Academic Communication
in (Astro)Physics

Lecture 6: Academic Journal Papers II

Methods

Results

Discussion

Structure of a scientific paper

Opening → Challenge (Knowledge Gap) → Action → Resolution

Title, Authors, Abstract, Keywords

References

Acknowledgments

Descriptive information: helps readers search for an article.
Most people will only read these, so try to encapsulate the main story!

What is the context/background for this project?
How does it fit with the other research in the topic?
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WHY?

What did the author(s) do to answer the question?

HOW?

What did the author(s) find?
This is often shown in figures and tables.

WHAT?

Did you answer the question?
What is the significance of your results?
How does this fit in with what is known about the topic?
Are there any limitations/remaining open questions?

SO WHAT?

Materials the author(s) cited when writing this paper.

Thank the reviewer, colleagues, funding agencies, etc.

Methods

Methods

What did the authors do to answer the question formulated in the introduction?

- This is a great starting place for writing a paper!
- Describe what you did.
- Should not include interpretation or results.
- Provide enough details and references to enable a trained scientist to evaluate or repeat your work.
- Provide literature references where needed, name codes/ software used where relevant.
- Indicate any statistical analysis performed.

Methods: Structure

- **No rigid structure:** the Methods part of a paper can consist of
    - a single section (if straightforward enough), or
    - a section containing subsections, or
    - multiple sections of equal hierarchical level.
- If you break it up into subsections, order those **logically**: e.g., most to least important, chronologically.
- Your paper will likely be skimmed by more people than read in depth – so logically organizing in subsections with **clear headings** is probably helpful.
- Use **LD structure (Lead-Development)** for paragraphs: topic sentence with main point, then develop the details.
- **Signal and link the different topics** (use topic sentences and transitions).
- In terms of structure, there are many ways of getting the relevant information across – we'll look at some examples. **If you're stuck – look at similar papers for ideas!**

Methods: Structure

Example #1: Generic Observational Astronomy

- Section 2: Sample, Observations, and Analysis
  - Section 2.1: Sample
  - Section 2.2: Observations
    - Section 2.2.1: Imaging
    - Section 2.2.2: Spectroscopy
  - Section 2.3: Data reduction
  - Section 2.4: Statistical Analysis

Example #2: Generic Theory/Simulations

- Section 2: Simulation
  - Section 2.1: Simulation parameters, equations
  - Section 2.2: Simulation procedures
  - Section 2.3: Simulation analysis

Example #3: Generic Analytic Theory

- Section 2: Model
  - Section 2.1: Assumptions
  - Section 2.2: Equations
  - Section 2.3: Method of calculation

Slide adapted from Alice Shapley

The Origin of the Mass-Metallicity Relation: Insights from 53,000 Star-forming Galaxies in the Sloan Digital Sky Survey

Tremonti et al., 2004, ApJ 613, 898

A Simple Model for the Absorption of Starlight by Dust in Galaxies

Charlot & Fall 2000, ApJ 539, 718

Methods: How much detail?

- Provide enough detail that someone could reproduce your experiment.
- Make a judgement about whether details are relevant.
- Make sure the reader can understand how each procedure is linked to the central question of the paper.
- **You may go down many false paths in the course of your research. Readers don't need to read about all of them.** Don't distract the main flow – make sure that each description is feeding into the analysis that you actually carried out in the end to obtain the results presented later in the paper.

> "Our baseline optical observations consist of deep B_WRI imaging available as part of the NDWFS third public data release. The imaging was carried out using the MOSAIC-I camera at the KPNO/Mayall 4 m telescope, reaching a 5-sigma depth of ~26.5, ~25.5, and ~25.3 mag in a 2" diameter circular aperture in B_W, R, and I, respectively. Note that although K-band imaging from the NDWFS is also available for ~60% of the Bootes survey region, we do not use these older data in favor of the more recent near-infared (near-IR) observations described below."
>
> (Moustakas et al., 2011)

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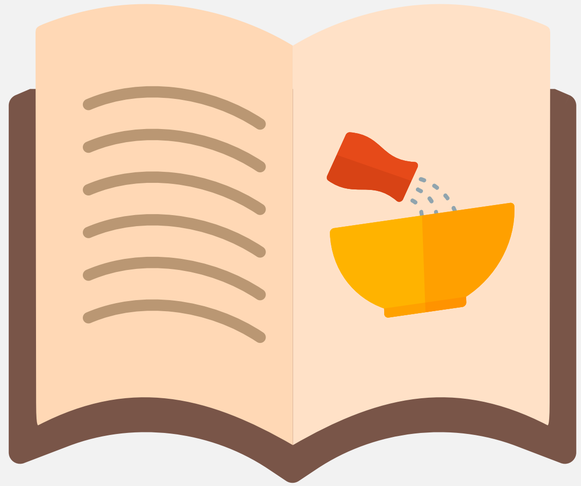
Methods: How much detail?

Examples of relevant information in observational astronomy:



Imaging:

- Telescope
- Instrument, Instrument set up
- Filters
- Detector area and pixel scale
- Integration time
- Image depth
- Image quality (PSF)
- Observing conditions

Spectroscopy

- Fibre, Slit, IFU etc
- Spectral range
- Spectral resolution

Data reduction:

- Flat fielding
- Cosmic ray rejection
- Background subtraction
- Combination of individual exposures
- Flux calibration
- Correction for Galactic extinction
- Astrometric correction

Slide adapted from Alice Shapley

Methods: How much detail?

- **New technique:** provide all necessary details.
- **Methods previously described in published work:** provide literature reference instead of a detailed description; but include necessary details so that the paper can stand on its own.
- **If part of the method is identical to previous work:** refer to the published paper, and describe the aspects that are new and different in your method.
- **Tap into established schemas:** many methods and techniques are common in the field, and they have specific names — use them when available.
- **Give credit where credit is due:** don't only refer to a recent paper where the technique is used. Make sure to refer to the paper in which it was originally described (to place the technique in historical context; be courteous to original author).
- **Statistical analysis:** terms like mean, standard deviation, correlation coefficient don't need a full description — only describe in full detail if you are doing a novel or original statistical analysis.
- Use **appendices** for lengthy details (detailed calculations, algorithms, large tables etc), so you don't interrupt the flow of the paper.

Slide adapted from Alice Shapley

Example LD paragraphs in Methods section

Our observations were taken in Band 4 (at a representative frequency of 152 GHz) using the total 7.5 GHz bandwidth available for continuum observations. Between 34 and 41 12 m antennas were used in the most compact array configuration in Cycle 3 (C34-1), with baselines ranging from 15 to 310 m. This antenna configuration was sufficient to achieve our desired resolution of 23, which allows us to separate the different sources in fields where there are multiple ALESS SMGs, while not resolving out each individual source (based on their typical sizes of ≲0.5”; Simpson et al. 2015; Hodge et al. 2016). The weather conditions were adequate for Band 4 observations (precipitable water vapor between 1.35 and 3.82 mm). The quasar J0334−4008 was used for atmospheric, bandpass, flux, and pointing calibration, and J0348−2749 was used as a phase calibrator. ALESS045.1 was also used as an atmospheric calibrator. Each of our 69 target fields was observed for 160 s.

We generate images from the ALMA visibilities using the CLEAN task in CASA. CLEAN performs a Fourier transform to map the *uv* visibilities onto the image plane on the sky, producing a "dirty image." This image is then deconvolved from the point-spread function (i.e., the synthesized "dirty" beam) using the clean algorithm (Högbom 1974) with robust (Briggs) weighting of the visibilities; we adopt robust = 0.5. The average rms obtained in our clean images is σ = 53 ± 2 μJy beam^{-1} (with the error representing the standard deviation of the noise among all the maps), and the average beam is 2.4” × 2.3”. This corresponds to a physical resolution of ~18 kpc at z ~ 1–3, the typical redshift range of our sample (da Cunha et al. 2015; Danielson et al. 2017). In Figure 1, we show the final cleaned ALESS Band 4 continuum images obtained using this procedure for the first six fields. Each image is 166" × 166", with a pixel scale of 0.46”. The noise and beam properties of all 69 maps are uniform. All the maps are good quality with rms below our 60 μJy beam^{-1} request and fairly circular beam (the beam axis ratio varies between 1.05 and 1.11); therefore, we use all the maps in a common source extraction step in the next section.

da Cunha et al., 2021

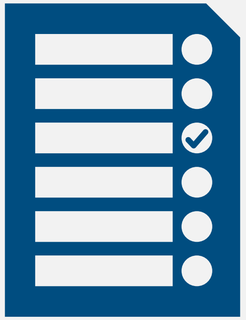
Methods: Writing guidelines

- Use **active voice** for things you did; **passive voice** when who did the action is irrelevant.
- Do not switch from one point of view (voice) to another for no apparent reason (confusing to readers).
- Distinguish between past and present tense: report completed actions in **past tense**, but use **present tense** for statements of general validity/those whose information is still true/when referring to figures and tables.
- You can choose to write everything in present tense.
- **Choose your words carefully.** E.g., definitions of words you might use in the Methods section:

Determine	To find by investigation, calculation, survey, or study
Measure	To find the size, length, amount, degree, etc
Quantify	To measure something precisely
Estimate	To determine roughly the size, extent, or nature of
Calculate	To work our or find out something by using numbers; to compute

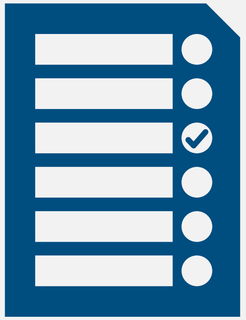
Checklist for Methods — structure & content

- ☐ Do the listed methods describe all procedures done to obtain the results presented?
- ☐ Are sufficient details and/or references provided?
- ☐ Are protocols (steps) logically grouped and organized?
- ☐ Are topics signalled and linked?
- ☐ Did you pay attention to voice?
- ☐ Did you pay attention to correct use of past and present tense?
- ☐ Did you choose your words carefully?
- ☐ Did you ensure that major results are not stated in the Methods section?
- ☐ Is the purpose of each step clear?
- ☐ Has sentence location been considered?
- ☐ Is the point of view consistent?



Checklist for Methods — style & composition

- [ ] Are paragraphs consistent and cohesive?
- [ ] Are key terms consistent?
- [ ] Are key terms linked?
- [ ] Are transitions used, and do they make sense?
- [ ] Is the action in the verbs? Are nominalizations avoided?
- [ ] Did you vary sentence length and use one idea per sentence?
- [ ] Are lists parallel?
- [ ] Are comparisons written correctly?
- [ ] Have noun clusters been resolved?
- [ ] Has word location been considered? (Verbs close to subjects, Old/new information)
- [ ] Have grammar and technical style been considered? (person, voice, tense, prepositions, articles)
- [ ] Are words and phrases precise?
- [ ] Have unnecessary terms (redundancies, jargon) been reduced?
- [ ] Have spelling and punctuation been checked?



Summary: Methods

- Provide enough details to let others evaluate and/or repeat your work.
- Do not describe commonly used methods – cite literature as needed.
- Emphasize differences in your methods/approach.
- Be precise and complete, but minimize complexity.
- Break into subsections and/or use topic sentences to signal different steps.
- Move lengthy materials to an appendix.

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Results

Results

What did the authors find?

- The Results section represents the core of the paper – this is where you show and describe your findings.
- This section often includes Figures and Tables: those are usually a good place to start.
- Doesn't necessarily need to be called "Results" in the paper, or need to be only one section – but it can be!
- **Results ≠ Data!**
    - Data = numbers, images, etc: they belong in Figures and Tables.
    - Results = Data + Interpretation

Results: What to present?

The most important decision you have to make when writing the Results is not *how* to present the data, but *which data* to present.

Prioritize data based on how relevant they are to your hypothesis/central point/question/purpose:

1) Results that are clear and relevant to your central point.
2) Results that allow to say something relevant about the central point, but that are less convincing that the results in category 1.
3) Results that are interesting, substantial and are worth presenting but they don't have anything to do with the central point.
4) Results that are not convincing and don't have anything to do with the hypothesis.

- **Don't present results in category 4:** yes, it is frustrating to get rid of results that you worked hard for. But you must keep in mind that the results must be robust and contribute to the scientific story.
- **Present most important first:** results in category 1 before category 2, and category 2 before category 3.
- Consider if the results in category 3 belong in a different paper.

Results: How to present

Report your main findings first, but also include other important findings and control results.

- You should include results that are pertinent to the information provided in the Introduction and Methods (i.e., **the results that fit in your scientific story/relate to your central point**).
- Exclude preliminary results or results that are not pertinent to the story.
- **Know the difference between leaving out irrelevant results and suppressing contradictory ones. Do not omit the latter!**
- **Data/results should come first**. You should be drawing your interpretations from them. When conclusions come before the data, it feels like you are imposing the "plot".
- Results should appear in the order from most important to least important.

Results: How to present

Point the reader to the data shown in tables & figures.

- Although most data should be presented in tables and figures, your main findings should be stated in the text as well, along with your interpretations of all data.
- **Reference tables and figures by number** (use \ref{} in LaTeX).
- Using tables and figures does not absolve you from the responsibility of making the text a coherent story. This doesn't mean that the text should present the same data as the figures – they do different jobs. **Tables and figures show the data with precision, the text helps clarify.**
- The text gives you an opportunity to **clarify** and **reinforce** those aspects of the tables and figures that will be particularly important when you come to the Discussion later. Draw attention to the parts that contain important data, to patterns, clarify the big picture presented.

Results: Tables vs Figures

Tables	Include exact numbers Show **quantitative** analysis of the results
Figures	**Qualitative** features + trends Astronomical images

- Tables need not be just rows and columns of numbers. Good tables should present the numbers in a way that **highlights the patterns, features, and exceptions in the data**.
- **Tables and Figures should both be "self supporting"** – readers should not have to read the text to understand what they are presenting. Neither they should be compelled to read a table or figure to discern what the text is about.
- **Always mention them in the text!** (i.e., no free-floating Tables/Figures that aren't mentioned anywhere). But no need to describe every single part of them in text.

Results: How to present

Interpret your data for the reader.

- Do not just present data, but summarize and interpret their meaning for the reader by presenting them as results. Only data that have been interpreted will be meaningful for your readers.
- **Distinguish between data and results.**

> *Data:* Among the sample of 100 IR-selected AGN, 63 objects satisfy the X-ray AGN selection criteria.
>
> *Result:* Among the sample of 100 IR-selected AGN, 63 objects satisfy the X-ray AGN selection criteria, indicating that X-ray selection misses a significant fraction of IR-selected AGN.

- **Don't provide the raw data with no context** – synthesize them into a pattern and fit them into the larger story to provide context. You do this by telling a short story about each data set with a clear opening to introduce and frame the presentation. Use an LD structure: first frame the main point or pattern, then flesh out the details.

Results: Organisation within segments

Organise your results into different segments (e.g., paragraphs, sub-sections).

In each segment, state:

- **Purpose or background of the experiment**
- **Experimental approach**
- **Results**
- **Interpretation of results**

➡ Use topic sentences – usually to indicate the purpose and/or context.
➡ Experimental approach: very short, about half a sentence. Follow immediately by the results.
➡ Place important or general results first in the segment.
➡ Always provide a brief interpretation of the results to make them meaningful to the reader.
➡ Avoid lengthy interpretations, speculations, or conclusions – save those for the Discussion.
➡ Use transitional phrases and clauses.
➡ Signal all the elements with appropriate language.

Results: Statistics and stories

Place statistical information with data. Do not use it instead of results.

Descriptive statistics	mean/median standard deviation confidence intervals *p*-values sample size
Bivariate analysis	chi-square *t*-test regression analysis

- **Statistics are essential for establishing the credibility of your conclusions, but remember that the story is not in the statistics – it is in the data themselves.**
- Ensure that you always interpret descriptive statistics for your readers. Do not just list them.
- Statistics reinforce your data but should not replace their interpretation.

Statistics and stories

You could describe both Panels A and B as "The number of detections is significantly larger in our sample (p=0.02)".

That would be true, but the stories in panels A and B are different. In panel A, there is a large difference and in panel B, a small one.

Instead, you could describe panel A by saying "The number of detections in our sample is 2.3 times larger than in the control sample (p=0.02)".

For panel B: "The number of detections in our sample is only 30 percent higher, but the difference is statistically significant (p=0.02)".

Statistics and stories

Panel C: One could say: "There is no significant difference in number of detections between the samples".

Most readers would infer from this there is no *difference* between the samples – but in fact they differ by a factor of 2.3. That is not the "same". Also, p=0.07.

Also, saying there was no significant difference mixes results and interpretation.

When you do a statistical test, the p value is the result. Deciding whether the test is significant is the interpretation.

Instead, you could describe panel C by saying "The number of detections in our sample is 2.3 times larger than in the control sample (p=0.07)". Or, to be conservative, "The number of detections in our sample is 2.3 times larger than in the control, but this is only significant at p=0.07".

Results: Writing guidelines

- **Choose words carefully.** Choose the most precise and descriptive words that reflect what you want to say, but keep the wording simple. Pay particular attention to:
  - **use neutral descriptions such as "did not"** rather than "could not" or "failed to"; e.g., "we did not detect any infrared emission in the galaxy".
  - **omit "clearly/it is clear/obvious" and similar subjective phrases**. They make the authors seem arrogant, and they appear as if they are trying to influence the reader — the results should be clear on their own.
  - **use "significant" only when you mean "statistically significant"** and quantify significance level. If you do not plan to provide significant details, use "markedly" or "substantially" — but you should still quantify these qualitative words by using precise values or referring to data (e.g., "the luminosity decreased substantially (by 23%)").

Results: Writing guidelines

- **Use signals to highlight diverse elements of the Results.**

  Pay particular attention to signalling the most important result so the reader cannot miss it.

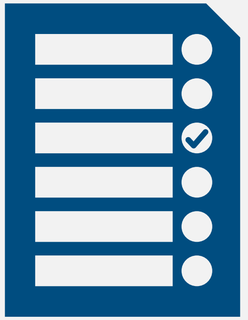
Purpose/Question	Experimental Approach	Results	Interpretation of Results
To determine... To establish if... Z was tested... For the purpose of XYZ...	...we did... X was subjected to... ...by/using... ABC was performed... Imaging showed...	We found... We observed... We detected... Our results indicate that... that...	...indicating that... ...consistent with... ...which indicates that... This observation indicates that... A is specific for...

Common problems of the Results section

- Missing components (purpose of the experiment, experimental approach, results, or their interpretation)
- Inclusion of irrelevant or peripheral information
- Including irrelevant overview sentences, referring to figures and tables (“…They are listed in Table 1” vs “…(Table 1)”).
- Excessive experimental details (those should be in the Methods)
- Inclusion of comparisons, speculations, and conclusions beyond the interpretation of results (those should go in the Discussion)

Checklist for Results — structure & content

- [ ] Did you report all main findings as well as other important findings?
- [ ] Are your most important results and their interpretation provided in the beginning of the Results section?
- [ ] Are the data for your most important results also mentioned in the text?
- [ ] Is the organization from most to least important within the paragraphs?
- [ ] Does each Results segment or paragraph contain all components (purpose of experiment, experimental approach, results, and their interpretation)?
- [ ] Are all components signalled?
- [ ] Are results emphasized?
- [ ] Did you place statistical information with data?
- [ ] Is the reader pointed to figures and tables?
- [ ] Are control results included?
- [ ] Are irrelevant statements and peripheral information avoided?
- [ ] Have general conclusions, speculations, or comparisons with other studies been excluded?



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Discussion

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So what?

- Present your thoughts and interpretations of your key findings. Draw conclusions.
- Put your findings in context: compare with other work.
- Summarize and generalize your results. What have you contributed to the field? What are the observational and theoretical implications of your findings?
- Address the questions raised in the Introduction. Did you achieve the purpose of your study?
- Sometimes lumped together with Conclusion and/or Summary
- Good style and clear, logical presentation are especially important here.

Discussion: organize in a pyramid structure

Interpretation of key findings – mention relevant results.

Evidence supporting findings.

Comparisons/Contrast to previous studies.

Limitations of your study.

Unexpected findings.

Hypotheses, models, speculation.

Summary

Significance/Implication

Start by writing a list of arguments/paragraphs to be developed.

The Discussion should tell a story.

Follow an **LDR structure**.

(OCAR may be appropriate sometimes.)

Discussion: what arguments to include?

Assess and prioritize your arguments:

1) Arguments that are relevant to the original hypothesis/research question and which allow you to make a positive statement of acceptance or rejection.

2) Arguments that are relevant to the original hypothesis/research question but which for some reason are equivocal, or which lead you to suggest further experimentation or observation before acceptance or rejection.

3) Arguments based on your results, not relevant to your original hypothesis/research question but which you consider sufficiently new or interesting to be worthwhile including.

4) Arguments based on your results, not relevant to your hypothesis and of marginal interest.

Give the right visual impression of priority of arguments to the reader: Position the best arguments first and make sure that lesser arguments take up less physical space than major arguments.
Don't include category 4 arguments.

The paragraph as a vehicle for your arguments

The paragraph is the development of the argument towards the conclusion.

Physically, it helps readers by breaking up the Discussion in parts and allowing them to absorb your points one at a time. At the end of each paragraph they should be satisfied that they grasped the implications.

A good paragraph should have:

1) **The topic sentence** signalling precisely what the paragraph is about and/or main point, link to previous paragraph if needed. If you use good TS they should work as subheadings!
2) **The logical development** – this is where you develop the argument, provide comparisons etc.
3) **The conclusion** where you wrap up the argument for the reader – what should the reader retain from the paragraph?

Always include all three elements in each paragraph of the Discussion.

Discussion elements

First paragraph(s): State your answer to your research question.

- Begin the Discussion with a summary and interpretation of the key findings, which should present the answer to the question posed in the Introduction.
- **This is the most important statement in the Discussion, so it should come first.**
- Don’t distract with secondary information.
- Support with specific evidence taken from the Results section.
- You can restate the purpose of the study or provide a brief context before stating the answer – but that should not exceed more than a few sentences. You want to get right to the answer! If the answer is at the start, you readers are sure not to miss it.

Discussion elements

Context in the field

- How do your findings fit in with existing knowledge on the subject?
- **Compare/contrast with results found by others.** If a previous result disagrees with yours, it is very important to try to explain why. If you can't, then state clearly that that's the case.
- Make sure that you are doing a fair comparison with other studies (make an apples-to-apples comparison, or, if you can't, explain why it's difficult to make a fair comparison).
- **This is not a review of the literature** – all results of others that you cite should add meaning to your own work. Remember: begin with your own findings, then describe how other's work relates to yours.
- **Compare with both observational and theoretical results** – regardless of the kind of results you are finding.

Discussion elements

Limitations & Unexpected findings

- It's important to mention limitations and unexpected findings as these indicate the way forward.
- **State what your simplifying assumptions are** (e.g., spherical symmetry, objects in your sample are all the same in some specific property, objects don't evolve, some ratio is constant, etc.)
- **State what the limitations of the study are** (e.g., small sample size, low S/N, low-resolution simulation, simulation doesn't run to z=0, incompleteness of sample, systematic uncertainties of measurements or inferred physical properties, etc.)
- **Unexpected findings: be flexible!** Even if you didn't set out to discover something, it can be a part of the story. Don't automatically assume an unexpected finding is a mistake. Signal to the reader: "Unexpectedly", "To our surprise", "Serendipitously" etc. Give a possible explanation without going into too much detail.

Discussion elements

Hypotheses, models, speculation

- If you can **develop a model or physical picture to explain your results**, or interpret your results with a model, this is the place to do it.
- Explain how you arrived at your hypothesis or model. Consider illustrating complex models with figures. Describe how your hypothesis or model works, incorporating a discussion of any figures if needed.
- **Describe ways to validate your model/test your hypothesis** (observations, simulations, experiments).
- David Lindsay: **"good speculation is the spice of science"!**
    - Good speculation: derives from the results in the same way as an hypothesis/question was developed in the Introduction, can be tested/validated by further work.
    - Bad speculation: does not fit the known information, or cannot be tested/validated using known methods/technology.

Discussion elements

Last paragraph: Summary, significance, implication

- **One-paragraph conclusion that summarizes your interpretation** (very often in astro papers this goes in a separate Conclusion section).
- Readers expect two things: an analysis of the most important results and the significance of the work.
- **Analysis of most important results:** complete the big picture by restating your answer (interpretation of key findings); generalize findings to a broader context.
- **Significance:** include far-reaching interpretations and conclusions – practical applications, theoretical models, connections with other branches in the field, recommendations, and speculations.
- Speculations should still be based on solid evidence – not wild and random guesses. Signal with words, e.g., “we speculate that…”, “…may…”, etc.
- **Future directions:** avoid recommendations that could have been addressed with the current data/ experiment, as that sounds like you’ve done inadequate work on your own data.

Let's look at the last paragraph of some example papers...

The quest to understand how the chemical properties of galaxies couple to their star formation histories has been given added impetus of late by measurements of the metallicity-luminosity relation of galaxies at intermediate ($0.3 < z < 1.0$; Kobulnicky et al. 2003; Lilly et al. 2003; Maier et al. 2004) and high ($z > 2$) redshifts (Kobulnicky & Koo 2000; Pettini et al. 2001). Our results imply that metallicity is not a straightforward metric of galaxy evolution because metals can escape galactic potential wells. However, the strong correspondence of metal loss with the size of the potential has interesting implications if effective yields can be measured reliably. The combination of the intermediate- and high-redshift data with the correlations we measure at $z \sim 0.1$ will provide an important benchmark for successful models of feedback and galaxy evolution.

Tremonti et al. (2004)

Let's look at the last paragraph of some example papers...

The model we have developed for computing the absorption of starlight by dust in galaxies can be combined easily, by design, with any population synthesis model. The observed mean relations for starburst galaxies can also be reproduced by the following simple recipe: use an effective absorption curve proportional to $\lambda^{-0.7}$ to attenuate the line and continuum radiation from each stellar generation and lower the normalization of the curve, typically by a factor of 3 after 10^7 yr, to account for the dispersal of the birth clouds. This recipe accounts at least as well as the one by Calzetti et al. (1994, and as modified by Calzetti 1997 and D. Calzetti 1999, private communication) for the effects of dust on the nonionizing continuum radiation. In addition, it fully resolves the apparent discrepancy between the attenuation of line and continuum photons in starburst galaxies. Our model and the recipe derived from it provide simple yet versatile tools for interpreting the integrated spectral properties of starburst and possibly other types of galaxies. In future work, we plan to apply them to the growing body of observations of high-redshift galaxies.

Charlot & Fall (2000)

Let's look at the last paragraph of some example papers...

This work confirms the dust emissivity index between 1.5 and 2.0 that is typically assumed in most high-redshift studies. This implies that the properties of dust at z∼1–3 are similar to the properties of local galaxies. This is true at least for SMGs, which, based on their relatively high stellar masses ($M_* \gtrsim 10^{10} M_\odot$; da Cunha et al. 2015; Dudzevičiūtė et al. 2020), are likely to have already reached solar metallicities in their ISM. We speculate that therefore they are likely to have reached a critical metallicity for their dust-grain evolution to be happening mainly through ISM growth (see Dudzevičiūtė et al. 2021), which is also thought to be the dominant mechanism in the Milky Way and other present-day galaxies (e.g., Asano et al. 2013). A larger number of robust measurements of the emissivity index of high-redshift galaxies of lower masses/ metallicities with ALMA would help establish whether there is an evolution of the dust-grain properties in galaxies with a less chemically evolved ISM.

da Cunha et al. (2021)

Discussion: Writing guidelines

- **Tone: make your writing convey confidence and clarity**

Show that you are knowledgeable about the subject, and take responsibility for your conclusions. Do not be afraid to take a stand, but do not be too boastful, either (for non-native English speakers, it may be helpful to run things by a native speaker, who will be more aware of the nuances of their language).

- **Support your arguments**

Every statement needs to be supported either by your Results or by previous work (cite appropriately).

- **Use first person and active voice**

Avoid third person and passive voice in the Discussion – first person and active voice will make the discussion livelier. “We” is perfectly ok, even if you are a single author (I prefer it to using “I”).

- **Use past tense for completed actions; present for general rules and statements that are still valid**

Use present tense for the answer to your scientific question and for the statement of significance.

- **Ensure continuity**

This is especially critical in the Discussion. Use topic sentences, transitions, and key terms. Ensure that the topic sentence of each paragraph is logically linked to the preceding paragraph, as well as to your research question.

Example: confident and clear tone (Tremonti et al. 2004)

The most straightforward interpretation of the correlation…

In contrast, our results imply…

…Of course, it is quite likely that even in the absence of winds chemical evolution does not proceed in the simple manner we have assumed. It is worth considering if other factors could explain the trends we observe…

…We therefore consider it unlikely that metal-poor inflow is solely responsible for the low yields we observe.

It is our view that the strong positive correlation between effective yield and baryonic mass is most *naturally* explained by the increasing potential barrier that the metal-laden wind must overcome to achieve "blowout." While the correlation is not particularly tight (±0.15 dex), its very existence nevertheless implies two very interesting things…

…This suggests that blowout is either a very frequent occurrence or very catastrophic. In the coming years numerical and semianalytical models should help to address these questions. In the meantime we emphasize our empirical findings: galactic winds are ubiquitous and extremely effective in removing metals from galaxies.

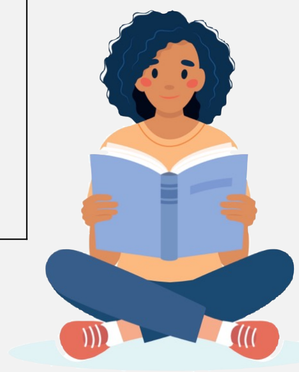
Discussion: signals for the reader

Answer	Key Findings	Summary	Significance
In this study, we have shown that... Our study shows that... Our findings demonstrate that... This paper describes...	In our observations/ simulations... ...can be attributed to... We determined X by... We found that... Our data show that... ...has been demonstrated by...	In summary, ... In conclusion, ... Finally, ... Taken together, ... To summarize our results, ... We conclude that... [overall question] Overall, ...	Our findings **can/will serve to...** We **recommend** that X is... Y **should** be used for... **...is probably...** Y **indicates** that X **might...** These findings **imply** that X **may...** Here we **propose** that... ...we **hypothesize** that...

level of certainty

Discussion: signals for the reader

Comparisons	Conflicting results	Limitations	Unexpected findings	Proposed hypothesis
...consistent with... (ref.) Similar to... (ref.) ...has also been observed by... (ref.) X had been demonstrated... (ref.)	However, other studies found that... (ref.) ...is controversial... (ref.) ...does not agree with... (ref.) ...has also been reported... (ref.)	...was not possible... ...could not be measured... ...was limited by... Further observations are needed to...	Surprisingly, ... To our surprise, ...was not expected.	Our results lead to the conclusion that... From these data, we hypothesize that... We propose the following new principle...

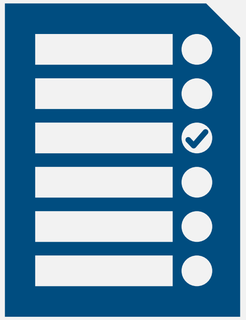


Common problems of the Discussion section

- **The answer/interpretation of your key findings is not provided in the first paragraph.**
  - ➡ If you fail to provide the answer in the first paragraph of the discussion, your readers will jump straight to the last paragraph in hopes of finding it there.
  - ➡ This can be a problem if you divided your Discussion into various subsections; consider providing an overview paragraph at the start.
- **No concluding paragraph provided; the importance/significance of the study is not clear.**
  - ➡ Take a position – you are the expert in your study now.
  - ➡ Remember the last paragraph is a power position.
- **Irrelevant or peripheral information is included.**
- **Results are repeated or summarized in the Discussion.**
  - ➡ Don’t be afraid to make the Discussion shorter rather than longer.

Checklist for Results — structure & content

- ☐ Did you interpret the key findings/provide the answer to your research question?
- ☐ Is the interpretation/answer to the research question provided in the first paragraph?
- ☐ Is the answer stated precisely (and in present tense)?
- ☐ Is the answer followed by supporting evidence?
- ☐ Does the discussion follow a pyramid structure?
- ☐ Is a summary paragraph placed at the end of the Discussion?
- ☐ Is the significance of the work apparent?
- ☐ Did you organize the topics according to the science or from most important to least important in the middle of the discussion?
- ☐ Did you compare and contrast your findings with those of other published results?
- ☐ Did you explain any discrepancies, unexpected findings, and limitations?
- ☐ Did you provide generalizations where possible?
- ☐ Did you avoid restating or summarizing the results?
- ☐ Are all elements signalled?



Results vs Discussion

The Discussion section should contain main comparisons with other work (observational and theoretical), big-picture speculation.

In the Results, simply present the data and immediate interpretation.

Stated another way: draw technical conclusions in the Results section, and scientific conclusions in the Discussion section.

An alternative: combined Results & Discussion section

The results are discussed right after they are presented so the reader can understand why they are important immediately. ***All results will have to be presented and discussed***, and not just the most important summarized results of your paper. In such a section it is ***critical that results are distinguished from discussion*** (structure, language signalling).