# X-RAY PROPERTIES OF PROTOSTARS IN THE ORION NEBULA CLUSTER: PRELIMINARY RESULTS.

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We study the X-ray properties of young stellar objects (YSOs) in the Orion Nebula Cluster from their initial protostellar phase (Class 0/I objects) to the more evolved Pre-Main Sequence (PMS) stage of no longer accreting and disk free stars (Class III objects). The present analysis is based on the deep and uniform data set of X-ray emission, obtained with the *Chandra* Orion Ultradeep Project (COUP) (Getman et al., 2005), and the most deep and complete photometric catalog from the UV to 8 $\mu$m available up to now obtained using joint observations of the HST Treasury Program, the deep and simultaneous UBVI ($V_{lim} \sim 23.0$) and JHK ($K_{lim} \sim 19.0$) images taken, respectively, with WFI@2.2m ESO and ISPI@4m CTIO telescopes and the Spitzer-IRAC imaging.

Using these data we are able to select stars of different classes in the ONC and compare their fundamental properties. To this aim, we use a selection criterion as conservative as possible, even if uncomplete, in order to avoid the contamination of highly reddened different class objects in the selected samples. This constraint allows us to compare the X-ray properties of the stars in different classes. With this conservative criterion, however, we are not considering many of the protostars with peculiar SED that will be examined later on. We then consider the following preliminary results as the first step of our analysis. Although the constraint of our criterion of class selection, we have, for the first time, a statistically significant sample of Class 0/I objects with an X-ray detection. We are able, for the first time, to compute an X-ray Luminosity Function (XLF) of the sample of Class 0/I stars and to compare it with those of Class II and Class III stars.

## 1 YSO classification

**Class 0/I** candidate objects within the COUP field of view were classified by computing the slopes $\frac{\Delta log(\lambda F_\lambda)}{\Delta log \lambda}$ corresponding to adiacent bands (from K to 8$\mu$m) and considering Class 0/I objects those for which the slopes are all larger than 0, i.e. objects with rising SEDs. We included in our sample of Class 0/I objects those for which we have at least three of the five magnitudes in order to be able to compute at least two slopes. This allow us to include objects detected only in the K, 3.6$\mu$m and 4.5$\mu$m bands but not at 5.8-8.0$\mu$m: because of the bright background at these wavelengths, and in part due to the lower sensitivity at 8$\mu$m, many protostars are not detected in these two bands. Using this criterion, we selected 34 Class 0/I candidates; 16 of them, i.e. almost 50%, have an X-ray counterpart in the COUP data. Our list of X-ray detected Class 0/I objects is the largest sample of Class 0/I stars with evidence of X-ray emission.

**Class II** candidate objects were selected using the condition $0.2 < [3.6] - [4.5] < 0.7$ and $0.6 < [5.8] - [8.0] < 1.1$. Using this criterion we can lose reddened Class II objects that, however, would have [5.8]-[8.0] colors bluer than our selected Class 0/I objects and therefore do not contaminate that sample. We assume that X-rays properties of Class II stars are independent from the reddening and that our sample is representative of the Class II population. Using this selection, we find 161 Class II candidate stars; 135 of them (more than 80%) are X-ray detected.

**Class III** candidate objects are the more evolved diskless PMS stars and do not show IR excesses and therefore were selected as those having IR colors at the IRAC magnitudes around zero. However, in order to include all the stars not detected in the longer wavelength IRAC bands, we considered all stars with $K - [3.6] < 0.5$. From this sample we excluded those with $[3.6] - [4.5] > 0.2$ or $[4.5] - [5.8] > 0.2$ or $[5.8] - [8.0] > 0.6$, i.e. objects with IR excesses in at least one of the three colors, since they are not compatible with the colors of unreddened class III stars. However, we included the objects for which we do not have detections at the IRAC bands with wavelength longer than $3.6\mu$m. Using this criterion we selected 116 class III candidate stars; 92 of them (about 80%) have an X-ray counterpart. Among the X-ray detected Class III stars, 85 are in the list of Hillenbrand (1997). The 24 objects without an X-ray detection could be either Class III stars with low X-ray activity or field stars in the same field of view.

The spatial distributions of the three different populations show that Class 0/I objects are mainly concentrated in the central and north-east parts of the COUP field of view; in particular, most of the X-ray detected objects are located near the edge of the central nebular emission while the X-ray undetected Class 0/I stars are both within the bright nebular emission and outside of it. On the contrary, Class II stars are quite uniformly spread over in all the field and the more evolved Class III objects are preferentially distributed in the external regions.

## 2 X-ray luminosities

We used the results of the spectral analysis derived in Getman et al. (2005) to compare the X-ray properties of the three different populations of YSOs in the Orion Nebula Cluster. For the X-ray detected stars of each of the three classes in the ONC, the unabsorbed X-ray luminosities $L_{t,c}$ in the total band 0.5–8.0 keV were taken from Table 8 of Getman et al. (2005), where $L_{t,c}$ has been derived from spectral fit of X-ray data. In order to compare unbiased luminosity functions of the three IR selected classes, the upper limits to the X-ray counts were derived for the Class 0/I X-ray undetected objects. To convert upper limits

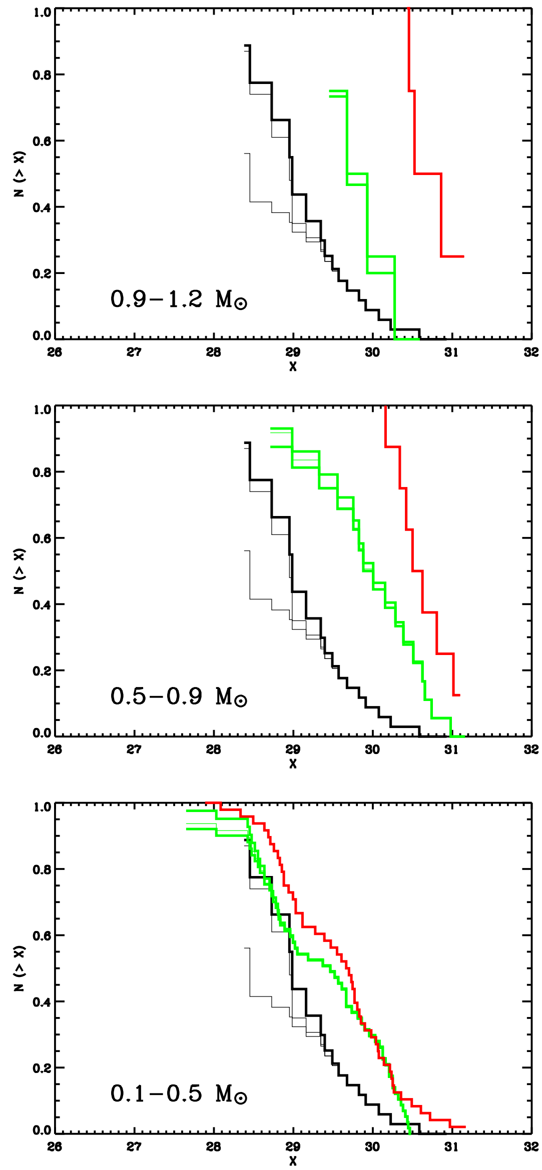


Figure 1: Cumulative XLF of the three populations in the ONC for three different mass ranges. The *red* and *green lines* indicate the XLF of Class III and II objects, respectively, with masses in the given range, while the *black lines* are the XLF of Class 0/I stars, for which masses are unknown and are therefore the same in the three panels. The same color lines in each panel show the XLF using the three different luminosity conversion factors adopted for the X-ray nondections of each subsample.

to X-ray luminosities we derived three plausible unabsorbed luminosity conversion factors, which strongly depend on the extinction.

Since X-ray luminosity depends on the stellar mass (Preibisch & Feigelson, 2005; Preibisch et al., 2005), we considered from the Class II and III samples only stars for which the mass has been estimated using the Siess et al. (2000) PMS model (Getman et al., 2005). With this constraint, we have 83 X-ray detected Class II stars and 8 X-ray undetected Class II objects for which upper limits were retrieved from Table 11 of Getman et al. (2005). For the Class III samples, instead, we have 67 X-ray detected and 3 X-ray undetected, again retrieved from Table 11 of Getman et al. (2005). Of these latter three objects, we consider the only star with an high proper motion membership probability.

X-ray luminosity functions (XLF), shown in Fig. 1, were derived using the Kaplan-Meier maximum-likelihood estimator. Statistical tests show that for the two highest mass ranges, the XLF of the three populations are cleary different, with the X-ray luminosities of Class III stars highly elevated with respect to those of Class II stars and these, in its turn, highly elevated with respect to those of Class 0/I. There is a clear evidence of systematic difference of the X-ray activity from Class 0/I, the least X-ray luminous objects, up to Class III, which show the highest X-ray luminosities.

## 3 Summary

We have selected a sample of 34 Class 0/I candidate objects in the ONC using the deep $JHK$ images taken at the ISPI@4m CTIO telescope and Spitzer-IRAC observations. New deep optical observations taken with the WFPC2 camera of HST and the WFI camera of ESO 2.2 m are used to exclude Class 0/I candidate objects with optical counterparts. Almost 50% of the Class 0/I stars have been observed with COUP and this allows us to study their X-ray properties. Samples of Class II and III stars in the same region have been selected in order to compare protostars with more evolved stars and examine the evolution of their X-ray activity.

We have derived the unabsorbed X-ray luminosities $L_{t,c}$ and computed the X-ray Luminosity Functions for the three samples of YSOs. Class 0/I stars are significantly less luminous in X-rays than more evolved stars. Their spectral properties are similar to those of the more evolved Class II and III objects except for a larger absorption likely due to the enhanced local density surrounding protostellar objects. The three different classes show a similar temporal behavior of the X-ray emission since Class 0/I stars present variability similar to those of the more evolved YSOs of Class II and III.

## References


Getman, K. V., Flaccomio, E., Broos, P. S., et al. 2005, ApJS, 160, 319

Hillenbrand, L. A. 1997, AJ, 113, 1733

Preibisch, T. & Feigelson, E. D. 2005, ApJS, 160, 390

Preibisch, T., Kim, Y.-C., Favata, F., et al. 2005, ApJS, 160, 401

Siess, L., Dufour, E., & Forestini, M. 2000, A&A, 358, 593