Some notes on SNRs

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These notes are assembled for my own self-edification, to learn about (1) X-ray astronomy, both physics and observational pipeline, (2) supernovae and their remnants, and (3) Tycho's SNR, and the physics relevant to my summer project. Information comes from the literature, *Chandra* info from the CXC, various textbooks, and discussions with my mentors Brian Williams and Rob Petre. Information may easily be wrong and I make no claims to accuracy/quality, though I will aim to cite sources where possible.

This is a summer 2014 internship project under the auspices of GSFC and CRESST. Mentors are Dr. Robert Petre and Dr. Brian J. Williams.

1 GSFC logistics

Notes from 1st meeting, Tues May 27.

Some things to attend. July X-ray meeting to be moved.

- 662 meeting – 1st Friday of every month, 10:30am, Rm W120
- Coffee (just socializing) – Weds 10am
- ASD colloquium – Tues 3:45p (3:30p meet speaker), Rm W150
- GSFC colloquium – Fri 3:30p, Bldg 3, Goett Auditorium

2 Introduction

A little bit about the project. Builds on Ressler et al. (ApJ, in press). Goal is to obtain FWHM of Tycho filaments.

If there is time, we will proceed to try perhaps Kepler, even Cas A (both are quite a mess). SN 1006 was HARDER than Tycho, really... so this is supposed to be fairly straightforward!

3 X-ray astronomy

First, where are X-rays on the EM spectrum? X-rays generally have energies from 0.1 to 100 keV. They are divided into *soft* and *hard* X-rays, where the division is at a few (1–10) keV. Beyond ∼100 keV we move into gamma rays; below ∼0.1 keV we move back into ultraviolet.

Next, what emits X-rays? What processes are probed? X-ray emitting temperatures are about 10^6 to 10^7 K.

Finally, what instruments conduct X-ray astronomy? The big ones are *Chandra*, *XMM-Newton*, and *Suzaku* (older ones incl. Einstein, ASCA, ROSAT). Swift does have X-ray capability, but is designed for GRB detection; its X-ray, UV, and optical imaging are for GRB afterglows. It is also handy for transient detection (e.g., if a nearby SN goes off...). K. Dyer has put together a nice table of past/present x-ray satellites.

Nearby, NuSTAR is covering hard X-rays (10 to 100 keV). Fermi is very far away, at 20 MeV to ∼50 GeV. In UV, the optical astronomers kind of cover the near UV (e.g., HST). GALEX, FUSE, EVUE also have been flown but seem to be done? Low end of extreme UV is ∼0.1 keV.

Apparently, the tie between radio and X-ray observations is due to the imaging of *synchrotron radiation*? So we can probe very energetic processes in both bands.

3.1 Radiative processes

Synchrotron radiation, thermal (line) emission, etc.

4 *Chandra* observations

Our SNR observations are generally made with ACIS-I (occasionally ACIS-S). ACIS has energy range about 0.7 to 8 keV, see Figure 1. The suffixes (I,S) refer to the CCD array configuration, square for I and lined up for S. No grating is used. Gratings would be used for spectroscopy – perhaps HETG with ACIS-S (up to 1000 bins from 0.4 to 10 keV).

How does ACIS work? It's a CCD that enables photon counting, basically. As Rob as noted, we get four pieces of information: time, energy, polarization, and location on the sky. We don't really care about time/polarization here (since we are neglecting, or correcting for, proper motion).

The spectral resolution is frequency dependent (of course), but also *row number* dependent (i.e., depends on where on the CCD you strike). The FWHM resolution is around 100–300 keV, with decreasing resolution at higher energy (FWHM scales as sqrt of energy); this assumes that a charge transfer inefficiency correction is applied in CIAO. Spectral resolution depends on how well we can measure the energy deposited (in the form of mobilized charges, electron-hole pairs) by each photon. Apparently, the front-illuminated (FI) CCDs were damaged because they were previously left in the focal plane during radiation belt passages. So now they move it each time, which has minimized the damage!

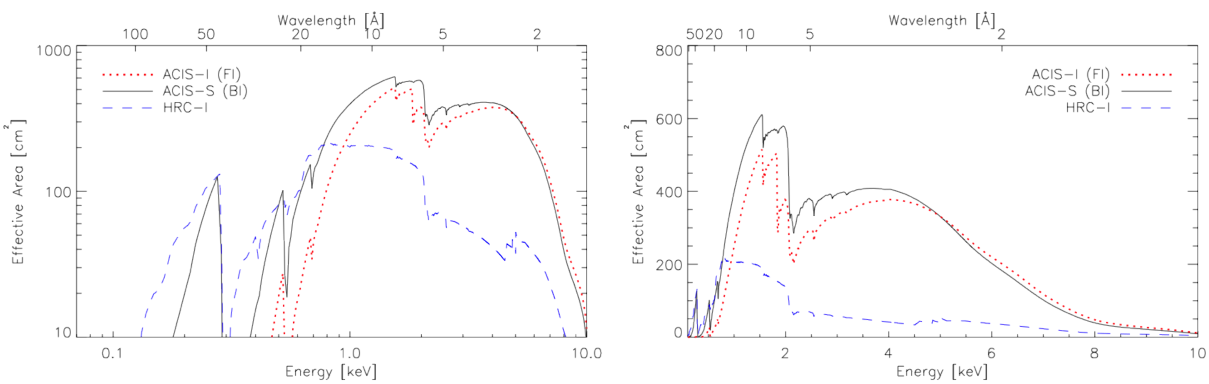

Figure 1. On-axis effective areas for *Chandra* instruments, predicted for Cycle 16 observations (2015?). Plot is for an integrated point source (?). Modified from *Chandra* Cycle 16 POG, Figure 1.3.

Observations are broken into exposure chunks of ∼10 to 180 ksec, limited by radiation belts and thermal considerations.

Information about specific observation runs are on *Chandra* WebChaSeR (simply search 'Tycho' or 'SN 1006'). Here you can get raw data, which can be processed with CIAO and CALDB. Information about the ACIS instrument is in Chapter 6 of the proposer's guide.

5 Supernova physics

Velocities of forward shock in supernovae are about 10^4 km/s. Very fast, very energetic.

6 Tycho's SNR (SN 1572)

Aliases: G120.1+1.4 Tycho, 3C10, SN1572 Bibliography on Tycho, up to 2009: http://www.mrao.cam.ac.uk/surveys/snrs/snr
Also more papers (up to 2014) http://www.physics.umanitoba.ca/snr/SNRcat/SNRrecord.php?id=G120.1p01.4

Acciari et al. 2011 ApJL, find TeV gamma rays in a smush, around the SNR BEAUTIFUL picture of a CO cloud possibly interacting, and the gamma ray emissions is offset as well. Short, sweet paper.

Giordano et al. 2012 ApJ, Fermi LAT observation of Tycho. Describe emission as due to pion decays from cosmic-ray acceleration into ISM. http://iopscience.iop.org/2041-8205/744/1/L2/

B field amplification (2004) http://arxiv.org/pdf/astro-ph/0409453v2.pdf (Tycho and similar) Nonthermal filaments study (2005) http://iopscience.iop.org/0004-637X/621/2/793/pdf/0004-637X_621_2_793.pdf

6.1 SN 1006