Long autobiography by Geoffrey Marcy
June 2006

My two sets of grandparents met in the Panama Canal Zone. There, Sylvain Misrahi and Pearl Sper (on my father's side) and Saul Moishe (Martin) Isaacs and Ethyl Hiller (on my mother's) gave birth to their only children, Robert Misrahi and Gloria Isaacs, respectively, who became my parents. Both families encouraged education, music, and sports, the same activities that filled my childhood in the San Fernando Valley in the suburbs of Los Angeles.

My mother and father, with college educations in anthropology and aerospace engineering, respectively, made a home in which curiosity, discussion, and science were encouraged. I remember vividly my mother actively supporting civil rights for minorities in the early 1960's. She went door to door in our neighborhood explaining to people the need for a "Fair Housing Act" that, finally in 1968, prohibited discrimination in the sale or rental of homes on the basis of race or religion. She also campaigned for equal educational opportunities for African-Americans (then called "negroes"). Her efforts taught me that we should be vigilant about our own biases and that general principles of equal treatment under the law were paramount to a civilized society. I wondered what other inequities persisted in modern society that remained unidentified. I would later realize that women and homosexuals were not treated fairly.

My father inspired me to stretch for goals that seemed out of reach. He would often explain the ingenuity of the designs of jet engines, supersonic flight, and the Space Shuttle. He told me in the mid-1960's that future space flight would take us to the Moon and thereafter to Mars. He also taught me the world of sports, including baseball, football, basketball, and tennis. I spent hundreds of hours throwing a baseball with him. I remember his saying that if I reached out to catch a baseball with my glove but the ball glanced off the edge, that I should have tried harder. The message was quite influential: I could always try a little harder and someone (my dad?) would always be watching to see if I really tried as hard as I could.

When I was 13 years old, my parents bought me a poster of the Solar System, showing all 9 planets and their rings and moons. I used to lie in bed gazing at that poster and memorizing the names of planets, moons, and asteroids. When I was 14, my parents bought me a used, 4 1/4-inch Newtonian telescope. Every evening, I would climb out the window of my bedroom onto the patio roof to examine planets, nebulae, and the galaxies. I was amazed that Titan moved noticeably from night to night in its orbit around Saturn, taking 16.0 days to complete one cycle by my measurements (Fig. 1). The predictable forces and the clockwork of the universe seemed profound and beautiful to me.

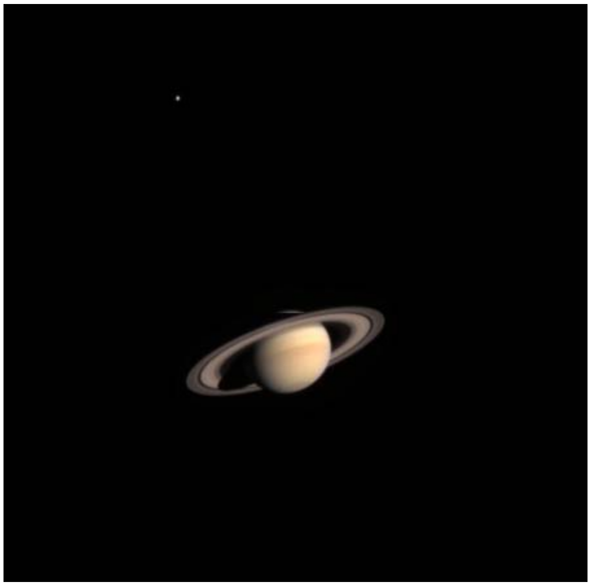

Fig. 1 Saturn and Titan. This image was taken by NASA’s Cassini Spacecraft when it was about 285 million km from Saturn. Titan, on the upper left of the photo, is the largest moon of Saturn. Image Credit: NASA/JPL/Southwest Research Institute.

My entire education was in public schools for which I cannot thank enough the people in the state of California. I heard adults talk with pride about the California school systems as the best in the United States, a view I don't hear much any more. From 1959 to 1972, I attended Plummer Elementary School, Patrick Henry Middle School, and Granada Hills High School, all in Los Angeles. I feel lucky that I participated in a public educational system that offered children of all economic strata nearly equal education and opportunities.

The facts I learned in school seem relatively unimportant, such as names of wars, presidents, and capitals of countries. But I learned to write and to think mathematically, thanks to teachers who painstakingly red-inked my essays and led me through word problems. More importantly, my teachers taught me to think carefully and to question my assumptions. My teachers asked questions that sometimes had no clear answers. I remember one essay question asking whether humans had fundamentally changed in the past 500 years, and another one asking which 7 people I would choose to take into a bomb shelter if we were under attack. One teacher asked us to write an essay on whether we could be in love with more than one person. I learned about shades of gray and that my first answer was not always right, nor the second.

I struggled to get high grades in my high school classes, indeed dropping out of the honors math sequence in high school. But I loved learning about chemistry and physics. I was deeply impressed that the complexity of the universe could be understood as the combined behavior of uncountable atoms, each one obeying simple physics principles. I was amazed that a few laws of physics could explain a grand piano, our human bodies, and spiral galaxies. I was inspired to devote my life to learning how these laws worked and how they might bring a deeper perspective to our lives on Earth.

My undergraduate education at UCLA offered me a rich education in math, physics, and astronomy. But in my free time, I played cello in the orchestra and sports in the intramural leagues. I took inspiring courses on cultural anthropology where I learned that people are fundamentally similar worldwide and that value judgments of other cultures and religions were fraught with biases. With the Vietnam War as backdrop, I learned that we humans have a remarkable proclivity to fear other peoples and to render them dangerous when told so by authorities. We humans seem programmed to believe fervently in some particular deities that our parents happened to teach us. Ancient peoples who painted their faces, pranced in circles, and bowed to holy men seem strange and primitive only if we ignore modern-day cosmetics worn at a church dance.

But I spent most of my time, including evenings and weekends, in the physics or astronomy library doing my homework. Among my many inspiring professors at UCLA were Ray Orbach, George Abell, and Mike Jura. When I floundered at a simulation of the balance of heating and cooling in interstellar gas, professor Jura admonished me, "If nature can do it, so can you." That can-do attitude proved invaluable a decade later when I decided to hunt for planets around other stars. My UCLA professors imbued me with the interconnectedness of everything in the universe in which our Earth and brief lives, occupy tiny dots in both space and time. They taught me to peer outside our dots.

In graduate school at UC Santa Cruz, I did most of my research under the supervision of Dr. George Herbig. He took me to the Lick Observatory "120-inch" telescope every month to help with observing. The painstaking precision and insight with which he did his research set a standard of integrity that I admired greatly. He taught me stellar spectroscopy, and gave me a project to measure Doppler shifts of "T Tauri" stars more precisely than anyone had before, by using photographic spectra intensified with a "Varo tube" and digitized with a microdensitometer. That project inspired me to think about sources of systematic error in Doppler measurements. Every week, I sheepishly reported to professor Herbig about my slow progress. He would typically seem empathically unsatisfied at the persistent errors. I wondered why we couldn't do better. Why couldn't we measure Doppler shifts to arbitrarily high precision? Meanwhile at Santa Cruz, a young phenomenal professor, Steven Vogt, starting building new, high resolution spectrometers and detectors that ultimately would enable precise Doppler measurements, making planet detection possible.

After finishing my Ph.D. dissertation on the Zeeman effect in Sun-like stars, I felt lucky to receive a Carnegie Fellowship at the "Mt. Wilson and Las Campanas Observatories" in Pasadena. Alan Sandage there supported my application, hoping I would provide support for the famous, but light-pollution ridden, Mt. Wilson 100-inch telescope. During my first year there, I suffered from feelings of inadequacy and incompetence. My Zeeman work was criticized in print (by Robert Kurucz), and indeed I saw little future in my research.

Depressed, I sought help from a therapist who offered me the perspective and strength to ignore both the critics and the competitiveness that are pervasive in astrophysics research. I struggled to learn to appreciate myself despite limitations in my perceived abilities. I also tried to recognize my oversensitivity to the judgments of others. Desperate for some new project that came from within, I was lingering in the shower one morning. It hit me to try answering a nearly forgotten question regarding the existence of planets around other stars.

Attempting to avoid the competitive fast lane of astrophysics research, I took a faculty position at San Francisco State University knowing that I would enjoy teaching, albeit three classes per semester. A brilliant student there, Paul Butler, was pursuing both a bachelor's degree in chemistry and a Master's degree in physics. We decided to search for planets, using a new technique inspired by the Canadian astronomers, Bruce Campbell and Gordon Walker. They had ingeniously employed a glass cylinder filled with Hydrogen Flouride gas at the telescope to serve as a wavelength standard. Meanwhile, Bob Howard at the Carnegie Institution of Washington had used iodine gas in that same role for Doppler measurements of the Sun (as described to me by a colleague at Mt. Wilson, Dave Bruning). In 1986, Paul hunted for 6 months to find a chemical alternative to the corrosive and hazardous HF gas, finally settling on molecular iodine at 50 C as optimal.

We had no access to professional telescopes at S.F. State nor did we have any professional computers. But Lick Observatory (under directors Bob Kraft and Joe Miller) generously offered us a few nights on the "Coude Auxiliary Telescope" (CAT) with its small 24-inch diameter mirror. They also gave us one or two nights during full moon on the "120-inch" telescope each semester. From 1987-1995, we took repeated spectra of 120 nearby stars, but our Doppler shift precision was no better than 15 meters per sec, inadequate to detect the stellar wobble caused by an analog of Jupiter. When we told other astronomers about our search for extrasolar planets, they would often smile politely, look down at their shoes, and change the subject. It was understood that detecting planets was well beyond current technology.

However, Paul spent thousands of hours inventing and testing a wide variety of computer algorithms to improve the Doppler precision. We knew that a precision of 10 meters/sec was necessary to detect an analog of Jupiter tugging on our stars. A breakthrough came in the early 1990's when we realized that the spectrometer's instrumental profile was smearing the spectrum asymmetrically, causing false Doppler shifts. Paul and I spent several years implementing and improving our forward-modeling approach that incorporated this symmetry. When Paul went to the University of Maryland to obtain a Ph.D., he continued the development of the Doppler code while we also continued to acquire spectra at Lick. With my significant teaching obligations at S.F. State, Paul was the engine that powered our planet search to success.

In early 1995, our algorithms were finally achieving a precision of 5 meters/sec, just as the Swiss team led by Michel Mayor announced the first extrasolar planet in a shocking 4.2-day orbit. We confirmed that planet around 51 Pegasi within 10 days at the 120-

inch telescope, setting off a firestorm of media coverage, including interviews by every major television and newspaper. We then used our new Doppler algorithms to process the spectra from the 120 stars we had been observing, with Paul "borrowing" computer time from about a dozen machines throughout U.C. Berkeley.

On Saturday, 30 December 1995 at 8am, my wife, Susan Kegley, and I were home, preparing for a New Year's Eve party when Paul phoned me from our office at UC Berkeley. (It is telling that Paul was working at 8am on such a day.) All he said was, "Geoff. Get over here." I'll never forget arriving at the office 10 minutes later and seeing the graph of velocity versus time for 70 Virginis (Fig. 2). It showed a clear periodic velocity variation, obvious evidence of a planet that resided in an eccentric orbit with a period of 116 days. The next month, January 1996, at the American Astronomical Society meeting in San Antonio, we announced that planet and another one orbiting 47 Ursae Majoris with a period over a year (Fig. 2).

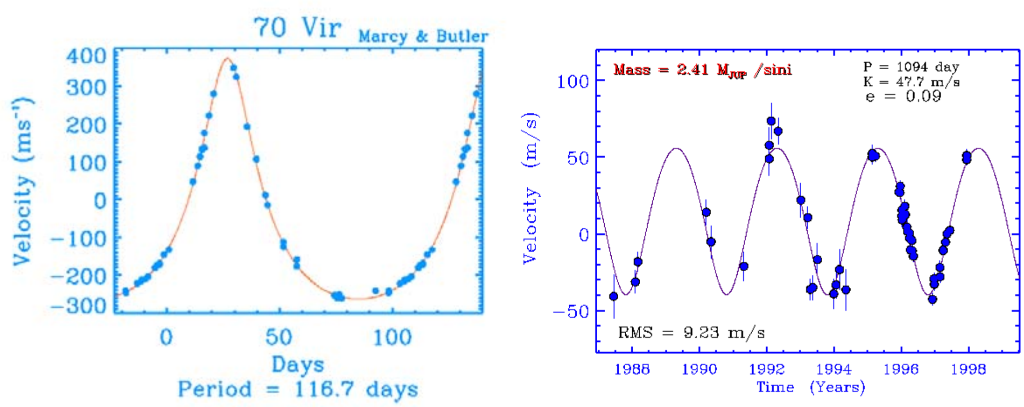


Fig. 2 The velocity vs. time graph for 70 Virginis (left) and 47 Ursae Majoris (right).

These two planets with their long orbital periods placed extrasolar planets on firm footing, in contrast to the odd 4-day period of 51 Pegasi. The eccentric orbit of 70 Vir yielded a skewed plot of velocity versus time that was unmistakably caused by orbital motion and the long periods of both planets were similar to orbital periods of planets in our own Solar System. Within two years we had found 10 more planets. By the end of 2005 our team had found 107 exoplanets (the smallest being 7.5 Earth-masses that we followed for three years before announcing it in 2006). To date, we haven't made a single false claim of a planet.

It was understandable, but frustrating, that much of the astrophysics community held doubts about the existence of our planets for several years. Some suspected that the stars were merely pulsating while others supposed that the orbits were mostly face-on, artificially diminishing the Doppler amplitude. We published, and placed on web pages, strong counterarguments to those doubts. But not everyone appreciated the arguments, including a few journalists who relished the open debate.

Then in 1999 we discovered the first multiple-planet system (around Upsilon Andromedae) with its three lovely planets that orbit a common star (Fig. 3). This configuration had the clear architecture of a planetary system, similar to our Solar System, offering a wonderful link between extrasolar planets and those orbiting the Sun. We also discovered the first transiting planet (orbiting HD 209458, Fig. 4) that dimmed the star every orbit, proving the planet's existence (for those who still doubted). I can still remember the email dated 10 November 1999 from Greg Henry, who did the photometry, that said simply, "Geoff, Call me ASAP !!!! Greg." Simultaneously Dave Charbonneau and Tim Brown found that same transiting planet. Most naysayers were finally satisfied that planets had indeed been detected around other stars.

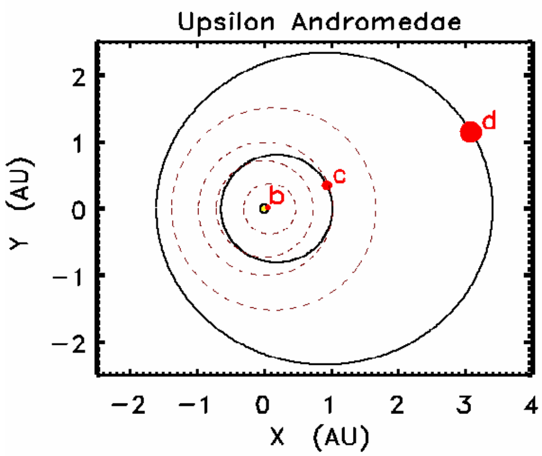


Fig. 3 Orbits of three planets (b, c, d) around Upsilon Andromedae. Dashed curves show the orbits of Mercury, Venus, Earth and Mars for comparison.


Fig. 4 Artist’s conception of the planet around the Star HD 209458. Image credit: NASA/G. Bacon (STScI).

During the past 10 years of planet discoveries, Paul Butler has remained the powerhouse of Doppler ideas, algorithms, and productivity. Perhaps few people appreciate the challenge of maintaining the Doppler precision, now at 1 meter/sec, that amounts to spectrum displacements of less than 1/1000 of a pixel on the CCD light detector. And fewer still realize the difficulty of maintaining that precision, with a consistent zero-point in the velocity scale, during decades that allows the detection of planets having orbital periods of decades. Paul senses that the velocity measurements themselves, during 30 years or more for the nearest 1000 stars, will carry information about orbiting companions long after we're gone. His historical and long view affords him the peace of mind to weather the exoplanet "projects du jour" that garner the headlines (and funding grants) so often.

Meanwhile, Steve Vogt's spectrometers, at Lick and Keck Observatories, have made our planet discoveries possible. The HIRES spectrometer at Keck 1 works with unceasing integrity and reliability, delivering spectral resolution and throughput that allow us to survey 1300 nearby stars of spectral type FGKM. His next spectrometer, for the Automated Planet Finder telescope that we plan for Lick observatory in 2006, will have even higher throughput (by a factor of 3) and higher resolution.

Meanwhile, Debra Fischer, who was also a student of mine at San Francisco State University, has become the source of new scientific ideas in our planet search while she also carries out the venerable Lick Observatory planet search. Working with my friend and colleague, Jeff Valenti, Debra has measured the abundances of numerous chemical elements in our stars, showing that the abundance of heavy elements (such as iron) correlates with the occurrence of planets around stars. Using that result, she launched a new planet search, "N2K", in 2003 that is based on the clever notion that more transiting planets could be found by Doppler measurements of stars that are rich in heavy elements, increasing the yield of exoplanets. Her work has led to the most significant exoplanet result in the past 5 years. The planet around HD 149026 apparently has a high abundance of heavy elements, constituting over 50% of its mass, despite being a “gas giant” planet. Debra's result strongly suggests that gas giant planets grow from the agglomeration of dust particles that collide, stick, and grow into massive rocky cores that subsequently acquire gravitationally hydrogen and helium gas. I feel lucky to have Paul, Steve, and Debra as colleagues, friends, and family.

The discovery of extrasolar planets seems to have spawned the search for Earth-like, habitable worlds and for life in the universe. The interest from the public and scientific community has overwhelmed my available time. My wonderful wife, Dr. Susan Kegley, could not have known what she was getting into when she married me in 1994. But she has helped by teaching me the basics of organic chemistry and even more by putting up with my long hours and attention drawn away from home life. Meanwhile, Steve, Debra, Paul and I, with the invaluable support of the University of California Observatories' technical shops, are building a new 2.4-meter telescope that is designed to find the rocky, terrestrial planets in short period orbits around the nearest 250 stars. If we are lucky, we will catch signals from planets of a few Earth masses.

Inspired teachers and remarkable collaborators have given me a chance to participate in a wonderful chapter in science. The experience has left me feeling fortunate and dizzy. The coherence of the universe that connects biology to the big bang seems more compelling than ever. I will enjoy seeing what the next-generation of young scientists teach us about other earths and the possibility of life in the universe.