Laboratory astrophysics:

Investigating the mystery of low charge states of Si in the HMXB Cyg X-1

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ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Lawrence Livermore National Laboratory

The High Mass X-ray Binary Cygnus X-1

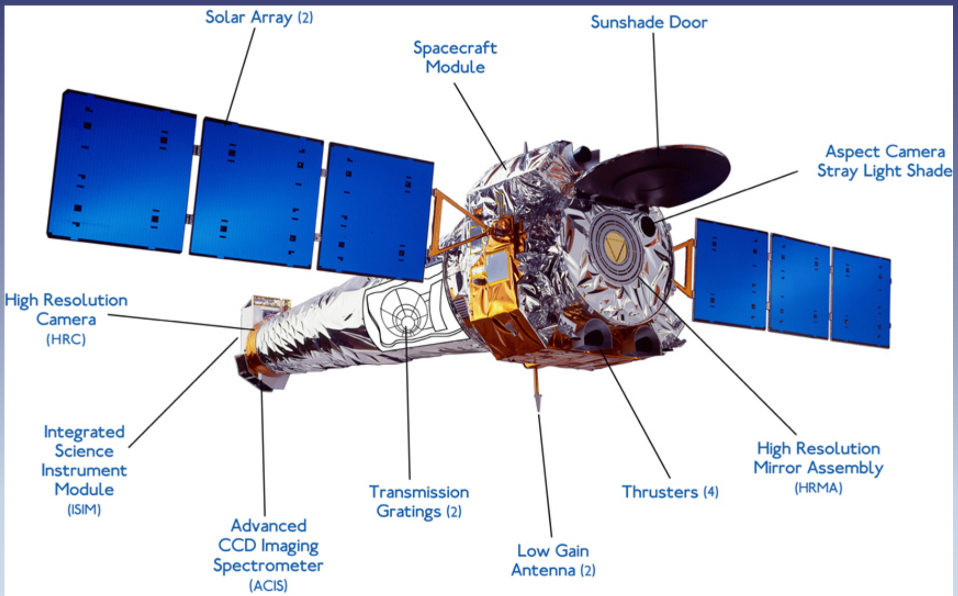
http://www.spacetelescope.org/static/archives/posters/screen/cygnus_x1.jpg

- binary separation $a = 41\,R_\odot$
- orbital period $P = 5.6d$
- inclination $i \approx 35^\circ$
- distance $d = 6000\,\mathrm{ly}$

HDE 226868: O9.7 supergiant
$M_\star = 18M_\odot$
$L_\star = 250\,000L_\odot$
$R_\star = 17R_\odot$
fills $\approx 90\%$ of Roche lobe volume
wind mass loss $\dot{M}_\star = 3 \cdot 10^{-6}M_\odot$

Cyg X-1: black hole
$M_{\mathrm{BH}} = 10M_\odot$
$L_X \approx 10\,000L_\odot$

Chandra's view



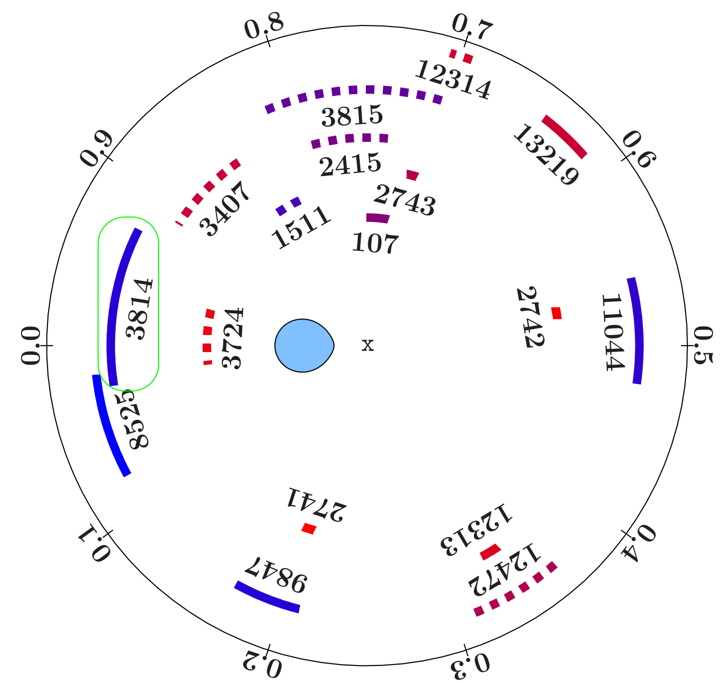
http://www-xray.ast.cam.ac.uk/xray_introduction/Chandra.html

Chandra:

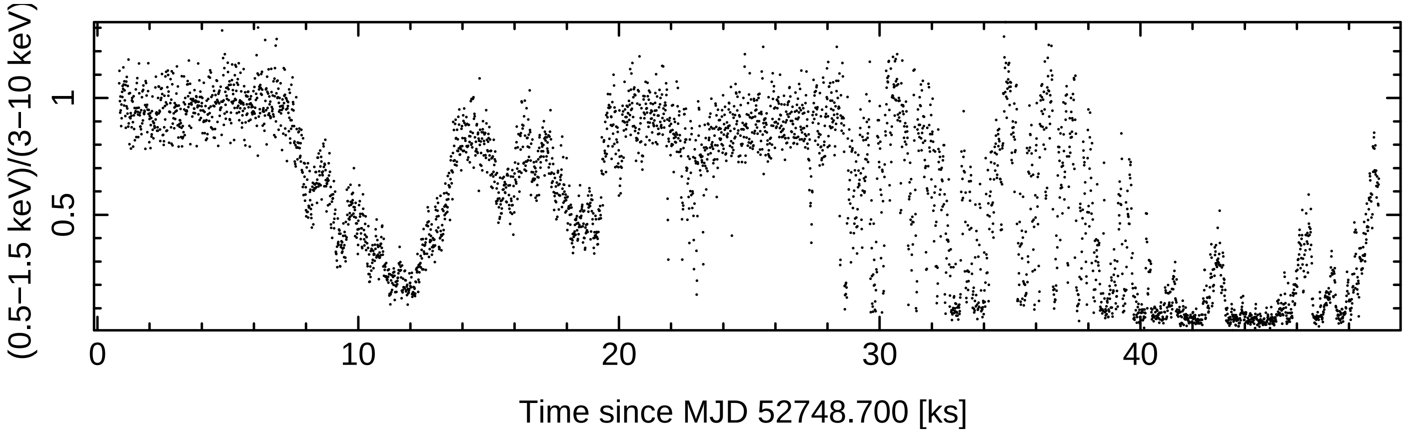
- launched in 1999
- energy range 0.1-10 keV
- HETG: High Energy Transmission Grating

ObsID 3814:

- 19/20 April 2003
- 48 kilo seconds
- phase -0.08 - 0.03



Low charge states of Si



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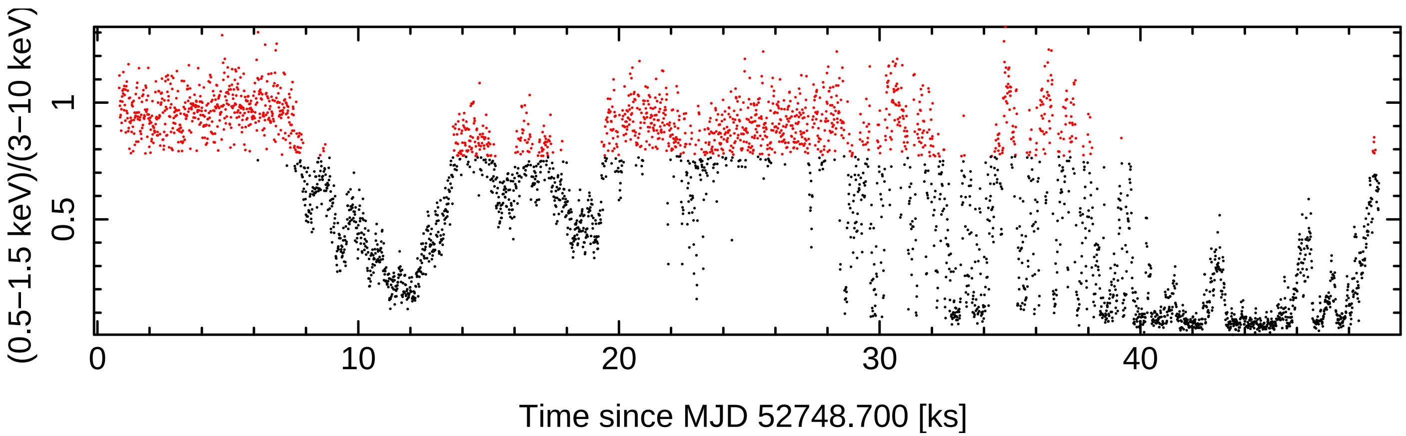

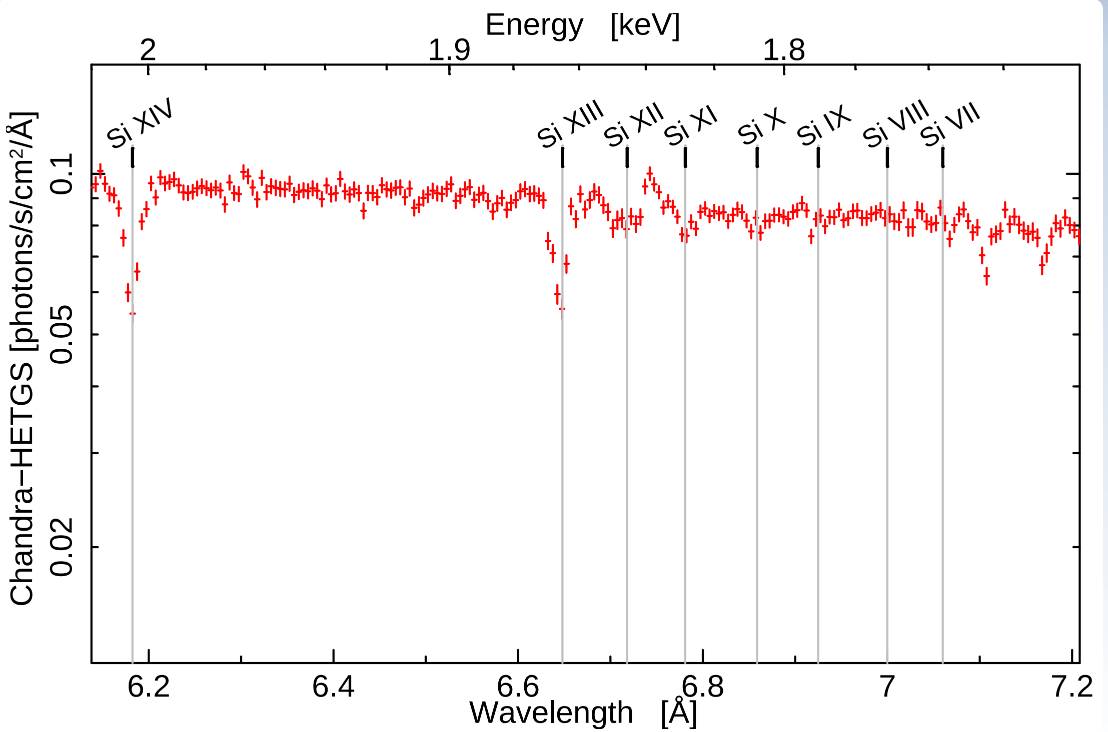

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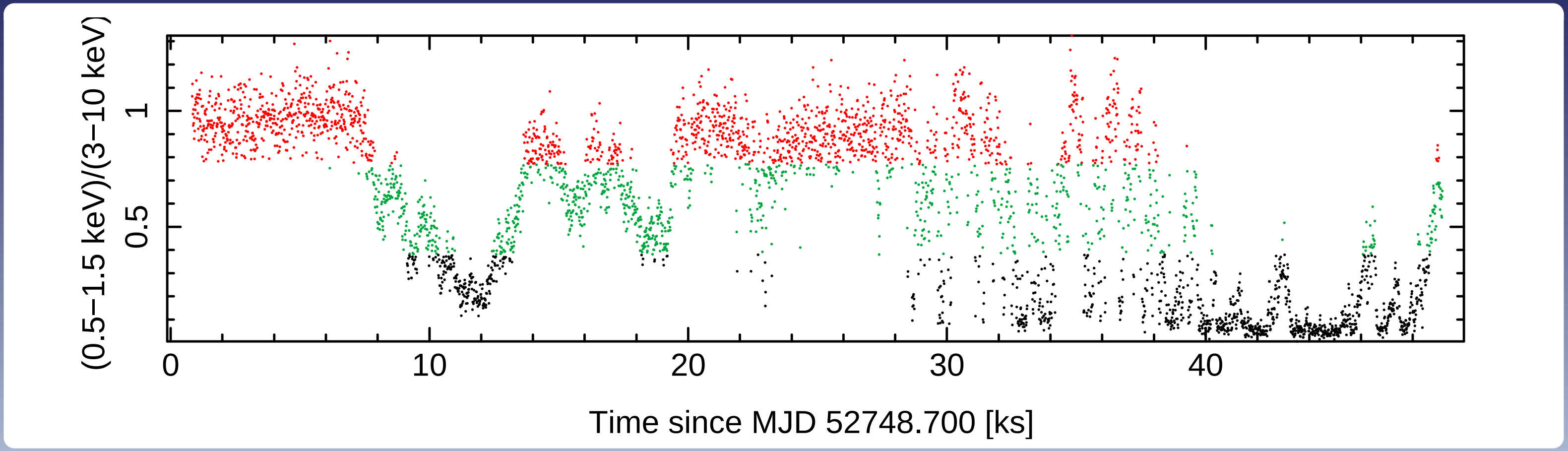

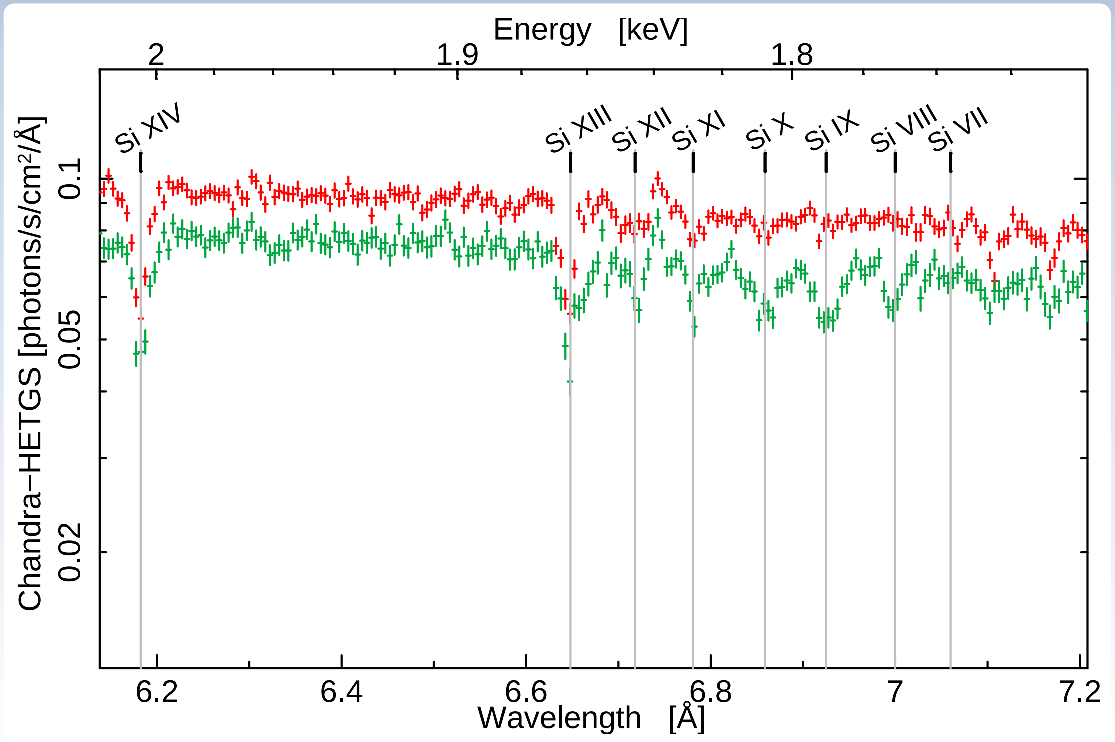

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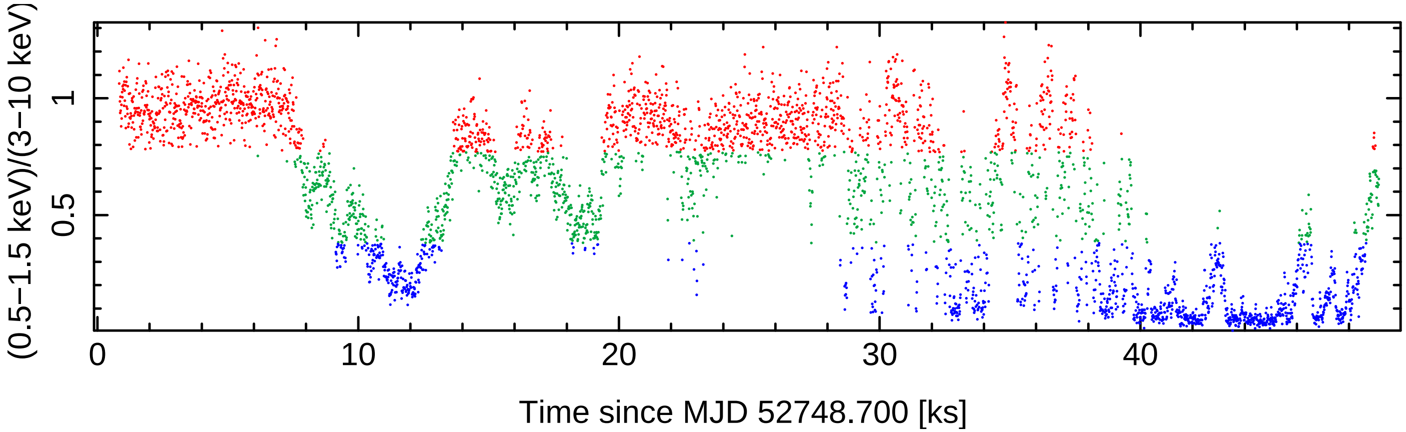
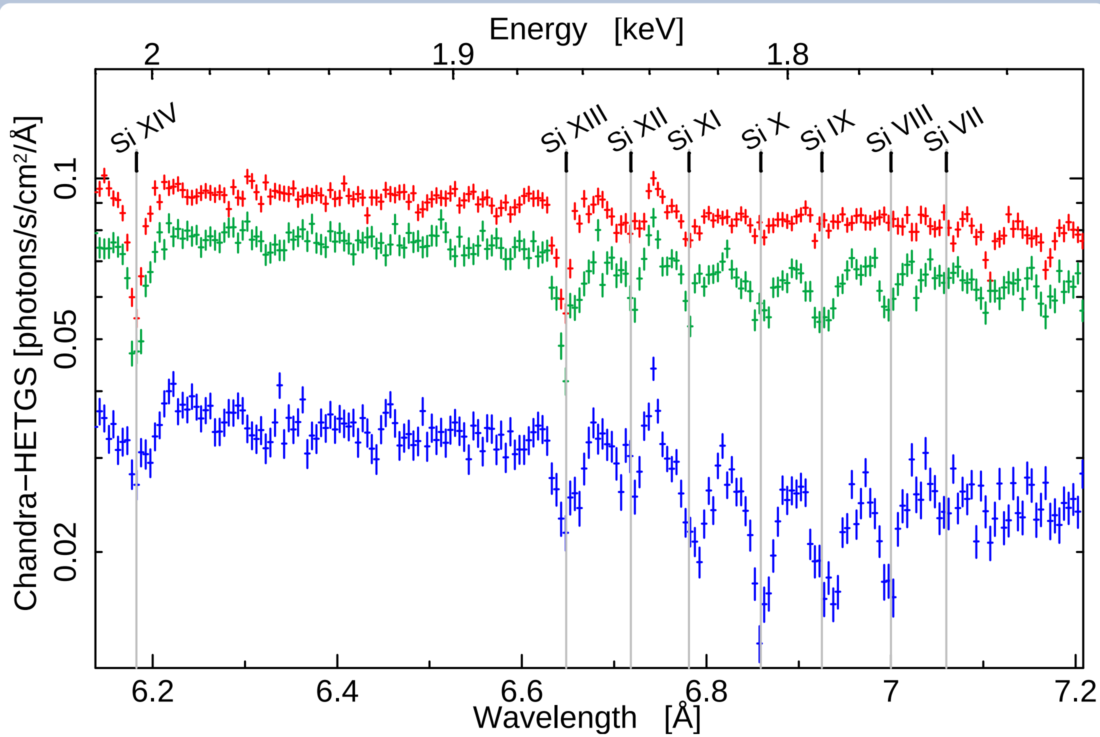
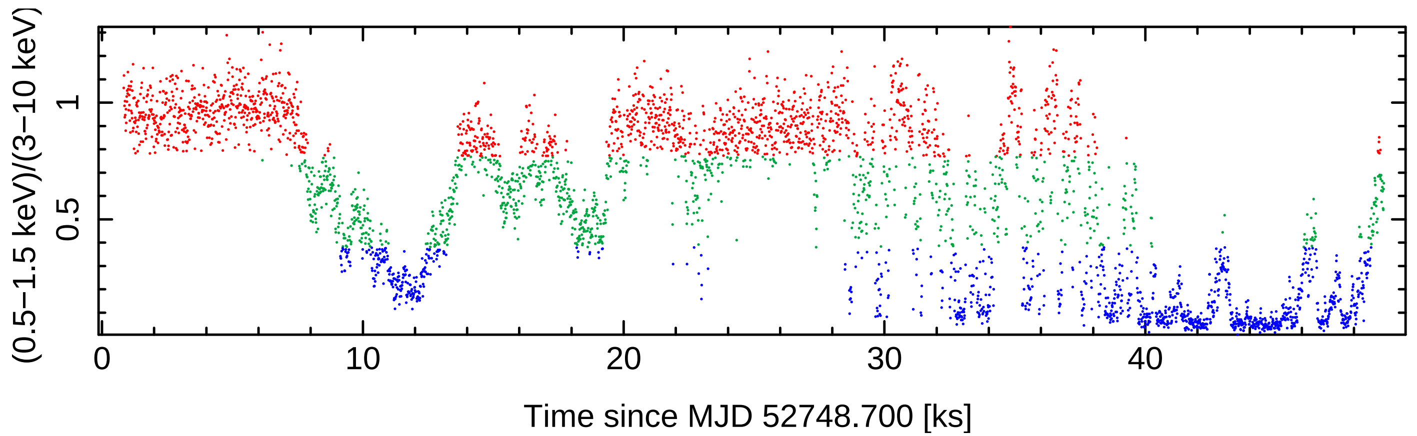
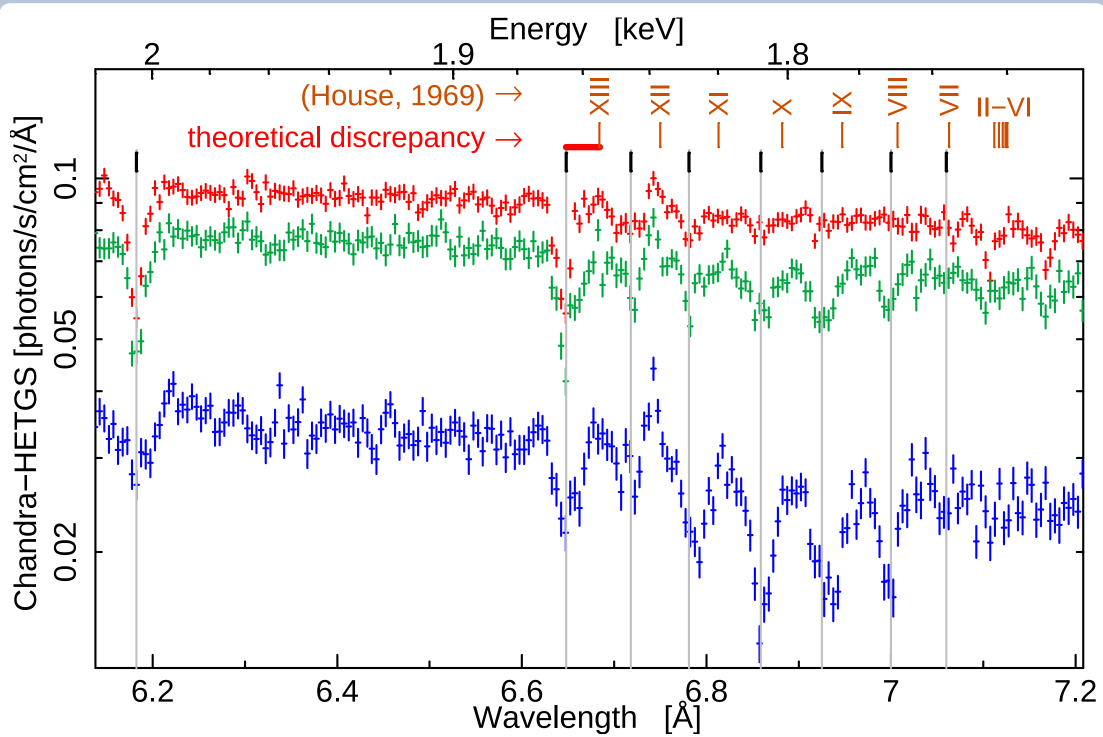




lower charge states of Si with increasing dipping!

Low charge states of Si

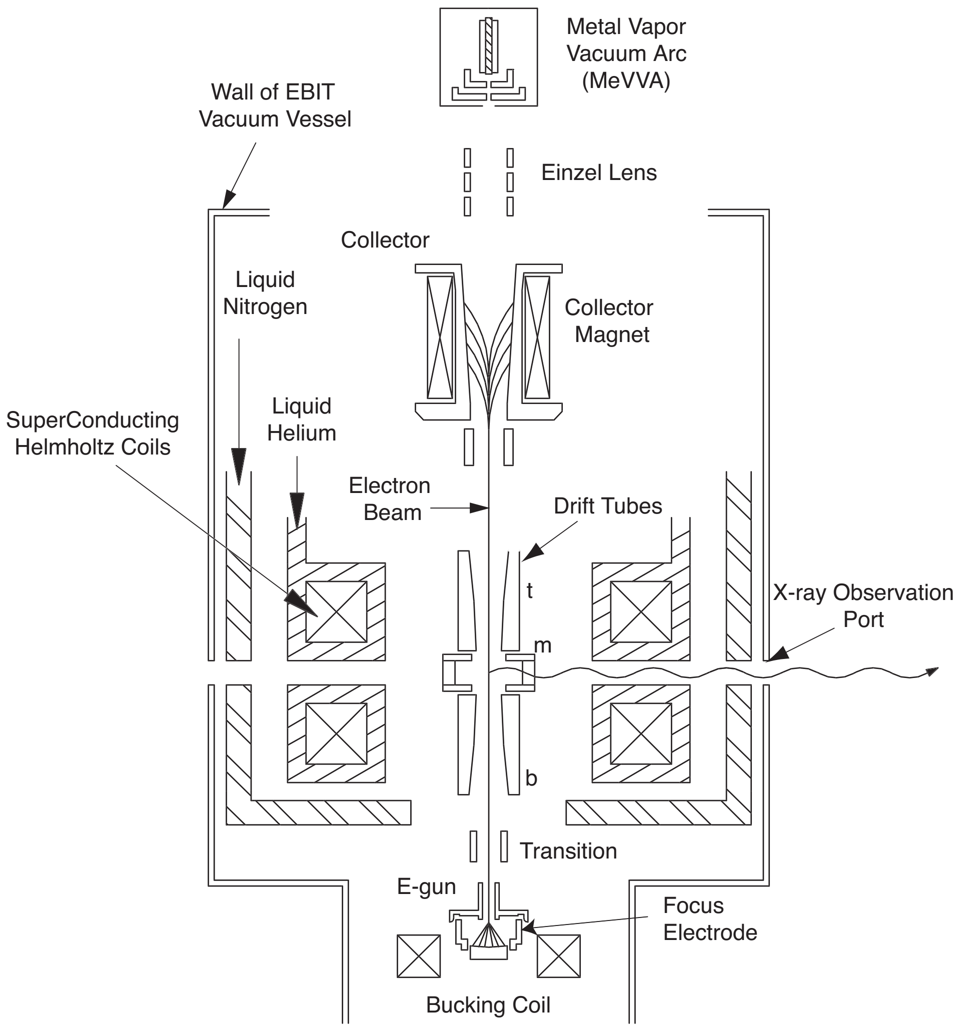




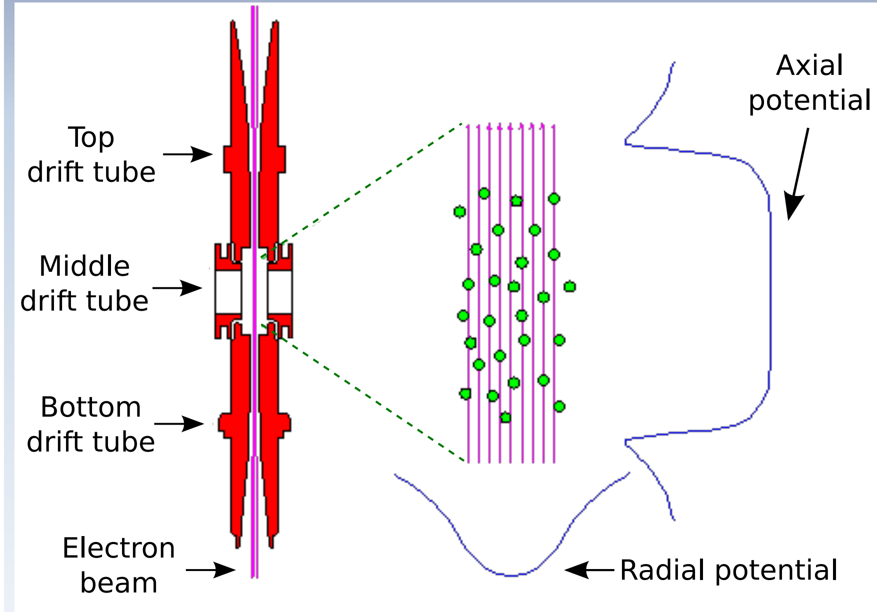
large difference between Si line centers in Cyg X-1 and theoretical values

$\Rightarrow$ Doppler shifts or atomic physics?

The Electron Beam Ion Trap (EBIT)

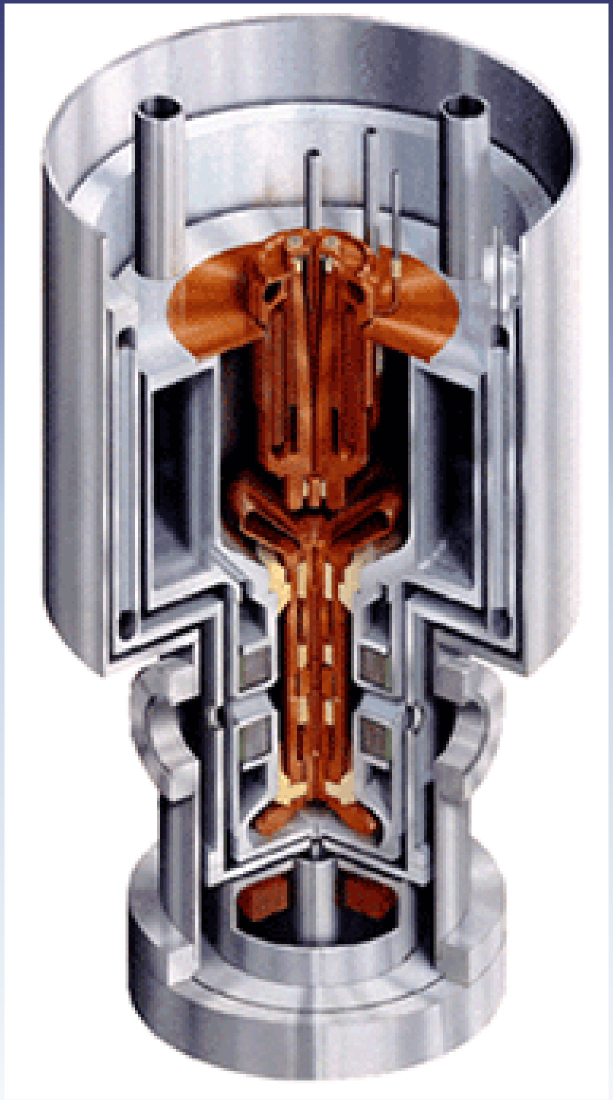


G. V. Brown

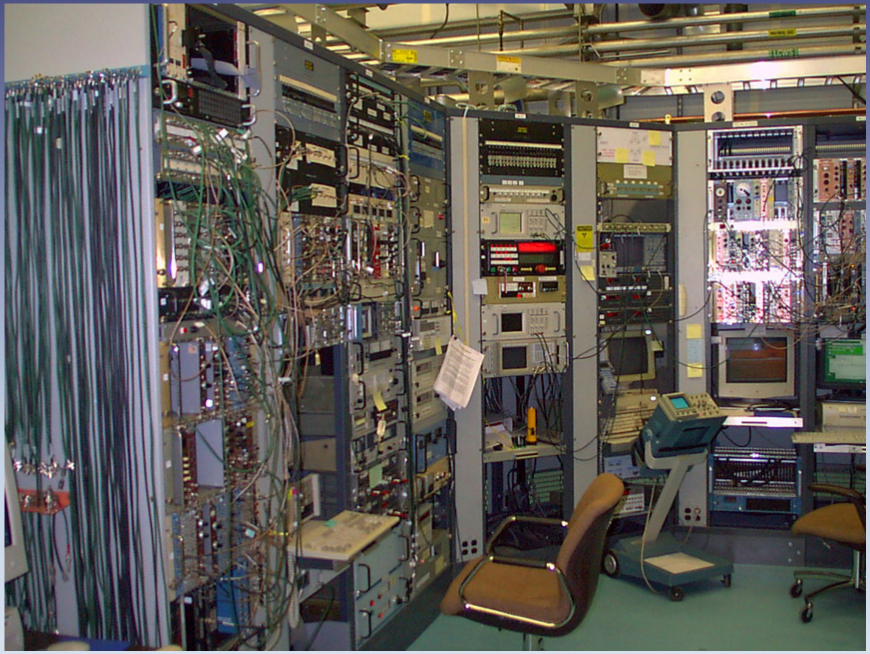


https://ebit.llnl.gov/overviewEBIT.html

EBIT-I @ LLNL



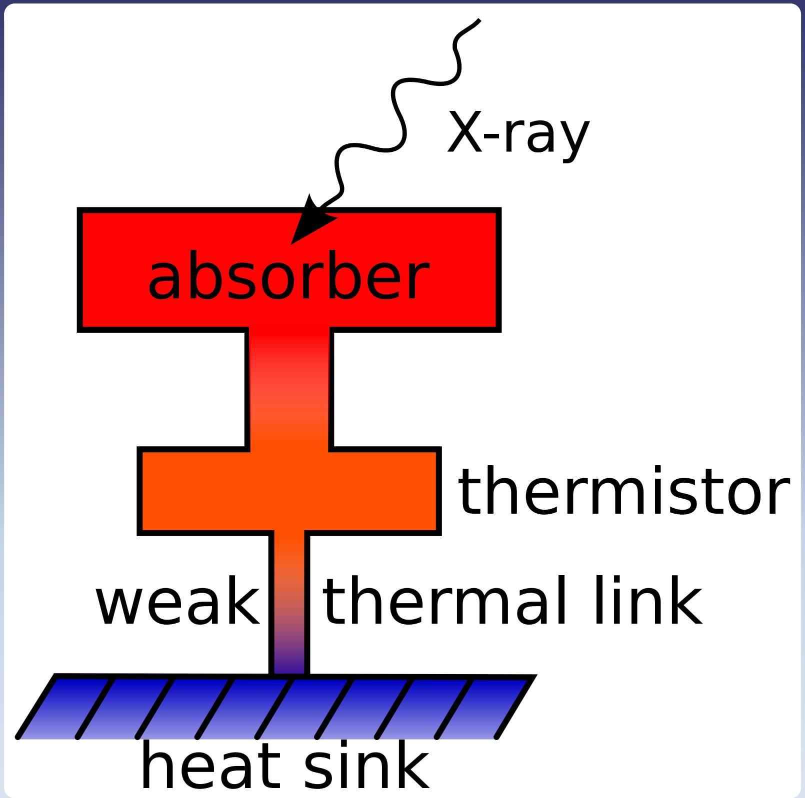
https://ebit.llnl.gov/



https://ebit.llnl.gov/EBITPhotoGallery.html

high energy variant, SuperEBIT, can produce bare Uranium (U^{92+})

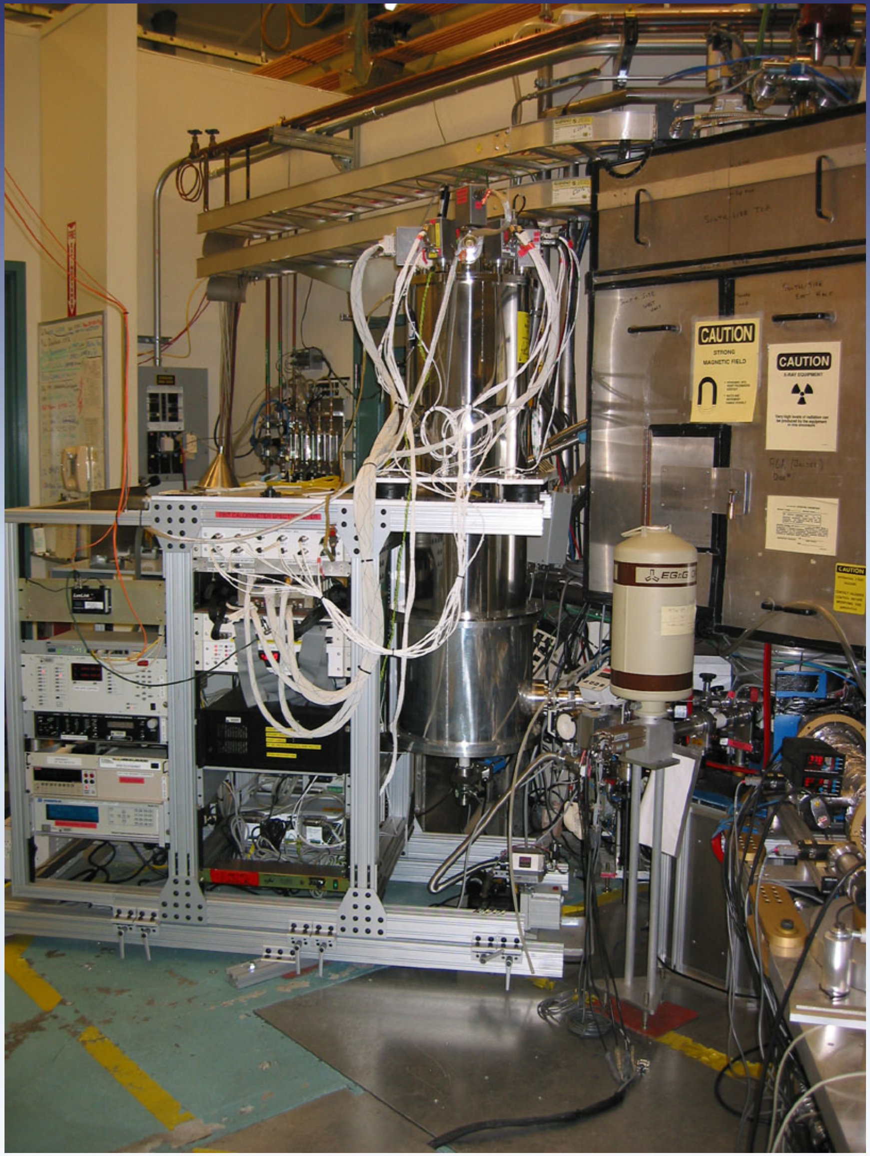
Principle of a microcalorimeter



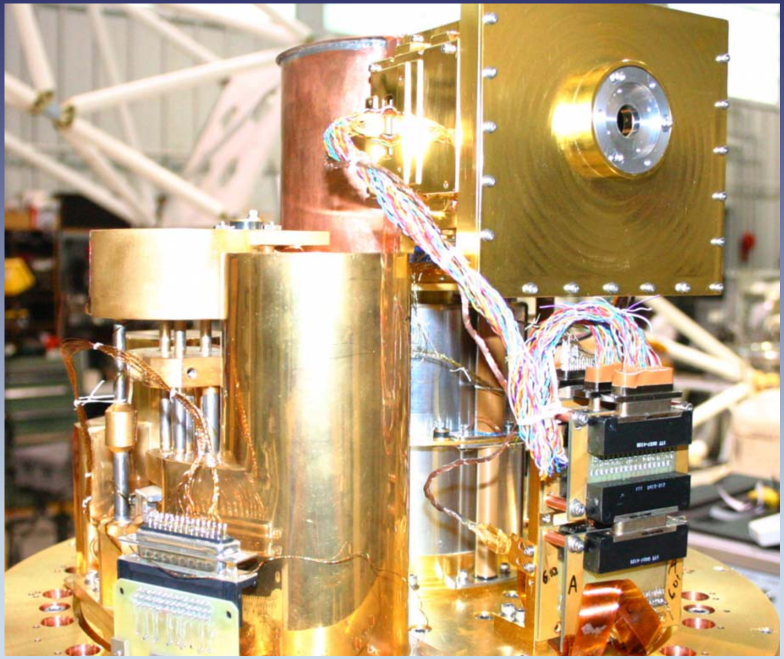
- Absorber: low heat capacity
- Thermistor: electrical resistance strong function of temperature
- Heat sink: Adiabatic Demagnetization Refrigerator: $T < 0.1\,\mathrm{K}$

- X-ray photon knocks electron loose
- photoelectron rattles in absorber $\rightarrow$ rise in temperature $\Delta T \sim E_{\mathrm{photon}}$ (few mK!)
- wait for thermal equilibrium $\rightarrow$ measure resistance

The EBIT Calorimeter Spectrometer (ECS)



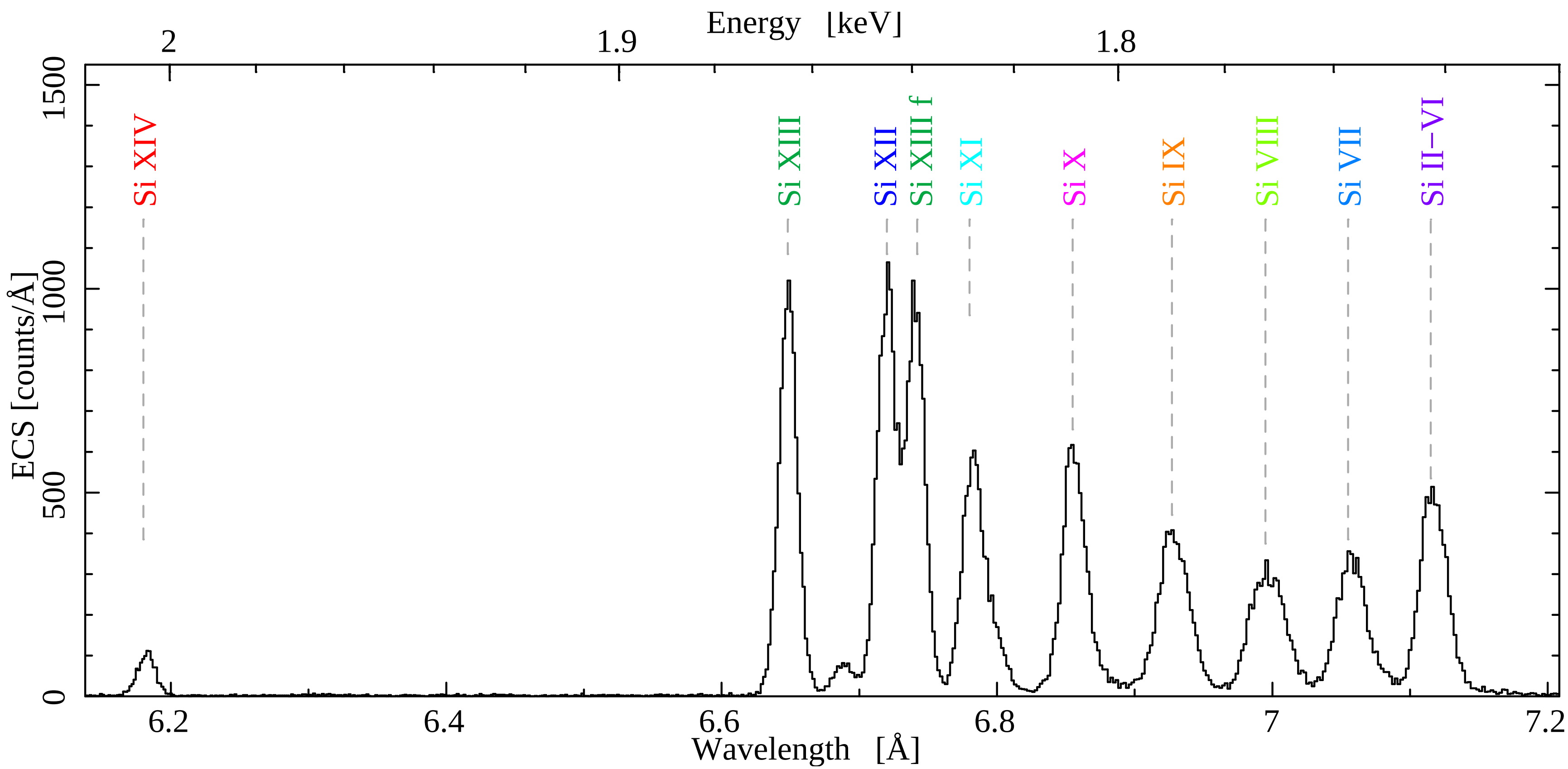
`https://ebit.llnl.gov/EBITPhotoGallery.html`



F. S. Porter 2008

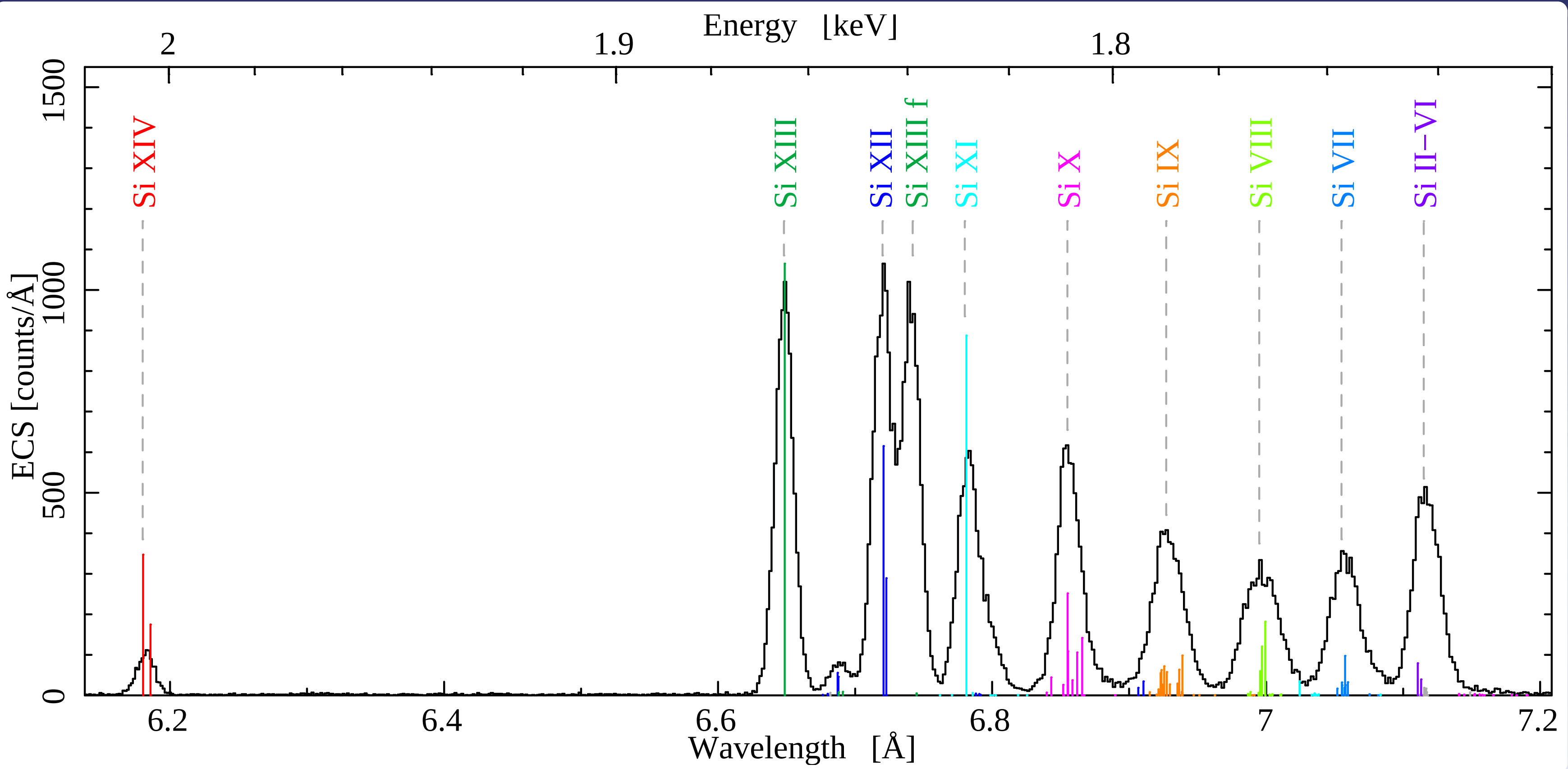
- operated at 50 mK
- 32 HgTe pixels:
- 18 mid energy: 0.1-10 keV
  625 x 625 μm^2, 8 μm thick
- 14 high energy: 0.5-100 keV
  625 x 500 μm^2, 100 μm thick

The Spectrum



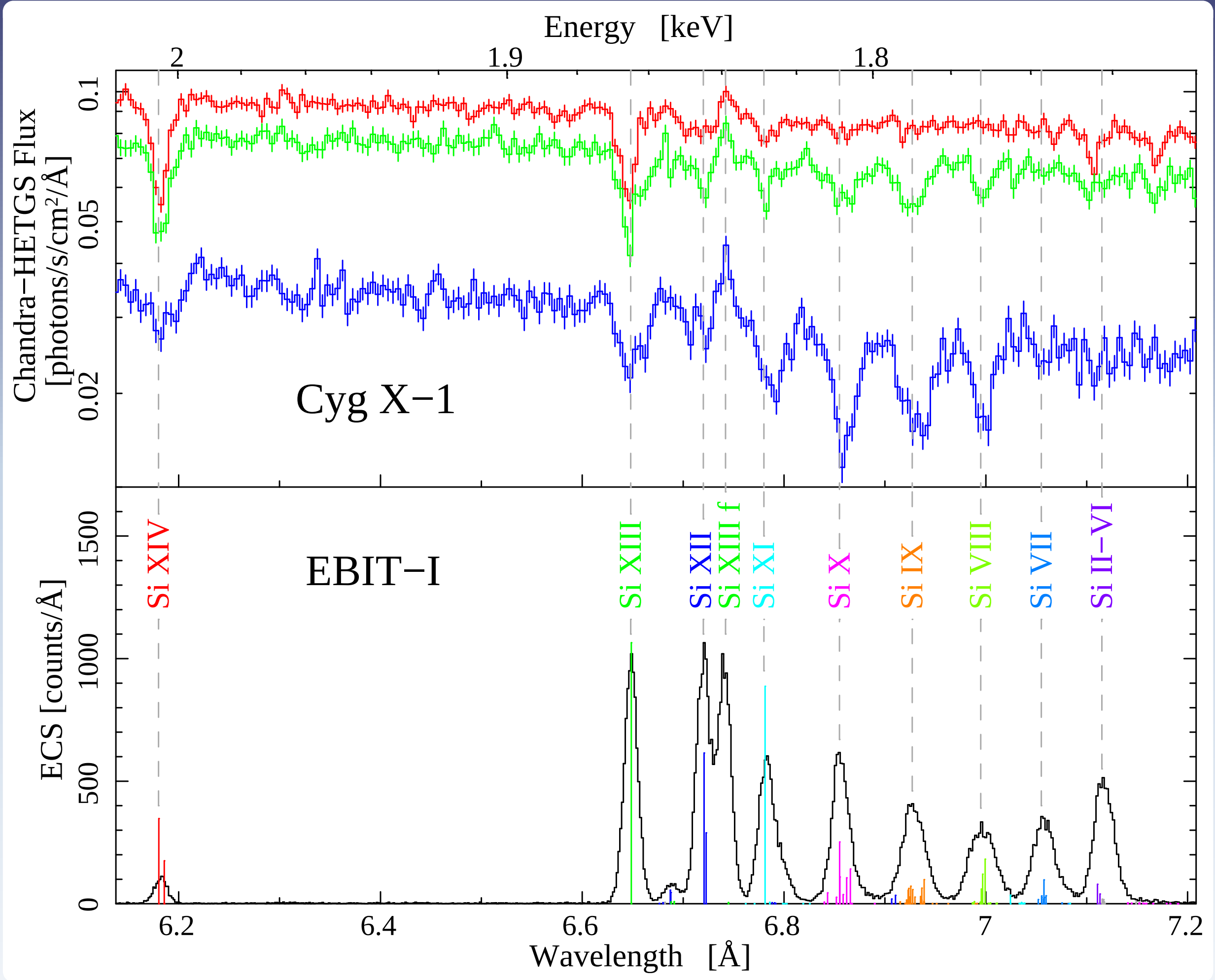
- resolution: 4.47 eV FWHM
- line w: fit: 1864.801 eV theory: 1864.9995 eV (Drake'88)
- Ly α: fit: 2005.64 eV theory: 2005.49 eV (Garcia'65)

The Spectrum



- colored sticks: output of the Flexible Atomic Code (FAC; M. F. Gu 2004)
- compare theoretical predictions with fits to help the line identification

Closing the circle



much better agreement of Cyg X-1 with laboratory spectrum than with theory

Doppler shifts of the order of few ten to $\sim$ 100 km/s