High-resolution X-ray spectroscopy: the coming-of-age

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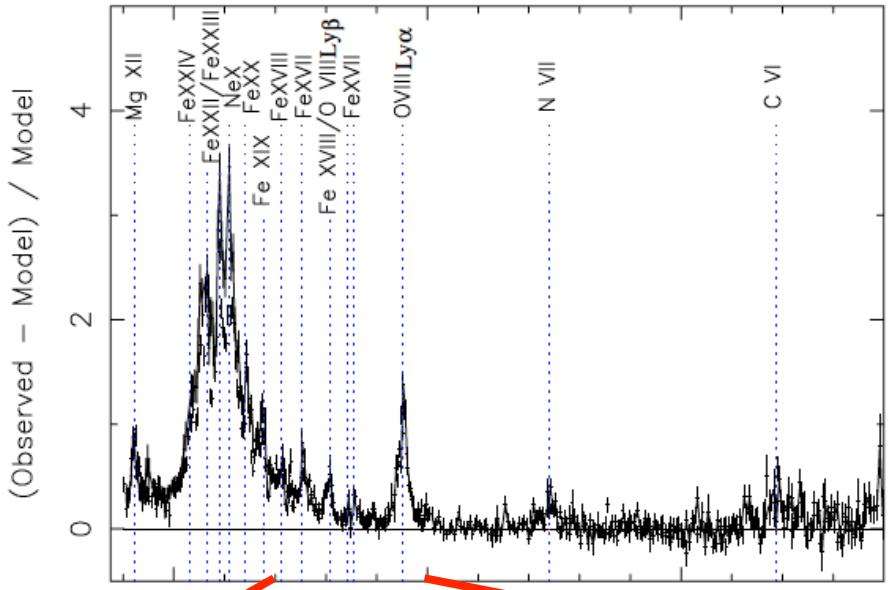
XMM-Newton now

Present-day X-ray instruments

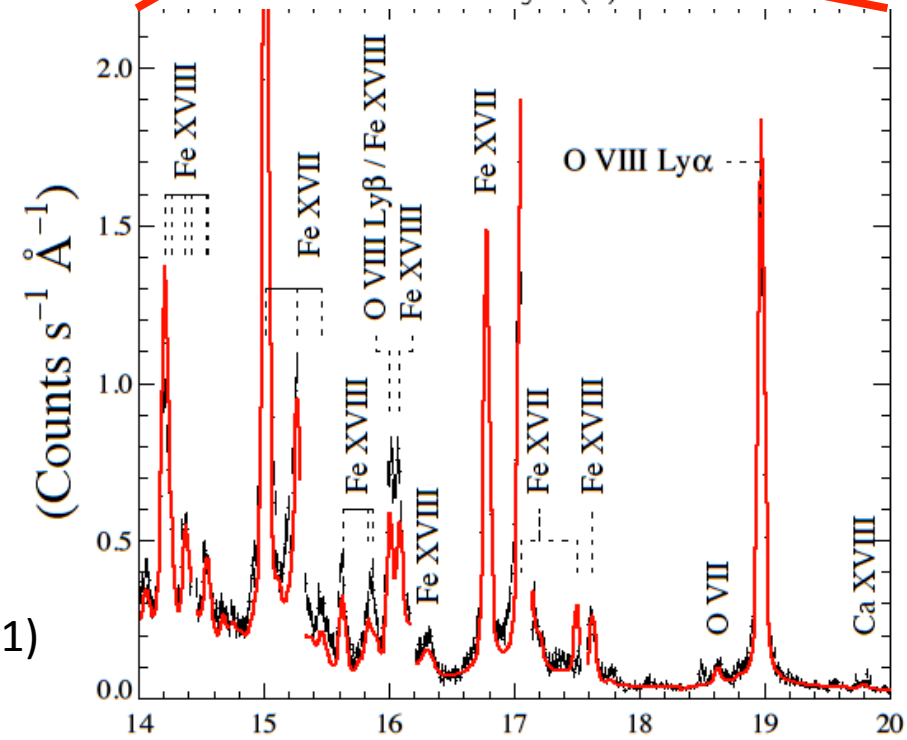
- *High throughput* but medium/*low spectral resolution*: CCD cameras (e.g. on XMM-Newton & Chandra)
- *Low throughput* but *high spectral resolution*: grating spectrometers (e.g. on XMM-Newton & Chandra)
- Grating spectrometers *only for point sources* (or for XMM-RGS for sizes < few arcmin)

Gratings & point sources

M 87 (Werner et al. 2006)

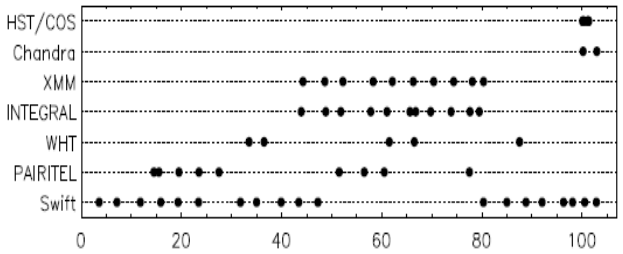


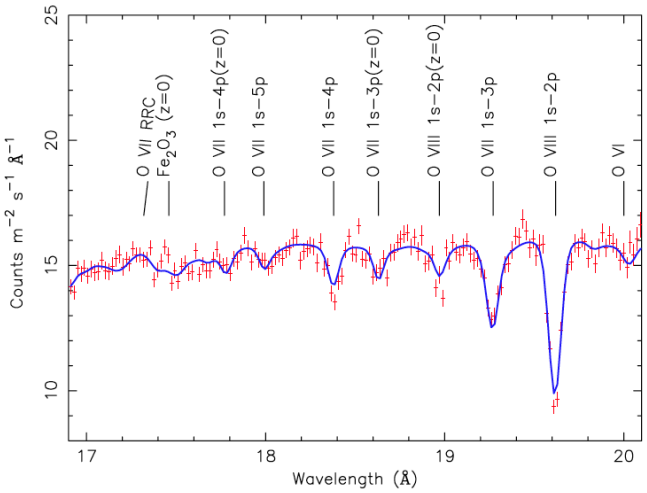
Capella (Audard et al. 2001)

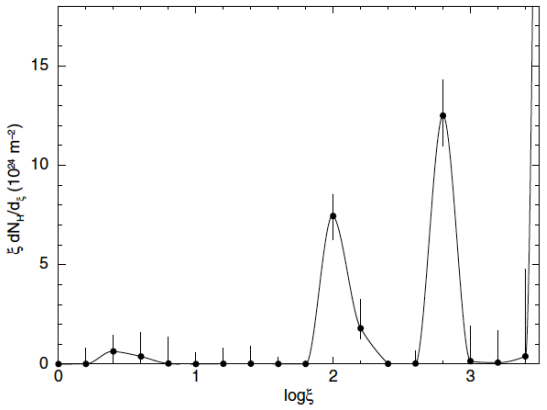


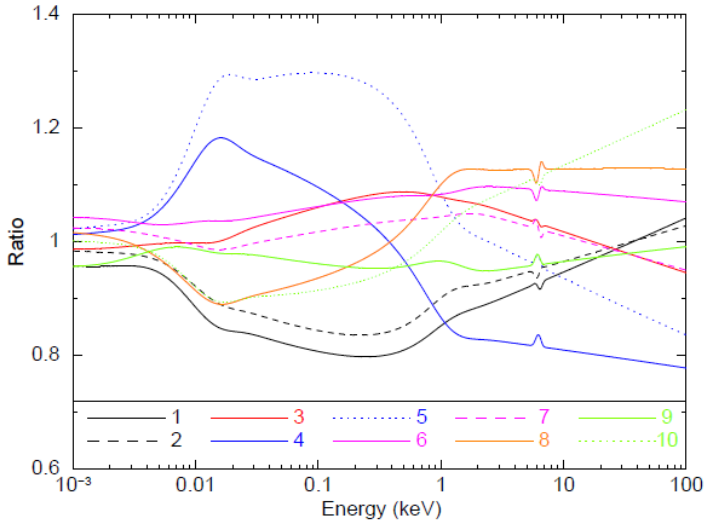
AGN monitoring campaigns

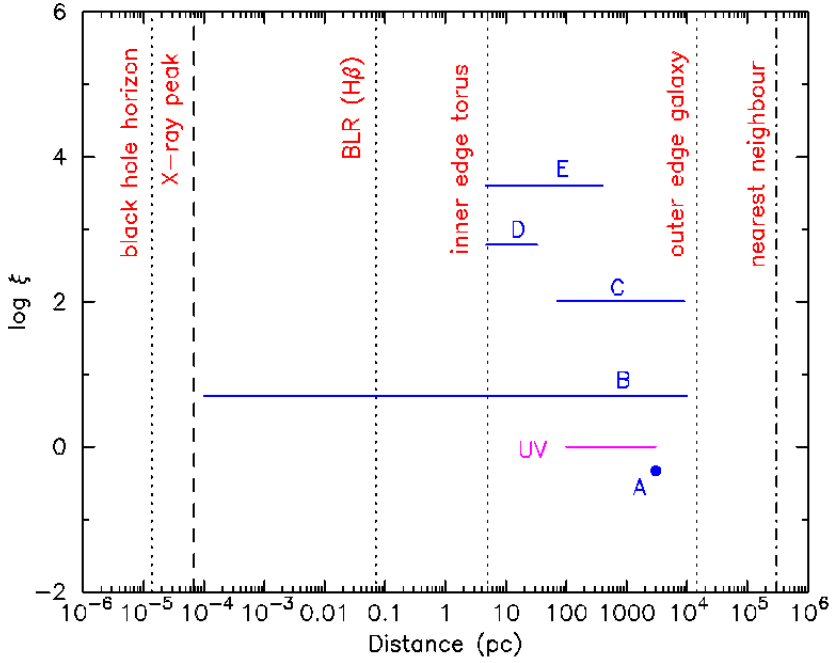
Example: Mrk 509 campaign
Total 600 ks XMM ➔ 15 refereed papers, 300 citations



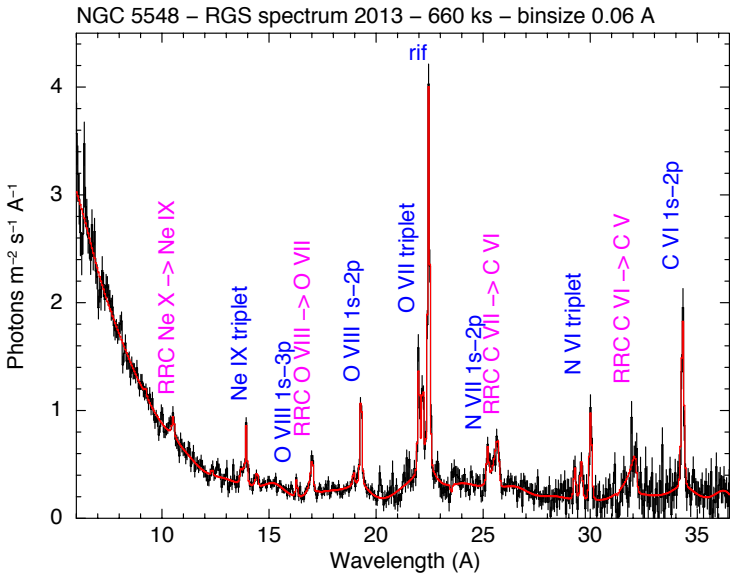


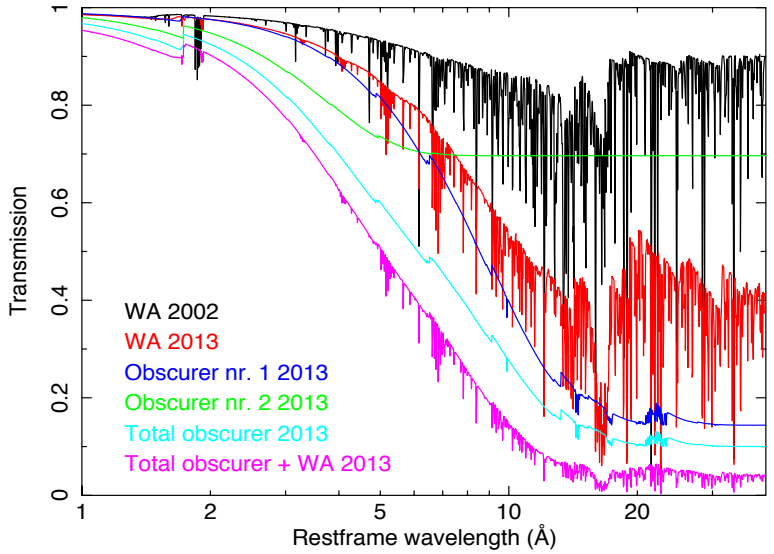


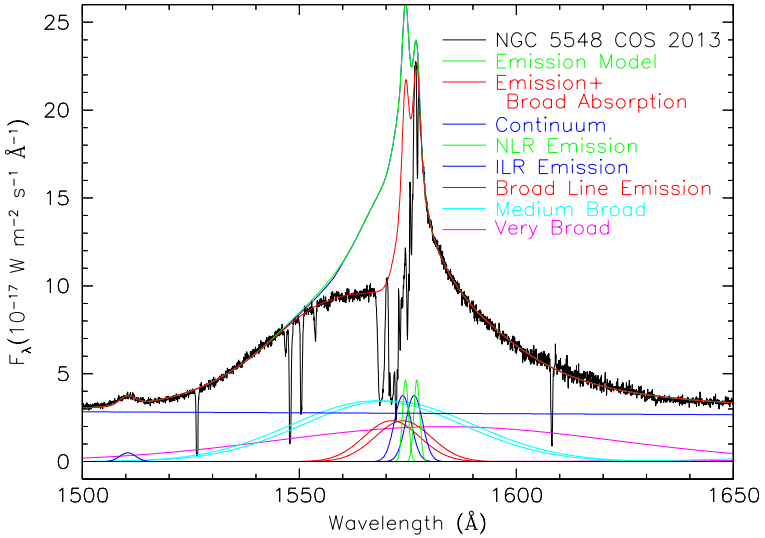


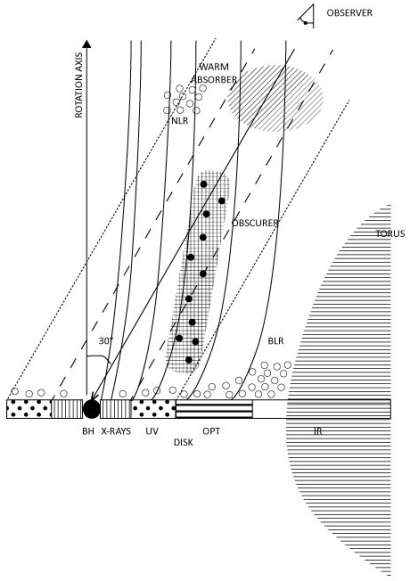


AGN monitoring campaigns: NGC 5548







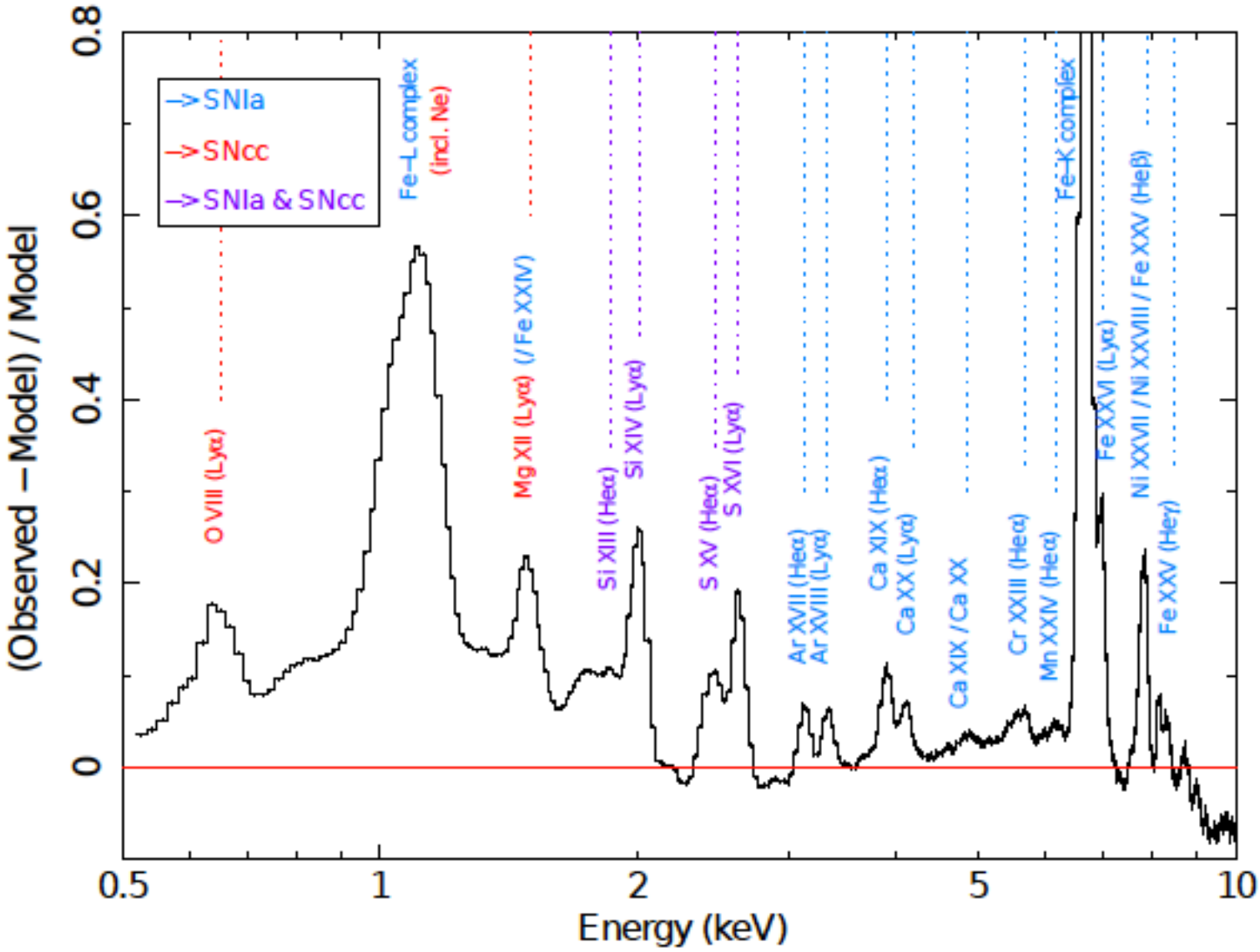


Stacked cluster spectra

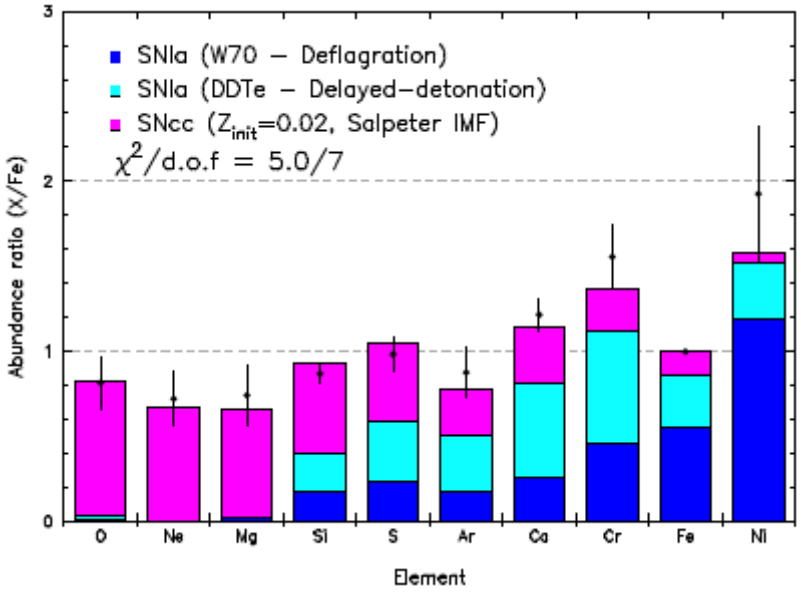
44 clusters, 4.5 Ms exposure

Best fit continua subtracted, de-redshifted

See poster François Mernier

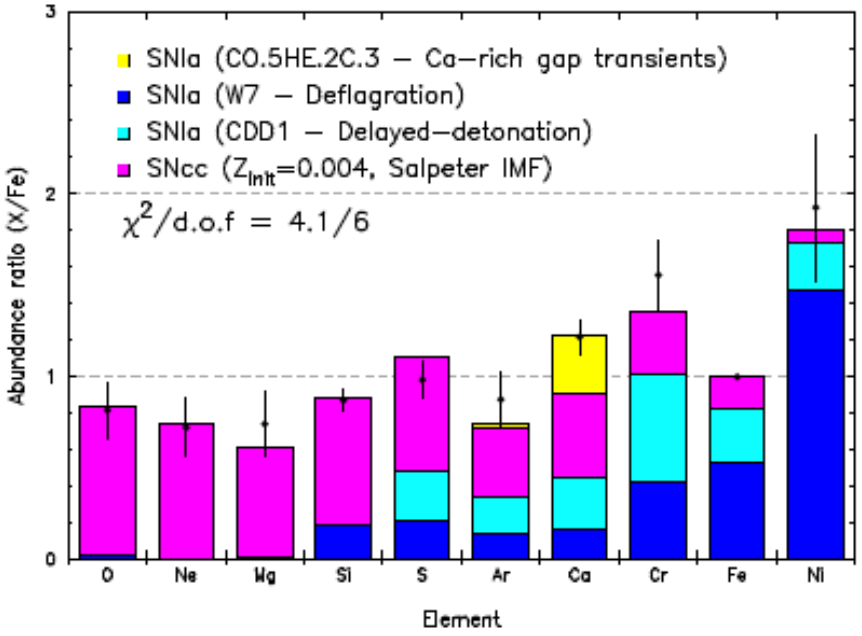


Cosmic chemical evolution



Mernier et al. 2016

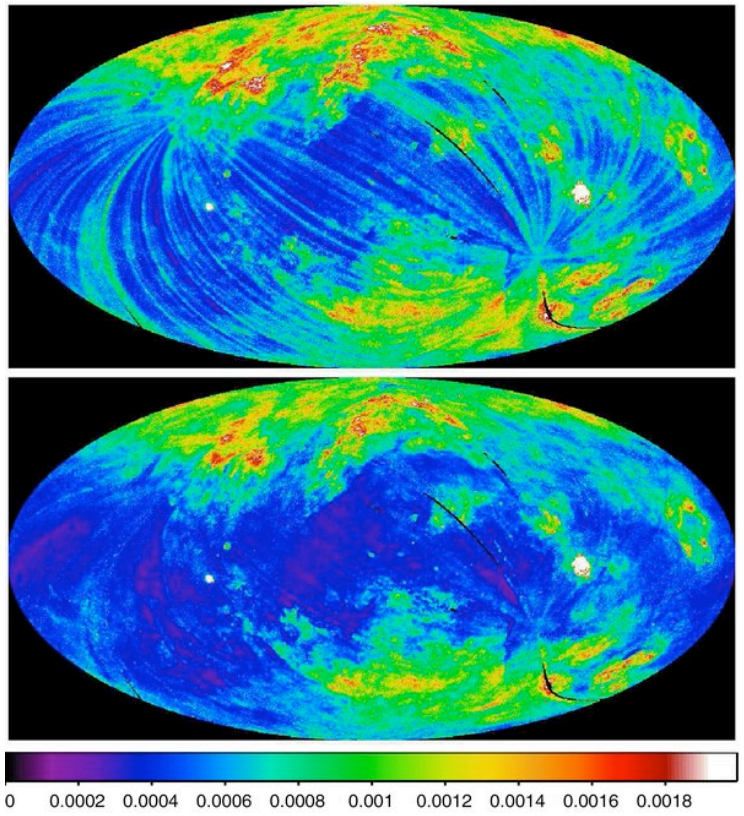
See also poster I02



Charge exchange

(with Liyi Gu)

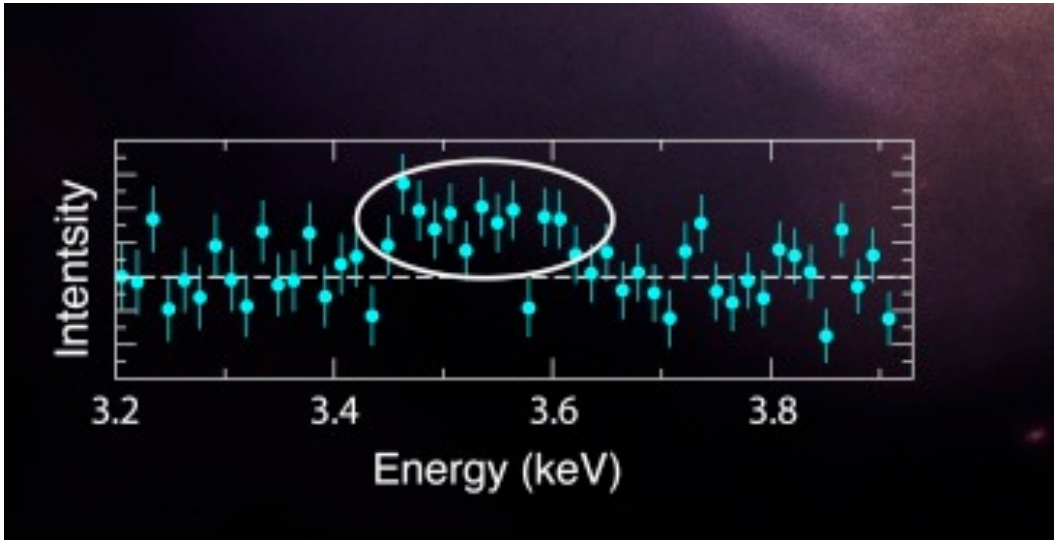
- Rosat ¼ keV band raw image shows *stripes* (upper panel)
- Cause: Solar Wind *Charge Exchange* (wind ions colliding with neutrals)
- Time variability solar wind → time *variable* X-ray background component
- Emission consists of *lines*
- Need *model* for analysis spatially extended sources with Hitomi
- → make model, including many ions (Gu et al. 2016)



Images: Snowden et al.

Sterile neutrino's

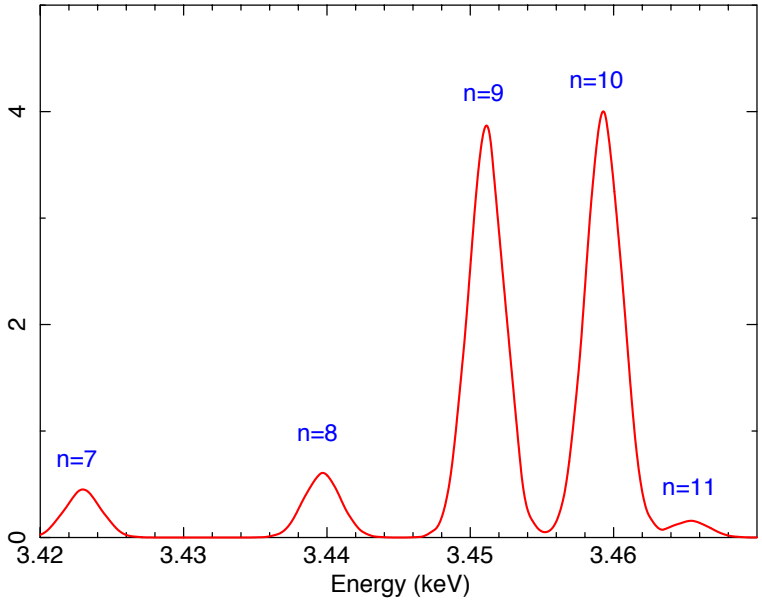
- Bulbul et al. (2014), followed by Boyarski et al. (2014) report 3.5 keV line in cluster spectra, not associated with known atomic line
- Interpreted as possible decay of sterile neutrino's, a dark matter candidate

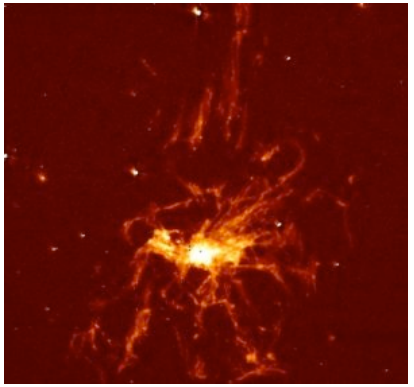


Alternative explanation: charge exchange of S^{16+} with neutral H

(Gu et al. 2015)

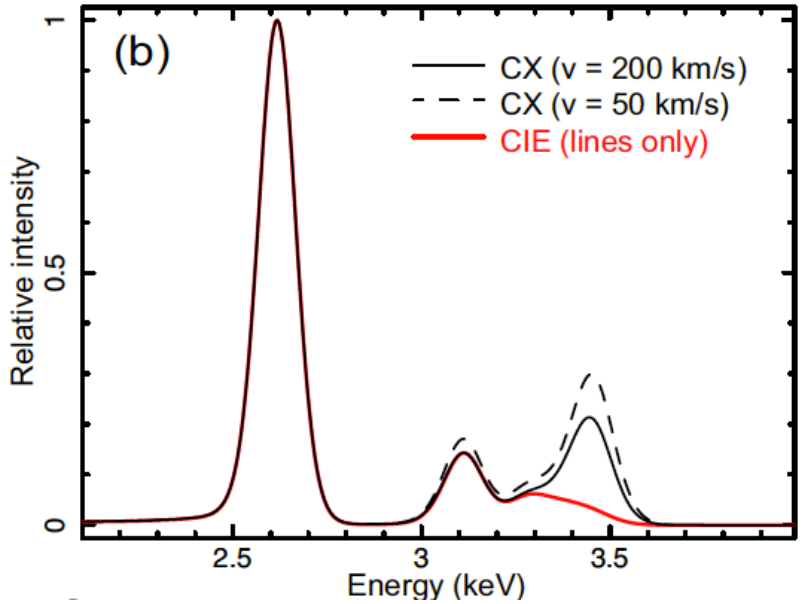
- CX of S^{16+} with H: capture at n=9 and neighbours
- ➔ lines near 3.5 keV, unresolved by CCD, but resolved by calorimeter (8 eV separation, Hitomi…)
- Clusters have both hot gas with S^{16+} and cold gas: measured flux (if real) easy explained

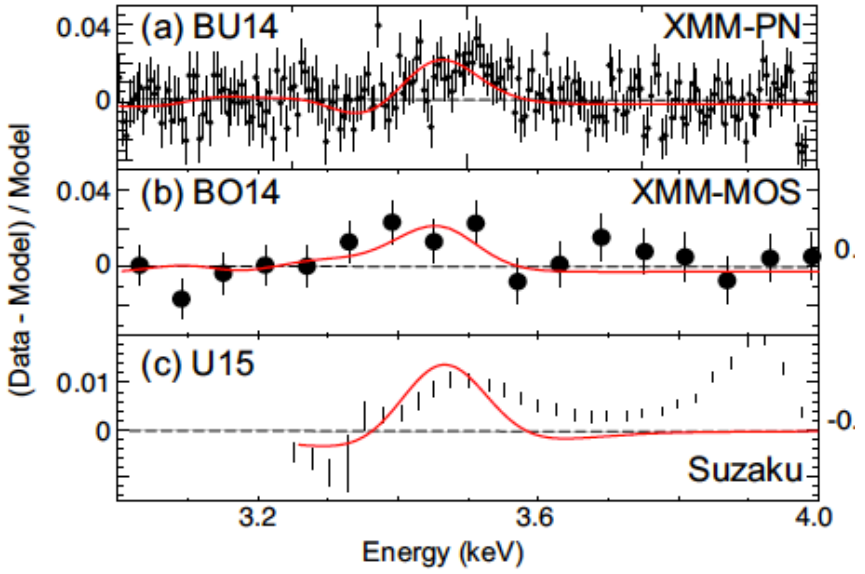




Perseus core in Hα
(from Cambridge X-ray astronomy site)

Consistency CX model with data





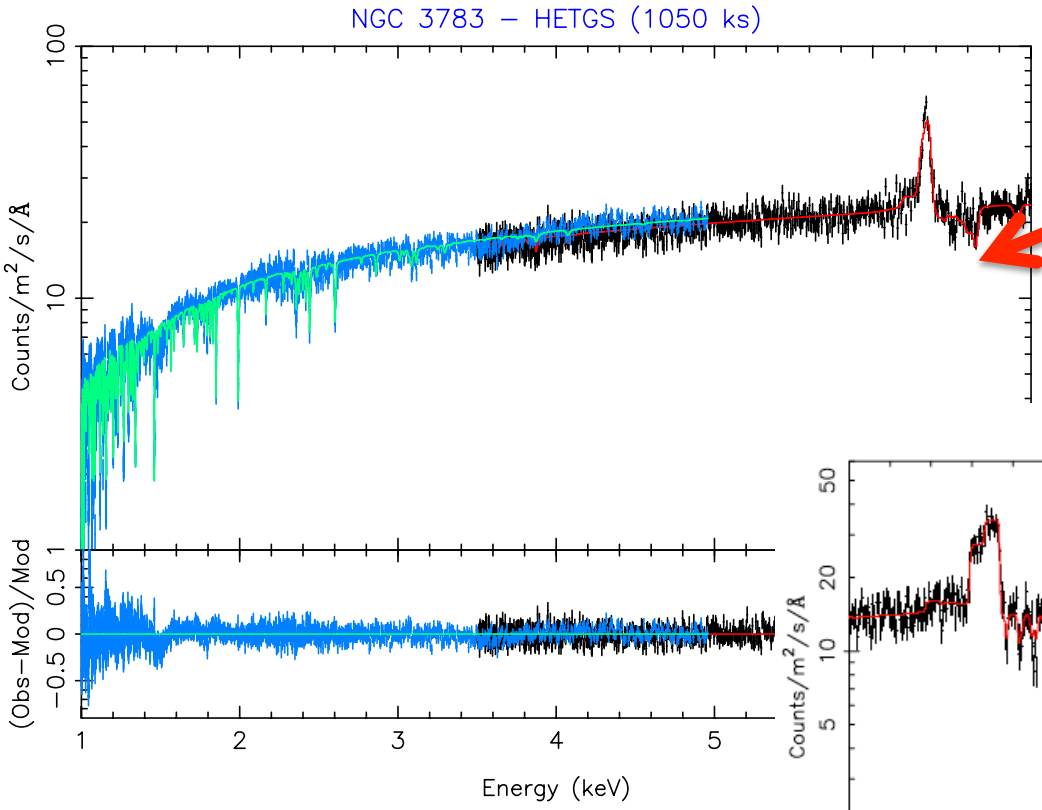
Spectra at CCD resolution

Hitomi

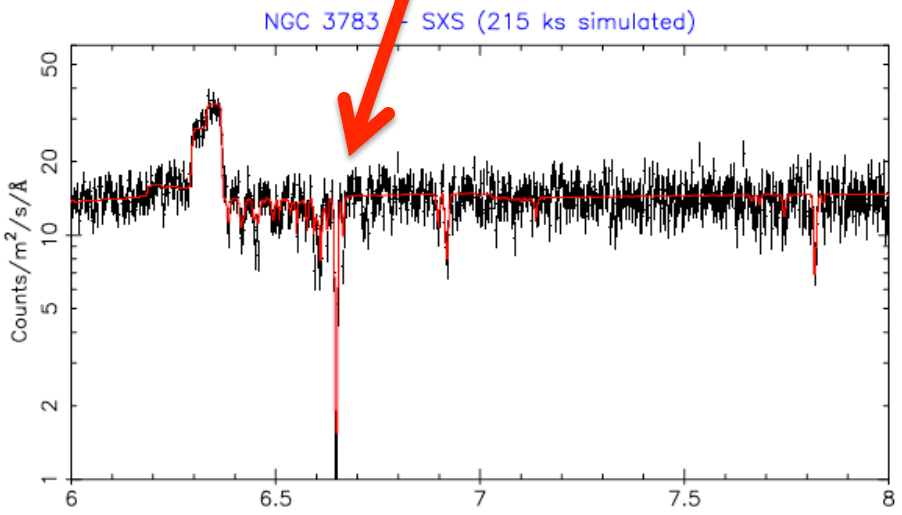
Scientific strengths

- high-resolution spectroscopy of spatially extended sources
- high sensitivity in Fe-K band
- broad-band coverage 0.3 – several 100 keV

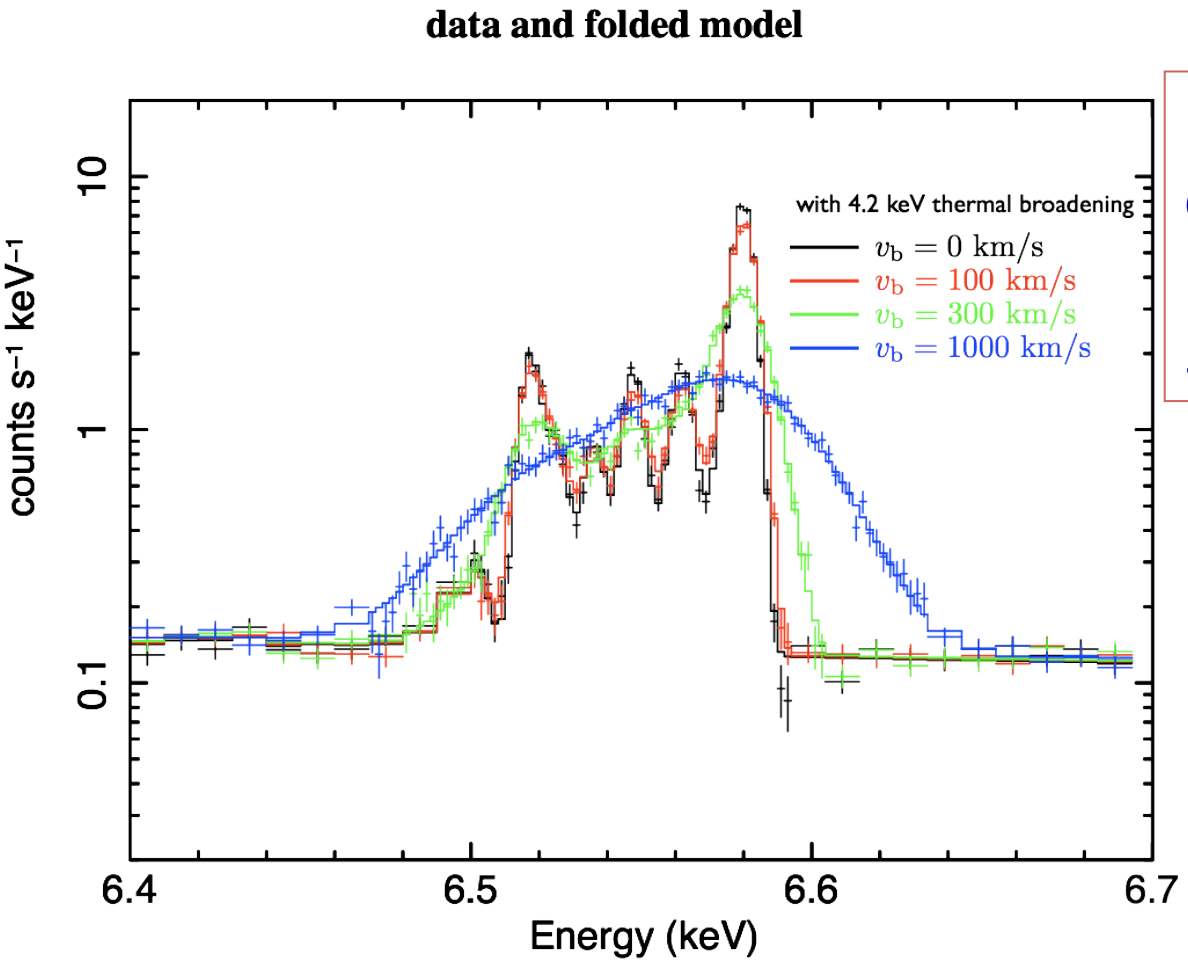
Example: high sensitivity in Fe-K band



Fe XXV absorption line:
Chandra 2-3σ in 1050 ks
SXS 20-30σ in 200 ks

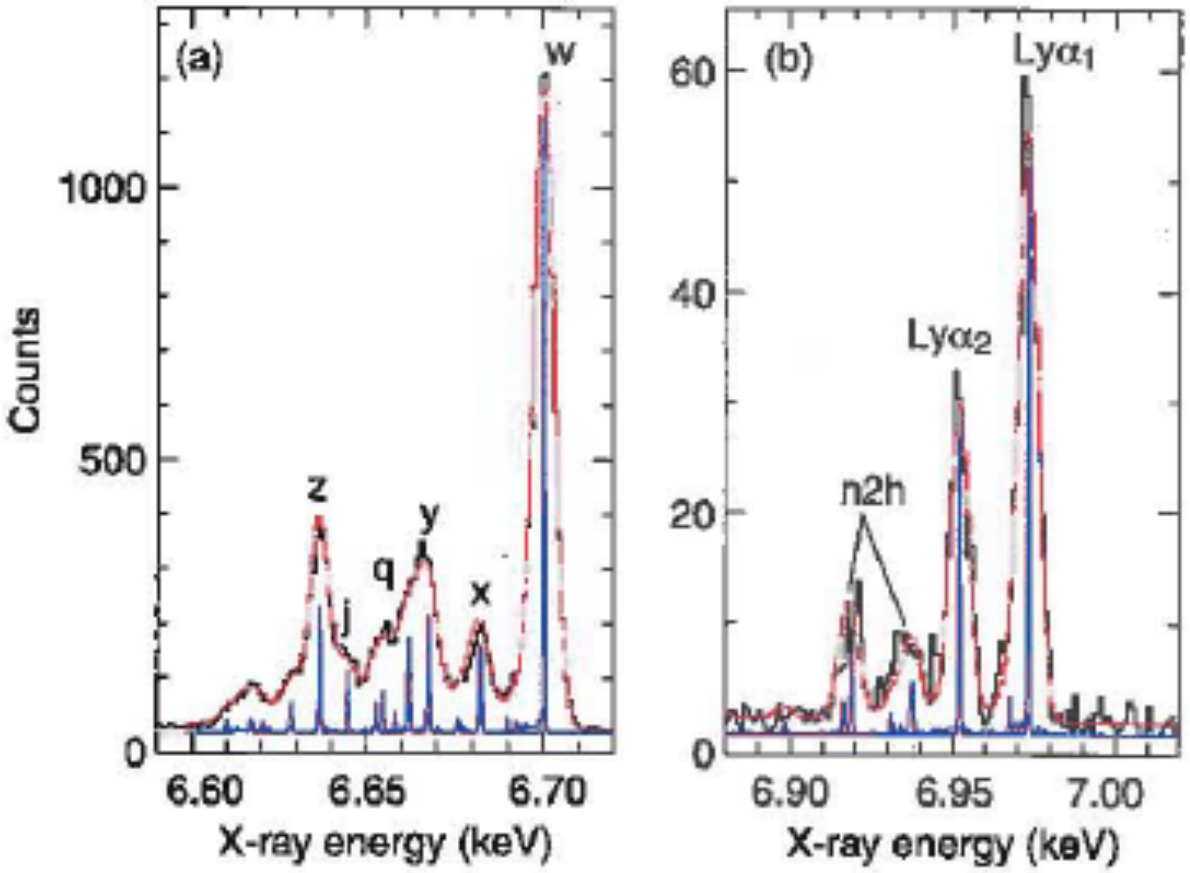


Perseus cluster simulated spectrum:
measuring turbulence



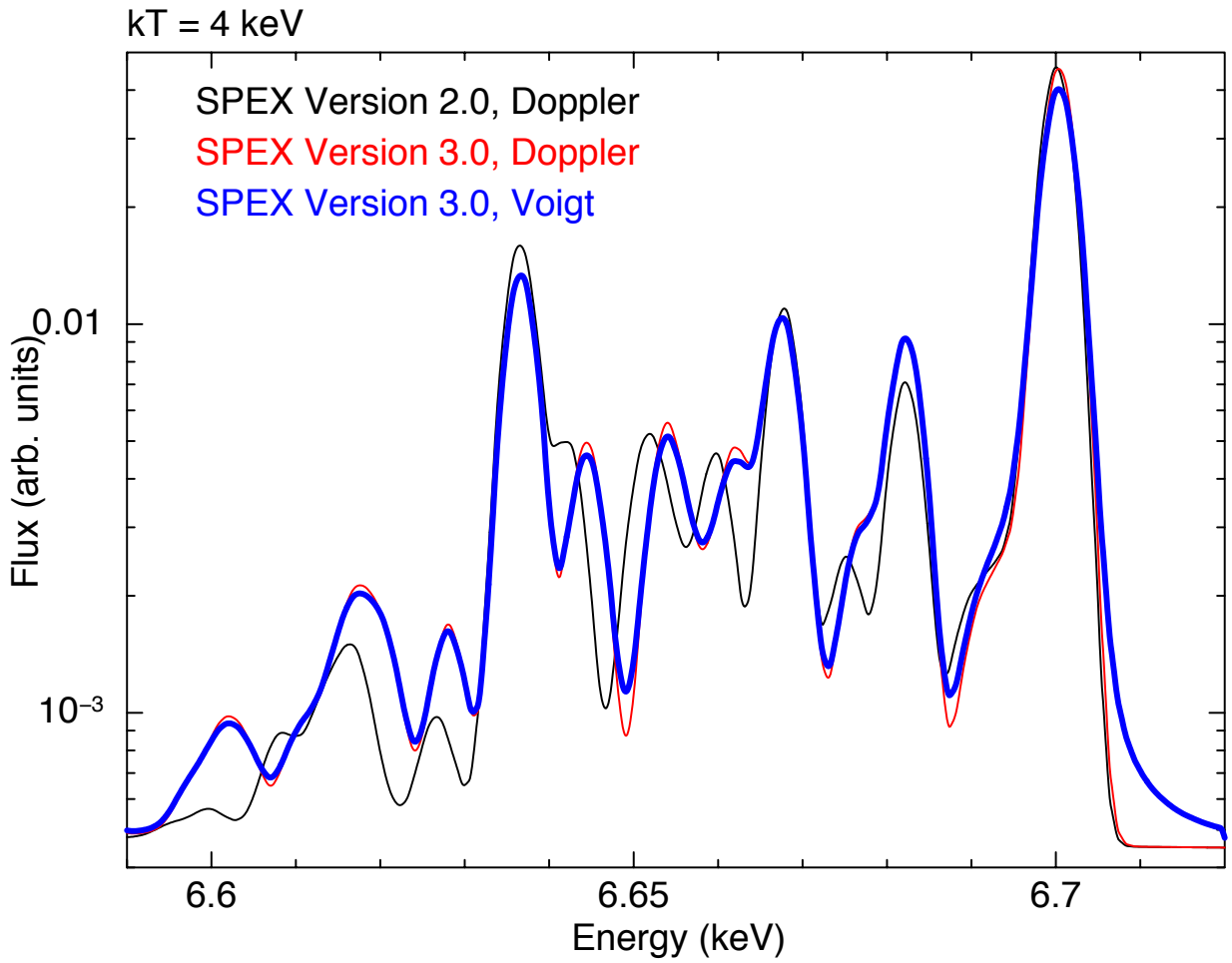
100 ks
central 3'×3'
Perseus cluster
5 eV resolution

Perseus in the lab



- EBIT measurements @ kT=4 keV of Fe-K emission
- M. Gu et al. 2012
- Detector: spare XRS detector Suzaku

Spectroscopic codes



Future prospects

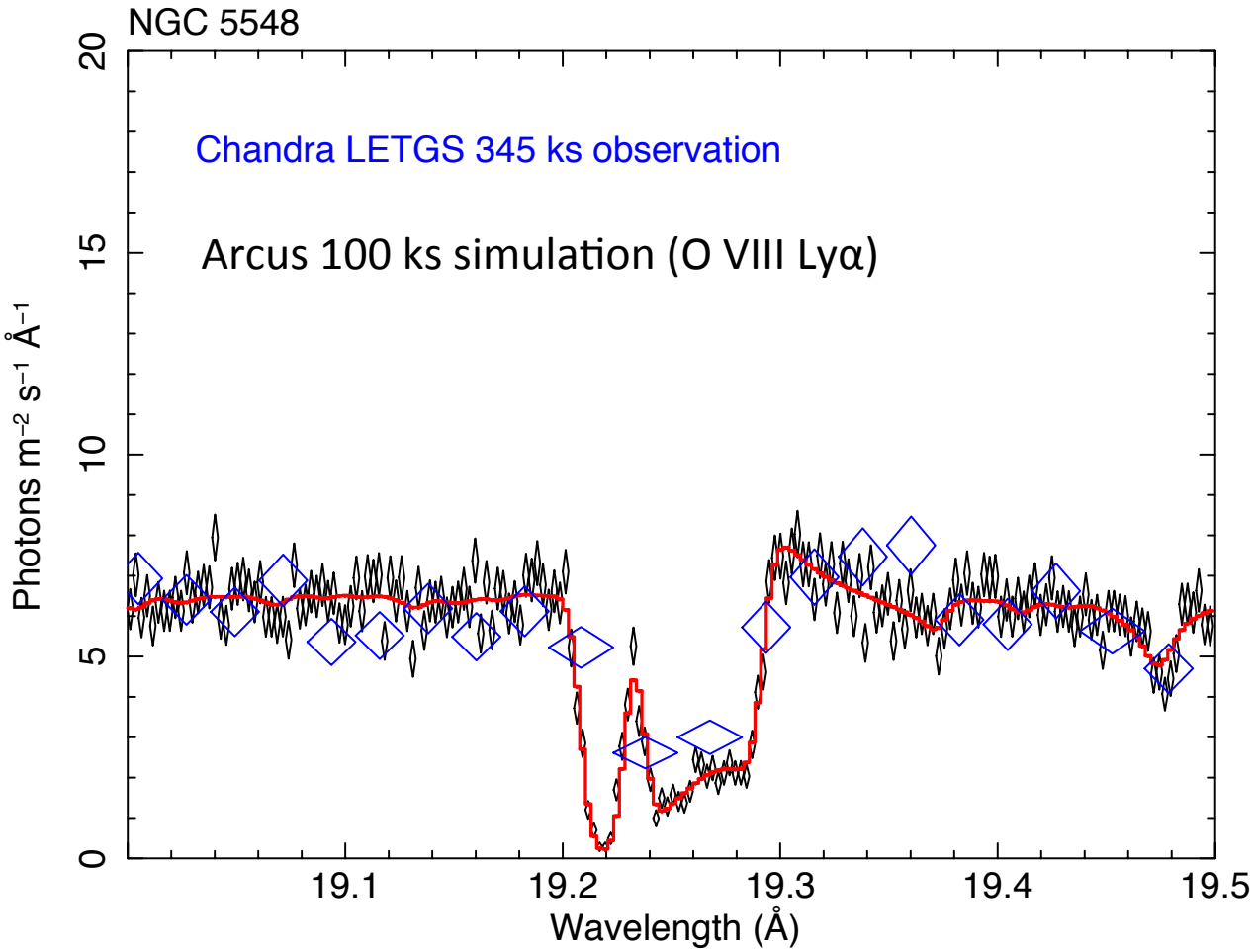
- ~~2016: Calorimeter, *Hitomi* if recovered~~
- 20xx: *Hitomi 2* ??? (would hope so…!)
- Early 2020s: *DIOS* (small Japanese wide-angle calorimeter mission; not yet selected)
- 2023: *Arcus* (NASA Midex proposal), grating R=3000
- 2028: *Athena* (ESA selected mission), TES array, large effective area
- Now-2029(+?): *XMM-Newton!*

Arcus

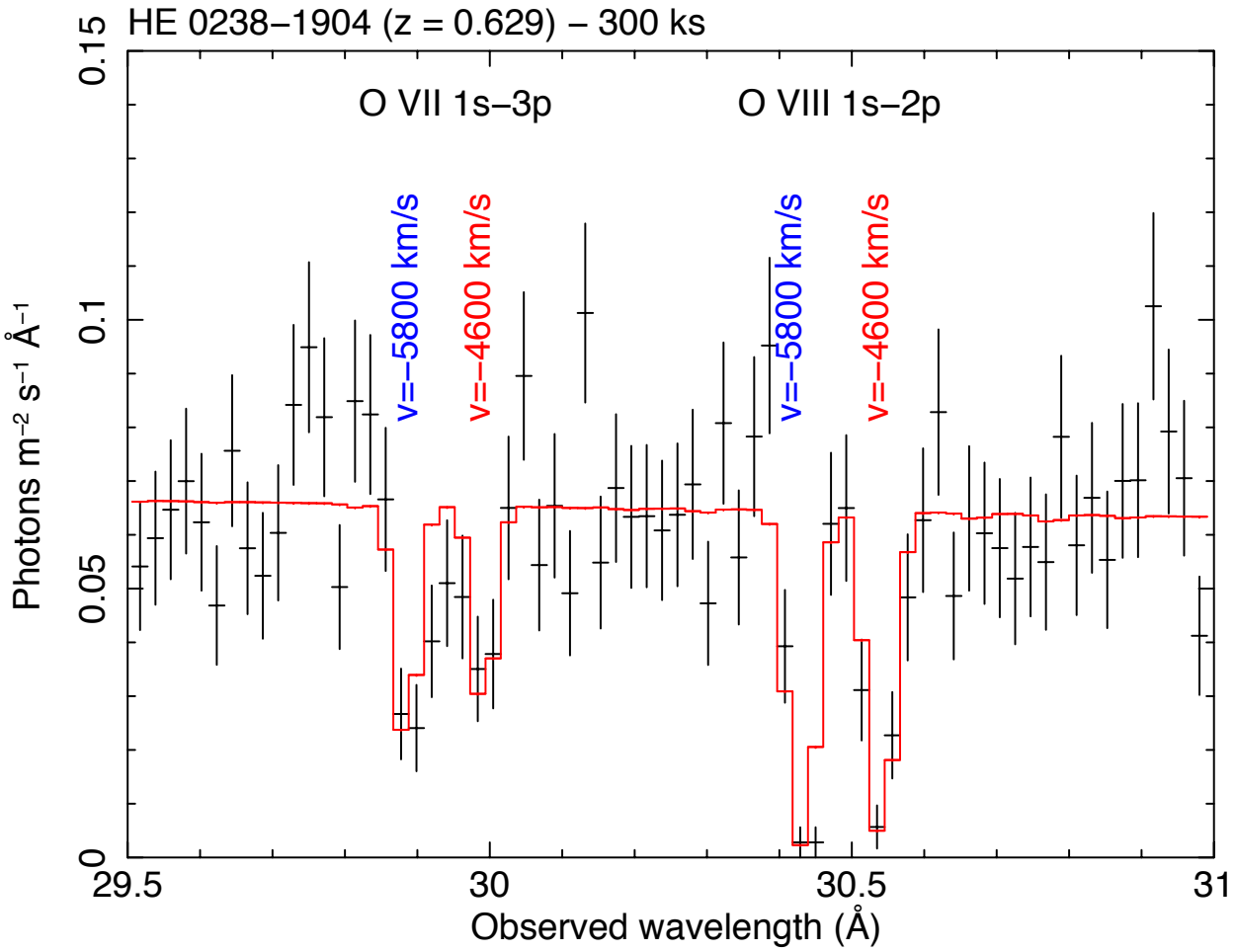
Arcus

- Mission idea for NASA Midex mission
- PI Randall Smith
- If approved launch ~2023
- Basically: like RGS with
  - 10 x effective area
  - 10 x resolution
- Science goals:
  - Milky Way gas halo
  - AGN feedback
  - & others ….

Nearby AGN


NGC 5548
Chandra LETGS 345 ks observation
Arcus 100 ks simulation (O VIII Lyα)
Photons m^{-2} s^{-1} Å^{-1}
0
5
10
15
20
19.1
19.2
19.3
19.4
19.5
Wavelength (Å)

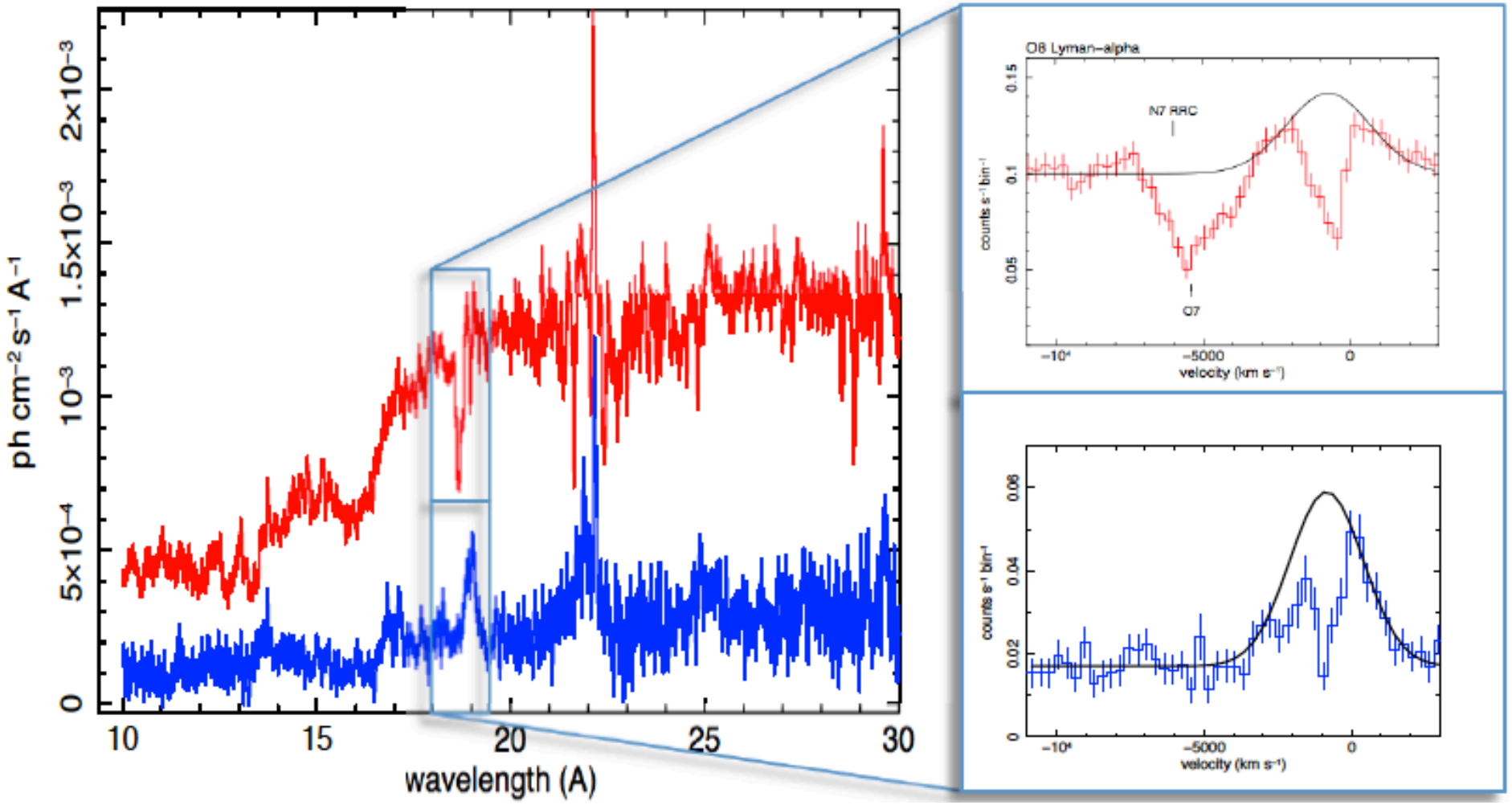
Outflows in distant quasars



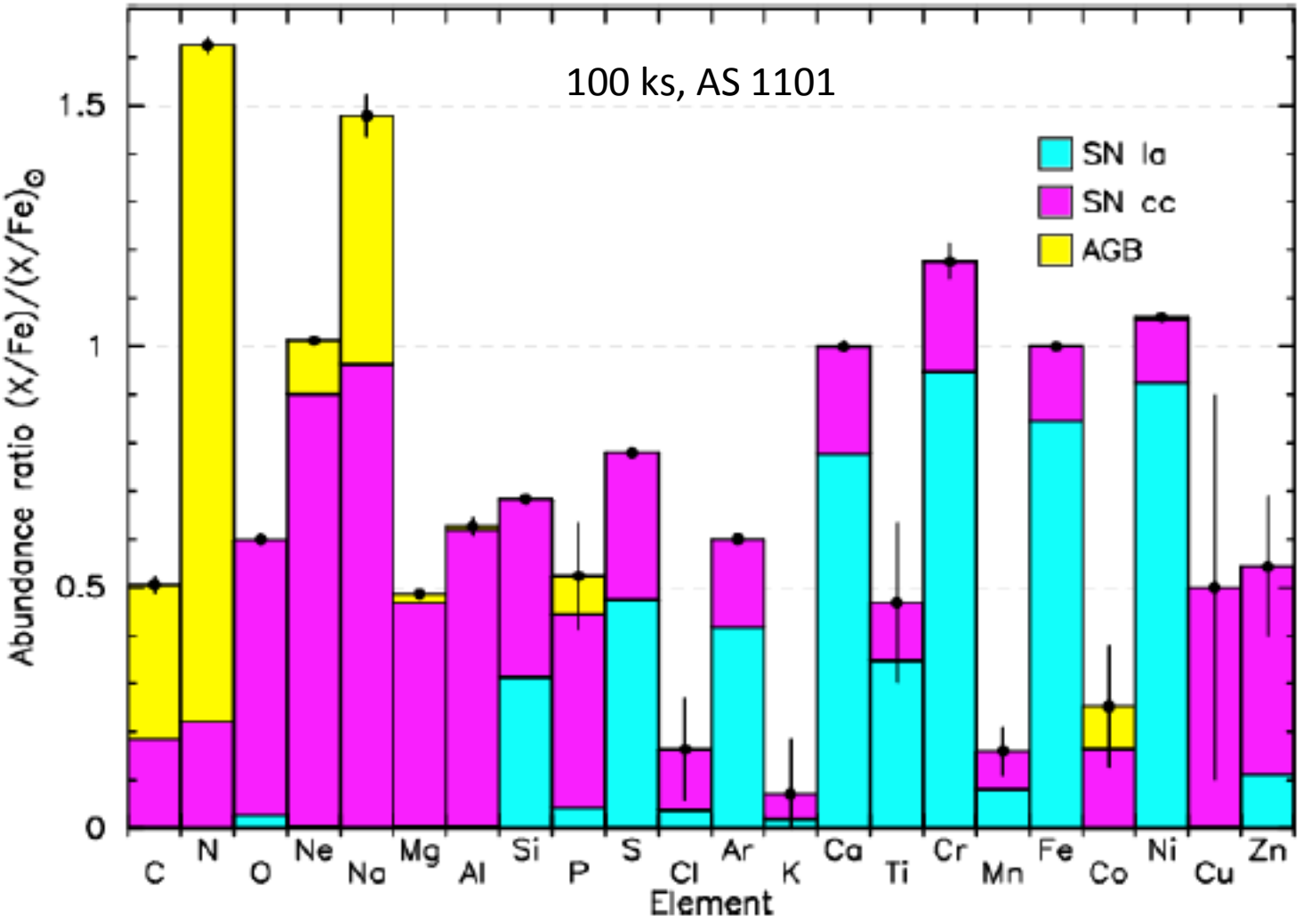
Athena

Time-resolved spectroscopy of AGN

NGC 4051 - 1 ks only (Cappi,Done et al. 2013)

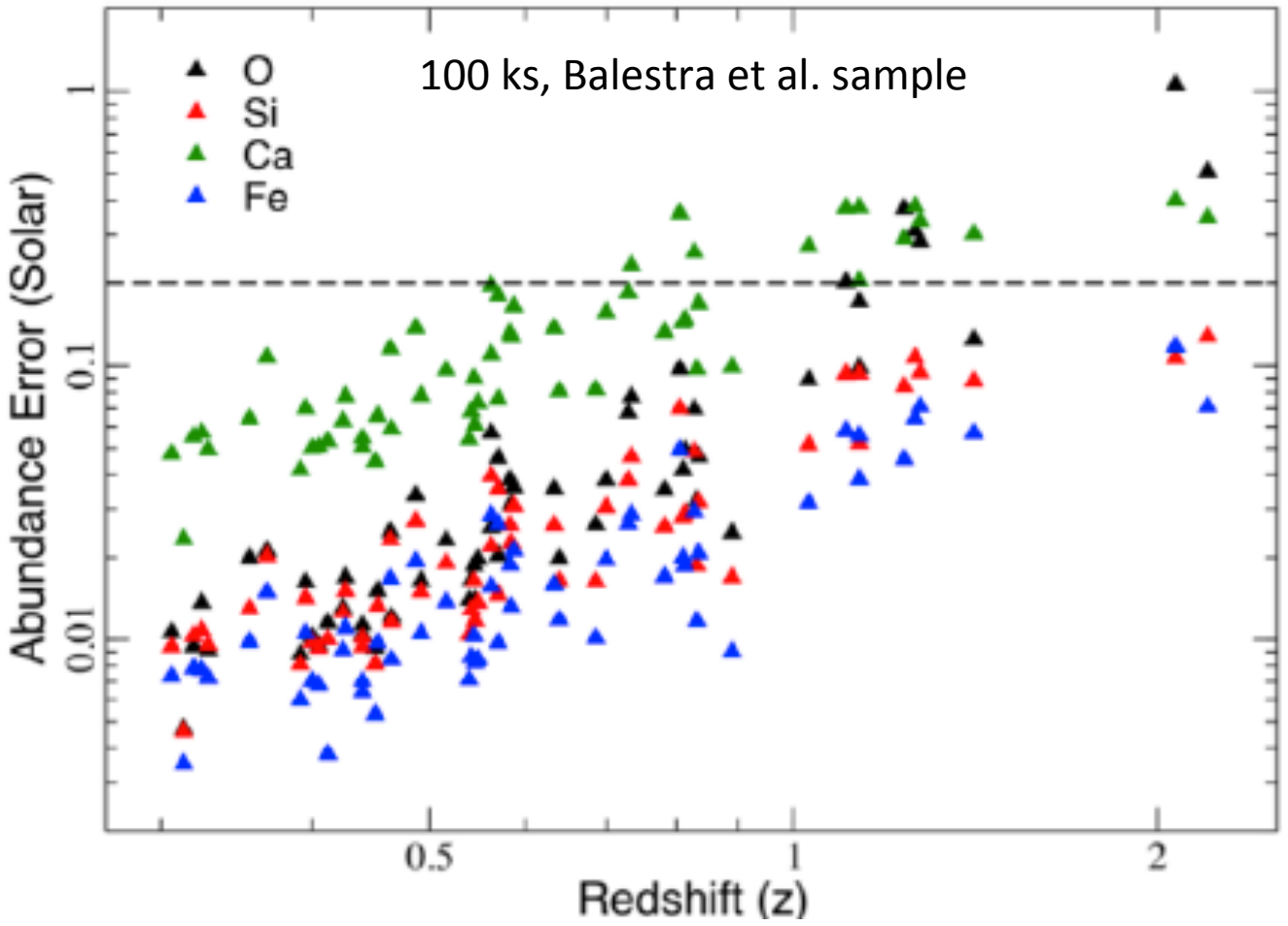


Characterising chemical evolution in nearby clusters



Ettori, Pratt et al. 2013

Chemical evolution over cosmic time



Pointecouteau, Reiprich et al . 2013

XMM-Newton: the next decade

What can we do now?

- First 4+ years *no new spectroscopy mission*
- Some science really needs the high-resolution, high throughput *but*:
- *Long, deep spectra* (RGS, EPIC & OM!) of bright sources can already give new insights
- Holds for *most classes* of objects
- As long as *systematic* calibration limits not reached

Example: monitoring variable sources

- AGN vary on *multitude of time-scales*: from minutes to decades
- In most cases *poor sampling* or only sampling at some time scales
- *Monitoring campaigns* cover such time scales & give excellent *time-averaged spectra* (Ms-scale exposures)
- Needs to do this *multi-λ* e.g. HST, NuSTAR, ground-based, etc. (as short/long these other facilities exist)

Conclusions

- 16+ years XMM-Newton spectroscopy has delivered fascinating science
- Even now *new topics* appear: triggered by
  - Carefully investigating large available databases
  - Serendipitous discoveries
  - New views made possible by other facilities
- While waiting for new missions, XMM-Newton can make significant progress by going *deeper & longer* in the coming decade