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The importance of being stable: New results about the survival of PAHs in extreme astrophysical environments

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Abstract. Increasing observational evidence shows that a non-negligible fraction of the cosmic carbon is locked into macromolecules like Polycyclic Aromatic Hydrocarbons (PAHs). Interstellar PAHs live in extreme environments where there are processed by energetic photons (UV and X-rays) and by ions and electrons accelerated in hot shocked plasma and arising from cosmic rays. It is therefore important to quantify the capability of PAHs to survive under these extreme conditions and to determine the structural modifications induced by such energetic processing. I will present some novel results on this topic, focusing on the bombardment by ions and electrons in interstellar shocks. This work shows the importance of pairing an appropriate physical description of the interaction between target and projectiles with updated laboratory measurements of the relevant physical parameters. The results from physical modeling allowed to derive updated astronomical lifetimes for PAHs.

Keywords. shock waves, dust, extinction, supernova remnants

1. Introduction

Polycyclic Aromatic Hydrocarbon (PAH) molecules have been proposed as carriers of the Aromatic Infrared Bands, their emission is used as a tracer, e.g., of star formation, and they provide catalytic surfaces for the formation of molecules like H_2. PAHs are heavily processed by interstellar shocks generated by supernova (SN) explosions. In the shocked gas, the molecules are bombarded by ions (H, He, C) and electrons. This might result in damaging and destruction. The aim of this work has been to re-evaluate the lifetime of PAHs in shocks using the measurements of relevant physical parameters which have recently become available.

2. Modelling

When PAHs enter interstellar shocks, they are bombarded by ions which have to specific velocity profiles. The first one, identified as inertial profile, is due to the relative velocity between the ions and the PAHs resulting from the bigger inertia of the molecules with respect to the projectile ions. The second one, identified as thermal profile, is due to the thermal velocities which the ions acquire in the hot shocked gas. Our shock velocities range from 50 to 200 km s^{-1}, resulting in gas temperatures of the order of 10^4-10^5. For the projectiles, these correspond to inertial velocities between 10 eV and 3 keV and to thermal velocities between 5 and 50 eV.

If the energy transferred to the target in a binary collision exceeds the threshold value T_0, a single carbon atom will be removed from the target, causing damage to the aromatic structure of the PAH. Because of the lack of measurements for T_0, in Micelotta *et al.* (2010) we adopted a reasonable maximum value of 15 eV. The work from Stockett *et al.* (2015) now provides an experimental value, $T_0 = 23.3$ eV, together with an estimate from Molecular Dynamics simulations, $T_0 = 27$ eV. We used these data to re-evaluate the cross section for single carbon ejection, necessary to estimate the PAH lifetime in shocks.

3. Results and Conclusions

The newly determined cross sections for single carbon atom ejection have been used to calculate the fractional carbon atom loss as a function of the shock velocity, adopting the formalism developed in Micelotta *et al.* (2010) for PAHs containing 50 and 200 carbon atoms. With this is hand, we calculate the timescale, $t_{\rm PAH}$, for supernova shocks to destroy interstellar PAHs in the Galaxy, using the method of McKee (1989):

$$t_{\rm PAH} = \frac{M_{\rm ISM}}{(1/\tau_{\rm SN}) \int \varepsilon(v_{\rm S})\, {\rm d}M_{\rm S}(v_{\rm S})} \tag{3.1}$$

where $M_{\rm ISM} = 4.5{\times}10^9\, M_{\rm SUN}$ is the mass of the Galactic interstellar medium (gas and dust including PAHs), $\tau_{\rm SN} = 125$ yr is the effective interval between supernovae McKee (1989), $\varepsilon(v_{\rm S})$ is the efficiency of PAH destruction by a shock of velocity $v_{\rm S}$, for which we adopt our calculated fractional C-atom loss, and $M_{\rm S}$ is the mas of gas shocked to at least $v_{\rm S}$ by a supernova remnant in the Sedov-Taylor stage.

The resulting lifetimes are $t_{\rm PAH} = 8.7{\times}10^8$ yr and $t_{\rm PAH} = 7.7{\times}10^8$ yr for PAHs with 50 and 20 C-atoms respectively. These results have to be compared with the timescale for PAHs formation and injection into the ISM, which is $\sim 2.5{\times}10^9$ yr (Jones *et al.* 1996). The new PAH lifetimes against ion bombardment are longer than those previously estimated by Micelotta *et al.* (2010) because of the higher value of T_0, but they are still shorter than the injection timescale. In addition, we find that PAHs in shocks are still efficiently destroyed by electrons, for which the lifetimes are $1.6{\times}10^8$ yr (50 carbon atoms) and $4.3{\times}10^8$ yr (200 carbon atoms). The conclusions from our previous work still hold and therefore a reformation and/or protection mechanism is required to explain the ubiquitous presence of PAHs indicated by observations. We find that small PAHs are more affected by electrons while large PAHs are more affected by ions. An important conclusion is that the results obtained taking into account astrophysical conditions might be very different from what can be expected in a terrestrial laboratory. This is exemplified by the role of carbon, whose very low abundance makes it ineffective in space despite the highest cross section for C ejection in PAHs.

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