The RAPTOR (RAPid Telescopes for Optical Response) telescopes and GeV/TeV gamma-ray astronomy
Fast Response:
• Begin imaging anywhere in the sky in < 6s
• Seven 0.4m class telescopes
• T: True Simultaneous Multi-Color: Clear, V, R, I
• Z: Fast cadence: 7Hz

Persistent Monitoring:
• Real-time transient detection
• Q: Full Sky to 18th Rmag in 20s
• K: 16th Rmag in 30s, Full Sky 7m

RAPTOR, Thinking Telescopes
The RAPTOR/Thinking Telescopes Project---Autonomous Robotic Astronomy

**Observational Science**
- Sensor technology
- Wide-field sky monitoring
- Fast response telescopes

**Information Technology**
- Data mining
- Advanced database technology
- Co-designed Computing

**Theory and Modeling**
- High-Energy Astrophysics, Stellar Astronomy

**Real-time data pipelines**
- Autonomous robotic Instruments
- Intelligent, distributed sensor networks

**Machine learning**
- Object classification
- Anomaly and change detection

An Autonomous Engine for Discovery in the Time Domain

Aspen Meeting---Galactic GeV/TeV sources
Distributed “Thinking” Telescopes Network

38 km baseline

LANL Central Decision System

Vestrand

Aspen Meeting---Galactic GeV/TeV sources
Potential *Fermi* Science Areas

- Revealing the identities of unidentified Fermi GeV gamma-ray sources
- GeV emitting Blazars
- GeV emitting explosions in Galactic Sources
- GeV emitting Gamma-ray Bursts (GRBs)
Unidentified Fermi Sources

- More than 1000 new sources have been discovered, most (~600) are unidentified.
- Gold standard for identification is finding of optical counterpart through correlated variability.
- Most localized to ~1 degree. Each has many possible counterparts even at depth of 16th magnitude.
- In survey mode, Fermi scans the sky in 180 minutes.
- Challenge for optical systems --- scan the sky at a similar cadence.
Full Sky Persistent Monitoring

RAPTOR-K

- Scans the full sky at site in 10 minutes
- Sensitivity of $R \sim 16^{th}$ magnitude in 30s
- 16 telescope array
- $10^3$ deg-sq FOV
Persistent monitoring of localized (<0.5 deg) sources

RAPTOR-T

• Each site monitors about 100 sources of interest twice per night.

• Simultaneous cVRI Imaging, $C_R=19.9$ in 90-sec.

• RAPTOR-T North (built and operating since 2008)
  • RAPTOR-T South (built)

• (Also monochrome monitoring with RAPTOR-S and two RAPTOR-W telescopes)
Potential *Fermi* Science Areas

• Revealing the identities of unidentified Fermi GeV gamma-ray sources
• GeV emitting Blazars
• **GeV emitting explosions in Galactic Sources**
• GeV emitting Gamma-ray Bursts (GRBs)
How do you establish the existence of new classes of transients?

- Seen simultaneously by multiple instruments in the same wavelength/energy band.
- Or, in a single instrument, see enough of them to exclude instrumental or man-made effects.
- Seen simultaneously in different energy band with both having a distinct (and uncommon) temporal signature.
Are there Explosive, >100 MeV gamma-ray emitting, galactic sources? (not counting the Sun)

EGRET Detection of Cen X-3 outburst

• Found as part of an EGRET GI program to survey suspected TeV emitting x-ray binary systems
• Detected an outburst of >100 MeV with a flux of $9 \times 10^{-7}$ photons cm$^{-2}$ s$^{-1}$ ($\sim 5\sigma$ significance) during a two week interval in October 1994.
• Cen X-3 is a disk-fed pulsar in orbit around an O-type supergiant companion ---2.09 day orbit period, 4.8 second spin period
• Detected during an interval of rapid x-ray pulsar spin-down
Cen X-3 Outburst

- $L_\gamma \approx 5 \times 10^{36}$ ergs/sec ---- $L_x \approx 10^{38}$ ergs/sec
- Spectrum – power law with index $1.8 \pm 0.4$

Was it a background Blazar? Maybe but...

- Six Parkes sources within the 95% contour, using the standard gamma/radio flux ratios for EGRET blazars one predicts a 5 Ghz flux of $\sim 4500$ mJy ---- all potential candidates have fluxes less than 70 mJy. (But maybe it is an outlier...)
Evidence for gamma-ray modulation at drifting x-ray spin period

• No sign of 2.09 day orbital modulation
• No sign of nominal (steady) 4.8 second orbital modulation
• But pulsar was undergoing an interval of rapid spin-down during the EGRET observations. When the gamma ray arrival times were folded with the simultaneous BATSE measurements of the drifting x-ray spin period, we found modulation at the 3.5-sigma significance level for the EGRET detected gamma-rays.
• We did the timing analysis at four other positions in the field as controls, those locations showed no modulation.
Are there new classes of Galactic GeV/TeV transients?

GeV emission from Recurrent Nova?

- Nova, detected in the optical at 8th mag on March 10, 2010—V407 Cygni
- White dwarf accreting from Red giant star wind, material acquires and triggers thermonuclear explosion
- In ATEL #2487 Cheung et al. report the emergence of Fermi J2102+4542 on March 12 and associate it with the V407 Cygni
- Did a strong shock in the wind generate GeV emitting particles?
- Suggests that bright optical outbursts could signal the pending onset of gamma-ray outbursts. (as it sometimes does for x-ray outbursts)
Conclusion

• Time domain astronomy employing advances in robotic instrumentation, real-time knowledge extraction, and global networking of heterogeneous observing platforms is fundamentally changing the way we search and interrogate astrophysical transients.

• Autonomous, Robotic, Optical instruments like RAPTOR have the potential to make important contributions to the study of explosive GeV/TeV transients. I would be very interested in talking about potential collaborations.