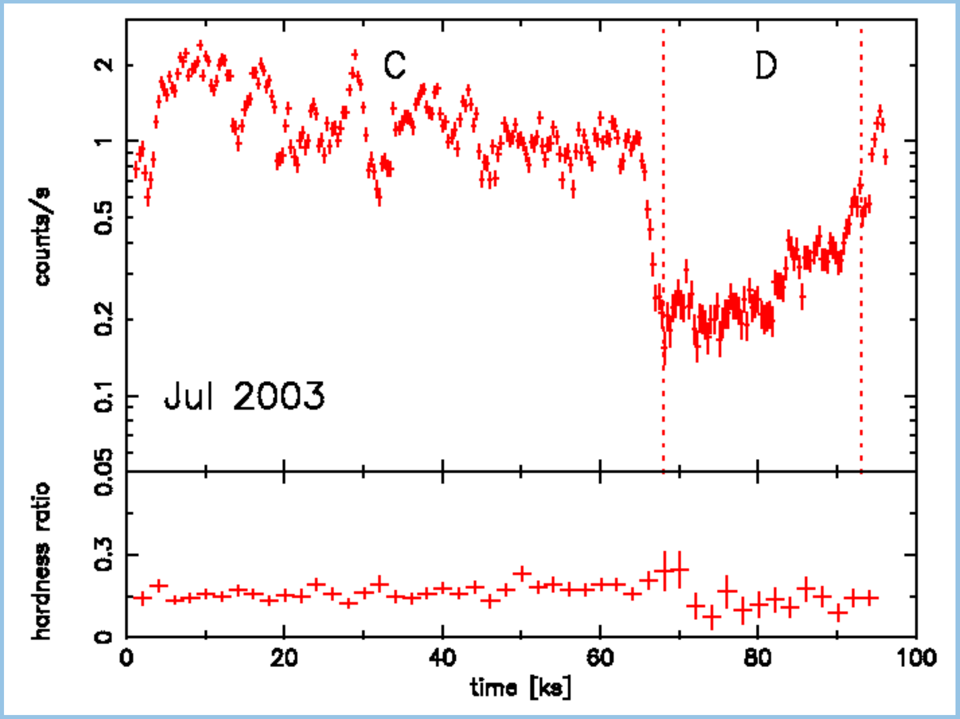
Locating the warm absorber in NGC 4051

Katrien C. Steenbrugge
St John's College, University of Oxford
Jelle S. Kaastra, Elisa Costantini
SRON Netherlands Institute for Space Research
Frank Verbunt
Astronomical Institute, Utrecht University

NGC 4051: introduction

- Seyfert 1 galaxy at a distance of 18.6 Mpc.
- Detected and classified by Seyfert (1943).
- Discuss 2 LETGS observations of ~95 ks each and separated by 18 months.
- Exists HETGS and RGS spectra: high velocity component (-2340 km s^{-1}, Collinge 2001; relativistic and Gaussian broadened emission lines, Ogle 2004).
- Uniqueness of the 2^{nd} observation is that the flux dropped by ~5, with relative stable flux levels before and just afterwards.

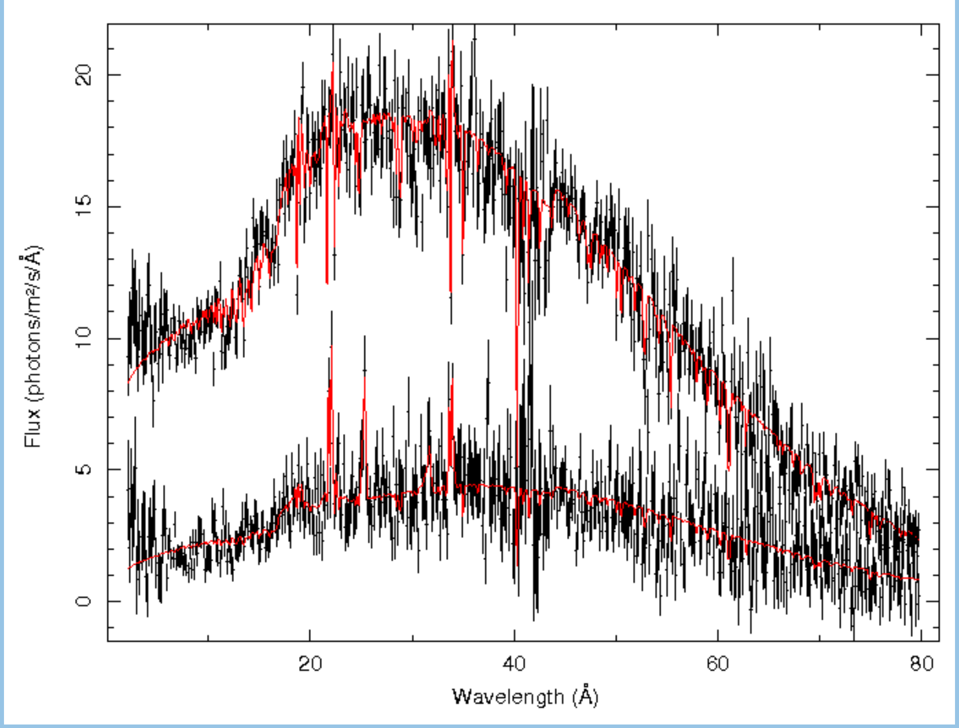
Lightcurve NGC 4051



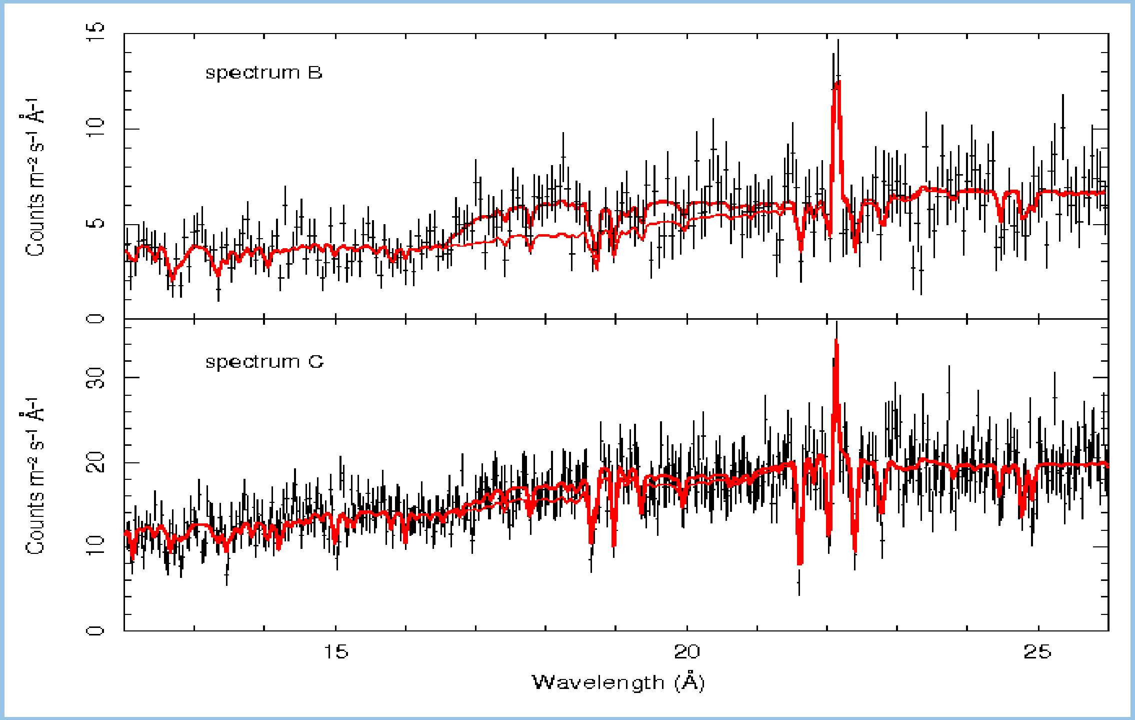
- Flux level during part C, lasting ~65 ks was at the average long time flux.
- Drop occurred in 3 ks.
- In part D flux is at the low state for ~20 ks before rising again.
- Also split 1st observation in 2 parts, a very low state A and a similar flux level as D, called part B.

Continuum

- Extracted 4 spectra for the different parts of the lightcurve.
- Fitted the continua of the spectra separately.
- The black body temperature to 1st order follows the flux, highest in spectrum C and lowest in spectrum D.
- Power law slope becomes softer with time.



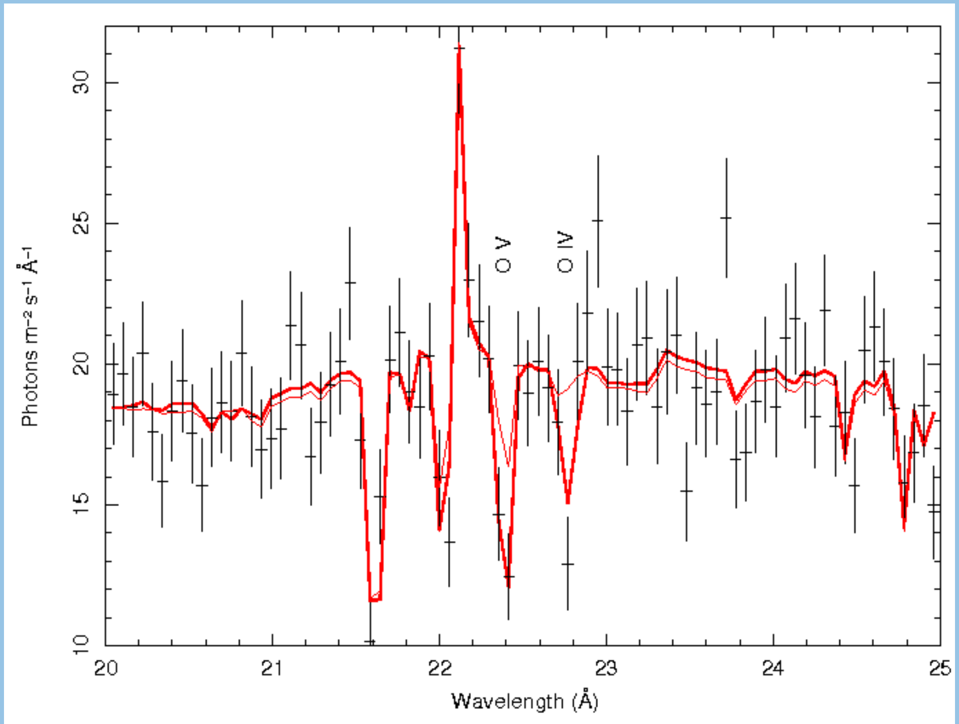
Continuum



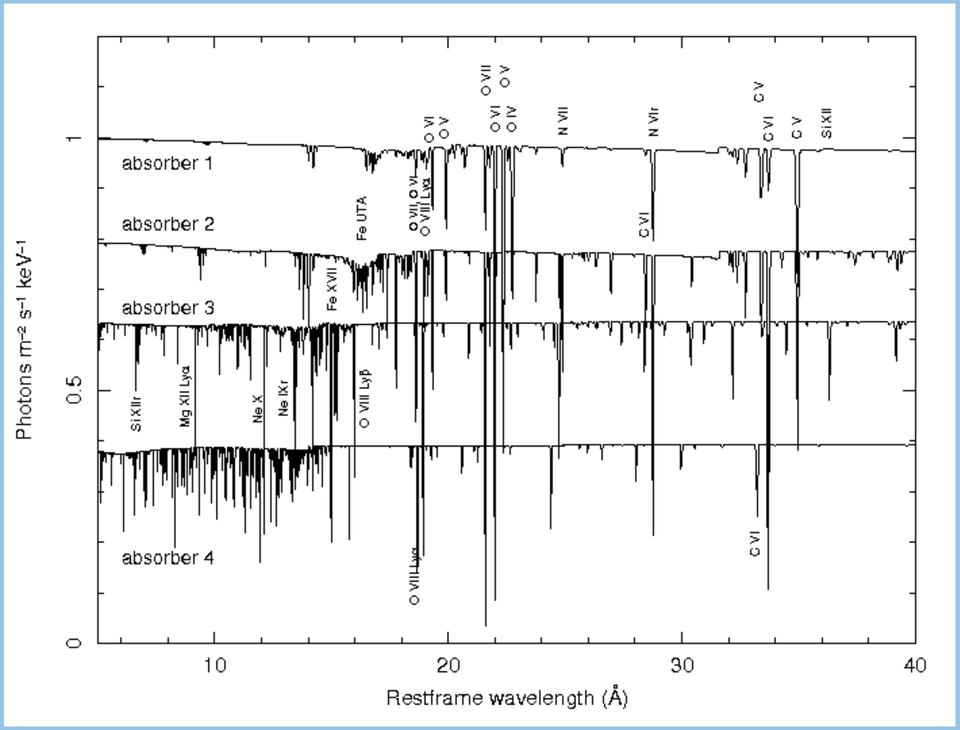
- The power law and black body components do not fit parts of the continuum adequately.
- There are several Å-wide parts of the continuum showing excess emission, best fitted by relativistically broadened emission O VIII Lyα and broadened O VII triplet and C VI Lyα. Consistent with the results of Ogle et al. 2004 from the RGS analysis.

Spectra

- Extracted separate spectra for the different parts of the lightcurve.
- Spectrum C, due to the highest flux and longest exposure time, has the highest signal-to-noise ratio.
- Fitted spectrum C first, then used the model spectrum for fitting spectrum A, B and D.
- Need 4 photo-ionization components.

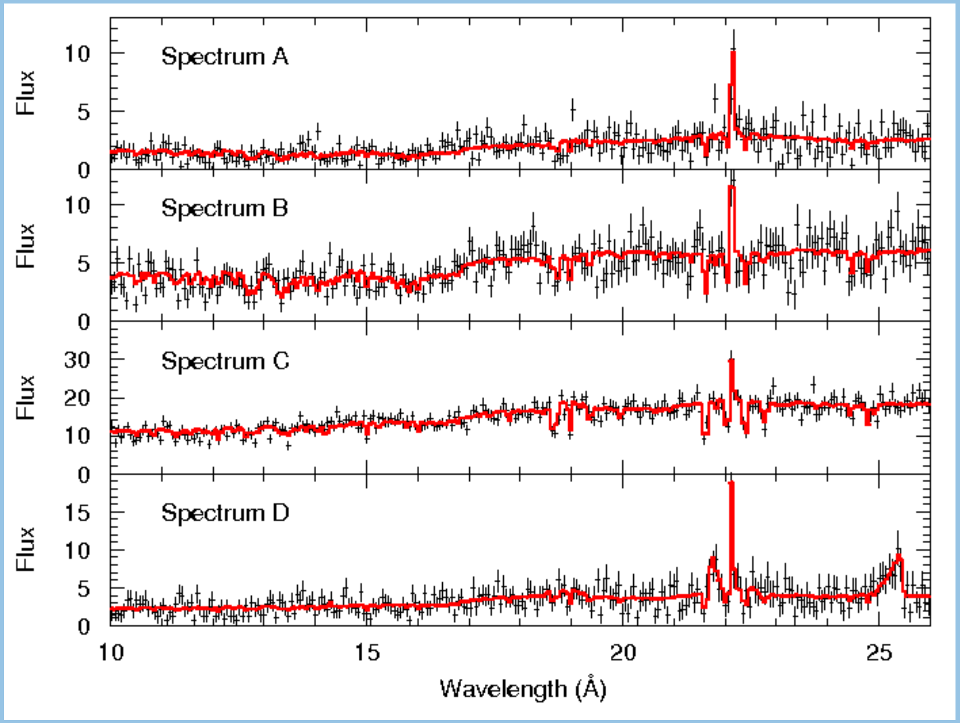


Spectra



- Spectrum C was fitted by 4 photo-ionization components (xabs), leaving hydrogen column density, ionization parameter and outflow velocity free parameters.
- The best fit model for spectrum C was used as a template of which only the ionization parameter and continuum parameters were free for spectrum D.
- Similarly for spectrum B and A.
- For spectrum B, D and A only 3 components are needed.

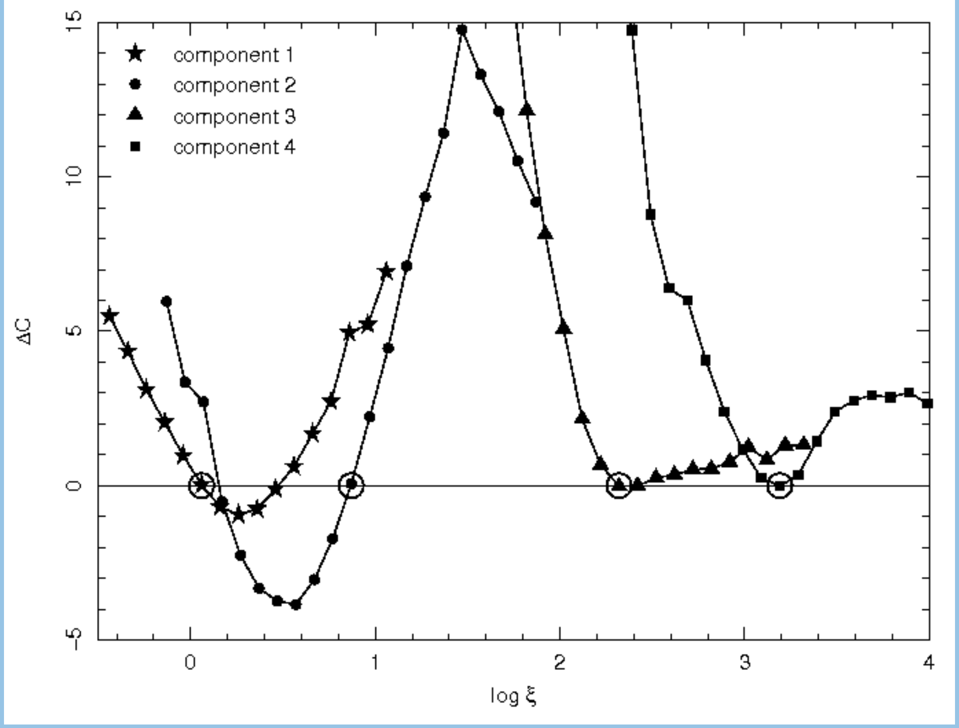
Spectral variability



- Spectrum D shows radiative recombination continua (RRC) from C VI and possible C V.
- From the emission measure and temperature we can determine corresponding hydrogen column density and ionization parameter and try to match this component to one of the absorption components.
- There is no absorption component with the combination.
- Alternative, arising from the accretion disk.

Spectral variability

- Using model for C we fit spectrum D, stepping through different ionization parameters, at each point refitting the spectrum.
- For absorption components 1,3 and 4 the best fit is for an unchanged ionization parameter.
- For component 2 the best fit ionization parameter is lower, 0.52 instead of 0.87 (log in 10^{-9} W m).
- This decrease is smaller than the decrease in flux, possibly the gas is still recombining or the flux change in the far UV (important for the ionizing flux at low ionization parameters) did not decrease as drastically.



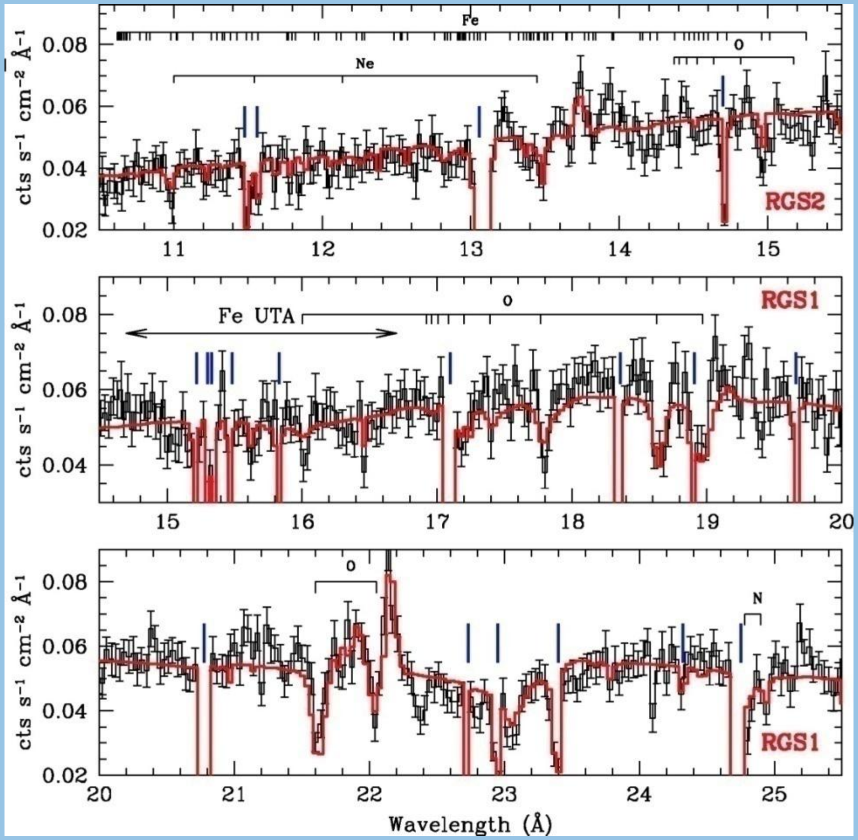
Distance of the absorbers

- From spectral variability, or the lack thereoff in 3 components, the luminosity and the ionization parameter, one can obtain the distance.
- For component 2 we determine a likely distance of 3×10^{15} m (110 lightdays or 0.1 pc).
- For the other components the lower limits are: 330, 19 and 27 lightdays.
- Comparing with spectra A/B we find upper limits for component 3 and 4 of 1100 and 1500 light days.

Conclusions

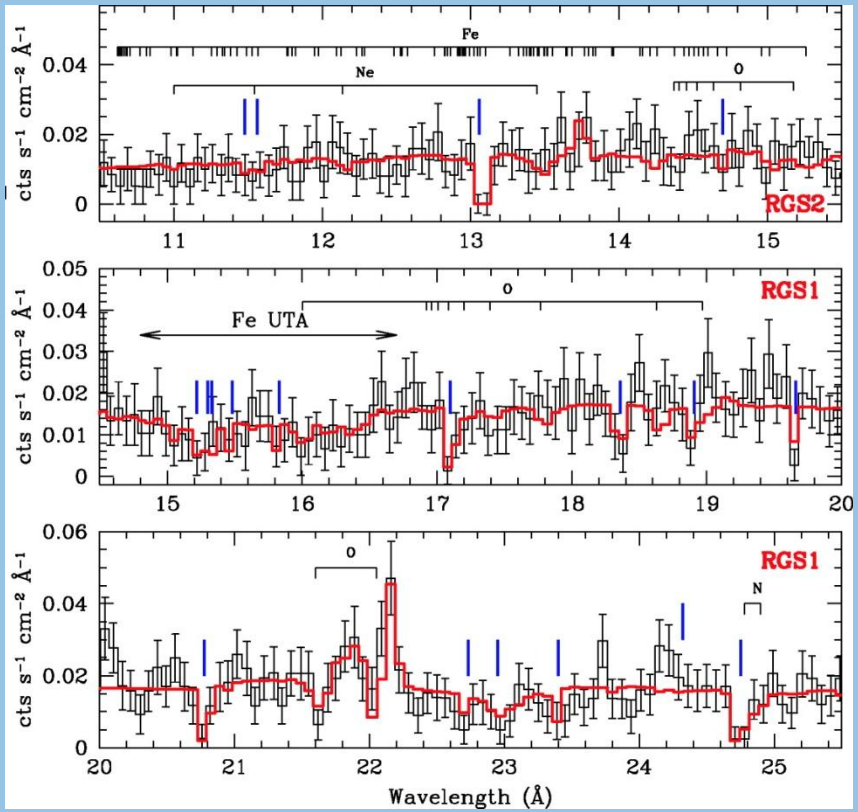
- NGC 4051 is a complex system, with a variable continuum, relativistically and non-relativistically broadened emission, and a wind consistent of 4 photo-ionized components.
- Spectrum D has RRC of C VI, indicating a recombining plasma, possibly the accretion disk.
- For 1 of the photo-ionized components we detect a change in ionization parameter and derive a distance of 110 lightdays.
- Two other components are located between 19 and 1500, and 1 component is located further out than 330 lightdays.

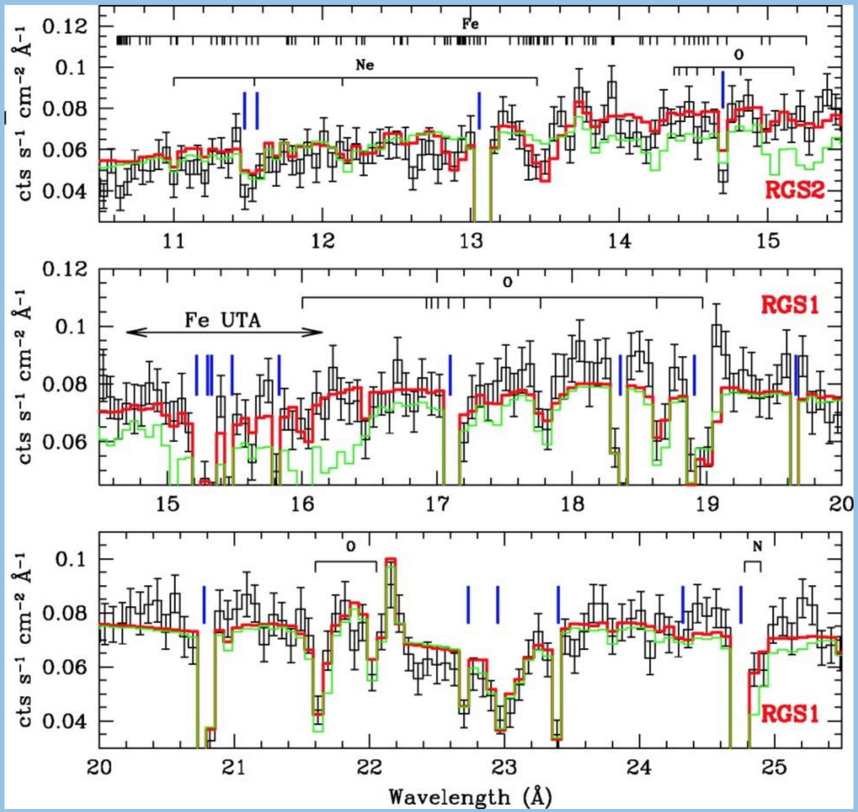
Krongold spectra



Full RGS spectrum, note OV not fit, O VIIr poorly fit, continuum poorly fit between 17-20 Å.

Krongold spectra





Low state RGS spectrum: O VIIr is this time under-predicted rather than over-predicted. O VI is over-predicted, O VIII is slightly under-predicted.

High state RGS spectrum, O VI is under-predicted, again the continuum between 17 and 20 Å is poorly fit. O VIII is over-predicted.