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Doppler shift effect as a possible explanation to the Hubble-Lemaitre constant tension

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Abstract

The difference in the Hubble-Lemaitre constant determined by different probes is a yet unexplained observation. This paper proposes the contention that the tension could be explained by the Doppler shift effect of Ia supernovae or Cepheids, driven by the rotational velocity of their host galaxies relative to the rotational velocity of the Milky Way. While the effect of the Doppler shift is expected to be mild, observations show that it can lead to systematic differences in the apparent brightness, and consequently the estimated distances. A simple experiment is done by repeating a previous analysis. When using the original set of supernovae, H_o is 73.758±1.943 km/s/Mpc. When using a subset of supernovae such that the host galaxies rotate in the same direction as the Milky Way, H_o drops sharply to 69.049±3.42 km/s/Mpc, showing a far milder tension with the H_o determined by the CMB. When using a subset of Ia supernovae that rotate in the opposite direction, H_o does not decrease, but instead it increases the H_o tension to 74.182±3.2. Further analysis will be required to determine the link between H_o observed by using Ia supernovae or Cepheids and the rotational velocity of the host galaxies.

1 Introducion

Recent advancements in research instruments allowed to measure the expansion of the Universe with higher precision. These studies revealed statistically significant differences between the Hubble-Lemaitre constant H_o when measured using different probes (Wu and Huterer, 2017; Mörtsell and Dhawan, 2018; Bolejko, 2018; Davis et al., 2019; Pandey et al., 2020; Camarena and Marra, 2020; Di Valentino et al., 2021; Riess et al., 2022). While these differences are statistically significant, there is still no single definite proven explanation to the tension. Because the different probes measure the same Universe, one of the possible explanations is that some of these measurements is affected by a certain unknown systematic inaccuracy.

The Doppler shift effect is expected to change the apparent magnitude of objects based on their rotational velocity compared to the rotational velocity of the observer. For instance, a star in a galaxy that rotates at velocity V_r relative to a stationary observer will have an apparent bolometric flux $F = F_o(1 + 4 \cdot \frac{V_r}{c})$, where F_o is the flux of the star when it is stationary relative to the observer, and c is the speed of light (Loeb and Gaudi, 2003; Rybicki and Lightman, 2008).

Ia supernova is a common probe to measure distances, and one of the probes used to measure H_o. Since the absolute magnitude of an Ia supernova is expected, its apparent magnitude can be used to determine its distance. Supernovae are created from stars, and therefore inherit the angular momentum of the stars from which they are created. If the apparent magnitude of an Ia supernova is affected by the rotational velocity of its host galaxy, that can lead to slight but systematic change in its estimated distance. The same can also apply to Cepheids, which are stars and therefore have rotational velocity with their host galaxies. Their apparent luminosity can therefore change based on their rotational velocity relative to the rotational velocity of the Milky Way.

As discussed in (Shamir, 2020, 2022, 2023), assuming rotational velocity similar to the Milky Way, Doppler shift can lead to magnitude difference of about 0.006. But as shown experimentally, the link between the rotational velocity of galaxies and their brightness might be also stronger than expected (Shamir, 2016, 2017, 2020, 2022, 2023). If such difference affects the brightness of Ia supernovae or Cepheids, it can lead to a change in the estimated distances, and therefore a different H_o. The purpose of this experiment is to repeat a previous experiment (Khetan et al., 2021) when using a subset of supernovae that rotate in the same direction as the Milky Way to correct or reduce the impact of the Doppler shift effect.

2 Results

The empirical experiment is based on the code and data developed and used by Khetan et al. (2021). The original analysis (Khetan et al., 2021) was based on a collection of 140 Ia supernovae taken from the Combined Pantheon (Scolnic et al., 2015), and calibrated with two sets. The calibration sets are 19 objects from SH0ES, and 24 objects from SBF (Khetan et al., 2021). The analysis was done with the open code and data accessible at `https://github.com/nanditakhetan/SBF_SNeIa_H0`.

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Rotation	#	H_o	3% error range	SD
All	96	73.758	70.193-77.404	1.943
Same direction	22	69.049	62.955-76.005	3.42
Opposite direction	36	74.182	68.758-79.915	3.2

Table 1: The H_o computed when using the original set, and when using subsets of supernovae that their host galaxies spin in the same direction as the Milky Way, or in the opposite direction compared to the Milky Way. Supernovae at z<0.02 are excluded. The number of supernovae used in the analysis in each experiment is specified in the table.

Rotation	#	H_o	3% error range	SD
All	140	71.069	67.739-74.321	1.758
Same direction	34	69.060	62.998-75.082	3.122
Opposite direction	48	73.824	68.484-79.976	3.158

Table 2: The H_o computed when using the full set and the different subsets of supernovae. Supernovae at z<0.02 are not excluded.

The first experiment used the same data used in (Khetan et al., 2021) with the SH0ES calibration. The second experiment was done with a subset of 34 Ia supernovae that rotate in the same direction. Since the supernovae used in (Khetan et al., 2021) are both from the Southern and Northern hemispheres, the subset was selected to include supernovae in the Northern Galactic hemisphere that their host galaxies rotate clockwise, as well as supernovae in the Southern Galactic hemisphere that their host galaxies rotate counterclockwise. The calibration set was selected in a similar manner, providing a set of nine galaxies that rotate in the same direction. Similarly, another subset was selected such that the host galaxies rotate in the opposite direction. That subset contained 48 supernovae, and the calibration set included nine galaxies that rotate in the same direction. The rest of the supernovae did not have identifiable spin directions, or were more than 60^o from the Galactic pole. Because Cepheids are more common in late-type spiral galaxies, the SH0ES collection allows to identify the spin direction of 18 out of the 19 host galaxies.

Table 1 shows the H_o computed with the full set and with each of the subsets. As was done in (Khetan et al., 2021), supernovae at z<0.02 were excluded from the analysis. Table 2 shows the same analysis, but without excluding supernovae at z<0.02. As both Tables show, when using just supernovae that their host galaxies spin in the same direction as the Milky Way, the H_o drops, and shows much lower tension with the H_o determined by the CMB. When using supernovae that their host galaxies rotate in opposite direction compared to the Milky Way, not only that H_o does not drop, but it increases and further grow the tension with the CMB.

3 Conclusion

Probes that are used to determine distances such as Ia supernovae and Cepheids have host galaxies, and are therefore affected by the rotational velocity of their host galaxies relative to the rotational velocity of the Milky Way. While the effect of Doppler shift is expected to be small, the physics of galaxy rotation is still not fully understood. Several previous empirical studies with SDSS (Shamir, 2016, 2017, 2020), Pan-STARRS (Shamir, 2017), HST (Shamir, 2020) and DECam (Shamir, 2022, 2023) show that the brightness of galaxies change significantly based on their rotational velocity relative to the rotational velocity of the Milky Way. If the brightness of objects is affected by the rotational velocity of its host galaxy, that can lead to a systematic difference in the estimated distance, and therefore a different H_o value.

The results shown here suggest that when normalizing the rotation direction of the host galaxies, the Hubble-Lemaitre constant tension is reduced. But even after normalizing the rotation of the host galaxies, the tension is not solved completely. That can be explained by the fact that the galaxies that are used are not exactly on the Galactic pole, have different inclinations, and different rotational velocities. These limitations of the experiment are expected to prevent from the analysis to fully solve the H_o tension. Naturally, another explanation is that galaxy rotational velocity is not the explanation to the H_o tension. Still, the observed H_o after normalizing the rotation of the host galaxies is within statistical error from the H_o determined by the Planck CMB radiation.

Further experiments with more data will be required to test whether the rotational velocity of the host galaxies affect the H_o. A possible link between the type and properties of host galaxies and the H_o has been noted (Khetan et al., 2021; Meldorf et al., 2022; Dixon et al., 2022). These links can be explained by the correlation between the galaxy properties and its rotational velocity. Because the rotational velocity is linked to galaxy properties, a link between the H_o and galaxy rotational velocity can be observed as a link between H_o and galaxy properties. A possible link between Ia supernovae brightness and dust (Brout and Daniel, 2020) can also be linked to rotational velocity, as late-type and early-type galaxies are different not merely in the prevalence of dust, but also in their rotational velocity.

Other related observations can be the cosmological-scale anisotropy observed through Ia supernovae (Javanmardi et al., 2015; Lin et al., 2016), that can be expected if Ia supernova brightness depends on the rotational velocity of its host galaxy relative to the Milky Way. If further experiments show that the Hubble-Lemaitre constant tension is reduced when the rotational velocities of the host galaxies are normalized, these observations can be linked to the Doppler shift effect on brightness, and consequently on the distances.

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