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RESEARCH ARTICLE

Writing Scientific Papers in Astronomy

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Abstract

Writing is a vital component of a modern career in astronomical research. Very few researchers, however, receive any training in how to produce high-quality written work in an efficient manner. We present a step-by-step guide to writing in astronomy. We concentrate on how to write scientific papers, and address various aspects including how to crystallise the ideas that underlie the research project, and how the paper is constructed considering the audience and the chosen journal. We also describe a number of grammar and spelling issues that often cause trouble to writers, including some that are particularly hard to master for non-native English speakers. This paper is aimed primarily at Master's and PhD level students who are presented with the daunting task of writing their first scientific paper, but more senior researchers or writing instructors may well find the ideas presented here useful.

Key words: Science writing; publishing

1 Introduction

Writing papers is key to sharing your research results and advancing your career. Yet most scientists, including astronomers, never receive much training in academic writing. They may consider that writing is not important, or chose a career in the sciences to avoid a focus on language and writing skills. To complicate matters, many astronomers are not native speakers of English, so writing a research paper may become a real struggle.

There are numerous books and papers to provide guidance to young writers. Several examples, mainly focussed on biomedical and engineering research, are Ashby (2005), Sterk and Rabe (2008), the Clinical Chemistry Guide to Scientific Writing[1], or G. Gopen and J. Swan's The Science of Scientific Writing[2]. Saramäki (2018) and the related series of blog posts[3] provide many tips for writing papers as well as Master's and PhD theses, though more specific to the field of computer science. These publications cover the whole writing process from planning the paper to final editing and polishing, but do not completely meet the needs of astronomy students. Resources focussed on astronomy include a series of book chapters, unfortunately not freely available, covering in great detail the writing process, graphics, and ethics (Sterken, 2011a,b,c), and a recent handbook aimed at undergraduate and graduate students (Stevance, 2021).

1 https://www.aacc.org/science-and-research/clinical-chemistry/clinical-chemistry%C2%A0guide-to-scientific-writing
2 https://www.americanscientist.org/blog/the-long-view/the-science-of-scientific-writing
3 https://jarisaramaki.fi/

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The main objective of the current paper is to provide concise guidelines for scientific writing in astronomy for beginners all over the world, published under open access. Our target audience consists of Master's and PhD students, but the material may also be of interest to astronomers who are more experienced writers, or to writing instructors. The information here is based on writing classes given to graduate students by JHK and DB, as well as on the experiences of a young writer (NC).

In this paper, we first describe various aspects of getting ready to write your paper, including how you can convince yourself to put words on paper, and where and how we publish papers in astronomy. We then discuss how the various sections and parts of a paper can collectively bring your message across. We conclude by giving a series of hands-on tips on how to write in correct English, specifically highlighting astronomy-related examples.

2 Developing the Idea: From Thinking to Paper Outline

2.1 Think Before you Write

Before students write their first paper, they may be asked to write a summary or abstract of their research project for departmental reports or submission to a scientific conference. In the experience of NC, writing an abstract for a conference was one of the very first encounters she had with a scientific writing assignment as a graduate student. However, what she wrote about in her first draft was a summary of the methodology she was developing for her project (as that is what she spent her days working on) rather than the main scientific question her project was meant to address and what preliminary result was expected or achieved thus far in the analysis. She was absolutely surprised when one of her thesis advisors returned a completely different abstract as commentary on her draft, which made her think to herself, 'Oh is *that* the whole point my project?!' This is one of many experiences that has led us and other writers (e.g. Sterk and Rabe, 2008) to identify the first golden rule on scientific writing: *think before you write*.

For instance, to write the Introduction section of a paper (Sect. 5.5), you require knowledge of the literature, a recognition of the primary and secondary sources needed to place your project in the astrophysical context, the gap in the literature that your project aims to fill and how the content in the paper is an important step towards filling this gap (e.g. Is it a new, efficient method? Have you acquired higher-quality data on an astronomical source?). Collecting all these resources to place your project in the broader context of the field is 'thinking before writing'. Of course, the thinking needed for each section of the paper will be different and may require feedback from co-authors (consider for example how you think about the interpretation of your results for the discussion section; Sect. 5.8).

When gathering background resources, students also need to read and think critically. Critical reading, thinking and writing are academic practices that many astronomy students may not be familiar with or have never encountered during their education as not all programmes offer such courses. To these readers, it is important to understand that to be critical of an idea or paper does not necessarily mean to be negative. The Oxford Learner's Dictionaries[4] defines critical also as '*involving making fair, careful judgments about the good and bad qualities of someone or something*'; in other words, to evaluate the validity of an idea and question when it may or may not hold true. Obviously, readers can be critical about an idea only if they have sufficient knowledge[5] or expertise about the subject in question. Even more problematic is that many first year PhD students struggle to read scientific papers. This is not only because the style of scientific writing is very different from novels or popular articles, but very few scientific papers are written well enough for non-experts or students to follow them easily.

We suggest a number of useful tips that new writers in astronomy may find helpful when reading the literature. These guidelines are adapted to astronomy from Wallace and Wray (2021, mainly Chapter 4) and may help students skim through papers in an efficient manner to identify which articles could be most relevant to their field of study.

i. Think about why you are reading this paper. Are you looking for an answer to a specific research question? Or evidence to support an assumption used in your study? Write down a list of questions or expectations for your literature review even before you start reading papers.
ii. Why did the authors write this paper? Read the title and abstract first—do they raise more questions than answers to your initial questions? This is completely normal as authors cannot include all the information in a title and abstract. Annotating the abstract as you read it could help you highlight which sections of the paper would be most relevant to your study and determine whether you need to skim through the introduction to determine the main aim of the paper.
iii. Study the figures of the paper and read the captions—what story do they tell you?
iv. What are the main conclusions of the paper? In astronomy, the main claims of the authors can usually be found in the conclusions section. Are these claims warranted by the evidence presented in the figures? If not, why not?
v. Finally, what use is this paper to you? Go back to point 1 and think about how this paper could be a resource to your own work—does the paper require an in-depth reading?

2.2 Use your own Thinking Style

Some people think primarily in pictures, while others think primarily in words (Nishimura et al., 2015). Over many years of teaching we have seen that some people need to draw pictures and diagrams to explain a point—these are visual thinkers. When visual thinkers pick up a new publication, they look first at the figures and graphs. Other people tend to talk through problems, and may like to write words and text to think things through. These verbal thinkers pick up a new publication and start reading the text to learn what the paper is about. We have had students who think in terms of graphs, perhaps a variation on thinking in pictures, and others that tended to focus on sounds, colours, or moving processes (the latter are really good at solving a Rubik's cube). Yet others may immediately see the solution to maths problems but cannot easily verbalise why.

So what does thinking style have to do with writing? Understanding how you and your co-authors think may help you in planning your paper. People who think in pictures may like to plan the paper with flow charts, colours, and arrows—later turning these images into words (Ashby, 2005). On the other hand verbal thinkers may prefer making a classical outline or using bullet points to plan the paper. Understanding that your colleagues may have a different thinking style may help avoid conflicts in writing. If for example your supervisor says you must begin by making an outline, but that does not work for you, then

4 https://www.oxfordlearnersdictionaries.com/definition/american_english/critical

5 But what does it mean to have knowledge on a subject? It turns out that this is a major philosophical question (e.g. Chrisman et al., 2016, Chapter 2), so do not worry!

explain that you work better with coloured flow charts or perhaps make your flow chart and use that as a step in developing an outline that your supervisor and co-authors can understand.

2.3 Learning to Write

Construct your paper carefully, as if producing a painting by starting out with a rough sketch and then filling in the details. Do not start off by sitting down with a blank sheet of paper or newly opened file, and pretend you will simply start writing at the beginning and keep writing until the end. Even the best writers find this almost impossible to do.

The following would be our idea of writing a paper, from start to submission:

- The single most important item to consider before you even start writing is to define the message you want to convey to the reader, and what story you want to tell. Define that clearly, and writing will become possible. Fail to define that and you will struggle.
- Second, draft the title and abstract of your paper.
- Third, on a blank sheet of paper, or a whiteboard, or in a computer file, brainstorm and sketch out how your paper will look. As we discussed in Sect. 2.2, your personal preference will steer you towards creating an outline with words, pictures, or colours.
- Fourth, define your sections and subsections and then add the key figures and tables that you want to include in the right place. Draft the captions.
- Fifth, add paragraphs, identified by their contents and by what you need to say.
- Sixth, fill in the paragraphs and (sub)sections with a very rough and quickly written first draft of the text. You may want to start with the easiest sections (usually sample, data, methods) and leave the hardest for later (discussion).
- Seventh, edit.
- Eighth, edit more.
- Ninth, tenth, ...etc. More and more and more editing and polishing (including incorporating comments from others). Don't be afraid to delete!
- Last and extremely important step: decide that enough is enough, or run up against a deadline, and submit your paper.

Start each bit of your paper like a Sister Sledge song: start off with the main message. Start each section and subsection with a sentence on what you are going to write and why, then write it, and sometimes you can even end it with a concluding sentence summarizing what you just wrote.

Very rarely does a writer write the perfect text in a first draft. Often the most productive writers write very quick and sloppy first drafts, and then edit and edit and edit. *Usually a deadline rather than having reached perfection determines when your paper is finished.* If you are not sure about a fact or figure, do not let this slow down the writing. Just make a note to yourself to add the missing bit of information later.

Always ask others to read your work before you submit it. Do not wait until you have a perfect near-final version, but share early drafts to collect early feedback. Apart from your co-authors, you can ask supervisors, or colleagues, or friends, or family members to read your draft. If you are unsure about a certain aspect, ask them explicitly to check that (spelling, grammar, maths, literature completeness, etc.).

3 Choice of Journal and Submission Process

3.1 Where to Submit?

You may be invited to submit a research paper, for instance to include in the proceedings of a conference you have attended, or to contribute an invited paper. If you are not invited, however, you and your co-authors will need to decide where to submit your manuscript. Some general guidelines to help you are as follows.

- Consider the field, scope and readership of the journal, making sure your paper 'fits'.
- Check the author's instructions of 'your' journal to make sure you can submit your paper.
- For your career development, refereed professional journals are best.
- Impact is important: a well-known 'famous' journal is better than less-known ones (see Box 1, below, for impact factor).
- Aim as high as is reasonable. For astronomy research papers, this means a small list of 'main' journals which include the Monthly Notices of the Royal Astronomical Society (MNRAS), Astronomy & Astrophysics (A&A), the Astrophysical Journal (ApJ), the Astronomical Journal (AJ), Icarus, and Nature Astronomy. Many of these journals will ask you to pay page charges, but you can request that they be waived if you have no funds. Do ask before submitting your manuscript, not after it has been refereed!
- Do not decide *a priori* that a certain journal will not accept your paper. Let the editor and referee accept at such a decision. Ask advice from more experienced researchers before submitting your paper if you are not sure.
- There are many other refereed journals, including open-access ones, but most do not have the same impact as the main journals and may not make the same impression on your CV. Many are commercial so check any costs before agreeing to publish. Some journals are even considered 'predatory' (Eriksson and Helgesson, 2017).[6]
- Once you and your co-authors have made a choice, follow the author's instructions to produce your manuscript for submission.
- If a paper is rejected, analyse why (ask your co-authors or other colleagues with more experience) and if you do not agree with the decision consider submitting a revised version of your paper to the same journal, or to another journal.

6 We know of a case where a research group had submitted to a real journal, then received a message from a predatory one with a similar name, and almost got tricked into sending their final version to the wrong place.

Box 1: On Impact Factors and Citations
Journals have impact factors, but the impact of individual researchers or papers is measured through citations.
A journal's impact factor is the yearly average number of citations of articles published in the journal in the last two years. For journals like Nature it is very high (over 40) but due to a few very highly cited papers, often in other fields (mainly in the life sciences). For the main astronomy journals it is of order 5. For smaller journals, at or below 1.
You can count the number of citations to any given paper (also provided by the Astrophysics Data System, ADS[7]). For an individual researcher, you can count the total number of citations, or those to first-author papers, or the number of well-cited papers (the *h*-index is the number of papers, *x*, with more than *x* citations). ADS provides all this information and more. Remember that total citations are often driven by papers with many authors, and that the *h*-index tends to increase with the age of the scientist.

3.2 Co-author Complications

Single-author papers are rare in modern astronomical research. The first author is often the person who has done most of the work, by some integrated measurement. In large collaborations, author lists are sometimes alphabetical and the person who can claim most authorship may in that case be identified as 'corresponding author'. In many fields the last position in an author list is an honorary one, often given to a key senior colleague. In astronomy, however, this person would be second or third in the list. As evaluations for jobs, promotions, grant competitions, etc. normally consider first positions on an author list (and second and third to some extent), it is important that you explain in your CV or application materials what your role has been if you were not first (2nd, 3rd) author—and that you ask your referees to confirm this in their letters.

Co-authors are typically those who made substantial contributions to a paper. They can include colleagues who had the original idea or developed the instrumentation or code, or put the funding in place. People who only were on, e.g., the observing proposal or provided limited assistance during an observing run typically are acknowledged rather than made co-author. Co-authorships are sometimes offered to students by researchers outside their supervisory team, for instance where the student has in some way contributed to the paper, or forms part of a larger collaboration.

When writing your own paper, and as there are no accepted rules for who will become a co-author, as a junior scientist you should not unilaterally remove prospective co-authors unless you particularly fancy interpersonal conflict. If you have doubts, ask a senior colleague for advice. Many papers have co-authors who have done little, and who probably should merely have been acknowledged. On the other hand, people may have made key contributions to a project at an earlier stage, which are not visible to latecomers but remain vital. As it is such a grey area and people may hold strong views, it is best to accept as a fact of life that every now and then a person becomes your co-author who you would personally not have given that much glory.

3.3 On Names and Numbers

It is a good idea to consider how you want to be known in the scientific world before you submit your first paper. Names are much affected by local culture. For instance, Chinese nationals and many others start their name with what in English would be the last name, followed by their first (or given, or fore-) name(s). In Spain and other countries, people have two last names, their father's (first) last name traditionally followed by their mother's. In Portugal, two last names are also used, but the mother's traditionally comes first. If you have more than one first name, or a middle name, you may wish to add the name, or its first initial (as current author JHK does). Americans sometimes wish to maintain 'the third' or other annotations as part of their name. Some female scientists prefer to sign with initials rather than first names so they are not immediately identified as female (current authors NC and DB do not). In some regions, people only have one name (they are *mononymous*) and not all editors and publishers are ready to accept this.

You should consider the conventions in our field along with your own preference when choosing how you will be named in scientific publications. Citations are key, and it is important that your papers be readily identified with you. Decide which name(s) to use and which additional initials or other signs to maintain. If the first name you are known by does not correspond with your initials, be careful and at least consistent in how you publish your name. Spanish speakers often hyphenate their two last names to avoid being cited with their second last name only (the first last name being considered a middle name, or second first name!). Some journals now allow authors to add their name in Chinese, Japanese or Korean characters after the English version of their name. Another positive novelty is that several journals now allow authors to change their names (for reasons including gender identity, marriage, divorce, or change of religion).

This may look messy, and it is. It is sometimes impossible to find a reliable overview of a person's papers because they, for instance, are inconsistent in how they are referred to as authors, have a common name, or have changed their name. For all these reasons and many more, we recommend that all authors register with ORCID[8] to obtain a free persistent digital identifier (ORCID iD) which is basically a number that is tied to your person. By coupling your professional information, papers but also affiliations, grants, etc., with your ORCID iD, all your products can be identified as yours even if searching by your name does not yield unique or conclusive results.

3.4 LaTeX

In astronomy, as in much of physics and engineering, LaTeX is used to prepare manuscripts. LaTeX is a software system for document preparation which offers significant advantages over word processors such as LibreOffice Writer, Microsoft Word, or Apple Pages. For instance, LaTeX is free software distributed under a public license, a LaTeX document is prepared in plain text rather than an often proprietary internal format, and LaTeX is excellent at typesetting mathematical expressions (as well as non-Latin scripts).

Most journals provide their own LaTeX macro packages to prepare manuscripts. Many text editors and software packages are freely available for all main computing platforms. Overleaf[9] is increasingly used as an online tool to allow multiple co-authors to share the editing of a LaTeX document.

As you start out in astronomy, it is worth investing time and effort to master at least the basics of LaTeX. You will need it in professional astronomy. And as you start putting your paper together, if you use the LaTeX macro package of your favourite journal your manuscript will immediately start to look 'real'!

7 https://ui.adsabs.harvard.edu/

8 https://orcid.org/

9 http://www.overleaf.com/

3.5 Roles of Referee, Editor, and Language Editor

You write your paper, typeset it to perfection using LaTeX, and submit it to the journal. A scientific editor will consider your manuscript and decide whether it might be suitable for publication in their journal. An editor is usually a senior scientist and a subject specialist. They will send your manuscript to a referee (in astronomy, usually only one, in related fields, up to five) for peer review. The referee is a colleague who is a specialist in the topic of the paper. They will write a report containing a recommendation to the editor and suggestions for improvement to the authors. The role of a referee is to make sure the paper is technically sound, but the referee is not a co-author of the paper. A referee can thus recommend acceptance without agreeing with everything written in a paper.

In astronomy, most referees are supportive, and after authors submit a revised version of their manuscript taking into account the recommendations of the referee, most papers are accepted for publication. Sometimes multiple rounds of refereeing and revision are needed, sometimes a second referee is sought to adjudicate in a stalemate situation, and sometimes a paper is rejected. When dealing with difficult referee reports, is it always a good idea to consult with more experienced colleagues. Bertout and Schneider (2004) provide more background information on the roles of editors and referees at the journal Astronomy & Astrophysics (A&A).

Once a referee recommends acceptance and the editor indeed accepts your paper, it will enter the production stage. A language editor will typically proofread your manuscript and make changes to perfect both English usage and compliance with the journal or publisher house style. Language editors are usually very good at their job, but they are not astronomers. So if you are asked to check the page proofs (and answer any queries a language editor may have identified) it is very important to check your paper line by line, word by word, to make sure no inadvertent changes have been made. As the language editor's changes are usually identified, this is also a learning opportunity to see where your phrasing or typesetting was not optimal. A&A has an instructive list[10] of things that their language editors often need to correct, which is well worth looking through.

At the page proof stage you can still make small changes or additions if absolutely necessary (such as including a missing reference that has been pointed out to you after you prepublished your paper on the preprint server ArXiV). After that, the paper is typeset, gets a formal journal reference, and is published. It is indexed and will form part of the body of scientific literature—in perpetuity!

4 Basic Points on Writing Style

Before writing a manuscript, it is important to define WHAT you are going to write, and HOW (Sect. 2). A refereed research paper is very different from an outreach article. A first key question to consider is the language. In professional astronomy, this is almost always English, but in particular for outreach (but also some grant proposals and job applications) it may be another language. Writing in English means for most of us writing in a language which is not our own.

The basic concepts to consider are the **Audience**—who, level of expertise, what do they know and what do they need to know?; **Purpose**—inform (science paper) or entertain (popular)?; and **Tone**—objective, neutral, emotional? For scientific papers in refereed journals, your audience will be professionals in the field. However, they will not necessarily be experts in your sub-field, or aware of all the methods, techniques or tools you use. So explain all the specifics needed to understand your work, while avoiding jargon on the one hand and explaining the obvious on the other.

The purpose of a scientific paper is to inform, to describe your experiment and results in a scientific way. This means that you give enough detail and references that your results and conclusions can be verified and reproduced. So do not write 'we reduced the data in the standard way' but rather 'we followed the standard procedures for data reduction as described in detail by Author et al. (year)' or 'we reduced the data in the standard way by first ..., then ... and finally ... .'

The tone to be used is formal. So, for instance, do not use contractions (use do not, cannot, will not, it is, etc., rather than don't, can't, won't, it's), do not address the reader directly in the imperative (say 'the data are...' and not 'note that the data are...'), and avoid colloquialisms and slang, or references to fashionable popular culture. Section 6.4 contains more tips on sentence structure.

A formal tone also implies that any criticism of others' work should be phrased in professional terms, polite, and without personal sneers. So instead of the insulting 'X et al. clearly showed their lack of understanding of the basics of statistics when they published...' one could be highly critical but still professional: 'The recent study of X et al. fails to properly account for ... in their statistical analysis.'.

Finally, it is important to consider how to organize your product. In a research paper, we tend to use IMRaD (=Introduction, Methods, Results and Discussion, see also Sect. 5.4) but a press release, for instance, is structured very differently. If you are not sure how your writing style fits the purpose, read similar writings, or ask more experienced colleagues.

Towards Inclusive Language

In recent years, the field of galaxy formation and evolution has seen the emergence of a number of terms which in real life signify violent, highly unpleasant and mostly illegal acts, sometimes with misogynous or racist undertones. Some of these terms, such as a hierarchical scenario, cannibalism, stripping, strangulation or starvation, are by now so integrated into the professional vocabulory that in particular younger scientists may consider their use 'normal'. We would urge exercising constraint in the use of violent terminology, and to consider using alternatives. Vallejo and Moreno Soto (2018), for instance, suggest more collaborative and inclusive terms to replace the violent ones, including an ancestral scenario, collectivism, sharing, collaboration and preservation for the five mentioned above as examples. You can define these terms when you first use them in the text to ensure that readers understand what you mean.

5 Step by Step Guide to Writing a Scientific Manuscript

5.1 Title: Clear, Informative, Short

The title is the main marketing tool for your paper—it is hard to get right but you need a good one to catch a potential reader's attention. Ideally, it compresses the entire message of the paper, the 'narrative', or story, into a maximum of 10 words. The title needs to match the abstract and the rest of the paper. It needs to be accurate. Keep the title as short as possible. Use simple words, no jargon, no abbreviations, no new concepts. Include all important key words (search engines and other indexing tools will later on allow others to locate your paper). Avoid vague titles. Avoid starting with 'On...' or 'Towards...' (instead, say what you've done!). Avoid jokes or references to modern culture

10 https://www.aanda.org/contacts-bottommenu-162/69-author-information/language-editing

which may not age well. If possible, package the main conclusion of your paper into it.

As an exercise, you can take a recent issue of a major journal and consider what you think of the various paper titles. You do not need to understand what the papers are about, but can ask yourself questions like does the title inspire me? Does it inspire me to read the abstract? Is it silly, or cheesy? Is it so technical, or long, or complicated, that it puts me off reading further? Then compare your own draft title(s) with what you have seen.

5.2 Abstract

The abstract sets the scene, identifies the problem, outlines how you will solve that problem, and then describes what you have done, how, and what you have concluded (ideally coming back to 'setting the scene'). In the abstract, you try to tell the whole story of your paper in ten lines. Bertout and Schneider (2005), at the time editors of A&A, phrased the importance of an abstract as follows.

> Confronted with a huge volume of new information every week, researchers in the physical sciences can no longer read all the literature that is published on scientific matters that interest them. The paper's abstract, undoubtedly the most visible part of any scientific article, has therefore in recent years become particularly important as a filter for deciding what articles are worth taking the time to read in detail. This is particularly true for astrophysics articles, since the abstract is referenced and widely accessible in the NASA Astrophysics Data Service, in topical newsletters, and in other abstract databases.
>
> Whether a colleague will read your paper or not thus depends in large measure on the level of interest that is gained from reading your paper's abstract. When writing it, one must therefore make sure that it conveys the essential elements of the article to the reader: its objective, the methods used to reach it, and the results obtained. This must be done in a concise yet informative way, without using external references that will not be referenced in the abstract databases. Finally, the style must be pleasing.

Bertout and Schneider (2005) then propose using so-called 'structured abstracts', with explicit headings Context, Aims, Methods, Results, and Conclusions. The journal A&A recommends but does not enforce using a structured abstract, but even if you do not use it explicitly, make sure you include the main concepts in your abstract.

A useful exercise is to compare abstracts from different papers, for instance when you make a literature review (Sect. 2.1). Which ones call your attention, and invite you to read the paper? How many fail to set the stage and start by telling you what they did, rather than why? If you do not have the time to read the whole paper, do you think the abstracts will allow you to vaguely remember the results later on? Can you recognize a structure of the kind proposed by Bertout & Schneider?

5.3 Figures and Tables

It is often useful to develop an idea very early on about which figures and tables will need to be included in the paper. You will need to find the balance between including all the key ones, without including too many. Series of figures and tables, as well as long tables, can be published electronically only, and/or in an Appendix. As usual, a journal's instructions for authors will inform you how to produce your tables and figures.

Figures need to be easy to understand and of high quality. Try to make them as vector graphics (pdf is vectorial, jpeg is not) so they can be scaled up. Always deliver figures of the highest possible quality to the publisher, even if you use smaller versions for other purposes (e.g. ArXiV or talks). Include all lines, points, labels, etc. that you need, but omit any that are not strictly necessary. Explain all elements of the figure in the caption. Do not make your figures too complicated: you want them to catch the reader's attention. And try to make your figures tell the story of the paper: some people will look at the figures in your paper, or see them in a conference presentation, without reading your carefully worded text (sometimes even without reading the caption). Actively looking for the key message in other papers in title, abstract, and figure captions can help you try to act like the audience to your own paper when writing it!

In terms of presentation, use a colour scheme that can be interpreted by all, including those with colour vision deficiency ('colour blindness', affecting up to 10% of your colleagues). Simple but effective tips include using both line/point style and colour to distinguish different elements (never only colour), and using a colour scheme that is appropriate for colour blind people. Many resources are available online.[e.g.11,12] You may want to use the same format for all your figures. And you may want to end each caption with a one-sentence conclusion of what the figure shows. That way, if a reader scans the figures of your paper, or someone tweets your figure, the context and implications directly come with it.

5.4 Building up your Paper

The typical structure of a research paper in our field is the following: Introduction, Sample/Data/Methodology, Results, Discussion, Conclusion (IMRaD). Try not to mix these sections. Keep them logical and as short as you can. Use sub-sections and paragraphs to separate the text into 'bite-sized chunks' that can be digested easily by a reader. Tell the story of the paper, using the 'narrative' that you have defined before you started writing.

Keep an overall 'hourglass' shape of the paper in mind: it starts broadly, with the 'big picture' first part of the introduction, then narrows down into the details of methods and results, before broadening again at the end, when the discussion and conclusion sections place the new findings in a wider context.

5.5 The Introduction

The Introduction has several roles, which you can use in this order to draft it.

i. Present the problem, in a wide context. The 'Big Picture'. Example 'topic' sentences (Sect. 6.1) could start with 'The Sun is...' or 'In modern cosmology, ...'
ii. Narrow the focus, by introducing the specific sub-topic you will be describing, e.g. 'magnetic fields around sunspots...' or 'galaxy mergers ...'
iii. Point out the gaps in the existing knowledge which you want to fill in with your work, e.g. 'however, the exact role of... is unclear'.
iv. Now present what you did in your study, and define the exact problem tackled. 'The aim of the current study is...'
v. Finally, describe what you have done, 'We therefore observed...'
vi. In many papers the Introduction ends with a preview of what follows. 'This paper presents...' or 'we present our sample in Sect 2...'

A good introduction is concise, focusses on the main issues, avoids repetition and includes references to relevant work. This allows the reader to place the work in context, and to find key background papers if they want to know more. You can also

11 https://jfly.uni-koeln.de/color/index.html
12 https://bconnelly.net/posts/creating_colorblind-friendly_figures/

introduce other relevant aspects, such as a specific telescope, instrument, simulation, or survey, or a particular object. Keep it short and reasonable. Unless you write a full review paper, you do not need to refer to every paper ever written on the topic. Use 'e.g.' and then give the most important or relevant ones, or cite a review paper. Make sure you include modern work, and references from the current year. This shows that your research is relevant and timely. On the other hand, do not *only* include modern papers. Almost all work rests on key papers that may have been published before you were born, but you must be aware of them (Box 2, below, gives some tips on how to find key papers in your field). In any case read and check all papers you cite to make sure they in fact support your claim and do not assume previous authors have done this.

Consider for what statements you need a reference. Basically, for textbook-level basic knowledge, no; specific statements or results, yes. Do not be afraid to cite your own relevant papers, or those of your friends. Do not overdo it either, papers that only quote own work are bound to have less impact.

Box 2: Finding Key References with ADS

i. Find a modern, well-written, relevant paper by a leading author or group and open the abstract page in ADS.
ii. In the left column, click 'References'. This shows all the papers referenced in the paper.
iii. Click 'View this list in a search results page'
iv. Order the resulting list by 'Citation count' (in the drop-down menu which says 'Author count' by default)
v. You can now see the most-cited papers among those referenced in your selected paper. Many of these will be catalogues, or survey description papers. But very quickly you can identify papers in the specific field of your study which are classic and important.
vi. Repeat this process a few times for different modern papers, and the classic, pioneering, critical papers in the field will soon bubble up.
vii. Click on one or more of these key papers, and check which papers cite it. The most recent ones will quickly give you a superb overview of what is currently going on in the field!

5.6 Sample, Data, Methods

This is probably both the most boring and technical section of your paper, and the easiest to write (and often also the first section that researchers write). In an observational paper, for instance, you describe what data you used, how you obtained and reduced them, and what analysis methods you used. Do not describe the results—that comes in the next section. The most you do here is show the reduced image (or similar) in a Figure, but the astrophysical description of what you see comes in the next section.

The main aims of this section are to allow others to (1) judge how you reached your results, and how reliable, good, novel, etc. your data and methods are to the field, and (2) reproduce what you did. While point 1 is generally straightforward to assess, point 2 reflects an open issue and ongoing debate in astronomy. There are many solutions to make a scientific paper reproducible, each with their own caveats (see for example the recent work by Akhlaghi et al. (2021) who promote an exactly reproducible model for papers, from its figures to the underlying pipelines in the analysis—see also the critique by Kuttel (2021)). We will not review all currently available solutions to this issue here, but do point out that it is particularly important to include all critical details in the paper. Too often when we refer to older papers it is impossible to reproduce the methodology in detail because the data or methods were not described well enough, are unusable, or even not publicly available now (see also Sect. 5.11). Do not hide any caveats of your methods, and be honest—identify and address either how you have solved these issues or why they do not affect your results (if possible, in a quantifiable way). On the other hand, do not describe everything you ever did, and ignore issues that do not affect the main line of the paper.

Often in astronomy we repeat methods already described by others. In that case, a statement such as 'we followed the data reduction procedures as described by Author et al. (year) ...' is appropriate but then do describe anything you did differently. Even if you follow previous work by your own group (or yourself) never copy *verbatim* a previous description of a method you have followed. This is plagiarism, even if you copy your own words (in which case it is called self-plagiarism—arguably just as bad).

In some journals (such as Nature) most of the details of this sort go into a separate online section 'Supplementary Material'. Similarly, in other journals you can place non-critical or background information in an appendix. In either case, make sure you reference the background material in the main paper. Be honest, and if there is a significant problem or doubt, do not bury it in an appendix or in the supplementary material.

Keep the most technical parts in specific subsections or paragraphs, so a reader can skip them if they want. Finally, we recommend using the past active tense: 'we used...' (not 'we use...' or 'we have used...'), but more important than that is to be consistent: use whatever you choose throughout the Section.

5.7 Results

In astronomical professional writing, this is where you describe what you have found. There is no need to discuss all the implications yet, or to make detailed comparisons with other work, because that will come in the Discussion. But do not be too dogmatic about this, because if you strictly only report what you see in this section and leave anything more profound to the discussion section the paper will become hard to read in a logical way.

The results section is illustrated with figures. Select those first, define (or remind yourself of) your narrative, and use a logical structure by employing sub-sections and paragraphs. Section and sub-section titles allow the reader to scan the paper quickly. As we suggested in Sect. 5.1, keep (sub-)section titles short but include the key words or even the key message you want the reader to pick up even if they just scan them and do not read the actual text.

An effective writing trick is to start each section and subsection with a sentence saying why you looked at the particular aspect you are about to describe. Compare these two ways of starting: (i) *In Figure 3 we plot our data for all the stars in our sample*; and (ii) *To demonstrate how parameter x relates to y, we show the results for all the sample stars in Figure 3*. The second approach clearly leads the reader to look at Figure 3.

5.8 Discussion

This is where we come back to the hourglass shape of the paper (Sect. 5.4). The previous sections, methodology and results, were very specific and probably very technical. In the discussion, you place your results in the context of other work, or compare them to theory, modelling, or observations. The other main aim of the discussion section (which is really 'critical discussion') is to describe the limitations of the results you have just presented.

Once again, use sub-sections with well-chosen titles to break up your discussion into manageable parts, choose your paragraphs strategically, and use first sentences to set the

scene. Then include final sentences or paragraphs in each section or subsection to summarise the main point.

Some key aspects you can include in the discussion section, broadening up the 'hourglass' as you go down the list, are the following.

1. Repeat why you carried out this study.
2. Return to the main question you posed early on in the abstract, and answer it.
3. Explain how your answer is supported by your data, model, figures, derivations, results.
4. Discuss how your results, and your answer, relate to other work in the literature. Say how they are supported, how they support other work, but also where they disagree.
5. Give your view on why there is disagreement, and/or discuss any alternative explanations.
6. Add what future work or observations can provide more clarity or advancement.
7. Finally, broaden up to describe wider implications, applications, and recommendations.

5.9 Conclusions

Always include your conclusions. If you do not make a separate Conclusion section, then at least call the previous one 'Discussion and Conclusions' (and make sure you explicitly add the conclusions in the text). One of the main reasons for this is that many readers do not have time to read the whole paper, but may skip to this section to get a quick overview of what you have done and found.

Keeping this in mind, start the conclusions section by summarizing very briefly the why, how and what of your paper. Repeat key points like what the aim of the study was, the sample size, with what telescope you observed the objects or which pipelines or codes you ran, and then make a concise and logical summary of the main results and how you interpret them. You may want to refer back to your key figures in the conclusions section, to tempt those readers who read only this section to also look at your artwork.

Finish up with a strong concluding sentence. Do not just say something bland like 'more research is needed' but try to summarise your whole paper in one final sentence. Something like 'our results show how galaxy metallicities confirm...'.

5.10 Acknowledgements, References, Appendices

Acknowledgements are important. This is both in a formal sense, for instance because your funding agency will insist that you acknowledge their financial support, and in an informal one, because you want to record your appreciation of the help you have received from others—colleagues who helped you with specific aspects of the work, or friends or family who are not colleagues but who for some reason you feel deserve to be thanked publicly for their role in the work you have managed to complete and publish.

References will need to be included in the form prescribed in the instructions for authors of the particular journal you have chosen. Ensure that the references are complete because their use is to allow others to find the papers. Do not save on citations—our colleagues are our referees too, and everybody likes to see their own work referred to by others. Consider whether you can, or need to, add software or other products which are not strictly research papers to your formal reference list. Citations are often needed by the relevant authors or developers to secure future funding, or to show that their work has been useful. Where references are not needed or possible, then add the software or other products to the acknowledgements section.

Finally, use appendices to include material that would make the paper too long, or that is necessary but too technical to include in the main body. Sometimes you can also move additional tests or explorations to the appendices. As appendices are almost always published electronically, length restrictions tend to be either absent or less of an issue.

5.11 Data and Software

A key aspect of ethics in science is that scientists are open about their work and what they have done, and about the data and tools they used. So whenever you can, publish your data and/or your software or code with your paper. Both MNRAS and A&A have a contract with the CDS[13] which guarantees long-term archival. Git[14] or GitHub[15] are often used to publish software.

When you publish your software or code, ideally you license it under a free-software license.[16] If you do, you grant your colleagues the right to 'run, copy, distribute, change and improve' the software. It is interesting that if you make your software publicly available but without an explicit licence, it is copyright-protected under the Berne Convention Implementation Act of 1988 and other astronomers are legally forbidden from copying the software, modifying it, distributing it, or distributing a corrected or improved version (as pointed out in the Ethics Statement of the European Astronomical Society[17]).

Avoid making data available through your own website, or your institute's, or your research project's. The websites will disappear with time, or the URLs will change. The only way to guarantee that your data or software will remain accessible (even after you have changed your career path, or have retired) is to formally publish it in a repository like the CDS.

6 Writing Mechanics for Manuscript Development

6.1 Paragraphs

Well-structured paragraphs begin by expressing the main idea in the first sentence (topic sentence), then develop that main idea with facts, examples, or analysis.[18] A paragraph can end when the necessary information has been given, or provide a summation or linkage to the next idea. A topic sentence may be very general, for example *a galaxy is a group of stars*. This very general sentence could lead to description of the types of galaxies. Such general sentences are common at the beginning of an introduction. A topic sentence in a methodology section could be something like *to measure x, we followed several steps*. This topic sentence very obviously leads to a list of steps, probably using words such as *first, next, finally*. Topic sentences in a results section often refer to a figure or table. *Table 3 shows the measurements of xxxx*. This sentence would then lead to a systematic presentation of each result. Paragraphs do not need a special sentence to end, but sometimes in a results or discussion section, it is helpful to give a conclusion, for example *these*

13 https://cdsweb.u-strasbg.fr/
14 https://git-scm.com
15 https://github.com
16 http://www.gnu.org/philosophy/free-sw.html.en
17 https://eas.unige.ch//documents/EAS_Ethics_Statement.pdf
18 This structure is common in academic writing. In other types of writing, for example novels, the structure may be looser. Furthermore, paragraphs may follow a different structure in other languages, for example, in Chinese, where the main idea is expressed at the end of the paragraph.

results suggest that xxxx. Another way to end is with a transition sentence, for example, *the next Section describes xxxx*.

Paragraphs should be neither too long nor too short. A paragraph must contain just enough information to explain your ideas to the reader, but avoid unnecessary detail. Nowadays, paragraphs in academic writing tend to contain three to seven sentences, though the length is somewhat journal-dependent. In any case, avoid tremendously long and discouraging-looking paragraphs that go half a page or more. Split the long ones up into two smaller ideas, each with its own topic sentence.

Inexperienced writers may have problems writing well-structured paragraphs. For example, they may find themselves writing wandering paragraphs without any clear point. The reader tries to follow, but starts to wonder 'where is this paragraph going? What is the point the author is trying to make?' Often the problem is the lack of a topic sentence. Example: what is the point of the following paragraph?

In 2018 Brown measured x. Similarly Jones published y. Recently Smith reported z.

Perhaps the writer intended to show that there has been a lot of research on galaxy Q. In this case, a good topic sentence could clarify the significance of these facts.

Recent research has focussed on the galaxy Q. In 2018 Brown measured x. Similarly Jones published y. Recently Smith reported z.

Another common problem for beginning writers is trying to cram too much into one paragraph. What is wrong with the following paragraph?

We used several approaches to measure x. First we did a. Then we did b and c. After measuring x, we also measured y.

This paragraph begins by describing the measurement of x, but then gets off track by unexpectedly mentioning the measurement of y. There are two possible ways to fix this problem. Either change the topic sentence to include the measurement of y (*we used several approaches to measure x and y*) or put the measurement of y into a paragraph of its own.

6.2 Sentence Linkage

Beginning writers, particularly non-anglophones, often write bumpy text that does not seem to flow. This problem can be fixed by linking sentences to each other. In English the beginning of a sentence always provides context and linkage, generally by repeating a word or concept that has already been mentioned, while the end of the sentence presents the new information.[19] Here are several examples showing good linkage.

Galaxy W was recently discovered by Brown. This galaxy... Renaming the noun *galaxy* links the sentences and leads probably to a description of the galaxy.

Galaxy B has been well characterized. In 2018 Brown reported..., while a year later Jones published... In this case, 'well characterized' suggests research, which is listed in the following sentences, so this structure leads to a good flow. The use of the dates provides a bit of extra context, showing that this is recent research.

There are currently three missions studying the comet. First... Second... Third... Here, the specific mention of 'three missions' (or perhaps 'several missions') leads the reader to expect the list that follows.

Another technique to improve linkage and flow is the use of 'sign-post' words that tell the reader the relationship of the ideas. To list examples, you can use phrases like 'for example,' 'for instance,' and 'such as.' To show chronological order, use dates like 'in 2012' or words like 'first,' 'second,' 'next,' and 'finally.' To show cause and effect, use words or phrases like 'consequently' or 'as a result.' To suggest similarity, use words like 'similarly' or 'likewise.' To show contrast, use phrases like 'in contrast' or 'on the other hand.'

6.3 Avoiding Plagiarism

Many journals automatically scan uploaded manuscripts for plagiarism, using a service such as Crossref Similarity Check, powered by iThenticate.[20] Thus it has become very important to avoid the appearance of plagiarism.

To avoid plagiarism, make sure to cite the sources of ideas and to write text in your own words. If you are quoting a definition or standard description, put the quoted text between quotation marks and provide the source.

Plagiarism may arise for several reasons. For example, you cannot think of a better way to say it. To solve this problem, improve your vocabulary and check sources like the Manchester Academic Phrasebank[21] for ideas to expand your own vocabulary of words and phrases. Or perhaps you copy a text, thinking 'I will change it later.' But then you forget to change it, and end up plagiarizing. To avoid this problem, do not take notes by copying and pasting—always take notes in your own words. For a full discussion of these and other tips on avoiding plagiarism, see Roig (2015). [22]

6.4 Tips for Nice Sentences

Make sentences just the right length. Sentences in academic writing range on average between 18 and 32 words, with some longer or shorter. Shorter sentences can provide a nice antidote if the previous sentence was rather long. But sentences can get too long and too complicated by the stringing together of clauses, especially those that begin with 'which' or 'that.' Aim to make these longer complex sentences represent no more than one out of three or four in your paper.

Stick to a subject-verb-object structure. This structure puts the verb right after the subject, where it belongs. So not 'characteristics such as a, b, c, d, e, f, and g were measured,' but much better 'we measured a, b, c, d, e, f, and g.'

Prefer active voice. Active voice leads to more lively writing, as demonstrated by the example in the previous paragraph. Using active voice does not mean beginning every sentence with 'we.' Inanimate objects can also be the subject: *this paper presents...; the next section explains...; the results show...; this model provides...*.

Use verb tenses correctly. The main verb tenses used in academic writing are Present, Present Perfect, and Past.

Present tense for

1. facts and definitions

Ex: *These giant low surface brightness galaxies form an interesting class of objects.*

2. referring to the paper or figures or tables in the paper

Ex: *Fig. 1 shows.../ X is shown in Fig. 1/this paper presents...*

Past tense for things you did in the past, or that somebody else did in the past.

Ex: *For each bin, we calculated the surface brightness.*

Ex: *The European Space Agency launched the Gaia satellite at the end of 2013.*

19 In some languages, such as Persian, the structure is just the opposite: the new information comes at the beginning of the sentence, while the old, familiar, linking information comes at the end.

20 https://www.ithenticate.com/

21 https://www.phrasebank.manchester.ac.uk/

22 https://bsc.ua.edu/wp-content/uploads/2017/07/plagiarism-1.pdf

Present perfect

1. to announce work done in the 'recent' past with emphasis on the current relevance.
Ex: *We have explored the nature of the disc truncations in two edge-on nearby Milky Way-like galaxies.*
Ex: *Algorithms have been proposed along this line.*
2. for a process that began in the past and continues up to now.
Ex: *Over the last twenty years, there has been intensive research into...*

Keep subject and verb close together.

Not: A number of galaxies, some with spirals arms and others with both spiral arms and a prominent bar, were observed.

But: We observed a number of galaxies, some ... etc.

Use appropriate verbs. People often mix the action we take, as observers, or researchers, with what an object like a star or a galaxy does.

An example: *Galaxies concentrate a lot of dust in their central regions.* (Not necessarily, we see that the dust is concentrated there but did the galaxy do it? Write *A lot of dust is concentrated in the central regions of galaxies.*).

6.5 Place Modifiers Carefully

A modifier is a word or phrase which gives additional information about another word or phrase.

Look at this example: *orbiting at x km above the earth, we could see the satellite.* Are you really orbiting above the earth, or is it the satellite? Verbal phrases, like *orbiting at x km above the earth* should be placed directly before or directly after the word they modify. So you can correctly write *orbiting at x km above the earth, the satellite could be seen with the naked eye* or *we could see the satellite orbiting the earth at x km above the earth.*

What about *last weekend when I was camping, I looked out of my tent and could see the satellite in my pyjamas*? What is that satellite doing in your pyjamas? Prepositional phrases like *in my pyjamas* usually work best right after the noun they modify. In some cases, the sentences really need a bit of rewrite. We could put the part about the pyjamas into a separate sentence or drop it, and tell about *the satellite in the Western sky.*

6.6 Correct Punctuation with Relative Clauses

First we need to define a few grammatical terms. A *clause* is a group of words that contains a subject and a verb. So a clause might be a whole sentence that can stand alone (an independent clause). Or a clause might not be able to stand alone (a dependent clause). Here we are concerned with a particular class of dependent clauses, those that begin with *which, who,* or *that*. This type of clause is known as a relative clause, since the pronoun (*which, who*, or *that*) relates back to a previously mentioned noun. Here is an example of a sentence containing a relative clause: *Prof. Smith, who discovered the galaxy, won the Nobel prize*. In this case, *who* refers to Prof. Smith.

The words *which* and *who* can be used in two ways: to give defining information or extra, nondefining information.

Defining information is used to specify which person or thing you are talking about.

Example: *The professor who has a red shirt discovered a new galaxy*. In this case, there are several professors in the room, and your friend is pointing out which one you should look at. Thus the clause 'who has a red shirt' defines which professor your friend is talking about. Note that there are no commas around the defining clause.

When talking about people, we usually use the pronoun *who*, but for things, it is possible to use *that* or *which* to introduce defining information.

Example: *The galaxy which was discovered last week is amazing*. Note that here the clause 'which was discovered last week' defines which galaxy we are talking about, so there are no commas. In this case, we could also use *that* instead of *which*: *the galaxy that was discovered last week is amazing*. Some writers prefer to use *that* for defining information and save *which* for nondefining information (see below), but in fact both these words are in common use for the defining clauses.

Nondefining information gives extra information about the person or thing, but it is already clear which person or thing you are talking about.

Example: *Prof. Smith, who discovered the new galaxy, will give the next lecture*. In this case, we know exactly which professor your friend is talking about: Prof. Smith. The clause 'who discovered the new galaxy' gives nondefining information, so in fact this clause could be put into a separate sentence like this: *Prof. Smith will give the next lecture. She discovered the new galaxy*. Note that in this case, the commas around the defining clause indicate that this is extra, nondefining information that you could put some place else.

Note that the pronoun *that* is never used to give nondefining information.

Who cares? Why does it matter whether I use commas or not? Well, sometimes, putting in commas or leaving them out changes the meaning of the sentence.

Example without commas (defining relative clause): *The model which I developed fits the data*. In this case there are many models under discussion, but the particular one that I developed fits the data.

Example with commas (nondefining relative clause): *The model, which I developed, explains the data.* In this case, there is only one model under discussion, it explains the data, and by the way, I developed it. The information about who developed the model could be put in a separate sentence: *I developed a model. The model explains the data.*

In summary, if you need the information in the relative clause to specify who or what you are talking about, then do not use commas around the clause. If the information could just as well be put into another sentence, then do use commas around the clause.

6.7 Avoid Ambiguity with *This*

A common mistake is referring to something with 'this', without defining what it refers to. Such as here:

In many galaxies, secular evolution leads to the formation of pseudo-bulges and also to other changes in their morphology. This can be observed in both optical and radio imaging. What can be observed? The secular evolution? The formation of pseudo-bulges? Or the changes? To solve this problem, you write *this evolution can be observed*.

6.8 Tricky Plurals

While most plurals in English are formed by adding 's' or 'es,' science uses some irregular plurals. 'Data' is usually used as a plural, with the singular form being 'datum' or 'a piece or item of data.' In singular/plural pairs, here are a few tricky plurals: analysis/analyses, spectrum/spectra, phenomenon/phenomena, criterion/ criteria, matrix/matrices.

6.9 Use of the Articles a/an/the

Articles (*the* dog, *a* galaxy) can be extremely tricky for many non-native speakers because many or even most people in the world do not use articles at all in their first language, or do not use them like in English![23] It is thus very common in their drafts to see 'the' and other articles where an English native speaker would not place one, or to leave out an article where an anglophone would place one.

You should also note that for native English speakers (or for speakers of languages which treat articles in the same way as English, such as Dutch or German and to a lesser extent French and Spanish) the use of articles is often completely intuitive and crystal-clear, and they may not understand how others can possibly have a problem with articles.

Here are the basic rules.

1. Does the reader know which one or ones you are talking about? Then use 'the.' The reader might know which one you are talking about for the following reasons:

a. Known because you just introduced it.
   There was an association between a and c. The association remained robust after...
b. Known because you mention something related.
   ...galaxy x. The structure of the galaxy is... [every galaxy has a structure]
c. Known because you define it in the sentence.
   The causes of this rotation are...
d. Known because you name it.
   We used data from the SIMBAD database. [You define the database by giving the name, SIMBAD]
e. There is only one. The Milky Way. The Sun. However, do not use 'the' for the names of people. *I sent the data to Peter* (not 'the Peter'). Do not add 'the' to names of countries, but be aware that 'the' forms part of the name of some countries (the United States, the Netherlands). *The conference was in Spain; next year it will be in the Netherlands.*

2. If rule 1 does not apply and the noun is singular, use 'a' or 'an.' 'A' is used before a consonant sound: a galaxy, a star, a DVD. 'An' is used before a vowel sound: an element, an hour, an X-ray emitter.

3. If rule 1 does not apply and the noun is plural or noncountable, do not use any article.[24] Generally speaking, abstract terms used in a broad, general sense are noncountable and are not introduced with 'the'.

Examples with abstract nouns used in a general sense:
You need more information about the university program. ('Information' is used in a general sense.)
Phrasal verbs can be used in speech, but not in academic writing. (Both 'speech' and 'academic writing' are used in a general sense.)

But when using these abstract terms in a restricted and specific sense, rule 1 applies, and 'the' is used.

Examples with abstract nouns used in a restricted, specific sense:
The information in that folder is not correct. (Specific information)
The speech you hear on the street in New York is different from the speech you hear in London. (Specific examples of speech)
The writing in this paper is excellent. (Specific example of writing)

4. Some confusion may arise because some nouns can be either countable or noncountable, depending on their usage. To make matters worse, some nouns are countable in English but not in other languages, and vice versa.

Examples of nouns used as countable:
We gave the students some exercises to help them practice the use of articles. (countable, plural 'exercises')
I was so busy in the lab yesterday! I did 72 analyses. ('analyses' refers to analysed samples)

Examples with the same nouns used as noncountable:
You should not sit in front of the computer all day; you should get some exercise. ('Exercise' in general—maybe walking or cycling. This is quite a different meaning than the written exercises to practice the use of articles in the example above)
He entered the data into the computer for analysis. (In this case, 'analysis' is used as a general abstract noun, like 'information' in the example above.)

For those whose native language does not use articles, practice the rules (you can find exercises on the internet), or analyse some of the sentences in this paper. Can you identify why an article is used or not? You will not perfect your use of articles overnight, but with some regular attention to the issue, you can improve a lot within a year or two. For those who are anglophones, remember that articles are very difficult for your nonanglophone colleagues. Be helpful, not critical. After all, is your Indonesian/Russian/Persian perfect?

6.10 Adverbs

An adverb describes a verb, an adjective, or another adverb. It tells us how, where, when, how much, how often, etc. Adverbs of time (such as never, often, sometimes, also) usually do not cause trouble, but the adverbs that end in -ly can be confusing.

They are formed:

- For most adjectives, add -ly: wonderful—wonderfully
- If an adjective ends in y, change y to i and add -ly: easy—easily
- Ending in -able or -idle, change -e to -y: horrible—horribly
- Ending in c, add -ally: automatic—automatically
- Some adverbs are irregular and do not end in -ly: good—well
- And some do not change at all: fast—fast.

In fact, academic writing does not use a lot of adverbs to modify adjectives or adverbs, except in the special case of past participles used as adjectives. Examples are *previously reported data, a recently launched satellite, a carefully written report*.

6.11 Amount vs Number

Use 'number' for countable objects, and 'amount' for measured quantities.

Correct: *The number of stars of a given mass...*

Correct: *The total amount of fuel needed to launch the satellite...* (or else *the number of litres of fuel*, since litres are countable).

Correct: *The amount of time needed for the project...* (or else *the number of months needed for the project*, since months are countable).

6.12 UK vs US Spelling

There are some differences in spelling between American and British English. Examples are the American -or words which

23 See https://wals.info/feature/37A$#$2/19.6/35.5

24 Some languages do not differentiate between singular and plural nouns, which leads to confusion with articles and matching up the verbs. For example, in Indonesian, the structure is something like 'one book is brown; two book is brown.' If this situation is the case in your mother language, be careful to make nouns singular and plural, and to match the verb to the noun in English, so you have 'one book is brown; two books are blue.'

are written with -our in British English: color/colour, neighbor/neighbour. American English ends some words with -er, while British English uses -re: center/centre, meter/metre. American English has words that must end in -ize, while British English also writes them with -ise: analyze/analyse, categorize/categorise. Use the style and spelling appropriate to your journal, and use the relevant spell checker to avoid mistakes. Perhaps most importantly: be consistent throughout your paper.

6.13 Literature

'Literature' is poetry, novels, and plays; 'the literature' is the published body of work in your field.

6.14 Avoid Phrasal Verbs in Formal English

English uses many phrasal verbs, such as 'break down' or 'talk about,' but these are informal. They can be used in speech but not in formal writing. In almost all cases, there is a single, more formal word that can replace the phrasal verb, for example, 'destroy' or 'decompose' are more formal than 'break down,' and 'discuss' is more formal than 'talk about.' The more formal versions are derived from a Latin root and often resemble words in French or Spanish. Other examples are using the formal 'investigate' instead of 'look into' or the formal 'continue' rather than 'go on.'

6.15 Infinitives and Gerunds as Nouns

Confusingly, English uses both infinitives and gerunds as nouns. The infinitive is the 'to' form, like 'to eat,' and the gerund is the noun form that ends in 'ing,' like 'eating.' In some cases, either the infinitive or the gerund can be used: *we began to investigate the star* or *we began investigating the star*. But depending on the main verb, it may be necessary to use the infinitive or the gerund. *We wanted to investigate the star* because 'want' requires the infinitive. *We considered writing a paper* because 'consider' requires the gerund. Some verbs that are commonly used in academic writing can be used in several different ways. For example, *the supervisor advised taking more observations* because 'advise' requires the gerund. It is also correct to use the structure *the supervisor advised me to take more observations*; the infinitive is required when the person receiving the advice is mentioned. In case of doubt about the correct usage, check a dictionary such as The Longman Dictionary of Contemporary English.[25]

7 Concluding Remarks

This paper is a self-help guide to writing papers in astronomy for students and beginning writers. Often, the expectation is that students will learn how to write papers from their mentors or supervisors but not all mentors are the best of writers or are trained, or even willing, to teach students how to write! We hope our guide provides students with a clear framework to begin writing their first paper. It is also aimed to encourage them to first think before writing and, most importantly, to recognise that writing is a process that can be learned and constantly improved. For instance, by learning how to critically approach papers in the literature, you may then identify and learn how to present the key message and findings of your own paper in a self-critical, compelling and efficient manner.

Without a doubt, if you continue to practice and pay attention to good planning and writing, it will become easier to produce well-written papers. We also remind graduate programme coordinators that writing in astronomy is an essential skill for the future success of young researchers. We believe that the writing experience of students would be greatly enhanced if programmes included courses in academic writing as part of their early scientific education or graduate research training.

This paper also summarises the writing process, from planning the paper and choosing a journal, through the organization of the paper, to the mechanics of writing and polishing text, with some tips given along the way to avoid plagiarism. We concentrate on scientific papers to be submitted to refereed professional journals in astronomy. Based on our experience, we believe that every researcher can learn to write clearly, competently and even gracefully. We provide these guidelines based on our experience as writers and teachers, but take these guidelines as just that—only guidelines which will help you find your own way to becoming a good writer. Your reward will be when a colleague compliments you on your beautifully written paper!

8 Declarations

8.1 Ethical Approval (optional)

Not applicable.

8.2 Consent for Publication

Not applicable.

8.3 Competing Interests

The authors declare that they have no competing interests.

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8.5 Author's Contributions

All authors developed the manuscript together. Individual authors drafted sections and gave critical comments on the other sections.

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10 Authors' Information

JHK is a research professor of astrophysics with three decades of experience of (co-)writing over 200 refereed research papers in astronomy. He has edited a number of books and given courses on academic writing. NC is a young author and postdoctoral fellow in astronomy. Recognising that most of her Spanish-speaking colleagues had a hard time writing papers, she organised the first scientific writing school at the Instituto de Astrofísica de Canarias, Tenerife for PhD students in 2019. The week-long course was given by DB, whom she and JHK met during a SUNDIAL-ITN workshop, and inspired the making of this guide. DB taught classes on publishing in English at the University of Groningen, the Netherlands, for 16 years. She is now retired.

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