# Class: Black Holes: Looking Into The Void (Physics)
# Workshop 2: When Black Holes Collide

60 – 75 minutes: The Inspire Scholars Programme for Years 9, 10 & 11

**Learning Objectives (skills-based)**

Present and illustrate two features of light waves; Reflection and Interference
Construct a model of the LIGO experiment used to detect gravitational waves
Assess the use of research funding to detect properties of black holes

**Learning Points (knowledge-based)**

1. Waves have the key features: Wavelength, Amplitude and Frequency
2. Reflection is when light bounces off the surface at the same angle from which it hits it
3. When light waves are in phase they can undergo constructive or destructive interference
4. Gravity is a force that pulls things with mass towards one another.
5. Black holes have a huge mass.
6. When two black holes collide they generate gravitational waves
7. The LIGO experiment was used to detect gravitational waves in 2015
8. Research is expensive - considerations of costs and benefits must be weighed before committing to large projects such as LIGO.

**Materials required**

Online resources on computer screen and projector (with sound) are required for materials C. and E. below.

A. The Discovery booklet and pencils (**to print/bring**, 1 per student)
B. Discovery sheets: Reflection (2x) and Interference (2x)
C. YouTube video resource https://www.youtube.com/watch?v=4GbWfNHtHRg
D. Model LIGO components - one box, one 'laser', one 'detector', one transparent screen and two mirrors (2x set) & one roll of tape
E. YouTube video resource https://www.youtube.com/watch?v=mM0t10hujdY&feature=emb_err_watch_on_yt
F. Discovery sheet: LIGO cost and other things $1.1 billion could be spent on (4x)

**Video resources**

Videos (Vid-1 to Vid-5) are included in the resources for this workshop. These videos are designed as an example of the workshop being delivered. They are intended to be used flexibly to support the workshop as required. You may use all or none of these videos to help run the workshop, in the way you find most helpful.

- **Clarification**: play videos as specified when looking through this lesson plan to clarify points, demonstrate activities and see worked through answers.

- **In class**: play videos (or sections of videos) directly to the students. For example:
    - The start of a video where new ideas are introduced
    - The end of a video where solutions to particular activities are outlined.

Pause points are included to allow students to complete activities. In this lesson plan, pause points are referred to as **(pause -time- Vid-X).** The corresponding video will display a screen 'Pause here'. These points are designed to give students time to complete the corresponding activity or discussion in the lesson plan.

St John's inspire programme

**Session outline**

| Time (mins) | Activity | Key skills | Materials |
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| 10 | • Allow students 5 minutes of reading time to read **Light and the EM spectrum**, and then go through the questions below in a verbal recap. (*pause 00:39 Vid-1*)<br>• Recap this material verbally.<br>  ○ For example, ask one student to summarise each of:<br>  ○ What are the key features of a wave?<br>  ○ Visible light is one type of electromagnetic waves – name some other examples…<br>  ○ Which type of electromagnetic wave has the longest **wavelength**? | • State the key features of an electromagnetic wave | A<br>Vid-1 |
| 10-15 | • Introduce the theme of this session: **What happens when two black holes collide?**<br>• Two features of light waves are important for the experiment which measures black holes colliding – **Interference** and **Reflection**.<br>• Split the students into four groups of 2-4 students. Assign two groups 'Reflection' – hand out one Reflection discovery sheet to each group. Assign two groups 'Interference – hand out one Interference discovery sheet to each group.<br>• Students should read their discovery sheet, and work as a group to develop a 3 minute way to explain their topic to other students. They should use the space in their Discovery Booklets to design a **diagram,** which aids in their topic explanation. (*pause 01:08 Vid-2*) | • Explain one key feature of light waves which helped scientists detect black holes colliding.<br>• Design a diagram to explain a scientific concept | A,B<br>Vid-2 |
| 10 | • Pair up each Reflection group with one Interference group. Reflection groups should explain their topic for 3 minutes, using their diagrams. Afterwards, the Interference group should do the same. (*pause 01:43 Vid-2*)<br>• Listen to both sets of groups, to confirm that all students have an understanding of both Reflection and Interference. (*A summary of both concepts is provided at 01:54 Vid-2 – this is not intended to be played to students*)<br>• Student who are listening to an explanation have a space in their Discovery Booklet to include a definition of the other property to the one they studied. | • Present one key feature of light waves to other students.<br>• Understand Reflection and Interference in light waves. | A,B<br>Vid-2 |
| 5 | • Explain that students will now apply what they have learnt about light waves to understand the experiment that detected two black holes colliding. | • Define gravity as a force | A<br>Vid-3 |

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| | • Remind students that black holes result from very large stars when they collapse. They have an incredibly strong **gravitational field** that not even light can escape from.<br>• Ask students what they know about **gravity** or **gravitational fields** already – possible answers may include 'it is a force' 'it pulls us towards the Earth' 'It keeps us in orbit'.<br>• **Gravity** is a force that pulls anything with mass towards one another. We experience the **gravity** that pulls us towards Earth as our **weight**. | | |
| 15 | • However, there is another way to think of gravity: Einstein predicted in his **Theory of general relativity** that gravity is a distortion in space-time, caused by massive objects.<br>• Watch the video introducing **gravitational waves** (0:00 – 3:05). https://www.youtube.com/watch?v=4GbWfNHtHRg<br>• Although **gravitational waves** were proposed in the late 1800s-early 1900s, they were only directly measured in 2015 by a piece of equipment called LIGO (Laser Interferometer Gravitational-Wave Observatory).<br>• Students have a brief introduction to the LIGO equipment in the video above. However, the details are not gone into.<br>• Students should work in their two groups from earlier (each made of one 'Reflection' group and one 'Interference' group).<br>• Each group of students should receive one box, one 'laser', one 'detector', one transparent screen and two mirrors. Then should place the equipment into the box to create their own LIGO model, based on what they have seen and their understanding of interference and reflection. The 'laser' model does not fire a laser beam, therefore students should draw on the 'laser beams' to illustrate how their model works.<br>• *Vid-4 shows an example of a model students may build – this video is not intended to be played to students.* | • Discuss how gravity impacts on space-time<br>• Assemble a model of LIGO | A, C, D<br>*Vid-4* |
| 5-10 | • Each student group should briefly explain how their model LIGO would measure gravitational waves.<br>• Watch the video on the LIGO detector (0:00 – 1:25). https://www.youtube.com/watch?v=mM0t10hujdY&feature=emb_err_watch_on_yt<br>• Students should compare their models to the LIGO video explanation, and modify them if necessary. | • Identify key components of the LIGO detector | D, E |
| 10+ | • It cost approximately $1.1 billion to build LIGO.<br>• Since LIGO detected the first gravitational wave, scientists have also been able to use gravitational | • Weigh the cost of the LIGO project against other | F |

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| | waves to 'see' new things in space (similarly to using light or radio waves to see).<br>• LIGO has been hailed as starting a 'new era', as it allows us to understand new things about our universe – we cannot know all of the possible advantages just yet, but an immediate one is to start to identify other black holes that surround our Earth. This will be important as our ability to travel in space increases!<br>• Provide students with the Cost of LIGO Discovery sheet, which lists other things $1.1 billion might be spent on.<br>• Discuss as a group the use of money on scientific research and specifically on LIGO – what are the pros and the cons?<br>• *This activity can take as little or much time as you have available in the session.* | applications of $1.1 billion. | |
| *0* | • *Further work (for at home) – Students have a Recap summarising some key information this workshop.*<br>• *The Further Thoughts page reminds/tells students that Radio waves were used to image the black hole. Students should watch the YouTube video about the SKA project.* https://www.youtube.com/watch?v=uIC4w5Dk2ZM *The SKA project cost just over half the price of LIGO. Building on the discussion they had in class, students should assess whether the SKA project (looking for SETI) is a better or poorer use of research funding than the LIGO project (in their opinion).* | • *Evaluate which recent black hole project the student believes was the better use of research funding* | A Vid-5 (YouTube – link in student booklet) |

**Syllabus links to national curriculum (KS3)**

***Syllabus correct from following sources, 15th November 2019.***
*https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/335174/SECONDARY_national_curriculum_-_Science_220714.pdf*

**Physics**
**Light waves**

- the transmission of light through materials: […] specular reflection at a surface
- use of ray models to explain imaging in mirrors, […]

**Space Physics**

- our Sun as a star, other stars in our galaxy, other galaxies
- gravity force, […], different on other planets and stars; gravity forces between Earth and Moon, […] (qualitative only)

**Syllabus links to national curriculum (KS4)**

***Syllabus correct from following sources, 15th November 2019.***
*https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/800342/GCSE_single_science_updated_May_2019.pdf*

**Physics**
**Waves matter**
***Waves in air, fluids and solids***

- describe wave motion in terms of amplitude, wavelength, frequency and period; define wavelength and frequency […]

**Light and electromagnetic waves**
***Frequency range of the spectrum***

- recall that light is an electromagnetic wave
- describe the main groupings of the spectrum – radio, microwave, infra-red, visible (red to violet), ultra-violet, X-rays and gamma-rays, that these range from long to short wavelengths and from low to high frequencies, and that our eyes can only detect a limited range.

***Lenses***

- use ray diagrams to illustrate reflection […].

***Use of mathematics***

- construct two-dimensional ray diagrams to illustrate reflection […] (qualitative -equations not needed) (5a, 5b)

**Space physics**
***Solar system; stability of orbital motions; satellites***

- recall the main features of our solar system, including the similarities and distinctions between the planets, their moons […]

**Equations in physics**

- gravity force = mass x gravity constant (g)

**Syllabus links to national curriculum (KS5)**

Although the aim is not to teach KS5 material, introducing students considering science A-levels to KS5 material, where relevant, will help them when they come to learn these topics.

***Syllabus correct from following sources, 15th November 2019.***
*https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/593849/Science_AS_and_level_formatted.pdf*

**Physics – knowledge and understanding**

- path difference, phase and coherence, interference