Swift observations of GW 170817

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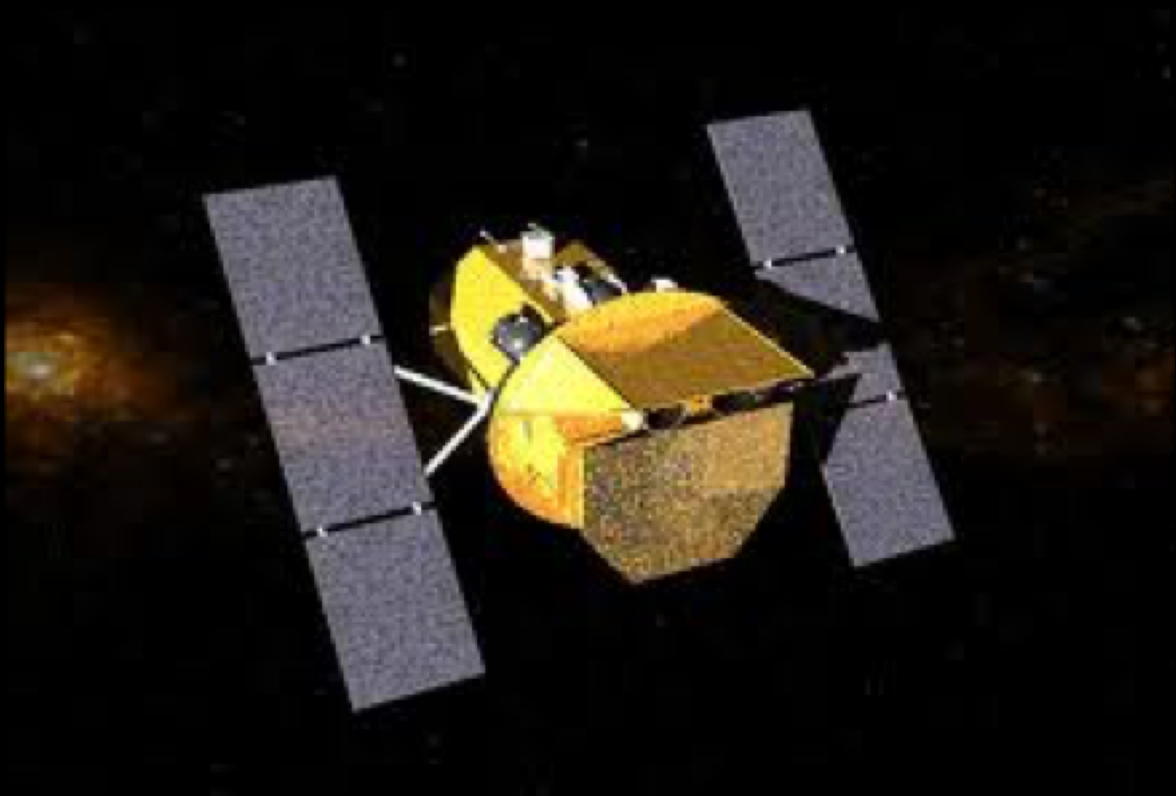
UNIVERSITY OF LEICESTER

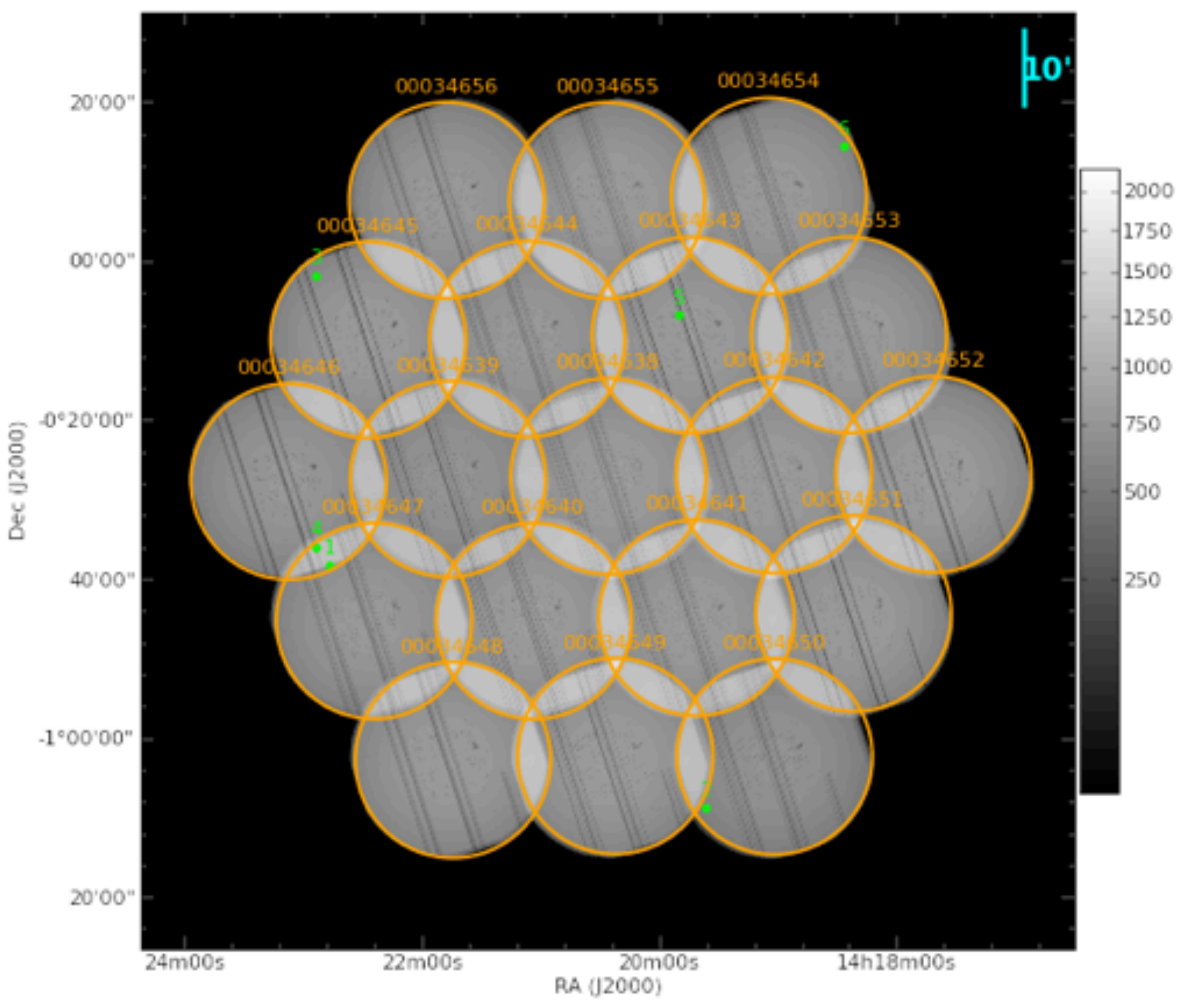


Neil Gehrels
1952-2017

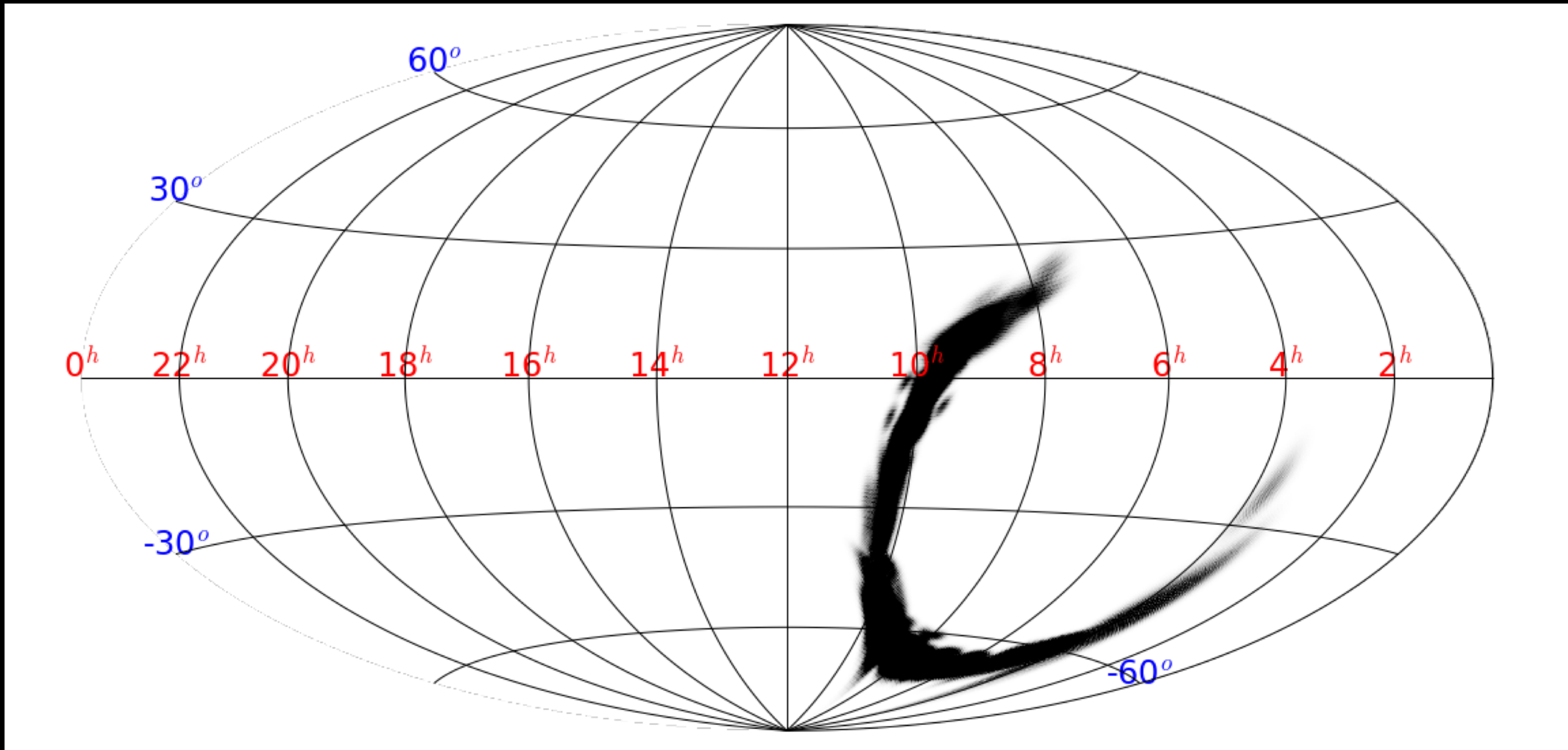
The Neil Gehrels Swift Observatory

Original proposal submitted 20 years ago…18/8/98.

The slightly mad idea of tiling the sky



O1 solution: GWGC catalogue



Evans+ 2016b, MNRAS, 2016, 460, L40

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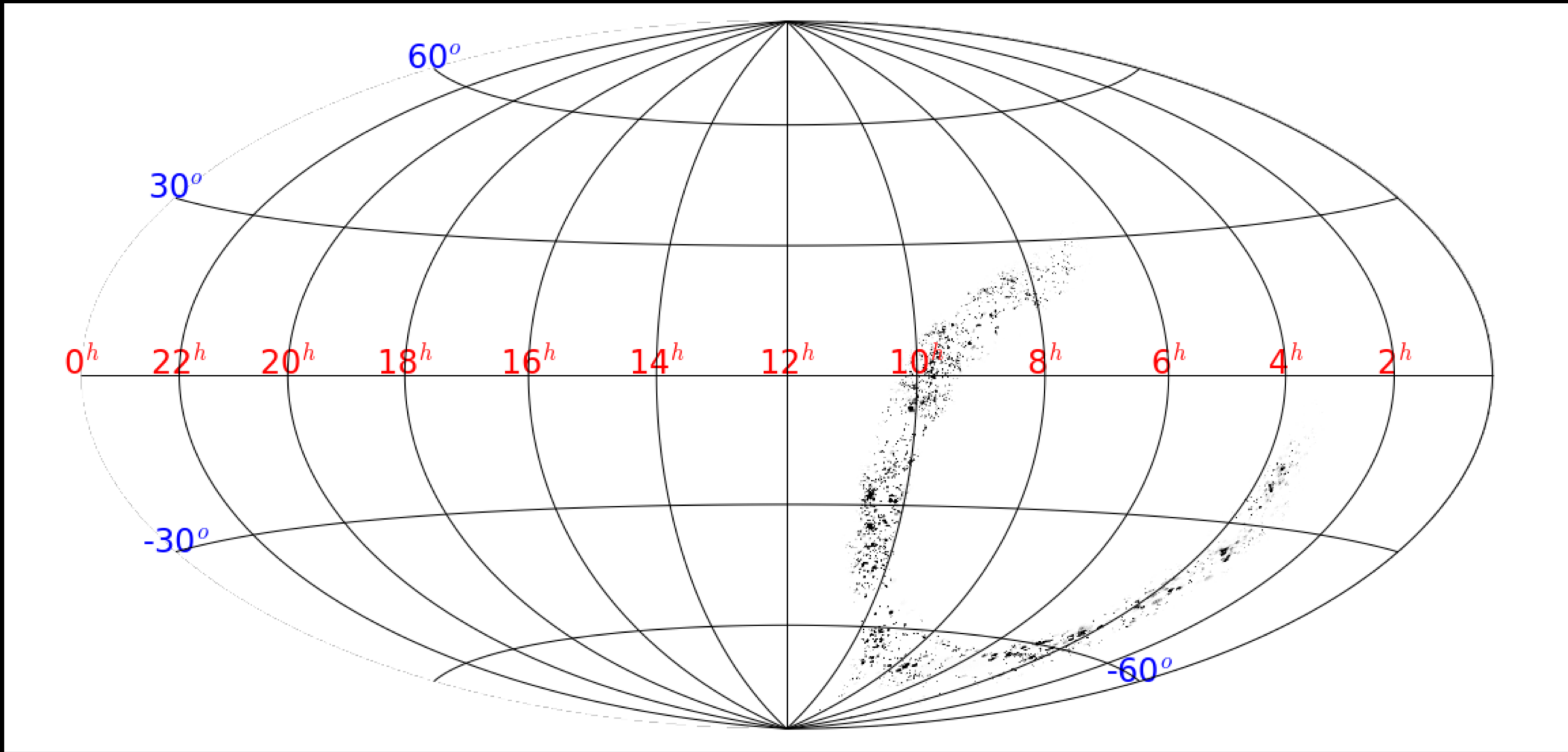


Evans+ 2016b, MNRAS, 2016, 460, L40

GWGC: 55% complete up to 100 Mpc (spectroscopic redshifts)

With 3-D GW information

For the last "O2" GW observing run, 3-D skymaps were introduced, 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:

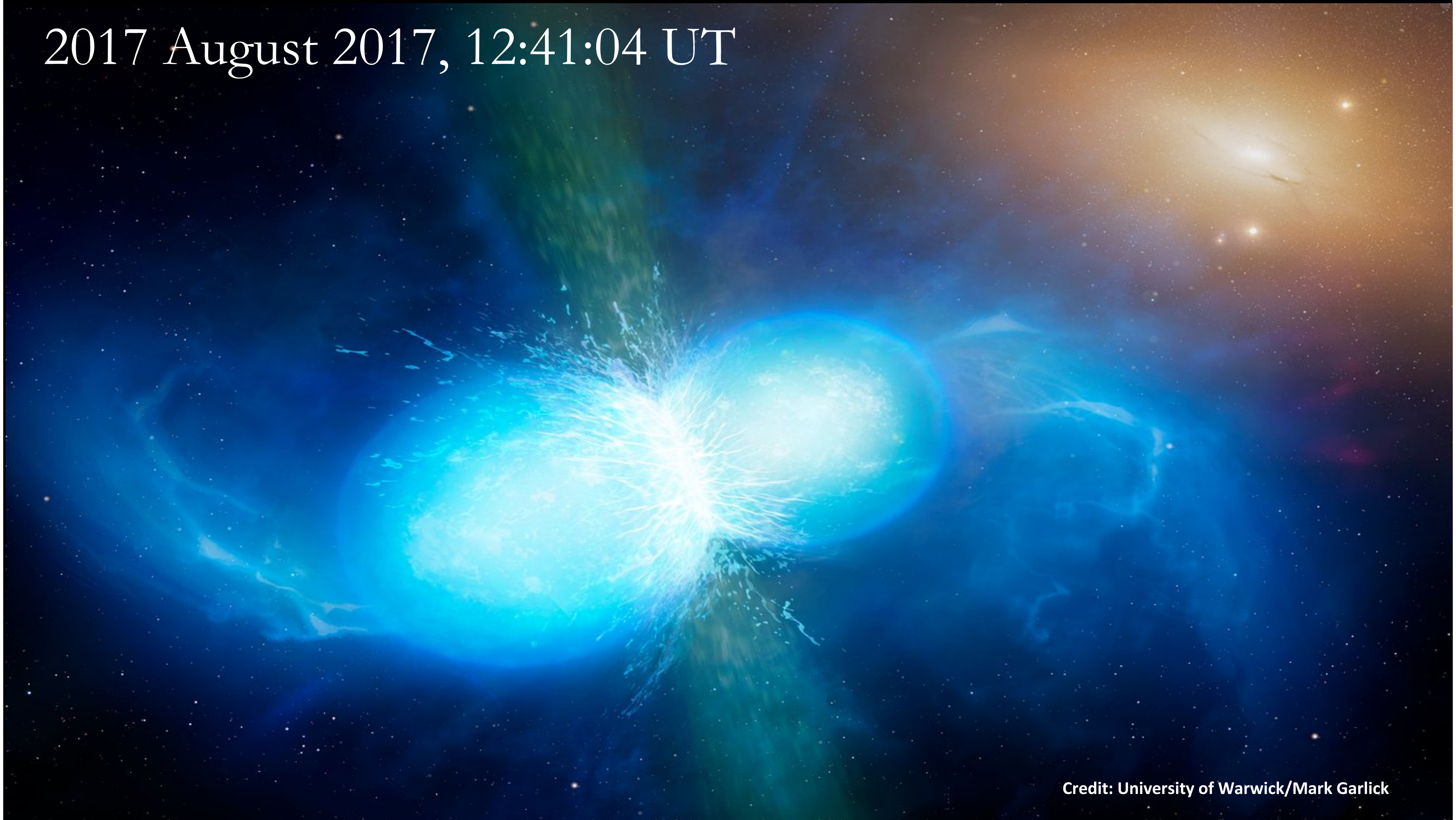
$P = P_{GW}(1-C) + P_{GW}(C\, P_G)$

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.

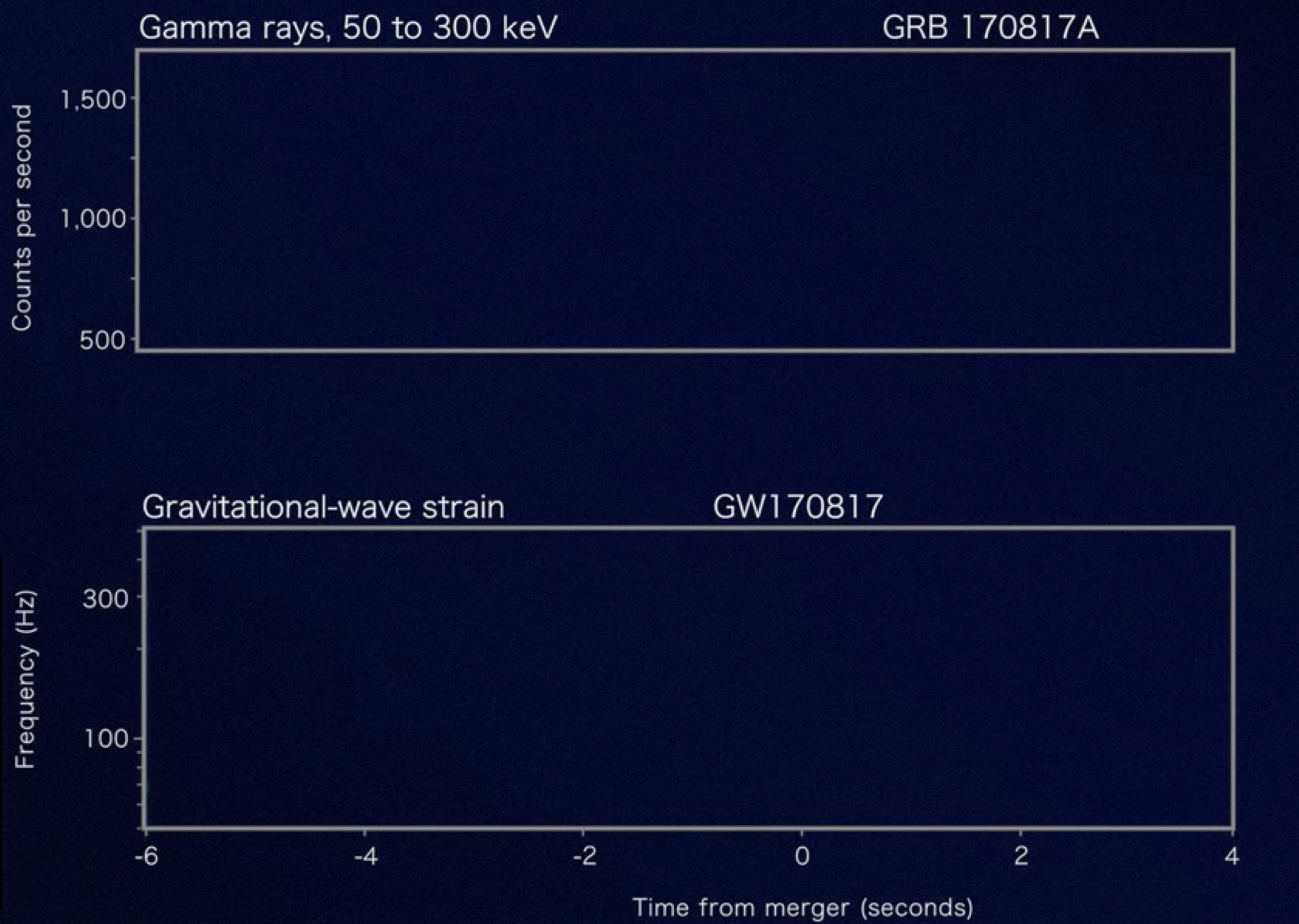
$P_G \propto L\, P_{GW}(D)\, P_G(D)$

Using this method, simulations suggest we would find the 'right' location in about 170 fields – can be done in <1 day

2017 August 2017, 12:41:04 UT



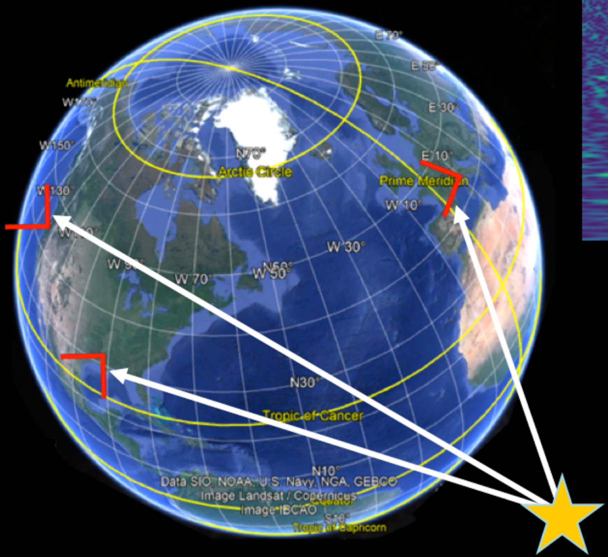
Credit: University of Warwick/Mark Garlick

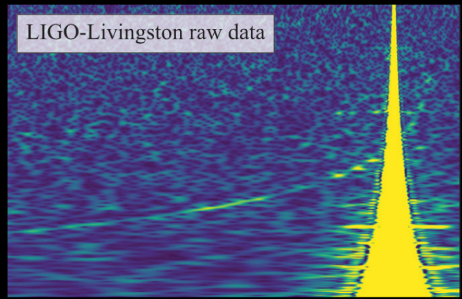


Credit: NASA's Goddard Space Flight Center/CI Lab

Coalescence of neutron star binary

17 August 2017, 12:41:04 UT





instrumental noise

→ 17:54:51

31 deg^2

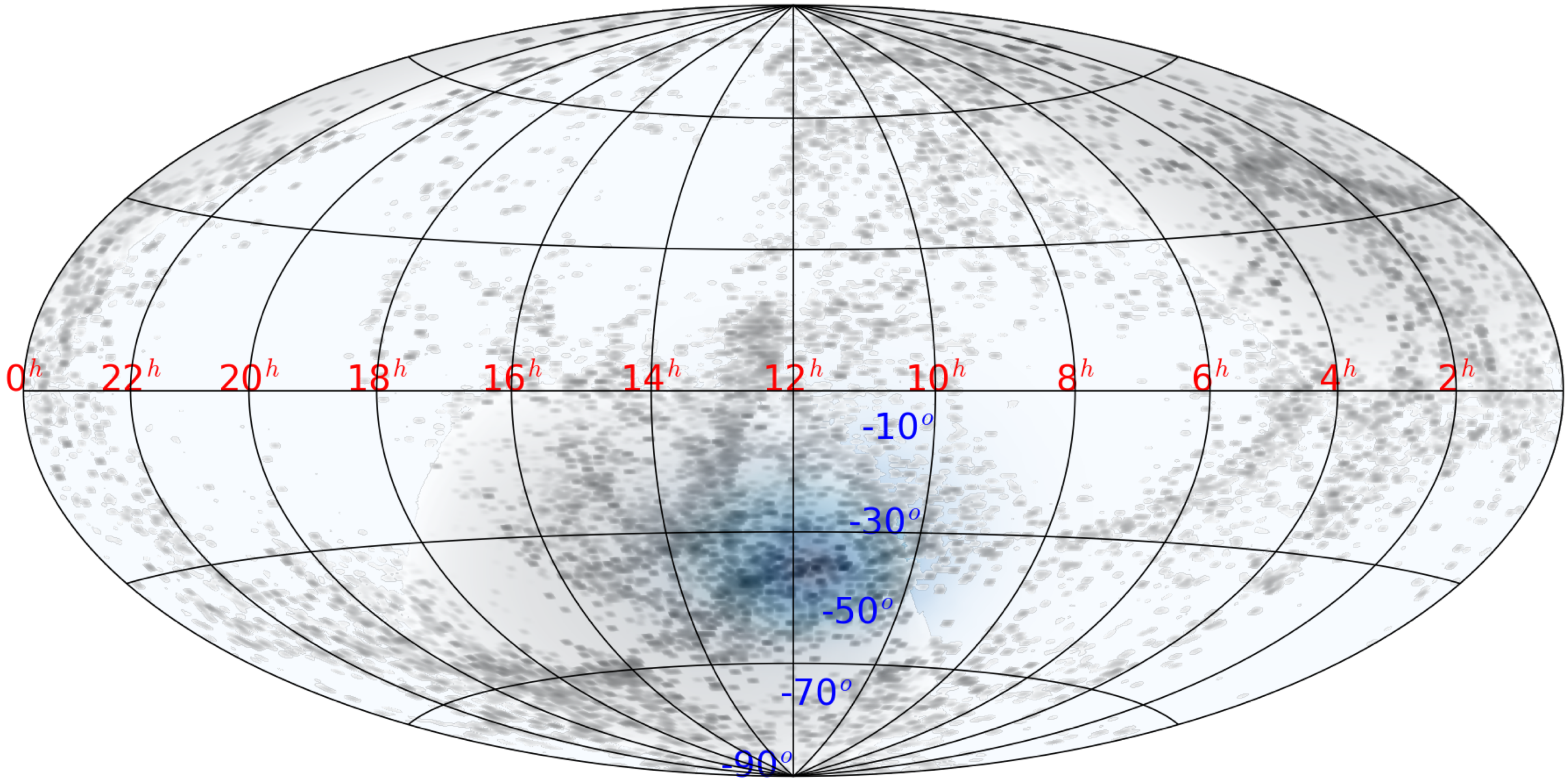
Credit: LIGO/Virgo/NASA/Leo Singer

GW 170817

2017 August 17:

- 12:41:04 UT LIGO-Hanford triggers on a binary merger.
- 12:41:06 UT Fermi satellite detects & announces a short Gamma-Ray Burst.
- 13:08 UT LIGO announces to partners a probably binary neutron star mergers, with a very poor skymap!

GW 170817



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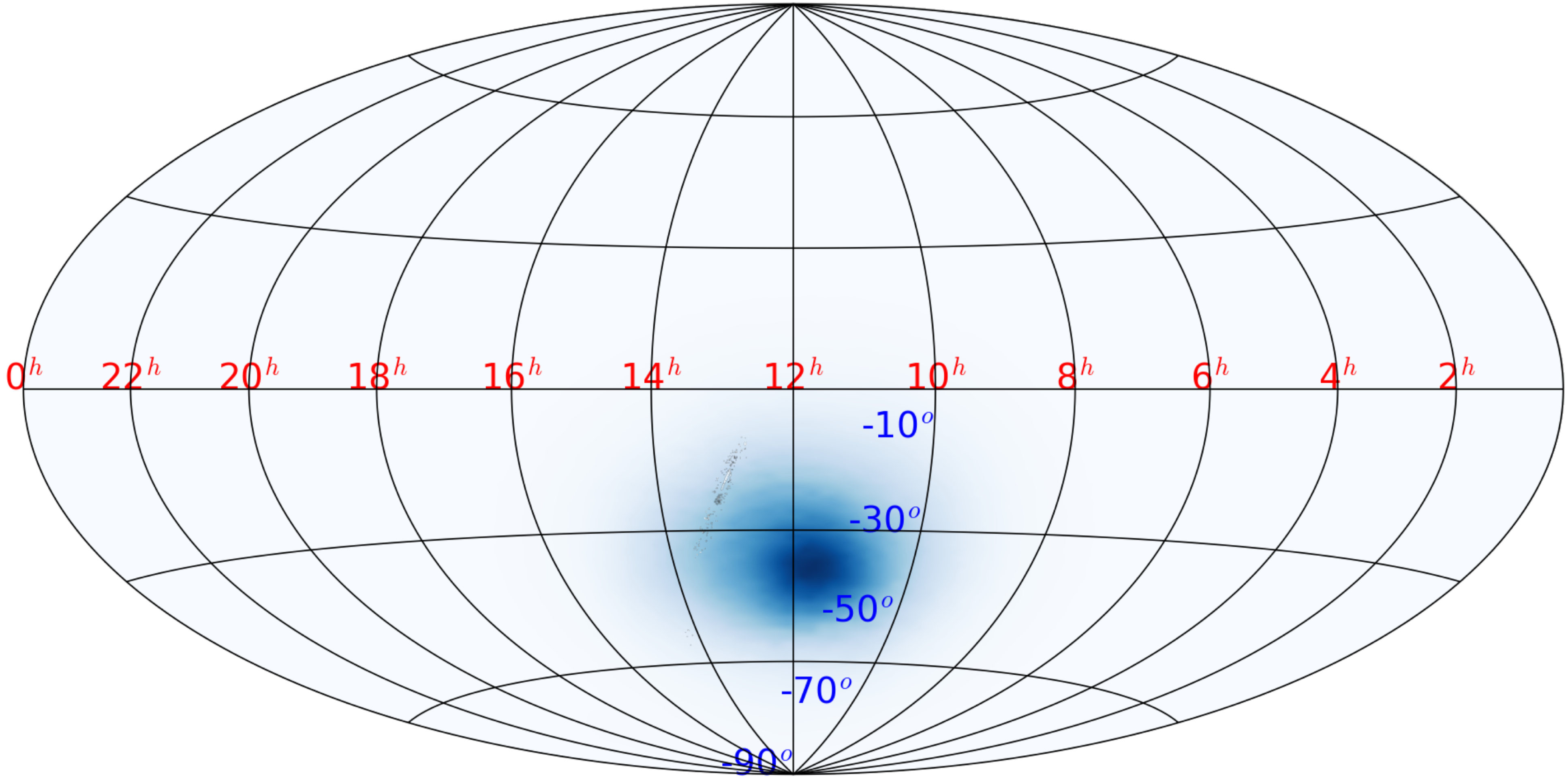
- 13:37 UT *Swift* starts observing the centre of the *Fermi* GBM error region.
- 17:16 UT *Swift* starts observing the combined LIGO and GBM error region.
- 17:51 UT LIGO-Virgo release a better skymap (all 3 detectors)

NB We would not have started observing at 17:16 had we known an updated skymap was coming half an hour later…

GW 170817



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- 17:16 UT *Swift* starts observing the combined LIGO and GBM error region.
- 17:51 UT LIGO-Virgo release a better skymap (all 3 detectors)
- 20:23 UT *Swift* starts observing the revised LIGO-Virgo skymap.
- 23:33 UT The *Swope* telescope observes NGC 4993
- 23:34 UT VISTA starts searching nearby galaxies
- 23:55 UT VISTA observes NGC 4993

GW 170817

2017 August 18:

- 01:05 UT *Swope* announce an optical transient in NGC 4993
- 03:34 UT *Swift* observes NGC 4993
- 06:05 UT *VISTA* announces an IR transient in NGC 4993
- 08:24 UT *Swift* reports UV detection but X-ray non-detection.

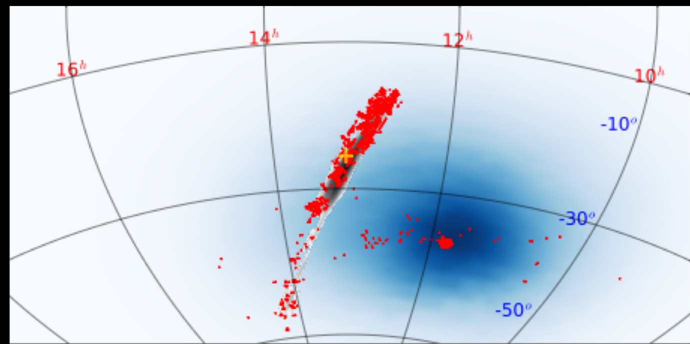
In addition to this, other teams across the globe were taking data. This includes satellites such as HST, Chandra, NuSTAR, and ground-based observatories like VLT, Gemini and VLA.

NB. Swift could have been much quicker to observe NGC 4993 had we not optimized on slewing – we will not do that next time!

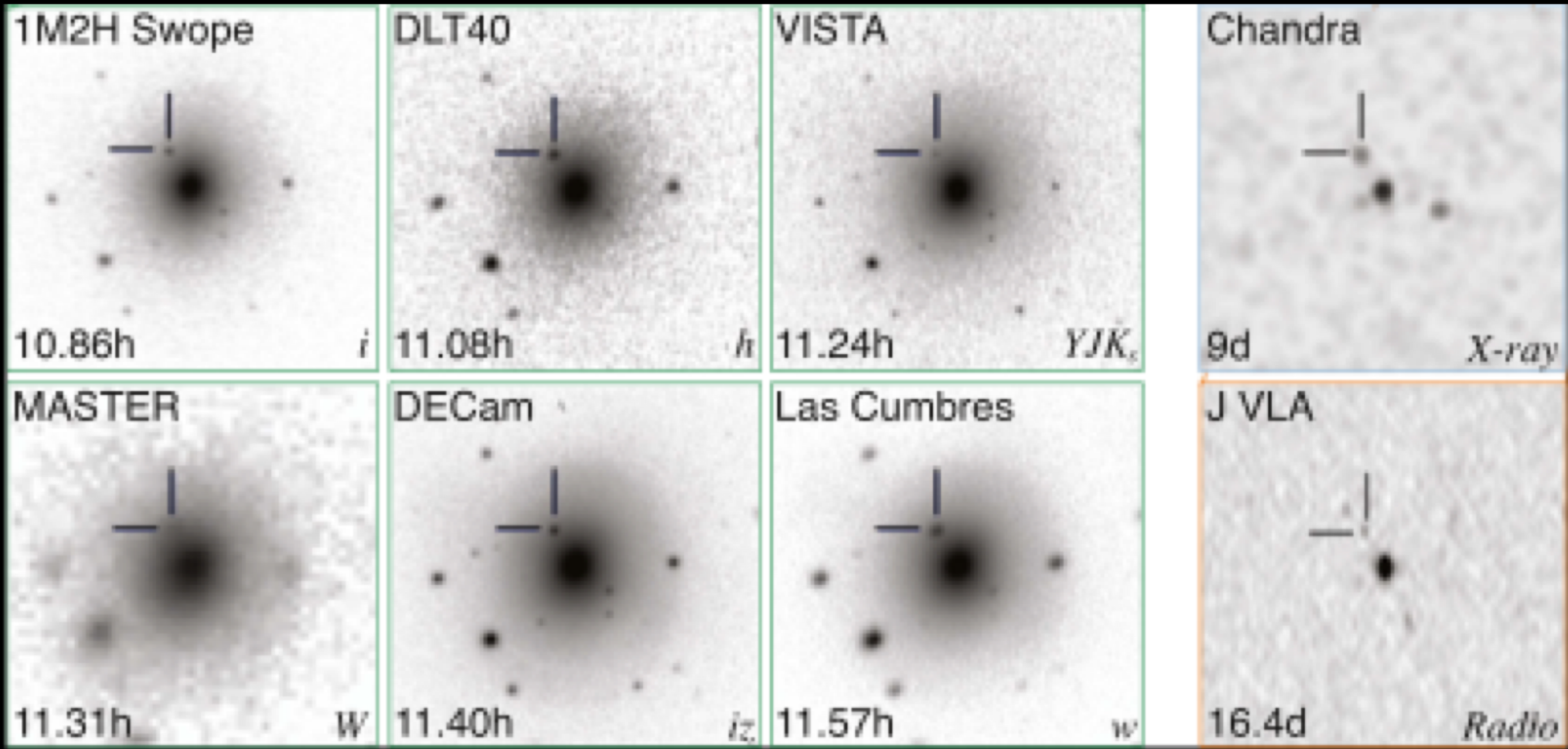
Penalty of over-optimising

- Swift started observing GW 170817 way before sunset on the ground.
- NGC 4993 was one of the highest probability fields to observe.
- It was waaaaaaay down our schedule. Why?

1. Given the distance of the LVC 'banana' from the GBM position, and history of LVC positions 'jumping', various people wanted some 'systematic' adding to LVC. Only way to do this was to lower the minimum probability per field.
2. To optimise the slew vs exposure, I prefer 'neighbour' fields.
3. Generally only consider total P enclosed by a plan, not P vs time.



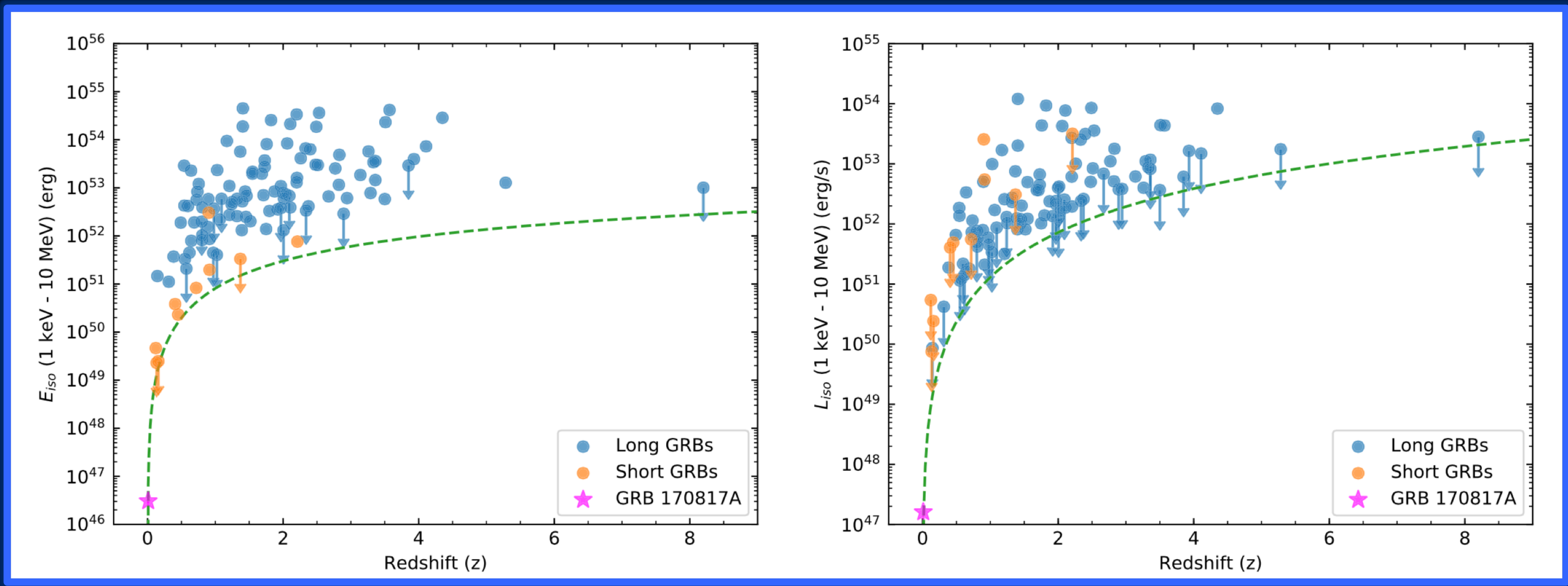
GW 170817 - detections



Abbott et al (very, very et al), 2017,
ApJL 848, L12

GRB 170817A

- 100 times closer than typical GRBs observed by Fermi-GBM
- it is also "subluminous" compared to the population of long/short GRBs
- $10^2 - 10^6$ less energetic than other short GRBs

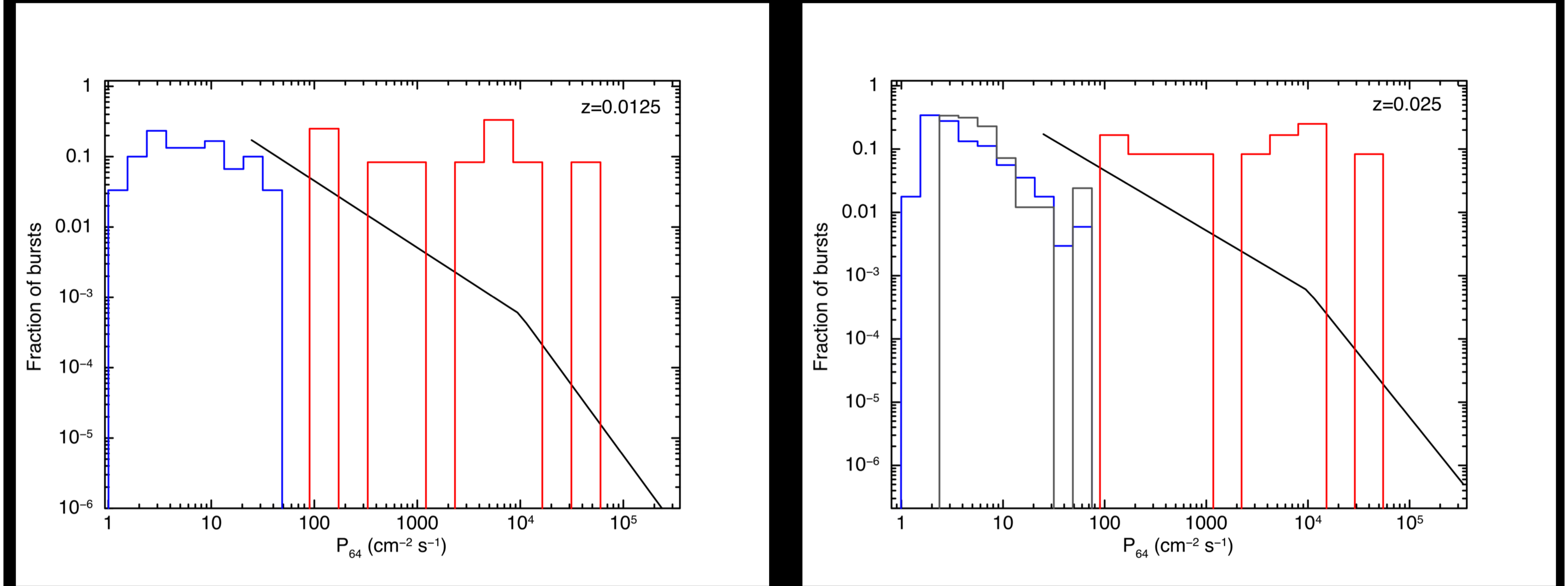


Abbott et al. 2017, APJL, 848, L13

Intrinsecally sub-luminous event

or a classical short GRBs viewed off-axis?

A GRB prediction



GRB flux distributions

Red: *Swift* short GRBs with known z, scaled to 109 Mpc

Blue (left): *Swift* short GRBs without z.

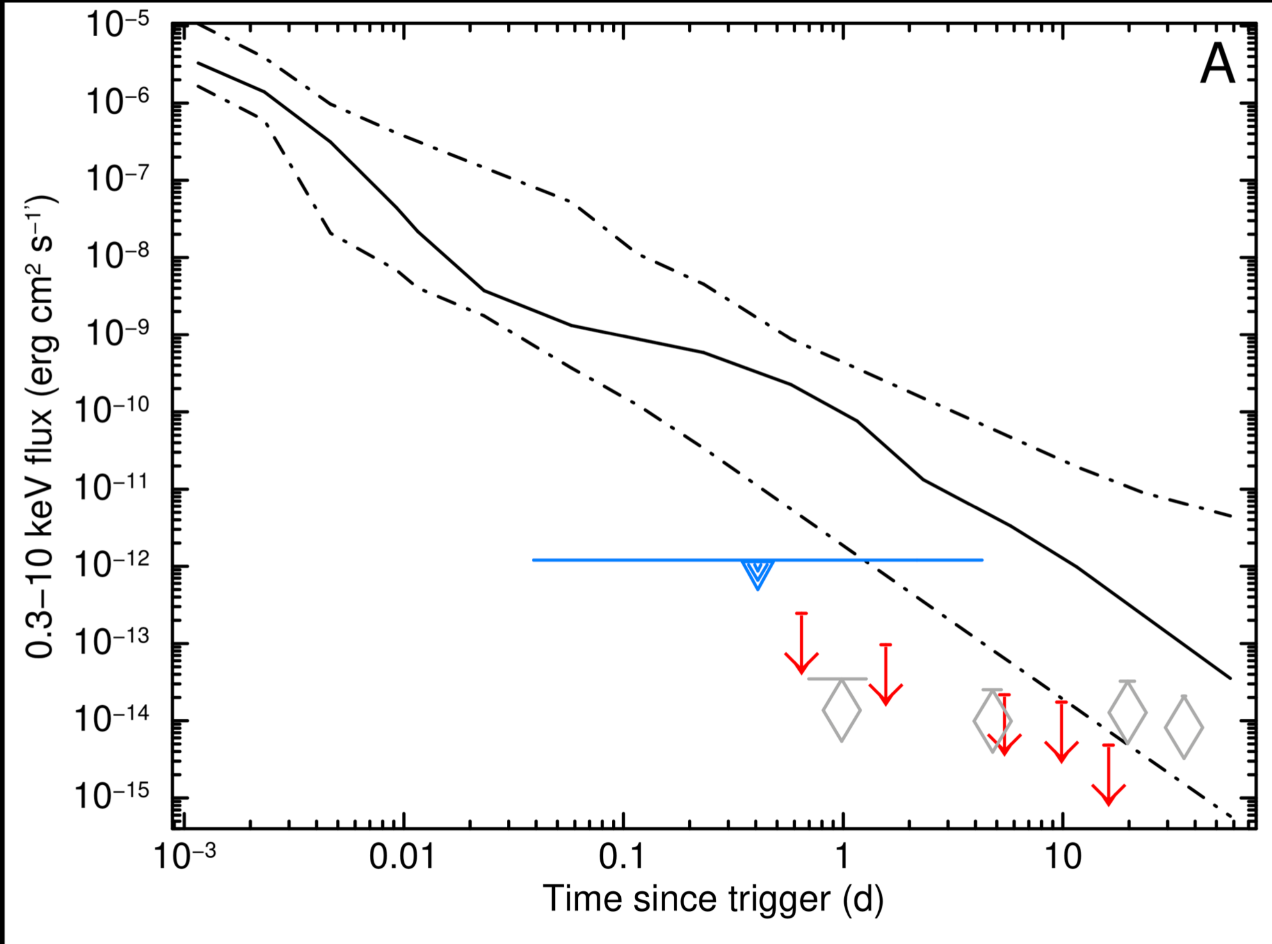
Blue (right): BATSE short GRBs

Grey (right): GBM short GRBs.

Evans et al. 2016a, MNRAS, 455, 1522

No early X-ray detection…

- GRB is very low luminosity ~3 orders of magnitude too low. (as predicted in Swift paper)
- There is no early detected X-ray afterglow.

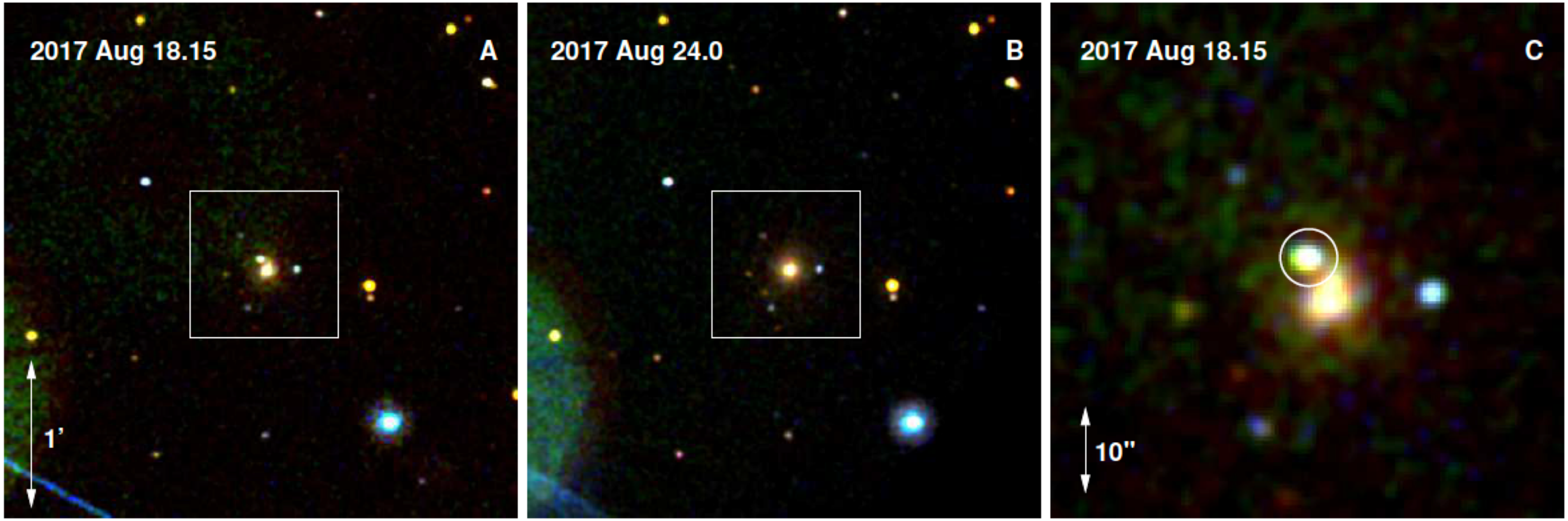


- This is in **flux**.
- Median sGRB z=0.72.
- GW 170817 ~ 40Mpc

i.e. GW170817 should be ~12,000 times brighter than normal!

Evans et al., 2017
Science, 358, 1565

Swift UVOT detection

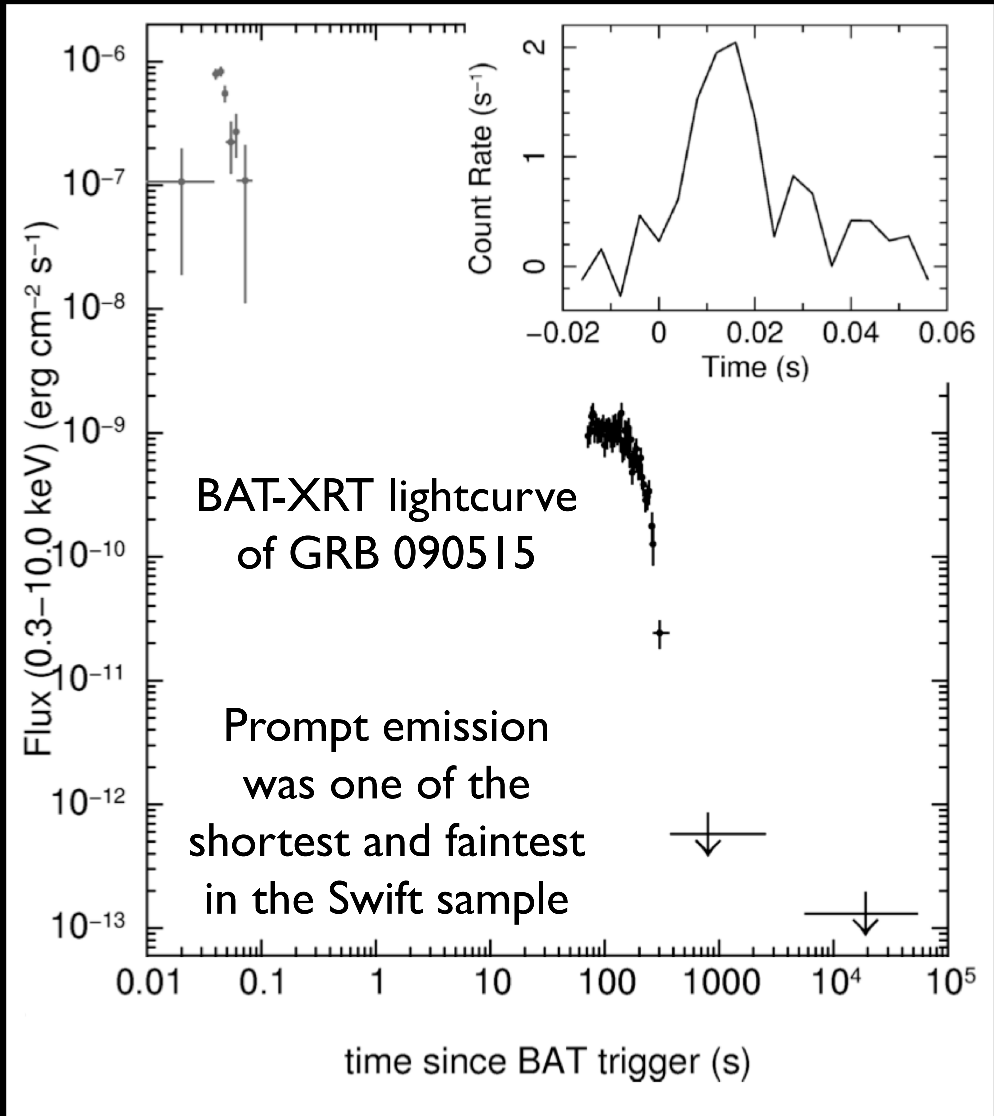


3-colour UV images

Evans et al., *Science* 2017, 358 1565

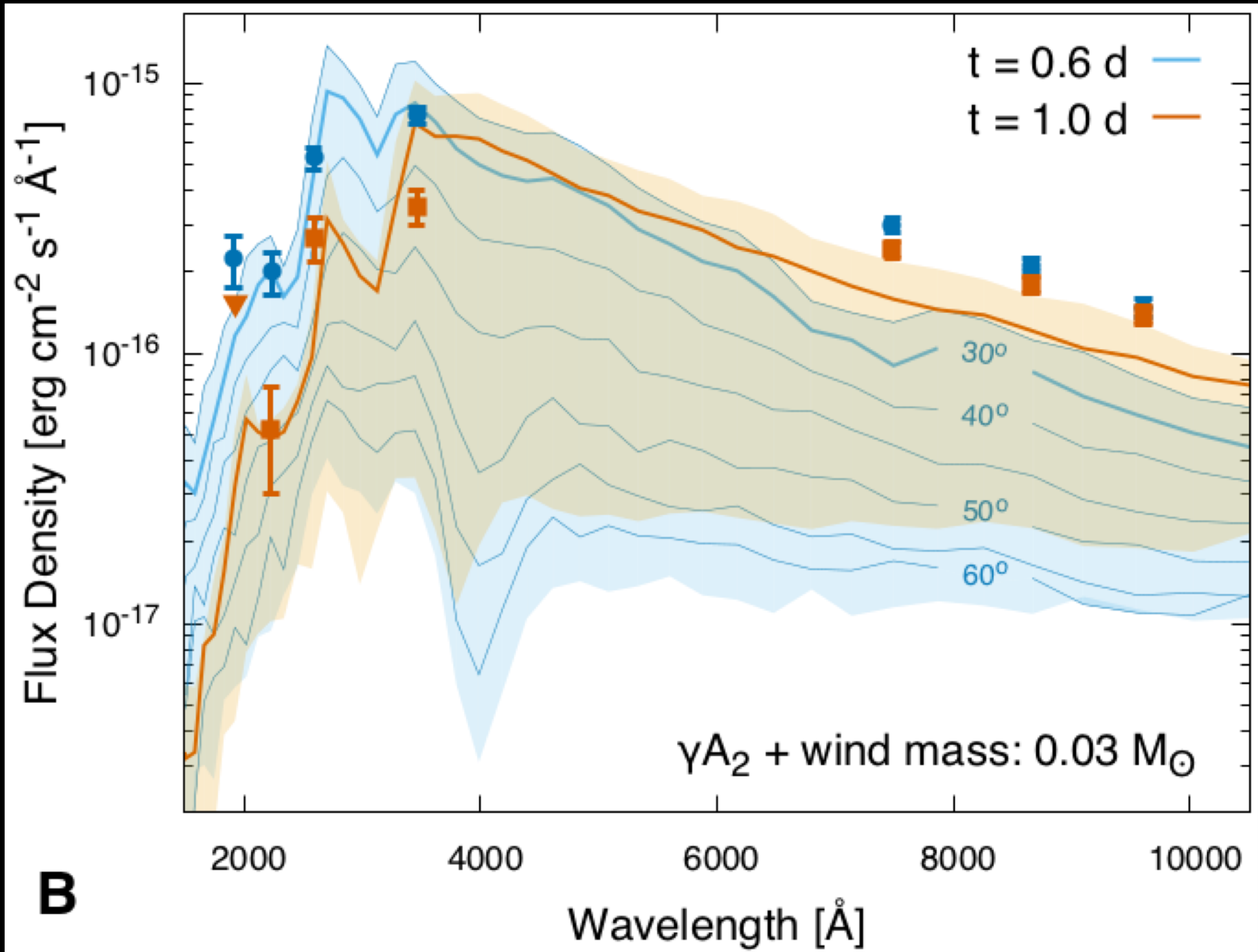
NB: No X-ray detection!

NB in passing…odd short GRBs



Rowlinson et al. (2010b) - but this GRB has no early UV

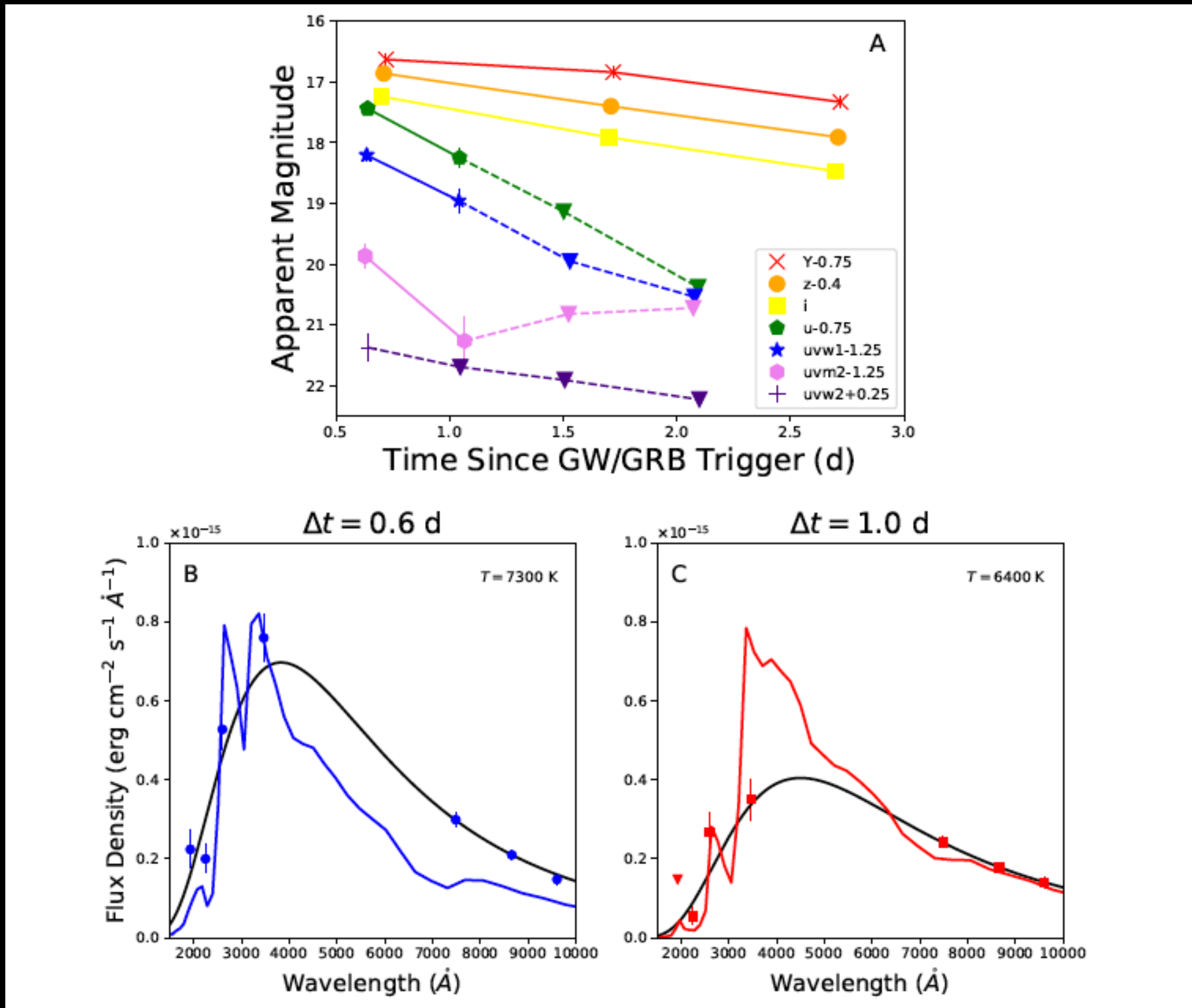
Swift results – neutrino irradiated wind



Evans et al., *Science* 2017, 358 1565

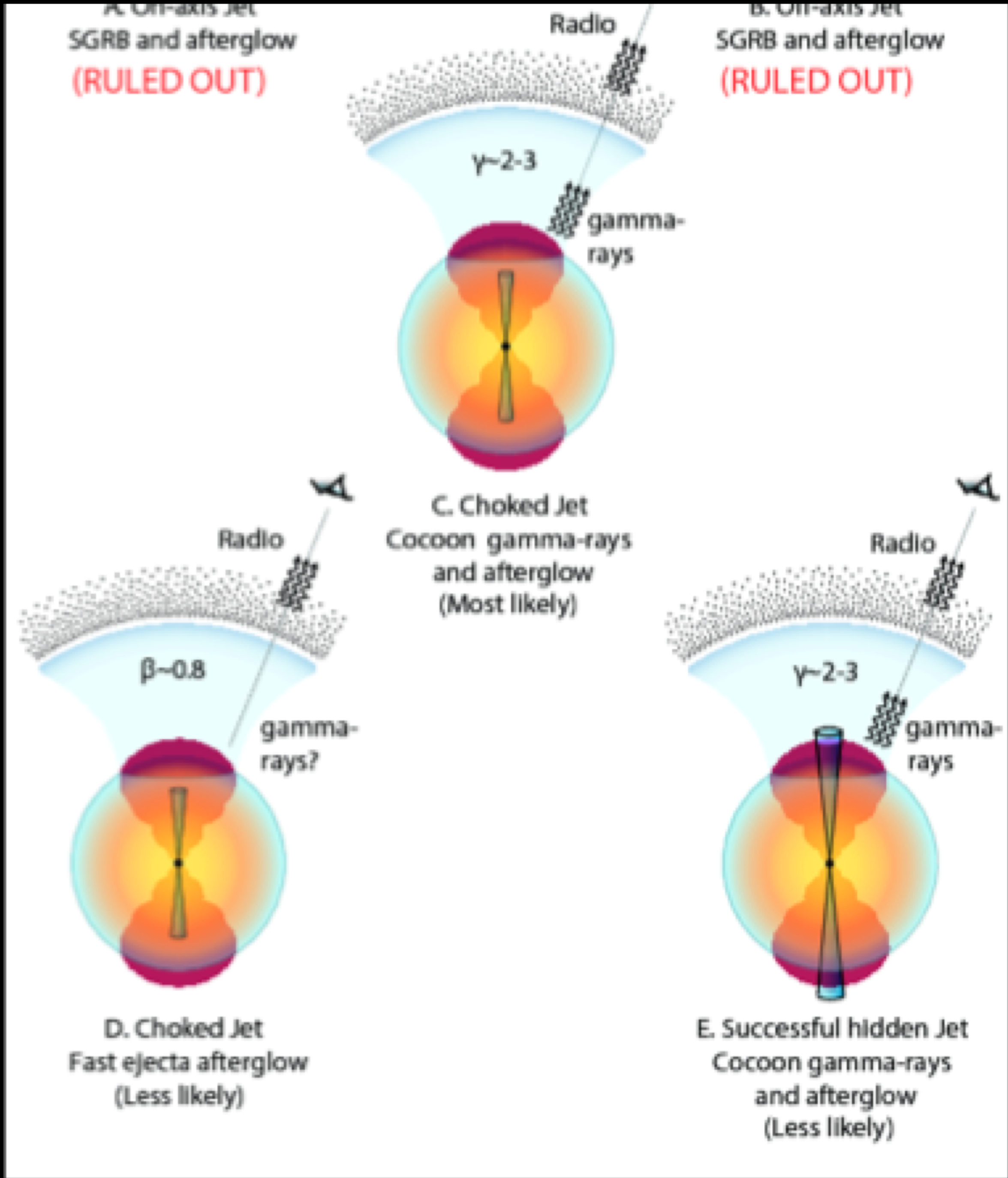
Can fit with wind with a modest electron fraction, but would underpredict optical

Cooling wind?



Evans et al., *Science* 2017, 358 1565

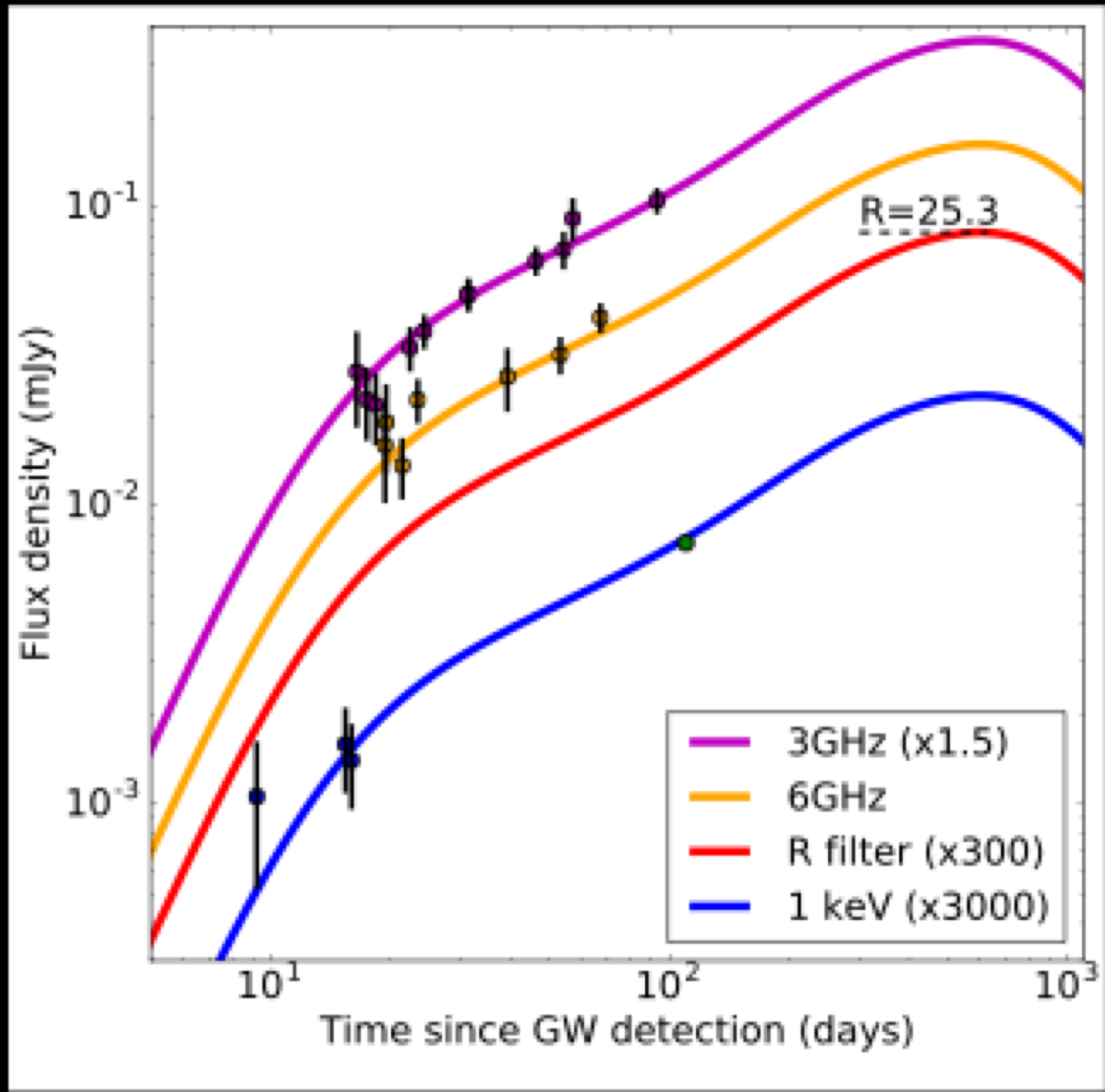
Coalescence of neutron star binary



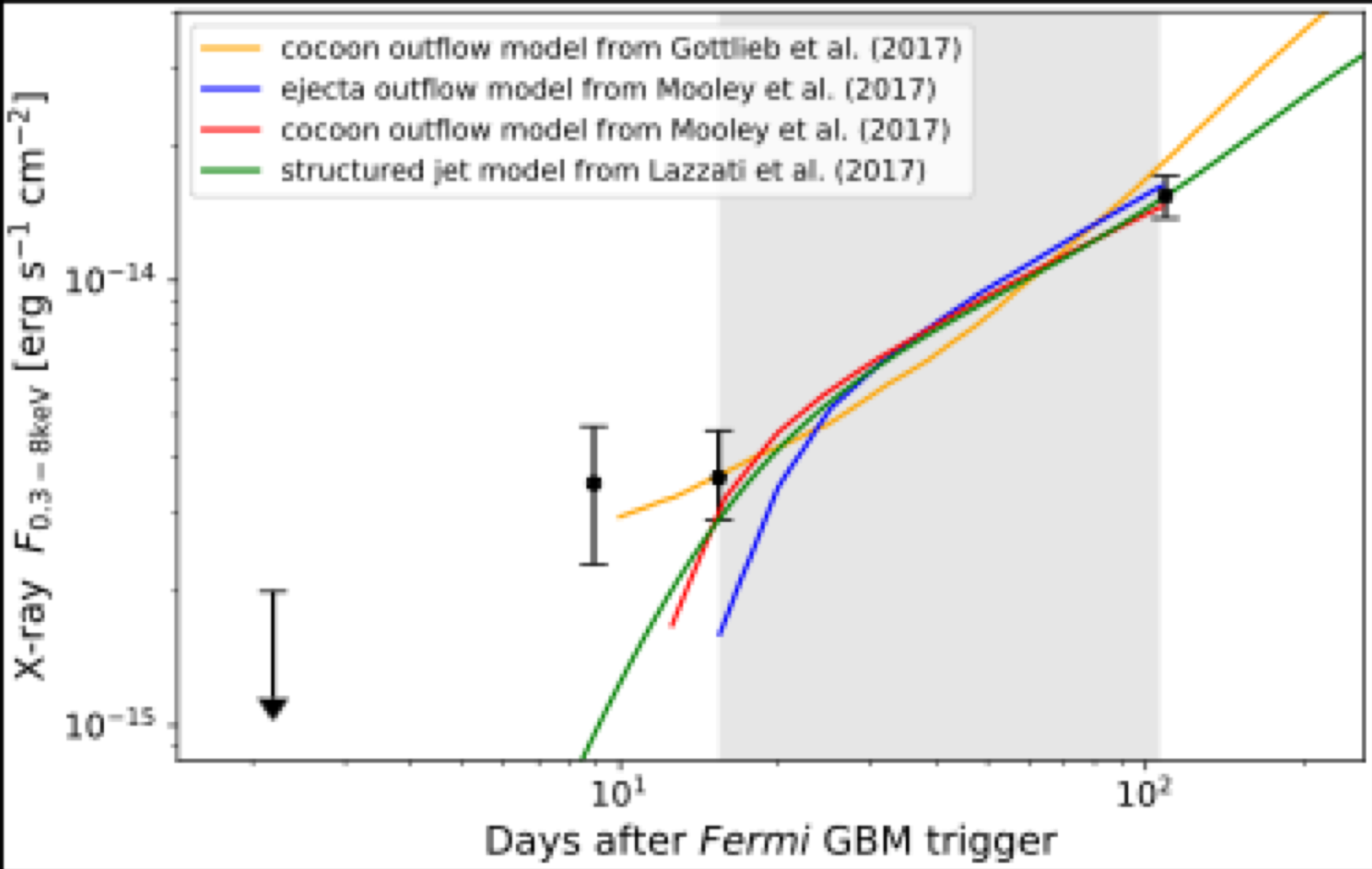
Mooley et al., 2018
arXiv 1711.11573

Alternatively: a structured jet

- Lazzati et al (arXiv: 1712.03237) instead show that a ‘structured jet’, where the velocity is a function of angle from the jet axis (as opposed to the classical ‘top-hat’ jet) can explain the multi-wavelength observations.



Late-time X-ray data…oh.



Ruan et al., 2018, ApJL, in press

Even later time…

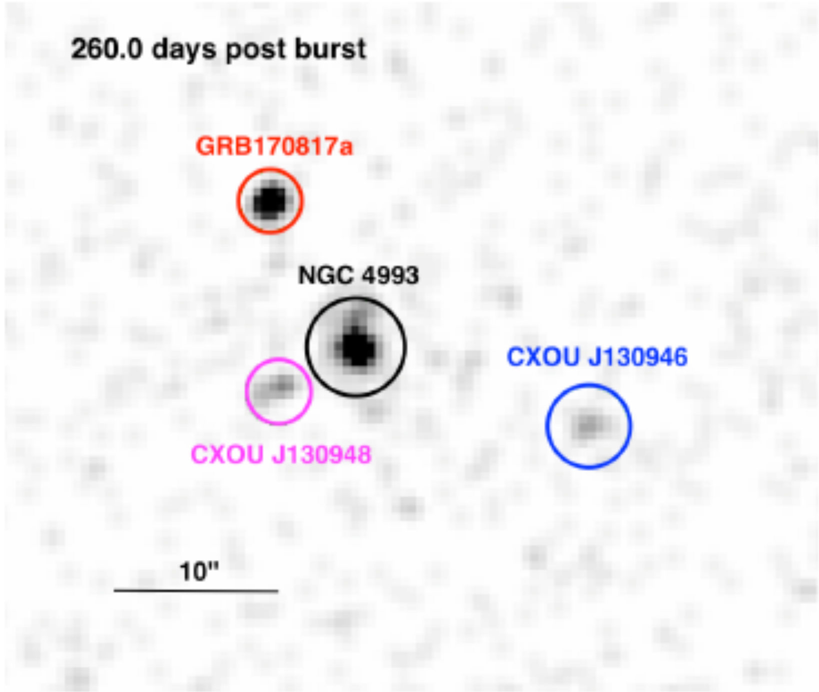
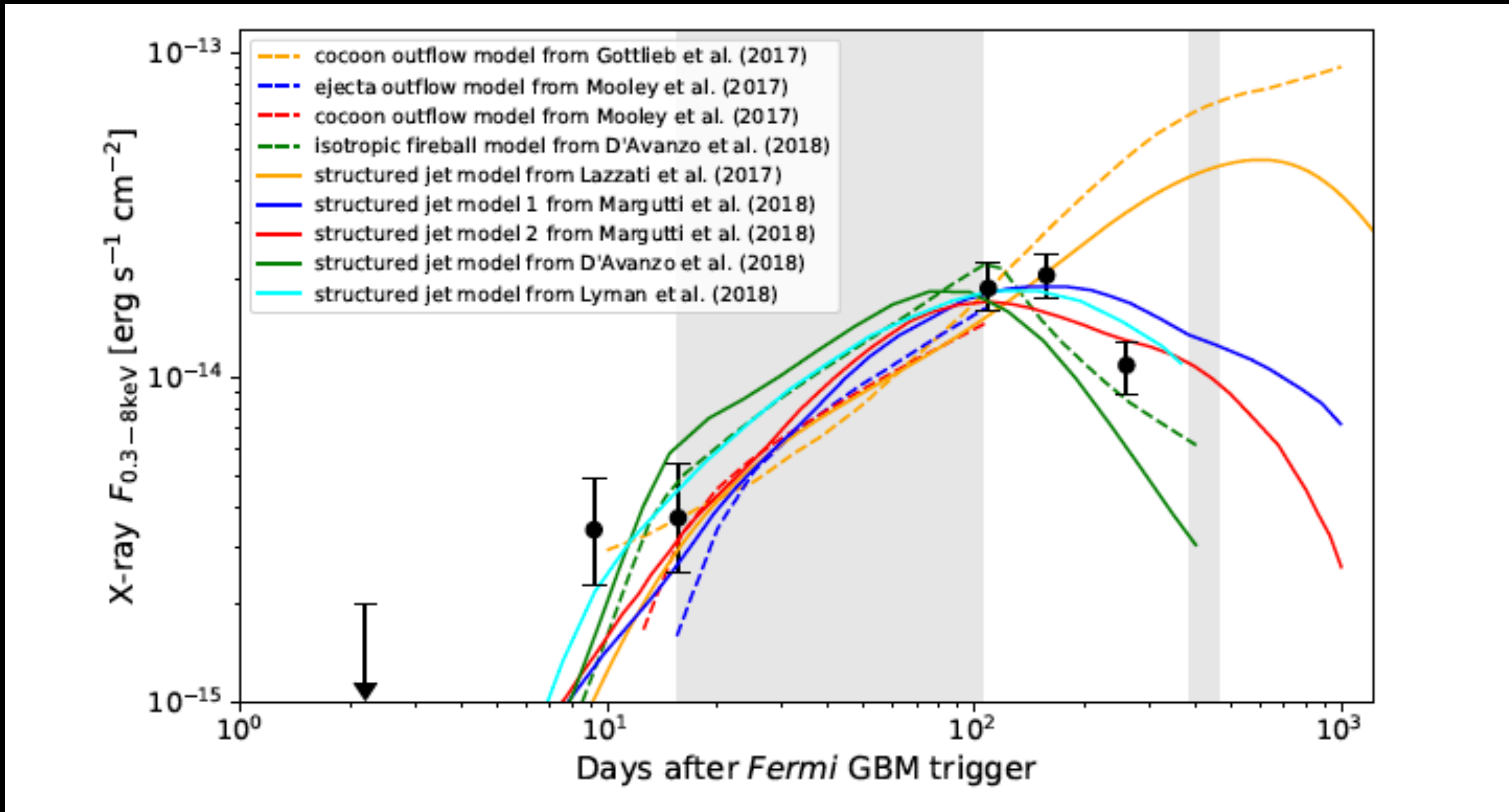


Figure 1. The latest *Chandra* 0.5 – 8.0 keV X-ray image of GRB170817A at 260 days post-merger, in a 96.8 ks total observation. The X-ray afterglow of GW170817/GRB170817A is still clearly detected, along with X-ray emission from the host galaxy (NGC 4993) and two other previously-detected sources in the field. This image is shown on a linear scale, and has been smoothed with a 2-pixel Gaussian kernel.

Nynka, Ruan, Haggard, 2018, submitted
(shows challenge for relatively poor PSF instruments if source weak)

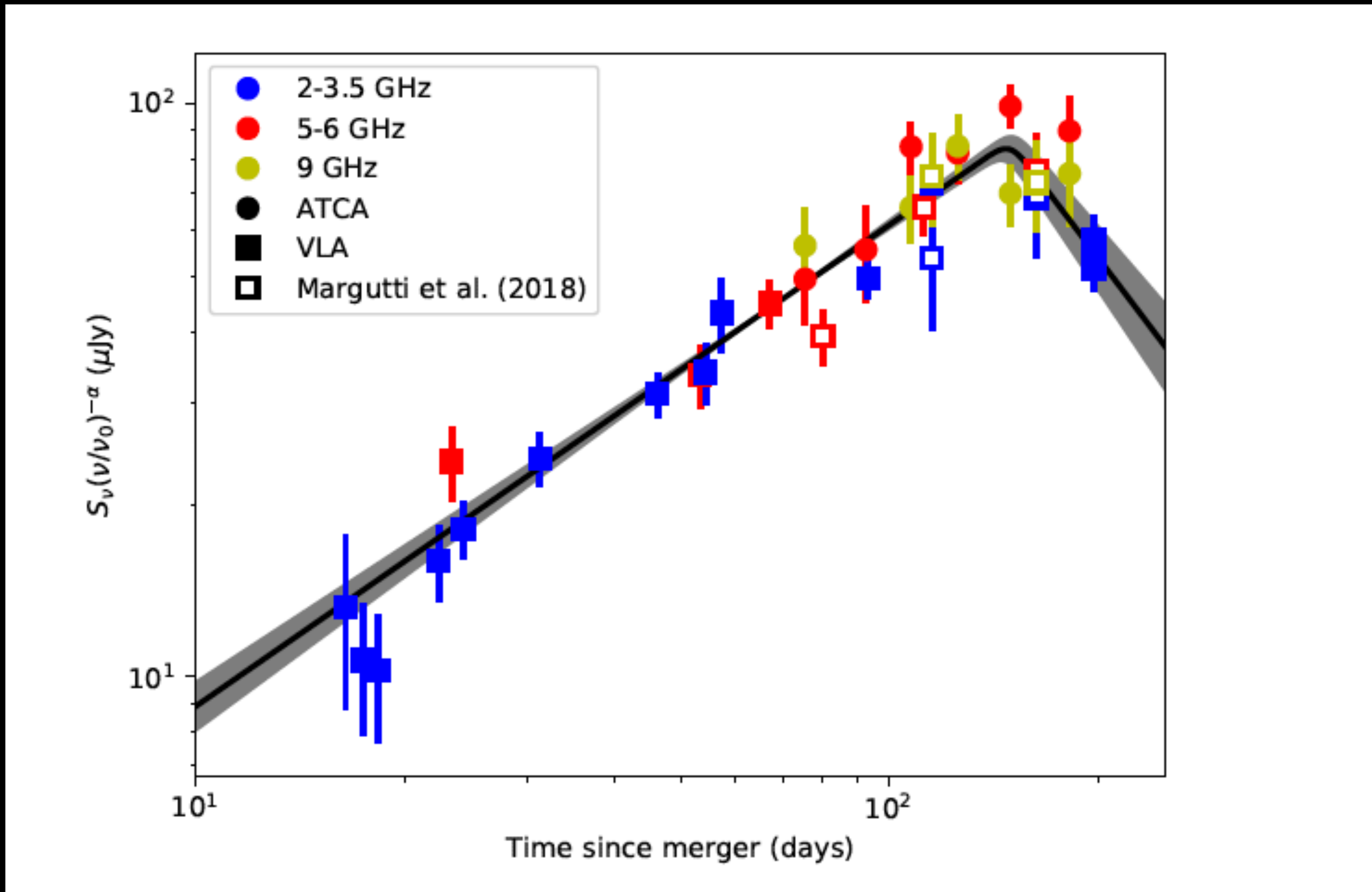
Still can't tell…



Nynka, Ruan, Haggard, 2018, submitted

"These observations remain consistent with synchrotron afterglow emission from either a quasi-spherical mildly-relativistic outflow that is now decelerating, or a off-axis structured successful jet in which emission from the jet core has already entered the line of sight."

Nor from radio…



Dobbie et al., 2018, submitted

"…we cannot distinguish between a lower-energy jet and more isotropic emission."

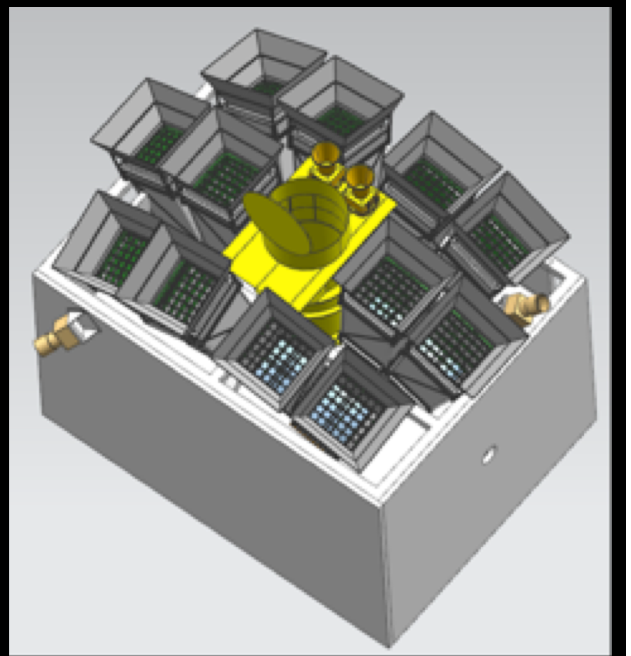
Evolving Swift strategy

- Take account of UV detection
- UVOT FoV too small to tile entire probability region in a reasonable time. Still use XRT pointings, but may try to ensure any 'nearby' galaxy within tile is in the UVOT FoV
- Debating which UVOT filter to use (UV or U). [I'd prefer UV as unique data, but is less sensitive)
- Also need a filter which can maximise contrast between counterpart and host (UV?)

Future for high-energy transients

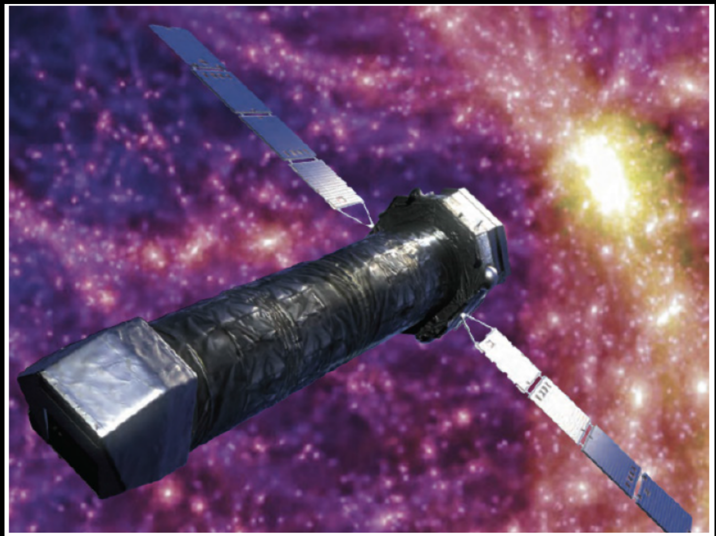
- SVOM can do a great job on large area GW EM searches
  - ECLAIRS has a 6400 sq deg FOV

- The Chinese Einstein Probe will in orbit at the same time as SVOM
  - 3600 square degrees at ~7 cm^2 effective area
  - Wide-field X-ray focussing optics
  - High sensitivity in soft X-rays

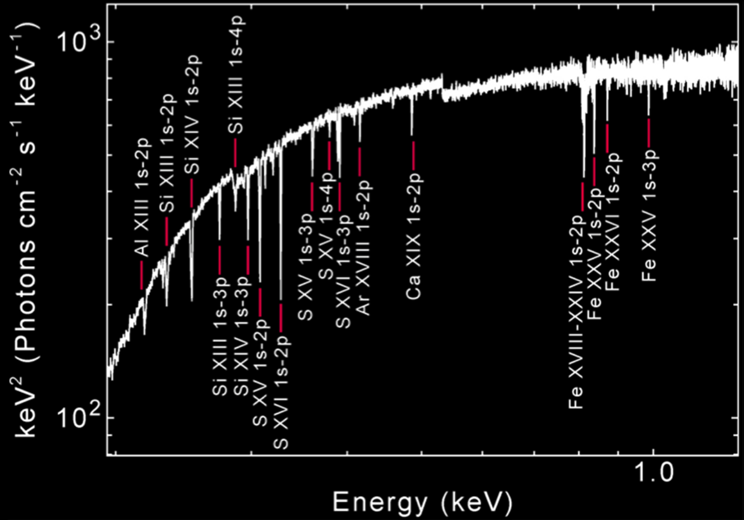


Future for high-energy transients

- ESA large X-ray mission Athena due for launch in 2028-30
  - Extraordinary spectral sensitivity

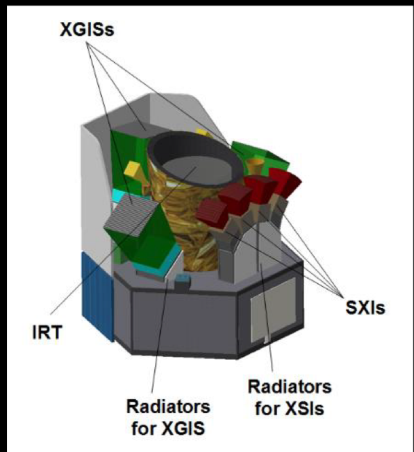


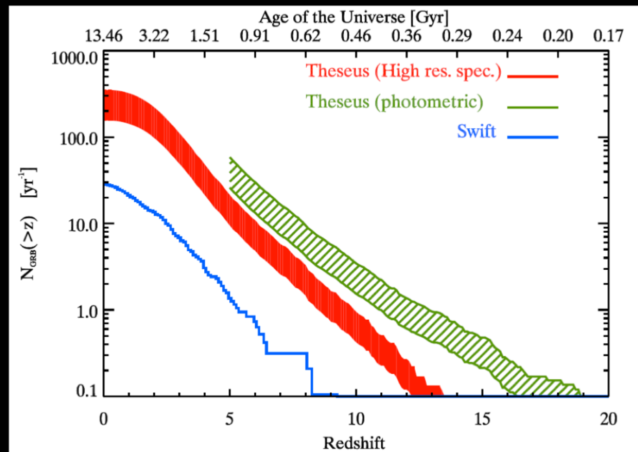
Gamma Ray Burst at z=7 by ATHENA-XIFU



Jonker, O'Brien et al., 2013 arXiv1306.2336

- THESEUS proposed to ESA
  - Selected for Phase A
  - Launch would be 2030s





Stratta et al., 2018 submitted