OPTICAL AND RADIO INFORMATION

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The six or eight optically identified X-ray sources comprise starlike objects and extended supernova remnants in the Galaxy, well as as a radio galaxy and a quasar. Both X-ray and radiofrequency radiation penetrate the entire galactic plane, but only two or three galactic radio sources have been identified with X-ray sources. This has led Hayakawa *et al.* (**1**) to postulate that detectable X-ray sources are not farther than 1 kpc. However, other studies suggest that there is a cluster of a few intrinsically bright sources actually near the galactic nucleus and a scattering of weaker sources near the sun (**2, 3**).

The distances of X-ray sources can be estimated from extinction by interstellar gas or intergalactic gas on spectra above 10 Å, but the method ultimately depends on the radio and optical data of the gas. Conversely, interstellar densities of certain elements with large photo-ionization cross-sections may be determined from the absorption of X-rays, after calibration of source distances by the methods of optical astronomy. As soon as Tau XR-1, Cas XR-1, and Vir XR-1 were identified with optical objects, their distances were established. The optical distances can lead to the estimation of power outputs, linear sizes, volume emissivities, and ultimately to physical mechanisms. The most recent synthesis of the Crab Nebula (**4**) incorporates an X-ray source of thermal bremsstrahlung. Scargle (**5**) has observed an excess brightness of 0·12 mag at 3500 Å, which is only 2 times larger than the model's prediction. Further accounts of the optical and radio propreties of the Crab, Cas A, Vir A, and 3C 273 are given elsewhere.

The optical identifications of Sco X-1 (**6**) and Cyg X-2 (**7**) do not give concomitant distances because these 13th and 16th mag 'stars' do not clearly fall into classes for which the method of parallax measurement is obvious. The distance of Sco X-1 has been estimated by hypothesizing a relationship with the Galactic Spur (**8**) or with surrounding dust clouds (**9**). If they are relevant, these phenomena must contain clues to the history as well as the distance of Sco X-1. Wallerstein (**10**) has measured the equivalent widths of interstellar Ca II H and K in the spectrum of Sco X-1 and nearby comparison stars. On the assumption that the radiation field of Sco X-1 has not altered the surrounding medium so as to increase the number of Ca^+ ions, he finds that Sco X-1 is more distant than the comparison stars, or $\geqslant$270 pc. The nil proper motion (**11, 12**) also stands against very small distance. Unless the distance is small, the neutral-hydrogen data in the direction of Sco X-1 (**13**) combined with

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photo-ionization cross-sections (**14**) suggest that the optical depth is as large as $\tau = 12$ at 50 Å.

The bright, blue irregular variable very near the position of Sco X-1 (**6, 11**) has remained secularly stable back to 1895, the date of the first known plate of the field by Barnard. In 1966–67 $+0{\cdot}07 \leqslant B\text{-}V \leqslant +0{\cdot}26$ and $-1{\cdot}15 \leqslant U\text{-}B \leqslant -0{\cdot}64$ for $12{\cdot}14 \leqslant \leqslant V \leqslant 13{\cdot}09$, with little correlation between the variables in these ranges (**6, 15, 16, 17**). D. E. Mook (**18**) observed on 41 consecutive nights at Cerro Tololo, and W. A. Hiltner made further observations there. Their work suggests that the light curve varies in character with no established periodicity, that the amplitude increases with decreasing wavelength of passband, and that *B-V* and *U-B* decrease as *V* magnitude brightens. Bursts of 0·2 mag in as little as 90 sec are noted in continuous monitoring. Other observations and autocorrelation tests also fail to demonstrate periodicity in the light curve of Sco X-1 in the range 2–300 sec (**19**). A discussion of the possible disparity between the observed *V* magnitudes and the magnitude to be extrapolated from the observed X-ray data would involve the interstellar extinction and much faith in the absolute photometric accuracy of the X-ray data. The optical polarization is nil (**11**) within 0·015 mag (**20**).

The spectrum of Sco X-1 in the blue resembles the spectrum of an old nova (**6, 11, 21**). Weak emissions of H, He I, He II, O II, C III, and N III are broadened several angstroms with no simple dependence on wavelength or ion. Radial velocity is not easy to observe in Sco X-1; there is a measurement of 0 ± 100 km/sec on June 27, 1966 (**11**). The reporter's spectrograms of April 18, 1967, reduce to -300 ± 100 km/sec, but the question of the value and the variability of the radial velocity calls for many observations.

Spectrophotometry of Sco X-1 (**22, 23**) shows that the continuum in the range 3200–7500 Å can be either the black-body radiation of a thick hot gas or the bremsstrahlung of a thin hot gas. The observed gradient is $\langle d\,\mathbf{AB}/d(1/\lambda)\rangle = 0{\cdot}25$ mag microns in terms of magnitudes $\mathbf{AB} = -2{\cdot}5 \log S - 48{\cdot}55$, where S is absolute flux density in ergs $cm^{-2}\,sec^{-1}\,(c/s)^{-1}$. This corresponds to $T = 6.2 \times 10^4\,°K$ in the spectrum of bremsstrahlung, but, if the X-ray bremsstrahlung $T = 5 \times 10^7\,°K$ extrapolates into the optical range, we can account for the gradient by the hypothesis of interstellar reddening equal to $E_{B-V} = 0{\cdot}11$ mag. A Rayleigh-Jeans distribution would require greater reddening to fit the gradient, namely about $E_{B-V} = 0{\cdot}55$ mag. Changes in the gradient or color can be explained by changes of temperature, especially in a thick gas at frequencies near the peak of radiation. However, magnitude is not correlated with $d\,\mathbf{AB}/d(1/\lambda)$ precisely, and there is no systematic departure from linearity in the graph of **AB** vs. $1/\lambda$ (**23**). Variable monochromatic emissions should produce little effect on colors since their total equivalent width is about 1% of the continuum in the *B* passband, and this is a larger percentage than in *U* or *V*. Also, brighter monochromatic emissions should decrease *B-V* but increase *U-B*, whereas these color indexes were observed to vary in the same sense (**18**). None of the data, including one at 1·6 μ (**24**), supports the presence of any cool photospheric component in the spectrum of Sco X-1. A dwarf star cooler than K5 V or a hotter star sufficiently below the main sequence could go undetected (**23**). Until binary nature is indicated by observations, theorists might tell us how to have a single 'star' of $M_v = +8$ but $L = 500\ L_\odot$ living for at least three-score and ten years so quietly that astronomers never noticed it.

The equivalent widths of the monochromatic emissions of Sco X-1 (**6, 21, 23**) suggest that the line-emitting gas is much cooler than the X-ray emitting gas at $5 \times 10^7\,{}^\circ$K, that the cool gas occupies a much smaller volume than the very hot gas, that the Balmer series is radiatively excited, that the He/H ratio is high, and that some characteristic of Of spectra and novae spectra are present (**23**). Variability of the line emissions with respect to each other and with respect to the continuum has been studied only enough to say that it is complex in Sco X-1. H. Spinrad has observed variations of Hα relative to the adjacent continuum in short time intervals, and J.C. Golson has observed some variation of Hβ, He II 4686, and adjacent continua.

Sco X-1 and Cyg X-2 are the only two identified X-ray sources which are not observed to be radio sources. For Sco X-1 flux densities of $< 0{\cdot}09 \times 10^{-26}\ W\,\mathrm{m}^{-2}\ (\mathrm{c/s})^{-1}$ at 4170 Mc/s (**25**) and $(0{\cdot}01 \pm 0{\cdot}016) \times 10^{-26}\ W\,\mathrm{m}^{-2}(\mathrm{c/s})^{-1}$ at 15·3 Gc/s (**26**) have been set as limits, significantly below the extrapolated value of 0·07, or 0·7 if the Gaunt factor increases by 10 between 2 Å and 2 cm. Sco X-1 must become optically thick at radiofrequencies.

Several other very tentative identifications of X-ray sources have been suggested (e.g. (**27**)). But in order to bind X-ray and optical astronomy together, a larger share of X-ray observations must be devoted to accurate positional work. Simultaneous optical and X-ray observations of identified sources should be done regularly, especially with improved X-ray photometric accuracy.

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