A Conceptual Framework for a Cosmic Time System Based on Photon Travel

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Abstract

Conventional timekeeping systems are defined in terms of Earth-related cycles, such as the planet's rotation (days) or revolution around the Sun (years). While practical locally, these measures are not universal. On cosmological scales, it is natural to ask whether a time system can be constructed on the basis of universal physical processes. In this paper, we outline a conceptual framework in which time is defined relative to the distance between galaxies and the travel time of photons across that distance. We develop the model in stages: (1) defining the unit of time from galaxy separations, (2) introducing a normalized scale, (3) distinguishing between instantaneous and actual photon travel times, and (4) examining how observers at different epochs would perceive these quantities.

Introduction

Human measures of time are historically tied to Earth's motions. However, such measures lose relevance when considering the universe at large. A more universal system might be constructed by anchoring time to fundamental constants and large-scale cosmological properties.

A natural candidate is the **photon travel time** across the average separation of galaxies. This distance evolves as the universe expands, which means that such a time system is directly linked to cosmic dynamics rather than to arbitrary planetary motions.

1 Defining the Basic Unit of Time

Let the present average distance between two galaxies be denoted by D_0. Observational estimates suggest

$$D_0 \sim 3 \times 10^{22}\,\mathrm{m}. \tag{1}$$

The corresponding photon travel time is defined as

$$T_0 = \frac{D_0}{c}, \tag{2}$$

where $c = 3 \times 10^8\,\mathrm{m/s}$ is the speed of light.

Substituting values, we find

$$T_0 \approx \frac{3 \times 10^{22}\,\mathrm{m}}{3 \times 10^8\,\mathrm{m/s}} \approx 1 \times 10^{14}\,\mathrm{s}, \tag{3}$$

which corresponds to approximately 3×10^6 years.

Since this value is extremely large, we define a normalized time

$$\tilde{T}_0 = \frac{T_0}{10^{10}} \approx 1 \times 10^4\,\mathrm{s} \approx 2.8 \text{ hours}. \tag{4}$$

2 Cosmic Expansion and Time Evolution

The universe expands with acceleration. Therefore, the galaxy separation increases by different increments at different times. Let these increments be

$$a_1, a_2, a_3, \ldots \tag{5}$$

with

$$a_{k+1} > a_k \quad \text{(if we ignore the effect of gravity)}, \tag{6}$$

indicating accelerated expansion.

At epoch n, the average galaxy separation is

$$D_n = D_0 + \sum_{k=1}^{n} a_k, \tag{7}$$

and the corresponding photon travel time is

$$T_n = \frac{D_n}{c} = \frac{D_0 + \sum_{k=1}^{n} a_k}{c}. \tag{8}$$

The normalized time at epoch n is

$$\tilde{T}_n = \frac{T_n}{10^{10}}. \tag{9}$$

3 Instantaneous vs. Actual Photon Travel Time

The snapshot approximation above assumes that a photon experiences a static galaxy separation at each epoch. In reality, a photon travels while the universe continues to expand.

To model this more precisely, we define:

- **Comoving distance**, D_c, which remains fixed in expanding coordinates.
- **Scale factor**, $a(t)$, which characterizes the expansion of the universe.

Photon propagation satisfies

$$\sum_{i=1}^{n} \frac{c\,\Delta t_i}{a(t_i)} = D_c, \tag{10}$$

where $\Delta t_i = t_i - t_{i-1}$.

The actual photon travel time is

$$T_{\text{actual}} = \sum_{i=1}^{n} \Delta t_i, \tag{11}$$

subject to the condition above.

Two notions of time exist:

1. **Snapshot time:** $T_n = D_n/c$
2. **Actual travel time:** obtained by integrating the expansion effect during propagation.

4 Relative Observations by Different Epochs

Consider two observers at different cosmic times.

Observer at $t = 1$

The observed separation is

$$D_1 = D_0 + a_1, \tag{12}$$

with corresponding travel time

$$T_1 = \frac{D_1}{c}. \tag{13}$$

Observer at $t = 6$

The observed separation is

$$D_6 = D_0 + \sum_{k=1}^{6} a_k, \tag{14}$$

and the travel time is

$$T_6 = \frac{D_6}{c}. \tag{15}$$

Each observer calculates the photon travel time based on the instantaneous galaxy separation.

5 Differences Between Epochs

The difference in perceived photon travel time between two epochs is

$$\Delta T_{p,n} = T_p - T_n = \frac{\sum_{k=n+1}^{p} a_k}{c}. \tag{16}$$

For example, between epochs 6 and 1:

$$\Delta T_{6,1} = \frac{a_2 + a_3 + a_4 + a_5 + a_6}{c}. \tag{17}$$

Later observers measure longer photon travel times since the expansion increments are positive and increasing.

6 Discussion and Interpretation

This model highlights an important distinction:

- **Instantaneous estimates** (T_n) depend on the observer's epoch and reflect only the galaxy separation at that time.
- **Actual travel time** requires integrating over the scale factor, which cannot be directly observed by a single epoch observer.

Thus, observers at different epochs will disagree on photon travel time if they rely only on instantaneous measurements. This framework offers a way to conceptualize cosmic time based on photon travel rather than Earth-based cycles.

7 Conclusion

We have outlined a conceptual cosmic time system based on photon travel across average galaxy separations. The framework distinguishes between normalized snapshot times and the actual integrated photon travel time, and it shows how observers at different epochs perceive different values.

While simplified, this model captures the essence of a universal measure of time independent of planetary cycles and directly tied to cosmic expansion. It also illustrates how relative perception of time emerges naturally in an evolving universe, providing a foundation for further mathematical and cosmological development.