The Photon:
Spotlight

Physics Alumni | UM Physics Research

# *On Alumnus Mark L. Lupisella*

I have a vague memory of my father making a home movie of me standing next to our television while Neil Armstrong walked on the moon. I believe it was then that I wanted to be involved in space exploration.

I got to do that after I graduated from Maryland with my B.S. in Physics. I started out in Aerospace Engineering and through the Maryland Co-op program, I got a co-op at the Glenn L. Martin Wind Tunnel, which then led to a co-op job at NASA Goddard in 1988.

NASA has paid for all of my education ever since then. My management allowed me to change my major to physics without compromising my chances of getting a full-time job there when I graduated.

But I was never particularly good at physics. It didn't come naturally to me as it did to many of my fellow students - or maybe it was just the math. But looking back, I think physics appealed to me so much because it was about trying to understand the world in the most fundamental way possible, from the inside out, from the bottom up and from the top down - all of that at the same time. Almost any angle on the world was possible.

My exposure to physics inspired me to explore a broader picture, a context in which I might better understand physics, the pursuit of knowledge in general, and how society was impacted by such pursuits. Off the top of my head, I remember at least four big thoughts from my years as a physics undergrad that nudged me in the direction of philosophy. Three were from professors, the fourth from a student running down the hall.

In a one-on-one meeting, Physics Professor Douglass Currie said to me, "The world is consistent. People should be too." (I suspect he was defending a grade I didn't think I deserved.) I remember being provoked by that, and I've been thinking about it ever since.

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# *On Quantum Computing*

## ***Quantum Computing with rf SQUIDs***

*By J.R. Anderson*
*Professor, UM Physics*

Computer components have been steadily decreasing in size and increasing in power required, tending to follow Moore's empirical "law," which states that computing power doubles approximately every 18 months. However, extrapolation suggests that within about 10 years the size of a transistor logic gate element will be only a few atoms. Consequently, computer power will soon reach a limit, unless another approach for computing can be developed. Quantum computing is one possible approach.

An ordinary electronic computer uses two-level logic, zero and one. A quantum computer, on the other hand, has states corresponding to zero and one and all linear combinations in a single element called a qubit. A quantum computer would consist of many qubit gates with entangled states. These gates could be addressed in parallel by unitary transformations, which must be carried out reversibly, implying no loss of energy in a gate operation. Quantum computers are "wired" so that they can do many calculations as the same time. This is known as "parallelism" and represents the power of a quantum computer.

The quantum computer would be superior to the classical computer for two important problems: finding the factors of a large number and searching an unstructured database.

## Q & A

**What is a quantum computer?**
Unlike ordinary computers, a quantum computer uses quantum mechanics to do calculations. While ordinary computers use a system of "logic" based on either zeros or ones, quantum computers would use a logical system that is based on zeros, ones or a combination of both. This combination would theoretically allow a quantum computer to do certain calculations, like finding the two factors of a particular product, **exponentially** faster than the conventional computers of today.

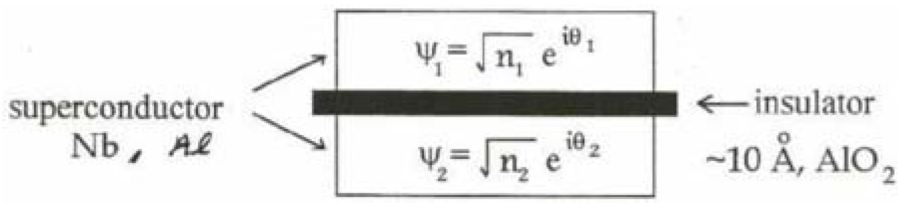
**What is an rf SQUID?**
A radio frequency superconducting quantum interference device, or an rf SQUID, is a magnetic field measuring device made of a loop of superconducting material with an insulating barrier. The particular rf SQUIDs worked with at UM are made of thin films of aluminum and niobium and are roughly the diameter of a human hair (about 50 microns).

**How are quantum computers and rf SQUIDs related?**
The research group at Maryland is trying to make the rf SQUID to the quantum computer what a bit is to today's computers. In other words, the rf SQUID is used as a qubit, or a quantum bit, in a quantum computer.

Since it is far easier to find the product of two numbers than to find the factors of such a product (a nearly impossible task for conventional computers), industry and banks use this asymmetry to transmit information securely. In other words, the factors of a particular product are the key to many encrypted security systems, and if one could find the factors of a large number quickly, this security would be lost.

Searching an unstructured database may become crucial as the information on the World Wide Web expands. Here, again, the parallel processing quantum computers would provide an exponential speed-up.

Several systems have been proposed for quantum computing including trapped ions, quantum dots, and Josephson junctions. Although there are advantages and disadvantages to all systems, we believe that Josephson junction arrays have the greatest potential for realizing the entangled qubits of a quantum computer.



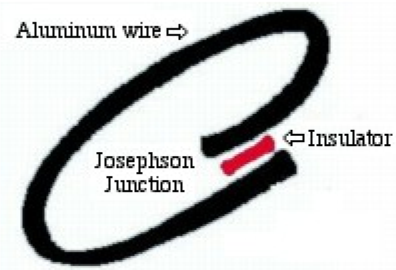

*Schematic of a Josephson junction. A thin insulator of aluminum dioxide is sandwiched between two superconducting layers of niobium and aluminum.*

In 1961, Brian Josephson, a graduate student at Cambridge University, published a Physics Letter with a remarkable conclusion, i.e. coupled electron pairs could tunnel across a narrow insulating barrier between a pair of superconductors without the development of a potential difference across this junction. In addition, if a voltage were applied across the junction, the phase difference of the electron wavefunctions on the two sides of this barrier would be oscillatory with its derivative proportional to the voltage. If this barrier were part of a superconducting loop, an applied voltage would produce an alternating current. These conclusions were confirmed by experiment shortly after Josephson's publication.

Our approach to quantum computing takes advantage of the "Josephson Effect". We plan to use radio frequency (rf) superconducting quantum interference devices (SQUIDs) as qubits. An rf SQUID is a single Josephson junction loop, which can be modeled as an loop inductance **L** in parallel with the junction and a capacitance **C** and a resistance **R**. If we ignore the resistance, adjust to an appropriate critical current through the junction, and apply an appropriate small biasing magnetic field through the loop, then we believe that it is possible to treat the rf SQUID as a qubit with flux (magnetic field times area of the loop) as the relevant macroscopic quantum variable. That is, in a simple picture, clockwise current through the loop can be taken as 1 and counter-clockwise current as 0. This can be modeled as a double potential well. Coupling among qubits arises because the magnetic field from one qubits influences the properties of a neighboring qubit.

This project on quantum computing began last summer with support from

Department of Defense. The research is very difficult because the experiments must be carried out at mK temperatures in a special $He^3$-$He^4$ dilution refrigerator and the SQUIDs must be well isolated from outside interference in order to have long coherence times. Our approach to the development of a quantum computer is sequential.




*Schematic of an rf SQUID. A thin wire of aluminum is formed into a loop and cooled to superconducting temperatures, with an insulator at the join forming a Josephson junction.*

First, we must prepare very good junctions, probably from aluminum or niobium. At the same time, we must learn how to isolate our system in the dilution refrigerator from external noise. Next, we must prepare rf SQUIDs and exhibit tunneling from one well to another in the SQUID. This is called macroscopic quantum tunneling or MQT. The quantum mechanical energy levels in the double-well system are separated by energies in the GHz range. The next step will be to look for enhanced absorption of microwaves at frequencies corresponding to the separations of the energy levels. This is called energy level spectroscopy. Then, we must see if there is quantum coherence, that is look for coherent tunneling between the two wells. This is called macroscopic quantum coherence (MQC) and may be the most difficult aspect of the research. Finally, we must prepare arrays of rf SQUIDs and look for interactions among them.

At the present time, four faculty (J. R. Anderson, A. J. Dragt, C. Lobb, and F. C. Wellstood), two post-docs (Roberto Ramos and Phil Johnson), and four students (Mark Gubrud, Mikkel Erjnaes, Jim Farrell and Dan Sullivan) are involved in this research, which is being carried out primarily in our Center for Superconductivity. In addition, Dr. Manheimer is setting up a parallel system with a dilution refrigerator at the Laboratory for Physical Sciences. We have already made very good $Al/Al_O/Al$ junctions as demonstrated by their current-voltage characteristics. One of the dilution refrigerators, a 50 μW system, is operating successfully down to 90 mK and the second, a 100 μW system, is being modified and with it we already have reached temperatures below 20 mK. There is a long way to go before successful realization of a quantum computer. A first step will be to demonstrate that quantum mechanics really applies to a system of rf SQUIDs. Experts have predicted that 40 years should be allowed for the development of a working quantum computer.

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I also vividly remember the first day of my first quantum mechanics course when Professor Hornyak remarked that what scientists did was create models or approximations to explain and predict the world. Truth, I remember him suggesting, was in some sense irrelevant - or at least, strictly speaking, not something scientists had absolute access to. I've been thinking about that ever since.

The third big thought also came from Professor Hornyak. He thought human beings were a way for the Universe to know itself. I've been thinking about that ever since.

The fourth thought came from a hurried student who was challenging a friend. His voice faded as he passed by me, sitting in the lobby, no doubt panicked over an upcoming exam. I didn't see him, but heard him say, "Yeah, but these are all just theories made up by people. Look, this guy and this guy..." He must have been pointing to those great pictures of all the famous physicists that I used to stare at in the hallways of our building. "They're people, just people. People create these theories." I knew he what trying to say, and I've been thinking about it ever since.

I went on to take coursework in astrophysics at Johns Hopkins and just recently finished my Master's in philosophy from Maryland, with an emphasis in the philosophy of science. Through a NASA Full-Time Study Fellowship, I'll be pursuing a Ph.D. in biology full-time for the next two to three years, to help me prepare for my continuing work in astrobiology and related fields.

I've had opportunities to work in a wide variety of very rewarding fields ranging from being a system engineering and software development manager for Hubble Space Telescope to Human Mars mission planning. I've also had opportunities to travel many places around the world presenting papers and giving talks.

Today, I work in two areas. I'm a Co-Investigator on a proposal for an advanced wearable computer, and I also work in the field of astrobiology. My engineering work has always been rewarding, and I'm very excited about being at the forefront of the next wave of computing technology with my work on wearable computers. But, it's the field of astrobiology, understanding the origin, distribution and future of life in the universe, that I'm most strongly drawn to.

In astrobiology, I've been involved in Human Mars mission planning, specifically in the area of mitigating possible adverse effects to potential indigenous Martian life. I've covered every aspect of this issue from science and mission planning to policy, ethics, and philosophy.

I just defended a Master's Thesis investigating how artificial life can address how typical terrestrial life is of life in general. Ultimately, this may help us discern how much we can apply terrestrial life research to extraterrestrial life issues including the fundamental question as to whether other instants of life even exist - a critical open question.

I am also inspired by astrobiology's third major theme: the future of life in the universe. This breathtaking theme is right in line with something I proposed this year at the United Nations UNISPACE III conference in Vienna, Austria. A group of us went out on a limb and presented a proposal noting a particular irony - while we are the first and only species sufficiently aware and capable of proactively ensuring our long-term survival, we do not do so with the attention and rigor it requires. Therefore, we suggested a formal global body be formed to pursue issues relevant to the long-term survival and prosperity of humanity.

Believe it or not, people took this seriously, and I had a chance to present some of the details at a recent NASA Symposium on Societal Impacts of Astrobiology. Recently, I took what I think is an important first step in this pursuit and wrote, for a biology class, a preliminary grant proposal entitled, "Multi-generational Altruism in Humans?" to investigate, via a global survey, the extent to which people care about and take action regarding the long-term survival of their descendents and our species.

I'm really looking forward to giving a seminar at the University of Colorado entitled, "Can Astrobiology Tell Us if the Universe Has Meaning?" This talk is based on some writing that I've been doing on how worldviews might be affected by the discovery, or lack thereof, of extraterrestrial life.

I am thankful that I can pursue activities that are of great inspiration to me. The University of Maryland is where much of it started, and having a background in physics has been an invaluable foundation on which to build.

• See Mark's profile
• Mark's research papers and projects

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