Some Applications of 'Observational Astrophysics II' (Bleeker and Verbunt)

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1. X-ray astronomy; *Chandra* and *XMM-Newton*

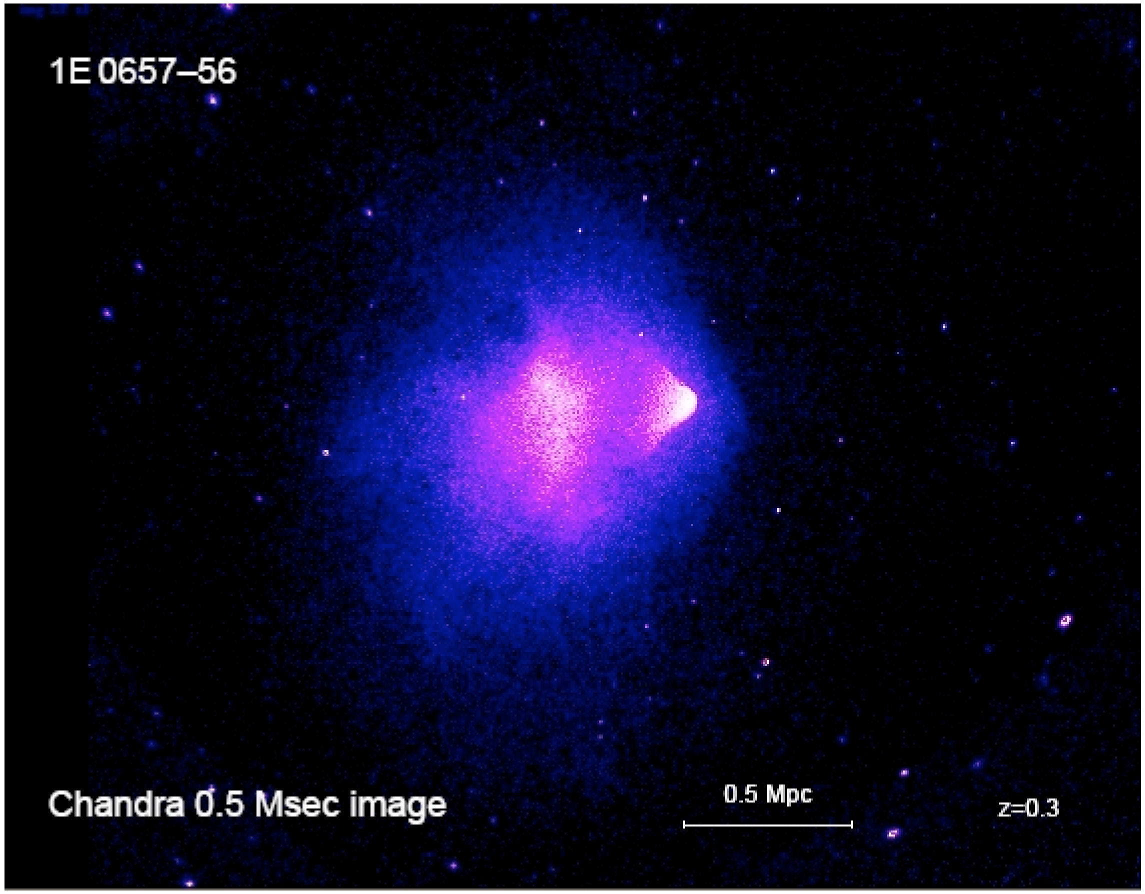
2. FP's involvement: X-ray spectroscopy

3. Some general spectroscopic ideas; requirements, disappointing performance of ionization detectors; illustrates OAII, Sect. 4.6

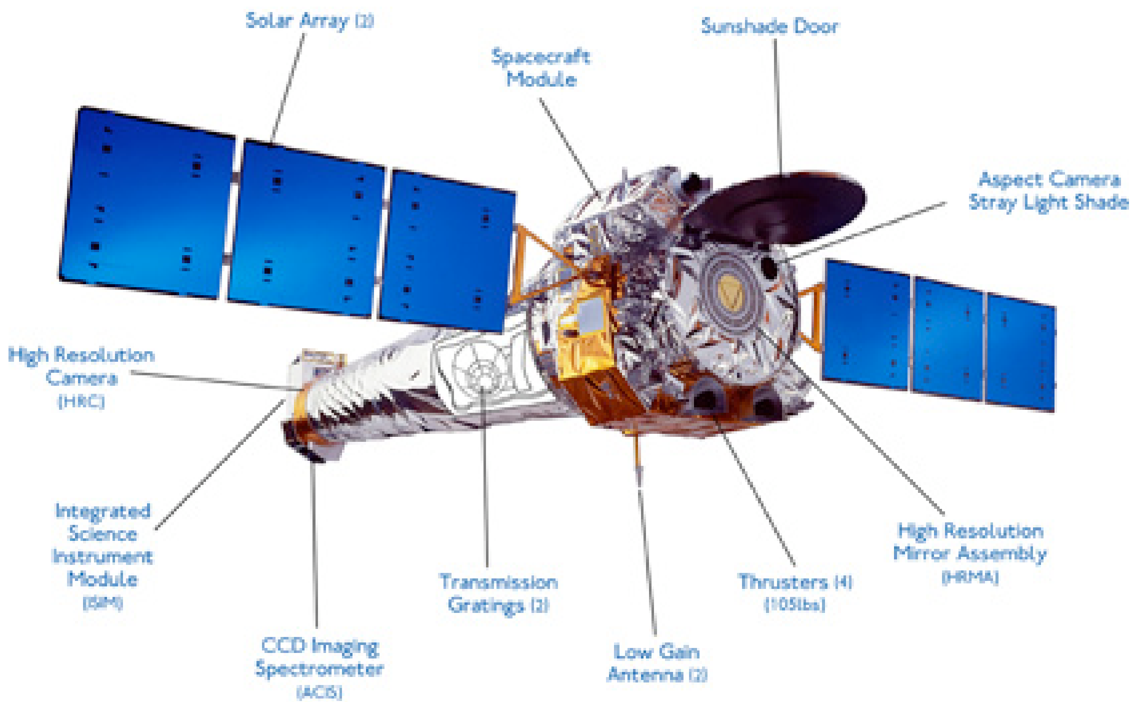
4. Diffraction Grating Spectrometers
   illustrates van Cittert-Zernike Theorem (OAII 3.3); basics of Fourier transforms; and an aside on the history of Quantum Mechanics

5. Quantum Microcalorimeters
   illustrates Bose-Einstein statistics; also Fourier transforms and thermal noise (OAII, 1.4, 1.5); the Debye temperature as a Nyquist frequency

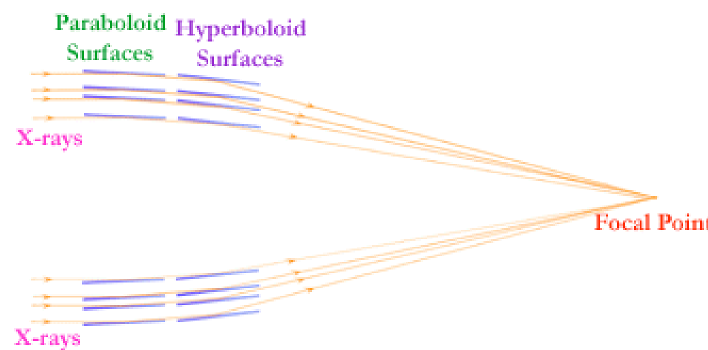
1. X-ray astronomy



X-ray emission from a distant cluster of galaxies (the famous 'Bullet Cluster')



Chandra X-ray observatory



'grazing incidence' focusing telescopes

XMM-Newton

XMM-Newton preparation

Image courtesy of D. Parker

European Space Agency

Image courtesy of D. Parker and ESA.

2. X-ray spectroscopy

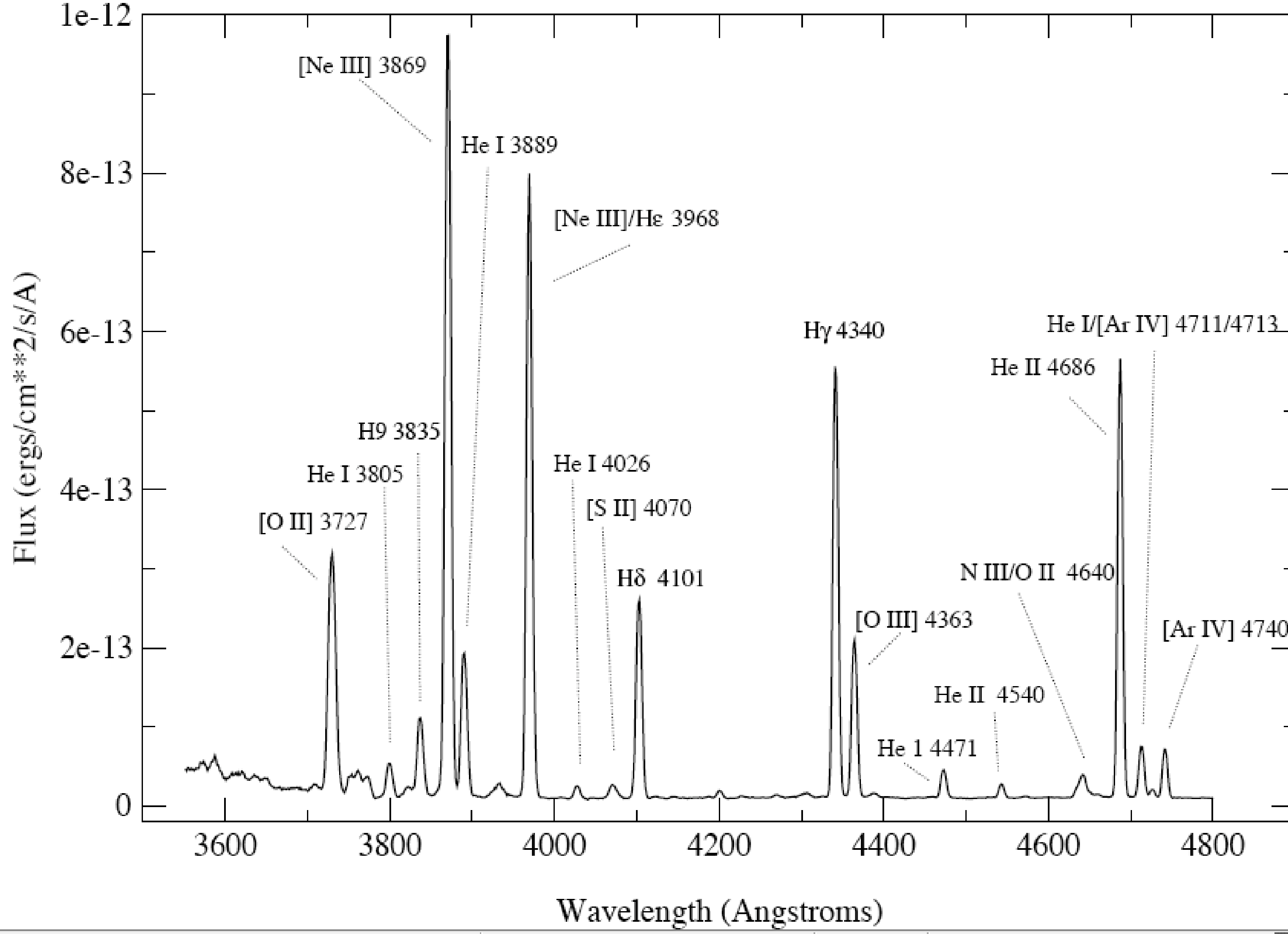
Bohr model: $E_i = Z^2.Ry$ (Z: nuclear charge)

H-like Oxygen: Z = 8, E_i = 870 eV (14.24 Angstrom)
Ly α: 18.97 Angstrom

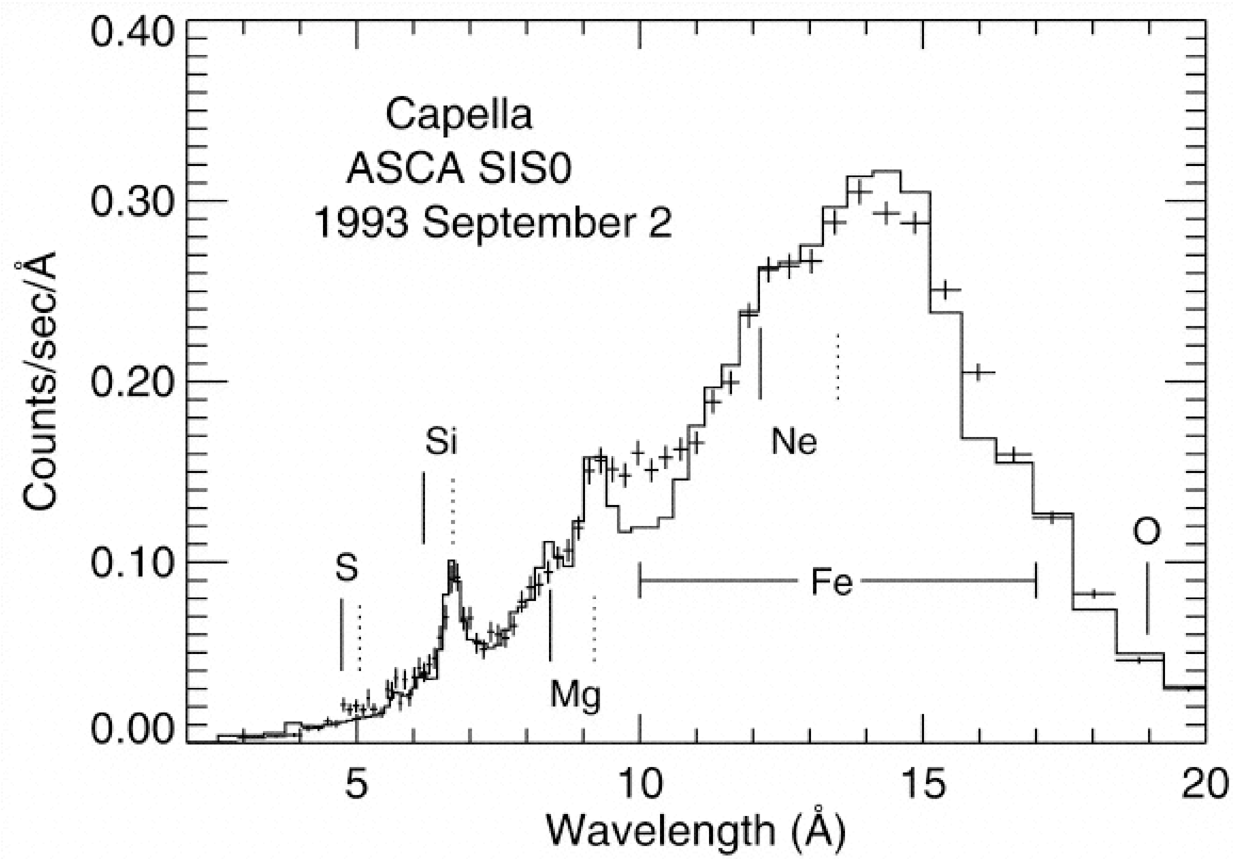
Optical band: 4000-8000 Angstrom
Soft X-ray band: 10-100 Angstrom; spectra of
highly ionized C, N, O, Ne, Mg, Si, S, Fe

Optical spectrum (planetary nebula)

www.williams.edu

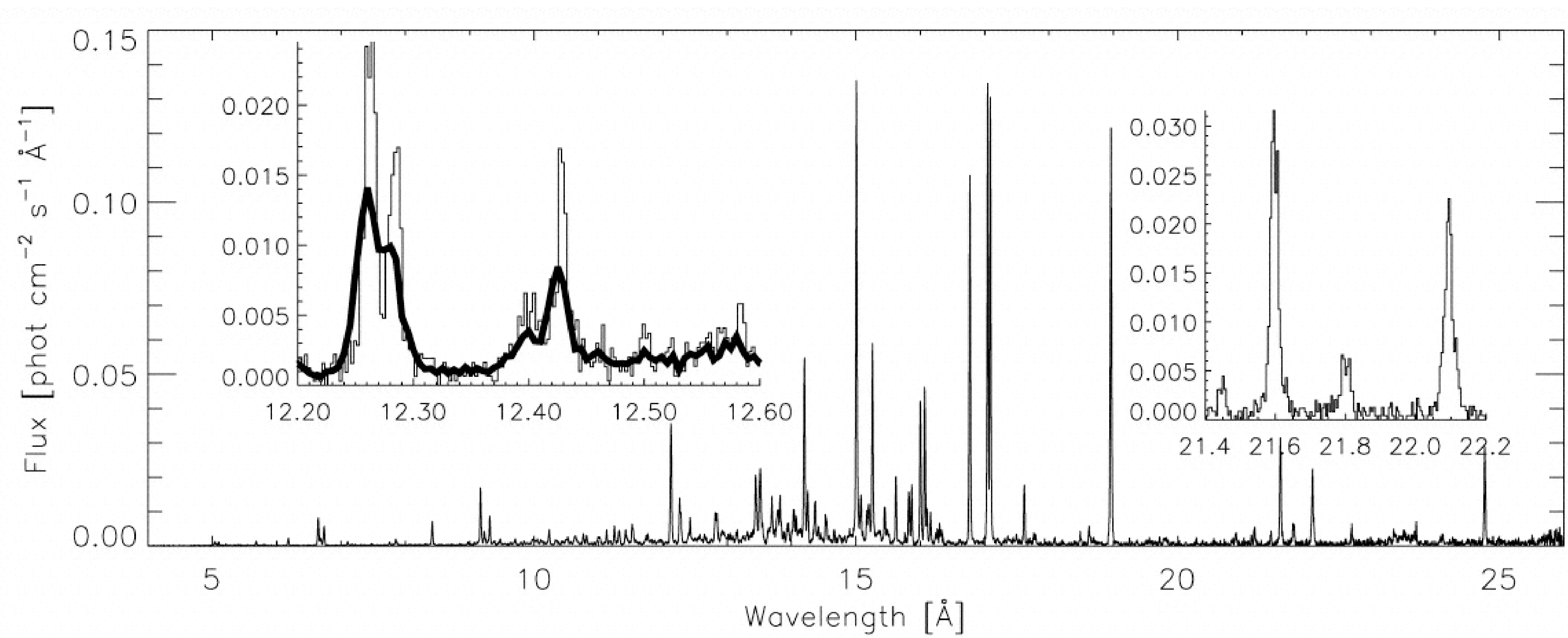


X-ray spectrocopy: best possible spectrum with ionization detector (CCD's; discussed later)



Corona of Capella; Brickhouse et al., 2000, *Ap.J.,* **530**, 387.

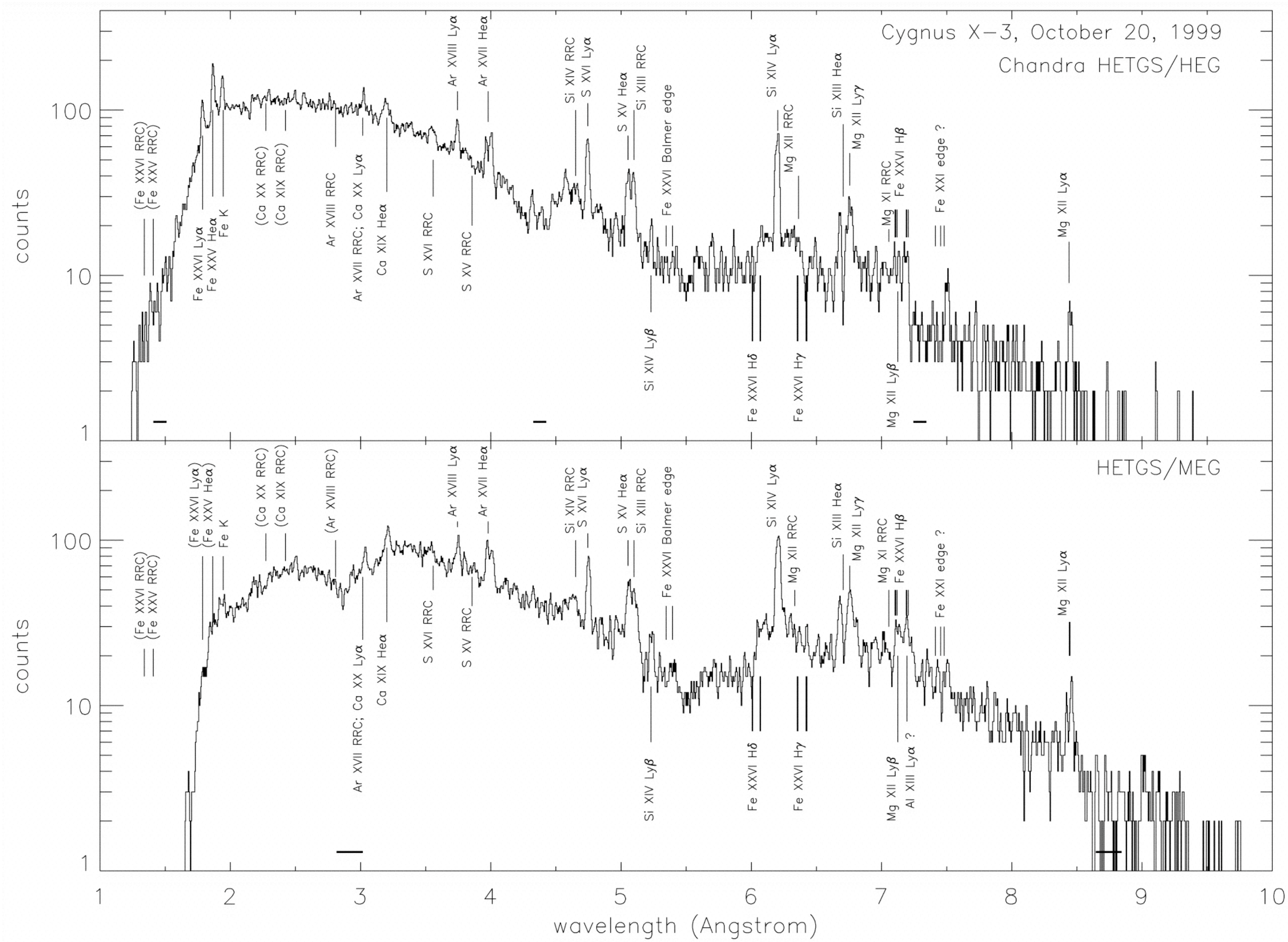
Tremendous progress since 2000: diffraction grating spectrometers on *Chandra* and *XMM-Newton*



Chandra HETGS spectrum of Capella;
Canizares et al., 2000, *Ap. J.*, **539**, L41

HETGS spectrum of Cygnus X-3

(Paerels et al., 2000, *Ap.J.*, **533**, L135)



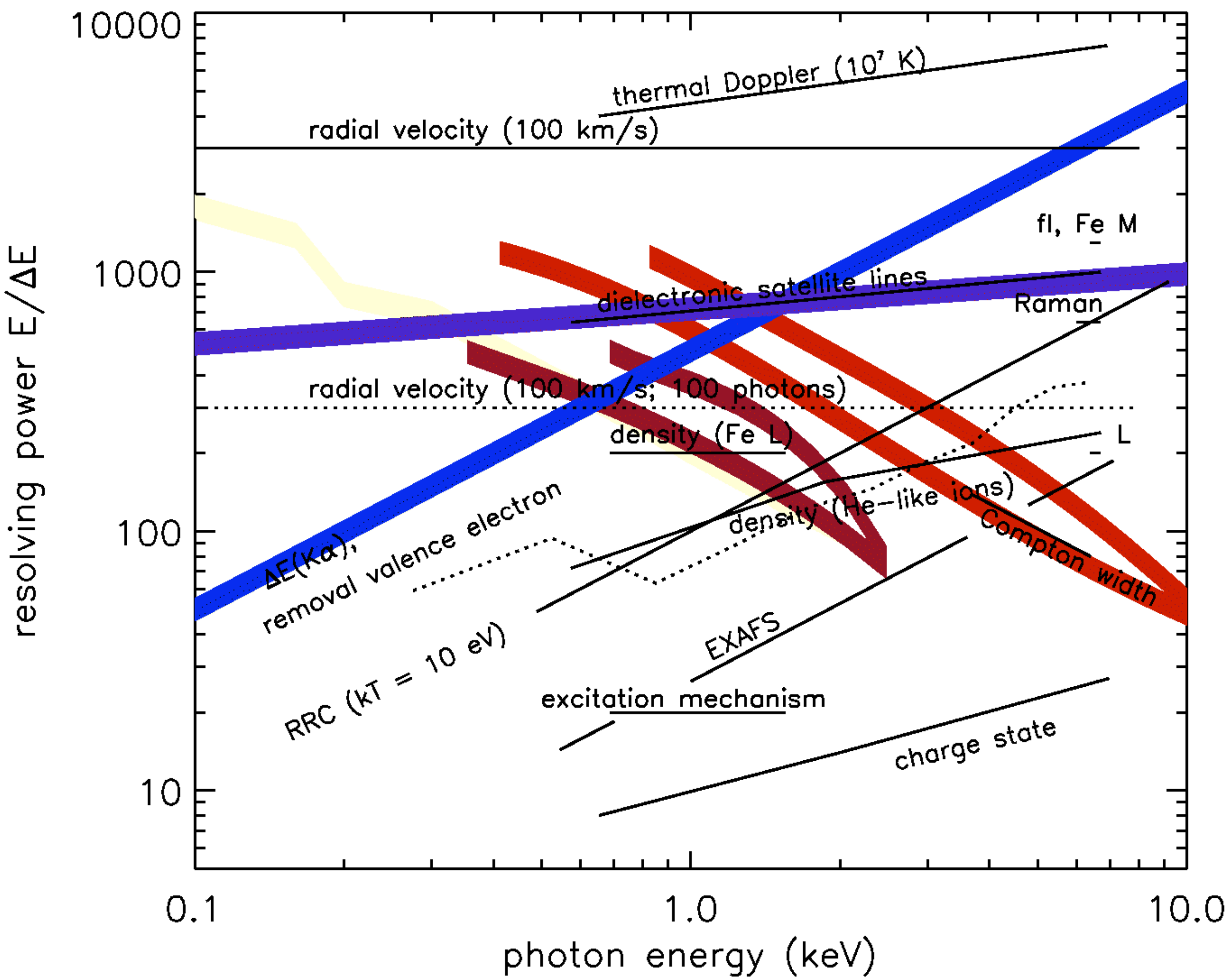
When does X-ray spectroscopy become interesting?

Example: want to be able to separate at least n=1-2 transitions in H- and He-like ion (gives you the ionization balance)

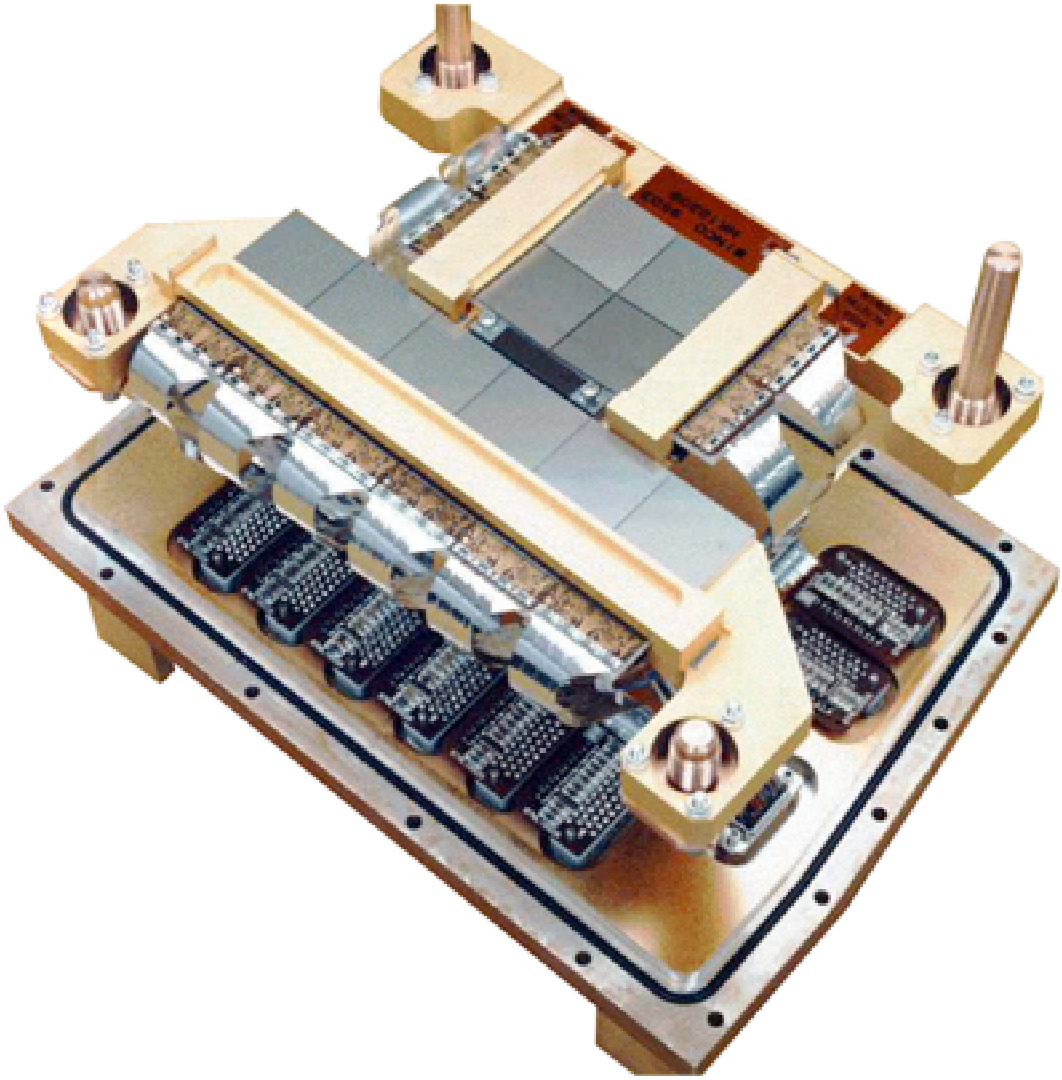
$$E(n=1-2, \text{H-like}) = (3/4)\ Z^2.\ Ry$$
$$E(n=1-2, \text{He-like}) \sim (3/4)\ (Z-1)^2.Ry$$

Ratio: $Z^2/(Z-1)^2$; for Z=8: 1.30, so need (energy) resolution of 30%

Spectroscopy in the X-ray band



Why is a CCD so …bad? *(cf. AOII, Sect. 4.6)*



ACIS (Advanced Camera for Imaging Spectroscopy on *Chandra*)

Two roads to higher resolution:

Diffraction Gratings

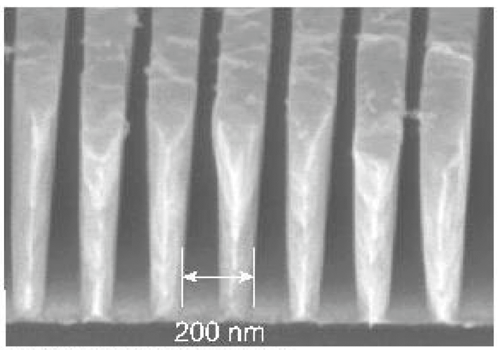
(dispersion gives small $\Delta\theta$ compared to dispersion angle θ; I'll show you in a minute)

Cryogenic spectrometers

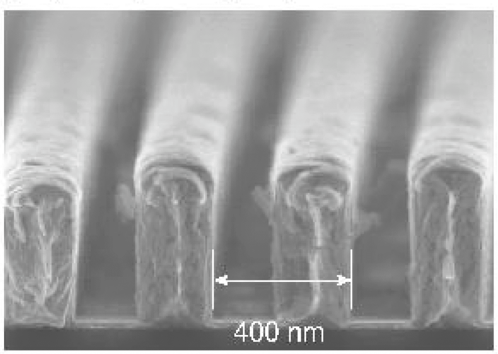
(for *w*, don't use ionization energy, but binding energy of Cooper pairs; or excitation energy of phonons: get much larger N!)

X-ray transmission gratings

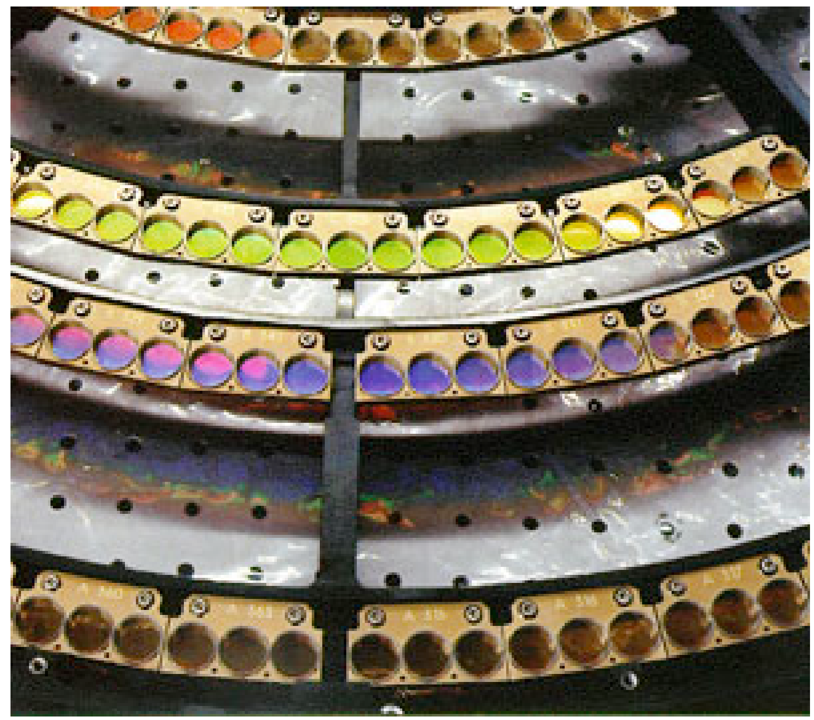
…bar-slit-bar-slit-bar-slit….



(a) High Energy Grating (HEG).

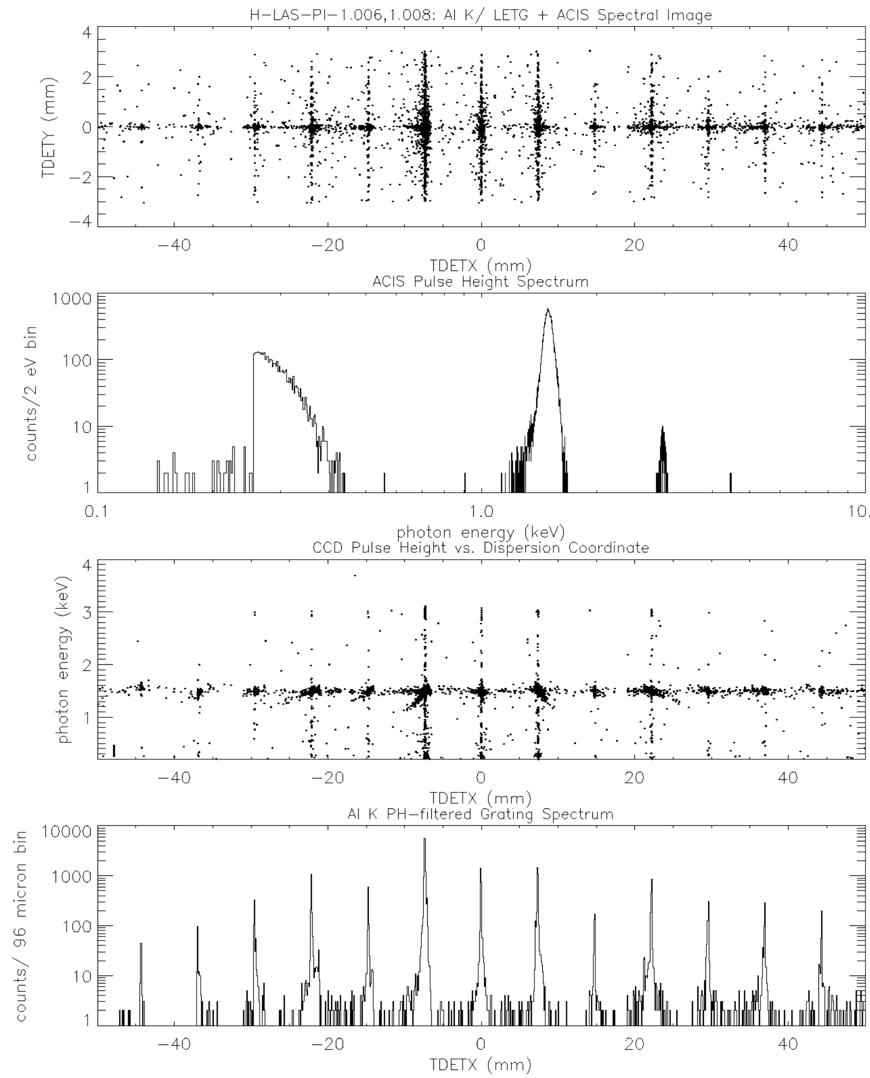


(b) Medium Energy Grating (MEG).

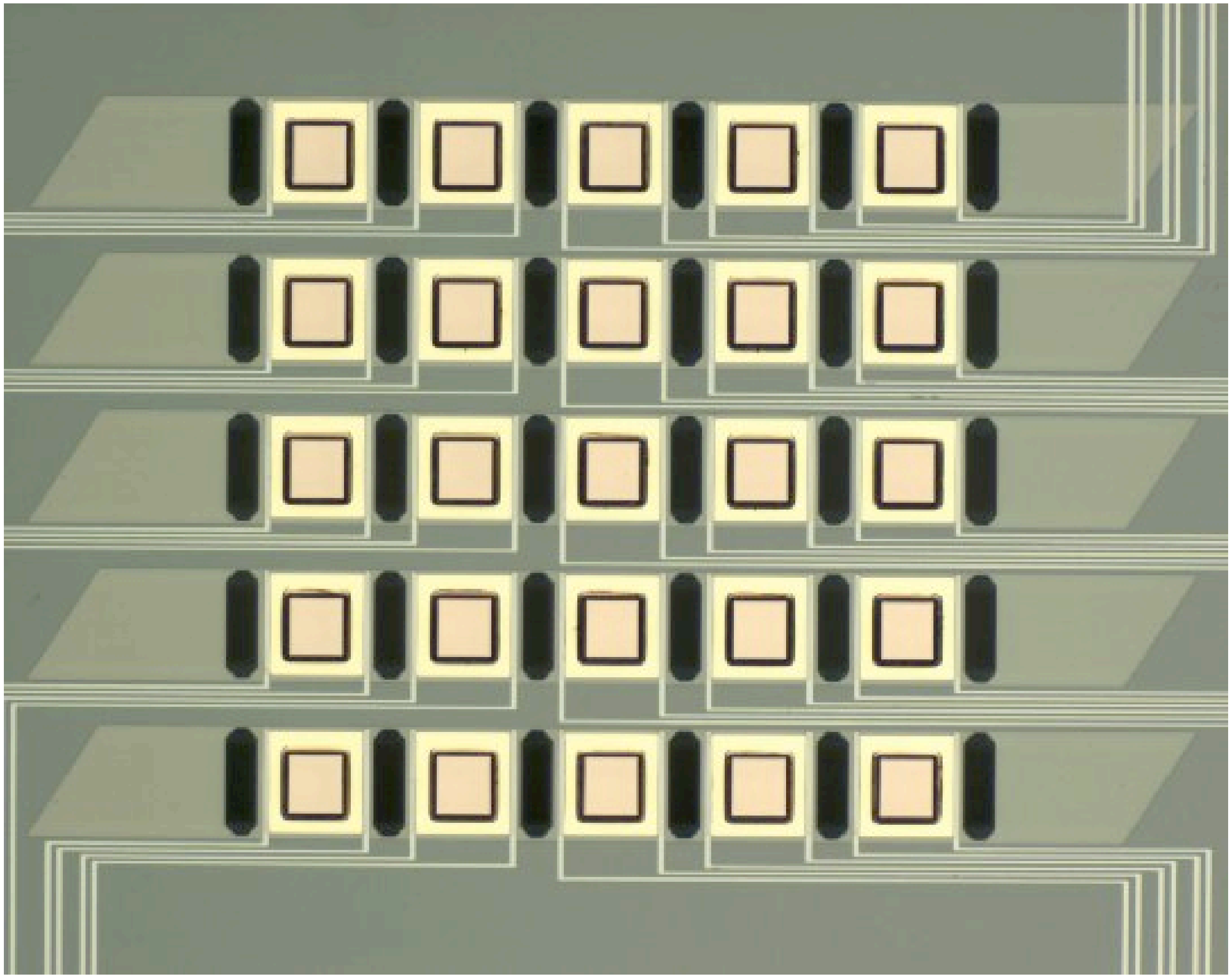


Low Energy Transmission Grating Spectrometer on *Chandra*

Scattered light in *Chandra* grating spectra?

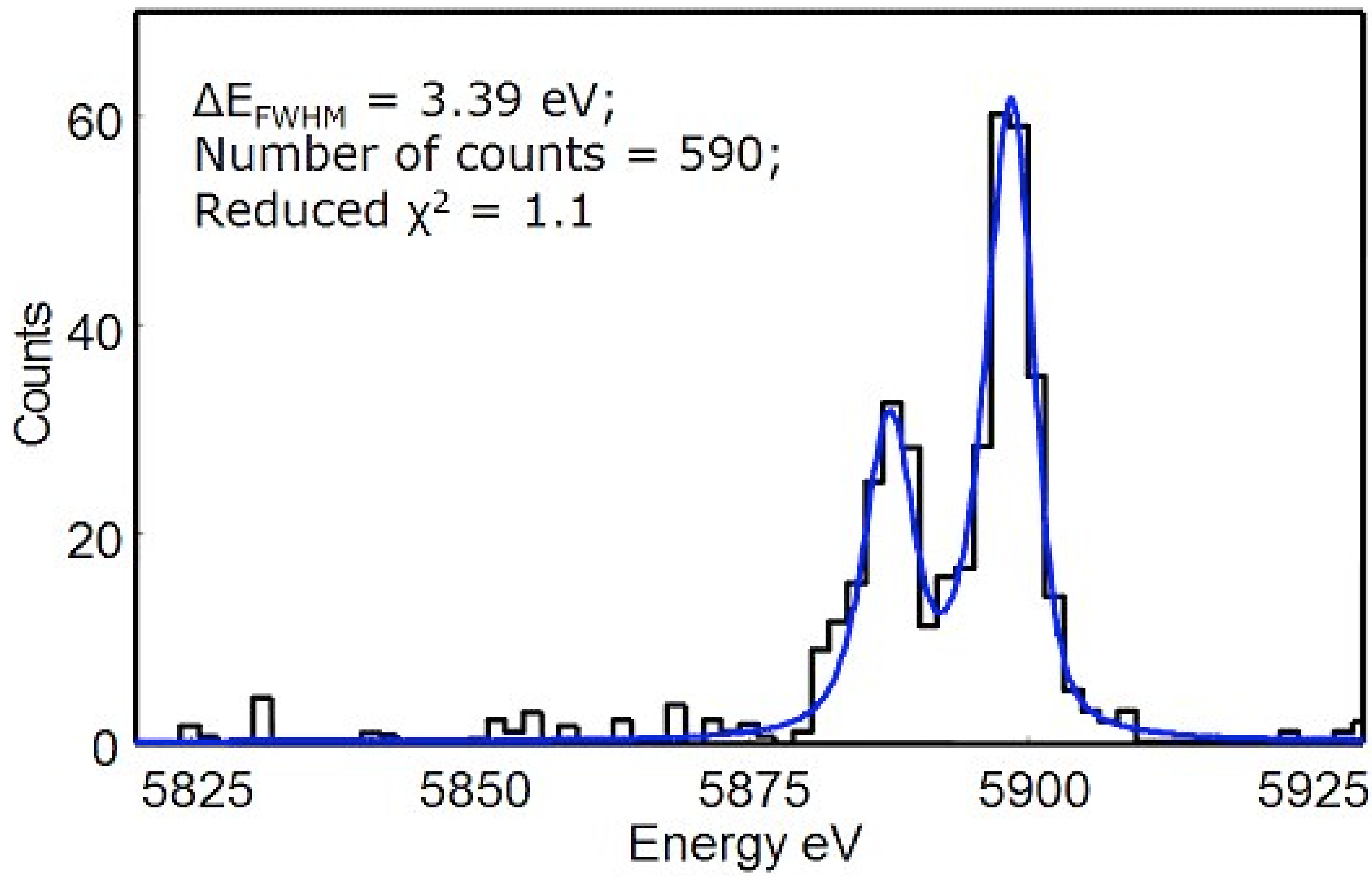


Microcalorimeters

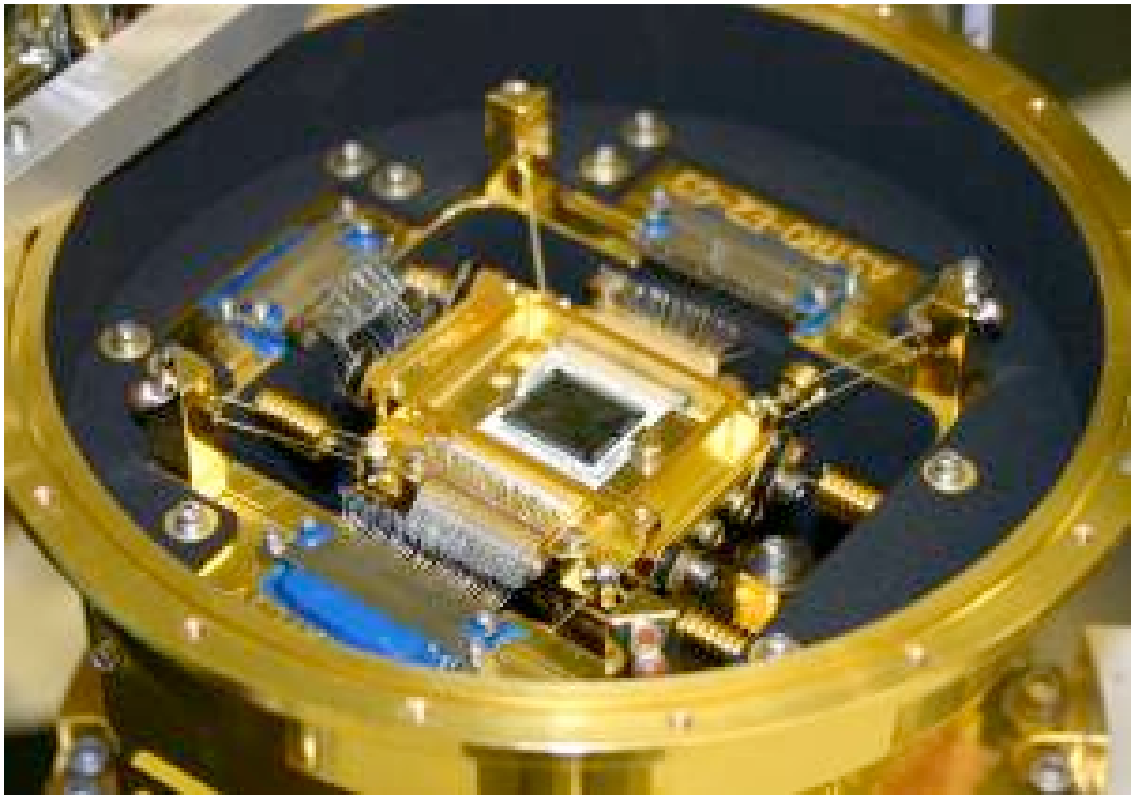


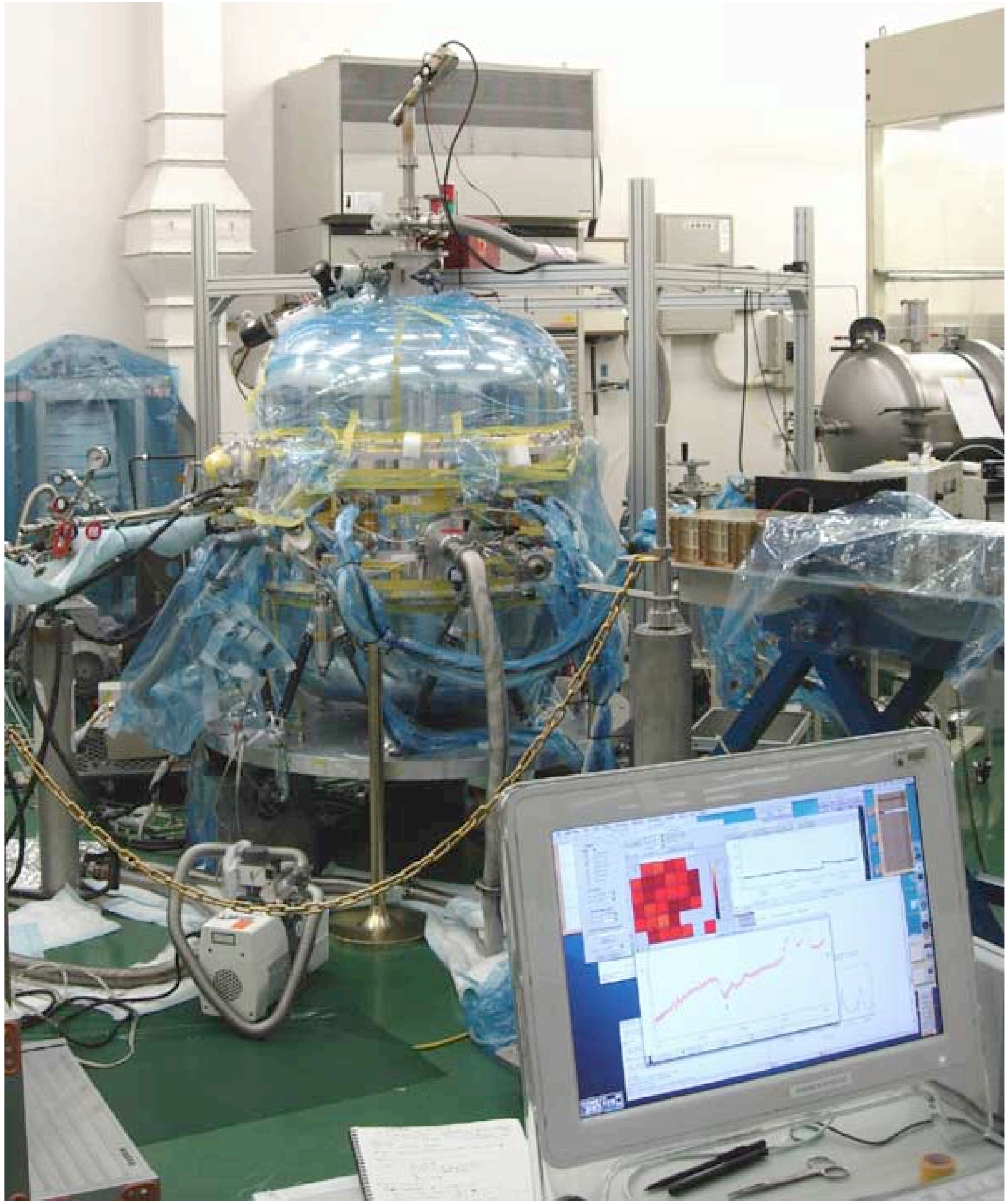
5x5 array of μcal, produced at SRON

Measured performance at Mn Kα:
Resolving power ~ 2000!



Tragic story of the μcal spectrometer array on Astro- E and Astro-E2 (*Suzaku*)





Cryostat for *Suzaku* being calibrated

And $\Delta E = 4$ eV is not the limit!