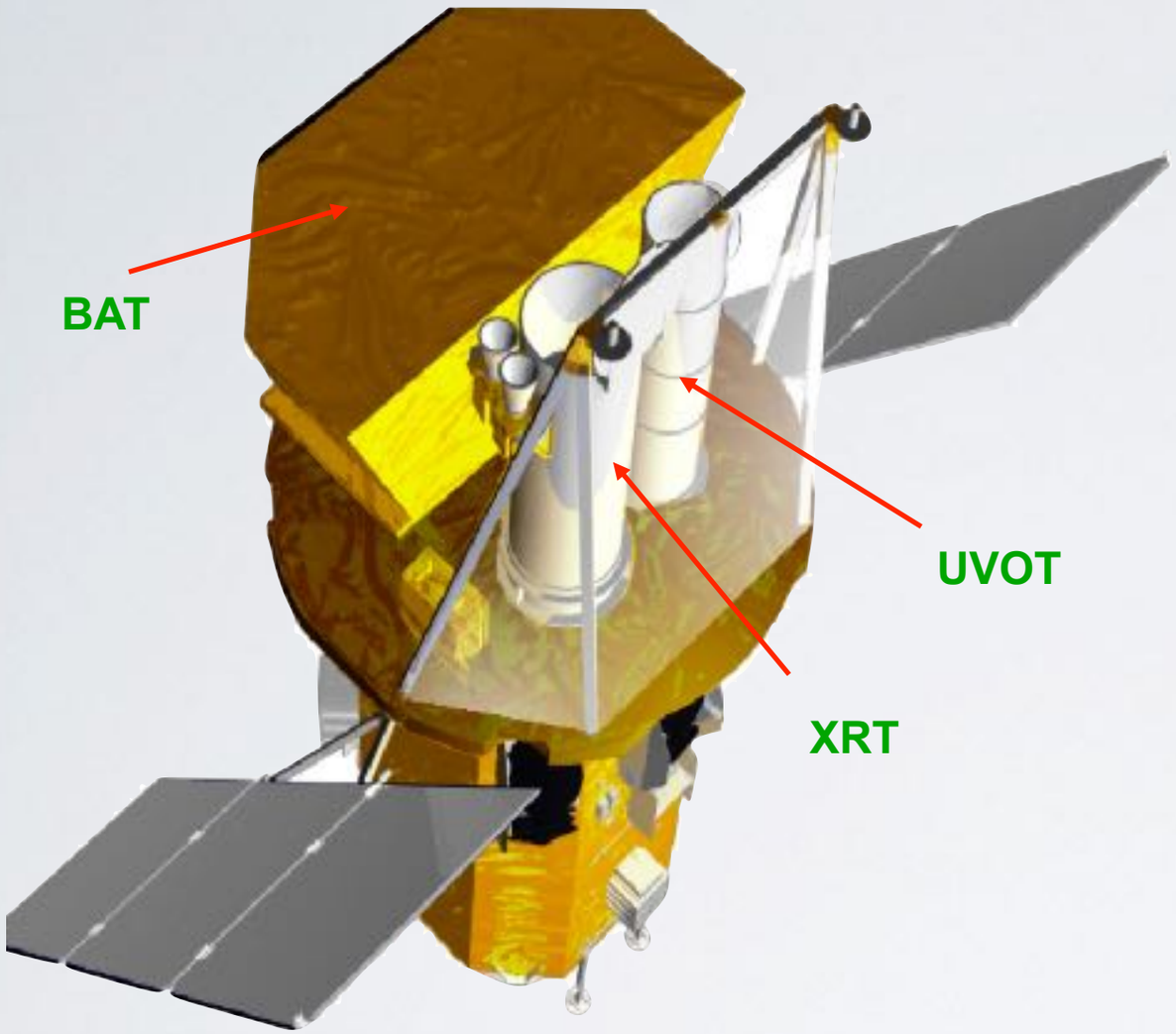
THE *SWIFT*/*MAXI* TRANSIENT COLLABORATION: 7 YEARS OF SUCCESS

JAMIE A. KENNEA (Penn State),
P. A. Evans, A. P. Beardmore (U Leicester), H. A. Krimm (NSF),
P. Romano (INAF-IASFPA), K. Yamaoka (Nagoya U.),
M. Serino (RIKEN) and H. Negoro (Nihon U.)

"7 Years of MAXI", December 5th - 7th, RIKEN

SWIFT

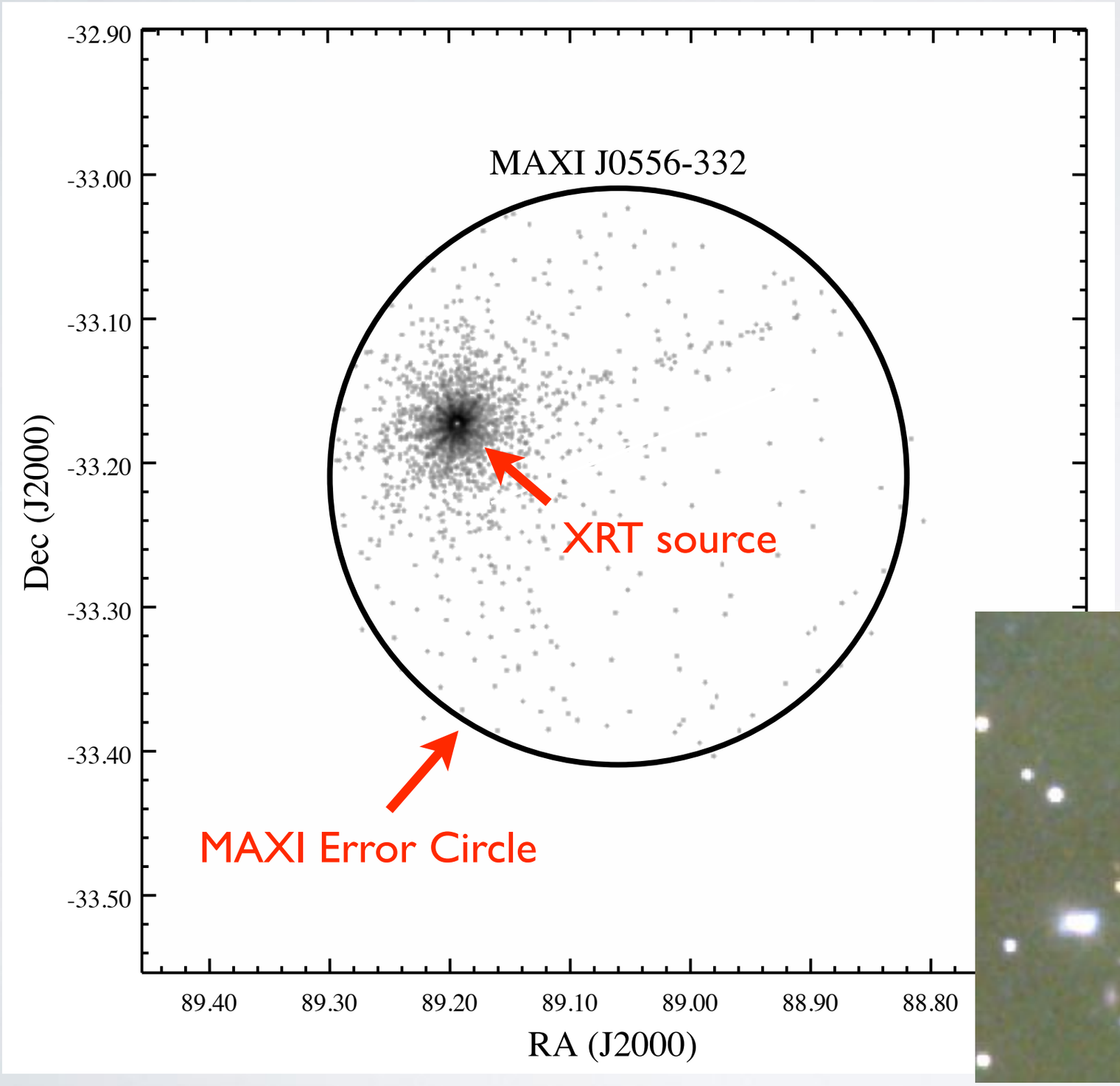


- **Burst Alert Telescope (BAT)**
  - 15-150 keV
  - 2 sr field of view
  - CdZnTe detectors
  - Detects ~100 GRBs per year
- **X-Ray Telescope (XRT)**
  - 0.3-10 keV
  - 23.8 arcminute diameter FOV (~0.12 sq degree)
  - few arcsecond (as good as 1.8") positions
  - CCD spectroscopy
- **UV/Optical Telescope (UVOT)**
  - 170 – 650 nm
  - 17 arcminute width square FOV (~0.8 sq degree)
  - Sub-arcsecond positions
  - Grism spectroscopy
  - 6 UV/optical broad-band filters
  - 22nd mag sensitivity (filtered)

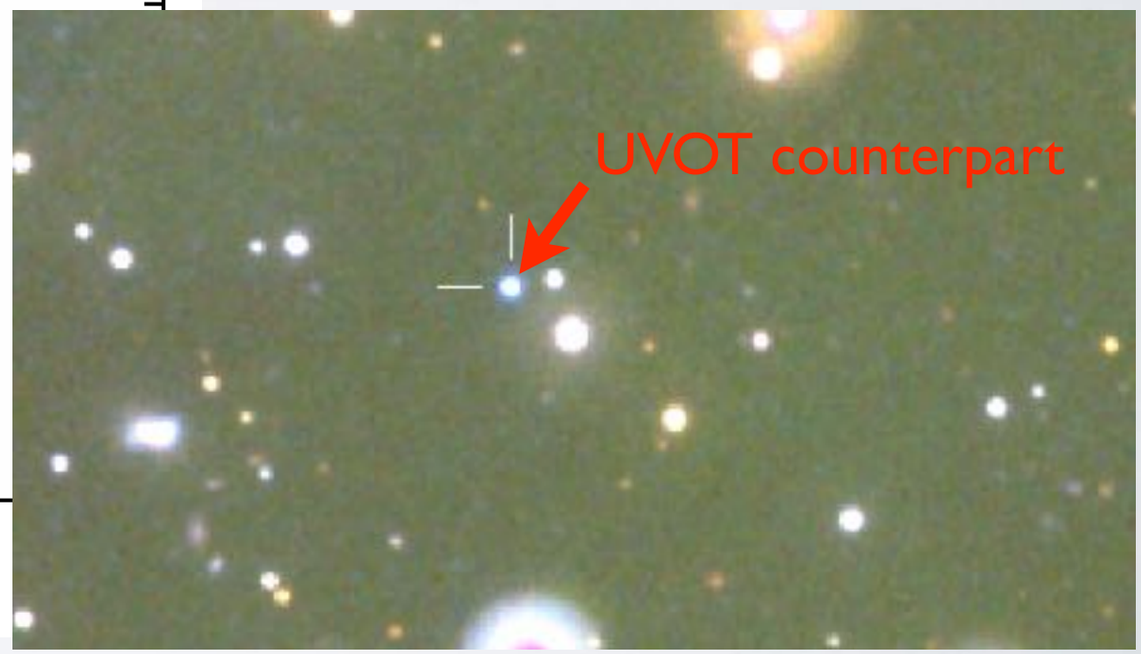
SWIFT AS A GALACTIC TRANSIENT MISSION

- Swift is an ideal as a tool to localize and follow-up MAXI X-ray transients:
  - Accurate localization:
    - XRT ~3.5 - 1.5 (UVOT corrected) arc-sec radius (90% confidence).
  - FOV well matched with MAXI error average error size (~0.2 deg rad)
  - Rapid slewing means low overhead, so short high cadence observations possible.
  - Capability to command Swift to autonomously observe TOOs.
    - Swift can be on target within minutes to hours of a transient detection
- Swift is TOO driven:
  - **1300 approved** TOOs in 2015, 1,125 so far in 2016.

MAXI/SWIFT LOCALIZATION EXAMPLE



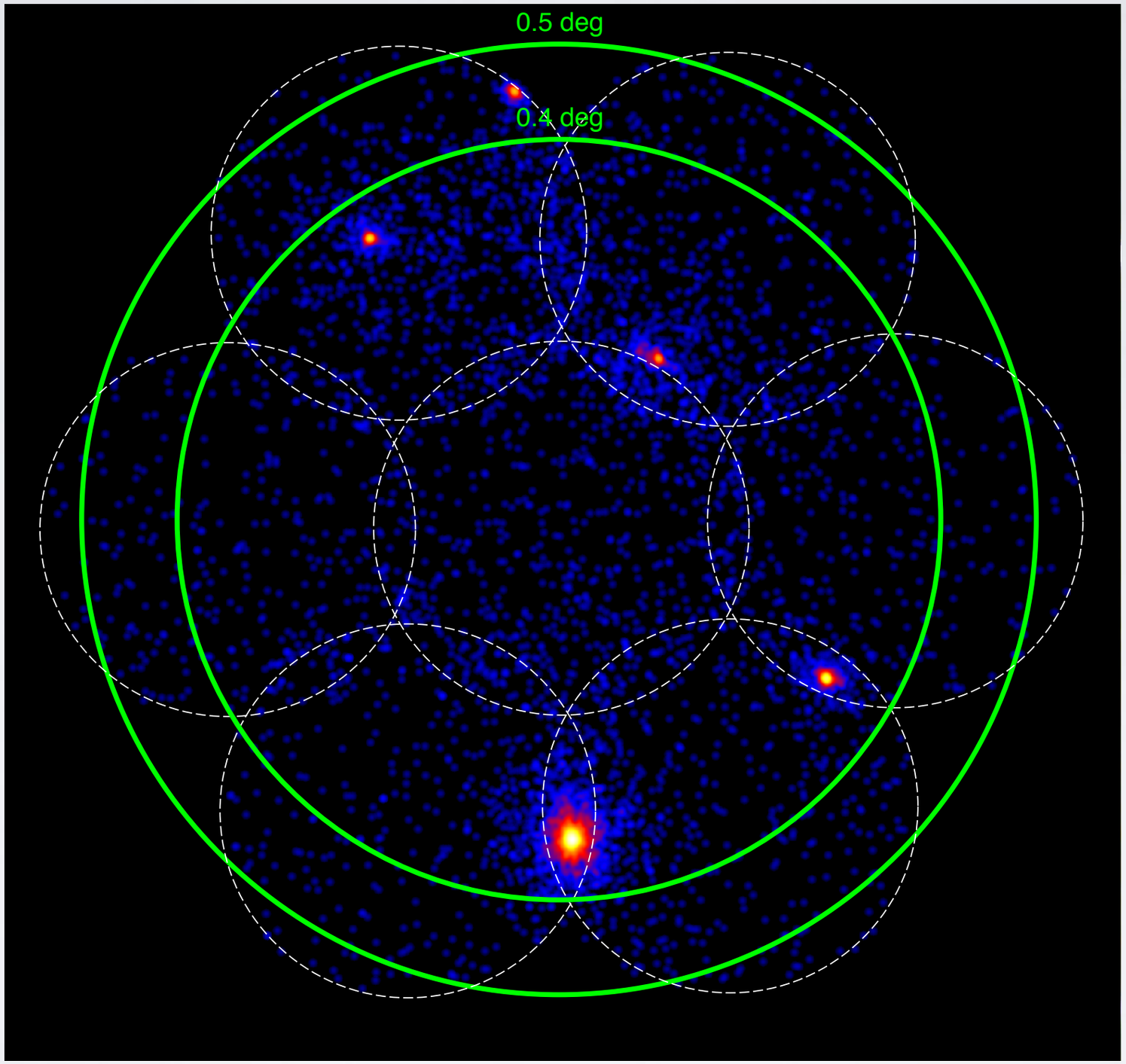
Error radii:
MAXI = 0.2 deg
XRT = 3.5 arcsec
XRT/UVOT = 1.7 arcsec
UVOT = 0.26 arcsec



THE SWIFT/MAXI GALACTIC TRANSIENT GROUP

- Aim to localize all MAXI detected **new** Galactic (and SMC/LMC) X-ray transients.
- Supported by the Swift GI program.
  - Approved program for Swift Cycles 6,7,8,9,11,12 (submitted for 13, waiting for result of that review)
- Team contains both Swift and MAXI Team members.
- Program began April 1st, 2010.
- 55 TOO requests submitted for localizing MAXI transients so far.
- Observations either a single XRT pointing (for <0.2deg error) or 4-, 7- and 19-point tiling for larger error regions.

SWIFT 7 TILE EXAMPLE



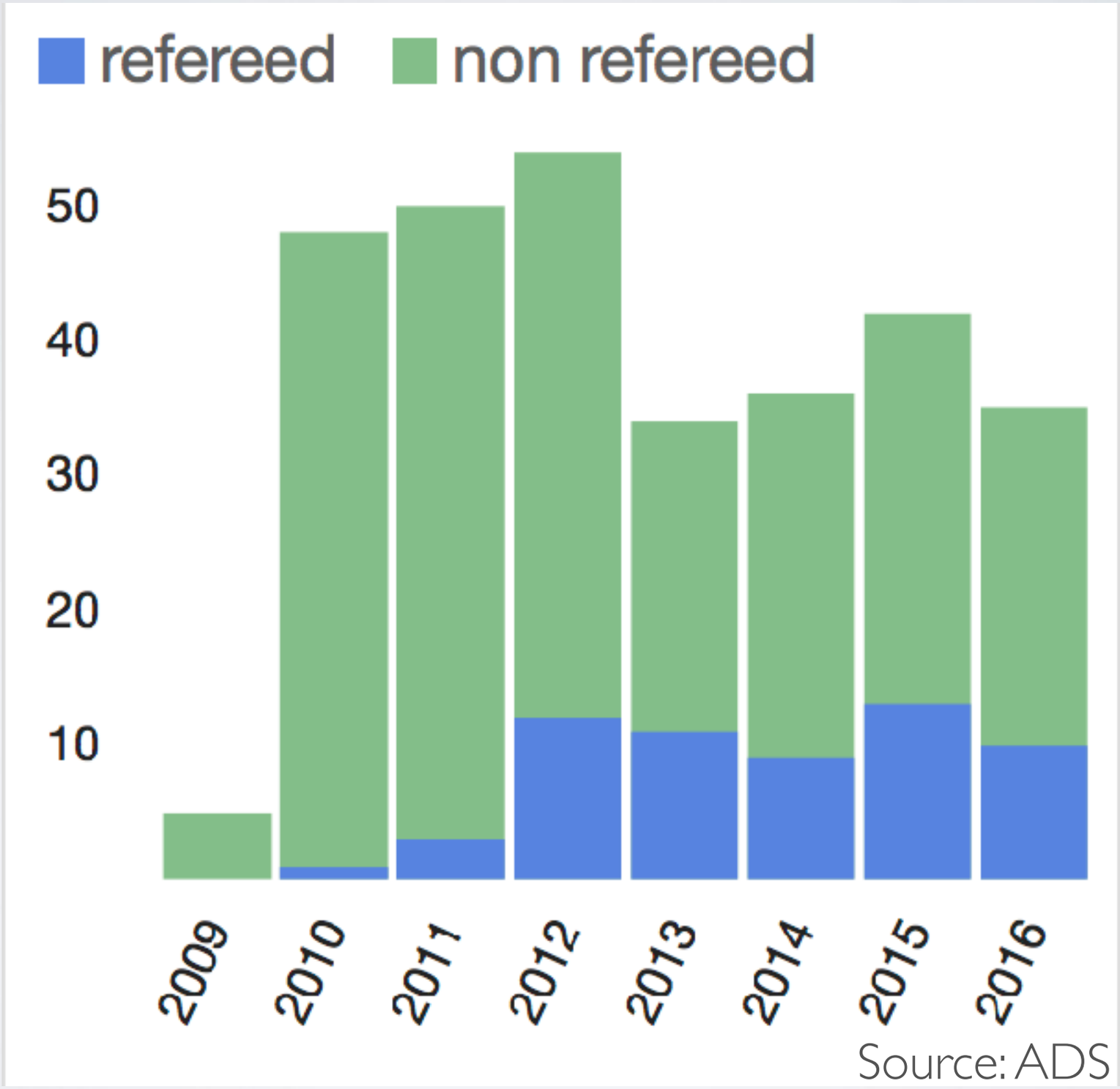
FUTURE UPDATE TO TILING

- Currently Swift is limited to performing circular (actually hexagonal) tiling of 4,7,19 or 37 tiles.
- New mode coming online in next 6 months allows more flexible tiling!
  - Allows upload of list of tiles and exposure times
  - Allows for coverage of non-circular error regions
  - Mode works through TDRSS (rapid uploads)
  - Developed for LIGO follow-up, but can be used for any odd-shaped error region:
    - Better coverage of MAXI error regions in the future

MAXI/SWIFT TRANSIENT SUCCESS

- Detected, localized and monitored (see Prof Negoro's talk):
  - 6 new Galactic Black Hole candidates localized and monitored:
    - MAXI J1659-152 (Kennea et al., 2011), MAXI J1836-194 (Ferrigno et al, 2012), MAXI J1543-564 (Stiele et al, 2011), MAXI J1828-249 (Filippova et al., 2014), MAXI J1910-057 (AKA Swift J1910.2-0546, Reis et al., 2013), MAXI J1305-704 (Morihana et al., 2013).
  - 6 new NS transients
    - 1 white dwarf (MAXI J0158)
- Confirmed outburst from many known sources, that could not be definitely identified by MAXI alone.
- This program has published **56** Astronomers Telegrams reporting results quickly to the community.
- Combined Swift/MAXI observations have been published in 67 refereed papers, over 112 non-refereed ADS entries (excluding ATELs).

SWIFT+MAXI PUBLICATIONS



"7 Years of MAXI", December 5th - 7th, RIKEN

RECENT SCIENCE RESULTS

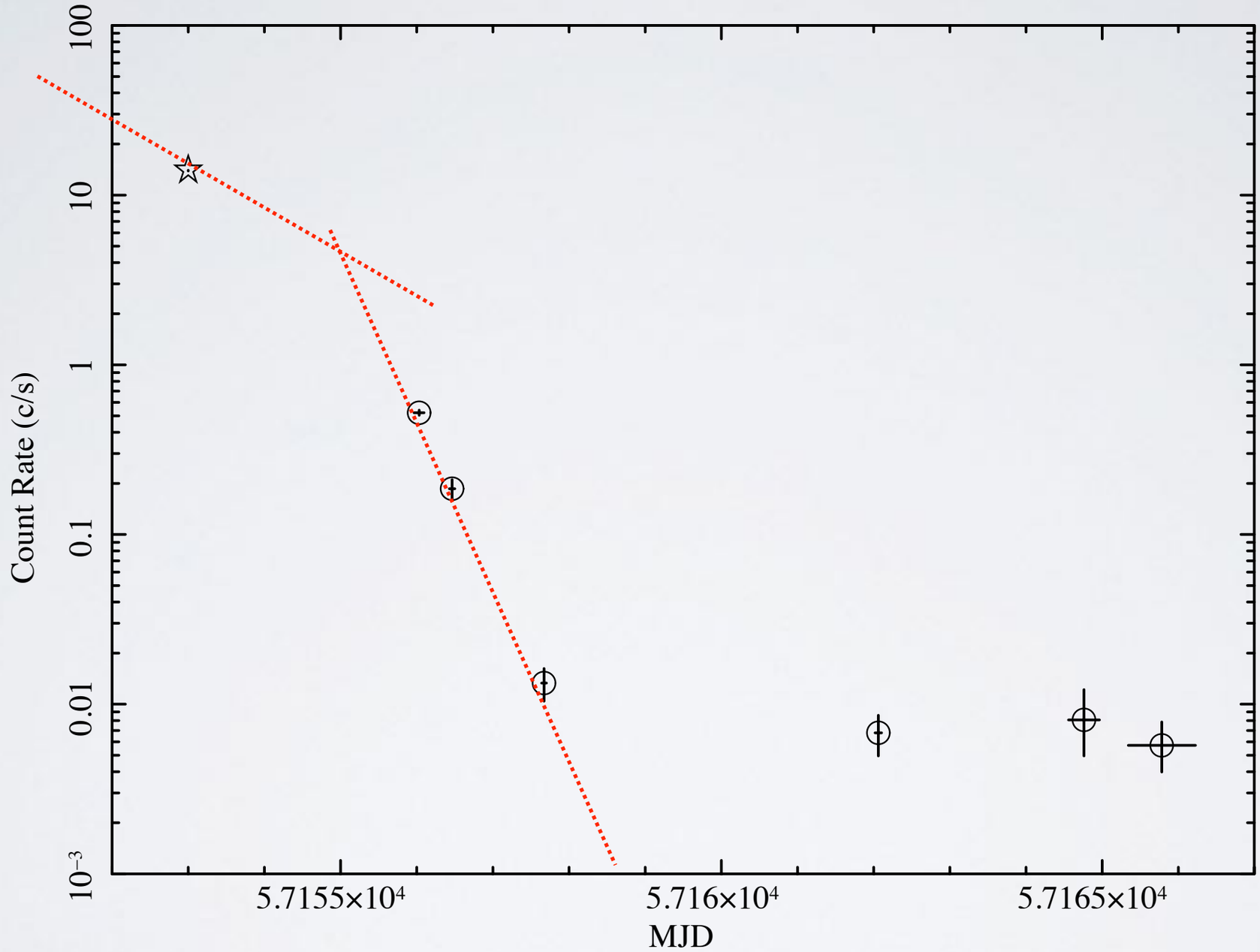
…BECAUSE COVERING 7 YEARS OF RESULTS WOULD TAKE TOO LONG AND WE ARE STILL GETTING GREAT SCIENCE!

"7 Years of MAXI", December 5th - 7th, RIKEN

MAXI J1957+032

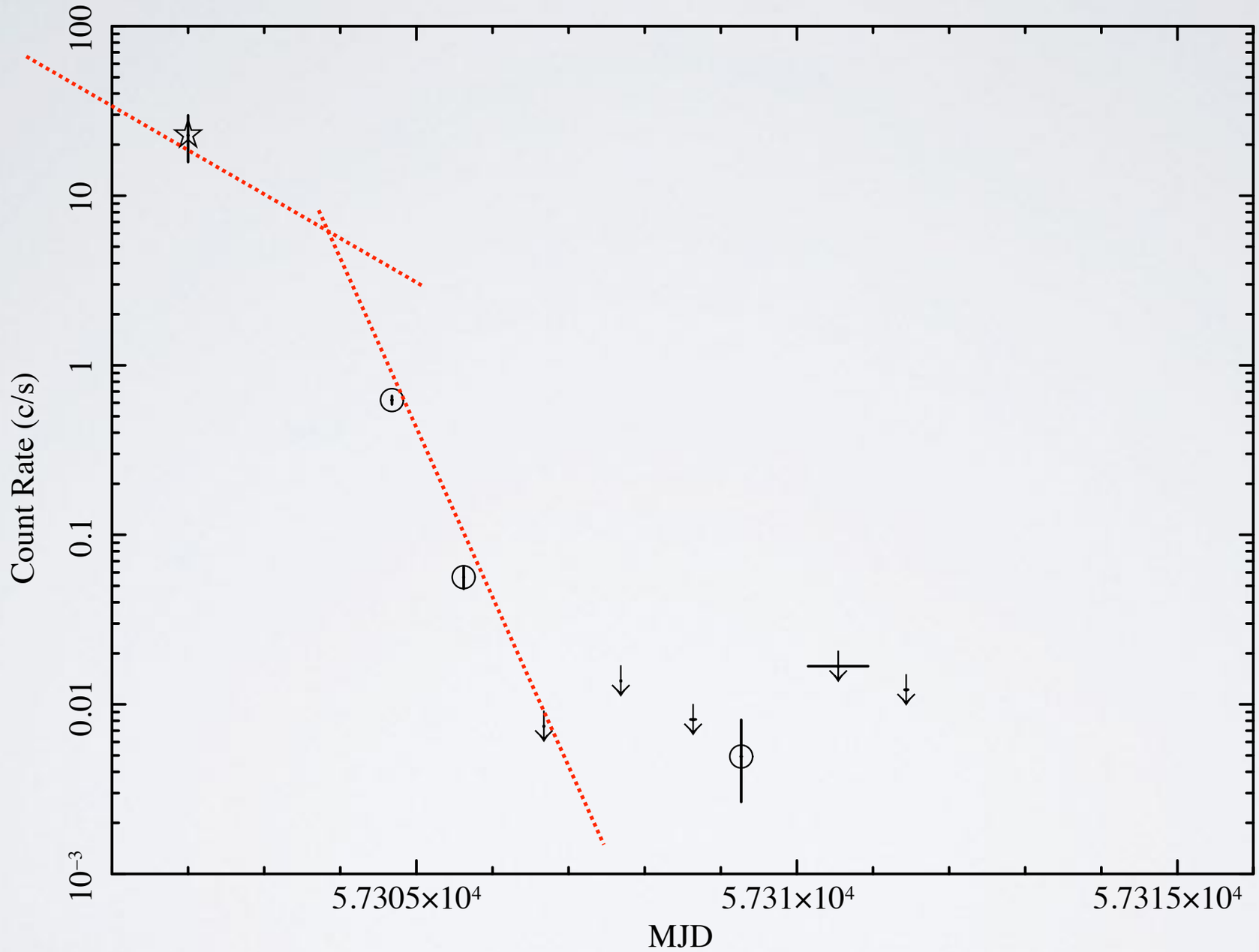
- 4 outbursts seen by MAXI so far, 3 followed up by Swift:
  - May 11, 2015 (Negoro et al. , ATEL #7504, also INTEGRAL)
  - Oct 6, 2015 (Sugimoto et a., ATEL #8143)
  - Jan 7th, 2016 (Tanaka et al., ATEL #8529)
    - To close to the Sun for Swift
    - Sept 29th, 2016 (Negoro et al., ATEL #9565)
- Outbursts last <6 days.
- Spectrum appears to be highly variable over outburst:
  - Correlation between brightness and source softness

MAXI J1957-032: FIRST DETECTION



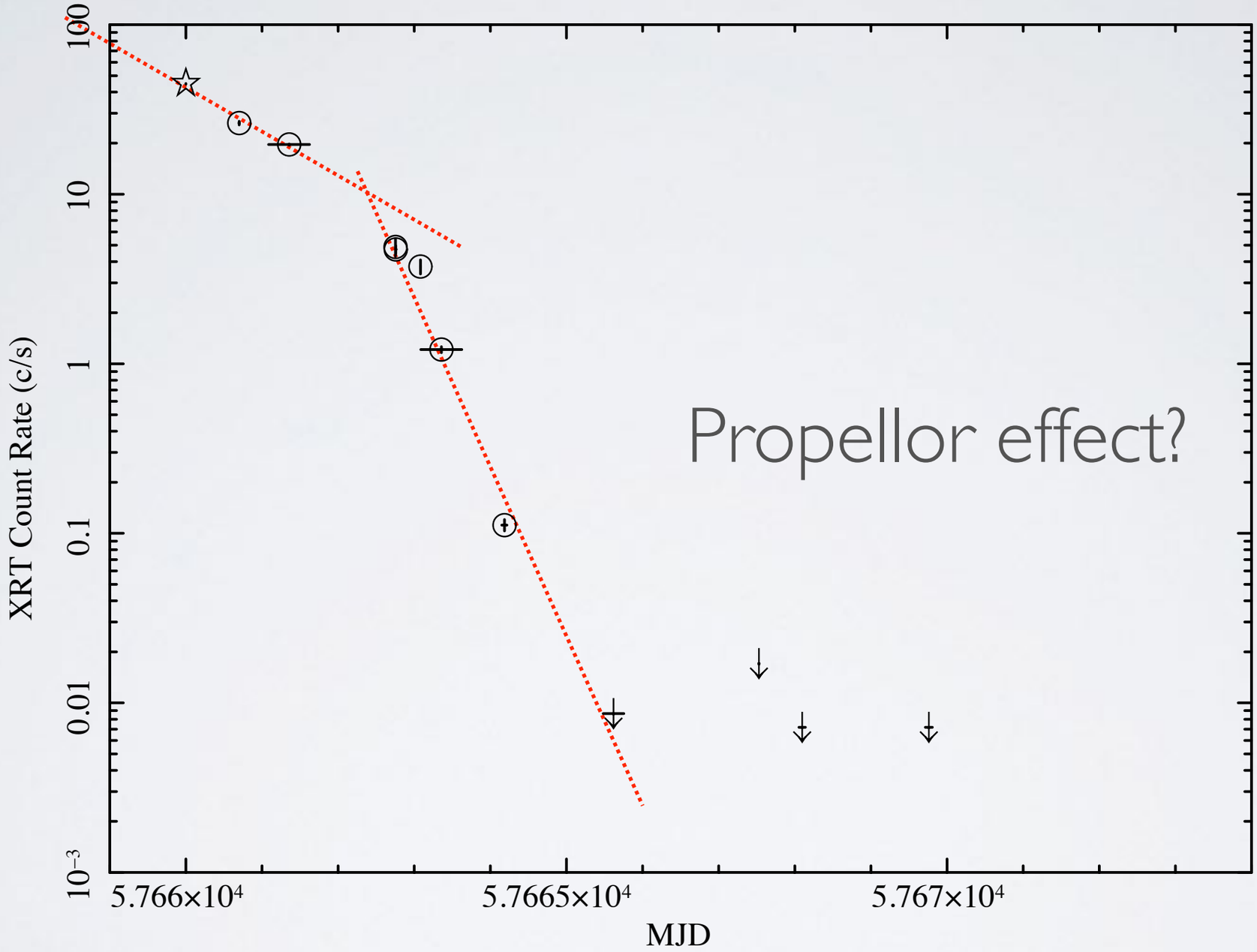
Detected 2015 May 11 (Negoro et al., ATEL #7504)

MAXI J1957-032: SECOND OUTBURST



Detected Oct 6, 2015 (Sugimoto et a., ATEL #8143)

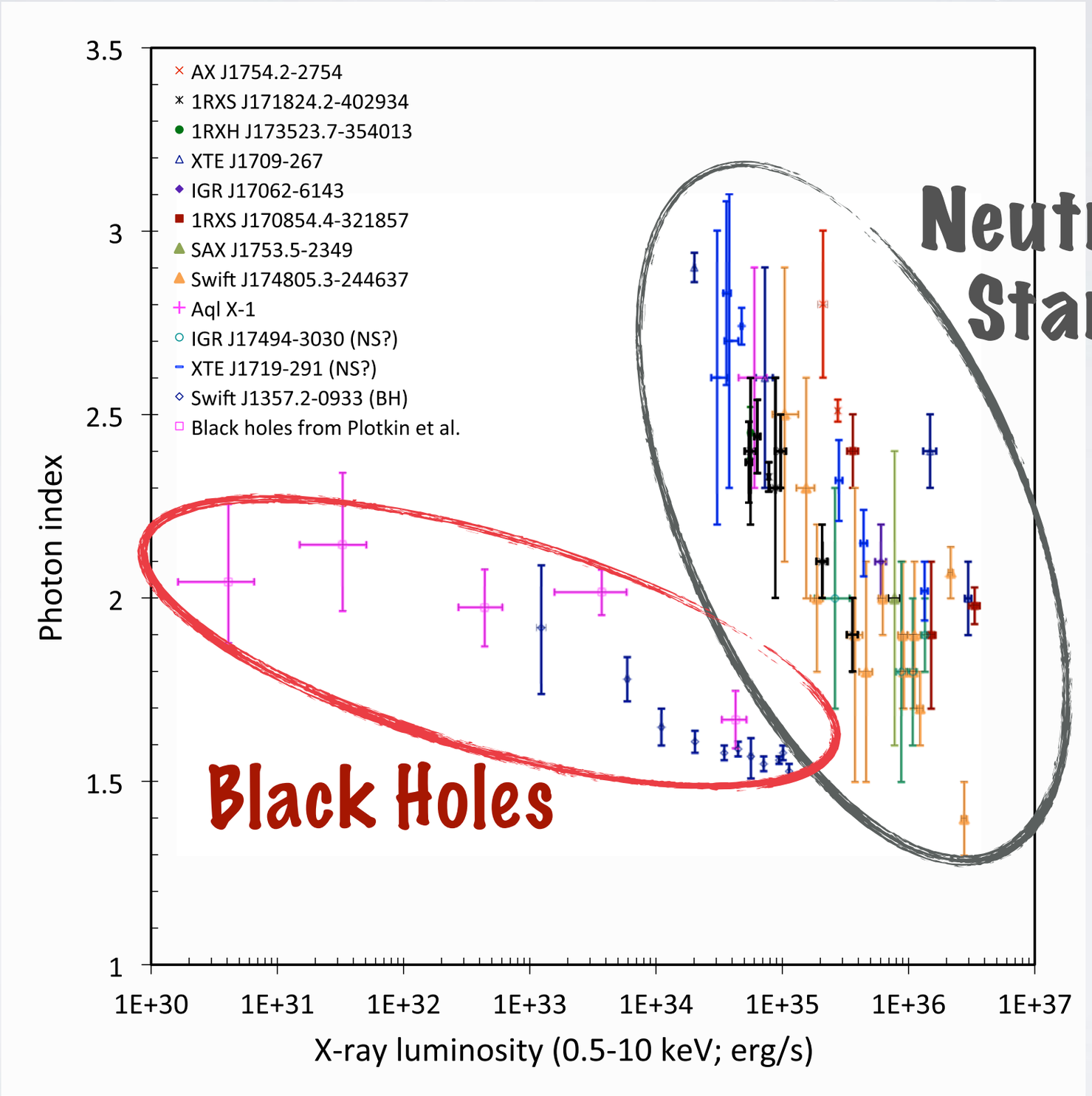
MAXI J1957-032: FOURTH OUTBURST



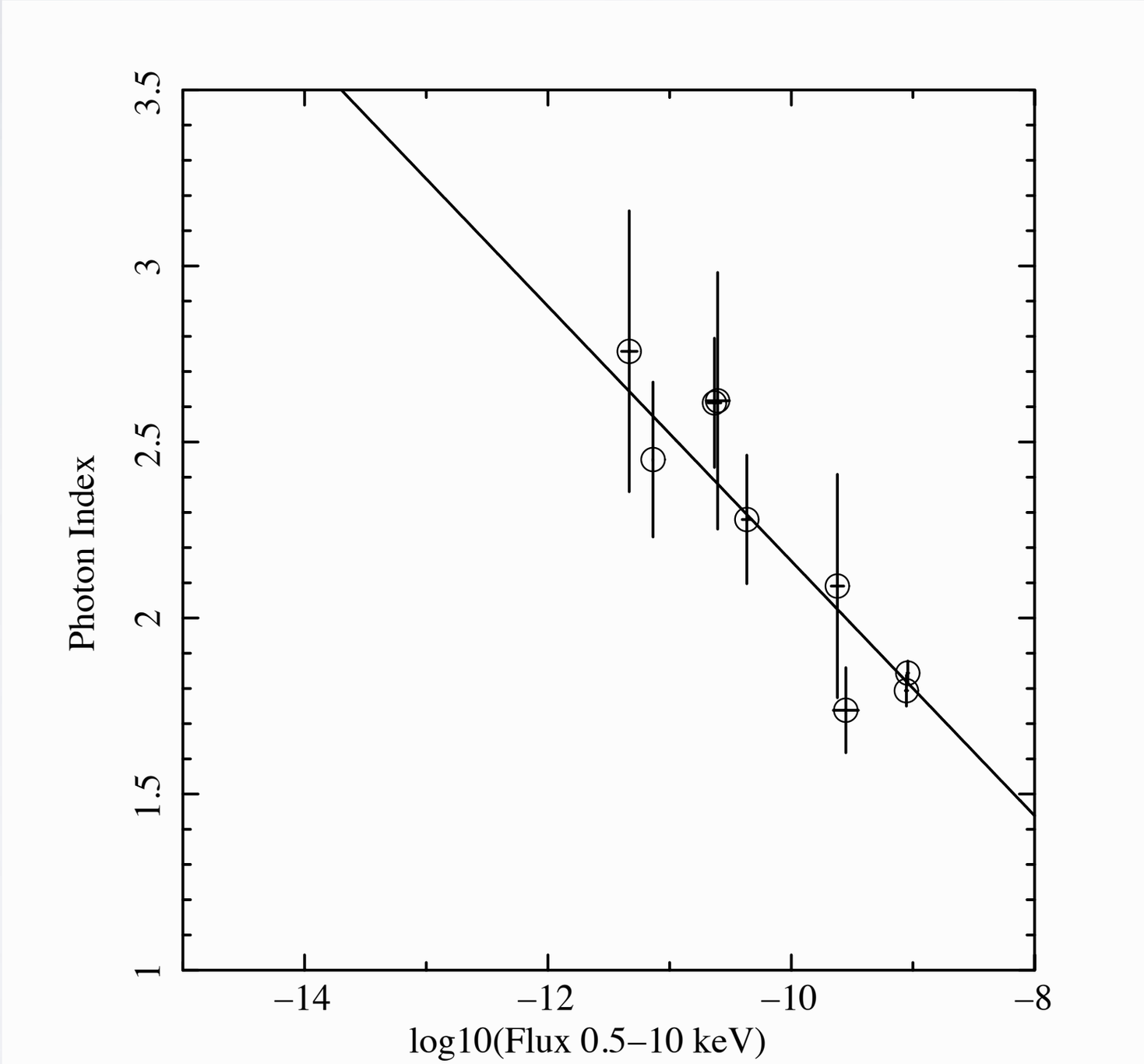
Detected Sept 29th, 2016 (Negoro et al., ATEL #9565)

HARDNESS VS FLUX

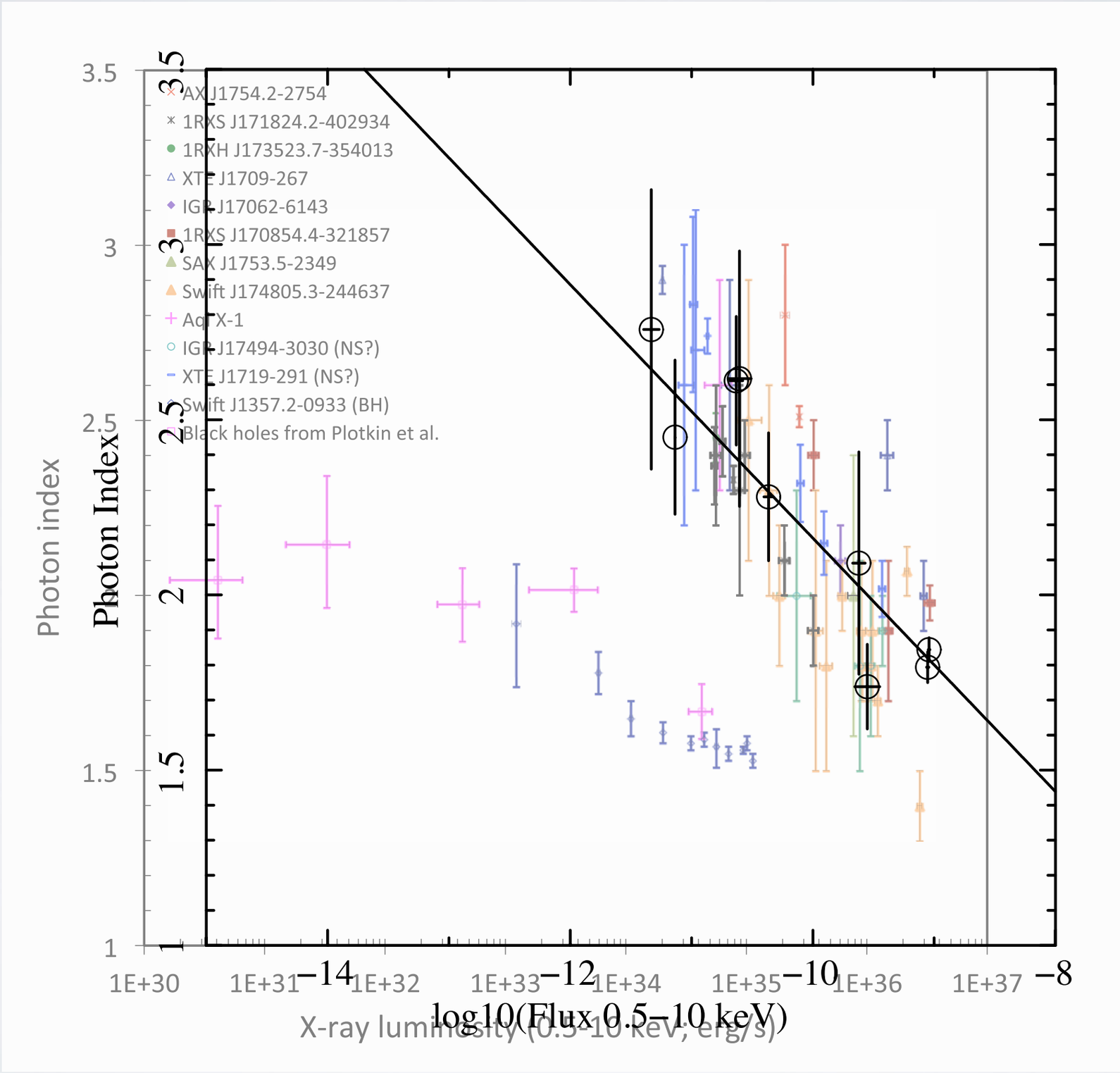
From Wijnands et al (2015)



MAXI J1957: PHOTON INDEX VS FLUX



MAXI J1957-032

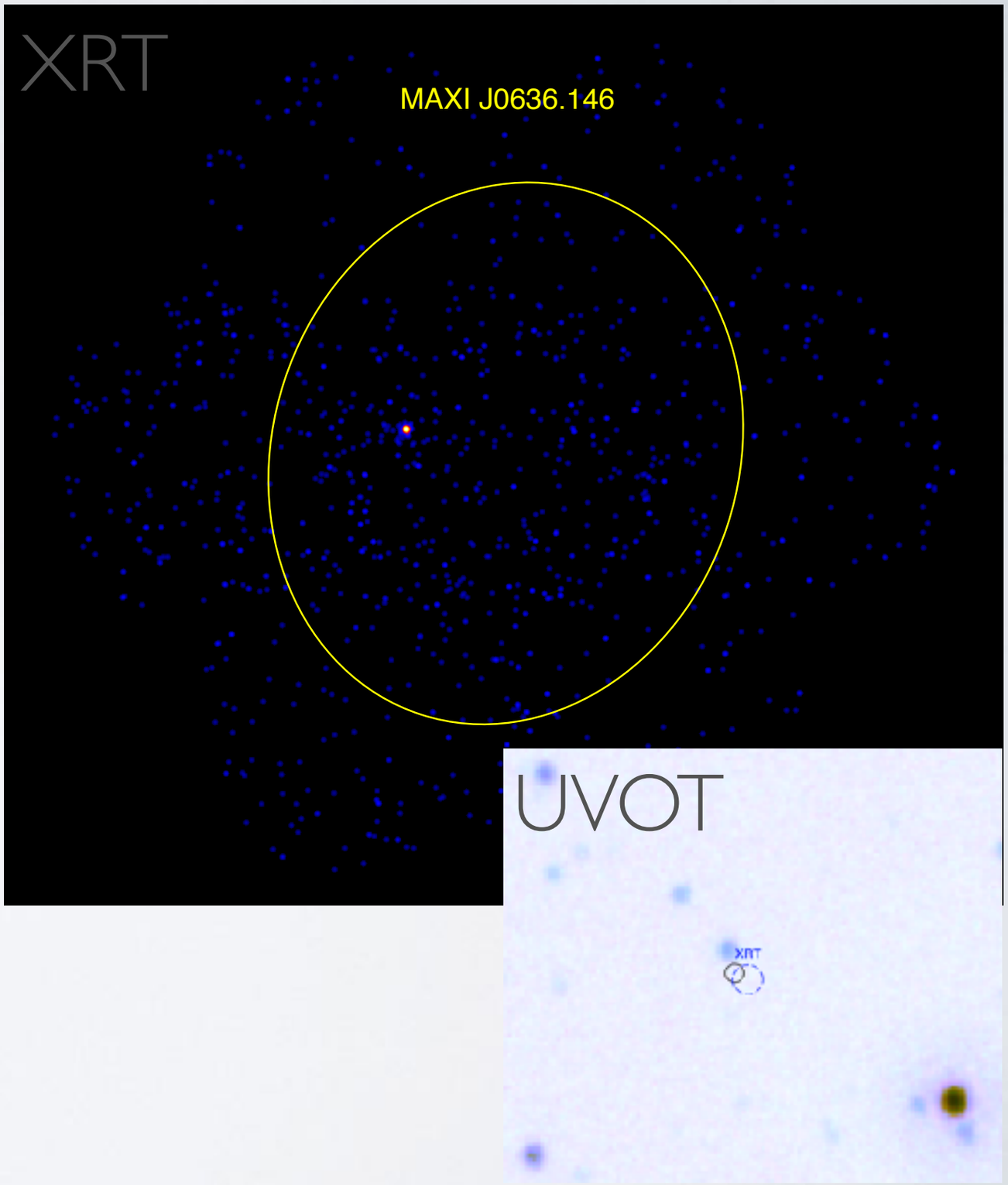


MAXI J1957-032

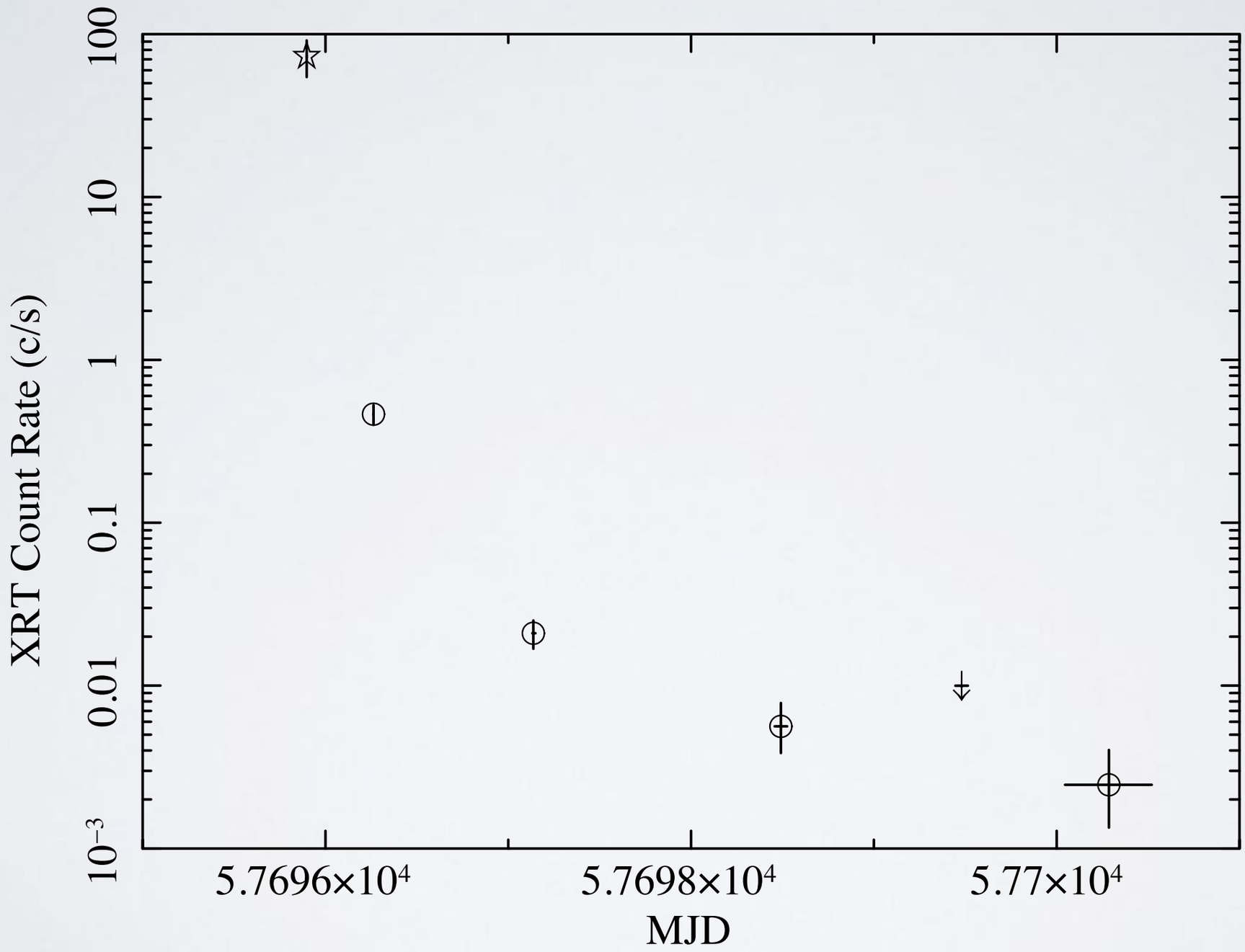
- Based on the Wijnands et al. (2015) relationship, MAXI J1957-032 spectral evolution looks like a neutron star.
- Aligning the flux with the luminosity range in the Wijnands relationship, we get a distance of ~2-4 kpc.
- Outburst light appears initially slow, then rapid, followed by a possible low level emission, rapid decline a sign of propellor effect? (i.e. Neutron Star)
- Rapid decline in outbursts show need to rapidly follow-up sources with high sensitivity X-ray instruments.
  - Recent trigger we got on target within 4 hours of MAXI detection. Caught the source at ~22 c/s brightness.
  - Need longer observations when brighter to get more detailed look at outburst and search for pulsar period?
- Work in progress right now, watch this space.

MAXI J0656+146: ANOTHER MAXI J1957?

- Detected by MAXI at 02:20UT November 4th, 2016 (Negoro et al, ATEL #9707) at 51 ±13 mCrab over 2 transients, then gone.
- Localized by Swift in observation taken at 06:12UT November 4th, 2016 (Kennea et al., ATEL #9710).
  - Less than 4 hours after detection by MAXI!
  - Swift position confirmed MAXI J0656+146 as a new transient
  - No UVOT candidate consistent with XRT.
- Swift monitoring observations performed over 5 day period (until source was no longer detected).

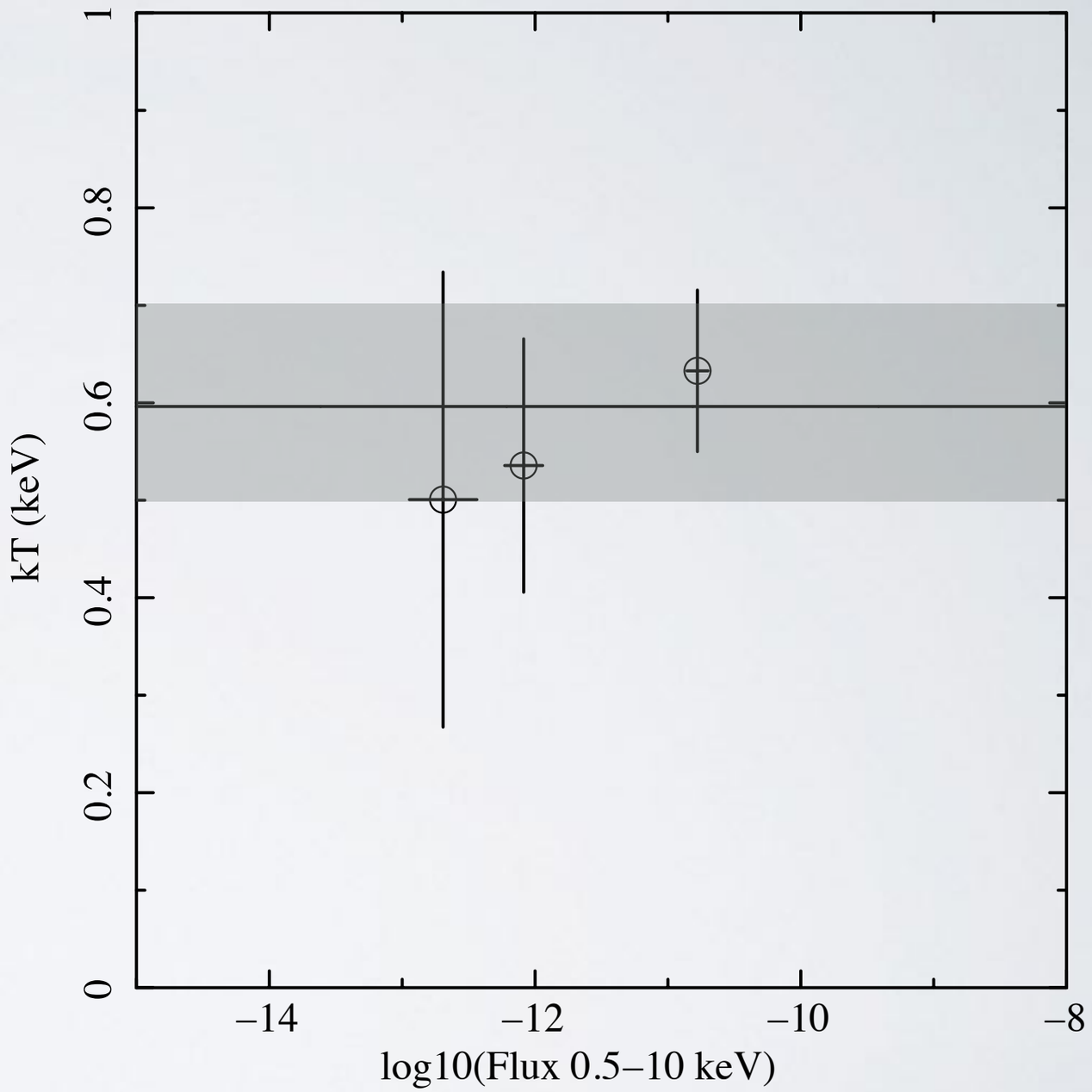


MAXI J0636: MAXI/SWIFT LIGHTCURVE



MAXI J0636+146

- **No significant spectral variability during Swift monitoring.**
- Swift Spectrum is very soft (Gamma = 3.5) suggesting thermal spectrum.
- Fit with Blackbody model: kT = 0.6 +/- 0.1 keV
  - Very low significance evidence for correlation of flux with temperature (i.e. cooling).
  - Very low absorption.
- Not another MAXI J1957!
- Not clear the nature of this source. No optical counterpart?

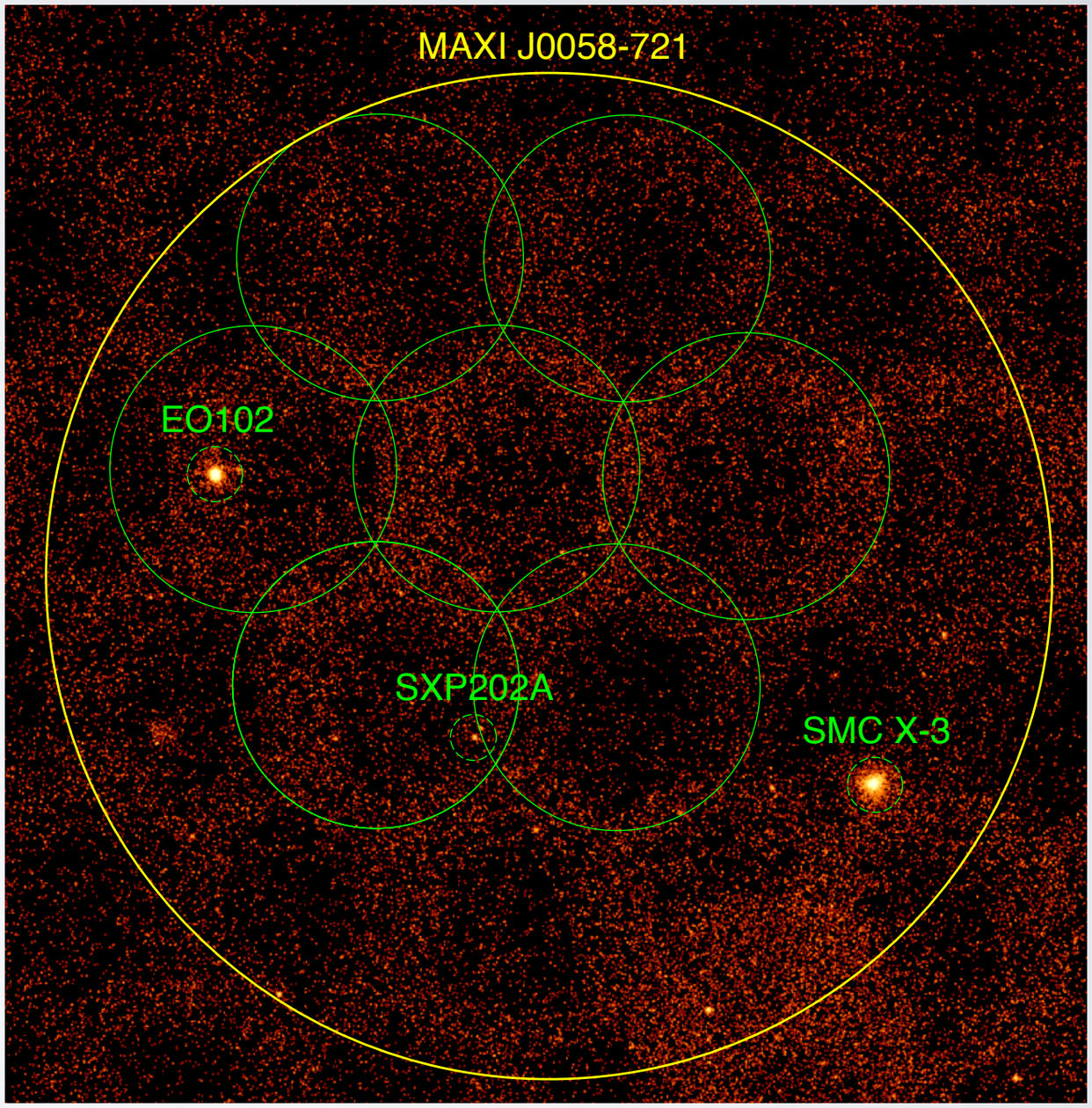


MAXI TRIGGER ON SMC X-3

- SMC X-3 has not had an outburst during entirety of Swift and MAXI mission lifespans.
- At 13:17UT on August 8th, 2016, MAXI nova-alert system triggered on a new source: MAXI J0058-721.
  - Initial brightness ~7
- At the time not associated with SMC X-3 due to SMC being a very crowded region of transients.
  - SXP 6.85 was active at the time and nearby (Kennea et al., ATEL #9299)
  - Consistent with the location SXP 202A, which was in outburst at the time (Coe et al., ATEL #9307)

SWIFT MISSES SMC X-3

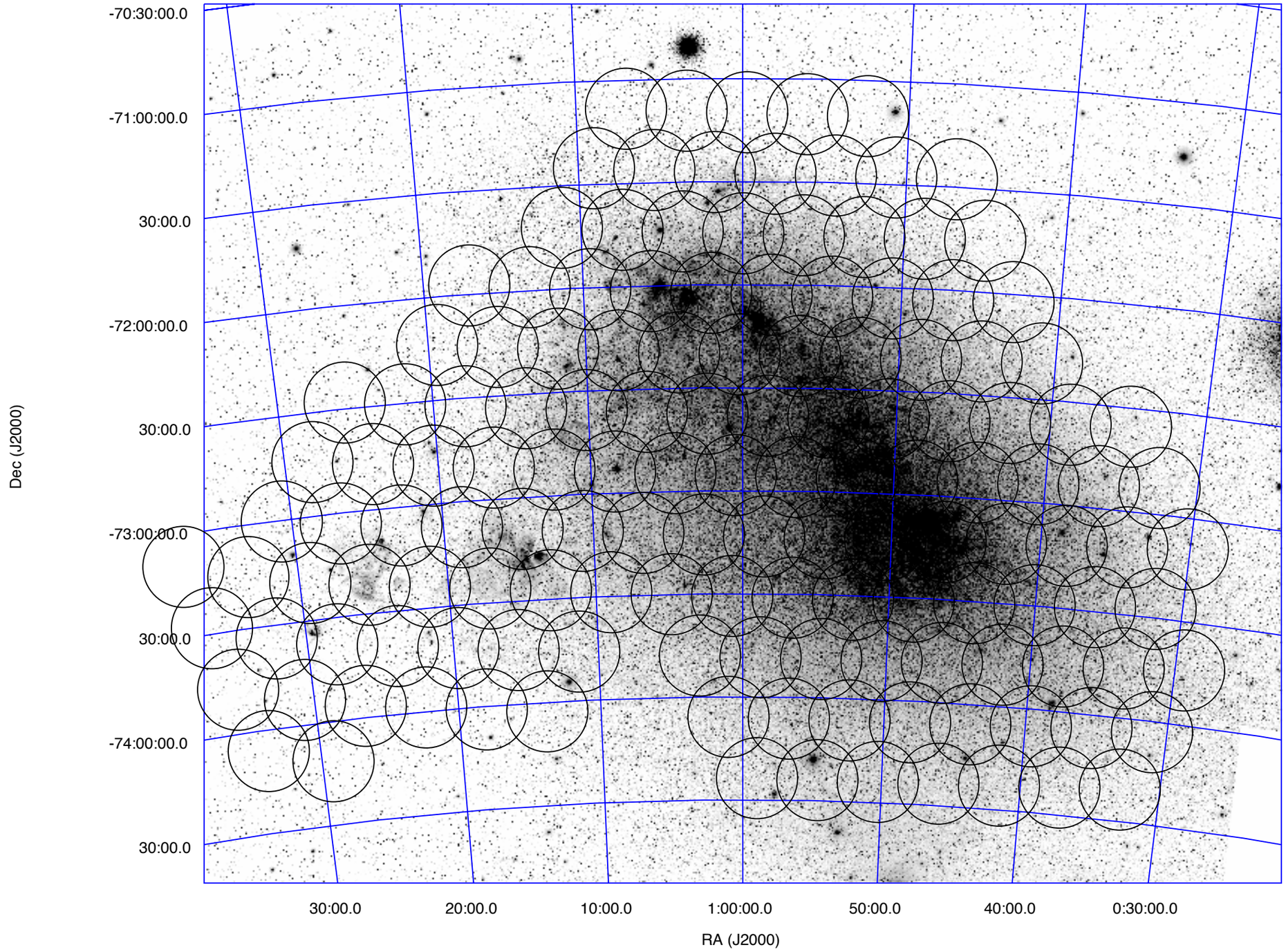
- Aug 9th, 2016 MAXI reported on source in SMC (MAXI J0058-721, Negoro+ ATEL#9348)
- Swift did 7-point tiling of initial localization.
- Didn't cover whole error circle, missed the actual source of the flare: **SMCX-3.**
- Luckily Swift covered the region as part of "**S-CUBED**" the next day.
- Determined MAXI transient was SMC X-3 in outburst (Kennea+ ATEL #9362).



INTRODUCING: S-CUBED

- The Swift SMC Survey (S-CUBED) is a shallow, wide, high cadence survey of the Small Magellanic Cloud to search for X-ray transients.
- Approved as one of 4 core initiatives in the Swift Senior Review proposal.
- The SMC is filled with HMXB, many Be/X-ray binaries, which frequently go into outburst.
  - Due to SMC distance, these are often only seen in deep searches by INTEGRAL, which only surveys the SMC once per year.
  - Only the very brightest outbursts can be detected by Swift/BAT or MAXI.
- S-CUBED covers the SMC (+ "Wing") in 142 overlapping Swift pointings.
  - Each pointing uses an exposure of 60s, a new observing mode developed this year.
  - 142 individual tiled pointings taken every week.
  - At SMC distance of ~61 kpc, in 60s we are sensitive to outbursts as faint as 1% Eddington.

S-CUBED TILING PATTERN



1 degree

E0102

SMC X-3

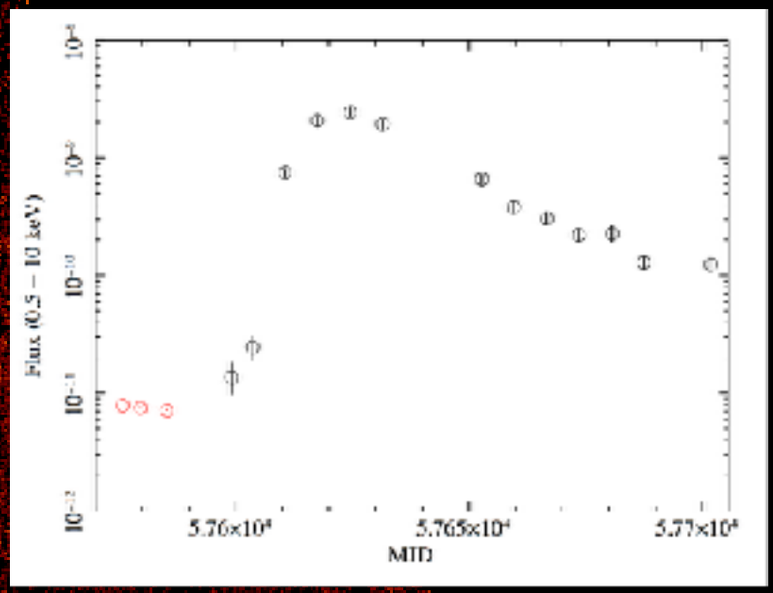
SXP 6.85

SXP 2.16

SMC X-1

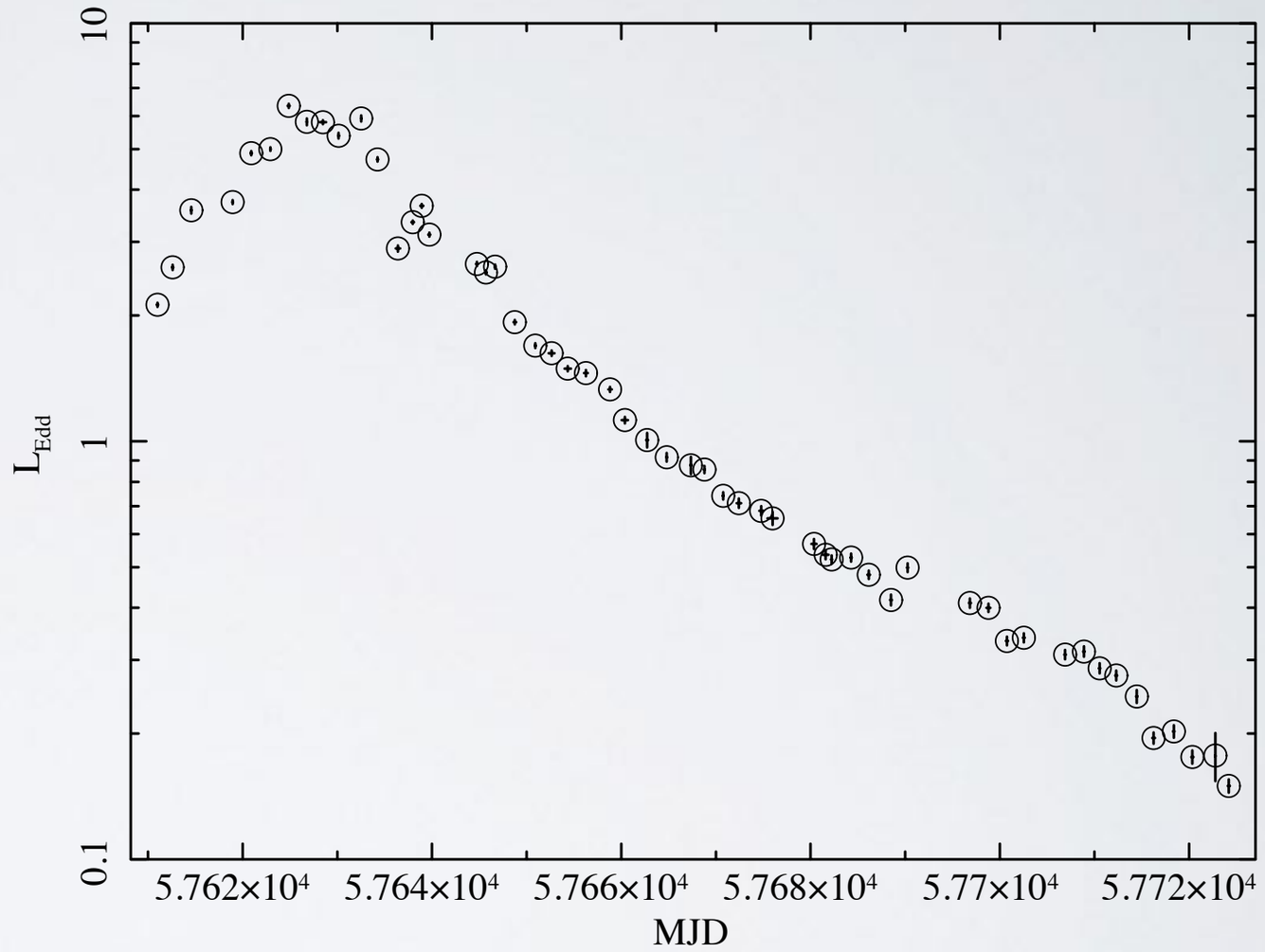
AGN

SXP 15.6



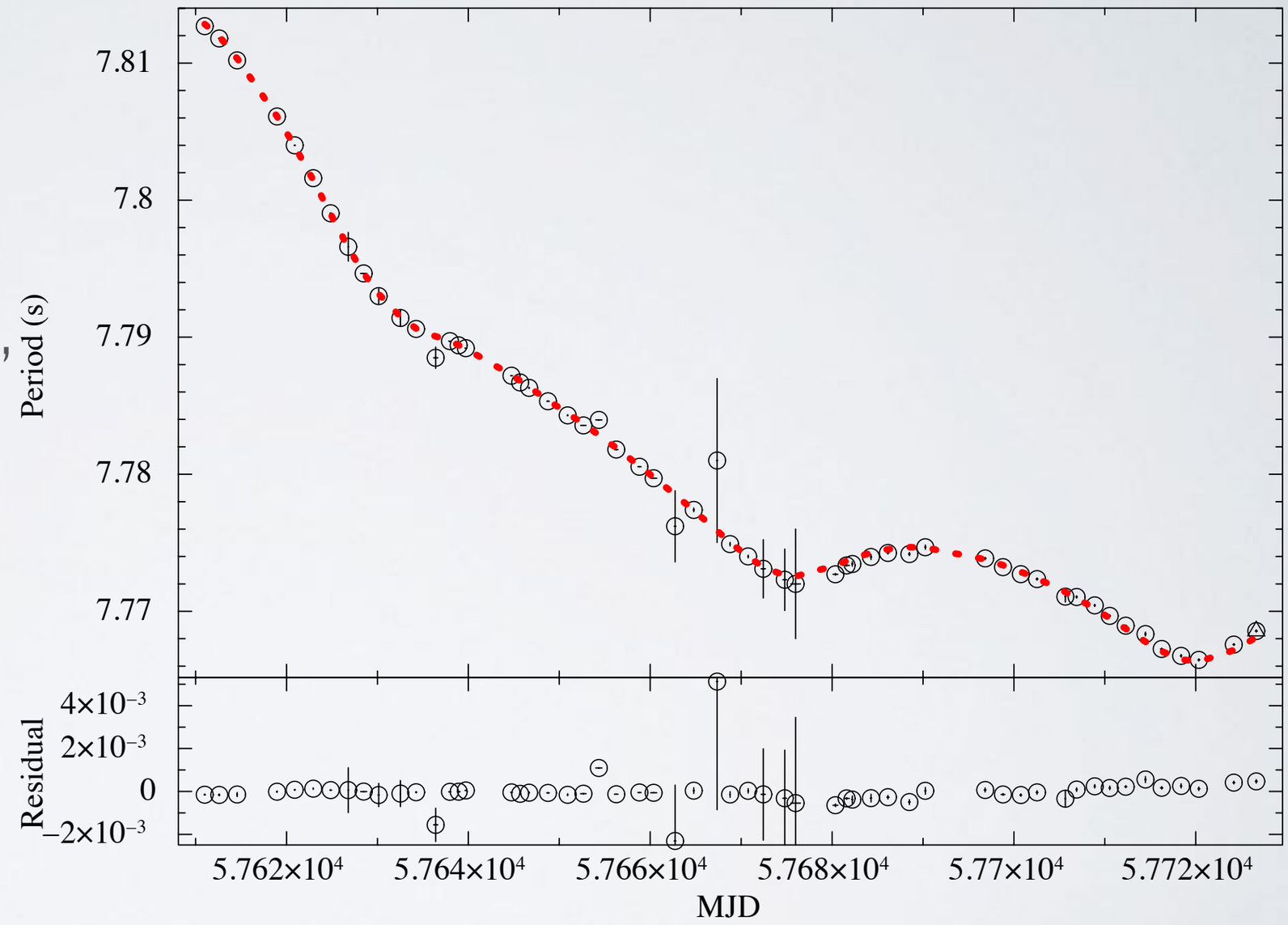
SMC X-3: FLUX MONITORING

- SMC X-3 is a Be/X-ray binary.
- Type II outburst covering 3 orbital periods so far.
- Flux at peak is super-Eddington (~6 L_{Edd})
- Outburst still on-going.
- NuSTAR observations taken, but no cyclotron lines detected.



SMC X-3: PERIOD EVOLUTION

- Pulsar period ~7.78s
- Fitted spin-up with model that is linked to source luminosity (e.g. Takagi et al., 2014 after Ghosh and Lamb, 1979, also Dr Suguzaki's talk on Friday).
- Period is Doppler shifted due to orbital motion, so we use this to model the orbital parameters.



SMC X-3: DERIVED ORBITAL PARAMETERS

P_{orbit}	45.383 ± 0.421 days
Eccentricity	0.22 ± 0.01
Omega	208.77 ± 2.86 degrees
$a_x \sin(i)$	196.2 ± 3.7 light-s
$T_{periastron}$	MJD 57676.90 ± 0.56

- Orbital period from optical photometry is 44.86 days (Cowley and Schmidtke 2004).
  - Swift determined period 1.2σ off from optical.
  - Differences in X-ray measured orbital periods and optical are common, but in this case the difference is not significant.
- First direct measurement of orbital eccentricity of SMC X-3.
- Look for publication on this: Townsend, Kennea, Coe et al. (2017) currently in prep.

CONCLUSION

- Swift/MAXI are a perfect match for the discovery and localization of new X-ray transients.
- This collaboration has driven a large amount of science done both by members of the Swift/MAXI teams and others (thanks to data being public)
- In recent months, MAXI continues to make exciting new discoveries:
  - New outburst of SMC X-3, allowing orbital parameters to be derived
  - Nailing down the nature of fast X-ray transient MAXI J1957+032
  - Fast outburst from new transient MAXI J0636+146
- MAXI and Swift together will continue to make great science discoveries together!

"7 Years of MAXI", December 5th - 7th, RIKEN