Learning Resources

Below are some resources that you can dip into before attending 'Chasing the Waves'. This will enable deeper learning by the pupils, familiarising them with some of the concepts explored in the show.

1. **Einstein's Messengers (documentary, 20 minutes)** – produced by the National Science Foundation, this provides a good introduction to gravitational waves and LIGO (20 minutes). Available online at: https://www.nsf.gov/news/mmg/mmg_disp.jsp?med_id=58443&from=vid.htm and https://www.ligo.caltech.edu/video/ligo01032005v. There are potential follow-up questions here: http://www.einsteinsmessengers.org/questions.htm

2. **Gravity Spy (online activity) –** When scientists search for gravitational waves using LIGO, they have to filter out a lot of 'noise' – these are signals *other* than gravitational waves. The detectors are so sensitive that anything from an earthquake hundreds of miles away to a train going past can produce a signal. These signals are called "glitches". In this online activity, students identify real-life glitches from LIGO data: https://www.zooniverse.org/projects/zooniverse/gravity-spy

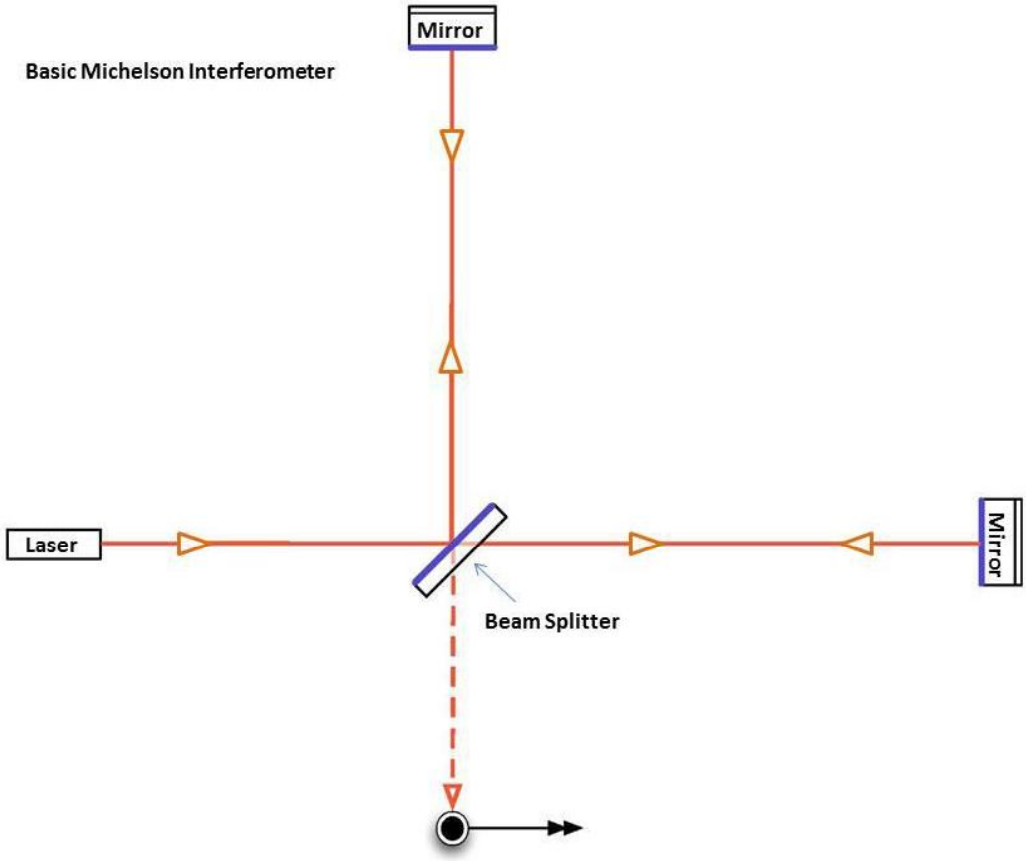
3. **Spacetime Quest (computer game) –** What would you do with a science budget of £100 million? This fun game developed by GW Optics invites pupils to build their own gravitational wave detector, making decisions about how to spend the budget on its development. What factors will affect the detector sensitivity? Can you spend the money wisely and make a detection? Available at: http://www.gwoptics.org/processing/space_time_quest/

4. **Gravitational Waves TED Talk (talk, 15 minutes) -** Professor Martin Hendry is a member of the LIGO Collaboration and the lead scientist on our 'Chasing the Waves' show. He fact-checked the script and was interviewed, to help inform the story. This is Martin's TEDx talk about gravitational waves: https://www.youtube.com/watch?v=LfYIoEifk2o

5. **Glossary –** You may find it helpful to discuss the concepts provided in the glossary with your pupils. These concepts will be explored in the live show; exposure to concepts prior to the show may help reinforce learning.

Glossary

Interferometer – An instrument which works by merging two or more sources of light to create an interference pattern, which can then be measured and analysed. Interferometers were invented in 1887 by Albert Michelson.



A **laser beam** is passed through a **'splitter'**, which splits the beam into **two identical beams**. The beams pass down the two **'arms'** of the interferometer and are **reflected back** to the splitter by **mirrors**.

The two beams then **‘merge’** back into a single beam. In ‘merging’, the beams bump into or **‘interfere’** with one another, before travelling to a photodetector, which measures the beam’s brightness.

If the two **arms** of the interferometer are exactly the **same length**, then each beam will travel exactly the **same distance**; this means that when the beam comes back after merging, it will be exactly the **same brightness** as before.

But if the two arms ***change*** **lengths**, one beam has to travel **further** than the other – meaning it takes longer to travel back and ‘merge’ with the other beam. Since the two beams arrive back at different times, the beams’ **waves** will be **slightly offset** when they merge. This means the ‘merged’ beam will be **brighter or dimmer** than it was when the arms were the same length.

In an interferometer, any change in the light intensity (higher or lower) means that something has happened to **change the length** of one of the arms. The interference pattern can be used to **calculate precisely** how much change in length has occurred.

Read more online on the LIGO website

Animation of LIGO Interferometer in action

LIGO – Laser Interferometer Gravitational-Wave Observatory. This consists of two massive gravitational wave detectors (interferometers) in the USA: one in Hanford, Washington and the other in Livingston, Louisiana. The LIGO Collaboration consists of over 1000 scientists working together to develop the detectors, observe and analyse the data.

Gravitational wave – Ripples in the fabric of space-time caused by some of the most violent events in space, from exploding stars to colliding black holes.

Black hole – An extremely dense region of space where matter has collapsed in on itself. Gravity pulls so hard in a black hole that not even light can get out. This means black holes are invisible and scientists must find other ways of detecting them that don't rely on light.

Albert Einstein – A famous German scientist who first predicted the existence of gravitational waves 100 years ago, in 1916. Einstein won a Nobel Prize in 1921. He is considered one of the most influential physicists of the 20th Century.