MULTIWAVELENGTH OBSERVATION OF SS 433 JET INTERACTION WITH THE INTERSTELLAR MEDIUM

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SS 433 is an X-ray binary emitting persistent relativistic double sided jets that expand into the surrounding W50 radio nebula. The SS 433/W50 system is then an excellent laboratory for studying relativistic jet interaction with the surrounding interstellar medium. In this context, part of W50 nebula has been mapped with ISOCAM at 15 micron, where the large scale X-ray jets are observed. I will show the results, particularly on the W50 western lobe, on two emitting regions detected in IR with IRAS, and observed in millimeter wavelength (CO(1-0) transition). It is uncertain whether these regions are due to heated dust by either young stars or the relativistic jet, or to synchrotron emission from shock re-acceleration regions as in some extragalactic jets from AGN. In this latter case, INTEGRAL might detect soft gamma-ray emission.

1 Introduction: the SS 433 / W50 system

SS 433 is an X-ray binary composed of probably a massive star and probably a neutron star, but the nature of none of them has been confirmed. The binary system emits compact relativistic jets observed at subarcsecond scales in radio, and which characteristic is to show a precession movement. The Doppler shifted lines observed in the optical spectrum enable to calculate the precession model parameters, resulting in relativistic ($v = 0.26 c$) jets covering a cone with a half opening angle of $\theta = 19.8^\circ$, which axis has an inclinasion angle of $i = 78.82^\circ$ to the line of sight, and a precession period of about 162.5 days, the binary period being close to 13.08 days (Margon 1984). The feature of these precessing jets is that during a small time interval of the precession, the eastern jet which is approaching most of the time recedes, and the western jet approaches instead of receding.

This binary is the center of the “sea-shell” radio nebula W50 shown at 20 cm (from Dubner et al. 1998) in the figure. This $2^\circ \times 1^\circ$ nebula ($\sim 120 \text{pc} \times 60 \text{pc}$ at a distance of 3.5 kpc) has a circular central shape considered as a supernova remnant, with two extensions called lobes or “wings” resulting in this sea-shell or goose beak form. The eastern wing exhibits a clear helical pattern which mirrors at large scales the precession of the jets from SS 433. The western wing, smaller and brighter, appears to interact with a denser medium. So different ambient conditions may result in different acceleration and emission mechanisms occurring inside the remnant. On figure the projection of the precessing movement on the sky plane is superimposed on the 20 cm image of the nebula showing that these wings are well constrained inside the precession cone. Thus W50 structure reveals the connection between the subarcsecond relativistic jets from SS 433 and the extended nebula over $\sim 5$ orders of magnitude in scale.
Figure 1: W50 at 20 cm with the projected precession cone on the sky plane. The cone axis has a position angle of 100° according to Hjellming and Johnston (1981). The two radio lobes lie within this cone.

2 Multiwavelength observations

2.1 ISOCAM

In order to prove that the W50 elongated shape is due to jets, we observed it with ISOCAM, the infrared camera on board of the Infrared Space Observatory (ISO), at 15 µm (large band filter 14-16 µm) with a spatial resolution of 6" × 6" per pixel. We could not map the whole nebula so we mapped a small part of the eastern lobe where an X-ray knot lies, the north-east quarter of the central circular part of W50, and nearly all the western lobe.

There is no particular 15 µm emission in the observed eastern parts of W50, and no correlation was found between the IR images and the corresponding ones in X-ray (with ROSAT and ASCA) and radio (at 20 cm), both for the central field and for the X-ray knot area. This is not surprising as the central part of W50 must have been swept away from its material by the supernova explosion, and the eastern lobe is described as faint in radio and less dense than the western one by Dubner et al. (1998). The X-ray knot, the brightest knot seen by ROSAT at 0.1–2.4 keV and called “e2” by Safi-Harb and Ögelman (1997), is coincident with an optical filament and is probably due to shocks with the supernova remnant (Safi-Harb and Petre 1999), but it is not visible at 15 µm with ISOCAM sensitivity.

Thus in the following we will concentrate on the western lobe. Its map at 14–16 µm shown on figure reveals infrared structures at distances > 20′ away from SS 433, consisting in faint extended emissions and “hotspots”. The two main emitting regions are aligned with the direction of the precession cone axis. The IR emission zones may indicate denser region inside the western lobe partly hit by the relativistic jet. In order to understand these IR emissions, let us draw a comparison with other wavelength observations.
2.2 radio

Figure 2 shows the superimposition of the 20 cm contours on the ISOCAM image. The radio and 15 μm emissions are partly spatially coincident, only at the edge of the western “ear” of W50, where the radio emission is the strongest. There may be no IR emission souther because of a less dense medium.

2.3 X-ray

The western X-ray lobe was observed with ROSAT (0.1–2.4 keV) by Brinkmann et al. (1996), and with ROSAT and ASCA (0.5–9 keV) by Safi-Harb and Ögelman (1997) who could not conclude if its emission is thermal or not. X-ray lobes are found to fill the gap between SS 433 and the radio ears, with their spectrum generally softening away from SS 433 along the precession jets axis (Safi-Harb and Petre, 1999). The hard X-ray emission detected with ASCA (0.5–9 keV) is knotty, appearing at > 15′ from SS 433, and focused on the precession axis cone as the ISOCAM emission (see figure 3 top). Due to ASCA limited field of view the edge of the lobe was not observed, but there seems to be a spatial anticorrelation between hard X-ray and and the farest mid-IR emissions from the binary system. The brightest X-ray knot is 31′ west from SS 433, where there is 15 μm emission, but X-ray observation with a better spatial resolution is needed to be conclusive. The soft X-ray emission seen by ROSAT (0.11–2.35 keV) is also knotty and diffuse (see figure 3 bottom). It is faint and spatially anticorrelated with the 15 μm emission, although there is very faint (too faint to be drawn as contours on figure 3) and very soft X-ray
emission at the edge of the radio mid-IR emitting ear (Brinkmann et al. 1996).

The nature of the X-ray emission is still uncertain between thermal and non thermal model, the absence of observed thermal emission line suggesting that either the plasma is very hot (a few keV) or the spectrum is non thermal. It is possible that both thermal and non thermal emission mechanisms are present, as would be expected from the interaction of a jet with a inhomogeneous medium. Thus the question is: are the X-ray knots particles acceleration zones ? If yes, they should be detectable with INTEGRAL.

Figure 4: Comparison between ISOCAM 15 $\mu$m image of W50 western lobe and ASCA 0.5-9 keV (top) and ROSAT 0.11-2.35 keV (bottom) contour images. Spatial resolution are $6'' \times 6''$ per pixel for ISOCAM, $15'' \times 15''$ for ASCA and $12'' \times 12''$ for ROSAT, these latter being smoothed with a 1' FWHM Gaussian.

2.4 IR and millimetric

W50 had already been observed in IR with the IRAS satellite before ISO. Band (1987) thus discovered several IR knots at 12, 25, 60 and 100 $\mu$m, three of them being in the ISOCAM field of view as shown on figure 5 where the circles represents the size of these knots as seen by IRAS, and the names are those given by Band (1987). The $6'' \times 6''$ per pixel ISOCAM spatial resolution enables to reveal their structure for the first time. The 15 $\mu$m knots emission is diffuse with punctual or not “hot spots”. As “knot 6” projection onto the sky plane is at the external limit of the W50 radio nebula and has probably no link with it, we will concentrate on “knot 2”, the nearest region from SS 433 and “knot 3”, the farest.

W50 western lobe has been observed with the millimetre telescope SEST and MOPRA. No emission from the CO(1-0) transition line at 2.6 mm (115 GHz) is observed between SS 433 and “knot 2”, as in IR at 15 $\mu$m in the ISOCAM image (see bottom of figure 5). Two CO(1-0) emitting regions are coincident with the two IRAS knots as shown in figure 5 (data kindly provided by Durouchoux, private communication) and so these molecular clouds are aligned with
the precession cone axis in projection onto the sky plane. Their CO(1-0) line Doppler velocity is \( \sim 50 \text{ km.s}^{-1} \) which corresponds to the same distance of \( \sim 3.5 \text{ kpc} \) from the Earth as W50. The limits of these clouds are not known because of the limited field observed, so we do not know if these two clouds are linked or not. Some data still have to be reduced and may answer to this question. If not, we will carry a new observation campaign.

![Figure 5: CO(1-0) emission contours obtained with MOPRA (bottom and knot 3) and SEST (knot 2) telescopes compared to ISOCAM 15 \( \mu \text{m} \) image of W50 west lobe.](image)

Figure 5 zooms on these two CO emitting regions. Their shapes are similar to the ISOCAM shapes, so the IR and millimetre emissions are unlikely coincident by chance but must be physically linked. So the observed 15 \( \mu \text{m} \) emissions are due to regions lying inside W50 and including molecular clouds. Knot 2 has also been observed for the CO(2-1) line which emitting region has the same shape as the CO(1-0) one. This may indicate a shock excited region, the study of which is in progress. Thus the nature of the IR emission is still uncertain. It could be simply thermal emission from young stars regions still embedded in their dust clouds. More interesting it could be thermal emission from dust heated by the jet interaction with molecular clouds, the high energy particles of the jet hitting the CO and dust grains. Otherwise, the mid-infrared emission could be of synchrotron nature, coming from the very energetic particles of the jet, reaccelerated by shocks with the western lobe denser medium. These particles would lose their energy by synchrotron radiation in X-ray, then in IR as they travel further from SS 433.

3 **Analogy with extragalactic cases**

The case of SS 433 and W50 is interesting in the context of the quasar / microquasar global analogy. Two examples can illustrate this, showing as for SS 433 / W50 knotty structures in their
jet, with X-ray and radio emission not spatially coincident: the quasar 3C273 (see Marshall et al. 2001) and the FR II radio galaxy Pictor A (see Wilson et al. 2001).

4 Conclusion

I have shown indications of SS 433 jet interaction with the medium of W50 western lobe: the radio lobes lie within the relativistic jets precession cone, the observed IR hotspots and extended emission are coincident with molecular clouds and aligned with the jet axis, and there is a possible link with the X-ray emission. The mid-IR emission could be either thermal or not (see discussion in section 2.4). The prospects to answer this question are new observations: with XMM-Newton and Chandra to determine the X-ray emission nature (thermal or not, or both), in near-IR to find possible embedded stars, in millimeter to complete the CO cloud mapping and find traces of shocks, and finally with INTEGRAL, SS 433 being part of the guaranteed time, a detection in soft γ-ray would prove that knots are sites for particle acceleration. Any results about SS 433 / W50 should be regarded in the context of the quasar / microquasar analogy.

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