X-raying Supernova Remnants in the Magellanic Clouds

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CEA Saclay

The XMM-Newton LMC survey collaboration:
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and F. Acero & J. Ballet (CEA Saclay)

Our Galaxy is not suited for *population* studies

Large sample (~300 SNRs), but:

- Distance uncertainties
- Line-of-sight confusion/crowding
- Absorption/reddening

	MW	MCs
Distance	☒	✓
Multi-λ coverage	✓	✓
Absorption N_H	$\gtrsim 10^{22}$ cm^{-2}	$\lesssim$ few 10^{21} cm^{-2}

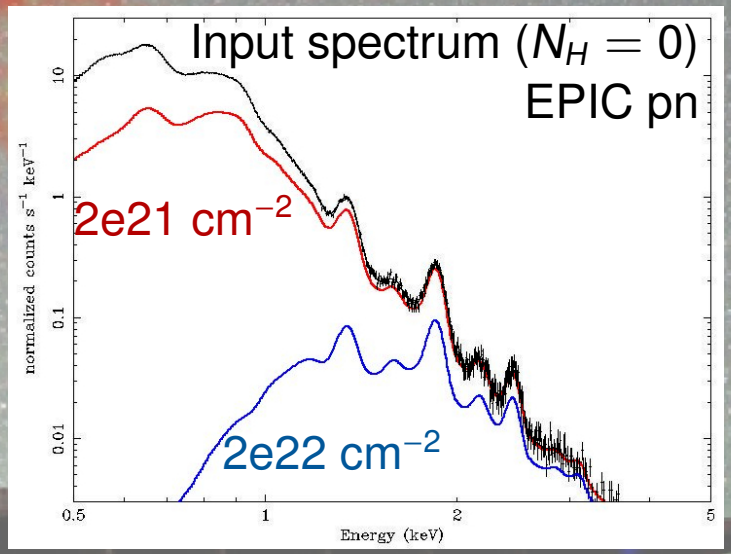
... but the LMC and SMC are

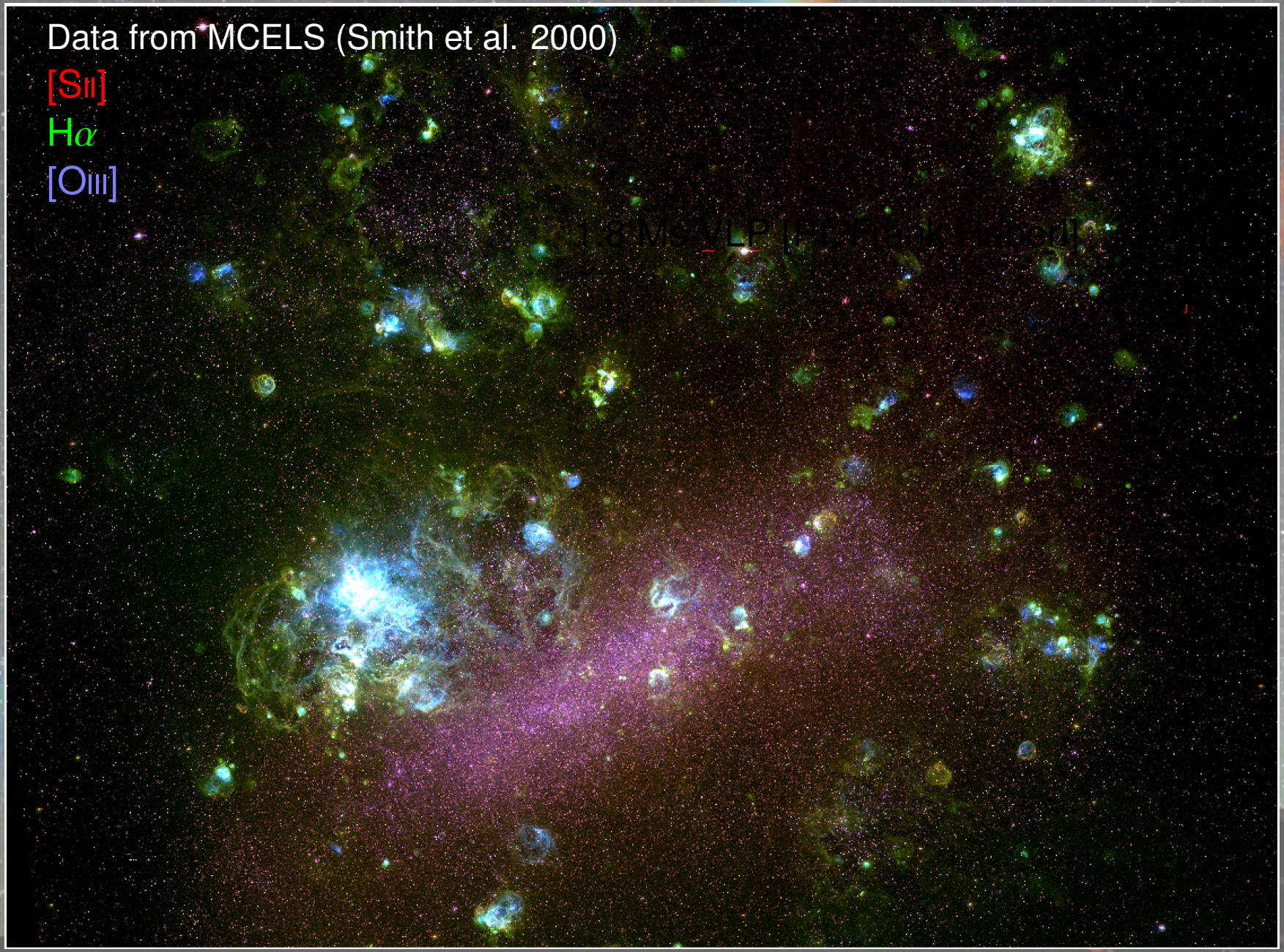
Nearest star-forming galaxies

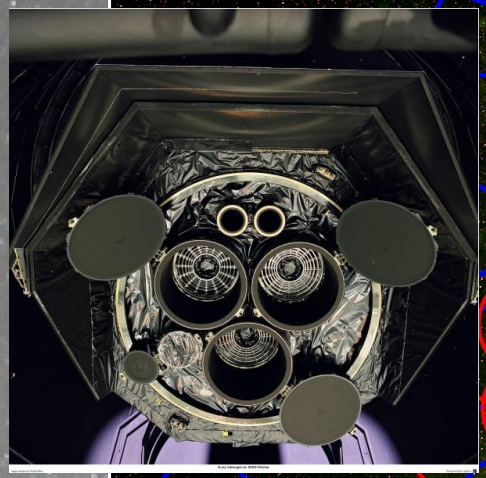
50 & 60 kpc

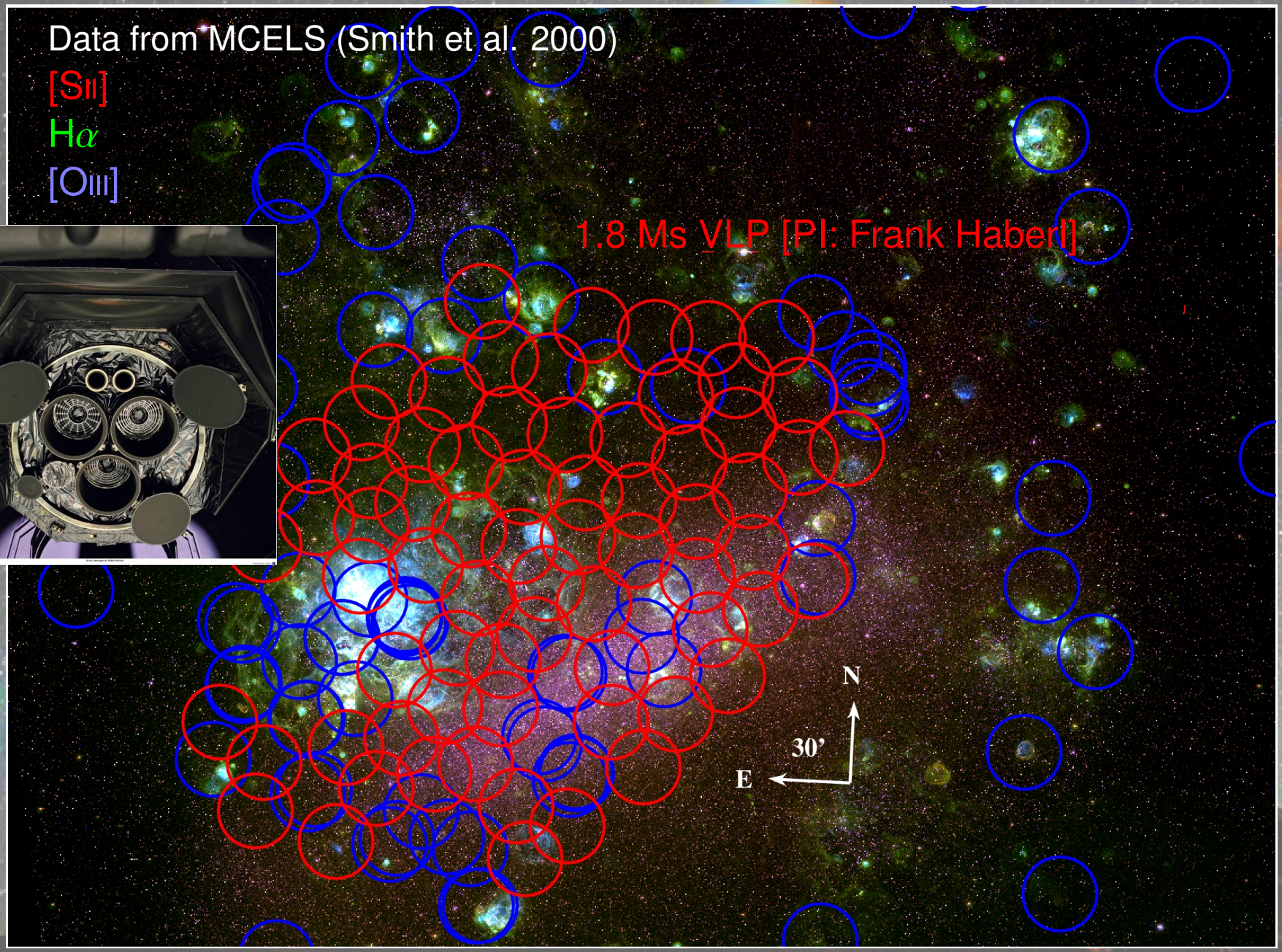
Out of Galactic plane

$\mapsto$ Ideal for population studies



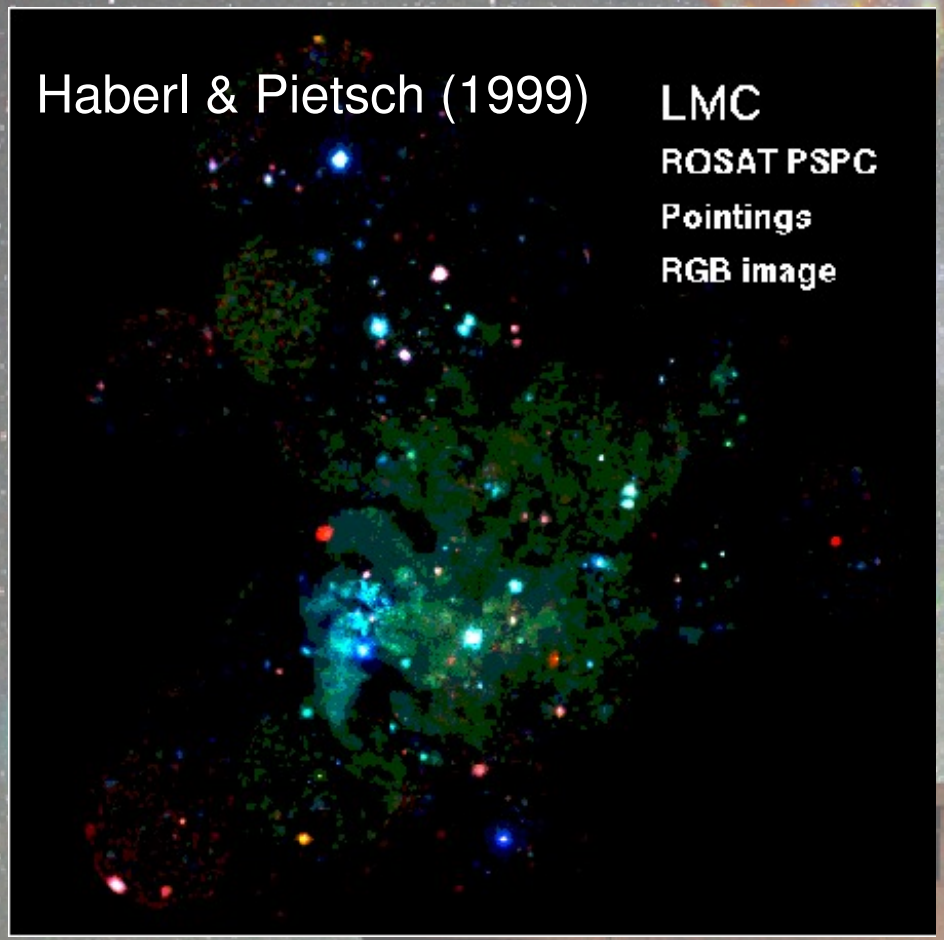

Data from MCELS (Smith et al. 2000)
[SII]
Hα
[OIII]

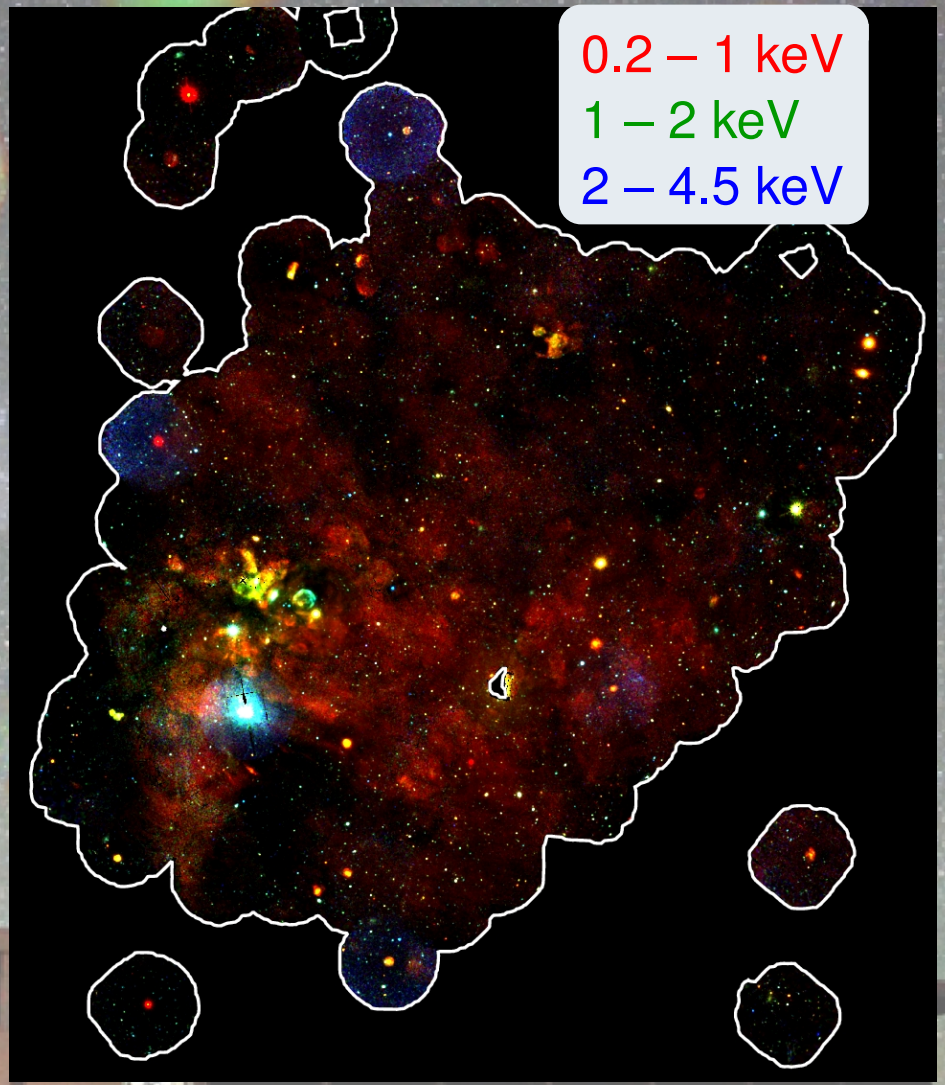


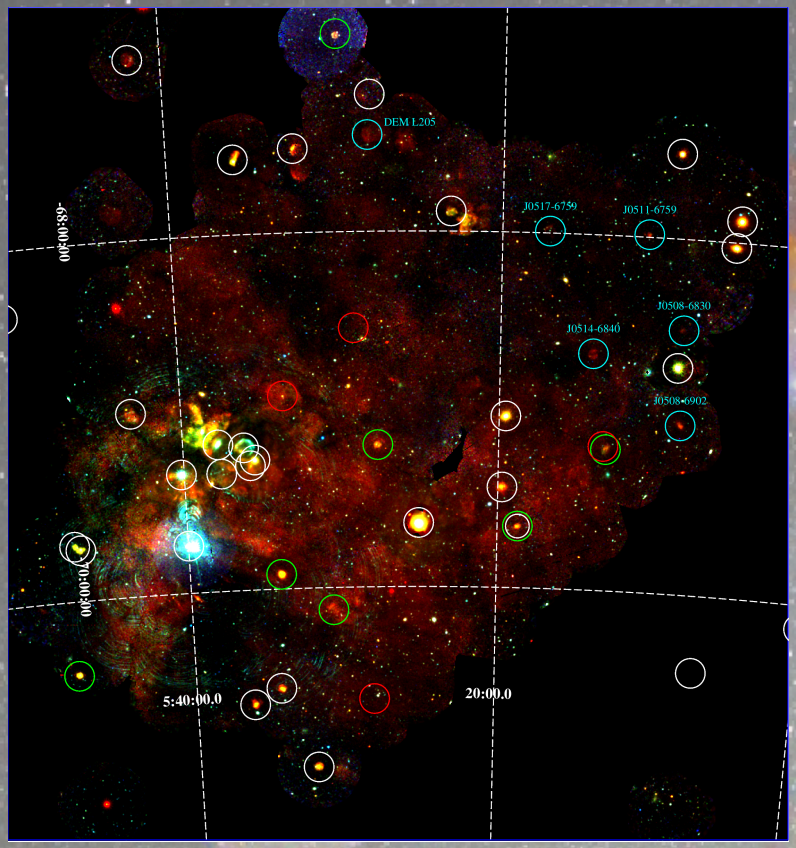

Data from MCELS (Smith et al. 2000)
[SII]
Hα
[OIII]
1.8 Ms VLP [PI: Frank Haberl]
N
E
30'

From ROSAT to XMM-Newton

- 10× more sources, diffuse emission
- Spatial/spectral analysis of all SNRs

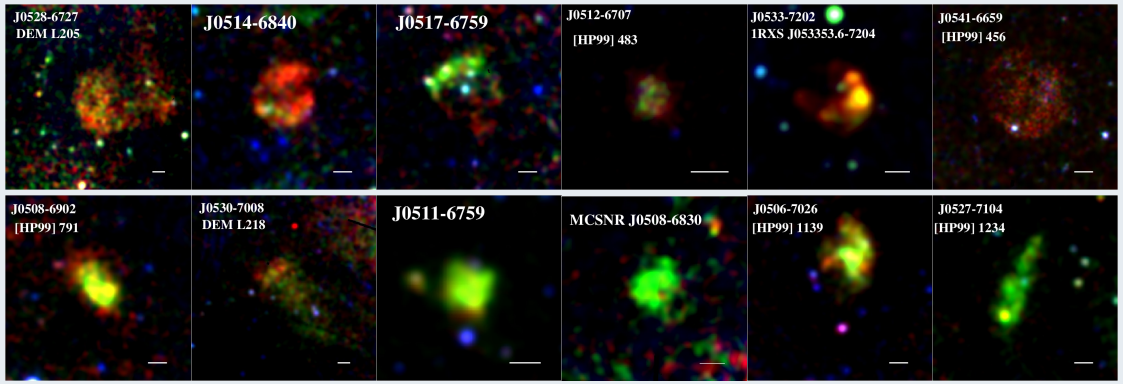




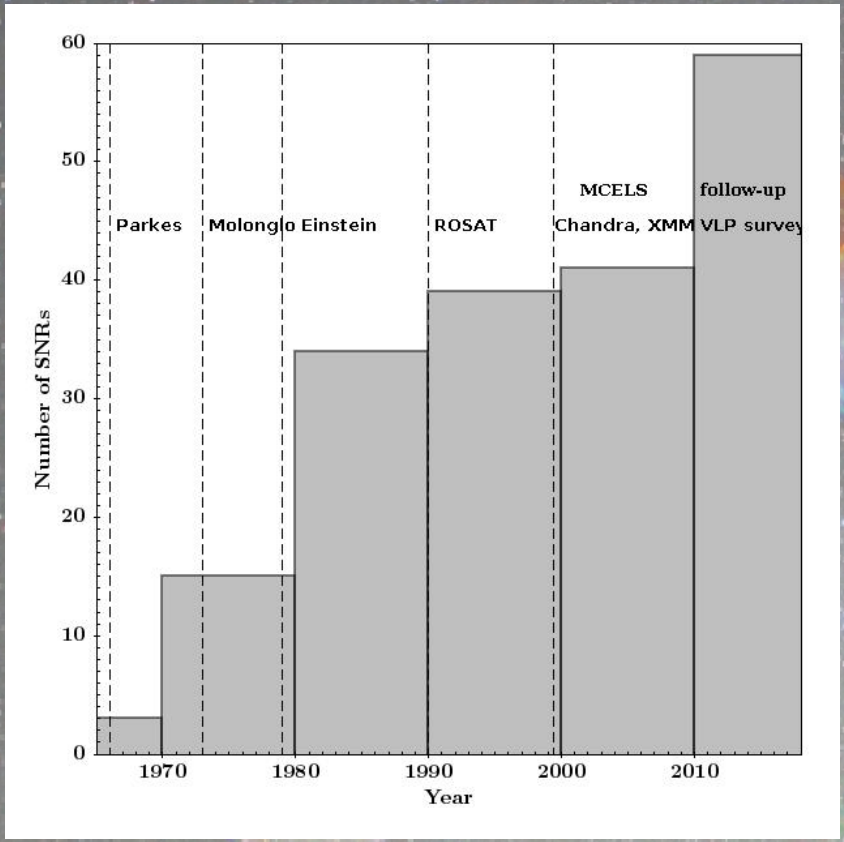


59 confirmed SNRs

- 51 covered by XMM, many for the 1st time
- 12 new with our XMM programmes
- 6 serendipitously in the survey



Grondin+2012
de Horta+2012
Maggi+2012, 2014
Bozzetto+2014
Kavanagh+2013, 2015



59 confirmed SNRs

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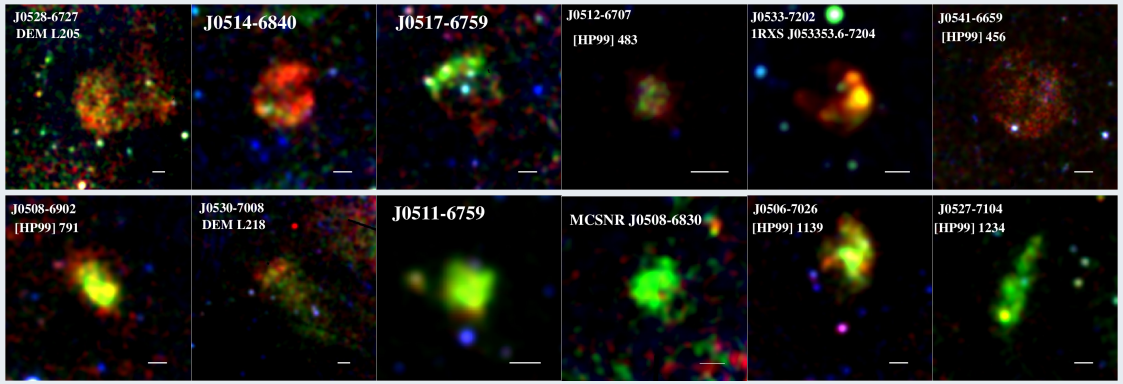
↦ First homogeneous global X-ray analysis

- Catalogue of spectral parameters
- Complete census of SNRs :
  - with Fe K emission
  - with SN ejecta emission

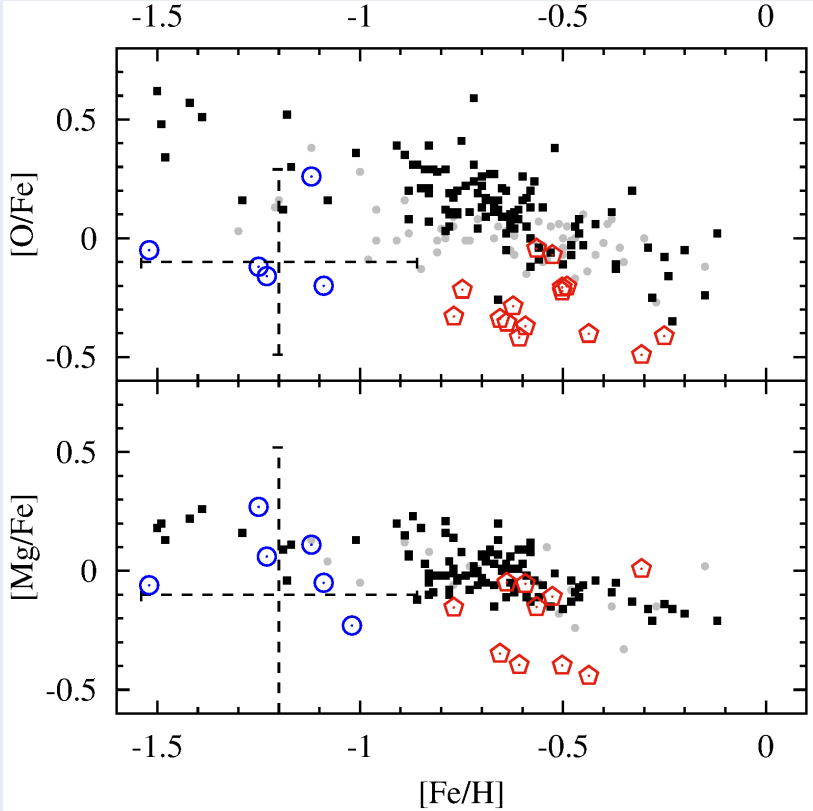


Grondin+2012
de Horta+2012
Maggi+2012, 2014
Bozzetto+2014
Kavanagh+2013, 2015

LMC abundances measured with SNRs

- Using sub-samples unaffected by SN ejecta ↦ LMC ISM abundance
- Metallicity between 0.2 and 0.5 solar
- Lower [O/Fe] (by 0.15 dex) compared to *ASCA* SNRs (Hughes et al. 1998) ↦ SN ejecta contamination (confirmed with *Chandra*, Schenck et al. 2016)

	O	Ne	Mg	Si	Fe
$X/X_\odot$	0.21	0.28	0.33	0.69	0.35
RMS	0.08	0.08	0.19	0.42	0.12



Chemical enrichment history

- Higher metallicity, lower [α/Fe] than older populations

How to type all the sample ?

- Typing methods are limited to relatively young, bright remnants
  - ↦ More than half unknown

⇒ Tentative typing of the whole sample based on the **local stellar environment**

N_{CC}/N_{Ia} is 1.47 (1.2–1.8) based on star formation, or 1.35 (1.1–1.5) including spectral results (SN ejecta/pulsars)

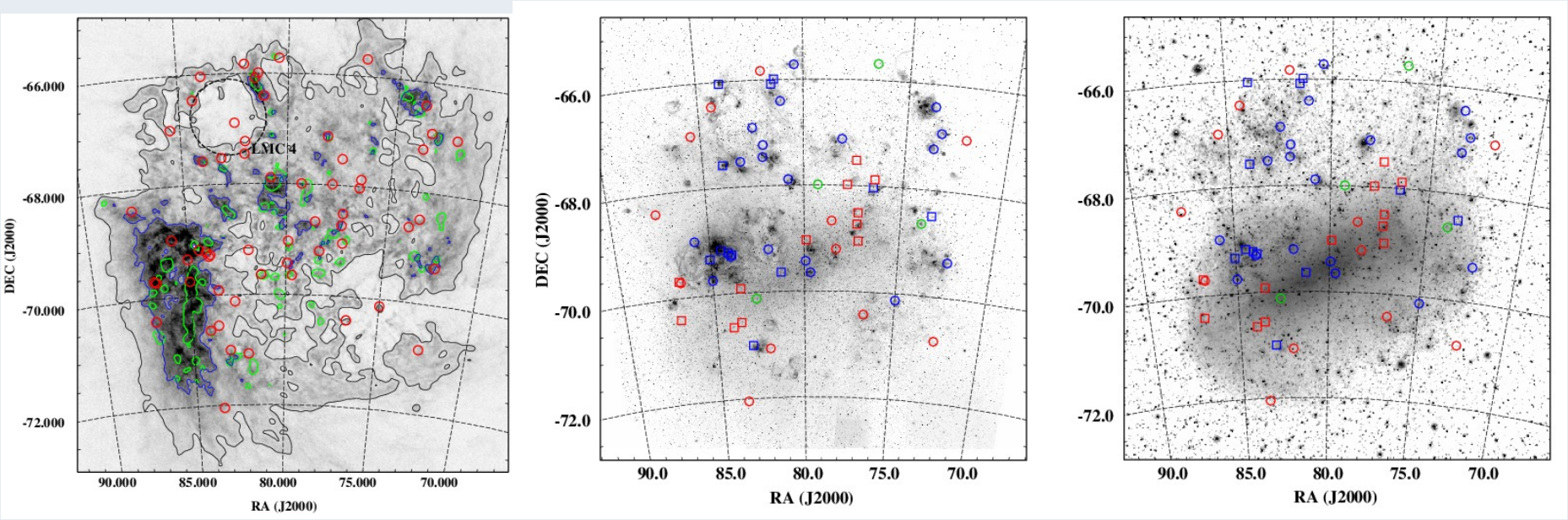
Method	N_{CC}/N_{Ia}	Ref.
LMC SNRs	1.1–1.5	this work
Local SNe	3	Li+2011
Abundances in galaxy clusters	3.5 (2–4)	Sato+2007
	1.7–3.5	de Plaa+2007
	1.5–3	Lovisari+2011

More type Ia SNe in the LMC ?

- Unlikely biased either way

↦ Specific SFH of the LMC (bursts 0.5 and 2 Gyr ago)

\+ Timescale of type Ia SNe (the majority explodes within 2 Gyr)



Position of SNRs in the LMC compared to H I, Hα, and red continuum

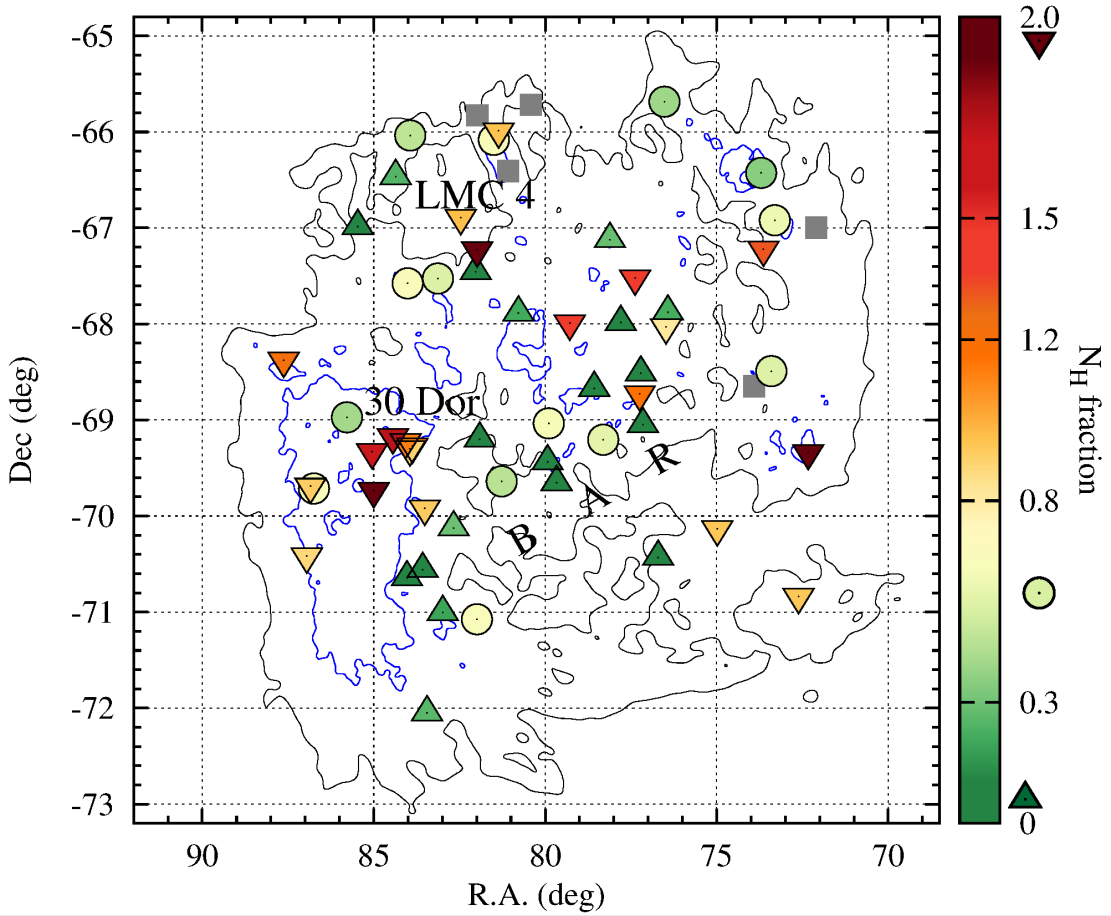
Spatial correlation with:

- Sites of star formations (giant H II regions, supergiant shells) $\mapsto$ CC SNRs
- High stellar densities, or "empty" regions $\mapsto$ type Ia SNRs

"N_H **fraction**" $= N_H^X / N_H^{21\,\mathrm{cm}}$ gives the line-of-sight position relative to the main gas disc

- **SNRs in the Bar** are (almost) all in front of the disc :
  ▸ Supports the (challenged) findings that the Bar is indeed "floating" in front of the disc
- **SNRs in 30 Dor** → behind:
  ▸ Confirms that 30 Dor is on the far side of the LMC
- N_H **fraction** $\gg$ **1.2 ?**
  ▸ molecular phase!

Adding a sense of depth with X-ray spectra



(Contours: $N_H = 1$ & 3×10^{21} cm^{-2} (Kim et al. 2003)

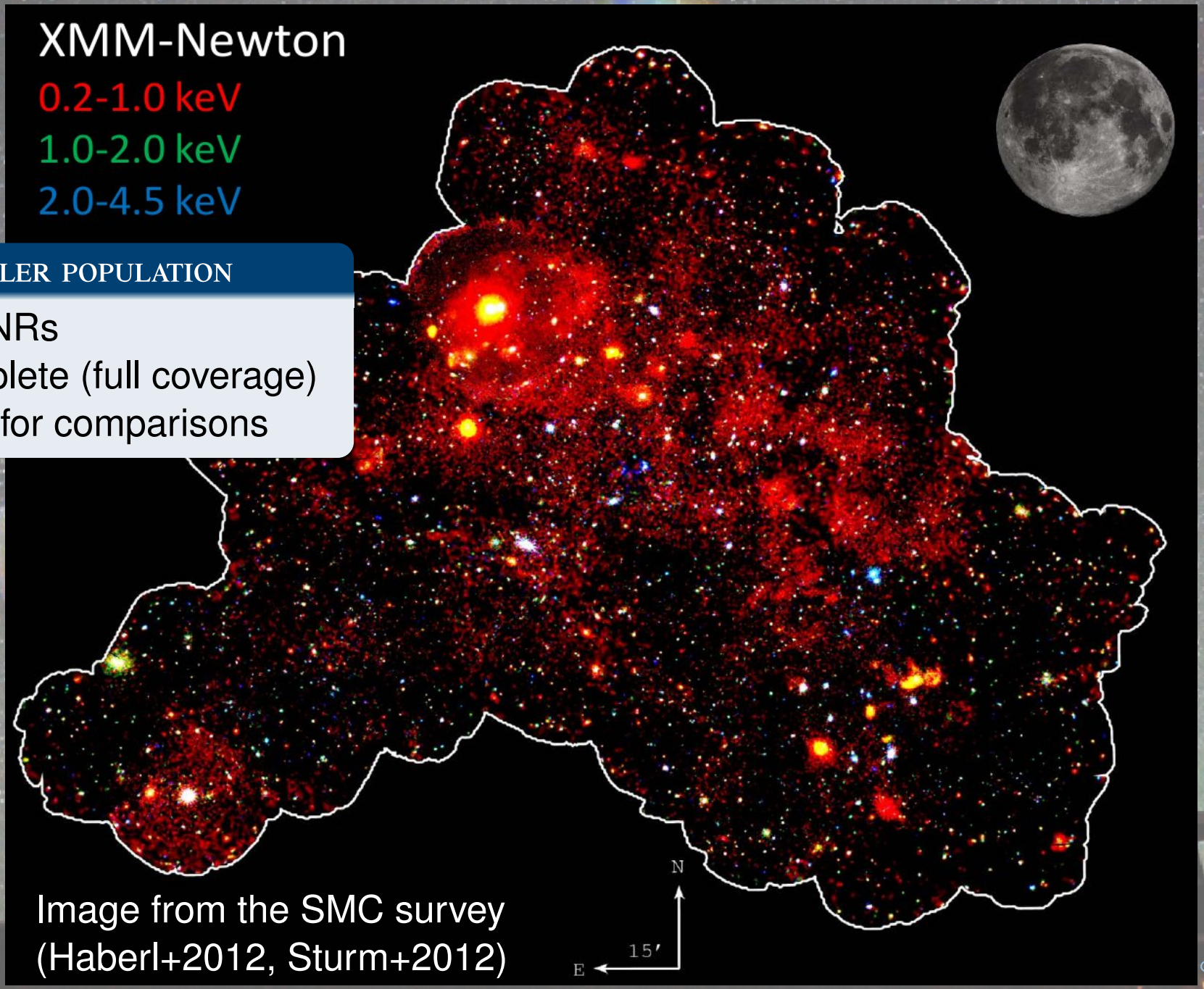
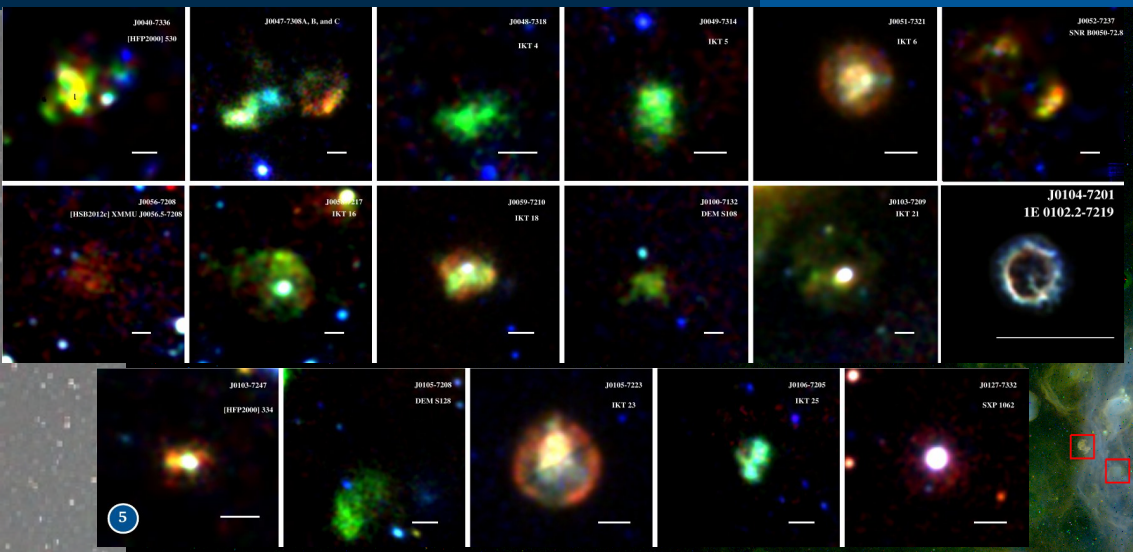


Image from the SMC survey (Haberl+2012, Sturm+2012)

A smaller population

- 19 SNRs
- Complete (full coverage)
- Ideal for comparisons

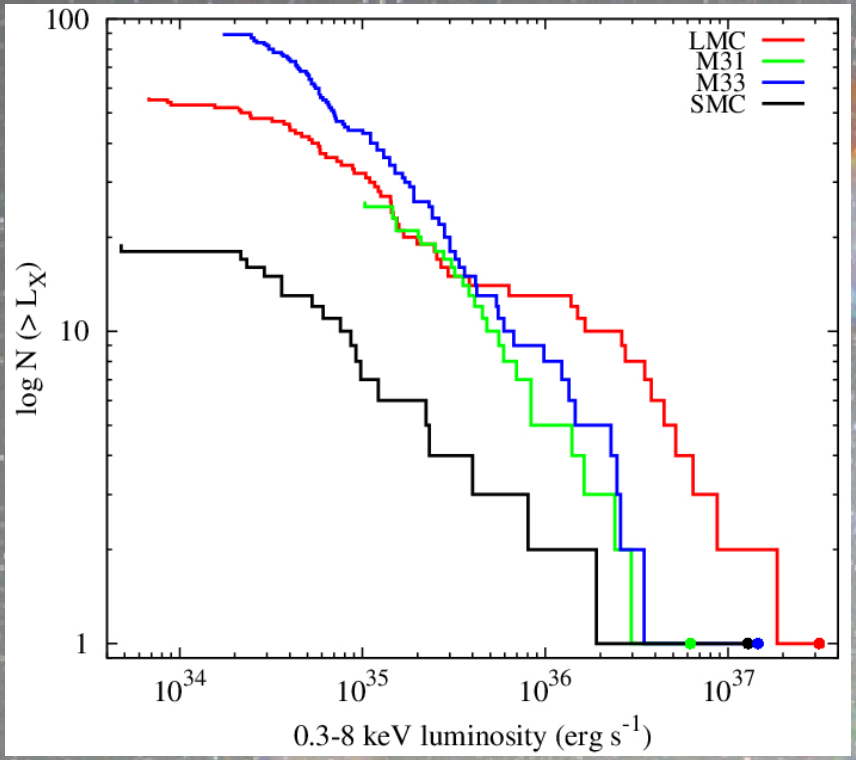


SMC ISM abundance (Preliminary !)

	O	Ne	Mg	Fe
$X/X_\odot$	$0.20^{+0.14}_{-0.04}$	$0.20^{+0.25}_{-0.07}$	$0.25^{+0.32}_{-0.10}$	$0.18^{+0.15}_{-0.06}$

- 8 SNRs instead of 3 (van der Heyden+04)
- Higher [O/Fe] (by 0.25 dex) than in LMC

↪ different ancient SFH ?



XLF (Maggi+2016)

Main differences:

- **Numbers:**

M33 dominates (better coverage ?)

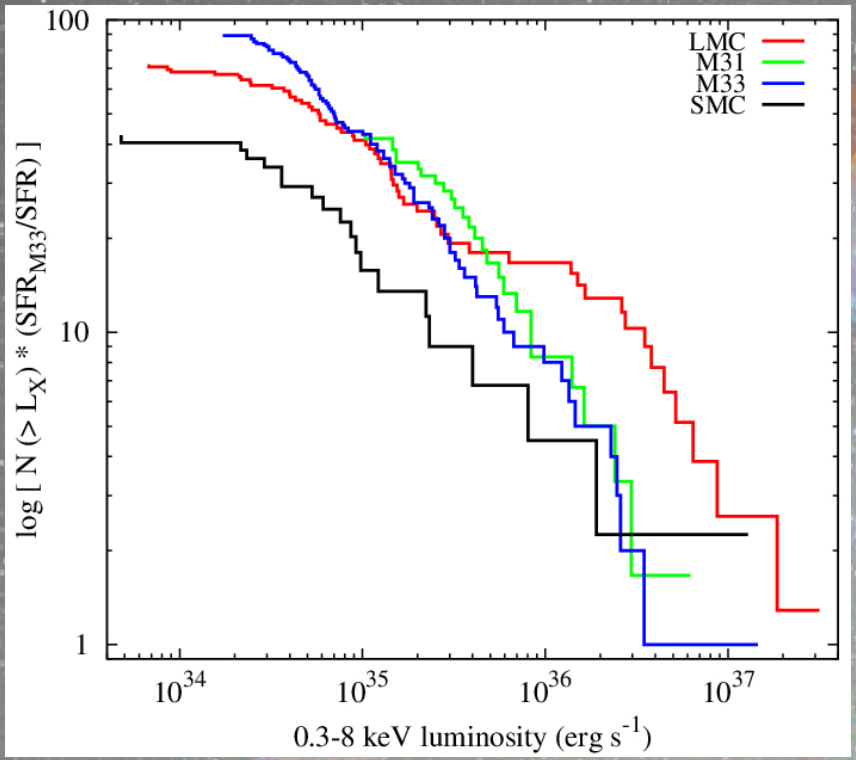
- **Shape:**

M31 ~ M33, SMC flatter

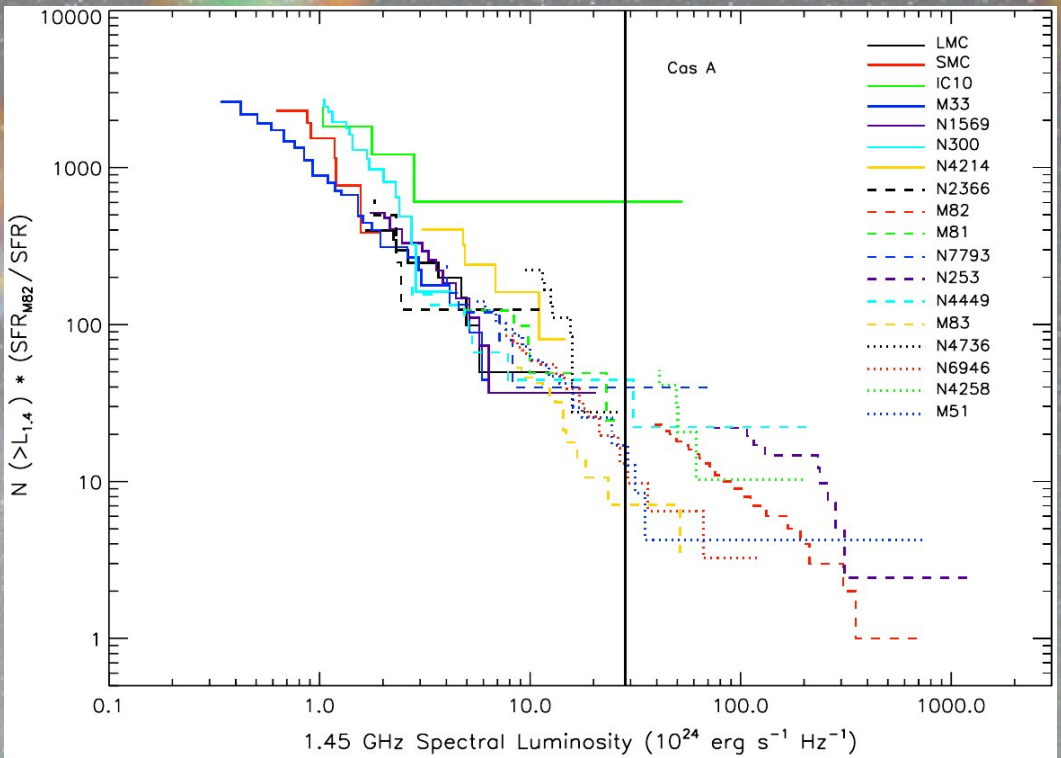
LMC shape is more complex:

Bright tail

Flat faint end (incomplete)



XLF scaled by SFR

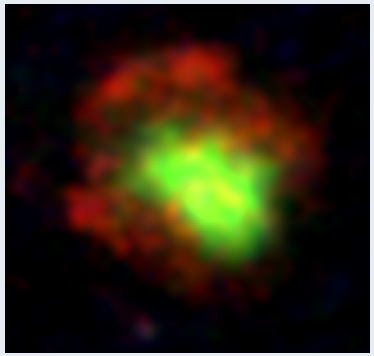


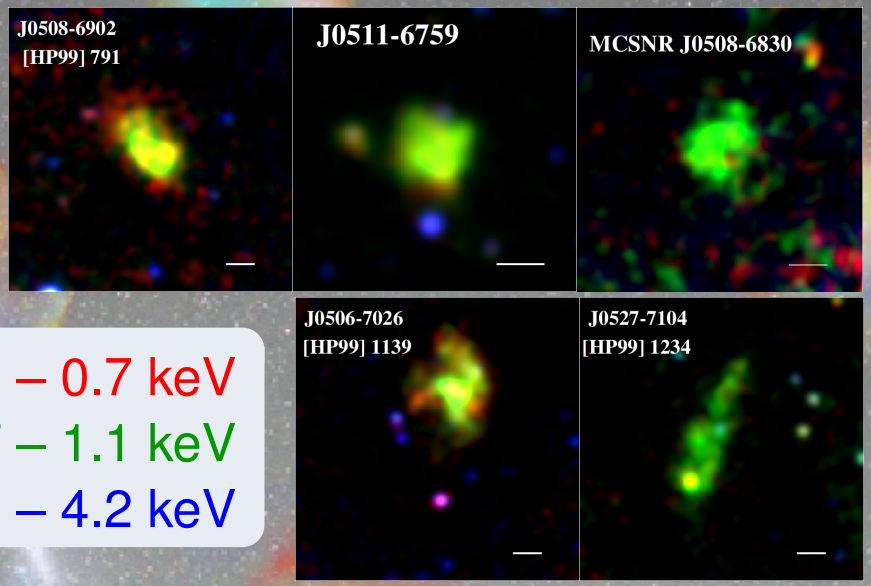
radio LF, Chomiuk & Wilcots 2009

Shape differences subsist (particularly in SMC, completeness issue in LMC).
X-ray luminosity function is not universal, unlike **radio** LF
$\mapsto$ effects of metallicity and ISM density

Prototype: DEM L238 (Borkowski+2006)

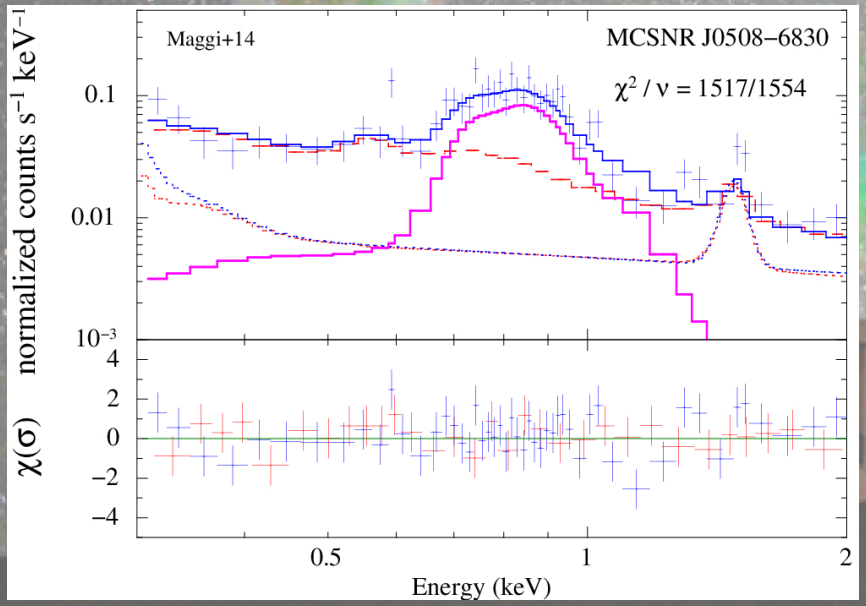
- Shell: shocked ISM
- **Iron-rich** core, X-ray bright





0.3 – 0.7 keV
0.7 – 1.1 keV
1.1 – 4.2 keV

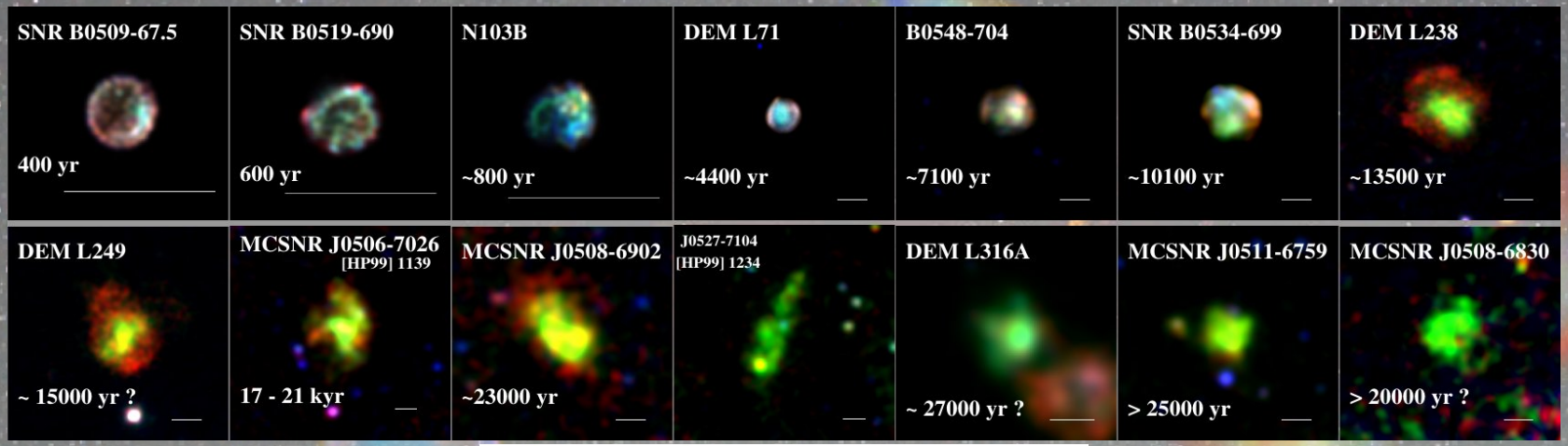
Iron-rich SNRs discovered in Maggi+2014, Bozzetto+2014, Kavanagh+2015

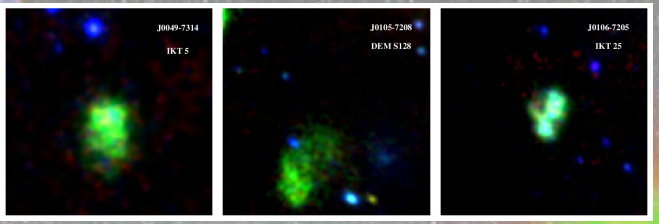


Iron-rich gas in the interior

- kT_{Fe} is 0.6 keV – 1 keV
- Inferred M_{Fe} 0.5 to 1.5 $M_{\odot}$

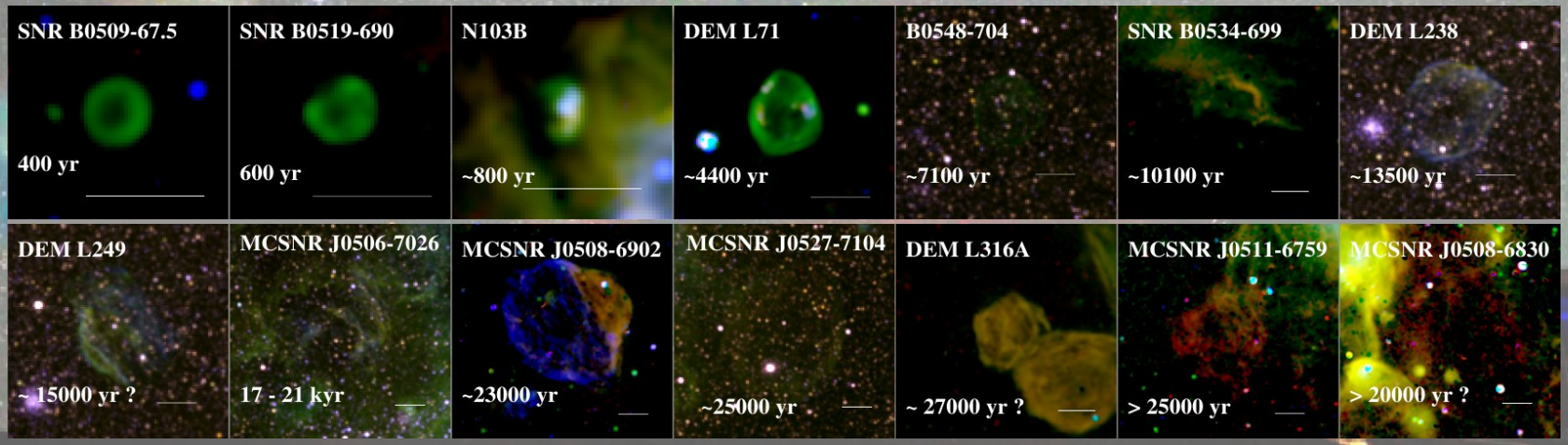
Could NOT be observed in the Galaxy

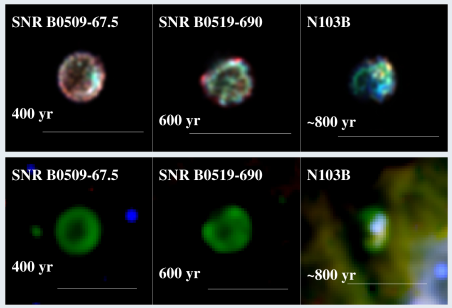




+ Three Fe-rich SNRs in the SMC

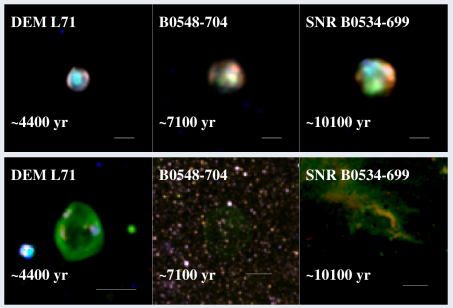
Optical images (MCELS data): [S II] Hα [O III]





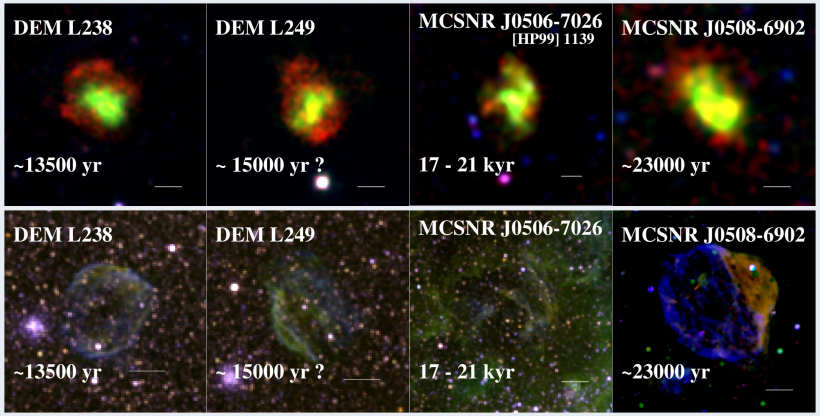
Phase I:

- Ejecta-dominated (X)
- Balmer-dominated (O)
- Lyman-dominated (UV)



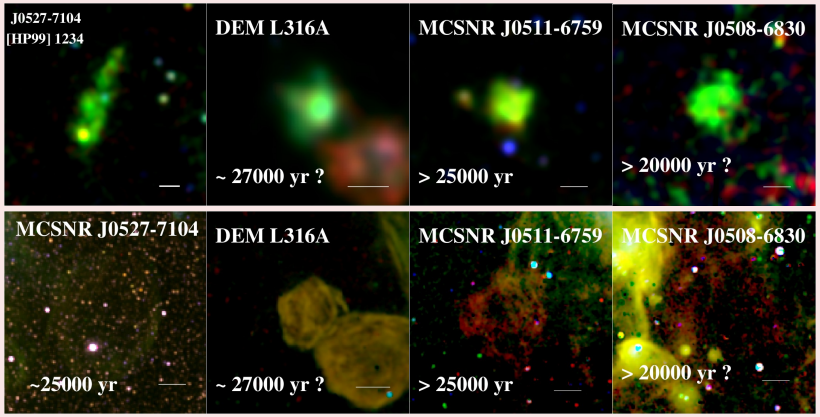
Phase II:

- Early Sedov phase; ejecta + ISM shell (X)
- fading in optical
- little/no UV



Phase III:

- Fading-shell, central iron emission (X)
- Radiative cooling of shell traced by [O III] lines (O) and C III and O VI (UV, Blair+2006)

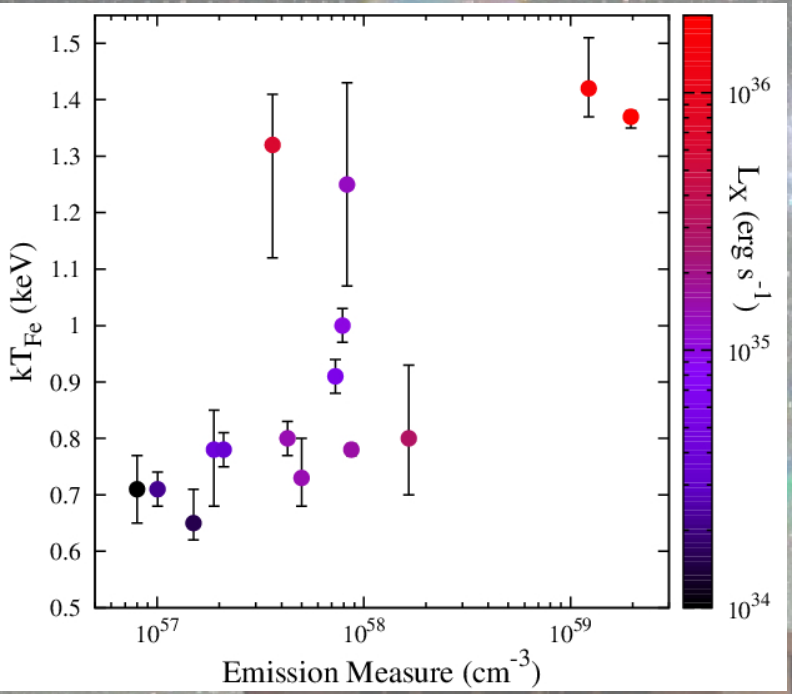


Phase IV:

- No shell (too cool), Hot iron cores (X)
- (very) faint "fossil" [S II] lines (O)
- No UV (?)

- Origin of the (asymmetric) morphology of the iron cores ?
- Evolution/fate of the iron cores ?

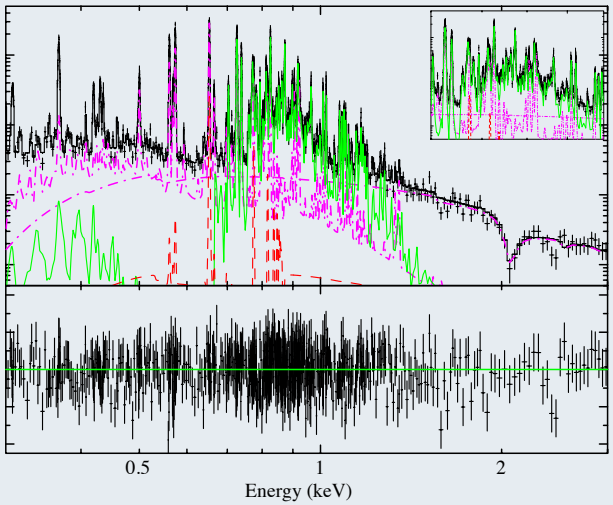
↪ Clues in deeper observations, finding new or missing objects, statistical analysis



Temperature of the hot iron cores as function of their emission measure $\left(\int n_e n_H dV\right)$.

Ideal targets for calorimeter

~~Hitomi~~, Athena, will resolve the forest of Fe L-shell lines



20 ks **ATHENA**/X-IFU (MCSNR J0527-7104, Kavanagh+2015)

Thank you for your attention !

(Background: X-ray SNRs in the night sky over La Silla, Chile