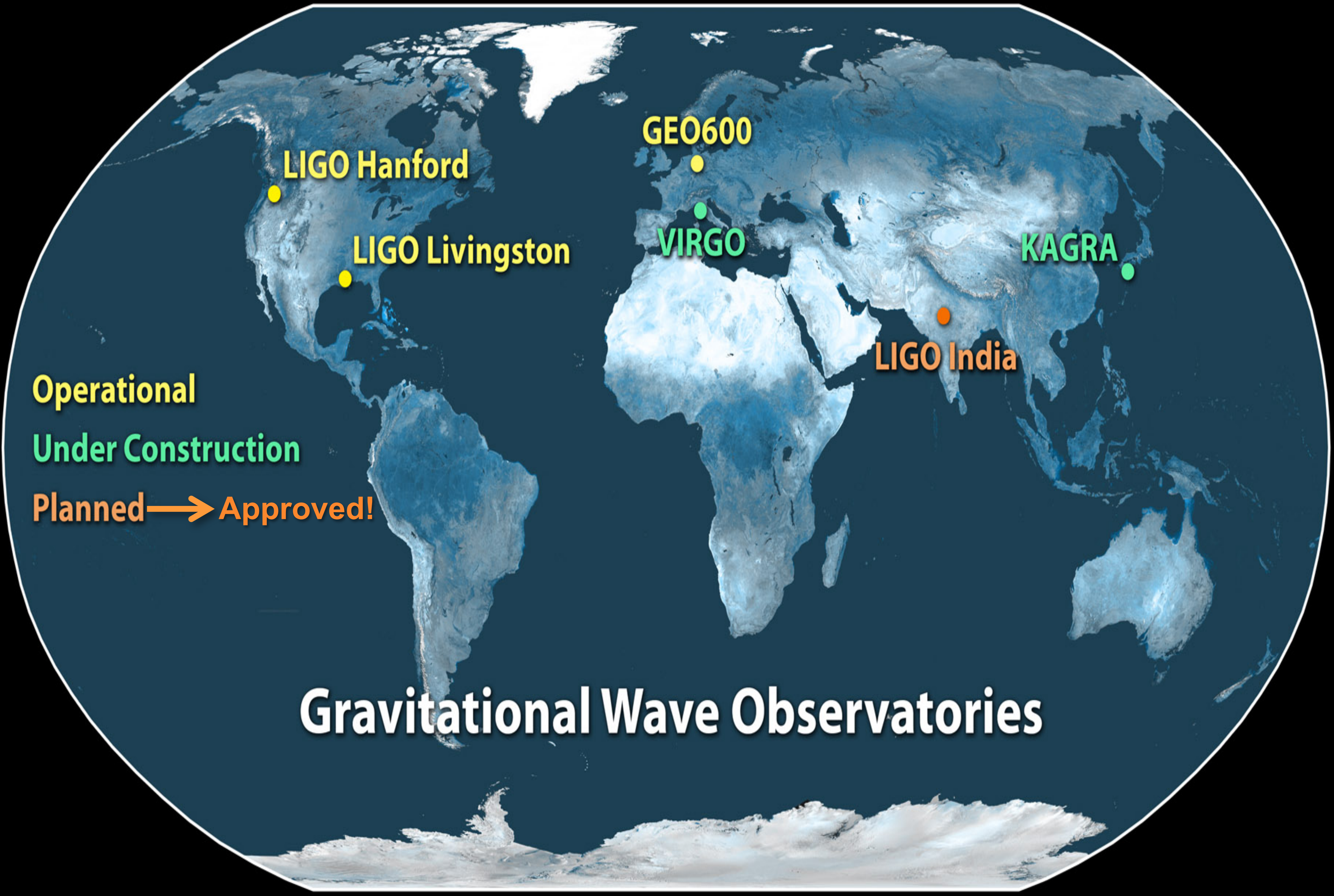
Annular ERM



Slide Credit: Peter Fritschel

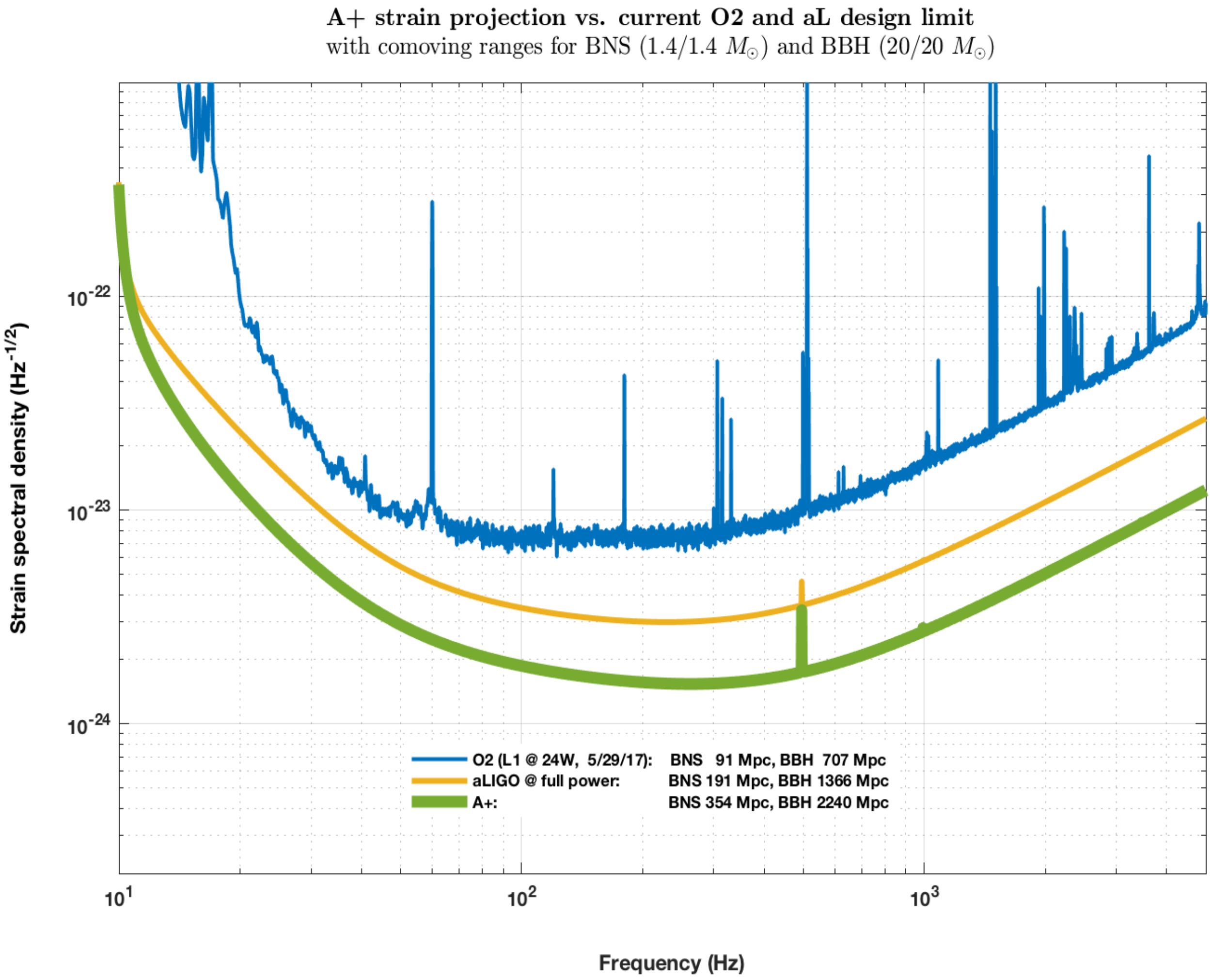
Beyond Advanced LIGO:
The A+ Upgrade
2020-2025

Gravitational Wave Observatories



A+: a Mid-Life Enhancement for Advanced LIGO

- Near term: ‘A+’, a mid-scale upgrade of Advanced LIGO
  - Improvements across all bands
- Projected time scale for A+ operation: 2023 - 2025



Why A+?

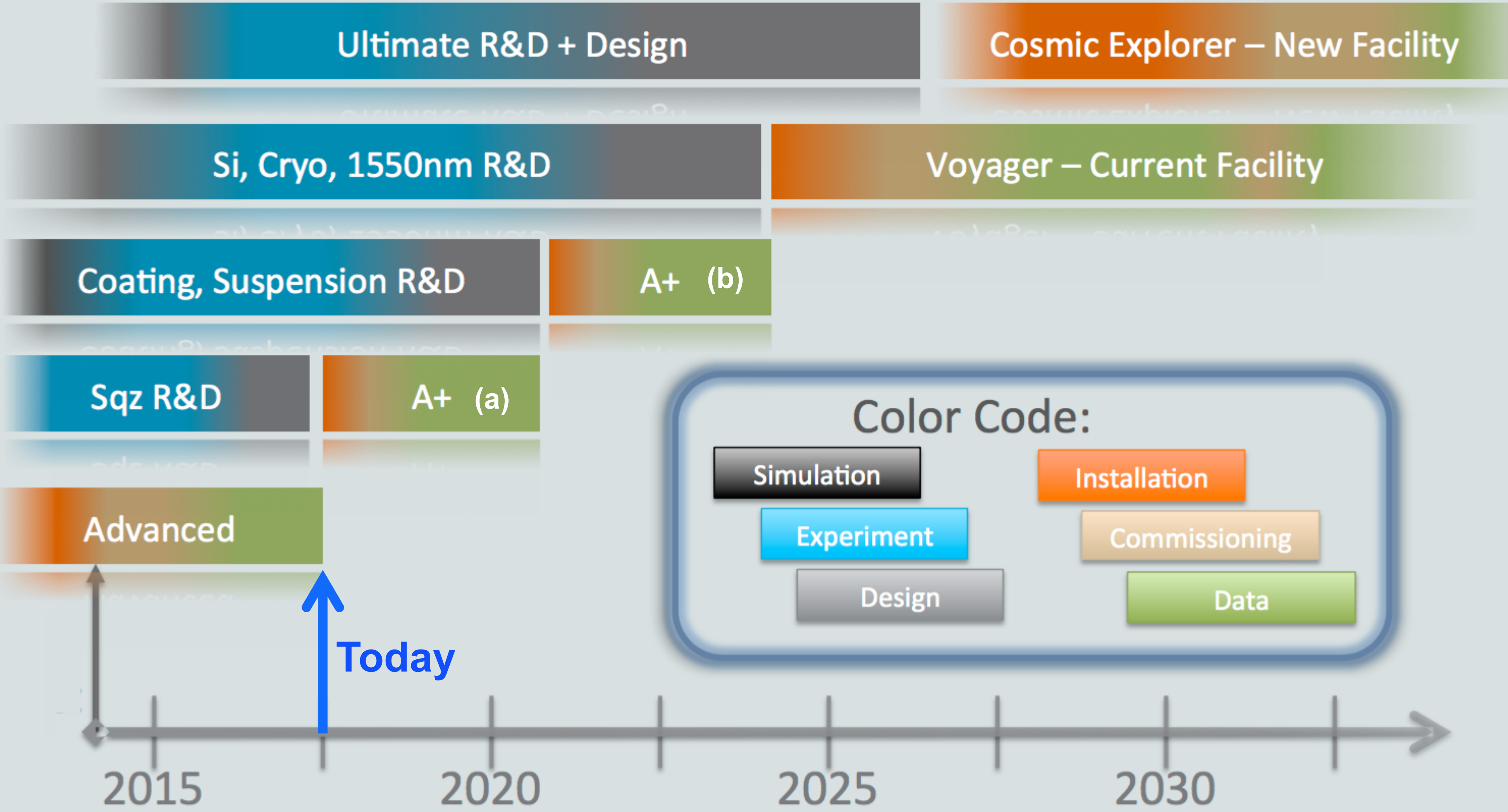
- An incremental upgrade to aLIGO *that can happen in the next 5-7 years*
- A+ leverages existing technology and infrastructure, with minimal new investment, and moderate risk
- Target improvement: factor of 1.7* increase in range over aLIGO

  → ***About a factor of 5 greater CBC event rate***
- Stepping stone to 3G detector technology
- Can be observing within 5 years (possibly late 2022)
- "Scientific breakeven" within 1/2 year of operation
- Incremental cost: *a small increment of the aLIGO cost*

***BBH 20/20 $M_{\odot}$:**	**1.64x**
***BNS 1.4/1.4 $M_{\odot}$:**	**1.85x**

Conceptual LIGO Upgrade Timeline

LSC Instrument Science White Paper 2016-2017, LIGO-T1600119–v4



Ultimate R&D + Design

Cosmic Explorer – New Facility

Si, Cryo, 1550nm R&D

Voyager – Current Facility

Coating, Suspension R&D

A+ (b)

Sqz R&D

A+ (a)

Advanced

Today

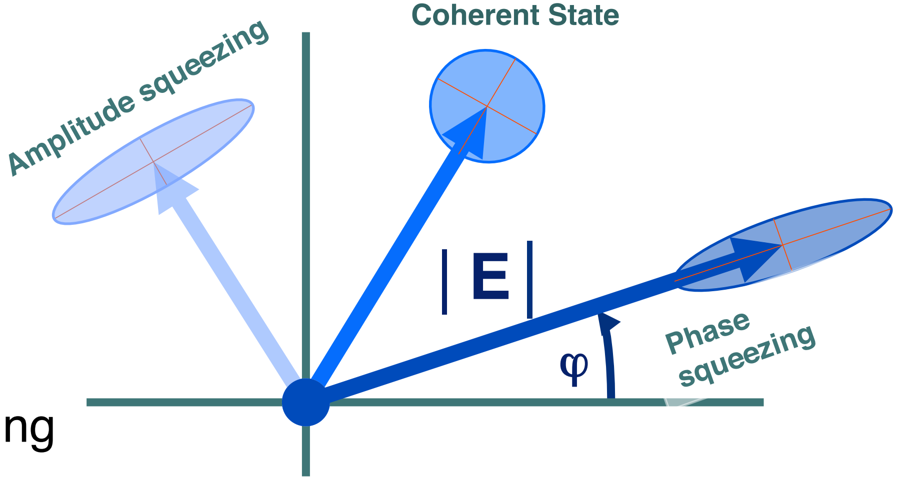
Color Code:

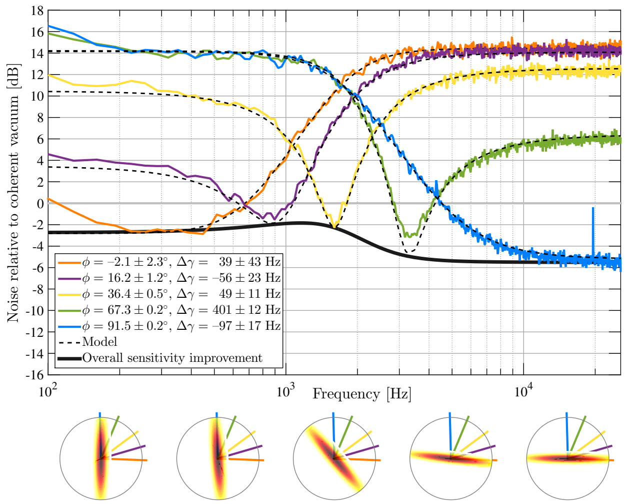
- Simulation
- Experiment
- Design
- Installation
- Commissioning
- Data

LIGO Summary of Major A+ Upgrades

Key A+ parameters:

- Frequency-dependent squeezing
  - Phase squeezing at high frequencies; amplitude squeezing at low frequencies
- 12dB injected squeezing
  - 15% readout loss
- 100 m filter cavity
  - 20 ppm round trip filter cavity loss
- Coating thermal noise half of aLIGO





Oelker, et al., “Audio-band Frequency-dependent Squeezing”, Phys. Rev. Lett. **116**, 041102 (2016).

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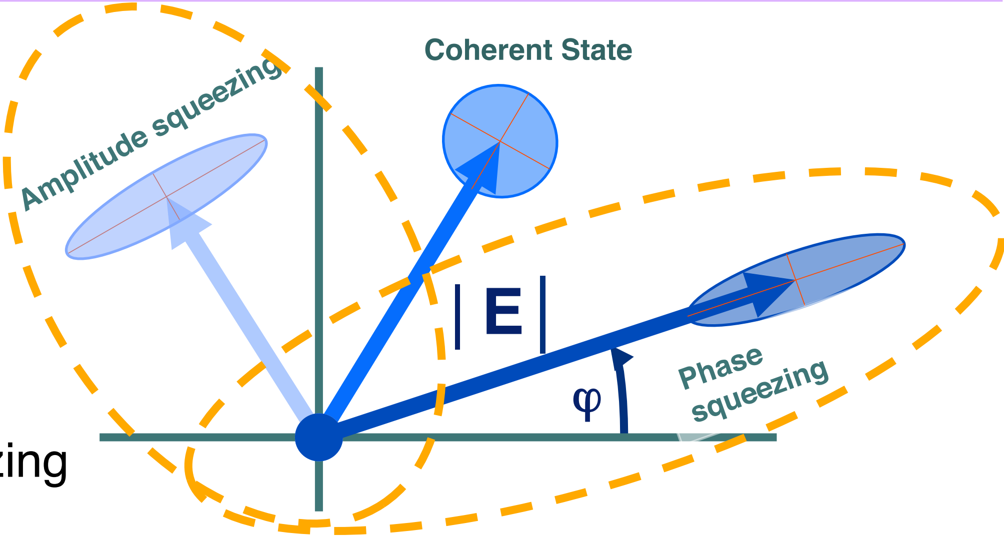
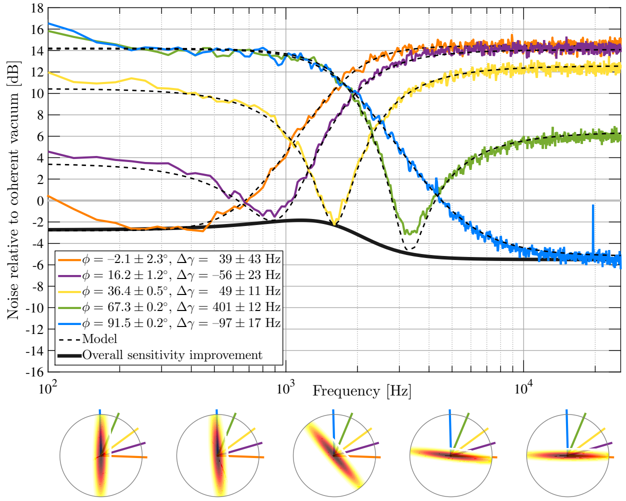
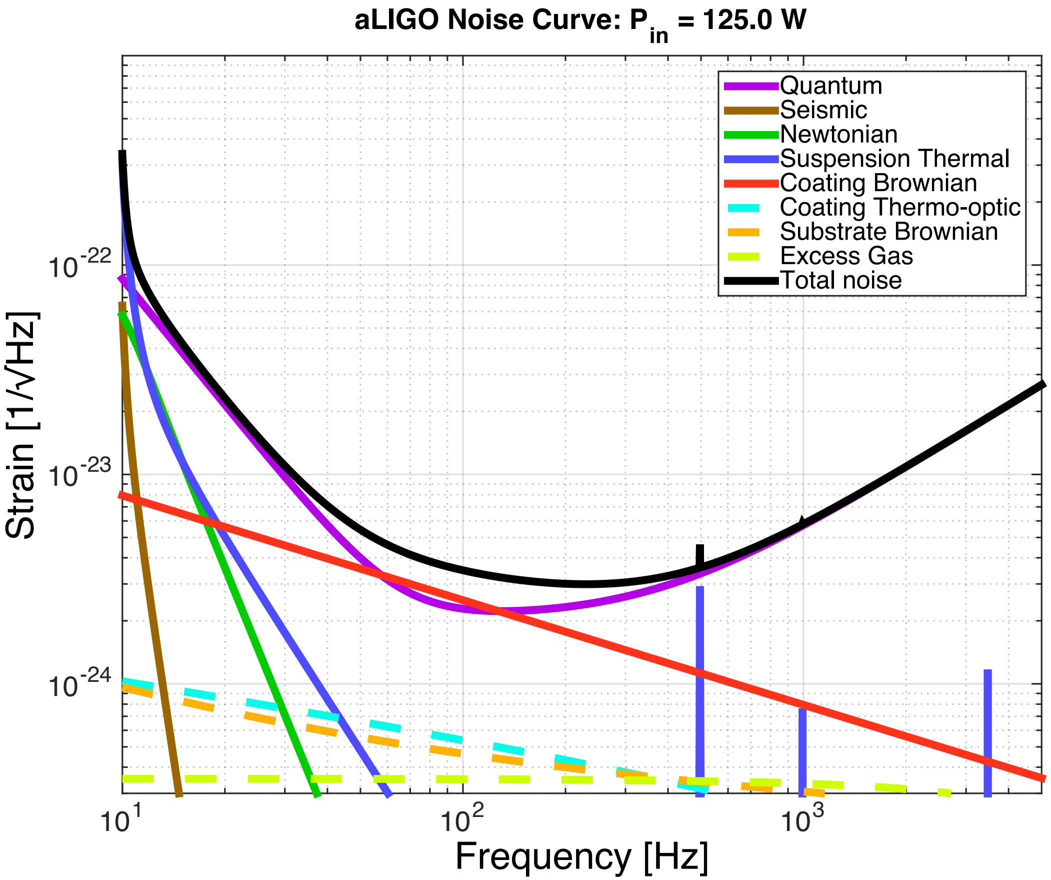




Oelker, et al., "Audio-band Frequency-dependent Squeezing", Phys. Rev. Lett. **116**, 041102 (2016).

What can be improved?
aLIGO limiting noise at full power



ALIGO Parameters:

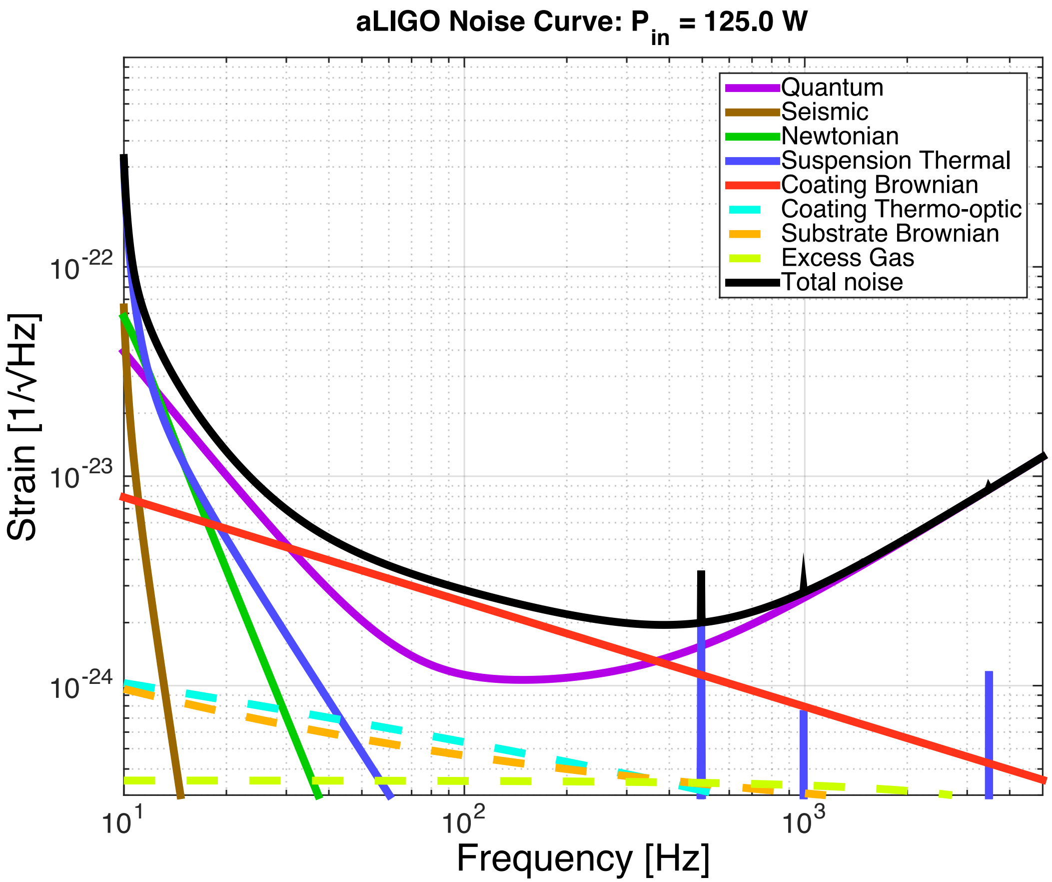
Laser Power: 125.00 Watt
SRM Detuning: 0.00 degree
SRM transmission: 0.3500
ITM transmission: 0.0140
PRM transmission: 0.0300
Finesse: 446.41
Power Recycling Factor: 40.54
Arm power: 710.81 kW
Power on beam splitter: 5.07 kW
Thermal load on ITM: 0.385 W
Thermal load on BS: 0.051 W

ALIGO Astrophysics:

BNS range: 191.04 Mpc (comoving)
BNS horizon:436.32 Mpc (comoving)
BNS reach: 272.08 Mpc (comoving)
BBH range: 1.37 Gpc (comoving, z = 0.3)
BBH horizon: 3.24 Gpc (comoving, z = 0.9)
BBH reach: 2.12 Gpc (comoving, z = 0.5)
Stochastic Omega: 2.42e-09

Slide Credit:
Mike Zucker

..plus squeezing with ~100m scale filter cavity



A+ Parameters with Squeezing:

Laser Power: 125.00 Watt
SRM Detuning: 0.00 degree
SRM transmission: 0.3500
ITM transmission: 0.0140
PRM transmission: 0.0300
Finesse: 446.41
Power Recycling Factor: 40.54
Arm power: 710.81 kW
Power on beam splitter: 5.07 kW
Thermal load on ITM: 0.385 W
Thermal load on BS: 0.051 W

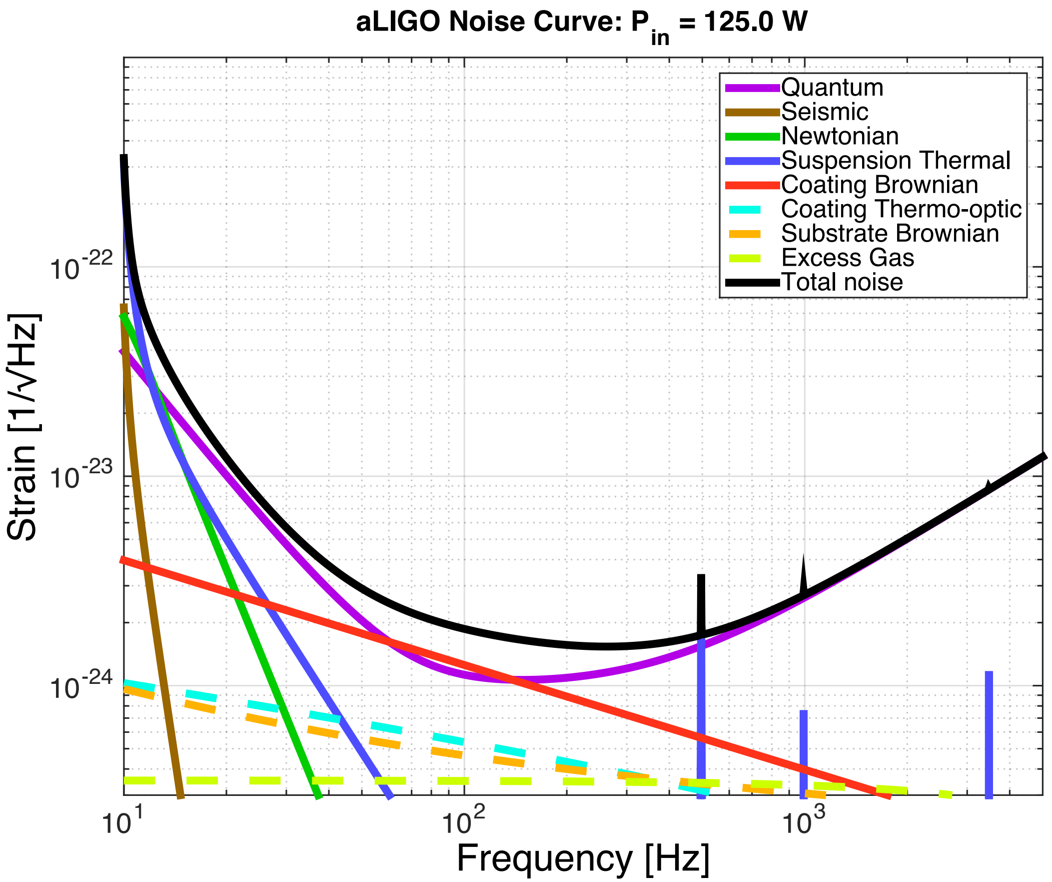
A+ Astrophysics with Squeezing:

BNS range: 258.72 Mpc (comoving)
BNS horizon: 592.49 Mpc (comoving)
BNS reach: 370.29 Mpc (comoving)
BBH range: 1.74 Gpc (comoving, z = 0.4)
BBH horizon: 4.14 Gpc (comoving, z = 1.3)
BBH reach: 2.77 Gpc (comoving, z = 0.5)
Stochastic Omega: 9.32e-10

LIGO-G1701020

Slide Credit:
Mike Zucker

..plus coating thermal noise reduction



<u>A+ Parameters with Squeezing/CTN:</u>

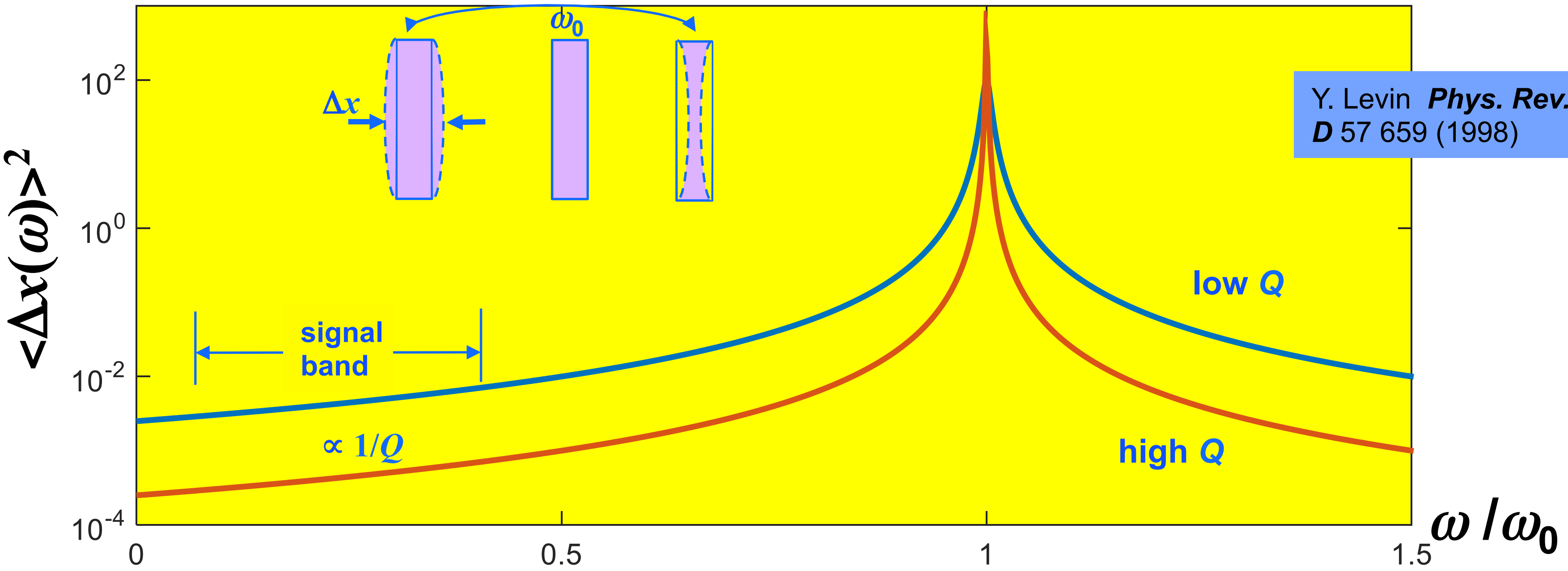
Laser Power: 125.00 Watt
SRM Detuning: 0.00 degree
SRM transmission: 0.3500
ITM transmission: 0.0140
PRM transmission: 0.0300
Finesse: 446.41
Power Recycling Factor: 40.54
Arm power: 710.81 kW
Power on beam splitter: 5.07 kW
Thermal load on ITM: 0.385 W
Thermal load on BS: 0.051 W

<u>A+ Astrophysics with Squeezing/CTN:</u>

BNS range: 354.06 Mpc (comoving)
BNS horizon: 814.04 Mpc (comoving)
BNS reach: 510.28 Mpc (comoving)
BBH range: 2.24 Gpc (comoving, z = 0.6)
BBH horizon: 4.14 Gpc (comoving, z = 2.1)
BBH reach: 2.77 Gpc (comoving, z = 1.1)
Stochastic Omega: 6.78e-10

Slide Credit:
Mike Zucker

Challenge: Thermal Noise in Optical Coatings



Y. Levin **Phys. Rev. D** 57 659 (1998)

- Simple picture: kT of energy per mechanical mode, viscous damping
- For coating dominated noise and structural damping:

coating thickness

coating elastic loss

$$S_x(f,T) \approx \frac{2k_BT}{\pi^2 f}\frac{d}{w^2Y}\phi\left(\frac{Y'}{Y}+\frac{Y}{Y'}\right)$$

beam radius

$$\phi_{\mathrm{TiO_2:Ta_2O_5}} = 2\times10^{-4}$$
$$\phi_{\mathrm{SiO_2}} = 4\times10^{-5}$$

Compare: Bulk Silica $\phi \sim 10^{-6}$-10^{-8}

Slide Credit:
Marty Fejer

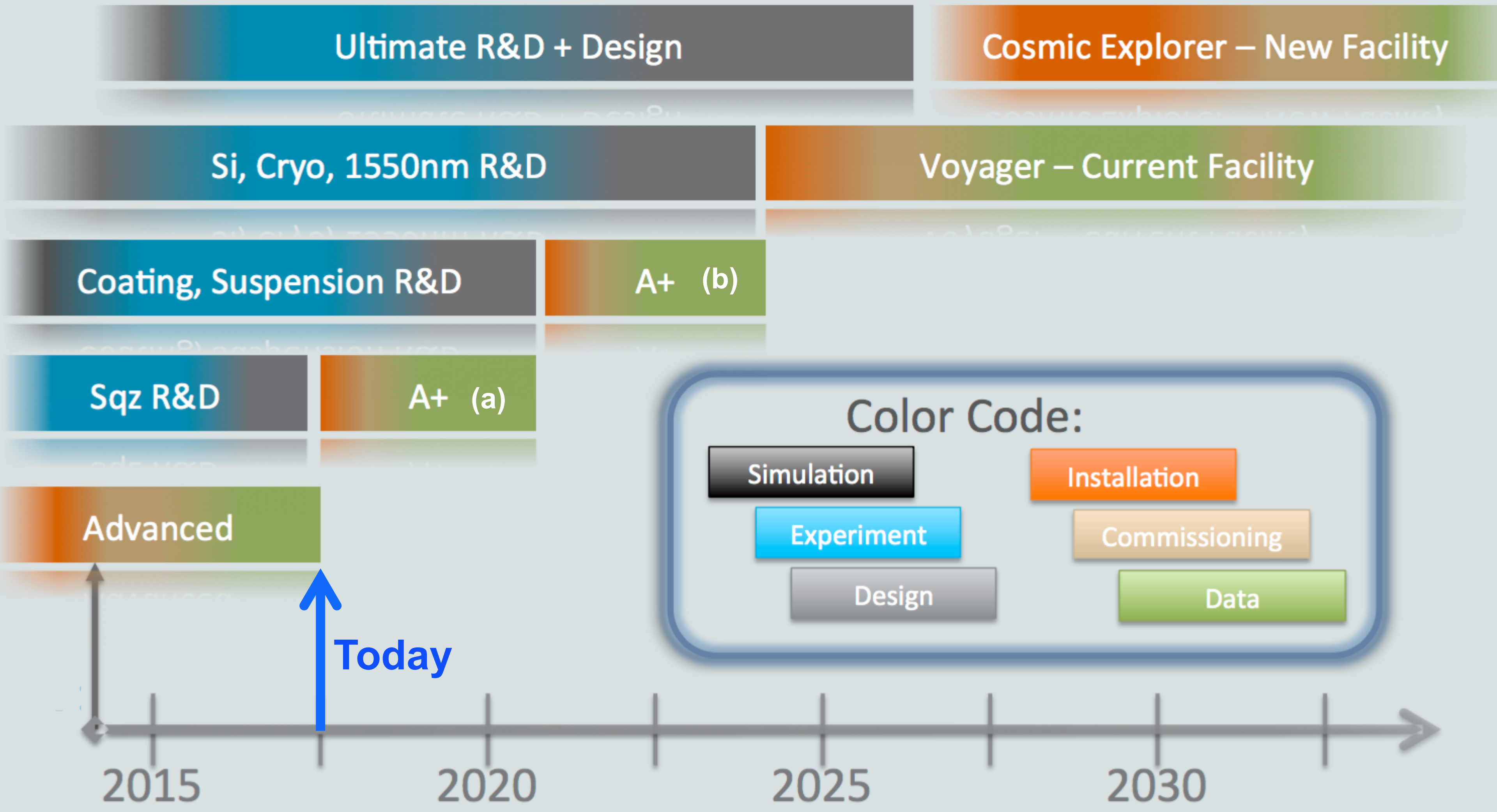
Probing the Horizons of the Gravitational-wave Universe:

Voyager & Cosmic Explorer

2025 - 2035+

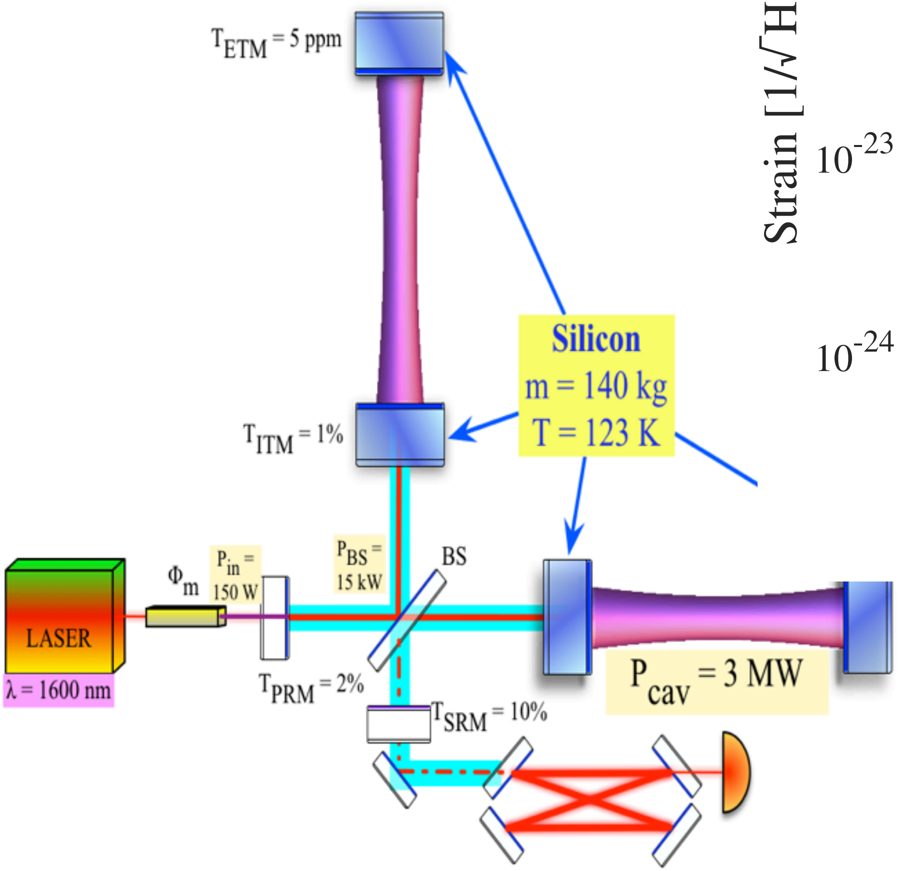
Conceptual LIGO Upgrade Timeline

LSC Instrument Science White Paper 2016-2017, LIGO-T1600119–v4

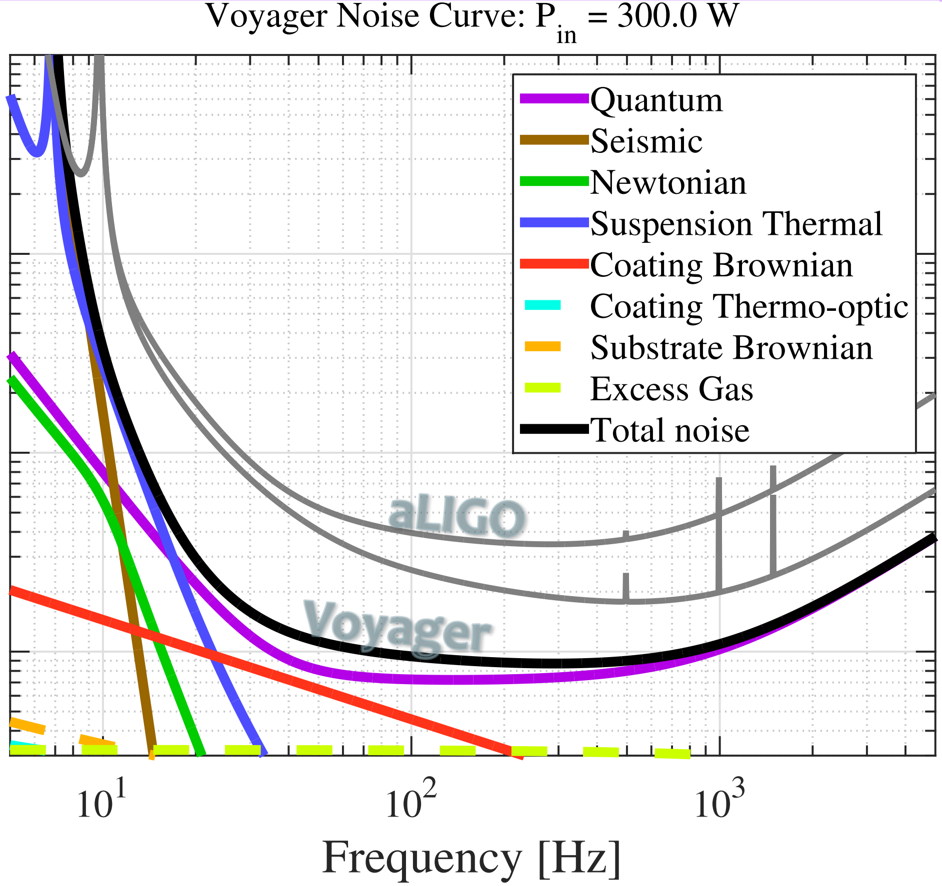


LIGO Voyager:
Fully Exploiting the Current LIGO Facilities

Si optics, > 100 kg
Si or AlGaAs coatings
(Mildly) Cryogenic
λ~2 μm, 300 W



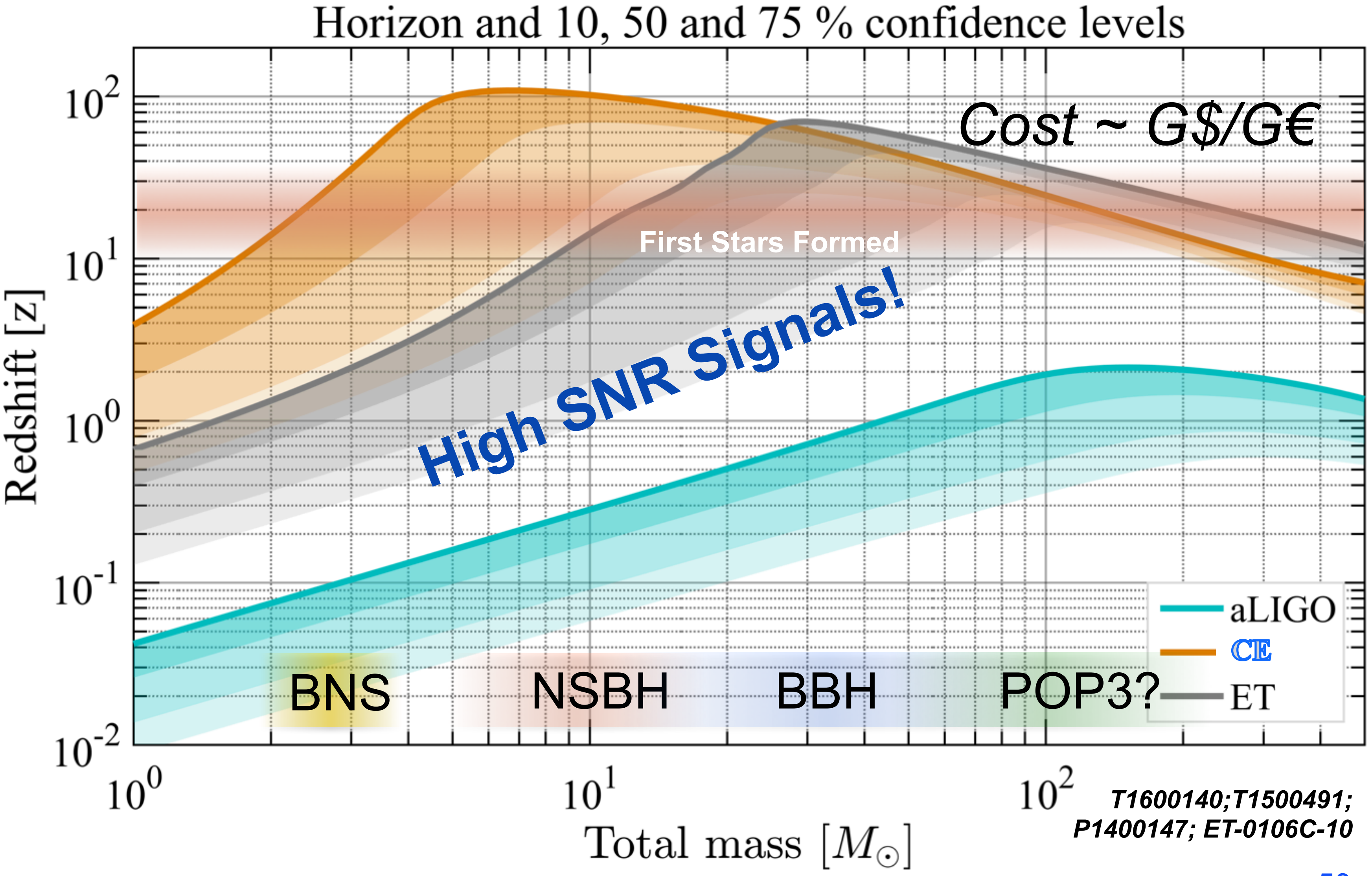
Voyager Noise Curve: P_{in} = 300.0 W



BNS *R* < 800 Mpc
BBH *z* < 5 (@10 $M_\odot$)
~100M$

https://dcc.ligo.org/LIGO-T1400226,
https://dcc.ligo.org/LIGO-T1200031,
https://dcc.ligo.org/LIGO-T1200099
https://dcc.ligo.org/LIGO-T1600140

Einstein Telescope, Cosmic Explorer: New Observatories



T1600140;T1500491; P1400147; ET-0106C-10

How to Get From Here to There?

GWIC (Gravitational Wave International Committee)

Body formed in 1997 to facilitate international collaboration and cooperation in the construction, operation and use of the major gravitational wave detection facilities world-wide

- Affiliated with the International Union of Pure and Applied Physics
  - From 1999 until 2011, GWIC was recognized as a subpanel of PaNAGIC (IUPAP WG.4).
  - In 2011, GWIC was accepted by IUPAP as a separate Working Group (WG.11).

Links to the:
International Astronomical Union (IAU)
International Society for General Relativity and Gravitation (ISGRG)

Who is GWIC?

The membership of GWIC represents all of the world's active gravitational wave projects*, as well as other relevant communities, covering gravitational wave frequencies from nanohertz to kilohertz. Each project has either one or two members on GWIC depending on size.

ACIGA Bram Slagmolen

AURIGA Massimo Cerdonio

Einstein Telescope Michele Punturo

European Pulsar Timing Array Michael Kramer

GEO 600 Karsten Danzmann, *Sheila Rowan (Chair)*

IndIGO Bala Iyer

KAGRA Yoshio Saito, Takaaki Kajita

LIGO Dave Reitze, David Shoemaker

**LISA Neil Cornish, Bernard Schutz,
Ira Thorpe, Stefano Vitale,**

NANOGrav Xavier Siemens

NAUTILUS Eugenio Coccia

Parkes Pulsar Timing Array George Hobbs

Spherical Acoustic detectors Odylio Aguiar

Theory Community Clifford Will

Virgo Fulvio Ricci, Jean-Yves Vinet

IUPAP AC2 (ISGRG) Beverly Berger

IAU D1 Vacant

**Executive secretary : David Shoemaker
Co- secretary: Stan Whitcomb**

***no CMB community membership**

GWIC's role in coordinating 3G detector development

GWIC Subcommittee on Third Generation Ground-based Detectors

GWIC subcommittee purpose and charge:

With the recent first detections of gravitational waves by LIGO and Virgo, it is both timely and appropriate to begin seriously planning for a network of future gravitational-wave observatories, capable of extending the reach of detections well beyond that currently achievable with second generation instruments.

The GWIC Subcommittee on Third Generation Ground-based Detectors is tasked with examining the path to a future network of observatories/facilities

Membership

Co-Chairs: Michele Punturo – ET/David Reitze - LIGO

Federico Ferrini – European Gravitational Observatory
Takaaki Kajita - KAGRA
Vicky Kalogera – Northwestern (co-opted)
Harald Lueck, AEI (co-opted)
Jay Marx, LIGO (co-opted)
David McClelland, ACIGA (co-opted)
Sheila Rowan - GWIC Chair
Bangalore Sathyaprakash – Penn State (co-opted)
David Shoemaker – Executive Secretary

Goals

1) *Science Drivers for 3G detectors:* (Kalogera, Sathyaprakash + subcommittee)

commission a study of ground-based gravitational wave science from the global scientific community, investigating potential science vs architecture vs. network configuration vs. cost trade-offs, recognizing and taking into account existing studies for 3G projects (such as ET) as well as science overlap with the larger gravitational-wave spectrum.

2) *Coordination of the Ground-based GW Community:* (Lueck, McClelland + subcommittee

develop and facilitate coordination mechanisms among the current and future planned and anticipated ground-based GW projects, including identification of common technologies and R&D activities as well as comparison of the specific technical approaches to 3G detectors. Possible support for coordination of 2G observing and 3G construction schedules.

3) *Networking among Ground-based GW Community:* (Punturo, Reitze)

organize and facilitate links between planned global 3G projects and other relevant scientific communities, including organizing:

- **town hall meetings to survey the community**
- **dedicated sessions in scientific conferences dedicated to GW physics and astronomy**
- **focused topical workshops within the relevant communities**

Goals (cont'd)

4) *Agency interfacing and advocacy:* (Rowan)

identify and establish a communication channel with funding agencies who currently or may in the future support ground-based GW detectors; communicate as needed to those agencies officially through GWIC on the scientific needs, desires, and constraints from the communities and 3G projects (collected via 1) – 3) above) structured in a coherent framework; serve as an advocacy group for the communities and 3G projects with the funding agencies.

5) *Investigate governance schemes*: (Ferrini, Marx + subcommittee)

by applying knowledge of the diverse structures of the global GW community, propose a sustainable governance model for the management of detector construction and joint working, to support planning of 3rd generation observatories.

The subcommittee should provide a preliminary report and set of proposed actions recommendations to GWIC no later than the 2017 GWIC meeting.

Subsequent reports should be delivered future GWIC meetings.

Upcoming Near Term Meetings of Interest

6-7 July, 2017 **Syracuse, NY**	What's Next for Gravitational Wave Astronomy? Marriott Syracuse Downtown, 100 E Onondaga St, Syracuse, NY 13202
9-14 July, 2017 **Pasadena, CA**	12th Edoardo Amaldi Conference on Gravitational Waves Hilton Pasadena, 168 S Los Robles Ave, Pasadena, CA 91101
28 Aug-1 Sep, 2017 **Geneva, Switzerland**	LIGO-Virgo Collaboration Meeting CERN, Geneva, Switzerland

The committee will need your input and help to develop the proper path forward!

gwic-3g@sympa.ligo.org

The Dawn of Gravitational-waves Physics and Astronomy

LIGO's second observing run O2 is underway!

- Began November 30, 2016, slated to end on August 25, 2017
- L1 detector is more sensitive than in O1; H1 is slightly less sensitive
- *One more confirmed black hole merger: GW170104!*

12- 15 month break planned for Fall 2017

- Sensitivity goal for O3: H1, L1 > 120 Mpc binary neutron star inspiral range
- Substantial work planned at both Hanford and Livingston

Planning and R&D underway to upgrade Advanced LIGO detectors

The next few years will be very interesting ones for the field of gravitational-wave science!

Stay Tuned…

LIGO

LIGO Scientific Collaboration

LSC

TRINITY UNIVERSITY

UNIVERSITY OF MARYLAND 1856

Andrews University

WASHINGTON STATE UNIVERSITY

CALIFORNIA STATE UNIVERSITY FULLERTON

THE UNIVERSITY OF ALABAMA IN HUNTSVILLE

SONOMA STATE UNIVERSITY

indigo

MONTCLAIR STATE UNIVERSITY

University of Glasgow

Australian National University

WHITMAN COLLEGE

AMERICAN UNIVERSITY WASHINGTON, DC

UNIVERSITY OF THE WEST of SCOTLAND UWS

TEXAS TECH UNIVERSITY

Tsinghua University

R·I·T

Max Planck Institute for Gravitational Physics ALBERT EINSTEIN INSTITUTE

UNIVERSITY OF STRATHCLYDE

MICHIGAN

CITA ICAT
Canadian Institute for Theoretical Astrophysics
L'institut Canadien d'astrophysique théorique

Università degli Studi del Sannio

NASA GODDARD SPACE FLIGHT CENTER

ICTP SAIFR

THE UNIVERSITY OF WESTERN AUSTRALIA

PAH

ACU

UNIVERSITY OF CAMBRIDGE

THE UNIVERSITY OF CHICAGO

MONTANA STATE UNIVERSITY

SOUTHERN UNIVERSITY Agricultural & Mechanical College

COLUMBIA UNIVERSITY IN THE CITY OF NEW YORK

THE UNIVERSITY OF ADELAIDE AUSTRALIA

Caltech

UNIVERSITY OF MINNESOTA

THE UNIVERSITY of MISSISSIPPI

UNIVERSITY OF BIRMINGHAM

THE UNIVERSITY OF MELBOURNE

UIB Universitat de les Illes Balears

UNIVERSITY OF WASHINGTON

GEO 600

UTRGV

UNIVERSITY of WISCONSIN UWMILWAUKEE

CARDIFF UNIVERSITY PRIFYSGOL CAERDYD

Northwestern

MONASH University

INPE

UF UNIVERSITY of FLORIDA

Georgia Institute of Technology

Korean Gravitational-Wave Group

LSU LOUISIANA STATE UNIVERSITY

ACIGA

University of Southampton

CHARLES STURT UNIVERSITY

EMBRY-RIDDLE AERONAUTICAL UNIVERSITY

Leibniz Universität Hannover

PennState

Science & Technology Facilities Council Rutherford Appleton Laboratory

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Rana Adhikari
Salvo Vitale
Matt Evans

ligo.caltech.edu

LIGO
LASER INTERFEROMETER GRAVITATIONAL-WAVE OBSERVATORY

www.ligo.org

Support: National Science Foundation