



# STATUS OF THE VIRGO GRAVITATIONAL-WAVE DETECTOR AND THE O3 OBSERVING RUN

—  
DIEGO BERSANETTI 

INFN Genova

on behalf of the Virgo Collaboration

EPS-HEP2019, GHENT (BE)

JULY 13TH 2019

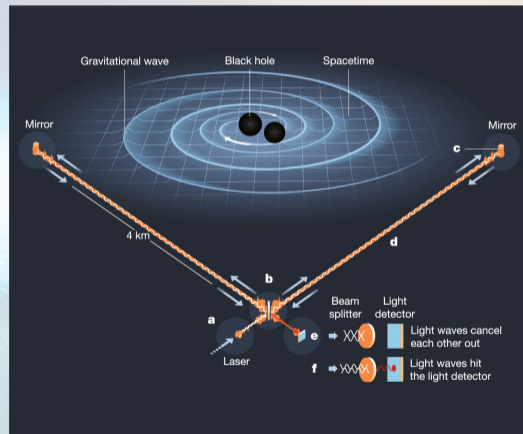
- 
- 1 Introduction
  - 2 Upgrades & Commissioning for the O3 Observing Run
  - 3 Status of Advanced Virgo in O3
  - 4 After O3: Advanced Virgo Plus

Background Image Credit: *University of Warwick and Mark Garlick*

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# Interferometers: Working Principle

- Interference between laser beams
- “Null signal” at the output port
- A GW signal makes light to leak out
- Phase difference converted in length, then into gravitational wave strain  $h(t)$





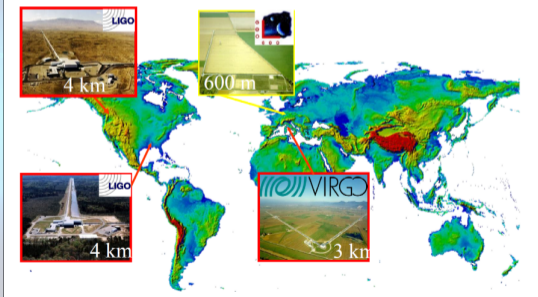
# World-Wide Effort

Advanced Virgo project has been formally completed on July 31, 2017  
 Part of the international network of 2nd generation detectors  
 Started O3 run on April 1, 2019

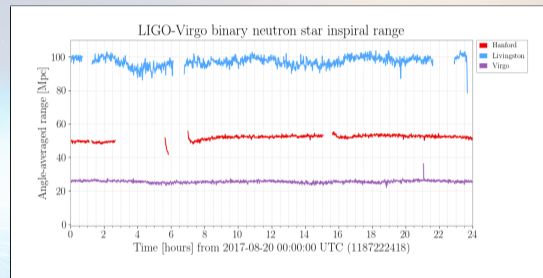
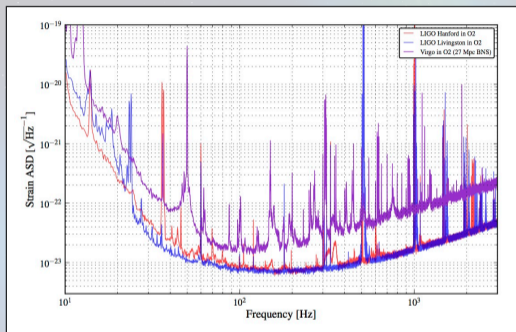
New: ILM and Navier, UMaastricht



8 European countries



# Where we were: the O2 Observing Run

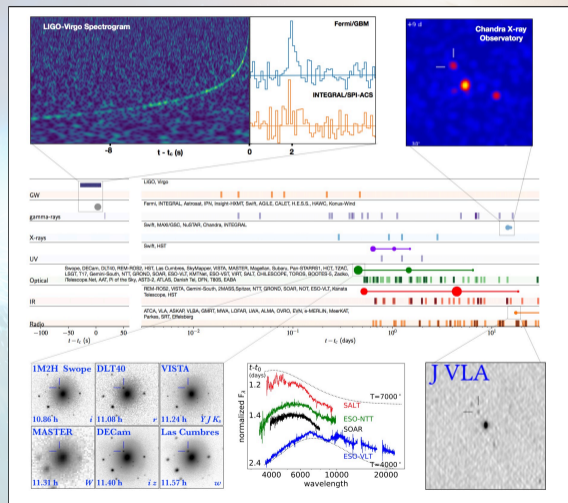


- Advanced Virgo joined O2 on August 1st, 2017
- Lower sensitivity than LIGO, very good stability and duty cycle

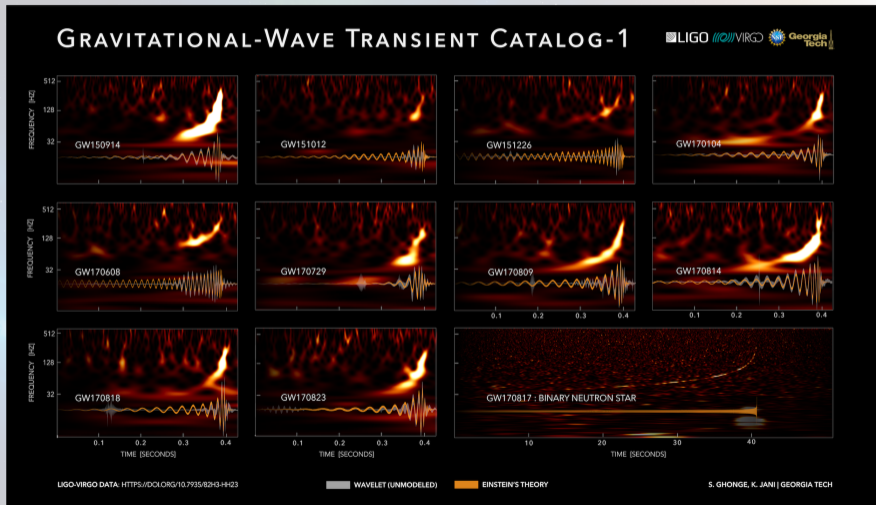
- Very useful to be in “Science Mode”
- Two big detections: **GW170814** and **GW170817**

# GW170817: First GW Detection from BNS Merger

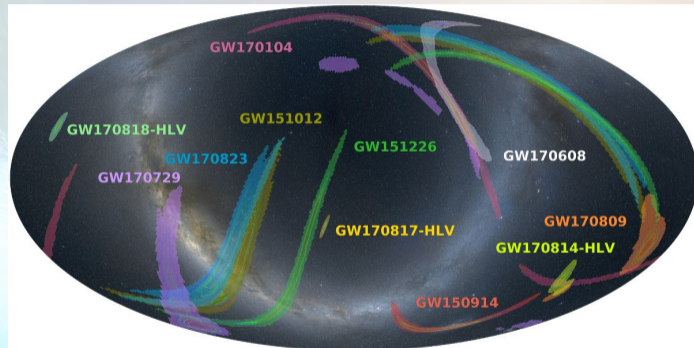
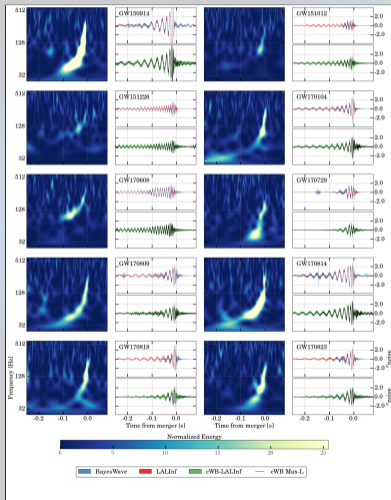
- On August 17th, 2017, three-detector signal
- Immediate alert sent to astrophysical partners
- Electromagnetic counterparts were found:  
**GRB170817A** from galaxy **NGC 4993**
- Global effort of GW and astronomers



# Gravitational Wave Transient Catalog 1 (1)



# Gravitational Wave Transient Catalog 1 (2)

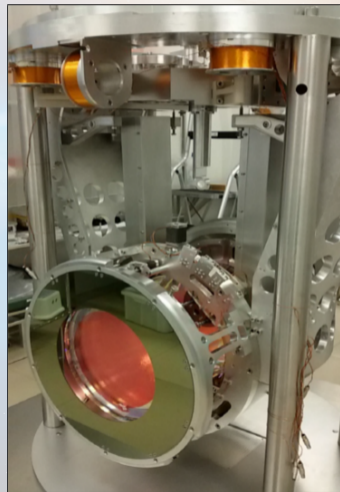


Three-detector signals are a game-changer for sky localization

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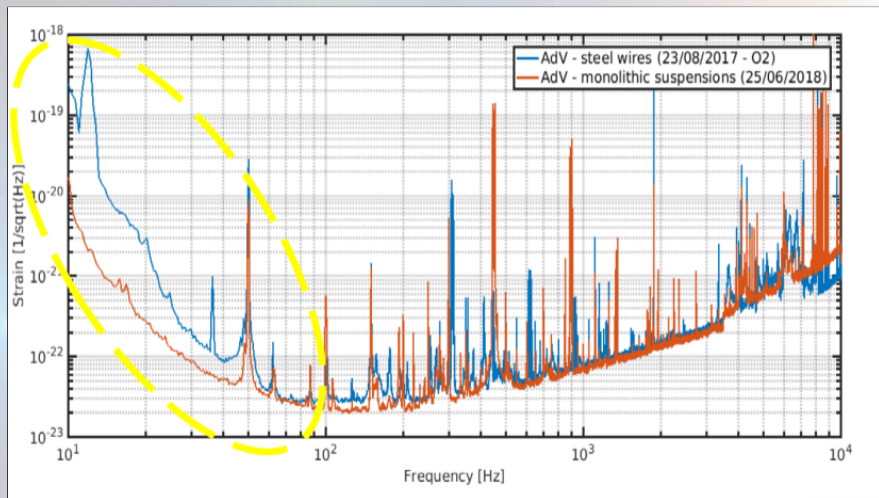
# Monolithic Suspensions (1)

- $\text{SiO}_2$  fused silica fibers 400  $\mu\text{m}$  thick hold the mirror
- Already used in Virgo+ (1st Gen.)
- Reverted to steel wires for O2 because of several breakages
  
- Cause found: contamination of dust particles from vacuum system
- Mitigation: vacuum system cleaning, separated venting pipe
- After mitigation, no more failures in 1.5 y

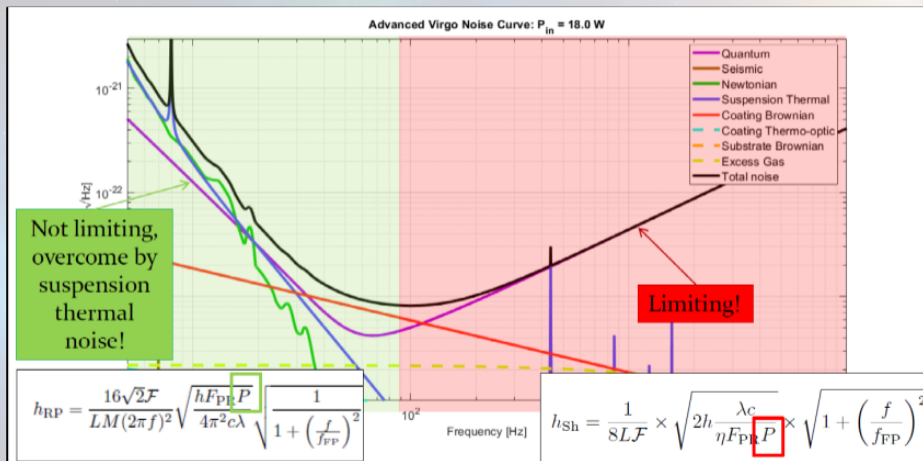




# Monolithic Suspensions (2)



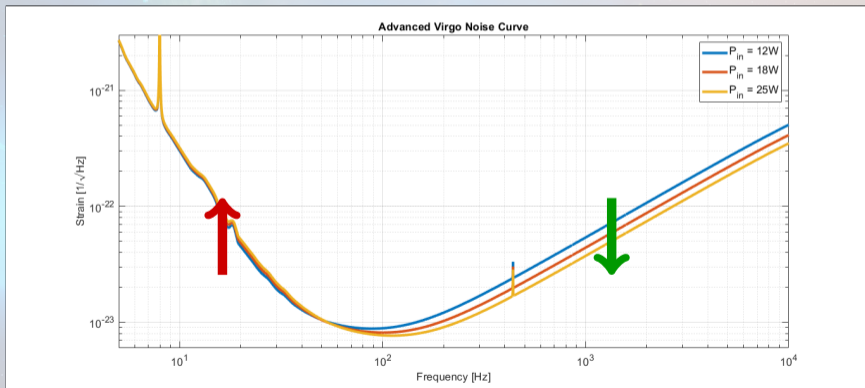
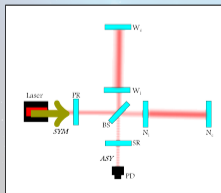
# Quantum Noise



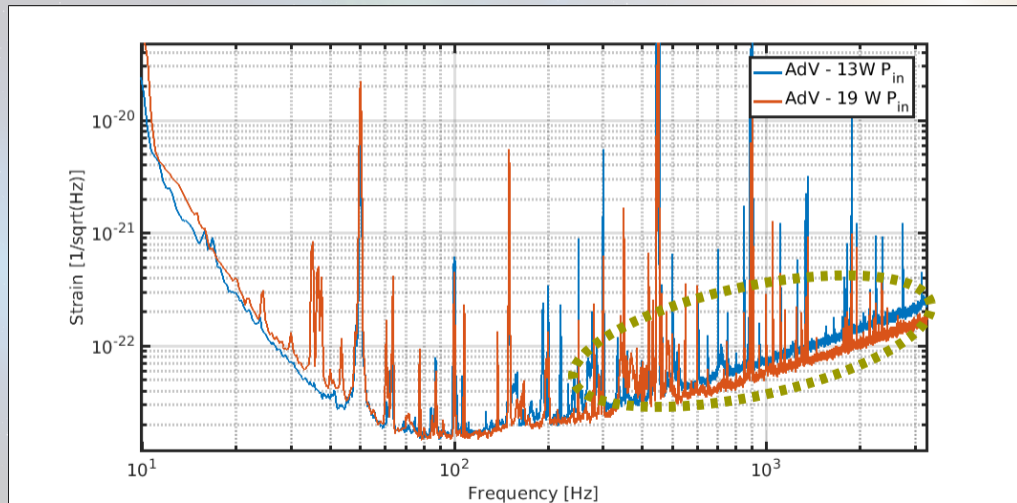
# Increase of the Input Laser Power (1)

Input power raised from 13 W to 18 W:

- ✓ Shot noise naturally reduced
- ✓ Little to no effect at low frequency
- ! Thermal issues become relevant!



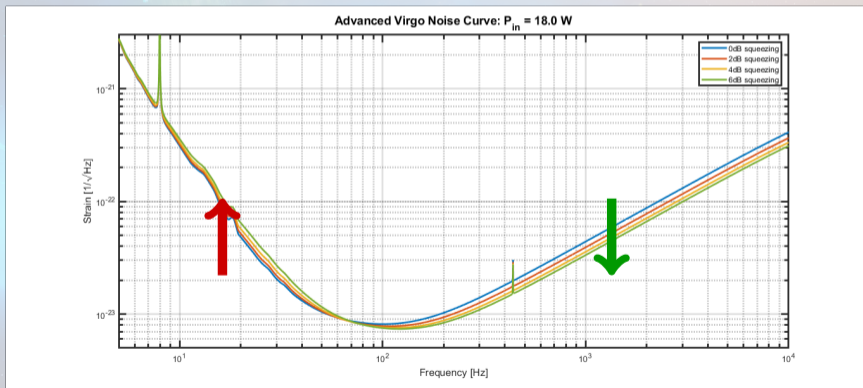
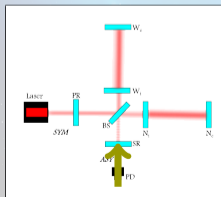
# Increase of the Input Laser Power (2)



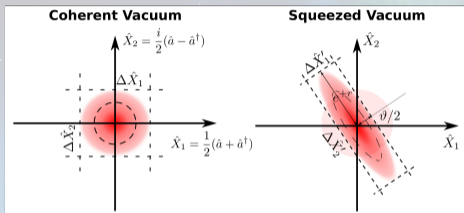
# Injection of Squeezed Vacuum States (1)

Injecting squeezed states *from the output port*:

- ✓ Shot noise gets reduced
- ! Possible effect at low frequency
- ✓ No thermal issues arise!



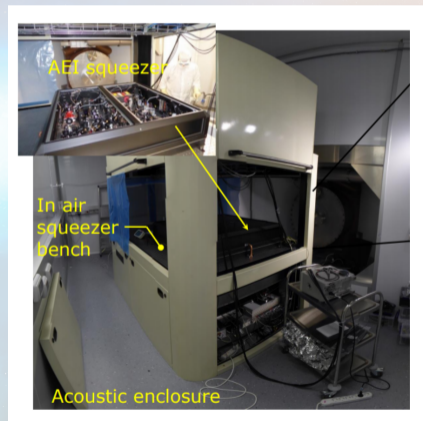
# Injection of Squeezed Vacuum States (2)



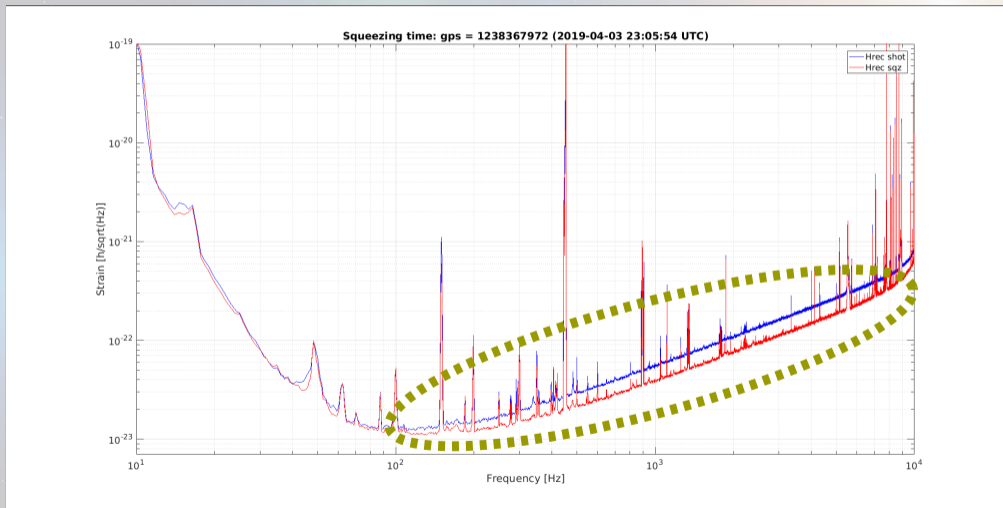
- For a standard, “*coherent*” state, the uncertainty principle holds:  

$$\Delta X_1 \Delta X_2 \geq 1$$
- We can **squeeze** the uncertainty on phase, at the cost of increasing the amplitude one

- Squeezer source from AEI-Hannover



# Injection of Squeezed Vacuum States (3)

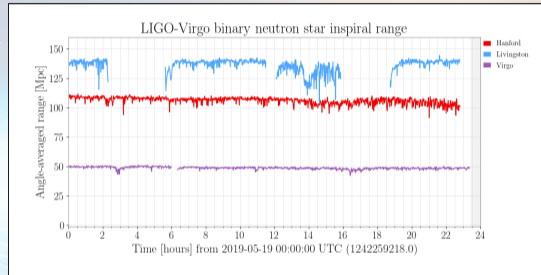
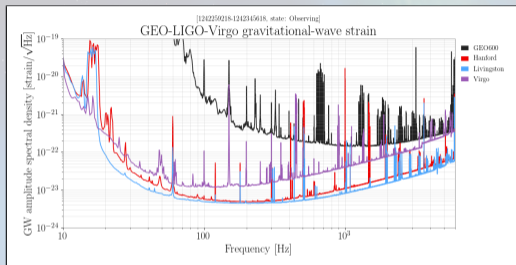




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# Where we are: the O3 Observing Run

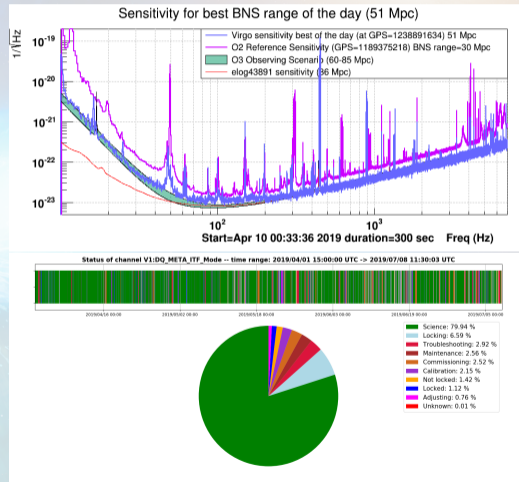
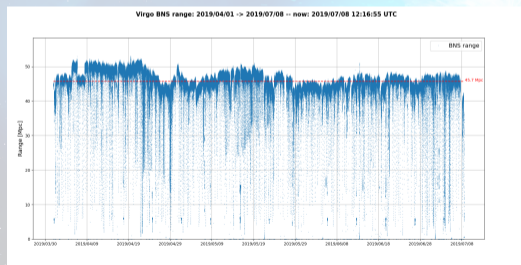


- Advanced Virgo and Advanced LIGO started O3 on April 1st, 2019
- Trying to catch up with LIGO, but some gap is still there
- O3 will last one calendar year
- Configuration is fixed, but small tasks can be carried out



# Advanced Virgo in O3 (1)

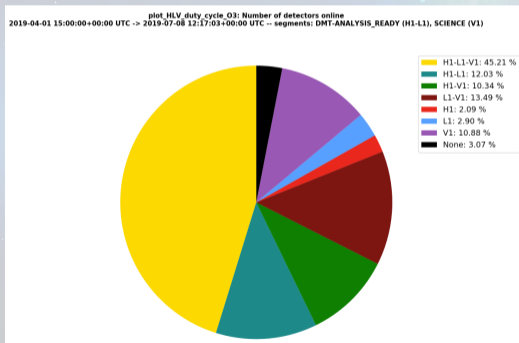
- Target was **60 Mpc**: close, but not there
- “Flat” Noise is the major culprit
- Stability and duty cycle still very good



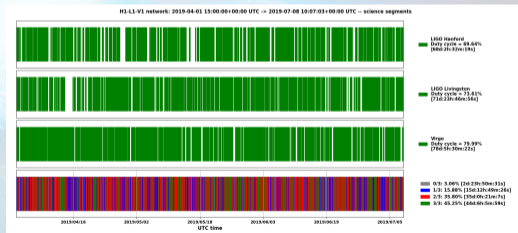


# Three Detectors as a Network

- The three detectors run as a network



- Maintenance, Commissioning and general downtimes synchronized to favor triple-coincidence detections



# Open Public Alerts

- From O3 onwards, Open Public Alerts are issued for Events and Superevents
- GraceDB is the place to look at
- About 1 event/week detected so far

## GraceDB — Gravitational Wave Candidate Event Database

Latest — as of 11 July 2019 15:49:25 UTC

This and PCC events and superevents are not included in the search results by default, see the [help](#) for information on how to search for events and superevents in these categories.

Query:

SEARCH FILTER:

UID	Labels	L_start	L_end	L_end	FAIR (bits)	UTC	Content
L16037A	HE_READY_ADUX SWING_READY_EMBRIGHT_READY_PASTED_READY_COQ_GCN_PBLIM_SENT	1248827219.146828	1248827219.146828	1248827219.146828	1.2456-12	2019-07-07 00:35:44 UTC	
L16037B	HE_READY_ADUX SWING_READY_EMBRIGHT_READY_PASTED_READY_COQ_GCN_PBLIM_SENT	1248840518.101941	1248840518.101941	1248840518.101941	1.8634-06	2019-07-06 21:38:47 UTC	
L16037AB	HE_READY_ADUX SWING_READY_EMBRIGHT_READY_PASTED_READY_COQ_GCN_PBLIM_SENT	1248848863.059383	1248848863.059383	1248848863.059383	1.8749-06	2019-07-06 20:35:24 UTC	
L16037AC	HE_READY_ADUX SWING_READY_EMBRIGHT_READY_PASTED_READY_COQ_GCN_PBLIM_SENT	1248859842.179329	1248859842.179329	1248859842.179329	1.4376-13	2019-06-30 16:52:26 UTC	
L16037AD	HE_READY_ADUX SWING_READY_EMBRIGHT_READY_PASTED_READY_COQ_GCN_PBLIM_SENT	1248939384.846246	1248939384.846246	1248939384.846246	1.8634-06	2019-06-02 07:58:31 UTC	
L16037AE	NOVO_SWING_READY_EMBRIGHT_READY_PASTED_READY_COQ_GCN_PBLIM_SENT	1247376163.494669	1247376163.494669	1247376163.494669	1.8714-06	2019-05-24 04:52:36 UTC	
L16037AF	HE_READY_ADUX SWING_READY_EMBRIGHT_READY_PASTED_READY_COQ_GCN_PBLIM_SENT	1242478856.453438	1242478856.453438	1242478856.453438	1.5056-10	2019-05-31 07:48:23 UTC	
L16037AG	HE_READY_ADUX SWING_READY_EMBRIGHT_READY_PASTED_READY_COQ_GCN_PBLIM_SENT	1242426564.447266	1242426564.447266	1242426564.447266	1.8634-06	2019-05-21 03:02:30 UTC	
L16037AH	HE_READY_ADUX SWING_READY_EMBRIGHT_READY_PASTED_READY_COQ_GCN_PBLIM_SENT	1242135166.559875	1242135166.559875	1242135166.559875	1.7626-06	2019-05-10 10:36:04 UTC	
L16037AI	NOVO_SWING_READY_EMBRIGHT_READY_PASTED_READY_COQ_GCN_PBLIM_SENT	1242124276.474889	1242124276.474889	1242124276.474889	1.8634-06	2019-05-10 19:19:39 UTC	
L16037AJ	HE_READY_ADUX SWING_READY_EMBRIGHT_READY_PASTED_READY_COQ_GCN_PBLIM_SENT	1242057676.959577	1242057676.959577	1242057676.959577	1.3754-06	2019-05-07 10:12:23 UTC	
L16037AK	NOVO_SWING_READY_EMBRIGHT_READY_PASTED_READY_COQ_GCN_PBLIM_SENT	1241818868.756166	1241818868.756166	1241818868.756166	1.7346-13	2019-05-13 20:54:46 UTC	
L16037AL	HE_READY_ADUX SWING_READY_EMBRIGHT_READY_PASTED_READY_COQ_GCN_PBLIM_SENT	1241719951.418386	1241719951.418386	1241719951.418386	1.8634-06	2019-05-13 20:07:43 UTC	
L16037AM	NOVO_SWING_READY_EMBRIGHT_READY_PASTED_READY_COQ_GCN_PBLIM_SENT	1241462197.239158	1241462197.239158	1241462197.239158	1.8204-06	2019-05-10 01:00:10 UTC	
L16037AN	NOVO_SWING_READY_EMBRIGHT_READY_PASTED_READY_COQ_GCN_PBLIM_SENT	1240944861.288554	1240944861.288554	1240944861.288554	1.8765-06	2019-05-03 01:34:26 UTC	
L16037AO	HE_READY_ADUX SWING_READY_EMBRIGHT_READY_PASTED_READY_COQ_GCN_PBLIM_SENT	1240377132.311669	1240377132.311669	1240377132.311669	1.8474-06	2019-04-30 22:12:15 UTC	
L16037AP	NOVO_SWING_READY_EMBRIGHT_READY_PASTED_READY_COQ_GCN_PBLIM_SENT	1240218902.812584	1240218902.812584	1240218902.812584	1.5366-12	2019-04-20 08:18:28 UTC	
L16037AQ	HE_READY_ADUX SWING_READY_EMBRIGHT_READY_PASTED_READY_COQ_GCN_PBLIM_SENT	1239817053.220077	1239817053.220077	1239817053.220077	1.4806-06	2019-04-21 11:18:34 UTC	
L16037AR	HE_READY_ADUX SWING_READY_EMBRIGHT_READY_PASTED_READY_COQ_GCN_PBLIM_SENT	1239692261.140573	1239692261.140573	1239692261.140573	1.8634-06	2019-04-13 01:32:33 UTC	
L16037AS	HE_READY_ADUX SWING_READY_EMBRIGHT_READY_PASTED_READY_COQ_GCN_PBLIM_SENT	1239476209.288949	1239476209.288949	1239476209.288949	1.8114-10	2019-04-06 01:18:17 UTC	
L16037AT	NOVO_SWING_READY_EMBRIGHT_READY_PASTED_READY_COQ_GCN_PBLIM_SENT	1239112307.883646	1239112307.883646	1239112307.883646	1.4154-04	2019-04-03 01:01:36 UTC	

- Instructions are at the [Public Alerts User Guide](#) page

## LIGO Scientific Collaboration LIGO/VIRGO Public Alerts User Guide

Primer on public alerts for astronomers from the LIGO and Virgo gravitational-wave observatories.

Navigation  
Getting Started Checklist  
Observing Capabilities  
Data Analysis  
Alert Contents  
Sample Code

Change Log  
Glossary

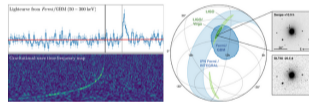
Question? Issues?  
Feedback?

Email [enflow@support.ligo.org](mailto:enflow@support.ligo.org)

Quick search


## LIGO/VIRGO Public Alerts User Guide



Welcome to the LIGO/VIRGO Public Alerts User Guide! This document is intended for both professional astronomers and science enthusiasts who are interested in receiving alerts and real-time data products related to gravitational-wave (GW) events.

Three sites (LHO, LLO, Virgo) together form a global network of ground-based GW detectors. The LIGO Scientific Collaboration and the Virgo Collaboration jointly analyze the data in real time to detect and localize transients from compact binary mergers and other sources. When a signal candidate is found, an alert is sent to astronomers in order to search for counterparts (electromagnetic waves or neutrinos).

Advanced LIGO and Advanced Virgo began their third observing run (O3) on April 1, 2019. For the first time, **LIGO/VIRGO alerts are public**. Alerts are distributed through NASA's Gamma-ray Coordinates Network (GCN). There are two types of alerts: human-readable GCN Circulars and machine-readable GCN Notices. This document provides a brief overview of the procedures for vetting and sending GW alerts, describes their contents and format, and includes instructions and sample code for receiving GCN Notices and decoding GW sky maps.

Contents

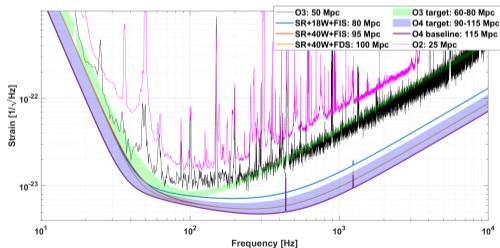
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# What next: the Advanced Virgo Plus project

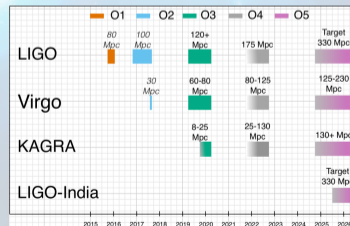
## ◆ Phase 1: hitting the thermal noise wall:

- Signal Recycling mirror
- Frequency *Dependent* Squeezing
- Increased laser power (40 W)
- Newtonian Noise Cancellation



## ◆ Phase 2: pushing down the thermal noise:

- Larger beams on bigger & heavier mirrors for the End Test Masses
- Higher laser power (100 W)
- Better mirror coatings (TBC, R&D ongoing)





The background is a cosmic scene with a dark blue and black space filled with stars. A bright, glowing blue energy burst or nebula is centered in the lower half of the image, with wispy, ethereal structures extending outwards. In the upper right, there is a bright, yellowish-white light source, possibly a star or galaxy core, with a soft glow. A horizontal white bar with a green border is positioned across the middle of the image, containing the text "THANK YOU" in a green, serif font.

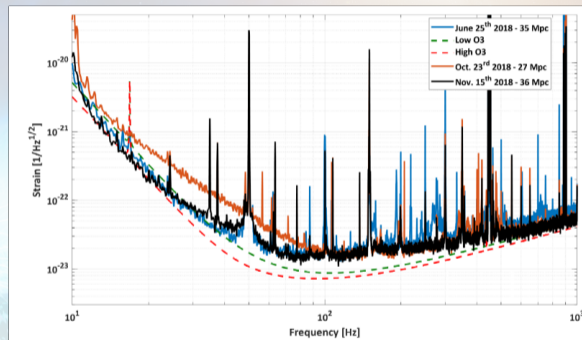
THANK YOU

The background of the image is a deep space scene. In the center, there is a bright, glowing blue energy burst or nebula with intricate, filamentary structures. The colors transition from a vibrant cyan and blue in the center to a darker, more muted blue and green towards the edges. In the upper right corner, there is a bright, yellowish-white light source, possibly a star or a distant galaxy, with a soft, hazy glow around it. The entire scene is filled with numerous small, distant stars of varying brightness. Overlaid on this background is a horizontal rectangular box with a white interior and a thin green border. Inside this box, the word "BACKUP" is written in a bold, green, serif font, centered horizontally.

**BACKUP**

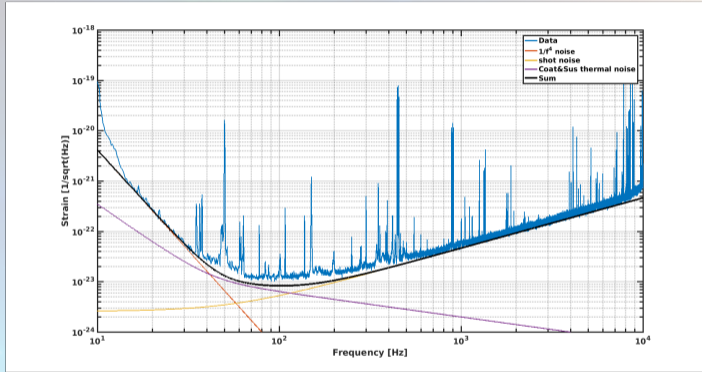
# Mystery Noise #1: the $f^{-2.5}$ Noise

- Spotted at the beginning of August 2018
- Unfortunately, several activities on the detector were performed in a short time
- Difficult to find the culprit
  
- Cause found: coupling of the electronics common mode with the residual charge (not randomly moving) over the mirror surface



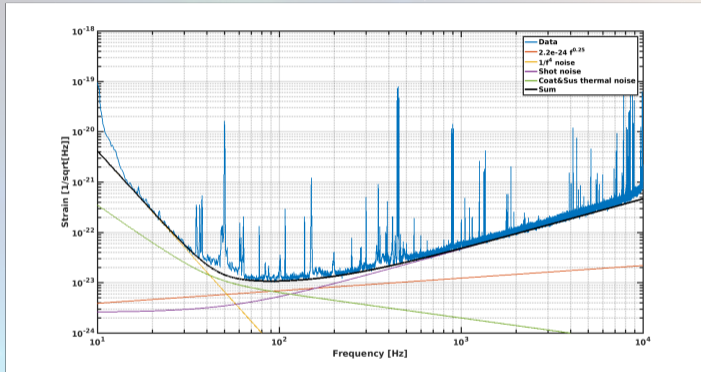
- Mitigation: reduction of the actuators' common mode

# Mystery Noise #2: the “Flat” Noise



- Mystery noise in the most important region **Mpc**-wise
- Cause(s) still under investigation
- Initially considered as frequency independent, then remodeled as  $f^{0.25}$
- First priority for next Commissioning

# Mystery Noise #2: the “Flat” Noise



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