Final Project Report: OS 177/1-1

Physical and Chemical Processes in the Warm and Dense Interstellar Medium (WADI)

September 30, 2011

1 General information

1.1 DFG reference number

OS 177/1-1

1.2 Applicants

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1.3 Institute

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1.4 Topic

Physical and Chemical Processes in the Warm and Dense Interstellar Medium

1.5 Report and Funding Period

36 months: July 1, 2008 - June 30, 2011

1.6 Most important publications from the project

1.6.1 Accepted refereed publications

Röllig, M., *Refit to numerically problematic UMIST reaction rate coefficients*, 2011, A&A 530, 9

Röllig, M.; Kramer, C.; Rajbahak, C.; Minamidani, T.; Sun, K. et al., *Photon dominated regions in NGC 3603. [CI] and mid-J CO line emission*, 2011, A&A 525, 8

Ossenkopf, V.; Ormel, C. W.; Simon, R.; Sun, K.; Stutzki, J., *Spectroscopic [C I] mapping of the infrared dark cloud G48.65-0.29*, 2011, A&A 525, 9

Ossenkopf, V.; Röllig, M.; Simon, R.; Schneider, N.; Okada, Y. et al., *HIFI observations of warm gas in DR21: Shock versus radiative heating*, 2010, A&A 518, 79

Ossenkopf, V.; Müller, H. S. P.; Lis, D. C.; Schilke, P.; Bell, T. A. et al., *Detection of interstellar oxidaniumyl: Abundant* H_2O^+ *towards the star-forming regions DR21, Sgr B2, and NGC6334*, 2010, A&A 518, 111

Falgarone, E.; Ossenkopf, V.; Gerin, M.; Lesaffre, P.; Godard, B. et al., *Strong* CH^+ $J = 1 - 0$ *emission and absorption in DR21*, 2010, A&A 518, 118

Dedes, C.; Röllig, M.; Mookerjea, B.; Okada, Y.; Ossenkopf, V.; Bruderer, S. et al., *The origin of the [C II] emission in the S140 photon-dominated regions. New insights from HIFI*, 2010, A&A 521, 24

Joblin, C.; Pilleri, P.; Montillaud, J.; Fuente, A.; Gerin, M.; Berné, O.; Ossenkopf, V. et al., *Gas morphology and energetics at the surface of PDRs: New insights with Herschel observations of NGC 7023*, 2010, A&A 521, 25

1.6.2 Submitted publications

Röllig, M.; Szczerba, R.; Ossenkopf, V.; Glück, C., *Full SED fitting with the KOSMA-*τ *PDR code*, 2011, submitted to A&A (attached)

1.7 Patents

none

2 Summary

By combining the analysis of new observations of photon-dominated regions (PDRs), using the Herschel satellite and complementary ground-based data, with the improvement of the KOSMA-τ numerical model for the physics and chemistry of PDRs we performed a big step ahead in the understanding of the detailed physical and chemical processes in these regions.

The combination of the KOSMA-τ with the MCDRT dust radiative transfer code allowed to compute for the first time the full spectral energy distribution emitted from PDRs including all major cooling lines and the dust continuum to allow a direct comparison with the complete set of infrared observations.

For selected PDRs, we resolved the three dimensional density, velocity and chemical structure. It turns out that the main energetic impact, affecting the global temperature structure, chemical balance, and the excitation of most species stems from the impinging radiation field. Shocks produced by outflows from young stars affect the clouds dynamically, leading to a mixing of species and possibly driving some turbulence, but they have a negligible effect on the global energetic structure. In an iterative process we succeeded to fit the observed spectra of numerous species observed in several PDRs with the KOSMA-τ numerical model proving the overall consistency of the physical relations implemented in the model and the observational data. However, we noticed systematic deviations for a number of sulfur and nitrogen bearing species. At the moment, we still do not understand which effects might alter the chemical network affecting those species.

We obtained an accurate theoretical and observational determination of the water abundance in PDRs showing it to be lower than previously expected. As a consequence, the cooling power of the water lines can be neglected for the overall energy balance. However, we also learned that the water freeze-out at low temperatures is somewhat weaker than expected, indicating a higher cosmic ray rate or stronger turbulent mixing.

We obtained for the first time a complete picture of the gas heating efficiency as a function of the dust properties, and the fraction of neutral and ionized PAHs. It turns out that the fraction of PAHs and very small grains providing most of the overall surface is the critical parameter for the photoelectric yield and the H_2 formation heating. Additional H_2 formation on PAHs boosts the temperature of the PDR surfaces, visible in the excitation of high-J CO lines. The production of ionized PAHs in more diffuse regions, in contrast, lowers the heating efficiency. The change of the UV attenuation by the different dust sorts only affects the deeper layers of the clouds providing the bulk of the mass.

With respect to the PDR kinematics and their dynamical evolution we quantified the expected pressure gradient at the PDR surface and find systematic gas flows driven by the radiation pressure. In contrast to the expected evaporation flows, we measured radiation driven cloud compression. This could be the first direct observation of the dynamics of pillar formation.