Survey of Micro Quasars

Microquasar
From Wikipedia, the free encyclopedia

Microquasars are smaller cousins of quasars. They are named after quasars, as they have some common characteristics: strong and variable radio emission often seen as radio jets, and an accretion disk surrounding a black hole. In quasars, the black hole is supermassive (millions of solar masses); in microquasars, the black hole mass is a few solar masses. In microquasars, the accreted mass comes from a normal star and the accretion disk is very luminous in optical regions and X-rays. Microquasars are sometimes called 'radio-jet X-ray binaries' to distinguish them from other X-ray binaries. A part of the radio emission comes from relativistic jets, often showing apparent superluminal motion.

Microquasars are very important for the study of relativistic jets. The jets are formed close to the black hole, and timescales near the black hole are proportional to the mass of the black hole. Therefore, ordinary quasars take centuries to go through variations a microquasar experiences in one day.

See also

- SS_433
• Reminder: what is a microquasar?

• Established and Candidate microquasars

• Gamma ray candidates:
  – LSI +615, LS 5039
  – As seen in DC2

• Models for gamma ray spectra
What and Where

microQuasar $\equiv$ X-ray binary with jets

Figure 2.3: Angular distribution of galactic HMXBs (solid lines) and LMXBs (thick green lines) against the galactic latitude (left panel) and longitude (right panel). These two graphs illustrate the well-known fact that HMXBs are strongly concentrated towards the galactic plane. An important difference in the longitude distributions of HMXBs and LMXBs can be noticed, with the second ones significantly concentrated towards the galactic center/bulge and the former distributed in clumps approximately coinciding with the location of tangential points of the spiral arms (whose position is marked by arrows in the right panel). The LMXBs number is divided by 3 on the right panel (from Grimm et al. 2002).

High Mass XRB live near galactic plane
Low Mass XRB live in the bulge
Candidate Microquasars

Table 2.1: Microquasars in our Galaxy

<table>
<thead>
<tr>
<th>Name</th>
<th>Position (J2000)</th>
<th>System type(s)</th>
<th>(D) (kpc)</th>
<th>(P_{\text{orb}}) (d)</th>
<th>(M_{\text{compact}}) ((M_{\odot}))</th>
<th>Activity radio(*)</th>
<th>(\beta_{\text{app}})</th>
<th>(\theta^\circ)</th>
<th>Jet size (AU)</th>
<th>Remarks(*)</th>
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<td><strong>High Mass X-ray Binaries</strong></td>
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<tr>
<td>LS 1 +61 303</td>
<td>(02^h 40^m 31^s 06)</td>
<td>BEV +61\°34’45’’ +NS?</td>
<td>2.0</td>
<td>26.5</td>
<td>p</td>
<td>(\geq 9.4)</td>
<td>10–700</td>
<td></td>
<td>Pre?</td>
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<td>V4641 Sgr</td>
<td>(16^h 19^m 21^s 48)</td>
<td>B0III</td>
<td>~ 10</td>
<td>2.8</td>
<td>9.6</td>
<td>t</td>
<td>(\geq 9.5)</td>
<td>10–10(^3)</td>
<td>Pre?</td>
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<td>LS 5039</td>
<td>(15^h 26^m 15^s 05)</td>
<td>O6.5V(f)</td>
<td>2.9</td>
<td>4.1</td>
<td>1–3</td>
<td>p</td>
<td>(\geq 0.15)</td>
<td>&lt; 81\°</td>
<td>Pre?</td>
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<td>XTE J1118+480</td>
<td>(11^h 18^m 10^s 35)</td>
<td>K7V–MV</td>
<td>1.9</td>
<td>0.17</td>
<td>6.9±0.9</td>
<td>t</td>
<td>–</td>
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<td>(\leq 0.03)</td>
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<td>Cirrus X-1</td>
<td>(13^h 20^m 40^s 9)</td>
<td>Subgiant</td>
<td>5.5</td>
<td>16.6</td>
<td>–</td>
<td>t</td>
<td>&gt; 15</td>
<td>&lt; 6\°</td>
<td>&gt; 10(^4)</td>
<td>XMR</td>
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<td>XTE J1550−564</td>
<td>(15^h 50^m 58^s 70)</td>
<td>G8–K5V</td>
<td>5.3</td>
<td>9.4</td>
<td>2</td>
<td>t</td>
<td>&gt; 2</td>
<td>~ 10(^5)</td>
<td>XMR</td>
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<td>Sco X-1</td>
<td>(16^h 19^m 55^s 1)</td>
<td>Subgiant</td>
<td>2.8</td>
<td>0.8</td>
<td>1.4</td>
<td>p</td>
<td>0.68</td>
<td>44\°</td>
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<td>GRO J1655−40</td>
<td>(16^h 54^m 00^s 25)</td>
<td>F3V</td>
<td>3.2</td>
<td>2.6</td>
<td>7.02</td>
<td>t</td>
<td>1.1</td>
<td>72\°−85\°</td>
<td>8 × 10(^3)</td>
<td>Pre?</td>
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<td>GX 339−4</td>
<td>(17^h 02^m 49^s 5)</td>
<td>B0III</td>
<td>&gt; 6</td>
<td>1.76</td>
<td>5.8±0.5</td>
<td>t</td>
<td>–</td>
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<td>~ 4 × 10(^4)</td>
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<td>1E 1740.7−2942</td>
<td>(17^h 43^m 5.483)</td>
<td>B0III</td>
<td>8.5?</td>
<td>12.5?</td>
<td>–</td>
<td>p</td>
<td>–</td>
<td>–</td>
<td>~ 10(^6)</td>
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<td>XTE J1748−288</td>
<td>(17^h 48^m 05^s 06)</td>
<td>B0III</td>
<td>&gt; 6</td>
<td>?</td>
<td>&gt; 4.5?</td>
<td>t</td>
<td>1.3</td>
<td>–</td>
<td>&gt; 10(^4)</td>
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<td>GRS 1758−298</td>
<td>(18^h 02^m 12^s 40)</td>
<td>B0III</td>
<td>8.5?</td>
<td>18.5?</td>
<td>–</td>
<td>p</td>
<td>–</td>
<td>–</td>
<td>~ 10(^6)</td>
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<td>GRS 1915+105</td>
<td>(19^h 15^m 11^s 55)</td>
<td>K−M III</td>
<td>12.5</td>
<td>33.5</td>
<td>14.44</td>
<td>t</td>
<td>1.2–1.7</td>
<td>66.6−70\°</td>
<td>10–10(^4)</td>
<td>Pre?</td>
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Notes: (a) NS: neutron star; BH: black hole. (b) p: persistent; t: transient. (c) jet inclination. (d) Precc: precession; XMR: X-ray jet. *Reported by Corbel et al. 2002. †Recently reported by Gallo et al. 2004.
**LS 5039 & LS I +613**

2EG J0431+6119 (aka 3EG J0435+6137)

\[ \Phi = 9.2 \pm 0.6 \times 10^{-7} \text{ cm}^{-2}\text{s}^{-1} \quad \text{E}>100 \text{ MeV} \]

\[ \Gamma = 2.46 \]

Not visible by HESS

**HESS:** \( \Gamma = 2.12 \)

\[ \Phi = 35.2 \times 10^{-8} \text{ cm}^{-2}\text{s}^{-1} \quad \text{E}>100 \text{ MeV} \]

\[ \Gamma = 2.2 \]

R. Dubois
HESS: Detected again this year

LS 5039 / 2004-2005

LS 5039 18.9 live hours
ON=827 OFF=6917 (α=16.0)
395.2 γ, σ=16.2 S/B=0.9 (Single OFF: σ=10.4)
0.35 ± 0.03 γ/mn

H.E.S.S. preliminary
H.E.S.S. lightcurve (2004)

No significant variations

Aharonian et al., Science 309(746), 2005

R.Dubois
**H.E.S.S. spectrum: hard**

\[
F_{\nu} \sim \nu^{-1.12 \pm 0.15}
\]

\[
L_{\gamma} \approx 10^{33} \text{erg s}^{-1}
\]

Aharonian et al., Science 309(746), 2005
**LS 5039, LS I +615 & Friends**

*Candidates in DC2*

Toby’s HEALPIX map + Saclay sources

- Cyg X1
- SS 433
- GRS 1915+105
- V 4641 Sgr
- GRS 1758-258
- GGRO J1655-40
- Circinus X1
- XTE J1550-564
- 1E 1740.7-294.2

- LS I +615
  - $\Gamma = -2.75$
- LS5039
  - $\Gamma = -2.42$
Models for $\gamma$-ray Emission

Figure 4.3: Sketch of the general situation discussed in this chapter. A relativistic jet is injected close to the black hole in Cygnus X-1. This jet must traverse photon fields created by the cold accretion disk, the hot corona, and the stellar companion. Inverse Compton up-scattering of some of these photons is unavoidable. Here $\theta$ is the half-opening angle of the cone defined by a possibly precessing jet.
Standard Disk Model: Star, Disk, Corona

- Star
  - blackbody – $T \sim 10^4$K – peak @ $kT$ – $E \sim 10$ eV

- Accretion Disk
  - Energy emission due to angular momentum transport
  - Inner radius $\sim 3r_s \approx 9 M_x$ km (eg 18 km for 2 solar masses)
    - $T_{in} \sim 2 \times 10^7 M_x^{-1/4}$ K
    - 1 solar mass $\rightarrow$ 10M K $\rightarrow$ $\sim 1$ keV
    - Integrate radial temp spectrum

Figure 2.5: The integrated spectrum of a steady accretion disk that radiates a local black-body spectrum at each point. The units are arbitrary, but the frequencies corresponding to $T_{out} = T(R_{out})$ and $T_x$ are marked (from Pringle 1981).
• Observations show hard x-ray spectra
  
  - Requires $10^9$ K
  - Hence postulate corona

Figure 2.7: Spectra from the hybrid pair plasma. Solid curves show dependence on hard compactness $l_h$. Other parameters: $l_h/l_e = 10$, $l_{nth}/l_h = 0.1$, $\tau_p = 1$, $\Gamma_{inj} = 2.5$, $T_{bb} = 0.2$ keV. The resulting electron temperature and optical depth are $(kT_e, \tau_T) = (126$ keV, 1.0002), (125 keV, 1.02), and (82 keV, 1.47) for $l_h = 1, 10, 100$, respectively ($l_h$ increases from the bottom to the top of the figure). For a higher compactness, the spectrum has a sharper cut-off at energies above 1 MeV due to larger optical depth for photon-photon pair production. These spectra are similar to the spectra of Galactic BHs in their hard state. Dashed curves show dependence on $l_{nth}/l_h$. Here we fixed $l_h = 10$, $l_{nth}/l_h = 0.5$. The resulting electron temperature and optical depth $(kT_e, \tau_T)$ are $(104$ keV, 1.07), (39$ keV, 1.02), and (5$ keV, 1.01) for $l_h/l_e = 10, 1, 0.1$, respectively. Increase in $l_h$ results in a more pronounced blackbody part of the emerging spectrum. The blackbody is modified by Comptonization on thermal electrons (from Poutanen 1998).
Dynamics in Disk-Jet System

High luminosity from inner disk;  
Soft x-rays

Low luminosity from corona;     
Hard x-rays

Figure 2.10: The configuration of the accretion flow in different spectral states shown schematically as a function of the total mass accretion rate $\dot{m}$. The coronal region is indicated by dots and the thin disk by horizontal bars. (Adapted from Esin et al. 1997)
• μQ jets too small to image anytime soon
• complicated MHD calculations!

• practical models of jets used in calcs:
  • inject blobs of plasma at some height above the disk, bulk Lorentz $\Gamma$ (eg 5)
  • isotropic lepton spectrum in blob, power law (-2) with min, max $\gamma$ corresponding to inferred max E in TeV range

Figure 2.9: Four ways to make jets with magnetic fields. A: dipole field of a rotating neutron star. B: A collapsing object drawing and winding up an initially uniform field. C: Poloidal magnetic field from a magnetized accretion disk. D: Frame-dragging near a rotating black hole resulting in strong coiling of the magnetic field lines. Types C and D (possibly also A) may be relevant for X-ray binaries; type A for isolated pulsars; types C and D for AGN (from Meier et al. 2001).
Jet Interactions with Stellar Photon Field

**Figure 3.2:** Inverse-Compton spectral energy distribution for a microquasar with a massive stellar companion. Leptons in the jet are assumed to have a power-law energy distribution with an index $p = 2$ and a high-energy cut-off at multi-TeV energies. Notice the softening of the spectrum at high-energies due to the Klein-Nishina effect.
Jet Interactions with Disk, Corona

Figure 4.4: Results of the model for an injection electron spectrum with index $p = 1.5$ in a cylindrical jet forming a viewing angle of 30 degrees. The bulk Lorentz factor is $\Gamma = 5$ and the electron power law extends from $\gamma_1 = 2$ to $\gamma_2 = 10^3$. Three different components are shown, resulting from the up-scattering of photons from the star (top panel), the disk and the corona (bottom panel, solid and dashed lines respectively). Notice that the contribution from the coronal photons is not a power law because of the Klein-Nishina effect.
Leptonic Jet Models

- Inverse compton from star dominates at high energy
- ignores variability and non-contemporaneous measurements

Dermer
\[ \Gamma = 2; \ p = 2.25 \]

Parades
\[ \Gamma = 1.1; \ p = 2.2 \]

Includes \( \gamma \gamma \) annihilation with stellar field

Fig. 3. Comparison of the spectral energy distribution of LS 5039 computed from the present model, at the periastron passage and using the parameters of Table 1, with the observed data. We show the different components of the emission as well as the sum of all of the them, which is attenuated due to \( \gamma \gamma \) absorption (solid line). The points observed are from Marli et al. (1998) (VLA, diamonds), Clark et al. (2001) and Drilling (1991) (optical, circle, corrected of absorption), Bosch-Ramon et al. (2000a) (RXTE, square), Harrison et al. (2004) (BATSE, diamond filled), Collmar et al. (2003) (COMPTEL, square filled), Harrison et al. (1999) (EGRET, circle filled) and Aharonian et al. (2005a) (HESS, triangle down filled). The arrows in the EGRET and HESS data represent upper limits (5\sigma).
Recall from $\mu$Q II: LS 5039 Spectral fit assuming it is a pulsar

Pulsar wind parameters:
$10^{36}$ erg/s, $\gamma_w=10^6$ and $\sigma=0.001$

But TeV and star photons create $e^+e^-$ pairs! 

no absorption 

nebular emission
Additional Variability

- Two potential sources:
  - Precession of jet by drag of star gravity on disk
  - Assumed to transmit to jet

For “LS5039”, \( \theta \approx 10^0 \rightarrow T \approx 100 \) days

Huge variation depending on angle of jet to disk

SS 433 shows 162 day period

GRO J1655-40, V 4641 Sgr show significant misalignments

R. Dubois
Variability 2

- Orbital effects on accretion ("two-peak" accretion model) and extinction of $\gamma$'s by stellar field

From $\mu Q$ II:
Extinction at high $E$ due to $\gamma\gamma$ interactions vs orbital phase

Figure 31: EGRET data vs. orbital phase. Massi et al. 2004b (see text). Colours represent 3 epochs.

Figure 20: The accretion model for an eccentric orbit. Martí & Paredes 1995. Top: Accretion rate versus stellar wind. The vertical axis is in units of the Eddington accretion limit, whose limit is indicated by the dashed line. Bottom: Accretion rate for different velocities of the stellar wind. The values are in km s$^{-1}$. Note how the second super-critical event shifts gradually towards earlier orbital phases for high values of the wind velocity.
What will GLAST Contribute?

• There is only statistics of TWO for observations in GLAST energy range (LS 5039, LS I +613)
  – And LS 5039 might not even be a microquasar!

• Need more candidates
  – Survey mode should allow us to examine known candidates
  – Hopefully ACTs will see more (eg LS I +613 from some northern telescope?) before we go up
    • Definitive IDs from precise positions, variability

• Keep an eye out for variability
  – MW observations with x-ray, radio
  – Correlate gamma ray variability with disk-jet variations?
  – Untangle precession, orbital effects
  – Hopefully more understanding of disk-jet variations by then