4U 1957+11: The Most Rapidly Spinning Black Hole in the Galaxy?

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-with-
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Low Mass X-ray Binary (9.3 hr Period)
Persistent Soft (Disk Dominated) State
Quenched Jet: < 11.4 μJy (3 sigma)
300–800X Lower than Hard State Correlation (Russell et al. 2011, ApJL)
Low Neutral Column: 1–2 X 10^{21} cm^{-2}, Ne IX Absorption from Warm ISM
Distance > 5 kpc — In Galactic Halo

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- Low Mass X-ray Binary (9.3 hr Period)
- Persistent Soft (Disk Dominated) State
- Quenched Jet: < 11.4 μJy (3 sigma)
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- Distance > 5 kpc — In Galactic Halo
Complex Lightcurve

Periodicity has been:
- Absent
- ±10% Sinusoidal
- ±30% Complex
- Highly Inclined;
  Optical disk partially occulted?
  \( i \sim 75^\circ \)

(Hakala et al. 1999)

(Bayless et al. 2011:
  \( i \sim 20–70^\circ \))
BACKGROUND:

- Unknown Mass & Distance; only limits for the inclination
  - Nominally *bad* for spin measurements, but ...
- High Disk Temperature: 1.3–1.6 keV
- Low Disk Normalization
Disk Radius

Disk Temperature

3–18 keV Flux (ergs cm\(^{-2}\) s\(^{-1}\))

Disk Normalization\(^{1/2}\)

3–18 keV Flux (ergs cm\(^{-2}\) s\(^{-1}\))

Disk Temperature (kT)

RXTE: Disk + Comptonization Fits

(Nowak et al. 2008)
DISKS: TWO PARAMETERS

\[ \frac{R^2 \cos i}{D^2} , \ kT_{\text{max}}^4 \]
RXTE: Disk + Comptonization Fits

(Nowak et al. 2008)
HOW MIGHT A DISK CHANGE?

Accretion Rate

“ADAF” Like
DISTINCT IN SUZAKU BAND:

Accretion Rate

“ADAF” Like
Energy (keV)

$v F_v$ (ergs cm$^{-2}$ s$^{-1}$)

Detector Features

(Nowak et al. 2011)
(Nowak et al. 2011)
Photons cm\(^{-2}\) s\(^{-1}\) keV\(^{-1}\) (Nowak et al. 2011)
Joint Fit to All Three

FE Line?

$5 \times 10^{-10}$

$\nu F_{\nu}$ (ergs cm$^{-2}$ s$^{-1}$)

Ratio

0.98 1 1.02

Energy (keV)

4 5 6 7 8
JOINT SPECTRAL FITS:

I. Comptonization (eqpair):
- Common column & disk normalization
- Different corona & disk kT

II. Spinning black hole (kerrbb):
- Common mass, spin, distance, column, & color correction ($T_{app}/T_{eff} \sim 1.7$)
- Different accretion rates
- “Fudged” hard tail (simpl - mimics aspects of optically thin Compton)
Comptonization Fits:
Compactness -
\( \frac{l_h}{l_s} = 0.04 - 0.4 \)
- **Comptonization Normalization:**

\[
\frac{(M/M_\odot)^2 \cos i}{(D/\text{kpc})^2 f_c^4} = 0.003 \frac{(M/3\ M_\odot)^2 \cos(i/75^\circ)}{(D/10\ \text{kpc})^2 (f_c/1.7)^4}
\]

- **Measure only 0.0002**
- **Increase the Distance to 40 kpc.**
- **Decrease the radius of peak emission to \( \sim 2.5\ GM/c^2 \) (i.e., a Kerr black hole).**
- **Increase the color-correction factor to 3.3.**
\[ y \equiv \frac{4kT}{511 \text{ keV}} \tau^2 \approx f_c = 3.3 \]

\[ \tau \approx 9.8 \left( \frac{4 \text{ keV}}{kT} \right)^{1/2} \left( \frac{f_c}{3} \right)^{1/2} \]

- Optical depths of order 10?
- Relatively unexplored Comptonization regime
Maximally Spinning Hole: 3 Solar Masses, 10 kpc, $f_c = (T_{\text{app}}/T_{\text{eff}}) = 1.2$
DISK SPIN MODEL SCALING:

- If $L/L_{Edd}$ fixed (faintest $\geq$ low state transition):
  \[
  \left(\frac{T_{\text{app}}}{f_c}\right)^4 \propto \frac{(L/L_{Edd}) \cdot M}{R^2} \propto \frac{(L/L_{Edd})}{M}
  \]

- $T_{\text{app}}$ is fixed by observation:
  \[
  M \propto f_c^4
  \]

- $L/L_{Edd}$ is fixed by assumption:
  \[
  \frac{\dot{M}}{M} \propto \text{constant} \Rightarrow \dot{M} \propto f_c^4
  \]
Flux is fixed by observation:

\[
\frac{M^2}{D^2 f_c^4} \propto \frac{f_c^8}{D^2 f_c^4} \propto \text{constant} \Rightarrow D \propto f_c^2
\]

3 Solar Mass, 10 kpc, \(f_c \sim 1.2\)

16 Solar Mass, 22 kpc, \(f_c \sim 1.7\)
\[ f_c = \frac{T_c}{T_{\text{Eff}}} \]

16 Solar Mass, 22 kpc

3 Solar Mass, 10 kpc
CONCLUSIONS:

- Could be low mass, high $L/L_{\text{Edd}}$, at large distance (~40 kpc)
- But why so little X-ray variability?
- High $kT$ & Low Normalization is consistent with rapid spin
- High spin can be avoided with large color-correction factors
- Low $kT$, High Optical Depth Corona
- But why such stable properties?
ADDENDA: QUESTION RESPONSE

- Is Cyg X-1 rapidly spinning?
- Soft state - disk dominates, but normalization is lower than expected
- Low norm driven by new low distance (Reid et al. 2011), & new high mass estimate (Orosz et al. 2011)
- Similar story as 4U 1957+11
- Consistent with High Spin (Gou et al. 2011)
- ... or it must have a color correction factor \( \approx 3 \) (high optical depth, low kT corona?)
Cygnus X-1: Soft State

Energy (keV) vs. \( \nu F^{\nu} \) (ergs cm\(^{-2}\) s\(^{-1}\))

- Background
- ISM Edges
- Disk
- Non-thermal Comptonization
- Relativistic Reflection
- Narrow+Relativistic Line

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Cygnus X-1: Soft State

Cygnus X-1: Hard State

Energy (keV)

$F_\gamma$ (ergs cm$^{-2}$ s$^{-1}$ keV$^{-1}$)

10$^{-8}$

10$^{-9}$

1

2

5

10

100

Ratio

arXiv:1107.2391
Cyg X–1 Mass (Solar Mass) vs. Cyg X–1 Inclination (°)

- $a^* = 0.3$
- $a^* = 0.5$
- $a^* = 0.7$
- $a^* = 0.9$