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# Bulk Flow Motion in the Local Universe with Pantheon+ Type Ia supernovae in the ALFALFA survey region

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**Abstract.** Peculiar velocities of galaxies near us compete with the Hubble flow, particularly in the radial direction, affecting the measurement of their recession velocities. Therefore, the knowledge of the main *bulk flow* features is important for a better determination of relative motions in the Local Universe, contributing to an accurate calculation of the Hubble-Lemaître law at very low redshifts. Our analyses aim to calculate the *bulk flow* velocity using the recently released SNe Ia data Pantheon+ catalog of Type Ia supernova data. To do this, we selected supernovae within the range of 45 to 175 Mpc (in the reference frame of the Cosmic Microwave Background) in opposite hemispheres within the region covered by the Arecibo Legacy Fast ALFA Survey (ALFALFA). We then used the Hubble-Lemaître diagram to calculate the Hubble constant, $H_0$, in each hemisphere. Our results indicate the presence of a net dipolar motion of the host galaxies of supernovae, resulting in a directional variation of $H_0$ of 2.29 km/s/Mpc.

**Resumo.** As velocidades peculiares das galáxias próximas a nós competem com o fluxo de Hubble, especialmente em direção radial, impactando a medição das suas velocidades de recessão. Portanto, o conhecimento das principais características do fluxo em massa (*bulk flow*, em inglês) é importante para uma melhor determinação dos movimentos relativos no Universo Local, contribuindo para um cálculo preciso da lei de Hubble-Lemaître em baixos redshifts. Aqui calculamos a velocidade do *bulk flow* utilizando o recém-lançado catálogo Pantheon+ de supernovas do tipo Ia. Selecionamos supernovas no intervalo de 45 a 175 Mpc (no referencial da Radiação Cósmica de Fundo) nas 2 regiões mapeadas pelo survey ALFALFA em hemisférios opostos. Utilizamos o diagrama de Hubble-Lemaître para quantificar a constante de Hubble, $H_0$, em cada região. Nossos resultados mostram um movimento dipolar efetivo das galáxias hospedeiras das SNIa, resultando em uma variação de $H_0$ da ordem de 2.29 km/s/Mpc.

**Keywords.** Cosmology: observations – large-scale structure of Universe - supernovae: general

## 1. Introduction

Peculiar velocities are produced by gravitational fields originated from the matter distribution (Peebles 1980). As a collective phenomenon, these velocities are termed *bulk flow*. One important motivation to analyse the features of the bulk flow, is due to the dynamical effects that it can produce, as large peculiar velocities in our nearby galaxies; therefore, studying in detail such features contributes to an accurate calculation of the Hubble-Lemaître law at very low redshifts. Previous works (see, e.g., Tully et al. (2019); Turnbull et al. (2011)) calculate the magnitude of the bulk flow velocity and the direction where it points. Our analyses aim to calculate the velocity of the bulk flow using the recently released SNe Ia data Pantheon+ catalog (Brout et al. 2022), using the Hubble-Lemaître diagram for SNe in opposite hemispheres around the region covered by the Arecibo Legacy Fast ALFA Survey (ALFALFA).

## 2. Data selection

The Pantheon+ catalogue contains 1701 type Ia SNe, along with information such as the sky's angular position, redshift, distance modulus, all accompanied by their respective uncertainties, and the covariance matrix, which we will use in our analyses.
To determine the distance interval, we performed multiple tests in which we sought the smallest root-mean-square error of the $H_0$ values obtained within that interval. We also considered the fact that galaxies very close to us are not expected to follow the Hubble flow, due to the dominance of local gravitational fields. Thus, we selected SNe within the range of 45 to 175 Mpc (in the Cosmic Microwave Background reference frame) in the region covered by the ALFALFA, forming a sample of 200 SNe Ia (Figure 1).

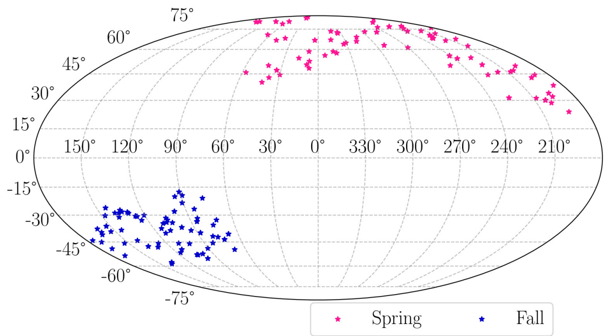


**Figure 1.** SNe Ia from Pantheon+ Catalog in the ALFALFA region in galactic coordinates system.

## 3. Methodology

We initiate our analyses by calculating the distances of each SNe Ia. For this purpose, we compute first the luminosity distance using the relation

$$D_L \equiv 10^{\frac{\mu-25}{5}} , \tag{1}$$

where $\mu$ is the modulus distance and where $D_L$ is given in Mpc. For the recession velocity of SNe Ia at low redshifts, we employed the non-relativistic relation

$$v = c\, z_{CMB} , \tag{2}$$

where $z = z_{\rm CMB}$ is the SN redshift in the CMB frame. To plot the Hubble-Lemaître diagram in the Local Universe, $H_0$ is given by the constant of proportionality between distances, $D_L$, and redshifts, $z$, in the relation

$$H_0 = \frac{c\, z_{CMB}}{D_L} \,. \tag{3}$$

### 3.1. The Bulk Flow in the ALFALFA region

The magnitude of the dipole is proportional to the projection of the bulk flow (Turnbull et al. 2011) velocity and inversely proportional to the effective distance R (Avila et al. 2023),

$$R = \frac{\sum D_L/\sigma^2}{1/\sigma^2} \,, \tag{4}$$

$$V_{BF} = \frac{1}{2}\frac{\delta H_0 R}{\cos\theta} \,, \tag{5}$$

where $\theta$ is the angle formed between the dipole $\overrightarrow{\delta H_0} \equiv \overrightarrow{H_0^S} - \overrightarrow{H_0^F}$ and the bulk flow direction that can be found in Avila et al. (2023).

### 3.2. Uncertainties in Peculiar Velocities of SNe Ia

To compute the effective distance R, it is essential to verify the values of $\sigma_{v_{pec}}$. To accomplish this, we employ the Hubble-Lemaître Law in conjunction with error propagation tools, resulting in the derivation of the following expressions

$$v_{pec} = H_0 D_L - c\, z_{CMB} \,, \tag{6}$$

$$\sigma_{v_{pec}} = \frac{1}{\sqrt{2}}\sqrt{D_L^2\sigma_{H_0}^2 + H_0^2\sigma_{D_L}^2} \,. \tag{7}$$

## 4. Results

Our measurements of the Hubble constant show a dipolar feature, as observed in the Hubble diagram 2, we obtain $H_0^S = 71.91 \pm 0.56$ km/s/Mpc and $H_0^F = 69.62 \pm 0.53$ km/s/Mpc for the spring and fall regions, respectively.

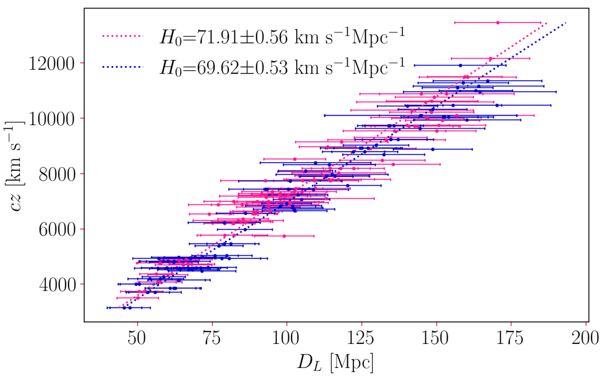


**Figure 2.** Hubble-Lemaître diagram for the SNe Ia data shown in Figure 3 (north and south galactic regions of ALFALFA survey).

The observed difference in measurements of the Hubble constant can be attributed to the relative motions of cosmic objects in the Local Universe, specifically the interplay between the motion of supernova host galaxies resulting from cosmic expansion, known as the Hubble flow, and their intrinsic peculiar motions in relation to the matter structures in the universe, including the bulk flow. Considering that $\theta \simeq 68°$ is the angle between the dipole $\delta H_0 = 2.29 \pm 0.77$ km/s/Mpc and the bulk flow direction in the ALFALFA region and the effective distance $R = 87.71 \pm 9.33$ Mpc obtained using equation 4, we can calculate the velocity of the bulk flow using equation 5

$$V_{BF} = \frac{1}{2}\frac{(2.29 \pm 0.77)(87.71 \pm 9.33)}{\cos 68°} \,, \tag{8}$$

where one finds $V_{BF} = 268.1 \pm 118.7$ km/s. Our results are robust, and in good agreement with the values reported in the literature, and is also consistent with the expected value within the standard model of cosmology as can be observed in Figure 3.

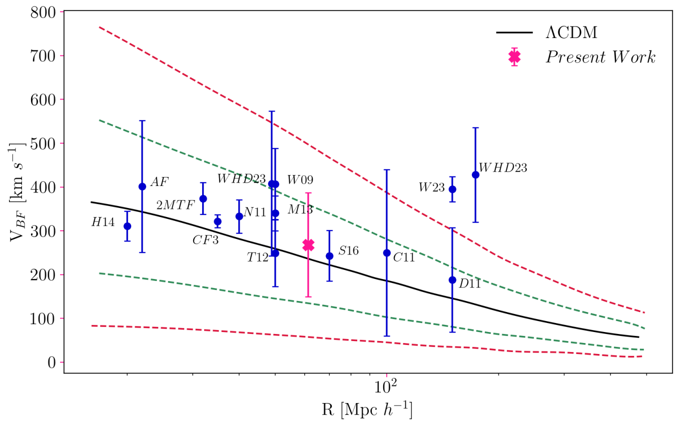


**Figure 3.** Bulk flow velocity measurements compared with the literature: the continuous line represents the expected value for the bulk flow velocity, light-blue and yellow dashed lines represent $1\sigma$ and $2\sigma$, respectively (adapted from Avila et al. (2023)).

## 5. Conclusions

The study of matter clustering, and the effects it produces in the 3D matter distribution, is important to understand the cosmic structure formation (Marques et al. 2018; Marques & Bernui 2020; Avila et al. 2018, 2019, 2021; de Carvalho et al. 2020; Dias et al. 2023; Oliveira et al. 2023; Franco et al. 2023). Our analyses indicate that, indeed, there is a bulk flow motion manifested through the dipolar behavior of $H_0$ in the ALFALFA regions as detected by our SNe Ia analysis, with a variation of $H_0$ of 2.29 km/s/Mpc in the directions inspected, providing a measurement of the *bulk flow* velocity that agrees in 1 $\sigma$ with the expected value.

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