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SUBMILLIMETER OBSERVATIONS OF CASSIOPEIA A

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RESUMEN

Presentamos una imagen a 850 μm del remanente de supernova Cas A obtenida con SCUBA en el JCMT. La morfología de la emisión es muy parecida a la de imágenes a longitudes de onda más grandes, en el radio, lo que sugiere que la emisión en el submilimétrico sigue siendo principalmente de origen sincrotrónico. El flujo total medido a 850 μm es significativamente más alto que la predicción obtenida a partir de la extrapolación de los datos a más baja frecuencia. Sin embargo, no es claro si este exceso es real, y refleja la presencia de cantidades altas de polvo frío, o si es un artefacto de la técnica de observación.

ABSTRACT

We present an 850 μm image of the young supernova remnant Cas A obtained with SCUBA on the JCMT. The morphology of the emission is very similar to that at longer wavelengths, in the radio domain, implying that synchrotron remains the dominant emission mechanism at sub-millimeter wavelengths. The total flux of Cas A measured at 850 μm does present a fairly large excess over the flux expected from synchrotron emission alone (as extrapolated from lower frequency data), but it remains unclear whether this excess is real and reflects the presence of large amounts of cold dust, or if it is an artifact of the observing technique.

Key Words: **ISM: DUST, EXTINCTION — ISM: INDIVIDUAL (CAS A) — ISM: SUPERNOVA REMNANTS — RADIO CONTINUUM: ISM — RADIO LINES: ISM**

1. INTRODUCTION

Supernovae produce large amounts of heavy elements, a fraction of which is now known to condense as dust (Kozasa et al. 1989). This could have important cosmological implications because supernovae can produce dust very early in the history of the Universe, at the first generation of stars. Dust has been seen through its infrared continuum emission in the ejecta of SN 1987A (Kozasa et al. 1991), and in Cassiopeia A (Cas A: Dwek et al. 1987; Lagage et al. 1996).

It would be interesting to have a quantitative estimate of the total amount of dust formed in supernova remnants. However, in the near- and mid-infrared, only hot and warm dust can be detected, with an amount of approximately $3.8 \times 10^{-2}\,M_\odot$ in Cas A (Arendt, Dwek, & Moseley 1999). This is considerably less than the amount of condensable elements that might have a mass of approximately $1\,M_\odot$ for a $25\,M_\odot$ progenitor (Dwek & Werner 1981). Cold dust might, therefore, be present in the central regions of the Fast Moving Knot ejected by Cas A or in cool knots not immersed in dense, very hot gas. Using the ISOPHOT photometer on board *ISO*, Tuffs et al. (1999) have tentatively detected an excess radiation from Cas A at 170 μm with respect to the extrapolation of the emission of the dust seen by Dwek et al. (1987) with *IRAS*. They suggest the existence of some $0.15\,M_\odot$ of cool dust at about 32 K. However, difficulties with the background and with the relatively large extent of the source makes this result uncertain and it is clearly worth looking for the emission of cold dust at longer wavelength in the sub-millimeter and the millimeter wavelength ranges.

2. OBSERVATIONS

Cas A was observed at 850 μm[5] on 1998 June 29 and 30 with the Sub-millimeter Common User Bolometer Array (SCUBA: Holland et al. 1999) of the James Clerk Maxwell Telescope (JCMT). The observing conditions on those days were excellent with a zenith opacity at 850 μm of about 0.2, corresponding to 0.05 at 225 GHz. At 850 μm, the field of view of SCUBA is $2\rlap{.}'3$. In order to map a region of $10' \times 10'$ around Cas A, the camera was used in scan-map mode, during which it is scanned at a rate of $3''$ per second back-and-forth across the field, while the secondary mirror is chopped with a frequency of 7.8 Hz in right ascension or in declination to subtract out fluctuations from the atmospheric signal.

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[5]An image at 450 μm was obtained simultaneously, but appeared to be affected by poorly understood background variations. It will not be used here.

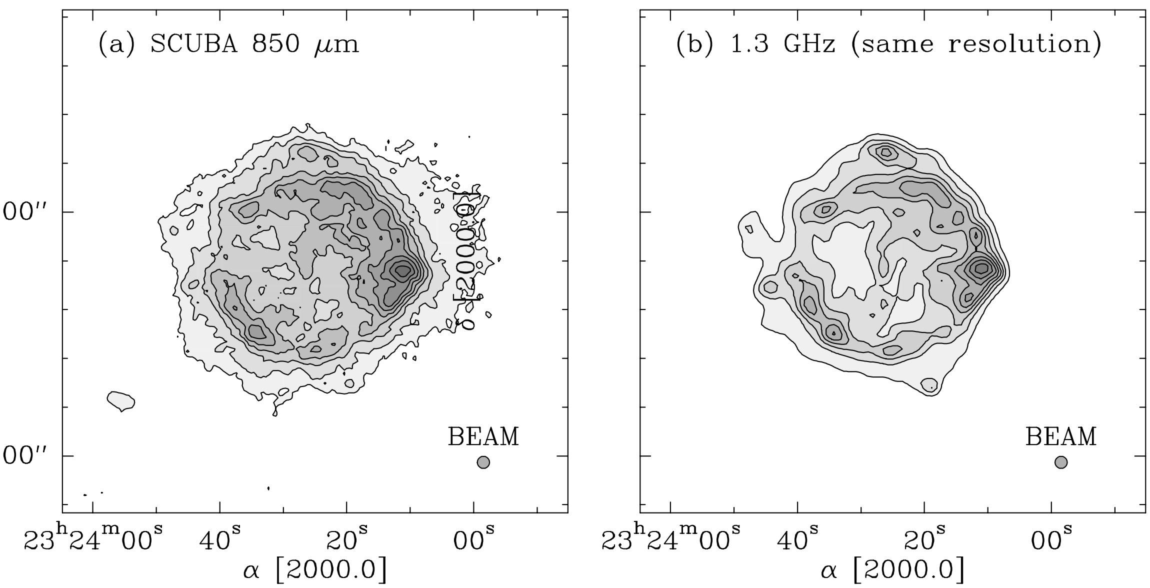

Fig. 1. Comparison between the 850 μm SCUBA image and the VLA 1.3 GHz image (of synchrotron origin). (*a*) 850 μm (347.8 GHz) image; the first contour and the contour spacing are at 40 mJy beam^{-1}. (*b*) 1.3 GHz VLA emission smoothed to the angular resolution of the SCUBA image. The first contour and the contour level are at 3 Jy beam^{-1}.

The scan-angle across the field ($15.5 \pm 60°$) is chosen so that the resulting image is fully sampled.

Figure 1*a* shows the resulting 850 μm map of Cas A with 3″ pixels. The rms noise level is 10 mJy beam^{-1}, but systematic variations in the background are present. In order to measure the total flux and to account better for the error beam, we used aperture photometry over a comparable field on both Uranus and Cas A, resulting in a total 850 μm flux for Cas A of 53.5 ± 7 Jy. The quoted uncertainty is the geometric mean between an uncertainty of about 10% measured by using different apertures and the 10% uncertainty associated with the absolute flux calibration. Comparing the total flux of Uranus from the aperture photometry, we estimate a contribution from the error beam of about 20%.

3. RESULTS

3.1. *Total Fluxes*

The total radio flux of Cas A has been measured for a large range of frequencies lower than 20 GHz. After reduction to a standard epoch (traditionally 1965) to account for its secular decrease, it appears to follow a power-law dependence on the frequency $F_\nu \propto \nu^{-0.77}$ (Baars et al. 1977). The observations at 2 and 3 mm (140 and 86 GHz) reported by Liszt & Lucas (1999) were found to fall on the same curve. The integrated flux we measured at 850 μm (347.8 GHz, see Figure 2) is 53.5 ± 7.0 Jy, which corresponds to 57.3 ± 8.6 Jy reduced to 1965. The synchrotron flux predicted by the $\nu^{-0.77}$ law is 35.3 Jy (see Fig. 2), significantly lower than the observed value. However, since the determination of the total flux is not very reliable, this excess cannot be blindly ascribed to thermal dust emission. The morphology of the emission needs to be investigated to obtain further insight.

3.2. *Morphology of the Sub-Millimeter Emission*

The morphology of the SCUBA image at 850 μm is very similar to that at radio frequencies (Figs. 1*a* and *b*), suggesting that synchrotron is still the dominant emission process at sub-millimeter wavelengths. The difference between the SCUBA image and the scaled VLA image (not shown here) shows that the "excess" 850 μm emission peaks somewhat to the west of Cas A, and has a structure mildly reminiscent of the ISOPHOT images of at 200 μm (Tuffs et al. 1999). This might suggest that it does indeed trace cool dust. However, such a large, rather smooth structure could also easily be produced by a varying background. Consequently, it cannot be safely decided whether the "excess" is real or not. Additional observations at a somewhat different frequency (e.g., at 750 μm) might help decide this point, because the artifacts due to the observational technique and the uncertainties on the background would most likely be different for observations obtained on a different date and at a different frequency. Much credibility would be lent to the excess detected here if such observations were to reveal a similar excess.

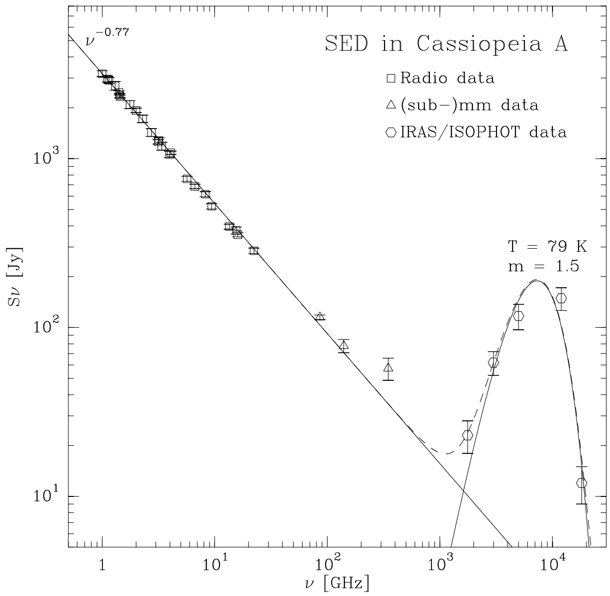

Fig. 2. Spectral energy distribution in Cassiopeia A from 1 GHz to 2×10^4 GHz. The squares are the radio data, and the straight line represents the synchrotron emission $F_\nu \propto \nu^{-0.77}$. The diamonds are the *IRAS*/ISOPHOT data taken from the literature, and a fit by a modified blackbody curve of the form $F_\nu \propto B_\nu(T) \times \nu^{1.5}$ to these points is shown. Finally, the triangles are the millimetric (taken from Lizst & Lucas 1999) and sub-millimetric SCUBA data points.

4. DISCUSSION AND CONCLUSIONS

The observations presented here demonstrate the difficulties of finding cold dust in young Galactic supernovae remnants. Possible background variations across the large fields required hamper the determination of sub-millimeter fluxes. Even without this problem, the flux determination would be limited by the 10% flux uncertainty inherent to millimetric or sub-millimetric observations. Young supernova remnants are powerful synchrotron emitters, and an uncertainty of 10% on the measured flux will leave ample room for the presence of large amounts of cold dust. For instance, the lack of excess at 2 and 3 mm in Cas A reported by Liszt & Lucas (1999) cannot rule out the presence of several Solar masses of cold dust there. High-frequency (200 or 350 μm) far-infrared or sub-millimetric observations might help, because at higher frequencies the synchrotron fades away. However, high-frequency observations are also more difficult to calibrate. In particular, the far-infrared observations presented by Tuffs et al. (1999) might be affected by background problems similar to those affecting our SCUBA observations.

If supernovae do produce large amounts of cold dust, observations in the sub-millimetric range of nearby *extra-galactic sources* might offer the best prospects because they would be smaller, and therefore less affected by background problems. At the distance of the Magellanic Clouds, objects as young as Cas A would have a size of about 10 to 20″. In the nearest spirals (M 31, M 33), it would be about 2″. With a field of view of about 30″ at 1 mm, and 15″ at 0.5 mm, the future large interferometer ALMA might provide the best prospect for such a search.

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