Supernova Remnants in M33: Results from the Chandra ACIS Survey of M33 (ChASeM33)

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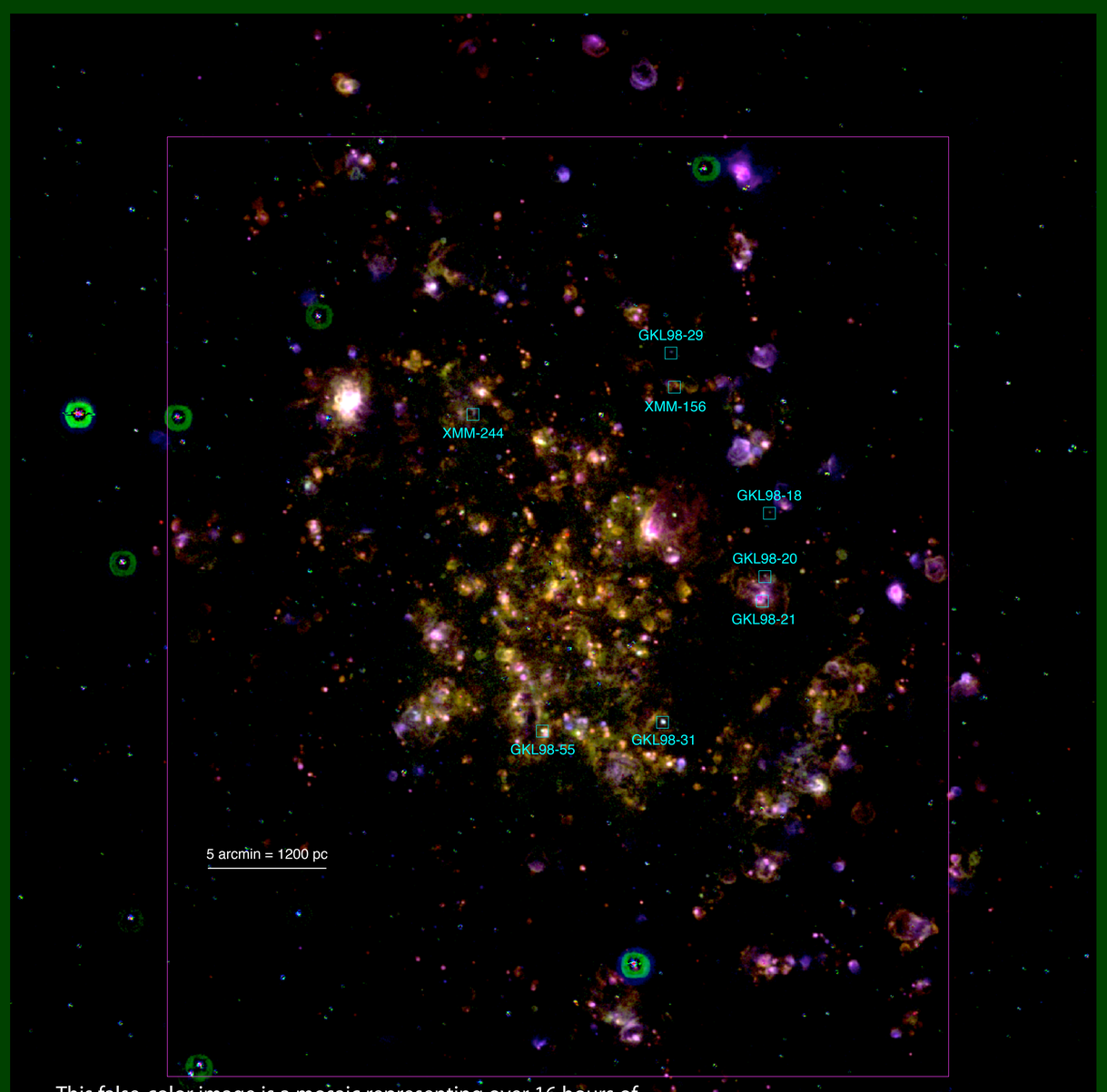
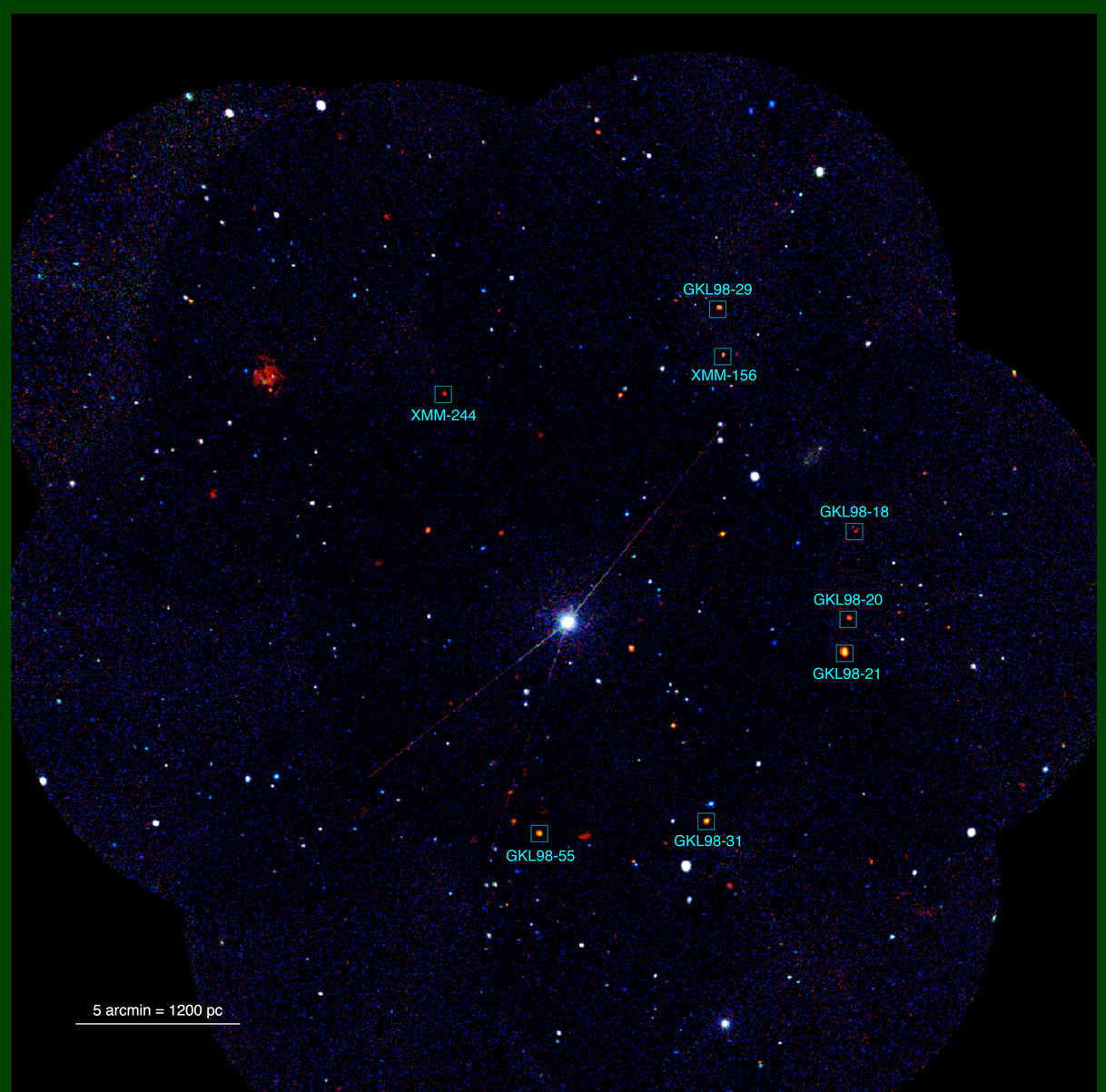


This false-color image is a mosaic representing over 16 hours of observations from the 0.6-m Burrell Schmidt telescope on Kitt Peak. The stars have been largely subtracted away, revealing the faint diffuse gas structures that pervade the galaxy. The colors represent the emission lines in our survey. The large Magenta box outlines the field of the ChASeM33 mosaic shown at right. Small cyan boxes show the positions of SNRs shown in more detail to the right below.

Red Hα 6563 Å
Green [S II] 6716,31 Å
Blue [O III] 5007 Å



Red 0.35 - 1.1 keV
Green 1.1 - 2.6 keV
Blue 2.6 - 8.0 keV

The ChASeM33 survey comprises 7 overlapping fields, each of which was observed in a pair of ~100 ks pointings separated by 6 months or more. This is the exposure-corrected mosaic including all the data with off-axis angle < 8′′. We have cataloged almost 400 sources, 23 of which are clearly extended. SNRs are typically soft sources, so appear as reddish in this 3-color image. A few examples (the cyan boxes) are highlighted in the larger scale images below.

Identifying SNRs in M33: Methods and Scorecard

Optical:

SNRs identified as nebulae with high [S II]/Hα line ratios, resulting from the cooling tail behind radiative shocks (mainly secondary shocks into relatively dense material).

- Gordon et al (1998 = GKL98) identified 98 optical SNRs in M33, the most of any galaxy beyond the Milky Way.
- Using images like the one above and the Local Group Galaxies Survey (LGGS, Massey et al. 2006), we have identified a 23 additional candidate SNRs and larger supershells—many of these in outer regions of the galaxy not included in the GKL98 survey. Most of these are very extended old objects, and appear not to be strong X-ray sources.

Radio:

SNRs typically have non-thermal radio spectra, $\alpha > 0.2$ ($S_\nu \sim \nu_\alpha$, and are spatially extended—characteristics that can in principle distinguish them from H II regions (typically flat spectra, $\alpha \sim 0.1$) or background AGNs (steep non-thermal spectra, $\alpha \sim 0.8$, and not resolved). In practice, limited spatial resolution and source confusion make it difficult to classify radio sources in external galaxies on their radio properties alone.

- Gordon et al. (1999) found non-thermal radio emission associated with 53 of 98 SNRs from the GKL98 catalog.
- 55 of these coincide with optical remnants from GKL98.

X-Ray:

SNRs are typically soft sources, often extended.

• ROSAT	10 IDs		(Long 1996; Schulman & Bregman 1995)
• XMM-Newton	21 IDs	23 candidates	(Pietsch 2004).
		11 candidates	(variability eliminates some; Misanovic 2006)
• Chandra	33 IDs	> 5 candidates	(Ghavamian 2005; Plucinsky 2008)

Chandra SNR IDs

• 28 of sources in “first look” catalog coincide with GKL98 SNRs, but 2 probably unassociated	26
• 5 additional GKL98 SNRs from “SNR-optimized” search of somewhat different data set (Ghavamian 2005)	5
• 2 Chandra sources = XMM candidates are clearly extended, almost certainly SNRs	2
TOTAL	**33**

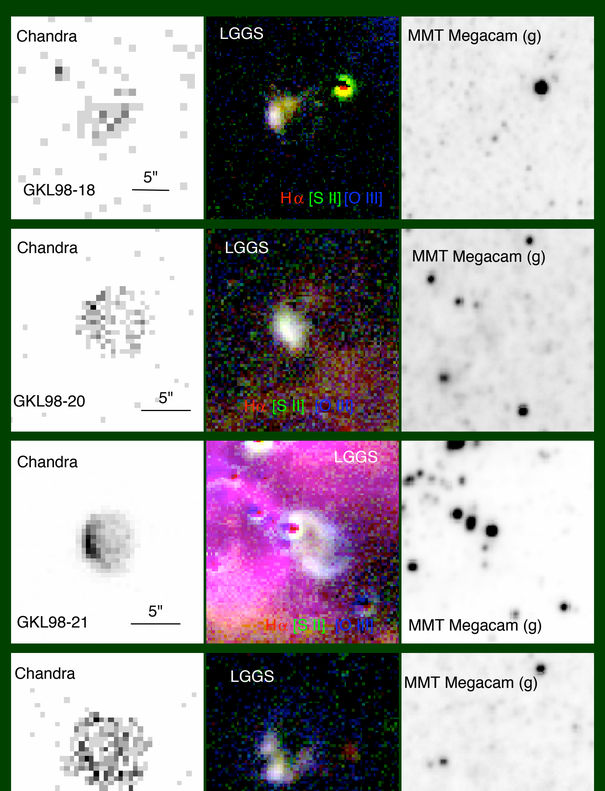
Luminosities of ChASeM33 sample ~ 10^{35} – 10^{37} ergs s^{-1}

ABSTRACT: The Chandra ACIS Survey of M33 (ChASeM33) provides the deepest and highest resolution X-ray view to date of this, the closest face-on spiral galaxy. The 1.4 Ms survey covered the central portion of M33, out to a radius of 18′ (~ 4 kpc), in seven overlapping fields. Our X-ray imaging shows a complex interstellar medium and a spectacularly rich population of both point and (slightly) resolved sources, including numerous supernova remnants (SNRs) and newly detected X-ray binaries. The survey region includes nearly one hundred SNRs identified in previous optical and radio surveys: we find ChASeM33 sources coincident (within 10 arcsec) with 31 of these. A number of the ChASeM33 sources are spatially resolved, showing X-ray emission clearly extending beyond the size of the point-spread function. We also find several soft, extended X-ray sources that are likely SNRs not yet identified in other bands. We will report on some of the most interesting cases, and initial results on statistical properties of the entire sample. In addition to the analysis of the new X-ray SNR candidates, we will also report on several candidate SNRs and larger supershells recently discovered in ground-based optical surveys.

Chandra Imaging of SNRs

At 800 kpc distance, 1′′ ~ 4 pc; some SNRs are spatially resolved. These “postage stamp” images show some examples; in each we show (left) Chandra image (0.35 - 8 keV); (center) optical emission-line image from Local Group Galaxies Survey (Massey 2006) with continuum subtracted; (right) optical image in line-free continuum g band from MMT Megacam, to show stellar population.

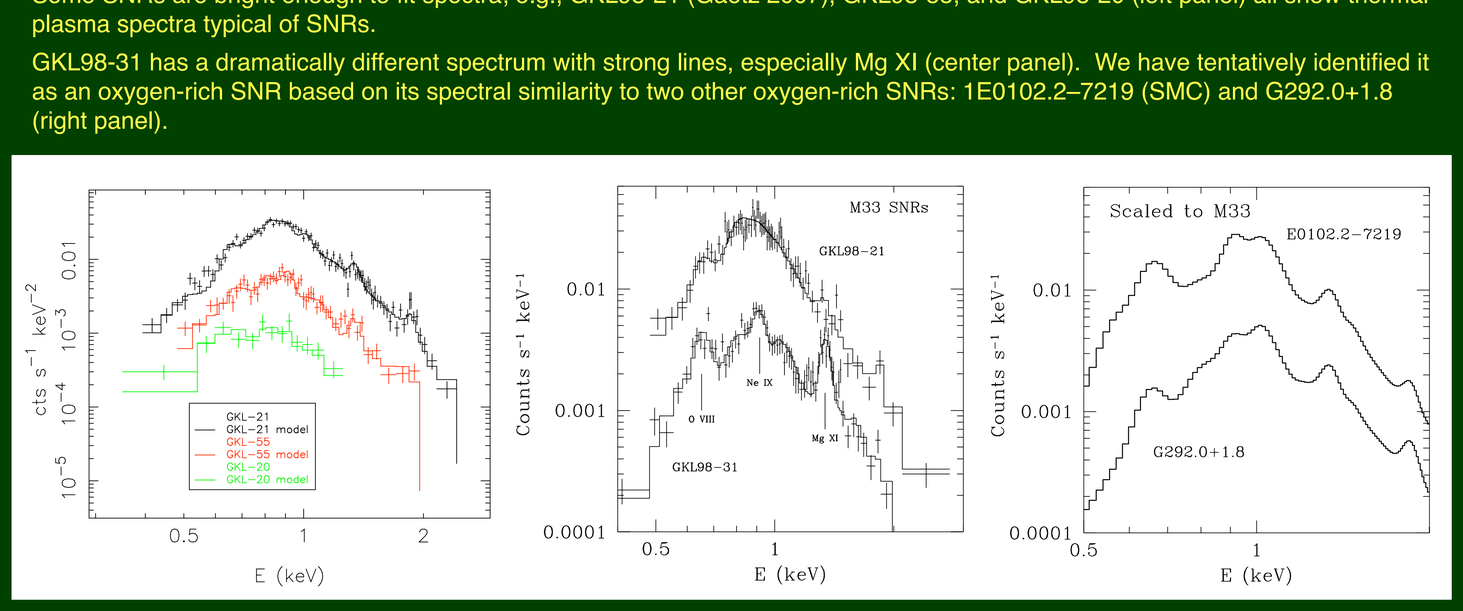
- First 5 are all extended X-ray sources coincident with GKL98 SNRs. GKL98-21 is embedded in a bright H II region; Chandra shows that the X-rays are clearly from the SNR (Gaetz 2007).
- Two XMM-detected candidates show spatial extent, confirming identification as SNRs.
- GKL98-31, while marginally resolved from Chandra, shows very strong emission lines in its X-ray spectrum (below, center). It is likely an oxygen-rich SNR identified in X-rays.



Chandra ACIS X-ray Spectra of M33 SNRs

Some SNRs are bright enough to fit spectra; e.g., GKL98-21 (Gaetz 2007), GKL98-55, and GKL98-20 (left panel) all show thermal plasma spectra typical of SNRs.

GKL98-31 has a dramatically different spectrum with strong lines, especially Mg XI (center panel). We have tentatively identified it as an oxygen-rich SNR based on its spectral similarity to two other oxygen-rich SNRs: 1E0102.2–7219 (SMC) and G292.0+1.8 (right panel).



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Acknowledgements

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