THE HORIZON PROBLEM

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A **Horizon** is defined as a '*frontier between things observable and things unobservable*'. Rindler [1] defines two kinds of horizons. The **Event Horizon** for a given *fundamental observer* **A**(one at rest with respect to the universe) is a hyper-surface in space-time which divides all events into those that have been, are or will be observable by **A** and those that are forever outside **A**'s possible powers of observation. In the Minkowskian space-time, this would consist of the Future and Past Light-cones. The **Particle Horizon** for **A** for a given instant divides all particles into those that have already been observable by **A** at that instant and those that have not. In Minkowskian space-time this would correspond to the whole of space. It is this horizon that concerns us when we speak of the horizon problem.

To state the problem mathematically we require a metric. We use the **Friedman-Robertson-Walker** metric as it is the most general metric for a homogenous and isotropic universe. The corresponding line-element is as follows:

$$ds^2 = c^2dt^2 - a^2(t)[\frac{dr^2}{\sqrt{1-Kr^2}} + r^2(d\theta^2 + sin^2\theta d\phi^2)]$$

where $a(t)$ is the expansion factor for the universe (it is this factor that differs from model to model of the universe) and K is the curvature parameter which takes the values 0, 1 and -1 depending on whether the curvature is zero, positive or negative respectively.

Let the oberver **A** be at $r = 0$. Now if a particle at $r = r_1$ sends a light wave (let it be radial) at $t = t_1$ such that it reaches **A** in the present instant $t = t_0$ the co-ordinate distance travelled by the wave is is given by

$$\int_{t_1}^{t_0} \frac{cdt}{a(t)} = \int_0^{r_1} \frac{dr}{1-Kr^2}$$

If in the limit as $t_1 \to 0$ (this corresponds to the zero of time which we may identify as the Big-bang epoch) the integrals converge to a finite value, then the corresponding r_1 would be the maximum radial coordinate from which causal connection is possible at $t = t_0$. This would give us a finite **Particle Horizon**. A diverging integral would mean an infinite Horizon. To get the corresponding Proper Distance R_p one has to multiply the integrals by $a(t)$.

In the Einstein-de Sitter model for example, R_p is finite and goes as t. $a(t)$ itself goes slower than t implying that more of the (early) universe will become observable with time.

Ironically, it is the homogeneity and isotropy of space (plus a finite R_p) that leads to the **Horizon Problem**. The observation that the **Cosmic Microwave Background Radiation** is isotropic to the extent that the temperature variations between different parts of the 'visible' universe are only one part in 10^4 proves that the universe is homogenous to a large extent. Homogenization between two separate can happen only when they can exchange photons (atleast!). But the existence of a finite R_p means that there exist regions which are sufficiently far apart so that they cannot have homogenized! This, in brief, is the **Horizon Problem**.

A solution was provided by Alan Guth [4] in 1981 wherin he assumes an **Inflationary** model for the universe.

References

[1] W.Rindler, Monthly Notices of The Royal Astronaomical Society, Vol. 116, No. 6, (662-667), 1956

[2] Steven Weinberg, *Gravitation and Cosmology*, John Wiley and Sons, Student edition, 2004

[3] Jayanth Vishnu Narlikar, *An Introduction to Cosmology*, Cambidge Publishers, Third edition, 2002

[4] Alan.H.Guth, *Inflationary Universe: A Possible solution to the Horizon and Flatness Problems*, Physical Review D. Vol. 23, No. 2, 347-356, 1981