Olbers’ Paradox and the Age of the Universe
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Introduction
How can the sky be dark at night, if the Universe is infinitely big and uniformly filled with sources of light? (Fig. 1) This question has become known as Olbers’ paradox after the Prussian doctor who wrote about it in 1823, although he was not the first to notice it, and did not resolve it [1]. First to state the paradox clearly was Kepler in 1610. Replying to Galileo, who had observed thousands of new stars through the newly invented telescope, Kepler retorted that then, “in an infinite Universe the stars would fill the heavens as they are seen by us!” His conclusion was that the Universe must be finite. (This resolution still survived as late as 1917, in the form of Shapley’s “island Universe” model.) Olbers, including Olbers and the Swiss astronomer de Chéseaux before him in 1744, decided that the night sky must be darkened by some sort of absorbing medium. At least a dozen other explanations were offered over the centuries, some (like fructals and curving space) anticipating developments in modern physics [1].

The first correct resolution to Olbers’ paradox came not from a scientist but a poet, Baltimore’s Edgar Allan Poe. In his prose poem Eureka (1848), Poe realized that the finite speed of light means that when we look farther away, we also look farther back in time. Thus it may be that most of the light sources in the Universe are so far away that their light has not yet had time to reach us. Not only was Poe’s basic insight correct, but it can also be turned in its head: we can use observations of the exact level of darkness of the night sky to deduce the age of the Universe.

That is our objective in this project.

Theory
We model the Universe for argument’s sake as a sphere filled with luminous gas (Fig. 2). Its radius—the farthest that we can see—is the distance that light has traveled for the entire history of the Universe: $R = \frac{c t}{4}$ (where $c$ is the speed of light and $t$ the age of the Universe). The luminosity density of this gas is

$$L = \frac{\rho_{\text{lum}} c^2}{4} = 3 \times 10^{-33} \text{W/m}^3, \tag{1}$$

where $\rho_{\text{lum}} = 0.005 \psi_{\text{Sun}}$ is the average density of luminous matter in the Universe, $\psi_{\text{Sun}} = 3.827 \times 10^{33}$ photons/$\text{m}^3$ is the critical density that distinguishes flat from curved space, $H_0$ is the Hubble expansion rate and $G$ is Newton’s gravitational constant [1].

To convert from photon count to intensity, we divided by the telescope aperture area $A = (d/2)^2$ and by the CCD plate scale $s = (0.63 \text{arcsec})/\text{pixel}$. Converting to conventional angular units, we finally obtained

$$Q_0 = \frac{1.26 \times 10^{-17} \text{photons/s/pixel}}{\text{arcsec}^2} = 10,000 \times 5000 \text{nW/m}^2 \text{sr}. \tag{4}$$

Discussion
Our measured $Q_0$ is much larger than the predicted EBL intensity $Q_0$, but that is because this small extragalactic signal is overwhelmed by “noise” from much larger foreground sources. The largest of these is undoubtedly light pollution from street lamps, etc. Our observing site in Towson ranks at the bottom of the Bortle scale (class 9/9), implying an artificial night sky brighter than 18 magnitudes/arcsec² (Fig. 5). This alone contributes an intensity to the diffuse background light of at least $Q_\text{diff} \approx 6000 \text{nW/m}^2 \text{sr}$.

The three next-largest contributions are caused by airglow (light from air molecules in the Earth’s atmosphere that have been excited by cosmic rays), starlight scattered from dust in our own Galaxy, and zodiacal light (sunlight scattered off dust in the plane of the Solar System). These produce foreground signals of about $Q_\text{agn} \approx 3000 \text{nW/m}^2 \text{sr}$, $Q_\text{diff} \approx 500 \text{nW/m}^2 \text{sr}$ and $Q_\text{zod} \approx 400 \text{nW/m}^2 \text{sr}$ [4]. Subtracting, we find a small remainder that is consistent with the EBL intensity: $Q_0 > Q_\text{agn} - Q_0 - Q_\text{diff} - Q_\text{zod} = 100 \times 5000 \text{nW/m}^2 \text{sr} = Q_0$.

With the launch of the James Webb telescope in early 2019 [5], we may be able to resolve these quantities with higher precision, of order nW/m²/sr. We would then be able to deduce the age of the Universe $t_d$ directly from our measured value of $Q_0$, using Eq. (2)—a remarkable fact that deserves to be better known.

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References