Following the Path of Least Resistance

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Abstract The reason a path may be the path of least resistance is because it may be the path for which you are most suited. For you it may look like a stroll in the park; for someone else, it may look like climbing Everest. Or vice versa. Taking the “easy” route is not copping out; it is a form of playing to your strength. Here I detail my professional path from digging holes for antennas in graduate school to designer and builder of energetic neutral atom imagers that have flown and continue to fly throughout the heliosphere.

Plain Language Summary This article is meant to provide some general insights that I’ve developed over a 50-year career in Space Physics. Some may find it baffling, others may find it entertaining, hopefully some will find it useful.

1. Introduction

Growing up in a household in which my father was a physics professor (at Michigan Technological University), my mother a pianist whose father and grandfather were both astronomers (both heads of the Dudley Observatory in Albany, NY), it might be surmised that my path was preordained. Yet little of that heritage directly influenced my career. I was a good student, but had no particular passions, other than trying to understand how things worked, being outdoors, and playing basketball. Given this lack of a specific direction, my goal as a teenager and young adult was to remain in school until I stumbled on something that both suited me, and seemed like I could make a career of it.

Following high school, I chose to attend the University of Michigan (in-state, and so reasonable tuition, but still 600 miles from home, sufficient distance to begin developing some independence). Having had an excellent chemistry teacher in high school, and an incompetent physics teacher, I started out at Michigan planning to be a chemistry major. In my second year I was required to take introductory physics (from a very good teacher—it matters a lot), which suddenly made sense and in which I did well. At the same time, I took organic chemistry, and discovered one has to have a functioning memory to excel in that. Not having one, I switched to physics, where you can derive everything from first principles, and need to memorize very little. For me, that was the path of least resistance, and it has been a rewarding one. (It did get harder, but that was OK—it remained interesting.)

After Michigan, still not seeing a career path forward, I applied to several graduate schools (some in oceanography, based simply on my love for the ocean, and some in physics—but one criterion was that it be located close to the ocean, where I might have the opportunity to get out on the water). The University of New Hampshire accepted me, and met my rather arbitrary requirement of being close to the water, so that is where I went. It didn't hurt that it was only a half day's drive from our family cabin on the coast of Maine, where I'd spent nearly every summer of my life to that point.

Graduate school was a bit of a rude awakening. Until then, I'd been able to do reasonably well simply by attending class, doing the assignments, and binge studying prior to exams. Now, I had to work much harder to progress.

When applying to graduate schools, I had still not settled on a specialty. At University of New Hampshire (UNH), space physics was the primary focus of the department, so in a very un-directed, nearly random-walk fashion, I ended up in a PhD program that was nearly a perfect juxtaposition between my father's physics, and my grandfather's astronomy—a mix of luck, fate, and aptitude.

At this time, Ed Roelof was teaching at UNH, and he became my thesis advisor. Ed had a collaboration with a couple of researchers at the University of Iowa, Will Cronyn and Stan Shawhan, who had just been funded to install a radio scintillation phased-array antenna on Clark Dry Lake in the Anza Borrego Desert in southern California. My thesis topic became solar wind studies based on radio scintillation measurements using data from this array. However, the array had not yet been built, so I spent a couple of summers drilling 11,000, 2.5' deep,
2” diameter holes in the dry lake bed, driving in redwood posts, stringing coax cable, and repairing guy-lines that the coyotes developed a habit of chewing through. For someone who grew up in Michigan's upper peninsula, who considered any temperature over 80° F to be possibly life-threatening, this was indeed trial by fire. Yet I survived, learned to love the desert, and eventually wrote my thesis based on analyzing data from the array (Mitchell & Roelof, 1976).

After graduating, I followed Ed to Applied Physics Laboratory (APL), and began analyzing energetic particle data on IMP 7 and 8, and ISEE-1 (Mitchell et al., 1990). This introduced me to solid-state detector (SSD) telescopes, and to some of the responses of the SSDs to stimuli for which they were not originally intended. Other than cosmic ray background, these included solar UV, solar X-rays, solar wind heavy ions, which led to papers on solar wind iron in high-speed streams (Mitchell & Roelof, 1980; Mitchell et al., 1981; Mitchell et al., 1983), as well as energetic neutral atoms (Roelof et al., 1985; Williams et al., 1992).

At APL, having found some of these peculiar responses of energetic particle telescopes to such diverse stimuli as photons and heavy ions in the solar wind, I was tasked with helping to conduct some energetic ion beam experiments on flight spare and engineering model SSDs, using the Van DeGraff accelerator at Goddard Space Flight Center. This was my first exposure to hardware, and opened up a whole new understanding of the sensors whose data I had been analyzing. In particular, it sensitized me to the fact that not all of the features seen in the data are generated by the stimuli you are attempting to analyze, and that depending on their configuration in a sensor, the detectors may be measuring new phenomena for which the sensor was not originally intended. It then becomes a small extension of that understanding to conceive new sensors configured specifically to measure some of those newly realized stimuli.

Motivated by the unique signatures and characteristics of energetic neutral atom (ENA) emissions, and their potential for global imaging, I (along with several others) began musing about ways to use energetic ion measurement techniques to measure, and image, ENA emission, from Earth's magnetosphere, and later from Saturn's and Jupiter's magnetospheres. These musings—typically conducted away from my desk, while driving, showering, or walking the dog when one's unfettered mind is free to imagine—were when I worked out most of the details of notional designs for such imagers. This was not done in a vacuum, and in particular Barry Mauk, Ed Keath, Steve Jaskulek and I bounced ideas back and forth frequently. The first such ENA imager design to be funded was the Ion and Neutral Camera (INCA), part of the Magnetospheric Imaging Instrument (MIMI) for the Keath, Steve Jaskulek and I bounced ideas back and forth frequently. The first such ENA imager design to be funded was the Ion and Neutral Camera (INCA), part of the Magnetospheric Imaging Instrument (MIMI) for the Cassini-Huygens mission to Saturn and its moon. Titan (Krimigis et al., 2004; Mitchell et al., 1993, 1998). And that sensor, originally a single dimensional imager (McEntire & Mitchell, 1989) designed to rotate on a rotation platform provided to the fields and particles instruments by the spacecraft, soon had to be redesigned completely as a two-dimensional imager when the rotation platform was descoped. While INCA launched on Cassini in 1997, a second ENA imager, HENA (Mitchell et al., 2000), a near-clone of INCA, was included on the IMAGE MidEx mission, launched in 2000, and returned images of Earth's magnetosphere between 2000 and 2005 (e.g., Mitchell et al., 2001), whereas INCA only began its primary mission at Saturn in July 2004. The INCA data at Saturn returned global images and movies throughout the 13 years in Saturn orbit (e.g., Krimigis et al., 2007; Mitchell, Krimigis, et al., 2009; Mitchell et al., 2005). INCA also served as a high angular resolution ion sensor (by turning off the deflection high voltage), providing observations critical to analyzing various auroral particle populations at Saturn (Mitchell, Kurth, et al., 2009). INCA response to dust impact in Saturn's equatorial plane was also exploited to discover and characterize dust precipitating from Saturn's innermost ring, the D-ring, into the equatorial ionosphere and atmosphere (Mitchell, Perry, et al., 2018). Additional development funded by NASA resulted in a new, improved ENA imager, JENI (Figure 1, Mitchell et al., 2016), now integrated on the JUICE mission to Jupiter and Ganymede, slated for launch in 2023, and JENI's clones, the Ultra sensors on the Interstellar Mapping and Acceleration Probe (IMAP) mission, to launch in 2024.

Meanwhile I was also thinking about how to return better angular coverage for energetic ion instruments, which led to the hockey puck design (fliown on Energetic Particle Detector on MESSENGER to Mercury, PEPSSI on New Horizons to Pluto, JEDI on Juno to Jupiter, RBSPICE on Van Allen Probes (Mitchell, Gkioulidou, & Ukhorskiy, 2018; Mitchell et al., 2013) and EPS on Magnetospheric MultiScale mission to Earth). The hockey puck was designed for a spinning spacecraft; for the Parker Solar Probe, the 80-aperture mushroom design is currently returning new and exciting data from near the sun (Mitchell et al., 2020), as the EPI-Lo instrument (Figure 2, Hill et al., 2017), part of the ISOIS suite (McComas et al., 2016).
So that is, in brief, the path I’ve taken through my career. Along the way, I’ve discovered approaches that I’ve found valuable, and made mistakes that have taught me as well. Instruments have clearly been a focus, but keeping them tuned in flight, and reaping the rich data sets they’ve produced that have led to new scientific insights has been the ultimate goal and reward.

Figure 1. The JENI instrument for JUICE.

Figure 2. EPI-Lo instrument on Parker Solar Probe, generically known as “the Mushroom”.
1.1. Work to Your Strength

There is a confession in the title of this paper. Although I'm sure many who know me already know this about me, I am inherently a bit lazy, by which I mean I tend to avoid tasks for which I am ill suited. I consider this to be a character trait that, while not enviable, can in its own way be useful. It leads me, as that title indicates, to either pursue a line of investigation or abandon it, depending on whether I see it as a good fit to my particular aptitudes, or not. So when I say follow the path of least resistance, in this case I mean work on what is interesting to you (motivation is critical), as well as what you are good at (even if it is interesting, if you are not strong in the tools needed to tackle a problem, it is more likely to end in frustration and yield little in the way of useful insights). Many times, if the interest is there, you can enlist collaborators to fill the gaps in your capabilities—the fact that it is interesting implies at least sufficient understanding to ask the right questions, and that is key to making advances. And of course, you can teach yourself new tricks, which I'd encourage you to do, unless it involves beating your head against the wall with nothing gained.

1.2. Curiosity Drives Progress

It has been my experience that most of the good ideas I've had while working on a new area of research, or even returning to one that was left unfinished, come to me when I'm not working at my desk. My desk is where I write those ideas down, where I test them, where I find the flaws in them, but the ideas come while walking the dog, taking a hike, taking a shower, going to lunch, falling asleep. They come then because my mind is relaxed and open to considering new approaches, yet the problem under study is always near the surface. So work on whatever you simply don't want to stop mulling over in your mind, because it is so interesting you can't keep it out. What this generally requires is some quiet time in the rest of your day, time when you are not in conversation, watching TV, listening to the radio, or reading—time when you are perhaps running or hiking, or doing something mundane that requires little intellectual focus. Then, in much the same way you sometimes process information in the back of your mind during sleep, the questions and problems you've been focusing on at work may resurface in surprising and productive ways. If you do not create blocks of that kind of time with low external stimulus, then you may miss the opportunity to have things you've been working on fall into place seemingly on their own; or miss the insight to realize that your thinking has overlooked an aspect that disproves the hypothesis you've been developing—just as valuable.

1.3. Learn From Your Mistakes

Don't beat yourself up over mistakes, they are unavoidable. But they are often also useful, if you allow them to be. For example, when designing and building the HENA instrument for IMAGE, I made the mistake of not including sufficient filtering in the thin foils to keep light from driving noise in the SSDs that formed half of the imaging back-plane of the sensor. This was actually a series of mistakes, but ones I did not realize I had made until after launch, when that subsystem worked well only when the spacecraft was in eclipse, and so not exposed to either sunlight or Earth-shine. In looking back, I found I had: (a) insufficiently understood the response of the SSDs to light; (b) ignored the fact that in the laboratory during the integration and test of the instrument, the SSDs only worked well when we turned off the lights in the laboratory; and (c) not subjected the design to a rigorous peer review before finalizing it. In retrospect, it would have been simple to add some light absorption to the thin foil that covered the SSD portion of the back plane, at the small cost of a slightly elevated energy threshold. From this, I learned a lot about detectors and their responses to environmental backgrounds. I also learned a lot about the need to understand the system you are developing as well as you can, before you send it into space. Don't assume that those working on the system (engineers, other scientists) know enough to keep you safe—sometimes they don't. So do your research, try to confine your mistakes to the engineering unit, or the first draft, or whatever constitutes the early stages of a project when it is generally easy to fix, and subject your instrument, or idea, to whatever stresses you can imagine. If they hold up under all such tests, they are probably good to go. If they fail, better to find out early.

1.4. Remain Skeptical

I've always found that a healthy dose of skepticism is useful. If something doesn't look quite right, it probably isn't. If something looks too good to be true, it probably is. I never thought I'd quote Ronald Reagan, with whom I
disagreed on almost everything, but I did agree with him when he said, “Trust, but verify.” In physics, I find this useful in applying to results in the published literature, as well as to my own results. If a piece of work is trustworthy, it should be possible to verify it through your own analysis. This applies equally to your own work—it should stand up to a variety of analytic approaches. If it doesn't, it probably isn't right, regardless of how attractive it may seem. But when directed toward others, be gentle in your skepticism. No need to make enemies over it. As Tom Krimigis often told me (and I think he was quoting someone else, perhaps Herb Bridge?), “Friends come and go, but enemies are forever.” So disagree when you must, but do so kindly (advice I try to follow, not always successfully).

2. Diversify

Don't stay in one narrow subject for too long. Not only will it become boring, but you also deprive yourself of the insight that diversity spawns. As mentioned earlier, I started out (my thesis work) in interplanetary radio scintillation, helping to build a phased array antenna in the southern California desert, and analyzing the data to understand the latitude structure of the solar wind. For a variety of reasons (aside from the fact that it was intrinsically noise to begin with), this was noisier than any data I have worked with since. This taught me to appreciate data sets that were only mostly noise—to quote Billy Crystal, “Big difference!” From there I studied actual solar wind data, then upstream (of Earth's bow shock) energetic particle events. I then moved into the magnetosphere, looking at the magnetopause and the low-latitude boundary layer, and from there to the plasma sheet, and its embedded current sheet. Then, after discovering ENA signatures in IMP-8 and ISEE-1 energetic particle SSD telescope data, I was spurred to develop concepts for ENA imagers, eventually having one selected for flight to Saturn on the Cassini spacecraft. Saturn turned out to be the most fascinating place I have studied, and an excellent location for ENA imaging. Big place, single S/C, so global imaging was a big plus; and most of the emission was confined close to Saturn's equatorial plane, making interpretation of the line-of-sight integrated images particularly tractable. While there, we used the ENA imager (INCA) to also image the heliospheric boundary at energies above those covered by the IBEX mission, transporting me back into the solar wind, and the interstellar medium. Based on some of the limitations of the INCA imager, I embarked on a development program to address those shortcomings. The resulting instrument, the JENI ENA imager, is now part of the PEP suite on the ESA JUICE mission to Jupiter and Ganymede, to be launched in 2023. From there, I've gone to the other extreme, close to the sun on the Parker Solar Probe with the EPI-Lo energetic ion composition instrument, part of the ISOIS instrument suite. And more recently still, I've been involved with the Ultra instrument on IMAP, essentially a JENI clone but for imaging the heliospheric ENAs from L1.

Needless to say, I have not been bored! But more importantly, each of these different plasma environments informs the others. Phenomena well known and understood in one sub-field are sometimes unknown in others—by having a diverse, cross-disciplinary background, I've been able to bring a new perspective to the understanding of phenomena that stem from similar physical conditions in very different environments/locations. Of course, I might also be accused of being a dilettante, and that may well be justified, but it's been fun!

2.1. Listen to the Leaders in the Field

I have found that I have gained tremendous understanding by listening to the first generation of Space Physicists—and it has been my good fortune to have followed closely behind them. Of course, I've been particularly indebted to my direct mentors—Ed Roelof, who was my thesis advisor and with whom I've worked closely on many topics over the years; Don Williams, who took me under his wing as a post-Doc and let me have free reign with his splendid ISEE-1 data set, and who guided me through several important publications until I was able to forge ahead more on my own; and Tom Krimigis, who gave me the opportunity of a career in allowing me to develop the INCA ENA camera for Saturn, to serve as the Cassini MIMI instrument scientist, and eventually to transition to be PI for Cassini MIMI. In addition to these pioneers in the field, I've gained invaluable insights working closely with Margaret Kivelson (whose imagination and intuition, appropriately constrained by an unparalleled grasp of the physics, continues to amaze me), Ted Northrup (who guided me through some very tricky mathematics while revealing himself as a referee on my paper on thin current sheets in the Earth's plasma sheet), Lou Lanzerotti (who has been very supportive throughout my career, and led the RBSPICE instrument science investigation on Van Allen Probes for which I served as Instrument Scientist), Jim Burch (who brought me on to his IMAGE MidEx mission after selection and always supported and treated me with respect and honesty) and Barry
Mauk (with whom I shared an office early in both our careers, who helped me in many ways to develop the ENA imagers, who unselfishly promoted me to lead the INCA development and implementation, and whose physical insights have helped me and kept me on course on multiple occasions). There are of course many, many others, but these are the people to whom I owe the most, and from whom I learned the most.

2.2. If You Like Good Instruments, Design Them

This sounds like a no-brainer, but really, I was not a likely candidate to design instruments. To this day, I am of virtually no use in a laboratory. I have no background in engineering. But with good, imaginative engineers to work with, those deficits need not prevent one from delving into designing instruments. And if you want to make a measurement to advance your scientific interests, and the right instrument does not exist, then let your imagination run wild. But not too wild. The most important things are to understand how instruments work; to understand when you are asking the impossible as opposed to when you are merely asking the very difficult; to learn how to advise the engineers as to when a change they want, or need, to make is OK for your measurement goals, and when it is not; to develop your concepts well in advance of when you might have an opportunity to fly them; and to keep building on what works, abandon or fix what doesn't, and keep thinking about how to make the next version better. There is little in this business as satisfying as getting high quality data back from a new place never before visited, or of phenomena never before measured. Exploration is exciting, and going to new places with new instruments is bound to return new discoveries.

3. Just Say No

Wow. Quoting another Reagan. Well, not the same context, anyhow. What I mean by that is, don’t try to take on too many responsibilities, tasks, or roles. The longer I stay in this field, the more frenetic it seems to grow. I see so many people, especially early and mid-career, split in so many directions that they are ineffective in most of them, and driving themselves toward burn-out at an alarming rate. Although I have just gone on about how much I’ve diversified over the course of my career, it has been mostly serial, not parallel. Yes, you do need to make sure you are doing something that will continue to pay you to work. And yes, there is a certain amount of taking on jobs that may not be your favorites. But try to limit that. Just because it looks shiny, it doesn’t mean you need to bring it back to your nest. Or just because someone asks you to take on something extra, you need not always say yes. Your sanity, and the quality of your work, will eventually suffer. So recognize your limits, and stay on the right side of them. Yes, sometimes there will be crunches, and you have to power through. But it shouldn’t be like that all the time. If it is, you are either not delegating when you should, or you are being unrealistic. In either case, you are not likely to do a great job. For me, this has usually been simple. My level of competency in some areas (management, organization) is so poor, that people don’t even think to ask. Some of that I come by naturally, but some of it I cultivate. I recommend that you recognize your strengths, recognize your weaknesses, and stick to the former. So, this is a corollary to “Work to your strength,” with the difference being that others may not recognize those strengths and weaknesses, and ask you do take on something for which you are poorly suited. That’s where you need to say, “no.”

4. Curb Your Ego

Try not to let your ego get too involved—it usually leads to inefficiency, learning little, offending others, taking offense to criticism when instead you might learn something, and unnecessary crashes. Humility allows you to ingest the good ideas of others, and use that information to take those ideas further or inform your own thinking. And try to credit others for what they have given you in that process.

This is a tough one—you will not always succeed (I certainly haven’t!). But to the extent that you can follow it, it will serve you well.

5. Help Others

Be generous with your time, and to the extent that you control it, with your data. You can’t do it all yourself, and you will need to receive help to accomplish what you’d like to do. There is tremendous reward in working with young researchers, teaching them what you’ve learned, and in return having them extend that in new ways,
while supporting your own endeavors in ways you could not on your own. You learn a lot over a long career, and others will benefit from having you pass on what you know. And by sharing data with others, you both get the benefit of the additional analysis they can do that you can’t, but you can also short-circuit the tendency that many non-instrumentalists have to analyze noise or instrumental artifacts without realizing it. Data is complex, and instruments are not perfect. Often some of the more striking features in a line plot or energy spectrogram or fast Fourier transform are instrumental, not environmental, and by helping others to understand those features, you help both them and yourself in not having to publish comments or corrections.

And, in helping and teaching others what you know, you learn a lot from them in the process, and you are helped by them in return.

6. Have Fun!

If it isn’t fun, you are not likely to want to make a career of it. But give it some time; truth be told, my first several years were not especially fun—lots of uncertainty about my future, self-doubt, fear of public speaking. Eventually through the support of peers and mentors, and through growth in my self-confidence I began to gain expertise in certain domains, discovering what I was good at, this changed from anxiety to enthusiasm, and the satisfaction of helping to solve problems no one has solved before keeps it interesting.

Data Availability Statement

Data were not used, nor created for this research.

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