Chandra and XMM Observations of the ADC Source 2S0921-63
T. Kallman, L. Angelini, J. Cottam (GSFC) B. Boroson (CfA)

- 2S0921 is a 9.02 day binary with a K0 companion
- Distance estimate is D~7 kpc (Cowley et al. 1982) based on optical spectral type,
- This implies the X-ray luminosity is L~2.4 x 10^{35} erg/s
- L_x / L_{opt} ~1 implies intrinsic L_x is much greater than we observe.
- Mason et al (1987) fit X-ray light curve if i=75-90°
- The Fe K equivalent width is among the largest for LMXBs (Gottwald)
- We observed with Chandra HETG and XMM for 70 ks during X-ray minimum
Accretion Disk Coronae

- Disks in X-ray binaries are expected to be heated to $\sim 10^7$-$10^8$K by Compton scattering of continuum photons from the compact object (Shakura and Sunyaev, 1971; White and Holt 1981; Begelman et al. 1982).

- Corona is expected to be marginally Compton thick, producing gradual light curves observed from high inclination sources.

- Intermediate ionization region is expected at base of corona.

- If so, high inclination sources should have high intrinsic luminosities, and also large line equivalent widths.

- Examination of existing equivalent width distribution (eg. Gottwald et al., 1996) does not confirm this.
Fe K equivalent width vs. luminosity
Lightcurves

MOS

HEG

MEG
HEG and MEG residuals to power law
Xstar model fit to HETG spectrum
RGS residuals to power law
RGS fit to xstar model
HETG and RGS

- Continuum fits to single absorbed power law
- Lines observed from H and He-like ions of abundant elements O-Fe.
- Line equivalent widths $\sim$10-50 eV
- Lines are narrow, $v<600$ km/s
- Line spectrum fits adequately to xstar model or sum of two models, $\log(\xi)=1.5, 4.$
- From O VII f/i ratio, $n<10^{11}$ cm$^{-3}$. 
## Summary of Line fits

<table>
<thead>
<tr>
<th>ID</th>
<th>Wave(A)</th>
<th>Energy (keV)</th>
<th>F(photon/cm²/s)</th>
<th>L (erg/s)</th>
<th>Width (keV)</th>
<th>EW (eV)</th>
<th>log(P)</th>
<th>Inst</th>
<th>V8</th>
<th>log(R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>?</td>
<td>23.22</td>
<td>0.53 +/- 0.01</td>
<td>5.3 +/- 7</td>
<td>2.5E+32</td>
<td>0.005 +/- 0.005</td>
<td>2.8</td>
<td>-1.06</td>
<td>RGS</td>
<td>2.8</td>
<td>9.4</td>
</tr>
<tr>
<td>?</td>
<td>22.92</td>
<td>0.54 +/- 0.01</td>
<td>7.1 +/- 8</td>
<td>3.4E+32</td>
<td>0.005 +/- 0.005</td>
<td>3.5</td>
<td>-1.34</td>
<td>RGS</td>
<td>2.8</td>
<td>9.4</td>
</tr>
<tr>
<td>O VII 1-2 f</td>
<td>22.1</td>
<td>0.56 +/- 0.01</td>
<td>4.5 +/- 5</td>
<td>2.2E+32</td>
<td>0.005 +/- 0.005</td>
<td>2.2</td>
<td>-1.15</td>
<td>RGS</td>
<td>2.7</td>
<td>9.4</td>
</tr>
<tr>
<td>O VII 1-2 i</td>
<td>21.77</td>
<td>0.57 +/- 0.01</td>
<td>5.9 +/- 12</td>
<td>3.0E+32</td>
<td>0.005 +/- 0.005</td>
<td>3.3</td>
<td>-2.27</td>
<td>RGS</td>
<td>2.6</td>
<td>9.4</td>
</tr>
<tr>
<td>O VIII Lα</td>
<td>19</td>
<td>0.65 +/- 0.01</td>
<td>7.6 +/- 2</td>
<td>4.4E+32</td>
<td>0.005 +/- 0.005</td>
<td>5.4</td>
<td>-14.35</td>
<td>RGS</td>
<td>2.3</td>
<td>9.5</td>
</tr>
<tr>
<td>O VIII Lβ</td>
<td>15.97</td>
<td>0.78 +/- 0.0015</td>
<td>1.4 +/- 2</td>
<td>9.6E+31</td>
<td>0.005 +/- 0.005</td>
<td>1.2</td>
<td>-0.84</td>
<td>RGS</td>
<td>1.9</td>
<td>9.7</td>
</tr>
<tr>
<td>Ne X Lα</td>
<td>12.16</td>
<td>1.02 +/- 0.0015</td>
<td>2.4 +/- 1.5</td>
<td>2.2E+32</td>
<td>0.0025 +/- 0.0025</td>
<td>6.65</td>
<td>-19.2</td>
<td>HETG</td>
<td>0.7</td>
<td>10.5</td>
</tr>
<tr>
<td>Ne X Lβ</td>
<td>10.65</td>
<td>1.17 +/- 0.004</td>
<td>2.1 +/- 1.5</td>
<td>2.1E+32</td>
<td>0.005 +/- 0.005</td>
<td>2.9</td>
<td>-3.09</td>
<td>RGS</td>
<td>1.3</td>
<td>10.1</td>
</tr>
<tr>
<td>Mg XII Lα</td>
<td>8.56</td>
<td>1.45 +/- 0.0025</td>
<td>7 +/- 5</td>
<td>9.0E+32</td>
<td>0.005 +/- 0.005</td>
<td>0.19</td>
<td>-0.06</td>
<td>HETG</td>
<td>1.0</td>
<td>10.2</td>
</tr>
<tr>
<td>Si XIV Lα</td>
<td>6.18</td>
<td>2.01 +/- 0.004</td>
<td>1.95 +/- 0.2</td>
<td>3.5E+32</td>
<td>0.0025 +/- 0.0025</td>
<td>10.2</td>
<td>-34.3</td>
<td>HETG</td>
<td>0.4</td>
<td>11.1</td>
</tr>
<tr>
<td>S XVI Lα</td>
<td>4.73</td>
<td>2.62 +/- 0.001</td>
<td>1.03 +/- 1</td>
<td>2.4E+32</td>
<td>0.0025 +/- 0.0025</td>
<td>13.2</td>
<td>-4.09</td>
<td>HETG</td>
<td>0.3</td>
<td>11.4</td>
</tr>
<tr>
<td>Fe I- XVII Kα</td>
<td>1.94</td>
<td>6.4 +/- 0.01</td>
<td>1.1 +/- 2</td>
<td>6.2E+32</td>
<td>0.015 +/- 0.015</td>
<td>26.2</td>
<td>-2.03</td>
<td>HETG</td>
<td>0.7</td>
<td>10.6</td>
</tr>
<tr>
<td></td>
<td>6.38</td>
<td>0.14 +/- 0.15</td>
<td>7.9E+32</td>
<td>0.29</td>
<td>+/- 0.15</td>
<td>14</td>
<td>-99</td>
<td>PN</td>
<td>13.6</td>
<td>8.0</td>
</tr>
<tr>
<td>Fe XXV 1-2</td>
<td>1.87</td>
<td>6.65 +/- 0.01</td>
<td>1.4 +/- 2</td>
<td>8.3E+32</td>
<td>0.015 +/- 0.015</td>
<td>31.1</td>
<td>-3.28</td>
<td>HETG</td>
<td>0.7</td>
<td>10.6</td>
</tr>
<tr>
<td></td>
<td>6.68</td>
<td>0.03 +/- 0.2</td>
<td>3.4E+33</td>
<td>0.05</td>
<td>+/- 0.05</td>
<td>63</td>
<td>-5.59</td>
<td>PN</td>
<td>2.2</td>
<td>9.6</td>
</tr>
<tr>
<td></td>
<td>6.7</td>
<td>0.14 +/- 1.0</td>
<td>2.4E+33</td>
<td>0.05</td>
<td>+/- 0.05</td>
<td>1500</td>
<td>-7.5</td>
<td>MOS</td>
<td>2.2</td>
<td>9.6</td>
</tr>
<tr>
<td>Fe XXVI Lα</td>
<td>1.8</td>
<td>6.9</td>
<td>0.15</td>
<td>1.0</td>
<td>6.1E+32</td>
<td>0.015</td>
<td>+/- 0.05</td>
<td>50.1</td>
<td>-0.2</td>
<td>HETG</td>
</tr>
<tr>
<td></td>
<td>6.96</td>
<td>0.07</td>
<td>2.4E+33</td>
<td>0.05</td>
<td>+/- 0.05</td>
<td>49</td>
<td>-99</td>
<td>PN</td>
<td>2.2</td>
<td>9.6</td>
</tr>
<tr>
<td></td>
<td>6.98</td>
<td>0.12</td>
<td>7.3E+32</td>
<td>0.05</td>
<td>+/- 0.05</td>
<td>288</td>
<td>-1.95</td>
<td>MOS</td>
<td>2.1</td>
<td>9.6</td>
</tr>
<tr>
<td>?</td>
<td>1.59</td>
<td>7.8</td>
<td>0.13</td>
<td>9.0E+32</td>
<td>0.25</td>
<td>+/- 0.25</td>
<td>23</td>
<td>-3.74</td>
<td>PN</td>
<td>9.6</td>
</tr>
<tr>
<td>?</td>
<td>1.51</td>
<td>8.2</td>
<td>0.14</td>
<td>1.0E+33</td>
<td>0.15</td>
<td>+/- 0.15</td>
<td>25</td>
<td>-5.58</td>
<td>PN</td>
<td>5.5</td>
</tr>
</tbody>
</table>
MOS Spectrum and power law fit
PN spectrum 5-8 keV
EPIC fits

- Lines: 3 components of Fe K: 6.4, 6.7, 6.97 keV.
- PN sets lower limit on Fe XXVI L\(\alpha\) width.
- PN continuum is not adequately fit by single power law
- Requires either cutoff power law, E\(\text{cut}=7\) keV, plus
- Or power law plus edges at 7.1 and 8.4 keV
- Curved continuum+Gaussians fits better due to narrow
- Similar to ASCA spectrum of 1822-37
Line velocities
Line Widths

- Grating spectra give limits on line widths corresponding to Doppler velocities $v < 600$ km/s for the HETG (eg. SiXIV $\text{L}\alpha$).

- For emission from a Keplerian disk at $90^\circ$ inclination with a 1.4 solar mass primary, this corresponds to $R > 5.2 \times 10^{10}$ cm.

- Using the PN data, the Fe XXVI $\text{L}\alpha$ line width is measured to be in the range $430$ km/s $< v < 3900$ km/s.

- This corresponds to radii $1.2 \times 10^9$ cm $< R < 1.0 \times 10^{11}$ cm.

- For comparison the primary Roche lobe size is $\sim 1.1 \times 10^{12}$ cm, and the secondary size is $6.75 - 7.2 \times 10^{11}$ cm.
System
Geometry

During eclipse we see only the outer disk
Emissivity curves for observed lines
DEM fit to measured line strengths
Line Luminosities

- Optical distance estimate is $D \sim 7$ kpc. If so, typical line luminosities are $\sim 10^{32} - 10^{34}$ erg/s.

- For $\log(\xi) \sim 1-4$, typical emissivities are $j \sim 10^{-24}$ erg cm$^3$ s$^{-1}$, so that the emission measure must be $\sim 10^{56}$ cm$^{-3}$.

- DEM analysis is consistent with this.

- Xstar model fits imply total emission measure $\sim 10^{55}$ cm$^{-3}$ if $L_x \sim 10^{35}$ erg/s.
He-like line density diagnostics
Gas Density and Ionization Parameter

- From O VII f/i line ratio we infer density $n<10^{11}$ cm$^{-3}$.
- O VII recombination emission is most efficient for log($\xi$)$<2$.
- The primary Roche lobe size is $R\sim10^{12}$ cm.
- If the emission comes from within this region then the ionizing luminosity impacting the O VII gas must be $L<10^{35}$ erg/s.
- This conflicts with the traditional arguments about ADC sources, eg. $L_x/L_{opt}\sim1$. 
What does this mean for other LMXBs?

- Systems with larger intrinsic luminosities have line equivalent widths less than ~ a few eV
- Could $\sim 10^{34}$ erg/s lines could be hiding in these spectra?
- Maybe the reason we observe lower luminosities from "ADC" sources is that the occultation is happening in the inner region of the disk.
- If so, all Z sources should be ~low inclination.
Inclination $\sim 0$

Inclination $\sim 90$

Line emitting gas