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Detection of dark matter in early-type galaxies with X-ray haloes using absorption spectral lines

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Abstract. In this contribution, which is a summary of my PhD thesis, I discuss the existence of dark matter in the early-type galaxies with and without X-ray haloes. I show that using high quality long-slit integrated stellar spectra obtained from various sources related to the field, binary, group and cluster galaxies there is no strong evidence for dark matter out to three effective (half-light) radii.

Key words. Dark Matter – Galaxies – Spectral lines

1. Introduction

The problem of dark matter remains perhaps the most important astrophysical problem in contemporary cosmology and extragalactic astronomy. Although its nature is still unknown, general opinion is that it exists and that it is a necessary ingredient of every viable cosmological model. The existence of the dark matter in spiral galaxies (late-type galaxies), like our own, Milky Way, is rather clear mainly because of existence of cool gas which provides a powerful tool for obtaining rotation curves that are, for most spirals, nearly flat thus indicating presence of dark mass in their outer parts – dark haloes. However, the problem of dark matter in elliptical galaxies (early-type galaxies) is more complicated – it is more difficult to confirm the presence of dark haloes around ellipticals because they contain little or no cool gas and one cannot use 21-cm observations to trace kinematics of neutral hydrogen out to large radii, as it is possible in the case of spirals. Hot gas can be found in the X-ray haloes with $T \sim 10^7$ K. These haloes can provide a means of measuring the amount of dark matter at large distances from the nucleus, a means potentially as powerful as rotation curves in spirals.

2. Results

In my PhD thesis (Samurović 2004) I explored the existence of dark matter in the early-type galaxies with and without X-ray haloes. I used high quality long-slit integrated stellar spectra obtained from various sources related to the field, binary, group and cluster galaxies from which, after the reduction procedure, I extracted full line-of-sight velocity profiles which include: velocity, velocity dispersion and the Gauss-Hermite parameters, h_3 and h_4, that describe asymmetric and symmetric departures from the Gaussian, respectively (van der Marel & Franx 1993). The an-

Send offprint requests to: Srdjan Samurović alyzed spectra extend from the center out to one to three effective (half-light) radii. Some published data from the literature related to the kinematical and photometric parameters were also used.

I modeled the velocity profiles as a truncated Gauss-Hermite series, taking into account aforementioned quantities. I performed modelling of the velocity profiles using two- and three-integral modelling approaches. *Two-integral models* are based on the solving of the Jeans equations and have as basic assumptions axisymmetry and isotropy of the velocity dispersion tensor (cf. Binney et al. (1990); Cinzano & van der Marel (1994)). In this modelling it is necessary to do the inversion of the luminosity profiles to obtain three-dimensional luminosity density that provides the mass density (under the assumption of constant mass-to-light ratio). Then, one calculates the potential (assuming the distribution function which depends on two-integrals: $f(E, L_z)$, where E is the energy and L_z is the angular momentum of the individual star about the symmetry axis of the galaxy). Finally, a comparison is done of the projected kinematical quantities from the model with the observed kinematic parameters; a disk, and/or a dark halo are also included in the modelling procedure. From the two-integral modelling I infer that some galaxies (most notably IC 1459 and IC 3370) could not be fitted perfectly with this approach thus leading to the conclusion that their distribution function depends on three integrals of motion. This kind of modelling, however, provided useful constraints on the mass-to-light ratios in these galaxies. It was shown that in all cases for which two-integral approach was applied (IC 1459, IC 3370, NGC 3379 and NGC 4105) the modelling of the velocity dispersion shows that there is no need for the massive dark haloes within the last observed points (at most $\sim 3R_e$). The constant mass-to-light ratio is ~ 7 (in the solar units, in the B-band) and is typical for the early-type galaxies.

Three-integral models based on the Schwarzschild's (1979) numerical orbital superposition model were made for the four galaxies mentioned above and also for the galaxies from the Fornax cluster and several galaxies from the literature. This kind of modelling is used for modelling of triaxial systems and it is assumed that the distribution function has the form $f = f(E, L_z, I_3)$, where I_3 is the third integral for which no general expression exists. The basic steps of this approach are the following: one specifies the mass model $\rho(r)$, finds its potential and then constructs a grid of cells in position space. Then initial conditions are chosen for a set of orbits and for every orbit one integrates the equations of motion for many orbital periods and measures how much time the orbit spends in each cell (that measures how much mass the orbit contributes to that cell). Finally, one needs to determine the non-negative weights for each orbit such that the summed mass in each cell is equal to the mass given by the original $\rho(r)$. General conclusion about the three-integral approach is that using the three-integral modelling technique one can obtain better fits to the observed galaxy kinematics but the price that one has to pay is rather high. This method is very CPU intensive and requires large disk storage and therefore its application is rather difficult. This kind of modelling can only provide a useful hint about applicability of a given potential (spherical, axisymmetric or flattened triaxial) for a given set of orbits. I found that this method should (or better, must) be used in combination with other approaches to infer the existence of dark haloes. Some preliminary results regarding observations and both two- and three–integral dynamical modelling were given in Samurović (2003). A general conclusion is that, while some galaxies can be fitted without the inclusion of dark matter in their haloes, judging from the three-integral models, one cannot reject its existence, because the models are marginally consistent at larger radii with this assumption.

I studied X-ray haloes of early-type galaxies in general and analyze the mass of five galaxies from my samples that possess X-ray haloes (IC 1459, NGC 1399, NGC 1404, NGC 4105 and NGC 3379) using X-ray haloes methodology. The obtained results for the mass-to-light ratios are in general in good agreement with the ones obtained using two- and three-integral modelling out to distances for which I had the spectra ($\sim 3R_e$). I note however that there is a discrepancy between the mass-to-light ratios at the larger radii ($\sim 6R_e$) obtained using other methodologies (for example planetary nebulae methodology – the case of NGC 3379) and the predictions obtained using X-rays. The results concerning four early type galaxies (IC 1459, IC 3370, NGC 3379 and NGC 4105) are given in Samurović & Danziger (2005a). In this paper we presented observational material and two–integral modelling related to these galaxies and for three of them which posses an X–ray halo (IC 1459, NGC 3379 and NGC 4105) we also presented the results of the X–ray modelling.

I also studied absorption features present in the integrated stellar spectra of early-type galaxies which provide information on the chemical evolution of these objects. Using the long-slit spectra of the galaxies from my samples I extracted absorption line indices and compared them with the available models of chemical evolution of galaxies. I showed that in some cases (most notably IC 3370) a model without dark matter provides a better agreement with the observed data.

The thesis is organized as follows. In Introduction I give the basic features of early-type galaxies and present a detailed review of the dark matter research in these galaxies. Particular attention is given to the research of the integrated stellar spectra. In Chapter 1 I present theoretical concepts related to the stellar kinematics in early-type galaxies; I also describe the reduction procedures which I apply. In this Chapter all observational results regarding galactic kinematics of the galaxies from my samples are given. Dynamical modelling of these galaxies is given in Chapter 2: after theoretical concepts I present the modelling results for two- and three-intergral modelling procedures. Chapter 3 is dedicated to the galaxies with X-ray haloes: basic formulas related to the hot gas in the X-ray haloes are given and applied to the galaxies from my samples which possess X-ray haloes. Comparison is made between the results concerning mass obtained using this approach and results obtained using stellar dynamics. In Chapter 4 I study abundance indices for some galaxies from my samples and make comparison with the results from chemo-dynamical modelling. In Chapter 5 I draw the conclusions. In Appendices I present some additional information related to some mathematical (ill-posed problems and regularization; non-negative least-squares; self-organizing maps) and dynamical (orbits in different potentials) aspects; I also present the stellar kinematics and abundance indices in table form.

Since the long–slit spectra are limited to $\sim 3-4R_e$, the next natural step is to try to probe dark matter using different techniques beyond these regions. To this end one can use different mass tracers (such as globular clusters and/or planetary nebulae) which can be observed at much larger radii. In citetSam05b we presented our results for the galaxy NGC 1399, the central early–type galaxy of the Fornax clusters, based on the kinematics of the globular clusters. We used the recently published data of Dirsch et al. (2004) which extend out to ~ 10 arcmin ($\sim 13R_e$). We applied a new "tracer mass estimator" (Evans et al. 2003) in order to get a mass estimate based on the globular clusters which is then compared to a mass obtained using X–rays. Our conclusion is that again interior to ~ 3 effective radii there is no need for dark matter. Beyond this region the velocity dispersion increases (between 2 and 4 arcmin) and then it starts to decrease (beyond ~ 5 arcmin). We conclude that in spite the fact that velocity dispersion decreases in the outer region the observations nevertheless show the evidence of dark matter in the outer parts of NGC 1399.

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