01

02

03

04

Project #3:

Measuring Gravitational Waves

By Ainsley, Maggie, and Lisa

Our Motivations

Why study gravitational waves?

Prove Einstein's Theory

Gravitational waves prove his theory that a collision between accelerating and massive objects create a ripple in space-time.

The Existence of Black Holes

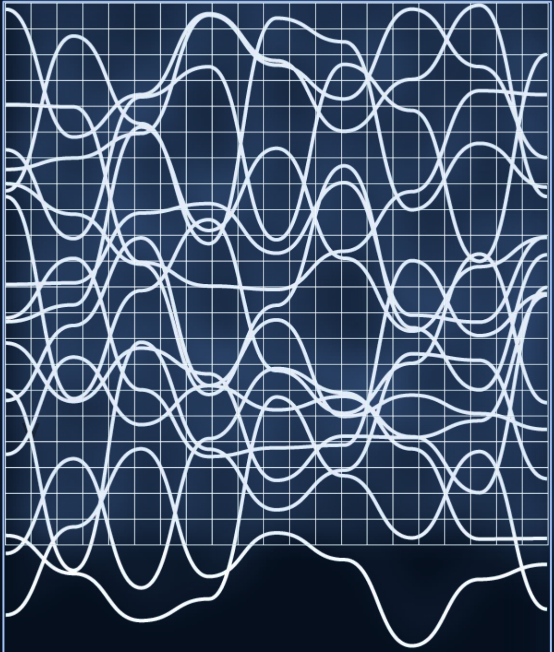
Gravitational waves can only be created by black holes or neutron stars. Acts as direct evidence of their existence.

Further Insight on Events

Provides insight on the mergers' mass and distance that is otherwise undetectable with a telescope.

Important Background:

- Each event is different!
  - Many events with different masses and distances
    - Black holes and neutron stars
- Detected using sensors from two locations
  - Reduces the chances of false positives
  - More data is always better!



Our Process

01

Our Event Data

GW200129_065458 says hello- import its data.

02

Comparing Data

Compare LIGO Livingston to LIGO Hanford.

03

The Chirp

Turn the identified signal into something listenable.

04

Mass and Distance

Calculate the mass and distance of the merger.

02

03

04

Importing and Plotting Data

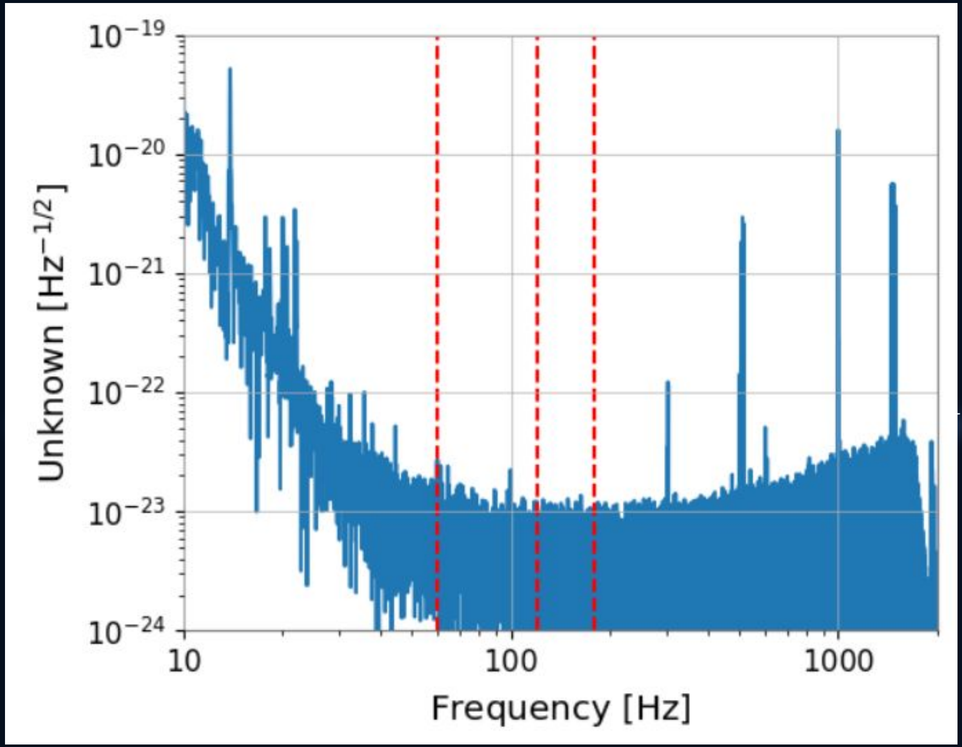
Installing and Importing

- Installing GWPY
  - Specifically used for reading GW
- Downloading time data from the time we want to look at
  - GW200129_065458 Happen at: 1264316116.4
    - Observing 16 seconds before and after to event

```
from gwpy.timeseries import TimeSeries
hdata = TimeSeries.fetch_open_data('H1', 1264316100, 1264316132)
```

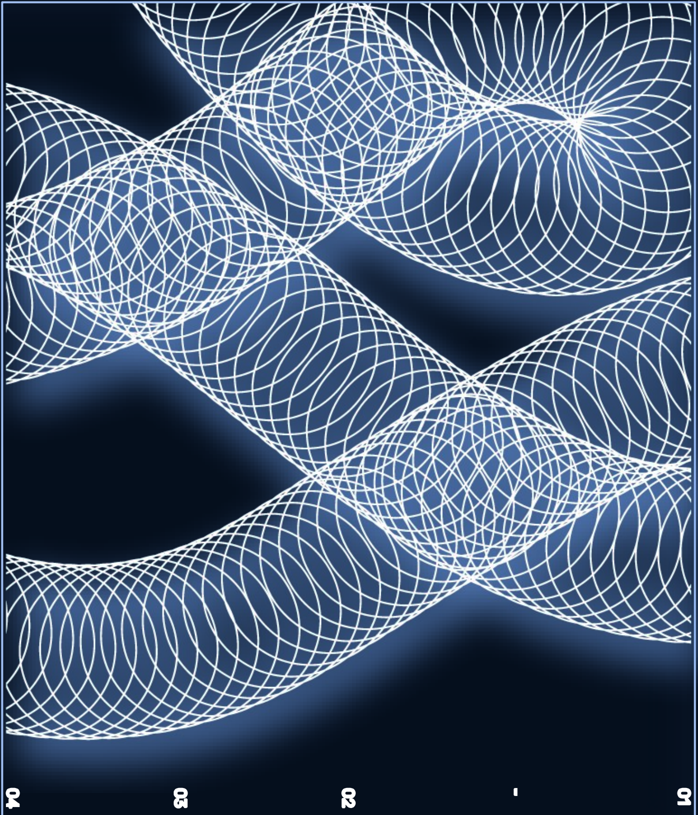
Making Initial Graph

- Importing tool used for plotting
- Plotting the frequency data
  - Dashed lines indicate where interference/noise from AC currents would be (60, 120, 180 Hz)



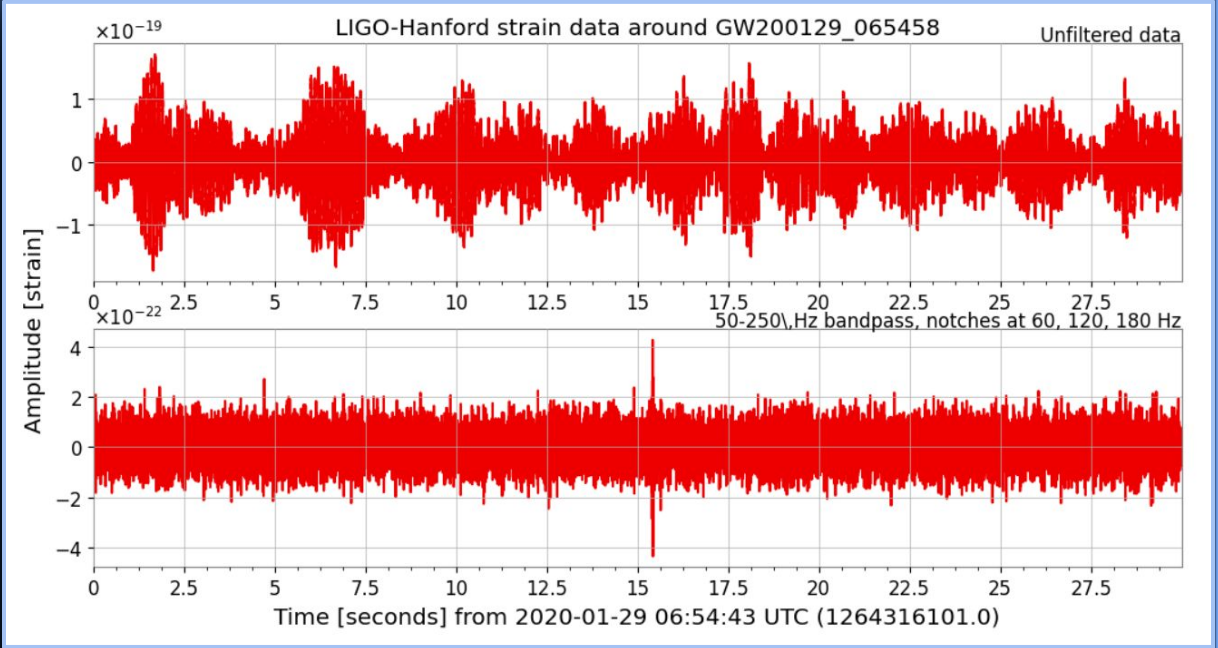
Filtering Unwanted Data

- Filtering unwanted data at the marked points using GWPY
- Cropping the Data further
  - 1264316102.0 - 1264316130.0
    - 14 seconds on either end



Making Strain the Graph

- 2 ways to plot
  - Using Matplotlib
  - Using gwpy.plot
- Both result in 2 graphs
  - 1st shows unfiltered
  - 2nd shows filtered
    - The “spike” indicated the event



02

03

04

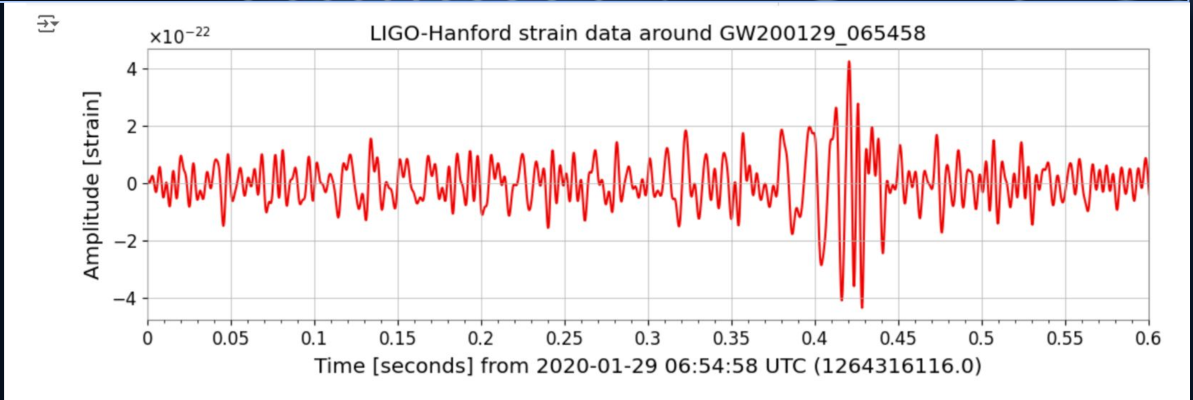
Comparing LIGO Centers

LIGO Centers

- Hanford Center
- Livingston Center
- 207,000 m apart

Hanford, Alone

- Plot the Hanford Strain alone
  - What one center heard
- Reduce the window of time to capture the event
- Note the flare in the amplitude!



From 16 seconds to 0.6 seconds– the merge happens fast!

The Difference

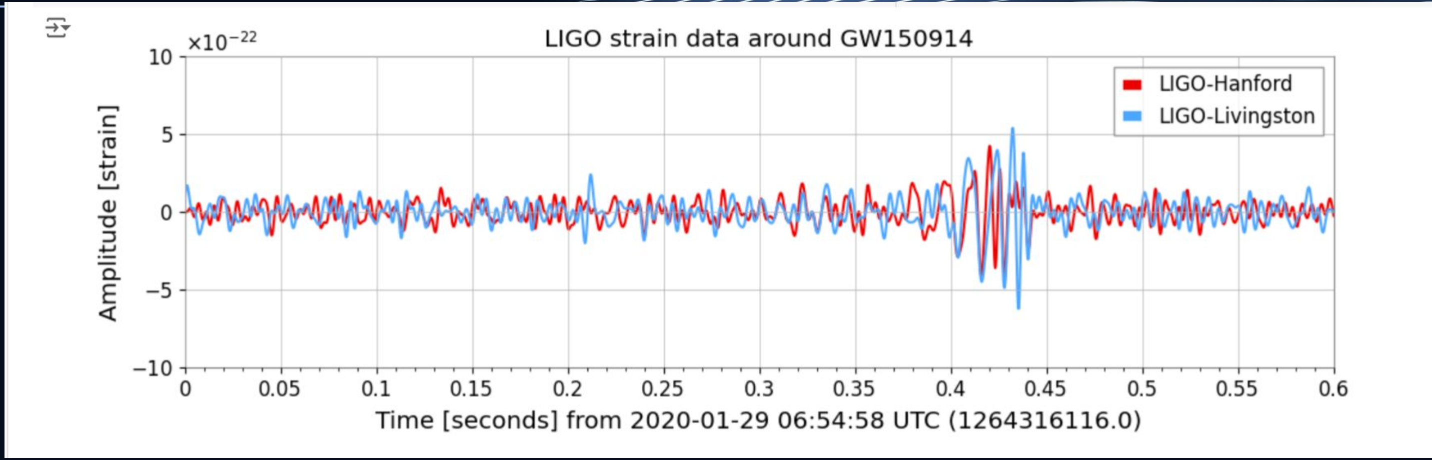
```
[11] import astropy.units as u #import a Python package to call certain units.
     D = (0.0069 * u.s) * (3e8 * u.m/u.s) #calculate the distance between Livingston and Hanford using the speed of light and the given timeshift.
     print(D) #printing this value, which is accurate, shows that the timeshift makes sense.

     2070000.0 m

[12] lfilt.shift('6.9ms') # this shift in the data accounts for the time difference in the two different places.
     lfilt *= -1 #invert the signal (part of accounting for the time difference).
     #Light travels the distance between Hanford and Livingston (207000m) in 6.9 milliseconds.
     #The wave travels at an angle, hitting one place first, and then the other.
```

- Frameshift of 6.9 ms
  - To superimpose the two centers' data, we need to account for the difference in the time the waves hit the centers
- Invert signal
  - Accounts for the difference in orientation of the two systems

Both, Together



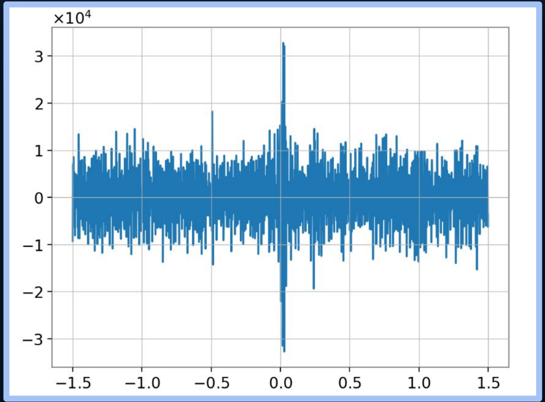
- Plot the Hanford and Livingston Strains together
    - Same signal detected– this is from gravitational waves!

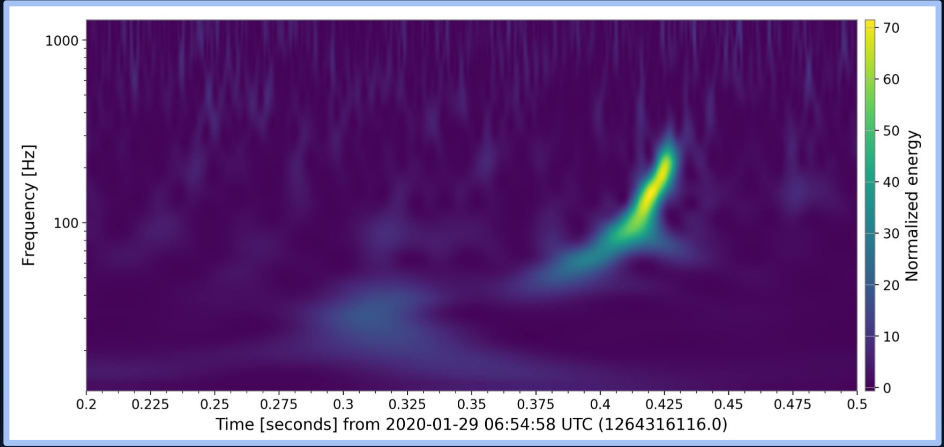
02

03

04

Making ‘The Chirp’





The Sound

- Gravitational waves can sound like a bird's chirp
    - We aren't able to hear them because they are outside the range of audio frequency that human ears can detect

02

03

04

Mass and Distance

Mass, Distance, and Energy of the Black Hole Merger

- Mass: 65 Sol Masses

```
T = (0.4258 - 0.4201) * u.s
M_BH = (T * ac.c**3) / (4 * np.sqrt(2) * np.pi * ac.G)
print(M_BH.to(u.solMass))
```

- Distance: 1102 Mpc

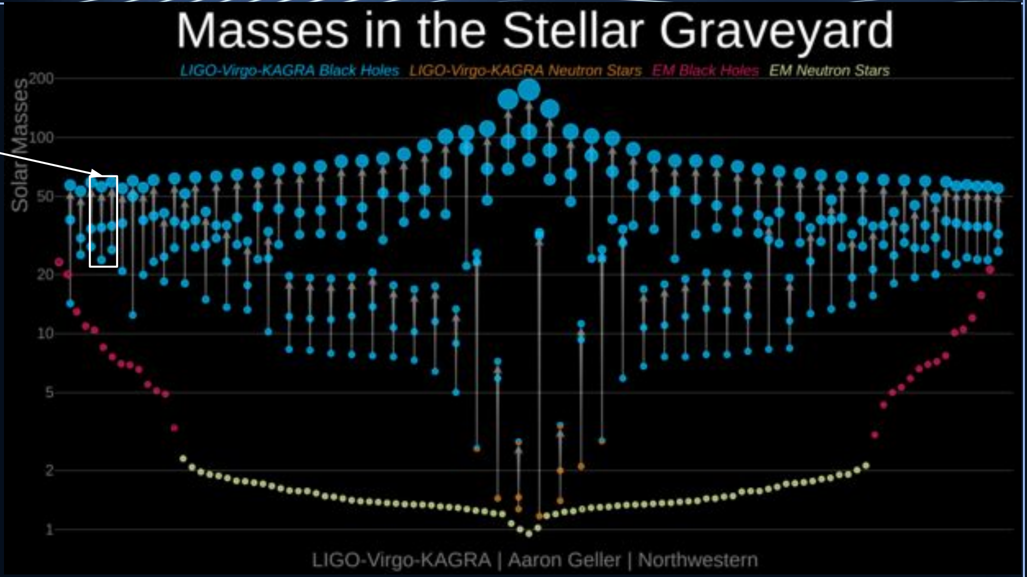
```
S = 1e-21
D = T * ac.c /(16 * np.pi * S)
print(D.to(u.Mpc))
```

- Energy: 6 x 10^47 J

```
M_Real = 60.2 * u.solMass
M_Tot = (34.5 + 29) * u.solMass
E = (M_Tot - M_Real) * (ac.c**2)
print(E.to(u.J))
```

Calculated versus Actual

- Our Event
  - Mass 1: 34.5 Sol Mass
  - Mass 2: 29.0 Sol Mass
  - Final Mass (Calculated): 65.0 Sol Mass
  - Final Mass (Actual): 63.3 Sol Mass



Our Conclusion

- To examine the event GW200129_065458, we started by making a strain graph with data detected by LIGO-Hanford to clearly capture the event.

- We then compared this graph to the data found at LIGO-Livingston and found that both LIGO detectors detected the same signal.
  - With this data, we were able to recreate the sound of the gravitational wave so we can hear it!

- Finally, with information about time and strain, we calculated the masses of the black holes, distance, and energy lost in GW200129_065458
  - Mass: 65 Sol Masses
  - Distance: 1102 Mpc
  - Energy: 6 x 10^47 J

Thank You!