The origin of elements in cluster cores

Jelle de Plaa

SRON

Netherlands Institute for Space Research

Netherlands Organisation for Scientific Research (NWO)

Outline

- **Introduction**
  - Chemical enrichment in the early universe
  - Enrichment of the cluster ICM
  - Origin of elements (SN Ia and core-collapse supernovae)
- **Measurements in local clusters**
  - Detection of chemical elements in X-rays
  - Latest results
- **Measurements in high-redshift clusters**
- **Future missions**
  - Astro-H SXS Microcalorimeter array

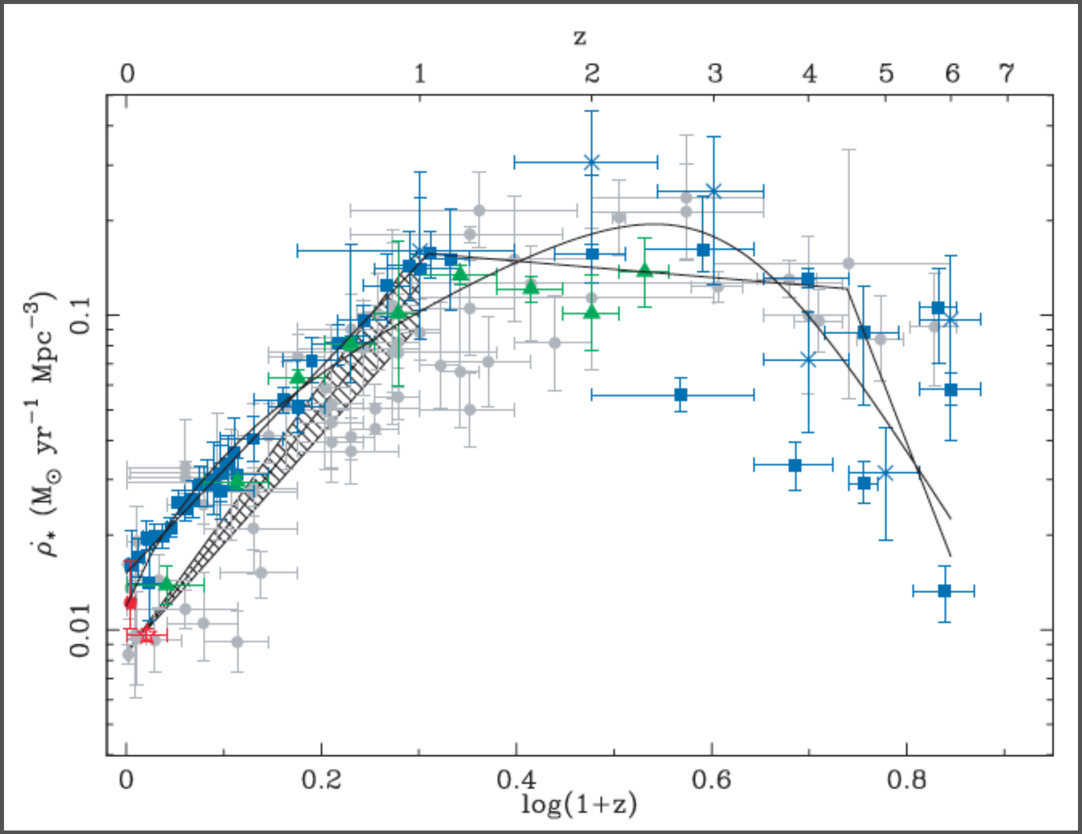
Population III stars

- First star formation starting epoch re-ionisation
- Thought to be massive stars, but also intermediate-mass stars possible (Vangioni et al, 2011)
- Star formation starts around z~10
- Enriches pristine gas (H,He) with metals
- Pop III is minor contribution to later enrichment (Matteucci & Calura 2005)

SRON

Observed
Star formation history

- The star formation rate has been measured up to z~7
- Peak of star formation is around z~2-3
- In clusters, the star formation declines more rapidly between z~1-2 due to ICM growth and feedback
- ~90% of the metals end up in a hot phase (Ferrara et al., 2005)



Hopkins & Beacom (2006)

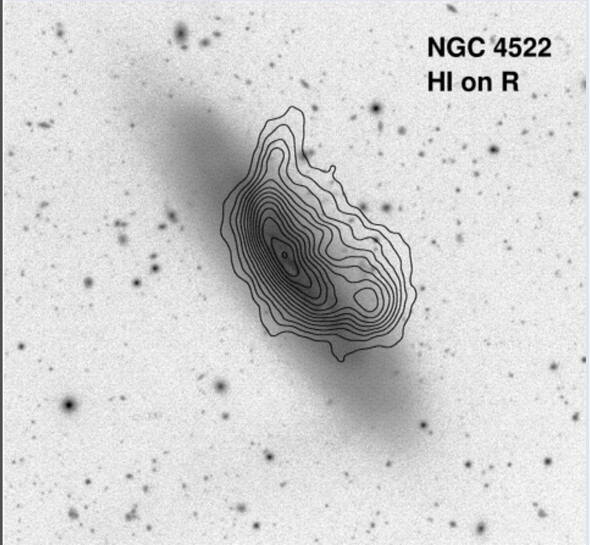
SRON

Cluster enrichment mechanisms (1)

Galactic winds	AGN Feedback
	
Superwinds in M82	Metal uplift by AGN blown bubbles (M87)

SRON

Cluster enrichment mechanisms (2)

Ram-pressure stripping	Merger induced sloshing	Galaxy-galaxy interactions
		

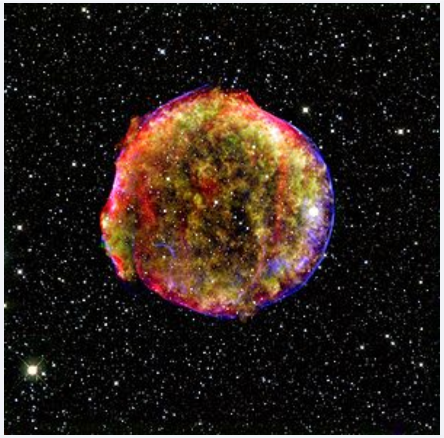
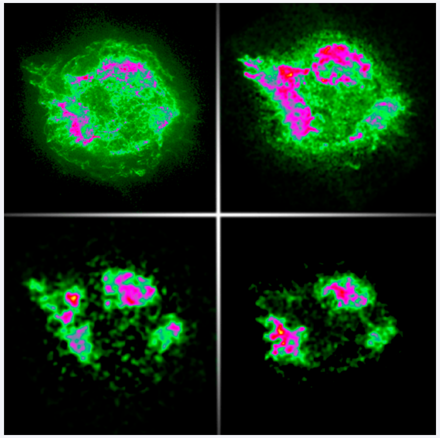
Origin of elements in clusters

2A 0335+096

- Metals originate from star burst at z~2-3
- Main components:
  - Type Ia supernovae
  - Core-collapse supernovae
  - Intermediate-mass AGB stars

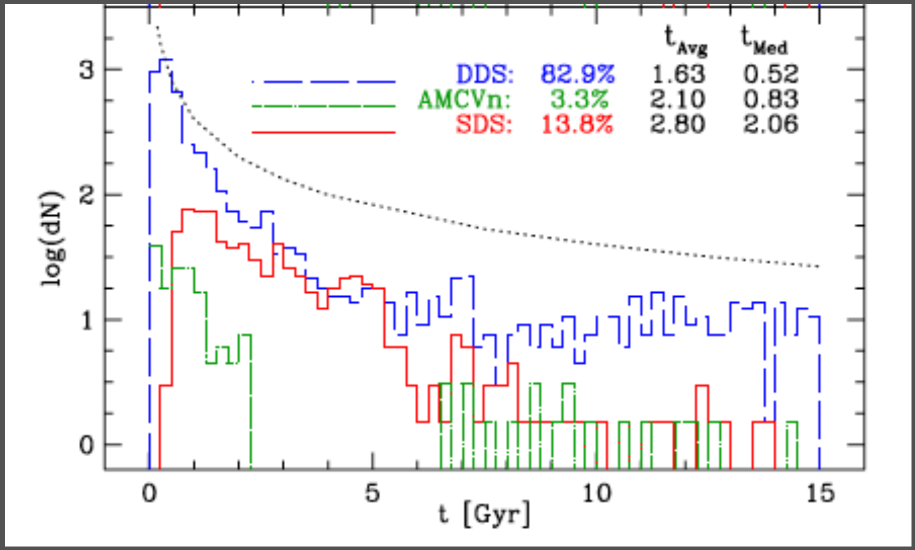
SRON

Sources of metals

Intermediate mass stars (AGB) $M < 8\ M_{sun}$	Type Ia Supernovae	Core-collapse Supernovae
•Nitrogen & Carbon •Strong winds	•High-mass elements (Si, S, Fe, Ni) •Explosive ejection into ISM	•Low-mass elements (O, Ne, Si) •Explosive ejection into ISM
		

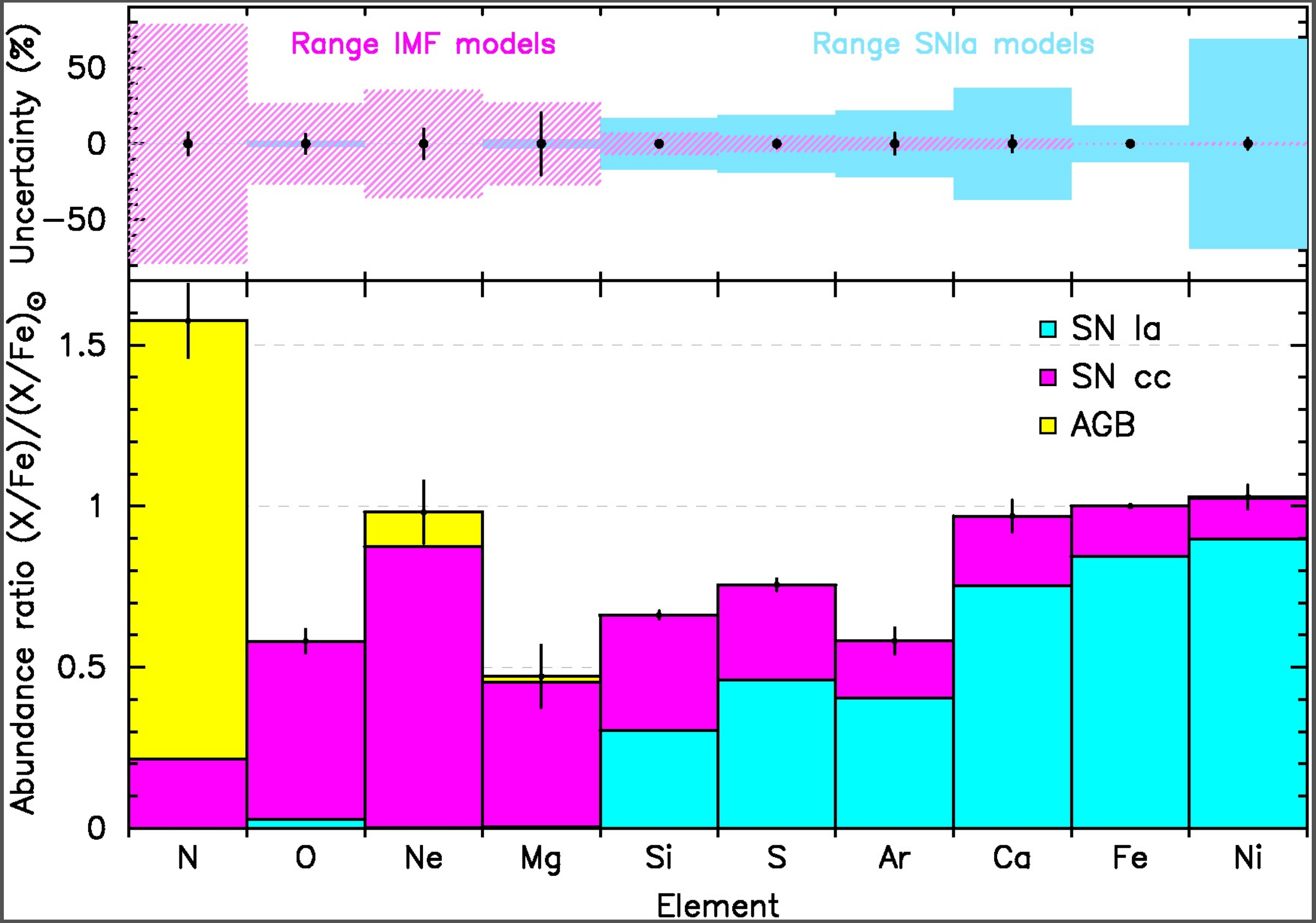
Type Ia explosion mechanism

- Still discussion about progenitor type Ia
- Double degenerate scenario appears to dominate single degenerate.
- Type Ia's ignite when carbon burning temperature is reached



Ruiter et al., 2009

Expected ICM abundances from SN/AGB models



SRON

Open questions

- What is the nature of the z~2-3 stellar population?
  - What was its IMF?
  - What was its initial metalicity (Pop III)?

- What is the SNIa explosion mechanism?

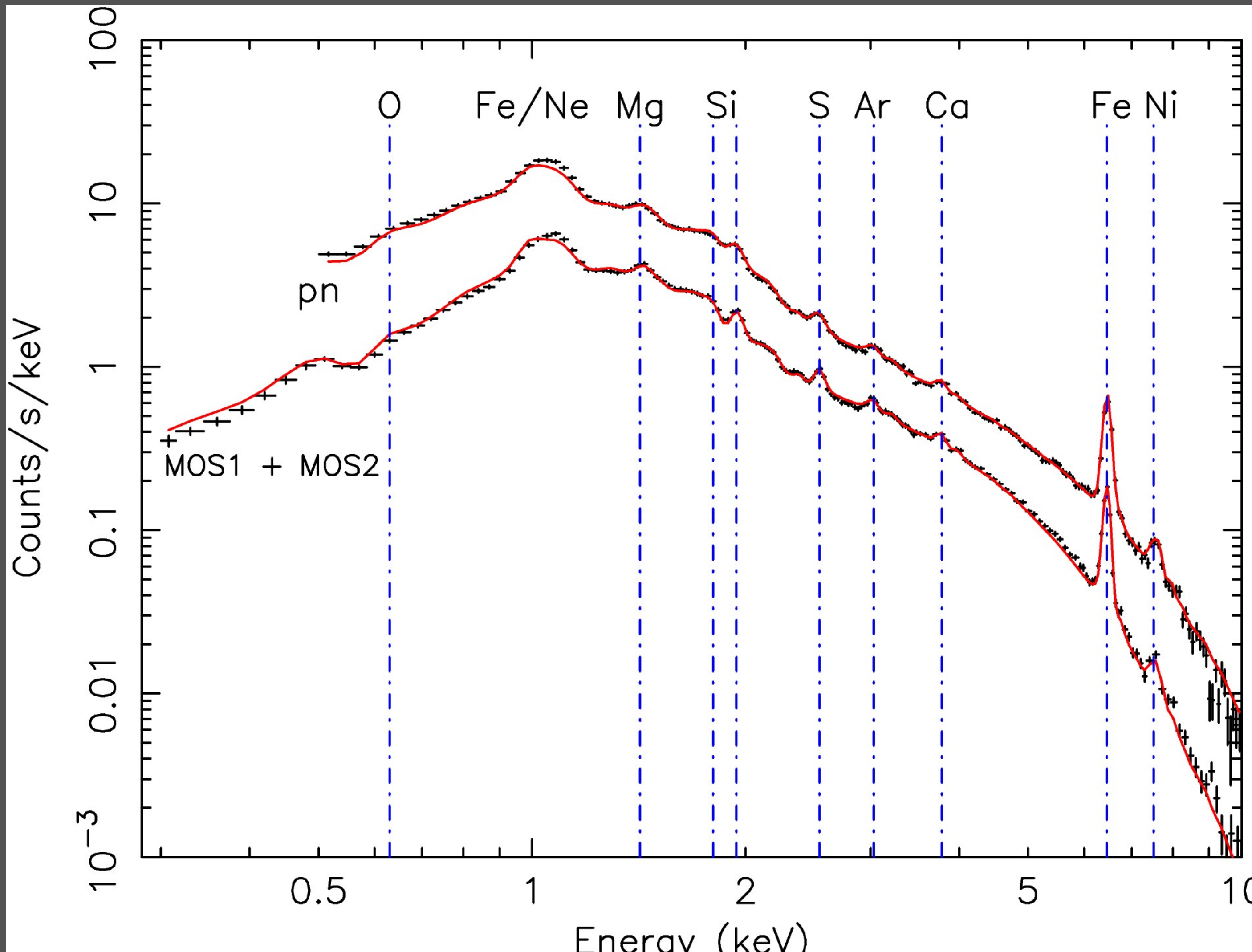
- How and when did the metals reach the ICM?

Clues and answers can be found
in the hot ICM of local clusters!

SRON

Measurements in local clusters

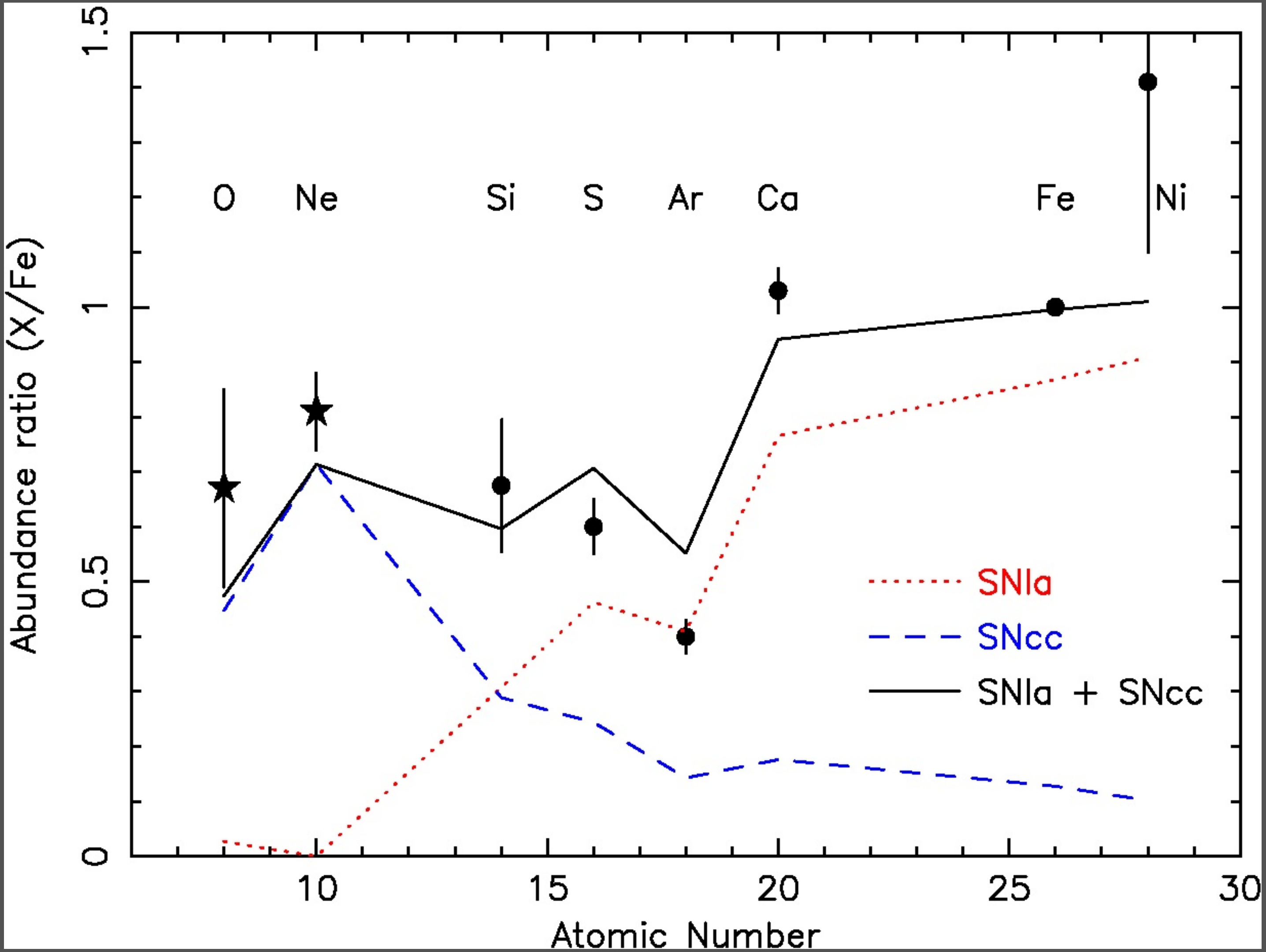
EPIC Spectroscopy



2A 0335+096 Werner et al., 2006

SRON

Cluster enrichment with XMM-Newton



(de Plaa et al., 2007)

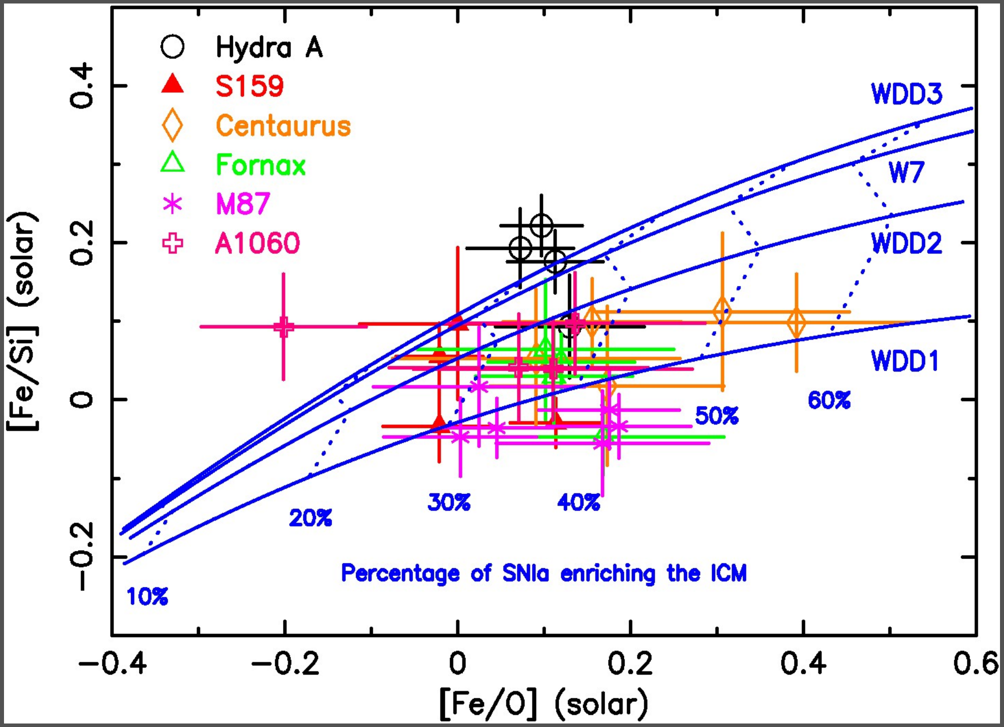
SRON

SNIa ratio

Model	SNIa/SNIa+SNcc	χ^2/dof
Constant		418/5
Solar	0.15 ± 0.08	64/4
W7	0.22 ± 0.06	152/4
W70	0.26 ± 0.07	104/4
WDD2	0.37 ± 0.09	84/4
WDD3	0.22 ± 0.06	105/4
CDD2	0.32 ± 0.08	86/4
Tycho	0.72 ± 0.17	26/4

De Plaa et al. (2007)

Improvements from XMM-Newton & Chandra



Simionescu et al. 2009

- Fe/Si and Fe/O ratio should discriminate between models
- Different clusters → slightly different answers

However, systematics in Si and O abundance found

SRON

Recent development: Direct fitting with snapec

TABLE 3

The Best-fit Parameters of the snapec Model Obtained Using T95, I99, and M10 SN Yields and XMM-Newton EPIC Spectra.

SN Ia Model	SN cc Model	kT_e (keV)	N^{SNe} ($\times 10^9$)	R	$R^{Ia}_{\%}$ (%)	χ^2 (1683 dof)
T95 (W7)	T95	3.49 ± 0.02	1.06 ± 0.02	0.40 ± 0.01	28.6 ± 1.0	2737.7
I99 (W7)	I99	3.50 ± 0.02	1.06 ± 0.03	0.40 ± 0.01	28.6 ± 1.0	2737.8
I99 (W70)	I99	3.50 ± 0.02	1.06 ± 0.02	0.39 ± 0.01	28.1 ± 1.0	2723.9
I99 (WDD1)	I99	3.47 ± 0.02	0.82 ± 0.02	0.76 ± 0.03	43.2 ± 2.9	2893.6
I99 (WDD2)	I99	3.49 ± 0.02	0.89 ± 0.02	0.51 ± 0.01	33.8 ± 1.0	2783.9
I99 (WDD3)	I99	3.47 ± 0.02	0.91 ± 0.11	0.42 ± 0.02	29.6 ± 1.9	2749.8
I99 (CDD1)	I99	3.41 ± 0.01	0.82 ± 0.11	0.81 ± 0.03	44.8 ± 2.9	2927.6
I99 (CDD2)	I99	3.50 ± 0.02	0.87 ± 0.11	0.49 ± 0.02	32.9 ± 1.9	2767.1
M10 (W7)	I99	3.51 ± 0.02	1.06 ± 0.01	0.40 ± 0.01	28.6 ± 1.0	2744.1
M10 (CDEF)	I99	3.54 ± 0.02	1.36 ± 0.11	0.77 ± 0.03	43.5 ± 2.9	2775.8
M10 (CDDT)	I99	3.39 ± 0.02	1.11 ± 0.10	1.28 ± 0.07	56.1 ± 6.5	3627.5
M10 (ODDT)	I99	3.49 ± 0.02	0.83 ± 0.13	0.82 ± 0.04	45.1 ± 3.8	2842.3

Bulbul et al. (2012)
Arxiv 1205.2706

SRON

Other studies

- Suzaku observations slightly prefer W7 over WDD2
  Confirm SNIa/SNcc ratio
  However, no Ar, Ca, Ni measurements (Sato et al., 2007&2009)

- Other XMM-Newton measurements (De Grandi & Molendi, 2009)
  SNIa/SNcc uncertainty dominated by SN model uncertainty
  Systematic errors abundances < 20-30%

Main point:

Abundances from X-rays are robust enough to test SN models!

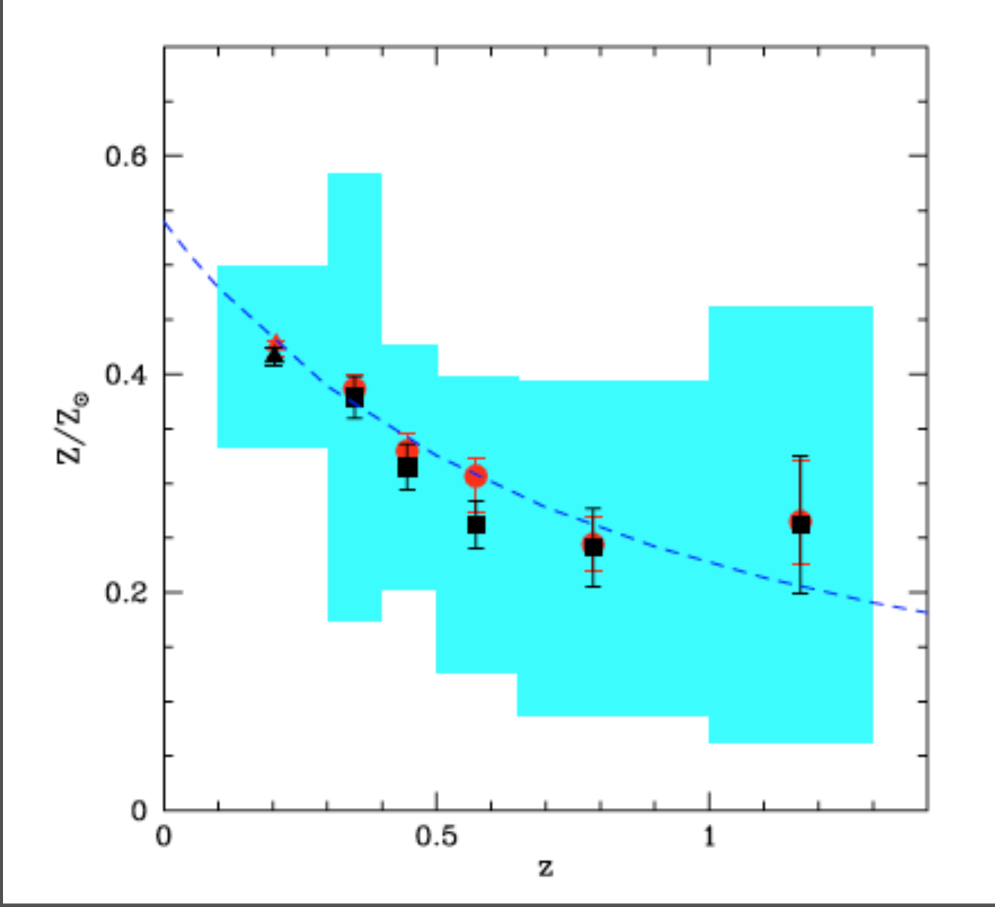
SRON

Evolution with redshift

Redshift evolution of Fe (status 5 years ago)

- Strong hint of evolution of Fe in cores of clusters
- Factor of 2 since z=1.3

- Since star formation is suppressed, enrichment in core is mainly SNIa from cD
- Note that ejecting metals into ICM takes time

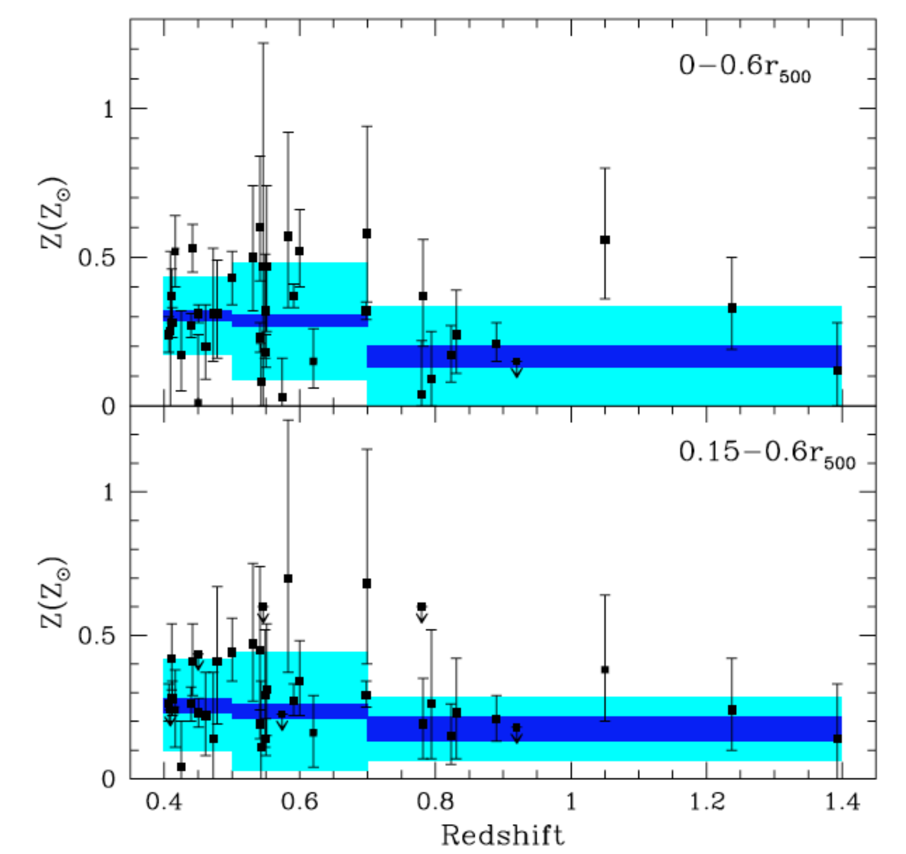


Balestra et al., 2007

SRON

Analysis of another cluster sample

- Only 2 sigma hint of abundance decline with redshift
- Larger and deeper sample needed to obtain significant results
- No strong relation would imply early enrichment



Baldi et al. (2012)

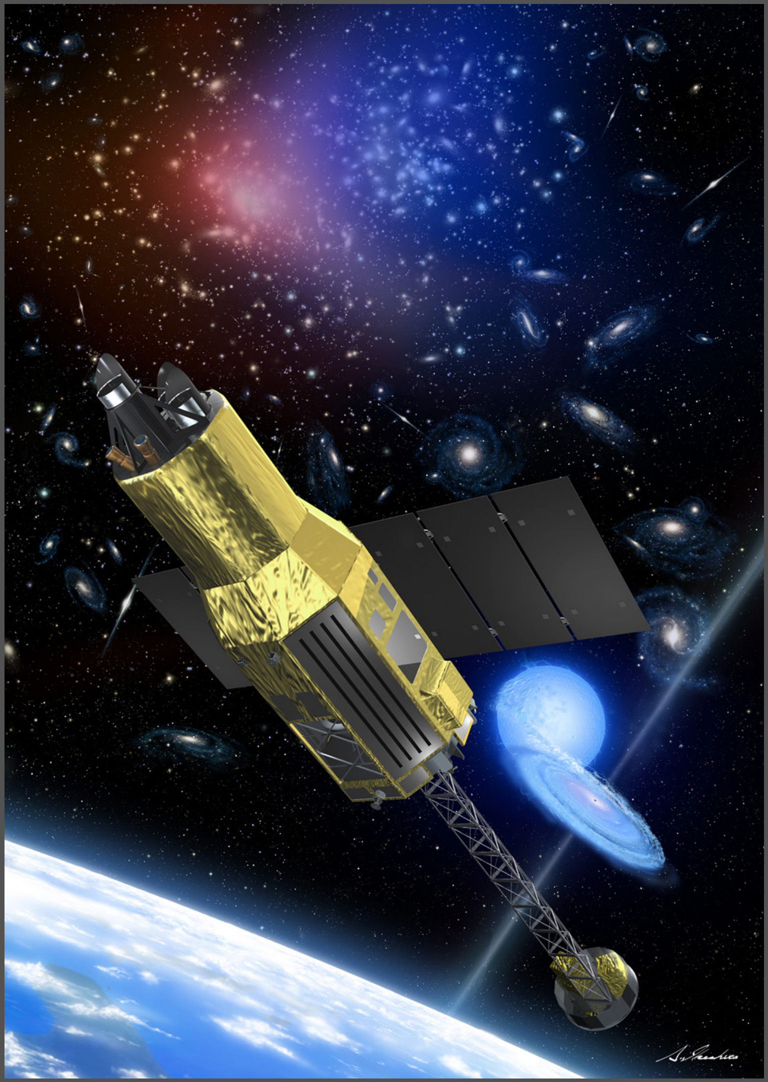
SRON

Future missions

New missions: ASTRO-H

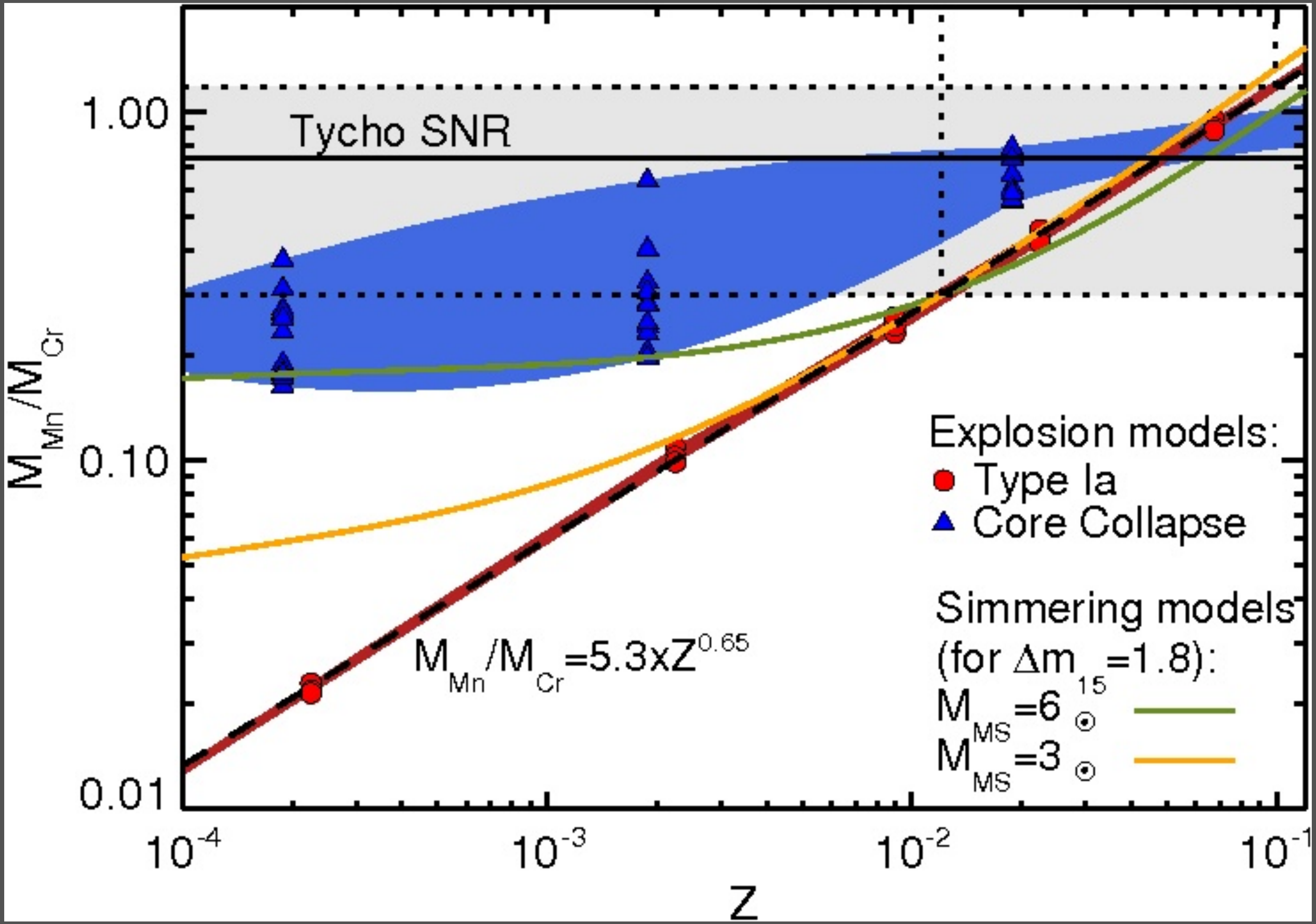
- Microcalorimeter SXS
- Expected spectral resolution: ~5 eV
- Launch 2014

- High spectral resolution will help to resolve weak lines, also from less abundant elements!



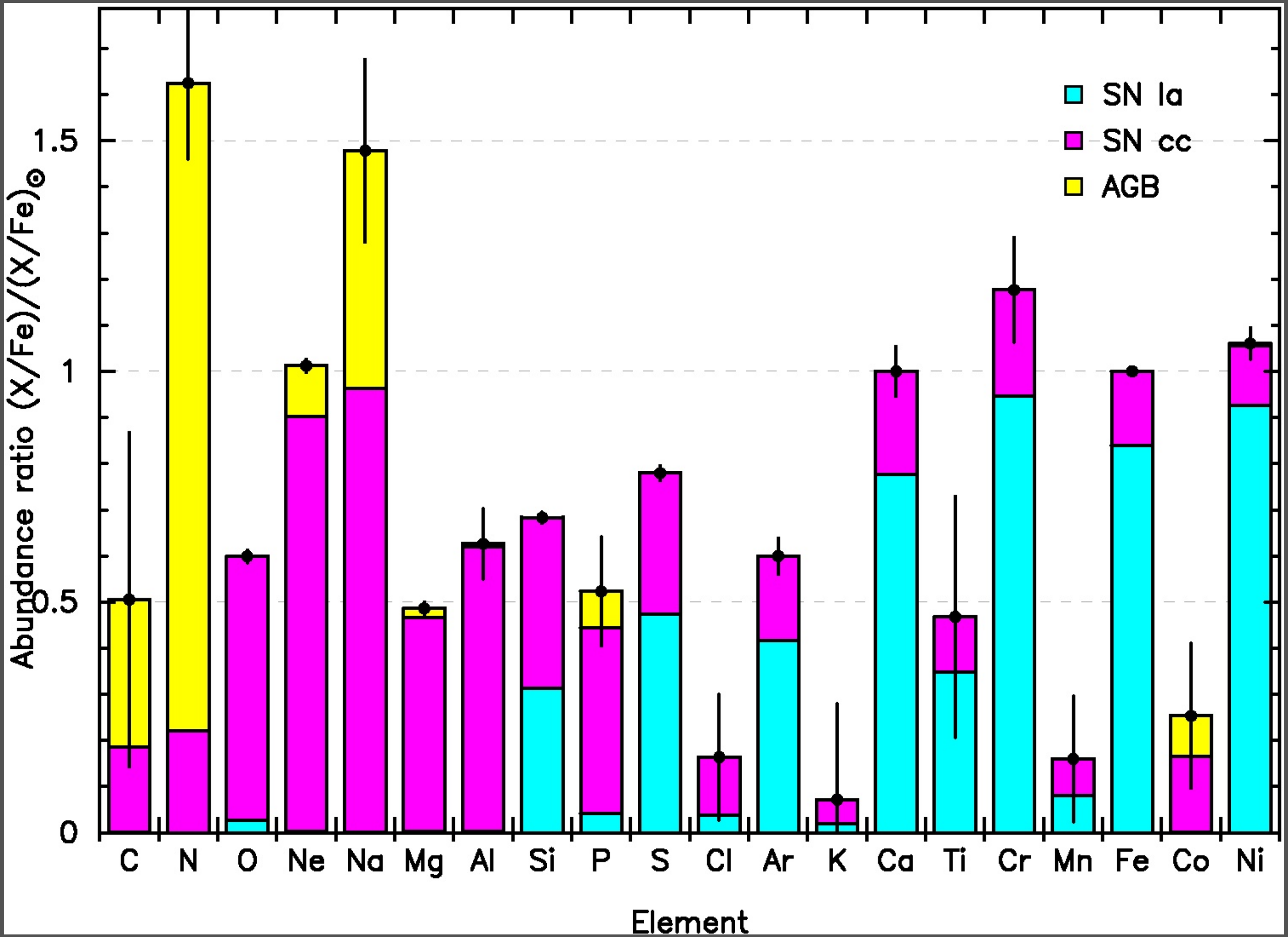
SRON

Mn/Cr as tracer of SNIa progenitor metallicity

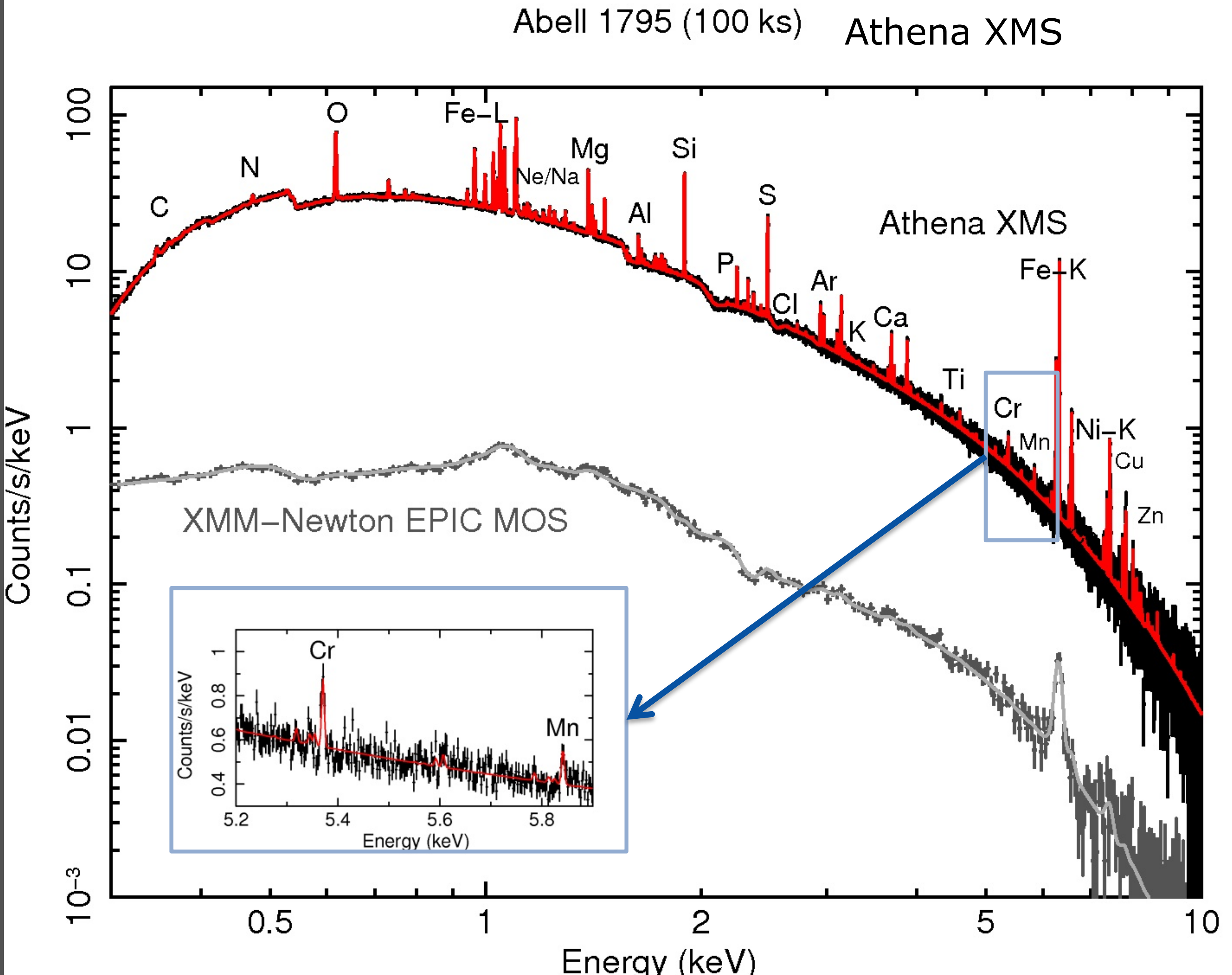


Badenes et al., 2008

Astro-H simulation 100 ks typical cluster



SRON


Abell 1795 (100 ks)
Athena XMS
Athena XMS
XMM–Newton EPIC MOS
Counts/s/keV
Energy (keV)
C
N
O
Fe–L
Ne/Na
Mg
Al
Si
P
S
Cl
Ar
K
Ca
Ti
Cr
Mn
Fe–K
Ni–K
Cu
Zn
100
10
1
0.1
0.01
10^{-3}
0.5
1
2
5
10
Cr
Mn
Counts/s/keV
1
0.8
0.6
0.4
5.2
5.4
5.6
5.8
Energy (keV)

SRON

Conclusions

- The cluster ICM contains clues about its chemical history
- Supernova type Ia models and IMFs can be tested/fitted

- Current measurements limited by:
  - Statistics, spectral resolution and systematic effects
  - Systematic errors are estimated to be <20-30%, but enough to constrain SNIa models

- Future work to improve results:
  - Improve atomic databases (investment!)
  - New instruments with high spectral resolution (Astro-H)

SRON