Modelling 30 Doradus in the Large Magellanic Cloud

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ABSTRACT

The H II regions in the Large Magellanic Cloud (LMC) provide an ideal laboratory to study various processes of dust formation and evolution. The LMC has been targeted by many space-based telescopes, including NASA's *Spitzer Space Telescope* and more recently, JAXA's *AKARI* satellite owing to its known distance and nearly face-on orientation with respect to the Miky Way (MW). The highest LMC reddening occurs in the 30 Doradus H II region where the color excess E_{B-V} reaches a maximum of 0.29. We have done correlation studies in this region between far-ultraviolet (FUV) observations made by the *FUSE telescope* and infrared (IR) observations made by *AKARI* in the recent past. In this work, we have attempted to model the FUV scattering by 20 hot stars in the 30 Doradus region within a 1 deg radius. We have chosen an ideal dust distribution facilitating us to study the emission properties around the centre of the nebula. We will also model the IR emission later to conclusively prove the dust properties in the region.

Keywords: (ISM:) dust, H II regions; infrared: ISM; ultraviolet: ISM; galaxies: Magellanic Clouds

1. INTRODUCTION

The Large Magellanic Cloud (LMC), at a distance of 50 kpc (Feast 1999), is the nearest extragalactic system in which stars can be resolved and studied alongside the interstellar gas and dust. The LMC provides us an ideal opportunity to study various type of objects ranging from normal stars, supernova remnants, planetary nebulae to H II regions (Pagel et al. 1978). A survey of the entire LMC was done by the *Spitzer space telescope* in its SAGE Legacy program (Meixner et al. 2006). In recent times, the Japanese IR astronomical satellite, *AKARI* (Murakami et al. 2007), has observed the LMC in the entire infrared spectrum.

From the advent of infrared telescopes, the LMC H II region 30 Doradus, also known as the Tarantula nebula, has been the focus of studies owing to it being one of the most famous massive star forming regions (Kennicutt 1984) and the most powerful source of Hα emission in the LMC (Townsley et al. 2006). At its core is the young massive cluster R136, which is a compact region hosting a very large concentration of massive hot and luminous stars as revealed by the *Hubble Space Telescope* (Selman et al. 1999; Massey & Hunter 1998). The nebula is a giant starburst region where the energy from the bright, hot young stars creates huge voids and filaments in the surrounding clouds of gas. Its environment resembles the extreme conditions of the early universe in terms of dust content, metallicity and rate of star formation and because of these reasons, 30 Doradus has been the target of a range of multiwavelength studies (infrared, optical, ultraviolet and X-ray) to try and understand its structure in terms of not only its stellar populations but also the distribution of gas and dust (Torres-Flores et al. 2013).

In this work, we first present the FUV–IR correlation results from our earlier work and then we try to model the central 30 Doradus region using a FUV scattering model. We have tried to understand the nature of dust species present alongwith its distribution in the region and infer how the scattered FUV radiation from hot stars affects the surrounding dust. We will subsequently model the IR emission in the region to conclusively prove its dust properties.

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2. OBSERVATIONS AND MODEL

In our previous work Saikia et al. (2016), we had selected a list of 81 LMC locations observed by *FUSE telescope* in the FUV from Pradhan et al. (2010). Out of these, 28 locations were observed by *AKARI* which we found in the *AKARI* legacy archive at 15 μm, 24 μm and 90 μm. The 15 μm and 24 μm data was taken by the *AKARI* Infrared Camera (IRC; Onaka et al. 2007) which made observations using three independent camera systems: NIR (1.7–5.5 μm), MIR-S (5.8–14.1 μm) and MIR-L (12.4–26.5 μm). The 90 μm data was taken by the *AKARI* Far-Infrared Surveyor (FIS; Kawada et al. 2007) which was the all-sky survey instrument onboard *AKARI* observing effectively at four wavelength bands: N60 (50–80 μm), WIDE-S (60–110 μm), WIDE-L (110–180 μm) and N160 (140–180 μm).

Fortunately for us, 8 among these 28 *AKARI* achival data locations coincided with the 30 Doradus H II region as shown in Figure 1.

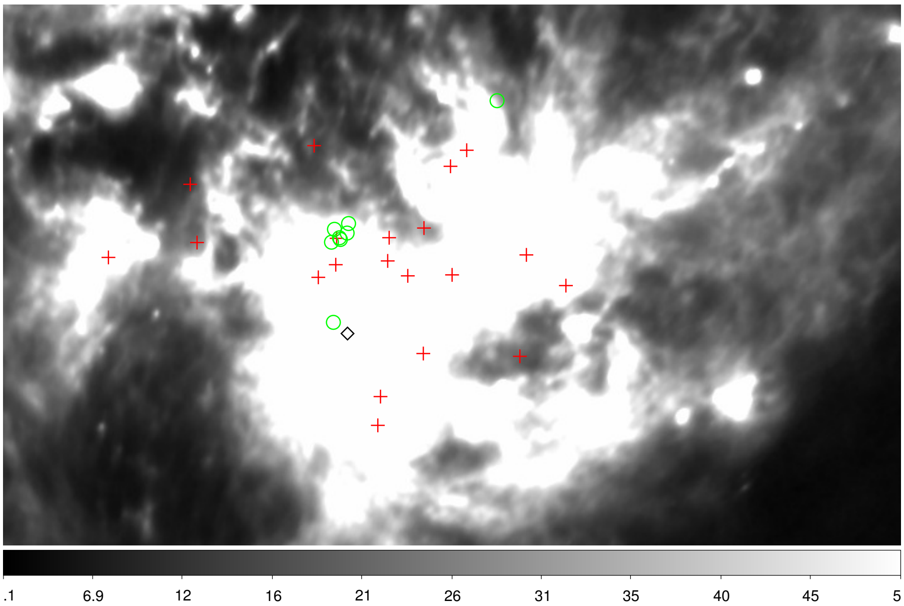

Figure 1. Image of the LMC 30 Doradus central region taken by the *AKARI*–FIS. The 30 Doradus centre is represented by the black diamond symbol. The green circles represent our dust locations for which we have done FUV–IR correlation studies. The stars used for the FUV scattering model are shown symbolically as red crosses.

We have used the Monte-Carlo based model by Shalima & Murthy (2004) for the FUV scattering calculations. The code simulates the scattered emission from a star in an arbitrary scattering geometry. Since it is Monte-Carlo based, each photon from a star is emitted in a random direction following which the photon continues to travel in that direction until an interaction occurs. On interaction, the photon's effective weight is reduced by a factor of the dust grain albedo (α), and the Henyey–Greenstein (Henyey & Greenstein 1941) scattering phase function is used to calculate a new direction for the photon:

$$\phi(\theta) = \frac{(1 - g^2)}{4\pi[1 + g^2 - 2g\cos(\theta)]^{\frac{3}{2}}}$$

where 'g' is the asymmetry factor and 'θ' is the angle of scattering. A value of g close to zero represents isotropic scattering while a value of g close to 1 implies strong forward scattering. The photon is followed through a sequence of interactions until it either leaves the area under consideration or its intensity drops to a negligible value. Since 30 Doradus is a star-forming region, we have considered a list of 20 hot stars (O, B stars) in a 1 deg radius (Walborn 1991) from the centre of the region as shown in Figure 1. We have used data from the MAST *International Ultraviolet Explorer (IUE)* archives at 1110 Å to calculate the fluxes of our stars. We have made use of the SIMBAD database to specify the stellar spectral types, locations and distances of the stars. The details of our 20 stars are shown in Table 1.

Table 1. Details of the 20 stars considered for our model calculations.

Name	gl $\left(^0\right)$	gb $\left(^0\right)$	$V_{\rm mag}$	Spectral type
HD269923	279.9267	-31.6133	10.30	OB D
HD269700	278.9047	-32.3539	10.54	B1.5Iaeq C
CPD-69416	279.5928	-31.8760	12.16	BC1Ia C
HD269846	279.5088	-31.8783	11.63	OB D
HD269992	280.2496	-31.3535	11.22	B2.5Ia C
CPD-69436	279.7620	-31.7806	12.12	BC1.5Ia C
HD37974	279.8220	-31.8383	10.99	B0.5e D
HD269997	279.4172	-31.4400	11.20	B2.5Ia C
HD37836	280.1820	-31.8999	10.69	B0e(q) D
HD269786	280.2705	-31.9087	11.18	B1I C
CPD-69400	279.6586	-31.9433	12.29	B0.7Ia C
HD269859	279.9523	-31.7928	10.730	B1Ia C
HD269668	279.3338	-32.3813	12.01	OB D
CPD-69445	279.7882	-31.7008	12.032	B1Ia C
CPD-69514	279.9403	-31.2628	11.3	OB D
HD270019	279.3409	-31.3700	12.197	OB D
HD269705	279.8110	-32.2314	11.71	OB D
SK-68121	279.2160	-32.2146	12.17	OB D
RMC148	280.2022	-31.5141	12.080	B3I(a) C
CPD-69491	279.6509	-31.4661	11.88	B3I C

3. RESULTS AND CONCLUSIONS

From our FUV–IR correlation studies (Saikia et al. 2016), we find that the *AKARI* 15 μm, 24 μm and 90 μm emission intensities show a good correlation with one another which implies that they originate from similar hot environments as shown in Table 2. The average FUV/IR(90 μm) ratio in 30 Doradus is high at 0.0475 which explains the lower FUV–IR correlation values due to low extinction with high density of stars being unaffected by dust grains. The low emission at 24 μm is possibly due to the destruction of VSGs in the star forming regions. The I_{15}, I_{24} and I_{90} in Table 2 represent the intensities at the three IR wavelengths (Saikia et al. 2016) while $I_{0.11}$ represents the *FUSE* FUV intensity at 1110 Å from Pradhan et al. (2010).

Table 2. Correlations for the 8 *AKARI* 30 Doradus locations from Saikia et al. (2016)

	Rank correlation	Probability
$I_{0.11} - I_{24}$	0.452	0.260
$I_{0.11} - I_{90}$	0.452	0.260
$I_{15} - I_{24}$	0.952	0.000
$I_{15} - I_{90}$	0.880	0.003
$I_{24} - I_{90}$	0.905	0.002

We have executed the Monte-Carlo based code using our 20 stars as input for all possible values of α (0.1, . . . , 0.9) and g (0, 0.1, . . . , 0.9). We have then combined the results for each individual star to obtain a composite output with all the contributing stellar inputs in the region under consideration as shown in Figure 2. The model images shown in Figure 2 correspond to an albedo of $\alpha = 0.2$ and asymmetry factor of $g = 0$ (image on left) and $g = 0.9$ (image on right). We know from Draine (2003) that for an average LMC carbonaceous–silicate dust model, we have $\alpha = 0.2276$ and $g = 0.6414$ at

FUV 1110 Å. The model images (in z-scale) seem to be from a single source but that is due to the fact that all the 20 stars are very closely placed in a 1 deg radius which makes it difficult to resolve them individually at such high intensities. We see a faint distinction in minmax scale which we have not shown here.

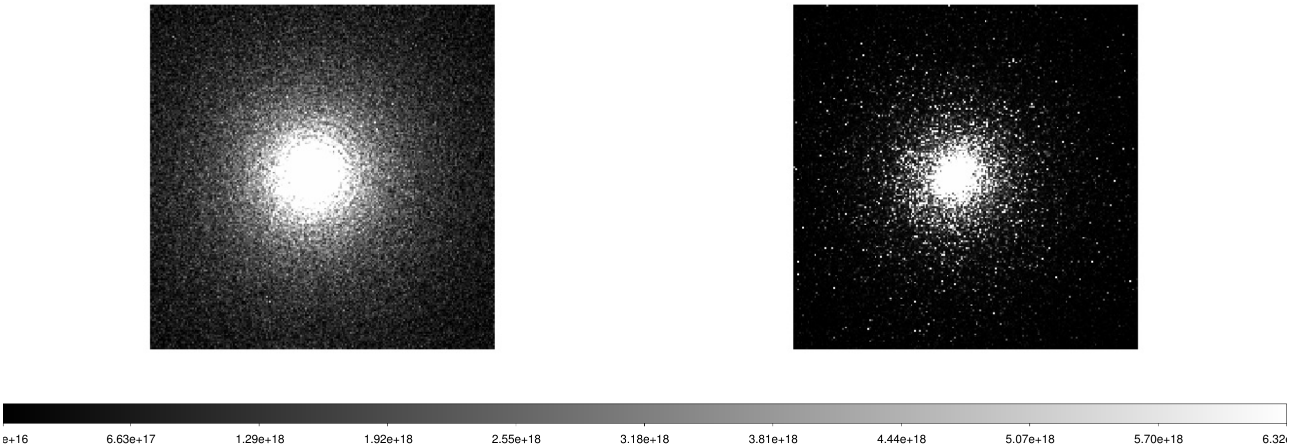

Figure 2. Model images of FUV scattering by dust in the 30 Doradus central region. The image on the left corresponds to $g = 0$ and the image on the right corresponds to $g = 0.9$.

Thus, our FUV dust scattering model works fine for the 20 stars in a 1 deg radius around the 30 Doradus centre. We can easily get the scattered intensities at our dust locations from the model images which can be compared for best fit with FUV observational data to constrain and compare the α, g values from our model with those existing in literature such as Draine (2003). As a future work, we will model the IR emission in the same dust locations to get a complete picture of the dust properties using appropriate models and dust mixtures.

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