Name: _____

Other group members: _____

Tutorial #10

PHYS 1240: Sound and Music

Wednesday, August 7, 2019

Instructions: Work in groups of 3 or 4 to answer the following questions. Write your solutions on this copy of the tutorial—each person should have their own copy, but make sure you agree on everything as a group. When you're finished, keep this copy of your tutorial for reference—no need to turn it in (grades are based on participation, not accuracy).

1. Assume a typical CD holds exactly 74 minutes of audio, has a sampling rate of 44.1 kHz (kHz = "1,000 samples per second"), and has a bit depth of 16 bits per sample.

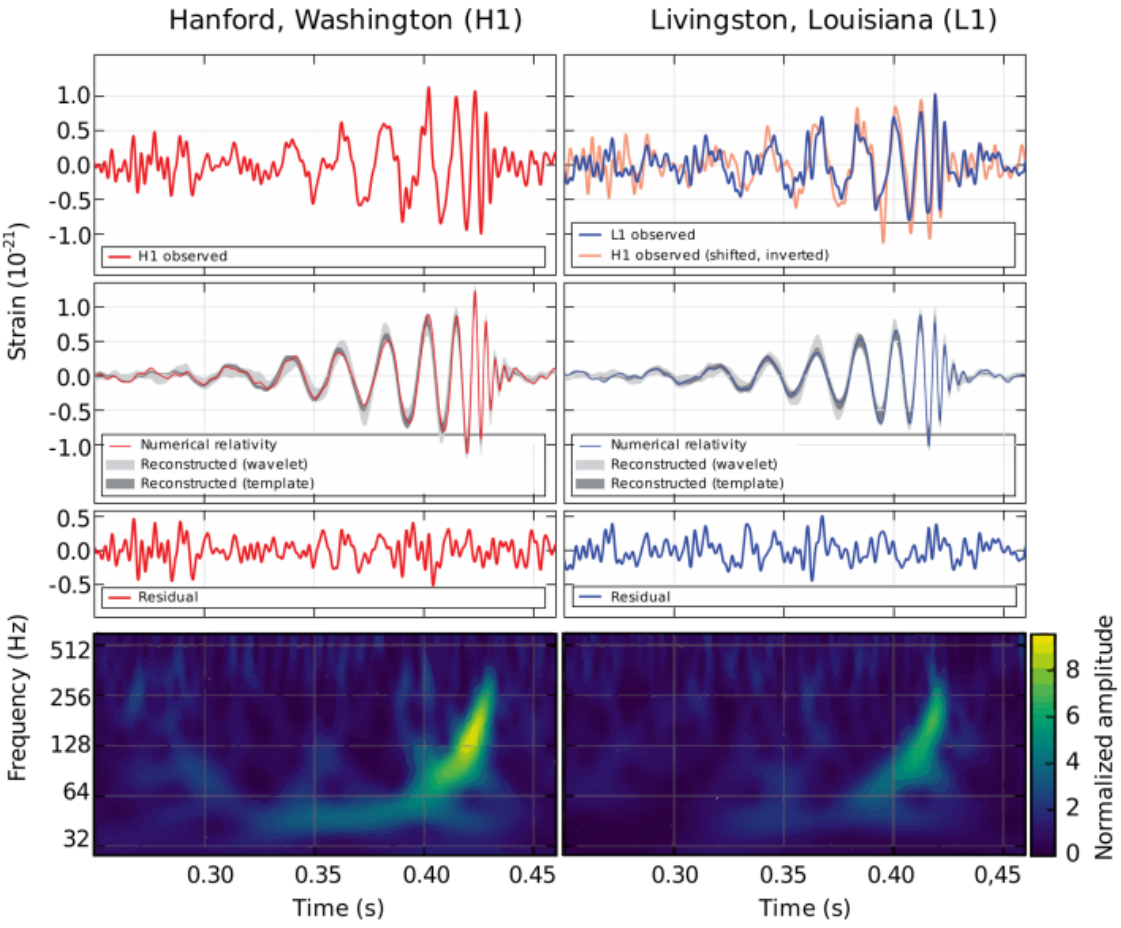
   (a) First, use the sampling rate and the bit depth to find the bit rate of the CD (the number of bits per second, a measure of the audio quality). Assume the CD is stereo, which means that there are 2 channels of audio running simultaneously (how will this affect the sampling rate?).

   (b) Convert this bit rate to MB (megabytes) per hour. The prefix mega- represents 10^6 (a million), and 1 byte = 8 bits.

   (c) Use the duration of the CD to determine how many megabytes you are able to store on the CD.

(d) If you convert the audio file stored on this CD to an MP3 file which only contains 10% of the data (e.g. 10 MB instead of 100 MB), what will be the new bit rate, in kbit/s? For comparison, the bit rate for telephone quality is 8 kbit/s, for Youtube 240p videos is 400 kbit/s, for Youtube 480p videos is 1 Mbit/s, and for Blu-ray Disc is 40 Mbit/s.

2. The Laser Interferometer Gravitational-Wave Observatory (LIGO) observed gravitational waves from the merger of a pair of black holes for the first time on September 14, 2015, an event tagged GW150914. The observation ushered in the era of gravitational wave astronomy, and was a spectacular confirmation of the predictions of general relativity in a strongly gravitating system. During two observing runs over the next two years, LIGO, joined during the second run by the European gravitational wave observatory VIRGO, detected a total of 9 black hole mergers and 1 neutron star merger. Use the data shown below to answer the following questions.



(a) Qualitatively describe the shape of the "chirp" waveform that the detectors saw from GW150914. Be sure to describe how both the frequency and amplitude change over time.

(b) The orbital frequency f of a binary containing two objects of combined mass M a distance R apart is approximately

$$f \approx \sqrt{\frac{GM}{R^3}}$$

The two objects merge into a single black hole when the orbital separation R has decreased to approximately the Schwarzschild diameter, $R \approx 4GM/c^2$. Substitute this value of R into the equation above to determine an equation for the orbital frequency at the time of the chirp. Which will produce higher frequency gravitational waves, a more massive or a less massive binary system?

(c) The LIGO detectors are sensitive to frequencies of 30 Hz and higher. From the data on the previous page, for roughly how long was GW150914 detectable prior to the merger?

(d) The neutron star merger event GW170817 had a combined mass M that was about a factor of 20 smaller than the black hole merger GW150914. By looking at the data on the previous page, what would the approximate maximum frequency be for the neutron star merger? Why do you think the neutron star merger was able to be detected for a much longer time (almost a minute!) than the black hole merger?