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Determination of the Hubble constant from blue dwarf galaxies

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In modern cosmology there is a problem of the „Hubble tension" — a discrepancy between independent estimates of the Hubble parameter H_0 from relic radiation and from local observations at the $\sim 4\sigma$ level. Accumulation and refinement of observational data can help to solve this problem. This work is devoted to an independent determination of H_0 from an analysis of the distance scale of blue dwarf galaxies. For this purpose, 5605 objects with redshifts $z < 0.3$ were selected from the SDSS DR17 catalogue. A value of $H_0 = 68.98 \pm 0.21$ km/s/Mpc was obtained from the sample analysis, which is in good agreement with the results of other independent studies.

Keywords: Hubble constant, HII regions, dwarf galaxies, cosmology.

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Introduction

The standard ΛCDM cosmological model, which describes the dynamics of the expansion of the universe at all stages of its evolution, is in good agreement with most of the observational data obtained for different cosmological epochs from the Big Bang to the present day. However, there are several points where ΛCDM model predictions differ from observations. One of such problems is the known problem of „the Hubble crisis" („H_0-tension"). It consists in the fact that the direct observational estimates of the Hubble parameter value H_0, describing the current speed of the Universe expansion disagree with the model-dependent estimates produced on the basis of the analysis of cosmological observations, at the level $\sim 4\sigma$ [1]. The reason for this discrepancy is currently unclear and is one of the most acute problems in modern cosmology.

The indirect prediction H_0 is based on the measured values of the standard cosmological parameters of the ΛCDM-model [2]. The values of these parameters are calculated by analysis of the anisotropy of the cosmic microwave background (CMB), which is formed in 380 thousand years after the Big Bang [3]. These measurements are in excellent agreement with independent measurements of the same parameters based on observational data from other cosmological epochs (e.g., from measurements of primary element abundances) [4,5]. The relevant value of the Hubble constant within ΛCDM-model has the value of $H_0 = 67.5 \pm 0.5$ km/s/Mpc [3].

Direct estimates of H_0 are obtained from analysing the local distance scale, i.e. measuring the distance to „standard candles" and measuring their removal rate [1]. The „standard candles" in astrophysics are the objects, the absolute luminosity of which may be calculated on the basis of certain indirect observational signs [2]. The most common standard candles used to determine the local value of the Hubble parameter are the type Ia supernovas and cepheids [6]. The relevant value of the Hubble constant measured along the local scale of distances has the value of $H_0 = 73.2 \pm 1.3$ km/s/Mpc [6].

The present work focuses on the determination of H_0 from the analysis of a distance scale based on observations of blue dwarf galaxies with redshifts of $z < 0.3$. For this purpose, we use the relation between the total luminosity in the Hβ line L and the velocity dispersion in the σ galaxy, first described in [7]. To determine the value H_0, a sample of galaxies is used that was specially prepared for this task, with the galaxies chosen from the open SDSS DR17 catalog [8].

1. Sample of objects

The open SDSS DR17 catalog [8] contains spectra of 88 490 blue dwarf galaxies. The objects for research were selected using the criterion of the presence of measured emission lines of the Balmer series (Hα, Hβ, Hγ and Hδ) and metals ([OIII] 4363 Å and 4959/5007 Å, [SII] 6717/6731 Å, [NII] 6548/6584 Å) in the spectrum at the level of signal–noise ratio ≥ 3.5. For this purpose, continuum modelling was performed in the vicinity of each line, the noise magnitude was estimated, and compared to the peak height of the emission line. To automatically select the spectra for this task, the software was written using Python 3 language. Using this software, 5,605 objects were selected for further analysis from all spectra of dwarf galaxies from the SDSS DR17 catalog. The produced sample is one of the largest in the world among those used to define H_0.

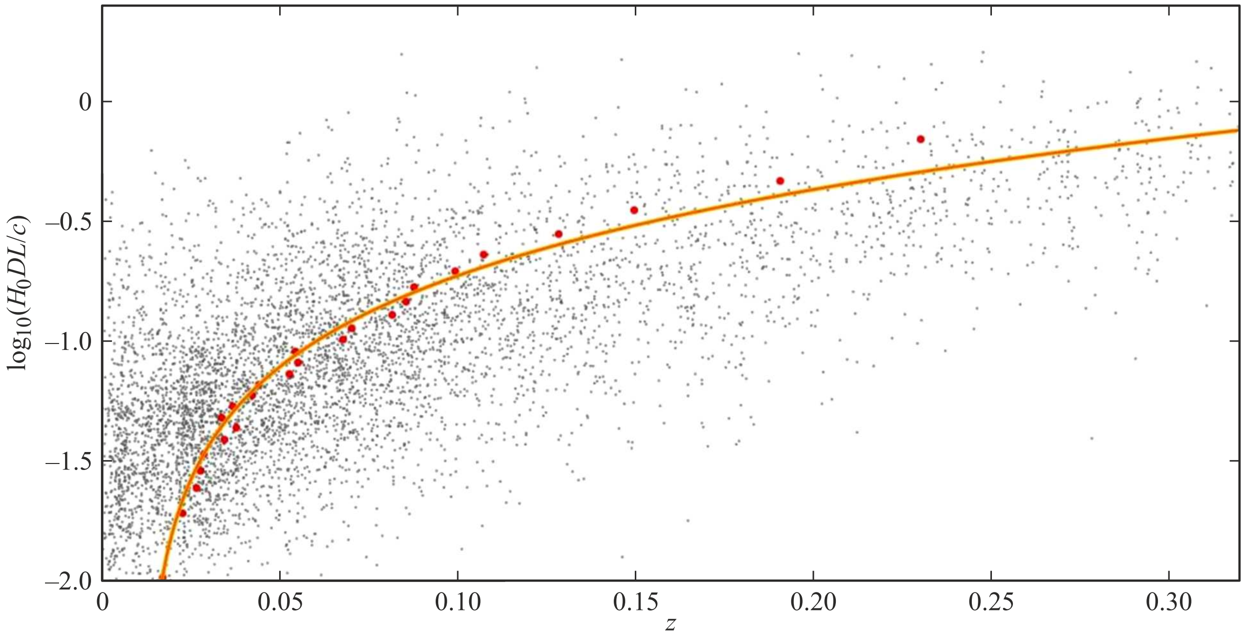

Diagram „D_L-z“ for 5605 objects selected from the SDSS DR17 catalog. Grey dots — data on each object, red dots — weighted average values, yellow line — model function $D_L(z)$.

2. Data analysis

In order to define the Hubble constant using HII regions of dwarf metal-poor galaxies, it is necessary to measure their red shift and distance to them. The red shift of such objects is defined with very high precision, since the spectra of these objects have powerful emission lines of hydrogen, the laboratory wavelengths of which are known. To determine the distance, the ratio $F_0 = L/4\pi D_L^2$ is used, where F — observed flow in the line, L — initial luminosity of the line, D_L — photometric distance to the galaxy. To define the initial luminosity of the object in the line, the ratio $L-\sigma$ is used from paper [9]:

$$\log L = (33.71 \pm 0.21) + (4.65 \pm 0.14) \times \log \sigma.$$

It makes it possible to define the full luminosity of the galaxy in the line Hβ, based on the measured value of dispersion of the galaxy velocities σ. The observed line Hβ is additionally widened due to the hardware function of the spectrograph and due to thermal broadening. Therefore, the required value σ is calculated using the ratio:

$$\sigma^2 = \sigma_0^2 - \sigma_a^2 - \sigma_t^2,$$

where σ_0 — the observed dispersion of the velocities, $\sigma_t = \sqrt{kT/m}$ — thermal dispersion of velocities (T — temperature of HII-region), $\sigma_a = 69$ km/s — width of the hardware function of SDSS telescope [8].

Also, when calculating the distance, interstellar reddening — attenuation of the measured line fluxes due to scattering on interstellar dust — must be taken into account, which is accomplished using the formula

$$F_0 = F_{obs} \cdot 10^{3.1\mathrm{C(H}\beta)/f(\mathrm{H}\beta)},$$

where C(Hβ) — logarithmic coefficient of reddening, defined using Balmer decrement, $f(\lambda)$ — reddening function from [10].

Two programs were written in Python 3 to analyse the objects:

1) program to measure hydrogen, oxygen and sulphur emission line fluxes by modelling the continuum and fitting a Gaussian profile to the observed line profile. The optimal parameters of the profile are defined using the Monte Carlo method, the fitting confidence is assessed using the criterion χ^2;

2) program to determine the physical conditions in the galaxy (temperature and electron concentration), and to account for corrections for the systematic effects of underlying absorption [11] and interstellar reddening. The physical conditions are also defined using the Monte Carlo method.

Using these programs, the physical conditions were defined for each of the 5,605 objects, and their red shift was calculated, as well as the distance thereto. The calculation results are presented in the figure.

To determine the Hubble parameter using the Monte Carlo method, the measured data were fit to distances and redshifts using the relation from
jcite2:

$$D_L(z) = \frac{z}{H_0}\left(1 - \frac{z}{2}q_0\right),$$

where H_0 — Hubble parameter, q_0 — deceleration parameter, which defines the acceleration of the Universe expansion. The following estimates for these parameters were obtained: $H_0 = 68.98 \pm 0.21$ km/s/Mpc, $q_0 = -0.65 \pm 0.05$.

The produced estimate is between the estimates obtained on the basis of the CMB anisotropy analysis

($H_0 = 67.5 \pm 0.5$ km/s/Mpc) and on the basis of „late" observations ($H_0 = 73.2 \pm 1.3$ km/s/Mpc), and at the same time it has noticeably higher accuracy. Further increase of the sample and improvement of the photoionization model of HII-regions will make it possible to confirm the produced estimate H_0, and, potentially, help solve the problem of H_0-tension.

Conclusion

In work we analysed the spectra of blue dwarf galaxies selected from the SDSS DDR17 catalogue in order to measure the present-day value of the Hubble constant. Within the paper, 5,605 objects were selected, the analysis of which produced the following estimates for the value of the Hubble constant and the acceleration of the Universe expansion: $H_0 = 68.98 \pm 0.21$ km/s/Mpc, $q_0 = -0.65 \pm 0.05$. The produced results agree well with other independent estimates of the Hubble parameter [1], and at the same time they have much higher precision. In the future, it is planned to expand the sample of objects and estimate the magnitude of the systematic error of this method, as well as to take into account the following terms of the $D_L(z)$ expansion, which will significantly improve the accuracy of the Hubble parameter and other cosmological parameters.

Conflict of interest

The authors declare that they have no conflict of interest.

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