AN X-RAY AND INFRARED STUDY OF GRAINS IN THE PUPPIS A SUPERNOVA REMNANT

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Final Report

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Title:	An X-ray and IR Study of Dusty Nonradiative Shock Waves
Authors:	VANCURA, O.; RAYMOND, J.; DWEK, E.
Affiliation:	AA(SAO)
Journal:	American Astronomical Society Meeting, 184, #57.03
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Abstract

We have constructed models that predict the dynamic evolution and infrared (IR) emission of grains behind nonradiative shock waves. We present a self-consistent treatment of the effect of grain destruction and heating on the ionization structure and X-ray emission of the postshock gas. Incorporating thermal sputtering, collisional heating, and deceleration of grains in the postshock flow, we predict the IR and X-ray fluxes from the dusty plasma as a function of swept-up column density.

Heavy elements such as C, O, Mg, S, Si, and Fe are initially depleted from the gas phase but are gradually returned as the grains are destroyed. The injected neutral atoms require some time to ''catch up'' with the ionization state of the ambient gas. The non-equilibrium ionization state and gradient in elemental abundances in the postshock flow produces characteristic X-ray signatures that can be related to the age of the shock and amount of grain destruction. The effects of grain destruction on the X-ray spectra of shock waves are substantial. We will compare model predictions to observations of the Cygnus Loop and Puppis A.

This project is supported by the NASA Astrophysics Data Program under grant NAG5-2453 to the Smithsonian Astrophysical Observatory.

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The subject grant supported an investigation of grain evolution behind nonradiative shock waves in supernova remnants. The primary work involved improvements of existing shock code to produce a 3-D Sedov model for dust and shock evolution. These results were then applied to ROSAT and IRAS observations of several SNRs. Here we submit our final report on this study.

The primary results from the shock code were presented at the 1994 American Astronomical Society (AAS) meeting in a paper entitled "An X-ray and IR Study of Dusty Nonradiative Shock Waves" (Vancura, Raymond, & Dwek 1994, AAS, 184, #57.03). A paper summarizing these results entitled "A Study of X-ray and Infrared Emissions from Dusty Nonradiative Shock Waves" (Vancura et al. 1994, ApJ, 431, 188) was published in ApJ.

Further modifications to the model were described in the ApJ paper "Cooling, Sputtering, and Infrared Emission from Dust Grains in Fast Nonradiative Shocks" (Dwek, Foster, & Vancura 1996, ApJ, 457, 244). These results were presented at the ROSAT Workshop in Wurzburg in a paper entitled "A Study of Dusty Nonradiative Shock Waves" (Vancura & Raymond 1996, Proc. Roentgenstrahlung from the Universe', eds. Zimmermann, H.U.; Trumper, J.; and Yorke, H.; MPE Report 263, p. 281-282).

Results from our model calculations were applied to an investigation of the remnant G299.2–2.9 where we compared calculations of the predicted X-ray and infrared flux with ROSAT and IRAS results for this remnant. This study was published in an ApJ paper entitled "A Study of the Evolutionary State of the Supernova Remnant G299.2-2.9" (Slane, Vancura, & Hughes 1996, ApJ, 465, 840).

Final modifications to the modeling code were reported in papers presented to the AAS entitled "X-ray and IR Signatures of Dusty Adiabatic Shock Waves" (Vancura & Raymond 1996, AAS, 190, #55.02) and "Models of Dust Emission and Destruction in Shocks" (Raymond, & Vancura 1997, AAS, 190, #37.05).

Copies of abstracts for each of the papers described are attached as part of this final report.

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Title:	A study of X-ray and infrared emissions from dusty nonradiative shock waves
Authors:	VANCURA, OLAF; RAYMOND, JOHN C.; DWEK, ELI; BLAIR, WILLIAM P; LONG, KNOX S.; FOSTER, SCOTT
Affiliation:	AAHarvard-Smithsonian Center for Astrophysics, Cambridge, MA, US ABHarvard-Smithsonian Center for Astrophysics, Cambridge, MA, US ACNASA. Goddard Space Flight Center, Greenbelt, MD, US ADJohns Hopkins Univ., Baltimore, MD, US AEJohns Hopkins Univ., Baltimore, MD, US AFUniv. of Maryland, College Park, MD, US
Journal:	The Astrophysical Journal, Part 1, vol. 431, no. 1, p. 188-200
Publication Date:	08/1994
Category:	Astrophysics
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NASA/STI Keywords:	ABUNDANCE, COSMIC DUST, EMISSION SPECTRA, INFRARED RADIATION, INTERSTELLAR EXTINCTION, SHOCK WAVES, SUPERNOVA REMNANTS, X RAY SPECTRA, ASTRONOMICAL MODELS, COLLISIONAL PLASMAS, PLASMA HEATING, SPECTRUM ANALYSIS, STELLAR COMPOSITION, STELLAR EVOLUTION
Bibliographic Code:	1994ApJ...431..188V

Abstract

We have constructed models that predict the dynamic evolution and infrared (IR) emission of grains behind nonradiative shock waves. We present a self-consistent treatment of the effect of grain destruction and heating on the ionization structure and X-ray emission of the postshock gas. Incorporating thermal sputtering, collisional heating, and deceleration of grains in the postshock flow, we predict the IR and X-ray fluxes from the dusty plasma as a function of swept-up column density. Heavy elements such as C, O, Mg, S, Si and Fe are initially depleted from the gas phase but are gradually returned as the grains are destroyed. The injected neutral atoms require some time to 'catch up' with the ionization state of the ambient gas. The nonequilibrium ionization state and gradient in elemental abundances in the postshock flow produces characteristic X-ray signatures that can be related to the age of the shock and amount of grain destruction. We study the effects of preshock density and shock velocity on the X-ray and IR emission from the shock. We show that the effects of grain destruction on the X-ray spectra of shock waves are substantial. In particular, temperatures derived from X-ray spectra of middle-aged remnants are likely to be overestimated by approximately 15% if cosmic abundances are assumed. Due to the long timescales for grain destruction in X-ray gases over a wide range of temperatures, we suggest that future X-ray spectra studies of supernova remnants be based on depleted abundances instead of cosmic abundances. Our model predictions agree reasonably well with IRAS and Einstein IPC observations of the Cygnus Loop.

Title:	Cooling, Sputtering, and Infrared Emission from Dust Grains in Fast Nonradiative Shocks
Authors:	DWEK, ELI; FOSTER, SCOTT M.; VANCURA, OLAF
Journal:	Astrophysical Journal v.457, p.244
Publication Date:	01/1996
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ApJ Keywords:	ISM: DUST, EXTINCTION, INFRARED: ISM: CONTINUUM, RADIATION MECHANISMS: THERMAL, SHOCK WAVES
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Abstract

We model the dynamics, the destruction by sputtering, and the infrared (IR) emission from collisionally heated dust grains in fast ($\geq$400 km s^{-1}) astrophysical shocks in order to develop IR diagnostics for the destruction of grains in these environments. The calculations take into account the feedback from sputtering and IR emission on the gas-phase abundances, the cooling, and the ionization and thermal structure of the shock.

Sputtering changes the initial grain size distribution, creating a deficiency of small (radius $<$50 Å) grains compared to their preshock abundances. The altered grain size distribution depends on shock velocity and the density of the interstellar medium. Dust particles with sizes below $\approx$300 Å are stochastically heated, undergo temperature fluctuations, and radiate an excess of near-infrared emission ($\lambda \leq 40$ μm) over that expected for grains in thermal equilibrium. This near-infrared excess is a measure of the abundance of small grains and therefore a powerful diagnostic for the amount of destruction the grains were subjected to in the shock. We present here IR spectra from collisionally heated dust for a variety of shocks, and depict the changes in the spectra as a function of postshock column density. Our studies compliment those of Vancura et al. that examined the effects of the release of the sputtered refractory elements on the ultraviolet and X-ray emission. Multiwavelength observations at X-ray, UV, and IR wavelengths are therefore essential in piecing together a comprehensive picture of the physics of grain destruction in fast astrophysical shocks.

Subject headings: dust, extinction — infrared: ISM: continuum — radiation mechanisms: thermal — shock waves

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Title:	A Study of Dusty Nonradiative Shock Waves
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Journal:	Proc. 'Röntgenstrahlung from the Universe', eds. Zimmermann, H.U.; Trümper, J.; and Yorke, H.; MPE Report 263, p. 281-282
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A STUDY OF THE EVOLUTIONARY STATE OF THE SUPERNOVA REMNANT G299.2−2.9

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ABSTRACT

Using archival data from the *Einstein* Slew Survey (ESS) and the *Infrared Astronomical Satellite* (*IRAS*), as well as results from the *ROSAT* All-Sky Survey (Busser et al.), we present an investigation of the newly discovered supernova remnant (SNR) G299.2−2.9. The object appears morphologically similar in the IR and X-ray bands, with a partially complete shell that is brightest in the northeast. The radio morphology is also similar, although a bright region in the western portion of the remnant is also evident. Results reported from the *ROSAT* Position Sensitive Proportional Counter (PSPC) observation include a low value for the line-of-sight interstellar column density, suggestive of a nearby remnant (distance ~0.5 kpc), leading Busser et al. to conclude G299.2−2.9 is a young remnant that has not yet entered the adiabatic stage of evolution. We investigate the properties expected from such a scenario and find that the results imply an extremely underluminous SNR. As an alternative, we consider an interpretation whereby the SNR is at a larger distance and in the Sedov phase of evolution. Using a model for a nonradiative shock propagating through a dusty interstellar medium, we show that a self-consistent model can reproduce the X-ray and IR fluxes. We discuss the plausibility of each of these models and propose observational tests to differentiate between the two scenarios.

Subject headings: ISM: individual (G299.2−2.9) — supernova remnants — X-rays: ISM

1. INTRODUCTION

Supernovae (SNe) are believed to result from either the core collapse of a massive star (Type II/Ib, c SN) or the thermonuclear explosion of an accreting white dwarf (Type Ia SN). Observations of SNe near maximum brightness show that these events involve the ejection of stellar material with kinetic energies in the range $\sim 10^{50}$–10^{51} ergs. Although the uncertainties in the determination of this quantity for any individual SN are large, there does not appear to be any strong evidence for a correlation between SN type and explosion energy, which may be surprising given the very different explosion mechanisms and range of possible progenitors involved. As SNe evolve into remnants by sweeping up the ambient circumstellar or interstellar medium (ISM), much of the ejecta's kinetic energy gets converted into the thermal energy content of the shock-heated ISM. Thus, studies of the energetics, thermodynamic state, and evolutionary state of supernova remnants (SNRs) can provide critical information about the initial explosion energies of SNe. In this paper, we study the evolutionary state of a recently discovered SNR, G299.2−2.9, to determine whether the data on the remnant fits within this established scenario or whether it indicates the need for a hitherto unrecognized new class of subluminous remnants of subenergetic supernova explosions.

2. OBSERVATIONS

First discovered as the extended source 1ES 1212−651 in the *Einstein* Slew Survey (ESS) data (Elvis et al. 1992), G299.2−2.9 is a recently identified SNR (Busser et al. 1995a, b) in the *ROSAT* All-Sky Survey (RASS) data (Snowden & Schmitt 1990). The remnant is relatively bright (3.2 counts s^{-1} in the PSPC) with a diameter of ~15′. The Position Sensitive Proportional Counter (PSPC) spectral data also suggest a temperature $T \sim 8 \times 10^6$ K with a neutral hydrogen column density $N_H \sim 3 \times 10^{20}$ cm^{-2}, yielding an unabsorbed flux $F_x \sim 3.3 \times 10^{-11}$ ergs cm^{-2} s^{-1}. Based upon the derived N_H value, Busser et al. (1995a, b) estimate a source distance $d \approx 0.5$ kpc assuming a mean ISM number density of $\bar{n} = 0.2$ cm^{-3}. At this distance, the luminosity is $L_x \sim 1 \times 10^{33}$ ergs s^{-1}, and the radius of the remnant is $R \sim 1.1$ pc. We note, however, that the RASS exposure of ~220 s (Busser et al. 1995b) leads to considerable uncertainty in the derived spectral parameters; a considerably larger column density, for example, is not ruled out at the 2–3 σ level.

The ESS image of the remnant is illustrated in Figure 1, where we have smoothed the data with a 1′ Gaussian. While limited to only ~55 counts in the 33 s effective exposure, the remnant morphology appears to be that of an incomplete shell with the brightest emission concentrated in the east. Busser et al. (1995a) report a centrally brightened morphology, in apparent conflict with Figure 1. We note that the emission from this region was identified as two distinct sources in the ESS (see Table 1): 1ES 1212−651 (the northern region) was classified as an unidentified extended source, while 1ES 1212−652 (the southern region located ~6′ away) was identified as a point source. Using a circle of radius 7′.5 to extract counts, we find an IPC count rate of 1.4 s^{-1}, in excellent agreement with the PSPC rate given the derived spectral parameters.

A column density $N_H = 3 \times 10^{20}$ cm^{-2} implies optical extinction $E_{B-V} = 0.05$ (Gorenstein 1975), suggesting that any optical emission from the remnant should be readily observable. Indeed, the ESO/SRC red survey plates show faint filaments around the southern rim of G299.2−2.9, with emission in the western and central regions as well (see Fig. 1). Busser et al. (1995b) report emission of [S II] and [O III], which is typically associated with the recombination zone of radiative shocks.

A ring of emission is also evident in the *IRAS* data. Figure 2 is a map showing the ratio of 60 μm to 100 μm flux that illustrates the infrared emission, presumably associated

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Authors:	VANCURA, O.; RAYMOND, J. C.
Affiliation:	AA(CfA)
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Abstract

We have previously constructed a steady-state dusty shock model which is a self-consistent treatment of the effects of destruction, thermal heating, and deceleration of the grains on the gas-phase abundances, ionization structure and X-ray emission.

We have now adapted the code to predict emissions from a dusty adiabatic blast wave. We make specific predictions about the X-ray spectrum and thermal IR grain emissions emanating from the postshock material.

We will compare these new predictions to approximations adapted from the steady-state modeling. We will also compare to global observations of primary shocks in the Cygnus Loop and Puppis A SNRs in an effort to broaden our understanding of dusty shocks and remnant evolution.

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Title:	Models of Dust Emission and Destruction in Shocks
Authors:	RAYMOND, J. C.; VANCURA, O.
Affiliation:	AA(CfA)
Journal:	American Astronomical Society Meeting, 190, #37.05
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Bibliographic Code:	1997AAS...190.3705R

Abstract

Infrared emission from dust can dominate the cooling rate of shocked gas, and elemental depletion has important effects on the intensity and spectral distribution of X-ray and UV emission. The shocks are vital to the dust population as well, as sputtering and grain-grain collisions in shocks dominate dust destruction in the ISM. While the infrared emission is observed directly, models are required to interpret UV and X-ray spectra in terms of the liberation of refractory elements from dust.

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