Massive Star Birth: A Crossroads of Astrophysics
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Chandra observations of massive star forming regions

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Abstract. I review selected results obtained using *Chandra* X-ray observations of high mass star forming regions. Discussed topics include diffuse X-ray emission; the mechanism of X-ray emission in stars from the highest to the lowest masses; the role of imaging X-ray observations in the identification of star forming region members and the implications for star formation studies. Special attention will be given to results recently obtained for the Orion Nebula Cluster by the *Chandra* Orion Ultradeep Project (COUP).

Keywords. stars: activity, stars: formation, X-rays: stars

1. Introduction

Since the launch of the first X-ray telescopes with good imaging capabilities, *Einstein* and *ROSAT*, it was readily recognized that young stars of all evolutionary stages and masses, with the possible exception of late-B and A type stars, are intense sources of X-rays. For low mass stars, the temporal and spectral characteristics of the X-ray emission indicated a plausible coronal origin, as observed on the Sun and implied for main sequence (MS) stars, even though at levels well above that of the Sun and MS stars. See reviews by Feigelson & Montmerle (1999) and Favata & Micela (2003). High mass stars on the other hand were thought to produce X-rays in small scale shocks produced by instabilities in their powerful winds (Lucy & White, 1980). However, several fundamental problems remained open: X-ray activity of low mass pre main sequence (PMS) stars did not follow the activity-rotation relation observed for older MS stars and taken as evidence for the action of stellar dynamos in determining the coronal magnetic field and ensuing activity. At the high-mass end, X-ray luminosities and spectra of several early type stars were in disagreement with that predicted by wind shock models.

Another issue that remained unresolved with these early telescopes was that of the existence of diffuse X-ray emission in massive star forming regions, predicted by some theoretical models as a result of the interaction of the powerful O-star winds with the star forming cloud. Although indications came from *Einstein* and *ROSAT* observations, they were for the most part inconclusive, either because the observed diffuse emission was likely dominated by supernova remnants in slightly evolved regions such as the Carina Nebula (Seward & Chlebowski, 1982) or because of the uncertain contribution of large numbers of spatially unresolved low mass stars, such as in the case of the Rosette Nebula (Leahy, 1985; Dorland & Montmerle, 1987).

Other than for the understanding of the mechanisms responsible for the observed X-ray emission, X-ray observations of star forming regions have proved to be particularly useful for the selection of their low mass members. This is due to the much higher X-ray luminosity of PMS stars with respect to field objects: the large majority of X-ray sources detected in the direction of a star forming region are indeed associated with members, while the often numerous field object in the same field of view (FOV) remain for the most part undetected. In comparison with other member selection methods, X-rays have several advantages: with respect to methods using optical data, they allow the study of more embedded regions, thank to the high penetrating power of X-rays. They are much more efficient with respect to spectral indicators of youth, such as the Li line, as these require high resolution optical spectroscopy of a large number of candidates. They allow the selection of both classical and weak-lined T-Tauri stars (W/CTTS), both bright in X-rays, contrary to methods that make use of indicator of accretion or of disk presence, such as the H_α line or near infrared (NIR) excesses. X-ray observations can thus give a fundamental contribution in the star formation field, e.g. for the study of the initial mass function (IMF), star forming history, disk lifetime, etc. A dramatic example is the discovery of large numbers of previously unrecognized WTTS, that indeed constitute, for associations older than ~2Myr, the majority of members.

I will review selected results of *Chandra* observation of high mass star forming regions. *Chandra*, launched by NASA in Summer 1999, is the X-ray telescopes with the highest spatial resolution ever built. Some results obtained with ESA's *XMM-Newton*, the X-ray telescope with the largest effective area, will also be discussed. In spite of the larger collecting area of *XMM-Newton*, *Chandra* is arguably the most useful of the two for the study of massive star forming regions. The superb spatial resolution of its imaging instruments (better than 1 arcsec on axis) and the low background result in a better sensitivity. Moreover, massive star forming regions, being rich and relatively distant (>400 pc, but more typically 1-2kpc), often have very high source sky densities. Spatial resolution is thus essential to resolve the individual low mass stars, both for the study of their X-ray emission and, if studying diffuse emission, for their removal.

This review covers many topics, still it is far from exhaustive. I will in part focus on recent results of the *Chandra Orion Ultradeep Project* (COUP). First of all I will present COUP. I will then discuss some results from the study of high mass star forming regions regarding diffuse X-ray emission. I will then discuss X-ray emission form massive early type stars, from intermediate mass stars and from low mass (T-Tauri) stars. Finally I will present some example of star formation studies made possible by X-ray selection of members, including the study of the BN-KL and OMC-1 South sub-cluster in the OMC.

2. The *Chandra* Orion Ultradeep Project (COUP)

COUP is a large collaboration of about 30 scientists (P.I. E. Feigelson), that in January 2003 obtained the longest stellar exposure ever performed with *Chandra*: 850ksec, about 10 days, of nearly continuous observation of the Orion Nebula Cloud. As many as 1616 X-ray sources were detected in the observation, 90% of which (Getman *et al.* 2005a) are associated with young stars in Orion Molecular Cloud, either belonging to the foreground ONC population or to the more embedded population within the OMC-1. The data analysis, source catalog and X-ray source characteristics are presented by Getman *et al.* (2005b). The result is a rich collection of spectral and temporal variability characteristics that can be exploited for a variety of goals. Twelve more studies are to appear in a special ApJ Supplement issue, covering a variety of topics, from high and intermediate mass stars to T-Tauri stars, brown dwarfs, the embedded OMC population, study of flares, X-ray rotational modulation, detection of the iron fluorescent line, etc.

3. Diffuse X-ray emission

The superb spatial resolution and sensitivity of *Chandra* has allowed for the first time the unambiguous detection of diffuse X-ray emission from a number of massive star forming regions. These include M17, the Rosette Nebula, the Arches cluster, NGC 3603,

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Trumpler 14 (see Townsley *et al.* 2003). In some cases (e.g. Trumpler 14 and NGC 2362) the observed diffuse emission can be attributed, at least in part, to supernova remnants: although important for the structure and evolution of star forming clouds, the presence of this X-ray emitting plasma is a long acknowledged consequence of the star formation process. In other cases, e.g. in M17 and in the Rosette Nebula, the X-ray emitting hot plasma is most likely produced by the interaction of the powerful winds of early O stars (<O6) with the cloud and/or with other similar winds. The resulting X-ray emission is soft, with temperatures between ∼1 MK and ∼10 MK and fills the whole cavity in the molecular cloud where the massive stars are located. In cases such as M17 the hot plasma appears to flow out of the cavity, in a sort of "X-ray fountain" (Townsley *et al.* 2003, see also contribution in this volume).

4. X-ray emission from early type stars

Early type stars have been known to be strong X-ray sources for more than 25 years (Harnden *et al.* 1979). One of the nearby regions with the largest concentration of massive stars is the Carina Nebula. In addition to η Carinae, one of the most massive stars known, it contains several massive clusters (Trumpler 14, 15 and 16), three Wolf-Rayet stars and dozens of O2-O9 stars, several of which have evolved off the main sequence. It is therefore one of the best fields in the sky for the study of massive stars and their X-ray emission. Results from two observations with present-day telescope have been published so far, one by Albacete Colombo *et al.* (2003) based on a 44ksec *XMM-Newton* observation, the second by Evans *et al.* (2003,2004) with a short (10Ksec) *Chandra* exposure. In summary, these works confirm only in part earlier results that indicated that X-ray emission from O stars was soft (kT ∼ 0.1-0.5 keV), rather constant in time and with intensity proportional to the bolometric luminosity: $L_X/L_{bol} \sim 10^{-7}$ (e.g. Berghöfer *et al.* 1997). Although most non-evolved (i.e. MS) O-type stars in the Carina Nebula have soft emission components with luminosities roughly scaling with L_{bol}, many also have a hotter component that is not generally observed in older stars of the same type and whose emission does not correlate with L_{bol}. The soft emission can be well explained by the classical Lucy & White (1980) model of small scale shocks in line driven winds (and following refinements, e.g. Owocki & Cohen 1999). The presence of the harder component however implies some additional physical mechanism, able to heat the plasma to higher temperatures. Given the fact that several O stars are found in binary system with other O-type stars, plasma heating in the wind-wind interaction zone is, depending of the wind and orbital parameters, a viable explanation (Luo *et al.* 1990; Stevens *et al.* 1992).

The hard X-ray emission from O-type stars is not unique to the Carina Nebula: some O and B stars in the ONC, as well as τ Sco have similar characteristics (Schulz *et al.* 2003). Stelzer *et al.* (2005) studied the X-ray emission of 9 O7-B3 ONC stars observed with COUP. They identify two groups: four stars have soft and constant emission, compatible with the small-scale wind shock model. The remaining five, among which the three most massive ones, show instead a combination of the characteristics of small-scale shock wind-emission and magnetically related phenomena such as flares and rotational modulation.

Evidences for a discrepancy from the classical wind shock model arises also from high resolution X-ray spectroscopy obtained with both *Chandra* and *XMM-Newton*. One of the best studied examples is the O6-7 member of the Trapezium, θ^1 Ori C, which, in addition to high plasma temperatures, also shows narrow, symmetric and non-shifted emission lines (Schulz *et al.* 2001,2003; Gagné *et al.* 2005), at odds with the prediction of classical small-scale wind shock models. These models predict that X-rays are produced in the outer wind (i.e. were the wind has reached its terminal velocity) producing wide, asymmetric and blue-shifted lines. In θ^1 Ori C, the observed hard X-ray spectrum resemble instead that of low mass coronal sources. The idea that magnetic fields may be involved in the X-ray emission of θ^1 Ori C is also suggested by the observed X-ray rotational modulation ($P_{rot} \sim 15$ days), as observed in many magnetic rotating astrophysical systems. Of particular interest is in this respect the magnetically channeled wind shock (MCWS) model, first proposed by Babel & Montmerle (1997): in the presence of an intense stellar magnetic field, assumed bipolar, the otherwise spherical wind is forced to follow the magnetic field lines and to collide with itself at the magnetic equator, producing hot and dense X-ray emitting plasma. In this scenario rotational modulation can occur in oblique rotators (such as θ^1 Ori C, for which the rotation and magnetic axes form a 42° angle) if X-rays are emitted at the magnetic equator very close to the stellar surface. A significant fraction of the emitting plasma is then eclipsed by the star when the magnetic equator is seen edge on. Whether the MCWS mechanism is at work depends of the relative strengths of the magnetic field and of the wind through the parameter $\eta = (B_{eq}^2 R_\star^2)/(\dot{M} v_\infty)$, where B_{eq} is the equatorial dipole magnetic field, $R_\star$ the stellar radius, $\dot{M}$ the wind mass-loss rate and v_∞ the wind terminal velocity. Gagné *et al.* (2005) have recently published new model calculations. Using independently measured stellar parameters as inputs for their MCWS model, they compare the model results with four *Chandra* HETG high resolution spectra taken at four different phases in the rotation cycle of θ^1 Ori C. They find good agreement in the X-ray luminosity, plasma temperature, modulation amplitude, line widths and profiles, and distance of the emitting plasma from the stellar surface.

The MCWS model thus appears promising for explaining X-ray emission in O-type stars with magnetic fields. The scatter in L_X observed for stars with the same spectral type may be ascribed to a scatter in magnetic field strengths. However the MCWS model is not likely to account for all the discrepancy of the observational data with respect to the Lucy & White (1980) small scale wind shock model: as noted above in the case of binary systems X-ray emission from wind-wind collisions can also be important.

5. Intermediate mass stars

Ever since the early observations performed with *Einstein* (Caillault & Zoonematkermani, 1989), the X-ray properties of intermediate mass, late B and A stars, have been confusing. Simple theoretical considerations suggest that they should not be X-ray emitters: they lack the strong winds that are responsible for the X-ray emission of earlier type stars and, lacking a convective layer (according to current models) they should not be able to sustain a dynamo, which is held responsible for the presence of an X-ray emitting corona around low mass stars. Nevertheless, a substantial number of intermediate mass stars were detected in X-rays. However, because of the low spatial resolution of the X-ray telescopes used, some doubts remained as to the correct identification of the X-ray sources: it was speculated that the X-ray sources might instead be cool coronally active companions to the intermediate-mass stars.

Recent high spatial resolution *Chandra* observations have indeed verified the companion hypothesis in a number of cases (Stelzer *et al.* 2003). However other cases are less clear, as their X-ray emission cannot be explained by any *known* companions. This is especially true for the youngest A and B stars still surrounded by accretion disks, i.e. the Herbig Ae/Be stars, for which magnetic fields have been measured and X-ray emission has been suggested to originate in star-disk magnetic interactions (Hamaguchi *et al.* 2005). It is however worth noting that the multiplicity of these stars has not been well studied. Stelzer *et al.* (2005) have addressed the issue of emission from intermediate mass stars using COUP data. They analyze the characteristics of nine O7-B3 (see above), and 11 B5-A9 stars. Even though seven of the stars in the latter group are detected, the overall characteristics of their X-ray emission, such as luminosity, spectra and variability, are compatible with it originating in unseen lower mass companions. The multiplicity status of these stars is currently unknown.

6. T-Tauri stars

The X-ray emission from T-Tauri stars has so far escaped full understanding. Their thermal X-ray spectra and flare-dominated variability point toward an origin similar to that believed to explain activity on MS stars: a solar-like corona in which hot plasma is confined, structured and heated by dynamo-generated magnetic fields. For main sequence stars the principal evidence that the ultimate responsible for activity is the stellar dynamo rests on the activity-rotation or activity-Rossby number relations† (Noyes *et al.* 1984, Pizzolato *et al.* 2003): stars with shorter rotation period (P_{rot}) or smaller Rossby number (R_0) have higher X-ray luminosity, both in absolute terms (L_X) and relative to their bolometric luminosity (L_X/L_{bol}). At small values of R_0, MS activity is seen to saturate at $L_X/L_{bol} \sim 10^{-3}$, and at even smaller values a so called "supersaturation" regime is likely observed, characterized by a direct relation between L_X/L_{bol} and R_0. The physics of the saturation and supersaturation regimes are not understood.

Figure 1a, from Preibisch *et al.* (2005), shows the L_X/L_{bol} vs. P_{rot} plot for ONC stars (COUP data) and MS stars (Pizzolato *et al.* 2003, Messina *et al.* 2003). The ONC T-Tauri stars do not follow the same relation as MS stars. Most of them appear to have high activity levels, close to saturation but with a large scatter. Plots like that shown in Figure 1a have questioned the applicability of the dynamo paradigm to T-Tauri stars. However the relation of activity with Rossby number (as opposed to P_{rot}) has not often been investigated for PMS stars, mostly because of the difficulty of estimating the convective turnover time, τ_c, at the base of the convective layer. On one hand this estimate has to rest on theoretical models of convection, one of the least understood ingredients in stellar structure models; on the other hand most low mass T-Tauri stars are believed to be fully convective and there is no base of the convective layer! In spite of these problems Preibisch *et al.* (2005) computed the Rossby number using the Yale evolutionary models (Yi *et al.* 2001) and computing τ_c at the stellar center for fully convective stars. The result is the plot in Figure 1b, where the locus of ONC stars in the $\log L_X/L_{bol}$ vs. $\log R_0$ plane is compared with the typical location of MS stars (shaded area). Owing to the large values of τ_c at early ages, it appears that T-Tauri stars have Rossby numbers at which they should be saturated or supersaturated. The lack of an activity-rotation relation is therefore explained. However activity is *not* at the saturation level, but shows a large scatter. The most likely explanation for this scatter is accretion. Flaccomio *et al.* (2003a) and Preibisch *et al.* (2005) find that while non accreting stars (WTTS) have activity levels which are quite compatible with the saturation level, stars with signatures of circumstellar accretion (CTTS) have lower activity levels on average and present a larger scatter in L_X or L_X/L_{bol} at any value of other stellar parameters. The same results was obtained by Flaccomio *et al.* (2003b) for stars in NGC 2264 and in the Chamaeleon I region. Previous similar results by Damiani & Micela (1995) and

† The Rossby number is defined as the ratio of the stellar rotation period over the convective turnover time, τ_c, at the base of the convective layer. It is a measure of the dynamo efficiency.

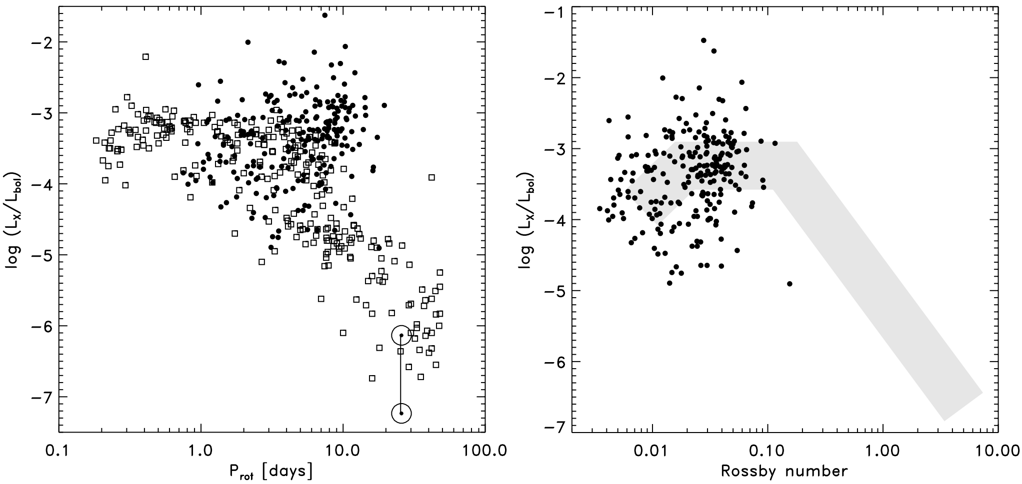

Figure 1. Figures from Preibisch *et al.* (2005). a)[left]: L_X/L_{bol} vs. P_{rot} for MS stars (empty squares; data from Pizzolato *et al.* 2003, Messina *et al.* 2003) and for ONC T-Tauri stars. b)[right]: L_X/L_{bol} vs. Rossby number for ONC T-Tauri stars. The shaded area indicates the locus of MS stars.

Stelzer & Neuhäuser (2001) for the Taurus region had either been questioned because of the small statistics or interpreted in terms of other correlations.

It thus appears that circumstellar accretion depresses, on average, X-ray activity in T-Tauri stars. On the other hand there are also evidences that circumstellar accretion can induce X-ray emission through different mechanism than those possible in isolated stars. *Chandra* and *XMM-Newton* high resolution X-ray spectra of the only two CTTS for which such data have been published, TW Hydra (Kastner *et al.* 2005; Stelzer & Schmitt 2004) and BP Tau (Schmitt *et al.* 2005) have revealed significant differences with respect to the emission of WTTS. In both cases the f/i ratio of forbidden to intercombination lines of He-like ions, which is sensitive to plasma density and/or UV flux, indicates that a substantial fraction of the emission originates close to accretion shocks. Although the statistics is so far limited, it appears that some additional contribution to the coronal X-rays may therefore come from X-rays produced in the accretion shock.

There is also new indirect evidence that the presence of a circumstellar disk can substantially modify the geometry of the X-ray emitting coronae. Favata *et al.* (2005) analyze in detail several bright flares observed in the COUP dataset. The decay phase of flares has long been used to estimate the sizes of the magnetic loops responsible for these events. Results of such modeling, when taking into account the possibility of non-impulsive heating of the loop, have always indicated rather compact structures, qualitatively similar to those observed on the Sun. Favata *et al.* (2005) interestingly find for the first time that some of the most powerful events observed in ONC T-Tauri stars can only be explained assuming loops with lengths of tens of stellar radii. These long magnetic structures are best understood by assuming that they extend from the stellar surface to the inner edge of the circumstellar disk. This sort of magnetic structures are predicted by current models of magnetically channeled accretion.

It is important to keep in mind that the previous result only applies to a few selected flares that were powerful enough to be modeled in detail, while for the vast majority of flares seen in the COUP data no such analysis could be performed. We can then wonder whether the X-ray emission of CTTS is actually *dominated* by these long loops

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or whether these are rare events. The first possibility appears unlikely, given other evidence that points toward more compact coronae. Flaccomio *et al.* (2005) exploit the exceptional length of the COUP observation (13 days) to study X-ray rotational modulation in sample of 233 ONC stars whose rotation period is known from optical studies. Notwithstanding the numerous difficulties in detecting a periodic signal in light curves only slightly longer than the typical rotation period and in the presence of frequent flares, rotational modulation is detected in at least 10% of the studied sample. This implies that (1) X-ray emission is not uniformly distributed in longitude, (2) emitting structures are compact with sizes $< R_\star$, or they would not undergo self eclipse.

The tentative picture that emerges for activity on T-Tauri stars is that of a solar-like corona which, in the absence of accretion, emits at the saturation level, in agreement with the activity-Rossby number relation observed for MS stars. The presence of an accretion disk, magnetically connected with the star, modifies the structure of the unperturbed corona in such a way as to lower X-ray emission, but also induces X-ray emission from the accretion shock and from magnetic reconnections in long star-disk loops.

While accretion disks seem to sensibly influence X-ray emission of T-Tauri stars, the opposite seem also to be true. X-rays are likely the most important source of ionization of the circumstellar material, and may therefore play a role in regulating processes such as mass accretion onto the central object and planet formation (Glassgold *et al.* 2000, 2004; Wolk *et al.* 2005). The chemistry of circumstellar disks can also be influenced by X-rays. Finally if, like on the sun, flares are associated with production of energetic particles, the observed flare characteristics of "young" Suns (Wolk *et al.* 2005) can account for many of the isotopic anomalies that are observed in meteors. Direct evidence of the ionization of disk material by stellar X-rays comes from the detection of the Fe 6.4keV fluorescent line in several young stellar objects: Imanishi *et al.* (2001) find such evidence on YLW 16A, a class I protostar in ρ Ophiuchi. Tsujimoto *et al.* (2004), using the COUP dataset finds 7 more examples in the ONC and convincingly argues that the 6.4keV line must result from the fluorescence of stellar X-rays on the circumstellar disk surface. Kastner *et al.* (2005), again using COUP data for the study of "proplyds" in the Trapezium finds at least one case of a nearly edge-on disk, as determined in the HST images, trough which we see the stellar X-ray emission, absorbed by a column density as large as $n_H = 6 \cdot 10^{23}$ cm^{-2} ($A_V \sim 300$). This observation clearly indicates that X-rays can penetrate deep into circumstellar disks; on the other hand the measured column density is too low for standard disk models with ISM metal abundances, possibly indicating that the disk has undergone substantial gas-phase metal depletion.

7. X-ray selection of star forming region members

As argued in the introduction, X-ray detection is one of the most effective way to select PMS members of a star forming region. I now give three examples to demonstrate this point. First two star forming regions, NGC 2264 and NGC 6530, for which the low mass stellar census, as determined with classical methods, in certainly incomplete. The third example regards the deeply embedded population of the Orion Molecular Cloud, as investigated with the COUP dataset.

7.1. *NGC 2264 and NGC 6530*

NGC 2264 is a medium mass star forming region at a distance of ~760pc, hosting the O7 star S Mon. Its total stellar mass and density seem to be intermediate between that of the ONC and the lower mass regions in the solar neighborhood such as Taurus and Chamaeleon I. It is therefore of interest for studies of the influence of the environment

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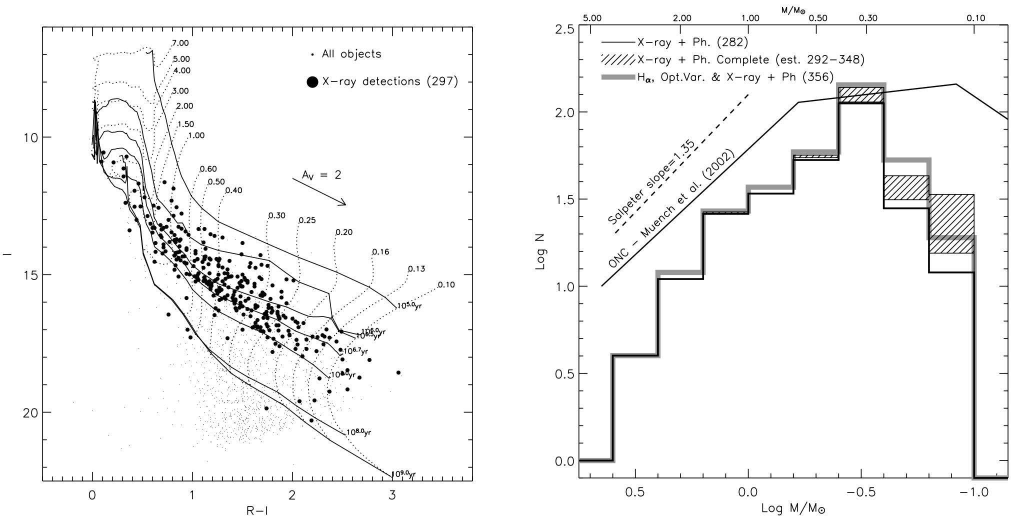

Figure 2. a)[left]: Color-magnitude diagram of: 1) all the objects in the FOV of the *Chandra* ACIS observation of NGC 2264 discussed in §7; 2) counterparts of X-ray sources. Note how the X-ray sources trace the expected cluster locus. b)[right]: The resulting IMF, as determined by Flaccomio *et al.* (2005) using X-ray sources as the member sample (black line), corrected for incompleteness (shaded area), and adding to the X-ray sources other likely members selected on the basis of H_α and optical variability (Lamm *et al.* 2004).

on the star formation process and early evolution of young stellar systems. Flaccomio *et al.* (2005) have analyzed a *Chandra* ACIS observation of a $17' \times 17'$ field in the region. Another similar field has been studied by Ramírez *et al.* (2004). In the former field 420 X-ray sources are detected, the most part of which are associated with low mass NGC 2264 members. Figure 2a shows the optical color magnitude diagram for all stars in the *Chandra* FOV and for counterparts of X-ray sources. Note how the latter sample is located preferentially where cluster members with an age of 1-10 Myr are expected to lie. Contamination from MS/giant background and foreground stars appears to be very small among the X-ray sources. It can be further minimized by excluding the handful of X-ray sources that lie below the "cluster locus". Figure 2b shows the mass distributions resulting from this X-ray selected sample (∼280 stars) and from the same complemented with ∼70 other members selected on the basis of H_α and optical variability as determined by Lamm *et al.* (2004). Note that this latter sample, mostly CTTS, gives a significant contribution at low masses, where the X-ray observation is not sensitive enough to detect all the CTTS (see §6). Also shown is the completeness corrected IMF, as derived from the X-ray sample assuming that stars in NGC 2264 have the same X-ray luminosity function as in the ONC. The completeness corrected IMF and the "X-ray+H_α+variability" IMF agree quite well indicating that we have selected a reasonably complete sample of stellar mass members. Comparing this IMF with that derived for the ONC by Muench *et al.* (2002) we note that NGC 2264 appear to have a smaller fraction of very low mass stars.

NGC 6530, associated with the M8 (Lagoon) Nebula, is with respect to the ONC, a much more massive star forming region. It contains 3 O stars and about 60 B stars (the ONC has ∼15 OB stars). Like NGC 2264 it is therefore an interesting target to investigate the dependence of the star formation process on the environment. Its low mass population was, until recently, very poorly determined. Damiani *et al.* (2004) have observed the region with *Chandra* ACIS for 60ksec. They detect about 900 X-ray sources

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and from a comparison off-cluster observation they determine that ∼90% of them are associated with cluster members. Combining the member list with deep optical photometry (Prisinzano *et al.* 2005), a systematic study of star formation in NGC 6530 was initiated. Among the first results are a better determination of the cluster distance (1.25 Kpc), the determination of the median members age (2.3 Myr), the discovery of sequential star formation as indicated by the younger stellar ages in the southern part of the field, and, finally, the determination of the IMF down to $0.4M_\odot$

7.2. *The BN-KL and OMC-1South regions*

The BN-KL region, located behind the 1Myr old ONC cluster inside the OMC-1 cloud is a bright IR source ($\sim 10^5 L_\odot$), the closest known region of high mass star formation, and quite certainly the most studied molecular hot core. OMC-1S, about 90" south of BN-KL, is the second density peak in the OMC-1, with roughly 10% of the luminosity of BN-KL. Both regions are very complex with several embedded sources, many Herbig-Haro objects, ultracompact H II regions and maser outflows. Grosso *et al.* (2005) have investigated the stellar population of the two regions based on the deep COUP X-ray observation. One hundred and five sources are detected in the two region, about 60 so which are very absorbed, with absorption column densities, n_H, between 10^{22} and 10^{24} cm^{-2} (corresponding to $A_V \sim 500$!). They therefore are members of the embedded molecular cores†, while the less embedded sources are associated with the foreground ONC cluster. Twenty-two of these sources are not detected in very deep VLT K-band photometric data and are therefore likely associated with Class I/0 young stellar objects. In the BN-KL region, X-ray sources close to BN, IRc3-i2, IRc2-C, and source 'n' were detected. The spectral and variability characteristics of the X-ray emission from these sources are more similar to those of T-Tauri stars rather than to those of massive stars (see §4 and §6), so that the observed emission might be due to low mass companions rather than to the high mass protostars. Note however that there is considerable uncertainty on the X-ray emission of massive protostars. The COUP source close to BN shows a periodicity of ∼8.3days, which is the same as the periodicity observed for BN in the NIR. However, because of the large offset from the radio position of BN (0.9") this source is not BN, but likely a low mass companion; there is instead evidence of a faint source in the wings of the brighter one that lies at only 0.4" from BN and which could be either another low mass companion or BN itself. Note that the presence of a physical companion, if confirmed, would pose a problem for the scenario that wants BN to have been ejected in a three body encounter (Tan 2004). The radio source I, considered one of the main source of luminosity in the BN-KL region is not detected.

Finally, comparing the X-ray luminosity functions of sources in BN-KL and in the OMC-1S regions with that of the unabsorbed ONC population, Gagné *et al.* (2005) estimate the total stellar population in the two regions. They find that, in spite of the factor of 10 difference in IR luminosities, the expected population is very similar, ∼50 stars in both cases, maybe indicating a difference in the IMFs or in the evolutionary stages.

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† Field star and extragalactic contamination are negligible because of the small FOVs

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