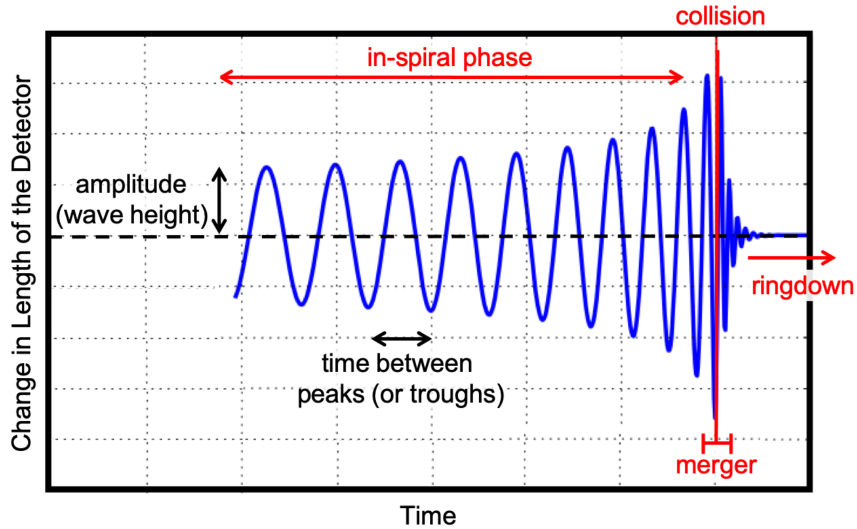
Detecting Gravitational Waves

In this activity, you'll learn about how the Laser Interferometer Gravitational-Wave Observatory (LIGO) detects gravitational wave signals. Your team will be provided with a set of templates for gravitational waves signals from mergers of binary black hole (BH) systems in circular orbits:



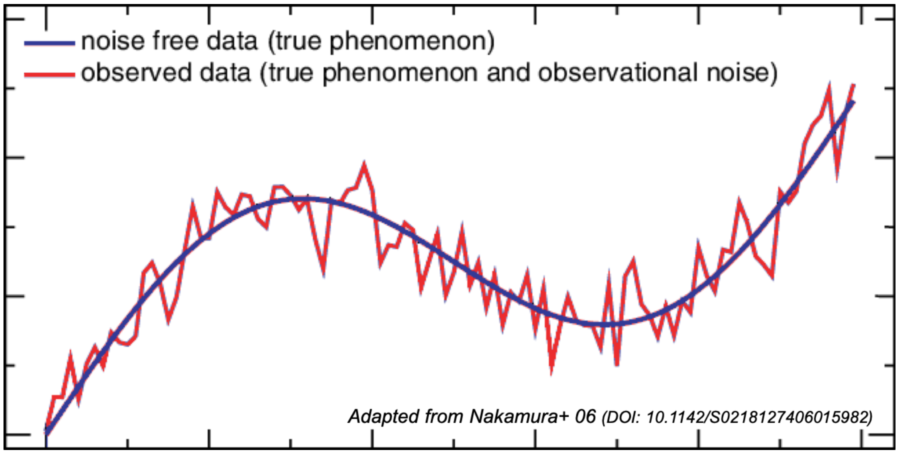
1) Referring to the illustration above, answer the following:
   a) How does the time between peaks change before collision?

   b) How does the amplitude change before **and** after collision?

2) Using the templates and what we've discussed in lecture, assuming all initial orbital parameters are the same, how does the amplitude **and** duration of the in-spiral phase of the gravitational wave signal change when you increase the total mass of the black holes?

STOP CHECK IN HERE ***Check in with an instructor before continuing.***

LIGO detects gravitational waves by trying to match templates to its data. While LIGO is a very sensitive instrument, its data contains “noise” (like the static “snow” on old TV sets or the noise you hear when tuning a radio station) causing variability in the data:



Example of real data with noise (red) versus the true phenomenon (blue). The templates we’ve given you are equivalent to the blue curve. When comparing a template to actual data, you have to consider how the noise will affect the appearance of signals in the data.

3) First, consider **Data A** on page 5 of this LT.

   a) Does the data contain a gravitational wave signal? That is, do you see a pattern in the data that looks like a gravitational wave signature? **Note that not all data may contain a gravitational wave signal.**

   b) If so, identify when the collision happens.

   c) If there is a gravitational wave signal, which template (if any) matches the data? *Hint: Line up the data’s collision point with one of the templates. Do the signals match? Consider the (1) amplitude, (2) time between peaks, **and** (3) duration of the in-spiral phase.* If the template doesn’t match the data, try a different template. Is that one a good match? **Note that not all data sets may have matching templates.**

4) Next, consider **Data B** on page 5 of this LT.

   a) Does the data contain a gravitational wave signal? That is, do you see a pattern in the data that looks like a gravitational wave signature? **Note that not all data may contain a gravitational wave signal.**

   b) If so, identify when the collision happens.

   c) If there is a gravitational wave signal, which template (if any) matches the data? *Hint: Line up the data's collision point with one of the templates. Do the signals match? Consider the (1) amplitude, (2) time between peaks, **and** (3) duration of the in-spiral phase.* If the template doesn't match the data, try a different template. Is that one a good match? **Note that not all data sets may have matching templates.**

5) Finally, consider **Data C** on page 7 of this LT.

   a) Does the data contain a gravitational wave signal? That is, do you see a pattern in the data that looks like a gravitational wave signature? **Note that not all data may contain a gravitational wave signal.**

   b) If so, identify when the collision happens.

   c) If there is a gravitational wave signal, which template (if any) matches the data? H*int: Line up the data's collision point with one of the templates. Do the signals match? Consider the (1) amplitude, (2) time between peaks, **and** (3) duration of the in-spiral phase.* If the template doesn't match the data, try a different template. Is that one a good match? **Note that not all data sets may have matching templates.**

Check in with an instructor before continuing.

6) Consider the following debate between students regarding the previous question.

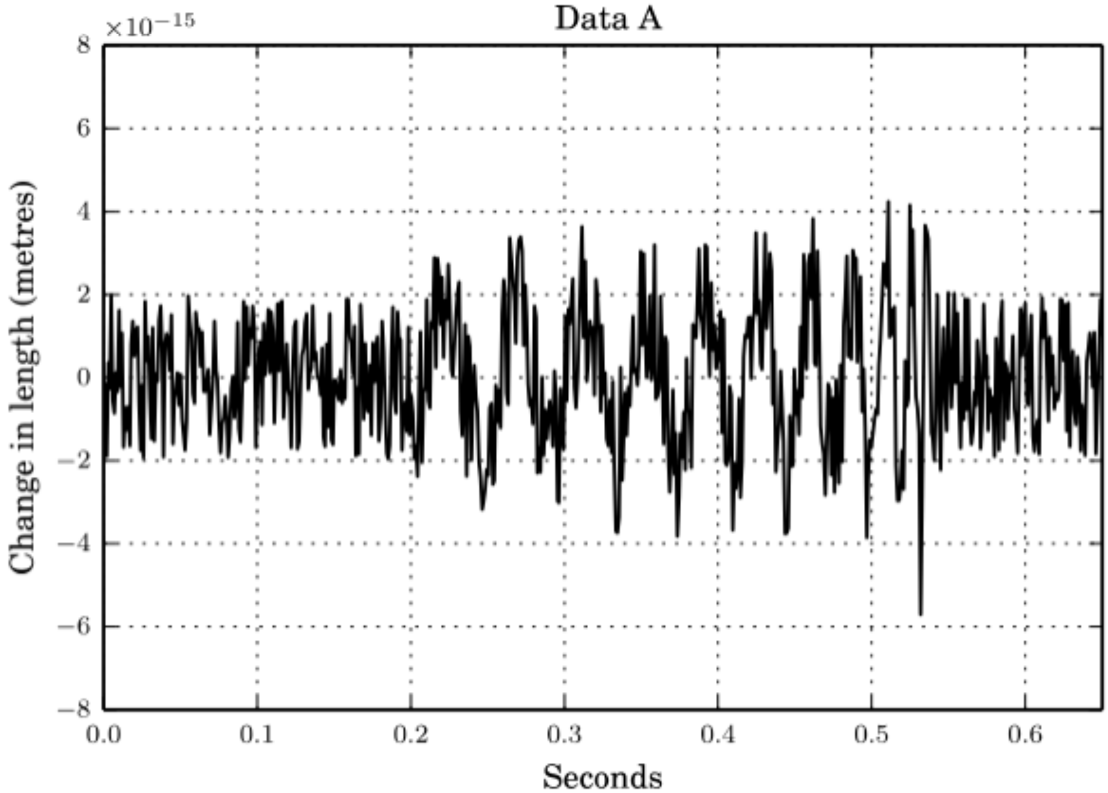
Student 1: All three datasets were just noise. They have varying levels of noise, but it's just noise.

Student 2: I disagree; two of the datasets had a gravitational wave signal in them. Data A starts off with just noise, but at 0.2 seconds, a wave pattern emerges, and it matches Template 2. For Data B, on the other hand, there's no portion of the signal where the amplitude changes or where a wave-like pattern emerges from the noise. With Data C, there's noise amongst the wave pattern, but there's a clear pattern from the beginning until the collision, and it matched Template 3.

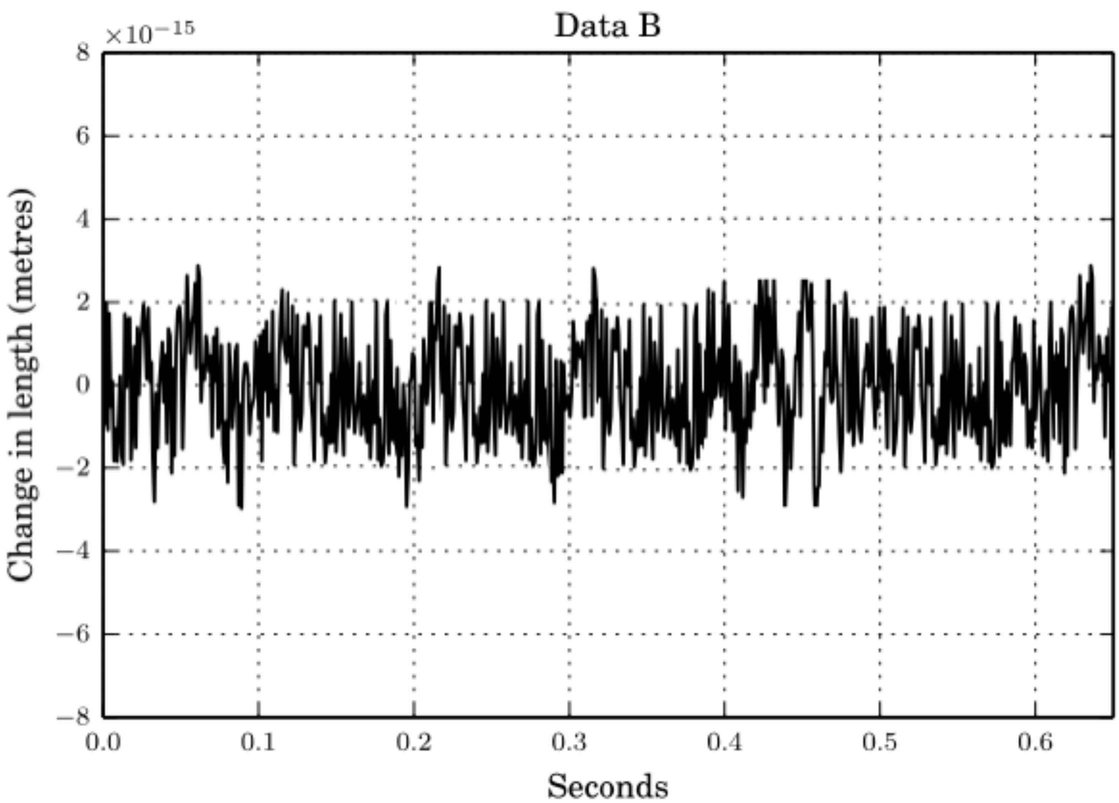
Student 3: No, Data C did not have a matching template. While Template 3 had a similar frequency as Data C, the template's amplitude was much less than the amplitude in the signal in Data C and the duration of the in-spiral phase was off. Data C must've come from a higher-mass system. I also thought both Data A and Data B had signals as well - there's a pattern of oscillation and a clear place where the amplitude grows much larger at the time of collision.

Do you agree or disagree with any of the students? State so explicitly and explain your reasoning.

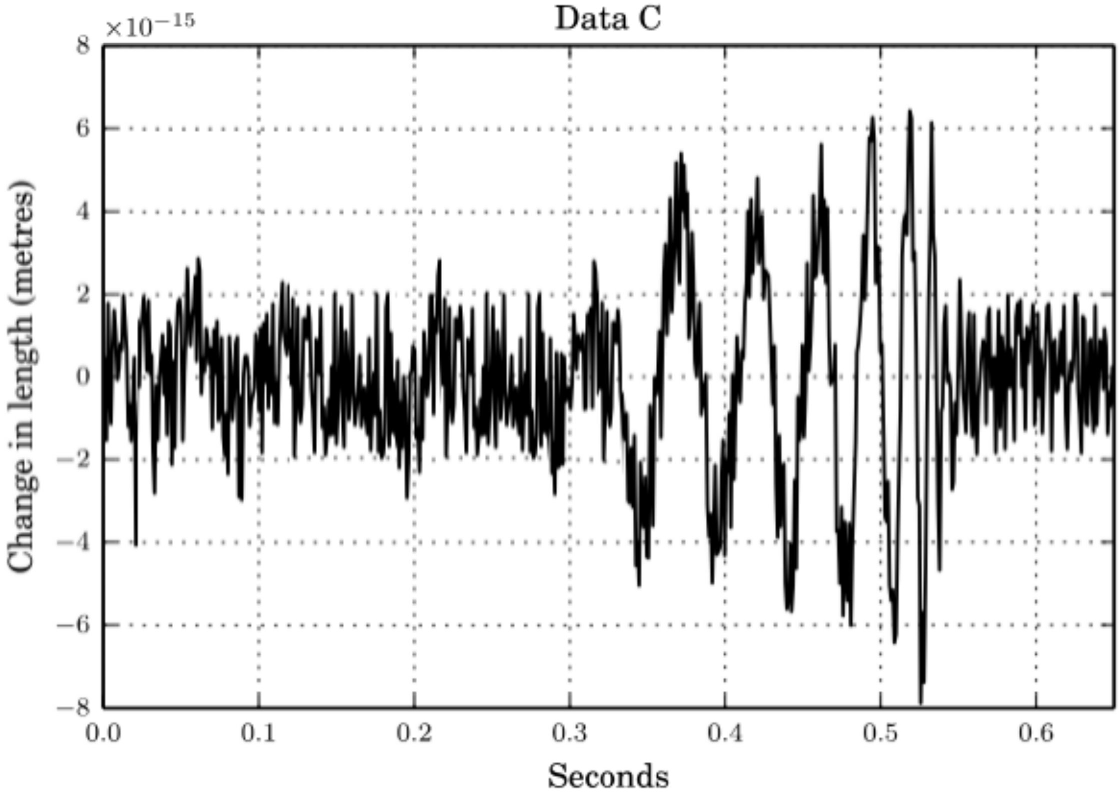
Check in with an instructor before continuing.

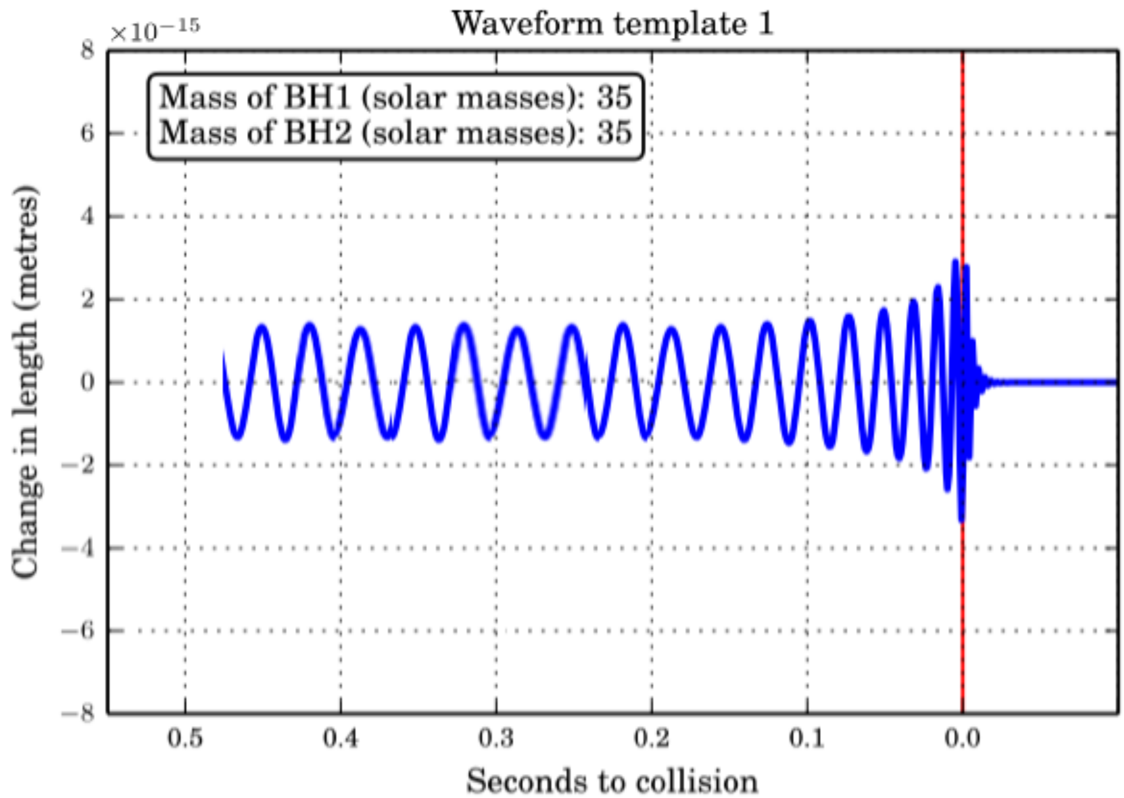


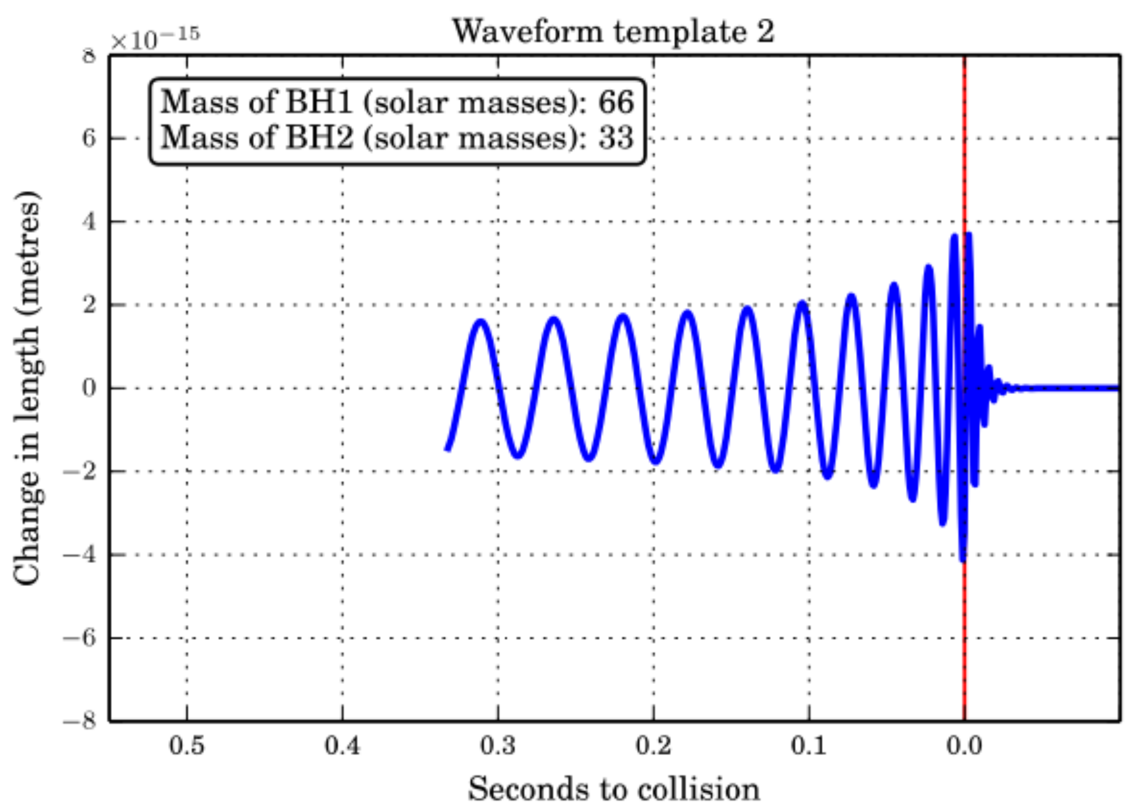
Data A
×10−15
8
6
4
2
0
−2
−4
−6
−8
Change in length (metres)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Seconds

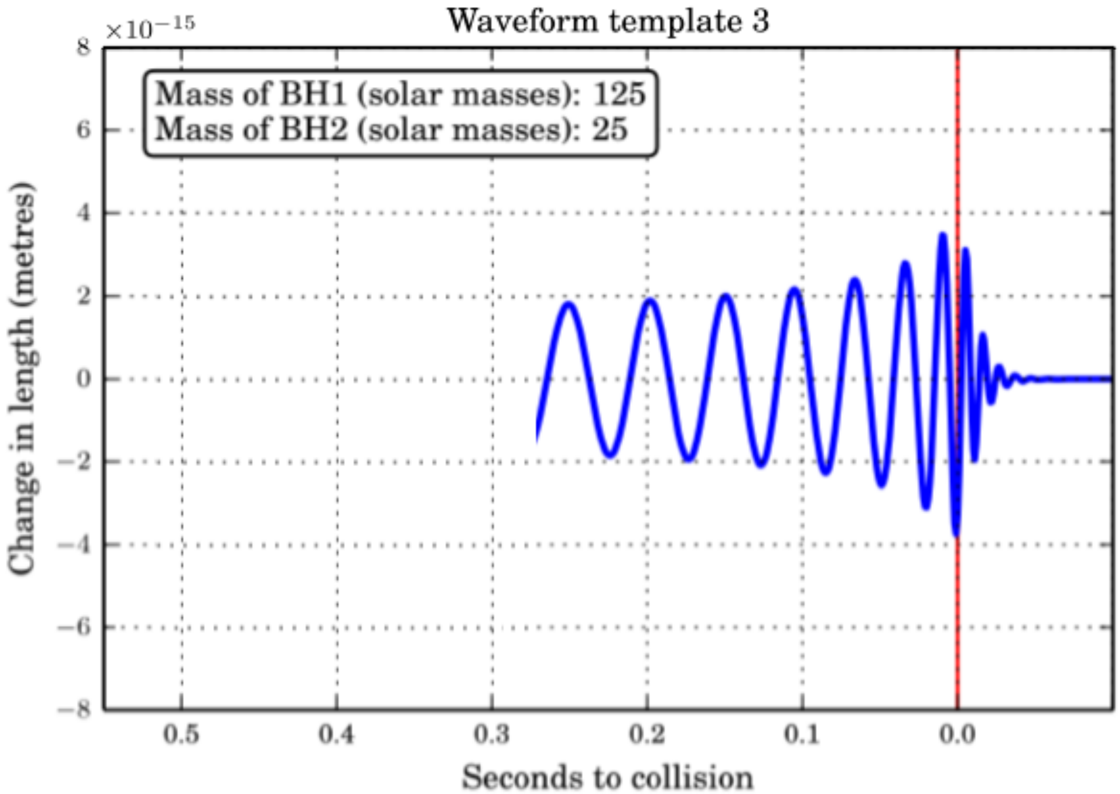


Data B
×10−15
8
6
4
2
0
−2
−4
−6
−8
Change in length (metres)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Seconds


Data C
×10^−15
8
6
4
2
0
−2
−4
−6
−8
Change in length (metres)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Seconds


Waveform template 1
×10^−15
Mass of BH1 (solar masses): 35
Mass of BH2 (solar masses): 35
Change in length (metres)
8
6
4
2
0
−2
−4
−6
−8
0.5
0.4
0.3
0.2
0.1
0.0
Seconds to collision


Waveform template 2
×10^−15
Mass of BH1 (solar masses): 66
Mass of BH2 (solar masses): 33
Change in length (metres)
8
6
4
2
0
−2
−4
−6
−8
0.5
0.4
0.3
0.2
0.1
0.0
Seconds to collision


Waveform template 3
Mass of BH1 (solar masses): 125
Mass of BH2 (solar masses): 25
Change in length (metres)
×10^-15
8
6
4
2
0
−2
−4
−6
−8
0.5
0.4
0.3
0.2
0.1
0.0
Seconds to collision