"All change on the Cosmological Front ?".

Two recent results have been presented to the public and amateur astronomers that have caught my attention. The first was an article in *Astronomy* (March 2003) by Steve Nadis entitled "*Will dark energy steal all the stars ?*". The other was a news article (published on the BBC News webpages by Dr David Whitehouse) on the latest results from the analysis of data collected by the Wilkinson Microwave Anisotropy Probe ("Map reveals strange cosmos" [1]). Taken together these have caused me to pause and consider whether our current cosmological models are going to stand the test of time.

Cosmology is one of the most challenging sciences. It attempts to match theories of nuclear synthesis and the Big Bang, with others that describe the effects of gravity and how the structure of space is affected by the distribution of matter and energy (and visa versa). It looks at the Universe from the smallest scales of sub-atomic particles, to the largest clusters of galaxies (like the "Great Wall"). Combining these theories with observational results allows models for the evolution of the Universe to be tested. And this is the fundamental goal of cosmology; to be able to explain the properties of the observable Universe (and make guesses at those we can't see), describe how it has evolved to the state we see today, and to help us make predictions for its long-term future.

Over time there have been many cosmological theories, some more successful than others. For centuries Newtonian mechanics was a complete description of "how the Universe works" and remains largely applicable today. Yet it is based upon simple assumptions about space and time. These include the concept that the physical properties of space are not affected by the distribution of matter or energy (homogeneity); and that these properties are the same in all parts of the Universe, no matter the direction in which we look in (isotropy). By using these assumptions, along with a few others, it is possible to derive Newton's Laws of Motion [2]. Of course, Einstein famously resolved the flaws in Newton's work and developed more robust physical laws via the theories of Special and General Relativity.

We should not lose sight of the fact that although Einstein's work appears to be "right", it could still be flawed. The history of science is full of examples of one theory being overturned in favour of another which better explains the phenomena being considered. Indeed, the current inability to tie together quantum theory with General Relativity is suggestive that there may be problems in one or both of them.

We have now developed our 'understanding' of the Universe to the point where some scientists are confident enough to try and model its evolution over the next 100 *billion* years (see the article by Nadis). Such exercises assume that our current "laws" of physics will apply over these immense periods of time. Indeed, modern cosmology is based on the "cosmological principle" which asserts that the Universe is, at all times, homogeneous and isotropic.

This is where the latest results from MAP may suggest a cause for concern. Theories about the Big Bang predict that there should be an "afterglow" background radiation that permeates throughout all of space. This afterglow represents the photons released

from the Big Bang "fireball" at the moment of 'decoupling' (when electrons and ions combined to form neutral atoms and radiation was no longer completely scattered). Due to the expansion of space these photons have been shifted through the infrared and into the microwave regions of the electromagnetic spectrum. If we plot measurements of the relative intensities of these photons against their frequencies we discover a curve which matches a black-body spectrum (in this case the 2.73 ° K spectrum).

MAP has measured the Cosmic Microwave Background (CMB) radiation to great accuracy. The data resolves temperature variations of millionths of a degree, against an 'average' CMB of about 2.73° K. The results support and strengthen confidence in the Big Bang Theory (with Inflation) [3], but have also revealed something unexpected.

Dr Max Tegmark has processed the MAP data to produce a spherical projection of the CMB variations (with the Earth at the centre) and found that some components of its symmetry across the sky have a non-random structure. He says that "… the octopole and quadrupole components are arranged in a straight line across the sky, along a kind of cosmic equator" (the picture on the BBC news article illustrates this very well). This symmetry is disturbing because it shows that the CMB has preferred directions in space, ie it is not isotropic. Maybe the cosmological principle is not valid at high redshifts ?

If we cannot rely on the cosmological principle then the Universe becomes a lot more complicated. We can no longer assume homogeneity and isotropy; and consequently it becomes possible for physical laws to vary between local regions of space-time.

Is the stage set for new, fundamental, cosmological theories to replace our current ones ? Possibly. Tegmark says that the CMB symmetry may be "… telling us something about the shape of space on the largest scales. We did not expect this and we cannot yet explain it".

We should watch this space, and do so carefully, because we may be living at a special time in the Universe' evolution. Some of the models of the Universe' evolution suggest that it's rate of expansion could eventually exceed the speed of light. There could be a horizon beyond which we would never be able to observe the rest of the Universe. In 100 billion years we might be unable to see further than 40 billion light years, and the only thing contained in that sphere might be our own galaxy. Still, that's enough 'time' for a lot of observing !

[1] - see internet article at http://news.bbc.co.uk/1/hi/sci/tech/2814947.stm
[2] - see Space, Time and Cosmology Block 1, Open University, ISBN 0 7492 8158 8
3 - NASA WMAP Press Release 03-064,
http://map.gsfc.nasa.gov/m_or/PressRelease_03-064.html

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