MULTI-WAVELENGTH OBSERVATIONS
OF CYGNUS X-3

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High mass X-ray binary (HMXBs), made of a Wolf-Rayet companion star and of a compact object:

Distance \( \sim 9 \) kpc, orbital period 4.8h (more typical of a LMXB).

Due to tight orbit (d\( \sim 10^{11} \) cm), the compact object is enshrouded in stellar winds (v\( \sim 1000 \) km/s).

Still uncertainty on nature and mass of compact object.

Microquasar scenario (black hole + relativistic jets) scenario is favored.
Cygnus X-3 is a reasonably strong persistent galactic radio source:

- Strong persistent radio emission at ~60-100 mJy, in quiescent state.

- VLBI observations show milli-arcsec relativistic jets ($v \sim 0.81c$), with angle to the line of sight of <14°.

- Sufficiently long (>3 days) quenched radio states (~1-15 mJy) are followed by giant radio outburst (~1-20 Jy).

Tudose et al. 2007
**CYGNUS X-3 RADIO STATES**

- **Major flaring:** ~1-20 Jy
- **Minor flaring:** <1 Jy
- **Quiescent states:** ~60-100 mJy
- **Quenched states:** ~1-15 mJy

Image courtesy of Karri Koljonen
Correlation & anti-correlation between hard x-ray and radio.

Correlation radio/hard x-ray during major flares and quenched state.

Anti-correlation radio/hard x-ray during quiescence.

McCollough et al. 1999
Anti-correlation between Swift/BAT (15-50 keV, top) hard x-rays and RXTE/ASM (1.3-12 keV, bottom) soft x-rays.

The hard x-rays are anti-correlated with the soft x-rays during the periods of the Fermi/LAT active state, shown by the orange-shaded areas.

Szostek et al. 2008
Multi-wavelength plot of Cygnus X-3:

- AMI-LA, (radio, 15 GHz)
- PAIRITEL, (IR, K$_s$ mag., 2.2 μm)
- Swift BAT (hard x-ray, 15-50 keV)
- AGILE (γ-rays, 0.1-3 GeV)
- Fermi LAT (γ-rays, 0.1-100 GeV)
- VERITAS (γ-rays, 0.1-30 TeV)

Grey area: radio-quenched state.

1$^{st}$ dotted line: major radio flare onset.

2$^{nd}$ dotted line: major radio flare peak.
**Multi-wavelength plot of Cygnus X-3:**

- AGILE detection of $\gamma$-ray emission (0.1-3 GeV *before* onset of major radio flare and before Fermi LAT.

- AGILE has a high live time (~40%), more suited for brief impulse events (<1 day).

- $\gamma$-ray emission before radio may give support for **leptonic model**: $\gamma$-rays from IC upscatter of jet electrons, with subsequent *radio emission* (cooling electrons become transparent to own synchrotron emission).
Multi-wavelength plot of Cygnus X-3:

AGILE detection of $\gamma$-ray emission is observed before the descent into radio-quenched state.

Detection by AGILE (0.1-3 GeV) at a harder spectral index $\Gamma \sim 1.8$ than Fermi LAT (0.1-100 GeV) ($\Gamma \sim 2.7$), for $\gamma$-ray active states.

AGILE live time $\sim 40\%$ versus $\sim 15\%$ of Fermi LAT.
Multi-wavelength plot of Cygnus X-3:

- Peak IR emission (K mag., 2.3 μm) before onset of major radio flare.

- IR emission before radio emission may be due to cooling electrons, but hard to point to IR emission origin (disk, jet, Wolf-Rayet star).

- AGILE and PAIRITEL peak emission observations for MJD 55640 have overlap. Overlap of IR/AGILE γ-ray event in 2010 as well.
Cygnus X-3 Infrared Spectrum:

- Average waveband-centered IR data points for J (1.26 μm), H (1.60 μm) and K_s (2.22 μm) magnitudes.
  - Red curve: average spectrum for flaring radio state.
  - Blue curve: average spectrum for quiescent radio state.
- Spectral break may be due to exhaustion of electron energy in synchrotron process, but other IR contributions (i.e. dust) possible.
- Synchrotron contribution increases from IR to radio, while WR star contribution opposite.

Mike McCollough, 8th INTEGRAL Workshop, 2010
Multi-wavelength plot of Cygnus X-3:

- Swift XRT (1-8 keV), decrease in soft x-ray emission, with decrease in disk accretion following major radio flare.

- Two peaks in the Swift BAT emission (15-50 keV), during soft x-ray descent ➔ hard x-ray response to major radio flare.

- Possible explanation of hard emission: **internal shocks in jets**.

- Fermi and AGILE emission region: shaded blue area.
Multi-wavelength plot of Cygnus X-3:

Swift XRT (1-8 keV): increase in soft x-ray emission during Fermi LAT active state which precede descent into radio-quenched state.

Possible explanation of soft x-ray emission: **half-day radio-quenched states**?

Radio-quenched region: shaded grey area.
Multi-wavelength plot of Cygnus X-3:

- VERITAS observations following radio flare (MJD 55648-55662).

- 99% c.l. upper limits on TeV observations, following major radio flare peak.

- TeV production most likely in descent/exit of quenched radio/hard x-ray state, more likely to occur closer to GeV emission area (blue shaded area).
SUMMARY

- Two types of $\gamma$-ray emission: descent into and exit from quenched radio states, as confirmed by both AGILE and Fermi.

- Possible support for leptonic model, from AGILE data before onset of March 2011 radio flare.

- Possible internal shocks in jets, visible from comparison of soft x-ray (disk) and hard x-ray (jet) emission.

- Hard to pinpoint location of major infrared contribution (disk, jet, Wolf-Rayet star).

- Release of soft x-rays in between $\gamma$-ray emission $\Rightarrow$ half-day long radio-quenched states preceding final successful attempt into quenched state?

- TeV emission possibly occurs closer to GeV emission area, but hard to catch due to transient nature of event (~days).