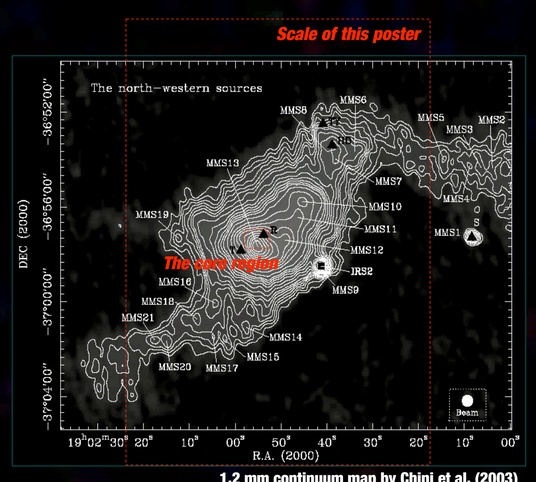
Discovery of Extremely Embedded X-ray Sources in the R CrA Cloud Core

K. Hamaguchi[1,2], M. F. Corcoran[1,3], N. E. White[1], B. Stelzer[4], K. Nedachi[5,6], N. Kobayashi[5,6]
[1]NASA / Goddard Space Flight Center, [2]National Research Council, [3]Universities Research Association (USRA), [4]INAF Observatorio Astronomico di Palermo, [5]Tokyo University, [6]National Observatory of Japan, Hawaii observatory
E-mail: kenji@milkyway.gsfc.nasa.gov

R Corona Australis (R CrA) Star Forming Region

- Nearby ongoing low and intermediate-mass star forming region (*d* ~130 pc)
- IRS7 region: Promising host of Class 0 sources with strong millimeter continuum emission

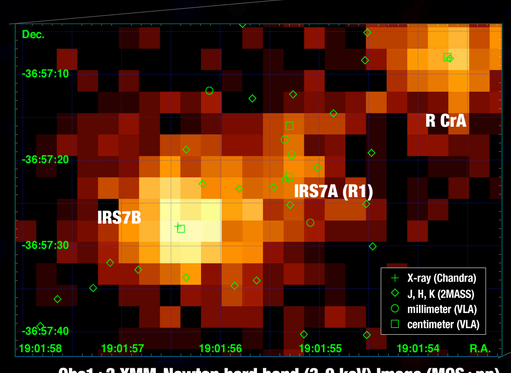


1.2 mm continuum map by Chini et al. (2003)

Extremely Embedded X-ray Sources (IRS7A, 7B) Detected

in two XMM-Newton observations in 2003

- Obs1: March 28 for 36 ksec
- Obs2: March 29 for 32 ksec



Obs1+2 XMM-Newton hard band (3-9 keV) Image (MOS+pn)

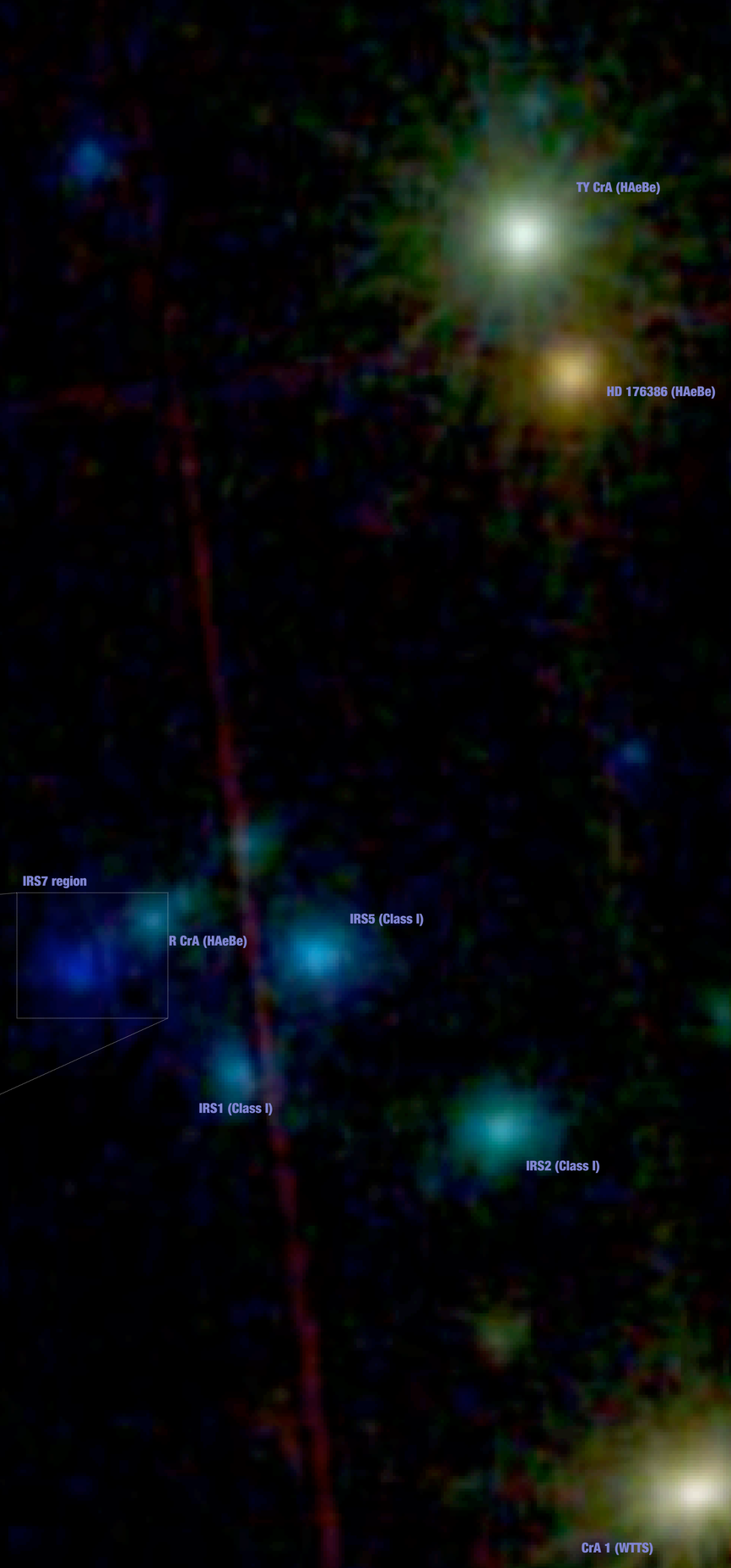
Counterparts

- Near-IR in our UH88/Subaru data
  - IRS7A: K ~13.3^m, IRS7B: K <19.1^m
- Plausible sources in centimeter and millimeter radio (Feigelson et al. 1998, Choi & Tatematsu 2004)

➔ They are promising Class 0 protostars.

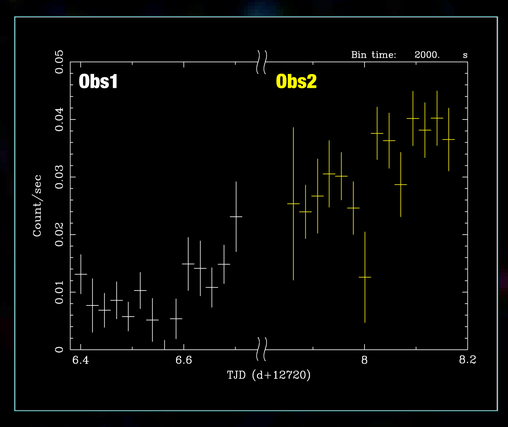
Caption of the Background Image

X-ray true color image of the R CrA region combined of Obs1 and Obs2. Image is color coded to represent hard band (3-9 keV) to blue, medium band (1-3 keV) to green and soft band (0.2-1 keV) to red. Abbreviations in source names - HAeBe: Herbig Ae/Be stars, (W)TTS: (Weak-lined) T-Tauri star, Class I: Class I protostar



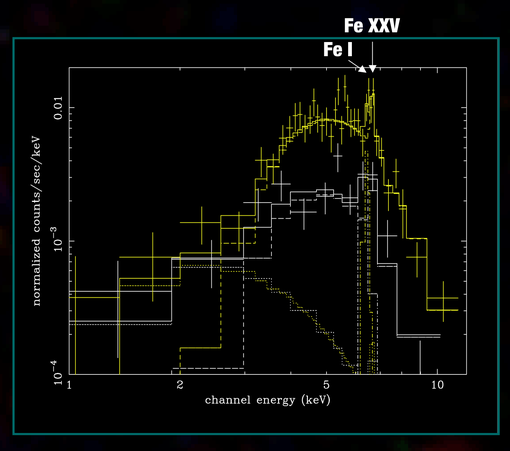
X-ray Property

IRS7B



Light Curve (2000 sec bins)

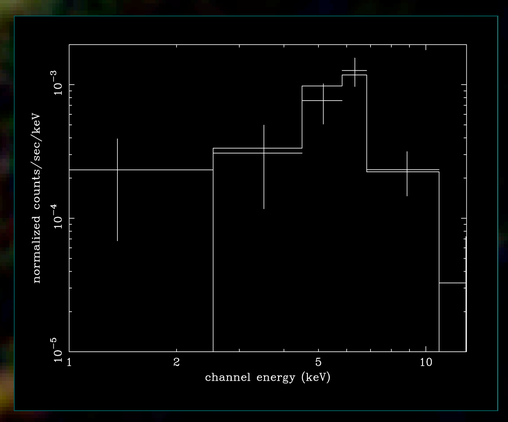
Gradual flux increase in Obs2



Spectra (Fit assumes absorbed 2T plasma)

Strong hard continuum and He-like Fe line
➔ Hot plasma (*kT* ~3-5 keV)
➔ Small Metal abundance (Z_{solar}~ 0.2 in Obs2)
Strong absorption below 3 keV
➔ N_H~ 2.8 x10^{23} cm^{-2} (equivalent to Av ~130^m)
Large X-ray luminosity (0.5-10 keV)
➔ Log *Lx* (ergs s^{-1}): 30.2 (Obs1) 31.0 (Obs2)
Fe I line, EW (eV) ~340 (Obs1), 108 (Obs2)
➔ Reflection of the incident X-rays by ambient gas and/or disk

IRS7A



Spectra (Fit assumes absorbed 1T plasma)

It could be as hot as, and as deeply embedded as, IRS7B though statistics are limited.

- N_H~ 3 x10^{23} cm^{-2} (Av ~ 150^m)
- *kT* ~ 5 keV
- Log *Lx* (ergs s^{-1}): 30.2 (Obs1: 0.5-10 keV)

Introduction to Young Stellar X-ray Activity

Earlier observations suggest:

- Low mass Pre-main-sequence stars (T-Tauri stars, Class I protostars) have strong X-ray emission.
- The high energy activity would be produced by magnetic activity on or around proto-stellar cores.
- X-ray plasma is hotter in the earlier Class I protostar phase than in the T-Tauri phase (Imanishi et al. 2001).

X-ray emission from the earliest phase of protostars (dynamical accretion phase, so called Class 0)

- is first detected in the OMC-2/3 region (Tsuboi et al. 2001).
- has N_H ~ 1-3 x10^{23} cm^{-2} and *Lx* ~ 10^{30} ergs s^{-1} assuming *kT* =3.2 keV (photons are limited).
- might be produced by collision of outflows with interstellar matter (Tsujimoto 2003).
- had never been detected from other Class 0 protostar candidates. Bona-fide Class 0 protostars might not have strong X-ray activity (Montmerle 2003).

Discussion

Detected X-ray sources are promising Class 0 sources
➔ Some Class 0 prototstars would have as strong X-ray activity as Class I protostars.

Hot plasma (*kT* ~4 keV) require at least *v* ~2000km s^{-1} if it is produced by colliding shocks.
Variation time scale is relatively short (~10 ksec timescale).
Apparent small metal abundance is oftern seen in young stars (e.g. Favata et al. 2003, Hamaguchi et al. 2003)
➔The X-ray emission might be produced by magnetic activity as Class I protostars and TTSs.

Equivalent width (EW) of Fe I line in Obs1 (~340 eV) is consistent with X-ray sources surrounded by absorbing matter with N_H~ 3x10^{23} cm^{-2} (Inoue 1985).
The Obs2 (~110eV) spectrum has smaller EW than the Obs1 spectrum.
➔Time delay effect of the reflection component? Then, Scale of the absorber is >20AU.

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