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THE OUTBURSTS OF THE RECURRENT NOVA T CORONAE BOREALIS

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For decades, the recurrent nova T Coronae Borealis (1866, 1946) has been regarded by astrophysicists as something of a freak among cataclysmic variable stars. Whereas none of the other 30-odd such systems with known binary periods have orbital periods longer than $16^h\ 25^m$ (GK Persei), T CrB revolves in $227\overset{d}{.}5$. All of the other systems contain low-luminosity main sequence stars, probably not much more massive than about a solar mass at most, losing mass to their companions; T CrB has a red giant of about 2.6 $M_\odot$ and luminosity more than a thousand suns in its place. All of the other well-known cataclysmic binaries apparently contain white dwarf companions to the main sequence stars, but the mass of the blue star in T CrB is apparently at least $1.9M_\odot$, well above the theoretical upper limit to the masses of white dwarfs, 1.4 $M_\odot$.

The first recorded observation of T CrB is apparently that of Argelander, in 1855, published in his catalog as +26°2765, $m_v = 9.5$. A nearly continuous observational record for this system exists from its first recorded outburst on May 12, 1866, to present. It is now possible, with the help of these many years of patient observation, largely by members of the AAVSO, to develop a coherent picture of what happens in the eruptions of T CrB, a picture which furnishes clearer insights into the nature of these outbursts than hitherto found for any of the other cataclysmic variables.

For nearly 27 years prior to its outburst in 1946, T CrB was regularly observed by members of the AAVSO, principally Mr. Leslie Peltier. Aside from a slight brightening in 1938, it had hovered for many years near tenth magnitude. In May, 1945, Mr. Peltier recorded a sudden drop in its brightness, over a period of about a month, to nearly eleventh magnitude, from which T CrB slowly recovered over the succeeding half year or so. Figure 1.

There were also apparently some regular variations in the recovery from light minimum, with a period now estimated at about 41^d, and amplitude, about $0\overset{m}{.}1$ to $0\overset{m}{.}15$.

In the early hours of the morning of February 9, 1946, after several months in which T CrB had been too near the sun for observation, Armin Deutsch, at Yerkes Observatory, discovered it at magnitude 3.2. T CrB immediately became the center of widespread attention, and its very rapid decline (6th magnitude a week later, 8th magnitude two weeks later) was followed worldwide by professionals and amateurs alike. Within a month, it had returned to virtually its original brightness.

At the beginning of June, T CrB began brightening again. Over the next two months, it slowly recovered to about eighth magnitude, varying by some tenths of a magnitude as it did so. Toward the end of 1946, T CrB was again declining, but at a much slower rate than in the initial outburst, and it has apparently been very slowly becoming fainter ever since. Aside from some observations of the second maximum at Mt. Wilson and Pasadena, this whole period in the life of T CrB has been nearly the exclusive domain of amateur astronomers. Figure 1.

What happened to T CrB in 1946? The picture which emerges is this: In May, 1945, the red giant, for reasons which are only partially understood, found itself so nearly filling its Roche lobe, the theoretical surface at which it becomes unstable to mass loss to its companion, that material suddenly began rushing out towards the companion. A huge blob of gas, more than half the mass of Jupiter, was ejected, and began falling in towards the companion star, leaving the giant pulsating in its wake. But because of the orbital revolution of the binary, and the relatively small size of the companion, this mass of gas swung by the companion star in a great elliptical orbit. It continued to orbit that star in a giant ellipse for a further four or five passages, while the binary system as a whole completed another whole revolution. Gradually, the internal pressure in this gas glob dispersed it into a stream around its orbit, until suddenly one part of the stream collided with another. In a great cascade, the various portions of the stream came crashing together in enormous, supersonic collisions, generating the huge outburst of energy seen in the principal eruption. When the collisions finally died away, a ring of gas, nearly circular in its orbit, was left surrounding the companion star.

Now, according to Newton's laws of motion, the inner edge of this gas ring would orbit the companion star slightly more rapidly than the outer edge. This relative motion results in a kind of friction, which slows the inner edge of the ring, and speeds up its outer edge. As the inner edge slows, however, it drops towards the surface of the star, while the outer edge, which is speeded up, migrates further and further away from the star. Moreover, the friction generates a certain amount of heat, depending on how rapidly neighboring gas masses are moving relative to each other, that is, upon the local shearing of the gas. This whole process gradually broadens the ring of gas into a disk. After several months, the inner edge of the disk approaches the surface of the companion star. As it does so, the frictional heating increases rapidly, and the whole system brightens again. This was probably the cause of the second maximum.

From the height of the second maximum, it is possible to determine the surface potential energy of that star, that is, how much energy is generated by matter falling from infinity to its surface. Because the second maximum was relatively faint compared with the first, it is clear that the accreting star is fairly large. In fact, it turns out to be a main sequence star, and not a white dwarf at all. Over a time-scale of many years, matter in the disk gradually settles onto this star, and the disk slowly dissipates.

Where will T CrB go from here? Theories of binary star evolution indicate that it is in an extremely precarious state. When a giant star is more massive than its companion, mass-loss from the giant to the companion tends to run away on an extremely rapid time-scale (astronomically speaking). It is clear that T CrB is just beginning this phase in its life. Theoretically speaking, it is not likely to survive as a recurrent nova for more than about 500 years. Outbursts will probably become more and more frequent, until it becomes continually active, perhaps a symbiotic variable.

With more than half a dozen recurrent novae known, the chances are not remote that at least one of these objects will reach this transition within our lifetimes. Perhaps V1017 Sagittarii is already well on its way. In any case, the careful documentation of this phase of evolution will be enormously valuable. This is clearly a role for which the amateur astronomer is well equipped. To be sure, the task will often be tedious (80 years is a long time to wait for an outburst!), but the potential rewards are beyond reckoning.

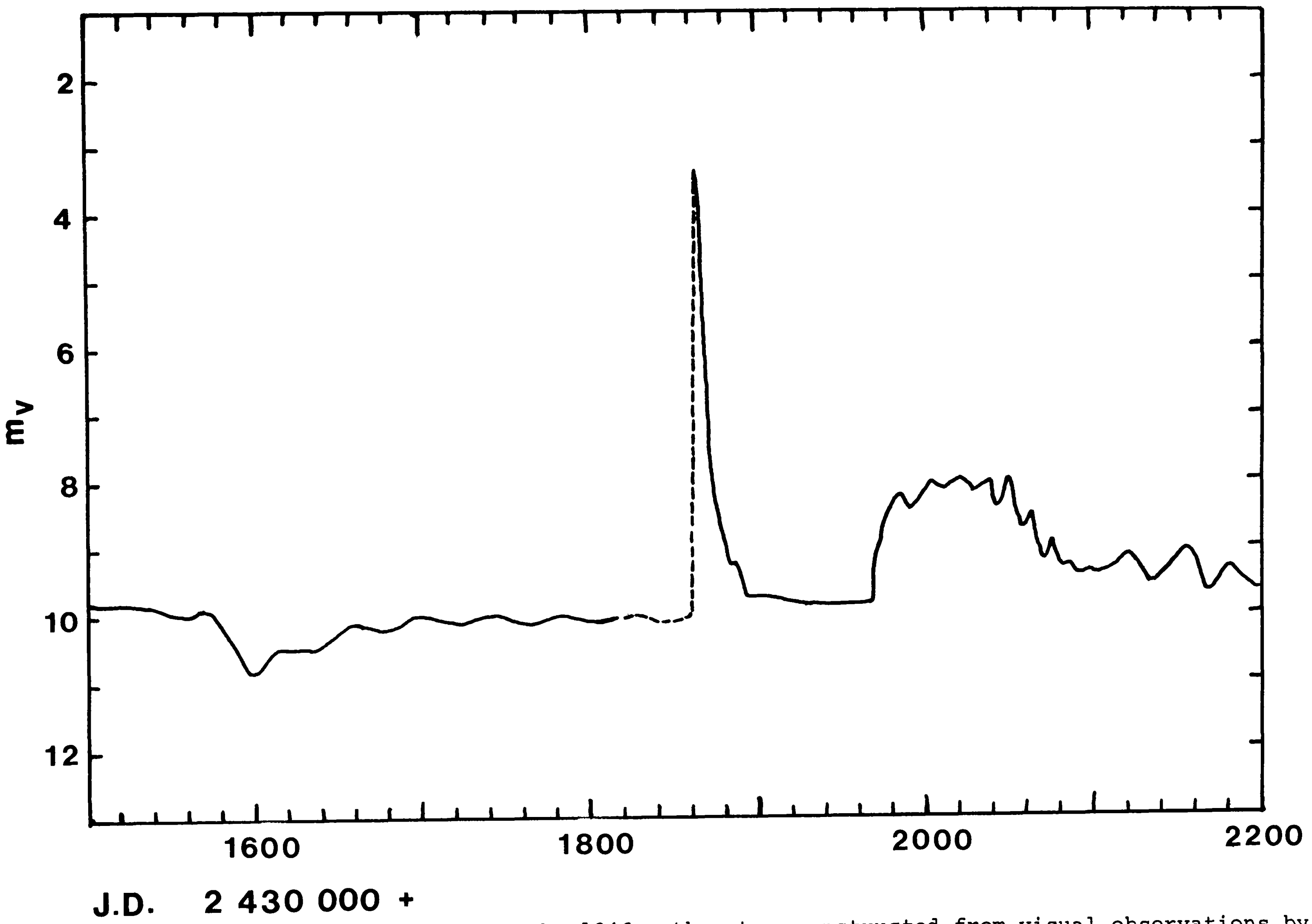

Fig. 1. The light curve of T CrB during the 1946 outburst, reconstructed from visual observations by members of AAVSO.