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The Chandra View of the Very Young Cluster IC 348

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Abstract. We summarize some of the initial results of a deep (53 ksec) X-ray imaging study of the very young stellar cluster IC 348 with the Advanced CCD Imaging Spectrometer on board the *Chandra X-Ray Observatory*. Our image with a sensitivity limit of $\sim 1 \times 10^{28}$ erg/sec reveals 215 X-ray sources. About 80% of all cluster members known from optical/infrared spectroscopic studies which have masses between $\sim 0.15\,M_\odot$ and $2\,M_\odot$ are detected as X-ray sources. We discover X-ray emission at levels of $\sim 10^{28}$ erg/sec from 7 of the known brown dwarfs and brown dwarf candidates in IC 348. The X-ray properties of the brown dwarfs are similar to those of late M-type field stars, suggesting that the X-ray emission of the sub-stellar objects originates from a hot corona.

1. Introduction

IC 348 is a very young ($\sim$ 1.5 Myr) stellar cluster located near the eastern edge of the Perseus molecular cloud complex (distance $\sim$ 310 pc) and is still embedded in its parental molecular gas cloud. For a long time, the cluster was believed to consist of just a dozen T Tauri members (Herbig 1954), but recent sensitive optical (Herbig 1998 [H98 hereafter], Scholz et al. 1999), near-infrared (Lada & Lada 1995; Luhman et al. 1998 [L98 hereafter]; Luhman 1999 [L99 hereafter]; Najita et al. 2000 [N00 hereafter]), and ROSAT X-ray observations (Preibisch, Zinnecker, & Herbig 1996) have shown that IC 348 contains at least a few hundred stars.

2. Chandra Observations and Data Analysis

The Chandra observation of IC 348 was performed on 25 September 2000 utilizing the Advanced CCD Imaging Spectrometer ACIS in its imaging configuration. The total exposure time was 52 956.8 sec (14.7 hours). Our ACIS image of IC 348 is shown in Figure 1. Utilizing the WAVDETECT source detection program we could identify a total of 215 individual X-ray sources in our image.

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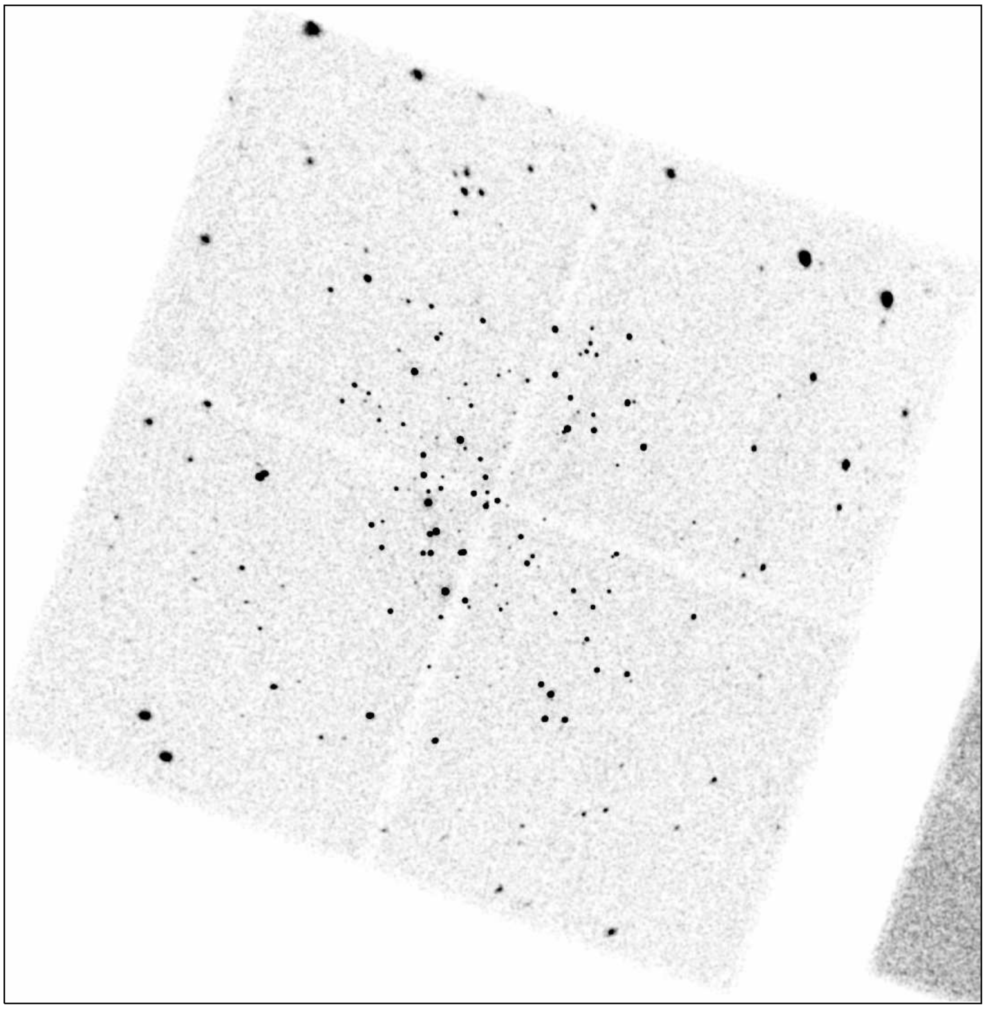

Figure 1. Full ACIS-I image of IC348. The field of view is $17' \times 17'$, the image was smoothed with a Gaussian function with a FWHM of $1.5''$.

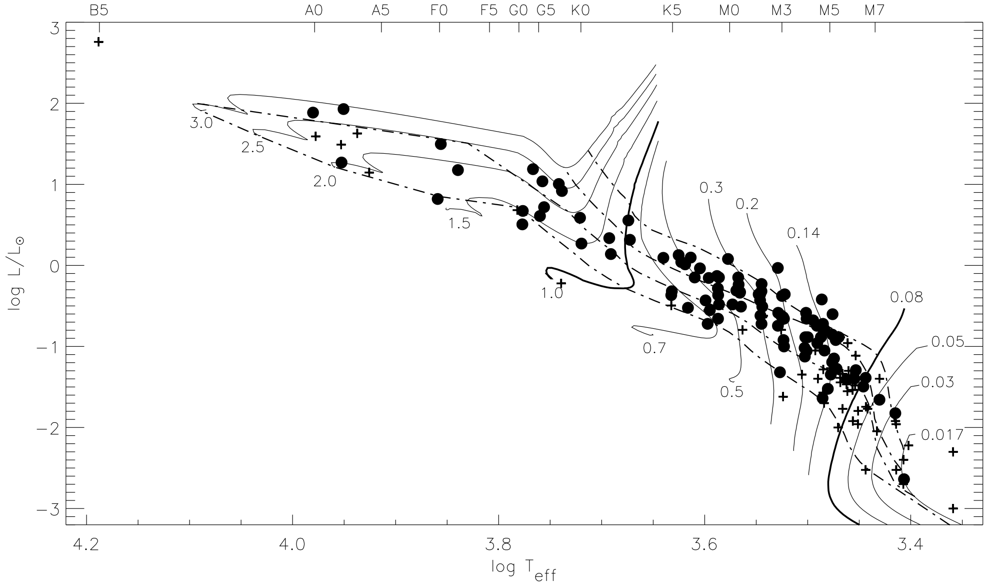

Figure 2. HR diagram of IC 348 based on the data for stars listed in L98 and L99. X-ray detected objects are plotted as solid dots, non-detected objects as crosses. The solid lines show the evolutionary tracks of the D'Antona & Mazzitelli (1997) PMS models for masses between $0.017\,M_\odot$ and $3\,M_\odot$. The evolutionary tracks for $0.08\,M_\odot$ and for $1\,M_\odot$ are plotted as thick lines. The dashed-dotted lines show isochrones for the ages of 3×10^5 yr, 1×10^6 yr, 3×10^6 yr, and 1×10^7 yr.

3. Results

Here we can only provide a short summary of our results, and briefly discuss the X-ray detections among the very-low mass objects. A detailed description of all the results of our study can be found in Preibisch & Zinnecker (2001a,b).

172 X-ray sources can be identified with optical or infrared counterparts. 40 X-ray sources have no counterpart down to $K \sim 14.3$; these objects are most likely not stellar cluster members but (probably extragalactic) background objects. Cross-correlation of our X-ray source list with a catalogue of optical/infrared cluster members shows that 115 of the 175 known cluster members in the field of view of our Chandra image are detected as X-ray sources. We detect the population of cluster members with spectral types between F and M4, i.e. stellar masses between $\sim 3\,M_\odot$ and $\sim 0.2\,M_\odot$, with a completeness of $\sim 80\%$ (see Fig. 2). For spectral types later than M4 ($M_\star < 0.2\,M_\odot$), the detection frequency drops sharply to $\sim 30\%$; this drop corresponds to the sensitivity limit of our image.

3.1. X-ray emission from very-low mass stars and brown dwarfs

Up to now, X-ray emission has been detected from only very few brown dwarfs. (Neuhäuser et al. 1999; Rutledge et al. 2000; Garmire et al. 2000) An open question is whether, and if so, *how* brown dwarfs can sustain an X-ray emitting, hot corona, as they are fully convective and therefore a standard solar-like α-Ω dynamo cannot work.

The studies of Luhman (1999) and Najita et al. (2000) have revealed several very-low mass objects in IC 348. One major uncertainty in the study of these objects lies in the estimation of their masses. For the classification of the very-low mass objects in IC 348 we therefore adopt the following, rather conservative scheme: An object is classified as a *brown dwarf* (BD) if all available mass determinations with the different theoretical models yield a value below $0.075\,M_\odot$. Otherwise, it is classified as a *brown dwarf candidate* (BDC). Using this classification, there are 13 BDs and 12 BDCs in IC 348.

Two of these objects can immediately be identified with detected X-ray sources. These are the BD 042-03 (M-subtype=7.6) and the BDC 045-02 (M-subtype=7.1) from N00. For the other objects we have performed a detailed investigation of the corresponding positions in our Chandra image. For each object we extracted the detected counts in a source region centered at its optical position and a corresponding background region. We used the Bayesian statistics method described by Kraft et al. (1991) to infer the probability for the existence of an X-ray source. Cases with $P > 0.995$ were considered as detections, in the other cases we determined the 90% confidence upper limits for the number of source counts. In addition to the two objects mentioned above, we detected a significant number of counts at the positions of 2 BDCs and 3 BDs. From the source count rates (or count rate upper limits) of these objects we computed their X-ray luminosities (or upper limits) in the [0.2 – 8] keV band using the individual extinctions of the objects and assuming a thermal plasma spectrum with $kT = 1$ keV as typical for young objects (cf. Preibisch 1997). The resulting X-ray luminosities of the 4 X-ray detected BDs and the 3 X-ray detected BDCs range from 8×10^{27} erg/sec to 3.6×10^{28} erg/sec. In Fig. 3 we compare their X-ray- and bolometric luminosities to those of other X-ray detected BDs and nearby very-low mass (fully convective) stars. The typical fractional X-ray luminosities of the BDs, $(L_\mathrm{X}/L_\mathrm{bol}) \sim 10^{-4} \ldots 10^{-3}$, are quite similar to those of the very-low mass stars. The observed $(L_\mathrm{X}/L_\mathrm{bol})$ ratios are also basically the same as typically found for coronally active, fully convective very-low mass stars. This suggests an coronal origin of the X-ray emission from the BDs. The nature of the underlying coronal heating mechanism is unclear. While solar-like dynamo activity is not possible in fully convective stars and BDs, non-standard dynamo mechanisms might be at work. One possibility seems to be small-scale dynamo action in a highly turbulent convection zone (cf. Giampapa et al. 1996 and references therein). Another possibility might be an α^2-dynamo as suggested by Küker & Rüdiger (1999) for the magnetic field generation in fully convective stars.

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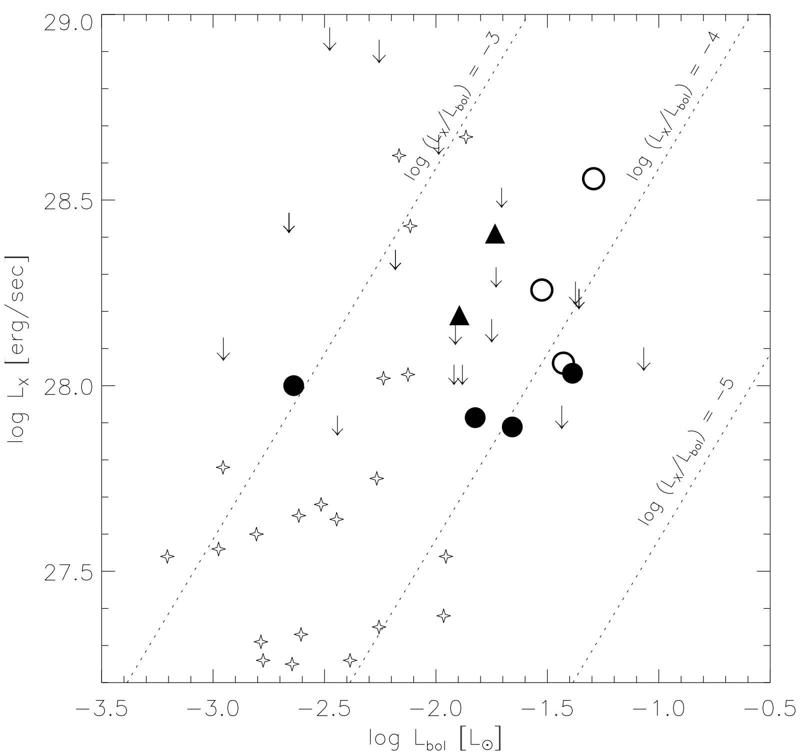

Figure 3. X-ray and bolometric luminosities for BDs and BD candidates. X-ray detected BDs in IC 348 are shown as big solid dots, X-ray detected BD candidates in IC 348 as open circles. Upper limits for the undetected BDs and BDCs in IC 348 are shown as downward pointing arrows. The X-ray detected BDs Hα1 and GY 202 from Neuhäuser et al. (1999) are shown as solid triangles. In addition, the asterisks show data for nearby dwarfs (spectral type M5 or later) from Giampapa (1996) and Fleming et al. (1995).

References

Fleming, T.A., Schmitt, J.H.M.M., & Giampapa, M.S., 1995, ApJ 450, 4 01

Garmire, G., Feigelson, E.D., Broos, P., Hillenbrand, L.A., Pravdo, S.H., Townsley, L., & Tsuboi, Y., 2000, AJ 120, 1426

Giampapa, M.S., Rosner, R., Kashyap, V., Fleming, T.A., Schmitt, J.H .M.M., & Bookbinder, J.A., 1996, ApJ 463, 707

Haisch, K.E., Lada, E.A., Pina, R.K., Telesco, C.M., & Lada, C.J., 2001a, AJ 121, 1512

Haisch, K.E., Lada, E.A., & Lada, C.J., 2001b, AJ 121, 2065

Herbig, G.H., 1954, PASP 66, 19

Herbig, G.H., 1998, ApJ 497, 736 [H98]

Kraft, R.P., Burrows, D.N., & Nousek, J.A., 1991, ApJ 374, 344

Küker, M., & Rüdiger, G., 1999, A&A 346, 922

Luhman, K.L., Rieke, G.H., Lada, C.J., & Lada, E.A., 1998, ApJ 508, 347 [L98]

Luhman, K.L., 1999, ApJ 525, 466 [L99]

Najita, J.R., Tiede, G.P., & Carr, J.S., 2000, ApJ 541, 977 [N00]

Neuhäuser, R., & Comeron, F., 1998, Sci 282, 83

Neuhäuser, R., et al., 1999, A&A 343, 883

Preibisch, Th., 1997, A&A 320, 525

Preibisch, Th., Zinnecker, H., & Herbig, G.H., 1996, A&A 310, 456

Preibisch, Th., Zinnecker, H., 2001a, AJ 122, 866

Preibisch, Th., Zinnecker, H., 2001b, in preparation

Rutledge, R.E., Basri, G., Martin, E.L., & Bildsten, L., 2000, ApJ 538, L141

Scholz R.D., Brunzendorf J., Ivanov G., Kharchenko N., Lasker B., Meusinger H., Preibisch Th., Schilbach E., Zinnecker H., 1999, A&AS 137, 305