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Emmy Noether-Programm
Deutsche Forschungsgemeinschaft
DFG

Supernova remnants and candidates detected in the *XMM-Newton* M31 Large Survey

Manami Sasaki
(Institut für Astronomie und Astrophysik Tübingen)

Wolfgang Pietsch (MPE)
Frank Haberl (MPE)
Holger Stiele (INAF)

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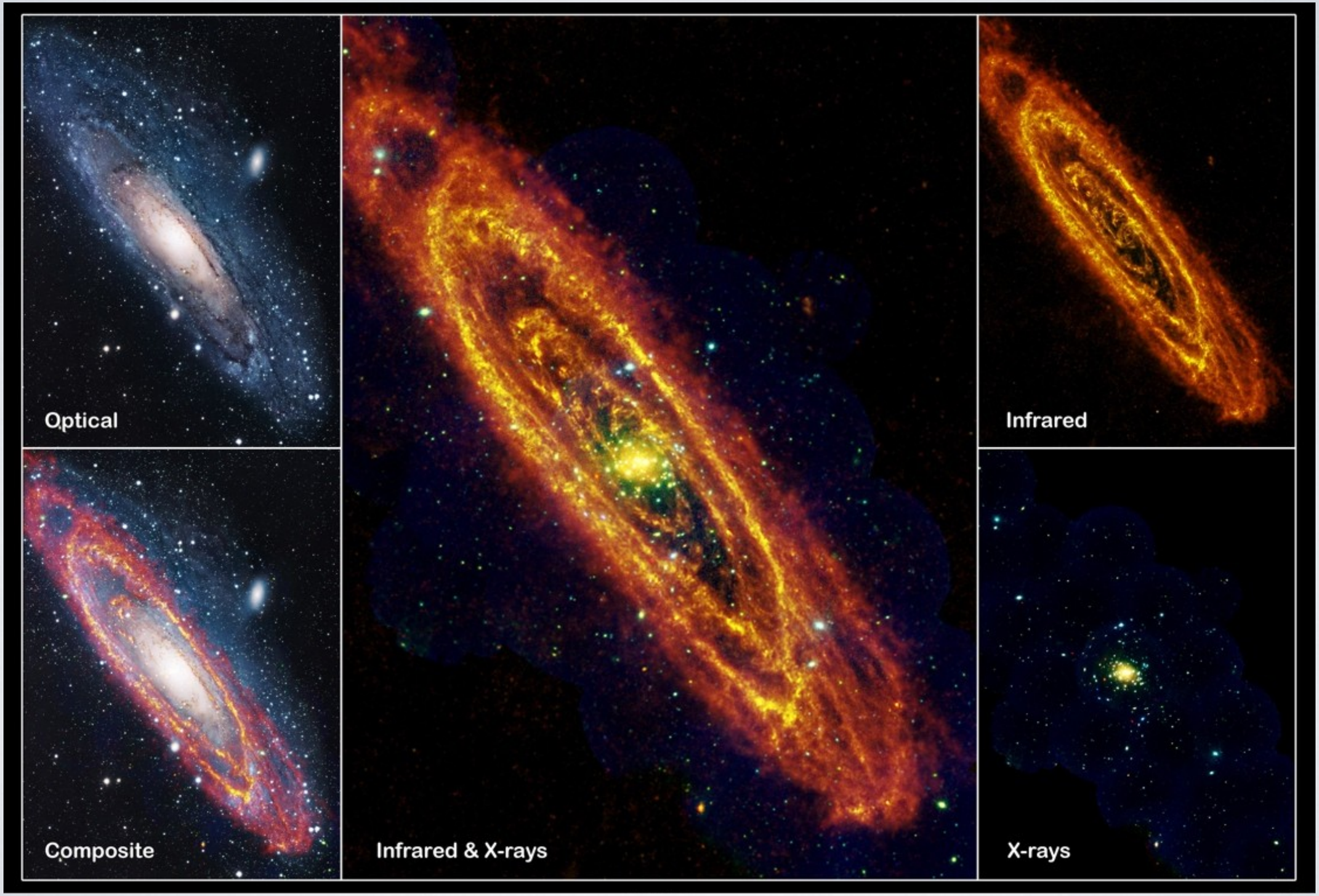
Institut für Astronomie und Astrophysik



Credits: infrared: ESA/Herschel/PACS/SPIRE/J. Fritz, U. Gent; X-ray: ESA/XMM-Newton/EPIC/W. Pietsch, MPE; optical: R. Gendler

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M31 – Andromeda galaxy

- First X-ray source catalogues of M31 with *Einstein* (van Speybroeck et al. 1979, Trinchieri & Fabbiano 1991) and *ROSAT* (Supper et al. 1997, 2001).
- *XMM-Newton* and *Chandra* source catalogues (e.g., Osborne et al. 2001, Kong et al. 2002, Kaaret 2002, Pietsch et al. 2005).
- New supernova remnants (SNRs) confirmed and resolved with *Chandra* observations (Kong et al. 2003, Williams et al. 2004).
- SNRs in M31 have mainly been discovered in optical and radio observations so far.

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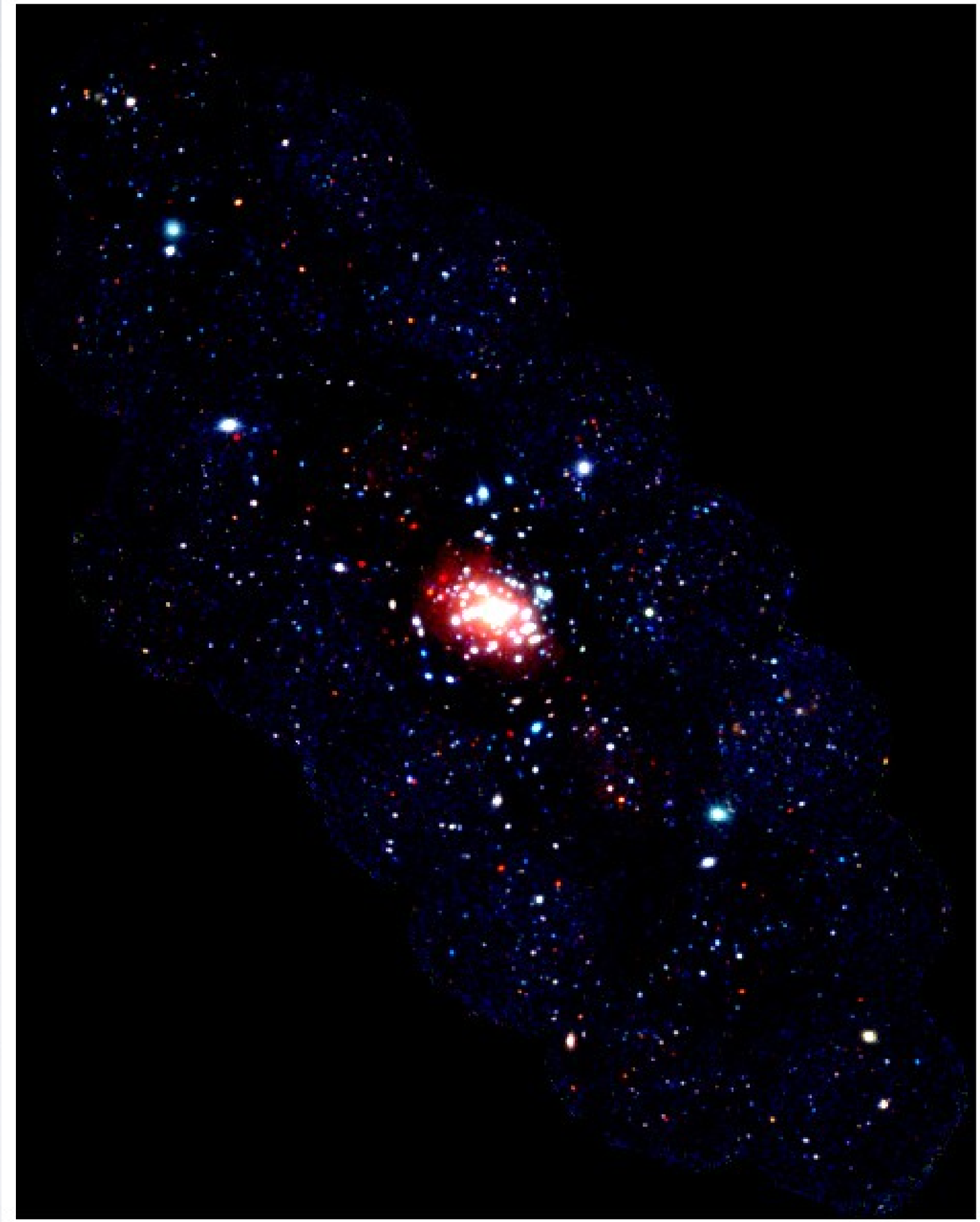
XMM-Newton

RGB mosaic image

(red: 0.2 - 1 keV,
green: 1 - 2 keV,
blue: 2 - 4.5 keV)



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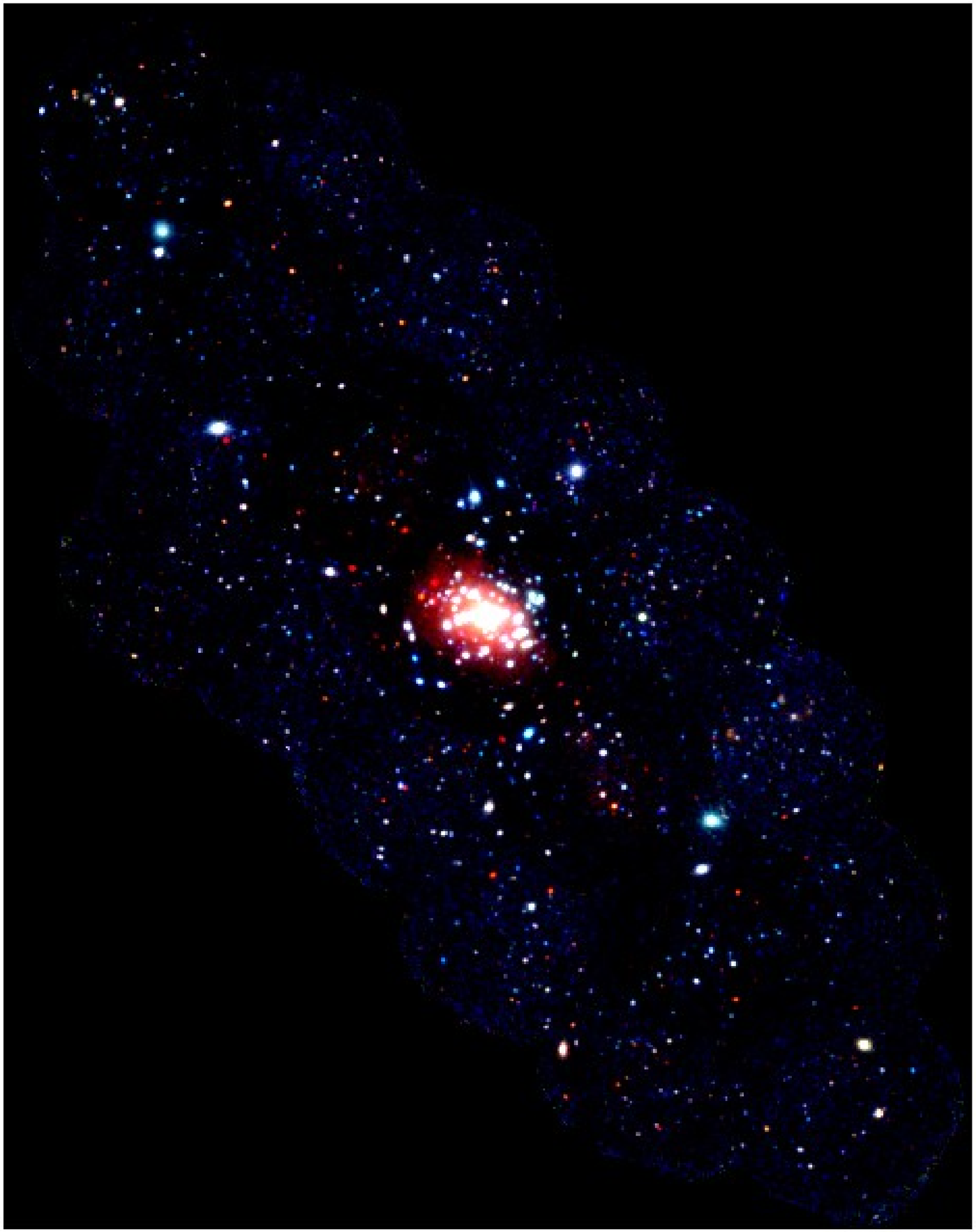
XMM-Newton survey of M31

- Large Program, PI: W. Pietsch + archival data.
- 38 Observations.
- Exposures: 5 – 49 ksec.
- Sensitivity limit of 10^{35} erg/s in the 0.2–4.5 keV band.
- Source catalogue with 1897 sources (Stiele et al. 2011).
- 56 SNRs and candidates.



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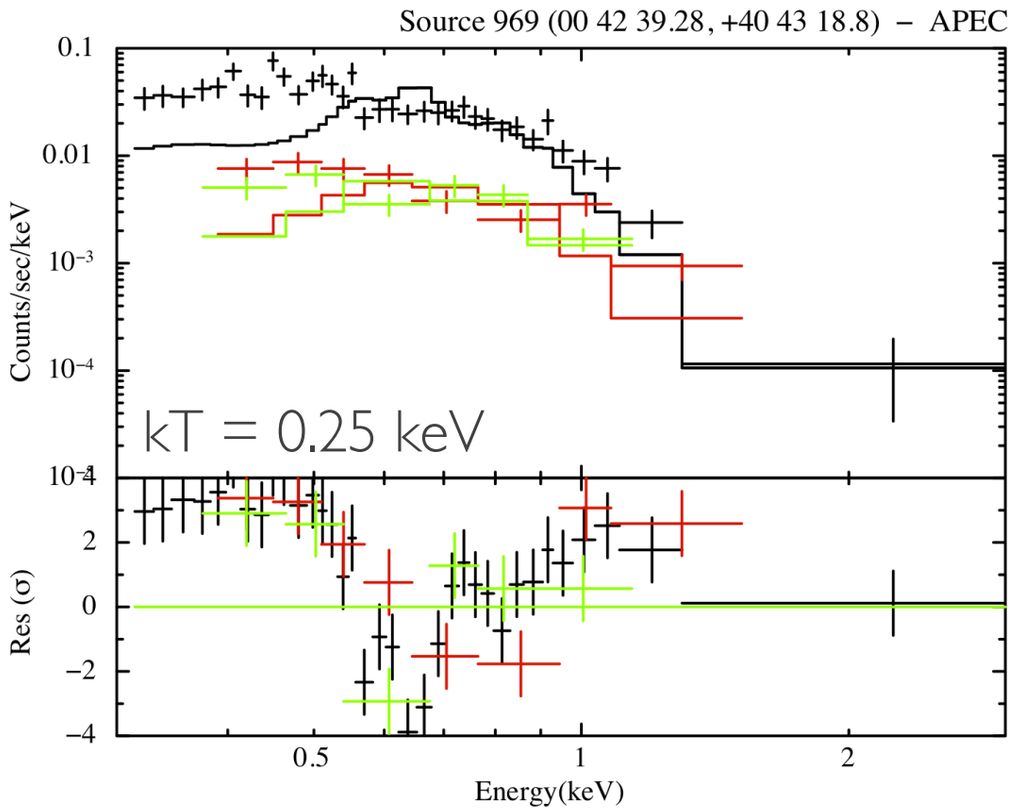
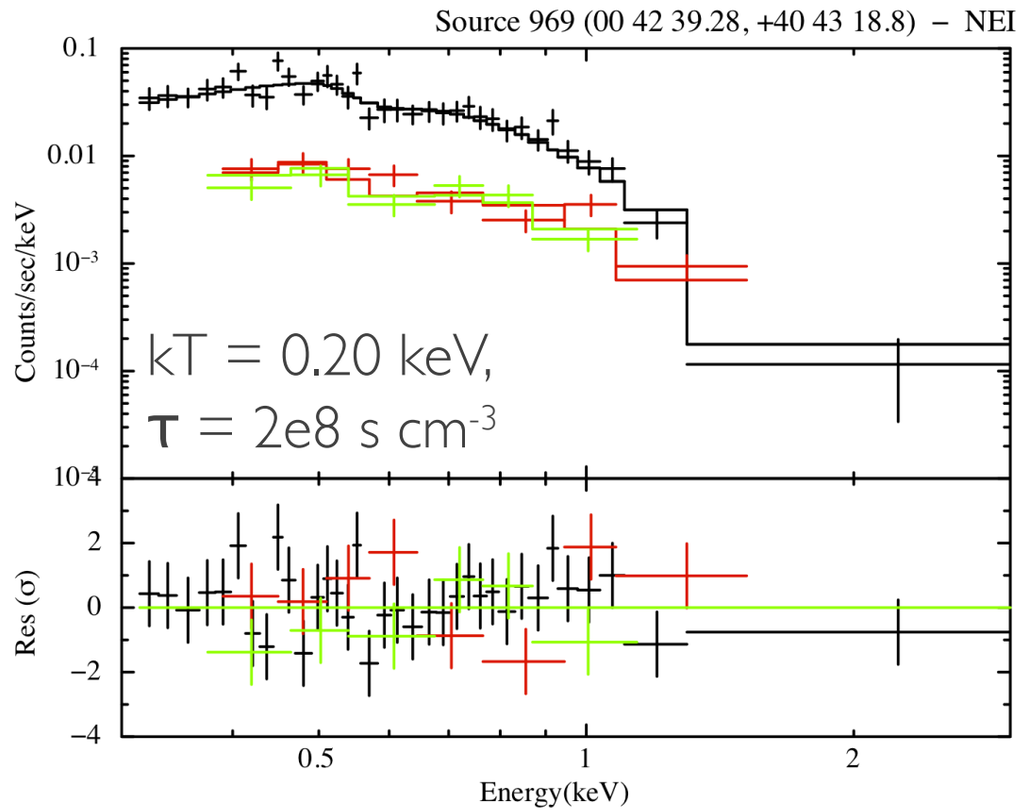
X-ray data

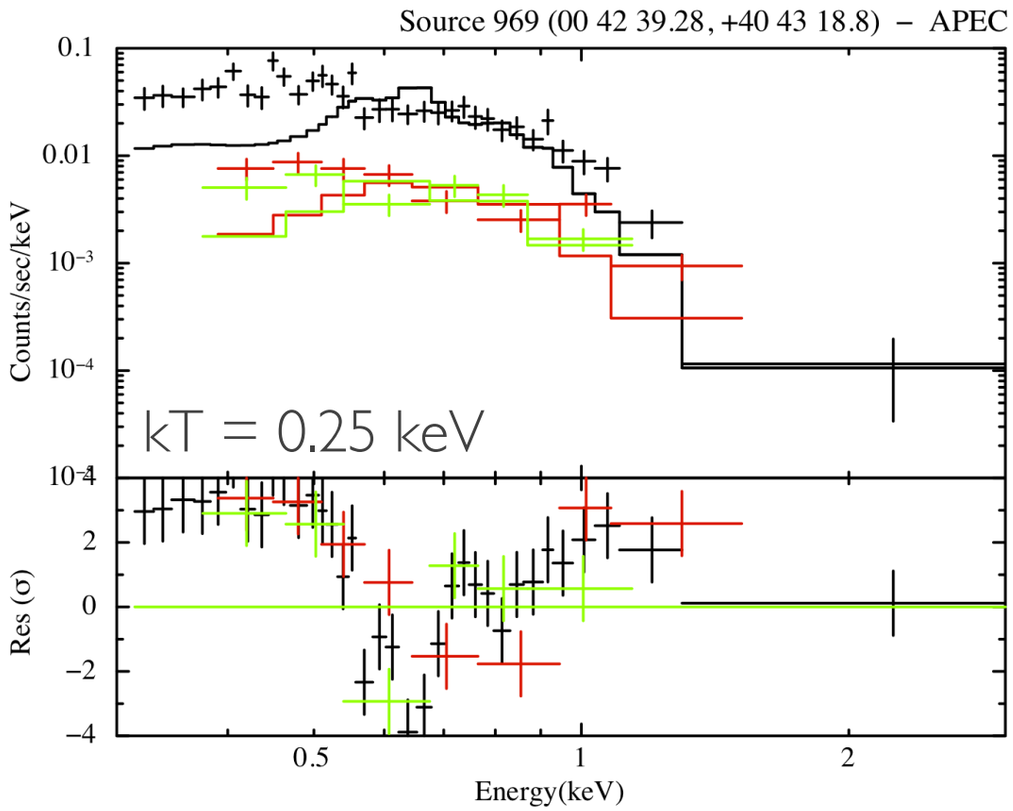
- *XMM-Newton* survey (Stiele et al. 2011):
  - SNRs were identified based on X-ray hardness ratios (indicating soft spectrum) and cross-correlation with optical and radio catalogues.
  - SNR candidates were classified based on the hardness ratios and the absence of a point source in the optical as potential counterpart.
- Analysis of the X-ray spectrum of the brightest SNRs and candidates.
- Two brightest sources allowed detailed analysis of their spectra:
  - 969 (SNR candidate, XMMM31 J004239.82+404318.8) and
  - 1234 (SNR, XMMM31 J004327.93+411830.5).

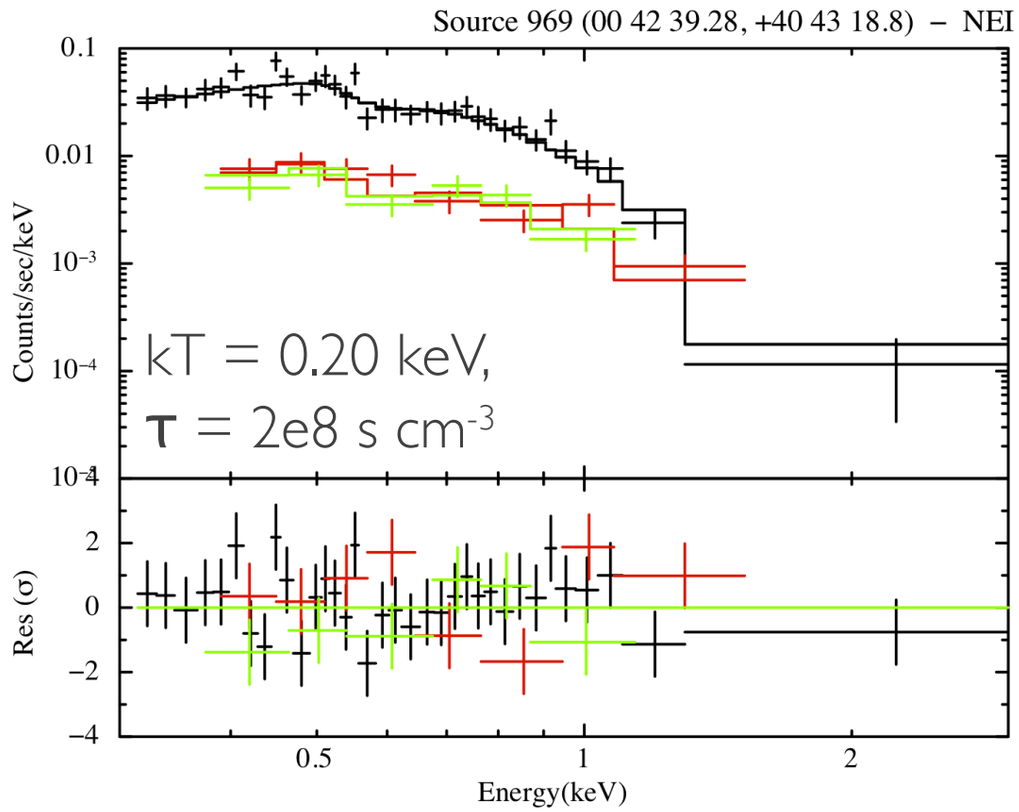


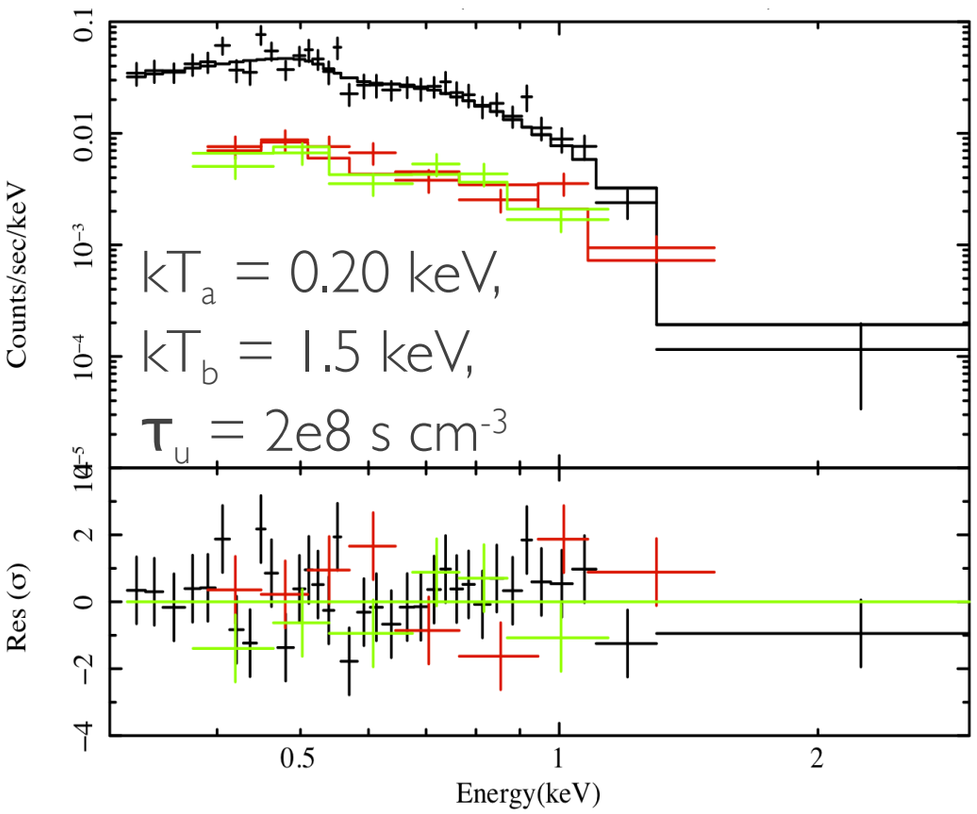


- APEC: red. $\chi^2 = 6.6$, DOF = 46
- NEI: red. $\chi^2 = 1.1$, DOF = 45

EPIC spectra of source 969







- APEC: red. $\chi^2 = 6.6$, DOF = 46
- NEI: red. $\chi^2 = 1.1$, DOF = 45
- NPSHOCK: red. $\chi^2 = 1.1$, DOF = 44

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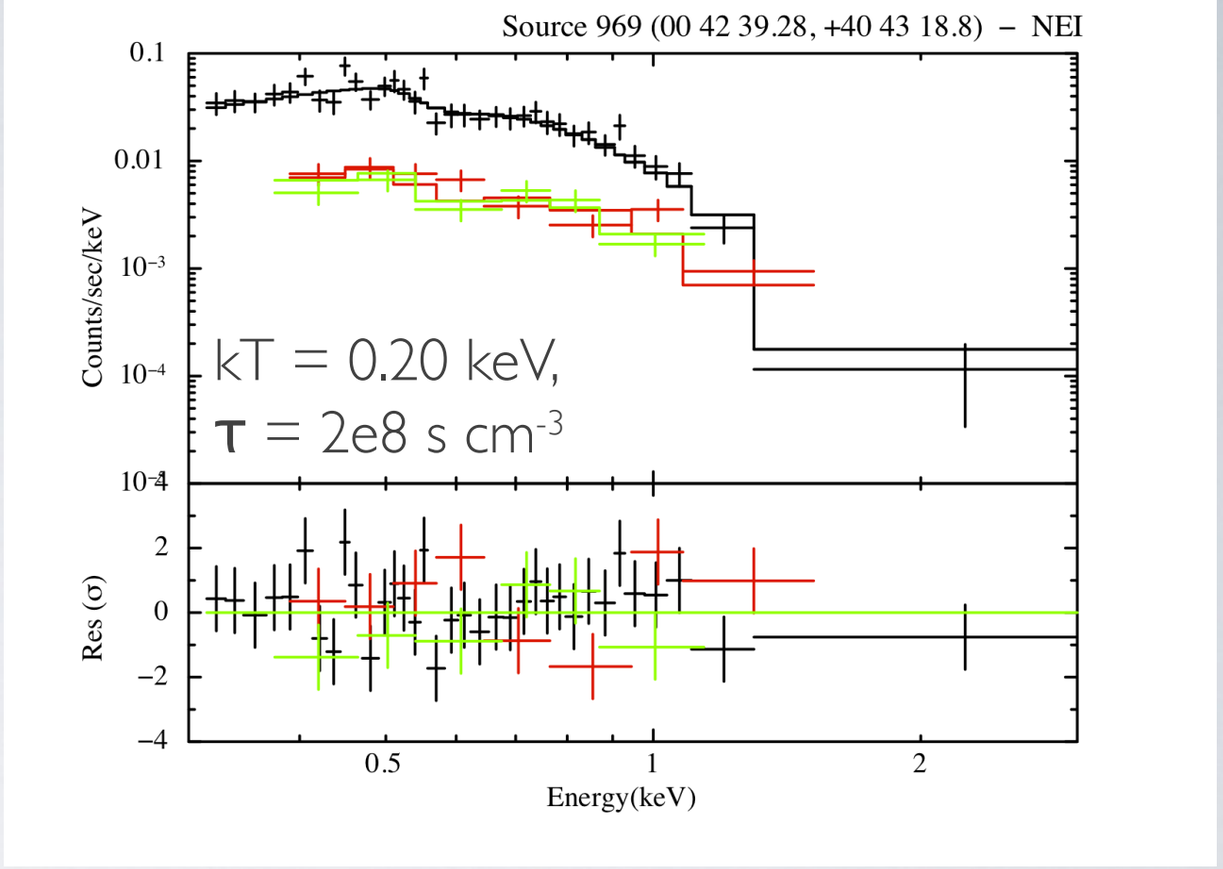
- Source 969: SNR candidate with very soft X-ray spectrum. No optical counterpart.



- Best fit with NEI or NPSHOCK model (kT = 0.20 keV, τ = 2e8 s cm^{-3}).
- Low temperature: old SNR?
- Ionisation timescale τ = 2e8 s cm^{-3} = 6 yrs cm^{-3}. For an assumed age of t = 10,000 yrs, n_e = 6e-4 cm^{-3}, very low density.

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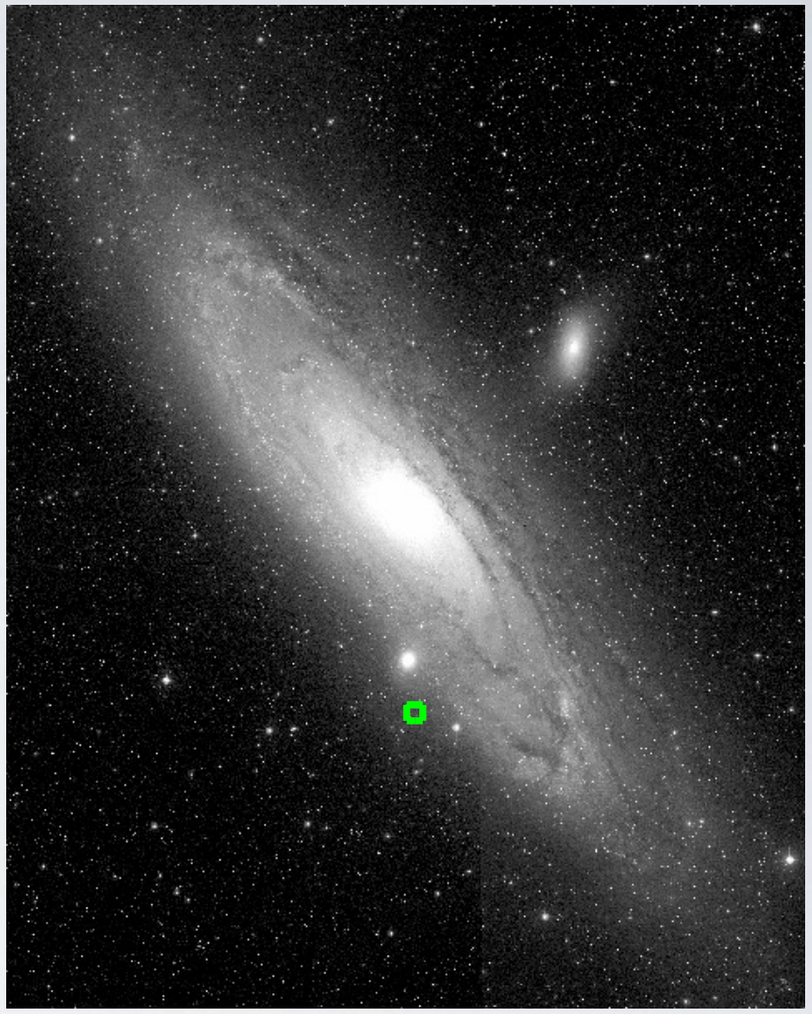

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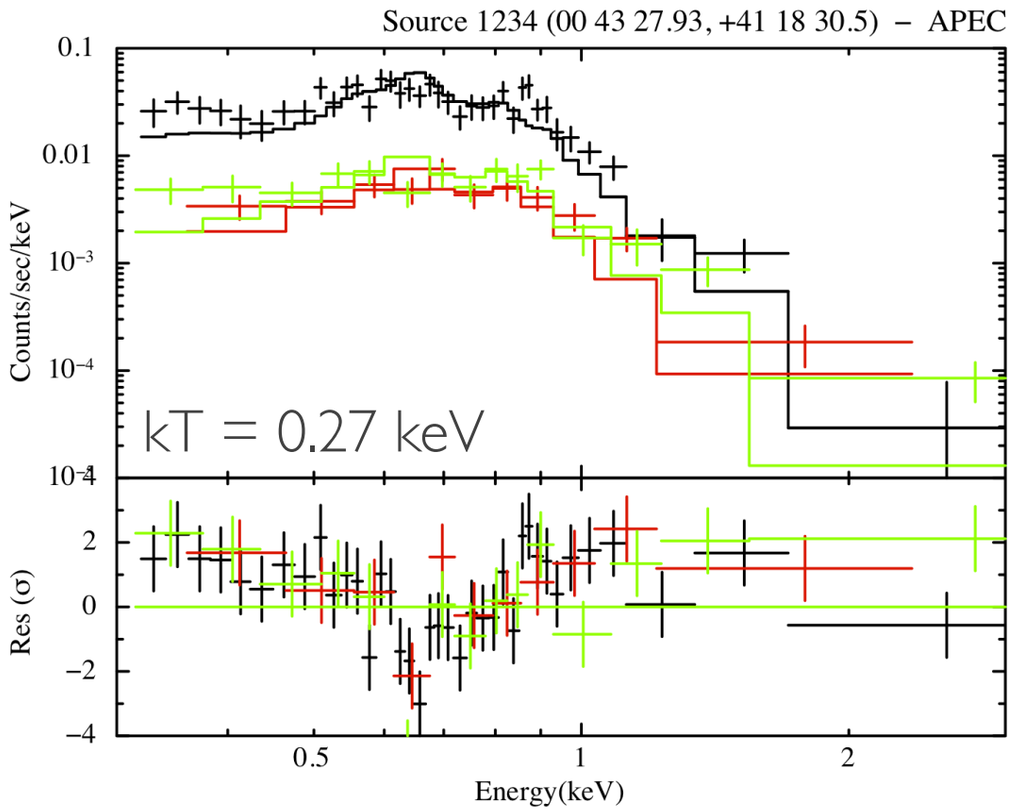
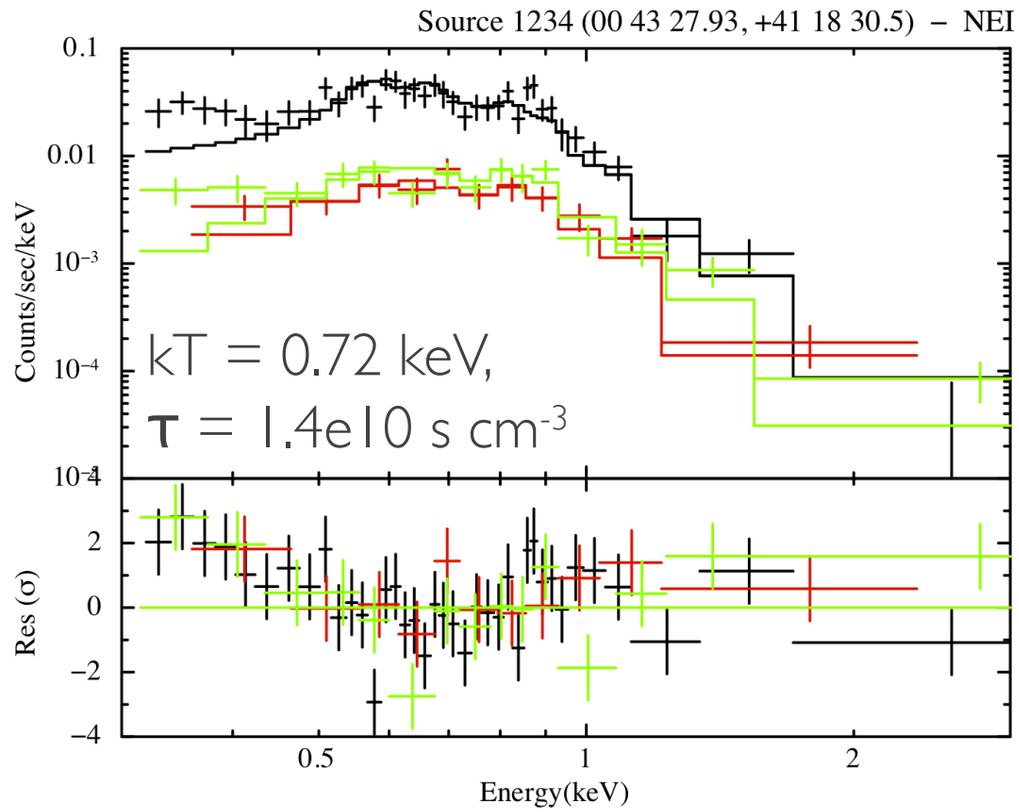
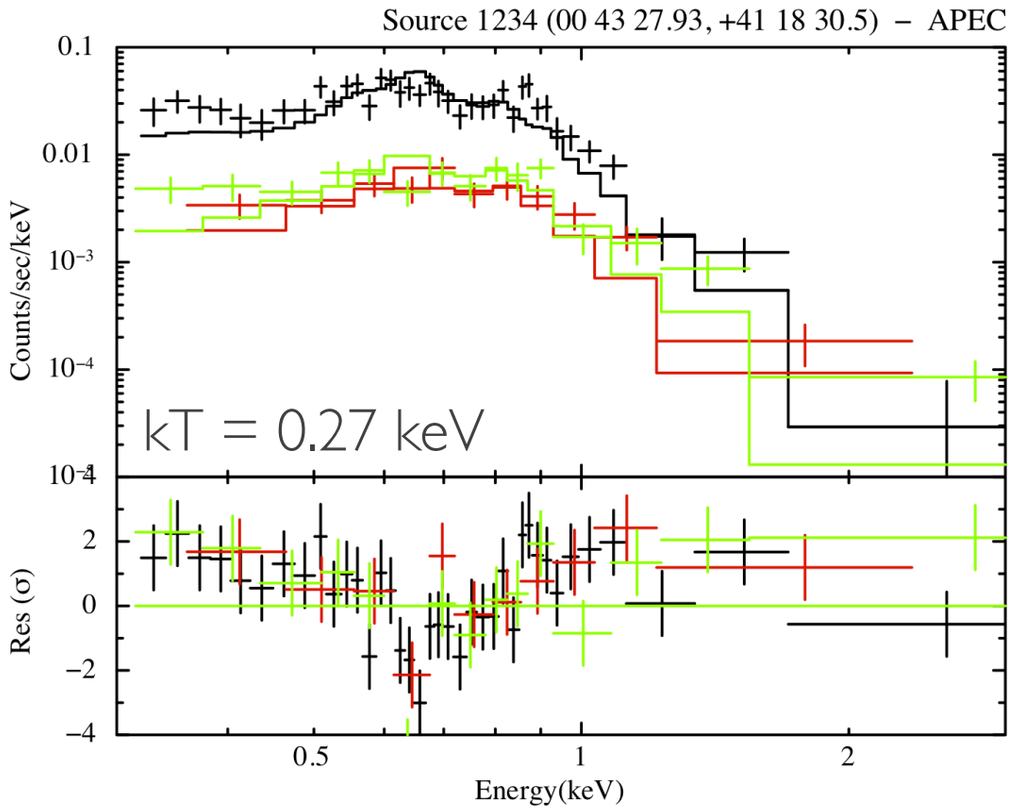
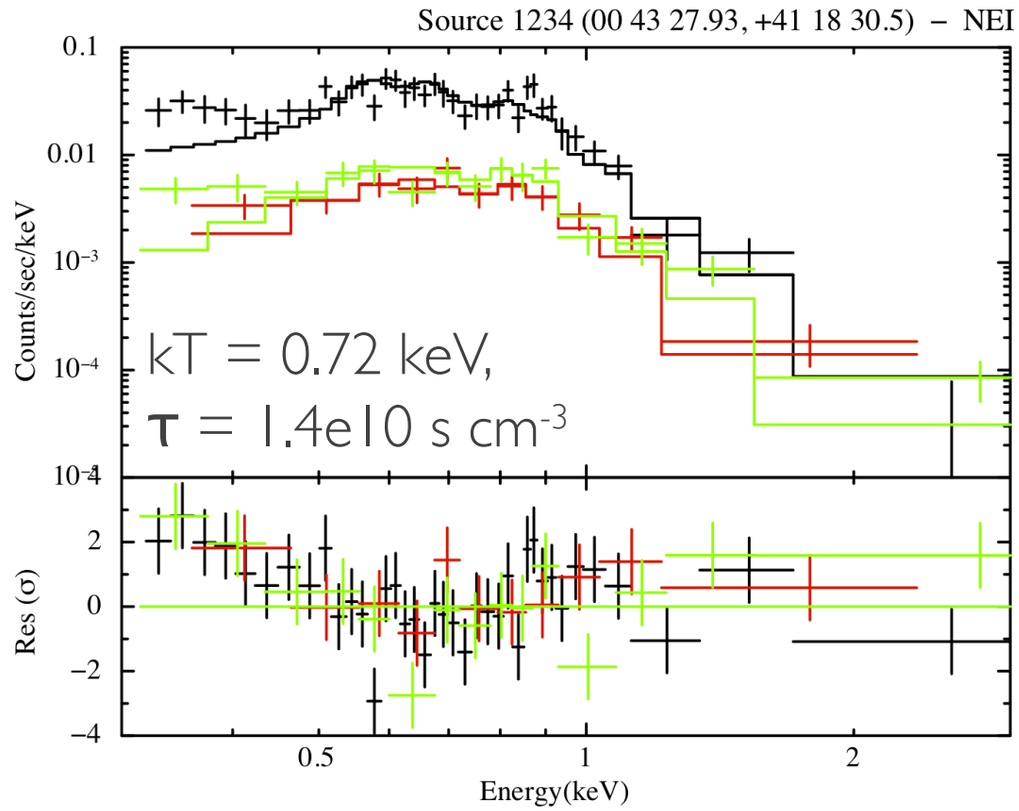


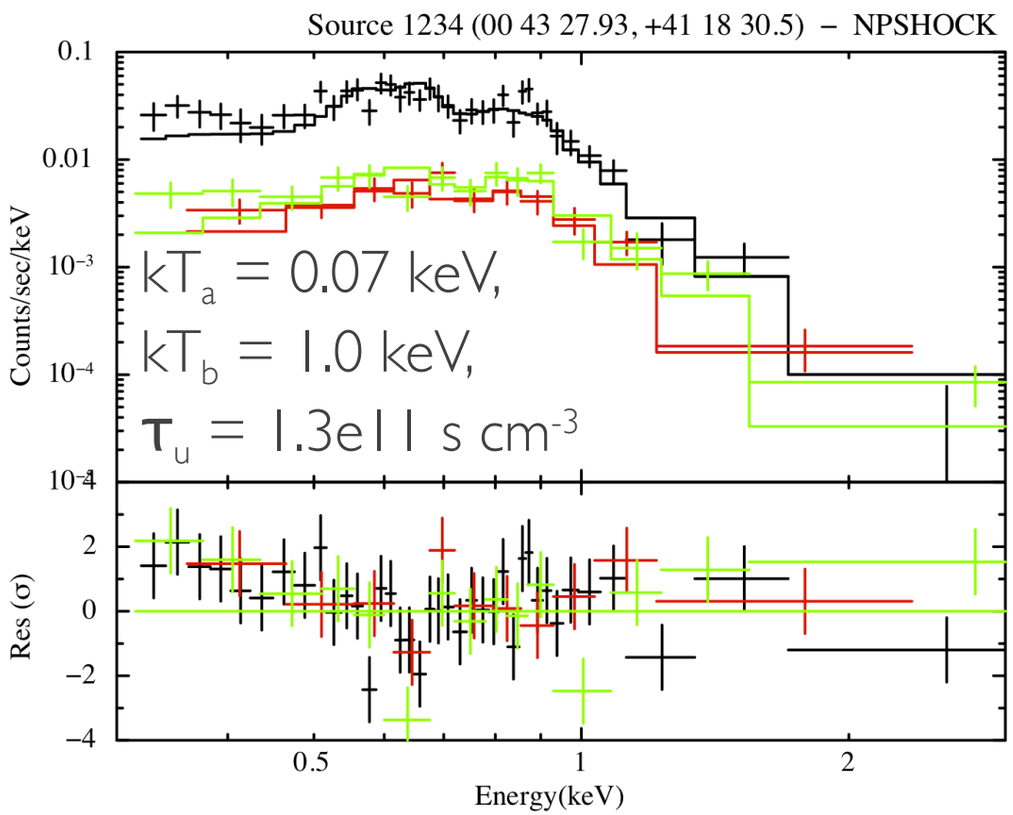


- APEC: red. $\chi^2 = 2.3$, DOF = 61
- NEI: red. $\chi^2 = 1.6$, DOF = 60
- Residual soft emission below 0.5 keV.

EPIC spectra of source 1234







- NPSHOCK: red. $\chi^2 = 1.5$, DOF = 50

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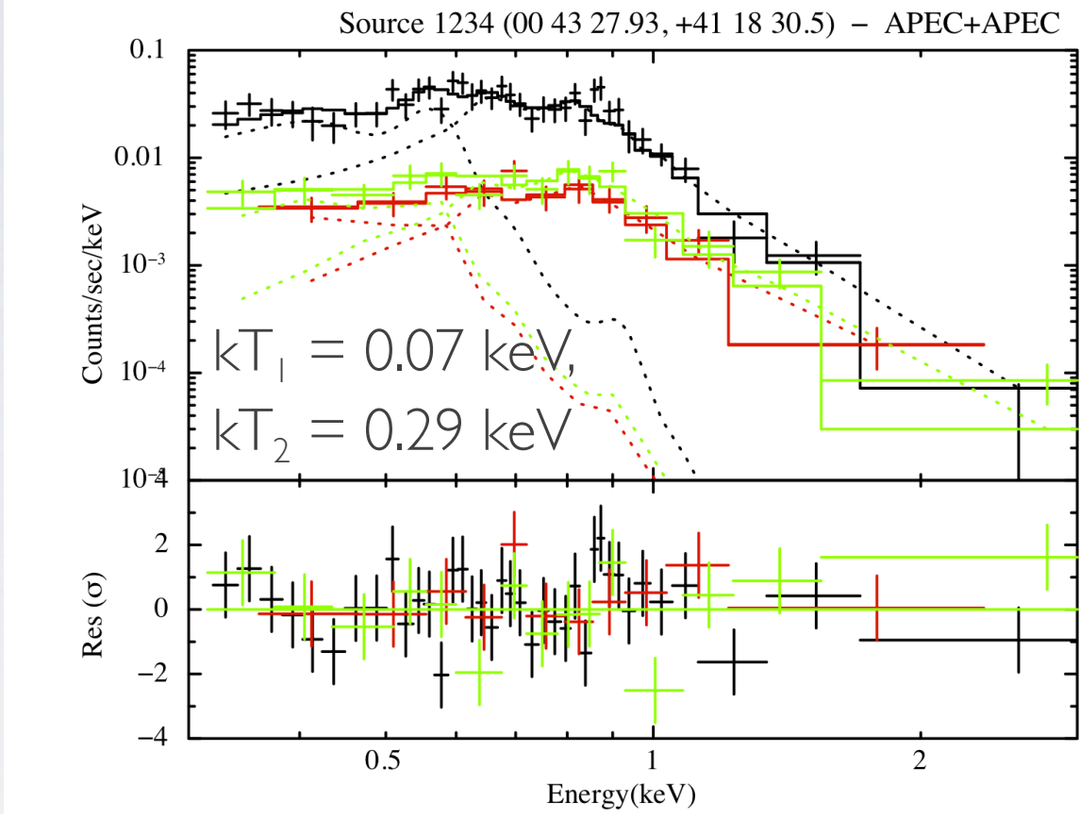
- Two APEC model components: red. $\chi^2 = 1.0$, DOF = 59
- Soft emission well reproduced.
- Emission from hot gas inside a HII region?



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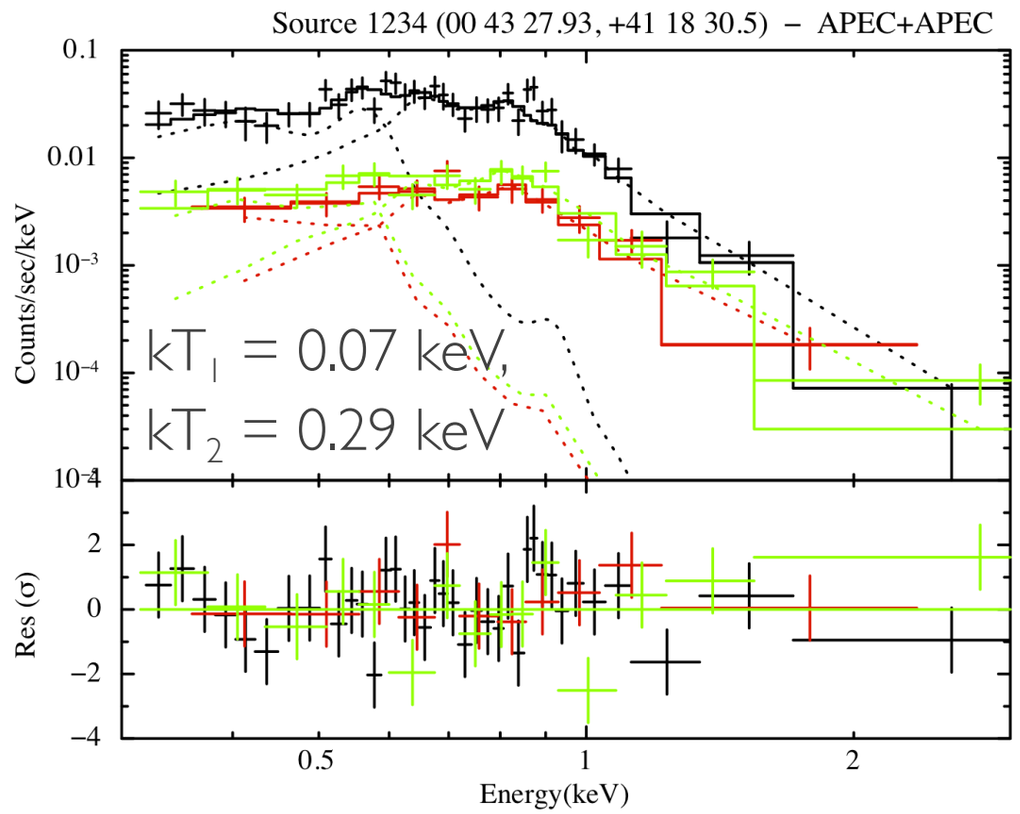
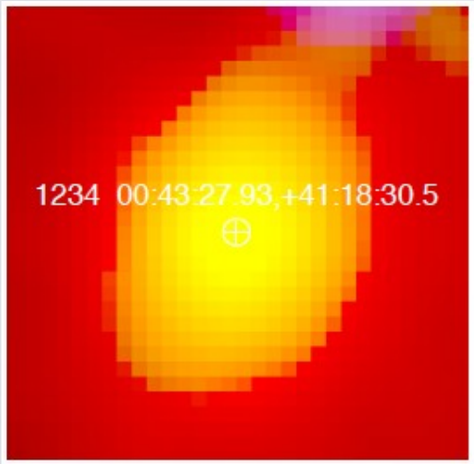
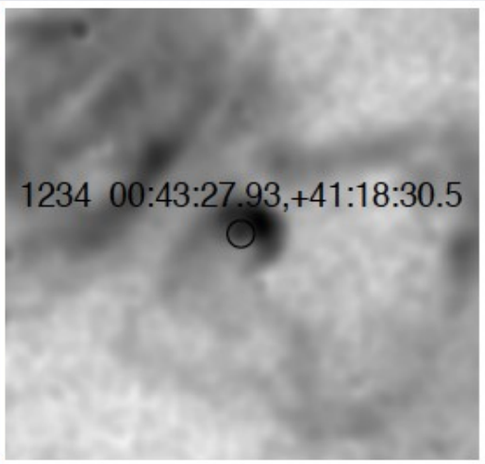


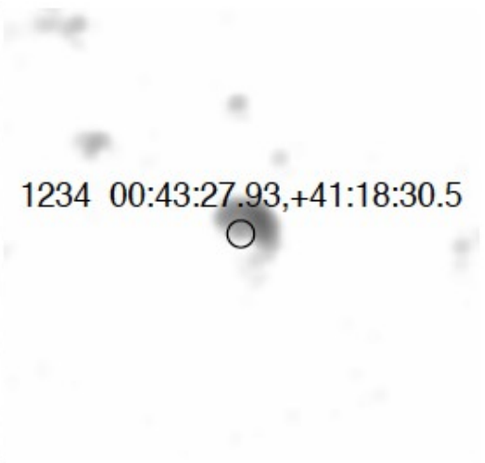


SNR

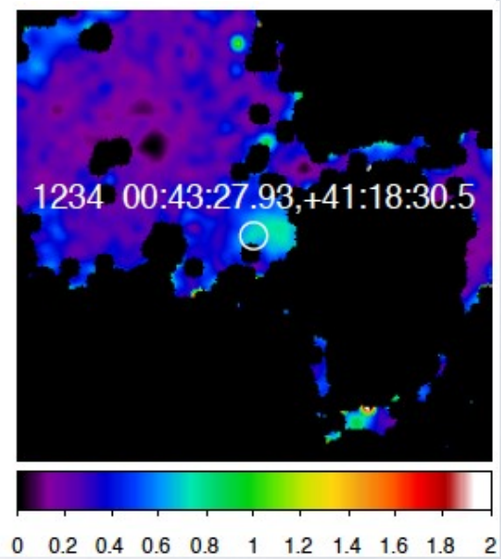


Hα

[S II]



[O III]



XMM RGB [S II]/Hα

Optical emission-line images (Local Group galaxy Survey, Massey et al. 2006)

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Optical data

- Optical data: Local Group galaxy Survey (LGS @ KPNO and CTIO, Massey et al. 2006).
- SNRs, like H II regions or planetary nebulae, can be bright in Hα.
- Optical flux ratio [S II]/Hα > 0.5 for shock-ionised gas in SNRs and < 0.5 for photo-ionised gas in, e.g., HII regions (Braun & Walterbos 1993).
- Use SDSS images to look for optical counterpart if no LGS data are available.

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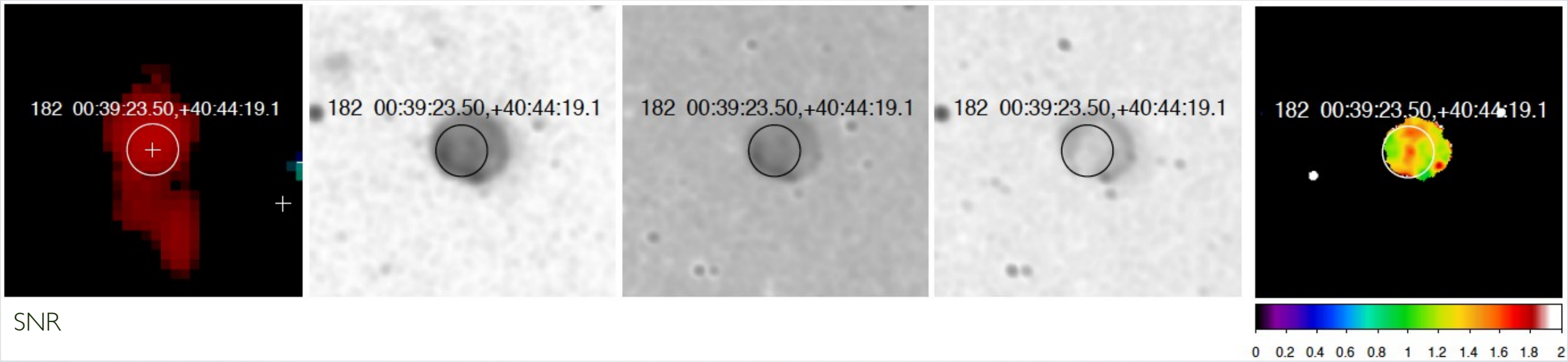
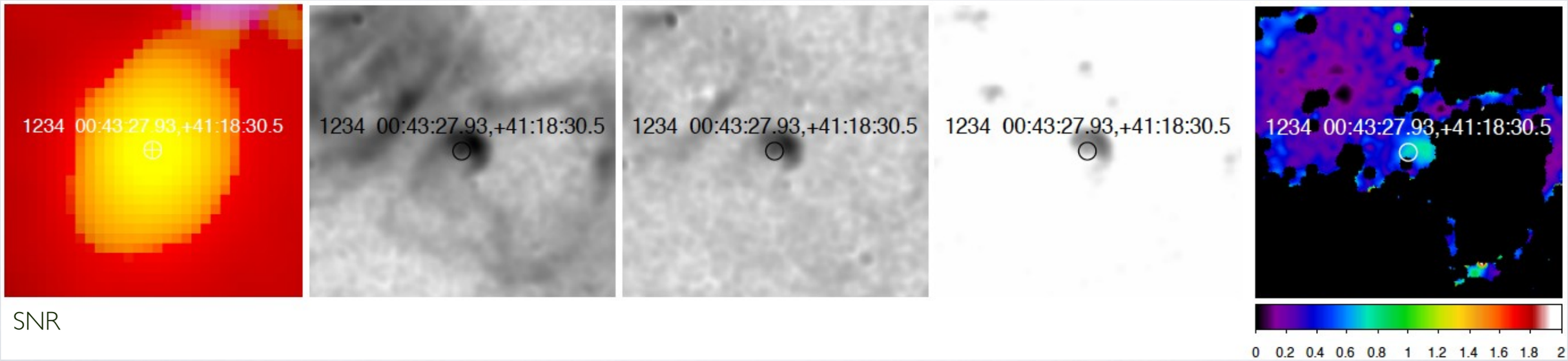
XMM RGB | Hα | [S II] | [O III] | [S II]/Hα



SNR



SNR

Optical emission-line images (LGS)

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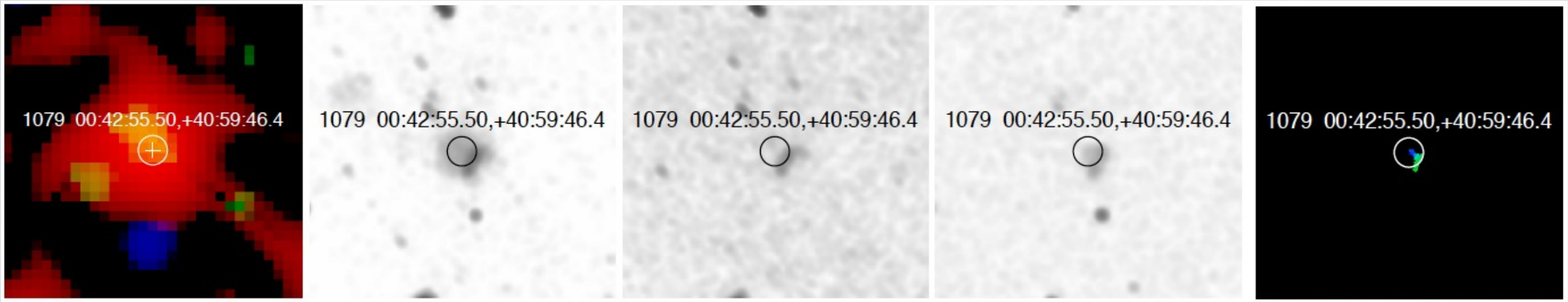
XMM RGB Hα [S II] [O III] [S II]/Hα



New SNR

Optical emission-line images (LGS)

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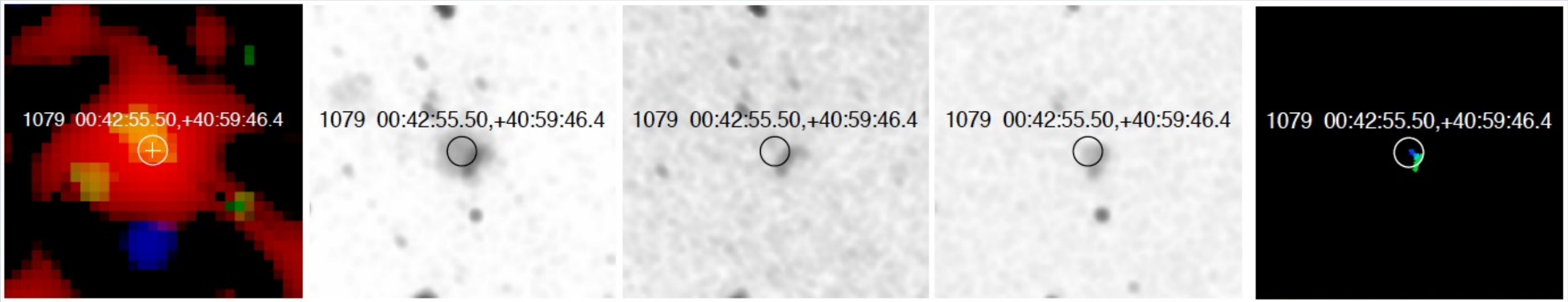
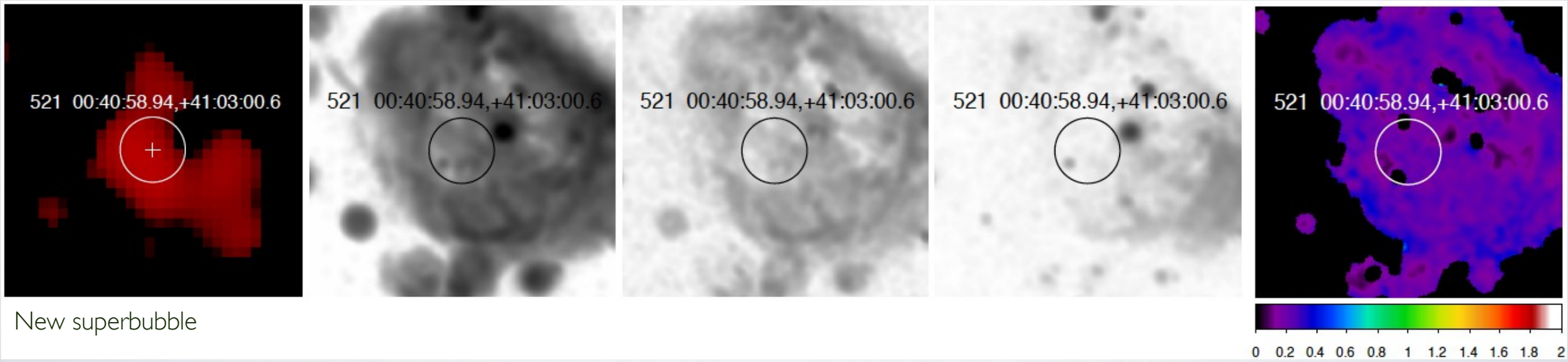
XMM RGB | Hα | [S II] | [O III] | [S II]/Hα



New SNR



New superbubble

Optical emission-line images (LGS)

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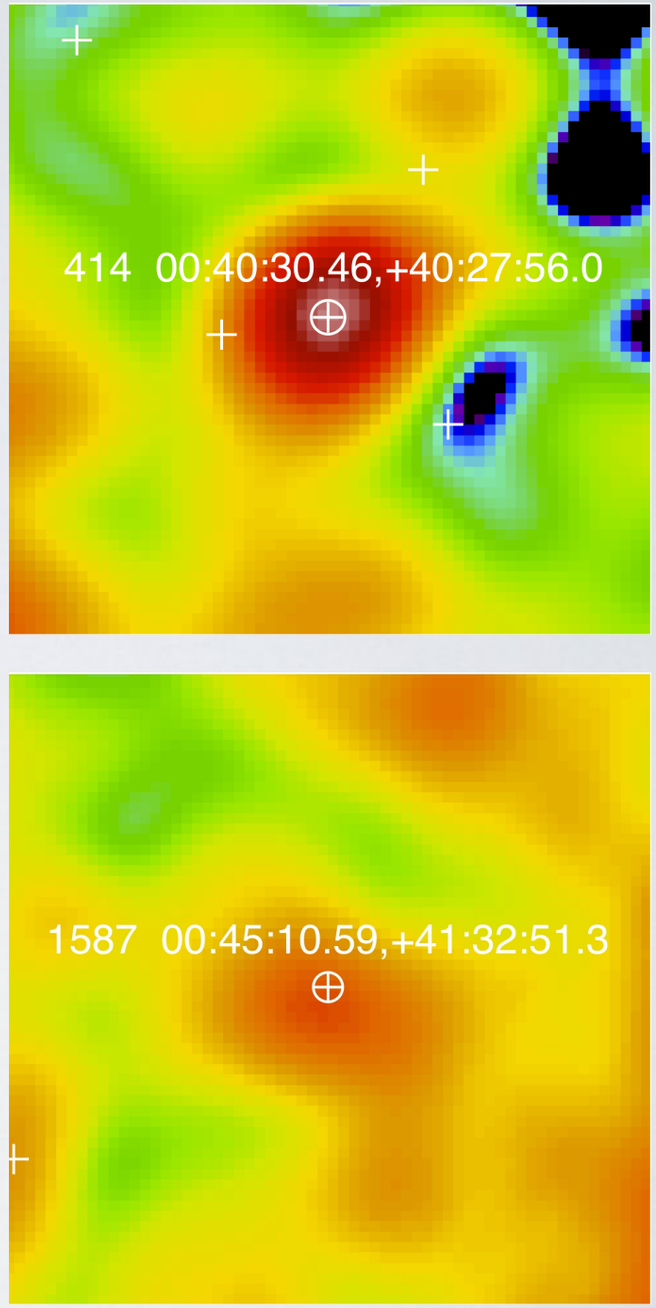
Classification

- Confirmed 23 known SNRs.
- Six new opt./X-ray SNRs: significant Hα, [S II], and [O III] emission as well as [S II]/Hα > 0.5.
- Two new radio/X-ray SNRs: radio counterparts in Braun (1990), Gelfand et al. (2004).
- Four superbubbles: diffuse, extended optical source with [S II]/Hα < 0.5.
- Three sources are hard X-ray sources with neither optical nor radio counterpart: no SNRs.



XMM-Newton position on VLA 20cm (M. Filipović, UWS)

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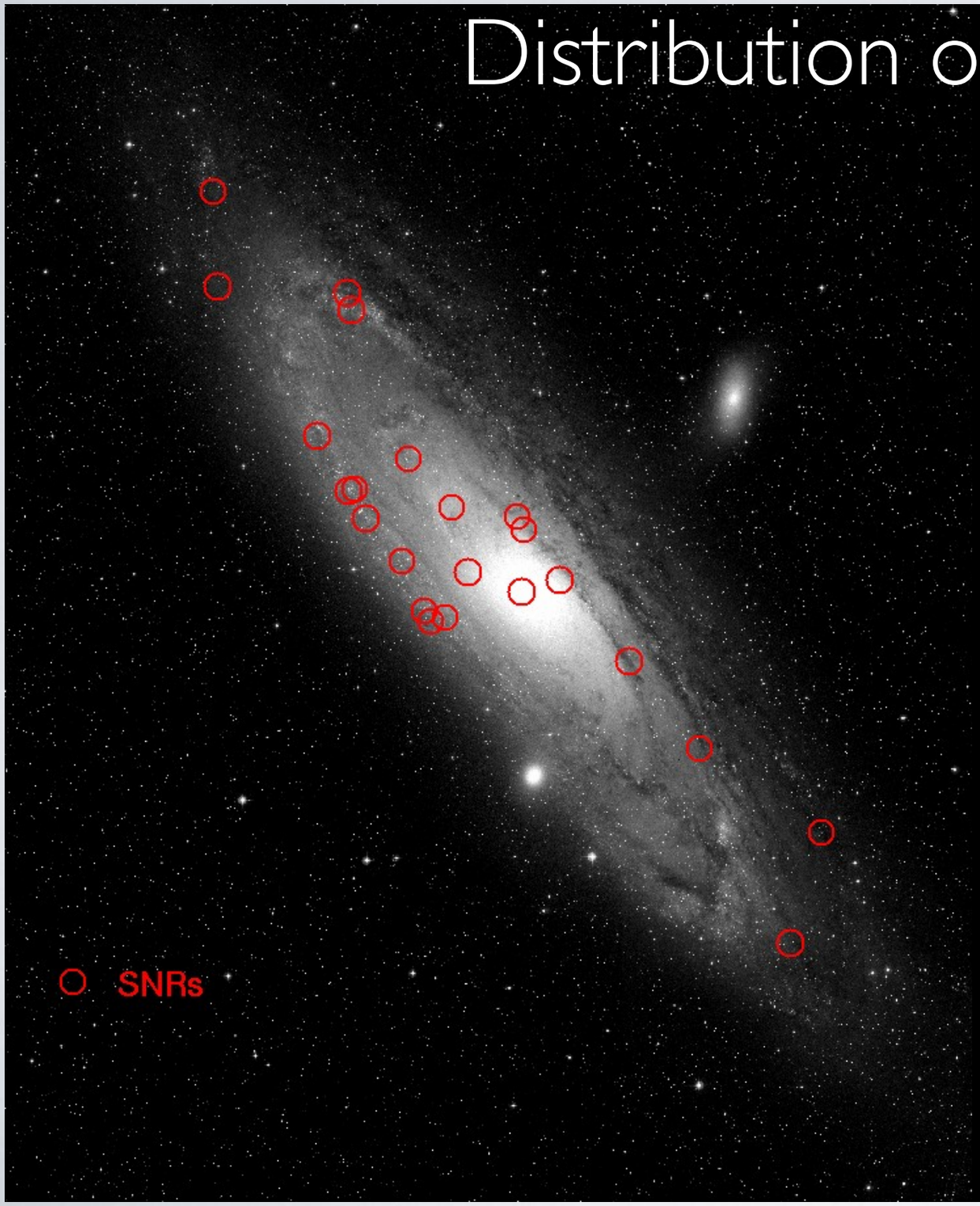
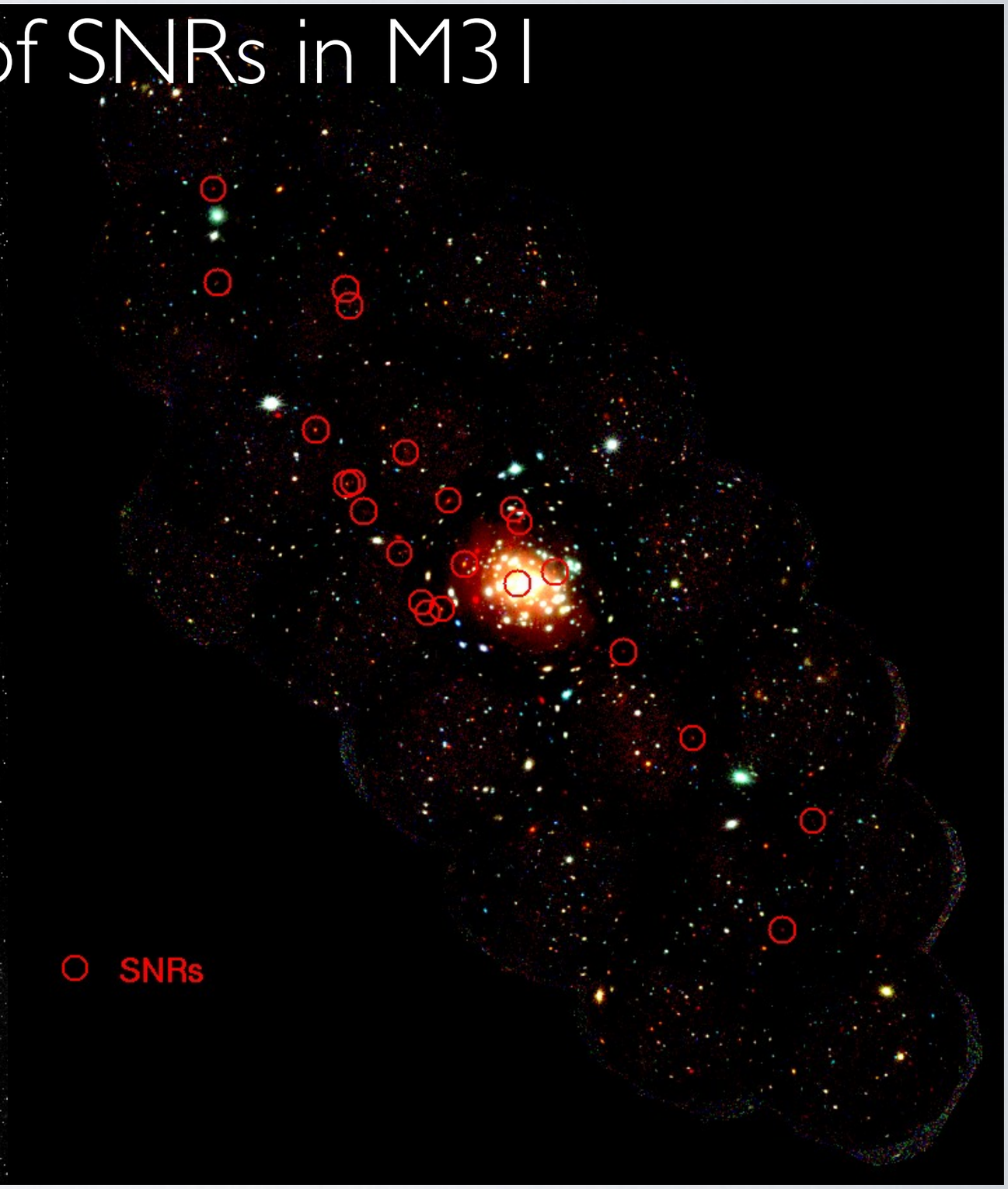
Distribution of SNRs in M31





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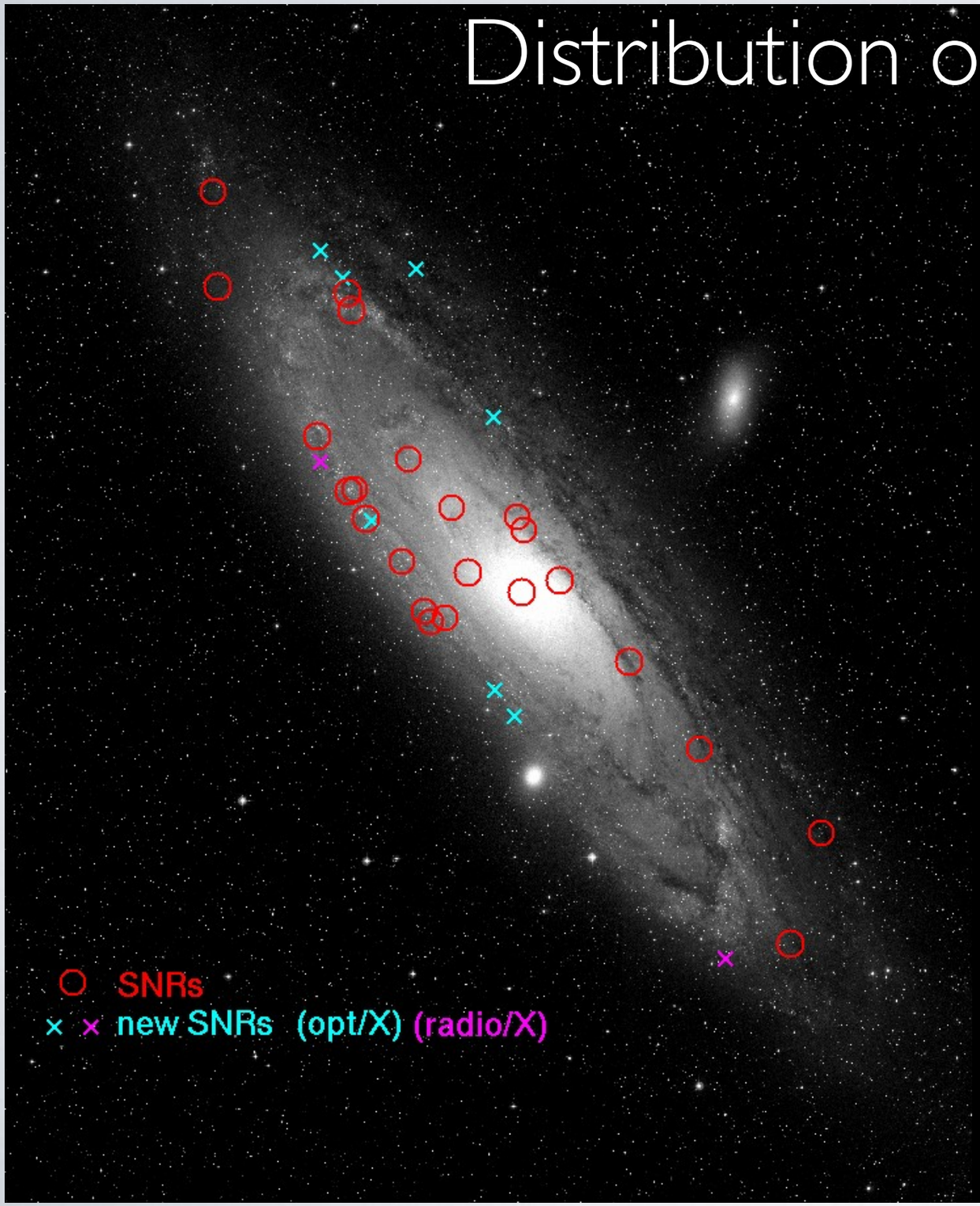

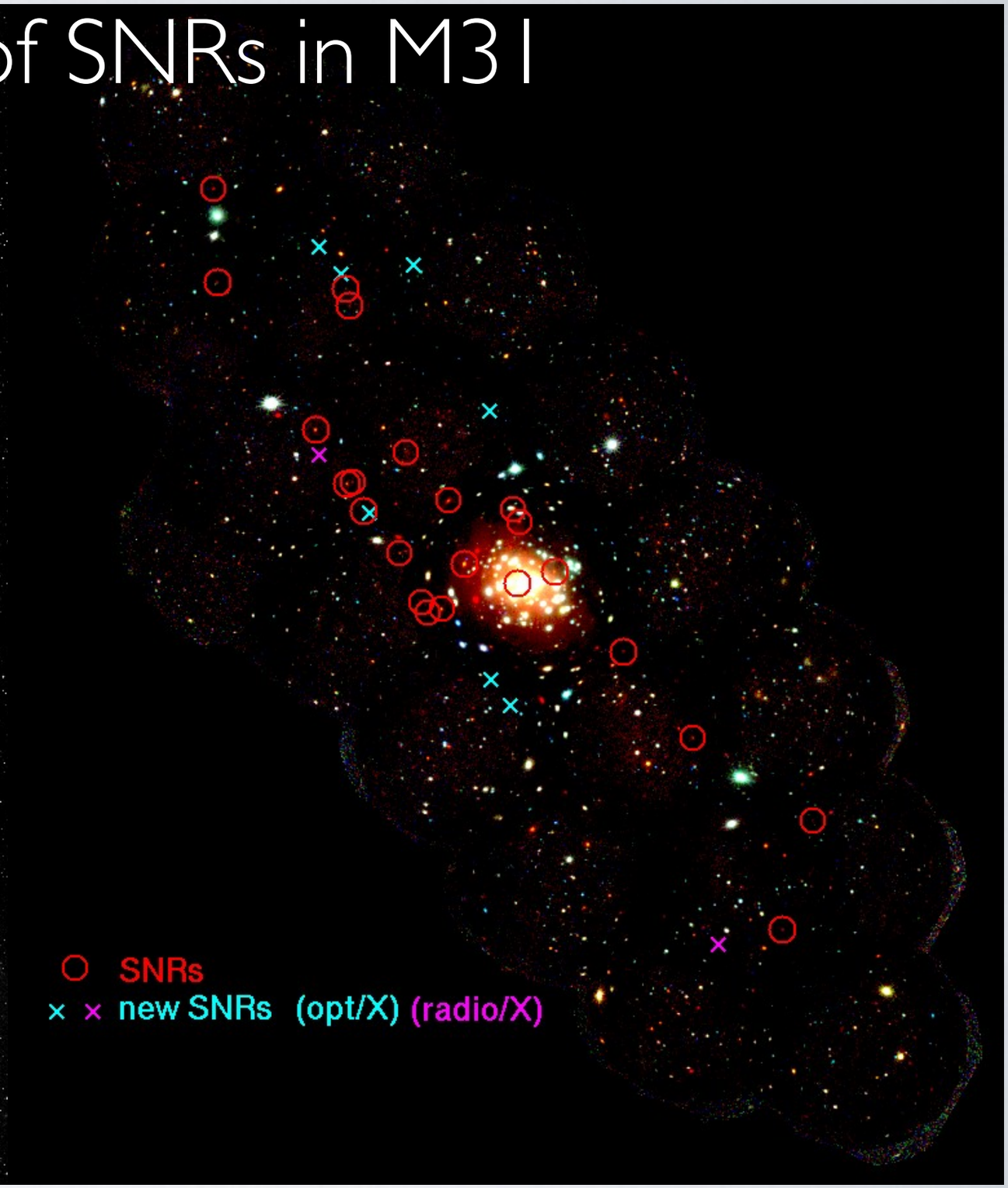

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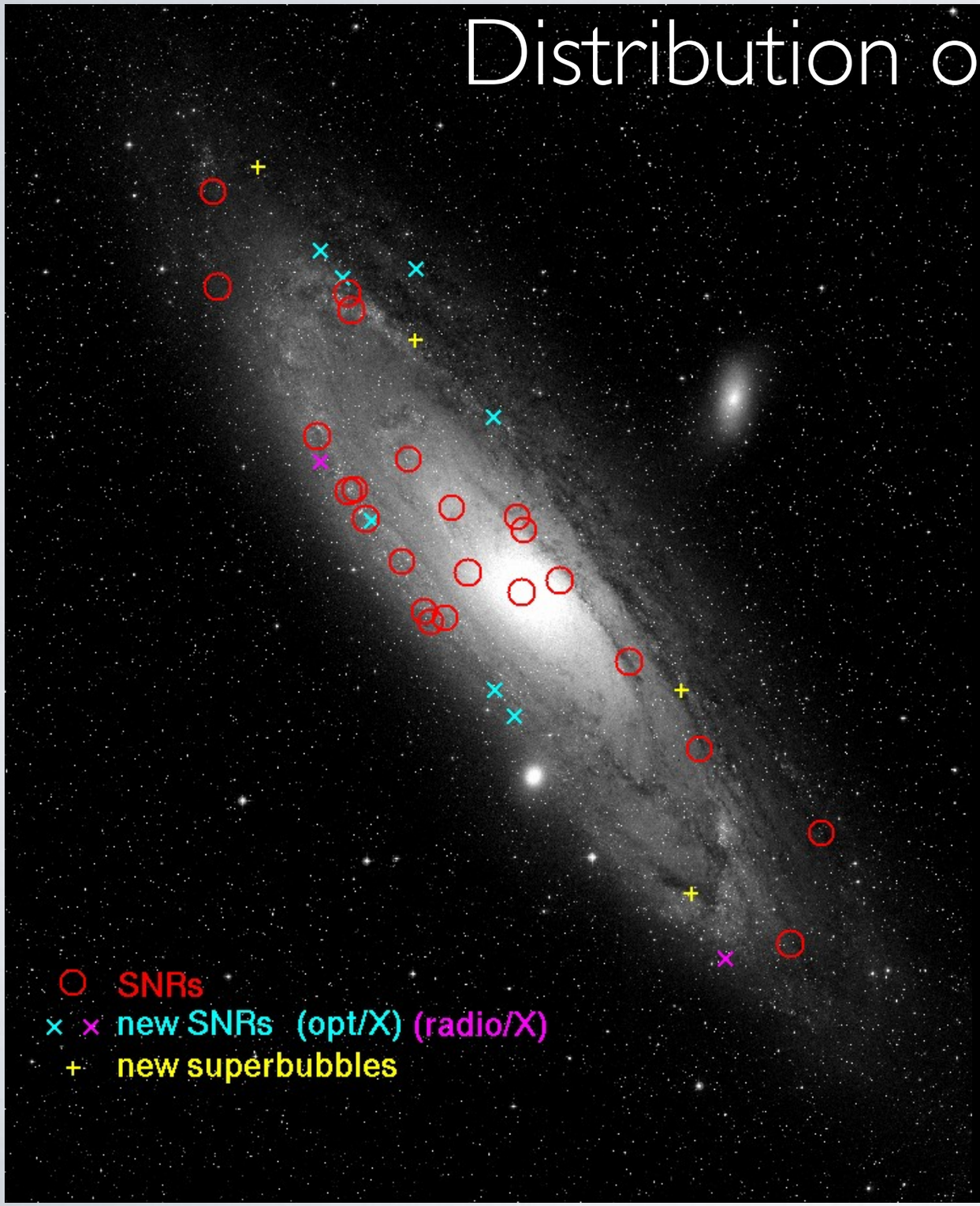

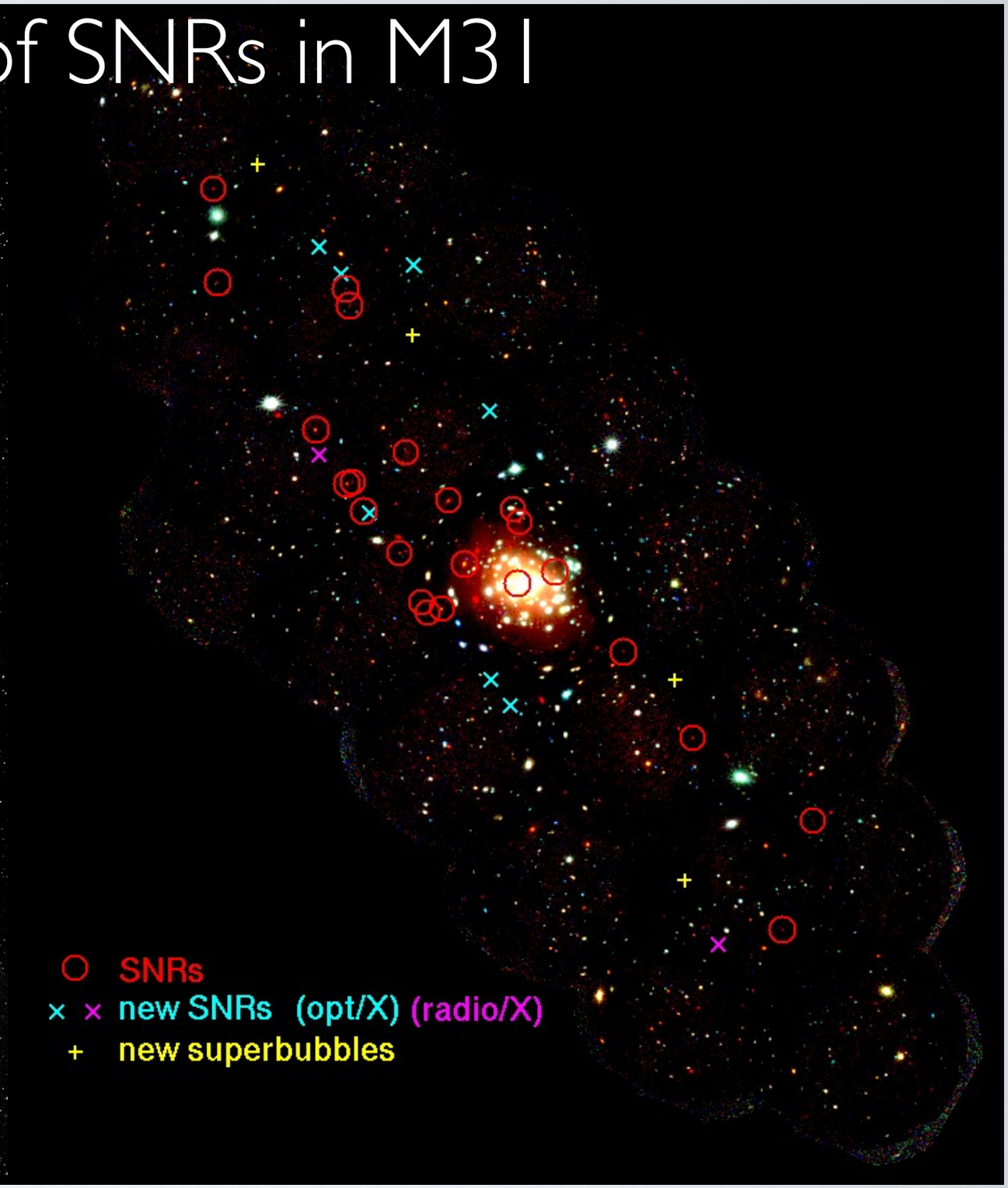

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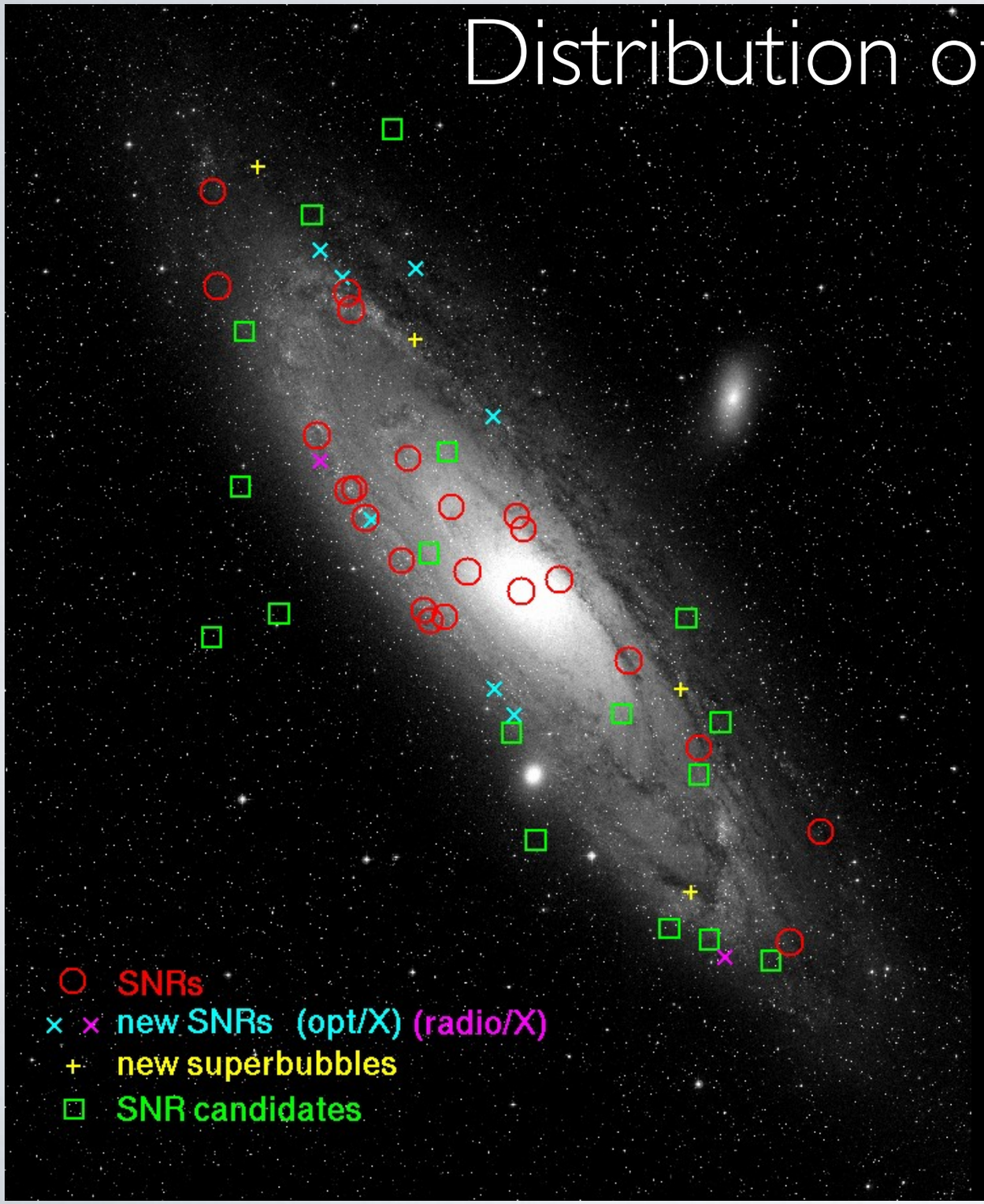

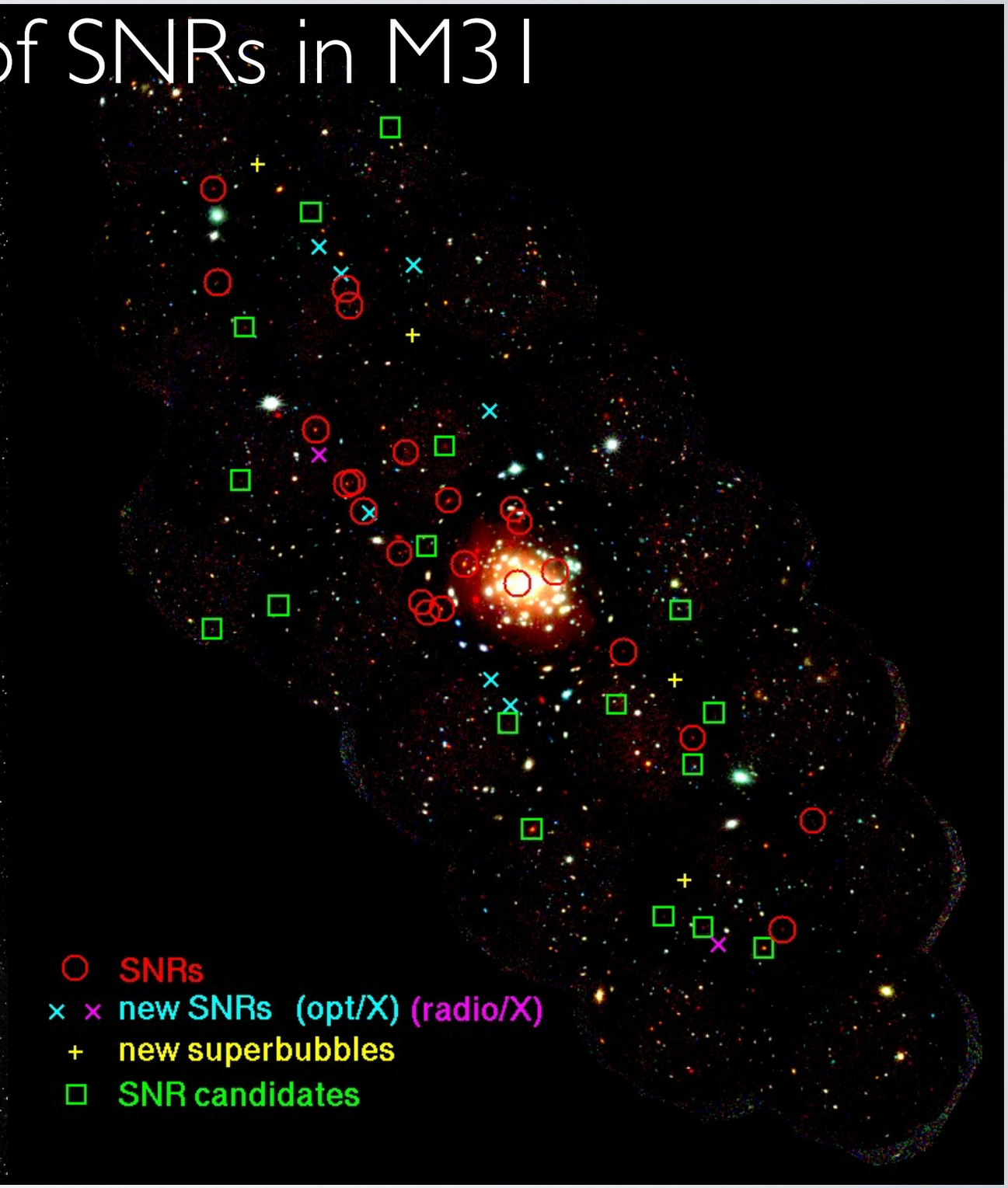

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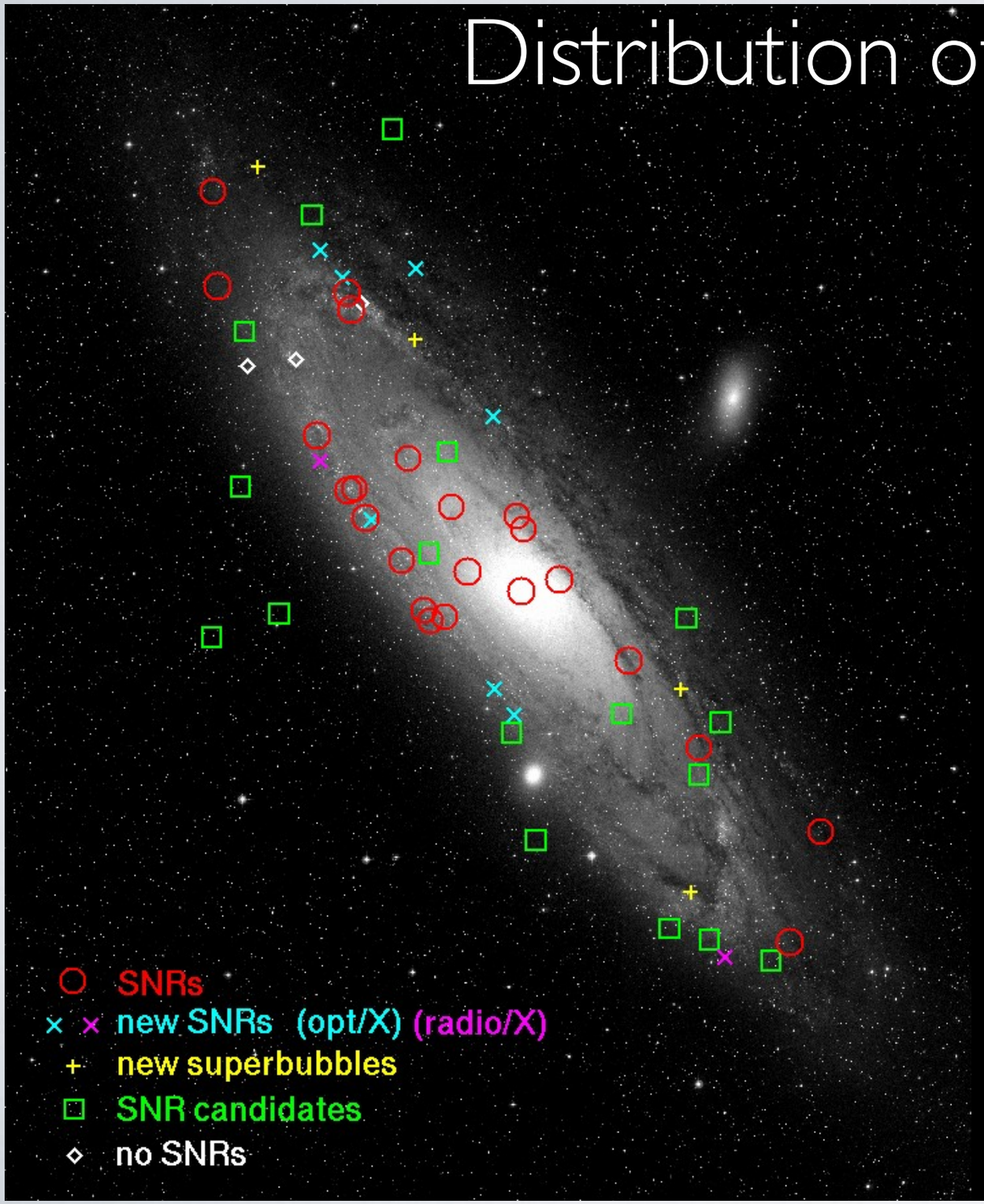

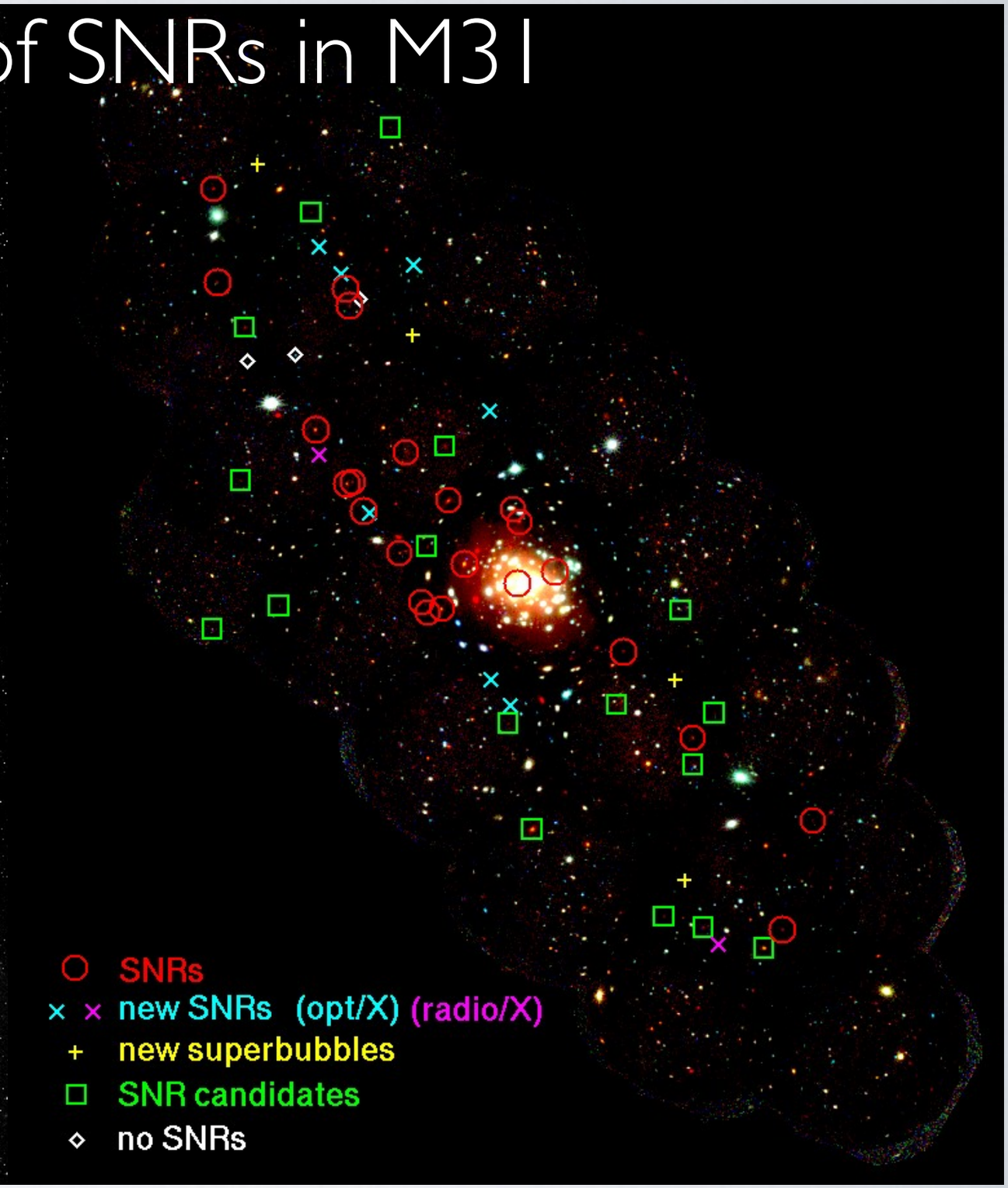

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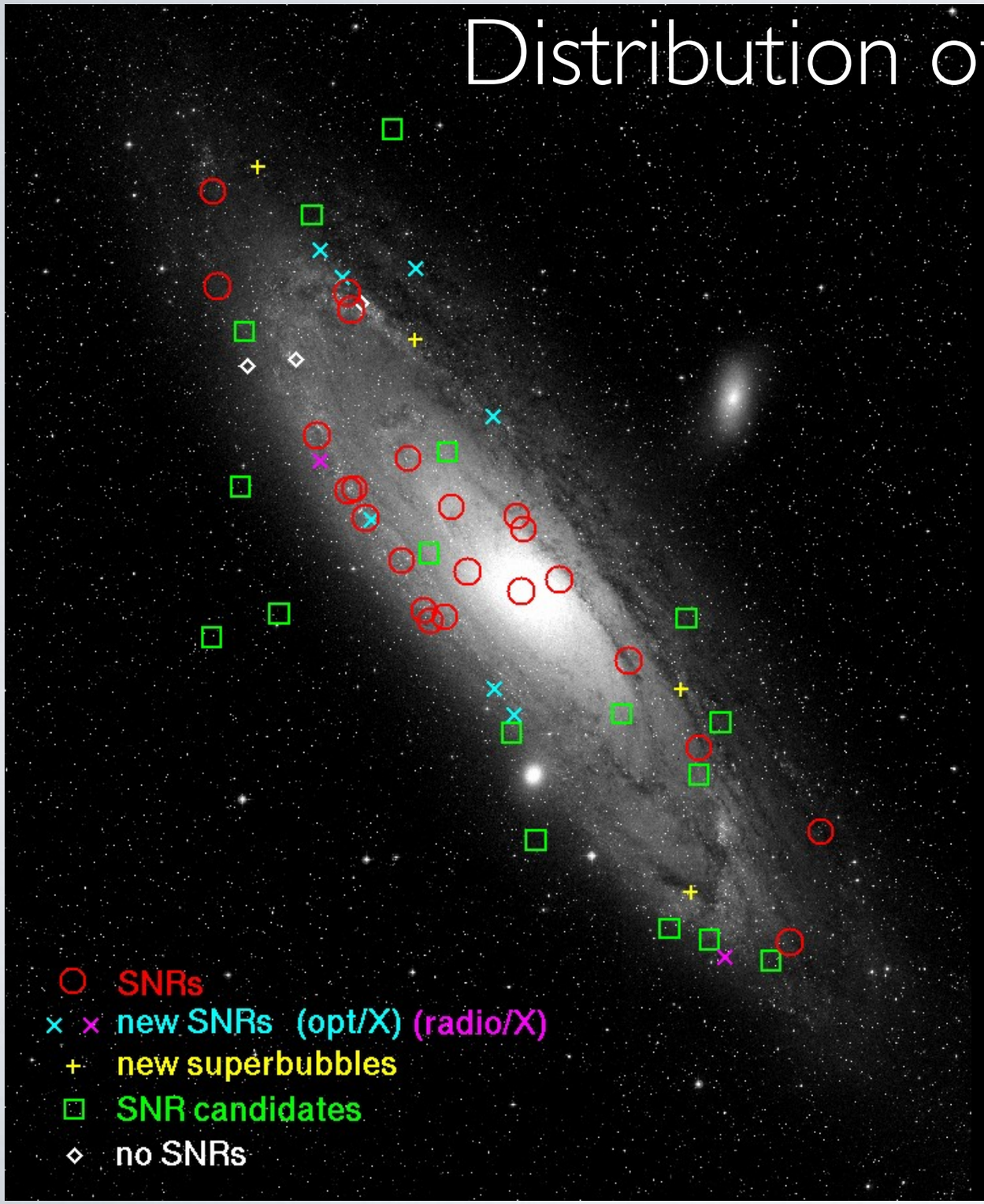

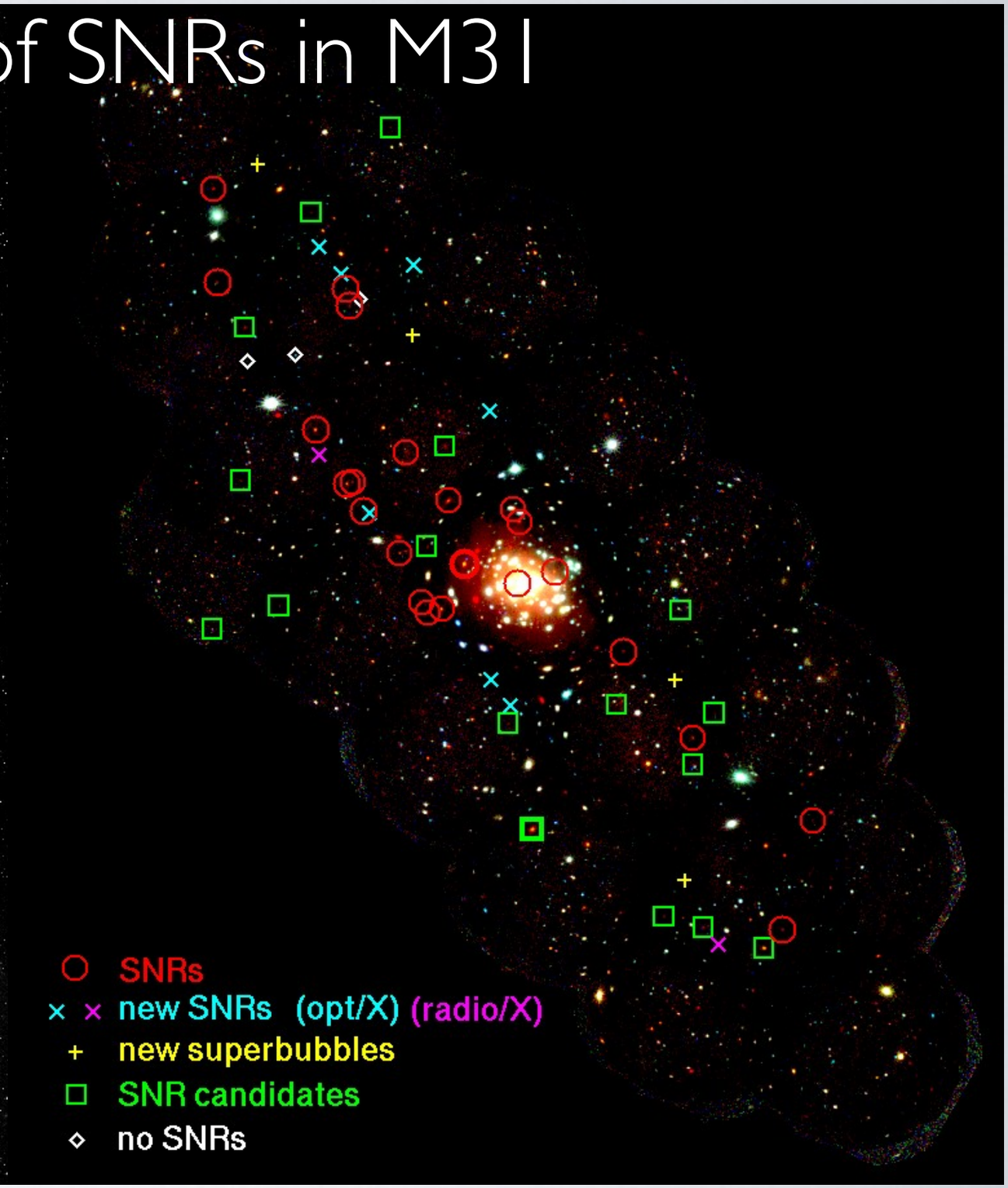

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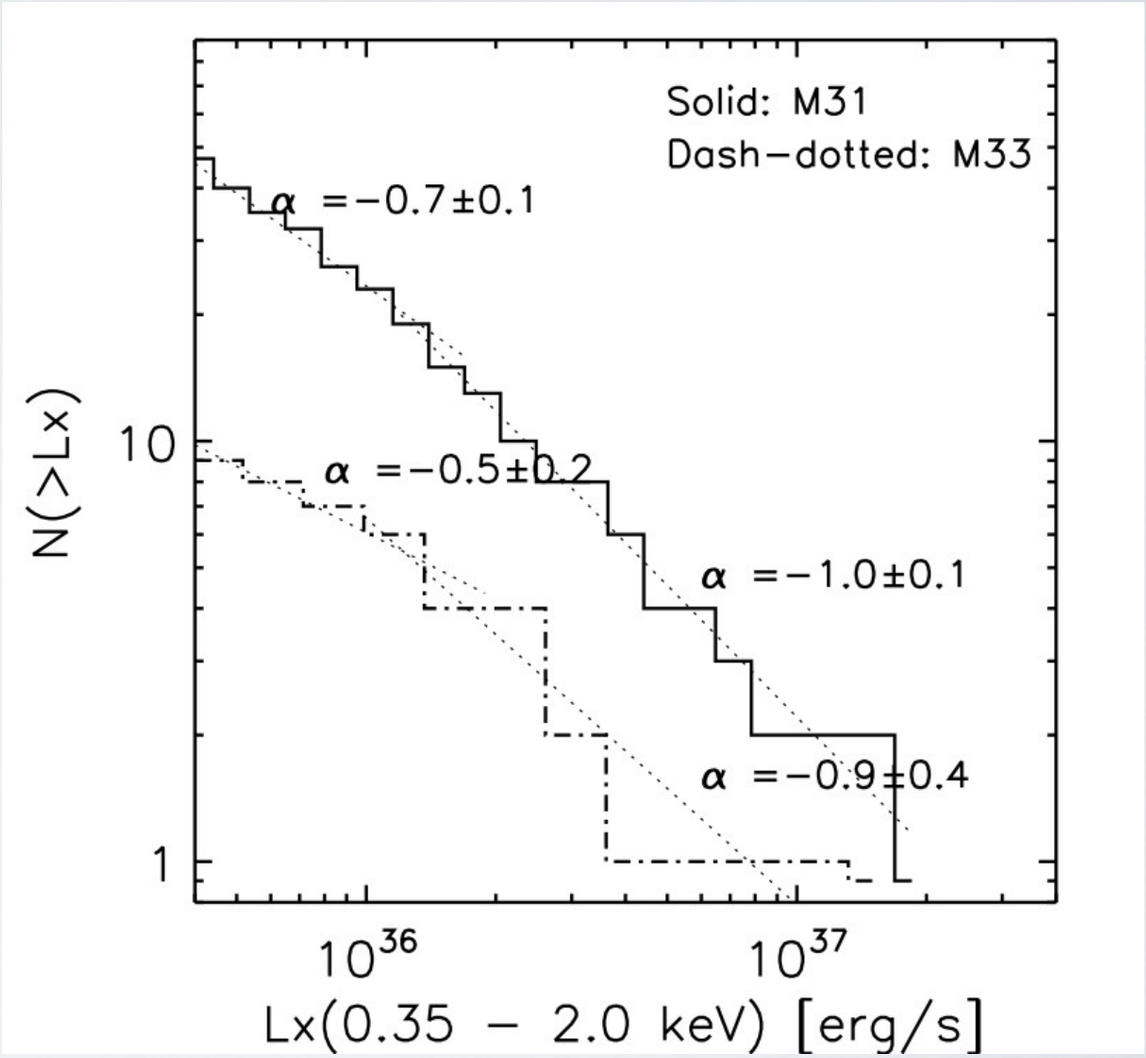
Cumulative X-ray luminosity distribution of SNRs

- X-ray luminosity functions of SNRs in M31 and M33 (ChASeM33, Long et al. 2011; talk by Paul Plucinsky) are similar and seem to have a break at about 10^{36} erg/s.
- Relatively high number of SNRs in M33.



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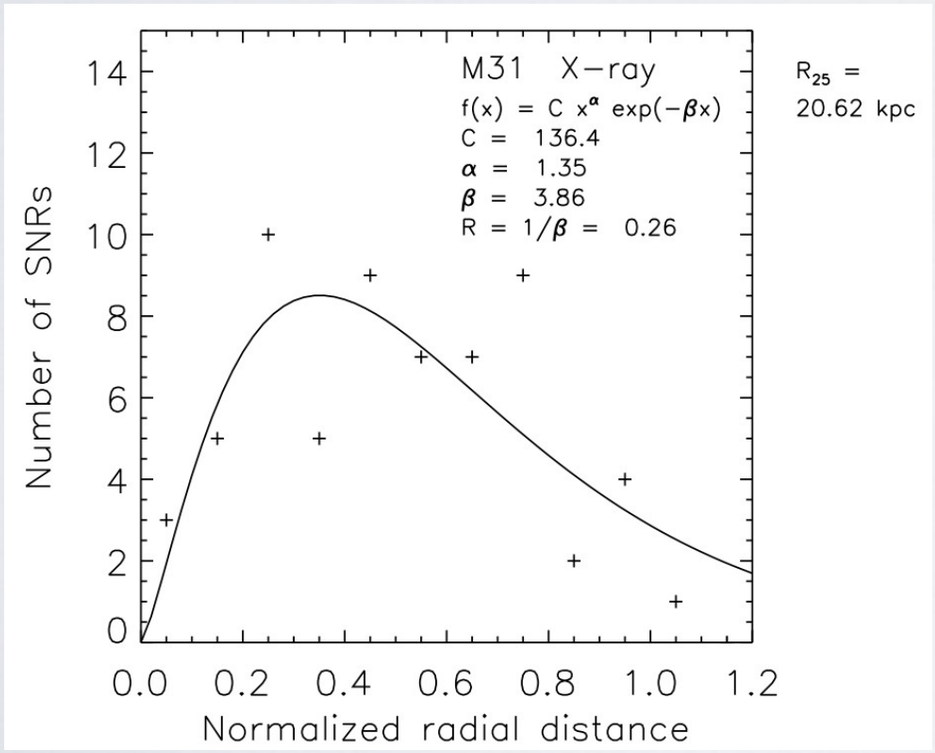
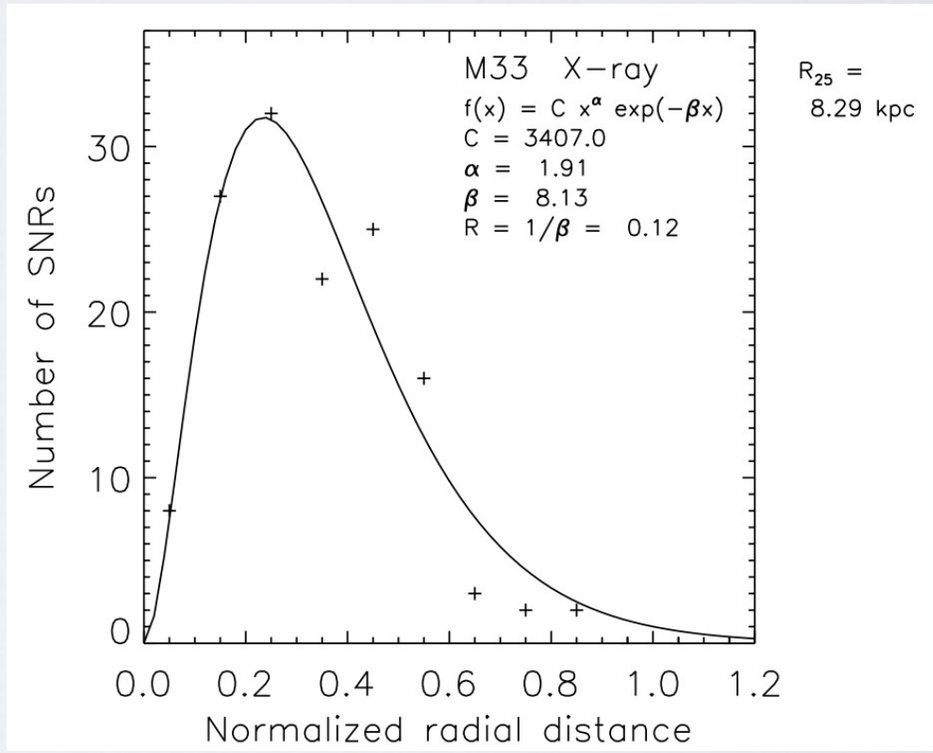
Radial distribution of SNRs

- Exponential decrease.
- Does not follow the distribution of mass in a galaxy.
- Correlated with dust ring in M31.



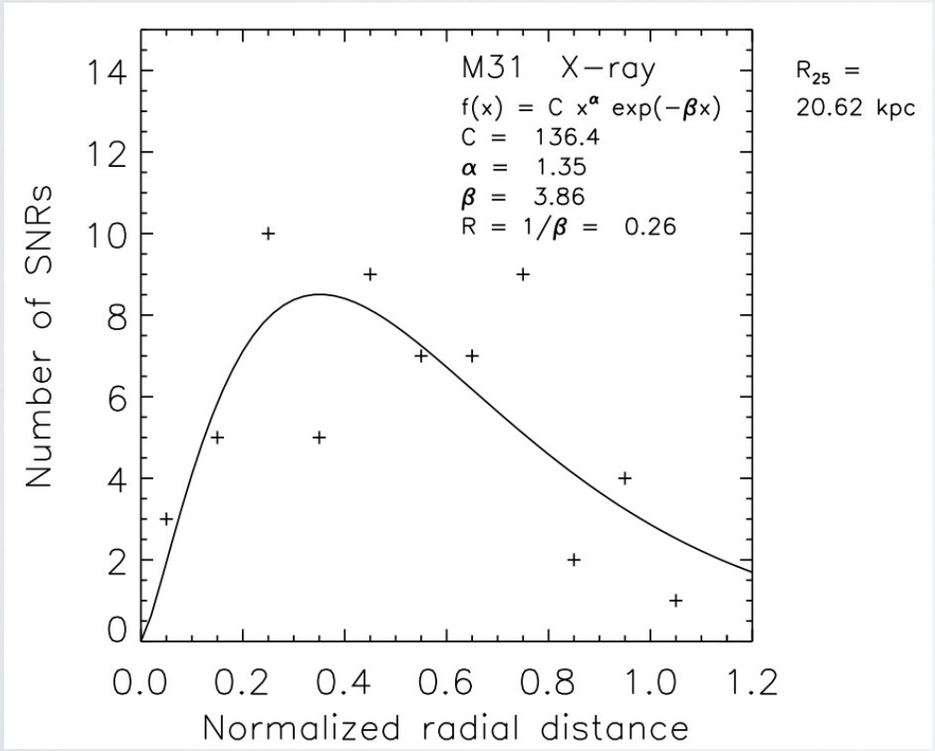


EBERHARD KARLS
UNIVERSITÄT
TÜBINGEN

The X-ray Universe 2011, Berlin
Manami Sasaki
Institut für Astronomie und Astrophysik

Radial distribution of SNRs

- Exponential decrease.
- Does not follow the distribution of mass in a galaxy.
- Correlated with dust ring in M31.



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Summary

- X-ray spectral analysis and optical flux measurements of SNRs and candidates in the source catalogues of the *XMM-Newton* Large Program Survey (Stiele et al. 2011) using optical data of the Local Group galaxy Survey (Massey et al. 2006).
- Eight new X-ray SNRs and four superbubbles confirmed.
- Three sources are excluded from the list of candidates.
- XMMM31 J004239.82+404318.8: peculiar spectrum with low ionisation timescale.
- XMMM31 J004327.93+411830.5: SNR in a HII region.
- X-ray luminosity distribution and radial distribution of SNRs confirm that
  - the SNR population in M31 is consistent with the star formation activities in this grand-design spiral galaxy, which occurs in the spiral arms and thus in the prominent dust ring, and
  - the SNR population is larger in M33 than in M31 if scaled with the masses of the galaxies.