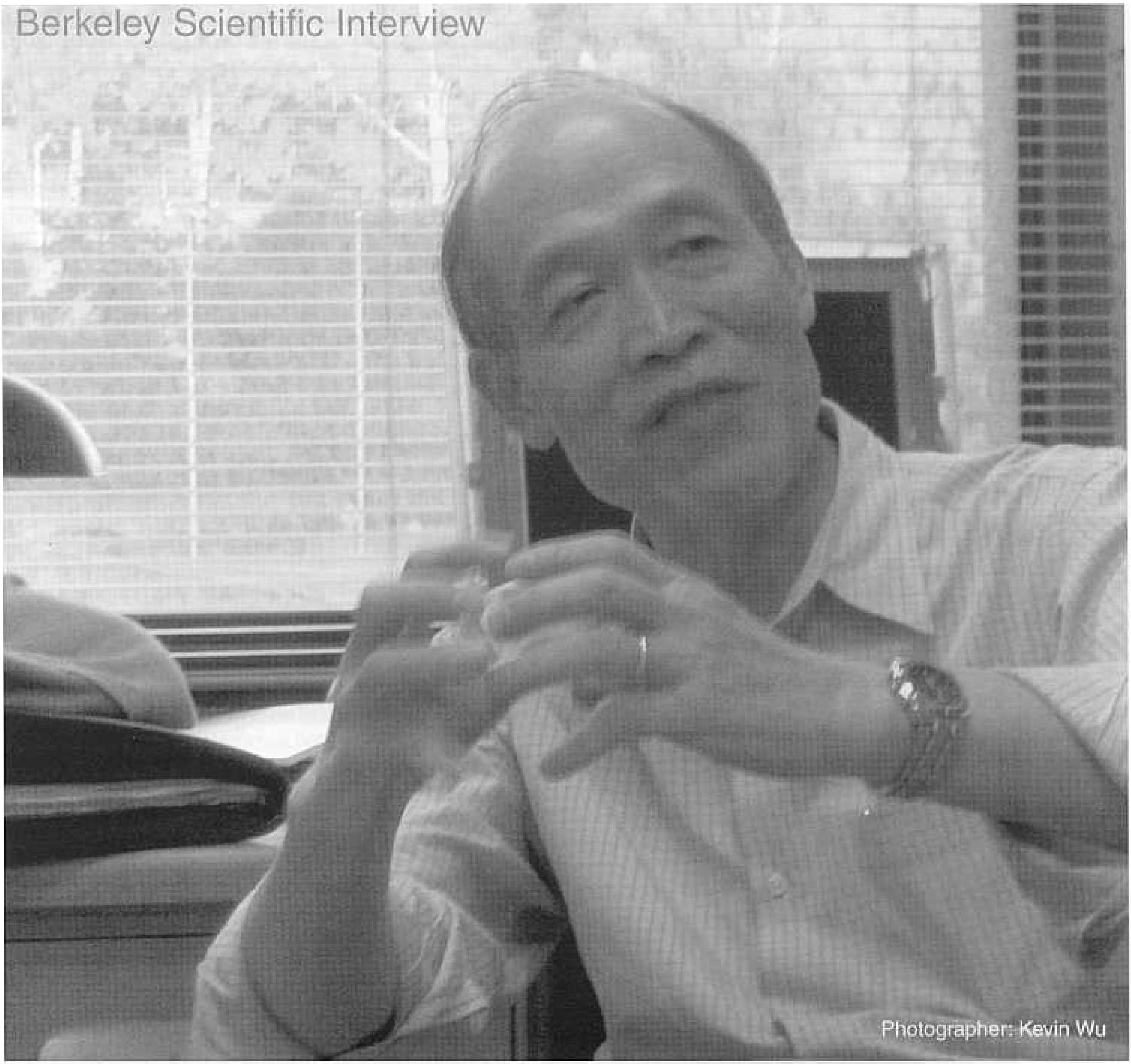


Photographer: Kevin Wu

# Robert Lin

**An interview with the Director of the Space Sciences Laboratory at Berkeley on his research, his ties with NASA, and the future of astrophysics.**

By: Barbara Chiang, Jennifer Moitoza, Liat Zavodivker, Mausam Damani,
Kevin Wu, Teresa Ko, Deeshali Patel,and Cindy Chien
With an Introduction by Barbara Chiang

*Robert Lin's ties to Berkeley extend almost forty years back, starting when he completed his Ph.D. in Physics from the University of California, Berkeley, after receiving his B.S. at the California Institute of Technology. Since then, he has worked as a research physicist with the Space Science Laboratory and taught as a professor in both the Astronomy and Physics Departments at UC Berkeley.*

*Today, Lin holds the prestigious title of Director at the Space Science Laboratory where he has been able to pursue his interests in high energy astrophysics, experimental solar and heliospheric physics, space plasma and magnetospheric physics, and planetary science. He currently serves as the principle investigator for the RHESSI (Ramaty High Energy Solar Spectroscopic Imager) mission, and has worked on countless other space science projects, resulting in numerous NASA awards including the NASA Mars Global Surveyor Group Achievement Award, the NASA Lunar Prospector Group Achievement Award, and the NASA Ames Research Center Honor Award to Lunar Prospector Science Team. Most recently, Lin received the 2004 George Ellery Hale Prize from the Solar Physics Division of the American Astronomical Society for his pioneering work on high energy solar radiation and particles.*

*In addition to his own research, Robert Lin is also very concerned with his students. He strongly believes that undergraduates should engage in research, and has set up a mentoring program with his research group and graduate students. Because of his efforts and guidance, Lin was awarded the Distinguished Research Mentoring of Undergraduates Award by the College of Letters and Science in 2001.*

**BSJ:** What inspired you to become an astrophysicist?

**Robert Lin:** I was a student at the time when the space program was beginning to get started in the early 60's. People were sending instruments into space for the very first time, and you could study things that you never had access to before. On top of that, you didn't know how to do it yet, so it was very interesting if you like challenges like that. I was interested in astrophysics, and this was an opportunity to do it in space. I thought, "this is really going to be great."

**BSJ:** How did you begin your research at Berkeley?

**Robert Lin:** There was a professor who had arrived a year or two before I started my research. He was one of the first to get experiments on spacecraft. I talked to him about doing research. I also looked at other areas of physics but this was the most interesting.

**BSJ:** What did he do exactly?

**Robert Lin:** He was studying what we call cosmic rays, very high-energy particles in the universe whose origins are unknown. Some are so high in energy that they produce showers of secondary particles that you can see from the ground. No one knew what the lower energy cosmic rays are like, since to study those you have to actually get above the atmosphere. He was starting to do that using high altitude balloons and that's how he got started in space experiments.

**BSJ:** How did you map the surface magnetic fields of Mars and the Moon?

**Robert Lin:** Researchers started looking at what is in space and found it is filled with what physicists call plasma, not blood plasma, but a mixture of electrons and positively charged ions. You know that if you start out with a solid and you heat it up, it melts and becomes a liquid. If you heat it up some more it becomes a gas; if you heat it even more the atoms and molecules of the gas breaks up and you get the electrons and the positively charged ions. Most of the universe is filled with this type of plasma. Since these particles are charged, they are affected by electric and magnetic fields.

In the early 1970's we designed a small subsatellite (about three feet high) to orbit the Moon as part of the Apollo program. On both the Apollo 15 and 16 missions, the astronauts carried these subsatellites to the Moon in their orbiting module. When the astronauts had finished their mission on the lunar surface and returned to the orbiting module, they just dropped the subsatellites out before returning to Earth. The satellites were designed to study the behavior of plasma in the Earth's magnetotail; we hadn't planned on doing any lunar science at all, but the sub-satellites' instruments sometimes detected electrons coming back from the surface of the Moon.

After thinking about it, we realized what was happening. The electrons in the plasma heading toward the lunar surface would usually just hit the surface and be lost, but if a magnetic field was present at the surface, it would reflect the electrons. The stronger the field the stronger the reflection.By accident we had stumbled onto a way to measure magnetic fields remotely on the surfaces of planetary bodies, just by measuring the reflected electrons.

Nobody had realized that the surface of the Moon would have patches that are very magnetic. The Moon doesn't have the ordered global magnetic field of the Earth, which is what allows us to use compasses for direction finding. You may know that there are lodestones found on the Earth. These naturally magnetized stones were used to make the earliest compasses. What must have happened is that parts of the Moon's crust got magnetized

> If you happen to be an astronaut in space then, you could get a dose of radiation from these high energy particles; if you happen to be really unlucky, the radiation could actually be enough to kill you.

in the past. This implies that a strong magnetic field must have been present when the crust was formed. From studies of the returned lunar samples, it appears that the Moon had a strong magnetic field about 3.6 to 4 billion years ago.

Mars doesn't have a global magnetic field either, so we decided to propose an instrument optimized for electron reflection magnetometry for a spacecraft going to Mars. We had a hard time convincing people; most thought there wouldn't be any significant magnetic fields on Mars. Before the Mars Global Surveyor (MGS) spacecraft reached Mars, our team had a contest; each of us would guess the magnetic field strength that we would see at Mars. The guesses ranged from zero to very high.

When MGS got there, as it went over different parts of Mars, every predicted value was seen at one time or another, but there were also fields that were many times stronger than any of the predictions. Mars must have had very strong fields about 4.5 billion years ago to magnetize its crust. It's still a big mystery how this happened.

**BSJ:** How will it help future planetary and lunar exploration?

**Robert Lin:** You won't be able to use a compass to tell direction because the field is too jumbled. The crustal fields tell us something about the history of the planet and maybe something about what's in the interior of the planet. The Earth has a strong field because it has a molten core and heat to drive convection, essentially like a pot of water boiling. Because the molten material is electrically conducting it can carry currents, and these currents produce the magnetic field of the Earth. Something like that process most likely had happened on the Moon and Mars very early on, but they are smaller planetary bodies than the Earth. A smaller body has a larger surface area relative to its volume, so it cools faster. The interiors of Mars and the Moon were likely to have cooled down, so they don't have molten cores any more, so the magnetic field is gone. Whether that's really right or not, nobody knows yet.

**BSJ:** What are solar flares, and how do they affect the solar system?

**Robert Lin:** Solar flares are the most powerful explosions in the solar system. A big solar flare is the equivalent of a few billion one-megaton hydrogen bombs going off at once. What we found early on was that flares were actually releasing most of their energy in the form of high-energy particles, so they were very efficient particle accelerators. The man-made particle accelerators on Earth, for example, at Stanford or at CERN in Switzerland, take up as much as power to run as a small city, but only a tiny fraction of this energy comes out in high-energy particles. Flares, for some reason, are very efficient at producing high-energy particles; to me that's already pretty interesting.

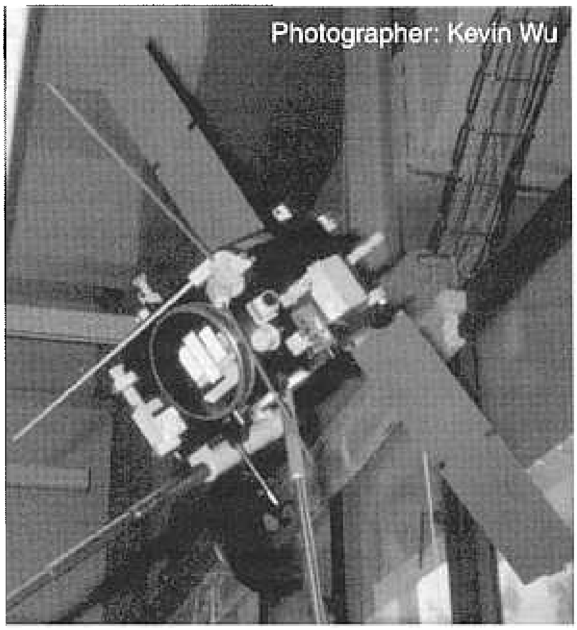
Large flares are often associated with coronal mass ejections (CMEs) that eject a huge amount of plasma from the Sun and also accelerate particles to high energies. The CME material travels up to about 1500 miles per second. That sounds fast to the normal person, but it's slow compared to high-energy particles that typically travel at a significant fraction of the speed of light. Some of those high-energy particles from flares and CMEs escape the Sun, get out into our solar system and sometimes come to the Earth. If you happen to be an astronaut in space then, you could get a dose of radiation from these high energy particles; if you happen to be really unlucky, the radiation could actually be enough to kill you.

Sometimes the CME plasma hits the Earth. Because the plasma is charged, it squeezes the Earth's magnetic field and produces currents in the Earth's atmosphere. Those currents can then induce currents in conductors on the Earth, such as power grids that supply electricity to homes. About twenty


Photographer: Kevin Wu

At the missions operation center in the Berkeley Space Lab, Robert Lin and his fellow colleagues operate some of the space crafts they send into orbit.

years ago, a CME hit the Earth and the currents induced into the power grid in Canada caused a blackout. The CMEs also produce brilliant aurora, and the high energy particles can adversely affect radio communication, in particular short-wave (ham radio) bands.


A Model of the HESSI spacecraft

Photographer: Kevin Wu

CMEs can also pump up the Earth's trapped radiation belts and damage satellites. For example, the weather satellites and many of the communication satellites are right in the middle of the radiation belts. When a fast CME hits, those satellites sometimes fail or stop working for some time. All these things affect us, for the most part, because we have a technologically advanced society. A hundred years ago we didn't have satellites up in space, the power grid was very rudimentary, so these things didn't bother us, but now they do.

**BSJ:** Where did you gain your first insight into solar flares and electromagnetic activity?

**Robert Lin:** Well, when I started doing space research, our first experiments were to measure the kind of particles and radiation in outer space. We saw that whenever there was a flare at the Sun there would be X-rays emission, and then about 10-20 minutes later high-energy particles would arrive near the Earth. I got interested in the origins of these high-energy particles (they clearly were associated with flares) and started designing other experiments that would show us more about that. The high energy particles at the Sun produce X-rays and gamma-rays. We now have quite a powerful instrument in space that images the X-rays and gamma rays from the Sun.

> About seven years ago, we put a proposal into NASA. We were very happy to win, because the competition includes all kinds of science, not just solar physics.

**BSJ:** What methods do you use to gather information on solar flares and solar cosmic rays?

**Robert Lin:** You know how telescopes work on the ground, right? You use a glass lens or a mirror and you focus the rays to form an image. X-rays and gamma rays are the most energetic kinds of light, so energetic that they don't reflect off a mirror or refract in a lens, so you have to use a different technique. We image by making shadows. For example, suppose I hold two comb-like grids (linear arrays of alternating slits and slats) a few feet apart and look at a distant source of light through the grids. As I move the pair of grids across the light source, sometimes the light gets through the slits and sometimes it is blocked by the slats, so you see the intensity of the light modulated in time. The modulation pattern contains information about where the light is coming from and how large the light source is. By using a number of these bi-grid collimators with different slit-slat widths, and combining the information from the patterns, it's possible to reconstruct the image. Now you won't get an image that has the resolution of a digital camera with several megapixels. You'll get an image of maybe has a few thousand pixels, so the images are not as detailed as what you can do with a mirror or a lens, but they're the only images we can get for high energy X-rays and gamma-rays. These images are very important, because the main output of flares seem to be high energy particles that produce X-rays and gamma rays, not visible light.

We also use special detectors in back of the grids to measure the "color" of X-rays and gamma rays. Normally you use a color camera for visible light. Color is actually a measure of the energy of the light. Our detectors measure the energy of each X-ray and gamma ray to get the "color".

**BSJ:** What were the biggest concerns in your development of the Ramaty High Energy Spectroscopic Imager (RHESSI) and what is the most valuable information that you have obtained while using this instrument?

**Robert Lin:** Well, we obtained the very first images at very high energies. That tells us where the high-energy particles are. Then we can find out about the environment there, to understand what's actually going on. For example, where is it relative to where sunspots, regions of strong magnetic fields, are? How hot and dense is that region? What we actually get are movies. The flare goes by in minutes. During that time the sources are moving around; that is also a clue to what's happening.

The first gamma rays images were really quite interesting. People had obtain X-ray images before, at lower energies. [However] the X-rays are produced by electrons, while the gamma rays are produced by ions, so for the first time we know where the high-energy ions are. It turns out that contrary to what everyone thought, the ions were in a different place than the electrons. People thought that all the high energy particles are accelerated in one place, and then all the ions and electrons should be seen in the same place. In fact, it turns out not to be true. This was completely unexpected, and now everyone is trying to figure out how that could happen.

**BSJ:** Could you explain your involvement in the RHESSI project?

**Robert Lin:** In fact, it started about quite a long time ago when we realized that most of the energy of a solar flare was coming out in high-energy particles. We started to think about how to design an instrument that would allow us to see where this is happening, and give us information on the high energy ions and electrons and so forth. We had an idea for this kind of instrument and started to develop it; i.e., figure out how to build it, what kind of spacecraft it would need, and what we would need to get the data down to the ground, etc. Every few years, NASA would ask for proposals for small

A clean room, like the one shown here, helps Berkeley Space Lab technicians build everything to NASA's specification.

space missions. About seven years ago, we put a proposal into NASA. We were very happy to win, because the competition includes all kinds of science, not just solar physics.

If you look up at the East Bay hills, you'll see a building at the very top – that's the Space Sciences Lab – that's our laboratory where we build these things. Building space experiments is different from building experiments for a laboratory on the ground. If you build an experiment here and it doesn't work, you can go in and fix it. If you build an experiment for space and it doesn't work when it gets up there, you're out of luck, so there's a huge premium on reliability and quality control. It's a quite different process and so the kind of lab that we have up there is quite different. NASA prescribes even the way you solder something and so forth because you have to avoid failure. It's very expensive to get up there. If it doesn't work when you get up there, oh boy.

In the rest of the universe we know that there are other explosions that are much, much more energetic, but all you see is a flash of light and you can't resolve it spatially. Your chances of understanding how that works are pretty slim. We have a good chance of understanding something that we can look at in detail. Then what we learn from that might apply to these much larger, faraway explosions.

**BSJ**: How do you process the data that you get on a day-to-day basis?

**Robert Lin**: Actually it's sort of neat. Our spacecraft goes around the Earth once every 95 minutes or so, at an altitude of about 600 kilometers. Now, we can't tell when a flare is going to go off, so the RHESSI instrument stares at the Sun all the time. When a flare goes off, suddenly huge numbers of X-rays and gamma rays are detected, and the data are stored in a 4-gigabyte memory on board the spacecraft. When that satellite flies over Berkeley, it transmits the data down to a big (11 meters diameter) antenna near our lab. The spacecraft takes about ten minutes to go over Berkeley. The data then is radioed down from the memory at a rate of about 4 megabits per second. Six times a day the spacecraft will pass over Berkeley, sending down a total of about 1 to 2 gigabytes a day. All that data is stored until we get a chance to analyze it. Then, we make images of it – that's the first thing – and then we look at the color and the color images of it, and try to figure out what's happening.

**BSJ:** Regarding the activity that you've measured, do you get enough information from solar flares so do you have to wait long periods of time?

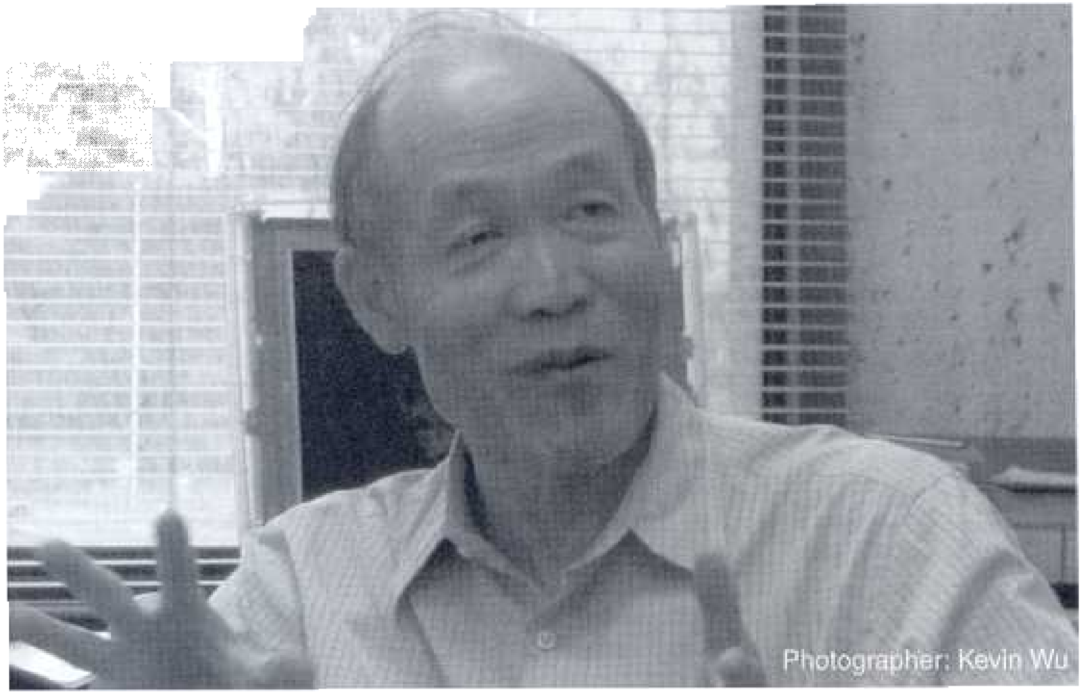
**Robert Lin:** The really huge flares happen rarely. Last October and November the biggest flares of the last 30 to 40 years occurred. We were lucky to get those. Typically, a spacecraft operates for several years and catches a few really big flares, but the smaller the flares, the more frequently they occur. There are micro-flares (a million times less energetic than the largest flare) that happen every few minutes. If your instrument were sensitive enough, you would see things popping off all the time. It may be that most of the heating of the corona, the hot part of the Sun's atmosphere, is done in little bursts, in micro-flares or maybe even nano-flares or even tinier. RHESSI can see down to micro-flares and maybe a little bit weaker, and as the Sun gets quieter it might be able to see even weaker events. One of the big questions how the hot corona is being heated, and we hope to look at that.

**BSJ:** And so in a sense how long do you think this process will take? Is it indefinite?

**Robert Lin:** It isn't indefinite but it will take time. We proposed to observe for two years, minimum, as our prime mission. We just finished our second year in March, but if the satellite's working well, we can ask for an extended mission, which we did this last spring. NASA liked our results so much that they extended our mission for a couple more years. Since newer satellites get launched and NASA has a limited budget, they'll eventually say "that's enough, we prefer to spend the money on new satellites," but we're hoping to keep it going for at least several more years

**BSJ:** How do the studies that you are doing, affect the Earth and its inhabitants?

**Robert Lin:** Well, we'd like to understand how flares actually work. What sets them off? How do you release the energy? If we could answer those questions, we might be able to predict them. Then we'd be able to say, "this not a good time for an astronaut to go out there, or we'd better watch our power grid now because something's likely to happen." It can help society in that way but in fact, my real reason for doing this is that I'd to understand how these huge explosions work because they're proba-


Photographer: Kevin Wu

bly the best example of explosions that we can study in detail. In the rest of the universe we know that there are other explosions that are much, much more energetic, but all you see is a flash of light and you can't resolve it spatially. Your chances of understanding how that works are pretty slim. We have a good chance of understanding something that we can look at in detail. Then what we learn from that might apply to these much larger, faraway explosions.

**BSJ:** In that sense, the limitations that are pressed onto humans can be applied to once you understand something close by?

**Robert Lin:** For science in general, you basically look at the universe and see what principles seem to govern its behavior. For example, Newton noticed that generally if a force is applied to an object, it accelerates. From that kind of analysis, he arrived at Newton's laws of motion. Then, we're able to use these laws to design useful moving objects such as cars. Similarly, the principles that were discovered about solid-state physics can be used to make transistors. To reach that point you do experiment after experiment, and from those experiments you understand that things behave in certain ways; they follow certain laws, certain principles.

Later on, as you investigate things at the extremes you might find that it doesn't really follow the law. For example, Einstein realized that when an object goes very fast, it no longer follows Newton's Laws. He was clever enough to figure out that Newton's Laws only apply at low velocities, that they are just the low speed part of a much more elegant set of laws called special relativity. When you're doing science, you're beginning to understand nature well enough so that you can make use of it. That's really what has propelled modern society. Now we're beginning to understand DNA and you can see what's happening. Once you understand how that works, how life and reproduction work, then you can manipulate it for the betterment of mankind. Of course, you can also manipulate it for bad things, too. You have to make those decisions separate from science.

**BSJ:** How do you differentiate between the fields of physics and astrophysics?

**Robert Lin:** That's hard to say, I am in the physics department and I do astrophysics. There is an astronomy department; they do astrophysics. Physics aims to understand how things work, and so does astronomy, but physics tries to look at the fundamentals. Physicists will want to know, for example, what is matter? Astronomers will look at something in the sky, an object, that produces certain kinds of radiation, and they'll use physics to try to understand what that thing is, but they may not be as interested in the basic laws of physics.

**BSJ:** It's more of an applied physics?

**Robert Lin:** You can think of it as physics applied to the universe.

**BSJ:** What advice would you give to an aspiring physicist who wishes to enter your field?

**Robert Lin:** Well, of course you have to take all these courses to learn the basic tools. The other thing that I would strongly recommend, especially at a university like Berkeley is try doing research while you are still an undergraduate. This is one of the best places in the world to try that, and I tell all of my physics advisees that they should try research while at Berkeley. This is one of the things that distinguishes Berkeley from a small liberal arts college. It may be a really great liberal arts college, but you won't get a chance to try cutting edge research there; you'll get a chance to do it here. Once you do it then you'll decide either you like it or that you don't like it. And that's what I did; once I started doing research I thought, "this is great." Now I get paid for doing things I like to do. That's great.

**BSJ:** What kinds of options are out there for a budding astrophysicist?

**Robert Lin:** There are a lot of options, and the reason is partly due to space. Only certain kinds of radiation, visible light, can get down to the surface of the Earth, so you can use a visible light telescope. That's a very small part of the electromagnetic spectrum. Once you get into space you can see everything from very low frequency radio all the way up to gamma rays at the other end of the spectrum. You probably increase the amount of information you can get by several orders of magnitude. The field of astrophysics is still growing rapidly because of that. We're now doing X-ray and gamma ray astronomy, but until recently only rudimentary instruments had been flown. People are now beginning to design the gamma ray equivalent of a big optical telescope. I believe the potential for advance in these areas is enormous.