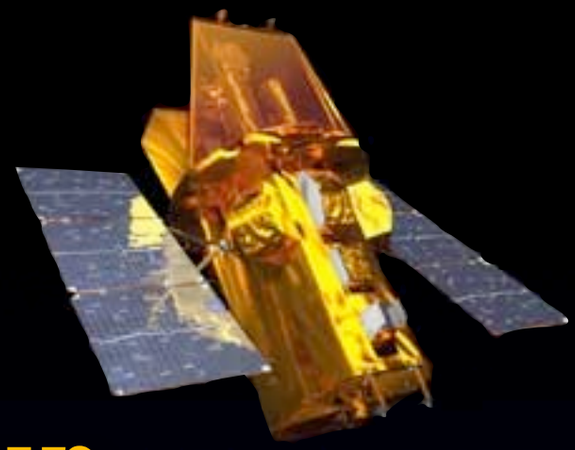
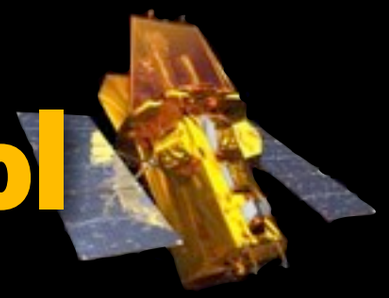


A Swift Program of Follow-up Observations of MAXI Galactic Transients

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)

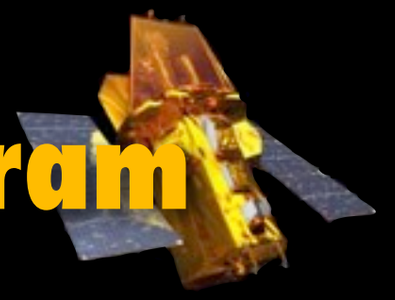
JAXA/RIKEN/MAXIチーム

Swift as a Transient Follow-up Tool



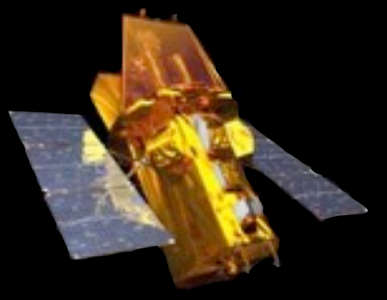
- ➡ Swift is an ideal as a tool to follow-up and localize new X-ray transients:
  - ★ Broad band observing:
    - ✳ BAT, Hard X-ray: 15-150 keV
    - ✳ XRT, Soft X-ray: 0.3-10 keV
    - ✳ UVOT, Optical/Ultra-violet: u,b,v and 3 UV filters + "white" and grisms.
  - ★ Accurate localization:
    - ✳ XRT ~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



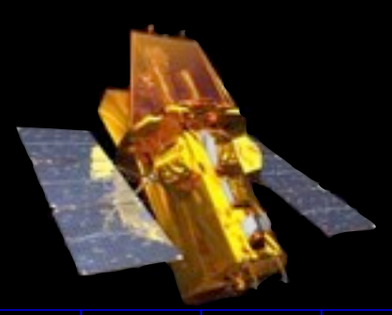
- Goals:
  - ★ To more accurately localize new Galactic Transients detected by MAXI.
  - ★ Aide the search for new black hole candidates discovered by MAXI.
- 0.2 degree diameter XRT FOV is well matched to the typical error circles for well-localized MAXI detected point sources (i.e. not "short" transients 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: 1st April 2010-March 31st 2011
  - ★ Resubmitted for Cycle 7.

Swift/MAXI Transients Progress

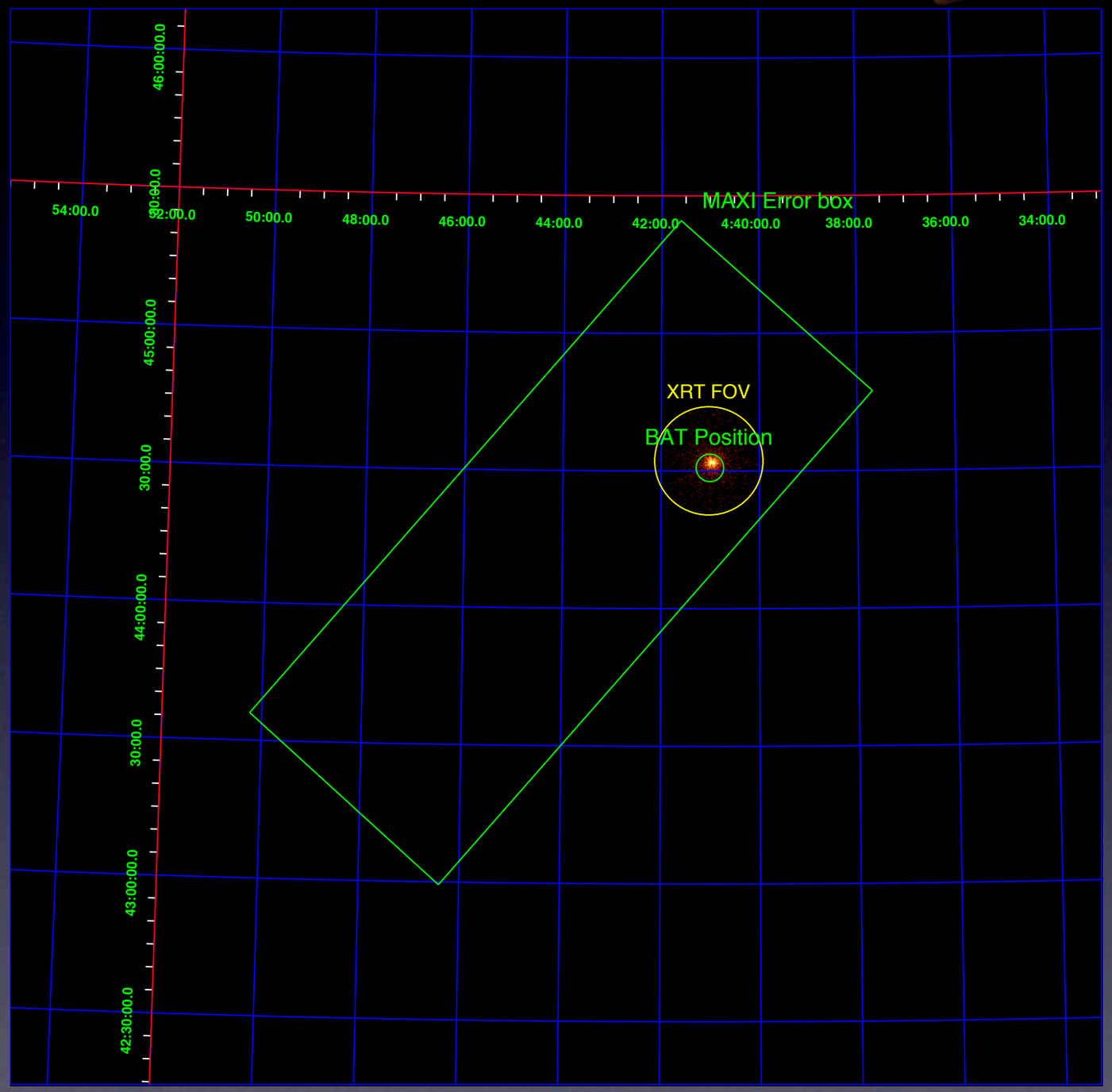


- ➡ Program started April 1st, 2010
- ➡ 6 triggers of program so far
- ➡ 2 of those were bright enough that they also triggered Swift/BAT
- ➡ Summary:
  - ★2 observations identified MAXI outburst with previously known source
  - ★2 observations identified previously unknown transient
  - ★One did not find any source in obvious outburst.
- ➡ Also an additional MAXI transient observed outside of the program:
  - ★4U1137-65/GT Mus

LS V +44 17/RX J0440.9+4431

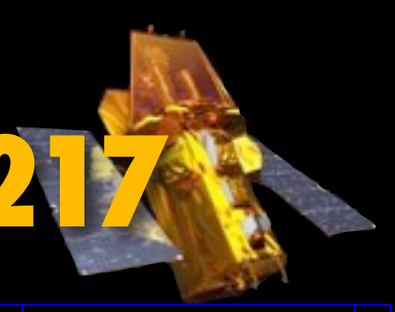


- MAXI reports possible detection of outburst (Morii et al, ATEL #2527) on March 31st, 02:10:23UT.
- Submitted GI TOO to Swift (on first day of AO6), was due for upload at 19:11UT, when BAT triggered on the LS V +44 17 @18:34 UT and Swift observed it autonomously.
- XRT data confirmed MAXI transient was indeed LS V +44 17 (Stratta et al, GCN #10561)

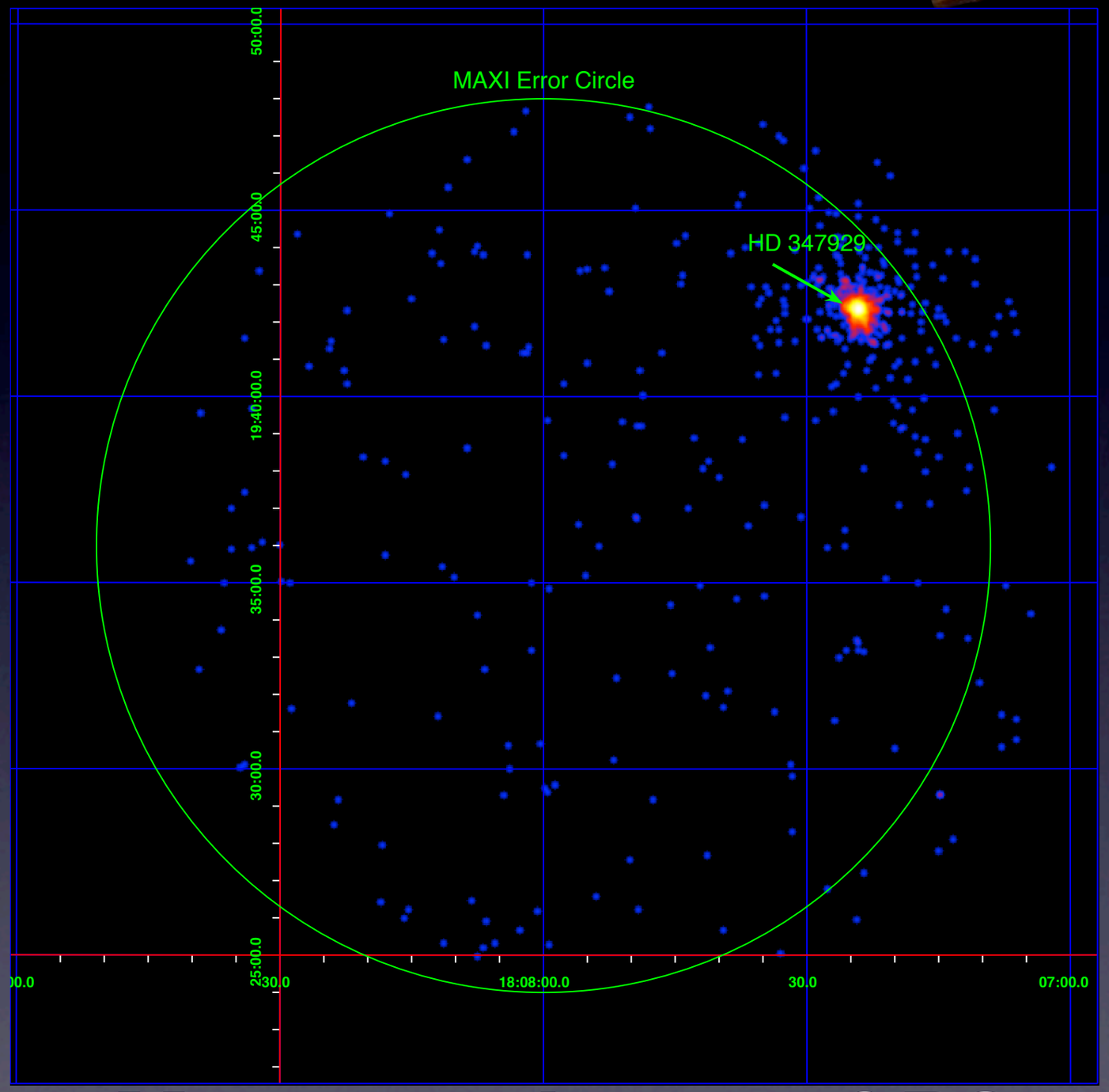


X-ray outburst of Be/ X-ray Binary

HD 347929/1RXS J180724.2+194217

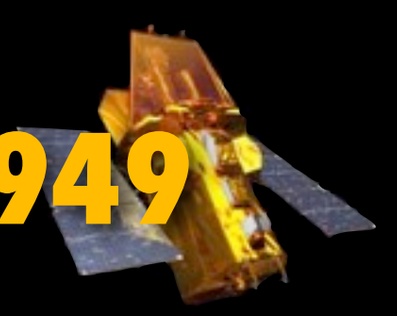


- Detected by MAXI June 27th, 2010 08:27UT (Usui et al., ATEL #2700)
- Swift TOO uploaded June 29th, 00:10UT.
- Bright source detected: HD 347929/1RXS J180724.2+194217 in outburst.
- Reported by Kennea et al. (ATEL #2701)

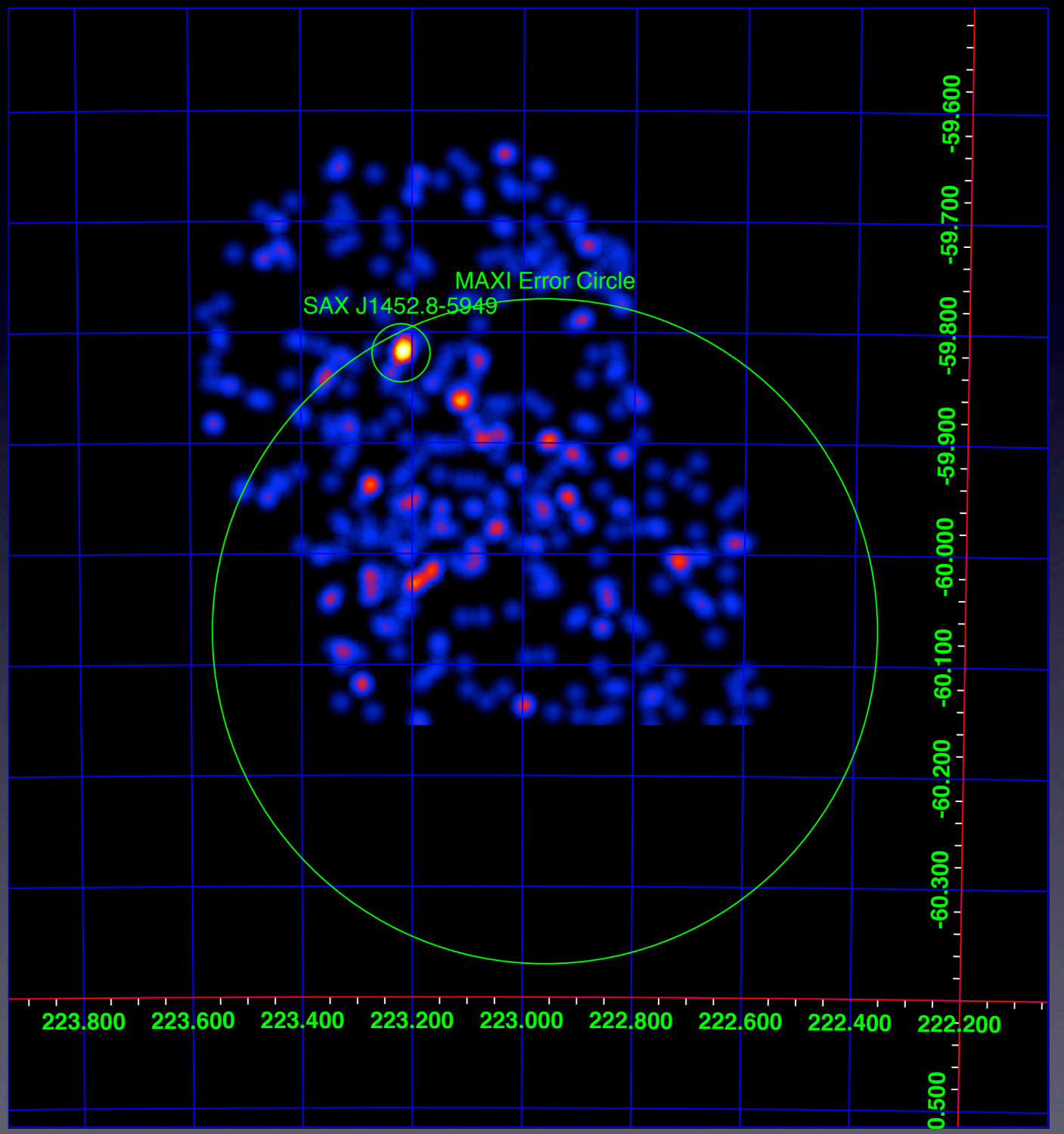


X-ray outburst of RS CVn star

MAXI transient near SAX J1452.8-5949

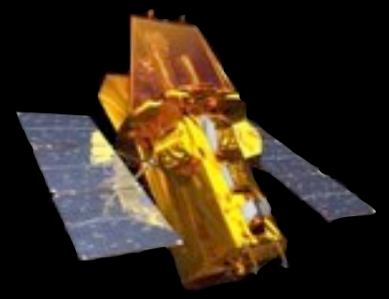


- Transient reported on August 17th (Kawai, priv. communication), MAXI measured brightness 100x brigher than XMM level of SAX J1542.8-5949.
- 2 pointings performed. One at MAXI location, another at position of SAX J1452.8-5949
- Observations show a low significance detection of SAX J1452.8-5949, but no enhanced emission.

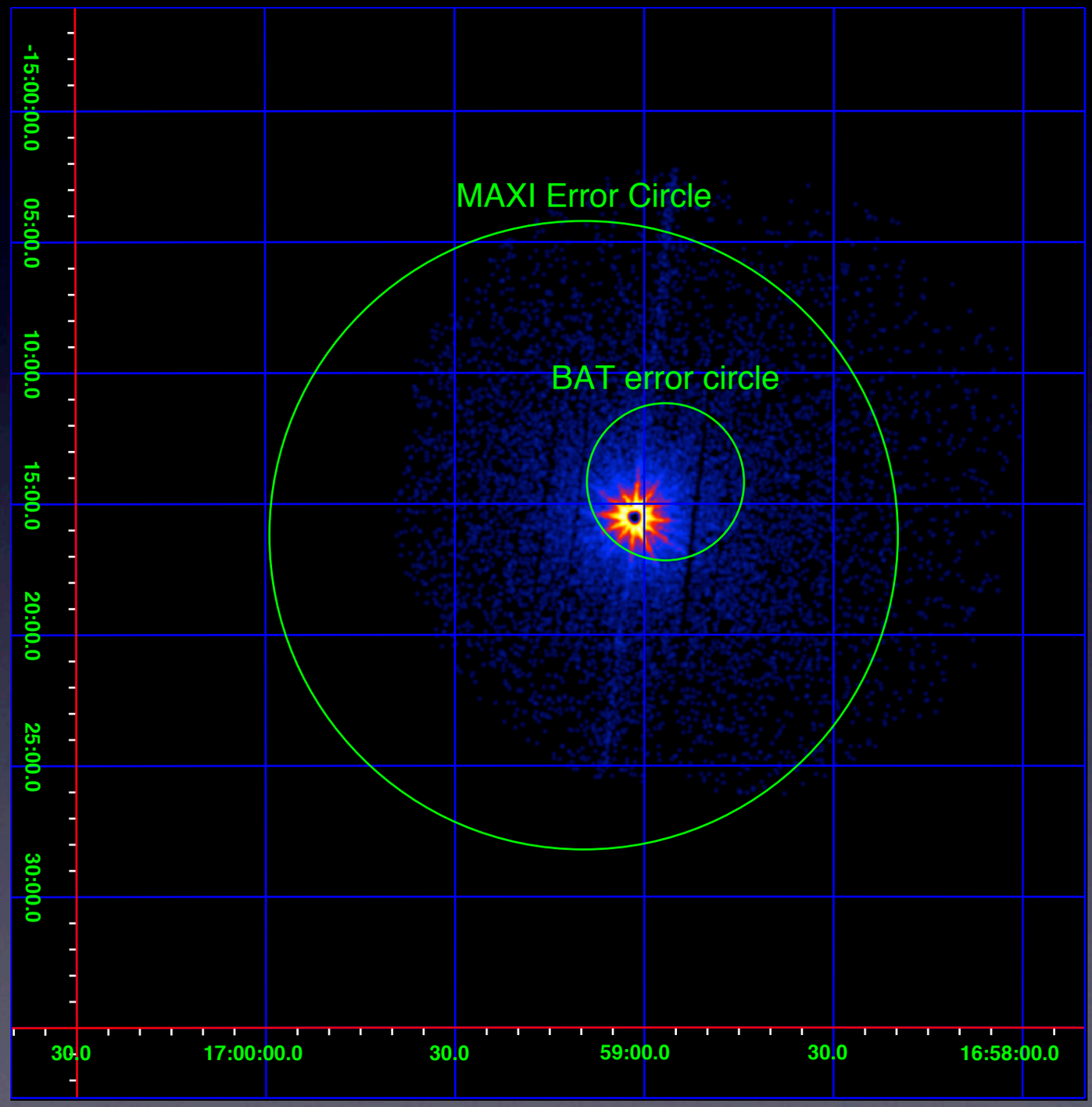


Inconclusive

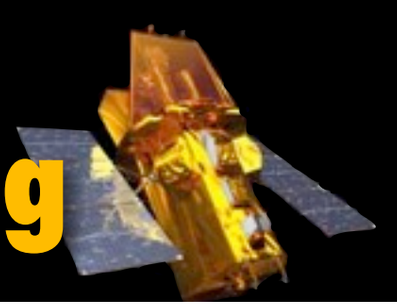
MAXI J1659-152



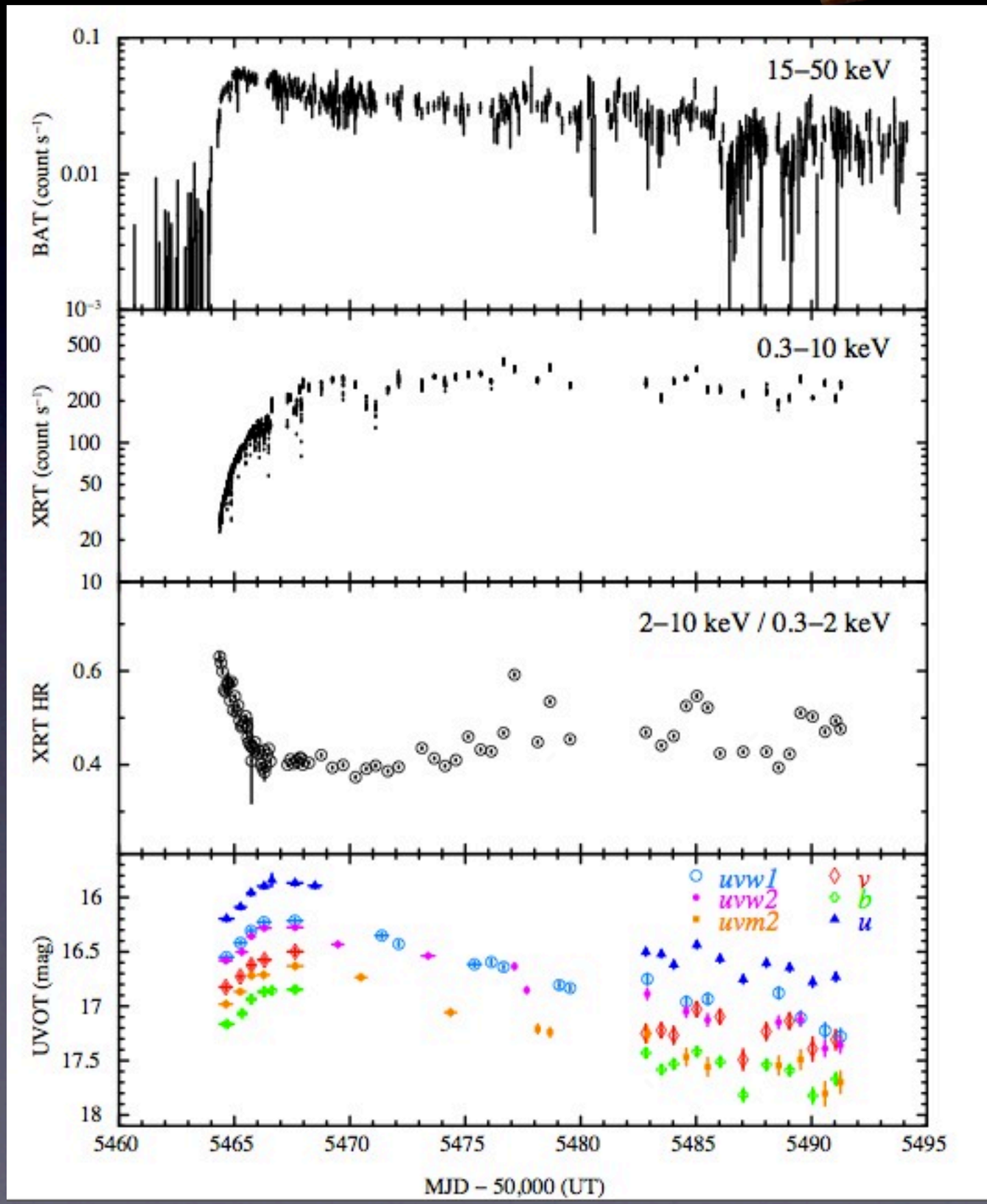
- Triggered BAT at 08:05 UT on Sept 25, 2010, but was mis-identified as a GRB (Mangano GCN #11296). Followed up by XRT/ UVOT 31 mins later.
- MAXI reported detection at 02:30UT (Negoro ATEL #2873), confirming this was a new Galactic Transient.



MAXI J1659-152: Swift Monitoring

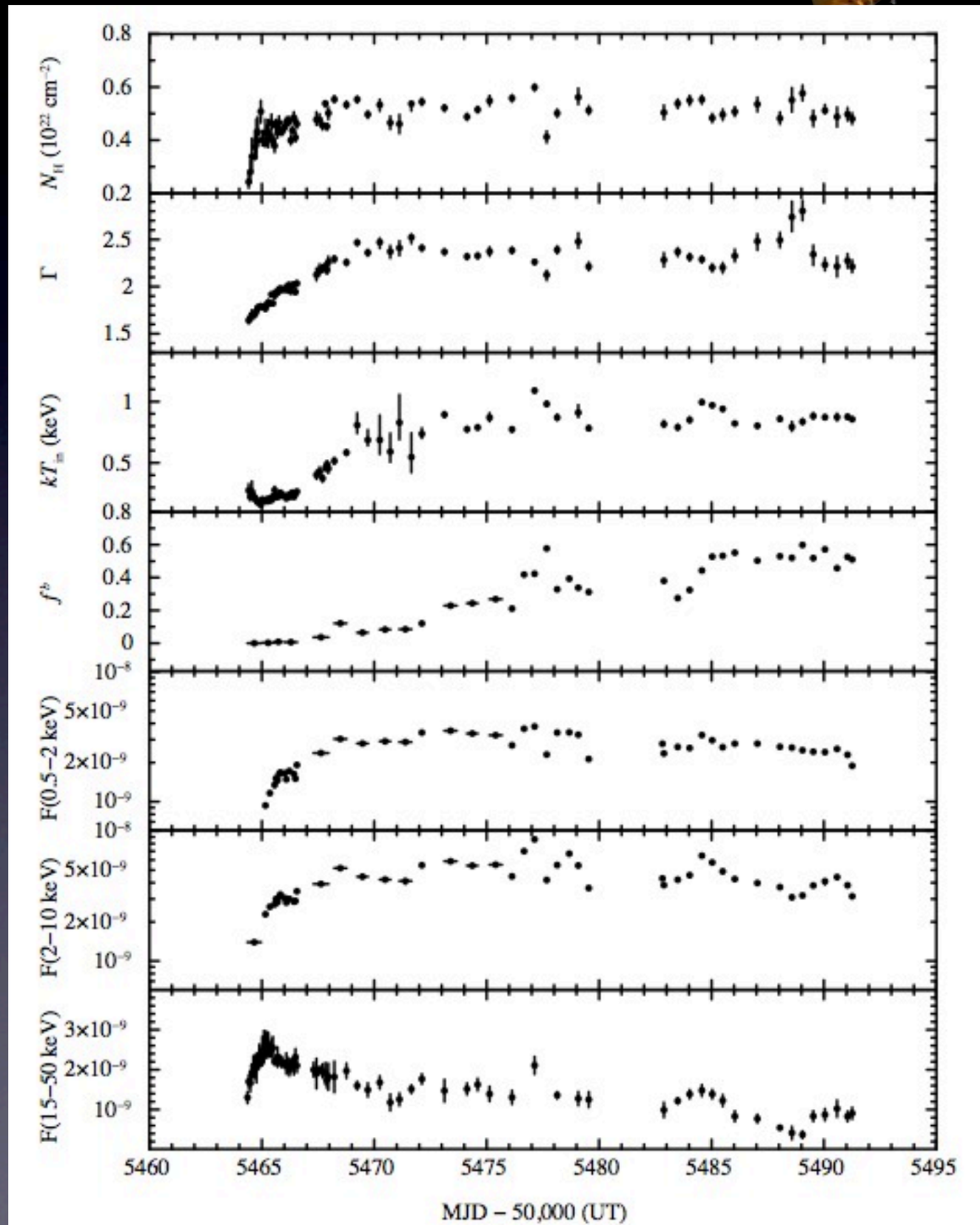


- MAXI J1659 was monitored by Swift over 27 days until it entered a Sun constraint.
- Standard "FRED" like shape in Hard X-ray (BAT)
- X-ray lightcurve rises more slowly than BAT and appears more flat. Shows significant early changes in hardness ratio.
- UV lightcurve correlated with hardness ratio.



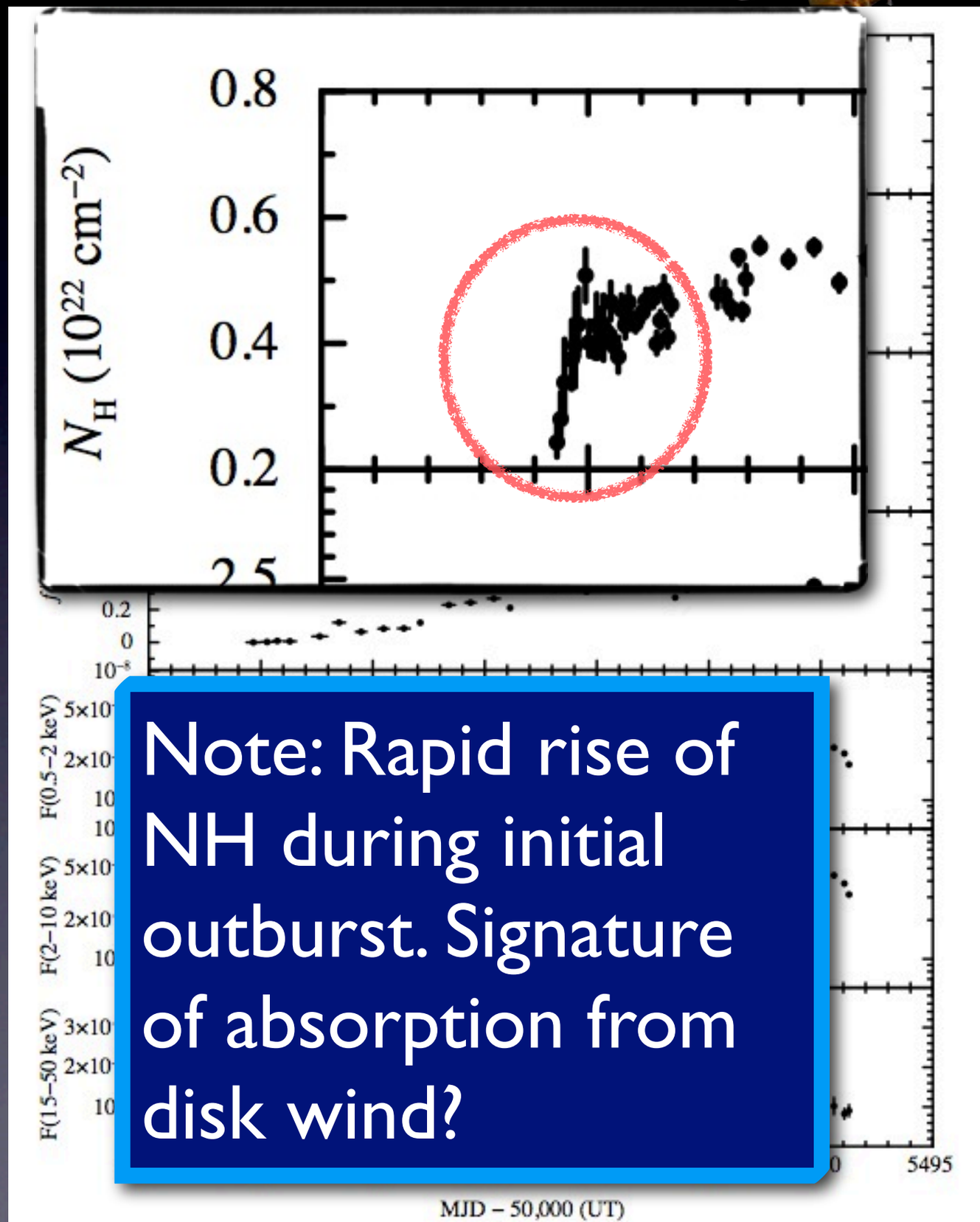
MAXI J1659-152: Spectral Evolution

- 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 Γ=1.5 (Low/Hard State)
  - ★ Quickly evolves to Γ=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.

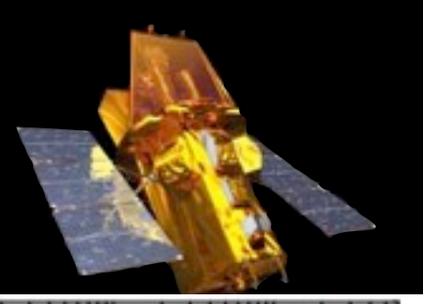


MAXI J1659-152: Spectral Evolution

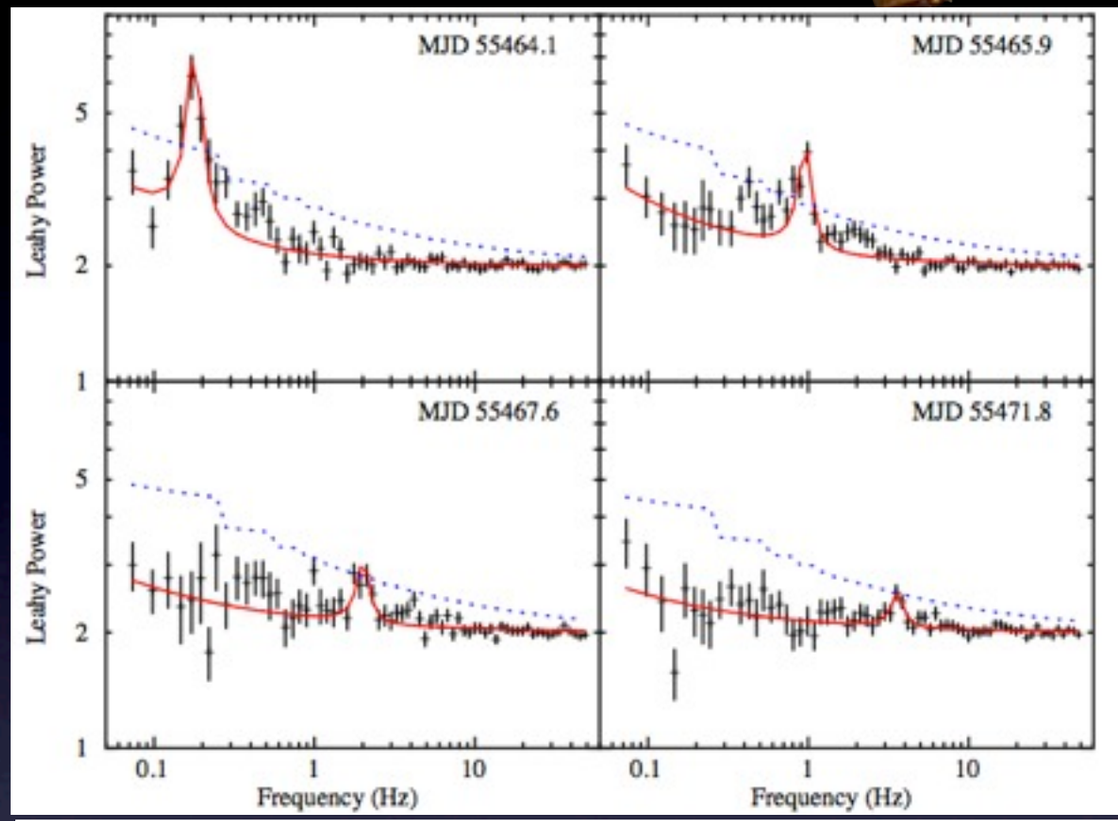
- BAT + XRT spectra modelled with standard "tbabs(po +diskbb)" model.
- See canonical state changes associated with Black Hole Binaries:
  - ★ Spectrum initially dominated by PL with Γ=1.5 (Low/Hard State)
  - ★ Quickly evolves to Γ=2.5 ("Steep Power-Law State" AKA "Intermediate State")
  - ★ Thermal 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.

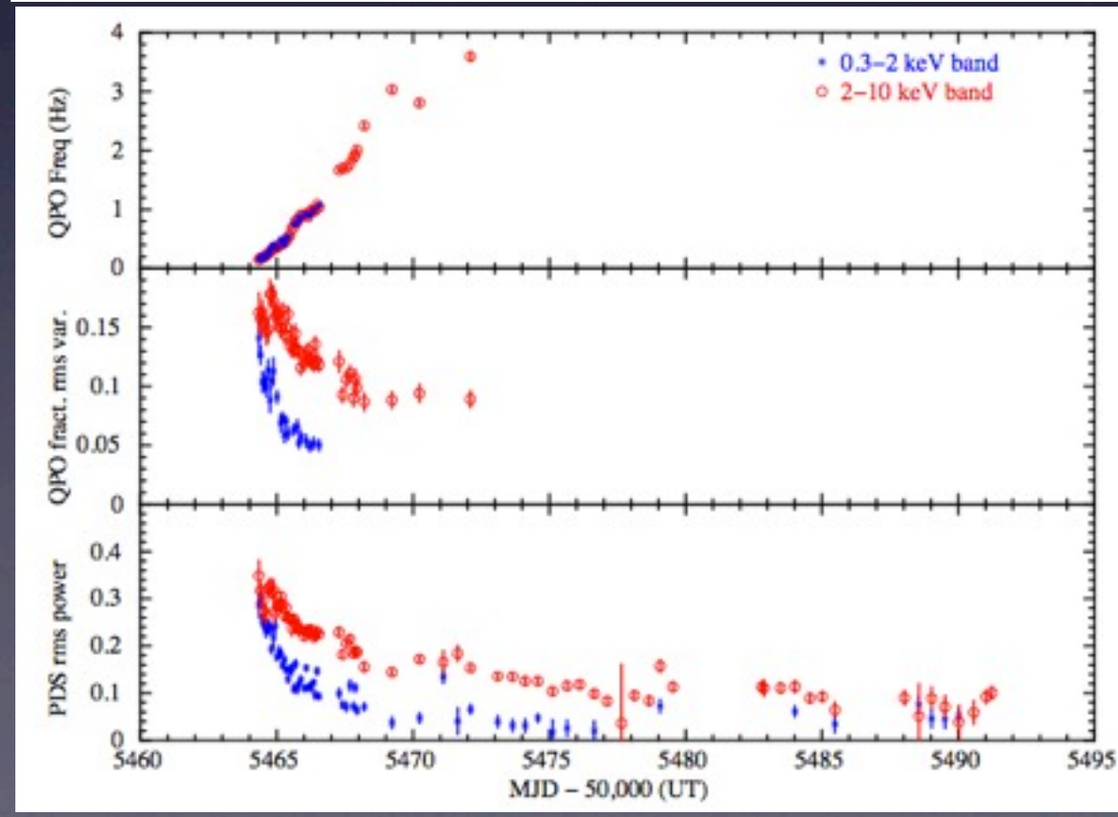


MAXI J1659-152: QPOs

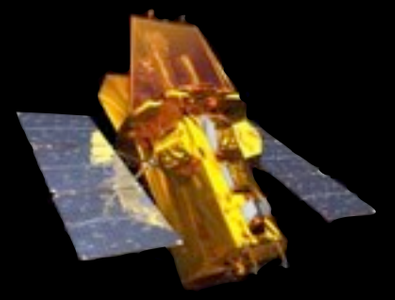


- Evolving QPOs seen in WT data
- QPO frequency correlated with Γ in initial stages, as seen in other BHBs (e.g. 4U 1543-47, Kalemci et al. 2005.) As well as increasing frequency, QPOs evolves to higher energies.
- QPO behaviour consistent with other black-hole binaries.



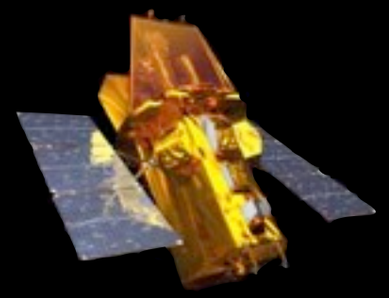


MAXI J1659-152: Periodicity



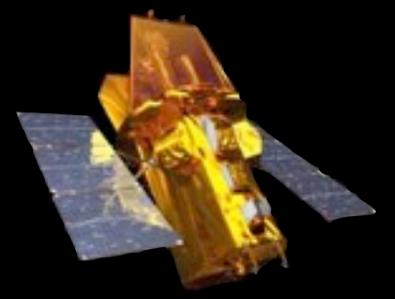
- Lomb-Scargle analysis of Swift/XRT WT data finds period of 2.42 +/- 0.09 hours.
- Note this is close to 1.5x 96 min Swift orbit, which made initial confirmation of periodicity difficult, due to worries about aliasing.
- RXTE/XMM measurements confirm 2.4 hour periodicity, therefore we are confident 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

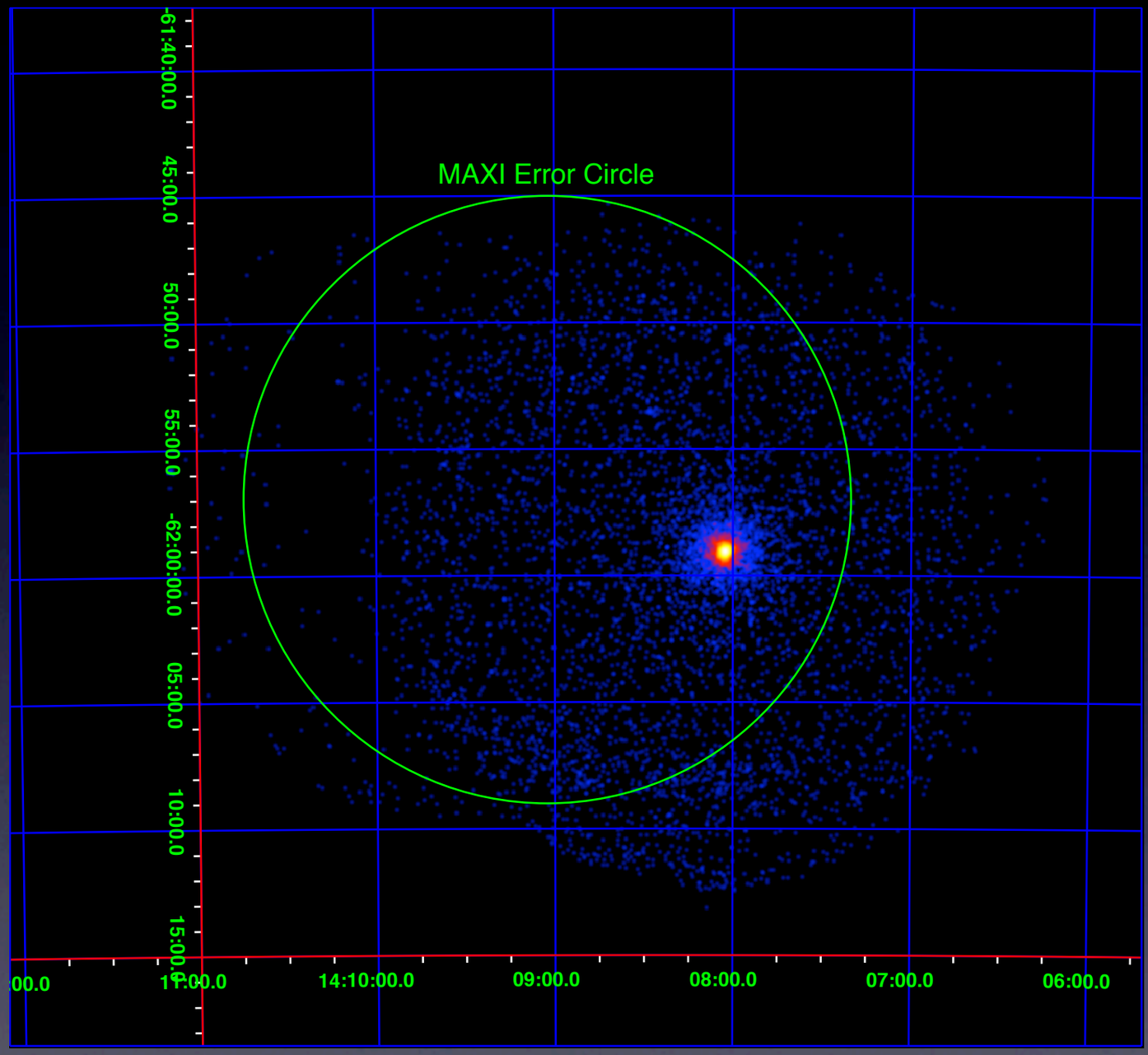


- ➡ Transient shows many signatures of black hole binaries:
  - ★QPOs and PDS variability
  - ★Characteristic spectral model and light-curve shape
  - ★Canonical state changes
- ➡ Evidence of rapidly increasing N_H during the initial day of the detection. Evolving wind from the disk?
- ➡ X-ray detected 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?).

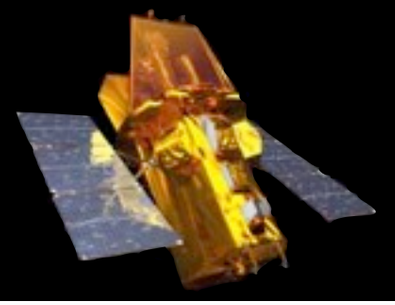
MAXI J1409-619



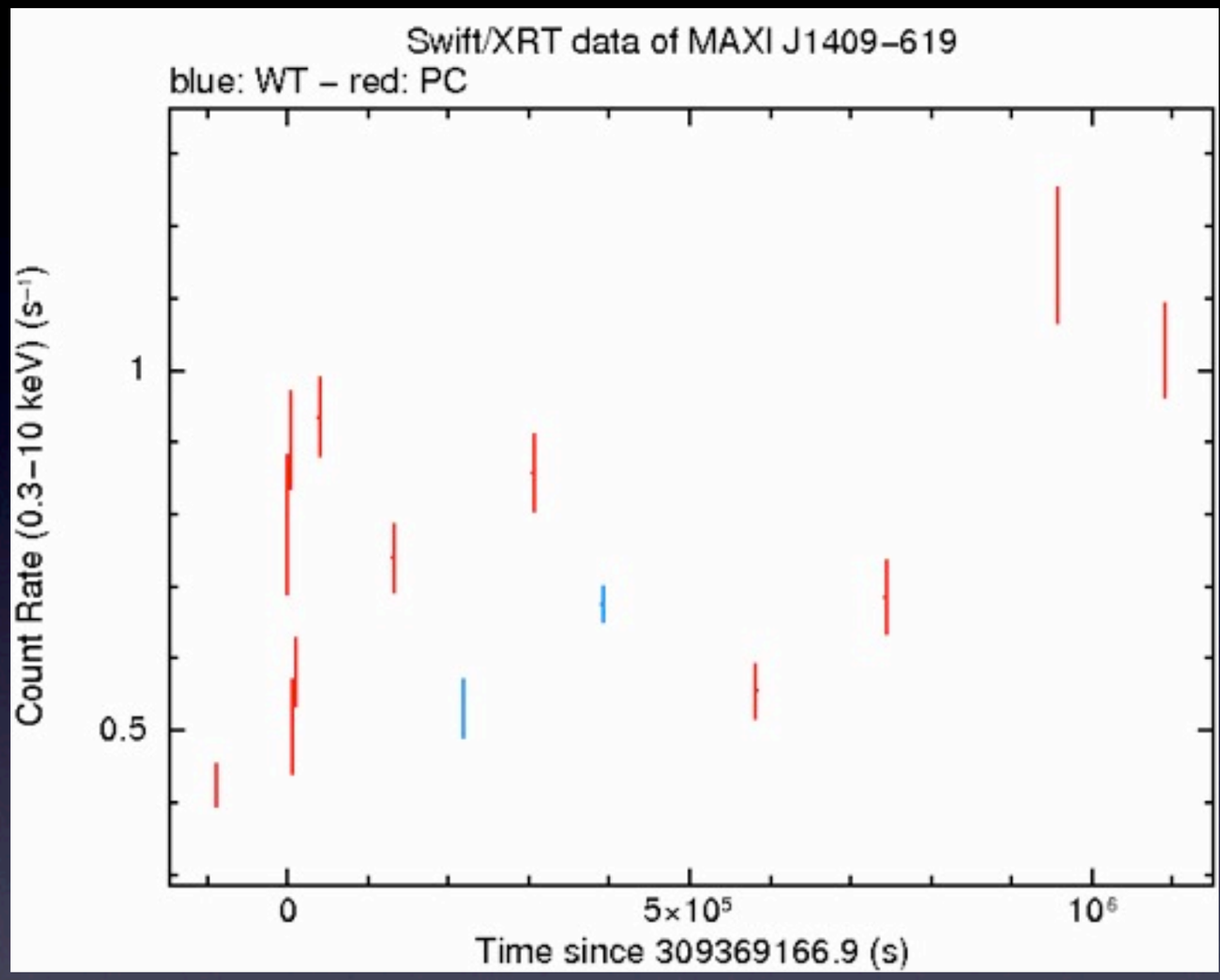
- Detected by MAXI on Oct 17th, 2010 at 41mCrab, reported Oct 20th by Yamaoka et al (ATEL #2959)
- Swift observed at 15:14UT (4 hours after ATEL) for 1ks. Found a bright new transient (no catalog match other than 2MASS).
- This is the first "MAXI only" new Galactic Transient found. Didn't trigger BAT or other mission, and was unlikely to.



MAXI J1409-619: What is it?

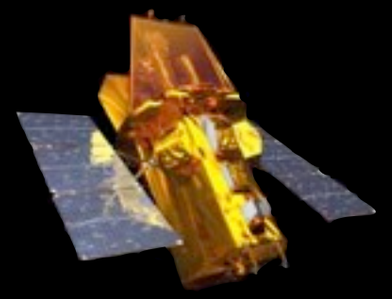


- ➡ Initially thought to be a candidate SFXT.
  - ★ Highly absorbed X-ray spectrum (4×10^{22} cm^{-2})
  - ★ 2MASS IR counterpart to source
  - ★ 6.5+/-0.2 keV ~200eV Iron line reported from RXTE (Yamaoka et al., ATEL #2969), seen in Swift PC mode data at ~6.7 keV.
- ➡ Monitoring by Swift over 23 days 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.

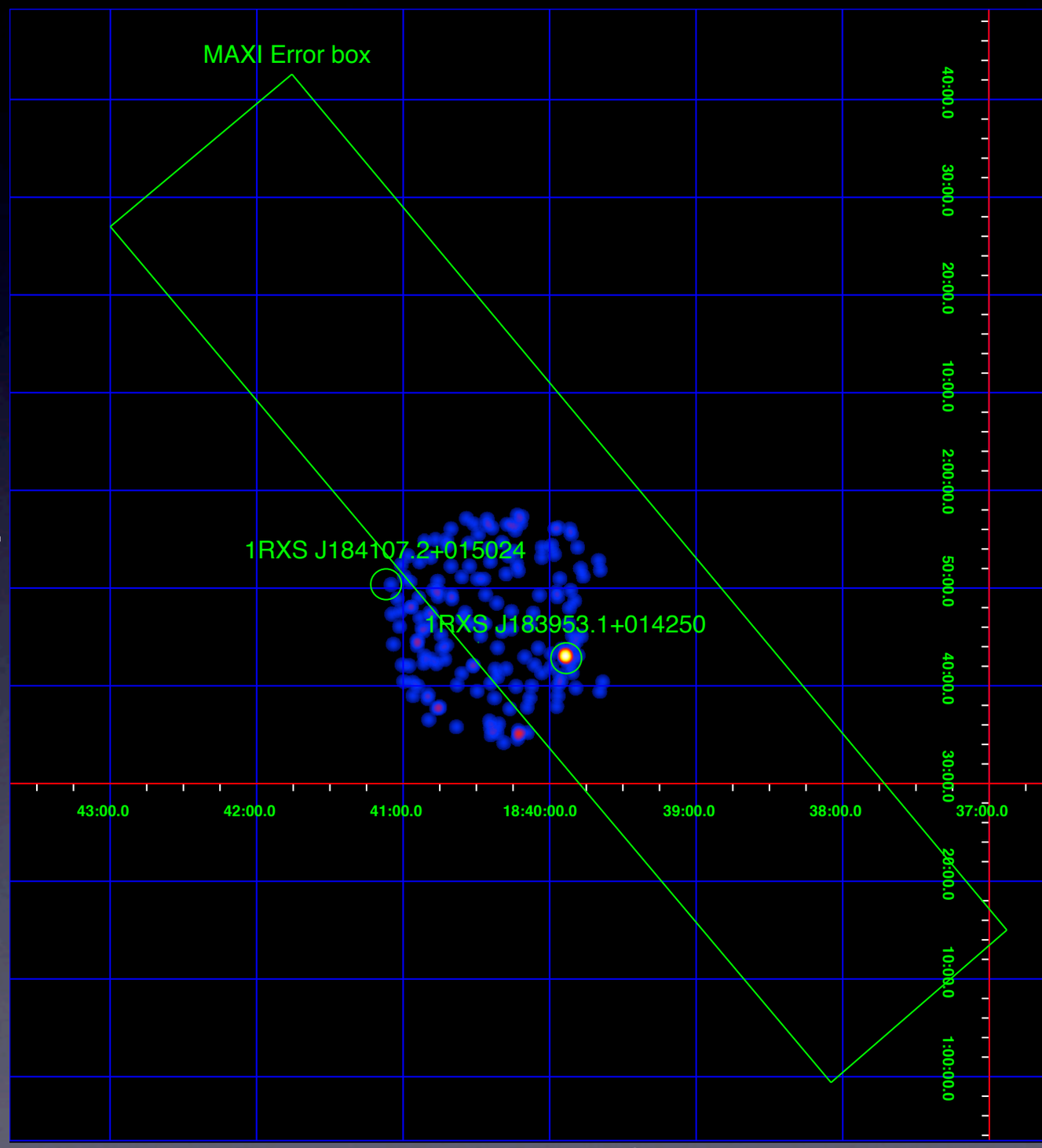


MAXI J1409-619: A HMXB?

"Short X-ray Transient"

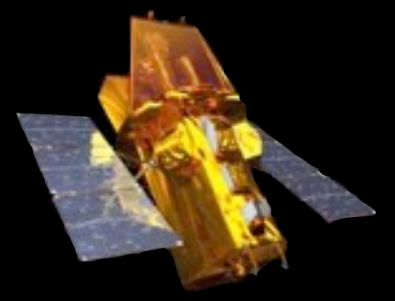


- Tomida et al. (ATEL #2990) report detection of a short X-ray transient on Oct 30th, 2010 at 09:07UT.
- On Nov 1st @ 18:31 Swift took a 1ks TOO observation of this target.
- Pointing was taken to maximise likelihood of observing 2 ROSAT X-ray sources in the error box.
- 1RXS J183953.1+014250 was detected, but not bright. 1RXS J184107.2+01524 was not detected.
- Results inconclusive, but only small fraction of the error box covered.

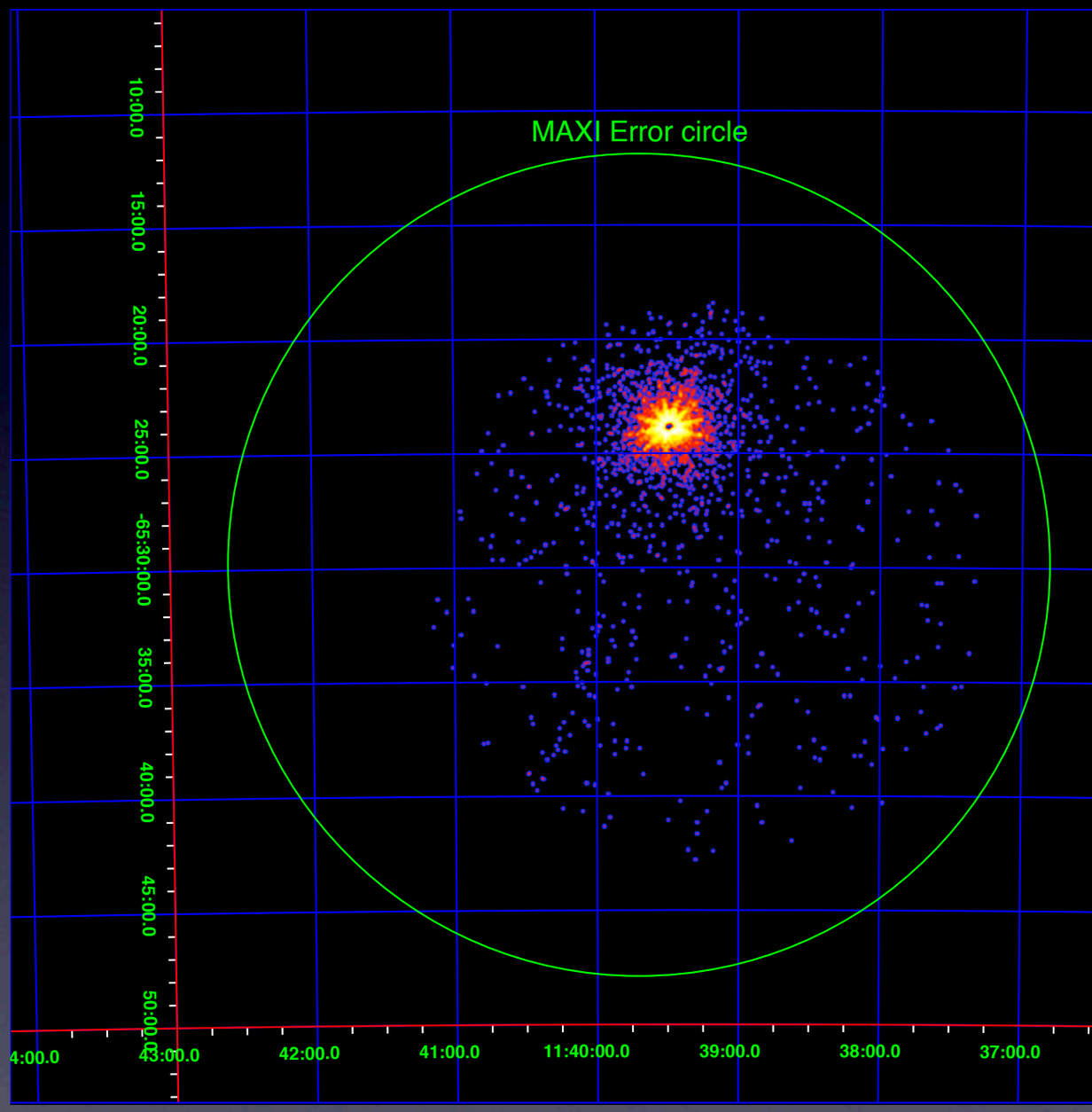


Inconclusive

4U1137-65/GT Mus

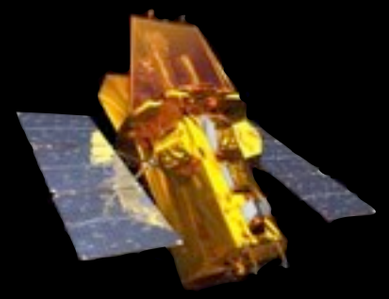


- MAXI reported detection of outburst consistent with GT Mus (Nakajima et al., ATEL #3025) Nov 10th, 2010 @ 6:17UT
- Swift on target at 23:13UT. 1ks observation confirms detection of GT Mus in X-ray outburst (Kennea et al, ATEL #3025).



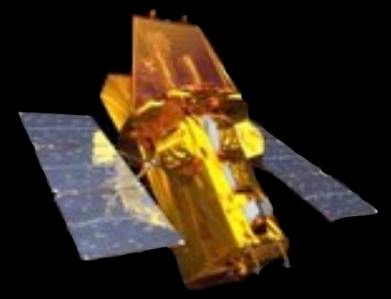
Detection of outburst from RS CVn star.

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)
  - ★ Their 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).