Mem. S.A.It. Vol. 75, 282

Memorie della

Coronae in the Coronet: simultaneous X-ray to radio monitoring of a young stellar cluster

J. Forbrich, Th. Preibisch, and K. M. Menten

Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, D-53121 Bonn, Germany

Abstract. X-ray to radio multi-wavelength monitoring of Young Stellar Objects (YSOs) can provide important information about physical processes at the stellar surface, in the stellar corona, and/or in the inner circumstellar disk regions. While several multi-wavelength studies have been performed for field stars and $\sim 1-10$ Myr old T Tauri stars, no such study so far has succeeded in detecting simultaneous X-ray to radio variability in very young objects like class I and class 0 protostars. Here, we present results of the first simultaneous X-ray, radio, near-infrared, and optical monitoring of the YSOs in the *Coronet* cluster, located in the Corona Australis star-forming region. Seven YSOs are detected simultaneously in the X-ray, radio, and optical/infrared bands. Most of these exhibit clear intra-band variability in the X-ray, optical and infrared data, but none show significant radio variability. No evidence for time-correlated multi-wavelength variability is found. This result suggests that there is no direct link between the emission in the different wavelength ranges and supports the notion that accretion is *not* an important source for the X-ray emission of these YSOs. Furthermore, the deep X-ray and infrared data of the *Coronet* region provide a complete census of YSOs in this star-forming region.

Key words. stars: pre-main sequence – stars: individual: R CrA, S CrA – radio continuum: stars – X-rays: stars – Infrared: stars

1. Introduction

Strong, often flare-like variability is an ubiquitous phenomenon of Young Stellar Objects (YSOs) at almost all wavelengths. Multi-wavelength correlations contain important information on the underlying emission mechanisms. For example, one may expect some kind of correlation between the X-ray emission from hot thermal and the non-thermal centimetric radio emission, which is interpreted as gyrosynchrotron radiation due to magnetic fields, because both types of radiation are mainly produced in the same innermost regions around a protostar. For a discussion of radio and X-ray observations of (proto-)stellar coronae, we refer to Güdel (2002, 2004). The Sun displays mainly uncorrelated X-ray and radio variability, but also a particular kind of radio–X-ray correlation, known as the Neupert effect, which has also been observed also towards other stars (e.g. the dMe flare star UV Cet) Güdel et al. (1996). If accretion shocks would be a significant source of X-ray emission in YSOs, one would expect to see some kind of correlated variability in the X-ray band and at optical/near-infrared wavelengths.

Send offprint requests to: Jan Forbrich,
e-mail: `jforbrich@cfa.harvard.edu`

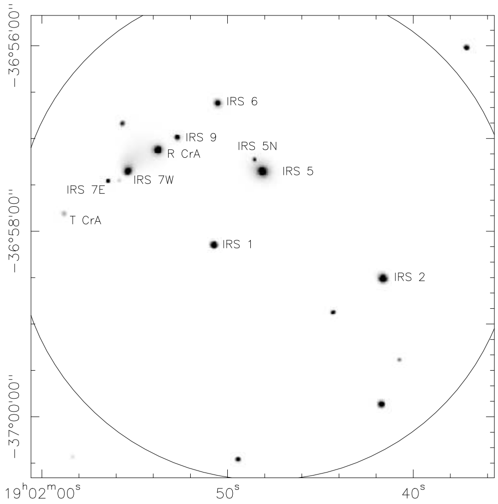

Fig. 1. Combined *Chandra* data (Obs ID 5402-5406, smoothed). The circle denotes the approximate VLA half-power primary beam (at λ = 3.5 cm). Coordinates are J2000; from Forbrich et al., 2007.

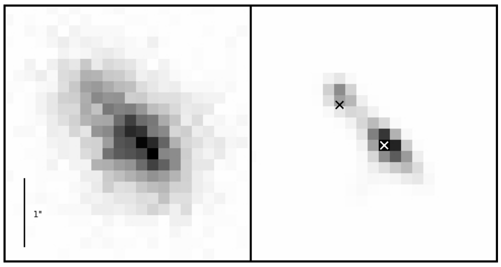

Fig. 2. *Chandra* image of the IRS 5 a/b region, original data and maximum-likelihood–reconstructed super-resolution image. The crosses mark the positions of the double infrared source relative to the peak emission (from Nisini et al., 2005).

2. The Coronet Cluster

The *Coronet* cluster in the Corona Australis star-forming region (see Neuhäuser & Forbrich, 2007 for a recent review) contains a few dozen YSOs, including two Herbig AeBe stars, numerous T Tauri stars, at least five class I protostars and one class 0 protostar candidate. Due to its distance of only 130 pc and its compact projected size (most of the YSOs concentrate in a $5' \times 5'$ region), it is an ideal target for simultaneous multi-wavelength studies. Most of the YSOs were detected at radio, infrared and X-ray wavelengths in previous observations (Forbrich et al., 2006). Fig. 1 shows the central part of a *Chandra* X-ray image and indicates also the approximate field of view of the radio observations obtained with the Very Large Array (VLA).

3. Observations

Simultaneous radio, X-ray, and optical/near-infrared observations of the *Coronet* cluster were performed in August 2005. Due to the far southern declination of the *Coronet* cluster (nearly −37°), the region is accessible for the VLA only during a few hours per day. Thus, five 4h duration *Chandra* -ACIS observations were scheduled on (nearly) successive days. Within these, simultaneous VLA observations were scheduled. Additionally, simultaneous and/or near-simultaneous near-infrared and optical observations were collected at telescopes in Chile and South Africa (ESO NTT, IRSF, CTIO). For details about these observations, see Forbrich et al. (2007).

4. Results

The main results can be summarized as follows:

- While the YSOs in the *Coronet* show strong variability in X-rays and near-infrared/optical emission, no significant variability could be detected at radio wavelengths. However, the radio flux densities of most YSOs differ from previously measured values, indicating long-term variability.
- No clear multi-wavelength correlations were found for any object. The optical/near-infrared variability appears to be uncorrelated to the X-ray variability. This suggests that there is *no* direct causal link between the sources of optical/near-infrared and X-ray variability and that

accretion is not a dominant source of X-ray emission in these stars (we note that similar results have been obtained in a study of YSOs in the Orion Nebula Cluster by Stassun et al., 2006). The properties of the observed X-ray emission is consistent with the assumption of coronal emission.

5. A deep X-ray view of the Coronet

The X-ray data collected in our simultaneous multi-wavelength project were combined with archival *Chandra* data to form an exceptionally sensitive dataset of the *Coronet* region with a detection limit of $L_{X,min} \sim 5 \times 10^{26}$ erg/sec for lightly absorbed sources. Fourty-eight X-ray sources could be identified with optical and/or near/mid-infrared counterparts. *Spitzer* data allowed to determine the near- to mid-infrared spectral energy distributions of the YSOs and thus to evaluate their evolutionary state. X-ray emission was detected from *all* of the previously known optically visible late-type (spectral types G to M) stellar cluster members, from five of the eight brown dwarf candidates, and from ten embedded objects ("protostars") with class 0 or class I SEDs in the field of view. The X-ray data also to identify several new stellar members of the star-forming region, mainly T Tauri stars without strong infrared excesses.

The analysis of the X-ray spectra showed very high plasma temperatures for almost all YSOs, as typical for coronal X-ray emission from magnetically active stars. No hints towards possible X-rays from accretion shocks could be found. The plasma temperatures of objects in different evolutionary stages were found to differ systematically: the class 0/I protostars show the highest plasma temperatures, class III objects the lowest ones. The Ae star R Cra shows a peculiar X-ray spectrum with an extremely hard component. Spectral fits suggest a two-plasma temperature model with different extinction factors for the two components, corresponding to an extinction of A_V = 7.25 mag for the cooler ∼ 10 MK component and A_V = 20 mag, for the extremely hot (> 600 MK) component.

The X-ray emission of the class I protostellar binary IRS 5 was spatially resolved for the first time (Fig. 2). This may be an interesting aspect for an answer to the still unsolved question why IRS 5 is the only object showing non-thermal centimetric radio emission in the *Coronet* region. Furthermore, it could be shown that the X-ray data provide a complete census of YSOs in the *Coronet* region.

References

Forbrich, J. & Preibisch, T. 2007, A&A, submitted

Forbrich, J., Preibisch, T., & Menten, K. M. 2006, A&A, 446, 155

Forbrich, J., Preibisch, T., Menten, K. M., et al. 2007, A&A, 464, 1003

Güdel, M. 2002, ARA&A, 40, 217

Güdel, M. 2004, A&A Rev., 12, 71

Güdel, M., Benz, A. O., Schmitt, J. H. M. M., & Skinner, S. L. 1996, ApJ, 471, 1002

Marraco, H. G. & Rydgren, A. E. 1981, AJ, 86, 62

Neuhäuser, R. & Forbrich, J. 2007, in Handbook of Star-forming Regions, ed. B. Reipurth

Nisini, B., Antoniucci, S., Giannini, T., & Lorenzetti, D. 2005, A&A, 429, 543

Stassun, K. G., van den Berg, M., Feigelson, E., & Flaccomio, E. 2006, ApJ, 649, 914

Taylor, K. N. R. & Storey, J. W. V. 1984, MNRAS, 209, 5