Carbon and silicate dust formation in V1280 Sco

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Abstract. This study investigates the temporal evolution of the infrared emission from the dusty nova V1280 Sco over 2000 days from the outburst. We have revealed that the infrared spectral energy distributions at 1272, 1616 and 1947 days are explained by the emissions produced by amorphous carbon dust of mass (6.6–8.7)$\times 10^{-8}$ $M_\odot$ with a representative grain size of 0.01 μm and astronomical silicate dust of mass (3.4–4.3)$\times 10^{-7}$ $M_\odot$ with a representative grain size of 0.3–0.5 μm. Both of carbon and silicate dust travel farther away from the white dwarf without an apparent mass evolution throughout those later epochs.

1. Introduction

Classical novae are valuable phenomena which provide us unique opportunities to investigate the process of dust formation in the stellar ejecta. The composition of dust formed in the stellar ejecta (e.g., carbonaceous or silicate dust) depends on the C/O ratio in the envelope [1]. However, recent infrared observations of some dusty novae have revealed the presense of both carbonaceous and silicate dust: e.g., Nova V842 Cen [2]; Nova QV Vul [3], Nova V705 Cas [4]. Infrared monitoring observations of nearby dusty novae over several years from their outbursts are crucial in identifying the origin of such dual chemistry.

V1280Sco is a dusty nova discovered on 2007 February 4.86 by Y. Nakamura and Y. Sakurai [5]. It is located at the distance of 1.1 kpc [6]. Dust formation has been reported on 23 days after the discovery [7, 8]. Long-term photometric monitoring observations of V1280Sco in the optical and the near-infrared have shown that the light curve evolution of V1280Sco is extremely slow and, therefore, the white dwarf mass of V1280Sco is expected to be 0.6 $M_\odot$ or smaller [9, 6]. During the initial 150 days from the discovery, the VLTI/AMBER and MIDI interferometric observations of V1280Sco were carried out by Chesneau et al. [10] and linearly expanding dust shell with 0.35 mas day^{-1} was recognized.

In this proceedings paper, we report the results of spectral energy distribution (SED) analyses based on the late-time multi-epoch infrared observations of V1280 Sco (see [11] for details).

2. Dust Properties Formed in V1280 Sco

Mid-infrared imaging and spectroscopic observations of V1280 Sco were carried out on 2007 July 7 (Day 150) with Subaru/COMICS and on 2010 August 1 (Day 1272), 2011 July 10 (Day 1616), and 2012 June 6 (Day 1947) with Gemini-South/TReCS. The infrared spectral energy distributions (SEDs) at Days 150, 1272, 1616 and 1947 are shonw in Figure 1.

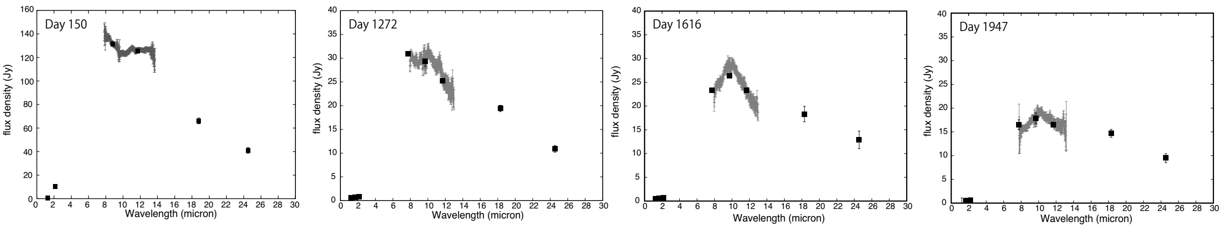

Figure 1. The infrared spectral energy distributions of V1280 Sco collected on Days 150, 1272, 1616 and 1947.

A notable point in the near- to mid-infrared SEDs of V1280 Sco at Days 1272, 1616 and 1947 is a clear appearance of the 9.7 μm and 18 μm amorphous silicate features in emission, which were not seen in the SED obtained at Day 150. The mid-infrared image collected at Day 1947 with Gemini-S/TReCS is consistent with the geometry of dusty nebulae ejected in the bipolar directions (see Figure 2), we assume a simple geometry in which both of the amorphous carbon and astronomical silicate components are distributed in bipolar cones with a common opening angle ϕ and is viewed edge on (see also [12]). We assume the density distributions of amorphous carbon (e.g., [13, 14]) $[n_{a.car.}(r)]$ and astronomical silicate (e.g., [15, 14]) $[n_{a.sil.}(r)]$ to be

$$n_{a.car.}(r) = \begin{cases} 0 & (r < r^{in}_{a.car.}) \\ n^{ini}_{a.car.} \times \left(\frac{r}{r^{in}_{a.car.}}\right)^2 & (r^{in}_{a.car.} < r < r^{out}_{a.car.}) \\ 0 & (r^{out}_{a.car.} < r) \end{cases} \quad (1)$$

and

$$n_{a.sil.}(r) = \begin{cases} 0 & (r < r^{in}_{a.sil.}) \\ n^{ini}_{a.sil.} \times \left(\frac{r}{r^{in}_{a.sil.}}\right)^2 & (r^{in}_{a.sil.} < r < r^{out}_{a.sil.}), \\ 0 & (r^{out}_{a.sil.} < r) \end{cases} \quad (2)$$

respectively, as a function of distance r from the white dwarf, where $r^{in}_{a.car.}$ and $r^{in}_{a.sil.}$ are the inner wall radii, $r^{out}_{a.car.}$ and $r^{out}_{a.sil.}$ are the outer wall radii, and $n^{ini}_{a.car.}$ and $n^{ini}_{a.sil.}$ are the initial number densities at the position of the inner wall for amorphous carbon and astronomical silicate, respectively. We assume the stellar parameters for the white dwarf at Days 1272, 1616, and 1947 as $T_{\rm WD} = 1.0 \times 10^5$ K and $L_{\rm WD} = 1.8 \times 10^4 L_\odot$ [16].

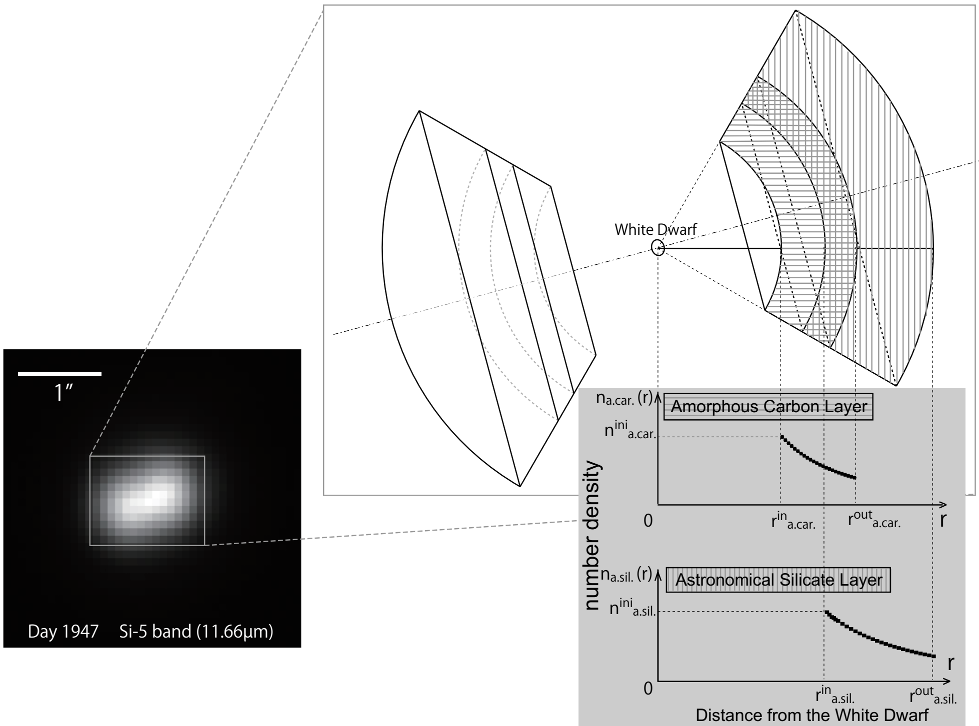

Figure 2. The 11.66 μm image of V1280 Sco at Day 1947 and the schematic view of dust geometry assumed in V1280 Sco at Days 1272, 1616, and 1947.

Based on above assumptions, an infrared spectrum produced by amorphous carbon and astronomical silicate in bipolar lobes of V1280 Sco is calculated for a geometric configuration characterized by 7 free parameters; $n^{ini}_{a.car.}$, $n^{ini}_{a.sil.}$, $r^{in}_{a.car.}$, $r^{in}_{a.sil.}$, $r^{out}_{a.car.}$, $r^{out}_{a.sil.}$, and ϕ. The optical depth at 9.7μm, $\tau_{9.7} = 0.24 \pm 0.01$, due to interstellar silicate towards V1280 Sco is fixed. Least-squares fitting is carried out to obtain a set of 7 best-fit parameters at Days 1272, 1616 and 1947 for each case of different grain sizes ($a_{a.car.}$,$a_{a.sil.}$)=(0.1, 0.1), (0.01, 0.01), (0.01, 0.1), (0.01, 0.2), (0.01, 0.3) and (0.01, 0.5) in μm. Particularly, inner wall radii $r^{in}_{a.car.}$ and $r^{in}_{a.sil.}$ are quite sensitive to the grain size. The values of $r^{in}_{a.car.}$ and $r^{in}_{a.sil.}$ obtained as a result of the fitting are shown in Figure 3. Because $r^{in}_{a.sil.}$ must be close to the semi-major axis of the deconvolved 7.73μm image of V1280 Sco at Day 1272 (i.e. 0".27) and $r^{in}_{a.sil.}$ must be smaller than the semi-major axis of the deconvolved 24.56μm image of V1280 Sco at Day 1947 (i.e. 0".45), the typical grain size of amorphous carbon is estimated as $a_{a.car.} = 0.01$ μm and that of astronomical silicate as 0.3 μm< $a_{a.sil.}$. We also find that $r^{in}_{a.sil.}$ is always larger than $r^{in}_{a.car.}$ when $a_{a.car.} = 0.01$ μm and $a_{a.sil.} < 0.5$ μm. As a conclusion, we obtained the typical size of amorphous carbon dust formed around V1280 Sco as $a_{a.car.}$ =0.01 μm and its mass as $M_{a.car.} \sim 8{\times}10^{-8}$ $M_\odot$, and the corresponding values for astronomical silicate as 0.3μm $< a_{a.sil} <$ 0.5μm and $M_{a.sil.} \sim 4{\times}10^{-7}$ $M_\odot$.

The dust formation scenario around V1280 Sco suggested from our analyses is that the amorphous carbon dust is formed in the nova ejecta followed by the formation of silicate dust in the expanding nova ejecta or as a result of the interaction between the nova wind and the circumstellar medium. Cool clumpy clouds produced via interactions between the pre-existing

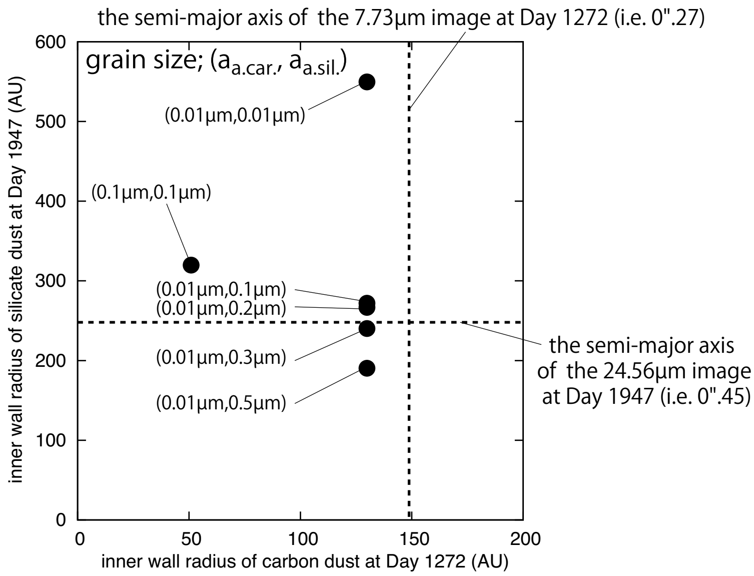

Figure 3. The plots of inner wall radii $r^{in}_{a.car.}$ at Day 1272 and $r^{in}_{a.sil.}$ at Day 1947 obtained as a result of the fitting for each case of different grain sizes ($a_{a.car.}$,$a_{a.sil.}$)=(0.1, 0.1), (0.01, 0.01), (0.01, 0.1), (0.01, 0.2), (0.01, 0.3) and (0.01, 0.5) in μm.

circumstellar gas and high velocity nova ejecta may have provided a favorable condition for the silicate dust to attain a large grain size (i.e., $0.3\mu\text{m} < a_{a.sil} < 0.5\mu\text{m}$).

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