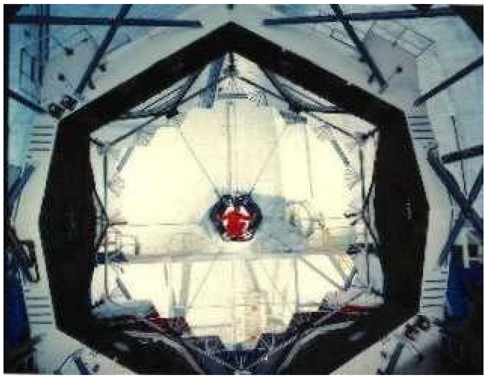
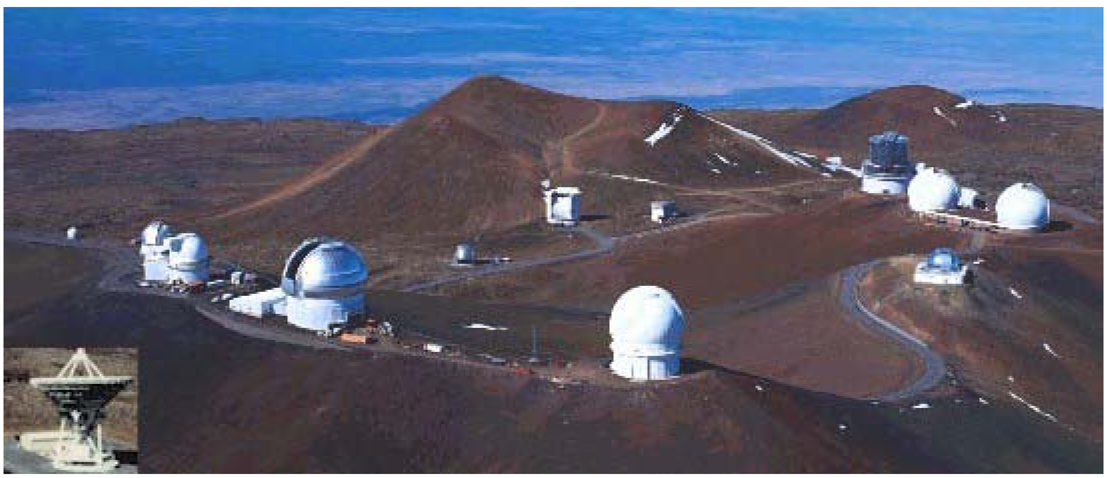
A New *Hubble Space Telescope* Project for Fresno State, by Fred Ringwald.

In 2001 August, I had an observing run on Keck I, the largest telescope on Earth, on Mauna Kea, Hawai'i. Here are some pictures of Keck:



Looking down the Keck I telescope's tube. The primary mirror is comprised of 36 hexagonal segments, held in correct shape by computer control, and has an aperture of 10 meters. That small figure in the center is a person. (Keck)

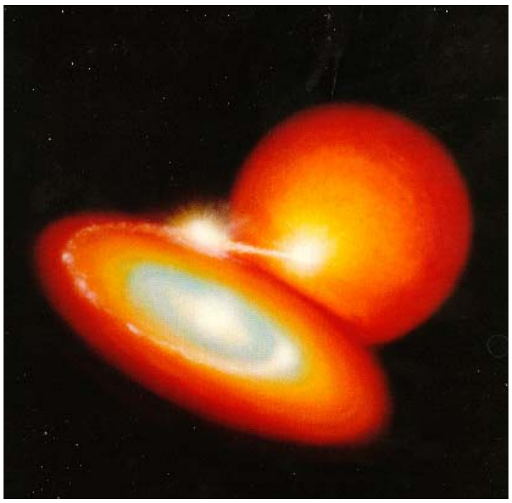
A side view of the Keck I telescope, taken with a wide-angle camera, with the photographer lying on the floor. The mirror, to the right, is about the same size as the inside of the Downing Planetarium's dome (W.M. Keck Observatory)



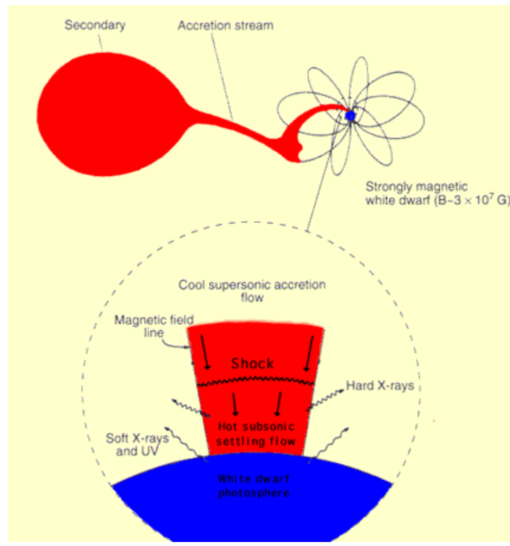
Mauna Kea Observatory, in Hawai'i. The Keck I and (slightly smaller) Keck II telescopes are in the twin domes, at right. Altitude sickness is often a problem at the 4,200-meter (13,800-foot) summit (see http://www.ifa.hawaii.edu/mko/maunakea.htm). I didn't have any of the usual nausea and only a slight headache, but so help me, it felt like there was an elephant standing on my chest! (UHawai'i)

I am now pleased to announce we will be extending this work with *Hubble Space Telescope*. My collaborator is Steve Saar, who was my first-term college roommate and is now at Harvard (actually, Smithsonian Astrophysical Observatory, in the Harvard-Smithsonian Center for Astrophysics, one of the largest collections of Ph.D. astronomers in the world). Steve pioneered the night-time use of the big solar telescope on Kitt Peak, Arizona, to observe many phenomena in bright stars that were originally discovered in the Sun. Most are caused by magnetism, including starspots, flares, and coronae. That's why the committee liked our observing proposal for *Hubble Space Telescope*: Steve studies stellar magnetism, and I like cataclysmic variables, so it's fitting that the two of us should observe magnetic cataclysmic variables.

The project is to get ultraviolet spectra of two magnetic cataclysmic variables, AM Her and AR UMa. Magnetic cataclysmic variables are unusual star systems: both AM Her and AR UMa are called AM Her stars, named after the prototype of the class, AM Her. AM Her stars are a sub-class of cataclysmic variables. All cataclysmic variables are close binary star systems, in which two stars orbit each other in just a few hours (3.09 *hours* for AM Her, and 1.93 hours for AR UMa; 1 year for the Earth and Sun, of course). The two stars are so close, gas from one star spills onto its companion star. In all cataclysmic variables, the stars losing the gas are relatively normal K-M dwarfs, probably not terribly unlike the Sun (a G2 dwarf), only less massive. In all cataclysmic variables, the stars that are being spilled upon are white dwarf stars, or the burned-out cinders of what used to be normal stars, like the Sun.



A regular, non-magnetic cataclysmic variable (CV). A K-M dwarf spills gas, through its L1 point, onto a white dwarf, via an accretion disk. (Art by Dana Berry, Space Telescope Science Institute.)

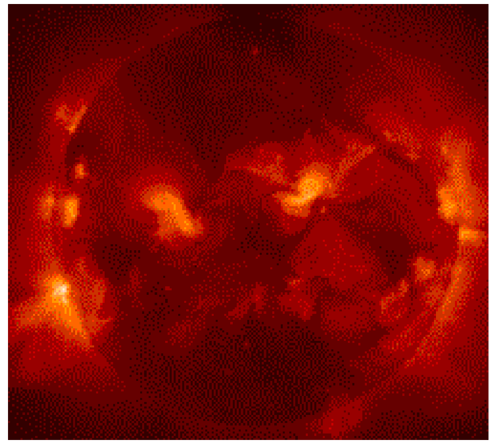


A strongly magnetic cataclysmic variable, also called an AM Her star (also called a polar). The white dwarf has such a strong magnetic field, the gas from the mass-losing star is attracted directly onto its magnetic poles (NASA/HEASARC).

What's special about AM Her stars is that they have white dwarfs with strong magnetic fields, of over 100,000 Gauss. For comparison, the Earth's magnetic field is about 1 Gauss; the Sun's global magnetic field is about 10 Gauss; the field inside a big sunspot group is over 4000 Gauss. The white dwarf in AR UMa has the strongest magnetic field known in any magnetic cataclysmic variable, of over 200 million Gauss. This isn't as much as in a pulsar, which has a magnetic field of over a trillion Gauss, or a magnetar, with a field a million times stronger than this, but it's more than enough to remove your belt buckle from quite a long way off. It's also enough to cause the gas stream from the mass-losing star to spill directly onto one or both of the magnetic poles of the white dwarf: the gas in most other cataclysmic variables (which have non-magnetic white dwarf stars) flows into a disk, before settling onto the white dwarf.

One of Steve's best discoveries is that the lower the mass of a star like the Sun, the more powerful its magnetic field gets. An M dwarf, a star like the Sun but only 0.1 – 0.3 times as massive, has a global magnetic field of about 4000 Gauss: about the same as in a big sunspot group. M dwarfs are probably covered with spots, much more than the Sun ever is, and are well-known to have strong flares, thousands of times more powerful than solar flares. This is because normal, or main-sequence, stars that have masses lower than the Sun are cooler than the Sun. Cooler stars are more convective, with the gas in their interiors becoming turbulent, like boiling water. This moving gas makes a strong magnetic field, by Faraday's law.

The Sun, in visible light. Sunspots are strong patches of the Sun's magnetic field (NASA/ESA).



The Sun, in X-rays, which are made by gas at temperatures of over 1 million degrees, heated by magnetism (NASA/ISAS).

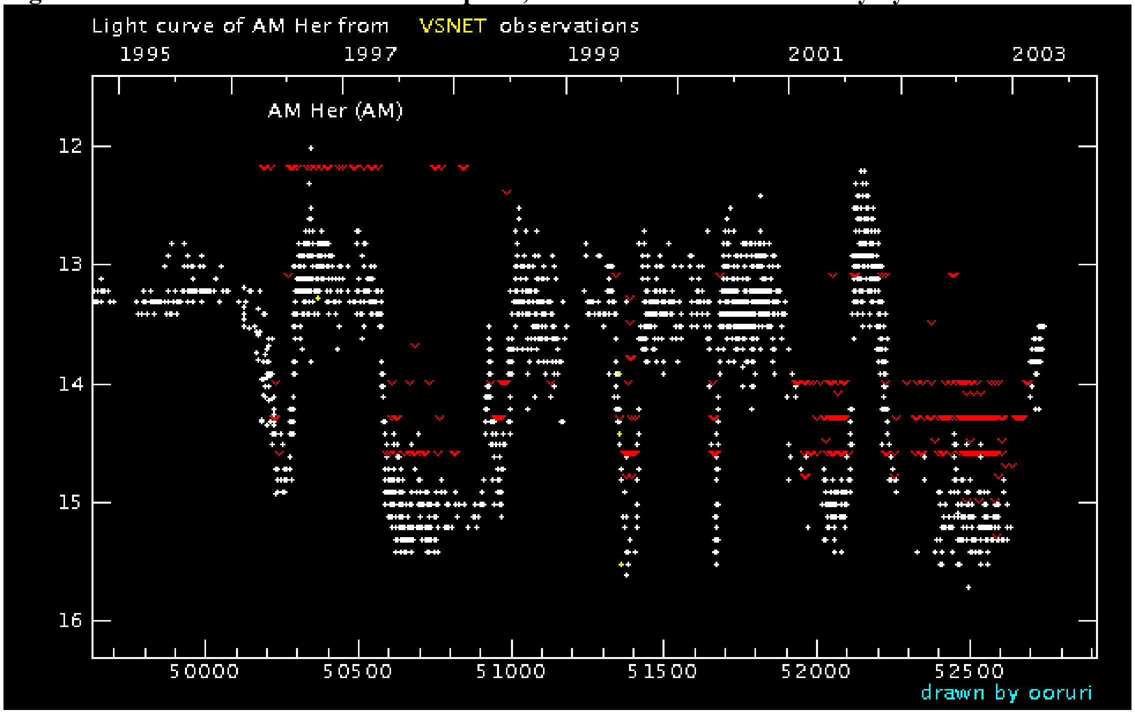
Low-mass stars have an apparent limit to how strong their magnetic fields can be. No one knows why. The mass-losing stars in magnetic cataclysmic variables should be among the most highly magnetized normal stars in the Galaxy: in them, we get to observe magnetism in normal stars at its most extreme.

Cataclysmic variables, or CVs, are a diverse class of stars. In addition to magnetic CVs, there are novae, which have nuclear-powered eruptions that give the class their names. There are dwarf novae, in which the mass transfer is unstable, which causes gravity-powered outbursts. There are also nova-likes: the name is a misnomer, because nova-likes don't have eruptions, they just look like novae, between eruptions.

All kinds of CVs have low states, in which the mass transfer between the stars seemingly switches off. Whatever causes this must be common to all CVs—and all CVs have similar mass-losing stars. Since these mass-losing stars are so highly magnetic, the current theory is that low states are caused by starspots, as they form or move over the L1 point, the spout on the mass-losing star where the gas spills to the white dwarf. I've always been a little skeptical of this, though: plasmas are well known for their ability to escape confinement. Still, if these low states are from magnetism on the secondary stars, *Hubble Space Telescope* will detect it, since it can see lines in the ultraviolet spectrum that form in magnetically heated gas.

This is a target-of-opportunity program: for *Hubble* to do these observations, either AM Her or AR UMa have to go into a low state, sometime between 2003 July and 2004 July. This means we need to start monitoring the magnitudes of both stars carefully now, with our own telescopes. This is where amateur observers come in: amateurs have long contributed valuable data to programs like this, such as the light curve below of AM Her from VSnet, the pro-am web page run by Kyoto University (vsnet.kusastro.kyoto-u.ac.jp/vsnet/index.html). This is also a fine project for students, at Fresno State's Campus Observatory. The low states last from weeks to many months, so we need not observe every night, but of course this would be welcome, and we should observe frequently when the observations are scheduled!

Light curve of AM Her from VSNET reports, based on observations mainly by amateur observers.



* White dots and red "v" symbols represent positive observations and upper limits, respectively. (VSnet.)

For more on this program, including finding charts for AM Her and AR UMa, see the Research Opportunities page (http://zimmer.csufresno.edu/~fringwal/opps.html), where I've added a new entry under "Planned science programs" (under the one on "Searches for black holes in old novae"). A whole book on CVs, specifically written for students amateur astronomers, is Cataclysmic Variables: How and Why They Vary, by an old colleague from England, Coel Hellier. Fresno State's Madden Library has a copy, and I have several, although they always seem to be in the hands of students. Chapter 1 gives a thorough introduction on how to make the observations we need. The magnitudes can be measured with the CCD photometry software included in another book, The Handbook of Astronomical Image Processing, by Richard Berry and James Burnell, and described in their Chapter 7.

Please contact me, too (e-mail: ringwald@csufresno.edu, phone: 278-8426), so I can get you started. The specifics of how to observe will vary greatly with your equipment, but the general idea is to get individual exposures each night, on as many nights as you can. Optimal exposures would be with the target star no more than halfway to saturation, so the photometry will be most accurate: it's important also to expose some stars in the frame of comparable brightness to the targets also to no more than halfway to saturation, as comparison stars. With the Campus Observatory's 16-inch telescope, this would require exposure times of only about 1-2 minutes: these observations aren't difficult, but we need consistency and patience, since the campaign will extend over the next year and a half. It will also be essential to get a full set of calibrations, including dark frames, flat fields, and darks for the flats, for every night we observe. In the meantime, Steve and I will try to get observing time on *XMM-Newton*, the European space telescope, so we can also detect X-rays from the coronae that powerfully magnetic stars must have. (*Chandra X-ray Observatory*, NASA's other billion-dollar space telescope, is unprecedentedly good for imaging X-rays—and difficult to get time on, since it's so in demand—but we need spectra, and besides, Steve and I like going to Europe.) It looks like we'll have a busy year ahead!