Why Galaxies Care About AGB Stars:
A Continuing Challenge through Cosmic Time
Proceedings IAU Symposium No. 343, 2019
F. Kerschbaum, M. Groenewegen & H. Olofsson, eds.

doi:10.1017/S1743921318005355

Circumstellar dust, IR spectroscopy, and mineralogy

Kyung-Won Suh

Dept. of Astronomy and Space Science, Chungbuk National University,
Cheongju, Chungbuk 28644, Republic of Korea
email: kwsuh@chungbuk.ac.kr

Abstract. We review the mineralogy of circumstellar dust grains around AGB stars as investigated through infrared spectroscopic studies. The expanding envelopes of AGB stars are chemically fresh because of the strong binding force of CO molecules. O-rich dust grains (silicates and oxides) form in O-rich envelopes and C-rich dust grains (amorphous carbon and SiC) form in C-rich envelopes. Amorphous silicate grains can be crystallized by annealing processes in various environments of AGB stars. We also discuss dust mineralogy for objects that have undergone chemical transition processes.

Keywords. circumstellar matter, stars: AGB and post-AGB, dust-extinction, infrared: stars, radiative transfer

1. Introduction

Asymptotic giant branch (AGB) stars are in the last evolutionary phases of low mass stars (M $\leq 10\ M_\odot$). They are long period pulsating variables with extended outer layers that provide good conditions for dust formation. The radiation pressure on newly formed dust grains may drive dusty stellar winds with mass-loss rates of $10^{-8} - 10^{-4} M_\odot\ \mathrm{yr}^{-1}$ (e.g., Suh 1999).

Since Wolf & Ney (1968) discovered and identified the 10 μm silicate feature from many M-type giant stars, the mineralogy of circumstellar dust around AGB stars has been one of the key problems in astronomy. Various species of O-rich dust grains (silicates, oxides, and water ice) in O-rich envelopes and C-rich dust grains (amorphous carbon and SiC) in C-rich envelopes are studied. We review the mineralogy of circumstellar dust grains around AGB stars, which is investigated by infrared observations, laboratory measurements, and theoretical models.

2. Infrared observations of circumstellar dust

For a large sample of AGB stars, infrared observational data are available from the Infrared Astronomical Satellite (IRAS), Infrared Space Observatory (ISO), Midcourse Space Experiment (MSX), Two-Micron All-Sky Survey (2MASS), AKARI space telescope, and Wide-field Infrared Survey Explorer (WISE).

2.1. *IR spectroscopy*

The IRAS Low Resolution Spectrograph (LRS; λ = 8-22 μm) data are useful to identify important features of O-rich and C-rich dust grains in AGB stars (e.g., Kwok, Volk, & Bidelman 1997). The LRS data were used to identify many O-rich and C-rich AGB stars in our Galaxy.

Table 1. Dust species in AGB stars

Acronym	Size [μm]	Description	Density [g cm^{-3}]	Reference[a]
SILw	0.1	amorphous warm silicate	3.3	Suh (1999)
Alu	0.1	amorphous alumina	3.2	Begemann *et al.* (1997)
FMO	0.1	$Fe_xMg_{1-x}O$ (x=0.4-1.0)	3.59−5.7	Henning *et al.* (1995)
SILc	0.1	amorphous cold silicate	3.3	Suh (1999)
ICE	0.1	crystalline water ice	0.92	Bertie *et al.* (1969)
SWC	0.1−0.2	SILc core, ICE mantle	1.22	core and mantle
FK	–	crystalline forsterite	3.27	Koike *et al.* (2003)
EK	–	crystalline enstatite	3.27	Chihara *et al.* (2002)
SFE10	–	SILc+FK(5%)+EK(5%)	3.3	a simple mixture
AMC	0.1	amorphous carbon	2.0	Suh (2000)
SiC	0.1	α-SiC	3.26	Pégourié (1988)

[a]Except for FK and EK for which mass absorption coefficients are given, all references provide optical constants.

The ISO Short Wavelength Spectrometer (SWS; λ = 2.4−45.4 μm) and the Long Wavelength Spectrometer (LWS; λ = 43−197 μm) provided high resolution spectra for many AGB stars in our Galaxy (Sylvester *et al.* 1999). The ISO spectral observations identified many fine spectral features of crystalline dust.

The Spitzer Infrared Spectrograph (IRS; λ = 5.2−38 μm) took high resolution spectra for many AGB stars in the Large and Small Magellanic Clouds (LMC and SMC). The IRS observed nearly 800 point sources in the LMC, taking over 1000 spectra (Jones *et al.* 2017).

2.2. *IR two-colour diagrams*

A large number of AGB stars have infrared photometric fluxes from the IRAS, AKARI, MSX, 2MASS, and WISE observations. Although less useful than a full spectral energy distribution (SED), the large number of observations in various wavelength bands can be used to form two-colour diagrams (2CDs) that can be compared to theoretical models. IR 2CDs are useful to distinguish statistically among AGB stars, post-AGB stars, and PNe (e.g., Suh 2015).

3. Mineralogy of circumstellar dust

Mineralogy of dust is revealed by the optical properties. Dust opacity is determined from the optical constants, shape, and size of a dust grain. By comparing the observational data with theoretical radiative transfer models for circumstellar dust, we may identify the mineralogy. The chemical and physical properties (chemical composition, solid structure, shape, and size) of circumstellar dust can provide crucial information on the astrophysical environment. Table 1 lists major dust species for AGB stars.

Due to amorphous silicate dust, low mass-loss rate O-rich AGB (LMOA) stars with thin dust envelopes show the 10 μm and 18 μm emission features. High mass-loss rate O-rich AGB (HMOA) stars with thick dust envelopes show absorbing features at the same wavelengths.

3.1. *Dust in LMOA stars*

Amorphous alumina (Al_2O_3) grains produce a single peak at 11.8 μm (Begemann *et al.* 1997) and influence the shape of the SED at $\lambda \sim 10$ μm. Comparing the theoretical models with the observations on various IR 2CDs for a large sample of AGB stars in our Galaxy, Suh (2016) found that amorphous alumina dust (about 10-40 %) mixed with amorphous silicates better model the observed data for LMOA stars. From modelling

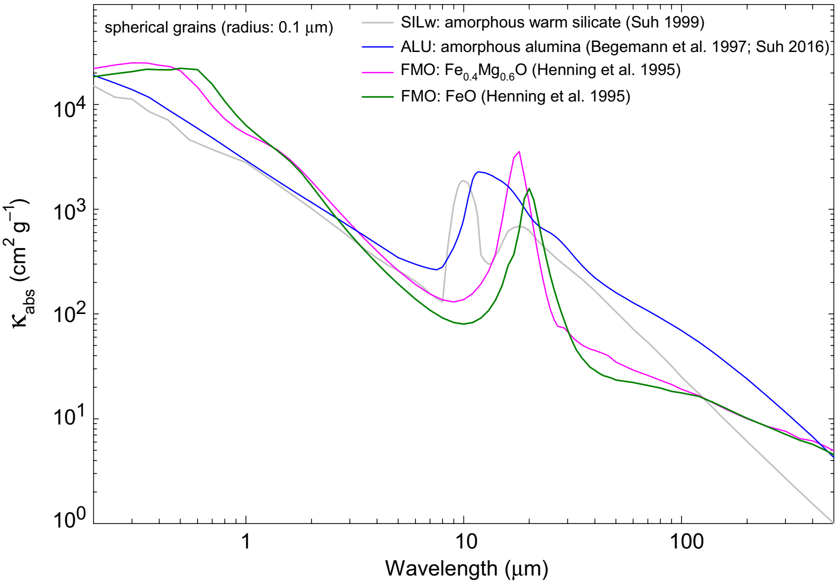

Figure 1. Dust opacity functions for low mass-loss rate O-rich AGB stars. See Table 1.

the Spitzer IRS spectra for O-rich AGB stars in LMC, Jones *et al.* (2014) showed that a mixture of amorphous silicates, amorphous alumina, and metallic iron, provides a good fit to the observed spectra.

Henning *et al.* (1995) presented the optical constants of $Fe_xMg_{1-x}O$ (x=0.4-1.0). Using ISO SWS data, Posch *et al.* (2002) detected and tentatively identified a broad dust emission feature peaking at 19.5 μm, which is especially prominent in LMOA stars, to be $Fe_{0.9}Mg_{0.1}O$.

Figure 1 shows the opacity functions of major dust species for LMOA stars. For the dust species for which the optical constants are available, the opacity functions are calculated for spherical dust grains using Mie theory (Bohren & Huffman 1983).

3.2. *Dust in HMOA stars*

The high resolution ISO spectroscopic observations detected prominent emission features of crystalline silicates in the spectra of HMOA stars but not from the spectra of LMOA stars (Sylvester *et al.* 1999). Fabian *et al.* (2000) investigated the thermal evolution of amorphous silicates and found that annealing at a temperature of 1000 K transformed amorphous silicate grains to crystalline ones on relatively short time scales. For HMOA stars, for which the dust formation temperature is about 1000 K (Suh 2004), the inner region of the outflowing envelope is warm (about 900−1000 K) during an extended period of time (several hundred days) for the annealing process to work (e.g., Suh 2004).

Water-ice features are found in SEDs of some HMOA stars (Justtanont *et al.* 2006). Suh & Kwon (2013) found that dust shell models with about 10% of crystalline silicates (Chihara *et al.* 2002; Koike *et al.* 2003), crystalline water ice (Bertie *et al.* 1969), and amorphous silicate can reproduce the observed SEDs for many HMOA stars (see Figure 2).

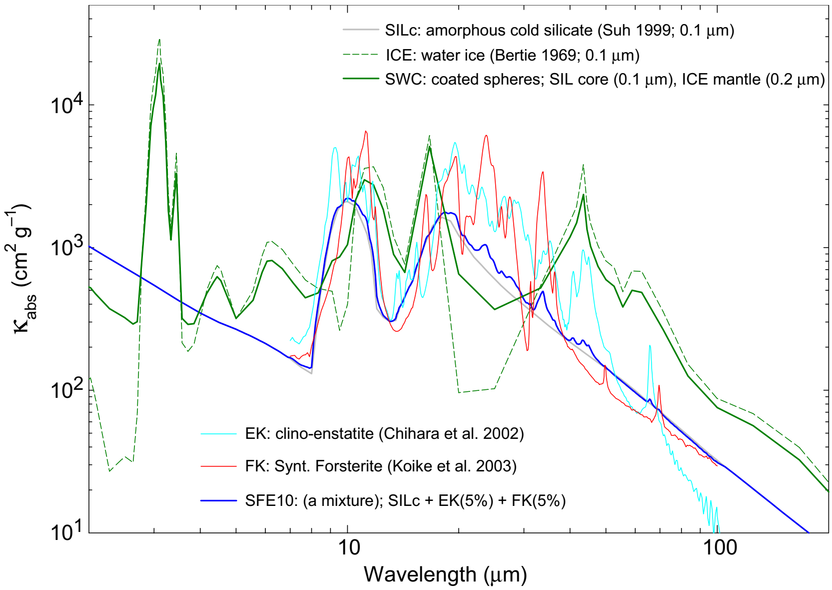

Figure 2. Dust opacity functions for high mass-loss rate O-rich AGB stars. See Table 1.

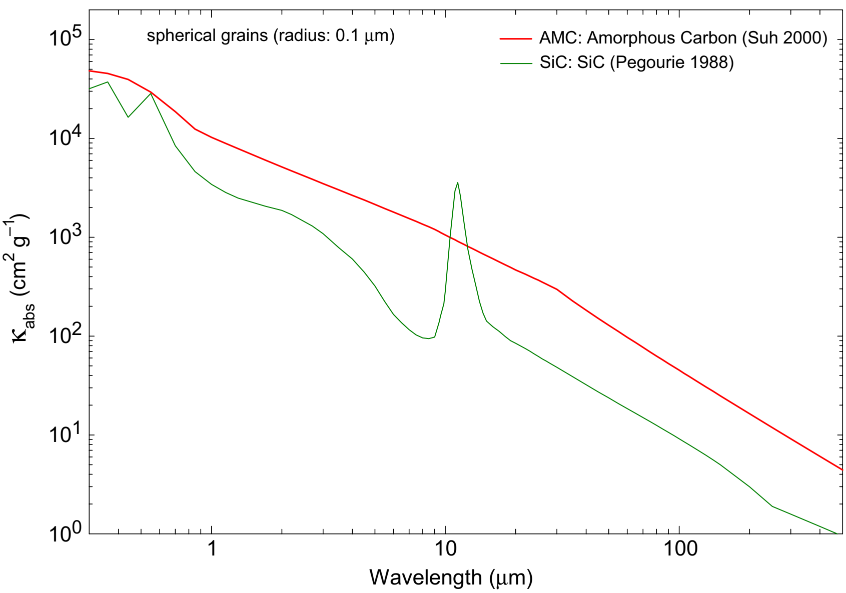

Figure 3. Dust opacity functions for C-rich AGB stars. See Table 1.

3.3. *Dust in C-rich AGB stars*

The main components of dust in the envelopes around carbon stars are believed to be featureless amorphous carbon (AMC) grains and SiC grains producing the 11.3 μm emission feature (Pégourié 1988; Suh 2000; see Figure 3). The carbon stars with SiC grains belong to the IRAS LRS class C.

Unlike AGB stars, C-rich post-AGB stars typically show polycyclic aromatic hydrocarbon (PAH) dust features. This could be due to UV radiation from the hot central stars.

https://doi.org/10.1017/S1743921318005355 Published online by Cambridge University Press

3.4. *Dust in silicate carbon stars*

Silicate carbon stars show the characteristics of a carbon star and circumstellar silicate dust features. A possible scenario for the origin of most silicate carbon stars would be that O-rich material was stored in a circumstellar (or circumbinary) disc and remains after the chemical transition from O to C. Up to now, about 29 silicate carbon stars have been identified in our Galaxy (e.g., Kwon & Suh 2014). Kraemer *et al.* (2017) identified a new silicate carbon star in the SMC using the Spitzer IRS data.

References

Begemann, B., Dorschner, J., Henning, T., *et al.* 1997, *ApJ*, 476, 199
Bertie, J. E., Labbé, H. J., & Whalley, E. 1969, *J. Chemical Phys.*, 50, 4501
Bohren, C. F., & Huffman, D. R. 1983, *Absorption and Scattering of Light by Small Particles* (New York: Wiley)
Chihara, H., Koike, C., Tsuchiyama, A., Tachibana, S., & Sakamoto, D. 2002, *A&A*, 391, 267
Fabian, D., Jäger, C., Henning, T., *et al.* 2000, *A&A*, 364, 282
Jones, O. C., Woods, P. M., Kemper, F., *et al.* 2017, *MNRAS*, 470, 3250
Justtanont, K., Olofsson, G., Dijkstra, C., & Meyer, A. W. 2006, *A&A*, 450, 1051
Henning, T., Begemann, B., Mutschke, H., & Dorschner, J. 1995, *A&AS*, 112, 143
Koike, C., Chihara, H., Tsuchiyama, A., *et al.* 2003, *A&A*, 399, 1101
Kraemer, K. E., Sloan, G. C., Wood, P. R., *et al.* 2017, *ApJ*, 834, 185
Kwok, S., Volk, K., & Bidelman, W. P. 1997, *ApJS*, 112, 557
Kwon, Y.-J., & Suh, K.-W. 2014, *JKAS*, 47, 123
Pégourié, B. 1988, *A&A*, 194, 335
Suh, K.-W. 1999, *MNRAS*, 304, 389
Suh, K.-W. 2000, *MNRAS*,315, 740
Suh, K.-W. 2004, *ApJ*, 615, 485
Suh, K.-W., & Kwon, Y.-J. 2013, *ApJ*, 762, 113
Suh, K.-W. 2015, *ApJ*, 808, 165
Suh, K.-W. 2016, *JKAS*, 49, 127
Sylvester, R. J., Kemper, F., Barlow, M. J., *et al.* 1999, *A&A*, 352, 587
Posch Th., Kerschbaum F., Mutschke, H., *et al.* 2002, *A&A*, 393, L7
Woolf, N. J., & Ney, E. P. 1969, *ApJ*. 155, 181

Discussion

L. Jones: The FeO identification at 20 μm is hard - just one resonance. This feature appears with several others - at 11, 13, and 28 μm. Ben Sargent has a paper coming out identifying all of these with the same alumina related carrier.

Suh: The two-colour diagram showed the effect of just the 20 μm feature. Of course, we can consider other features also.

O. Jones: How confident are you that FeO is present in O-rich AGB stars, given that the 20 μm amorphous silicate feature is so varied and their wavelengths overlap?

Suh: We need to consider various oxides (alumina and $Fe_xMg_{1-x}O$: x=0.4-1.0) as well as silicates to fit the observations in the wavelength range for low-mass loss rate O-rich AGB stars. Among all the oxides, this work showed that the FeO dust is especially useful to fit the WISE W4 data.

https://doi.org/10.1017/S1743921318005355 Published online by Cambridge University Press