UV Dose Rates in Parsamian Cometary Nebulae

Energetic Processing of C_2H_2, H_2CO & CH_3OH via Cosmic-Ray-Induced Irradiation

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Eruptive YSO Workshop
Konkoly Observatory, Budapest, Hungary
May 18–22, 2026

Introduction

The study demonstrates that collapsing Parsamian nebulae accumulate ionization doses more than an order of magnitude higher than static clouds because of density-enhanced Prasad–Tarafdar UV production, a result validated by Cloudy simulations. Acetylene is identified as the most sensitive and chemically important species, efficiently driving both PAH and prebiotic isoprene formation pathways, while secondary electrons dominate chemistry in the densest inner cores. The calculated doses exceed laboratory thresholds for glycine and isoprene precursor synthesis, indicating that collapsing Parsamian nebulae — particularly Pa 21 — provide favorable environments for prebiotic molecule formation and future observations with James Webb Space Telescope.

Key Numerical Results

- Static cloud dose: ~10^3 eV/molecule over 10^6 years
- Collapsing core dose: up to 10^4–10^6 eV/molecule
- Glycine formation threshold: ~9.5 eV/molecule → exceeded in all scenarios
- Isoprene precursor regime: reached at ≥ 10^3 eV/molecule eV/molecule (only in collapsing cores)

Objective

To investigate whether cosmic-ray–driven irradiation and secondary UV fields in collapsing Parsamian nebulae can provide sufficient energy for the formation of complex organic and prebiotic molecules.

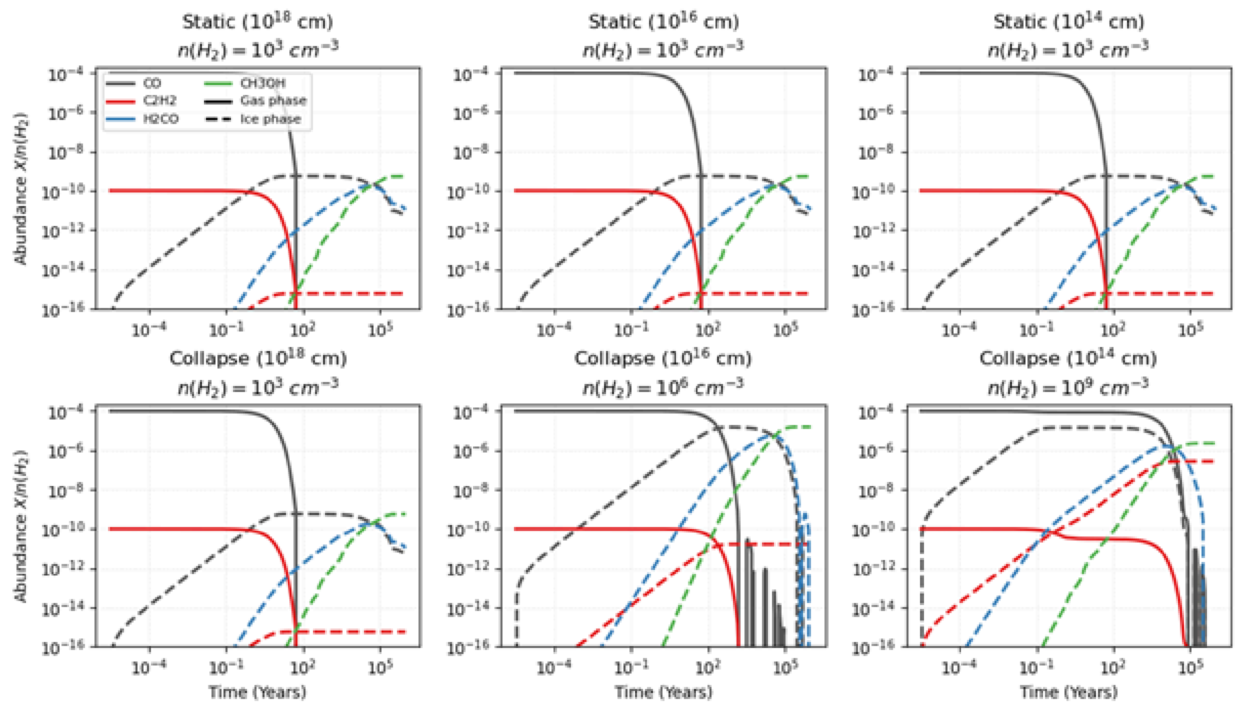


Fig. 1. Gas/ice evolution (CO, C_2H_2, H_2CO, CH_3OH) at 10^{18}–10^{14} cm: collapse drives transition from gas-phase chemistry to freeze-out and late desorption ($10^3 \rightarrow 10^9$ cm^{-3}).

Results

Collapsing cloud cores accumulate UV doses exceeding 10^4 eV molecule^{-1}, surpassing laboratory thresholds for glycine and isoprene precursor formation.

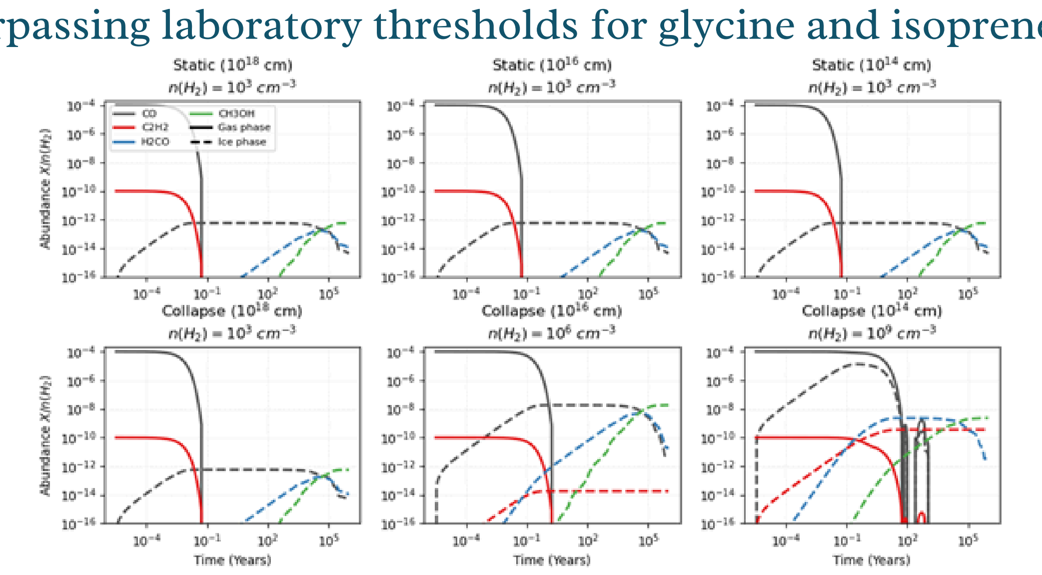


Fig. 2. Same as Fig. 1 at higher CRIR (10^{-13} s^{-1}): enhanced ionization accelerates C_2H_2 depletion and shifts r = 10^{14} cm toward ice-dominated chemistry (Parsamian 21 conditions).

Methods

We model two environments typical of Parsamian nebulae: a static cloud (constant density n(H2)=103 cm−3n(\mathrm{H}_2)=10^3\ \mathrm{cm}^{-3}n(H2)=103 cm−3) and a collapsing core with n(r)∝r−1.5n(r)\propto r^{-1.5}n(r)∝r−1.5 reaching 109 cm−310^9\ \mathrm{cm}^{-3}109 cm−3. The internal UV field from cosmic-ray–induced H_2 excitation is computed using the Padovani et al. (2024) formalism and checked with Cloudy.

Molecular evolution of C_2H_2, H_2CO, and CH_3OH is simulated in Python using the UMIST reaction network over 10610^6106 years.

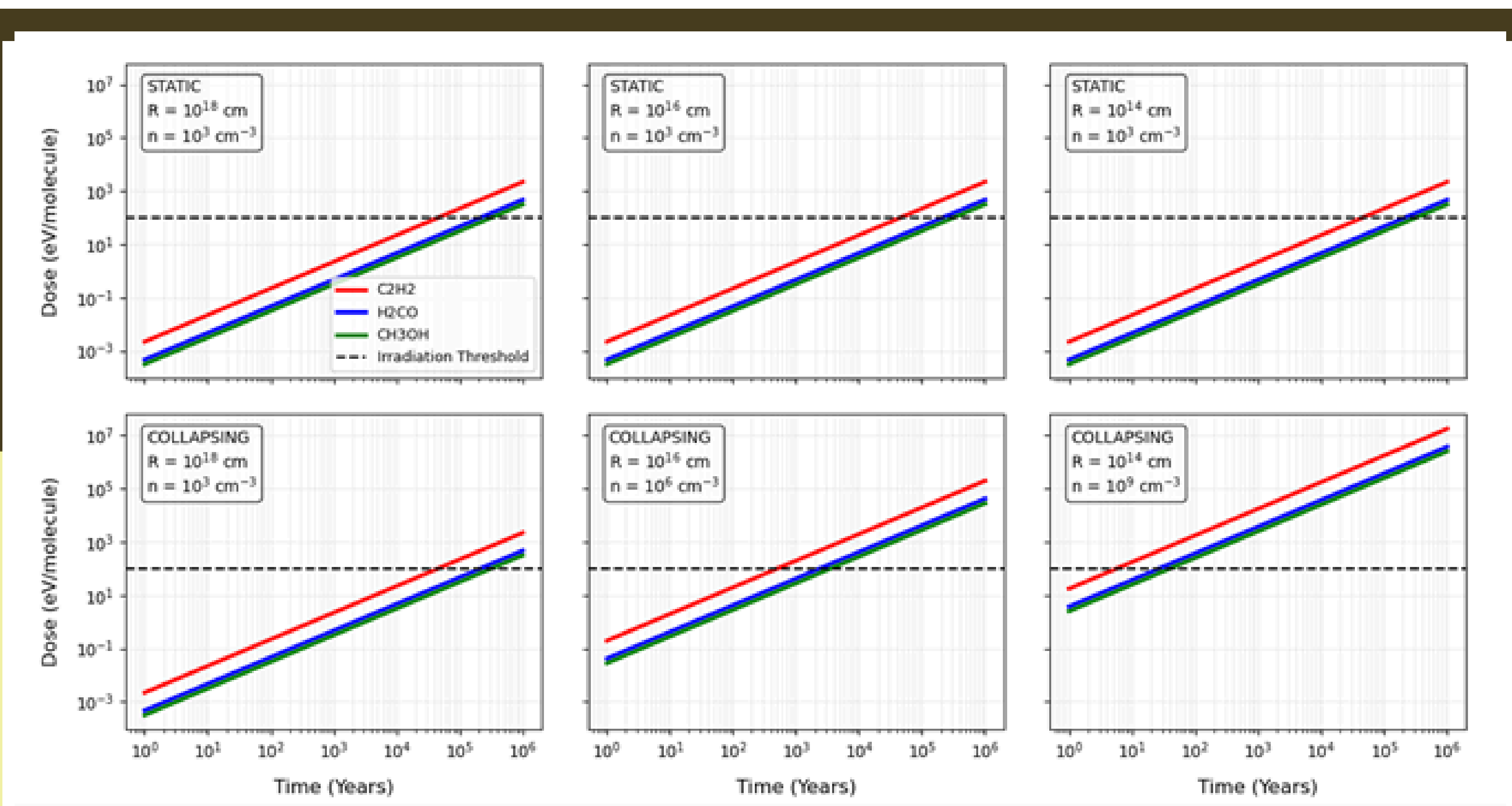


Fig. 3. UV dose vs time for C_2H_2, H_2CO, CH_3OH (10^{18}–10^{14} cm, CRIR = 10^{-16} s^{-1}): collapsing cores at 10^{14} cm rapidly reach ~100 eV molecule^{-1} within 10^4–10^5 yr, exceeding the glycine threshold.

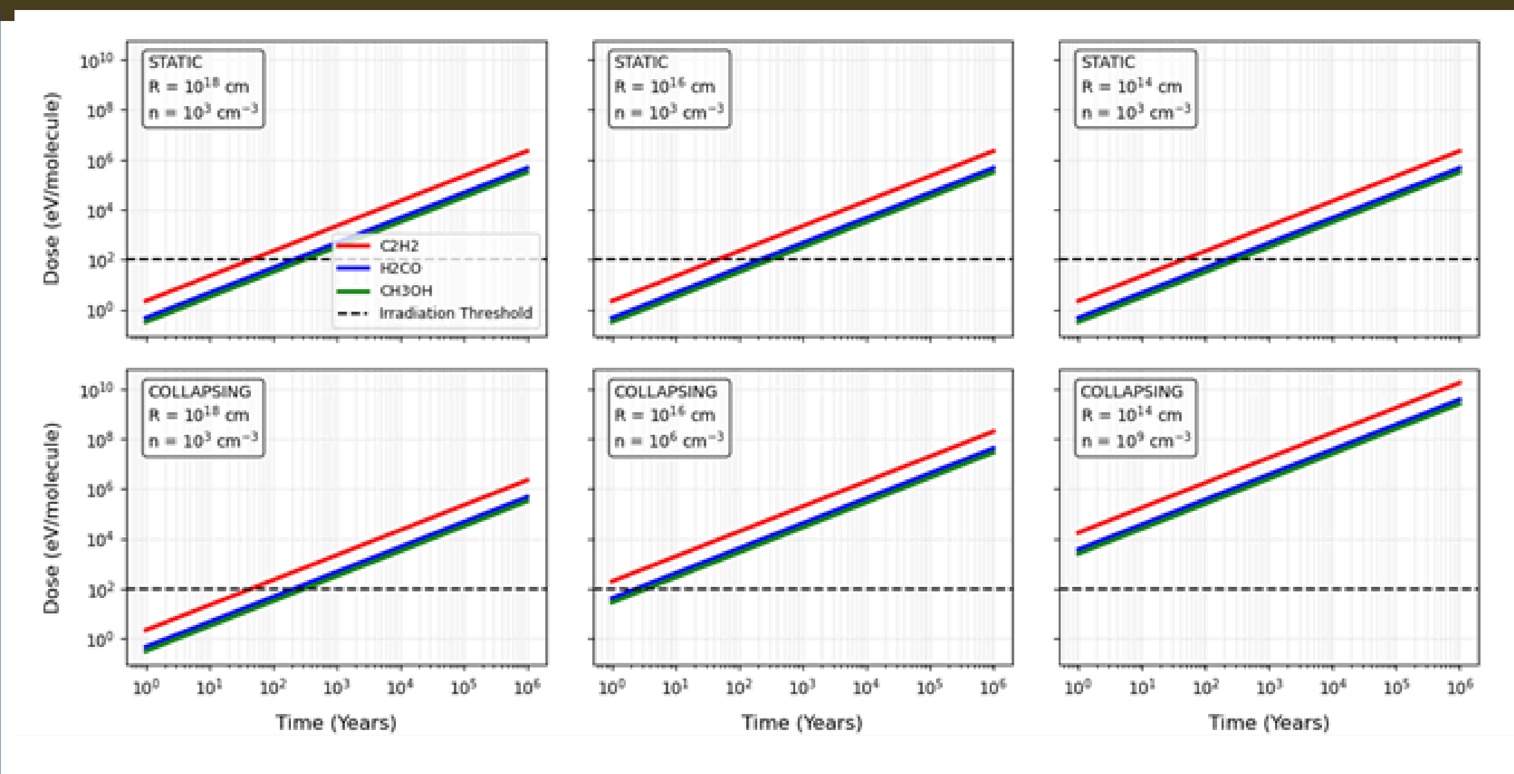


Fig. 4. UV dose vs time (C_2H_2, H_2CO, CH_3OH; r = 10^{18}–10^{14} cm, CRIR = 10^{-13} s^{-1}): doses increase ~10×, with C_2H_2 highest, reaching up to ~10^6 eV molecule^{-1} in collapsing cores, far above formation thresholds.

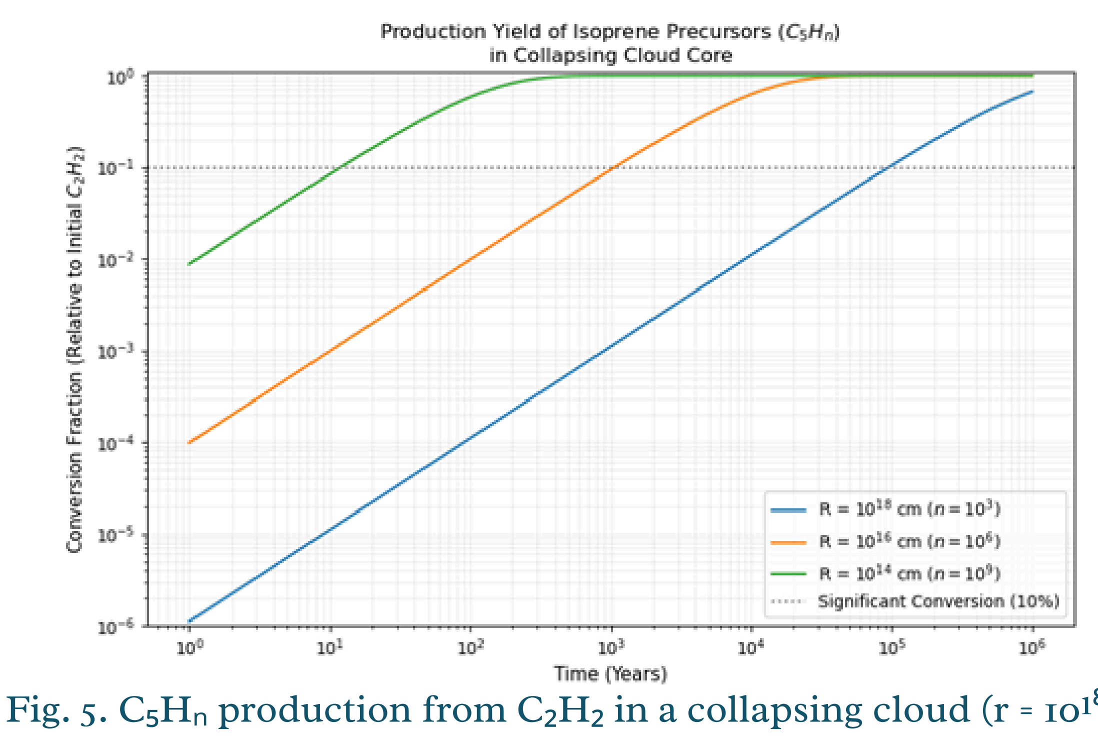
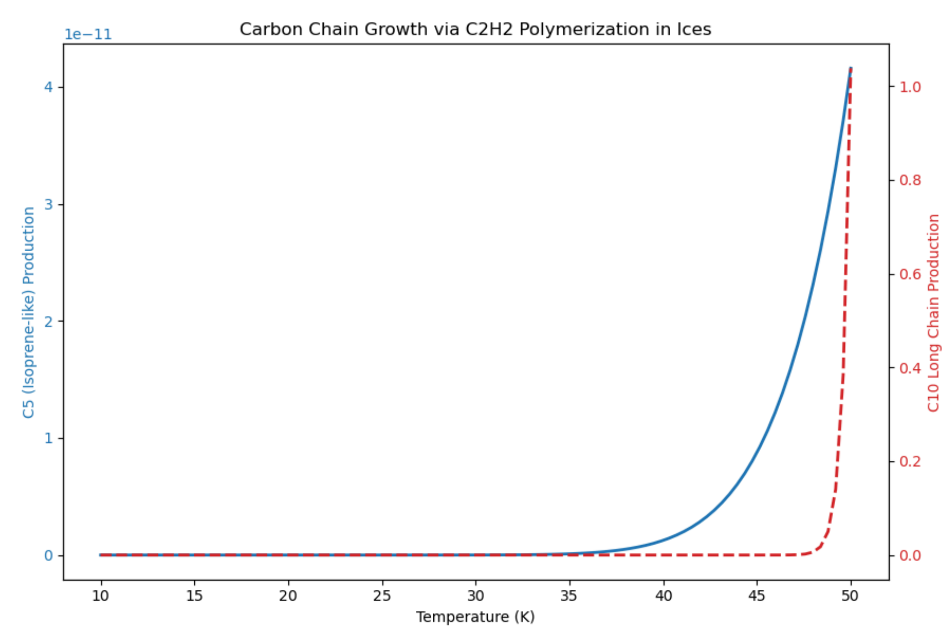


Fig. 5. C_5H_n production from C_2H_2 in a collapsing cloud (r = 10^{18}–10^{14} cm, n = 10^3–10^9 cm^{-3}): 10% conversion reached in ~10^2 yr at 10^{14} cm, slower (~10^5 yr) in outer regions, showing efficient isoprene precursor formation in dense cores.

Conclusion



The dense collapsing environments of Parsamian cometary nebulae are energetically favorable sites for complex prebiotic chemistry and future astrochemical observations.