Abstract

Spectroscopy is one of the most important techniques for obtaining information from the celestial objects. At Australian Astronomical Observatory in New South Wales, Australia, the most advanced method for obtaining multiple spectra has been developed in the last decade. This seminar will present the spectroscopy techniques developed and recent projects on 1.2-m UK Schmidt Telescope equipped with optical fibers to obtain up to 150 spectra of stars or galaxies simultaneously.
1 Introduction

This script is a product of the subject seminar, which is mandatory in the third grade of study on Fakulteta za matematiko in fiziko, Univerza v Ljubljani.

I am a student of astronomy direction, so I decided to prepare a seminar about the astronomical topic. Since I had a plan to go to the holidays in Australia after the winter semester of study year 2011/12, my mentor, prof. dr. Tomaž Zwitter, suggested me to visit the Australian Astronomical Observatory in New South Wales, Australia and prepare a seminar based on the visit and their work at the observatory.

My mentor arranged the visit and I had the opportunity to apprise with the 1.2-m UK Schmidt Telescope, instrumentation there are spectroscopic techniques developed for the multi-object spectroscopy.

In the second section of the seminar I present spectroscopy in general, in the third the AAO\(^1\) and UKST\(^2\) and in the last the 6dF\(^3\) and multi-object spectroscopy.

2 Spectroscopy

2.1 Prisms and Gratings

Spectroscopy is technique which analyzes the chemical structure of the observing object (typically a star, galaxy or nebula) dispersing the light into a spectrum. This can be achieved in many different ways. One and the most known is dispersing the light to a spectrum with a prism. The method is based on the fact that the refractive index \(n\) is a function of wavelength \(\lambda\). This results that different wavelengths of the incoming beam of light are dispersed to different angles, producing the spectrum, as shows the figure 1.

\[\text{Figure 1: Prism}\]

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\(^1\)Australian Astronomical Observatory
\(^2\)UK Schmidt Telescope
\(^3\)6-degree Field
The main advantage of using a prism is the high efficiency – all the incoming light is dispersed to the single spectrum, loosing the light mainly on the reflections on the glass surface.

Anyhow, the prisms are not used for research spectroscopy in astronomy anymore and have been mostly replaced with diffraction gratings, mainly because much more divergent outgoing spectrum can be achieved using gratings. We don’t have a glass with refractive index significantly different than 1, therefore the Snell’s law

\[ n_1 \sin \varphi_1 = n_2 \sin \varphi_2 \]  

(1)

shows that it is impossible to get very divergent spectrum if the \( n \approx 1 \) and \( n(\lambda) \) is a “weak” function\(^4\). How the refractive index changes with \( \lambda \) can be approximated by Hartmann dispersion formula:

\[ n(\lambda) = A + \frac{B}{\lambda - C} \]  

(2)

where typical value for constants A, B and C are\(^5\):

- \( A = 1.6 \)
- \( B = 2.1 \times 10^{-8} \)
- \( C = 1.4 \times 10^{-7} \)

Combining eq. (1) and (2) and assuming \( n_1 = 1, n_2 = n(\lambda) \) we can see that light with similar \( \lambda \) is refracted in almost the same direction.

Diffraction gratings work based on the interference of the reflected incoming beam of light. There are many different versions of spectrometers with reflective or transmissive gratings, based on the practical application and purpose of the instrument. The transmissive gratings are more common in stellar spectroscopy (figure 2).

For constructive interference the following equation applies

\[ d \sin \varphi = m \lambda \]  

(3)

where \( m \) and \( \lambda \) are the order of the diffraction and wavelength, respectively, whereas \( d \) and \( \varphi \) are illustrated in figure 2.

We notice that constructive interference for each different wavelength \( \lambda \) occurs at different angle \( \varphi \), therefore the spectrum of the incoming light can be gathered and captured on the other side of the grating.

The dust and other dirt is very likely to lay into the transmissive gratings and because it is very difficult to clean the surface again without damaging it (the “roofs” are usually just about 1 \( \mu \)m separated), the transmissive gratings are more commonly used.

### 2.2 Application of Optical Fibers

Optical fibers are very important nowadays for stellar spectroscopy since spectroscopes are large and very sensible to flextures. With use of optical fibers it is possible to catch

\(^4\)by “weak” I mean that the \( n \) does not change fast with different values of \( \lambda \)

\(^5\)ref. \[2\], page 323
the starlight and lead it to the spectroscope, which usually stands on stable ground, some-
where inside the observatory or underneath. Therefore it is not necessary to have large
and bulky spectroscope attached in the prime focus of the telescope. This schematically
shows the figure 4, the light from three different stars is captured into the fibers in the
focal plane of the telescope. Then it is led to the spectrograph practically without loss
of signal.

On the other hand, the objects we are capturing are more or less randomly positioned
across the field of view of our spectroscope, so the positions of the individual fibers must
not be fixed. We need a fiber positioner which takes care that the light from individual
objects is focused in the start of the fiber.
Australian Astronomical Observatory (formerly Anglo–Australian Observatory) operates within Siding Spring Observatory in New South Wales, Australia. The nearest town is Coonabarabran, about 10 km of air distance away. The observatory is located about 1150 meters above the sea level in the Siding Spring Mountain. The nearest bigger city, Sydney, is 330 km away in South-East direction. Consequently the location provides extraordinary observational conditions, especially regarding the darkness and clarity of the sky.

The seeing there is as good as the transparency, with 3 \textit{arcsec} on the average night, reaching 1 \textit{arcsec} some nights a year. Fortunately the good seeing conditions are not so important for multi-object spectroscopy.

The first telescopes there were built in 1967, primary because there are many interesting stellar objects visible exclusively from the Southern hemisphere (e.g. center of our galaxy Milky Way, and satellite galaxies Large and Small Magellanic Cloud) and there was a lack of astronomical observatories located South of equator till then.

Australian Astronomical Observatory operates two telescopes (figure 5):

- Anglo-Australian Telescope (3.9-m Cassegrain)
- UK Schmidt Telescope (1.2-m Schmidt)

### 3.1 Australian Astronomical Observatory

3.2 1.2-m UK Schmidt Telescope

The 1.2-m UK Schmidt Telescope was built in 1973. The design was chosen based on the predicted mission – to photograph the whole Southern sky. Digitized Sky Survey was
the first larger project which was running on the telescope for number of years, providing photographic sky atlases for the whole Southern night sky.

The Schmidt optical design has been applied to the telescope, as shown on figure 6.

The telescope sits on fork equatorial mount, tilted about 31° above the horizon line. The Schmidt optical design demands bigger primary mirror than the clear front aperture of the telescope is. At the top of the telescope tube sits 1.2 m large corrector lens, followed by mechanical shutter from the days when the telescope was exploited for photography. The primary mirror seize 1.8 meters in diameter and focuses the light towards photographic plate, which has now been replaced with the 6-degree Field plate.

The focal plane is not flat, but curved. This has never been a problem, since large photographic plates does not dictate flat plane nor the current instrumentation (6dF)
does. The photographic plates and field plates can be exchanged using plate loading
system, which grabs the plate and lifts it into the telescope.

The last photograph was taken with the telescope in 2005. Since then it is exclusively
used just for the purposes of RAVE\textsuperscript{6} project.

Figure 7: UK Schmidt Telescope inside the dome

This optical design provides 6.6 × 6.6 degrees field of view. This characteristic makes
it one of the largest telescopes in the world with wide-field FOV\textsuperscript{7}. This enables capturing
large areas of the sky with a single shot. The dimensions of the photographic plates
measure 14 × 14 inch (equals 356 × 356 mm).

The reasons why large telescopes with wide FOV are so uncommon are the optical
errors. The main effect which degrades the image far from the center of optical axis is
called coma (or comatic aberration). It originates from the rays which strike the mirror
or lens at an angle different than θ = 0° regarding optical axis (figure\textsuperscript{8}). The problem is
insignificant for the small apertures (e.g. for the lenses of commercial compact cameras),
but the coma rescales as a square of the aperture of the telescope, becoming main optical
error for the large parabolic mirrors. This way the useful FOV remains just some arc
minutes around the optical axis in prime focus of parabolic mirror. The effect of coma
can be minimized (or sometimes eliminated) using clever optical design. One of these
is also Schmidt optical system, for the price of the semi-shadowed primary mirror. As
can be seen on figure\textsuperscript{8}, the primary mirror is fairly larger than the clear aperture of the
telescope, meaning that the diameter of light-collecting surface for one point in the focus
is just 1.2 m in diameter.

\textsuperscript{6}Radial \textbf{V}elocity \textbf{E}xperiment
\textsuperscript{7}field of view
4 6dF and Multi–Object Spectroscopy

4.1 6-degree Field

In 2001 the UK Schmidt Telescope was upgraded with the 6-degree Field, which is a multi-spectroscopy system. The system includes three metal field plates with about 150 optical fibers, the robot fiber positioner, the computer which operates the robot and lift system for placing the configured 6dF field plate into the telescope.

The metal plates are about the same dimensions as the formerly used photographic plates. The surface has the same curvature as the focal plane of the telescope and it is made of ferromagnetic metal. The optical fibers end in the special type of “buttons” (figure 9), which have a small mirror inside to reflect the incoming light perpendicularly to the start of the individual fiber. The “buttons” have a magnet at the bottom, so once they are properly positioned on the plate, they do not move around anymore.

The robotic fiber positioner (figure 10) is controlled by a computer and automatically configures all the fibers on the plate. The accuracy of the positioned fibers is in the order of micrometers. The diameter of the fibers is 100 $\mu m$ so such precision is sufficient. Once the capturing area in the sky is defined, the computer needs to find out the optimal
configuration of more than 150 fibers and then it controls the robotic positioner to do the task. The process for configuring the plate takes about 20 minutes. Some fibers are also positioned to capture the light where is no object, for the calibration and processing purposes.

Once the 6dF field plate is configured it can be lifted into the prime focus of the telescope and start the exposition.

4.2 Spectrograph

All the fibers from the 6dF field plate are led to the single spectrograph, which sits on the optical table, in the full darkness inside the observatory. The light from the fibers
is then collimated into the parallel planes which fall into the grating one above the other. When the spectra are focused to the CCD detector, we get all the spectra one above the other vertically, with wavelengths distributed horizontally. This schematically shows the figure [12].

![Figure 12: Top and side view of the spectrograph](image)

The gratings, angles between the elements and distances can be changed, allowing the spectrograph to work in different ranges of wavelengths and different resolutions.

### 4.3 RAVE

The Radial Velocity Experiment started on the instrumentation in 2003, and from 2005 the telescope is exploited exclusively by RAVE. The project is about to be accomplished in 2012. The goal is to obtain about 600,000 spectra from the stars in our galaxy Milky Way, measuring the radial velocities, positions and characteristics of the stars.

Radial velocity can be determined from the Doppler shift of the absorption lines. The equation

$$\frac{\Delta \lambda}{\lambda_{\text{lab}}} = \frac{v_r}{c} \quad \Delta \lambda = \lambda_{\text{obs}} - \lambda_{\text{lab}}$$

(4)

describes how the radial velocity $v_r$ can be determined in the regime $v_r \ll c$. The $\Delta \lambda$ is the difference between the wavelengths of absorption lines for the certain gas measured in laboratory system and from the stellar light.

Besides the radial velocity, several other stellar parameters can be found out from spectra – the chemical composition of the star (metallicity), the effective temperature on the surface, the distance etc.

Several simulations could be supported based on the information gathered from RAVE, for example how the galaxies evolve, rotate and how the dark matter is distributed inside the galaxies.
4.4 Why Multi-Object Spectroscopy?

There are many good reasons why to capture multiple objects at the time instead of just one.

First of all, the numbers of the celestial objects to study are huge. For example, there are about 300 billion stars inside our galaxy, Milky Way. And there is about 500 billion galaxies out there. For creating a representative sample of such a large numbers, a considerable portion of these objects must be analyzed.

One would complain that there are other fields in physics where a large number of samples should be investigated individually, but it is not, for example the physics of elementary particles. The stars differ from elementary particles in a way that every single star is not the same as any other (which does not apply for the particles). More than that, even though the stars live for billions of years, some periods of their life last just a tiny part of it, let say just some thousands of years. To catch these interesting and exotic stars, large samples must be recorded and analyzed.

Multi-object spectroscopy is very promising branch of astronomy, with many running and planning projects. While one object demands up to an hour of observation time with the standard spectroscopy, the productivity of the same telescope can be pushed up for a factor of hundred or even thousand with multi-object spectroscopy system.

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References


