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Letter to the Editor: first results from ISO

ISOCAM view of high energy sources ⋆

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Abstract. We report the discovery of warm dust in the surroundings of the compact high energy sources SS433 and Cygnus X-1. In the jets of SS433 we have observed the infrared counterpart of the brighter X-ray knot at a distance of 50 pc from the compact source. The observation reported here suggests that dust formation takes place in the ejecta, and that their infrared luminosity exceeds their X-ray luminosity. In Cygnus X-1 we find that the compact source is surrounded by an infrared envelope of 0.2 pc radius. We propose that besides a gaseous component, warm dust components contribute to the infrared emission from the extended envelope.

Key words: Stars: individual: SS433, Cygnus X-1 – Stars: variables: other – ISM: clouds – Gamma rays: observations – Infrared: stars – X-rays: stars

1. Introduction

The ISOCAM program on compact X-ray sources is opening a new field of research at the interface between High Energy Astrophysics and the Physics of the Cold Interstellar medium. In this *Letter* we describe the first steps into this relatively unexplored domain of research. Although IRAS had shown the importance of infrared studies in the understanding of the late evolution of supernova remnants and classic novae, the detection of distinct infrared signatures in compact X-ray sources has so far been difficult (Beichman, 1987; Smith et al., 1990). Using the unprecedented capabilities of ISOCAM in the mid-infrared (Césarsky et al., 1996) on board of ISO (Kessler et al., 1996) we have detected extended emission around the prototype black hole of stellar mass Cygnus X-1, and the prototype stellar source of relativistic jets SS433.

If a compact source (black hole or neutron star) injects X-ray photons and/or collimated relativistic jets into its cold environment, it is expected that some fraction of the injected power will be dissipated by the interaction with the circumstellar gas and dust. Therefore, an infrared excess due either to free-free emission from an X-ray driven wind (van Paradijs et al., 1994), or thermal emission from heated dust should be observed. Because high mass X-ray binaries are on the galactic plane, the observations are usually contaminated by foreground and background emission along the line of sight, which makes uncertain the identification of energy dissipation in the mid-infrared. In this *Letter* we show that thanks to the improved sensitivity and angular resolution of ISOCAM we have been able to detect the signatures of these physical processes in the circumstellar medium of SS433 and Cygnus X-1.

2. Dust heated by the relativistic jets of SS433

The classic stellar source of relativistic jets SS433 is a high mass X-ray binary at a distance of ~ 5 kpc near the centre of the radio shell W50 (Margon, 1984). The latter may be either the supernova remnant from the formation of the compact object (Velusamy & Kundu, 1974), or a bubble evacuated by the energy outflow of SS433 (Begelman et al., 1980). Besides the well known relativistic jets seen at sub-arcsec scales in the radio, extended X-ray jets and radio lobes become visible at distances ~ 20 arcmin (~ 30 pc) from the compact source (Brinkmann et al., 1996). These large-scale X-ray jets and radio lobes are believed to be the result of the interaction of the mass outflow with

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the interstellar medium. From optical and X-ray emission lines it is found that the sub-arcsec relativistic jets have a kinetic energy of a few times 10^{39} erg s^{-1} (Margon, 1984), which is several orders of magnitude larger than the energy radiated in the X-rays and in the radio. The question on where is going the energy power of SS433 has so far remained without a clear answer.

Survey scans and special pointings of SS433/W50 were carried out with IRAS. At the position of the compact source SS433 an unresolved source (on the scale of 1 arcmin) was found, while the W50 shells had no IRAS counterpart (Band, 1987). Several infrared "knots" with extensions of 2-3 arcmin were detected along the large-scale western jet, which were interpreted as dust and gas clouds heated and partially ionized by collisions with relativistic electrons and protons in the jets (Wang et al., 1990). However, using the kinematic distances derived from ^{12}CO millimeter observations, Band & Gordon (1989) argued that these infrared "knots" are dark clouds in the foreground HII complex S74, concluding that their association with the SS433/W50 large-scale jets was spurious.

Table 1. ISOCAM fluxes[1] for the SS433 eastern knot.

Band (μm)	Flux[2] (mJy/arcsec^2)	Integrated Flux (mJy)	Energy[3] (erg/s)
5.0 - 8.5	3.4 10^{-2}	280	2.2 10^{35}
12 - 18	1.8 10^{-2}	150	3.8 10^{34}

[1]Uncertainties in the quoted fluxes are due to several factors (transient effect correction, photometric conversion factor, flat-field error, background subtraction) and the global uncertainty is estimated to be ~ 30%
[2]Mean flux for a ~8000 arcsec^2 region
[3]For a distance of 5 kpc

In this *Letter* we present the first unambiguous evidence for infrared emission associated to the large-scale X-ray jets in SS433/W50. So far we have made ISOCAM raster maps with the LW2 (5 - 8.5 μm) and LW3 (12 - 18 μm) broad band filters on a 9 x 9 arcmin region centered on the brighter X-ray knot in the jets of SS433, which is on the eastern jet at ~ 0.5° from the compact source (Brinkmann et al., 1996). Data reduction was performed with "CAM Interactive Analysis" (CIA)[1]. The LW3 map of the region around the bright ROSAT knot is shown in Figure 1. At the position of the bright X-ray knot there is an extended infrared feature that has a striking morphological resemblance with the ROSAT X-ray image. The feature has a size of 3 × 1 arcmin with the major axis at a position angle somewhat perpendicular to the jet axis, as expected in a structure that is the result of bow shocks.

[1] "CAM Interactive Analysis" is a joint development by the ESA astrophysics division and the ISOCAM consortium led by the ISOCAM PI, C. Césarsky, Direction des Sciences de la Matière, C.E.A., France.

Table 2. ISOCAM fluxes[1] of Cygnus X-1.

Band (μm)	Flux[2] (mJy/arcsec^2)	Integrated Flux (mJy)	Energy[3] (erg/s)
5.0 - 8.5	3.1 10^{-1}	280	5.5 10^{34}
12 - 18	7.8 10^{-2}	70	4.3 10^{33}

[1]Uncertainties in the quoted fluxes are due to several factors (transient effect correction, photometric conversion factor, flat-field error, background subtraction) and the global uncertainty is estimated to be ~ 30%
[2]Mean flux for a ~900 arcsec^2 region
[3]For a distance of 2.5 kpc

The background corrected fluxes in the LW2 (5 - 8.5 μm) and LW3 (12 - 18 μm) filters are given in Table 1. At a distance of 5 kpc the fluxes in Table 1 represent energies of 2.2 10^{35} erg s^{-1} in the 5-8.5 μm band, and of 3.8 10^{34} erg s^{-1} in the 12-18 μm band. These are larger than the 1.8 10^{34} erg s^{-1} luminosity observed by ROSAT in the 0.1-2.4 keV band (Brinkmann et al., 1996). A black body single temperature fit to the flux ratio $F_{5-8.5\mu m}/F_{12-18\mu m}$ = 1.9 would give a dust temperature $T_d \sim 780$ K, and an integrated IR luminosity for the bright knot of 7 10^{35} erg s^{-1}.

We wonder why IRAS did not detect this eastern knot when several other knots with comparable integrated fluxes and sizes were detected on the western side of SS433 (Brand, 1987). One possibility is that these knots are transient features that have appeared and vanished in the interval of time since the IRAS observations in 1983. In fact, the light crossing time for a feature of 3 arcmin extent at 5 kpc is 14 years, about the time since the IRAS observations. We point out that the knot in the jet of SS433 has properties comparable to the ejecta in Cassiopeia A (Lagage et al., 1996), and that in this context, it is possible that dust is formed in the ejecta of SS433.

3. Extended Infrared Emission in Cygnus X-1

In a search for infrared counterparts of possible extended radio jets from Cygnus X-1 (Martí et al., 1996) we have imaged a 12x12 arcmin region around this black hole candidate with the LW2 (5 - 8.5 μm) and LW3 (12 - 18 μm) filters. Data reduction was also performed with CIA. Although no infrared jet-like features are evident, we find an

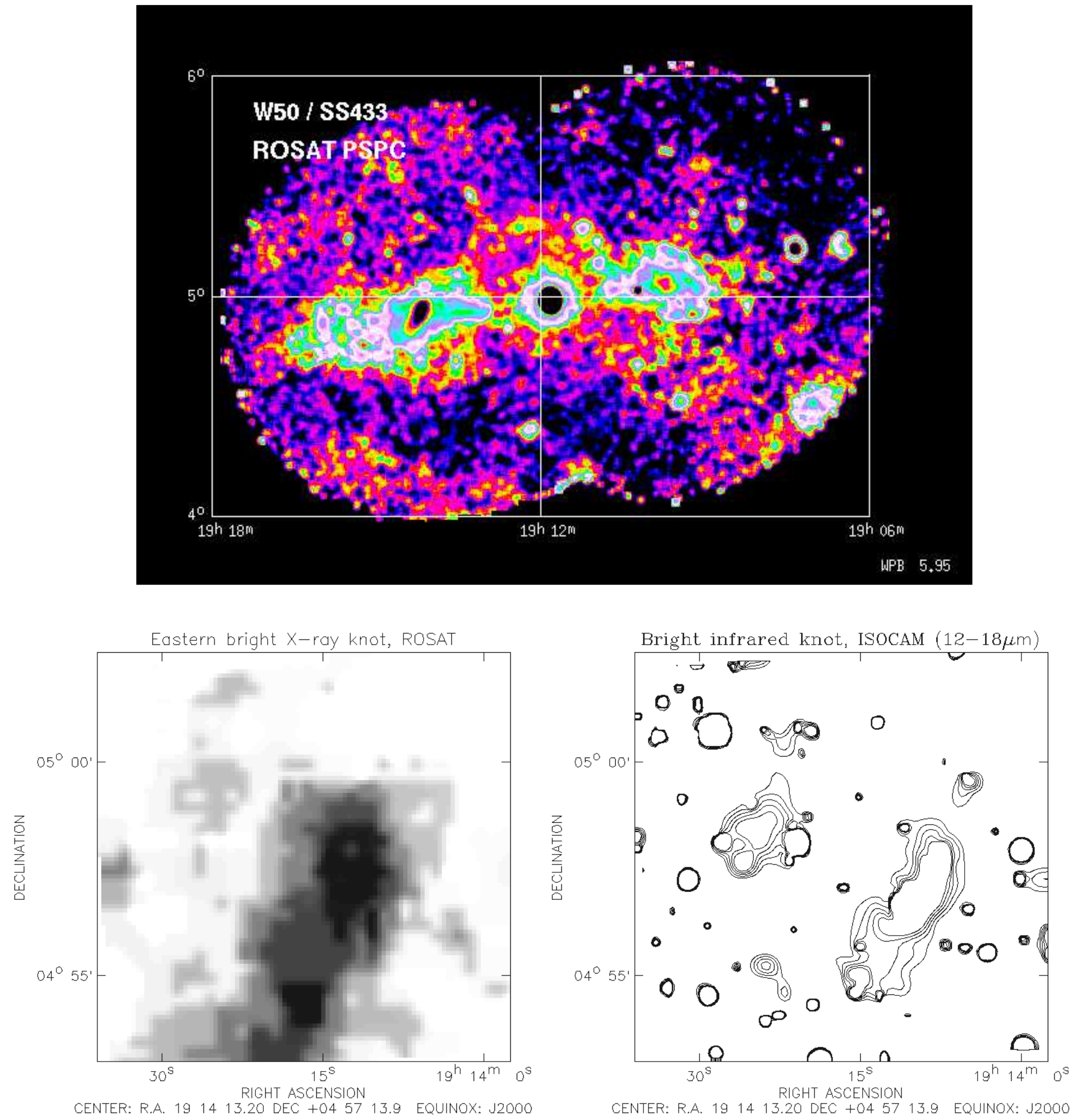

Fig. 1. X-ray and infrared images of the brighter X-ray knot in the jets of SS433/W50. The X-ray ROSAT images in the energy range 0.9 -2.0 keV shown in upper and lower left panels are from Brinkmann et al. (1996). The bright infrared knot in the ISOCAM image (12 - 18 μm) shown in lower right panel exhibits a striking morphological similarity to the X-ray bright knot in the jets.

extended halo of infrared emission around this high mass X-ray binary.

Figure 2 shows the envelope observed in the LW2 and LW3 filters. At a distance of 2.5 kpc (Oda, 1977) the 15 arcsec radius corresponds to 5.2 10^{17} cm ($\sim$ 0.2 pc or 35,000 AU). The observed fluxes given in Table 2 imply radiated energies of 5.5 10^{34} erg s^{-1} and 4.3 10^{33} erg s^{-1} in the LW2 and LW3 filter bands respectively.

The fluxes in Table 2 are consistent with the infrared measurements at 2.3, 3.6, 4.9 and 10 μm by Persi et al. (1980), who found in Cygnus X-1 an infrared excess above the stellar continuum for wavelengths $\geq$ 3.6 μm. Persi et al. (1980) proposed that this excess was due to optically thick free-free plus bound-free emission from a gaseous envelope. However, the IR excess emission seems to rise between 3.9 and 4.9 μm (see Figure 2 of Persi et al., 1980) and some fraction of it could be due to a warm dust component in the extended envelope of the high mass X-ray binary. A precise estimate of the temperature and flux from warm dust would require a model of the stellar IR continuum for the high mass binary companion, which is beyond the scope of this *Letter*. However, we point out that the idea of warm dust components in the surroundings of high mass X-ray binaries is supported by recent infrared ground based observations of the galactic source of superluminal jets GRS 1915+105 (Mirabel & Rodríguez,

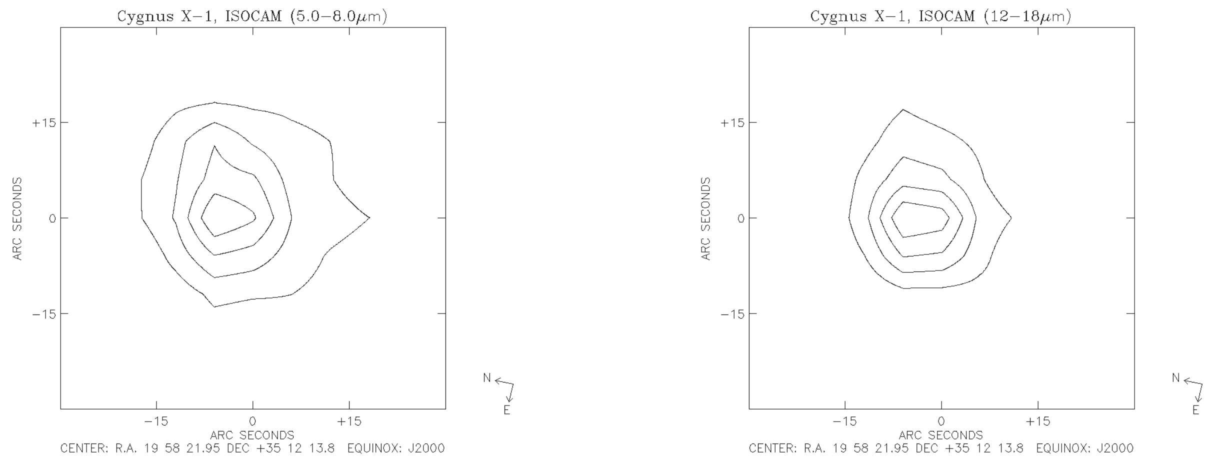

Fig. 2. LW2 (5 μm - 8.5 μm) and LW3 (12 μm - 18 μm) images of Cygnus X-1 made with a 6 arcsec pixel field of view.

1994), which revealed the presence of a dust component with $T_d = 2300$ K at distances $\sim 10^3$ AU from the compact object (Mirabel et al. 1996).

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