

MULTI-WAVELENGTH VARIABILITY OF YOUNG STELLAR OBJECTS IN THE CORONET CLUSTER. J. Forbrich, T. Preibisch, K. M. Menten, *Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, 53121 Bonn, Germany, (forbrich@mpifr-bonn.mpg.de)*, R. Neuhauser, B. Posselt, *Astrophysikalisches Institut und Universitäts-Sternwarte Jena, Schillergäßchen 2-3, 07740 Jena, Germany, et al.*

1 Overview

Young Stellar Objects are variable sources over a wide spectral range due to the energetic processes in their surroundings. Due to the observational difficulties involved, such variability until now has mostly been studied at single wavelengths. However, when looking at the variability of our sun, a system very different from an accreting protostar, some multi-wavelength correlations can be observed, even though there are also many effects observed only in certain parts of the spectrum. Of special interest in this context are possible correlations between the sometimes enormous protostellar X-ray flares and flares in (especially non-thermal) radio emission. Non-thermal gyrosynchrotron radiation is produced in the same hot coronal plasma giving rise to thermal X-ray emission. A correlation of soft X-ray and near-infrared variability would indicate that the X-rays are due to accretion.

There have been observational attempts at simultaneous multi-wavelength variability of YSOs before, however no class I protostars have until now been simultaneously monitored at radio, X-ray, and other wavelengths. Also, until now mostly single sources have been targeted while a compact cluster of YSOs increases the chances of detection.

The Coronet cluster in the nearby R CrA dark cloud ($d=150\text{pc}$) is such a compact sample of protostars detected at radio, X-ray, and near-infrared wavelengths. It is an ideal target for simultaneous multi-wavelength observations, because many interesting sources can be covered at once:

- at least four class I protostars (detected at X-ray and radio wavelengths), among others IRS5, the only class I protostar known to emit nonthermal radio radiation
- the most promising candidate source for an X-ray-detected class 0 source (IRS7E)
- the enigmatic radio and X-ray source IRS7W, probably a deeply embedded protostar
- R CrA itself, a Herbig Ae star seen in X-rays and radio emission, showing signs of extremely hot plasma (100 MK)
- several T Tauri stars in the Coronet cluster as well as in its surroundings

Most of these sources are detected at radio, X-ray, and infrared wavelengths and have very different properties in multi-epoch radio and X-ray observations as well as multi-wavelength simultaneous observations we report here.

In preparation for the simultaneous observations, we have studied nine epochs of radio data from 1998 as well as five epochs of archival X-ray data. In August 2005, observed

the Coronet Cluster in a coordinated, simultaneous multi-wavelength campaign involving *Chandra*, the NRAO Very Large Array, as well as infrared and optical telescopes, searching for correlations in the multi-wavelength variability of these sources.

2 The Coronet Cluster

The Corona Australis (CrA) molecular cloud complex is a nearby region with ongoing star formation, at a distance of only 150 pc, which is similar to that of the Taurus and ρ Oph dark cloud complexes. Taylor & Storey (1984) found a compact cluster of infrared sources in the densest part of the cloud complex close to the Herbig Ae star R CrA, calling it the Coronet cluster.

The Coronet Cluster was at the beginning of protostellar X-ray astronomy when Koyama et al. (1996) reported the detection of hard X-ray emission towards five protostars with ASCA. Recently, first results from *Chandra*-ACIS observations of this region were presented by Garmire & Garmire (2003) who detected more than 70 sources in a 20 ksec exposure. Hamaguchi et al. (2005) report the observation of an X-ray flare towards the class 0 protostar IRS7E.

The Coronet cluster has been analyzed at radio wavelengths already several times, most notably by Feigelson, Carkner, & Wilking (1998) who report on the discovery of circular polarization toward the class I protostar IRS 5. In fact this remains the only class I protostar known to emit nonthermal radio emission.

Nutter et al. (2005) present high-resolution submillimeter continuum data resolving a single emission peak known previously into two protostellar and one prestellar source where gravitational collapse has not yet started. This prestellar source is at the position of the class 0 source surmised earlier and is estimated to have a mass of 6 to 11 M_{\odot} , while the envelopes of some of the protostars considered here have sub-solar mass dust masses. The two protostellar sources are associated with unresolved radio and X-ray sources.

Using near-infrared spectroscopy, Nisini et al. (2005) constrain the accretion rates and evolutionary stages of some Coronet protostars, including the three most prominent class I sources IRS 1, 2, & 5. They conclude that IRS 1 and IRS 2 appear to be mostly accretion-powered (accounting for 80% to 65% of L_{bol} , respectively), while IRS 5 – a binary source – appears to be a deeply embedded, more evolved object with accretion accounting for only 20% of the bolometric luminosity of one of the components, IRS 5a. IRS 3 and IRS 6 show no signs of accretion. Comparing their derived stellar luminosities and effective temperatures to different models of pre-main sequence evolution, IRS 1 emerges as the youngest object in this sample with an age of about 10^5 years, while IRS 2, 5a

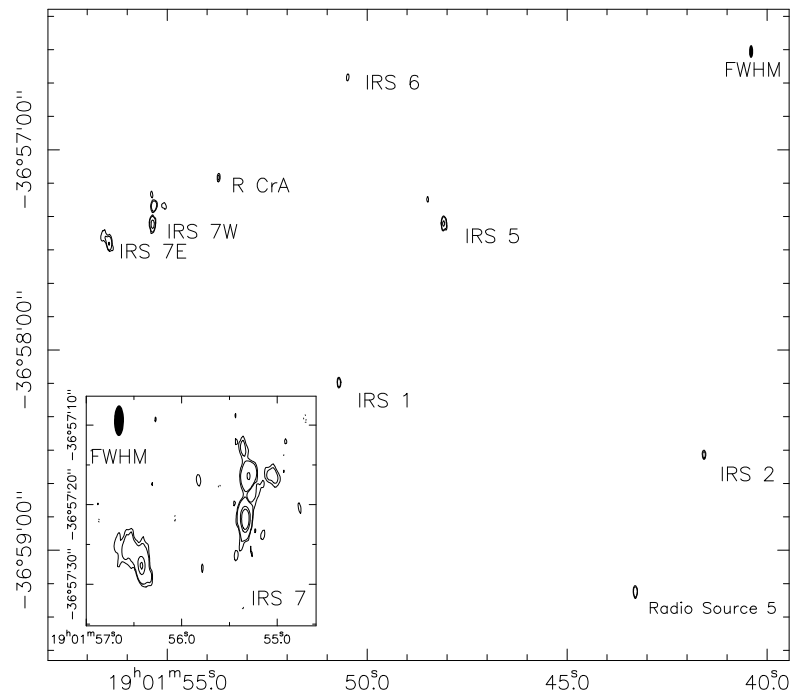


Figure 1: The VLA radio view of the Coronet cluster (see Forbrich, Preibisch, & Menten 2005 for details)

and 6a apparently have about the same age, closer to 10^6 years in spite of their different accretion properties.

3 Separate radio and X-ray variability of YSOs in the Coronet Cluster

In a preparatory study for our simultaneous multi-wavelength observations, we have studied nine epochs of 1998 VLA radio data as well as five archival X-ray datasets from *Chandra* and *XMM-Newton*. The results can be summarized as follows (see Forbrich, Preibisch, & Menten 2005, *in press*):

- In the Coronet cluster, eight sources are detected at radio and X-ray wavelengths. These sources are protostars, YSOs or related to such objects.
- IRS5, the only known class I protostar showing non-thermal radio emission, shows highly variable radio emission. Also in X-rays, it is very variable.
- The Herbig Ae star R CrA shows signs of very hot plasma (100 MK), as seen in its X-ray spectrum.
- Analysis of multi-epoch X-ray spectra of the class I protostars IRS 1, 2, & 5 shows that the emission of these sources can be explained by strongly absorbed hot plasma emission. However, the absorption derived from the X-ray spectra is at about half the values derived from near-infrared colors. The two fit parameters, plasma temperature and absorbing column densities, show tentative signs of variability with time.

While these are already very interesting results, even more lies in simultaneous data:

4 Simultaneous multi-wavelength observations in August 2005

In August 2005, we have observed the Coronet cluster in a simultaneous multi-wavelength campaign. Within a week, *Chandra* observed the region in five different epochs for about four hours each. During four of these epochs, the VLA, limited by the Coronet's short visibility on the northern hemisphere, observed for two hours, respectively. Additionally, simultaneous optical and near-infrared observations were obtained with several telescopes in Chile and South Africa. First results will be presented at the meeting.

References

- Feigelson, Carkner, & Wilking 1998, *ApJ* 494, L215
 Forbrich, Preibisch, & Menten, 2005, *A&A*, *in press*
 Garmire & Garmire 2003, *AN* 324, 153
 Hamaguchi, Corcoran, Petre, et al. 2005, *ApJ* 623, 291
 Koyama, Hamaguchi, Ueno, Kobayashi, & Feigelson 1996, *PASJ* 48, L87
 Nisini, Antoniucci, Giannini & Lorenzetti 2005, *A&A* 429, 543
 Nutter, Ward-Thompson, & André 2005, *MNRAS* 357, 975