# MULTI-FREQUENCY OBSERVATIONS OF THE 1985 OUTBURST OF RS OPHIUCHI

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ABSTRACT.

The 1985 outburst of the bright, recurrent nova RS Oph was almost simultaneously observed at X-ray, UV, optical, IR and radio frequencies at many epochs. The abundances in the ejected shell and the development of the bolometric luminosity as a function of time suggest that the cause of the outburst is a nuclear runaway on a massive white dwarf.

## 1. INTRODUCTION

The recent outburst of the bright, recurrent nova RS Oph presents a unique opportunity to study this poorly understood phenomenon over a wide frequency range. RS Oph has historically been extensively studied, in particular after the optically well observed 1958 outburst (Pottasch, 1967 and references therein). It is the first recurrent nova for which ultraviolet (Rosino et al. 1987; Snijders et al. 1986 hereafter SETAL) and X-ray (Cordova and Mason 1984; Mason et al.

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1986) data are available both before and during the outburst. This opens the unique possibility of studying the same object during the quiet and active states.

Two mechanisms to explain objects like RS Oph have been presented. Either some type of mass transfer instability is proposed (e.g. Livio et al., 1986) or a nuclear runaway on a massive white dwarf is suggested (e.g. Starfield et al. 1985).

Study of recent IUE results for classical novae (e.g. Stickland et al. 1981, Krautter et al. 1984, Snijders et al. 1984) shows that the very peculiar abundances in the ejecta, generated during a nuclear runaway, form an easily recognizable signature and the bolometric light curve has a well defined shape. The latter is possibly not a unique characteristic for a nuclear runaway but its presence or absence should be a strong argument at the very least.

The best model sofar available for the actual outbursts was constructed by Pottasch (1967) using data from the 1958 outburst. His model assumes that an ejected, high velocity shell, collides with surrounding stationary or slow moving material. The gradually slowing down, high velocity shell sweeps up the stationary material and increases in mass while shock waves heat some of the material to high temperatures which emit the strong coronal lines (Joy, 1961) observed during the outbursts.

Work on the companion has resulted in a classification as either an MOIII (Kenyon, 1983) or an M2III (Barbon et al., 1968) type star.

## 2. OBSERVATIONS

IUE observations of RS Oph were done by both the European and the

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American IUE Nova target of opportunity teams. During the 1985 outburst ultraviolet spectra were obtained on 14 epochs from Day 7.3 till Day 111. In addition spectra were obtained on Day 253 when the outburst was, at least in the IR, optical and UV finished. Following SETAL we adopt Jan 26.5 as Day 0. From Day 26 till Day 94 simultaneous optical observations were made at SAAO in South Africa. Full details of the IUE and optical observations and the data reduction will be given elsewhere (SETAL). In addition extensive optical observations were obtained at many other observatories and their results should eventually substantially extend our knowledge of the optical spectra of recurrent novae in outburst.

During quiescence IUE spectra were obtained in 1979, 1981 and 1982; only the 1979 data have been published (Rosino et al. 1982). Usually these data show a faint, rather underexposed continuum with the NIII] $\lambda$1750Å emission line and the 2175Å extinction maximum as the only recognizable spectral features. None of the pre-outburst spectra, which were obtained on 4 different epochs and show variability over roughly a factor 2.5, were as faint as the 1985 Day 253 spectra, obtained just after the outburst was over.

The IUE observations on Day 55.8, 61.6, 72.7, 93.7 and 253.2, are nearly simultaneous with X-ray observations by the EXOSAT satellite (Mason et al., 1986).

A large set of radio data has already been published by Padin et al. (1985) and Hjellming et al. (1986). These data show a completely different behaviour than the customary thermal spectra of classical novae (Davis 1986).

Extensive IR photometry and spectrophotometry was obtained during

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and after the 1985 outburst. Preliminary results from the IR data obtained at UKIRT and SAAO were recently reviewed (Evans, 1986). Many of these data were taken at the same time as the above discussed simultaneous optical/IUE/EXOSAT data further increasing the value of this multifrequency set of observations.

Apparently no IR spectroscopy was obtained between the 1967 and 1985 outbursts, only some photometry is available for this period (Evans 1986 and references therein). Of particular interest are the IRAS data which indicate the presence of a small amount of cool, 350K, dust in the system during quiesence (Evans, 1986).

## 3. REDDENING AND DISTANCE

Estimates for the interstellar extinction were obtained using the extinction law of Seaton (1978a) by SETAL. The flux ratio of the HeII $\lambda$1640 and $\lambda$3203 lines obtained from six epochs between Day 26 and Day 111 combined with theoretical recombination line ratios (Seaton 1978a) gives E(B-V)=0.73 $\pm$ 0.06. The 2175Å interstellar extinction feature is present in all the ultraviolet spectra. The data obtained during the outburst, from Day 26 till Day 111, gave E(B-V)=0.73 $\pm$ 0.10 (SETAL). Neither the HeII line ratio nor the strength of the 2175Å feature varied during the outburst.

Most pre-outburst IUE spectra are too noisy for an accurate determination of the reddening. Dereddening these data using E(B-V)=0.73 results in a satisfactory removal of the 2175Å feature. The spectra obtained after the outburst was over, on Day 253, are of better quality than the pre-outburst spectra and the 2175Å feature gives E(B-V)=0.70 $\pm$ 0.10 (SETAL). We adopt E(B-V)=0.73 $\pm$ 0.10 and we assume that the extinction had not varied since 1979.

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Using a subset of the same IUE data, Day 42.8, Day 55.8 and Day 72.7, preliminary results for the reddening (Cassatella et al.,1985) based on the extinction law of Savage and Mathis (1979) and again the HeII line ratio and the 2175Å extinction feature gave the same result: E(B-V) = 0.73. This ultraviolet colour excess is in excellent agreement with the results of Svolopoulos (1966) of E(B-V)=0.76 but far lower than other previous optical or near infrared results (e.g. Blair et al. 1983, Feast and Glass 1974). From the review by Evans (1986) it is clear that very little, if any, dust was formed during the outburst and circumstellar reddening both before and during the outburst was negligible.

A rich interstellar line spectrum was detected in the IUE data (SETAL, Cassatella et al. 1985) but only at velocities typical for our local spiral arm; their failure to detect material at velocities typical for the Carina arm in the direction of the nova at +19 km/s limits the distance to less than 2 kpc. However Hjellming et al. (1986) did detect 21 cm absorption from the Carina arm but not in the spectrum of RS Oph but in a nearby object with a slightly larger 21 cm column density than towards RS Oph, in excellent agreement with the results by SETAL. Hjellming et al. (1985) derived a distance of 1.6 kpc from the strength of the 21 cm absorption line in their radio data.

If we assume that the companion is a fairly normal red giant, one can use pre-outburst photometry to estimate the distance. Adopting a spectral type of M0III, Evans (1986) derived a distance of 1.3 kpc. Livio et al. (1986) assumed that the giant filled its Roche lobe and, combining that assumption with the available photometry, derived a distance of 3.1 kpc, which is clearly incompatible with the evidence

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from the interstellar lines in the radio and ultraviolet domains. In view of the abnormally strong UV nitrogen line observed in quiesence (section 2) the giant appears a rather peculiar object. We view the 1.3 kpc estimate as a lower limit to the distance. If the true distance is 1.6 kpc either the old M2III classification (Barbon et al. 1968) is correct or the object fills its Roche lobe at least partly.

A good method to determine the distance comes from observations of the nova outburst themselves. If the outburst were the result of a nuclear runaway, the object must have a plateau in its bolometric luminosity curve, shortly after maximum optical light and just below the Eddington luminosity of the white dwarf (Starrfield et al., 1985). The bolometric luminosity curve (Snijders 1986, SETAL) does indeed show the expected plateau between Days 8 and 35. Assuming that this plateau corresponds to 99% of the Eddington luminosity of a 1.38 $M_\odot$ white dwarf leads to d = 1.37 kpc for electron scattering in a pure hydrogen atmosphere. During the constant luminostiy phase most of the energy is emitted shortward of 2000A and an error of 0.10 in E(B-V) corresponds to an error of 30% to 40% in the distance. The precise composition of the ejected material is unknown but apparently closely resembles that of classical novae (Snijders, 1986). If the ejected material had the same composition as the CNO rich ejecta of Nova Cygni 1978 (Stickland et al. 1981) the distance would be 30% larger. Finally when we assume that the observed luminosity is the Eddington luminosity we assume that we see all the emitted light. After the first 25 days a substantial fraction of the energy is emitted in the Lyman continuum, or we have assumed that these photons are absorbed and reemitted at longer wavelength where they can be detected. The optical depth in the Lyman continuum is probably large enough in the clouds to absorb the photons but the covering factor might be less then 1.0. High reolution ultraviolet and optical (Cassatella et al. 1985, SETAL) line profiles show that the shell has well defined individual clouds and it is quite probable that some of the Lyman continuum can escape undetected. For a covering factor $f < 1$ we overestimate the distance by a factor between 1.0 and $\sqrt{1/f}$. Note that the errors due to underestimating the mean molecular weight and overestimating the covering factor will partly cancel.

From statistical relations between the absolute magnitude at maximum visual light and the nova speed class (Cohen, 1985) we can, in principle, estimate the distance to RS Oph. The validity of this approach for RS Oph is uncertain; if the outburst was not a nuclear runaway the method is certainly invalid and even if it is a runaway event a statistical method based on classical novae might not be applicable to recurrent novae. Cassatella et al. (1985) applied this method to the 1933 and 1958 outbursts and obtained distances of 2.4 kpc and 2.1 kpc respectivily.

We will adopt d = 1.6 kpc. This value is in agreement with the 21 cm column density, the Eddington luminosty estimates, our knowledge of the red giant infrared brightness and the absence of interstellar lines from the Carina arm in the spectra. This is less then the distance estimated from the decay time of the optical light curve but the difference is not statistically significant.

## 4. DISCUSSION.

The development of the ultraviolet spectrum as a function of time

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strongly resembles that of classical novae (Stickland et al. 1981, Krautter et al. 1984). The peak of the continuum flux gradually moves to shorter wavelengths and the ionization level increases with time. Just as during the 1958 outburst the profiles became gradually narrower. Immediately after outburst optical profiles (SETAL) show a Full Width at Zero Intensity (FWOI) in excess of 8000 km/sec. On Day 26 the FWOI was ~7000 km/s, on Day 94 the FWOI was ~2650 km/s and on Day 111, the last day of the IUE observations, the FWOI was only ~580 km/s. Additional information on the high resolution IUE data for the NIV] $\lambda$ 1486Å and CIV $\lambda$ 1549Å lines is available in Cassatella et al. (1985) and a detailed description will be given elsewhere (SETAL).

The great strength of the optical coronal lines in the spectrum of RS Oph during the outbursts is well known (e.g. Joy, 1961) but the rich coronal line spectrum observed in the ultraviolet is unique (Cassatella et al. 1985, SETAL). In particular the great strength of [FeXI] $\lambda$ 2648Å will make this line a suitable tool for the study of the coronal gas. These lines are presumably formed in the shocked gas, where the ejected shell meets the stellar wind from the companion and their appearance is not due to the hardening of the ionizing spectrum of the central source with time.

We can derive abundances from the IUE data using the method of Williams et al. (1981), which is based on the use of selected line ratios to estimate the CNO abundances. Preliminary results (Snijders, 1986) for CNO are $n(O)/n(N) = 1.10 \pm 0.17$ and $n(C)/n(N) = 0.16 \pm 0.04$ and a substantial overabundance of nitrogen over helium. These abundances are in the range recently derived for classical novae (e.g. table 2 in Snijders et al. 1984) and strongly suggest that a nuclear runaway did occur. However from the peculiar pre- and post-outburst spectra with their strong NIII] line, it seems clear that the material transferred from the giant is already enriched in nitrogen. Consequently the abundance argument should be treated with caution till the total abundance of CNO nuclei with respect to helium and/or hydrogen has been established (SETAL).

The bolometric luminosity curve shows that arguments in favour of an accretion mechanism for the outburst based on the rapid time scale of the event (Livio et al. 1986) are faulty. The fact that the optical outburst declines very rapidly is irrelevant, IUE data show that it takes 57 days for the source to drop by a factor 2 below the plateau luminosity. The fact that the plateau luminosity compares well with the Eddington luminosity of a 1.4 $M_{\odot}$ white dwarf at 1.6 kpc is a very strong argument in favour of a nuclear runaway model. Note that in this scenario the peak luminosity of the source was at least 4 times the Eddington luminosity which makes the very rapid acceleration to ejection velocities of 4000 km/s easier to understand.

Detailed analysis of the radio data (Hjellming et al. 1986, Spoelstra et al. 1986, Davis 1986) shows that the radio source contained at least two components with a very complicated, at present only partly understood, decay. Maximum radio brightness was reached around Day 40 at all frequencies (1.5 GHz to 24.5 GHz). The high brightness temperatures observed, $\sim 10^7$ K, clearly show the presence of non-thermal processes, quite different from the thermal emission of classical novae (Davis 1986). The possible discovery of a "radioflare" at 5 GHz suggests the occurence of magnetic field reconnection (Spoelstra et al. 1986). Both the VLA and the European VLBI network were able to resolve the radio source in March and April

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1985. Around Day 75 they both obtained a typical size of 0.1". The source was very asymetric and elongated in position angle ~84° and possibly unresolved perpendicular to this direction (Porcas, Davis and Graham, 1986).

The radio and X-ray observations are of special interest, they not only give us information about recurrent novae themselves but some of the physical processes involved are those normally observed during type II supernovae outbursts (Bode and Kahn 1985, Davis 1986, Hjellming et al. 1986). This object is closer than an extragalactic supernova and the multifrequency data are of much better quality at all stages of the outburst. Study of this object can therefore lead to a substantial increase in our understanding of the evolution of high velocity gas clouds (e.g. Spoelstra et al. 1986).

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