Supernova Remnants in the ChASeM33 X-ray Observations of M33

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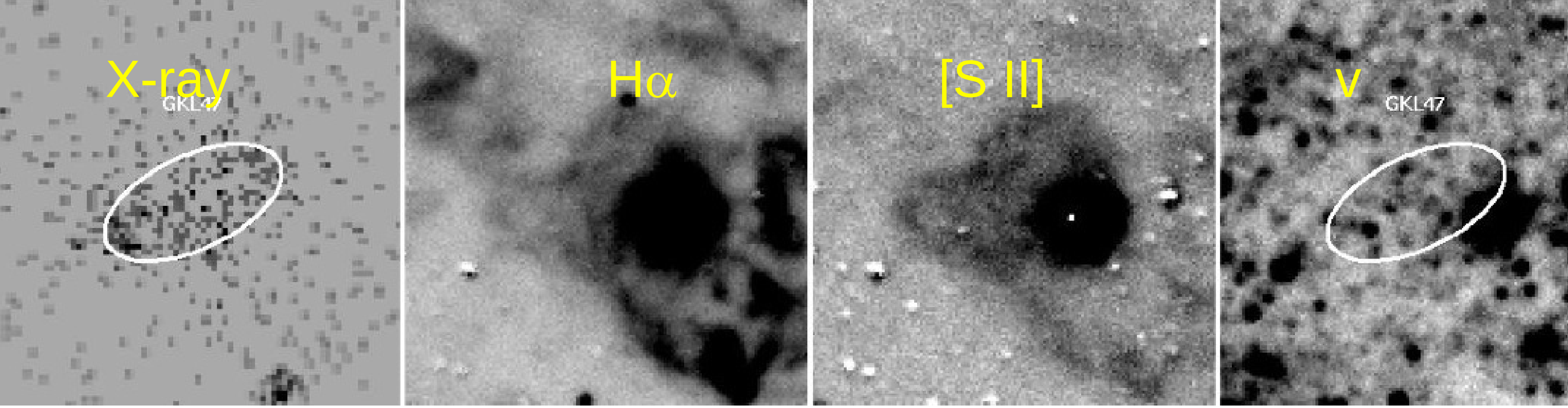
Abstract

M33 contains many emission nebulae identified as supernova remnants (SNRs) based on the high [S II]:H alpha ratios characteristic of shocked gas. Using Chandra data from the ChASeM33 survey with a 0.35-2 keV sensitivity of about 2 10^{34} ergs s^{-1}, we have detected more than 70 of these nebulae, yielding confirmation of their SNR identifications, and providing the largest homogeneous sample of remnants detected at optical, radio, and X-ray wavelengths in any galaxy, including the Milky Way.

A spectral analysis of the six X-ray brightest SNRs reveals that two, G98-31 and G98-35, have spectra that appear to be dominated by ejecta from a core-collapse explosion. In general, the X-ray detected SNRs have soft X-ray spectra compared to the vast majority of sources detected along the line of sight to M33. We found no new extended X-ray sources likely to be SNRs. It is unlikely that there remain to be discovered any other thermally dominated X-ray SNR with luminosities in excess of about 4 10^{35} ergs s^{-1} in the portions of M33 covered by the ChaSeM33 survey.

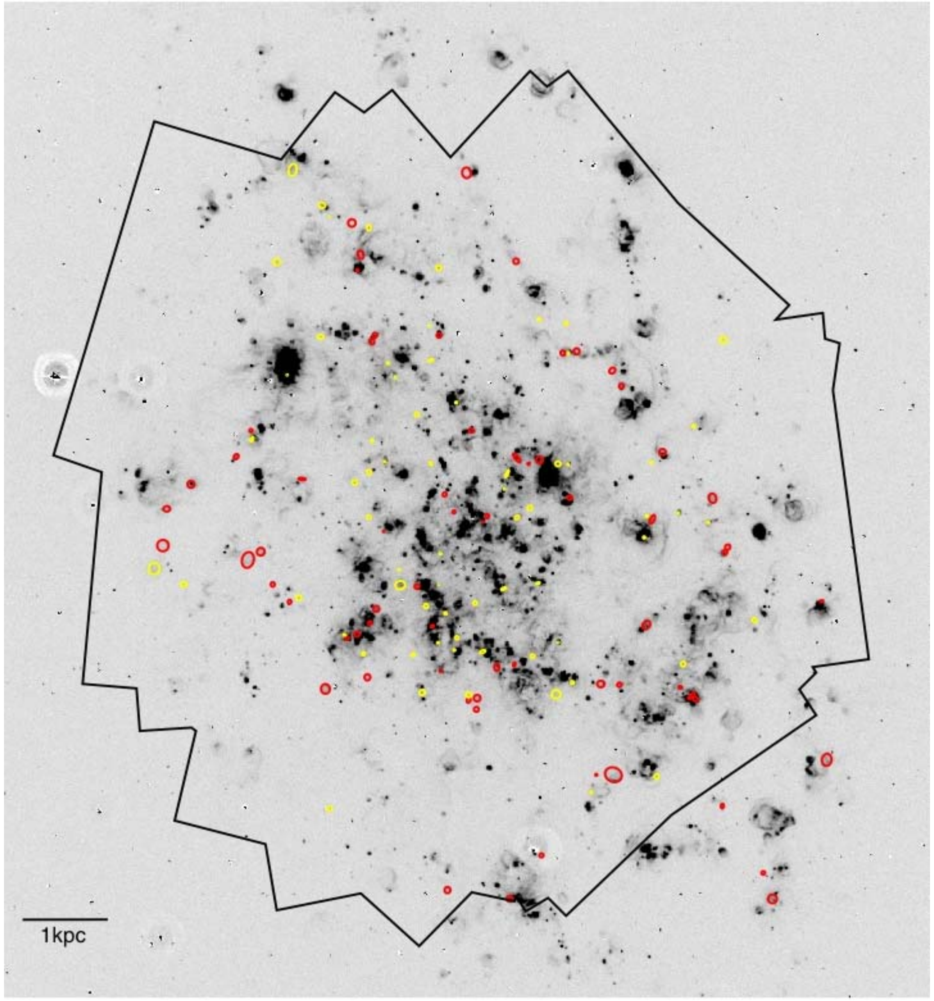
There are no close analogues of Cas A, Tycho's SNR or the Crab Nebula in M33, but we have found an X-ray source with a power law spectrum coincident with a small-diameter radio source that may be the first pulsar-wind nebula recognized in the galaxy.



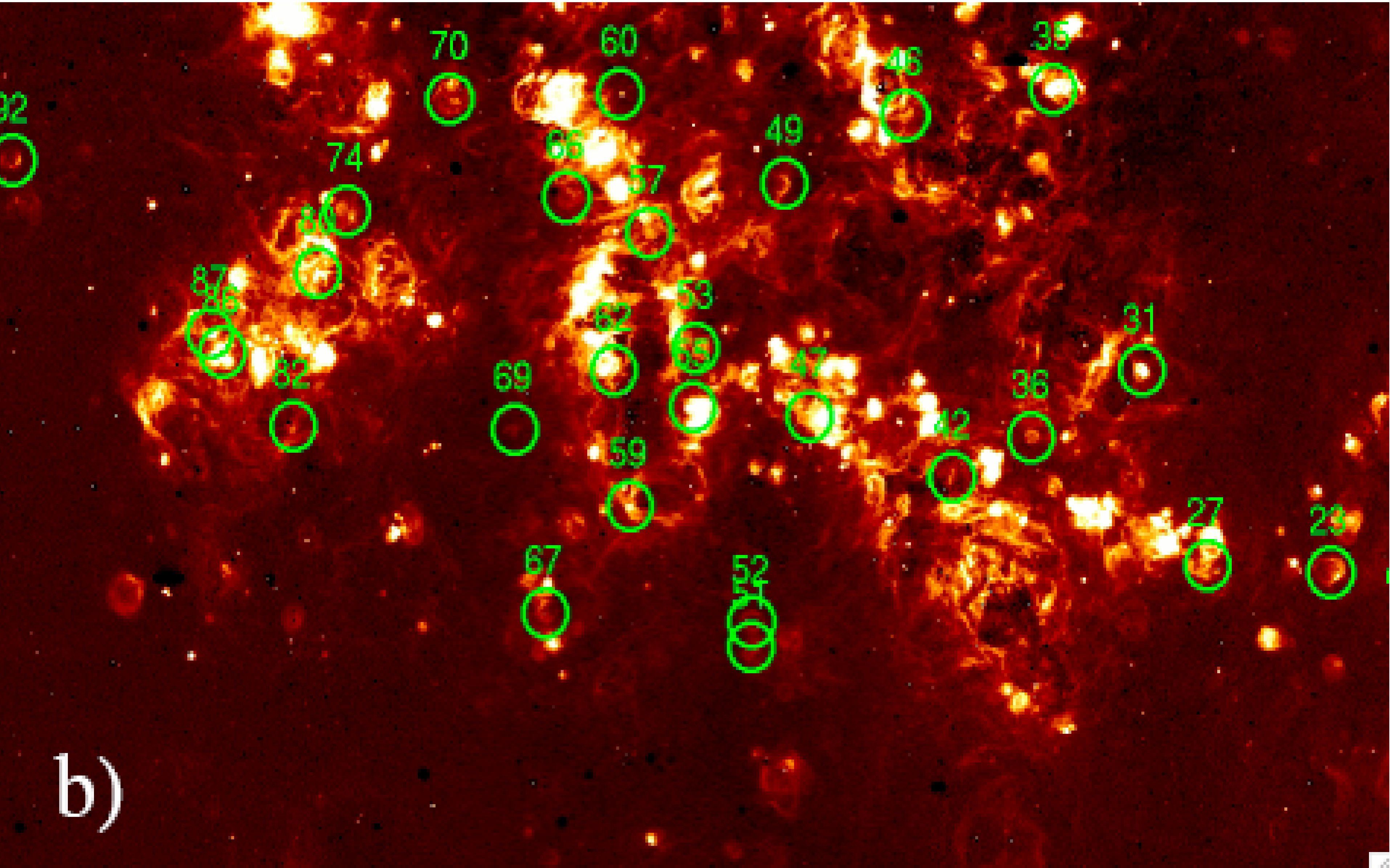
- SNRs in nearby galaxies identified primarily from [SII]:Ha ratios > 0.4. HII regions ~ 0.1
- ~100 optical SNRs had been identified in M33
  - 98 from [S II]: Ha imagery (Gordon et al 1998)
  - 53 have radio fluxes (Gordon et al 1999)
- Before Chandra and XMM, few SNRs detected in X-rays outside Galaxy and MCs. In M33:
  - 10 counterparts with ROSAT (Long et al.1996)
  - 22 with Chandra (Ghavamian et al. 2005)
  - 12 (+13 candidates) with XMM (Misanovic et al 2006)

ChASeM33

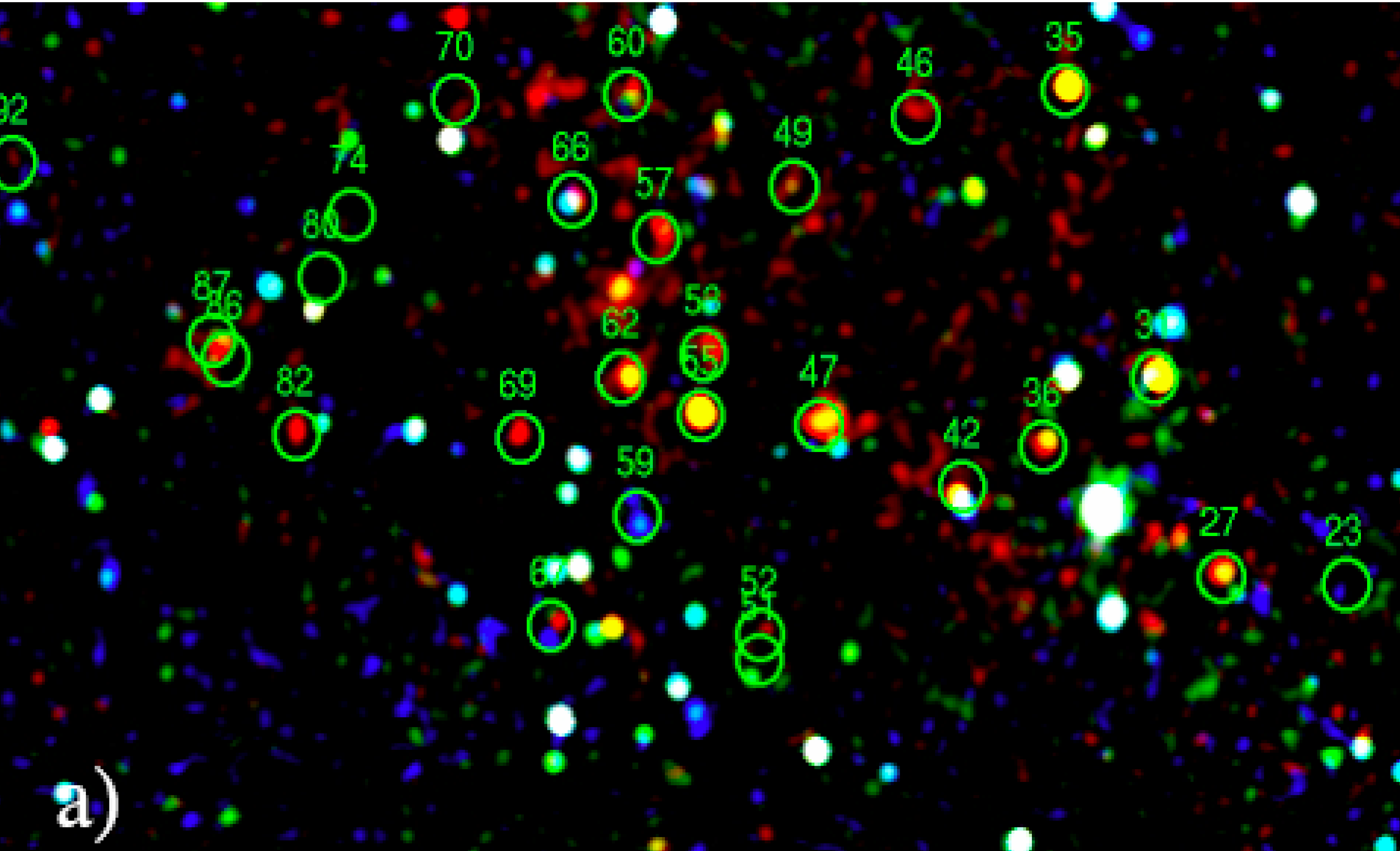
- Most of M33 to a minimum depth of ~ 200 ksec, 400 ksec typical.
- SNRs to $L_X \sim 2\ 10^{34}$ erg s^{-1}.
- M33 has 137 known or suggested SNRs
  - 98 from Gordon et al (1998)
  - Remainder X-ray suggested or our re-examination of optical
- FirstLook survey (Plucinsky et al 2007) identified 26 SNRs from half of the ChaSeM33 data and approach optimized for point sources
- We use full dataset and SNR sample



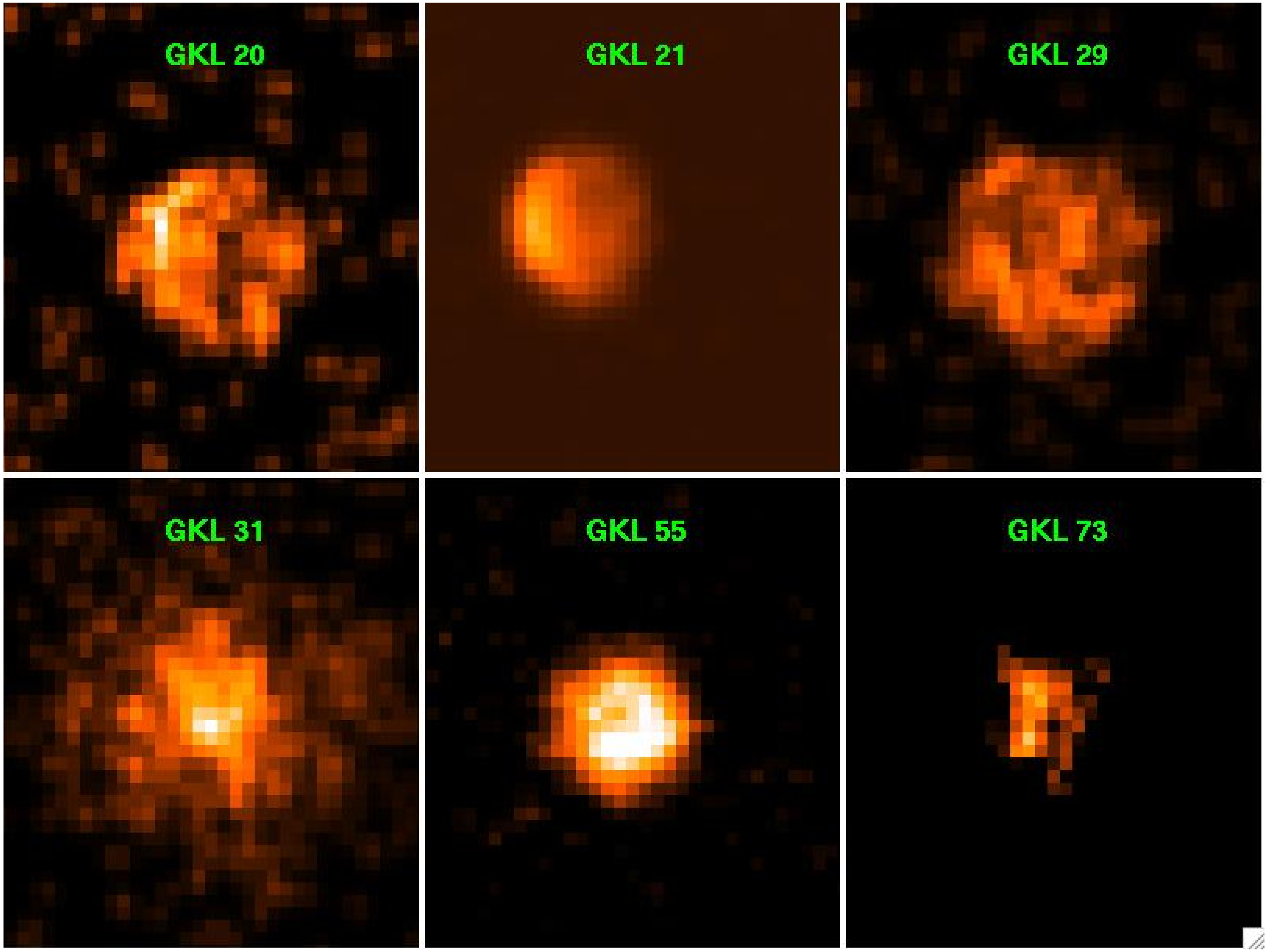
Hα images of Southern Arm



Optical SNRs in M33's southern spiral arm on Chandra image

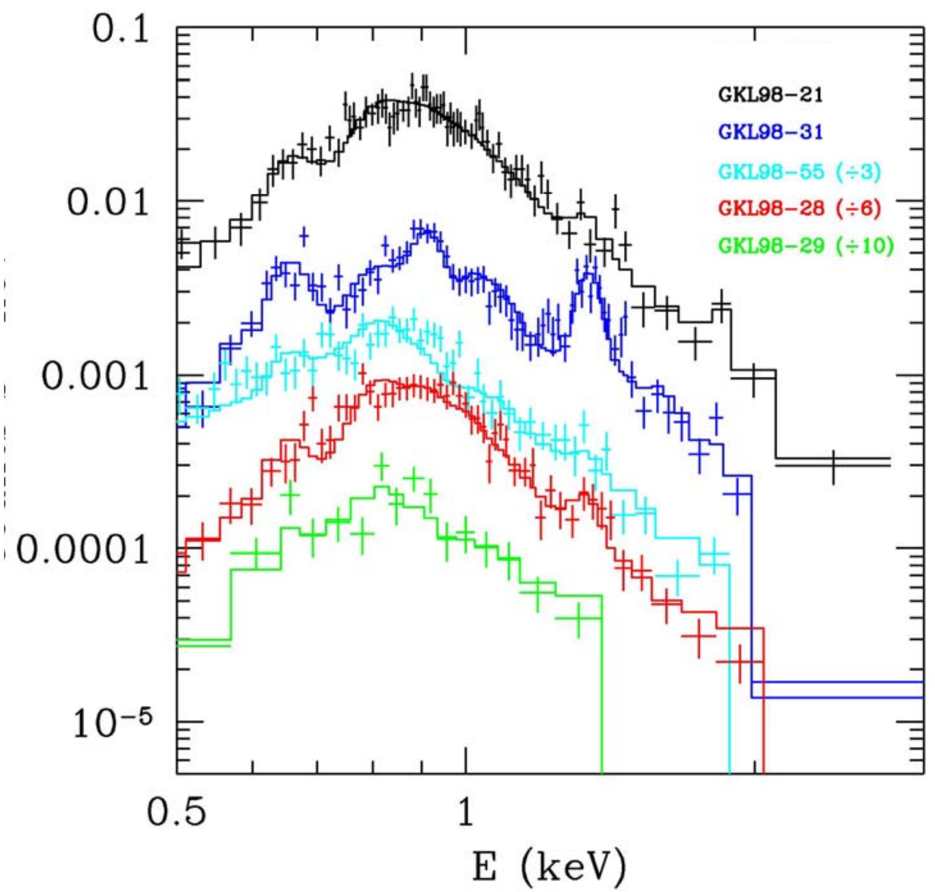


Imaging of Bright SNRs

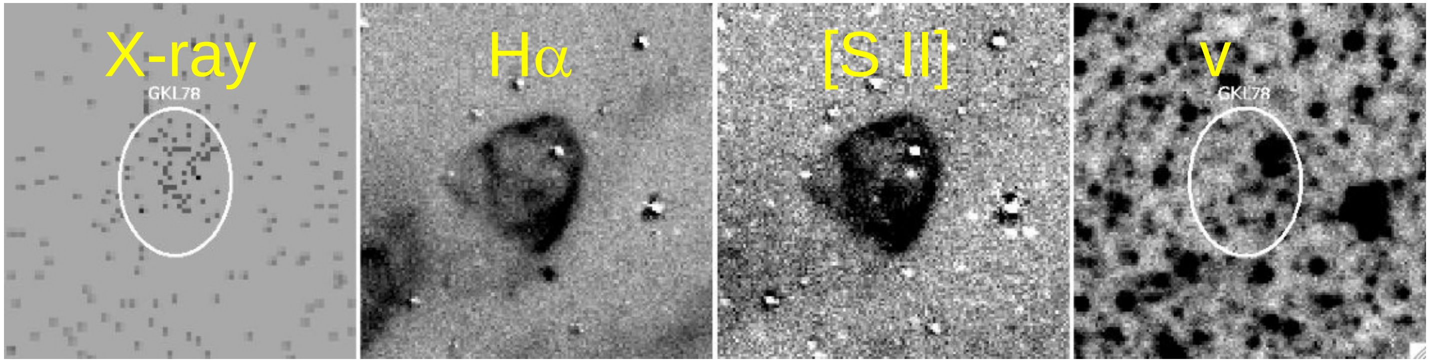


Spectroscopy of Bright SNRs

- 6 SNRs with enough counts for spectral analysis
- M33 SNR 21 is ISM-dominated expanding into dense molecular cloud (Gaetz et al 2007)
- M33 SNR 31 has a spectrum resembling the core-collapse object E0102 in the SMC



Finding X-ray SNRs

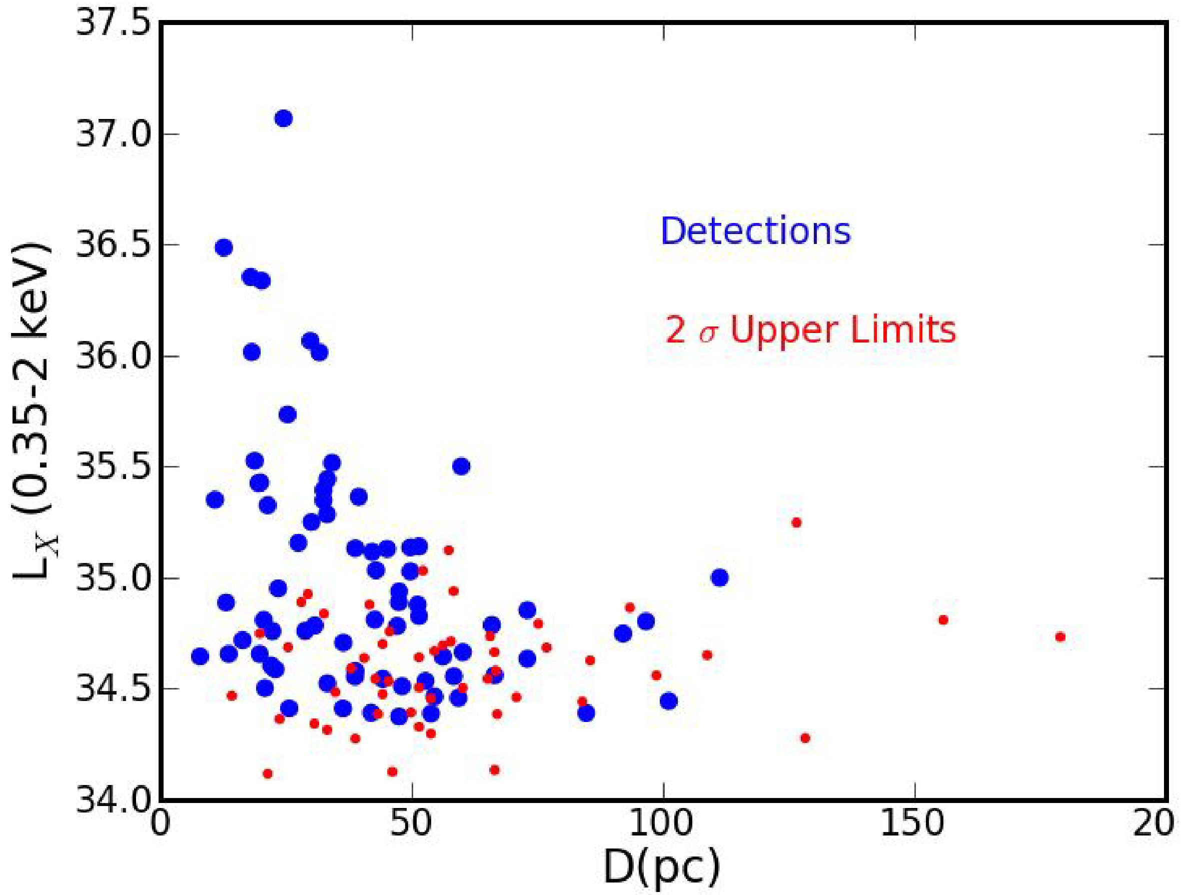


- We use Patrick Broos' AcisExtract since:
  - SNRs are only slightly extended in M33
  - M33 has both lots of SNRs and point sources
- We measure SNR sizes by inspecting optical and X-ray data
- The Procedure
  - Pass 1 - Carry out standard extraction treating all as point sources
  - Create SNR region files by expanding point source region files to account for SNR size
  - Pass 2 - Replace point source region files of SNRs and re-process the SNRs only
  - Check and edit SNR files to assure region files are appropriate
  - Repeat Pass 2 as necessary

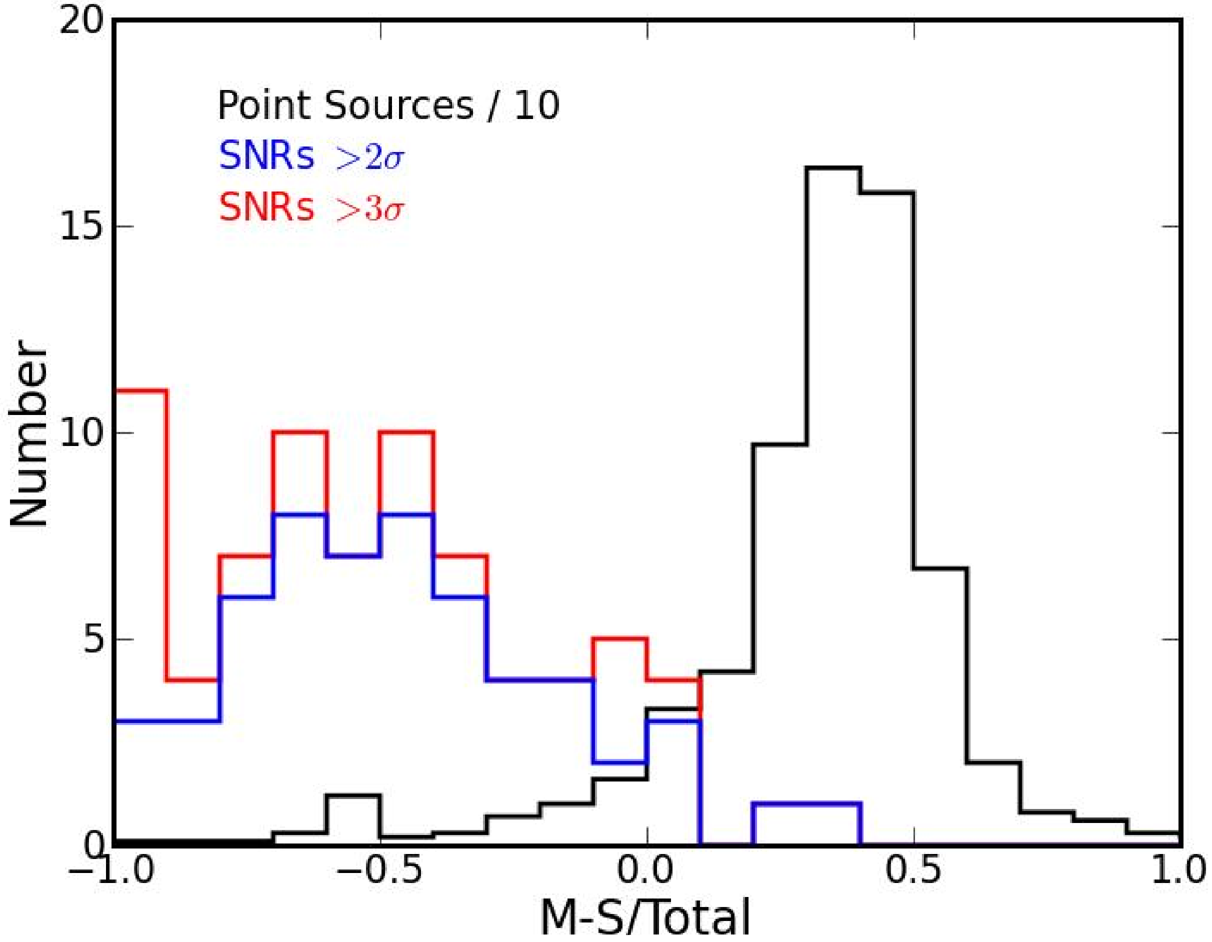
Finding X-ray SNRs - Results

- 57 (of 96) GKL SNRs
- 17 other SNR candidates also detected
- Chance probability low

74 SNRs (>2σ)

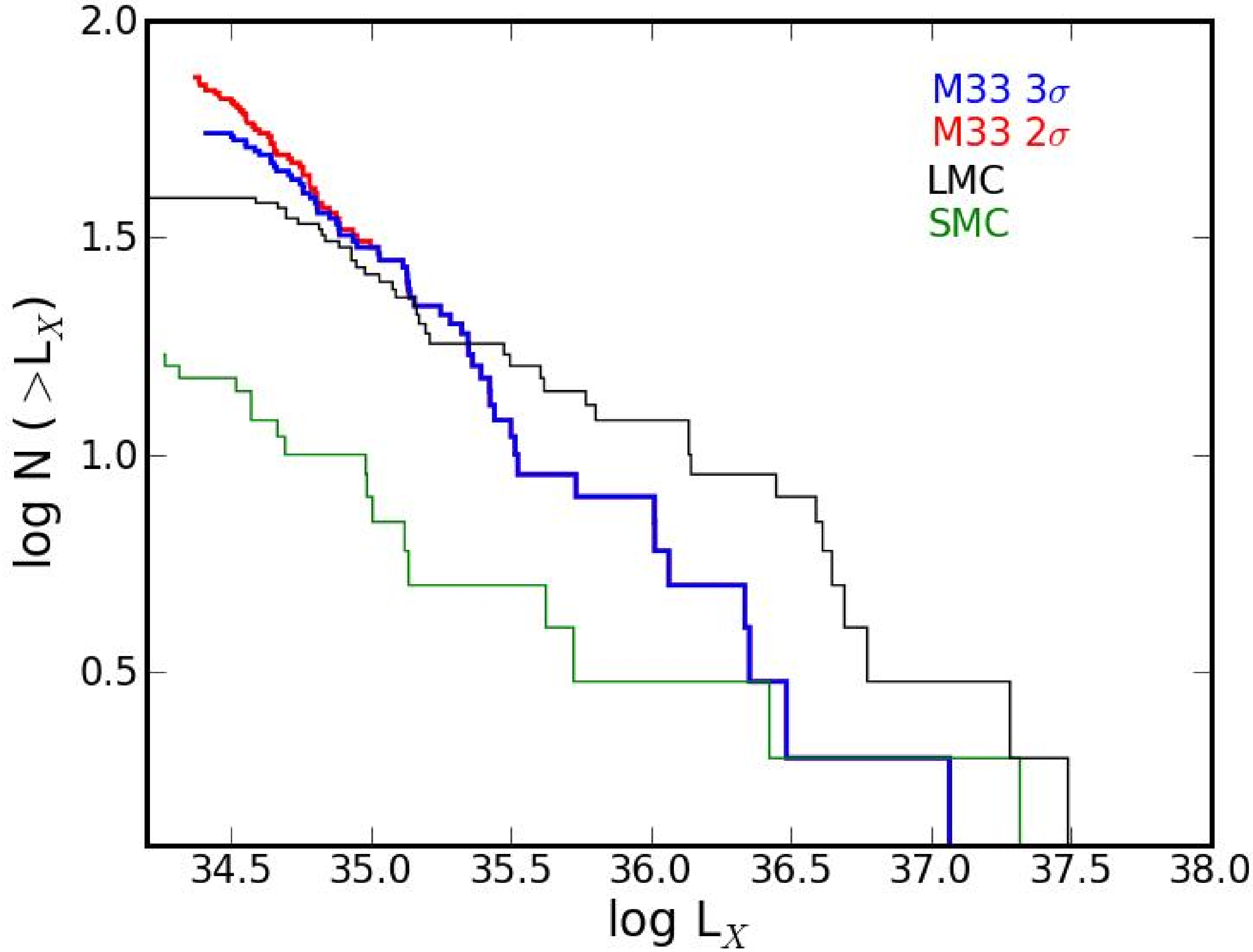


SNRs have soft X-ray spectra



S=0.35-1.2 keV, M=1.2-2.6 keV; Total=0.35-8 keV

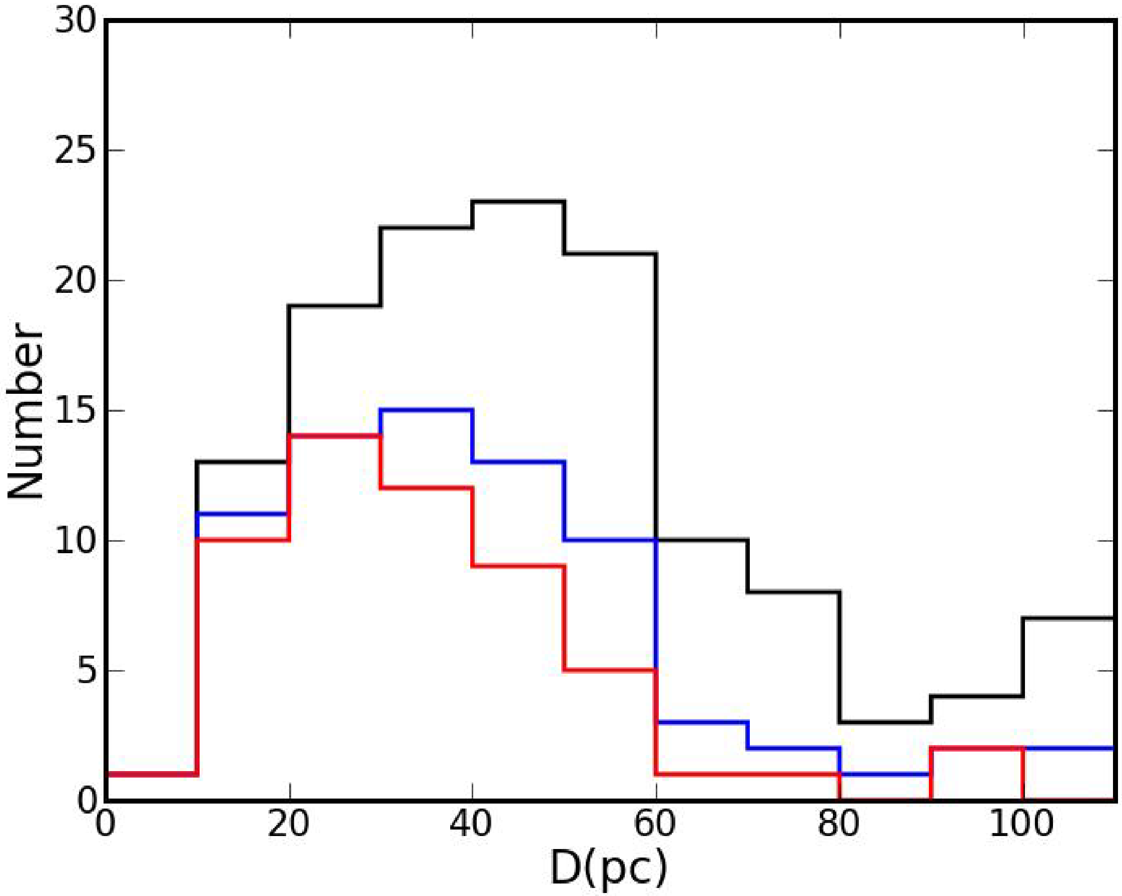
Luminosity Function



Mostly Middle-Aged SNRs

- Median diameters
- All= 44 pc
- Detected = 38 pc;
- Undetected = 54 pc

Sample, >2 σ , >3 σ



Simple Interpretation

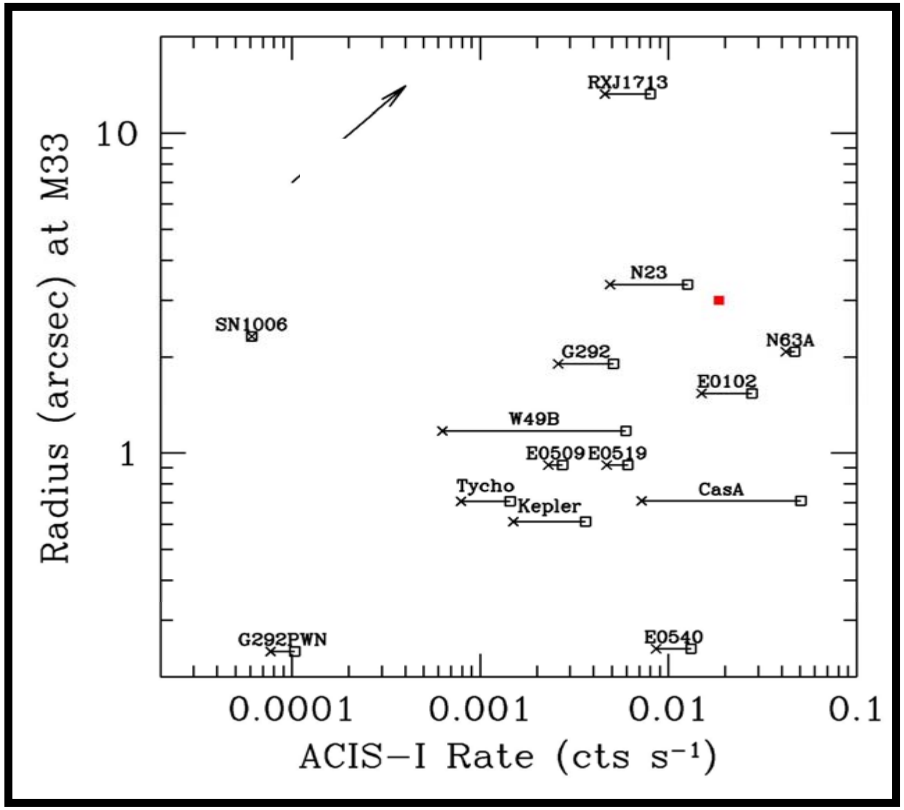
Just the Facts

- Middle age SNRs dominate the sample
- L_x at a single diameter is highly variable
- Very large objects are always faint
- Half sample is detected; half is not

It's the environment, stupid!

- $L_x \sim \eta\, n^2 R^3$
- η (0.35-2 keV) ~ constant kT>0.3 keV
- η drops rapidly kT<0.3 keV
- $M(M_o) = 83\ T(keV)^{-1}\ E_{51}$
- Implications
  - Small diameter objects are faint
  - Large diameter($R_{max} \sim n^{1/3}$) are faint
  - L_x of intermediate diameter objects strongly dependent on density (n^2)

Would your favorite SNR have been detected?



No objects as bright as Crab, but a possible PWN, coincident with slightly extended, non-thermal radio source

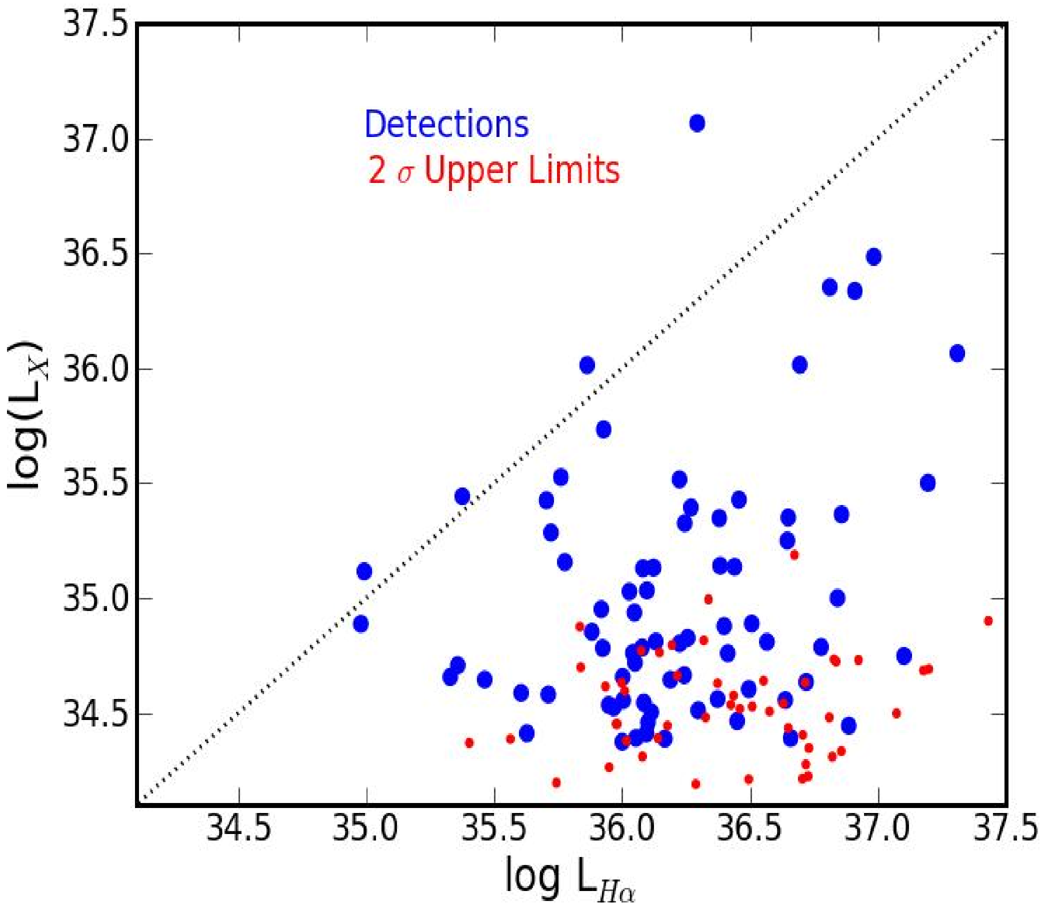
No bright sources showing evidence of soft thermal X-ray emission that are not stars or known SNRs

At the distance of M33, we should have detected

- Most of the bright SNRs in the Galaxy and Magellanic Clouds
- Most historical SNe - the Crab Nebula, Tycho, Cas A, & Kepler

Are X-ray properties correlated with other properties?

- Extreme X-ray SNRs are extreme in most respects
  - High L_x objects tend to be high $L_{H\alpha}$ objects
  - High L_x objects are generally to be radio detected
- Converse is often not true
  - High $L_{H\alpha}$ objects often not X-ray detected
  - High radio flux objects often not X-ray detected



Summary

- ChASeM33 has enabled the sensitive study of SNRs in M33 we had hoped
- Individual SNRs
  - GKL21, GKL 31, etc X-ray imaging and spectroscopy
- X-ray SNRs in M33 with $L_X > 2\ 10^{34}$ ergs s^{-1} now total 74
- Missing SNRs brighter than $L_X \sim 4\ 10^{35}$ ergs s^{-1} would be identified even without optical ID
- Large variations of properties at a given size; need to understand local environment to extract class properties