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FEATURE ARTICLE
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Key Points:

- Embracing serendipity and new opportunities could help advance one's scientific career
- A sustained effort in what excites you could be more productive and beneficial than switching topics
- Building a diverse team and relating your research to broader community interests will help your project grow faster

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From Theory to Large-Scale Simulations, or Living Without "The Paradox of Choice"

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Abstract Navigating the challenges we face at work and in life is often difficult, and can even make us question our past decisions. This dilemma is even worse nowadays because of the many options available to us, leaving us not enough time to explore them all: *the paradox of choice*. My life experience offers another perspective on how to make choices; wherein I had to rely more on serendipity, coincidence, and embracing risks. This paper presents a brief description of my career path in space science—from a small village in the countryside to one of the top science Laboratories in the world—and lessons learned through the process of becoming a more resilient scientist. I came to the United States from Bulgaria about 30 years ago, seeking a better education and job opportunities. Navigating a career of research scientist, not only did I find jobs that motivated me every day, I also met amazing people to work with along the way. As a woman in science, I hope my story can inspire and attract young researchers (girls and boys alike) to our community, helping to grow and diversify the next generation of space scientists.

Plain Language Summary This paper presents a brief description of my career path in space science that was full of serendipity, coincidences, and risks that I was eager to take. The lessons I learned throughout my professional journey and advice I could give to the future generation are that putting a sustained effort in one research area and specializing in it could be really rewarding.

1. Early Years in Bulgaria

As I was growing up in Bulgaria, it was hard to imagine that some day I would be living thousands of kilometers away in this legendary land of America's *wild west*. As a child, I used to spend my summers at my grandparents' farmhouse in a small village in the countryside. One of our favorite times was in the evening, when we would take out the "World Atlas" and start looking at maps of various countries around the world. Since we could not travel abroad, we would wonder what life might be like in these faraway places. My love for travel was reinforced when my dad, who was a doctor, got an opportunity to work for a few years in Algeria and took his family with him. It was very exciting for all of us to live in a foreign country in Africa, learn a new language and experience another culture.

During my high school years, I developed an interest toward mathematics and physics. I always liked solving puzzles and doing math, but my favorite subject was physics; to me it meant making discoveries every day and understanding how the universe works. However, when I told my high school teacher in physics that I would like to continue studying physics at Sofia University, he was very concerned as "this was not a profession for women." My teacher in literature was also very concerned and she tried to convince me to study literature, because she thought I had a unique writing style. Thankfully, my parents, who embraced the sciences (my mother was a chemist) and were open-minded, encouraged me to apply to the physics programs, and to not worry about the tough competition and very limited student placements. Needless to say, I was extremely happy when, after a few months of preparation and exams, I learned that I had been accepted!

The 5 years I spent at the University of Sofia were among the most exciting of my life. I learned advanced mathematics and physics, and met colleagues that became friends for life, including my future husband. At the end of the fourth year, we had to choose a topic for our Master's thesis. Bulgaria had just launched its first satellite in 1981, in a near-polar orbit, on a rocket provided by the former Soviet Union. The satellite was named "Intercosmos Bulgaria 1300" after the 1300th anniversary of establishing Bulgaria as a sovereign state. After I heard a lecture from the Space Research Institute in Sofia about this launch, I decided to do my Master's thesis there, analyzing data from the instruments onboard this satellite. Thus, I spent a year studying the morphology and characteristics of field-aligned currents in the Earth's magnetosphere using magnetometer data from "Intercosmos Bulgaria

1300". The nontrivial problem of magnetosphere-ionosphere coupling increased my interest to pursue studies in this research area, however job openings in the field of space science were not available at that time in Bulgaria. To my disappointment, after graduating I was assigned by the Physics Department Placement Committee to work as a physicist at the Institute of Microelectronics in Sofia, with the explanation that my high grades guaranteed quick learning of solid-state physics. Thus, I spent several years at this institute analyzing the surface effects in semiconductors.

2. Graduate Studies at the University of Michigan

A rare opportunity presented itself to my family in 1990, after the end of the Cold War. I was married, with two daughters (about 3 and 5 years old), when my husband, Valentin Jordanov, attended an International Atomic Energy Agency (IAEA) training in the United States. During this training he received an invitation to visit the University of Michigan (U of M) and an offer to enroll in the PhD program of its Nuclear Engineering Department. The salary of a graduate student was not sufficient to support a family so the only way for us to be together was for me to find a job too. The Atmospheric, Oceanic and Space Sciences (now Climate and Space) Department attracted my attention, and I felt extremely lucky a few months later when I was accepted as a graduate student there. What followed were probably the most creative and productive years of my life. The learning opportunities were tremendous—I had a good theoretical background in physics from Bulgaria, but I did not know much about atmospheric and space plasma physics, nor numerical modeling, and I had the chance to learn from some of the best professors in the world! I deeply enjoyed many enlightening discussions with my fellow graduate students too.

The topic of my PhD thesis that we chose with my PhD advisors, Profs. Andrew Nagy and Janet Kozyra, was very interesting to me, developing a kinetic model of the Earth's ring current. My predecessor fellow student, Dr. Mei-Ching Fok, had developed a new kinetic model of ring current decay, and my tasks were to extend this model to arbitrary pitch angles and to include wave-particle interactions. I cannot say that these topics were dominant or attracting the most attention at the time. Due to the sparse observations of ion cyclotron waves in space, their role in ring current dynamics was unclear, but the concept of energy transfer between waves and particles was intriguing to me and its complexity made it very appealing. However, the more I read about these challenging topics and studied Dr. Fok's ring current model (Fok et al., 1993), the more I realized that I had to address the problem in a different way. The use of the first and second adiabatic invariants in the model as independent variables for the phase space distribution function was clever, since it simplified the transport equation. However, the use of energy and pitch angle variables was more suitable for including wave-particle interactions, and offered another advantage by allowing easy comparison of model results with observations. Thus, I derived the bounce-averaged kinetic equation using these new variables and implemented it numerically, creating the ring current–atmosphere interactions model (RAM) (Jordanova et al., 1997). The two spatial variables, radial distance from Earth and magnetic local time (MLT) remained the same in both ring current models. To properly incorporate the interactions between ring current ions and electromagnetic ion cyclotron (EMIC) waves, I derived general expressions for the quasi-linear diffusion coefficients in a multi-component plasma containing heavy ions (Jordanova et al., 1996). The RAM model has been used successfully in many studies over the past decades and I consider its creation to be one of my biggest contributions to the field of magnetospheric science.

3. Working in Academia

After graduating from the University of Michigan, I joined the Institute for the Study of Earth, Oceans, and Space (EOS) at the University of New Hampshire (UNH). Thus, at the beginning of 1996 I became a research scientist in the EOS Experimental Space Plasma (ESP) group. In preparation for the launch of the Cluster spacecraft, I began studying its UNH-built instruments as I was supposed to analyze their in situ observations once they were placed in orbit. Specifically, I got involved in the development of the data analysis software for the Electron Drift Instrument (EDI). Unfortunately, after the explosion of the Ariane 5 rocket carrying the four satellites in space, this project was delayed by 4 years while new instruments and spacecraft were rebuilt. Following discussions with the EOS Space Science Center Director, Prof. Roy Torbert, I turned my attention back to the further development of my ring current model. Getting new insights on geomagnetic storms from numerical simulations and

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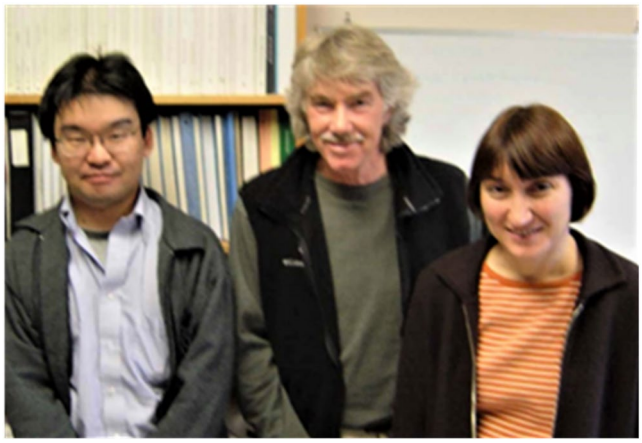

Figure 1. (left to right): Yoshizumi Miyoshi, Richard Thorne and Vania Jordanova at the University of New Hampshire, Durham, NH, in 2003.

comparisons of model results with observations was something that I could contribute to the ESP group's research program.

The large space science group at UNH provided possibilities for many collaborations, from studying the solar origin of storms, to their manifestation in the magnetosphere-ionosphere and further effects on the ground. With my colleagues Profs. Charles Farrugia and Lynn Kistler, we investigated ring current activity during magnetic clouds and the effects from various source and loss mechanisms on ring current dynamics. With the help of my graduate student Alex Vapirev and postdoc Dr. Yoshizumi Miyoshi, we extended RAM to more realistic electric and magnetic fields and to relativistic energies necessary for studies of radiation belt electrons (Miyoshi et al., 2006). We also started very successful collaborations with Prof. Richard Thorne (Figure 1) and his research group at the University of California Los Angeles (UCLA). We investigated the generation of EMIC waves, as well as their subsequent propagation in space and feedback on energetic particles, obtaining the first global modeling study of ring current proton precipitation by EMIC waves during storm time (Jordanova et al., 2001). In addition, we began studying the generation of whistler mode waves by the unstable electron populations. The RAM model was becoming a valuable and versatile model and was considered by many as a standard in the field.

In the meantime, in 1999, I received a promotion and became part of the research faculty of the UNH Physics Department, which gave me opportunities to teach several graduate classes in magnetosphere and ionosphere physics in the following years. I also became greatly involved with Project SMART (Science and Mathematics Achievement through Research Training), a 4-week long summer research institute for high school students at UNH, and became the lead organizer of its Space Science program. While I was enjoying teaching and outreach activities, I also realized that this effort took away time from doing research, and I missed the excitement of technical challenges and innovation. Around 2004, as interest in the space science community was building toward exploring radiation belt dynamics and the impacts of wave-particle interactions, I started a closer collaboration with colleagues from Los Alamos National Laboratory (LANL) that were interested in RAM. This led to a new chapter in my life.

4. Research at Los Alamos

In the fall of 2005, I was approached by LANL colleagues to join their Dynamic Radiation Environment Assimilation Model (DREAM) project, aimed at better understanding and modeling the Earth's radiation belts structure and dynamics, with Dr. Geoff Reeves as Principal Investigator (PI). A key element of this project envisioned obtaining a magnetically self-consistent ring current model and investigating its effects on the radiation environment. This offer was not only a great opportunity for me to continue the development of my ring current model, but also to visit the southwest that I had only heard about and seen in movies. It was also a good time to move across the country, since my daughters had finished high school and left for college. Thus, in the beginning of 2006, my husband and I relocated to Los Alamos and I joined the Space Science and Applications (ISR-1) group, which I am still part of.

With support from the DREAM project and team (Reeves et al., 2012) we achieved the successful two-way coupling of RAM with a three-dimensional (3-D) magnetospheric model developed by Zaharia et al. (2004) and obtained the Ring current-Atmosphere interactions Model with Self-Consistent magnetic (B) field (RAM-SCB) (Jordanova et al., 2006; Zaharia et al., 2006). For the first time we were able to calculate the 3-D magnetic field in force balance with the anisotropic ring current pressure, and to study its feedback on the particle dynamics. Preserving the anisotropy of energetic particle distributions in these simulations was crucial since they could lead to the generation of electromagnetic waves. We thus found that the large-scale magnetic field could be depressed compared to a dipolar field as close as ~4.5 Earth radii (R_E) during even a moderate geomagnetic storm. Also, the plasma pressure in the inner magnetosphere was lower in the self-consistent case, and exhibited fine structures like local gradients and double peaks. Finally, there was sufficient free energy to excite whistler

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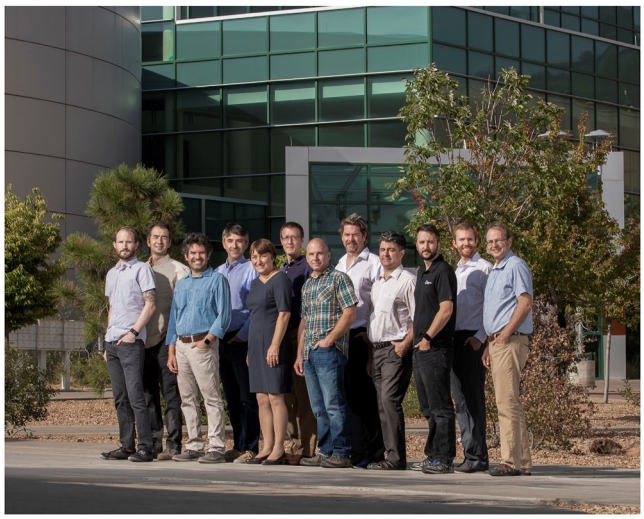

Figure 2. The Space Hazards Induced near Earth by Large Dynamic Storms team at Los Alamos National Laboratory (left to right): S. Morley, D. Svyatsky, H. Godinez, G.-L. Delzanno, V. Jordanova, C. Meierbachtol, M. Henderson, C. Jeffery, A.-D. Panaitescu, L. Vernon, J. Woodroffe and J.-D. Moulton, Los Alamos, NM, in 2018.

mode chorus waves in the post-midnight to noon MLT sector, EMIC waves predominantly in the afternoon to midnight sector, and magnetosonic waves over a broad MLT range both inside and outside the plasmasphere (Jordanova et al., 2012). The wave growth in a dipolar magnetic field had significantly smaller magnitude and spatial extent and thus underestimated the wave scattering effect on the energetic particles. These results indicated that the inclusion of a self-consistent magnetic field calculation was essential for a realistic representation of the inner magnetosphere.

The work at a national laboratory was quite different than the work at a university. One major difference was the availability of Laboratory Directed Research and Development (LDRD) programs at LANL. Its Directed Research (DR) component, being related to the strategic vision for the Laboratory, was supporting long-range investments in areas that were vital to Laboratory science missions. The Dynamic Radiation Environment Assimilation Model was one such LDRD-DR project. Although my research was funded by smaller NASA and National Science Foundation (NSF) grants, the LDRD-DR program made it possible to have much larger growth. The LDRD-DR proposals, however, were extremely competitive and hard to win. The first steps toward achieving such an ambitious goal were to increase the visibility, relevance, and benefits of magnetospheric modeling to the Laboratory. Thus, I became an advocate for broadening the space weather program at LANL, in particular adding the development of physics-based models of the near-Earth space environment to the ISR-1 research portfolio. Engaging many LANL colleagues (Drs. Michelle Thomsen, Joe Borovsky, Reiner Friedel, Michael Henderson, Gian-Luca Delzanno, to name a few), it took us several years to create the concepts of a multidisciplinary project and to form a collaborative team (Figure 2) to win a LDRD-DR "space weather" proposal. In 2014, the Space Hazards Induced near Earth by Large Dynamic Storms (SHIELDS) project that we had envisioned, to advance models toward prediction of the space environment and maximize satellite safety, was selected for funding by the LDRD-DR program. The SHIELDS project was led by myself as PI, in collaboration with the University of Michigan team, led by Dr. Gabór Tóth, and included several external collaborators from the Air Force Research Laboratory and the Aerospace Corporation.

The main objective of SHIELDS was to develop a new modeling capability of the complex near-Earth space environment, by adding exciting new physics that would address interactions across multiple scales/plasma regimes (Jordanova et al., 2018). The SHIELDS project also had important application aspects: to mitigate spacecraft charging effects, assist spacecraft designers, and help with the analysis of space system failures. It opened opportunities to enroll postdocs and early career scientists (Drs. Yiqun Yu, Daniel Welling, Jesse Woodroffe, Steven Morley), and to collaborate with theorists and computer engineers across the Laboratory. We were able to transform RAM-SCB from a research model to a highly sophisticated and robust code (Welling et al., 2018). We also coupled it with the magnetohydrodynamic BATS-R-US code (Tóth et al., 2012), which driven by solar wind data provided a realistic global context for the simulations (Yu et al., 2016). An implicit particle-in-cell code was embedded within the BATS-R-US code to cover regions where kinetic effects were important, and applied to study magnetic reconnection at the dayside magnetopause (Chen et al., 2017). Furthermore, the efficient acceleration of newly injected ring current electrons by whistler mode chorus was demonstrated (Jordanova et al., 2016); this process was facilitated by the large energy gradients that developed at the open/closed drift boundary after particle transport from the magnetotail. Another SHIELDS highlight was the implementation of new data assimilation techniques that employed in situ satellite data and obtained an order of magnitude improvement in the accuracy of predicted energetic particle fluxes (Godinez et al., 2016). In recognition of its achievements and worldwide impact, the SHIELDS project received an R&D 100 Award for innovation in 2017 (as one of the top 100 technological advances of the year) and a LANL Distinguished Performance Award.

5. Final Thoughts

As scientists, we have the responsibility to improve life, protect our planet Earth, and to pass down knowledge to future generations. Being women in science we have a responsibility to help break the gender bias, to promote diversity and inclusion, and to demonstrate that a healthy work-life balance is possible. I am glad to be able to contribute to these causes with my work. For more than 30 years I have been working in the space science and space weather fields, studying energetic particle dynamics during geomagnetic storms. These storms are driven by solar activity and could trigger hazardous effects both in near-Earth space and on the ground, thus endangering satellites, communications, and power grids. Over the years, I have enjoyed developing our modeling capabilities to better predict geomagnetic storms and their effects.

An important aspect of a scientist's career is presenting and publishing the results from the undertaken research. I have always found it stimulating to attend conferences and discuss my work with other scientists worldwide, to meet new colleagues and match their faces with the names on the publications I read. Such scientific meetings are great learning experiences that help advance understanding and establish new collaborations. On most of the international trips I have had the opportunity to take my family along with me, to share the excitement of scientific discoveries and of getting to know new people and countries. I have also convened numerous special sessions at international conferences. I was the main organizer of the International Symposiums on "Recent Observations and Simulations of the Sun-Earth System" (ISROSES–I, II, and III) held in Bulgaria in 2006, 2011 and 2016. These symposiums created a forum for researchers from cross-disciplinary communities worldwide to discuss the structure and complex interactions of the Sun–Earth System, and the challenges they pose for the development of models with predictive space weather capabilities. The main results presented at ISROSES were featured in special issues of the Journal of Atmospheric and Solar-Terrestrial Physics. Currently, I am the Chair of the NSF Geospace Environment Modeling (GEM) Steering Committee. The GEM program was created in 1991 to coordinate research on the near-Earth portion of geospace through annual workshops and challenge campaigns. Since then, with more than 1000 participants, it has become the flagship program for Earth's magnetospheric science. Being its Steering Committee Chair is a great recognition and responsibility, and a service to the community that I truly enjoy.

What lessons have I learned throughout my professional journey and what advice could I give to the up-and-coming generation?

First of all, it is important to obtain good knowledge and experience, which usually comes with education and practice. Let your specific interests and curiosity drive you, don't be discouraged by challenges, and take advantage of the support from friends and family. There will be obstacles at times and you'll have to put the extra effort to overcome these, but the accomplishments at the end will bring much satisfaction and happiness. Find good mentors to guide you and continue learning throughout your career.

There will always be interesting problems to explore; as we gain knowledge from solving one problem, more questions arise since we want to develop deeper understanding on the subject. Don't worry that the topic you are working on might not currently be the most popular problem to solve. The needs of the society change as science and technology evolve and many urgent problems are replaced by new ones. Keep working on the ones that interest you and try to get more people involved by relating these to broader community benefits.

Very often our work assignments depend on the financial support from government or private institutions. The best approach is to be proactive on obtaining the necessary funding, this will help grow your projects too. Finally, don't underestimate the power of team work. You will achieve much more and it will be more gratifying when you are surrounded with colleagues and friends. Don't hesitate to reach out to others for help, no matter whether it is to solve a small problem or to make the next big discovery. Building a diverse, yet collaborative team to investigate an exciting innovative idea is a proven recipe for success.

Data Availability Statement

Data were not used, nor created for this publication.

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