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.)

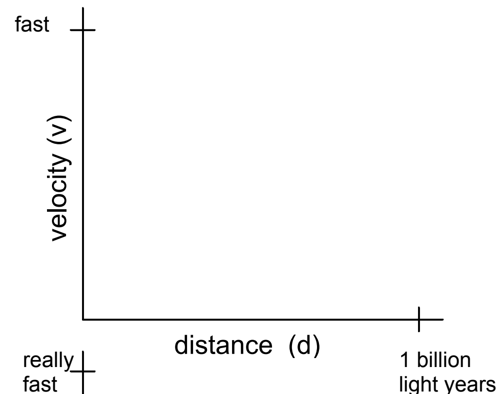
2. Based on the comparison you made in #1, and assuming the universe has had no "edge" from which light could escape, is the amount of light energy in the universe *increasing*, *decreasing*, or *staying the same*?

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

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?

Hubble Diagrams and The Case of Cosmic Acceleration

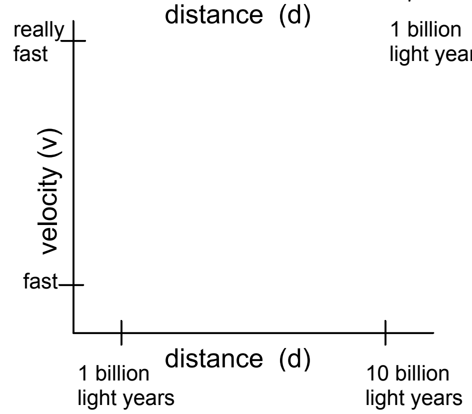
5. Plot a bunch of nearby (but not too nearby) galaxies on the plot at right, remembering Hubble's Law: $v = H \times d$. Don't worry about numbers, just get the relationship right.



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?

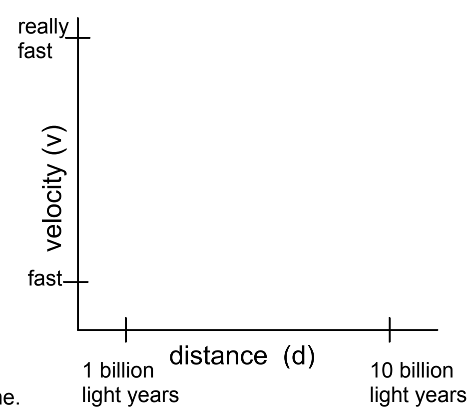
7. If the universe is dominated by normal gravitating mass, was the Hubble constant *larger* (faster expansion), *smaller* (slower expansion), or *the same* in the distant past?

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.



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*?

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



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

* *Relative to* the case with neither gravity nor 'antigravity' (empty universe). In fact, even if there were no gravity at all, the Hubble constant would be decreasing because, for any specific galaxy, d increases, but v is constant, so the Hubble constant v/d decreases with time. Therefore, to really be accurate, we must compare different universes, not different times in a same universe. However, this is a bit of a subtlety, and if we slightly modify our definitions of 'distance' and 'Hubble constant', the simplified reasoning in #9 is still accurate, and you can ignore this footnote if it confuses you – just think about how gravity and antigravity affect *v*.

Original worksheet by D. Perley