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COSMIC CONCEPTS: Frozen in Time?

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How do we look back in time? Because light travels at a finite (not infinite) speed, when we observe objects in space, we see them as they were *when the light left them*. For the Sun, which is a distance of about 8 light-minutes from Earth, we see it as it was 8 minutes earlier than when we receive the light. For the outermost planets in our Solar System, being a few light-hours in distance away from us, we see them as they were a few hours ago. For galaxies across the observable Universe, we see them as they were when the Universe was *much younger than it is now*. Thus, studying distant objects means looking back in time, enabling us to learn about cosmic history.

What is the significance of the sky being dark at night? Many have pondered that if the Universe is infinite, and if stars are eternal and if they are distributed throughout infinite space, and if there is nothing to absorb the light, then there shouldn't be any direction from Earth in which there isn't starlight. Streetlamps apart, we are very familiar with the fact that the sky is dark at night. This was pondered by many people including Lord Kelvin and Edgar Allan Poe, but is usually credited to Heinrich Wilhelm Olbers, and known as Olbers' Paradox.

What is the nature of research in science? The word "proof" doesn't belong to empirical science (but it does belong to mathematics). Empirical science proceeds by gleaning evidence from measurements, observations and theory which confront and challenge one another. Bona fide science is that which can be refuted or verified, i.e. it is *testable*.

What is the nature of research in cosmology? Cosmology is different from other sciences in that we cannot perform experiments: there is only one Universe and, moreover, it formed a long time ago. Despite this, the cosmos is amenable to scientific investigation. Like other sciences, theory and observation challenge and drive progress in our understanding.

What is the Copernican Principle and who was Copernicus? The Copernican Principle, sometimes called the Cosmological Principle, (approximately) states that we are not at the centre of the Universe! It states that the Universe is the same wherever you look. It is not exact and holds better on larger scales, but is an important statement of our underlying presumptions. This principle is named after Nicolaus Copernicus who introduced the heliocentric paradigm: the fact that the Earth goes around the Sun and not the other way around.

How do we measure the speed at which a galaxy is moving? This is actually a routine measurement and straightforward with modern technology. It turns out that when gas in a galaxy is giving off light it gives particular features in the spectrum known as emission lines. These distinctive features are observed to move to shorter or longer wavelengths if the galaxy is moving towards us or away from us respectively. (This phenomenon is known as the Doppler Effect.) The shift in wavelength directly gives a measure of the speed of the galaxy relative to us.

How are most galaxies moving with respect to our Galaxy? Away from us! Apart from a few galaxies in the Local Group, almost all galaxies are moving away from us. The pioneering measurements were made by Vesto Slipher and systematically pursued by Edwin Hubble who identified the fact that the *further* away a galaxy is from us, the *faster* it is moving away from us.

So why do we think the Universe is expanding? Consider the following: if you imagine a row of galaxies, evenly spaced from one another, and then imagine each galaxy starts moving from its nearest neighbour at the same rate as one another. It follows that next-but-one neighbours will move apart at twice that rate, and next-buttwo neighbours will move apart at three times the rate. The proportionality between the distance a galaxy is from us and the speed it recedes from us is a strong indicator that the gaps between the galaxies are expanding and, overall, their separation is expanding.

What is the Cosmic Microwave Background? This is "background" radiation in the sense that we observe it whichever direction we look at in the sky. It is remarkably smooth and uniform, but the tiny variations in it are the seeds of structure formation. The uniformity of the temperature of this background radiation (close to 270 degrees below the freezing point of water) all across the sky is an important indicator about the nature of the hot Big Bang.

How do the galaxies come about? This is a big question! However, if you consider regions of plasma that are denser than others, gravity will be at work and these regions will become increasingly dense. As the Universe expands, it cools. When the matter is cool enough it can collapse under gravity. Locally, gravitational collapse leads to extremely high temperatures, so high that nuclear fusion can proceed. Fusion is the means by which stars shine, and collections of stars, gravitationally bound together are called galaxies.

How do the elements come about? In the modern day, thanks to Dmitri Mendeleev, we have the Periodic Table which lays out the different types of chemical elements, from the lightest (hydrogen) to much more massive ones. The hydrogen atom is comprised of one proton and one electron, which were both present in great abundance one second after the Big Bang. The top of the Periodic Table comprises elements besides hydrogen, such as helium and lithium. These elements are formed just a few short minutes after the Big Bang. The ratios of these (known as abundances) are inferred from the oldest stars we know (thought to be made from the most pristine gas from the Big Bang, not from the decay products of other exploded stars). The normal evolution of stars gives us elements such as Carbon, Nitrogen and Oxygen, and even Iron. The so-called "heavier elements" arise from supernova explosions (that arise from the rapid evolution of massive stars) and from nova explosions (that arise when too much matter has been pulled off a nearby star onto the surface of a compact "white dwarf" star that gets so hot a process called a thermonuclear runaway takes place.

What are the tenets of the hot Big Bang theory? There are four principle tenets of the Big Bang theory: the expansion of the Universe, the existence and the spectrum of the Cosmic Microwave Background radiation, the relative abundances of the light element such as helium and lithium, and the anisotropies in the Cosmic Microwave Background which are the seeds of structure formation.

Further reading and references:

"An Introduction to Modern Cosmology", Andrew Liddle, Wiley, 2015

"A Very Short Introduction to Cosmology", Peter Coles, Oxford University Press, 2001

"An introduction to Galaxies and Cosmology", Robert Lambourne, Cambridge University Press, 2015

"A single low-energy, iron-poor supernova as the source of metals in the star SMSS J031300.36-670839.3", Keller, SC, et al, Nature, 2014, 506, 463-466