Chandra Observation of the Trifid Nebula: X-ray emission from the exciting O star Complex and Pre-main sequence stars

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Introduction: Trifid Nebula

- Textbook optical picture of classical HII region: red ionized gas from O7 star, trisected by dark dust lanes
- Recent studies show
  - A youngest HII region with $3 \times 10^5$ yr
  - Active star forming region showing HH399,
  - 4 massive protostars,
  - ~85 TTS and YSO
1300um IRAM bolometer observation: dust continuum map ⇒4 massive protostars, HCO+, SiO (J=2-1) show broad bipolar wings, Masses of 17-60 M☉ (Lefloch et al. 2000, 2001, 2002)
• Complex of ionization fronts: photoionized photoevaporative interfaces

• Evaporating gaseous globules (EGGs)

• HH 399: ~300km/s jet
  Jet is very knotty structure

• Young stars undergoing episodes of violent mass ejections

(Hester et al. 1999)
Previous X-ray observations

First X-ray image and spectra for the Trifid (Rho et al. 2001)

Images: a dozen of X-ray sources including the exciting O star HD 164492 and a few TTS and YSO (identified from near-IR)

Spectroscopy: hard X-ray photons- two T thermal models with $T=1.2\times10^6$ K and $4\times10^7$ K

(Rho et al. 2001)
2MASS: JHK diagram
IR excess (Lada & Adams 1992) => 85 PMS candidates of TTS/YSO
Chandra Observation

- ACIS-I observation: FOV is 17’ square resolution of 1arcsec.
- The data are taken on June 13, 2002
- Standard data reduction (CIAO) with charge inefficiency transfer (CIT) correction package by Towsley et al. (2001)
- Astrometry: correlation with 2MASS source catalog: 72 sources are coinciding.
Chandra Image

- 304 sources in the Trifid using wavelet method
- One-thirds are hard sources (embedded)
- Multiple sources around the O star
- Two-thirds have 2MASS counterparts

Chandra image: 14’ FOV
Red (soft 0.5-1 keV), green (1-2 keV) and blue (hard 2-8 keV) sources
Chandra Image after adaptive filters

(FOV: 7.5'x7.5')
Sources around HD164492: components A-F

A : O star
B : B6V star
CD: Brightest star – B/Be (B6V and Be) stars
C2: new X-ray source

X-ray contours superposed on HST image.

Chandra image at the central part of HD164492 complex.
HD 164492 A (O star) and B (A2)

Component A: O star (O7.5III)
- Spectrum is soft emission (kT of 0.5 keV); stellar wind
- Lack of high temperature seen in theta Ori A, C, E suggests a magnetically confined wind shock was not developed.
- 20% time variability, while theta Ori A shows 50% variability.

Component B: A2Ia
- Rare to have X-ray emission from A star
CD-C2 blend (B/Be stars)

Spectrum is hard: $kT_1=0.6$ keV and $kT_2=5.9 (>2)$ keV
C2 source is highly time variable
-CD blend and hard sources are responsible for the hard emission seen in ASCA spectrum, not the exciting O star.
X-ray emission from Class 0

X-rays in Class 0 objects (infalling stage)

- X-ray ionization is involved in bipolar flows or X-rays from accretion from the circumstellar disk

Chandra three color image superposed on 1300um contour map in OMC-3. Source 8 and 10 are X-ray counterparts of Class 0 candidates.
Discovery of X-rays from Class 0 objects in the Trifid Nebula

X-ray counterparts from massive Presettlar cores

TC1: - bipolar outflow, 0.2 pc, 0.16 Jy at 1300um => 23 M_
-no 2MASS counterpart
-X-ray spectrum: NH=6e22 /cm^2, kT=1.7 keV, Lx=4.7e31 erg/s

TC4: - bipolar outflow, 0.29 pc, 0.6 Jy (@1300um) => 58 M_
-SED shows T of 20 K
=> Clear class 0
-Chandra psf was poor
-X-ray spectrum: NH=4e22 /cm^2, kT=1.1 keV, Lx=1.9e31 erg/s

Both X-ray hardness ratios are high

Two X-ray counterparts of class 0 candidates superposed on 1300um Map in Trifid Nebula
Time Variable sources: flares

- X-ray emission from PMS: flares, magnetic dynamo processes like solar-type activities => fast rise and slow exponential decay
- Most of them has near-IR (classified TTS/YSO) or optical emission
- Two flare stars have no other counterparts, unstable light curve => early stage of star formation, earlier than class I.
Light curves (flares) from Class I PMS in rho Oph

Light curves (flares) from PMS (first three) in Trifid Nebula
A number of flare sources from ASCA/ROSAT
- 81 sources are detected using Chandra
- 70% sources of Class I objects are X-ray emitting and a lot of them show flares → X-rays from violent Magnetic reconnection events (Imanishi et al. 2001)
- Class I (YLW16A) shows strong fluorescent 6.4 keV Fe line: X-rays will shine upon and ionize the circumstellar disk
Conclusions

- Chandra observation detected ~304 X-ray sources; one third are hard sources, and two-thirds have near-IR counterpart.
- Central HD164492 complex shows O, B, B/Be stars: A, B, CD and C2 are detected in X-rays.
- The exciting O star shows soft spectrum, from wind shock, suggesting no magnetically confined wind shock: 20% variability => shock instabilities.
- CD(B6V and Be) spectrum shows very high temperature component. New Component C2, highly variable source is revealed in the Chandra image.
- X-ray emission is detected from two prestellar cores of TC1 and TC4.
- A dozen variable sources are detected: most of them have near-IR, optical counterparts. Strong PMS flare stars are likely class I candidates which light curves are similar to those in rho Oph. A few X-ray only flare stars are detected, unstable flare.