Uncovering Early Galaxy Evolution in the
ALMA and JWST Era
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Lyα generation in intermediate velocity shock waves

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Abstract. We update the Paris-Durham shock model, a state-of-the-art magnetohydrodynamic (MHD) shock code developed with a focus on molecular chemistry, in order to account for the self-generated UV field produced in shocks at velocities in the range 25-50 km/s. In these shocks there is significant excitation of atomic Hydrogen, with a large flux of Lyα photons escaping ahead of the shock to heat, ionize and drive molecular chemistry in a large slab of preshock gas.

Keywords. Lyα, shock waves, UV

Introduction

Recent ALMA observations of CH^+ emission from a sample of high redshift starburst galaxies (Falgarone *et al.* 2017) have uncovered molecular gas with extreme velocity dispersions (∼1000 km/s). The presence of molecules at such high velocities is difficult to explain, as shocks at these speeds produce an X-ray emitting hot plasma devoid of H_2. However, a picture has emerged of large-scale outflows triggering a turbulent cascade in a multiphase medium with significant mechanical energy dissipating in molecular shocks at much lower velocities (Lesaffre *et al.* 2013).

Paris-Durham Shock Code

The Paris-Durham public† shock code (Flower & Pineau des Forêts 2015) solves the steady-state plane-parallel MHD equations coupled with chemical equations using an extensive reaction network appropriate to the insterstellar medium. The latest version is described in Godard *et al.* (2019). In molecular shocks with velocities $V_s \gtrsim 25$ km/s, collisional dissociation destroys H_2 and the region where atomic H starts to dominate is where the majority of the UV production takes place. To overcome computational challenges caused by extreme optical depths, we have implemented an accelerated Λ-iteration scheme to solve for the radiative transfer of a 3-level hydrogen atom to compute the Lyα (1216 Å), Lyβ (1026 Å) and 2-photon continuum emission. Fig. 1 shows temperature profiles of shocks with velocities 25-50 km/s propagating into molecular gas at $n = 10^4$ cm^{-3}. The emergent UV radiation is strong enough in these shocks to produce a warm slab (∼100 K) of molecular gas over $\sim 10^{17}$ cm. Shocks with velocities 30 km/s and under produced negligible UV.

Lyman-α and other chemical probes

In fig. 2 (left) we show Lyα spectra at three positions in a representative 40 km/s shock: emerging from the shock front (black), deep in the postshock (blue), and in the preshock

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† available on the ISM platform https://ism.obspm.fr

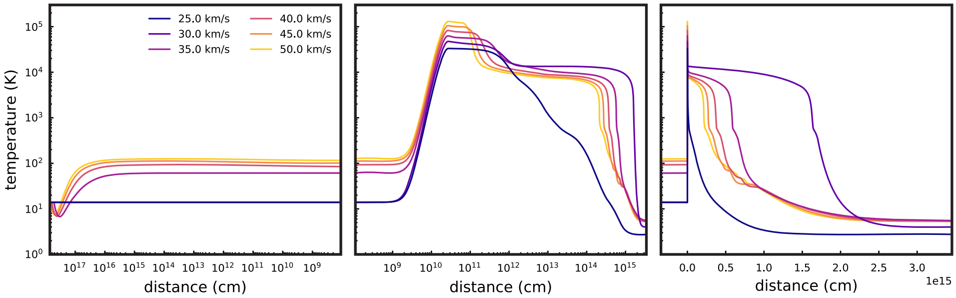

Figure 1. Temperature profiles of shocks from 25-50 km/s propagating into molecular gas at $n = 10^4$ cm^{-3}. (Left) preshock, with distance measured from the shock front in log scale, (middle) postshock in log scale (right) postshock in linear scale.

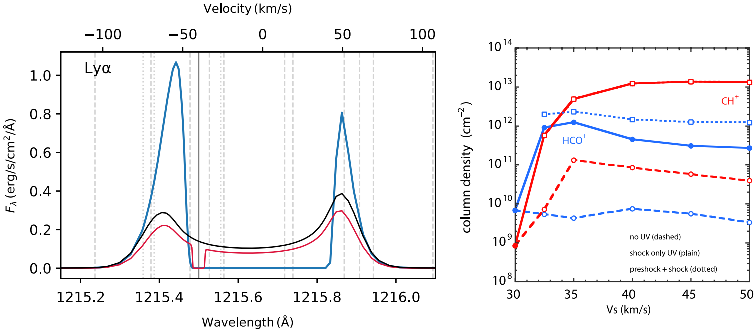

Figure 2. (Left) Lyα profiles at three positions in a 40 km/s shock. (Right) Column densities of CH$^+$ and HCO$^+$.

(red). The solid grey vertical line shows the Lyα central wavelength doppler shifted by the shock velocity, and the fainter vertical lines show line centres of H_2 Lyman and Werner band rovibrational lines. The cold hydrogen in the preshock cannot significantly attenuate the broad shock emission, and so the size of the preshock is determined by dust absorption. The photoelectric effect due to these Lyα absorptions causes the preshock heating to ∼100 K seen in fig. 1. Photodissociation by the UV radiation can heavily affect the abundances of several species both inside and ahead of the shock. In fig. 2 (right) we show how column densities of CH$^+$ and HCO$^+$ vary with shock velocity including (solid) or not including (dashed) the self-generated UV. These column densities increase by orders of magnitude at these velocities, showing the importance of treating Lyα in these shocks. Recent ALMA observations of CH$^+$ in high-z starburst galaxies (Falgarone *et al.* 2017) may require these kind of shocks to be explained.

References

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