Unexpectedly Bright:
High energy emission from SNRs

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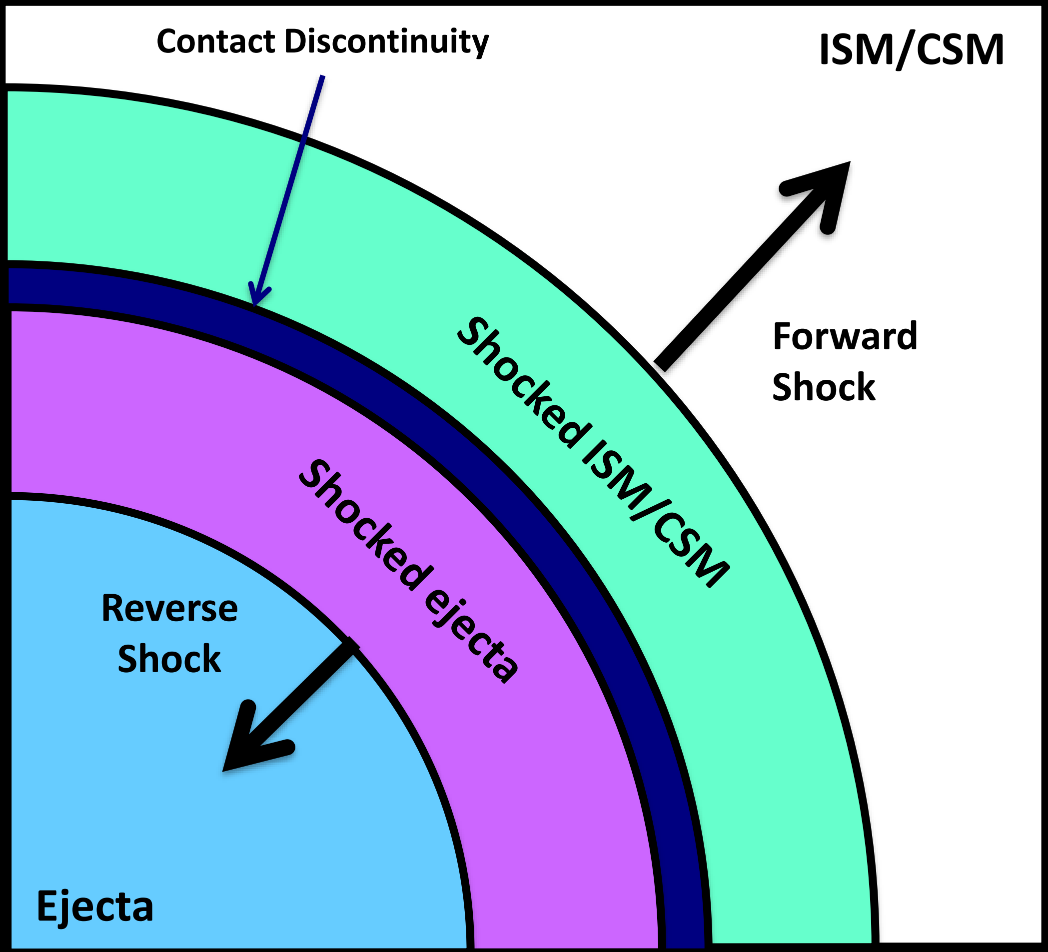
Environment affects the evolution of a star

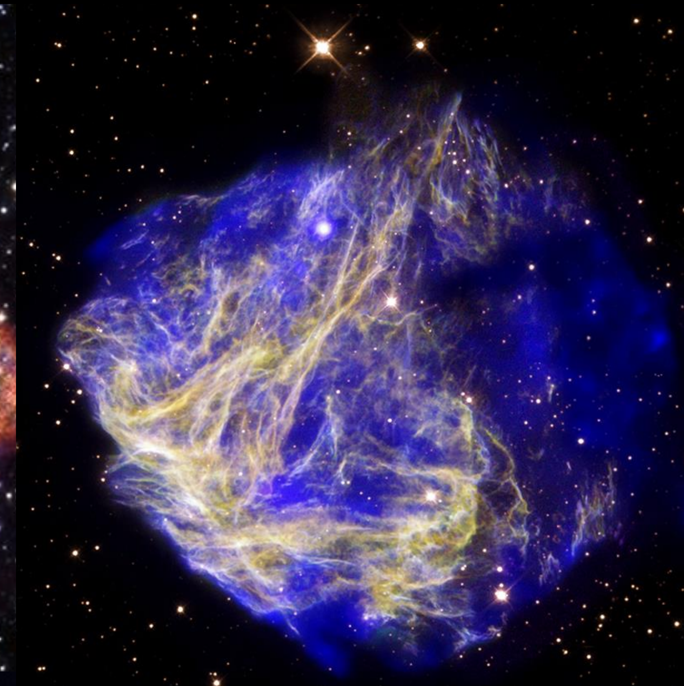
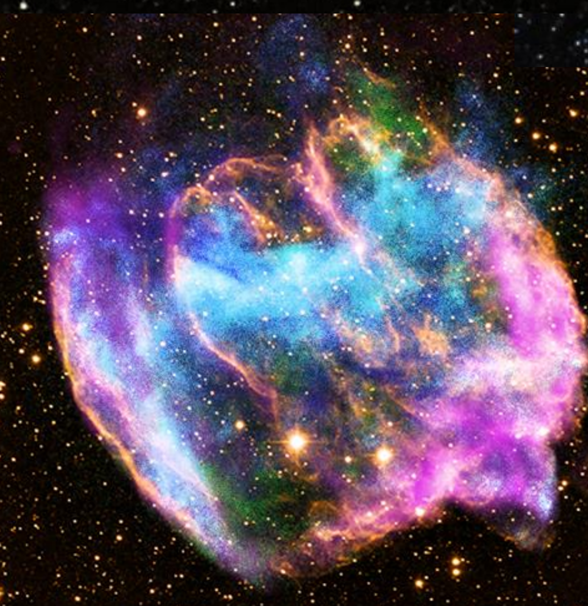
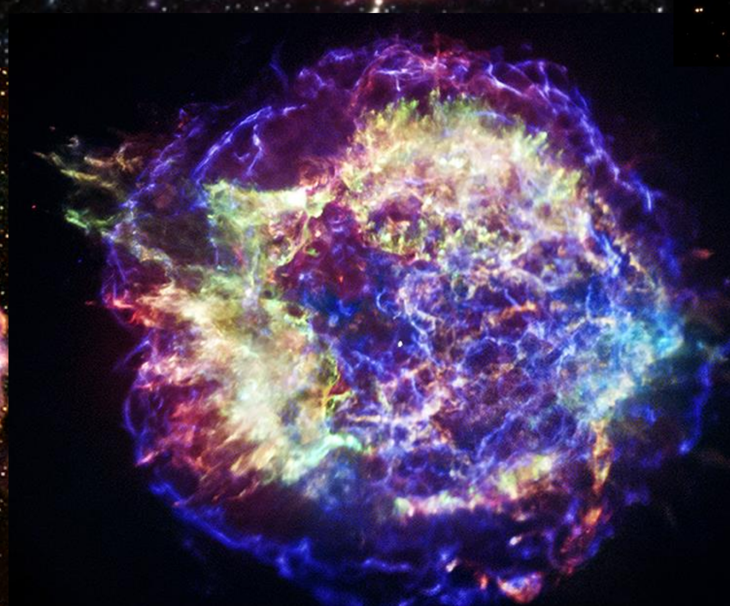
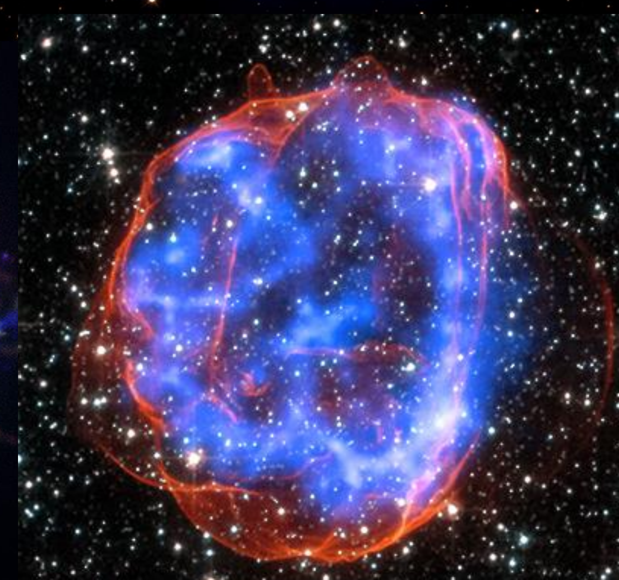
Expanding shock-front

- *The shock-front produced by the SNe expands and heats the stellar ejecta and swept-up ISM to X-ray emitting temperatures.*



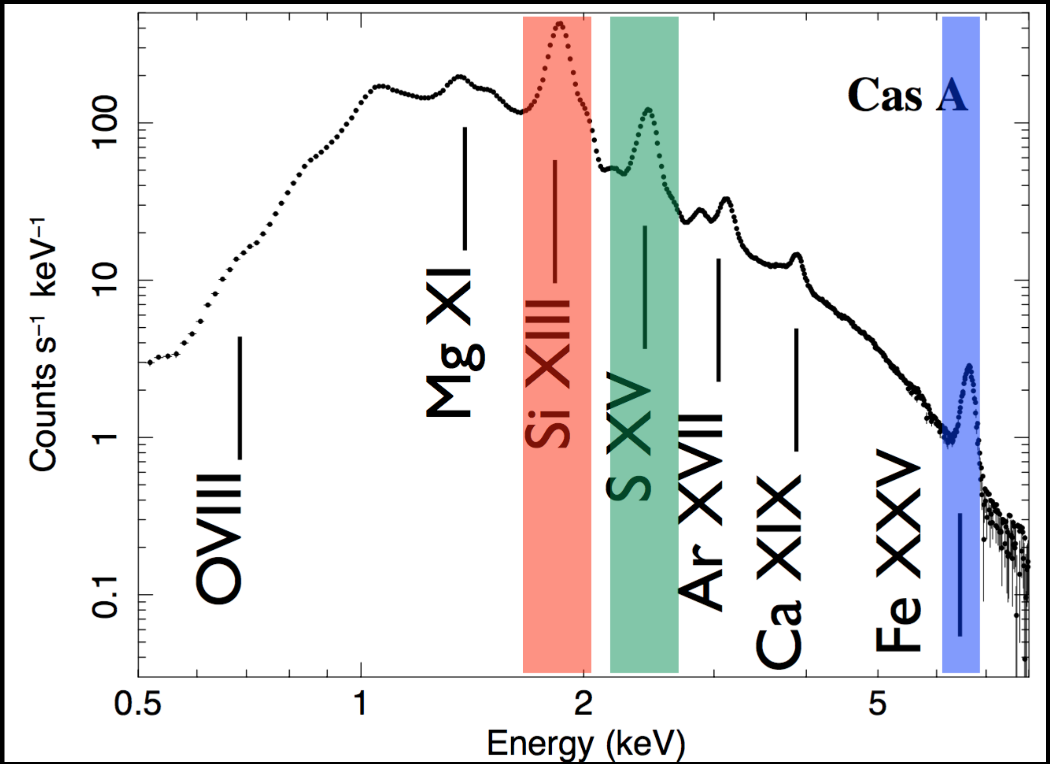
The remnants of a supernova

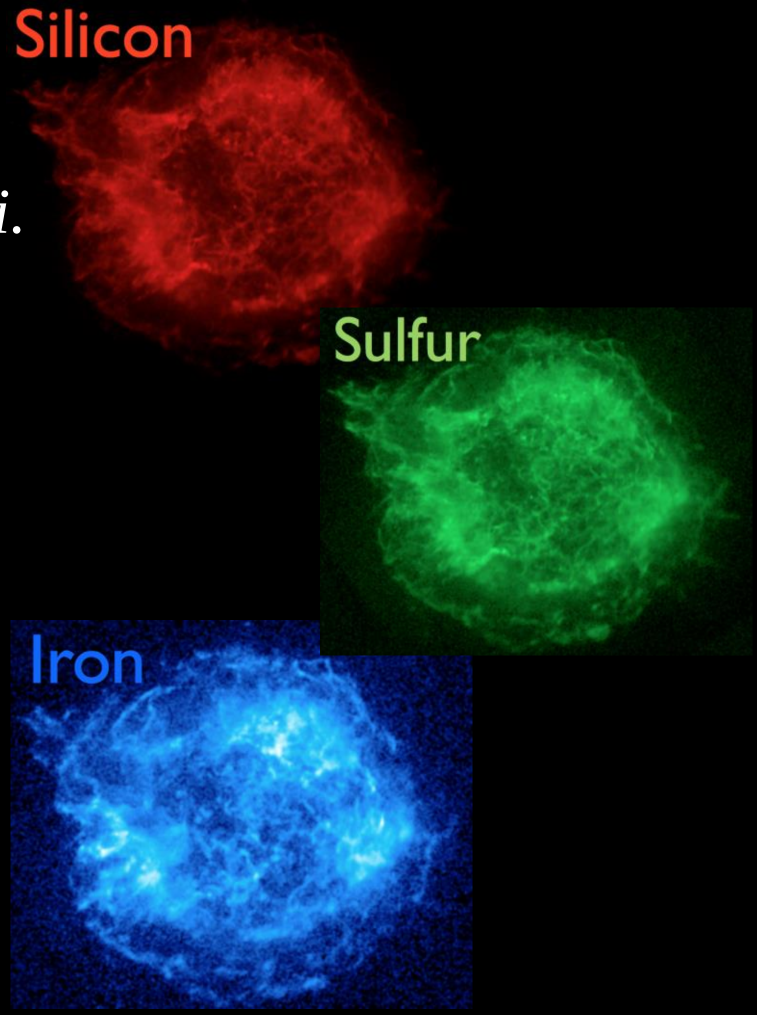


Discover the star we didn't see

- *Determine the nucleosynthesis yield of the parent star.*
- *Mass of the progenitor.*
- *Explosion mechanism:*
    - *Type Ia SN have lots of iron*
    - *CC SN have lots of O, Ne, Mg, Si.*

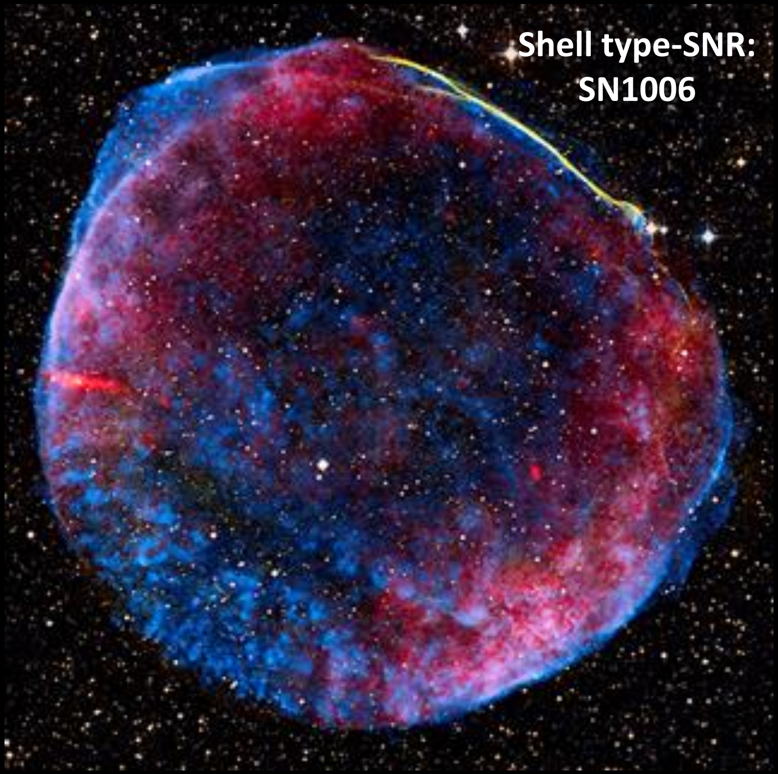




The remnants of a supernova

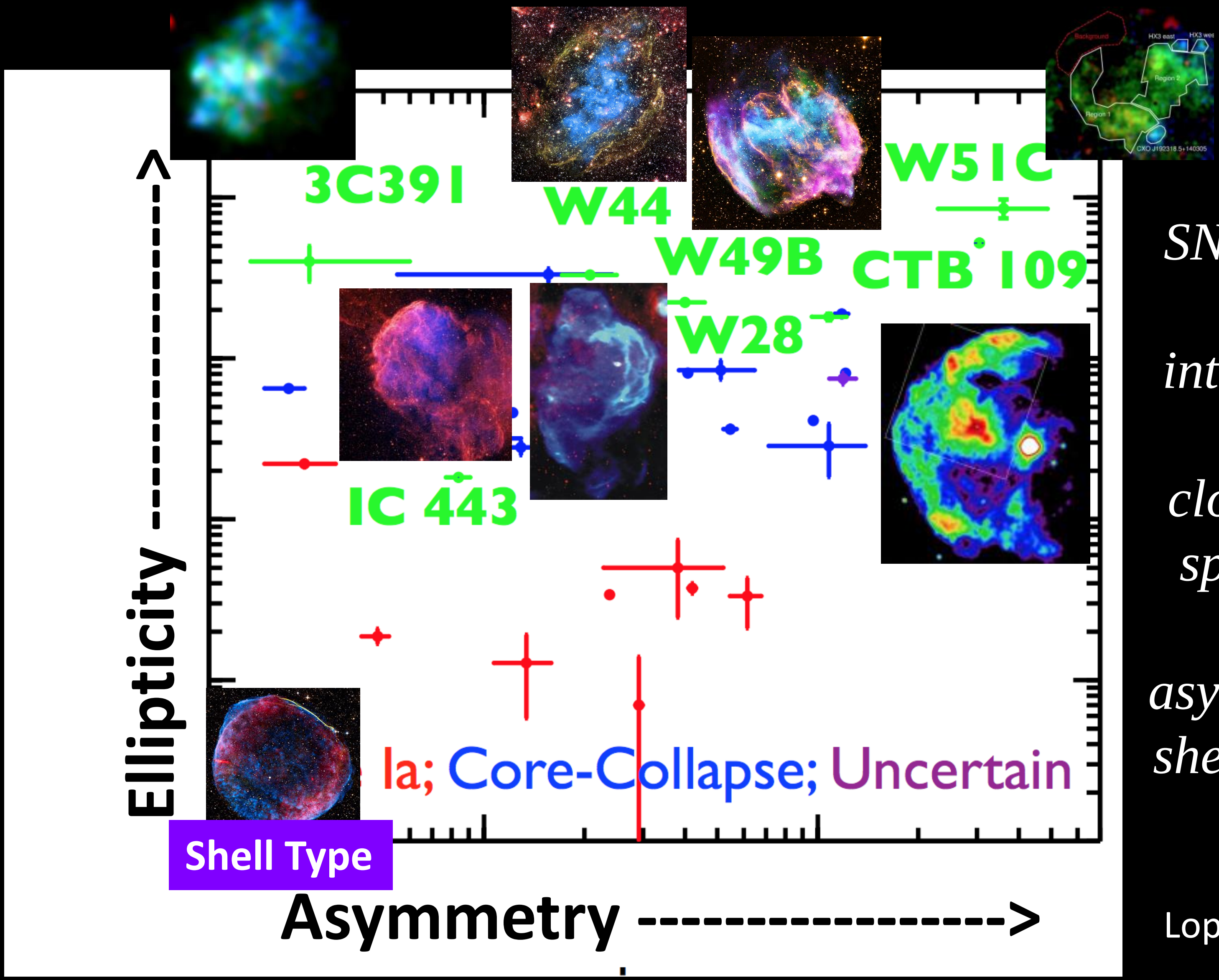
A dense environment has a profound effect on the morphology and properties of SNRs.

Centrally peaked X-ray morphology



- *Centrally peaked X-ray morphology which arises from a collisional hot plasma (Lazendic et al. 2006).*
- *These mixed-morphology SNRs are middle aged.*

Highly asymmetric

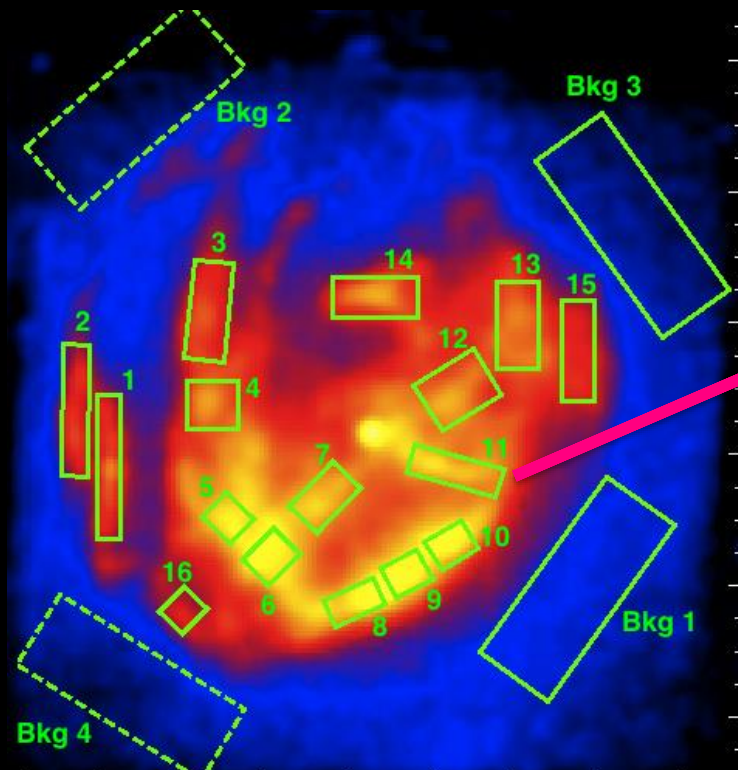


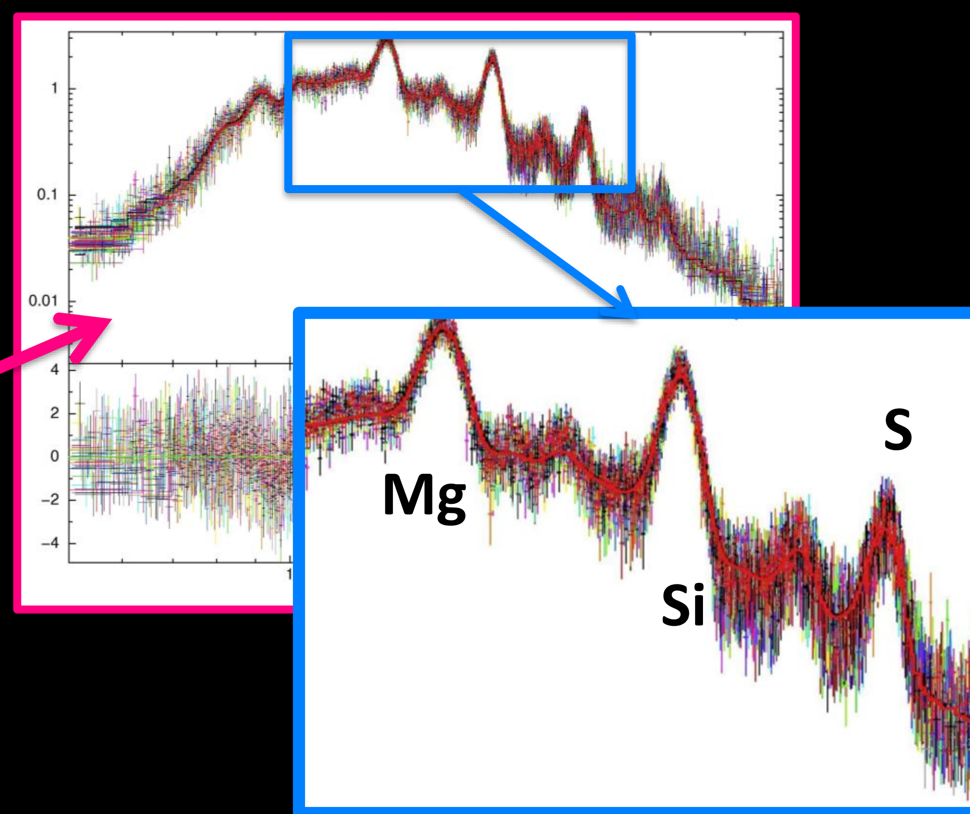
SNRs known to be interacting with molecular clouds are less spherical and are more asymmetric than shell type SNRs.

Lopez et al. 2013

Enhancement & Rapid cooling.

- *Strong X-ray lines imply super solar abundances of stellar ejecta.*
  - *Expect to see ejecta only in young SNRs, not middle aged SNRs.*
- *Rapid cooling in the form of radiative recombination features.*
  - *Only see in SNRs interacting with MCs.*





Kes 79 - Auchettl et al. 2014

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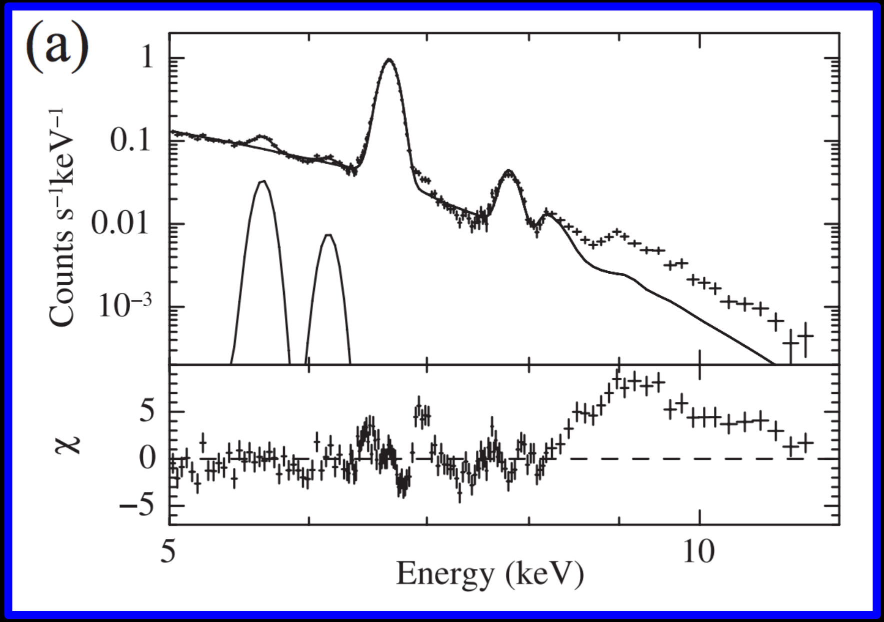
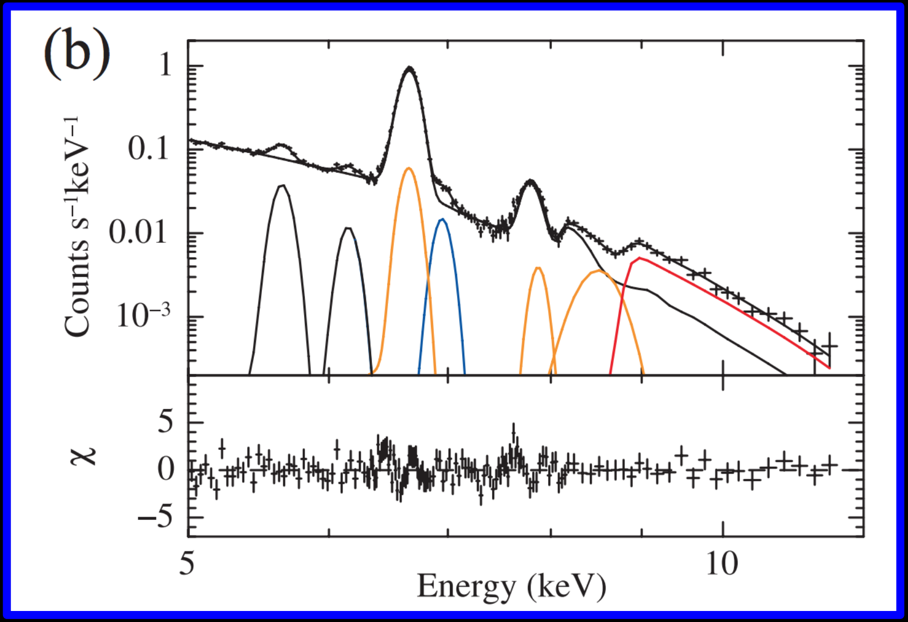
Ozawa et al. 2009



Fitting X-ray spectrum of W49B without recombination

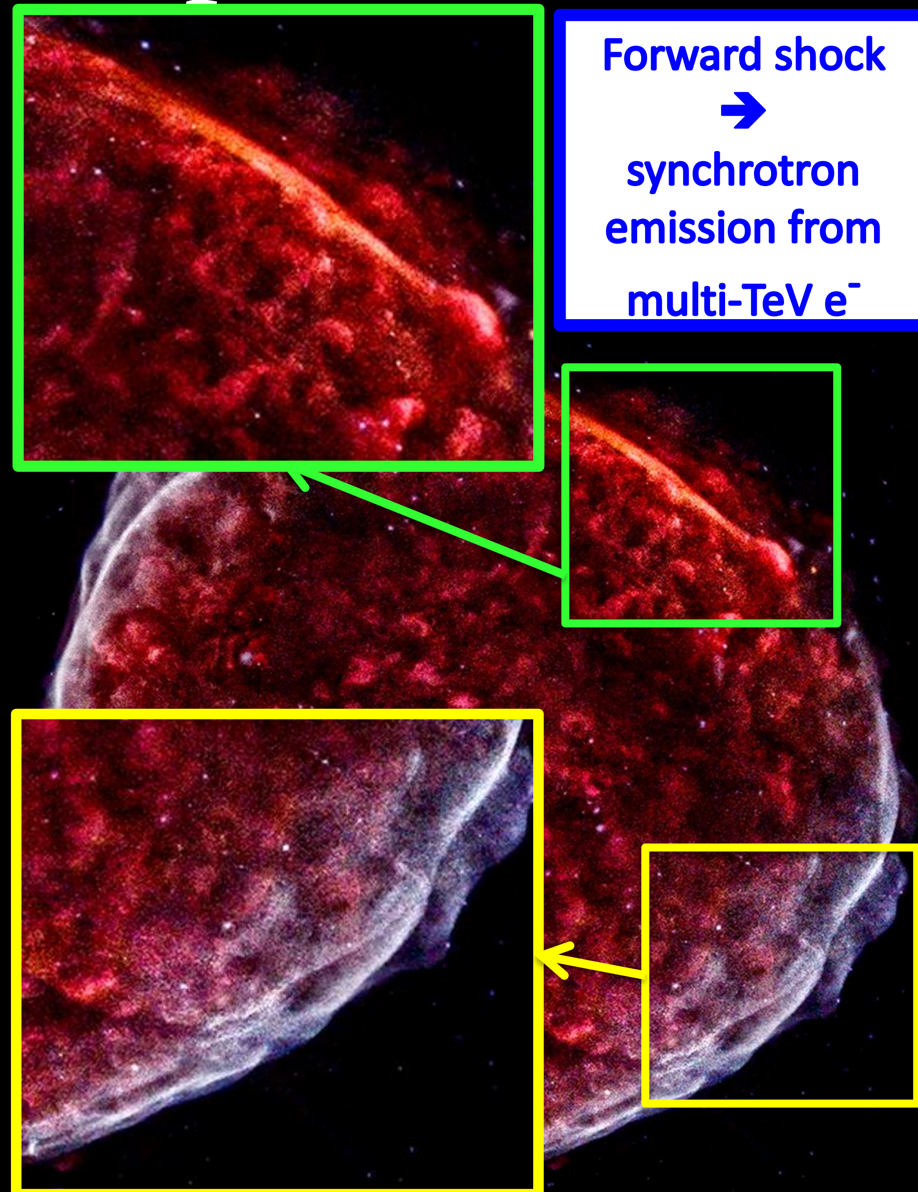


RRC seen in red + recombination lines seen in orange and blue added to fit.

SNRs accelerate particles

- *Forward shock (& reverse shock??) of a SNR can accelerate particles*
  - *e.g., SN1006*
- *Lagage & Cesarsky (1983) applied diffusive shock acceleration to shell-type SNRs and concluded that:*
  - *Particles in SNRs can be accelerated up to 10 -100TeV.*

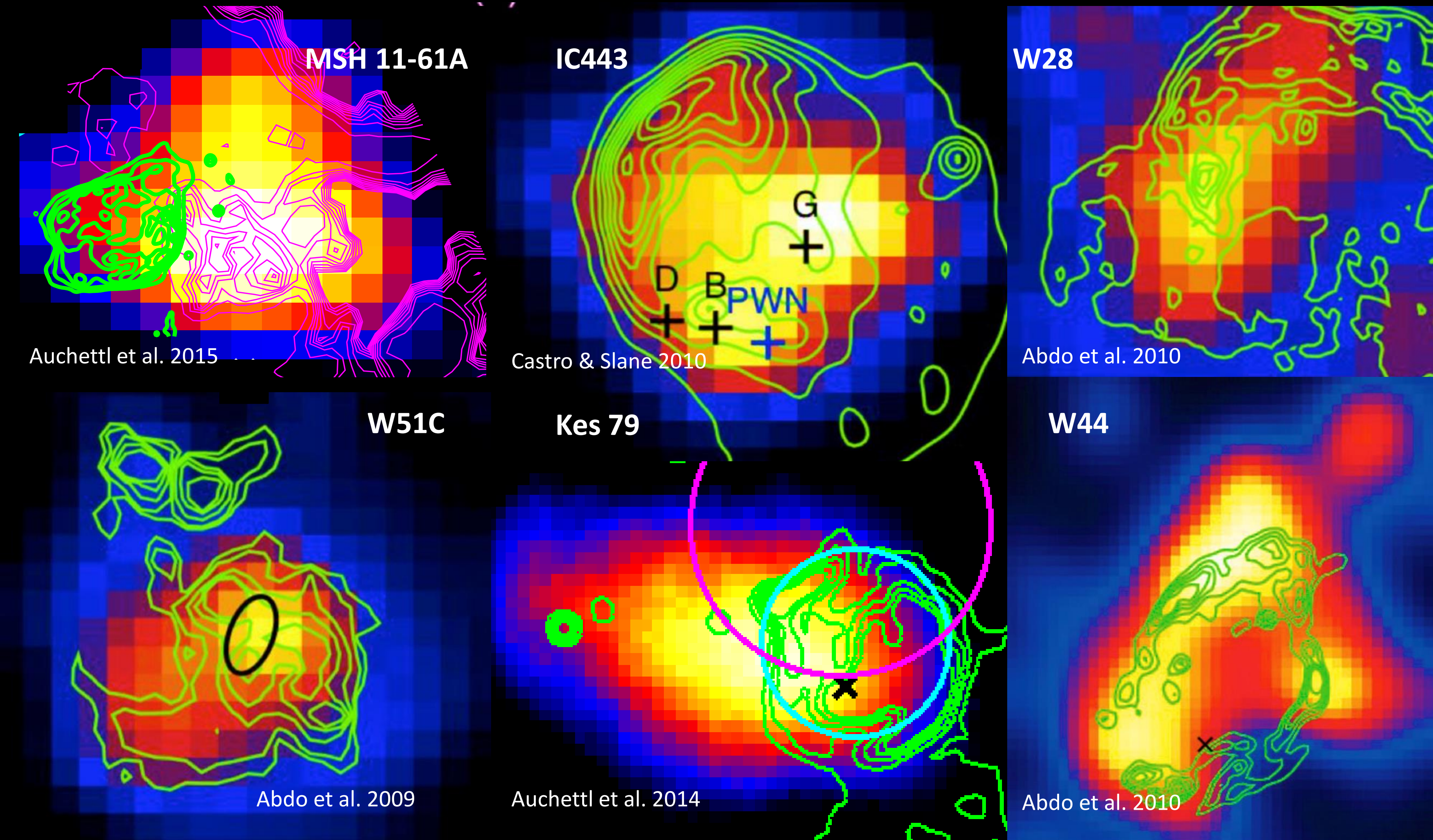
➔ *SNRs can accelerate cosmic rays!*



Chandra X-ray image(NASA/CXC/Middlebury College/F.Winkler)

Sources of gamma-rays

Surprising as MM SNRs are thought to have too slow of shocks but a significant of these a interacting with MCs.

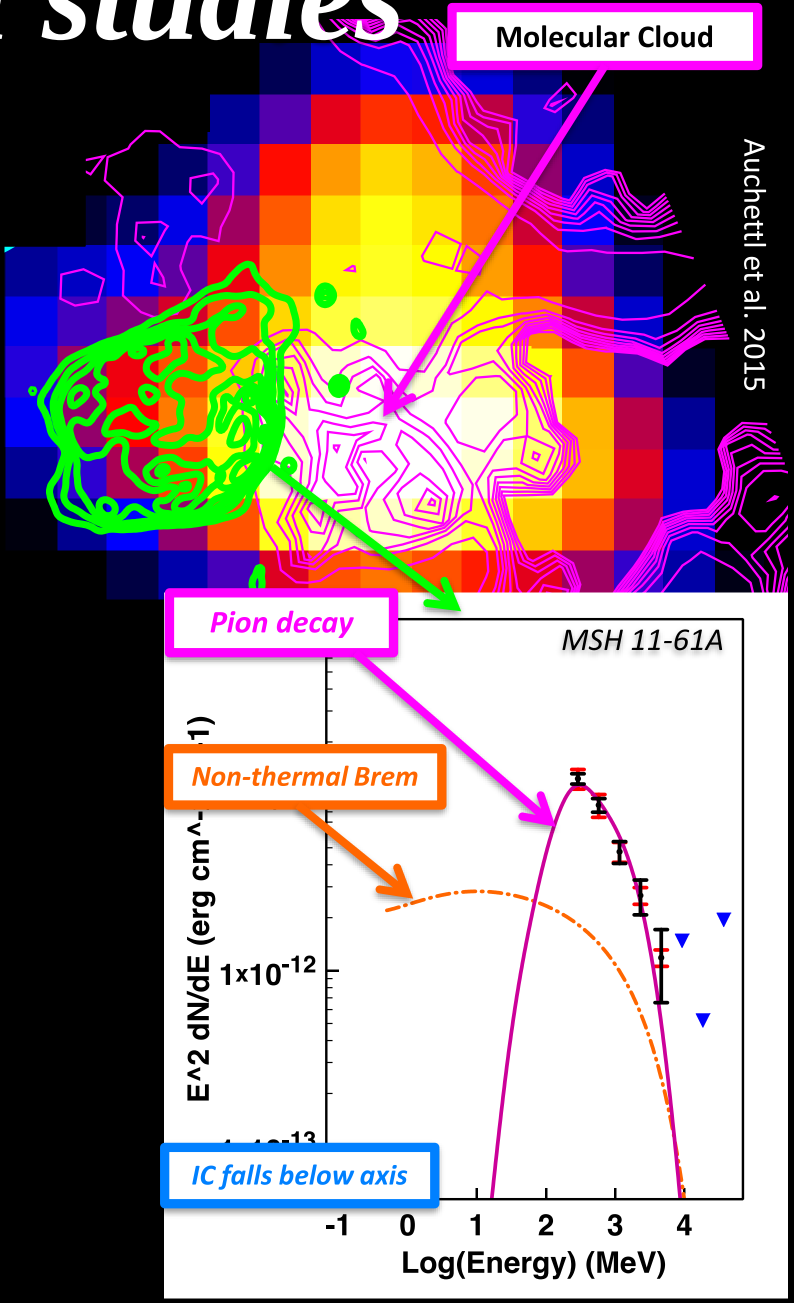


Individual studies

- *~1/3-1/2 of all MM SNRs have been studied by the Fermi-LAT.*
  - *E.g., Ackermann et al. 2010, Castro & Slane 2010, Auchettl et al. 2015….*
- *Significant fraction (1/3) of the GeV emitting SNR population!*
  - *But only ~13% of Galactic SNRs.*
- *Emission dominated by pion decay.*

$$p + p \longrightarrow \pi_0 + X \longrightarrow \gamma + \gamma + X$$

- *Density required to produce observed γ-rays is much larger than that derived from X-ray studies.*
  - *Shock interacting with cold dense material that does not radiate in X-rays.*



Auchettl et al. 2015

Global analysis

- *However, each SNR is analysed slightly differently.*
  - *Different energies, data ranges and background models etc.*
- *Difficult to determine whether:*
  - *All MM SNRs emit in GeV γ-rays?*
  - *Do all have the same γ-rays properties?*
    - *i.e., are they all pion decay?*
  - *How do their properties differ from those of other GeV emitting SNRs?*
  - *How do these properties correlate with other wavelengths?*
  - *Why are they so special?*

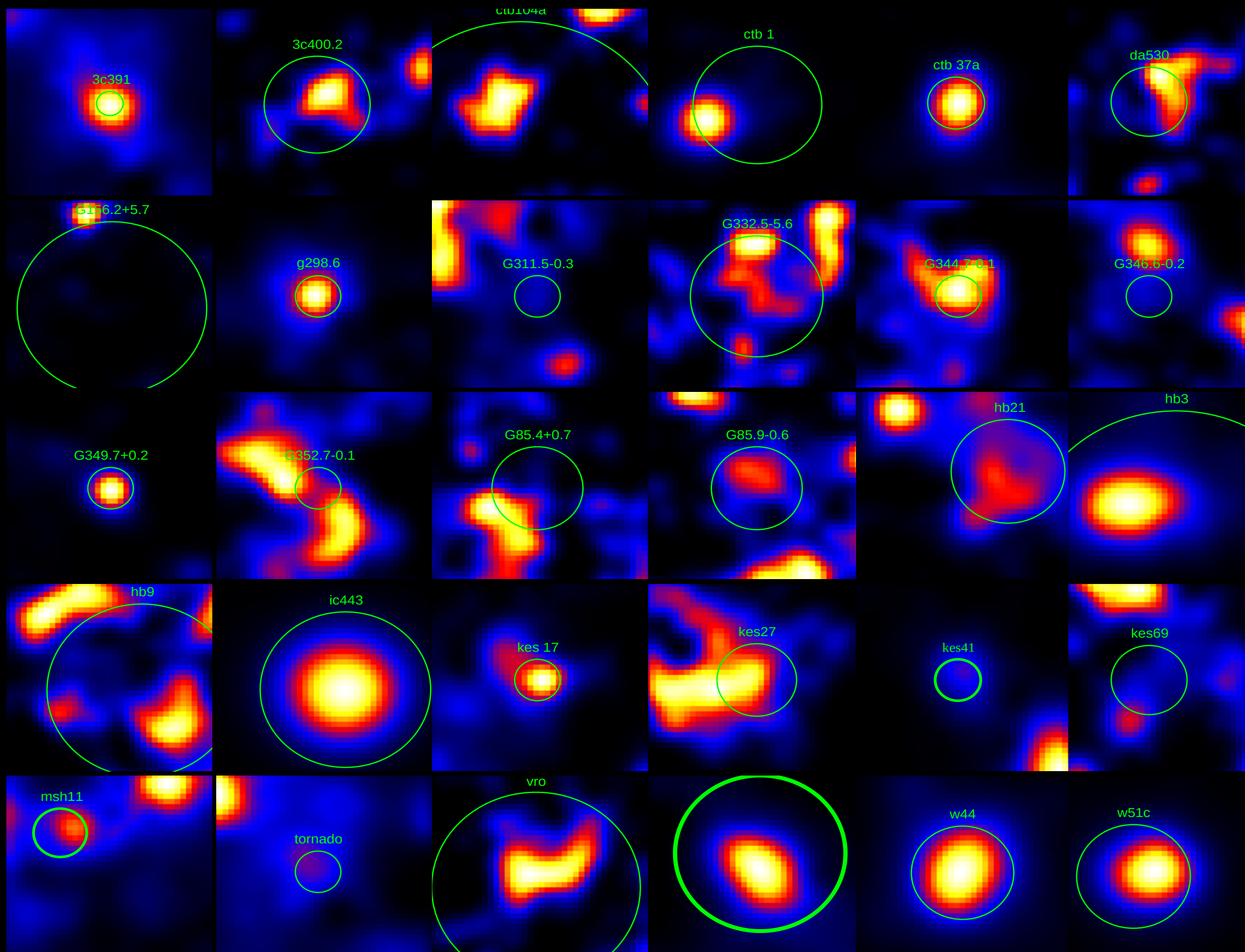
Table 1: Mixed Morphology Supernova Remnants

Name	Other Names	Distance (kpc)	GeV gamma-ray emission?	OH masers?	Overionsed plasma?
G000.0+00.0	Sgr A East	8	-	-	-
G000.1-00.1		8	-	-	-
G001.0-00.1		8	-	-	-
G006.4-00.1	W28	1.9	Y	Y	Y
G007.5-01.7		1.7	-	-	-
G008.7-00.1	(W30)	4.5	Y	Y	-
G021.8-00.6	Kes 69	5.2	-	-	-
G031.9+00.0	3C391	8.5	Y	Y	Y
G033.6+00.1	Kes 79	9.4	Y	Y	-
G034.7-00.4	W44	2.8	Y	Y	Y
G038.7-01.3		4	-	-	-
G041.1-00.3	3C397	7.5	-	-	-
G043.3-00.2	W49B	10	Y	Y	Y
G049.2-00.7	W51C	6	Y	Y	-
G053.6-02.2	3C400.2	2.8	-	-	Y
G065.3+05.7		0.8	-	-	-
G082.2+05.3	W63	1.5	-	-	-
G085.4+00.7		3.5	-	-	-
G085.9-00.6		4.1	-	-	-
G089.0+04.7	HB21	0.8	Y	Y	-
G093.3+06.9	DA 530	2.2	-	-	-
G093.7-00.2	CTB 104A	1.5	-	-	-
G116.9+00.2	CTB 1	1.6	-	-	-
G132.7+01.3	HB3	2.2	Y	-	-
G156.2+5.7		2	-	-	-
G160.9+02.6	HB9	4	Y	-	-
G166.0+04.3	VRO 42.05.01	4.5	Y	-	-
G189.1+03.0	IC443	1.5	Y	Y	Y
G272.2-03.2		10	-	-	-
G290.1-00.8	MSH 11-61A	7	Y	-	Y
G304.6+00.1	Kes 17	8	Y	Y	Y
G311.5-00.3		2.3	-	-	-
G327.4+00.4	Kes 27	5	Y	-	-
G332.5-5.6		3	-	-	-
G337.8-00.1	Kes 41	9.5	Y	Y	-
G344.7-00.1		6.3	-	-	-
G346.6-00.2		7	-	Y	Y
G348.5+00.1	CTB 37A	11.3	Y	Y	Y
G349.7+00.2		11.5	Y	Y	-
G352.7-00.1		7.5	-	-	-
G355.6-00.0		13	-	-	-
G357.7-00.1	Tornado	11.8	Y	Y	-
G359.1-00.5		8	Y	Y	Y
G359.79-0.26		8	-	-	-

1

GeV properties of MM SNRs

- *Consistently analyse >8 yrs of Fermi-LAT data of all MM SNRs.*
- *Generate: Spectra, detection signficance maps, count maps, etc.*
- *Characterise: γ-ray emitting properties of these remnants.*



Detection Significance maps of some MM SNRs.

PRELIMINARY

Auchettl et al (2017), In prep

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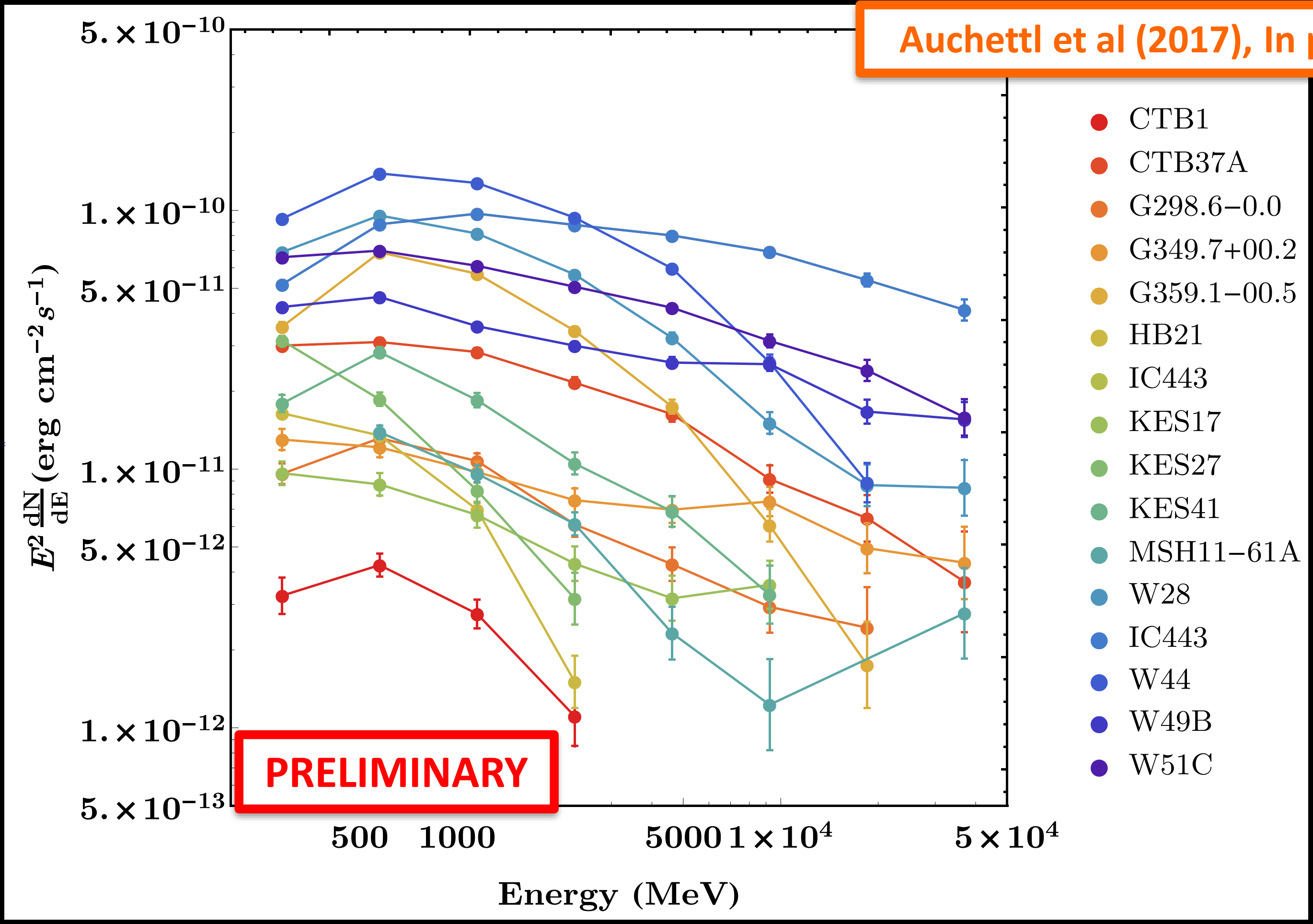

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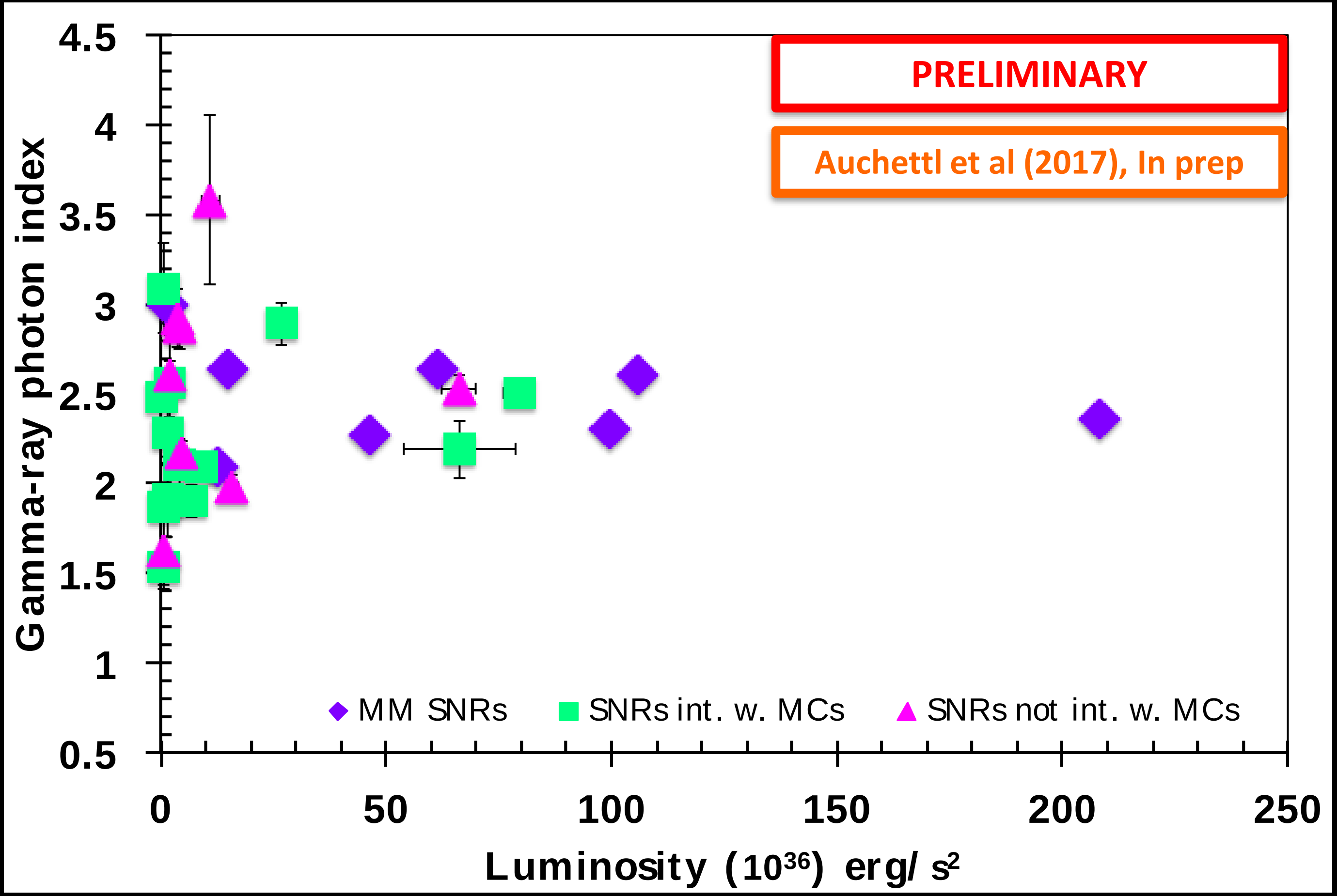


MM SNRs.

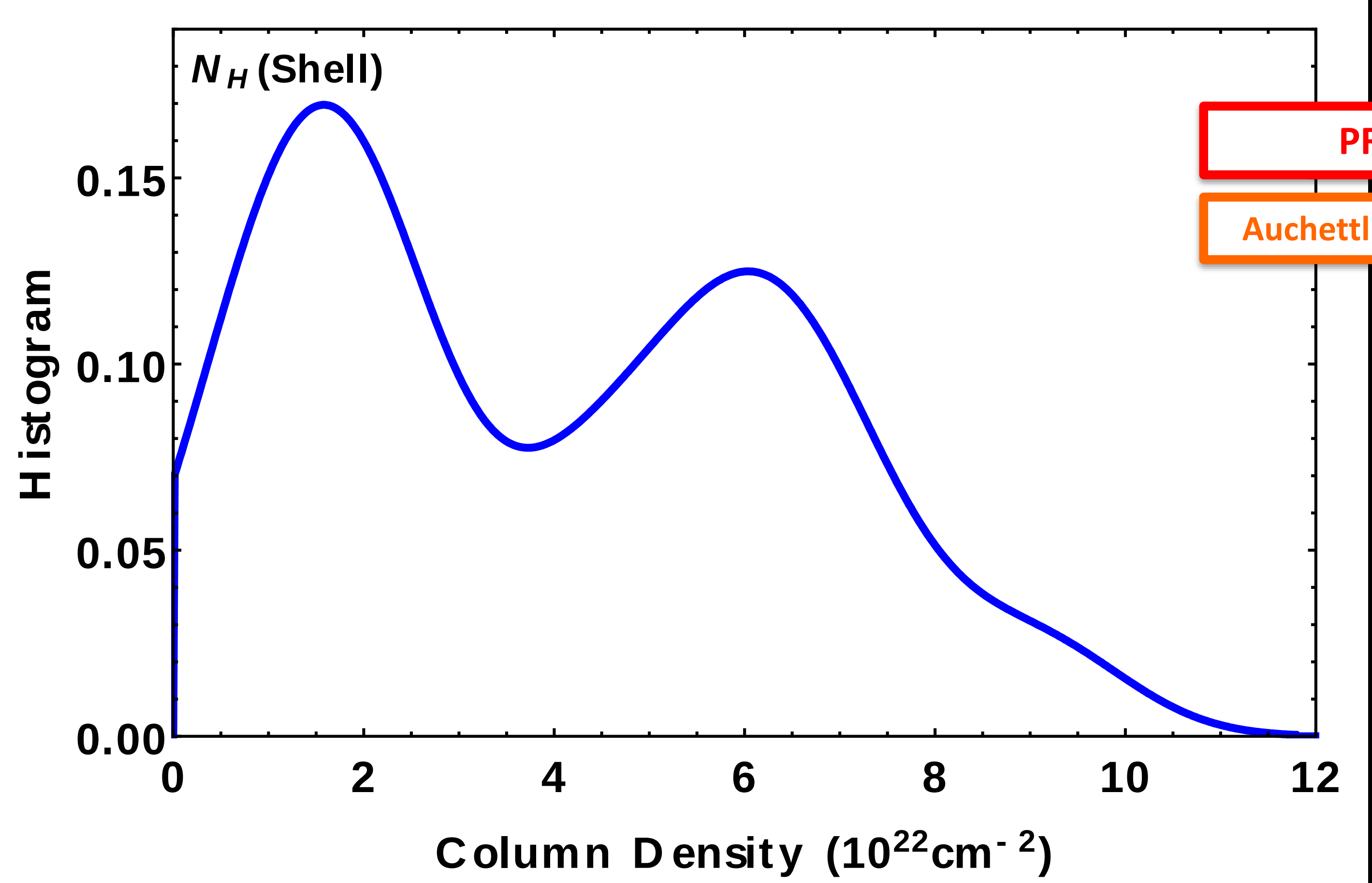
SNRs interacting with MC but are NOT MM SNRs

SNRs NOT interacting with MCs.

Note indexes and luminosities in Green and pink taken from 3FGL catalogue.

X-ray properties of MM SNRs

- *Rho & Petre (1998) analysed ~10 MM SNRs using ROSAT:*
  - *Uniform temperature*
  - *Emission arises from ISM*
- *However more recent studies show they are more complicated.*
- *We systematically analyse archival X-ray data of all MM SNRs.*



PRELIMINARY

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Consistent with being in higher density regions of the Milky Way.

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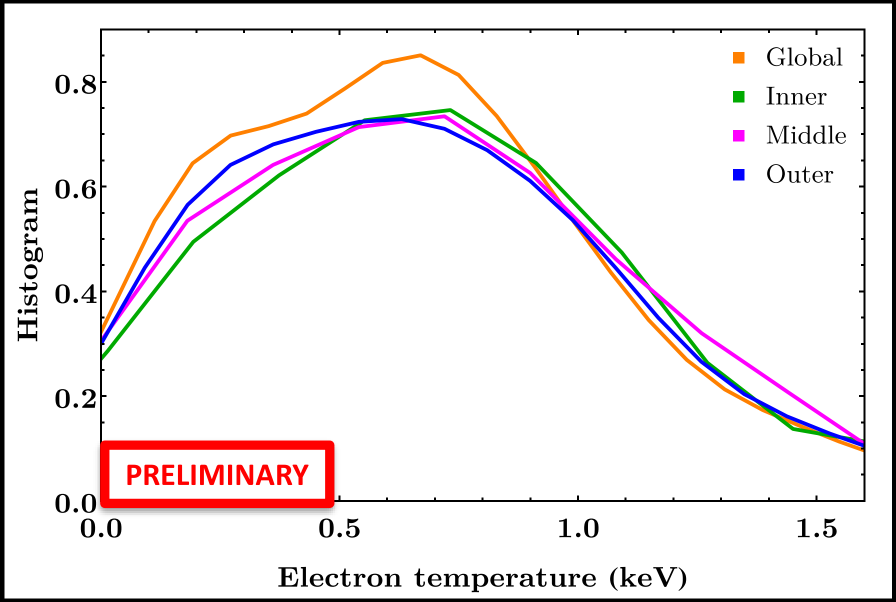
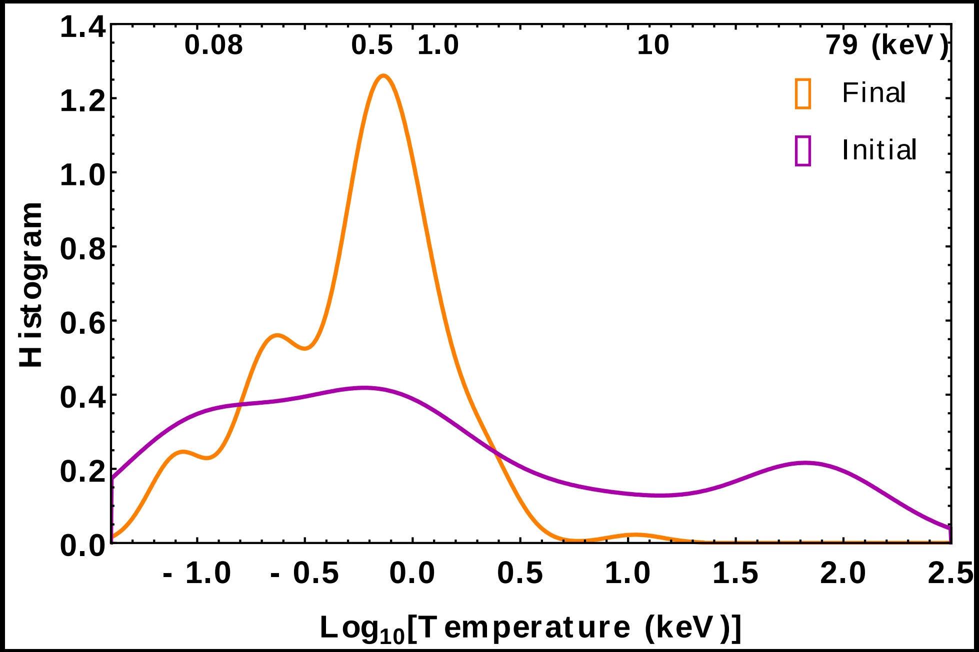


Median electron temperature ~ 0.66 keV

Inner (~0.65 keV) > Outer (~0.60 keV)

Approximately ~50% MM SNRs show evidence of overionisation.



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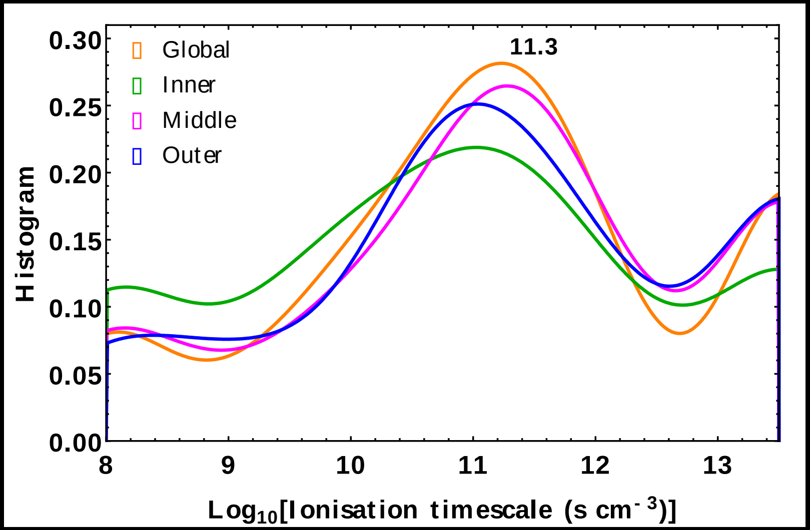
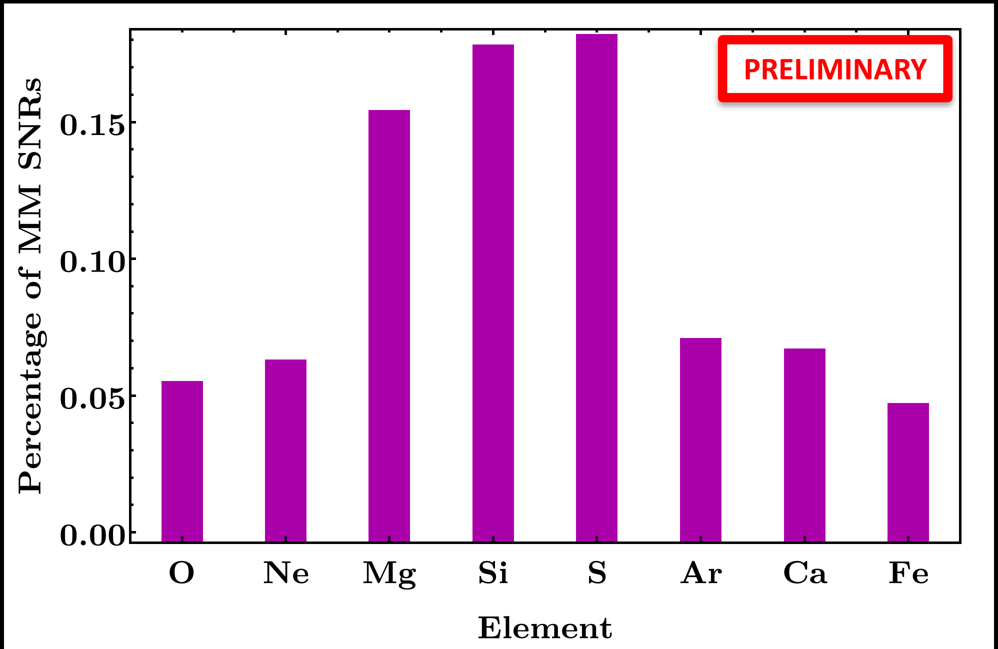
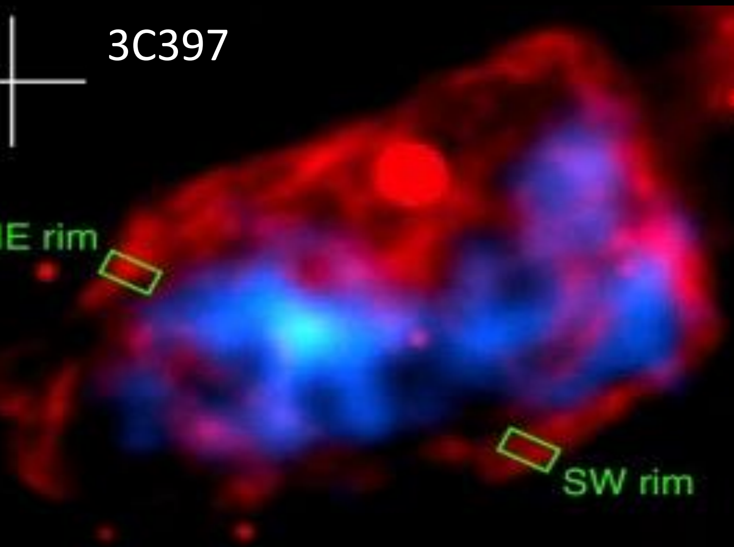
Median ionisation timescale ~2×10^{11} s cm^{-3} :
Partial non-equilibration; all ions are equilibrated, but without electron-ion equilibration

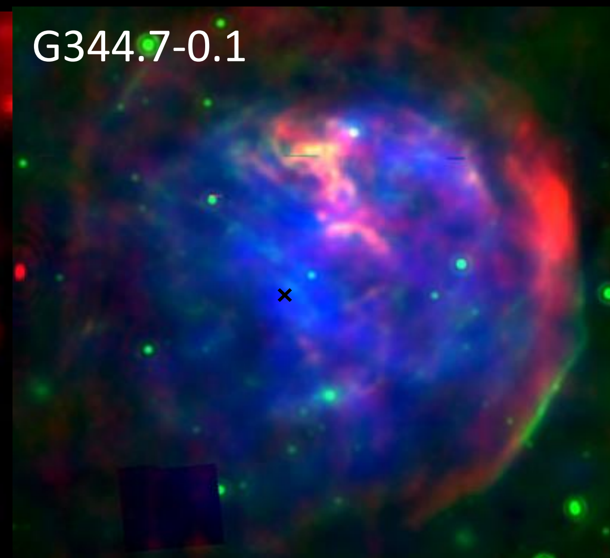


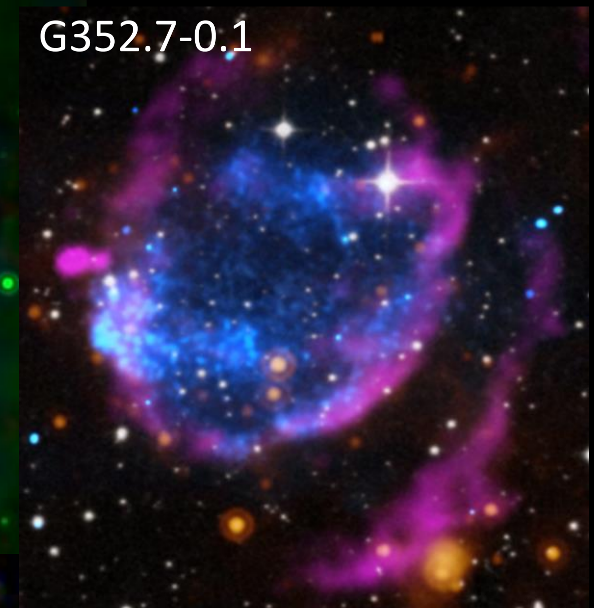


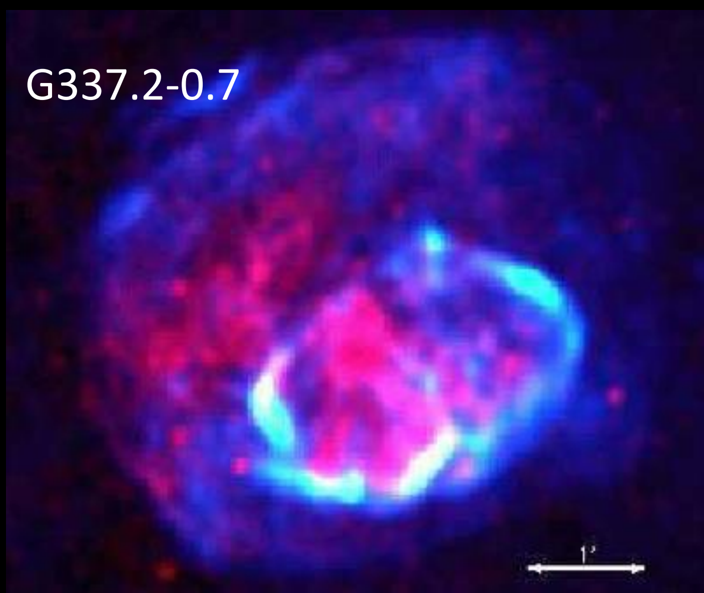
Most remnants show enhanced abundances of: Mg, Si and S.
Most have abundances consistent w. CC SNRs?

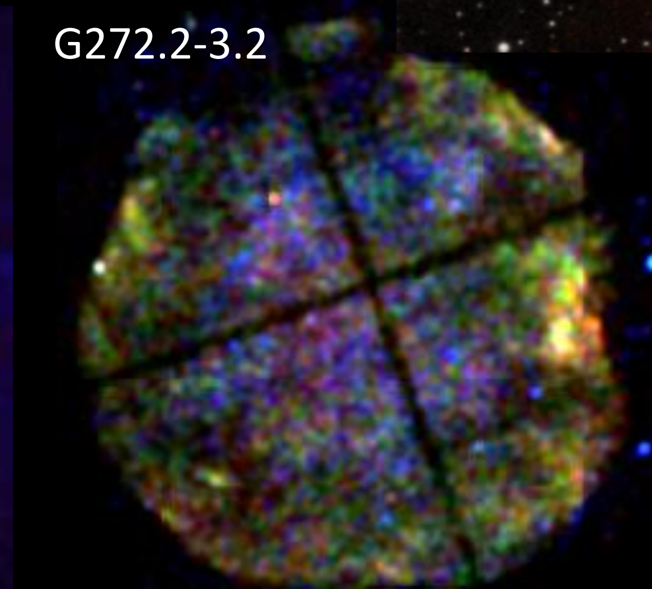
Type Ia MM SNRs interacting with molecular clouds.



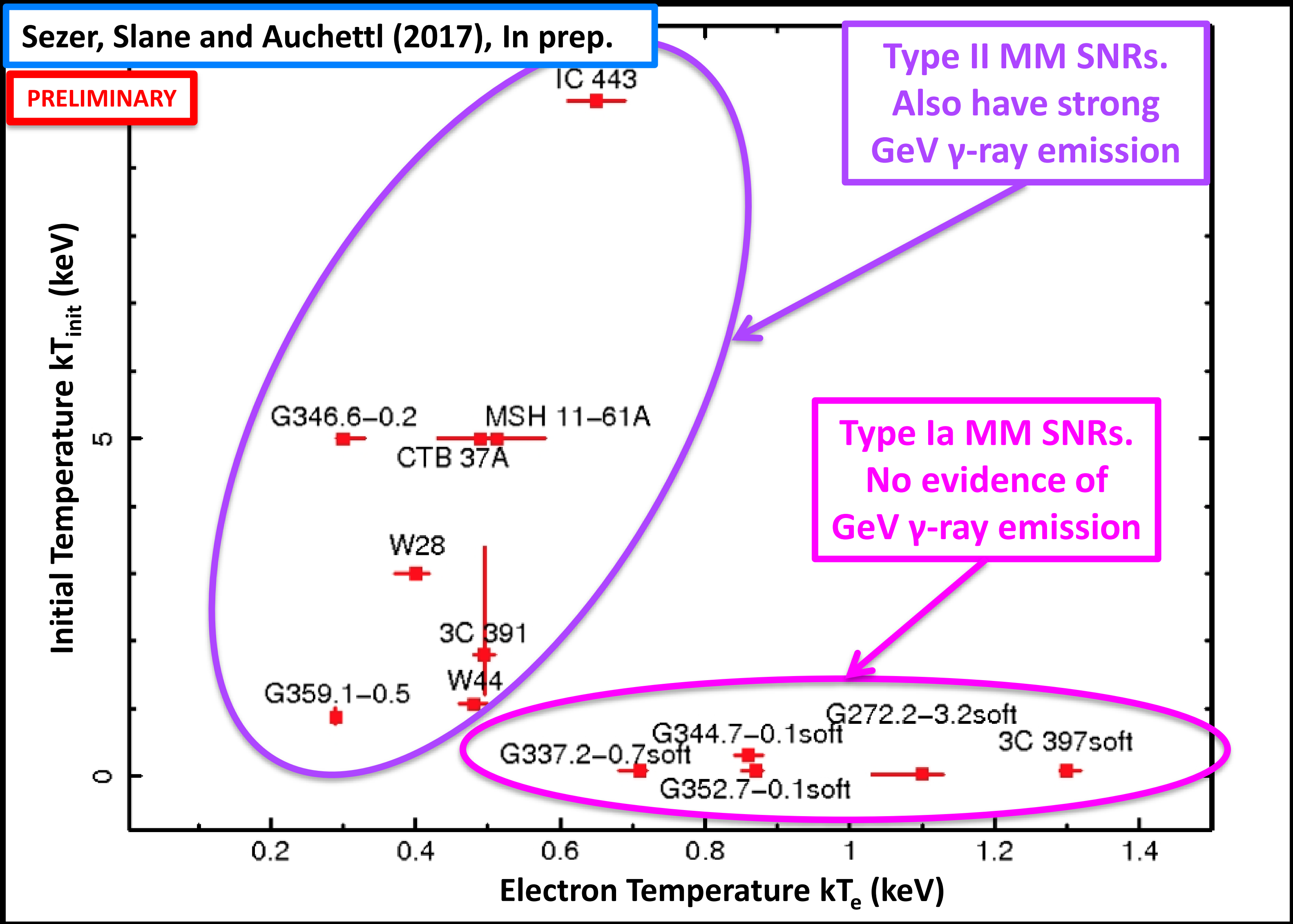




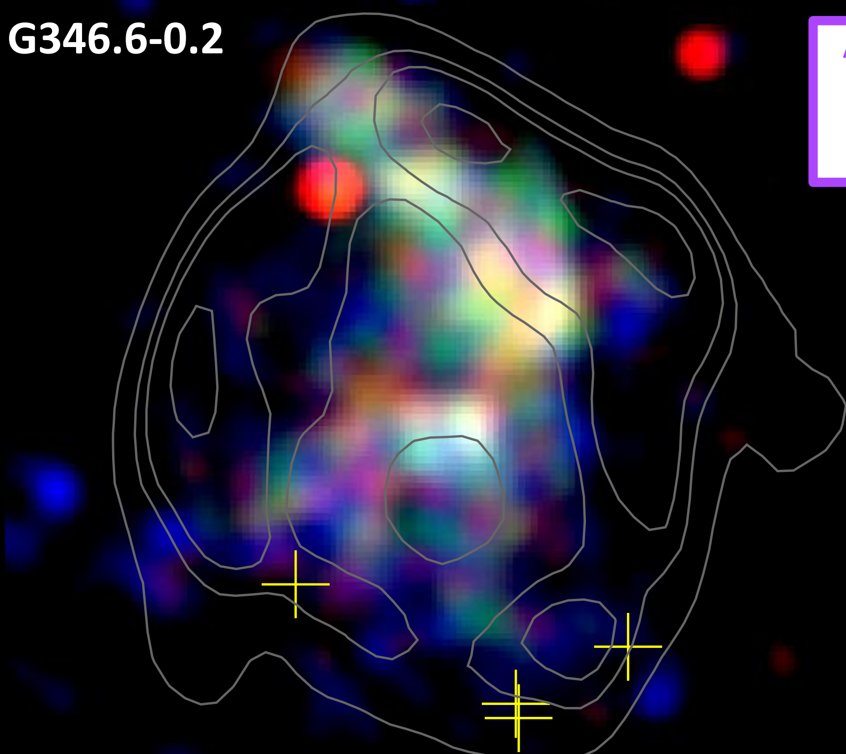




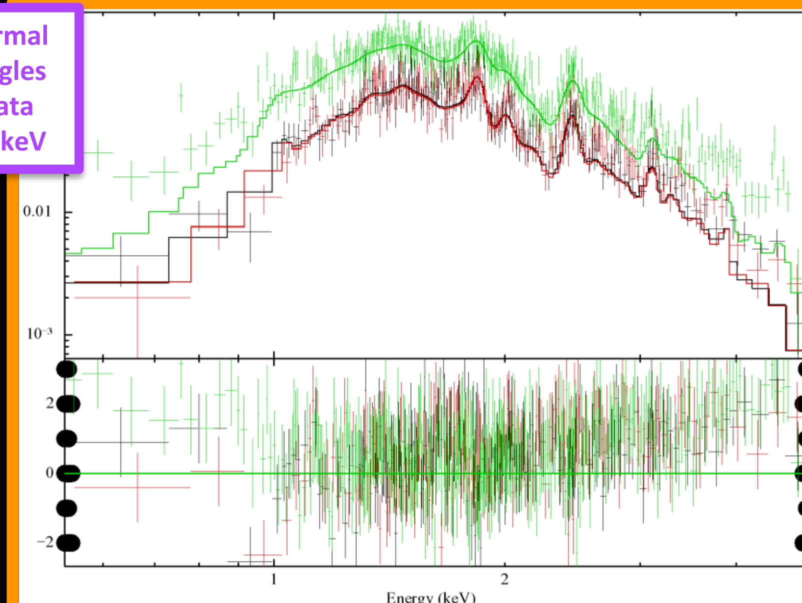
Type Ia vs. CC MM SNRs.

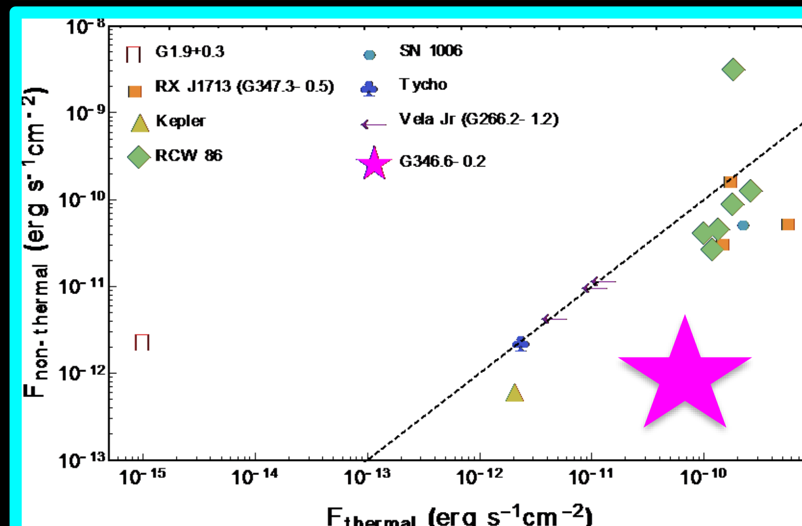


MM SNRs produce X-ray synch.?



A single thermal model struggles to fit the data above > 3.5 keV





Auchettl et al. 2017; arXiv:1707.09370

Hard X-ray component consistent with:

1. *Galactic Ridge Emission (located close to Galactic plane).*
2. *X-ray synchrotron emission (assuming upperlimit of B field derived from Zeeman).*
3. *Unidentified PWN.*

Summary

- *SNRs given an insight into the star we did not see.*
- *Dense environments dramatically affect the properties of SNRs.*
  - *In both X-ray and gamma-ray energy bands.*
- *Global studies can provide us with a wealth of knowledge about both the acceleration and plasma properties of MM SNRs.*
  - *Pion decay dominated?*
  - *Type Ia vs. CC MM SNRs.*
  - *Enhanced abundances?*
  - *Re-acceleration?*
  - *All overionised plasmas?*
  - *Flat temperature profile?*
  - *Any have non-thermal X-ray components consistent with particle acceleration?*