High-energy studies of the SNR CTB 37B hosting a young magnetar

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Supernova remnants (SNRs) and pulsars

- SNRs are formed by the violent explosion of a massive star (> 8-10 solar mass) at the end of its life.
- Forward shock --> heats and ionizes the interstellar medium.
- Reverse shock --> heats the expelled material (ejecta) to X-ray emitting temperatures.
- Sometimes, a neutron star or pulsar is left behind.

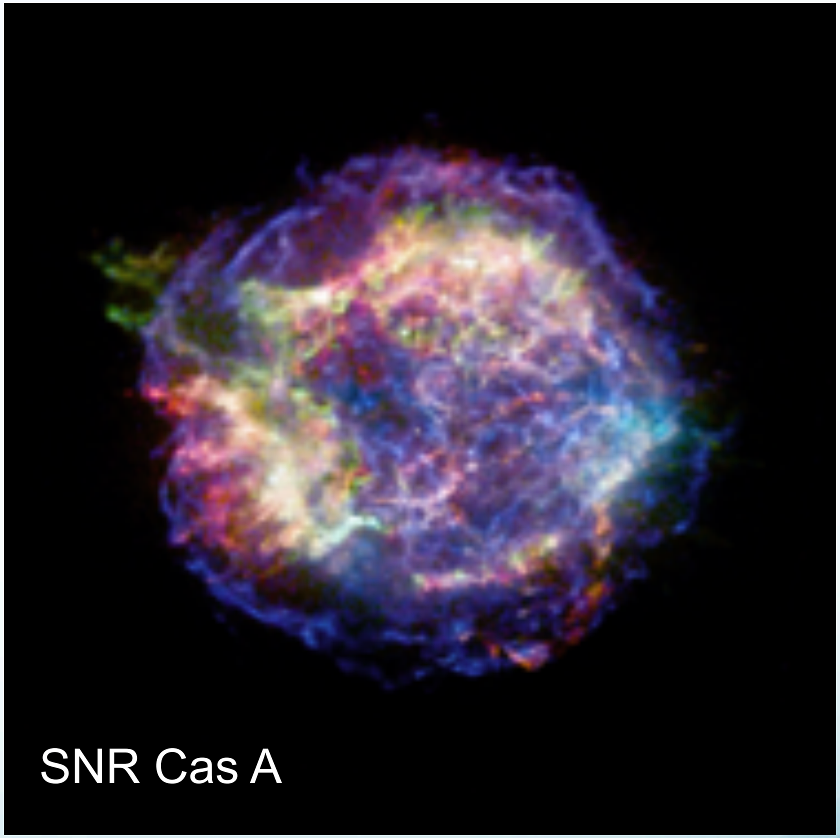


Image: NASA / CXC / SAO / D. Patnaude et al.

Highly magnetized neutron stars

- Different types of neutron stars with magnetic fields **B ~ 10^{9-15} Gauss**, powered by either rotation, accretion, or internal residual heat.

- **Magnetars**: – **Most magnetic objects known so far in the universe**.
  - Powered by magnetic field decay, typically **B ~ 10^{14-15}**, bright X-ray pulsars, shows bursting activity and spectral changes, ~23 discovered.

- **High magnetic field pulsars (HBPs)**: -- mostly discovered as radio pulsars, B-field intermediate between classical pulsars and magnetars **B ~ (4-9) x 10^{13} Gauss**, 7 discovered.
  - One of them (PSR J1846-0258) showed bursts and spectral changes (Kumar & Safi-Harb 2008; Gavriil et al. 2008).

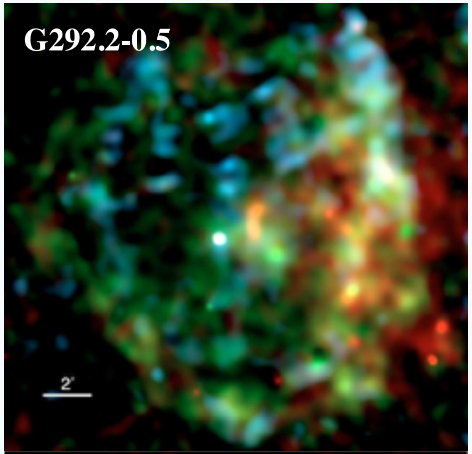
What causes a neutron star to be born as a normal radio pulsar or a magnetar?

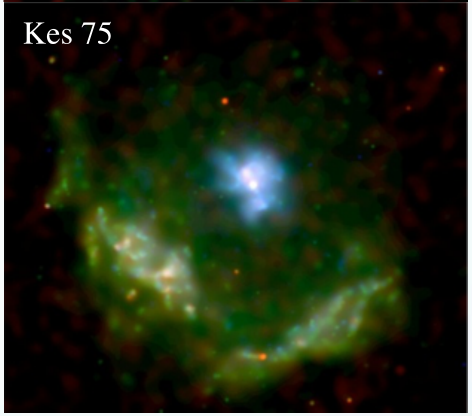
Why study CTB 37B?

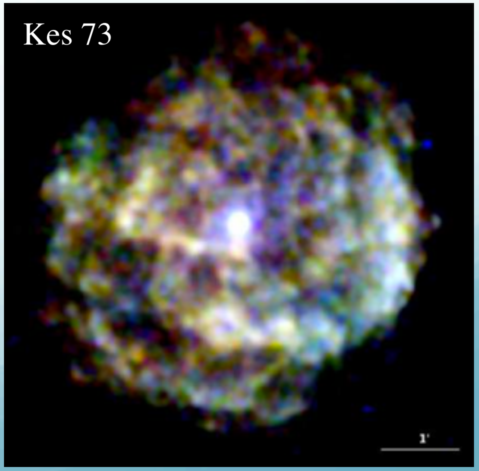
- A handful of these highly magnetized neutron stars are associated with supernova remnants.

Study the environs (SNRs) of highly magnetized neutron stars to understand their evolutionary links!

SNR CTB 37A hosts a magnetar!



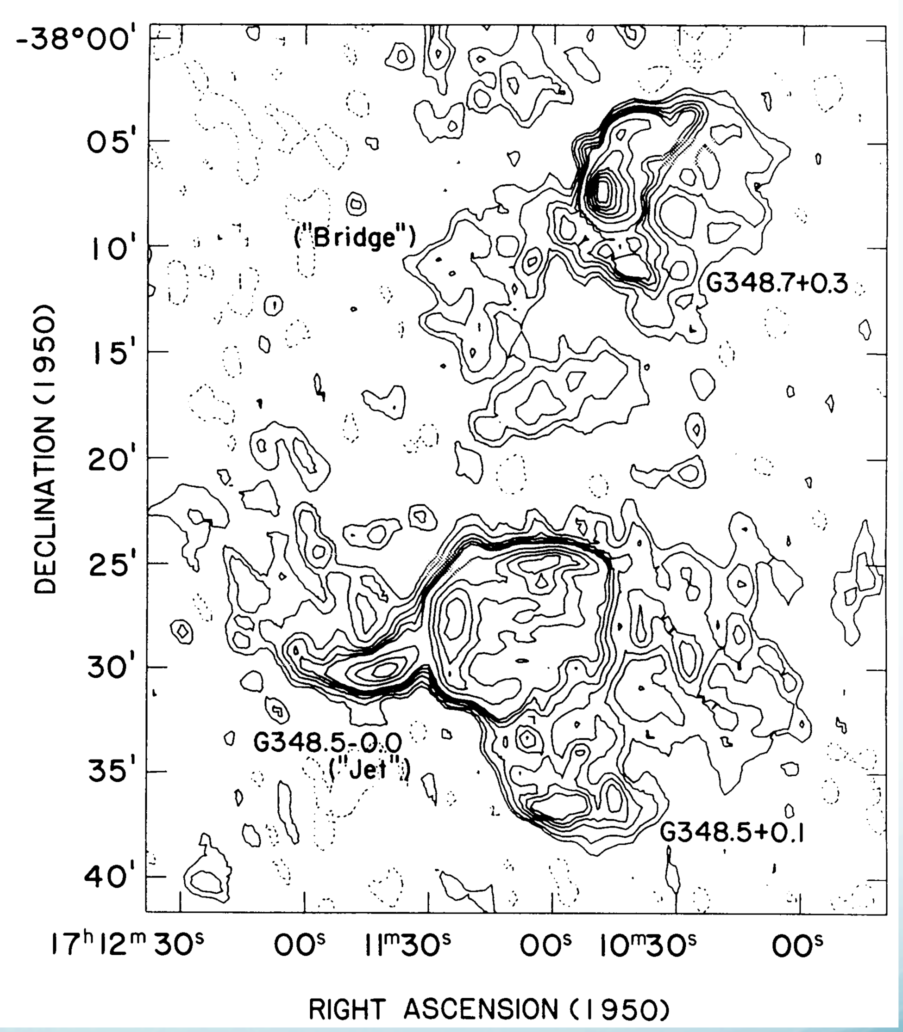




Kumar & Safi-Harb 2008; Kumar et al. 2012, 2014; Safi-Harb & Kumar 2013)

The CTB 37 complex

- A complex region consisting of 3 SNRs:
  - G348.5+0.1 (CTB 37A)
  - G348.7+0.3 (CTB 37B)
  - G348.5+0.0
- Originally thought to be 2 SNRs + a bridge and a jet from CTB 37A.



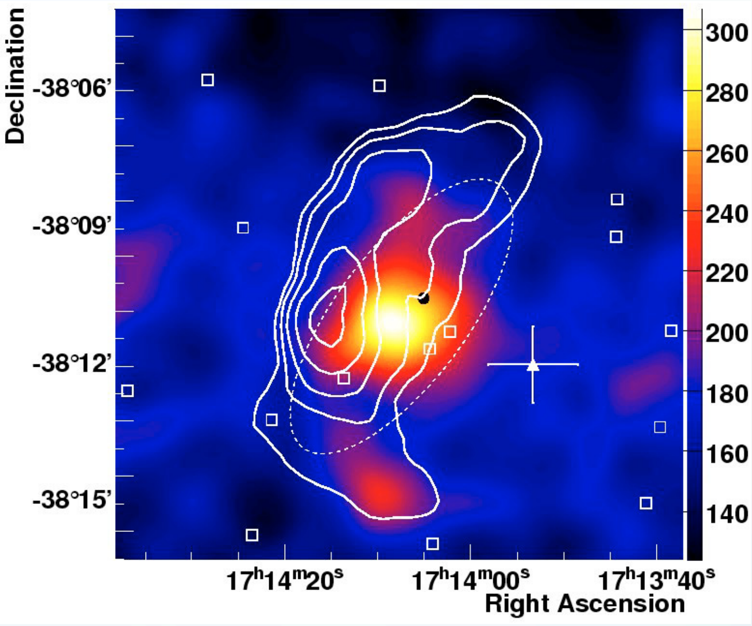
90 cm VLA map of CTB 37 complex (Kassim et al. 1991)

SNR CTB 37B

- Associated with the magnetar CXOU J171405.7-381031 (Halpern & Gotthelf 2010).
  - B-field ~ 4.8 x 10^{14} G, Characteristic age ~ 1030 yrs
- At radio wavelengths, CTB 37B shows a partial SNR shell (Kassim et al. 1991).
  - Spectral index ~0.3, Radius ~ 5.1 arcmin
- Different distance estimates ranging from 5-13.2 kpc (Caswell et al. 1975; Brand & Blitz 1993; Tian & Leahy 2012).
- We use a distance of ~10.5 kpc for the discussion of X-ray results (Roland Kothes, private communication)
- Different age estimates ranging from 600-5000 yrs (Clark & Stephenson 1975; Aharonian et al. 2008; Nakamura et al. 2009).

Previous X-ray studies of SNR CTB 37B

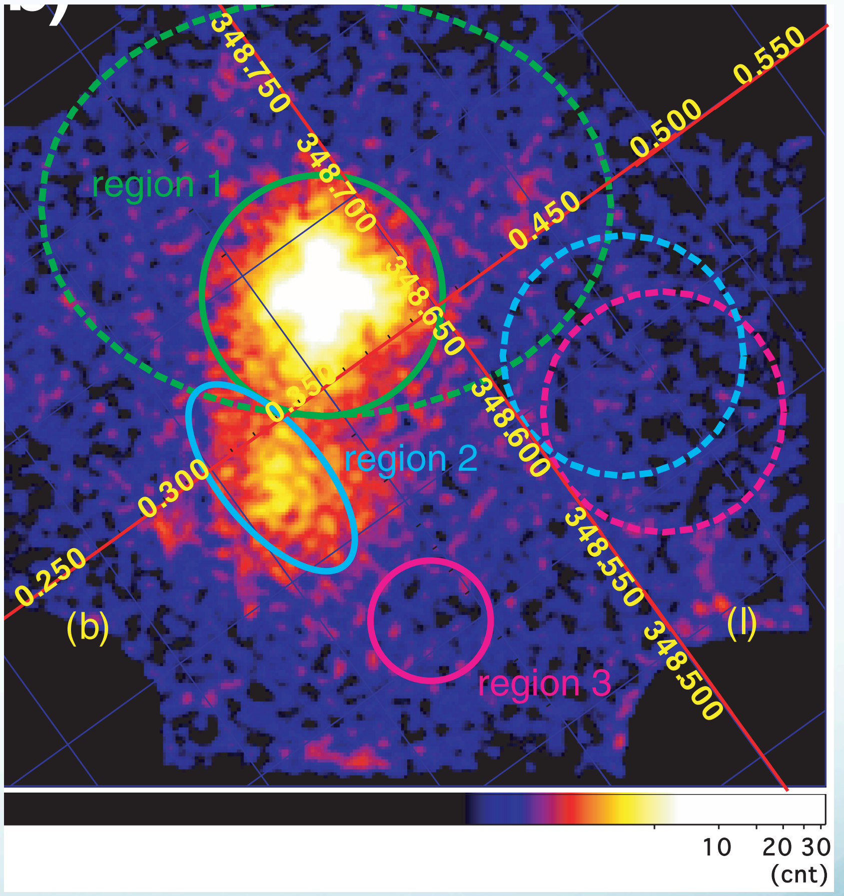
- *ASCA* (Yamauchi et al. 2008)
  - Part of the SNR detected in the galactic plane survey.
  - Poor statistics; GIS spectrum fitted with PL model gives gamma ~ 4 and a thermal model gives temperature kT ~ 1.6 keV.
- *Chandra & HESS* (Aharonian et al. 2008)
  - Diffuse emission modeled by thermal (kT ~ 0.8 keV) model; age ~ 5000 yrs.



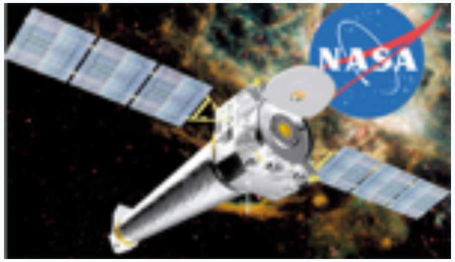
Chandra 1-5 keV image overlaid with radio contours; HESS emission marked by white cross (Aharonian et al. 2008)

Previous X-ray studies of SNR CTB 37B

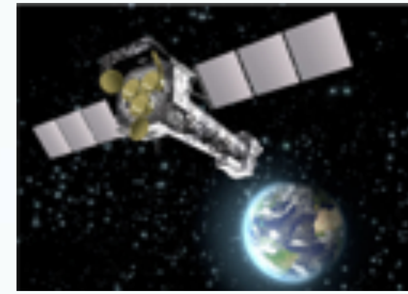
- *Suzaku* (Nakamura et al. 2009)
  - SNR emission: thermal + non-thermal.
  - Thermal (NEI) model gives kT ~ 0.9 keV and a very young age ~ 650 yrs.
  - No enhanced abundances
  - Non-thermal (PL) emission from the southern part of the remnant; gamma ~ 1.4
- *XMM-Newton*
  - Compact source within the SNR was identified as a magnetar (Sato et al. 2010).



3-10 keV Suzaku image (Nakamura et al. 2009)



X-ray observations of CTB 37B

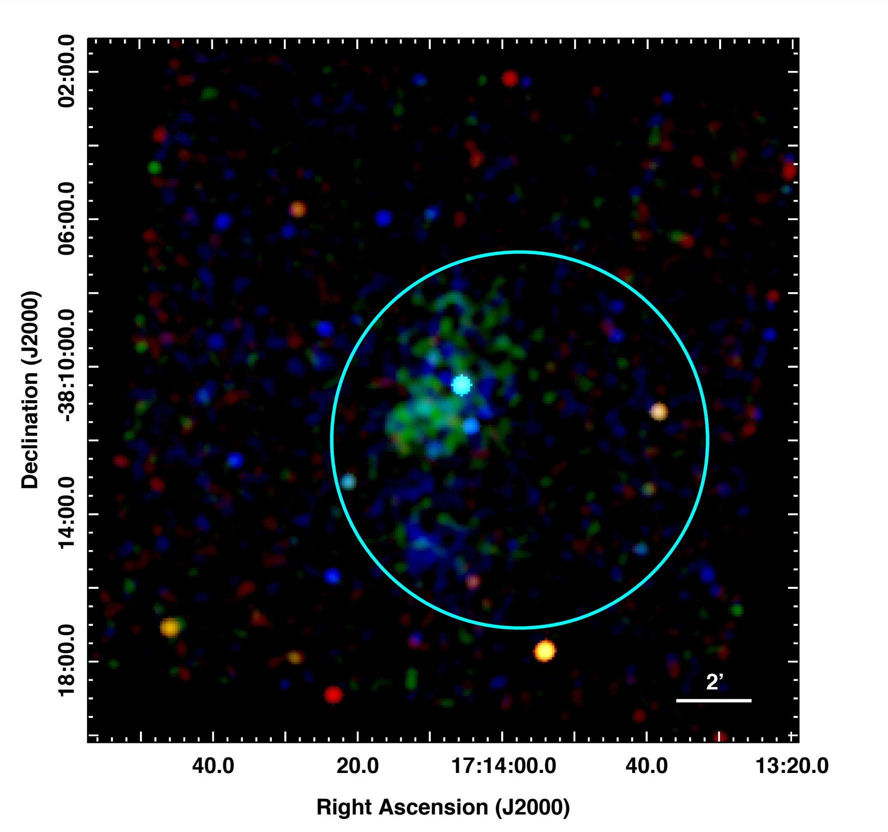


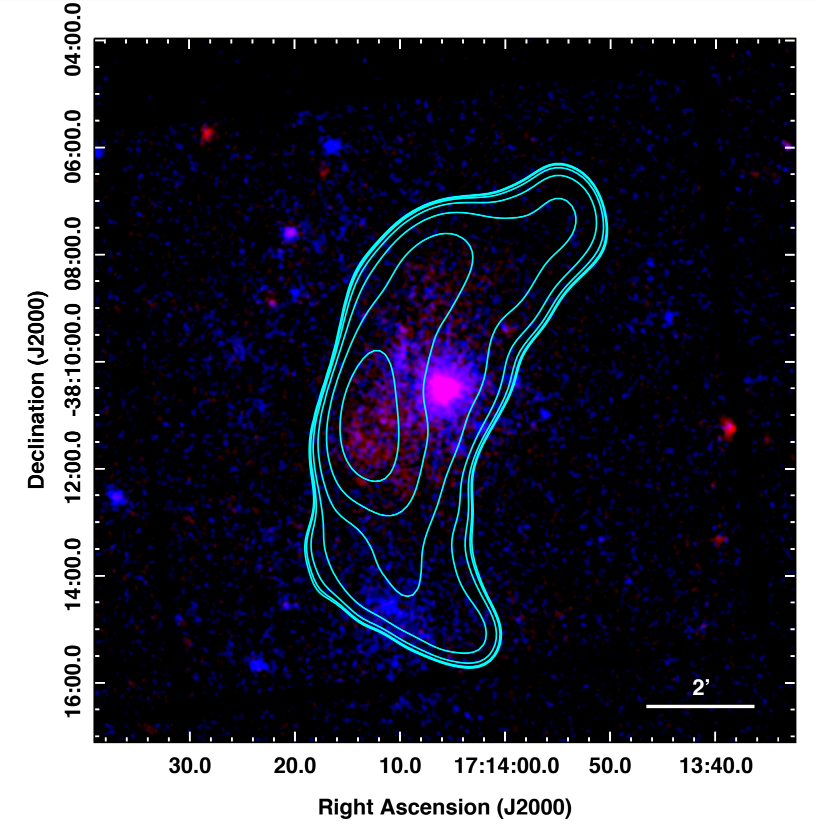
- Present study combines all the *Chandra* and *XMM-Newton* (0.5-10 keV) archived observations of SNR CTB 37B with the goal:
  - To perform a spatially resolved spectroscopic study targeted to search for ejecta signatures expected from a young remnant.
  - To revisit the estimate of the age of the remnant and determine the SN explosion energy and the ambient density.
- 1 *Chandra* (~25 ks) + 2 *XMM-Newton* observations (~120 ks)

Imaging analysis of CTB 37B

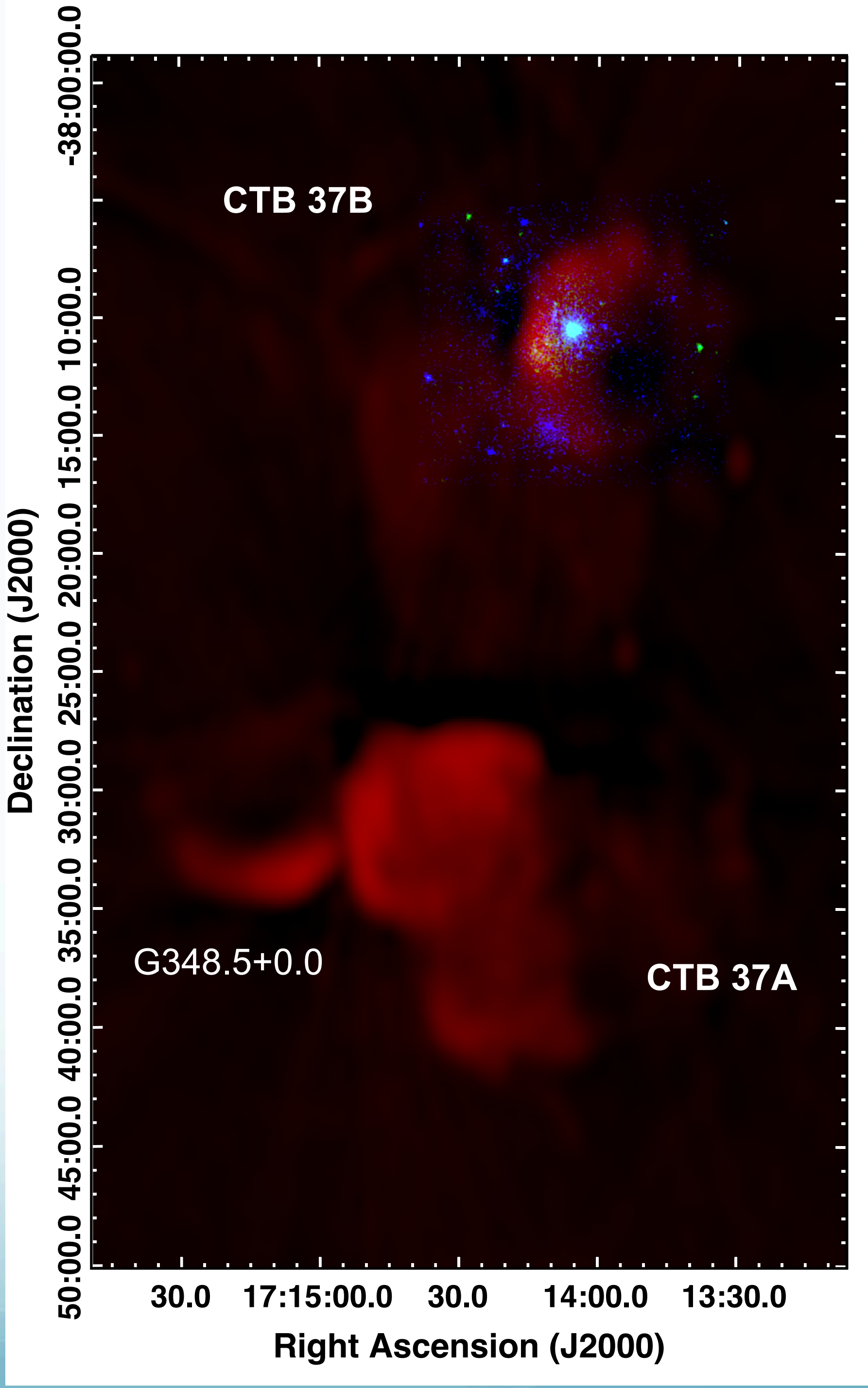
- Left: Smoothed *Chandra* true-color image [0.5 – 1.2 keV (red); 1.2 – 2.0 (green); 2.0 – 7.0 keV (blue)].

- Right: XMM-Newton 2-color image [0.5 – 2.0 keV (red); 2.0 – 7.0 keV (blue)] overlaid with radio contours (MOST).



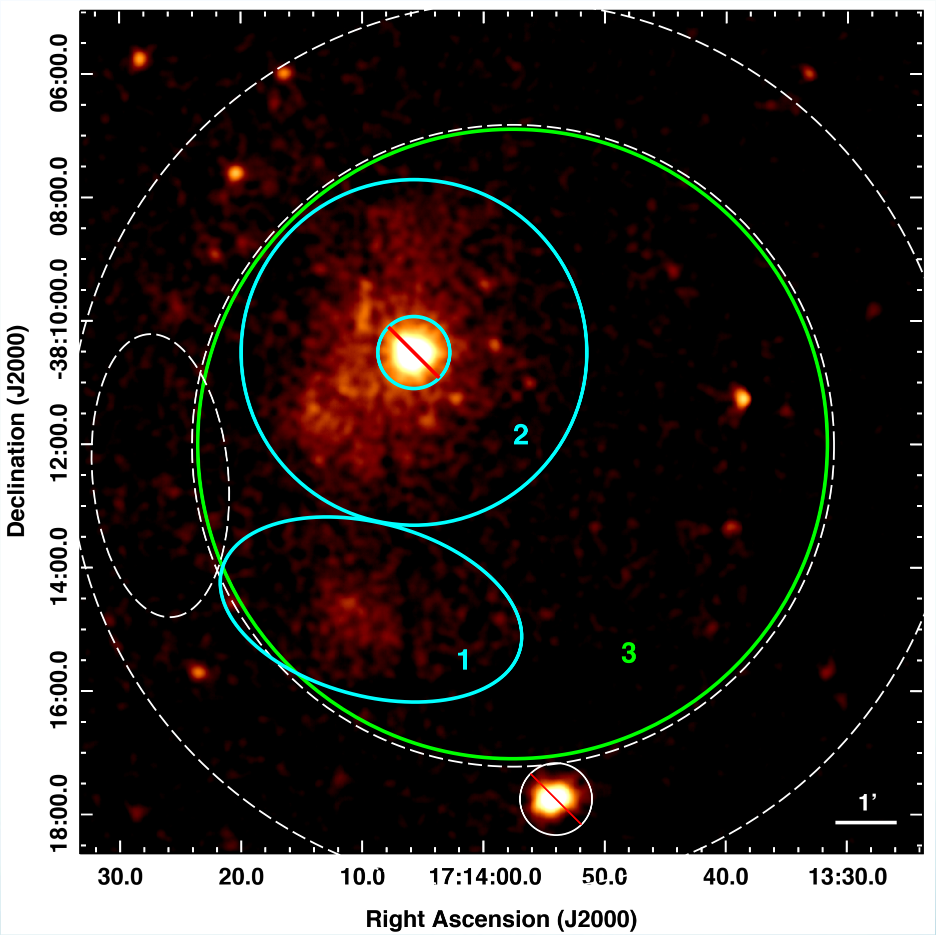


Radio (red) – MOST data
X-ray (blue) – XMM-Newton data



Spectral analysis of SNR CTB 37B

- Diffuse emission regions selected from both *Chandra* and *XMM-Newton* data.
- Region 1: Elliptical region towards south (cyan).
- Region 2: Central diffuse emission (cyan).
- Region 3: Global SNR ~ 5.1 arcmin (green, from radio) excluding the pulsar and other point sources.
- Background (dotted annulus and ellipse in white).

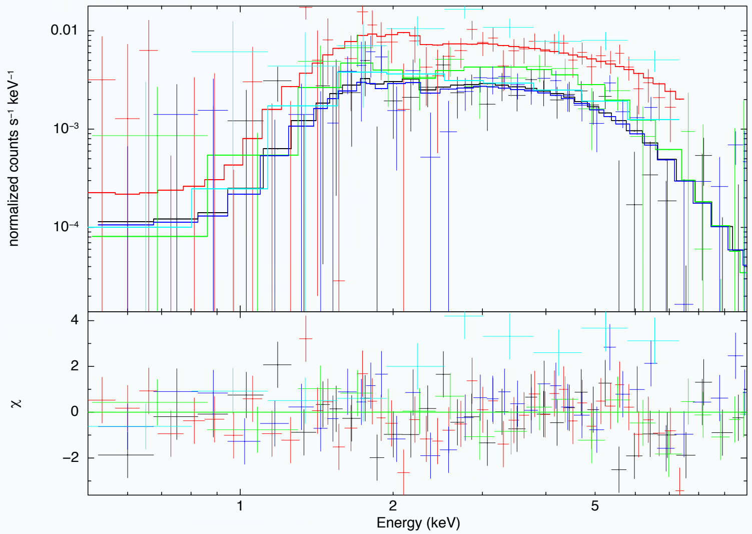


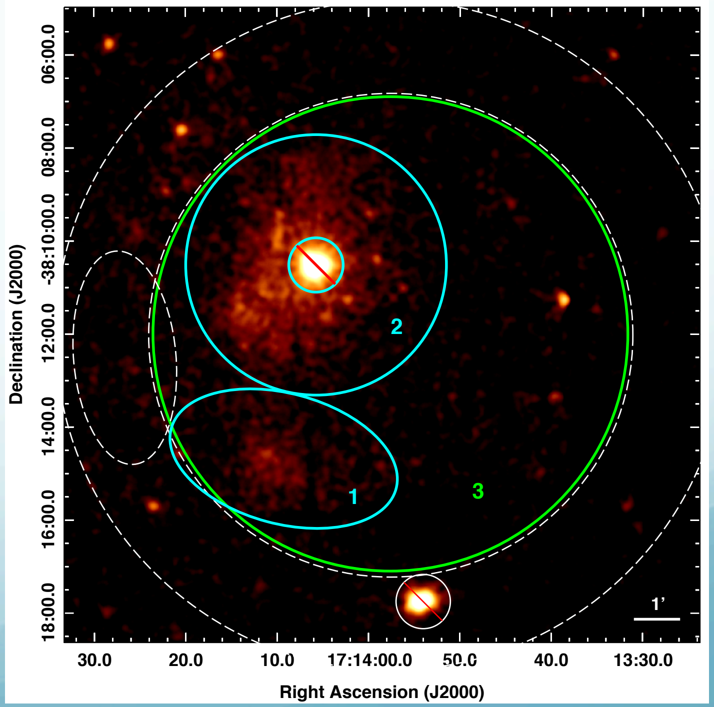
XMM-Newton image of CTB 37B showing the regions and background selected for spectroscopy.

SNR spectroscopy results

- *Region 1 (south region): Nonthermal emission*
  - Gamma = 1.4 (1.1 – 1.7) keV.
- *Region 2 (central diffuse):* thermal +non-thermal emission
  - kT_s = 0.7 (0.5-1.3) keV.
  - Nearly solar abundances.
  - Gamma = 3.4 (consistent with the magnetar photon index).

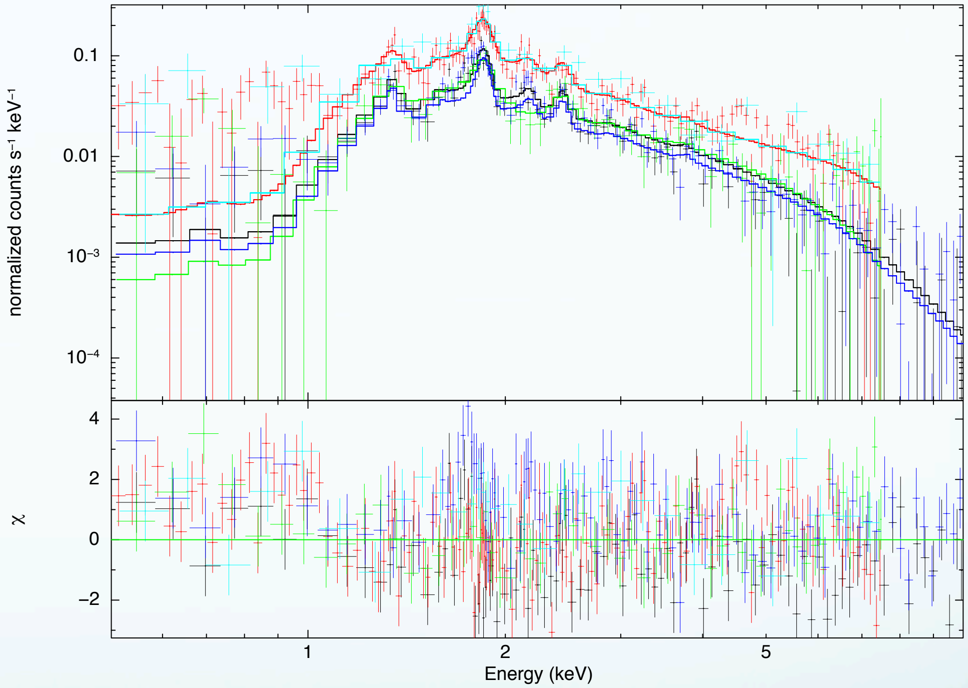
PL fit





SNR spectroscopy results

- *Global SNR*
  - Gamma = 1.4 (frozen to that obtained for the southern region).
  - kT ~ 1.5 keV.
  - Mg, Si, S emission lines - solar abundances



Global whole SNR fitted with a thermal (vpshock) + powerlaw (PL) model;
$N_H = 2.9 \times 10^{22}$ cm^{-2}

SNR CTB 37B X-ray properties (preliminary results)

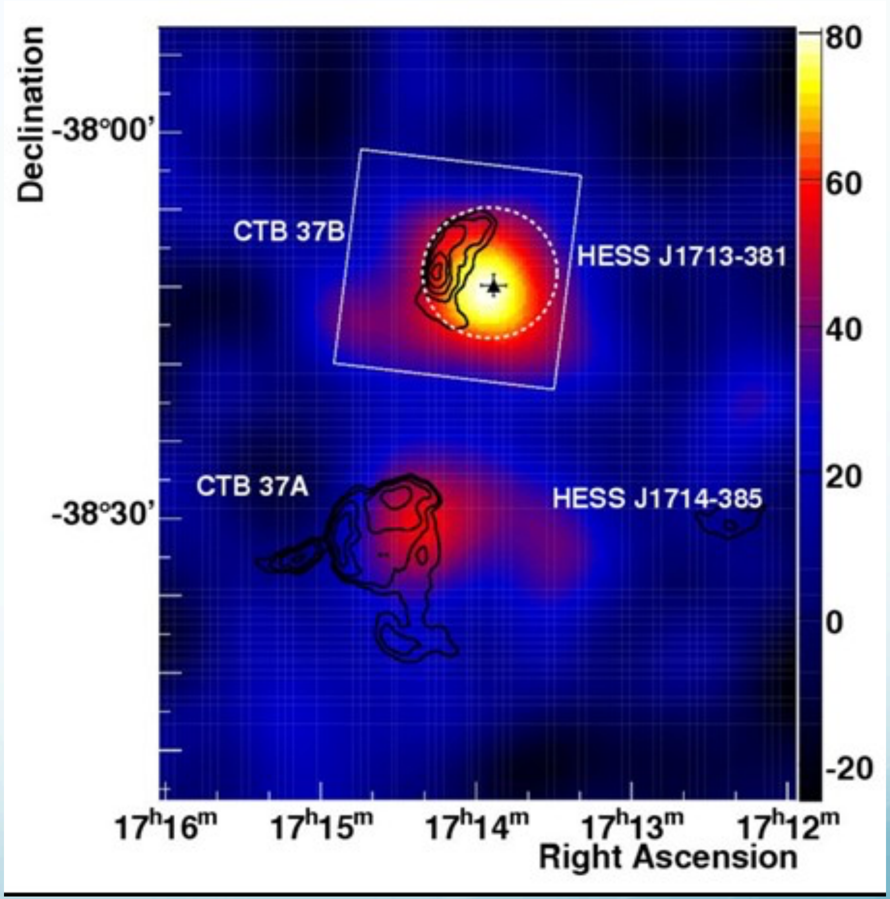
- SNR free expansion age ~3000 $D_{10.5kpc}$ yr, assuming an expansion velocity of ~ 5000 km s^{-1} (Distance ~ 10.5 kpc).
- We use the VPSHOCK component fit to the global SNR spectrum:
  - Shock velocity ~ 1100 km s^{-1}.
  - SNR age ~ 5400 $D_{10.5kpc}$ yr.
  - Explosion energy ~ 3 x 10^{50} ergs.

  The inferred SN explosion energy is comparable to other "typical" SNe.
- First spatially resolved spectroscopic study of the SNR using all available *Chandra* + *XMM-Newton* data -- shows both thermal + non-thermal emission

Kumar, Safi-Harb & Kothes (2015) in prep.

Gamma-ray studies of CTB 37B

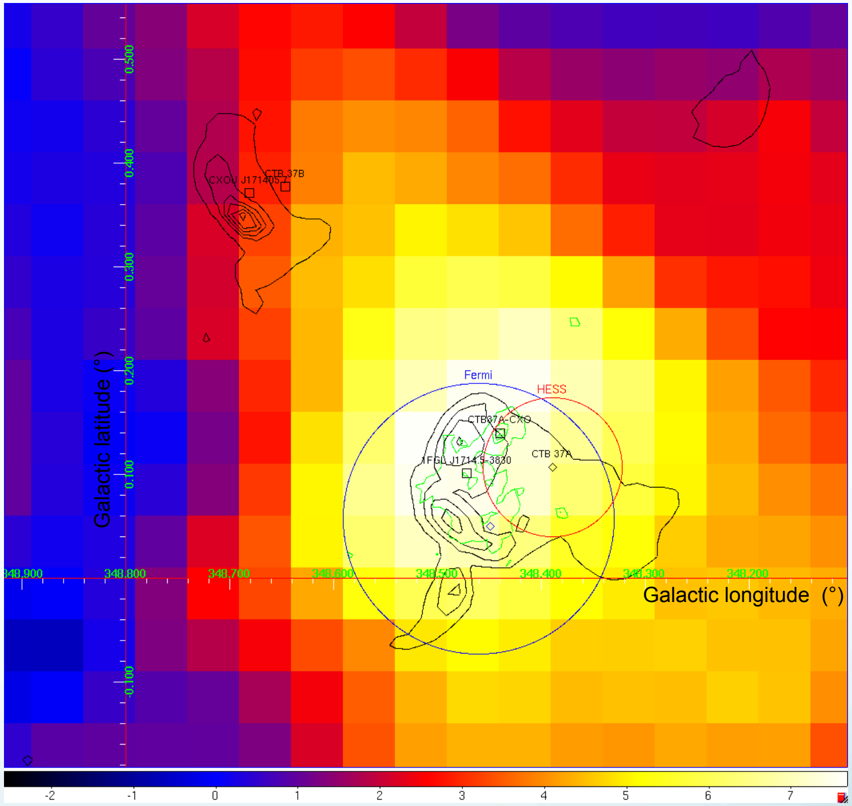
- HESS detection of the CTB 37 complex.
- VHE gamma-ray source detected – HESS J1713-381 – coincident with CTB 37B.
- HESS J1713-381 spectrum fitted with a PL (gamma ~ 2.7).
- Origin of TeV emission: from the SNR shell, and partly from the neutron star.



Aharonian et al. 2006, 2008

What about Fermi?

- So far, no detection (although CTB 37A has been detected with Fermi; Castro et al. 2013).
- No pulsations from a blind search
- Possibility of Fermi detection with more years of data?
- An upper limit would be also useful for modeling the radio to gamma-ray data.



Fermi LAT residual map using 18 months of data (2008-2010) in the 0.2-50 GeV energy range.

Future direction

- Fermi-LAT has not detected any magnetar emission yet, but GBM has caught many magnetar bursts!
- Possibility of detection with more years of data?