Inference of the Shock-Type of L1157-B2 Based on the Desorption of Complex Organic Molecules

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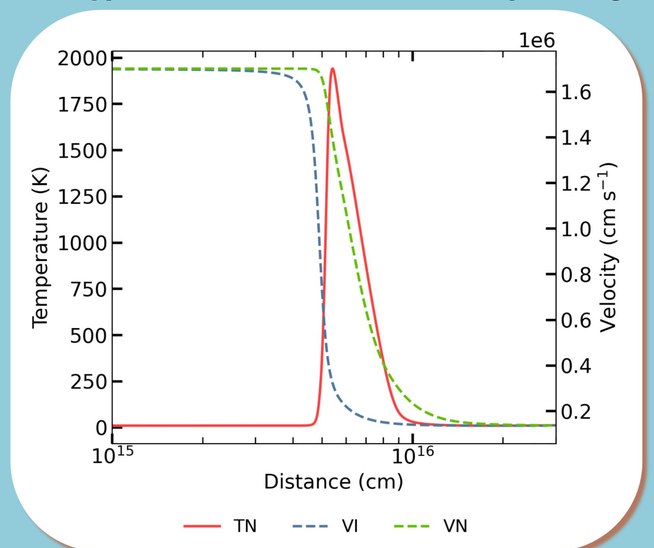
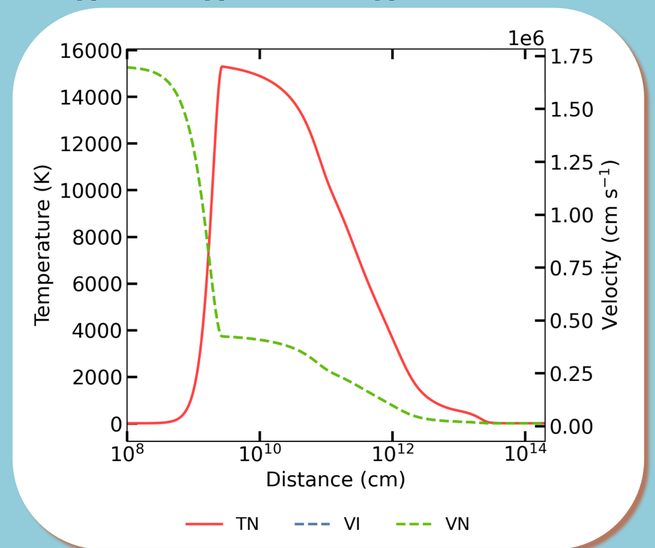
Introduction

There are four types of interstellar shocks depending on the physical conditions: C-type, CJ-type, and J-type with/without irradiation.



C-type (or CJ-type*) shocks

- Long Distance
- Low Temperature
- Presence of a strong magnetic field
- Low fraction of ionization
- Decoupling between Ions and Neutrals leading to an Ion-Neutral Drift
- Not Irradiated for a C-type shock and Irradiated for a CJ-type shock



J-type shocks

- Short Distance
- High Temperature
- Presence of a low magnetic field
- Coupling between Ions and Neutrals
- With irradiation or not

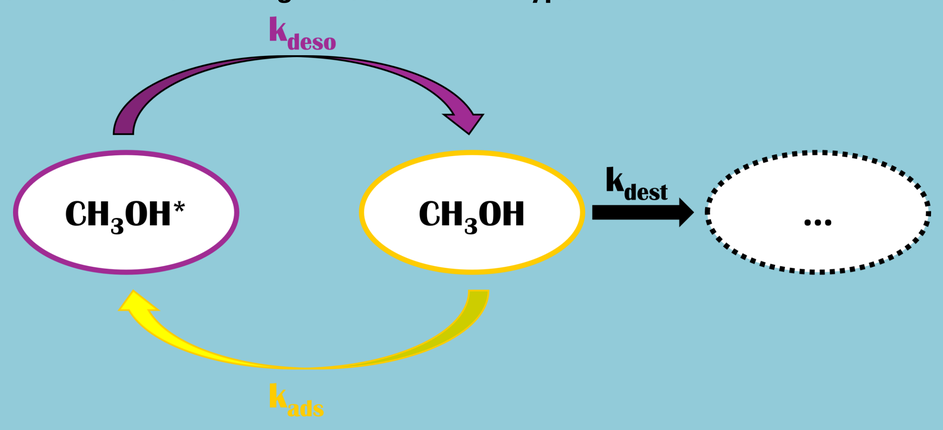
The diagnosis of the shock-type is not straightforward due to the lack of observations. For instance, L1157 B2—an old shock near a protostar—is still poorly constrained, with an undetermined shock-type. Nevertheless, peculiar physical conditions lead to chemical differentiation of the shock types. We proposed a new method based on methanol desorption to diagnose shocks and more particularly L1157 B2.

Methods

Desorption of Complex Organic Molecules (COMs) mainly formed in the icy mantle phase such as methanol is found to be highly shock-type dependent. Moreover, for a specific category of COMs, their post-shock chemistry is simpler than for species formed in the gas phase and can be reduced to desorption, adsorption, and destruction processes, making them less dependent on the chemical network. We highlighted that COMs presenting the following caracteristics belong to this category and should be envisaged as potential shock type tracers:

- The molecule does not undergo enhanced formation/destruction in the gas and the ice phase before sputtering;
- The gas phase abundance of the molecule at the sputtering peak is representative of the ice phase abundance before sputtering;
- The hot gas-phase chemistry does not significantly impact the gas-phase abundance of the desorbed species.

Simulations were done using the Paris-Durham Shock code [1] to follow the evolution of methanol abundances through the four shock types.



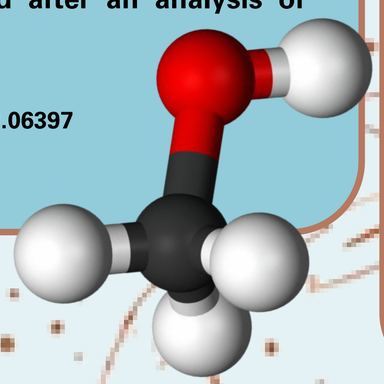
Reduced chemical network of gas phase (CH_3OH), icy mantle phase (CH_3OH^*) methanol and subproducts (...).

Making use of easily observable data, i.e. post-shock gas phase methanol abundance and pre-shock icy mantle phase methanol abundance, we computed the average desorption percentage $\%_{deso}$ in the post-shock region following:

$$\%_{deso} = \frac{\chi_{post-shock}[CH_3OH]}{\chi_{pre-shock}[CH_3OH^*]} \times 100\%$$

and compared it with real values for L1157 B2 (± 73%) obtained after an analysis of astrochemical modeling [2] and observations [3].

[1] Godard, B., Pineau des Forêts, G., Lesaffre, P., et al. 2019, A&A, 622, A100
[2] Lu, Y., Quan, D., Chang, Q., Chen, L.-F., & Li, D. 2024, arXiv e-prints, arXiv:2412.06397
[3] Bachiller, R. & Pérez Gutiérrez, M. 1997, ApJ, 487, L93
[4] Faure, M., Bacmann, A., Faure, A., et al. 2025, A&A, 693, A30



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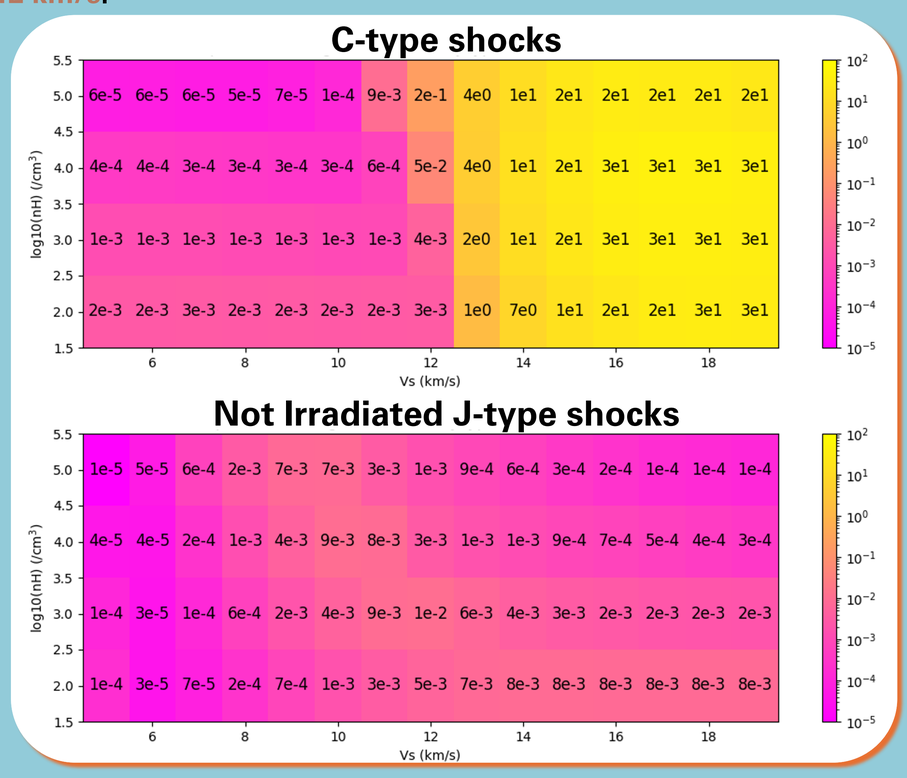
Results and Discussion

From our simulations, only non-irradiated C-type shocks can afford the high desorption percentage of methanol in L1157 B2. It has been concluded that this region is likely a non-irradiated C-type shock with shock velocity (Vs) higher than 12 km/s.



Desorption percentage of methanol in non-irradiated shocks

Pros

Methanol (and potentially similar COMs) is a good shock-type tracer. Indeed, its desorption percentage:

- Is almost independent on initial conditions due to the linearity of the system;
- Presents a good contrast between each shock type as compared to previous, non-linear techniques;
- Is weakly model-dependent as it does not depend on the entire chemical network.

Further Developments

While L1157 B2 is well identified as a C-type shock, further progresses should be made to increase the contrast between the other types:

- Enhancing the chemistry on grains and the completeness of the chemical network;
- Including binding energy distributions instead of single values;
- Including fragmentation after desorption, which has been postulated to be at work for CH_3OH in [4];
- Evaluating other COMs as potential shock tracers.