PROCEEDINGS OF SCIENCE

Dust mineralogy in the circumstellar envelope of SVS13[*]

Takuya Fujiyoshi[†a], **Christopher M. Wright**[b] and **Toby J. T. Moore**[c]
[a]*Subaru Telescope, National Institutes of Natural Sciences, National Astronomical Observatory of Japan, 650 North A'ohoku Place, Hilo, Hawaii 96720, USA*
[b]*School of Physical, Environmental and Mathematical Sciences, UNSW Canberra, Canberra ACT 2600, Australia*
[c]*Astrophysics Research Institue, Liverpool John Moores University, IC2, Liverpool Science Park, 146 Brownlow Hill, Liverpool L3 5RF, UK*
E-mail: `tak@subaru.naoj.org`, `C.Wright@adfa.edu.au`, `tjtm@astro.livjm.ac.uk`

It is of great interest to study the mineralogy of circumstellar dust around young stars as it represents the original constituents of planetesimals, hence of the rocky planets like our own Earth. To this end, we have obtained an N-band ($8-13$ μm) spectrum of a pre-main-sequence star SVS13, using the facility mid-infrared imaging spectrometer COMICS on the Japanese 8.2-m Subaru Telescope atop the summit of Mauna Kea, Hawaii. We have fitted various emissivities/absorption coefficients of dust species to the spectrum to examine dust mineralogy in the circumstellar envelope of this remarkable young star. In this presentation, we outline the modelling and highlight some of our findings.

The Life Cycle of Dust in the Universe: Observations, Theory, and Laboratory Experiments - LCDU 2013,
18-22 November 2013
Taipei, Taiwan

---

[*] Based on data collected at Subaru Telescope, which is operated by the National Astronomical Observatory of Japan.

[†] Speaker.

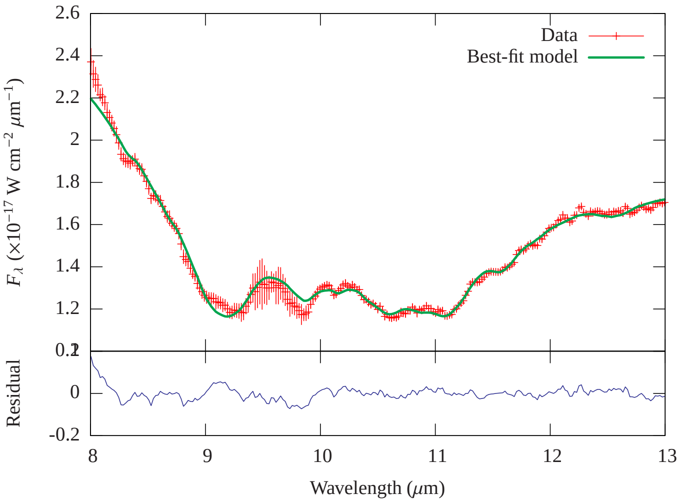

Figure 1: *Upper panel*: COMICS N-band spectrum of SVS13 overlaid with the best-fit model (solid line). Note that error-bars only represent standard deviation in the sky background. *Lower panel*: Fitting residual plot.

1. Introduction

SVS13 (star number 13 in [1]) is a low-luminosity ($\sim$45 $L_\odot$ [2]; their estimate of 115 $L_\odot$ at 350 pc scaled to an updated distance of 220 pc [3]) Class 0/I pre-main-sequence star [4], thought to be driving the Herbig-Haro objects 7$-$11 [5] near the reflection nebula NGC1333 in the Perseus molecular cloud. It underwent brightening sometime between 1988 December and 1990 September ($\Delta m_V \sim 3.3$ mag, $\Delta m_K \sim 1.2$ mag [6]). The 2.3-μm CO overtone band-heads, indicative of the presence of hot ($\sim$3000 K) and dense ($\geq 10^{10}$ cm^{-3}) molecular gas [7], probably in the shape of a circumstellar disc, have been observed in emission (e.g., [6] [7]). N-band spectro-polarimetry revealed an ‘unusual’ intensity spectrum [8] and a possible presence of SiC grains [9].

2. Observations and results

Subaru/COMICS N-band low-resolution ($R \sim 250$) mode observations were conducted in 2009 November. Figure 1 shows the COMICS N-band spectrum of SVS13. It is clear that the spectrum exhibits rather ‘unusual’ shape and quite complex (unique) absorption features compared to the single amorphous silicate band prevalent in spectra of other embedded young stars.

3. Model fitting

We have selected species that are common in dust modelling towards young stars (except perhaps SiC). These include amorphous silicates (Trapezium emissivity [10]), crystalline silicates (aerosol forsterite and enstatite [11]), amorphous and annealed SiO$_2$ [12], and SiC (carbon star emissivity [13]). The fitting function can be expressed as $F_\lambda \propto B_\lambda(T) \times e^{-\alpha}$, where $B_\lambda(T)$ is the Planck black-body function at temperature T, $\alpha = \sum_{i=1}^{k} \tau_i$ is the total optical depth of k absorption components and τ_i is the optical depth of each component (i.e., all absorptive). In Figure 1,

Model	χ^2_ν	$T(K)$	Trap	err	SiC	err	Cr fors	err	Cr enst	err	Am SiO_2	err	Cr SiO_2	err
1-comp	30.0	319	1.11	2 %										
2-comp	10.5	298	0.94	1 %	0.18	4 %								
2-comp+cr fors	8.33	300	0.86	1 %	0.14	13 %	0.08	34 %						
2-comp+cr enst	6.51	301	0.66	4 %	0.18	13 %			0.23	13 %				
2-comp+cr fo&en	3.74	302	0.55	2 %	0.15	4 %	0.10	5 %	0.24	1 %				
4-comp+am SiO_2	1.95	313	0.56	< 1 %	0.17	2 %	0.12	4 %	0.24	2 %	0.15	6 %		
4-comp+cr SiO_2	**1.67**	**309**	**0.60**	**1 %**	**0.18**	**3 %**	**0.11**	**5 %**	**0.21**	**5 %**			**0.16**	**2 %**
4-comp+am&cr SiO_2	1.67	310	0.59	< 1 %	0.18	3 %	0.11	6 %	0.21	3 %	0.02	29 %	0.14	4 %
4-comp−SiC	14.7	314	0.56	< 1 %			0.18	4 %	0.23	4 %			—	—

Table 1: Results of various model fitting [the best-fit model (4-comp+cr SiO_2) is highlighted]. The goodness of fit is given by the reduced chi-square (χ^2_ν). Black-body temperature [$T(K)$], and optical depth of each component and their associated uncertainties are listed.

the *N*-band spectrum of SVS13 is overlaid with the best-fit model (solid line), which comprises amorphous silicates, crystalline silicates (forsterite and enstatite), annealed SiO_2, and SiC (see also Table 1).

4. SiC?

Silicon carbide has never been observed in the diffuse interstellar medium (ISM) [14], although it is produced in carbon star ejecta and is undoubtedly injected into it. So where does it go? One possible solution is proposed by [14]; oxidation. It is argued that the ejected SiC grains could be selectively destroyed by surface oxidation in the O-rich interstellar environment. For example, in volatilisation experiments of SiC grains under solar nebula-like oxidising conditions, either partial or continuous SiO_2 layers are formed, depending on oxygen fugacities [15]. However, although the mantle does seem to add new features arising from the presence of SiO_2 to the spectrum, it does not appear to suppress significantly the SiC feature at $\sim$11 μm [16]. An alternative explanation was also briefly mentioned by [14], namely formation of an amorphous carbon layer on the SiC grains effectively hiding its features [17] [18]. A short letter has been published in a surface science journal that reports the dissolution of the amorphous carbon layer into the SiC core, when the core-mantle grain was heated [19]. A sequence of events similar to the one just described may be able to explain not only the absence of the SiC features in the diffuse ISM but also the resurgence of it in a warm environment such as the circumstellar envelope of a pre-main-sequence star like SVS13. This scenario should however be treated with caution, as a self-absorbed SiC band has been detected towards extreme carbon stars (e.g., [20]), where amorphous carbon might be expected to dominate. Nonetheless, as mentioned earlier, the *N*-band spectro-polarimetry provides further support for the presence of SiC. Amongst many different materials (water ice, etc.) considered, only SiC has the unique ability to suppress the polarisation due to amorphous silicates at 10 μm (see also [9]). Finally, if SiC is taken out of the best-fit model, the goodness of fit significantly worsens ($\chi^2_\nu = 1.67 \rightarrow 14.7$, see Table 1), worse even than the simple 2-component model (amorphous silicates + SiC; $\chi^2_\nu = 10.5$), perhaps signifying need for the SiC inclusion.

References

[1] S.E. Strom, F.J. Vrba and K.M. Strom, *Infrared surveys of dark cloud complexes* V. *The NGC 7129 region and the Serpens dark cloud*, *ApJ* **81**, 314 (1976)

[2] S. Molinari, R. Liseau and D. Lorenzetti, *The exciting sources of Herbig-Haro objects.* I. *A catalogue of 1−20 µm observations*, *A&AS* **101**, 59 (1993)

[3] K. Černis, *Interstellar extinction in the vicinity of the reflection nebula NGC 1333 in Perseus*, *A&SS* **166**, 315 (1990)

[4] C. Aspin, *The evolutionary state of stars in the NGC 1333S star formation region*, *ApJ* **125**, 1480 (2003)

[5] R. Bachiller, F. Gueth, S. Guilloteau, M. Tafalla and A. Dutrey, *The origin of the HH 7−11 outflow*, *A&A* **362**, L33 (2000)

[6] J. Eislöeffel, E. Guenther, F.V. Hessman, R. Mundt, R. Poetzel, J.S. Carr, S. Beckwith and T.P. Ray, *An optical/infrared outburst in the exciting source of HH 7−11*, *ApJ* **383**, L19 (1991)

[7] J.S. Carr, A.T. Tokunaga and J. Najita, *Hot H_2O emission and evidence for turbulence in the disk of a young star*, *ApJ* **603**, 213 (2004)

[8] D.K. Aitken, C.M. Wright, C.H. Smith and P.F. Roche, *Studies in mid-infrared spectropolarimetry.* I *- Magnetic fields, discs and flows in star formation regions*, *MNRAS* **262**, 456 (1993)

[9] C.M. Wright, D.K. Aitken, C.H. Smith and P.F. Roche, *Mid-infrared spectropolarimetry and the composition of cosmic dust*, in proceedings of *Formation and evolution of solids in space*, p.77 (1999)

[10] F.C. Gillett, W.J. Forrest, K.M. Merrill, B.T. Soifer and R.W. Capps, *The 8−13 µ spectra of compact H* II *regions*, *ApJ* **200**, 609 (1975)

[11] A. Tamanai, H. Mutschke, J. Blum and G. Meeus, *The 10 µm infrared band of silicate dust: A laboratory study comparing the aerosol and KBr pellet techniques*, *ApJ* **648**, 147 (2006)

[12] D. Fabian, C. Jäger, Th. Henning, J. Dorschner and H. Mutschke, *Steps toward interstellar silicate mineralogy.* V. *Thermal evolution of amorphous magnesium silicates and silica*, *A&A* **364**, 282 (2000)

[13] D.K. Aitken, P.F. Roche, P.M. Spenser and B. Jones, *8−13 micron spectrophotometry of planetary nebulae*, *ApJ* **233**, 925 (1979)

[14] D.C.B. Whittet, W.W. Duley and P.G. Martin, *On the abundance of silicon carbide dust in the interstellar medium*, *MNRAS* **244**, 427 (1990)

[15] R.A. Mendybaev, J.R. Beckett, L. Grossman, E. Stolper, R.F. Cooper and J.P. Bradley, *Volatilization kinetics of silicon carbide in reducing gases: an experimental study with applications to the survival of presolar grains in the solar nebula*, *Geochimica et Cosmochimica Acta* **Vol.66**, No.4, p.661 (2002)

[16] Th. Posch, H. Mutschke and A. Andersen, *Reconsidering the origin of the 21 micron feature: Oxides in carbon-rich protoplanetary nebulae?*, *ApJ* **616**, 1167 (2004)

[17] M. Frenklach, C.S. Carmer and E.D. Feigelson, *Silicon carbide and the origin of interstellar carbon grains*, *Nat* **339**, 196 (1989)

[18] T. Kozasa, J. Dorschner, T. Henning and R. Stognienko, *Formation of SiC grains and the 11.3µm feature in circumstellar envelopes of carbon stars*, *A&A* **307**, 551 (1996)

[19] Y. Kimura, Y. Saito and C. Kaito, *High-temperature behavior of an amorphous carbon layer on SiC particles*, *Surf Sci* **527**, L219 (2003)

[20] A.K. Speck, M.J. Barlow and C.J. Skinner, *The nature of the silicon carbide in carbon star outflows*, *MNRAS* **288**, 431 (1997)