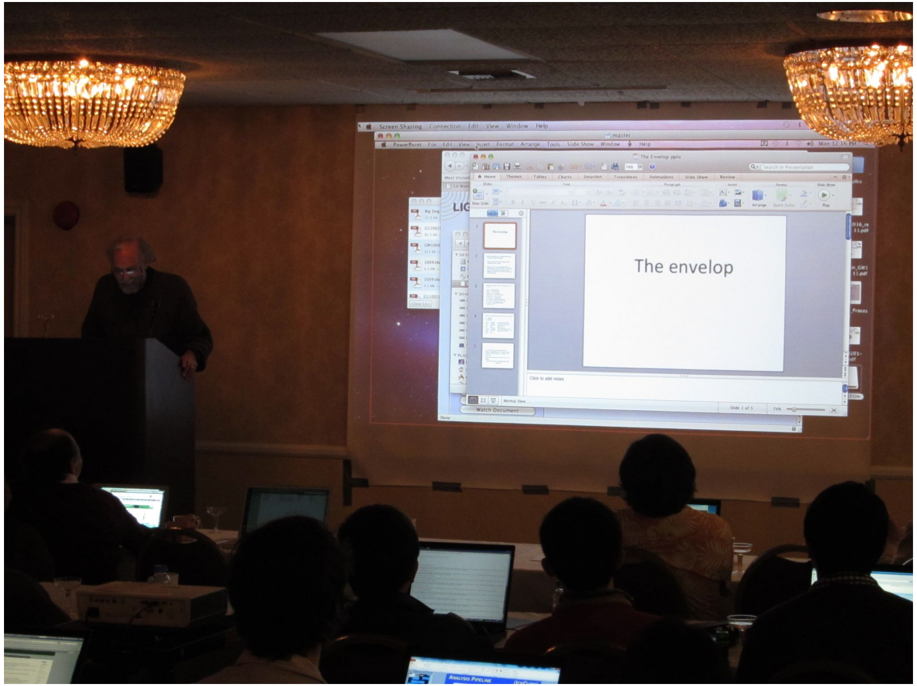
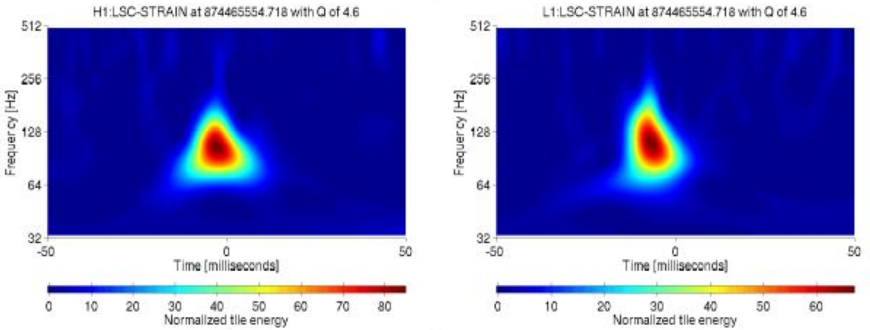
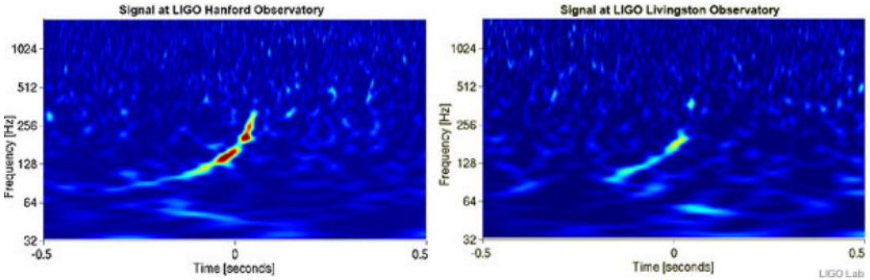
LIGO-Virgo “firedrills”

Erik Katsavounidis, MIT
SNEWS Collab Meeting 2021





Lindy Blackburn, MIT PhD thesis 2010
https://dspace.mit.edu/handle/1721.1/68965



https://www.ligo.org/news/blind-injection.php

LIGO Document G2100988

The Challenge:
Detection and physical interpretation of <u>rare events</u>

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Pronunciation | Spellings | Etymology | Quotations | Date chart

1. The mental attitude of trusting in or relying on a person or thing; firm trust, reliance, faith. Const. *in* (†*to, on, upon*).

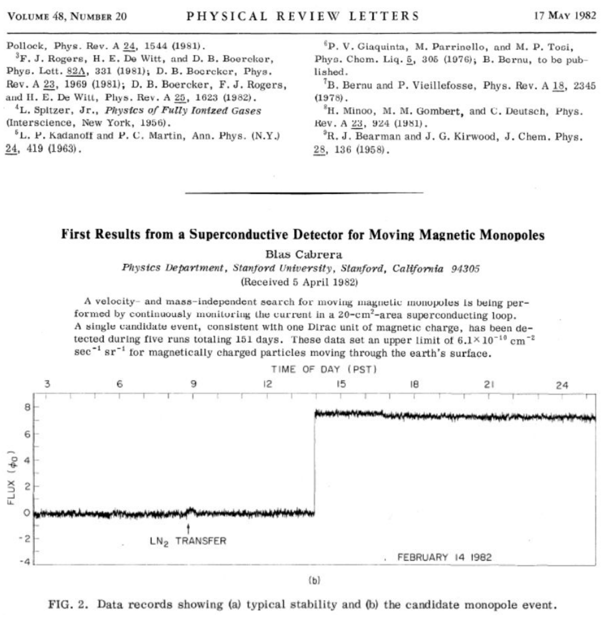
*c*1430 LYDG. in *Pol. Rel. & L. Poems* 47 Alle verteu..Made stable in god by gostly confidence. **1490** CAXTON *Eneydos* xxv. 93 The whiche goddes, hauynge confydence in trustynge his sayd promysse. **1535** COVERDALE *Ps.* cxvii. 9 It is better to trust in the Lorde, then to put eny confidence in man. **1557** NORTH tr. *Gueuara's Diall Pr.* 133b/1 The sonne..will not haue to his father any great confidence. **1593** SHAKES. *Rich. II*, II. iv. 6 The King reposeth all his confidence in thee. **1649** BP. REYNOLDS *Hosea* iv. 48 Confidence..in foraigne ayde. **1774** GOLDSM. *Grecian Hist.* I. 310 The king would place more confidence in the engagements of the nobility than upon those of the..capricious multitude. **1837** BARONESS BUNSEN in Hare *Life* I. x. 448 He..never abused the most implicit confidence.

2. a. The feeling sure or certain *of* a fact or issue; assurance, certitude; assured expectation.

1555 EDEN *Decades* III. III. 104 They..with no lesse confydence licke their lippes secreately in hope of their praye. **1611** SHAKES. *Wint. T.* I. ii. 414 He thinkes, nay with all confidence he sweares, As he had seen't. *a*1698 TEMPLE *Ess. Heroic Virtue* Wks. 1731 I. 230 The very Confidence of Victory..makes Armies victorious. **1790** BEATSON *Nav. & Mil. Mem.* I. 209 Wrapped up in a vain confidence of his own abilities. **1872** FREEMAN *Hist. Ess.* (ed. 3) 12 This story..I affirm with less confidence.

- Find the probability p=f(n>=x|b) → threshold on p → claim a detection?
- Ultimately, a detection has to be accompanied by a physical interpretation
- Confidence in a detection may not come only by a low p value
- Need to have a comprehensive list of tests a candidate will have to withstand, tests that will allow to assess our confidence to it → <u>detection checklist</u>
- No multiple detections can always be afforded

Firedrills generators*



VOLUME 48, NUMBER 20 PHYSICAL REVIEW LETTERS 17 MAY 1982

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First Results from a Superconductive Detector for Moving Magnetic Monopoles

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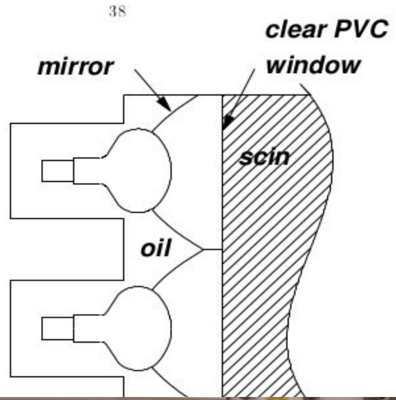
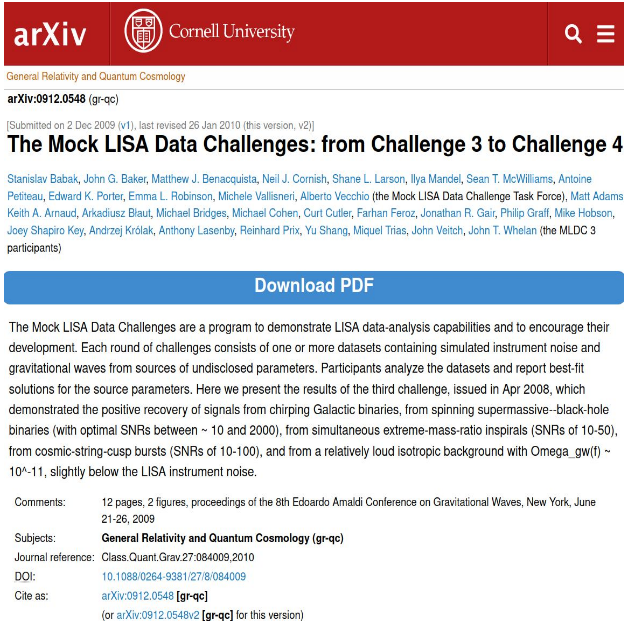
(Received 5 April 1982)

A velocity- and mass-independent search for moving magnetic monopoles is being performed by continuously monitoring the current in a 20-cm^2-area superconducting loop. A single candidate event, consistent with one Dirac unit of magnetic charge, has been detected during five runs totaling 151 days. These data set an upper limit of 6.1×10^{-10} cm^{-2} sec^{-1} sr^{-1} for magnetically charged particles moving through the earth's surface.

FIG. 2. Data records showing (a) typical stability and (b) the candidate monopole event.





General Relativity and Quantum Cosmology

arXiv:0912.0548 (gr-qc)

[Submitted on 2 Dec 2009 (v1), last revised 26 Jan 2010 (this version, v2)]

The Mock LISA Data Challenges: from Challenge 3 to Challenge 4

Stanislav Babak, John G. Baker, Matthew J. Benacquista, Neil J. Cornish, Shane L. Larson, Ilya Mandel, Sean T. McWilliams, Antoine Petiteau, Edward K. Porter, Emma L. Robinson, Michele Vallisneri, Alberto Vecchio (the Mock LISA Data Challenge Task Force), Matt Adams Keith A. Arnaud, Arkadiusz Blaut, Michael Bridges, Michael Cohen, Curt Cutler, Farhan Feroz, Jonathan R. Gair, Philip Graff, Mike Hobson, Joey Shapiro Key, Andrzej Królak, Anthony Lasenby, Reinhard Prix, Yu Shang, Miquel Trias, John Veitch, John T. Whelan (the MLDC 3 participants)

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The Mock LISA Data Challenges are a program to demonstrate LISA data-analysis capabilities and to encourage their development. Each round of challenges consists of one or more datasets containing simulated instrument noise and gravitational waves from sources of undisclosed parameters. Participants analyze the datasets and report best-fit solutions for the source parameters. Here we present the results of the third challenge, issued in Apr 2008, which demonstrated the positive recovery of signals from chirping Galactic binaries, from spinning supermassive--black-hole binaries (with optimal SNRs between ~ 10 and 2000), from simultaneous extreme-mass-ratio inspirals (SNRs of 10-50), from cosmic-string-cusp bursts (SNRs of 10-100), and from a relatively loud isotropic background with Omega_gw(f) ~ 10^-11, slightly below the LISA instrument noise.

Comments:	12 pages, 2 figures, proceedings of the 8th Edoardo Amaldi Conference on Gravitational Waves, New York, June 21-26, 2009
Subjects:	**General Relativity and Quantum Cosmology (gr-qc)**
Journal reference:	Class.Quant.Grav.27:084009,2010
DOI:	10.1088/0264-9381/27/8/084009
Cite as:	arXiv:0912.0548 **[gr-qc]**
	(or arXiv:0912.0548v2 **[gr-qc]** for this version)

Nature

Hardware-induced simulated signals

Software-added simulated signals

*Other than human mistakes

Rules of engagement

- Few (3-4) people define and carry out a small number (possibly zero) of hardware injections mimicking gravitational-wave transients → any information about this process is kept secret and recorded in an "envelope"
- Signature of events being hardware injections is retained at all times as part of the complete data stream (~200,000 channels, 10MBps per instrument written on disk) → analysts must abide by an honor code not to access hardware injection channels
- Define and exercise the procedure to apply for a landmark detection in the field of gravitational-wave physics
- Prepare a final publication with the results, the submission of which will proceed as-is if the "envelope" is empty (i.e., no blind injections)

Key questions addressed

- Are our search algorithms capable to make (the right) detections? How about extracting their physical parameters?

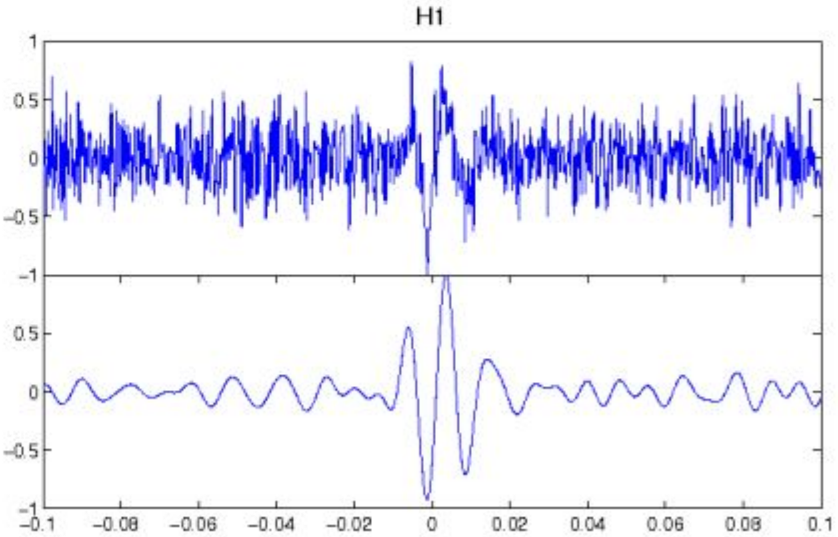
- Establish a comprehensive detection checklist
  - Sanity and integrity of data
  - State of the instruments and vetoes
  - Properties of the event
  - What is happening in the same second, minute, hour of the event
  - Role of calibration
  - Re-examine statistical and systematic errors

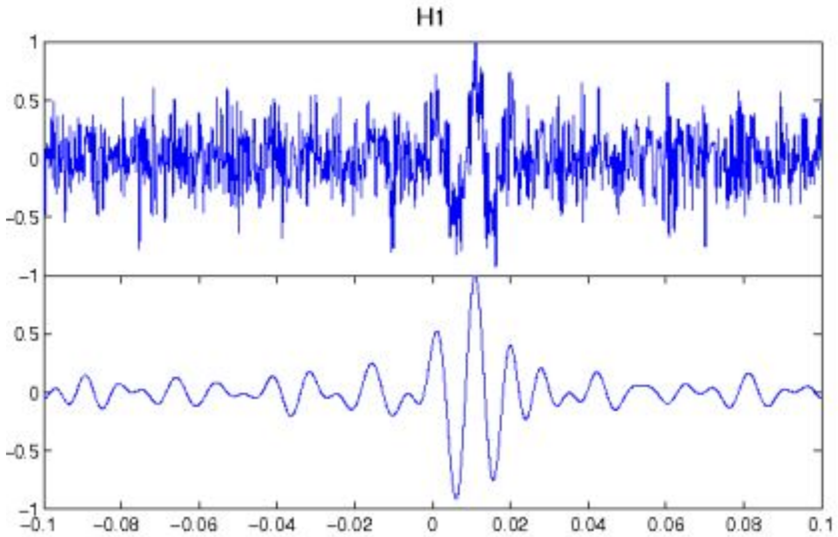
- The inverse problem: advance the understanding of the astrophysics behind the measurement (interpretation)

- Ponder on the role of multi-messenger observations in establishing confidence and astrophysical setting

- Can 1000+ physicists agree on the title of a PRL for a landmark GW detection?

Example: If this is a real signal, what is the astrophysics behind it?





Equinox event

Equal mass, no spin, 70+70 solar mass black hole merger

Lindy Blackburn, MIT PhD thesis 2010
https://dspace.mit.edu/handle/1721.1/68965

Example: Role of multi-messenger observations

From LV-Swift Online Processor
Subject **LIGO-Virgo Swift ToO Alert**
To Me <kats@ligo.mit.edu>, 6179351397@tmomail.net, 6179351275

```
Processed e-mail From: Erik Katsavounidis 721763 <kats@ldas-grid.mit.edu> with
 Subject: LVACWB
 sent   by ldas-grid.ligo.mit.edu (8.13.8/8.13.8/Submit) id o8G6meWX020316;
 and received by the Swift Processor at (YYYYMMDD-HHMMSS, Eastern US Time) 20100916-024846
 (randomized additional tag for internal bookkeeping: 10110)
 Top-level web page: http://swifttool.mit.edu/~online/protected/events3/20100916-024846-10110/a-summary.txt

 This is a MCWB (type#2, search=r) event occured at 968654557.9373 (Sep 16 2010 02:42:22.9373 EDT) and for wh

 Processing DQ flags: event must pass CAT1&2 in all instruments; notice CAT3= 1(1 to apply and pass) and CAT4
 DQinV1, cat1/2/3/4/5: 1 1 1 1 0 (1=PASS,0=FAIL)
 DQinL1, cat1/2/3/4/5: 1 1 1 1 1 (1=PASS,0=FAIL)
 DQinH1, cat1/2/3/4/5: 1 1 1 1 1 (1=PASS,0=FAIL)
 DQ outcome:          1  (1=PASS,0=FAIL)

 Rate significance analysis: the inverse target rate is         3024000.0 (sec, or       35.00 days). Backg
 BckndFrom:     Counts  1sigmaErr      Livetime(secs and in days)   Rate (in Hz) InverseRate(in sec and in da
 1job-10min          0        0.0                  -1.0         0.00    0.000000000                 -1.0         0
 6job-1hrs           0        0.0                  -1.0         0.00    0.000000000                 -1.0         0
 24x6jobs1d          0        0.0                  -1.0         0.00    0.000000000                 -1.0         0
 SinceStart          8        2.8           132060272.3      1528.48    0.000000061           16507534.0       191
 According to the applied criteria the significance decision is:  1 (1=PASS, 0=FAIL)

Cumulative probability of the 5 highest adjusted probability pixels for Swift is: 8.09E-01
This is for the following tile(s):
 1 R.A.: 110.800000 decl: -27.600000 Probability:   4.81E-01
 2 R.A.: 109.900000 decl: -27.600000 Probability:   1.11E-01
 3 R.A.:  75.000000 decl: -26.000000 Probability:   1.11E-01
 4 R.A.: 119.400000 decl: -50.800000 Probability:   5.53E-02
 5 R.A.: 109.200000 decl: -24.800000 Probability:   5.00E-02

Cumulative probability of the 3 highest adjusted probability pixels for QUEST is: 7.68E-01
This is for the following tile(s):
 1 R.A.: 109.485600 decl: -27.252940 Probability:   6.02E-01
 2 R.A.:  73.083375 decl: -27.252940 Probability:   1.11E-01
 3 R.A.: 119.618550 decl: -49.963720 Probability:   5.53E-02

Probability of the highest adjusted probability pixel for TAROT is: 6.00E-01
This is for the following tile(s):
 1 R.A.: 110.800000 decl: -27.600000 Probability:   6.00E-01
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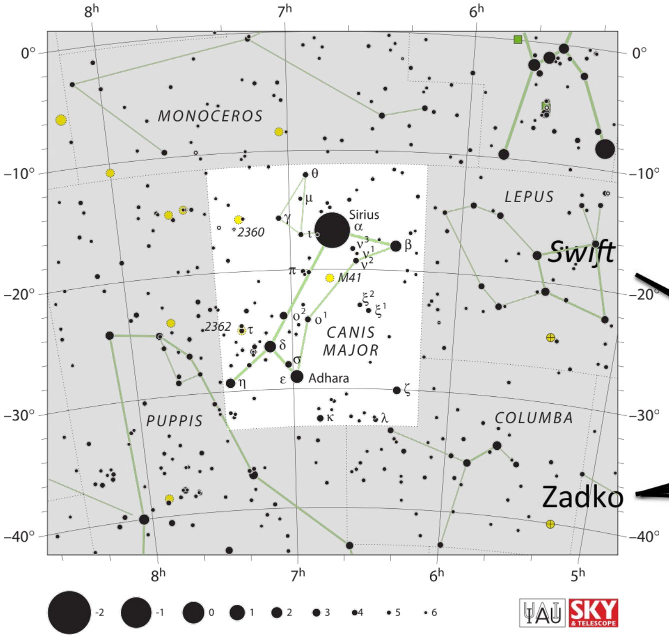
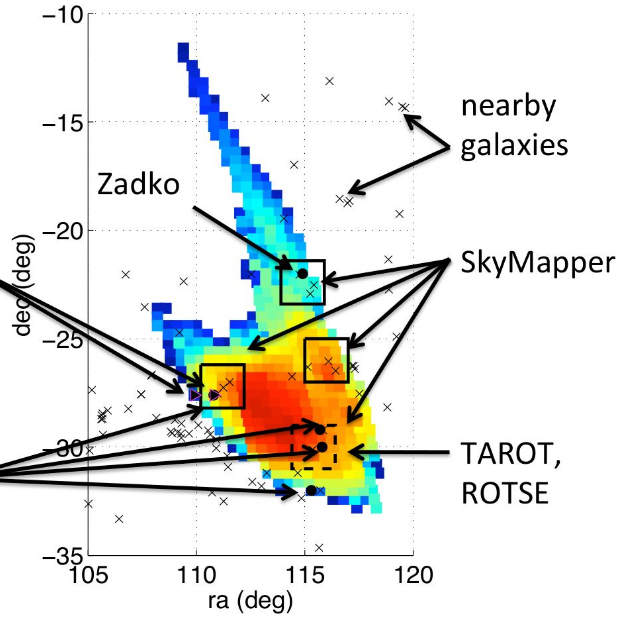
a 02:48 AM EDT wake-up phonecall!



By IAU and Sky & Telescope magazine (Roger Sinnott & Rick Fienberg) - individual constellation chart of Canis Major from IAU (International Astronomical Union) website, CC BY 3.0, https://commons.wikimedia.org/w/index.php?curid=15406243

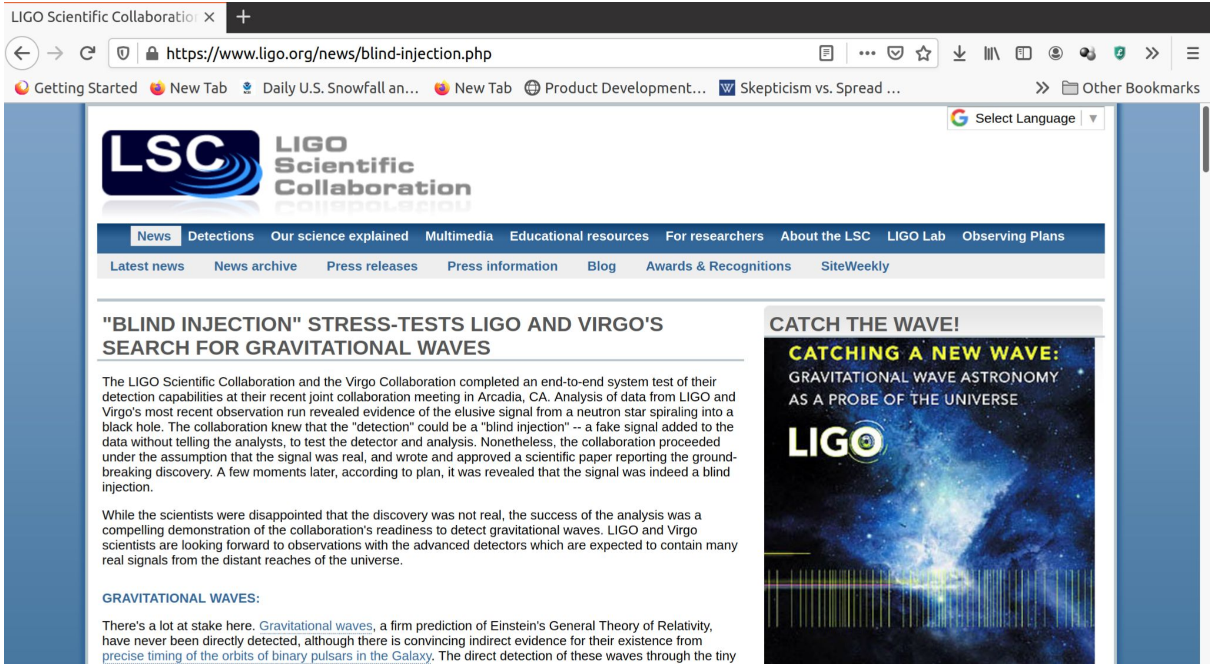


Swift and 5 ground optical telescopes were on the target within hours. No significant counterparts were identified.

The end game

Evidence for the Direct Detection of Gravitational Waves from a Black Hole Binary Coalescence

The LIGO Scientific Collaboration[1] and The Virgo Collaboration[2]



LIGO Scientific Collaboration

https://www.ligo.org/news/blind-injection.php

Getting Started | New Tab | Daily U.S. Snowfall an... | New Tab | Product Development... | Skepticism vs. Spread ... | Other Bookmarks

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"BLIND INJECTION" STRESS-TESTS LIGO AND VIRGO'S SEARCH FOR GRAVITATIONAL WAVES

The LIGO Scientific Collaboration and the Virgo Collaboration completed an end-to-end system test of their detection capabilities at their recent joint collaboration meeting in Arcadia, CA. Analysis of data from LIGO and Virgo's most recent observation run revealed evidence of the elusive signal from a neutron star spiraling into a black hole. The collaboration knew that the "detection" could be a "blind injection" -- a fake signal added to the data without telling the analysts, to test the detector and analysis. Nonetheless, the collaboration proceeded under the assumption that the signal was real, and wrote and approved a scientific paper reporting the ground-breaking discovery. A few moments later, according to plan, it was revealed that the signal was indeed a blind injection.

While the scientists were disappointed that the discovery was not real, the success of the analysis was a compelling demonstration of the collaboration's readiness to detect gravitational waves. LIGO and Virgo scientists are looking forward to observations with the advanced detectors which are expected to contain many real signals from the distant reaches of the universe.

GRAVITATIONAL WAVES:

There's a lot at stake here. Gravitational waves, a firm prediction of Einstein's General Theory of Relativity, have never been directly detected, although there is convincing indirect evidence for their existence from precise timing of the orbits of binary pulsars in the Galaxy. The direct detection of these waves through the tiny

CATCH THE WAVE!

CATCHING A NEW WAVE: GRAVITATIONAL WAVE ASTRONOMY AS A PROBE OF THE UNIVERSE

LIGO

- Firedrills have been very helpful for LIGO-Virgo in honing detection criteria, establishing follow-up investigations, including a role that observations in the electromagnetic spectrum may play in first detection(s).
- All-in-all they brought the search groups and the collaborations as a whole together in thinking what it means to have made the first direct detection of GWs. Added confidence in feeling ready to deal with the first astrophysical event.
- They have also been an interesting sociology experiment (papers+books have been written in this area, too), with 1000+ physicists needing to agree on what and how such a smashing result can be reported.
- However, they came with a non-trivial tax on people’s time and publication schedules.

“Firedrills” and SNEWS: a personal take

- Firedrills involving hardware-injected signals can be expensive both for setting up the experiment, but also for carrying it out and concluding it
- The very possibility of a blind injection may reduce the attention and wish of analyzers to undertake searches → a predetermined, short interval over which such experiment is conducted may mitigate this
- A prompt resolution to a blind injection challenge with satisfactory findings may win in a cost-benefit analysis over a slow, lengthy resolution that will bring perfect findings
- Firedrills may involve specific questions within SNEWS’ mission that can be addressed via blind tests, for example,
  - Establishing multi-detector response and analyses (beyond mere coincidence)
  - Test multi-detector localization
  - Dress rehearsal for an EM follow-up program
  - Interpret results in absence of an EM signal
  - pre-SN benchmarking
- Firedrills may be undertaken with signals added (secretly) in software and past each instruments’ data archiving system but entering all the rest of the analyses downstream
  - Multiple “parallel” streams s(t_i) of different astrophysical/model assumptions containing the signal **only** can be chosen to flow in sync with the instrument data n(t_i), with all searches downstream expected to analyze the “linear” sum s(t_i)+n(t_i)
- **Firedrills can be fun, but this is true for roller-coasters too**