Determination of the Combination of Cosmological Parameters $\Omega_m^{\alpha}\sigma_8$

S. L. Parnovsky*
Taras Shevchenko Kiev National University, pr. Akademika Glushkova 2, Kiev, 03680 Ukraine
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Abstract—We have obtained new constraints on the cosmological parameters $\Omega_m$ and $\sigma_8$ from the peculiar velocities of flat edge-on spiral galaxies from the RFGC catalog. Based on these results presented graphically, we have found the quantitative condition $(\Omega_m/0.3)^{0.37}\sigma_8 = 0.92 \pm 0.05$. The estimates of $\Omega_m$ and $\sigma_8$, along with their combinations $\Omega_m^{\alpha}\sigma_8$ for various $\alpha$, are compared with the estimates by other authors.

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INTRODUCTION

In the last decade, substantial progress has been made in cosmology. It concerns not only the qualitative change in the present views of the Universe, which gave rise to the concepts of dark matter and dark energy, but also the transition to an exact cosmology. The accuracy of measuring the cosmological constants has improved significantly. Instead of errors of several tens of percent typical of the previous stage of cosmology, we are now dealing with much smaller errors. In this case, it is particularly important to compare the cosmological parameters obtained by different methods. Agreement between estimates suggests that there are no fundamental contradictions in the existing models for the origin and evolution of the Universe. In addition, dissimilar estimates allow joint constraints to be imposed on the cosmological parameters.

In this paper, we deal with two cosmological parameters: $\Omega_m$, the ratio of the density of matter, including dark one, to the critical density, and $\sigma_8$, which characterizes the amplitude of the initial perturbations on a scale of $8h^{-1}$ Mpc. These parameters were estimated by Parnovsky et al. (2006) based on the peculiar velocities of 1492 galaxies from the RFGC (Revised Flat Galaxies Catalogue). The RFGC (Karachentsev et al. 1999), along with its previous version, Flat Galaxies Catalogue (Karachentsev et al. 1993), were specially compiled to study the large-scale collective motions of galaxies. The RFGC contains data on 4236 flat edge-on spiral galaxies. The redshifts and H I line ($\lambda = 21$ cm) widths or the optical rotation curves were measured for 1561 galaxies. This allowed the distances to the galaxies to be estimated from a generalized Tully–Fisher relation in the form “linear diameter–H I line width” (Parnovsky et al. 2001; Parnovsky and Tugay 2004). As a result, the radial peculiar velocities were found and published for a sample of 1561 galaxies (Parnovsky and Tugay 2005). Once the misses have been eliminated, the sample size decreased to 1492 galaxies.

The data on the peculiar velocities of these galaxies taken from Parnovsky and Tugay (2005) were processed by the method applied in Feldman et al. (2003). For this purpose, the mean relative peculiar velocities of pairs of galaxies were calculated as a function of the distance between them, $V_{12}(r)$. These velocities are related to $\Omega_m$ and the two-point correlation function of the mass density fluctuations from which $\sigma_8$ can be determined (Juszkiewicz et al. 1999). By processing the data using the maximum-likelihood method, we found the joint distributions of $\Omega_m$ and $\sigma_8$ from $V_{12}(r)$. The results of this processing are presented in Fig. 1 taken from Parnovsky et al. (2006). This figure shows the estimates of $\Omega_m$ and $\sigma_8$ and the boundaries of the $1\sigma$, $2\sigma$, and $3\sigma$ regions. Two models of the distance dependence of the correlation functions were used for the fitting. The results of our calculations based on more and less complex dependences are shown in Figs. 1a and 1b, respectively. Parnovsky et al. (2006) compared the results obtained with the estimates of cosmological parameters obtained both from the data of one year of WMAP observations and from other data. In addition, the curves of Fig. 1 were plotted in the same figure together with the joint constraints on $\Omega_m$ and $\sigma_8$ from Seljak et al. (2004) obtained from

*E-mail: par@observ.univ.kiev.ua
Fig. 1. Constraints on $\Omega_m$ and $\sigma_8$ obtained by Parnovsky et al. (2006): panels (a) and (b) show the results based on more and less complex fits, respectively. The points correspond to the most probable values; they are surrounded by the boundaries of the 1σ, 2σ, and 3σ regions.

the data on cosmic microwave background (CMB) anisotropy, clustering of SDSS galaxies, supernova explosions, and Ly-α forest. In all cases, our results are in good agreement with those obtained by other methods.

The main drawback of the results by Parnovsky et al. (2006) shown in Fig. 1 is that they are presented in graphical form. This complicates their use by other researchers. However, the graphical form was chosen, because the constructed confidence regions were narrow, but long. Therefore, each of the quantities $\Omega_m$ and $\sigma_8$ individually has an error that exceeds the error in its determination by other methods. In this paper, we obtain a numerical estimate for a combination of cosmological parameters of the form $\Omega_m^{\alpha}\sigma_8$, where $\alpha$ is the exponent lying in the range from 0.3 to 0.6. By considering such combinations, we can compare the results by Parnovsky et al. (2006) with those presented in the form of such a combination. Note that the combination $(\Omega_m/0.3)^{\alpha}\sigma_8$ is encountered more frequently. The peculiar velocities of galaxies yielded a set of such estimates for $\alpha = 0.6$. Studies of weak gravitational lensing yield estimates of this combination for $\alpha \approx 0.5$. In this paper, we find our constraints for such combinations and compare them with those obtained by other authors. The second objective of this paper is to select the exponent $\alpha$ that provides the most accurate estimate of the combination of cosmological parameters.

COMPARISON WITH THE RESULTS OF OTHER AUTHORS

Since the publication of the paper by Parnovsky et al. (2006), new estimates of the cosmological parameters that are worthy of comparing with our results have been established. These primarily include the results of processing the three-year-long WMAP observations (Spergel et al. 2007). Because of the decrease in the height of the third peak in the distribution of CMB fluctuations in multipole moments, new estimates have been obtained, $\Omega_m = 0.241 \pm 0.034$ and $\sigma_8 = 0.761 \pm 0.048$. These are farther from our results than the results of processing the first-year WMAP observations. Accordingly, the agreement between our results and the constraints found by combining the WMAP results with other estimates (Seljak et al. 2006; Tegmark et al. 2006; Lesgourgues et al. 2007) is poorer. However, the estimate of $\sigma_8 = 0.876 \pm 0.048$ obtained by Lesgourgues et al. (2007) from weak gravitational lensing alone agrees well with our second estimate. The estimates found by analyzing the catalog of clusters of galaxies (Gladders et al. 2007), the estimate by Mantz et al. (2007) established from the X-ray luminosity function of galaxies from the MACS survey, and, particularly, the estimate of $\sigma_8 = 0.92 \pm 0.1$ by Schrabback et al. (2007) turned out to be off our results as well. However, the latter result is far from all the remaining results (except for the estimate by Masters et al. (2006)) and was called by the authors a local estimate based on one field. At the same time, the estimate of $\sigma_8 = 0.92 \pm 0.1$ by Rozo et al. (2007), which was also obtained by analyzing the clustering, agrees well with our results. Our estimates are also in good agreement with the results based on an analysis of weak gravitational lensing. These include Fig. 14 from Hetterscheidt et al. (2007) and the constraints obtained by Hoekstra