Galactic Star Formation Across the Stellar Mass Spectrum
ASP Conference Series, Vol. 287, 2003
J.M. De Buizer and N.S. van der Bliek, eds.

X-ray and Optical Observations of NGC 1788

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Abstract. We report on the results of ROSAT High Resolution Imager (HRI) X-ray observations and optical wide-field spectroscopy and imaging in the star forming region NGC 1788. Several new low mass pre-main sequence (PMS) stars have been found based on intermediate resolution spectroscopy. Many new PMS candidate members of NGC 1788 are selected using the spectroscopically confirmed PMS stars to define the PMS locus in color-magnitude diagrams. Some objects with very red colors detected just above the limiting magnitude of our images, are good candidates for young Brown Dwarfs (BDs). The BD nature of these objects need to be confirmed with subsequent IR observations.

1. Introduction

In the course of our previous studies of the large scale distribution of ROSAT All-Sky Survey (RASS) X-ray sources in the general direction of the Orion star forming region (SFR), several over-densities of X-ray sources with high probability of being low mass pre-main sequence (PMS) stars were identified (Sterzik et al. 2003; Walter et al. 2000). One density enhancement was found near the reflection nebula NGC 1788. The relatively small width of the enhancement

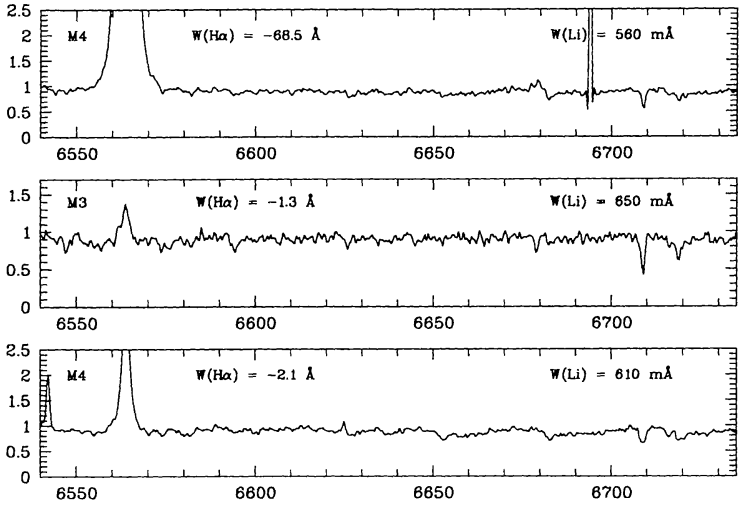

Figure 1. Examples of HYDRA spectra. The stars with prominent Hα emission also have IR excess. Note the strong Li λ 6708 Å absorption line. The spectral types are given in the upper left of each panel.

would indicate a diffusion age of less than 5 Myr, if these stars have formed in a central cluster with a dispersion velocity of 2 km/s. In these proceedings we report some results of ROSAT X-ray High-Resolution-Imager (HRI) observations, as well as of optical wide-field imaging (WFI) and spectroscopic follow-up observations in NGC 1788.

2. ROSAT-HRI Observations

Three X-ray pointed observations of 18, 10, and 18 ksec, respectively, were performed using the HRI on-board the ROSAT satellite. The data were processed using the standard techniques of the extended X-ray scientific analysis system (eXsas) pipeline. The HRI pointings were merged and 27 X-ray sources were detected with high confidence level. Two stars that were detected in our X-ray observations were already known to exhibit strong Hα emission. One of these is the T Tauri star LkHα-333, the other is KisoA-097414. More details on the X-ray observations and analysis will be published in a separate forthcoming paper.

3. Spectroscopic Identifications

Spectroscopic identifications of the X-ray sources were performed in two sites: 1) long-slit spectra of the possible optical counterparts to the X-ray sources were acquired using the CTIO 1.5m telescope in winter 1999. The spectral range was 4750–6750 Å. The nominal resolution of about 4 Å (FWHM) was sufficient to identify the Li λ 6708 Å absorption line, which was used as the primary youth indicator for stars with spectral types later than G5; 2) intermediate resolution spectroscopy was also performed in January 2000 using the multi-

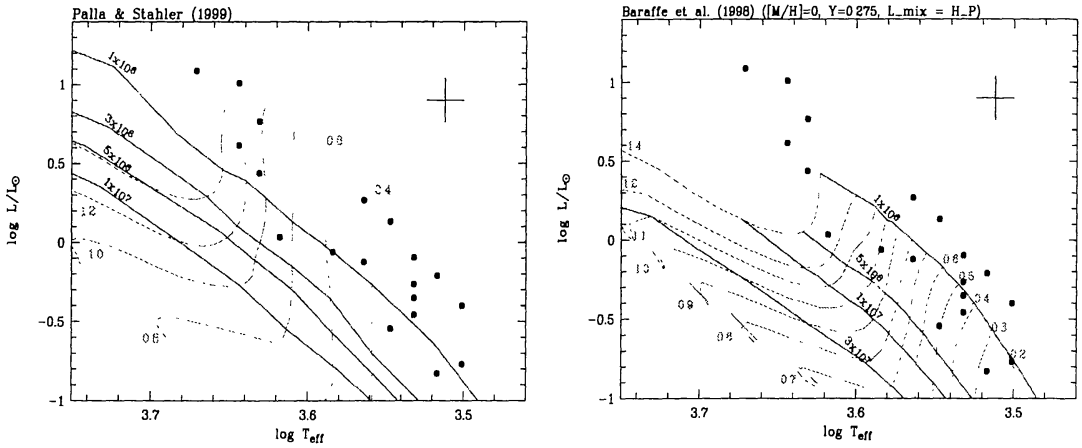

Figure 2. HR diagrams of the spectroscopically confirmed PMS stars in NGC 1788. The thick and thin lines represent the PMS evolutionary tracks for different masses and isochrones, respectively, by Palla & Stahler (1999) **(Left)** and by Baraffe et al. (1998) **(Right)**. The black dots represent the spectroscopically confirmed PMS stars. The mean errors are indicated in the upper right of each panel.

fibre spectrograph HYDRA, attached to the WIYN[2] 3.5m telescope at Kitt Peak. These observations were part of an unbiased lithium survey aimed at searching for new PMS stars in several of the regions with over-densities of X-ray sources discussed in the introduction (Alcalá et al. in preparation). The spectral range was 6100–7000 Å. The nominal spectral resolution was about 1.5 Å (FWHM). At such resolution, the Li line is well resolved from the Ca λ 6718 Å absorption line and measurements of the Li equivalent width can be performed with an average error of less than 50 mÅ, depending on the S/N ratio of the spectra and the spectral types (see Covino et al. 1997). Since HYDRA covers a field of view of 1 square degree, practically all the sources investigated with the CTIO 1.5m telescope were also observed with HYDRA. Some examples of HYDRA spectra are shown in Figure 1. All the data reduction was done with IRAF. The CTIO spectra were mainly used for the lithium detection and for the spectral type classification, while the HYDRA spectra were used to measure Li equivalent widths and radial velocities. The details on these topics will be published in a forthcoming paper.

4. Wide-field Imaging and Near-IR Data

CCD mosaic imaging in the BVRI and Hα bands was done using the Wide-Field Imager (WFI) at the ESO/MPIA 2.2m telescope at ESO La Silla in March 2000. Several Landolt fields were observed for the photometric calibration. The

[2]The WIYN telescope is maintained and operated by a consortium whose members include the University of Wisconsin, Indianan University, Yale University, and NOAO.

data were reduced using the *mscred* task under IRAF. The stellar objects were extracted using both SExtractor and Daophot, with consistent results. More than 7000 objects were extracted from the R-band image above the 3σ level. Our completeness and limiting magnitudes are 21.0 and 22.0 respectively in the V-band. More details regarding the WFI observations, data reduction and catalog extraction will be published in a forthcoming paper. Twelve of the spectroscopically confirmed PMS stars fall in the WFI images and hence have B,V,R and I photometry. In addition to the optical WFI data, we retrieved infrared data from the Two Micron All-Sky Survey (2MASS) database, for all the confirmed PMS stars in the sample. The optical and IR data were used to determine bolometric luminosities.

5. Results

5.1. New PMS Stars

Some 20 new low mass PMS stars have been found so far in the region. Spectral types (SpT) were assigned using a grid of standard spectra with similar resolution as the PMS star spectra. Effective temperatures (T_{eff}) were determined using the SpT vs. T_{eff} relation by de Jager and Nieuwenhuijzen (1987) for luminosity class IV. The WFI and 2MASS IR data were used to derive bolometric luminosities as explained in Alcalá et al. (1997), assuming a normal extinction law and a distance of 460 pc. The comparison of the position of the stars in the HR diagram with theoretical PMS evolutionary tracks (shown in Figure 2) indicates that the stars have masses less than $1.5M_{\odot}$ and are younger than 5 Myr.

5.2. PMS Candidates

Based on color-magnitude diagrams and theoretical isochrones, fainter PMS stars than those found so far are selected using the spectroscopically confirmed PMS stars to define the PMS locus. More than 200 stars are selected in the $30' \times 30'$ WFI field around NGC 1788, that are expected to be low mass PMS stars. This procedure is shown in Figure 3. These stars await future spectroscopic observations in order to firmly establish their PMS nature, through the detection of Hα emission and lithium absorption.

5.3. Young Brown Dwarf Candidates

By similar selection criteria as above, several young brown dwarf (BD) candidates are also selected in NGC 1788, just above the detection limit of the WFI images. Examples of such candidates are shown in Figure 3. By inspection of the color-magnitude diagrams, we expect some 30-40 objects fainter than about V=19 which might be good candidates for young BDs. The possible BD nature of these objects will be studied with future spectroscopic observations in the near-IR.

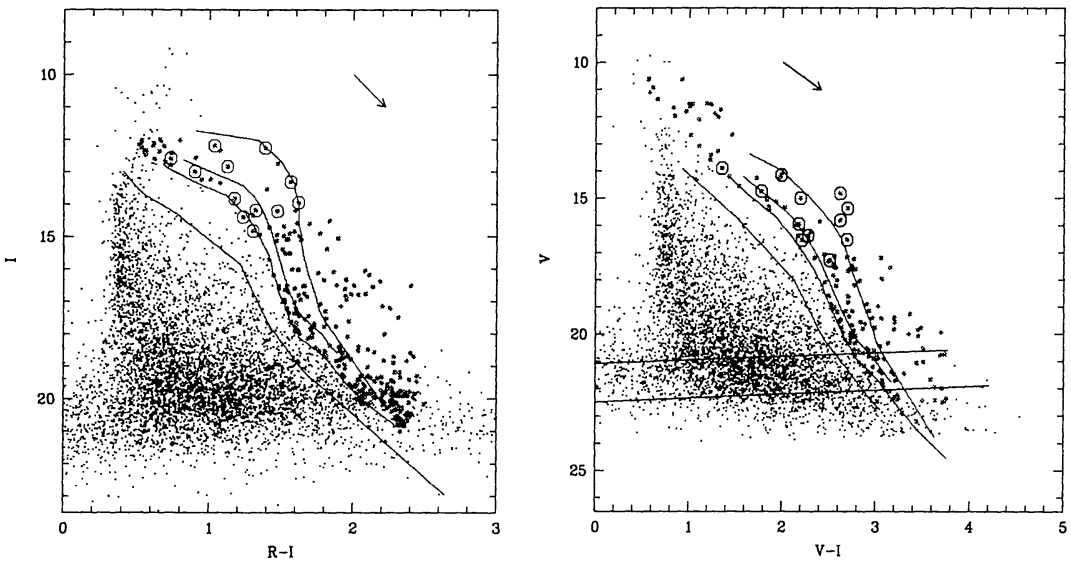

Figure 3. I vs. (R-I) **(Left)** and V vs. (V-I) **(Right)** diagrams for the extracted objects in the $30' \times 30'$ field in NGC 1788. The continuous lines represent the theoretical PMS isochrones by Baraffe et al. (1998) for 1, 5, 10 and 50 Myr, respectively, shifted to a distance modulus of 8.3 (d=460pc). The 12 spectroscopically confirmed low mass PMS stars in the WFI images are indicated with circles. The bigger dots represent the PMS candidates selected above the 10 Myr isochrone. The A_V= 1 mag. reddening vector is also shown. The almost horizontal lines in the V vs. (V-I) diagram represent the completeness and 3σ limiting magnitudes respectively.

6. Conclusions

The confirmation of the PMS nature of the candidates will allow us to characterise the NGC 1788 star population and derive the luminosity function of the association. The results from optical spectroscopy in combination with those for the young BDs will also allow a complete census of the PMS population in the NGC 1788 region and, hence, determine the Initial Mass Function (IMF) down to the very low-mass domain.

Although NGC 1788 is a relatively isolated region, some 10° west of the Trapezium in Orion, we have shown it to be an active star forming region. The region is devoid of very high mass stars. Therefore, an important goal for the future will be to compare the mass function in NGC 1788 with that of other T and OB associations in order to investigate whether the absence of high mass stars has any impact on the IMF in the very low mass domain.

The frequency of young BDs, as well as the incidence of their circumstellar disks is another issue that shall deserve further study in the near IR using eight-meter class telescopes.

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