A Swift Program of Follow-up Observations of MAXI Galactic Transients

Jamie A. Kennea (Penn State)
and
P. Romano, V. Mangano (INAF Palermo)
A. P. Beardmore, P. A. Evans (U Leicester)
P. A. Curran (CEA/Saclay)
H.A. Krimm (GSFC/CRESST/USRA)
K. Yamaoka (Aoyama Gakuin Uni)
Swift as a Transient Follow-up Tool

Swift is an ideal as a tool to follow-up and localize new X-ray transients:

- **Broad band observing:**
  - BAT, Hard X-ray: 15-150 keV
  - XRT, Soft X-ray: 0.3-10 keV
  - UVOT, Optical/Ultra-violet: u,b,v and 3 UV filters + “white” and grisms.

- **Accurate localization:**
  - XRT ~3.5 arc-sec radius, with UVOT correction can reduce to ~1.5 arc-sec radius (90% confidence)

- **Low overhead observations.**
  - Rapid slewing means that 1ks observations can be made easily and often.
  - Low slew-time overhead means short (1 ks) daily or even orbit-by-orbit monitoring is possible.

- **Capability to command Swift to autonomously observe TOOs.**
  - Swift can be on target within minutes of a transient notice being distributed (more typical is 30 mins to a day once decision to observe is made).
  - Delays are usually caused by “human-in-the-loop” issues, e.g. delayed notification, out of hours response. Also delays caused by ground station passes.
MAXI/Swift Galactic Transient Program

- Goals:
  ★ To more accurately localize new Galactic Transients detected by MAXI.
  ★ Aide the search for new black hole candidates discovered by MAXI.
- 0.2 degree diameter XRT FOV is well matched to the typical error circles for well-localized MAXI detected point sources (i.e. not “short” transients where error boxes are large, where tiling is necessary).
- Trigger criteria:
  ★ Previously unknown, within the Galaxy
  ★ Has a MAXI error circle ~0.2 degrees radius.
  ★ Expanded sometimes to include checking up on possible known sources.
- Approved program for 1ks localization and one follow-up
  ★ Follow-up monitoring programs are frequently approved if the initial observations are a success.
- Swift Cycle 6 GI approved program
  ★ Cycle 6: 1\textsuperscript{st} April 2010-March 31\textsuperscript{st} 2011
  ★ Resubmitted for Cycle 7.
Swift/MAXI Transients Progress

- Program started April 1st, 2010
- 6 triggers of program so far
- 2 of those were bright enough that they also triggered Swift/BAT

**Summary:**
- ★ 2 observations identified MAXI outburst with previously known source
- ★ 2 observations identified previously unknown transient
- ★ One did not find any source in obvious outburst.

- Also an additional MAXI transient observed outside of the program:
  - ★ 4U 1137-65/GT Mus
MAXI reports possible detection of outburst (Morii et al, ATEL #2527) on March 31st, 02:10:23 UT.

Submitted GI TOO to Swift (on first day of AO6), was due for upload at 19:11 UT, when BAT triggered on the LS V +44 17 @18:34 UT and Swift observed it autonomously.

XRT data confirmed MAXI transient was indeed LS V +44 17 (Stratta et al, GCN #10561)
HD 347929/1RXS J180724.2+194217

- Detected by MAXI
  June 27th, 2010
  08:27UT (Usui et al.,
  ATEL #2700)
- Swift TOO uploaded
  June 29th, 00:10UT.
- Bright source
  detected: HD
  347929/1RXS
  J180724.2+194217 in
  outburst.
- Reported by Kennea
  et al. (ATEL #2701)

X-ray outburst of RS
CVn star
Transient reported on August 17\textsuperscript{th} (Kawai, priv. communication), MAXI measured brightness 100x brighter than XMM level of SAX J1452.8-5949.

2 pointings performed. One at MAXI location, another at position of SAX J1452.8-5949.

Observations show a low significance detection of SAX J1452.8-5949, but no enhanced emission.
MAXI J1659-152

- Triggered BAT at 08:05 UT on Sept 25, 2010, but was mis-identified as a GRB (Mangano GCN #11296). Followed up by XRT/UVOT 31 mins later.

- MAXI reported detection at 02:30UT (Negoro ATEL #2873), confirming this was a new Galactic Transient.
MAXI J1659-152: Swift Monitoring

- MAXI J1659 was monitored by Swift over 27 days until it entered a Sun constraint.
- Standard “FRED” like shape in Hard X-ray (BAT)
- X-ray lightcurve rises more slowly than BAT and appears more flat. Shows significant early changes in hardness ratio.
- UV lightcurve correlated with hardness ratio.
MAXI J1659-152: Spectral Evolution

- BAT + XRT spectra modelled with standard “tbabs(po +diskbb)” model.
- See canonical state changes associated with Black Hole Binaries:
  - Spectrum initially dominated by PL with $\Gamma = 1.5$ (Low/Hard State)
  - Quickly evolves to $\Gamma = 2.5$ (“Steep Power-Law State” AKA “Intermediate State”)
  - Thermal disk component rises from $kT_{in} = 0.2$ to 0.8-1 keV, and disk fraction slowly rises peaking at around 50% (evolution to “Thermal State” AKA “High/Soft State”).
  - No final state change seen.
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Note: Rapid rise of NH during initial outburst. Signature of absorption from disk wind?
MAXI J1659-152: QPOs

- Evolving QPOs seen in WT data
- QPO frequency correlated with $\Gamma$ in initial stages, as seen in other BHBs (e.g. 4U 1543-47, Kalemci et al. 2005.) As well as increasing frequency, QPOs evolves to higher energies.
- QPO behaviour consistent with other black-hole binaries.
MAXI J1659-152: Periodicity

- Lomb-Scargle analysis of Swift/XRT WT data finds period of 2.42 +/- 0.09 hours.
- Note this is close to 1.5x 96 min Swift orbit, which made initial confirmation of periodicity difficult, due to worries about aliasing.
- RXTE/XMM measurements confirm 2.4 hour periodicity, therefore we are confident of this value.
- This makes MAXI J1659-152 the shortest period black-hole candidate binary yet known (previous confirmed is Swift J1753.5-0127 at 3.2 hours (Zurita et al. 2008)).
MAXI J1659-152: Conclusion

- Transient shows many signatures of black hole binaries:
  - ★ QPOs and PDS variability
  - ★ Characteristic spectral model and light-curve shape
  - ★ Canonical state changes
- Evidence of rapidly increasing $N_{\text{H}}$ during the initial day of the detection. Evolving wind from the disk?
- X-ray detected period of 2.4 hours is shortest yet known for a black hole binary.
- Swift results by submitted to ApJ Letters (Kennea et al. 2010/11?).
Detected by MAXI on Oct 17th, 2010 at 41mCrab, reported Oct 20th by Yamaoka et al (ATEL #2959)

Swift observed at 15:14UT (4 hours after ATEL) for 1ks. Found a bright new transient (no catalog match other than 2MASS).

This is the first “MAXI only” new Galactic Transient found. Didn’t trigger BAT or other mission, and was unlikely to.
Initially thought to be a candidate SFXT.
★ Highly absorbed X-ray spectrum (4 x 10^{22} cm^{-2})
★ 2MASS IR counterpart to source
★ 6.5+/−0.2 keV ~200eV Iron line reported from RXTE (Yamaoka et al., ATEL #2969), seen in Swift PC mode data at ~6.7 keV.

Monitoring by Swift over 23 days showed no obvious drop to quiescent state.
★ Not likely an SFXT, which typically decay after ~1 week.

Source appears bright and variable.
★ No pulsar period yet detected.
Tomida et al. (ATEL #2990) report detection of a short X-ray transient on Oct 30th, 2010 at 09:07UT.

On Nov 1st @ 18:31 Swift took a 1ks TOO observation of this target.

Pointing was taken to maximise likelihood of observing 2 ROSAT X-ray sources in the error box.

IRXS J183953.1+014250 was detected, but not bright. IRXS J184107.2+01524 was not detected.

Results inconclusive, but only small fraction of the error box covered.
MAXI reported detection of outburst consistent with GT Mus (Nakajima et al., ATEL #3025) Nov 10\textsuperscript{th}, 2010 @ 6:17UT

Swift on target at 23:13UT. 1ks observation confirms detection of GT Mus in X-ray outburst (Kennea et al, ATEL #3025).

Detection of outburst from RS CVn star.
Future/improvements

» Program has been resubmitted for Swift Cycle 7 for almost identical program as Cycle 6.

» Swift improvement: Dealing with large error boxes
  ★ Currently if tiling is necessary, we can only upload one position every 96 mins. This is slow and a high load on the Swift operations team.
  ★ Swift auto-tiling
    ✴ Automated Tiling of larger error circles is being developed by the Swift/BAT team which may in future make searching larger MAXI error boxes easier and quicker.
    ✴ Multiple tiles of large circular regions will be possible in one orbit, rather than taking hours to days.

» Improvements that will help from MAXI side:
  ★ More rapid reporting of transients - especially if Swift tiling is needed.
  ★ Improved error circles always help!
Conclusion

➡ Swift is well matched to localize MAXI transients when:
   ★ The error box is small (~0.2 degrees)
   ★ There is a strong candidate for Swift to point at and confirm if in outburst.

➡ Results:
   ★ Confirmed outburst from 2 RS CVn stars, 1 Be/X-ray binary.
   ★ 2 Observations inconclusive.
   ★ 2 previously unknown X-ray transients found
     ✴ MAXI J1659-152 - Black-hole Binary.
     ✴ MAXI J1409-619 - HMXB?
   ★ 5 out of 7 observations successful in accurately localizing counterpart to MAXI transient.

➡ Reproposed for Swift Cycle 7, under review (decision expected early 2011).