X–RAY VARIABILITY IN THE ORION NEBULA

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ABSTRACT. We have examined each of the 172 EINSTEIN X–ray sources in Orion for both short (100–10,000 seconds) and long (1 day to 2 years) timescale variability. No strong flares were seen in 75,000 total seconds of observations. We compare the Orion variability results with those from the ρ Oph star–forming region, solar X–ray flares and dMe U–band flares.

1. Introduction

The Orion Nebula is the best known and best studied site of recent star formation in our galaxy. A rich history of optical, radio, and infrared work provides an invaluable background for observations in the X–ray regime, while its age and proximity mark it as an essential target in studies of the evolution of stellar properties.

Orion was observed by the EINSTEIN Observatory for a total of ~ 140 ksec over a 23–month span with 13 IPC (75 ksec) and 6 HRI (65 ksec) pointings within the central $2^{\circ} \times 2^{\circ}$ region centered on the Trapezium. Some work on these observations has already been presented (Ku and Chanan 1979; Pravdo and Marshall 1981; Ku, Righini–Cohen, and Simon 1982; Smith, Pravdo, and Ku 1983), but these focussed on only 1 HRI and 2 IPC pointings (totalling ~ 25 ksec). More recently, Caillault and Zoonematkermani (1989) have discussed the unexpected X–ray emission from the B6–A3 main sequence stars in the Nebula. We discuss herein our analysis of the variability characteristics of the X–ray sources.

In particular, we compare our results with those obtained by Montmerle, et al. (1983) for the ρ Oph star–forming region. They concluded that the X–ray emission from the young stars in that cluster was the result of continual flaring. This was based, in part, on the fact that the amplitude distribution of flux variations was similar to those for solar X–ray flares and dMe U–band flares.

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2. The Observations

The X–ray data were obtained using the EINSTEIN Observatory imaging proportional counter (IPC) and high–resolution imager (HRI). The IPC provided a $1^\circ \times 1^\circ$ field of view with 1' resolution in the 0.15–4.5 keV band. The HRI provided a ~ 25' diameter field of view with ~ 4" resolution in the slightly softer 0.1–3.0 keV band; further instrumental details can be found in Giacconi, et al. (1979). The primary survey consists of 13 overlapping IPC pointings; effective exposure times ranged from 100 to 30,000 seconds, yielding minimum detectable soft X–ray fluxes of ~ 10^{-13}ergs $cm^{-2}s^{-1}$ in individual fields (but an order of magnitude fainter upon merging). This corresponds to an X–ray luminosity threshold of ~ 2.5×10^{30}ergs s^{-1} assuming a distance to Orion of 450 pc. Six HRI images were also taken, with exposure times ranging from 3,000 to 22,000 seconds.

Each of the 13 IPC fields was analyzed using a source detection algorithm initially developed for study of the LMC (Wu, Hamilton, and Helfand 1988). This method incorporates, in addition to the normal telescope vignetting, mirror scattering and instrument dead time corrections, a flat–field correction, a cosmic–ray particle count rate correction, and allows for the subtraction of sources which would otherwise contaminate the calculation of the local background for source detection. We have used only those sources with significance $> 3.5\sigma$ in the subsequent discussion.

Most of the X–ray sources were analyzed for X–ray variability on a variety of timescales ranging from 100 sec (limited by counting statistics) to the 23–months separating the first and last observations. A χ^2 – distribution test was performed for each light curve, and although many sources varied over the long–term interval, none showed significant (> 3x) flaring activity during any one pointing ($< 3 \times 10^4$ s).

3. The X–Ray Variability

Although no single flares were seen, we have detected many sources which display large variability (> 10x); an example of this is the source $\alpha = 5^h32^m02.16^s$, $\delta = -5^\circ02'36"$ (tentatively identified as V652 Ori = P1496). The average count rate for the source on 1979 day 65 was 0.1270 counts s^{-1}, while on 1980 day 265 it was 0.0097 counts s^{-1}, a factor of 13 difference. Of course, this type of analysis may only be performed on sources which have been detected in more than one image.

There are a number of sources which were detected only once and then not seen (and with upper limits lower than the flux when detected) in subsequent observations of the same region; these are probably "flare" sources, too. However, we ignore these sources for the time being other than to note their existence and prevalence (there are 26 of them).

For those sources which have been detected in multiple fields, we follow an analysis similar to that which Montmerle, et al. (1983) conducted for the variable X–ray sources in the ρ Oph star–forming region. They assumed that all of the single X–ray sources belong to one type of X–ray object, seen at different levels of activity. They defined a quantity F_x as the ratio of the flux of an X–ray source in any observation to the flux of that source in its minimum, or "ground", state of activity. A histogram $N(F_x)$ of the normalized amplitude distribution of the fluxes of the Orion X–ray sources is shown in Figure 1. This histogram is derived from

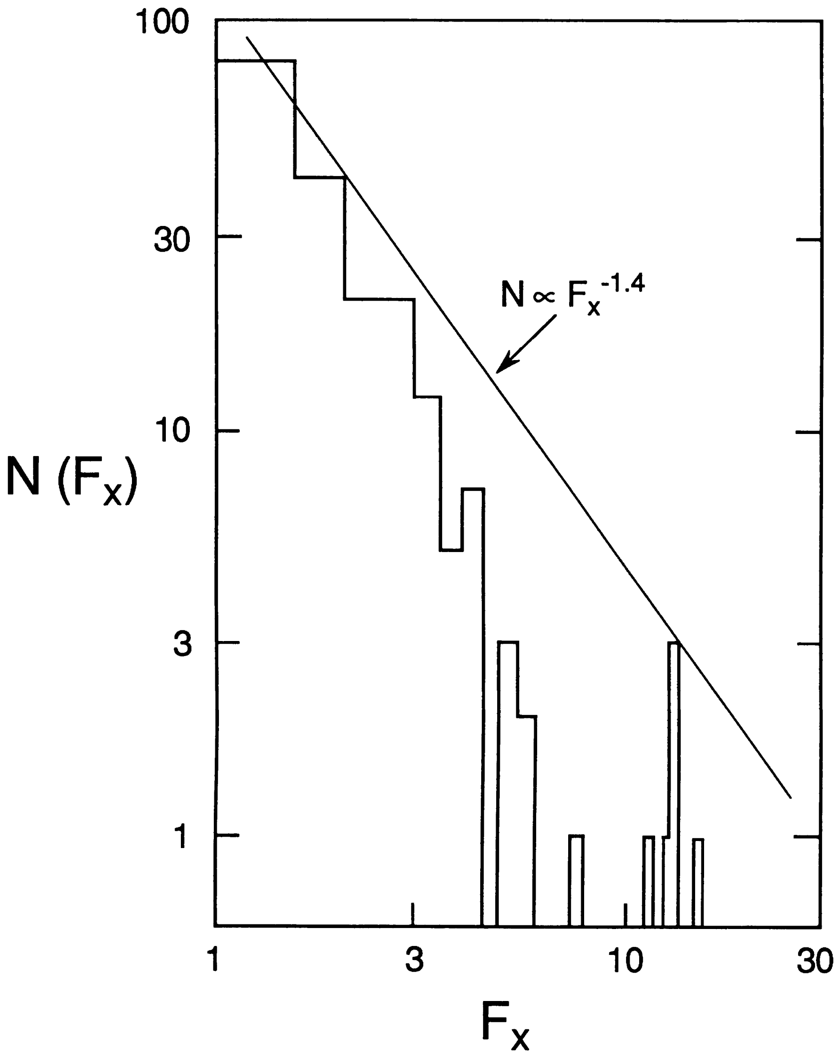

Figure 1. A histogram $N(F_x)$ of the normalized amplitude distribution of the fluxes of the Orion X–ray sources.

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201 points = Σ (number of sources [= 80]) x (number of positive detections above the ground state), which we assume is statistically equivalent to one single source observed 201 times. Comparison with the results from the ρ Oph study and from Drake's (1971) study of the time–integrated flux of solar X–ray flares shows that all of these distributions may be described by a power law with exponent $\alpha \sim -1.4 \pm 0.2$. These similarities suggest that the observed X–ray variations may be interpreted in terms of strong stellar flares. This conjecture is further supported by the amplitude distribution found by Kunkel (1973) for U–band flares in dMe stars.

4. A Possible Explanation

Theories of flare phenomena regard flares as the manifestation of instabilities which relax stressed systems toward configurations of lower potential energy (Svestka 1976). Rosner and Vaiana (1978) have shown that the power–law behavior observed for flares is shown to follow from the assumption that flaring is a stochastic relaxation phenomenon and from the requirements that the *e*–folding time for energy storage be constant (independent of the instantaneous free energy accumulated) and that the energy released, E, be large when compared with the energy of the unperturbed state, E_0. This latter requirement implies that most of the observed X–ray sources in Orion are the result of flares releasing more energy than is contained within the flaring volume itself during quiescent conditions, since, for small ratios of E/E_0, the Rosner and Vaiana (1978) model predicts a saturation effect, i.e., the power–law distribution turns over such that the frequency approaches a constant.

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