A New Study of Radio SNRS in M33

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Abstract

We have carried out new 6 and 20 cm observations of M33 with the Jansky Very Large Array, primarily to study the properties of supernova remnants in the galaxy. Our scaled array observations have a limiting sensitivity of about 25 uJy (5 sigma) and a resolution of 5” (FWHM), corresponding to a spatial resolution of 20 pc at the distance of M33. We detect about 85 of the SNRs contained in the list of 137 optically identified SNRs described by Long et al. (2010), and a few additional objects from the survey of Lee & Lee (2014). A substantial fraction of the optical SNRs not detected are in regions where emission from H II recombination makes identification of non-thermal emission from the SNR difficult. We also discuss a blind search for SNRs based on the radio emission alone. Of the SNRs we detect in this search at radio wavelengths, 53 have also been detected at X-ray wavelengths. Thus we are able to make a direct comparison of the X-ray, optical, and radio properties of the SNRs in M33, the first time that has been possible to a significant extent in an external spiral galaxy.

SNR are multi-wavelength objects

- SNR appearance depends on SN and the surrounding medium and age
  - SNR diameter is not a proxy for age
- X-ray → primary shock physics, thermal content, ISM density, ejecta abundances
- Optical → secondary shock physics, densities and (occasionally) shock speed and abundances
- Radio → particle acceleration
- → To understand SNRs as a class, high quality data are required at multiple wavelengths

SNR samples

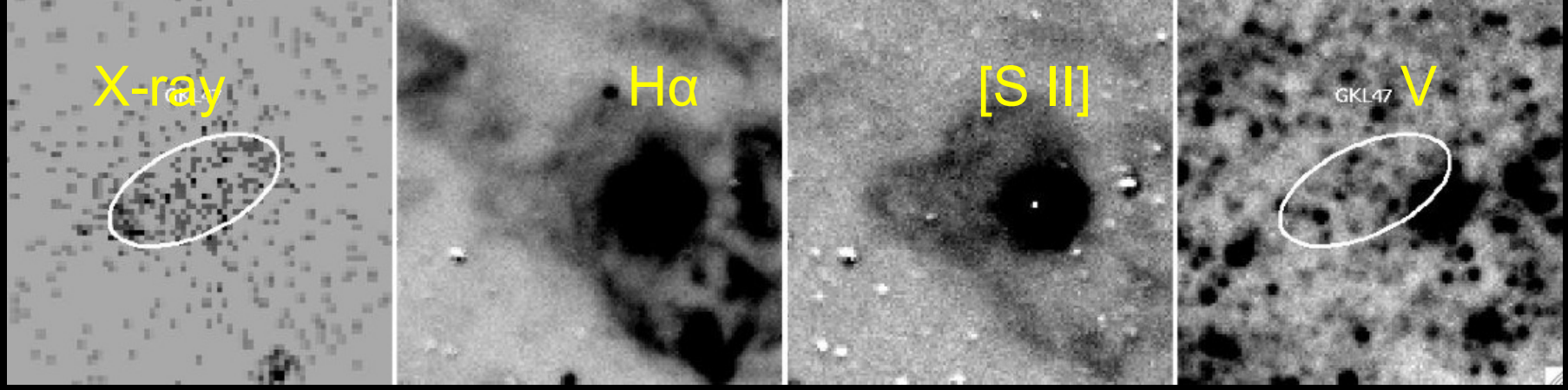
Galactic

- 294 SNRs in the Galaxy (Green 14)
- Where are they detected?
  - Radio – nearly all
  - Optical – 30%
  - X-ray – 40%
- Advantages
  - Spatially resolved
  - Detailed studies of individual objects possible
- Disadvantages
  - Distances are poorly known
  - Variable absorption

Extragalactic

- 1400 SNRs and SNR candidates (beyond MC)
- Where are they detected
  - Radio 10%
  - Optical 95%
  - X-ray 15%
- Advantages
  - Distance is known
  - Absorption is less of a problem
- Disadvantages
  - Not spatially resolved in all bands
  - Photons are few

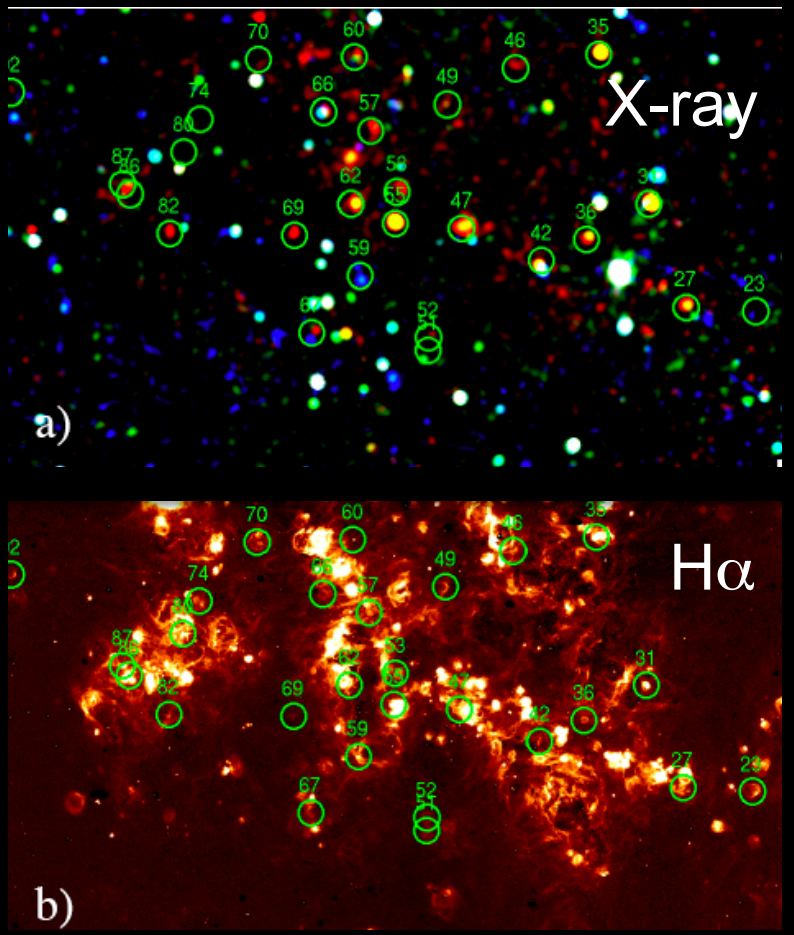
Magellanic Cloud samples are important, but not today's talk



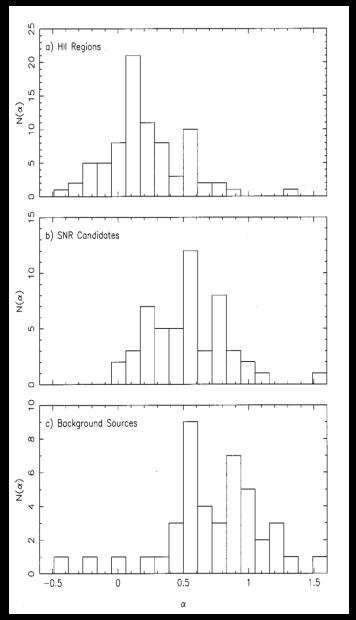
- SNRs in nearby galaxies identified primarily from [SII]:Hα ratios > 0.4. HII regions ~ 0.1
- X-ray only IDs have usually not been made though some sources can be recognized as SNRs in M31 & M33
  - Sensitivity is the limiting factor
- Radio-only IDs usually based a non-thermal radio source at a position where there is diffuse Hα emission.
  - In a few galaxies, notably NGC6946, the non-thermal radio sources line up along the spiral arms and so identifications seem firm
    - Lacey+01 identified 35 non-thermal radio sources in NGC6946 all in the spiral arms of the galaxy, few of which were in the optical catalog of Matonic+97
  - Elsewhere, background radio sources are a concern, especially if sample size is small
- Consequently, most radio detections of SNRs are detections of radio sources at the positions of optical SNRs

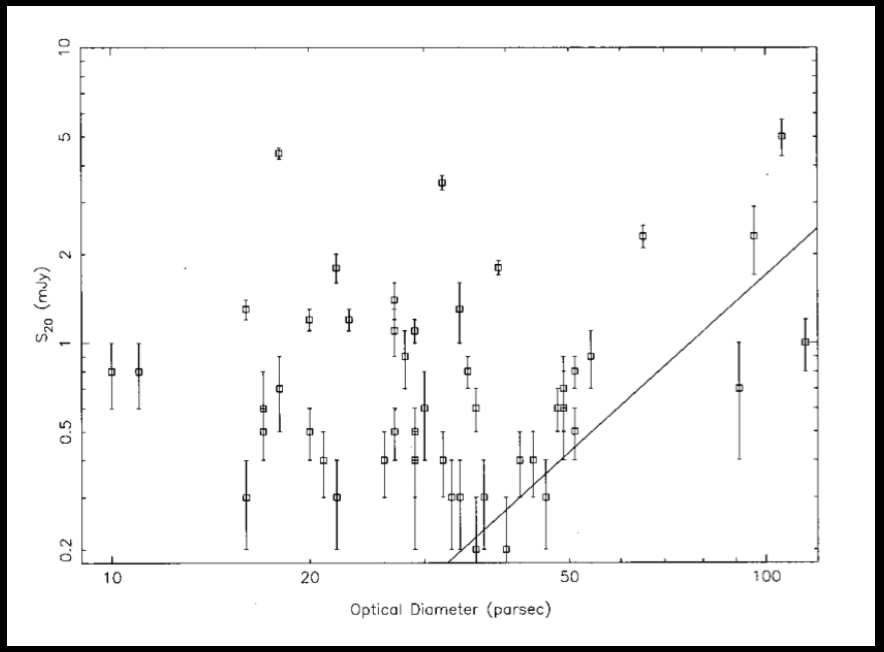
M33 is obvious

- Nearby
- Low extinction
- Reasonable size
- Well-studied
  - Optical – Hodge's Local Group Galaxy Survey
  - X-ray - Chandra 1.4 Msec
- Lots of SNRs known
  - Optical 137 (Long+10) + 199 (Lee+14) → 217
  - X-ray – 82 (of 137)



Radio - Gordon+99

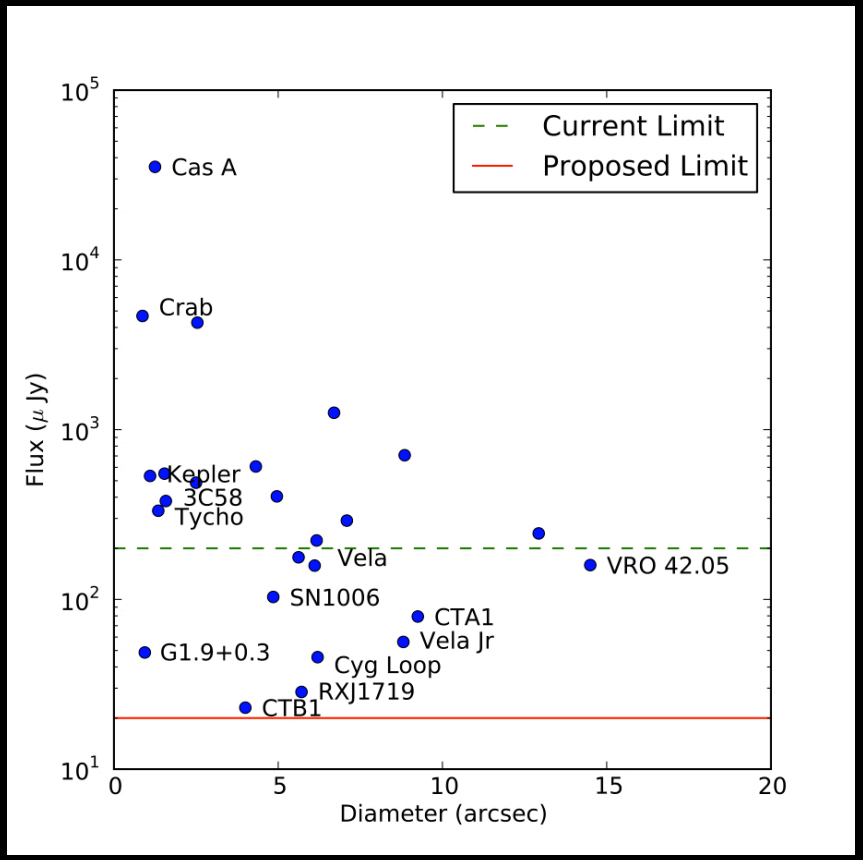




- Observations with the VLA and WSRT @ 6 & 20 cm with a limiting sensitivity of ~300 μJy
- Detected emission at 20 cm from 53 optically identified SNRs
  - Chomiuk & Wilcots 1995 argue that there are actually 77 radio SNRs in M33 (non-thermal + Hα)
  - Gordon+99 assumed these were background sources
- Wide range of fluxes at a given diameter
  - Consistent with results from LMC and SMC that radio Σ-D relations are not very reliable estimates of distance

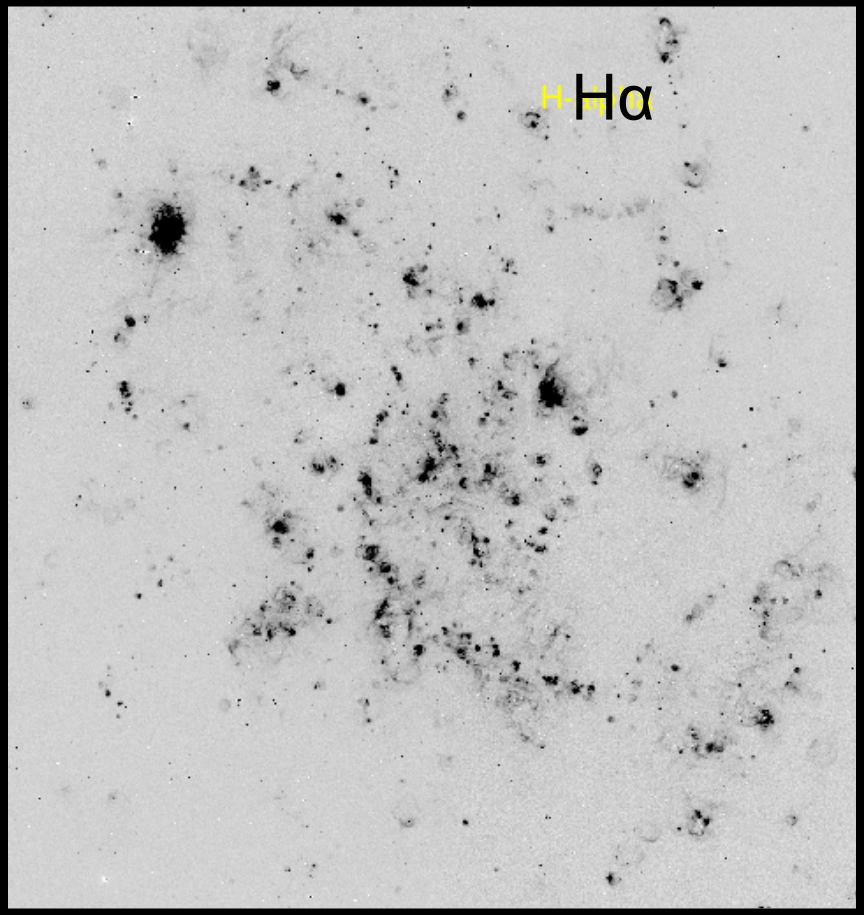
A new EVLA radio survey

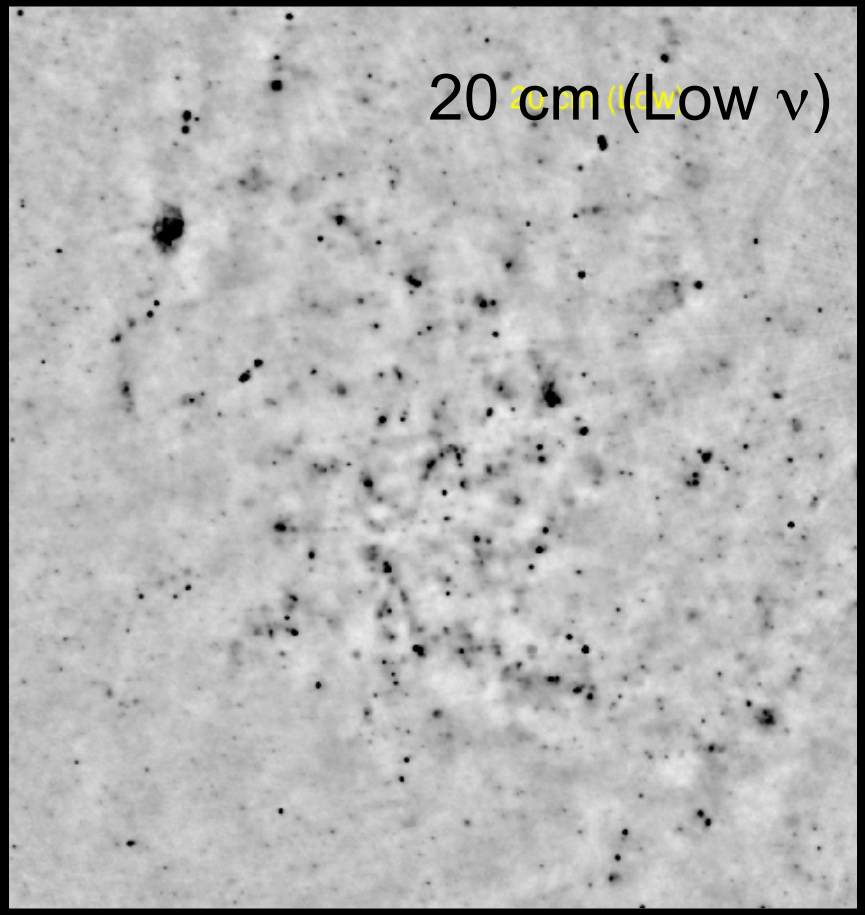
- 1.4 GHz (20 cm)
  - C – 12 hr
  - B – 32 hr (7 fields)
  - (A – 16 hr)
- 5 GHz (6 cm)
  - C – 48 hrs (41 fields)
- Goals
  - 10x the sensitivity of Gordon+99
  - Better measurement of spectral indices



Today's talk is a progress report on the results

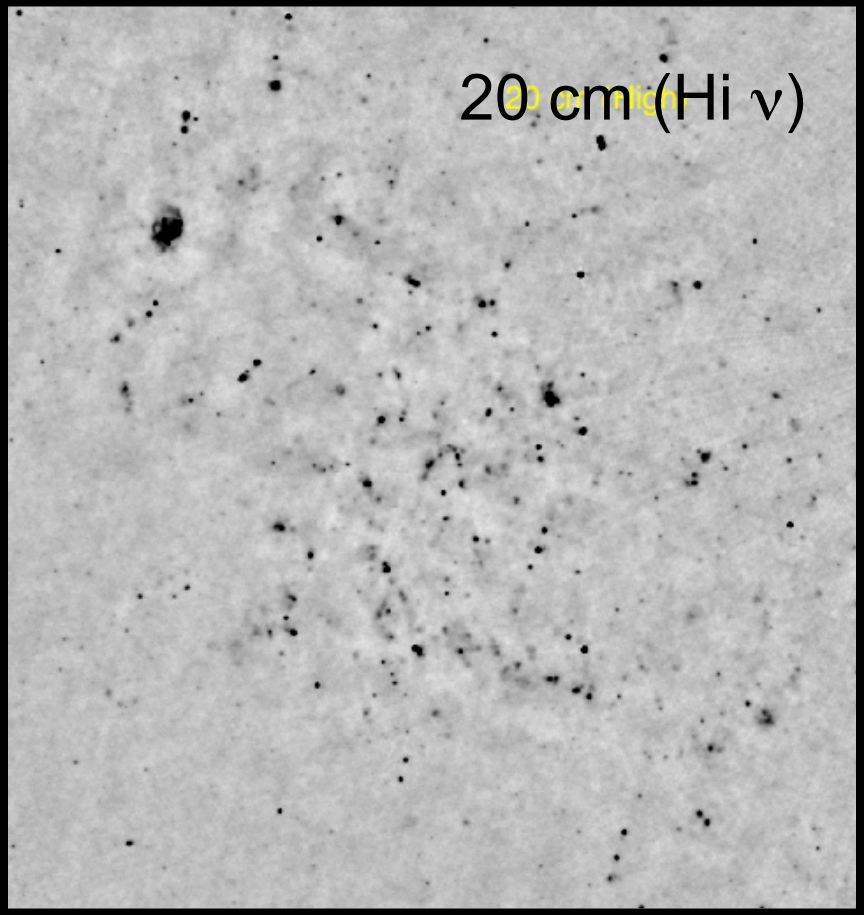
Hα and 20 cm (Low ν)

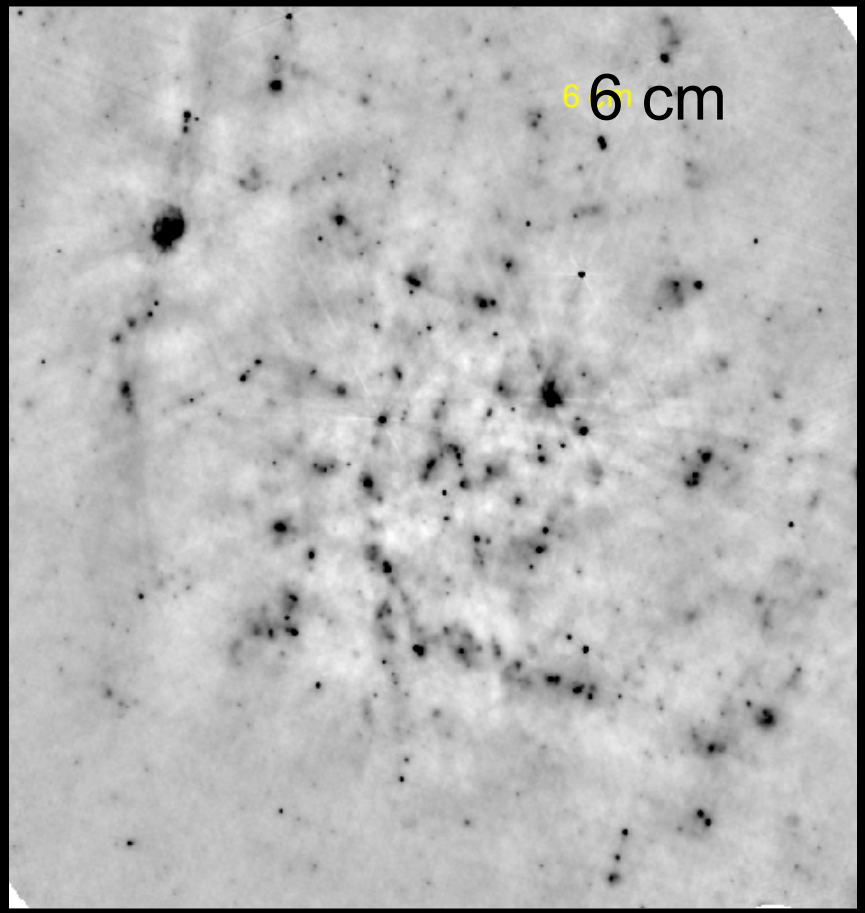




Most of the matching sources are HII regions

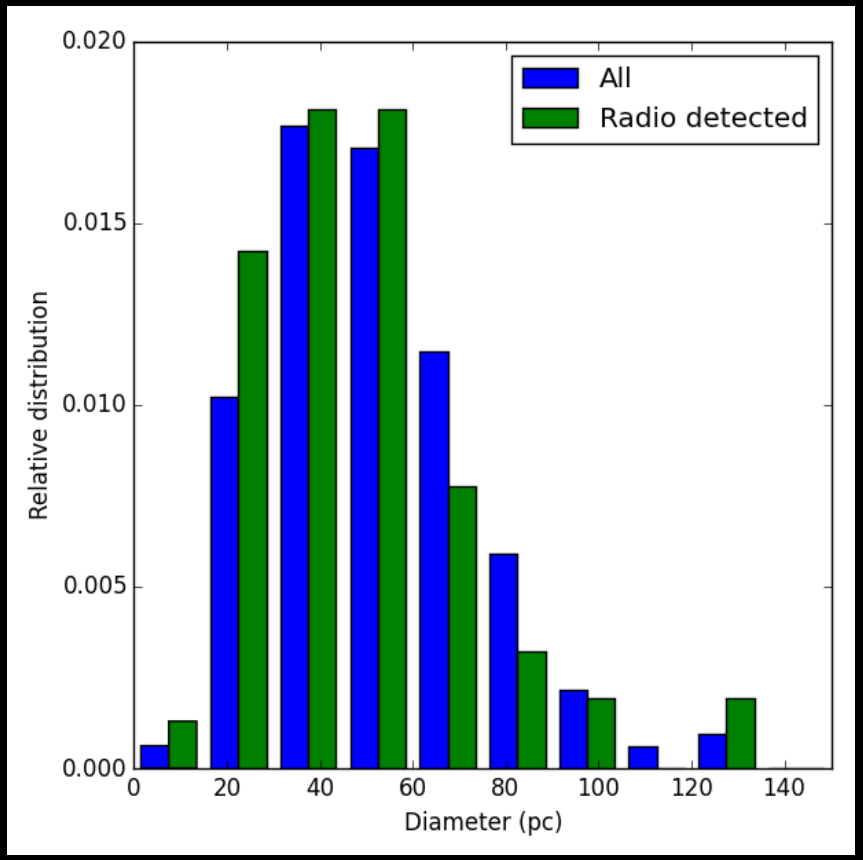
20 cm (Hi ν) and 6 cm



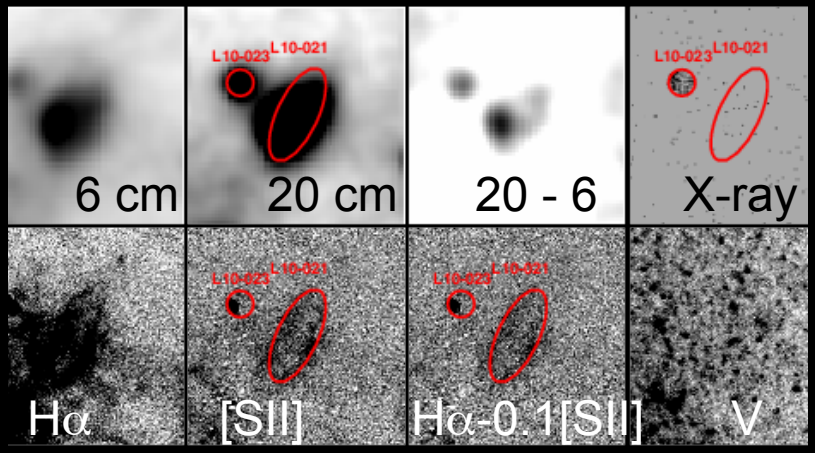


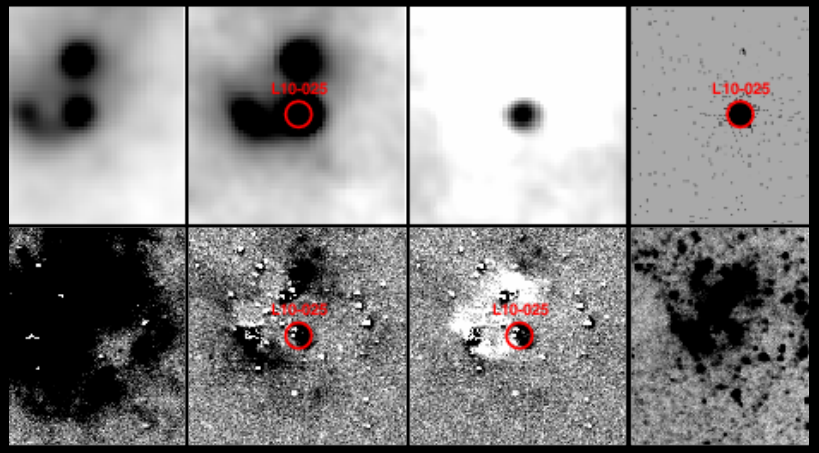
Radio detected SNRs

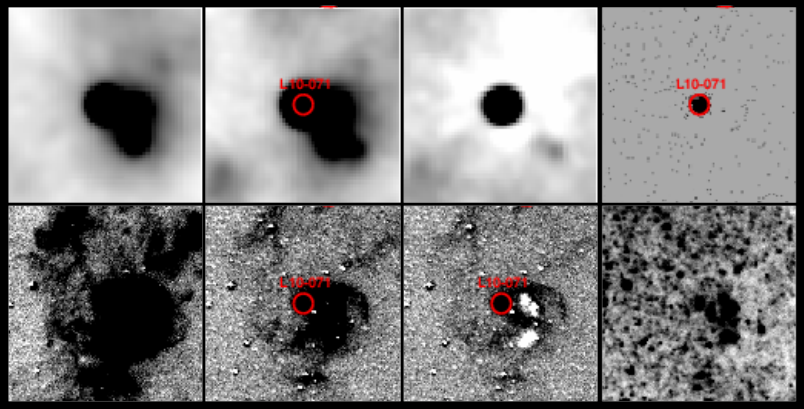
- 217 optical SNRs, 13 outside field of both radio images
- Visual inspection shows 104 radio-detected SNRs
  - 94 from 137 in L10
  - 10 more from new LL14 objects
- Radio detected objects are skewed slightly toward smaller D
  - Optical median diameter – 50 pc
  - Radio detected – 44 pc

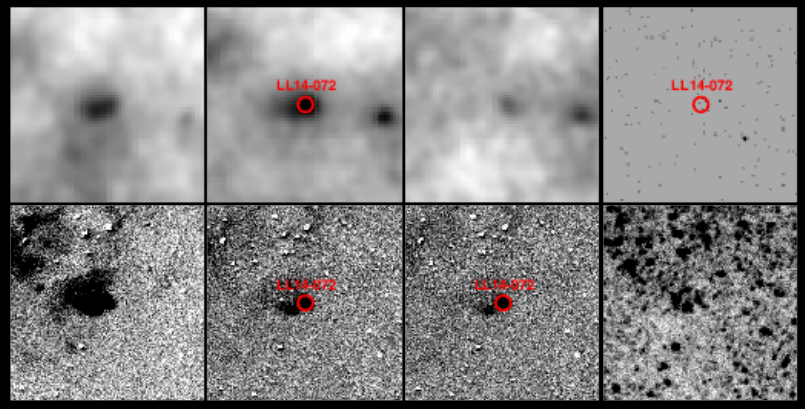


Examples – SNRs

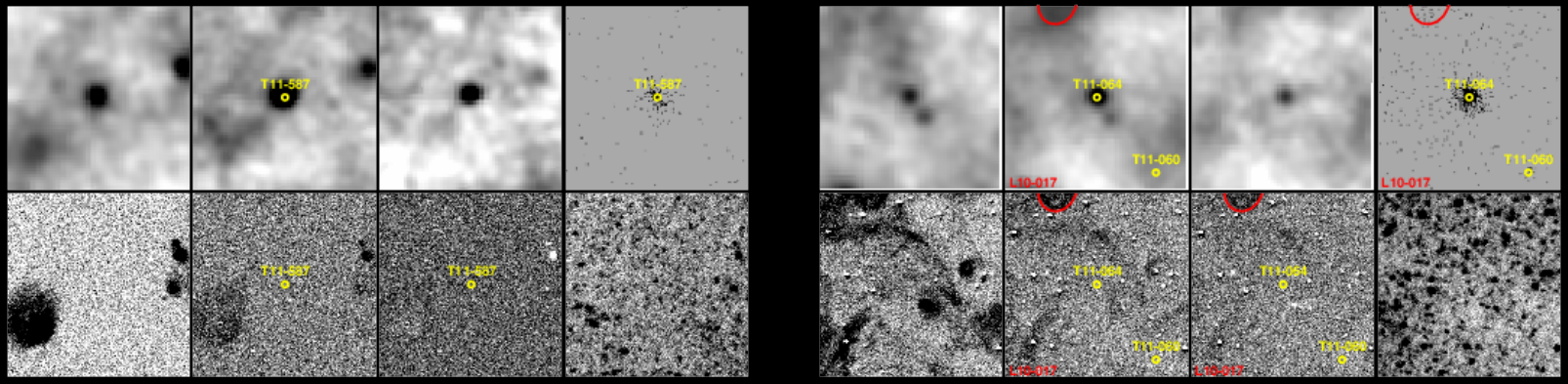






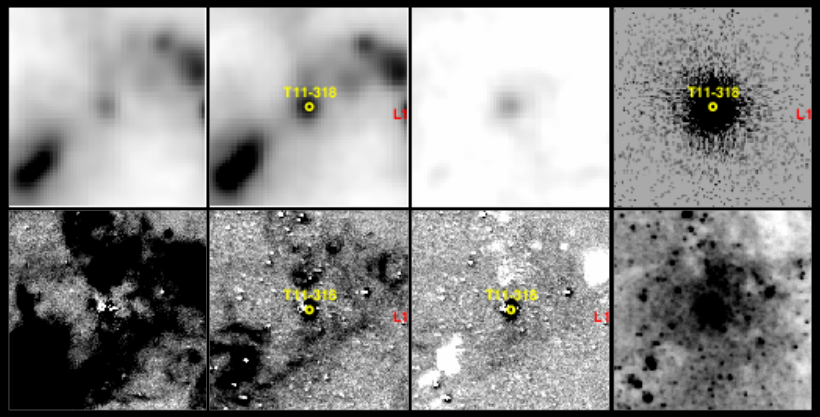


X-ray Sources



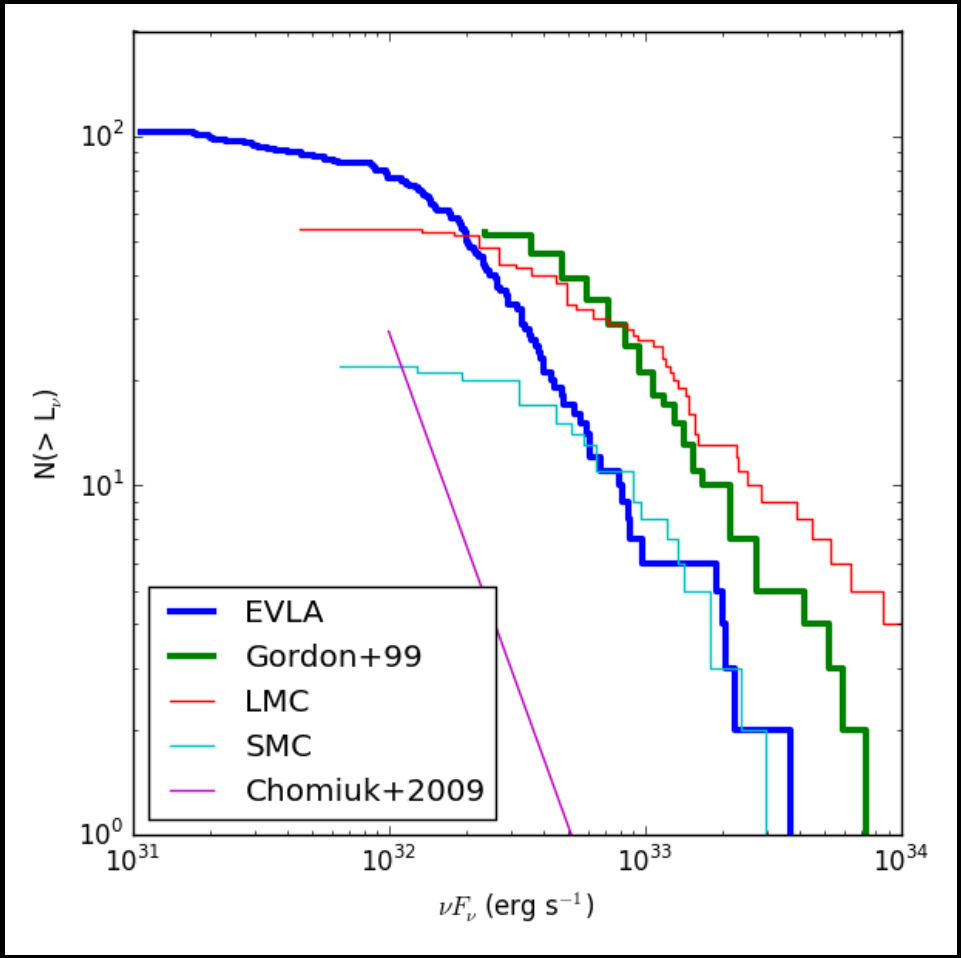
- Tuellmann+11 found 662 X-ray sources in M33 ACIS survey
- The vast majority of these sources are background AGN based on estimates of the number of AGN seen in field
- ~ 100 X-ray sources have radio counterparts with non- thermal radio indices
- Most, but not all, are not associated with Hα emission so are unlikely to be SNRs

To date – no new SNRs

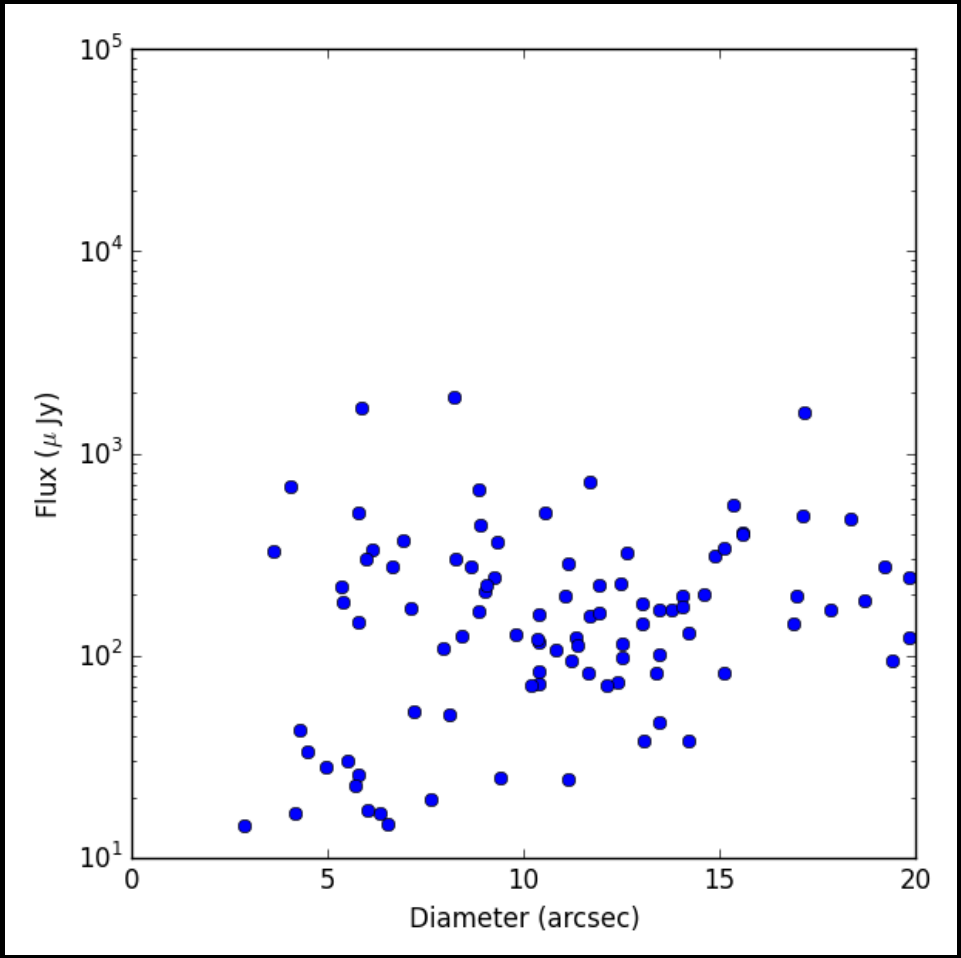


- T11-318 is a good example of the issues
- Why interesting
  - Non-thermal radio source in nebulosity with some evidence of excess [S II]
- Why likely not a SNR
  - X-ray source has hardness ratio (H-S)/ Tot 0.45, most SNRs -0.5
  - Spectrum can be fit with a power law
- Tentative conclusion – bright AGN which happens to be behind an H II
- But unusual to see a source this bright from an AGN
- Systematic search for SNRs from non-thermal radio sources ongoing

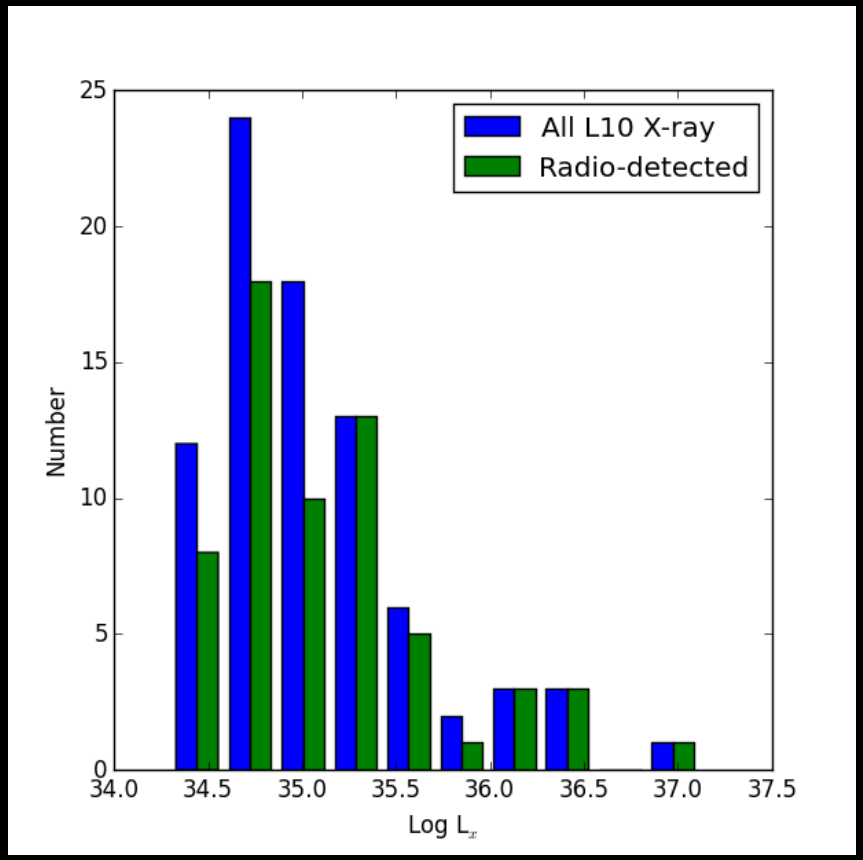
Luminosity Function

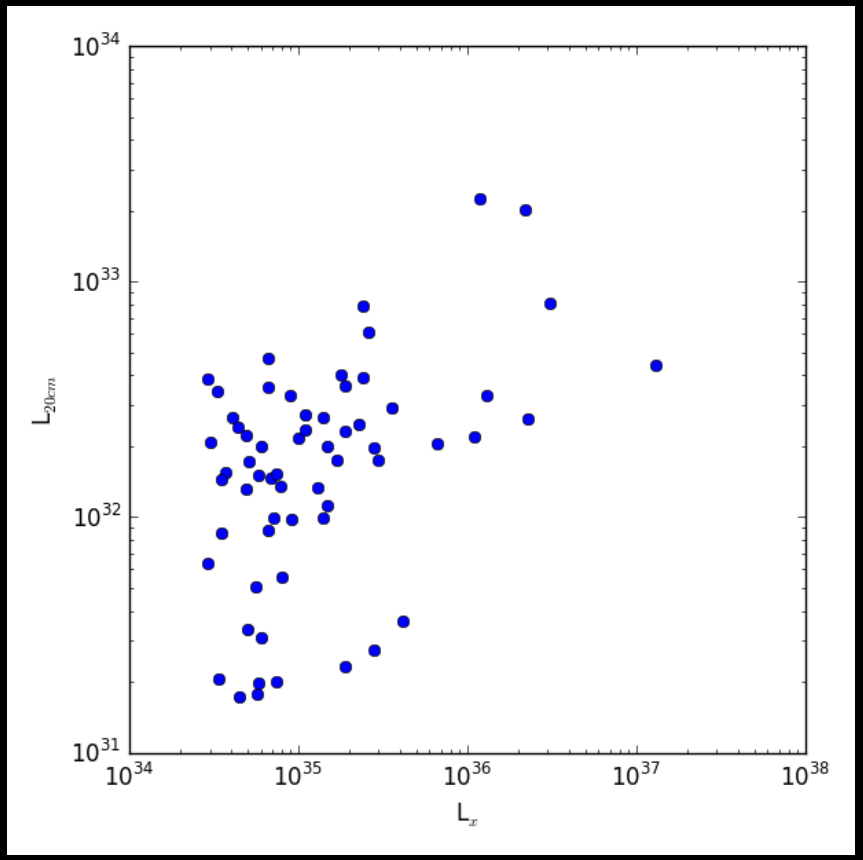


Flux vs. diameter



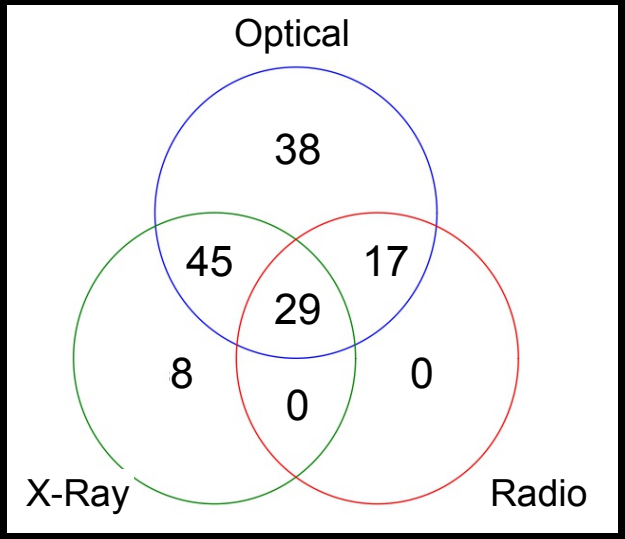
X-ray radio comparison



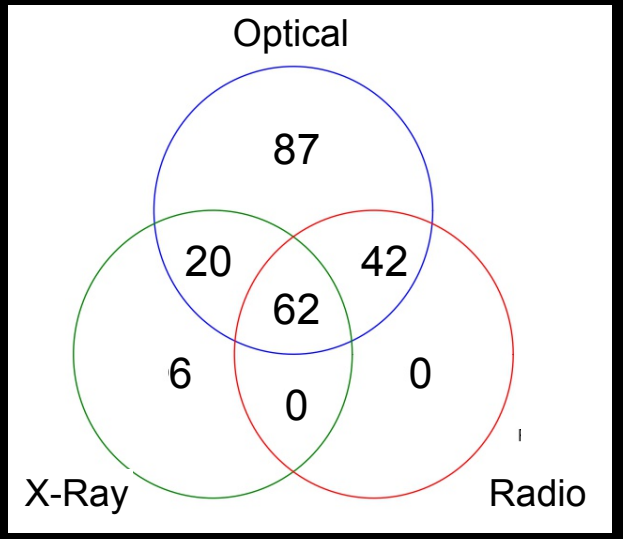


Summary

2010



2016



- Identification of radio counterparts to known SNRs and in independent survey for radio SNRs is necessary to understand SNRS as a group
- EVLA M33 survey is a step in this direction filling in the radio properties of the sample
- So far the main result is that we have expanded the sample of radio SNRs by about a factor of 2
- There are probably not large numbers of radio-only SNR in M33 but that part of the program is still on-going as is any detailed interpretation