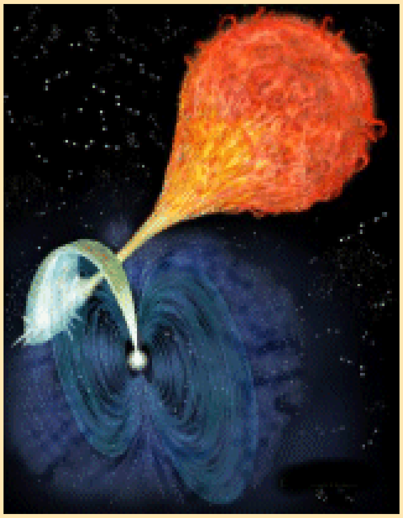
Variable Star Of The Month

June, 2001: AM Herculis (1813+49)

A man's friends are his magnetisms.
Emerson. *Conduct of Life: Fate*



Artistic impression of an AM Her system. The blue haze represents the white dwarf's magnetosphere.
Image copyright Russell Kightley Media

The exotic star AM Herculis is the namesake of the "AM Her stars" or "polars", a unique class of cataclysmic variables in which the magnetic field of the primary star (white dwarf) completely dominates the accretion flow of the system. With the discovery of AM Her comes the discovery of "polars" and a lesson learned that even familiar objects will reveal exciting discoveries if they are approached in the correct way. AM Her was discovered in 1923 by M. Wolf in Heidelberg, Germany during a routine search for variable stars. It was then listed in the *General Catalogue of Variable Stars* as an irregular variable with a range from 12th to 14th magnitude. The listing remained as such until 1976, when the true complexities of AM Her were finally revealed. Berg & Duthie of the University of Rochester (1977) initially suggested that AM Her could be the optical counterpart of the weak X-ray source 3U 1809+50 which was detected by Uhuru, the first Small Astronomy Satellite. They noted that the variable star lay just outside of the region of certainty where the weak X-ray source was believed to be. Subsequently, a better position for 3U 1809+50 was determined and the position of the X-ray source and the variable star were shown to be the same. In order to prove that these observations were coming from the exact same source, however, more evidence was needed.

In May 1975, Berg and Duthie made the first photoelectric observations of AM Herculis. They found that the light from AM Her "flickered incessantly". This rapid light variability had been seen in two other stars which were associated with X-ray sources, so the team was optimistic that AM Her would turn out to be the optical counterpart of 3U 1809+50.

By May 1976, word had spread throughout the astronomical community that AM Herculis was an important object to observe in as much detail as possible. The Chilean astronomer S. Tapia, at the University of Arizona, had access to a polarimeter and used it to observe this star. The results were startling. He discovered in August 1976 that AM Her is both *linearly and circularly* polarized (these concepts are discussed later in the article) at optical wavelengths (Tapia 1977a). The detection of variable circular polarization was surprising since it was only known to exist in 9 other stars, all magnetic white dwarfs. The circular polarization in AM Her signified the presence of an immense magnetic field. This confirmed the suspicion that AM Her was the optical counterpart to the X-ray source. Consequently, a new class of magnetic cataclysmic variables called "AM Her stars" or "polars" was born.

Magnetic Cataclysmic Variables

The discovery of AM Herculis introduced a new class of highly magnetic stars to the group of cataclysmic variables known at the time. A cataclysmic variable is a close binary system with a white dwarf primary and a red dwarf secondary. Due to the evolution of the system, the red main sequence star loses matter in the direction of the primary, forming an accretion disk around the white dwarf. A *magnetic* cataclysmic variable is distinguished by the presence of a magnetic field around the white dwarf star that radically affects the whole nature of accretion flow in the system. Thus the cataclysmic variables are divided into two groups, the *non-magnetic* group (dwarf novae, nova-like, recurrent novae; for further review of non-magnetic CVs visit VSOTM for SS Cyg, U Gem, Z Cam, or RS Oph). and the *magnetic group* (polars). Magnetic cataclysmic variables are divided further into two classes based on the strength of their magnetic fields:

1. *Intermediate Polars (DQ Her stars)*
   The intermediate polars or DQ Her stars (named after the prototype DQ Her) show magnetic field strengths around the white dwarf star on the order of 1-10 Mega Gauss. An accretion disk forms, but is disrupted close to the white dwarf (primary) star due to the magnetic field. The magnetosphere is **not** strong enough to synchronize the orbits of the rotating white dwarf with the orbital period of the system (as seen in AM Her stars).
2. *Polars (AM Her stars)*
   The polars or AM Her stars (named after the prototype AM Her) display magnetic field strengths on the order of 10-100 Mega Gauss. This magnetic field is so powerful that it prevents the formation of an accretion disk around the white dwarf and locks the two stars together so they always present the same face to each other. Thus the white dwarf star spins at the same rate as the two orbit each other - a *synchronous rotation* that is the defining characteristic of an AM Her star. (About 10% of AM Her stars are asynchronous, where the rotations of the white dwarf and the orbit are off by ~ 1%) (Hellier 2001)

Model of an AM Her system

Southern Lights and Shuttle Glow
Credit: STS-39 Crew, NASA
Bands of the Aurora Australis shine at a height of 50-80 miles with the glow from the shuttle Discovery engines at left. Aurora are caused by charged particles from the sun channeling into Earth's atmosphere at the magnetic poles, a path similar to the acretion flow in polars.

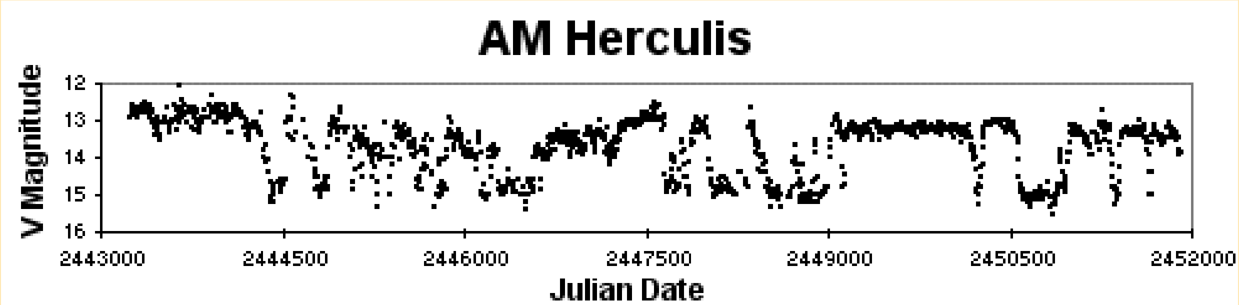
AM Her stars are especially interesting to study because of their strong magnetic fields. In an AM Her system the magnetic field around the white dwarf primary is so strong that no accretion disk is able to form like it does in non-magnetic cataclysmic variables. Material from the secondary flows toward the primary until it reaches the point where the magnetic field dominates the system. At this point, the energy associated with the *magnetic field lines* is much greater than the energy of the bulk flow of material coming from the secondary star so the material is forced to follow the path set by the field lines. This is usually a dipolar pattern that is similar to the configuration obtained by scattering iron filings around a bar magnet. Thus, to follow a field line the accretion stream splits into two, one part heads for the “north” magnetic pole and the other for the “south” pole. The field lines converge as they approach the white dwarf, squeezing the streams of matter and funneling them onto tiny accretion spots near the poles, whose radii are only ~ 1/100th of the white dwarf star (Hellier 2001). Liller (1977) describes the funneling of matter onto the magnetic poles of the white dwarf as resembling a “superviolent tornado”. The flow of material to the magnetic poles is also similar to the aurora phenomenon on Earth, where solar particles enter Earth’s atmosphere at those regions.

The material in this funnel, or accretion column, is channeled by the magnetic field towards the white dwarf in virtual free-fall. The potential energy is converted to kinetic energy and the stream slams into the white dwarf at roughly the ~ 3000 km/s escape velocity. In the resulting accretion shock the kinetic energy is converted into X-rays and radiated away. Magnetic cataclysmic variables emit most of their energy as X-rays and extreme-ultraviolet photons (Hellier 2001).

It is found that in an effort to obtain the lowest-energy configuration for this system, the magnetic field of the white dwarf often tilts over, so that one magnetic pole “points” towards the direction from which the stream comes. As a result, material flows preferentially onto that pole; material can still flow to the other pole, but only by going the long way around and only a fraction of the material succeeds in doing this. Eclipses in AM Her systems provide a graphic illustration of this stream geometry. Lightcurves reveal that the tiny and thus rapidly eclipsed, accretion spot at the magnetic pole emits roughly half of the total light; the other half comes from the extended stream, which enters and leaves eclipse more gradually (Hellier 2001).

A Look at the Light Curve

The light curve of AM Her appears to have the temperament of a superviolent tornado itself. There is apparently more than one source of radiation wreaking havoc on our star. The variations in AM Her may be thought to belong to two groups, the long-term changes and the short-term changes. The *long-term changes* are characterized by the existence of two different states, one the “active” or “on” state, in which the luminosity fluctuates around visual magnitude 13.0, and the other “inactive” or “off” state, where the brightness remains at about 15.0 magnitude (Hoffmeister et al 1985). These two states are thought to be the result of active and inactive mass-transfer rates from the secondary to the primary star (Hessman et al 2000).



Visual light curve of AM Herculis from the AAVSO International Database; August 1976 through March 2001.

Some of the *short-term phenomena* in the light curve of AM Her can be explained by the orbital motion of a binary system with a period of 3.1 hours. The 3.1 orbital period was discovered in AM Her from the eclipsing light-changes, the strongly variable linear and circular polarization, and the periodic radial velocity changes in the H and He lines (Hoffmeister et al 1985). Liller (1977) explains two kinds of optical variations associated with the orbital motion that are taking place in AM Her.

First, the red dwarf star is distorted into an egg-shaped figure by the attraction of its companion, toward which the long axis of the egg points. When we see the normal star broadside, it appears slightly brighter than when end on. Hence, as the entire system rotates, there are two long weak brightness maxima and two long shallow minima per period. Second, there can sometimes be observed brightness fluctuations due to the heating of the surface of the red secondary star by X-rays emitted by the collapsed star. This "hot spot" is periodically lost from view on the far side of the rotating normal star. Moreover, the short term light variations described earlier as "incessant flickering", occur due to the turbulent nature of the transfer of mass from the secondary to the white dwarf star (Hellier 2001).

Polarized Light

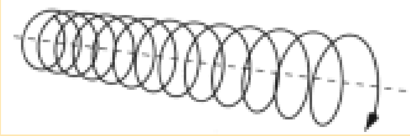


Fig. 1 An electron in an AM Her system spirals around the magnetic field line producing cyclotron emission. *Credit: Hellier 2001*

The name *polar* was introduced by the Polish astronomers Krzeminski and Serkowski (1977) for AM Her and related objects, on account of the strong, and variable, linear and circular *polarization* in the light from these stars. Normal light is composed of electric vectors that are arranged randomly (always perpendicular to the direction of travel). *Polarized light*, in contrast to normal light, is composed of electric fields in a direction that is not random. If the electric vectors of a set of photons all point in one direction then the radiation is said to be *linearly polarized*.

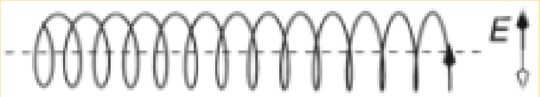


Fig. 2 When the field line is seen side on the apparent motion of the electrons are up and down, producing photons that are linearly polarised in this direction. *Credit: Hellier 2001*

AM Her displays both linear and circular polarized light for the following reason. The ionized material in an AM Her accretion stream does not simply follow a magnetic field line; instead it spirals around the field line (Figure 1). Consider looking at this field line side on (Figure 2). From this viewpoint, an electron spiraling around the field line will appear to be oscillating perpendicularly to the field line. The photons produced by this motion will always have an electric vector in the direction of this oscillation, and so the light is *linearly polarized*.

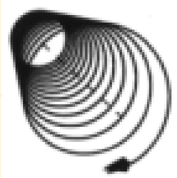


Fig. 3 When we look directly at a field line, the apparent motion is circular, producing circularly polarised photons. *Credit: Hellier 2001*

Now consider viewing the field line head on (Figure 3). The electron will appear to be circling, and so the electric vector of the emitted photons (which follows the electron's motion) will be continually rotating, tracing out a circle. Such light is said to be *circularly polarized.*

Thus, movement along the field lines beams *linearly polarized* light perpendicular to the field line and *circularly polarized* light along the field line. This type of emission is called cyclotron emission because spiraling electrons emit the photons that we see. Since the cyclotron emission can be as much as half the total light of AM Her stars, they are the most polarized objects in the sky (Hellier 2001).

Observing AM Her

It has only been a little more than two decades since AM Her was originally listed as the enigmatic "irregular" variable star in 1975. Since that time, astronomers have learned so much about AM Her that they have been able to create a good model for a new class of magnetic cataclysmic variable stars. Many of the questions were answered by correlating multi-wavelength data with optical data   AAVSO observations. Ground based observations like those that amateur astronomers can contribute have been, and will continue to be a critical link in understanding this star. A system as violent as AM Her cannot continue to exist in this state for long so it will be interesting to watch what happens to it over the next couple of decades. AM Her is a great target for interested CCD observers as it is usually found shining around visual magnitude 13.0 to 15.0. The AAVSO has a wide variety of charts available to help you locate AM Her in the sky. Also, a published AAVSO Monograph on AM Herculis contains a long-term light curve, which includes more than 10,000 visual observations of AM Her from 177 observers around the world.

A photograph of the constellation Hercules
Credit: Bill and Sally Fletcher

For More Information

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This month's **Variable Star of the Month** *was prepared by Kate Davis, AAVSO Technical Assistant, Web.*

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