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A Spatially Resolved Study of the Cold Dust in NGC 205

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Abstract. We present IRAC and MIPS observations of NGC 205, the dwarf elliptical companion of M31, obtained with the *Spitzer Space Telescope*. The extended dust emission is spatially concentrated in three main emission regions. Based on our mid-to-far infrared flux density measurements alone, we derive a total dust mass estimate of the order of $3.2 \times 10^4 M_\odot$, at a temperature of $\sim$ 20K. The gas mass associated with this component matches the predicted mass returned by the dying stars from the last burst of star formation in NGC 205 ($\sim$0.5 Gyr ago). Analysis of the *Spitzer* data combined with previous 1.1mm observations over a small central region or "Core" (18$''$ diameter), suggest the presence of very cold (T$\sim$ 12K) dust and a dust mass 16 times higher than is estimated from the *Spitzer* measurements alone. Assuming a gas to dust mass ratio of 100, these two datasets, i.e. with and without the millimeter observations, suggest a total gas mass range of 3.2×10^6 to 5×10^7 $M_\odot$.

1. Introduction

The galaxies of the Local Group, because of their proximity and our ability to carry out high spatial resolution studies in nearby systems, provide us with powerful templates to understand the chemical, morphological and kinematical characteristics, plus star formation history, of more distant galactic systems (Mateo 1998). Dwarf ellipticals follow a different "fundamental plane" than normal ellipticals but still share many of their characteristics, in particular the presence of a mostly old stellar population (Mateo 1998). One of these local dwarf systems is NGC 205, a low surface brightness dwarf elliptical companion of M31. NGC 205 is interesting because of its very conspicuous dark clouds, which were detected in some of the earliest photographic plates of M31 and its surroundings (Hodge 1973) (NGC 205 lies $\sim 36'$ NW from the M31 nucleus). These visually dark clouds reveal the presence of an interstellar medium in a stellar population dominated by old stars, that is, in an elliptical galaxy.

Several stellar population indicators suggest that NGC 205 was the site of a star forming episode some 10^8 years ago which was followed by a replenishment of its interstellar material. Although there is no consensus on the process which triggered such a burst, gravitational tidal interaction of NGC 205 with M31 has always been an appealing mechanism because it simultaneously explains the twisted surface brightness isophotes (Hodge 1973), the tidal trail of blue metal poor RGB stars (McConnachie et al. 2004) and the kinematically distinct behavior and morphology of its interstellar medium, particularly of the HI gas (Young & Lo 1997).

The ISM in NGC 205 has some peculiarities. Based on the last burst of star formation $\sim 5 \times 10^8$ yr ago (Wilcots et al. 1990; Bertola et al. 1995), one can estimate the amount gas injected back into the ISM, which is $\sim 2.6 \times 10^6 M_\odot$ (following Faber & Gallagher 1976). This mass is about three times larger than that measured by Sage, Welch & Mitchell (1998) of $7.2 \times 10^5 M_\odot$. This difference in masses led to the idea that gas is being removed by the young stars in NGC 205, either by stellar winds or supernova explosions (Welch, Sage & Mitchell 1998).

2. Observations

The mid-IR observations were obtained with IRAC, the infrared camera on board *Spitzer* on 20 January 2005 as part of the GO1 program to map M31 (PI: Barmby, Program ID: 3126). The region around NGC 205 was observed with four dithered 30 sec frames per sky position. The final mosaics have a 2″ FWHM spatial resolution. The far-IR data were obtained with the multiwavelength photometer MIPS on board *Spitzer* on 25 August 2004 (Program ID 99). The NGC 205 observations have a depth of 84 sec per pixel, and are part of a 1° × 3° mosaic of M31 (Gordon et al. 2006). The final 24, 70, and 160 micron images have spatial resolutions of 6, 18 and 40″ FWHM, respectively.

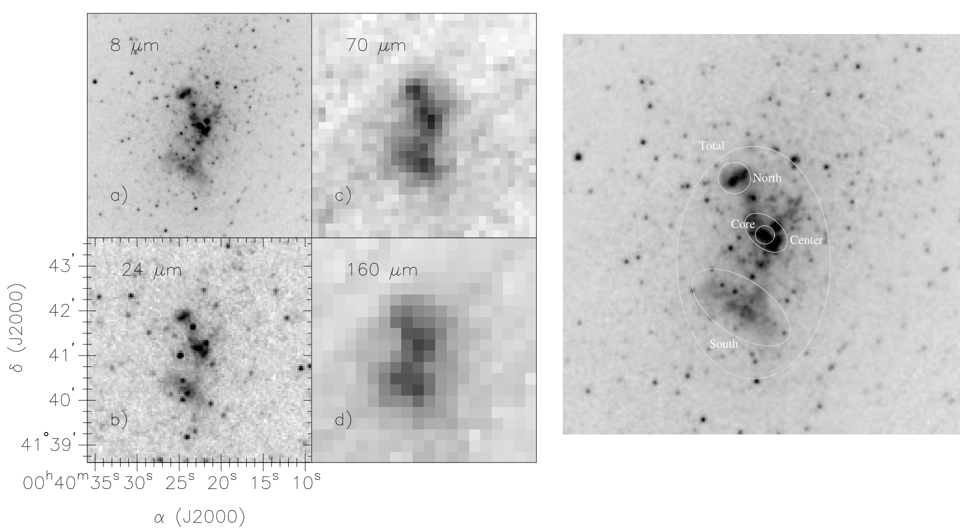

Figure 1. *Left:* IRAC 8 μm MIPS 24, 70 & 160 μm images of NGC 205. The FOV of each image is 5′ × 5′ with N up and E to the left. *Right:* The three main emission regions – “North”, “Center”, “South”– as well as the “Core” and “Total” regions are shown overlayed on the IRAC 8 μm image of NGC 205. The FOV is 5′ × 5′ with N up and E to the left.

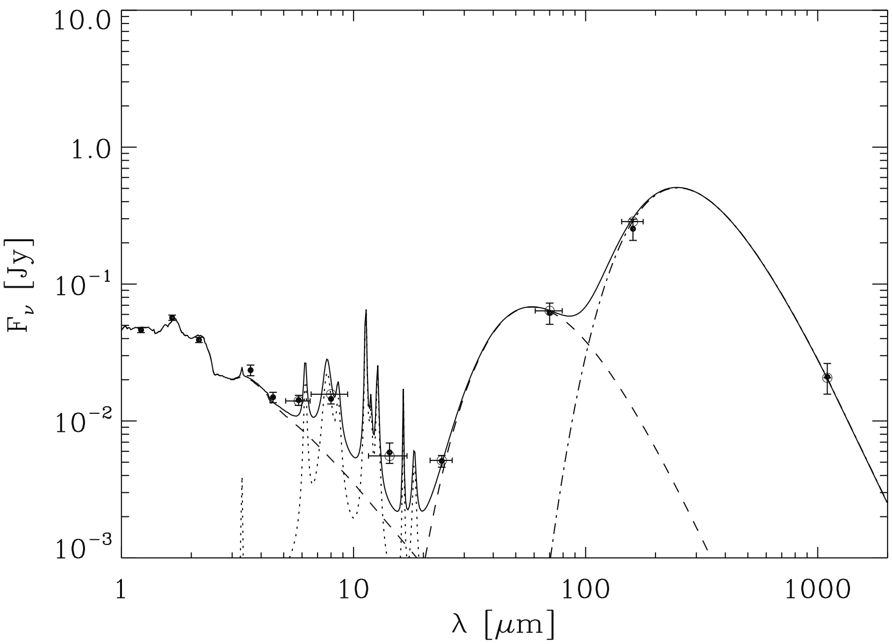

Figure 2. Infrared SED of the "Core" regions of NGC 205, with a fit to the IRAC, 14.3 μm ISO, and MIPS measurements, plus the 1.1mm data point measured by Fich & Hodge (1991). The *solid* points are the data (stellar photospheric component removed) and the *open* points are the model multiplied with the passband and integrated over wavelength. The *dotted* line is the PAHs component, the *dashed* is the warm silicates component, the *dot-dashed* is the cold silicates component and the *solid* one is the total of all.

3. Results

Figure 1 shows the images of NGC 205 taken with IRAC at 3.6 & 4.5 μm (stellar emission dominant) and at 5.8, 8, 24, 70 & 160 μm (dust emission dominant). The morphology of the diffuse emission is complex and clumpy; nevertheless we can clearly identify three spatially distinct emission regions, ranging in sizes from 120 to 300pc. Even at the lower resolution of the 70 and 160 μm bands (Fig. 1), where the bulk of the emission is produced by dust emission from the larger grains ($\sim$ 0.1-0.5 μm, Li & Draine 2001), one can easily identify the same three large regions seen at shorter wavelengths. We have included also a "Core" region with a diameter of 18.″4 for which 1.1mm observations are available (Fich & Hodge 1991).

New IRAC and MIPS observations of NGC 205 give a better assessment of the total dust mass in this prototypical dwarf system. The *Spitzer* data have been complemented with ISOCAM archival data to create a well defined spectral energy distribution in the 3.6 to 160 μm wavelength range. The higher sensitivity and angular resolution of IRAC and MIPS provide a detailed view of the morphology of the interstellar medium in NGC 205. At 8 and 24 μm the spatial structure of the warm dust is clearly resolved, displaying a complex structure. To facilitate our analysis of the color temperature and dust masses, we identified three main regions (Fig. 1). The dust clouds within these regions are bright and conspicuous at the longer wavelengths too, having sizes ranging from $\sim$ 100 to 300 pc, and dust masses of $\sim 10^3 - 10^4 M_\odot$. A larger "Total" area encompasses the three regions, and covers most of the bright 160 μm dust emission.

The derived dust masses, based on the 70 to 160 μm flux ratio and a best fit to the SED, imply gas masses – assuming a standard gas-to-dust mass ratio of 100 (cf Young 2000) – that are consistent with each other and larger ($3.2 - 6.1 \times 10^6 M_\odot$) than previously estimated from CO and HI observations. This indicates that a significant contribution to the dust and gas masses is coming from a fainter component surrounding the brightest emission regions. Adding the 1.1mm detection to our measurements of the "Core" region of NGC 205 increases by a factor of sixteen the estimate of the cold dust in that region (Fig. 2). Our gas mass estimate in NGC 205 is a factor of four larger than previously detected, but it could be still larger if the distribution of the very cold dust ($\sim 12 - 14$ K) spreads out to the three selected regions. If this is the case, the gas mass would be sixteen times the "Total", i.e. $5 times 10^7 M_\odot$ for a gas-to-dust mass ratio of 100. Overall the gas estimates are therefore consistent with the predicted mass return from dying stars, based on the last burst of star formation, 5×10^8 yr ago.

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