Cosmic distance measurements

Abstract: This seminar talk conceptually outlines the systematic approach of cosmologists to increase the constraints on the currently prevailing cosmological model through the experimental determination of cosmic distances. It first presents the model and its relation to cosmic distances, and then the conceptual ideas behind the methods of their measurement.

Their importance for cosmology

Fundamental assumptions of cosmology

Cosmology, i.e. the systematic pursuit of perceiving and understanding the universe's evolution, relies heavily on the use of telescopic observations. The efforts of improving the accuracy and precision of these observations over the last 400 years led to the view of a dynamic universe that can spatially expand or contract in response to the distribution of the energy densities Ω_i of different components i like matter and radiation [1, 2]. Thereby, the expansion occurs in such a way that the other two, likewise observationally motivated, assumptions about the universe are not violated. These two assumptions are called **cosmological principle** (CP) and state that at large scales the universe looks the same at any point in space and in any direction [3, 4].

Parameterization of cosmology

The CP automatically restricts the expansion, and thus the entire kinematic of the universe, to one that is comparable with the stretching of a balloon surface during inflation and can be fully described by a single parameter $a(t)$, called the **scale factor** [3, 4]. Its application to the Einstein field equation yields a complete description of $a(t)$ in terms of the energy densities Ω_i, called **cosmological parameters**, which is shown in the following [3, 5].

$$\frac{\dot{a}(t)}{a(t)} = \dot{a}(t_0) \cdot \sqrt{\Omega_{m,0} \cdot a(t)^{-3} + \Omega_{\Lambda,0} + \Omega_{k,0} \cdot a(t)^{-2}}$$

The parameters correspond respectively to their component's energy share of the universe, and the goal of today's cosmology is to constrain their values by measuring $a(t)$ and fitting them [3, 6, 7].

Parameterization linked to distance

The CP also gives rise to another fundamental relation, namely the **Hubble law**, which relates the recession speed and the distance of a cosmological object directly to $a(t)$, if the distance is sufficiently large. This makes the determination of these two quantities the new objective of cosmology [3, 8].

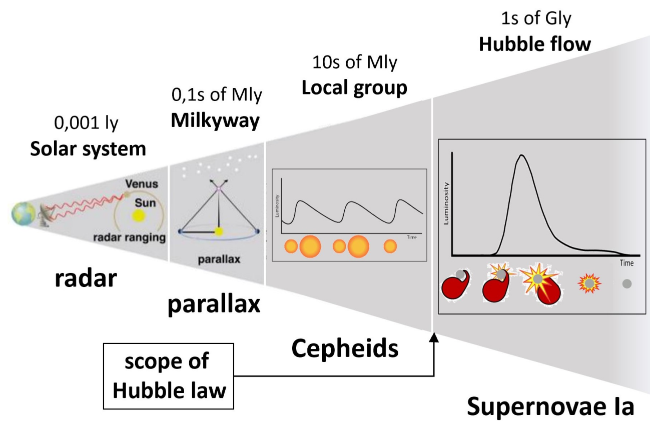

Fig. 1: Exemplary steps of the distance ladder with their ranges. Inspired by: [9]

Their conceptual obtainment

Fundamental ideas

Contrary to the recession speed, the measurement of the distance has been a major challenge for the entire history of the cosmological endeavor [10]. To cope with it, fundamentally, so-called **standard candles** are used, which are identifiable groups of objects with identical, known intrinsic brightness L. Comparing their L with the measured apparent brightness of an individual of that group, then lets one determine the individual's distance. Now a concept, called **cosmic distance ladder**, uses multiple standard candles, visible at different ranges, to respectively calibrate the subsequent group, enabling distance measurements ever farther away [10].

Exemplary realizations

Figure 1 shows a schematic illustration of one of the most commonly used, sets of steps of the ladder and their respective reaches. The first two steps, **radar** and **parallax**, form the fundamental basis of any realization of the distance ladder and are not linked to the concept of standard candles [10, 11].

Today's efforts

Determining $a(t)$ through **Cepheids** or **Supernovae Ia** is one of the pillars of modern cosmology and is subject of large scientific studies, aiming to better understand the evolution of our universe [7, 12].

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