Massive Amounts of Cold Dust in Small Magellanic Cloud Supernova Remnant 1E 0102-7219

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Abstract

Currently, the primary source of interstellar dust is a subject of debate as models relying on evolved asymptotic giant branch stars fail to produce sufficient dust in the appropriate timescale. However, core collapse supernovae (CCSNe) have a much shorter lifecycle and are a plausible alternative for dust production in early Universe galaxies. Estimates suggest that each SNR would need to generate 0.1-1M_{sun} of interstellar grains if CCSNe are indeed the major sources of dust in high redshift galaxies[1,2]. Numerous reports exist for warm dust masses several orders of magnitude below this 0.1-1M_{sun} range, but some recent studies incorporating longer wavelength data show large masses of low temperature dust from remnants such as CasA[3] and the Crab[4] Nebula.

Here, using data from Spitzer Space Telescope's MIPS instrument with PACS and SPIRE data from Herschel Space Observatory, we detected massive amounts of cold dust in E0102, a 1000 year old oxygen rich remnant at a distance of 62.1kpc in the Small Magellanic Cloud (SMC). After removing SMC background signals, a polynomial interpolation was applied across an annulus of pixels surrounding the remnant to construct a map of local interstellar dust emission and to extract the residual signal attributed to E0102 alone. We then applied a Bayesian SED model to fit remnant dust emission to warm and cold dust components for a variety of grain species. For one, $Mg_{0.7}SiO_{2.7}$ grains, a 0.106 ± 0.032 M_{sun} cold component at dust temperature T_d=50 ± 5K was found in addition to a minor 0.003 M_{sun} warm component at T_d=194 ± 29K. This mass is orders of magnitude larger than previous estimates for SNR E0102 which ranged from .003-.015M_{sun} [5,6]. Such data bolsters the argument that CCSNe may serve as efficient producers of dust in the early universe.

Methodology

In this study, MIPS 24 and 70um; PACS 70, 100, and 160um; and SPIRE 250 and 350um images were gathered from the SAGE-SMC project[7] and HERITAGE project[8] respectively. SPIRE 500um data was left out due to its insufficient resolution.

Background noise was removed and all images and error maps were convolved down to the SPIRE 350um resolution. Subsequently, bicubic interpolation was performed on the convolved images to create pixels matching the SPIRE 350um pixel size.

Using radio flux data from the Vizier catalog, a synchrotron component was calculated for the remnant and found to have a spectral index of -0.69. At the wavelengths used in this study, the contribution of the synchrotron component was minimal, but was subtracted where appropriate.

Lastly, the local background was modeled and ultimately removed in order to isolate a residual signal attributed to the remnant alone. The process was complicated by the proximity of N76, an emission nebula lying near to the line of sight for SNR 1E 0102. Several approaches were tried in order to best account for the steep increase in signal that occurred at the borders of the nebula. Ultimately, the background signal was determined by masking the remnant region and applying a polynomial interpolation across the field of view, as seen in Figure 1. This modeled background was then subtracted from the image data to isolate the residual flux from SNR 1E 0102 alone.

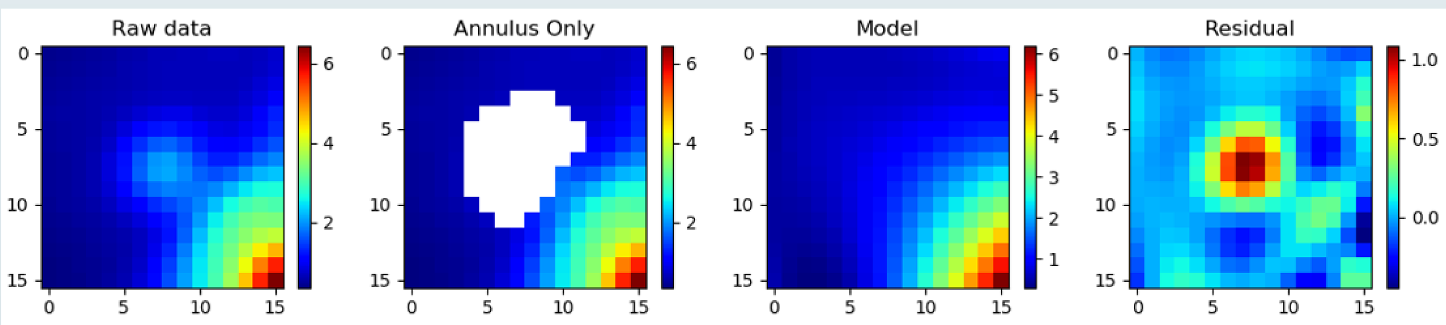

Figure 1: Modeling background signal at 24um with polynomial interpolation. SNR residual on the right after background subtraction. Due to possible contamination from the adjacent N76 emission nebula, only the non-adjacent half of the remnant was considered when calculating the remnant SED. We then applied a Bayesian SED model to fit remnant dust emission to warm and cold dust components for a variety of grain species.

Model spectral energy distributions (SEDs) were created for SNR 1E 0102 based on the input SED from the processed images which represented the integrated flux from the half of the remnant most distant from N76. This region was chosen in order to reduce any potential contamination which remained after subtracting the local background, particularly at longer wavelengths. The model relied on a random walk Markov chain Monte Carlo method (MCMC) to sample the probability distribution of parameters and ultimately converge on the observed SED. Uncertainties applied to the fit took the form of a covariance matix that was produced by combining background uncertainties and the errors on observed fluxes due to instrument effects. The remnant was modeled as a resultant spectra produced by the combination of a warm and cold dust component. Additional free parameters included dust mass, temperature, and scaling factors for the radiation field. For the results described here, the SN dust was modeled as Mg-Protosilicate grains, $Mg_{0.7}SiO_{2.7}$, $Mg_{2.4}SiO_{4.4}$.

Results

Shown below are the results of dust models for various Mg Silicate grain species. Depending on the composition, total dust masses range from 0.001 – 0.01Msun and in each case has a prominent cold dust component. Though it was performed, carbon grain based fits were poor, as would be expected for an oxygen rich remnant such as 1E 0102, and are not included below.

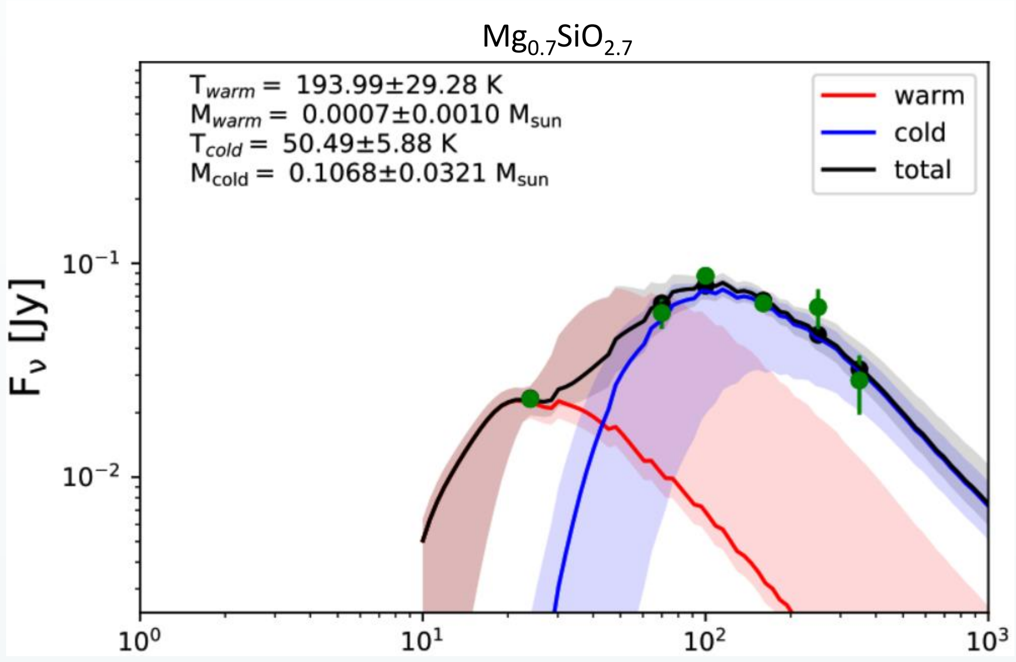

Figure 2: Dust mass for the warm and cold components of $Mg_{0.7}SiO_{2.7}$ grains.

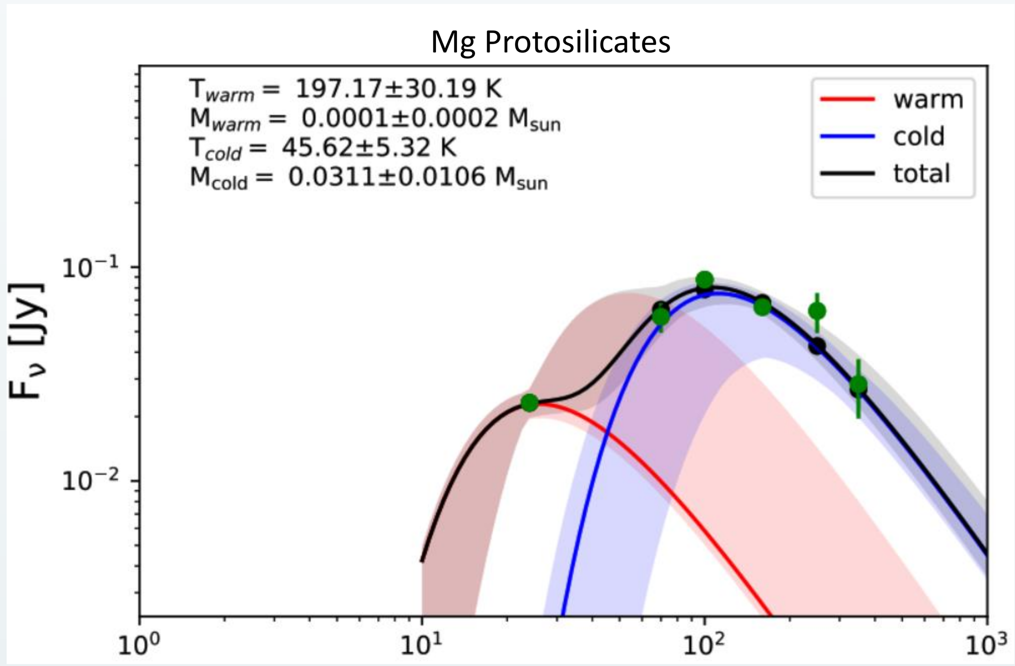

Figure 3: Dust mass for the warm and cold components of Mg protosilicate grains.

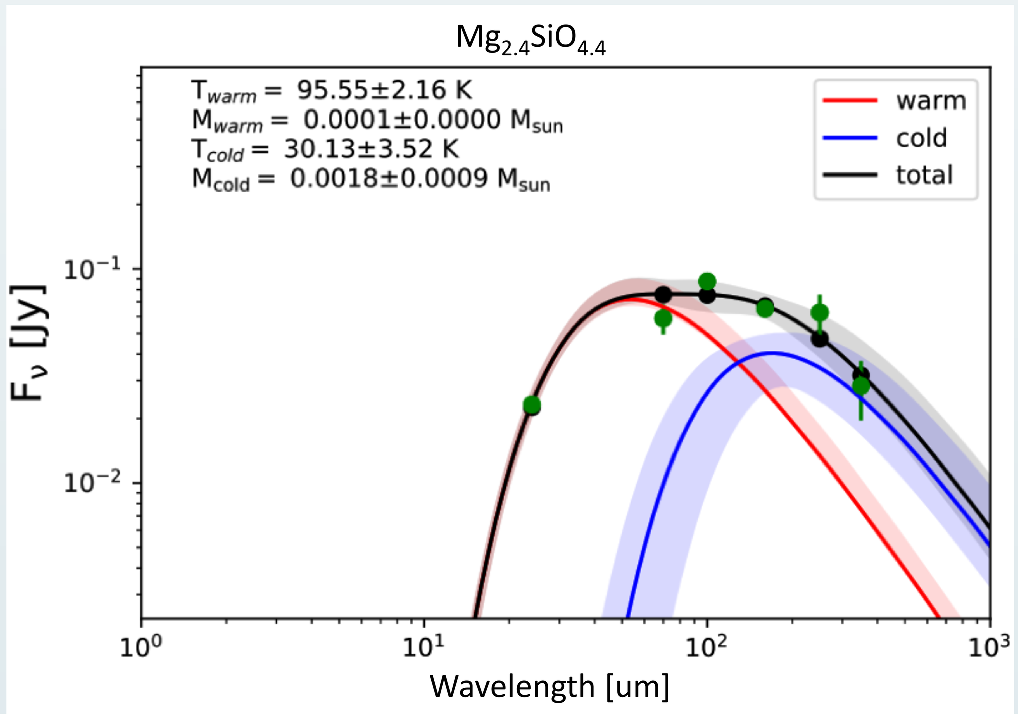

Figure 4: Dust mass for the warm and cold components of $Mg_{2.4}SiO_{4.4}$ grains.

Conclusion

The observation of massive dusty galaxies at high z has challenged traditional models of interstellar grain formation which relies on the slow evolution of asymptotic giant branch stars to produce dust. To account for dust formation on a shorter timescale, alternative sources of dust production have been proposed. In particular, models suggest that CCSNe are capable of yielding the requisite dust mass to supply these early Universe galaxies.

After removing background signal from the adjacent emission nebula, N76, and by incorporating long wavelength Herschel Space Observatory data, we show evidence for a massive reservoir of cold dust that is previously unreported in studies of SNR 1E 0102. In light of such evidence, this remnant may join others such as CasA and the Crab nebula that have been shown to have similarly large cold dust components. Together, this data provides evidence that CCSNe may indeed be efficient producers of dust for early universe galaxies.

Here, our study limited by uncertainty in background, in part due to challenges modeling N76 at longer wavelengths. Additional work remains on incorporating the effects of grain destruction, modeling dust mass on a pixel by pixel basis to generate resolved maps of dust mass, and considering alternate grain species which may provide an optimal fit to the data.

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