Chemical Enrichment History Of Abell 3112 Galaxy Cluster Out To The Virial Radius

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Introduction and Motivation

Chemical Enrichment by Supernova Explosions

- **The types of supernova explosions (SNe) enriching the ICM can be broadly classified in two types; Type Ia (SN Ia) and core collapse (SN cc).**

Type	**SN Ia**	**SN cc**
Spectra	Si, S, Fe, Ni	O, Ne, Mg, Si
Explosion	Thermonuclear explosion (low-mass stars)	Core-collapse (massive stars)
SN Yields	W7 & W70 (I99) WDD & CDD (I99) CDDT & ODDT (M10)	10-50 $M_\odot$ 0-1.0 $Z_\odot$ (I99)

*I99: Iwamoto et al., The Astrophysical Journal Supplement Series, 125, 2, 1999.
*M10: Maeda et al., The Astrophysical Journal, 712, 1, 2010.

Methodology

A Robust Model to Constrain Supernova Fractions: *SNapec* Model

- **A newly developed XSPEC model which determines the total number of supernova explosions and the ratio of SN Ia to SN cc supernova explosions by directly fitting the X-ray spectra.**

- ***snapec* combines *apec* with all up-to-date relative abundance scenarios (~ 122).**

- **The model derives the mass of the i-th element in terms of;**

Total number of SN explosions

$$\boxed{\frac{Z_i^{SNe}}{Z_i^{\odot}} = \frac{N^{SNe}}{M_i^{\odot}(1+R)}[Ry_i^{Ia} + < y_i^{cc} >]}$$

SN yields

$$\boxed{M_i^{\odot} \approx \frac{M_{ICM} Z_i^{\odot} A_i}{m_N}}$$

$$\boxed{R = N^{Ia}/N^{cc}}$$

Ratio of total number of SN Ia to SN cc

- **It has five parameters;**

kT: Temperature
N$^{\mathbf{SNe}}$: Total number of SN explosions
R: SN Ratio
SNIModelIndex: Type Ia SN yields
SNIIModelIndex: Core Collapse SN yields
z: The cluster's redshift
Norm: Emission measure

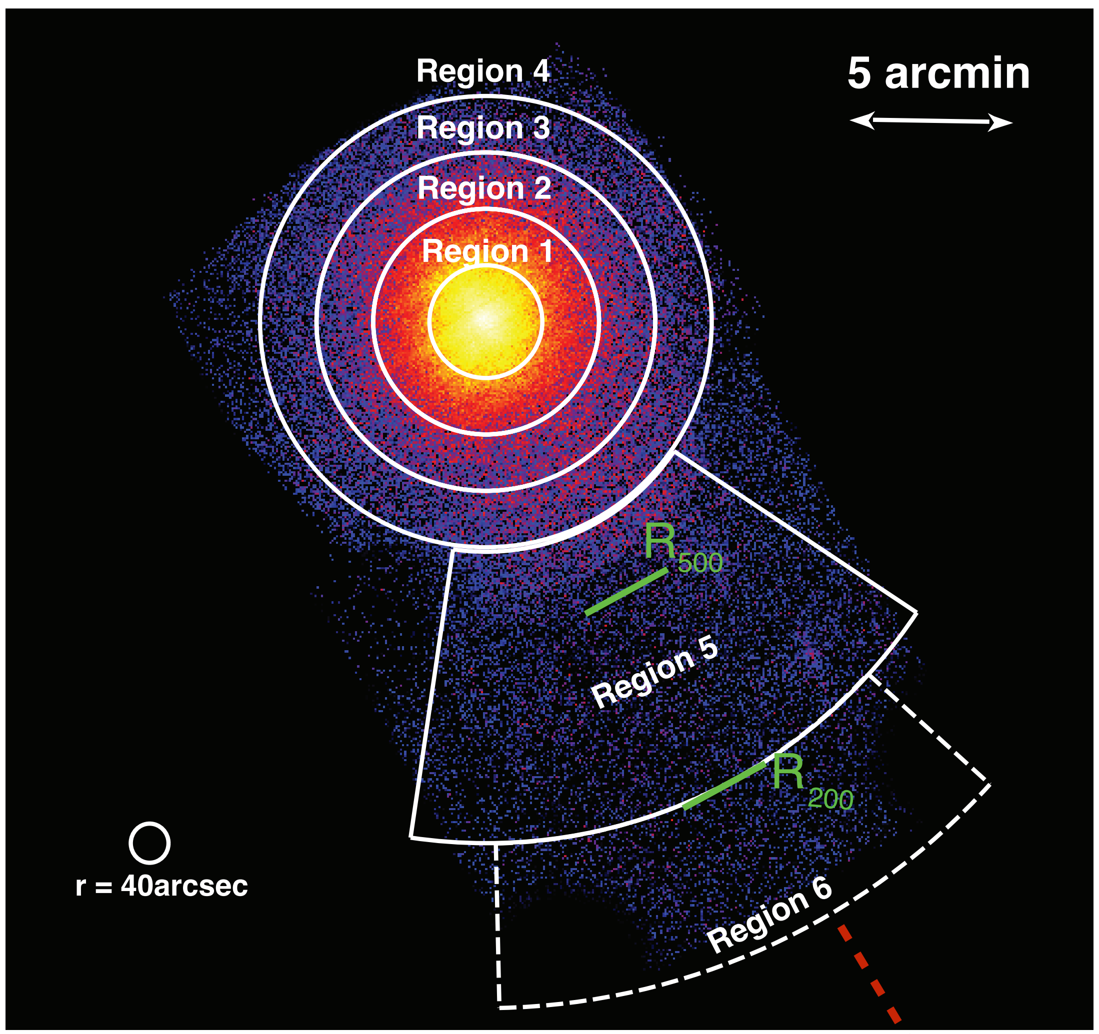
*snapec: Bulbul et al., The Astrophysical Journal, 753, 1, 2012

Analysis

Abell 3112

- Abell 3122 is an archetypal relaxed cool core cluster at redshift 0.0752, making it ideal target for studying its chemical enrichment history.

1.2 Ms of XIS exposure

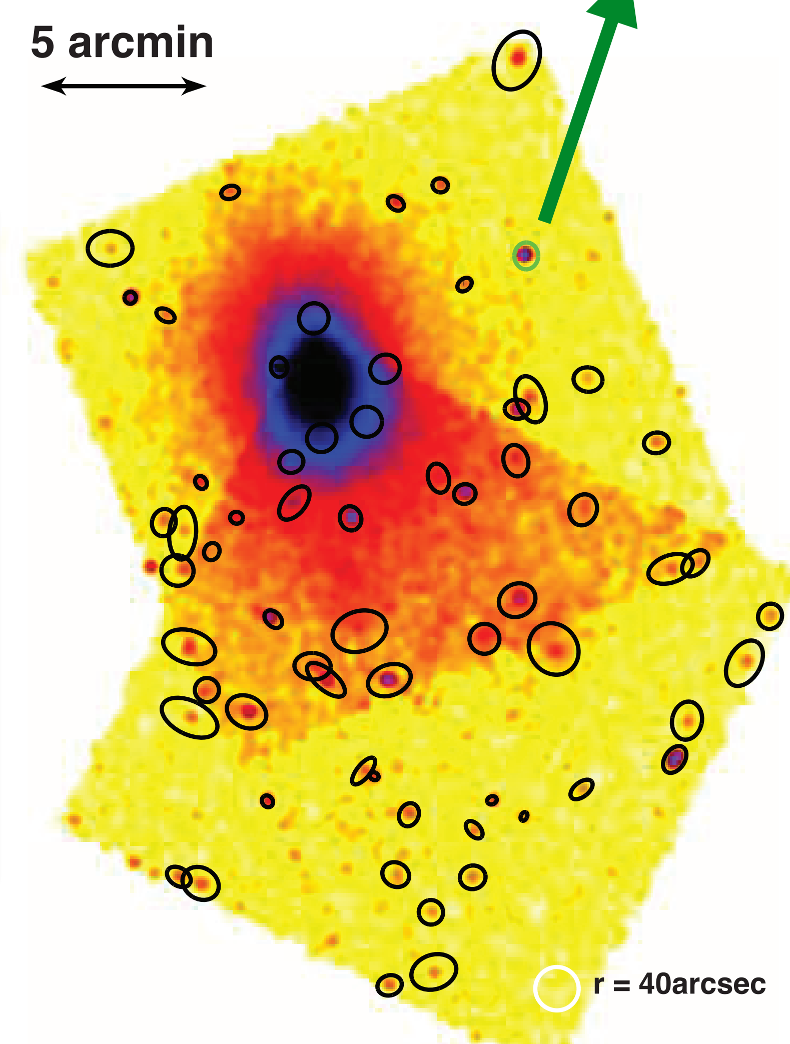


Images: 0.5 - 7.0 keV energy band

Local Background

Brightest Point

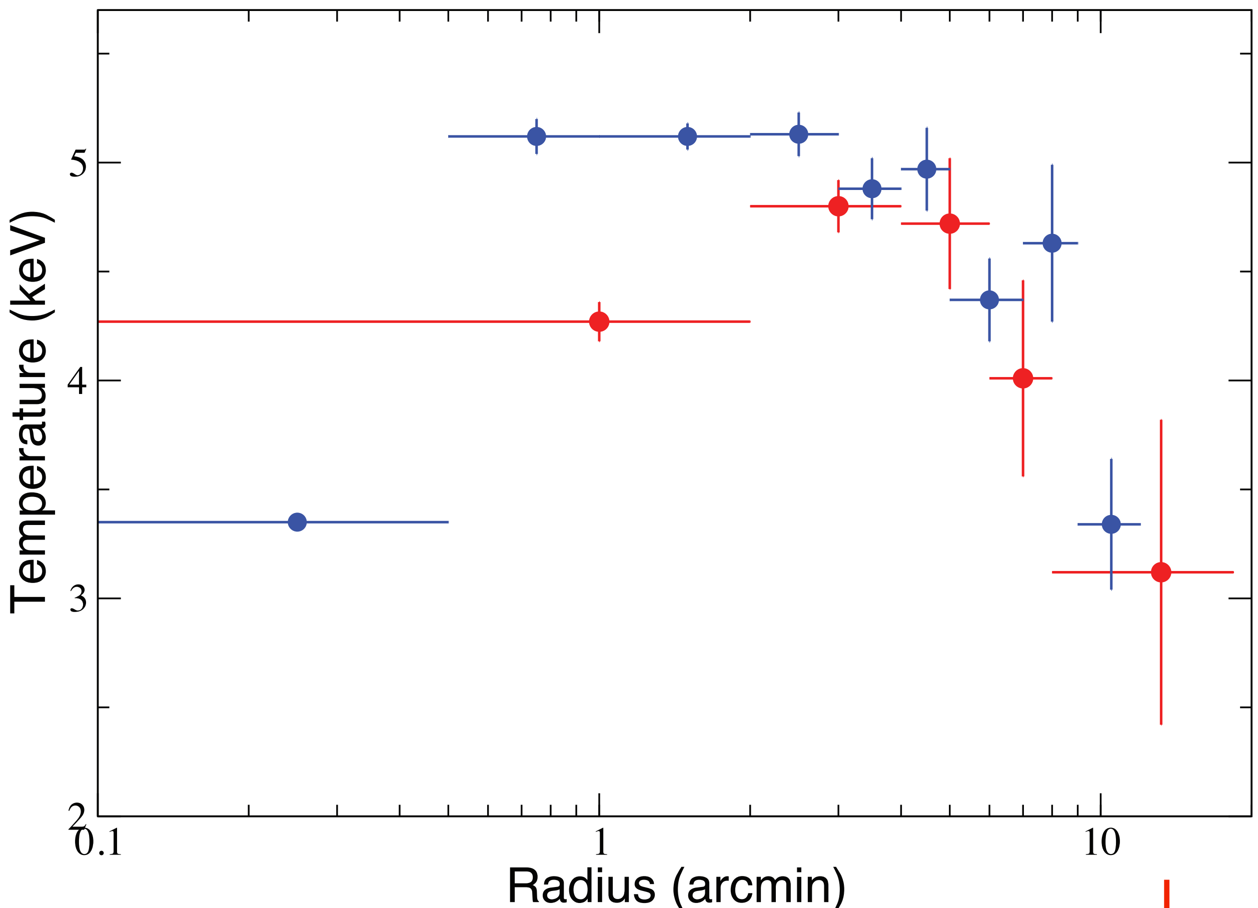
72 ks of ACIS exposure

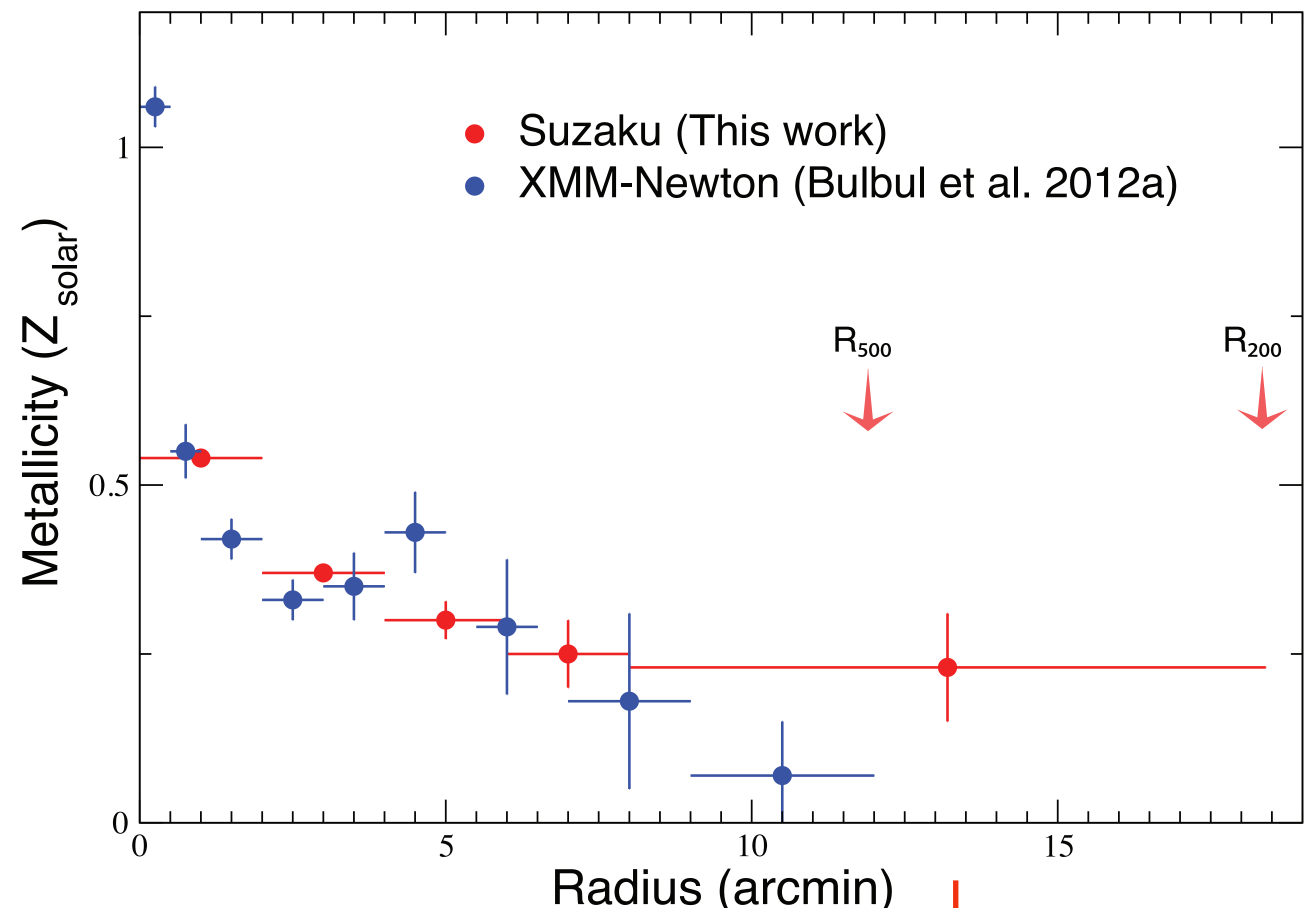


Results

Results 1: Global Spectral Properties: 1T *apec* Model

*The best fit parameters of Suzaku observations, 1σ statistical errors together with systematics are over-plotted.





The First Time Measurements in literature

*Ezer et al., The Astrophysical Journal, 836, 1, 2017

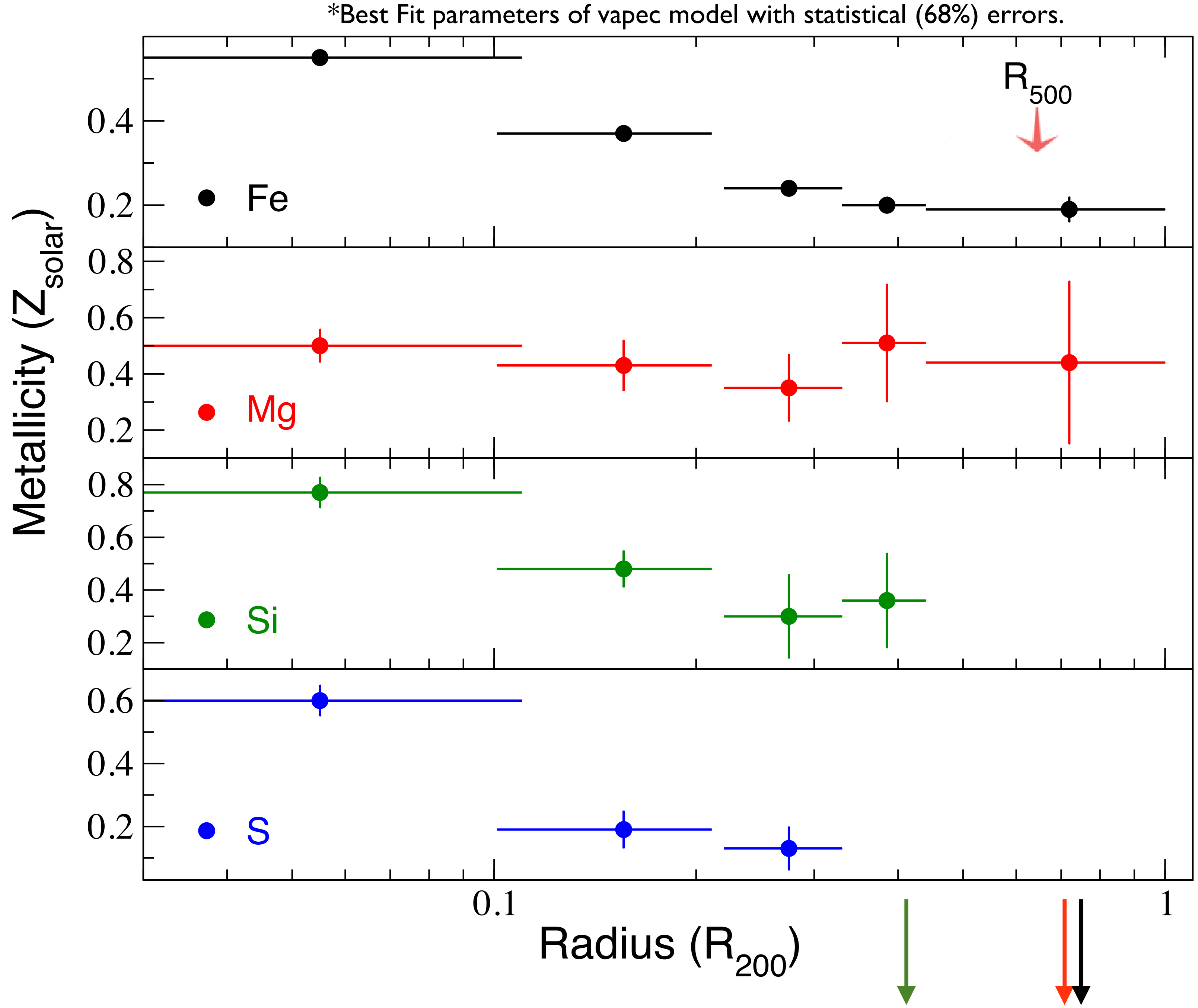
Results

Results 2: Global Spectral Properties: 1T *Vapec* Model

- **We further investigate the radial abundance distributions of individual α-elements, such as silicon (Si), sulfur (S), iron (Fe), and magnesium (Mg) out to R_{200}.**

- **The Fe, Si, S, and Mg elemental abundances are allowed to vary independently while other elemental abundances are fixed to the measured Fe abundance at the outskirts, 0.25$Z_{\odot}$.**

*Best Fit parameters of vapec model with statistical (68%) errors.

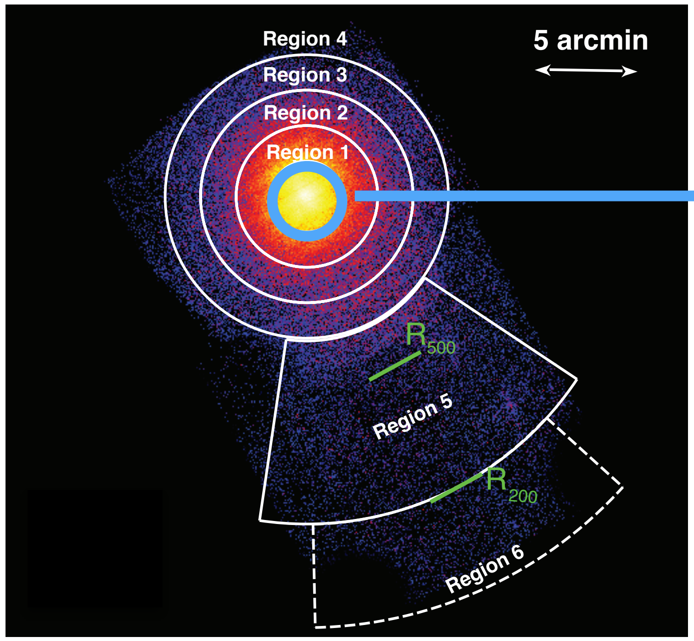


The First Time Measurements in literature

*Ezer et al., The Astrophysical Journal, 836, 1, 2017

Results

Results 3: Chemical Enrichment History: *SNapec* Model



- To investigate chemical enrichment history out to R_{200} of Abell 3112, we fit the innermost spectra (Region 1) with 1T snapec model for various SN yields.

Table1: Best Fit parameters of snapec model for the innermost (0' - 2') region.

SN Ia Model	N_{SNe} ($\times 10^9$)	R (N^{Ia}/N^{cc})	C-stat (dof)
W7	3.61 ± 0.16	0.10 ± 0.01	1112.4 (840)
W70	3.59 ± 0.25	0.10 ± 0.02	1108.9
WDD	3.24 ± 0.10	0.12 ± 0.02	1108.1
CDD	3.18 ± 0.15	0.12 ± 0.01	1108.8
CDDT	3.08 ± 0.28	0.41 ± 0.09	1173.3
ODDT	3.06 ± 0.21	0.18 ± 0.03	1112.3

We find that 1D delayed detonation WDD model for SN Ia is the best describing the Suzaku data of the immediate core region.

The 2D delayed detonation symmetric CDDT model can at best achieve fits that are less significant than other models, suggesting they are not a dominant process enriching the ICM.

Results

Results 3: Chemical Enrichment History: *SNapec* Model

- **To determine the distribution of SN fraction out to R_{200} rather than individual testing, we use WDD model which gives the best fit for the highest signal-to-noise region.**

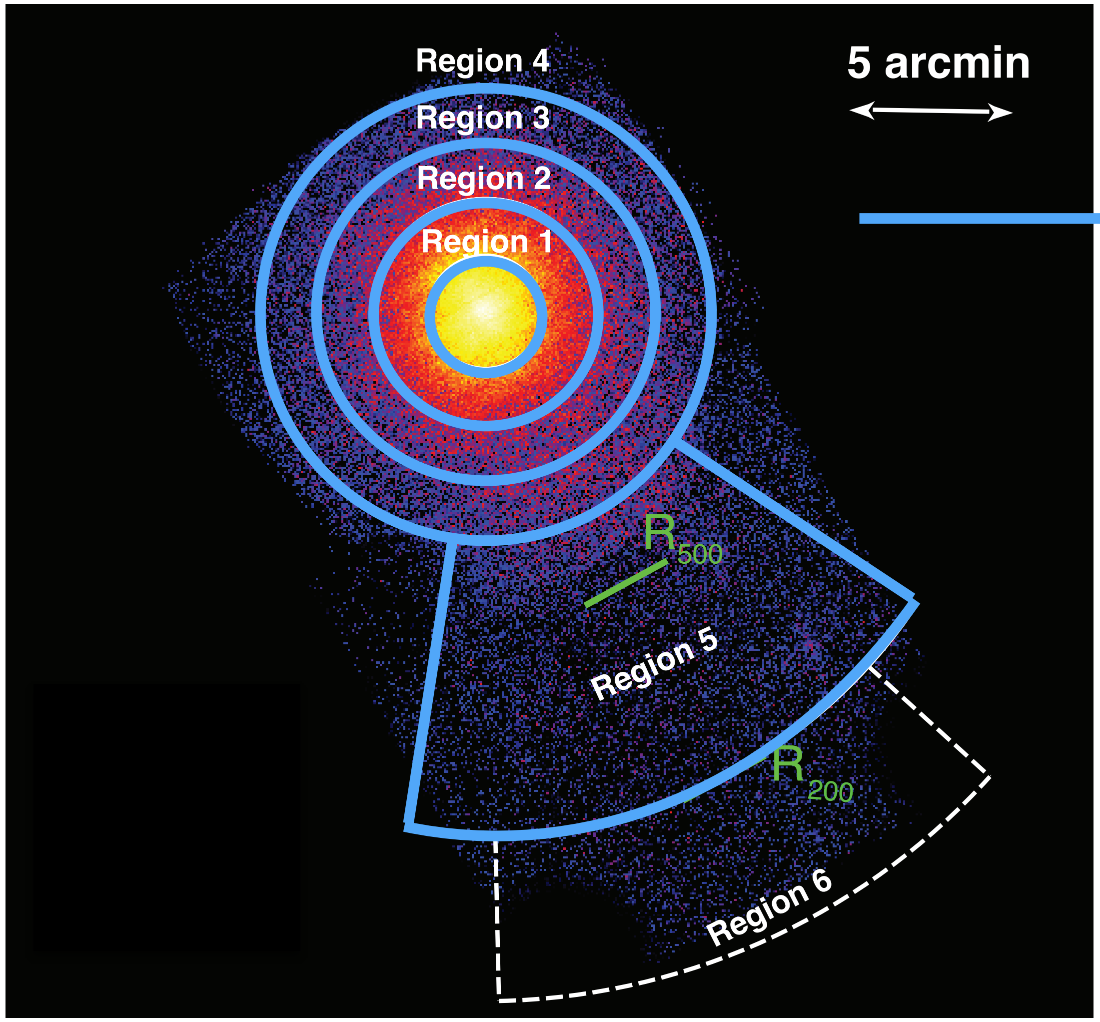


Table 2*: Best Fit parameters of snapec model parameters with 1σ statistical and systematic uncertainties are added in quadratures.

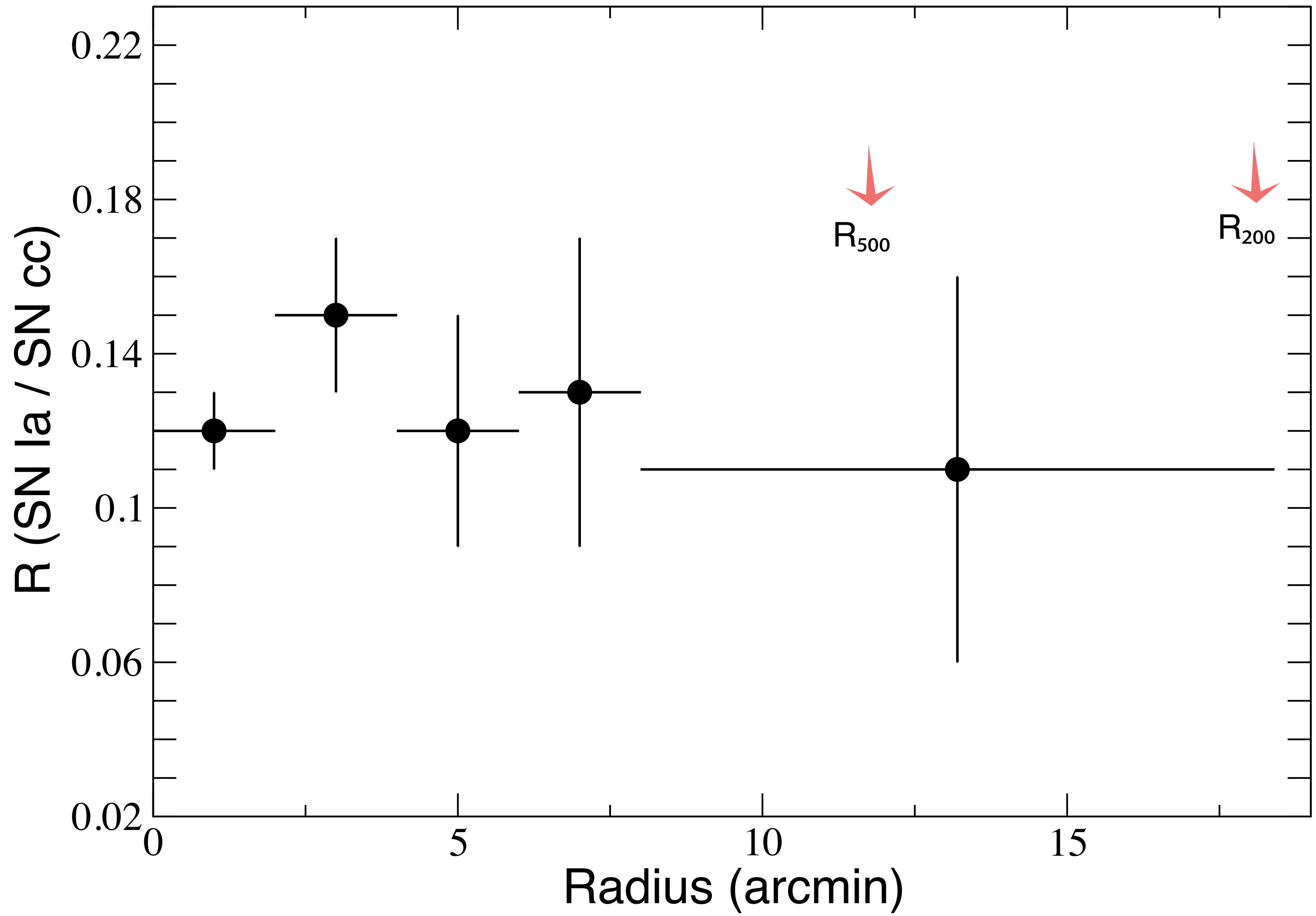
SN Models	Regions (arcmin)	N_{SNe} (x10^9)	R	C-stat (dof)
SN Ia: WDD (I99) SN cc:10-50 M⊙, 0-1 Z⊙ (I99)	0' - 2'	3.24 ± 0.10	0.12 ± 0.02	1108.1 (840)
	2' - 4'	1.96 ± 0.36	0.16 ± 0.02	1079.9 (842)
	4' - 6'	1.48 ± 0.13	0.12 ± 0.04	1008.9 (850)
	6' - 8'	1.22 ± 0.12	0.13 ± 0.05	337.3 (259)
	8' - 18'	0.87 ± 0.17	0.11 ± 0.06	244.2 (151)

*Ezer et al., The Astrophysical Journal, 836, 1, 2017

Results

Results 3: Chemical Enrichment History: *SNapec* Model

The ratio of SN Ia to SN cc is fairly UNIFORM from the core to the outskirts.



*Ezer et al., The Astrophysical Journal, 836, 1, 2017

Conclusions

- **Deep Suzaku (1.2 Ms of total XIS exposure) and Chandra (72ks) observations of Abell 3112.**
- **Global spectral features with single and multi temperature structure: temperature peaks around ~ 4.8 keV and declines to 3.37 keV in the virial radius.**
- **The metallicity of the ICM: 0.22 ± 0.08 $Z_\odot$ (near the virial radius) consistent with Virgo & Perseus. Uniform Fe profile at radius > $0.2R_{200}$.**
- **Snapec (XSPEC model) for calculation of SN Ia to SN cc ratio.**
- **Our results favor 1D W7, CDD, and WDD SN Ia models. (A 2D delayed detonation SN Ia model CDDT produces less significant fits compared to priors, overestimate the observational Si abundance).**
- **The fractional distribution of the SN Ia (199 WDD) to SN cc between 0.12–0.16. (In agreement with the observed fraction in our Galaxy!)**
- **The distribution of the SN Ia fraction is fairly UNIFORM out to R_{200} indicating:**
    - **Metal enrichment at an early epoch (z~2–3)**
    - **Mixing originating from an intense period of star formation activity**
    - **Metals are well-mixed into the ICM**

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