IONOSPHERIC EFFECTS OF X-RAYS FROM DISCRETE GALACTIC SOURCES*

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Abstract. Observation of the field strength of low frequency radio waves (164 kHz) transmitted during night hours from Tashkent and received at Ahmedabad show increased absorption around the sidereal times of the transit of the X ray stars Sco X-1 and Tau X-1. It is estimated that the ionization in the D region produced by these X-ray stars can explain the observed changes in field strength.

1. Introduction

Since the discovery of discrete X-ray sources in the galaxy about 7 years ago by Dr. Giacconi and his collaborators, numerous measurements have been carried out, particularly by the Naval Research Laboratory and the American Science and Engineering Co. of the U.S.A., to determine their exact location, angular diameter and spectral features. Of particular interest among the 40 or more sources discovered so far, are Sco X-1 located in the constellation Scorpio (Right accension $\alpha = 16$ h 15 m, Declination $\delta = -15\overset{\circ}{.}5$), Tau X-1 in the Crab nebula ($\alpha = 5$ h 31 m, $\delta = +22\overset{\circ}{.}1$), Cygnus X-1 ($\alpha = 19$ h 53 m, $\delta = +34\overset{\circ}{.}5$) and Centaurus X-2 ($\alpha = 13$ h 24 m, $\delta = -62°$). The present paper reports the results of an investigation to find out the effect on low frequency radio waves reflected from the upper atmosphere by X-rays from Sco X-1 and Tau X-1.

2. Low-frequency Recording Equipment at Ahmedabad

Since 1960, we have been recording at Ahmedabad the field strength of 164 kHz radio waves transmitted from Tashkent (42°N, 69°E). The radiated power is in the neighbourhood of 150 kw and the transmission is on the air for approximately 20 hours a day. The receiving equipment is very simple and consists of a loop aerial, or a Wave Antenna terminated in the direction of the transmitter, feeding into a communication receiver, the detected output of which is amplified and fed to a strip chart recorder. Frequent calibrations are carried out with the aid of a standard signal generator. Care is taken to maintain the stable operation of the receiver. Basically, the instrument measures the variations in the amplitude of the radio waves caused by its passage through the atmosphere below the reflecting level. The normal height of reflection is in the D region round about 70–75 km, during the day and 85–90 km during the night. This region is ionised by X-rays from the sun, particularly during solar flares.

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3. Solar X-Rays and the D-region

It is well known that solar flares cause marked increases of ionization in the D-region resulting in short-wave fade-outs at broadcast frequencies and sudden anomalies in field strength of radio waves of long and very long wave lengths (30–300 kHz and 3–30 kHz). The work of Burnight (1948) and of Friedman's group at the Naval Research Laboratory clearly established that solar X-rays were primarily responsible for these effects. It is now known that ionization in the height range 65–90 km is very sensitive to X-radiation of wavelengths shorter than 10 Å (Labeyrie, 1968).

4. Effect of X-Ray Fluxes on the 164 kHz Field Strengths at Ahmedabad

Before describing the effects produced by the galactic X-ray sources, some details of the propagation path may be considered. The great circle distance between the transmitter at Tashkent and receiver at Ahmedabad is 2150 km, the single hop reflection point being located at geographic latitude 32 °N, longitude 71 °E. The radio waves

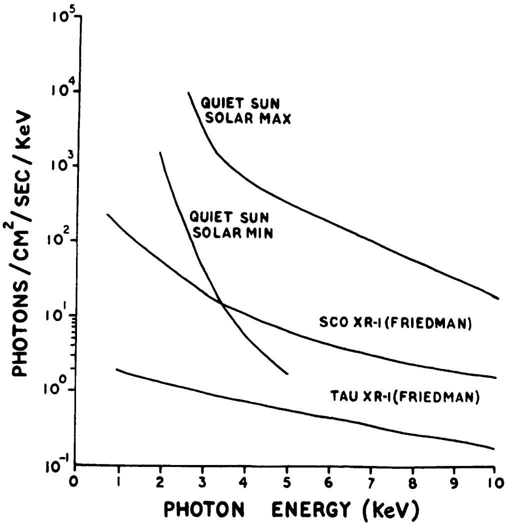

Fig. 1. Comparison of non-flare solar X-ray spectra (sunspot maximum and minimum) with measured X-ray spectra of Sco X-1 and Tau X-1.

from Tashkent may arrive at Ahmedabad after a single oblique reflection in the ionosphere (single hop) or after two reflections in the ionosphere and one at the ground (two-hop) or even after more hops. In general the one-hop mode predominates up to distances of about 2500 km from the transmitter. The equivalent critical frequency for vertical incidence reflection corresponding to the oblique one-hop transmission frequency of 164 kHz is about 29 kHz.

An examination of the coordinates of the four sources, Sco X-1, Tau X-1, Cyg X-1 and Cen X-2, showed that the first three were favourably situated with respect to the reflection point to affect the field strengths at Ahmedabad. In the succeeding paragraphs the changes in the field strength produced by the transit of Sco X-1 and Tau X-1 across the reflection meridian will be discussed. A brief report of the ionospheric effects of X-rays from Sco X-1 is under publication (Ananthakrishnan and Ramanathan, 1969).

The records of nighttime field strengths (between 21 hr local time and 04 hr local time (were scrutinized. During daytime, it would be difficult to separate the effect of

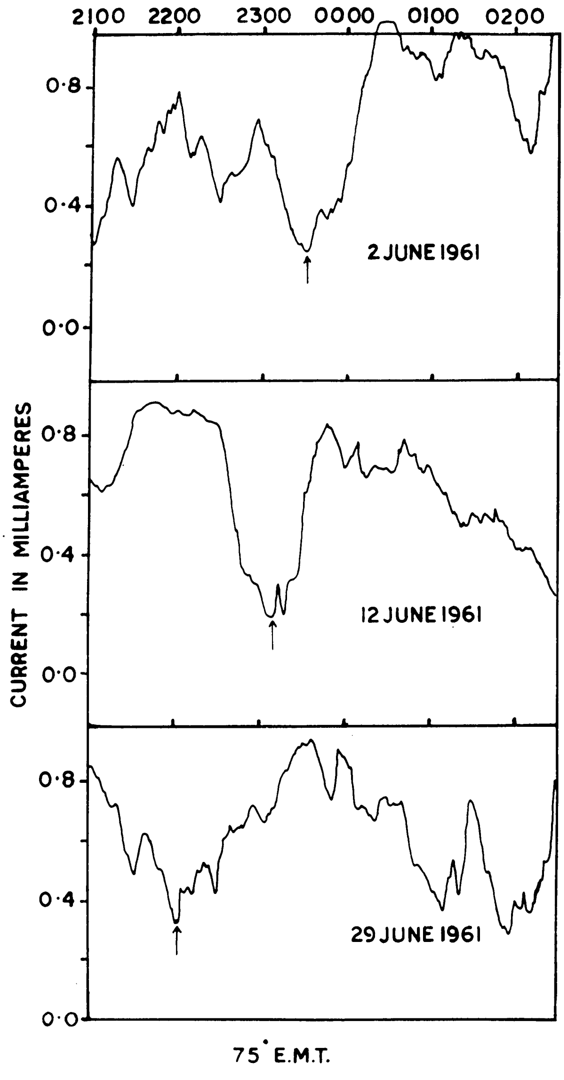

Fig. 2. Night-time field strength of Tashkent (164 kHz) radio transmissions received at Ahmedabad. Arrows indicate meridian transit of Sco X-1.

stellar X-rays from the effect of X-rays from the sun. The X-ray spectra of Sco X-1, Tau X-1 and of the quiet sun in sunspot maximum and minimum conditions are compared in Figure 1. The spectrum of the sun`during sunspot minimum has been measured by Bordeau *et al.* and is taken from Whitten and Poppoff (1965). The spectrum for solar maximum is taken from an article by Labeyrie (1968). It may be noted that in sunspot minimum conditions, the flux of radiation from Sco X-1 can be greater than that from the sun in the high energy region above 4 keV. Calculations of the increase of electron density produced by the X-ray flux from Scorpio in the height range 70–90 km with currently available loss coefficients, show that the increase would be sufficient to produce a noticeable effect on reflected LF and VLF radio waves.

A simple calculation shows that Sco X-1 would transit over the reflection meridian at about midnight in June of each year. Examination of the field strength records for this period showed that there were significant decreases in the amplitude of the 164 kHz field strengths associated with the transmit. An example is shown in Figure 2. The arrows in the figure indicate the times at which the source reaches its maximum altitude at 32°N, 71°E.

The sidereal shift of about $1\frac{3}{4}$ hr between June 2 and June 29 can clearly be seen. In addition to the pronounced minimum associated with the transit of Sco X-1, indicated by the arrows, other minima of sporadic nature are occasionally observed on the records.

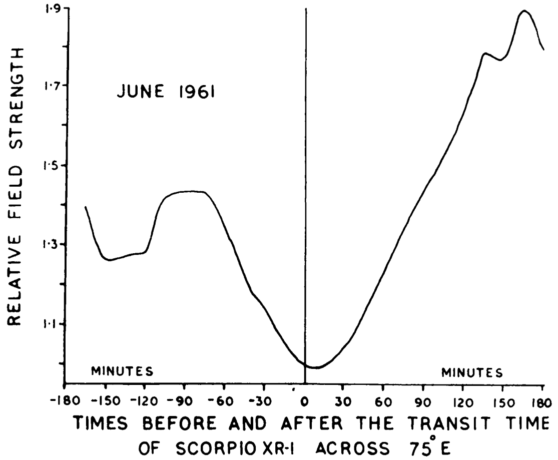

Fig. 3. Decrease in amplitude produced by the X-radiations from Sco X-1 as brought out by superposed epoch analysis.

Figure 3 shows the result of a superposed epoch analysis carried out for the period May–June 1961. The diagram brings out clearly the decrease in amplitude of the signal strength produced by Sco X-1.

Figure 4 shows the result of a similar analysis carried out for Tau X-1. The reduction in amplitude, though clearly evident, is much weaker. The flux of radiation from this source is about an order of magnitude lower, in the energy range of interest.

5. Conclusion

The results discussed in Section 3 show that both Sco X-1 and Tau X-1 produce an increase in absorption, which means a change in ionization in the night-time lower ionosphere, of a magnitude large enough to affect the amplitude of low frequency radio waves traversing this region. A few remarks may be made by way of conclusion.

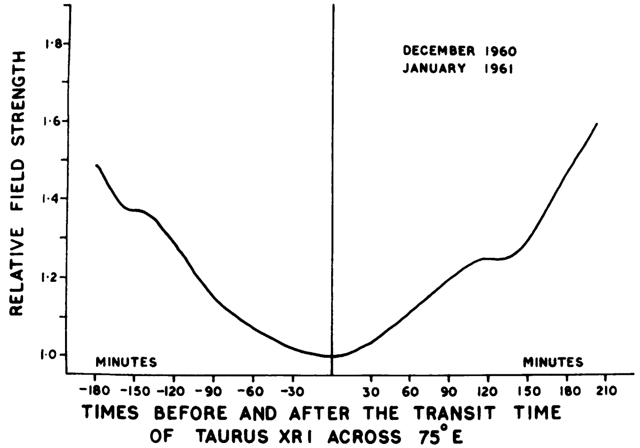

Fig. 4. Decrease in amplitude produced by the X-radiations from Tau X-1 as brought out by superposed epoch analysis.

The inability of rockets to carry out observations for more than a few minutes and the inaccessibility to balloons of D region levels where the softer X-rays are absorbed, show the importance of ground-based observations which can show up the effect of X-ray fluxes from the sun, stars and galaxies. We can look back into the earlier low-frequency records to see if any time-variations in the fluxes can be found.

Acknowledgements

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References

Ananthakrishnan, S. and Ramanathan, K. R.: 1969, *Nature* (in press).
Burnight, T. R.: 1949, *Phys. Rev.* **76**, 165.
Labeyrie, J.: 1968, in *Electromagnetic Radiation in Space* (ed. by J. G. Emming), D. Reidel Publ. Co., Dordrecht, Holland, p. 125.
Whitten, R. C. and Poppoff, I. G.: 1965, *Physics of the Lower Ionosphere*, Prentice-Hall, Inc., p. 30.