SALT Observations of Circinus X-1 and SXP1062

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SALT Science Day
North West University – 11\textsuperscript{th} November 2013
Brief History of Cir X-1

- An extremely peculiar X-ray binary.
- Rediscovery of bursting X-ray behaviour in May 2010 (Papitto et al. 2010) confirms Neutron star class binary.
- \( P_{\text{orb}} = \text{MJD}43076.27+16.57913n+0.0000421n^2 \) (HartRAO, George Nicolson). \( e=0.45 \) (Jonker et al. 2007).
- Highly reddened optical counterpart with magnitudes \( V=21.4 \) to \( K=11.0 \).
- Optical counterpart still unclassified possibly 3-5M\( \odot \) subgiant or 10M\( \odot \) supergiant (Jonker et al. 2007).
- Radio jet, inclination angle \( \sim5^\circ \) (Fender and Hendry 2000)
- System is similar to BeXRBs, but with a lower B-field due to non detections of pulsations.

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A return to strong radio flaring by Circinus X-1 observed with the Karoo Array Telescope test array KAT-7

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• Clear spectral evolution from +2.0 to -0.5.

• Typical of synchrotron-flaring sources (van der Laan, 1966).

• Outbursts peaks later and less energetically at given frequency.

• X-ray – Radio relationship is complex.
  - Linked to variations in accretion rate?
  - Or precession of disk/jet?
The Big Campaign
11th – 26th June 2012
Light Curves

SALT Log 2012-06-19 - “Photometric dark night with seeing varying from excellent to mediocre. Lots of science done”

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http://maxi.riken.jp/top/
SALT Observations

• ToO time assigned to program 2011-3-RSA_UKSA-001 was used to observe Cir X-1.
  – This program was set up to perform high resolution red spectroscopy of X-ray binaries throughout outbursts.
  – 2 epochs during April 2012

• 2012-3-RSA_UKSA-003 Cir X-1 specific proposal.
  – 4 epochs; 2 in June and 2 in August 2012.

• 3x1200s Hα (6160-7000Å) and 1x688s Paschen lines (7925-8980Å). Totalling 46.5ks.

• Grating PG2300 with a slit width of 1.5” producing medium resolution, R=4400 and 5400 spectra.

• Dispersion of 0.13 and 0.16Å per pixel
Ha Emission Line

EW = -25.0+/−0.5 \quad \phi = 0.32

EW = -38.2+/−0.3 \quad \phi = 0.15

EW = -9.4+/−0.5 \quad \phi = 0.70

EW = -7.8+/−0.2 \quad \phi = 0.51

EW = -12+/−1 \quad \phi = 0.91

EW = -60.9+/−0.5 \quad \phi = 0.22

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Historical Hα Emission Measurements

<table>
<thead>
<tr>
<th>UT Date</th>
<th>Phase</th>
<th>$W_{\lambda, H\alpha}$ (Å)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1999 Jul 11</td>
<td>0.880</td>
<td>81</td>
</tr>
<tr>
<td>1999 Aug 20</td>
<td>0.292</td>
<td>80</td>
</tr>
<tr>
<td>1999 Aug 21</td>
<td>0.350</td>
<td>79</td>
</tr>
<tr>
<td>1999 Aug 22</td>
<td>0.411</td>
<td>83</td>
</tr>
<tr>
<td>2000 May 16</td>
<td>0.622</td>
<td>12.2</td>
</tr>
<tr>
<td>2000 May 22</td>
<td>0.985</td>
<td>10.1</td>
</tr>
<tr>
<td>2000 Jul 12</td>
<td>0.073</td>
<td>25.0</td>
</tr>
<tr>
<td>2000 Jul 13</td>
<td>0.129</td>
<td>26.3</td>
</tr>
</tbody>
</table>

Figure 1. Line profiles of Hα, showing the Gaussian fits to the lines and their sum. The spectra have been normalized by a polynomial fit to the continuum. The spectra are shown in order of phase, with the spectrum taken at phase 0 (1999 May 22) repeated at phase 1 for clarity. The spectrum at phase 0 is symmetric, with a broad component on the blue wing appearing at phases 0.1–0.5. At phase 0.6 the line appears to be double-peaked (or flat-topped?), while clear double peaks are seen at phase 0.9.

Johnston et al. 2001
Hα Emission Line

EW = $-25.0+/−0.5 \quad \phi = 0.32$

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Hα Emission Line Fits
**SXP1062**

Chandra detection near NGC602

2dFS 3831
RA = 01:27:46
Dec = −73:32:56
P_\(s\) = 1062s
Pdot_\(s\) = 94.9 syr\(^{-1}\)


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**Figure 5.** MOSAIC H\(\alpha\) image and MCELS H\(\alpha\), [S \(\text{ii}\)] and [O \(\text{iii}\)] images of a region centred on the position of 2dFS 3831 = SXP 1062 and showing the shell nebula detected around the target. H'enault-Brunet et al. 2012
Long-term evolution of the neutron-star spin period of SXP 1062

XMM-Newton
- 1071.01s period
- $P_{\text{dot}} = 2.27 \text{ syr}^{-1}$. Implies an initial magnetic field $\sim 10^{14} \text{ G}$
- $\Gamma \sim 0.774 +/- 0.009$

SALT Program:
2012-1-RSA_UKSC-003
- PI: Schurch.
13th/14th October 2012.
2x400s in blue
180s in red.
Observing conditions: 3"

Fig. 1. Upper panel: OGLE-IV $I$-band light curve. Dashed lines indicate the time of optical spectroscopy observations. Middle panel: X-ray fluxes in the (0.2–10.0) keV band from Swift (open squares) and XMM-Newton (open circles) including the 2009 slew-survey data and the 2010 measurements. Lower panel: NS spin period as measured with XMM-Newton.
**Fig. 5.** SALT blue and red (left and right respectively) smoothed spectra of SXP 1062. Clearly visible are the chip gaps between the three CCDs. Dotted lines indicate: Balmer lines (black), He I (green), He II (light blue), Silicon (red) and other metal lines (dark blue).

SALT (Oct 2012) $EW_{\text{Ha}} = -26.65 \pm 0.09$ Å
SALT (Oct 2012) $EW_{\text{Hb}} = -2.40 \pm 0.29$ Å
2df (Sept 1999) $EW_{\text{Ha}} = -22.02 \pm 0.05$ Å
2df (Sept 1998) $EW_{\text{Hb}} = -1.58 \pm 0.10$ Å
**Fig. 6.** Left: Hα as seen with SALT (normalised) and according modelling with two Gaussians and continuum. The lowest line gives the residuals. The 2dF spectrum is shown on the top for comparison. Middle: same as before, but for Hβ. Right: Hγ as seen with VLT FLAMES (top), 2dF (middle) and SALT (bottom).

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\text{2df (Sept 1999) } EW_{H\alpha} = -22.02 \pm 0.05 \text{ Å}
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\text{SALT (Oct 2012) } EW_{H\beta} = -2.40 \pm 0.29 \text{ Å}
\]
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\text{2df (Sept 1998) } EW_{H\beta} = -1.58 \pm 0.10 \text{ Å}
\]
SXP1062 Periodic Outburst?

- Outburst in July 2014?
- Accepted joint Chandra and Swift proposal
  - Swift monitoring will trigger Chandra.
  - 24 x 2ks observations.
  - 120ks Chandra time (4 observations)
- Propose for simultaneous KAT-7 and SALT observations.

Figure 3: Mock X-ray light-curve to illustrate our observing strategy. Swift monitoring is over 24 weeks (2ks). At flux level $6 \times 10^{-12}$ Chandra observations are triggered with medium response time (red diamonds). The 120ks Chandra observing time can be split on exposures of any duration. Swift observations resume afterwords.
Summary

• Circinus X-1
  – Large variation in Hα emission line between outburst cycles, but small variation within a single orbit.
  – Consistent with previous observations (Johnston et al., 2001).
  – Full comparison of data with KAT-7 and HartRAO monitoring is still to be done. Should be published early 2014.

• SXP1062
  – Confirmation of spectral type.
  – Basic modelling of circumstellar disk emission lines.
  – 2014 observations planned.