Tracing the Ancestry of Galaxies (on the land of our ancestors)
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Cold Dust and its Heating Sources in M 33

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Abstract. We have mapped the nearby face-on spiral galaxy M 33 in the 1.1 mm dust continuum using AzTEC on Atacama Submillimeter Telescope Experiment (ASTE). The preliminary results are presented here. The observed dust has a characteristic temperature of ~ 21 K in the central kpc, radially declining down to ~ 13 K at the edge of the star forming disk. We compare the dust temperatures with K_S band flux and star formation tracers. Our results imply that cold dust heating may be driven by long-lived stars even nearby star forming regions.

Keywords. (ISM:) dust, galaxies: ISM

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1. Introduction

Dust in galaxies have a range of temperatures, but are known to be broadly characterizable by two distinct temperatures, namely the warm ~ 50 K and cold ~ 20 K

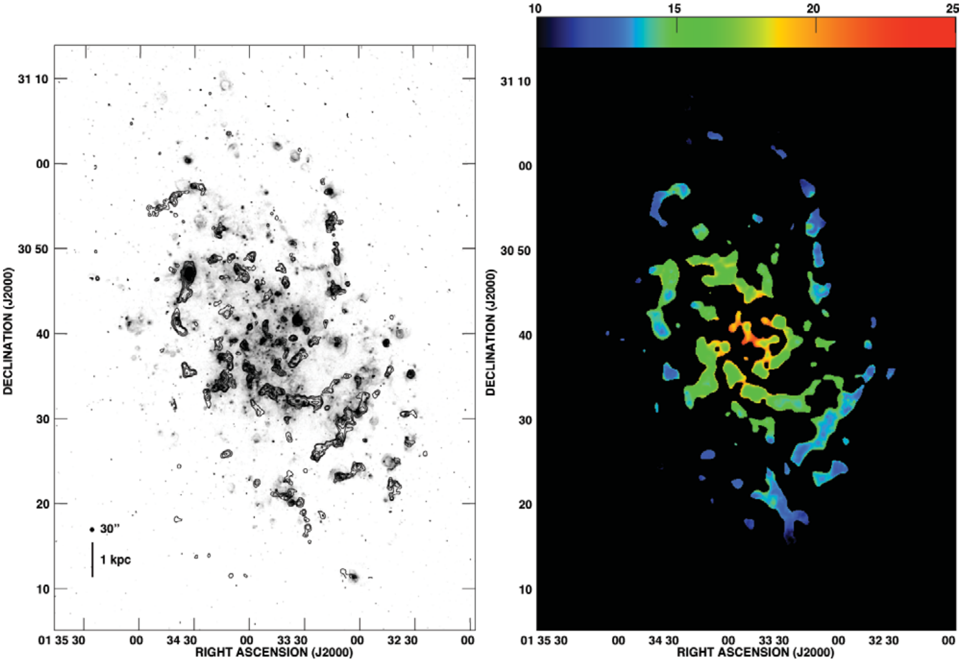

Figure 1. Left : 1.1 mm contours on Hα image of M 33. Note the spatial correspondence between the two. Right : Dust temperature map constructed from 1.1 mm - 160 μm ratio.

components. The distribution of dust temperature within galaxies, however, is not well known. As such, the heating sources of these components (i.e., which stellar population) is still controversial, especially for the cooler component where large scale, high resolution mapping surveys at far-infrared to submillimeter wavelengths are necessary.

M 33 is the nearest face-on galaxy, and makes it an ideal target for high angular resolution continuum surveys. The Atacama Submillimeter Telescope Experiment (ASTE; Ezawa *et al.*, 2004, Kohno *et al.*, 2005, Ezawa *et al.*, 2008) was used with the AzTEC millimeter camera (Wilson, *et al.*, 2008) in 2007-2008 to observe the whole star forming disk of M 33, attaining an angular resolution of $30'' \sim 120$ parsecs, just enough to resolve giant star forming complexes.

2. Preliminary Results

The left panel of figure 1 shows the obtained 1.1 mm map of M 33 as contours, overlayed on a greyscale Hα image (Walterbos & Greenawalt, 1996). The dust continuum is detected out to a radius of 7 kpc, and clearly outlines the spiral structure that is seen in Hα, and also corresponds to the spiral structures observed in both CO and HI (Onodera *et al.*, 2010, Tosaki *et al.*, 2011). Such spatial correlation with Hα has lead previous studies to conclude that the heating source of far-IR dust is heated by massive stars (e.g., Devereux *et al.*, 1997), but spatial correlation alone cannot distinguish whether dust is actually warmer near these star forming regions or there is just more dust mass. We attempt to shed light on this issue by deriving the local temperature distribution within the galaxy.

2.1. *Temperature Distribution*

The right panel of figure 1 is a color temperature map obtained from a ratio of the 1.1 mm map with a *Spitzer* MIPS 160 μm image retrieved from the Spitzer Science Center

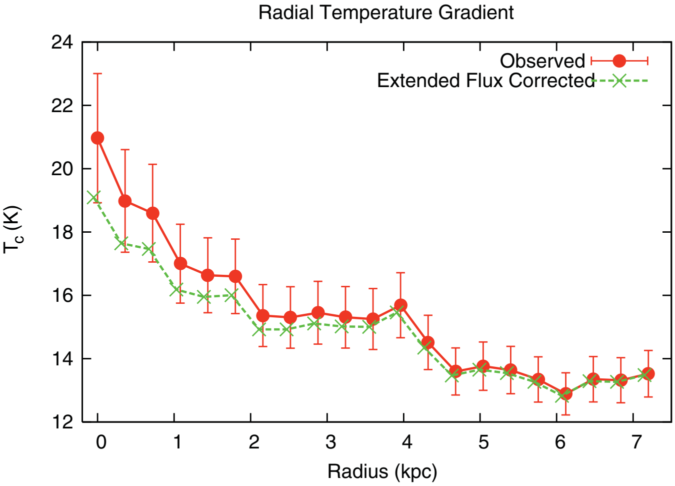

Figure 2. Radial dust temperature variation. Errors are computed from the observed flux errors. Shaded dashed lines correspond to values after a correction for extended flux subtraction is made.

data archive, assuming a dust emissivity index of $\beta = 2.0$. Although some temperature enhancements are evident in a few number of intense star forming regions, the dominant scale of temperature fluctuations is global, and not local to the individual star forming regions which are smaller than 1 kpc. Figure 2 is the radial variation of the temperature map. A smooth radial gradient is present. It is important to note that extended structures (typically $> 5'$) have been subtracted out in the 1.1 mm map during the reduction process, which we estimate to be $\sim 50\%$ of the total flux. We have estimated a correction for this by adding in an exponential disk structure to the observed 1.1 mm map. The resulting temperature gradient is shown as the shaded dashed line. The radial temperature gradient persists, declining from $\sim$ 20 K in the central kpc to $\sim$ 14 K in the outer star forming disk. The temperature distribution and radial gradient shows that the driving heating source of dust seen here does not fluctuate at small scales, which should be expected in case massive stars (as traced by the star forming regions) heat the dust.

2.2. *Dust Temperature and Stellar Population*

In order to directly compare the possible heating sources of cool dust, we have performed aperture photometry on individual HII regions with Oxygen abundance measurements. Dust temperature in each of these regions were compared to K_S band flux and ionizing flux as measured by a combination of Hα and 24 μm flux (Calzetti *et al.*, 2007), using a circular aperture with $36''$ radius. Figure 3 shows the comparison between these measurements. The K_S band, assumed to be dominated by flux from long-lived stars, are found to be correlated with the dust temperature with correlation coefficient $r = 0.71$. The measure of ionizing flux, however, does not show a marked correlation with $r = 0.26$. This is not expected in the case where massive stars heat dust at 1.1 mm, in which case we should see a correlation between the intensity of star formation and the dust temperature.

3. Discussion

We showed that continuum flux at 1.1 mm concentrated near star forming regions are the result of more dust mass in these regions, not necessarily the result of higher dust

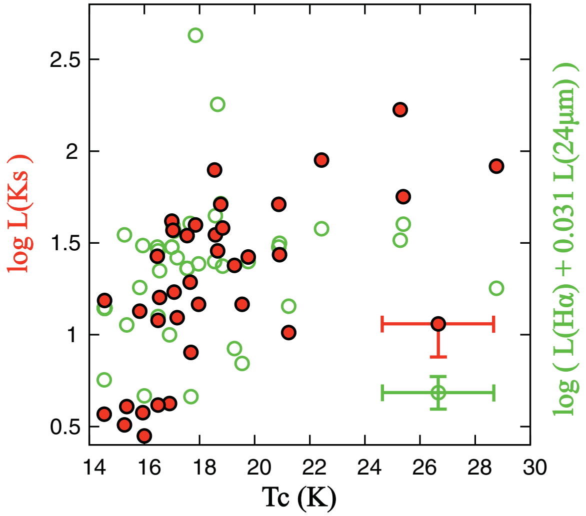

Figure 3. Dust temperature on x-axis, K_S (filled circles) or Hα + 24 μm photometry (open circles) flux on y-axis. The y-axis is arbitrary shifted for comparison.

temperature. This gives important implications on the heating source of submillimeter dust.

Long-lived stars are known to be responsible for dust heating in diffuse regions which are devoid of massive star complexes. Our the smooth radial temperature gradient and the correlation of the dust temperature and K_S flux suggest that heating of dust observed at 1.1 mm, tracing a cooler component, may be driven by long-lived stars even for dust concentrated near star forming regions at scales smaller than 1 kpc. Such dust heating dominated by photons from long-lived stars could result if the dominant dust observed here are large, and absorbs optical photons efficiently in addition to UV (Draine & Lee, 1984, Xu & Helou, 1996, Bianchi *et al.*, 2000).

Although this is a case study of M 33, it poses an important question on how we should interpret submillimeter flux when it becomes possible to detect normal star forming galaxies with upcoming telescopes like ALMA.

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