The chemical evolution of clusters of galaxies

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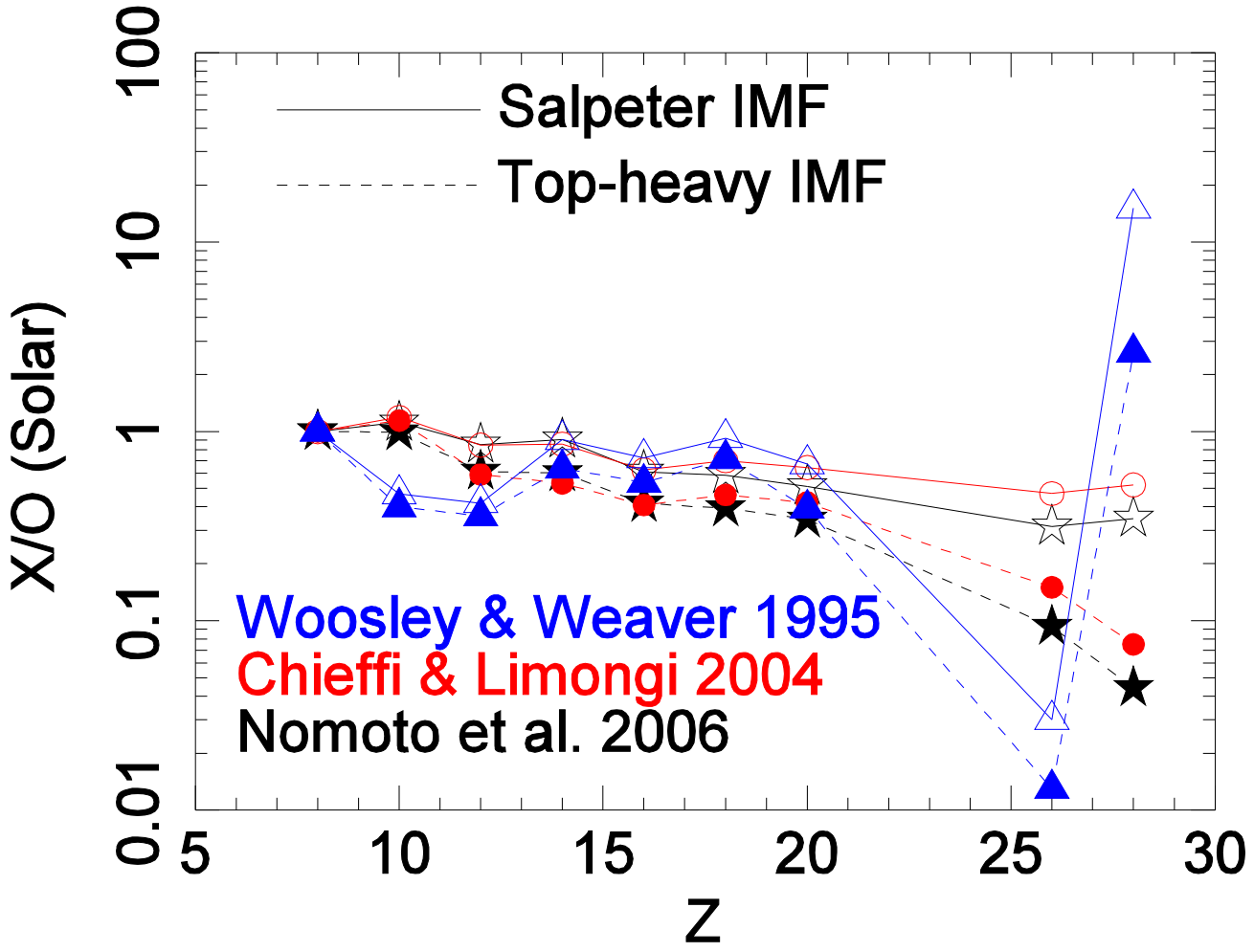
Importance clusters of galaxies for abundance studies

- Largest bound structures
- Fair samples of the Universe
- Deep potential wells, retains most of the gas
- Hot gas: no significant “hiding” of metals in dust (& more gas than stars)
- Spatial extent allows mapping

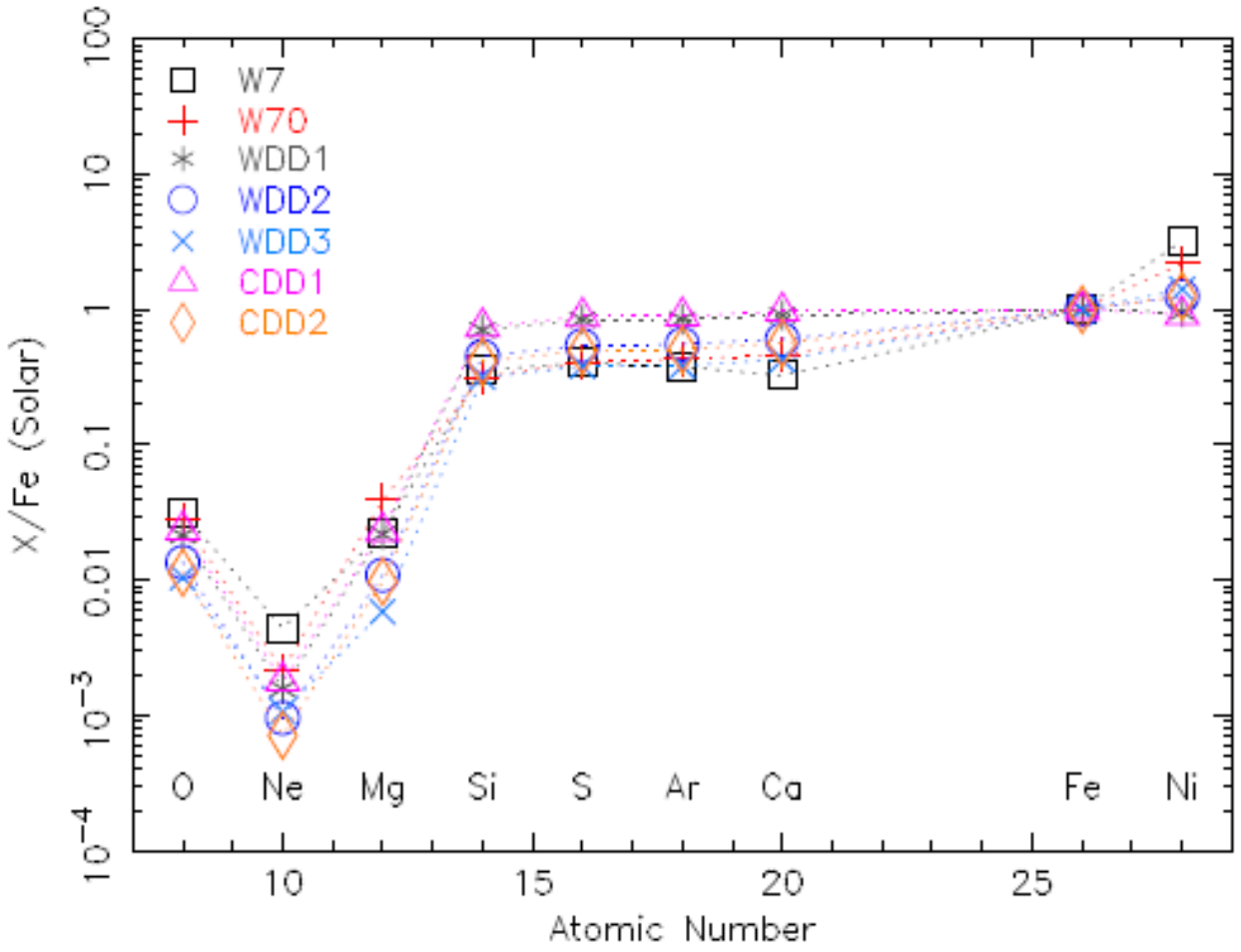
Three main sources metals

- Core collapse Supernovae: massive progenitors, produce relatively much α-elements (like O, Ne, Mg, Si, …)
- Type Ia Supernovae: older progenitors, produce much Fe-group elements
- Low & intermediate mass AGB stars: predominantly C, N, O

Supernova yields: core collapse

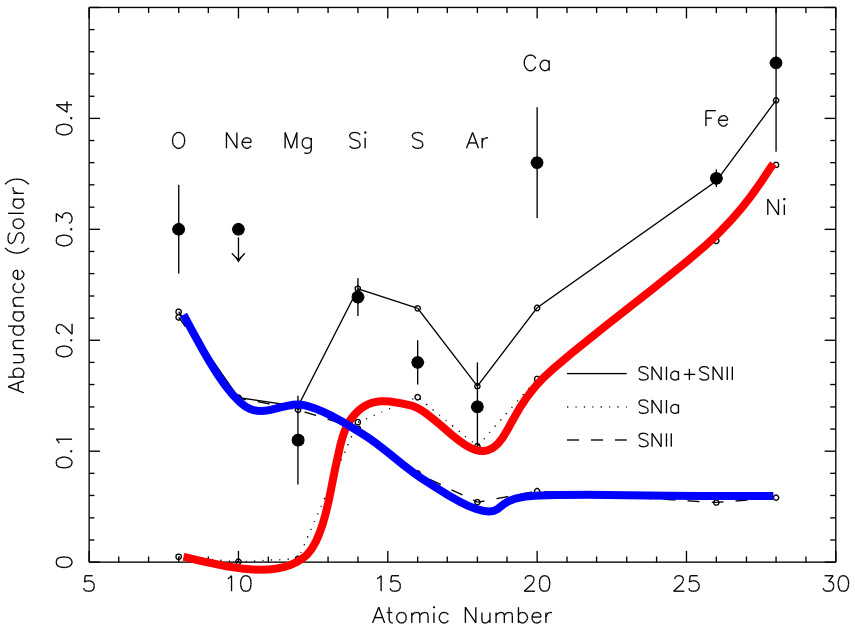


Supernova yields: Ia



Decomposing abundances into SN types
(De Plaa et al. 2006)

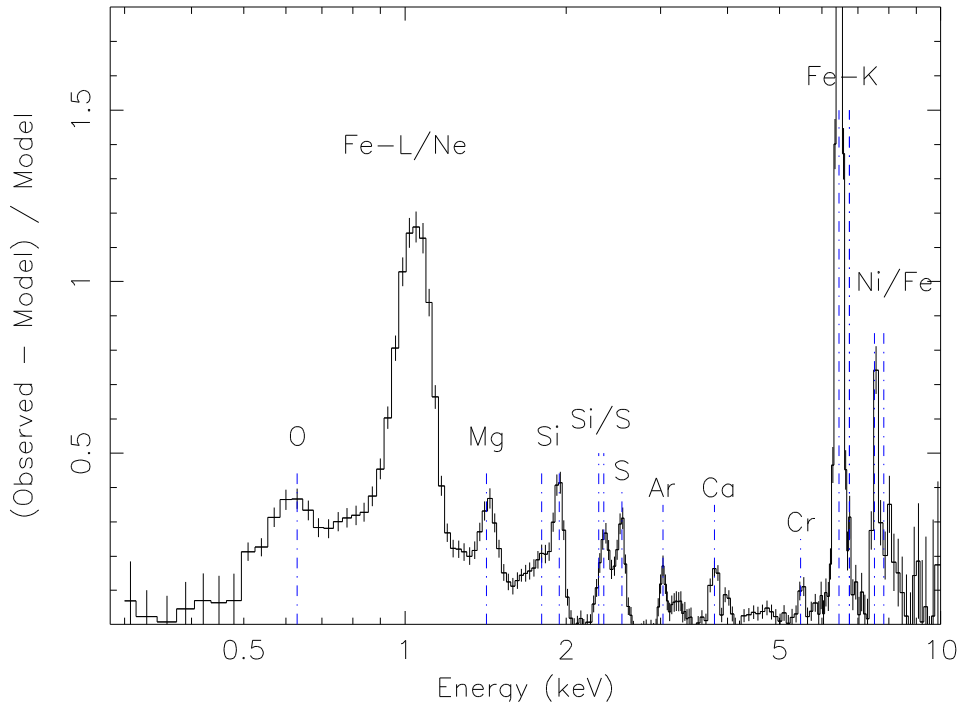
- Deep exposure XMM-Newton Sérsic 159-3
- Data include RGS
- ~50 % SN Ia by number
- Ca problem



Another case: 2A 0335+096

(Werner et al. 2006)

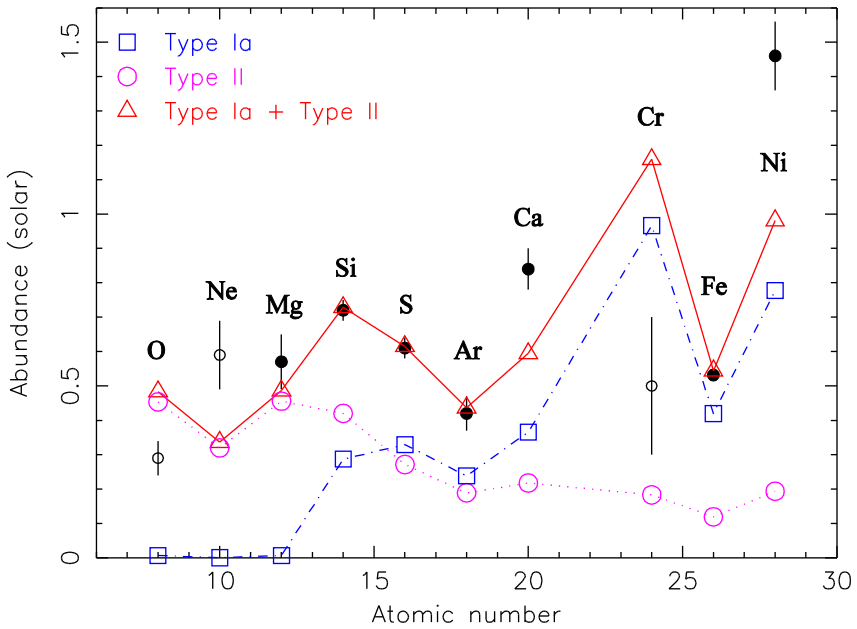
- Current best case: deep XMM-Newton observation of one of brightest clusters
- First evidence of traces of Cr (0.5±0.2 Solar)



2A 0335+096, Werner et al. 2005

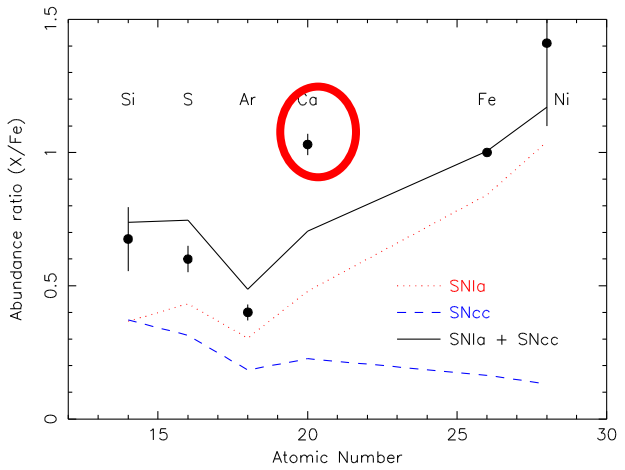
Decomposing 2A 0335+096
(Werner et al. 2006)

- Central 3 arcmin:
- Sn Ia: 25 %
- Also here Ca problem

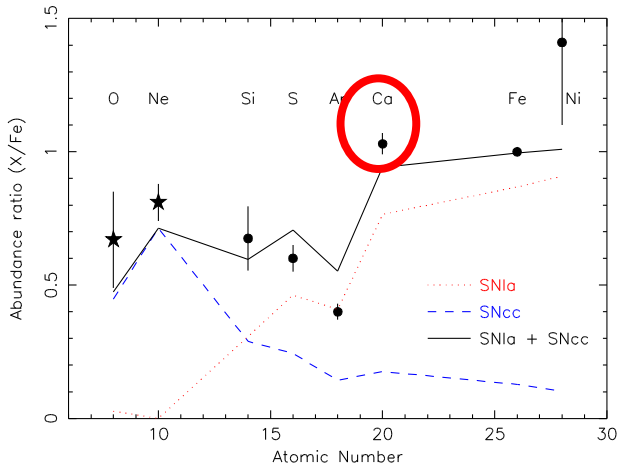


Solution to the Ca problem
(De Plaa et al. 2007)

- Also sample 22 clusters shows Ca excess
- Solution: adop SN Ia yields based on Tycho SNR (Badenes et al. 2006)
- Best fit Ia/(Ia+cc) number ratio: 0.44±0.05



WDD



Tycho

CNO abundances

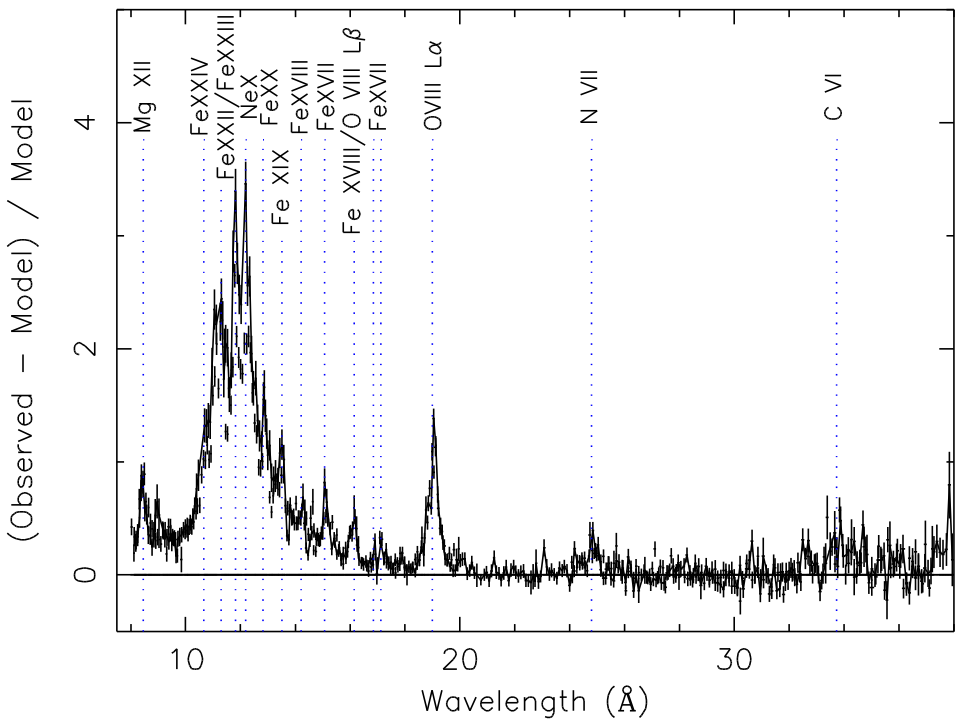
- XMM-Newton RGS currently the best for moderately extended sources, like cooling cores of clusters
- Currently only instrument capable measuring C & N
- Only few deep exposures available

RGS results: M 87
(Werner et al. 2006)

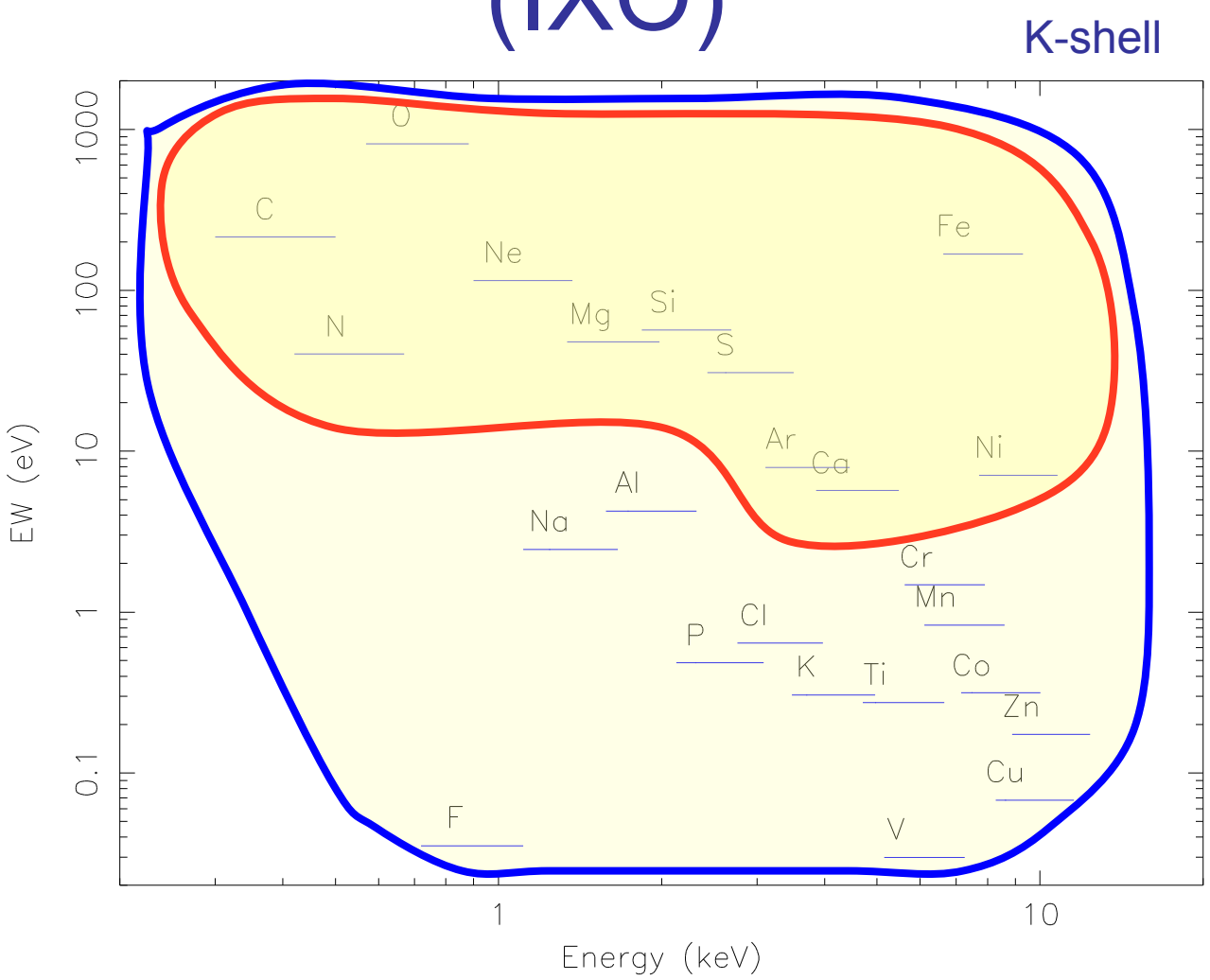
- Exposure time: 169 ks
- Lines from O, N, & C
- C/Fe: 0.74±0.13
- N/Fe: 1.62±0.21
- O/Fe: 0.59±0.04
- Ne/Fe: 1.25±0.12
- Mg/Fe: 0.60±0.06
- Fe: 1.06±0.03

✂ ➔ AGB winds for CN!

Continuum-subtracted RGS spectrum

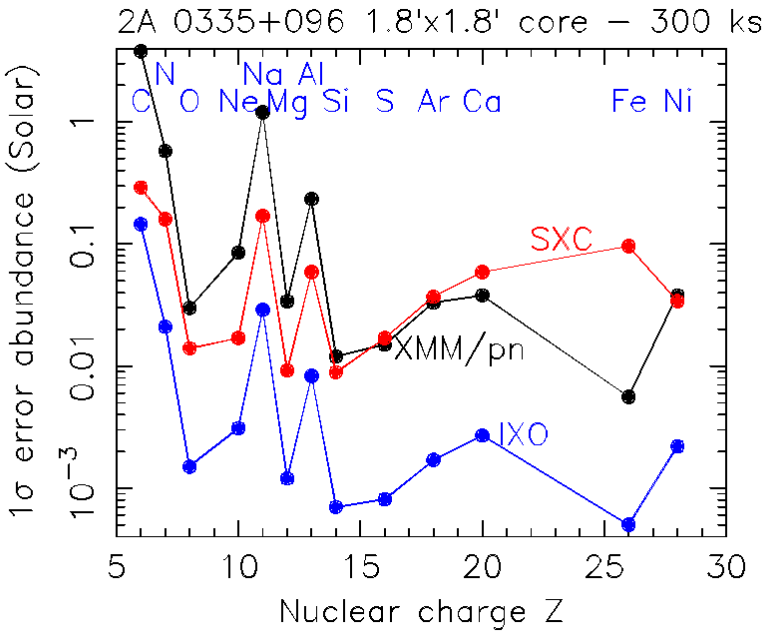


Which elements will we see? (IXO)



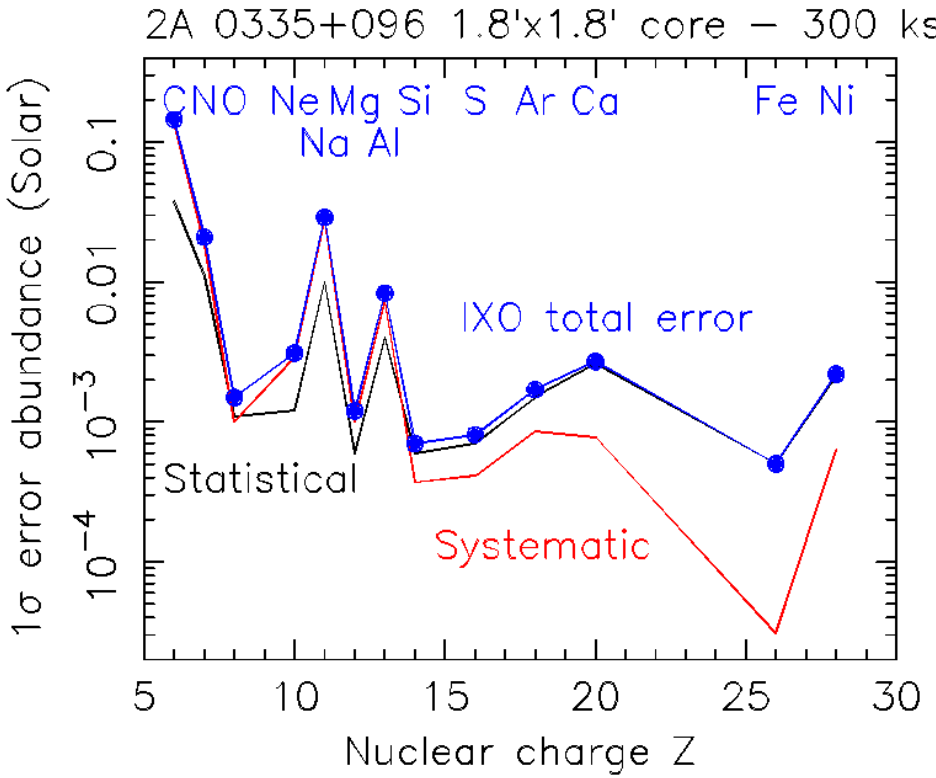
What can IXO do for you?

- Test: compare 300 ks simulations of 2A0335+096 (T~3 keV, z=0.035, cooling core, N_H~3x10^{21})
- Consider 1.8x1.8 arcmin core
- XMM-pn, SXC, IXO (TES array)



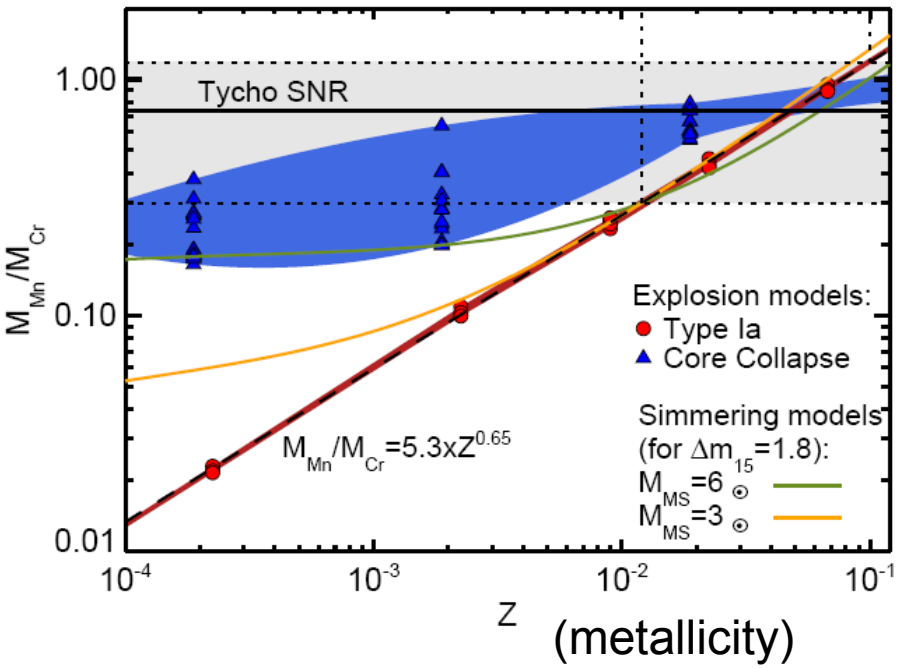
How accurate can we get?

- There is a limit to enhancing exposure time (or eff area)
- Systematic eff. Area uncertainties of 0.5 % per FWHM may exist
  ➔ limiting accuracy for weaker lines



Age diagnostics: Mn/Cr

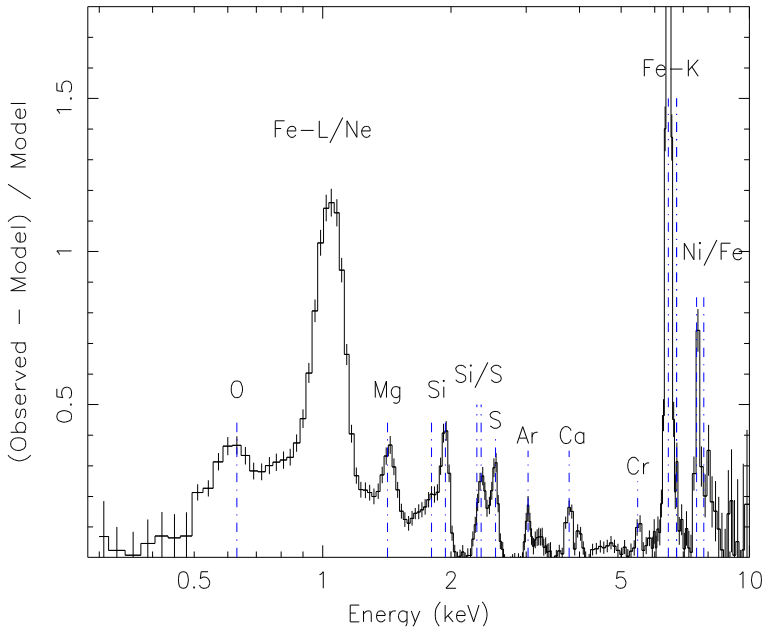
- For type Ia remnants, Mn/Cr ratio strong function of metallicity (Badenes et al. 2008)
- Mn/Cr➔metallicity➔ age progenitor



Badenes et al. 2008

Mn/Cr ratio applied to clusters

- With EPIC, Cr & Mn few % above continuum ("*weak*" lines); 5-7x weaker than Ca or Ni lines
- IXO/TES-array ~50x better ΔE ➔ Cr-K and Mn-K lines few x continuum level ("*strong*" lines)
- IXO 300 ks obs 2A0335+096: abundance Cr & Mn better than 0.005 x Solar for 2x2 arcmin region➔ average age type Ia SN accurately determined

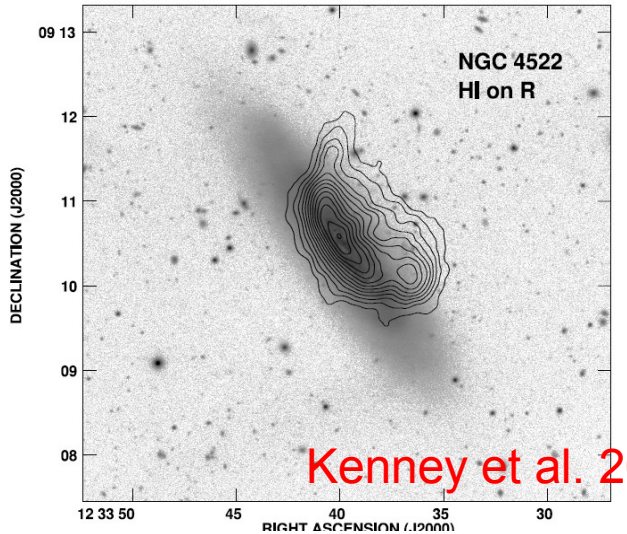


2A 0335+096, XMM-Newton

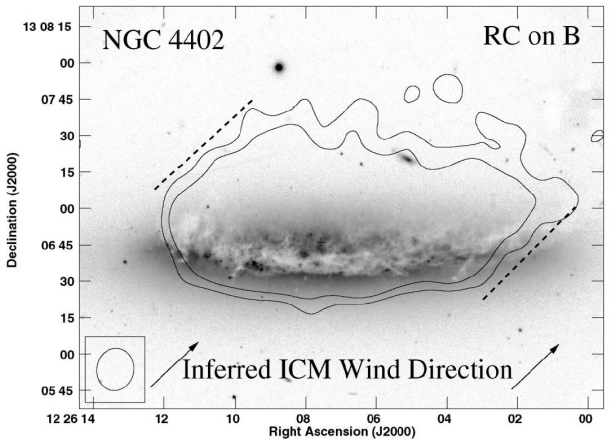
(Werner et al.)

Spatially resolved spectroscopy: why?

- Study enrichment processes in situ, for instance ram pressure stripping
- Needs high accuracy abundances (for differential maps) with ~10” resolution
- 2’/10=10”; stat error in each 10x10”pix 10% of stat error 2x2’region



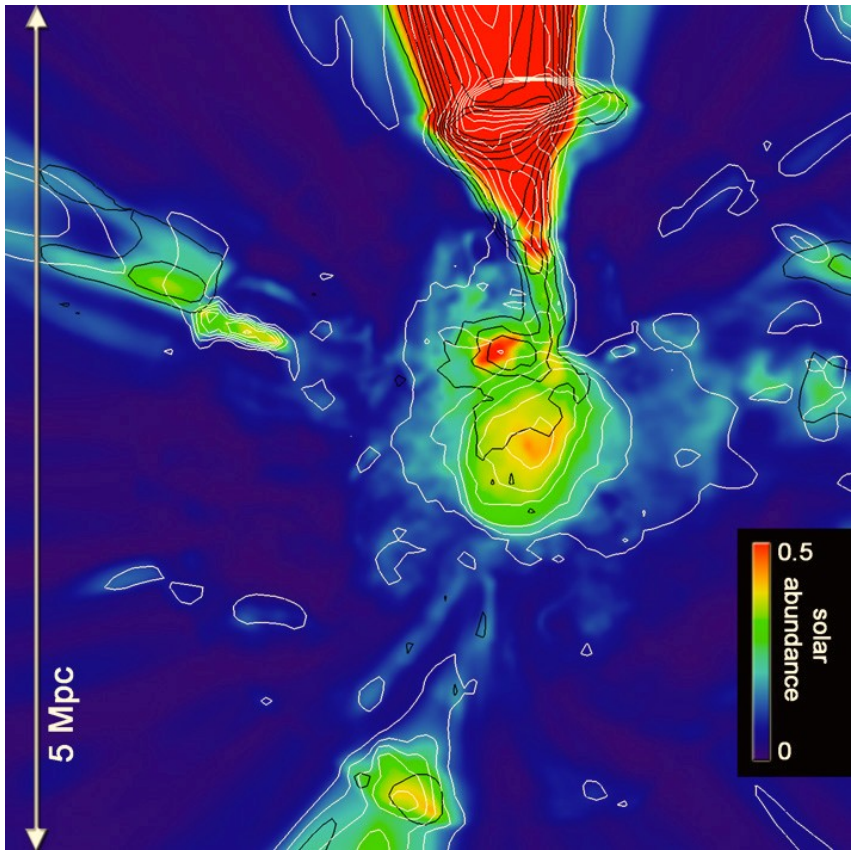
Kenney et al. 2004



Crowl et al. 2005

Spatially resolved spectroscopy: why? (II)

- Enrichment inhomogeneous
- In particular important to study *simultaneous with dynamics* (➔ high spectral resolution, Doppler shifts, sufficient spatial resolution)

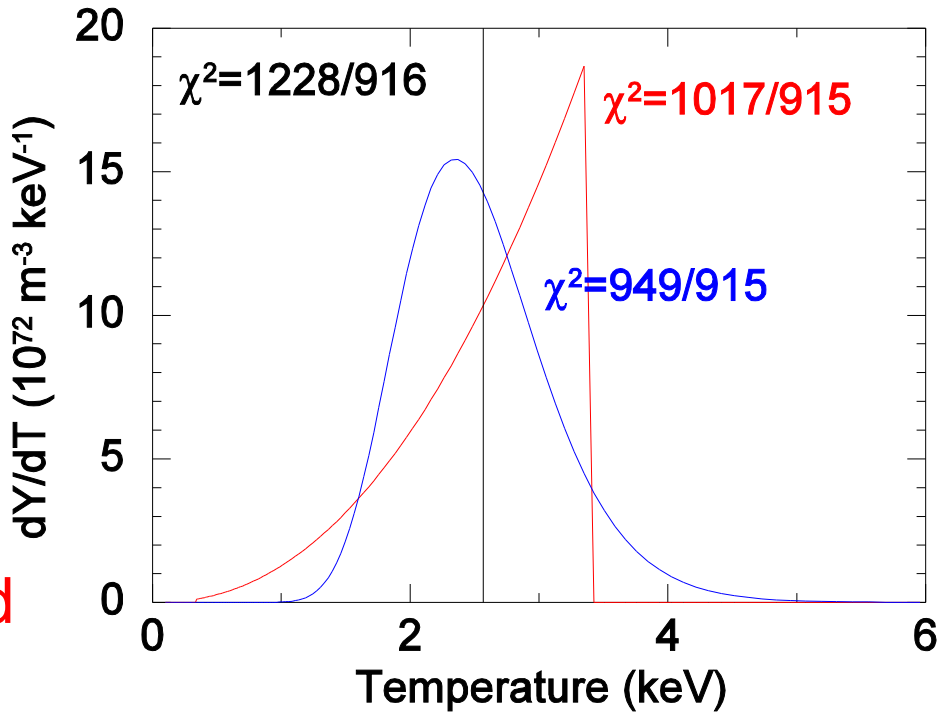


Kapferer et al. 2007

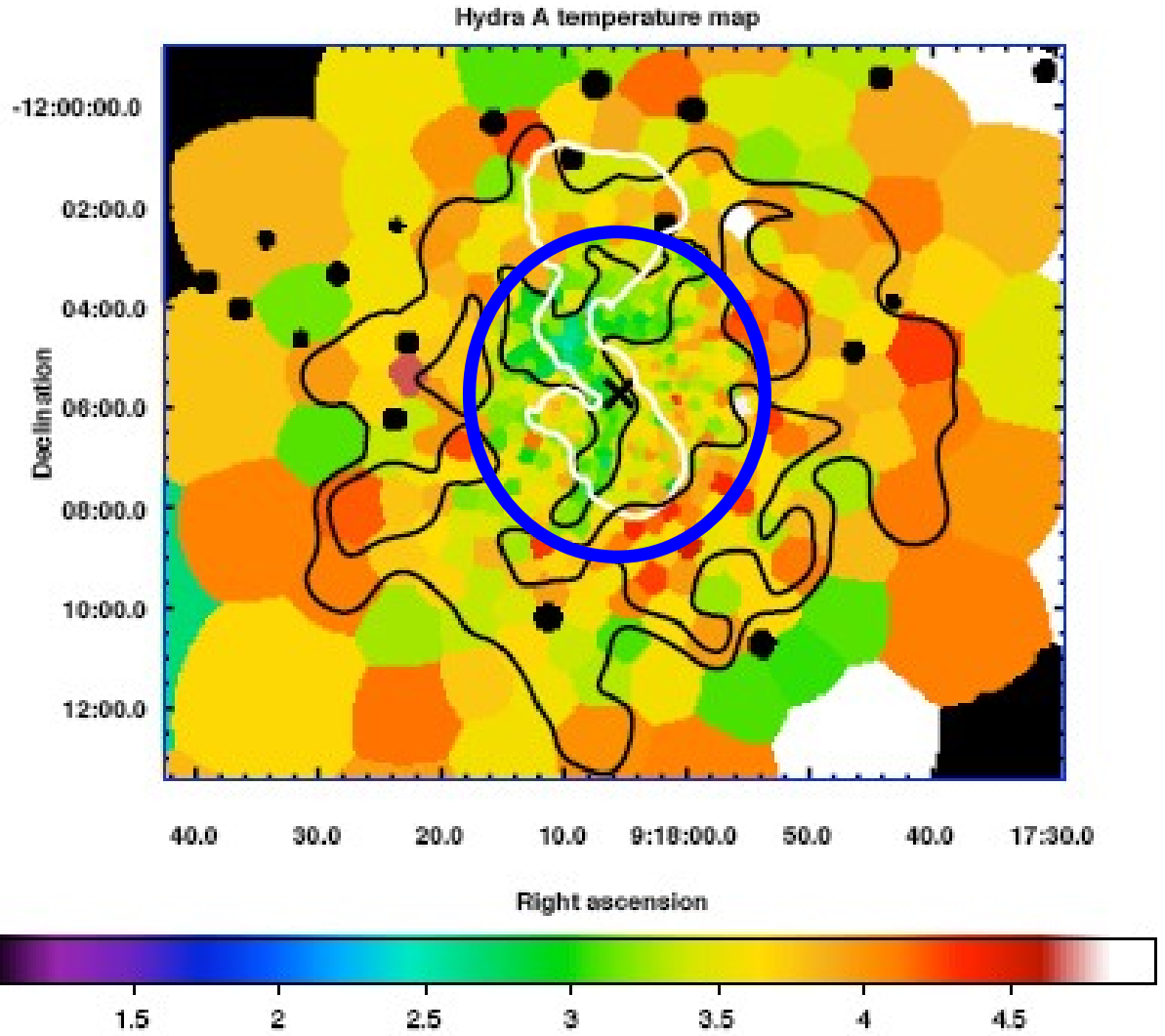
A caveat: need for high quality data

(de Plaa et al. 2006)

- Sérsic 159-3, central 4', deep XMM-Newton obs.
- Better fits
  1T➔wdem➔gdem
- *Implication for Fe:*
  0.36➔0.35➔0.24
- *Implication for O:*
  0.36➔0.30➔0.19
- High quality spectra needed for each spatial bin also for IXO!



Temperature maps
(Hydra A, Simionescu et al. 2008)



Conclusions

- IXO observations of clusters of galaxies can disentangle contributions different SN types and AGB stars in clusters of galaxies
- Need full area, FOV, spatial & spectral resolution even for nearby clusters