POSSIBLE ROLE OF THE WHITE DWARF IN GRAIN FORMATION IN CATACLYSMIC VARIABLE SYSTEMS

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ABSTRACT. We consider the possibility that carbon, in the form of the allotrope carbyne, might form in the atmosphere of the white dwarf in a cataclysmic variable system, and be expelled from the system by radiation pressure. It seems that, under some circumstances, cataclysmic variable systems may indeed have carbon dust in their vicinity.

1. Introduction

We present some very preliminary ideas about the possibility of the white dwarf in a nova or cataclysmic variable (CV) system producing dust grains or grain precursors.

2. Phase Diagram for Carbon

Zhilyaev & Zubko (1983, 1984) have calculated model atmospheres for white dwarf stars where there is a possibility of carbon condensing into liquid drops or solid particles. These are cool white dwarfs (T ~ 3500 - 7000 K), with little hydrogen ($H/He \leq 10^{-5}$) and normally abundant carbon ($C/He = 10^{-3}$, C/O ~ 1 - 10). They find that, for T ~ 5000 K, there is a layer of carbon droplets in the atmosphere, sometimes with an overlying layer of solid carbon. Leiknes & Havnes (1984) have also discussed the physical properties of dust grains (graphite, silicate and iron) in white dwarf atmospheres, including the ratio of gravitational to radiation pressure on spherical grains.

Whittaker (1978) has presented a version of the phase diagram for carbon which has a region where the formation of carbyne is thermodynamically favoured over the formation of graphite. Carbyne has a linear structure (...-C≡C-C≡C-C≡C-C≡C-C≡C-C≡C-...) rather than a planar structure like graphite. Because the ratio of cross-section to mass is much higher for a thin cylinder, a cylinder has a much better chance of being blown out of the atmosphere by radiation pressure.

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Furthermore, we might expect $Q_{pr}(\lambda)$ for cylinders of finite length to peak strongly at ~ $\lambda/4$, corresponding to "dipole" behaviour of the carbyne needle (although to date we have only considered infinite cylinders). The models of Zhilyaev & Zubko overlap the carbyne region (allowing for differences in the assumed triple point for carbon, still a contentious value); our assumed phase diagram for carbon, which is based mainly on Whittaker (1978), is shown in Fig. 1, together with the locus of white dwarf model atmospheres given by Zhilayev & Zubko.

3. Gravity and Radiation Pressure

We suppose that the carbon grains that form high in the atmosphere of the white dwarf are needle-like in form. We have calculated $\langle Q_{pr}(T)\rangle$, the planck mean radiation pressure, averaged over a random grain orientation, for a number of infinite cylinders. The approximation to cylinders of finite length should be valid as long as the length of the cylinder is very much greater ($\gtrsim$ 100 ×) than its radius. We find that the ratio ρ of radiation pressure (F_{pr}) to gravitational (F_g) forces on a cylindrical grain of radius $\underline{a}$ is

$$\rho \sim 2.5 \times 10^{-2} \, (Q_{pr}/1)(R_{wd}/10^4 \mathrm{km})^2 \, (T_{wd}/5000 \mathrm{~K})^4 \times$$
$$\times \, (M_{wd}/1 \, M_\odot)^{-1} \, (a/10 \mathrm{~A})^{-1}.$$

We see that, even for a grain of radius 10 A (10^{-3} μm), gravity generally overcomes radiation pressure for cylinders, as it does in the case of spherical grains (Zhilyaev & Zubko 1984; Leiknes & Havnes 1984).

However, in the case of a non-polar cataclysmic variable system, the white dwarf is surrounded by an accretion disk and there is a possibility that the luminosity of the accretion disk can provide sufficient additional radiation pressure to drive a grain out of the binary system. We have used the temperature gradient of a standard steady state accretion disc (e.g. Pringle 1981) to estimate the radiation pressure on a grain in the vicinity of the CV system. If we approximate the accretion disk by an infinite flat plate, the radiation pressure efficiency, averaged over the flux distribution of the accretion disk, is ~ $\beta \langle Q_{pr}(T_o)\rangle$, where T_o (~ 35000 K) is the maximum temperature in the disk and $\beta \simeq 0.2$. If a grain can be transported out of the white dwarf atmosphere initially (e.g. by convective turbulence in the non-degenerate surface layers, a flare or a "cool" wind), we find that there may be several CV systems in which the combined radiation pressure of the accretion disk and white dwarf can blow grains out of the system very effectively. Indeed in some cases the radiation pressure from the accretion disk can dominate over that from the white dwarf and in this case

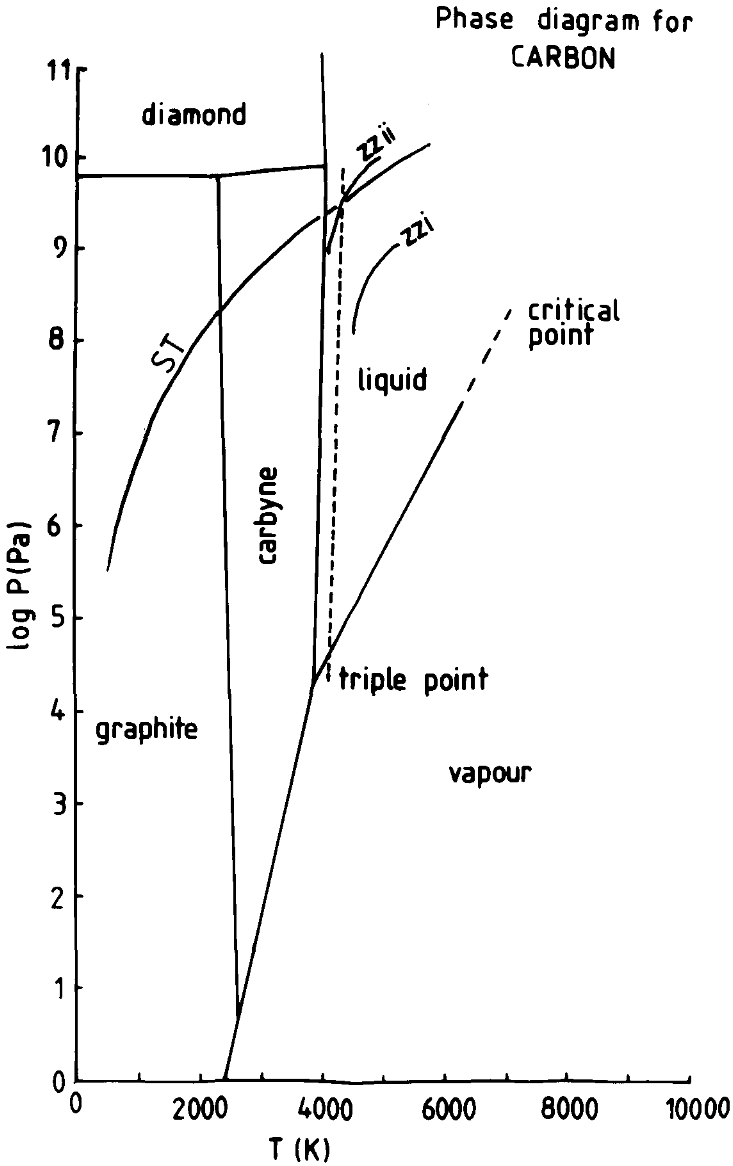

Fig. 1: Assumed phase diagram for carbon, based mainly on Whittaker (1978), and modified by Zhilayev & Zubko (broken curve). Curves marked ZZ represent white dwarf model atmospheres of Zhilayev & Zubko; curve marked ST represents the model atmosphere in Shapiro & Teukolsky (1983), scaled to coincide with the "ZZii" curve.

$$\rho \simeq 2.6\ (\Sigma/0.01\ \mu m^2)\ (m_g/10^{-14} g)\ (\dot{M}/10^{17} g\ s^{-1}) \times$$
$$\times\ (R_*/10^4 km)\ \beta \langle Q_{pr}(T_o)\rangle$$

Here Σ and m_g are the grain geometrical cross-section and mass respectively, $\dot{M}$ is the mass transfer rate and R_* is the white dwarf radius. Clearly for small grains and white dwarf masses $\gtrsim 0.5\ M_\odot$ radiation pressure can overcome gravity. Reference to the phase diagram (Fig. 1) suggests that, as carbyne whiskers recede from the system and cool down, a phase transition to graphite (or some other allotrope of carbon) is likely to occur. However if rapid cooling occurs the carbon will remain in carbyne form. These remarks also apply of course to grains that may originate in the cooler regions of the accretion disk itself, where the density may in some cases be high enough to encourage grain formation.

4. Possible Consequences

On the basis of the above discussion, it is possible that some non-polar CV systems may possess circumstellar dust shells, the composition of which may reflect the nature of the white dwarf or of the secondary. Indeed for those cases in which grains originate in the accretion disk the circumstellar dust shell may be transient, as mass transfer (and hence the density of the accretion disk) varies with time.

Furthermore, in classical nova systems, this process may provide grain precursors or nucleation centres, on which larger grains might grow during a classical nova outburst. The understanding of grain formation in novae is hampered by the difficulties of initial nucleation (see Callus et al., this volume); pre-exising carbyne whiskers, such as may be produced by the process discussed here, may provide suitable nucleation centres well before the nova outburst itself.

The possible existence of carbyne in CV systems may perhaps be tested by infrared spectroscopy of systems in which the accretion disk is seen "face on". Carbyne needles are expected to have features in the 2 - 6 μm wavelength range, resulting from the stretching mode. Suitable observations would be valuable to test these ideas.

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