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CATACLYSMIC VARIABLES AS PROBES OF X-RAY PROPERTIES OF INTERSTELLAR GRAINS

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ABSTRACT

Interstellar-grain properties have previously been probed at wavelengths ranging from the infrared to the ultraviolet. Recent work by other authors has shown that we may also observe the effects of scattering by such grains at X-ray wavelengths. In this paper we suggest that investigations of the X-ray properties of interstellar grains may profitably be conducted in sight lines to variable sources. Particular emphasis is given in this context to catclysmic variables and related objects.

I. INTRODUCTION

The prediction that scattering by interstellar grains of X-rays from celestial sources would tend to extend the images of such sources was first made by Overbeck (1965). Hayakawa (1970) and Martin (1970) both stressed that observations of these effects would lead to a fuller understanding of dust grain types, sizes and number density distributions. Trümper and Schünfelder (1973) suggested that by observing time variable scattered haloes around variable sources, extinction independent source distances could be derived. As grains preferentially scatter soft X-rays it was in this domain that it was suggested the search should be made.

EINSTEIN with its imaging capabilities gave the first real opportunity to look for scattered haloes. Indeed, for any plausible interstellar grain population these effects must be detectable at some level. However, X-ray telescope optics themselves introduce an instrumental scattering of X-rays from celestial sources (the point response function-PRF) making the detection of relatively faint haloes all the more difficult. Despite this and other problems, recent work by Rolf (1983) and Catura (1983) has uncovered detections of haloes in EINSTEIN IPC and HRI images of five distant, bright sources.

Perhaps a more promising method of detecting haloes and one which would potentially yield more information has been suggested by Norwell et al. (1983) and is outlined below. In essence if a variable source suddenly enters a low state (due to the end of an outburst for example) the scattered halo will persist due to finite light travel times. Thus it would be more easily visible against any intrinsic halo from the low state source formed by the effects of the telescope optics. In this short paper we will briefly outline the theory appertaining to the potential detection of transient haloes from variable sources. Particular attention will be paid to the detection of such effects around cataclysmic variables.

II. MODEL

At X-ray wavelengths interstellar grains of radius $a \leq 0.2 \mu\text{m}$ are assumed to scatter according to the Rayleigh-Gans approximation (Hayakawa, 1970). The differential scattering cross-section (a measure of the fractional energy scattered into angle θ from the source-grain vector per unit solid angle) is thus given by

$$\frac{d\sigma}{d\Omega} = 2a^2 \left(\frac{2\pi a}{\lambda}\right)^4 |m-1|^2 \left(\frac{j_1(x)}{x}\right)^2 (1 + \cos^2\theta) \quad (1)$$

In equation (1) λ is the wavelength of observation; m is the wavelength dependent complex refractive index of the grain material and $j_1(x)$ is the first order Bessel function where

$$x = \left(\frac{4\pi a}{\lambda}\right) \sin\left(\frac{\theta}{2}\right).$$

The halo surface brightness can be calculated from

$$I_{\lambda}(\alpha, t) = I_{\lambda}(t) n_g \int \frac{1}{4\pi r^2} \frac{d\sigma}{d\Omega} \exp(-(\tau_1 + \tau_2)) \frac{\sin(\alpha + \theta)}{\sin^2(\alpha + \theta)} d\Omega \quad (2)$$

$\Theta_H(\alpha, t)$

where I_{λ} is central source luminosity per unit wavelength; n_g is the

Figure (1). Scattered halo geometry in the case of an intrinsically variable source. S, O and G are positions of source, observer and grain respectively. Scattered X rays are seen only from grains lying between two ellipses defined by 'echo' of the source switching on and off. Distance $ST = ct/2$ where t is time from observed source switch on.

interstellar grain number density; d is the source observer distance (SO in figure (1)) and r is the source-grain distance (SG in figure (1)).

Angles α and θ are as defined in figure (1). Optical depths τ_1 and τ_2 are those for paths SG and GO respectively. These include wavelength dependent extinction contributions from the interstellar grains and absorption from the interstellar gas, the latter as given by equation (3.2) of Hayakawa (1970).

For a constant central source $\theta_A = 0$ and $\theta_B = \pi - \alpha$. However, if the source suddenly "switches on" at observer time $t=0$ and then "switches off" at time $t=\Delta t$ then, due to light travel time effects, an observer will see scattered X-rays arising from scatterings occurring between two confocal ellipsoids of revolution with the source and observer lying at the respective foci. For any given azimuthal angle α from the central source the integration limits θ_A and θ_B will thus be time dependent.

The central source X-ray behavior has been chosen to approximate that which might be expected from certain dwarf novae at outburst. Observations by Rappaport et al. (1974) and Mason et al. (1978) and others have for example shown that U Gem and SS Cyg have increased in soft X-ray luminosity by factors of up to 100 at optical outburst. In these calculations, we have assumed $L_{\max} = 100 L_{\min} = 10^{33} \text{ ergs s}^{-1}$ and

$\Delta t \approx 2$ days. The emission is assumed to be black body with $T=10^6$ K (cf. Cordova et al., 1980).

In order to compare the expected halo brightness with the possibilities of observation, equation (2) was integrated numerically over θ and then with respect to λ , over the energy range 0.23-2.48 keV. This energy range is that for which refractive indices of grain materials at X-ray wavelengths are available (Rolf, 1980) and approximates to part of the EINSTEIN IPC band (0.1-4.5 keV).

III. RESULTS

Figure (2) shows the temporal evolution of the halo surface brightness as a function of α for 0.1 μ m silicate (olivine) grains with interstellar number density $2 \cdot 10^{-12}$ cm $^{-3}$. Superimposed are approximate illustrative levels of 3000s IPC background and the PRF for the low state source.

It can immediately be seen that the resulting halo takes the form of a transient ring of soft X-ray emission about the central source. The ring may be visible above background for several days after outburst. The angular radius of the peak of the ring emission increases with time from ~ 2.5 arcmin at $t=2.5$ days to ~ 9 arcmin at $t=4.5$ days. At the distance of the source (200 pc) the expansion appears superluminal.

IV. DISCUSSION

The foregoing results indicate that the detection of transient haloes arising from scattering of soft X-rays by silicate grains may indeed be feasible. Further calculations have been performed using grains of varying sizes and compositions (e.g. graphite), and the evolution of the halo is found to be sensitive to both these variables. Halo evolution will also depend on soft X-ray light curves and source distances. If we can constrain some of these otherwise free parameters by using related observations (for example determination of the optical and ultraviolet extinction laws; monitoring the X-ray outburst light curve, etc.) we should in principle be better able to derive grain types and source distances. Of more than 30 dwarf novae observed by EINSTEIN, seven were observed <10 days after an optical outburst. It might be instructive to re-examine these IPC fields in the soft X-ray bands to look for possible extended, time variable structure.

Application of this model can of course be made much more widely to include any suitably variable source of soft X-rays. Extrinsic variable sources (i.e. those showing eclipses) would also be worth considering, though the variable halo model would of course be somewhat different in detail.

Figure (2). Temporal evolution of scattered halo intensity, I (in $\text{ergs s}^{-1} \text{cm}^{-2} \text{sterad}^{-1}$) as a function of azimuthal angle from source, in the energy band 0.23-2.48 keV. Results shown are for $0.1 \mu\text{m}$ silicate grains and model parameters as given in text. Approximate 3000s IPC background and PRF of low state source (Rolf 1980) are shown as dashed line.

V. CONCLUSION

We have shown that suitably timed imaging X-ray observations of cataclysmic variables and related objects should in certain cases show evidence of transient scattered soft X-ray haloes. The study of such haloes will undoubtedly lead to a greater understanding of interstellar dust grain properties.

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