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Variable Star Of The Month

May, 2000: RS Ophiuchi

RS Oph

Located in the equatorial constellation of Ophiuchus lies the variable RS Ophiuchi. RS Oph belongs to the cataclysmic variable (CV) class of stars, and is further classified as belonging to a smaller, seemingly "exclusive" group of CVs termed recurrent novae (NR) - of which there are only 7 confirmed members. This class of stars has a physical system similar to the nova and dwarf nova type of CVs, however, NR display outburst properties such that they cannot be categorized into either group. While novae are classified as stars that undergo one outburst (8-15 magnitudes) with great rapidity, later to slowly decrease to pre-outburst amplitude, and dwarf novae are known for their frequent (10-1000 day), moderate-amplitude (2-6 magnitudes) outbursts, recurrent novae seem to exhibit characteristics somewhere in between. These stars typically vary by 4-9 magnitudes, on a 10-100 year period. As such, it seems almost appropriate that RS Oph is situated in the "Snake Charmer" constellation, since the observer watches this variable patiently, waiting and almost charming this elusive variable into outburst.

Based on AAVSO data, RS Oph varies in visual magnitude from 12.5 at minimum to a maximum of 4.8, thus being visible by the unaided eye during eruption. Over a century of observations shows that the variable has undergone 5 recorded outbursts with very irregular frequency: 1898, 1933, 1958, 1967, and 1985. With over 34,000 observations in the AAVSO International Database from hundreds of observers worldwide since 1918, RS Oph is one of the most observed stars of its class.

In the Beginning...

The earliest known maximum of RS Oph was not discovered until the early 1900s. An investigation of the Henry Draper Memorial photographs by Williamina Fleming revealed a spectrum that closely resembeled that of Nova Sagittarii and Nova Geminorum (displaying hydrogen lines of H-zeta, H-epsilon, H-delta, H-gamma, H-beta, and also two lines which correspond with the bright bands 4656Å and 4691Å, in gamma Velorum). In Harvard College Observatory Circular No. 76 (March 21, 1904), it is noted that "no other variable star having this type of spectrum has hitherto been found." Futhermore, after examining the photographs, Mrs. Fleming recorded the star as "Nova?", according to Harvard College Observatory Circular No. 99 (May 15, 1905). Upon publication of the 1905 circular, Edward Pickering confirmed that the star, based on the spectrum and light curves, be "regarded as a Nova, rather than a variable star, and its proper designation will be Nova Ophiuchi, No. 3." A study of the light curve by Annie Jump Cannon yielded that the "nova" had reached a significant increase in light output in 1898, in which it had most likely attained a maximum of about 5th magnitude.

During the late 1800s/early 1900s, Edward Pickering, director of Harvard College Observatory, hired many women to function as "computers" to reduce astronomical data. Pictured here are two of "Pickerings' Women": Williamina Fleming (top) and Annie Jump Cannon (bottom). Both women are well known in the astronomical community for, among other things, their work with classification of stellar spectra.

And Then There Was Light...Again

In 1933, RS Oph reappeared at 6th magnitude brightness, changing its nova status. With that year and the years following that outburst, AAVSO observers have proved to be the watchers of the night for the return of the great beacon.

1933: The 1933 outburst was first detected by Eppe Loreta (AAVSO observer initials LT), from Bologna, Italy. Mr. Loreta had been observing Y Ophiuchi when he serendipitously noticed a bright object about 50 arcminutes SW of Y Oph. The detection of this luminous star resulted in the second recorded outburst of RS Oph. An independent discovery of this activity was made several days later by Leslie Peltier (P) while making his routine check of the variable.

1958: The 1958 outburst was detected by Cyrus Fernald (FE), located in Longwood, Florida. Mr. Fernald's monthly report for July 1958, containing 345 observations, displays a note in which he comments:

> *"Not too good of a month outside of the RS Oph observations (19 in total). It was interesting to watch the change in color as the star faded. It was reddish-yellow the first night, then yellowish-red, and so on. The last observation was the reddist star that I have ever seen."*

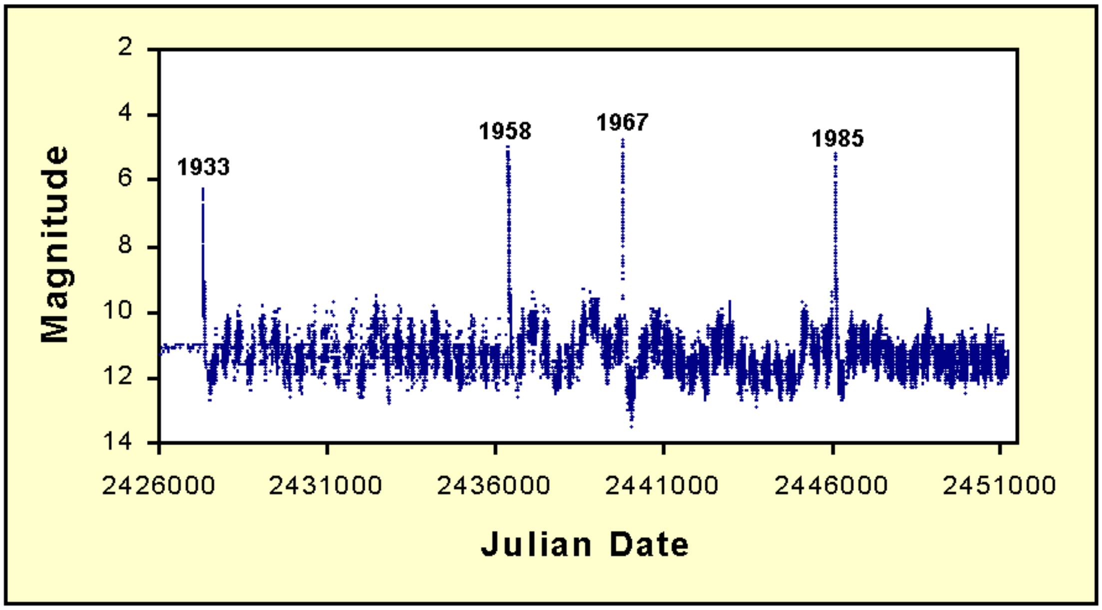
The crimson color of which Mr. Fernald speaks is indicative of the strong H-alpha emission displayed in the several days following the outburst.

1967: The 1967 outburst was again detected by Cyrus Fernald (FE), however, Mr. Fernald was not given credit for the earliest observation of maximum. For on the same evening, Dr. Max Beyer (BY), located in Hamburg, Germany, observed the variable at 6th magnitude. Due the 6-hour difference in time zones, Dr. Beyer was credited with the first report.

1985: In January of 1985, Warren Morrison (MOW) of Peterborough, Canada discovered RS Oph to again be in outburst (see IAUC 4030). The headline in AAVSO Alert Notice 73 (January 28, 1985) boasted the triumphant return as:

"Recurrent Nova RS Ophiuchi in Eruption - At Last!"

20??: Could the next outburst of RS Oph be detected by you?



Observations of RS Ophiuchi from the AAVSO International Database. The 1933, 1958, 1967, and 1985 outbursts are clearly evident.

A Look at the Oubursts

Former AAVSO high school summer assistant Benjamin Oppenheimer studied RS Oph in detail. His work was presented at the IAU General Assembly in 1994 (IAU Symposium 165) by Janet A. Mattei, AAVSO Director. At the time, Ben was 16 and was recoginized for being the youngest astronomer to ever have his paper presented at such a meeting. Ben is currenlty a graduate student in astronomy at the University of Arizona.

Amazingly, the outbursts of RS Oph behave very similar to each other in nature. Typical outbursts display a rapid rise in brightness from quiescence to about 5th magnitude within a 24-hour time period. The decline occurs in three distinct stages: the first stage of decline (t1) is fast, the second (t2) slower, and the third (t3) is intermediate, as indicated in the table below. The variable then generally returns to its minimum magnitude within 100 days or so after outburst, after which there is a slight brightening to 9th magnitude around 700 days after the onset of the outburst. In contrast, the intervals between outbursts tend to differ from each other, with no common period detected. At minimum, the light curve shows irregular brightness variations of between 1 and 3 magnitudes. A table summarizing each of the outburst characteristics is shown below (slightly modified from Oppenheimer and Mattei 1993).

Ouburst Year	JD Max (2400000+)	Max mag	delta t1 (days)	Rate of delta t1 (mag/d)	delta t2 (days)	Rate of delta t2 (mag/d)	delta t3 (days)	Rate of delta t3 (mag/d)
1898	14442?	-	51	0.06?	112	0.01?	128	0.06?
1933	27297	6.4?	48	0.06?	81	0.02	118	0.06?
1958	36399	5.4	41	0.10	89	0.02	117	0.04
1967	39791	4.9	39	0.12?	89	0.02?	140	0.04
1985	46094	5.4	38	0.10	65	0.02	111	0.05
Average		5.5	43	0.09	85	0.02	123	0.05

Missed Opportunity?

Since RS Oph was believed to be of nova type for much of the early 1900s, the variable was not very well observed until the 1933 outburst, which cemented its status as a recurrent nova. Could this variable have had an episode during this time when nobody was watching? It's not likely, for who would have missed a star so brilliantly shining? However, it is possible that the star could have been active during the seasonal gap. In fact, Oppenheimer, et al. suggest that perhaps an outburst was missed in 1945 as a result of such an event. The AAVSO data archives show that on JD 2431784 a magnitude of 9.9 was reported. However, for the next 68 days the star disappeared in to the seasonal gap. On JD 2431854, it was observed at magnitude 9.6. The days thereafter show that the light curve exhibited variations indicative of a typical outburst, with the characteristics displayed in the following table (modified from Oppenheimer and Mattei 1993).

Ouburst Year	JD Max (2400000+)	Max mag	delta t1 (days)	Rate of delta t1(mag/d)	delta t2 (days)	Rate of delta t2 (mag/d)	delta t3 (days)	Rate of delta t3 (mag/d)
1945?	31786?	-	-	-	76	-	118	0.05?

1985 Brings a Unique Look at RS Ophiuchi

The 1985 eruption represented the first time that the recurrent nova could be viewed (nearly simultaneously) at differing wavelengths. During this episode, RS Oph was observed in X-ray, UV, optical, IR, and radio frequencies. For those interested in learning about RS Oph beyond its optical regime and for a comprehensive review of these observations, see the references by M.F. Bode (1987), and M. Hack and C. la Dous (1993) listed below.

Observing RS Ophiuchi

The best way to find out if RS Oph, or any other star, is presently undergoing an outburst is to keep up-to-date with current variable star activity announced in the AAVSO News Flashes, and for special and rare activity, the AAVSO Alert Notices. In addition, the Quick Look file provides a view of recent observational data.

The AAVSO has finder charts available online to be used when observing this star. Using these charts, RS Oph should be observed every clear night during quiescence (which is fainter than visual magnitude 10.0). If you happen to find RS Oph to be brighter than 10th magnitude, it is important to monitor the star every 15 minutes to watch for activity, especially since the variable reaches brightest light within 24 hours. During decline from maximum, RS Oph should be observed 2-3 times a night, until quiescence is again achieved. Observations may then be submitted to the AAVSO for inclusion in the permanent database.

Recurrent Nova Outbursts

It has already been mentioned that recurrent novae belong to the cataclysmic variable class of stars. Within the CV family, there are several groups with differing characteristics. The main thread connecting these stars is that they are composed of a close binary system, with the primary component as a white dwarf star, and the secondary a main-sequence, or Sun-like, star (with exceptions, as you will see below). Due to evolutionary effects, the secondary star is losing matter which is streamed into the direction of the primary. The physics of the system is such that the matter cannot "fall" directly onto the white dwarf, but rather it circles the star in an accretion disk around the star. What happens from there and to what extent is what sets these systems apart from each other.

> ***Cataclysmic variable stars*** *are divided into different types: novae, recurrent novae, nova-like, dwarf novae (for examples, see former VSOTM features: U Gem, SU UMa, and Z Cam), and magnetic variables. Although the close binary system is indicative of such stars, frequency, amplitude, and nature of outbursts set them apart.*

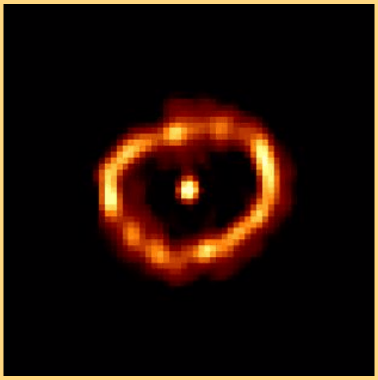
Recurrent novae are close in nature to dwarf novae (in terms of the outburst reoccurrence) and classical novae (in terms of the amplitude of outburst). In fact, recurrent novae are classified such that they are believed to consist of two or more classical nova-like outbursts. An overview of dwarf novae, novae, and their relation to recurrent novae is given below.

Dwarf Nova Summary

Dwarf nova oubursts are believed to be the result of changes in the luminosity accretion disk surrounding the white dwarf component. There are currently two different suggested mechanisms for such an occurance: (1) the mass transfer burst model, and (2) the disk instability model. With the mass transfer burst theory, it is thought that the increase in disk brightening is the result of a sudden increase of mass transfer from the secondary. Alternatively, the disk instability model is based on a relatively constant mass transfer rate. When a critical surface density in the disk is achieved, thermal instabilities within the disk give rise to an increased viscosity, which in turn, causes the matter to be quickly accreted on to the white dwarf. In any event, dwarf novae typically vary by 2-6 magnitudes on a timescale of 10-1000 days. Risetime to maximum is very short (<1 day) and the decline is much longer (2-15 days).

Classical Nova Summary

Classical novae are characterized by their well known large amplitude outbursts associated with the ejection of a shell. The basic theory describing the mechanism for the outbursts involve thermonuclear processes occurring on the surface of the white dwarf. At the evolutionary stage of the primary, the main source of power has been exhausted. Hence, the stellar remnant ceases to burn hydrogen and helium on its surface, but rather is strongly enriched with inactive C, N, and O. Hydrogen flows from the secondary and eventually forms a layer on the surface of the primary. The extremely dense white dwarf star presents a high gravitational force and with continuing transfer of matter, the base layer becomes compressed and heated until the critical temperature for thermonuclear reactions is achieved and runaway processes give rise to an explosion. This explosion results in the expulsion of the outer shell of the primary star. Novae typically undergo one flare during which the amplitude may change by 8-15 magnitudes.



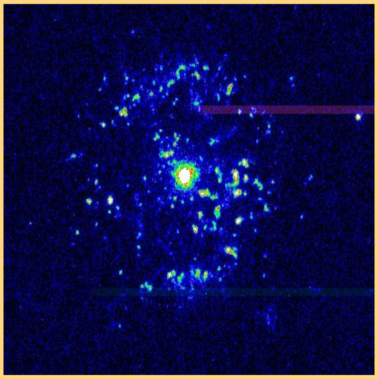
The magnificent Nova Cygni 1992 reached visual magnitude at maximum light, resulting in one of the brightest novae in recent time. This image was taken by the Hubble Space Telescope nearly two years after outburst.

Recurrent Novae in Relation to Classical Novae

Photometric and spectroscopic findings suggest that the physical mechanism for novae and recurrent novae is probably the same, however, in the case of recurrent novae the secondary component may be a red giant star. The light curves of recurrent novae are similar to those of novae as they are both characterized by a rapid rise to maximum. Generally speaking though, the decline is faster than that of a nova. Recurrent novae amplitudes may increase in brightness by 4-9 magnitudes during outburst and may recur every 10-100 years. It has been thought that perhaps all novae are recurrent, if given enough time.

Presently, the characterstics which distinguish a variable as a recurrent nova are provided by Webbink (1987) et al. and are given by two parameters: (1) the star must exhibit two or more nova-amplitude outbursts with an absolute visual magnitude (M_v) less than/approximately equal to -5.5, and (2) the ejection of a shell must have an expansion velocity of greater than/approximately equal to 300 km s^{-1}. Nevertheless, NR seem to constitute a somewhat heterogeneous class of stars, with T Pyx having a slow recurrence time of 80 years and with U Sco, T CrB, and RS Oph having outbursts on a timescale of just a couple of decades.

Two Classes of Recurrent Novae Proposed



Recurrent nova T Pyxidis, as imaged by the Hubble Space Telescope.

It has been thought that there may be more than one type of recurrent nova. Webbink et al. (1987) suggest that there are clearly two different mechanisms at work behind the outbursts, and as such, there are two different classes of NR. While dwarf novae are driven by accretion-powered events, novae are the result of thermonuclear runaway occurring on the surface of a white dwarf star. Since NR seem to be somewhere in between the two types of CVs, recurrent novae can be classified in to two groups as prescribed by the outburst mechanism:

Recurrent Novae, type A (NRA): outbursts are a result of thermonuclear runaway on the white dwarf. T Pyx is an example of such a system.

Recurrent Novae, type B (NRB): eruptions are driven by the accretion from a red giant on to the companion star. In such events, the outbursts may be generated by an instability in the cool companion or by a disk instability. T CrB, RS Oph, and V745 Sco are examples of this type.

What To Do If You Suspect RS Ophiuchi Of Being In Outburst

Since an outburst of RS Oph is rare, time is of the essence. In order to get good coverage of the entire outburst, the astronomical community needs to be notified. Therefore, if you suspect that RS Oph is active, contact the AAVSO *immediately* by either telephone, e-mail, or fax and clearly indicate the time and magnitude of your observation(s). Also include any other pertinent information, such as your observing conditions, and the chart(s) and comparison stars that you are using. With this information we can then alert astronomers worldwide of its activity, with hopes of learning even more about this magnificent variable.

Happy hunting and good observing!

For More Information

- AAVSO Monograph #7: RS Ophiuchi 1890 - 1995

- AAVSO Standard Charts for 1744-06 RS Oph: "a", "b", "c", and "d" scales
- Bode, M.F., ed. *RS Ophiuchi and the Recurrent Nova Phenomenon*. Utrecht: VNU Science P, 1987. ISBN 90-6764-074-3
- Hack, M. and C. la Dous, eds. *Cataclysmic Variables and Related Objects*. Washington, DC: NASA Scientific and Technical Information Branch, 1993.
- Livio, Mario, James W. Truran, and Ronald F. Webbink. "A Model for the Outbursts of the Recurrent Nova RS Ophiuchi." *The Astrophysical Journal*, 308, 1986, 736-742.
- Mauche, Christopher W. has a wonderful and informative website in which he gives an excellent review of cataclysmic variables.
- Oppenheimer, Benjamin D., and Janet A. Mattei. "Analysis of Long-Term AAVSO Observations of RS Ophiuchi." *Journ. AAVSO*, 22, 1993, 105-109.
- Sekiguchi, K. "Recurrent Novae." *Astrophysics and Space Science*, 230, 1995, 75-82.
- Snijders, M.A.J. "Multi-Frequency Observations of the 1985 Outburst of RS Ophiuchi." *Astrophysics and Space Science*, 130, 1987, 143-254.
- Warner, Brian. *Cataclysmic Variable Stars*. New York: Cambridge UP, 1995. ISBN 0-521-41231-5.
- Webbink, Ronald F., Mario Livio, James W. Truran, and Marina Orio. "The Nature of Recurrent Novae." *The Astrophysical Journal*, 314, 1987, 653-672.
- Webbink, R.F., M. Livio, J.W. Truran, and M. Orio. "The Nature of Recurrent Novae." *Astrophysics and Space Science*, 131, 1987, 493-495.

This month's **Variable Star of the Month** *was prepared by Kerri Malatesta, AAVSO Technical Assistant.*

- Variable Star of the Month Archive