Writing papers in astronomy (and physics?)

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Link: “Short seminar on paper writing”
https://gherczeg.github.io/writingcourse/

Photo by PhD student Ma Chao

Have you written a first author paper?

- If yes, raise your hand

Goals of this lecture

Follow along!
Link: "Short seminar on paper writing"
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- Think about the standard structure of papers
  - Standard ApJ/A&A/MNRAS paper
    - High impact journals, physics, other fields have some differences
    - My background is observational, but similar concepts apply across all science areas (with field-specific differences)
- Provide you with some tools to improve your editing
  - If you improve as an editor, you will improve as a scientist
    - Better able to see strengths, weaknesses in logic
    - Where do ideas come from? Logical gaps lead to future papers!

I will skip some material!

Raise your hand if you hate writing

Follow along!
Link: "Short seminar on paper writing"
https://gherczeg.github.io/writingcourse/

Raise your hand if you enjoy your research

Follow along!
Link: "Short seminar on paper writing"
https://gherczeg.github.io/writingcourse/

Why write papers?

- Communication of results is a fundamental part of the scientific method!
  - And also for your career!
  - "If you haven't written it, you haven't done it."
  - "If you write it, but no one reads it, then you still haven't done it."

- Technical writing enables (self)-interrogation
  - **Editing: critically evaluate your own logic**
  - **Where do ideas come from?**

- **Share the joy and excitement of your discovery with others!**

Throughout this lecture,

please interrupt me when you have questions!

Some slides will be only very

briefly covered or skipped entirely

How to learn to write?

It's hard! Practice makes perfect, or at least better

- Mostly by copying approaches that others take.
  - Astronomy papers have a specific flow that readers expect.
  - Flow makes following arguments easier
- Courses
- Sometimes reading!
- Sometimes editing
  - don't just implement comments, learn from them!
  - Overleaf is a tool and a problem
  - LLMs are a very powerful tool, and a serious problem

Practice as a writer and **as an editor**!

Problems with Scientific Writing

Most frequent problems:

- Dense & boring 对牛弹琴
- difficult to read
- grammatically sloppy
- **logic is unclear (maybe even to the author!)**

Goal: communicate by describing as simply as possible your methods and results

General rules

- There are guidelines but no rules.
  - It's reasonable for people to disagree with some things I teach
  - Think about your logic and structure, then make decisions tailored to your paper
  - There is a recommended process
  - writing is mostly an art, not an exact science. Every paper has its own needs.

- Logical flow is most important and focus of today
  - Focus, focus, focus!
  - Tools can help with grammar

- EDITING: critical to good writing
  - When first writing, "throw up on the page"
  - If easier for you write in Chinese, translate, then edit!
  - Copy structures from others!
  - Don't try to become a good writer, **try to become a good editor.**

- Tell a story of discovery (but not in chronological order)
  - **Show, don't tell**

The Writing Process

- Work on global (big picture) issues first
  - conceptual or developmental level
  - content, organization
  - structure, logic
  - assumptions, evidence, arguments, relationships

- Work on local issues second
  - paragraph, sentence, word level
  - reconsider style, terminology
  - pay attention to mechanics: grammar, spelling

Beginning Considerations: your topic

Need something to write about!

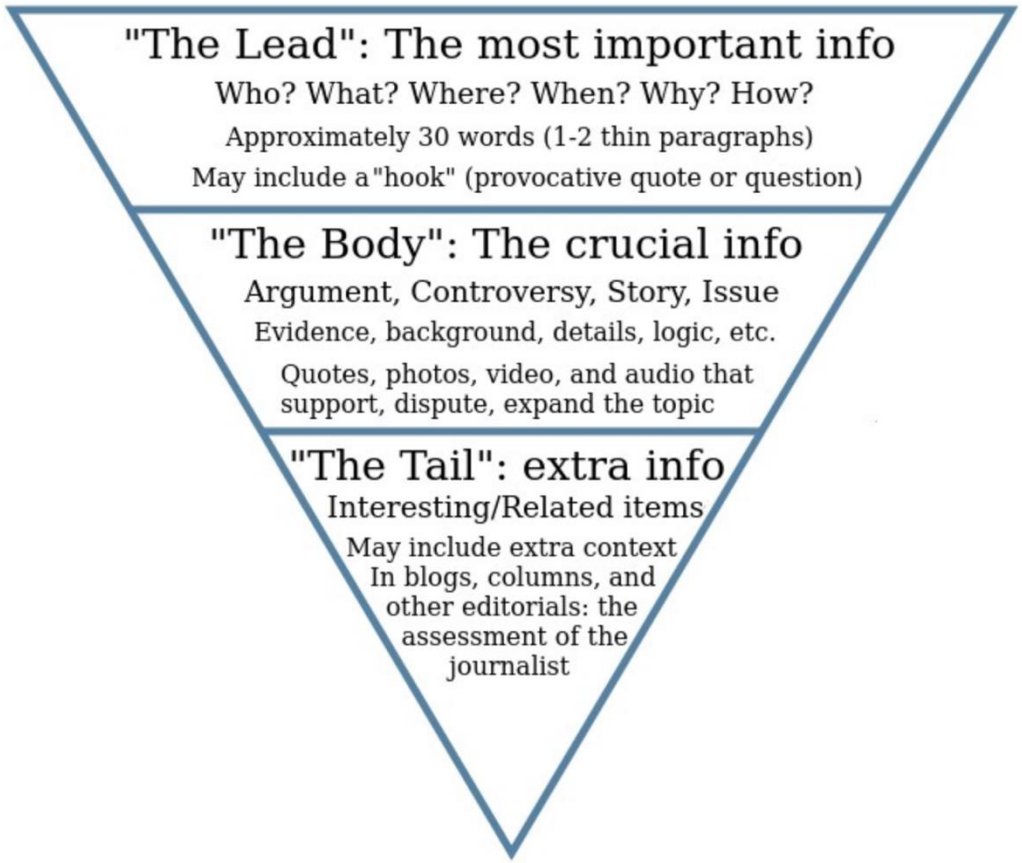
- Topic and details
- Expression of content in a single sentence
  - "thesis sentence":
    - Single sentence in abstract: what are your results+methods?
    - In proposals, this sentence is boldfaced and is critical
  - "elevator speech"
- Need to know your topic. In fact, **own it**.
  - This is not the goal of this lecture.
  - This *is* the goal of your PhD.

The purpose of writing: to convey and explain information

- Logical approaches
  - Chronological / narrative (avoid in papers)
  - Process / step-by-step (avoid in papers)
  - Problem and solution
  - Compare and contrast
  - Cause and effect
  - Definition and classification
- Every paper includes these each of these logical steps
- Astronomy papers have a specific flow that readers expect
  - Flow makes following arguments easier

Remember, readers are busy and will be lazy.

Logic: funnel flow structure



Funnel Flow or Inverse Pyramid

start big and get smaller

- This guideline applies both to the structure of a section and to each paragraph in the structure

DO NOT: build up to a surprising conclusion!

- This is not Avengers; conclusions come first!
- Both in abstract/introduction, but also in sections, subsections, and paragraphs

Start at the end: no cliffhangers

- Begin from the end, not the beginning.
  - Tell the story in plots, then explain the plot
- Figure out what you are trying to say!
  - Writing and ideas is an iterative process
  - Every paper has edits that require new analysis
- Be guided by the needs of the reader/user
- Follow the steps of an academic writing framework (outlining and logic)

Generic outline of a research paper

Focused on your story

- Title: orients reader
- Abstract: tells reader what happens
- Introduction: prepares reader with context/importance
- Observations/methods:
- Results: dig into details
- Analysis: apply results
- Discussion:
  - Connect analysis back to introduction
    - why are your results important?
    - May need to rewrite introduction!
- Conclusion: Summarize your results
  - What are the most important results
  - Repeat important limitations and caveats

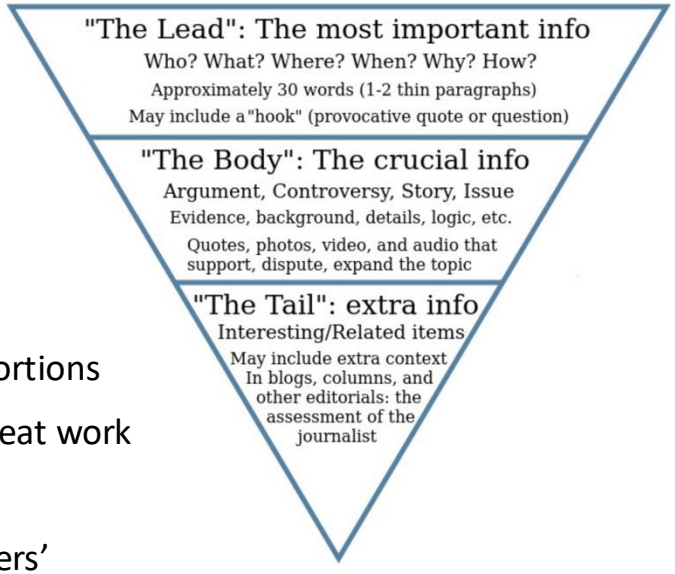
Generic outline of a research paper

- Title
  - Exact
  - Clear and complete, but succinct
  - Strong and noticeable or boring
- Abstract
  - Optional: one sentence intro
  - Key information expressed concisely
  - Enticing and inspirational
  - Descriptive

The title and abstract are the two elements that will attract readers to your work!

Generic outline of a research paper

- Introduction
  - context for your research
  - Sets up problem and how your paper will fit in



- Middle
  - Observations, simulation setup, equations
  - Data reduction or equation development
  - Analysis techniques and figures/narrative, in digestible portions
  - All of above in enough detail for a trained scientist to repeat work
  - Findings (results) and interpretation
  - Discussion of and implications of results; compare to others'

- End
  - Summary, conclusions, future work (nothing new)
  - Acknowledgements
  - References

Introduction

- Motivation and importance of problem (the “why?”)
- Background, history, context, previous literature (theory)
- Current state and unknown/s (the questions)
- What and how of current contribution (the hypothesis)
- Approach, scope and limitations (the objective)
- Layout of presentation (the roadmap)

The introduction prepares the reader and generally follows a cohesive “funnel flow” or “inverse pyramid” structure.

Be careful when getting carried away in the introduction. Often that extended material belongs elsewhere, especially the discussion.

Generic Introduction

- Paragraph 1: Big picture, ends with some general need or problem
  - Observational papers often frame with theory
  - theory papers often frame with observations
- Paragraph 2: Develop the importance of the problem in context of field
  - Flow to specific problem
- Paragraph 3: Previous efforts to address this problem
  - How were they successful? What's missing?
- Paragraph 4: Start to develop your approach
  - what are you building on?
- Paragraph 5: Roadmap for paper

Activity: reverse outline the introduction of the next paper you read.

You will see that 95% of all papers follow the same flow!

Observations (methods)

- Describe fully the parameters of the observations, simulations, or codes
  - Why did you choose the setup or sample?
  - Details matter here (seeing, calibrations, accuracy)
  - How were data reduced? Sky subtraction, nods, etc.
- Usually past tense
  - other parts of the paper usually present tense
- Be sure to provide appropriate citations and credit
  - Download data? Who took it? Has it been previously published?
  - Survey data? Describe the survey!
  - 2MASS, WISE, Gaia: all have citations!
  - Codes were written by someone
  - Instruments were built by some group of people
- Use subsections to split different data types
- **Enough detail for paper to be repeatable**

Results: empirical

- Function: objectively present key results in an orderly and logical sequence
  - Data-driven: usually without interpretation
  - Logic often organized around Tables and Figures
    - Make Tables and Figures first, build around them
- Style: concise and objective
  - Interpretation left for “analysis” section
- Usually few citations (methods-based citations)
- What are the key empirical results?
  - Highlight them!
  - Be sure to describe negative results and assumptions

Results: empirical

- Key results: put up front
  - often in a summary!
- Subsections: different results
  - Each subsection should focus on one topic
  - Roughly 3-6 paragraphs/subsection
  - Start with the results in the first paragraph
    - Next paragraphs support those results
- Text describes figures and tables
  - Leave details of Figures (the red line shows…) for caption; scientific description for text
  - For key results, if they are controversial, then people will only believe them if they can see the results for themselves
    - People will believe boring results that conform to expectations
- Sometimes: Results split into multiple sections

Analysis

- Results: data-heavy
- Discussion: broad interpretation and importance
- Analysis: connects results and discussion

- Broaden out from results
  - Physical interpretations?
  - Equations for interpretation?
  - Modeling observations (or observational predictions from models)

- Logical flow to arguments (as everywhere):
  - Conclusions at front
  - Each subsequent paragraph develops and demonstrates those conclusions

- Sections/subsection titles can tell a story

Discussion

- Place your results in context of other work
  - Do your findings agree with what others have shown?
  - If not, do they suggest an alternative explanation or perhaps a unforeseen design flaw in your experiment (or theirs?)

- Do your results provide answers to your testable hypotheses?
  - If so, how do you interpret your findings?

- Given your results+analysis, what is our new understanding of the problem you investigated and outlined in the Introduction?
  - If warranted, what would be the next step in your study, e.g., what experiments would you do next?
  - Connect back to Introduction (perhaps including rewrite of intro)
  - Why is this important?

- Some speculation is ok (sensationalism is not ok)
  - Always identify “speculation” as such: preferred interpretations that are consistent with data
  - Always identify assumptions and caveats clearly

Conclusions

- Summarize main points
  - Include most important caveats
  - Never add new results or ideas
- Some reminder of comparisons to previous works
- links from the conclusions back to the paper can help those that read the conclusions first, especially for long papers
- Some readers will skip to the conclusions, so make sure that:
  - detailed enough to communicate information (more than abstract)
  - Interesting enough to draw the reader to important points
  - Highlight new ideas in paper and anything controversial
  - Ensures that the most important caveats also described

Appendix: for random topics that would otherwise break your focus

- Details of a source or a code
- Investigations that are tangential to main results
- Extras
  - Data
  - Plots
  - Tables
  - Formula and derivations

Section titles and sub-titles

- “Results”, “Analysis”, “Discussion”
  - no information

- Descriptive title sections
  - Invites readers in
  - Tells readers where information is located
  - Provides readers an obvious outline

- Parallel subsection titles when possible

Vague section headings hide meaning

Parallel arguments

- Always keep orders of arguments the same

- Keep flow parallel
  - If two competing ideas are presented in Section 4.1 and 4.2, then try to have paragraphs match
    - Sentence by sentence can match structures

Big picture outlines

- Section/subsection titles!
- Plots and tables
- Summaries and conclusions
- Guide the reader in multiple, parallel outlines

Outline your draft and sections/subsections early!

(you will revise later)

Starting the Document

Start from Outline OR Figures (OR Introduction)

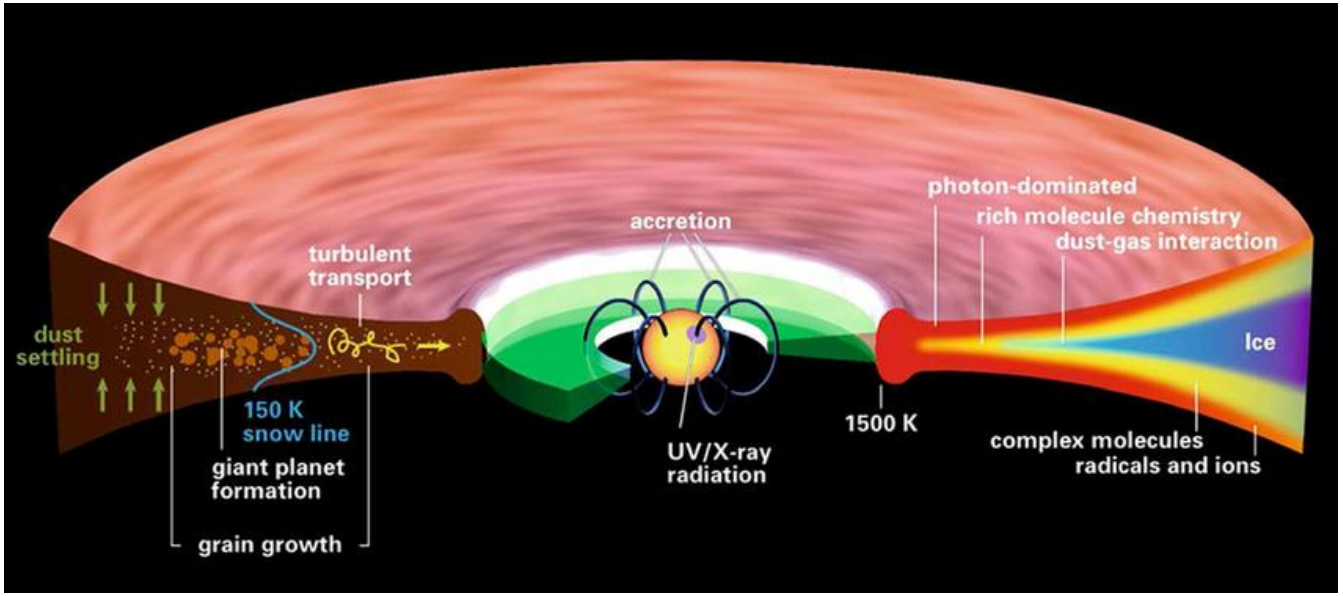
- Adjust and refine the outline as you write
- I often start with figures, then write text to explain the figures, then structure the text
- Remember that less is more!
  - Sometimes ideas need to be cut
  - Focus reader attention on main points and supporting logic
  - Provide enough detail, but too much gets confusing
- Make sure the Title and Abstract
  - reflect content of paper
  - draw both people and search engines to your work
  - I usually write the abstract and finish the title as the last step in the draft

Visuals: **Show, don't tell!**

- helps reader interpret, remember complex information in simplified form
- can show:
  - how analysis looks or works
  - how analysis or data are organized or actions are performed
  - how elements or data are related
- visuals should be audience-centered
  - keep as simple as possible
  - include explanatory labels, title, caption
  - use visuals to enhance your story
  - Should stand on own: can I see story without reading anything?
- should use fewest number of plots that tell the story

Visuals

- Most readers look at visual first
  - Clear captions to help readers who are not reading the text
  - Some exceptions: look at visuals only if logic or results are surprising
- Visuals need to tell the story
  - Story is told in text and in visuals
- Not just plots, also illustrations
- Spend time on the plots! Make them clean and easy to understand!



Henning & Semenov 2013

Guidelines for Figures

- Visually appealing and clear figures
  - place independent variable on abscissa (x-axis) and dependent variable on ordinate (y-axis)
  - ensure figure points, lines, axes, scales are **easy to interpret**
  - No “confusograms”
  - legend/caption should be descriptive of content
  - Thick lines!!! Large fonts!!! Clear data points!!!

- Not sure if your plot is easy to understand?
  - Show your friend and do not give them any context!
  - Figure should explain itself, caption is for details

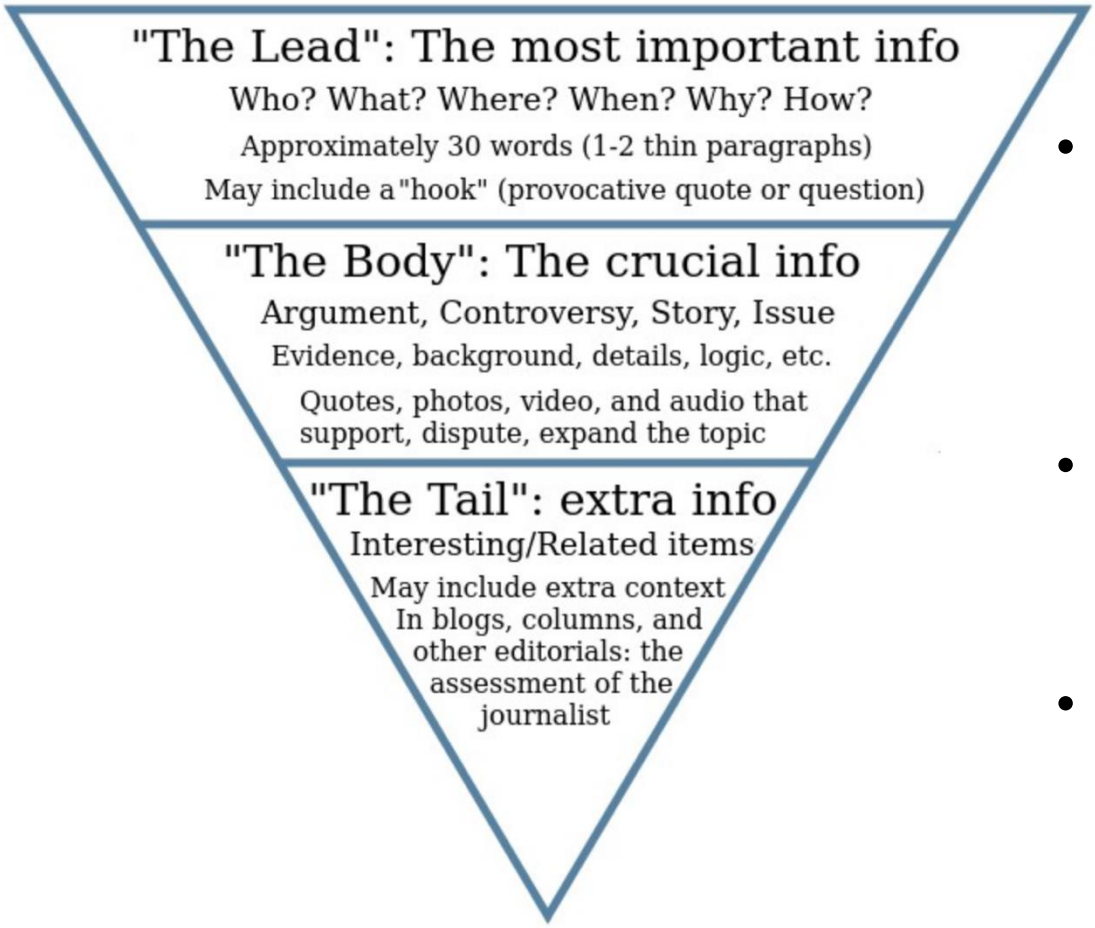
- Outlining: tell the story through figures
  - Results/analysis: describes the analysis that goes into the figures
  - Discussion: interprets the figures

Guidelines for Tables, Equations

- Tables
  - keep table structure simple: how will people use your table?
  - place familiar content on left and new important information towards right
  - design table title to identify specific topic
  - label dependent variables in column headings and independent variables in row headings
  - Include DOI/links!
  - Long data catalogs? check with co-authors to make sure they can use it!

- Equations
  - treat equations and formulas as part of text
  - define variables
  - state assumptions
  - Keep as simple as possible
  - For most papers, leave derivations in the Appendix

Paragraphing: outline each subsection



- Start subsections with an outline and conclusions
  - (not always, but often)
- Subsequent paragraphs support those conclusions
- Readers should not be surprised

Paragraphing

- Different types of paragraphs
  - Introductory: sets stage
  - Supporting: traditional stand-alone content
    - Topic is clear
    - Unity of sentences in developing topic
    - Coherence of sentences is establishing conclusion
  - Transitional: brief; provide logical continuity
  - Concluding: wrap up

- Paragraphs should flow together
  - Look for opportunities for parallel structures
  - Connect first sentence of paragraph with previous paragraph (transition sentence)

- Each paragraph should FOCUS on a single topic
  - Usually identified in the first sentence of the paragraph
  - Then get more detailed in that paragraph

Activity: reverse outline a paper that you need to read!

Shape information within paragraphs

- Topic sentence (optional) provides overview
  - **Begin with the important (inverse pyramid) and flow to details**
  - **First sentence guides reader for the focused topic of the paragraph**
- Supporting sentences expand, clarify, provide details
- Maintain consistent point of view
- Maintain consistent verb tense
  - Usually present tense for work done in paper
  - Past tense for actions at a specific time in past (“we observed”)
  - Some differences based on author preferences (but stay consistent)
- Repeat key terms:
  - Continuity to link ideas
- Use links within sentences, transitions between sentences to provide logical flow:
  - therefore, thus, consequently, as a result; however, nevertheless, alternatively, unfortunately, instead, in contrast; in addition; in particular, finally, furthermore, moreover, for example, currently…. [never use ”Besides” without a nounce, ie, “Besides this data”]
- Each sentence: what is it about and how does it move the argument along?
  - Eliminate irrelevant information
- Sentences must be shorter than 35 words (subject/verb/object+ 1 clause max)
- Paragraphs should be shorter than 150 words.

Tasks during Revision

- reorganize information
  - often move entire paragraphs!
- deepen or extend analysis
- narrow focus, scope
- add data and supporting information
- adjust details of argument
- eliminate repetition and/or restating the obvious
- allocate space to highlight or diminish points

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Emphasis of Important Points

- Repetition without redundancy
- Short sentences, dashes, colons
- Dependent clauses, subordination
- Lists
- Figures / Tables
- Look for opportunities for parallel arguments
  - Consistency facilitates understanding

Strengthening sentences

- Clear language helps reader understand logic

- Do not worry about writing strong sentences
  - Write sentences as they come to you
    - (or as translation software spits them out)
  - Strengthen sentences during editing!

Language: clear

- say what you mean
  - don't say what you don't mean
  - Don't say anything else!
- avoid ambiguity, which can arise with poorly chosen words
  - Jargon
  - pronouns

    Never use "This" without an immediate noun

    position of modifiers (e.g., does "only" modify the right word?)

- keep to the simplest words and sentences that do the job, without too many:
  - Syllables
  - Words
  - Prepositions
  - Semicolons
  - Ideas

Language: concise and fluid

- Concise
  - establish importance
  - eliminate excessive detail, repetition, and redundancy
  - attention to wordiness and run-on sentences
  - no lethargic sentences that just don't go anywhere
  - Limit clauses: subject/verb/object+1 clause max

- Fluid / Fluent
  - smooth
  - not stagnant or discontinuous (transitions!)
  - combine related ideas
  - use parallel structure
  - move from common ground to the unfamiliar/beyond

Lead with familiar; put new information last

- consistently begin sentences with familiar (old) information and conclude sentences with unfamiliar (new) information

- What happens when you begin a sentence with new information?
  - Your reader gets a new idea without any context and may link the idea to the previous sentence or to other thoughts
  - The reader has guided themselves, perhaps away from the point you are making

- Think of this in the same way as writing your introduction: the very first sentence is something that all of your readers will know
  - Provides readers with something familiar to start the paper

Keep subjects near verbs

- A sentence tells readers: who and what action

- The sentence will be straightforward to understand when the subject and verb are close to each other

Language: active versus passive

- Do not use: "It is", "there are"
  - some rare exceptions, as with everything
  - Your sentences have subjects!
- Do not use: "This" without a noun immediately after
- Action verbs are more descriptive
- Avoid "we" (not at all costs):
  - your subject is science, not the scientists
  - Challenging to have an active voice without "we"
  - Balance needs is difficult

Use passive voice rarely

- Active: The dog chased the ball.
- Passive: The ball was chased by the dog.

Active: more straightforward. Subject does an action.

Also avoid excessive use of “we” (let science be the subject)

Let the science be the subject!

Editing technique: underline all “we”; at most one “we” per paragraph

Activity: Underline the noun and verb of every sentence. Is the verb active? Is the subject noun doing the verb.

Use passive voice primarily when you want to say something indirectly

- Sometimes it’s more polite
- Speculation can be passive

- Put actions in verbs

Action	Nominalization
to regulate	regulation
to analyze	analysis
to occur	occurance
to understand	understanding
to investigate	investigation
to delineate	deliniation
to perform	performance

We performed an analysis on the data

$\Rightarrow$ We analyzed the data

Verbs should be actions!

Ineffectual phrases

- Note that
  - Worse: “It should be noted that”
  - If something should be noted, it’s in the paper. If something shouldn’t be noted, it’s not in the paper.
- It is important to realize
  - If an idea is important, do not tell me it’s important, **describe why it’s important**
- So-called (sometimes I like this, but it’s snarky – best to avoid)

These are all pointless phrases and should be deleted

(but we all have our own style, so sometimes it’s ok)

Parallel Structure in lists

- Seonjae likes hiking, swimming, and to ride a bicycle

⇒Seonjae likes hiking, swimming, and riding a bicycle

or

⇒Seonjae likes to hike, (to) swim, and (to) ride a bicycle

Also important in addressing topics: parallel sentence structures for similar ideas

Quantify comparisons

- The mass of galaxy A is different than the mass of galaxy B
- Galaxy A is more massive than galaxy B
- Galaxy A is three times more massive than galaxy B

Quantify comparisons (when possible)

Avoid almost all acronyms
(may differ for other fields)

- Your advisor may differ. That's ok, your advisor is correct!
- Words convey meaning! Use them to guide readers
- Exceptions:
  - Telescopes/Instruments
  - ISM, AGN, FRB (but not many more – these are "universal")
  - PDR: photon-dominated? Photo-dissociation? Just PDR…
  - MRI, PAH, COM: very complicated to say, acronym facilitates meaning

- Unsure? Ask a friend who is out of your subfield
  - Do they know what you mean, without context?
  - If not, are you writing PAH, COM, or MRI? If so, ok…
    - What's a PAH? And nobody can say MRI.
  - Otherwise, write out the science.

Omit needless words

- Phrases to avoid:
  - Note that
  - It should be noted that
  - Respectively
  - It is important to realize/it is well known
  - So-called

Use few adjectives/adverbs

- “Very” is very overused
  - Especially for Chinese writers
- “very interesting”, “very important”
- “extremely”

Omit words that stress how good your analysis is!

- ”carefully”: is it really?
  - If you describe details, the reader will see and understand the care
- Figure 3 clearly shows: does it really?
  - If the Figure is clear, you don’t need to insist
- Proven, doubtless

These words are “red flags” for me

Prefer simple words

Word Complexity

Instead of	Consider
elucidate	show
putative	(nothing)
methodology	method
utilize	use
etiology	cause

“important”

- Don’t tell the reader that something is important.
- Describe to the reader **why** that thing is important.

Excessive hedging

- “Our results suggest that our method may possibly identify highly obscured quasars”
  - “suggest”, “may”, “possibly”
  - Some hedging is good, but “may” or “suggest” is sufficient.

Demeaning adverbs

- “obviously”, “clearly”, “undoubtedly”, “well-known”
  - These words are not helpful
  - Ideas clear to you may not be clear to the reader

- Be specific in pointing to results
  - “Figure 5 clearly shows that…” is a red flag.
  - Show me, don’t tell me

When to use “the”

- https://owl.purdue.edu/owl/general_writing/grammar/using_articles.html

- “The galaxy”: a very specific galaxy
- “A galaxy” or “Galaxies”: general term
- [still, often not obvious]

- Uncountable and unspecific: do not use A/The
  - ”The data provided information needed to identify”
  - “The data provided the information we needed to identify…”

Few/a few: opposites!

- “Few students attended class”: negative
- ”A few students attended class”: positive

(sometimes I hate English)

Priorities for sentence construction

1) Complete sentence
2) Not a run-on sentence
3) Sentence and language is simple
4) explaining why something is important
   - Important that the logic is there, even if the idea needs to be split into two sentences
   - Show, don't tell (but ok to split if needed)
5) subject close to the verb
6) Familiar information first, new information last
7) Fit to surrounding sentences

   Don't jump around – focus!

   Transition from one idea to the next

Punctuation rules: have sentences be read one way

- separate ideas into individual sentences
- Pauses when you speak/think
  - Provide traffic signals for readers
- Colon: introduces a formal list, long quotation, equation, or definition.
- Semi-colon: separates complex items in a list
- Semi-colon: a semi-colon either joins two independent clauses (closely linked in thought)
  - Common saying: you can use a semi-colon six times in your life. Do you want this to be one of them?
  - Personally, I like semi-colons, but they are difficult to use.
  - Just do not use them!
- Comma: a comma separates details in a sentence.
  - In a complex sentence, if you have two distinct subjects, use a comma before the "and";
  - if subject is the same for both verbs, do not use a comma
- Dash: acts as parenthesis to separate items that cannot be separated by a comma
- Use parentheses rarely!

Tasks while Editing

- correct any remaining weaknesses in organization
- improve coherence / transitions
- drop unnecessary information and eliminate “wordiness”
  - “when in doubt, cut it out” – paragraphs, sentences, words
  - goal is more succinct without losing breadth, depth, or complexity
- create “audience appeal”
- improve sentence structure and correct grammar
- improve vocabulary and word choice
- finalize graphics (tables, figures, pictures, etc.)
- provide or adjust visual aspects of text (title, headings, layout, font, etc.)

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Structural edits

- Does the structure flow?
  - Try to move all measured quantities to Results
  - Are sections and subsections focused?
- Missing logic?
  - Any data or arguments need to be added
- Can readers see what is coming next
  - Add summary paragraphs at beginning of sections
  - Add intro paragraphs in subsections
  - (try to avoid too much repetition)
- Don’t do everything
  - Cut papers down to size
    - nobody reads 20 page papers (definitely not 30 page papers)
    - Shorter papers can be easier to write
  - Focus your arguments
    - Use appendices for random tangents, barely relevant details
    - Short paragraphs and focused subsections
    - Use subsections to frame and outline

Emphasis of Important Points

- Repetition without redundancy
- Short sentences, dashes, colons
  - Sometimes a short sentence stands out
- Dependent clauses, subordination
- Lists – items!
  - Bullets (\itemize) can be ok
  - Order as (1), (2), (3) or (a), (b), (c)
    - Parallelism: Discuss items in same order!
- Figures / Tables
  - Also their placement in the text

Language editing

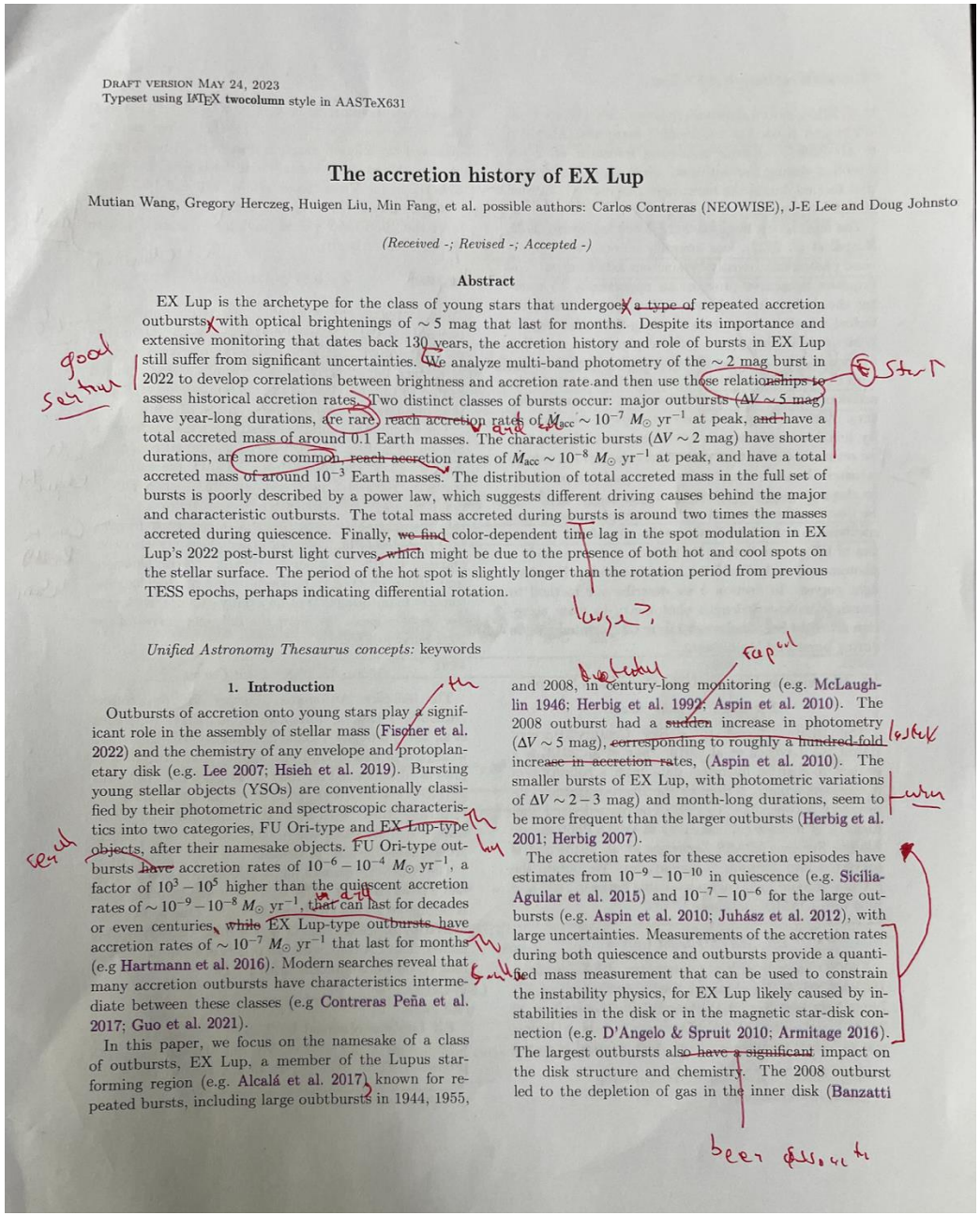
- Separate from structural and science edits
  - Cannot edit everything at once
- Paragraphs and sentences:
  - look for opportunities for parallelism
- Read sentences out loud! If the sentence sounds awkward, it probably reads awkwardly
- Editing Techniques:
  - Read out loud
  - Rely on others to edit
  - Can always share drafts with each other
  - Underline looking for different things

Underlining

- Noun/verb should go together
  - Singular/plural
  - Also should be close in the sentence
  - Underline subject/verb in every sentence!
- Underline new information in the sentence
  - Is it at the end of the sentence?
- Comparisons: quantified?
- Clauses: more than one in a sentence?
  - Subject/verb/object plus one clause! Limit “and”, “which”, etc.
- Every verb to look for actions
  - Underline and rewrite every “there are” or “it is”
  - Passive voice or active voice (where is the subject of the sentence? – hopefully at the beginning!)
- Underline types of words
  - “we”
  - Nominalizations (where actions are verbs,
  - Hedge words (suggest, may, etc.)
  - ”And”: never start a sentence with “and”

Editing Figures and Tables

- Are Figures clear? Readable?
  - Large fonts, thick lines
  - Keep simple
- Are Tables useable?
- Are they located where you want them?
  - Usually finalize at end, but it annoys co-authors to see them in random places
- Spend a lot of time on your most important figures!



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The accretion history of EX Lup

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Abstract

EX Lup is the archetype for the class of young stars that undergoes a type of repeated accretion outbursts with optical brightenings of ~ 5 mag that last for months. Despite its importance and extensive monitoring that dates back 130 years, the accretion history and role of bursts in EX Lup still suffer from significant uncertainties. We analyze multi-band photometry of the ~ 2 mag burst in 2022 to develop correlations between brightness and accretion rate and then use those relationships to assess historical accretion rates. Two distinct classes of bursts occur: major outbursts ($\Delta V \sim 5$ mag) have year-long durations, are rare, reach accretion rates of $\dot{M}_{\rm acc} \sim 10^{-7}\ M_\odot\ {\rm yr}^{-1}$ at peak, and have a total accreted mass of around 0.1 Earth masses. The characteristic bursts ($\Delta V \sim 2$ mag) have shorter durations, are more common, reach accretion rates of $\dot{M}_{\rm acc} \sim 10^{-8}\ M_\odot\ {\rm yr}^{-1}$ at peak, and have a total accreted mass of around 10^{-3} Earth masses. The distribution of total accreted mass in the full set of bursts is poorly described by a power law, which suggests different driving causes behind the major and characteristic outbursts. The total mass accreted during bursts is around two times the masses accreted during quiescence. Finally, we find color-dependent time lag in the spot modulation in EX Lup's 2022 post-burst light curves, which might be due to the presence of both hot and cool spots on the stellar surface. The period of the hot spot is slightly longer than the rotation period from previous TESS epochs, perhaps indicating differential rotation.

Unified Astronomy Thesaurus concepts: keywords

1. Introduction

Outbursts of accretion onto young stars play a significant role in the assembly of stellar mass (Fischer et al. 2022) and the chemistry of any envelope and protoplanetary disk (e.g. Lee 2007; Hsieh et al. 2019). Bursting young stellar objects (YSOs) are conventionally classified by their photometric and spectroscopic characteristics into two categories, FU Ori-type and EX Lup-type objects, after their namesake objects. FU Ori-type outbursts have accretion rates of $10^{-6} - 10^{-4}\ M_\odot\ {\rm yr}^{-1}$, a factor of $10^3 - 10^5$ higher than the quiescent accretion rates of $\sim 10^{-9} - 10^{-8}\ M_\odot\ {\rm yr}^{-1}$, that can last for decades or even centuries, while EX Lup-type outbursts have accretion rates of $\sim 10^{-7}\ M_\odot\ {\rm yr}^{-1}$ that last for months (e.g Hartmann et al. 2016). Modern searches reveal that many accretion outbursts have characteristics intermediate between these classes (e.g Contreras Peña et al. 2017; Guo et al. 2021).

In this paper, we focus on the namesake of a class of outbursts, EX Lup, a member of the Lupus star-forming region (e.g. Alcalá et al. 2017) known for repeated bursts, including large oubtbursts in 1944, 1955, and 2008, in century-long monitoring (e.g. McLaughlin 1946; Herbig et al. 1992; Aspin et al. 2010). The 2008 outburst had a sudden increase in photometry ($\Delta V \sim 5$ mag), corresponding to roughly a hundred-fold increase in accretion rates, (Aspin et al. 2010). The smaller bursts of EX Lup, with photometric variations of $\Delta V \sim 2-3$ mag) and month-long durations, seem to be more frequent than the larger outbursts (Herbig et al. 2001; Herbig 2007).

The accretion rates for these accretion episodes have estimates from $10^{-9} - 10^{-10}$ in quiescence (e.g. Sicilia-Aguilar et al. 2015) and $10^{-7} - 10^{-6}$ for the large outbursts (e.g. Aspin et al. 2010; Juhász et al. 2012), with large uncertainties. Measurements of the accretion rates during both quiescence and outbursts provide a quantified mass measurement that can be used to constrain the instability physics, for EX Lup likely caused by instabilities in the disk or in the magnetic star-disk connection (e.g. D'Angelo & Spruit 2010; Armitage 2016). The largest outbursts also have a significant impact on the disk structure and chemistry. The 2008 outburst led to the depletion of gas in the inner disk (Banzatti

Editing my own writing

- Paper close to submission
- Led by a then-masters student, but this part was mostly written by me
- Already heavily edited before this draft!
- Still lots of edits!
  - Red pen is not replaceable!

Small tips

- vs.: always spell out versus
- Combine sentences where it makes sense
  - Break sentences when they are too long
  - Single idea/sentence
  - “It is” ; “There are”: weak sentences, rewrite with science as the subject
  - Focus paragraphs, often with first sentence as overview
- Parallel arguments
- locates” => “is located”
- Avoid “besides,” (always needs to be followed by a noun, ie, “Besides this exception, ”)
- Relative terms need a comparison

Tools for editing

- Use Grammarly
  - Free version works well
  - Overleaf and MS underlines problems, so fix them!

- Use ChatGPT or similar tools for translation
  - Write in Chinese first, if English is a problem
  - If you use ChatGPT to create text (not just editing), you must check it and credit ChatGPT in the acknowledgements

- Your classmates!
  - You become a better writer by editing other people's work
  - My collaborators always see science with a different perspective and identify unclear writing/logic

How many of you have used LLMs?

How to use LLMs

- Often but carefully!
- Outline and connect ideas
- Grammar editing
- Important pitfalls
  - Details and phrasing of specific science
  - Citations
  - Overreliance on LLMs
    - We need to be able to criticize ourselves
    - Criticism is easiest done when we edit!

Suggested use of LLMs

(but we are all learning how to use them)

- Grammar editing (but with checks)
- Some coding (but with checks)
- Broad structures (with checks)
- Figures/cartoons! [I have no idea how to do this]

LLMs cannot replace the logic editing that is essential for your growth. **DO NOT BE LAZY ABOUT EDITING!**

- Be sure to acknowledge LLM use in papers, as appropriate
  - Acknowledgements are a good way to spread credit

Submission and referee process

- Submit your paper
- Editor finds an appropriate referee
  - Most people first referee in their postdoc
- Referee submits a report within 3-4 weeks
  - Average evaluation time: 4 weeks
    - Distribution has an unfortunately long tail out to 3 months
  - 6-7 weeks: email the editor!

I am always impressed with the dedication and seriousness of referees. Good reports take time and effort.

Referee report

- Address to the editor, not the authors
  - Never use “you”: report is to editor
  - Try to be positive, especially in first paragraphs
- Editor decides on acceptance/revision/rejection
  - Referee report makes recommendations

One minor suggestion for future reports: I tend to use "The authors" rather than "You" in reports for two reasons: the bureaucratic reason is that the referee report is technically for the editor to inform the editor of whether or not the paper should be accepted, it's not meant for the authors. The more practical reason is that when the referee report is harsh, using "you" can seem more confrontational, while "The authors" defuses some of that tension by being more impersonal and deflecting it to the editor.

Referee reports

- I usually ask authors to consider my comments
  - In some cases, I will request changes before the journal considers the paper for publication
- Try to find logical flaws, weak points, unclear figures and text, and other problems
  - What is the main point of the paper?
  - Why might the authors be wrong (but they are experts and know more, so they are probably right)
- Referees are not perfect!
  - I try to identify all potential problems, let the authors push back
  - It's the author's paper, not mine
- **CLARITY OF ARGUMENTS!**

How to respond to referee reports

- Clearly!
- Point by point!
- Separate Referee and Response clearly (color differences and/or in other ways)
- Clearly mark the changes! (sometimes I'll list CHANGES) in addition to REFEREE and RESPONSE
- All major changes identified at the start of your response to the referee

```
REFEREE:   As a general remark, the use of the word "background" across the
paper is sometimes misleading. It generally means actually "off-cloud",
instead of the more common meaning of "located behind". I suggest that the
authors use "off-cloud" instead of background when they mean that.

RESPONSE:  Changed throughout the text to "off-cloud", where we mean "off-
cloud", including in Figure 3.
```

How to respond to referee reports

- Deep breaths
  - Read quickly
  - Send to co-authors
  - Put aside until tomorrow

- Most referee reports help to better explain the results to the readers: this is helpful!
- Sometimes referee reports will be more challenging
- The authors are writing to the editor, not to the referee
- The paper is yours, do not let the referee force you to say something you don’t want to say!
  - Some exceptions and be pragmatic

Useful tools for refereeing

(these are included in email after accepting an assignment, but nobody reads the email)

A Referee Primer for Early Career Astronomers
https://baas.aas.org/pub/2022i051

AAS Author and Referee Guidance
https://www.youtube.com/playlist?list=PLFhVT3VzlwKrlUsUKc1YfqLeZ8_5JOkol

In addition, please be aware of the AAS ethics policy:
https://journals.aas.org/professional-and-ethical-standards-for-the-aas-journals/

Please be aware that at present the use of LLMs or other AI tools in preparing a referee report is a violation of confidentiality in the review process. The company providing the service is under no obligation to treat the text as confidential and will be using it for training purposes.

Referee process is just one aspect of peer review

- Referee process is not perfect!
- Most journals have one single referee
  - Not an expert on everything in your paper!
  - Some advantages/disadvantages to one referee
- How is your work evaluated by the collection of your peers, not a single person
  - Citations
  - Outreach to peers: talks, facebook, twitter

How to start your paper?

- A paper is built on many small steps
  - Don't write everything at once. Write a paragraph or outline a subsection today.
  - Or: pick a plot and write about what it says and how you analyzed the data to make the plot
  - Write in Chinese, then translate? (some advisors recommend against this; follow advisor's advice)
  - Copy the structure of a subsection or paragraph from a different paper, then replace the words with your own needs

- Outline! Plots, subsections, paragraphs
  - Inverse pyramid
    - Big concepts come first
    - Introduce what will come next

If you can’t get started

- Make your plots and tables
- Write about everything that went into those plots and tables

If you still can’t get started

- Read a related paper
- Copy their structure
  - Large scale or at the paragraph level

- Sometimes read papers for structure
  - You will pick up content along the way

If you really can’t get started

- You can!
  - Start the overleaf
  - Build a large structure
- Then go to small scales
  - Write about what you have done
  - Don’t write a full section: write a sentence, then another sentence, then a paragraph
  - How did you make your figure? Start with that.
- Turn your wifi off??? No wechat message interruptions!

How to continue?

- Edit your own work heavily and continually
  - Thesaurus/LLM when editing to avoid word repetition
  - Spend 10x as much time editing as writing
  - Underlining (noun/verb; ”and”, “we”)

- Learn from comments
  - LLM – ask why it made some changes
  - Overleaf!
  - Don’t blindly implement them

- Break paper into smaller pieces
  - If you try to finish your paper in two weeks, you won’t
  - Go home and finish a paragraph tonight!

Time allocation and your papers

- Write initial versions quickly!
  - Take your time in editing
- If you have been at your desk for an hour and have not made progress, move on to something else
  - This applies to writing and everything else
  - Your time is precious
- Don't be paralyzed by perfection
  - Perfect is the enemy of the good
  - Don't drive yourself crazy
- Focus on logic, not grammar (then run Grammarly)
- Work with others, accept criticism and feedback
  - Other people will strengthen your work
  - Identify flaws in logic
  - Add expertise that you lack – you cannot be an expert in everything
- ***Enjoy sharing your discovery with others***
  - **Own your PhD topic**. It's yours, know it and love it!
  - Goal: you are the expert teaching your advisor

What to do tonight?

- Start your overleaf
- Outline something!
  - Start simple
  - Copy structures from a similar paper
  - Outline your section
  - Ask deepseek to help outline (but not write!)
- Improve your figures
  - Please improve your figures!
- Make a cartoon
  - ChatGPT?

Resources

- Common Mistakes in Writing Astronomy and Physics Literature in English
  - https://arxiv.org/abs/1011.5973
  - Mostly in Chinese
- Writing Scientific Papers in Astronomy
  - https://arxiv.org/abs/2110.05503
  - https://www.astro.caltech.edu/~lah/ay31/
  - https://ui.adsabs.harvard.edu/abs/2022NatAs...6.1021K/abstract
- Writing Centers
  - https://owl.purdue.edu/
  - https://sites.duke.edu/scientificwriting
- Grammar editing (but cannot help with structure)
  - Grammarly
  - ChatGPT
- Each other!
  - Share drafts and proposals!