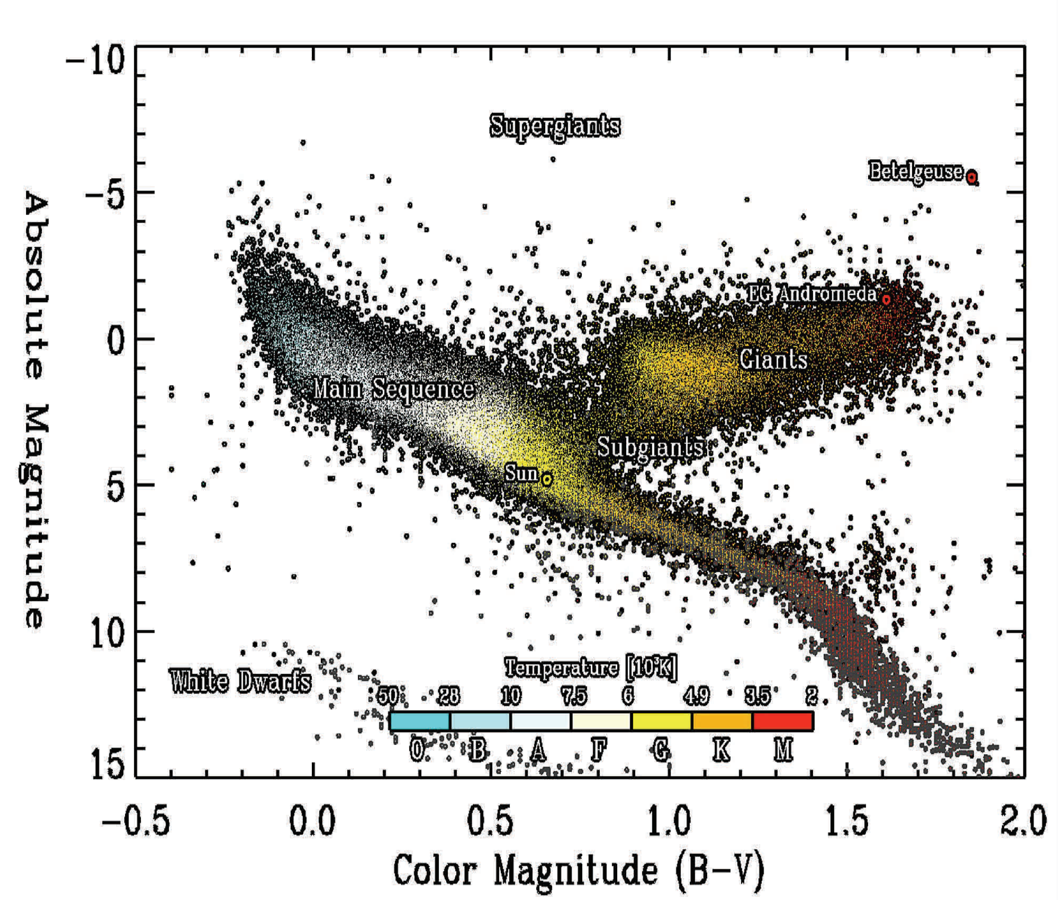
BAV MAGAZINE SPECTROSCOPY



Paul A. Higgins (Astrophysics Research Group / Trinity College Dublin)

OF THE GERMAN ORGANIZATION & WORKING GROUP VARIABLE STARS BAV

EDITOR
BUNDESDEUTSCHE ARBEITSGEMEINSCHAFT
FÜR VERÄNDERLICHE STERNE E.V. (BAV)
MUNSTERDAMM 90
12169 BERLIN

ISSUE No. 05 06/2019 ISSN 2566-5103

BAV MAGAZINE SPECTROSCOPY

Imprint
The BAV MAGAZINE SPECTROSCOPY appears half-yearly from June 2017. Responsibilty for publication: German Working Group for Variable Stars e.V. (BAV), Munsterdamm 90, 12169 Berlin

Editorial
Ernst Pollmann, 51375 Leverkusen, Emil-Nolde-Straße 12, ernst-pollmann@t-online.de
Lienhard Pagel, 18311, Klockenhagen Mecklenburger Str. 87, lienhard.pagel@t-online.de
Roland Bücke, 21035 Hamburg, Anna von Gierke Ring 147, rb@buecke.de
The authors are responsible for their contributions.
Cover picture: stargazerslounge.com

Content **Page**

E. Pollmann: Editorial 1

R. Berry: Student Spectrophotometry of the Planets: What Worked and What Did Not 2

M. Bröcker & S. Striewski: Hochauflösende Spektroskopie des Doppelsterns β Aurigae 16

M. Trypsteen: Determination of Planetary Rotation Velocities (Part II) 25

EDITORIAL

From the stars we basically receive only their electromagnetic radiation of different wavelengths, and we "see" essentially only the surface of the radiating bodies. By evaluating the light, we obtain information about:

- the direction of the radiation (positions and movement of the stars)
- the quantity of the radiation (brightness)
- the quality of the radiation (color, spectrum, polarization)

For amateurs, only the narrow band of visible light is easily accessible. In this spectral region, however, both the brightness (photometry) and the spectra of the objects can be examined. Today's amateur astronomy, with its instrumental and computer-assisted equipment, enjoys observation possibilities that were reserved exclusively for professional astronomers until a few years ago.

Thanks to the development of CCD technology, the types of observational perspectives have become much more varied. For example, in the area of variable star observation, there are many new possibilities in addition to already existing approaches.

Professional variable star research employs techniques and observation methods to study the physics and atmospheres of the stars in a holistic manner, considering all aspects and occurrences. Thus, this means that the collected radiation must be understood as a complex storage medium of the physical processes on and in the observed star.

This is appropriate for the intensity of the light, as well as for its spectral composition. The linking of brightness measurements and spectroscopy, a matter of course in professional astronomy, reflects this connection.

Along with brightness changes that occur in variable stars (which can occur quite frequently) variable changes in the state of the stars also can take place and often are revealed in the corresponding spectrum.

Ernst Pollmann

Student Spectrophotometry of the Planets: What Worked and What Did Not

by Richard Berry, Berry, Alpaca Meadows Observatory, Lyons, Oregon

Abstract

In summer 2016 I worked with two high-school students on a relatively advanced spectrophotometry project at the University of Oregon's Pine Mountain Observatory. My plan had been to use an ALPY 600 spectrograph on a 65 mm refractor to do an introductory survey of stellar spectral types. But when the small telescope's mount died, I asked the students what they wanted to do. They said: Let's do planets! Since Pine Mountain Observatory's 24-inch f/13 Cassegrain was available, we put the ALPY on the 24-inch, and shot spectra of Jupiter, Mars, Saturn, Titan, Uranus, Neptune, Triton, and the Moon. Everything worked perfectly (the success part!), but understanding what the data meant required more chemistry, physics, math, and software skills than the students could begin to absorb (i.e., not a success).

Introduction

We will hear a lot of success stories at this meeting. But I'm going to tell you about an experience that I had about a year ago that was a good part of my motivation for coming to this meeting. Let me paint a picture: we're at the University of Oregon's Pine Mountain Observatory, at 6,500 feet elevation, doing a four-day summer astronomy workshop for high-school students. The students stayed in an adjacent campground an easy walk from the observatory.

The workshop was put on by six amateur astronomers who served as mentors. The six of us who did this felt the need to pay back the experiences we'd had in the 50s and 60s that got us interested in astronomy or interested in computers, and ultimately led us to science-related careers. The projects were based on what those of us

involved were interested in, or into, or excited by. Each of us mentored two to four high-schoolers; two were assigned to me. Projects included taking pretty pictures, asteroid orbit determination, and measuring scintillation noise. Since I had been playing with a new spectrograph, I planned to introduce my two students to stellar spectroscopy.

Although Pine Mountain Observatory has a 24-inch f/13 Boller and Chivens Cassegrain reflector, all of the mentors brought their own equipment, much of it high-end amateur gear. For example, the guy doing asteroid orbits brought a heavy-duty AstroPhysics mount with a 120 mm Takahashi refractor. The different projects were spread along the walkway between the 24-inch dome and the 32-inch dome (the 32-inch was not functioning).

Student Spectrophotometry of the Planets: Richard Berry

We had four beautifully clear and moonless nights in a row. Each group of students was expected to give an afternoon presentation on their activities on the lastday of the workshop. Mentors gave talks in the mornings. In addition to producing an "instant talk," some students expected to use the data we collected in a senior-year project at their high schools. The younger of my two was just entering tenth grade, but the older would be in her senior year that fall. My plan – to introduce stellar spectroscopy – was that we would collect spectra from a list of "Oh Be A Fine Girl Kiss Me" stars so the kids would see what is involved in taking astronomical data. While still under the stars, we would take a quick look at each spectrum, and it would be clear that the spectra of stars vary. We could discuss what we were seeing, and during the day I hoped that we would have time to reduce the data and then attempt to arrange the spectra in some logical order, just as astronomers did in the early 20th Century.

The equipment I brought was rather modest: an ALPY 600 spectrograph mounted on a 65 mm f/6.5 refractor and Celestron AVX mounting. The ALPY is a compact design that provides a spectral resolution of 500 over a range from 375 to 750 nanometers —the whole visual spectrum. The ALPY has two CCD cameras: one to capture the spectra and one to view the slit of the spectrograph. With large telescopes, seeing enlarges the star images, so only a fraction of a star's light enters the spectrograph. The beauty of using a spectrograph on a small refractor is that the refractor forms tiny, clean star images, so nearly all the light from a star goes into the ALPY's 23-micron slit. Relative to expectations, the small system outperforms larger ones because all the light gets used. When you are guiding, you can see that the entire star image disappears into the slit.

Fig. 1: Our original observing plan employed a 65mm refractor with a Shelyak ALPY 600 spectrograph. Observers were seated at apicnic table on the north side of thetelescope. The second instrument was asmall Newtonian telescope for recreational visual observing during longer exposures.

Student Spectrophotometry of the Planets: Richard Berry

We set up the telescope, mount, and spectrograph on a graveled area, and located the students and a computer with control software on a picnic table beside it. Once everything was working - at least in theory - the mount, spectroscope, and CCD cameras could be run remotely from the computer ten feet away. We got started quickly enough; we soon had spectra of bright stars of different types.

I sat with them and made sure everything kept working. I may have helped them too much by finding the stars for them, but they quickly picked up the skills for centering stars, guiding on the slit, starting exposures, and saving spectra to the hard drive. Well, it got cold on the mountain. No matter what you tell high-school kids, they don't believe the temperature might drop to 32 degrees with a 15 mile an hour wind in the middle of summer. So they were freezing to death, and they were not used to staying up late at night. By midnight they were miserable and their brains had stopped working, so we called it quits.

The next morning I found the students had already begun to prepare their presentation. They hadmined Wikipedia for stuff about stars, and the question they had for me was, "What is our hypothesis?" The Scientific Method, they had been taught, involved framing a hypothesis that wewould test using our observations. We had a long discussion during which I learned about the older student's project from the previous year that involved the dissolution of coins in various acids and solvents. Collecting an O-B-A-F-G-K-Msequence did not fit into a scientific method scheme, so I suggested we try something different: "Let's look at M stars, the red ones with the bumpy spectra.

Fig. 2: Even when the screens were reduced to their lowest intensity, the laptop computer screens effectively blinded the observers controlling the CCD spectrum and guide camera. Thenight was clear and became quite chilly, so the student observers, who sat whileoperating the CCD camera from thecomputer, became very cold.

We can look for stars with different amounts of carbon, oxygen, and nitrogen." It was not a very good idea, but I hoped we could put together something that would be suitable for her senior project.

It proved tough to come up with a list of suitable type M stars. They needed to be oddballs, and they needed to be reasonably bright for the small aperture of the telescope. The evening started fairly well. After the first several stars, I left the kids gathering spectra and went off to see what the other groups were up to. When I came back, I noticed that the telescope was pointing far from the nominal target. A quick check showed that the spectra they had taken were not M stars at all. For some reason, the mount was pointing at anything but the target stars. Added to that, it was cold again.We gave up some time after midnight.

What Did Work

The next morning I took a walk with the students. I said, "You guys, we've got nothing . . . we don't have a hypothesis with this project. We've collected some spectra of stars around the sky. It's like a collection of leaves from different trees. We don't know enough about trees or leaves to make a hypothesis."

"However," I said, "We have two more nights, so at least we ought to have some fun. What would you like to do?" And they said, "We want to do some planets!" Mars, Jupiter, and Saturn had been temptingly lined up across the southern sky that July, shining brilliantly, and, for most people, planets are more familiar and comprehensible than stars. So I said. "Okay. I'll see whether we can hang our spectrograph on the 24-inch telescope, and I don't think anyone else is using it. It will be fun. Besides, it'll be warmer inside the dome than it is outside in the breeze."

So we hung the tiny ALPY spectrograph on the rear of the huge 24-inch Cassegrain, and strung the control wires to the students sitting at a folding table beneath the telescope. As darkness fell, we aimed the big telescope at Jupiter. With its 8 meter focal length, Jupiter was fully half the height of the slit. Although the seeing was not great, and cloud bands were visible in the guide camera image. We carefully aligned the ALPY so the slit ran along the Jovian equator, and then shot a series of 10-second exposures. That's when the serendipity kicked in: three of the Jovian satellites were visible.

We grabbed a 300-second exposure of each one, and then moved the telescope over to Mars. Since the polar caps were visible, we captured a series of 5-second spectra from the polar caps as well as the east and west limbs of the planet. I explained that I did not know whether our spectra would show any differences in the light reflected from the planet's red deserts and icy polar regions, but if we took the spectra, we would find out.

Student Spectrophotometry of the Planets: Richard Berry

Saturn proved to be a delight. With the slit running along the equatorial axis, spectra of the ball of theplanet were flanked by spectra of the rings. Each Saturn exposure required 60 seconds. All three of the parallel spectra showed Fraunhofer lines, but only the ball of the planet showed obvious dark absorption bands. More serendipity: there was Titan, a satellite with an atmosphere! Would wesee methane there, too? The best thing that happened that night – at least it was fun for me –
occurred after we finished Saturn.

The younger student had already conked out. I checked anephemeris, and proposed to the older student, "Do you think you have the energy to wait for Neptune to come around? We've done two giant planets, Jupiter and Saturn, but Neptune is another giant planet." Would it be like Jupiter and Saturn, or would it be different?

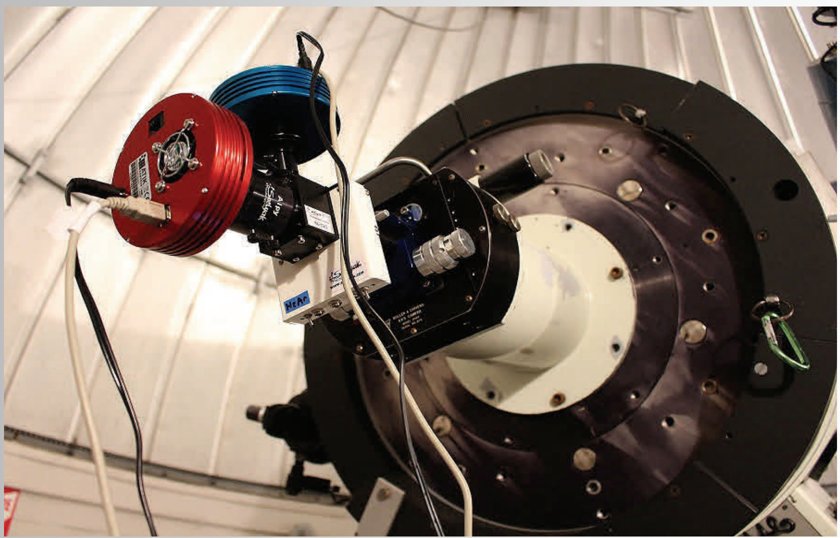


Fig. 3: The compact ALPY 600 spectrograph worked extremely well on Pine Mountain Observatory's 24-inch f/13 Cassegrain telescope. All functions of the ALPY were controlled "by wire" by the observers seated at a table below the telescope.

"Well, maybe," she said. "It'll be up in two hours, so why don't we do some calibration spectra on stars?" So the two hours went by quickly as we gathered spectra of some type A stars that were high in the sky. When Neptune came around, we did ten five-minute exposures and got some nice Neptune data. We even tried one of Triton, the eighth-magnitude satellite of Neptune. Then I sprung it on her: "In another hour, we can get Uranus," and when it rose we spent another hour taking 5-minute exposures of Uranus' spectrum.

Student Spectrophotometry of the Planets: Richard Berry

By now, dawn was coming and the sky had begun to brighten. I looked out the dome slit and I saw that the Moon was coming up. “Look, we can get a calibration spectrum that will fill the entire slit, and it’s a solar spectrum from an airless body, modified only by passage through the Earth’s atmosphere.” We pointed the telescope at the Moon as soon as it cleared the dome wall, and got some fine lunar spectra for calibration.

We parked the telescope and closed the dome a little before the Sun came up. We had ended up with beautiful spectra of Jupiter, Saturn, Uranus and Neptune, Mars, and the Moon – as well as three of the Galilean satellites of Jupiter, and Saturn’s moon Titan. We had beautiful data. Wehad methane and ammonia bands on the giant planets, and when we had done Mars we also had the equatorial regions versus the polar caps. The following night, the last night, we shot more images of Saturn in the early evening and left the CCDs taking bias frames dark frames until dawn.

Fig. 4: The younger student, seated at his computer, attempted to process spectra in real time. With more compatible computers and software, this could have worked very nicely.

Because we undertook making planetary spectra in the spirit of fun, the students seemed to enjoy the process much more than they had the previous nights of taking stellar spectra for a scientific presentation. It helped that it was relatively warm in the dome. Also, I think the 24-inch was closer to their conception of “telescope,” and the planets were more varied and “sexy” than stars. Both students mastered focusing the image using the in/out focus motor, centering objects on the slit,guiding to keep an object on the slit, setting exposure times, taking exposures, savingexposures, as well as keeping a written log of the objects, exposures, and context data.

Student Spectrophotometry of the Planets: Richard Berry

We had a lot of time in the dimly lit dome to discuss what we were doing, and made informal scribbles on a legal pad. The younger student fell asleep at midnight, but before he did, he had taken his turns guiding the telescope. I had enough time to find out how much (and how little) they already knew, and how we might be able to shape their presentation to report what we had accomplished.

Fig. 5: The screen of the computer we used to control the spectrograph displayed images from the spectrum camera (on the left) and the slit-monitor and guide camera (on the right). The students used the telescope control paddle to center and guide images of the planets.

I won't delve into the science of spectrophotometry,except to explain, in as few words as possible, what we got. The Sun illuminates the planets, and ist spectrum is the classic Fraunhofer spectrum, full of spectral absorption lines. When sunlight reflects from a body in space, the body modifies the solar spectrum. The straight reflectance spectrum of Saturn combines the effects of the solar spectrum with the reflectance spectrum of Saturn. The gas giant planets Jupiter and Saturn, and the water giant planets, Uranus and Neptune, absorb energy due to the molecular absorption bands of methane and possibly ammonia. We were fortunate in getting a beautiful set of reflectance spectra of the Moon, which has no atmosphere, so its spectrum consists of the sunlight that is only slightly yellowed by the minerals in the lunar surface. When you divide Saturn's spectrum by the lunar spectrum, the Fraunhofer lines common to both divide out and – BINGO – you see the absorption lines standing out loud and clear on the ball of the planet, but no such features on the rings. The younger student quickly became adept at usingImageJ. When he asked me how to extract aone-dimensional profile from a spectrum, I told him I did not know, but it was such a basic operation that Image. I was sure to do it.He figured it out on his own in about five minutes.

What Didn't Work

Computers. I had a PC. They had Macs. Software? The program I had intended to use for reducing the spectra, Tom Fields' RSpec, did not at that time run on Macs. I like RSpec: it's easy to use, has a short learning curve, and it teaches as you learn to use it1 But there's nothing magic about extracting a one-dimensional profile from a two-dimensionalimage. I fished up and installed ImageJ, a flexible image-processing program that ran on their Macs as well as on my PC. The younger student was clearly impressed with its capabilities. So that turned out okay.

The students knew all about Google Drive; I had only heard about it. I logged in and fifteen minutes later we were in business. We used Google Drive to move our data from my computer to theirs, and various Google apps to prepare their presentation. Although the Internet connection on the mountain was slow, it was fast enough to let us locate and download ImageJ, and it allowed us to work effectively with Google apps. It also gave the students access to Wikipedia, which they considered essential to preparing the presentation expected of them.

Fig. 7: With the help of Google Docs and Google Show, the students reduced the data and prepared their presentation. The younger student, on the left, using ImageJ, produced intensity profiles, while the older student researched spectroscopy and prepared slides.

That, in fact, highlights the mismatch in thinking between the students and me. The students felt pressured to get the "right" results. They were acutely aware they would be speaking to other bright high-school kids, to their teachers, and to the other mentors.But I had gone out with the attitude: I'm not sure what we're going to get with these planets.

Student Spectrophotometry of the Planets: Richard Berry

I knew in general what we would get —methane in the giant planet atmospheres would surely be unmissable —but I had only a rough idea what the exposures would be required for planets on the big telescope, or how good our data would be. Basically, I was improvising and learning as we went. We would shoot a spectrum, measure the pixel values in it, and try another exposure. That initially freaked them out. They wanted me to be the expert; someone who could guide them safely through a mysterious process, someone who was going to tell them what was going to happen next.

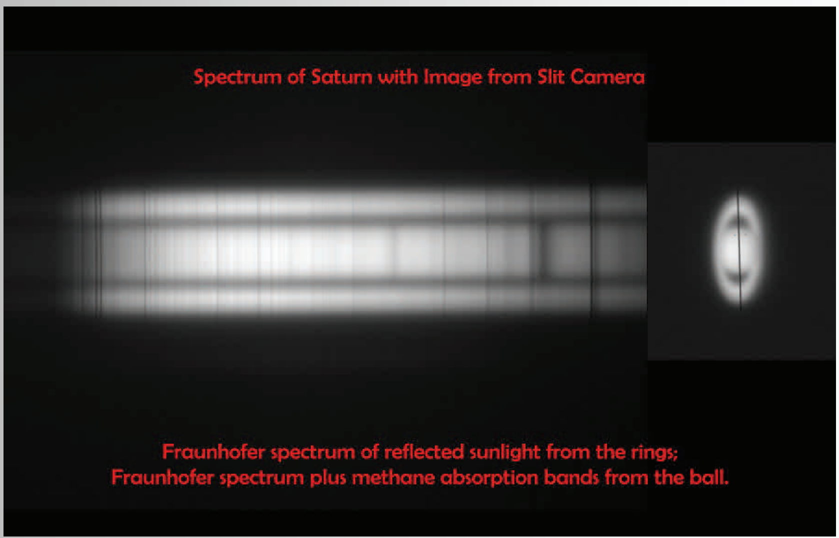


Fig. 8: Saturn demonstrates reflectance spectroscopy of the planets. At right, the image of Saturn rests on the slit of the spectrograph, while the spectrum appears on the left. The solar Fraunhofer spectrum appears in the spectrum of the ball and the rings of the planet, but methane absorption bands appear only in the spectrum of the ball.

I think that the younger student understood the idea first: try an exposure, measure the result, adjust the exposure, try again. The enormous size of the planetary images from the big telescope —two millimeters across Saturn's ring system —meant that only a tiny fraction of the planet's light entered the 23-micron slit of the spectrograph. It turned out that our Saturn spectra required 60 seconds, but we needed only 300 seconds for its very much dimmer satellite Titan, courtesy of Titan's compact star-like image. That was a nice surprise!

In a school setting, you'd have a month or so to teach students about light, what a spectrum is, etc.:

all that background needed to comprehendspectroscopy. In a four-day workshop setting, with one student going into tenth grade and one goinginto twelfth grade, they were unsure in their knowledge of the solar system and which planetswere which.

Student Spectrophotometry of the Planets: Richard Berry

Astronomy is not taught in Oregon schools, but in the popular media, characters routinely fly off to planets and galaxies with equal ease. Given what they see and hear, it's not hard to understand why basic astronomy is confusing.

What They Learned

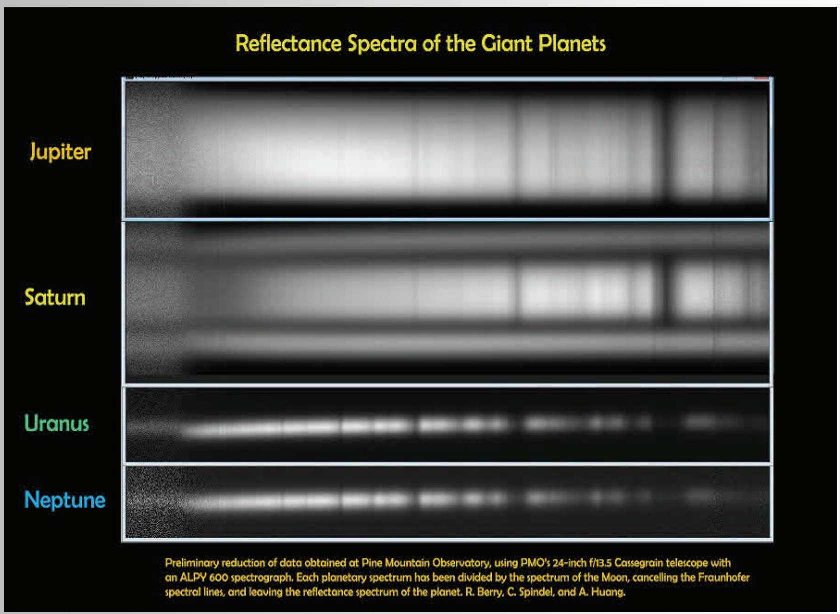
It's difficult to assess - and partly speculation on my part - what the students actually learned from their experience at Pine Mountain Observatory. Based on the presentation they gave for the otherstudents, their teachers, and the other mentors, as well as on comments they made at the time, I offer the following:

- It gets cold on a mountain at night.
- The big telescope was fun to use!
- Data are precious.
- When you try to find a star, they all look alike.
- Five-minute exposures take forever.
- You must guide to keep Saturn on the slit.
- Data does not analyze itself by itself.
- Spectra are smeary streaks.
- Spectrum data is a bumpy line.
- Some of the bumps mean Jupiter has gas.

"Some of the bumps mean Jupiter has gas." Well, you have to admit that although it may sound simplistic, that statement is true enough. So in some respects, they did grasp the basic rationale for what we were doing. The younger student, who did the bulk of the work extracting spectral curves from the spectrum images, may have gained a better understanding, but the older student prepared most of their presentation. What they didn't get in the presentation is the big picture. In their presentation, they did not explain that the Sun has a spectrum with Fraunhofer lines in it, that the Sun shines on the planet, the planet modifies the spectrum when reflects the sunlight, and that, we, viewing the planet through the Earth's atmosphere, can, through clever manipulation of the spectral data that we took, deduce something about the properties of the planet's surface. They did not even come away from the experience, I think, with a sense of joy from getting out there and looking closely at some aspect of the real Universe. They were trying to force-fit their "doing science" experience into their understanding of the scientific method, with a hypothesis and so on. They were aware that astronomers already have textbook answers, and they were concerned about getting the right answers. During those hours in the 24-inch dome, I stressed, "There is no right answer. What we observe here and now is what is actually out there." I don't think they really understood that what we do as astronomers and observers informs the textbooks, not the other way around.

Afterword

I closed my talk at the RTSRE conference saying, "If we're going to do these summer research projects more effectively, we must adopt better methods and better thinking. In the six months since that time, I have thought about this a good deal. The very simplest change would be to meet with the students two or three weeks ahead of the workshop, and spend a day talking through what the projects would be and what doing them would involve. Given a basic grounding, the opportunity to ask questions, and some time to do some on-line research, they could arrive both prepared and ready for the direct experience.It may be difficult, but I think we owe it to potential scientists to tell them that the scientific method is a high-level description of a process that working scientists usually honor only in the breach.



ig. 9: Our spectra from Pine Mountain Observatory show gas absorption bands for the giant planets. In each case, the raw reflectance spectrum has been calibrated and then divided by the reflectance spectrum of the Moon, thereby removing the solar Fraunhofer lines. Jupiter shows both methane and ammonia bands, Saturn's ball shows methane and weak ammonia bands while the rings display no absorptions. The spectra of Uranus and Neptune show very deep methane absorption.

We work, we think, we discuss, we make observations, we get inspirations — and afterwardwe write it up as if it had been a systematic process. The reality is that we muck around exploring the territory, making observations just to see what's going on. In an observational science like astronomy, this often occurs when we get new instruments or observing tools.

Student Spectrophotometry of the Planets: Richard Berry

This open pattern of exploration is what I planned to do with the students and the spectrograph: “Let’s look at a bunch of stars and see what is out there.” Of course, I wanted the spectra we took to include every type of star, not just the common A, F, G, and K stars, so I had salted the list with the relatively rare O, B, and M-type stars.

Once we think we understand the territory, scientists tend to standardize methods of collecting data. That is more or less what the students and I did with our spectra of the planets. Instead of searching, we followed an observing protocol to make scientific measurements. Much of ordinary science consists of doing this type ofbread-and-butter observation; filling in gaps, populating databases, and keeping our eyes openfor anything out of the ordinary. A formal scientific method is far from our minds most days; we’re working inside a well-established body of knowledge, decorating the walls with more stuff that fits the prevailing meme.

So when does the scientific method come into play? In my experience, we drag it out and apply it when the going gets sticky. We have observations that don’t fit. We have a hunch that might explain what’s going on. The purely creative process breaks down, and we start writing things down. We make a list of hunches. We run gedanken experiments. We do the math. We need access to a bigger telescope, so we write a proposal to the timeallocation committee, and have to get everything down on paper. I think that when we explain how science really works — a creative endeavor that is both loosy-goosy and extremely demanding —we’ll find that more students will get excited and want to join in playing this grand game.

It’s important to point out that I’m a 70-year-old guy who has been playing with telescopes and gadgets for 58+ years, so I have a lot of experience to fall back on when things go awry. For example, I had no qualms about operating PMO’s 24-inch Cassegrain telescope with ten minutes instruction from the observatory’s tech support guy. I knew that a nominally f/5 spectrograph would work happily on the f/13 telescope, and I knew enough to know that a focal-ratio mismatch could have been a problem. I knew enough to get the telescope focused despite a quirky focus motor. I’ve had enough experience with both PCs and Macs to recognize that we could use ImageJ on both, and was delighted to discover the existence of AstroImageJ. Finally, I’m not in the teaching profession. I’m having fun doing this. I have no skin in this game. I can be wrong and it doesn’t matter.

I was greatly intrigued by the Freed and Genet ”communities of practice” concept. Although not intended as a teaching environment, between my junior and senior year in high school I was a summer “observer” at Yale University’s Bethany Station near New Haven. My job was to operate a20-inch telescope with a four-channel spectrophotometer.

Student Spectrophotometry of the Planets: Richard Berry

This meant running all systems from rewinding the weight-driven clock drive to servicing the photomultiplier tube coolant loop each night with dry ice. I was in hog heaven! On clear nights we observed possible flare stars all night long. On cloudy nights we observed the dark current in the photomultiplier tubes all night long. During the days, I was free to annoy the graduate students operating radio telescopes observing Jovian decametric radiation (it had been recently found to be modulated by Io) with endless questions.

Since the RTSRE conference, I have had a very positive experience working with four undergraduate physics student from Portland Community College. The project was to recreate the Eddington Experiment of 1919 using modern amateur equipment during last summer's solar eclipse. Although their professor has no practical experience in observational astronomy, he is good at getting grants, and had spotted this project as a good one. I was recruited, in part, because my property and my observatory were nearly on the center line. T

hese students are "non-traditional" in different ways. Two are in their early 30s, one in his late 30s, and one is a home-schooled high-school-age student who has been taking college-level courses for several years. Four months before the eclipse, even before the RTSRE conference, we had set up a small telescope with a CCD camera on my property. Two students trained on that telescope and the other two trained with a portable telescope.

We had more than a dozen sessions together. We worked through a large number of problems to be able to carry out high-precision astrometry with small telescopes. About three days before the eclipse, I pulled back and let the students work out the details between themselves. I could see they were a bit scared, but during the eclipse, when there would be no time to ask questions, they had to be self-sufficient.

They captured excellent data — in focus and properly exposed — consisting of 23 eclipse images and 10 astrometric reference images. Our next challenge would be to reduce these images to determine whether the gravitational deflection predicted by Einstein's General Relativity agrees with the deflections we measured this summer.

However, we had failed to consider how complex data reduction would prove to be. I proposed writing reduction software using Python's NumPy, SciPy, and AstroPy libraries — only to learn that not one of the students had any prior experience writing software, and at that point I was just beginning to learn Python. Not surprisingly, progress has been slow; a few key routines are now written and we have produced a few pretty charts.

Student Spectrophotometry of the Planets: Richard Berry

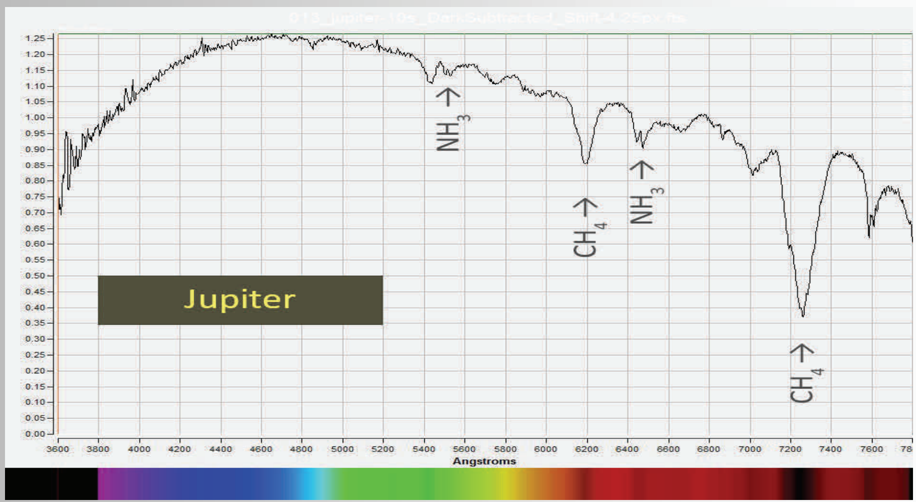


Fig. 10: Jupiter divided by lunar spectrum.

But the students have regular spring-semester classes, and the Eddington Experiment is a non-class activity that does not even offer them extra credit. I am hoping to rouse their interest this coming summer, to complete the data reduction. My suspicion is that no amount of theory or classroom work could have prepared these students for this experiment as doing the grunt work and solving the practical problems we encountered. The "hands-off" nature of robotic telescopes worries me. Observational astronomy seems to require a certain "gut feel" for the costs and pitfalls of gathering actual data. You get cold. You get sleepy. A technician puts the wrong filter in the filter wheel. You erase the wrong directory. Power supplies fail. Only after teachers and their students experience the good, the bad, and the ugly of working hands-on with the tools of their trade, can they properly love, appreciate, trust, and distrust aremote robotic telescope.

Acknowledgements

I would like to thank the Pine Mountain Observatory, its Director, Scott Fisher, and Alton Luken, Operations Manager, for opening the Observatory and its facilities to volunteer educational activities. Pine Mountain Observatory, located 34 miles southeast of Bend, Oregon, isperched atop a mountain at an elevation of 6,300 feet. The observatory's location is well placed tomake the most of the dark skies that the Eastern Oregon high desert provides. The observatory isoperated by the University of Oregon, Department of Physics, under a special use permit from theDeschutes National Forest. The observatory'sprimary function is research and other astronomical observations, including basic andadvanced scientific research. However education atall levels is also an important function andobjective of the observatory. The current schedule of activities is located at https://pmo.uoregon.edu.

Hochauflösende Spektroskopie des Doppelsterns β Aurigae

von Marius Bröcker & Samuel Striewski (Teil I)

Einleitung

Es ist erstaunlich, dass Astronomen seit Anbeginn der Wissenschaft Erkenntnisse über weit entfernte Sterne und Sonnensysteme gewinnen konnten, ohne unseren Heimatplaneten je verlassen zu haben. Selbst heutzutage, wo Raumfahrt seit langer Zeit Wirklichkeit geworden ist, ist es uns immer noch unmöglich, entfernte Sterne zu bereisen. Um dennoch den Rätseln unseres Universums auf den Grund zu gehen, haben wir uns dazu entschieden, den Projektkurs Astronomie zu wählen und die Chancen der Sternforschung wahrzunehmen. Nachdem wir uns ausführlich mit der Spektralanalyse beschäftigt hatten, sind wir zu dem Entschluss gekommen, uns in unserer Projektarbeit ebenfalls mit Spektroskopie zu beschäftigen. Nach erfolgreichen Messungen und guten Ergebnissen fiel die Entscheidung, mit dem Projekt zusätzlich bei Jugend forscht teilzunehmen.

In unserer Arbeit haben wir uns mit einem Doppelsternsystem namens β Aurigae beschäftigt, da gerade in der Spektroskopie Doppelsterne ein hochinteressantes aber anspruchsvolles Thema dar-stellen. Zudem stand β Aur zum Zeitpunkt unserer Messungen günstig am östlichen Himmel und bot sich daher zur beispielhaften Bestimmung der systeminternen Parameter an. Das Ziel unseres Projek-tes war, mit den gegebenen Messinstrumenten möglichst nah an die Ergebnisse von professionellen Astronomen heranzukommen und damit die Qualität der Messinstrumente sowie die korrekte Messweise zu erlernen. Das ausgewählte Sternsystem β Aur ist ein sogenannter spektroskopischer Doppelstern. Die beiden Sterne sind gravitativ aneinandergebunden und nur mit Hilfe von Spektroskopie auffindbar, da sie für uns nicht optisch auflösbar sind. Im Falle von β Aur handelt es sich in Wirklichkeit um ein Dreifachsternsystem. Allerdings leuchtet der dritte Stern neben β Aur A und B sehr schwach und ist weit entfernt von seinen Geschwister-Sternen, so dass er für die folgende Messung keine Rolle spielt und man das Sternsystem weiterhin als Doppelstern ansehen kann.

Zur Berechnung waren zunächst Aufnahmen von mehreren Spektren nötig, die über einen längeren Zeitraum die Umkreisung der Sterne umeinander dokumentieren sollten. Da die beiden Sterne um einen gemeinsamen Massenschwerpunkt kreisen, bewegen sie sich in regelmäßigem Abstand auf den Beobachter hin und wieder von ihm weg. Durch den Doppler-Effekt ist bekannt, dass sich die Wellenlänge von Licht verändert, wenn sich die Lichtquelle relativ zum Beobachter bewegt. Somit können wir auch von der Erde aus, durch zeitliche Veränderungen der Wellenlängen im Doppelstern-Spektrum, auf die Geschwindigkeit der Sterne zu jedem Zeitpunkt Rückschlüsse ziehen.

Hieraus kann man anschließend Erkenntnisse auf die Eigenschaften der Umlaufbahnen beider Sterne ableiten und diese folglich recht genau bestimmen. Zu diesen Eigenschaften bzw. zu diesen Parametern gehören beispielsweise die Umlaufzeit der Doppelsterne, die Entfernung zueinander und ihre Massen, die Exzentrizität der Umlaufbahn usw.

Theoretische Grundlagen

Herleitungen aus dem Gravitationsgesetz

Aus den Messergebnissen, die im Verlauf dieser Arbeit entstanden sind, solle die Masse der einzelnen Sterne M_1 und M_2, sowie deren Abstand r zueinander berechnet werden. Die benötigten Formeln für diese Berechnung lassen sich mit Hilfe des Gravitationsgesetzes von Isaac Newton und der Skizze aus Abb. 1 herleiten:

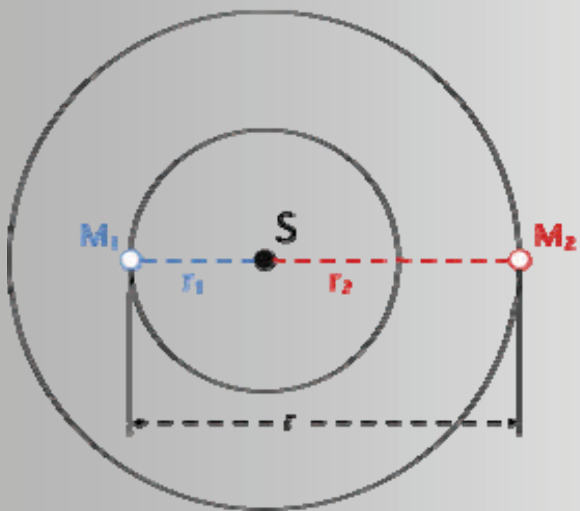


Abb. 1: Skizze zur Massenbestimmung von Doppelsternen

Die Massen der beiden Sterne des Doppelsternsys-tems werden mit M_1und M_2 bezeichnet. In einer ersten einfachen Annahme bewegen sich die beiden Sterne auf Kreisbahnen mit den Radien r_1 und r_2 um den gemeinsamen Massenschwerpunk S. Dabei ist r die Summe von r_1 und r_2.

Für jeden der beiden Sterne gilt, dass die Gravitations-Wechselwirkung mit dem jeweils anderen Stern eine Zentralkraft darstellt, die den Stern auf einer Kreisbahn um S hält.

Damit wird die Zentralkraft Fz durch die Gravitation Fc verursacht und es gilt folglich für jeden der beiden Sterne:Fz=Fc

Aus der Definition von Fz und Fc folgen damit die beiden Gleichungen:

I. $M_1 \cdot \omega_1{}^2 \cdot r_1 = G\frac{M_1 \cdot M_2}{r^2}$ und II. $M_2 \cdot \omega_2{}^2 \cdot r_2 = G\frac{M_1 \cdot M_2}{r^2}$

ω steht für die Winkelgeschwindigkeit des Sterns. G ist die Gravitationskonstante, eine Naturkonstante mit dem Zahlenwert $6{,}67408 \cdot 10^{-11}\ m^3\ kg^{-1}\ s^{-2}$. Nun lässt sich in den Formeln I und II M_1 bzw. M_2 wegkürzen. Ersetzt man nun in einem weiteren Schritt ω durch $2\pi/T$ (T = Umlaufszeit des Sterns in Sekunden), so erhält man folgende Gleichungen:

III. $\frac{4\pi^2}{T_1} \cdot r_1 = G\frac{M_2}{r^2}$ und IV. $\frac{4\pi^2}{T_2} \cdot r_2 = G\frac{M_1}{r^2}$

Nun gilt $T_1 = T_2 = T$, da sich wegen der Konstanz der Abstände $r_1 + r_2 = r$ beide Sterne mit derselben Winkelgeschwindigkeit um ihren gemeinsamen Schwerpunkt bewegen. Um zwei „bequeme" Formeln für die Massen M_1 und M_2 zu erhalten, werden im nächsten Schritt die Formeln III und IV addiert bzw. dividiert. Zunächst die Addition von III + IV:

V. $$\frac{4\pi^2}{T} \cdot (r_2 + r_2) = \frac{G}{r^2} \cdot (M_1 + M_2)$$

Es gilt: $r_1 + r_2 = r$ (siehe Abb. 1). Durch weiteres Umstellen der Formel V erhält man so:

VI. $$M_1 + M_2 = \frac{4\pi^2}{G} \cdot \frac{r^3}{T^2}$$

Dividiert man die Formeln III und IV durcheinander, so erhält man das Massenverhältnis der beiden Sterne aus dem umgekehrten Verhältnis der Abstände zum Schwerpunkt:

VII. $$\frac{\frac{4\pi^2}{T_2} \cdot r_2}{\frac{4\pi^2}{T_1} \cdot r_1} = \frac{G\frac{M_1}{r^2}}{G\frac{M_2}{r^2}}$$ daraus folgt: $$\frac{M_1}{M_2} = \frac{r_2}{r_1}$$

Nun haben wir zwei Gleichungen (VI und VII) mit zwei Unbekannten (M_1, M_2). Die beiden letzten Gleichungen VI und VII gelten übrigens auch für Doppelsternsysteme mit elliptischen Umlaufbahnen, wenn man anstatt der Abstände r_1 und r_2 die entsprechenden Bahnhalbachsen wählt. Da die Abstände der beiden Sterne im (spektroskopischen) Doppelsternsystem β Aur optisch mit unseren Teleskopen an der Schulsternwarte nicht auflösbar sind, kann r und das Abstandsverhältnis r_1/r_2 nicht ohne weiteres bestimmt werden. Mit Hilfe der Spektroskopie und dem Dopplereffekt können jedoch Aussagen zur Geschwindigkeit gemacht werden, daher müssen wir die Abstandsangaben mit Hilfe der Beziehungen der elementaren Kreiskinematik durch Bahngeschwindigkeiten ersetzen. Mit dem Zusammenhang $v = \omega * r = (2\pi/T) * r$ kann der Radius, den die Kreisbahn besitzt, durch $r = T * v / 2\pi$ ersetzt werden.

Die spätere Auswertung unseres Spektroskopie-Experimentes ergibt zwei Sinusfunktionen, die von der Geschwindigkeit v und dem Winkel i ,der die Inklination, also den Neigungsgrad gegenüber dem Beobachter angibt, abhängen. Beide Kurven besitzen jeweils einen Maximalwert K_1 bzw. K_2, der durch die Gleichung $K = v * \sin(i)$ ausgedrückt werden kann. Formt man diese nach v um und setzt es anschließend in die Gleichung für den Radius der Kreisbahn vom vorherigen Absatz ein, so erhält man:

VIII. $$r = T \cdot \frac{K}{2\pi \cdot \sin i}$$

Abstandsberechnung

Setzt man nun für die Radien die Formel VII ein, kürzen sich T und $2\pi * \sin(i)$ weg und es bleibt als Gleichung das Massenverhältnis zum umgekehrten Verhältnis der Maximalwerte K_2 und K_1:

IX. $$\frac{M_1}{M_2} = \frac{K_2}{K_1}$$

Beide K-Werte sind als maximale Radialgeschwindigkeiten aus dem Graphen ablesbar und somit kann bereits durch die Messpunkte das Massenverhältnis der Sterne im Doppelsternsystem β Aur bestimmt werden. Um absolute Werte für die Massen der Sterne berechnen zu können, wird der Winkel i benötigt. Die Rechnung geht aus dem oben bereits umgeformten Gravitationsgesetz (VI) hervor. Der Gesamtabstand r wurde als $r_1 + r_2$ definiert und mit VIII eingesetzt in VI folgt:

X. $$M_1 + M_2 = \frac{4\pi^2}{G \cdot T^2} \cdot \left(\frac{T \cdot K}{2\pi \cdot \sin i}\right)^3$$ bzw. XI. $$M_1 + M_2 = \frac{T}{2\pi \cdot G \cdot \sin^3 i} \cdot (K_1 + K_2)^3$$

Formt man IX. nach M_1 um und setzt es in X. ein, erhält man den absoluten Wert von M_2:

XII. $$M_2 = \frac{T}{2\pi \cdot G \cdot \sin^3 i} \cdot \frac{(K_1 + K_2)^3}{\frac{K_2}{K_1} + 1}$$

Massenformel

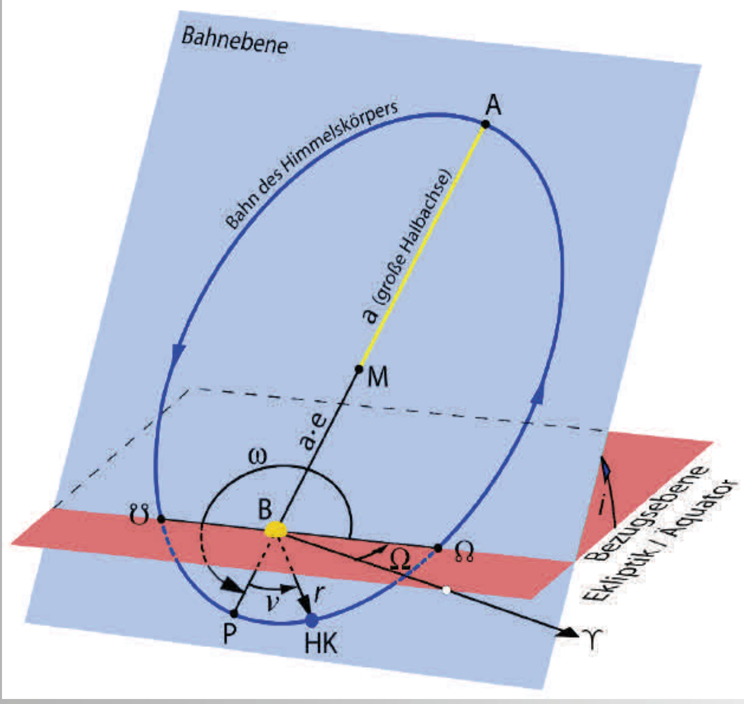
Gleichermaßen gilt nach Umformung für M_1:

XIII. $$M_1 = \frac{T}{2\pi \cdot G \cdot \sin^3 i} \cdot \frac{(K_1 + K_2)^3}{\frac{K_1}{K_2} + 1}$$

Abgesehen vom Neigungswinkel können alle weiteren Schritte zur Berechnung der Massenverhältnisse und der absoluten Werte für die Masse ohne äußere Zusatzwerte vollzogen werden. Lediglich die Umlaufdauer *T* und die Grenzgeschwindigkeiten K_1 und K_2 müssen nun bestimmt werden, wofür zunächst mit der Aufnahme eines Sternspektrums von β Aur zu beginnen ist.

Radialgeschwindigkeit

Die Radialgeschwindigkeit eines Himmelskörpers, in unserem Fall die von β Aur, bezeichnet die Geschwindigkeitskomponente des Objekts relativ zum Beobachter, also der Erde.



a: Große Halbachse der Bahn
e: nummerische Exzentrizität
i: Bahnneigung (Inklination)
r: Radiusvektor
ν: wahre Anomalie
ω: Periastronwinkel
Ω: Länge des aufsteigenden Knotens
P: Periastron
A: Apastron
t: Epoche des Periapsis-Durchgangs
M: Zentrum der Ellipse
γ: Richtung zum Frühlingspunkt. Dieser ist der Schnittpunkt von Äquator und Ekliptik beim Durchgang der Sonne von Süden nach Norden.

Abb. 2: Bahnelemente und ihre Parameter

Definiert ist sie als positiv, wenn sich das Himmelsobjekt in Richtung der Sichtlinie des Beobachters entfernt. Ist das der Fall, so tritt auch die sogenannte Rotverschiebung im Spektrum auf, da sich die Wellenlängen durch den Doppler-Effekt strecken und –mathematisch gesehen – größer werden. Die genaue Messung der Radialgeschwindigkeit bietet letztendlich Aufschluss über die systemrelevanten Bahnparameter von β Aur. Für die Umlaufbahn eines Sterns gelten die Parameter neben Abb. 2. Das zweite Keplersche-Gesetz zeigt, dass die Oberflächengeschwindigkeit konstant ist: Der zweite Stern bewegt sich also beispielsweise schneller, wenn er sich näher am ersten Stern befindet. Mathematisch drückt sich dieser Sachverhalt folgendermaßen aus:

I. $$\frac{r^2}{2} \cdot \frac{dv}{dt} = \frac{\pi \cdot a^2 \sqrt{1-e^2}}{T}$$

Der Abstand *r* zwischen beiden Sternen wird angegeben als:

II. $$r = \frac{a(1-e^2)}{1+e \cdot \cos v}$$

Schließlich folgt aus dem dritten Keplerschen-Gesetz der Zusammenhang zwischen der Gesamtmasse M des Systems (in Sonnenmassen) und der großen Bahnhalbachse a (in astronomischen Einheiten) und der Umlaufzeit T (in Jahren):

III. $$\frac{a^3}{T^2} = M_1 + M_2$$

Die ersten beiden Keplerschen-Gesetze implizieren: In einem Doppelsternsystem wird zur Beschreibung der Umlaufbewegung der globalen Systemgeschwindigkeit Vy eine periodische Radialgeschwindigkeit Vr hinzugefügt.

IV. $$V_r = V_\gamma + K \cdot [e \cdot \cos \omega + \cos(\omega + v)]$$

Formel der Radialgeschwindigkeit

Die Hälfte der Amplitude, genannt K_I (für den i-ten Stern) wird berechnet aus:

V. $$K_{1,2} = \frac{2\pi \cdot a_{1,2} \cdot \sin i}{T \cdot \sqrt{1-e^2}}$$

Dabei ist a_1 die Bahnhalbachse der Umlaufbahn um den Massenschwerpunkt. Im Falle von spektroskopischen Doppelsternsystemen, wie β Aurigae, ist neben K_1 auch K_2 im Spektrum messbar. So ist es uns möglich, die Parameter über die Radialgeschwindigkeit zu bestimmen.

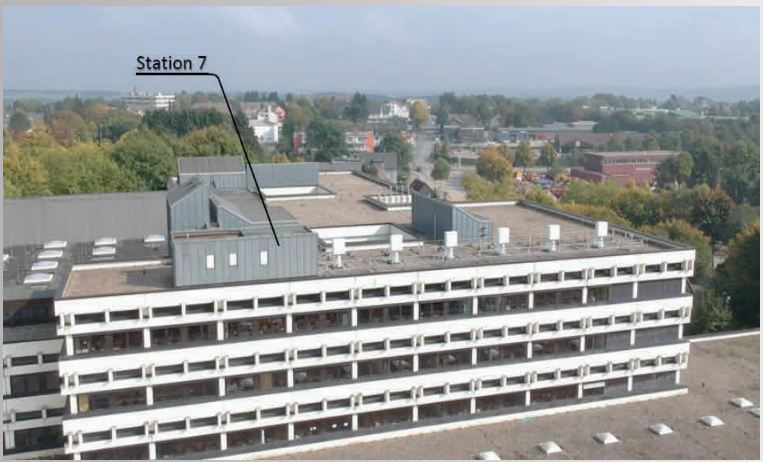


Abb. 3: Die Sternwarte auf dem Dach des CFG

Das Schülerlabor

Die Messungen wurden im Schülerlabor Astronomie auf dem Dach des Carl-Fuhlrott-Gymnasiums (CFG) durchgeführt (Abb.3). Neben 6 weiteren Stationen steht auch eine Aufnahmestation, die Station 7, mit einem CDK-20 Teleskop zur Verfügung, welches für die Aufnahmen genutzt wurde.

Abb. 4: Auf der Sternwarte am CFG ist das CDK-20 fest auf der parallaktischen Montierung GM 4000 HPS II montiert.

Bei dem CDK 20 in der Station 7 handelt es sich um ein Spiegel-Teleskop mit einer Öffnung von 20.5 Zoll, was einem Durchmesser von 520.7 mm entspricht (Abb.4). Die Lichtsammelleistung des Teleskops liegt bei circa 5250 und signalisiert, dass sie 5250 mal so viel Licht wahrnehmen kann wie das menschliche Auge.

Die Brennweite von 3454 mm und das Öffnungsverhältnis f/6,8 ordnen das CDK 20 zu den schnellen Optiken ein. Für weit entfernte Deep-Sky-Objekte oder Sterne wie β Aur eignet es sich daher besonders gut, da durch die größere Sammelleistung die Belichtungsdauer kurz wird und man schärfere Bilder erhält. Sowohl der elliptische Hauptspiegel mit einem Öffnungsverhältnis von f/3 und einem Durchmesser von 520.7 mm, als auch der sphärische Fangspiegel mit 190.5 mm Öffnung ist aus austemperiertem Pyrex gefertigt und qualitativ sehr hochwertig, besonders für eine Sternwarte, die von Amateurastronomen, wie uns Schülern, genutzt wird.

Eine Optik allein reicht für erfolgreiche Beobachtungen jedoch noch nicht aus. Damit man Objekte präzise ansteuern und nachführen kann, wird eine gute Montierung benötigt, welche sowohl Stabilität für das schwere Teleskop bietet, als auch uneingeschränkte Schwenkmobilität gewährleistet, in unserem Fall die parallaktische Montierung GM 4000 HPS II (**H**igh **P**recision and **S**peed) (Abb. 3).

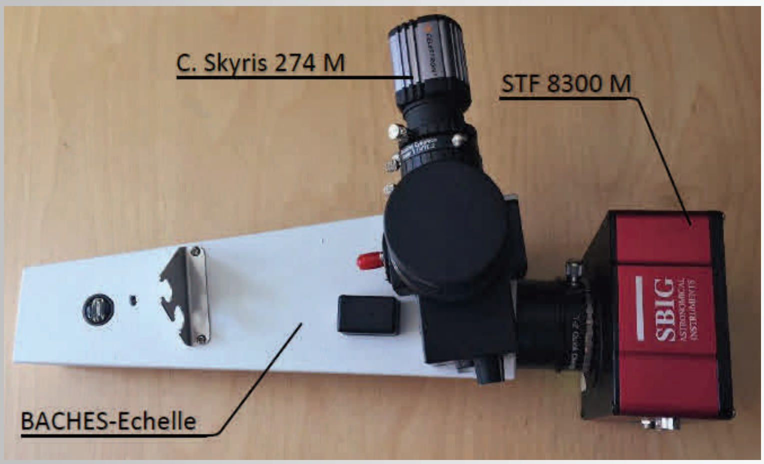


Abb. 5: Die Celestron Skyris und die SBIG Kamera installiert am BACHES-Echelle Spektrograf.

Um die hochwertige Qualität von Teleskop und Montierung angemessen nutzen zu können, wurde die Aufnahmekamera SBIG STF 8300 M verwendet (Abb. 5). Damit bei den Spektralaufnahmen überprüft werden konnte, ob der Stern nach wie vor an der richtigen Position stand, nutzten wir die Guiding Kamera Celestron Skyris 274 M (Abb. 5).

Das eigentliche Kernstück der Arbeit ist die Aufnahme der Spektren. Diese wurden mit dem hochauflösenden BACHES-Echelle Spektrograf aufgenommen (Abb. 5). Durch ein Sprossengitter, auch genannt Echelle-Gitter, wird das eintreffende Licht in seine Wellenlängen zerlegt und auf ein zweites Gitter reflektiert.

Da die einzelnen Sprossen im Größenbereich der Wellenlänge des sichtbaren Lichtes liegen, sind sie vergleichbar mit vielen Einzelspalten, sog. Ordnungen, für die Wellenlängen im Bereich von 392 nm bis 800 nm. Für diesen Bereich wird durch das zweite Gitter ein durchgehendes Spektrum erzeugt, welches in Abschnitten übereinander geordnet ist (Abb.6). Daraus folgt eine vielfach größere Auflösung des Spektrums, notwendig für unsere Messungen.

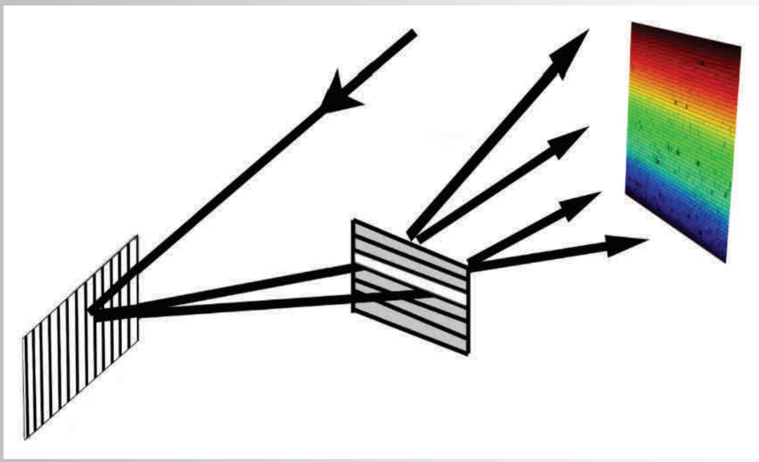


Abb. 6: Zustandekommen der Ordnungen im BACHES-Echelle Spektrograf

Durchführung

Ablauf des Experiments

Das Ziel unseres Projektes war die Bestimmung möglichst vieler Bahnparameter des Doppelsterns β Aur. Um eine erfolgreiche und vor allem eine auf eigenen Daten basierende Auswertung zu erreichen, werden viele Datensätze benötigt. Ein Datensatz besteht aus drei verschiedenen Messungen:

1. Erzeugung eines kontinuierlichen Flatfield-Spektrums mit Hilfe einer Halogenlampe. Das Flatfield-Spektrum dient zur Ordnungserkennung des Sternspektrums sowie zur Entfernung von eventuell vorhandenen Staubpartikeln.

2. Erstellung eines Referenzspektrums der Thorium-Argon-Lampe, mit welchem dem Sternspektrum die zugehörigen Wellenlängen zugeordnet werden.

3. Aufnahme eines Spektrums von β Aur, dass nach der Kalibrierung mit dem Flatfield- und dem Thorium-Argon-Spektrum ausgewertet wird.

Die Aufnahme dieser Spektren geschieht an dem CDK-20, an dem der BACHES-Echelle Spektrograf angeschlossen ist. Über ein Faserkabel ist der Spektrograf an die Remote Calibration Unit angeschlossen, welche manuell zuschaltbar ist. Anschließend werden die Spektren mit der Astrosoftware *MaxIm DL* mit optimalen Belichtungszeiten aufgenommen. Danach erfolgt die Aufnahme der Flatfield-Spektren und der Referenzspektren. Zuletzt werden die Doppelsterns erfasst.

(Wird fortgesetzt)

Determination of Planetary Rotation Velocities with BASS, VSpec and ESO-MIDAS (Part II)

by Marc Trypsteen

Abstract

The Doppler effect is used in astronomical spectroscopy to register the movements of planets and stars along the line of sight. Here rotation velocities of the planets Jupiter and Saturn were calculated. Spectra of Jupiter have been recorded during the month of May 2015 and spectra of Saturn during the month of July 2015. The equipment consisted of a C9.25 F10 telescope coupled with a LHIRES III spectrograph equipped with a 2400 L/mm grating and a 35 μm slit.

As a user of the Linux distribution "Ubuntu" I highly recommend this Debian-based operating system as a working platform for ESOMIDAS. It is preferable to install an Ubuntu LTS (Long Term Support) release because these versions are supported for five consecutive years. Currently version 18.04 LTS is operational and will be supported until 2023. Former versions can be upgraded to a more recent LTS version. [10]

A major advantage of Ubuntu is that Canonical, the company and software house behind the Ubuntu distributions, has provided an integrated system for installing software packages more smoothly and correctly, automatic updates included. Fig.8 illustrates how the latest version of ESO-MIDAS (currently version 17.02pl1.2) is obtained from the Ubuntu software center. Alternatively the ESO-MIDAS package can be downloaded directly from the Ubuntu launchpad. [11].

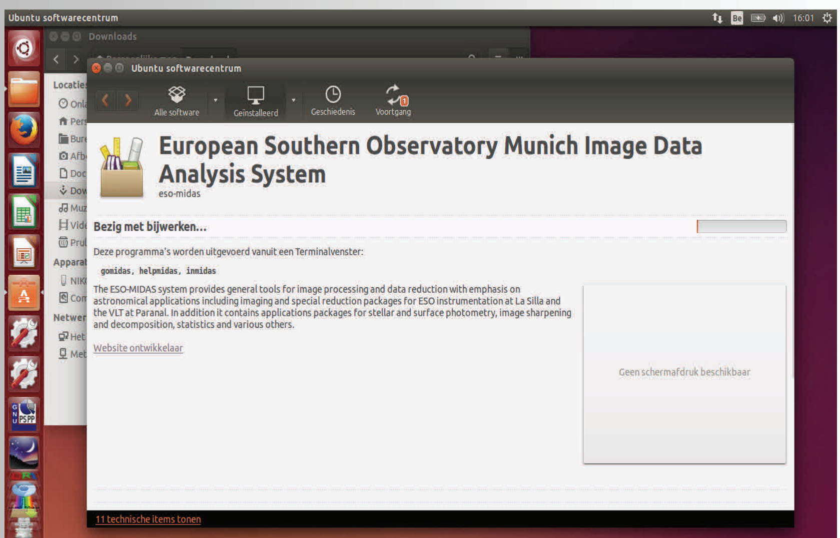


Fig. 8: ESO-MIDAS download from the Ubuntu Software center

Determination of Planetary Rotation Velocities, M. Trypsteen

The evolution of the available ESO-MIDAS Debian packages, more specifically data on the version number, the possibilities, the stability, etc. can be consulted online [12].After a successful installation of the operating system and ESOMIDAS, one types "Terminal window" on activities or right- click on the desktop and select “terminal”. On the terminal window, username @ ubuntu: - $ or similar is displayed. With the command "ls" you will get a quick overview of the files and the directories or folders. The program can be executed as user or as "root". In the latter case, the command "sudo SU11 is entered followed by the correct password.

For a good operation of ESO-MIDAS, it is best to work from the directory or folder containing the files of the spectra. For this purpose it is necessary to create in advance a folder with a suitable name, using the command "mkdir new folder name".With the "cd folder name" command, one is working from the correct directory. Pay attention that the entered names of searched files or folders are either upper or lower case sensitive. From the folder containing the recorded spectra, enter the start command for ESO-MIDAS "inmidas". The opening window appears with the version number at the top.On the next line the cursor is ready after the entry "Midas 001>" (Fig.9).

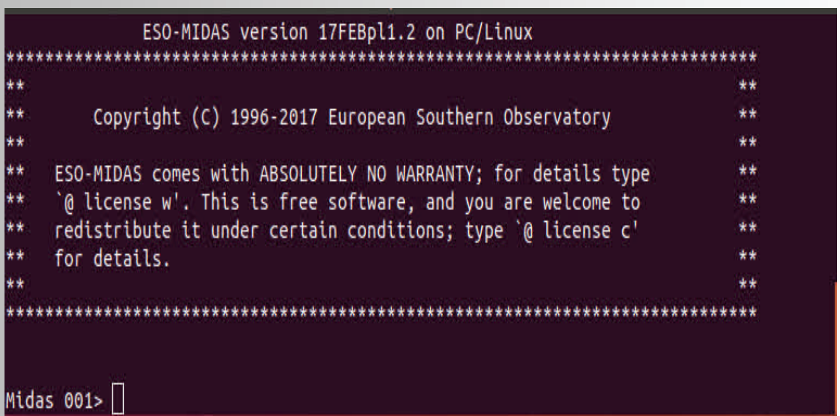


Fig.9: Start screen for ESO-MIDAS

ESO-MIDAS uses its own language, the MCL (Midas Command Language). Besides executing commands , it also features programming options that result in the so-called MIDAS procedures. Additionally one can also write (small) programs or adjust existing scripts for ESO-MIDAS to execute. The typical basic structure of the program assignment consists of a "command" and a so-called "qualifier" separated by a slash /. These commands are insensitive to upper or lower case letters, so commands such as "COMMAND / QUALIFIER" are as valid as "command / qualifier". Examples of commands are load, create, plot, center, set, label, etc. Qualifiers describe the object of the command such as image, graph, axes, gauss, row, etc ...

Determination of Planetary Rotation Velocities, M. Trypsteen

The first task is to create a graphical frame with the commands "create / graph" and "plot / axes" to add the horizontal and vertical axes. The size and location of the frame can be individually adjusted by entering coordinates. Here we use the default settings of ESO-MIDAS. A next step is now to load the recorded spectrum with "load / image filename". Here, the file name "SAT4.fit" is used as an example.

Remark: Before starting ESO-MIDAS it is useful to display the contents of the folder with the recorded spectra using the command "ls". It is then easier to scroll upwards later to check the correct spelling of a filename. In the right part of Fig.10 the command "load / image SAT4.fit" represents the recorded high-resolution spectrum of Saturn in the area around the Sodium Doublet. On the left, the spectrum is then graphically displayed with the command "plot / row SAT4.fit".

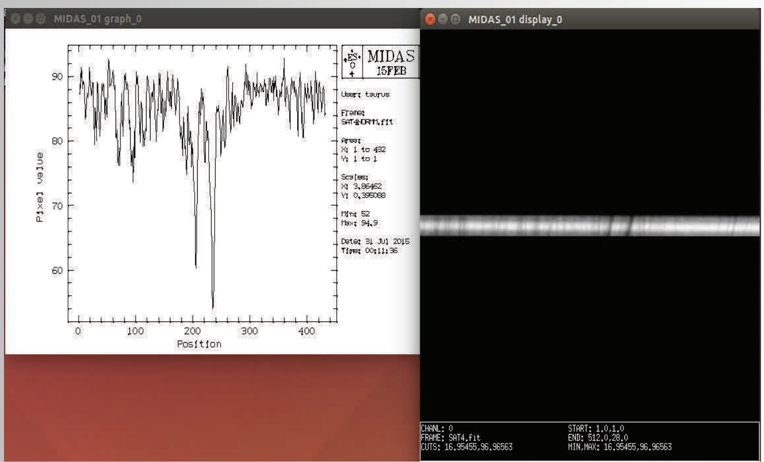


Fig.10: High-resolution spectrum of Saturn in the area of the Sodium Doublet

Subsequently, normalization and Gaussian calculations can be performed. For normalization, use the command "@a normalize filename normalized name" and for the Gaussian calculation of the barycenter the assignment "center/gauss gcurs? a",where "gcurs" is the abbreviation of "get cursor", the "?" Indicates that one can click the left mouse button on certain locations of the spectral lines and the "a" indicates that it concerns absorption lines. The values of the barycenters calculated by ESO-MIDAS are immediately displayed on the screen.With a right click this "center / gauss" assignment is stopped. The Gaussian calculation of the barycenter can be used here as the spectral lines show a good symmetry.Figure 11 represents the spectrum of the right and left sides of Saturn with the calculation of the barycenter for both lines of the Sodium Doublet.

Determination of Planetary Rotation Velocities, M. Trypsteen

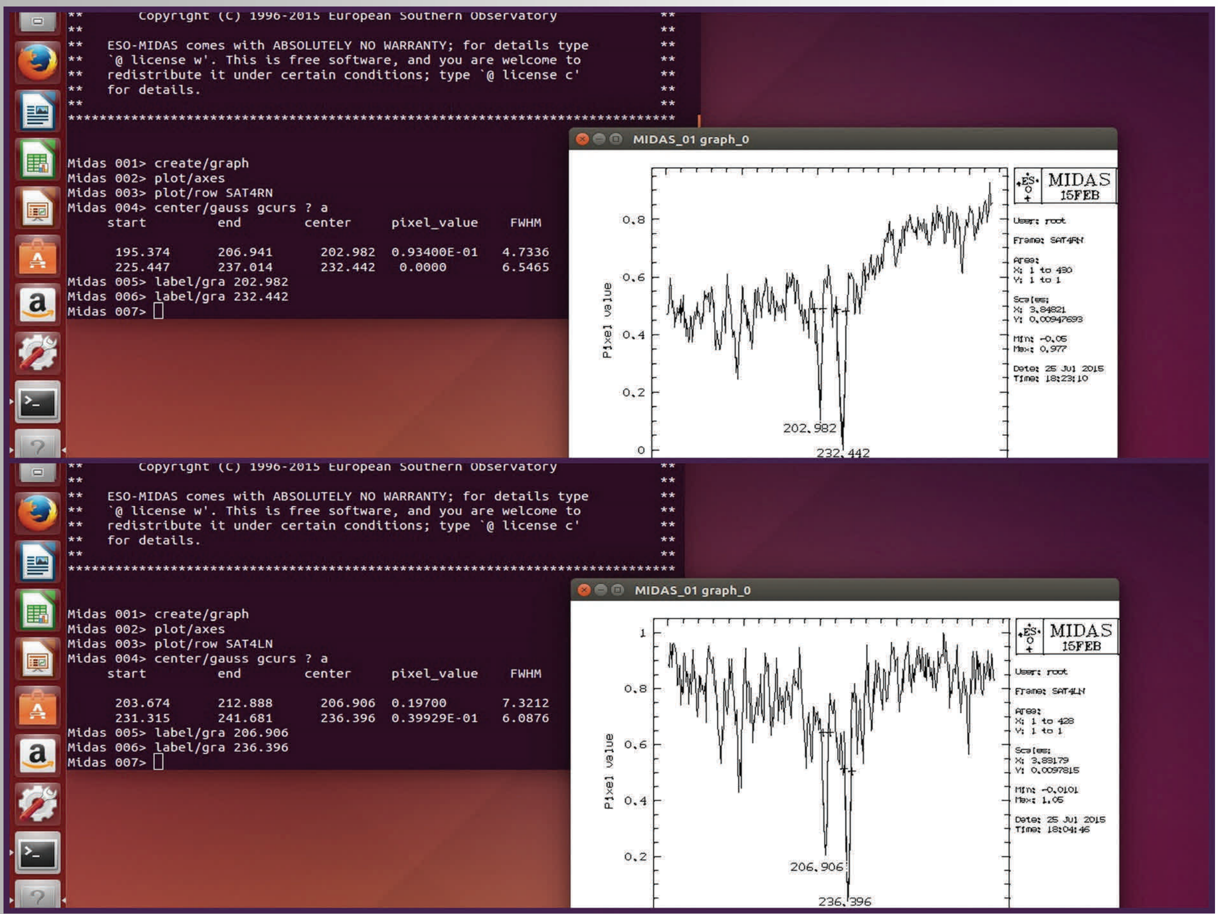


Fig.11: center/gauss command in ESO-MIDAS –spectrum of left and right side of Saturn. (Source: Marc Trypsteen).

Calibrating a normalized spectrum with the example name SAT4N of Fig. 13 requires a script specifically for the spectral lines involved. As an example I wrote a script for the Sodium doublet lines in Fig.12. This small program can be created with the text editor and is then saved under the name twolines.prg.

All scripts created in this way are preferably placed in the correct user folder, which is /home/user/midwork. In this way, each time the "twolines" command is given, the specific script is correctly executed by ESO-MIDAS. It is also possible to adapt the script itself for other spectral lines based on this example, provided of course that the wavelengths and the definitions are adjusted.

```
twolines.prg ×
!
!Two point calibration program based on the sodium doublet NaD1/D2.
!
!Call: @@ twolines P1 P2 P3
!
!P1 Image name
!P2 Pixel number of D2
!P3 Pixel number of D1
!
DEFINE/PARA P1 ? I "image name:"
DEFINE/PARA P2 ? N "D2:"
DEFINE/PARA P3 ? N "D1:"
!
DEFINE/LOCAL m/r/1/1 0 ! linear dispersion
DEFINE/LOCAL I0/r/1/1 0 ! start wavelength
DEFINE/LOCAL dx/r/1/1 0 ! pixel difference
!
dx = {P2}-{P3}
IF dx .EQ. 0 THEN
WRITE/OUT " I CANNOT DIVIDE BY ZERO"
RETURN
ENDIF
m = (5889.9 - 5895.9)/dx
WRITE/OUT "Linear dispersion : {m} Angstrom/Pixel"
I0 = 5889.9 - m*{P2}
COPY/II {P1} I{P1}
WRITE/DESCRIPTOR I{P1} start/d/1/1 {I0}
WRITE/DESCRIPTOR I{P1} step/d/1/1 {m}
PLOT/ROW I{P1}
RETURN
```

Fig.12: ESO-MIDAS CML calibration script for the Sodium doublet spectral lines of Saturn. (Source script: Marc Trypsteen)

The actual calibration command is "@@ two lines filename pixel1value pixel2value" Fig.13 represents the final result : a normalized and calibrated spectrum.

Important remark: before executing numerous other scripts, it is recommended to check applic/proc in the ESO-MIDAS parent folder to know how the commands are indicated in each program. For example, it may be that the program assignment starts with @a instead of with @@. Therefore it is possible that scripts distributed on the internet or in books are not recognized by certain versions of ESO-MIDAS and therefore can not be executed.

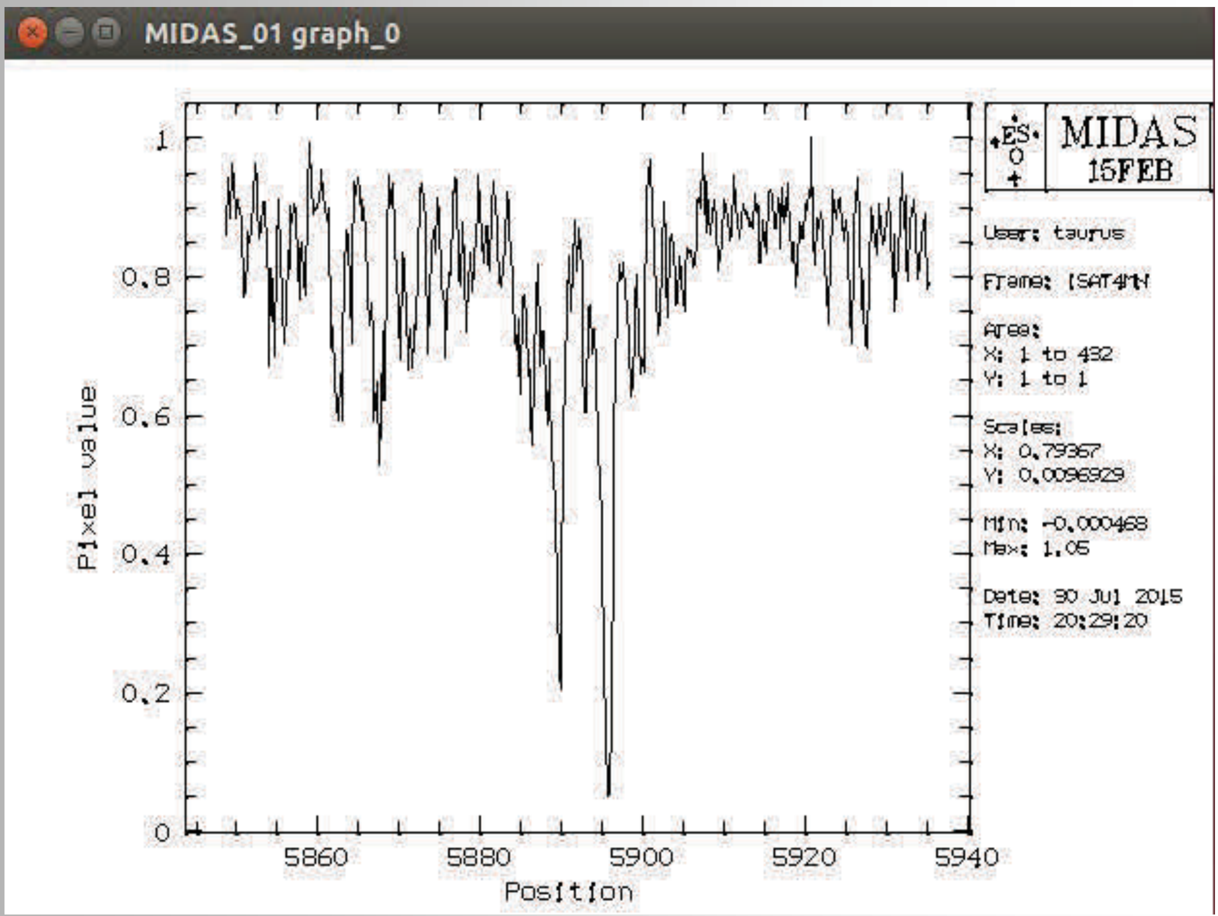


Fig.13: Normalized and calibrated high-resolution spectrum of Saturn in the Sodium doublet area. (Source: Marc Trypsteen).

In order to determine the Doppler shift and ultimately to calculate the rotational speed of Saturn with the above mentioned formula, with the command "overplot / row filename" both spectra obtained in Fig.11 are superimposed. (Fig.14).To change the colors, use the command "set / graph color = number" where 0 = white, 1 = black, 2 = red, 3 = green, 4 = yellow, 5 = blue and 6 = purple. To improve the accuracy of the calculations, various corrections can be made. Heliocentric corrections require different parameters such as the date and time, the coordinates of the observation site, the right ascension and declination of the observed object at the time of the observations.

Heliocentric corrections can be calculated either via the PyMidas module, which forms the interface between ESO-MIDAS and the Python programming environment[13].

Additionally ESO also offers an online calculating tool for heliocentric corrections for certain locations [14]. Alternatively the influence of the heliocentric correction can be calculated using following formula:

$$\lambda_{helcor} = \lambda_{obs} \cdot \left(1 + \frac{Radial\ Velocity\ \left(\frac{km}{s}\right)}{299792\frac{km}{s}}\right)$$

As an example the heliocentric corrected wavelength for planet Jupiter is 5889.37 Å compared to the reference Sodium D2 line of 5889.95 Å. This corresponds to a deviation of approximately 0.01% for the wavelength and a mean correction of 0.001 km s-1 for the rotation velocity. The graph can finally be labeled with the command "label / graph text and / or number" and clicking on a chosen position. To terminate ESO-MIDAS, the "bye" command is given and the terminal window is closed with the "exit" command.

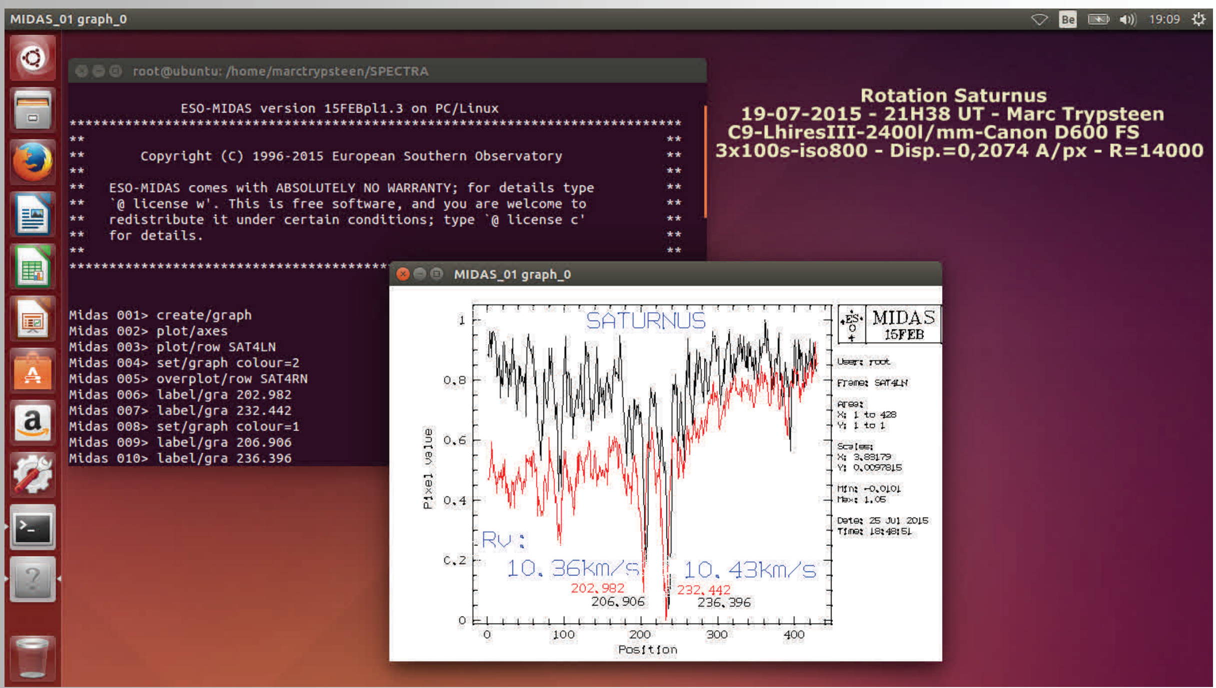


Fig.14: overplot / row and label assignment in ESO-MIDAS - superposition of left and right side spectrum of Saturn. (Source: Marc Trypsteen).

Determination of Planetary Rotation Velocities, M. Trypsteen

An overview of the calculated results by each software package compared to reported literature values for the rotation velocities of planets Jupiter and Saturn is presented in the table below. Taken into account measurement errors, slit position and inclination angle, which influence the accuracy, the results are reasonably close to the real values.

PLANET RV in Km s-1	BASS	VSpec	ESO-MIDAS	LITERATURE
JUPITER	13.11	13.08	13.05	12.70
SATURN	10.53	10.45	10.40	10.28* 9.88**

*Based on System I **Based on System II

References

1. G. Wolfschmidt, 2004: Christian Doppler (1803-1853) and the impact of the Doppler effect in astronomy: Astron. Nachr./AN 325, Suppl. Issue 1- 8 p72.
2. W. Tobin, 2014: Fizeau, Armand-Hippolyte-Louis. In: Hockey T. et al. (eds) Biographical Encyclopedia of Astronomers. Springer, New York, NY
3. M. Mobberley, 2004: An 'off the shelf' plastic runoff shed observatory : Journal of the British Astronomical Association, vol.114, no.2, p.68-72.
4. M.Trypsteen and R.Walker, 2017: Spectroscopy for Amateur Astronomers, Cambridge university Press, Ch.12, p103 -113.
5. R.Walker, 2018: Spectral Data Reduction for Amateur Astronomers: http://www.ursusmajor.ch/downloads/spectral-data-reduction-2.0.pdf
6. V. Desnoux, 2015: Visual Spec: manuals: http://astrosurf.com/vdesnoux/download.html#manual tutorials: http://astrosurf.com/vdesnoux/tutorial.html
7. J. Paraskeva, 2014: Basic Astronomical Spectroscopy Software (BASS) manuals and tutorials: https://uk.groups.yahoo.com/neo/groups/astrobodger/info
8. Banse K., 2003: The Munich Image Data Analysis System. In: Heck A. (eds) Information Handling in Astronomy - Historical Vistas. Astrophysics and Space Science Library, vol 285. Springer, Dordrecht
9. https://www.eso.org/sci/software/esomidas//
10. https://www.ubuntu.com/download
11. https://launchpad.net/ubuntu/+source/eso-midas/17.02pl1.2-2build1
12. https://tracker.debian.org/pkg/eso-midas
13. https://www.eso.org/sci/software/esomidas//pymidas/
14. http://www.eso.org/sci/observing/tools/calendar/airmass.html