Near-Field Cosmology with Dwarf Elliptical Galaxies
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The Sagittarius dwarf mass-to-light ratio

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Abstract. We report on the use of high-resolution spectra to obtain a detailed description of the Sagittarius dwarf spheroidal internal dynamics, its Mass and Mass to Light ratio (M/L). Our direct measure of the central velocity dispersion of SGR give $\sigma_{SGR} = 8.1 \pm 0.4$ km/s which translates in a total mass estimate of $M_{SGR} = 1.6 \times 10^8 M_\odot$ and corresponding $(M/L)_{SGR} = 9.1(M/L)_\odot$. We also report on a possible detection of rotation in the core of SGR.

Keywords. dwarf galaxies – kinematics – mass

1. Introduction

The Sagittarius (SGR) dwarf galaxy is actually the nearest companion of the Milky Way undergoing a tidal disruption. Its vicinity represent a unique opportunity to look in detail a possible Searle & Zinn (1978) galactic fragment formed in the outer halo, later captured by the inner Galaxy and actually under its final stages of disruption: in the hierarchical galaxy formation scenarios this kind of galaxies may represent the basic building blocks of larger galaxies.

A very important aspect of the SGR structure is represented by its internal kinematics and the kinematics of its stellar tails. While for this later aspect the group of Majewski (Law *et al.* 2005) has recently performed a very complete observational-theoretical study of the SGR dynamical history using the kinematics of the tails, no direct measurements yet exist on the dynamics of the core of SGR and of its relation with the M54 globular cluster. The only kinematic information on the body of SGR comes from the work of Ibata *et al.* (1997), who used radial velocity measurements from low resolution spectra claiming an $(M/L)_{SGR}$ of as much as $\simeq$50, implying the presence of a big dark halo. This estimate has been revised by Majewski *et al.* (2003) using an updated total luminosity for the SGR body proposing an $(M/L)_{SGR} \simeq 25$. The recent work of Law *et al.* (2005) on the modeling of the stellar tidal tails, set the following constraints on the total mass and mass to light ratio: $M_{SGR} = 2 \div 5 \times 10^8 M_\odot$ and $(M/L)_{SGR} = 14 \div 36(M/L)_\odot$.

In this paper we present the first direct measurement of the central velocity dispersion and Mass estimate based on high-resolution spectra for a large sample of stars in the core of SGR.

2. Observations

The data presented here are part of the Guaranteed Time Observations (GTO) awarded to the *Ital-FLAMES* consortium (see Cacciari 2003) who collaborated with ESO at the development, construction and installation of the VLT FLAMES facility (Pasquini *et al.*

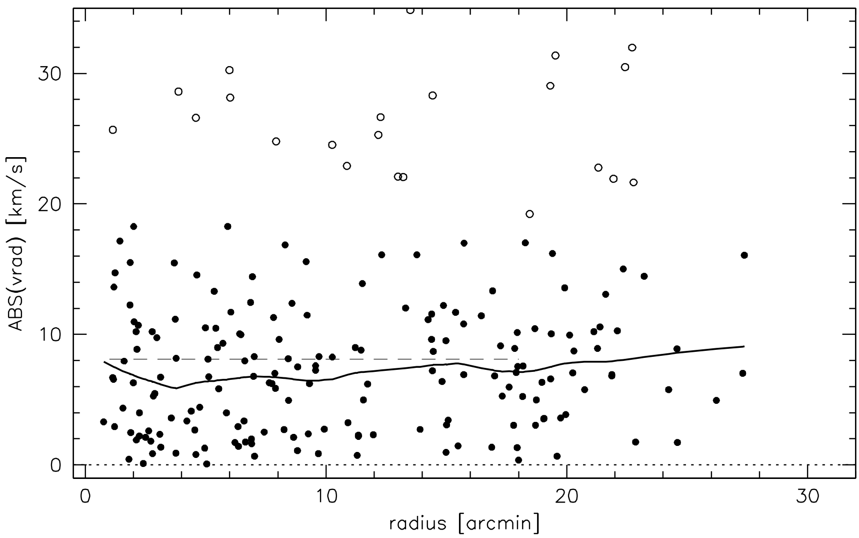

Figure 1. Radial velocity dispersion profile in the core of the SGR galaxy. The single radial velocities are folded around the mean: filled dots SGR members, open dots non-members; the continuous line is the LOWESS estimate of the velocity dispersion profile; the dashed line is the velocity dispersion of the whole sample of objects.

2000). FLAMES is installed at the Nasmyth A focus of the VLT/UT2 telescope and is composed by a fiber positioner, OzPoz, which feeds the dedicated medium-high resolution GIRAFFE (resolving power ∼20000) and the UVES (resolving power ∼40000) spectrographs. FLAMES has a multiplex capability of 132 single fibers with GIRAFFE (in the MEDUSA mode) and 8 fibers with UVES, over a large field of view of ≃28 arcmin in diameter. We aimed at obtaining a S/N ratio of the spectra of better than ≃20 in two different GIRAFFE setups: HR09 centered at 515 nm and HR14 at 650 nm.

For the present program it was used 1 GTO night in May 2003 in order to observe a total of 280 stars with GIRAFFE, both in the SGR field and in the Globular Cluster M54. One year later, in July 2004, we obtained additional observing time for a total of 5 hours spread on two adjacent fields connected to the 2003 fields. In this case we observed a total of 230 stars. The two samples, 2003 and 2004, totaled 510 stars of which 189 turned out to be radial velocity members of SGR.

The 4 observed FLAMES fields cover: the center of the cluster M54 (supposed to be coincident with the center of SGR, Monaco *et al.*, 2000; Majewski *et al.* 2003), and 3 fields at 12 arcmin East, West and North of the center. Being FLAMES a "blind" instrument (it has no pre-imaging capabilities) it needs a very high precision astrometric catalog for the input targets. The selection of the targets were performed on the Monaco *et al.* (2002) V, I photometric and astrometric catalog (based on EIS Pre-FLAMES images Zaggia *et al.* 2001) which contains nearly half-million objects over 1 square degree around the center of SGR. We selected objects with magnitude in the range $16 \div 17.5$ in a diagonal strip of the (V−I) color which cross the RGBs of M54 and SGR in order to search for any possible metallicity present.

The reduction of the GIRAFFE multi-spectra have been performed using the FLAMES data reduction pipeline developed by the Geneva Observatory Blecha *et al.* (2001) while UVES spectra have been reduced with a modified UVES pipeline. The radial velocities have been extracted using a traditional cross correlation technique. We also obtained the

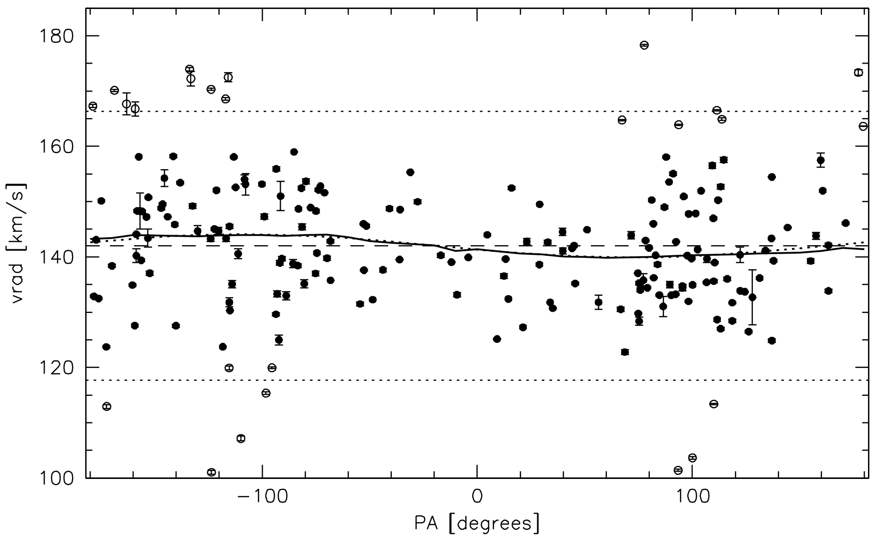

Figure 2. Radial velocity rotation curve. Filled dots are SGR members while open dots are non-members. The continuous line shows the running mean of radial velocity along the position angle calculated in strip of 10°. The dotted line a sinusoidal fit.

metallicity of each object using an automatic program properly suited for this kind of spectra (Bonifacio and Caffau 2003).

3. SGR Central Dynamics

The derived Mass and $(M/L)_{SGR}$ depends on the structural parameters of the galaxy and on its central radial velocity dispersion. Majewski *et al.* (2003) from a complete analysis of SGR M-stars with 2MASS obtained new values for the core radius, tidal radius and total luminosity of the galaxy and used them to estimate a better value of the Mass and M/L (compared to the estimate of Ibata *et al.* (1997)) with the standard King method. The value obtained is M/L= 25 which is based on an *inferred* central velocity dispersion of ≃11.4 km/s from the Ibata *et al.* (1997) field “f7” in the SGR central regions. With a different approach the tidal tails modeling of Law *et al.* (2005) constrains on the total mass in the regime $2 \div 5 \times 10^8 M_{\odot}$ and the mass to light ratio in $14 \div 36 (M/L)_{\odot}$.

Our high precision radial velocity measurements permitted us to perform the first analysis of the central radial velocity dispersion of the SGR galaxy. Radial velocity measurements have a mean error of 0.33 km/s with 97% of objects with errors <0.65 km/s. Membership selection was performed in a multi-parametric way. Objects have been classified as dwarfs or giants on the base of the comparison with appropriate templates and only giants were kept. Second, a 3 sigma clipping in radial velocity has been applied and, finally, we used the metallicity measurements to isolate and remove the M54 globular cluster stars.

The radial velocity dispersion profile of the galaxy is presented in Figure 1 where the folded (around the mean) radial velocities of the single objects are shown. The velocity dispersion of the whole sample of 189 stars is $\sigma_{SGR} = 8.1 \pm 0.4$ km/s. The radial profile do not seems to show strong internal gradients as shown after a smoothing with the LOWESS estimator (continuous line). The velocity dispersion value is significantly lower than the

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Ibata *et al.* (1997) value of field “f7” and imply a total mass of $M_{SGR} = 1.6 \times 10^8 M_\odot$ and a corresponding $(M/L)_{SGR} = 9.1(M/L)_\odot$ calculated following the King methodology and SGR morphological parameters of Majewski *et al.* (2003).

This low value of M_{SGR} seems to be compatible with the expected range of masses implied by the central velocity dispersion from the modeling of the tails of SGR of Law *et al.* (2005), but is incompatible with the masses constrained by the measured velocity dispersion of the SGR tails: in this case the “lower” bound of the acceptable mass of SGR is $2.5 \times 10^8 M_\odot$, i.e. ∼50% larger than our measured value. Our Mass value seems to be compatible with the ”Model II” of Helmi & White (2001) having an initial mass of 1.7×10^9 $M_\odot$ that, when evolved for a Hubble time, reproduce all data available for SGR.

We finally show in Figure 2 a possible detection of rotation in the core of SGR. In the figure the radial velocity shows a clear sinusoidal trend with Position Angle. A fitted sin curve to the running mean (in step of 10°) of radial velocity members give a $v_{rot} = 2.1 \pm 0.4$ km/s at a PA of maximum rotation of $\mathrm{PA}_{rot} = -100° \pm 15°$. This value is larger than the expected trend in radial velocity due to projection effects or to the orbit of SGR (see Ibata *et al.* 1997). The possible rotation is mis-aligned with the Major Axis of SGR by ≃30 and could possibly be the signature of a decoupled core. A better understanding of this aspect could only be obtained with a bigger sample of objects at larger radial distances.

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Discussion

Zhao: Does the new M/L ≈10 of Sgr bring down the total mass of Sgr or bring up the total luminosity?

Zaggia: It brings down the total mass of Sgr. The luminosity I used is the one of Majewski *et al.* (2003, astro-ph/0304198).

Caldwell: Doesn’t the difference in mean metallicity between M54 and the core of Sgr argue that M54 is not the (a) nucleus?

Zaggia: Monaco *et al.* (2004) clearly demonstrated from a morphological point of view that M54 is not the nucleus of Sgr. This finding is also confirmed by the metallicity difference.