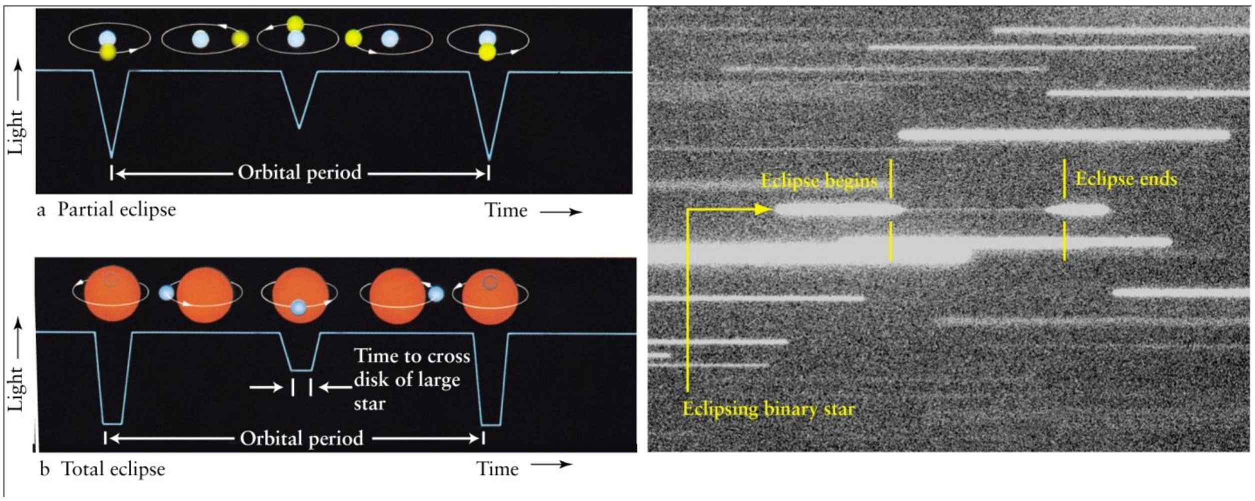
WORK ACCOMPLISHED

The bulk of the work accomplished during my sabbatical leave was the observation of the eclipsing binary star, V 1178 Cassiopeia. An eclipsing binary is a pair of stars orbiting one another, and which eclipse one another in turn, as seen from Earth. The period between eclipses ranges from hours to centuries, depending on the distance between the stars. Analysis of the way the light varies with time can yield a wealth of information about the individual stars.



Shown above left are graphs of light intensity vs. time for two eclipsing binaries. Lower left is a totally eclipsing system; upper left is a partially eclipsing system. Totally eclipsing systems (those where the smaller star fits within the circumference of the larger star when passing across the front or back of the larger star) are flat at the bottom of eclipse. Partially eclipsing systems are pointier at the bottom of the eclipses.

Eclipsing binaries are of major importance in modern astrophysical research. Their study yields fundamental data on masses, radii, ages, atmospheres, and interiors of stars as well as tests of stellar evolution theory. Without eclipses most of these parameters could not be determined. And, of course, studying binaries returns essential information about…BINARIES.

Choosing a suitable object for study requires a literature search. Ideally there would be little already published on the object. Repeating work that has already been done is usually of little value, and hard to get published. V 1178 Cas was found in an online catalog of eclipsing binary stars published by the Czech Astronomical Society.

At the time, I didn't know much about the Czech Astronomical Society. I didn't know if they were mostly amateurs, or pros. Their website is very well done, and very useful, but I didn't know if it could be trusted.

Their data indicated that V 1178 Cas had not been observed much. I checked that out by searching the astronomical literature for papers published on V 1178 Cas. Most of the astronomical literature is available online via the powerful SIMBAD search engine. I found nothing published on V 1178 Cas. The Czech catalog did list a time of minimum (i.e. a precise time of mid eclipse for some past eclipse of the binary), and a precise period of orbit. The data was contributed by someone with a Czech name, but the name meant nothing to me. I didn't know if there was any vetting, refereeing, etc., of contributions to the catalog, or if just anybody could post observational results. For all I knew, his/her measurements might have been garbage. And what about the object's reported position, in the catalog? There is a star at that position in online star charts, but the name on the star chart is not V 1178 Cas. It goes by some other catalog name. I know now that the Czech society would be more aptly termed the European Astronomical Society. It's a huge outfit, consisting of pros and amateurs, facilitating the advancement of professional and amateur astronomical research.

The only thing you can do is stop worrying and start observing, and hope you are not wasting your time. If observations showed no change in brightness, it could mean the star at the reported position is not an eclipsing binary, the reported time of eclipse is wrong, or the period of orbit is wrong. It didn't take too long to discover that the brightness DID in fact change, indicating a probable eclipse (since it was listed as an eclipsing binary; stars CAN change in brightness for other reasons). So I started observing the hell out V 1178 Cas. I was excited that I'd found something shoved to the dusty back corner of the astronomy closet, something ignored, for which I could contribute something really NEW. And it has a catchy name, too.

Why has this eclipsing binary been ignored? Well, it's dim, for one thing. To get quality data you need a big telescope, and maybe you don't have one. Professional research installations have big telescopes, but you have to apply for time on big instruments. And you have to travel, most likely.

V 1178 Cas is a tough nut to crack. A difficult beast. Not only is it really dim, it has a fairly long period. 8.662 days. It takes a long time to get observations covering the entire cycle. The object is well positioned in the fall for long nights of observing, but in summer and winter it isn't above the horizon for very long. The average night of observing is probably five or six hours. So you get these snapshots of parts of the 8.662 day cycle. Some nights you can't observe at all, for whatever reason. Clouds, for example. This type of work is called photometry, and for that skies must be perfect.

Getting a few nights of observing time here and there at a professional observatory could mean many years to get a publication out of V 1178 Cas. A project like this needs somebody with a BIG (big, as privately owned telescopes go) small telescope in his own back yard, of research grade, and a lot of time on his hands (say, on a sabbatical). Somebody who can observe whenever he has time and conditions are favorable, because the telescope is always there. Somebody who always approves telescope time for his own research proposals. Somebody like me.

Small telescope astronomical research has grown in the last few decades, due in large part to the development of low cost, yet high quality, telescopes and instruments, as well as their detectors. The use of small telescopes for the production of significant research has advantages over large telescopes in the areas efficiency, availability, flexibility and serendipitous and speculative observation. Small telescopes have an increasingly important role to play in modern astronomy.

V 1178 Cas was observed for sixty-three nights between July 2018 and Jan 2019, amounting to over three hundred hours of observing time, and well over a thousand individual observations. Observations were carried out at Gregory T. Thurman Memorial Observatory, using a sixteen inch-aperture reflecting telescope, equipped with a CCD (charge coupled device) camera. Each image taken by the camera through a particular filter constitutes an observation.

Gregory T. Thurman Memorial Observatory, shown above, was built with money left me by my late brother, Greg. The observatory is located on my property, in Deerhorn Valley (east of Jamul), at about 2600 feet elevation, under moderately dark skies.

Seen above, the observatory building is being assembled around the telescope, which is mounted on a steel pier bolted to a four-foot-deep block of concrete. The telescope can't fit through the door, which is why the telescope had to go in first.

The camera's CCD has millions of light sensitive pixels which build up electric charge as light falls on them. Computer software can read the amount of electric charge on each pixel and convert it into a number which is a measure of brightness. An image is taken through each of five filters, each of which passes a chunk of the electromagnetic rainbow: Ultra Violet, Blue, Visible (yellow), Red, and Infra-Red. Imaging the light through these filters yields various kinds of astrophysical information, such as surface temperatures of stars.

I am buried in a mountain of V 1178 Cas data, reducing and analyzing it as I am able. The period of orbit reported in the Czech catalog looks correct, but the time reported for an arbitrary past eclipse (called the epoch) was off by about one day. The epoch and the period together are called the ephemeris. My work has improved the ephemeris, but there is much more to do.

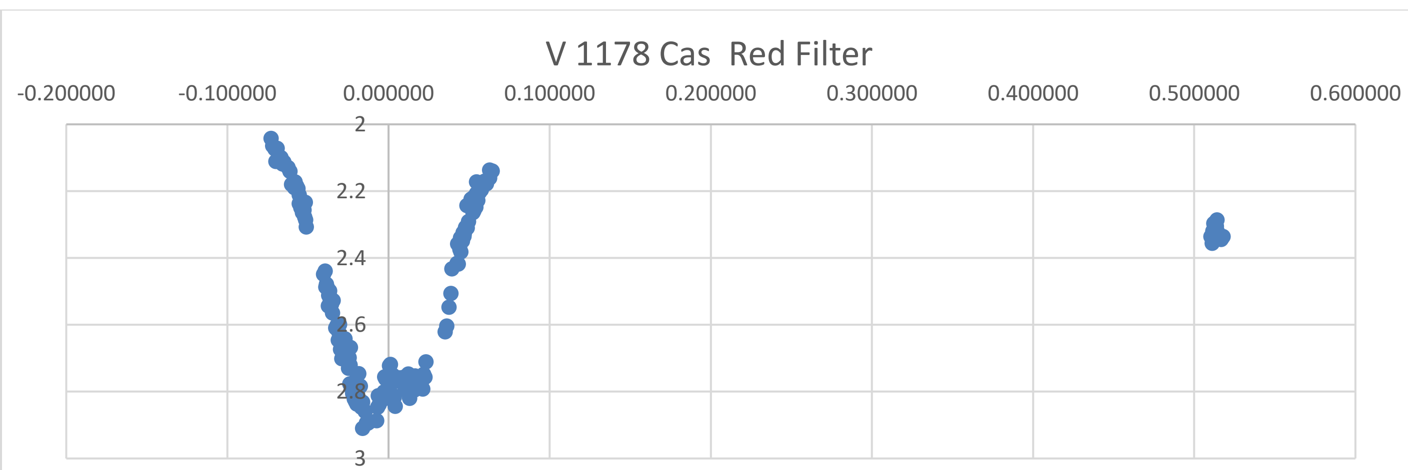
The problem with trying to combine/compare data from different nights and/or different telescopes/investigators is that the numbers you get depend not only on the astrophysical object being observed, but on how a particular telescope and its instrumentation respond to light of a given wavelength, and on atmospheric conditions for a particular night. Atmospheric conditions change from night to night, not surprisingly, but even the telescope/instrumentation itself changes over time. As a trivial example, the optics may get dustier, or, if cleaned, less dusty.

The solution is to observe *standard stars*, enabling the transformation of the data to a standard system. Then data from many nights and many observers can by compared/combined.

Standard stars are stars that have been observed many times by a "standard" telescope. The telescope is nothing special; it's just the one that was used. A large number of stars over a wide range of brightness and color are observed. Several standard systems exist.

To convert the V 1178 Cas data to the standard system, I have observed about ten standard stars over several nights on which V 1178 Cas was also observed. Simple mathematical methods are employed to correct for atmospheric effects and transform the V 1178 Cas data to the standard system. The more standard stars observed, the more reliable the transformation to the standard system. Results for the transformation have been good so far. I am very pleased, because in the photometry business, you just never know. Another whole season of observing V 1178 Cas is coming up, and more standard stars will be observed. Once photometric data has been placed on the standard system, astrophysical quantities of interest can be obtained, for example, luminosity (power output) and surface temperature.

The V 1178 Cas project has a long way to go. I need a lot more data. The entire orbit needs to be observed, as many times as possible. Analysis of the light curve can begin before all the observing is done, however. The *light curve* is a plot of light intensity vs. phase, through a particular filter. Phase is just whatever point in the orbit a given observation was made. Phase runs from 0.0 to 1.0.



Seen above is a plot of some red-filter data for V 1178 Cas. Primary eclipse (the eclipse with the deepest dip in light) is on the left. Notice the relatively flat bottom.   A few secondary eclipse points are shown on the right.

The SDSU collaboration discussed in the sabbatical proposal was stillborn; a stupendous failure. I had introduced myself to a professor who was initially very interested in working with me. I was prepared to spend a lot of money on a multi-processor Linux box which would enable me to do work for him and his partner, another SDSU professor. We were furiously exchanging emails on the subject of what I would buy, and then they suddenly stopped communicating with me. I made several attempts to reestablish communication, but for no apparent reason they were no longer interested.

The collaboration with SDSU did not turn out to be necessary, after all. I wanted to learn from SDSU astronomers, and have access to, the powerful eclipsing binary code, Wison-Devinney. But, there was no room at the inn. So I had to fend for myself. I found a free, online version called PHOBE, which has a windows-type interface. PHEOBE is built around Wilson-Devinney. I have downloaded it and the user's guide. The program runs fine. I'll learn it on my own. SDSU astronomy was not a total waste of time, however. The advice I got regarding multi core computers, where to buy, and which version of Linux to use was valuable.

The Wilson-Devinney/PHOBE computer code models eclipsing binary light curves. Meaning, you give it starting guesses for the parameters of the system (e.g., mass, luminosity, separation, surface temperature and many others), and it then generates a theoretical light curve that it compares to the real one. The code then chooses the next set of guesses, and makes a new theoretical curve. By iterating in this way, the code can figure out all the important parameters of the system. I have so much data to process that I won't be getting heavily into the modeling for a while, but I can start learning PHEOBE.

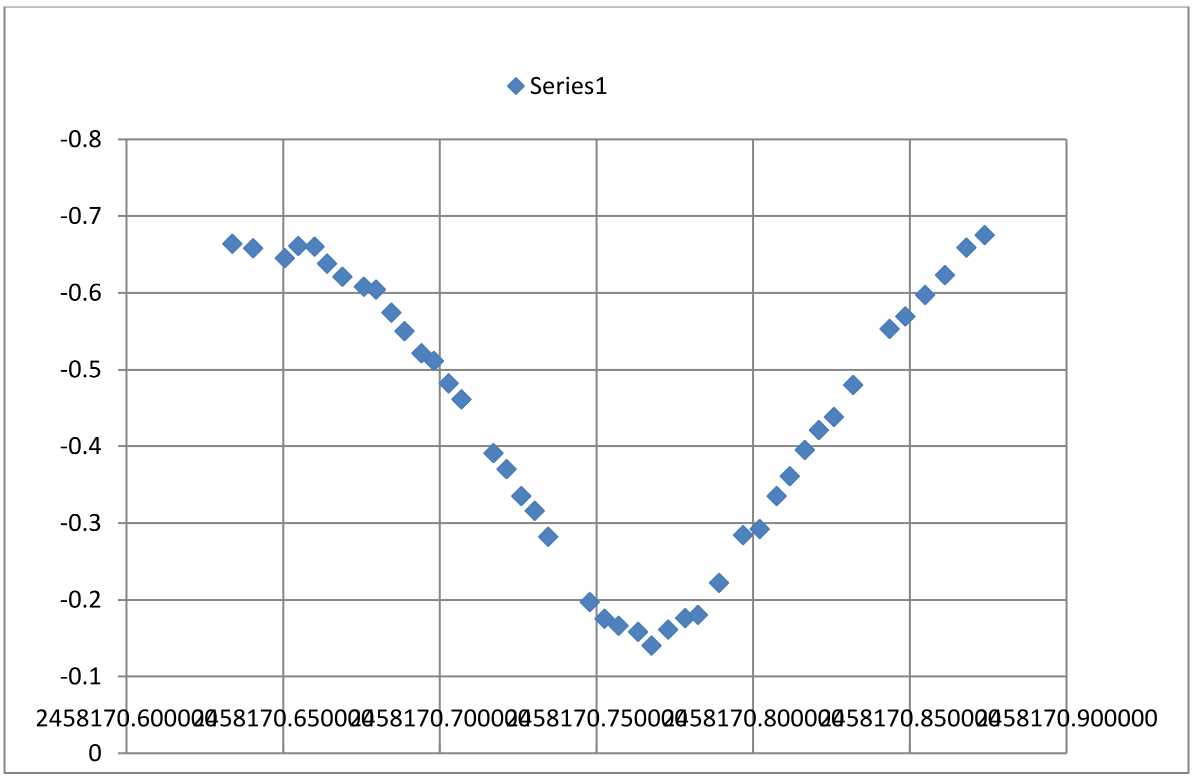
EG Serpentis is another project that moved forward thanks to the sabbatical time. It is a photoelectric study of an eclipsing binary; all written up and ready to submit to a journal. It is derived from my astronomy master's thesis. The work is old, but contributes much more data than the only other paper published on the object. There is a risk it could be rejected for not adding enough new to what has already been published. That is why I have been delaying sending it in. I'm thinking of modeling the object with PHOEBE and comparing it to the model in the thesis, which was computed using a much less sophisticated modeling program.

I reached out to my old astronomy master's chair, another SDSU prof, but retired. I wanted him to collaborate with me on the EG Ser paper. He was initially very enthusiastic, and so we got to work. I wrote the paper and sent it to him, he suggested some revisions, I made them, and then totally lost contact with him. The SDSU ass-tronomical community apparently was not done rejecting me. This snub happened right around the time the other two SDSU guys dumped me, and as result I suffered a persecution complex for a while. What the hell was I doing wrong?

God, what a time to run out of benzodiazepines. A third party helped me get in touch with my old mentor, but he told me that he was tired of doing science and just wanted to relax in retirement. What an about face! That's fine, but why just break off communication? Email etiquette is weird. It seems that it is acceptable to say, NO THANKS, by just ignoring someone.

Well, happily, the email exchanges with my master's chair were very good for the paper, and it got written anyway. Without him and his SDSU Foundation money, however, I am going to have to pay the steep page-charges myself. And as discussed above, what I hoped to gain from collaboration with the other two professors, I have achieved on my own, anyway.

Still other projects benefitted from the sabbatical time. For example, observation of eclipsing binary GZ Ursa Majoris, or GZ Uma. My data looks good, but like V 1178 Cas, there is still much to do, including more observing.



Seen above is a primary eclipse of GZ Uma. Notice the rounded bottom of the eclipse, indicative of a partially eclipsing system. The smaller star never passes entirely within the circumference of the larger star.

A little sabbatical time was devoted to an astrometry project. Astrometry of binary stars is not concerned with studying light per se, but with measuring the position in the sky of each of the two stars as they slowly orbit one another. Binary stars in general are not eclipsing, and it is the non-eclipsing ones that are the targets for astrometry. A completely different kind of software is used for this work, but will not be discussed here.

The Washington Double Star Catalog (WDS) maintained by the United States Naval Observatory is the world's principal database of astrometric double and multiple star information. The Journal of Double Star Observers is one of the principal sources of double star measures for the WDS. It's a peer reviewed journal, but gently refereed, meaning it's an easy publication to get. I have enough data for a paper, but it isn't written yet. If the WDS uses any of the data I publish in the Journal of Double Star Observers, I will take my place alongside William Herschel and other classical-astronomy greats whose work appears in the catalog.

Instead of wasting the daylight hours of my sabbatical trying to get some sleep, I spent the time working on my radio telescope project. Shown above, in the foreground, is a thirty-foot diameter radio dish. The job of attaching half-inch poultry mesh between the ribs is ongoing. It should be done by the end of June. A crane will then lower the dish onto the thirteen-foot tower seen at left. The tower is sunken in 30,000 pounds of concrete. If the tower looks crooked, it's because it is. I did my best. The tower has motors to move the dish in altitude and azimuth. And an 8000:1 gearbox from a 1940s aircraft, which was used with a motor to change the plane's prop pitch. Not only will this dish be capable of hearing natural radio sources in the sky, but it will also be used to transmit signals to the moon, which will bounce back and be heard not just at my station, but at stations around the world. In case this sounds farfetched, "moon bounce" has been accomplished by amateur "ham" radio operators for many decades. What better way to celebrate the fiftieth anniversary of the first Moon landing, than to send my own voice to the Moon and return it safely to the Earth.

Every semester students come to my home to enjoy observing through my large optical telescope. When the radio telescope is finished, my students will enjoy radio astronomy when they come to my house, as well as optical.

Shown above, surrounding The Visionary, are just a few of the many fine young people, some students, some former students, some friends of students, who donated their brains and brawn to the optical and radio observatory projects. Many of my helpers knew me, but many didn't know me at all, or had only met me once. It's just amazing how many people will chip in to help somebody they hardly know, if they think the project is worthwhile.

IMPLICATIONS FOR THE INDIVIDUAL

My sabbatical work was of greatest benefit to me and to the astronomical community, and to a lesser degree, students and the discipline.

I am a scientist. There is no greater satisfaction for me than doing scientific research and contributing to the fund of knowledge by publishing. Four papers ultimately will, in part, come out of the sabbatical. Three need much more work and one was well on its way before the sabbatical began. The greatest benefit to me is that research has made me a better scientist, brought me the joy of making a publishable contribution to astronomy, and enriched my inner life. Of course, the astronomical community benefits from my sabbatical, because I will publish the research I accomplished.

IMPLICATIONS FOR THE STUDENT

I turn to trickle-down theory to argue that students will benefit from my sabbatical. Investigations into the question of whether doing research makes a better teacher have found no evidence that it does. I haven't seen those studies and don't know how convincing they are. It seems like there would be variables difficult to control for. For example, researchers at Ph.D. granting institutions are under pressure to publish, and probably give their time to their research more than teaching, which could negate any teaching benefit from doing research. Even if researchers are not better teachers (and I don't know that this is true; absence of evidence is not evidence of absence), there may be other benefits for students.

Someone active in research may be more excited about science than someone who is not interested in DOING science. That excitement could rub off on a student. One of my former students told me that when I showed to her and the rest of the astronomy class a periodic table of the elements, she changed her major from Spanish to Physical Science. She got excited, and I give the periodic table some credit, but I take some credit, too. I've very much enjoyed my past professor's stories of their research adventures. It makes the subject come alive. Stories of real research can interest students in a scientific career.

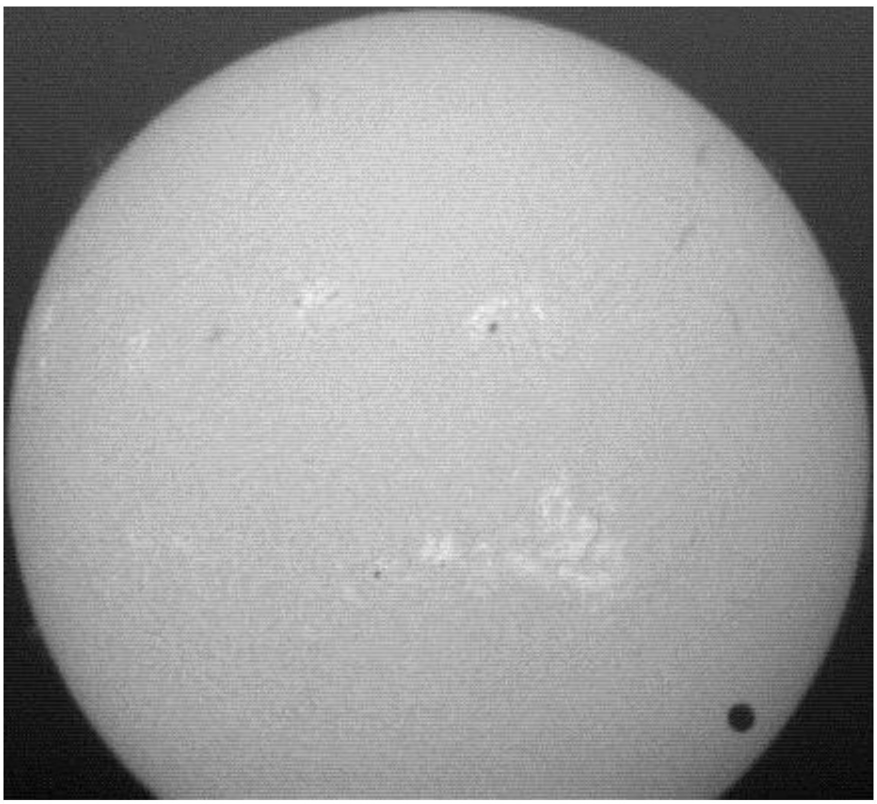
Teachers actively engaged in research can probably offer students more insight into how research is done than someone who is out of the game. It is important for the public to know how science is done, because the public has to vote/make decisions on matters of science.

How science progresses, as presented in textbooks, is usually unrealistic. Any researcher knows the advance of science is messy and inelegant. Science can move in many wrong directions before a step forward is taken. Most researchers know this and can offer students a realistic view. In my own experience, research is even chaotic on the scale of a single project. Any research project seems like a mess most of the time; fraught with uncertainty and anxiety, especially if a degree or grant is at stake.

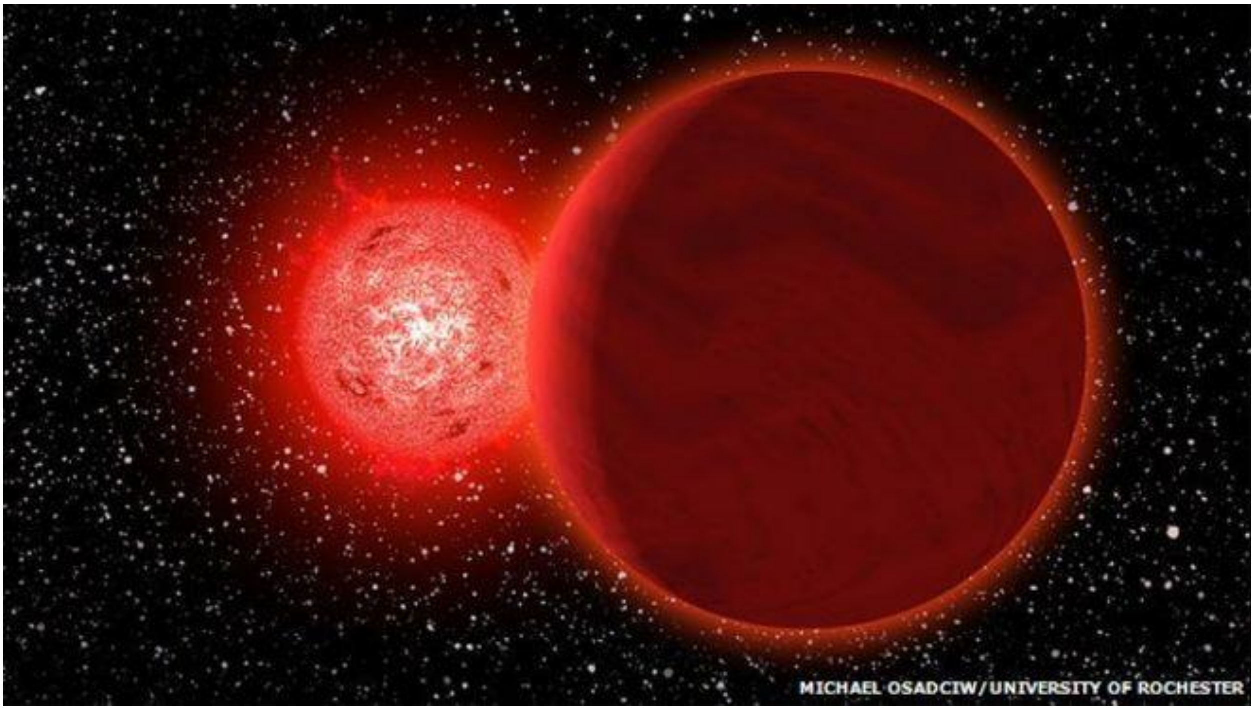
Research/scholarship can yield unexpected benefits for me and the student. For example, someone from the Czech Astronomical Society recently contacted me by email, via an intermediary – the American Association of Variable Star Observers (AAVSO), of which I am a member. An interesting coincidence. I hadn't heard of the Czech Society until I discovered their eclipsing binary catalog, the source of the centerpiece of my sabbatical, V 1178 Cas. Within a year they had reached out to ME.

The leader of the Habitable Exoplanet Hunting Project, a research group within the Czech Astronomical Society, told me they were interested in my observatory and its capabilities, and invited me to join the Project.   They may have mined the AAVSO for publishers (like me) of quality astronomical data, who would likely have the required skills and telescope power for detecting planets that are good candidates for harboring life, orbiting other stars.

The Habitable Exoplanet Hunting Project is an intriguing one. There are thousands of dim red stars (red dwarfs) near our solar system. Seventy percent of all stars are of this type. Small rocky planets orbiting these stars in the "habitable zone (just the right distance from the star to allow liquid water to exist on the planet)" can be detected by a telescope like mine if the planet happens to pass in front of (transits) its star and dims the light. Most solar systems are not oriented in space in such a way that the planets would pass in front of the star as seen from Earth, but some are. The closer a planet is to its star, the more likely it is that it will transit, as seen from Earth; and the habitable zone around red dwarfs is VERY close to the star.



Shown above is picture I took several years ago, of Venus transiting the Sun. Images like this, of planets transiting their stars, are not possible as seen from Earth. Stars are too far away. But a tiny bit of light is blocked by the planet, and it's enough to measure.



Shown above is a fantasy planet orbiting very close to a red-dwarf star.

Red dwarfs stars are prone to flares (depicted above), which could destroy/preclude life on a nearby planet, so flare stars are excluded from the hunt. I am going to hunt for transits of planets in the habitable zone of non-flare stars in the neighborhood of our sun.

Involvement in research, *generally*, has serendipitously made me into a hunter of habitable planets, *in particular*. And I can do it from my back yard. Coincidentally, the two SDSU profs who dumped me are exoplanet hunters, but they mine Kepler-mission data.

This is a project that could conceivably interest students. Who isn't interested in the question, Are we alone? My astrometry project, mentioned above, might also interest students. Astrometry is not as glamorous as the search for exoplanets that can support life, but it can get a student an easy publication. Authorship or co-authorship on a publication improves a student's chances of obtaining a scholarship, as a result of their demonstrated research experience, and encourages STEM careers.

To this end I hope to attend an Astronomy Research Seminar Workshop in Provo, Utah. This workshop prepares high school and college instructors to start their own Astronomy Research Seminar. A dozen high schools and colleges offer this seminar which has produced 150 published papers with over 500 coauthors.

Learning and performing music is good cross training for any brain, and greatly adds to the rich inner life I seek. Indeed, in my sabbatical proposal, I promised to perform music. And so I did. I performed two concerts with the Cuyamaca College Concert Band. I don't have any photographic evidence of that, but shown below is a pic of me after a performance with the Poway Symphony, along with friends, family, fans, and other adoring hangers-on.

THAT'S ALL, FOLKS!