



The Cyberinfrastructure of Gravitational-Wave Astronomy and the March Towards Open Data

Duncan Brown
Syracuse University

About 1.3 billion years ago...

As massive objects move around, the curvature of space changes

Information about the changing spacetime curvature propagates out at the speed of light as gravitational waves



Typical strains from astrophysical sources when the waves arrive at the Earth are

$$h \sim \frac{G}{c^4} \frac{E_{\text{NS}}}{r} \sim 10^{-21}$$

However, the energy radiated is enormous

$$L_{\text{GW}} \sim \left(\frac{c^5}{G} \right) \left(\frac{v}{c} \right)^6 \left(\frac{R_{\text{S}}}{r} \right)^2 \sim 10^{59} \text{ erg/s}$$

Solar luminosity $L \sim 10^{33}$ erg/s

Gamma Ray Bursts $L \sim 10^{49-52}$ erg/s

Proxima Centauri



250,000,000,000,000 miles

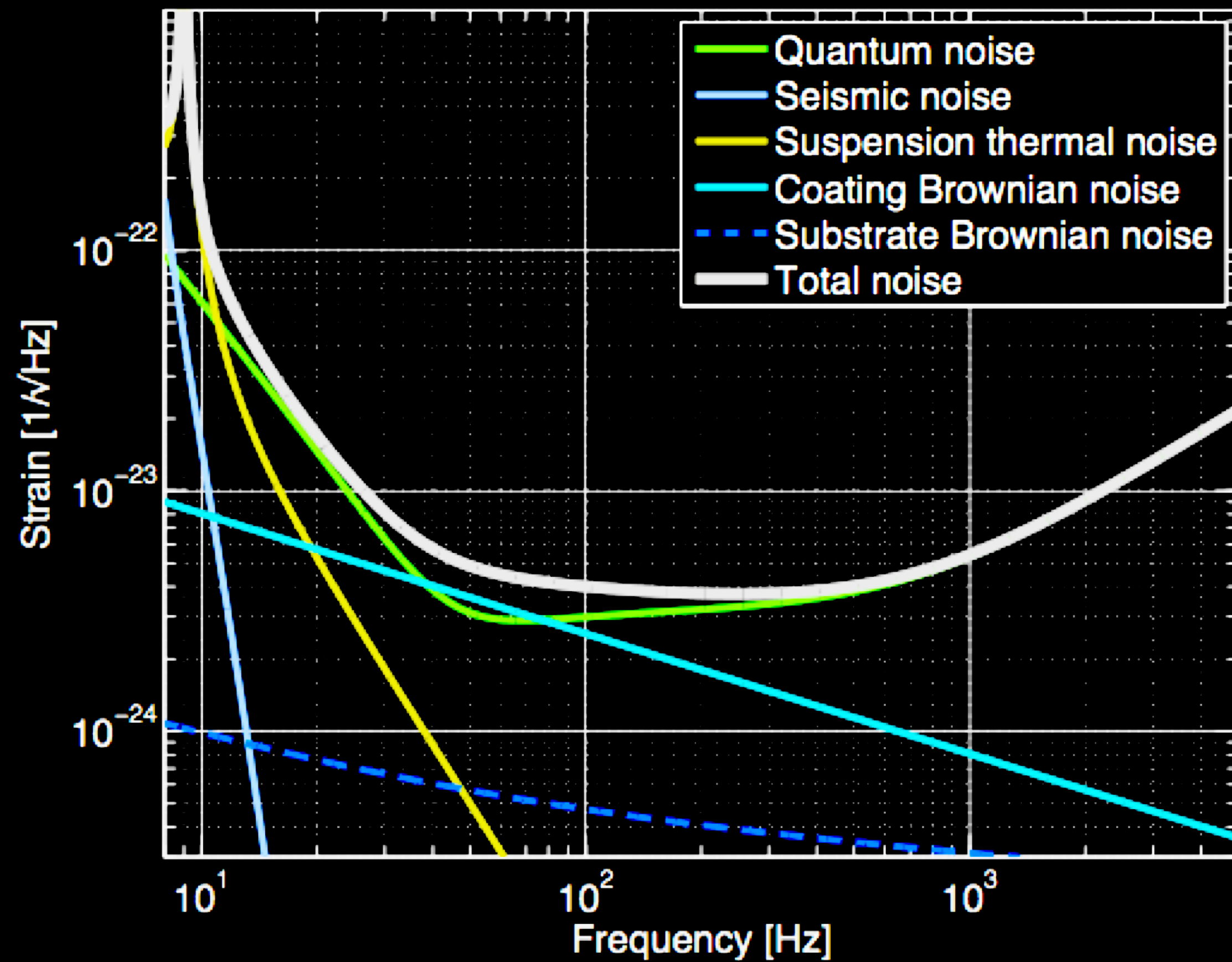
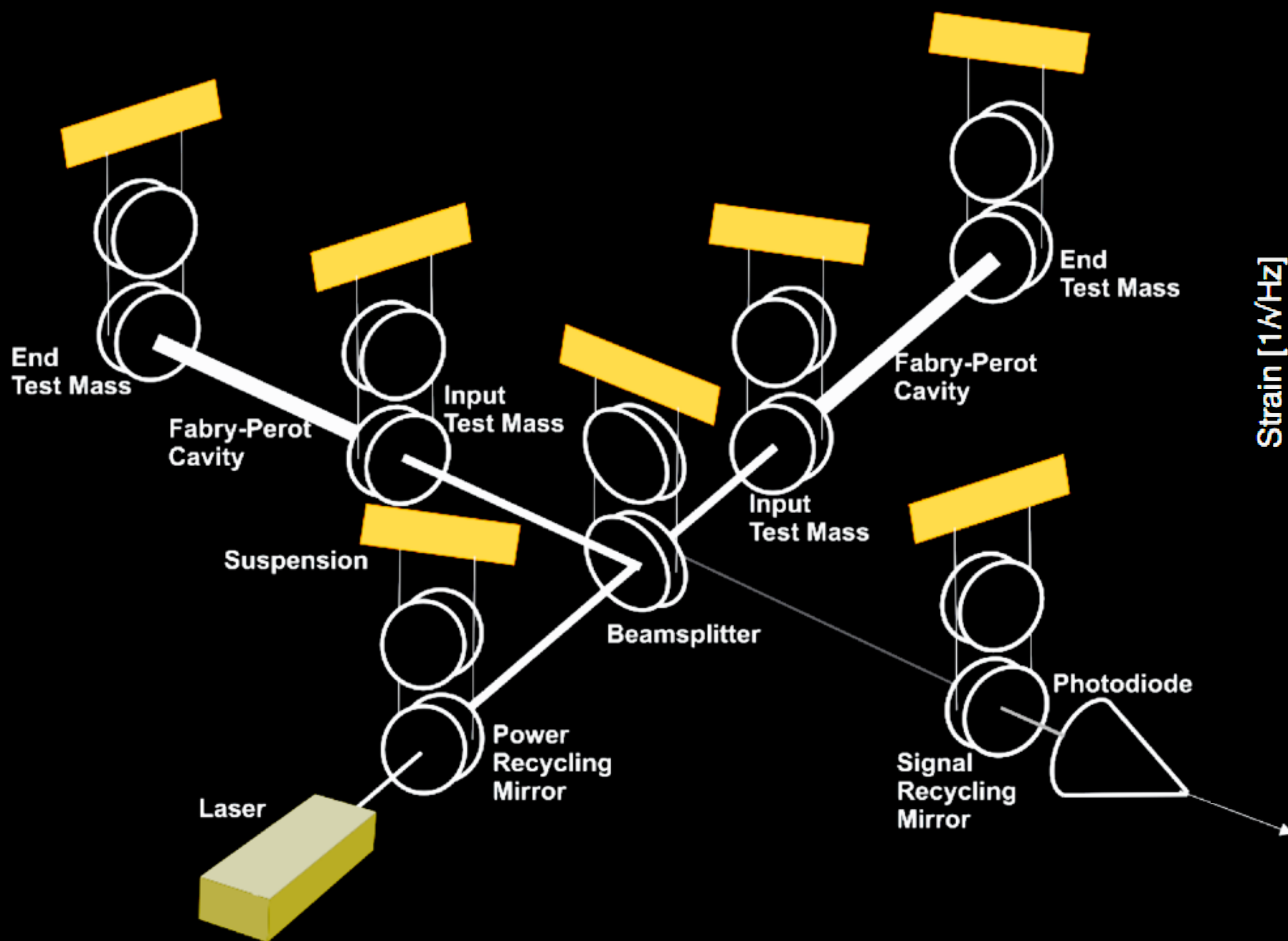
(4.2 light years)

Imagine measuring this distance to a precision of **ten microns**

Smaller than the width of a human hair!



Advanced LIGO



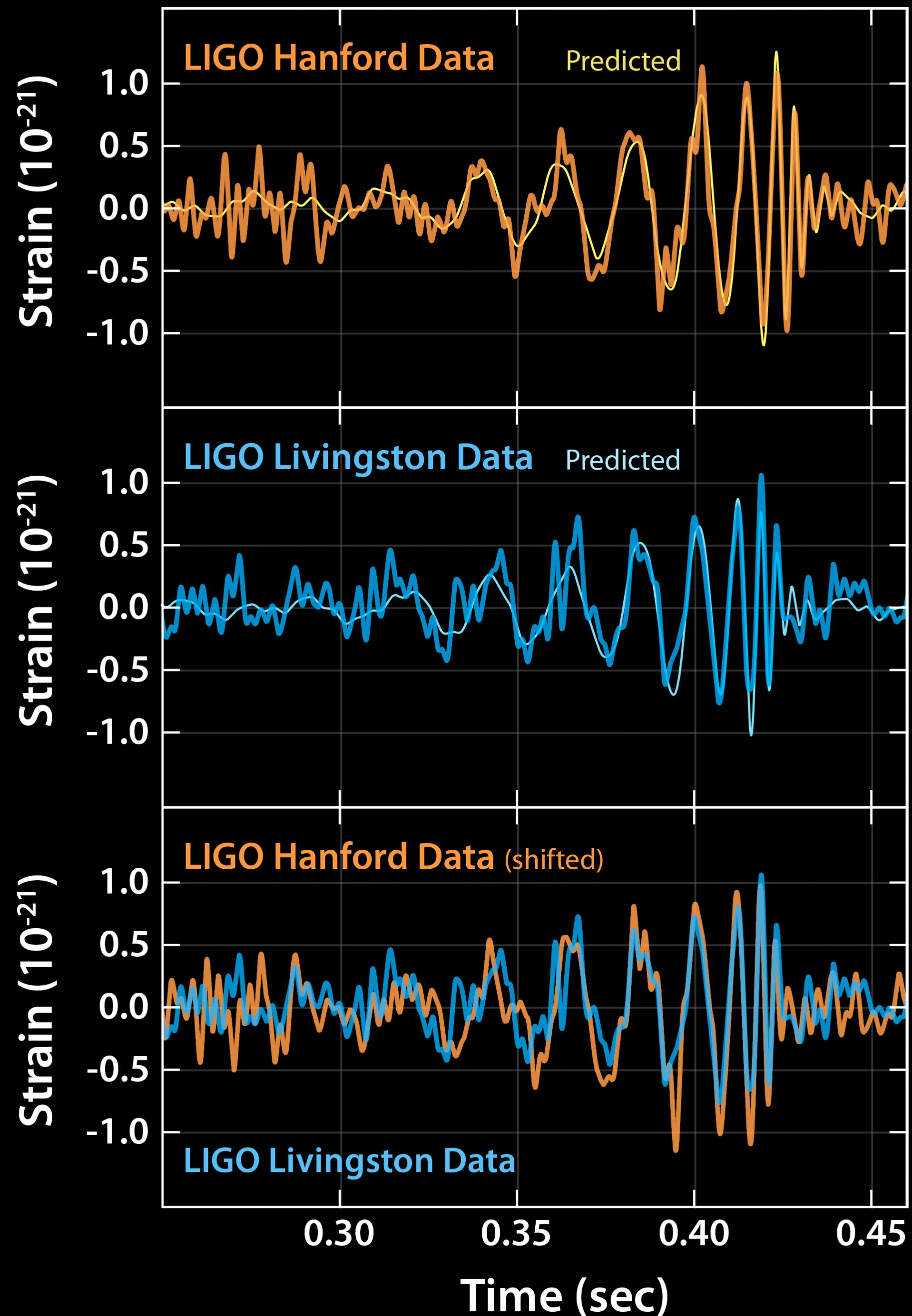








GW150914



- Observed September 14, 2015 09:50:45 UTC
- The signal is seen first by the Livingston detector and then 7ms later at Hanford
- Over 0.2 seconds, the signal increases in frequency and amplitude in about 8 cycles from 35 Hz to a peak amplitude at 150 Hz

- Use this to measure the "chirp mass"

$$\mathcal{M} = \frac{(m_1 m_2)^{3/5}}{(m_1 + m_2)^{1/5}} = \frac{c^3}{G} \left[\frac{5}{96} \pi^{-8/3} f^{-11/3} \dot{f} \right]^{3/5}$$

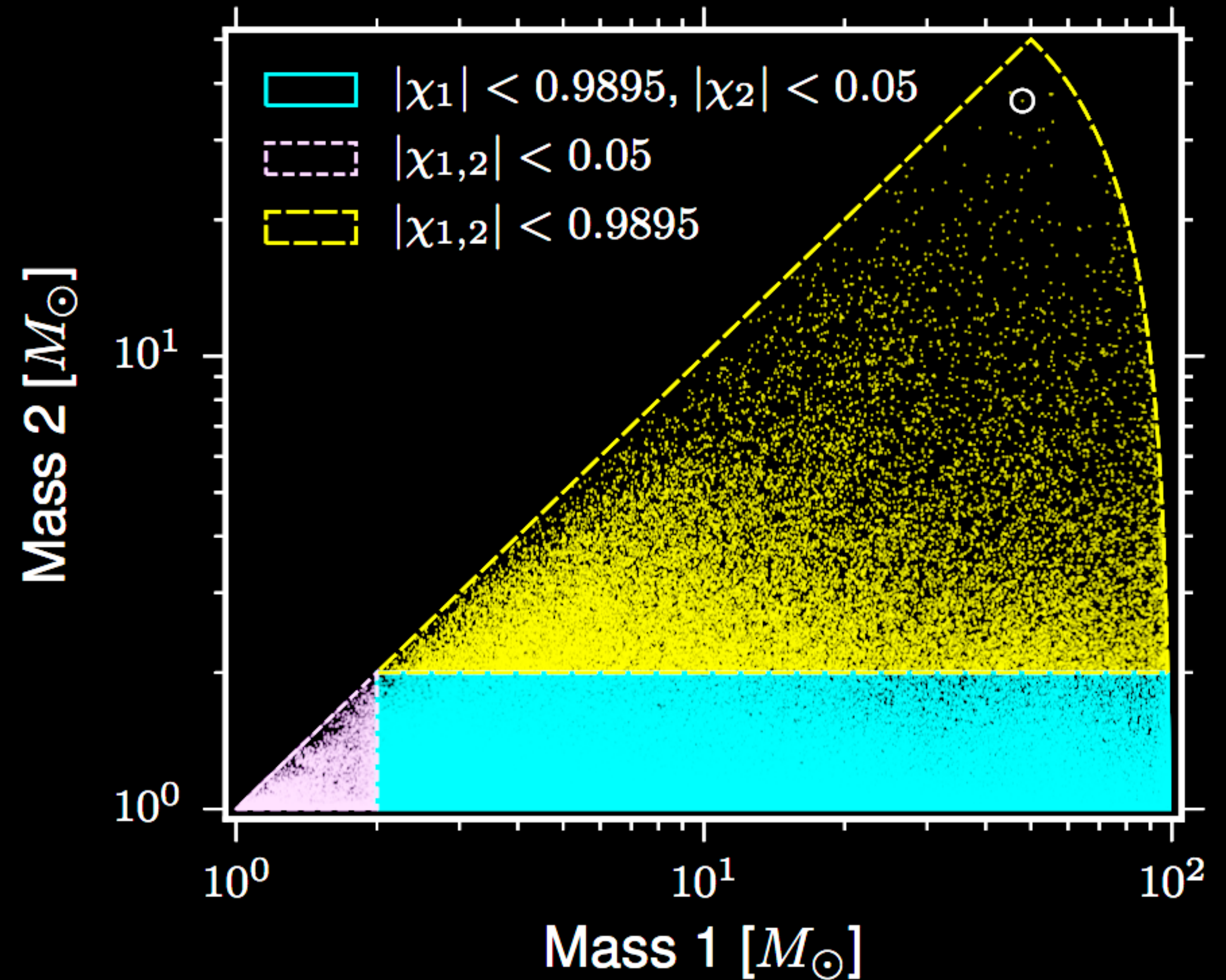
- From this we can bound the total mass $M = m_1 + m_2 \gtrsim 70M_\odot$
- The components must reach an orbital frequency of 75 Hz without touching each other
- Black holes are the only known objects compact enough to do this

To detect signals from compact-object binaries, we construct a bank template waveforms and matched-filter the data

$$\rho = \frac{\langle s|h \rangle}{\sqrt{\langle h|h \rangle}}$$

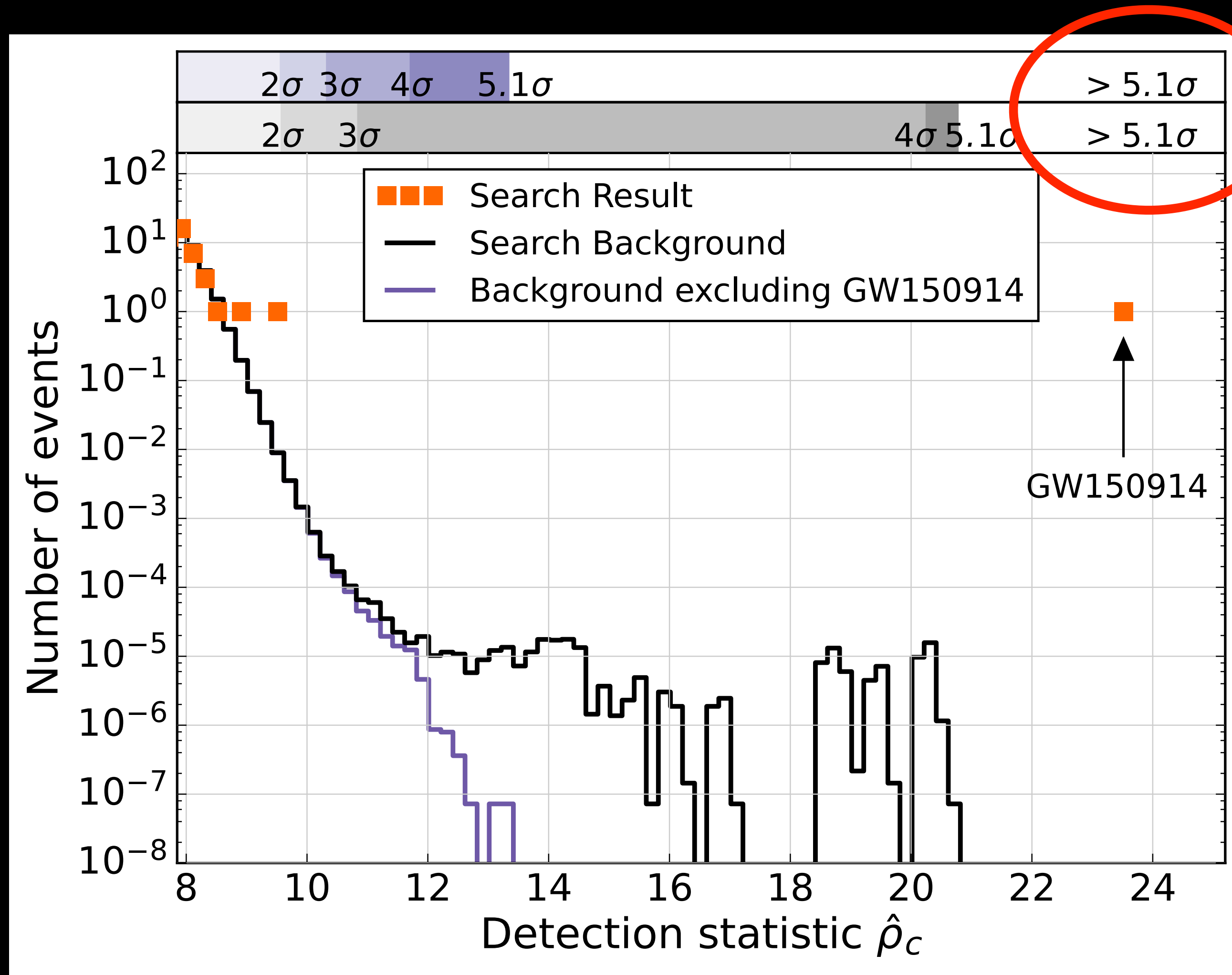
$$\langle a|b \rangle = 4\text{Re} \int_{f_{\text{low}}}^{f_{\text{high}}} \frac{\tilde{a}(f)\tilde{b}(f)}{S_n(f)} df$$

Apply additional waveform-consistency tests to separate signal from noise



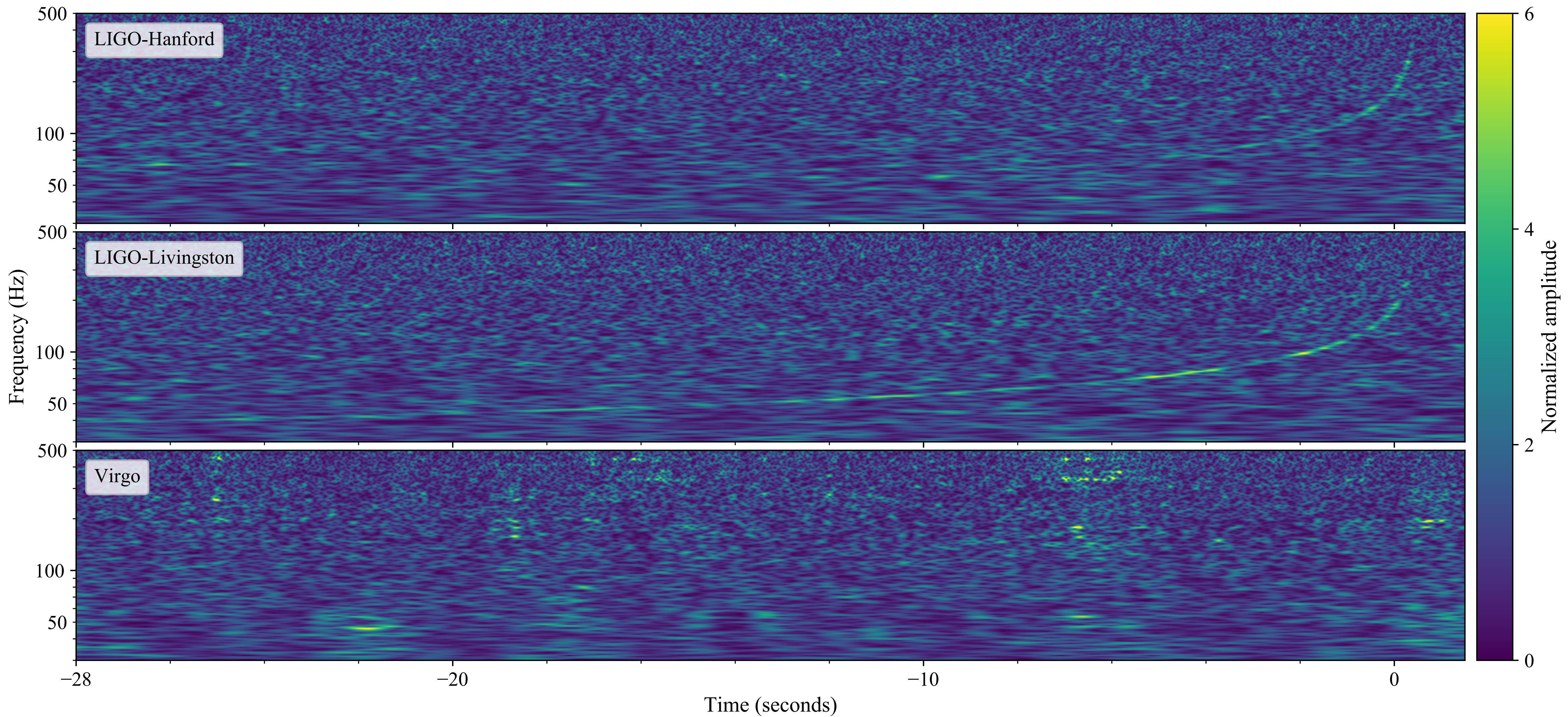
Allen, ... , DAB, et al. Phys Rev D 85 122006 (2012)
 Babak, ..., DAB, et al. Phys Rev D 87 024033 (2013)
 Usman, ... DAB, et al. arXiv:1508.02357
 Capano, et al. arXiv:1602.03509
 Abbott, ..., DAB, et al. arXiv:1602.03839
 DAB, et al., Phys. Rev. D 86 084017 (2012)

Significance of the Signal



- Matched filter search for signals from compact-object mergers in data taken between Sep 12 and Oct 20, 2015
- Approximately 250,000 templates
- Measure the noise background by introducing artificial "time-shifts" and re-analyzing these data
- False alarm rate < 1 in 203,000 yr

GW170817



GCN 21509 at 10:09 am EDT announcing significant BNS candidate coincident with the Fermi GBM trigger...

TITLE: GCN CIRCULAR
NUMBER: 21509
SUBJECT: LIGO/Virgo G298048: Identification of a binary neutron star candidate coincident with Fermi GBM trigger 524666471/170817529
DATE: 17/08/17 14:09:25 GMT
FROM: Reed Clasey Essick at MIT <ressick@mit.edu>

The LIGO Scientific Collaboration and the Virgo Collaboration report:

A binary neutron star candidate was identified in data from the LIGO Hanford detector at gps time 1187008882.4457 (Thu Aug 17 12:41:04 GMT 2017). The signal is clearly visible in time-frequency representations of the gravitational-wave strain in data from H1. The current significance estimate of $\sim 1/10,000$ years is based on data from H1 alone. Information about this candidate is available in GraceDb here

<https://gracedb.ligo.org/events/view/G298048>

The effective distance to this candidate is approximately 58 Mpc and the current localization estimate using gravitational-wave data alone is quite broad because it only makes use of data from H1. We note that this is only an estimate of the effective distance, and the actual luminosity distance to the source is likely larger.

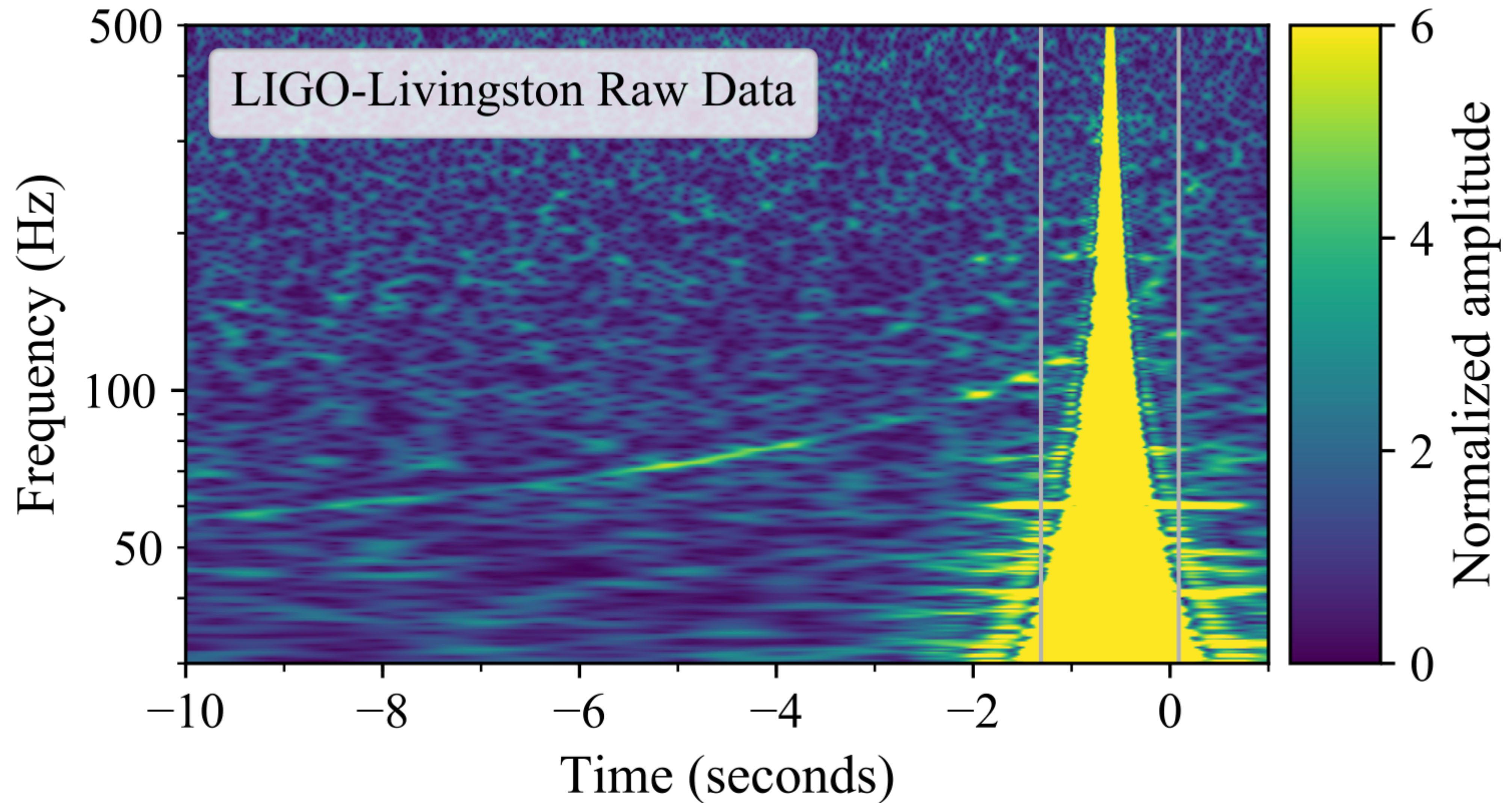
The neutron star coalescence candidate is also clearly visible in data from the LIGO Livingston detector, although there is a coincident noise artifact in the L1 data. To be clear, the binary neutron star candidate is clearly visible in the L1 data on top of the noise artifact. There is no evidence for any noise artifact at H1. Virgo was online at the time, although its data was not used to estimate the candidate's significance. It is expected to be visible in all detectors once the data has been analyzed.

The gravitational-wave candidate was found in coincidence with Fermi GBM trigger 524666471/170817529, which occurred at gps time 1187008884.47 (Thu Aug 17 12:41:06 GMT 2017). This is approximately 2 seconds after the gravitational-wave candidate's coalescence time. The Fermi trigger's localization estimate from Fermi data alone can be found here

https://heasarc.gsfc.nasa.gov/FTP/fermi/data/gbm/triggers/2017/bn170817529/quicklook/glg_locplot_all_bn170817529.png
https://heasarc.gsfc.nasa.gov/FTP/fermi/data/gbm/triggers/2017/bn170817529/quicklook/glg_locprob_all_bn170817529.fit

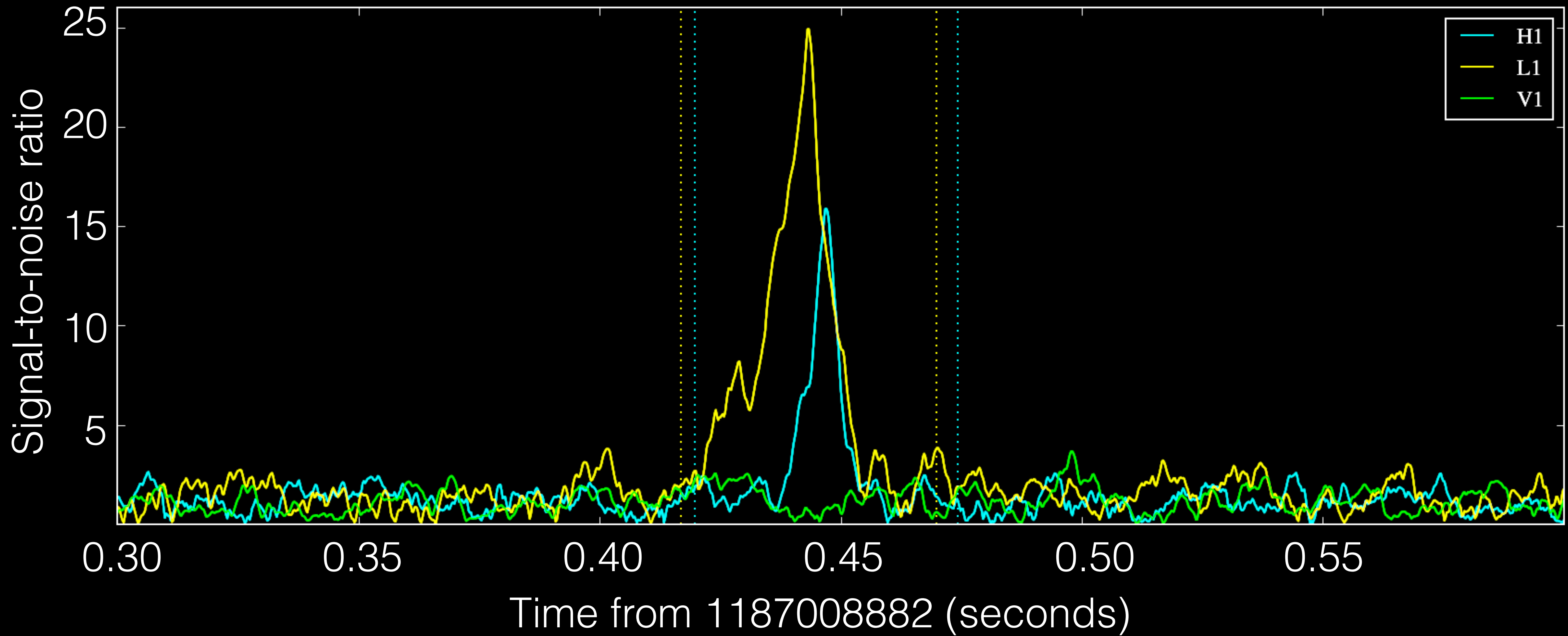
Analyses including data from H1, L1, and V1 are ongoing and a sky-map using gravitational-wave data will be made available as quickly as possible.

[GCN OPS NOTE(17aug17): Per author's request, the LIGO/VIRGO ID was added to the beginning of the Subject-line.]



Usman,... DAB, et al. *Class. Quant. Grav.***33** 215004 (2016)

Abbott,..., DAB et al. *PRL* **119** 161101 (2017)



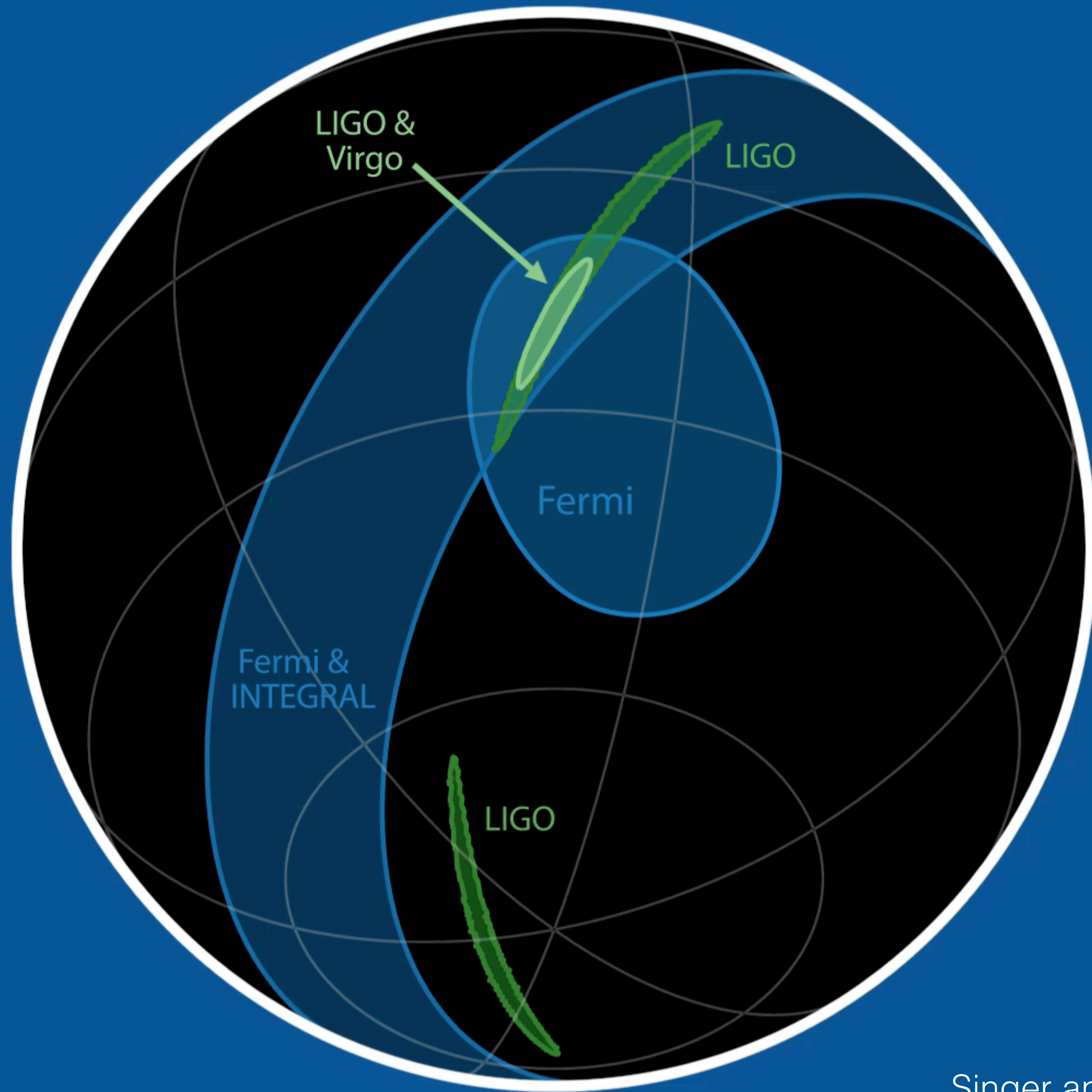
GCN 21513 at 1:54 pm EDT with localization...

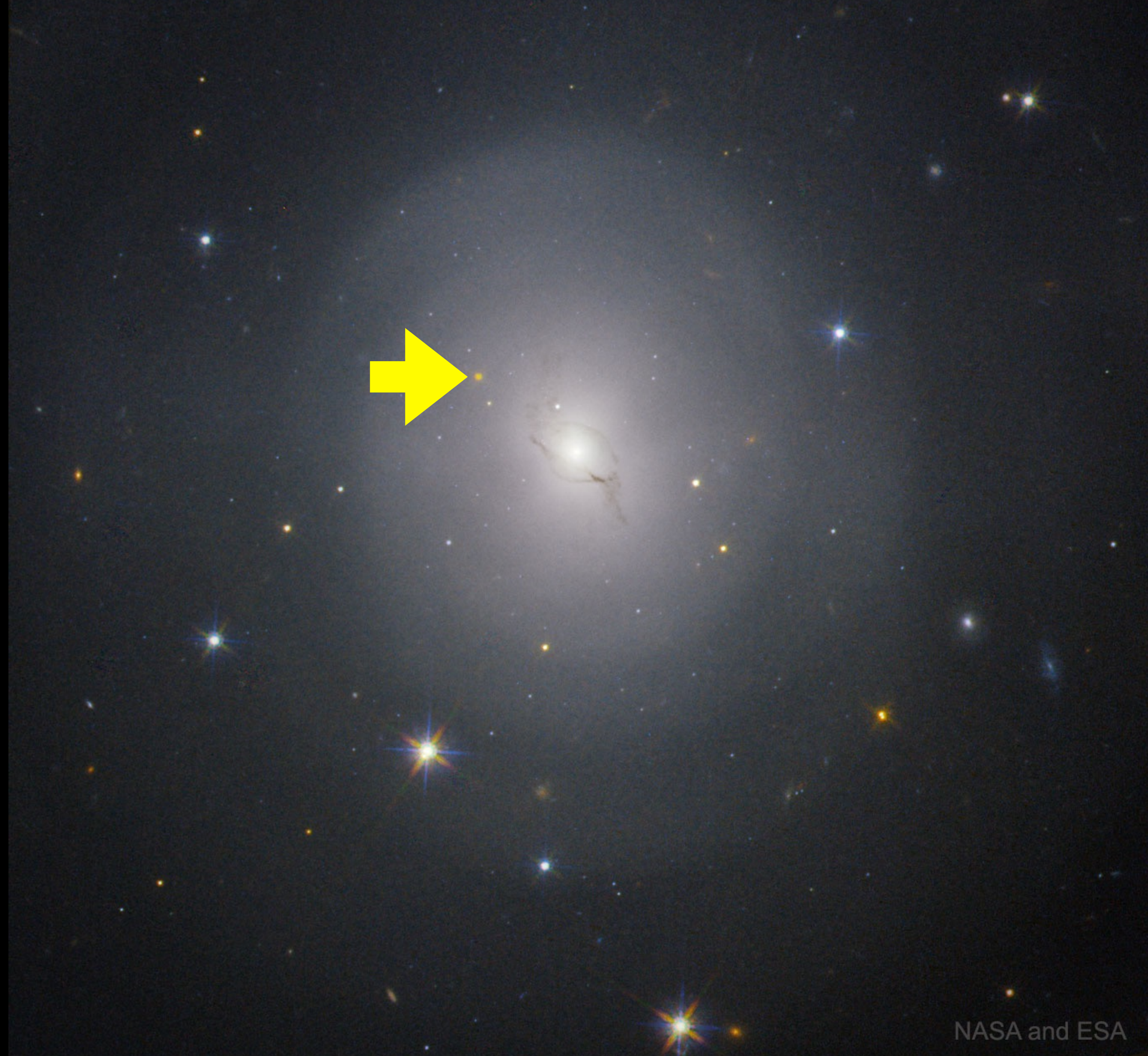
TITLE: GCN CIRCULAR
NUMBER: 21513
SUBJECT: LIGO/Virgo G298048: Further analysis of a binary neutron star candidate
DATE: 17/08/17 17:54:51 GMT
FROM: Leo Singer at NASA/GSFC <leo.p.singer@nasa.gov>

The LIGO Scientific Collaboration and the Virgo Collaboration report:

We performed a preliminary offline analysis using the PyCBC search (Nitz et al. arxiv:1705.01513, 2017) of the binary neutron star candidate G298048 (LSC and Virgo, GCN 21505, 21509, 21510) identified in low-latency by the gstlal online search (Messick et al. Phys. Rev. D 95, 042001, 2017).

A trigger consistent with a binary neutron star merger is observed at GPS time 1187008882.443 (2017-08-17 12:41:04 UTC) in both the LIGO Livingston (L1) and LIGO Hanford (H1) detectors. The trigger is below threshold in Virgo because of the antenna pattern for Virgo (V1) at the time and location of this event, but the Virgo instrument contributes to the localization. The duration of the gravitational-wave signal is approximately 74 seconds from the search's low-frequency cutoff of 27 Hz to the binary merger.



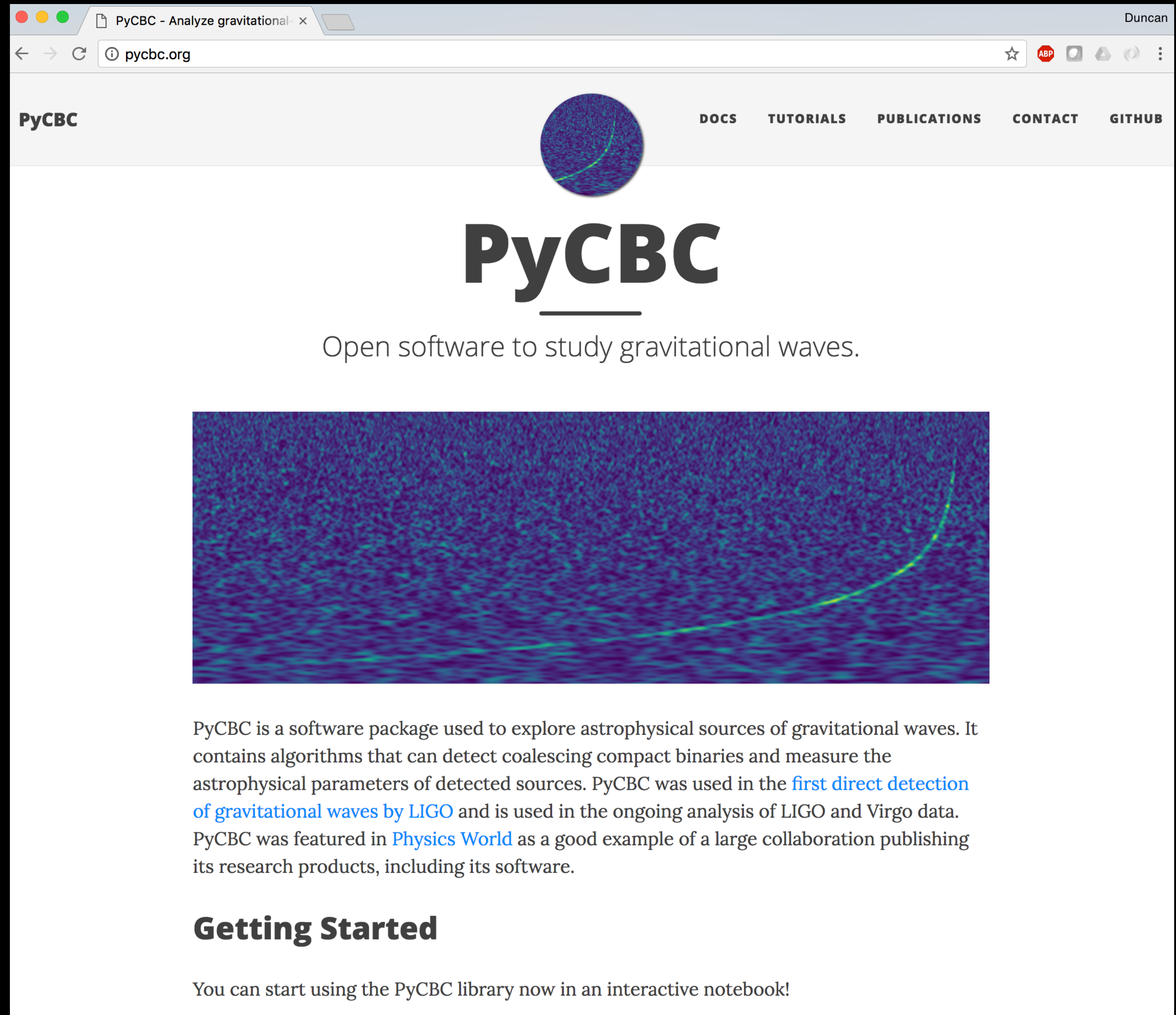


- <https://pycbc.org>

Core science funding through: NSF Gravity program grants to PIs; Max Planck Society; UK/EU investigators

Infrastructure through NSF ACI grants

Relies on Pegasus and HTCondor for job execution

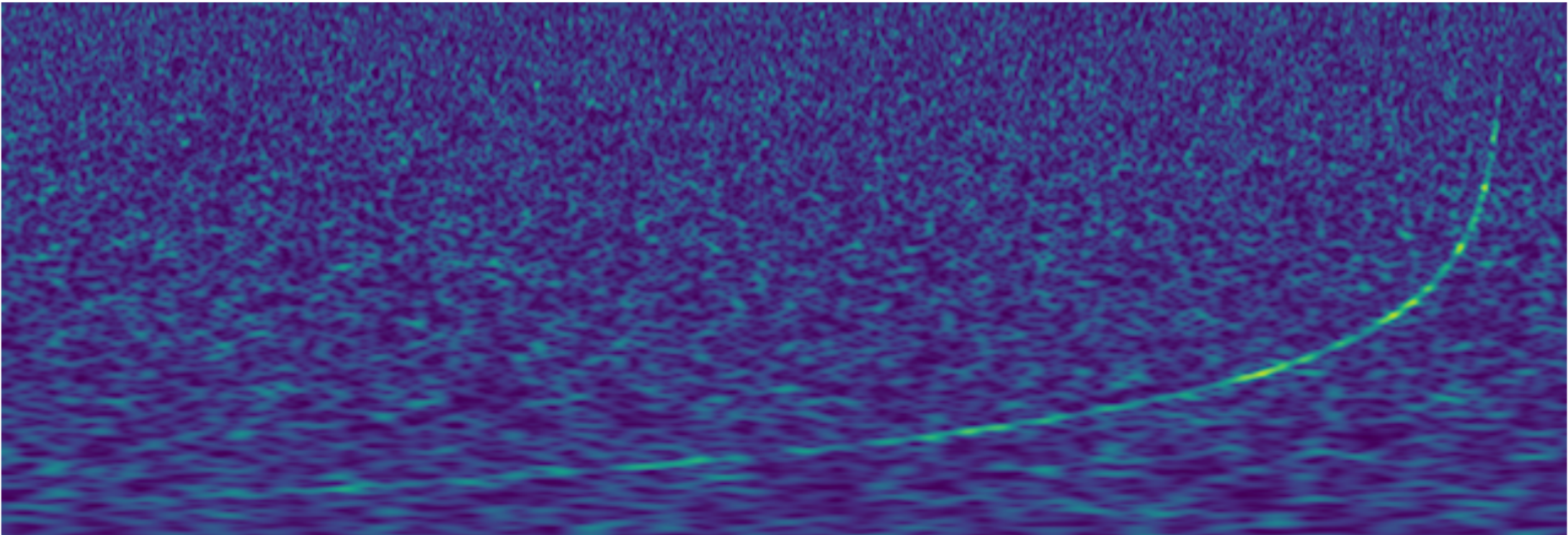


PyCBC

DOCS TUTORIALS PUBLICATIONS CONTACT GITHUB

PyCBC

Open software to study gravitational waves.



PyCBC is a software package used to explore astrophysical sources of gravitational waves. It contains algorithms that can detect coalescing compact binaries and measure the astrophysical parameters of detected sources. PyCBC was used in the [first direct detection of gravitational waves by LIGO](#) and is used in the ongoing analysis of LIGO and Virgo data. PyCBC was featured in [Physics World](#) as a good example of a large collaboration publishing its research products, including its software.

Getting Started

You can start using the PyCBC library now in an interactive notebook!



Chris Biwer



Collin Capano



Soumi De



Alex Nitz



Miriam Cabero



Daniel Finstad



Tito Dal Canton



Ian Harry

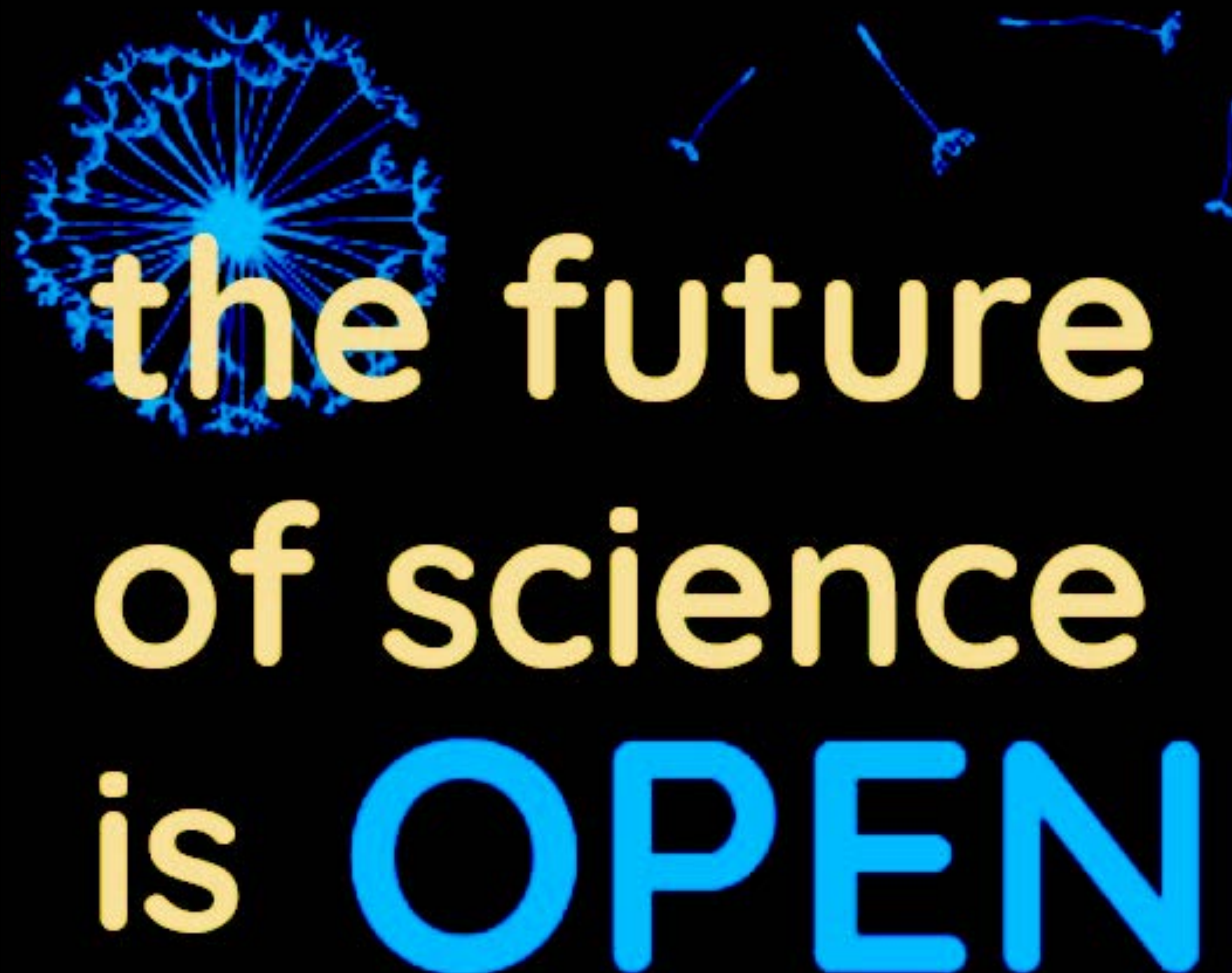
- I joined the LIGO Scientific Collaboration in 1999
- First LIGO paper:

Abbott,..., DAB,..., Zweizig, “Analysis of LIGO data for gravitational waves from binary neutron stars” Phys. Rev. **D69** 122001 (2004)
- Author 38 out of **368** co-authors
- Cited by **145** since 2004

- Last LIGO paper:

Abbott, ..., DAB, ..., Zweizig, “GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral” Phys. Rev. Lett. **119**, 161101 (2017)

- Author 137 out of **1125** co-authors
- Cited by **2057** since October 2017
- Left the LIGO Scientific Collaboration in January 2018



the future
of science
is **OPEN**

fosteropenscience.eu

- LIGO Data Management Plan: <https://dcc.ligo.org/M1000066/public>
- *"Release of events and important non-detections will occur with publication of one or more papers discussing these observational results in the scientific peer-reviewed literature."*
- All O1 and O2 events available now
- *"The transition to Open Data, with the regular release of data during observation runs and prompt public alerts of transient events [will begin in April 2019]"*

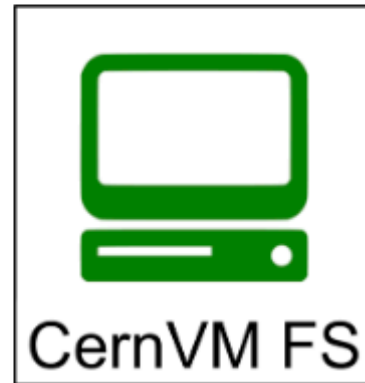
- O3 alerts can be viewed at <https://gracedb.ligo.org>

UID	Labels	t_start	t_0	t_end	FAR (Hz)	UTC Created
S190602aq	ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1243533584.081266	1243533585.089355	1243533586.346191	1.901e-09	2019-06-02 17:59:51 UTC
S190524q	ADVNO SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1242708743.678669	1242708744.678669	1242708746.133301	6.971e-09	2019-05-24 04:52:30 UTC
S190521r	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1242459856.453418	1242459857.460739	1242459858.642090	3.168e-10	2019-05-21 07:44:22 UTC
S190521g	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1242442966.447266	1242442967.606934	1242442968.888184	3.801e-09	2019-05-21 03:02:49 UTC
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S190518bb	ADVNO SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1242242376.474609	1242242377.474609	1242242380.922655	1.004e-08	2019-05-18 19:19:39 UTC
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S190513bm	ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1241816085.736106	1241816086.869141	1241816087.869141	3.734e-13	2019-05-13 20:54:48 UTC
S190512at	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1241719651.411441	1241719652.416286	1241719653.518066	1.901e-09	2019-05-12 18:07:42 UTC
S190510g	ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1241492396.291636	1241492397.291636	1241492398.293185	8.834e-09	2019-05-10 03:00:03 UTC
S190503bf	ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1240944861.288574	1240944862.412598	1240944863.422852	1.636e-09	2019-05-03 18:54:26 UTC
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S190421ar	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1239917953.250977	1239917954.409180	1239917955.409180	1.489e-08	2019-04-21 21:39:16 UTC
S190412m	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1239082261.146717	1239082262.222168	1239082263.229492	1.683e-27	2019-04-12 05:31:03 UTC
S190408an	PE_READY ADVOK SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK GCN_PRELIM_SENT	1238782699.268296	1238782700.287958	1238782701.359863	2.811e-18	2019-04-08 18:18:27 UTC
S190405ar	ADVNO SKYMAP_READY EMBRIGHT_READY PASTRO_READY DQOK	1238515307.863646	1238515308.863646	1238515309.863646	2.141e-04	2019-04-05 16:01:56 UTC

- *"Releases will occur every 6 months, in blocks of 6 months of data, with a latency of 18 months from the end of acquisition of each observing block (Expect to shorten the 18 month period)"*
- O1 and O2 data available now
- O3A April 2019 + 6 months + 18 months = April 2021

Large Data Sets for High Performance Computing

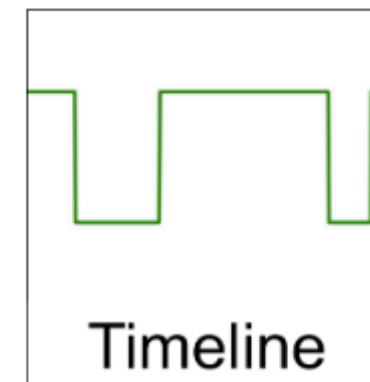
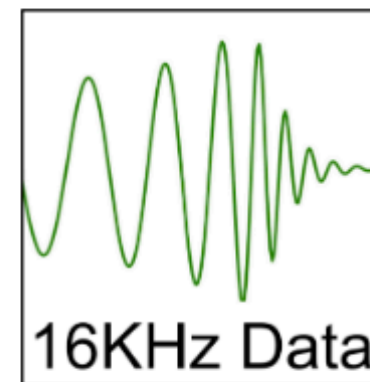
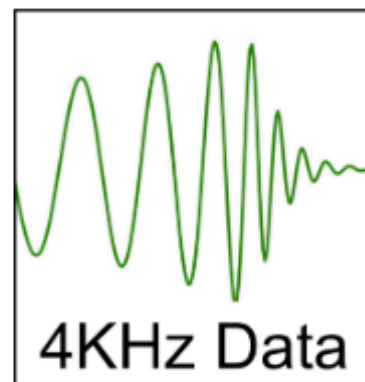
For users of computing clusters, **CernVM-FS** is the preferred method to access large data sets:



02 Data Release

02 Time Range: November 30, 2016 through August 25, 2017

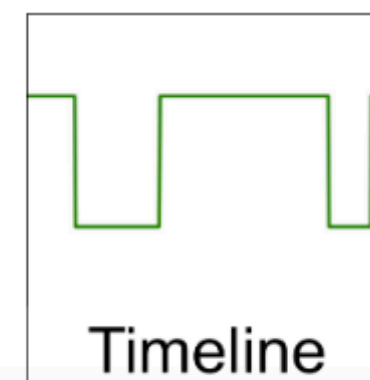
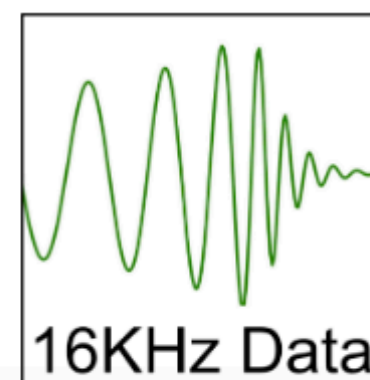
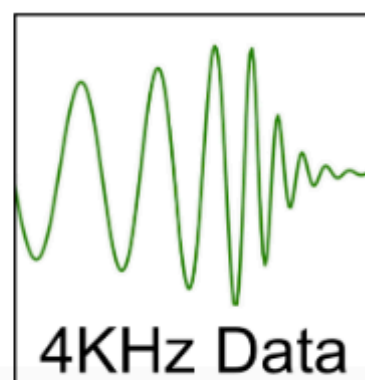
Detectors: H1, L1 and V1



01 Data Release

01 Time Range: September 12, 2015 through January 19, 2016

Detectors: H1 and L1



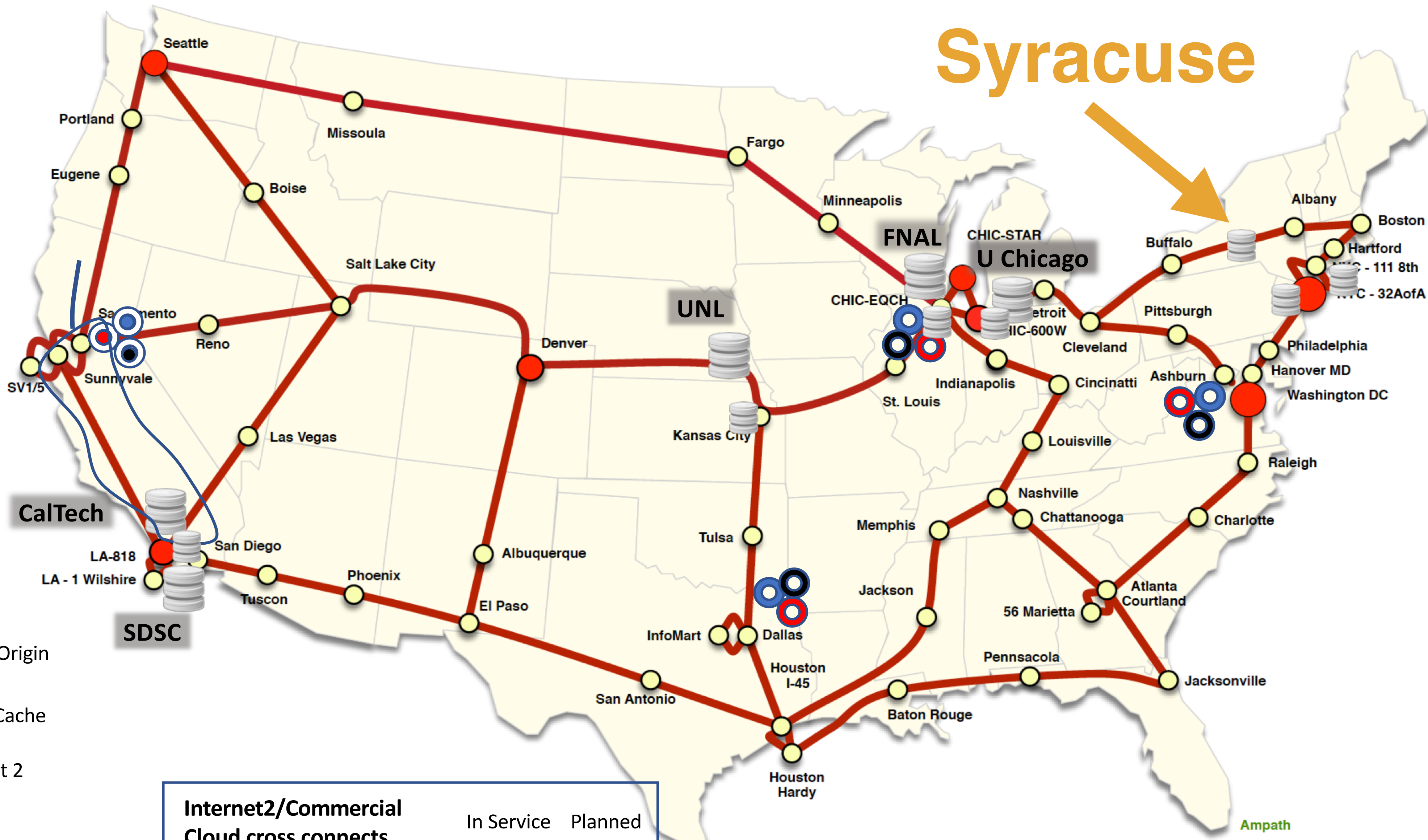
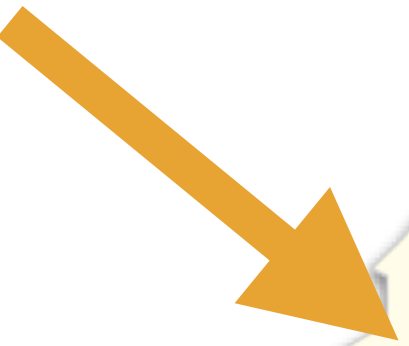
- Calibrated LIGO gravitational-wave strain data is (basically) CD-quality audio
 - 16 kHz sample rate, 64 bit, 2 x channels
 - + Virgo (32 bit) makes three channels
- ~ 1 hour of strain data can be downloaded for each event
- $\text{signal}(t) = \text{detector noise}(t) + \text{gravitational-wave strain}(t)$
- Full O1 strain data set $O(10 \text{ Tb})$





```
[Duncans-MacBook-2:~ root# df
Filesystem      512-blocks      Used    Available Capacity    iused      ifree %iused  Mounted on
/dev/disk1      974496000  901859432    72124568    93%  112796427    9015571    93%  /
devfs           507          507          0    100%      878          0    100%  /dev
map -hosts      0            0            0    100%          0          0    100%  /net
map auto_home  0            0            0    100%          0          0    100%  /home
drivefs         974496000  905491264    69004736    93% 18446744069414608791 4294967295 75385141272638368% /Volumes/GoogleDrive
cvmfs2          33554432000 2505007344 31049424656    8%          32          0    100%  /cvmfs/config-osg.opensciencegrid.org
cvmfs2           8388608000 6215123376 2173484624    75%     118085          0    100%  /cvmfs/gwosc.osgstorage.org
cvmfs2          33554432000 2505007344 31049424656    8%      81964    11615465    1%  /cvmfs/oasis.opensciencegrid.org
cvmfs2          33554432000 2505007344 31049424656    8%      2722    232938041    0%  /cvmfs/singularity.opensciencegrid.org
```







A terminal window titled "1125122048 — -bash — 80x24" is shown. The user is dbrown@Duncans-MacBook-2. The terminal shows the following commands and output:

```
[dbrown@Duncans-MacBook-2 1125122048]$ pwd
/cvmfs/gwosc.osgstorage.org/gwdata/01/strain.16k/frame.v1/H1/1125122048
[dbrown@Duncans-MacBook-2 1125122048]$ ls
H-H1_LOSC_16_V1-1126072320-4096.gwf      H-H1_LOSC_16_V1-1126113280-4096.gwf
H-H1_LOSC_16_V1-1126076416-4096.gwf      H-H1_LOSC_16_V1-1126117376-4096.gwf
H-H1_LOSC_16_V1-1126080512-4096.gwf      H-H1_LOSC_16_V1-1126121472-4096.gwf
H-H1_LOSC_16_V1-1126084608-4096.gwf      H-H1_LOSC_16_V1-1126125568-4096.gwf
H-H1_LOSC_16_V1-1126088704-4096.gwf      H-H1_LOSC_16_V1-1126137856-4096.gwf
H-H1_LOSC_16_V1-1126092800-4096.gwf      H-H1_LOSC_16_V1-1126146048-4096.gwf
H-H1_LOSC_16_V1-1126096896-4096.gwf      H-H1_LOSC_16_V1-1126150144-4096.gwf
H-H1_LOSC_16_V1-1126100992-4096.gwf      H-H1_LOSC_16_V1-1126154240-4096.gwf
H-H1_LOSC_16_V1-1126105088-4096.gwf      H-H1_LOSC_16_V1-1126158336-4096.gwf
H-H1_LOSC_16_V1-1126109184-4096.gwf      H-H1_LOSC_16_V1-1126162432-4096.gwf
[dbrown@Duncans-MacBook-2 1125122048]$
```

Syracuse



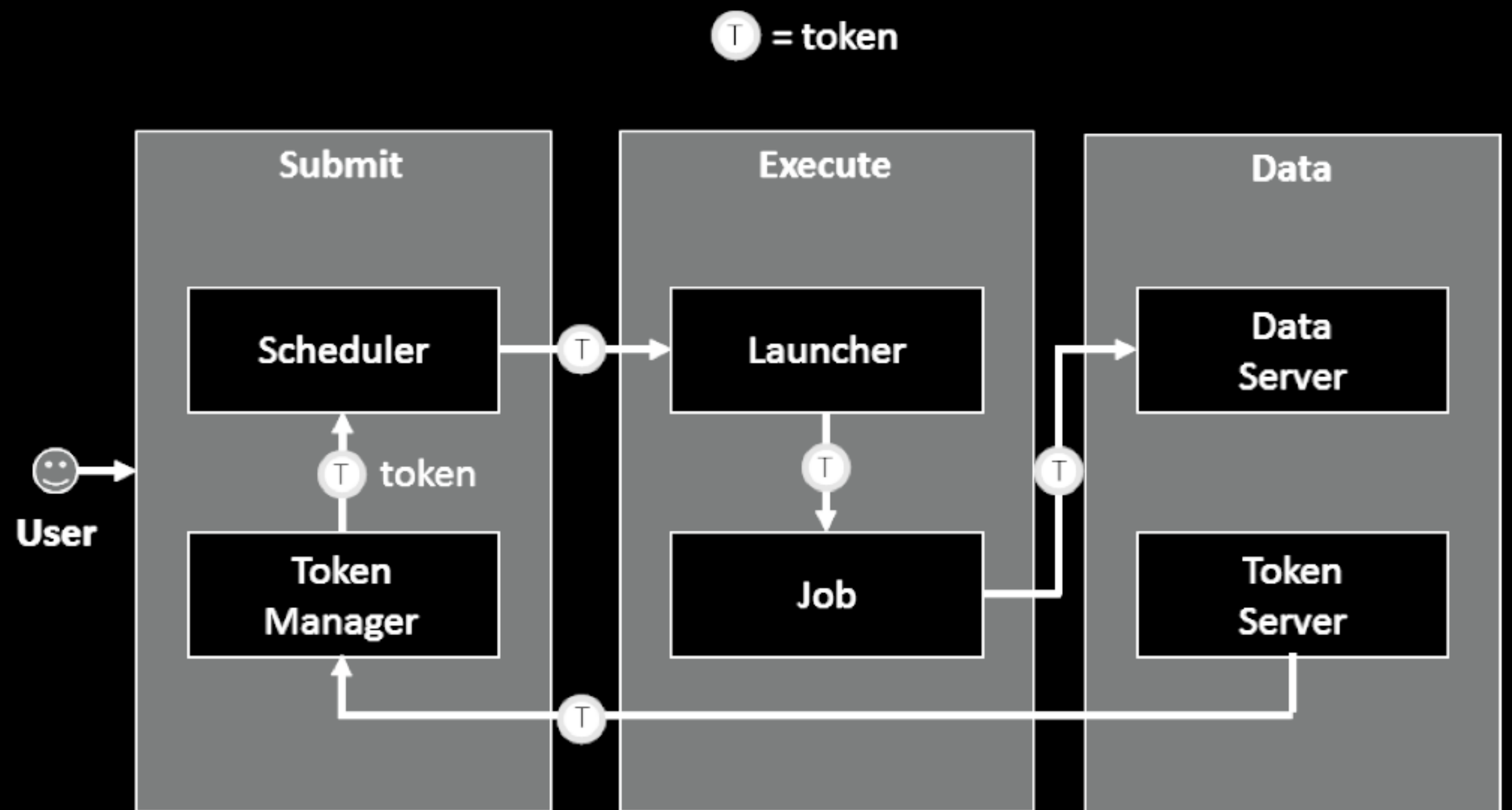
-  OSG Data Origin
-  OSG Data Cache
-  Internet 2
-  CENIC

Internet2/Commercial Cloud cross connects	In Service	Planned
Amazon Direct Connect		
Google Dedicated Interconnect		
Microsoft Azure ExpressRoute		



The SciTokens Model

Capability-based
authorization
for science










Directory ↕	Bytes ↕
/gwdata/O1	1.227PB
/pnfs/fnal.gov/usr/des	744.692TB
/pnfs/fnal.gov/usr/minerva	502.826TB
/user/ligo	200.539TB
/user/bbockelm	184.699TB
/pnfs/fnal.gov/usr/dune	131.776TB
/pnfs/fnal.gov/usr/nova	34.639TB
/user/cwalter	18.966TB
/user/jeanjack	17.566TB

THE ASTROPHYSICAL JOURNAL

OPEN ACCESS

1-OGC: The First Open Gravitational-wave Catalog of Binary Mergers from Analysis of Public Advanced LIGO Data

Alexander H. Nitz^{1,2} , Collin Capano^{1,2} , Alex B. Nielsen^{1,2} , Steven Reyes³ , Rebecca White^{3,4} ,
Duncan A. Brown³ , and Badri Krishnan^{1,2} 

Published 2019 February 25 • © 2019. The American Astronomical Society.

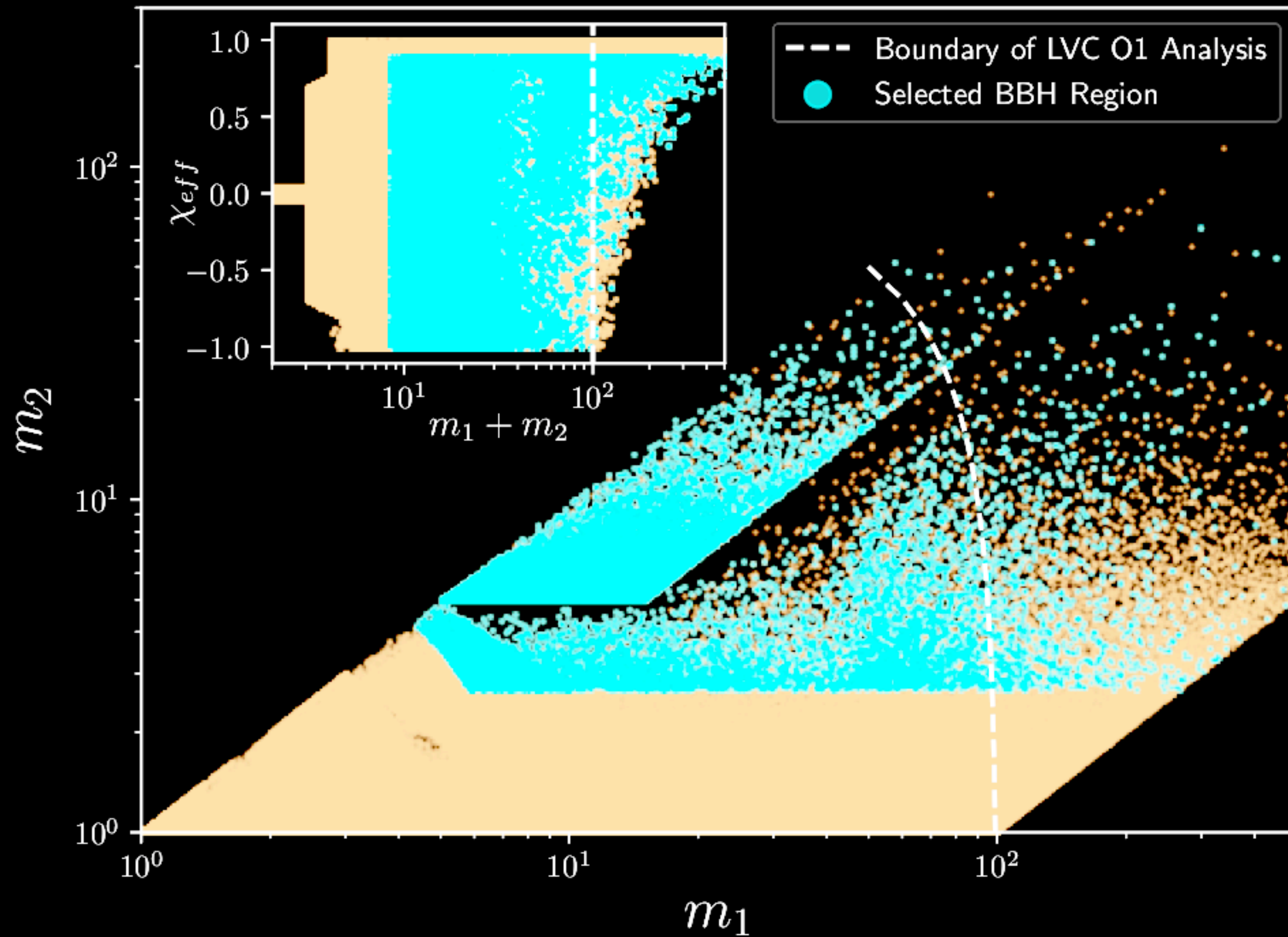
[The Astrophysical Journal](#), [Volume 872](#), [Number 2](#)



Article PDF



Article ePub



README.md

Instructions for generating the 1-OGC catalog on the Open Science Grid

Alexander H. Nitz^{1,2}, Collin Capano^{1,2}, Alex B. Nielsen^{1,2}, Steven Reyes³, Rebecca White^{4,3}, Duncan A. Brown³, Badri Krishnan^{1,2}

1. [Albert-Einstein-Institut, Max-Planck-Institut for Gravitationsphysik, D-30167 Hannover, Germany](#)
2. Leibniz Universitat Hannover, D-30167 Hannover, Germany
3. Department of Physics, Syracuse University, Syracuse, NY 13244, USA
4. Fayetteville-Manlius High School, Manlius, NY 13104, USA

This directory contains the scripts and configuration files necessary to reproduce the 1-OGC catalog using public data and code using the [Open Science Grid](#).

These instructions are designed for users familiar with [PyCBC](#), [Pegasus WMS](#), [HTCondor](#), and [OSGConnect](#) and who would like to reproduce our results. We assume that the reader has familiarity with [running PyCBC in Singularity containers](#) and is able to [troubleshoot HTCondor errors](#) that can happen when running large workflows.

The contents of this directory are:

1. [A script for generating, planning, and running the workflow on the Open Science Grid](#)
2. [A script for generating, planning, and running the workflow on Syracuse University's Orange Grid](#)

- Only requirement is an account on OSG Connect
- Run PyCBC from a Singularity container
- Create a workflow which is planned using Pegasus WMS and run under HTCondor
- LIGO Open Data is read from CVMFS
- stashcp is used to stage intermediate data products and store output
- SciTokens is used for authentication

Accessing the Catalog: 1-OGC.hdf

There are two datasets within the file, `/complete` and `/bbh`. The `complete` set is the full dataset from our analysis. The `bbh` set includes BBH candidates from a select portion of the analysis. See the 1-OGC paper for additional information.

```
import h5py

catalog = h5py.File('./1-OGC.hdf', 'r')

# Get a numpy structured array of the candidate event properties.
all_candidates = catalog['complete']
bbh_candidates = catalog['bbh']

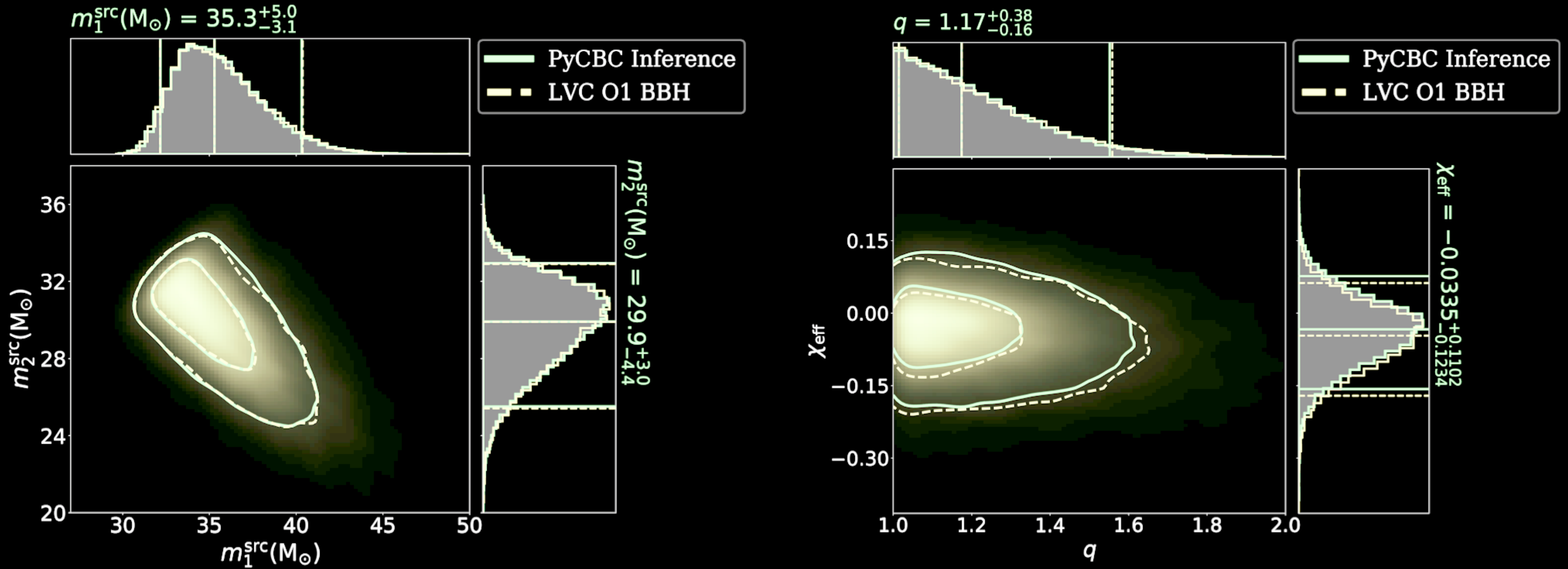
# Accessing a column by name
ranking_values = all_candidates['stat']

# Selecting parts of the catalog
region = all_candidates['mass1'] + all_candidates['mass2'] < 4
lowmass_candidates = all_candidates[region]
```

File format

Both datasets are structured arrays which have the following named columns. Some of these columns give information specific to either the LIGO Hanford or Livingston detectors. Where this is the case, the name of the column is prefixed with either a `H1` or `L1`.

GW150914



Biwer, Capano, De, Cabero, DAB, Nitz PASP **131** 024503 (2019)

De, Biwer, Capano, Nitz, DAB Nature Scientific Data **6**, 81 (2019)

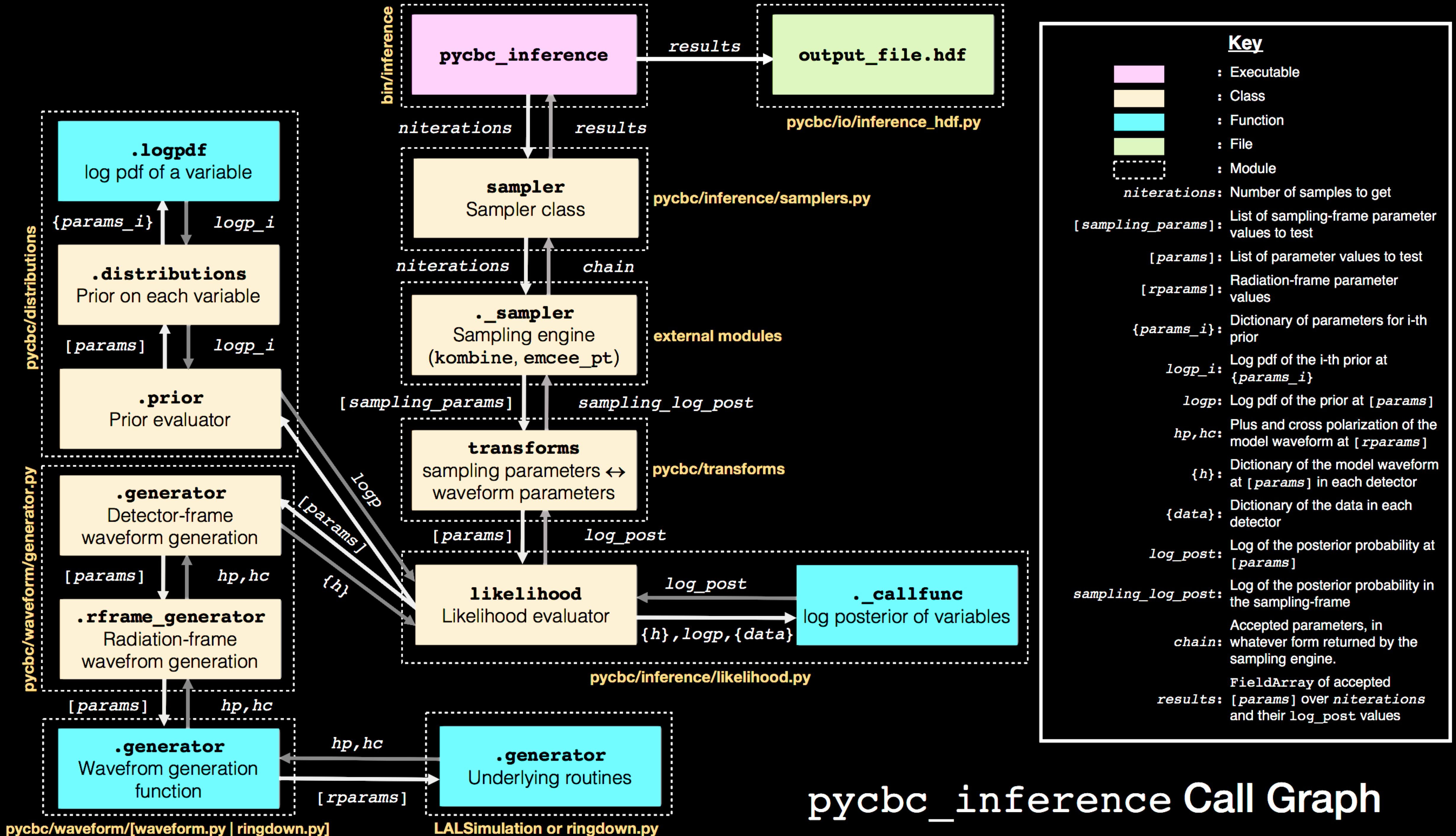
$$p(\vec{\theta} | \vec{d}(t), H) = \frac{p(\vec{\theta} | H) p(\vec{d}(t) | \vec{\theta}, H)}{p(\vec{d}(t) | H)}$$

Need the data, $\vec{d}(t)$ from GWOSC ✓

Need a model, $H \equiv h(t; \alpha, \delta, m_1, m_2, \vec{s}_1, \vec{s}_2, \lambda_1, \lambda_2, \dots)$ from PyCBC ✓

Need a likelihood, $p(\vec{d}(t) | \vec{\theta}, H)$ from PyCBC ✓

Need priors, marginalization, and visualization, from PyCBC ✓



pycbc_inference Call Graph

PyCBCInferenceWorkshopMay2019

Repository for the PyCBC Inference workshop in Portsmouth, UK, 14 May - 16 May 2019.

This repository contains all of the tutorials and talks that were presented at the workshop; it provides a good introduction to PyCBC Inference, and Bayesian inference in general. We recommend following the [Program](#). The links listed there link to the tutorials/lectures in this repository.

How to run the tutorials

Using SciServer

To run the tutorials, we recommend using [SciServer](#):

1. If you don't already have one, create a SciServer account (it's free). Then go to apps.sciserver.org/compute.
2. Click "Create container". Give it a name; in the "Compute Image" drop-down menu click "Python + R". Then click "Create."
3. Click on the container you just created; this will open a new tab in your browser that is a Jupyter notebook interface.
4. Clone this repository into your SciServer container: Click "New" -> "Terminal". This will open another tab that with a bash terminal in it. Change directory into "workspace" by typing `cd workspace` . Now type:

```
git clone https://github.com/gwastro/PyCBCInferenceWorkshopMay2019.git
```

This will download a copy of this repository to your directory on SciServer.

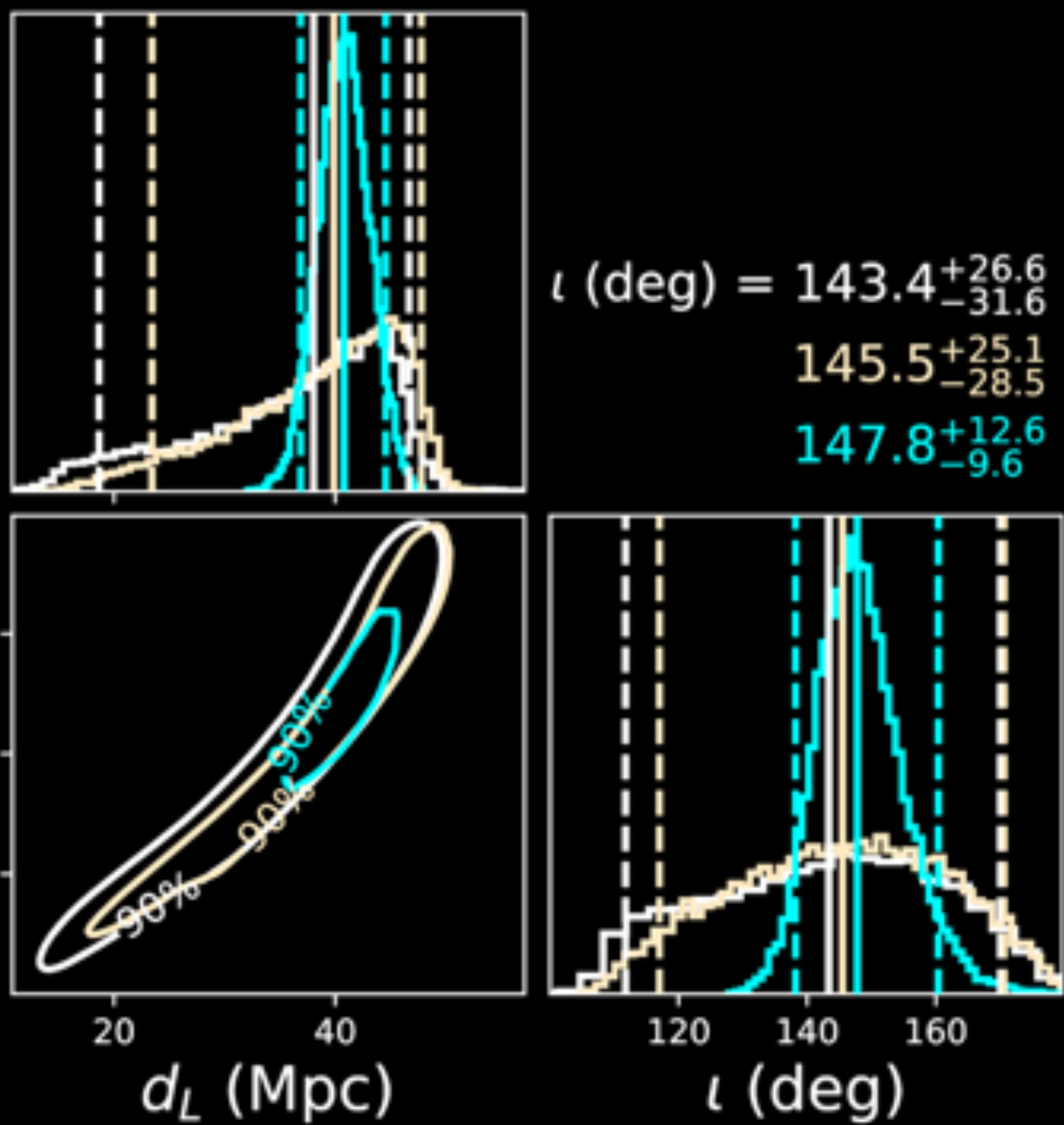
$$d_L \text{ (Mpc)} = 38.01^{+8.64}_{-19.35}$$

$$39.84^{+7.94}_{-16.41}$$

$$40.77^{+3.79}_{-3.89}$$

Viewing angle is $32^{+10}_{-13} \pm 1.7$ deg

Lower limit of ≥ 13 deg
robust to choice of prior



Daniel Finstad

Distance-constrained GW observations
of viewing angle are consistent with
EM observations

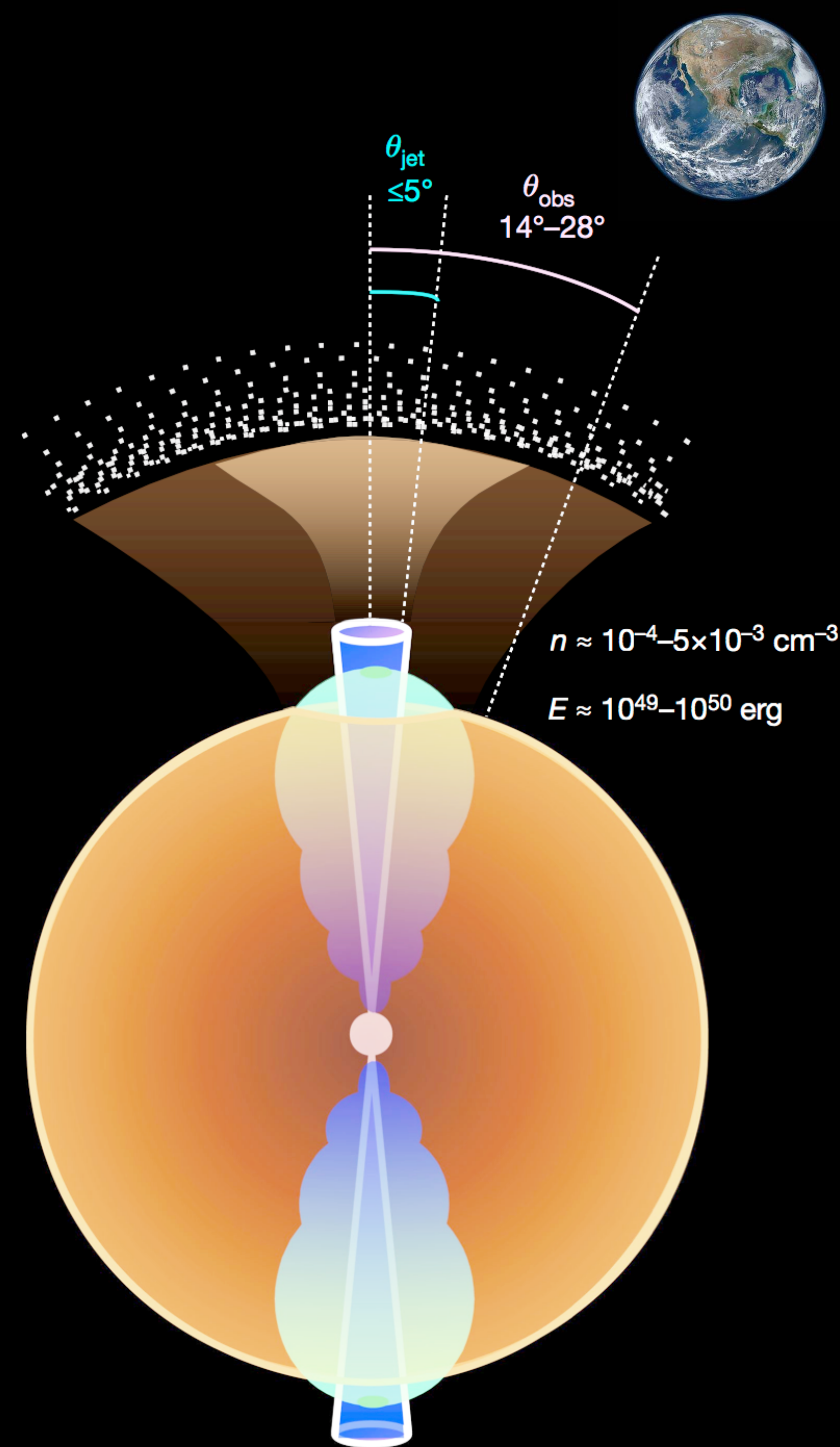
Mooley et al. report 14 - 28 deg from radio

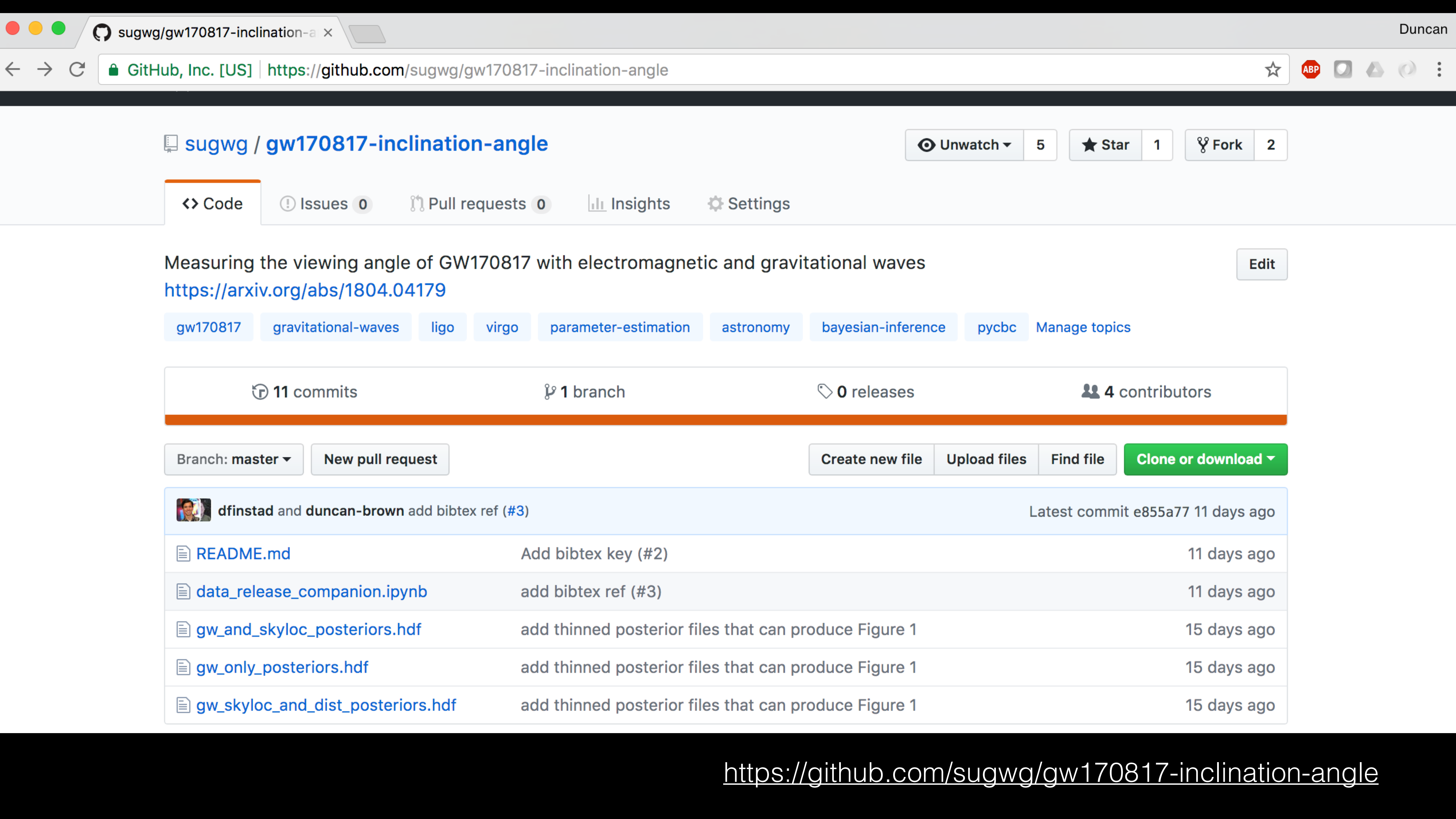
Troja et al. report 21 - 29 deg from
broad band observations

GW and EM observations support
successful-jet cocoon model
(structured jet)

Mooley et al. Nature **561**, 355 (2018)

Troja et al. arXiv:1808.06617





sugwg / gw170817-inclination-angle

Unwatch 5 Star 1 Fork 2

Code Issues 0 Pull requests 0 Insights Settings

Measuring the viewing angle of GW170817 with electromagnetic and gravitational waves

Edit

<https://arxiv.org/abs/1804.04179>

gw170817 gravitational-waves ligo virgo parameter-estimation astronomy bayesian-inference pycbc Manage topics

11 commits 1 branch 0 releases 4 contributors

Branch: master New pull request Create new file Upload files Find file Clone or download

dfinstad and duncan-brown add bibtex ref (#3)		Latest commit e85a77 11 days ago
README.md	Add bibtex key (#2)	11 days ago
data_release_companion.ipynb	add bibtex ref (#3)	11 days ago
gw_and_skyloc_posteriors.hdf	add thinned posterior files that can produce Figure 1	15 days ago
gw_only_posteriors.hdf	add thinned posterior files that can produce Figure 1	15 days ago
gw_skyloc_and_dist_posteriors.hdf	add thinned posterior files that can produce Figure 1	15 days ago

Using the posterior probability data

The posterior data is stored as flattened arrays in the `samples` group of the hdf files in this repository. The parameter names for each of the arrays that exist in a file can be accessed through a `variable_args` attribute of the file:

```
In [2]: fp = h5py.File("gw_only_posteriors.hdf", "r")
print fp.attrs['variable_args']
fp.close()
```

```
['tc' 'ra' 'dec' 'mass1' 'mass2' 'coa_phase' 'inclination' 'polarization'
 'distance' 'spin1z' 'spin2z']
```

Each of these parameter names can then be used to access that parameter's data in the `samples` group of the file. For example, the inclination angle posterior samples (in radians) from our run using the GW signal as well as EM sky location and Gaussian distance prior can be accessed this way:

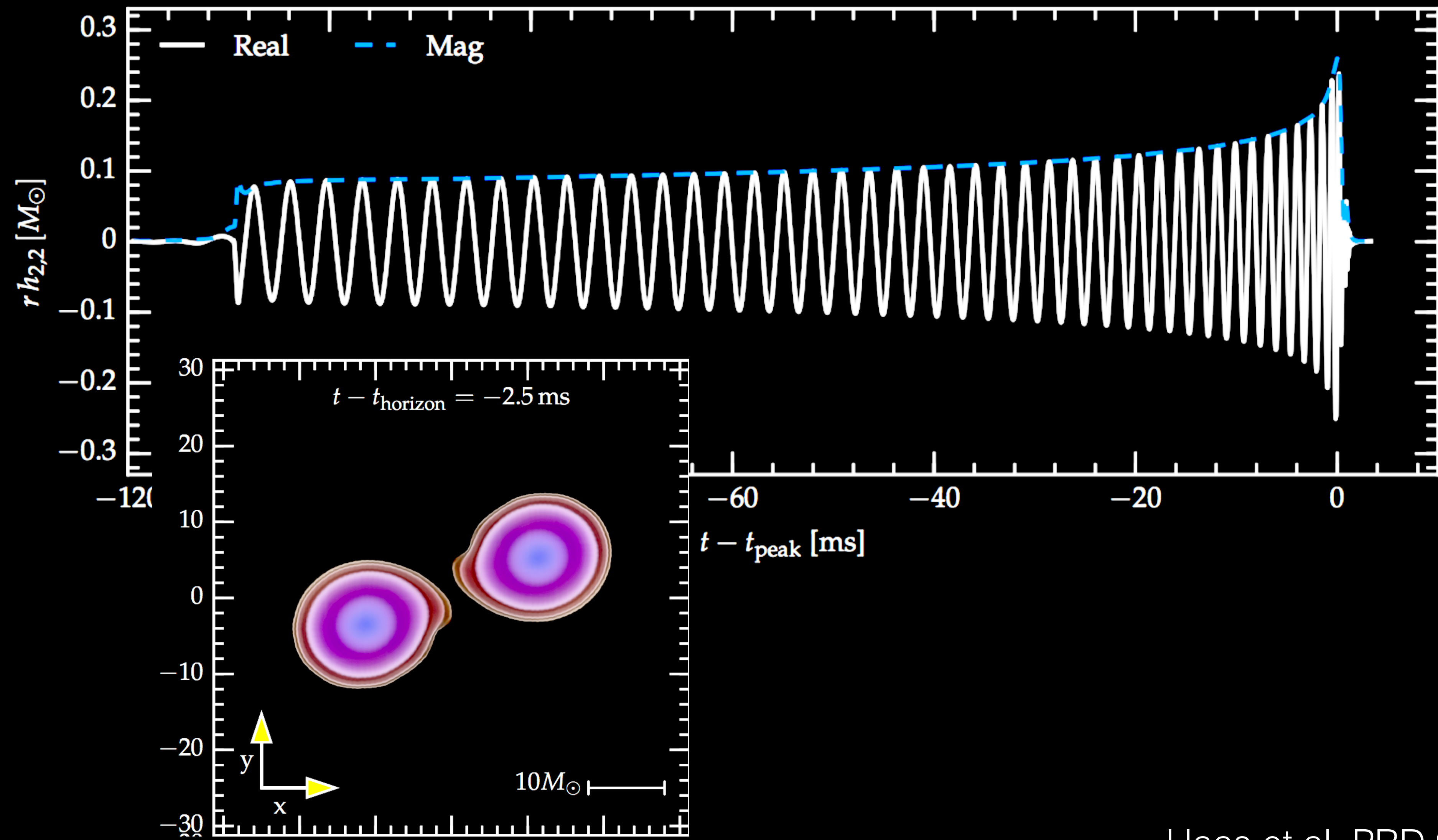
```
In [3]: fp = h5py.File("gw_skyloc_and_dist_posteriors.hdf", "r")
inc_samples = fp['samples/inclination'][:]
fp.close()
print inc_samples
```

```
[2.74223087 2.58393159 2.49176962 ... 2.53901635 2.61125559 2.45446383]
```

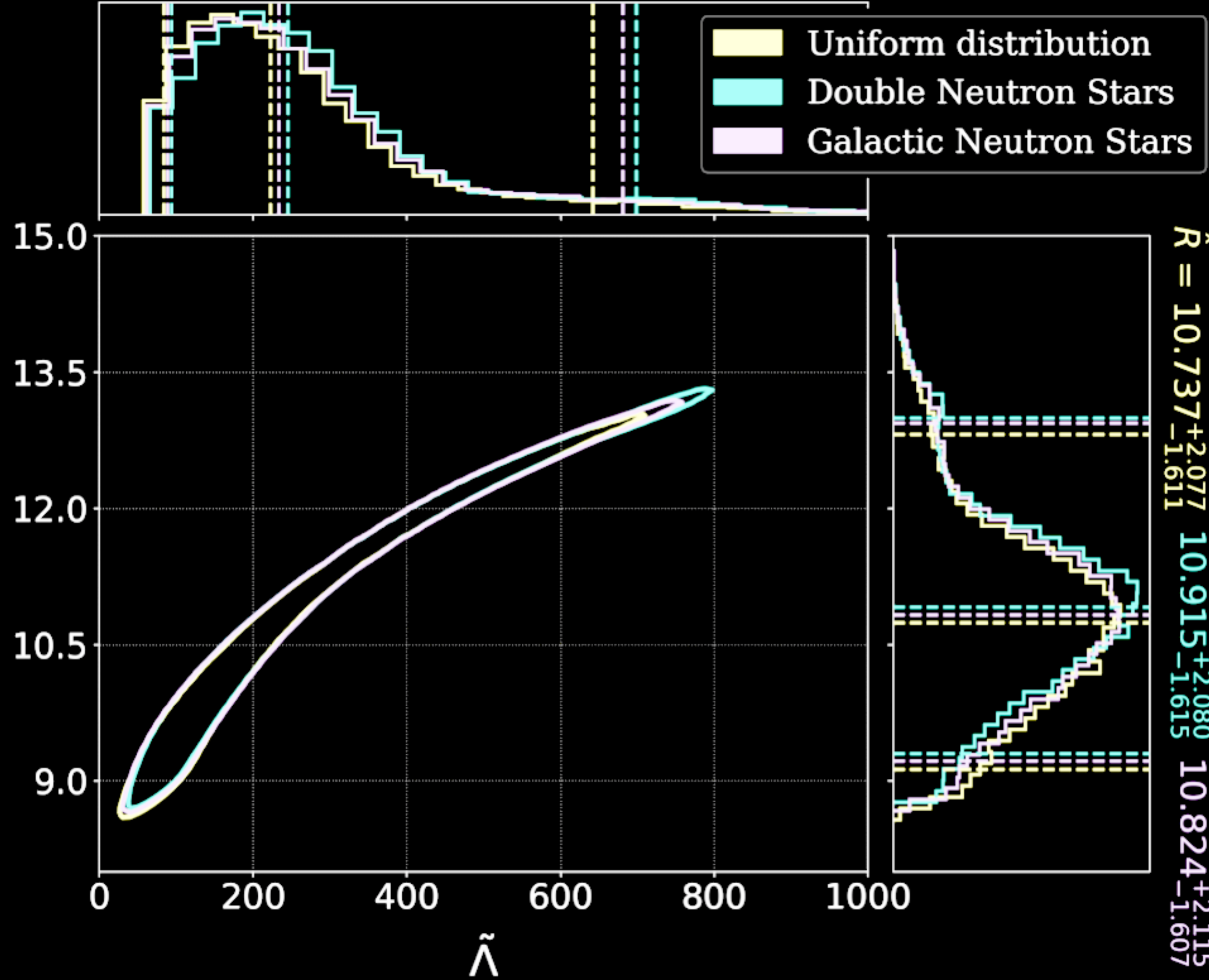
By default, the PyCBC software used to create these files stores the mass parameters only as `mass1` and `mass2`, but other mass parameters like chirp mass and mass ratio can be derived from these. For example, using the PyCBC toolkit:

```
In [4]: from pycbc import conversions

fp = h5py.File("gw_and_skyloc_posteriors.hdf", "r")
mass1 = fp['samples/mass1'][:]
mass2 = fp['samples/mass2'][:]
fp.close()
```



$$\tilde{\Lambda} = 222.29^{+419.83}_{-138.48} \quad 245.39^{+453.12}_{-151.53} \quad 233.39^{+447.55}_{-144.40}$$

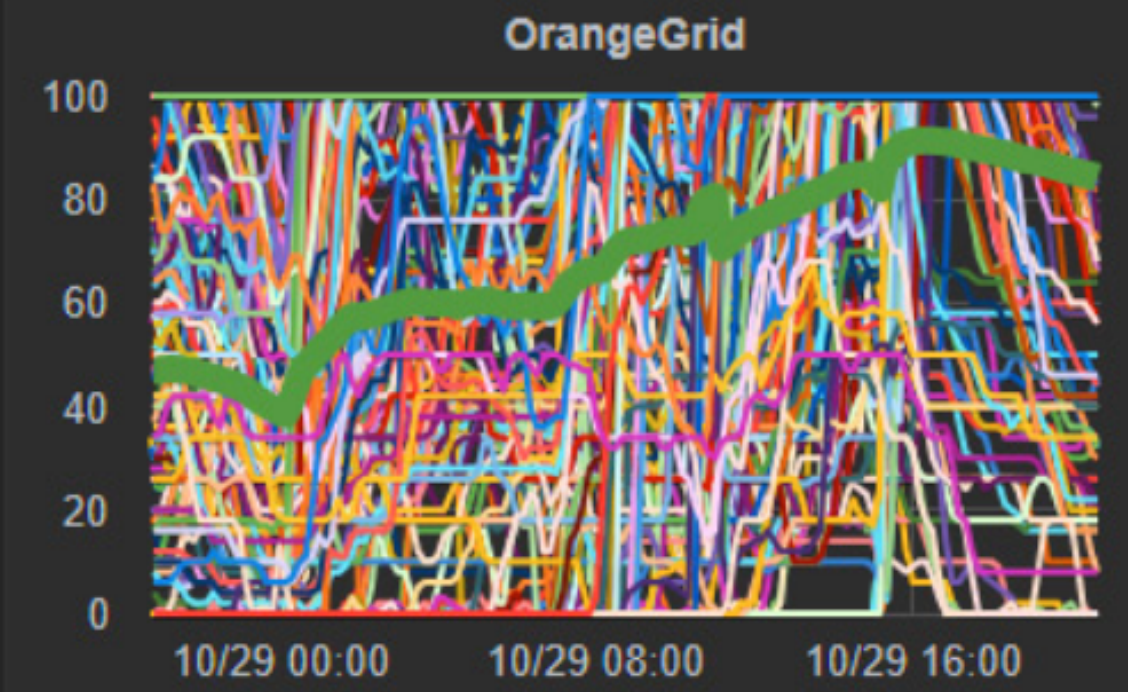
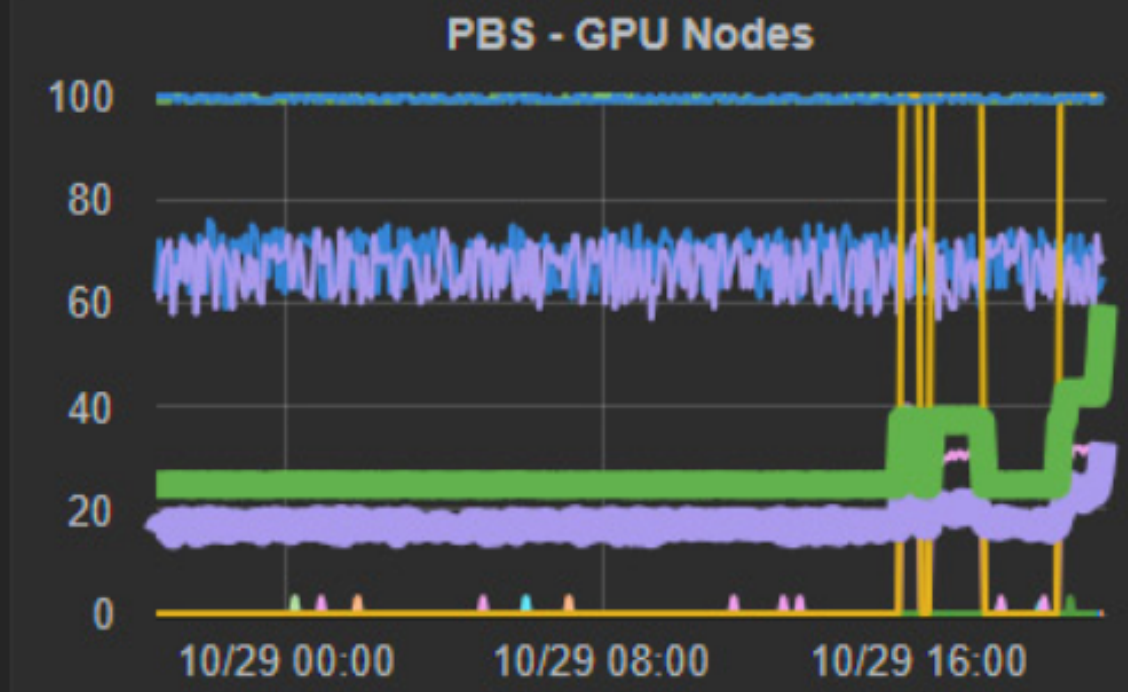
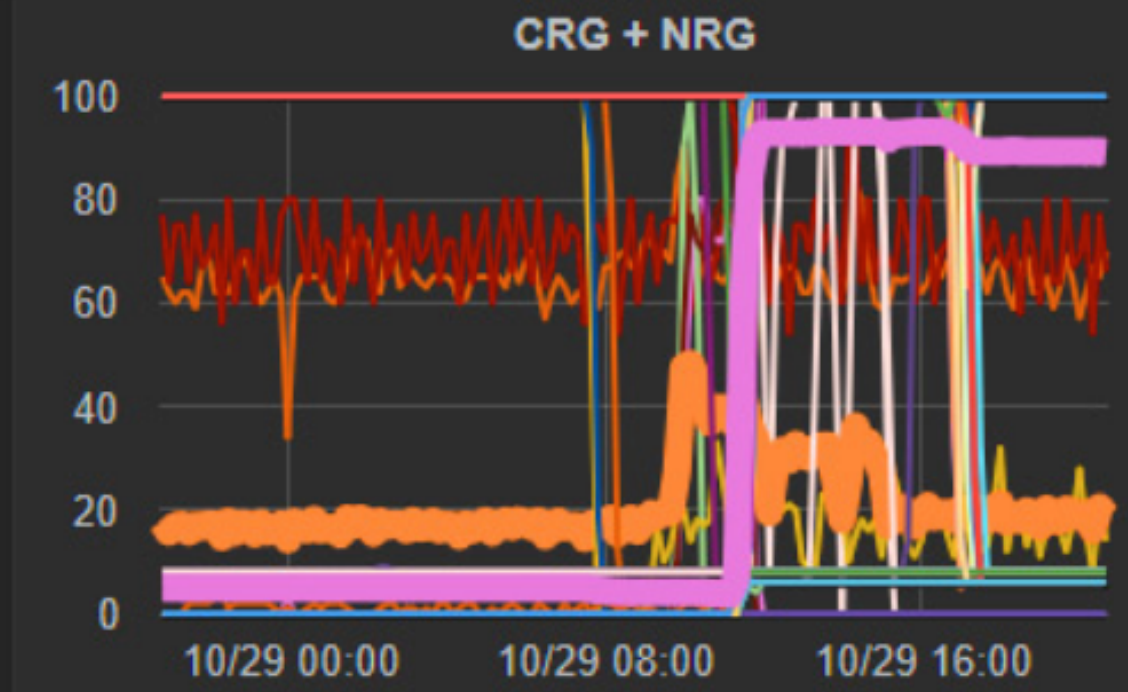
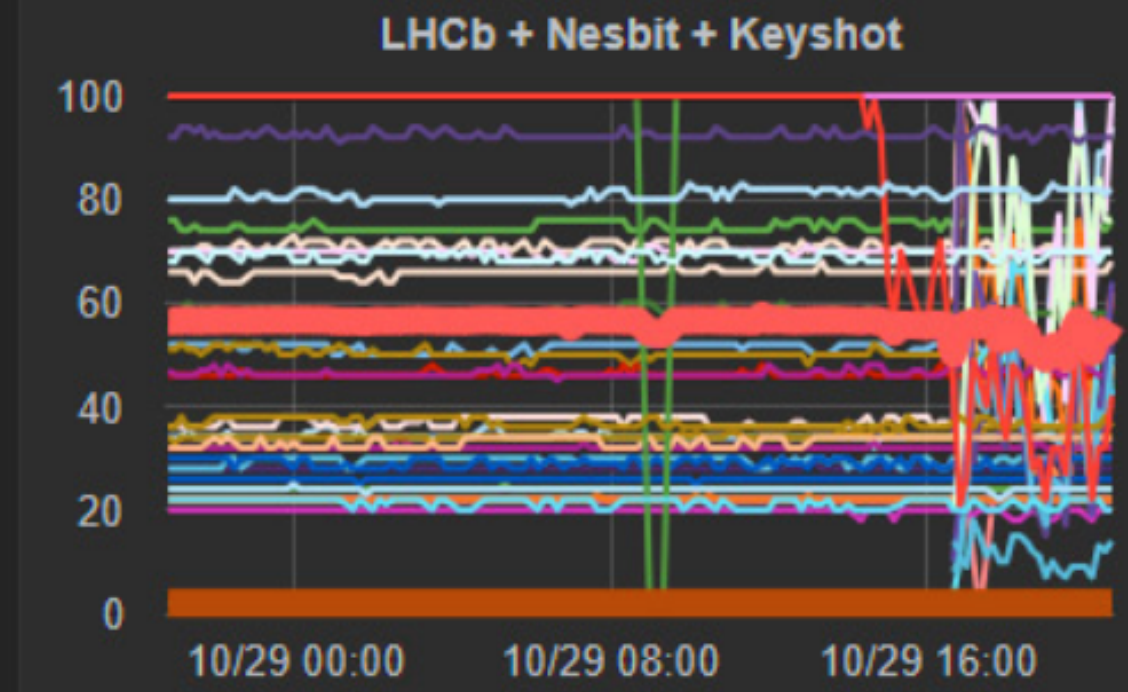
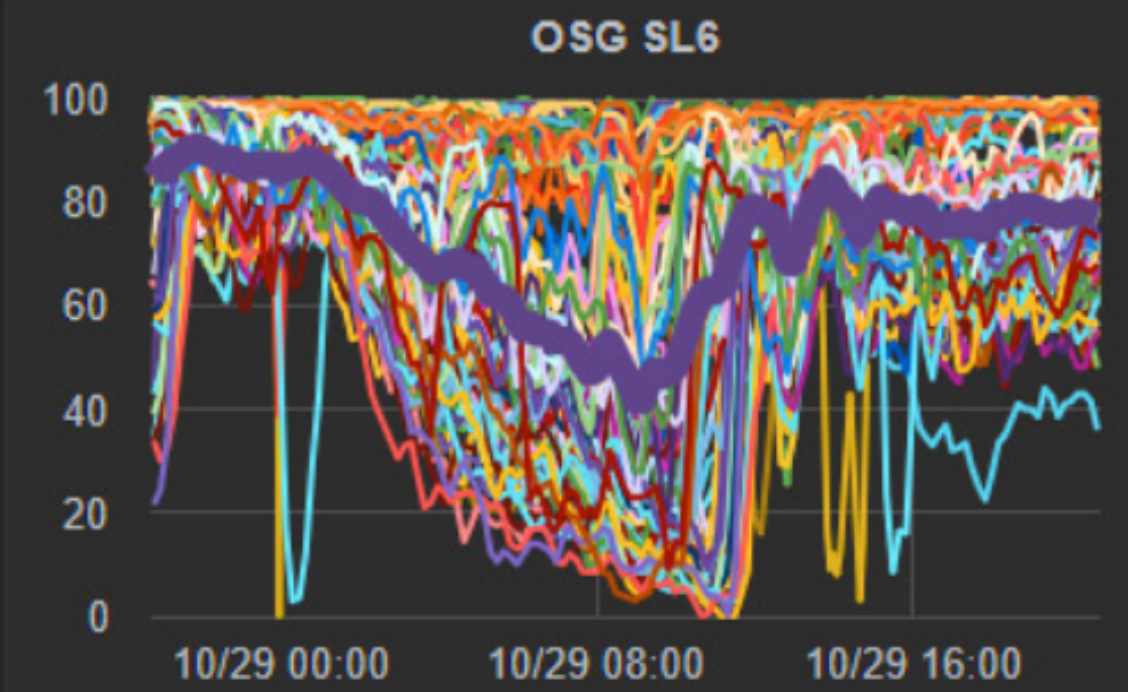
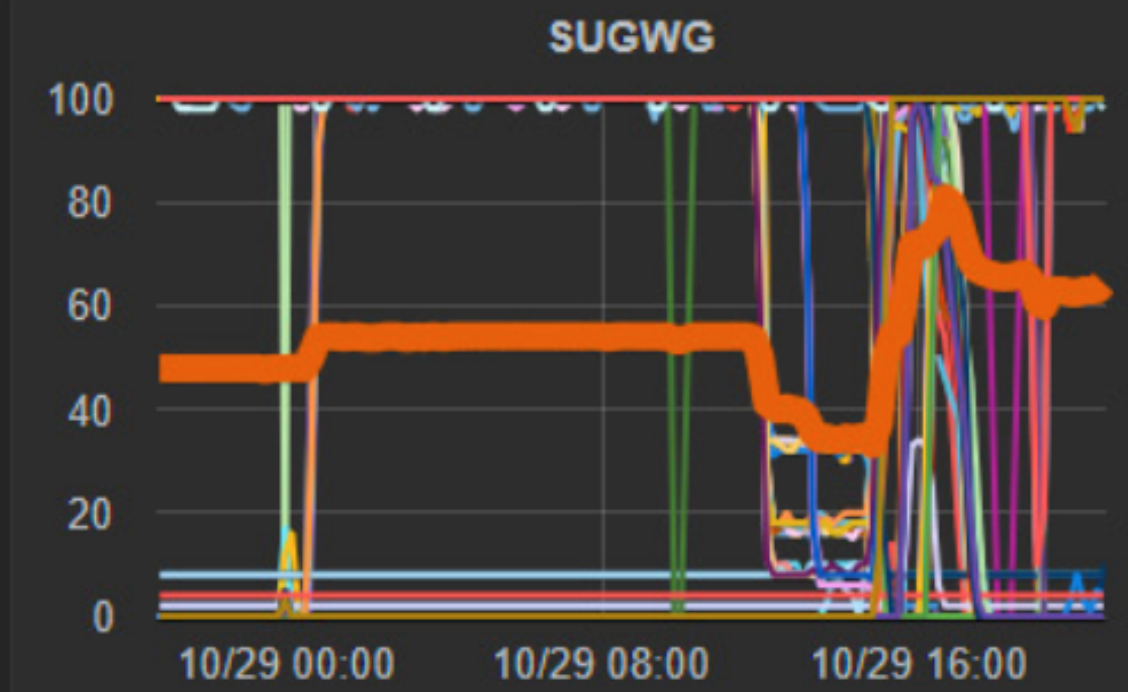
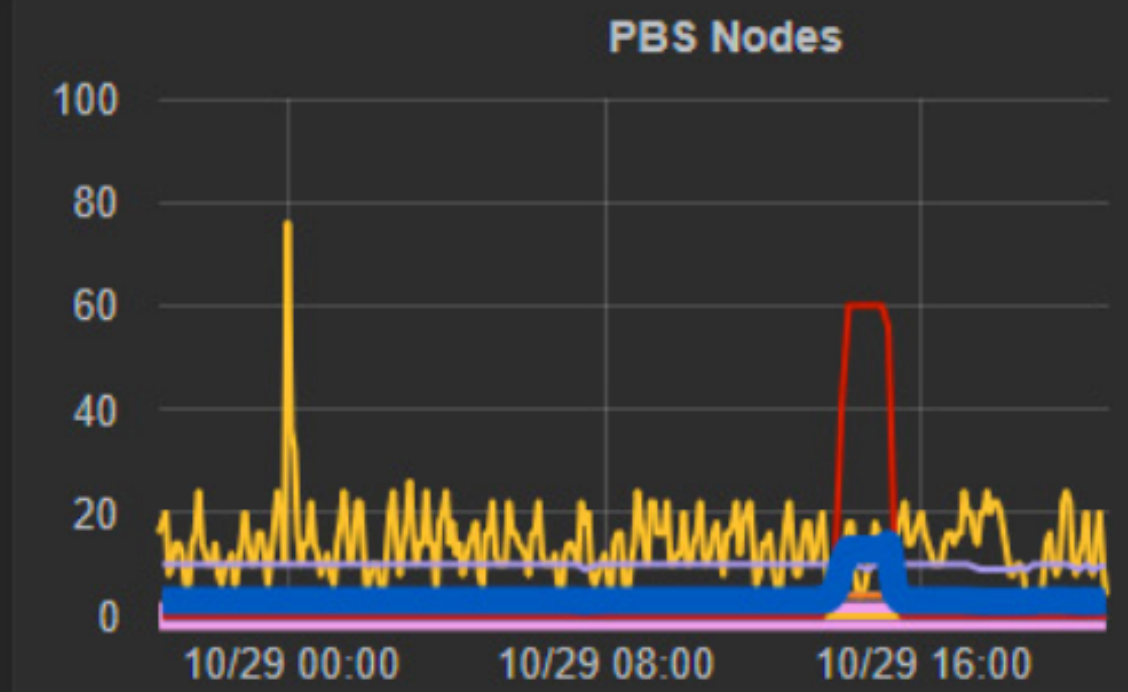
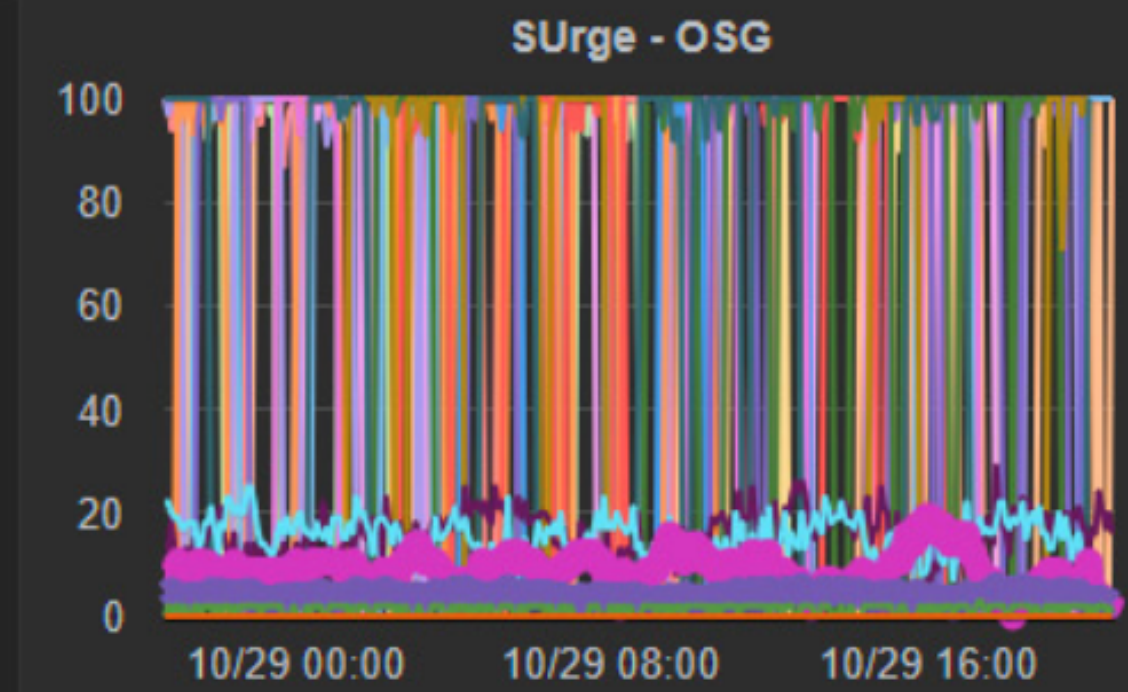


$$\langle \hat{R} \rangle = 10.8 \text{ km}$$

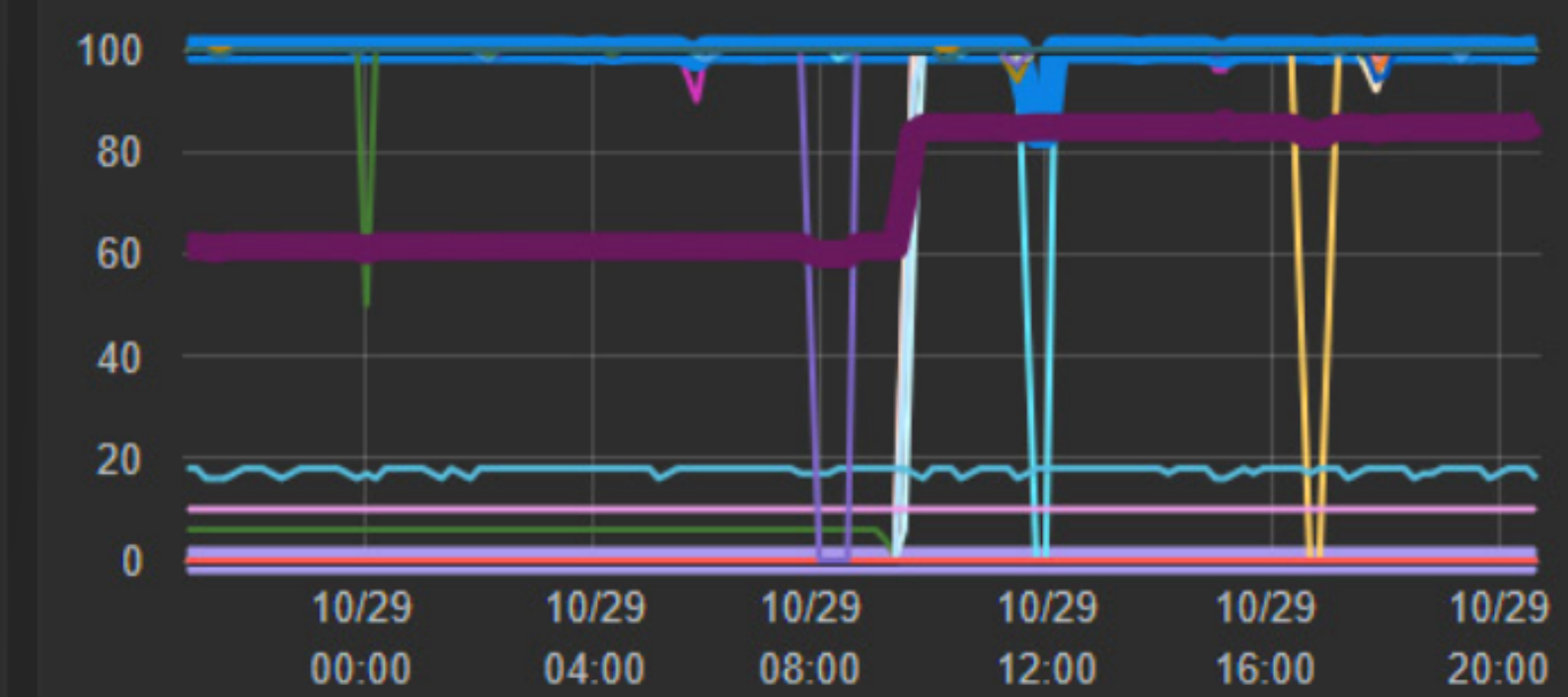
$$8.9 \leq \hat{R} \leq 13.2 \text{ km}$$



Soumi De



Crush Cloud: A Medium-Scale Virtualized Research Cloud





Scavenged HTC Resources from
Campus Desktop Computing.

(Not just undergrad labs!)

Virtualization and containerization
makes both ITS and
researcher happy.



ubuntu

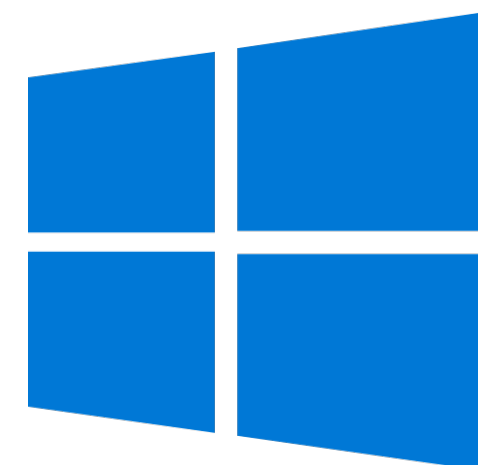


Microsoft
Hyper-V



CVMC

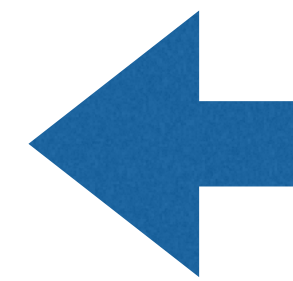
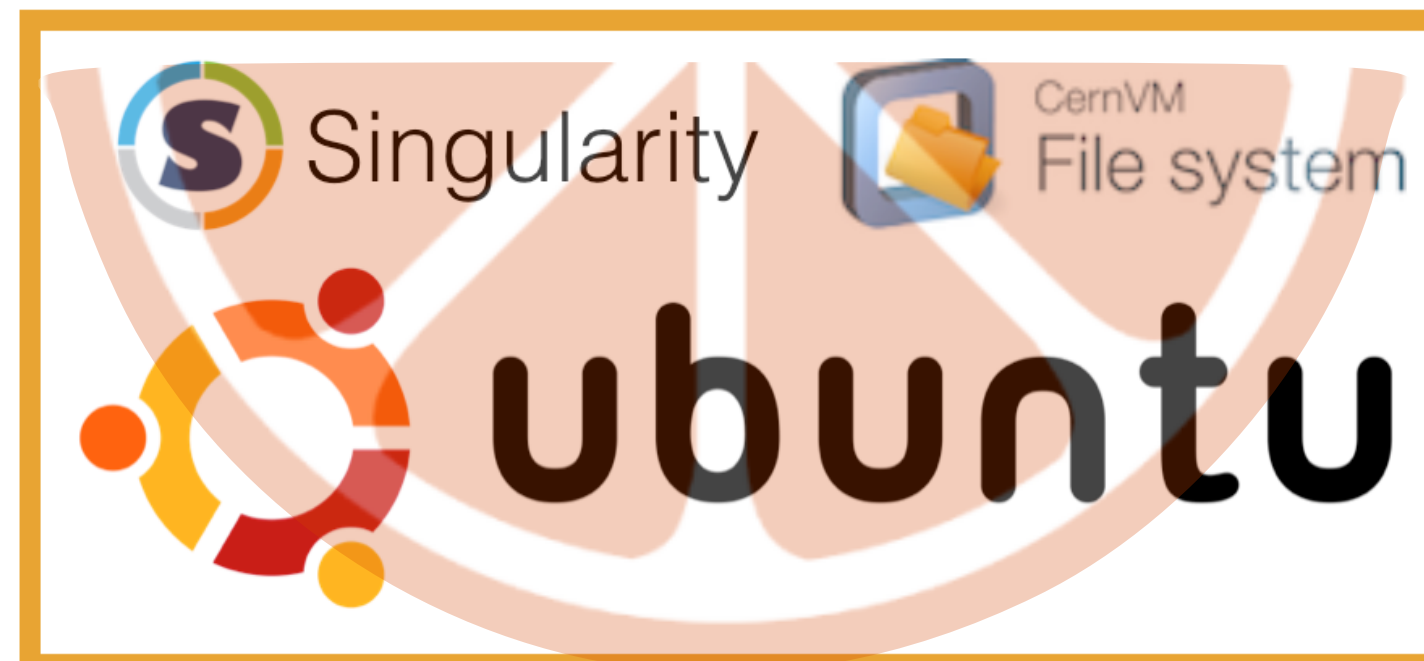
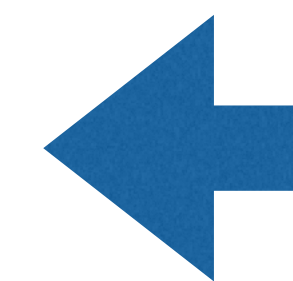
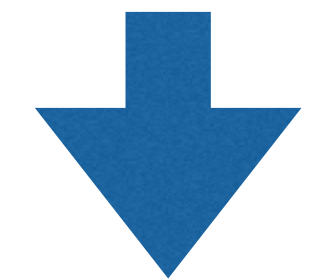
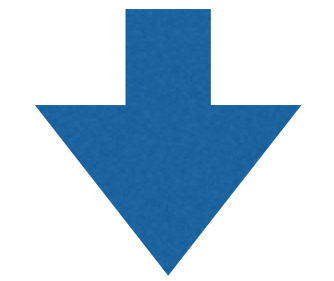
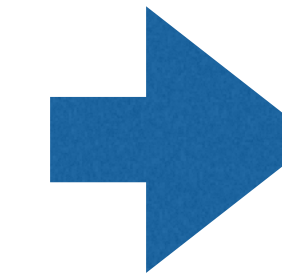
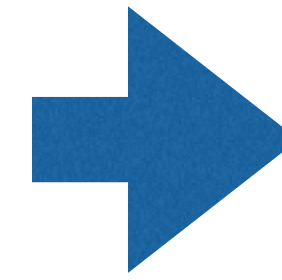
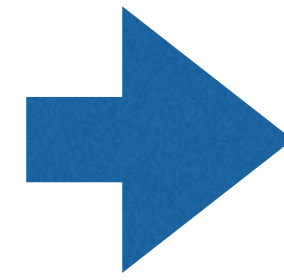
Microsoft
Active Directory



Windows 10

PyCBC

Free and open software to study gravitational waves.



```
[dabrown@comet-ln3 ~]$ module load singularity
[dabrown@comet-ln3 ~]$ singularity shell --home /home/dabrown/pycbc_test/~/srv --pwd /srv --bind /cvmfs --bind /tmp
--contain --ipc --pid /cvmfs/singularity.opensciencegrid.org/sugwg/dbrown\:latest
Singularity: Invoking an interactive shell within container...
```

```
PyCBC Singularity d76c65d7aee60864bad32abe226cc761ddba479b757c144a0cf2c2cc888ec8:~> pycbc_inspiral --version
--- PyCBC Version -----
Version: 786b52
Branch: master
Tag: None
Id: 786b5243147c94c9236d54617c3bd0fcd37cf618
Builder: Unknown User <>
Build date: 2019-05-18 00:06:43 +0000
Repository status is CLEAN: All modifications committed
```

```
[Imported from: /usr/lib64/python2.7/site-packages/pycbc/__init__.pyc
```

```
--- LAL Version -----
Branch: None
Tag: lalsuite-v6.54
Id: 1dd42e82f34cab2e3e66c71823a60f4938ffaeb8
```

- Code
- Issues 0
- Pull requests 0
- Projects 0
- Wiki
- More
- Settings

Files for running PyCBC Inference on SDSC Comet


Edit

Manage topics

3 commits 1 branch 0 releases 1 contributor

Branch: master

- Create new file
- Find File
- Clone or download
- Gitpod

 duncan-brown Create README.md		Latest commit bd46995 5 days ago
Dockerfile	initial entry	6 days ago
README.md	Create README.md	5 days ago
astropy.tar.gz	initial entry	6 days ago
inference_chi_0.4.ini	initial entry	6 days ago
mpi-demo-sub.sh	initial entry	6 days ago
mpi-demo-wrapper.sh	initial entry	6 days ago
mpi-demo.py	initial entry	6 days ago
pycbc-inference-sub.sh	initial entry	6 days ago
pycbc-inference-wrapper.sh	initial entry	6 days ago

PHYSICAL REVIEW LETTERS

Highlights

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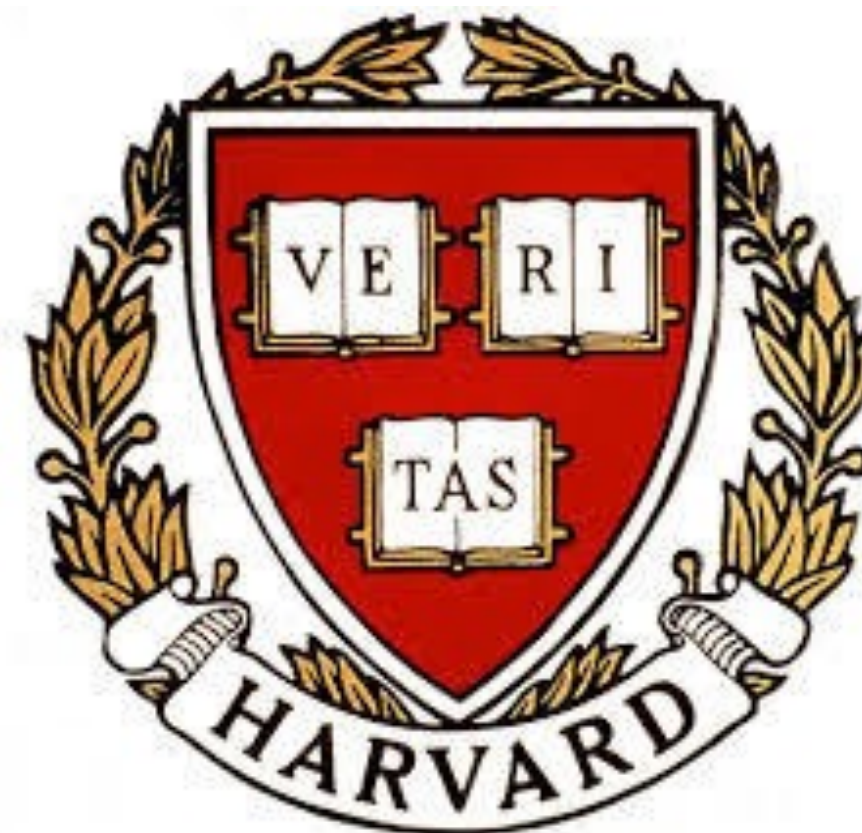
Press

About

Tidal Deformabilities and Radii of Neutron Stars from the Observation of GW170817

Soumi De, Daniel Finstad, James M. Lattimer, Duncan A. Brown, Edo Berger, and Christopher M. Biwer
Phys. Rev. Lett. **121**, 091102 – Published 29 August 2018; Erratum [Phys. Rev. Lett. **121**, 259902 \(2018\)](#)

Syracuse
University





BETA

Federation Info: [About](#) [Organizations](#) [Entities](#)

InCommon Entity Categories

Entity Category	# of SPs	# of IdPs
hide-from-discovery	0	30
research-and-scholarship	109	105
research-and-scholarship	0	78

Check out these **NEW** Entity Categories!

- [Hide From Discovery Category](#)
- [Registered By InCommon Category](#)

Entities in the latter category are filtered from these web pages since currently *all entities in production metadata are in the Registered By InCommon Category*.

Note: Service Providers (SPs) marked in **green** meet the requirements of the [REFEDS R&S Entity Category](#) specification. Identity Providers (IdPs) marked in **green** release attributes to **all** R&S SPs, including R&S SPs in other federations, whereas the remaining IdPs release attributes to R&S SPs *registered by InCommon only*.

IdPs

SPs

The following identity providers either belong to or support the indicated entity category:

Identity Provider Name	Entity Category
American Museum of Natural History - Richard Gilder Graduate School	research-and-scholarship
American University	research-and-scholarship
Arizona State University	research-and-scholarship
Auburn University	research-and-scholarship
Augusta University	research-and-scholarship
Bates College	research-and-scholarship
Baylor University	research-and-scholarship
Binghamton University	research-and-scholarship
Boston College	research-and-scholarship
Boston University	research-and-scholarship
Bowling Green State University	hide-from-discovery
Brookhaven National Laboratory	research-and-scholarship
Brookhaven National Laboratory	research-and-scholarship
Brown University	research-and-scholarship
Bucknell University	research-and-scholarship
California Community Colleges Chancellors Office	hide-from-discovery
California Institute of Technology	research-and-scholarship

Apache

Created by Rod Widdowson, last modified by Scott Cantor on Oct 16, 2018

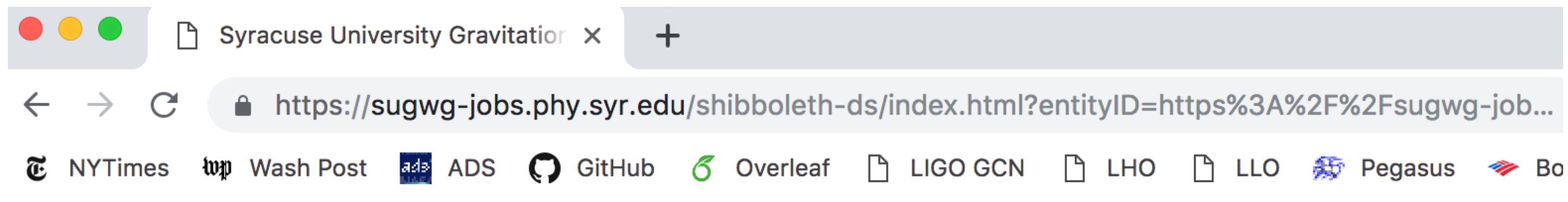
⚠ Apache 2.4 Support

You should review this page and the [htaccess](#) page thoroughly because Apache 2.4 is much more complicated than earlier versions. In particular, if you're trying to combine Shibboleth with other authentication schemes (like Basic), you may need to enable the `ShibCompatValidUser` option, documented below.

Half of Shibboleth runs within the web server. For Apache, this half is implemented in a module called `mod_shib_13.so`, `mod_shib_20.so`, `mod_shib_22.so`, or `mod_shib_24.so` depending on the Apache version. Like all Apache modules, the initial configuration is controlled with Apache's configuration file(s), but one of the primary options there (normally implicit/defaulted) is to point the module at the overall SP configuration file ([shibboleth2.xml](#)) where a lot of the options not specific to Apache are controlled.

At runtime, the module has the ability to process both a variety of Apache commands and rules specified in the SP configuration and make sense of both. This allows for a choice of approaches based on the need for native integration with Apache or for portability between web servers. Native integration using Apache commands is the better choice and is more secure.

- [Prepping Apache](#)
- [Loading the Module](#)
- [Properly Routing Handler URLs](#)
- [Global Options](#)
- [Server / VirtualHost Options](#)
- [AuthConfig Options](#)
- [Enabling the Module for Authentication](#)
- [Authorization](#)
- [Content Settings](#)





Please select an identity provider to login

Choose an identity provider from the options in the box below

The first time that you log in, you should pick from the list or enter an or organization name. Your previous choice(s) will be different provider from this list.

Use a suggested selection:

 Syracuse University	 ORCID Id	 MAX-PLANCK-GESELLSCHAFT Max-Planck Institutes (in MetaDir...)
---	--	---

Or enter your organization's name

[Allow me to pick from a list](#) [Help](#)

Which provider should I choose?

- LSC/Virgo collaboration members should select one of the LIGO providers and log in with their LIGO.ORG credentials available at my.ligo.org.
- Syracuse University Gravitational Wave Group members who are not part of the LSC can log in with their NetID. You can find more information at myslice.syr.edu
- Other scientists can log in with an ORCID Id, which can be obtained from orcid.id.

Using a .htaccess file to control access

You can override the default access settings to any sub-directory in your ~/secure_html directory by creating a file in that directory called .htaccess and adding authorization directives in there.

Setting up Shibboleth

The first two lines of this file should be the directives that turn on Shibboleth authentication and authorization:

```
AuthType shibboleth
ShibRequestSetting requireSession true
```

Then you can add lines to give access to specific people. These are implemented as a logical OR so you can specify multiple people on multiple lines.

Syracuse users

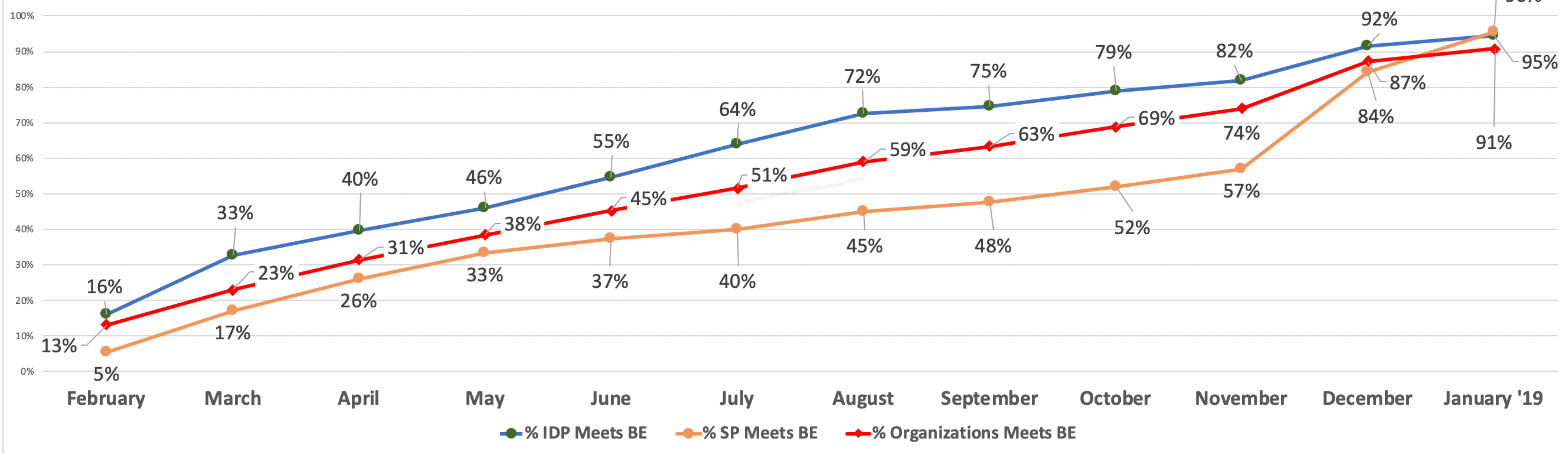
For Syracuse users, you can authorize people using their eduPersonPrincipalName, which is their [Syracuse NetID](#). For example, the following lines authorize people in our group:

```
require shib-attr eduPersonPrincipalName dabrown@syr.edu
require shib-attr eduPersonPrincipalName sdel01@syr.edu
require shib-attr eduPersonPrincipalName sdreyes@syr.edu
require shib-attr eduPersonPrincipalName dfinstad@syr.edu
require shib-attr eduPersonPrincipalName elawsonk@syr.edu
require shib-attr eduPersonPrincipalName chafle@syr.edu
require shib-attr eduPersonPrincipalName cmbiwer@syr.edu
```

LIGO/Virgo users

LIGO users can be authorized using their [LIGO.ORG username](#) as the eduPersonPrincipalName, for example:

% Meet Baseline Progress



But...

Only 94 of 530 IdPs in InCommon support research and scholarship internationally (many don't support R&S at all!)

- Open data, open code, and open analysis allow new, reproducible science
- The community should push for more openness in gravitational-wave astronomy to get the best science for everyone and for the long-term health of the field
- Federated identity management tools can make collaboration much easier

HTCondor

High Throughput Computing



CernVM
File system



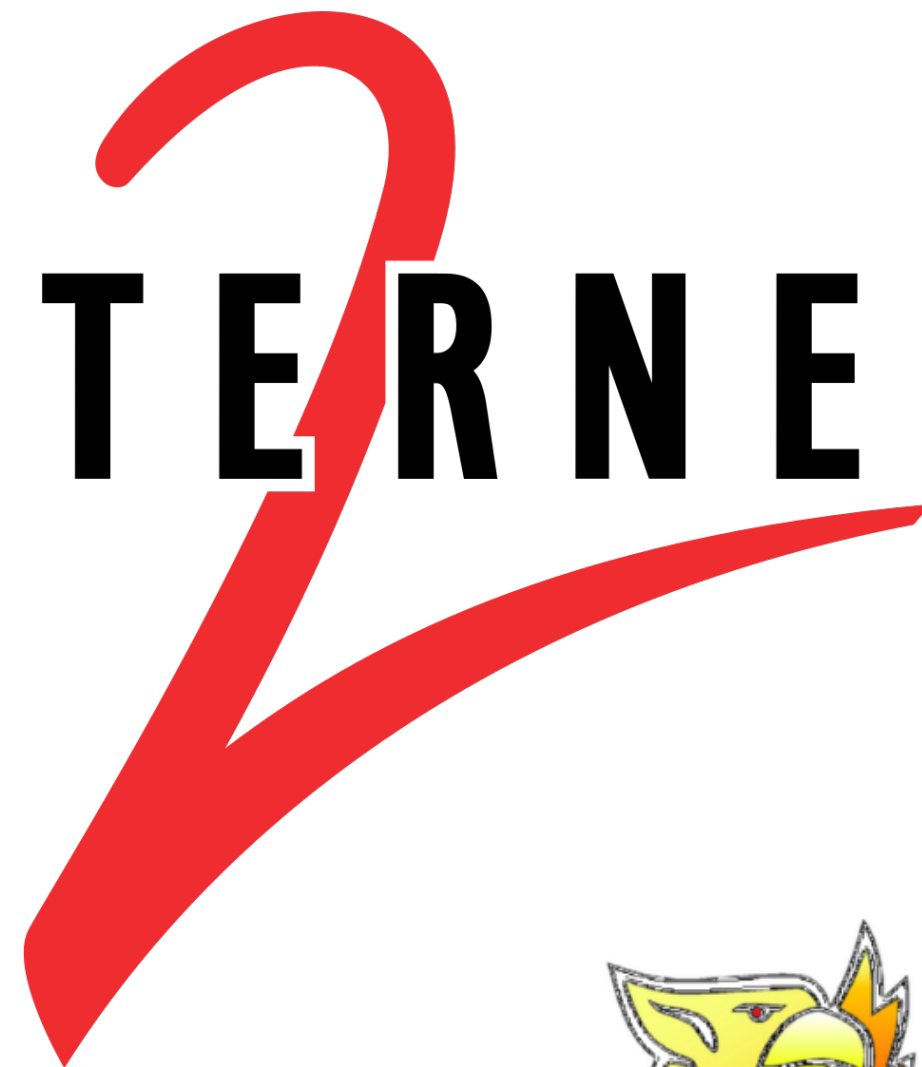
Open Science Grid



Pegasus

INTERNET[®]

INTERNET[®]

A large, stylized red swoosh graphic that starts under the letter 'I' and curves upwards and to the right, ending under the letter 'T'.

A logo icon for eduGAIN featuring a stylized orange and red swoosh with a starburst at the top left.

eduGAIN



Shibboleth[®]



Grouper[™]

InCommon[®]



COmanage™



CILogon



spherical cow
group

Friday, 04 March, 2011 01:13:57