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

NGC 5548 – RGS spectrum 2013 – 660 ks – binsize 0.06 Å
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
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

data and folded model

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

$kT = 4\text{ keV}$

SPEX Version 2.0, Doppler
SPEX Version 3.0, Doppler
SPEX Version 3.0, Voigt
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)
Outflows in distant quasars

HE 0238–1904 (z = 0.629) – 300 ks

O VII 1s–3p

Observed wavelength (Å)

O VIII 1s–2p

Photons m$^{-2}$ s$^{-1}$ Å$^{-1}$

v = 5800 km/s

v = 4600 km/s
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

100 ks, Balestra et al. sample

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