The Transition from Atomic to Molecular Interstellar Medium

Pei Zuo[1], Di Li[1], Joshua E. G Peek[2], Lei Qian[1], Zhiyuan Ren[1], Lei Zhu[1]
[1]National Astronomical Observatories, Chinese Academy of Sciences
[2]Columbia University Department of Astronomy

ABSTRACT

Stars form in the dense molecular interstellar medium (ISM). The transition from atomic gas to molecular gas is an essential initial step in star formation. In order to measure atoms inside molecular cloud accurately, we developed a radio technique, the HI Narrow Self-Absorption (HINSA, Li et al. 2003-hereafter paper I, Goldsmith et al. 2005-hereafter paper II). By using HINSA and analytical models, we intend to study systematically the ratio between atoms, molecules and dust throughout the Milky Way. Until now, we have observed three nearby isolated dark clouds CB45, B227, and L1574 using SPIRE on board the Herschel Space Observatory and the ALFA array of the Arecibo Observatory. We have obtained the temperature distribution of the dark cores based on a combined SED fitting of 2MASS and SPIRE bands. Preliminary HINSA and HI abundance results are also presented here.

Introduction

The transition from diffuse atomic to dense molecular ISM is an important process for star formation. It is difficult to directly trace the HI to H_2 transitions because the lack of a good tracer. In paper I and II, we present the measured quantity of cold HI inside a sample of molecular clouds through HINSA, derived the abundance of [HI]/[H_2]. A simple static chemical model of H_2 formation puts the cloud age at over 7 Myr (lower limit) and our measurement has been cited as evidence for a longer star formation time scale.

Better describe the program. The three isolated dark clouds we observed by Herschel & Arecibo are selected based on their intriguing morphology of displacement between CO, 2MASS extinction, and cold atomic gas traced by HINSA. These data allow us to construct the temperature distribution of dust and further understand the properties of dark clouds.

Observation

Herschel Space OT1 Project

The three sources, CB45, B227, L1574 were observed with SPIRE instrument on board the Herschel Space Observatory on 2011, September 11, during an OT1 Program, the total observation duration was 1.3 hours. The data used SPIRE filters centered at wavelengths of 250 µm, 350 µm, and 500 µm, with angular resolution of 18″, 25″, and 36″ respectively.

Arecibo Project

We observed HI absorption of CB45, B227 and L1574 at Arecibo Observatory on 2012, May and November. The data used the Arecibo L-band Feed Array (ALFA), operating near 1.4 GHz, and using the Total-Power mode for the observations. The ALFA system temperature is about 30K, and the HI emission temperature is about 70K for standard Cold Neutral Medium (CNM). Thus, we used a nominal 100 K system temperature for the sensitivity calculations. The four pointings of ALFA can cover a beam-filled area of about 15′×15′. The spectrometer we used is GALFASPEC, with 0.18 km/s channel after averaging two polarizations.

Data Reduction

Herschel Data

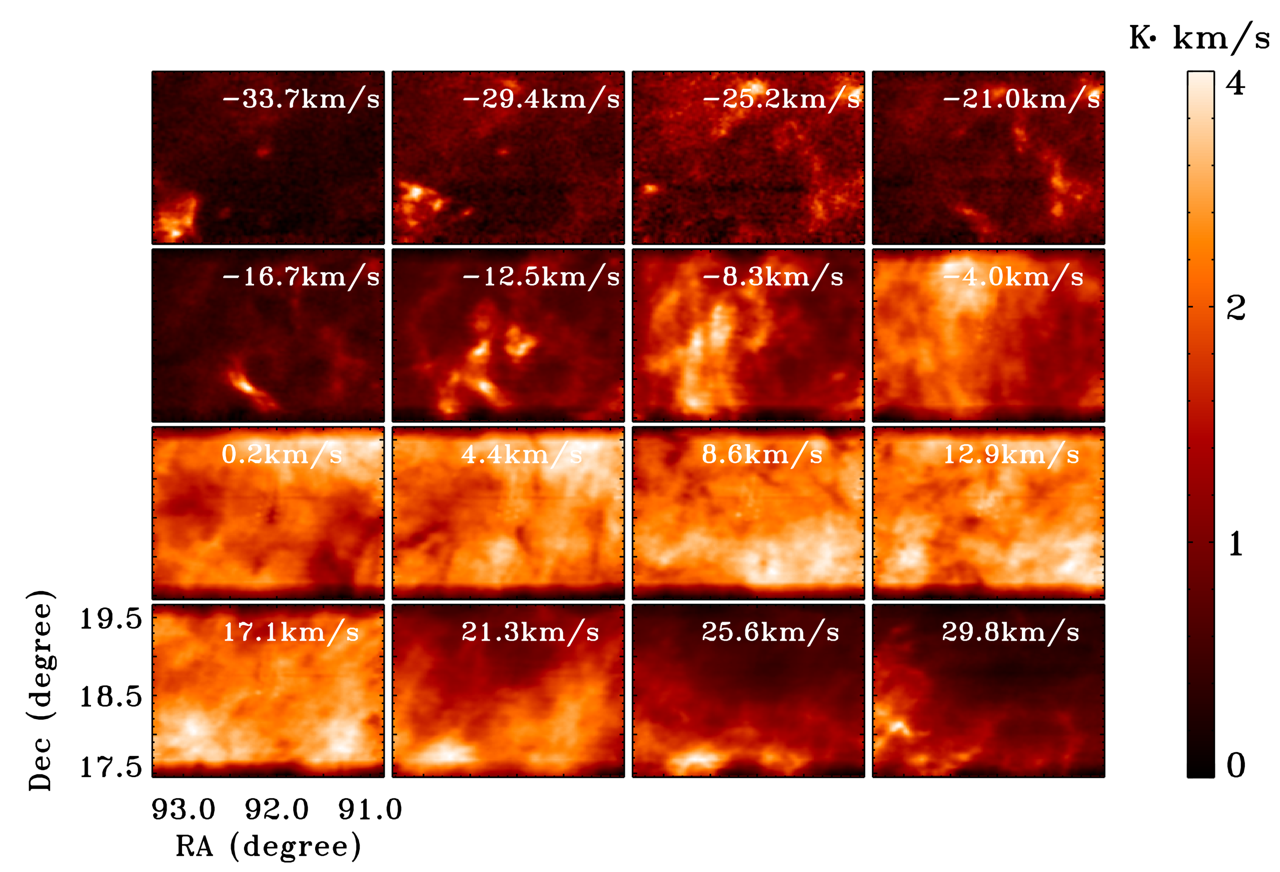
Herschel SPIRE provided a crucial piece of the puzzle in thermal dust emission at a high angular resolution. The data were processed within the software package HIPE, version 11.0.1, with the standard photometer script up to level 1. The resulting maps showed residual stripes along the scan direction, and we used the script Baseline Removal and Destriper to remove the SPIRE observation baseline and a correction for the relative gain of bolometer was applied. The rms of data is measured from 3 sigma of background.

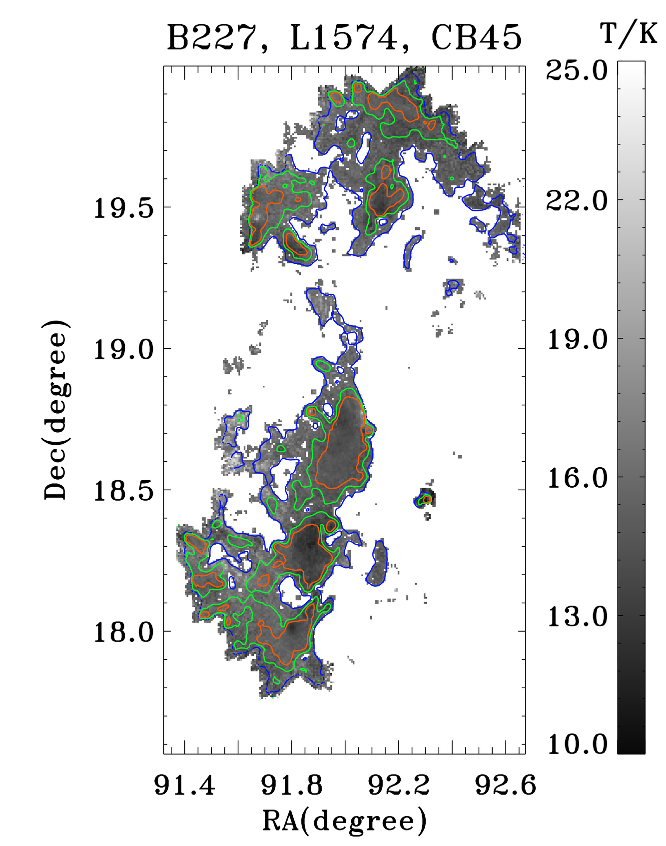
Arecibo Data

The HI data were reduced with GALFA-HI Standard Reduction pipeline version 2.6, which is set up by Joshua E. G. Peek (2009). It is the so-called "basket-weaving" designed for the ALFA in order to take the time-ordered data (TOD) that comes out of GALFASPEC, over a single region and turn it into a calibrated, gridded spectral (PPV) data cube. The resulting data also showed stripes along the scan direction, we destriate the data by running the procedure to use the places the data cross each other to self-calibrate the gains of each beam. The channel map of reduced data is shown in Fig. 1.

Temperature

We obtained the temperature distribution from SED fitting by combining the dust emission with 2MASS extinction. For each pixel of image, an SED was extracted and fitted with a single−temperature modified black-body of the form $S_\nu = \Omega B_\nu(\nu, T_d)(1-e^{-\tau(\nu)})$.





Left: Fig.1. Channel map of HI emission for three isolated dark clouds. Right: Fig.2. The temperature distribution of three dark clouds (the white area is null), overlaid with Herschel SPIRE observation of same sources at 350 micron (blue: 0.03Jy, green: 0.15Jy, red: 0.27Jy).

The 2MASS extinction data is calculated based on method from N. Chapman (2011). We used the dust opacity model of the form $\kappa_\nu \propto \nu^\beta$, and assumed $\beta = 2$. Combined the flux from the dust emission of three bands and 2MASS extinction, we obtained the dust temperature distribution, shown in Fig. 1.

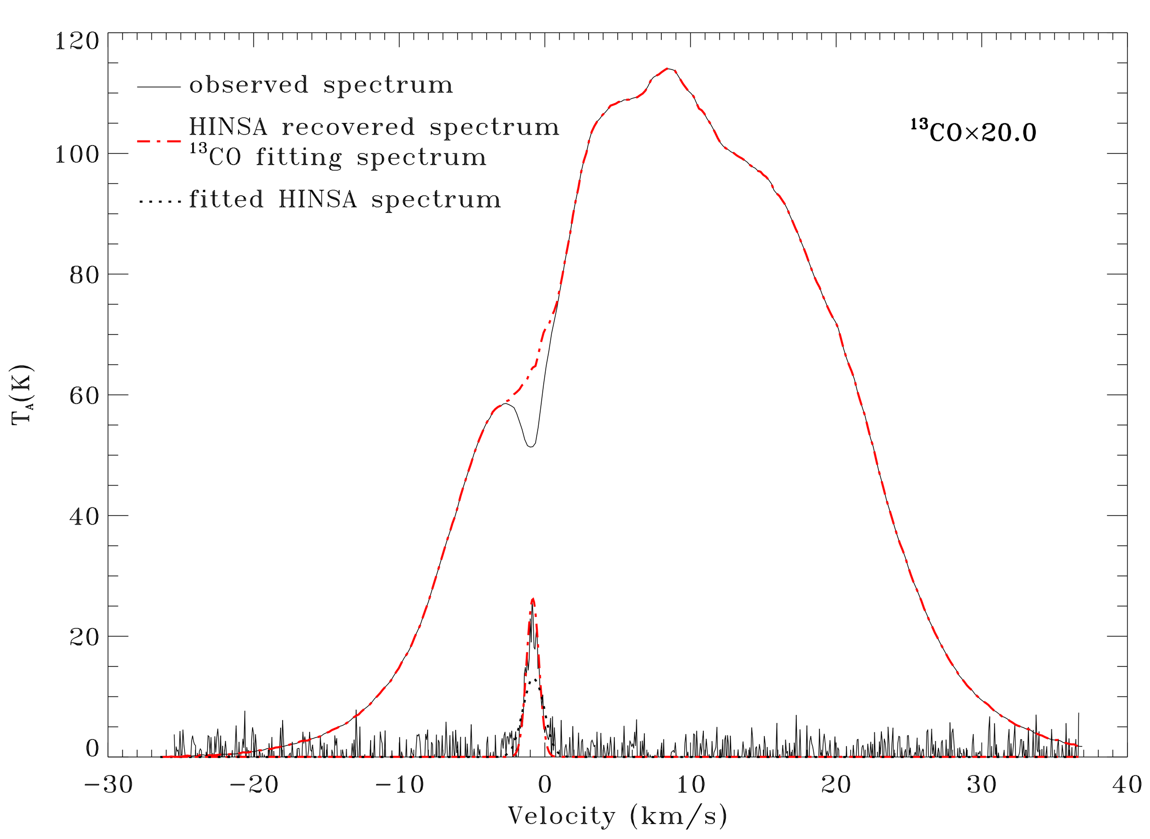


Fig. 3. A typical HINSA fitting.

Column Density Modeling of HI

The column density measurement of the HI component come from Krčo et al. (2008). we calculated HI column density by using $\frac{N_{HINSA}}{cm^{-2}} = 1.82\times10^{18}\frac{\tau_0}{p}\frac{\sigma_H}{km/s}\frac{T_{dust}}{K}$, where τ_0 is the peak optical depth of HINSA spectrum which can be obtained from τ, the fitted optical depth of absorbing HI gas around 21 cm, σ_H is the width of a HINSA feature which is set by the width of the corresponding ^{13}CO line, p accounts for foreground correction Krčo et al. (2008). A typical fitted HINSA is shown in Fig. 3.

Current Status

We already have the ^{13}CO emission data from FCRAO observation. Based on the simple H_2 formation model (paper I), we predict to obtain the transitional timescale of dark clouds. By combining HI, ^{13}CO abundance with dust temperature, we will provide the chemical evolution of molecular clouds and advance the understanding of the transition from atomic to molecular ISM.

References

Goldsmith, P. F., & Li, D. 2005, ApJ, 622, 938 (paper I)
Krčo, M., Goldsmith, P. F., Brown, R. L., & Li, D. 2008, ApJ, 689, 276
Li, D. & Goldsmith, P. F. 2003, *HI Narrow Self Absorption in Dark Clouds*, ApJ, 585, 823 (paper II)
N. Chapman. 2011, from private communication
Peek, J. E. G., Heiles, C., Douglas, K. A., et al. 2011, ApJS, 194, 20

Contact: peizuo@nao.cas.cn