Lab report (template & guidance sheet)
version 1.0 - August 2021 - created by David Gruner

Astrophysical Lab Course

Handed in by

Name of student 1	Matriculation number
Name of student 2	######
Name of student 3	######

for the observation

NX – Project Name
Example: N1 – Stellar Spectroscopy

Contents

1 Introduction

As a lab course student, you are asked to write lab reports for the observation you have done. These lab reports have a number of objectives from an educational point of view:

1. You learn scientific writing. This includes a clear presentation of not only your results, but also a description of how you get there, in a way that other people understand your results and conclusions.

2. You learn data analysis as well as scientific interpretation of your results; specifically you learn that the last number you calculate is not the final point of your work on a topic.

3. You learn the technical details on how to write a scientific documents, such as typesetting conventions, proper referencing, and (potentially) working with LaTeX.

This document's contents will guide you with the first two of these points, tailored to the needs of the astrophysical lab course. The fact that you see the layout of this document and we supply you with its original LaTeX code, will help with the third point.

In the beginning, it is difficult to judge which particulars of observations and data analysis need to be included and described in the report. The following sections give an overview of the content that needs to be included in the report. However, we also want to give an estimate for the page count for a report. Even if that might be difficult to quantify. A report, excluding the appendix, should have around $10-12$ pages. It may be shorter or longer, depending on how concise you are able to write. However, a report with only around 5 pages will clearly miss several important points, while a report that exceeds 30 pages will include too many details and repetitions. Hereby, the content should be distributed as follows:

- It starts with an introduction that should not exceed 1 page, but also be longer than 4 sentences.

- The theoretical overview should be at least $3-4$ pages and not exceed 6 pages.

- The details of the observations and the data reduction should also be described in $3-4$ page.

- The analysis of the results fills $2-3$ pages.

- The final point is a discussion of around 1 more page.

- A list of references has to be included. For a report this is short, i.e., generally less than one page.

- A subsequent appendix is not limited in page count and not necessary in all cases.

All these page counts assume reasonable spacing, font sizes, and margins similar to the way it is used in this document. Here, we have used $10\,\mathrm{pt}$ font size and the side margins

$$\text{left} = 1.75\,\mathrm{cm}, \qquad \text{right} = 1.75\,\mathrm{cm}, \qquad \text{top} = 1.5\,\mathrm{cm}, \quad \text{and} \quad \text{bottom} = 2.5\,\mathrm{cm}.$$

The order in which the points above are given is the one you should try to follow as long as there is not a good reason to deviate from it.

While using this document to identify the important points for your own work, also pay attention to the type setting details. Things like referencing to external sources, such as papers and websites, and figures and tables within the text are done in the way it is expected in a scientific document.

It may seem like a lot of effort to follow all the regulations, however, doing so will vastly improve your work and its recognition among its readers. Always have in mind that this report is the first step in learning how to write scientific documents, whose main goal is later to convince your readers that your findings and conclusion are accurate and valid. As a scientist, you will be judged by the quality of your publications, it is a long journey that starts here.

This document provides the typical structure of a lab report as well as of a scientific document. For each section we give a general idea of its content and then have a subsection for each of the lab course observations (N1, N2, and S1/S2) with specific instructions. In appendix C, we give some advice on the practical aspects of report writing and in D, we give an overview of technical details and conventions that apply for scientific documents. Among them are descriptions on how to write references or equations.

2 Theoretical background

This section provides the theoretical background for the readers, in order to allow them to understand the goal of the observation and the content of the report. You iterate scientific knowledge that is the basis for your observation, the results and the derived conclusions. Imagine yourself as a reader who only has basic knowledge of the field you are writing about. Include all the explanations that you deem necessary to be able to understand you final arguments.

A theoretical background section is unique to a lab report (or any other educational writing for that matter). In a peer reviewed scientific paper this part is replaced by an introduction that gives an overview of the past work on the topic of the paper. It usually leads to a motivation why this work had to be done and is interesting.

The contents of the overview in the following subsections are largely identical to the descriptions of the individual observations in the OST Wiki[1].

2.1 Contents for N1

Briefly describe the basics of formation of stellar spectra (absorption line spectra). This includes the interplay of the stellar continuum radiation (explain the concept of black body radiation, and how a star is similar to and different from it) and line absorption in an atom or molecule. Explain why a different temperature changes the outlook of a spectrum.

Give an basic overview of different spectral types with their main characteristics (which lines are visible) and properties (general physical parameter). Outline the concept behind the Doppler shift and radial velocity measurements from spectra. Describe the different velocities that add up to observable velocity of a star (such as Earth's orbiting around the sun).

2.2 Contents for N2

For this experiment, the theoretical overview in the report should describe an open and a globular cluster with emphasis on the type of the cluster you have observed. Describe what makes star cluster different from associations and groups of stars. Briefly explain the concept of Hertzsprung-Russell diagrams (HRD) and the color-magnitude diagrams (CMD) and the difference between them. Shortly describe the evolution of stars of different masses in the context of a HRD. Explain the concepts of isochrones and the turn-off point and how one estimates the age of a cluster using them.

2.3 Contents for S1/S2

Give a short introduction to the Einsteinturm and its instrumentation. Describe how the rotation of the sun is calculated from an observable line shift and the physical background behind it. Mention further geometric corrections that need to be accounted for.

Then describe the basics for the Zeeman effect and how we use it in this experiment with the help of

$$B[\text{T}] = \frac{4\pi m_{\text{e}} c}{e} \cdot \frac{\Delta\lambda}{g\lambda_0^2} = 2.142 \cdot 10^7 \cdot \frac{\Delta\lambda[\text{nm}]}{g\lambda_0^2[\text{nm}^2]} = 2.142 \cdot 10^4 \cdot \frac{\Delta\lambda[\text{pm}]}{g\lambda_0^2[\text{nm}^2]}. \tag{1}$$

This includes a derivation for the Eq. (1). Discuss the importance of the Zeeman splitting for this laboratory course (e.g., which polarization components are visible and which are measured in our observation).

3 Observations and data reduction

In this section, you describe how you got your data. Describe the details of the observations itself, the instruments used, targets observed, etc. This is supplemented by describing the data reduction and processing so that it becomes clear how you obtained the measurements used for drawing scientific conclusions. The data reduction can include things like wavelength calibration (e.g. for N1 and S1/S2), image stacking (e.g., for N2), and a readout method, such as aperture photometry (e.g., for N2).

While writing this section, imagine your data being part of a public archive (which is the case for most data), and that a reader wants to take the same data, process the data in the same way, and end up with the same results. What information do they need to know to reproduce your results? Every correction made, every parameter set in a process has to be listed. Because only then a reader can follow your steps. This transparency is crucial for the credibility of your results and conclusions. Non-reproducible results are mostly worthless.

You do not need to include the most obvious and basic parts of the data reduction. No one needs an example image of a dark-frame or a flat-field unless them being out of the ordinary.

3.1 Contents for N1

Describe how the observations went and the details of the recorded data (targets, exposure times, etc.). For the data reduction, highlight points that deviate from general description in the OST Wiki and list all the parameters you set for the extraction (number of orders, which lines were used for the calibration) and those that result from the reduction, such as the number ThAr lines identified by Midas. Furthermore, include all the plots (order identification, spectral resolution) of the data reduction in the report (a few in the text, most of them in the appendix).

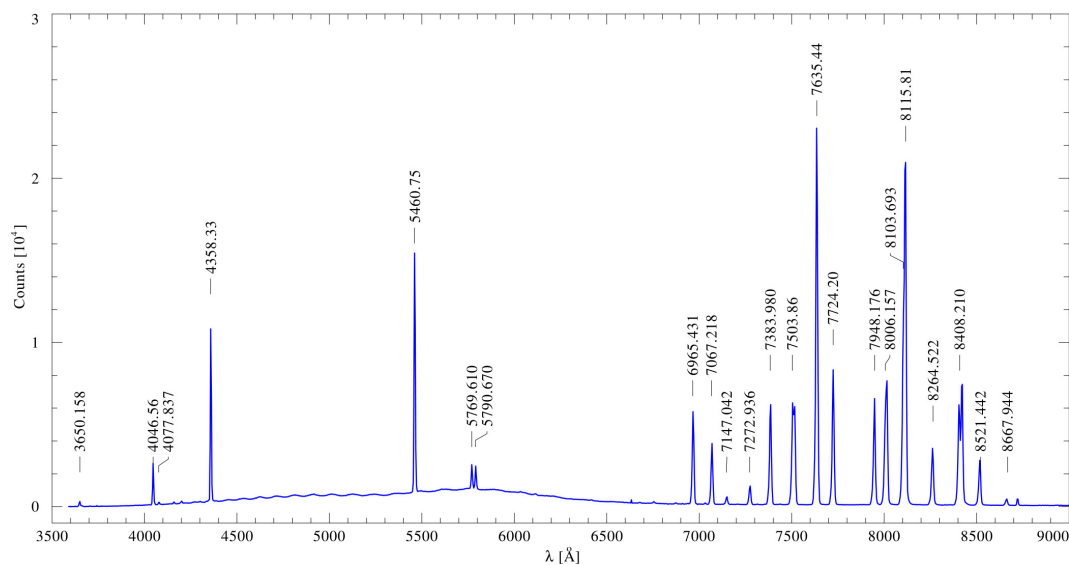[1]`polaris.astro.physik.uni-potsdam.de/wiki/doku.php?id=en:start`

Figure 1: Spectrum of the HgAr calibration lamp with the strongest line features identified. Note that the strength of the individual lines change from exposure to exposure.

If you use Dados spectra for N1, follow the above mentioned instructions, but deviate where the data situation is different. However, you still need to include the figures from the data reduction and wavelength calibration. For the calibration process of Dados, you can use the line identification provided in Fig. 1.

3.2 Contents for N2

In the methods section describe how the observations went and what the data situation is that you start with. Do you have to sort out images? If yes, why? Highlight points that deviate from general description of the data reduction in the OST Wiki, and list all the parameters you set for the process. Latter includes cutting of the image and the new image sizes, as well as the parameters of the `find` routine. Further, include all the plots of the data reduction in the report (a few in the text, most of them in the appendix). Describe the calibration procedure and list the stars (identifiers, magnitudes, colors) you use and the shifts you determine. Provide a copy of your GDL script as part of the appendix.

3.3 Contents for S1/S2

Describe the observations. Highlight points that deviate from general description of the extraction of the spectra, and list all the parameters you set for the extraction (pixel range, shifts, etc.). Perform a wavelength calibration for all images you use and list the parameters (ideally in the shape of a table). Search for an image of the investigated sunspots in the SOHO[2] or SDO[3] archive.

4 Results

In this section the results of your observations after the data reduction are presented. Everything that results immediately from your data and can be scientifically analyzed is shown here. This can be calibrated spectra or values directly read from the data (such as fluxes or magnitudes, or line shifts). This section also includes a description of said results, found features, etc. Simple calculations based on your data are also included in this section.

4.1 Contents for N1

The results part presents and describes the spectra of the stars (a few selected significant orders of each star are sufficient to be shown here, the rest goes into the appendix). It also includes the measurement of the radial velocity of each star from the line shift (including an error estimate) and the barycentric velocity correction for one of them. Do not forget to list the individual lines that you use with their respective rest frame wavelength, line shift, etc.
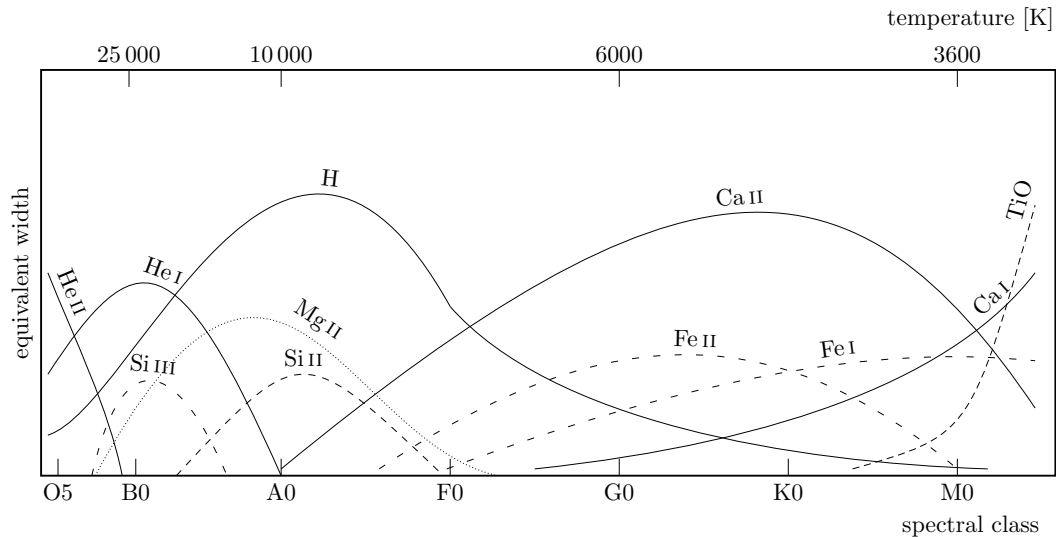
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[2] sohowww.nascom.nasa.gov
[3] sdo.gsfc.nasa.gov

Figure 2: Absorption line equivalent width of selected species for different spectral types. Figure taken from Struve (1959)

4.2 Contents for N2

Present the constructed CMDs for both clusters. This involves a description of the observed features of the cluster's CMDs. Typical cluster features to look for are the main sequence, turn-off point, giant branch, red clump, and blue stragglers. Identify stars that are likely unaffiliated with the cluster (fore- and background stars). Look up a literature information on the cluster distances and reddening. Apply both to the clusters to create a CMD in absolute brightness and intrinsic colors.

4.3 Contents for S1/S2

The results part presents the extracted solar spectra. It also includes the measurement of the radial velocity shift and the line splitting. Do not forget to list the individual lines that you use with their respective rest frame wavelength, line shift, etc.

5 Analysis

The analysis part of a report includes extensive derivations and calculations based on the data and the final scientific results and conclusions. This includes modeling, fitting, and the application to physical concepts. Often, the distinction between the analysis and result sections can be blurry and a rearrangement might be in order.

5.1 Contents for N1

The analysis of the spectra should lead to the the spectral classification of your target stars based on the characteristics that you have described in the theoretical background section. Begin with an estimate whether the star is hot (O, B, A, F – spectral type) or cool (G, K, M – spectral type). Continue to narrow down the spectral type to one class based on individual criteria from Sect. 2.1. Finally, use the provided spectral atlas in the OST Wiki to try to determine a the Luminosity class. Figure 2 can help with a first estimate of the spectral type. List which characteristics you use for each spectrum. That includes indications for, but also against, specific spectral types. This Website that may help with the identification of the spectral type.

5.2 Contents for N2

Obtain one (or more) set of isochrones and give a short description of them (what evolutionary phases do they cover, for what metalicity are they calculated?). Fit those isochrones to your calibrated, distance-corrected, and dereddenend cluster CMDs to estimate the ages of the clusters. Describe the quality of the fit and potential shortcomings. Calculate the cluster age based on the turn-off point in the cluster CMD.

5.3 Contents for S1/S2

Calculate the solar rotation period from the obtained line shifts and radial velocities. The strength of the magnetic field should be obtained from the measured line splitting via Eq. (1). For both calculation, think about potential effects of the geometry based on the miss-alignment between the sun's and earth's rotation axis. on the obtained values. See Fig. 3 for a visualization

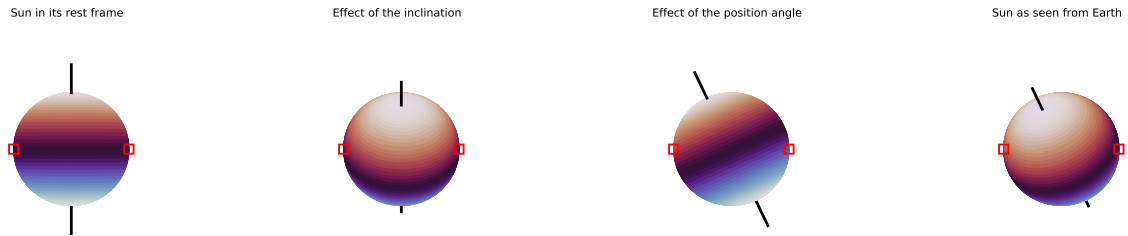Sun in its rest frame   Effect of the inclination   Effect of the position angle   Sun as seen from Earth

Figure 3: Schematic illustration of the Sun as seen from earth and the geometric effects that occur due to the miss-alignment between the rotation axis of earth and sun. The left panel shows the sun in its own reference frame. The two middle panels show the effect of the inclination (along the line of sight) and position angle (in the sky plane) each. The right panel shows a general view of how the sun appears from earth owing to those two effects. Indicated are the western and eastern limb of the sun as seen from earth (red boxes) where the spectra are taken. Geographic north is towards the top in all panels. Note that the inclination and position angles are shown in an exaggerated fashion.

of the effects. Search for solar ephemerides (tilt, inclination) calculate a geometric correction based on them. Classify the sunspot following the Waldmeier (Zurich) scheme based on the obtain image.

6 Discussion

The discussion is the part that places the results and the outcome of the analysis back into the larger physical context. This means, they are viewed under the light of the original goal of the observation. They are compared to previous results of similar work and the expectations with which the experiment had started. Deviations from expectations are investigated for the potential origins and sources of errors identified. The impact of other effects is taken into account and at least qualitatively discussed. Furthermore, the discussion brings arguments on the impact the findings have on the greater fields and the limitations and boundaries to it.

A discussion is often followed by a *Conclusions* section that summarizes the work and highlights the main findings and outcomes from the analysis and the discussion in a concise form. It can be part of a report, but is no required.

6.1 Contents for N1

Describe your results into the larger context of stellar spectroscopy. Be critical towards your own results. What difficulties and limitations did you encounter in classifying the spectrum of your target? Are there inconsistencies? Do you see specific and obvious features in the spectra you cannot explain? Are the values you retrieved reasonable, such as the radial velocities? Are there reoccurring features in all stars? If yes, what are they?

6.2 Contents for N2

Compare the found cluster ages to each other and to literature results. Do they match? If not, what could be a reason that they don't? How could one fix this? This also includes that you identify potential problems with the data, the data reduction, or the analysis (especially the isochrone fit) and think of possible solutions for them. Are their inconsistencies? Do you see specific and obvious features in the CMD you cannot explain, that do not match your expectations?

6.3 Contents for S1/S2

Bring your results into a larger context and make a literature comparison to known solar rotation period and typical magnetic field strength in sun spots. Are your results plausible? This also includes that you identify potential problems with the data, the data reduction, or the analysis and possible solutions for them. Are there inconsistencies? Do your resulting period and field strength match your expectations? If not, what are potential reason for that? https://astropixels.com/ephemeris/sun/sunkey.html

7 Conclusions

For a report, you may or may not finish your writing with a conclusion section that **briefly** summarizes what the previous text was about. It also includes a final highlighting of the main outcomes of your work described here.

References

Hawking, S. W. & Penrose, R. 1970, Proceedings of the Royal Society of London Series A, 314, 529

Hubble, E. 1929, Proceedings of the National Academy of Science, 15, 168

Lemaître, G. 1927, Annales de la Société Scientifique de Bruxelles, 47, 49

Riess, A. G., Filippenko, A. V., Challis, P., et al. 1998, AJ, 116, 1009

Struve, O. 1959, Elementary astronomy

A   The content of this template package

This pdf comes together with a number of zipped files to be used for report writing if you are to use LaTeX:

- `lab_report.tex` is the source file for this document you are reading right now.

- `lab_report_empty.tex` is a tex source file that is cleaned and can be used as a starting point for your report writing.

- `bibliography.bib` includes the bibtex entries for the references used.

- `aa.bst` is a bibtex stylefile that provides the citation layout used in astronomy.

- `bibdefinitions.tex` is supplementary file used for the bibtex processing.

B   Content of an appendix

The appendix contains all the information that need to be included, but whose presence in the main text body would disrupt the flow and overload the pages. For N1 for example, the data reduction produces dozens of individual plots of each spectral order for each star. Including them in the main text body would only create chaos and confusion, however, the full spectrum needs to be available to the reader. But, the discussion does need the spectra to support the assignment of specific spectral type to an individual star. The solution is to put all the spectral orders in the appendix and only have a few ones in the main text which are significant for the determination of the spectral type.

C   Tips for report writing

- It can be exhausting writing on a lengthy text over time. One gets blind for their own mistakes over time, things that made sense in your head may not when they are on paper. Leverage that you write this as a group, proof read each others contributions. Also, put the text to rest for one or two days and reread it to identify problems with the structure or wording, and find repetitions or gaps to be filled in the text.

- When thinking about what to include in your report as information, act according to this principle: what does someone need to know to understand your findings and the way you reach there? Which information do they need to be able to retrace your steps with your data to reproduce your results?

- Do not assume that every text, every sentence you write is going to stay the way it is. That means, do not try to be perfect with a newly crafted text, it is unnecessary effort. Text fragments will change their position in the text, sentences might get added that merit a later change, and some sentences might be erased entirely. First think about the content, fill the pages with bullet points rather then fully formulated sentences. Then you iterate on those, you change the order to create a flow of thought and have a logical and consistent structure. And when you are happy with it, then you can start to formulate sentences because now you know what comes before and after it.

- Use your own words to describe things. Please be aware that the supervisors (which will evaluate your report) already read dozens of other reports. Hence, they will immediately recognize whether you have copied text from e.g. the Internet, which is considered to be a plagiarism and which will result in an immediate disqualification.

- Do not overuse highlighting and emphasis of words or even full sentences in the text. The more you use it, the more individual highlight lose their meaning. Generally, try to avoid highlighting in the first place.

D   Technical details on scientific writing

In this section, we give some general advice on how to compose scientific document from a technical perspective. This includes, among others, typical writing conventions, referencing, and layout questions.

D.1   How to use structure text correctly

The layout of a report is generally not predetermined. For papers and other documents you will write later on, it very often is. However, independently of you getting a template to fill, there are certain rules regarding the layout of the text you fill it with. A few important ones are summarized here:

- No two headlines should follow each other immediately. This means avoid situations like

    2 Theoretical background

    2.1 The Sun

  Always have a short introduction to each (sub)section to tell the reader the intend of it. For example:

    2 Theoretical background

    In this section, we present the theoretical background needed to understand this report.

    We start with introducing the important properties of the sun.

    2.1 The Sun

- If you use subsections, always have more than one subsection to a superior section. If you only would create one, don't create one at all. This means avoid this

    2 Theoretical background

    2.1 The Sun

    3 Observations

  and instead use either

    2 Theoretical background

    2.1 The Einsteinturm

    2.2 The Sun

    3 Observations

  or none at all. The reasoning here is the following. If you want to create only one subsection to a section, why would you do that? Either the one subsection is the majority of the section, and as such it should be upgraded to a section. Or it is not the majority of the section and with that the rest should be worth a subsection itself.

- Think about how you use line breaks and paragraphs. They are the smallest structuring unit of a text. Think of each paragraph as one consecutive thought and you begin the new one with the next/a follow-up thought.

- Lots of terms in astronomy are used with an abbreviations or as an acronym. Independently on how popular and well known such a shorthand for something is, if you are going to to use it. You have to introduce it to the reader when you use it first. This introduction takes the following form:

    "The observations were taken with the Cosmic Origins Spectrograph (COS)
    on board the Hubble Space Telescope (HST)."

  and is done on its first occurrence in the text. Afterwards you can use the short form freely.

D.2   How to write equations, numbers and variables

There are some rules on how equations, numbers, and units are written in a scientific document. When one uses the LaTeX math mode, they are already applied. The math mode is more than only *italicize* the text.

- Math mode introduces spacing between operators and removes the joining of letters to highlight that they are individual variables. For example in text one writes "fl" where the f and l are clearly close together. This is normal for most typesetting and the case for many letter combinations (e.g., "wo", "wev"). However, in mathmode they are separated because they do not belong together: fl, wev. This also highlights the difference to italic writing as *fl*. Math mode also introduces a spacing to operators, compare for example the three different writings for a simple equation

$$a = b \text{ (based on \$a=b\$)} \qquad \text{a=b} \qquad \text{a = b (with artificial spaces).}$$

All these introduced spaces make it easier to read an equation and to understand its contents.

- Numbers and variables are always written in math mode: x is the variable, x is only a letter.

- Mathematical functions, operators and units are never in math mode. LaTeX does this for know operators automatically ($+ = / - ()\pm$ etc.) when they are typed in normal math mode. However, as one can see, they are slightly enlarged to increase their visibility.

- Physical units (m, kg, min, etc.) are never in math mode. It's $25\,\mathrm{kg}$, not $25kg$. Note that math mode has no impact on numbers.

- There is always a *thin space* between number and unit. A thin space is made with `\,`.

- Constants and parameters (e.g, speed of light, mass, radius, velocity) are always in math mode as c, M, R, and v (and not c, M, R, and v).

- To accomplish the writing of an equation that contains units (like for example in Eq. (1)) in the correct way, one needs to exclude the unit from the math mode. This can be easy when its just a single value (e.g., 25 kg, made from `$25$\,kg`), but can be more complicated when it's buried deep within an equation. Here one can use `\mathrm{}` or `\text{}` to exclude the units within math mode, such as in $9.81\frac{\mathrm{m}}{\mathrm{s}^2}$.

D.3 How to reference correctly

As soon as you adopt the results or conclusions of other people's work, or even just summarize what they did you achieve something, you have give credit to their work. This is generally done with citations. This means you state something as a fact and combine that with the reference to the work of those who discovered/described the fact. In Astronomy, we use the method that identifies a scientific paper/book/talk with its authors name and year of publication. This is provided next to the relevant statement in the text. A detailed listing with the exact publication (date, journal name, book name, page ref., etc.) is then given in the *References* section at the end of the text.

In the text, a reference appears for example in the form Hubble (1929) together with a corresponding entry in the *References* section:

Hubble, E. 1929, Proceedings of the National Academy of Science, 15, 168

In LaTeX, you can use the advantages of *bibtex* to have those managed in an easy way. Its complexity is too much to be included here. However, there are good tutorials[4] on the web that can be used as a starting point. The appearance of a citation in the text and in the appendix are determined by the used bibtex style. Together with the LaTeX code of this document we ship a file named *aa.bst* created by the journal *Astronomy and Astrophysics* (A&A)[5] that includes the right formatting.

If you are writing references by hand, follow the following rules:

- Hubble (1929) if it is one author.

- Hawking & Penrose (1970) if it written by two authors.

- Riess et al. (1998) if it is from more than two authors.

The way those are written are meant for them to be used as a part of a sentence, such as

For a long time, we attributed the discovery of the expansion of the universe to Hubble (1929).

But you can also use a reference as an addition in paranthesis:

But today we know that at least one more person had similar discoveries earlier (i.e., Lemaître 1927).

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[4]e.g., `latex-tutorial.com/tutorials/bibtex/`
[5]obtained from `www.aanda.org/for-authors`