PROCEEDINGS OF SCIENCE

Dust and Gas in diffuse interstellar medium of the Large Magellanic Cloud

Naslim N[*1], **F. Kemper**[1], **Y. Yang**[1], **S. Hony**[2], **J.-P. Bernard**[6], **K. D. Gordon**[4], **W. Reach**[8], **C. Bot**[5], **O. Morata**[1], **H. Hirashita**[1], **J. Seok**[1], **S. C. Madden**[3], **A. Hughes**[2], **R. Indebetouw**[7]
[1]*Academia Sinica Institute of Astronomy and Astrophysics, Taipei 10617, Taiwan R.O.C*
[2]*Max-Planck-Institute for Astronomy, Konigstuhl 17, 69117 Heidelberg, Germany*
[3]*Laboratoire AIM, CEA/DSM - CEA Saclay, 91191 Gif-sur-Yvette, France*
[4]*Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, USA*
[5]*Université de Strasbourg, Observatoire Astronomique de Strasbourg, 67000 Strasbourg, France*
[6]*CNRS, IRAP, 9 Av. colonel Roche, BP 44346, F-31028 Toulouse Cedex 4, France*
[7]*Department of Astronomy, University of Virginia, PO Box 400325, VA 22904, USA*
[8]*Stratospheric Observatory for Infrared Astronomy, Universities Space Research Association, Mail Stop 232-11, Moffett Field, CA 94035*
E-mail: naslimn@asiaa.sinica.edu.tw

We investigate gas and dust physical properties and chemistry of diffuse interstellar medium in the Large Magellanic Cloud (LMC). Photometric and spectroscopic data of total twelve diffuse regions were obtained as part of the LMC legacy programs, Surveying the agents of Galaxy Evolution and *Herschel* Inventory of The Agents of Galaxy Evolution. The *Spitzer* infrared spectra of these regions reveal low J rotational transition lines of H_2 and aromatic band emissions due to PAHs. By fitting the rotational diagram of H_2 we determine temperature and column density of warm molecular gas. Dust temperature and mass are measured by fitting the far-infrared spectral energy distributions obtained with the *Herschel* photometric images. In addition to *Spitzer* and *Herschel* data, we use HI map for atomic gas mass, and CO map to trace cold molecular hydrogen. Our goal is to constrain the state of ISM by determining mass, temperature and gas-to-dust ratio. From preliminary analyses, we present gas and dust physical properties and gas-to-dust ratios of two diffuse regions. We derive gas-to-dust ratios of 240 in these regions assuming a CO-to-H_2 conversion factor 2×10^{20} cm^{-2} K^{-1} km^{-1} s.

The Life Cycle of Dust in the Universe: Observations, Theory, and Laboratory Experiments - LCDU 2013,
18-22 November 2013
Taipei, Taiwan

[*]Speaker.

PoS(LCDU2013)081

1. Introduction

The nearby Large Magellanic Cloud (LMC) galaxy is an excellent site for the studies of chemical and physical properties of Interstellar medium (ISM) due to its proximity, ($\sim$ 49.97 kpc; [8]), low metallicity (0.5 $Z_\odot$; [9]), and favorable viewing angle ($\sim$ 24°; [7]). At a distance of $\sim$50 kpc, the LMC permits us to resolve ISM small scale structures in sub-parsec scales. We investigate the gas and dust physical properties and thereby gas-to-dust ratio of some selected extended regions in the LMC. The diffuse ISM regions of the LMC have been observed as part of the *Spitzer* legacy program, Surveying the agents of Galaxy Evolution (*SAGE-LMC*) [5]. As part of *SAGE* spectroscopic program (*SAGE-Spec*), spectral maps of 12 diffuse regions were obtained using Infrared Spectrograph (IRS) on the *Spitzer Space Telescope*. Spectra were integrated over an area of $1' \times 1'$ from each region in a wavelength range $5 - 38\,\mu$m. The details of observation and coordinates of observed diffuse regions can be found in Kemper et al. [3]. The integrated IRS spectra of these regions show strong H_2 low J rotational lines, $S(0)$ ($v = 0-0$, $J = 2-0$, $28.2\,\mu$m) and $S(1)$ ($v = 0-0$, $J = 3-1$, $17.0\,\mu$m). At shorter wavelengths ($5-12\,\mu$m) the most intense transitions $S(2)$ through $S(7)$ are highly contaminated by strong aromatic bands of Polycyclic Aromatic hydrocarbons (PAHs). In addition to the *Spitzer* data, we use *Herschel* Inventory of The Agents of Galaxy Evolution (HERITAGE) photometric images for dust measurements [6]; HI map [4] to trace the atomic gas; and CO maps to trace the cold molecular hydrogen. In this proceeding, we present measurements of gas and dust physical properties in two diffuse regions.

2. Dust mass and temperature

To determine dust temperature and mass, we use the Far Infrared (FIR) Spectral Energy Distributions (SEDs) constructed with PACS[1] (100 and 160 μm) and SPIRE[2] (250 and 350 μm) fluxes, which were integrated over $30''$ aperture radius for each sample region. The SEDs were fitted with single-temperature modified balckbodies [2]. In our fitting method, the emissivity β is allowed to vary between $1 < \beta < 2$. Dust masses were obtained for $160\,\mu$m fluxes, assuming that dust is mostly spherical silicate grains with mass density ρ=3 g cm^{-3}, radius $a = 0.1\,\mu$m and absorption efficiency $Q_{em}(160) = 5.5 \times 10^{-4}$ following the method reported in Gordon et al [2]. The two observed regions show dust temperature in the range $18-22$ K with dust masses $69 \pm 20\,M_\odot$ and $35 \pm 8\,M_\odot$ respectively (see, Table 1).

3. H_2 column density and excitation temperature

Using the IDL package PAHfit [10], we measured the spectral line intensities [10]. PAHfit can simultaneously fit every dust feature, starlight, atomic and molecular lines, and returns the best fitted parameters (Figure 1). Using the measured line intensities, the level populations were calculated by assuming that lines are optically thin and the level populations are thermalized in the Local Thermodynamic Equilibrium (LTE). Consequently, we determined the excitation temperature T_{ext} and H_2 column densities $NH_{2(ext)}$ by fitting the rotational diagrams. In our analyses,

[1] *Photodetector Array Camera and Spectrometer*
[2] *Spectral and Photometric Imaging Receiver*

Table 1: Dust and gas physical parameters

Reg	Dust temp	T_{ext}		$^{3}NH_{2(ext)}$	$MH_{2(ext)}$	M_{dust}	NHI	MHI	$^{2}NH_{2(c)}$	$MH_{2(c)}$	$^{1}M_{tot}$	gas/dust
	K	T_1 K	T_2 K	cm^{-2}	$M_\odot$	$M_\odot$	cm^{-2}	$M_\odot$	cm^{-2}	$M_\odot$	$M_\odot$	
				10^{19}			10^{21}	10^{3}	10^{21}	10^{3}	10^{3}	
1	21.8 ± 3.0	109 ± 7	<1020	1.4(0.2)	38 ± 6	68.5 ± 20	4.8	6.4	3.8	10.0	16.5	240
2	18.9 ± 2	92 ± 10	<870	110(20)	$3.0\,10^{3}$ $\pm2\,10^{2}$	34.0 ± 8	3.7	5.0	0.09	0.22	8.1	240

1: $^{1}M_{tot}$: MHI + $MH_{2(ext)}$ + $MH_{2(cold)}$ 2: $^{2}NH_{2(c)}$: Cold molecular hydrogen column density was calculated assuming a Galactic X factor ($X_{co,20}$ = 2.0 $cm^{-2}\,K^{-1}\,km^{-1}$ s [1]) 3: Excited H_2 column density using excitation diagram measurements.

two-temperature model was used to fit the rotational diagrams: a cold component with temperature in the range $70-130$ K and a warm component with an upperlimit <1200 K. Rotational digram of H_2 along with two-temperature model fits for two diffuse regions are shown in Figure 2.

The cold molecular gas is traced by CO ($J=1-0$) observations obtained with the MAGellanic Mopra Assessment (MAGMA; resolution $1'$) and the NANTEN (resolution $2.6'$) surveys [11]. The CO integrated intensities were extracted over a $30''$ radius aperture size for every diffuse regions. These intensities (K km/s) were then converted to H_2 (cold) column densities $NH_{2(c)}$ and masses assuming the Galactic CO-to-H_2 conversion factor of 2×10^{20} $cm^{-2}\,K^{-1}\,km^{-1}$ s [1]. The atomic gas is traced by 21 cm line emission observations by the Australia Telescope Compact Array (ATCA) and Perkes single dish telescope spanning $11.1^\circ\times12.4^\circ$ on the sky at a spatial resolution $1'$ [4]. The HI intensities were integrated within the aperture radii $30''$ from HI map and converted to column densities. The gas-to-dust ratio was determined by dividing total gas mass which was derived by the sum of atomic gas, cold molecular gas and warm molecular gas, to total dust mass.

4. Results

The gas-to-dust ratios along with atomic, cold molecular, warm molecular gas masses and dust masses are given in Table 1. We derive a gas-to-dust ratio 240 in both regions. The cold H_2 mass fraction is negligibly small in region 2, while warm H_2 is approximately 40% of gas mass. In region 1, the cold H_2 is >50% of total gas mass and the warm H_2 mass is very small fraction compared to cold molecular and atomic components. Atomic gas is nearly 40% of total gas in region 1 and more than 50% in region 2.

References

[1] Bolatto. A. D., Wolfire. M., Leroy. A. K., et al. 2013, *The CO-to-H2 Conversion Factor ARAA*, **51**, 207-268.

[2] Gordon, K. D., Galliano, F., Hony, S., et al. 2010, *Determining dust temperatures and masses in the Herschel era: The importance of observations longward of 200 micron*, *A&A*, **518** 89.

[3] Kemper, F., Woods, P. M., Antoniou, V., et al. 2010, *The SAGE-Spec Spitzer Legacy Program: The Life Cycle of Dust and Gas in the Large Magellanic Cloud*, *PASP*, **122**, 683-700.

[4] Kim, S., Staveley-Smith, L., Dopita, M. A., et al. 2003, *A Neutral Hydrogen Survey of the Large Magellanic Cloud: Aperture Synthesis and Multibeam Data Combined*, *ApJS*, **148**, 143-486

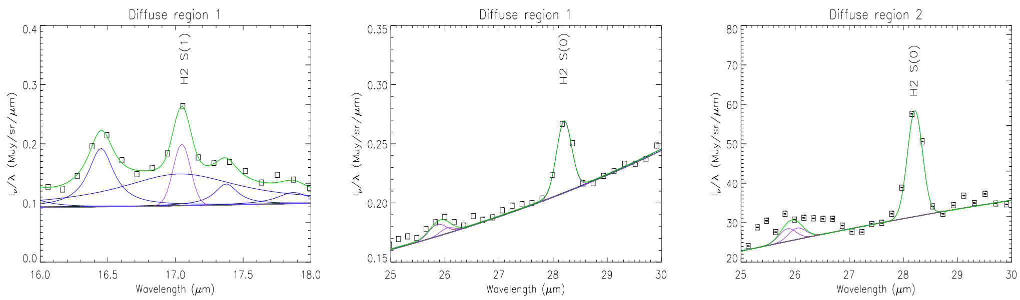

Figure 1: Segments of H_2 S(0) and S(1) line fits using PAHfit. The black squares indicate the observed spectra, superimposed are: the best fit model (green), PAH features (blue) and spectral line features (violet).

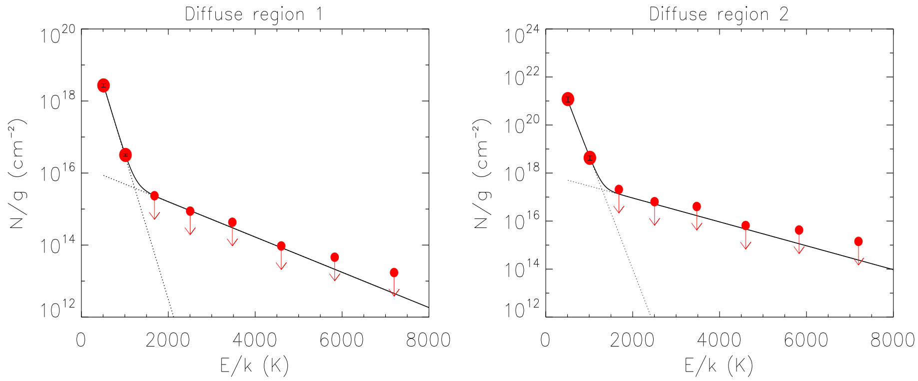

Figure 2: Rotational diagrams of H_2 for two observed regions along with the best fit two-temperature models.

[5] Meixner, M., Gordon, K. D., Indebetouw, R., et al. 2006, *Spitzer Survey of the Large Magellanic Cloud: Surveying the Agents of a Galaxy's Evolution (SAGE). I. Overview and Initial Results*, *AJ*, **132**, 2268-2288.

[6] Meixner, M., Galliano, F., Hony, S., et al. 2010, *HERschel Inventory of The Agents of Galaxy Evolution (HERITAGE): The Large Magellanic Cloud dust*, *A&A*, **518**, 71

[7] Nikolaev, S., Drake, A. J., Keller, S. C., et al. 2004, *Geometry of the Large Magellanic Cloud Disk: Results from MACHO and the Two Micron All Sky Survey*, *ApJ*, **601**, 260-276.

[8] Pietrzyński, G., Graczyk, D., Gieren, W., et al. 2013, *An eclipsing-binary distance to the Large Magellanic Cloud accurate to two per cent*, *Nature*, **495**, 76-79.

[9] Russell, S. C. and Dopita, M. A. 1992, *Abundances of the heavy elements in the Magellanic Clouds. III - Interpretation of results*, *ApJ*, **384**, 508-522.

[10] Smith. J. D. T., Draine. B. T., Dale. D. A. 2007, *The Mid-Infrared Spectrum of Star-forming Galaxies: Global Properties of Polycyclic Aromatic Hydrocarbon Emission*, *ApJ*, **656**, 770-791.

[11] Wong, T., Hughes, A., Ott, J., et al. 2011, *The Magellanic Mopra Assessment (MAGMA). I. The Molecular Cloud Population of the Large Magellanic Cloud*, *ApJS*, **197**, 16