Gamma-ray emission from Microquasars

S. Sabatini
(INAF IAPS)
on behalf of the AGILE Team

11° AGILE Workshop – ASI, Rome May 16-17, 2013
Relativistic jet

Compact object

Ultra-violet and optical emission

Accretion disk

γ-rays

Mirabel, 2006; 2012

Micro-blazars

S. Sabatini - Gamma-ray emission from Microquasars
Micro-quasars before the AGILE/Fermi era: The X-ray picture

Comptonization of soft thermal photons from disk by a hybrid population of electrons (thermal + non-thermal) in the corona.

2 main X-ray spectral states:

**Soft** → thermal emission (BB) from disk
  + Comptonization by cold thermal electrons (Soft Excess)
  + Comptonization by non-thermal high-energy electrons
    (power-law tail)

**Hard** → Comptonized emission by
  hot quasi-thermal population of electrons
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(Zdziarski et al. 2002) (Szostek et al., 2008)
**Micro-quasars before the AGILE/Fermi era: The X-ray picture**

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(Zdziarski et al. 2002) (Szostek et al., 2008)
AGILE all sky map (E > 100 MeV)

GRS 1915+105
Galactic Centre
GRO 1655-40
SS 433
GRS 1758-258
Cyg X-3
Cyg X-1

S. Sabatini - Gamma-ray emission from Microquasars
Agile monitoring of the galactic sources and micro-quasars is on-going

optimal PSF
Gamma-Ray PSF: AGILE vs. Fermi (front-LAT) - Crab

100 - 400 MeV

AGILE vs. Fermi

AGILE

Fermi

On-axis angle < 30°

On-axis angle < 35°
Gamma-Ray PSF: AGILE vs. Fermi (front-LAT) - Crab

100 - 400 MeV

400 - 1000 MeV
Gamma-Ray PSF: AGILE vs. Fermi (front-LAT) - Crab

AGILE and Fermi have the same PSF!
**Agile monitoring** of the galactic sources and micro-quasars is **on-going**

optimal PSF  
+  
source exposure
Fermi exposure vs. time (arXiv:1008.3235)

20 min every 3 hours
Daily source visibility of AGILE (pointing mode) vs. Fermi: Cyg X-3 flare (3 Nov 2008)
Agile monitoring of the galactic sources and micro-quasars is on-going

optimal PSF
+
source exposure
=

daily monitoring of sources
Agile monitoring of the galactic sources and micro-quasars is on-going

optimal PSF

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= daily monitoring of sources

First detection at gamma-rays for micro-quasars
Intense gamma-ray emission is **rare**

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Microquasars in the Cygnus region:

AGILE-GRID INTENSITY MAP (100 MeV-10 GeV)

November 2007 – July 2009,

2 microquasars

S. Sabatini - Gamma-ray emission from Microquasars
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<td>4-15 M☉ BH</td>
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<td><strong>Period</strong></td>
<td>5.6 days, orb. r. ~ 3.4 x 10^{12} cm</td>
<td>4.8 h, orb. r. ~ 3 x 10^{11} cm</td>
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<td><strong>Companion</strong></td>
<td>O9.7 Supergiant, L ~ 10^{39} erg/s</td>
<td>Wolf Rayet, L ~ 10^{39} erg/s</td>
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<td><strong>Companion wind</strong></td>
<td>~ 10^{-6} M☉/yr, v ~ 2000 km/s</td>
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**Cygnus X-3 is unique in orbital separation, luminosity of the companion star and inclination** -> different processes are expected to dominate in the two systems.
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**REPETITIVE PATTERN !!**

- bright soft X-ray states *(soft-to-hard state transitions)*
- state preceeding strong radio flares.

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S. Sabatini - Gamma-ray emission from Microquasars

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Tavani et al. Nature 2009
**Cygnus X-1**

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**Fermi-LAT: γ-ray active periods**

(Abdo et al., 2009, Science)

- **AGILE-GRID** (Piano et al., 2012)
- 8 Jun – 2 Aug 2009

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S. Sabatini
Cygnus X-1

Compact Object 4-15 M\odot BH
or
10 M\odot BH

Period 5.6 days, orb. r. \~ 3.4 \times 10^{12} cm

Inclination Angle 30\degree < 145 S.

SabaAni et al. 2012

Cygnus X-3

Tavani et al. Nature 2009

SPORADIC

2 episodes:

- Hard state
- Hard-to-soft transition

REPETITIVE PATTERN !!

- bright soft X-ray states (soft-to-hard state transitions)
- state preceeding strong radio flares.

S. Sabatini - Gamma-ray emission from Microquasars
previous gamma-ray detections by AGILE are reproduced for the first time with LAT

fluxes and TS comparable to previous results

TS differential map (MJD 55277. TS ~ 17)
CYGNUS X-3
\(\gamma\)-ray activity detected by AGILE \(\text{(November 2007 } \rightarrow \text{ July 2009)}\) in the context of the multiwavelength emission

All the flaring episodes are associated with:

- bright soft X-ray states \(\text{(soft-to-hard state transitions)}\)
- very low hard X-ray emission
- state preceeding strong radio flares.
Cygnus X-3 $\gamma$-ray spectrum

By integrating the 7 $\gamma$-ray flares:

$(E \geq 100 \text{ MeV})$

6.7$\sigma$ pre-trial

5.5$\sigma$ post-trial

$(l,b) = (79.7, 0.9) \pm 0.4^\circ \text{ (stat.)} \pm 0.1^\circ \text{ (syst.)}$,

$F = (158 \pm 29) \times 10^{-8} \text{ ph cm}^{-2} \text{ s}^{-1}$

$[F_{\text{steady}} = (14 \pm 3) \times 10^{-8} \text{ ph cm}^{-2} \text{ s}^{-1}]$

S. Sabatini - Gamma-ray emission from Microquasars
**LEPTONIC model:**

- corona “evacuation” ($\rightarrow$ Hypersoft State)
- relativistic electrons/positrons scattering off soft photons (disk + WR star)

$\rightarrow$ gamma-rays from **IC processes** in the jet

Star: $L \sim 10^{39}$ erg/s

Disk: $T_{bb} \sim 1.3$ keV

plasmoid: $r \sim 3 \cdot 10^{10}$ cm

Inclination: $i = 14^\circ$
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HADRONIC model:
- injection of mildly relativistic protons
- inelastic scattering of hadronic gas of the WR strong wind with hadrons in the jet: $p + p \rightarrow \pi^0 + \ldots$; $\pi^0 \rightarrow \gamma + \gamma$

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Disk: $T_{bb} \sim 1.3$ keV
plasmoid: $r \sim 3 \cdot 10^{10}$ cm
Inclination: $i = 14^\circ$
AGILE-GRID Cyg X-3 flares (seven 1-day episodes)

- Hadronic model (neutral pion decay)
- Leptonic Model (IC)
AGILE-GRID Cyg X-3 flares (seven 1-day episodes)

Hadronic model (neutral pion decay)

Leptonic Model (IC)

\[ \log \left[ E F_E \ (\text{erg cm}^{-2} \text{s}^{-1}) \right] \]

\[ \log \left[ E \ (\text{MeV}) \right] \]
GAMMA-400
1-day sensitivity
@100 MeV

AGILE-GRID Cyg X-3 flares (seven 1-day episodes)
Fermi-LAT Cyg X-3 steady (2FGL)
Fermi-LAT Cyg X-3 active (4-months integration)
Cyg X-1 TRANSIENT ACTIVITY in GAMMA-RAYS

S. Sabatini - Gamma-ray emission from Microquasars
FAST FLARING ACTIVITY

- VHE (>100GeV) flare lasting \(~1\)hr (MAGIC; Albert 2007)
  - An intense peak in hard X-rays followed it (INTEGRAL; Malzac 2008)

- Transient relativistic RADIO jet \(~20\)min (MERLIN; Fender 2006)
GAMMA-RAY FLARING EPISODES

HARD STATE
1-day duration (or less)

SIGNIFICANCE: $5.3\sigma$

$F_\gamma = 232\pm66 \times 10^{-8}$ ph/cm$^2$/s

(Sabatini et al. 2010)

S. Sabatini - Gamma-ray emission from Microquasars
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SOFT STATE
2-days duration (or less)

SIGNIFICANCE: $3\sigma$

$F_\gamma = 145\pm78 \times 10^{-8} \text{ph/cm}^2/\text{s}$

(Sabatini et al. 2013)

S. Sabatini - Gamma-ray emission from Microquasars
AGILE observing periods – soft state

BAT/Swift hard X-rays

MAXI X-rays

AMI-LA radio, 10 GHz
GAMMA-RAY FLARING EPISODES

SOFT STATE

1-day duration (or less)

SIGNIFICANCE: 5.3 \( \sigma \)

\[ F_\gamma = 232 \pm 66 \times 10^{-8} \text{ph/cm}^2/\text{s} \]
(Sabatini et al. 2010)

SOFT STATE

2-days duration (or less)

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\[ F_\gamma = 145 \pm 78 \times 10^{-8} \text{ph/cm}^2/\text{s} \]
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SOFT STATE

![Graphs showing flux variation over time for different energy bands](image-url)
AGILE candidate flare: 30 June – 2 July 2010

Possible violations of comptonization model during gamma-ray flares

SIGNIFICANCE:
\( F_{\gamma} = 145 \pm 78 \times 10^{-8}\) ph/cm\(^2\)/s (SabaAni et al. 2013)
Modelling the jet component

ONE ZONE MODEL

SSC only

Figure 5. The data are the same as in Fig. 1. The red solid and blue dashed curves show the model synchrotron and Compton components, respectively. (a) Model 1 for $\gamma = 1.35$, accounting for the observed MeV tail, which corresponds to the approximately maximum jet emission allowed by the data. (b) Model 2 for $\gamma = 2.5$, in which case the jet emission is well below the MeV tail, which tail is then most likely emitted by hybrid plasma in the accretion flow. See S. Sabatini - Gamma-ray emission from Microquasars
Possible modelling of the jet component

broken power-law
(gamma_b=1800, gamm_max=gamma_b)

\( \delta \sim 2 \)

K=10^9 cm^-3

B=2e3 Gauss

r=10^9 cm.

Not univocally determined (other parameters are allowed, eg \( \delta =1.5 \) and \( r=5\times10^9 \) with a smaller K…)

S. Sabatini - Gamma-ray emission from Microquasars
CONCLUSIONS

- Intense gamma-ray emission is **rare** in microquasars

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• Contribution of the jet observed for the first time at gamma-rays -> during transitions (Cyg X-3 and possibly Cyg X-1)
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• Intense gamma-ray emission is rare in microquasars.
• Contribution of the jet observed for the first time at gamma-rays -> during transitions (Cyg X-3 and possibly Cyg X-1).
• Cyg X-3 repetitive pattern is deterministic. Leptonic or hadronic scenario still allowed.

Improved sensitivity is needed!
Next generation of gamma-ray instruments (GAMMA-400?):

- give strong constraints to the SED of the $\gamma$-ray flares
- give strong constraints to the duration of the $\gamma$-ray flares (do they really last 1-2 days, or less?)
- discriminate leptonic/hadronic scenarios
- detect the steady emission in 1 day @100 MeV (?)
- analyze the spectral evolution during the $\gamma$-ray flares
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THANKS FOR YOUR ATTENTION