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Water Based Space-Time Model Depicting Gravitational Lensing

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ABSTRACT: Space is enormous and observing the astronomical phenomena in outer space is not easy. Gravitational lensing is a phenomenon where the bending of space-time deviates the light passing nearby from its original path. Thereby, it is hypothesized, that one may use a water-based model that mimics this extravagant phenomenon. A layer of water on a smooth surface with a hydrophobic region mimics the way the light bends around a black hole. Here, the water layer is equivalent to the space-time consortium and the hydrophobic region is equivalent to the event horizon. Based on the model proposed here, it can be concluded that the size or length of the virtual image is directly proportional to the size of the black hole in the 'not aligned' case and inversely proportional to the 'aligned' case. As the study progressed, it was noticed that the virtual image formed at different positions also followed the pattern of magnetic field lines around a bar magnet. The proposed model makes visualization of the space-time consortium concept easier in that it captures the 'event horizon' and 'ergosphere' while it derives its proof from the phenomenon of gravitational lensing (Figure 1).

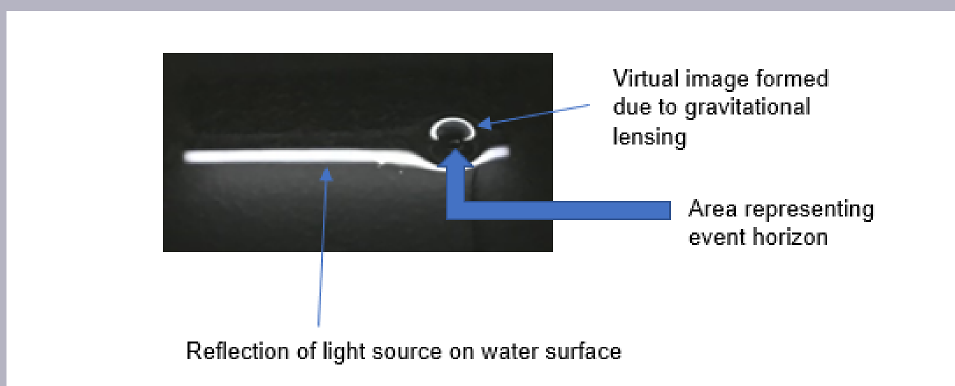

Figure 1: The image of the non-aligned situation of the proposed model is discussed in detail in the results and discussion section.

KEYWORDS: Physics; Astrophysics; Gravitational lensing; Space-time consortium; Event horizon; Ergosphere.

Introduction

The famous physicist Albert Einstein helped develop the idea of space-time as part of his theory of relativity.[1] When people talk about space-time, they often describe it as resembling a sheet of rubber. This, too, comes from Einstein, who realized as he developed his theory of general relativity that the force of gravity was due to curves in the fabric of space-time. Objects like the Earth, the Sun, and other massive celestial bodies create distortions in space-time that cause it to bend. These curves, in turn, constrict the ways in which everything in the universe moves, because objects must follow paths along this warped curvature. Motion due to gravity is actually motion along the twists and turns of space-time.[2]

As the light emitted by distant galaxies passes by massive objects in the universe, the gravitational pull from these objects can distort or bend the light (Figure 2). This is called 'gravitational lensing'. Strong gravitational lensing can actually result in such strongly bent light that multiple images of the light-emitting galaxy are formed. Weak gravitational lensing results in galaxies appearing distorted, stretched, or magnified. Although difficult to measure for an individual galaxy, galaxies clustered close together will exhibit similar lensing patterns.[3]

Analyzing the nature of gravitational lensing patterns tells astronomers about the way dark matter is distributed within galaxies and their distance from Earth. This method provides a probe for investigating both the development of structure in the universe and the expansion of the universe. It is apparently impossible to visualize the phenomenon of gravitational lensing or bending of light in the vast universe.[4-7]

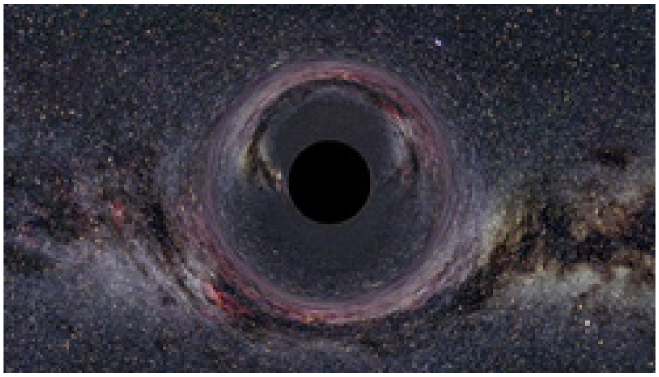

Figure 2: An image depicting similarity with the proposed model. (A simulated black hole of ten solar masses as seen from a distance of 600 km with the Milky Way in the background). Courtesy: https://theconversation.com/explainer-black-holes-7431.

Method

A thin layer of water on a smooth surface (bathroom tile in this study) with a small dried circular region is created either by dropping a soapy solution (due to surface tension) or sweeping a part of the water layer with a soft hand. The hydrophobic area (HA) thus created is equivalent to the 'event horizon', which when hit by the reflection of the light source mimics the phenomena of gravitational lensing. The circular area around HA is the ergosphere equivalent. Figure 3 represents the cross-sectional view of the model depicting space-time curvature around the black hole and Figure 4 shows the correlation with the proposed model.

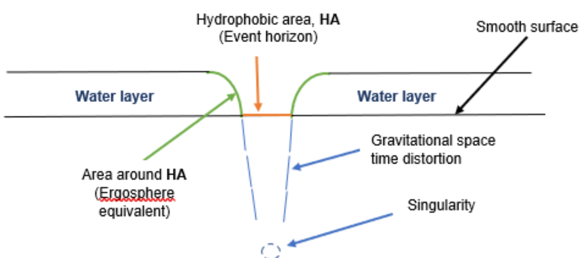

Figure 3: Cross sectional view of the model.

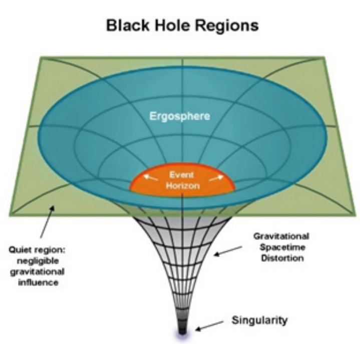

Figure 4: Defining the regions of black hole. Courtesy: https://qph.fs.quoracdn.net/main-qimg-f5e156aa5952733ce726a1f8db60c807-c

The light source used in the experiment is a standard 10W, 240V/50 Hz LED and 54 cm in length and is at a height of 215 cm.

The distance from the base of the wall on which the light source is fixed to the center of the tile on which the experiment is set up is 46 cm (Figure 5). The dimensions mentioned here are not limited to conducting this experiment.

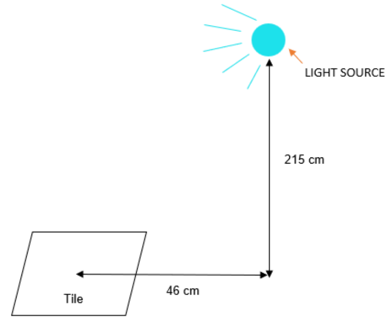

Figure 5: Sketch showing the experimental setup

The observer must position themself in such a way that the circumference of the ergosphere (Figure 4) is just on the tip of the reflected light source and just starts to distort the shape of the reflected light source as in Figure 6a. The length of the virtual image formed opposite to the reflected light source was measured and the observation was recorded. The above-mentioned procedure is good to study the aligned case, however, the observer can position themselves based on the case interested in (not aligned case as in Figure 7a or overlapping the reflected light source case as in Figure 8a).

To prove that the unique effects observed in the case of heavier bodies are different from that of the lighter objects, another experiment was conducted by replacing the hydrophobic area with a lighter object (LO) like a tiny ball of fiber heavy enough to keep a depression on the water layer (Figure 9a). The observer must position themself in the same way as mentioned above to experience the difference.

To experience the resemblance between the virtual image and the magnetic field lines, an experiment was conducted with a colored tip of the reflected light source wherein the bending of the virtual image is following the same pattern as observed in the case of a magnetic field around a bar magnet (Figure 14 a-g).

Results and Discussion

As previously known, due to the presence of massive celestial objects, the light deviates from its path. Einstein proposed the space-time consortium to visualize this effect in which space is imagined as it is placed on a piece of fabric. The curving of space-time depends on the mass of the object.

The different situations this proposed model correlates with are as follows:

A) Virtual image opposite to the reflected light source (in case of heavier celestial objects)

1. Hydrophobic area aligned with the reflected light source
2. Hydrophobic area not aligned with the reflected light source
3. Hydrophobic area overlapping the reflected light source

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B) Virtual image not opposite to the reflected light source (in case of lighter celestial objects

2. Lighter object (dirt particle in this experiment) not aligned with the reflected light source

3. Lighter object (dirt particle in this experiment) overlapping the reflected light source

A1: Hydrophobic area aligned with the reflected light source:

When the hydrophobic area of the model is aligned with the reflected light source then a virtual image is observed opposite to the reflected light (Figure 6a), also depicted diagrammatically in Figure 6b.

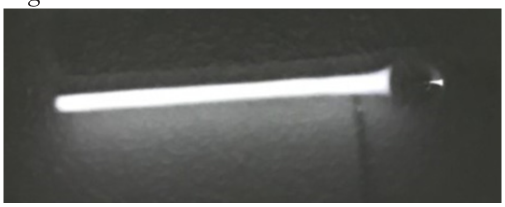

Figure 6a.

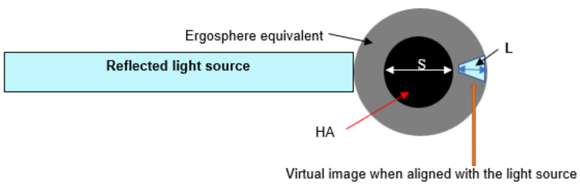

Figure 6b: Diagrammatic representation of Figure 6a.

It is observed that the length of the virtual image (L) is inversely proportional to the size of the HA (S) as mentioned in Table 1.

Length = L

Size = S

L α 1/S

A2: Hydrophobic area not aligned with the reflected light source:

In case the reflected light source is not aligned, then the virtual image is observed as a curved line opposite to the reflected light source (Figures 7a and 7b).

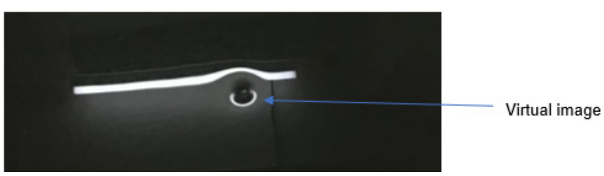

Figure 7a.

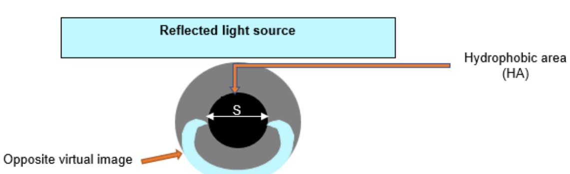

Figure 7b: Diagrammatic representation of Figure 7a.

It is observed that the length of an arc of the virtual image is directly proportional to the size of the hydrophobic area (S).

A3: Hydrophobic area overlapping the reflected light source:

If the HA appears to overlap the reflected light source, then the light around the HA shows a combination of effects arising from both the aligned and not-aligned situations on either side (Figures 8a and 8b).

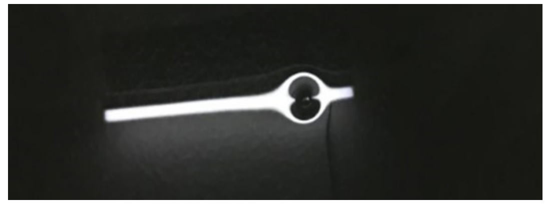

Figure 8a.

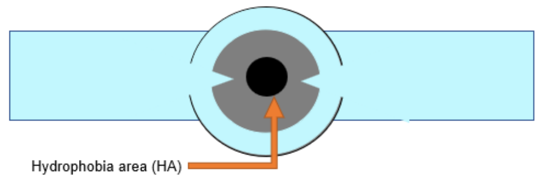

Figure 8b: Diagrammatic representation of Figure 8a.

B1: Lighter object (dirt particle in this experiment) aligned with the reflected light source:

It was observed that the virtual image of the reflected light source is on the same side of the light source (Figures 9a and 9b) in the aligned case.

Figure 9a.

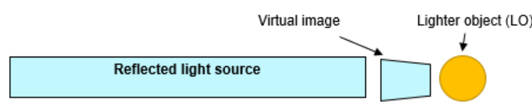

Figure 9b: Diagrammatic representation of Figure 9a.

B2: Lighter object (dirt particle in this experiment) not aligned with the reflected light source:

It was observed that the virtual image of the reflected light source is on the same side of the light source (Figures 10a and 10b) in the not aligned case.

Figure 10a.

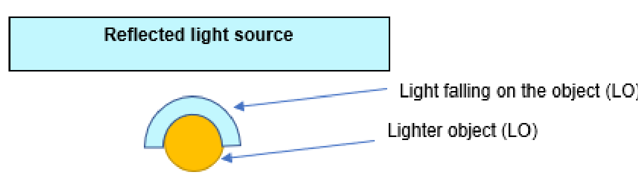

Figure 10b: Diagrammatic representation of Figure 10a.

B3: Lighter object (dirt particle in this experiment) overlapping the reflected light source:

In case the lighter object overlaps the reflected light source based on our view, the object blocks the source of light, and it appears that the light source is broken into two parts (Figures 11a and 11b).

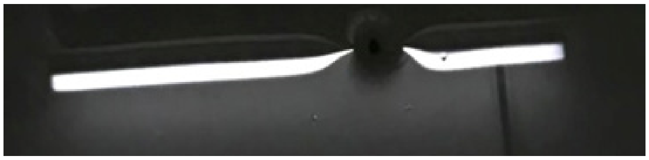

Figure 11a.

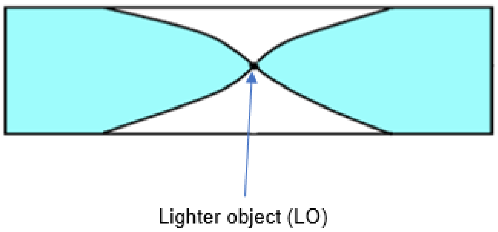

Figure 11b: Diagrammatic representation of Figure 11a.

Virtual image and its resemblance with magnetic field lines:

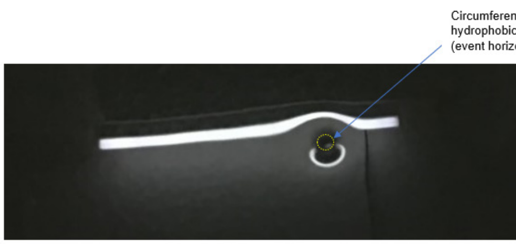

Figure 12.

As observed in Figure 12, the curve of the virtual image resembles the shape of the magnetic field lines around a bar magnet (Figure 13).

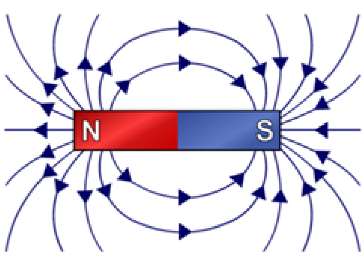

Figure 13.

Figure 14 depicts the pattern observed with the colored tip experiment with different viewing angles and shows the resemblance with the magnetic field lines. .

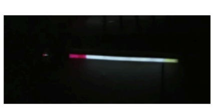

Figure 14a.

Figure 14b.

Figure 14c.

Figure 14d.

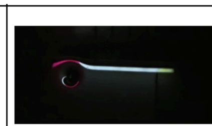

Figure 14e.

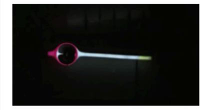

Figure 14f.

Figure 14g.

Figure 14 (a-g).

Data Figures:

The data shown in Table 1 and the graphical representation (Figure 15) show the relationship between the size of the HA (event horizon) and the length of the virtual image in case of reflected light in the aligned case. As predicted, the virtual image is inversely proportional to the diameter of HA.

Table 1: Data presenting the Relationship between the size of the HA and the length of the virtual image in case of reflected light in an aligned case.

Entry	Diameter of Hydrophobic Area (mm)	Error for HA diameter (± mm)	Relative error in diameter	Length of virtual image (mm)	Error for virtual image (± mm)	Relative error in virtual image	Relative error of diameter and virtual image	Ratio (image /width)	Error in ratio
1	0.6	0.1	0.17	4.0	0.1	0.03	0.19	6.67	1.28
2	0.8	0.1	0.13	3.9	0.1	0.03	0.15	4.88	0.74
3	1.0	0.1	0.10	4.0	0.1	0.03	0.13	4.00	0.50
4	1.0	0.1	0.10	3.8	0.1	0.03	0.13	3.80	0.48
5	1.0	0.1	0.10	3.7	0.1	0.03	0.13	3.70	0.47
6	2.0	0.1	0.05	3.5	0.1	0.03	0.08	1.75	0.14
7	2.0	0.1	0.05	3.2	0.1	0.03	0.08	1.60	0.13
8	2.1	0.1	0.05	3.9	0.1	0.03	0.07	1.86	0.14
9	2.5	0.1	0.04	3.6	0.1	0.03	0.07	1.44	0.10
10	3.5	0.1	0.03	3.5	0.1	0.03	0.06	1.00	0.06
11	4.5	0.1	0.02	3.1	0.1	0.03	0.05	0.69	0.04
12	4.8	0.1	0.02	3.0	0.1	0.03	0.05	0.63	0.03
13	5.0	0.1	0.02	2.9	0.1	0.03	0.05	0.58	0.03
14	6.0	0.1	0.02	3.0	0.1	0.03	0.05	0.50	0.03
15	7.0	0.1	0.01	2.8	0.1	0.04	0.05	0.40	0.02
16	7.9	0.1	0.01	2.1	0.1	0.05	0.06	0.27	0.02
17	8.9	0.1	0.01	2.6	0.1	0.04	0.05	0.29	0.01
18	10.0	0.1	0.01	2.0	0.1	0.05	0.06	0.20	0.01
19	11.0	0.1	0.01	2.2	0.1	0.05	0.05	0.20	0.01

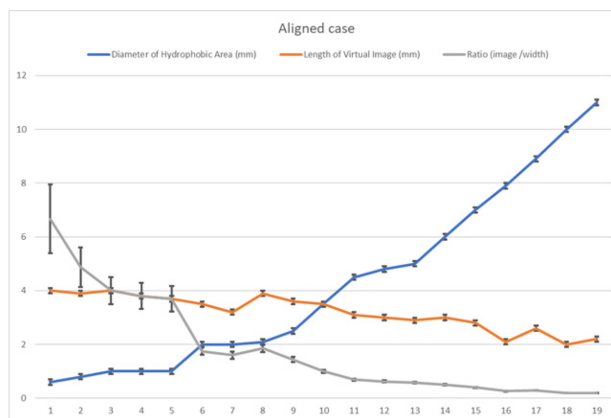

Figure 15: Graphical representation of the relationship of the size of the HA and the length of the virtual image in case of reflected light in aligned case.

Conclusion

The proposed model has a similarity with the space-time fabric model with the upper layer of water mimicking the fabric due to the phenomenon of surface tension. The model can help beginners interested in astrophysics and astronomy to study the concept of 'gravitational lensing'. The observations made in this study are in line with the animated simulation of gravitational lensing caused by a black hole going past a background galaxy.[8] Of the various possibilities, when a hydrophobic area **(HA)** mimicking the event horizon is aligned with the light source then the virtual image is observed op

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posite to the **HA**. The length of the virtual image formed opposite to the **HA** is inversely proportional to the size of the **HA**. When the **HA** is not aligned with the light source then an arc is observed opposite to it (Figure 7a) and in this case, the length of an arc is directly proportional to the size of the hydrophobic area.

The colored film experiment further shows that the virtual image of light is formed opposite to the light source (Figure 14). In the case of the lighter object **(LO)**, the virtual image of the reflection of light is on the same side of the light source (Figures 9a and Figure 10a). In case the **HA** is overlapping the reflected light source, it shows the combination of effects arising from both the aligned and not aligned cases (Figure 8a), whereas in the case of lighter objects **(LO)**, the reflected light is blocked (Figure 11a). It is also observed that the pattern of virtual images corresponds to the magnetic field lines of the bar magnet and hence hypothesizing it to be having some sort of relationship.

■ Acknowledgements

I thank my brother Kunal Srivastava for his constant support and for helping me in setting up the experiments. Due credit goes to my entire family for necessary guidance and constant motivation. Special thanks to my mother Hridaya Jyoti Srivastava and father Anil Srivastava who helped me in putting together this manuscript and identifying the gaps during my study towards this experiment.

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■ Author

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He loves playing and watching soccer and tennis and his favorite pastime is cubing (Rubik's cube).