Research Introduction

I generally study the evolution of galaxies through cosmic time, stretching all the way to the formation of the very first galaxies over 13 billion years ago. To do so, I study spectra from space-based observatories, particularly the *James Webb Space Telescope* (*JWST*). *JWST* has discovered the most distant galaxies known today and has completely revolutionized the field of galaxy evolution and astronomy as a whole.

Specifically, I study the conditions of stars and black holes at early cosmic times. This includes the formation of the very first stars (so-called Population III) from primordial gas, to their deaths and subsequent enrichment of the interstellar medium (ISM) with heavier elements to then form the next generations of stars. At the same time, the black holes in the centers of galaxies were forming and growing to become the supermassive black holes we observe throughout cosmic time. My ultimate research goals are to answer the questions:

How and when did the first stars and galaxies form?

How and when did the first black holes form?

How did both the stars and black holes evolve over cosmic time?

Astronomy and Physics Background

A general background in many facets of astronomy is critical to being a productive researcher in any subfield. There are many resources for introductory material, including the classic Big Orange Book (BOB): *An Introduction to Modern Astrophysics* by Carroll and Ostlie (this was my very first astronomy textbook, which I still have and occasionally refer to today). Functionally, background from texts like this or from course work in astronomy, physics, chemistry, and math/statistics is enough to begin doing astronomy research. Doing research is going to teach more in the long run than any other form of learning, but it’s often unavoidable that it will be more specific and directed in scope.

Here I list a number of background questions to consider that are central to my work (in no particular order):

- What is a spectrum? What information can we gain from emission/absorption lines?
- What do spectra from different types of objects look like?
- What do spectra at different wavelengths look like?
- What is dust and how does it affect our observations?
- How do stars form? How do stars die?
- What is the interstellar medium?
- How do black holes form and grow?
- How do black holes interact with their host galaxies? What is an 'active galactic nucleus' (AGN)?
- How does the Universe and the stuff within it change as a function of cosmic time?
- What biases do our observations suffer? How do we deal with them in the interpretations of our results?

Specific Background and Resources

For a more technical background/next step into reading papers, I have created a NASA ADS library of some major papers in extragalactic astronomy. I also recommend *Astrophysics of Gaseous Nebulae and Active Galactic Nuclei* by Osterbrock and Ferland for a great background on the physics of the ISM and AGN as observed through spectroscopy. You can also find many great review papers from the Annual Reviews of Astronomy & Astrophysics (ARA&A) by querying ADS, most of which have introductions suitable for any level of expertise. These are great resources and there should be some relevant review for almost any topic, including the very first astronomy paper I ever read. More on reading papers below.

I certainly don't require that anyone has an all-encompassing and hole-free background to begin doing research (nobody knows everything, regardless of level). However, having a stronger background will almost always allow for faster improvement and more effective research.

Science Communication

Research is only useful if properly communicated. I strongly believe that the accessibility and effective communication of results is one of the most important skills to learn as a researcher, regardless of field. The most effective ways to learn how to communicate science is to read and listen to others and to present science yourself.

This means: reading papers, going to talks, giving talks, writing papers (and proposals, etc.). All of these are critical to becoming an effective science communicator.

Papers

Before you can read a paper, you have to know where to find papers:

- The Astrophysics Data System (ADS) is probably the single most important resource for finding papers (or other materials). You can search by author/year/title/keyword etc., and find the most complete listing of publications from much of the last century.
- arXiv is a popular repository of physics/math/astronomy/etc. papers which updates daily. Anyone can submit to arXiv regardless of journal publication status.
- benty-fields is a digest of the arXiv which uses machine learning to rank papers by their relevance to you based on your previous reading. Many groups use benty-fields to host journal clubs.
- astrobites/astrobitos (ES): a reader's digest of astro-ph articles written by graduate students. Focuses deeply on removing technical jargon as a barrier to entry to maximize accessibility for non-experts.

General advice for reading a paper (and a paper about how to read and present papers):

- Try to read papers often; I try to scroll through benty-fields every day, but realistically do about three times per week.
- Every once in a while, try to read a paper that isn't directly in your subfield.
- Nobody is going to fully understand everything about a paper immediately. It is totally okay to read the abstract/conclusions of a paper and decide that it's not worth reading the rest.
    - Note: this is true for papers that aren't directly in the critical path of your research. Sometimes you unfortunately have to slog through a very dense or poorly communicated paper to get the information you need.
- If you read the abstract and decide to continue, start with the figures. Don't get bogged down in the text immediately. Try to find the one or two critical figures that make the authors' arguments.
- Come away with one or two key points, and then move on to the text only if you want more detail.

Talks

Go to whatever talks you can, even when they aren't on subjects you aren't deeply knowledgeable about. Often, if the speaker is an effective communicator, there will still be useful information for you. Additionally, you will learn effective versus ineffective strategies for communicating certain information, both verbally and visually through slides.

The next step is to start giving talks yourself. Often, this can start with as small of an audience as your immediate research group. Most departments/colleges/universities have some sort of student research presentations, often semesterly or yearly. These can be great practice for presenting to an audience with a wide range of expertise. I also highly recommend giving outreach (so-called ‘public level’) talks, which often come with questions you wouldn’t normally get from subject matter experts. I personally think that questions like ‘but what if X happens?’ or ‘why does Y exist at all?’ can be the most fundamental and make you think the hardest, and often come only from more general audiences.

Always remember: you are the expert on your research. Being asked questions is basically always a good thing, even if it doesn’t feel like it at the time. I guarantee that you will give some talk at some point in your career where it feels like you are getting berated by (often one specific member of) the audience; ask around - everyone has stories. Questions occur when people are interested in what you are talking about; it’s usually better to have ‘bad’ questions than no questions at all. Often the bad/negative questions stem from misunderstanding, so do your best to clarify the situation. Additionally, it is entirely okay to say that you don’t know something and move on; it’s better to do this than to dig a hole of misinformation.

The key point: practice as much as you can, to whatever audience you can.

Data Visualization

Often, our scientific arguments come in the form of plots/figures, so it is imperative that we make them as digestible and accessible as possible. The field of data visualization has been hotly discussed for over a century, and I make no attempt to summarize all of its history here. However, it would be very useful to familiarize yourself with the basic principles.

First, portray your data accurately and honestly. Secondly, keep it as simple as you can while getting the point across (don’t be fancy just for the sake of being fancy). Make all of your plots and figures with mindfulness of your audience. It is often very useful to have people who are not experts in your field to look at your figures, and ask them some questions:

- What do you get out of this figure?
- Did you need more information (e.g., legends, captions)?
- How long did it take you to fully digest this figure?
- Were any of the components of the figure unnecessary/distracting?

Often we find that we stare at our own work too much and forget that there are real people who will be looking at it someday, and they likely won’t come to us to ask us to explain things. First impressions are important, and people likely won’t take ten minutes to digest an overly complicated figure. It’s not always possible to make every figure immediately understandable (we all have examples of this), but make all of your figures being mindful of the fact that someone who isn’t you or your collaborators will be looking at it one day.

Side note about colors: Be mindful of color deficiencies when choosing color palettes. The easiest resolution to benefit the widest audience is to avoid red and green in one plot, but the theory behind color schemes and color deficiencies goes very deep. Use appropriate colormaps for your data (e.g., avoid using diverging colormaps for sequential data). Most of the time you are best off using a simple 'less to more' colormap (e.g., 'Reds' in matplotlib for redshift). And please, avoid rainbow colormaps in almost all situations unless you are plotting a literal rainbow. Remember the old adage: get it right in black and white.

The key point: present all of your results with accessibility in mind.

Programming

The overwhelming majority of modern astronomy research is done in python, IDL, julia, C/C++, or occasionally other languages. Python tends to be the popular choice (and my personal strongest language), and is my recommendation for a first (or only) programming language. Several of the resources I share here are python-specific, so if you are set on using a different language you may have to search more.

For a high-level overview of programming/computer science, I recommend turning to freely-available resources on the internet (these are things I have used myself). YouTube is a phenomenal resource for almost anything you might want in terms of programming languages and specific packages/libraries, and has a lot of information about general design principles.

- Harvard CS50: probably the most famous intro to computer science course, teaches the very basics. Touches on languages including scratch, C/C++, and python.
- Complete Python Course for Beginners: There are a million of these beginner python courses on YouTube, but this is the one I remember liking the most. I recommend coding alongside the lessons.

Functionally, my research consists of some specific uses on the programming side. There will be many options other than those I present here, so feel free to explore alternatives (though what I show will tend to be the industry standard):

- Making plots: this is often the most important facet of research in observational astronomy, as we tend to present our arguments through figures.
    - Matplotlib: the premier plotting library in python. Can do everything from basic scatter plots to interactive visualizations. I use this quite literally every day.
    - Seaborn: another plotting library with some more specific use cases than matplotlib; I recommend only looking into after being comfortable with matplotlib
- Data management/data analysis: this is the backbone from which all research arises. Here are some of the most important python libraries:
    - Numpy: basically a requirement for everything in python. Does everything from basic arithmetic to array manipulation. Will be a dependency for many other packages in python.

    - pandas: a wonderful tool for working with dataframes (think spreadsheets). Most data in astronomy are tabular, so knowing how to work with data in this form is critical.
    - Scipy: for algorithms like integration/interpolation/optimization/curve fitting.
- Astronomy-specific programming:
    - Astropy: has many useful tools from reading .fits files (a very common file format in astronomy) to working with astronomical coordinates and units.

Other programming/python recommendations:

- Be mindful of things like readability and clarity of code even if you are just starting out. It's a lot easier to start with good habits than spend years ingraining bad ones.
    - The Zen of Python: 19 principles governing python design
    - PEP 8 style guide: formatting and other recommendations for writing python code
    - Learn how to write functions and/or classes as soon as you feel comfortable with the basics. These improve readability and functionality of your code *significantly*, and any professional employer will expect you to be able to use them.
- Familiarize yourself with the Python Standard Library. Chances are there are tools which already exist for most of the basic tasks you need to perform.
- Pick an integrated development environment (IDE) or other code editor that works for you. I use Visual Studio Code, but many use Spyder, Jupyter, or others.
- Make an account on GitHub and start to learn the basics of git. This is the modern standard for version control.