

Light Energy, Dark Energy

Another View of Olber's Paradox

1. The Sun, a fairly typical star, emits about 60 million joules of energy every second from each square meter of its surface. In comparison, how much energy per square meter does it receive from other stars? (Don't give a number, just compare.)

The amount of light the Sun receives from other stars per square meter is comparable to the amount of light the Earth receives from other stars per square meter. Since it's extremely dark at night, we know that this number must be incredibly tiny. (By my calculation, about 10 millionths of a joule per meter squared each second.. a factor of about 10^{13} less than that of the Sun.)

2. Based on the comparison you made in #1, and assuming the universe has had no "edge" from which light could escape, is the amount of light energy in the universe *increasing, decreasing, or staying the same?*

The universe is filled with stars like the Sun, each one of them putting out way more light energy than it absorbs. Since this light has nowhere to go, it can only build up with time.

Technicality: You might ask, what about planets and gas and dust – can't they absorb the light?. Indeed they can, but that would cause them to heat up, and emit their own light by blackbody radiation (or other methods) that would compensate for the starlight they absorbed. You would need a cosmos filled with some sort of radiation "sink" which would soak up all the starlight, and emit nothing in return, to truly compensate for the stars on an infinite timescale. Black holes don't do the trick, either, since this would cause their mass to increase and eventually become infinite!

Caveat: If the universe were expanding fast enough, this would provide extra 'space' for the radiation to expand into and also redshift the photons themselves to lower energy, so the amount of light energy could still be constant.

3. Could your answer for #2 be true if the universe were infinitely old?

No – if the amount of something is increasing, it can only have been increasing for a certain amount of time. For example, the number of people on Earth is increasing now – but clearly this can't have been going on forever into the past.

*Technicality: This argument only says that there have been *stars* in the universe for a limited amount of time – perhaps a long, long time ago there were no stars anywhere. However, it would be pretty darn weird for the universe to have sat around with no stars anywhere for an infinite amount of time... and then suddenly start producing them. It's also technically possible for something to increase forever without becoming infinite if its curve is exponential (or of a similar form where the rate increases very rapidly with time) but that would also be very weird, effectively meaning there were "almost" no stars – in fact, infinitesimally small fractions of a star - far enough back into the past.*

4. Imagine that the Sun received exactly as much energy from other stars as it emitted – the amount of light in the universe was in "balance". What would the sky look like as seen from the Sun... or anywhere else?

If the Sun were receiving 60 million joules per second from the stars, then if you were standing on the Sun, the sky above would look just as bright as the surface of the Sun below: it would be a blinding inferno! And it would look just as bright from the Earth, or anywhere else in the universe.

Hubble Diagrams and The Case of Cosmic Acceleration

5. Plot a bunch of nearby (but not too nearby) galaxies on the plot at right, remembering Hubble's Law: $v = H \times d$. Don't worry about numbers, just get the relationship right.

This is just the equation for a line going through the origin.

6. What you just did assumes that Hubble's constant ($H = v / d$) is really a constant. Is it? If not, why do nearby galaxies still plot the way your diagram (hopefully) looks?

The Hubble constant is not actually a constant; it changes very slowly with time. However, for nearby galaxies, their light was all emitted quite recently (past billion years or less) when the Hubble constant was about the same today.

7. If the universe is dominated by normal gravitating mass, was the Hubble constant *larger* (faster expansion), *smaller* (slower expansion), or *the same* in the distant past?

Gravity would slow the expansion down, so the Hubble constant (which measures the expansion speed of the universe as a whole) would decrease with time. This means that it was larger in the past than it is now.

8. Plot how the diagram you made looks for much more distant galaxies, based on your answer to #7. Remember that since $H = v / d$, if H is different from what we "expect" at some distance as if it were a constant, v will be different in the same way.

The Hubble constant H is still about a constant for nearby galaxies, so the left-corner of the plot is still a line with the same slope as the line in #6. However, if the Hubble constant was larger in the past, very distant galaxies (which we see as they were long ago) will have a higher v / d and will plot above this line.

9. On the other hand, what if the universe were dominated by some sort of funky antigravity "dark energy"? Would the Hubble constant H be larger, smaller, or the same in the distant past?

Dark energy acts in the opposite way as gravity, causing the expansion of the universe to accelerate, meaning H would increase with time (if we were to correct for the effect of increasing distances in Hubble's law – see footnote in original). So long ago it must have been smaller than today.

10. Plot the Hubble diagram we would get if this were in fact the case.

The lower-left is still a line for the same reason as in #6. However, if the Hubble constant was smaller in the past, very distant galaxies (which we see as they were long ago) will have a smaller v / d and will plot below this line.

11. Which diagram (8 or 10) is the one that the observations actually agree with?

The observations support the diagram in #10 – the universe is dominated by dark energy! See CS- in your course reader.

