

# LVK Status, June 2020

Keita Kawabe



# Big-ish picture

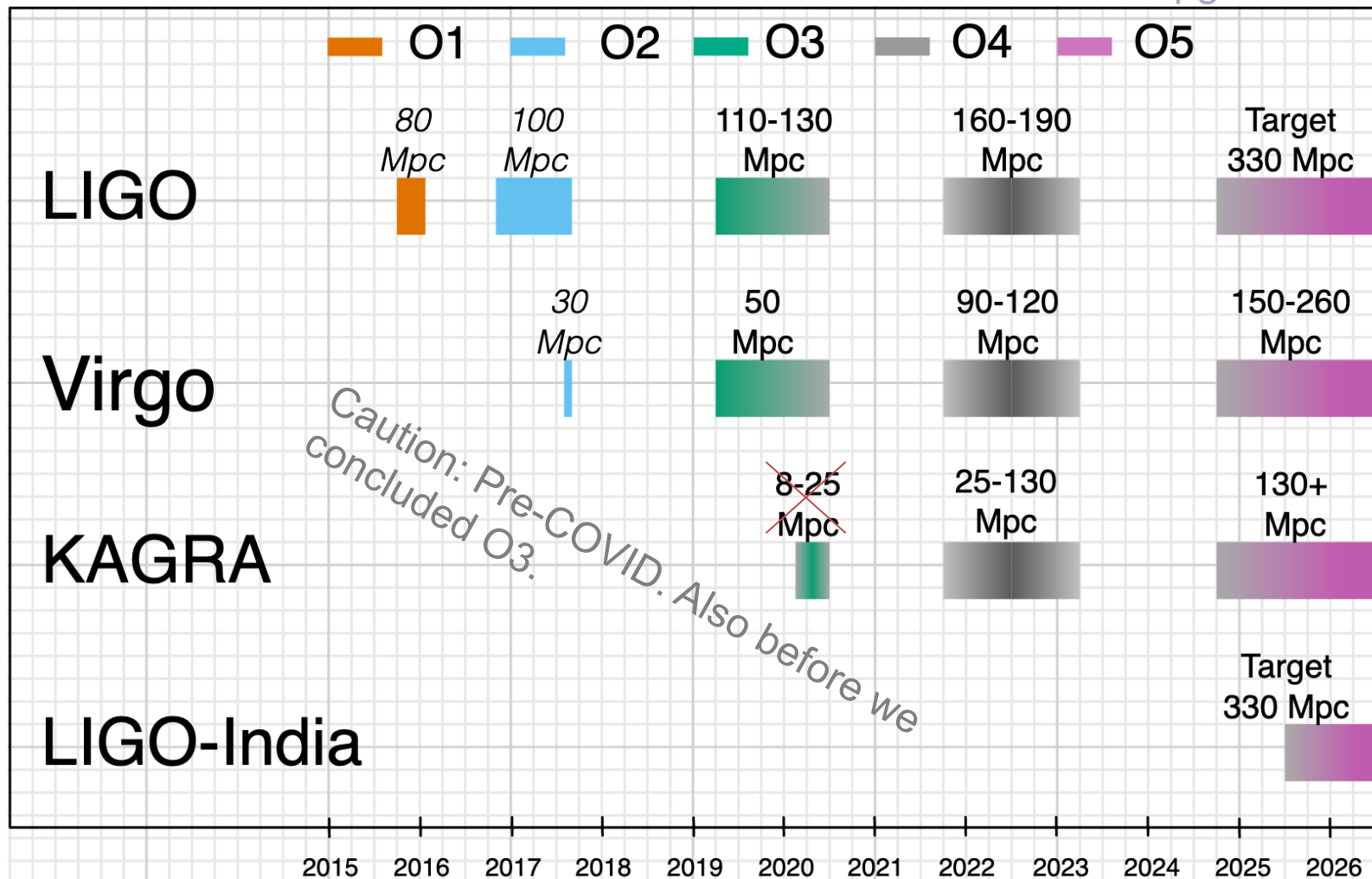
More discoveries,  
1<sup>st</sup> BNS, GW MMA era  
began.

Fix things, upgrades,  
some A+ elements in  
advance.

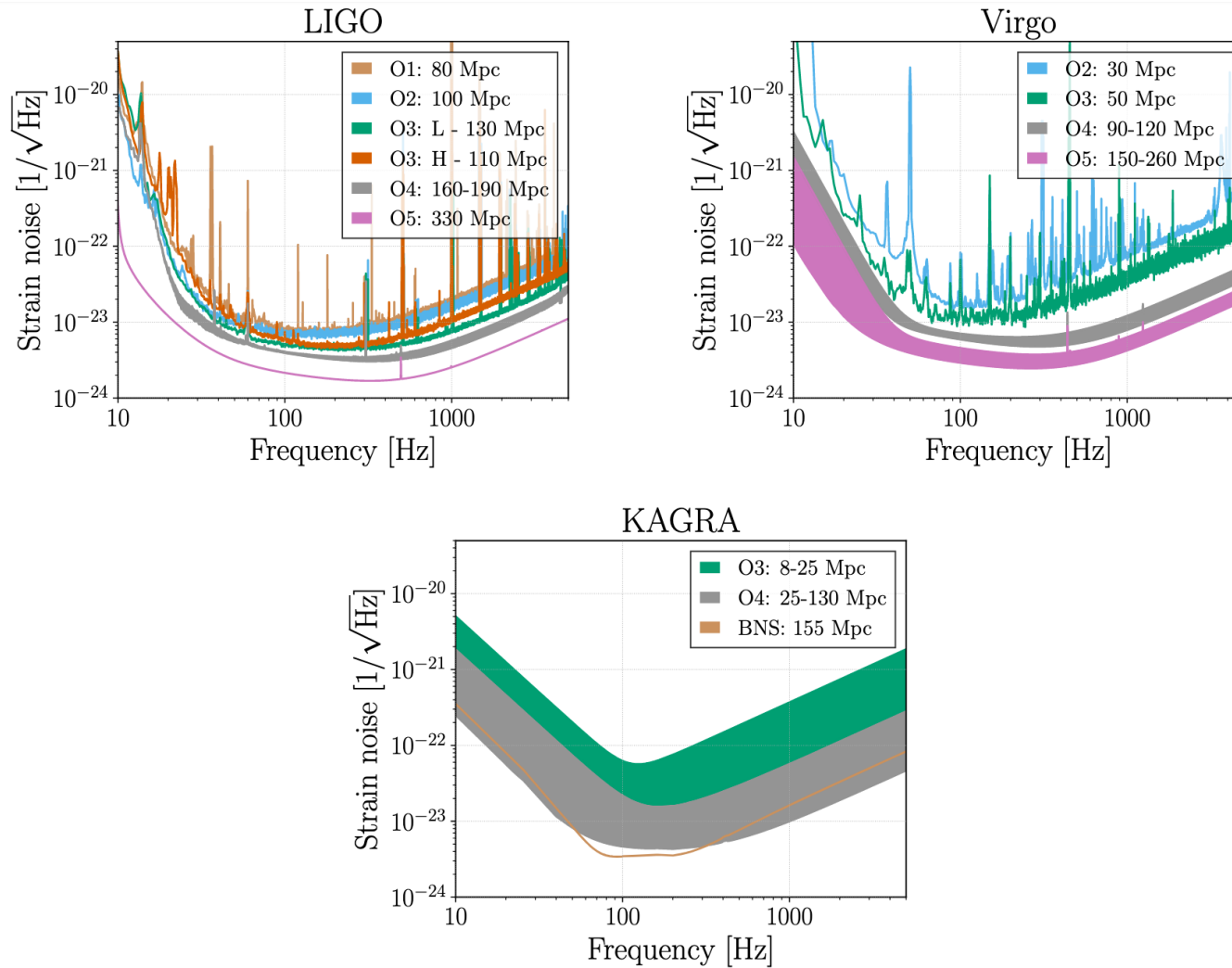
1<sup>st</sup> discoveries,  
All BBH.

Even more discoveries,  
low latency public alerts.

A+: The best LIGO could do  
with existing facility, many  
cool upgrades.



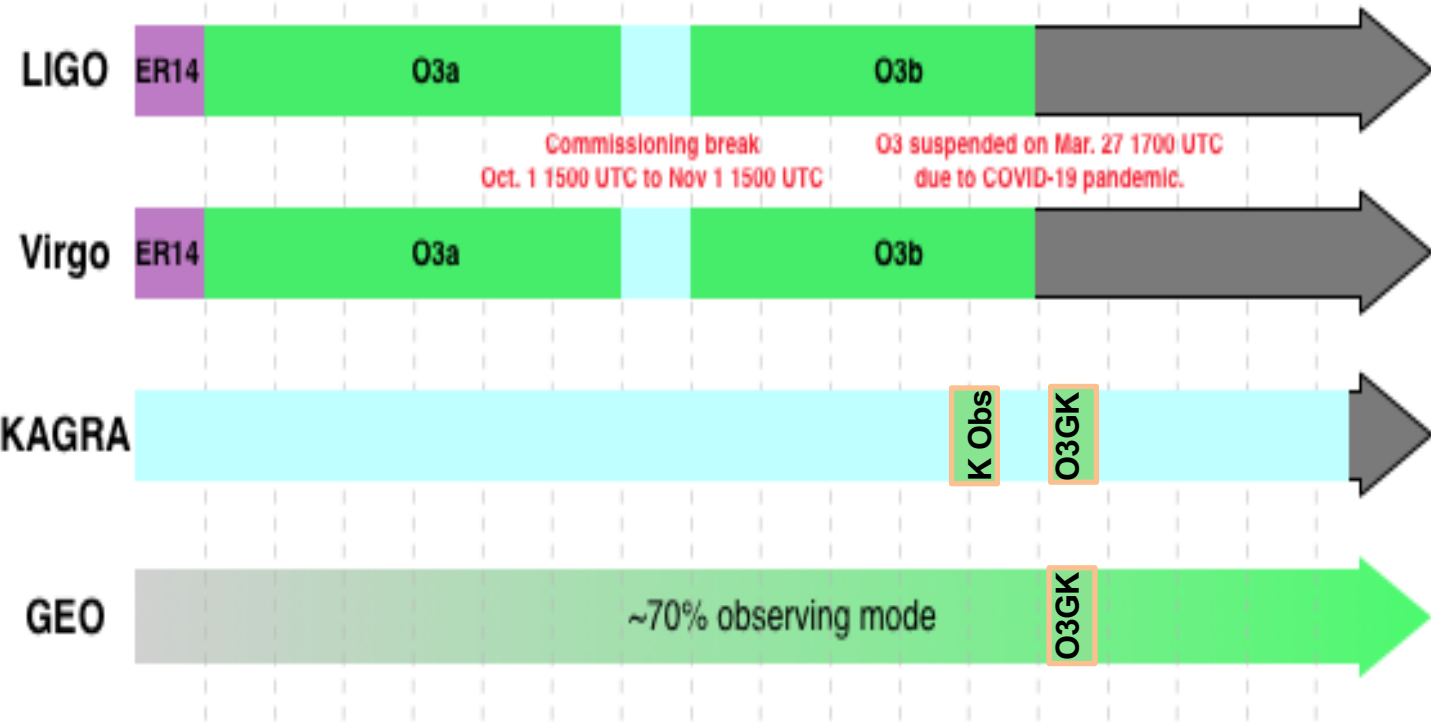
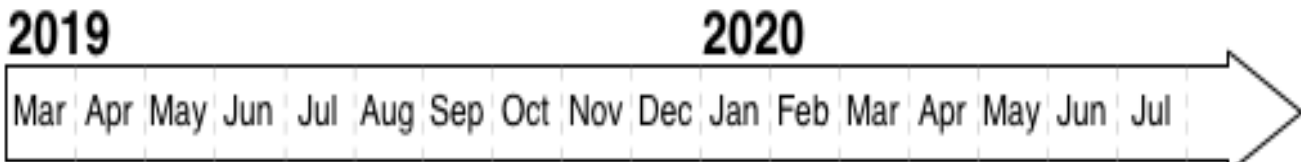
# (I'll skip this: Strain noise of the detectors for observation runs past and future)






# I'll talk about

- LIGO-centric report of O3.
- Future, COVID, how LIGO, Virgo and KAGRA are working (or not).

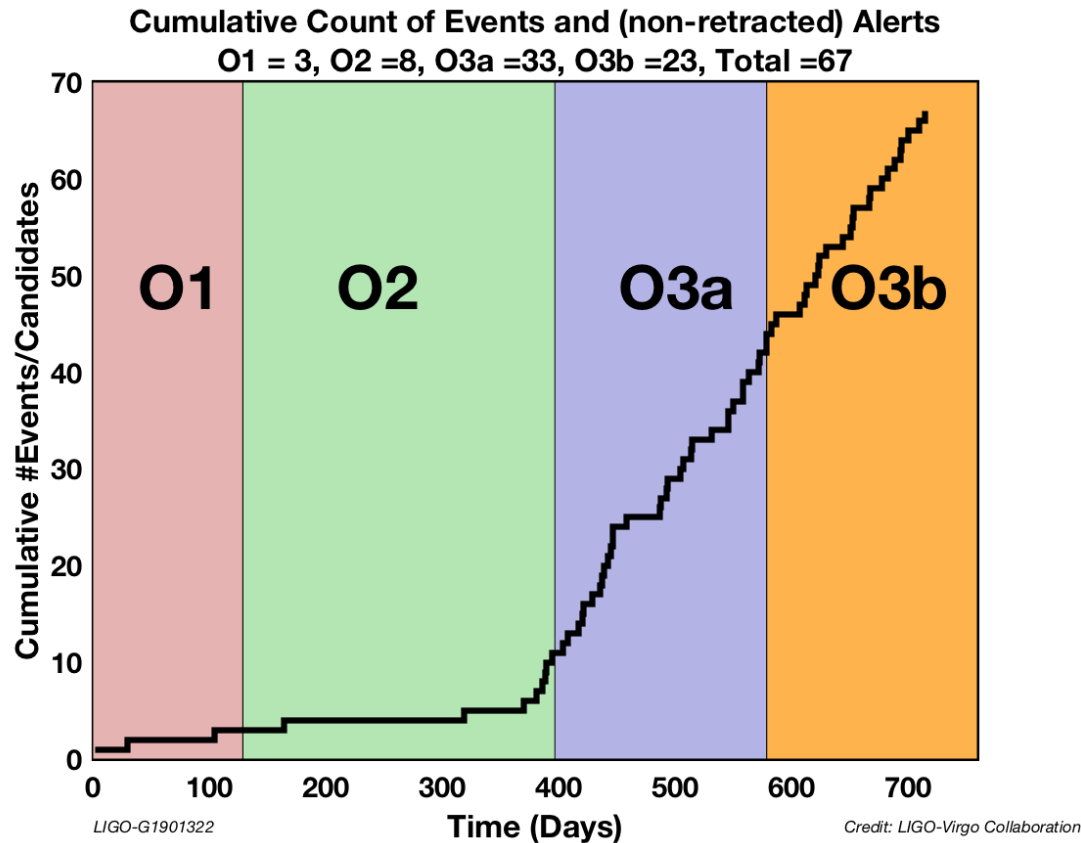
# O3 timeline



- **O3 began April 1, 2019**
- **1 month commissioning break in October 2019.**
- Was scheduled to end on **April 30, 2020.**
- **Suspended** due to COVID-19 on **March 27, 2020.**
- KAGRA observation Feb. 25 – Mar. 10, 2020 (not a part of O3.)
- GEO-KAGRA short run **O3GK, Apr. 7-21, 2020.**
- June 18, 2020: Decision **not to pursue resuming O3.**

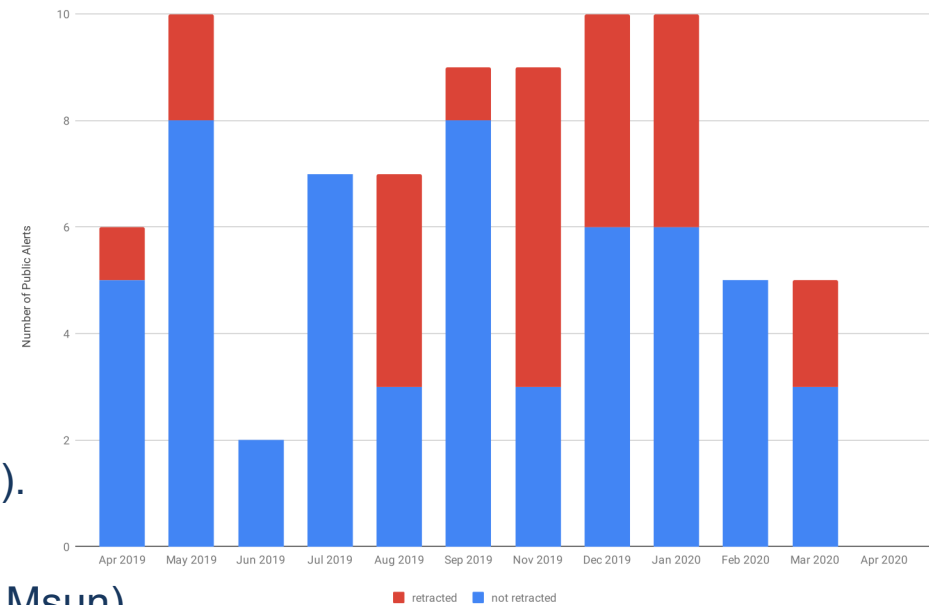
	Engineering Runs (ERs), possible GW alerts with human vetting		Observing
	Commissioning		Downtime (no Data)

# O3: A great success! Many public alerts, many discoveries.



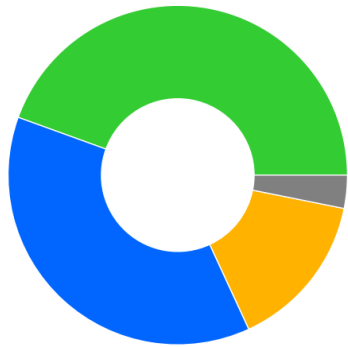
<b>Total Public Alerts in O3</b>	<b>80</b>
<b>Not Retracted</b>	<b>56</b>
<b>Retracted</b>	<b>24</b>

O3 Public Alerts (to date) by Month



- [GW190412](#): Large mass ratio BBH (~30 and ~8 Msun).
- [GW190425](#): Likely BNS @ ~ 160+-70 Mpc.
- [GW190814](#): “Mass gap” event (~2.6+-0.1 and ~23+-1 Msun).
- GW190521 near future.
- O3a catalog near future.

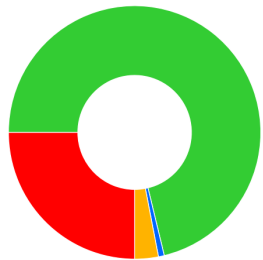
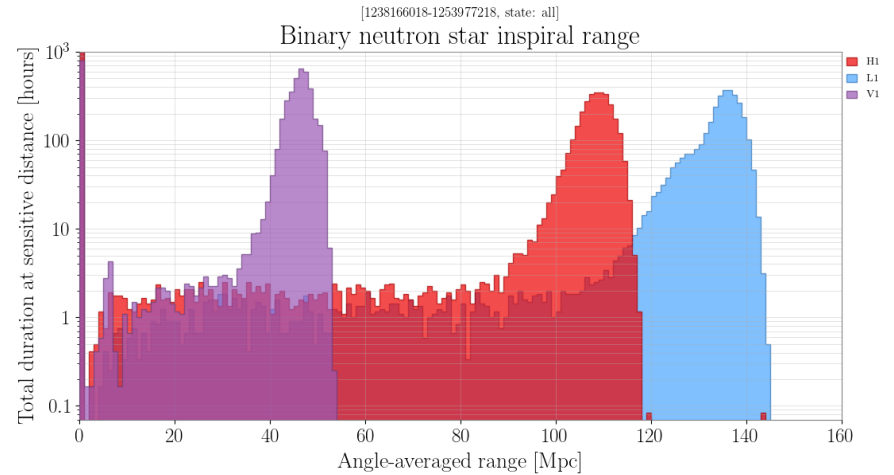
# O3a Performance



Network duty factor

[1238166018-1253977218]

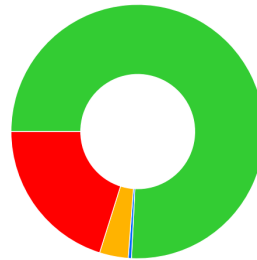
- Triple interferometer [44.5%]
- Double interferometer [37.4%]
- Single interferometer [15.0%]
- No interferometer [3.2%]



H1 operational state

[1238166018-1253977218, state: all]

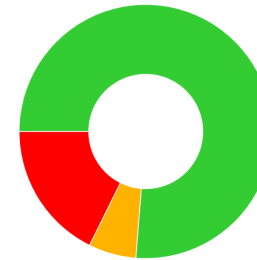
- Observing [71.2%]
- Ready [0.7%]
- Locked [3.0%]
- Not locked [25.0%]



L1 operational state

[1238166018-1253977218, state: all]

- Observing [75.8%]
- Ready [0.4%]
- Locked [3.7%]
- Not locked [20.1%]

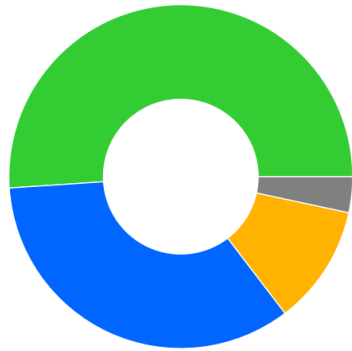


Virgo operational state

[1238166018-1253977218, state: all]

- Observing [76.3%]
- Locked [6.1%]
- Not locked [17.7%]

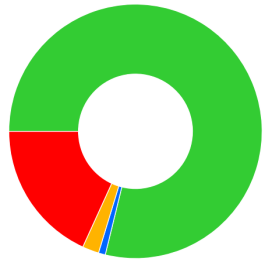
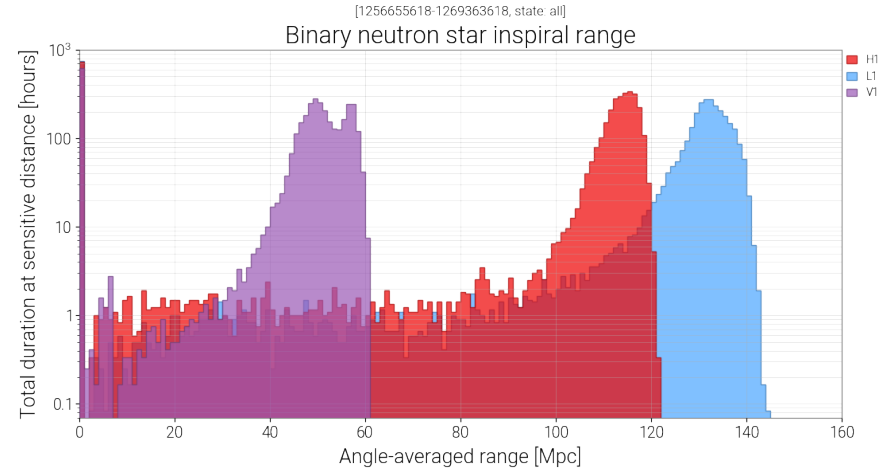
# O3b Performance



Network duty factor

[1256655618-1269363618]

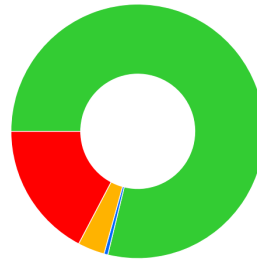
- Triple interferometer [51.1%]
- Double interferometer [34.3%]
- Single interferometer [11.3%]
- No interferometer [3.4%]



H1 operational state

[1256655618-1269363618, state: all]

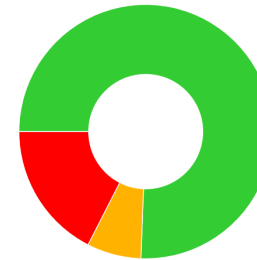
- Observing [78.8%]
- Ready [0.9%]
- Locked [2.1%]
- Not locked [18.2%]



L1 operational state

[1256655618-1269363618, state: all]

- Observing [78.8%]
- Ready [0.5%]
- Locked [3.4%]
- Not locked [17.3%]



Virgo operational state

[1256655618-1269363618, state: all]

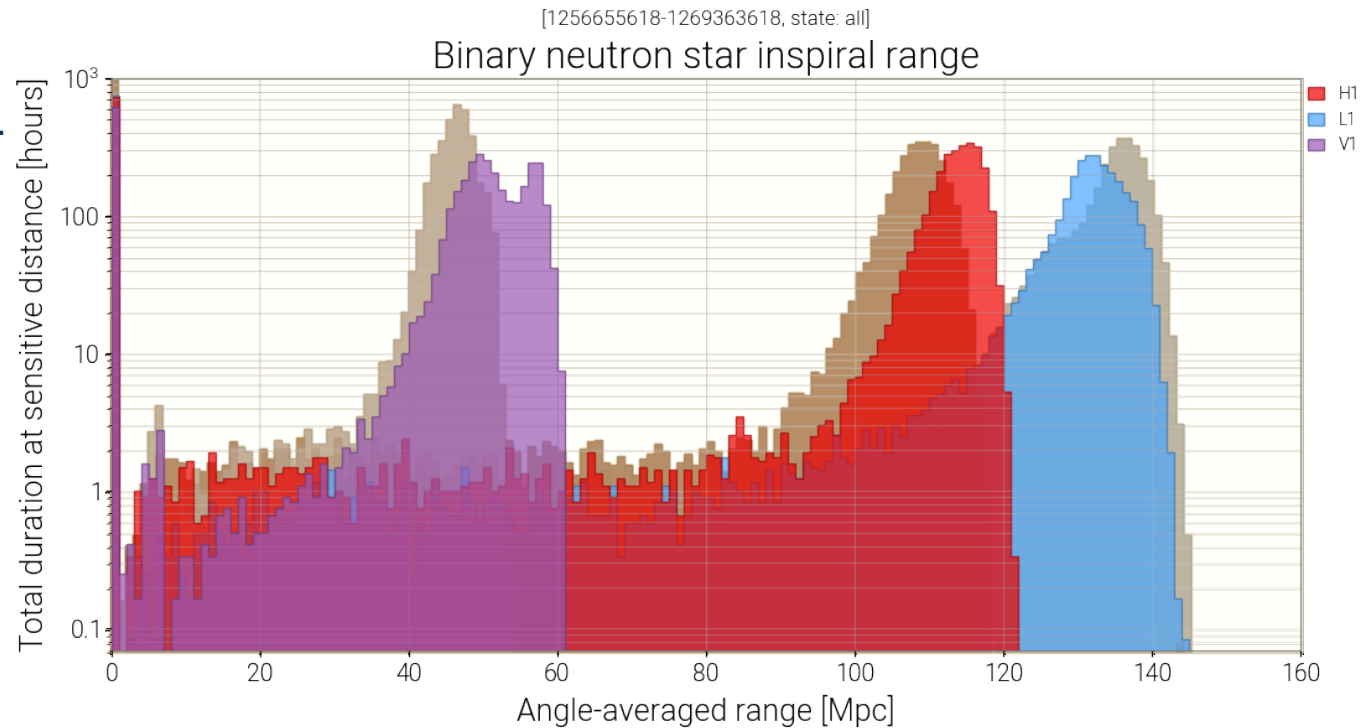
- Observing [75.6%]
- Locked [6.9%]
- Not locked [17.5%]

(KAGRA BNS range ~600kpc in Feb-Mar, 700k~1Mpc in O3GK)

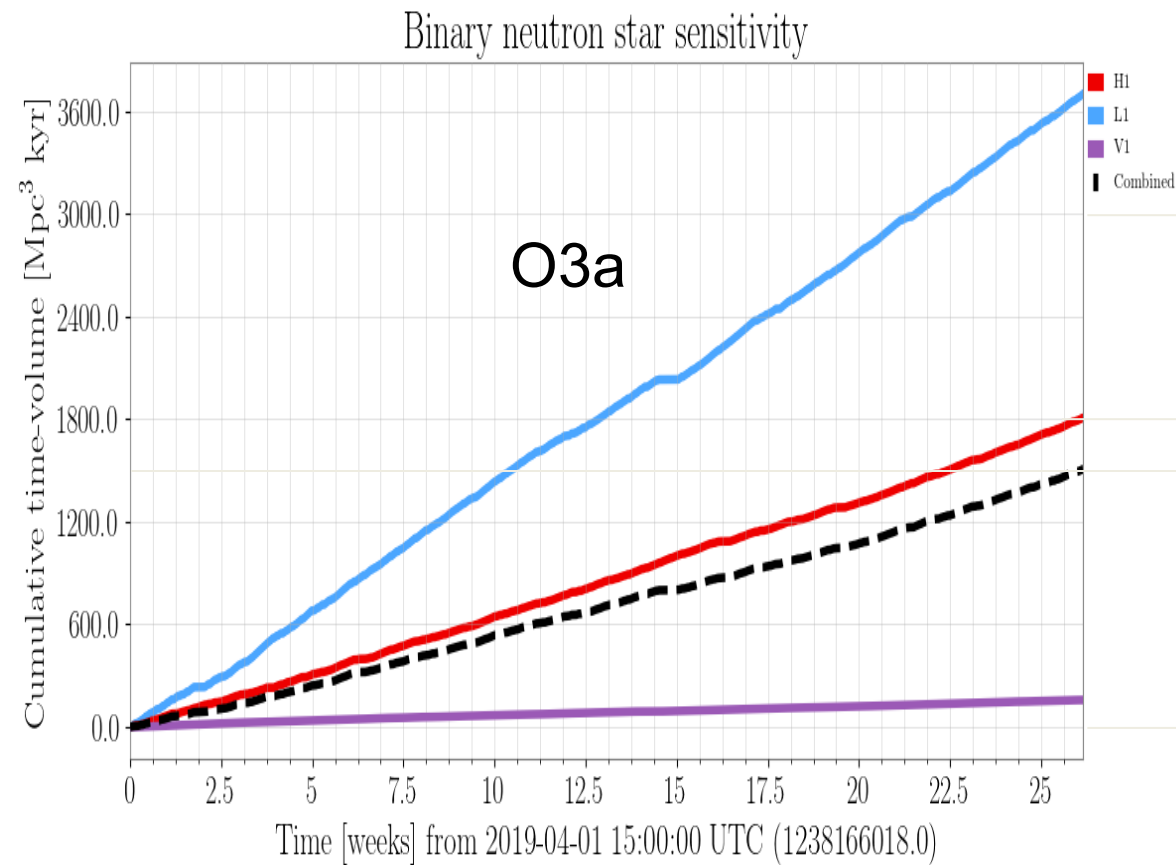


# October Commissioning Break Impact

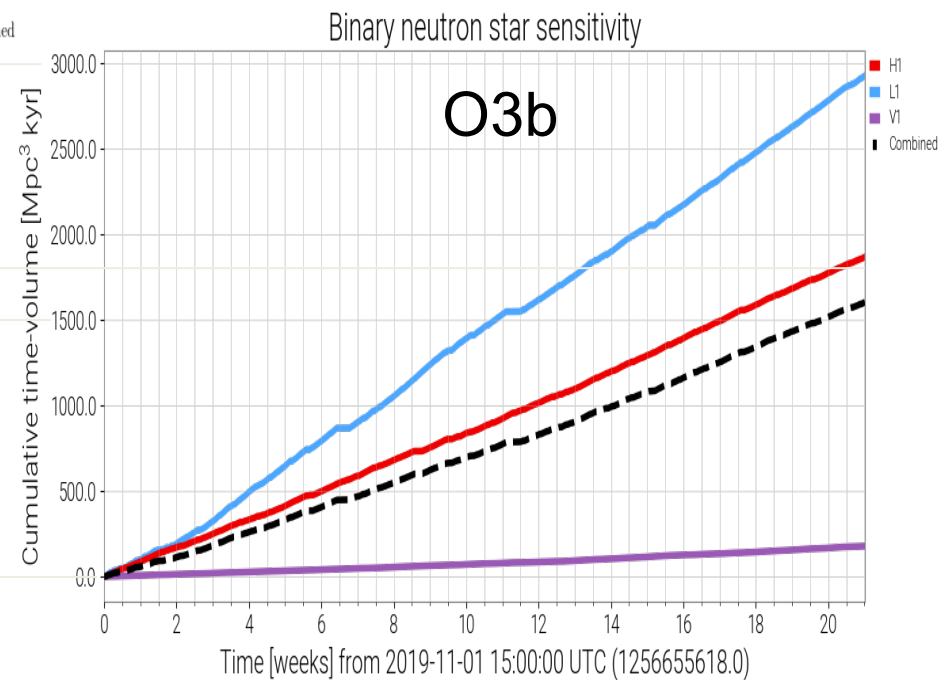
- V1 range improved.
- H1 range improved:
  - Various SQZ improvements.
  - Other tunings (e.g. spot position)
- L1 range reduced:
  - New point absorbers appeared which limited power buildup in the arms.
  - Some of the lost sensitivity was recovered by improved tuning of the squeezer.
- Some other improvements (e.g. glitch rate), see bonus slides, Jenne's talk, Detchar talks.



# Still a win: More BNS volume-time coverage in less than 5 months (148.08 days) than in 6 months (183 days).

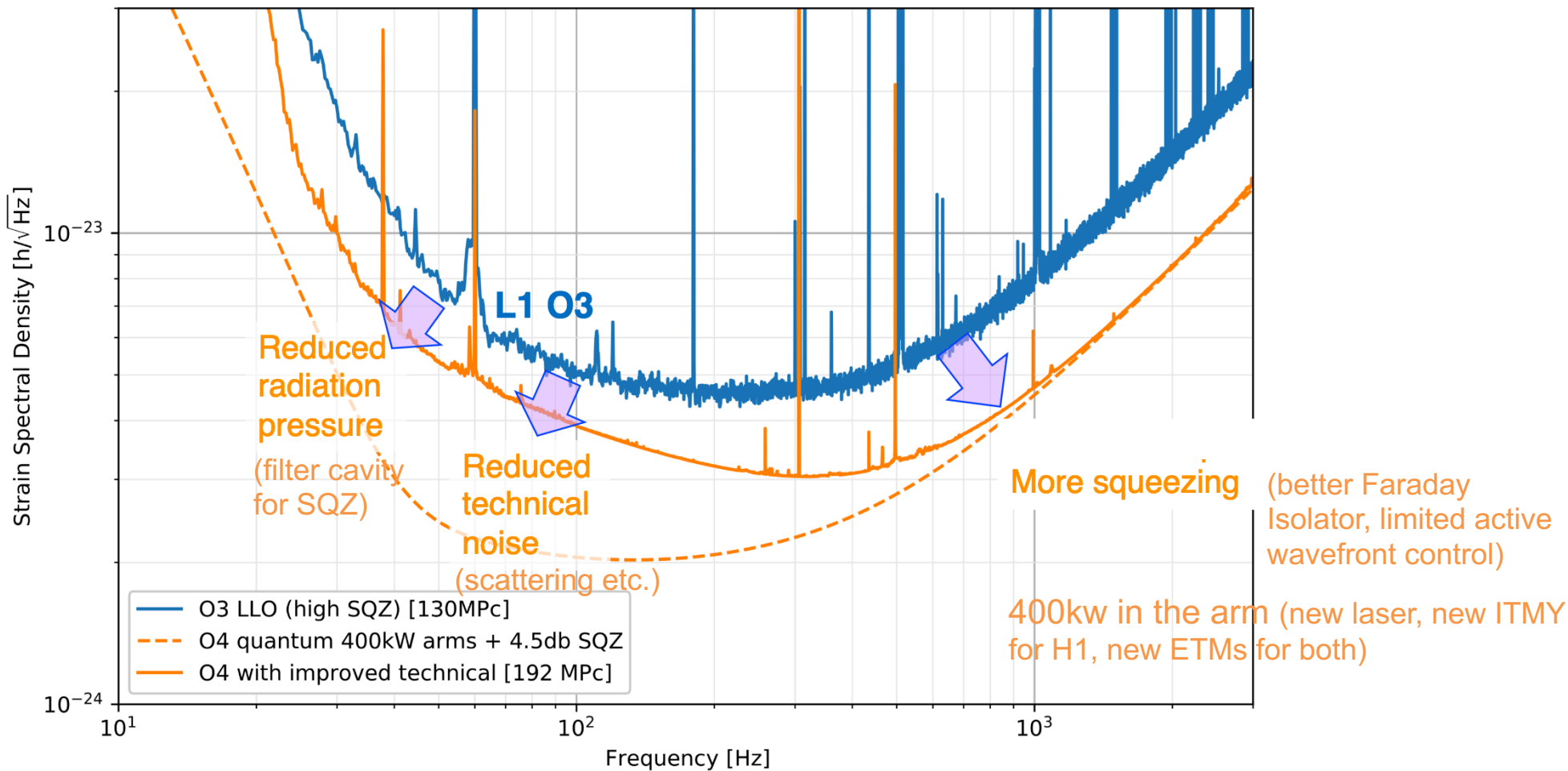


April 2020



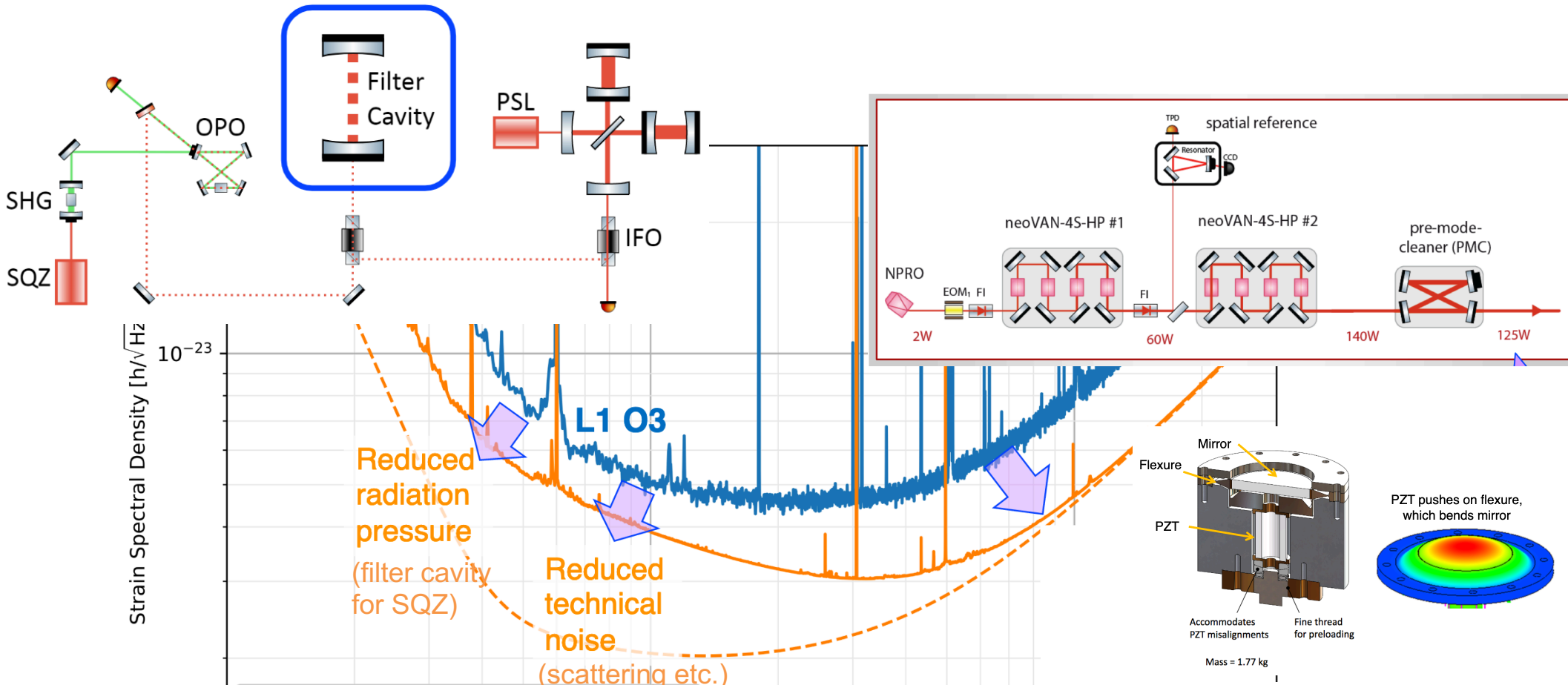
'EM, 02

# O4: This is what LIGO wants to implement.



New mirrors, a bunch of technical upgrades.

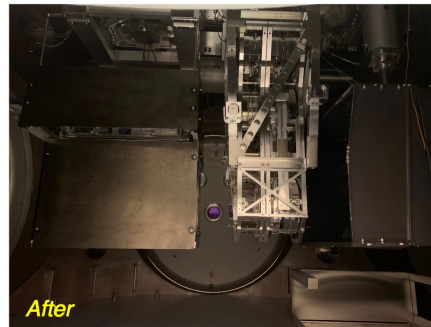
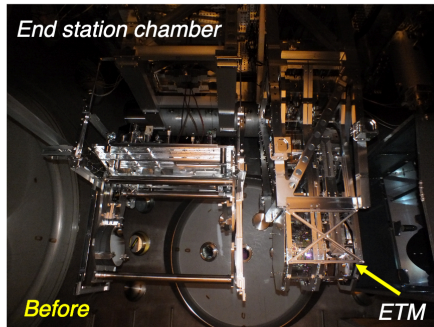
*FC Simple cartoon :*



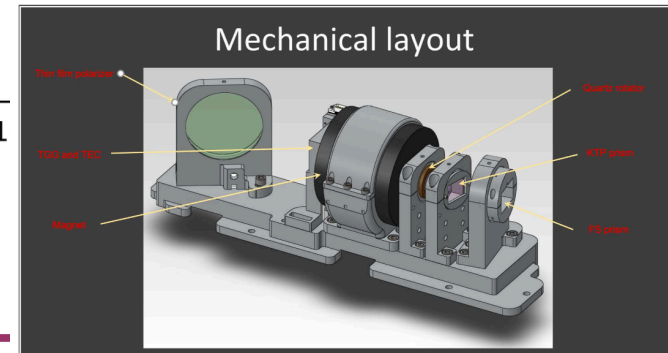
Shroud around ETM Transmission Monitor

1 installed, 3 more to go

Just one example of additional baffles for O4



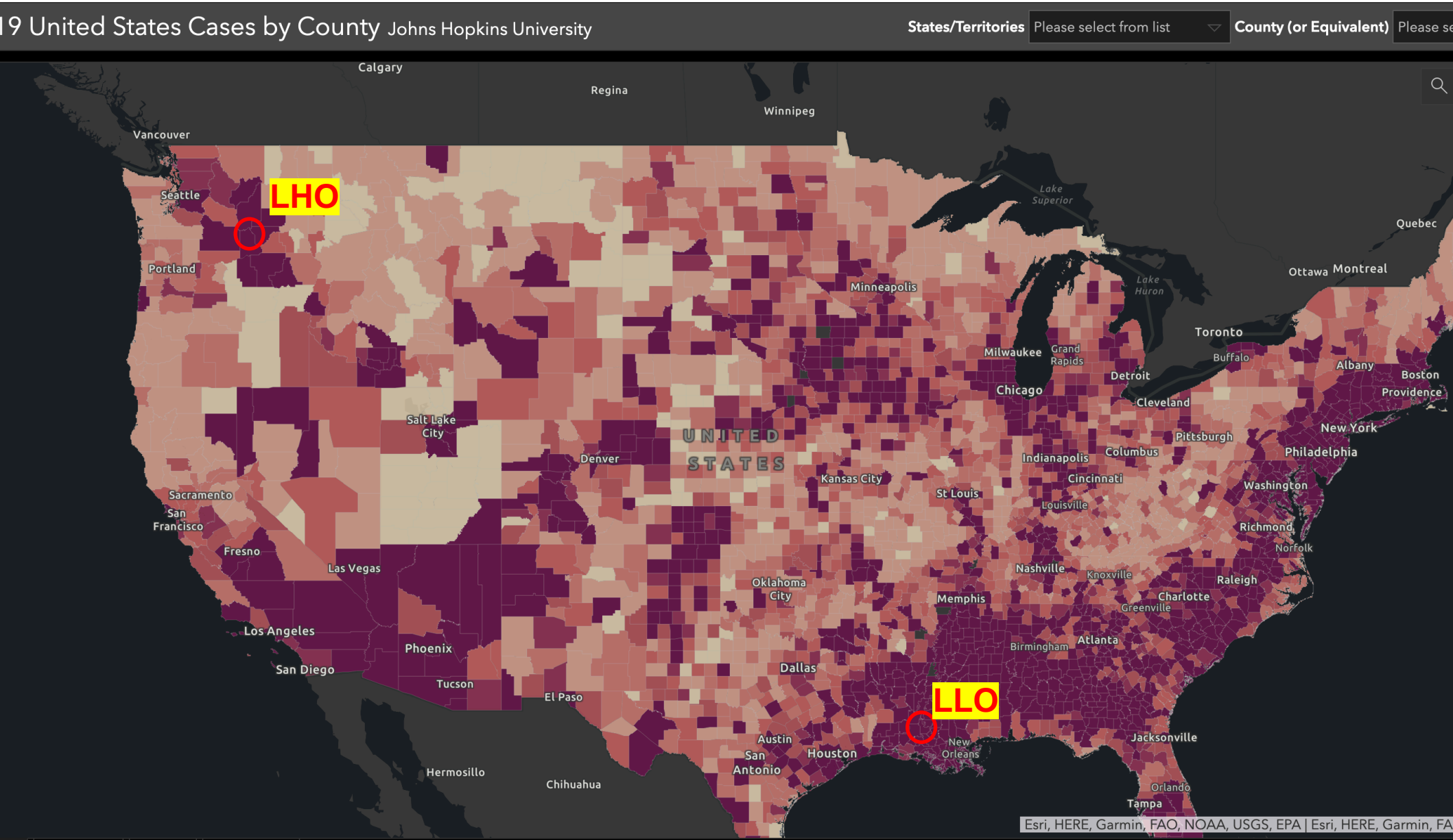
Output Faraday Isolator



# But, COVID.

- O3 was cut short by 1 month.
- LHO and LLO: LIGO-Phase 3 ([L2000119](#)) as of now, i.e. still shut down. No site activities except to maintain the integrity of the detector and the observatory facilities.
  - WA: Benton and Franklin Co (LHO): 2 of 3 Counties in WA that is still in WA Phase 1 (most restrictive).
  - Louisiana (LLO): State-wide Phase 2 since June 5 (one step looser than Phase 1). On June 22, transition to Phase 3 was postponed for at least 22 days.

# LIGO locations on COVID map.

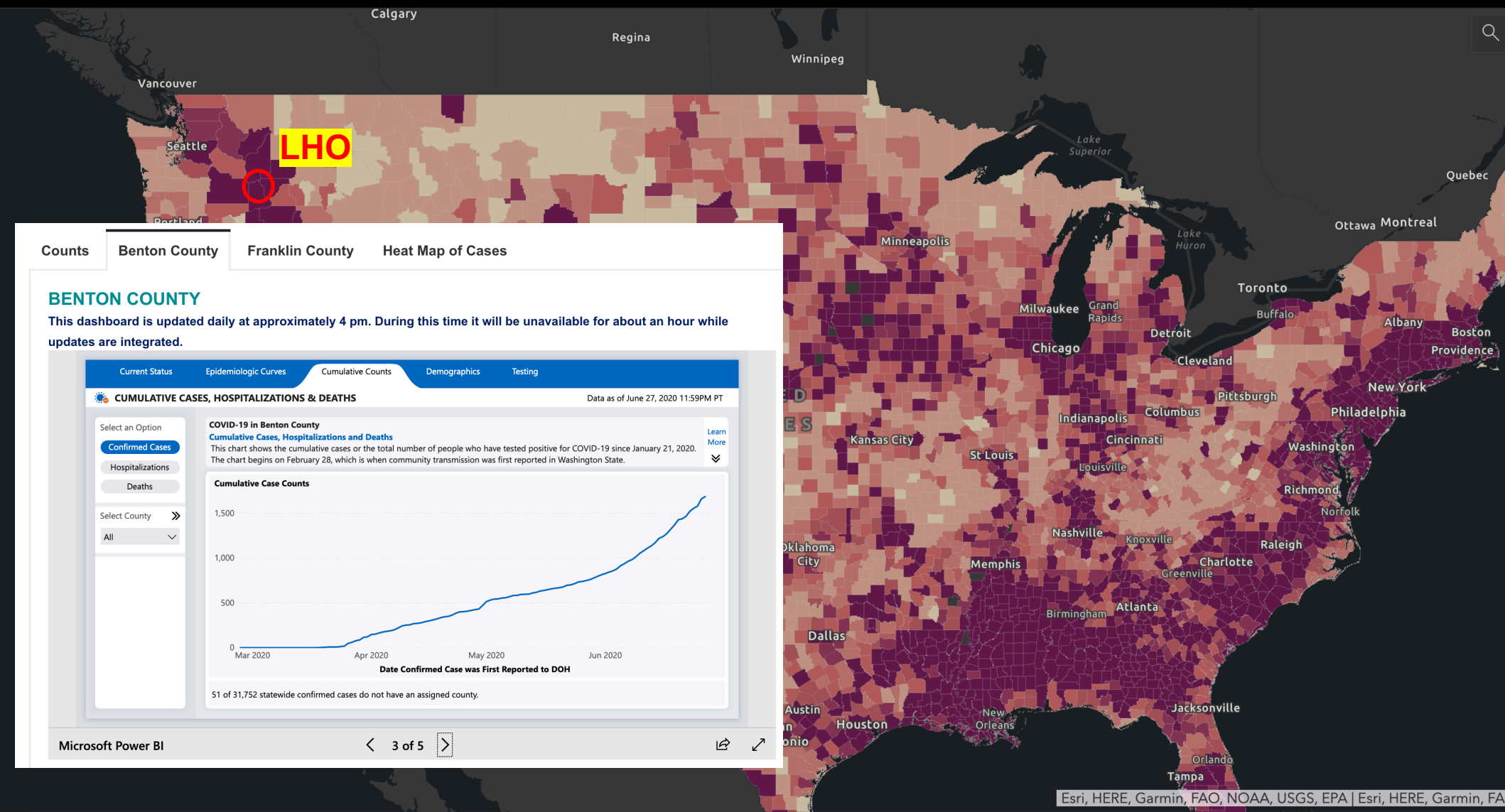


# 1<sup>st</sup> wave isn't gone at LHO

19 United States Cases by County Johns Hopkins University

States/Territories Please select from list

County (or Equivalent) Please select from list



It will take some time until we flatten the curve here. But we'll do it eventually.

19 United States Cases by County Johns Hopkins University

States/Territories Please select from list County (or Equivalent) Please select from list

Calgary Regina Winnipeg Vancouver Seattle Portland

**LHO**

Counts Benton County Franklin County Heat

**BENTON COUNTY**

This dashboard is updated daily at approximately 4 pm. During updates are integrated.

Current Status Epidemic Curves Cumulative Counts

**CUMULATIVE CASES, HOSPITALIZATIONS & DEATHS**

Select an Option

Confirmed Cases

Hospitalizations

Deaths

Select County

All

**COVID-19 in Benton County**

**Cumulative Cases, Hospitalizations and Deaths**

This chart shows the cumulative cases or the total number of cases. The chart begins on February 28, which is when community transmission began.

**Cumulative Case Counts**

1,500

1,000

500

0

Mar 2020 Apr 2020 May 2020 Jun 2020

Date Confirmed Case was First Reported to DOH

51 of 31,752 statewide confirmed cases do not have an assigned county.

Microsoft Power BI

3 of 5

TRI-CITIES INDEPENDENCE DAY

July 5<sup>TH</sup>

“WE THE PEOPLE” PACK COLUMBIA PARK

On July 5<sup>th</sup>, please bring family, friends, neighbors, and strangers to Columbia Park to bring back the POWER TO THE PEOPLE. This day of government defiance will be remembered as “TRI-CITIES INDEPENDENCE DAY”. Play games, go swimming, fishing, use the playground, or enjoy a nice picnic; the important thing is you’re there. Please repost this, take a picture, and send to everyone you know.

On Monday, July, 6<sup>th</sup>, we will return these beautiful cities back to their working order. **Please open up your small businesses, they will be heavily supported.** Do not require face masks in any

Ottawa Montreal Quebec Toronto Buffalo Albany Boston Providence New York Philadelphia Washington Richmond Norfolk Dallas Memphis Nashville Knoxville Raleigh Charlotte Greenville Atlanta Birmingham Dallas Austin Houston New Orleans Jacksonville Orlando Tampa

Esri, HERE, Garmin, FAO, NOAA, USGS, EPA | Esri, HERE, Garmin, FAO, NOAA, USGS, EPA



# Impact on O4 (BNS 160~190Mpc) and A+ (BNS ~330Mpc target).

- Day-by-day schedule slip. May/June are already gone, at least a few weeks of July too.
- No solid date for LIGO-Phase 2 transition yet.
  - LIGO MIGHT be able to transition without waiting for State- or County-level transition, though that's not preferred.
- Even in LIGO-Phase 2, work won't be as efficient due to physical distancing and limited number of people in chamber etc.
- People are making plans e.g. safety guideline, modified work protocol etc. to transition to Phase 2, modify installation schedule etc.
- Both LHO and LLO will first resurrect H1 and L1 to O3-level. Jenne's talk about LHO status.

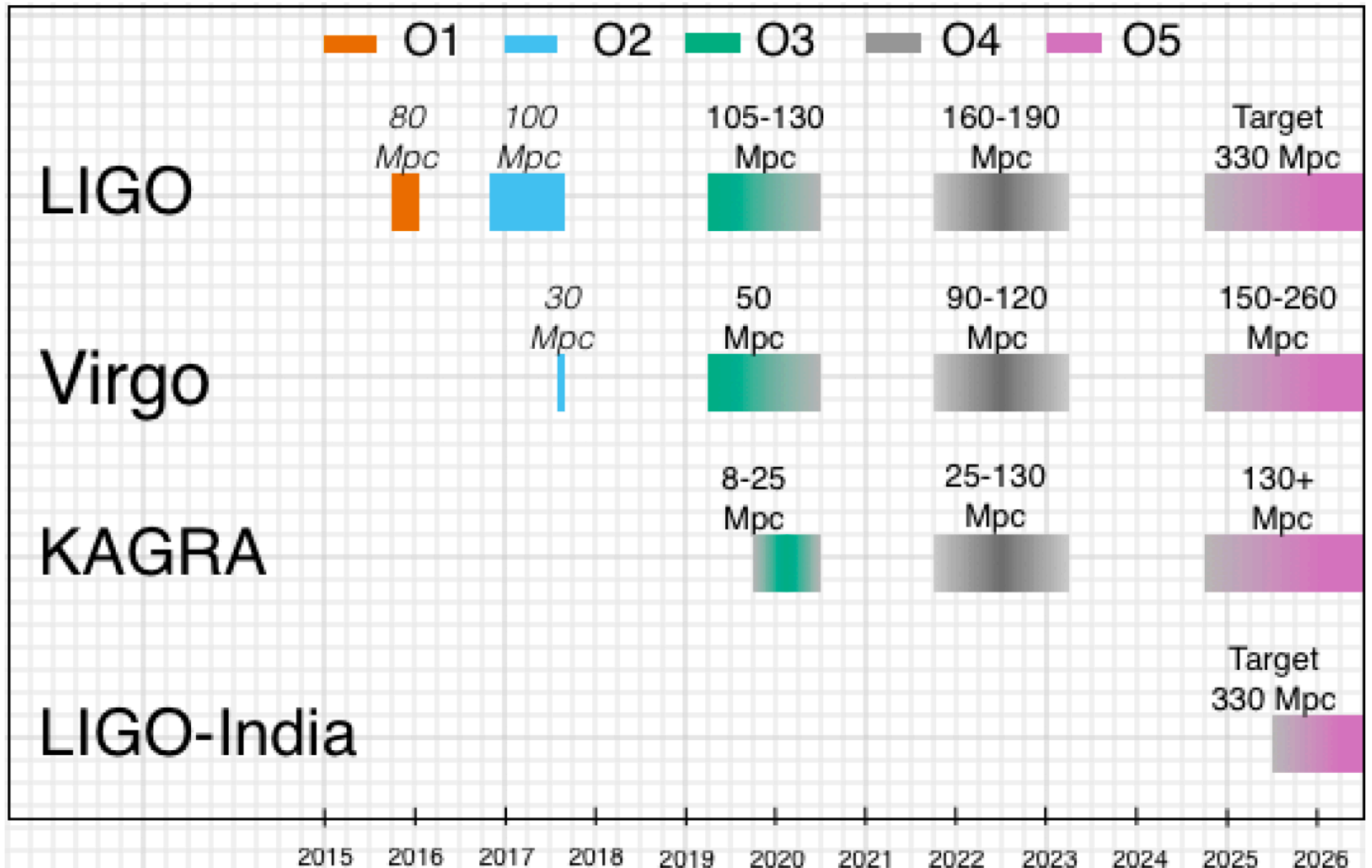
# Virgo in Italy. Saner.

- Situation is improving every week. People are working at the site.
- Adding Signal Recycling (or RSE)
  - Mirror arrived, gluing spacers and magnets.
  - SR payload will be assembled and installed inside the tower at mid-July.
- Adding guided lock acquisition like LIGO/KAGRA
  - Components of the auxiliary laser system are in production; the first complete SHG system should be ready and tested by end July to be installed in one terminal building;
- Infrastructure works for Frequency Dependent Squeezing (filter cavity etc.) are in progress.
  - Increasing the height of the tunnel for filter cavity (FC).
  - Central 150 m of the FC vacuum pipe have been installed.
  - All the other components (optics, mechanics, electronics) either are in production or have been ordered;

# KAGRA in Japan. Saner.

- U-Tokyo-Level 1 (30% of full capacity).
- Almost no new cases in Toyama, Japan, so 50% capacity is allowed at the site. Might loosen up further on July 6.
- O4 upgrade work starts in July.
  - Fixing/modifying all suspensions.
  - Dual Recycling with ASC (as opposed to no RSE, no full ASC).
  - Adding heater to cryostat.
  - Fixing leaks.
  - Adding baffles.
- Commissioning for sensitivity improvement scheduled from July 2021.

Pre-COVID Plan again. Lots of uncertainties. But we'll come back with greater performance than O3.



Thank you, let's listen to Jenne's LHO  
Status talk.



# Bonus: KAGRA

- A detector next to Super-K, Kamioka mine, Japan.
  - Cryogenic sapphire mirrors to reduce thermal noise.
  - Underground for smaller seismic displacement and seismic Newtonian noise.
- Everything installed, but no successful Signal Recycling (or rather Resonant Sideband Extraction) yet.
- **Cryogenic operation!**
  - Increased absorption at 30k and below: “Ice” layer of the residual gas molecules. Engineering solution under study.
  - This is an important problem to solve for **ALL 3G detectors**.
- Inhomogeneous birefringence of sapphire turns out to be a serious problem. Mitigation strategy under study.
- BNS range ~600kpc in observation, Feb 25-Mar 10, 2020. Didn't join O3 at this point.
- **O3GK** with GEO600, Apr 7-Apr 21 2020, 0.7~1Mpc(?).

# (Bonus: Squeezing)

PHYSICAL REVIEW LETTERS

Highlights Recent Accepted Collections Authors Referees Search Press About

Featured in Physics Editors' Suggestion Open Access

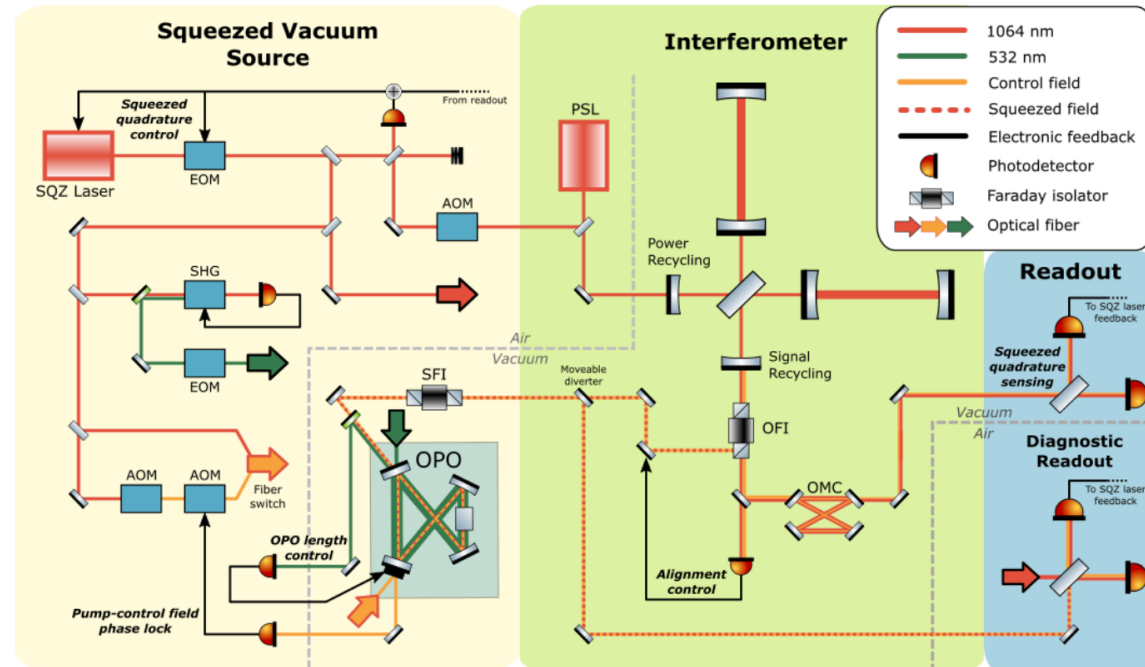
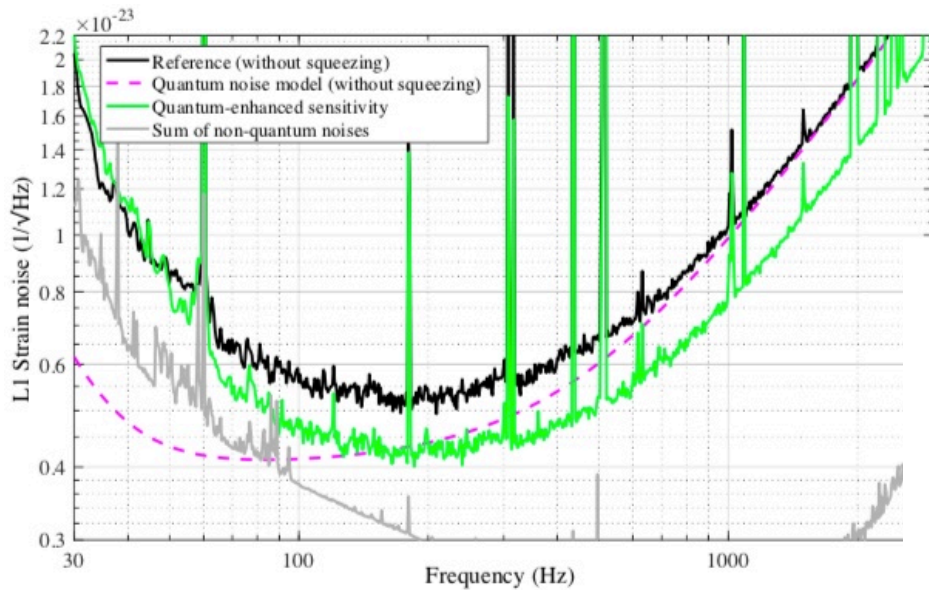
Quantum-Enhanced Advanced LIGO Detectors in the Era of Gravitational-Wave Astronomy

M. Tse *et al.*  
Phys. Rev. Lett. **123**, 231107 – Published 5 December 2019

299

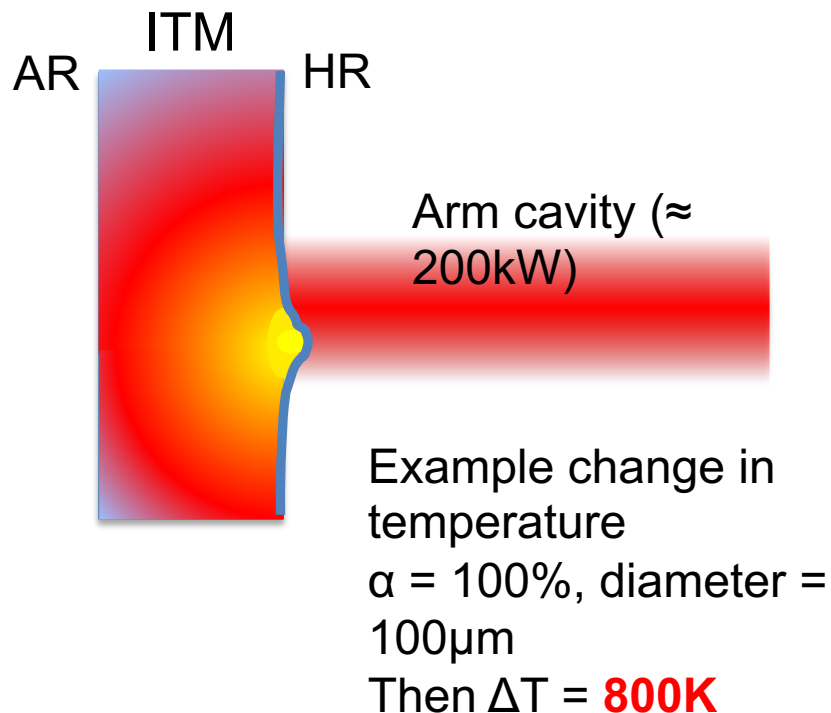
PhysiCS See Focus story: Squeezing More from Gravitational-Wave Detectors

Started using SQZ in O3a to improve quantum noise for high frequency.

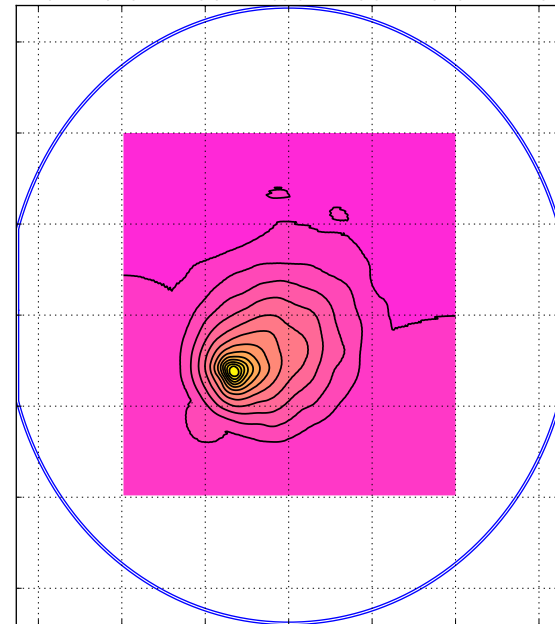


## Bonus: What is a point absorber?

- Localized small ( $\leq 100\mu\text{m}$ ),
- highly absorbing ( $> 1\text{E}4$  ppm)
- on test mass HR surface



Resulting thermal lens/surface deformation (example)





# Measured Point Absorbers

- Majority of optics measured show one or more point absorbers
  - Hartmann sensor (in-situ)
  - Photothermal common-path interferometry
  - Thermal imaging camera (under investigation)

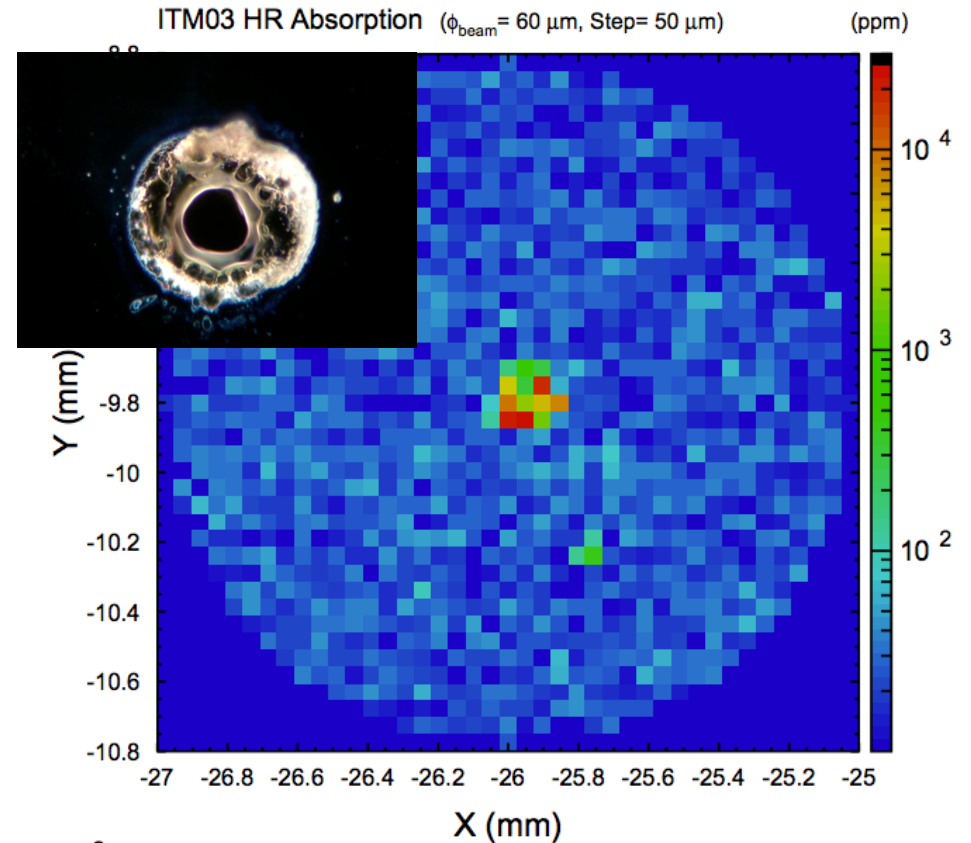
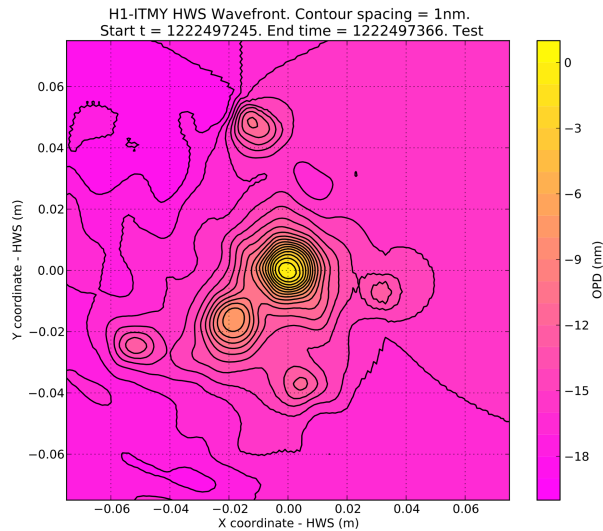
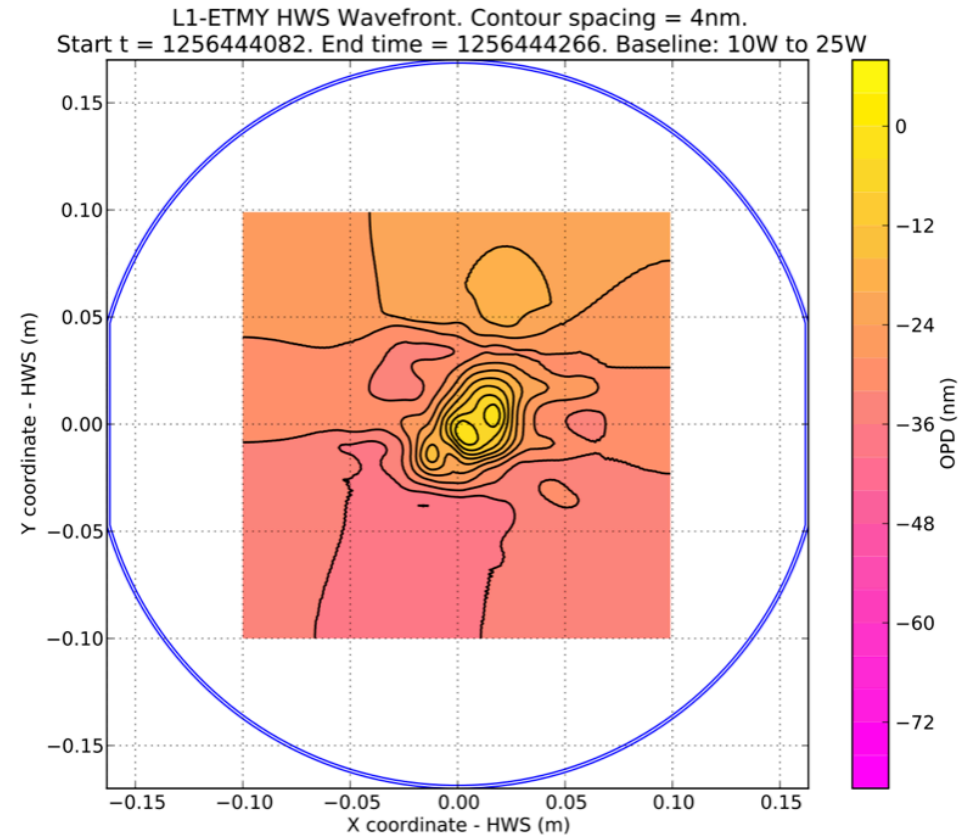
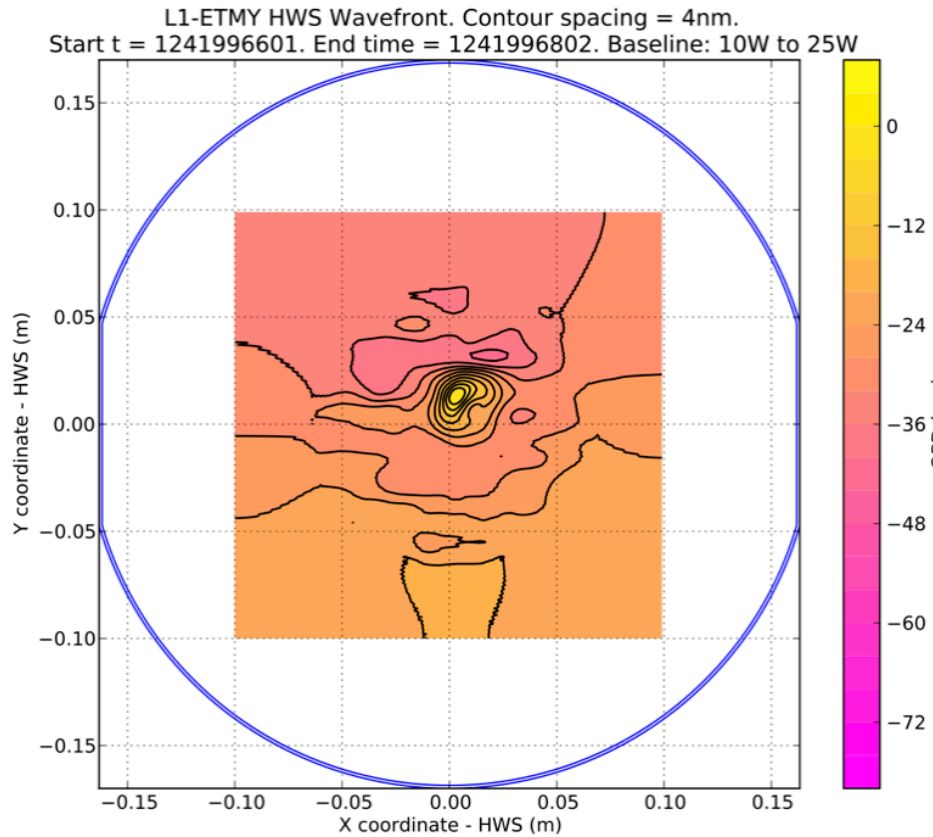


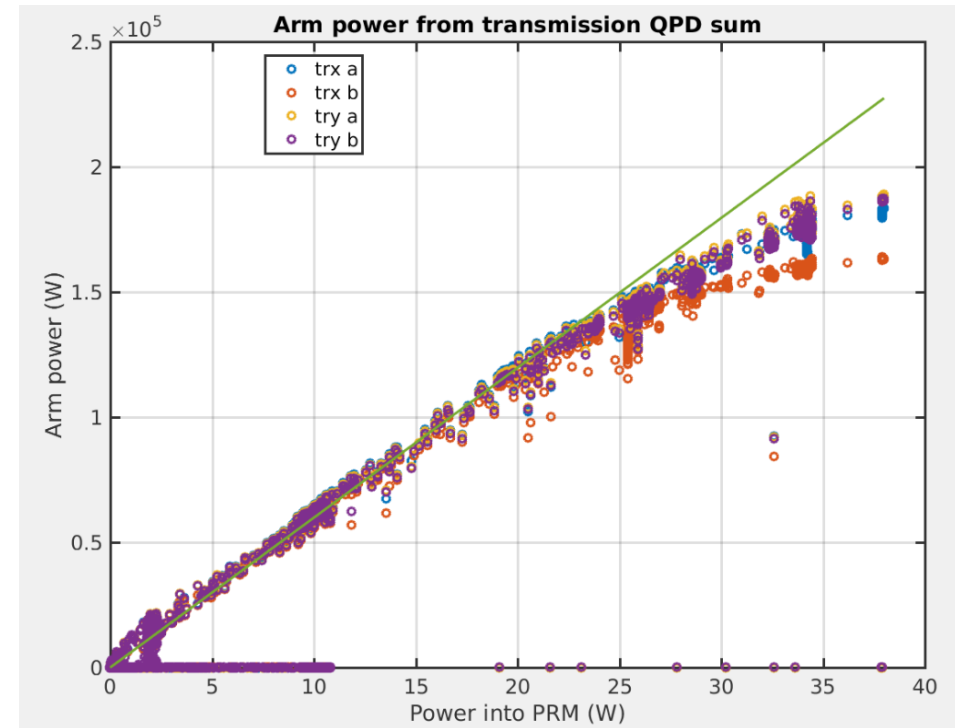
Image credit: Liyuan Zhang and GariLynn Billingsley

# (Bonus: New Point Absorbers at LLO in O3b)



## (Bonus: Point Absorbers)

- Hanford's large point absorber on ITMY limits circulating power and shot noise limited sensitivity
- Livingston circulating power reduced by 25% for O3b
  - **Tuning squeezing recovered BNS range**
- MIT and CIT groups are investigating possible point absorber mitigation strategies



[LLO alog 42639](#) Valera

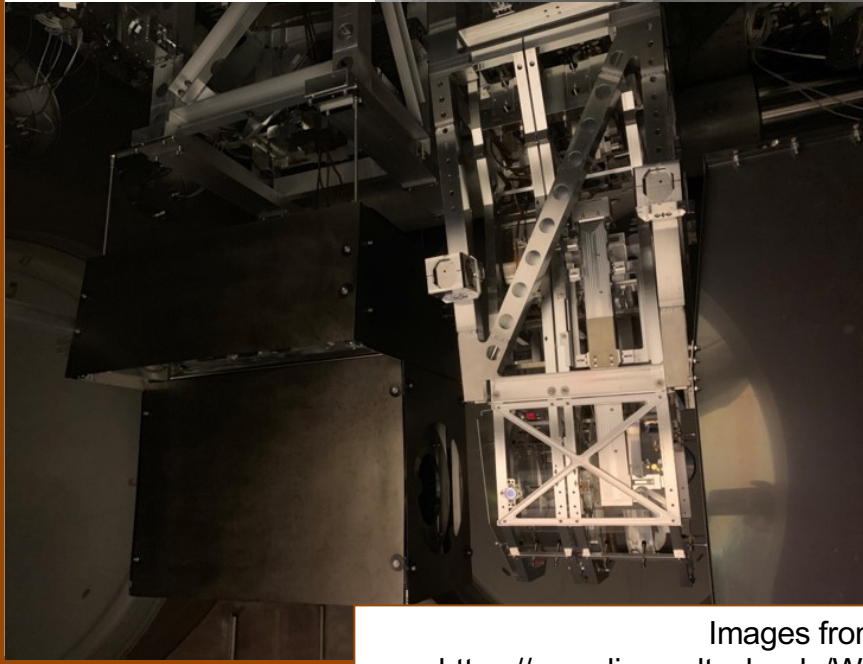
## Scattered Light Upgrades During October Vent

### LLO

- **Pcal baffles (EX & EY)**
- **TMSX shroud**
- **Nozzle baffles**



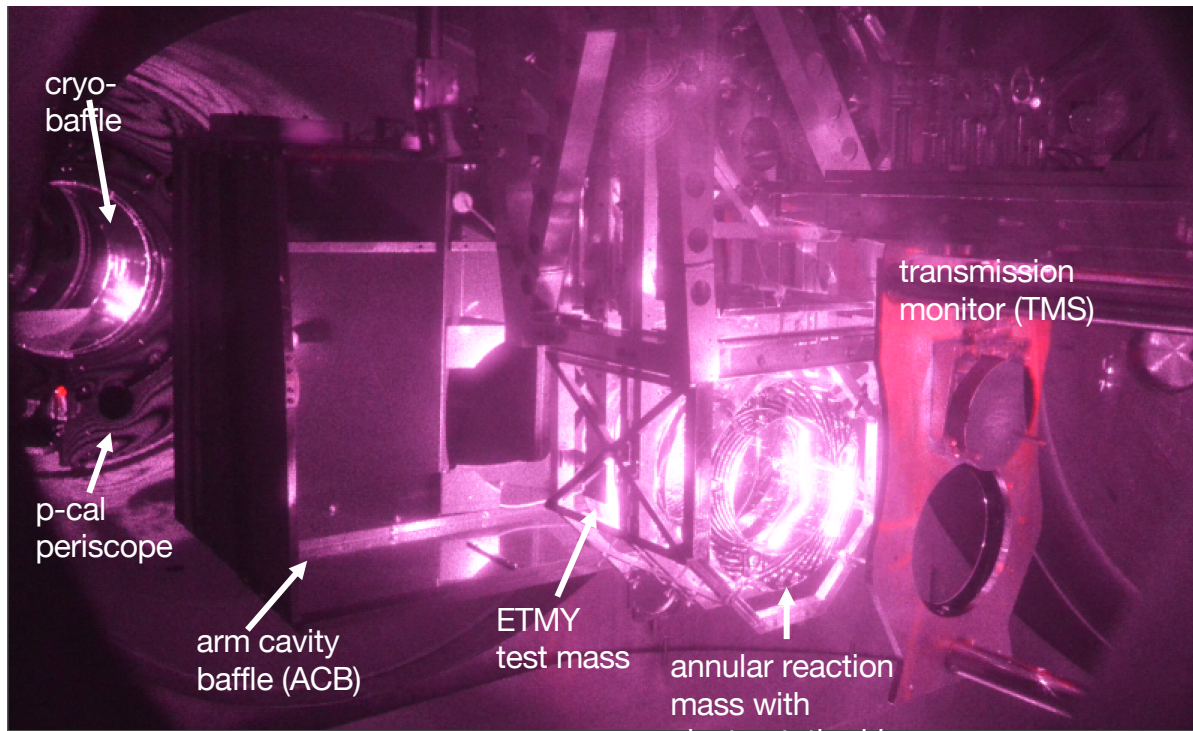
### LHO • **Angled septum window**



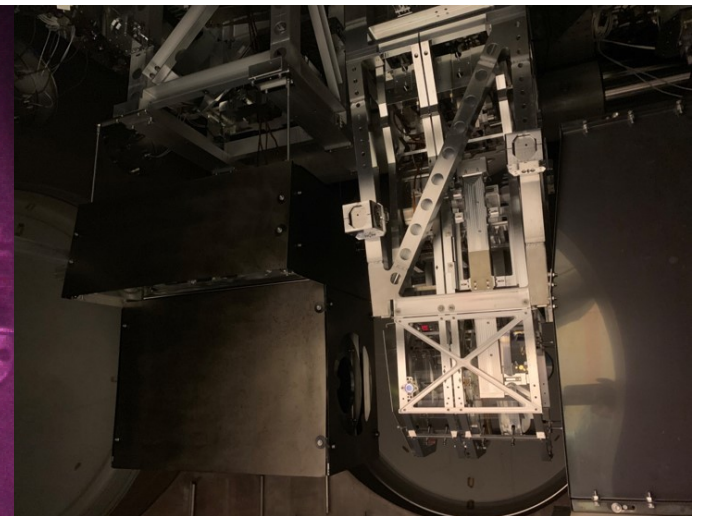
Images from:  
<https://www.ligo.caltech.edu/WA/news/ligo20191104>

# O3 Lessons Learned: Scattered Light

## ETMY

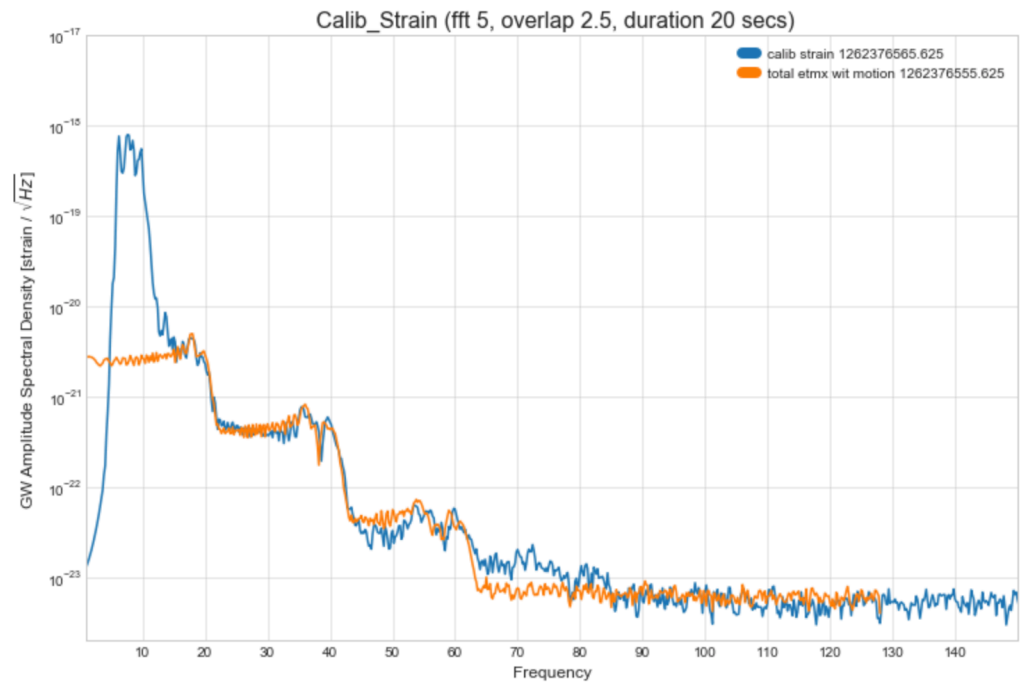


## ETMX



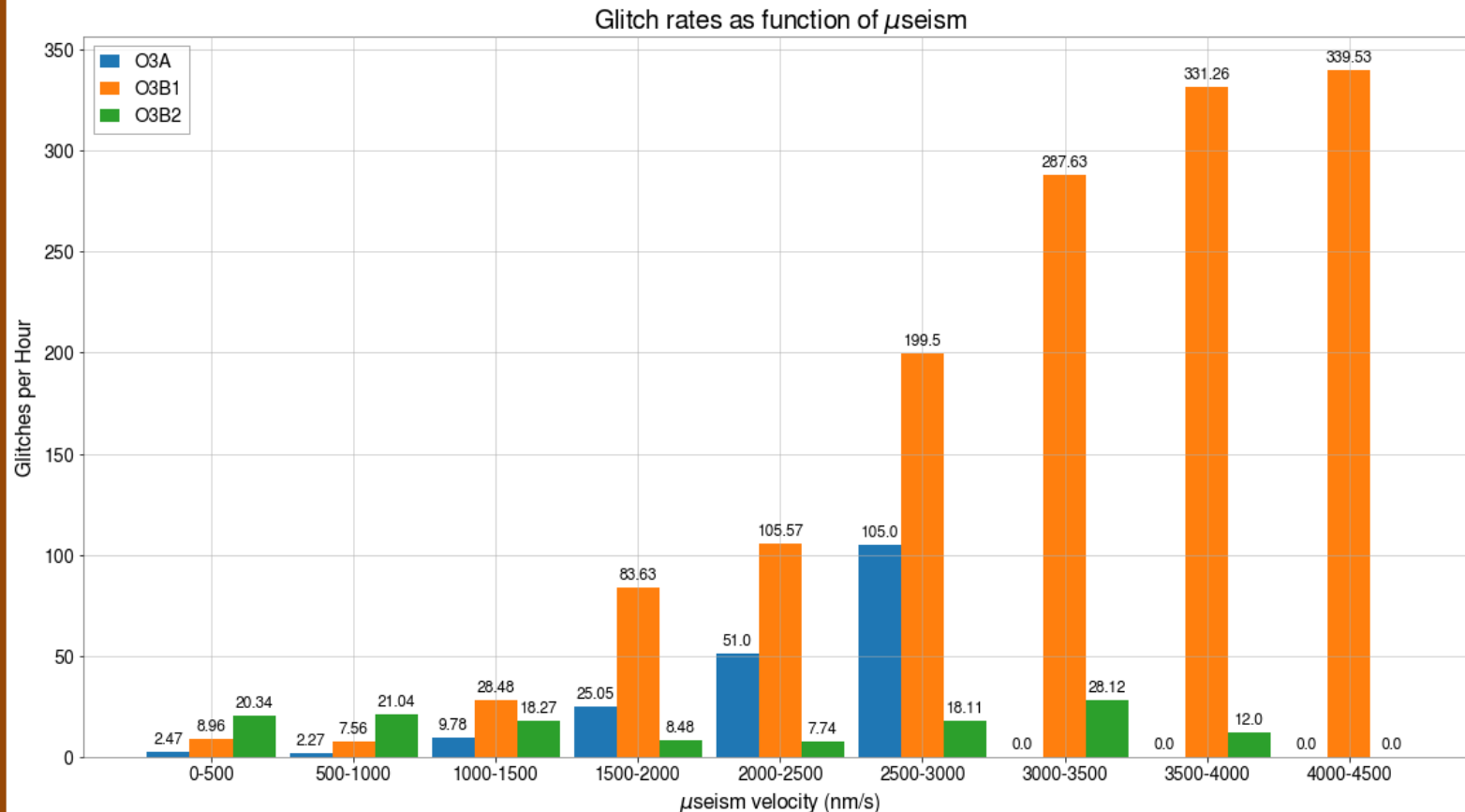
# O3 Lessons Learned: R0 Tracking

- Feed L2 Length OSEM signal back to R0 to reduce relative motion between test and reaction mass



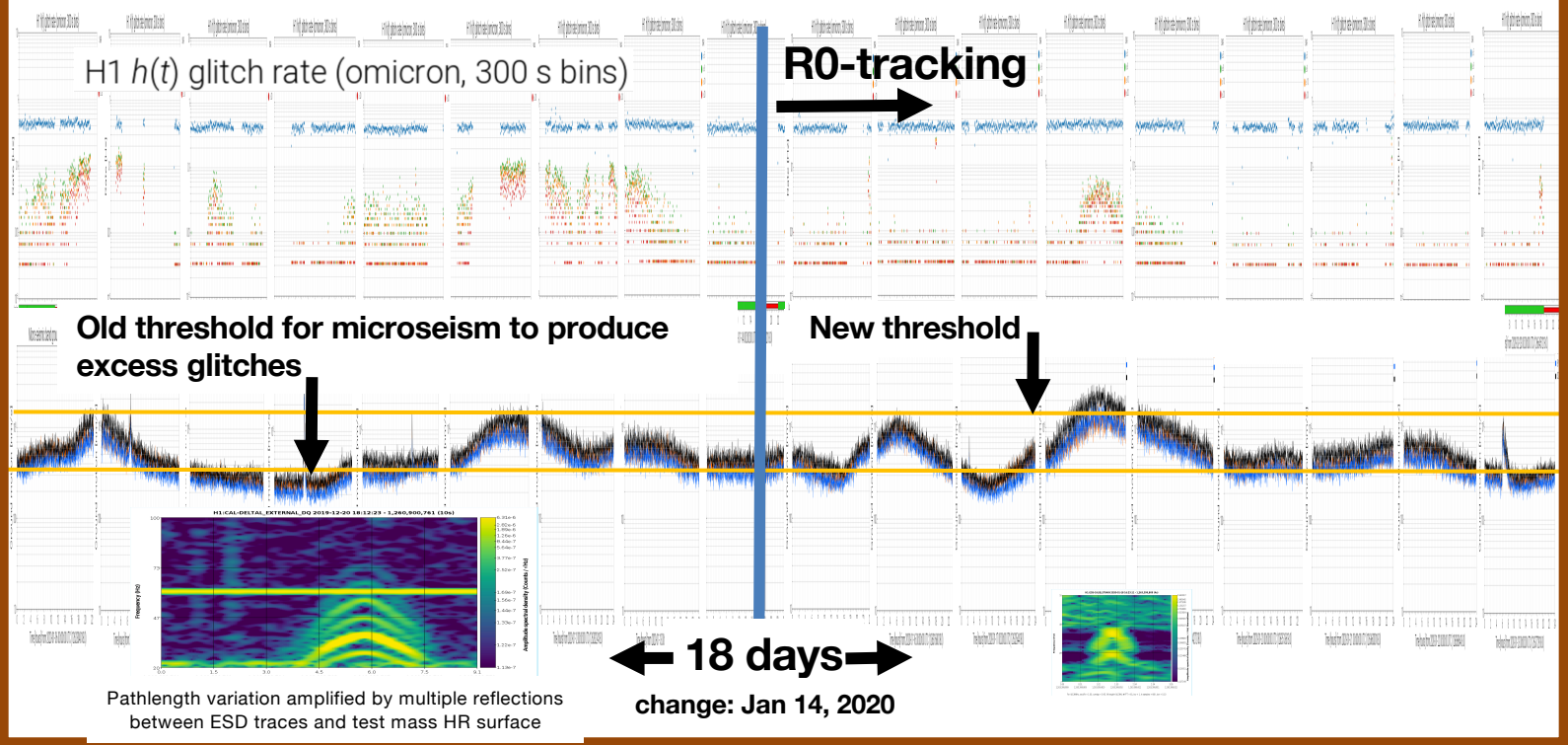
### 3) Glitch rate reduced at LLO

- **Rate of glitches identified by GravitySpy as scattered\_light greatly reduced at microseism above ~1 micron/sec**
- **SNR of glitches also reduced (Sidd alog 51594)**



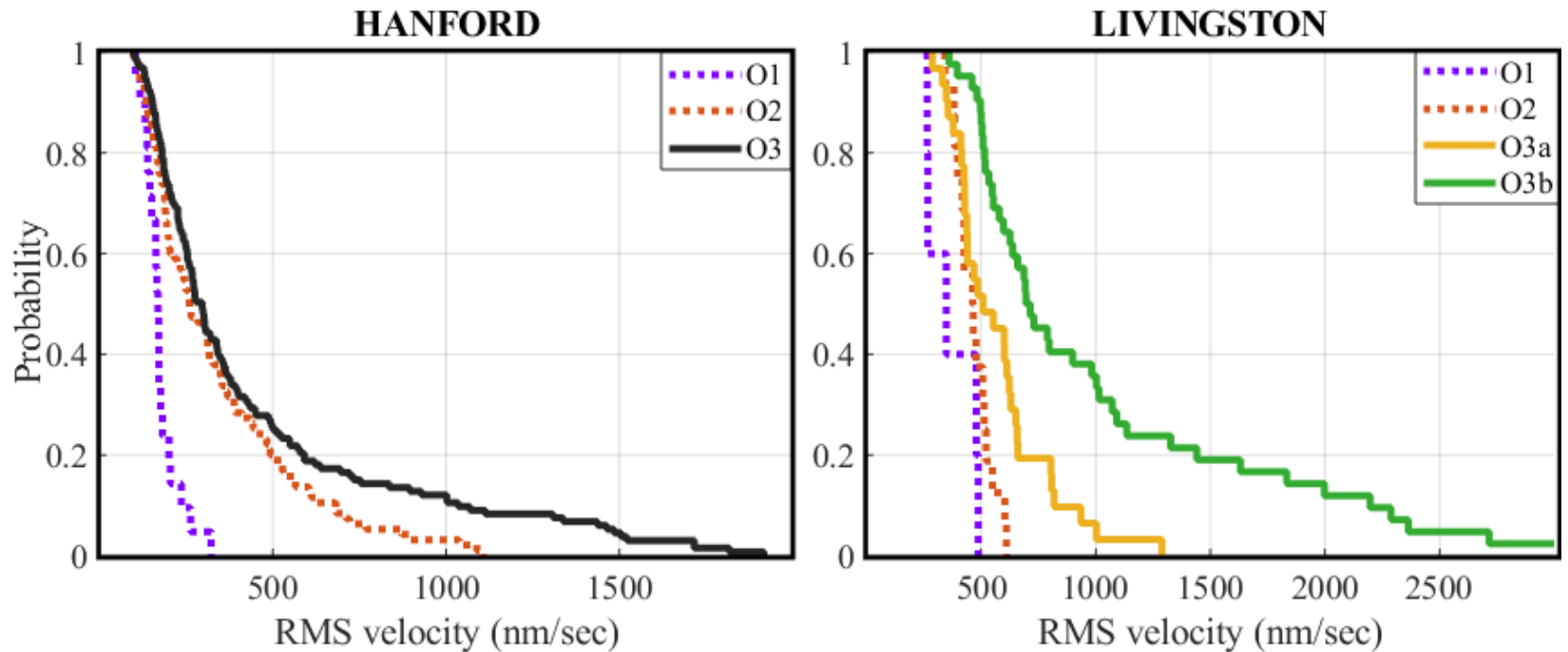
#### 4) Glitch rate reduced at LHO

- **Next level of scattering requires ~4 times higher microseism to produce excess glitching; investigating new dominant source – ACB, TMS, etc.**





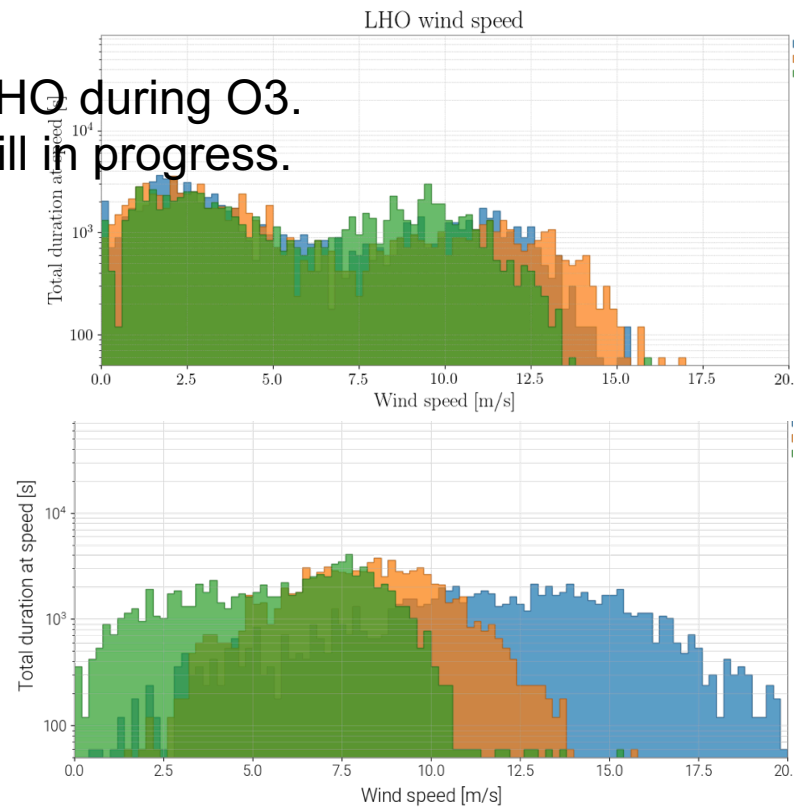
# O3 Lessons Learned: Earthquake Robustness



Source: E. Schwartz via email (from paper in progress)

# O3 Lessons Learned: Wind Resistance

- Wind Fence installed at the end stations in LHO during O3.
- Promising early results, analysis of impact still in progress.

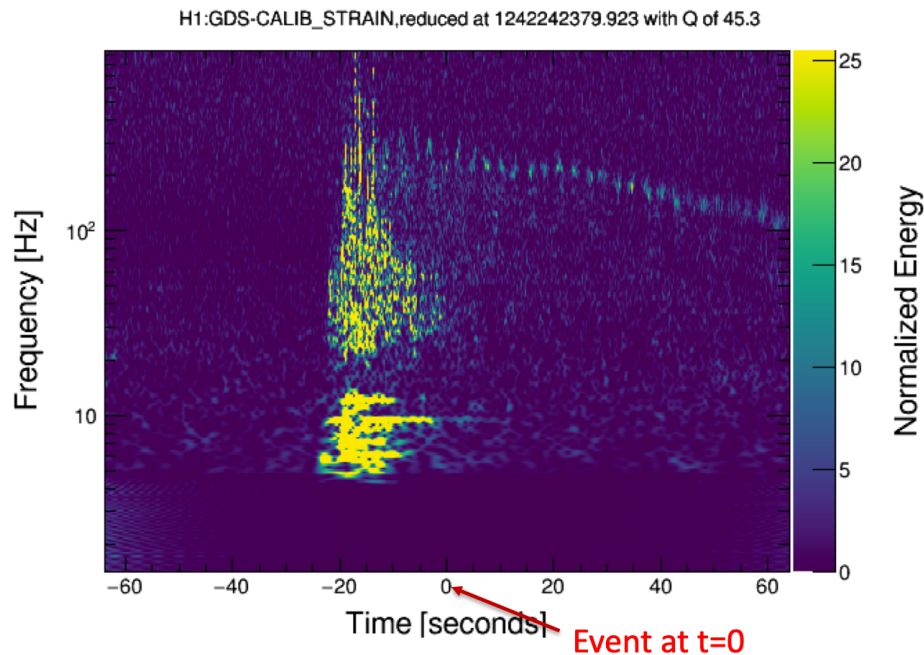


# Automation and Remote Operation

- H1 and L1 have high duty factors. Stay locked for ~80% of shifts.
- H1 relocks without intervention about half of the time.
- Livingston interferometer usually requires some minimal intervention. This was improving before run was suspended.
- CDS teams prepared remote work infrastructure to allow relocking from home.
- Automated alerts of various problems via text and email.
- Unattended operations trial at both LIGO sites, midnight to 8 am local at Hanford and 4 am to 8 am local at Livingston.
- Expect much more development for O4.

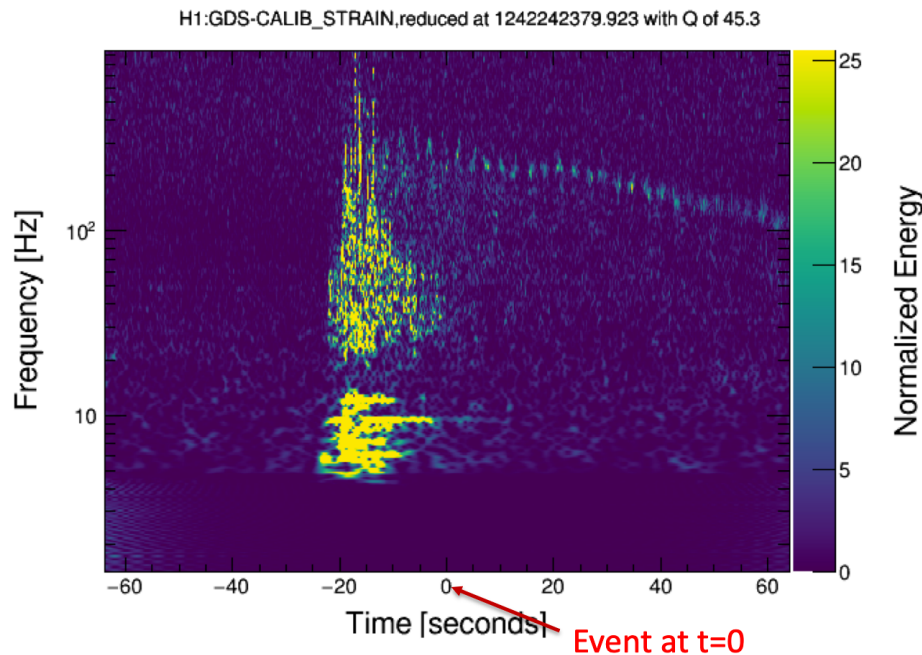
# Bonus: Retraction example: S190518bb

- Obvious clues:
  - [H1, L1, V1, netrowk] SNR = [11.7, 3.2, 5.0, 13.1].
  - [H1, L1, V1] chisquared=[2.7, “none”, 1.05].
  - Huge scattering noise in H1 starting -20s.
  - Tight localization because the source needs to be in dark spot of L1.

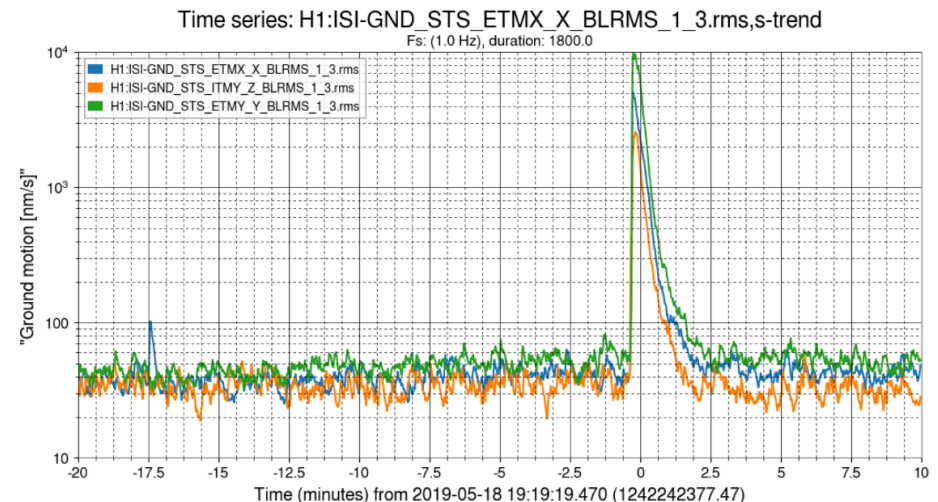


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Later we found a rare local earthquake was hitting the site.



# End of Bonus Slides

