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Dust distribution in HII regions in nearby galaxies from optical and IR studies

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Abstract. We report on our ongoing project "Statistical studies of HII regions in the nearby extragalaxies". In EWASS 2014 we presented the overview of our detailed study of warm dust in the nearby Galaxy NGC 4321 (M100), which included new relations between the Hα luminosity and the near-IR luminosity and temperature of some 275 HII regions in M100. In the present report, we show our new measurements the flux values in the 4 Spitzer-IRAC bands of a complete sample of 70 isolated luminous HII regions in NGC 4736 and 157 regions in NGC 4254. We estimate the near-IR luminosities and compare them with the Hα luminosities from the literature. We can now compare the results obtained from these three galaxies. We find a linear relation between the Hα luminosity and the Spitzer IRAC luminosity in the near IR for the HII regions, but no apparent relation between the luminosity and the colour temperature of the regions in M00, and now in NGC 4736 and NGC 4254. The colour temperatures of regions, notably in M100 and in NGC 4254 are confined to a surprisingly narrow range, with only a small fraction forming a higher temperature tail to the distribution. These results give new insight into the size function and the 3D distribution of the dust in these regions, and we propose scenarios to explain them.

Key words. galaxies: dust – galaxies: individual:(M100,NGC4736,NGC4254) – ISM: HII regions methods: infrared: statistical infrared: galaxies

1. Introduction

Statistical properties of extragalactic HII regions, which are observable through hydrogen recombination lines, provide important clues to physics of the massive star formation process. Infrared luminosity functions of HII regions in the galaxies provide insights into the physical processes connecting star formation to the interstellar medium in the galaxies as well as provide a vital diagnostic tool for studying star formation process.

One of the primary goals of this project is to compare the luminosity functions from infrared emission with the luminosity functions derived from Hα emission. This project is mainly divided into two schemes: pilot study and detail study. M100 is chosen as the "pilot galaxy" in the pilot study (see Chan & Beckman 2013) and detailed study that was reported in the EWASS 2014. In this report, we present the overview and first insights of the pilot study of NGC 4736 and NGC 4254.

2. Measurements and data analysis

The optical Hα images of NGC 4736 and of NGC 4252 are from Knapen et al. (2004) and their HII region catalogues are from Bradley et al. (2006).All of them are selected as our referenced data.

Both of them were obtained via SIMBAD. The SINGS/IRAC images of M100 obtained from the SINGS Public Data Set Achieve (http://sings.stsci.edu/) are selected as our primary data.

In the pilot study, only those HII Regions with radius 2.23" - 4.46" are selected. The total number of selected HII regions in NGC 4736 is 78 and 157 regions in NGC 4254. By using cross-reference technique between the optical Hα image, the catalogue of HII regions, and the Spitzer IRAC images, we locate the selected HII regions in the IRAC image frames. The detailed measurement procedure is described in (Chan & Beckman 2013).

2.1. The correlation between L(Hα) and L(IRAC)

One of the main result presented here is the strong positive correlation between the luminosity in Hα and the IR luminosity as measured with IRAC. The IR and Hα luminosities are clearly linearly proportional for our sample in M100 in Fig. 1.

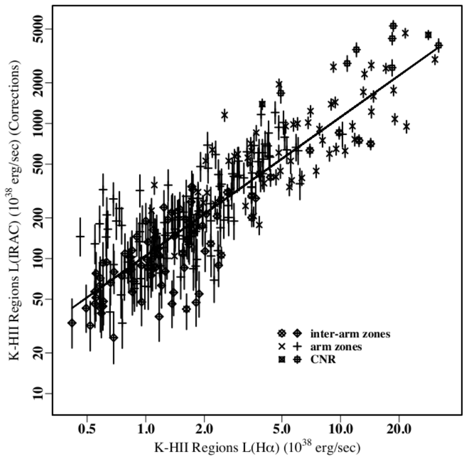

Fig. 1. The integrated IR luminosities of the HII regions in M100 plotted again their Hα luminosities. We use statitical fluctuation weight for the linear fitting. The figure also shows that ther correction does not depend on whether a region is in an arm or in the interarm zone in M100.

2.2. Hα luminosity and infrared colour temperature

Based on the spectral energy distribution of the HII Regions in the IRAC bands, we noticed that the 3.6 μm flux and the fluxes in the bands of 4.5 μm, 5.8 μm and 8.0 μm are most likely not from the same physical process origin. The IRAC-3 bands-colour-temperature $T_{col(IRAC)}$ of each HII region was obtained by blackbody Chi-Square fitting of the measured fluxes in the bands of 4.5 μm, 5.8 μm and 8.0 μm (see Fig.4 in Chan & Beckman 2013). Figures 2 show that the Hα luminosity, L(Hα) v. $T_{col(IRAC)}$, using corrected values. We can see that there is no correction between two variables. This range of colour temperatures, which can also be seen in Figures 2, is surprisingly restricted given the range of luminosities of the regions: some two orders of magnitude in either Hα or IR luminosity.

One of the main results of the present article is the set of $T_{col(IRAC)}$ values for the selected set of HII regions and in Fig. 3 we present these results as a histogram. We can see that the mode value is just over 300K, with a range

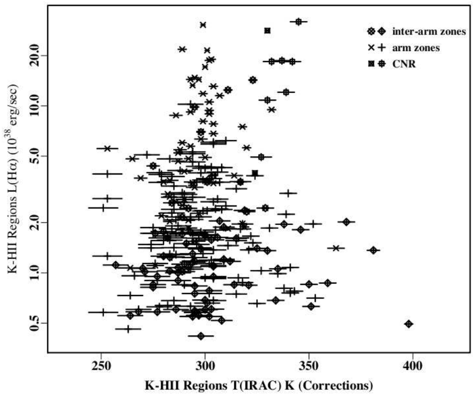

Fig. 2. (a) Interesting phenomena of colour temperature. Colour temperature again L(Hα) for the HII regions in M100. The figure shows that there is no correction between the two variables. Their positions in the arms, in the interarm zone or in the circumnuclear region (CNR) do not cause any systematic effect.

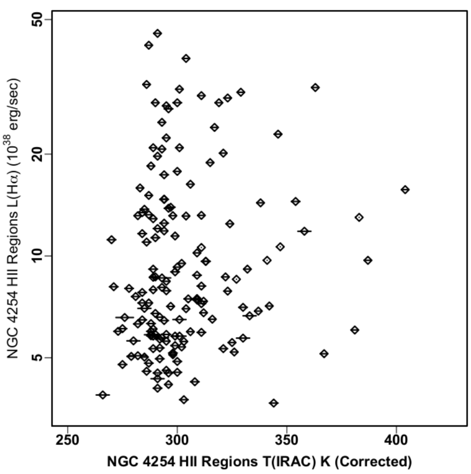

Fig. 2. (b) Interesting phenomena of colour temperature. Colour temperature again L(Hα) for the HII regions in NGC 4254.

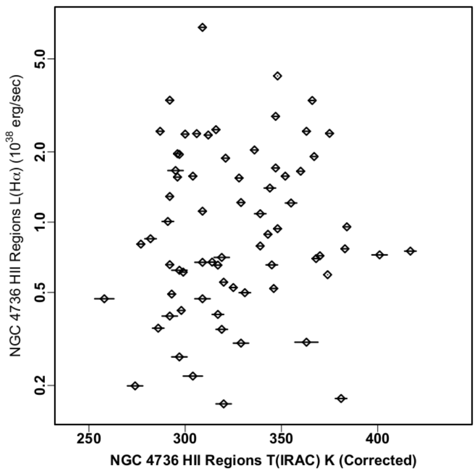

Fig. 2. (c) Interesting phenomena of colour temperature. Colour temperature again L(Hα) for the HII regions in NGC 4736.

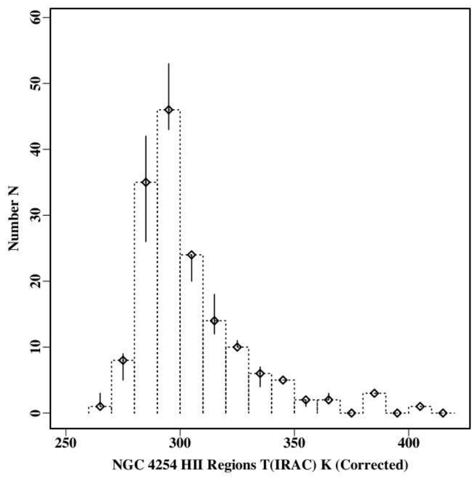

Fig. 3. Histogram of the colour temperature for 157 regions in NGC 4254

from 265K to 400 K, surprisingly restricted, given the wide range of luminosities of the regions. Figure 3 shows NGC4254 are confined to a surprisingly narrow range, with only a small fraction forming a higher temperature tail to the distribution.

3. Constant temperature and dust models

It is very interesting to note that there is no correction between L(Hα) and $T_{col(IRAC)}$. The mechanism(s) that might lead to this near-invariance of the temperatures we measure could be the following possible three scenarios or the combination of any of them.

Dust destruction model : The dust is ablated away in the inner zones of the HII regions, close to the OB stars, in such a manner that the more luminous the star cluster, the greater the range of this grain destruction. In consequence, the emitting grains turn out to have around the same temperature for all the regions, because the dust which emits has its inner limit at a greater radial distance from the cluster, the higher the luminosity.

Stellar-wind model : The dust in the ISM surrounding an ionising star cluster is swept out beyond a radial distance from the cluster, which depends on the cluster luminosity. In any HII region the dust emission would then come from a thick shell whose inner radius is larger, the higher the stellar luminosity.

Tiny stochastically heated grain model : We are probably observing stochastically heated nano-sized dust grains so that their "temperatures" are independent of the illuminating field. The heating mechanism for small grains is stochastic heating, in which a grain is heated by absorption of a single photon. This form of heating implies that the temperatures of the grains do not respond in the same way as they would if they were in thermodynamic equilibrium, so that their mean temperature does not depend on the luminosities of the stars supplying the photons, and depends only slightly on the temperatures of those stars.

4. Summary

The origin of the emission in the 3.6 μm and in the other IRAC bands is different. We suggest that the 3.6 m excess is mainly due to the PAH C-H stretching feature (PAHs with Nc < 50 carbon atoms. (see Fig.6 in Draine & Li 2007)

By using a Chi-squared fitting technique, we estimate IRAC 3-band colour temperatures from around 250 K up to around 400 K. There is a strong correlation between the L(Hα) and L(IRAC) of the selected HII regions. We propose that this strong correlation be used for studying star formation rate issues. Calibrating this relation and combining the IRAC luminosity with the mid-IR luminosity should allow a practical derivation of the star formation rates without direct recourse to Hα observations.

It is notable that the IRAC 3-band colour temperature shows no significant dependence on the HII region luminosity. These results give new insight into the size function and the 3D distribution of the dust in these regions.

The size distribution refers to the possibility that the dust grains are either all very small (tiny heated grain model) or at least a large fraction of the grains is very small.

The 3D distribution refers to the scenario related to combining of dust destruction model and stellar-wind

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