Instabilities in accretion onto black holes

Jean Swank

Studying black holes was recognized early to be an exciting possibility of X-ray astronomy

Elihu understood the theoretical implications for the instrumentation needed to learn more about the important aspects

We have made progress, but still haven’t reached the goal
Elihu’s 1975 remarks on Cyg X-1

“We have probably been provided with an ideal laboratory for the study of the behavior of matter as it falls into an object dominated by the laws of gravitational relativity.”

“Such studies will require X-ray observatories of large sensitive area, high temporal resolution and broad bandwidth, so that enough radiation is measured for characterizing each individual burst and long enough exposures to monitor this behavior for several binary periods.”
The first recognized black hole
Cygnus X-1

Cyg X-1 was discovered in a rocket flight in 1965. It was reported to be unusually variable in *Uhuru* observations.

Theorists (Shakura and Sunyaev) said in 1973 that accretion onto black holes might be very variable – with millisecond time scales.

Goddard’s X-ray group observed it with rocket flights in 1973 and 1974.
"Shot noise"

\[
\frac{\text{Var } N}{\Delta T} = \text{Rate } (1 + fm\Delta T / \tau)
\]

\[
= \text{Rate } (1 + fm)
\]

\[
\Delta T < \tau
\]

\[
\Delta T > \tau
\]
Millisecond bursts

Order of 10 counts in 1 msec. 12 such bursts, on tops of flares. Application of Poisson statistics with respect to local averages indicated these were unlikely to be random fluctuations.

Elihu had the concept that an enhanced density could persist for seconds and that rotation around the black hole, with relativistic beaming, could give rise to these bursts with a recurrence time of about 14 milliseconds, that appeared in a few seconds of data.

If that were the case, the mass and the angular momentum of the BH followed....
# Missions studying Cyg X-1 Timing

<table>
<thead>
<tr>
<th>Mission</th>
<th>Cm2</th>
<th>Count/s</th>
<th>Millisecond resol.</th>
<th>Tot sec expos</th>
<th>Publications (partial list!)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uhuru 1971</td>
<td>840</td>
<td>250</td>
<td>192</td>
<td>800</td>
<td>Terrell Weisskopf, Kahn &amp; Sutherland</td>
</tr>
<tr>
<td>Rocket 1973</td>
<td>1360</td>
<td>1500</td>
<td>0.32</td>
<td>50</td>
<td>Rothschild, Boldt, Holt &amp; Serlemitsos</td>
</tr>
<tr>
<td>Rocket 1974</td>
<td>1360</td>
<td>1500</td>
<td>0.16</td>
<td>180</td>
<td>Rothschild, Boldt, Holt &amp; Serlemitsos</td>
</tr>
<tr>
<td>EXOSAT 1983</td>
<td>1790</td>
<td>740</td>
<td>20</td>
<td>4070</td>
<td>Belloni &amp; Hasinger; Lochner, Swank &amp; Szymkowiak;</td>
</tr>
<tr>
<td>HEAO A2 1977</td>
<td>1318</td>
<td>760</td>
<td>80</td>
<td>2743</td>
<td>Lochner, Swank &amp; Szymkowiak</td>
</tr>
<tr>
<td>HEAO A1 1977</td>
<td>1650</td>
<td>1000</td>
<td>0.01</td>
<td>270</td>
<td>Meekins, Wood, Hedler, Byram, Yentis, Chubb &amp; Friedman</td>
</tr>
<tr>
<td>Ginga 1987</td>
<td>4000</td>
<td>4700</td>
<td>31</td>
<td>16220</td>
<td>Negoro, Kitamoto, Takeuchi &amp; Mineshige</td>
</tr>
<tr>
<td>RXTE 1996</td>
<td>6500</td>
<td>5000</td>
<td>0.122</td>
<td>11464</td>
<td>Focke, Wai &amp; Swank; Gerlinski &amp; Zdziarski</td>
</tr>
</tbody>
</table>
Better shot models - J Lochner

Measures:

- Variance with bin size $\Delta t$ rate $\lambda$
- Autocorrelation function $\tau$ (0.1-1 s)
- Skewness (3rd moment)
- Power spectrum $S(f) \approx 1/f$
- Phase portrait $\text{Flux}(t+\eta)$ vs $\text{Flux}(t)$

Models: $I(t) = \sum_k F(t-t_k)$

- Rectangular Terrell, Boldt
- Exponential Lochner
- Symmetric exponential Lochner
- Distribution of tau and height Lochner
Resolving individual shots – W Focke
The context of black hole states
A new Cygnus X-1

Another source – another opportunity to see details that will help understand

- How are the shots formed?
- Are there shorter timescale bursts?

If we had 10 times the area these would be clear!

N Shaposhnikov