The detection and follow-up of transients with *Swift*

Phil Evans

University of Leicester

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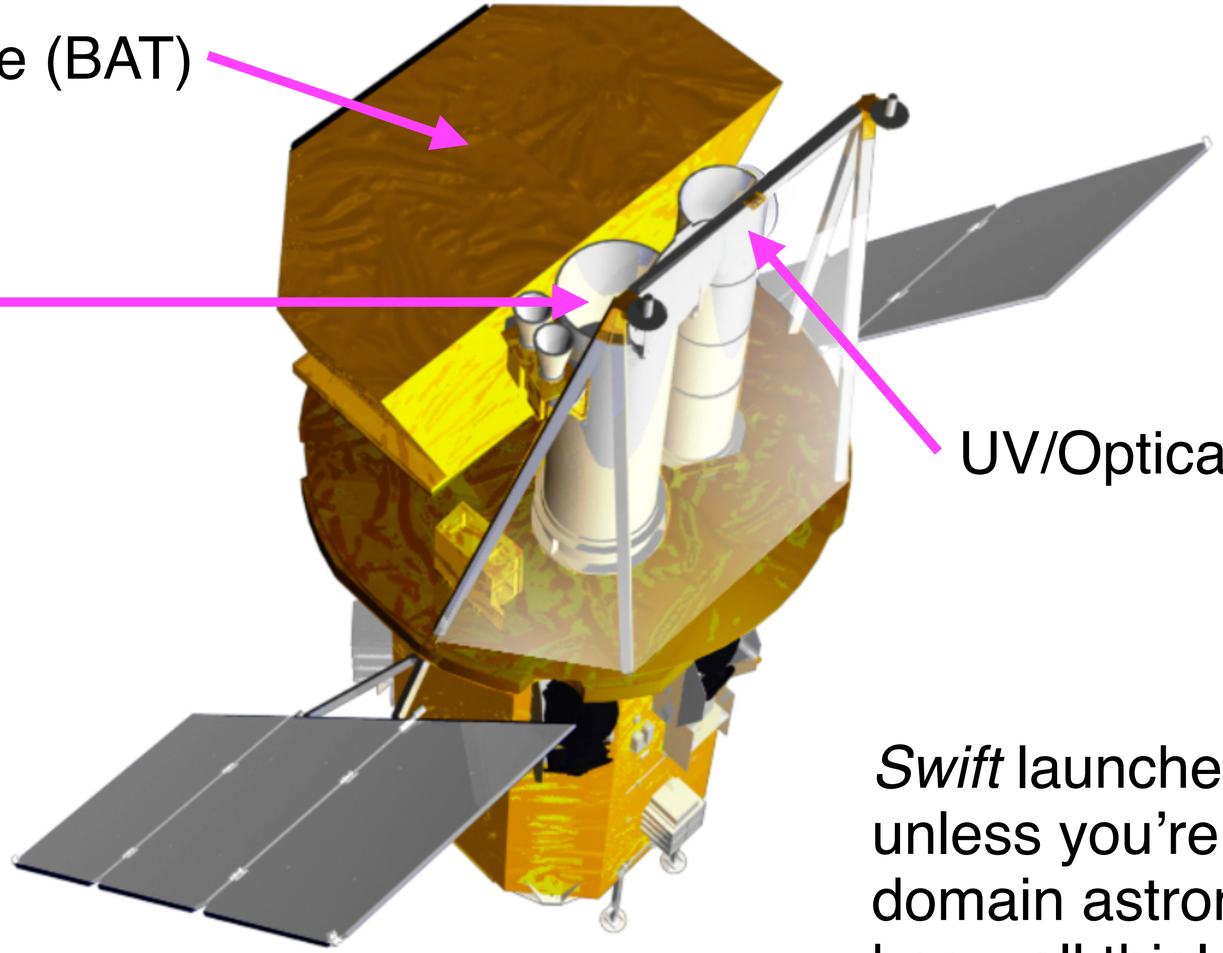
What is *Swift*?

Burst Alert Telescope (BAT)

X-ray Telescope (XRT)



UV/Optical Telescope (UVOT)

Swift launched in 2004, so unless you're new to time-domain astronomy, I hope you know all this!

GRB Results

- 1,593 GRBs to date.
  - All have automated XRT results, including live XRT GRB catalogue: https://www.swift.ac.uk/xrt_live_cat **And the `swifttools` Python module**
- Also follow up some triggers from other GRB missions.
- New initiative GUANO (**G**amma-ray **U**rgent **A**rchiver for **N**ovel **O**pportunities).
  - (An example of a **C**ont**R**ived **A**cronym. **P**ah!)
  - This is triggered by external events of interest, e.g. GRB, GW event, etc.
  - Stores the BAT event data (normally discarded) for downlink.
  - Allows sensitive, time-windowed offline search for BAT events.
  - Results distributed by GCN circulars.

Beyond GRBs

- *Swift* has evolved significantly over its lifetime, beyond “just” GRBs.
- The entire platform of daily planning, rapid response, fast slewing, high efficiency is in much demand as a time-domain platform.
- In January 2018 renamed *The Neil Gehrels Swift Observatory* in memory of Neil, and recognising its more general focus.

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Neil Gehrels
1952-2017

Neutrinos

- *Swift* has been following neutrinos from IceCube (ANTARES) since 2011 (2013).
  - Initially multiplet alerts, now the high-energy IceCube alerts.
- But neutrino localisations are not as good as BAT GRB localisations…

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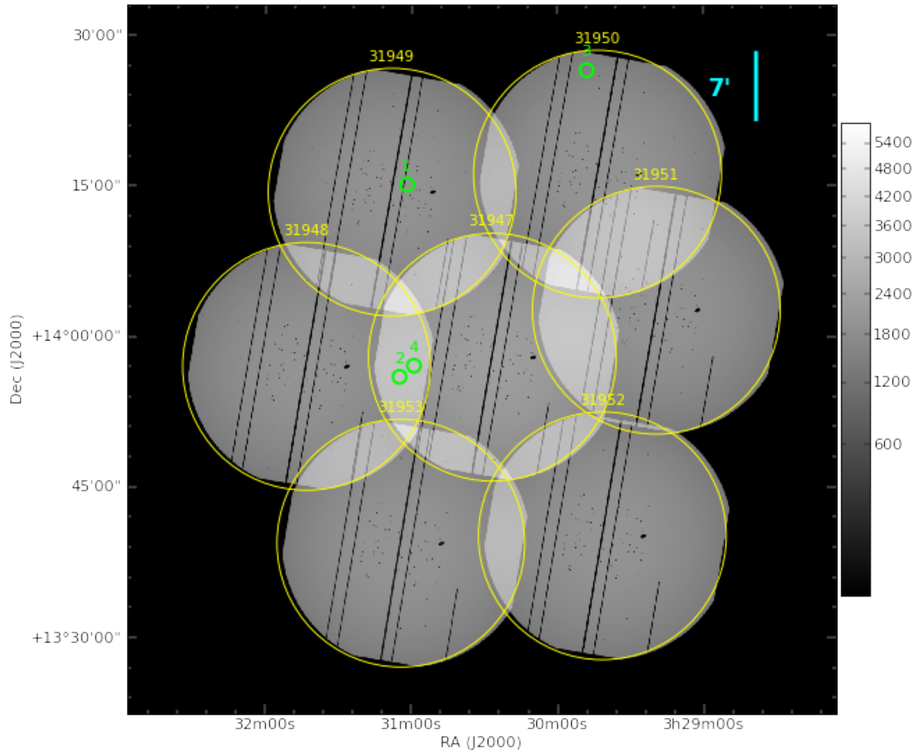

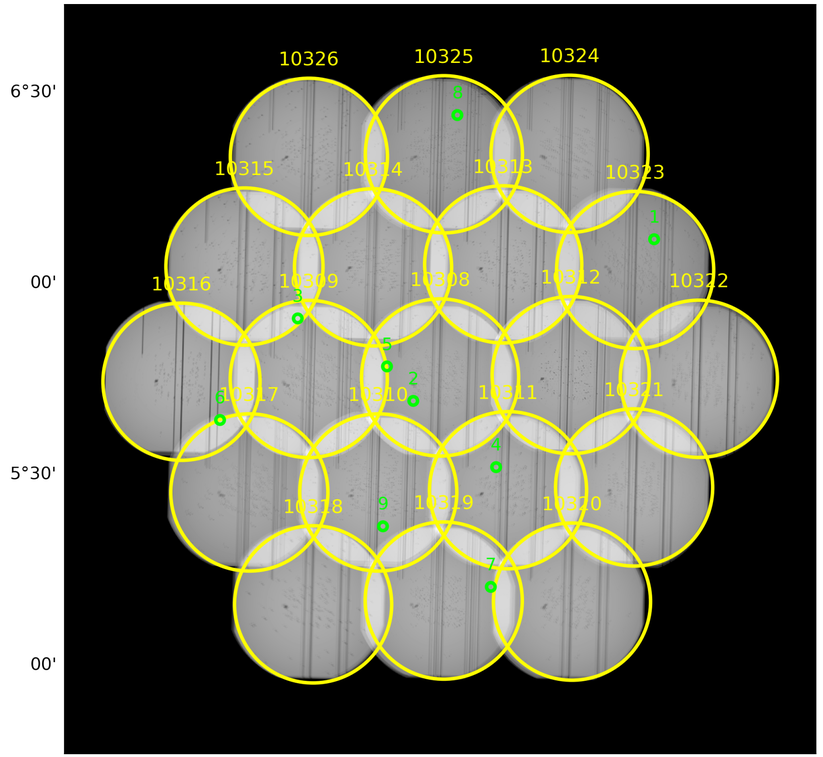

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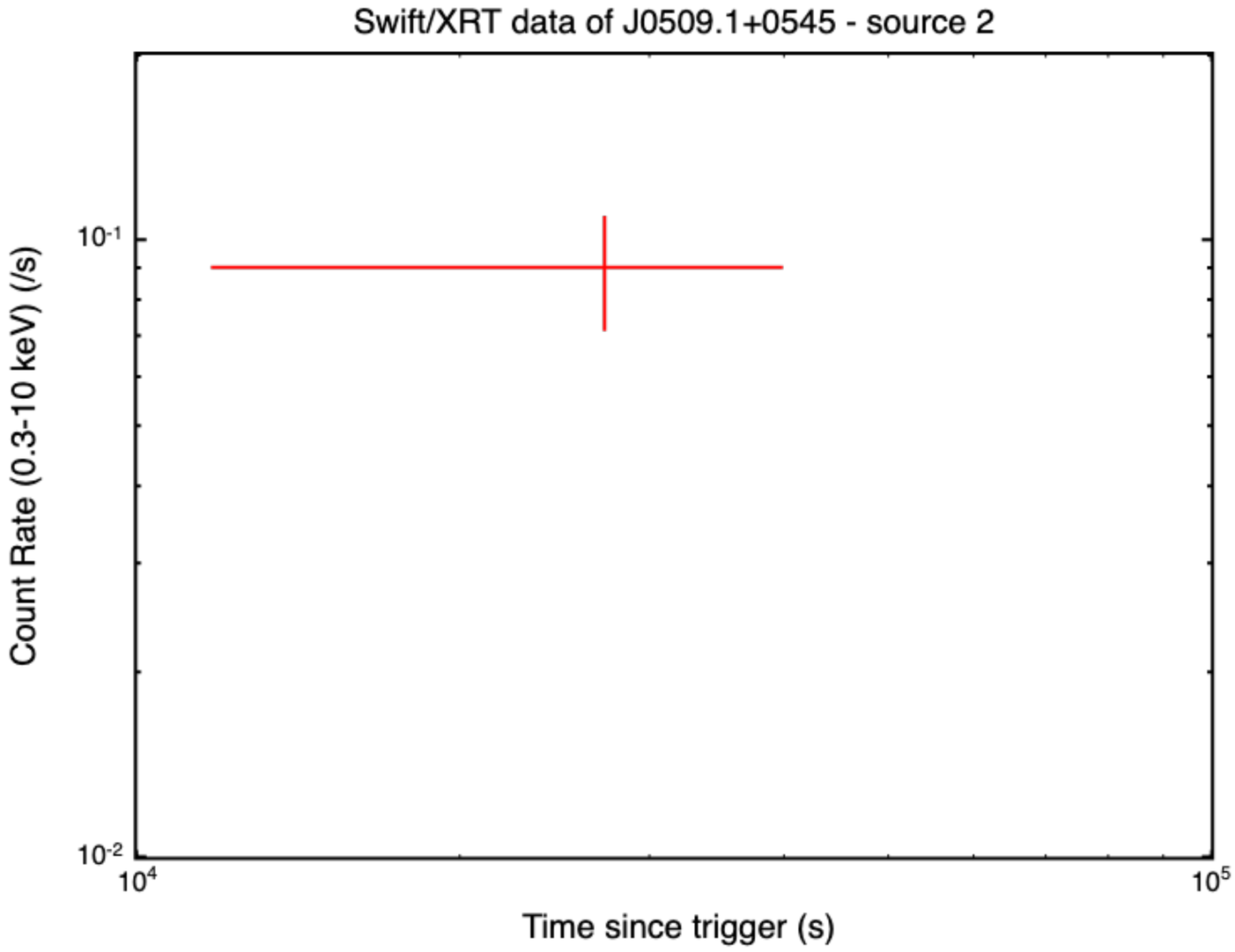
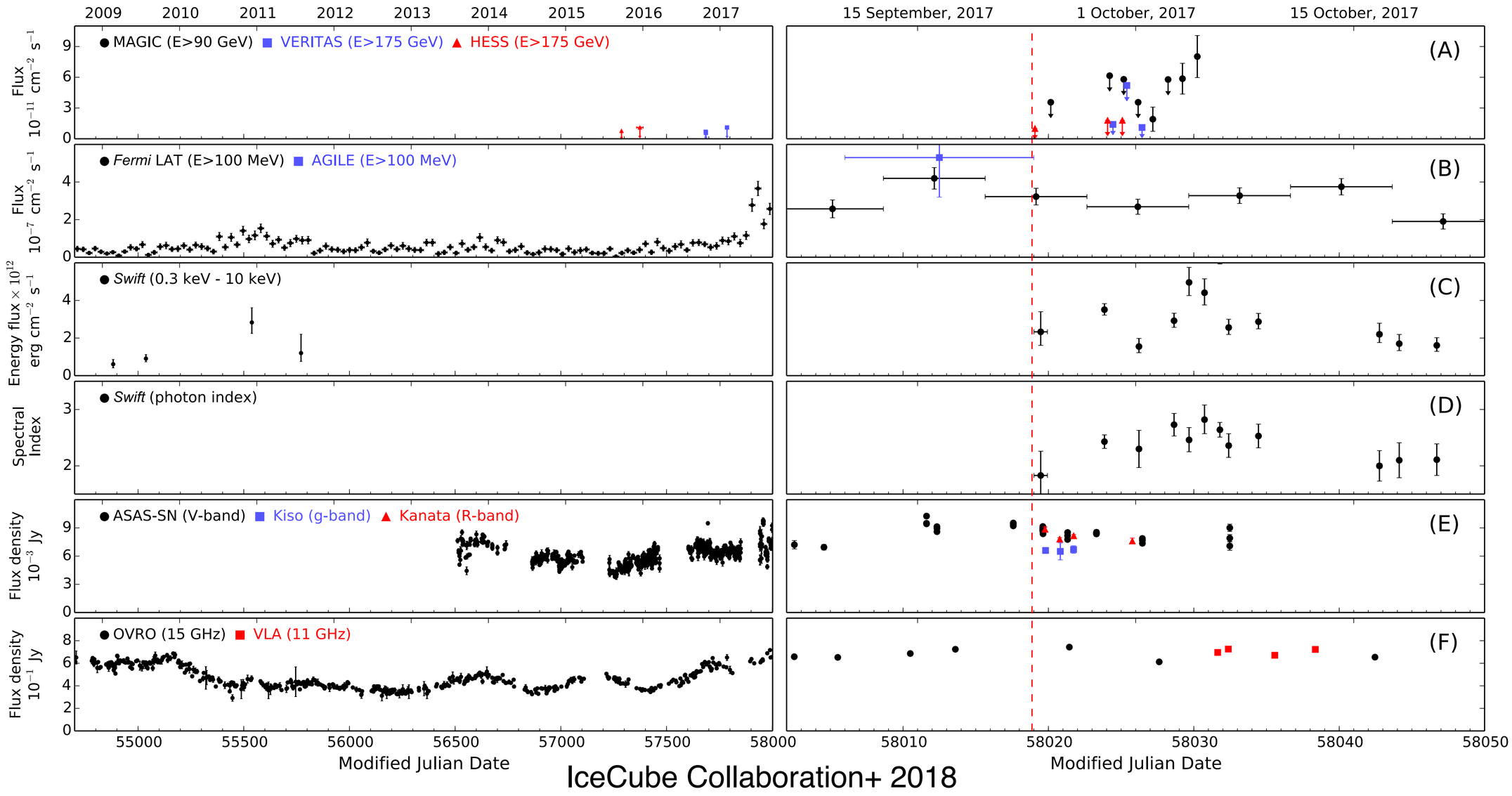
  - Initially multiplet alerts, now the high-energy IceCube alerts.
- But neutrino localisations are not as good as BAT GRB localisations…
- … tiling takes longer, but also yields more sources.
- ~350 s of XRT exposure reaches typical RASS / XMM SL limit.
- Currently, neutrino results shared by GCN / ATEL; web page coming “soon”.

IceCube 170922



Keivani, PE+,
GCN 21930
Sep 26 (14:34 UT)

Various challenges



IceCube Collaboration+ 2018

Gravitational waves

- Swift follows up selected GW triggers, those deemed likely to have a disrupted neutron star.
- XRT results are posted online: https://www.swift.ac.uk/LVC/
  - Sources are given an automated “rank” based on catalogue comparisons to decide how likely they are to be afterglows.
- Semi-automated UVOT pipeline exists, interesting sources shared via GCN.
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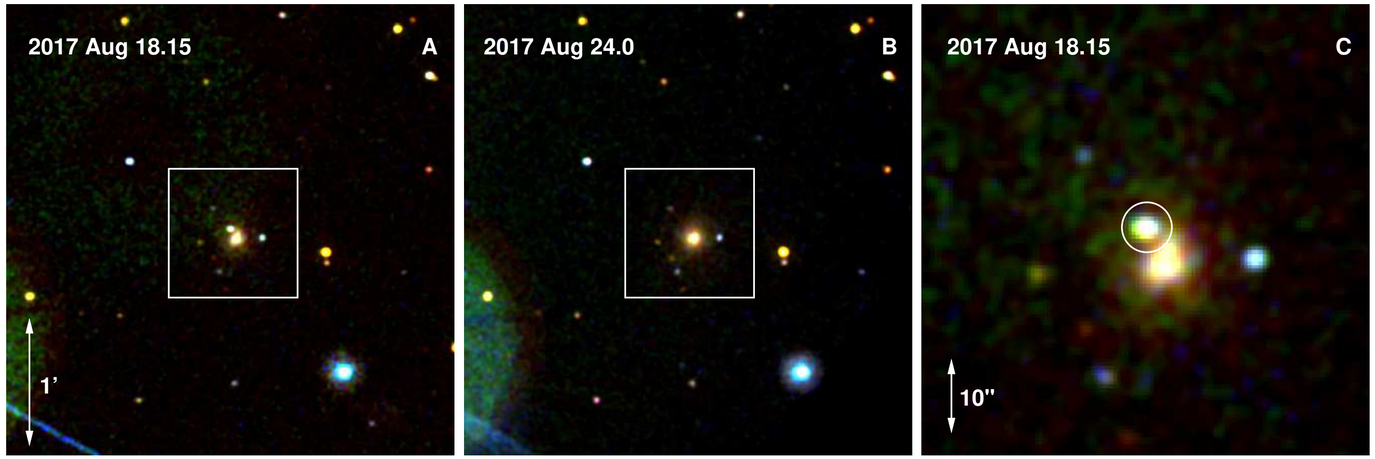
Evans+ 2017



New transient systems — LSXPS

- X-ray catalogues are always out of date…
  - 2SXPS: Published 2019 November; last dataset: 2018 August
    - 10 month delay.
  - 4XMM-DR11: Published 2021 August; last dataset: 2020 December
    - 8 month delay.

This has particular impact on transient detection, serendipitous or targeted.

arXiv: 2208.14478

https://www.swift.ac.uk/LSXPS

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LSXPS is “living” — updated in near real-time.

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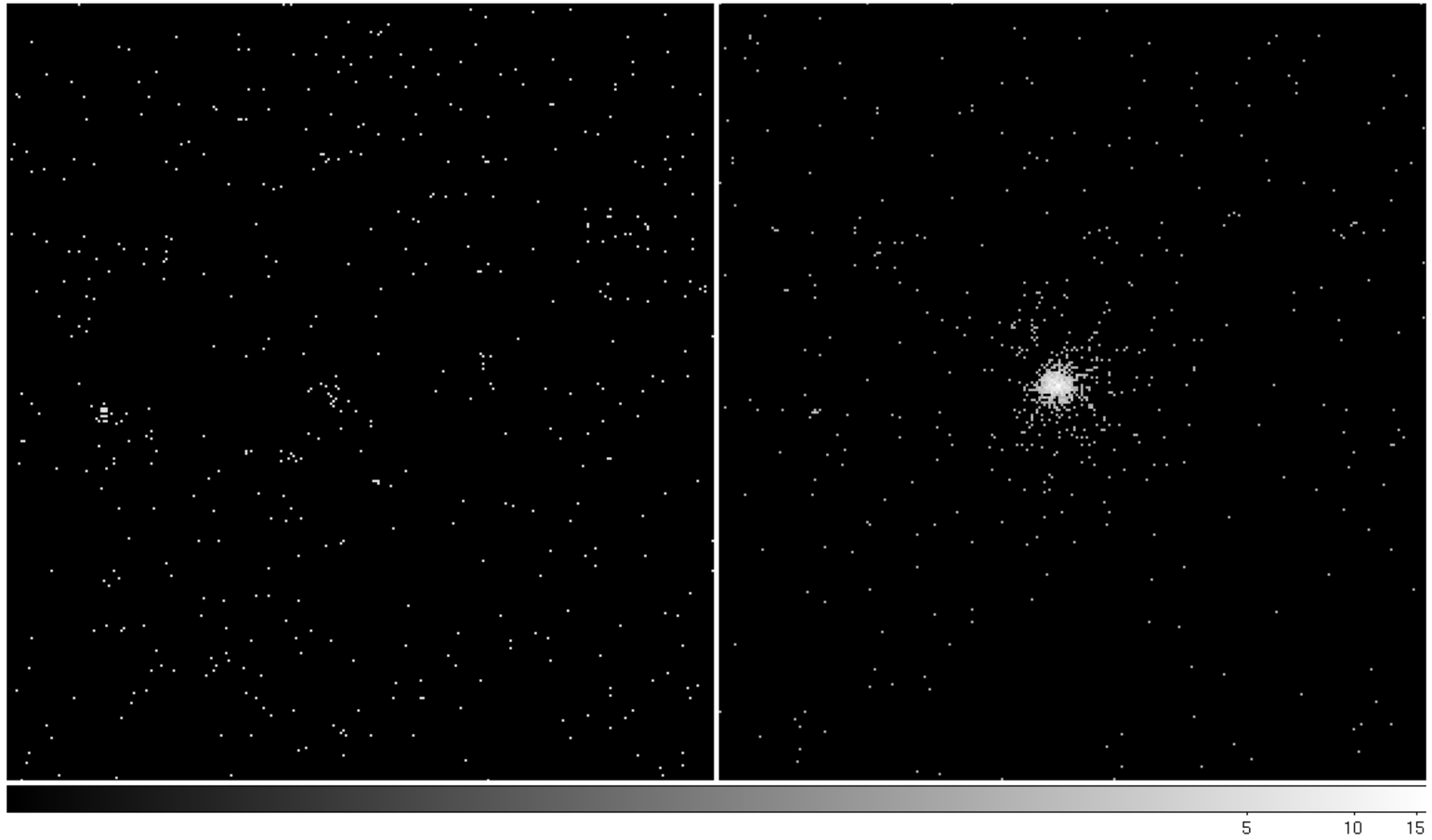
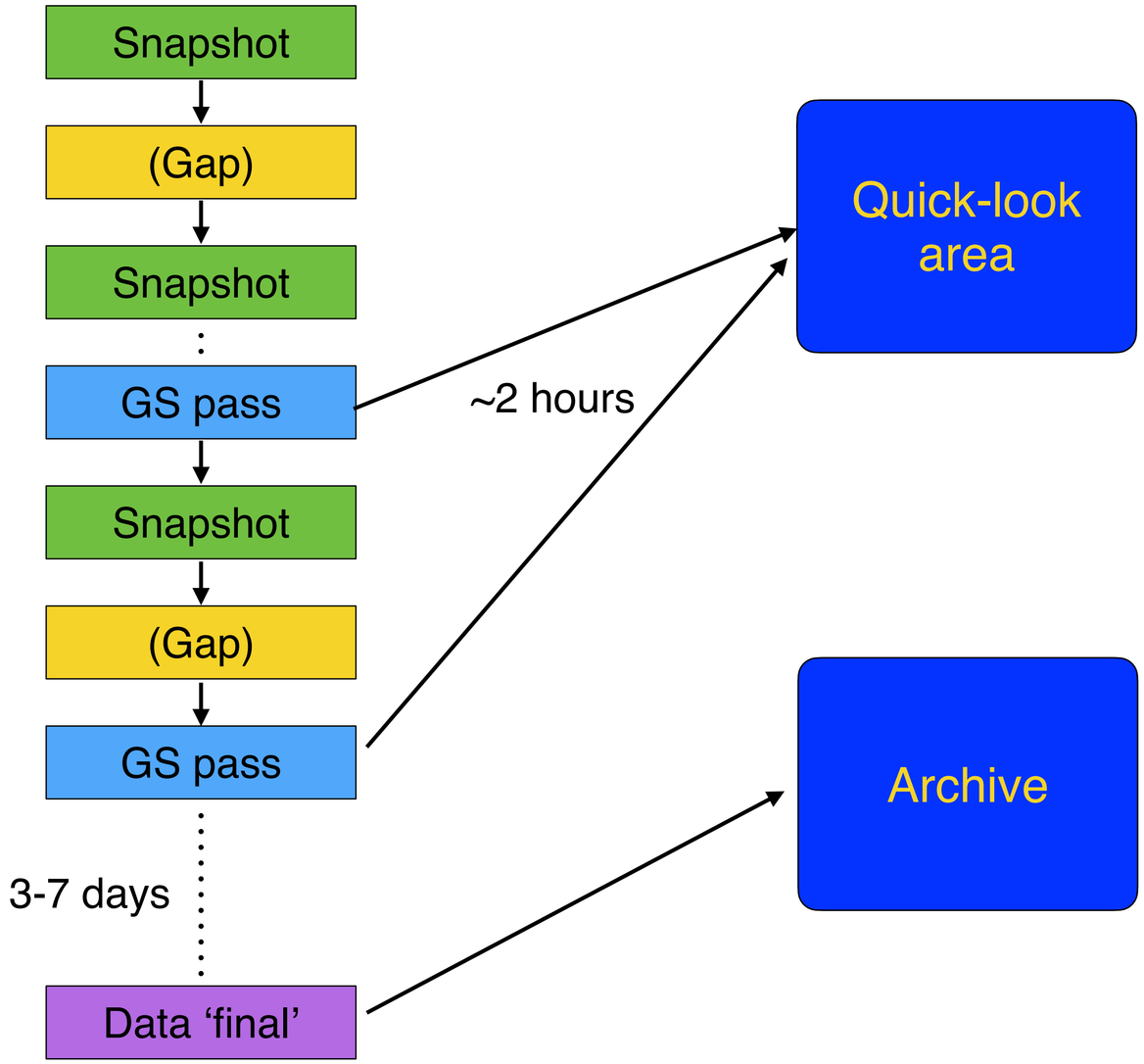
New transient systems — LSXPS



SN 2008D: Soderberg et al. 2008

Swift data flow



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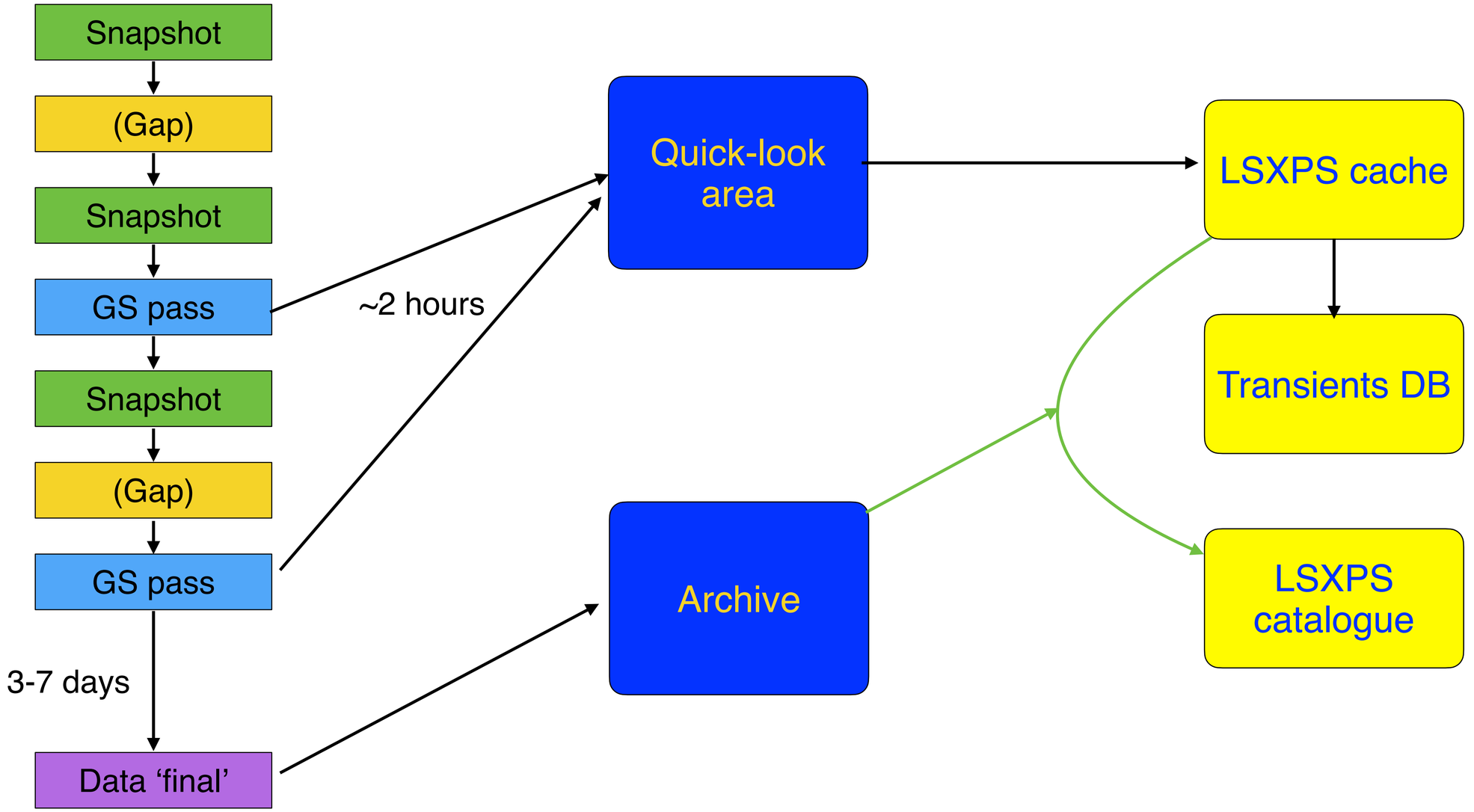

What is a transient?

Something that wasn't there before… and now is.

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Something that wasn't there before… and now is.

But what does this mean?

- 1-σ lower-limit on the count rate is above 3-σ upper limit in catalogues.
- RASS (0.1-2.4 keV) and XMMSL (2-10 keV) sensitivity is $\sim 3 \times 10^{-12}$ erg cm^{-2} s^{-1}.
- Often the best reference for LSXPS is itself.

Transient classifications

Transients have to be classified by hand before they are announced (for now). Mainly to remove:

- Targeted transients
- “Proprietary” transients
- Spurious sources
- Non-transients

Otherwise classified as:

- Outburst
- Low significance
- Needs follow up
- Confirmed transient

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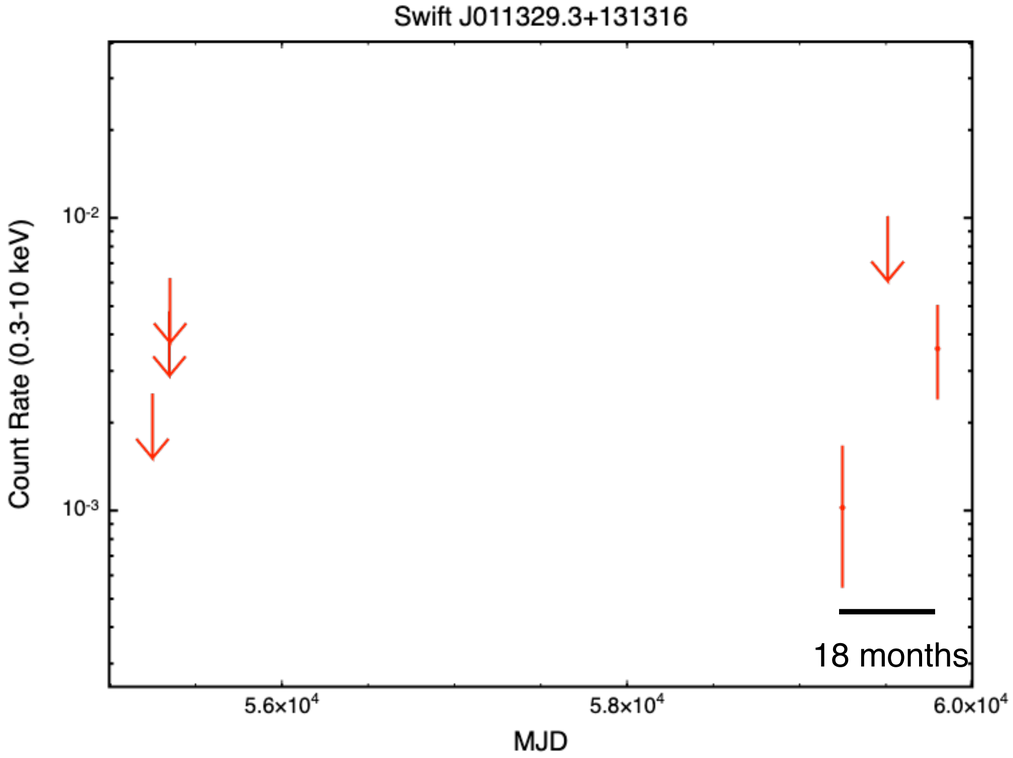

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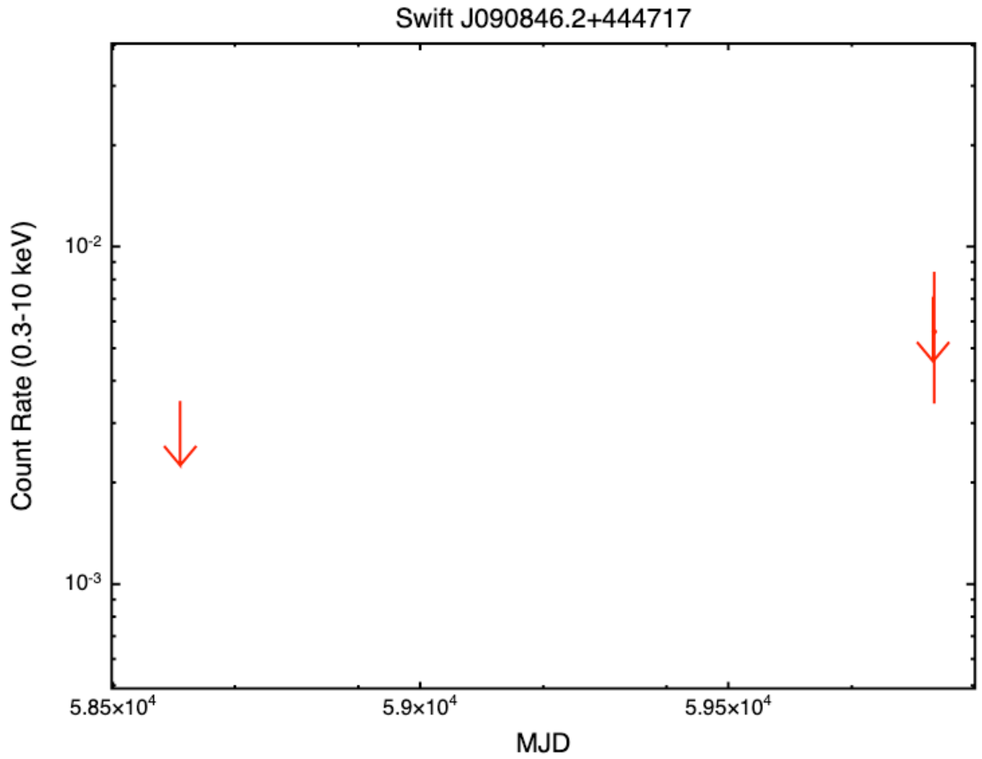
Peak rate	8 (+6, -4) $\times 10^{-3}$ (0.3 — 10 keV)
Historical upper limits	2.91 $\times 10^{-3}$ (0.3 — 10 keV; 3-σ) (from LSXPS [00011338002]) [Show all limits].
Outburst significance	1.19 σ



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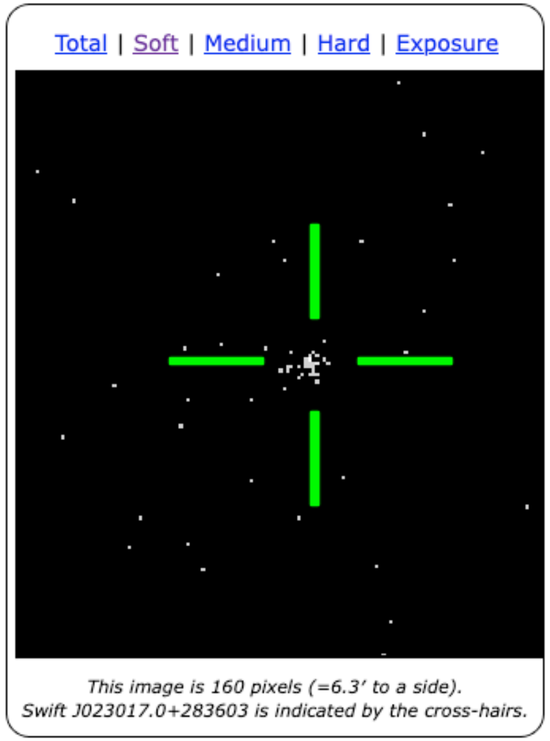
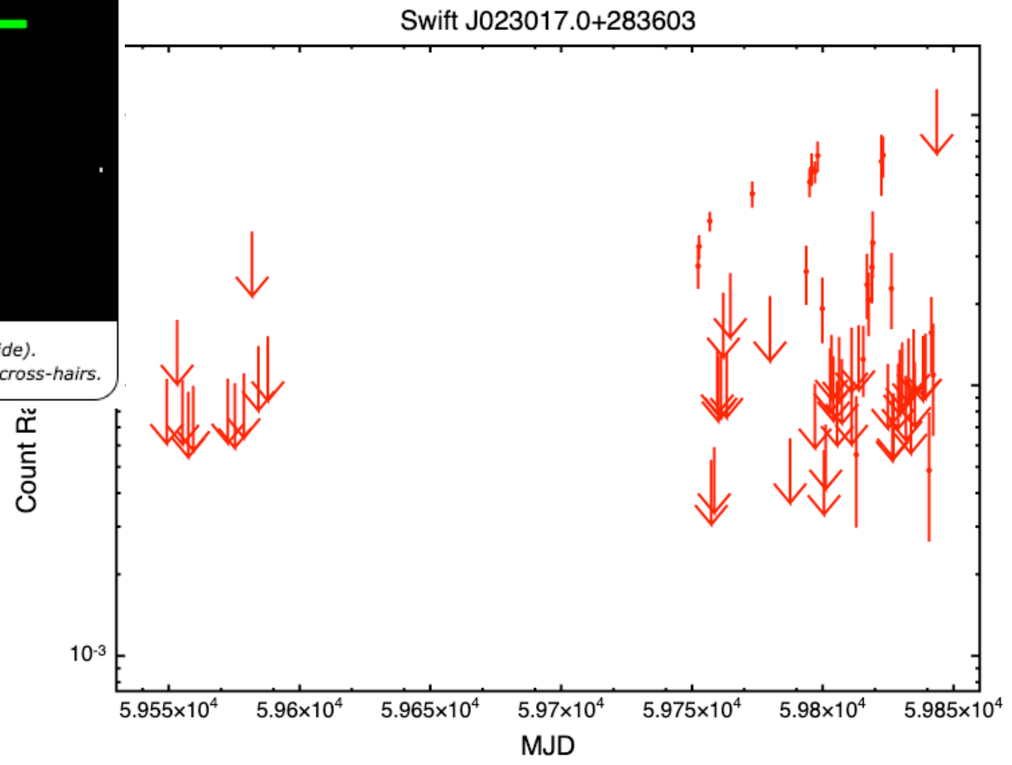
https://www.swift.ac.uk/LSXPS/transients

Example: Swift J023017.0+283603

Detection flag:	Good
RA (J2000):	$02^h\ 30^m\ 17.09^s$=37.5712°
Dec (J2000):	+28° 36′ 04.4″=+28.6012°
Err$_{90}$:	4.4′′
l:	+147° 51′ 33.9″=147.8594°
b:	-29° 26′ 31.6″=-29.4421°
LSXPS_ID:	LSXPS J023016.9+283603.
First detected:	2022-06-22 09:19:34 Obs 00014936012
Discovery time	2022-06-22 13:54:14
Peak rate	2.7 (+0.6, -0.5) $\times 10^{-2}$ (0.3 — 10 keV)
Historical upper limits	1.51 $\times 10^{-3}$ (0.3 — 10 keV; 3-σ) (from LSXPS [10000000668]) [Show all limits].
Outburst significance	5.13 σ
Search 5-σ radius	SIMBAD |Vizier.
XRT Team comments:	*Possible TDE, see ATEL #15454*



This image is 160 pixels (=6.3′ to a side).
Swift J023017.0+283603 is indicated by the cross-hairs.



Conclusions

- Swift is a powerful facility for both **detection** and **followup** of transients.
  - Including doing both aspects itself!
- Fast-response, flexible scheduling: great tool for TDAMM.
- We have ways of observing to support large error regions.
- LSXPS: new facility allows the **detection** of X-ray transients.
  - Opening new timescales and windows to study.
- Makes a natural ally of Astro-Colibri.

Deleted slides

Swift and GRBs

T0

2 min

30 min

~2 hr

~12 hr

days

Swift and GRBs

T0 BAT triggers on new GRB
Swift slews

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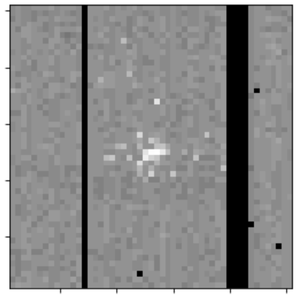

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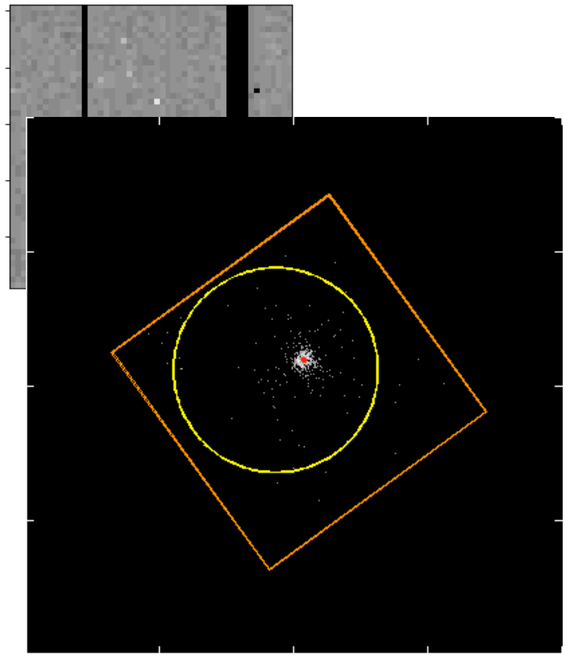

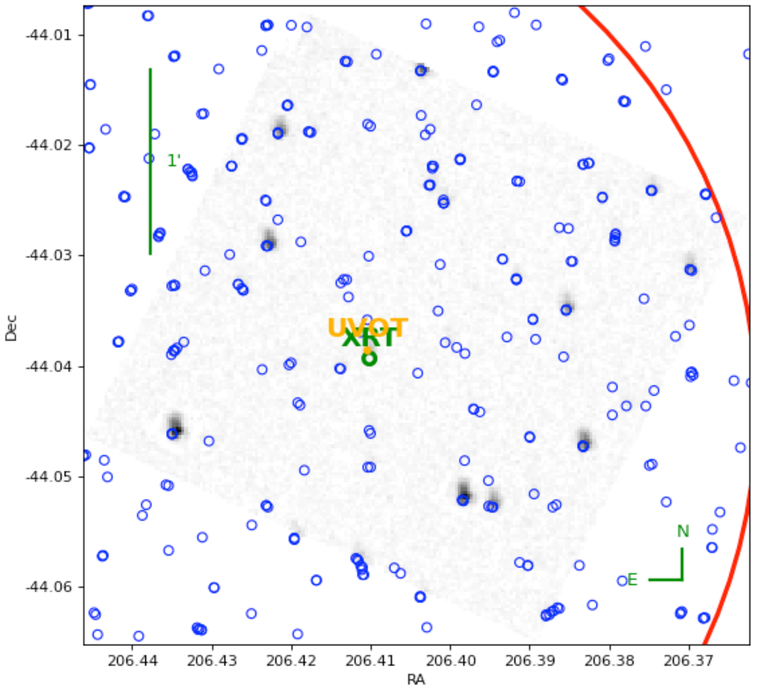

Swift and GRBs

T0 — BAT triggers on new GRB
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Prompt data products

30 min — Initial GCN Circular

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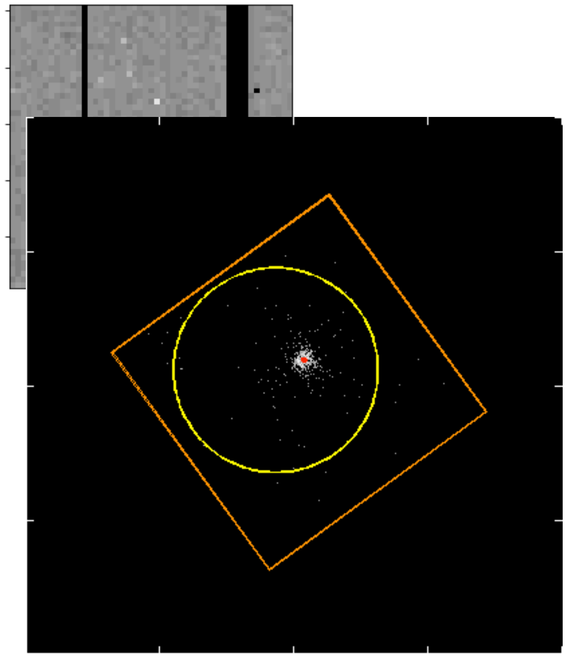

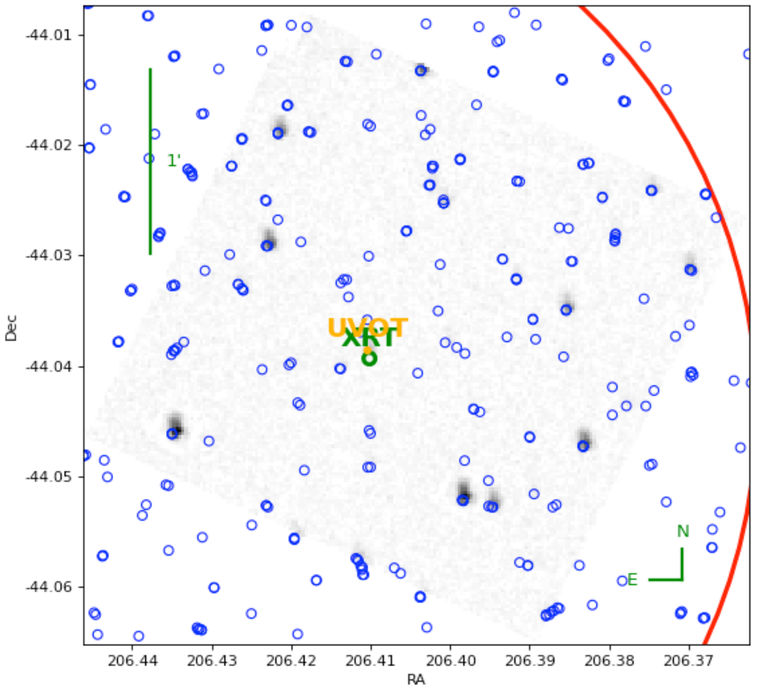

Swift and GRBs

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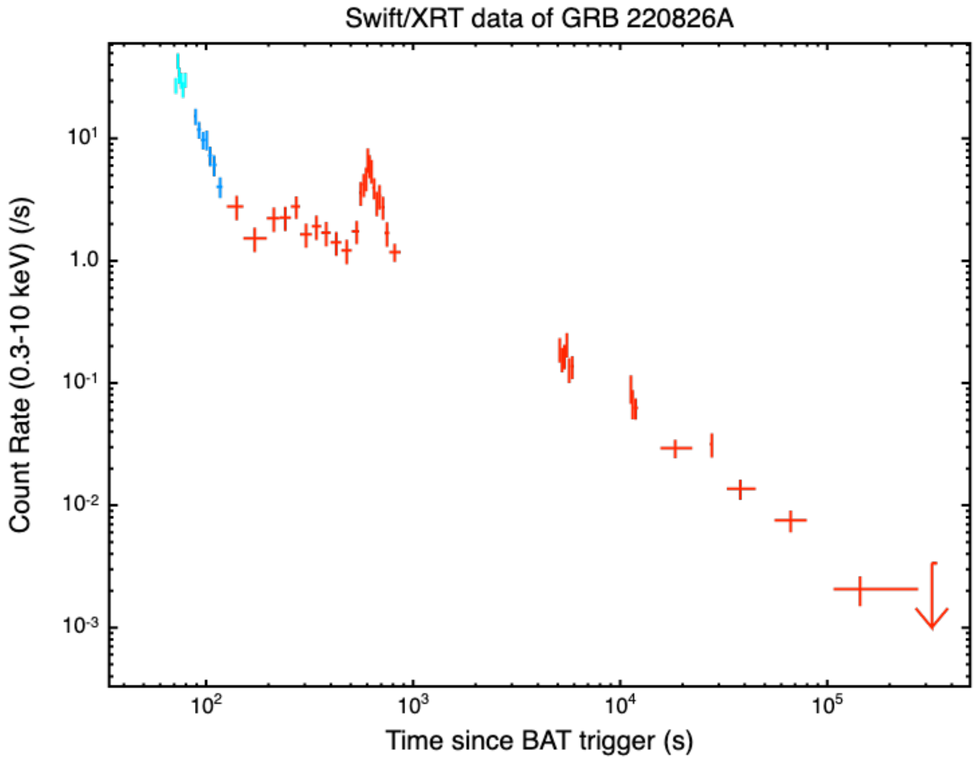

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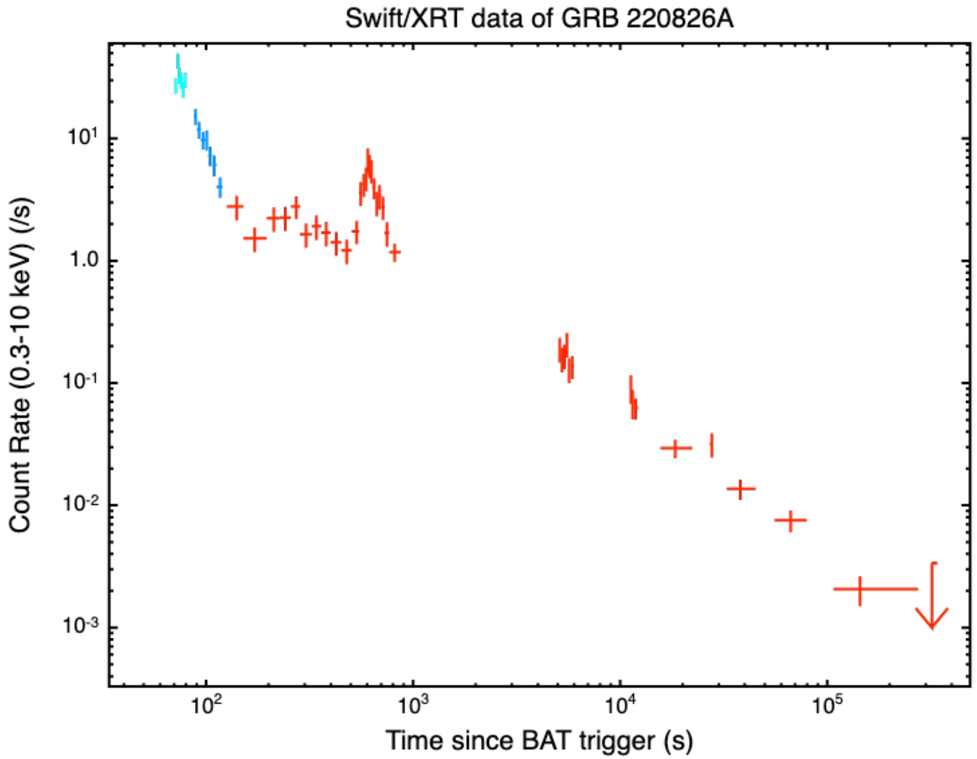

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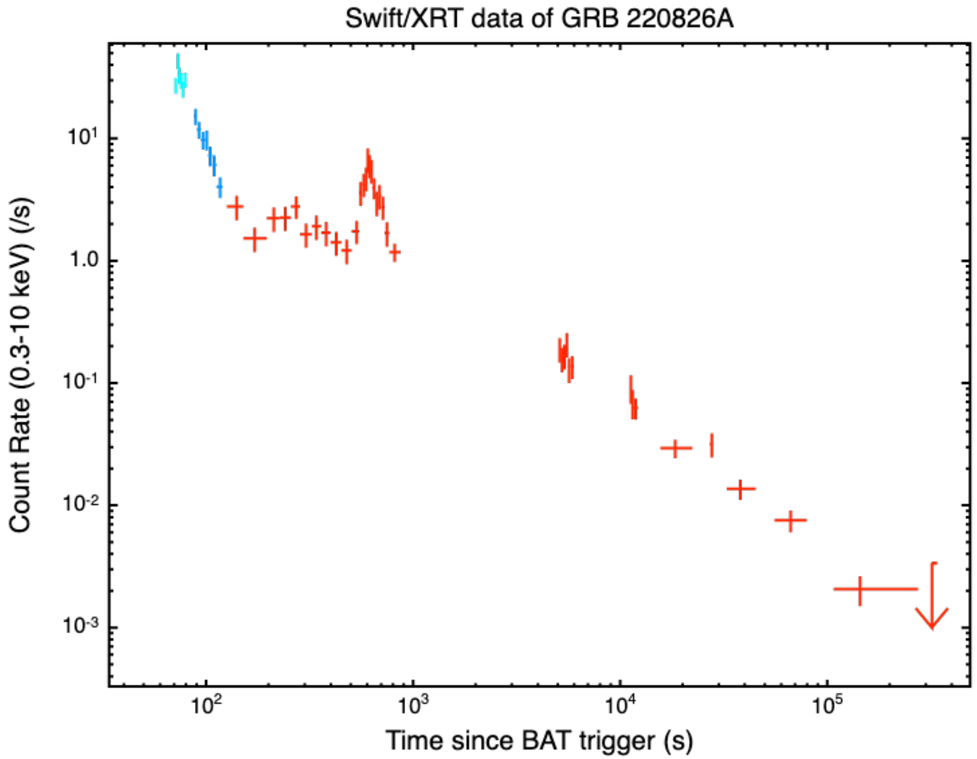
days	Ongoing observations



Gravitational waves

- Makes neutrinos look easy! Very large uncertainties.
- Optimisations are possible.

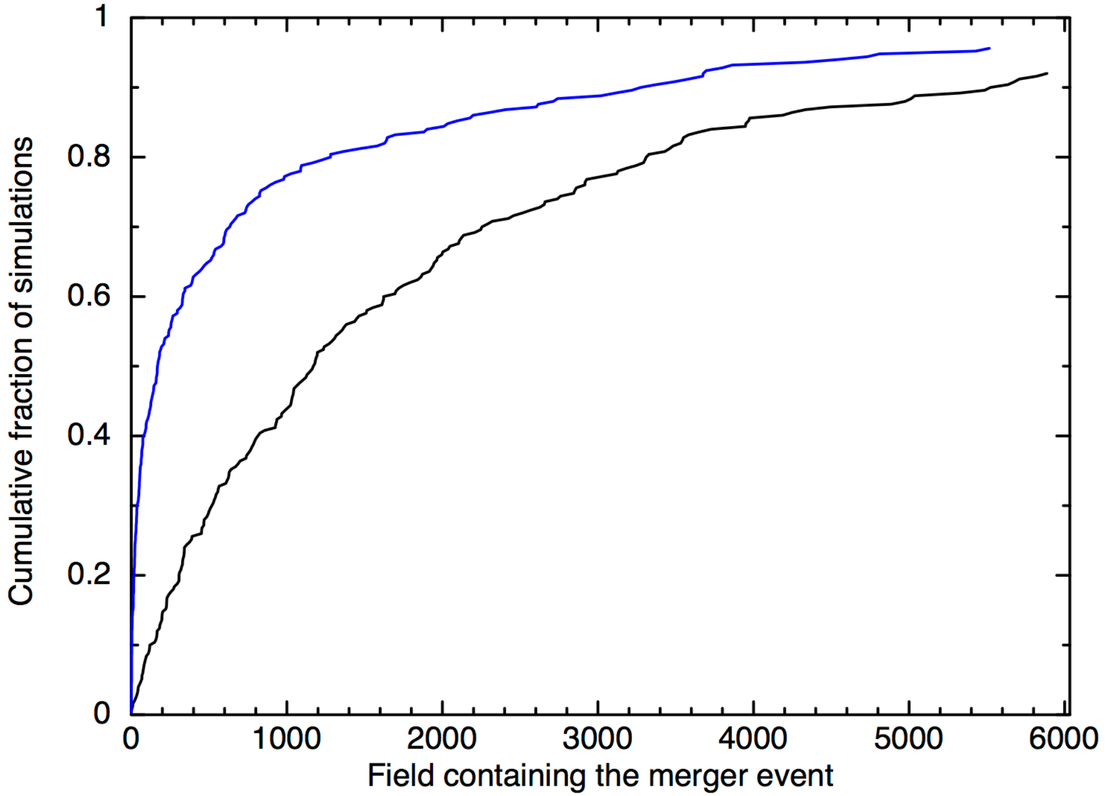
Gravitational waves

The LVC produce 3-D skymaps for compact binary coalescence events, providing for each line of sight both the probability that the event is on that line of sight, and P(D) if it is.

So, we can make use of this information:

$P = P_{GW}\,(1\text{-}C) + P_{GW}\,(C\,P_G)$

$P_G \propto L\,P_{GW}(D)\,P_G(D)$



Evans+ 2016c

C is the completeness of the galaxy catalogue.
P_{GW} is the GW probability.
P_G is the probability that the GW event is in a galaxy on this line of sight.

Various challenges

- If we find an X-ray transient in a large GW follow up, how likely is it to be unrelated to the GW event?
- Spotting “transients” is not as easy as you may think. Consider IceCube 170922…