X-ray survey of the Chamaleon I star forming region

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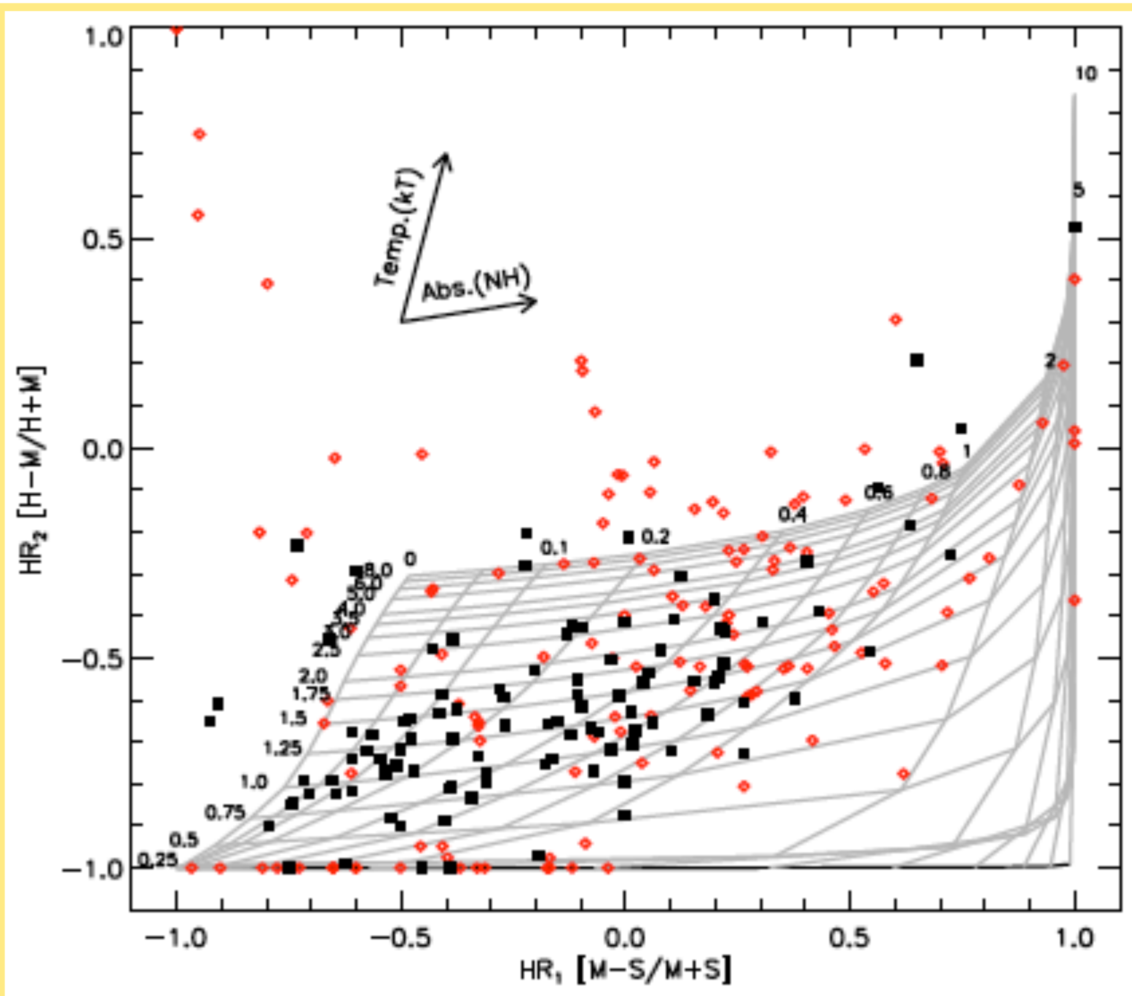
X-RAY CONTEXT: Out of 484 X-ray sources detected in this survey, 306 have more than 30 net photons in their spectra. This is a hard numerical restriction, but the uncertainty in the X-ray parameters and the X-ray flux itself is not only a function of the source photon statistic, it hardly depends of the intrinsic spectrum of the source (Albacete-Colombo, et al, 2014). We decided to accept fits where NH and kT relative errors are less than unity. This restriction discards out 41 sources that do not satisfy this condition. Finally we get reliable X-ray spectral parameters (Xred < 2) for a total for 265 X-ray sources.

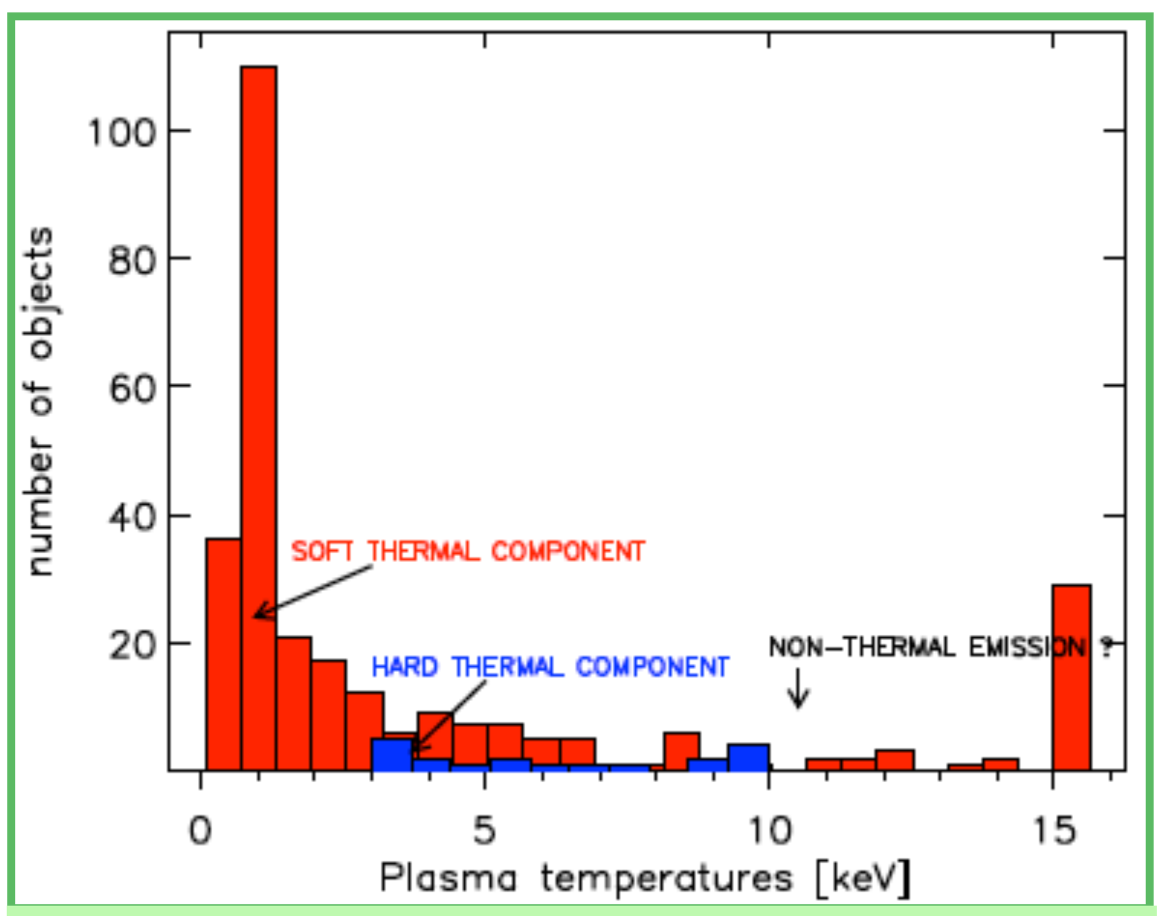
INTRODUCTION + ABSTRACT

The Chamaleon I dark molecular cloud, hereafter Cha I, is an active site of recent star formation located at high galactic latitude (b ~ -15 deg). It belongs to the Chamaleon complex which is one of the nearest SFR (d ~ 160 pc). These two characteristics result in low foreground extinction and poor contamination with background objects, which makes it of special interest for the unbiased determination of the true population of young stars. Cha I has been the target of a large number of studies, including spectroscopy in Halpha (Comeron et al. 1999, 2000), monitoring of photometric variability (Carpenter et al. 2002), and IR photometry (Luhman et al. 2000; Luhman 2004; Manoj et al. 2011), who carried out a thorough spectroscopic study to obtain precise spectral types and membership census of Cha I stars. The substellar limit in Cha I, based on the members of median age (Stelzer & Micela 2007), corresponds to the spectral type M6-M6.5 (Baraffe et al. 1998). Finally, X-ray studies using Einstein Observatory (Feigelson & Kriss 1989), ROSAT (Feigelson et al. 1993; Alcala et al. 1995, 1997), Chandra (Feigelson & Lawson 2004; Stelzer & Micela 2007) and XMM-Newton observations (Stelzer et al. 2004; Robrade & Schmitt 2007) have partially revealed the Cha I X-ray stellar population, but leaving a large part of it unexplored in the X-rays.

We present preliminary study of the Cha I X-ray stellar content and describe the nature of 484 X-rays sources detected in the analysis of 8 XMM-Newton X-ray observations. We correlate them with optical, mid- and near- infrared Spitzer and 2MASS counterparts. One third of the X-ray sources shows 2MASS counterparts and 14 X-ray sources out of 54 Spitzer sources, exhibit mid-IR colors, indicative of stars with circumstellar discs. The range of Av absorption is between 0.1 to 0.5 mag. We performed X-ray spectral analysis of X-ray sources with more than 30 X-ray photons in the spectra. The extinction is highly variable over the entire stellar field. We estimate X-ray plasma temperatures, abundances and fluxes of stars. Typical X-ray spectral parameters are log(NH) ~21.45 (cm^{-2}) with 1 sigma dispersion of 0.4 dex, and a not normal temperature kT~0.71 keV, with a hard tail temperature distribution towards 1.5 keV. We test the X-ray Luminosity Function (XLF) approaches as it was computed from spectral fits or via conversion factor (CF). It is biased by the effect of the NH absorption correction to the X-ray luminosity. The XLF of known SFRs could be biased if the Lx of stars were obtained via CF rather than the spectral fits.

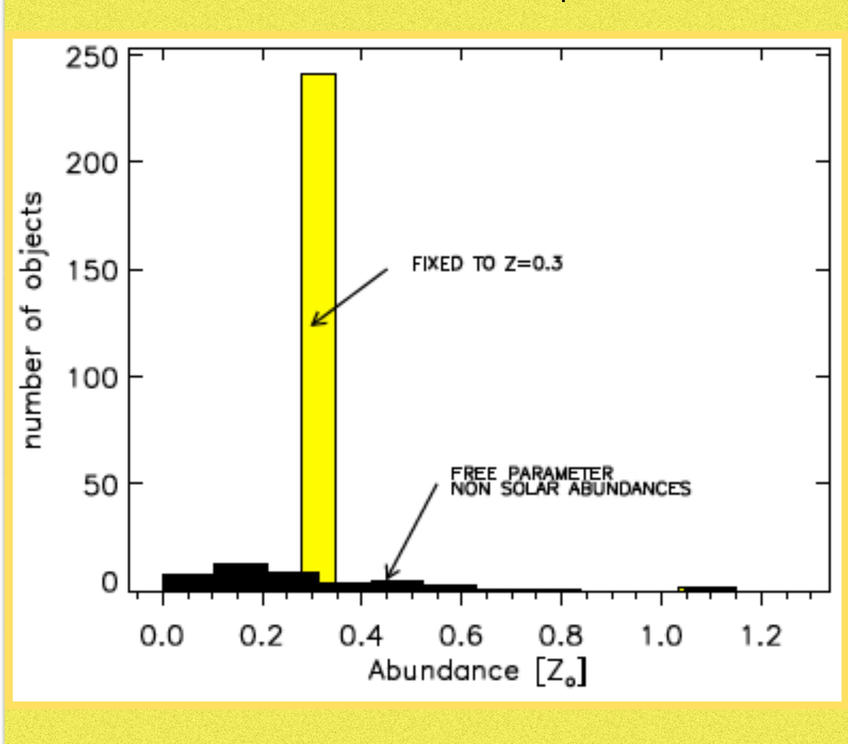


Hardness ratio diagram: X-ray color-color diagram for Cha I sources. The three energy bands: Soft (0.3-1.2 keV), Medium (1.2-2.5 keV) and Hard (2.5-4.5 keV) keV were used to compute grids by mean of a plasma APEC thermal emission models with different temperatures. *Red* diamonds points refer to sources with photon statistics greater than 40 but lower to 100 X-ray photons in the 0.3-8.0 keV band. *Black* filled boxes shown correspond to sources with more than 100 X-ray photons.
- **Source NH values are spread into log(NH) 21 to 21.3 cm^{-2}, while X-ray plasma temperature ranges from 0.75 to 1.75 keV.**

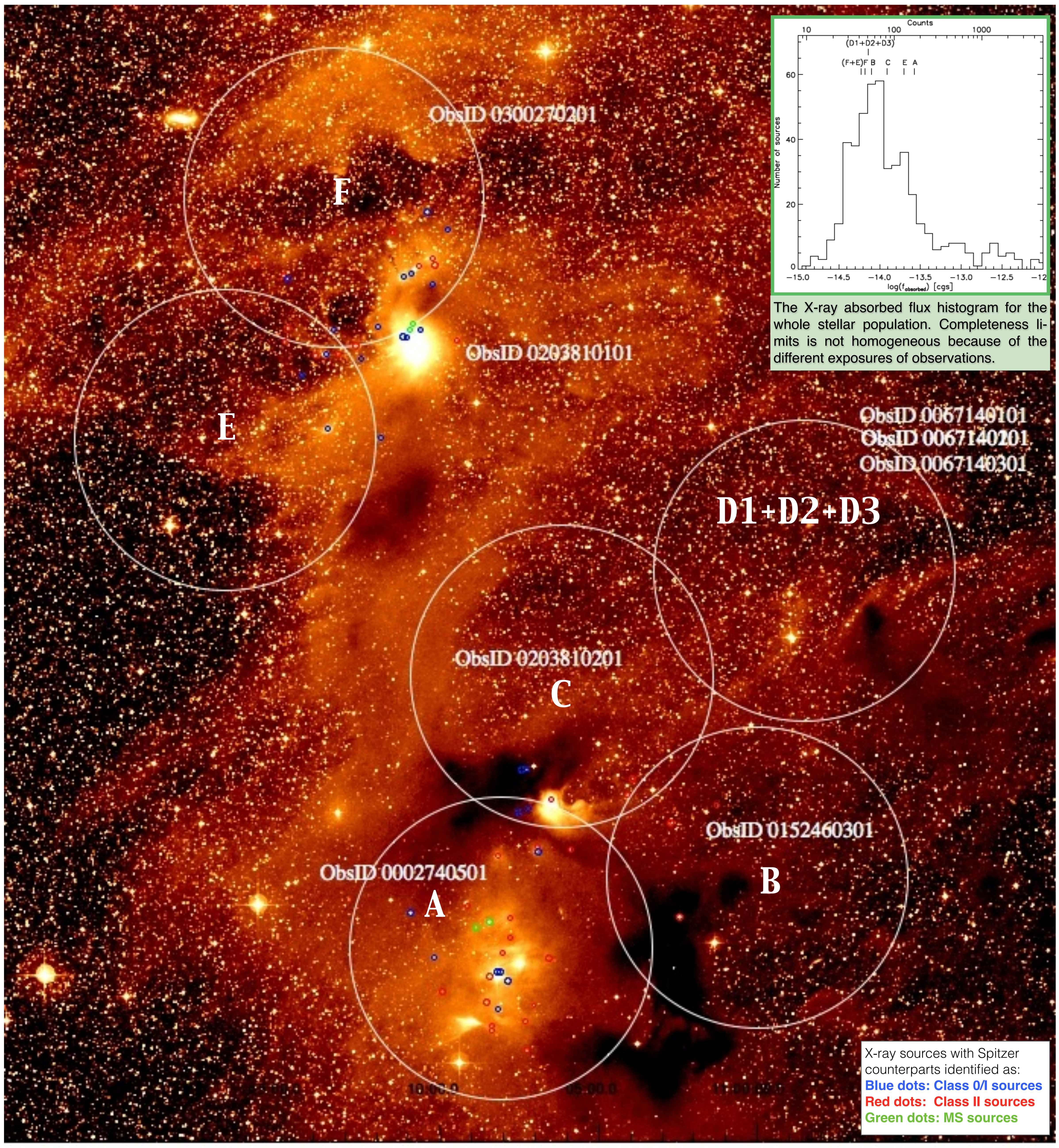


X-ray temperatures: distribution from spectral fits of 265 sources with more than 300 photons in their spectra is shown. The soft (kT$_{}$) component peaks at 0.8 keV and has a median 0.71 keV, higher temperatures are related to sources with a second thermal component in the spectra, which ranges from 1.5 keV to 5 keV, and in some cases shows an extended hard tail with a clear lack of spectral lines at temperatures of 6 keV or higher. **This high energy emission may be attributed to Weak Line T-Tauri Stars (WTTS) , that often produce compact non-thermal radio emission.**

X-ray abundances: Stellar abundances is one major key in the study of low-mass stars in SFRs. In low resolution spectra, elemental abundances are usually fixed at Z = 0.3 Zsun. While these fits are usually statistically successful, the assumptions are clearly astrophysical inadequate. Several studies of magnetically active stars show that many plasma components with a wide range of temperatures may be present, and that the chemical fractionation associated to magnetic reconnection flaring can produce strongly non-solar elemental abundance distributions (Kastner et al. 2002).



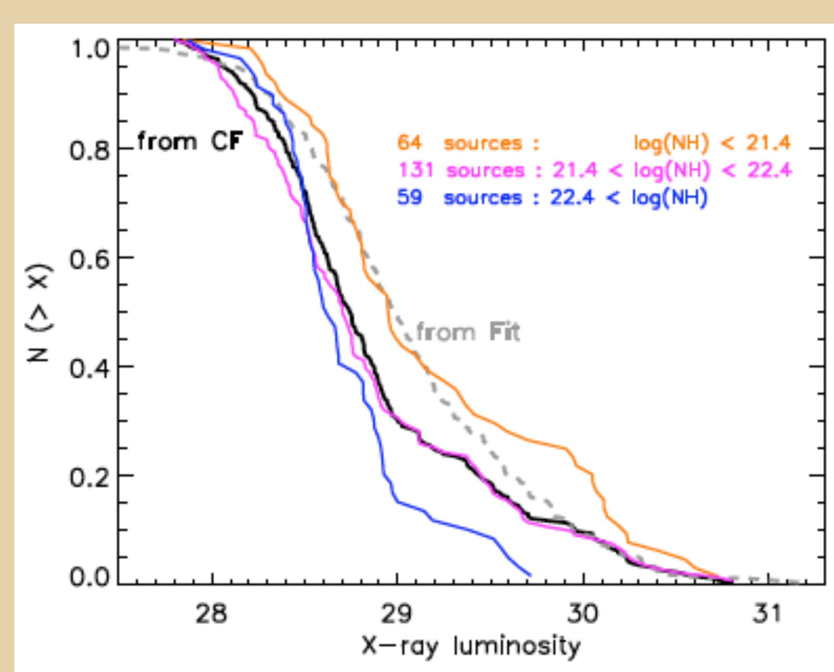
Non-solar values were fitted for sources with more than 1000 X-ray photons (20 sources). **The distribution of non-solar abundances peaks at 0.2 Zsun, with a large spread of values from 0.1 to 0.8, and even 1.2 Zsun Ten sources (i.e. 5% of the X-ray sample) displays values larger than 0.5 Zsun, indicating the effect proposed by Kastner et al. 2002.**



The X-ray absorbed flux histogram for the whole stellar population. Completeness limits is not homogeneous because of the different exposures of observations.

Bias on the X-ray luminosity function: The most important parameter that characterize the X-ray activity of stars is the un-absorved X-ray luminosity, which in an statistical sense let us to compute the X-ray luminosity function (XLF) for the stars belonging a given SFR. However, the true XLF is usually biased by the impossibility to get reliable X-ray luminosities for faint stars.

X-ray surveys on Orion and Taurus SFRs are those that combine proximity with long exposures of X-ray observations. This fact converts them in good candidates to study XLFs from spectral fitted sources. All known XLFs studied and compared to other SFR were based un-absorbed X-ray luminosities (Lx) computed using X-ray luminosity conversion factors (CFs), which is the median of the Lx/*countrate* from most intense sources of the sample. However, most intense X-ray sources are usually related to massive young stars as well as to low mass stars observed in flaring state. The adoption of a single CF from a such a different nature and astrophysical condition of plasma is a very roughly approximation, and do not represent the true astrophysical conditions in which most of stellar populations of young stars emits in X-rays.



Thanks to the proximity of this region (160 pc), we present the first quantitative result of comparison of both procedures. We computed unabsorbed X-ray luminosities for 254 sources with reliable spectral fits for the [0.3-10.0] keV energy range, leading to a log(Lx) range from 27.5 to 31.2 erg/s. CF was computed for PN camera which is deeper and most completes, and for sources with more than 100 photons in the X-ray spectra. CF is equivalent to 9.60x10^{30} erg/ph. Upper and lower values correspond to 1sigma uncertainties, respectively. The figure show the large discrepancy between XLFs from Fit to CF. Both distributions were compared using a two-dimensional Kolmogorov-Smirnov statistical test. The maximum distance between distributions is 0.20, which give a significance level of ~10^{-5} shows both distributions are quite different.
- **XLF from CF is biased by the effect of the NH absorption correction to the X-ray luminosity. A reliable XLF estimation should be computed by using Lx from spectral fits.**

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