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Bachelor Thesis

PREPARING VLA SKY SURVEY DATA FOR EDUCATION AND OUTREACH

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Abstract

How can the topic of radio astronomy be made approachable to a younger audience and what role can VLASS data play in this?

In the Astronomy Bachelor's research project *Preparing VLA Sky Survey data for Education and Outreach*, a lesson kit on radio astronomy using VLASS data has been developed. The kit is aimed at middle school students and consists of a set of three lessons including exercises, teacher notes with answer key and differentiation options and, a computer lab where actual VLASS datasets are used.

This thesis presents the motivation and theory behind the lesson kit. It details the steps taken in the design and development process and, discusses the possibilities and limitations of the final product.

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Introduction

The VLA Sky Survey (VLASS), conducted in three rounds using the Very Large Array in New Mexico, maps the sky in the radio. The data of the survey is available for anyone via the website of VLASS, yet young audiences often lack prior knowledge to use this data and grasp its wonders. In the USA and at international schools, radio astronomy is not covered by the average science curriculum. It is often considered a difficult topic and there are very little ready-to-use resources available. In this thesis, *Preparing VLA Sky Survey data for Education and Outreach*, a contribution is made to help make the VLASS data, and the topic of radio astronomy in general, approachable to a young audience.

This thesis is shaped around the question: '*How can the topic of radio astronomy be made approachable to a younger audience and what role can VLASS data play in this?*' The main goal of this project is to develop a lesson kit, including computer lab, which simultaneously enables students to work with real VLASS data sets and sparks their interest in the topic of radio astronomy. The lesson kit, accompanied by a manual for teachers, introduces students to the field of radio astronomy assuming no prior knowledge and gradually works towards the computer lab. This way, radio astronomy becomes more approachable for both students and teachers and there will be increased awareness for VLASS, making all involved parties benefit.

Presented in this thesis are the results of an outreach focussed project in which a VLASS related lesson set with teachers guide has been created. The chapters follow the steps of the project; in the first chapter, G*eneral Information*, brief descriptions of VLASS, science education in elementary and middle schools and the motivational factors of students are given. This represents the brainstorming and information gathering phase. In the next chapter, *Design,* the broad concept of 'a lesson kit' is narrowed down to a more concrete form, using, amongst others, the educational event planning tools acquired during the workshop *'Planning Astronomy Education and Outreach'*. The motivation behind the choices made to shape the lesson kit is provided. In the third chapter, *Development,* the process of creating the actual kit is examined. It describes how the kit was adapted to feedback from experts between various versions and what measures were taken to enable further development in the future. The final product is presented in chapter 4, where after the results are evaluated in the discussion.

Chapter 1: General Information

After a brief description of VLASS, this chapter will examine studies on science engagement in middle school education and the role of astronomy in the science curriculum and, existing classroom resources on radio astronomy.

VLASS[1]

The main aim of this project is to prepare VLASS data for education. In order to do this properly, it is first of all important to know what VLASS is. VLASS stands for Very Large Array Sky Survey. It is a series of radio telescope observations that maps out nearly the entire sky. The survey started on the 7th of September in 2007 and has recently started its second round of observing. There are three rounds in total so that one can not only see the long lasting but also the transient radio sources. VLASS maps 80% of the sky (all Northern sky of declination -40 degrees), as a minor part of the Southern sky cannot be covered by New Mexico's VLA. The NRAO expects VLASS to catalogue approximately 10 million radio sources and predicts the survey will be an important tool in the discovery of new radio objects.

The survey covers a frequency range from 2-4 gigahertz and has a resolution of 2.5 arcseconds. The data collected in the survey has been separated into 32 tiles, each covering a minor part of the sky. Quick look images of the VLASS data, images that have been processed using a fast and relatively simple imaging algorithm, are available to anyone via the VLASS webpages. According to these same webpages, the quick look images are adequately suitable for many scientific uses, but do have accuracies lower than the survey requirements and may contain phase errors. For the purpose of this lesson kit, where the computations done with the data will be very limited, the quick look images suffice. In addition, png cut-outs of the VLASS data, filtered from the quick look images by a neural network, will be used in the lab to classify radio sources[2].

Science Engagement and Motivation

How can one help students gain and maintain an interest in science? That is a question that has plagued many teachers and educators throughout modern history. According to a study on how motivational structures can predict engagement in middle school science done in 2016[3], students become less interested in science and achievement during their middle school time. The attitude of middle school students towards science is often indifferent and the vast majority of students who do have a positive attitude, do not aspire a career in science.[4] Luckily there is a lot of research done and going on to tackle this problem. Studies have been conducted to investigate and understand the underlying motivational factors which drive middle school students and many lesson materials and activities are developed to make science interesting for all groups and grades. One of the goals of the lesson kit developed in this project is to contribute towards the process of changing the attitude of middle schoolers towards science into a positive one.

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[1] General info on VLASS and a discussion of its relevance by the NRAO can be found on https://science.nrao.edu/science/surveys/vlass/vlass and https://public.nrao.edu/vlass/.

[2] Png images of VLASS data containing radio sources https://bablai.com/vlass/

[3] Christine S. Lee, Kathryn N. Hayes, Jeffery Seitz, Rachelle DiStefano & Dawn O'Connor (2016) Understanding motivational structures that differentially predict engagement and achievement in middle school science, International Journal of Science Education, 38:2, 192-215, DOI: 10.1080/09500693.2015.1136452

[4] Shaista Shirazi (2017) Student experience of school science, International Journal of Science Education, 39:14, 1891-1912, DOI: 10.1080/09500693.2017.1356943

Preparing VLA Sky Survey data for Education and Outreach

In order to bring about a change in students' attitude, it is important to understand what motivates them. Motivational factors can be divided into two categories: extrinsic and intrinsic factors. Extrinsic factors are influences from one's environments, outside of the individual. Examples include grades, praise, money, fame or approval. A student might be motivated to learn about science because it will help them score high on an upcoming exam. Completing the task, in this case learning something about science, has an external reward, in the example this would be a high grade or praise from a parent for studying this hard. Intrinsic factors come from within the individual. If someone studies science because he or she is genuinely interested in it or curious and eager to learn about a certain topic, this person is intrinsically motivated. When motivation comes from intrinsic factors, one can perform the task without necessary having a direct external reward. When students consider an activity fun, interesting or enjoyable and complete it for their personal satisfaction rather than external consequences, they are intrinsically motivated. It was already apparent in 1987[5] that students learn best when motivated by intrinsic factors as this stimulates spontaneous learning. Intrinsically motivated students are more likely to be involved in the lesson and develop a positive attitude towards the topic. This, of course, raises the following question: how does one make students intrinsically motivated towards science?

According to survey-based research on student experience of school science[4], in order to create educational materials on science which motivate students, it is important to bring the content with enthusiasm and in a lively and interactive way. Research showed that students find enthusiastic teaching an important component to help maintain or gain an interest in topics they perceive as challenging, such as mathematics and physics. Lack of enthusiasm and interaction was reported as an important cause for lack of interest. Long texts, repetitive exercises, a lack of experiments and no room for students' creativity causes demotivation. In addition the research stressed the importance of creating lessons in accordance with the level of the students. Content should be perceived as challenging, not too easy and pre-chewed yet not so tough it is perceived as difficult, for this can be discouraging. An attempt has been made to apply these recommendations in the lesson kit in various ways, examples included the puzzle-like exercises, links to 'fun' resources and activities that allow students to explore and experiment with the data instead of following a fixed trajectory. The teacher notes include suggestions to reduce the difficulty of each lesson, as well as suggestions to transcend the covered material by exploring additional topics, to keep the level of the kit just right for any class or student. These adjustments to make the kit both fun and challenging for students aim to provide them with intrinsic motivation. There will probably always be students who do not like the topic or the kit and who will not find an intrinsic motivational factor. To keep them involved in the lessons as well, the lesson kit will also link to some extrinsic motivational factors. The kit will work towards clear goals, such as the skillset needed to partake in the computer lab and a colourful 3D contour plot of real radio image, to provide extrinsic motivation.

Middle School Astronomy

In order to develop lessons that suit the intended audience, it is crucial to know which prior knowledge they already have and which skills they are expected to learn. Which facets of astronomy are covered in the standard middle school science curriculum and

[5] Malone, T. & Lepper (1987). Making Learning Fun: A Taxonomy of Intrinsic Motivations for Learning. In Snow, R. & Farr, M. J. (Ed), Aptitude, Learning, and Instruction Volume 3: Conative and Affective Process Analyses. Hillsdale, NJ

what knowledge have they already gained from their primary education? To answer this question, the science learning standards for elementary and middle school level, regarding astronomy, as set by various states were investigated.[6] All in all, there is very little astronomy in the required curriculum. After elementary school, students are expected to have learned the basics of solar, lunar and stellar motions, explored the science behind seasons and the length of a day and grasped the difference between apparent and actual brightness caused by distances. Physical concepts, which are relevant to astronomy, covered in elementary school include the notion of gravity and the concept of a wave, including amplitude and wavelength. Although these concepts are not covered in any detail. For the purpose of this lesson kit, it can thus be assumed that most students working with the kit have no prior knowledge on the topic.

In middle school, the science standards cover roughly the same astronomical topics as in elementary school, yet a little bit more in depth. Students learn to make models representing the motion of the earth and moon, the motion of planets in the solar system, the scale of the system, and how gravity relates to it all. Although this information helps students to become aware of the impact astronomy has on their daily lives, it is not really relevant to a lesson kit focussed at radio astronomy. The physics standards, on the other hand, do include some aspects that may be useful: the standards covers surface knowledge of electromagnetic radiation and mathematical ways to describe the properties of a wave. When explaining the 'radio' part of 'radio astronomy' these topics cannot be omitted.

Lastly, it is important to consider the mathematical skills middle schoolers are expected to have acquired. Mathematics plays an essential role in astronomical analysis. Therefore, in order to properly introduce students to the world of radio astronomy, the lesson kit will contain some questions that require calculations. According to the Common Core Standards, students should be able to perform basic mathematical operations, like multiplying two integers, and read off graphs. In the first year of middle school, students get acquainted with equations of the form $a + x = b$ and $px = q$, provided all unknowns are rational and positive.

Existing resources

Though one cannot speak of an abundance, there are already some existing resources on the topic of radio astronomy for young audiences. The pros and cons of several of these existing resources were investigated to determine conditions the VLASS lesson kit must satisfy.

The invisible universe[7]

The Invisible Universe is a guide to a set of lessons on radio astronomy, developed by EU Universe Awareness in between 2007 and 2013. The guide is aimed at teachers and the presented lessons are oriented at children between ages 8 and 12. Each lesson consists of instructions for teachers followed by a worksheet for students. The guide covers the electromagnetic spectrum, radio telescopes, waves and secret codes. Lessons are

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[6] The examined standards are: New York State P-12 Science Learning Standards, adopted 2016, http://www.nysed.gov/curriculum-instruction/science-learning-standards. The Common Core Standards, http://www.corestandards.org/ (Mathematics). The Next Generation Science Standards for Earth and Space sciences, https://www.nextgenscience.org/.The Standards for Science and Engineering of the state of Maine: https://www.maine.gov/doe/learning/content/scienceandtech/standards
[7] The Invisible Universe, UNAWE, ISBN: 978-94-91760-07-5, M. Ankoné and E. Arends: https://www.unawe.org/static/archives/education/pdf/Radioastronomy_activity_booklet.pdf

categorised based on age group, duration and required amount of supervision using a system of icons.

The Invisible Universe is one of the most recent and visually appeasing lesson guides on radio astronomy. It clearly aims to make the radio astronomy fun for the target audience via the inclusion of diverse puzzle-like exercises, including word search puzzles and a happy families game, and plenty of practical experiments. Quite some lessons cover the same content, the categories of the electromagnetic spectrum for example, in a slightly different format. Although repetition is indeed an important component of learning[8], the unfortunate side effect is that *The Invisible Universe* only covers the electromagnetic spectrum and the workings of a radio telescope, there is little room for the astronomy part. The guide does not contain lessons about astronomical sources radio telescopes might detect.

The strongest point of this resource is undoubtedly its attractive layout and playful setup. Though it may appear a bit chaotic when viewed digitally, it invites the audience to engage with the content. Along with aesthetic and structural elements, the clear description on single dish radio telescopes and their resolution served as inspiration for the VLASS lesson kit.

MIT Haystack Observatory Pre-College Lesson Plans[9]

The MIT Haystack Observatory offers a wide range of lesson plans on radio astronomy at high school level. In addition to the lesson plans, MIT Haystack Observatory has also created a web tutorial on radio astronomy, directed at high school students. This tutorial covers both the electromagnetic spectrum and the technique behind various types of radio telescopes in great detail and includes a few pages on data from radio sources. Although the tutorial contains an interactive glossary and colourful images, its out-dated plain layout and lack of exercises make it unappealing.

The lesson plans are very extensive and offer a complete ready to use set of science lessons which incorporate goals from the Next Generation Science Standards. Lesson plans are split into units containing a document with background information, a power point, teacher notes, worksheets for students and an answer key. The lessons contain plenty variation in exercises and provide clear diagrams of for example electromagnetic waves and their polarization. A major downside of the lesson kit is its layout, which is either plain or appears make-shift.

This resource links its content to existing learning goals, which has quite some advantages. Teachers might be more inclined to use the lesson set because they need to cover the goals anyway and have already reserved time for it. The lessons can also serve as a way to revise material already covered, yet in a topic which may be of more interest to the class. Additionally, it serves as an extrinsic motivational factor for students, because part of the covered material will reappear on their science exams. This idea is also applied in the VLASS lesson kit, which starts with electromagnetism and waves, topics covered in the physics standards, and contains some mathematical exercises with formulae of forms that are part of the goals for middle school mathematics.

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[8] Bruner, Robert. (2001). Repetition is the First Principle of All Learning
[9] Educational resources of the MIT Haystack Observatory: https://www.haystack.mit.edu/edu/pcr/radio_waves/index.html, https://www.haystack.mit.edu/edu/undergrad/materials/RA_tutorial.html

Space Based Astronomy[10]

The final resource that will be discussed is NASA's *Space Based Astronomy*, an educator guide with activities for science, mathematics and technology education. This 2001 guide is not focussed on radio astronomy, yet has been included in the research because it specifically targets grades 5-8, which is middle school. The guide consists of 5 activity units and accompanying background information. Each unit starts with a few pages directed at teachers containing an introduction, a summary of the unit goals and a brief section on the approach behind the unit. Next, various activities are described, including handouts for students. In addition, the guide contains a glossary, a list of suggested readings and, an evaluation survey which can be returned to NASA by post. As this last item might suggest, the guide is already a bit outdated. Though the guide is in black and white, the lessons and exercises are diverse and appear inviting. Unfortunately a large fraction of the linked websites yields an error 404.

This guide served as inspiration to include (active) references to external sources and suggested material to the lesson set and teachers guide. In addition the concept of a feedback survey returns in the VLASS lesson kit. The survey enables VLASS to examine whether the kit meets the expected goals and helps to identify ways in which the kit can be improved.

Comparison

Now that the existing resources have been examined, it is time for a comparison of their structural elements to determine the essential components of a lesson kit. Recurring elements included, exercises with variation, a glossary for quick reference and a separate set of supplementary information aimed at teachers. There also appeared to be an overall structure in the order in which topics are introduced: firstly the electromagnetic spectrum is examined, then the workings of a radio telescope -starting with the single dish version-, after which topics relevant to the goal of the lesson set, for example theory on radio sources, are discussed. It was chosen to follow this order in the VLASS lesson kit as well.

The examined existing resources were either aimed at a different target audience or covered only a part of the intended scope of the VLASS lesson kit. In the next chapter the needs of the audience and goals of the kit are examined in further detail, after which all the gathered information and requirements can be incorporated into the design of the kit.

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[10] Space Based Astronomy, NASA, EG-2001-01-122-HQ https://www.nasa.gov/pdf/58277main_Space.Based.Astronomy.pdf

Chapter 2: Design

As discussed in the previous chapter, the main aim of this project is to create a lesson kit containing VLASS data for classroom use. In the design-step, this broad aim is shaped into a concrete end product. The nuances made to achieve this as well as the motivations behind them will be explained.

EPO event planning grid

In order to reshape the rather broad *'preparing VLA Sky Survey data for Education and Outreach'* into a concrete classroom resource, the EPO event planning grid[11] was used, the event being a lesson set on VLASS. The grid is a tool specifically developed to help one plan an event or product with eye for the audience and measurable targets. This lead to the following specifications:

Audience

The target audience was chosen to consist of middle school level students, aged between approximately 11 and 14 years old. In an early stage of the project, the middle school level and the late high school level were proposed as possible target audiences. The middle school level was chosen because there are already quite some projects on radio astronomy and radio telescopes directed at high school level, for example NASA's radio JOVE[12], whereas there are very little resources aimed at the middle school level.

As shown in the previous chapter, middle school students do not have prior knowledge on radio astronomy. The lesson kit therefore assumes no prior knowledge and begins with a basic introduction and builds towards the computer lab. In the next chapter, *Development*, the learning path is further detailed.

To find the right writing style to approach the audience, to gain a better understanding of the manner in which they have already been acquainted with astronomical topics in their earlier education, and to discover the teacher side of astronomy education, the three week course: *Our Solar System and Beyond: Teaching Primary Science*[13] from the Royal Observatory Greenwich was followed. Though partaking in the course had an overall subtle impact in the use of language in the lesson kit, a concrete example in which its content is applied, is the paragraph on questions in the *final notes* of the *teacher notes*. Part of the course stressed the importance of providing a short yet clear definition of the scientific terms one introduces students to. This is in accordance with the glossary-trend observed in the examined existing lesson materials.

Goals and motivation

The main goal of the lesson set is science engagement, specifically: to get middle school students interested in (radio) astronomy. As the lesson set is intended for class room use, students will start working with it through external motivation, namely their teacher and perhaps the pressure to score well on exercises. The lesson kit will have to give them

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[11] The EPO event planning grid from the video workshop *Planning Astronomy Education and Outreach* by Jake Noel-Storr
[12] https://radiojove.gsfc.nasa.gov/
[13] Our Solar System and Beyond: Teaching Primary Science, Royal Observatory Greenwich: https://www.futurelearn.com/courses/primary-science

internal motivation to continue investigating VLASS and radio astronomy behind the brief introduction covered in class. To achieve this several measures are taken in the kit:

- The lessons contain plenty of images and colours and the theory is separated into small paragraphs to keep it visually appealing.
- Links to supplementary resources, including crafts and songs, at middle school level are provided as well as topics for follow-up research. This makes it easier for teachers to adapt the lessons to the level and interests of their class and brings students in contact with a diverse range of topics they might want to learn more about.
- Exercises use actual VLASS data and do not always have fixed answers. This is to provide students with a feeling that they are doing 'real science'. The exercises try to stimulate student's critical and creative thinking skills and allow them to explore rather than plainly learn about the topic. As the type of exercises varies, it is hoped that every student working with the lesson kit will encounter at least some tasks they enjoy completing.

Other goals of the project are to teach the audience about VLASS and to provide students with scientific skills that will benefit them in their middle school careers. This first goal is of importance from the perspective of VLASS, the supplier of the lesson kit. Students and teachers will learn about VLASS and might share this with their colleagues, friends and families, resulting in more awareness of VLASS by the overall public. The second goal provides students with another motivational factor: short term benefit, and makes the lesson kit attractive for teachers. By including a part of the required science curriculum for middle school, teachers can use the kit in the class time reserved for that topic or use the kit as supplement. Students will have more drive to work with the kit if its content may help them pass their next science test.

Location, layout and length

At the initial phase of the project it was determined that the lesson kit is intended for classroom use and will be available from the VLASS website. As the focus of the kit lies on a computer lab, it is logical to assume that students working with the kit have access to a computer in class. This means that both the lab and the lessons preparing for it can be designed for digital use, which comes with opportunities a paper format lacks. It was chosen to make the lesson kit and computer lab instructions in the form of an interactive pdf. The materials link both to their own content, e.g. the keywords link to their definitions in the glossary, and to external resources, for example a virtual tour of the VLA radio telescope. Some of the exercises require students to collect data from the NRAO website or do some online research on a side topic. The aim of these interactive elements is to encourage students to explore and discover more about the topics covered in the lessons.

The expected length of the kit in units of time is approximately 3 hours. This length was chosen because the kit serves as a supplement to the regular science curriculum and teachers may not have a lot of free lesson space for extracurricular content. The three lessons, including exercises, and the computer lab take around 45 minutes each to complete, meaning that teachers only need to reserve 2 or 3 lessons to run through the kit. As the amount of time it costs to complete the lessons and lab is strongly dependent on the level and pace of the class, the teacher notes contains material to help teachers adjust the lessons to the amount of time they have available.

Preparing VLA Sky Survey data for Education and Outreach

As the kit can be found on the website of VLASS, which is accessible to anyone, it might also be used outside of a classroom setting. A student might want to skim through the kit in preparation of a report on radio astronomy or an astronomy enthusiast might want to take part in the computer lab out of personal interest. There are many reasons someone might come across the kit and decide to use it for self-study. To make the kit suitable for this purpose, special instructions on how to use the kit for self-study have been added to the front page of the lesson set.

Measurable outcomes and statements of success

The VLASS lesson kit has been created with a specific set of goals in mind, yet how can one verify whether the kit actually achieves these goals? To determine whether the kit fulfils its purpose, the goals were converted into measurable outcomes. For each of these outcomes, a statement of success was determined. If all statements of success are satisfied, the project can be considered successful in achieving its goals. For overall convenience, it was chosen to measure the outcomes of the project via an online survey. The survey asks students and teachers about their opinion and experience with the lesson kit and contains a couple of question which directly relate towards the project's goals. In the table below, *table 1*, the goals and their corresponding statements of success are summarized.

Goal	Statement of Success
Students have learned about radio astronomy (on a surface level).	- 70% of the students agrees to have learned something, 60% provides an example.* - Teachers notice students do well on the exercises in the lesson kit.
Students have developed a positive attitude towards astronomy.	- 60% of the students agrees that the topic of the lessons was interesting.* - Over 70% of the students is neutral or in agreement with the statement: 'the lessons inspired me to learn more about astronomy.' *
The lesson kit is appropriate for classroom use.	- 40% of the teachers and students considers the level of the kit 'just right', 80% rates it either 'slightly too easy', 'just right' or 'slightly too tough'. *

*Table 1: Goals and Successes. *Responses in the evaluation survey*

The first goal revolves around the educational value of the lesson kit, did it actually succeed in teaching students about radio astronomy. As there is no way to ensure that everyone has answered the survey truthfully and there will always be reasons why someone disagrees with a statement, it was chosen to consider this goal achieved if 70% of the students taking the survey says they have learned something and working with the kit has increased their understanding of astronomy. The success bar for students actually being able to provide an example of something they learned was set slightly

lower, at 60%, because typing an answer requires more effort than clicking a button and respondents who are in a rush are likely to give no or a very short and perhaps non-useful answer to this question. Another way in which success of this goal becomes apparent, is the completion of the lab and the exercises. Teachers can measure whether students have understood the material by checking their answers with the answers and guidelines provided in the teacher notes. No concrete statement of success has been coupled to this way because it depends on too many variables, e.g. the overall level of each student in the class, the time taken for each lesson, the attitude of individual students, etc..

The second goal corresponds with the main goal of this project, to increase the interest of students in science. Measurable outcomes of this goal are that students indicate on the survey that they considered the topic of the kit interesting and that it has inspired them to learn more about (radio) astronomy. The statement of success for these two outcomes has been set to 60% and 70% respectively. 60% was chosen for the first outcome because this means the majority of the students considers the topic interesting, yet takes into account that the kit focusses on a specific branch of science and that not being interested in radio astronomy does not imply disinterest in all branches of science. It was chosen to consider the second outcome a success if at least 70% of the students indicated they were indifferent or in agreement with the statement *'the lessons inspired me to learn more about astronomy'*, because 'learning more about something' is an action that requires voluntary effort and thus a factor of intrinsic motivation. Although it would be ideal if a large majority of the students gets inspired through the lesson kit, it is more feasible to assume this will only be minor part and to include 'neutral', meaning the kit did not discourage them to learn more, in the success rate.

The third goal, ensuring the kit is suitable for classroom use, stands separately from the reasons for which the VLASS lesson kit has been developed. Instead, it takes into account that developing a lesson kit is long running project. Although the kit might be good lesson material in theory, there may be problems that become apparent once the kit has actually been tested in its intended setting. There are likely many undiscovered ways in which the kit can still be improved. As the kit is intended for classroom use and the level of individual students in a class varies, it was chosen to consider this goal a success if 40% of the students think the level of the kit was just right and 80% considers the level somewhere between slightly too easy and slightly too difficult. To help determine which parts of the kit should be adjusted to improve these rates, statements on specific parts of the kit and a couple of open questions have been added to the survey. Various experts were consulted during the development of the project, as detailed in the next chapter, yet additional feedback from students and teachers who have actually used the kit in class will be valuable to determine whether the kit indeed has the right level.

Privacy

A minor side note on the topic of privacy, as part of the kit is a survey. To ensure the privacy of teachers and students participating in the survey, participation is completely anonymous and no personal data of respondents is collected. Participation in the survey is on a voluntary basis and the results of the survey will only be used to evaluate and improve the kit and will not be shared with third parties.

Chapter 3: Development

Several weeks before this thesis was presented, the VLASS lesson kit was nothing but some conceptual ideas and a set of goals. Since then, it has grown into a four component kit ready for classroom testing. This chapter describes the steps that have been taken to develop the kit and shows how the kit was adapted to feedback from various experts.

Phase 1: the content

The first step in the process of developing the lesson kit was to determine its content. The focus of the kit lies on the computer lab. This is the part where VLASS data which had not yet been prepared for outreach purposes is used. The lessons in the kit are meant to prepare students for this lab. It was chosen to divide the lessons into three subjects: electromagnetic radiation, radio telescopes and astronomical radio sources. This built-up is in accordance with that of existing resources on radio astronomy.

In the first lesson, *Invisible Light*, students learn about the parts of the electromagnetic spectrum and their properties. This lesson helps to improve students' understanding of the data they are working with in the lab. It clarifies the 'radio' part of radio images. Additionally the content of this lesson overlaps with a part of the science curriculum for middle schools, which makes the lesson useful for students in follow up science classes.

The second lesson, *Radio telescopes*, explains how radio telescopes can detect the radio waves introduced in the previous chapter. After providing a brief history on radio telescopes to help students put the topic in a historical perspective, it discusses how single dish radio telescopes operate and works its way towards the VLA. This lesson introduces the students to VLASS and the VLA and gives them an idea how the data they will be working with in the lab has been collected.

In *Astronomical Objects*, the third lesson, students will learn which objects they might encounter in the VLASS data. This lesson shows how one's view of the universe changes when observing it at a different wavelength and discusses some common radio sources. After this lesson, students should be able to complete the computer lab.

The information presented in the lesson kit is openly available online. Each chapter was written after consulting several existing texts on the topic and bearing in mind the knowledge gained during university courses like *Introduction to Astronomy*[14] and *Physics of Galaxies*[15]. In addition, the research done when writing an astronomy-talk kit aimed at elementary school students for ASTRON[16], made it easier to find resources for this project. The information on VLA and VLASS was collected from the official webpages of the NRAO[1].

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[14] The literature used in this course: *Astronomy: A Physical Perspective*
, Marc L. Kutner, ISBN: 9780521529273, provides a clear explanation on topics like the electromagnetic spectrum, radio telescopes and radio galaxies.

[15] In this course, galaxies at multiple wavelengths and active galactic nuclei were discussed, which was useful when writing lesson 3. The book for this course was: *Galaxies in the Universe: an Introduction, L.S. Sparke & J.S. Gallagher, III, Cambridge University Press, 2000; second edition 200*

[16] https://www.astron.nl/sites/default/files/shared/Spreukbeurtpakket_Infoblad.pdf (Dutch), info pages on radio astronomy for individual use by Dutch elementary school students.

Phase 2: the lesson set

After the content of the kit was determined and the information was gathered, it was time to actually create the kit. The first, and most time consuming, part to be developed was the lesson set. The set consists of three lessons, which each consist of several paragraphs of theory and accompanying exercises.

The first choice made in this phase, was the layout of the set. As the VLASS website[1] is set in Verdana and its main colours are blue and dark red, it was chosen to make Verdana the main font type of the kit and to use blue and dark red as accent colours. To make the set a little bit more playful and to make it easier to distinguish between the formal theory and the more informal exercise part of the lessons, another custom font type was used as well. To make the set attractive, plenty of pictures and side notes were added and to improve the set's readability, texts were split into small sections with sub headings and bold printed keywords. A glossary of the keywords was added at the end of the lesson set.

To help encourage students to read the text thoroughly and think about it, and to help teachers to verify whether students have understood to content of the lessons, many exercises were added to the lesson set. Each lesson ends with a page long exercise that covers the content of the entire lesson and some smaller tasks are given following paragraphs that introduce an important new concept or formula.

Lastly, a clickable table of content and a disclaimer were added to the set. The table of content makes it easy to navigate to the lesson of interest. The disclaimer, which was later moved to the end of the glossary, explains that all images used in the lesson kit are classified as free for non-commercial re-use by the search algorithm used to find the images, unless mentioned otherwise. When images were found via a different route, its source was added to the set. This is to prevent getting into any copyright issues with the lesson kit.

Phase 3: teacher feedback and notes

To ensure that the kit is useable in middle school education, two teachers at the International School Haarlem[17] were asked to provide feedback during several stages of development. After the draft version of the first chapter was made, the teacher feedback helped to begin the development of another important part of the lesson kit: the teacher notes. The *teacher notes* is a document filled with material supplementary to the lesson set. It provides an overview of the key concepts of each lesson, a brief summary of the content of the lesson, suggestions on which material to skip or add to the lesson to adjust it to the desired level and time frame, links to additional resources, and answers to the exercises.

Apart from the inspiration to write the teacher notes, the teacher feedback also helped to make the text of the lesson set more understandable for students. A clear example of this is the way in which large numbers are represented in the lesson set. Although they are familiar with exponents, the scientific notation of numbers is not something middle schoolers are well acquainted with. To help students grasp the large numbers mentioned in the text, the numbers are rewritten with known representations. Thus instead of writing $1.49597870\cdot10^8$, the set uses 149,597,870 and mentions that it is approximately 0.15 billion. In addition a link was added with references to the SI-prefix table and the

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[17] https://www.internationalschoolhaarlem.nl/

teacher notes recommends teachers to discuss this topic in class if students have not encountered it before.

In the last round of teacher feedback, it became apparent that the section on electromagnetism was too advanced for the target audience and that students would benefit from more worked examples on exercises which require calculation. It was therefore chosen to move the section on electromagnetism to the teacher notes, as suggestion to increase the level of the lesson, and to use the new gained space in the lessons set for two more sample calculations.

Phase 4: the computer lab version 1

The computer lab in the lesson kit uses data provided by VLASS. A request for this data was sent within the first weeks of the project, yet the data finally arrived a week after the official development phase of the project had ended. As it was uncertain whether the data would still arrive in the final weeks of the project, a first version of the computer lab was created which uses the quick look images that are publicly available from the VLASS pages for scientists.

In the final exercise of the lesson set, students search for a radio source on the VLASS progress sphere[18] and attempt to identify it using an online catalogue. In the computer lab student learn how to make a 3D contour plot of this source. The lab first guides students through the installation of ImageJ, the program that will be used to analyse the VLASS data. Secondly, it teaches students were to find the right dataset based on the coordinates of the source and lastly, it contains a couple of tasks to encourage students to experiment with ImageJ and to create a colourful 3D contour plot of the data. As 2D datasets are used, the z-axis of the plot merely depicts the intensity of the light as a height and does not add any new information.

As this version of the computer lab focusses on representing the data set in a different way, it does not have an exciting conclusion with real scientific meaning. The next version of the computer lab adds some additional theory to the lab's content and does work towards a scientifically interesting conclusion.

Phase 5: student feedback and self-study

Teachers are a good source of feedback when it comes to making the lesson kit classroom ready, yet to know what the actual target audience thinks of the kit, you would need to consult the students. In phase 5 of the project, two middle school students of different grades skimmed through the lesson set and gave their feedback. It was pointed out that the kit was currently a little bit too tough when it came to mathematical exercises. To solve this issue, the answers to the mathematical exercises provided in the teacher notes include the calculations and tips are provided to make the formulae less difficult by rewriting them into different forms. In addition, the cover of the lesson set now specifically mentions that both teachers and those who use the kit for self-study can consult the teacher notes for supplementary information. Exercises requiring mathematics are labelled with a calculator symbol and it has been checked that the computer lab is also doable if these exercises are skipped. The student feedback thus helped to adjust the level of the kit and to provide the necessary guidance to enable self-study use.

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[18] https://public.nrao.edu/vlass/vlass-progress/

Phase 6: preparation for the future

As the kit reached its final stages of development, the project too, approached its end. It was time to think about the future of the kit. As considered in the design phase, there will likely be many ways in which the kit can still be improved that only become apparent when it is actually used. To collect feedback from future users of the kit, an evaluation survey was made, using Microsoft Forms, which asks questions intended to evaluate the goals of the kit and identify areas of improvement. The link and QR-code to the survey have been added to the teacher notes. To encourage respondents to finish the survey, it is not very long and it contains many clickable rather than open questions. An unexpected, yet positive surprise was that Microsoft Forms has an astronomy-themed survey layout. To ensure the respondents privacy, the survey results are anonymous and can only by accessed with the proper authorisation.

Phase 7: the computer lab version 2

At the end of the project, new links to the VLASS data arrived, enabling an upgrade to the computer lab. Whereas the first version of the lab mainly focusses on adjusting the visual representation of the data, the second version actually relates the data to a bit of astronomical theory. In addition to the content of the first lab, students now learn how to make a contour plot in ImageJ, find a ratio between distances and determine whether a radio source belongs to class I or class II.

The theory used in the lab can be found in an article from 1974[19], where a correlation is found between the relative position of high and low brightness regions in extragalactic radio sources and their luminosity. By determining the ratio between the distance between the regions with the highest brightness and the total extent of the source, the source is classified. If the ratio is smaller than 0.5, it belongs to class I. If it is larger than 0.5, it belongs to class II. The article finds that class II sources tend to be more luminous than sources of class I. In the lab, students will classify three different radio sources. To help students with the identification, examples are provided using old VLA maps of radio sources[20]. As it is hard to discover whether the sources have been classified before, students are encouraged to classify sources used by their peers to verify their results. The data used for this lab consists of png images from the quick look data, which each contain a radio source[2].

Phase 8: VLASS feedback

The final product of the project was presented to experts from VLASS during a video meeting, in the second to last week of the project. During and after the meeting, several experts provided feedback on various parts of the lesson kit. Whereas the teacher and student feedback mainly focussed on the educational side of the kit, the VLASS feedback also included comments on the science discussed in the kit, such as an explanation of the coordinate systems used in VLASS data and a list of suggestions to increase the scientific accuracy of the lesson set. In view of time, most of the feedback has been added to the discussion as a recommendation, yet the mentioned errors in the content of the kit have been corrected immediately.

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[19] Fanaroff, Bernie & Riley, J.. (1974). The Morphology of Extragalactic Radio Sources of High and Low Luminosity. Monthly Notices of the Royal Astronomical Society. 167. 31P-36P. 10.1093/mnras/167.1.31P.
[20] Caltech glossary webpage with classification examples: http://ned.ipac.caltech.edu/level5/Glossary/Essay_fanaroff.html

Chapter 4: Results

This chapter presents the results of this project: the VLASS lesson kit. The kit consists of the actual lesson set, a computer lab, teacher notes which accompany the lessons and an evaluation survey. All components can be found in appendix 1 till 4.

The Lesson Set

The lesson set is a 17 page document that covers the introductory theory for the computer lab targeted at students. The set consists of three chapters which each cover the content of one lesson. Apart from theory, the set also contains plenty of exercises, additional materials and a glossary. In the second chapter, students are invited to take a virtual tour of the VLA telescope and in the third chapter, students are tasked to make their own multiwavelength image using a web application developed by the NRAO. The exercises in the set were not only developed to check a student's understanding of the material, but also to challenge their critical thinking skills. For this reason, there are plenty of sub exercises which do not have one fixed answer. In these cases, guidelines for a nice answer are provided in the teacher notes.

The Teacher Notes

The teacher notes is a supplementary document targeted at teachers. It follows the content of the lesson set. The notes start with a brief instruction on how to use the lesson set, after which each chapter is discussed. The key points of each lesson are summarised and the answers to the exercises are given, including calculations. For each chapter suggestions are provided to alter the level of the kit. This includes additional topics like the energy of electromagnetic waves, the LOFAR telescope and the atmospheric window. The notes conclude with a link to the evaluation survey.

The Computer Lab

The computer lab is a separate pdf, which guides students through the installation of ImageJ, the search for the right data set and the processing of the data. In the first part of the lab, students will make a 3D contour plot of the radio source they discovered in the final exercise of the lesson set. In the next part, students learn about contour lines and the classification of radio galaxies. This knowledge will be used to classify radio sources in png images of VLASS data.

The Survey

The final element of the kit is the evaluation survey. The survey consists of fourteen questions which are meant to verify whether the goals of the kit are met and which improvements can still be made.

Chapter 5: Discussion

Considering the proposal of this project and the final product presented in this thesis, one can critically reflect on the project. This chapter discusses how and why the output of the project may differ from the initial proposal. It examines what went well and what could be improved and it suggests steps to be taken in the future.

The project proposal describes the project as follows:

An outreach focussed project which aims to create a VLASS related lesson set/guide for teachers. The project will involve the following steps:

- Brainstorm with experts from VLASS what kind of images and datasets are interesting for education and outreach and which d.i.y. computational experiments are appropriate and engaging for the target audiences.

- Find the right data for such an experiment; prepare the data for use in an educational setting; and set up a how to/guide/ lesson set + explain theory. Prepare for the evaluation of the developed materials.

- Create supplementary elements for the guide/lesson set such as for example a radio highlights tour in worldwide telescope with new VLASS images

Though the details may have varied, the overall aim of the project, to create a VLASS related lesson set/ guide for teachers has been achieved. As the final product contains both a lesson set and a guide for teachers, the result is more complete than initially predicted. The steps involved in the project have, however, differed from those in the proposal.

One of the main reasons for this is that the communication went a little less smooth than expected. It was hard to get in touch with the experts from VLASS: the first request for contact and data went out in the second week of the project, yet after a couple of reminders, the data for the lab finally arrived at the end of the eighth week. This delay may partly be caused by all the changes created by the corona crisis, which made the project period a little hectic for everyone. The first few weeks of the project thus involved more independent study and less collaboration than initially expected, but this grew better towards the end of the project. Therefore, instead of the brainstorm with experts from VLASS mentioned in the proposal, it was chosen to ask experts from the educational side, students and teachers, for feedback during various stages of the project. This ensured that the kit's content is appropriate and engaging for the target audience and thus meets the aim of that step in the proposal. The VLASS-oriented brainstorm on the computer lab was done with help of the project supervisor, who also provided papers on the theory of the second computer lab. Though communication is clearly a point which can be improved in a future project, in the end ways were found to successfully tackle this problem.

Days before the thesis deadline, the opportunity arose to join a meeting with the VLASS team. During the meeting, VLASS experts provided valuable feedback on the lesson kit and discussed possible ways in which the kit could be of use for VLASS. The team was very positive about the content of the kit and saw various opportunities to present, and further develop, the kit, for example as a resource aimed at amateur astronomy enthusiasts to peak their interest in VLASS. The main point of feedback was the team's

concern about the level of the kit. They expected that it will likely take much longer than the planned 2-3 lessons to complete the kit and that students might not be able to finish it completely as it is a lot of new information to take in. As the sudden arrival of the new data resulted in a computer lab of twice the prospected length and the teacher and student feedback also agreed that the kit appeared quite challenging, it can indeed be assumed that it will take students longer than 2-3 lessons to complete the kit. As the kit has not yet been tested in a classroom setting were students are aided by a teacher, it is hard to determine how long it would take to complete the kit and what further adjustments should be made to the content of the kit to find the right level. As shown in the *Development* chapter, various measures have been taken to make the content more approachable and to provide support for teachers and students. Members of the VLASS team suggested to investigate the level of the language used in the computer lab, as jargon and difficult expressions often unintendedly find their way into texts aimed at non expert audiences, and to add more content based questions to the evaluation survey, which helps to identify whether the audience has grasped the important concepts the kit tries to bring across. In view of time, it is recommended to implement these suggestions in a follow up project.

Apart from the first step, there was another part of the proposal that turned out differently from the initial idea. In the third step, a radio highlights tour in worldwide telescope using VLASS images is suggested as supplementary element. Unfortunately there was too little time to create this tour. This is because there were already many other supplementary elements added into the lesson set and teacher notes, which were not initially taken into account. After researching the important components of a lesson set, it was chosen to include exercises that use puzzles and 'fun' online resources. The topic of radio telescopes is, for example, introduced with a colourable matrix and the third chapter contains a pseudo-computer lab where students get to identify a radio source they discovered in a VLASS data sphere. It costed a little bit more time to create these exercises than it would have cost to make some plain calculations and questions on the text. In addition, the length and content of the set and lab already seemed sufficient for a few lessons and did not appear to require an additional radio highlights tour. This may, however, be a nice addition in a follow up project.

Another suggestion for a follow up project may be to create yet another version of the computer lab. Due to the delay of the data, the second version of the lab had to be developed in little more than a week. This resulting computer lab does fulfil the necessary requirements, it lets students work with actual VLASS data and perform some simple scientific experiment, but there are many more cool experiments that can be done with the data. In addition, the large amount of noise in the quick look images and .png files makes the accuracy of the experiments done in the lab quite limited. One of the VLASS experts made sample images with VLASS and NVSS comparisons of giant radio galaxies, which use a coordinate system that is likely less confusing to students than those in the .png images currently used, that may be of use in a new version of the lab. Perhaps one day someone with more time and a higher proficiency with radio imaging can upgrade the lab.

There are still other aspects of the project that could require attention in the future. After the lesson kit has been tested by classes and responses to the evaluation survey will begin to arrive, the kit can be improved based on the new feedback. In addition, once VLASS has been completed, the kit can be updated to also include data from newer

survey rounds. As new discoveries in (radio) astronomy are made every year, the kit should be renewed every once in a while to keep it relevant and interesting for future use. On the short term, one can think about the ways in which the kit will be promoted to the target audience. This topic falls outside of the scope of this project, but may be key to the success of the kit. There is plenty of possibilities to build on this project in the future.

Conclusion

This thesis narrates a journey through the process of creating the VLASS lesson kit. A lesson kit which helps to combat both the lack of lesson material on radio astronomy aimed at middle schoolers as well as the lack of resources which allow younger non-expert audiences to work with real scientific datasets.

In the first chapter, it was shown how various scientific papers and existing educational resources where examined to understand and explore the necessities of a lesson kit. This knowledge was combined with the circumstances for this specific project in the second chapter, after which the actual kit was developed. To ensure that the lesson kit is suitable for middle school classroom use, both teachers and students were consulted for feedback in between various stages of development. This resulted in a complete lesson kit which enables middle school students to work with VLASS data and encourages them to explore more about radio astronomy.

The title of this project, *Preparing VLA Sky Survey data for Education and Outreach*, suggests that the data is the project's main focus, yet due to the reasons provided in the discussion, the project turned out to be more oriented at *Preparing middle school classes for working with VLA Sky Survey data*. The resulting lesson set enables students to understand what the VLASS data in the lab represents, how it was taken by the VLA and why certain sources appear in the data. The teacher notes help teachers to guide their students and adapt the material to their needs. The computer lab lets students work towards a clear goal, a plot and classification, yet leaves plenty of room for them to explore the data by themselves. Lastly, the evaluation survey enables the lesson kit to grow in the future, it verifies whether the kit meets its targets and points out possible areas of improvement. The focus of the project may have slightly shifted but the overall outcome is indeed the intended *VLASS related lesson set*.

The kit was created with the aim to both teach students about radio astronomy as well as to increase their interest in the topic. To do this, it is important that the level of the kit is suitable and the exercises and design of the kit are engaging. Though the kit has been adapted to feedback from a small group of teachers and students, one can only tell whether it fulfils the requirements when it has been used by actual classes. In a follow up project, one can look at the survey results and improve the lesson kit accordingly. In addition, this project was limited to one target audience, middle schoolers and only involved the creation of the kit, so it might be interesting to develop a kit for other age groups, like early high schoolers, or to investigate how it can be ensured that the kit reaches its audience.

The future will tell whether the lesson kit has succeeded in its goals, yet it can be concluded that the goals of this project have been met.

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- The experts from VLASS, who provided feedback and put thought into the future of the kit, including Lawrence Rudnick, who examined the lesson set from the scientific expert perspective, and Heinz Andernach, who provided suggestions for the computer lab and identified the sources used in the examples.
- My grandpa, Jack van der Male, who helped to minimize the amount of spelling errors and ridiculously long sentences in the text.

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Appendices

1. The VLASS Lesson Kit
2. The Teacher Notes
3. The Computer Lab
4. Screenshots of the evaluation survey
   (when viewing this document digitally, click [here](#) for the survey)

VLASS Lesson Kit

Welcome to this lesson set on the VLA Sky Survey (VLASS). In this interactive PDF, you will be taken on a journey through the world of radio astronomy. In the first few pages you will take a look at invisible light, after which there are some chapters on radio telescopes like the Very Large Array (VLA) and the way they work. Next, you will learn about various sorts of radio sources in the sky, such as black holes and pulsars. Lastly, there is a computer assignment were you get to use actual VLASS data to figure out the speed of a radio source. Furthermore there are also plenty of puzzles and quizzes to test your new gained knowledge in a fun way.

Table of content

For teachers: Motivation behind the chapters and answers to exercises as well as some suggestions to adapt the material to the level and pre-knowledge of your specific class are given in the teacher notes.

For self-study: Consult the teacher notes for an overview of the key concepts of each chapter and the answers to the exercises. Mathematical exercises are marked with a calculator. These exercises can be tough if formulae have not been covered in your math classes yet. The final exercise and computer lab are also doable if the mathematical exercises are skipped.

This lesson kit was made by Marloes Bodegom as part of the bachelor research project: Preparing VLASS data for education and outreach.
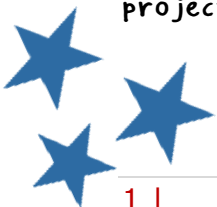
Invisible Light

There are plenty of light sources present in our daily lives, for example the sun, a candle or the glowing screen of your mobile phone. With our eyes we can detect light and thus see. Yet what exactly is light?

Wave

Light can be thought of as a wave. An **electromagnetic wave** to be precise. Like ripples in the ocean, a wave is a motion of peaks and valleys continuously repeating each other. The distance between those peaks and valleys is known as the **wavelength**. The wavelength is usually indicated with the Greek letter lambda, λ, and can tell us a lot about the properties of the wave.
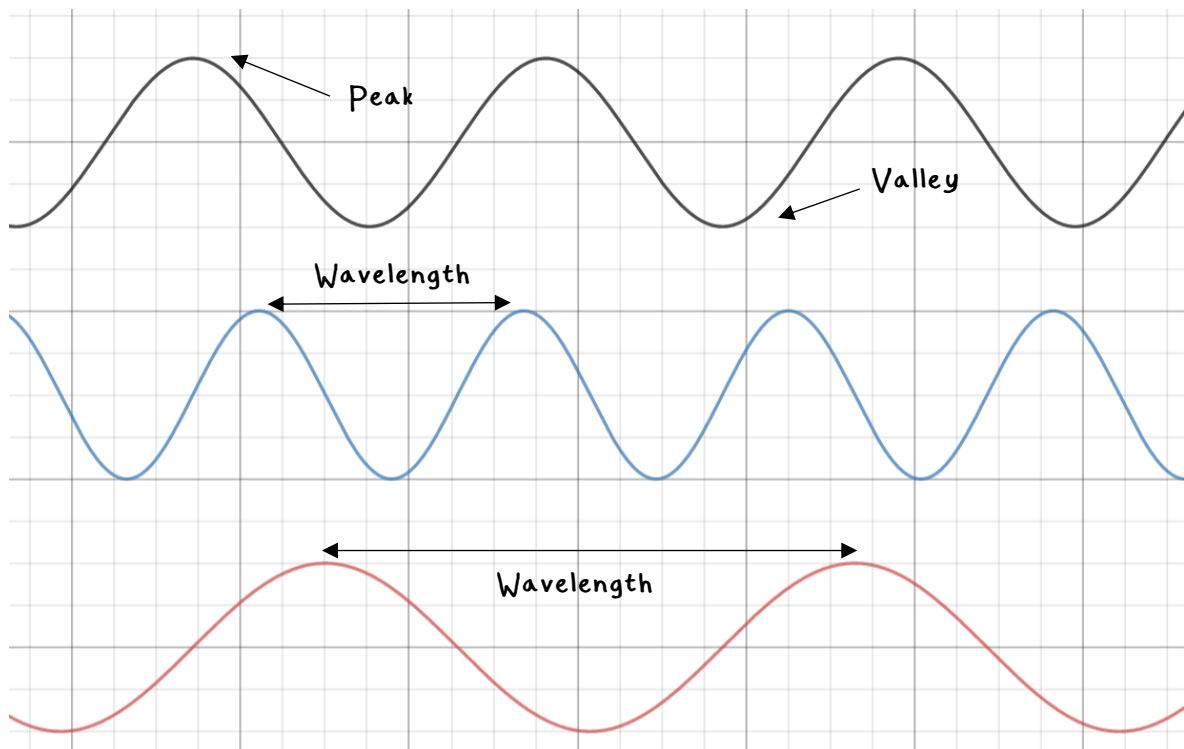
In the figure above, you can see three waves. Notice how the distance between the peaks and the valleys, the wavelength, is different for each wave. Compared to the black wave, the blue wave has a shorter wavelength and the red wave has a larger wavelength.

The electromagnetic spectrum

Light can have different wavelengths, ranging from less than a billionth of a meter all the way to several kilometres long. All these sorts of light together form the **electromagnetic spectrum**. The picture below shows the electromagnetic spectrum. You might recognize the rainbow in the centre. This part is known as **visible light**, and consists of the wavelengths we can detect with our own eyes.

THE ELECTRO MAGNETIC SPECTRUM
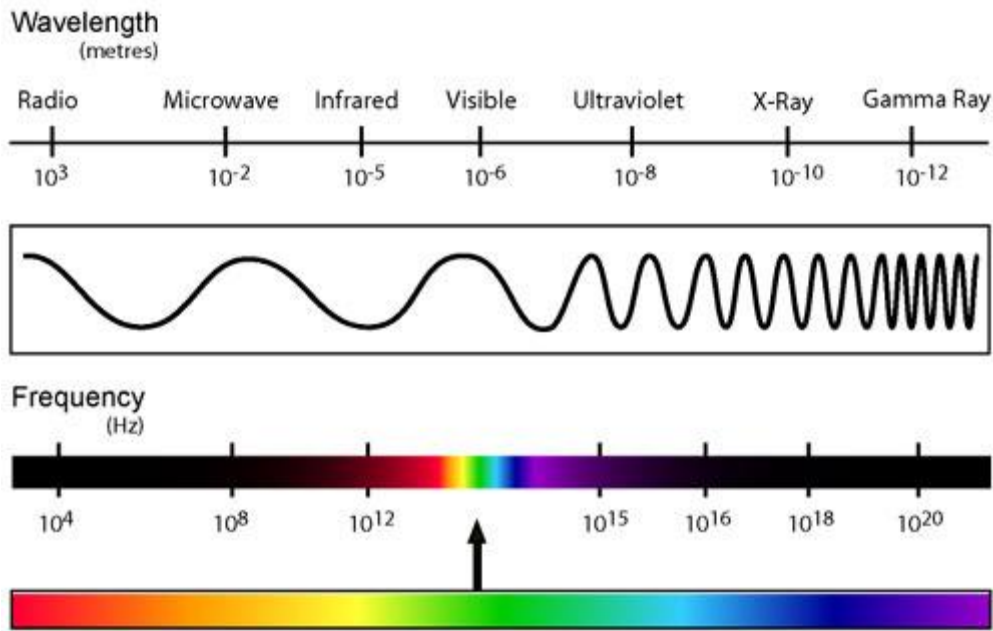
The electromagnetic spectrum

Visible light, however, is only a very small part of the spectrum. This means that there is also a lot of light we cannot see by ourselves. Let's take a look at the main categories of invisible light. Note that the boundaries of each category are more smooth regions than exact fixed wavelengths.

Radio

Light with very large wavelengths, up till many kilometres long, is known as radio waves. These wavelengths are used for telecommunication and, surprise, radio stations. Radio telescopes like the VLA observe in this band.

Microwave

Microwaves range from around 1 till 1000 millimetre. Radars and GPS-systems fall into this category. But also the microwave. Most household microwaves emit radiation with a wavelength of 12 centimetres.

Infrared

Humans and animals emit infrared radiation. Infrared has slightly longer wavelengths than visible light, ranging from 700 nanometres up till 1 millimetre. The heat radiating from a cow is shown on the right.
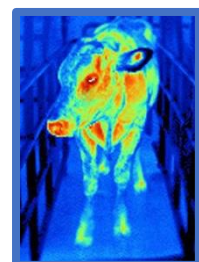
Ultraviolet

On the short wavelength side of the visible, or optical, part of the spectrum is the ultraviolet. Ultraviolet light is emitted by for example the sun and causes your skin to tan.

X-ray

X-rays have a wavelength ranging from 0.1 and 12 nanometres. These rays are used in hospitals to make pictures of your skeleton, but also in airport security to examine the content of your suitcase.

Gamma Ray

The shortest wavelengths and highest energy waves are gamma rays. Gamma rays are emitted by the decay of various radioactive elements. Gamma rays can be harmful but are also applied against cancer in the medical sector.

The speed of light

Light travels at the speed of light, c, which is approximately 300,000 km/s (300 thousand kilometres per second) in vacuum (empty space). This speed is the same for all wavelengths. The sun is on average 149,597,870 km (~0.15 billion kilometres) away from the earth, which means that sunlight has been traveling for a little more than 8 minutes before it reaches your eye. Astronomers sometimes says an object is several light years away. A **light year** is the distance light travels in a year, which is about 9.46 trillion (10^{12}) kilometres.

Speed of light example

Question: The distance between the Earth and the Moon is approximately 400,000 km. How long would it a ray of light to reach Earth from the Moon?

Answer: The speed of light is 300,000 km/s and the distance between the Earth and the Moon is 400,000 km. To get the time, we divide the distance by the speed:

$$time = \frac{distance}{velocity} = \frac{400000}{300000} = \frac{4}{3}$$
$$\approx 1.333 \; seconds$$

It would thus take only 1.3 seconds for light from the Moon to reach the Earth!

Questions:

1. Polaris is a star approximately 433 lightyears away from us. How many kilometres is that?

2. At their closest, Jupiter and Earth are 588 million kilometres apart. How long would it take light to travel between the planets when this is the case?

3. It takes light 8 seconds to travel from point A to B. How far are the points apart?
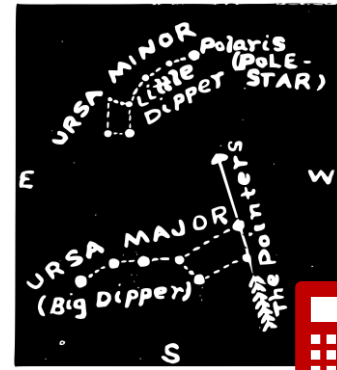
Frequency

Instead of referring to a type of light by its wavelength, you can also say it has a certain **frequency**. The frequency, f, is the number of waves (so a peak and valley) occurring per second. It is measured in **Hertz** which is the same as reciprocal seconds (s⁻¹). If the **period** of a wave is 0.1 seconds, then the wave will have repeated itself 10 times in a second so its frequency would be 10 hertz. Because light has a nearly fixed speed, you can easily determine the frequency from the wavelength of light and vice versa. The formula is:

$$c = \lambda f$$

Thus, if our microwave radiates at a wavelength of 12 centimetres and the speed of light is 300,000 km/s, which is 30 billion cm/s, then the frequency of the microwave is 2.5 gigahertz.

Click here for a quick reference on prefixes like giga, kilo and milli.

Wavelength frequency example

Question: Light with a wavelength of 505 nanometre has the colour cyan. What would be its frequency?

Answer: The frequency of light is found by dividing the speed of light, 300,000 km/s by the wavelength, 505 nm, which results in:

$$f = \frac{c}{\lambda} = \frac{300000 \ km/s}{505 \ nm} = \frac{3 * 10^{10} \ cm/s}{505 * 10^{-7} cm} \approx 594 * 10^{12} hz = 594 \ Thz$$

The frequency of cyan is thus 594 Terahertz. You can use the prefix reference page to make the units equal and to write the final answer in a short manner.

Questions:

1. What would be the wavelength in metres of light with a frequency of 3 megahertz? Which part of the electromagnetic spectrum is this?

2. A red laser has a wavelength of 632.8 nm. What is the frequency of this laser?
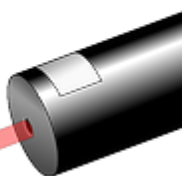
Electromagnetic spectrum puzzle

1. Match the images, wavelengths and frequencies with the right category of the electromagnetic spectrum.
2. Can you think of more elements that would fit into each category?

Radio

200 km

642 GHz

77 nm

Optical

30 EHz

2 MHz

3 m

Ultraviolet

Microwave

620 THz

100 PHz

1 pm

198 pm

Gamma ray

X-ray

7 Hz

42 μm

Infrared
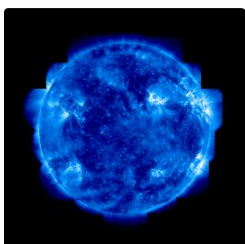
5 PHz

570 nm

Radio telescopes

In the previous chapter, you have learned that light with the longest wavelengths, or shortest frequencies, is known as radio waves. In this chapter, you will discover how astronomers can observe these radio waves from space with radio telescopes.

History

The start of radio astronomy is generally considered to be the discovery of noise from the Milky Way, in the 20 megahertz region of the radio band, by radio engineer Karl Jansky in the 1930s. Jansky had noticed a strange signal that seemed to repeat every 23 hours and 56 minutes, which is exactly a **sidereal day**. This inspired scientist Grote Reber to build a telescope in his own

> A *sidereal day* is the time it takes a fixed object in the sky, like a star, to reappear at the same spot.

backyard. The telescope consisted of an **antenna** and a **dish**, with a **diameter** of 9 meter. Using this telescope, Reber confirmed Jansky's discovery and found many other radio sources in the sky. In the next decades, more and more discoveries have been made in the field of radio astronomy and many radio telescopes have been built. In 1942, astronomers detected radio signals from the sun. In 1944, scientists realised that **hydrogen**, the element we encounter most in space, can be seen really well with a radio telescope. In the 1950's and 1960's, computers became powerful enough to do the complicated calculations to combine signals from several radio telescopes, greatly increasing the **resolution** of observations and the possibilities of radio astronomy. The American **VLA** and the Dutch LOFAR, are examples of modern telescopes that combine signals to become more powerful.

The anatomy of a radio telescope

The most iconic radio telescopes consist of an antenna and a dish, as shown in the sketch below. The antenna is held above the centre of the dish supported by the poles. Radio waves enter the dish and are all reflected to the same point, the **focal point**, which is the antenna.
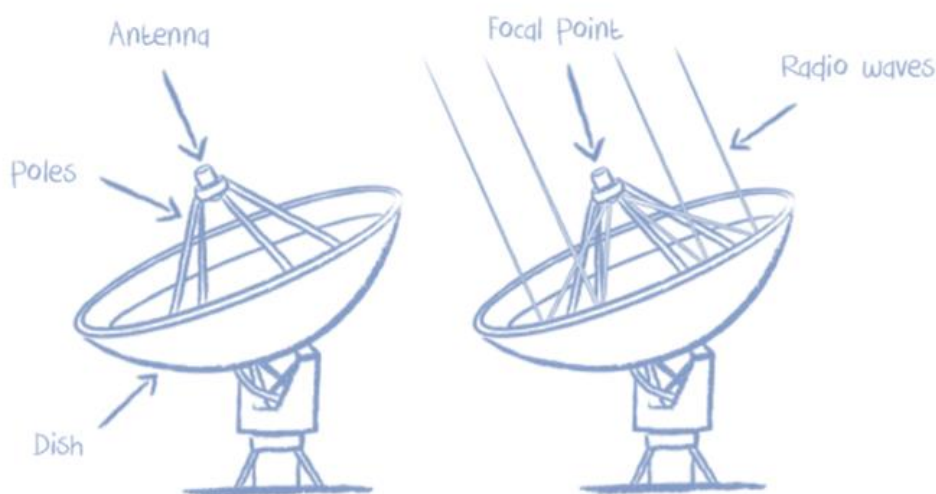
Picture from EU-UNAWE, the invisible universe, ISBN: 978-94-91760-07-5

Once you have measured the signal at one point of the sky, you can change the angle of the dish of the telescope to a point just next to it and repeat the measurements until you have a picture. As we cannot see radio waves with our own eyes, computers are used to transform the signal received by a radio telescope into a picture we can actually see. You can choose any colour scheme you want for such pictures.

Radio telescope puzzle

Using a single-dish telescope, 25 measurements have been done in the shape of a grid. The squares have been given a number based on the strength of the signal, 1 being the strongest. Colour the squares and discover the centre of the radio source.

1=red, 2=orange, 3=yellow, 4=green, 5=blue, 6= purple

It is hard to see a lot of detail in a small grid like this with only 6 possible strengths. Can you think of ways to obtain a more detailed picture of this radio source?

4	4	4	5	6
3	2	3	5	5
3	1	2	3	4
2	1	1	2	3
3	2	2	3	4

Resolution

Resolution can be described as the sharpness of an image. How far can you zoom into a photo, before you only see a blur? Take a look at these two images of a radio telescope. The first image has a much higher resolution compared to the second one. What determines the resolution of radio telescope images and how can this be improved?

The dish of a radio telescope catches the radio waves and redirects them to the antenna. One way of improving the resolution is by increasing the diameter of the disk. A diameter is the distance from one side of the dish to the other, through the middle. The **angular resolution** of a single dish telescope roughly scales with the wavelength of the light you are observing over the size of the dish:

diameter

$$R = \frac{\lambda}{D}$$
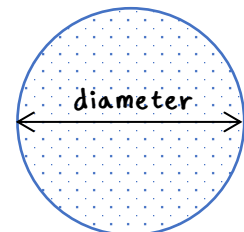
Resolution λ Wavelength   D Diameter

Thus, if a 9 meter diameter and an 18 meter diameter dish telescope would both observe the same radio source at 21 cm wavelength, the resolution of the 18 meter telescope would be twice as high. Based on this, astronomers have made telescopes with very large dishes. Currently, the largest single-dish telescope is the FAST in China (shown on the right), with a diameter of 500 metres.

There is, however, a downside to creating radio telescopes like these. Building a huge dish costs a lot of materials and therefore money. It also takes up quite some space. Luckily there is an alternative. Separate dish telescopes can work together to form one big telescope.

This happens via a procedure known as **aperture synthesis**. In this procedure, signals from multiple telescopes are combined to form one big picture. An example of a telescope that uses this principle is WSRT, in the Netherlands. Instead of images with an angular resolution determined by the diameter of one dish, here the diameter equals that of the entire array (row of telescopes).

It is also possible to place the telescopes in other shapes than a line and get even better images. However, the computational analysis needed to combine all signals into one image gets a little bit more complicated.

One final important way to improve the quality of a radio image is to reduce the **noise**. Noise is any signal the radio telescope picks up that is not part of the signal you want to observe. As radio signals from space are often very faint, simply using your mobile phone near a radio telescope can already cause quite some noise. Additionally, water produces noise at certain radio frequencies, thus, it is best to build your radio telescope in a place with little water vapour in the air. In order to minimize noise, telescopes are therefore often built in very remote and dry places, like the middle of a desert.

VLA

In the computer lab you will be working with data taken by the **VLA**. The VLA, which stands for Very Large Array, is a radio telescope form the **NRAO** located in New Mexico. The telescope consists of 27 smaller telescopes with 25 meter diameter dishes, arranged in 3 arms of 9 telescopes each. The telescopes are placed on rails so that the length of

the arms can be increased when one needs to zoom in for some observations. The telescopes can be very close together, resulting in a total diameter of only 0.96 kilometres, or very far apart, resulting in a total diameter of 35.4 kilometres. The VLA telescope is known for its iconic Y-shape, which can be seen from the sky, as in the picture on the right.


No time to visit New Mexico? Take the virtual VLA tour here :)

By changing the position of the separate telescopes, the VLA can be put in several configurations, the A configuration being the largest. In B configuration, the furthest telescopes are 11 kilometres apart. In this configuration you can already make images with a very high resolution.

VLASS

As New Mexico lies on the Northern hemisphere, the VLA can observe the entire Northern sky but parts of the Southern sky disappear below the horizon. By stretching the Northern arm (the B-nA configuration), the VLA can make images of objects near the Southern horizon with the same resolution as the Northern sky part. The chart below shows which configuration is used to map certain parts of the sky in the **VLASS**, the VLA sky survey.
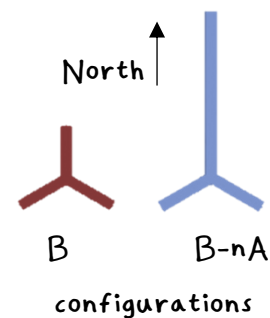
A sky survey is a map of a region in space. Unlike observations where astronomers are looking for something specific, a sky survey aims to make a general map of the region. The VLASS is a sky survey that lasts 7 years and will map 80% of the sky. It is expected that approximately 10 million radio sources will be registered. In the next chapter you will discover what radio sources VLASS might find.
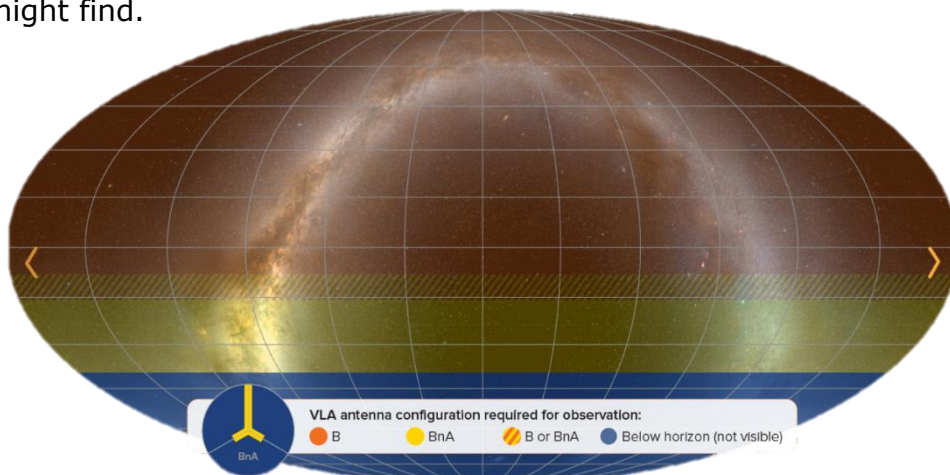
The VLA antennae configuration used for VLASS

(image from https://public.nrao.edu/vlass/)

Questions:

Assume all telescopes in the questions are observing at the 21 centimetre wavelength.

1. The small telescopes of the VLA have dishes with a diameter of 25 meter. What is the resolution of a small telescope? (Hint, use the formula from page 8 and look at the example below)

2. The FAST in China has a dish with a diameter of 500 metres. What is the resolution of this telescope and how does it compare to the telescope in question 1?

3. In configuration B, the effective diameter of the VLA is 11 kilometres. How does the resolution of the VLA compare to the previous two telescopes?

4. If you were to design a new telescope, what would it look like? Would you pick a single dish telescope or make an array of smaller ones? Where would you build it?

Angular resolution example

Question: The Parkes observatory (shown on the right) in Australia has a dish with a diameter of 64 meters. What is the angular resolution of this radio telescope observing at 21 cm?

Answer: The formula in the text shows that the angular resolution is the wavelength over the diameter, but before we can fill in the formula, we have to know what to fill in. Is D in metres or kilometres and what unit is the angular resolution R?

$$R = \frac{\lambda}{D}$$

Well, R is in radians. A radian measures the size of an angle, just like degrees. Yet instead of one full circle being 360°, a circle in radians is 2π. The answer will thus be a number between 0 and 2pi and we want it to be as small as possible, because then we can discern lots of details in the radio image. As R has no unit, the wavelength and diameter both need to have the same unit. Thus if D is in metres so should λ. Then, for the 64 metre Parkes observatory observing at a wavelength of 21 centimetres, which is 0.21 metres, we get:

$$R = \frac{\lambda}{D} = \frac{0.21}{64} \approx 0.003$$

Thus, the answer to the question is 0.003. This number might not say much to you on itself right now, but you can use it to compare the resolution of various telescopes.

Astronomical objects

Space is filled with countless stars and other astronomical objects like black holes and pulsars. These objects can look quite different in the radio when compared to their appearance in the optical. VLASS maps the sky in radio waves. What objects might you discover on VLASS images, and how would their appearance differ from optical images? These questions will be answered in this chapter.
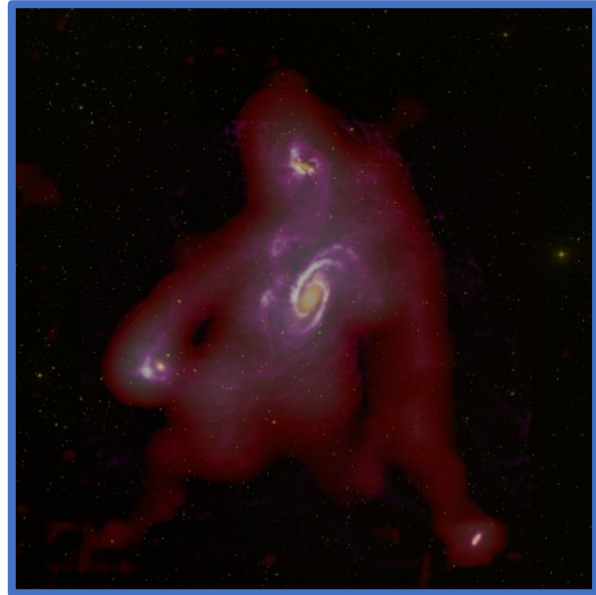
Multiwavelength Universe

The universe looks different at different wavelengths. The figure below shows the galaxy **Andromeda**, the neighbour of our own Milky Way, as viewed by 3 different telescopes.

In the optical image we can see the light emitted by Andromeda's many stars. The centre is the brightest and in the arms we can see some dark rings where the stars are hidden behind layers of **dust**. This dust is clearly visible in the infrared picture. In this picture we cannot distinguish stars and the centre looks very dark, but we can clearly see the spiral structure of the disk. Lastly in the X-ray image we can only see very energetic objects, like extremely hot stars and the galactic centre. In this picture it is hard to see the shape of the spiral arms, but the centre is clearly visible. By looking at multiple parts of the spectrum, astronomers can get a more complete idea of the galaxy's structure and the processes that happen inside it.
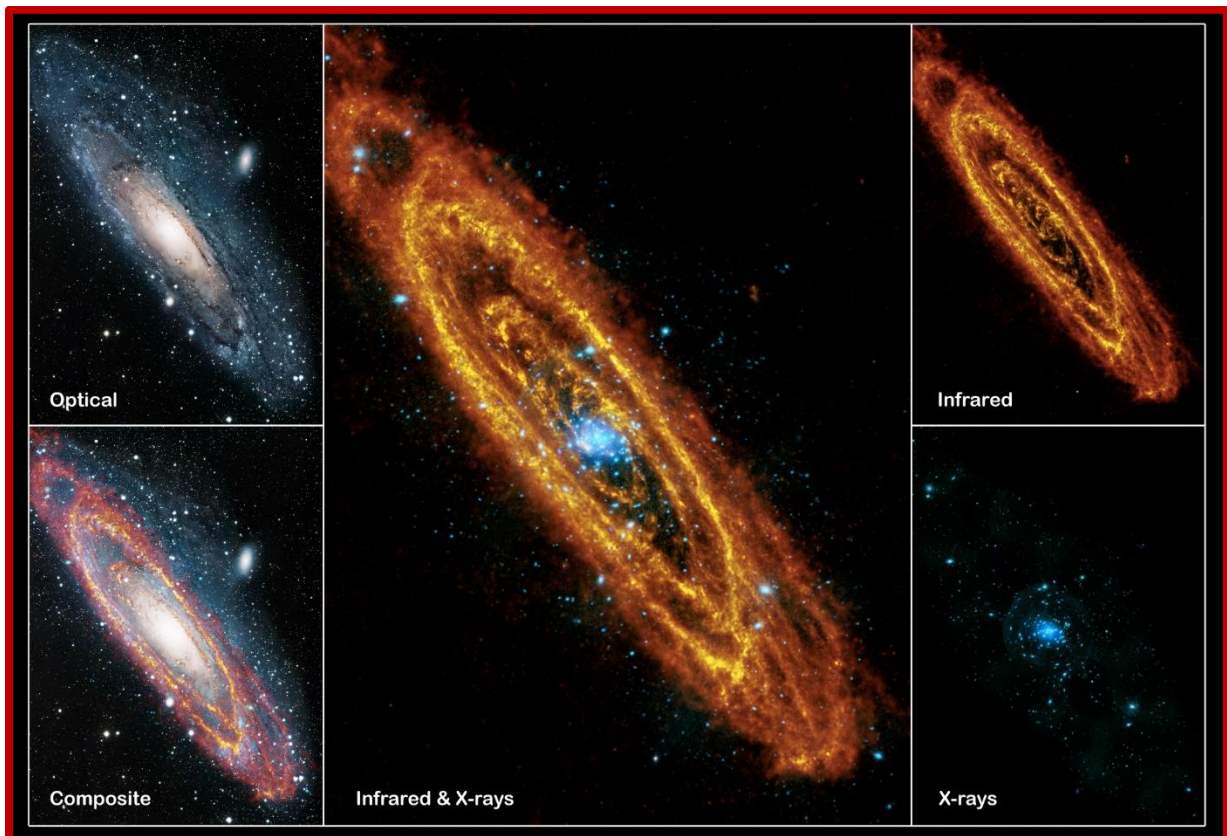
Hydrogen in galaxies

In the optical picture of the Andromeda example, some of the stars are hidden behind dust. With a radio telescope you can look through the dust. **Hydrogen**, the most common element in the universe, is visible within the radio. This is useful when you want to view the shape of a galaxy. On the right, you can see Bode's galaxy. In the optical, yellow, Bode's galaxy appears to consist of one large spiral galaxy and several small groups of stars around it. Yet, radio telescopes, the red and pink, reveal that all the stars seen in the optical are actually connected by clouds of hydrogen gas.

Task

Go to *this site* and explore the multi-wavelength view of the universe yourself. The radio images are taken with the VLA.

How does the image change when you look at other parts of the spectrum?

Think of experiments or observations you would like to do if you were an astronomer and which telescope would be most suitable.
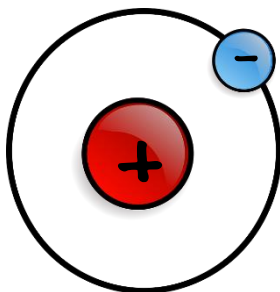
A hydrogen atom

21 centimetre

Over 90% of all detectable matter in space is hydrogen. Hydrogen is the most basic chemical element and it consists of a proton and an electron. Chemicals like hydrogen can absorb and emit light, but do so at very specific wavelengths. These wavelengths are called **spectral lines**. For the hydrogen atom, one of these lines is at 21 centimetres. The **21-cm line** is a very famous line amongst radio astronomers and is used to determine the location of hydrogen clouds.

Pulsars

Next to unravelling the underlying structure of hydrogen gas in galaxies, there are plenty of other cool phenomena to observe with a radio telescope. One of these is a **pulsar**. A pulsar is comparable to a space lighthouse. It is a neutron star that rotates very rapidly and has a strong magnetic field. It emits a radio signal from it poles, the purple beams on the picture. As the pulsar rotates, we receive a periodic signal, which can be a short as several milliseconds.
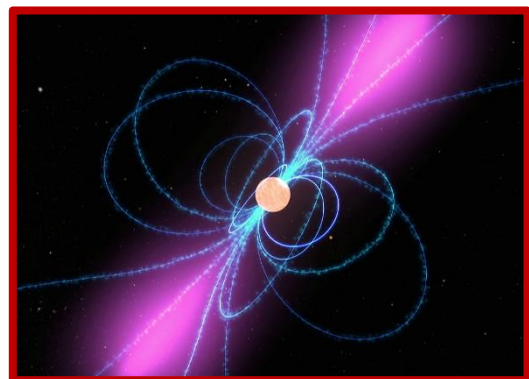
Quasars

Quasars are some of the brightest objects known. A **quasar**, quasi-stellar object, is a supermassive **black hole** with an **accretion disk** in the centre of a galaxy. A black hole is a place where gravity is so strong that even light cannot escape from it. As the black absorbs matter from its surroundings it can grow more and more massive. The biggest black holes are called **supermassive black holes**. The mass of a supermassive black hole can be millions or even billions that of the sun! A disk of matter can form around a super massive black hole,

An actual 'picture' of a black hole, made by several telescopes working together.

known as the accretion disk. As gas from the accretion disk falls into the black hole, a lot electromagnetic radiation is emitted. The **luminosity**, brightness, of a quasar can be several thousand times that of the Milky Way. Did you know that the first quasars were discovered in a radio sky survey, just like VLASS?
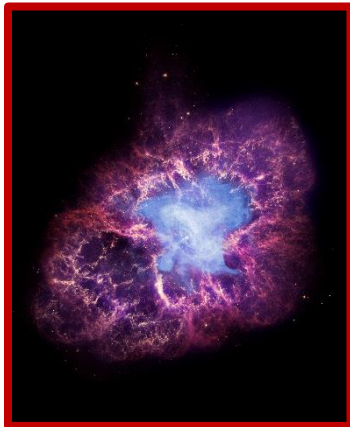
Supernova remnants

At the end of their lives, large stars may explode. This explosion is called a **supernova** and leaves behind a supernova remnant. Some of these are very visible in the radio, like the crab nebula on the left.

Collisions

High energy events in space, like the collision of two neutron stars and **gamma ray bursts** emit electromagnetic radiation of many kinds. These events will also be detectable in a radio sky survey.

Jets

Galaxies with an active centre sometimes show huge jets in the radio. On the right you can see 150 images from VLASS depicting galaxies with radio jets. Which one is your favourite?
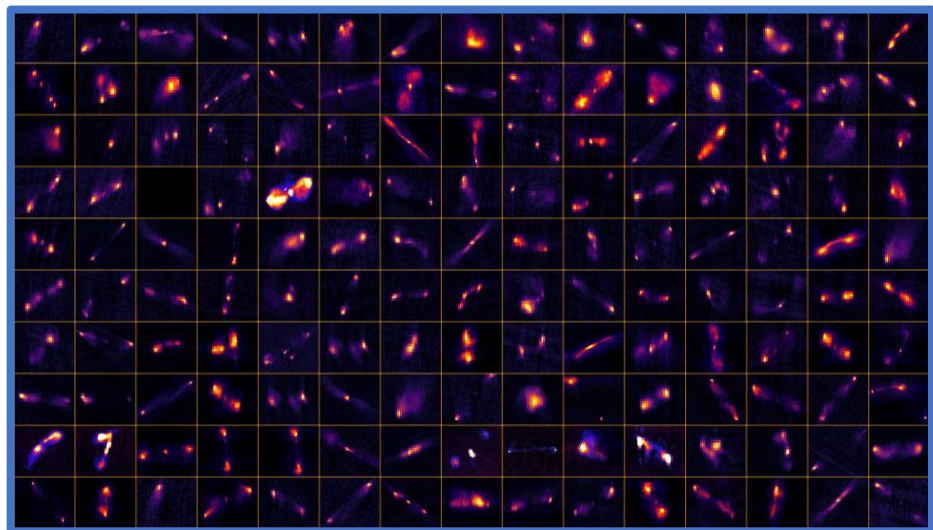

Credit: NRAO/AUI/NSF

VLASS Puzzle

In chapter 2 you learned about VLASS, the Very large Array Sky Survey. The first round of observations of the survey has already been completed. Below you will see some of the images taken by VLASS of famous radio sources.

1. What can you see on each picture and why is it visible in the radio?

2. Can you match the radio image with the optical image?

3. Take a look at *this webpage* to see the current progress of VLASS. Find a radio source by yourself and use write down the coordinates. Try to find the name of the source using a *catalogue*. What type of object is it?

4. In an earlier radio sky survey, quasars were discovered. Do you think something new will be discovered in VLASS as well? If you were an astronomer what object would you like to encounter in the survey?

> Is the radio source you found not in the catalogue? Ask your teacher to check the coordinates. Maybe you have discovered a new source!
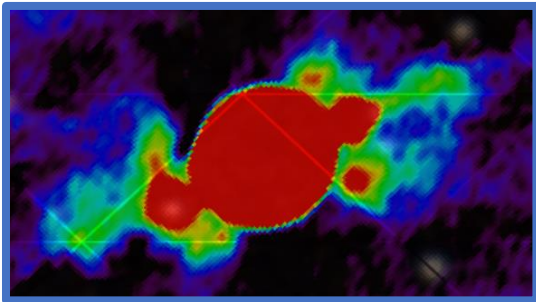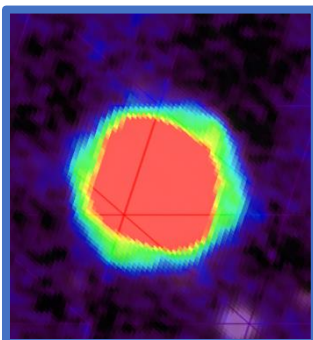

NGC 7354 Planetary Nebula
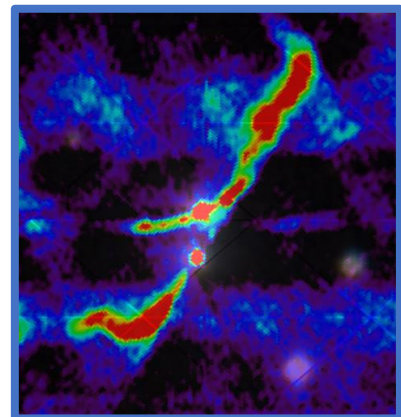
NGC 1128 Dumbbell Galaxy

Jupiter
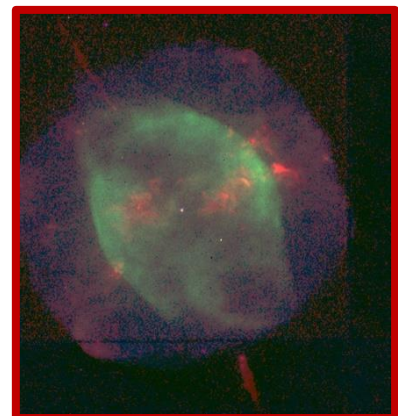
Glossary

An alphabetical overview of all the bold printed words in the text with definition for quick reference.

21cm-line: The wavelength at which atomic hydrogen has a spectral line. Useful for detecting hydrogen clouds in space.

Accretion disk: The disk of matter orbiting around a black hole.

Andromeda: The galaxy closest to us. The neighbour of the Milky Way.

Angular Resolution: The ability of a radio telescope to distinguish small details of an object.

Antenna: The receiver of radio signals.

Aperture Synthesis: The process of radio telescopes working together to create images with a resolution as if their diameter was equal to that of the array they form.

Black Hole: A place so dense that even light cannot escape from it.

Diameter: The length of the straight line connecting two points on a circle going through the centre of the circle.

Dish: The large bowl shaped part of a radio telescope, due to its shape all incoming waves get directed towards the antenna.

Dust: Small bits of matter in space. In optical images dust obscures light sources, in infra-red images dust lights up and in radio images you can see right through dust.

Electromagnetic spectrum: All electromagnetic radiation, or light, arranged by wavelength.

Electromagnetic waves: Light is an electromagnetic wave, it consists of an electric and magnetic field which alternate each other.

Focal point: The place to which all radio waves that fall into the dish of a telescope get directed. Focal comes from focus. When looking through a lens, the focal point is the point where you see an image the sharpest.

Frequency: The amount of times an event occurs in a unit of time. For example a wave with a frequency of 10 hertz occurs 10 times per second.

Gamma Ray Burst: A highly energetic explosion in space that emits gamma radiation for a brief period of time.

Hertz: The unit for frequency. A hertz is the same as one over a second.

Hydrogen: Hydrogen is the most abundant element in the universe. It consists of a proton and an electron.

Light year: The distance light travels in a year through a vacuum. A light year is about 9.46 trillion kilometres.

Luminosity: An absolute measure of the amount of light radiated by an object.

Noise: Undesired disturbances in a measured signal. E.g. background noise from neighbouring stars when measuring the brightness of a star.

NRAO: The National Radio Astronomy Observatory is an American organisation which e.g. operates the VLA.

Period: The time it takes for a signal to repeat itself. E.g. if the signal of a pulsar with a period of 1 second is detected by a radio telescope, it will be detected once again after 1 second has passed.

Pulsar: A rapidly rotating neutron star with a strong magnetic field. Pulsars emit radio waves similarly to lighthouses and optical light.

Quasar: A supermassive black hole with accretion disk in the centre of a galaxy.

Radio waves: Electromagnetic radiation with the longest wavelengths, or shortest frequencies. The VLA observes radio waves.

Resolution: The capability of a sensor to discern small objects.

Sidereal day: A sidereal day is the time it takes a fixed object in the sky, like a star, to reappear at the same spot. The length of a sidereal day is 23 hours and 56 minutes.

Spectral Lines: Every material can absorb and emit certain frequencies of light. When looking at a spectrum of light, you will see the spectral lines caused by the material. E.g. hydrogen clouds are very visible in at 21 cm wavelength because hydrogen has a spectral line there.

Supermassive black hole: The most massive type of black hole. The mass of a supermassive black hole exceeds that of the sun by millions yet their actual size is quite small, making them very dense.

Supernova: The explosion of a massive star at the end of its lifetime. Supernovas leave behind supernova remnants.

Visible light: The optical part of the electromagnetic spectrum. The wavelengths we can observe with our own eyes.

VLA: The Very Large Array is a y-shaped radio telescope in the desert of New Mexico.

VLASS: The VLA Sky Survey is a series of observations done with the VLA which maps 80% of the sky at radio wavelengths.

Wavelength: The length of a wave, measured from peak to peak, or valley to valley. Optical light has a wavelength of several hundreds of nanometres whereas radio waves have wavelengths that can be kilometres long.

All images used in this booklet are from the NRAO or free for re-use as determined by the Ecosia image search filter. Is one of the images used yours yet not referenced as desired? Contact us and the kit will be updated.

Teacher Notes

This document accompanies the VLASS Lesson Kit. It is directed at teachers and contains a brief explanation of each chapter as well as some suggestions to adjust the level of the chapter or create additional content. The answers to the exercises and puzzles are provided as well.

General notes

This lesson kit is aimed at middle (and early high) school students. The main purpose of the lesson kit is to introduce students to the field of radio astronomy and to generate enthusiasm for this branch of science. In the kit students will be able to work with actual data from the VLASS, which is also used by astronomers all over the world.

It is important that students get the feeling they are actually working towards/ doing some real astronomy when working with the kit. This is why apart from some basic mathematical problems and concept check questions, most exercises in the kit will not have a fixed correct answer. In these cases, the answer key will provide components a correct answer might have, or a sample solution. Students should be allowed to use a calculator for all exercises.

In order to make the lessons suitable for an audience without (much) prior knowledge, a glossary with the most important terms and concepts has been added at the end of the lesson kit. Students can benefit from using this glossary. As the lesson kit is meant to be used **digitally** (it also contains links to external sites), students can use *crtl f* to easily find a bold-printed word in the glossary.

This is the first version of the VLASS lesson kit and we would like to hear what you and your students thought about it. There is a link to the evaluation survey included on the final page of this document.

Chapter 1: Invisible Light

The aim of this chapter is to get your class acquainted with the electromagnetic spectrum. The most important concepts are:

- Light can be considered a wave, with a wavelength, frequency and velocity.

- We can only see visible light with our own eyes, but there are many other sorts of light, such as radio waves.

- Depending on the wavelength, light belongs to a certain part of the electromagnetic spectrum.

- All light travels at the speed of light, which is approximately 300,000 km/s.

In case the electromagnetic spectrum was already covered in an earlier science module, you can run through the chapter very quickly as a revision or simply skip it, as long as everyone has grasped the key concepts.

The figure on page 3 is the most important as it contains an overview of the entire electromagnetic spectrum. The section on *electromagnetism* is optional.

VLASS Lesson Kit Teacher Notes

Many resources have already been made to help students remember the various parts of the electromagnetic spectrum. If you want to cover this topic in more detail, please have a look at some of the following resources:

The Electromagnetic video series and companion book: Nasa

The Invisible Universe lesson set (also a useful supplement to the next chapters): UNAWE

(bonus: Songs on the Electromagnetic Spectrum: physisfun, Jam Campus, Universe Unplugged)

Questions

In the first set of questions, students will work with the concept of a light year. The main aim of the questions is to make the students aware of the huge distances you encounter in astronomy, although astronomers consider the objects used in the questions to be very close to us. Take a moment to realize that all light that reaches us from outer space has been traveling for a while.

> *1. Polaris is a star approximately 433 lightyears away from us. How many kilometres is that?* **Approximately 4.096·10¹² kilometres** (433x 9.46 trillion)

> *2. At their closest, Jupiter and Earth are 588 million kilometres apart. How long would it take light to travel between the planets when this is the case?* **1960 seconds or 32.7 minutes** ($588 * 10^6/30000$)

> *3. It takes light 8 seconds to travel from point A to B. How far are the points apart?* **2.4 million kilometres** ($8 * 3 * 10^5 = 2.4 * 10^6$)

In the next questions, the terms wavelength and frequency are connected via the speed of light. The questions are meant to help the students gain a basic understanding of the provided equation and to clarify why it does not matter whether scientists refer to a part of the electromagnetic spectrum by its wavelength range or by its frequency range. As prefixes, like mega and nano, are used in the questions, a link to an official reference table has been added to page 5. If this is new to the students, it might be useful to skim through the reference table in class. Keep in mind the importance of the units.

> *1. What would be the wavelength in metres of light with a frequency of 3 megahertz? Which part of the electromagnetic spectrum is this?* **The wavelength would be 0.01 m. This is 10 mm, which belong in the microwave part of the spectrum.** $\left(\frac{3*10^6}{3*10^8}\right)$

> *2. A red laser has a wavelength of 632.8 nm. What is the frequency of this laser?* **4.74*10¹⁴ hertz.** $\left(\frac{3*10^8}{632.8*10^{-9}}\right)$

Electromagnetic spectrum puzzle

The puzzle summarizes the content of the chapter. Students can convert the frequencies to wavelengths using the formula from the previous questions or

solve the puzzle with the following logic: *The larger the wavelength, the shorter the frequency*. In this puzzle students will encounter a radio telescope, which is the topic of the next chapter.
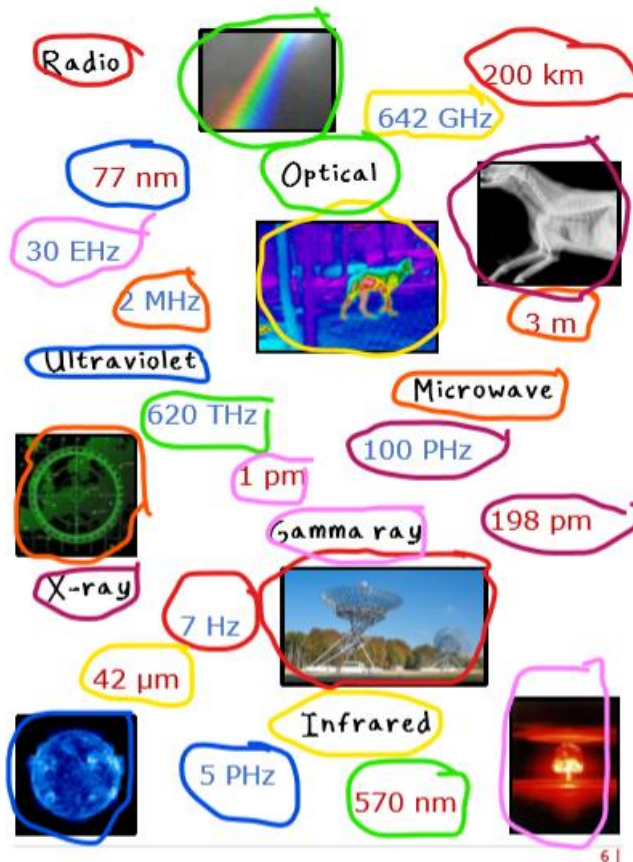
Suggestions

Students may ask what is meant by 'electromagnetic'. If this is the case, or they are ready for more depth, you can use the definition and figure below:

Light is electromagnetic radiation. But what is meant by electromagnetic? You might have noticed the word contains two terms that look like electricity and magnetism. An electromagnetic wave is a wave consisting of an electric and magnetic field that alternate with each other, as illustrated by the picture below. The electrical and magnetic component are perpendicular to each other and the direction of travel.
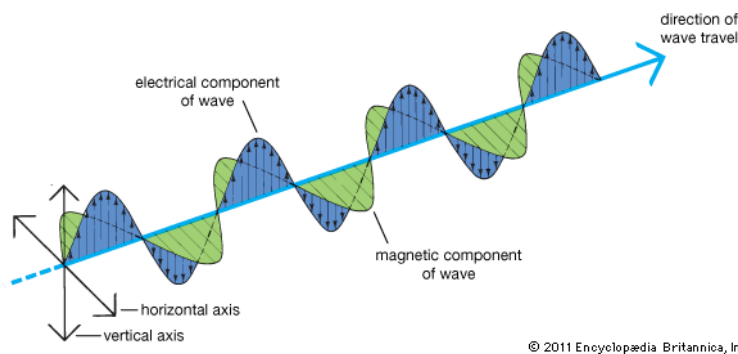
© 2011 Encyclopædia Britannica, Inc.

If your students have already worked with the electromagnetic spectrum or if they want an extra challenge, it might be useful (and fun) to connect wavelength with energy. The energy of a *photon* (light considered as a 'particle' of a certain wavelength) is given by:

$$E = \frac{hc}{\lambda} = hf$$

The h is Planck's constant. It has a value of 6.62607015×10−34 joules seconds or 4.135667696×10−15 electron volts seconds. This formula can be used to e.g. determine whether a photon would be able to free an electron from a piece of metal (The photoelectric effect for which Einstein has won a noble price). The formula is discussed in many textbooks on physics and astronomy, but for a quick overview you can also read this article on Khan academy.

If you want to decrease the level of this chapter, you can create supplementary exercises and split the formulae into separate versions, e.g.

$$c = \lambda f, \qquad \lambda = \frac{c}{f}, \qquad f = \frac{c}{\lambda}$$

Alternatively you could skip the calculations entirely.

Chapter 2: Radio telescopes

In this chapter students will learn what radio telescopes are, how they work and how multiple radio telescopes can collaborate. The key concepts are:

- Radio telescopes collect radio waves. The light is collected in the dish and redirected to the antenna.

- The resolution of a telescope depends on its wavelength and diameter.

- Radio telescopes can work together to improve the resolution.

- The VLA is a Y-shaped array of smaller radio telescopes. It was used for VLASS.

- VLASS is the VLA Sky Survey. It maps a large part of the sky in the radio.

The VLA and VLASS items are key concepts as they relate to the data that will be used in the final exercises and are central to this project. If the lesson kit is used as a more general introduction to radio astronomy, this is of lesser importance. The resolution formula is introduced to explain why multiple radio telescopes can make sharper images when they work together. A brief history of radio astronomy has been added to provide a historical perspective.

Radio telescope puzzle

The radio telescope puzzle shows how primitive single dish radio telescopes were used to obtain images… pixel by pixel. The centre of the source in the puzzle is the red area in the left bottom half. The important part of the exercise is the question that follows after the puzzle:

- *It is hard to see a lot of detail in a small grid like this with only 6 possible strengths. Can you think of ways to obtain a more detailed picture of this radio source?*

Possible answers might include the following points:

- Increasing the possible strengths (This would mean that you divide the strength of the signal into more bins. In this puzzle you would use more colours.)

- Decrease the size of the squares (Increasing the sensitivity of the telescope. The telescope would see a smaller part of the sky if the squares were smaller and would thus need to make more observations to get an image of the same area.)

Questions

The questions at the end of the chapter connect the concepts introduced in the chapter. In the first 3 questions students will discover the impact of aperture synthesis using rough resolution estimates. The 4th question is aimed to let students think both critically and creatively about the design of radio telescopes. The 21cm wavelength is used in the questions because this a famous line in astronomy. (it's fine structure line of hydrogen) A sample question with answer on resolution is provided in the lesson kit to help give meaning to the rather abstract number that is spit out by the formula.

Assume all telescopes in the questions are observing at the 21 centimetre wavelength. 1. The small telescopes of the VLA have dishes with a diameter of 25 meter. What is the resolution of a small telescope? (Hint, use the formula from page 8 and look at the example below) **0.0084**

2. The FAST in China has a dish with a diameter of 500 metres. What is the resolution of this telescope and how does it compare to the telescope in question 1? **0.00042**

3. In configuration B, the effective diameter of the VLA is 11 kilometres. How does the resolution of the VLA compare to the previous two telescopes? **VLA's configuration B resolution is 0.000019. This is 22 times smaller than FAST and 440 times smaller than a single telescope of VLA. VLA can thus see the sky in quite a lot of detail.**

4. If you were to design a new telescope, what would it look like? Would you pick a single dish telescope or make an array of smaller ones? Where would you build it?

Students can come up with telescopes that look like the traditional dish telescope or a more antenna based design. The telescope might be very large or consist of multiple smaller telescopes arranged in a certain shape. The most optimal location for a telescope is a high and dry environment, like a desert in the mountains. But a creative student might consider building a radio telescope in space (This is very expensive…). **Many answers are possible but students should explain their choices.**

Suggestions

To diver deeper into the content of this chapter, it might be fun to explore the ways in which radio telescopes can cooperate. Using complex trigonometry, it is not necessary for telescopes to be arranged in an array or Y shape. Take a look at the largest radio telescope on earth: LOFAR. The LOFAR telescope has stations that consist of antennae instead of classical small single dish telescopes. Using a process called beamforming the signals of the separate antennae are combined. This video explains the process. Click here for an interactive map of LOFAR.

In order to make the content easier, omit the term aperture synthesis (and perhaps the explanation and calculations on resolution) and summarize it as 'radio telescopes can work together to make better images'.

Chapter 3: Astronomical Objects

In this chapter students learn about radio sources, which they might encounter in the VLASS data. In the beginning of the chapter a multiple wavelength image of Andromeda is used to illustrate the significance of multiple wavelength astronomy. The key concepts of the chapter are:

- At each part of the electromagnetic spectrum you will see different features of astronomical objects.

- Hydrogen is the most abundant element in the universe.

- Radio observations can see through dust and observe e.g. clouds of hydrogen at 21cm wavelength.

- Astronomical objects that emit radio waves include: pulsars, supermassive black holes (quasars) and supernova remnants, like planetary nebulae.

This chapter provides a brief explanation on some of the most well-known radio sources. The main aim of the chapter is to encourage students to explore space themselves (using real telescope images).

Task

Go to this site and explore the multi-wavelength view of the universe yourself. The radio images are taken with the VLA. How does the image change when you look at other parts of the spectrum?

This exercise refers to an imaging tool made by the NRAO, as shown on the screenshot below. Students can experiment with the brightness and colour scheme of images taken of the same object but with various sorts of telescopes.

Several objects can be selected. **It is important that students think about the way the image changes when you turn on a different filter.**

Think of experiments or observations you would like to do if you were an astronomer and which telescope would be most suitable.

Once again there are many possible answers. Here is a list of the categories of the spectrum and objects you can observe:

- **Radio (and microwave):** hydrogen clouds, jets from radio galaxies, the cosmic microwave background, pulsars

- **Infrared:** dust, for example the dust in the arms of a spiral galaxy

- **Optical:** Starlight

- **Ultraviolet:** Light from very hot stars and gas clouds

- **X-ray and Gamma ray:** the most energetic events in space, like galactic centres and gamma ray bursts

Extra: Not all light can be observed from earth, a lot is blocked or absorbed by the atmosphere. The picture below shows the atmospheric window. Some experiments your students come with, might thus only be carried out using a telescope in space! It might also be cool to notice that our eyes are sensitive to precisely the tiny short wavelength region that can penetrate through the atmosphere.
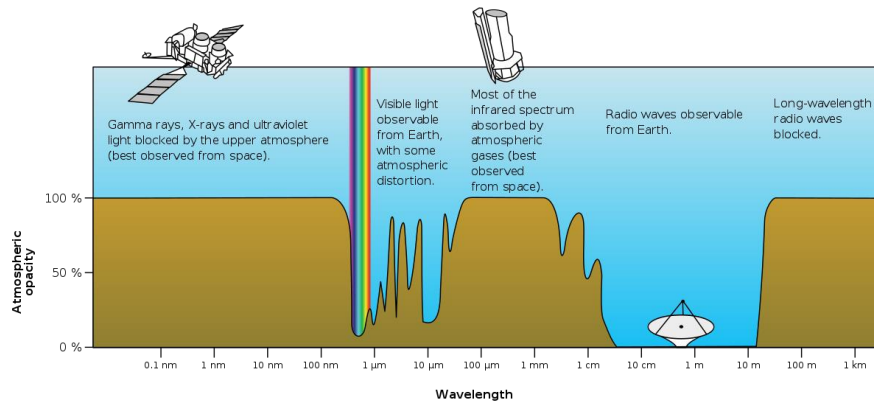
A sample observation might be determining the brightness of a neighbouring galaxy in the optical part of the spectrum. An experiment could be to determine the speed at which an astronomical object moves away from us, using doppler shift. There are many possibilities that are not discussed in the text and may have complex, yet interesting underlying physics. It is, therefore, encouraged that students do some research on possible experiments on the web themselves. Let them, for example, take a look at the science section of the websites of (radio) observatories as source of inspiration.

VLASS Puzzle

This exercise concludes the lesson kit. The first two questions revise the content of this chapter. In the third question students are asked to take a look at real data of VLASS. The fourth question is an open question that serves as a discussion starter.

In chapter 2 you learned about VLASS, the Very Large Array Sky Survey. The first round of observations of the survey has already been completed. Below you will see some of the images taken by VLASS of famous radio sources. 1. What can you see on each picture and why is it visible in the radio?

In the first VLASS picture, we see Jupiter. The two side blobs are due to the magnetic field of Jupiter.

In the second image we see the NGC1128 Dumbbell Galaxy. In the radio it looks like a long line, yet in the optical it appears to be a group of unconnected stars.

In the third image we see a planetary nebula, which is a supernova remnant. The blast is still visible in the radio.
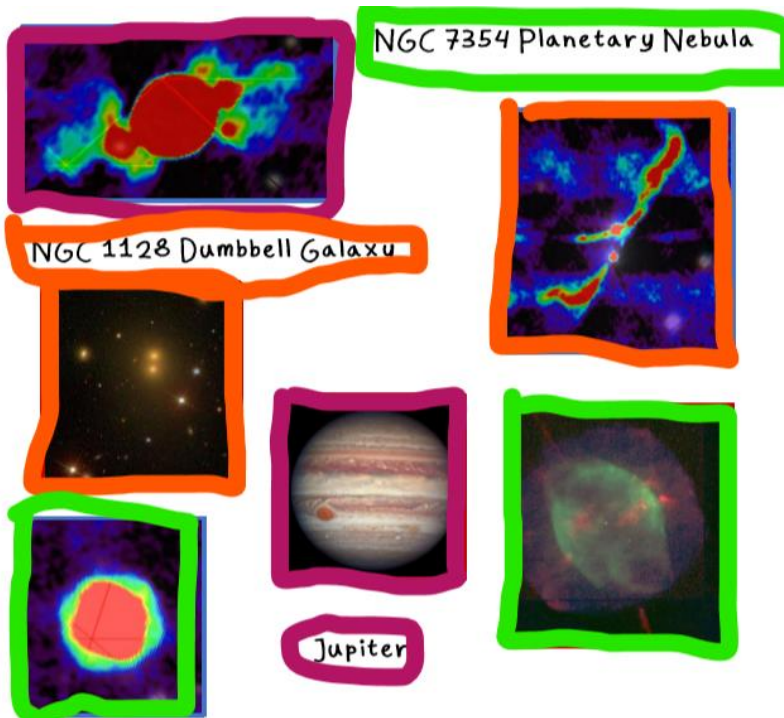
*2. Can you match the radio image with the optical image?*

3. Take a look at this webpage to see the current progress of VLASS. Find a radio source by yourself and use write down the coordinates. Try to find the name of the source using a catalogue. What type of object is it?

Example:

Step 1: Click on the first link. Navigate on the 'globe' of the sky till you encounter a radio source. Hoover across the image with your mouse to see the coordinates. Write them down.

Step 2: Click on the second link and enter the coordinates. Click submit query to view the results.
If many sources pop up, you might want to decrease the radius to, for example, 1 arc minute. If multiple sources appear, try to reason which one is most likely emitting radio waves. In this example we found a match with the Quasar 7C 0059+5808. Quasars are indeed known as radio sources so it's a rather cool discovery.
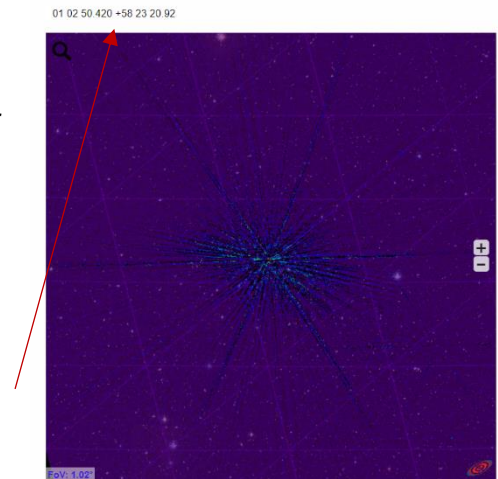
Basic data :

7C 0059+5808 -- Quasar

Distance to the center *arcsec*:	*22.49*
Other object types:	Rad (Ref,2014ApJS..215...14D,...), QSO (Ref,2016A&A...595A...5M,...), gam (1FGL,2FGL,...), Bla (Ref,[MGL2009],...), Bz? (Ref,[SRM2005]), * (Gaia), AGN ([SRC2012b]), IR (WISE), X (Ref)
ICRS coord. *(ep=J2000) :*	01 02 45.76238248 +58 24 11.1366009 (Radio) [0.0411 0.0414 90] A 2015AJ....150...58F
FK4 coord. *(ep=B1950 eq=1950) :*	00 59 43.47184227 +58 08 04.7180034 [0.0411 0.0414 90]
Gal coord. *(ep=J2000) :*	124.41931548718 -04.43594674093 [0.0411 0.0414 90]
Proper motions *mas/yr* :	-0.009 0.099 [0.099 0.116 90] A 2018yCat.1345....0G
Radial velocity / Redshift / cz :	V(km/s) 137862 [~] / z(emission) 0.644 [~] / cz 193066 [~] (Opt) D 2012ApJ...748...49S
Parallaxes *(mas)*:	0.1233 [0.0724] A 2018yCat.1345....0G
Angular size *(arcmin)*:	0.0000110 0.0000055 30 (Rad) D 2010AJ....139.1713C
Fluxes (5) :	B 20.09 [~] D 2006ARep...50..468P
	V 19.22 [~] D 2006ARep...50..468P
	R 18.57 [~] D 2006ARep...50..468P
	G 17.4766 [0.0570] C 2018yCat.1345....0G
	I 17.90 [~] D 2006ARep...50..468P

As this is actual survey data, your students might find a radio source that does not pop up in the catalogue. This might be something new! Before starting a full investigation of this mysterious object, it might be wise to check whether the coordinates have been entered correctly though. VLASS is expected to catalogue over 10 million radio sources, so there are a lot of new sources to explore, and your student might indeed have discovered one.

4. In an earlier radio sky survey, quasars were discovered. Do you think something new will be discovered in VLASS as well? If you were an astronomer what object would you like to encounter in the survey?

One of the most exiting parts of astronomy is that there is a lot going on in space. With every new series of observations new discoveries are made. Scientists might encounter something they had only hypothesised about before or perhaps something entirely new. There is, therefore, quite a chance that new things will pop up in the VLASS data. It will most certainly shed more light on the mysteries of our universe.

Suggestions

To make this last chapter less complicated, you can skip the parts on hydrogen and instead go through the practical exercises step by step. Focus on what students might see on the images rather than why to keep it simple.

To go further than the provided content, you could consider some of the following ideas:

- Link astronomical observations with ground and space based telescopes by explaining about the atmospheric window. Let students do some research on telescopes for a specific part of the spectrum and present their results in class.

- Look into cosmology, the branch of astronomy that looks at the history of our universe. Our universe is quite old, yet at 1.063 mm we can detect a signal from its early childhood. This signal is known as the cosmic microwave background and was accidentally discovered by a radio astronomer. There is a lot of literature available on cosmology and the cosmic microwave background in books as well as online.

Final notes

After completing the three chapters in the lesson kit, your students will have had a brief yet proper introduction to radio astronomy. They should be able to identify the parts of the electromagnetic spectrum, explain the way a radio telescope works and identify several astronomical radio sources.

Radio astronomy, or science in general, is about exploration and about discovering the theory behind phenomena we observe. There are still many unanswered questions in science. Students might ask questions that are not answered yet or require more theory than provided in this introductory lesson kit. In such cases you can do some research on possible answers or have a discussion about it. This may leads to some nice insights and help to develop scientific and critical thinking.

Author's note:

Thanks for trying out this lesson kit. I hope the teacher notes help to adapt the material to your class and that the kit provides a useful introduction to radio astronomy and research conducted in this field.

Survey

In order to evaluate and improve this lesson kit, your input would be appreciated. Both you and your students are invited to take **this survey**. The survey is anonymous and the result will only be used to improve and assess this lesson kit.

You can also access the survey via this QR-code

Computer Lab

This guide helps you to work with VLASS data. First you will learn how to find and open quick look images and how to turn the dataset into a 3D surface plot. Next, you will work with several images of radio sources and create contour lines. At the end of the lab, you will be able to classify a radio source based on the VLASS image.
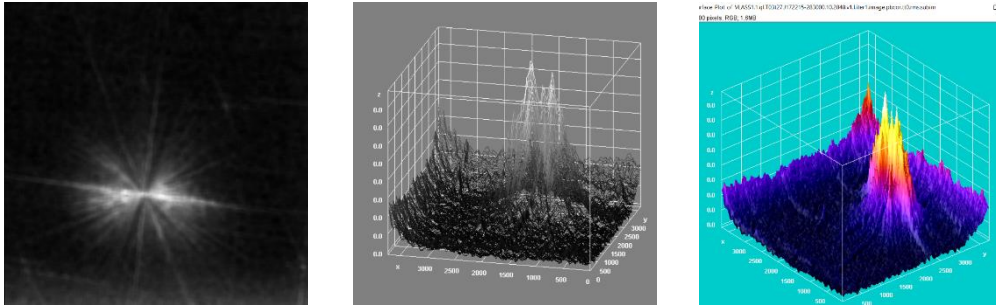
Quick look image VLASS1.1.ql.T03t27.J172215-283000.10.2048.v1.I.iter1.image.pbcor.tt0.rms.subim.fits in 2D, 3D and 3D colour surface plot.

Step 1: Install ImageJ
ImageJ is a program which can open FITS files, like the quick look images, and enables you to further process the data. The program can be downloaded from here. Pick the version suitable for your pc and unzip the program in a folder of your choice. When using Windows, it is recommended to unzip the program in your user folder, e.g. Windows>Users>Username, and not in a directory like 'Documents' or 'Downloads'. Go to the new Fiji.app folder and click on the ImageJ application to start the program.

Step 2: Find the right dataset
VLASS is separated into many tiles, ranging from T01t01 all the way to T32t02. These tiles each cover a small part of the sky. When you know the coordinates of the object or part of the sky you want to observe, you can find the name of the corresponding tile using this list.

Example: The coordinates of the UGC 01797 Galaxy are roughly 02 19 58.680, +01 55 48.59. In the list this corresponds to a declination between 0.00 and 4.00, and a right ascension between 2.00 and 2.67. This is the tile T11t04. The table also tells us that this part of the sky was observed in the first epoch of VLASS, on 30 November in 2017.

Now that you know the name of the tile, you can look for it in this archive. Click on the right epoch, e.g. VLASS1.1, select the tile, e.g. T11t04, and click on the image with the J……±…… combination closest to the coordinates of your source. Using the UGC 01797 Galaxy example, you will end up here.

In this directory, you will see to .fits files, these contain the actual data. One of the .fits files has rms in the name. This stands for root mean squared. This file contains a single image, which is the 'average' of the data from the other fits file, which is a data cube. For now we will work with the rms-file.

Step 3: Make the plot

Open your dataset in ImageJ. You will now see the quick look image. Note that these images have been made by processing the data collected by VLA using a quick but not very accurate algorithm. This results in quite blurry images, in which you can still see plenty of noise, especially around the edges. On the right you can see the content of the rms-.fits-file of the UGC 01797 Galaxy.

Click on the image and select a region. Under the *Analyze* tab, you will find tools to examine the selected region.
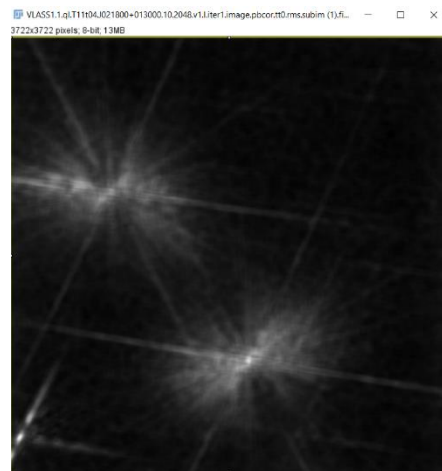
It can be difficult to determine the actual strength of a source with respect to the background when looking at the plain image. Using the *measure* option you can determine the minimum, mean and maximum value of your selected region. In the image below, we find that the signal from the maximum is 3.3 times as strong as the mean value and 5.15 times as strong as the signal from the darkest region. (The E-4 in the example stands for 10^{-4})

Questions:

1. What is the mean strength of the signal in the image you selected?

2. What is the maximum value and where do you think it comes from?

3. Compare the maximum with the mean and the minimum, how much stronger is the signal?

4. Select a smaller region and repeat the measurement, have the values changed? Why (not)?
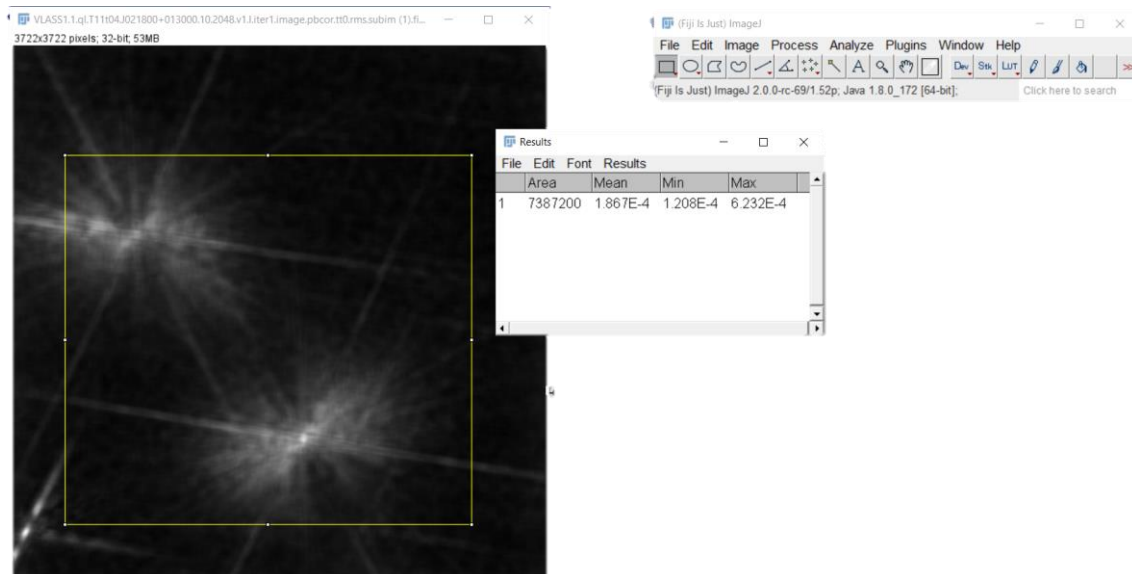
The *measure* option does not tell you the location of the maximum, only its value. By making a surface plot, you can see this much clearer. Click on *surface plot* under *Analyze* and you will see something like this:
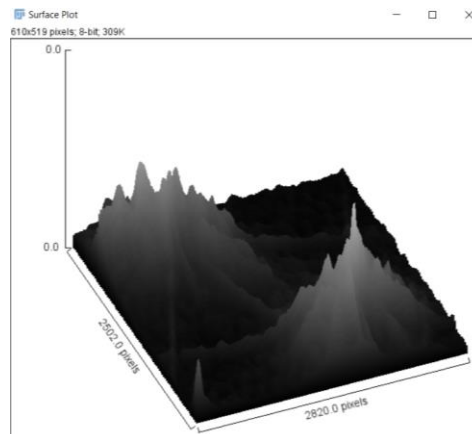
This plot shows the same greyscale data as the 2D image you started with, only now the value of each pixel is also represented as height. By clicking on *3D surface plot*, you will get an interactive and customizable version of this plot.

In the first field you can choose whether the data will be represented by points, lines or filled up. In the next field you can pick a colour map instead of the original grayscale. Using the bars below, you can change the size of the grid, the smoothing, perspective and lighting. The next buttons can be used to change the colour of the background and the lines. Hit the *Save Plot* button when you are satisfied with your plot.
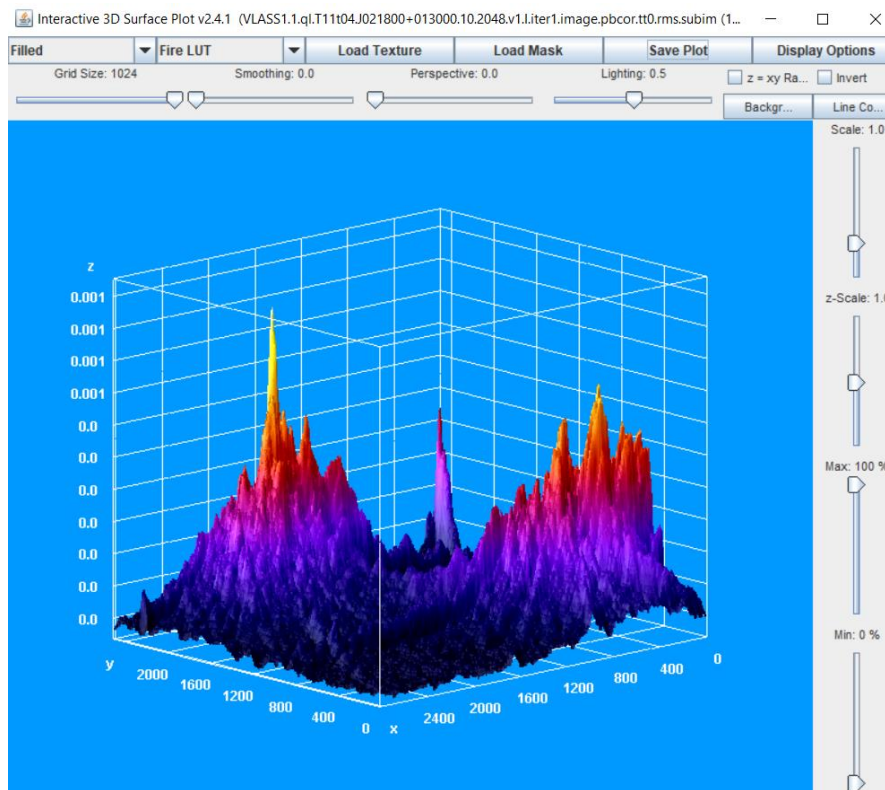
Questions:

1. Make a 3D surface plot of your data set. Where are the maxima?

2. Which pixels contain your radio source?

3. Compare the surface plot to the plain image. Which one do you find the most useful and why?

4. Try out some of the other function of ImageJ to learn more about the dataset. Present your findings to a fellow student.

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Step 4: Contour lines

In this step you will work with a subset of VLASS data, which contains .png images of radio sources. This site provides .png VLASS images which contain radio sources. Download the zip file for tile T14: FIGST14. Radio sources can be classified into two classes based on the position of the brightest regions in the galaxies. To determine the edges of those regions, it is useful to plot contour lines.

A contour lines marks the edges of specific region, for example the region where a mountain is higher than 100 meter, or the region where a galaxy is brighter than a certain value. The image on the right shows the contour map of a mountain. The mountain is 'sliced' into regions with a minimum height by the contour lines. The mountain-like 3D surface plot made in step 3, can also be sliced into regions of specific brightness.
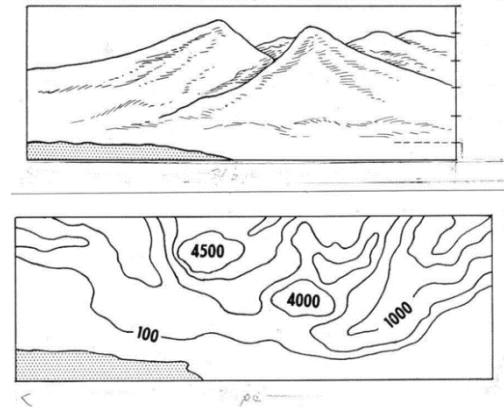
To plot contour lines of a dataset in ImageJ, you have to install a special plugin called Contour Plotter. Contour Plotter can be found here. Download the .jar-file and place it in the plugins directory of the Fiji.app folder. Restart ImageJ and you will see ContourPlotter under the plugins menu.

Open one of the png files in FIGST14, e.g. RA60.637DEC14.234.png, in ImageJ. Select the part of the image that contains the source and click on *Crop* under *Image* to adjust the size. Click on *ContourPlotter* to create contour lines. A menu similar to the one on the right will appear. Choose the values for which you want contour lines based on the given range and mind the noise in the image. If the range is 0 to 255.0, you could for example pick steps of 50 starting at 250.
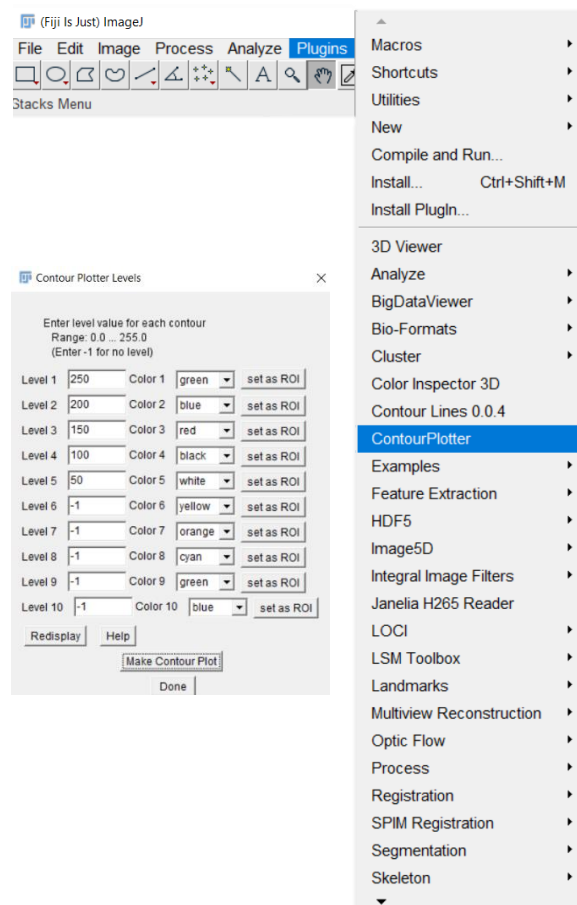
Click on *Make ContourPlot* to see the result. The contour plot menu will remain open until you click done. If the lines are hard to see, you can adjust the colours in the menu or you can zoom in on the image using the option found under

VLASS Computer Lab

Image, Zoom. Keep in mind that the data contains a lot of noise, this disturbs the contours of low values. In the picture below, the cyan contours are greatly affected by the background, whereas the higher value contour lines, e.g. the 150 and 100 line, contain most of the source. The brightest regions of the radio source lie within the 150 contours.
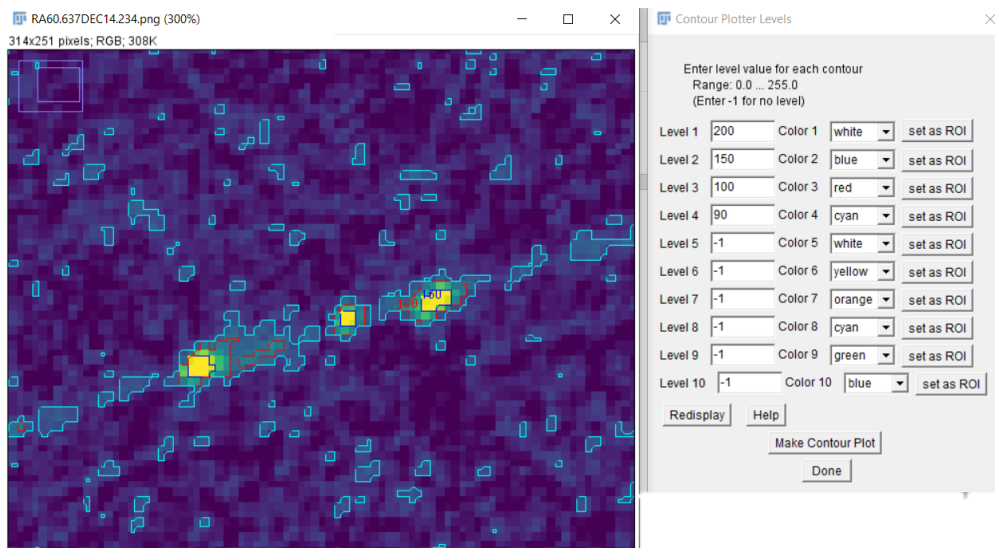

Questions:

1. Open an image from the FIGST14 folder in ImageJ and click on ContourPlotter. What is the range of values of your image?

2. Choose several values within this range and plot the contours. Which lines are clearly visible and which do not appear? Why?

3. Select an area of the image including the radio source and click on Analyze, Measure. What are the minimum and maximum value?

4. Make another contour plot with lines of values between the minimum and maximum value found in question 3. How does this plot differ from the one in question 2? Why?

5. Try to determine the position of the regions with the highest brightness. Are they close together or far apart? Also try to determine the entire size of the source. Where does it merge with the background? At which value do you think there is too much noise?

Step 5: Classify a radio source

This step is where the actual astronomy begins. In 1974, astronomers divided radio sources into class I and class II. This is useful because there is a link between the class of a radio source and its luminosity. Class II radio sources tend to be more powerful than those of class I. The radio sources are classified by looking at the ratio between the distance of its brightest regions and its outer regions. If the ratio is smaller than 0.5, the source is class I. If the ratio is larger, it belongs to class II. In general, a radio source is class I if the low brightness regions are closer to the centre than the high brightness regions and class II if this is the other way around.

$$ratio = \frac{distance_{brightest\ regions}}{distance_{outer\ regions}}$$
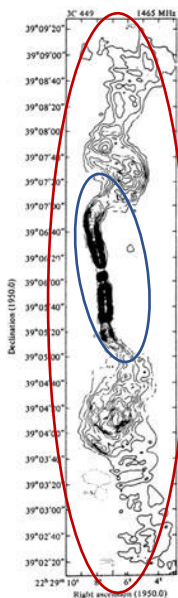
The plot on the left is a VLA map of the galaxy 3C 449, made in 1979. This is a **class I** radio source. The distance between the outer edges of the brightest regions, circled in blue, is less than 2'. The distance between the outer regions of the galaxy, circled in red, is approximately 7'. As $\frac{2}{7} \approx 0.286 < 0.5$, this galaxy belongs to class I.

The picture on the right depicts a source of **class II**. It is a VLA map of the quasar 3C 047. In this picture, the brightest regions are near the outer edges of the source. As both distances are thus nearly the same, the ratio approaches 1, which is much larger than 0.5.

VLASS Computer Lab
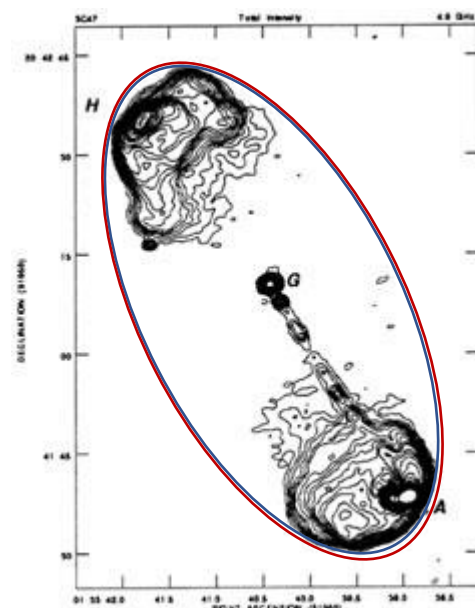
To determine whether a radio source from a VLASS image is class I or class II, you can make a contour plot and measure the distance between the brightest regions and between the source's outer edges. As there is quite some noise in the data, it is difficult to determine the boundaries of the source. The resulting ratio is thus of limited accuracy, but often far enough from the 0.5 to be useful to classify the source.

To find the ratio, you first make a contour plot of the data using the instruction from step 4. The resulting plot will look similar to the red image below. Keep the Contour Plotter menu open and select the line selection tool in the main tool bar. Draw a line from the outer edges of the brightest regions, the black contours in the example, and click on *Analyze, Measure* to measure the length of the line. (blue image) The contour plot might disappear whilst you draw the line, but clicking *Make Contour Plot*, will make it reappear. Draw another line between the outer edges of the radio source and measure its length. (Yellow image) The length of both lines is given in the measurement table.
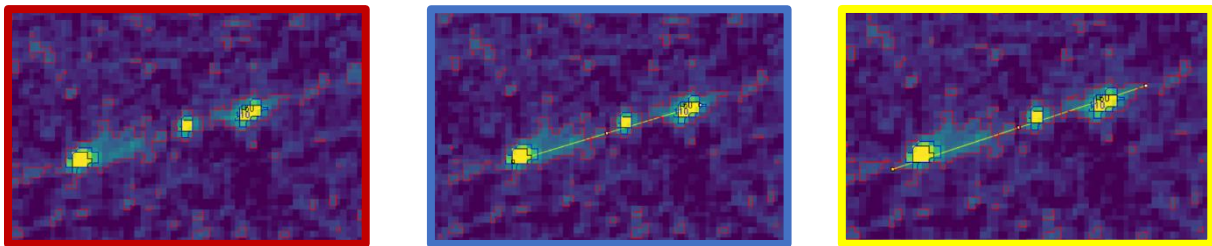
Next, use a calculator to determine the ratio between the two distances. In the example we find the following:

$$ratio = \frac{91.952}{114.580} \approx 0.80$$

As this is larger than 0.5, this is a type 2 radio source.

	Area	Mean	Min	Max	Angle	Length	
1	93	113.490	69.444	173.333	17.057	91.952	
2	116	107.827	69.349	173.333	18.277	114.580	

The right ascension, RA, and declination, DEC, of the source is given in the file name. Using an astronomical catalogue, like the one used in the lesson set, you can look up the source and see whether it has been classified before. You can also find additional information on the source in this google sheet.

Questions:

1. Choose a radio source from the FIGST14 images and determine its class using the method from step 5. What is the ratio? To which class does the source belong?

2. Read off the coordinates from the axes of the image and search for the source in an online catalogue like this one. What is the name of the source? Has it been classified before? If no source pops up, try to reason why.

3. Apart from tile 14, plenty other tiles have already been scanned for sources. Go back to this site and pick an image from another tile. Which class does the source belong to and what are its characteristics?

4. Exchange one of the datasets you used for question 1 or 3 with a classmate. Do you find a similar ratio and classification?
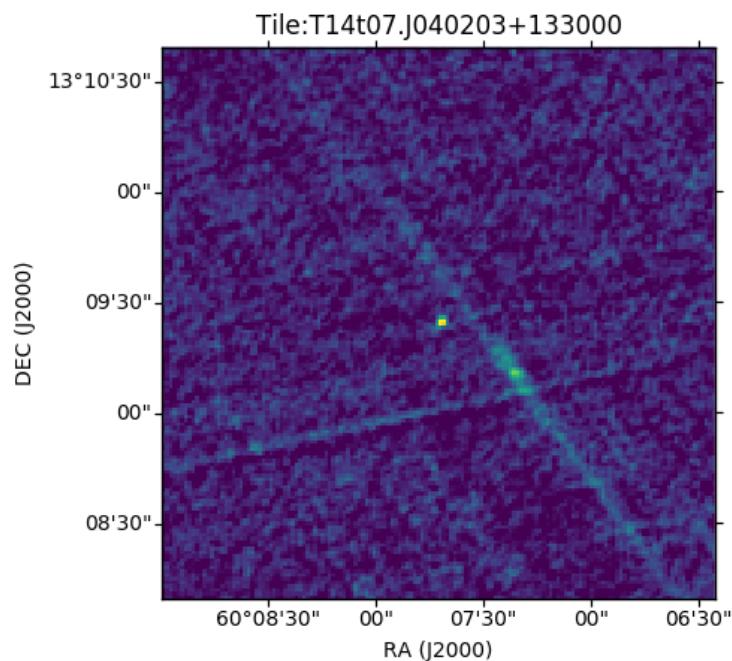
Coordinate Identification Example: above is the data of a part of tile 14 of the first survey round of VLASS. From the horizontal axis we can see that the right ascension is approximately 60°07'30'' and the vertical axis shows the declination is around 13°9'30'', these coordinates are in sexagesimal degrees. This can be entered in the online catalogue as 60d07m30s 13d9m30s. Do note that not all radio sources detected by VLASS are included in the catalogue.

VLASS Lesson Kit Survey

A survey to evalute and improve the VLASS Lesson Kit!

* Vereist

1. I'm a … *

    ◯ Student

    ◯ Teacher

    ◯ [Andere]

2. Have you learned something new from the lesson kit? *

    🔘 Yes

    ◯ No

3. Can you name something you have learned?

    [Voer uw antwoord in]

4. Has the lesson kit helped to increase your understanding about radio astronomy? *

    ◯ Yes

○ No

○ I was already an expert on this topic...

5. The level of the lesson kit was... *

○ too easy

○ slightly too easy

○ just right

○ slightly too tough

○ too tough

6. Please indicate how much you agree with the following statements:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The topic of the lessons was interesting	○	○	○	○	○
The explainations were clear	○	○	○	○	○
The puzzles and exercises were in line with the explainations	○	○	○	○	○
The exercises, puzzles and computerlab were doable	○	○	○	○	○
The exercises, puzzles and computer lab helped me understand the lessons	○	○	○	○	○
The lessons inspired me to learn more about astronomy	○	○	○	○	○

7. What did you like about the lesson kit?

Voer uw antwoord in

8. Do you have any suggestions to improve the lesson kit?

Voer uw antwoord in

9. Do you have any other remarks on the lesson kit or on this survey?

Voer uw antwoord in

Verzenden

Geef nooit uw wachtwoord. Misbruik melden

Deze inhoud is gemaakt door de eigenaar van het formulier. De gegevens die u verzendt, worden verzonden naar de eigenaar van het formulier.

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