Storytelling with Uniview #10:
Cosmology Misconceptions Part I

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Cosmology is an extremely tricky topic to teach, no matter what tools you have at your disposal. A recent Associated Press-GfK poll (http://www.cbsnews.com/news/americans-big-bang-evolution-ap-poll/) of the American public showed a slight majority (51%) did not have confidence that the Big Bang gave rise to the Universe. This is higher than the number (42%) who doubt evolution through natural selection. To make matters worse, explaining the Big Bang is difficult to do even without such active skepticism, and is fraught with the possibility that you will reinforce existing alternate conceptions by the learner, or even introduce new misconceptions. Unfortunately using Uniview does not necessarily help. In some ways, it's *easier* to promote erroneous thinking in cosmology with the visualization software than without! So let's go through some of the problems that might arise in this first of a two-part column.

Basic Cosmology 101

Before we begin, let's look at a very brief summary of what we know about the origins of the Universe, and the evidence we have for that knowledge.

In recent years, we have entered a period of "high precision" cosmology, where cosmological parameters describing the Universe are now known to within a few percent error or less (Planck Collaboration 2014), a precision that might have seen unthinkable just a couple of decades ago. The age of the Universe is 13.81 billion years old. It has been expanding ever since its appearance in an event we call the Big Bang. The expansion is in reality the expansion of spacetime itself, which carries matter along with it. We detect this expansion directly in the velocities of distant galaxies, which all have positive velocities away from us, redshifting the light. (This redshift, or increase in the wavelength of the emission, can be explained as the expansion of space stretching the wavelength of the light waves passing through that space.) We observe a linear relationship between velocities of distant galaxies and their distances: the further away they are, the faster they are receding from us, which is consistent with an expanding Universe. Measurements of this "Hubble law" is one of the observational pillars of the Big Bang.

The make-up of the Universe is 4.9% ordinary matter and radiation. This includes all matter made up of particles we are familiar with in everyday life—protons, electrons, and neutrons—in addition to the menagerie of baryons and mesons (made up of quarks), leptons, neutrinos, their anti-particles, and photons that we have come to know through the Standard Model of Physics. Dark matter makes up 26.3% of the mass-energy budget of the Universe. This is matter that does not emit or interact with electromagnetic radiation, and is detected only via its gravitational interactions with ordinary matter which we can observe directly. There is still considerable debate as to what type of particles make up dark matter, and how they fit into our physical models. And finally the most surprising result in astrophysics in recent decades has been the discovery of dark energy that makes up 68.6% of the energy in the Universe, and which causes space itself to expand at an increasing rate. We know even less about dark energy than dark matter: even its name is a placeholder for any number of proposed models of which one (or none) may be correct.

As the Universe expanded, the ordinary matter in it cooled and condensed, forming the nuclei of the first elements heavier than hydrogen. In less than half an hour, about 75% of the ordinary matter ended up as hydrogen nuclei (a single proton or ^{1}H), 25% in the form of helium (^{4}He), about 0.01% as deuterium (^{2}H), and even smaller trace amounts of lithium (^{7}Li) and beryllium (^{7}Be). All elements heavier than these initial species were spewed out later as a consequence of the life cycle of stars. The fact that the abundances of these lightest elements are more or less in the ratios predicted is the second observational pillar for the Big Bang model.

As the Universe continued to expand, the electrons combined with the naked nuclei to form the first atoms. Before this period of "recombination" 380,000 years after the beginning of the expansion, photons could easily bounce off and have their directions altered ("scattered") by encounters with electrons. But as the free electrons were locked up into atoms, there were not enough free electrons for the photons to encounter. The photons could now stream freely through space. As they do so, they retain an imprint of the temperature of the matter that they were interacting with, which was about 3000 degrees K, or 4900 degrees F.[1] As space expanded, the wavelength of the radiation expanded with it, until it ended up today in the microwave part of the spectrum. This became the cosmic microwave background (CMB) that pervades all space, and which has been detected and mapped by instruments in space and on the ground. The detection of the CMB provides the third observational pillar for the Big Bang.

Astronomers continue to observe and study the CMB, since many cosmological parameters for the Universe are wrapped up in its structure. The CMB is smooth and free of variations down to a factor of 1 in 100,000. These small density variations—areas that are slightly overdense and other spots that are underdense—grew over time, from hundreds of millions to billions of years, to form the galaxy clusters and galaxies that we see in the present day Universe. In fact, computer simulations have been able to show that the Universe with the above mix of ordinary matter, dark matter, and dark energy can evolve into a Universe that is remarkably similar to our own. The science is not completely settled; there are still details that the modelers are still working out. But the overall picture continues to be consistent with the Big Bang model.

Cosmology Misconceptions

The public's alternative conceptions about cosmology have not been studied as extensively as topics that are closer to home, like the phases of the Moon, seasons, and the cause of day and night. (For instance, the poll mentioned above about attitudes on the Big Bang suggest correlations with political and religious affiliations, but these linkages and the thinking of the people polled have not been properly studied.) But like these other topics, how people think about cosmology can be eye-opening. One of the most common misconceptions is that the Big Bang is like an explosion—no surprise given the words "big" and "bang." This implies that there is some pre-existing space in which the contents of the Big Bang, are being propelled outward, like the debris from a grenade (Wallace, Prather, & Duncan 2012). However in reality, spacetime is created in the aftermath of the Big Bang, so there *wasn't* any space prior to the Big Bang.

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[1] This coincidentally is a bit cooler than the surface of the Sun, but roughly about the temperature of the tungsten filament in an incandescent bulb. Thus if you were to travel back in time to 380,000 years after the Big Bang at the time of recombination, the gas all around you would be glowing with the spectral characteristics similar to the light from an old fashion light bulb.

For students who have heard about the Big Bang theory, most believe that it was an explosion that re-arranged existing matter; perhaps the result of the belief that the matter must have come from somewhere (Prather, Slather, & Offerdahl 2002). Many members of the public (and students before instruction) are not aware (and may be surprised to learn) that the Universe is expanding (Lightman & Miller 1989; Prather et al. 2002). Some students may think that the term "expansion of the Universe" is metaphorical, and merely describes how our knowledge of it has increased with time (Wallace et al. 2012).

There is also a common belief that there is a center to the explosion (Wallace et al. 2012); that is, there is a place in the Universe you can point to where the expansion originated. For more educated learners, this confusion may have its origins with the term "singularity." At earlier and earlier times, the matter in the Universe is increasingly denser and hotter, until at the Planck era 10^{-43} seconds after the Big Bang, the laws of physics break down and are no longer adequate in describing the physical conditions of those early conditions. Another place where you may hear about the known laws of physics not working is in the singularity of a black hole. And hence, the point singularity of a black hole is now associated with the origins of the Universe in the Big Bang. However the Big Bang happened everywhere in space equally, since all of spacetime had its origins from it. You cannot point to any one place in the Universe and say *that* is where it expanded from.

There is also confused understanding of the sequence of events after the Big Bang. Some college students believe that the Solar System formed soon in the aftermath of the Big Bang, instead of the event occurring 9 billion years later; or that the Big Bang was responsible for rearranging the matter to create Earth and the other planets in our Solar System, instead of via the nebular hypothesis (Simonelli & Pilashowski 2003). Some of this confusion might be traced to the fact that the public may not have a clear sense of what the terms "Solar System," "Galaxy," and "Universe" really mean. For instance, a survey of college students before they receive astronomy instruction (Bailey et al. 2012) show that there can be misunderstandings about the hierarchical relationship between these three terms. When asked to describe the Solar System, some students will include stars as being a component. Or galaxies are explained as containing planets and stars. Or "the solar system is made of many galaxies."

Bailey et al. also found that many students surveyed think the Universe has always existed, instead of having a finite age. And not surprisingly given the words that make it up, many believe a light year is a unit of time, instead of a unit of distance.

Given some of these alternate concepts that have been uncovered amongst students about the Big Bang and the Universe in general, what can we do when we talk about cosmology using Uniview? What shouldn't we do? We will discuss this in more detail in the next part of this column.

References

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