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JD14 – Examining the PDR-molecular cloud interface at mm and IR wavelengths

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Abstract. Much progress has been made in recent years towards a better understanding of the physical and chemical processes in Photo-dissociation/Photon-dominated Regions (PDRs), both observationally and in terms of detailed physical and chemical modelling. This article highlights some of the problems and new opportunities observers and modellers are facing.

Keywords. astrochemistry, ISM: clouds, ISM: evolution, ISM: kinematics and dynamics, ISM: structure, radio lines: ISM

1. Introduction

PDRs are regions of the interstellar medium (ISM), where the physical and chemical conditions and the structure of the clouds are dominated by the local photon density leading to photo-dissociation and photoelectric heating. As part of the cosmic cycle of matter, PDRs play a key role in the cloud/star-formation interaction and ISM evolution. They cover a wide range in UV field strength, density, geometry, and metallicity, and due to the filamentary and clumpy nature of clouds, PDRs are found everywhere. Understanding the origin of PDR emission in our Galaxy is crucial for the interpretation of observations in external galaxies, where individual PDRs cannot be resolved.

In PDRs, Far-UV (FUV) photons from young stars control the gas heating (photoelectric effect) and chemistry. The PDR gas cools predominantly in the Far-infrared (FIR) through dust continuum, but also spectral line emission (up to a few percent of the total cooling). Attenuation of the FUV radiation from the cloud edges to their more shielded interiors leads to gradients in the temperature and the chemistry. Chemical models predict an observationally confirmed layered structure with typical scales of a few 0.01 pc ($10''$ at Galactic distances). Details of this stratification can only be resolved in Galactic edge-on clouds where the spatial resolution is high.

2. Observations and modelling

PDRs are complex in various aspects (geometry, excitation, dynamics, clumpiness) and deriving physical parameters from observations is challenging due to the degeneracy of parameters such as abundance and excitation temperature. Physical modelling of the source structure, temperature, density, and UV field gradients together with the chemical modelling is therefore important. The Horsehead and Orion Bar PDRs (Goicoechea *et al.* (2009), van der Wiel *et al.* (2009)) are prime examples of extensively studied PDRs where such knowledge from observations is being incorporated in the models.

While current PDR models provide reasonable fits to many observed abundances and the general layering in the PDR, several details in the interplay between chemistry and dynamics or radiation transfer are still poorly understood. In some cases, this leads to orders of magnitude differences for predictions from different models and between models and observations. Hence, an important aspect in the study of PDRs is the intercomparison of the different models in benchmark studies (Röllig *et al.* (2007)) to identify strengths and weaknesses, trigger improvements, and ensure qualitative and quantitative agreement of the models in at least simple cases.

Two recent observational studies towards the Orion Bar and Horsehaed PDRs illustrate the discrepancies between observations and model predictions. First, the SO abundance predicted from single, large clump models of the Orion Bar (van der Wiel *et al.* (2009)) is much higher than observed, implying very high sulfur depletion, whereas CS and HCS^+ observations in the Horsehead (Goicoechea *et al.* (2006)) are compatible with low sulfur depletion. Second, the abundances of radicals such as HCO and small hydrocarbons are observed much higher in the Horsehead than predicted by steady state models (Pety *et al.* (2007), Gerin *et al.* (2009)). Whether such findings are due to peculiarities of the sources, abundant carriers or important processes missing in the models (neutral-neutral reactions (e.g., with oxygen), grain surface chemistry, photo-desorption of ices, and photo-erosion of grains) will require improvements in modelling and new observations alike, which are being pusued by the different research groups as knowledge progresses.

On the modelling side, such improvements include updates of chemical reaction rates, dissociative channels, and branching ratios where possible, inclusion of fractionation, H_2 formation and excitation, dust modelling (to cover arbitrary dust distributions and surface reactions), the impact of PAHs (evaporation and charged grains), sophisticated radiative transfer (non-local, non-LTE), influence of X-rays, dynamics and kinematics (turbulence, shocks, photo-evaporation, advection), time dependence, geometry (detailed modelling of 3D source structure), and clumpiness.

New observing opportunities with Herschel, STO, SOFIA, and ALMA, largely complementary to, e.g., IRAM 30 m, PdBI, JCMT, NANTEN2, APEX, Spitzer, will provide high spatial and spectral resolution observations with the goal to obtain a complete inventory of main cooling lines of warm and dense gas: mid-J CO, [C I], [C II], [O I], water, as well as N II and others to disentangle contributions to C II from various phases (warm ionized medium, H II regions). Herschel for the first time offers the unique opportunity to observe light hydrides (e.g., water, OH, CH, CH^+, NH), which are key species at the knots of the chemical networks and building blocks for larger molecules. In this context, the two Herschel guaranteed time key programs WADI and HEXOS are dedicated to the study of prototype PDRs (and shocks) to cover a large area in parameter space (WADI) and the full spectral range between 480 and 5000 GHz in the Orion Bar (HEXOS).

Building on a wealth of data already present in the literature, lots of preparatory observations for the two key programs are planned and well underway, including spectral line and continuum observations at the highest frequencies accessible with ground based telescopes and Spitzer spectroscopy. All these observations will enable a calibration of the chemical models and ultimately lead to a deeper understanding of PDRs and their role in the evolution of molecular clouds.

References

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