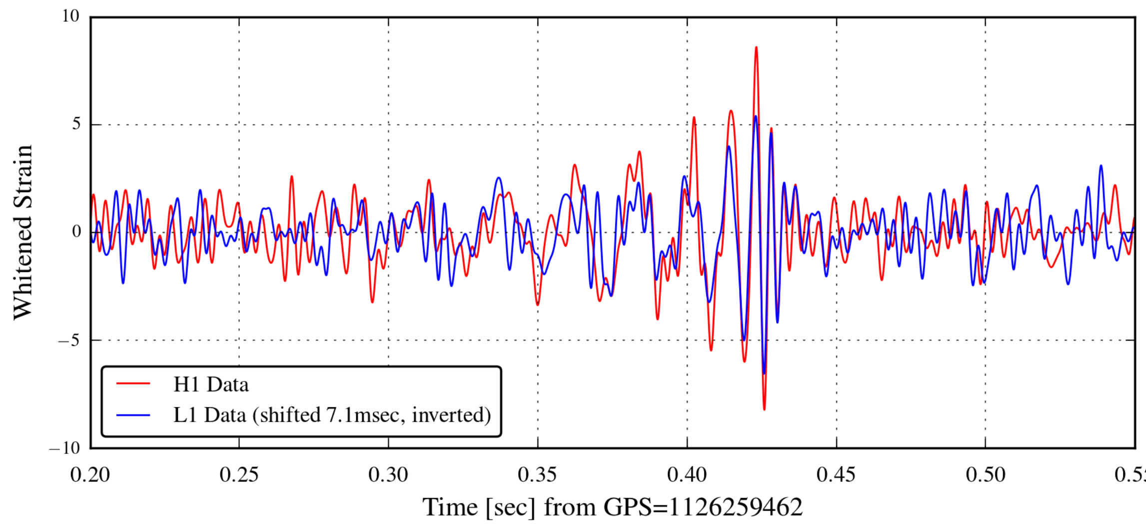
Advanced LIGO: Status & Prospects



Daniel Hoak for the LVC

LSC VIRGO

SciNeGHE, Pisa
19 October 2016

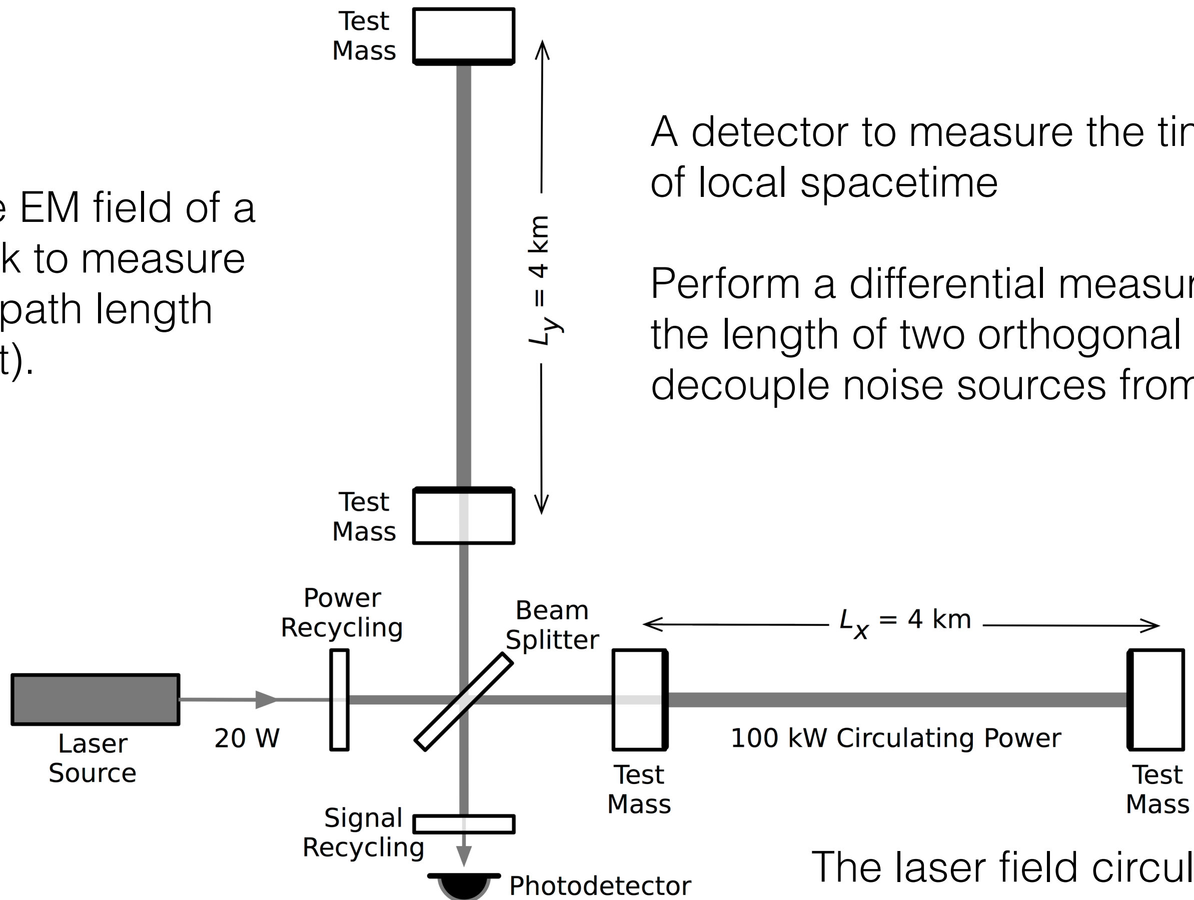
The Instruments

Laser Interferometric Gravitational-wave Detectors

Idea: use the EM field of a laser as clock to measure variations in path length (time-of-flight).

A detector to measure the time-varying shape of local spacetime

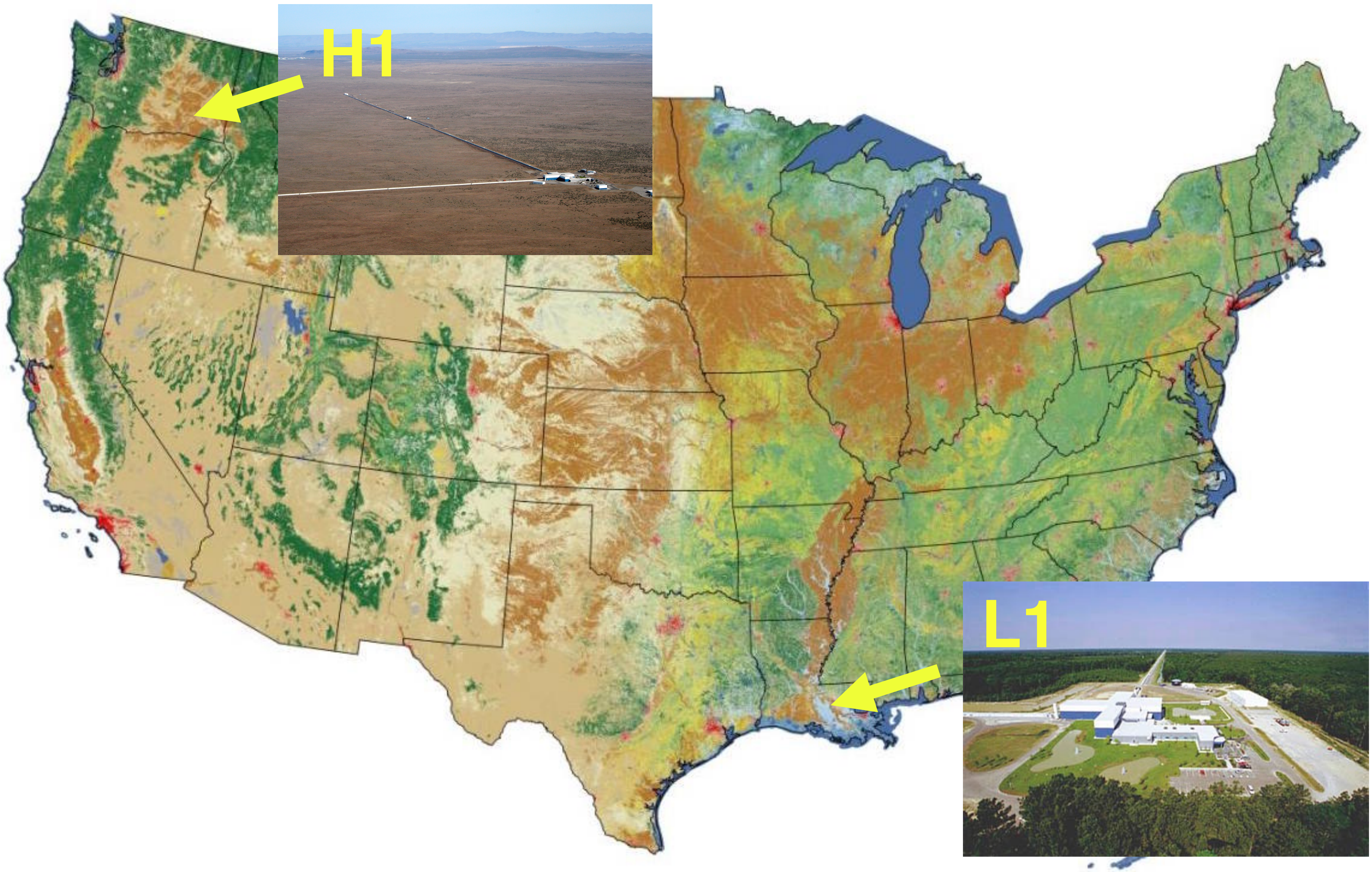
Perform a differential measurement (compare the length of two orthogonal arms) to decouple noise sources from the output



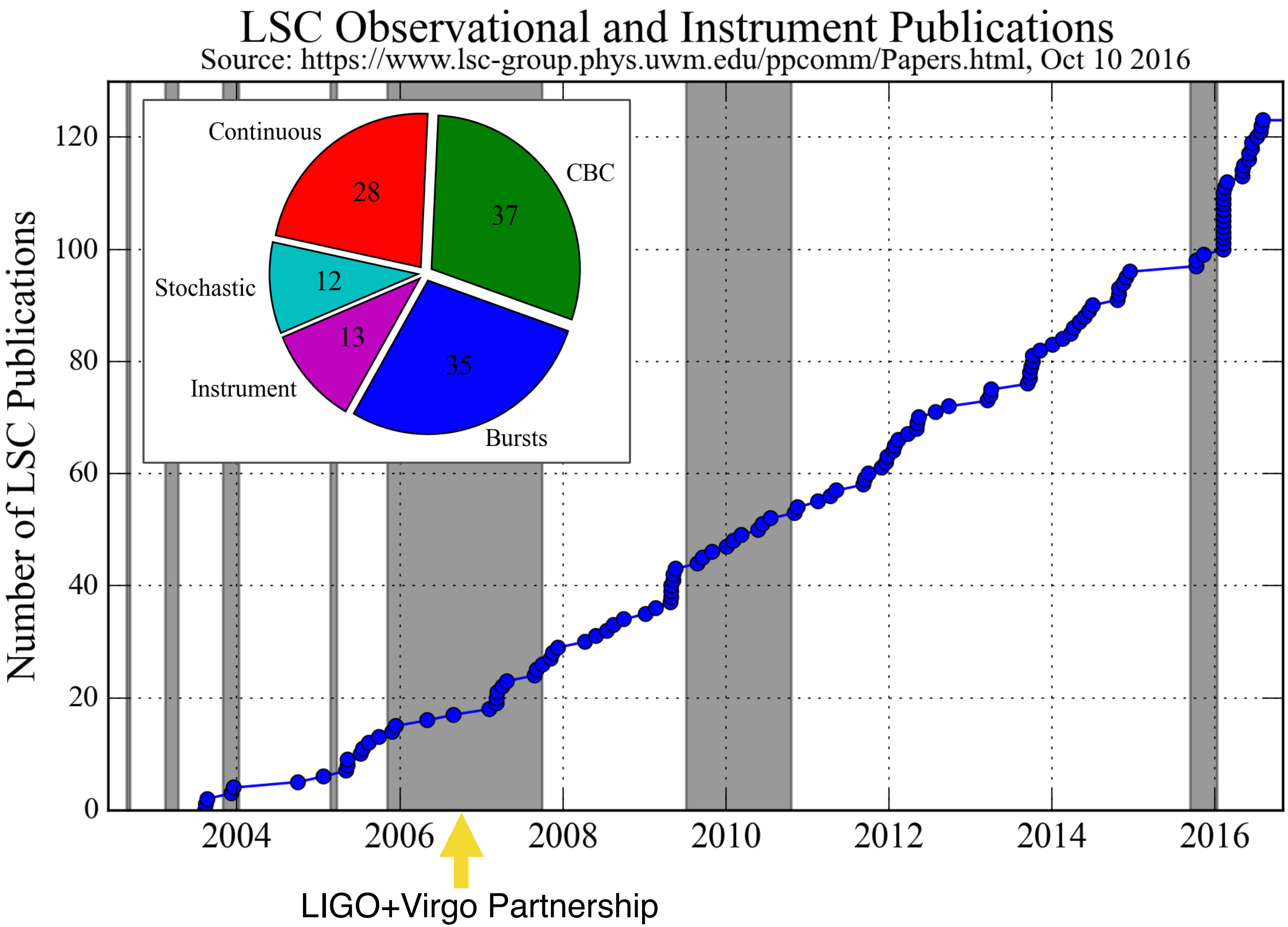
The laser field circulates in long optical cavities to amplify the GW signal

Challenges:
Be sensitive to a *tiny* time-varying displacement of the arm lengths
Make the earth—>test mass connection as small as possible
Control laser noises (frequency, intensity, beam pointing)
Distinguish quiet signals from background noise

The LIGO Observatories



LIGO - Results from the Initial Detector Era



The Advanced LIGO Upgrade

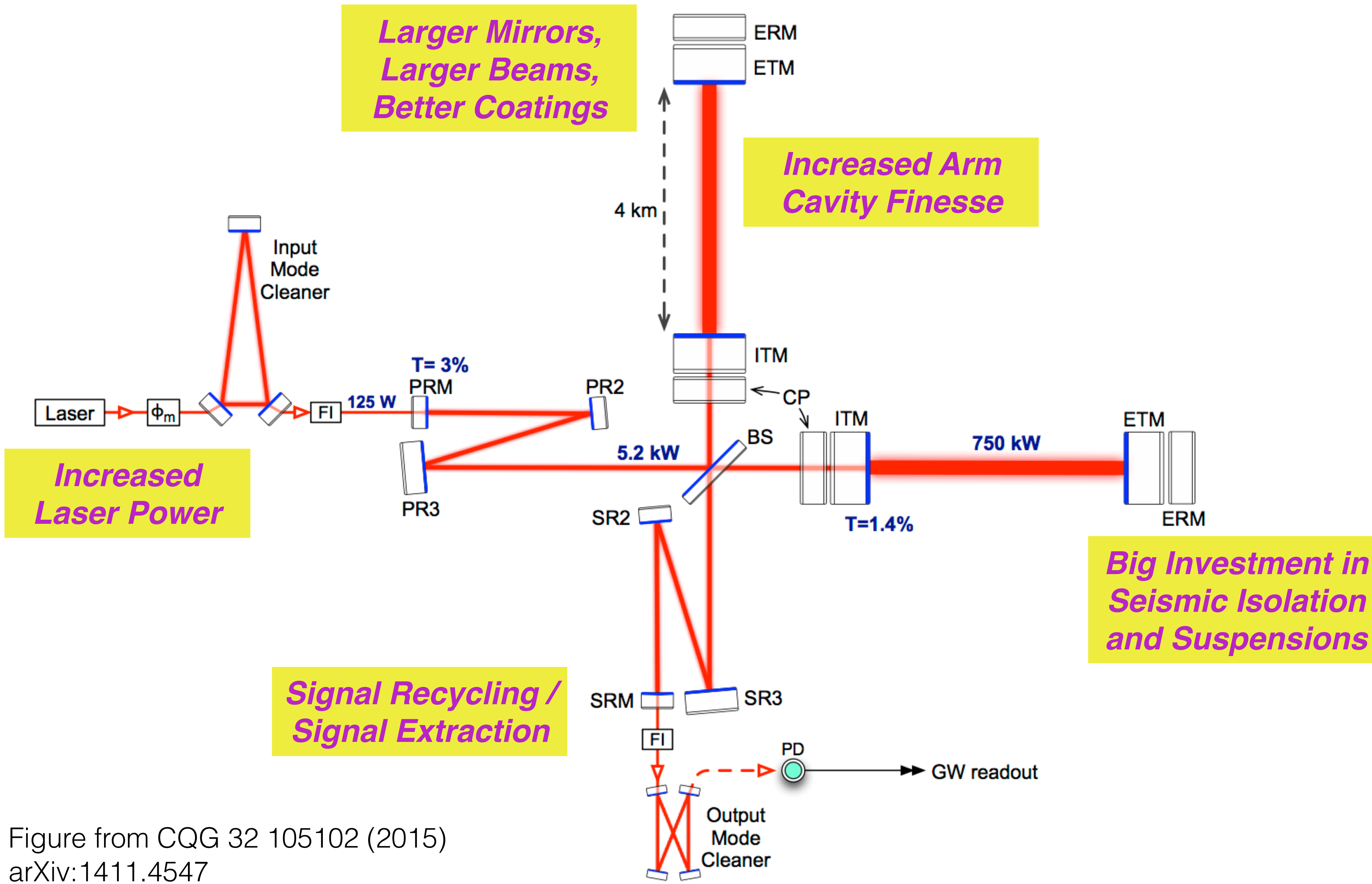
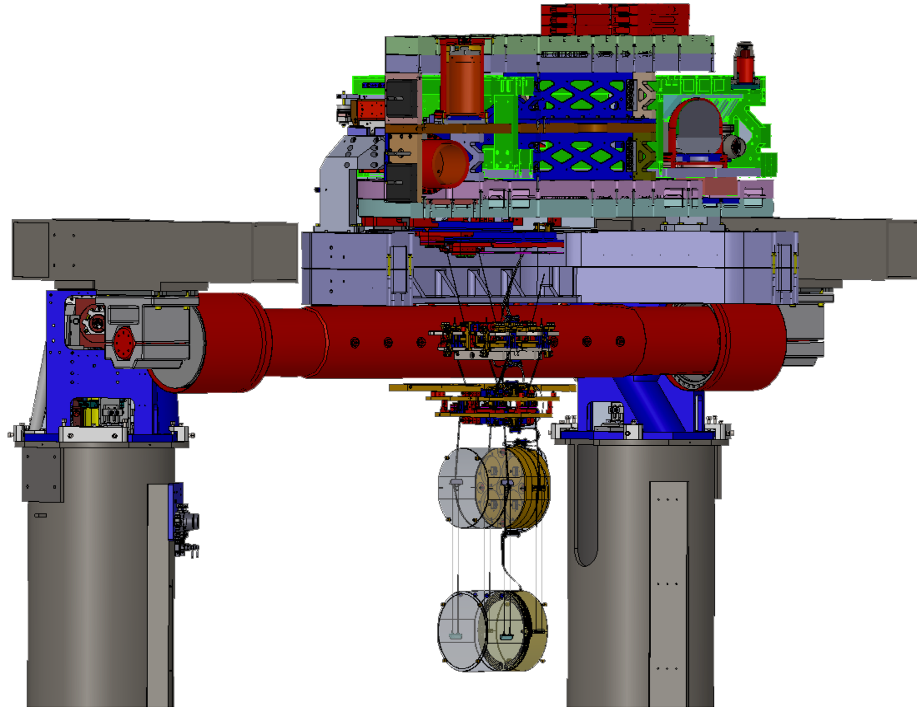
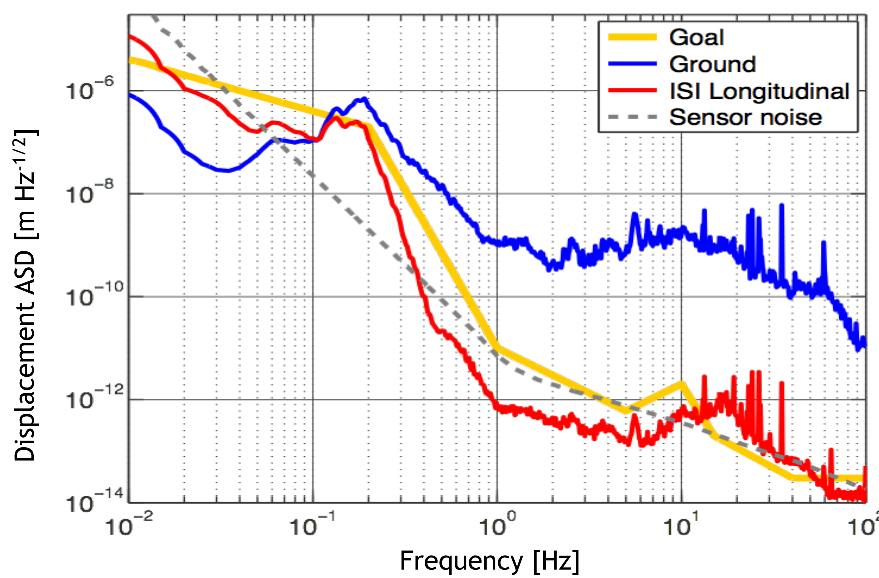


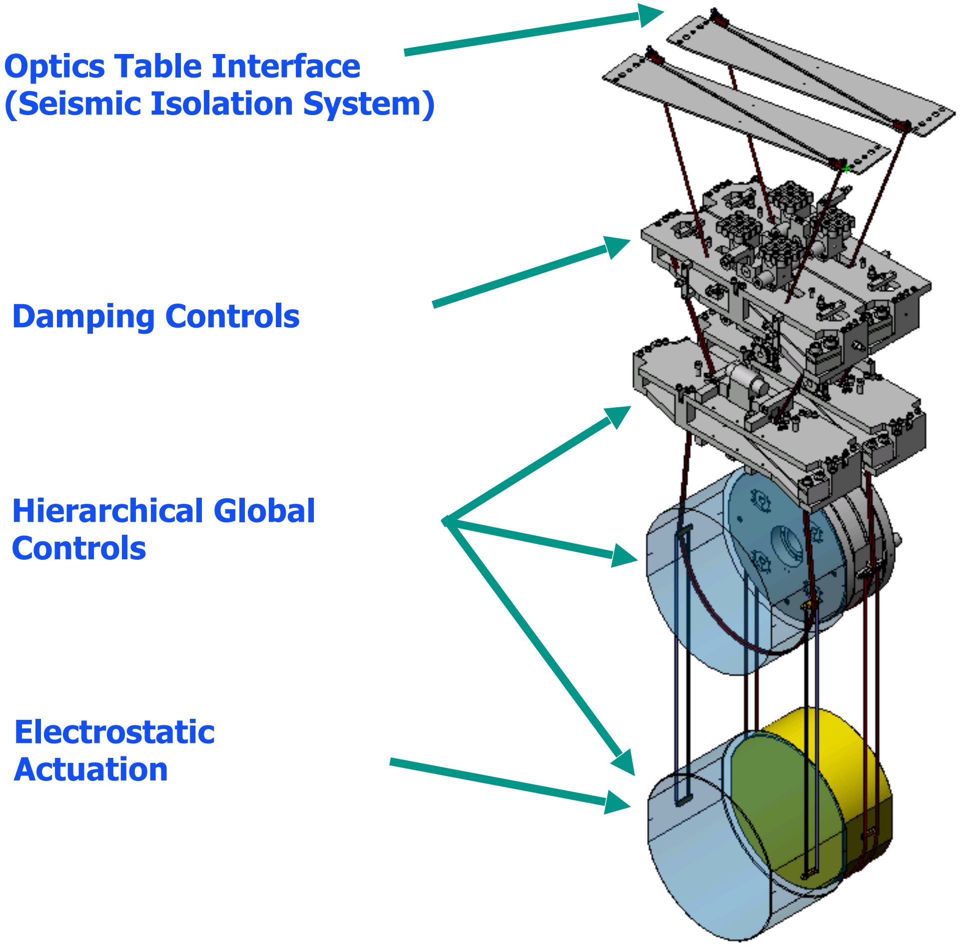
Figure from CQG 32 105102 (2015)
arXiv:1411.4547

Active Seismic Isolation For In-Vacuum Optical Tables





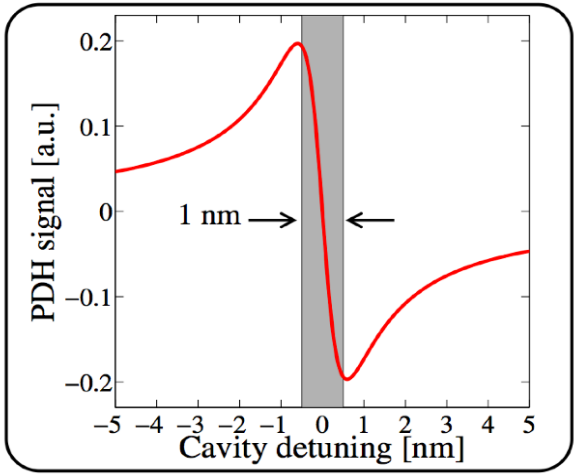
Four-stage monolithic suspensions, larger mirrors

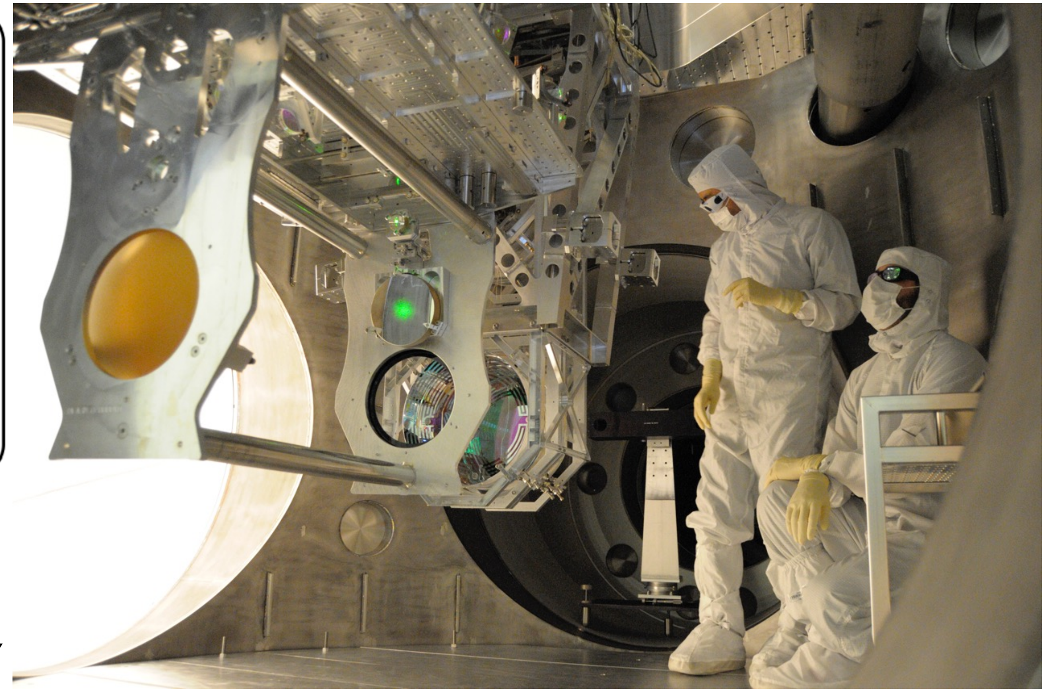


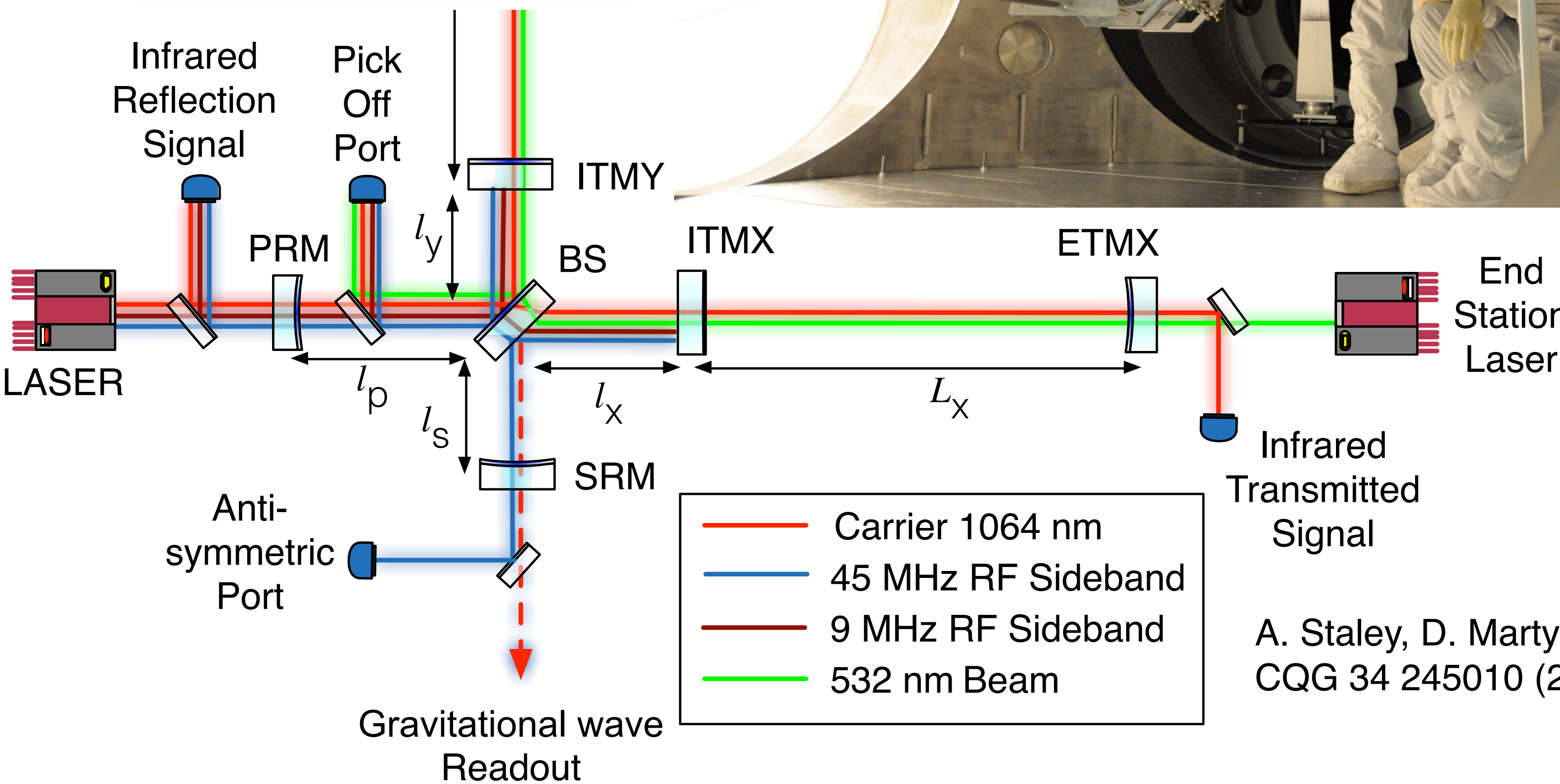
Larger test masses —> Larger beam size —> Coating thermal noise coupling is reduced
—> Less sensitive to radiation pressure from increased power

Arm Length Stabilization

LIGO-G1300524

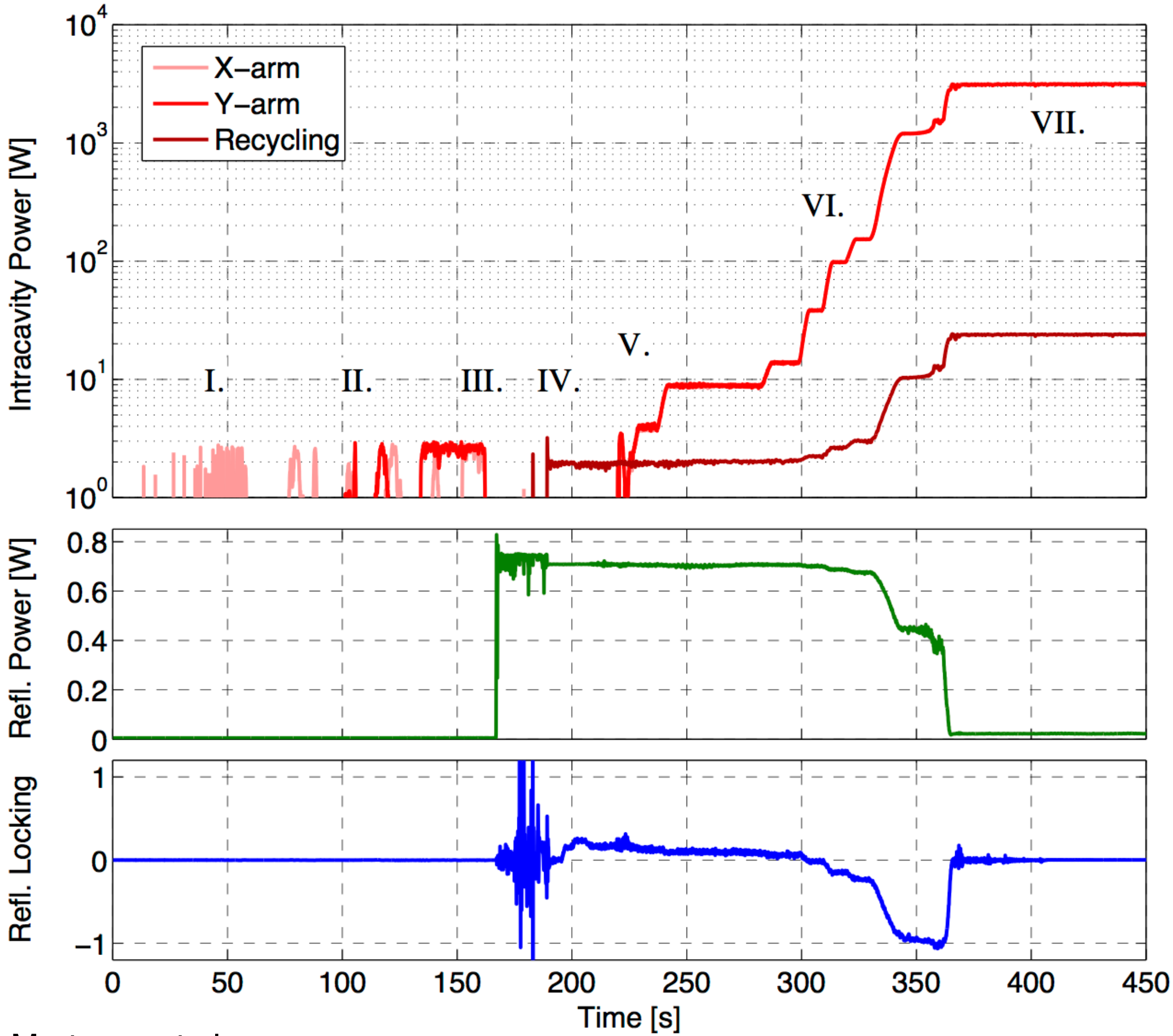






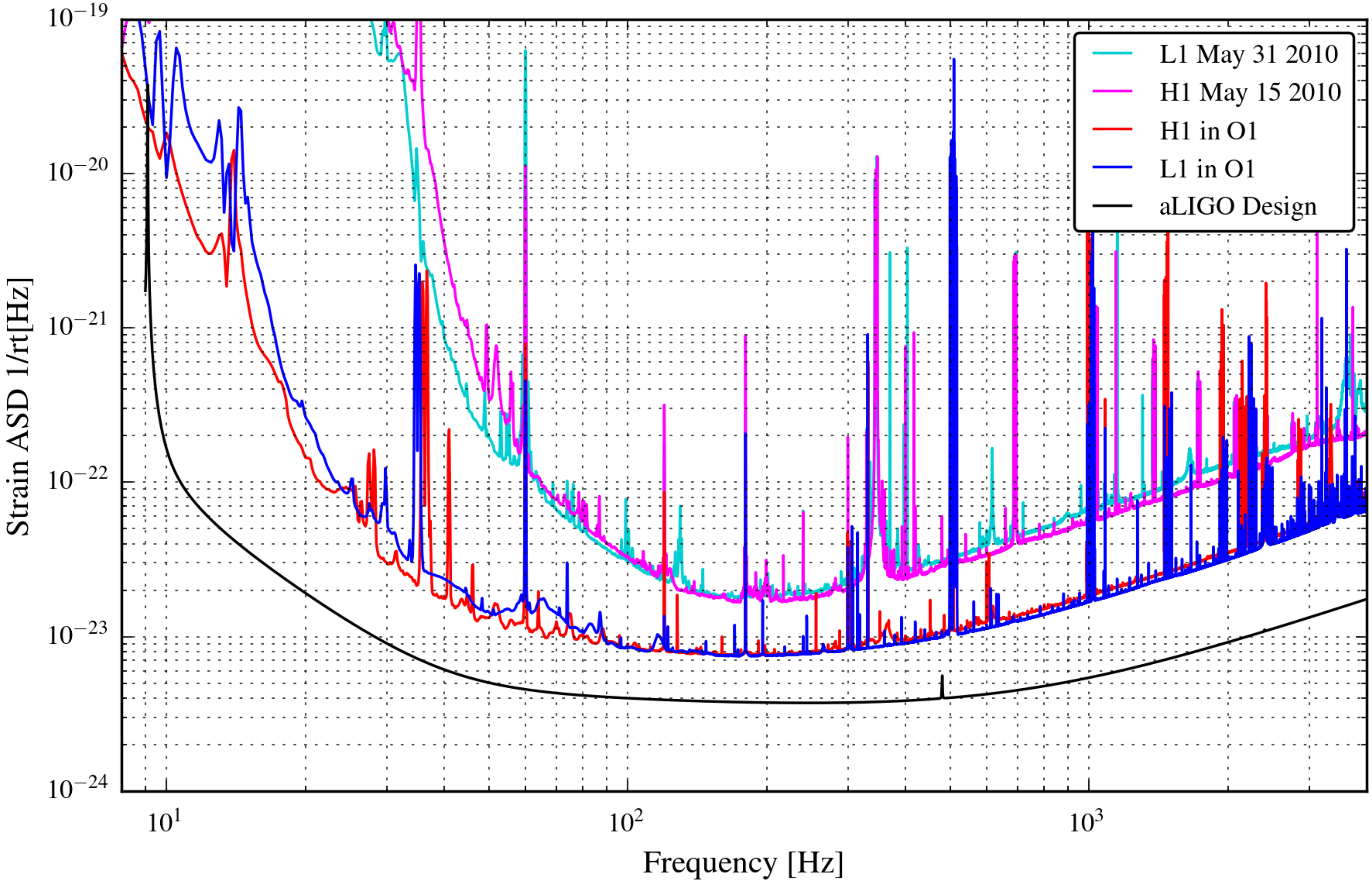
A. Staley, D. Martynov et al., CQG 34 245010 (2015)

Lock Acquistion Sequence: Fast & Automated



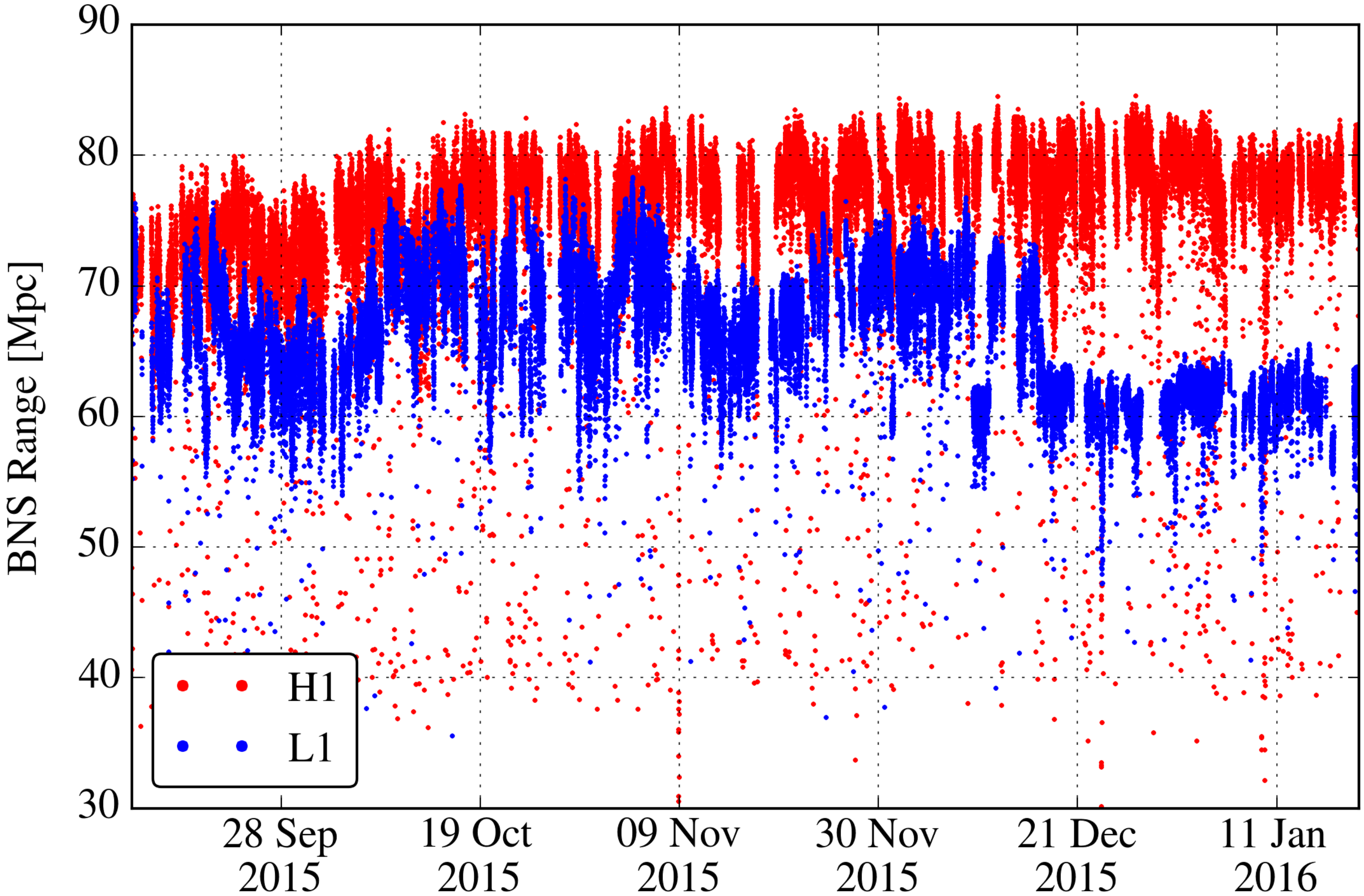
A. Staley, D. Martynov et al.,
CQG 34 245010 (2015)

Sensitivity Improvement



First Observing Run

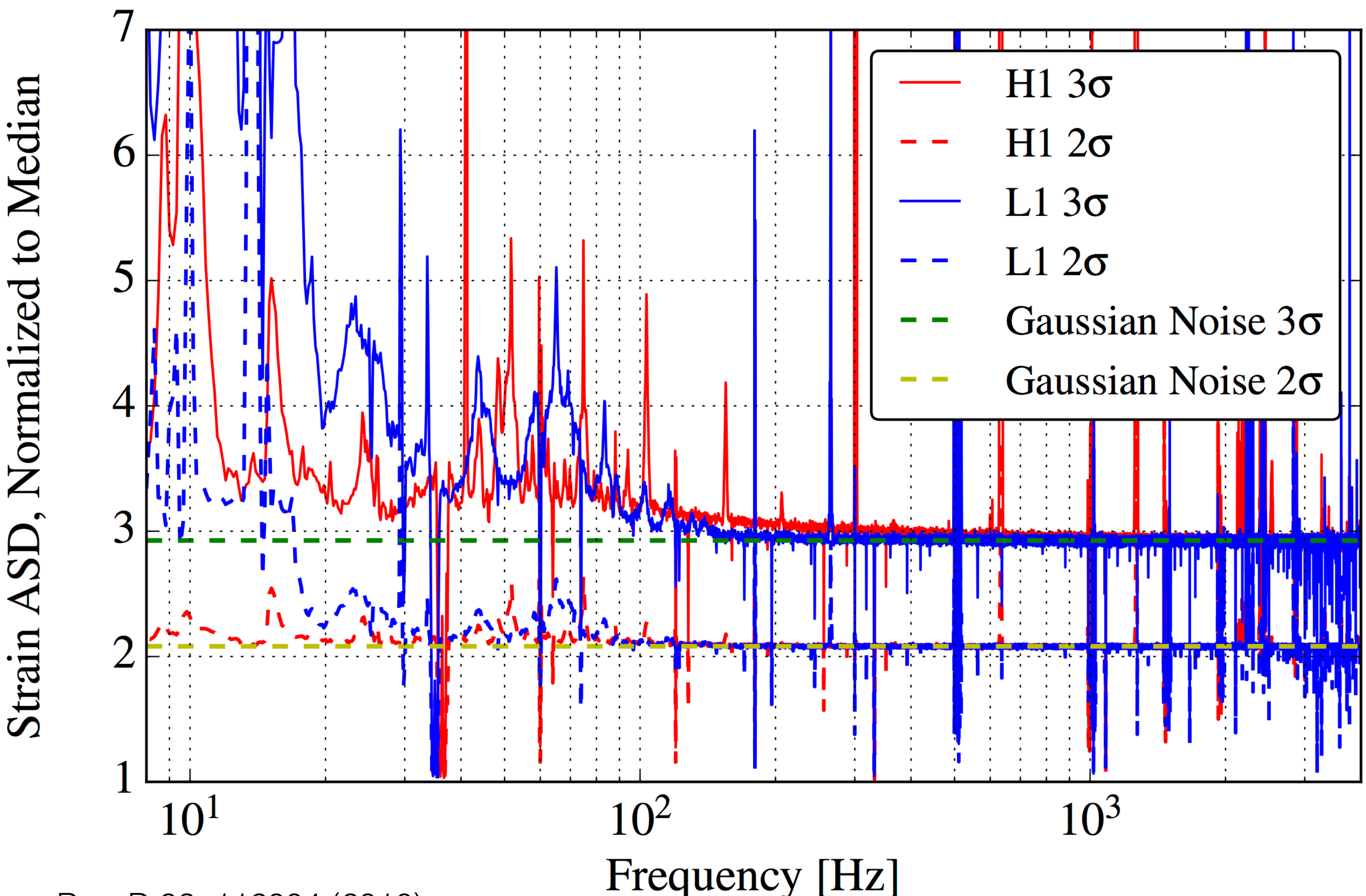
Sensitivity to neutron star mergers (“standard candle” in GWs)



Phys. Rev. D 93, 112004 (2016)
arXiv:1604.00439

2-detector duty factor: 50%

Noise Statistics



Phys. Rev. D 93, 112004 (2016)
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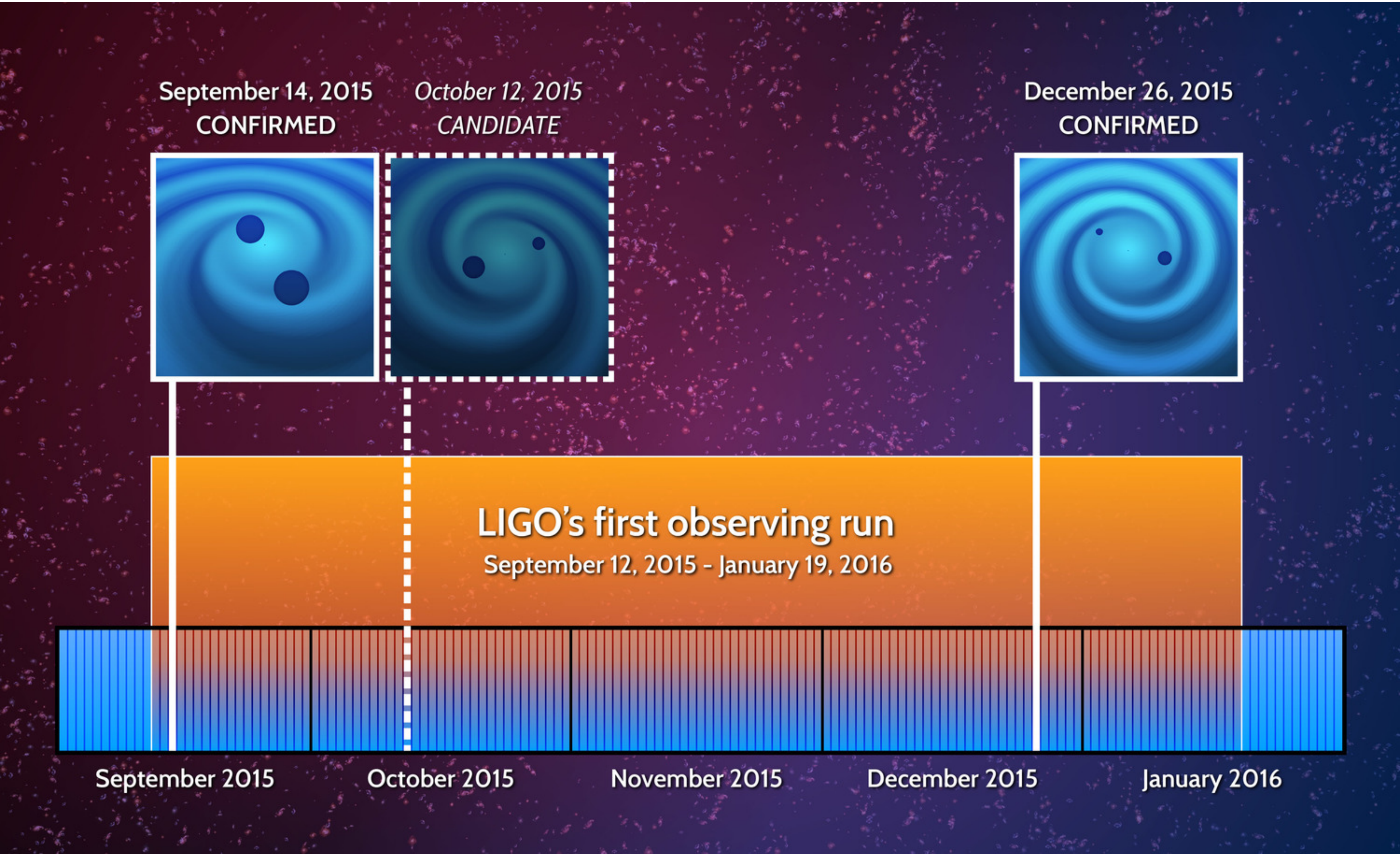
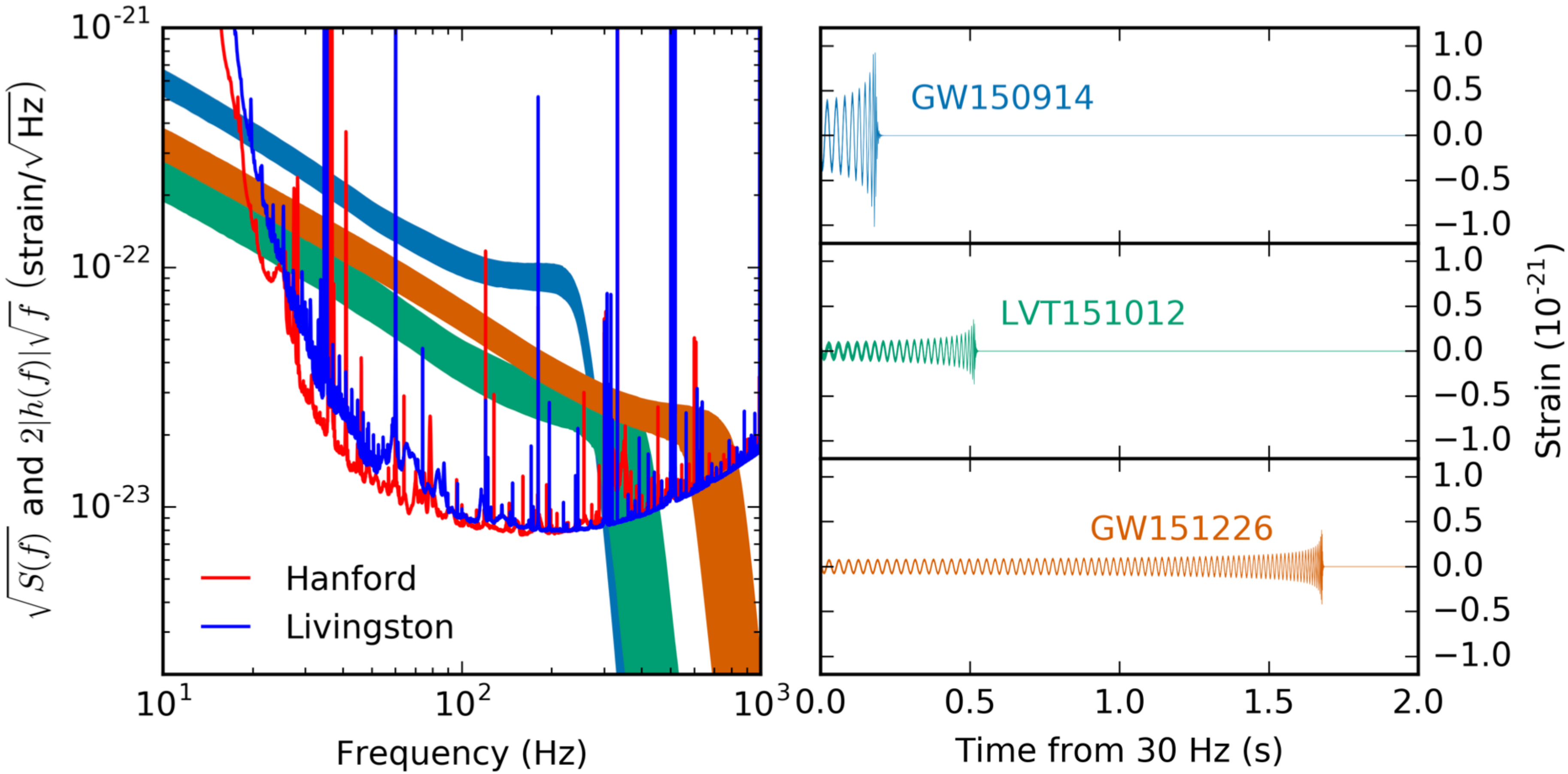
BBH Detections!

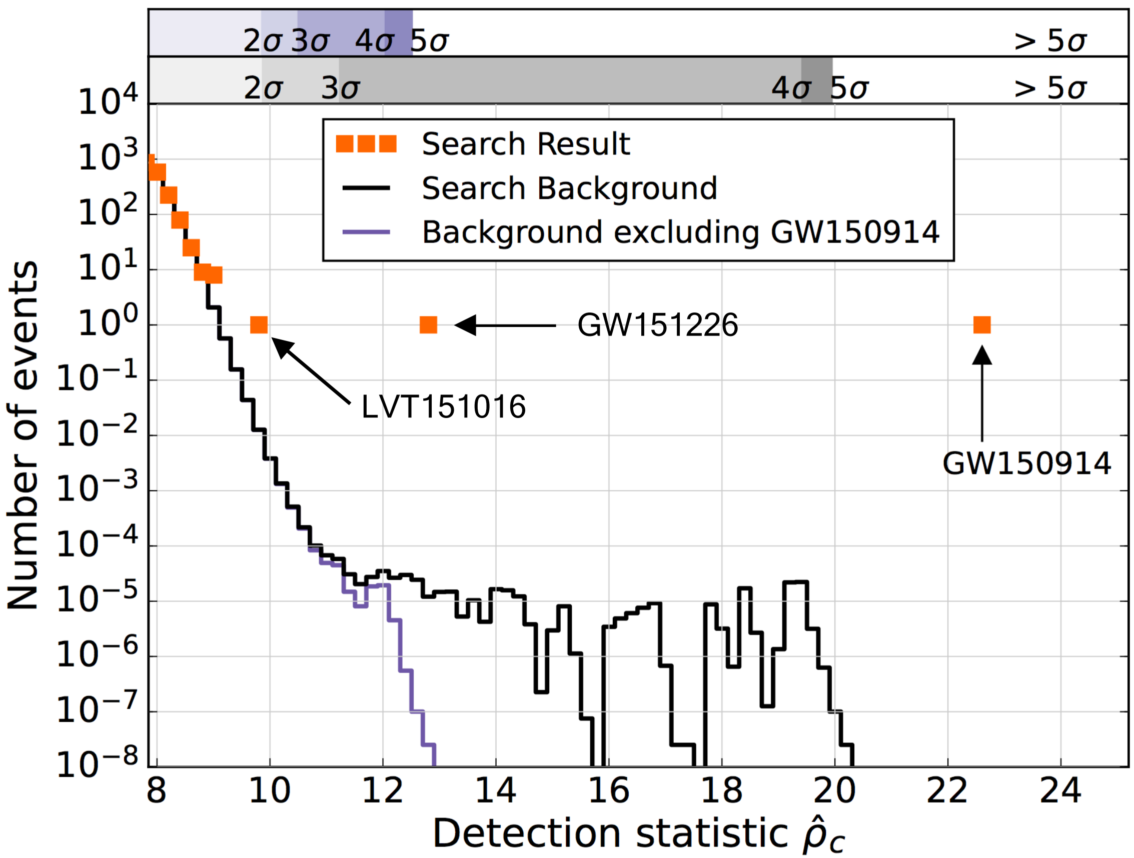


BBH Detections



arXiv:1606.04856

BBH Search Results

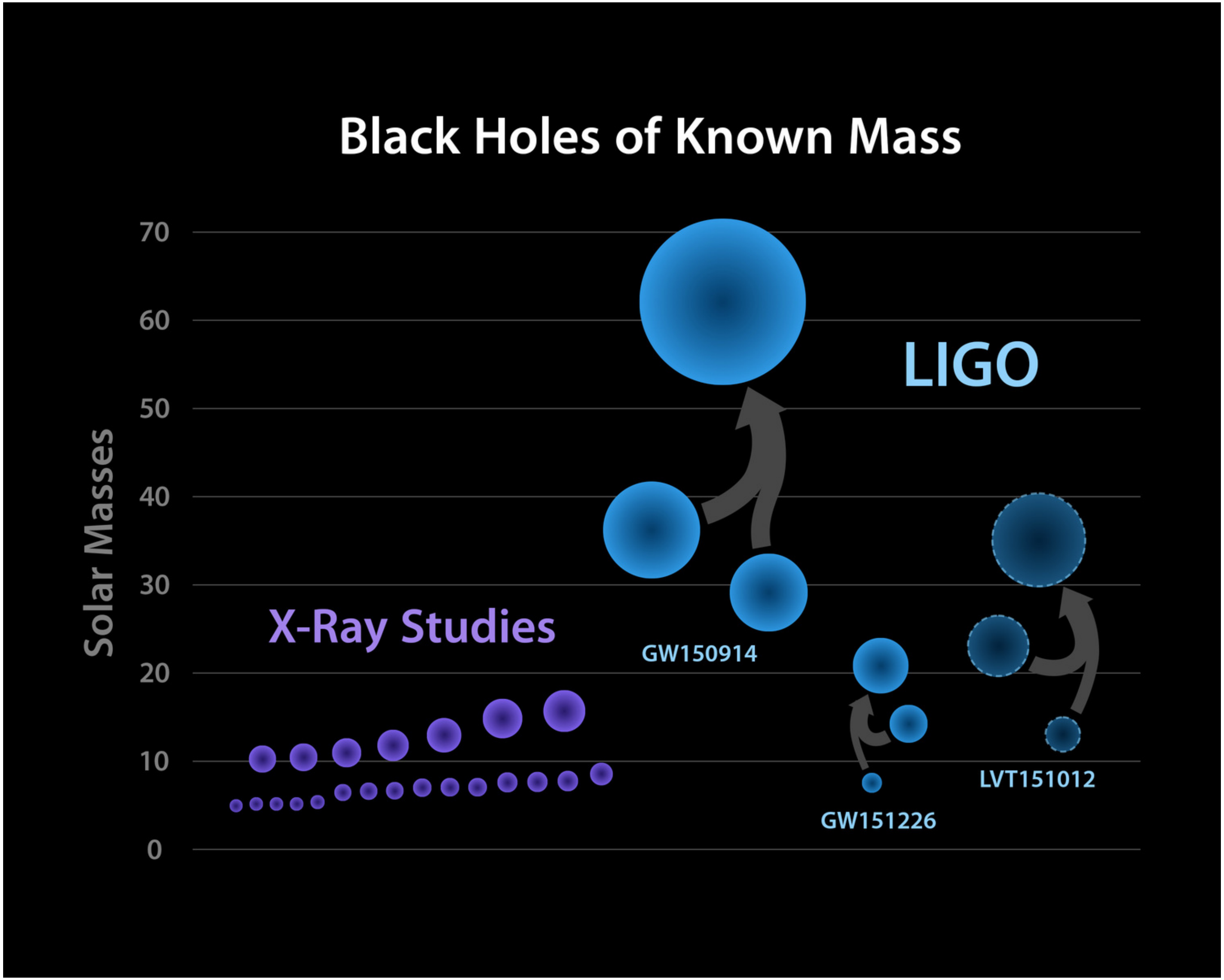


arXiv:1606.04856

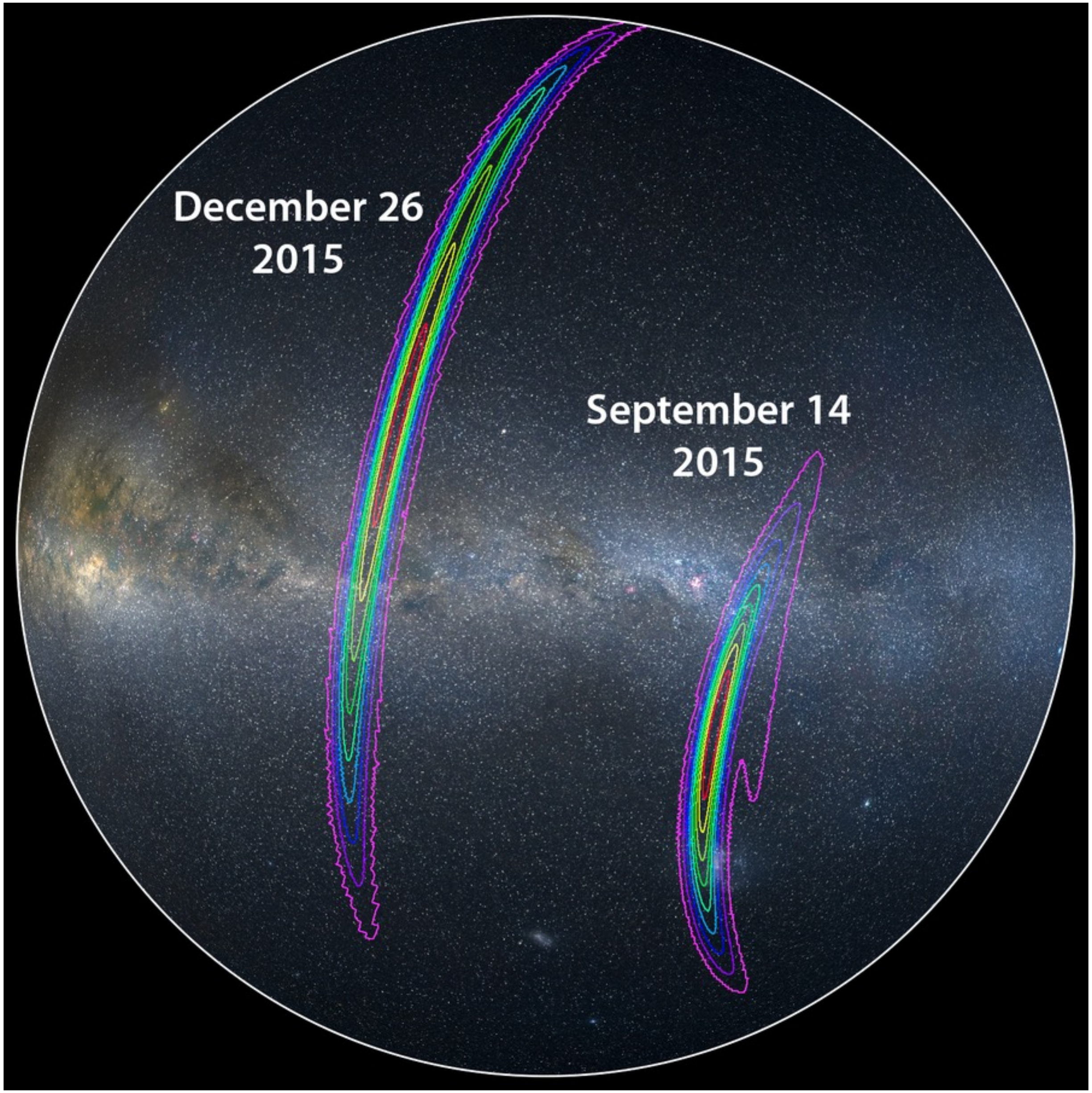
The data from GW detectors contains loud transient signals (glitches) that occur with a higher rate than would be expected from Gaussian statistics. They arise from instrument artifacts, environmental disturbances, etc.

The search background due to glitches cannot be modeled analytically, so we measure it empirically by repeating the searches with unphysical time shifts between the detectors. The resulting background is an estimate of the rate of random noise coincidences between detectors.

Black Hole Mass Spectroscopy

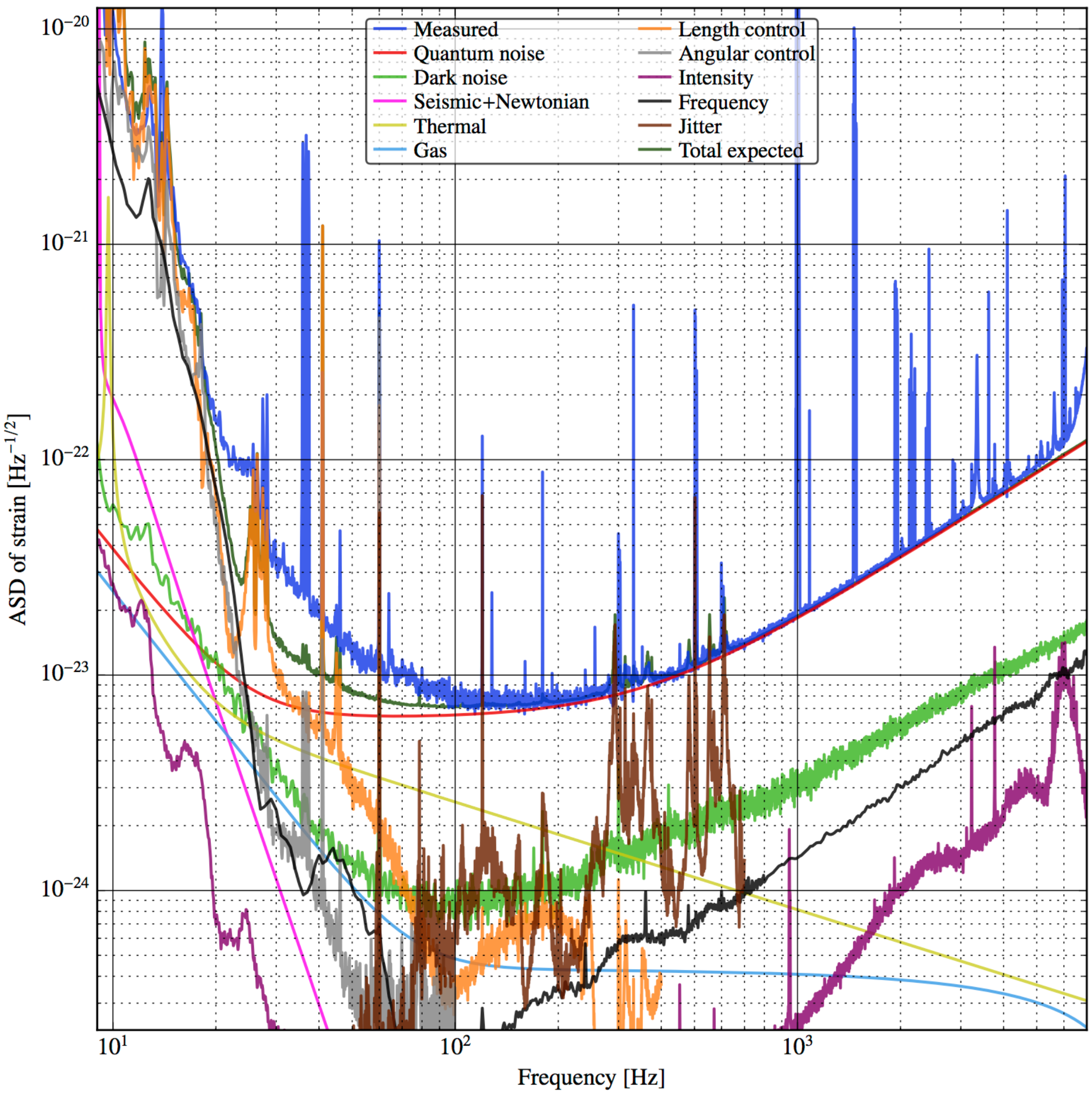


Sky Localization



Prospects for the Future

Noise Estimation



Summation of measured & estimated noise sources for LHO during O1 - figure by Evan Hall, Nov 2015.

Both detectors have “mystery” noise below 100Hz.

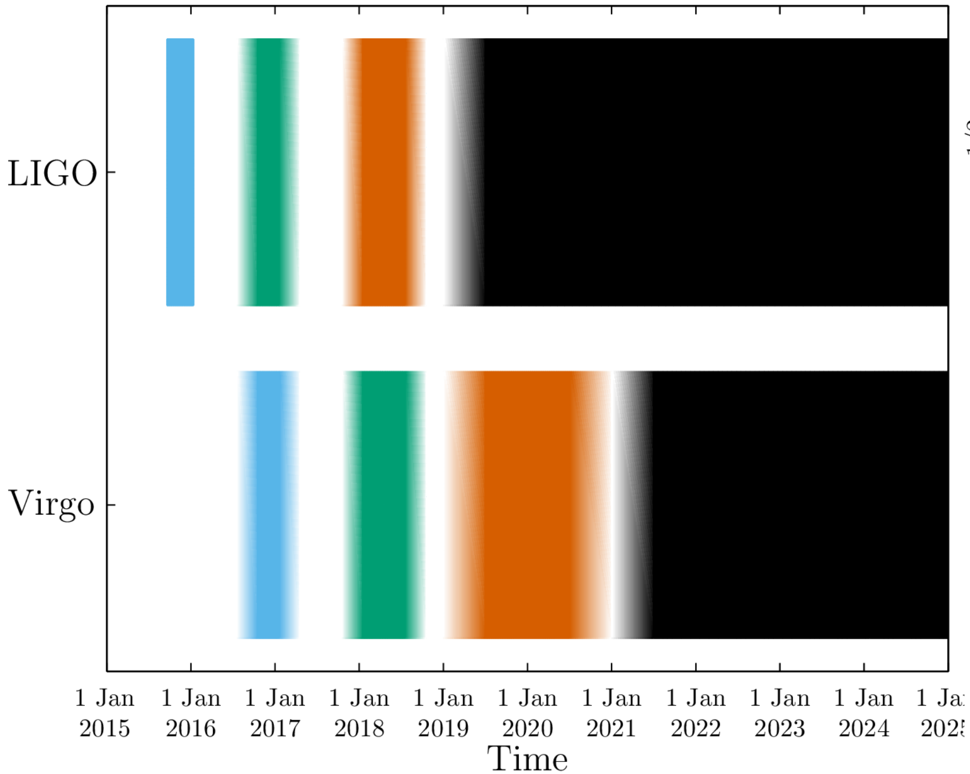
This noise **must** be fixed to improve sensitivity to BBH/BNS.

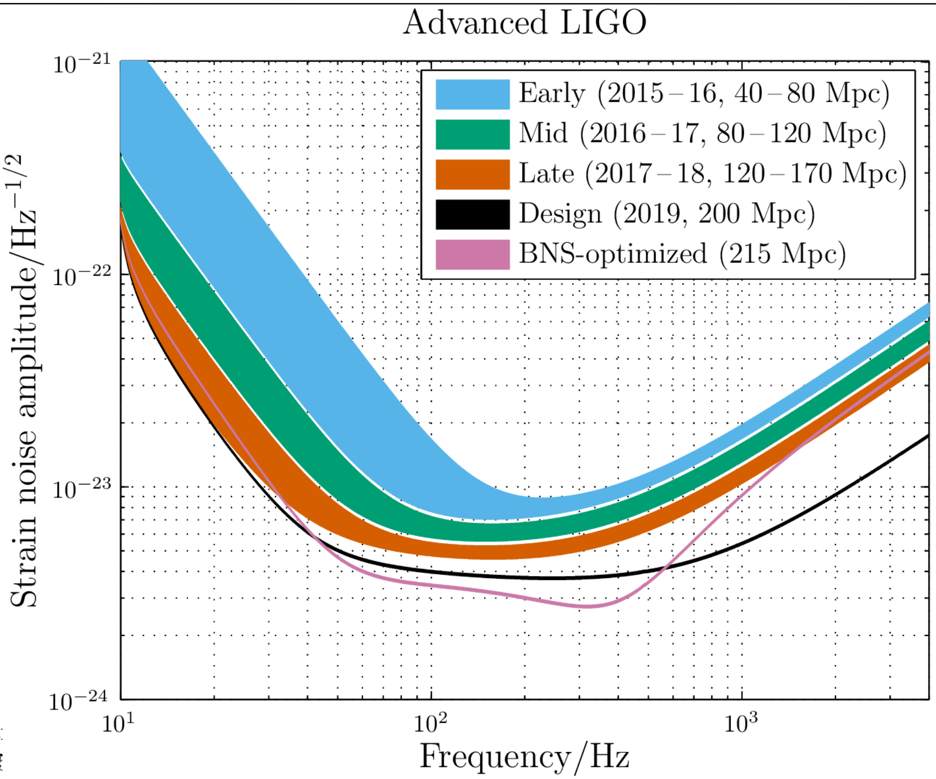
Increasing laser power improves high frequency, but complicates control, introduces intensity noise, beam jitter, etc.

Some recent progress - stay tuned for O2!

Phys. Rev. D 93, 112004 (2016)
arXiv:1604.00439

Future Observing Runs





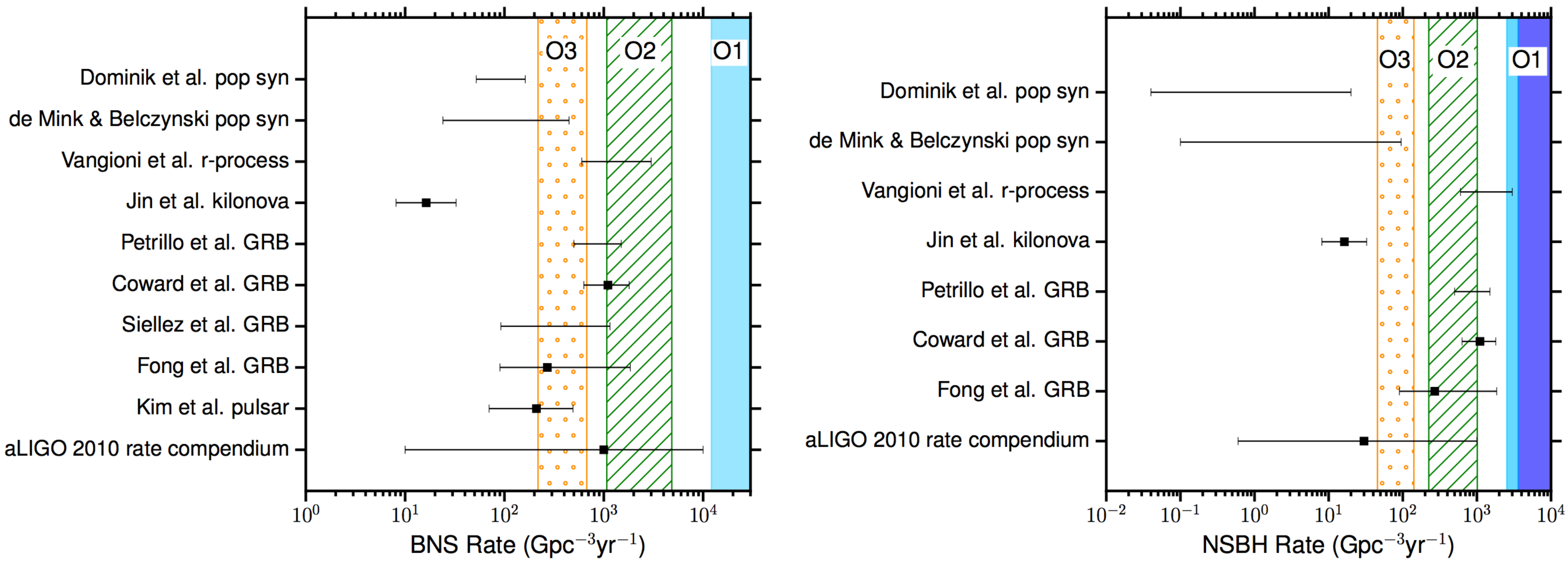
Second observing run (O2) will begin in November (slight delay), last until ~May. Second half will include Virgo.

LIGO expects a 20% sensitivity improvement -> 70% increase in sensitive volume

Six month run (50% more time), 70% increase in volume -> ~2.5x more BBH detections

Living Rev. Relativity 19 (2016), 1 arXiv:1304.0670

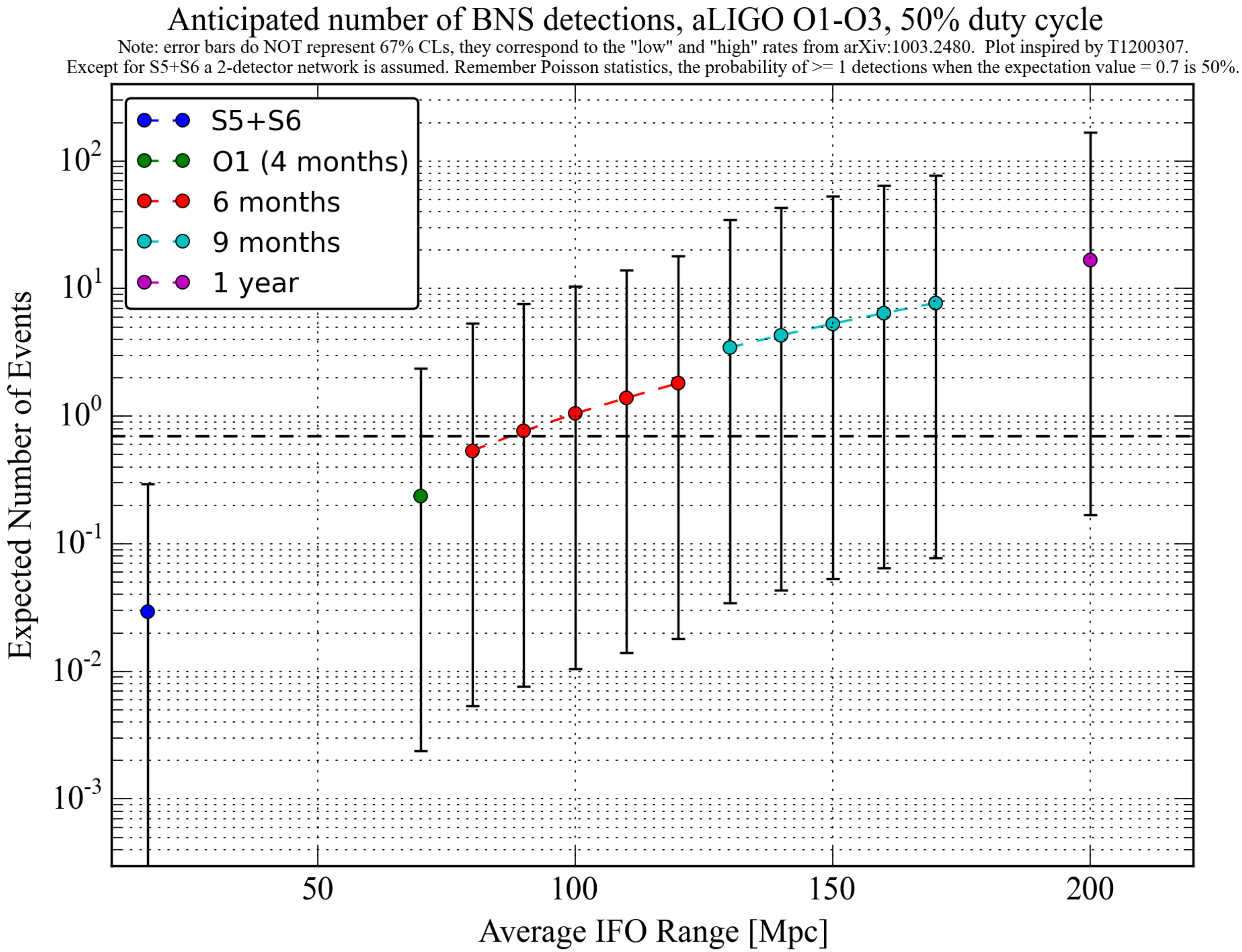
Prospects for EM-Bright Detections



arXiv:1607.07456

BNS/NSBH detections imminent? Depends on rate estimates. Sensitivity in O1 was not sufficient to exclude even the optimistic projections.

Prospects for EM-Bright detections



Gravitational wave astrophysics: a new field of discovery

First observing run was a huge success: detectors were upgraded on time and on budget, performance was ahead of schedule

Detections! Exciting science: BH mass spectroscopy, measure the “mass gap” caused by SN mechanism, metallicity in early universe, precision tests of GR in the highly relativistic regime.

Many more sources to explore: pulsars, stochastic background, GRBs!

BUT….

Many challenges remain. Progress in the field will be defined by instrument sensitivity.

Operating the detectors is not routine — an ongoing research & development project

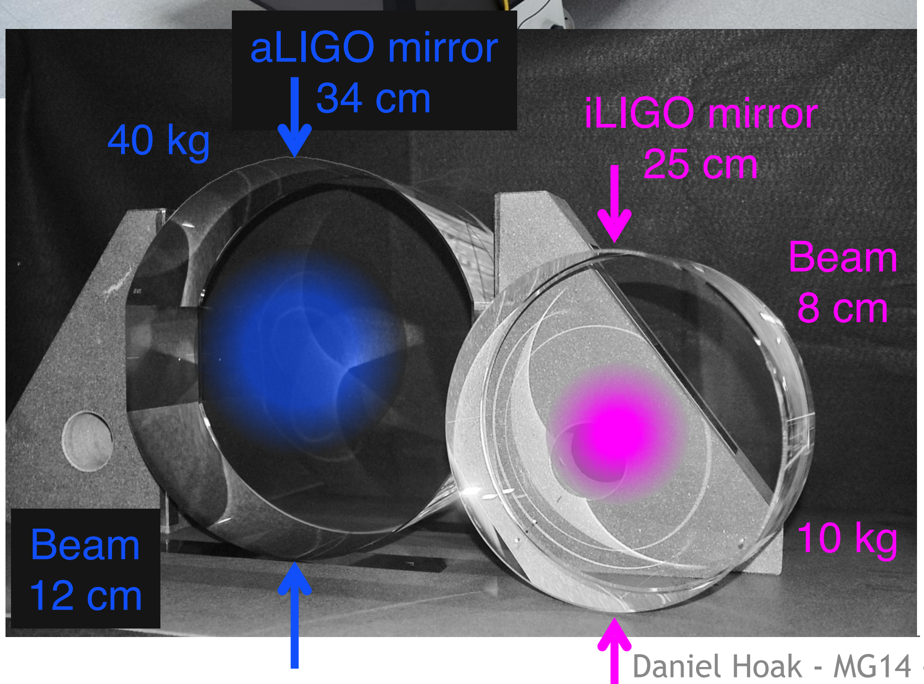
Technologies for next generation of detectors not settled

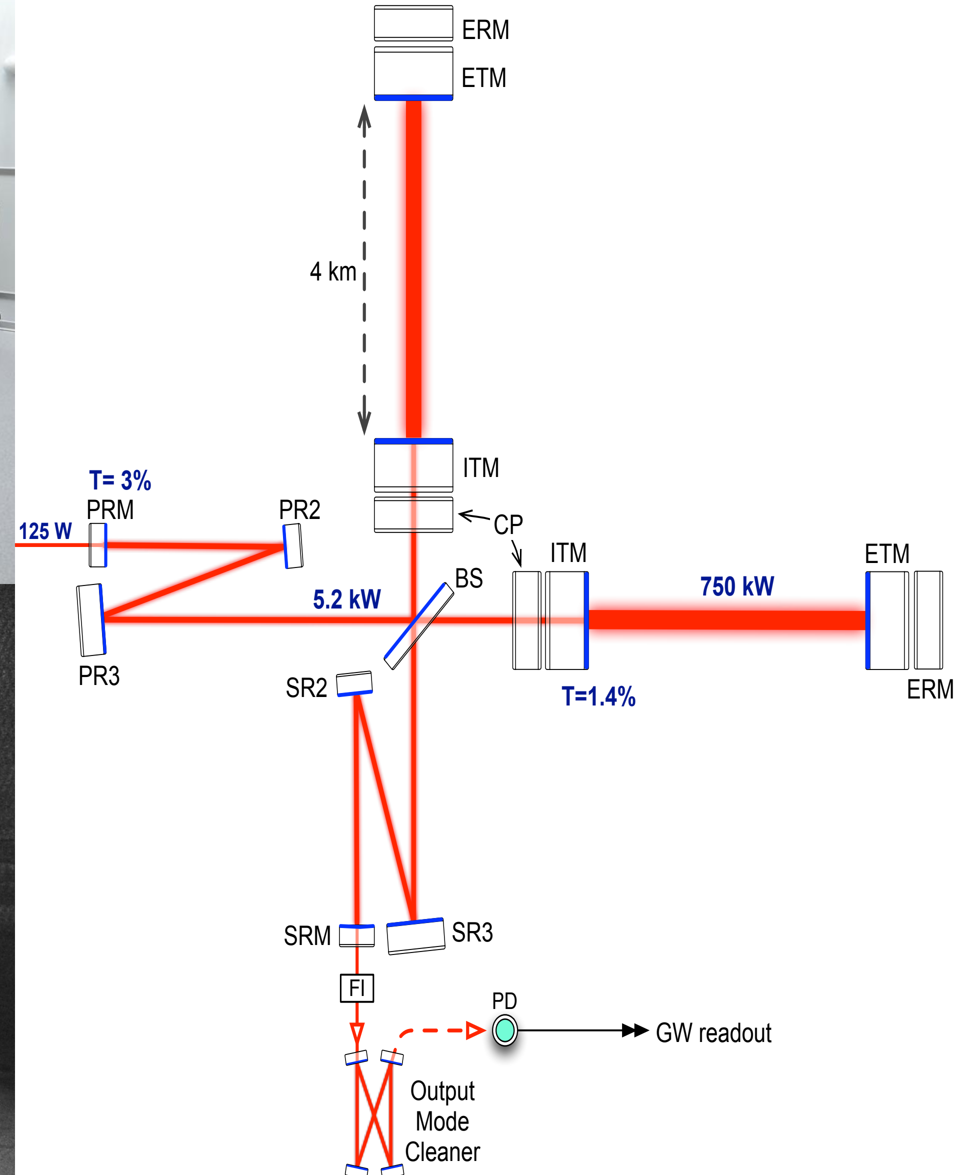
Theory and modeling required to exploit BBH and BNS detections

Investment of time & resources from EM community

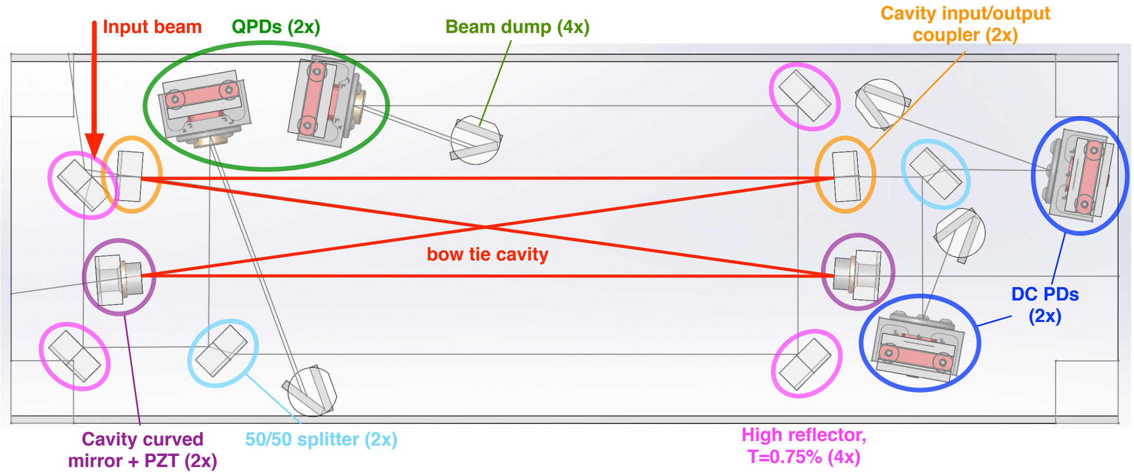
Supplemental Slides

Quantum Noise Reduction: 10x Laser Power, Larger Mirrors





Output Mode Cleaner

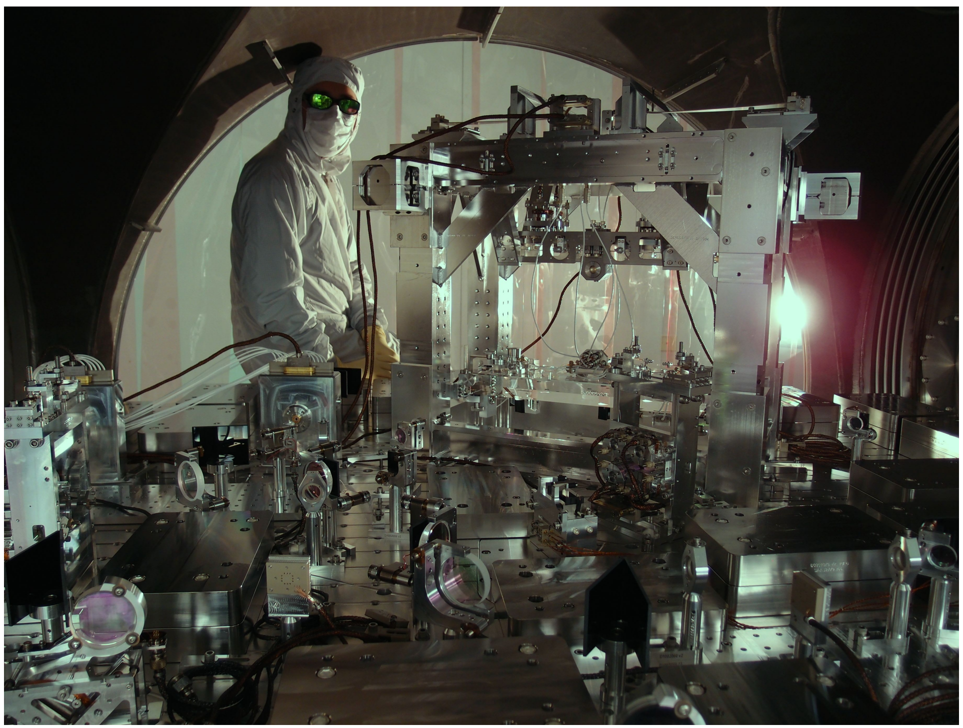


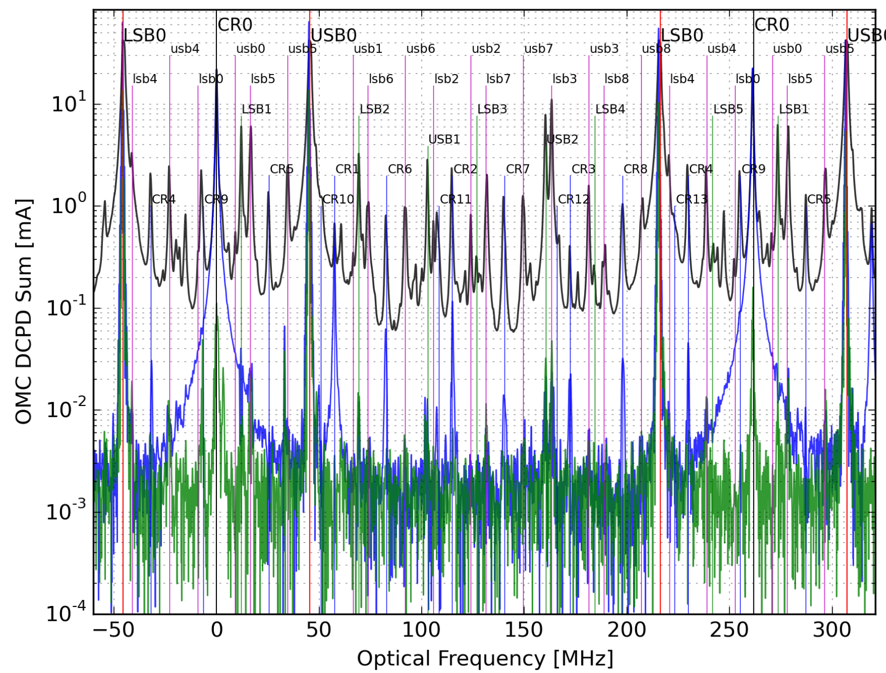
By K. Arai et al., T1000276

Finesse: 390, FSR: 261 MHz
TMS spacing: 0.219 x FSR
PZT actuation range: 2.4 x FSR

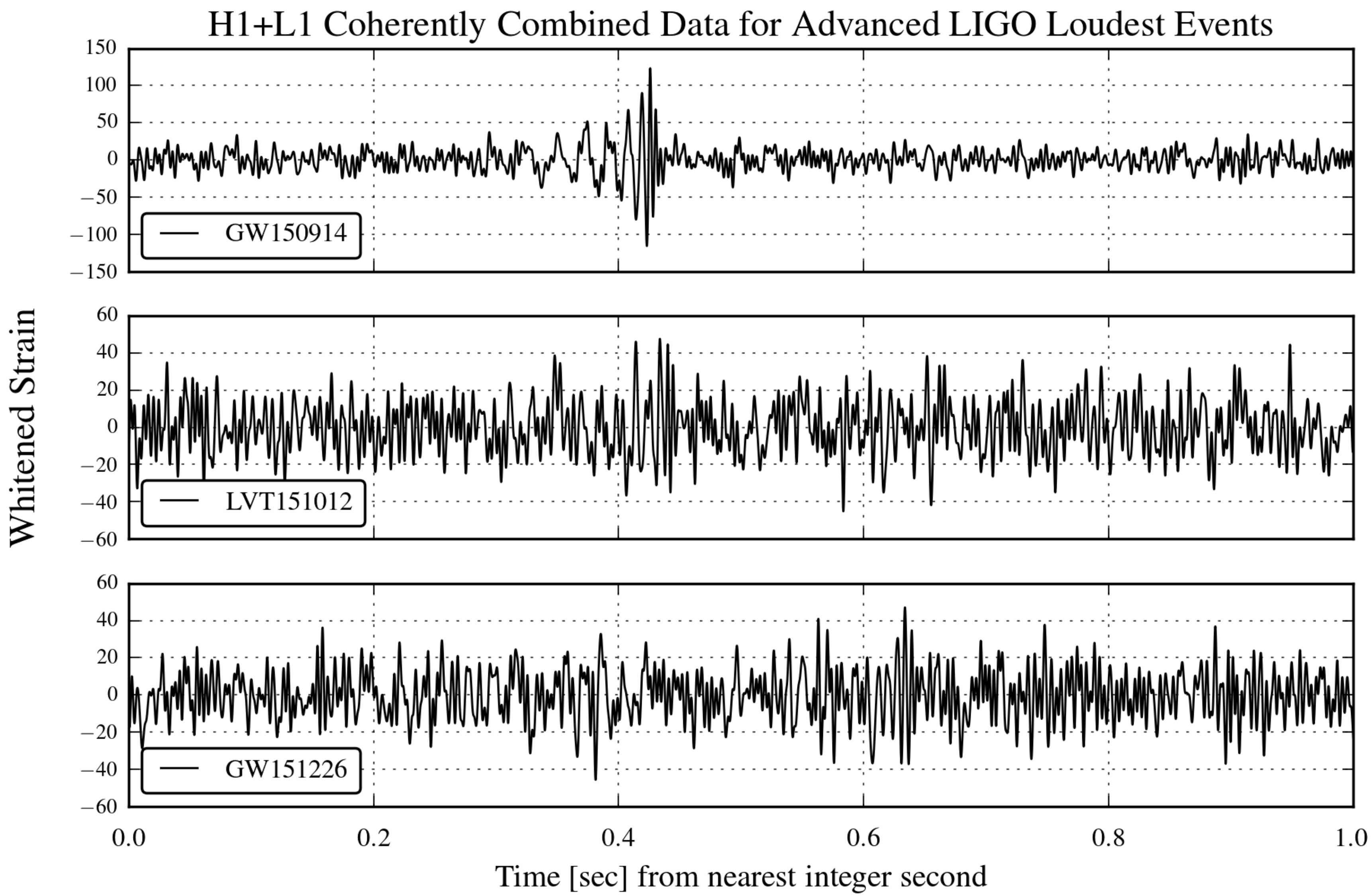
Results from mode scans in full lock:

- Carrier mode-matching ~99%
- Carrier contrast defect ~70ppm

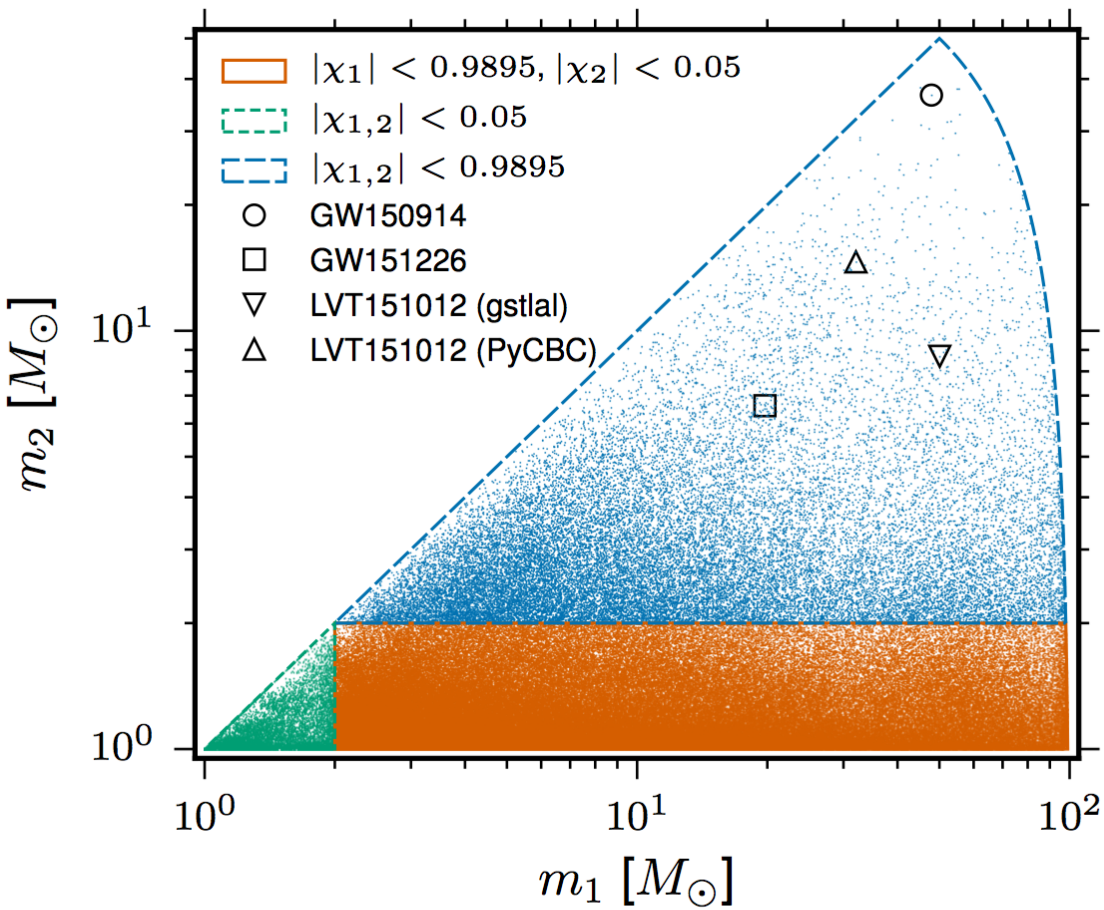




GW150914


H1+L1 Coherently Combined Data for Advanced LIGO Loudest Events
Whitened Strain
GW150914
LVT151012
GW151226
150
100
50
0
−50
−100
−150
60
40
20
0
−20
−40
−60
0.0
0.2
0.4
0.6
0.8
1.0
Time [sec] from nearest integer second

Template bank for CBC searches (detector-frame masses)



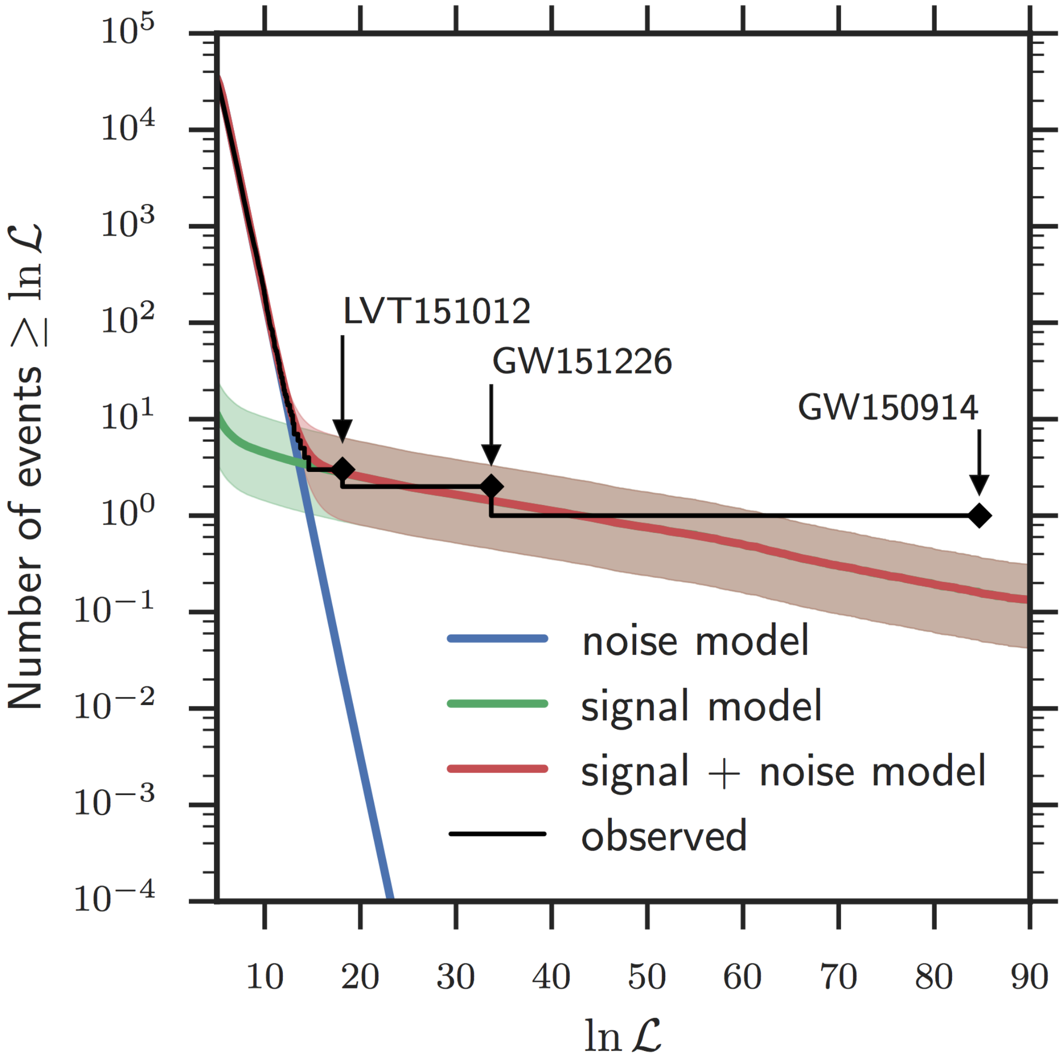
arXiv:1606.04856

BBH search results are binned by mass and spin. Templates with large mass, highly mismatched spin are sensitive to instrument artifacts.

The searches (pycbc, gstlal) require that the same template return the highest SNR in both detectors within the light travel time between the sites (10msec).

The event SNR is down-weighted in proportion to the chi-sq fit of the data to the waveform. Noise events don't match the waveform and are suppressed.

BBH Detection Rate

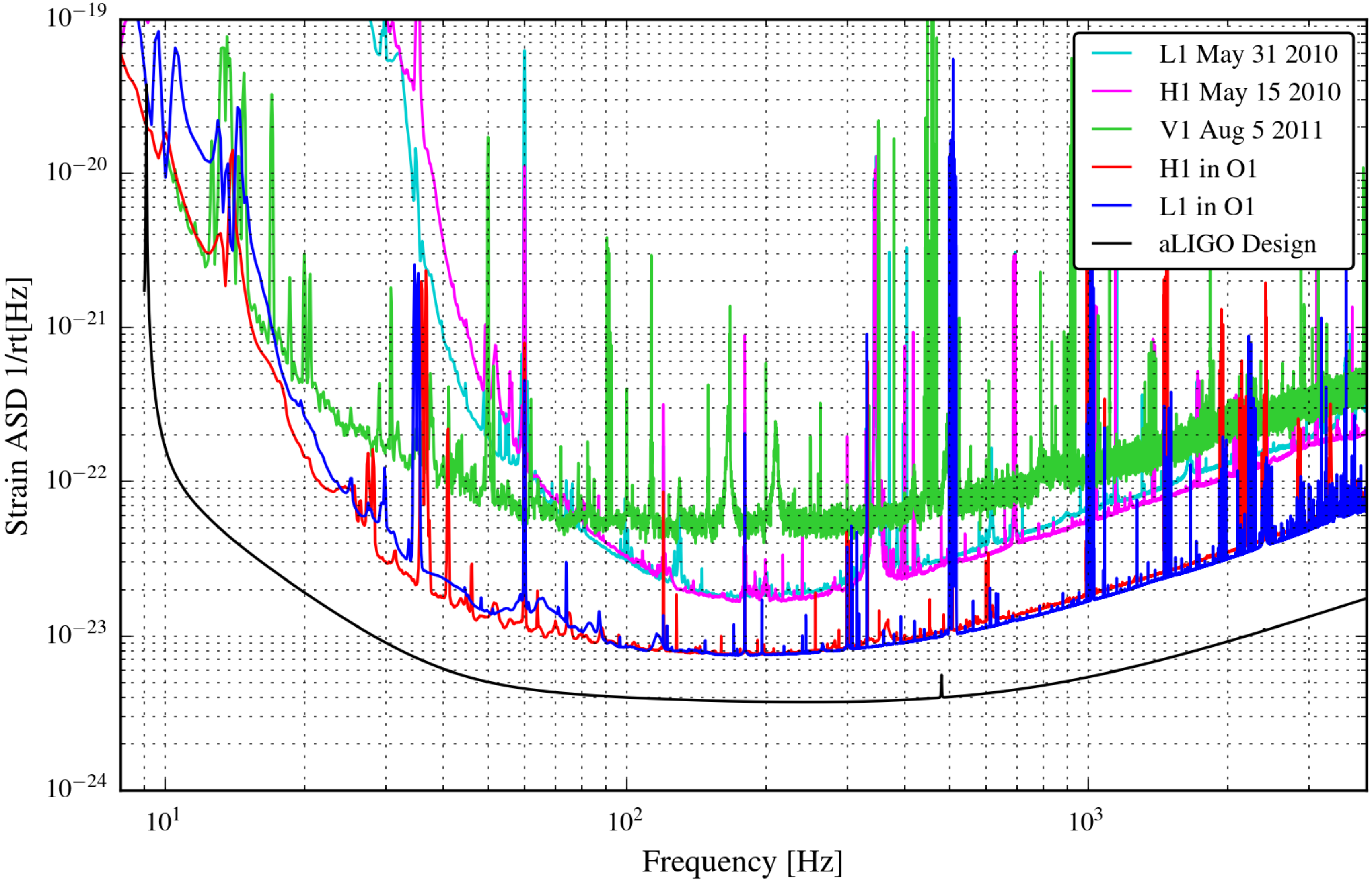


arXiv:1606.04856

We expect the rate of detections to be inversely proportional to the signal SNR. Beginning to see this with only 3 events.

GW150914 was a tremendous outlier - may take years to detect another signal as loud.

Sensitivity Improvement



Prospects for EM-Bright detections