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AN AUTOMATED APPROACH FOR PHOTOMETER AND DUST MASS CALCULATION OF THE CRAB NEBULA

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Abstract. Ample evidence exists regarding supernovae being a major contributor to interstellar dust. In this work, the deepest far-infrared observations of the Crab Nebula are used to revisit the estimation of the dust mass present in this supernova remnant. Our aim in this paper is to highlight the importance of the photometric methods and spectral energy distribution construction on the accuracy of inference for astrophysical parameters. Images in filters between 70 and 500 μm taken by the PACS and SPIRE instruments on-board of the Herschel Space Observatory are used. With a novel automated approach, we constructed the spectral energy distribution of the Crab nebula to recover the dust mass. The spectral energy distribution is found to be best fitted using a single modified blackbody of temperature $T = 42.06 \pm 1.14\,\mathrm{K}$ and a dust mass of $M_d = 0.056 \pm 0.037\,\mathrm{M}_{\odot}$.

Keywords: Dust mass, Crab Nebula, Far-Infrared (FIR), Image processing, Herschel, Synchrotron

1 Introduction

The astrophysical community has been in pursuit of the dust mass budget in the universe to analyze and constrain the baryonic matter. The amount of dust produced and ejected into the interstellar medium by the Asymptotic Giant Branch (AGB) stars is not enough to compensate for the known destruction rates (Zhukovska et al. 2008). On the other hand, Supernova remnants (SNR) are important dust suppliers. They emit the brightest in the IR waveband via an excess emission upon the synchrotron continuum (Trimble 1977), (Gomez et al. 2012), (Temim & Dwek 2013), (Owen & Barlow 2015), (De Looze et al. 2017). We target our efforts in this work on the Crab nebula remnant, since it presents many advantages as an astrophysical laboratory for dust mass budget analysis. It is one of the most commonly observed celestial objects, possesses a wealth of observational data, and the mass of swept-up material is small compared to the mass in the supernova ejecta since it has a relatively young age. Finally, it provides the cleanest view along the line of sight compared to other observed SNRs with nearly no interstellar medium contamination. The dust content of the Crab nebula is still not well constrained in the literature, ranging between 0.08 to 1.4 $\mathrm{M}_{\odot}$, hence we revisit in this work the estimation of its dust content using novel photometric images and image analysis techniques, showing the importance of the photometric analysis on the dust budget calculations.

2 Observations

Images used for the calculation of the flux densities of the Crab nebula were taken by the Herschel Space Observatory (Pilbratt et al. 2010). The Crab nebula was observed between September 2009 and September 2010. The PACS (Poglitsch et al. 2010) and SPIRE (Griffin et al. 2010) instruments performed photometry at 70, 100, 160, 250, 350 and 500 μm, as part both of a calibration program for the PACS observing modes, and of a Principal Investigator observing program (Gomez et al. 2012). In the present work we have for the first time included data that was obtained on the Crab nebula during the testing and qualification of PACS observing modes. As these data were obtained in an instrumental set-up which is identical to the operational one, they can be directly combined with the already published data, thus nearly doubling the depth of the resulting maps (at 70, 100, and 160 μm).

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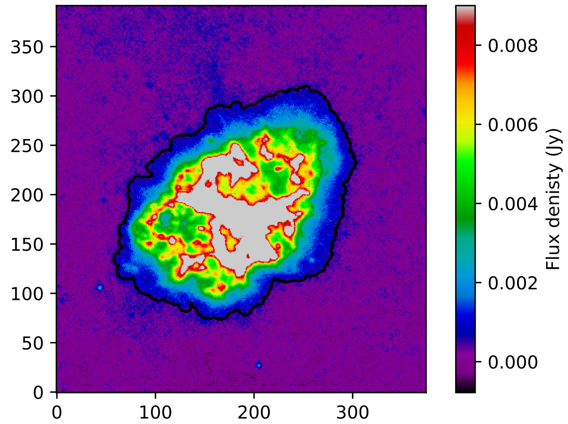
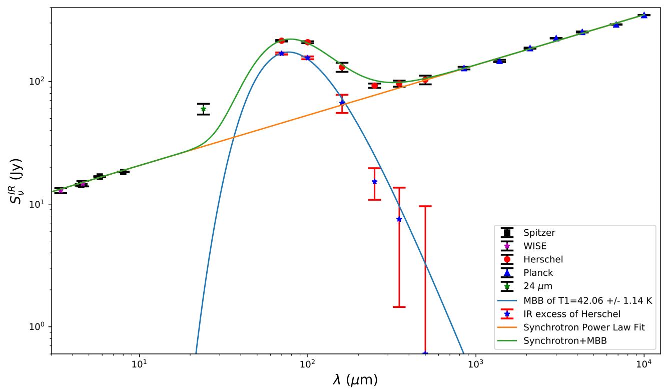
3 Photometry and Data Analysis

In this work, the photometric analysis and flux density calculations were done via a data driven iterative approach, where the aperture selection was done based on the morphological and spatial flux density distribution of the extended object Nehmé et al. (2019b). It enabled the construction of an improved spectral energy distribution (SED) of the Crab nebula and optimized the exclusion of background pixels. The optimum apertures for each wavelength are used to impose masks on the pixels which are assumed to contain the source. The unmasked pixels are then used to model the background sky by fitting them with a surface polynomial. The previously masked regions are interpolated and subtracted from S_ν^{tot}. Finally, to remove the synchrotron emission contribution from the integrated global flux density values, we gathered flux densities from other observations (see Nehmé et al. 2019b). These values were fitted by a power law and were followed by an interpolation process for the Herschel wavebands and removed.



(a) Histogram of flux density values and selection of initial threshold (100 μm).



(b) log-log scale plot of the SED showing the fitting process.

4 SED construction and results

The SED of the Crab nebula (see Fig. 1b) is crucial to study the thermal emission of the dust and constrain its parameters. After removing the contribution of the synchrotron radiation and the background sky from the integrated flux densities (S_ν) at each wavelength, an excess S_ν^{IR} of IR light characterizes the dust and is fitted by a single component modified blackbody function (MBB) (Nehmé et al. 2019a). At 500 μm, the emission is mostly composed of synchrotron. The warm dust is the dominant component in the Crab nebula. The synchrotron power law was modeled using wavelengths up to 10 000 μm since a spectral break existed after that point which was indicated by the Planck observations (Gomez et al. 2012). Although the 24 μm flux is likely contributed by dust it was not included in our fit because such an emission is hardly justified to correspond to a thermal equilibrium process such as the MBB. Furthermore, this would be an emission from hotter dust which will not affect significantly the total dust mass. The best best fitted parameters of equation of the MBB for the Crab nebula are retrieved at $T = 42.06 \pm 1.14K$ and $\overline{M_{d,cal=5\%}}$ 0.056 ± 0.037 $M_\odot$

5 Conclusion

We have presented an automated and improved method for calculating the flux densities using several image processing techniques. After comparing our flux densities to that of the literature (Nehmé et al. 2019b),we find that very little IR excess exist at 500 μm, leaving no place for a cold component. Thus our resulting SED is adequately modeled with a single component MBB. This produces dust parameters of mass and temperature comparable to the literature. Future works aim to better describe the mass dust budget in the Crab nebula spatially and account for the filamentary structure.

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