The Evolution of Ionization Fronts and PDRs at Low Metallicity: Preliminary Simulations and Comparison with JWST Observations

Atharv Patade, Sebastian Vider, Stefanie Walch
I. Physics Institute, Universität zu Köln
Contact : patade@ph1.uni-koeln.de

I. Introduction

Motivation

PDRs are the boundary where hot ionized gas meets cold molecular clouds. We still don't fully understand their structure. Recent JWST observations now allow us to probe low metallicity PDRs, which can give us new insights about their structure. It gives an opportunity to compare our simulations with observations.

Why Metallicity matters?

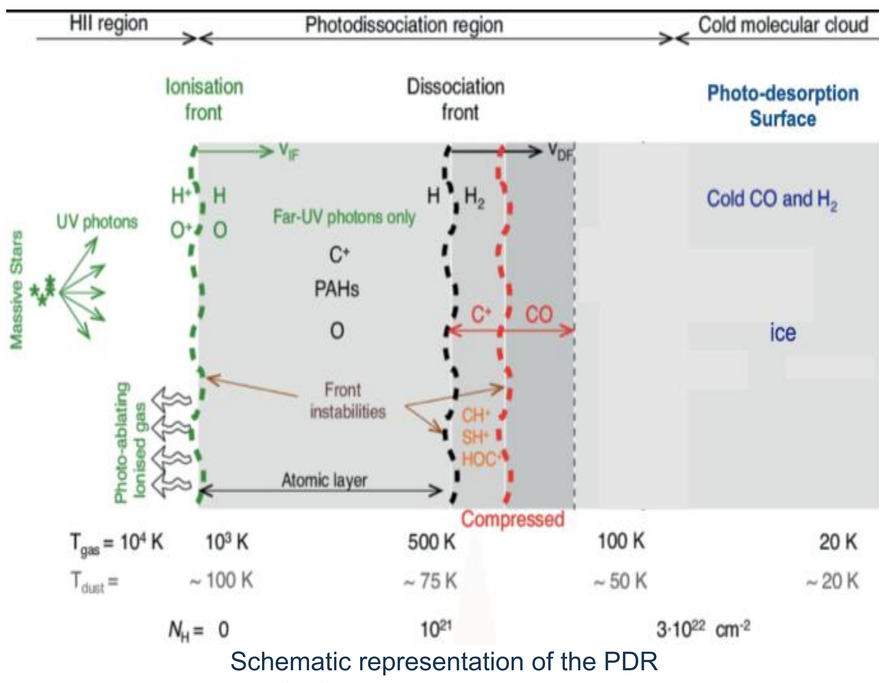
A lower dust-to-gas ratio, less C and O, leads to weaker shielding and cooling. This affects the chemistry and structure of PDRs. At low metallicities, the thickness of PDRs gets extended, which means that the separation between the H/H_2 and the C/CO transition increases, increasing the extent of **CO dark $\mathbf{H}_2$**.

What are PDR's?

Photon dominated regions (PDRs) are interstellar regions where stellar far-ultraviolet (6eV-13.6eV) radiation dominates the physical and chemical structure of the ISM. PDRs are the result of the strong feedback from massive young stars acting on their parental clouds and hence closely related to the process of star formation.

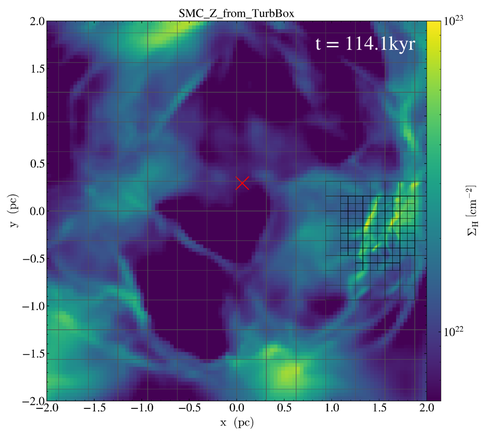
Goal

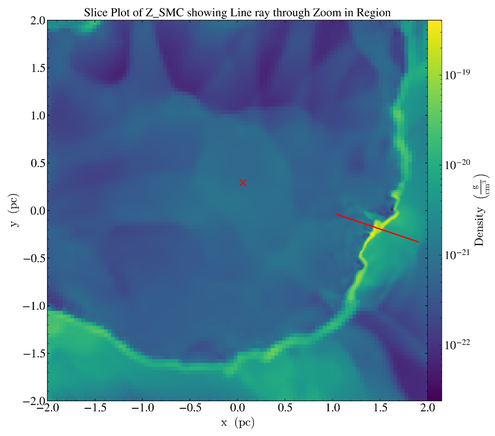
We investigate how ionization fronts and PDRs evolve at low metallicities using radiation hydrodynamical simulations with FLASH, and compare the results with JWST observations of the N13 region.



Schematic representation of the PDR
Tielens, A.G.G.M. (2023). Physics and Chemistry of PhotoDissociation Regions

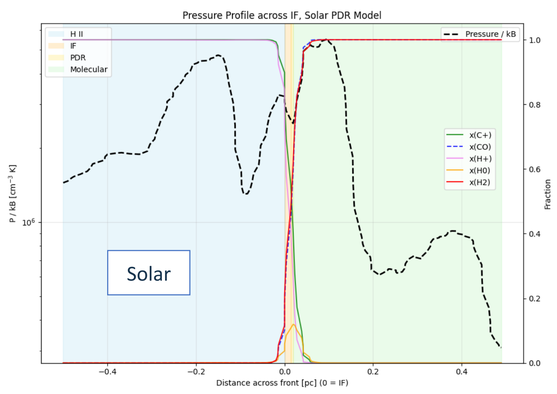
II. Simulation Setup

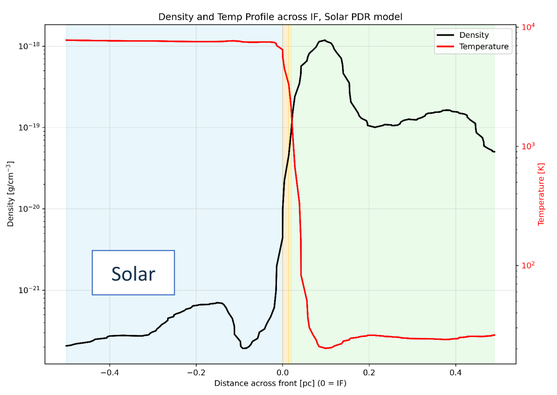


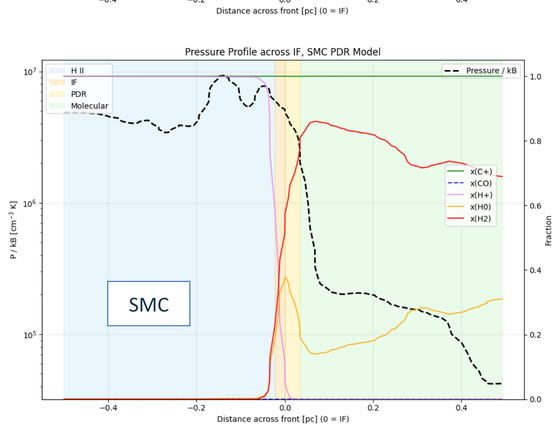


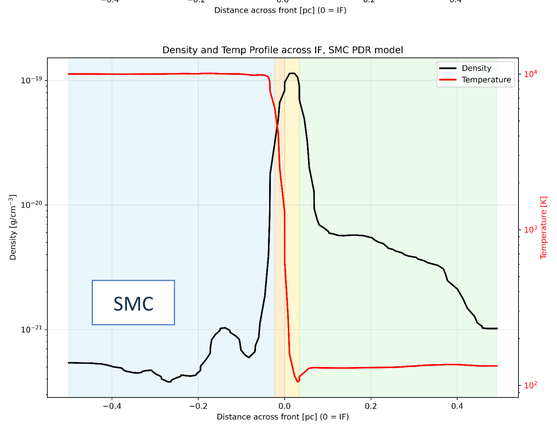
- Code - FLASH Hydro simulation
- Self-gravity, radiation transport of Extreme Ultra-violet(EUV) and Far Ultra-Violet(FUV)
- Non equilibrium chemistry of $\mathrm{H}, \mathrm{H}_2, \mathrm{H}^+, \mathrm{C}^+, \mathrm{CO}, \mathrm{O}$ and e^-. Chemistry module does the heating and cooling.
- We run two simulations with $Z_\odot$ and Z_{SMC} = 0.2 x $Z_\odot$.
- Turbulent box with n = 1000 cm^{-3}
- Turbulent velocity $\mathrm{v_{rms}}$ = 1 km/s
- Adaptive grid, Zoom in region (ZIR) on high density clump with resolution dx = 0.01 pc.
- Star with 36 $M_\odot$ marked as X.

III. Results



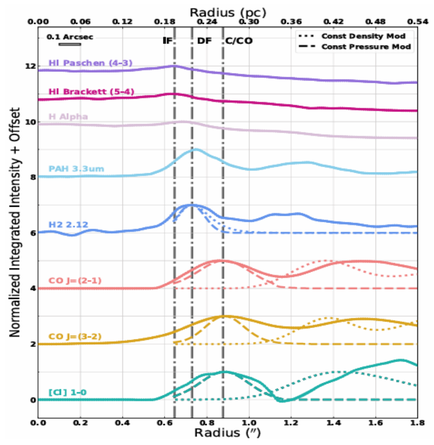






- Here we show pressure, density and temperature profiles of our $Z_\odot$ and Z_{SMC} simulations.
- We used fractional thresholds of $\mathrm{H}^+, \mathrm{H}\ \&\ \mathrm{H}_2$ to mark the boundaries of IF and PDR. We used H_2 fractions between 0.1-0.8 to mark the extent of the PDR.
- These profile plots are useful for understanding the chemistry happening in the PDR.
- As expected, we see that the SMC PDR is more extended than Solar PDR.
- Our results show that neither constant density nor the constant pressure models capture the complexity of real PDR.
- For SMC metallicity, higher densities are needed to form CO, which we were not able to reach in our simulations.

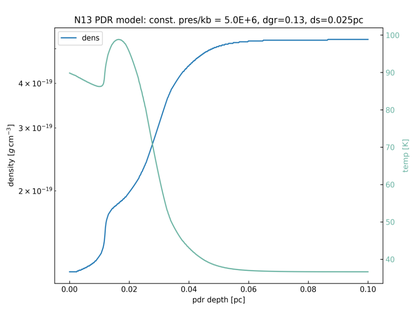
IV. JWST Comparison

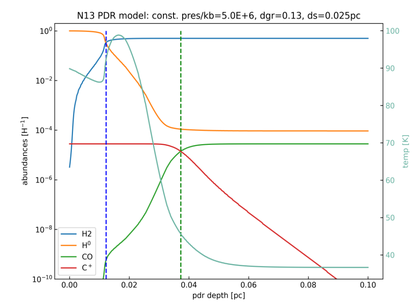


PDR Layer Separations

Separation Type	Arcsecond (″)	Parsec (pc)
IF → DF	$0''.083 \pm 0''.033$	0.025 ± 0.009
DF → $\mathrm{C/CO_{avg}}$	$0''.146 \pm 0''.042$	0.043 ± 0.013

Clark et al. 2025, arXiv:2504.06247





- In the Z_{SMC} run, the density is too low to form CO. Hence, we use our simple chemistry network in combination with a plane-parallel, constant pressure model to show the density profile and the amount of column density necessary to form CO in a low Z, high G_0 environment.
- We use a constant P/K_B = $5.0 \times 10^6\ \mathrm{K\,cm^{-3}}$(approx. value from our SMC simulation) and a gas to dust ratio 1/7.7 of the solar value for this model.
- We got similar separations between DF and $\mathrm{C/CO}$ as were found in the observations. It shows that the chemistry network we use in our hydro simulations is good enough to model these kind of PDRs.

V. Summary/Outlook

- With this work we tried to show the structure, chemistry and complexity of the PDRs.
- By adding turbulent box, we showed how an HII region expansion realistically would look like.
- From the analysis of profile plots of $Z_\odot$ & Z_{SMC} we showed the evolution of pressure, density and temperature along with the fractional species.
- Using the chemistry network we got similar results as they found in observations.
- To form CO we need higher densities in the Z_{SMC} simulation, which we were not able to reach with our current simulation.
- In future work, we will run both simulations with higher initial density and increase the maximum resolution in the ZIR to dx = 0.0025 pc

VI. References

- https://astro.uni-koeln.de/riechers/research/pdr
- Tielens, A.G.G.M. (2005) 'Photodissociation regions', in The Physics and Chemistry of the Interstellar Medium. Cambridge: Cambridge University Press, pp. 317–347.
- D.J.Hollenbach, Reviews of Modern Physics,Vol.71,No.1,January 1999
- Clark et al. 2025, arXiv:2504.06247

UNIVERSITÄT ZU KÖLN
ph1 Universität zu Köln
SFB 1601
2025 Astronomische Gesellschaft German Astronomical Society