Olbers' Paradox

Introduction

During a warm summer night last January, two couples of friends, my wife and I were having a great time while dining out in the open at the pavement of an enjoyable little downtown restaurant. Suddenly, at the final coffees, all lights were off. An unusual complete blackout had occurred.

Having realized that the best thing to do was just waiting for the lights to come back (instead of *"rapidly disappearing"*, like someone actually suggested) the amicable chat resumed under a complete darkness. Gradually, a myriad of stars began to materialize above our dark-adapted eyes, while a voluptuous Milky Way unquestionably assumed the leading role of such great spectacle. Less than ten minutes later everyone had become completely engrossed by the marvellous scene over our heads.

Knowing my great fondness for astronomy, all kind of questions were immediately shot over me, mostly the usual trivial ones. My ego was being nicely fed. Suddenly all the fun ended up, not by lights coming back but for a damned unexpected question: *"Please, tell me, if there are almost infinite suns as you say, doesn't the night have to be pretty much lighted?"*

Apparently simple and naive, my friends had posed a very hard question. Were the Universe filled with infinitely many stars for an also infinite time, it sounded reasonable that no night could exist, as heavens would be bright enough per se even though the Sun were below the horizon. I had not the slightest idea about the proper answer. A long silence followed up. I still vividly remember my next words: *"Waiter, please, the check!"*

Olbers' paradox

The question about the night's darkness involves not only a difficult topic by itself, but a truly essential one, as it is intimately connected with the structure and evolution of the universe as a whole. Assuming an infinite old universe with stars scattered more or less randomly throughout infinite space -the usual model since the end of medieval times- the night sky should not be dark as it obviously has ever been.

This evident contradiction between theory and reality became generically known as "Olbers' paradox", after the German amateur astronomer who wrote about it in 1823. Being his own explanation neither the first, nor the last, and even wrong, Heinrich Olbers' objective merits look quite disproportionate for such a tribute, thus seeming like the scientific community actually got two paradoxes for the price of one.

Under clear skies, the starry night appears wearing its very best party dress. Having the chance to ever observe it, urban citizens usually get immediately captured by its majestic beauty and begin wondering about its endless mysteries. Any kind of deep questions could consequently arise …

Newton thought that the universe had to be a static, infinitely old, unlimited expanse of stars homogeneously distributed. This model effectively resolved the otherwise problematic appearance of a privilege centre of gravity -in a non homogenous universe large gravitational forces would not be compensated at all[1]- but failed to solve the riddle of the sky darkness (which consequently became posed).

We now know that space and time are no longer independent entities as previously thought, but integrate a single reality called spacetime. According to Einstein's Theory of General Relativity, spacetime has the property to grip mass, telling it how to move, while at the same time mass grips spacetime, telling it how to curve. The geometry and history of our universe are currently described firmly buttressed on those foundations.

[1] Sometimes referred to as the "gravity paradox", it directly resulted from considering that the attraction between different parts of a finite universe would cause, in Newton' own words, *"to fall down into the middle of the whole space, and there compose one great spherical mass"*.

By joining together theoretical solutions derived from General Relativity, with practical compelling evidence obtained from our best observational instruments, most cosmologists agree that our universe (that is, all the space, matter, time, and energy) was "created" in a singular episode called the Big Bang, some 13.7 billion years ago, and it has been expanding ever since.

Regarding this widely accepted model, Olbers' paradox has now become resolved. However, the long and winding road actually travelled towards its definite solution is still worthy to be known, not only for being very instructive by itself, but at least as a deserved tribute to all other unreferrenced road-makers.

Analysis of the proposed solutions

Since first serious attempts to explain the cause of the night darkness, elaborated more than 400 years ago, many alternative solutions have been candidated to justify why the sky is not seen as fully covered by stars. Most of them have proved to be wrong, as they were based on incorrect models about the universe's structure and/or its evolution.

A succint presentation of each one of the more plausible proposed solutions is next discussed, including the author(s) and date(s), an explanation about its main argument and a conclusion evaluating its definite pertinence. The order of the following presentation actually corresponds to the chronological order of appearance (Harrison 2000).

"Starlight is too feeble": Originally proposed by Englishman Thomas Digges in 1576, it was based in the simple assumption that distant stars, although infinite in number, could be just too faint to be observed. This argument is clearly false, as the combined light of "invisible" stars should itself be visible anyway, which is not the case.

"Dark cosmic wall": Originally proposed by the great German Johannes Kepler in 1610, it was based in the concept that the universe is not infinite at all, abruptely ending towards a dark boundary that completely surrounds the starry space. Obviously this is not true.

"Stoic finite cosmos": Originally proposed by the Prussian Otto von Guericke in 1672, by the Irish Agnes Mary Clerke in 1890, and even by the famous American astronomer Harlow Shapley as late as 1917, it was based on the idea that the whole Universe was just a "one-island universe" floating in an infinite void of empty space, that is, the star-populated region suppossedly only extents up to a finite size, although the beyond remaining space spans endless. This solution is basically the same as the previous one, just that the "dark cosmic wall" has been replaced by a much more "scientifically-correct" infinite void. Anyway, this model of universe is wrong.

"Geometric effect": Originally proposed by English scientist Edmund Halley in 1720, it also was the first solution derived after a mathematical analysis of the question. By considering imaginary concentric spheres of increasing radius, forming a series of shells of constant thickness, Halley found that the respective starlight contribution of each shell does not depend on the given radius of the shell[2]. As this reasoning should have concluded that infinite shells would give a bright sky, the proposed solution was to assume that the combined light from distant shells actually resulted obstructed by nearby stars. Wrong argument, as despite the claimed obstruction every line of sight would still end at a star's surface, and the sky should be very bright anyway.

"Interstellar obscuration": Originally proposed by Swiss astronomer Jean-Philippe Loys de Chéseaux in 1744, and also suscribed by German Heinrich Olbers in 1823. Realizing that even the furthest stars would anyway contribute with some light to the sky, the darkness was attributted to the non-transparency of the space. This argument is false because any absorbed radiation will gradually heat the blocking material, which in time would end up by radiating light as stars themselves.

"Hierarchical structure": Originally proposed by British astronomers John Herschel in 1848, and Richard Proctor in 1870, it was based on the idea that matter in the universe tends to become progressively clustered around increasingly larger sizes, thus making that the minimum requested radius for assuring that every line of sight eventually ends at a star's surface accordingly increases up to become indefinitely large. This argument is at least compatible with our current cosmological believes, although its direct effect on the final night darkness is of relative secondary importance.

"Cosmic age too short": Originally proposed by American poet Edgar Allan Poe in 1848, and by German astronomer Johann Mädler in 1861. The basic idea was simply that light from distant stars still hasn't reached us, since light has a finite speed, and the universe a finite age. In 1901, the Scottish mathematician and physicist Lord Kelvin analysed quantitatively the connection between the sky-cover fraction by stars and its relative brightness, concluding that in order to obtain a sky continously bright as the Sun's surface, it would be necessary to include all starlight up to a distance of 3,000 trillion light years. As we can not receive any light that has travelled from longer than 13.7 billion years (the present cosmic particle horizon), this proposed solution is really on the right track.

"Static steady state": Originally proposed by the American astronomer William MacMillan in 1922. It was based in the assumption that the universe, although infinite in size and time, was in a perpetual state of evolution as matter slowly evolve into radiation, and viceversa (conserving the total energy), thus preventing "autotransforming" starlight from reaching distant locations. This model is incorrect, as shown by the irrefutable evidence of an expanding universe obtained after the 1930s.

"Redshift": Originally proposed by the American cosmologist Hermann Bondi in 1955. It was based in the fact that starlight from distant regions of the expanding universe becomes affected by the cosmological redshift, so that the arriving carried energy results increasingly weakened as the distance from stellar sources enlarges. This redshift effect effectively accounts for a barely darker sky, but is not one of its principal causes.

"Too little energy": Originally proposed by American cosmologist Edward Harrison in 1964. It was derived after computing the amount of energy required to create a bright sky,

[2] The total light received from the larger number of stars embraced by a further distant shell would result exactly compensated by the increased dilution due to the longer distance.

and finding out that it implies an overwhelming large number: the observable universe would need 10 trillon times more energy than it currently shows. This means that even if all matter in the universe were transformed into energy according to Einstein's famous formula, the night sky would be barely brighter than it really is. This argument is truly one of the few heavy weight solutions to the riddle.

The following table summarizes all major alternatives so far presented:

Proposed solution	***Author & Date***	***Viability***
Starlight is too feeble	Digges (1576)	wrong
Dark cosmic wall	Kepler (1610)	wrong
Stoic finite cosmos	Guericke (1672), Clerke (1890), Shapley (1917)	wrong
Geometric effect	Halley (1720)	wrong
Interstellar obscuration	Chéseaux (1744), Olbers (1823)	wrong
Hierarchical structure	Herschel (1848), Proctor (1870)	barely applies
Cosmic age too short	Poe (1848), Mädler (1861), Kelvin (1901)	truly important
Static steady state	MacMillan (1922)	wrong
Redshift	Bondi (1955)	barely applies
Too little energy	Harrison (1964)	truly important

The final explanation

As seen, just a few proposed solutions to Olbers' paradox are compatible with our current cosmological model derived from General Relativity'solutions and its description of the evolution of the universe from its main flagship: the Big Bang.

This definite beginning imposes a finite age for the universe. If it is 13.7 billion years old, then light from stars further away than 13.7 billion light years just has not had enough time to get here. This is true even if the universe is infinite. And we did not even consider the fact that the luminous age of stars is certainly limited, which actually makes "things even worse".

The scarcity of the contained energy and matter in the whole universe also becomes an independent valid reason to justify its darkness. As the contained amount of energy and matter are intimately related to the way that the universe has actually evolved according to General Relativity (Freedman & Turner 2003), it is the particular evolution of the universe which synthesizes at last the final explanation for the Olbers'paradox.

The darkness effect attributed to the cosmological redshift has been quantitative compared to the darkness effect just originated by the finiteness of the age of the universe in the aforementioned cosmological context (Wesson 1989), resulting that this latter argument is far more important. However, not all scientists agree with that model, and the redshift solution is still the accepted one for those defenders of the "expanding steady-state" theory (Vicino 2003).

Conclusions

The subject of the night darkness is an essential cosmological question, as it is intimately related to the actual architecture of the universe. In fact, the "easy" model of an endless spatial and perpetual universe immediately becomes controversial with our real night.

Many solutions have been proposed to solve the so called Olbers's paradox, almost each one based on a different explanation for the whole universe. The majority of those models have been proved to be wrong, as they collide to our current cosmological believes.

Nowadays we confindently can assure that there are just two principal factors that separately concur to produce a dark night sky: the universe is too young, and it also contains far less energy than it would be required to. Two other reasons (redshift and hierarchical structure) only contribute to just darken an already dark sky.

Finally, the author now feels self-confident again to resume answering astronomical layman questions from relatives and friends.

References

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The image included on page 2 (*"The magnificent Milky Way at Sagitarius"*) was taken by the author on September 14th, 2004 (piggyback, Kodak Ultra ISO 400, 135-mm, f/2.8, 4 min exp.)