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THE PROBLEM OF STELLAR ANISOTROPIES IN NEARBY GALAXIES

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Abstract. In this contribution I discuss the problem of stellar anisotropies in galaxies in the nearby Universe and its importance for solving some issues pertaining to galactic dynamics. First, I present a necessary theoretical background using long-slit spectra of nearby early-type galaxies. Then using these spectra I show how anisotropies might affect the estimates of the total mass of a given galaxy. I also discuss the sample of nearby galaxies (consisted of both early- and late-type galaxies) extracted from the Sloan Digital Sky Survey. This is largest sample of galaxies obtained to date which contains full kinematic profile of the objects (velocity, velocity dispersion and Gauss-Hermite h_3 and h_4 anisotropy parameters). Finally, I discuss the influence of anisotropies in the stellar motions on the determination of the Lick indices.

1. INTRODUCTION

When we study external galaxies we are faced with the problem of their distances, i.e. it not possible to measure proper motions and parallaxes for stars to infer the distribution function (Binney and Tremaine 2008, Chap.4) which fully determines the dynamics of a given galaxy. In the case of external galaxies only line-of-sight (LOS) velocities and angular coordinates are available. Also, because of the finite resolution in telescopes individual stars cannot usually be resolved and the majority of the light from stars is observed in the form of an unresolved continuum. Therefore, starlight coming from an external galaxy shows averages of stellar properties of the numerous unresolved stars that lie along different lines of sight (see Binney and Merrifield 1998, hereafter BM98, Chap. 11 for an excellent introduction to the problem). However, luckily, we are still able to infer a lot about the stellar kinematics and stellar chemistry by studying integrated stellar spectra. This brief contribution will address some of the most important aspects of the problems of stellar motions in nearby galaxies.

2. THEORETICAL BACKGROUND

Each star along different LOS will have a slightly different LOS velocity and its spectral features will be shifted by a different amount: $\Delta u = c\Delta\lambda/\lambda = v_{\rm LOS}$. The spectrum of a given galaxy is therefore shifted and broadened. Fig. 1.1 in Samurović (2007) (where some details regarding the analysis the spectra of early-type galaxies are also given) shows the example of the spectrum of the galaxy IC 3370 and the spectrum of the template star.

One starts the analysis of the shifts and broadenings by defining the line of sight velocity distribution (LOSVD, also called velocity profile, VP): this is a function $F(v_{\rm LOS})$ that defines the fraction of the stars that contribute to the spectrum that have LOS velocities between $v_{\rm LOS}$ and $v_{\rm LOS}+dv_{\rm LOS}$ and is given as $F(v_{\rm LOS})dv_{\rm LOS}$. If one assumes that all stars have identical spectra $S(u)$ (where u is the spectral velocity in the galaxy's spectrum; this is of course a very rude but useful approximation), then the intensity that is received from a star with LOS velocity $v_{\rm LOS}$ is $S(u-v_{\rm LOS})$. When one sums over all stars one gets:

$$G(u) \propto \int dv_{\rm LOS} F(v_{\rm LOS}) S(u - v_{\rm LOS}). \tag{1}$$

This relation represents the starting point for a study of stellar kinematics in external galaxies (BM98). The observer gets $G(u)$ for a LOS through a galaxy by obtaining its spectrum. If we use a star which represents a galaxy as a whole as mentioned above, one can estimate $S(u)$ using a spectrum of a star from the Milky Way galaxy (see the aforementioned Fig. 1.1 from Samurović (2007), lower part).

First we can define the simplest properties of a LOSVD. Its mean value is given as:

$$\bar{v}_{\rm LOS} = \int dv_{\rm LOS} v_{\rm LOS} F(v_{\rm LOS}). \tag{2}$$

Its dispersion is given as:

$$\sigma^2_{\rm LOS} = \int dv_{\rm LOS} (v_{\rm LOS} - \bar{v}_{\rm LOS})^2 F(v_{\rm LOS}). \tag{3}$$

One possible solution is to assume that the LOSVD has the Gaussian form. For historical details we refer the reader to BM98 and Samurović (2007).

The more recent and more detailed approach (van der Marel and Franx 1993) assumes that LOSVD can be modeled as truncated Gauss-Hermite ($F_{\rm TGH}$) series that consists of a Gaussian that is multiplied by a polynomial:

$$F_{\rm TGH}(v_{\rm LOS}) = \Gamma \frac{\alpha(w)}{\sigma} \left[1 + \sum_{k=3}^{n} h_k H_k(w) \right], \tag{4}$$

here Γ represents the line strength, $w \equiv (v_{\rm LOS} - \bar{v})/\sigma$, $\alpha \equiv \frac{1}{\sqrt{2\pi}} \exp(-w^2/2)$, where $\bar{v}$ and σ are free parameters. h_k are constant coefficients and $H_k(w)$ is a Gauss-Hermite function, that is a polynomial of order k. We will truncate the series at $k = 4$ (although higher values are also possible), for which the polynomials are given in van der Marel and Franx 1993. How a Gauss-Hermite function modifies a pure Gaussian function is given in Fig. 11.5 in BM98 and Fig. 1.2 in Samurović (2007). To obtain a successful fit we need to vary $\bar{v}$, σ, h_3 and h_4 until convolution of this function and stellar template best reproduces the observed galaxy spectrum. If LOSVD is close to Gaussian: $\bar{v}$ and σ will approximately be equal to $\bar{v}_{\rm los}$ and $\sigma_{\rm los}$. If one detects a positive (negative) value of the h_3 parameter that would mean that the distribution is skewed towards higher (lower) velocities with respect to the systemic velocity. As for the h_4 parameter, there can be two anisotropic cases: *(i)* $h_4 < 0$, a case for which tangential orbits dominate and *(2)* $h_4 > 0$, a case for which radial orbits dominate.

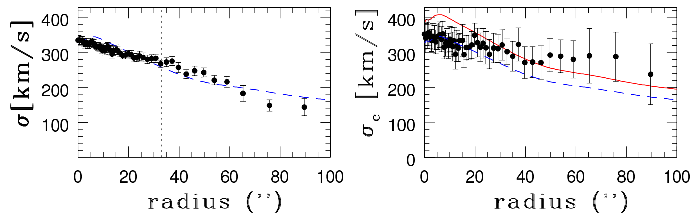

Figure 1: Dynamical modelling of IC 1459. *Left*: Dynamical modelling of the uncorrecred velocity dispersion. Dotted line denotes one effective radius (33 arcsec = 3.87 kpc for $h_0 = 0.7$). *Right*: Dynamical modelling of the corrected velocity dispersion.

3. STELLAR ANISOTROPIES IN NEARBY GALAXIES

The study of anisotropies in different galaxies is important because tangential (radial) anisotropies may mimic higher (lower) inferred mass in a given region. This is of a significant importance in external regions (haloes) of early-type galaxies where dark matter is expected to dominate (Samurović 2007). There, for example, excessive tangential stellar motions may mimic the existence of dark matter.

It can be shown (see van der Marel and Franx 1993) that the observed velocity dispersion should be corrected for the effects of non-zero values of the h_4 parameter:

$$v_{\rm corr} = \sigma_{\rm GH}(1 + \sqrt{6}(h_4)_{\rm GH}), \tag{5}$$

where the index "GH" is related to the Gauss-Hermite estimes.

Some examples of long-slit spectra of early-type galaxies are given in Samurović and Danziger (2005) (also in Samurović 2007). The kinematics of IC 1459 given there is a good example of the existence of radial anisotropies in the outer parts of this galaxy (note high values of the h_4 parameter there). In Fig. 1 (left panel) the values of the *uncorrected* velocity dispersion are showed together with the dynamical model for which mass-to-light ratio in the B-band is $M/L_B \sim 7$ (dashed line); in the same Figure (right panel) the values of the *corrected* velocity dispersion together with the same dynamical model for which $M/L_B \sim 7$ and the model for which $M/L_B \sim 10$ (solid line). It is obvious that higher M/L_B ratio provides a better fit in the outer regions implying the increase of the cumulative mass there.

The same methodology can be applied to late-type galaxies when one studies, for example, the inner regions and the possible influence of the central black hole: for brevity, we mention here Gültekin et al. (2009) who recently studied the kinematics of five galaxies (which includes Gauss-Hermite parameters).

Samurović, Lalović and Vince (2010) recently created a sample of galaxies extracted from the Sloan Digital Sky Survey (SDSS) catalog: it of 573 galaxies (243 early-type and 330 late-type) for which they extracted full kinematical profiles. In Fig. 2 we show the anisotropies as described with the h_3 and h_4 parameters.

Finally, we also address briefly the impact of stellar anisotropies on the Lick indices. S. Faber and her collaborators started in 1972 a long-term spectroscopic project that was aimed at the study of the stellar populations in globular clusters and early-type galaxies `Image Dissector Scanner (IDS)` on the Shane 3m telescope of Lick Observatory. They observed a large number of galaxies, and stars of all types, field and

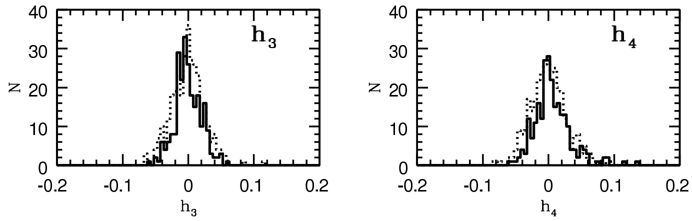

Figure 2: Anisotropies of the galaxies extracted from the SDSS sample. Left: the histogram of the h_3 parameter. Right: the histogram of the h_4 parameter. In both panels early-type galaxies are plotted using solid line and late-type galaxies are plotted using dotted line.

cluster giants, subgiants and dwarfs in the spectral range from $\sim$ 4000 Å to $\sim$ 6200 Å with a $\sim$ 8.6 Å FWHM resolution. We have recently tested (Samurović 2009) findings of Kuntschner (2004) and showed that the departures from the Gaussian LOSVD indeed cause erroneous determinations of the Lick indices. The impact of the introduction of non-Gaussian LOSVD differs for different indices. For the aforementioned galaxy IC 1459 it is shown that the iron indices are especially sensitive when the correction due to anisotropies is introduced: the corrections for Fe5270 and Fe5335 are $\sim$ 10 and $\sim$ 19 percent larger than the corrections obtained in case of a pure Gaussian, respectively. The corrections for Mg_2 index are shown to be negligible and the corrections of the H_β index due to anisotropies are also small (below $\sim$ 4 per cent at most).

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