MULTIWAVELENGTH ANALYSIS OF THE YOUNG OPEN CLUSTER NGC 2362

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ABSTRACT

We present a multiwavelength analysis of the young open cluster NGC 2362; $UBVRI_{C11}$ CCD photometric observations, together with available data in the Chandra database, near-infrared data from the Two Micron All Sky Survey (2MASS), and recently published H$\alpha$ spectroscopy were used to get information about the evolutionary stage of the cluster and the main physical properties of its stellar content. Cluster membership is estimated for every individual star by means of zero-age main sequence (ZAMS) and isochrone fitting. The cluster is confirmed to host a rich population of pre–main-sequence (PMS) objects and to contain a large number of X-ray-emitting stars, which reach from the PMS members of GK spectral type up to the most luminous OB main-sequence (MS) members. The PMS cluster members show no significant age spread, and the comparison to both PMS and post-MS isochrones suggests an homogeneous age for all cluster members. The analysis allows us to assess the validity of currently used PMS evolutionary models and supports the suggestion of a well-defined positive correlation of the X-ray emission from PMS stars with their bolometric luminosity. Clear differences are found between the X-ray activity properties of MS and PMS cluster members, both in the relation between X-ray luminosity and bolometric luminosity, and in spectral properties as well.

Subject headings: open clusters and associations: individual (NGC 2362) — stars: pre–main-sequence

Online material: machine-readable table

1. INTRODUCTION

The young open cluster NGC 2362 has been the subject of recent attention from several authors as an adequate object for the study of star formation processes (Moitinho et al. 2001; Haisch et al. 2001; Dahm 2005, hereafter D05). Located in the third Galactic quadrant, it is little affected by reddening and, despite its youth, shows a relative absence of intracluster material (Balona & Lane 1996). This allows the observation of its stellar population in a wide range of masses, from the low-mass PMS stars to massive OB stars populating the upper part of the color-magnitude (CM) diagram.

The photometric observations of NGC 2362 were carried out in the framework of a current project devoted to detect and study pre–main-sequence (PMS) stars among the members of young open clusters. This project is based on optical $UBVRI$, and eventually H$\alpha$, observations of Galactic clusters, in the age range between 1 and 10 Myr, and located at distances from the Sun not farther than 3–4 kpc. These constraints should result in objects with observable PMS members of spectral types from A to K, detectable in photometric diagrams deep down to $V = 21–22$, depending on reddening. These observations are feasible with small telescopes and can be obtained for a wide sample of clusters located in the regions of active and recent star formation in the vicinity of the Sun. A presentation of the results obtained up to now in this project will be the subject of another paper.

On the other hand, the investigation of X-ray emission from PMS stars received increasing attention in recent years after the new space missions were able to provide measurements of high spectral and spatial resolution. As a consequence, the debate about the physical mechanisms that originate this activity has gained in richness and insight (see Preibisch et al. 2005 and references therein). In this paper we collect $UBVRI_{C11}$ CCD photometry of our own, X-ray data on sources detected in the field by the Chandra Advanced CCD Imaging Spectrometer (ACIS), $JHK$ photometry from the 2MASS database, and H$\alpha$ emission and Li absorption from PMS cluster members (D05) in order to analyze the evolutionary stage of the cluster members and its connection with the X-ray activity.

2. THE DATA

The optical observations were secured during two nights in 2000 December at the Cerro Tololo Inter-American Observatory with the YALO 1 m telescope. Several frames, in a field of $10' \times 10'$ around the cluster, were obtained with short and long integration times in each of the $UBVRI$ bands. The frames were reduced using the standard routines in the IRAF package, and final instrumental magnitudes were obtained as weighted averages of the magnitudes in all frames. Standard $UBV$ colors were obtained through direct correlation of our instrumental magnitudes with published photometry, taken from the WEBDA database; $R_{C11}$ photometry is calibrated with the measurements of 23 standard stars in the Landolt Catalogue (Landolt 1992). The rms deviations of the residuals in these calibrations are an estimate of their uncertainty. They amount to 0.03, 0.04, 0.06, 0.03, and 0.04, respectively, in $V$, $(V-B)$, $(B-V)$, $(V-R)$, and $(V-I)$. The total uncertainties of the final values for individual stars are estimated as the squared

1 See http://cxc.harvard.edu/cda/.
2 See http://www.ipac.caltech.edu/2mass/.
3 YALO is the Yale, AURA, Lisbon, Ohio consortium (Bailyn et al. 1999); see http://www.astronomy.ohio-state.edu/YALO/.
4 The Image Reduction and Analysis Facility (IRAF) is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc. (AURA), under cooperative agreement with the National Science Foundation.
5 See the WEBDA database at http://www.univie.ac.at/webda/.
averages of all errors in our photometry: point-spread function and eventually aperture correction errors, and the quoted rms deviation of the residuals in the corresponding standard calibrations.

As mentioned above, these observations are included in a long-term search for PMS stars in young open clusters. A thorough presentation of the southern clusters observed in this program will be the subject of a forthcoming paper. This publication will also include the photometric catalog of all observed objects.

The pixel coordinates of our catalog were transformed to equatorial coordinates with the IRAF tasks eclip and xy2red, using matching files with stars in the 2MASS catalog. The matching provides UBVR_c(JHK) photometry for 725 stars. Among them, 551 have photometric quality flag A–D in all three JHK bands.

Data from Chandra ACIS in the field of NGC 2362 have been retrieved from the public data archive. NGC 2362 was observed with the Chandra X-Ray Observatory on UT date 2003 December (ObsID 4469). These data have been recently reported by Damiani et al. (2005). The data set was filtered using the light curve in the 0.5–8 keV band ACIS-S CCD. The CIAO 1c_clean tool was used to remove flare periods. The total exposure time, after removing periods containing flares, is 92.7 ks. The CIAO celldetect source detection routine was then used on the level 2 event data to produce a list of point sources. Cell sizes between 4 and 8 pixels were used. We have detected 231 X-ray point sources in the ACIS CCD in the range between 0.5 and 8.0 keV band. In this context, we quote here previous X-ray observations with ROSAT, which overlap with our field (Berghofer & Schmitt 1998). The spatial resolution of these observations is, however, much lower, and any meaningful comparison with the source catalog extracted from the Chandra observations is not possible.

The ACIS field of view in the Chandra observations covers 56% of the field in our UBVR_c(JHK) observations. Matching with the 2MASS coordinates resulted in the identification of optical counterparts for 152 sources. Of these, 127 fall in the region of the V, (B−V), and (V−I) CM diagrams occupied by the cluster members.

Finally, a recently published photometric and spectroscopic study of the cluster (D05), includes equivalent widths of Hα in emission for 99 stars in common with our photometric catalog. Sixty-nine of these stars also had measured equivalent widths in the absorption line of Li i at 6708 Å.

In the following, we consider in our analysis those stars classified as cluster members, on the basis of our optical photometry (see below), and with values in at least one of the databases used.

3. ANALYSIS

3.1. Optical Photometry

Distance, color excess, and cluster membership were determined with the procedure designed by Delgado et al. (1998). Briefly, using the ZAMS line (Schmidt-Kaler 1982) we calculated values of color excess E(B−V), visual absorption AV = 3.1E(B−V), and absolute magnitude MV for all possible main-sequence (MS) cluster members. A plot of V−AV versus MV allowed us to establish membership of evolved and unevolved MS members, and to discard possible nonmembers. Thirty stars were selected as MS members. The mean values of color excesses and distance moduli for the unevolved members were then used as reference values to analyze membership of the remaining stars.

We obtained E(B−V) = 0.12 ± 0.04, V0 − MV = 10.78 ± 0.15. The quoted errors are the rms deviations of the mean. These values coincide well with those given in previous studies (Johnson & Morgan 1953; Perry 1973; Balona & Lane 1996).

In this process, for every star we compute several values of the color excess and of the distance modulus by ZAMS fitting, and also the values obtained by comparison to theoretical PMS isochrones. In the absence of phenomenological reference lines for PMS stars, of the type of observational ZAMS, PMS isochrones are used to assign probable membership of each star. In particular, the values for the fainter stars, which do not have (U−B) color indices, are shifted assuming those values of color excess and distance modulus in every CM diagram. A star is considered as a member when the shifted values coincide (within the errors) with one isochrone, in at least two CM diagrams.

In this calculation, we used three sets of PMS isochrones by D’Antona & Mazzitelli (1997, hereafter D97), Palli & Stahler (1999, hereafter P99), and Siess et al. (2000, hereafter S00) for ages between 1 and 10 Myr. The theoretical isochrones by D97 and P99 were transformed to the observational CM diagrams with the calibrations by Kenyon & Hartmann (1995). A total of 276 stars were selected as PMS cluster members, with respect to at least one of the three isochrone sets used.

Because of the larger photometric errors for fainter stars, most of the PMS candidates are selected as members with respect to several isochrone lines. The average value of their corresponding ages provides a formal age for every assigned PMS member star, and the median of all members is adopted as the age of the PMS cluster sequence. The resulting ages for the three sets of isochrones were 4.3 ± 2.6, 6.0 ± 2.4, and 5.9 ± 2.1 Myr for D97, P99, and S00 isochrones, respectively. These values indicate coincidence of ages within the uncertainties and little age spread among PMS cluster members.

The plot in Figure 1 shows post-MS isochrones for 4 and 10 Myr from the Padova group (Girardi et al. 2002) and PMS isochrones for 1 and 10 Myr (D97, P99, S00) in the V, (V−I) CM diagram. The stars classified as members by the fittings described above are marked with larger dots, while those found to be optical counterparts of detected X-ray sources, as well as those in common with the ZAMS study by D05, are marked with plus signs and squares, respectively. We remark that 85% of the detected X-ray sources, with optical counterparts in the appropriate range of color and magnitudes, are selected as members by our procedure, and 66 out of 80 stars with Hα emission in the overlapping field and adequate magnitude range turn out to be assigned PMS members (in particular, 50 out of the 58 stars with both X-ray detection and Hα emission). The good agreement between these independent criteria of both the PMS nature of the stars and membership to the cluster shows the reliability of the membership classification by the procedure of isochrone fitting used—similar to the ZAMS fitting procedure commonly used to estimate distances for MS stars.

The relation of ages determined from PMS and post-MS isochrones, and the possible age spread among PMS cluster members, are addressed in almost every investigation dealing with PMS stars in young clusters, and the evidences are not conclusive in either sense. In our case, no significant age spread is found among PMS cluster members, although different values are found from the comparison to different PMS models. On the other hand, the visual comparison to post-MS isochrones, plotted in Figure 1, suggests an upper limit of 4 Myr for the most massive MS cluster members, a value of the same order of the lowest one calculated for PMS members, with the D97 isochrones. This could suggest a younger age for MS stars than for PMS stars, a trend that has

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6. See the catalog description at http://www.ipac.caltech.edu/2mass/releases/allsky/doc/.
been found, for instance, in the association Sco-Cen OB2 by Mamajek et al. (2002). However, with the uncertainties quoted for the PMS ages, all the estimates are compatible with an homogeneous age for all cluster members.

3.2. Chandra-ACIS data

For each source, the number of counts was computed in a circular region of 7 pixel radius (≈3.5'). The background was taken from an annular region 7 pixels wide. These values were chosen to include as many source photons as possible and to minimize contamination from nearby sources. The low and homogeneous crowding across the field allowed us to use a constant aperture.

The computation of X-ray luminosity from count rates for the detected sources proceeded after the selection of the best temperature model using diagrams of hardness ratios. We computed the ratios HRA = (C₂ - C₁)/(C₂ + C₁) and HRB = (C₃ - C₂)/(C₃ + C₂), where C₁, C₂, and C₃ are the total counts in the bands 0.6–1.6, 1.6–2.0, and 2.0–8.0 keV, respectively. The values for our sources were compared in the HRB versus HRA diagram to a single-temperature grid (Raymond-Smith) calculated with the Portable Interactive Multimission Simulator (PIMMS). This plot is shown in Figure 2. In the range between 0.4 and 4 keV, the temperature model that best reproduces the distribution of our sources corresponds to kT = 1.7 keV, with a hydrogen column density of 2.5 × 10^{21} cm⁻², consistent with the NH value from the H i map by Dickey & Lockman (1990). With these parameters, intrinsic fluxes are calculated for each source in the ranges 0.5–2.0, 2.0–8.0 keV, and the total flux in the range 0.5–8.0 keV. In order to compare these fluxes with the results obtained by assigning different temperature models to PMS and MS stars, we have also calculated the fluxes in the same ranges for temperatures of 2.16 and 0.6 keV for PMS and MS stars, respectively (Flaccomio et al. 2003).

In Table 1 we list the data for those stars in our photometric catalog, which are also detected in X-rays, or included in the D05 publication. The table lists the identification number and membership identification in columns (1) and (2); MS and PMS members are respectively denoted with 1 and 2 in column (2). Equatorial coordinates (J2000.0) are listed in columns (3) and (4). Color indices V, (U−B), (B−V), (V−R), and (V−I) are listed in columns (5)–(9); (H−K) increment with respect to the reddening line in the (J−H), (H−K) diagram are listed in column (10). Equivalent widths from D05 in H i and Li i λ6708 are listed in columns (11) and (12). Calculated X-ray fluxes (ergs s⁻¹ cm⁻²) in the bands 0.6–2.0 and 2.0–8.0 keV are listed in columns (11) and (12). X-ray luminosity (calculated as the decimal logarithm of the total intrinsic flux) and bolometric luminosity are listed in columns (12) and (13). The color excesses and slope of the reddening line in the (J−H), (H−K) diagram follow the reddening law from Cardelli et al. (1989). The intrinsic total flux is calculated with the distance obtained from our optical photometry. The contents of Table 1 are accessible in electronic format. The first evidence that stands out in the observations is the wide range of colors and magnitudes covered by the detected X-ray sources, in particular the considerable amount of MS stars showing this activity, as compared to other clusters of similar characteristics, such as NGC 6530 (Prisinzano et al. 2005). The deeper and more exhaustive observations of Orion, described by Stelzer et al. (2005), also show a generalized presence of X-ray activity among OB-type stars. The authors suggested a classification in two different types of mechanisms for the X-ray
# Table 1
Optical, Near-Infrared, and X-Ray Data for NGC 2362

| Star | Membership | R.A. (J2000.0) | Decl. (J2000.0) | $V$ | $U-B$ | $B-V$ | $V-R$ | $V-I$ | $\delta(H-K)$ | $W(H\alpha)$ (Å) | $W(Li)$ (Å) | $0.6-2.0$ keV (ergs s$^{-1}$ × cm$^2$) | $2.0-8.0$ keV (ergs s$^{-1}$ × cm$^2$) | log($L_X$) | log($L_{bol}$) |
|------|------------|----------------|----------------|-----|-------|-------|-------|-------|---------------|----------------|-------------|---------------------------------|---------------------------------|----------|-----------|
| 15... | 2          | 109.612655     | −24.997417     | 19.722 | ...   | 1.682 | 1.062 | 2.452 | −0.063 | 5.890          | 0.660       | 0.1159E−14 | 0.9974E−15 | 29.675   | 32.820    |
| 31... | 0          | 109.621123     | −24.951534     | 19.804 | ...   | 0.870 | 0.537 | 1.103 | ...   | ...            | ...         | 0.3071E−15 | 0.1441E−15 | 29.050   | 32.212    |
| 56... | 2          | 109.632713     | −24.948021     | 16.978 | ...   | 1.277 | 0.768 | 1.421 | −0.097 | 6.670          | ...         | 0.3170E−14 | 0.1006E−14 | 30.044   | 33.445    |
| 78... | 2          | 109.641909     | −24.980766     | 19.875 | ...   | 1.917 | 1.077 | 2.541 | 0.066  | 3.950          | 0.500       | ...         | ...        | 32.805   | ...       |
| 90... | 2          | 109.647094     | −25.009815     | 15.971 | 0.329 | 1.042 | 0.668 | 1.239 | −0.181 | 0.700          | 0.390       | 0.6102E−14 | 0.3130E−14 | 30.354   | 33.717    |
| 98... | 2          | 109.649026     | −24.944448     | 16.125 | 0.058 | 0.942 | 0.622 | 1.296 | −0.147 | ...            | ...         | 0.2568E−14 | 0.1200E−14 | 29.972   | 34.574    |
| 111... | 2         | 109.656144     | −25.024815     | 19.656 | ...   | 1.585 | 1.239 | 2.794 | −0.095 | 5.280          | 0.640       | ...         | ...        | 33.024   | ...       |
| 122... | 0         | 109.660273     | −24.981596     | 18.438 | ...   | 0.779 | 0.492 | 0.931 | ...   | 2.750          | ...         | 0.5802E−15 | 0.3811E−15 | 29.350   | 32.695    |
| 132... | 0         | 109.661298     | −24.981937     | 19.707 | ...   | 0.994 | ...   | ...   | −0.289 | 2.750          | ...         | 0.5802E−15 | 0.3811E−15 | 29.350   | 32.226    |
| 134... | 2         | 109.663546     | −24.942093     | 18.228 | ...   | 0.856 | 0.968 | 2.081 | −0.071 | 3.310          | ...         | 0.8119E−14 | 0.6336E−14 | 30.511   | 33.224    |

Note.—Table 1 is published in its entirety in the electronic edition of the *Astrophysical Journal*. A portion is shown here for guidance regarding its form and content.
activity in their OB-type MS stars. Following this classification, the X-ray activity detected from OB stars in NGC 2362 would be mainly ascribed to binary companions, rather than to the presence of strong winds. We note, however, that some of these member stars show signs of NIR excess in the $(J−H), (H−K)$ diagram (separation from the reddening line larger than their error bar; see Table 1). This could indeed originate from an unresolved binary companion but also suggests the presence of a certain amount of circumstellar material around these stars. The range covered by the $L_{X}/L_{\text{bol}}$ values for these stars (see below) suggests a mixture of causes for their X-ray activity (Stelzer et al. 2005).

Clear differences can be observed otherwise between the properties of X-ray activity in MS and PMS cluster members. Figure 3 shows a plot of log $L_{X}$ versus log $L_{\text{bol}}$; $L_{\text{bol}}$ is calculated with the bolometric corrections from the calibration by Kenyon & Hartmann (1995). The figure shows the different behavior of PMS and MS members, represented respectively as dots and plus signs. We observe that both PMS and MS stars cover the same range in $L_{X}$. On the other hand, there is a clear correlation between both luminosities for PMS stars up to spectral type F (log $L_{\text{bol}}$ $\simeq$ 34.4), which vanishes for earlier type PMS candidate members and for MS stars. This different behavior has been found as a characteristic feature in PMS versus MS stars (see Preibisch et al. 2005). We note that most PMS members fall into the category of the so-called weak-line T Tauri stars (WTTS), as has been shown by the Hα analysis of D05. In particular, only seven stars in our sample have equivalent widths of Hα in emission larger than 10 Å, usually adopted as the separating value between classical T Tauri stars and WTTS (D05).

As to the ratio $L_{X}/L_{\text{bol}}$, we quote the median values for PMS and MS stars, which amount respectively to log $(L_{X}/L_{\text{bol}})$ $=−3.5 ± 0.4$ and $−6.3 ± 0.8$ (mean deviations). The values agree with those obtained by Flaccomio et al. (2003) for the PMS stars in Orion of masses between 0.5 and 3 $M_{\odot}$ [log $(L_{X}/L_{\text{bol}})$ $=−3.5$] and Stelzer et al. (2005) for the hot MS stars in Orion (between $−4$ and $−8$).

The spectral characteristics of both subsamples also show a different behavior. In Figure 4 we plot the ratio between hard (2–8 keV) and soft (0.5–2 keV) fluxes, as listed in Table 1. A softening of the X-ray emission is observed for PMS stars as $L_{\text{bol}}$ increases. This trend again seems to disappear for the MS and for the earliest type PMS candidate members. As referred above, the same spectral model has been used to compute fluxes for both PMS and MS members, corresponding to a plasma at temperature of 1.6 keV. Some authors distinguish between both evolutionary stages, assigning harder spectra to PMS stars than to those in the MS (Flaccomio et al. 2003). We wish to stress that the tendency shown in Figure 4 is also apparent, and even enhanced, if we compute hard and soft fluxes with different models of 2.16 and 0.6 keV, respectively, for PMS and MS stars. The softening of X-ray activity for MS stars, even massive stars, as compared to PMS stars has also been established in recent works (Preibisch et al. 2005; Stelzer et al. 2005).

As mentioned above, we wish to specifically point out the behavior of the PMS candidate members of the earliest spectral type in the cluster (around AF). Even though they are PMS candidates according to the optical photometry and to the comparison to PMS isochrones, their X-ray activities show features closer to those from MS stars, both in the relation of $L_{X}$ to $L_{\text{bol}}$ and in the behavior of their hardness ratios as well.

Finally, from the analysis of several star-forming regions in a wide range of ages, Flaccomio et al. (2003) have concluded that X-ray activity increases with age, as the envelopes and disks of stars progressively disappear. Also, Stassun et al. (2004) have stated that the emission of X-rays can be obscured or modulated by accretion processes, but these are not the origin of the X-ray activity.

This behavior of the X-ray activity with age is not apparent in a sample where all stars belong to a cluster or association, and much less in a case like NGC 2362, where the age spread is small or even absent. However, the joint evidence from our data sources allows some check of this age effect, which can more properly be called evolutionary effect. For 36 stars in our sample, there are both X-ray emission and equivalent widths of the absorption Li i $\lambda$6708 (D05), commonly considered as a sign of PMS nature (Bertout 1989). The strength of this absorption $W$(Li) should be smaller for PMS stars closer to the MS (Martin 1997; Palla et al. 2005). When all stars can be considered to have the same age, a variation of $W$(Li) could still be expected simply because stars of different masses will have reached different PMS evolutionary stages in the same evolving time. Considering this, we can check the dependence of $L_{X}$ with $W$(Li), as an indicator of evolutionary status in the PMS phase. We simply compute a linear fit of log $L_{X}$ versus $(V−I)$ and plot the residuals versus $W$(Li). The plot is
shown in Figure 5, together with a median fit, which shows a not significant increase of the median. The lack of a trend in this plot confirms the narrow range of ages and evolutionary stages spanned by the PMS members in our sample.

4. CONCLUSIONS

The joint evidences discussed above lead to the following conclusions. The isochrone fitting procedure to establish PMS membership for individual stars provides reliable results. This follows from the agreement between membership assignments using isochrone fitting and the signs of PMS nature deduced from observed properties of the stars, such as X-ray activity and presence of specific spectral features, namely Hα emission and Li i λ6708 absorption.

The age estimates from the three sets of PMS isochrones used provide values that range from 4 to 6 Myr, with the models by D’Antona & Mazzitelli (1997), Siess et al. (2000), and Palla & Stahler (1999). This difference can be considered as an indication of little, if any, age spread among the PMS cluster members. The comparison of the upper CM diagram with post-MS isochrones from Girardi et al. (2002), shows an upper limit of 4 Myr for the age of the MS cluster members. This estimate is based on a visual comparison and is not incompatible with an homogeneous age for all cluster members.

A relatively large number of B-type MS cluster members, as compared with the findings for a cluster of similar properties like NGC 6530 (Prisinzano et al. 2005), are found to be optical counterparts of detected X-ray sources in NGC 2362.

A clearly distinct behavior is observed in the properties of the X-ray activity from PMS and MS stars. Those show a well-correlated increase with of LX with LBol, and a decreasing hardness ratio, calculated as the ratio of fluxes above and below 2 keV. The MS stars show values of LX in the same range covered by the PMS stars but do not show any correlation between both luminosities, and the suggested variation of hardness ratio with luminosity is also absent, whereby this parameter takes lower values than it does for PMS stars. These results agree with the findings and general properties of X-ray activity in PMS stars obtained from the analysis of closer star-forming regions (Flaccomio et al. 2003; Preibisch et al. 2005; Stelzer et al. 2005).

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REFERENCES

Bailyn, C., DePoy, D., Agostinho, R., Mendez, R., Espinoza, J., & Gonzalez, D. 1999, BAAS, 195, 8706
Balona, L. A., & Lane, C. D. 1996, MNRAS, 281, 1341
Bergmiller, T. W., & Schmitt, J. H. M. M. 1998, in ASP Conf. Ser. 154, Cool Stars, Stellar Systems, and the Sun, ed. R. A. Donahue & J. A. Bookbinder (San Francisco: ASP), 2091
Bertout, C. 1989, ARA&A, 27, 351
Cardelli, J. A., Clayton, G. C., & Mathis, J. S. 1989, ApJ, 345, 245
Dahm, S. E. 2005, AJ, 130, 1805 (D05)
Damiani, F., Micela, G., Sciortino, S., Huelamo, N., Harnden, F. R., & Murray, S. 2005, in Star Formation in the Era of Three Great Observatories (Cambridge: Chandra X-Ray Obs.), 33, http://cxc.harvard.edu/star05/agenda/program.html
D’Antona, F., & Mazzitelli, I. 1997, Mem. Soc. Astron. Italiana, 68, 807 (D97)
Delgado, A. J., Alayo, E. J., Moitinho, A., & Franco, J. 1998, AJ, 116, 1801
Dickey, J. M., & Lockman, F. J. 1990, ARA&A, 28, 215
Flaccomio, E., Micela, G., & Sciortino, S. 2003, A&A, 402, 277
Girardi, L., Bertelli, G., Bressan, A., Chiosi, C., Groenewegen, M. A. T., Marigo, P., Salasnich, B., & Weiss, A. 2002, A&A, 391, 195
Haisch, K. E., Jr., Lada, E. A., & Lada, C. J. 2001, ApJ, 553, L153
Johnson, H. L., & Morgan, W. W. 1953, ApJ, 117, 313
Kenyon, S. J., & Hartmann, L. 1995, ApJS, 101, 117
Landolt, A. V. 1992, AJ, 104, 340
Mamajek, E. E., Meyer, M. R., & Liebert, J. 2002, AJ, 124, 1670
Martin, E. L. 1997, A&A, 321, 492
Moitinho, A., Alves, J., Huelamo, N., & Lada, C. J. 2001, ApJ, 563, L73
Palla, F., Randich, S., Flaccomio, E., & Pallavicini, R. 2005, ApJ, 626, L49
Palla, F., & Stahler, S. W. 1999, ApJ, 525, 772 (P99)
Perry, C. L. 1973, in IAUS Symp. 50, Spectral Classification and Multicolour Photometry, ed. C. Fehrenbach & B. E. Westerlund (Dordrecht: Reidel), 192
Preibisch, T., et al. 2005, ApJS, 160, 401
Prisinzano, L., Damiani, F., Micela, G., & Sciortino, S. 2005, A&A, 430, 941
Schmidt-Kaler, T. 1982, in Landolt-Boèrnstein: Numerical Data and Functional Relationships in Science and Technology, Vol. 2b, ed. K. Schaifers & H. H. Voigt (Berlin: Springer), 14
Siess, L., Dufour, E., & Forestini, M. 2000, A&A, 358, 593 (S00)
Stassun, K. G., Ardila, D. R., Barsony, M., Basri, G., & Mathieu, R. D. 2004, AJ, 127, 3537
Stelzer, B., Flaccomio, E., Montmerle, T., Micela, G., Sciortino, S., Favata, F., Preibisch, T., & Feigelson, E. D. 2005, ApJS, 160, 557