ORIGIN OF PRESOLAR GRAINS: FORMATION OF TIC CORE-GRAPHITIC SPHERULES IN CARBON-RICH AGB STARS . Takeshi Chigai, Tetsuo Yamamoto, *Department of Earth and Planetary Sciences, Hokkaido University, Sapporo 060, Japan, chigai@cosmos.sci.hokudai.ac.jp, yamamoto@cosmos.sci.hokudai.ac.jp*, Takashi Kozasa, *Department of Earth and Planetary Sciences, Kobe University, Kobe 657, Japan, kozasa@kobe-u.ac.jp.*

The transmission electron microscopic study of presolar grains extracted from the Murchison meteorite revealed the presence of metal carbide cores at the centers of the graphitic spherules [1]. One of the formation sites of these spherules is considered to be carbon-rich AGB stars (carbon stars) from their isotopic compositions. The observed core-mantle structure implies that the metal carbide acts as the nucleation center for condensation of graphite. From the condensation sequence of metal carbides and graphite, Bernatowicz et al. [1] discussed the ranges of the C/O ratio and gas pressures at the formation sites on the basis of the chemical equilibrium calculations.

Actually, however, condensation of dust particles proceeds under non-equilibrium conditions. The degree of supercooling necessary for dust formation affects the condensation sequence, depending on the energy barrier for nucleation. The TiC core-graphite mantle structure of the grains observed in the meteorites indicates that the TiC grains condense prior to graphite condensation. Furthermore, the non-equilibrium condensation theory [2][3] claims that the physical conditions prevailing at the site of dust formation are well reflected to the size of dust particles. Thus, in addition to the condensation sequence, the size of dust particle imposes more stringent constraints on the formation conditions of the observed spherules.

Applying the non-equilibrium condensation theory we investigate formation of TiC and graphite grains as well as accretion of graphite on the pre-condensed TiC grains in the gas outflows from carbon stars. On the basis of the condensation sequence and the sizes of the TiC core and graphite mantle, we shall derive the formation conditions of the TiC core-graphite mantle spherules observed in the Murchison meteorite.

Figure 1a summarizes the derived formation conditions of TiC core grains on the C/O ratio and the gas outflow velocity v necessary for realizing the condensation sequence of observed spherules to form TiC core-graphite mantle structure and the observed TiC core sizes for the given mass loss rates $\dot{M}$ and the stellar luminosity $L = 10^4\,L_\odot$. The range of the observed sizes of TiC core grains is reproduced in the region bounded by the constraints on the maximum and minimum size of the observed TiC cores and the condensation sequence, which are denoted by the labels ‘‘core max’’, ‘‘core min’’ and ‘‘c-m’’, respectively. The constraint on the condensation sequence put an upper limit of the C/O ratio 1.26−1.48 depending on the mass loss rate. The constraint on the sizes results in the relation $2.5\,10^{-3} < v^2 L_4^{1/2}/\dot{M}_5 < 0.185$, where v, L_4 and $\dot{M}_5$ are in units of km/sec, $10^4\,L_\odot$ and $10^{-5}\,M_\odot$/yr (Fig. 1b).

Figures 2a summarize the derived formation conditions of TiC core-graphite mantle spherules on the C/O ratio and the gas outflow velocity v necessary for realizing the condensation sequence of observed spherules to form the TiC core-graphite mantle structure and the observed TiC core and graphite mantle sizes for the stellar luminosity $L = 10^4\,L_\odot$; the shaded region represents the conditions for the given mass loss rate $\dot{M}$. The region is bounded by the constraints on the observed maximum radius of the TiC cores, the observed minimum radius of the graphite mantles and the condensation sequence, which are denoted by the labels ‘‘core max’’, ‘‘mantle min’’ and ‘‘c-m’’, respectively. Figure 2b shows the allowed range of the gas outflow velocity v at the formation site versus the mass loss rate $\dot{M}$ for stellar luminosity $L = 10^4\,L_\odot$. The gas outflow velocity must be in the range given by the relation that $2.5\,10^{-3} < v^2 L_4^{1/2}/\dot{M}_5 < 1.35\,10^{-2}$.

In summary, the derived conditions are that the observed spherules are produced at locations of small gas flow velocity ($v = 0.016-0.4$ km/sec) in the circumstellar envelopes of carbon stars with the mass loss rate of $\dot{M} = 10^{-6}-10^{-4}\,M_\odot$/yr. The C/O ratio ranges from 1.01 to 1.48, depending on the gas outflow velocity at the formation site of TiC core.

The derived formation conditions do not conflict with a picture of the steady-state dust driven winds from carbon-rich AGB stars; TiC condenses in the inner subsonic region prior to the condensation of graphite which could be responsible for realizing the dust driven wind. It should be remarked here that the ratio of the size of the TiC core to the size of the graphite mantle is determined only by the abundance of C available for condensation of graphite relative to Ti. The C/O ratio of 1.01−1.48 leads to the size ratio of the graphite mantle to the TiC core ranging from 3.5 to 13, whereas the size ratio of the observed spherules with the TiC-rich core [4] ranges from 10 to 30. The discrepancy between the predicted and observed size ratios is due to a possibility of incomplete condensation of Ti into TiC grains and/or the abundance of Ti in the stellar sources of observed core-mantle grains being less than that in solar.

REFERENCES: [1]Bernatowicz, T. et al., 1996, *ApJ*, **472**, 760. [2]Kozasa, T. and Hasegawa, H., 1987, *Prog. Theor. Phys.*, **77**, 1402 [3]Yamamoto, T. and Hasegawa, H., 1977, *Prog. Theor. Phys.*, **58**, 816 [4]Bernatowicz, T. 1997, *private communication*

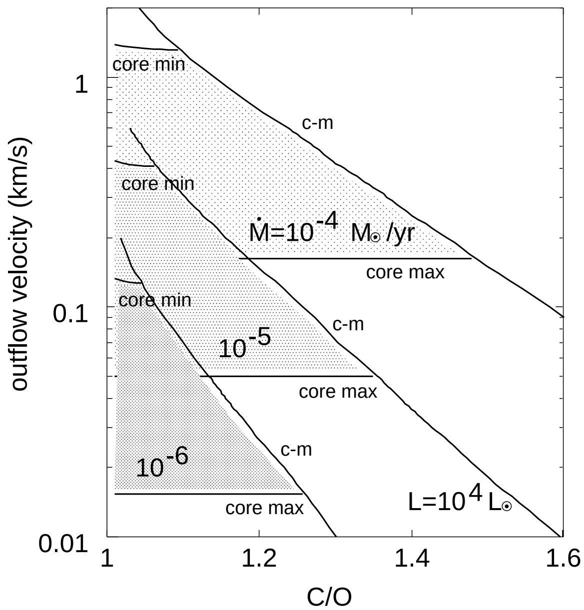

Figure 1a. The formation conditions necessary for formation of the observed TiC core grains in the C/O-v plane for given mass loss rates.

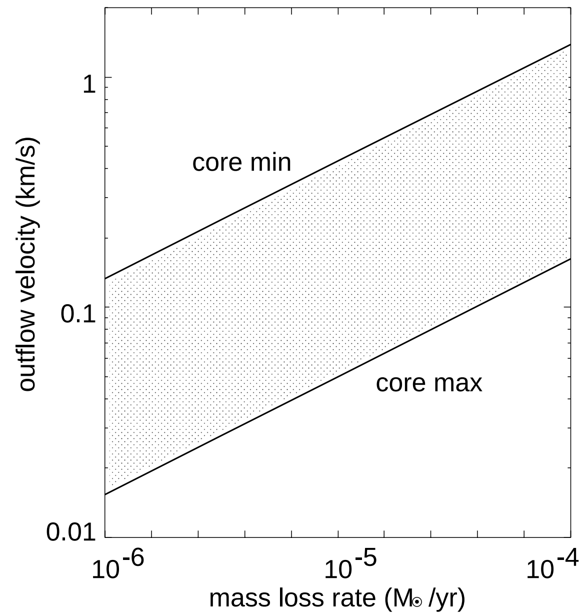

Figure 1b. The allowed range of the gas outflow velocity at the formation site versus the mass loss rate.

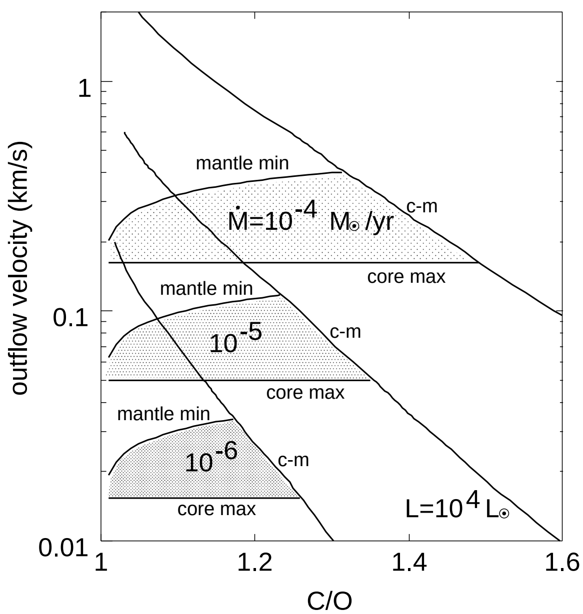

Figure 2a. The formation conditions necessary for formation of the observed TiC core-graphite mantle spherules in the C/O-v plane for given mass loss rates.

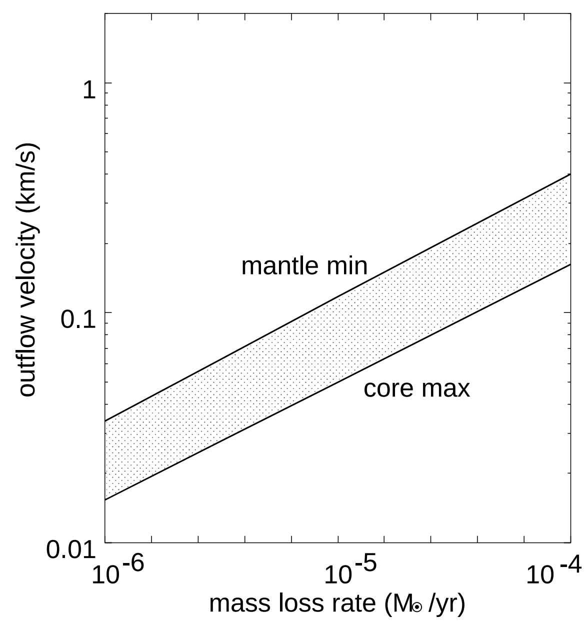

Figure 2b. The allowed range of the gas outflow velocity at the formation site versus the mass loss rate.