Pegasus Users Group

MEETING

PUG 2021

Leveraging Pegasus to find colliding black holes in the data from the LIGO and Virgo gravitational wave observatories

Ian Harry

"Senior Lecturer" at the University of Portsmouth

23/02/2021

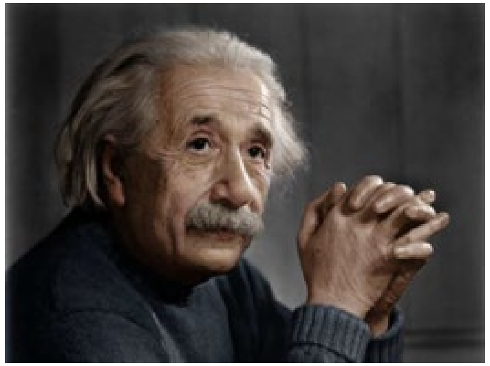
PUG 2021

PyCBC

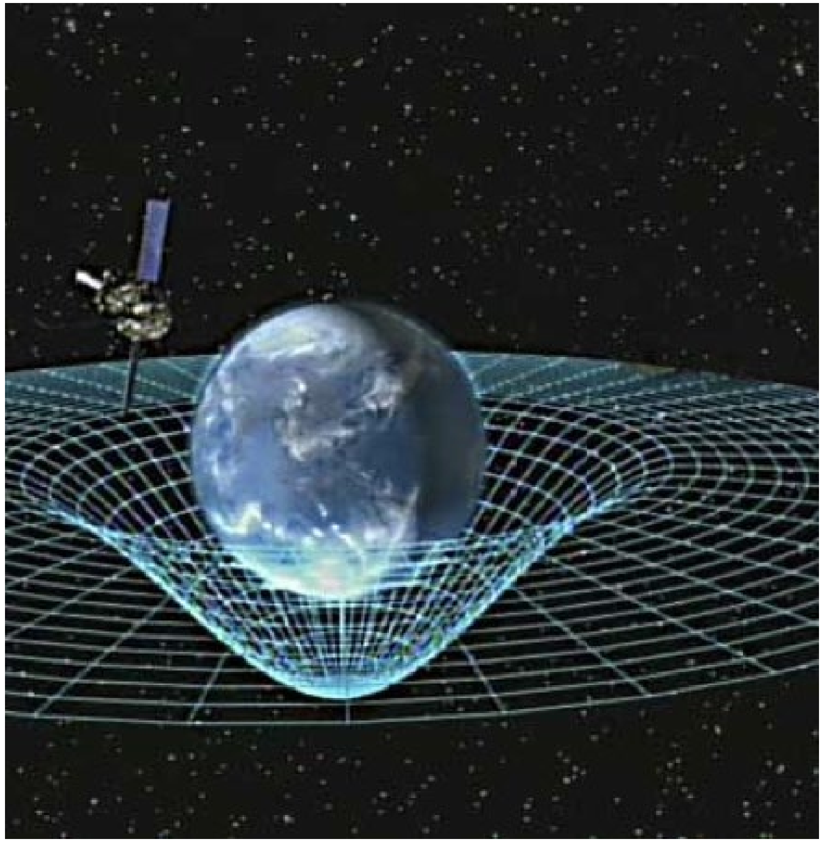
Overview

- What are gravitational-waves and why are they interesting?
- What is the computational problem we need to solve?
- How do we use pegasus to help us address these problems?
- What have we learnt from gravitational wave observations in the last 5 years?

General relativity and gravitational waves



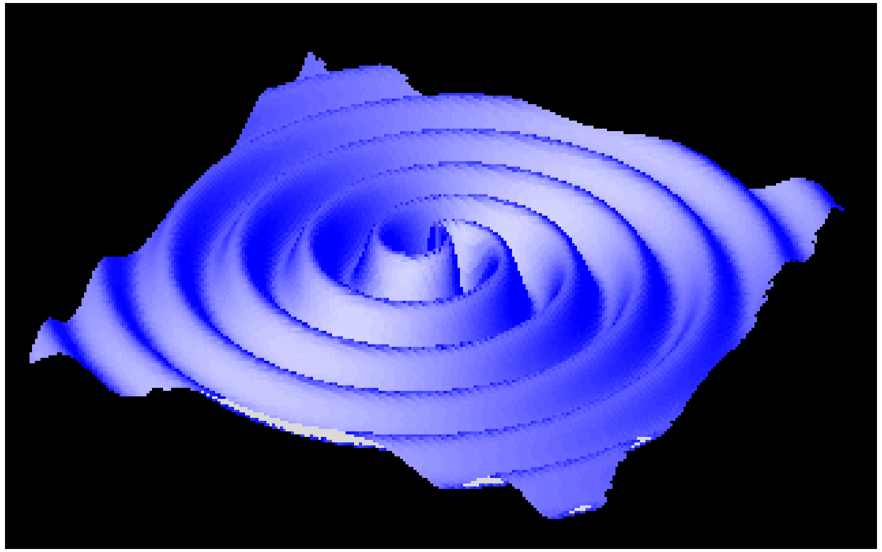
- Einstein's theory of general relativity redefined what we understand as "gravity"
- Gravity is reconsidered, no longer as a force, but as a warping of space and time
    - Caused by mass and energy in the Universe



Credit: NASA

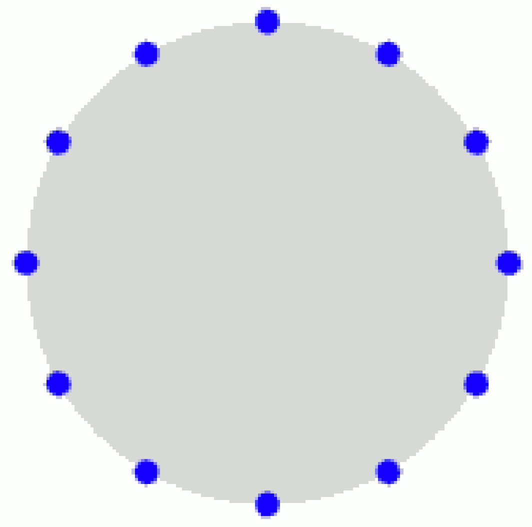
Gravitational waves

- A new prediction of general relativity, not present in Newtonian physics!
- Wave-like fluctuations in space-time, which propagate at the speed of light
- Emitted by accelerating masses with spherical asymmetry.



Effect of a gravitational-wave passage

- All particles affected by gravitational-wave passage
- Passing wave can cause a deformation in a ring of particles
- However, interaction with matter is extremely weak
- Observed signals have a strain of 10-21.



Observing gravitational-waves

LIGO Hanford, WA

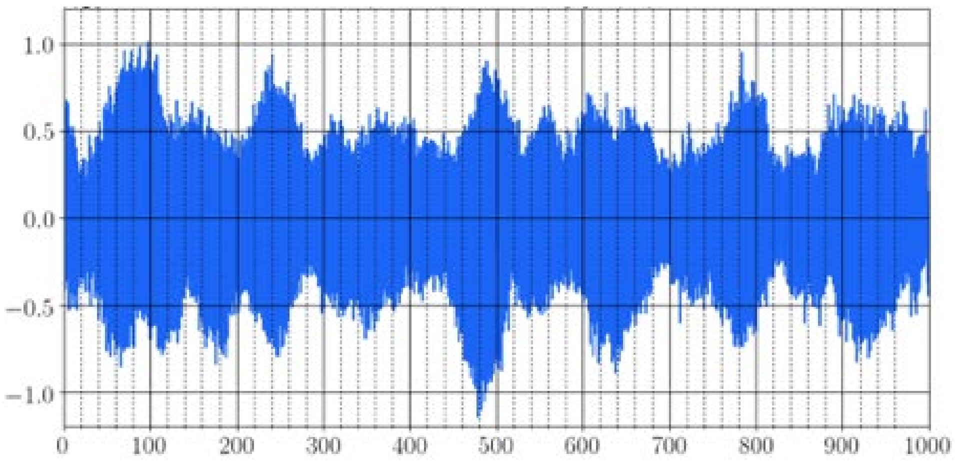
LIGO Livingston, WA

Virgo, nr. Pisa, Italy

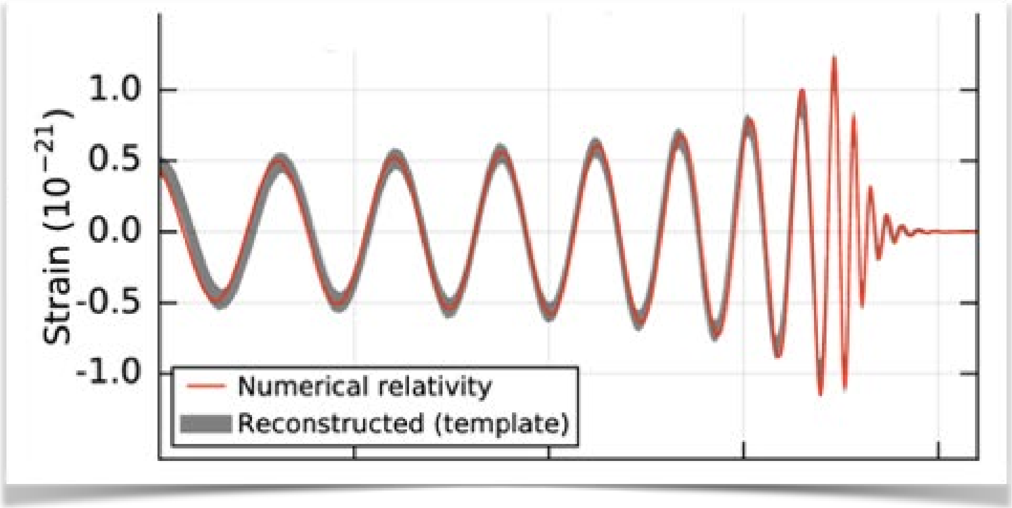
PUG 2021

PyCBC

Computationally - What is the problem?



+

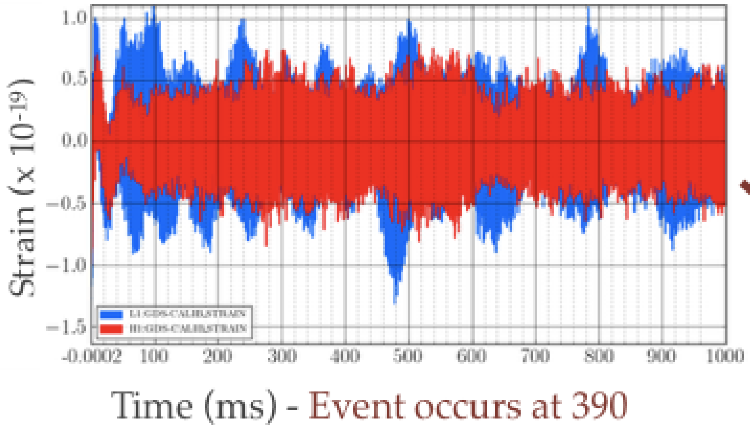


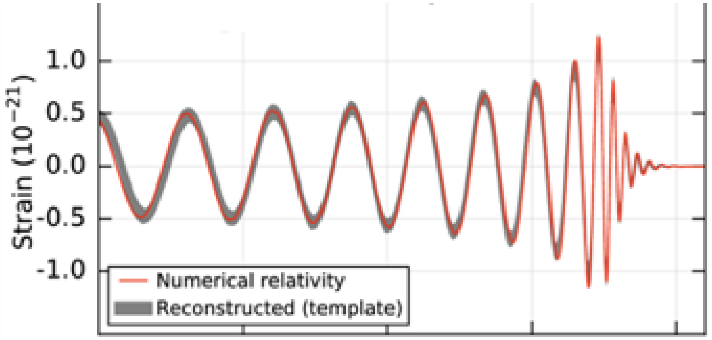
=

+

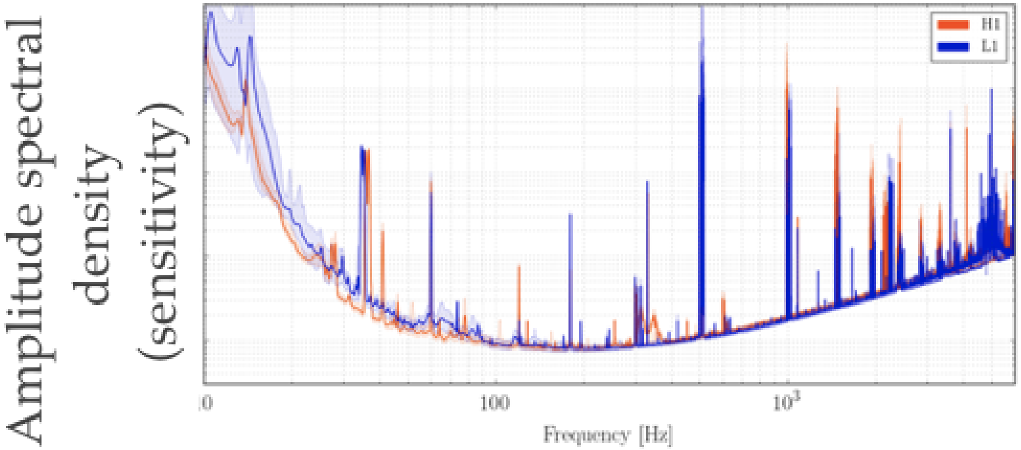
PyCBC

Matched-filtering



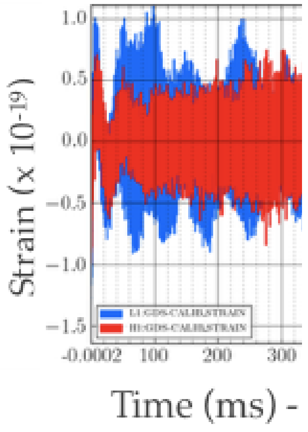


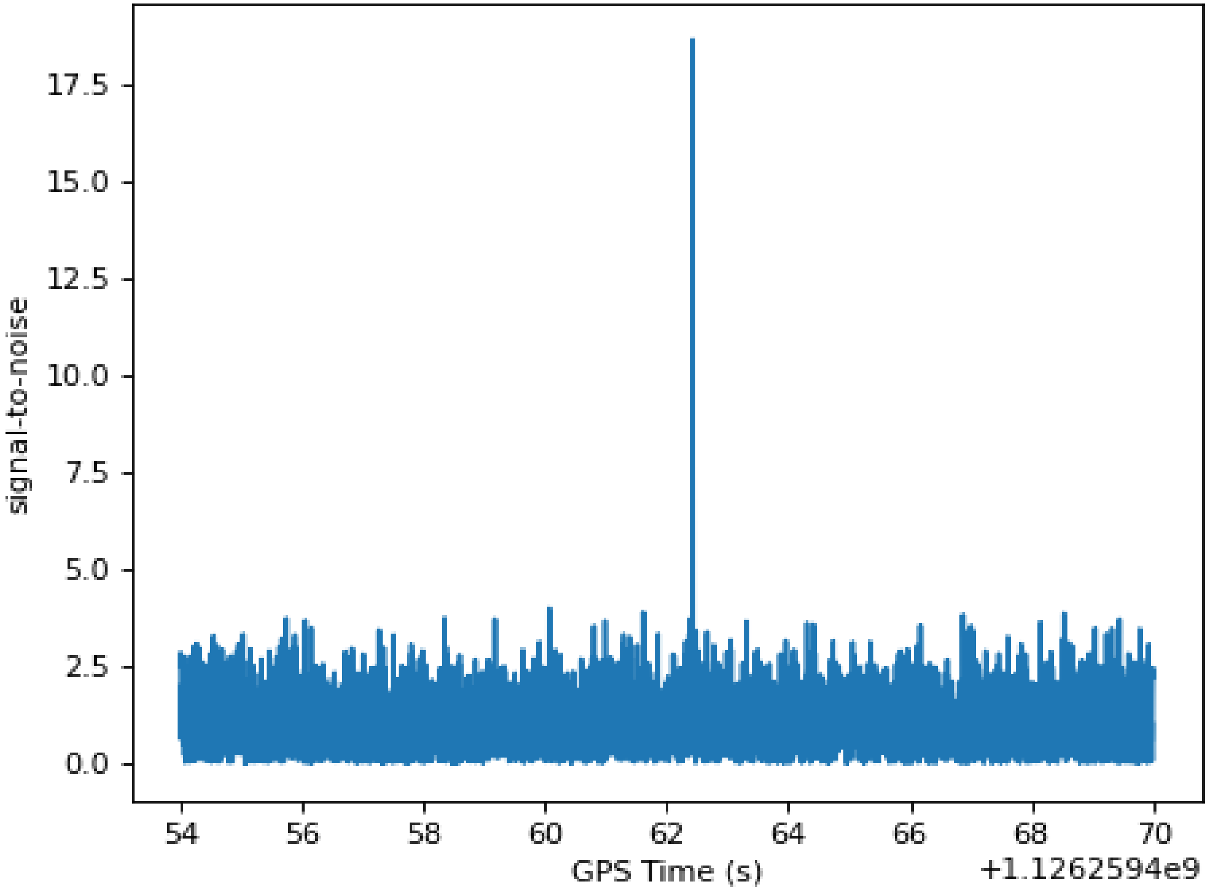
$$\langle s|h\rangle = \int_0^\infty \frac{\tilde{s}(f)\tilde{h}^*(f)}{S_n(f))} e^{-2i\pi t f}$$

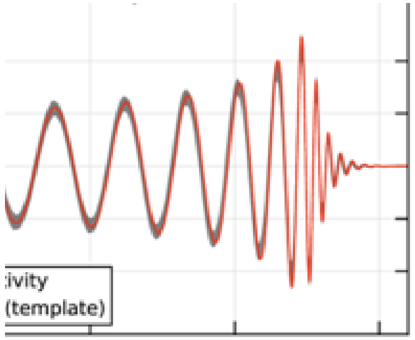


PyCBC

Matched-filtering







$\pi t f$

http://pycbc.org/pycbc/latest/html/gw150914.html

Basic workflow

A lot of pre-processing jobs. Takes a bit of wall-time but not much of the total CPU cost. Normally better done on a local compute cluster.

↓

Expensive matched-filtering jobs. Embarrassingly parallel, > 95% of total compute cost (10s of thousands of such jobs in “typical” workflow, each intended to run 4 - 12 hours). Have used OSG extensively for this (see talk Thursday). Can also utilize GPUs, or any CPUs available.

↓

A lot of post-processing jobs. Can take O(day) of wall-clock, but not so easy to parallelize. High memory requirements.

More detailed workflow

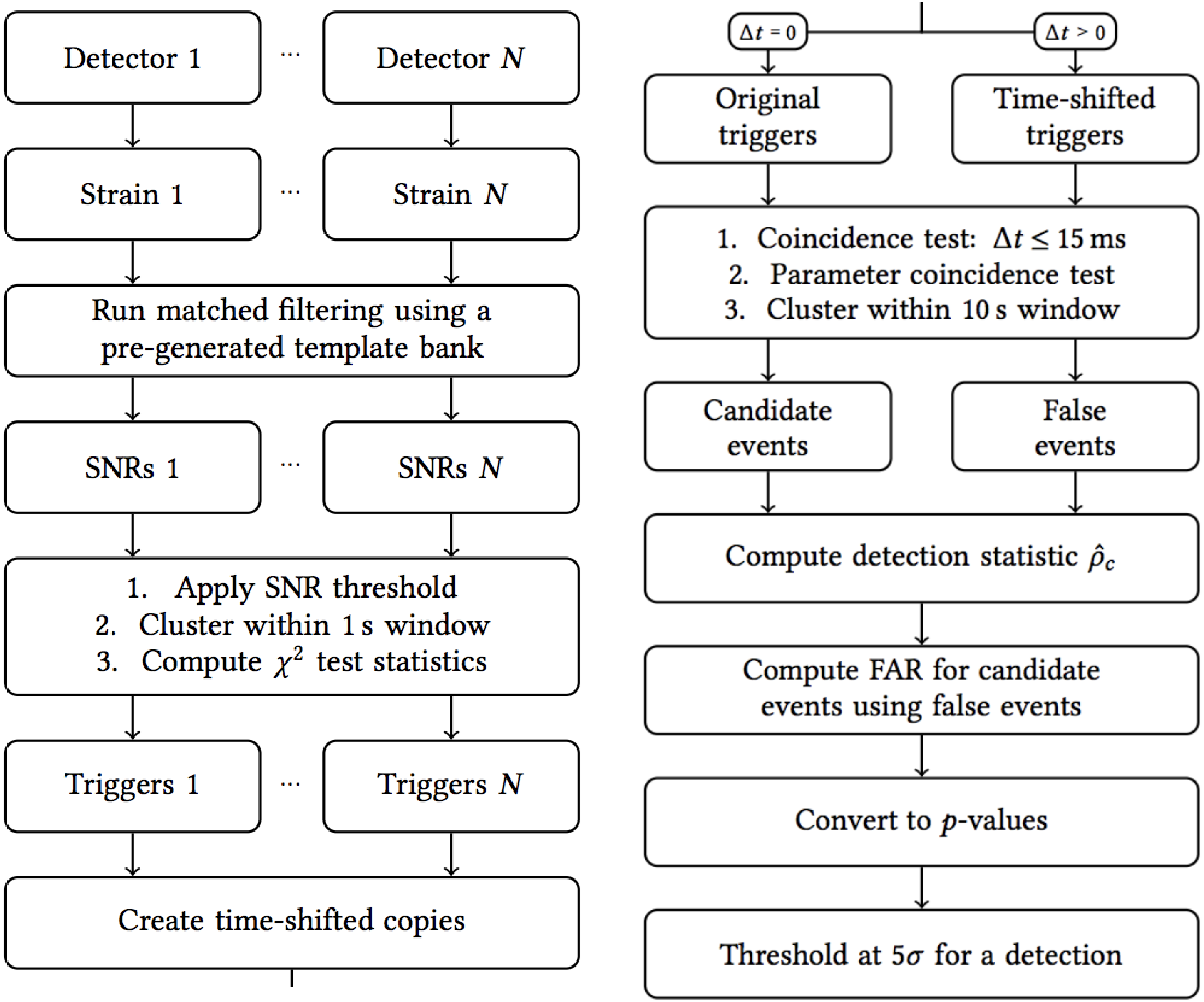


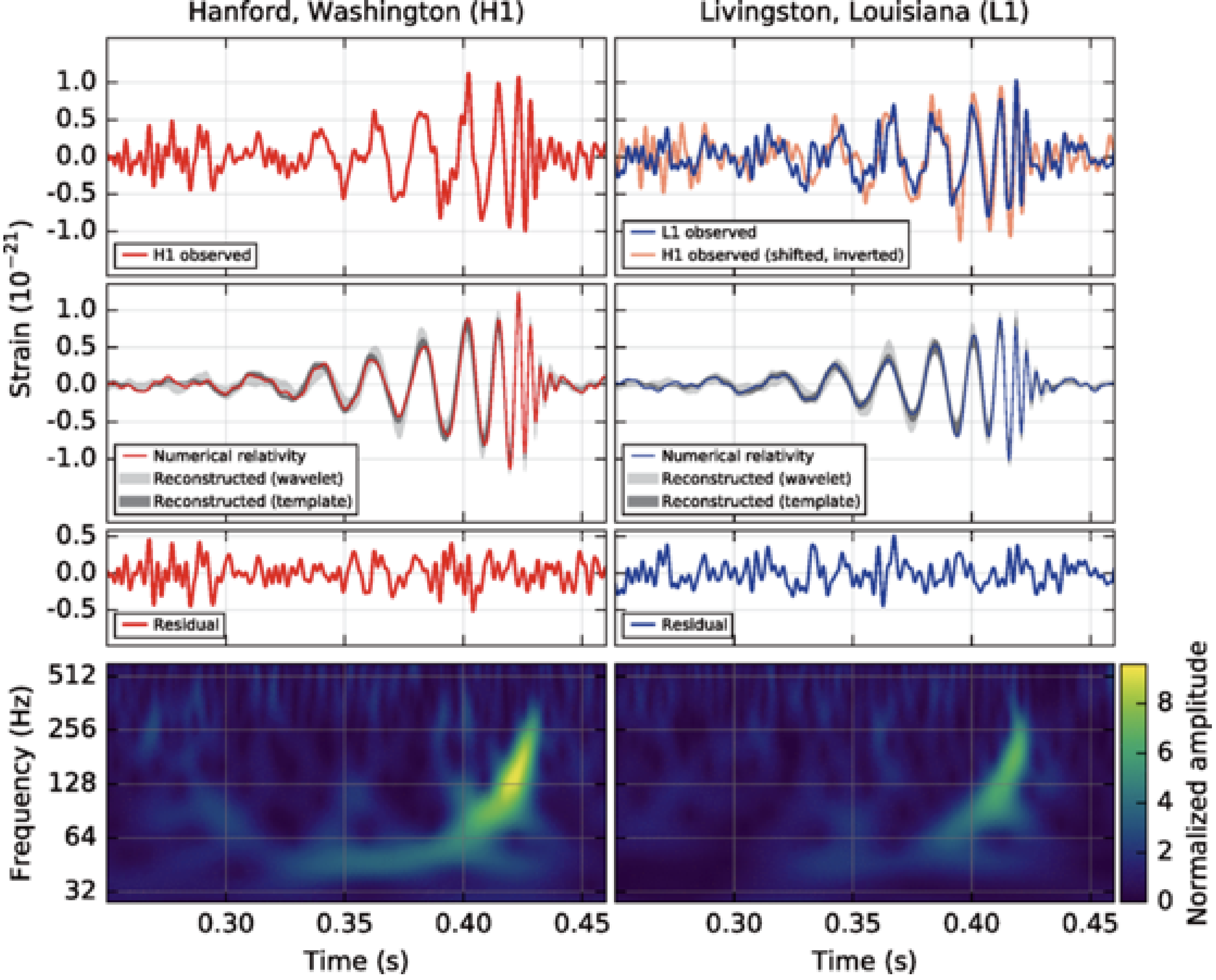
Image thanks to Niki Kilbertus and Timothy Gebhard

PUG 2021

PyCBC

PyCBC and Pegasus

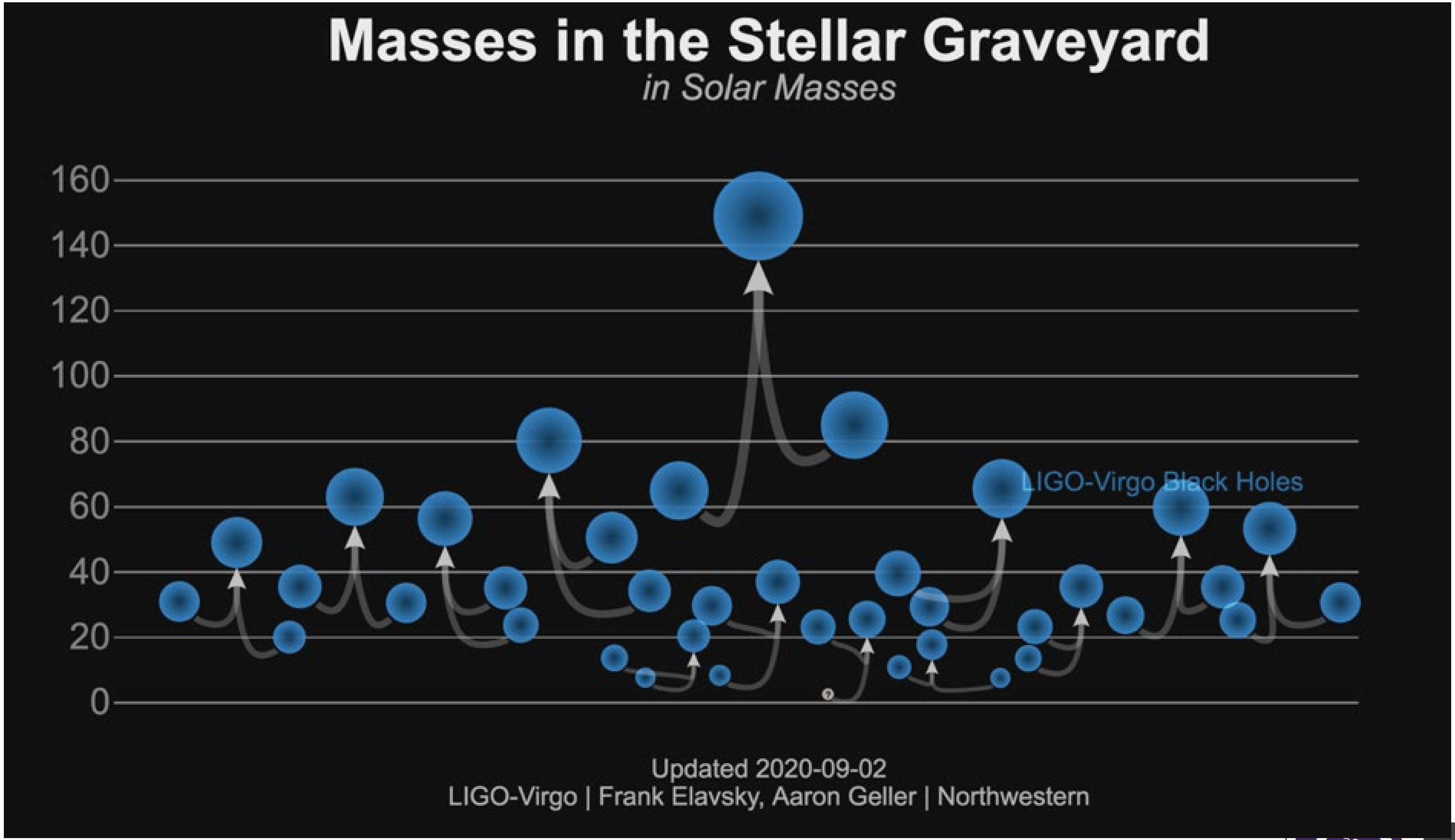
- PyCBC is one of the main analysis codes within LIGO and Virgo for observing black hole mergers.
  - Also used extensively by groups outside of the collaborations, including some key contributors.
  - It contains, modules, functions, utilities and programs to address numerous problems in the analysis and characterisation of colliding black holes, but finding them is arguably still it's main purpose.
  - Fully open source, on github, pypi and conda.
- PyCBC replaced an earlier C-based toolkit (with a bit of python) used during the 2000s ("lalapps")
- PyCBC first started using pegasus around 2012.
- This combination has observed and published more than 50 colliding black holes (and will continue to do so!)



GW150914 - The first observation

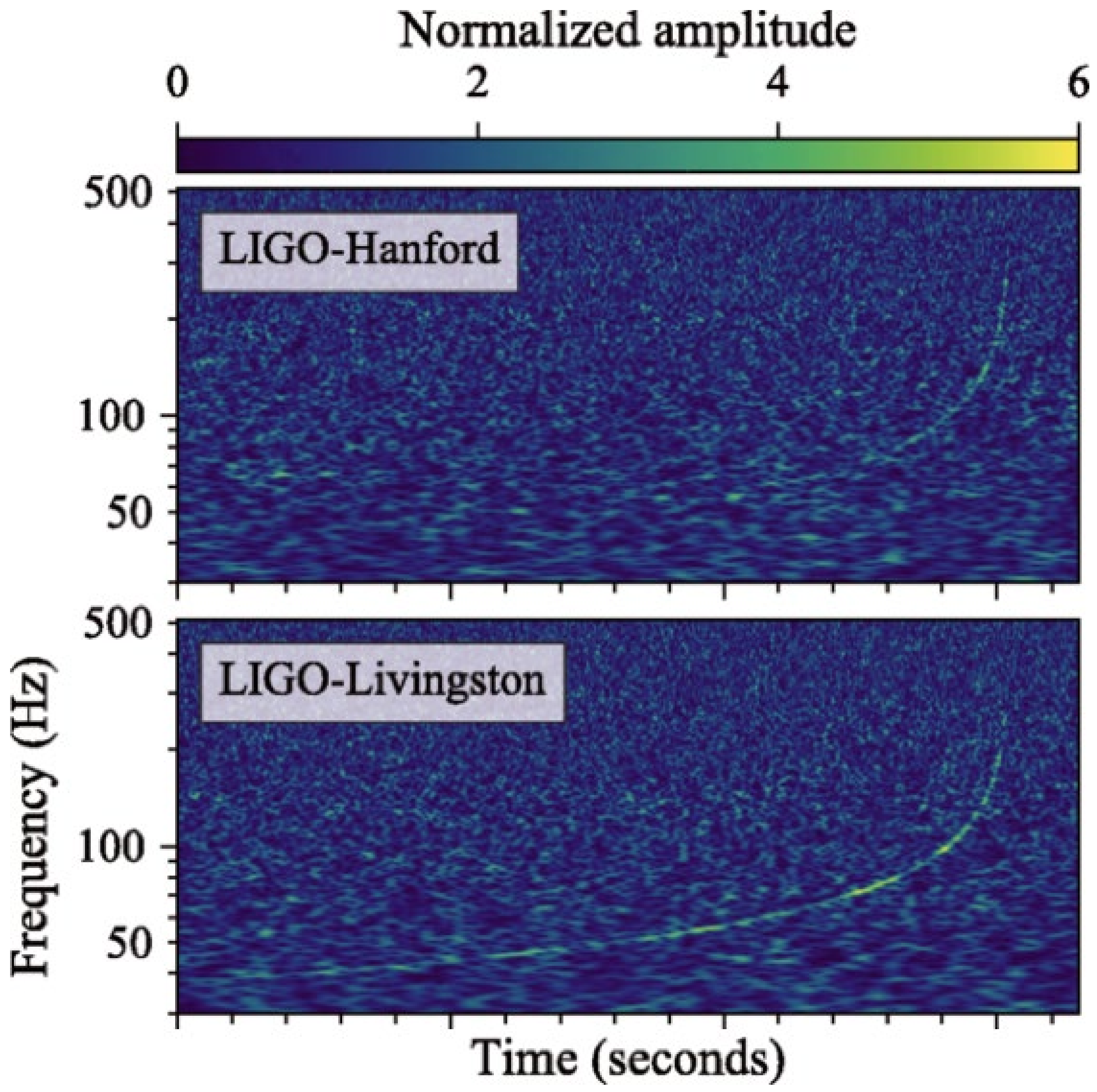
PyCBC

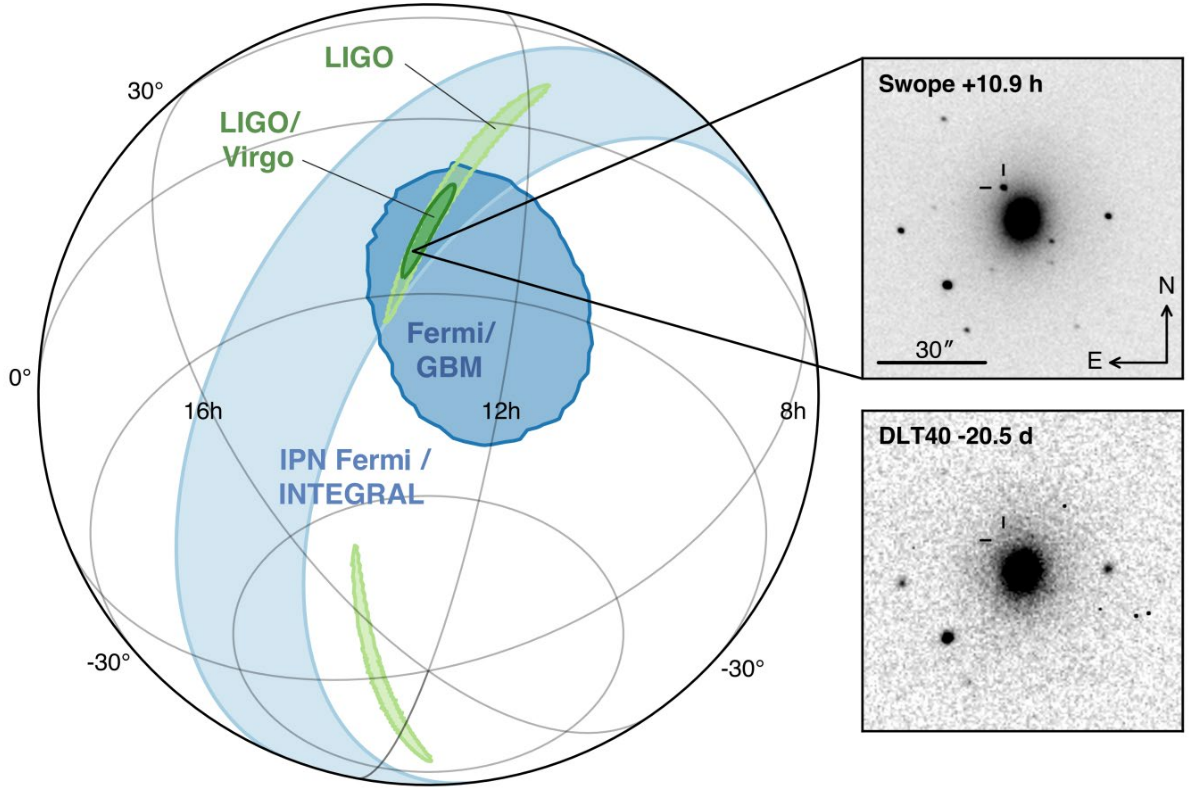
A catalogue of colliding stellar remnants



PyCBC

A visible collision of dead stars





Our Pegasus Feedback

Current PyCBC workflows can contain as many as 100,000 jobs. Having the dashboard to monitor this can be really useful. However, in maybe as many as 5% of workflows the monitoring process fails (or lags behind) and then we do not get accurate information. This makes it hard to use the dashboard, as it may not be clear that this has happened.

Most of our development team is now on European (or Indian) timezones. Can make collaboration difficult (but I don't see an easy solution for this!)

We are still porting our code to pegasus 5, we do have some minor technical requests that will come from this, but need some more work on our end before having these discussions.

Thank You!