STABILIZATION OF SYSTEMS OF GALAXIES

BY SUBCLUSTERING

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(Received 22 July, 1978)

Abstract. We investigate the contribution of gravitationally bound subsystems to the potential energy of systems of galaxies. We derive a statistical correction factor to the virial mass using Holmberg’s observed frequency function of multiple galaxies. It is of the order of ten for groups of galaxies and negligible for rich clusters. However, we emphasize that an individual treatment is necessary. As an illustration we calculate the contribution to the binding energy by observed binary galaxies in the de Vaucouleurs groups 48 and 49, and the Coma Cluster. In all three cases a single double galaxy removes the virial mass paradox. We conclude that corrections for subclustering are substantial in stability analyses of systems of galaxies, that they can remove easily mass discrepancies of the order of ten in groups and rich clusters, and that they should be made individually and not statistically.

1. Introduction

The ‘virial theorem paradox’ for systems of galaxies is now more than forty years old and still not solved in a satisfactory way. Already in the thirties Zwicky (1933) and Smith (1936) found that for the Virgo and Coma clusters of galaxies the masses $M_{VT}$, calculated from the virial theorem, are much higher than the luminosity masses $M_L$, derived from mean mass to luminosity ratios of the members. This ‘mass discrepancy’ problem has become less acute over the years as the number and quality of observations increased.

Thus taking into account faint members, observational errors and, for rich clusters of galaxies, regular density gradients, the ratio $M_{VT}/M_L$ could be lowered to approximately eight for the Coma cluster (Tarter and Silk, 1974) or even less (Peebles, 1970), and Materne and Tammann (1974) conclude that at least a substantial fraction of the 14 nearest groups of galaxies do not show a mass discrepancy. However, the problem still does exist, especially for irregular clusters of galaxies and a number of groups of galaxies.

In case that the virial theorem paradox cannot be removed by taking into account the factors mentioned above, it was proposed long ago that either there is some kind of 'hidden mass' in these systems, or that they are unstable. We do not discuss the latter, since it is difficult to accept (for details, see, e.g., Ozernoy, 1975). The hidden mass hypothesis is also not without serious problems. Without going into details, we want to mention the well-known fact that all attempts to hide the mass in a diffuse

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intracluster medium, be it neutral or hot gas, or dust, cannot be reconciled with observation. We are not considering here exotic explanations like an intracluster stratum of black holes of small mass. Supermassive black holes are excluded because of the lack of strong tidal distortions of cluster members which are not in close binaries (van den Bergh, 1969).

In this hypothesis the most plausible possibility is to hide the missing mass in massive halos around galaxies, exterior to the regions for which rotation curves are measured. There is some recent evidence for the existence of such halos. Thus, e.g., Turner gives mean mass-to-luminosity ratios $M/L$ for late type galaxies in binaries of 65 to 100 $M_\odot/L_\odot$ (Turner, 1976; Turner and Ostriker, 1977), whereas rotation curves yield for the same types $M/L \approx 10 M_\odot/L_\odot$ (Brosche and Reinhardt, 1977). However, this factor cannot explain all of the mass discrepancy for groups and clusters with $M_{vr}/M_*$ of up to $10^2$ to $10^3$. Moreover, if all galaxies would have massive halos, one could not understand why there are groups which do show a very serious mass discrepancy and others with similar population according to type which do not, even if the relative mass of the halo were dependent on type. This remark applies in particular to the hypothesis that the hidden mass is localized in very massive halos of giant ellipticals, since usually they do not occur in groups and open clusters of galaxies, which have on the average a much higher mass discrepancy than regular rich clusters. Therefore, it seems that the ‘massive halo’ assumption alone cannot solve the virial mass paradox. Recently Wesson and Lermann (1977a) have drawn attention to the fact that the binding energy of gravitationally bound subsystems might provide a clue to the virial theorem paradox in rich clusters of galaxies. Continuing the analysis of type segregation in groups of galaxies (Ozernoy and Reinhardt, 1976), the authors came independently to a similar conclusion which, however, differs in several points substantially from that of Wesson and Lermann. In this contribution we want to discuss the rôle of systems of galaxies in their stabilization.

2. The Contribution of Subclustering to the Virial Mass

2.1. The Model of Subclustering

Let us first consider a system of $N$ objects of equal mass $m$. Wesson and Lermann (1977a) assumed that the frequency of subsystems of multiplicity $n$ is $f(n) = 2^{-n}$. They based this assumption on de Vaucouleurs’s (1971) estimate of the frequency of multiple systems observed by Holmberg (1940) and van Albada’s (1968) results from numerical $n$-body experiments. However, de Vaucouleurs’ frequency function $f(n) = 2^{-n}$ for systems of multiplicity $n$ is due to a misreading of Holmberg (1940, 1962), whose observations give a relative frequency as quoted above not for the systems of multiplicity $n$ themselves, but for the number of galaxies in multiple systems. Thus the frequency function used by Wesson and Lermann (1977) overestimates the observed relative number of systems with multiplicity $n$ by a factor $n$. 