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A DUST SCATTERED HALO IN STARBURST GALAXY M82?

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INTRODUCTION

The source of the halo about M82 has been under discussion for several years; one explanation for it is the dust model of Solinger, Morrison and Markert (1977) in which they propose a diffuse cloud of dust through the M81 group, with M82 travelling through the group holding a denser cloud of dust around it.

This paper looks at the feasibility of the "dust" theory in the X-ray range, using the halo in the X-ray image of M82 taken by the Einstein Observatory. To this end the X-ray cross section for dust is presented, along with the single scattered image of an X-ray source surrounded by a dust cloud; multiply-scattered images have been simulated with a Monte-Carlo program; profiles of the halo along the major and minor axes of M82 are presented. Also presented is an accounting for line spectrographs of M82 that show unusual splitting (e.g. Axon and Taylor, 1978), using the dust model.

The final model proposed for the X-ray image requires dust (typically SiO_2, although the result is not overly sensitive to the choice of dust material) of radius 50 Å-300 Å, with density on the order of 10^{-7} cm^{-3} to 10^{-9} cm^{-3}, out to a distance of about 9 kpc for some regions. The HRI image of M82 is shown in Fig. 1.

CROSS SECTION

The cross section for dust in the Rayleigh-Gans limit is

$$\frac{d\sigma}{d\Omega} = 4R^6k^4|m-1|^2\left(\frac{1+\cos^2\theta}{2}\right)\left[\frac{\sin x - x\cos x}{x^3}\right]^2$$

where $x = 2Rk\sin(\theta/2)$ has been used for brevity; R is the dust grain radius, and k is the wavenumber for the X-rays, m is the index of refraction, and θ is the scattering angle.

The total cross section is

$$\sigma = 2\pi R^4k^2|m-1|^2.$$

Note that $|m-1|^2 \propto k^{-4}$.

SINGLE SCATTERING

The image of a point source is strongly dependent on the location of the scattering cloud. For a cloud of radius r about the source, the image intensity is given by

$$\frac{dI_z}{d\Omega dt} = \frac{L_z n}{\pi d}R^6k^4|m-1|^2\left(\frac{0.21}{Rk\psi} - \frac{d}{8.5r}\right)$$

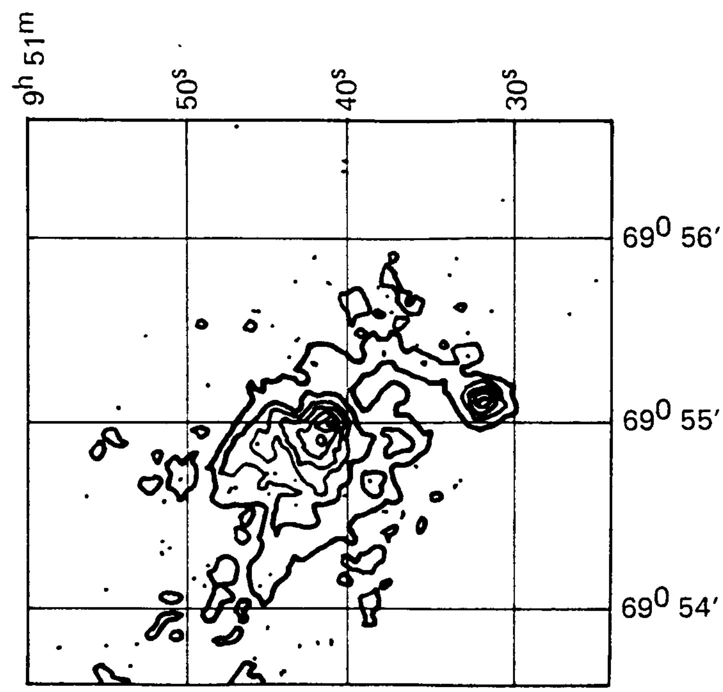


Fig. 1. The X-ray image of M82 taken by HRI-3 and smoothed with the point response function. Contours are at 0.1-0.7 counts/arcsec^2 for the observation.

where L_x is the luminosity in the range considered, n the dust density, d the source-observer distance, ψ is the separation in the sky from the source, and r is the extent of the cloud in front of the source.

In the case of M82, X-ray scattering by dust in our galaxy produces a halo with constant intensity beyond the field of the observing instrument; this is relegated to background.

It can be seen that the singly-scattered halo of the nucleus of M82 due to the diffuse dust proposed for the M81 group would be much smaller than the observed halo, and is 'washed out' by it.

MULTIPLE SCATTERING

Multiply-scattered images of a point source have been simulated by a Monte Carlo program. The program traces the photons to the surface of a spherical, homogeneous cloud of dust around the source, and notes the exit angle of each photon at the surface (from the normal). From this accounting, a distribution of exit angles can be obtained for any point on the surface; from this distribution an image can be calculated.

In the simulations done for M82 the dust used was SiO_2, we set a lower limit of 100 Å for the dust radius. The density had an upper limit of 10^{-7} cm^{-3}, and the cloud radius was kept at less than 10 kpc.

A further limit imposed was that the mass of the homogeneous sphere of scattering dust in the program was kept below 10^{11} solar masses. (This keeps the mass of dust required for M82 below 10^9 solar masses when we take into account filling factors and geometrical considerations.)

The simulated images were convolved with a $\sigma = 6''$ gaussian cut at 10" to account for the extent of the core of M82.

The resulting multiply scattered images can be quantified using some results from Alcock and Hatchett (1978), who showed that the variance of the angle between the path of a multiply scattered photon and the source-to-photon position vector (ϕ), after being multiply scattered, is

$$< \phi^2 > = \frac{\tau}{3} < \theta^2 >$$

where $< \phi^2 >$ is the variance of the cross-section for the scatterers and τ the optical depth.

Thus, a rough estimate for the width is given by

$$\sqrt{< \psi^2 >} \simeq r^{\frac{3}{2}} n^{\frac{1}{2}} R^2 / k.$$

The simulations follow this prediction (although some are at the limit of the small angle approximation for ϕ).

DATA

The data below was taken in one observation (of 13,110.7 sec) with the High Resolution Imager (HRI) aboard the Einstein Observatory. The HRI has a 25' diameter field of 0.5"x0.5" pixels, resolution ~1 arcsec. The energy range is 0.1 keV-4 keV, with no energy resolution.

To study the scattering of the nucleus of M82, two 90° cuts of the image, one along the SE major axis and one along the SW minor axis, were radially binned to obtain profiles. The cuts are centered at $\alpha = 9^h\ 51^m\ 41.8^s$, $\delta = 69^\circ$, 55', 56.2"; they are from 90° to 180°, and 180° to 270° on the image in Fig. 1, clockwise from the top (north). The numbers for the profiles are in units of counts/arcsec^2 for the whole (13110.7 sec) observation, a background of 0.017 counts/arcsec^2 (taken from an agreement between the edge of the field of the HRI and survey observations at similar galactic latitude) has been subtracted. The profiles are shown in Figures 2 and 3.

MODELS

A set of simulated profiles from the Monte-Carlo program, convolved with a gaussian nucleus of radius 10" and $\sigma = 6''$ are shown below in Figures 4 through 5, with the more extended profile from the two cuts superimposed. A successful model for M82 needs dust of radius <300 Å in a cloud between 2 kpc and 9 kpc deep, at optical depths $\geq$10. Lower limits can be set at 10^{-8} cm^{-3} density dust, 2 kpc cloud radius and with 5 optical depths of dust for workable models, though these can all be overcome by allowing more dust or much greater optical depths.

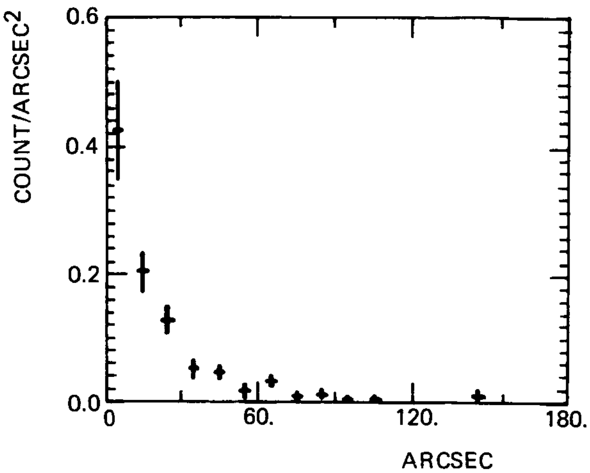


Fig. 2. Data from a 90° cut in the halo about the SW major axis

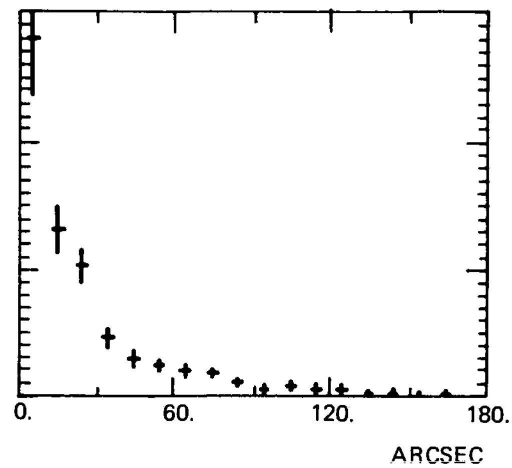


Fig. 3. Data from a 90° cut in the halo about the SE minor axis

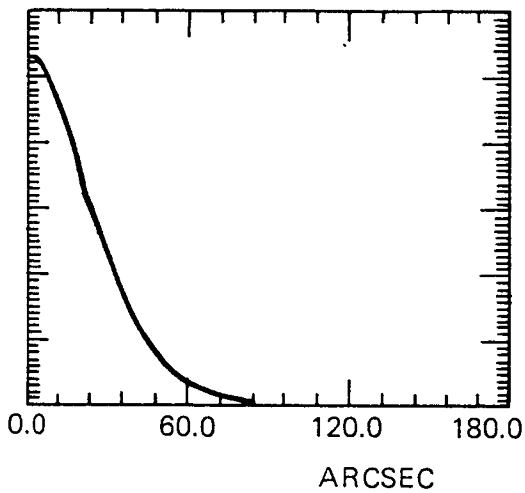


Fig. 4. Cloud radius 9 kpc
density $1.3 \times 10^{-7} cm^{-3}$
grain radius 100Å

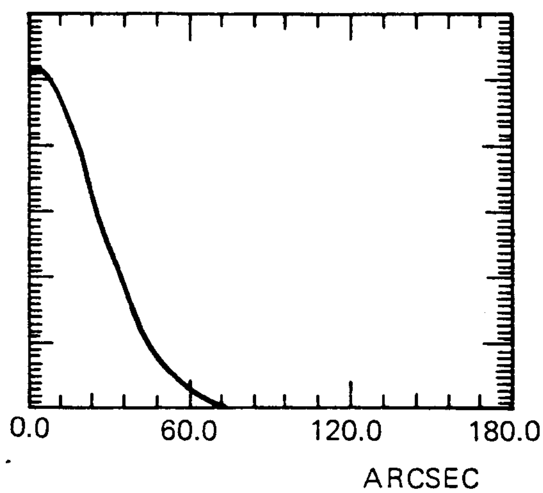


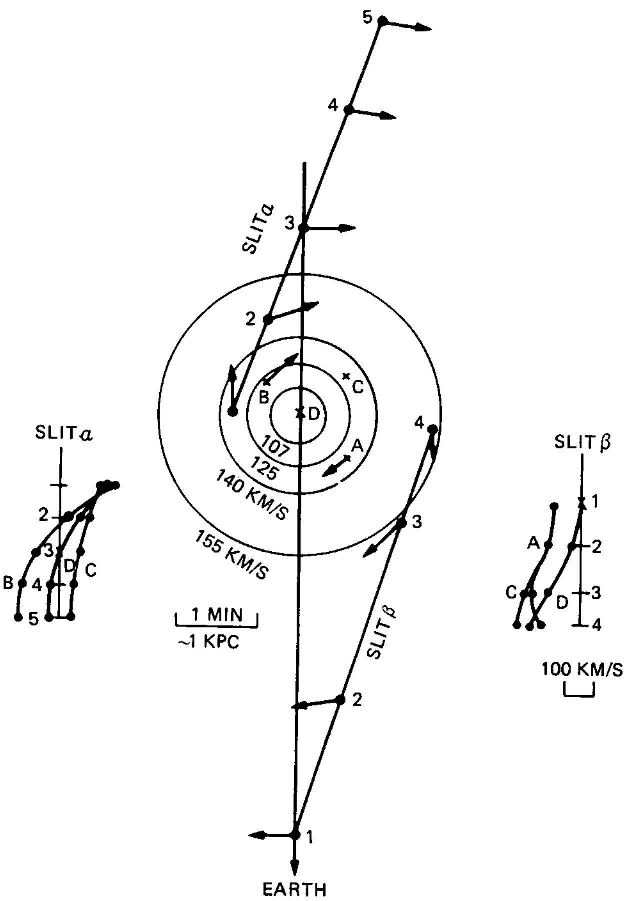
Fig. 5 . Cloud radius 5 kpc
density $7.4 \times 10^{-7} cm^{-3}$
grain radius 100Å

SPECTROSCOPIC OBSERVATIONS

The line splitting that has been observed in spectroscopic observations of M82 (Axon and Taylor, 1978) can be produced by scattering by dust within the disk of the galaxy. Simple models using sources moving within the nucleus (the existence of such bright sources has been shown by O'Connell and Mangano, 1978) and the rotation curve for M82 (from Burbidge, Burbidge, and Rubin, 1964) can produce both published lines and more complex possibilities.

Two sample slit spectrographs have been constructed in Figure 6. The drawing shows the galaxy from the top with some velocities marked and four sources labelled in the nucleus. The sections of the disc observed by slits α and β are drawn and labelled, and several sample scatterers have been placed on each slit. The shift for each scatterer-source pair has been plotted below the figure and the line splits interpolated, producing the observed line splitting.

Fig. 6. M82 viewed from the top: "α" through "β" are the sections of the disk viewed by two slits. Several scatterers and their velocities have been placed on each slit. The line shift due to each scatterer-source pair is plotted on the graph for each slit, and the shifted line for each source, have been drawn in.



The line splitting constructed shows the possibility of line splitting at either end as well as splits and crossovers, using only one or two sources. Curling, horizontal lines and sharp turns can also be produced in a spectrograph with the consideration of one additional source.

1. Alcock, C., and Hatchett, S. Ap. J. *222* (1978), 456.
2. Axon, D.J., and Taylor, K. Nature *274* (1978), 37.
3. Burbidge, E.M., Burbidge, G. and Rubin, V.C. Ap. J. *140* (1964), 942.
4. Hulst, H.C. van de, ***Light Scattering by Small Particles***, Dover Publications, New York, 1957, 1981.
5. Martin, P.G., Mon. Not. R. Astr. Soc. *149* (1970), 221
6. O'Connell, R.W., and Mangano, J.J. Ap. J. *221* (1978), 62
7. Solinger, A., Morrison, P., and Markert, T. Ap. J. *211* (1977), 707.