Using Eclipses to Probe the Jets in SS 433 using the Chandra High Energy Transmissions Grating Spectrometer

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Abstract and Introduction

The Galactic microquasar SS 433 is the only known astrophysical object to exhibit strong, relativistically red- and blue-shifted lines from elements such as S, Si, Fe, Ni. The X-ray emission lines originate in a bipolar jet outflow that is launched somewhere very close to the compact accretor. The pair of jets travels in opposite directions at 0.26c, and the jets precess with a period of 164 days. During 2018 August 10-14, SS 433 was observed using the High Energy Transmission Grating Spectrometer (HETGS) system on Chandra. During this epoch, one 20 ksec "short" observation was made three days before an eclipse of the compact object by the donor, and then a 96 ksec "long" observation started shortly after mid-eclipse. The short and the long observations were designed to take advantage of the eclipse and carry out time-resolved spectroscopy to infer spatial variation of physical properties such as composition, temperature, and density at different distances along the jet. In addition to phenomenological fits to determine the properties of the observed emission lines, here we present results from fitting collisionally ionized plasma models.

Spectra and Phenomenological Modelling

Fitting Results:
We used a blind fitting method to model the spectra using the Interactive Spectral Interpretation System software (Houck & Denicola, 2000). The underlying continuum was modeled by an absorbed power law and the emission lines modeled as Voigt profiles.

Discrepancies between the Observed and Ephemeris-predicted Redshifts

● Discrepancies in the Observed Redshifts

We compared the line fluxes between the short observation and the long observation of both Eastern and Western jets.

Evolution of Line Fluxes

We use a plasma diagnostic approach where emission lines correspond to four specific jet plasma temperatures (Marshall et al. 2002). Eastern and Western jets are fitted at the same time using this four-temperature plasma model.

Plasma Model

We use a plasma diagnostic approach where emission lines correspond to four specific jet plasma temperatures (Marshall et al. 2002). Eastern and Western jets are fitted at the same time using this four-temperature plasma model.

Parameter Table for the 20 ksec Reference Observation:

<table>
<thead>
<tr>
<th>Energy (keV)</th>
<th>N (10^18 cm^-2)</th>
<th>Emission Measure</th>
<th>Western Jet</th>
<th>Eastern Jet</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.3</td>
<td>1.876 ± 0.086</td>
<td>42.61</td>
<td>1.80 ± 0.12</td>
<td>1.89 ± 0.12</td>
</tr>
<tr>
<td>12.6</td>
<td>1.876 ± 0.086</td>
<td>42.61</td>
<td>1.80 ± 0.12</td>
<td>1.89 ± 0.12</td>
</tr>
<tr>
<td>30.1</td>
<td>1.876 ± 0.086</td>
<td>42.61</td>
<td>1.80 ± 0.12</td>
<td>1.89 ± 0.12</td>
</tr>
<tr>
<td>126.0</td>
<td>1.876 ± 0.086</td>
<td>42.61</td>
<td>1.80 ± 0.12</td>
<td>1.89 ± 0.12</td>
</tr>
</tbody>
</table>

Summary of the Results

● Within the long observation, no significant redshifts change were observed for either jet. Given Chandra’s spectral resolution, we should have detected a change in redshift as the jets precess. Such behavior was also previously noted by Marshall et al.(2013), and suggests strongly that the inner X-ray jet does not precess smoothly.

● While the observed Doppler shifts of the emission lines in the Western jet are close to their ephemeris predicted values, the Doppler shifts of the lines from the Eastern jet differ significantly from predictions (observed redshift = 0.0328 ± 0.001; predicted range: 0.078 - 0.096). This shows that directions, or speeds, or some combination of both, of the jets may be independently determined or affected by the environment. We are currently trying to understand the origin of this "unusual" behavior of SS 433’s jets.

● The flux of Fe XXVI from the Eastern jet increased in the long eclipse observation on average by 91.48% comparing to the short reference observation. The flux of Fe XXVI increased by 63%, S XVI increased by 190.5%, Si XIV increased by 141.9% and Si III increased by 141.9% in redshift as the jets precess. Such behavior was also previously noted by Marshall et al.(2013), and suggests strongly that the inner X-ray jet does not precess smoothly.

● The flux of Fe XXVI from the Eastern jet increased in the long eclipse observation on average by 91.48% comparing to the short reference observation. The flux of Fe XXVI increased by 63%, S XVI increased by 190.5%, Si XIV increased by 141.9% and Si III increased by 267.2% in the Eastern jet. This might strongly indicate that the inner X-ray jet does not precess smoothly.

Reference and Acknowledgement


We thank Chandra X-ray Observatory staff for carrying out the observation, and Chandra Grant GO8-19042X for supporting this research.