FABRY-PEROT OBSERVATIONS OF [FeX] IN THE CYGNUS LOOP AND IC443*

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Abstract: We present the first results of an observational program of SNRs in the coronal lines of [FeX] and [FeXIV] using the Fabry-Perot spectrophotometer of the Observatoire de Marseille. These support previously published brightnesses.

I INTRODUCTION

The coronal lines of iron present the best opportunity of studying the hot gas inside supernova remnants (SNRs) directly from the ground. Moreover, X-ray observations inform us of the average conditions (temperature and density) along the line of sight whereas the iron lines highlight specific ionization stages or (in an equilibrium situation) specific temperatures. The [FeX] line at 6374 A arises in significantly cooler media ($1\ 10^6$K) than the X-ray gas. Its prominence suggests that the density is locally enhanced inside the hot phase (assuming pressure equilibrium).

The first technique used to measure the intensity of these lines (e.g. Woodgate et al.,1979) involved a narrow-band filter. The continuum around the line was estimated and subtracted using nearby regions of the sky (outside the remnant) and of the spectrum. More recently, Teske and Kirshner (1985) obtained images using a CCD detector (and a narrow-band filter). Both groups detected emission clearly associated with the SNRs. Those techniques eliminate the night sky emission very well, but may be affected by the source's continuum or [OI] 6364 A line (in the wing of the [FeX] filter).

We have observed the Cygnus Loop and IC443 with an 80 cm telescope, using relatively large diaphragms (up to 5.2'). A region around the [FeX] wavelength was isolated with a 9 A FWHM interference filter and scanned with a Fabry-Perot interferometer. We adopted a rather low Fabry-Perot resolution (3 to 4 A FWHM) so as to have a high sensitivity for broad lines. This scanning approach is safer (the line can be 'seen') but less efficient than integrating over the whole filter bandpass. Ideally, the line width and the radial velocity can also be determined. We find that a line near 6374 A, which we attribute to [FeX], appears in many places along the filaments. Its intensity roughly matches those found by previous investigators.

II OBSERVATIONAL PROCEDURE

Absolute calibration of our instrument was done once or twice nightly on the stars 58 Aql and 121 Tau. The atmospheric transmission was monitored on the SNR Hα line. We did not attempt to subtract a background spectrum because of the variability of the night sky lines, but simply checked that the 6374 A feature did not show up outside of the SNR. One recording (50 scans) lasted about 15 min, well within the stability limit of the instrument against temperature variations. Successive observations of the

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same field were summed whenever statistically compatible.

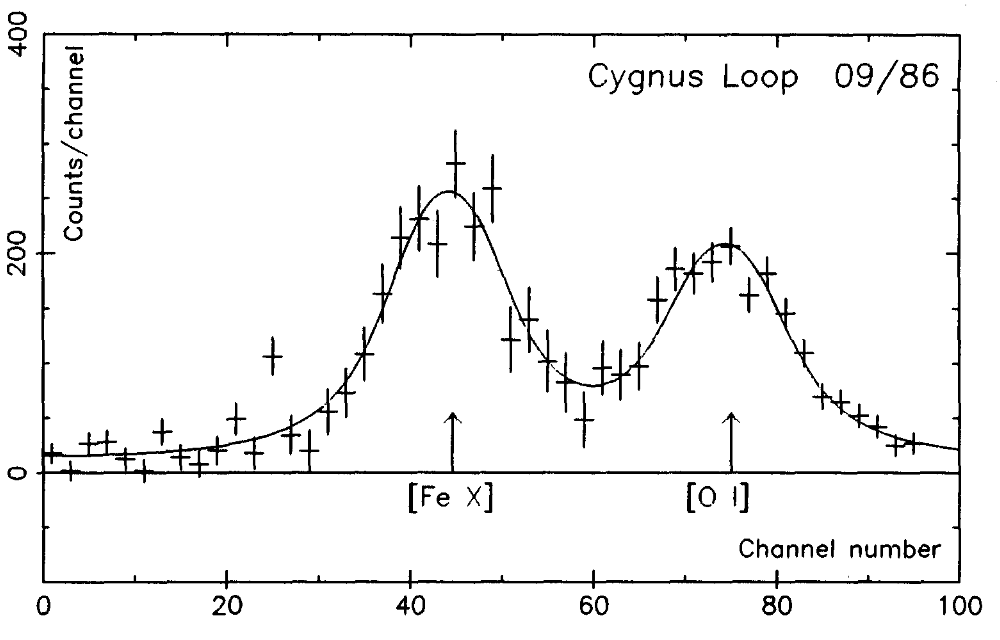
A typical spectrum is the sum of a small constant (photomultiplier dark noise), a filter-shaped continuum, and one, two or even three lines ([OI] 6364 A, [FeX] around 6374 A and OH 6379 A). The [FeX] line (at most 10% of the background) can be recovered only by fitting the continuum and the lines to the data. The shape of the lines (including [FeX]) was taken to be the Fabry-Perot response broadened to the width of the strongest [OI] lines in the filaments (about 75 km/s).

We estimate the uncertainties with the standard method of computing χ^2 as a function of the intensity of the iron line, leaving all other parameters free. The large number of parameters and their correlations with the iron line result in uncertainties larger than those inferred from the count rates and Poisson statistics. The uncertainty of the surface brightness (and the detection limit) is around 10^{-7} erg cm^{-2}s^{-1}sr^{-1} on a typical field. We should be able to lower this in the near future by closer monitoring of the slow wavelength drifts of the filter and the Fabry-Perot system.

Note that, because these observations of faint emission require a filter bandwidth which is smaller than the free spectral range of the Fabry-Perot, our methods differ from those used previously with this instrument (Caplan and Deharveng, 1985).

III The CYGNUS LOOP

Three areas of the Cygnus Loop were previously observed in [FeX]. Lucke et al. (1980) reported observations across the filaments in the north-east and west parts of the Loop. The surface brightness in their fields was at most 1.4 10^{-7} erg cm^{-2}s^{-1}sr^{-1}. Teske and Kirshner (1985) obtained a CCD image of a field in the east where the X-ray emission (Ku et al., 1984) is maximum. They derived much brighter structures (up to 10 10^{-7} erg cm^{-2}s^{-1}sr^{-1}) on much smaller scales (less than 1′).



The above figure shows the spectrum (continuum subtracted) obtained in 15 min on a field (5.2′ in diameter) including the bright part of Teske and Kirshner′s field. Wavelength increases to the left; the dispersion was 3 channels/A and the instrumental width 4 A. The [FeX] line (on the left) is not Doppler shifted and does not appear broader than the [OI] line. This is a common feature of all the fields where [FeX] is above the detection limit. Our data do not require the existence of velocities greater than ± 75 km/s. The surface brightness of the [FeX] line in this particular field - our brightest - is 4.5 ± 1.2 10^{-7} erg $cm^{-2}s^{-1}sr^{-1}$ (uncorrected for interstellar extinction). We reduced the diaphragm diameter to 3.7′: the surface brightness did not increase significantly (4.8 ± 1.8). The line was also detected (barely above the 90% confidence level) at the peak emission location reported by Lucke et al., at levels compatible with theirs. Precise comparison between their rectangular and our circular fields is difficult.

We observed the north-east part of the Loop during ten nights around the new moon in early September and early November 1986. The [OI] line in the wing of the interference filter usually dominates the spectrum, particularly in November because the lower temperature shifted the filter to the blue. It is much stronger than the [OI] night sky line in most of our fields. The continuum around the filaments is about equal to the sky background, indicating a potential problem in non-spectroscopic studies. We did not subtract the faint stars in our fields, but they are well below this intensity (equivalent to an 8.5 mag star). In 10 (out of 40) pointings along the filaments, the [FeX] line was above the 90% confidence threshold.

IV IC443

The bright north-east filaments of IC443 were observed by Woodgate et al. (1979). They report a peak brightness in [FeX] of 1.3 10^{-7} erg $cm^{-2}s^{-1}sr^{-1}$ somewhat inside the filaments, close to the maximum X-ray emission (Petre et al., 1983). Gensheimer and Teske (1987) obtained a CCD image (in the line) of the same area. As in the Cygnus Loop, their data indicate that locally brighter features (up to 5 10^{-7} erg $cm^{-2}s^{-1}sr^{-1}$) appear when a better spatial resolution is achieved.

We observed IC443 in early November 1986. Unfortunately, because of the cold, the filter let through much more [OI], which was often ten times stronger in our spectra than the λ6374 feature. Therefore the [FeX] emission at around 2 10^{-7} erg $cm^{-2}s^{-1}sr^{-1}$ that we found along the filaments must be confirmed under better conditions. On a warmer night, and far from the filaments ([OI] much fainter) we measured 2.9 ± 1.3 10^{-7} erg $cm^{-2}s^{-1}sr^{-1}$ in a 5.2′ circular field near 1(iv) of Woodgate et al.

In late January 1987 we used a new filter, whose bandpass was shifted 3 A redward. We reduced the diaphragm to 2.8′, and explored the bright fields of Woodgate et al. At only one location (see next figure) did we detect the line at the 90% confidence level (2.3 ± 0.9 10^{-7} erg $cm^{-2}s^{-1}sr^{-1}$), but the upper bounds in the other fields were not very tight (3 10^{-7}).

We have also, for this same region, observed the spectrum at the wavelength of [FeXIV] (5303 A). Beside the night sky line at 5299 A (OH) we find a feature, with a typical intensity of 1 ± 0.5 10^{-7} erg $cm^{-2}s^{-1}sr^{-1}$ in 5.2′ fields, which we believe to be [FeXIV] redshifted to 5304-5 A. This result is still very preliminary.

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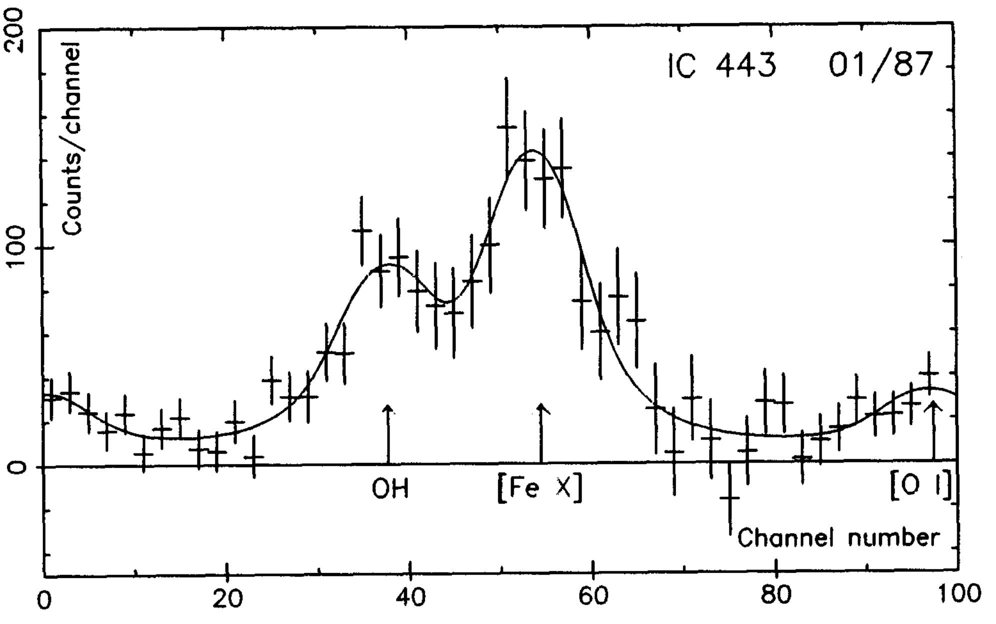

The above figure is the spectrum obtained in 45 min on a 2.8′ field near 1(iii) of Woodgate et al. Wavelength increases to the left; 6374 A is at channel 55. The dispersion was 3.5 channels/A and the instrumental width 3 A. The transmission of this new filter was much lower in the [OI] line (at channel 97, and channel 0 in the next order), but higher in the 6379 A line at channel 37 (probably OH) that did not appear in the former spectra (section III).

V CONCLUSION

We have adapted the Fabry-Perot spectrophotometry technique to the coronal [FeX] λ6374 line. The present sensitivity of the method is 1 10^{-7} erg $cm^{-2} s^{-1} sr^{-1}$. The line was positively measured in numerous fields in the Cygnus Loop and a few fields in IC443. Differences in size and shape between our diaphragms and those used for narrow-band filter photometry preclude a direct comparison, but no strong discrepancy exists. We note however that the very strong continuum in the filaments (locally as high as the night sky) must be allowed for in non-spectroscopic techniques.

There is no evidence in our data for lines broader than 2 A; the radial velocity dispersion from field to field is of this order. This pleads for [FeX] being attached to slow material ('clouds').

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