The Transition from Atomic to Molecular Intermediate-Velocity Clouds

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1 – Abstract

The correlation of HI emission to the far-infrared (FIR) brightness reveals molecular hydrogen (H_2) in the ISM. Deviations from a simple linear correlation indicate its presence. We combine data from the Effelsberg-Bonn HI Survey (EBHIS, Kerp et al. 2011, AN 332) covering the northern hemisphere and the Planck Satellite benefiting especially from the high angular resolution of 10.5′ in HI.

We find two intermediate-velocity clouds that, despite their similarity in HI, show very different FIR properties. **We propose that the two objects are at different stages in the dynamical transition from atomic to molecular clouds in the lower galactic halo**. Perturbations during the decent onto the Galaxy e.g. ram pressure act as the trigger by which the clouds condense and cool.

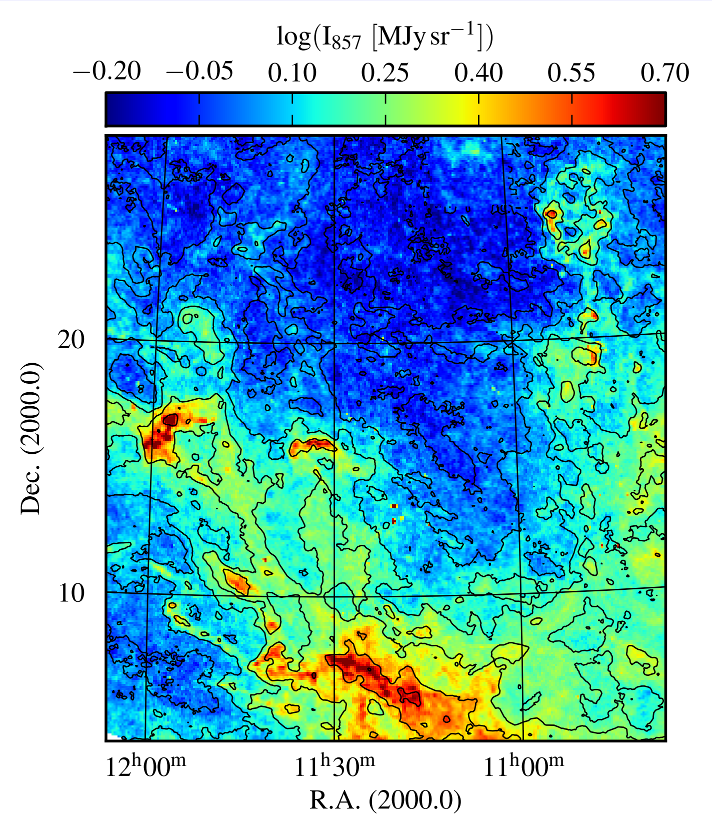
2 – The HI-FIR correlation

Infrared cirrus clouds show a linear correlation between gas and dust (e.g. Boulanger et al. 1996, A&A 312): $I_\nu = a_\nu + \epsilon_\nu \cdot N_{\mathrm{HI}}$. At high HI column densities molecular hydrogen can form which is "missing" in the HI-FIR correlation leading to a steepening – the FIR excess.

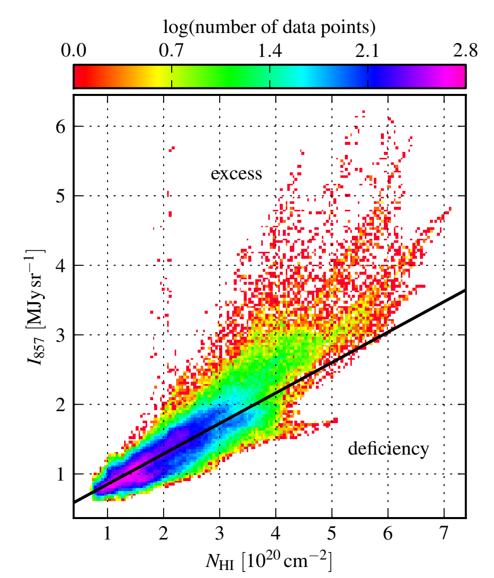
3 – The studied field in HI and FIR emission

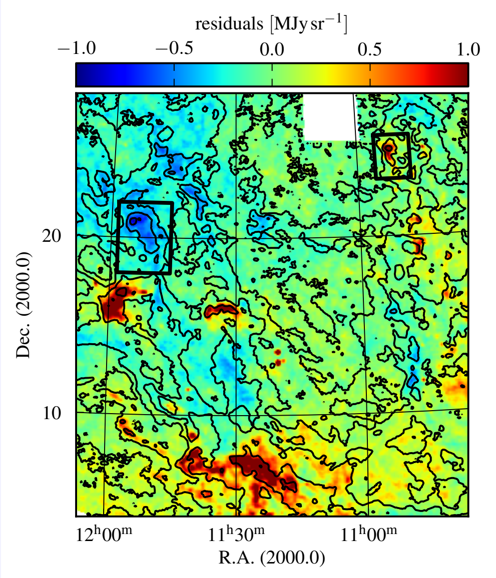
Intermediate-Velocity Clouds (IVCs) have radial velocities $30 \leq |v_{\mathrm{LSR}}| \leq 90\,\mathrm{km\,s^{-1}}$ which are at the extreme of a simple galactic rotation model. The IVCs in the field belong to the Intermediate-Velocity (IV) Arch and Spur which have near solar metallicities and distances between $0.3 \leq D \leq 2.1$ kpc (Wakker 2001, ApJS 136).

Image below: Planck data at 857 GHz in colour overlayed with HI contours



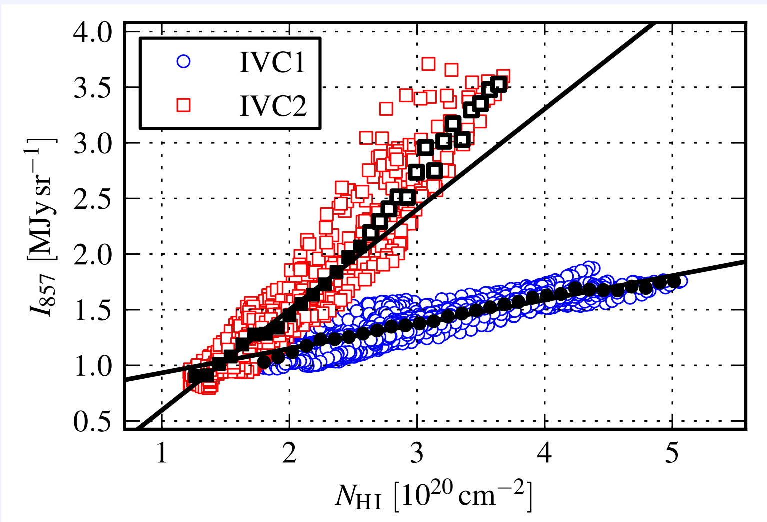
4 – Global HI-FIR correlation





Individual cirrus clouds show different dust emissivities. Residuals are derived by subtracting the calculated FIR brightness estimated from the linear FIR model (black curve in left figure). Many clouds show an excess suggesting molecular hydrogen, some have less emission. Two IVCs (black boxes in right figure) are similar in HI (black contours) but completely different in the FIR: IVC1 is FIR deficient while IVC2 has a FIR excess.

5 – FIR-deficient and molecular IVC



For IVC1 the correlation is linear indicating no traceable amount of H_2. For IVC2 above $N_{\mathrm{HI}} \simeq 2.6 \cdot 10^{20}\,\mathrm{cm^{-2}}$ there is FIR excess. From CO emission $N_{\mathrm{H_2}} \gtrsim 1.9 \cdot 10^{20}\,\mathrm{cm^{-2}}$ is inferred (Désert et al. 1990, ApJ 355) – much more than the typical diffuse distribution of $\log(N_{\mathrm{H_2}}/\mathrm{cm^{-2}}) = 14 - 16$ (Richter et al. 2003, ApJ 586). IVC2 is one of the few molecular IVCs (Magnani & Smith 2010, ApJ 722).

6 – A dynamical transition from atomic to molecular clouds

Significant amounts of H_2 can form in a gas with particle density $1 - 10\,\mathrm{cm^{-3}}$ in $\simeq 1$ Myr due to dynamical perturbations like turbulence or supernova shocks (e.g. Glover et al. 2007, ApJ 659; Dobbs et al. 2008, MNRAS 389). These perturbations increase the particle density rising the formation rate while providing shielding from the UV radiation field by which also the grain temperature decreases.

We propose that the transition from atomic to molecular IVCs is triggered by dynamical perturbations. In this picture the FIR-deficient IVC is at an initial state and it may turn molecular like IVC2 due to its decent onto the Galaxy and a compression in the process, e.g. by ram pressure, leading to a cooling of the cloud.