ORIENTATION OF GALAXIES IN STRUCTURES

E. Panko1,2, P. Piwowarska3, J. Godłowska4, W. Godłowski5, and P. Flin6

Investigating the orientation of galaxies is a standard test for scenarios of galaxy formation since different theories of galaxy formation make various predictions regarding the angular momentum of galaxies. A new method of analyzing galaxy alignments in clusters was proposed by Godłowski [1] and is improved upon here. The distribution of position angles for galaxy major axes was analyzed, as well as the distribution of the two angles describing the spatial orientation of the galaxy plane, both of which provide information about galaxy angular momenta. The orientation of galaxies in groups and clusters of galaxies is discussed, and the results illustrate the dependence of alignment with respect to cluster richness. The implications for theories of galaxy formation are also discussed.

Keywords: angular momenta, galaxies

1. Introduction

Different theories of galaxy formation (for example, [2-10]) make different predictions regarding the angular momentum of galaxies. Classical theories dealing with the formation of galaxies and their structures were revised and improved upon by various researchers (for example, [11-23]), yet the predictions still differ. In general, the observed variations in angular momentum represent simple but fundamental constraints on any model of galaxy formation [24].

Published in Astrofizika, Vol. 56, No. 3, pp. 349-359 (August 2013). Original article submitted June 12, 2013.
In the commonly accepted $\Lambda$CDM model, the Universe is considered to be spatially flat, as well as homogeneous and isotropic at the same appropriate scale. In this model, structures were formed from primordial adiabatic, nearly scale-invariant, Gaussian, random fluctuations [25-27]. Such a picture agrees with both numerous numerical simulations [28-30, 22] as well as observations. Unfortunately angular momenta are known for only very few galaxies. As a result, the spatial orientation of galaxies is more commonly investigated instead of their angular momenta. For that one investigates either the orientation of position angles for the major galaxy axis (Hawley & Peebles [31]), or the spatial orientation of galaxy planes (Oepik [32], Jaaniste & Saar [33], Flin & Godłowski [34]).

Godłowski et al. [35] suggest that the alignment of galaxies in clusters should increase with increasing cluster richness. It can also be noted that there is essentially no evidence of rotation for groups and clusters of galaxies, implying that groups and clusters of galaxies do not rotate (for example, [36-39]; see, however, [40] for an opposite opinion). Hwang and Lee [41] recently examined the dispersions and velocity gradients in 899 Abell clusters and found possible evidence for rotation in only six of them. Thus, any non-zero angular momentum in groups and clusters of galaxies should originate solely from the possible alignment of galaxy spins.

The conclusion that richer clusters should be associated with stronger alignments originates from analyses of the implications of theoretical relationships between angular momentum and mass of structures as well as from analyses of observational results for the alignment of galaxies at different scales. Although it is commonly believed at present that galaxies were formed before clusters, the above conclusion is not in conflict with that. It can be explained both in the tidal-torque scenario [42-44] and in the Li model [45].

The prediction that the degree of alignment should increase with cluster richness was confirmed by Aryal [46], but the analyses of both Godłowski et al. [35] and Aryal [46] were only qualitative. The problem was therefore analyzed in detail in papers by Godłowski et al. [47] and Godłowski [48, 49, 1]. There it was found that the degree of alignment of galaxy orientations in clusters depends on the number of members and increases proportionally with the number of cluster members. It is equivalent to the existence of a relationship between anisotropy and the number of galaxies in a cluster. Moreover, it was found that orientations of galaxies analyzed in a sample of rich Abell galaxy clusters are not random, i.e., that there exists an alignment of galaxies in rich Abell galaxy clusters. In the present paper we investigate the problem more deeply, improving upon the new method of analysis of galaxy alignment in clusters proposed in the earlier paper [1].

2. Overview

The orientation of galaxies is usually investigated either by analyzing the distribution of position angles of galaxy major axes or by analysis of the spatial orientations of normal lines to galaxy main planes in the investigated coordinate system. Two angles are determined to establish the spatial orientation of each galaxy: $\delta_D$ – the angle between the normal to the galaxy plane and the main plane of the coordinate system, and $\eta$ – the angle between the projection of the normal onto the main plane and the direction towards the zero initial meridian.

In our previous papers it was shown that analysis of the spatial orientation of galaxy planes can be used as a general, standard test of galaxy-forming scenarios [1, 34, 47, 50-53]. Any study of galaxy orientation based on their