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Variable Star Of The Month

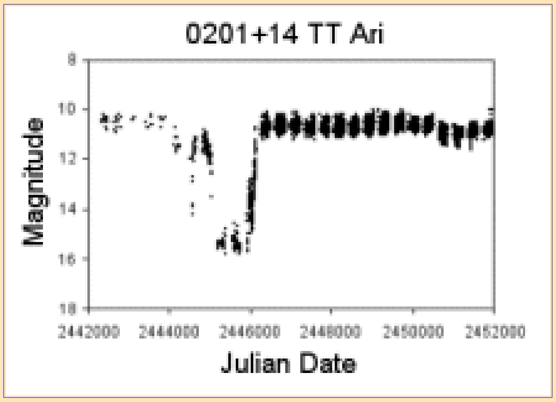
January, 2002: TT Arietis

The Mysterious Ways of TT Arietis

It is thought that stars depicted in Vincent Van Gogh's famous 1889 painting titled "The Starry Night" form the constellation of Aries -- with the addition of Venus and the Moon.

In the constellation of Aries resides one of the most peculiar variable stars. Intriguing to many but understood by none, TT Arietis' mysterious ways confuse those who try to understand its nature. Although TT Ari's variability was discovered in the mid-1950s, its curious behavior does not allow it to be neatly pigeonholed in with any one specific class of variable stars. In short, TT Ari is a very unusual and complex system. Photometrically and spectroscopically, the wondrous star exhibits several periods which are not only limited to the optical regime of the electromagnetic spectrum, but span many wavelengths with changes ranging on the order of minutes to years. In particular, the variable exhibits optical and X-ray variability on many timescales and also shows transient quasi-periodic oscillations.

Based solely on the fadings of its light curve, TT Ari was first thought to belong to the R Coronae Borealis (RCB) class of variable stars but has swiftly gone through several classification changes over the years. Spectroscopic studies by Cowley et al. (1975) revealed that TT Ari is a binary system. Further spectroscopic studies, first in the visible and later in the UV wavelengths, showed that the spectrum of TT Ari is similar to that of the cataclysmic variable (CV) class of variable stars, with strong emission lines during the low and intermediate states and absorption with weak emission in the high state (Udalski 1988) (see also Tremko et al. 1996 and references therein). With many subtypes and sub-subtypes of this CV group, TT Ari seems to possess many of the characteristics of each. Through the decades, TT Ari has been classified as a dwarf nova, novalike, and an intermediate polar -- all siblings in the CV family. Fickle in its behavior, TT Ari's bizarre characteristics allows it to elude exact classification.



AAVSO light curve for TT Arietis. Click image to enlarge.

Regardless of its specific classification, TT Ari is one of the brightest CVs with a recorded range in visual magnitude between about 10.5 and 15.5. Unlike other CVs, however, TT Ari spends the majority of its time at *maximum* light. In a similar fashion to the RCB stars, TT Ari is seen to go into action when it *fades to mininum*. Based on the AAVSO International Database, TT Ari has undergone one episode of fading in the early- to mid-1980s. In November of 1980, TT Ari approached an intermediate low when it reached 14th magnitude. Within a month the star was well on its way back to maximum, but halted at 11th magnitude where it remained for about a year. A slow decline then ensued before a sharp drop in March of 1982. With the drop, TT Ari shown at a visual magnitude of about 15.5 where it remained until September of 1984. A slow rise resulted with a return to its "normal" bright state in mid-1985. TT Ari has since remained at its preferred high state, with some fluctuation, where it continues to torment those who try to classify it.

In the X-ray

As mentioned above, TT Ari not only varies in the optical portion of the electromagnetic spectrum, but also shows great variability in the X-ray. First seen in this region with the Einstein X-ray satellite, TT Ari has been observed with many satellites including a multi-wavelength campaign combining observations of ROSAT and Ginga, both in the X-ray, IUE in the ultraviolet, and several ground-based observatories (Robinson and Cordova 1994).

Jensen et al. (1983) attribute 70-100% of the X-ray flux to X-ray flickering. While the most common explanation for emanating X-rays from non-magnetic cataclysmic variables is that this is the form radiation emitted at the boundary layer region between the white dwarf and the disk, analysis of the hard X-ray spectrum suggests that these events are not produced in the outer part of the accretion disk. In fact, the correlation between optical and X-ray fluxes may be linked to processes in the inner disk. It is thought that optical flickering occurs in a region of much lower temperature than X-ray flickering so that it is observed from two different temperature regions.

The second of NASA's High Energy Astrophysical Obsertories, HEAO-2, renamed Einstein after launch, was the first fully imaging X-ray telescope put into space. The lifetime of the satellite was from November 1978 through April 1981.

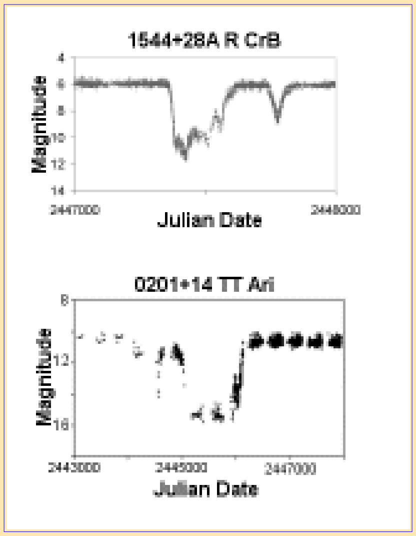
This X-ray behavior may surely give astronomers a clue about the nature of TT Ari, but then again it may just add more confusion to the mix...

The Usual Suspects

Why is the classification of TT Ari so ambiguous? Below is the line-up of the usual suspects outlining the similarities and, in some cases, differences with each proposed class.

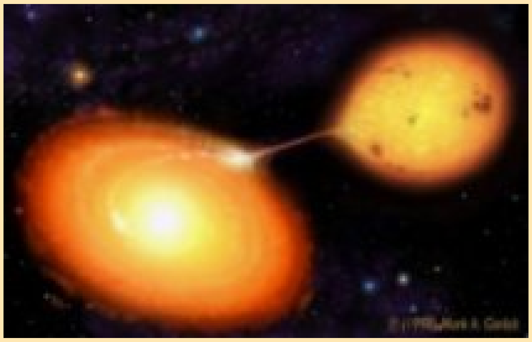
R Coronae Borealis Stars

The R Coronae Borealis variable stars are a class of luminous, hydrogen-poor, carbon-rich variables that spend most of their time at maximum light. At irregular intervals, such stars may fade by as much as nine magnitudes, followed by a slow recovery to maximum light on time scales of months to years.



With this description and a glance at the TT Ari light curve, one would instinctively categorize the variable to be of RCB type. The long intervals of nearly constant magnitude interrupted by declines of several magnitudes are surely indicative of the class. However, the spectrum of TT Ari reveals broad hydrogen absorption lines, an element of which almost all RCB stars are void.

Cataclysmic Variable Stars



An artist's impression of a cataclysmic variable star. Image credit: Mark A. Garlick.

Comparison of the minima and surrounding portions of light curves for R CrB and TT Ari as seen in the AAVSO International Database. Click the above image to enlarge.

The cataclysmic variable stars enlist several tiers of classes. The basic system for stars of this type is the same, consisting of a close binary pair with one of the components as a red dwarf-type star and the other being a white dwarf. Due to evolutionary effects, the red star loses matter to the dwarf star via a stream of gas. From here, the dynamics of the systems, outburst mechanisms, and resulting behavior differ. Although TT Ari's behavior can be classified as that of a CV, its exact variability type remains ambiguous. At the highest tier, TT Ari behaves, to some extent, as a novalike, a dwarf nova, an intermediate polar variable star.

Novalike - VY Scl Subtype

VY Scl stars, named for the prototype of the class, are one of subclasses of the novalike variable stars. Variables of this variety generally remain in high state for long periods of time and occasionally fade by 3-5 magnitudes. Also referred to as the anti-dwarf stars because of their non-conformist activity, VY Scl stars display photometric behavior similar to R CrB stars, but have the spectroscopic nature of the CVs. Hence, TT Ari's spectral nature and drop to low state earns it inclusion in the VY Scl membership. Additionally, VY Scl stars are typically found in a narrow range of orbital period, being about 3-4 hours. It is unclear whether the VY Scl behavior is common property of all cataclysmic variables with orbital periods near the 2-3 hour period gap and may be an evolutionary effect, or whether it is a property of the class of novalike variables clumped in the 3-4 hours period region (Shafter et al. 1985).

Cataclysmic variable stars are divided into different types: novae, recurrent novae (see RS Oph), novalike, dwarf novae (see SS Cyg, U Gem, SU UMa, and Z Cam), and magnetic variables (see AM Her). Although the close binary system is indicative of such stars, frequency, amplitude, and nature of outbursts set them apart.

Although TT Ari is seen to vary on many levels, the long-term trend shows that TT Ari is most similar to the VY Scl stars. Several theories to describe the VY Scl phenomenon have been proposed. While disk instability is generally the accepted theory for dwarf nova outbursts, extended maxima are hard to explain within the context of this theory since it predicts an immediate decline in flux once maximum light is achieved. The problem is only exaggerated if the theory is used to explain the VY Scl stars (Verbunt 1997). Alternatively, Wu et al. (1995) speculates that the decrease in magnitude may be the result of a temporary interruption in the heating process caused by shielding. "Because of the presence of an accretion disk around the white dwarf star, a significant portion of the radiation from the white dwarf or regions near the white dwarf can be blocked, thus reducing the radiation falling onto the secondary star. The rapid drop in brightness of these stars is probably due to a temporary interruption of the heating process caused by such shielding." Livio and Pringle (1994) propose that the change in magnitude could be the result of magnetic field anomalies, which involve migrating magnetic spots. Depending on where these spots are situated, they can interrupt the mass transfer rate from the secondary star to the primary component.

While the exact nature of the VY Scl stars is not fully understood, the tendency of objects which show such deep minima typically have orbital periods near the 2-3 hour period gap.

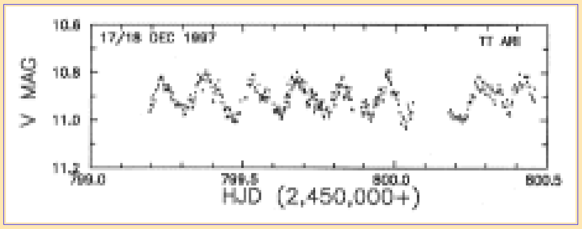
Dwarf Novae - SU UMa Subtype

SU UMa stars are seen to undergo two distinct types of outbursts: while one is faint, frequent, and short with a duration of 1 to 2 days, the other (referred to as a "superoutburst") is bright, less frequent, and long with a duration of 10 to 20 days. During such superoutbursts, small periodic modulation, or "superhumps" are seen to appear.

While TT Ari does not strictly resemble the SU UMa stars photometrically, Udalski (1988) suggests that they are similar to some extent:

> "The similarity of the high state of TT Ari to SU UMa type stars in superoutburst is striking. The light curves resemble the SU UMa type stars: the three hour modulation corresponds to the superhump, its period differs several percent from the orbital one and is not constant, the shape of the light curve is variable and not always well defined. When TT Ari fades into the intermediate and low state the three-hour modulation disappears and so do the superhumps in SU Uma stars. Due to the small orbital inclination only nonperiodic flickering is seen then."

Udalski (1988) also notes that differences between TT Ari and SU UMa are: (1) the orbital period of TT Ari lies on the long side of the period gap, while the SU UMa stars are on the shorter side and (2) the photometric period is shorter than the orbital period, with the reverse being true for SU UMa stars. Udalski supposes that there may be other stars similar to TT Ari and might be hidden among the VY Scl stars. The discovery of VY Scl stars with superhump periods shorter then orbital period would help support the idea of SU UMa-like behavior.



Evidence of superhump-like activity in TT Ari as found by Skillman et al. (1998). Click image for enlarged view.

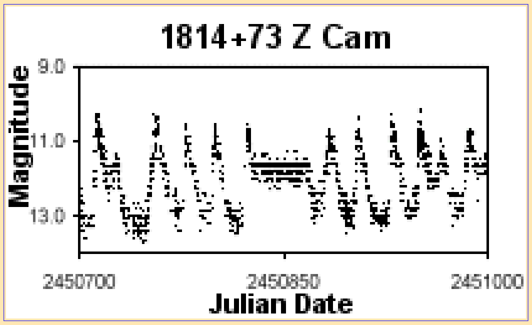
In its quest to further boggle the minds of astronomers, it seems that TT Ari must have been somehow alerted to Udalski's idea. For years, the main periodic signal from TT Ari varied but was found to average ~0.1329 d, 3.5% shorter than orbital period. However, in a 1997-98 campaign to obtain global photometry with the telescopes of the Center for Backyard Astronomy (CBA), Skillman et al. (1998) found that this signal disappeared all together and was replaced by a stronger at 0.14926+/-0.00006 day, a signal 8.5% longer than the orbital period! The new signal, they found, resembles superhumps which is reminiscent of the SU UMa stars during outburst. Hence, the negative superhump was found to have been replaced by the positive superhump. Skillman et al. (1998) further notes that no noticeable changes in spectrum or mean brightness accompanied the event.

Although the actual cause of superhumps is not fully understood, it is suggested that this new "positive superhump" may be the result of an eccentric accretion disk. Positive superhumps, as Skillman refers to them as, may arise from development of an eccentric instability in the accretion disk (see Skillman et al. 1998 and references therein). The accretion disk then precesses under the gravity of the orbiting secondary.

If SU UMa type processes are responsible for TT Ari behavior, then other CVs should have similar properties. According to Skillman et al. (1998), "TT Ari is an excellent candidate for observational studies which probe the origin of superhumps."

Dwarf Novae - Z Cam Subtype

The Z Cam stars exhibit cyclic variations, interrupted by intervals of constant brightness called "standstills." The standstills last an equivalent of several cycles, with the star "stuck" at a brightness approximately one-third of the way from maximum to minimum.



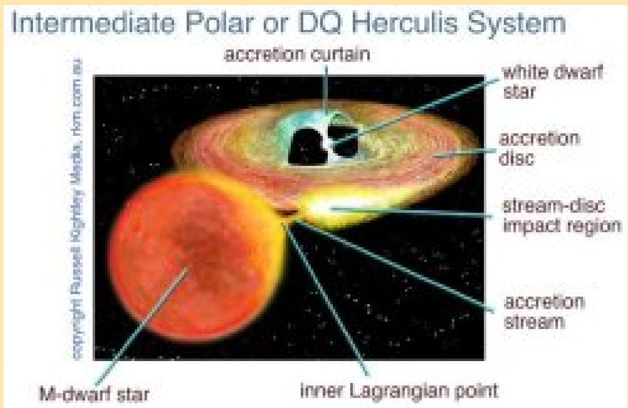
Click on the above image to see the long-term light curve for Z Cam.

While there is less support for similarity between TT Ari and the Z Cam stars, Krautter et al. (1981) suggest that long period of the high state is similar to that of the standstills seen in Z Cam stars. The difficulty with the Z Cam theory is that while TT Ari undergoes irregular minima, Z Cam stars undergo outbursts. Additionally, the episodes of constant brightness in Z Cam stars occur between a maximum and a minimum. TT Ari's maximum state and "standstill" are one in the same.

Intermediate Polars

The intermediate polar stars, also known as DQ Her stars, are cataclysmic variable stars containing an accreting, magnetic, rapidly rotating white dwarf star. The intermediate polar stars are characterized by strong X-ray emission, high-excitation emission, and stable optical and X-ray pulsations in their light curves.

Similarities between TT Ari and the intermediate polar class of CVs have also been explored. Warner (1983) indicates that the main argument for such a comparison is based upon the similarities in the differences between the photometric and spectroscopic period. In addition, the star possesses a strong X-ray luminosity and also like the intermediate polars, prefers to spend more time in the high state (Semeniuk et al. 1987).



While non-magnetic CVs possess an accretion disk around the primary star, the disk structure is interupted in magnetic (intermediate polar and polar) CVs. Deformation is to a lesser extent with intermediate polar stars (shown above) and more so with the polar variable stars. Copyright Russell Kightley Media.

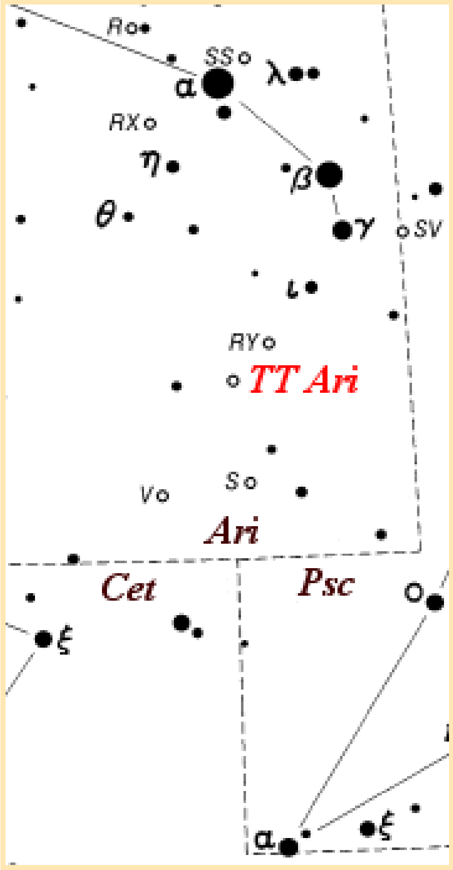
Noticing similarities between TT Ari and the intermediate polar star TV Col, Semeniuk et al. (1987) studied and compared the stars, with a focus on the periods. Since TV Col has a photometric and a spectroscopic period of 5.2 hours and 5.5 hours, respectively, in addition to two other photometric periods, one being the beat of the former two at 4.0 days and the other being the rotation period of the compact object at 32 minutes, the team thought they'd look for analogous periods in TT Ari. TT Ari, meanwhile, has a photometric period of 3.2 hours and a spectroscopic period of 3.3 hours (see Semeniuk et al. 1987 and references therein). In addition, the team found that TT Ari oscillates in photometric brightness with a period of around 20 minutes, and a mean amplitude of the oscillation being 0.06 mag in V and B and 0.07 mag in U, and noted that the period decreased rapidly from 27 minutes to 17 minutes in time interval of 1961-1985. Another period detected with 3.8-day frequency, was interpreted as the beat period of the 3.2-hour photometric and 3.3-hour orbital period. The similarities in the findings lead the authors to classify TT Ari as an intermediate polar! The Z Cam classification is further supported by the generous X-ray flux detected from TT Ari.

And the Verdict Is?

As can now be appreciated, TT Ari is an extremely complex system. In summary, over the long haul TT Ari looks like a VY Scl novalike variable star. The high state of TT Ari resembles properties of the SU UMa subclass of dwarf novae in superoutburst since, at maximum, TT Ari exhibits SU UMa-like superhumps. Based on the detected periods and X-ray luminosity, TT Ari resembles that of the intermediate polar class of CVs. In addition, it is thought that perhaps the mechanism causing TT Ari to remain in a high state is similar to that of the Z Cam stars. It could be possible that with TT Ari several instability mechanisms are responsible for the observed oddities. Unfortunately, the exact classification of TT Ari still cannot be stated.

Studying TT Ari as well as other CVs helps astronomers learn and understand not only more about the CVs themselves, but also about accretion disks and processes that arise in such systems. Accretion disks occur in many places in the universe, from proto-planetary systems to active galactic nuclei. CVs can provide astronomers with clues about how these disks react to varying mass accretion, tidal forces, and magnetic fields. In a sense, CVs can act as a laboratory for testing accretion disk physics.

Interested? Observe TT Ari



TT Ari is located near the imaginary constellation boundary lines of Arietis, Cetus, and Pisces, nearly in the middle of the two bright stars of alpha Ari and alpha Psc. Observers may use AAVSO 'd' and 'e' scale charts to make estimates of TT Ari. Observations may then be submitted to the AAVSO for inclusion in the AAVSO International Database.

If the star is observed to be at a visual magnitude fainter than 12.0, be sure to alert the AAVSO by e-mail, telephone, or fax as soon as possible. Since the star has not exhibited its mininum behavior since the 1980s, it would be of utmost importance to alert the astronomical community of its transition from a high to an intermediate or low state. During its high state, CCD and PEP observers are encouraged to monitor the star for oscillations and superhumps. With continued monitoring of this fascinating object, we can learn more about TT Ari and its counterparts!

For More Information

- AAVSO 'd' and 'e' scale charts for 0201+14 TT Ari
- AAVSO Monograph 12: TT Ari 1974-1995
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This month's **Variable Star of the Month** *was prepared by Kerri Malatesta, AAVSO Technical Assistant.*

- Variable Star of the Month Archive