LIGO-Virgo Detector Characterization (DetChar)

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Nicolas Arnaud (narnaud@lal.in2p3.fr)

Laboratoire de l'Accélérateur Linéaire (CNRS/IN2P3 & Université Paris-Sud)

European Gravitational Observatory (Consortium, CNRS & INFN)

On behalf of the LIGO and Virgo DetChar groups

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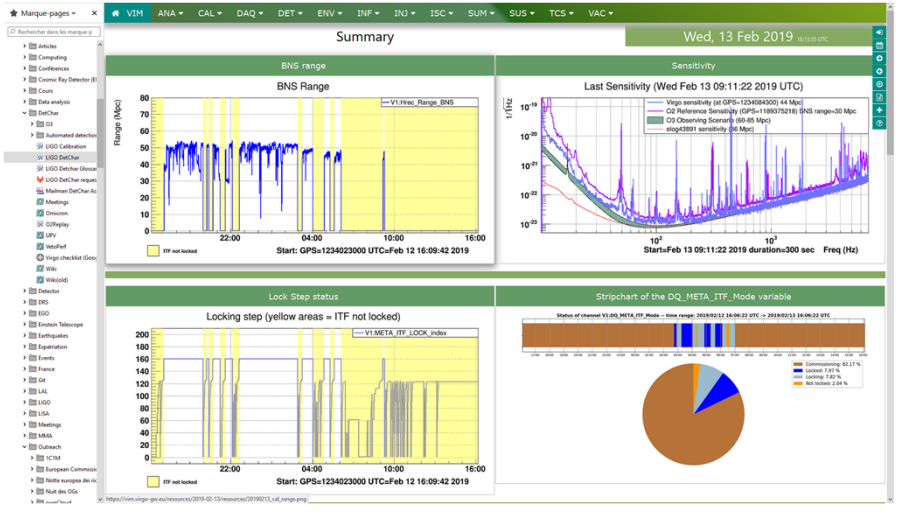
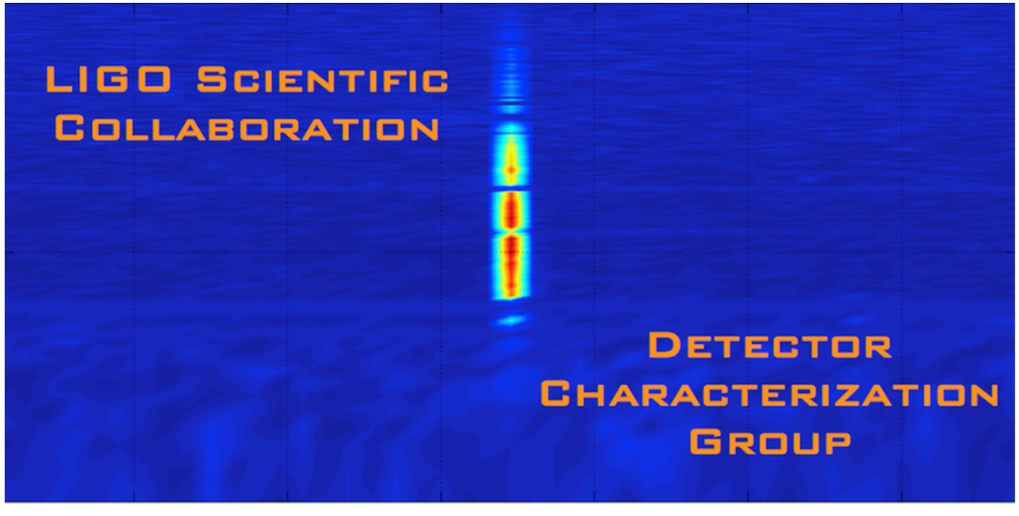


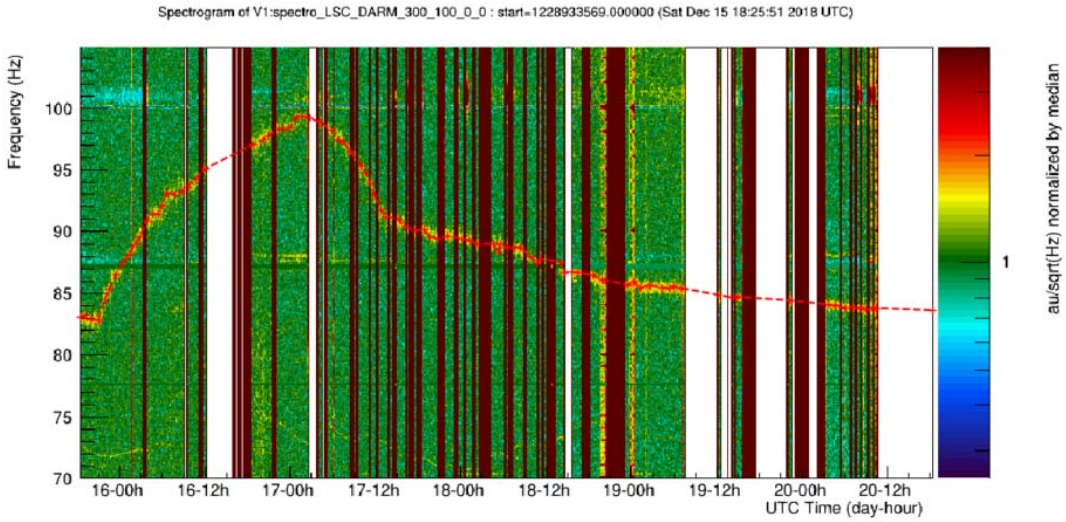


Outline

- DetChar in a nutshell
- Some highlights and challenges
- DetChar for O3
- A selection of tools
- Conclusions

Detector Characterization: DetChar

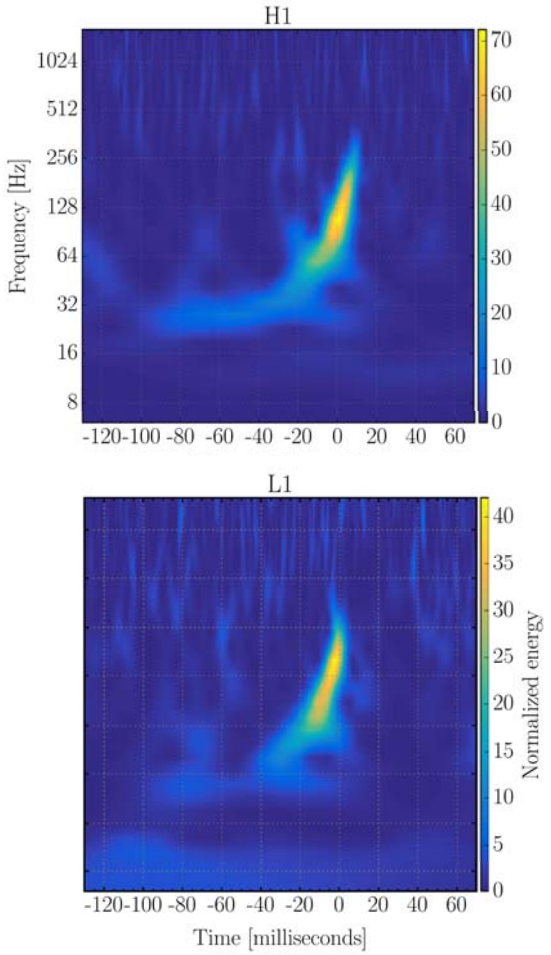
- Detector monitoring
- Detector noise characterization
  - Transient and spectral
  - Noise evolution: it is not stationary!



- Several partners
  - → Commissioning & ENV noise team
    - Data quality analysis
  - → Search groups
    - Data quality information
    - Vetoes: time and frequency domains
  - → DAQ / computing
    - Access to flags and vetoes for online and offline analysis
  - → Physics groups
    - Vet gravitational-wave (GW) candidates
- Virgo DetChar group
  - About 4.5 FTE spread among many people
  - Weekly meeting attendance: 20+ people on average over the past few months

Highlights and challenges

GW150914

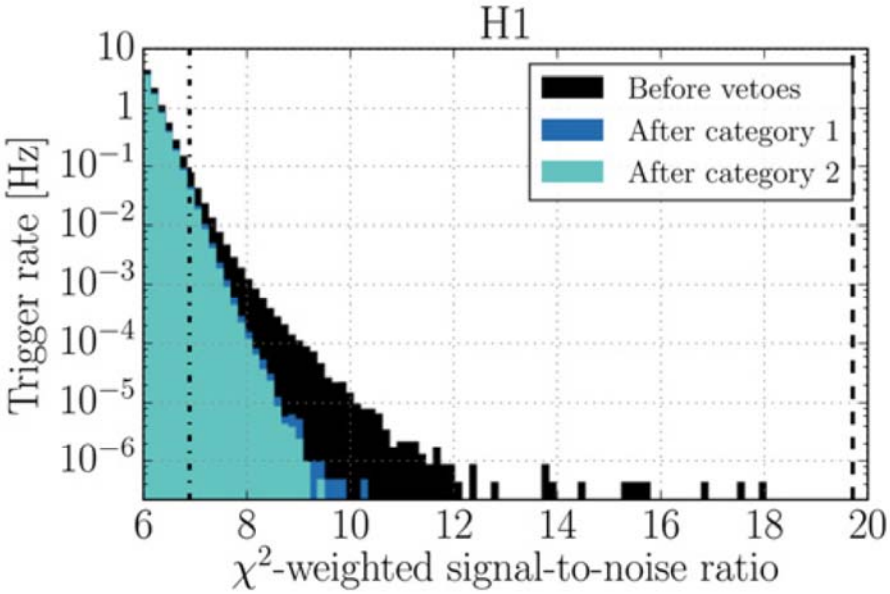


- GW150914: first direct detection of gravitational waves
  - Data recorded: September 15th, 2015
  - Announcement: February 11th, 2016

  → 5 month-work to acquire enough confidence that this event was a real binary black merger of astrophysical origin

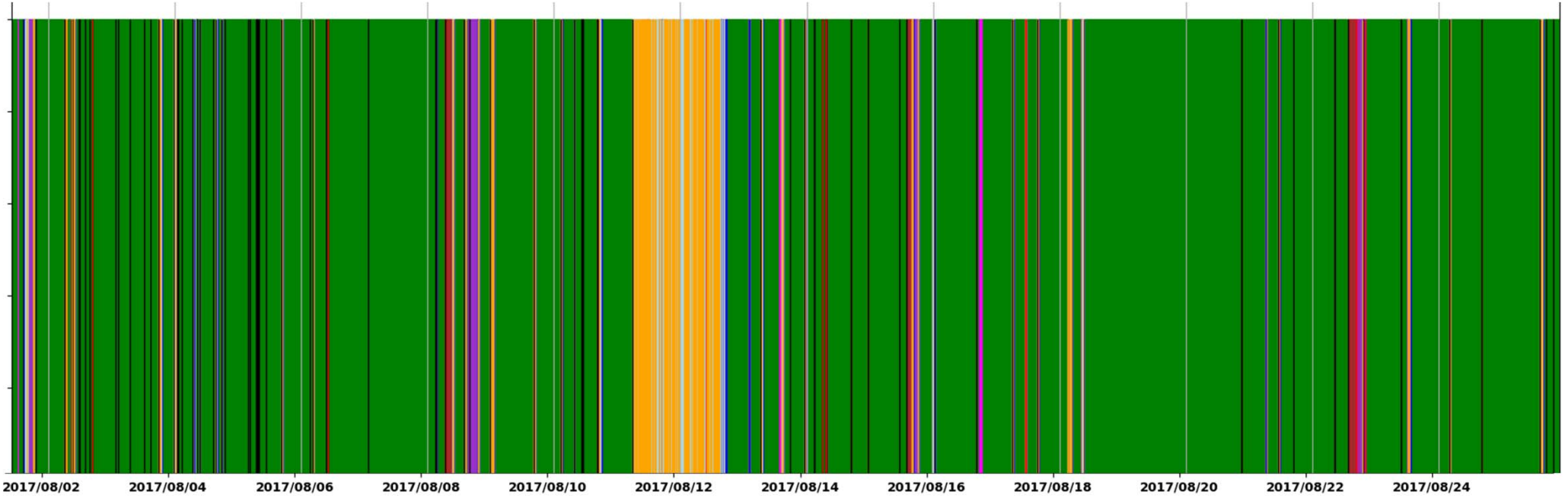
- DetChar companion paper to go along the announcement
  - DetChar strategy: identifying and mitigating noise sources
  - Pipeline background studies
  - Extensive studies of the data around GW150914

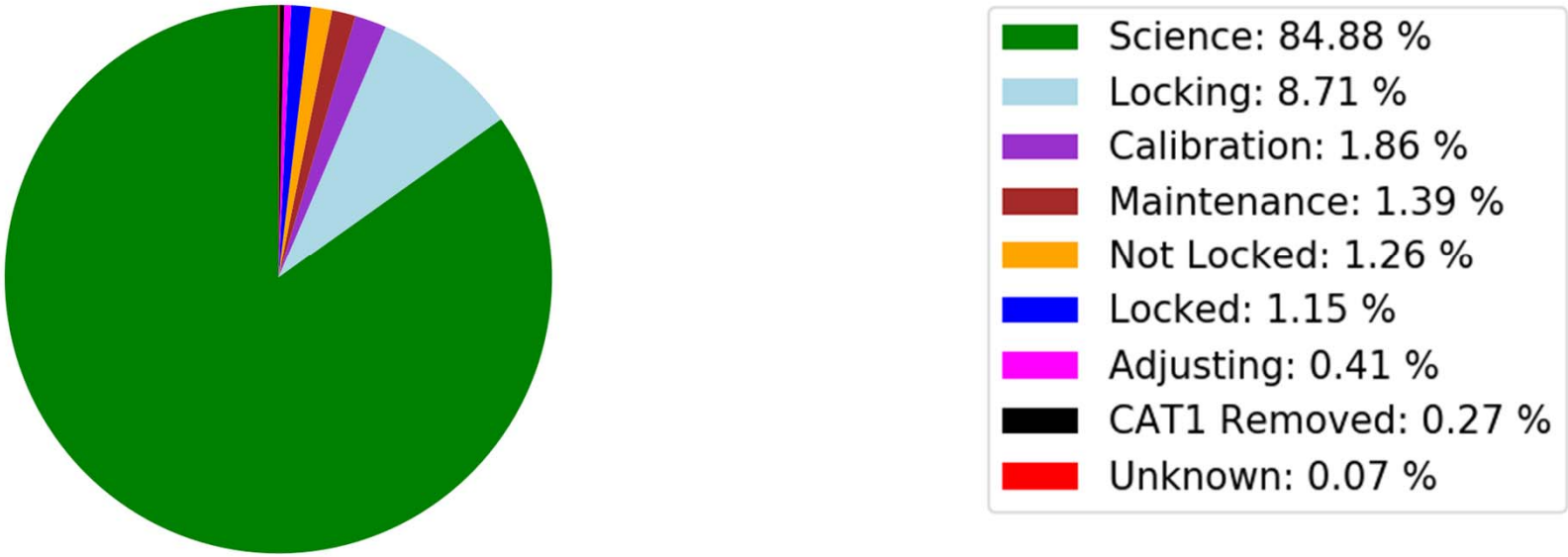
- Reference:
  Class. Quantum Grav. 33 (2016) 134001



August 2017: 3-detector network run

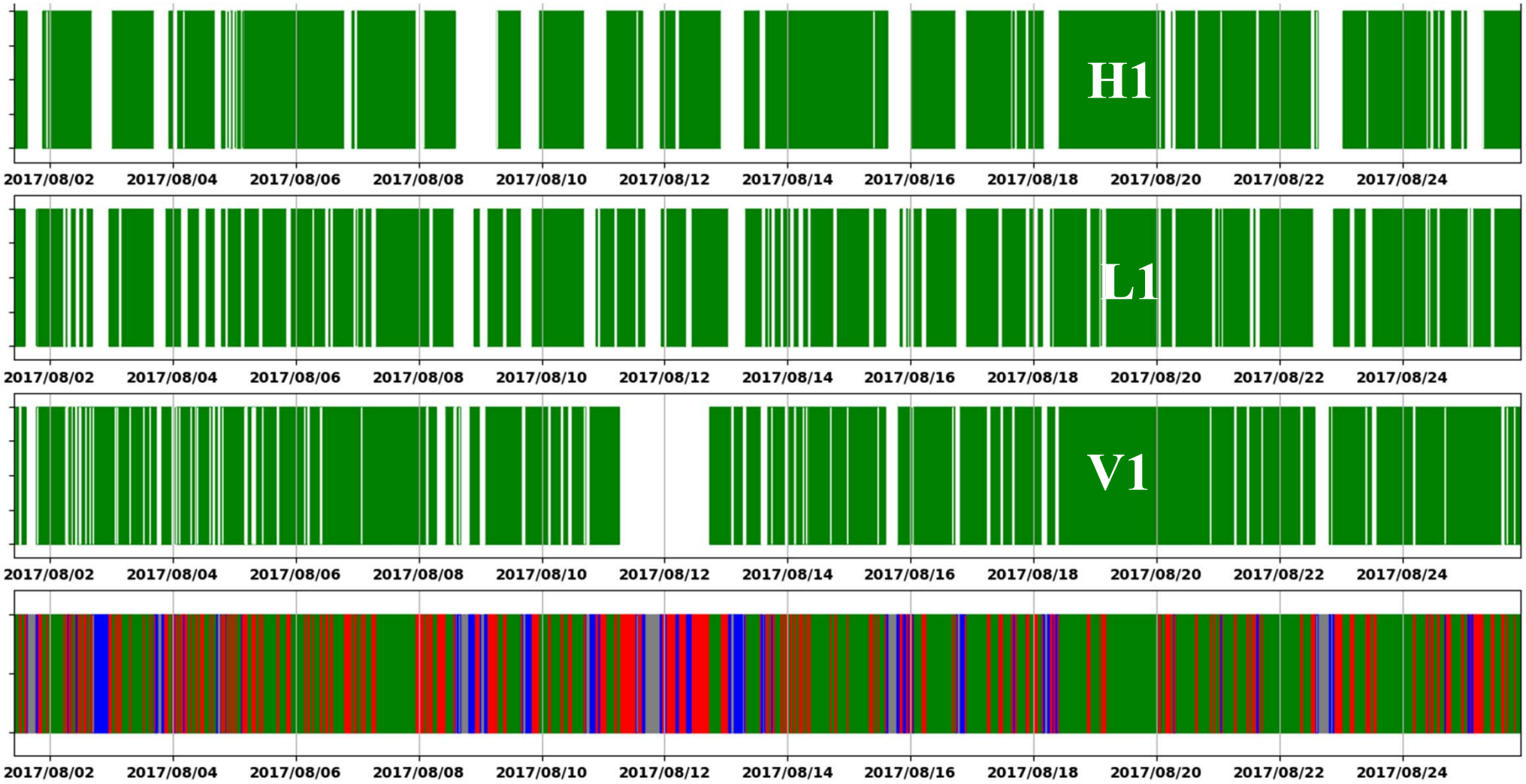
- Example of the Virgo detector performance





August 2017: 3-detector network run

- LIGO-Virgo network performance



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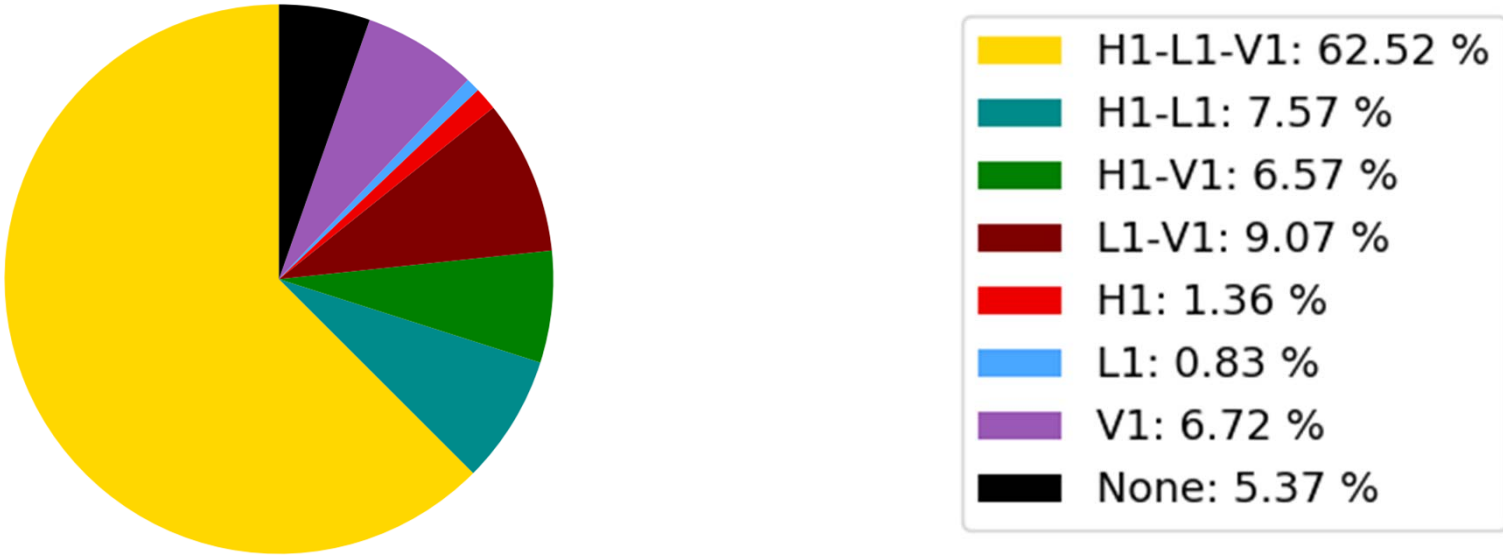
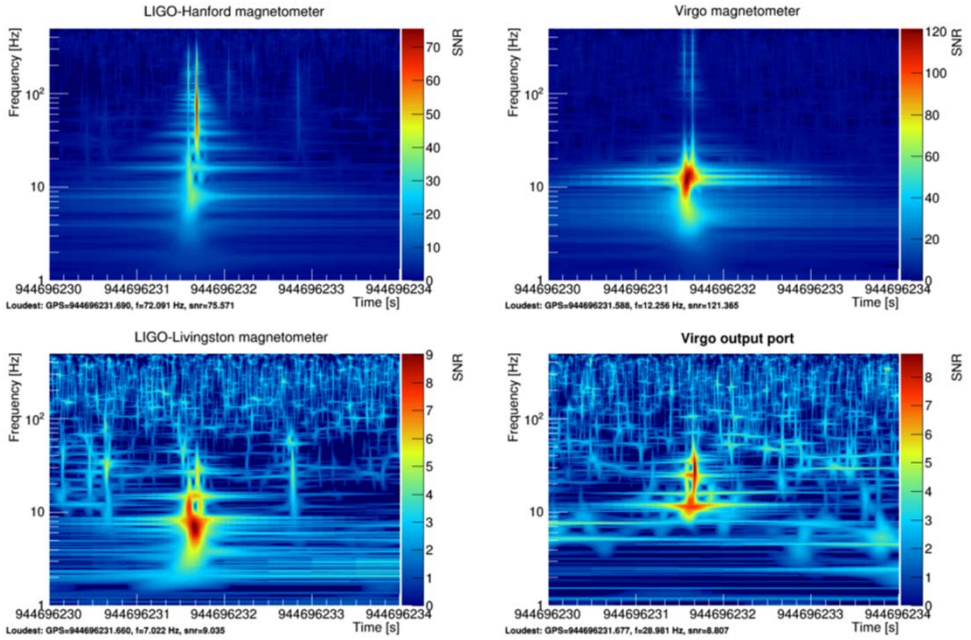
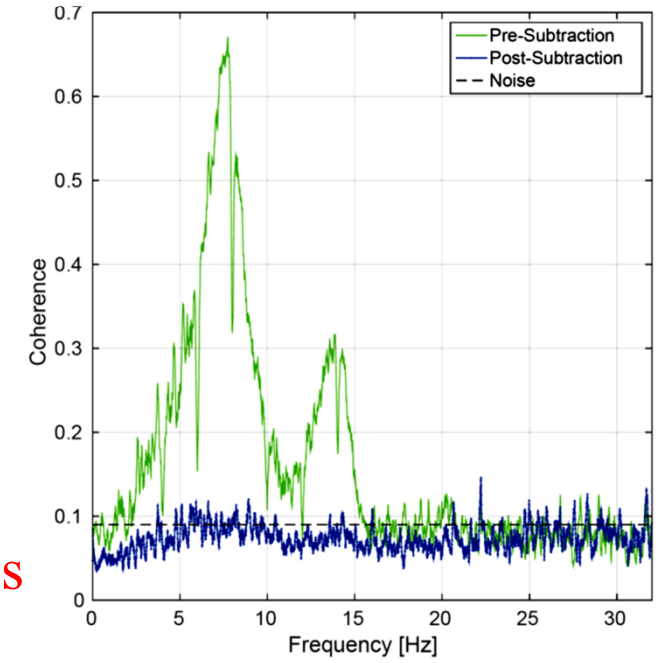


Schumann resonances



- Global electromagnetic resonances of the Earth-ionosphere 'waveguide'
  - Extremely low-frequency
  - Generated and excited by lightning
  - Magnetic fields coherent over global distances

→ Potential issue for stochastic background searches



- Use data from a network of magnetometers
  - At GW detector locations
  - At other sites (magnetically quiet)

  → Compute correlations

  → Remove them using Wiener filtering techniques

- References: Class. Quantum Grav. 33 (2016) 224003 [arXiv:1606.01011]
  Class. Quantum Grav. 34 (2017) 074002 [arXiv:1612.01102]
  Phys. Rev. D 97, 102007 (2018) [arXiv:1802.00885]

Observation run 3

- March 2019: Engineering Run 14
  - At least four week-long
    → Final test of all the systems: detectors + online data analysis path
- April 2019: start of Observation run 3
  - One year of global network data taking
  - Three detectors initially: LIGO Hanford, LIGO Livingston Virgo
    - KAGRA should join the network during O3
      → 4-detector configuration for the first time!
- Expected rate of GW signals
  - At least a few binary black hole mergers per month
  - Up to a few binary neutron star mergers
  - Possibly other sources, expected or not…
- Open public alerts
  - Lowest possible latency
  - Preceed vetting in most cases
    → Possible retractions at a later stage
    - Automate tasks as much as possible

Open data releases

- Gravitational Wave Open Science Center

- Data public around each event when published

- Current policy: whole dataset published 18 months after data taking is over
  → Tough schedule for the LIGO and Virgo collaborations
    - (Re)processings, analysis, validation, publication
  - O2 data to be released in a couple of weeks

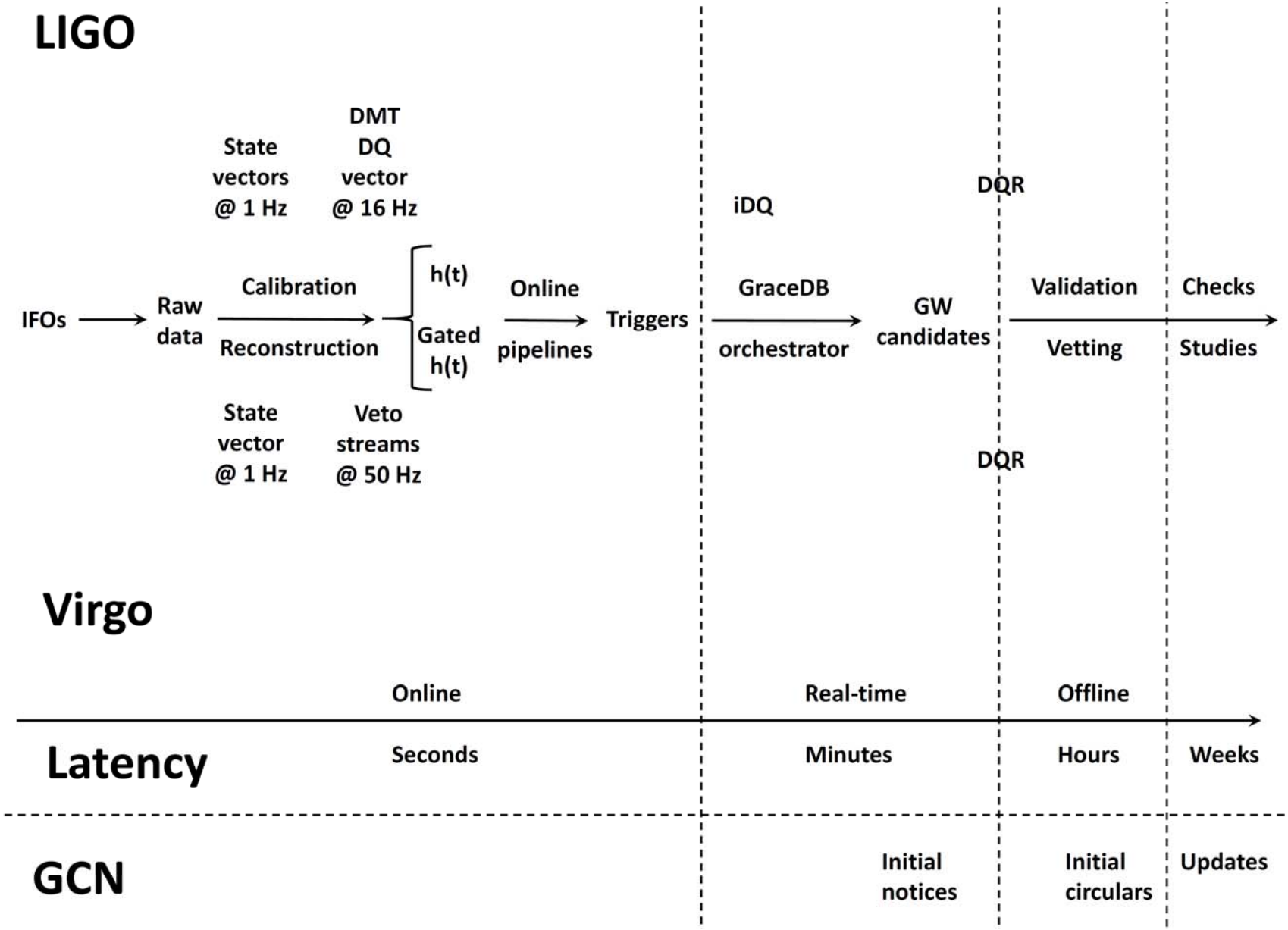
- Tens of projects already based on LIGO-Virgo open data
  - At all scientific levels, art & science, etc.

- Goal: users should be able to reproduce LIGO-Virgo results
  → Document everything
    - Including hardware injections!
  - For scientific consistency and with future open data releases in mind

LIGO & Virgo
DetChar in the O3 era

Dataflow

- From the detectors, to the offline validation of online events



Low-latency data quality

- Online data quality
  - Sets of bits encoding binary information
    - Calibration, h(t) reconstruction, clear detector problems

  → Reject bad data segments

- Vetoes
  - Various methods tested and implemented
    - Virgo veto streams: pipeline-dependent recipes based on 'safe' channels insensitive to GW
    - LIGO iDQ: compute the probability for a given trigger to be a glitch

  → Reject triggers from online pipelines

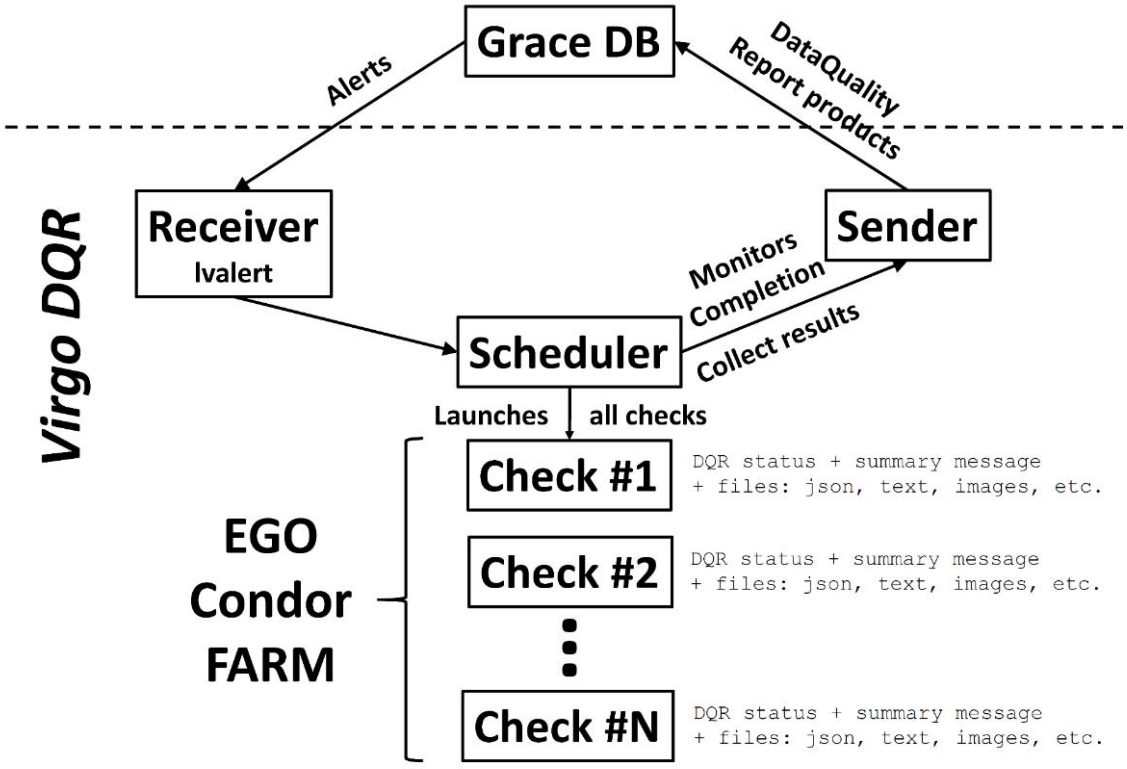
- Segment database – 1 s granularity

- Gating
  - Get round of extremely loud glitches while keeping the analysis pipeline running
    - Example: glitch around GW170817 in L1 data
  - Gating safety

  → Global (common) gating / pipeline-dependent gating

Data quality reports

- Data Quality Report (DQR)
  - Triggered by each (online) GW candidate
  - Runs various analysis on the available data:
    from basic to complex
    - Detector status, environment status, noise analysis, etc.
  - Each task reports a status
    → Helps final decision: keep or reject event
  - Runs simultaneously on data
    from all three detectors
    - Results gathered and linked to the data of the event that triggered the DQR



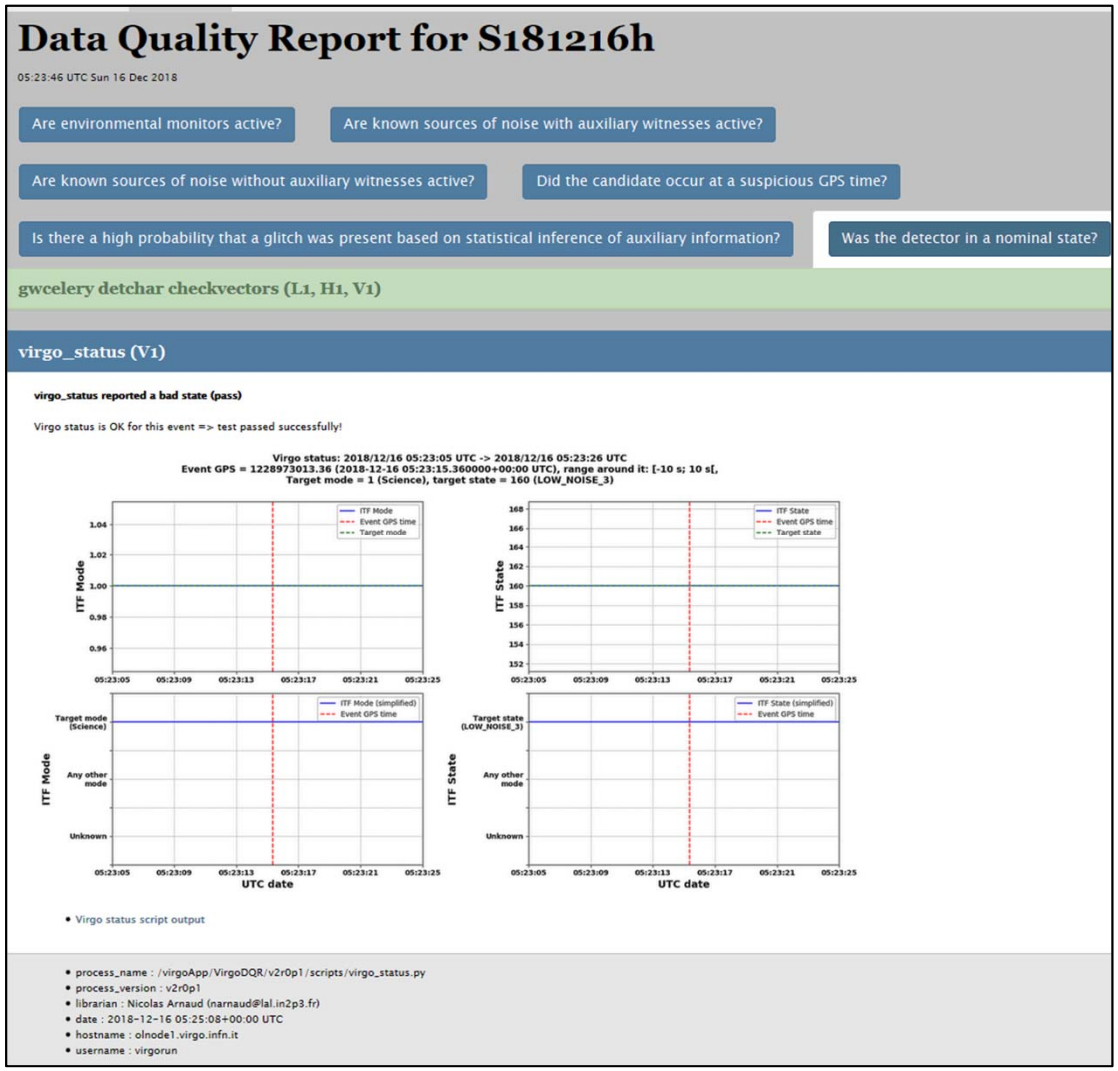
- Final tests and review of this new framework ongoing

- A good example of a joint LIGO-Virgo project!

DQRs

- Output examples from ER13
  - Right: joint LIGO-Virgo DQR
  - Below: logfile snippet showing check results being uploaded to the database

- Based on LIGO's data-quality-report package



120	Dec 16, 2018 20:39:44 UTC	Detchar	Tagged message 119: OmegaScan.	
119	Dec 16, 2018 20:39:44 UTC	Detchar	omegascan error report L1llhoftomegascan-S181216h.json	× OmegaScan
118	Dec 16, 2018 06:15:05 UTC	Virgo Detchar	omicronscanfull2048_figures omicronscanfull2048-V1-ASC_AcI_elapsed_time_OMICRONMAP-1228973013-16-S181216h.png	
117	Dec 16, 2018 06:15:04 UTC	Virgo Detchar	omicronscanfull2048_figures omicronscanfull2048-V1-ASC_AcI_elapsed_time_OMICRONMAP-1228973013-4-S181216h.png	
116	Dec 16, 2018 06:15:02 UTC	Virgo Detchar	omicronscanfull2048_figures omicronscanfull2048-V1-ASC_AcI_elapsed_time_OMICRONMAP-1228973013-1-S181216h.png	
115	Dec 16, 2018 06:15:00 UTC	Virgo Detchar	omicronscanfull2048_report omicronscanfull2048-S181216h.json	
114	Dec 16, 2018 05:59:52 UTC	Virgo Detchar	bruco_report bruco-S181216h.json	
113	Dec 16, 2018 05:41:57 UTC	Virgo Detchar	omicronscanfull512_report omicronscanfull512-S181216h.json	
112	Dec 16, 2018 05:39:56 UTC	Virgo Detchar	upv_report upv-S181216h.json	
111	Dec 16, 2018 05:33:26 UTC	Detchar	Lock status near event lock_check_dqr-S181216h.json	
110	Dec 16, 2018 05:33:25 UTC	Detchar	Lock status near event seg_short.png	

Shifts

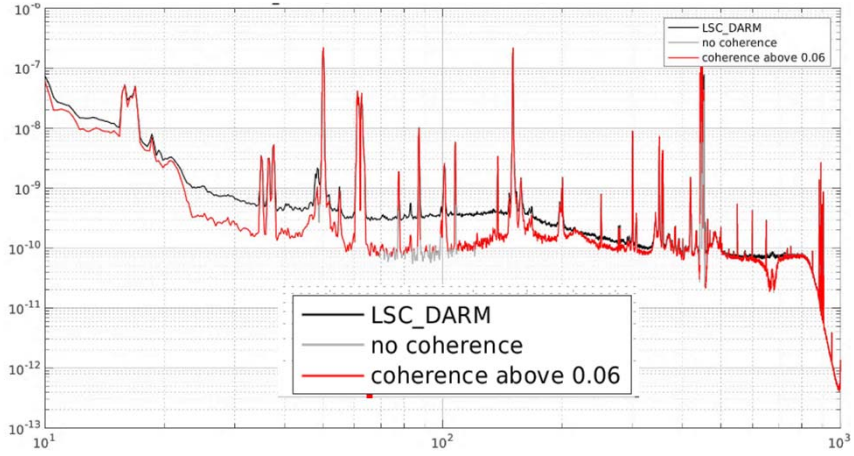
- Weekly shifts
  - Both for commissioning and during O3
  - LIGO: Monday → Sunday, 1 shifter / observatory
  - Virgo: Tuesday → Tuesday (in between two maintenance periods), 2 shifters
- Goals
  - Monitor and track changes in the noise behaviour: glitches, spectral lines
  - Help improving the sensitivity
  - Contribute to noise hunting campaigns
- Documentation and training
  - Tools and methods
  - Findings from previous shifters: follow-up, explore further
  - Long-term and short-term instructions
- Regular interaction with the control room

DetChar tools

Tools

- A variety of tools and methods available
  - Glitches / spectral lines
  - Counting / classification
  - Correlation finders: in time / in shape (slow variations)
    - Correlation does not imply causality
    - Thousands of auxiliary channels
    - Detector monitoring and alarm system
  - Generation of vetoes: online / offline
  - Data quality flags generation and bookkeeping
  - Event displays, monitoring plots and stripcharts

→ A (short) selection of representative tools in the following slides

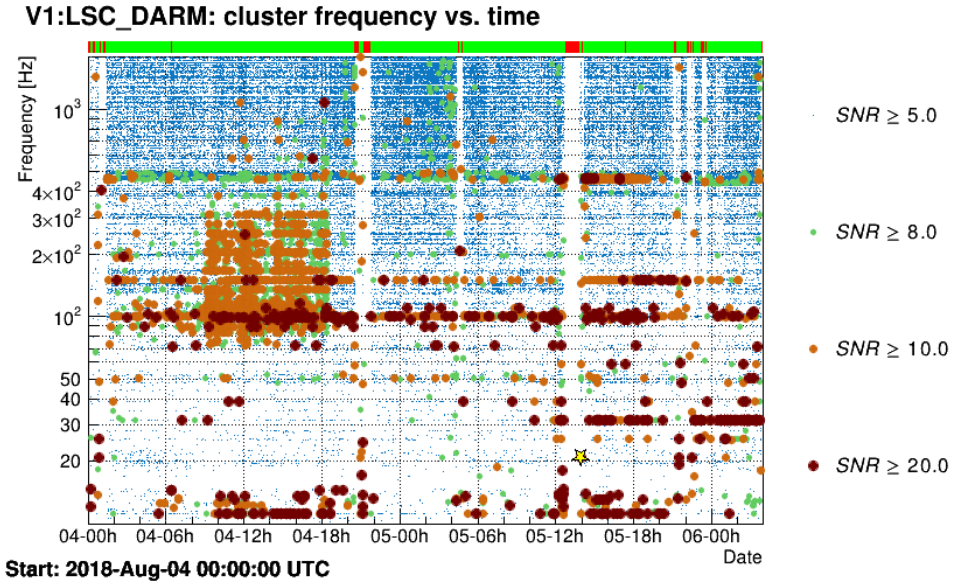


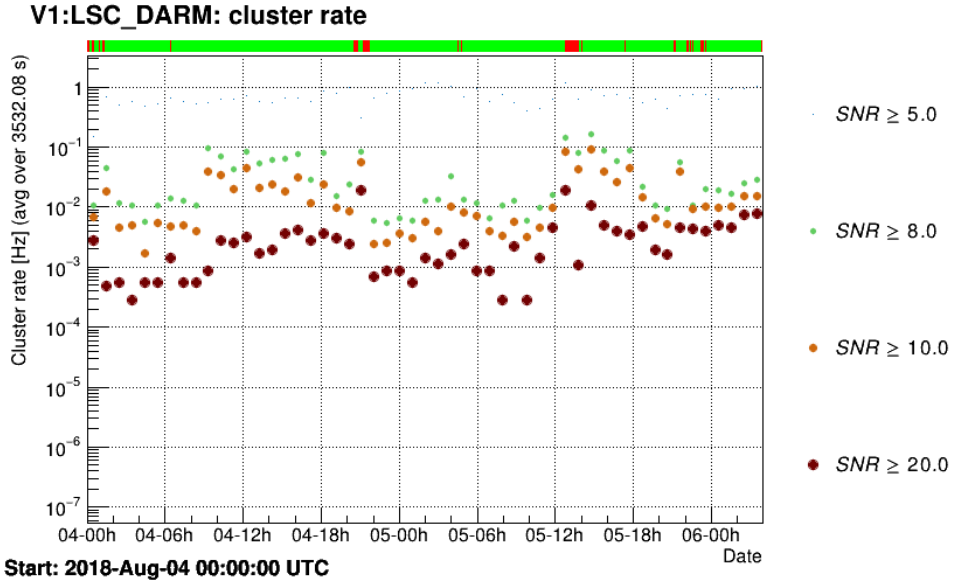
Omicron

- Transient noise event detection
  - Based on the Q-transform: overcomplete basis of sinusoidal Gaussian functions
    - Glitches defined by {time, frequency, SNR}
  - Hundreds of signals processed in quasi-real time
    - Computing load optimized
  - Several displays/plots provided

    → Investigate glitch origin

    → Identify and monitor families of glitches

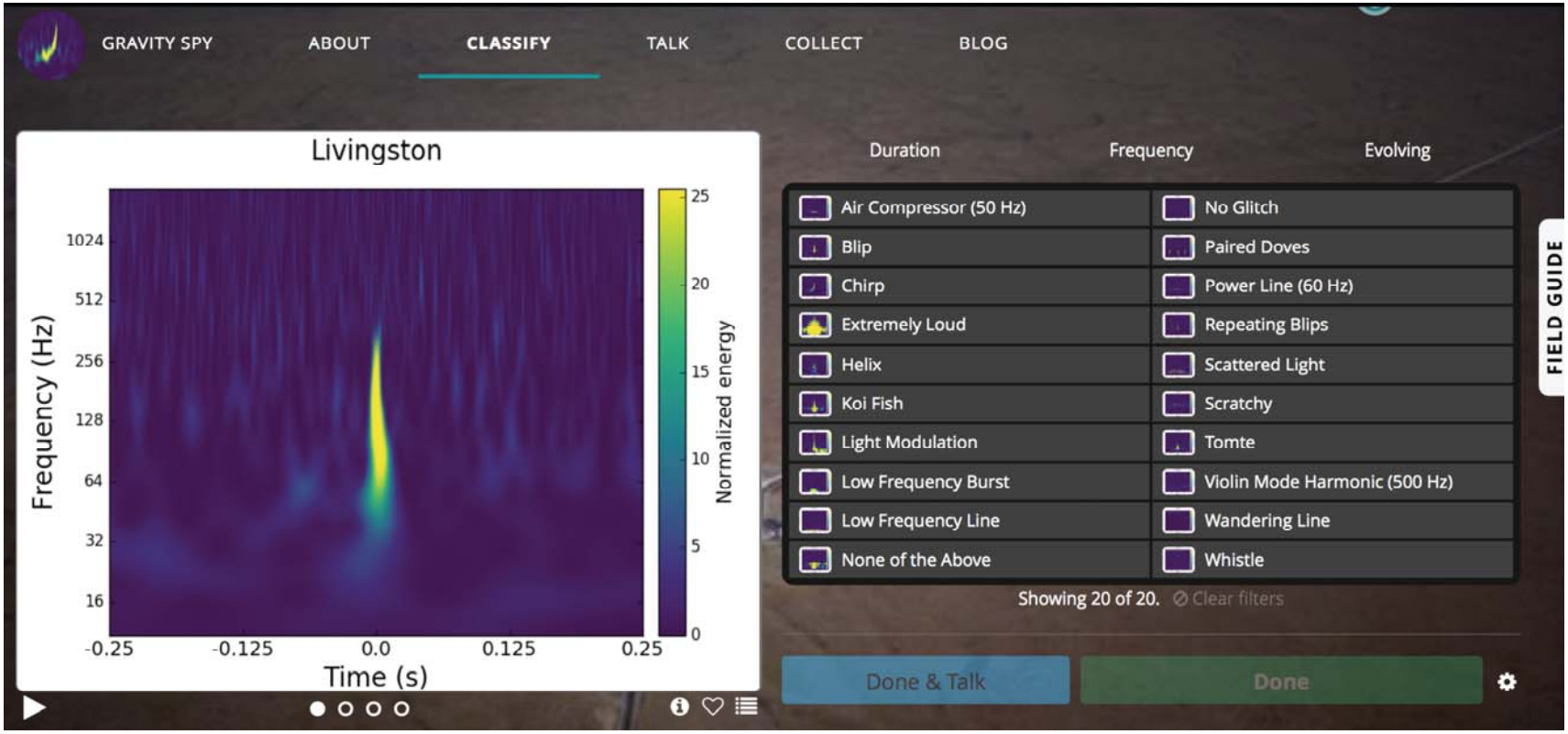




- Reference: public Virgo note

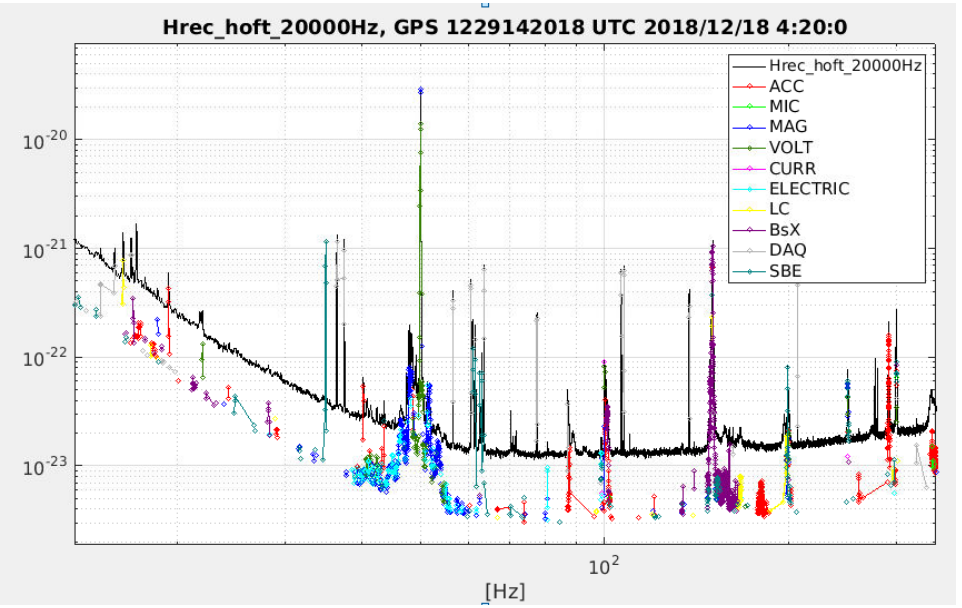
Gravity Spy

- Glitch classification based on time-frequency maps
  - DetChar
  - Citizen science
  - Machine learning



- Reference: Class. Quantum Grav. 34 (2017) 064003 [arXiv:1611.04596]
- Website: https://www.zooniverse.org/projects/zooniverse/gravity-spy

NoEMi



- Noise Frequency Event Miner
  - Monitor and identify noise spectral lines

- Framework rewritten in preparation for O3
  - New version up and running since ER13
    - 'Quicker, smaller, lighter, easier'

  → Testing and tuning in progress using O2 dataset
    - Final list of lines for the O2 data public release

- Parallel development of a line database
  - Catalogue known spectral lines
    - Calibration, suspension modes, etc.
  - Gather all information: known/new, origin, mitigation/suppression
    - Annotate entry, hide lines not more relevant, tag sets of lines
  - Search capability to be added
  - Eventually: automated uploads from NoEMi
  - Web interface

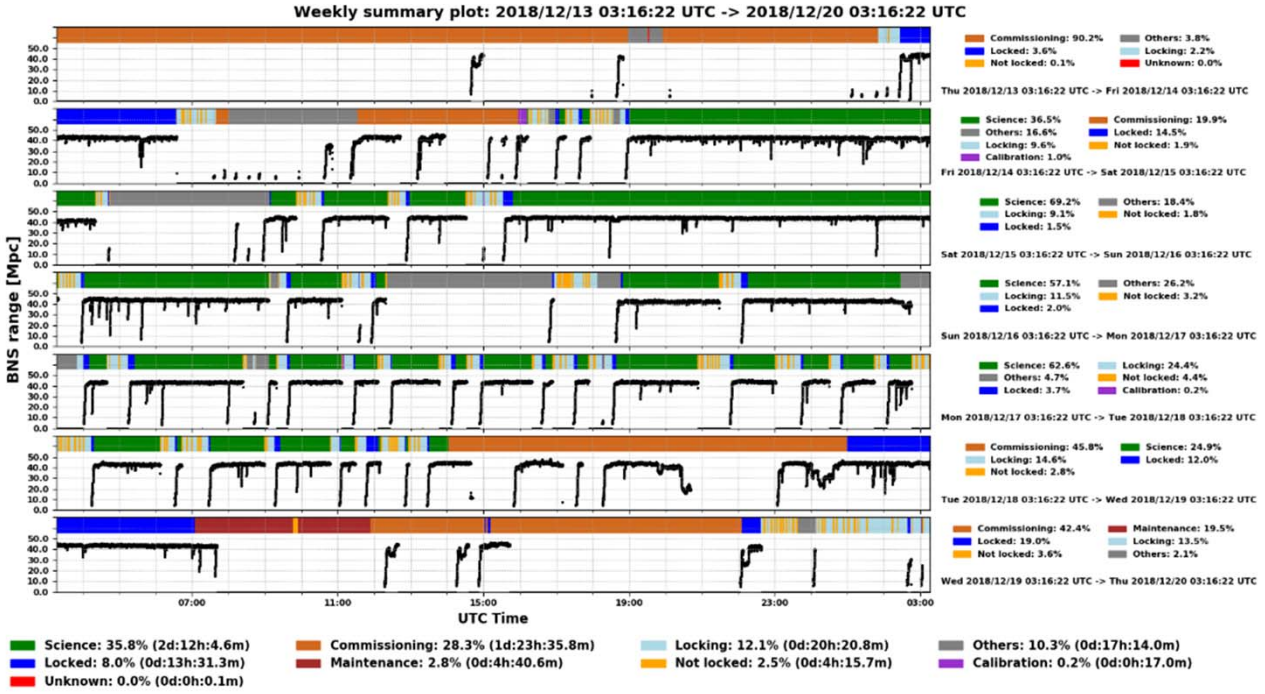
- Reference: Journal of Physics: Conference Series, Volume 363 (2012) 012037

Conclusion

Outlook

- DetChar: at the crossroads of many activities
  - From detector online data to the offline validation of GW candidates
- Joint work with various teams within each collaboration
  - Latest addition: open data releases
- Joint work between LIGO and Virgo DetChar groups
  - Common language, tools and procedures

→ Looking forward to fruitful collaborations with KAGRA



DetChar groups in a nutshell

LIGO	Virgo
• Wiki pages	
▪ https://wiki.ligo.org/DetChar/WebHome	▪ https://wiki.virgo-gw.eu/DetChar/WebHome
• Chairs	
▪ Jessica McIver Andy Lundgren	▪ Nicolas Arnaud
• Mailing lists	
▪ LIGO	▪ Virgo
• Meetings	
▪ LIGO Teamspeak server	▪ EGO Teamspeak server

On the DetChar channel

▪ Main call: Mondays 09:00 Pacific Working call: Thursdays 09:00 Pacific	▪ Fridays 10:30 Central European Time

• Other tools

▪ Slack