Scientific Writing
A few random comments

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My background

- I have never read a book on scientific writing, nor attended special training sessions.
- Editor of A&A Letters 1998–2006.
- Wrote two books, several major reviews, > 50 first-author journal papers, and many more where one of my students was first author (and which I corrected).
- Supervised and corrected ~ 40 dissertations, and read many more.
- Since 2015: Chair of the Euclid Consortium Editoral Board; main author of the Euclid Style Guide.
- Since 2000, three lecture courses (bachelor and master) per year at the University of Bonn.

Outline

- Motivation & purpose – why you should care about scientific writing
- Some initial basic questions – before you start writing
- Learning & learning by doing – how to make first steps
- Structure of your paper – how to order material
- Maximize clarity – how you communicate efficiently
- Ethical aspects – what you must, and must not do
- Writing papers together – collaborative writing
- Figures – how to best convey information
- After writing: Reading and revising – still more essential work to do
- Style/typesetting issues – what is most often done wrong

Motivation & purpose I

- Publications are among the main, or even sole, outcome of academic research.
- They are the prime way of communicating research methods and results.
- They form the basis on which others can learn about, check, appreciate, and comment on your work.
- Authors of a scientific publication or thesis should be proud of the product they deliver.
- Most people will read the arXiv version of publications, which renders the often-heared attitude that the editorial office of the journals will take care of style issues **absurd**. You need to get it right at the time of submission!
- Better to avoid errors and issues in the first place, rather than correcting them later.

Motivation & purpose II

- Issue of style and language will be commented on by supervisors, coauthors etc. and will thus unnecessarily multiply the number of comments on manuscripts, perhaps distracting from comments related to the scientific contents.
- It is a matter of respect to your readers to aim at a paper that can be understood and appreciated, and that that is free of style issues and other obvious weaknesses, as much as possible.

$\Rightarrow$ **One should prepare publications (and other science communication, e.g., presentations) with the same care as for the research itself.**

Note: Work that is not published is lost in most cases.

Some initial basic questions

- What do you want to write (scope of you paper, main focus, etc.)? Make sure you have something substantial to say, not just the "smallest publishable unit".
- Who do you want to address (only the specialists in the field, or a somewhat broader audience)? That should be kept in mind during the writing.
- Which journal (more specialized journal, or one with broader audience; page charges or not; journal owned by the community vs. commercial publisher; open access or not; allowance to put paper on the arXiv)? Better choose an established journal. Once chosen, get familiar with their instructions/style guide.
- When do you start writing a paper? Don't start too late.
- Are you up-to-date with the relevant literature? Need that for a proper introduction, and to relate your work to earlier ones. Are you sure that what you want to write has not been written before?

Learning & learning by doing

- Read (many) other research papers. Note which ones you like reading, which ones not, and note the reasons for it.
- Read the "Instructions for authors" of the journal carefully.
- The written notes on your work (those you make in order not to forget what you've done) can be drafted in the style of the journal, using their LaTeX template file – to practice your writing, and to allow your collaborators to understand (and to comment on) what you did early on.
- Some of the notes may later be copied and pasted into the paper, e.g., equations, tables, figures – saves some work.
- Some of your collaborators may criticize what and how you write; be attentive: even if they get it wrong, maybe there is a reason for it. The same holds for comments from other people, e.g., the referee.

Structure of your paper I

Depends a bit on the nature of your paper. Here's a generic example.

- Title, authors, affiliations, abstract.
- 1. Introduction. 2. Methods. 3. Data used. 4. Results. 5. Discussion & conclusion.
- Acknowledgement, references, appendix.

Choose a title that is concise, informative, and sounds interesting. Instead of "Discovery of a redshift 8.26 QSO", better use "HST discovery of the highest known redshift QSO, J2354+714, at $z = 8.26$". Also: scanning of titles on arXiv; search engines – title **very** important.

People usually read the abstract first, on the basis of which they decide to take a closer look. **Hence, it is important that the abstract gives the context, aims, methods, and (key) results of your work in a concise way.** Write the abstract after the rest of the paper is ready.

Structure of your paper II

The introduction should put your work into context, state its aim and what is new in your work, and fairly cite the relevant earlier literature. At the end, an outline of the paper may be given.

It can be very useful to structure your paper by introducing subsections, if individual sections are too long.

Acknowledge the people who helped you (and your coauthors) first; list the external funding sources. In some cases, specific acknowledgements are required for facilities.

Make sure the reference list is complete and correct. **Do not assume that BibTEX in connection with ADS bibentries give you a correct reference list! You must check it carefully.**

Maximize clarity I

Most important (beside correctness): **Clarity of your paper.** That has many different aspects:

- Every variable and acronym you use must be well defined ["where H_0 is the Hubble constant, ..."; "using the *Hubble* Space Telescope (HST)..."].
- Use unambiguous, precise language, so that the text can not be interpreted in different ways. Recall: The most precise language is mathematics. Be quantitative ("$\epsilon \lesssim 10^{-2}$", rather than "$\epsilon$ is fairly small") whenever possible.
- Make sure that there are no gaps in your line of arguments.
- List all assumptions, give all the relevant facts. Keep in mind that your results should be reproducible.
- Help the reader to follow your arguments [rather than "from the forgoing equations, we obtain...", better write "inserting the Fourier transform of Eq. (10) into Eq. (12), we obtain..."].

Maximize clarity II

- Make your paper as self-contained as possible. Instead of "We use the method of Miller et al. (2016)...", better write "We use Monte Carlo integration and importance sampling (see Miller et al. 2016 for details) ..."
- Don't pull rabbits out of the hat. The reader should be able to follow your line of arguments. If you introduce some external result, make that clear [e.g., "We now use $A = Bc^2$, that was derived by Brown (1992)..."].
- Most of the potential readers are not native English speakers. Therefore, use clear and simple language, short sentences, avoid rarely used expressions.
- Avoid as much as possible to refer to unpublished work or papers which are difficult to access.
- Avoid formulations like "it is easy to show that ...": if it's easy to show, then show it.
- Avoid formulations like "...is beyond the scope of this paper and will be considered in future work".

Ethical aspects I

- Plagiarism. **Must not be done!** Indeed, this could end your career as a scientist. If you use formulations of others, you must put them in "double quotation marks" and clearly give the source. In practice, that does not apply to brief generic formulations ("Galaxy clusters are the most massive gravitationally bound objects in the Universe.").
- Self-plagiarism: Must be avoided as well. These days, it is easy to check for plagiarism; arXiv does it automatically ("substantial text overlap with arXiv:yymm.nnnnn by other authors") and thus uncovers and displays your 'sins' to the public!
- Honesty: Be honest in your work and write-up. Don't say "It is easy to show" if one needs three pages of algebra, or even additional formulae not listed in the paper. Don't say "Using Eqs. (12,14, 17 & 25), we obtain ...", if you weren't able to do it by hand, but the 'we' was computer algebra: then say that you used Mathematica.

Ethical aspects II

- Honesty: Of course, **do not manipulate** (experimental or simulation) **data!** If you use only part of your data for the analysis (e.g., removing three objects from your initial sample; discarding spectral data beyond a selected range of wavelengths), state it, and the (hopefully objective) reasons for it. Best done **before** you perform the analysis – **be aware of selection biases!**
- Be truthful. Don't say "this finding is in contradiction to the prediction by the CDM model" if CDM does not make predictions on such small scales; instead say "this finding is not predicted by the CDM model".
- Scientific integrity: Do not hide problems with your result, e.g., mention explicitly that they apply only in the case of XXX. Also, if your code works fine for some cases, but shows problems with others, it must be mentioned.
- Do not overstate your work. "We are the first who derived ...": are your really sure? Better: "To our knowledge, this has not been derived before."

Ethical aspects III

- Do not praise your work (leave that to others): "Our method is the most precise currently available": maybe that is true, but it is better to let facts speak for themself: "Compared to the commonly used XXX and YYY approaches, our method reduces the uncertainty by at least a factor of five (see Fig.7)."
- Responsibility of all coauthors: **All authors are responsible for the contents of a paper!** And they should exercise this responsibility. If your name is on the paper, it affects your reputation. There's nothing like "I'm responsible only for the data reduction". All authors must agree on the paper before submission. All authors must agree to the response to the referee and to the revised version. It is the responsibility of the lead author(s) to inform and involve all authors at the various stages of a publication.

Ethical aspects IV

- Fairness in citations: Make sure you list and cite all input sources of your work – papers, software, data, etc. Your citations should be balanced: not only citing yourself, your close collaborators and friends; not only those papers with which you agree most, but also opposing views (unless they are unreasonable); cite and give credits to the original ideas, discoveries, etc. You should only cite those papers which you have read.
- Authorship and its order: Can be a very sensitive topic. Depends on, e.g., community (e.g., particle physics vs. astrophysics), kind of paper (private vs. consortium paper), etc. In general: Only those who at least read the paper critically should become author (necessary, but not sufficient condition). Just being "the boss" is not a sufficient reason to be an author.

Writing papers together

If the work is done by several people, plan how you organize the paper writing. Some possibilities:

- One person is *the* writer, the others don't touch the LaTeX file, but comment on various stages of the draft, and provide figures, tables, etc.
- One person is *the* writer, but others provide additional text elements (e.g., the section '2. Observations') that the writer pastes into the source file.
- Several people work on the text (conveniently organized e.g. with `Overleaf`), and comments by others are also done by editing. Lead author(s) must then check at the end that nothing unwanted was put in, and that the writing by multiple authors is homogenized and consistent (language-wise, style-wise, notation, level, etc.).

There are pros and cons for each of these, and they can be combined (e.g., several authors write together up to an advanced draft version, after which only one person can touch the source file, i.e., has full control).

Figures I

Figures often contain the main results of your paper and can form the backbone of the 'Results' section. They must be very carefully prepared.

- Make sure the information in figures can be grasped as easily as possible.
- Better to provide figure legends, instead of only stating "the blue long dashed-dotted curve shows..." or "the inverted green triangle is ..." in the caption.
- Pay attention to the thickness of lines and boxes, size of fonts on the axes.
- Use tickmarks on all four sides.
- **Never** use anisotropic scaling of figures (specifying both `width` and `height`)!
- Do not use 'invisible' colors like yellow, light cyan, etc., nor invent 'fancy' colors. Make sure that different lines are easily distinguishable. You may consider the needs of color-blind people when choosing your colors.

Figures II

- Make sure to have proper units on the axes (e.g., "Separation Δx/Mpc" or "Period T [days]"). Common mistake: log(Stellar mass M_*).
- In multi-panel figures, try to identify the different panels by proper labelling inside the panels, so you can write "Fig. 5b shows...", instead of saying "the middle panel in the second row of Fig. 5 shows...".
- There must be at least two numbers on each axis.
- Capitalize labels as normal text (first letter and proper names only). Variables as labels are best obtained by direct import of LaTeX symbols by the plotting software.
- Within a given paper, the style of the figures should be consistent – best use the same plot software for all figures.

Figures III

- Each figure should be designed for its final size as it will appear in the journal. Simply rescaling a figure to fit will in general yield wrong font sizes and line thickness. In particular, if similar figures are reproduced with different size, make sure the fonts are adjusted.
- Avoid to overload your figure.
- Make sure the caption is sufficiently informative, so that at least experts can grasp the contents of the figure even without reading the full paper.
- Captions should describe figures, not discuss them.

Some more comments

- Avoid excessive jargon.
- Run a spellchecker before showing the paper to others.
- Avoid noun clusters (such as "the gas metallicity mass distribution").
- Mathematical expressions are part of sentences, and one thus needs proper punctuation; that also applies to displayed equations. For example, in most cases you don't need a ":" before the equation.
- Number every displayed equation (is done by default in LaTeX), even if you are not referring to it later. But others may want to – e.g., the referee.
- For the same reason, it is useful to use line numbering.

After writing: Reading and revising I

- Most likely, the paper is written over a longer span of time (weeks or even months), not in one go. Read it in one go, to see whether it flows.
- Is it self-consistent? Same notation everywhere? Is the order of the arguments correct? Is the text (too) repetitive (at least use different words)? Are acronyms defined, and defined only once on their first occurrence?
- Is there a paper that should have been cited, but is not yet?
- Turn back to the journal's style guide to refersh your memory, and read the paper again with special attention to that.
- Are you happy with the layout? Does the discussion of a figure occur on or near the page where the figure is placed – you don't want the reader to flip back and forth through the paper. Do the figures look OK – right size, line thickness, and fonts?

After writing: Reading and revising II

- Are your numbers reasonable – e.g., "we find $\zeta = 3.61392 \pm 0.23712$" makes no sense. Not every digit that a computer spits out is meaningful!
- Check the reference list! Does every cited paper occur, and occur only once? Consistency – "A&A" vs. "Astron. Astrophy."; "arXiv:2012.34567" vs. "arXiv e-prints, arXiv:2012.34567" vs. "`[arXiv:2012.34567]`"; only first page vs. first and end page; same number of authors listed before "et al.": You may need to edit your `.bib` file.

I'm sorry to repeat myself, but...

Parts of a reference list of paper submitted to the ECEB

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vs. ApJ

vs. MNRAS

Same paper twice

arXiv e-prints
which journal??
record missing

which journal??
et al. after 1 author

Style/typesetting issues

Not only the scientific contents needs to be correct, but also the style.

I gess you anderstadn this sentene, but dueh to tpyos, it is not easi to raed.

But even *if* there are *no* typos, style and **fonts** can *n* distract *you*.

Similarly, language and style issues in mathematics distract from the scientific contents, and must be avoided.

Learning from errors: we'll provide two examples next.

eROSITA

Regarding sky coverage, angular resolution, and sensitivity, the performances of eROSITA will allow to detect ∼100000 galaxy clusters out to z∼1.5. It will detect essentially all clusters in the universe with $M > 10^{15} h^{-1} M_{\odot}$, where $h = H_0/100$. Furthermore, its angular resolution of ∼15" at E=1.5keV provides a clean separation of point like sources (AGN and stars) and extended sources like clusters. Its cameras are cooled to -90°C using a heat pipe system. As the first "Stage-IV" Dark Energy experiment, eROSITA will permit to get unprecedented constraints on the e.o.s. parameter w.

This brief text contains more than 10 (non-scientific) mistakes. Can you identify them?

eROSITA

Regarding sky coverage, angular resolution, and sensitivity, the performances of eROSITA will allow to detect ∼100000 galaxy clusters out to z∼1.5. It will detect essentially all clusters in the universe with $M > 10^{15} h^{-1} M_{\odot}$, where $h = H_0/100$. Furthermore, its angular resolution of ∼15" at E=1.5keV provides a clean separation of point like sources (AGN and stars) and extended sources like clusters. Its cameras are cooled to -90°C using a heat pipe system. As the first "Stage-IV" Dark Energy experiment, eROSITA will permit to get unprecedented constraints on the e.o.s. parameter w.

Every blue part of the text is at least one mistake; we'll go through them one-by-one.

- the performances of eROSITA ⇒ the performance of eROSITA

  'performance' can have a plural only in case they are countable (as in 'two performances of the circus on Sunday'); in almost all cases in physics, that is not meant, and performance is then always singular.

- will allow to detect ⇒ will allow one to detect; or: will allow the detection
  will permit to get ⇒ will permit us to get

  'allow' and 'permit' are transitive verbs, they require an object.

- the universe ⇒ the Universe

  Capitalize "Universe" when referring to the cosmos in which we live, reserving "universe" for different theoretical possibilities. Similarly: Sun, Solar System, Galactic extinction. They all refer to the one unique object.

- "Stage-IV" experiment ⇒ "Stage-IV" experiment

  Use "‘ ‘" and "’ ’", not the double-quote character found on English keyboards above the apostrophe. Note the difference between the opening and closing marks.

- z$\sim$1.5 $\Rightarrow$ $z \sim 1.5$
  $\sim$15" $\Rightarrow$ $\sim 15''$

  Remember (and apply) the simple rule: **mathematical expressions must be in math mode!** All of it!

- E=1.5keV

  Two things are wrong: First, must be in math mode. Let's put it in dollars to get $E = 1.5keV$. Now the units are in italics, but **units must be in roman**, thus it should read $E = 1.5\mathrm{keV}$. Still not right, spacing is missing. Finally, $E = 1.5\,\mathrm{keV}$.

- $10^{15}h^{-1}M_{\odot} \Rightarrow 10^{15}h^{-1}\mathrm{M}_{\odot}$

  Units must be in roman!

- Dark Energy experiment

  No reason to capitalize "Dark Energy".

- $h = H_0/100$

  Of course, units are missing. Which brings us to the Hubble constant...

Hubble constant

For decades, the value of H_0 was disputed; nowadays, we know pretty well its actual value. What is it?

1. $H_0 \approx 69\,\mathrm{km/sec/Mpc}$, or
2. $H_0 \approx 69\mathrm{km\,s^{-1}Mpc^{-1}}$, or
3. $H_0 \approx 69\,\mathrm{km\,sec^{-1}Mpc^{-1}}$, or
4. $H_0 \approx 69\,\mathrm{kms^{-1}Mpc^{-1}}$, or
5. $H_0 \approx 69\,\mathrm{km\,s^{-1}Mpc^{-1}}$, or
6. $H_0 \approx 69\,km/s/Mpc$, or
7. $H_0 \approx 69\,\mathrm{Km\,s^{-1}Mpc^{-1}}$, or
8. $H_0 \approx 69\,\mathrm{km\,s\,Mpc^{-1}}$, or
9. $H_0 \sim 69\,\mathrm{km\,s^{-1}Mpc^{-1}}$.

- ~100000 $\Rightarrow \sim 100\,000$

  First, spacing was incorrect, as not the whole expression was in math mode. Second, numbers with more than four digits should have small spacings to separate thousands. Note, $100\,000$, not $100,000$.

- -90°C $\Rightarrow -90^\circ\,\mathrm{C}$

  Minus signs **must be** in math mode! Always! Also in tables. Plus spacing.

- point like sources $\Rightarrow$ point-like sources

  Hyphenation was missing. Rules for hyphenation can be difficult, but there are some clear cases: It is "the power-law spectrum", but "a power law was fit" and "the high-ℓ behaviour", but "an effect seen at high ℓ." Similarly, "we measure redshift-space distortions in redshift space".

Lay-out

LaTeX and associated macro packages usually give you a good format for text and equations; in most cases, fiddeling with it does not lead to improvements. Some rules:

- Do not end lines with double backslashes to get a new paragraph. Simply use a blank line in the source code.
- There should be no blank line before or (particularly) after a displayed equation in your input file unless you really intend to start a new paragraph.
- **Do not ever** try to make equations fit by using small fonts (or other manipulations of fonts)!

$P(k)$ and $\xi(x)$

The power spectrum of galaxies $P_g(k)$ is related to the two point correlation function of galaxies $\xi_g(x)$ through a Fourier transform,

$$P_g(k) = \int d^3x \xi_g(x) e^{i\boldsymbol{xk}} = 4\pi \int dx x^2 (\frac{sin(k \times x)}{k \times x}) \xi_g(x),$$

(see, e.g., Peacock (1999)). Euclid will measure $N_z \sim 5\,10^7$ galaxy redshifts and obtain a $8-\sigma$ detection of BAOs for galaxies with mean redshift $< z > \sim 1.6$. The number of galaxies for measuring shear, N_s, will be much larger, $N_s >> N_z$.

This text is pretty much as bad as it can get. Can you figure out why?

- $P_g(k) \Rightarrow P_{\rm g}(k)$

  Use roman fonts for tags or labels in sub- and superscripts, e.g., $n_{\rm e}$, $z_{\rm rec}$, and for multi-letter operators. Hence, whenever a sub- or superscript denotes an abbreviation or a word, it *must* be in roman. If a sub- or superscript denotes a variable, it *must* be in italics. This avoids ambiguities by always explicitly distinguishing variables from abbreviations. For example, z_i might be the ith redshift under consideration, while $z_{\rm i}$ might be defined as the reionization redshift or the initial redshift at which a simulation starts.

- Derivatives, e and i

$$dx \Rightarrow {\rm d}x\ ; \qquad e^{i\boldsymbol{xk}} \quad \Rightarrow \quad {\rm e}^{{\rm i}\boldsymbol{x}\cdot\boldsymbol{k}}$$

  The differential operator must be written in roman, e.g., ${\rm d}y/{\rm d}x$. The Euler number ${\rm e} \approx 2.718$ and the imaginary unit ${\rm i} = \sqrt{-1}$ must also always be in roman. The vector product needs to be written with a 'cdot'.

- Spacings:

$$\int d^3x \xi_g(x) e^{i\boldsymbol{xk}} \quad \Rightarrow \quad \int {\rm d}^3x\ \xi_{\rm g}(x)\, {\rm e}^{{\rm i}\boldsymbol{x}\cdot\boldsymbol{k}}$$

- $sin(k \times x) \Rightarrow \sin(kx)$: Always use the standard LaTeX commands for operators (`sin, cos, tan, exp, ln,` etc.). Do not use `times` or `cdot` for normal multiplication; a small space is sufficient.

- Specify integral limits:

$$\int \mathrm{d}^3x \;\Rightarrow\; \int_{\mathbb{R}^3} \mathrm{d}^3x \;; \quad \int \mathrm{d}x \;\Rightarrow\; \int_0^\infty \mathrm{d}x \;.$$

- Size and nesting of brackets

$$\left(\frac{sin(k \times x)}{k \times x}\right) \quad \Rightarrow \quad \left[\frac{\sin(k\,x)}{k\,x}\right] \;.$$

  The usual ordering of brackets is $\{[(\ldots)]\}$. Only deviate from this if there is good reason, and never use the same type for adjacent brackets. Make sure that the vertical size of brackets corresponds to the vertical size of what they bracket.

- (see, e.g., Peacock (1999)) $\Rightarrow$ (see, e.g., Peacock 1999)

  No parenthesis within parenthesis. Similarly: "As was shown in Eq. (6), we ...", but: "... can be derived (e.g., from differentiating Eq. 6), so that ..."

- $5\,10^7 \Rightarrow 5\times10^7$: *Numbers* with powers of 10 shall be written as, e.g., 6.3×10^4, rather than $6.3\cdot10^4$ or $6.3\,10^4$. Reserve the operator `cdot` for the scalar product of two vectors.

- $8-\sigma \Rightarrow 8\sigma$, or possibly $8\,\sigma$, but not with hyphen, and **certainly not** with a minus sign!

- $< z > \Rightarrow \langle z\rangle$: you must use the `langle/rangle` macros.

- $N_s >> N_z \Rightarrow N_\mathrm{s} \gg N_z$

  use `gg` and `ll` for $\gg$ and $\ll$. Also note that 's' is an abbreviation for 'shear', but 'z' is not an abbreviation for redshift, but the variable z.

Therefore:

$$P_g(k) = \int d^3x\xi_g(x)e^{i\boldsymbol{xk}} = 4\pi\int dx x^2(\frac{sin(k\times x)}{k\times x})\xi_g(x),$$

$$\Rightarrow P_\mathrm{g}(k) = \int_{\mathbb{R}^3} \mathrm{d}^3x\;\xi_\mathrm{g}(x)\,\mathrm{e}^{\mathrm{i}\boldsymbol{x}\cdot\boldsymbol{k}} = 4\pi\int_0^\infty \mathrm{d}x\;x^2\left[\frac{\sin(k\,x)}{k\,x}\right]\xi_\mathrm{g}(x),$$

Final comments

- Aim towards becoming a good writer; try to avoid issues from the beginning, instead of correcting them afterwards.
- Being a good writer pays off: Well-written papers are more likely to be read and cited.
- Become aware of correct writing early on; once you get a bit used to it, it will be natural and easy, and saves you (and others) work lateron.
- **If a paper has a degree of sloppiness, how should one trust that the scientific analysis has been done with care?**
- Go to a few random papers on astro-ph and find their style mistakes – it's fun!

The end

- Thanks to Patrick Simon for comments on these slides!
- Thanks to my present and former collaborators and students, from whom I've learned so much.
- I found the slides from Sami Solanki ("How to write a scientific paper") very informative; see
  `www.mps.mpg.de/3963330/Paper_writing_2013_IMPRS-HANDOUT.pdf`
- A book recommended to me is David Lindsay, "Scientific Writing = Thinking in Words", Csiro Publishing, 2011
- **Thank you for your attention! Questions please!**