

# Perspectives of Earth and Space Scientists

## PERSPECTIVE

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### Key Points:

- A brief summary of my career, including lessons learned from key mentors, like the art of getting started and being okay with being wrong
- On navigating a career, listen more than talk, strive for kindness, be an ally, continue to learn
- On the future of Earth and space sciences, we must face the three pandemics of COVID-19, anti-intellectualism, and western chauvinism

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## Conducting Space Physics Research: Wind the Frog, Work Hard, and Be Nice

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**Abstract** This report briefly summarizes the key mentors in my scientific career and some lessons learned from those influential people. My primary advice to others: it is okay to do something wrong. By doing science we are doing something hard that, by definition, has not been done before. I believe that impostor syndrome is a real threat to researcher wellbeing and we should acknowledge its presence and support each other to get through it. Regarding an approach to science, I encourage you to get started and make something bad. Also, take time for yourself, it really does help your productivity. To lead others, I recommend to be enthusiastic, actively listen, and make connections across disciplines. I think it is important to foster creativity in those around you. I advocate that you actively make the future that you want to have.

**Plain Language Summary** It has been my great honor and privilege to work in magnetospheric physics for the past 30 years (25 since PhD). I love my job and especially many of the people with whom I have had the pleasure to interact. To paraphrase a famous adage, it takes a village to raise a scientist; this is true with me and I have had excellent mentors along the way, from whom I have learned much. Here I present some of those things that I have learned, both for conducting research and for serving in leadership roles. The three big ones: get started, even when you do know the right path forward; keep trying, even in the face of obstacles and dead ends; and be considerate, assuming positive intent in others and trying to view situations from their perspective. On the future of Earth and space sciences, we must face the three pandemics of COVID-19, anti-intellectualism, and western chauvinism. Let's work for the future that we want to have for our research community, including mitigating the impacts of these pandemics.

## 1. Introduction

Magnetospheric physics has been a field within space physics for over 100 years, since the connection was made between solar disturbances and magnetic activity at Earth (e.g., Carrington, 1859). Magnetospheric physics was the focus of the first scientific discovery of the space age (Van Allen et al., 1958). Still, there is much to learn about magnetospheres, not only the one around Earth but all others throughout the solar system, galaxy, and universe. My career in magnetospheric physics has taken me across several topics within the field, similar to the meandering trajectory of other space scientists (e.g., Kessel, 2022). Also similarly to others (e.g., Fuselier, 2022), I have learned from many great mentors along the way.

Below I briefly summarize my career path, focusing on the key mentors at each stage. This is followed by two sections with thoughts on navigating a successful career, regarding an approach to research as well as interactions with others. The last two sections offer considerations for the future of Earth and space science and a final distillation of my advice to others.

## 2. A Brief History: Lessons Learned From My Mentors

My father was a space scientist. Among his forty-something journal articles, his very first was in *Nature* (H. Liemohn, 1964), and he made significant contributions to whistler-mode wave propagation (e.g., H. B. Liemohn & Scarf, 1964), atmospheric gravity waves (e.g., Midgley & Liemohn, 1966) and radiation belt wave-particle interaction (e.g., H. B. Liemohn, 1967). He even organized amateur astronomers and radio operators around the world to track the Apollo 8 spacecraft to the Moon and back (H. B. Liemohn, 1969). While he had moved into engineering management by the time I was aware of his career, his love of space significantly influenced my childhood and eventual career path. I feel very fortunate to be a legacy scientist and I acknowledge that I have had a life of love, scientific curiosity, and privilege. From him I learned that science is cool.

Before my senior year in high school, I spent 3 weeks at Rose-Hulman Institute of Technology (RHIT), participating in their Operation Catapult engineering camp. While I had announced to my sixth grade teacher that I wanted to be a scientist when I grew up, this summer experience truly sold me on a technical career choice. I also fell in love with the Midwest—lightning storms and lightning bugs still fascinate me. A year later, I went back to RHIT for my undergraduate degree. My 4 years there were some of the hardest of my life, with too many late-night and all-night sessions to finish homework and projects. It was also a time of growth, not only in the classroom but in the many extracurricular activities I was able to do while there. It was a fantastically good choice for me leading to many lifelong friendships.

After my undergraduate time at RHIT, I went to graduate school at the University of Michigan (U-M) and worked with Dr. George Khazanov. He is an idea machine and I greatly enjoyed working with him, from our first publication on superthermal electrons (Khazanov et al., 1993) to our most recent (Glocer et al., 2017). Our collaboration was an excellent start to my career. From him I learned—originally in Russian—the phrase “slowly but surely,” a mantra that continues to motivate me to persevere through challenges.

Being at NASA Marshall Space Flight Center (MSFC) as a postdoctoral fellow led to a big revelation: data exists. That seems odd to write but it was true in many respects—my dissertation focused on the development and initial “model-model” comparative results from two kinetic transport codes (M. W. Liemohn et al., 1997; M. W. Liemohn & Khazanov, 1998). Drs. Tom Moore and Paul Craven were excellent role models for data analysis and introduced me to merging data and models, a topic for which I now have great interest (e.g., M. W. Liemohn, Keese, et al., 2021; M. W. Liemohn, Shane, et al., 2021; M. W. Liemohn, 2022a).

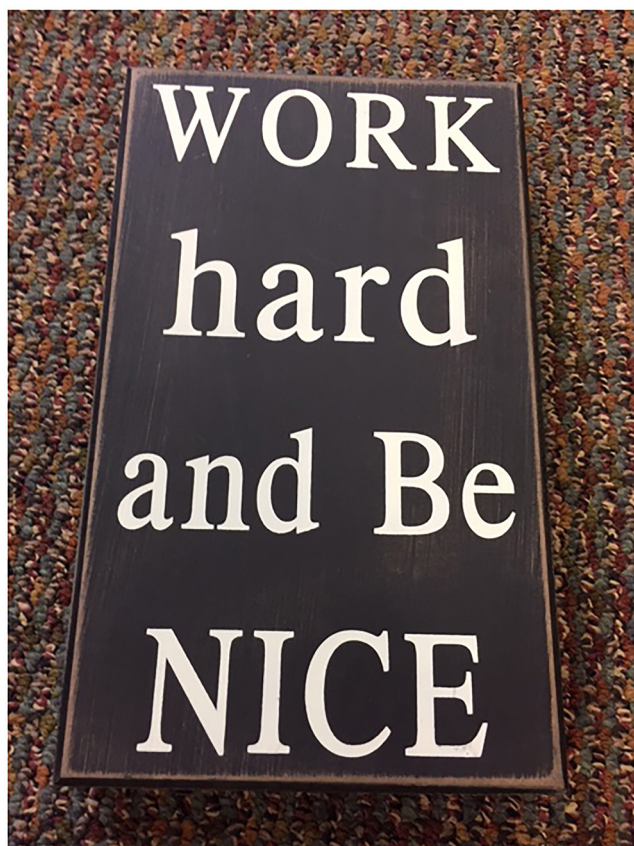
As I brazenly applied for faculty positions at the end of my time at MSFC, I asked Dr. Janet Kozyra for letters of recommendation. She offered me a research scientist position back at U-M, which I accepted. We embarked on inner magnetospheric hot ion studies (Kozyra et al., 2002; M. W. Liemohn et al., 1999) and eventually to studies of geospace at the system level (Kozyra et al., 2013, 2014). Her positivity and enthusiasm for both science and life are highly contagious; I would always leave her office excited to conduct the next step in the analysis and write the next paper. From her I learned to appreciate the awe of scientific discovery as I absorbed your excitement for the process, as well as learning that positivity is a great form of leadership.

While a research scientist at U-M, I had the honor of working with Dr. Andrew Nagy. One of the great thinkers of our field (Nagy, 2019), he encouraged me to apply my particle transport expertise to a new problem—superthermal electrons at Mars. I not only worked on this topic (e.g., M. W. Liemohn et al., 2003) but also several other problems across the field of space physics, like Mars ion loss (e.g., Fang et al., 2008; M. W. Liemohn et al., 2014), Saturn magnetospheric physics (e.g., Azari et al., 2018), and auroral physics at Earth and Mars (e.g., M. W. Liemohn, 2020a; M. W. Liemohn et al., 2007). I have not stuck to one particle population or spatial region but moved around through the broader domain of “charged particle motion through planetary space environments,” tackling a number of problems that I found interesting. Dr. Nagy taught me that it is okay to follow your passion and change specialties.

In 2006, I applied (and was selected) for an open tenure-track position in my department at U-M. The new time commitments of teaching classes and departmental committees was a large shift in daily work life. Being at a major research university, I was (and still am) expected to bring in funding to support a cadre of graduate students, mentoring them toward their dissertations. It is immensely rewarding, but with each year of being instructional faculty, I have less time to code and do the research myself, switching over to “manager mode” as I take on more leadership roles.

Perhaps the biggest service and leadership role I have done in the space physics research community was being the Editor in Chief (EiC) of the *Journal of Geophysical Research—Space Physics*. I served in this role for 6 years, from the beginning of 2014 to the end of 2019. During my term, I fully embraced the notion that I like data as much as I like numerical models, and this includes bibliometrics (M. W. Liemohn, 2020b; M. W. Liemohn & Wooden, 2019; Moldwin & Liemohn, 2018). I also learned how to use singular they and other aspects of inclusive and accessible research (M. W. Liemohn, 2022b). Through this role I met another mentor, Dr. Brooks Hanson. He cultivated my love long-term strategic planning. The annual EiC meetings were often focused on this type of activity, and I found it fascinating and engaging.

There are many more I could list, but a final mentor that I want to specifically mention here is Dr. Michelle Thomsen, with whom I have worked on several projects (e.g., Azari et al., 2018; M. W. Liemohn et al., 1999, 2010).



**Figure 1.** A word art sign in my office, a lesson I have learned from people like Dr. Michelle Thomsen.

Her perceptive insights have continually inspired me and her critical eye has regularly humbled me. She epitomizes one of my favorite adages, “work hard and be nice” (see Figure 1). From her I honed the art of scientific communication. A large part of our job as a scientist is interacting with other scientists through presentations, papers, and networking. This is a secret not emphasized in school, where science curriculum is often centered on learning to solve problems with known answers. That’s important to learn. But equally important, in order to be a successful scientist like Dr. Thomsen, are the so-called “soft skills” of interpersonal relationships and communication, in both written and oral form.

### 3. On Research: Make Something Bad

I like to think of research in terms of the scientific method, which can be idealized as a flowchart, as illustrated in Figure 2. It often begins with noticing some unusual feature in a data set. That “data” could be observations but also could be output from a numerical model; in either case, the feature you are noticing is something for which the explanation does not come readily to your mind. Your curiosity is piqued and you start the journey of scientific inquiry.

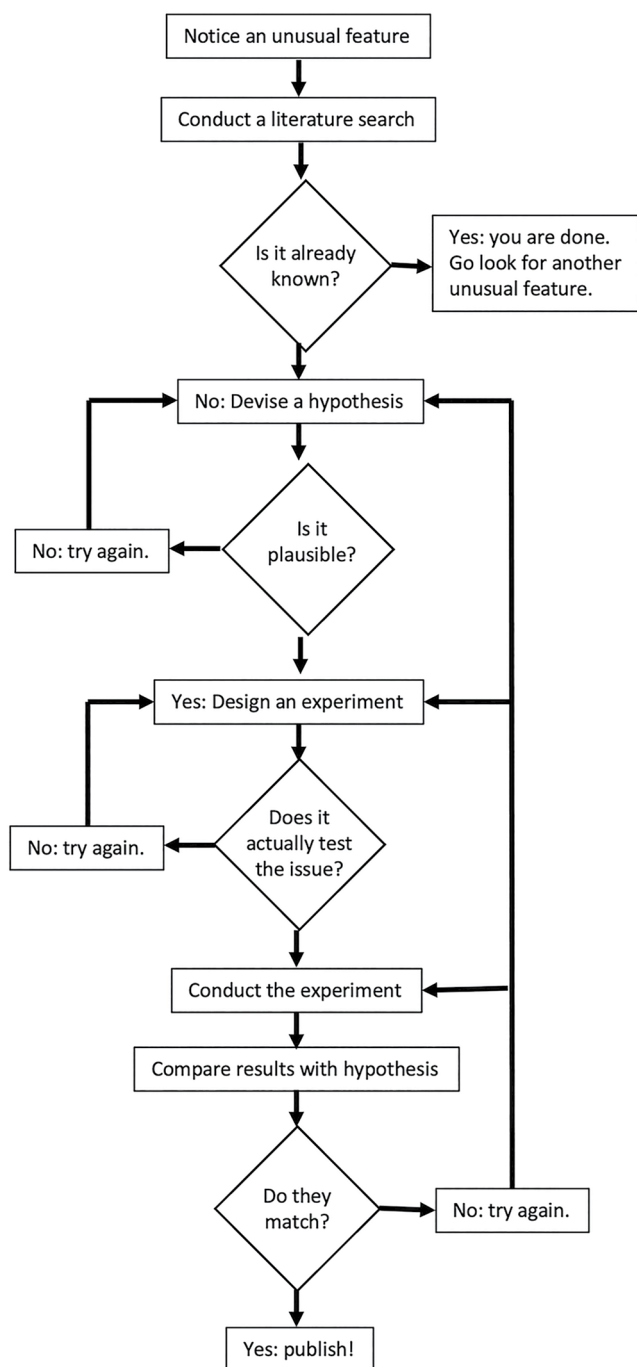
For me, the next step is to look it up. The chances are very high that someone else has already come up with a good explanation. If nothing can be found, then it is up to you to come up with that explanation. First, you should make a guess (an educated guess, i.e., a hypothesis). Next, come up with a way to test that guess. If the guess works, then great, you are ready to publish. It doesn’t mean that it is the right explanation, but your test of that hypothesis yielded positive results, so it is at least plausible.

What I have learned is that there are lots of ways to be wrong in this process. Some of these ways to be wrong are indicated with upward arrows in Figure 2.

The hypothesis might seem to work at first glance, but upon further consideration, won’t be a successful explanation. The test that you devise might seem to work, but it is good to check and make sure that it actually fully assesses the feature of interest. After conducting the experiment (which could be observational, numerical, or theoretical in nature) and comparing results, it could be that the results don’t work. This could be due to an issue with conducting the experiment, designing the experiment, or developing the hypothesis. Additionally, developing a good idea for investigating the feature could be hard, at any of these steps, and could take years before you get to move down the flowchart.

A mantra of mine was spoken by Woody from the movie *Toy Story*, “Wind the frog.” Once the toy frog was wound up, it was going to speed away and the plan would be in motion. I might be wrong and have to change the plan later—there are lots of places to be wrong along the way from idea formulation to publication, and even after publication—but I force myself to get started. Mozer (2022) offers similar counsel—“make the measurement.” Borovsky (2022) has a great piece of advice about getting started: draw a picture. I love the meeting table and large white board in my office.

The act of conducting original research is a process of doing something hard. Throughout my career, I have been wrong...a lot. I am fine with this, though, because it is part of my job. I have to make guesses and some of those will be bad. Sometimes, I even get to the publish stage and then, later, either I or someone else shows that it is wrong. That’s okay. I have contributed to the conversation and helped our community move our understanding forward. Scientific progress is a multi-step process that includes some backtracking and recalibration of what is right. My advice is that, when you realize that you are wrong about something, know that you are not alone. As Lockwood (2022) describes, being wrong is part of the job, not only in conducting the research but in many aspects of our work lives as scientists. Borovsky (2022) states the same idea in a way similar to Figure 2; being wrong indicates that you are taking on challenging problems. Mitchell (2022) also advocates that we learn from our mistakes, as well as remain skeptical of our successes. As scientists, we are all wrong, a lot. It is important to embrace our times of being wrong as signs of productivity (Schwartz, 2008).



**Figure 2.** A simple diagram of the typical scientific method, including many ways in which the scientist can be wrong throughout the process.

This repeated state of being wrong can influence our mental state. It should be noted that many scientists deal with burnout and impostor syndrome (e.g., Clance, 1985; Clance & Imes, 1978; Jaremka et al., 2020). You are not alone in having negative emotions about your work; I have felt this way. What we are doing is, by definition of being “original research,” hard because it is has not been done before. Stalcup (2016) offers some good advice regarding feelings of inadequacy.

One way to push through our wrongness is to make time for interrupted, concentrated effort on those hard tasks (Newport, 2016). Removing distractions and attaining a “deep thinking” mode gets you into the “stream” brain-set (Carson, 2010), which is a time when you can be particularly creative. This becomes increasingly difficult as demands on your time accumulate over the years. It is important to carve out the time for deep thinking. I urge people to learn this skill early in your career and maintain the discipline of reserving time in your schedule for your creative endeavors.

Beyond taking work time for yourself, I also encourage you to take time for yourself away from your work. I usually work more than 40 hr a week, but I intentionally step away from work. I make time to sleep, relax, and play. I meditate, journal, read, and jog. I love my job, but I am not my job. I love life and I put work aside to do other things I enjoy. I firmly believe that this is a positive feedback loop that allows me to love my job.

The take-away point regarding the task of conducting scientific research is that I highly encourage you to make “something,” even if, at first, it is bad. Make the guess and explore it. Make the test and conduct it. Make the plots and examine them. Make the paper draft and edit it. It's okay to start over. King (2022) posits that a scientific career path is often nonlinear; I agree. Our job is really hard, but I think it is necessary—and good—to heed the advice of the fictional Ms. Frizzle and “take chances, make mistakes, and get messy!” Dr. Thomsen is my real-life Ms. Frizzle and offers the same advice (Thomsen, 2022): have a passion for scientific discovery, be honest about difficulties, and work toward publication.

This extends to other mental and emotional challenges in our research community. We should normalize discussing tough issues so that we better understand each other. I encourage people to seek help for the challenges in their lives; please know that you are not the only one facing that type of challenge and that you do not have to face it alone.

#### 4. On Leadership: Be Quiet, Be Kind, Be an Ally

Since becoming tenure-track faculty at UM, I have held a number of leadership roles, both at the university and in the research community. As Kennel (2022) states, serving on committees is an excellent way to learn about leadership, management, policy, and politics; I agree. In particular, I think that I have learned a few things about being a good leader. First and foremost, be enthusiastic and positive. I think that the carrot is much better than the stick, and the stick should only be used when the other person asks for it as a way for you to motivate them.

It is important to actively listen to others, develop personal connections, and foster creativity. Pay attention and genuinely hear people when they talk with you. If you can, don't come up with a solution to the other person's problem; it is better to reflect their thoughts and ask questions to get them to come to a decision on the next step.

I think it is important to celebrate the process of scientific discovery, not simply the end result (Cuzzolino, 2021; Gottlieb et al., 2018). Conveying this sense of awe and wonder about your work, both within your research community and to the general public, provides a bigger impact and influence than negativity. Cassak et al. (2017) discuss the need for this type of positive engagement as a vital role in our field's continued existence.

Open and cordial communication leads to better creativity. In particular, I firmly believe that diversity, equity, and inclusion (DEI) matters for scientific success. The scientific community, including space physics, is dominated by white men, according to the summary of the American Geophysical Union 2018 membership demographics survey ([https://www.agu.org/-/media/Files/AGU\\_Membership\\_Demographics\\_2018.pdf](https://www.agu.org/-/media/Files/AGU_Membership_Demographics_2018.pdf)). This is unfortunate because a homogeneous team leads to limited solutions. Bringing different perspectives to the conversation, and then fostering a conversational culture that respects and promotes the inclusion of these different perspectives, leads to more innovative solutions (e.g., Ellison & Mullin, 2014; Ely & Thomas, 2001; Hunt et al., 2018). Furthermore, the practice of scientific research has structural disparities that go back many decades (e.g., Pollack, 2015), but still have an influence today. We need to not only change individual attitudes to elevate the civility and safety of the space physics workplaces but also change institutional policies, bending them toward equity, so that diversity and inclusivity are considered normal. My engagement with various DEI committees and groups is a highlight of my work life.

In addition, I think that interdisciplinary group meetings and seminar series are often worth the time they consume on your calendar. Others agree that attending seminars is highly useful (Wolf, 2023). Such meetings might feel like a lot of time spent talking about irrelevant topics, but then there will be the new connection with another person that allows for a substantial leap forward. I have learned so much from others in my role as Director of the University of Michigan Space Institute, an entity to foster cross-departmental conversations and collaborations toward better space research and education. It has been fantastic to get to know so many new people from across campus and even across the country.

I have encountered colleagues that bristle at DEI action in the workplace, reminding them of “political correctness” and causing them to feel constrained about making the wrong statement or action. To me, DEI action and political correctness is about being considerate to not only the majority demographic but also all others in the workplace. We should strive to be respectful to others and mindful of possible harm. Thinking about how others will perceive your comment or action is part of being a good colleague; it is viewing the situation through their filter (e.g., Taylor, 2016). If you misspeak or do something inappropriate, acknowledge your mistake and accept the correction from others. And, most importantly, try to do better next time.

I encourage every leader to be an ally to colleagues from historically excluded groups. I especially encourage you to get trained in bystander intervention tactics (one really good training program is <http://stepupprogram.org/>). Intervening is hard and it requires courage to address an uncomfortable situation (e.g., Brown, 2017). This takes practice, so I suggest that you repeat the training as often as you can. If you don't act in the moment, though, don't berate yourself about it. Post-intervention is also a tactic; go and talk to those involved, both with the perpetrator and with the victim. Each time you witness a microaggression, use it as a learning experience, emboldening yourself into consistent action.

My final comment about leadership is that the shift to leadership requires a loss—of doing the research yourself—and it is okay to grieve that loss. Each transition in your work life is not only a new beginning but also an end to how things were before. It is okay to go through the five stages of grief over changes in your work life. Take time for that and know that you are not alone in going through those feelings.

## 5. A Bold Future

M. W. Liemohn, Keesee, et al. (2021) recently outlined four instigators of change for magnetospheric physics, and Earth and space sciences in general. One is the miniaturization of spacecraft systems and instruments. I see enormous opportunity in fleets of small satellites providing a three-dimensional measurement set of geospace and other space environment realms. Ground-based instruments have also followed the same trend with significant reductions in size and resource needs, allowing for distributed arrays with little extra than a cell phone and a solar panel. I hope to witness not only the launch of a magnetospheric constellation (e.g., Angelopoulos & Spence, 1999) but also the creation of sensor networks in ways that we cannot yet imagine, allowing humans to examine and experience the natural world in a completely different manner.

The second is the continued growth of high-end computing and the advancement of code coupling techniques to take full advantage of these computational resources. The fastest computers continue to increase in performance every year, with massively parallel computers maintaining a rapid exponential growth in operations per second. While microchips are reaching the physical limits that will bring an end to Moore's law, the advent of quantum computing—storing information in the excited states of single atoms (e.g., Yung, 2018)—would transform the industry and set us on a new path to increased computational capabilities. This could—will—have tremendous impact on how science is conducted.

The third is the advent of techniques to handle, process, visualize, and mine large data sets. As the volume of numbers returned from new sensor arrays and numerical models balloons by orders of magnitude, data science is keeping pace with new methods to understand those number sets. This includes improved machine learning algorithms and database management tools as well as large-scale infrastructure capabilities (e.g., McGranaghan et al., 2018), such as continental ultrafast networks for moving these collections of numbers from a science data center to a researcher's local machines. Software and hardware advancements have already made a substantial impact on how we conduct scientific investigations; they will continue to do so.

The fourth instigator is the demographic changes and an increased focus on DEI. As mentioned above, the workforces of Earth and space science disciplines are not representative of the U.S. population, let alone the world's population, which means that there is significant potential for scientific discovery that is not being realized. Earth and space scientists are inequitable in their selection of journal reviewers and editors (Lerback & Hanson, 2017), in their selection of honorees for awards (Jaynes et al., 2019), and in their interactions with each other (Rosen, 2017). If we strive for diversity, foster inclusion, and work toward equity, then amazing opportunities could be attained.

The world is challenged by three big pandemics right now. The first is the physical one of the COVID-19 contagion. It put most of the world into a mode of hunker-down-and-survive, increasing career anxiety (e.g., Jemini-Gashi & Kadriu, 2022; Mahmud et al., 2021). It is still impacting many aspects of life. One for which there is clear evidence is the negative effect on professionals who are also caregivers (Feng & Savani, 2020; Heggeness, 2020). As the latter role increased in magnitude and concern, productivity at the former suffered. The ramifications of this uneven impact on careers will continue for many years; I hope for a future in which we are aware of COVID-19's negative impacts on careers and work to mitigate its effects on our workforce.

The second pandemic is the mental one of anti-intellectualism. It seems to be on the rise again, as it has in the past (e.g., Abelson, 1976; Hofstadter, 1963; Rigney, 1991). Within the Earth and space sciences, climate change denial has been an issue for decades (e.g., Lindzen, 1990; Singer, 1996), but it has lately spread to a disbelief in science and the scientific method (e.g., Lewandowsky & Oberauer, 2016; Merkle & Loewen, 2021). When “alternative facts” are equivalent to reality (e.g., Cuenca, 2022), the future of science is in jeopardy, negatively influencing career choices, especially among historically excluded groups (e.g., McGee et al., 2021). Regarding our mistakes along the way and the meandering path of scientific consensus, acknowledging uncertainty will hopefully combat the anti-intellectualism. Always portraying perfection makes it hard to adjust thoughts at the individual and group level. Embracing the difficulty of our work will allow others to better understand the scientific method and appreciate the process, and wonder, of scientific discovery.

The third pandemic is the emotional one of white supremacy and, more generally, western chauvinism. This is a mentality that arose centuries ago (see, e.g., Du Bois, 1933; Fredrickson, 1981; Elphick, 1983; Gordon-Reed, 2018) but has recently seen an upsurge in adherents (e.g., Beirich, 2022; Du Mez, 2020; Stern, 2019). This worldview sets up a disparity in how people treat others, especially others that look, act, or talk differently than traditional western culture. Embracing the benefits of diverse thinking, the kindness inherent in inclusion, and the institutional support structures of an equitable workplace will make the Earth and space science research communities into leaders toward combating this dreadful philosophy.

As a research community, we must rise to face this triple threat. Each one poses a unique challenge but they are all related. The COVID-19 pandemic has had a disproportionately large negative impact on the careers of women and historically excluded groups, and this could lead to additional negative effects from the second and third pandemics. While all three issues are much larger than Earth and space sciences, we can and should actively change our behaviors to mitigate and minimize their detrimental impacts on our research community. Let's boldly work toward the goal of a better future, together.

What does all of this mean for the future of my career? Regarding research, my primary methods have shifted from purely numerical modeling to a balanced mix with data analysis. I hope to be one that can help our research community achieve new levels of discovery through enhanced data-model comparisons and assessment techniques, especially through new measurement capabilities as I learn more about spaceflight hardware and project management. As I have been increasing my DEI awareness, understanding, involvement, and action over the years, I realize the privilege that I have had throughout my life and the accumulation of advantages that this privilege has yielded. I know that there is a disproportionate service load put on certain demographic groups; it is a good time for me to use my experience even more for the benefit of our community. I hope to continue actively working to mitigate the negative impacts of the three pandemics mentioned above, especially in the context of inclusivity and equity in the space physics research community.

## 6. Take-Aways

To summarize, let me begin by stating that you are more than your publication record and citation count. You are more than your ideas. You matter. Learn from those around you and be a mentor and role model for others. We are a research community.

As I approach the three solar cycle unofficial limit on providing advice (Mendillo, 2009), I feel marginally qualified to give a bit of it to the community. Here are a few key points from this article.

- Get started. This applies to any step in the scientific process, but especially on brainstorming hypotheses, conducting experiments, and writing the paper. It also applies to other aspects of your work and personal life.
- It's okay to be wrong. It is natural to be uncertain, frustrated, sad, or even angry about how your work is going. You do not have to face this alone. Many others feel this way, too.
- Hone your skills that develop community, including learning how to better listen to others and understand their perspective. These skills are as important as knowing the subject matter. Work hard and be nice.
- Continue to learn. When you see a new opportunity, it is okay to shift your research focus. Know, though, that this shift to the new might include diverting away from the old and it is natural to grieve that loss.
- Strive to love your job. I encourage you to make the most of the life before you, discover the joy in small steps forward, and foster deeper relationships with those colleagues that uplift you.
- Actively make the future that you want to have. Define that future and then work toward realizing that outcome.

I might be wrong; I am wrong a lot. I love my job, though, so, slowly but surely, I strive to be at peace with that.

## Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

## Data Availability Statement

Data were not used, nor created for this research.

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