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Kinematical mapping of the outskirts of elliptical galaxies using the OSIRIS tunable filters at GTC: a novel approach

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Abstract

We have developed an innovative 'index scanning technique" to map the stellar kinematics of early-type galaxies by measuring for the first time the absorption line strength of the near-IR CaII triplet with the Red Tunable Filters of OSIRIS at GTC. Unlike classical spectroscopy, these filters allow us to perform a two-dimensional study, taking advantage of a 10.4 meter class telescope with a unvignetted field of view of 7.8 $\times$ 7.8 arcmin. We show the velocity fields obtained for two Virgo elliptical galaxies of very different masses and their globular cluster systems reaching galactocentric distances beyond 2 effective radii.

1 Introduction

The current ΛCDM paradigm has proved to be very successful in explaining a wide variety of cosmological observational results [15, 23, 27, 14, 9, 28, 24, 19]. However, this theoretical framework starts to fail when we observe down to individual galaxies scales, in particular, when measuring the dark matter (DM) distribution [18, 21, 11]. Thus, it is necessary to put strong observational constrains to check the reliability of the ΛCDM paradigm. The outskirts of early type galaxies (ETGs) are an excellent target for kinematical studies, not only because it is there where the DM component is mostly driving the galactic dynamics, but also because measurements of the radial velocity and of the velocity dispersion of the stellar component could be used to test the strength of the standard theory of gravity [25, 22, 10].

The outskirts of ETGs are also a key piece in the galaxy formation and evolution puzzle. Several studies have recently revealed how massive galaxies show a continuous increase in size while comparing their effective radius at different redshifts [6, 26, 3], challenging the monolithic picture of ETGs passively evolving since z $\approx$ 2 [8, 13, 1]. By measuring the kinematics (i.e. radial velocity and velocity dispersion) of ETGs it is possible to shed some light on the understanding of the mechanisms responsible of such size evolution [2, 17, 5].

We show here how a recently developed technique using the unrivalled capabilities of the OSIRIS Tunable Filter (OTF) at the Gran Telescopio Canarias (GTC) can be used to recover both the radial velocity and the velocity dispersion by studying the near-IR CaII triplet absorption feature, reaching very large galactocentric distances with a reasonable observational time consumption.

2 OSIRIS tunable filters: *index scanning technique*

The OTF[1] [4] are a facility located at the GTC 10.4 m telescope. It consists of two different Fabry-Perot interferometers (the blue and red tunable filters) with a wavelength coverage from 365 to 935 nm and a unvignetted field of view (FOV) of 7.8 $\times$ 7.8 arcmin. Despite the fact that obtaining a monochromatic image is not trivial because of the bluenning in the FOV [16], their characteristics make them the perfect tools to study extended sources, with the advantage of the photometry over the more classical long slit spectroscopic approach.

The OTF have already been used in a wide variety of astrophysical fields [12, 20, 7], but always applied to emission lines. Our aim is to extend the usage of the OTF to absorption features thanks to a novel method: the *Index Scanning Technique*, to study the kinematics of ETGs well beyond the effective radius. The basic idea behind this new approach is schematically represented in Fig. 1. While the continuum is measured with an order sorter (OS) filter, we sample the deepest line of the near-IR CaII triplet absorption feature by tuning the red-OTF at different wavelengths, taking advantage also of the bluenning in the FOV of OSIRIS. In particular, this absorption line does not show any significant dependence either on age or on the metallicity for ages larger than $\sim$ 2 Gyr and metallicities greater than ~ -0.5 [M/H] [29]. After dividing the continuum measurement (using the OS) by the sampled absorption line (traced with the red-OTF), the resulting response curve (i.e., the ratio between the continuum over the absorption line) can be used to derive the radial velocity and the σ by measuring the centroid and the width of this latter response curve, which is properly modelled with the aid of stellar population models.

One of the greatest advantages of using the OTF to study the outskirts of ETGs is that we are able to recover the two dimensional field of radial velocity and σ and therefore perform a detailed kinematical analysis, dealing with much more information if we compare this technique with the standard long slit (and mono dimensional) approach. There are also facilities designed with the aim of studying the two dimensional kinematics of extended

[1] An extended documentation about the OTF can be found here

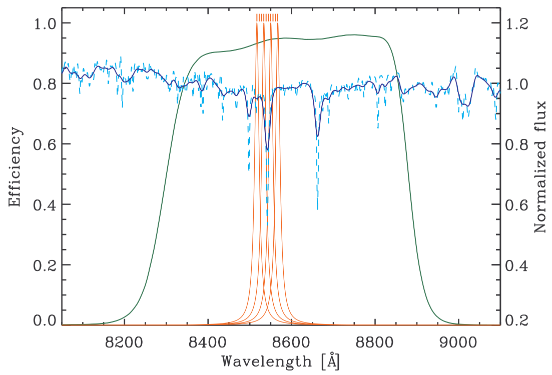

Figure 1: *Index Scanning Technique*. In blue: the spectrum of a galaxy represented by a single stellar population of 10 Gyr, solar metallicity and $\sigma = 50$ km s^{-1} (light dashed line) and the same spectrum as seen through the OTF (dark solid line). In red it is shown the transmission curve of the OTF with a FWHM = 12 Å and in green the transmission curve of the OS. The overall idea is to tune the OTF at different wavelengths and then measure how the index (i.e. the continuum divided by the OTF measurement) varies with wavelength.

sources (e.g. SAURON at the William Herschel Telescope; PMAS/PPAK at the Calar Alto observatory) but with a much smaller FOV (0.6 × 0.7 arcmin for SAURON; 0.8 × 1.3 arcmin for PMAS/PPAK) compared to the OSIRIS 7.8 × 7.8 arcmin FOV.

3 Data

To test the feasibility of the index scanning technique, we used two data sets taken from March to May 2010. We observed two galaxies of different masses in the Virgo cluster, as well as their globular cluster system. The basic information (from HyperLeda) about the sample is summarized in Table 1

Table 1: Sample information

Object	m_B [mag]	M_B [mag]	σ [km s^{-1}]	$R_{\rm eff}$ [arcsec]
NGC 4482	13.7	−18.7	40	21
NGC 4473	11.1	−21.8	180	21

3.1 Observational caveats

Two main problems appeared during the analysis of these data: the sky subtraction and the central wavelength tuning. The first one is due to the highly variable sky behaviour in the

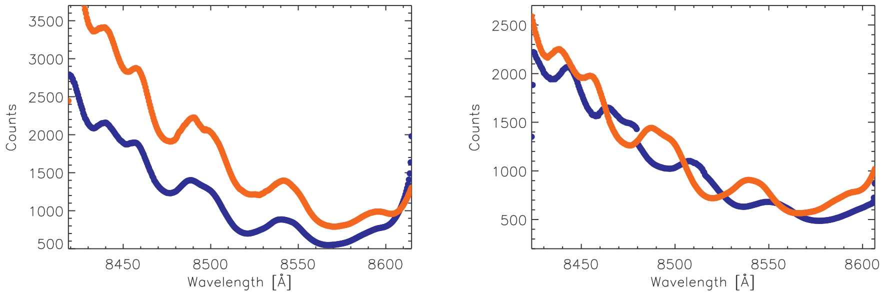

Figure 2: Two consecutive sky spectra, in orange and blue, obtaining by measuring the mean value of a OTF image at a fixed radial distance from the optical centre (equivalent to measure the sky spectrum because of the bluenning in the FOV of OSIRIS). *Left panel:* Apart from the strength of the sky lines, there is a clear wavelength dependence difference. *Right panel:* In some shots, we also found a wrong calibration in the central wavelength of the Red-OTF, appearing as a shift between the two sky spectra.

IR, in typical time scales of around 15 minutes. In Fig. 2 are plotted two sky spectra (in blue and orange), measured by averaging the number count in a OTF image at different radial distances from the optical centre. Because of the bluenning in the FOV of OSIRIS, these measurements at fixed radial distances correspond to the sky spectrum during the exposure time. The left panel of Fig. 2 shows how the sky spectra of two consecutive shots with the OTF are very different, showing also a dependence with the observed wavelength. In addition, as we are working in a low resolution spectroscopic mode (the FWHM of the red-OTF was set to 12 Å), we mix up different sky lines, each of them with a different emission strength. Finally, the second and main problem detected was that, for some shots, the central wavelength was not tuned at the desired wavelength. As can be seen in the right panel of Fig.2, there is a shift between the two sky spectra. This particular caveat has nothing to do with the observational strategy and it can only be solved by the observatory. However, with a careful designed observational plan both problems can be, at least, decoupled.

4 Preliminary results

In Fig. 3 we show the line profiles (blue dots) obtained by sampling the CaII triplet central line with the red-OTF for the two galaxies in our sample (top panels) and for two globular clusters of NGC 4482 (bottom panels). As we did not used the OS to calibrate the continuum in these profiles (because of the lack of reliable flats images), the index scanning technique was not fully applied. Instead, we fitted the data with a simple gaussian profile (solid line). However, the detected problems prevent us from going any further with the analysis of these results.

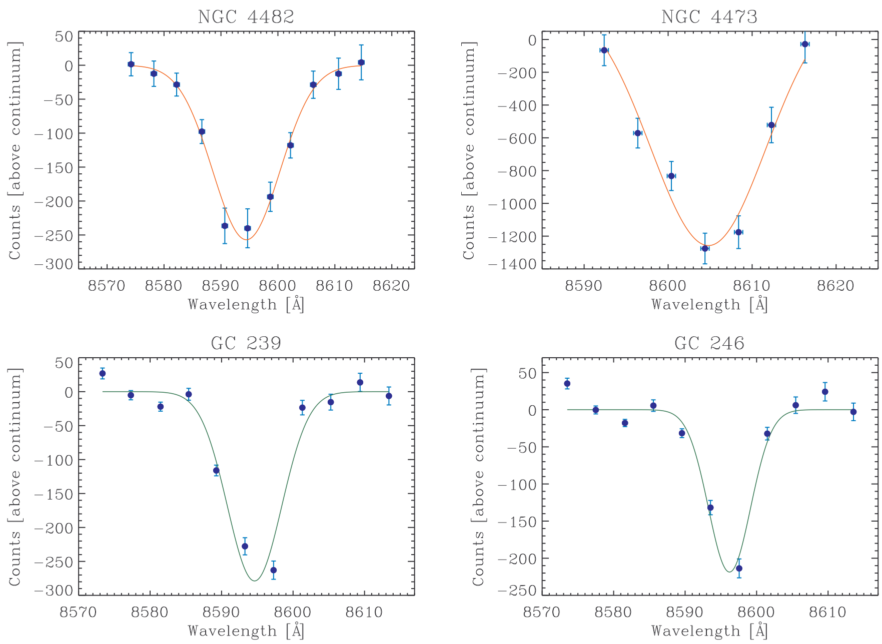

Figure 3: Absorption line profiles (blue dots) for the two galaxies in our sample (*top panels*) and for two globular clusters from the system of NGC 4482 (*bottom panels*). These profiles are just the sampling of the central line of the CaII triplet and not the result of the index scanning technique due to problems with the calibration images for the OS data. In solid lines we show the gaussian fit for each profile.

5 Conclusions

We have shown how the OTF can be used to study spectral absorption features. In particular, we have measured the near-IR CaII absorption lines with a novel technique, namely the *index scanning technique*, that can be used to trace the radial velocity and velocity dispersion beyond the effective radius of the galaxy.

Our preliminary results suggest that this technique is feasible, as we have been able to recover the near-IR CaII line profile from both the stellar light component and from the globular cluster systems. Also, the observational problems associated with this novel approach can be solved if a proper observational strategy is followed.

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