Don’t Kill the Messenger

Electromagnetic Spectroscopy of Black Holes

Frits Paerels
Columbia University

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Spectroscopic Measurement of BH Spins
Accretion, Outflows, Winds, …

extra:
photospheric spectroscopy of a neutron star

this talk is a few weeks too early:
first XRISM results are about to come out…

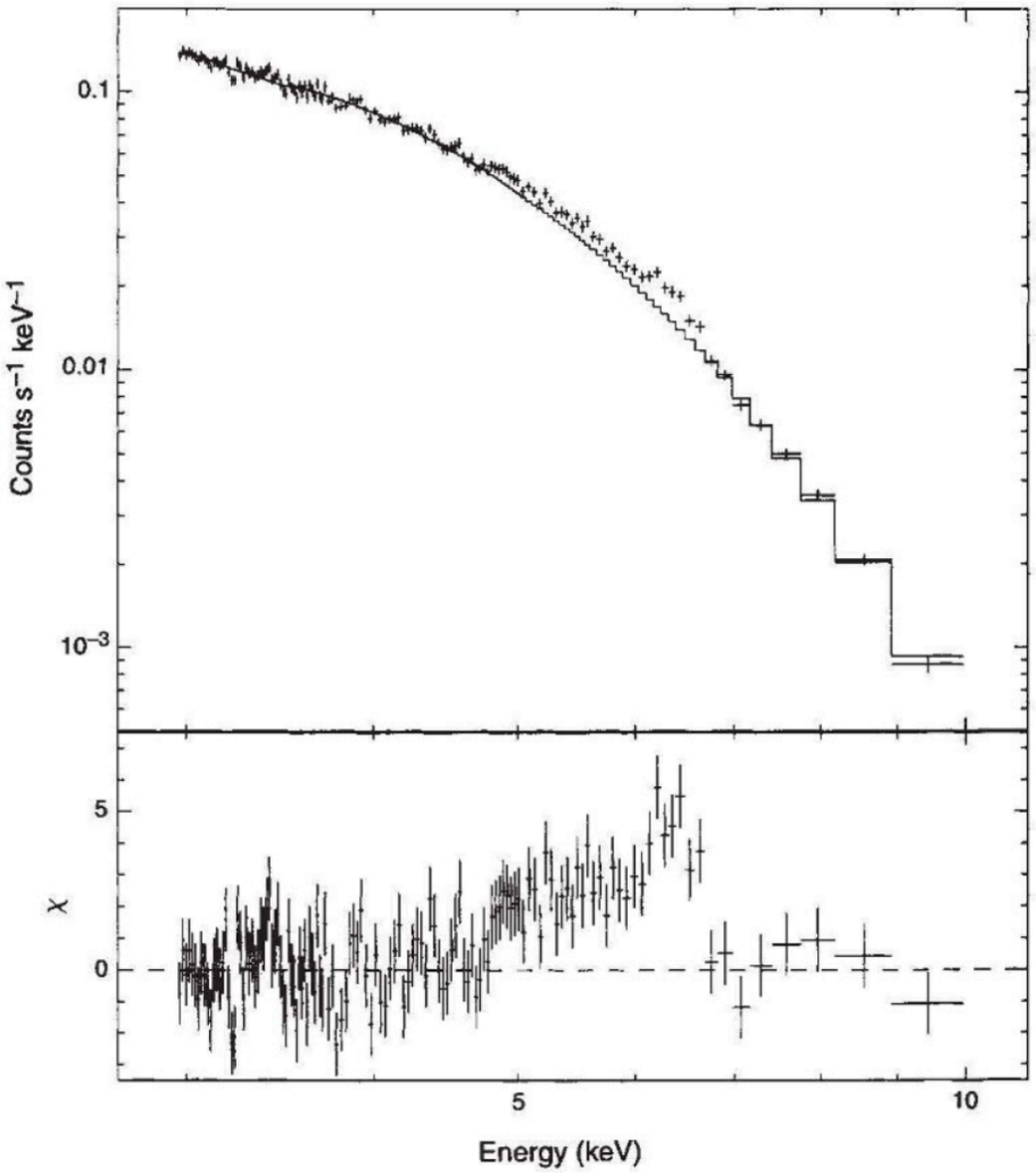
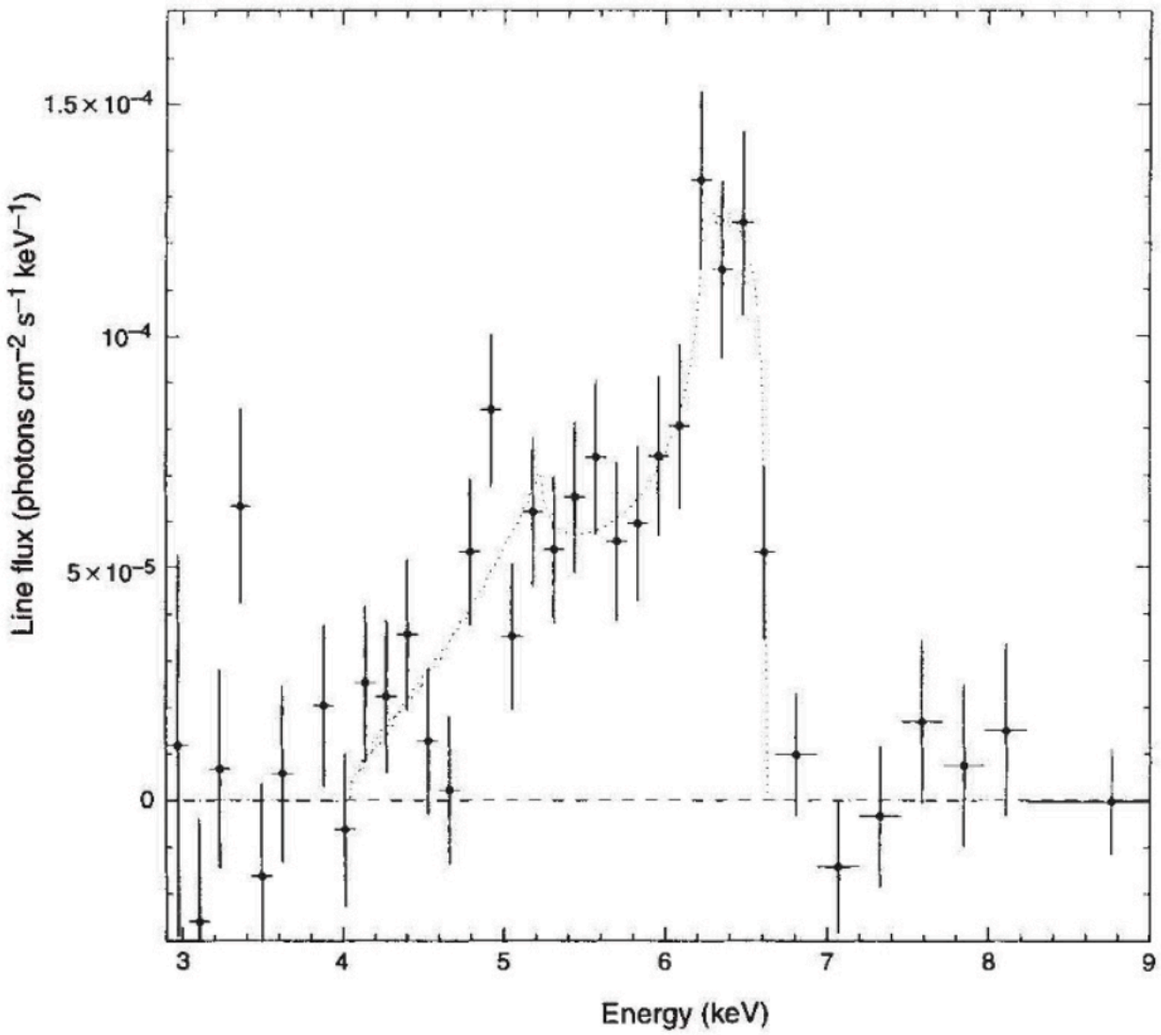


FIG. 1 X-ray spectrum of MCG−6−30−15, as observed by the ASCA satellite using the SIS detectors. Top panel, observed spectrum (crosses) and fitted 'power-law plus continuum reflection' model (stepped line; the model has the same energy bins as the data). This fit excludes data between 5 and 7 keV. Bottom panel, data-minus-model residuals. The emission line is clearly visible with an asymmetry to the red. Parametrizing the observed emission line with a single gaussian improved the fit by $\Delta\chi^2 = 82$ with a centroid energy of $E_K = 5.92^{+0.16}_{-0.15}$ keV, width $\sigma = 0.74^{+0.24}_{-0.18}$ keV and equivalent width $EW = 330^{+180}_{-120}$ eV. The power-law continuum has photon index $\Gamma = 2.05 \pm 0.07$. Adding an additional gaussian improved the fit further, with $\Delta\chi^2 = 39$, to $\chi^2 = 656.0$ (675 degrees of freedom). The double-gaussian parametrization consists of a relatively narrow ($\sigma = 0.18$ keV) component at 6.4 keV and a broader ($\sigma = 0.64$ keV) wing at ~5.5 keV. The red wing carries more flux than the core, with equivalent widths of 200 eV and 120 eV respectively.



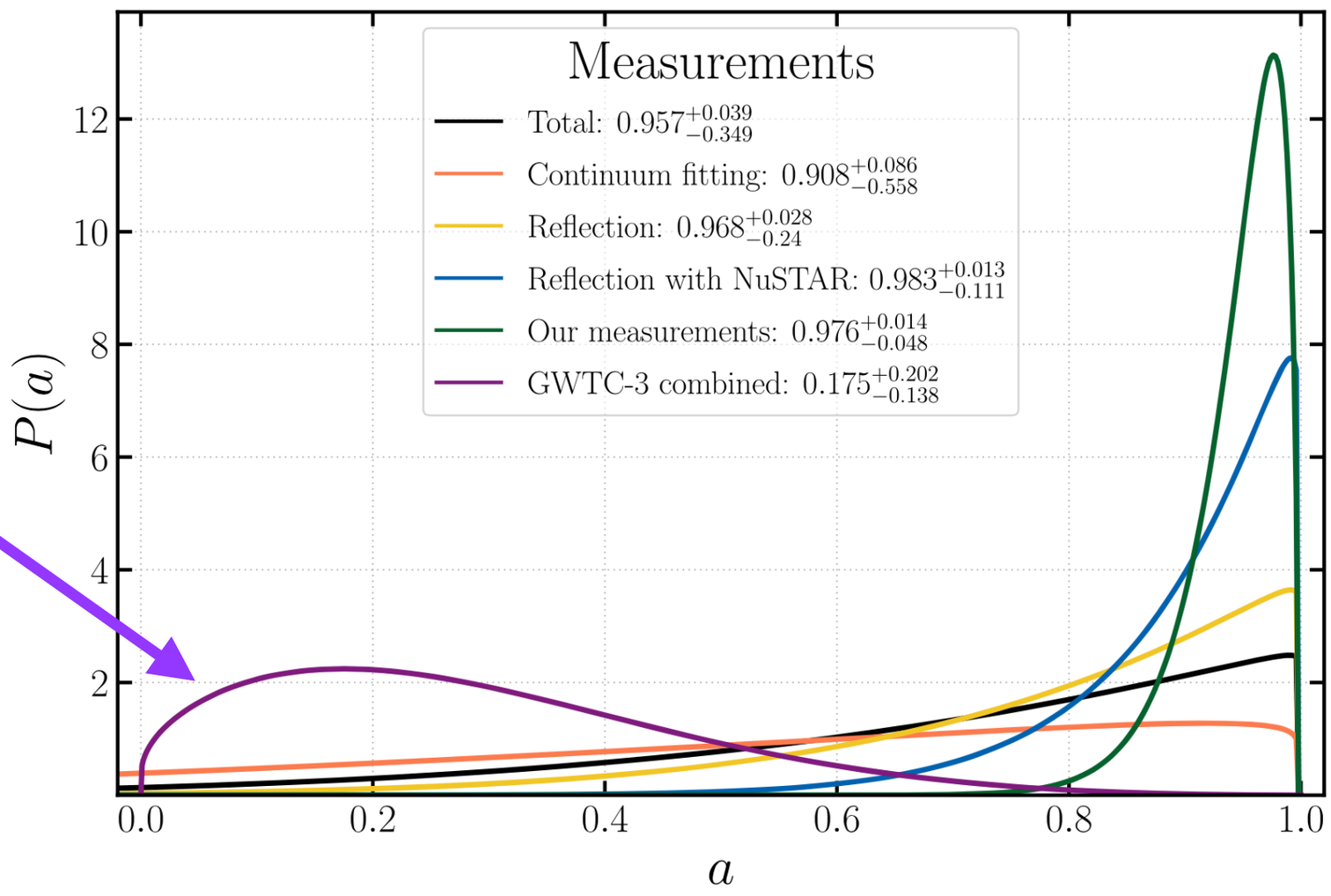
relativistically broadened Fe K emission lines at CCD resolution
(MCG-6-30-15 with ASCA; 1994)
measure BH spin

Tanaka *et al.*, *Nature*, **375**, 659 (1995)

distribution of spins ↔ formation and evolution

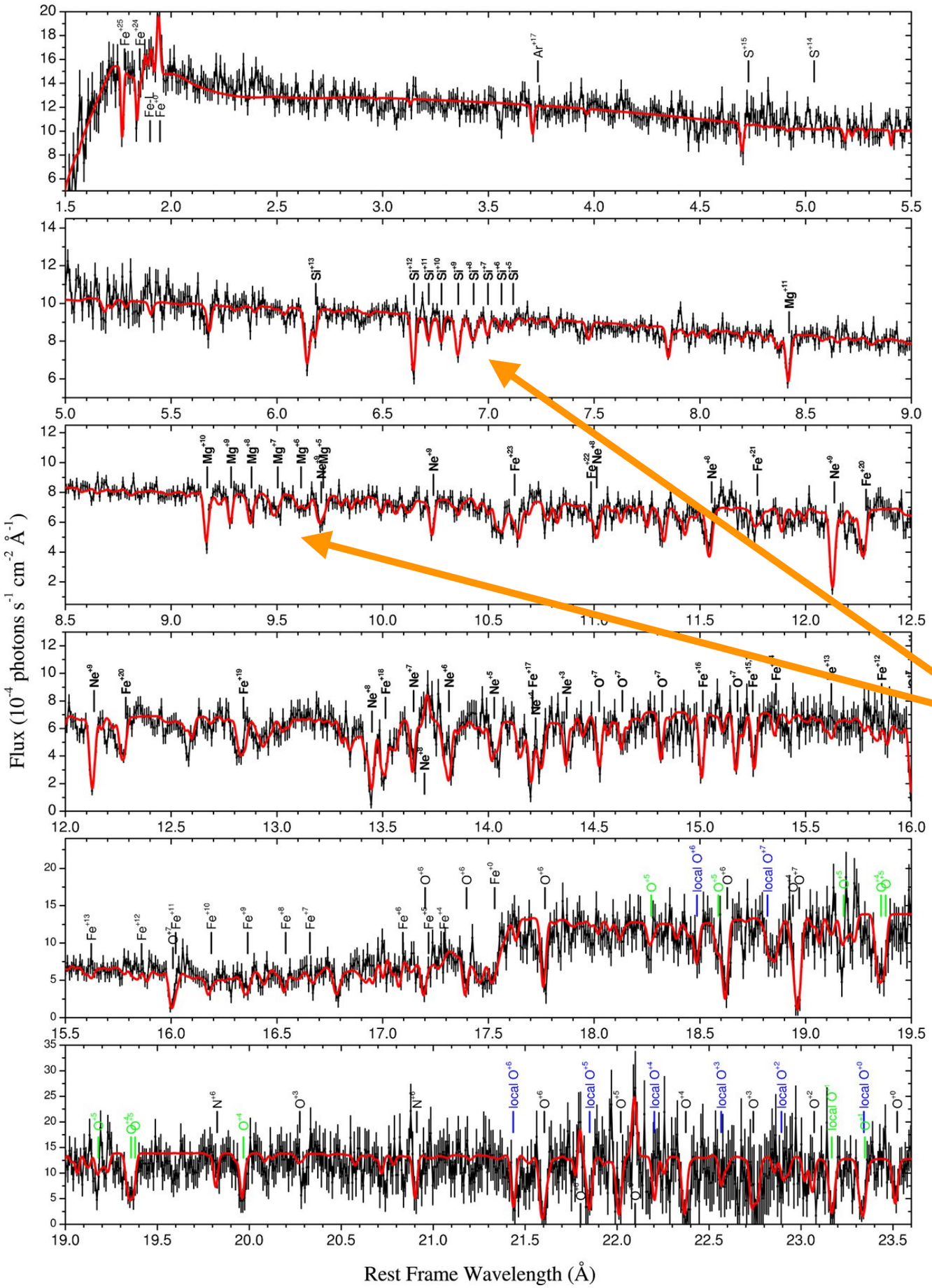
recent set of 10 XRB BH spins: EM spectroscopy

BBH
GW spins



Draghis *et al.*, *Ap.J.*, **946**, 19 (2023)

measured spins for SMBH likewise generally *high*



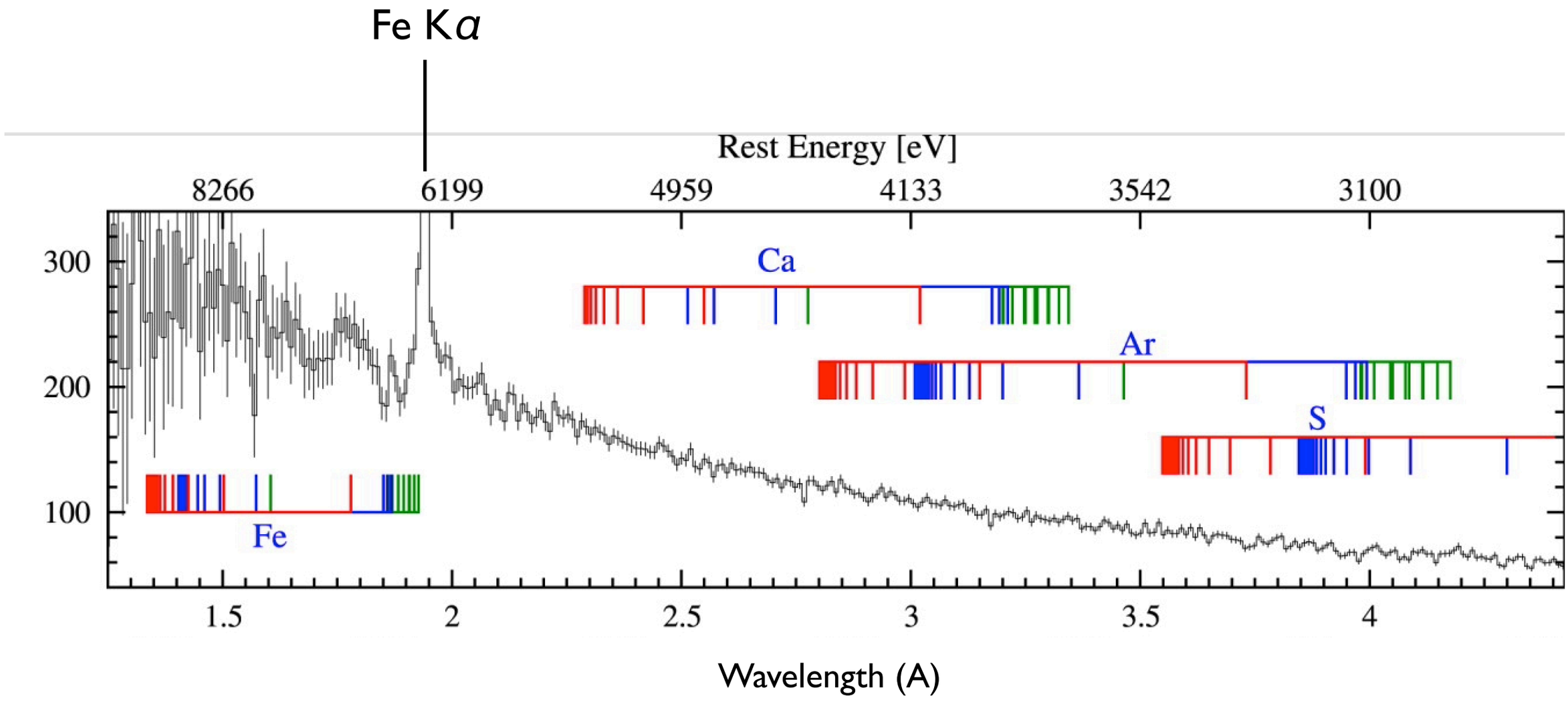
MCG-6-30-15 at higher resolution: 550 ksec with *Chandra* HETGS

There is a *lot* of material in the line of sight! with a wide range of ionization-
potentially worrisome for the Fe K band

Note for instance the innershell absorption from Mg(+5 - +10), Si(+5 - +12)

Holczer *et al.*, *Ap.J.*, **708**, 981 (2010)

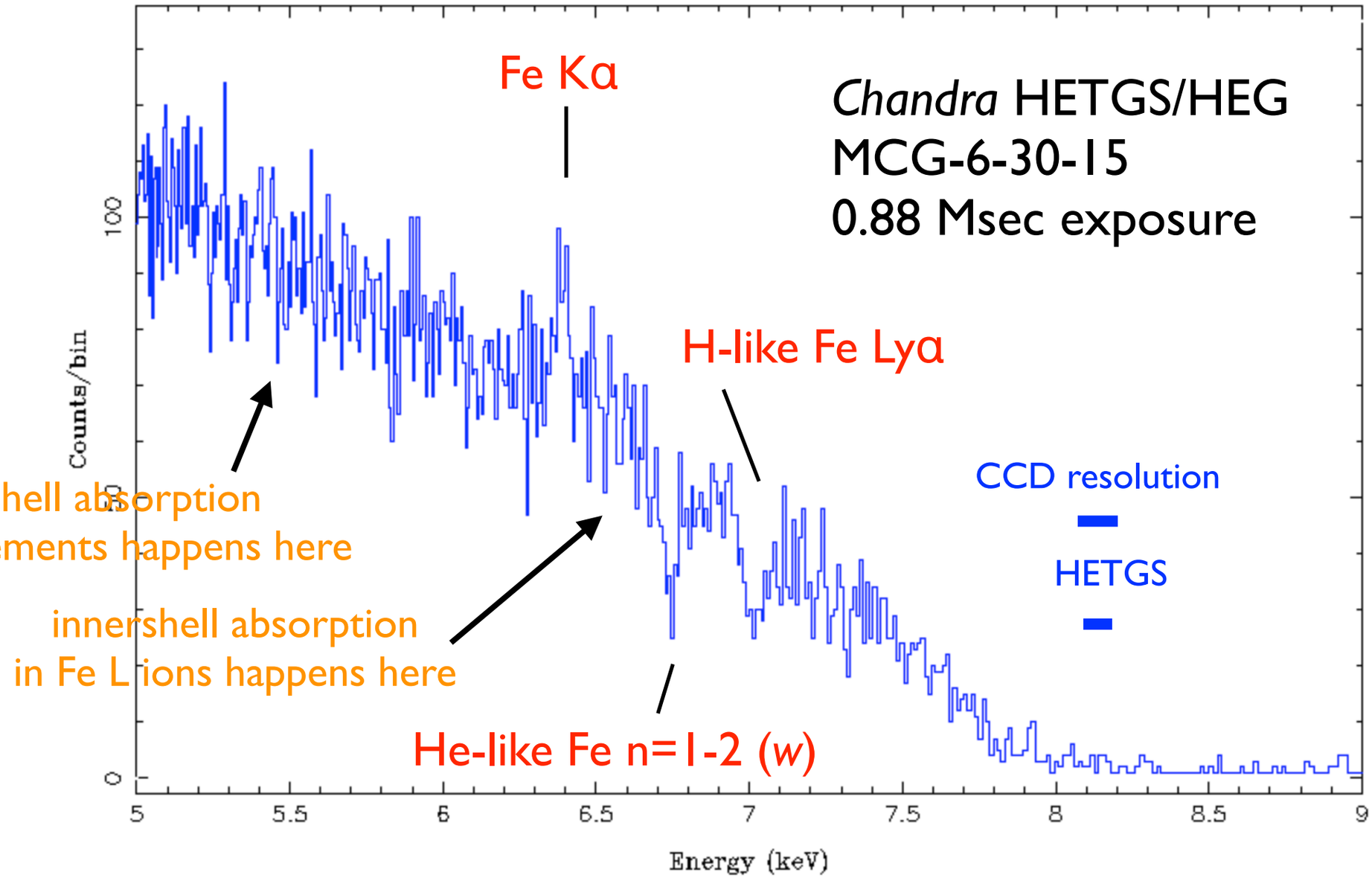
approximate width of relativistic Fe Kα



NGC 3783 *Chandra* HETGS/900 ksec

Kaspi *et al.*, *Ap.J.*, **574**, 643 (2002)

sensitive spectroscopy in the Fe K band…

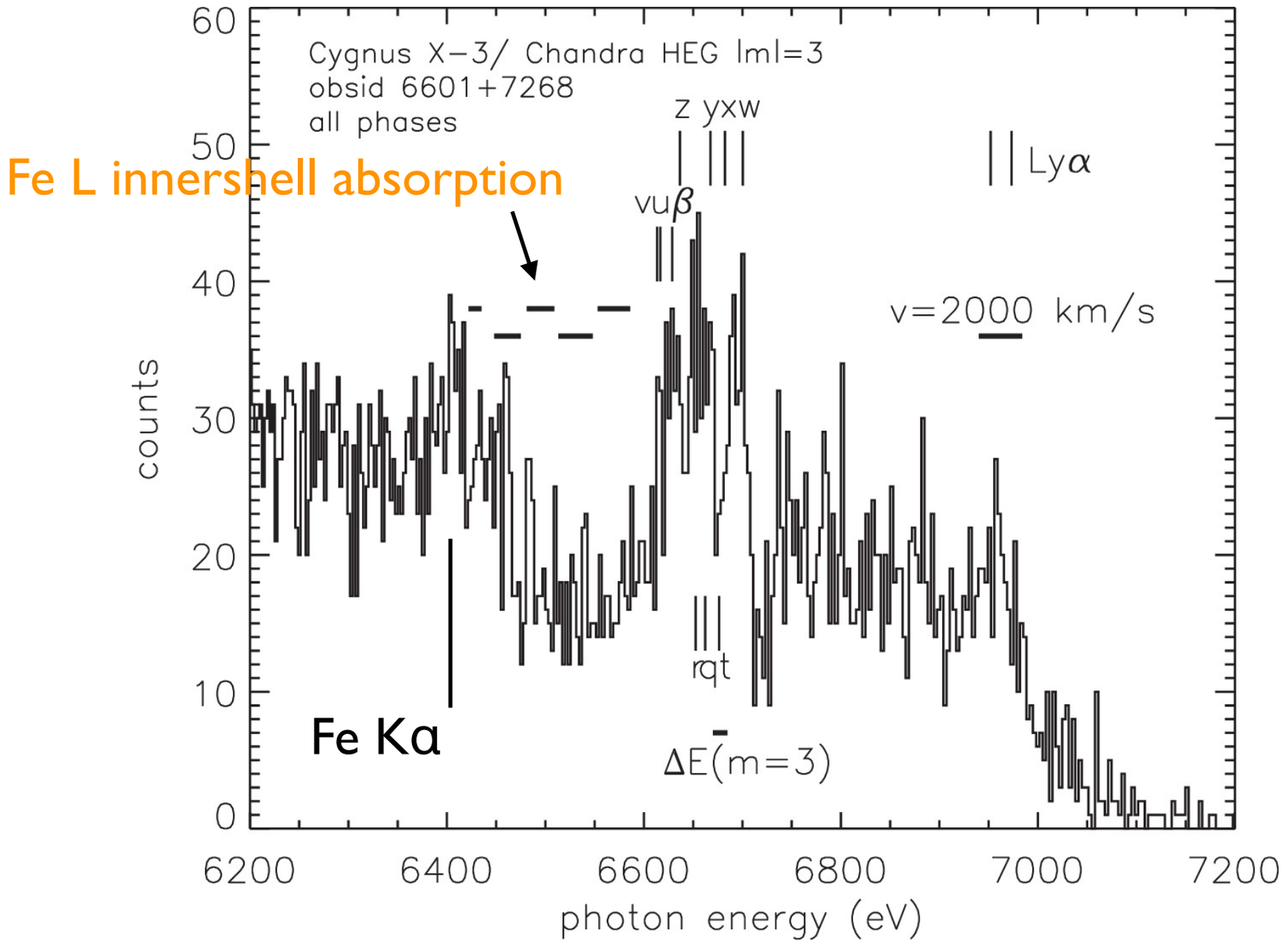


'rest frame' photon energy (z = 0.0077)

this is tough to do around Fe K with limited S/N

try the very nice *Chandra* spectral archive at `tgcat.mit.edu` !

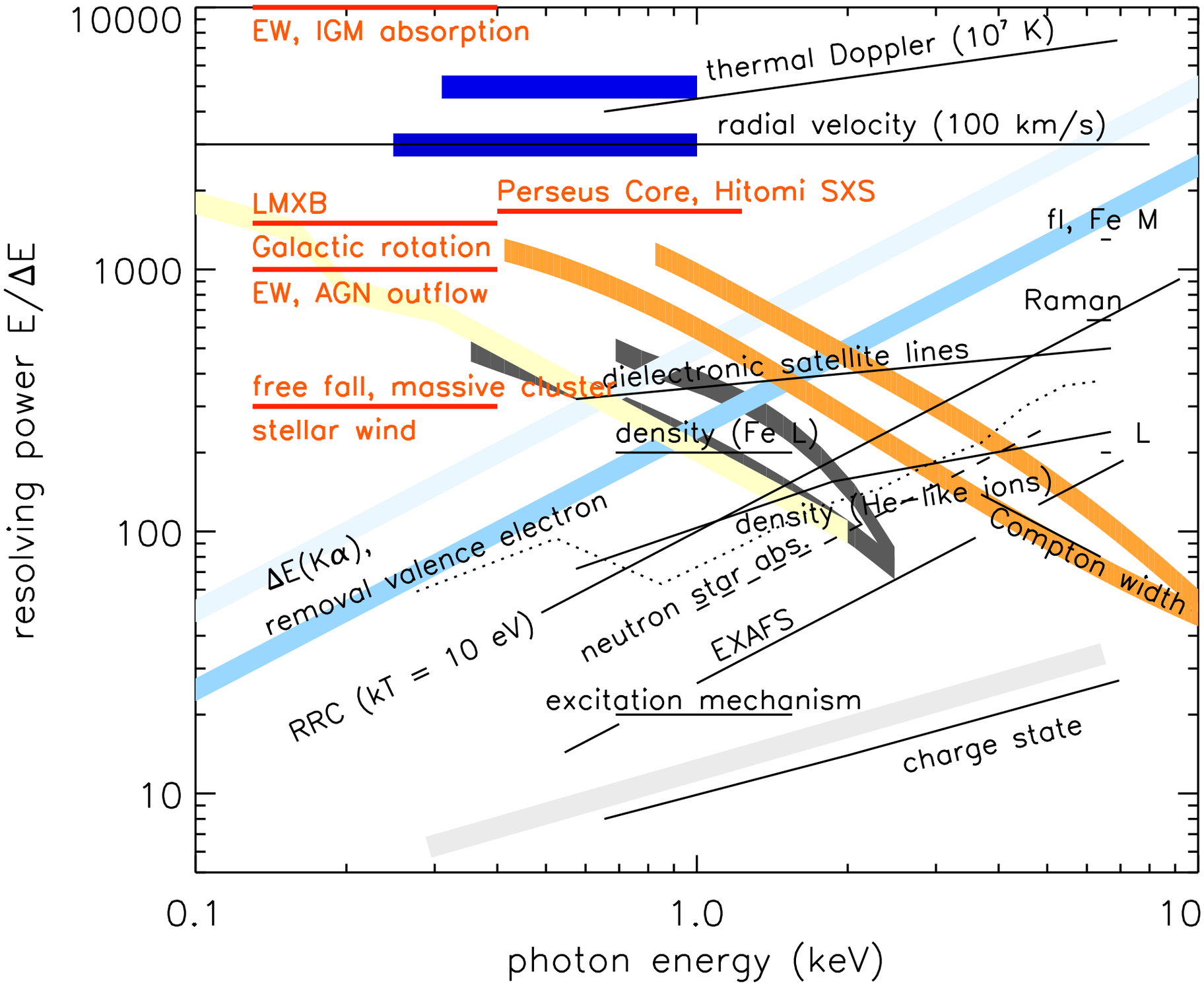
example from another photoionized source: Cygnus X-3



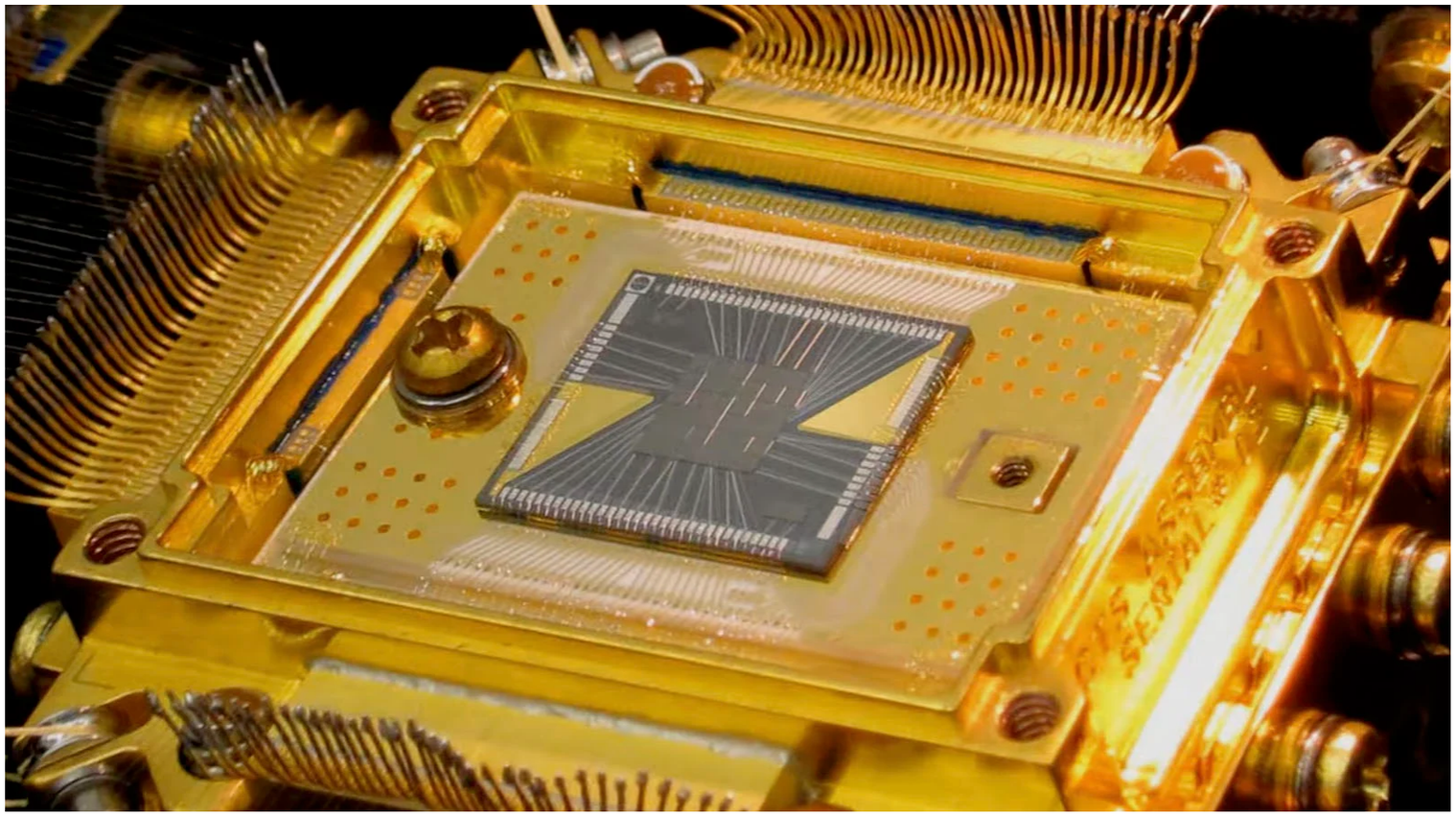
make sure to check out the XRISM spectrum of Cygnus X-3!!

Aswath Suryanarayanan *et al.*, *Ap.J.*, **969**, 110 (2024)

sensitive spectroscopy in the Fe K band…



the microcalorimeter spectrometer *Resolve* on XRISM
launched 1 year ago, just finished PV/SV; GO starting



© NASA

several Nobel prizes went into this instrument!

(liquid He: K. Onnes [1913]; ADR: Chien-Shung Wu → parity violation, Lee & Yang [1957]; quantum theory of heat capacity of solids: A. Einstein [1921])

6x6 array (3x3 arcmin); angular resolution 1.7 arcmin HPD (*)

ΔE = 4.5 eV

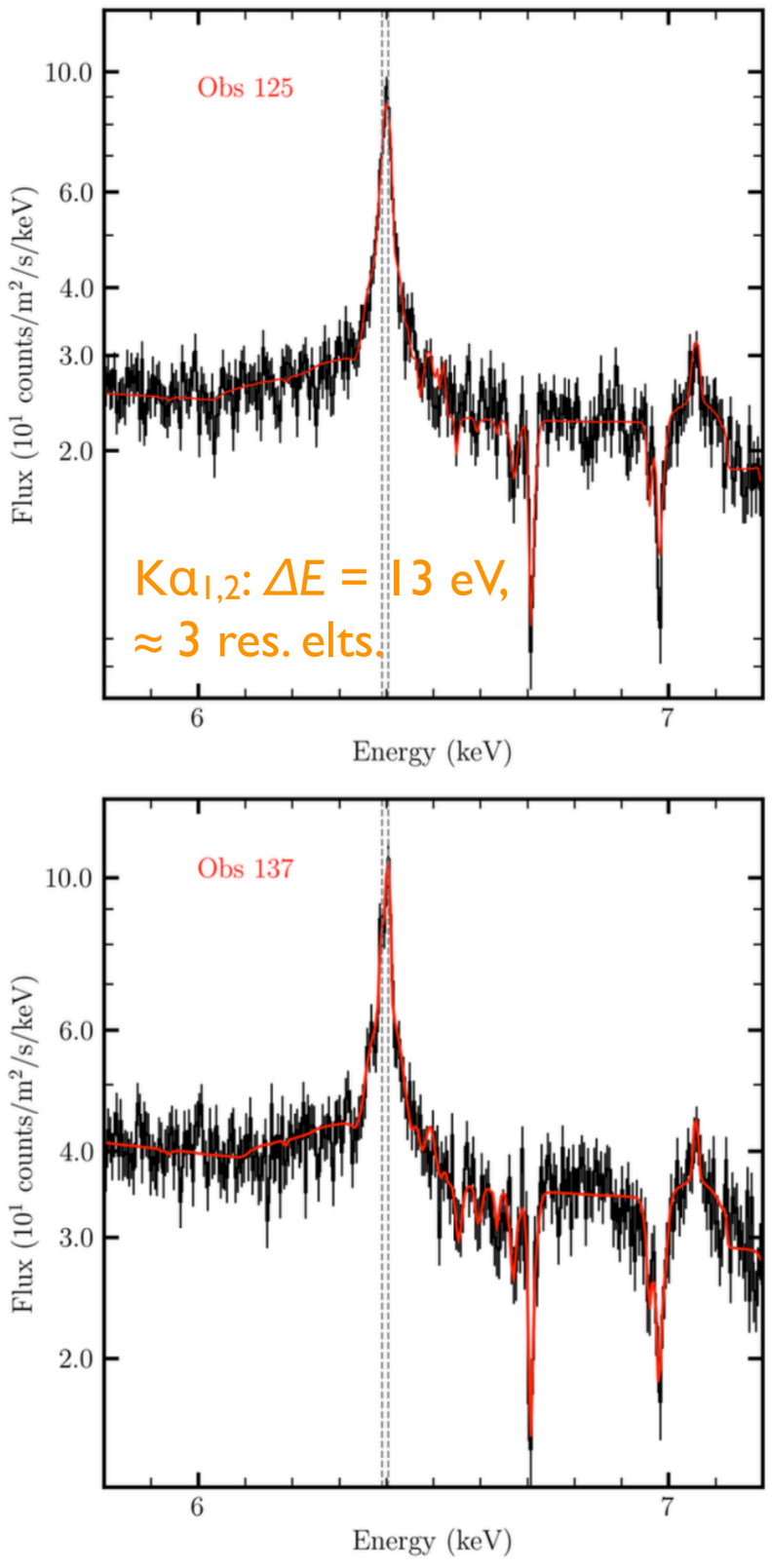
cooled to 50mK; cryogenic lifetime unlimited (even after LHe gone)

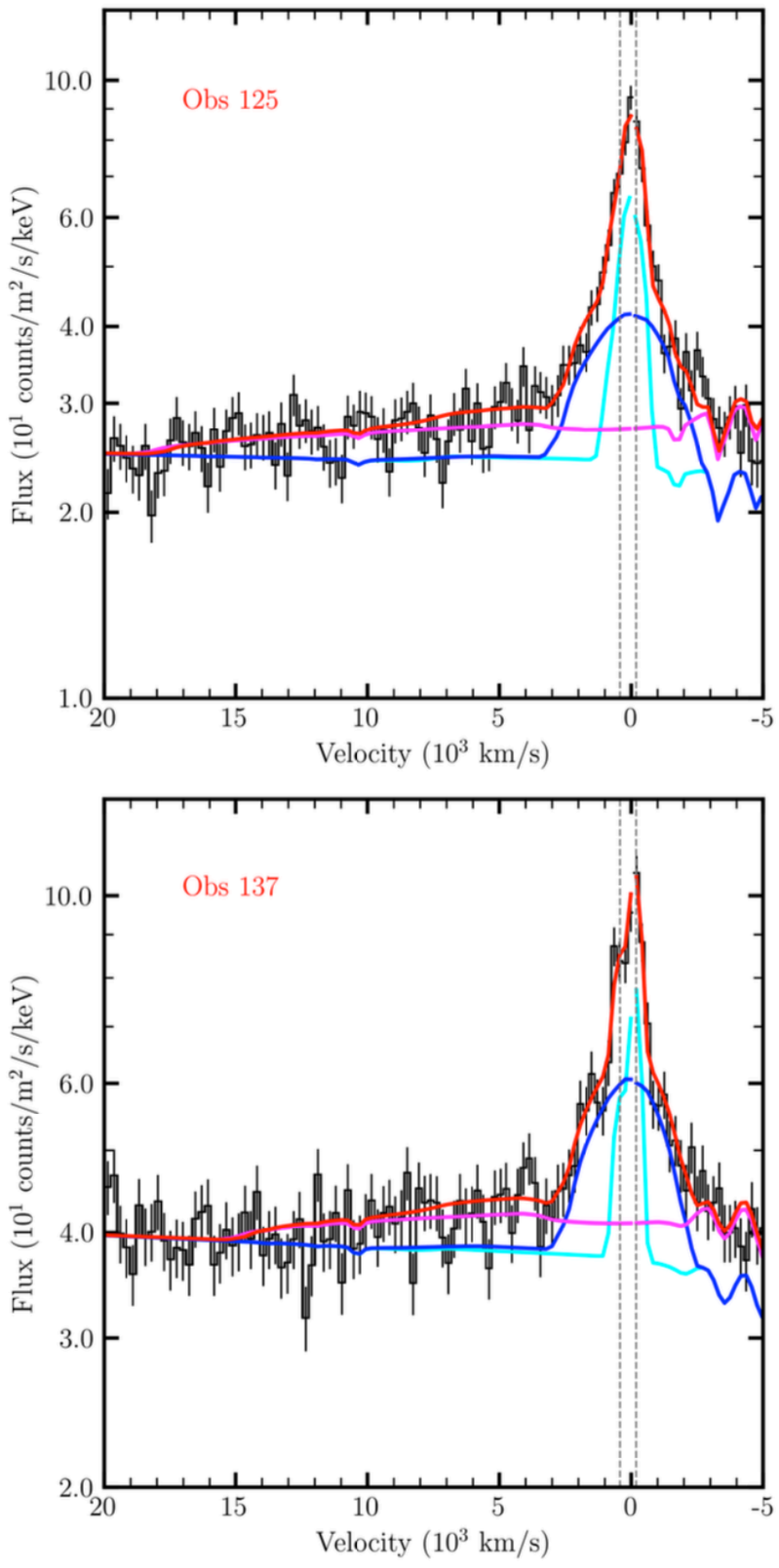
(*) but of course for point sources we don't care that 3.3 ≈ 1.7

outflows, winds:
mass- and angular momentum accretion balance

now probably entering new phase:
absorption spectroscopy
with microcalorimeter sensitivity

among first results from XRISM: Seyfert 1.5 NGC4151





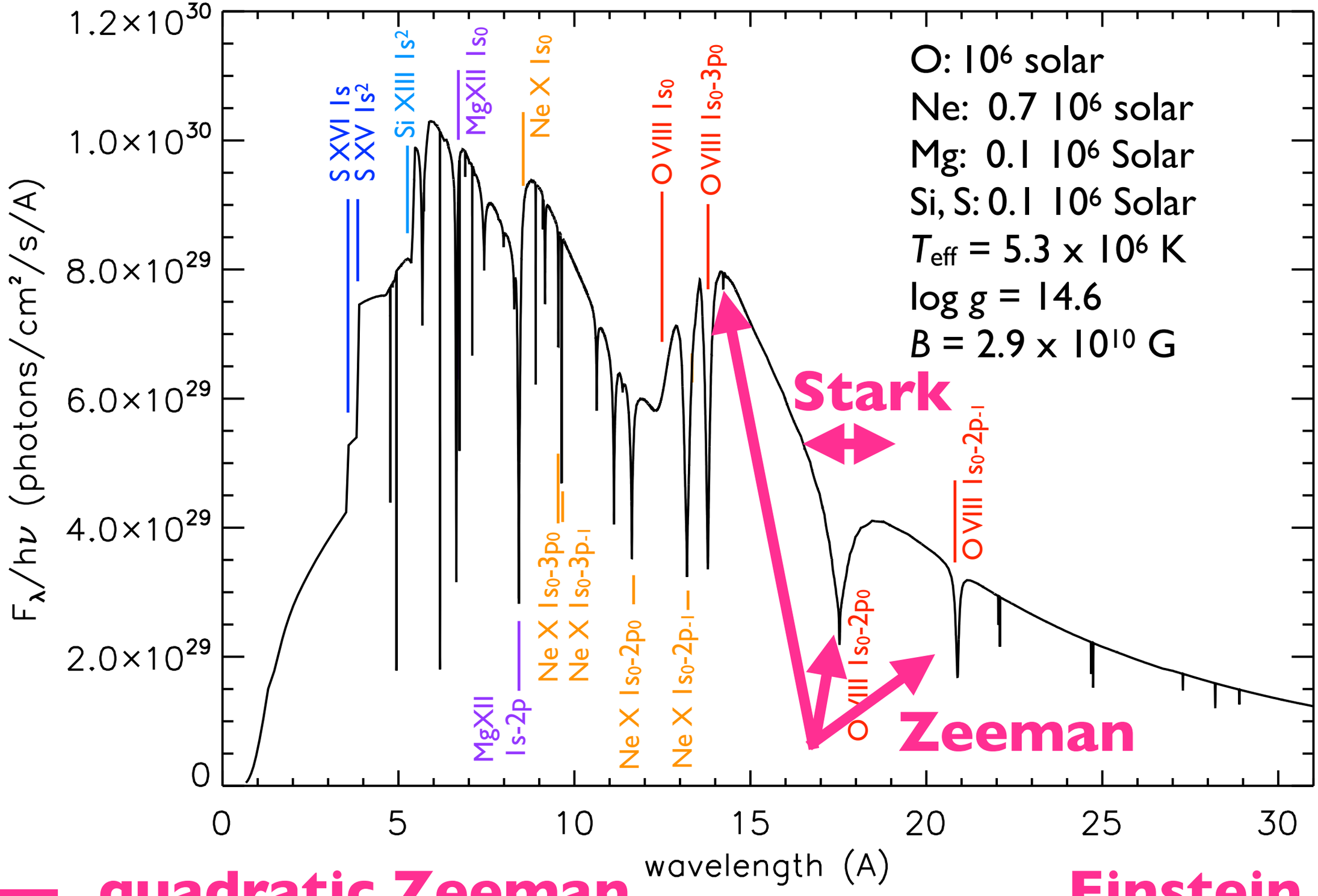
A 1.5, so presumably we see the BH vicinity, but there is also large EW fluorescent emission from distant 'torus' and related structures.
But just to make the point: we'll get high sensitivity view of nuclear region: outflows, fast (ultrafast?) winds

There will soon be a lot more like this!

XRISM collaboration, Jon Miller (C.A.), `arxiv` 2408.14300 (August 26, 2024)

spectroscopic dessert

Hot Neutron Star X-ray Spectrum: Zeeman, Stark, and Einstein



← **quadratic Zeeman** **Einstein** →

RX J0822-4300 Puppis A
Chandra LETGS 385 ksec

T_{eff} = 5.3 x 10^6 K
log g = 14.6
B = 2.9 x 10^{10} G
z = 0.29

counts/0.10 A

wavelength (A)

Si XIII $1s^2$
S XVI $1s$
S XV $1s^2$
Ne X $1s_0$
O VIII $1s_0$
Ne X $1s_0$-$2p_{-1}$
O VIII $1s_0$-$3p_0$
O VIII $1s_0$-$2p_0$
O VIII $1s_0$-$2p_{-1}$

What Other BH Spectroscopy Can We Think Of?

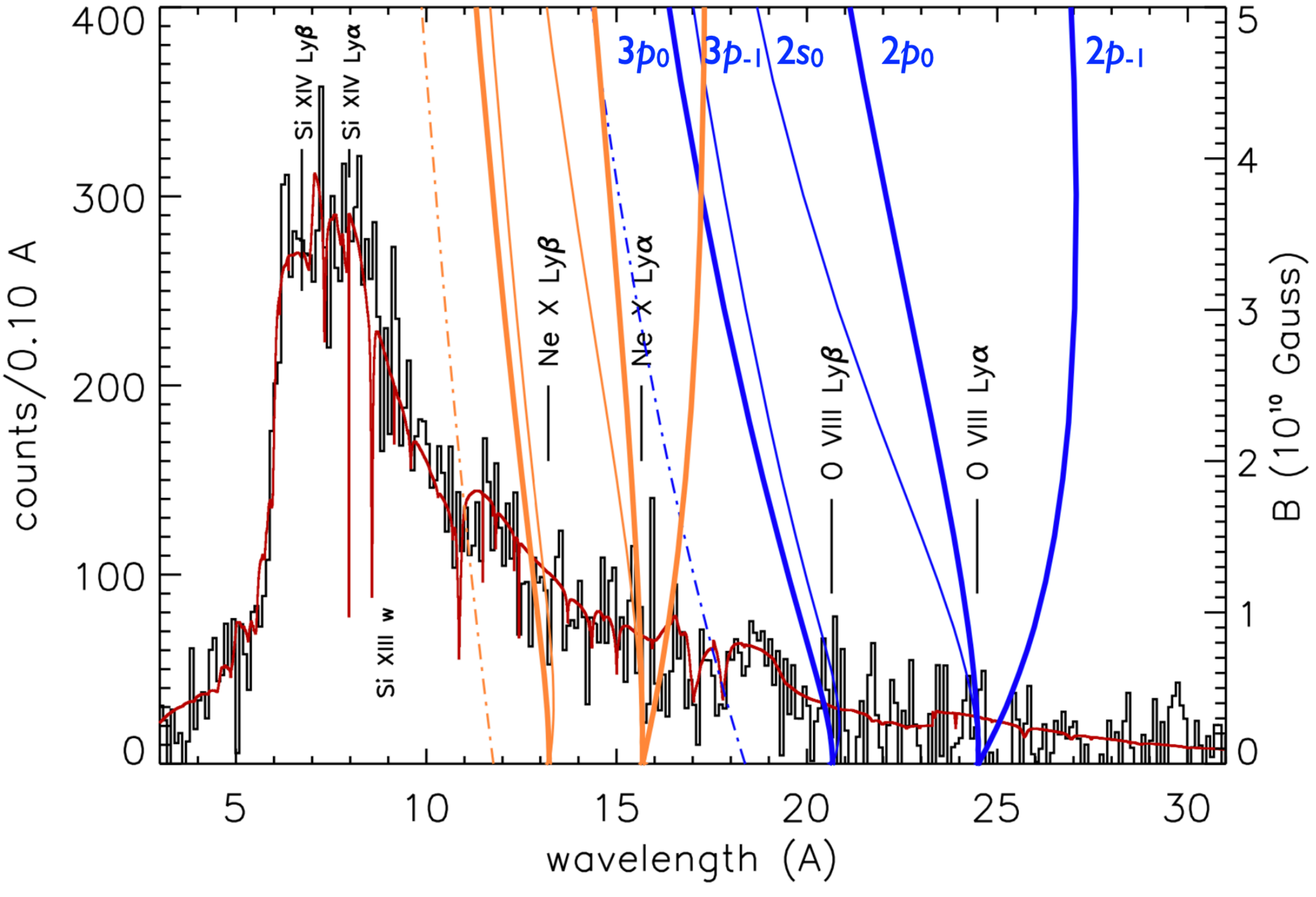
Maybe Fe Kα reverberation with XRISM?
gas flow at few GM/c^2

polarization and Zel'dovich' 'gravitational Zeeman effect' ??

.....

Thank you!

Zeeman!!


counts/0.10 A
400
300
200
100
0
Si XIV Lyβ
Si XIV Lyα
Si XIII w
Ne X Lyβ
Ne X Lyα
O VIII Lyβ
O VIII Lyα
3p0
3p-1
2s0
2p0
2p-1
5
10
15
20
25
30
wavelength (A)
B (10^10 Gauss)
5
4
3
2
1
0