WHY IS THE SKY DARK AT NIGHT?

Olbers' Paradox and its Resolutions

Kayleigh Gallagher[1] and James Overduin[2]

[1]North Harford High School, Maryland

[2]Towson University, Maryland

The Paradox

Named after the German astronomer H.W.M. Olbers, the paradox questions why the night sky is dark. In a universe filled with infinite stars and galaxies, every line of sight should end at a galaxy and therefore the sky should be filled with light [1,2]. Imagine standing in the middle of an infinite forest. Every line of sight will eventually end at a tree (Fig. 1). Although the light from individual galaxies becomes dimmer with distance, there are so many *more* galaxies as we look to greater distances that their combined light should fill the sky in every direction. All logic tells us that the night sky should be bright. So how come it is not?

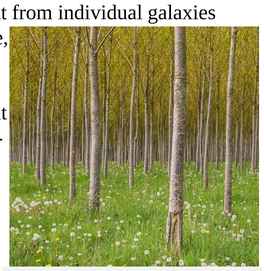


Fig. 1: in a large forest, every line of sight ends on a tree.

Historical Resolutions

1. Distance

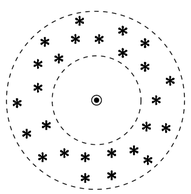
Thomas Digges, in 1576, was the first to write about the problem of the dark sky in an unbounded universe with infinite stars. However, his explanation was less of a resolution, and more of a start to understanding the problem. He reasoned that stars farther away from us appear dimmer until we eventually cannot see them at all. This idea would later re-appear in more sophisticated form in the tired-light theories of the twentieth century.

2. Island Universe

Johannes Kepler rediscovered the problem in 1610. His solution was that the universe must be finite, not infinite (Fig. 2). The many new stars discovered by Galileo must be fainter than the Sun. This continued to be an accepted resolution until the 1920s, when it finally became obvious that there were galaxies outside the Milky Way.

3. Tired Light

This idea was first explored by Rene Descartes, and applied to the paradox by Nicolaas Hartsoeker. Starlight might diminish and become "tired" on its way to us, so by the time it reaches Earth it has disappeared (Fig. 3). This idea was later revived by 20th century physicists seeking to explain galaxy redshifts without cosmic expansion.



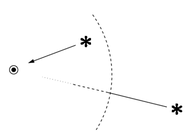


Fig. 2 (left): Kepler's island universe.
Fig. 3 (right): The tired-light hypothesis.

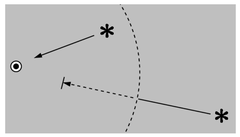


Fig. 4: light from distant sources absorbed in an intergalactic medium composed of gas and/or dust.

4. Absorption

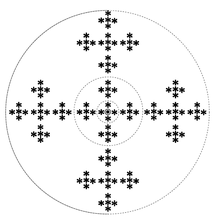
Jean-Philippe Loys de Chéseax wrote about this solution in 1744. He thought the power of light may decrease faster than the inverse square of distance if space consists of a fluid that is able to intercept a small amount of light. Olbers picked up on this theory in 1823. He believed that space is unlikely to be completely transparent and there must be a medium in space that absorbs light (Fig. 4). This theory fails as a resolution because the medium would heat up and, due to conservation of energy, end up glowing just as brightly as the light it absorbed. However, this could still be part of the answer, if the medium were to glow at wavelengths outside the optical range.

5. Fractal Distribution

In 1848, Herschel described his fractal universe theory. This theory described a universe that is organized in a fractal manner. Stars are organized into galaxies, galaxies into clusters, and so on, forever. This universe could explain a dark sky. Depending on the shape of the distribution. you could have an infinite universe where many lines of direction see only darkness (Fig. 5). While valid in principle, there is currently little interest in this solution because the universe appears to be almost perfectly isotropic (the same in all directions) on large scales.

6. Curved Space

A very interesting solution to the paradox was proposed by J.K.F. Zöllner in 1872. He proposed that all three dimensions of space are curved, so all parallel lines will eventually meet (Fig. 6). Zöllner said that space is unbounded yet finite, so there is a limited amount of light sources. This explanation fails in practice because light rays would be deflected by gravity and eventually reach us from every direction. However, it is amazing that by trying to explain the dark night sky, Zöllner anticipated Einstein's curved-space theory of general relativity by 43 years!



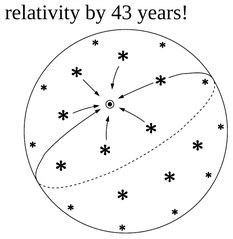


Fig. 5 (left): A fractal distribution with empty lines of sight.
Fig. 6 (right): Zöllner's model of a finite and spatially curved universe.

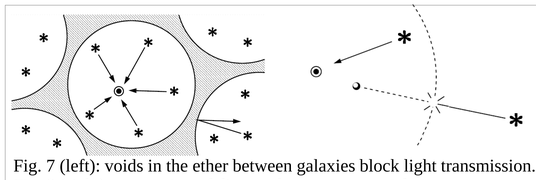


Fig. 7 (left): voids in the ether between galaxies block light transmission.
Fig. 8 (right): conversion of distant photons into particles en route to us.

7. Ether Voids

In 1878, S. Newcomb presented his new solution to the problem. He believed that the luminous ether was not smoothly distributed throughout the universe, but rather split up by ether voids. These voids would act as a boundary that light would not be able to travel through (Fig. 7). J.E. Gore further suggested that the Milky Way may be completely surrounded by such a void. But this idea fails because light from inside the galaxy would still "bounce off" the void and eventually fill the entire sky with light.

8. Light to Matter

Another attempt to explain the night sky was made by W. MacMillan in 1918. He proposed that the light from distant stars is converted into matter on its way to us to conserve energy, and that the opposite process occurs as well (Fig 8). In fact, such processes are now recognized to occur all the time in modern particle physics, but they do not affect the overall brightness of the sky.

Modern Resolutions

9. Finite Age/Energy

Since light has a finite speed, any light that we can see on Earth must have been emitted in the far past. In his 1848 prose poem *Eureka*, Edgar Allan Poe connected this information to the paradox by figuring that some stars must be so far away that their light has not reached us yet (Fig. 9). This was taken up by Johann Mädler, who also noted that the darkness of the night sky could be explained by combining finite light speed with a finite age. If the universe (or the stars in it) are young, then the sky simply has not had time to fill up with light. Stars also have finite energy and, as emphasized by Kelvin, there is not enough energy in starlight to light up the whole sky. Harrison expanded on this resolution by calculating that stars only convert around 0.1% of their mass into light. Even if they did convert all of their rest mass into light, it would only be about as bright as moonlight as seen on Earth.

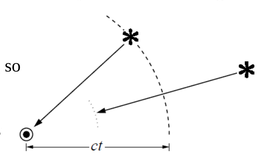


Fig. 9: Light has a finite speed c, so there is an imaginary horizon around us at a distance $d = ct$, beyond which light from sources has not had time to reach us.

Fig. 10: the authors holding copies of *Eureka* during a visit to the Edgar Allan Poe house in Baltimore (July 5, 2018)

It is truly remarkable that the true reason why the sky is dark at night was first comprehended, not by a scientist, but by a poet (Fig. 10). In Poe's own words:

> *"Were the succession of stars endless, then the background of the sky would present us a uniform luminosity, like that displayed by the Galaxy-since there could be absolutely no point, in all that background, at which would not exist a star.*
>
> *The only mode, therefore, in which, under such a state of affairs, we could comprehend the voids which our telescopes find in innumerable directions, would be by supposing the distance of the invisible background so immense that no ray from it has yet been able to reach us at all."*

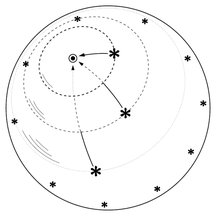


Fig. 11: expansion stretches and dims the light from distant galaxies

10. Expansion

A last resolution to the paradox came from H. Bondi, T. Gold, and F. Hoyle in 1948. They believed that the universe looks the same at all times, as well as all places (the "steady state" theory). Space expands continuously, stretching the wavelengths of starlight and spacing photons further apart (Fig. 11). Both effects reduce the intensity of the light we receive from distant galaxies, darkening the night sky The steady-state theory was disproved, but expansion is still accepted as part of the resolution to Olbers' paradox within the big bang theory, where it reduces the brightness of the night sky by about 40%.

Acknowledgments

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References

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[2] J.M. Overduin & P.S. Wesson, *The Light/Dark Universe* (Singapore: World Scientific, 2008)