The Warm and Dense ISM seen by Herschel


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- Motivation
- The energy balance of the heated gas
- The chemical structure
- The dynamical structure
Science goals

Understand the physical and chemical processes controlling the interaction between stars and their environment.
WADI science goals

• Young stars affect their environment by UV radiation and shock waves

• Molecular clouds can be compressed → triggers further star formation
• Molecular clouds can be dispersed → prevents further star formation

NGC7023 (Lula 2001) IC443 (Cuillandre & Anselmi 2003)
WADI science goals

• Impact of star-formation on neighboring molecular clouds
  → dynamic impact from winds and outflows
    → dispersion → prevents SF
    → compression → triggers SF
  → UV radiation heats the gas
    → temperature increase → prevents SF
  → UV radiation dissociates the gas
    → change of chemical structure
    → remove cooling agents → prevents SF
    → create cooling agents → triggers SF

• Understanding energy balance, dynamics, and chemistry of the interaction regions is a prerequisite to understand clustered star-formation.
Energy balance

Questions:

- distinguish role of UV radiation from shock heating
- gas heating efficiency
- role of H$_2$O cooling and dust heating and cooling

Example: DR21

Lane et al. (1990)
- Line shape comparison with ground based lines
Line profiles allow to:

- Distinguish line intensities from different velocity components
- Optical depth correction of line intensities

Model fit:

- Two-component PDR model fit all lines
- New HIFI data show two distinct UV fields: $10^5 \chi_D$ and $300 \chi_D$
- Dense clumps facing the blister outflow + clumpy large scale distribution

→ See P2.14 by M. Röllig
Photoelectric heating in NGC7023

[CII] traces PDR gas temperature

- Correlation with PAH distribution reveals their contribution for the PE heating

PAH⁺s contribute much less photoelectric heating than very small dust grains

→ See P1.16 by P. Pilleri
Molecule formation and dissociation

- Photo-induced chemistry
  - abundance profiles of light hydrides
  - $\text{H}_3\text{O}^+$ as central node in the chemical network
  - the influence of X-rays
  - sources of endothermic hydride formation
  - the role of surface-reactions and time-dependent chemistry

- Shock chemistry
  - Change of abundances of main coolants by the passage of shocks
  - the OH-water puzzle in shocked gas
Chemical structure

Observations

- Inventory the chemical network as function of UV intensity and shock velocity
- Simple hydrides as key nodes: CH, NH, H₂O, OH, CH⁺, NH⁺, OH⁺, H₃O⁺

“Calibration” of models:

Uncertainties in current models:

Röllig et al. (2007): CH distribution for a high-density, high-radiation-field PDR
CH$^+$ in DR21

- First frequency resolved CH$^+$ line
- Detailed modelling of absorption and emission profile:
  - $2.5 \times 10^{14}$ cm$^{-2}$

→ A&A paper by E. Falgarone
CH chemistry

- Combined emission-absorption profile of CH$^+$ in DR21
- Pure emission profile in CH

Seems to prefer turbulence driven-chemistry over UV-driven chemistry towards CH$^+$

• CH relatively constant across different PDRs → Contradiction to PDR models
• CH only/mainly bright towards embedded sources
The gas-phase path to $\text{H}_2\text{O}$

Goal:

- Measure temperature and abundance of $\text{H}_2\text{O}^+$, $\text{H}_3\text{O}^+$, OH, and $\text{H}_2\text{O}$ across the interfaces

![Chemical reactions](image)

Hollenbach et al. (2009)

First detection of interstellar $\text{H}_2\text{O}^+$ in DR21

- Exact frequency determination
- Column density: $> 2.3 \times 10^{13} \text{ cm}^{-2}$
Chemistry from line shapes

Line shape comparison between HIFI lines and ground based lines

- $\text{H}_2\text{O}^+$ absorption matches
  - OH absorption
  - [CII] emission
  - CH$^+$ emission wing
  - $\text{H}_2\text{O} \, 1_{11}-0_{00}$ emission wing
  - Nothing else!

→ Assignment of $\text{H}_2\text{O}^+$ to hot irradiated clumps traced by OH and [CII] and affected by the blister outflow
Dynamics and kinematics

- PDR dynamics
  - turbulent pressure distribution from HII regions to molecular clouds
  - impact of advection and turbulence
  - photo-evaporation of PDRs

- Shock structures
  - temperature and density structure in the post-shock gas
  - actual distinction between J(ump) and C(ontinuous) shocks

Gorti & Hollenbach (2002)
[CII] mapping - S140

- [CII] strongest from the PDR
  - quiescent-gas line profile
- Broad (wind?) contribution from ionized gas at IRS1

→ See P1.17 by C. Dedes
Line shape distinguishes contributions from PDR and ionized outflow

Extended foreground emission with velocity of the ridge

Blue wing traces blister outflow

Clump surfaces rather blown away than evaporating
Outlook

- Only 4.5% of the AORs (observing time) executed
  (another 936s in schedule for next week)
- No supernova remnant observations yet
  - shock chemistry
- No PACS observations yet
  - role [OI] cooling
  - high-J rotational lines from hot gas
- Majority of the target lines not covered yet
  - Most of the chemical analysis still to come
  - Science from the few observations already very promising
People and institutes instrument development/ICC


- And many people in the workshops of all the institutes involved

- SRON Netherlands Institute for Space Research; Leiden Observatory, University of Leiden; Joint Alma Observatory, Santiago; Physics Department, California Institute of Technology, Pasadena; Kosma, I. Physik. Institut, Universit‘at zu K‘oln, K‘oln; Centre d‘Etude Spatiale des Rayonnements, Université de Toulouse [UPS], 31062 Toulouse; CNRS/INSU, UMR 5187 Toulouse; Observatorio Astronómico Nacional (IGN), Madrid; 9 Observatorio Astronómico Nacional (IGN), Centro Astronomico de Yebes, Guadalaja; Chalmers University of Technology, Gothenburg; Astronomical Institute, ETH, Zurich; Jet Propulsion Laboratory, Pasadena; Université de Bordeaux, Laboratoire d’Astrophysique de Bordeaux, Bordeaux; CNRS/INSU, UMR 5804, Floirac; MPI fur Radioastronomie, Bonn; Istituto Fisica Spazio Interplanetario INAF, Roma; Department of Physics and Astronomy, University of Waterloo, Waterloo; MPI fur Sonnensystemforschung, Katlenburg-Lindau; Laboratoire d’Etudes du Rayonnement et de la Matiere in Physique, UMR 8112 CNRS/INSU, OP, ENS, UPMC, UCP, Paris; 21 Institute fr Hochfrequenz Techniques, ETH, Zurich, Zurich, Switzerland ETH HF; Department of Astronomy, Stockholm University, Stockholm; ; Space Research Center of the Polish Academy of Sciences, Warsaw; University of Massachusetts, Astronomy Dept., Amherst; N. Copernicus Astronomical Center, Torun; Experimental Physics Department, National University of Ireland, Maynooth; Netherlands Organisation for Applied Scientific Research (TNO); Applied Physics Department, Delft University; Northrop Grumman Aerospace Systems, Redondo Beach; Centro de Astrobiologia (INTA-CSIC), Madrid; Institut de Radioastronomie Millimetrique, IRAM, St Martin d’Heres; Osservatorio Astrofisico di Arcetri-INAF Firenze; European Space Astronomy Centre, ESA, Villanueva de la Canada; European Organisation for Astronomical Research in the Southern Hemisphere, Garching