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CHEMICAL COMPOSITION OF DUST GRAINS IN NOVAE

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ABSTRACT

We have investigated the chemical composition of dust grains in novae by computing the model spectra for the novae that showed temporary infrared developments shortly after their optical explosions. We find that a simple spherical dust shell models with hot blackbody central sources fit observations fairly well. Optical properties of dust grains deduced from modeling of AGB stars have been used for present calculations. We find that amorphous carbon grains appear to be the major infrared re-emission sources for the carbon-rich nova shells, and the silicate grains for the oxygen-rich nova shells.

1. INTRODUCTION

The temporal infrared developments in about 14 novae have been reported as an evidence of dust formation in novae shortly after their explosions (Gehrz 1988, Gehrz *et al.* 1992). Dust grains are believed to form in about 40 - 300 days after the visual explosion and they keep showing their infrared appearance for up to 600 days with variations in shape. Only medium speed novae are known to be related with the infrared developments, probably due to the fact that the fast novae accompany hot ionizing radiation which suppresses the dust formation and the slow novae do not provide enough material to produce notable dust grains (e.g., Gallagher 1977, Mitchell & Evans 1984). Novae provide an unique opportunity to monitor the process of dust formation, even though their contribution to the content of dust grains in the Galaxy is minor. The major contributors, namely the asymptotic giant branch stars, show the continuous process of dust formation for a long time but they hide the important information regarding dust formation in fresh (i.e. dust-free) environments.

We have examined the observational data of 14 novae which are believed to have formed dust grains, namely FH Ser 1970, V1229 Aql 1970, V1301 Aql 1975, V1500 Cyg 1975, NQ Vul 1975, V4021 Sgr 1977, LW Ser 1978, V1668 Cyg 1978, V1370 Aql 1982, GQ Mus 1983, PW Vul 1984, QU Vul 1984, Nova Her 1987, and QV Vul 1987. Among these 9 are positively identified as dust-forming novae. Most of these novae formed carbon dust grains (amorphous carbon and SiC) shortly after optical explosion and some novae formed oxygen dust grains (silicate) much later. And nova QV Vul 1987 formed both carbon and oxygen dust grains at different stages.

It is generally believed that the spatial structure of the novae envelopes are sometimes departed from spherical symmetry and the material is not smoothly distributed (e.g., Gallagher and Starrfield 1978). A number of authors favored a multiple shell ejection model in explaining the observations of some novae explosions (e.g., Solf 1983). Modeling a nova dust envelope with present skills of spherical symmetric radiative transfer model would not be very considerate approach for some novae, but the simplification to spherical symmetry and continuous mass distribution is unavoidable for the first attempt to make a realistic radiative transfer model.

The purpose of this work is to explain the energy spectrum changes of the novae using the spherical symmetric radiative transfer model calculations based on the central and shell model parameters and the optical properties of the candidate dust grain materials of possible chemical composition. This is one of the best way to identify the chemical composition of dust grains in novae more accurately than previous works. The optical properties of dust grains in the envelopes around M-type Miras, carbon stars, and OH/IR stars have been used for present work.

2. PROCEDURES OF RADIATIVE TRANSFER MODEL CALCULATIONS

We have used the radiative transfer code for spherical symmetric dust shells that is described in Egan *et al.* (1988) to model the dust shells around novae. In the present calculations, a radial grid of 125 points and a wavelength grid of 90 points were used and the scattering is accurately considered. The parameters for central hot source which is assumed to be a black body are the temperature and the luminosity. And the parameters for dust envelope are dust opacity at different wavelengths, the optical depth, and the dust density distribution.

Radiative transfer models for AGB stars are developed by a number of authors with various assumptions on input parameters and degrees of sophistication (e.g., Jones & Merrill 1976, Volk & Kwok 1988, Suh 1991b) assuming a smoothly distributed spherical symmetric dust shell. We have used the dust opacity for the amorphous carbon (AMC) grains from Suh (1992) which has been applied for carbon stars. For SiC, the experimental data and Rayleigh approximation have been used. And for silicate grains, the data from Suh (1991b) which have been obtained from experimental data and model fitting with observations of M-type Miras and OH/IR stars. The procedures for obtaining the opacity are summarized in Table 1. Figure 1 shows the absorption efficiency factors (Q_{abs}) and Figure 2 shows the scattering efficiency factors (Q_{sca}) for the 3 types dust grains.

Table 1. Opacity for dust grains

λ (μm)	Optical Constants	Q_{abs}	Q_{sca}	g
Amorphous Carbon				
0.2 - 0.7	Duley 1984	Mie Theory		
0.7 - 7	Koike et al. 1980	λ^{-1}	λ^{-4}	$\lambda^{-1.5}$
7 - 100	Modification	$\lambda^{-1.3}$	λ^{-4}	$\lambda^{-1.5}$
SiC				
0.2 - 20	Palik 1985	Mie Theory		
20 - 100	Rayleigh Scattering	λ^{-1}	λ^{-4}	$\lambda^{-1.5}$
Silicate				
0.2 - 100	Suh 1991b	Mie Theory		

The dust density distribution is assumed to be inversely proportional to the square of the distance. The dust condensation temperature (T_c) is assumed to be 1000 K and the dust condensation radius (R_c) is obtained after a few trials. The outer radius of the dust shell is always taken to be 1000 R_c. The radii of spherical dust grains have been assumed to be 0.1 μm uniformly. Finally, the dust optical depth (τ) at 10 μm (9.7 μm for oxygen rich novae) is obtained to fit the observations of each object.

For the central hot source, the luminosity is taken to be (1 - 10) $\times$ $10^4 L_{\odot}$. And the black body temperature in the range of 1000 - 15000 K is assumed. For each object, the best fitting parameters are found after some trials. The change of the luminosity does not affect the shape of the output spectra very much, it only affects the overall energy output throughout wide wavelength ranges. The change of the central blackbody temperature does affect the output spectra very sensitively.

3. RESULTS AND COMPARISON WITH OBSERVATIONS

We have obtained the results of model calculations with various possible stellar and dust envelope parameters. The results are compared with observations and more

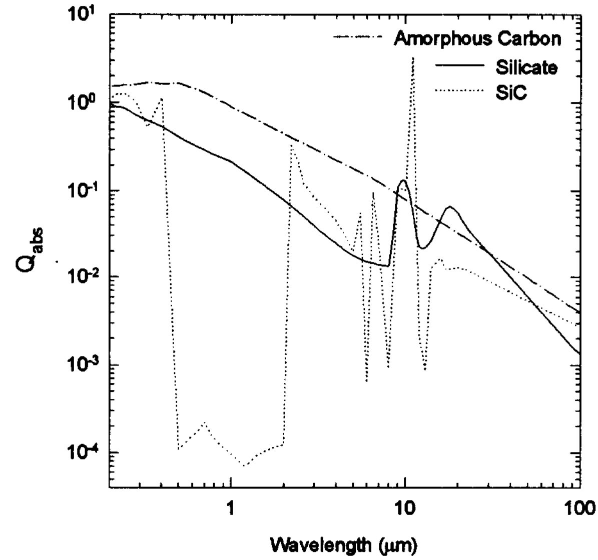

Figure 1. Absorption efficiency factors.

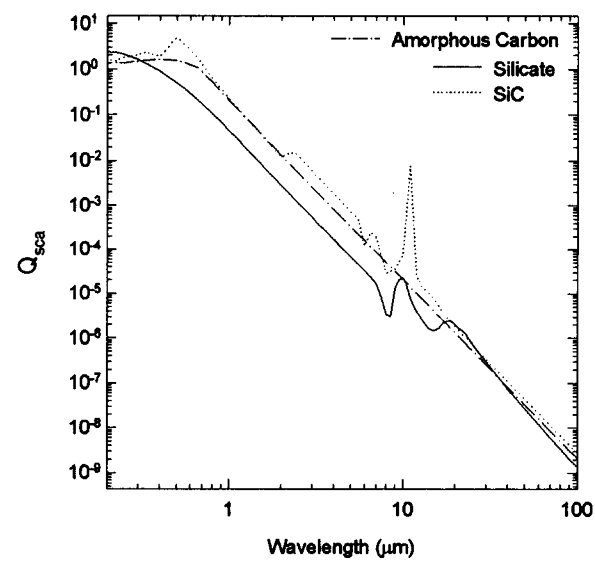

Figure 2. Scattering efficiency factors.

Table 2. Model parameters and the sources of observational data

Nova	t^a	T^b_{BB}	L^c	τ^d	Dust	Ref.
LW Ser 1978	69	5000	5	0.2	AMC	1
V1668 Cyg 1978	57	5000	5	0.05	AMC	2
V1370 Aql 1982	56	5000	5	0.3	AMC+SiC	3
QU Vul 1984	240	10000	10	0.04	Silicate	4
QV Vul 1987	102	5000	10	0.4	AMC	5
QV Vul 1987	278	10000	10	0.5	Silicate+AMC	5

[a] Days elapsed from optical outburst

[b] Blackbody temperature of the central hot source

[c] Luminosity of the central hot source in unit of $10^4 L_\odot$

[d] The optical depth at wavelength of 10 μm (9.7 μm for Silicate or Silicate + AMC)

References:

(1) Gehrz *et al.* 1980a; (2) Gehrz *et al.* 1980b; (3) Gehrz *et al.* 1984;

(4) Gehrz *et al.* 1986; (5) Gehrz *et al.* 1992.

reliable input parameters are obtained. The observational data are from many references for last 20 years of infrared observations of novae. The data are mostly in visual and infrared magnitudes are converted to an absolute flux unit (λF_λ; Watts/cm^2) by zero magnitude calibration processes (see e.g., Gehrz *et al.* 1987) considering the interstellar extinctions. Table 2 lists the times of infrared observations, the model parameters which fit observations best including central black body parameters and the optical depths, and the references for the observational data for 5 novae.

Figure 3 and 4 show the results of the model calculations (lines) superimposed on observational data (symbols) for Nova LW Ser 1978 and Nova V1668 Cyg 1978. The opacity for AMC has been used. Figure 5 shows the results of the model calculations superimposed on observational data for Nova 1370 Aql 1982. The solid line show the model result with AMC only and the dashed dot line show the model result with mixture of AMC and SiC. Snijders & Batt (1987) argued that this nova formed silicate dust grains attributing the very shallow peak at about 11 μm to be a silicate feature. But we find that the spectrum of this nova is best explained by a mixture of AMC and SiC.

Figure 6 show the results of the model calculations superimposed on observational data for Nova QU Vul 1984. This nova never showed the featureless continuum characteristic of carbon grains.

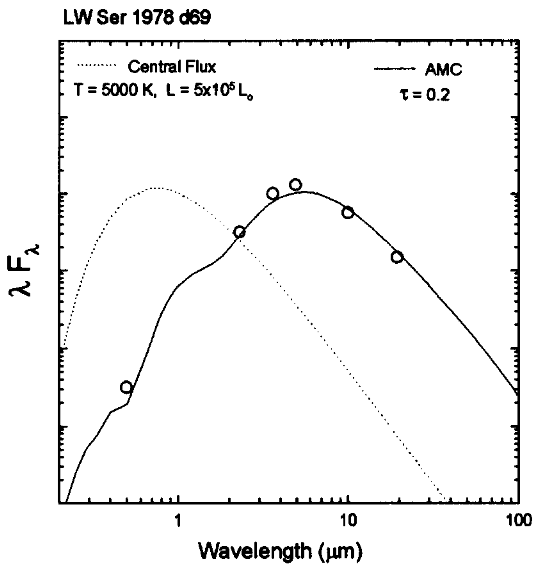

Figure 3. Nova LW Ser 1978.

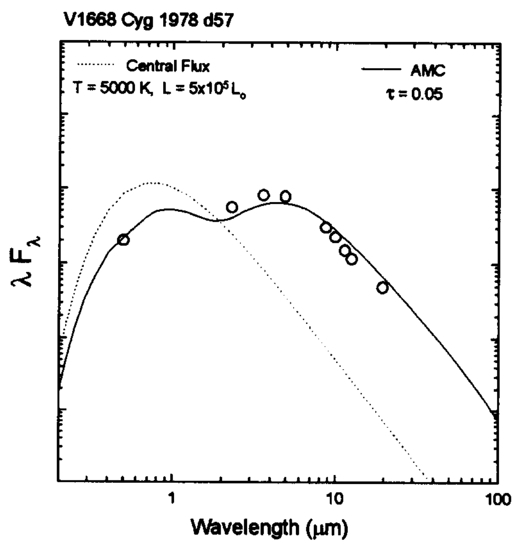

Figure 4. Nova V1668 Cyg 1978.

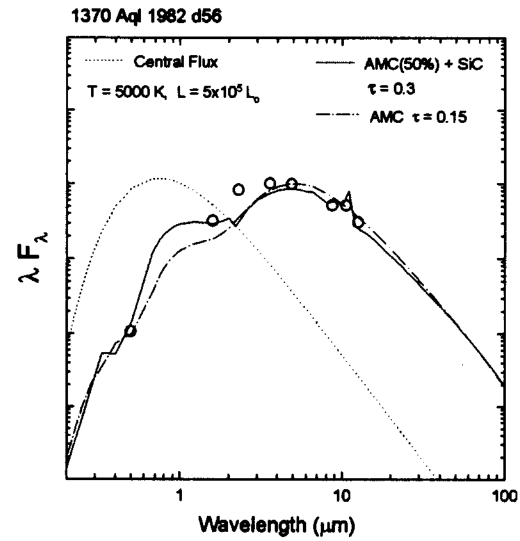

Figure 5. Nova V1370 Aql 1982.

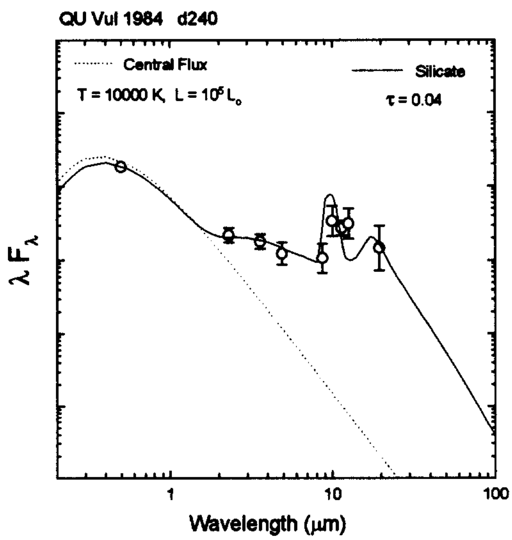

Figure 6. Nova QU Vul 1984.

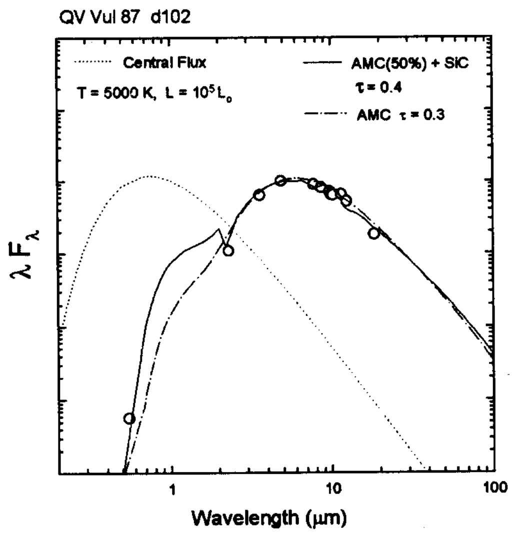

Figure 7. Nova QV Vul 1987 (day 102).

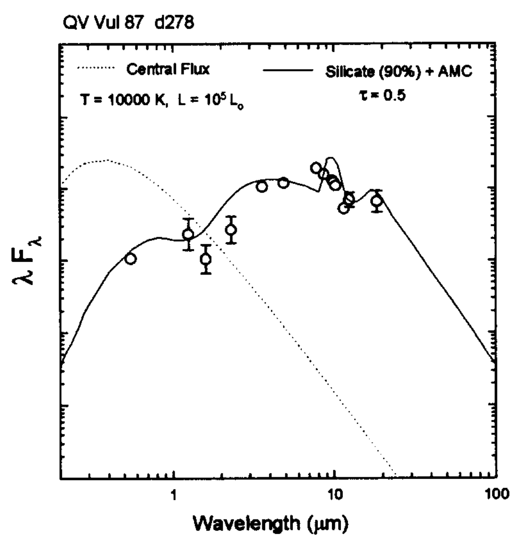

Figure 8. Nova QV Vul 1987 (day 278).

Figure 7 and 8 show the results of the model calculations superimposed on observational data for Nova QV Vul 1987. This nova showed the characteristics of all three types of dust grain materials; AMC, SiC, and silicate. Many types of arguments are possible to explain the formation of both carbon and oxygen dust grains in nova QV Vul 1987. In two separate shell model, the thermonuclear runaway may result in the ejection of fast moving polar plumes (or cones) and a slowly moving equatorial ring; the plumes move at roughly 3 times the velocity of equatorial ring. And plumes are expected to be rich in products of the CNO runaway, whereas the chemical composition of the equatorial ring should be predominantly hydrogen rich nonprocessed material. In an alternative model, CO formation did not go to completion. According to Suh (1991a), the dust formation time scales in novae resemble the results of theoretical calculations based on the classical nucleation theory. The author finds that oxygen grains form much later than carbon grains because of their thermodynamic properties.

4. DISCUSSION

The models with simple central black body sources with spherical dust shells fit observations reasonably well. The amorphous carbon grains appear to be the major infrared re-emission sources for the carbon-rich novae, and the silicate for the oxygen-rich novae.

The initial central black-body temperature of 10000 K appears to cool down to 5000 K until day 50 because of the thick re-emission materials inside the dust shell and rises again to 10000 K after day 200 due to the reduction of the optical depth of re-emission material inside the dust shell. The typical UV rises at about day 100 is marked by the decrease of the opacity of the material.

Materials blown from initial explosion re-emit the central radiation toward longer wavelength bands. The resulting radiation acting on dust grains is like cooler black-body. But at the time of oxygen grain formation, the resultant radiation becomes hot black body because the materials get ionized and the optical depth get smaller. Novae maintain high luminosity (about 5 $\times 10^4 L_\odot$ for relatively a long time (longer than 300 days) after their optical explosions. Re-emission by molecules and dust grains shift the energy spectrum toward longer wavelengths. Radio observations (e.g., Taylor *et al.* 1987) also support this idea.

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