The Experience of Two High School Students Doing Astronomical Research at ESO

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As a project for diploma work at the end of Swiss high school, long-slit kinematic data for two giant elliptical galaxies, observed with the FORS1 spectrograph at the ESO VLT, were reduced by two students. The reduction of these data was our first research experience. The preparation and reduction of the long-slit data is outlined. We also describe our impressions of this first encounter with the scientific research world.

We are two Swiss students who started work on the high school diploma two years ago. In Switzerland the diploma includes a research project that takes place during the last two years of high school: the project can be done in any of the subjects taught in this kind of school. Usually professors propose a list of projects for the students to choose from. We decided to work in astronomy, one of the most fascinating fields of physics. Our project, entitled "Spectroscopic analysis of elliptical galaxies", has led us to a whole new experience and to meet new people (including a few astronomers), but most importantly, has brought us to a mythical place in the astronomical world, namely the ESO observatories at La Silla, Paranal and Chajnantor (ALMA) in Chile, which are equipped with some of the world's best telescopes.

During the entire project, we were guided by our physics teacher, Nicolas Cretton, astronomer and ex-ESO fellow. Together with Hans-Walter Rix, he wrote the original ESO observing proposals (65.N-0285 and 68.B-0590) on which our project was based. During the entire work, we received a lot of help and advice from Piero Rosati, an astronomer at ESO. When the spectra were all reduced, Eric Emsellem from the Observatoire de Lyon (and now at ESO) extracted the kinematical quantities for each axis of the galaxies.

We visited ESO Headquarters in Garching twice during the summer of 2008 and could therefore learn a great deal about activities at ESO: telescope design and construction, observation preparation and realisation. At first, we felt a bit disorientated in this new world of scientific researchers. But soon we got acquainted with many nice and helpful astronomers who showed us the various research activities at ESO. We could also discuss our diploma project and get some precious advice. During this full immersion in the scientific world, something completely new for us, the impression was really positive and stimulating. At ESO, we found a nice and welcoming atmosphere: everybody was very helpful and the interactions between astronomers seemed to us very friendly. The desire to work one day in a research institute such as ESO has been an extra motivation for us to start, with even more enthusiasm, our university studies. During the visit to Garching, we also visited the outreach department where we were offered a lot of goodies: DVDs, posters, caps, postcards, etc.

The visits to ESO helped immensely in achieving the goals of the diploma project. Once the project was completed, we participated in various regional and national competitions. The most significant one was the national competition "Science and Youth" that took place in Geneva at the end of April 2009[1]: four days of project presentations and discussions with experts, other participants and the public. Presenting our project to such a wide audience turned out to be challenging, since we had to adapt our explanations to the various levels of scientific expertise. But the Geneva competition was not only work: there was a lot of free time to get to know all the other participants, who came from all over Switzerland.

Preparatory theoretical work

Since the high school programme contains little astronomy, before starting the data reduction work we had to learn a few necessary astronomical concepts: stellar evolution (life cycle of stars, Hertzsprung–Russell diagram), galaxy structure and morphology, dark matter in galaxies, long-slit spectroscopy (emission lines, absorption lines, line-of-sight velocity profiles, etc). A few technicalities, such as the working of telescopes, spectrographs and CCDs were also needed. This study constituted the first part of our project. The complete manuscript of our project report is available (in Italian) on the web[2].

Data reduction

The goal of our project was to fully reduce long-slit spectra of two giant elliptical galaxies, NGC 5018 and NGC 3706, and to obtain the corresponding kinematic quantities: mean line-of-sight velocities, velocity dispersions and higher order moments of the velocity profile. Figure 1 shows one of the target galaxies, NGC 5018. Spectra were obtained with the FORS1 spectrograph of the VLT in 2000 and 2001. The light of elliptical galaxies is dominated by the emission from red giant stars with spectral types such as our calibration templates stars. Visible absorption lines include the K, H lines of calcium, the Hβ, Hγ and Mgb lines (see Figure 2). These two galaxies had already been observed (e.g., Carollo & Danziger, 1994a,b and Carollo et al.,1995), but never with such a large telescope as the VLT. With these data, we tried to confirm and extend to larger radii previously published data. For both galaxies there is an indication of dark matter in the outer parts, so very extended kinematic data (up to two to three effective radii, R_{eff}) could improve the confidence on the presence of a dark halo. Previous work has shown the importance of both increased radial extension and the calculation of higher order moments in quantifying the amount of dark matter in elliptical galaxies.

It is notoriously difficult to measure dark halos in elliptical galaxies, since one has to rely on absorption spectra, which are very hard to obtain beyond one R_{eff} due to the sharp drop in stellar luminosity and because of the absence of an extended gas tracer, as in spiral galaxies. One alternative to stellar kinematics is to use planetary nebulae that can be detected at large radii. The present study confirms and extends previously published kinematic data such as those obtained by Carollo & Danziger (1994a,b) and Carollo et al. (1995). It therefore constitutes an

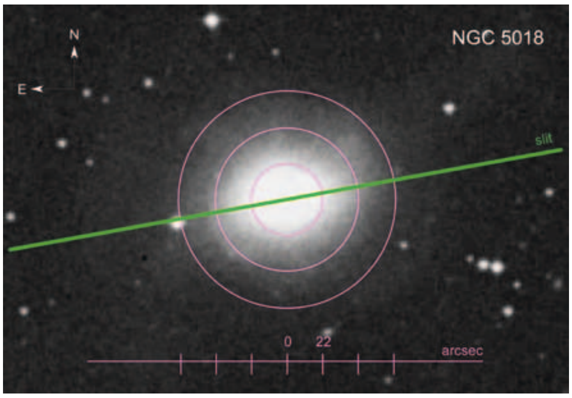

Figure 1. A Digital Sky Survey image of NGC 5018, with the position of the FORS1 long slit on the major axis (green) shown and the circles of radii 1, 2 and 3 R_{eff} overlaid (pink). Asymmetric features beyond 2 R_{eff} are probably the sign of a past merger in this galaxy.

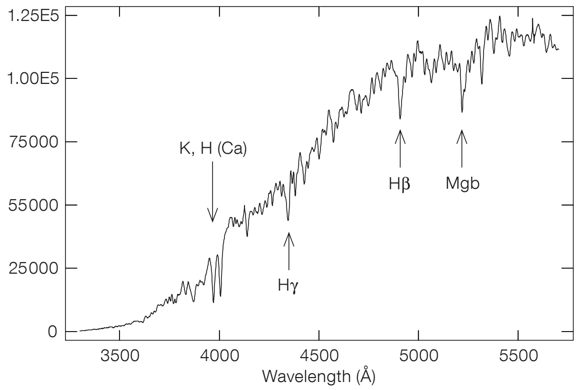

Figure 2. The central major axis spectrum of NGC 5018 is shown from the FORS1 observations. The major absorption lines of calcium, hydrogen and magnesium are indicated.

improved basis for the dynamical modelling that is needed to study the amount and distribution of dark matter in giant elliptical galaxies; such modelling is however outside the scope of our diploma project.

With the GRIS-600B+12 grism and a 1.31 arcsecond-wide slit, we had an instrumental spectral resolution σ_{instr} of 200 km s^{-1}, similar to the galaxy velocity dispersion, which is just sufficient to obtain good kinematic measurements. The wavelength resolution was 1.2 Å per pixel, which corresponds to 7.8 Å for the CCD pixels and slit size we used. The total exposure times for NGC 5018 are 200 minutes for the major axis and 150 minutes for the minor axis, whereas for NGC 3706 they were 135 minutes for the major axis, 90 minutes for the intermediate (45-degree) axis and 225 minutes for the minor axis.

As the first step, we obtained the raw data (science and calibration frames) for the FORS1 programme from the ESO Archive. From there, a lot of effort and time went into understanding: 1) the nature of the imaging and spectroscopic data and corresponding calibrations; 2) the methodology to remove instrumental signatures; and 3) the calibration procedures to go from instrumental to physical units. For all these tasks, we were also introduced to IRAF[3], which we ran on a Linux laptop as part of the ESO Scisoft package[4].

All raw spectra were bias-subtracted, flat-fielded, sky-subtracted and wavelength-calibrated following the various steps described in Massey et al. (1992) and Massey (1997). Particular attention was given to the sky subtraction, since we wanted to obtain reliable kinematic data at large distances from the galaxy centres. In this respect, the 408-arcsecond long FORS1 slit was very useful. We also reduced in the same manner spectra of calibration template stars observed at the same telescope: as templates we used the following giant stars, indicated with their respective spectral type: HR 4595 (K3III), HR 4790 (G3III), HR 4801 (K5III), HR 4818 (K4III).

Results: stellar kinematics of NGC 5108 and NGC 3076

To quantify the line-of-sight velocity distributions along the principal axis of the galaxies, Eric Emsellem computed the Gauss–Hermite moments with dedicated software (a C version of a penalised pixel-fitting routine, described by Cappellari & Emsellem, 2004): mean rotation velocity, velocity dispersion sigma, and

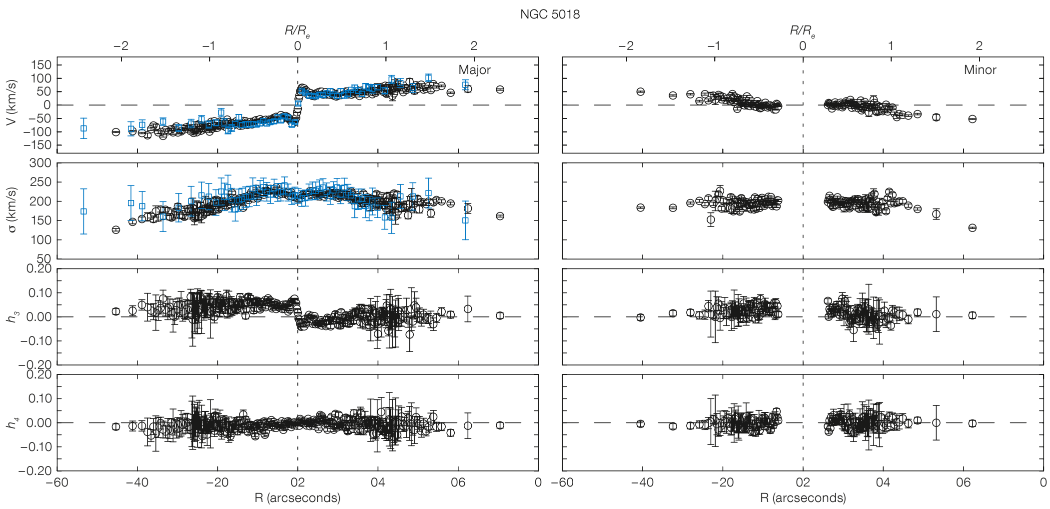

Figure 3. The stellar velocity, velocity dispersion, h_3 and h_4 profiles as functions of distance from the galaxy centre (in arcseconds) are shown along the major axis of NGC 5018, from top to bottom respectively and for the major and minor axes (left and right). Blue points are the data from Carollo & Danziger (1994b). For the minor axis, systematics on the detector prevented us from extracting the kinematics in the central few arcseconds for this galaxy. The top axes are labeled in effective radii R_{eff} (1 R_{eff} = 22 arcseconds). The velocity dispersion (around 200 km s^{-1}) dominates the mean rotation (around 60 km s^{-1}) and decreases only slowly towards the outer parts.

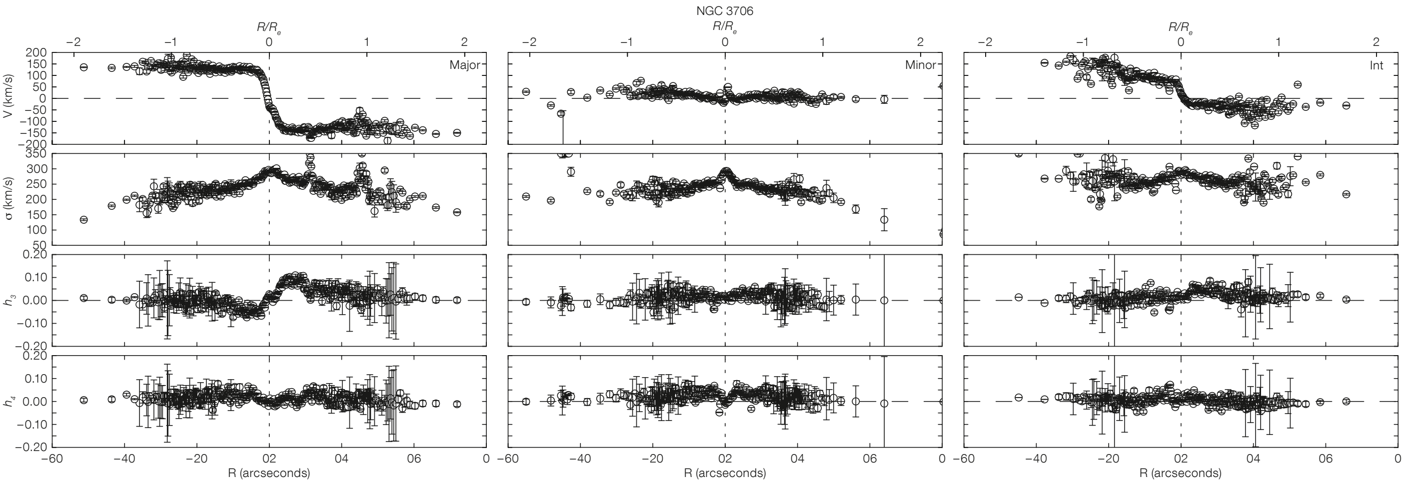

Figure 4. The stellar velocity, velocity dispersion, h_3 and h_4 profiles as functions of distance from the galaxy centre (in arcseconds) are shown along the major axis of NGC 3706, from top to bottom respectively and for the major, minor and intermediate axes (left, middle and right respectively). The top axes are labelled in effective radii R_{eff} (1 R_{eff} = 27 arcseconds). This galaxy rotates faster than NGC 5018: it has a mean rotation of around 150 km s^{-1}. As for NGC 5018, the velocity dispersion shows a slow decline with radius. A few foreground stars happen to lie on the slit and explain some of the observed disturbances in the profiles.

moments h_3 and h_4. Figures 3 and 4 show the results of such computations for the two galaxies: in both cases we go further than 2 R_{eff}. In NGC 5018 (Figure 3), there is some asymmetry between the left and the right side, which could be interpreted as a signature of a past merging event. Indeed NGC 5018 displays some tidal tails in the outer parts (see e.g., Rothberg & Joseph, 2006). There is central drop in the velocity dispersion, associated with a sharp rise in the mean velocity curve, probably the sign of a so-called "sigma-drop" interpreted as the result of past gas accretion in a central disc (Emsellem, 2006). In NGC 3076 (Figure 4), the stellar velocity reaches higher amplitudes and is quite regular except for a central feature also revealed by the h_3 profile. The dispersion is dropping slowly in the outer part. In both galaxies the h_4 moment is mostly consistent with zero.

The trip to Chile

Our data was obtained in service mode so we did not use the VLT ourselves to observe the two galaxies. Fortunately, at the end of our diploma work we were able to submit it to the national competition "Science and Youth", which in 2009 had a special prize for astronomical projects in honour of the International Year of Astronomy. This prize could not have been better chosen for us since it was a trip to Chile to visit the three ESO sites, La Silla, Paranal and Chajnantor in early September 2009 and a night of observations at the Swiss 1.2-metre Leonhard Euler telescope at La Silla. Together with another student, Andreas Cuni, we won the special prize and went to Chile to visit the famous telescopes. Below we describe our impressions of this trip.

Chile has many wonderful landscapes, but our trip was mostly enlightening from a scientific point of view. Indeed we could meet astronomers and engineers and see how they live and work. This experience was very useful in view of a possible future career in the scientific research world.

We first visited the observatory of La Silla, near La Serena (see Figure 5). We had to submit a proposal for a night of observations at the 1.2-metre Leonhard Euler telescope (2 September 2009). Since for our diploma we had worked exclusively on spectra, we decided to do photometry of galaxies and globular clusters in various

Figure 5. From left to right, Andreas Cuni, Clara Pelloni and Lia Sartori on their visit to the La Silla Observatory.

Figure 6. The authors Clara Pelloni and Lia Sartori (centre left and right) between Pierre Dubath (the organiser of the trip to Chile) at left, and Andreas Cuni (the other prize-winner), at right, shown in Paranal at the gate of the road leading to the VLT. Pierre Dubath (Geneva Observatory) had the idea of creating the special prize in astronomy and found the necessary funding for the trip to Chile.

filters. The idea is to use the globular cluster observations to construct a Hertzsprung–Russell diagram in order to compute their ages and distances. Due to time constraints, we could only observe two globular clusters (47 Tuc and NGC 362) and one barred spiral galaxy (NGC 1300). The clusters were observed in the *B*-, *V*- and *I*-filters, while the galaxy in *R* and *I*. The results were satisfactory, even if the full Moon and some clouds reduced the image quality. For us, it was particularly rewarding to work on the practical aspects of astronomical observations, such as the telescope preparation, the setting of coordinates and other parameters and to be able to see the results after a few minutes.

We went further, to Paranal, to visit the mighty VLT (see Figure 6). ESO astronomers showed us the various telescopes at the Paranal site, their instruments and the control room. It was particularly exciting to see the aperture opening of the dome of one of the four Unit Telescopes of the VLT. First the telescope is put horizontal, to reduce dust falling onto the primary mirror while the dome is opening. Then the dome opens, together with the various lateral windows. It is hard to imagine the real dimensions of such an instrument only from pictures; having been there in person is an unforgettable experience!

Last but not least, we went to Chajnantor to visit the ALMA site, near San Pedro de Atacama, at an altitude of 5000 metres. The final project will have 66 radio antennas, built to observe the cold Universe. At that time, only one telescope was ready and functioning (the ALMA Pathfinder Explorer, APEX). Other antennas are ready on the ALMA site, but without instrumentation they do not work yet. Here as well, it was possible to speak with the people working there and to get detailed explanations on the working of the radio telescopes.

Conclusions

During our diploma project at the end of high school, we fully reduced spectra of two elliptical galaxies, using the same professional software that astronomers use in their daily work. We could derive extended kinematics (up to about 2.5 R_{eff}) for NGC 5018 and NGC 3706, two giant elliptical galaxies. The derived mean velocity, velocity dispersions, and higher order moments h_3 and h_4 could be signposts for the presence of dark matter halos around these galaxies. For instance, at large distances from the galaxy centres, the velocity dispersions do not drop as sharply as naïvely expected on the basis of the distribution of the luminous matter. However, to quantify the amount of dark matter, detailed dynamical modelling is needed. This is outside the scope of our project, but our data constitute an excellent basis for such an analysis.

Our research project was our first encounter with the world of scientific research. It was a truly fascinating experience, thanks to the visit to ESO Garching and the various ESO telescopes in Chile and mostly thanks to the warm welcome, patience and enthusiasm of all the astronomers, engineers and technicians we met. After high school, we will continue studying science: physics for Lia and mathematics for Clara, both at the Zurich ETH institute.

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Links

[1] Science and Youth: http://www.sjf.ch/
[2] Diploma project report: http://www.nicolascretton.ch/Astronomy/index_LAM.html
[3] IRAF: http://iraf.noao.edu
[4] Scisoft: http://www.eso.org/sci/data-processing/software/scisoft/