e-VLBI observations of the first gamma-ray nova V407 Cyg

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Outline

• Fermi-LAT, e-VLBI, and their synergy
• Optical novae and the 2010 March event of V407 Cyg
• e-VLBI observations of V407 Cyg
• Summary and outlook
The Fermi Large Area Telescope

• A gamma-ray telescope launched on June 11, 2008
• **Covers full sky every ~3 hours**
  – unprecedented opportunity for MWL studies of single sources
• Second Fermi catalog (2FGL, Abdo et al. 2011, arXiv:1108.1435)
  – 1873 sources, mostly blazars (60%) and pulsars
  – unprecedented opportunity for population studies
• Flaring sources (above $10^{-6}$ ph s$^{-1}$ cm$^{-2}$) announced with ATels
  – 143 as of Oct 2011
  – trigger prompt reaction at several MWL facilities
More on LAT triggers...

- 143 Astronomer’s Telegram since Aug 2008
  - mostly blazars, including giant outburst of 3C454.3, high-z quasars, one radio galaxy, ...
  - 20 galactic plane, including Cyg X-3, Crab, other transients
  - 4 solar flares
- Events can be as short as a few hours, or last for rather long (~weeks)
- Several MWL facilities can respond very quickly (e.g. Swift in a few hours)
  - but many have relevant observational constrains, e.g. due to sun position
  - shortest time scales correspond to sizes that are far beyond the resolution of basically all observatories

Some elements supporting a strong synergy between Fermi-LAT and e-VLBI

- The gamma-ray sky seen with the sensitivity of Fermi is full of time variable sources: blazar flares, transient galactic sources, etc.

- Time variable sources are e-VLBI favorite playground!
  - Is a compact source there? Is it doing anything worth studying?

- Multi-wavelength and time resolved studies are essential to constrain emission models

- e-VLBI offers several significant practical advantages:
  - easier scheduling, prompt analysis of coordinated results
  - AGN studies can greatly benefit from eVLBI! (eg. Abdo et al. 2009, Giroletti et al. 2011)
Optical novae & V407 Cyg

• Novae
  – thermonuclear outburst in binary systems containing an accreting white dwarf (WD)
  – accreted material accumulates until pressure at base of accreted shell produces thermonuclear ignition; result is ejection of shell, expanding into surroundings

• V407 Cyg
  – symbiotic system comprising an accreting WD and a Mira-type red giant (RG)
  – optical monitoring of the system revealed an outburst with onset 2010 Mar 10; announcement of detection by Nishiyama and Kabashima (IAUC 2199, 2010)
  – Unusual aspect: a nova in a symbiotic system
    • The term “classical nova” usually refers to outbursts in WD accreting from low-mass companions, not RG

(Credit: David Hardy/PPARC)
V407 Cyg and the 2010 March gamma-ray event

- Fermi LAT detected a transient gamma-ray source in the Galactic Plane in routine LAT processing for transients
  - Fermi J2102+4542
  - Cheung et al, ATel 2487
  - >100 MeV flux of $(1.0 \pm 0.3) \times 10^{-6} \text{ ph cm}^{-2} \text{ s}^{-1}$ on March 13rd
  - $(1.4 \pm 0.4) \times 10^{-6} \text{ ph cm}^{-2} \text{ s}^{-1}$ on March 14th
- Initially, counterpart was unknown but X-ray Swift observations pointed to the optical V407 Cyg event, establishing:
  - first $\gamma$-ray detection of any nova
  - first clear $\gamma$-ray detection of any source associated with a white dwarf

see Abdo et al. (2010, Science 329, 817)
Radio background

- Historic data reported non detections
  - <0.06 mJy at 8.4 GHz (Wendker 1995; Ivison et al. 1995)

- Immediately after outburst, low resolution observations started, reporting significant flux and inverted spectrum (ATels 2506, 2511, 2514, 2529)

- What’s going on in there? need for new, high resolution observations! eVLBI offers:
  - prompt access to extremely sensitive array (European VLBI Network)
  - possibility to immediately know the state of the source and to plan future observations accordingly
• **Observations**  
  – started on March 30th (day 20) with the EVN  
  – frequency of 5 GHz, for 9 hours  
  – stations of Effelsberg, Medicina, Onsala, Jodrell Bank, Cambridge, Knockin, WSRT, Shanghai, Yebes  
  – J2102+4702 was used as a phase calibrator

• **Results**  
  – naturally weighted beam: 8.1 x 6.6 mas at PA= 84 deg  
  – field rms noise ~25 µJy/beam  
  – ~6 sigma significance level excess detected in position consistent with V407 Cyg  
  – circular Gaussian component model fit:  
    • RA = 21h02m09.8180s, Dec = +45d46'32.673" (J2000)  
    • flux density ~0.2 mJy  
    • nominal deconvolved FWHM diameter ~3 mas
e-VLBI observations: epoch A, considerations

- The total flux density detected in the region is about 0.4 mJy. This is significantly lower than 5.8+/-0.9 mJy measured at the same frequency two days earlier by ATA (ATel #2529)
  - the majority of the flux at this frequency is emitted on larger angular scales
- Thanks to real time correlation... by April 1st (day 22, no April fool!) we know the source is largely resolved but a compact component is there
  - also confirmed by visibility data inspection
- It’s worth continuing to monitor... possibly still with e-VLBI so we can plan accordingly
- e-EVN offers 1.6 GHz soon: new observations obtained on May
  - the spectrum is also getting less inverted
e-VLBI observations: epoch B

- ToO observation performed on April 23 (day 44 since optical event),
- Frequency of 1.6 GHz, as available from e-EVN run, 11.5 hr duration
- Still doing phase referencing given the faint 5 GHz structure observed in Epoch A...
  - ...surprising, wonderful, extended, bright structure!
- ...really worth continuing to monitor, THANKS E-VLBI & INCREDIBLY SENSITIVE EVN
e-VLBI: continued monitoring

• Other four epochs warranted
  – mix of 1.6 and 5 GHz
  – cover evolution up to 6 months after optical event
  – real time correlation less essential but still important to see the results as the source was changing

<table>
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<th>Epoch label</th>
<th>Date</th>
<th>Days since March 10</th>
<th>Freq. (GHz)</th>
<th>ToO?</th>
<th>total flux (mJy)</th>
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<td>March 30</td>
<td>20</td>
<td>5</td>
<td>Y</td>
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<tr>
<td>B</td>
<td>April 23</td>
<td>44</td>
<td>1.6</td>
<td>Y</td>
<td>2.7</td>
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<td>May 19</td>
<td>70</td>
<td>5</td>
<td>Y</td>
<td>8.3</td>
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<td>D</td>
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<td>203</td>
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Monitoring results: images

A, 5 GHz
B, 1.6 GHz
C, 5 GHz
D, 1.6 GHz
E, 5 GHz
F, 1.6 GHz
Monitoring results: inner and outer structure

- Complex structure continued to be detected at later epochs
- Source became more extended and fainter; final epochs not as spectacular but still providing valuable information
- Visibility plane model fit
  - 2 to 5 components always detected in inner ~100 mas
  - 1 component at ~400 mas north west detected in 1.6 GHz images
Fitting the expansion...

- **inner ejecta**
  - <43 days: expansion with a speed of 0.7 mas/day
  - 44-179d: 0.2 mas/day
  - >180days: 0.16 mas/day
- **outer blob**
  - speed of roughly 0.1 mas/day during the time we observe
  - if it started at day 0 in the center, it had to travel several mas/days during the first 43 days of the expansion
Size and velocities

• inner shell expanding at 3400 km/s in the first 44 days, then slows down to 900/1000 km/s
  – few thousand kilometers per second are rather normal values for these components
• outer blob need to be as fast as 30000 km/s if it started from the same origin
  – quite fast for a nova but still sub-relativistic
  – remember the total flux was largely resolved by VLBI at the early observations, so extended emission was there

assuming $d=2.45 \text{kpc}$

$1 \text{ mas}=1 \text{ AU @1 kpc}$
Summary

- An unprecedented (and unrepeated, so far!) event in gamma rays
- Combination of gamma rays, optical, and X-rays greatly helped in catching and understanding this event
  - Nova shell expanding into suitable environment might accelerate particles to high energy
- Prompt and sensitive radio observations helped to catch a view of this event with unmatched resolution
  - Expansion of inner shell directly seen
  - Outer component in need of interpretation...

...and let’s continue to exploit the Fermi/e-VLBI synergy for more great science!