PARSEC

Photodissociation Regions with Shocked zones using CLOUDY

CLOUDY@IUCAA
21st -26th Sept.
2015

Siddhartha Gupta[1], **Katherine Rawlins**[2], **José Espíritu**[3], **Mayra Mabel Valerdi Negreros**[3],
Kumar Venkataramani[4], **Suhail Ahmad Siddiqui**[5], **Rahul Anand**[6], **Sathyanarayan K.**[7]

[1] Indian Institute of Science, Bangalore, India & Raman Research Institute, Bangalore, India; [2] Centre for Excellence in Basic Sciences, Mumbai, India; [3] Universidad Nacional Autónoma de México, Mexico;
[4] Physical Research Laboratory, Ahmedabad, India; [5] Aligarh Muslim University, Aligarh, India; [6] Gorakhpur University, Gorakhpur, India; [7]Amrita Engineering College, Kollam, India

Abstract

Dynamic processes such as shocks are usually studied through hydrodynamic models. However, such models do not provide complete information about physical structure & chemical abundances. We couple the hydrodynamics code PLUTO[1] with the spectral synthesis code CLOUDY[2] to study the features induced by shocks in a photodissociation region. The aim is to construct a toy model that can later be applied to specific systems for detailed study.

Shocks & Photodissociation Regions (PDRs)

PDRs are formed in the vicinity of massive young stars which emit UV radiation. Fig. 2 shows the generally assumed slab geometry for a PDR. The region nearest to the star is ionized and called the H II region. Further from the star is the neutral PDR, and deeper in the shielded region is the molecular phase. Fig. 3 depicts the parts of a shock driving through the ISM. A shock wave may arise due to an individual star or a star cluster and affect the physical structure & chemistry of the ISM it passes through.

Fig.1: Tarantula nebula
Source : HST

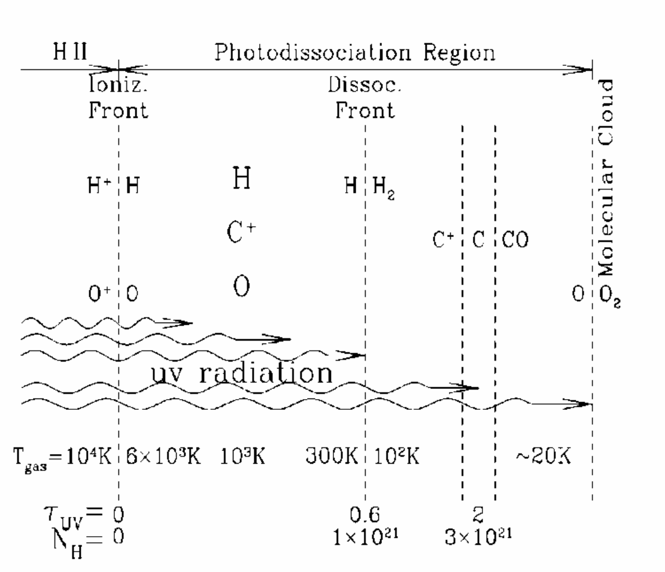


Fig. 2: Structure of a PDR[3]

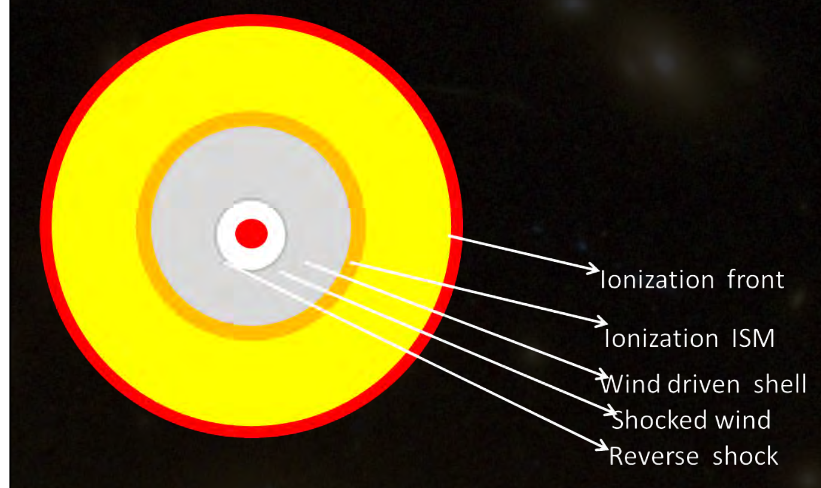


Fig. 3: Structure of a shock

Star cluster environment = Photodissociation region + Shocked ISM

Methodology

Starburst99, v6.0.3[4]

Parameter	Value
Mass of star cluster	10^5 $M_\odot$
Age	10 Myr
Initial Mass function	Standard Kroupa
Mass loss rate	~10^{-3} $M_\odot$ yr^{-1}
Mechanical luminosity	~10^{39} erg s^{-1}

+

Parameter	Value
ISM Density	10^3 particles per c.c.

PLUTO, v4.0

Temperature & density profile due to shock

Constant density model

Shock model

CLOUDY, c16 beta version

Parameter	Value
Blackbody temperature	10^5 K
Q(H)	50 photons s^{-1} (in log)
Abundances	ISM
Extent	100 pc
Cosmic ray ionization rate	2 × 10^{-16} s^{-1} (Galactic background)

Physical processes & Chemical abundances

Physical Properties

Shocks cause the PDR to form further away from the source of radiation. Fig. 4 summarizes the physical state of the ISM at different depths, providing a comparison between the constant density & shock models.

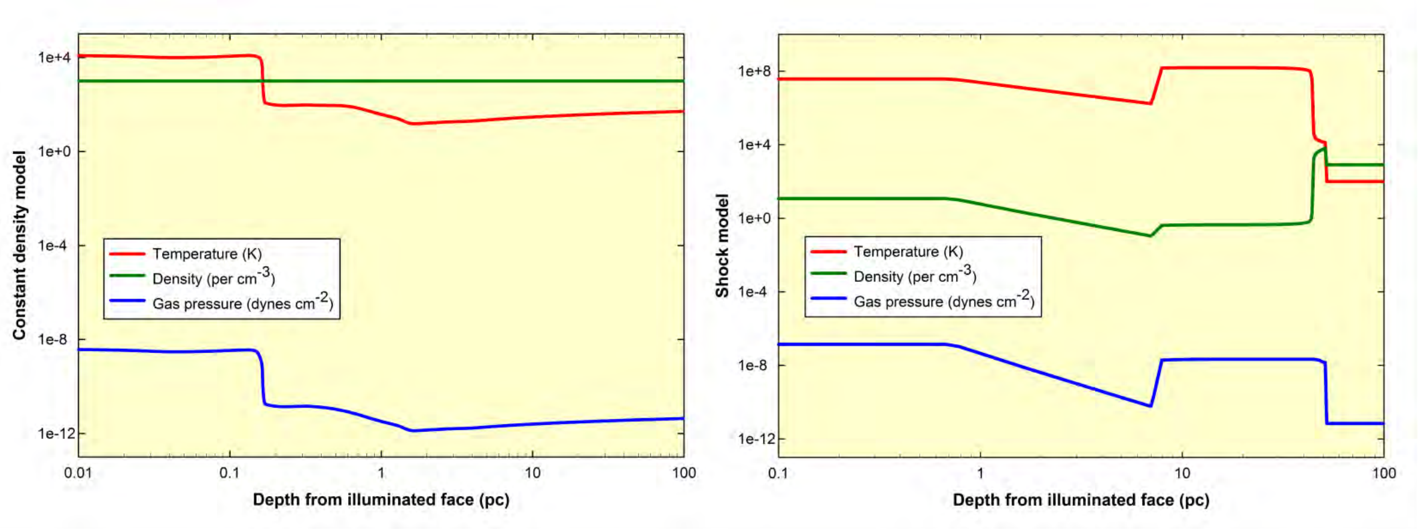
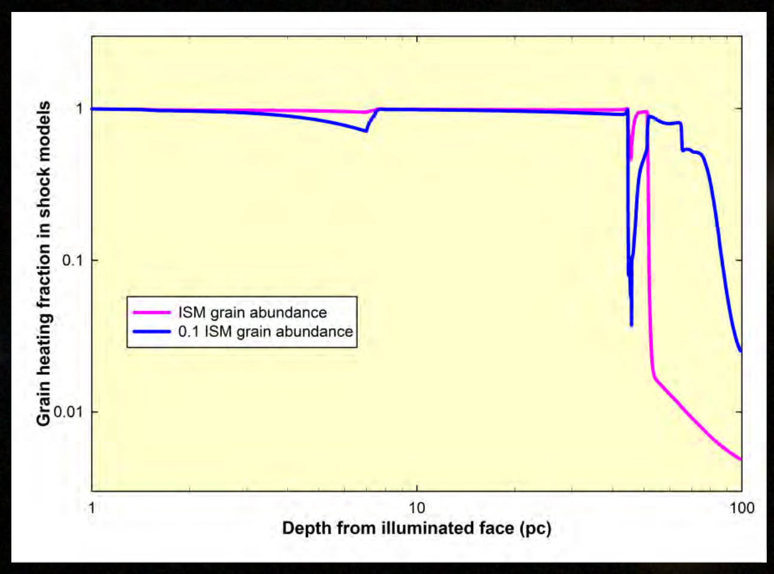


Fig. 4: Density, pressure & temperature profile for the constant density [left panel] & shock model [right panel]



Grain photoelectric emission is the major process that contributes to gas heating in the shock model. We study the effect of including lesser grains. Fig. 5 shows the evolution of the heating fraction accounted for by grain heating in 2 cases: (1) shock model with ISM grain abundance; (2) shock model with 0.1 ISM grain abundance.

Fig. 5: Heating fraction of grain photoelectric emission

Chemical Abundances

We study the fractional abundances of various species, chiefly of ionized and neutral atomic hydrogen along with the H_2 molecular fraction. The plots are shown in Fig. 6.

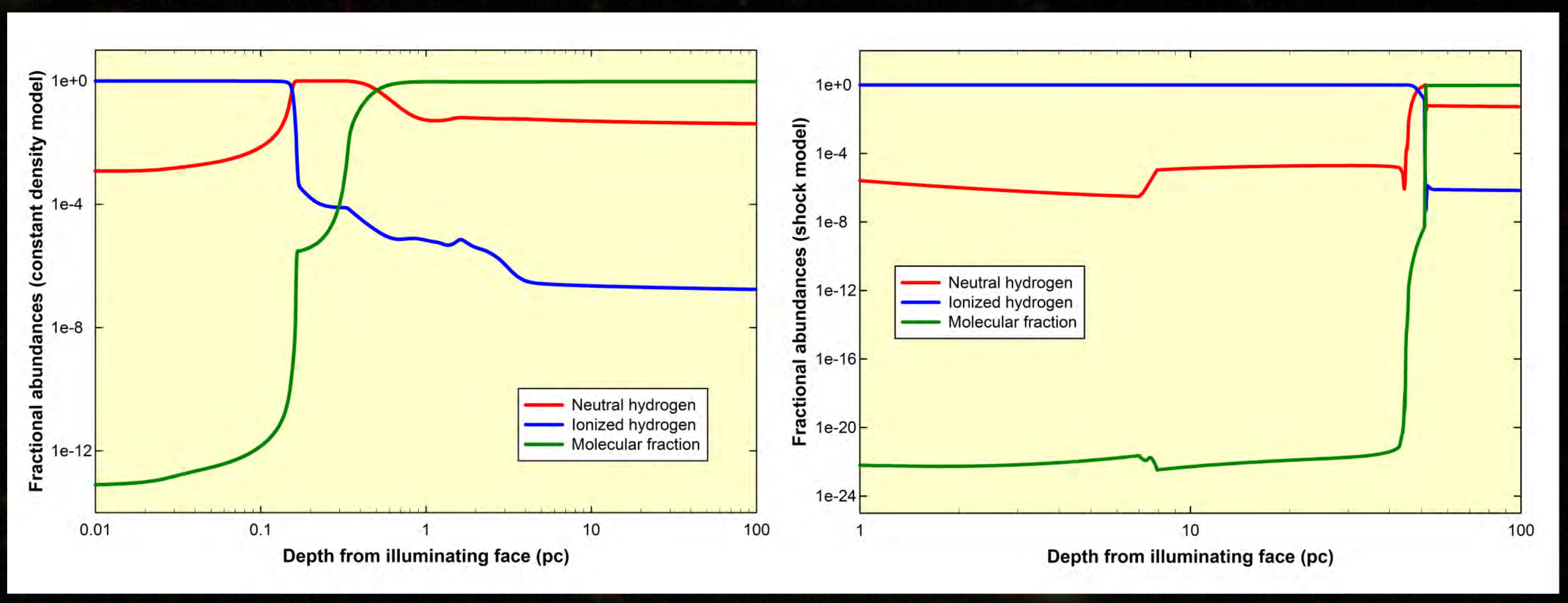


Fig. 6: Fractional abundances of H^+, H^0 and H_2 molecular fraction for the constant density & shock models

We also note the predicted column densities of some important molecular species. H_2 is suppressed by the presence of shocks. However CO is enhanced. Further, as we show in Fig. 7, CH^+/CH ratio is boosted in the shock model as expected[5]. The distribution of H_2 in the ro-vibrational levels differs in the 2 models. We mention details in Table 1. The notation is H_2 (v, J) where v is the vibrational quantum number & J is the rotational quantum number.

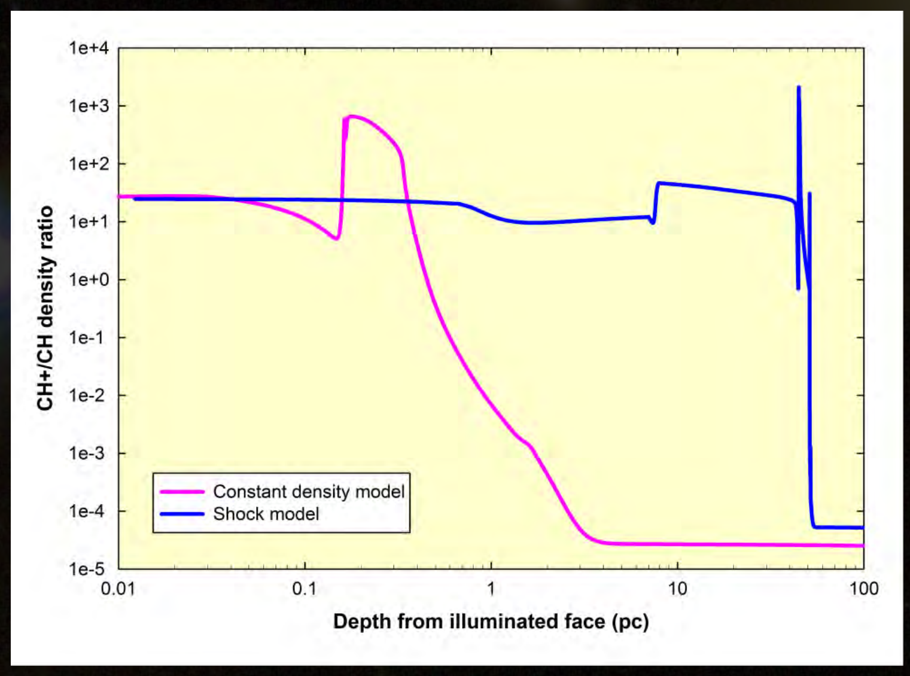


Fig. 7: CH^+/CH ratio for constant density & shock models

Ratio of ro-vibrational level to total H_2	Constant density model value	Shock model value
H_2 (0, 0)/H_2	~ 0.82	~ 0.42
H_2 (0, 1)/H_2	~ 0.18	~ 0.68

Table 1: The proportion of total H_2 in the ground state is lower in the shock model

Incident & Emitted Spectra

Fig 8. shows the spectra of the 3 models we have computed: (1) constant density model with ISM grain abundance; (2) shock model with ISM grain abundance; (3) shock model with 0.1 ISM grain abundance. The incident radiation field is the same for all the models. The shock models show emission at higher energies due to bremsstrahlung. The difference between the emitted spectra of the 2 shock models is due to the difference in visual extinction.

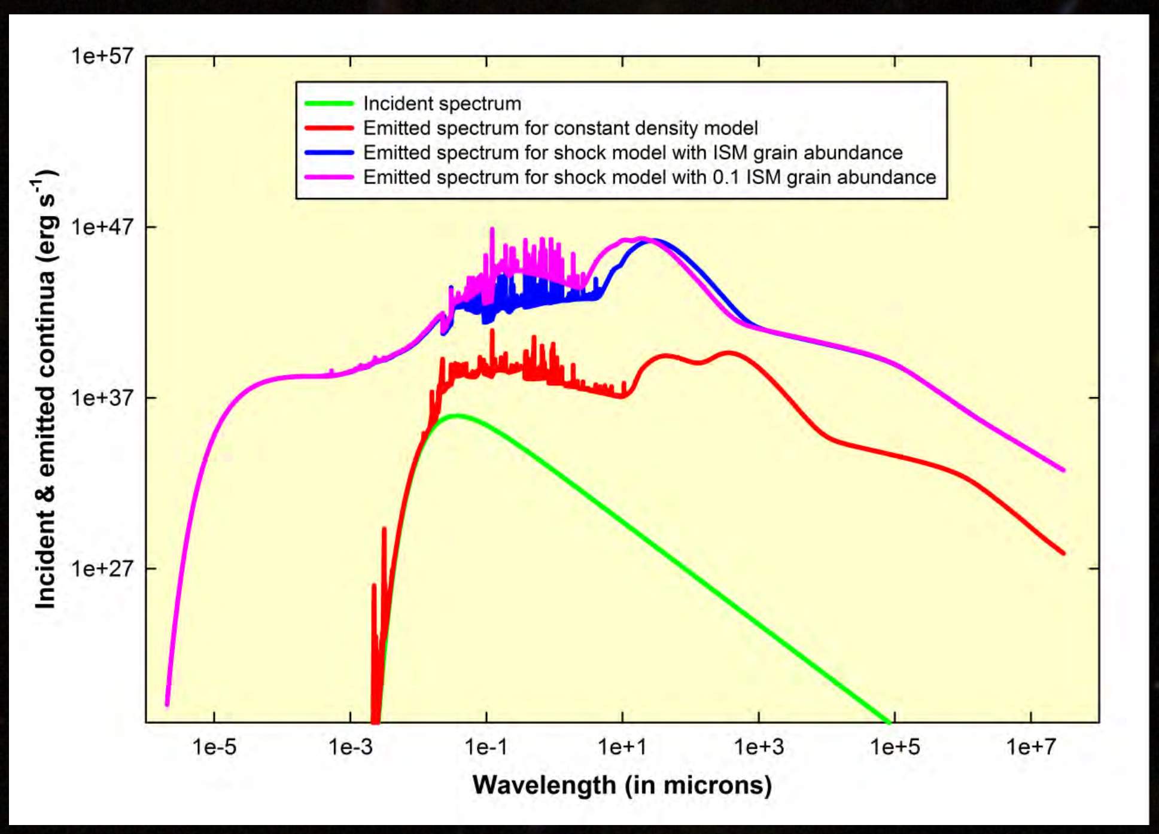


Fig. 8: Incident & emitted spectra of the 3 models

Summary & Future Possibilities

- Shocks push the PDR further away from the ionizing source.
- Gas heating in the shock model is produced mainly due to grain photoelectric emission.
- CH^+/CH ratio is enhanced in presence of shocks.
- Time variability of the shock-induced temperature & density profiles on the features of the photodissociation region can be studied in the future.
- The model can be applied to astrophysical regions where shocks exist, such as sites of star formation, gamma ray burst environments etc.

References & Acknowledgements

1. Mignone A., Bodo G., Massaglia S., Matsakos T., Tesileanu O., Zanni C., Ferrari A., 2007, ApJSS, 170, 228
2. CLOUDY c16 beta version, last CLOUDY review: Ferland G. J. et al., 2013, RMxAA, 49, 137
3. Physics of the Interstellar & Intergalactic Medium, Bruce Draine, 2011
4. Leitherer C. et al., 1999, ApJS, 123, 3
5. Draine B., Katz N., 1986, ApJ, 310, 392

We thank Prof. Gary Ferland & Dr. Gargi Shaw for valuable guidance & discussions on the CLOUDY models. We acknowledge Prof. Biman Nath & Prof. R. Srianand for their insightful comments. We are grateful to Prof. Gulab Chand Dewangan & IUCAA for organizing this workshop.

Contact:
siddhartha@rri.res.in
katherine.rawlins@cbs.ac.in
jespiritu@astro.unam.mx