Olber's paradox: why is the sky dark?

Sometimes, an everyday observation can lead to extremely far-reaching conclusions. An example is the so-called *Olber's paradox* based on the observation that the night sky is mostly dark.

(a) Argue that under the assumptions that the universe is infinite, homogeneous on large scales, and static, the sky should be infinitely bright.

(b) Give a plausible resolution of the paradox.

(c) Is it possible to resolve the paradox by assuming that the light from distant stars is absorbed by interstellar dust?

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Solution

(a) If the Universe were indeed static, the light from a distant star would reach us without changing color, and the intensity of the light would drop as $1/R^2$ with the distance R from the star. Now, imagine a spherical shell centered on Earth with average radius R and a given thickness δR, which we assume to be sufficiently thick, so it contains many stars. The number of stars in the shell, assuming uniform density of stars in the Universe, is proportional to the volume of the shell, $4\pi R^2 \delta R$, and the intensity of the light from the shell reaching the Earth is independent of the radius of the shell. Summing up the shells up to $R = \infty$ (under the assumption of infinite Universe), leaves us with infinitely bright sky – the Olber's paradox.

(b) Two assumptions that lead to the Olber's paradox are not, in fact, correct. First, the Universe is finite. Crudely, the size of the Universe can be estimated by multiplying its age, ≈ 14 Gy, by the speed of light. (In fact, the radius of the observable Universe is usually quoted about three times larger; this is because of the *general relativity* effect of curved space-time.) Second, the universe is not static. According to the *Hubble's law*, the stars are receding from us with a speed proportional to the distance R. Because of this, the light from the distant stars is shifted towards longer wavelengths due to the *Doppler effect*. The consequence is a reduction of the intensity of the light reaching the Earth, which is faster than $1/R^2$ without the *red shift*.

(c) An attempt at an explanation of the Olber's paradox by absorption of the light by interstellar dust (while retaining the assumptions of a static infinite Universe) runs into a problem that the dust absorbing intense light from the bright distant sources would heat up, and become a secondary source of radiation, bringing us back to the original problem.