Search for X-ray Counterparts of Gravitational Wave Events

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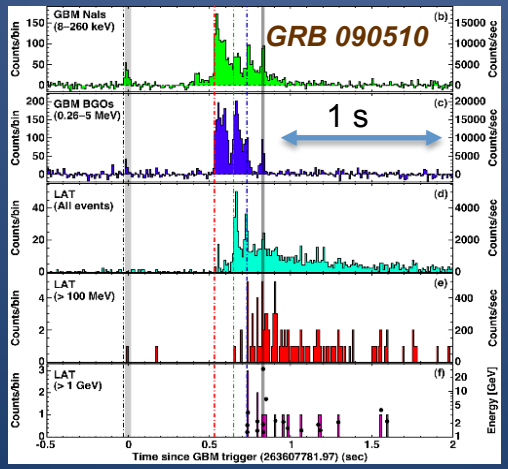
on behalf of the MAXI Team

- Introduction: X-ray counterparts
- Observations for GW 150914 and results in context
- Observations for GW 151226

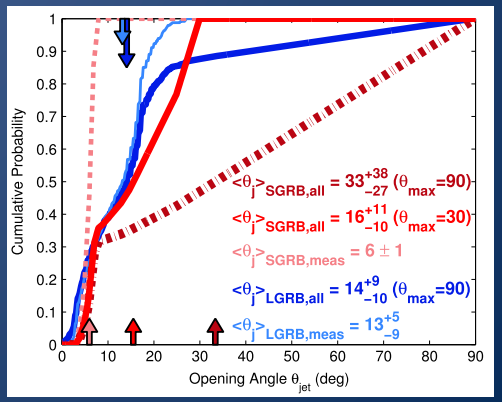
X-ray/γ-ray counterpart of GW

- Expected for NS-NS, NS-BH
  - not for BH-BH
- "Short GRB" has been the prime candidate for EM counterpart of promised GW source (i.e. DNS)
- But jet opening angle≈6–30°⇒ 4% seen on-axis


image credit: NASA

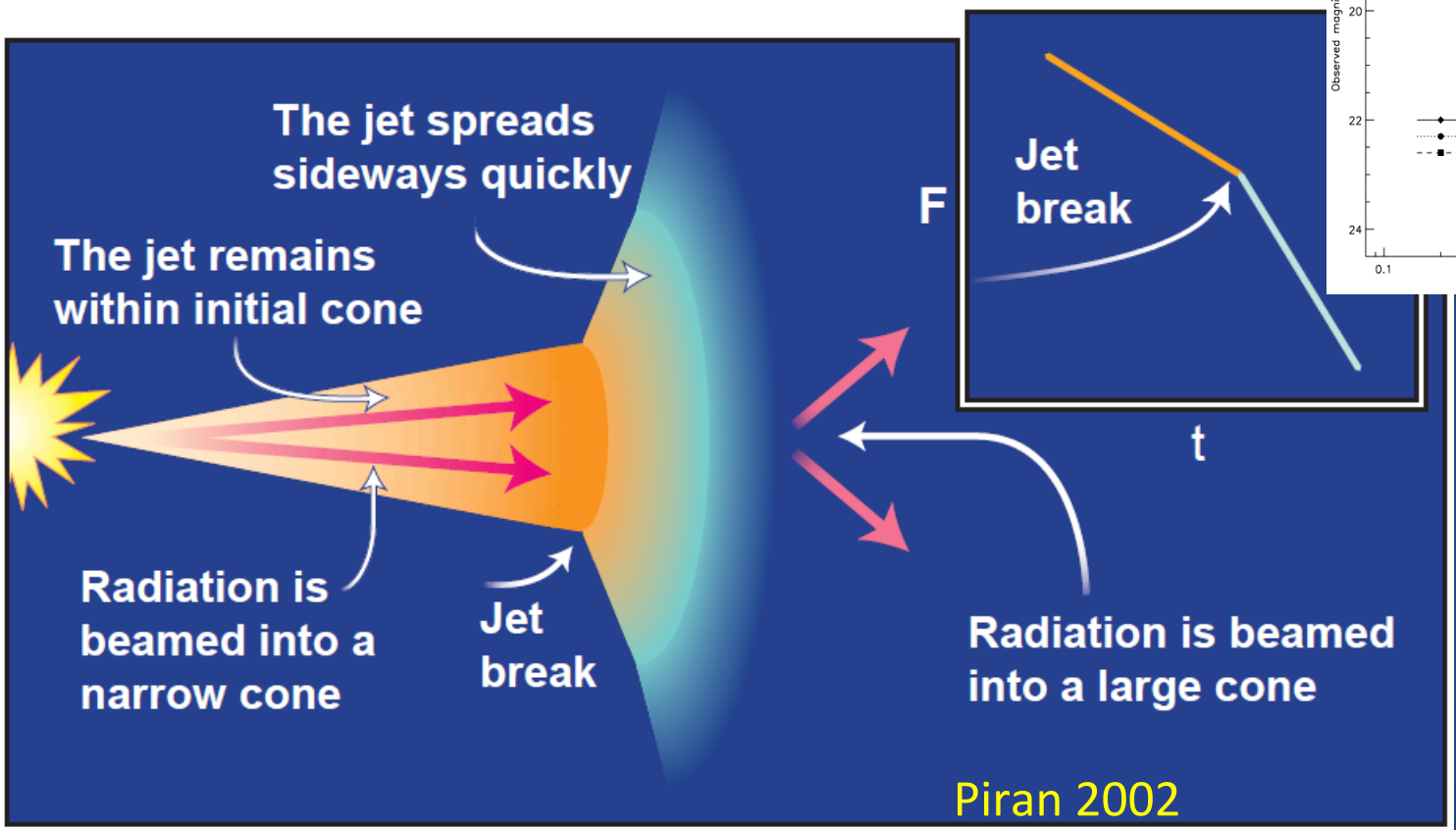


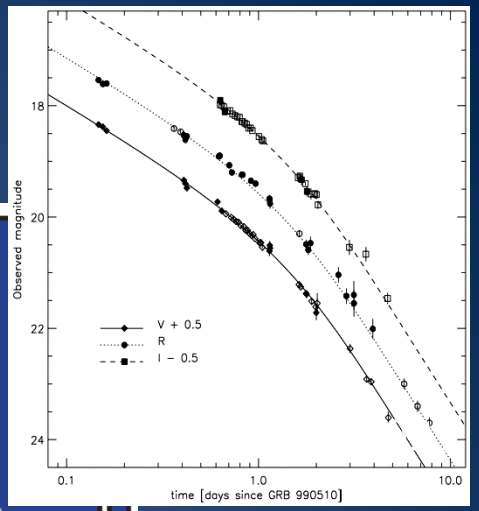
Abdo et al. 2009



Fong et al. 2015

“jet break”

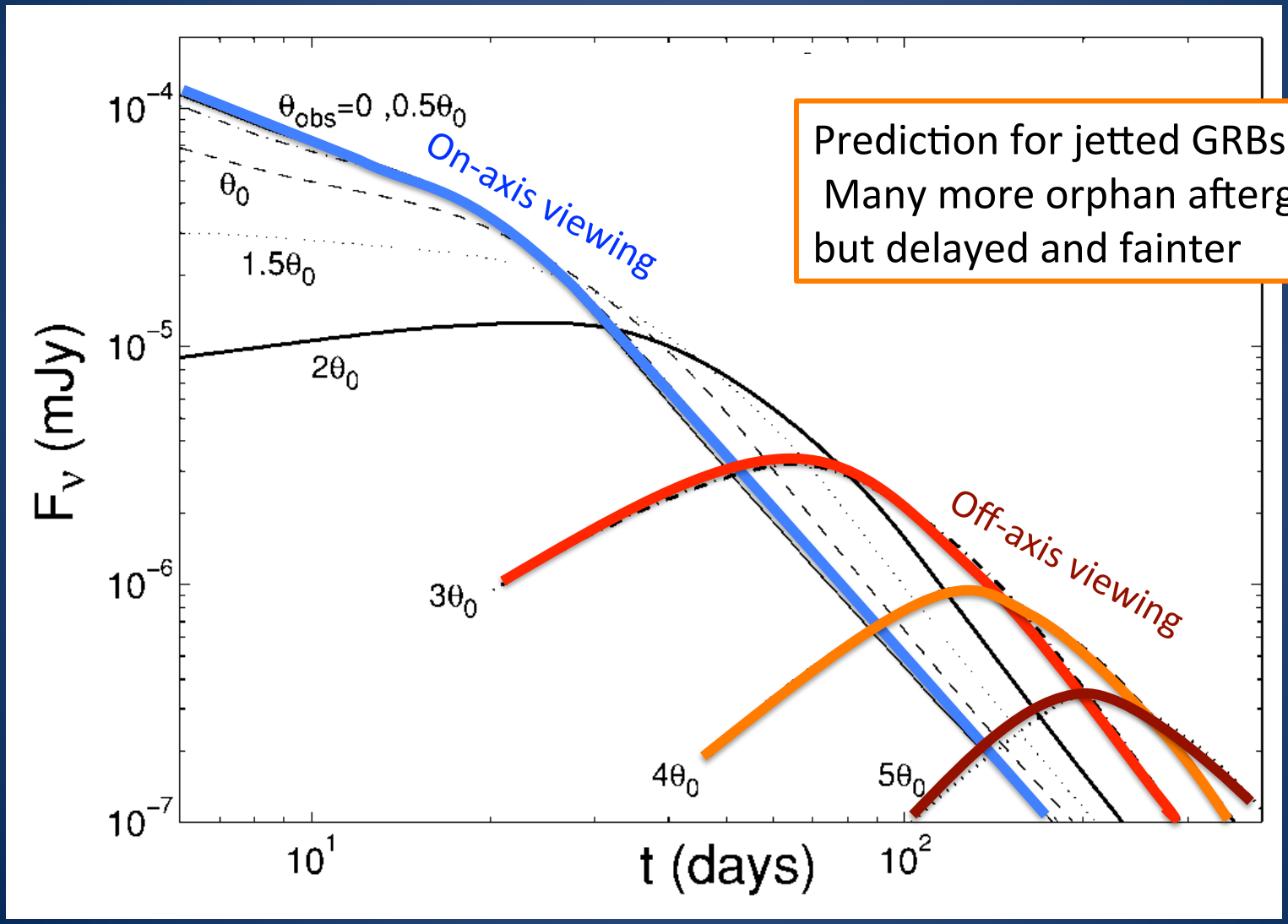




Beamed emission. A relativistic jet with a Lorentz factor γ and an opening angle θ moves forward until its Lorentz factor $\gamma = \theta^{-1}$. Then it expand sideways rapidly, resulting in a “jet break” in the light curve. A schematic light curve is depicted at the top right.

Orphan afterglow for off-axis GRBs

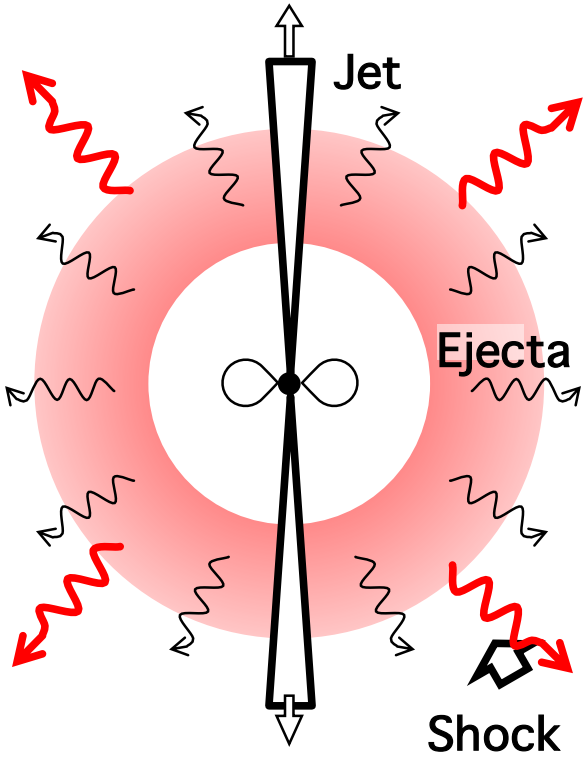
Granot et al. 2002



Prediction for jetted GRBs:
Many more orphan afterglows, but delayed and fainter

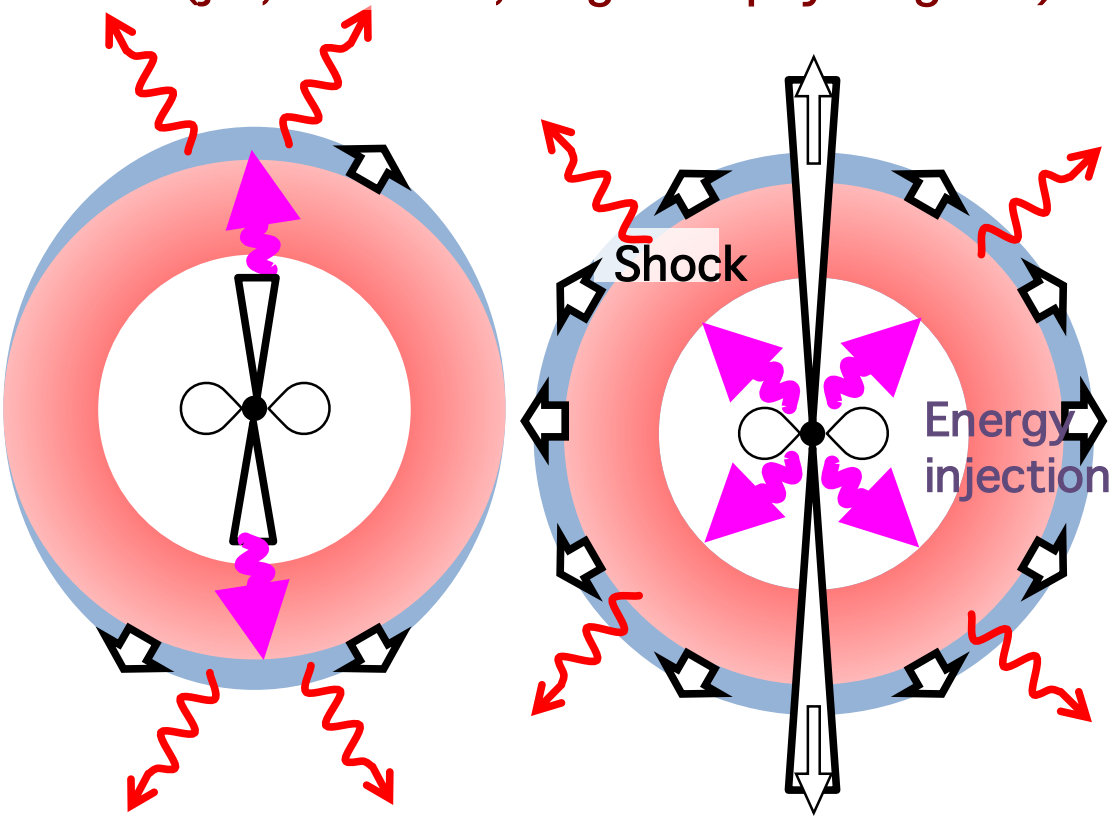
Possible soft X-ray production

Nuclear decay powered



Leaking thermal X-rays

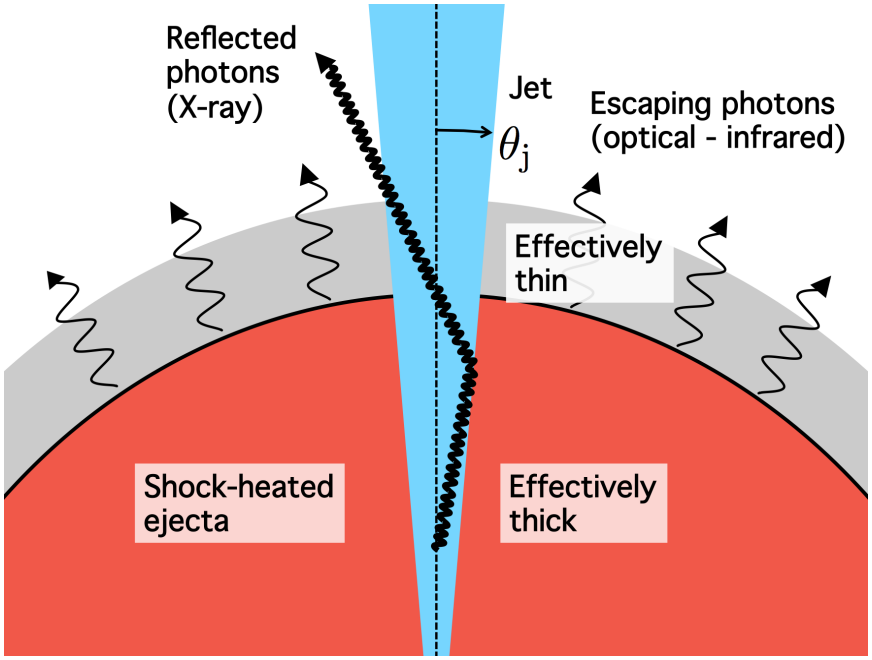
Engine powered
(jet, disk wind, magnetar poynting flux)

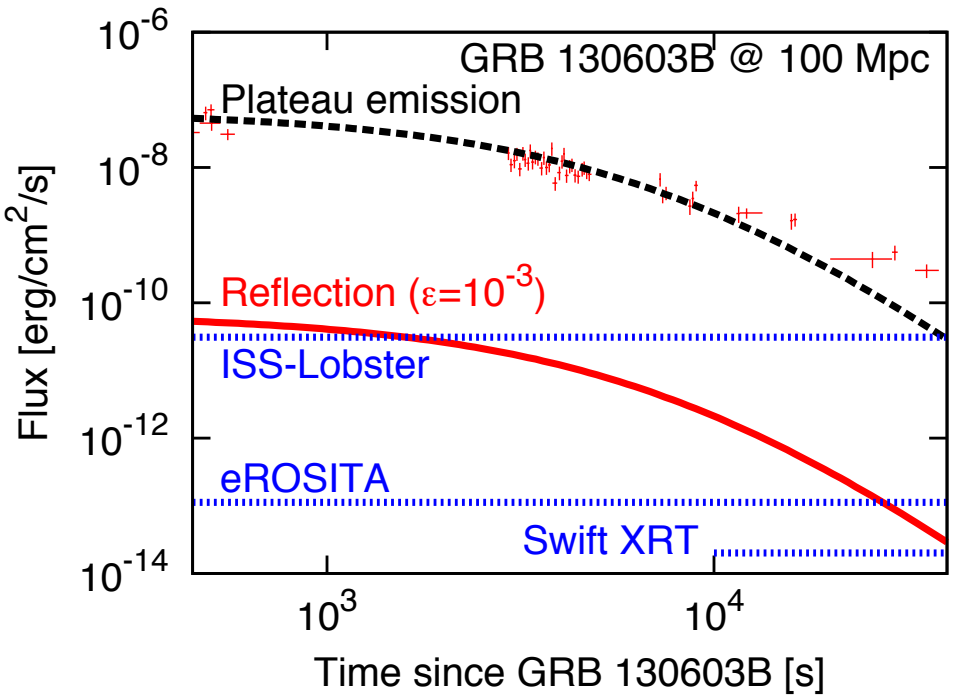


heated/shocked thermal X-rays

modified from Kisaka, Ioka & Takami 2015

Possible soft X-ray production





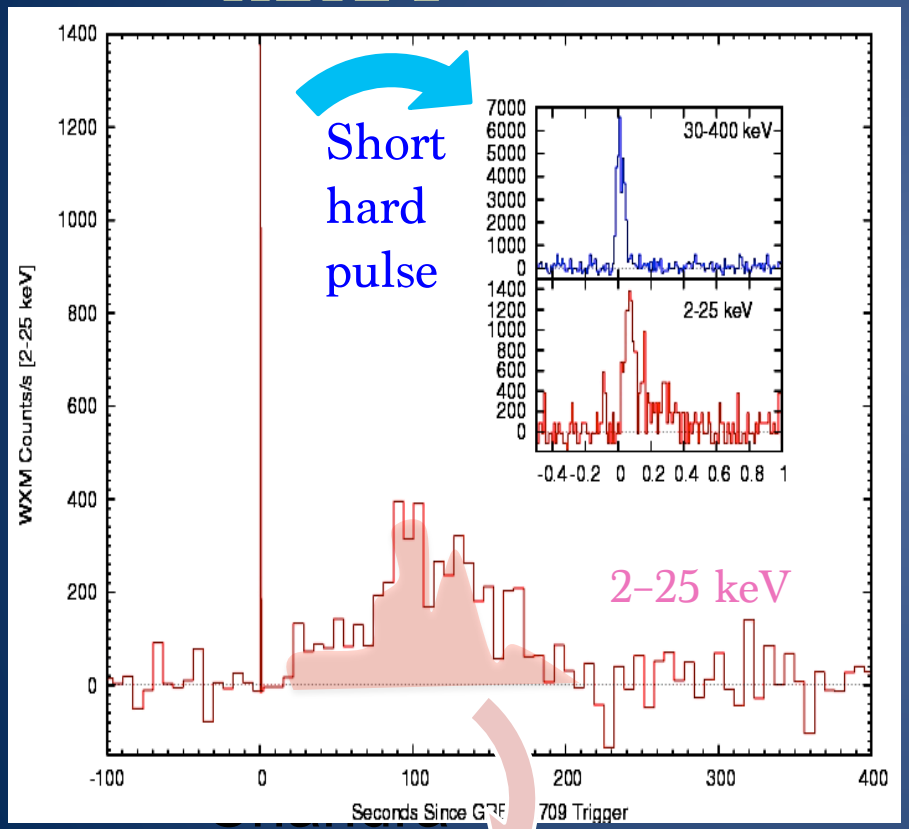
(scattered) plateau emission from jet

Kisaka, Ioka & Nakamura 2015

Short GRB 050709

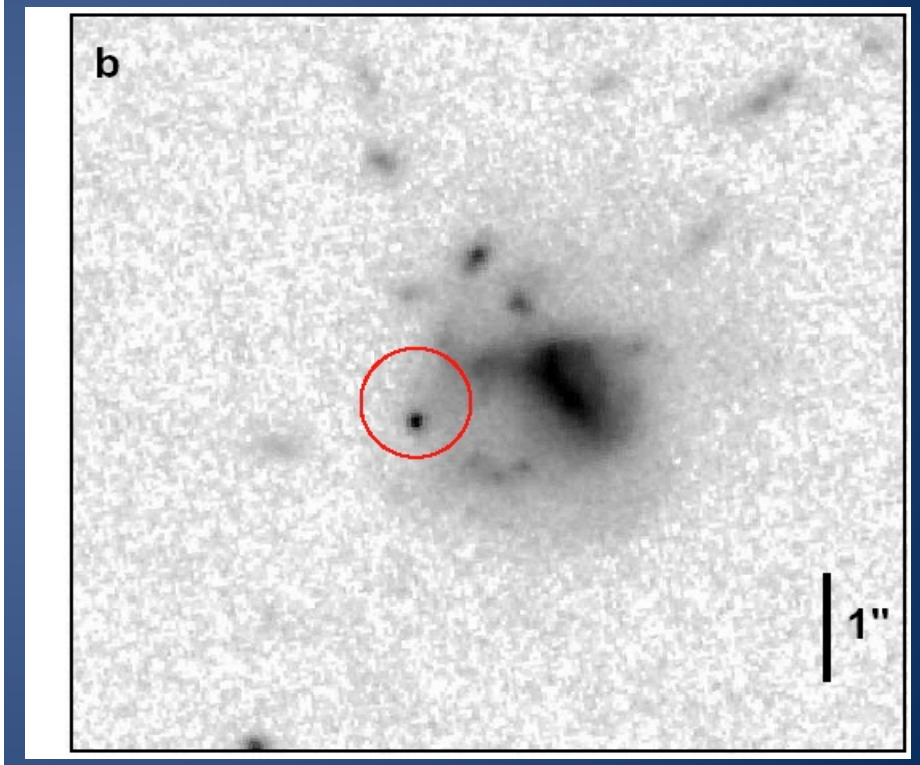
The only short GRB observed in soft X-ray

HETE-2 Villasenor et al. 2005



"Soft extended emission"

HST Fox et al. 2005

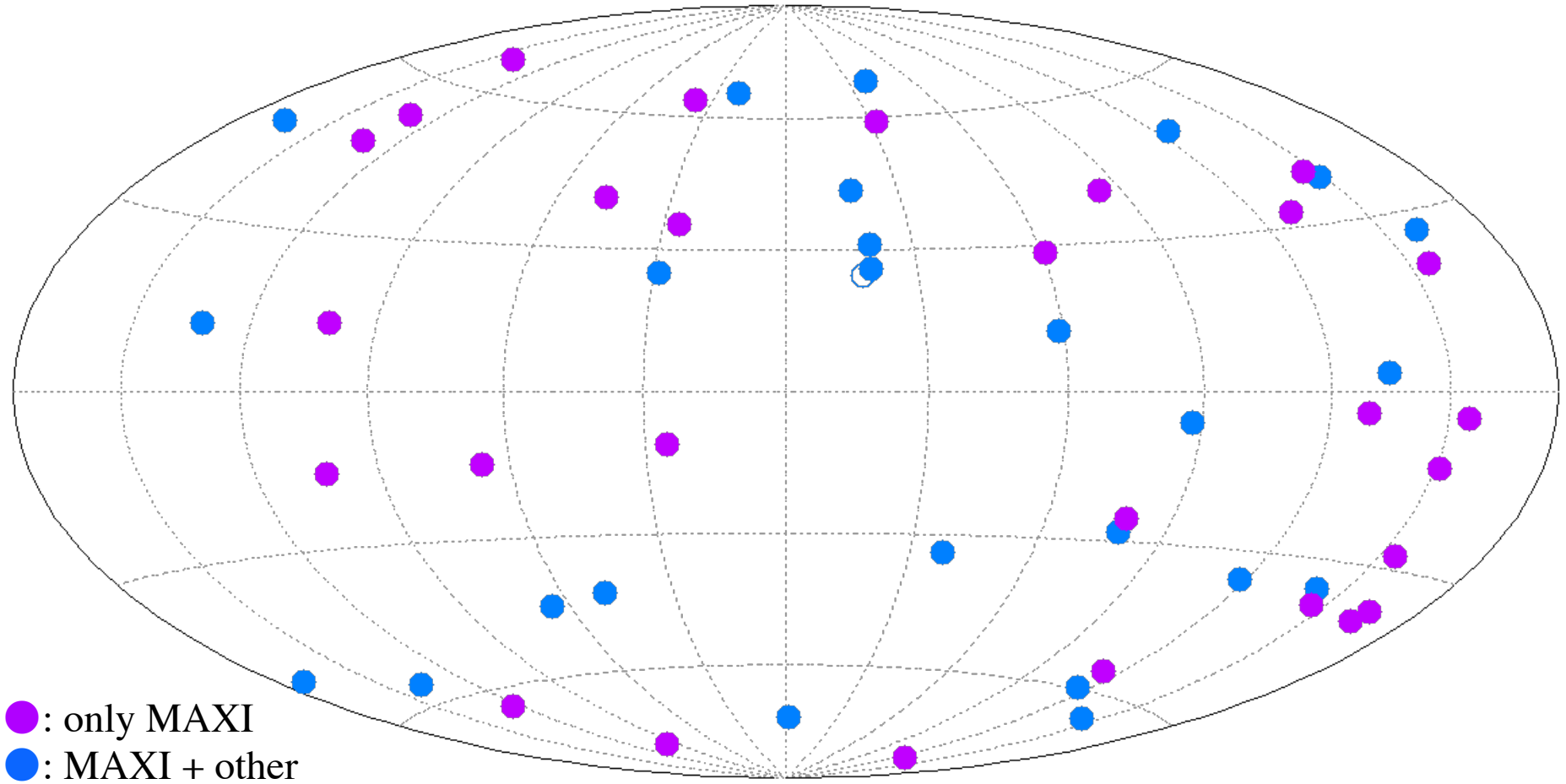


z=0.160

Dwarf irregular galaxy

SFR = 0.2 M_{sun}/yr

MAXI GRBs and short transients

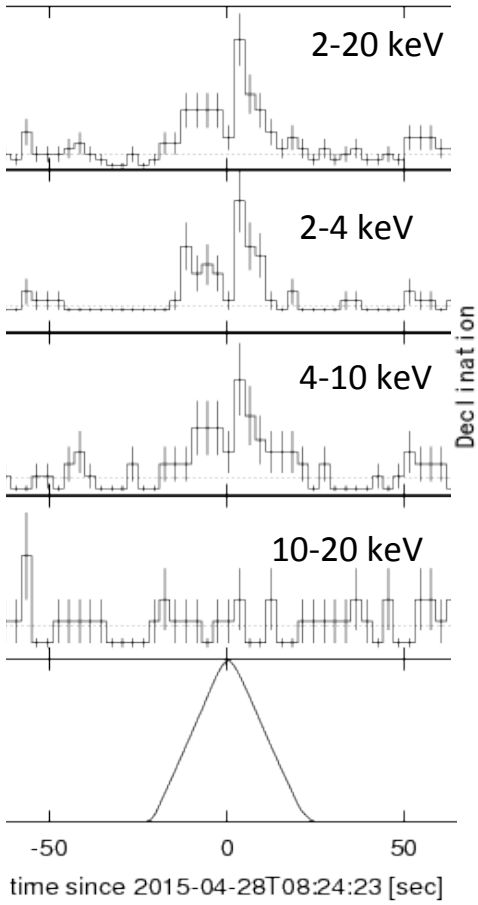


Serino et al. (2014)

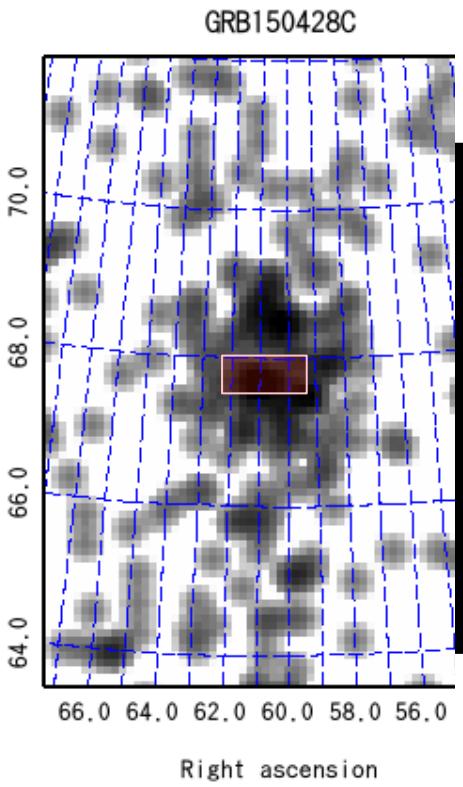
http://maxi.riken.jp/grbs/

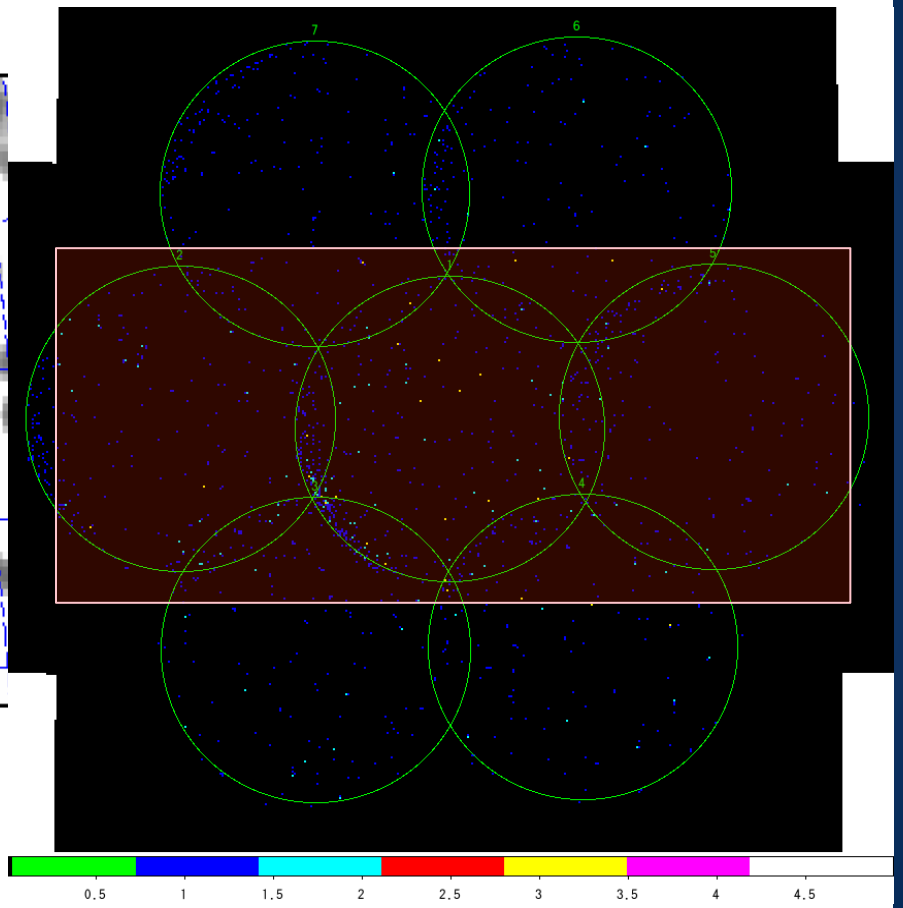
“MUSST”

GRB 150428C (l, b) = (139.1, +11.3)



Light curves : Not corrected for scan profile





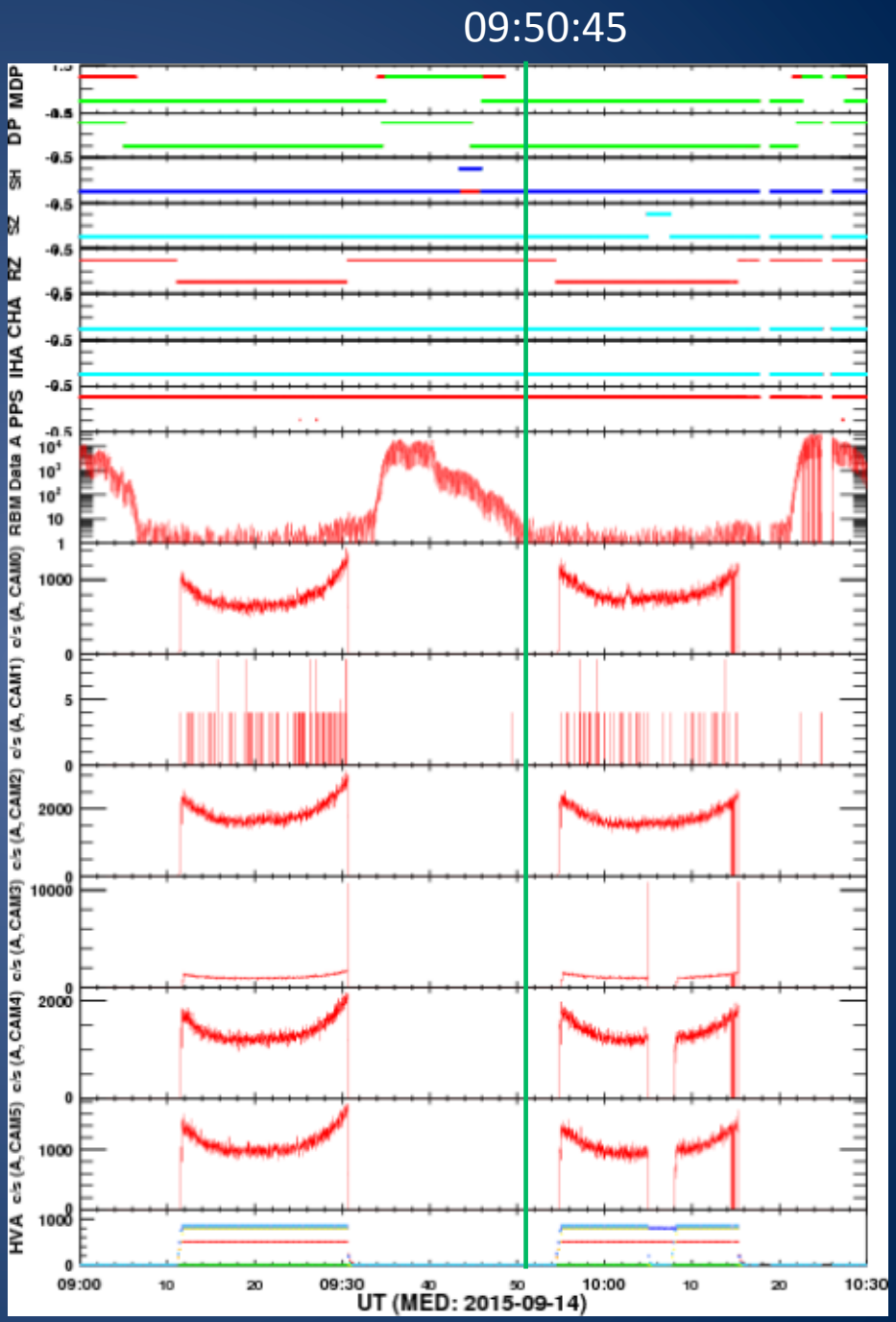
No afterglow fouund with Swift XRT follow-up

GCN #17772

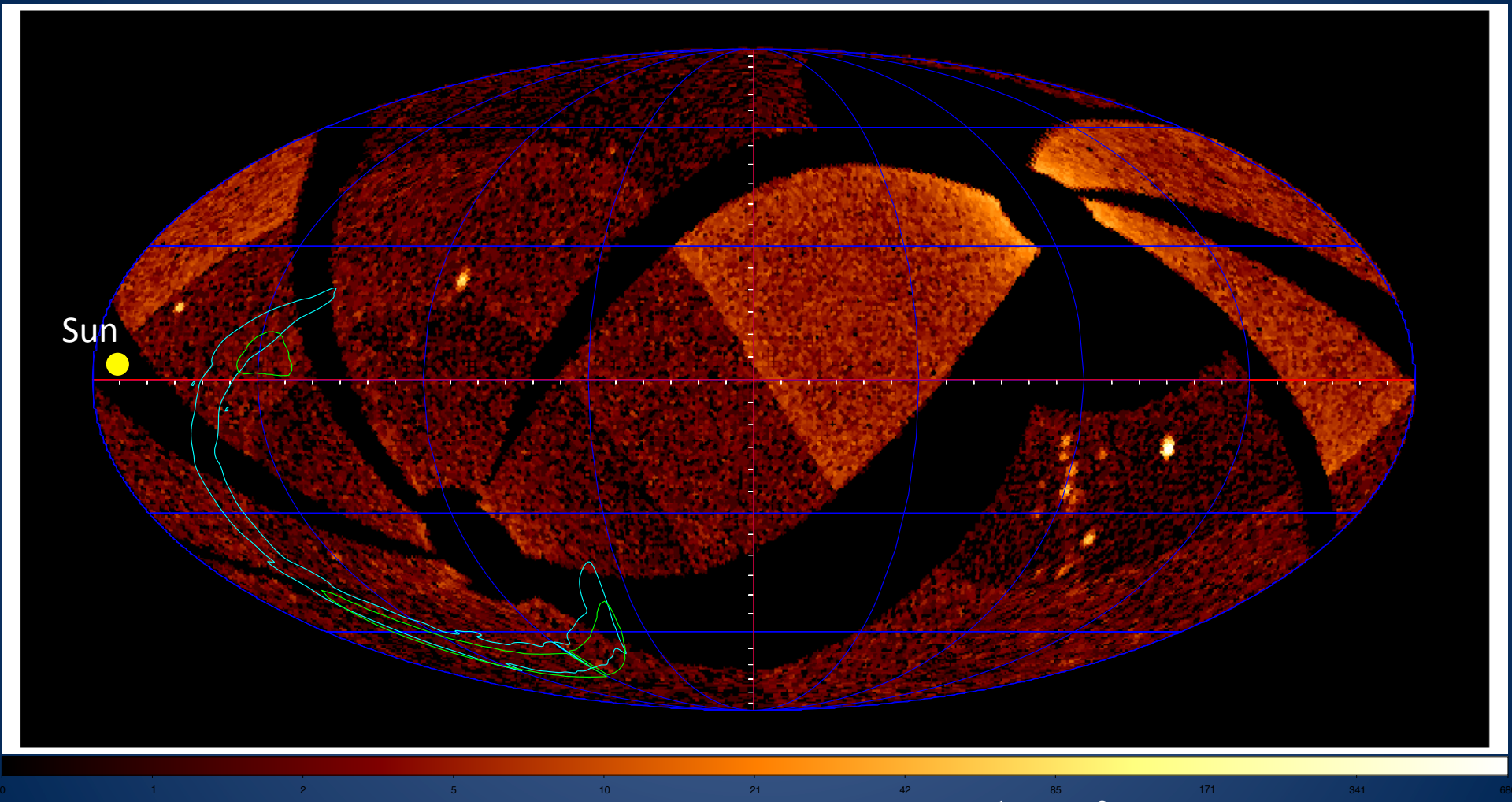
GW 150914

At 2015-09-14 9:50:45 the ISS was about to leave the region with a high particle flux

MAXI resumed observation 4 min later



GW150914 (T0+4~92 min)

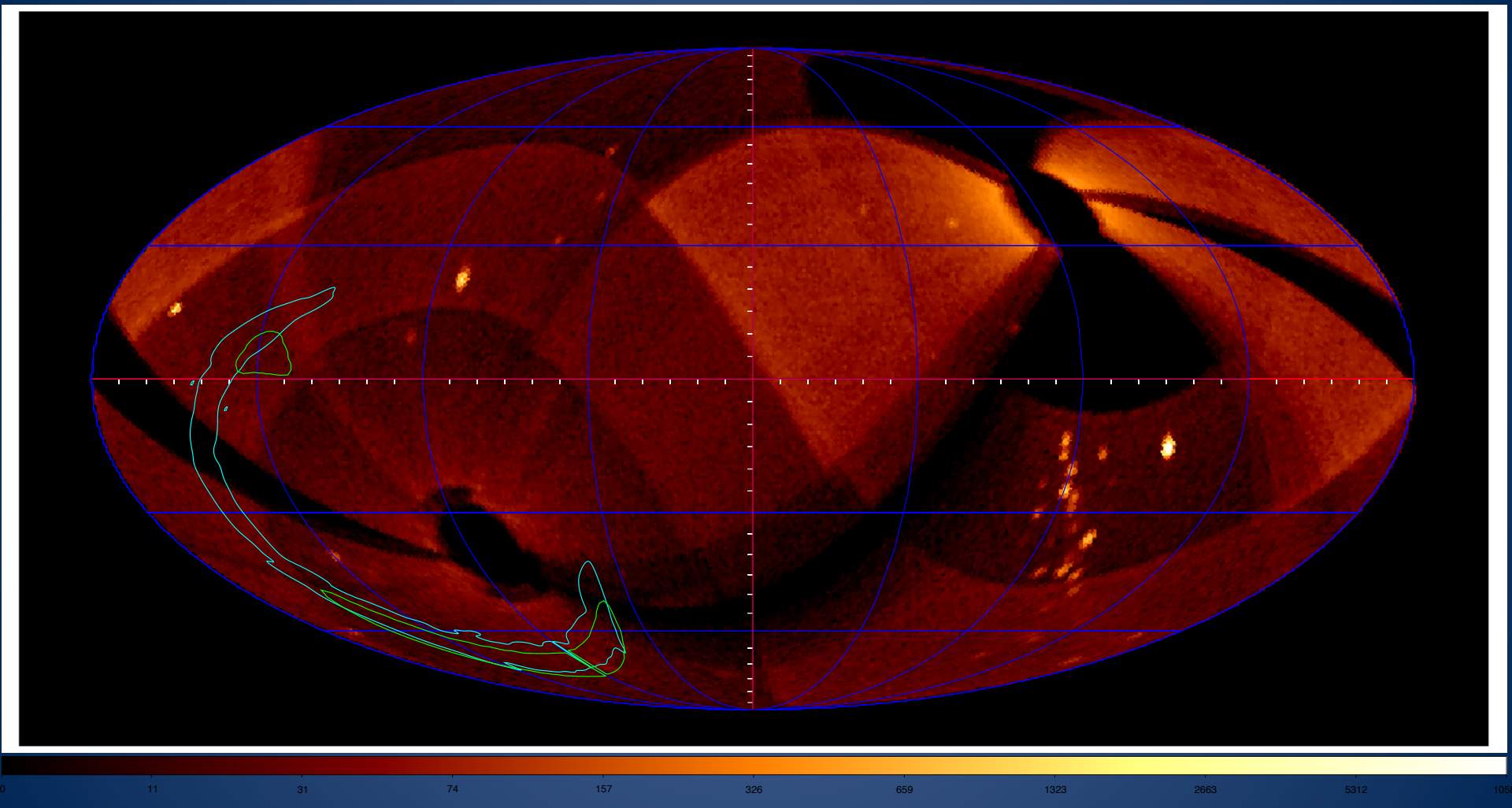


2-20 keV 3-σ upper limit: 0.1 counts s^{-1} cm^{-2} ≈ 30 mCrab

≈ 1×10^{-9} erg s^{-1} cm^{-2}

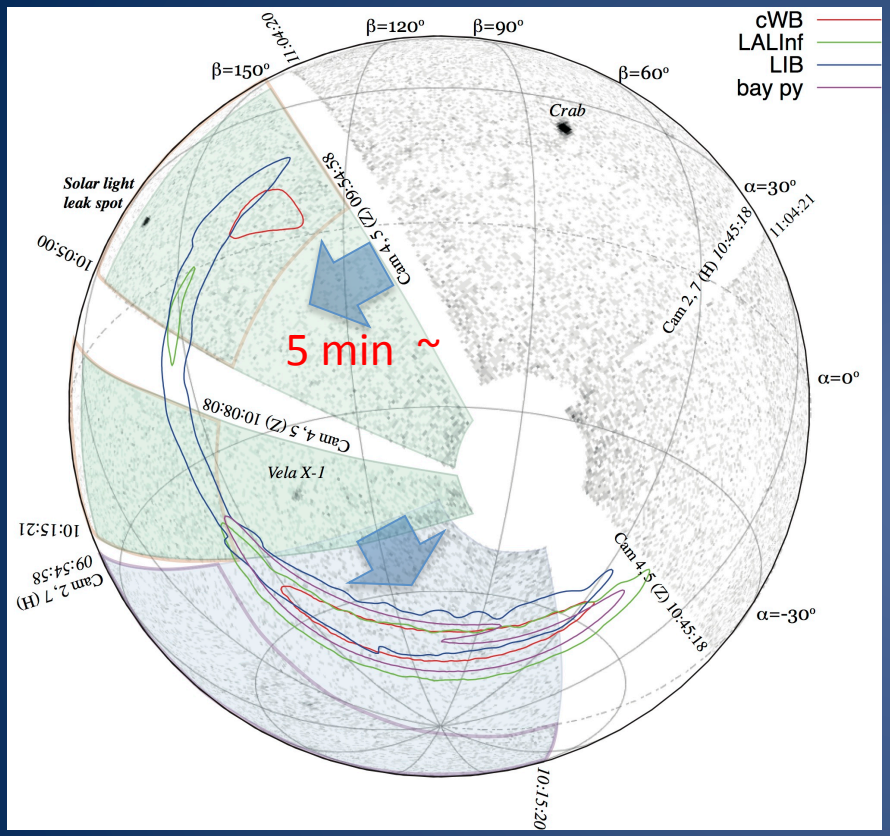
(Serino et al. GCN 19013)

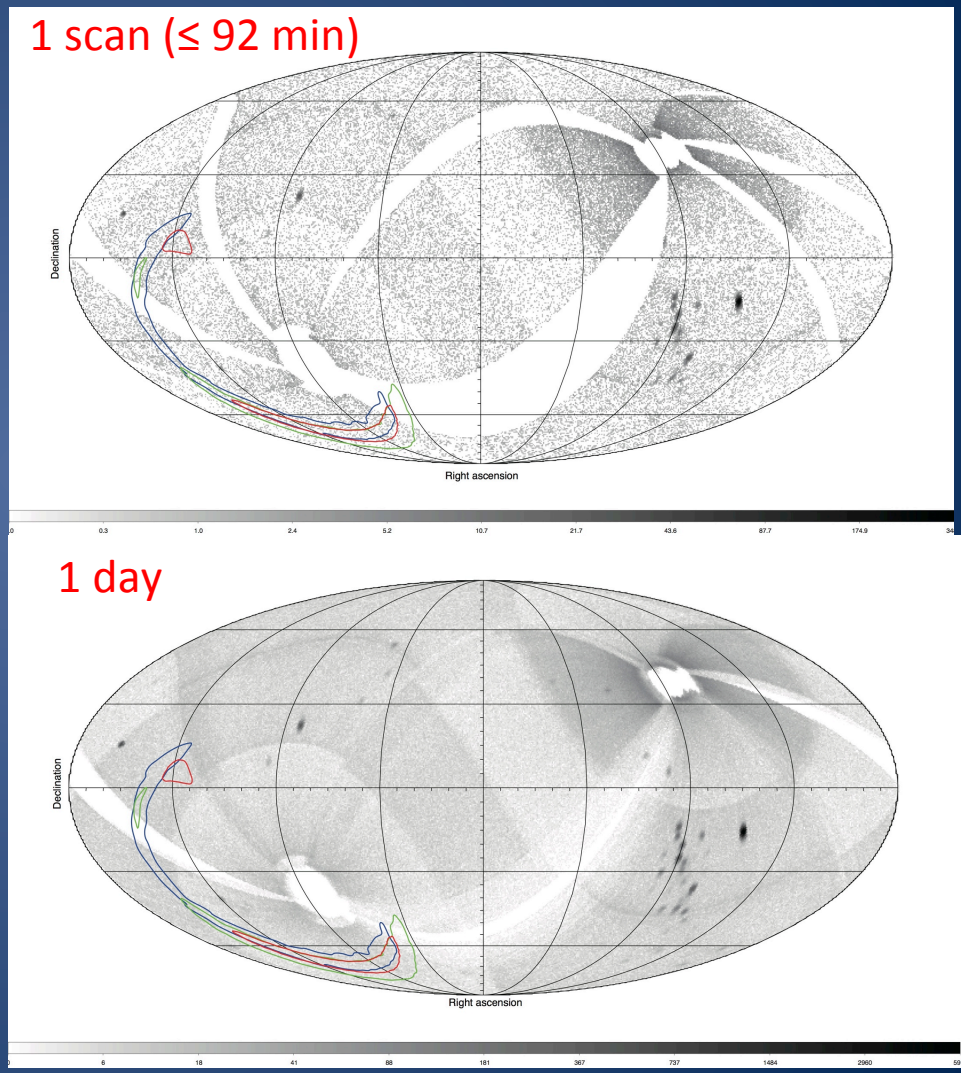
GW150914 (T0+0~1 day)



2-20 keV 3-σ upper limit: 8 mCrab ≈ 3×10^{-10} erg s^{-1} cm^{-2}

MAXI on GW150914





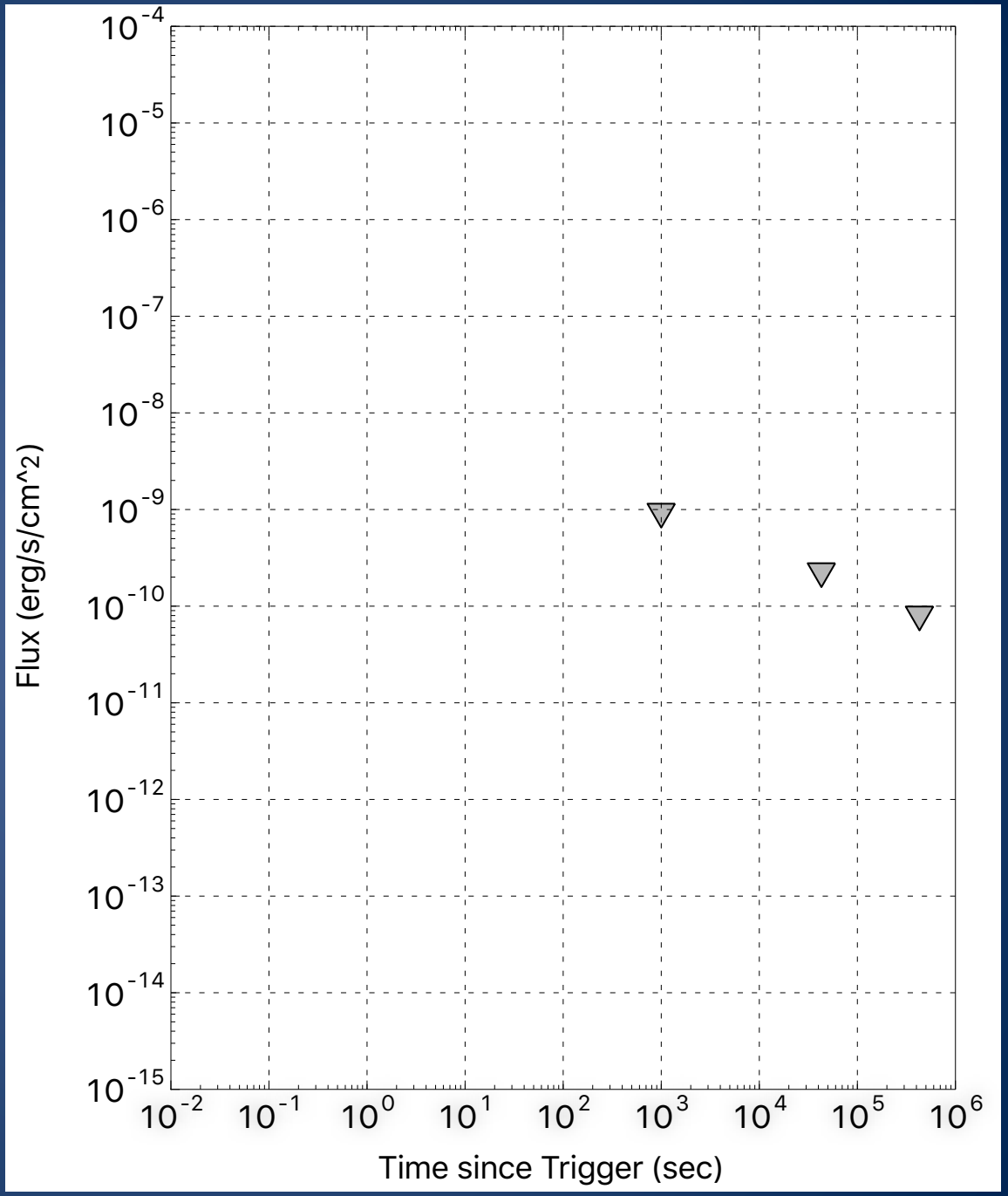
MAXI observations for GW150914

	Timescale (s)	**Flux** (erg s^{-1} cm^{-2})	**Luminosity*** (erg s^{-1})	**Radiated Energy (erg)**	E_X/E_{GW}
1 orbit	1000	$< 9.5 \times 10^{-10}$	$< 1.9 \times 10^{46}$	$< 1.9 \times 10^{49}$	$< 3.5 \times 10^{-6}$
1 day	8.6×10^{4}	$< 2.3 \times 10^{-10}$	$< 4.6 \times 10^{45}$	$< 4.0 \times 10^{50}$	$< 7.4 \times 10^{-5}$
10 days	8.6×10^{5}	$< 0.8 \times 10^{-10}$	$< 1.6 \times 10^{45}$	$< 1.4 \times 10^{51}$	$< 2.6 \times 10^{-4}$

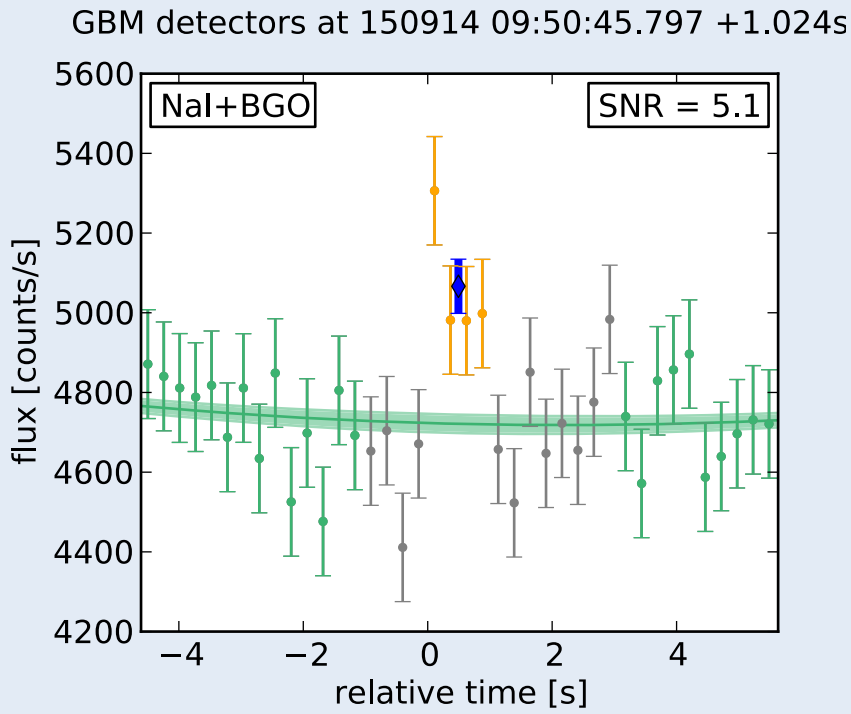
* Distance 410 Mpc assumed

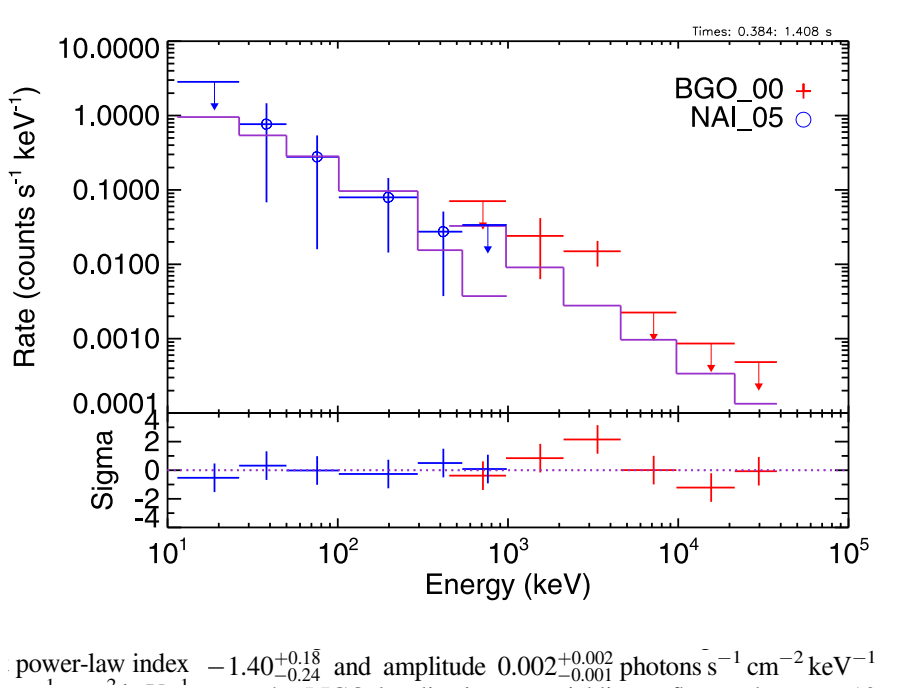
- Eddington luminosity for 62 $M_\odot$ BH $\approx 10^{40}$ erg s^{-1}
- Radiated energy in GW: $E_{GW} = \Delta M c^2 \approx 5.4 \times 10^{54}$ erg

MAXI on GW150914



Possible detection of gamma-ray emission by Fermi GBM

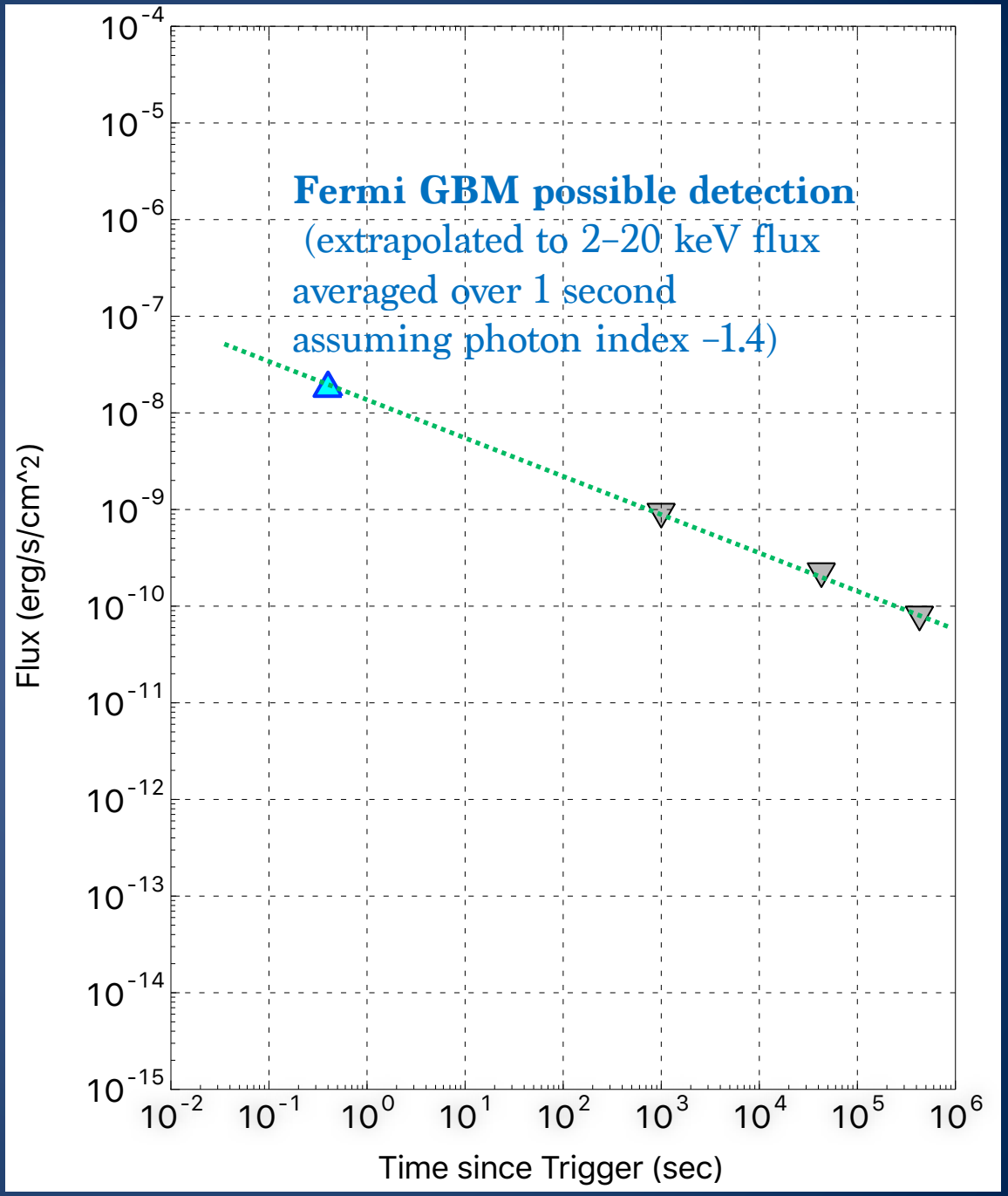




Connaughton et al. 2016

MAXI on GW150914

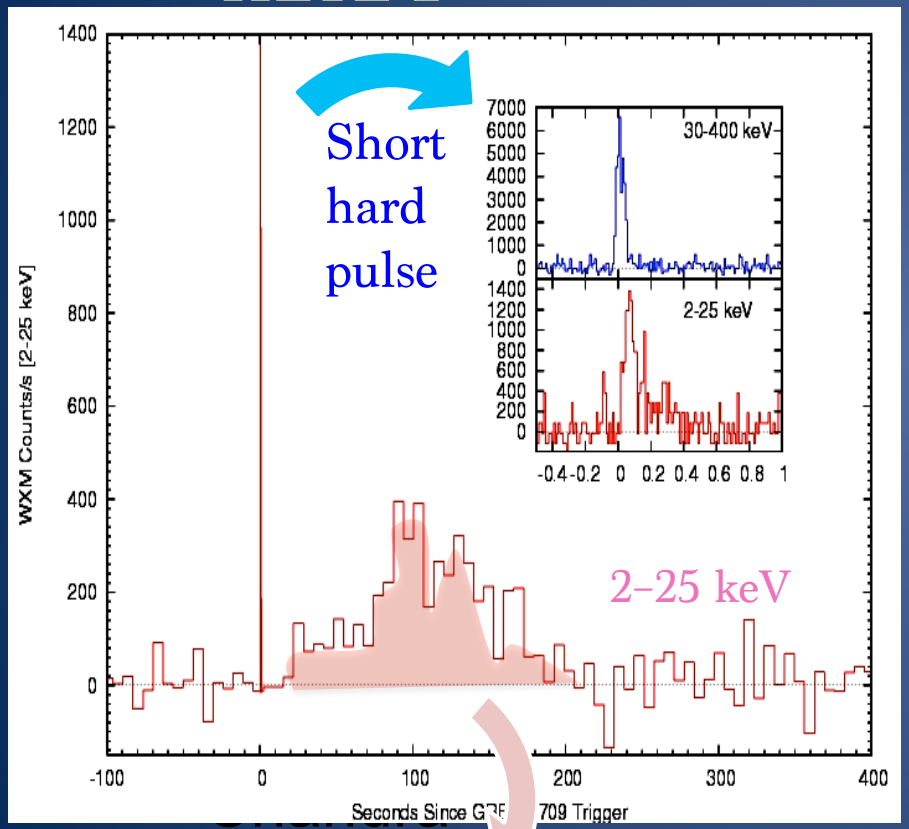
MAXI could have marginally detected GBM SGRB if it was in the field of view



Short GRB 050709

The only short GRB observed in soft X-ray

HETE-2 Villasenor et al. 2005



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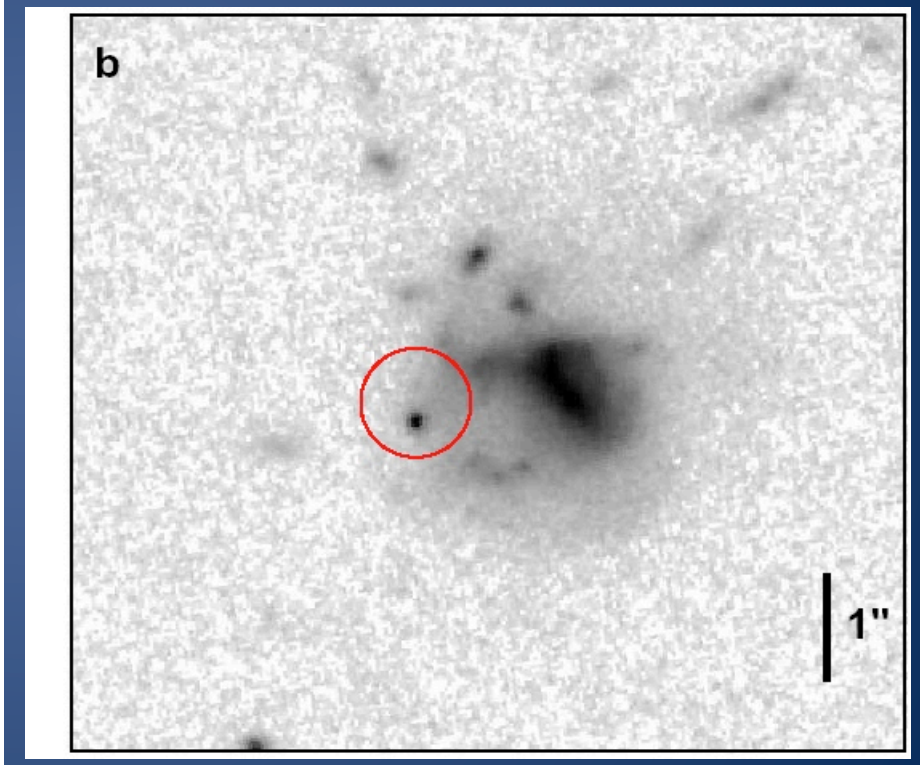


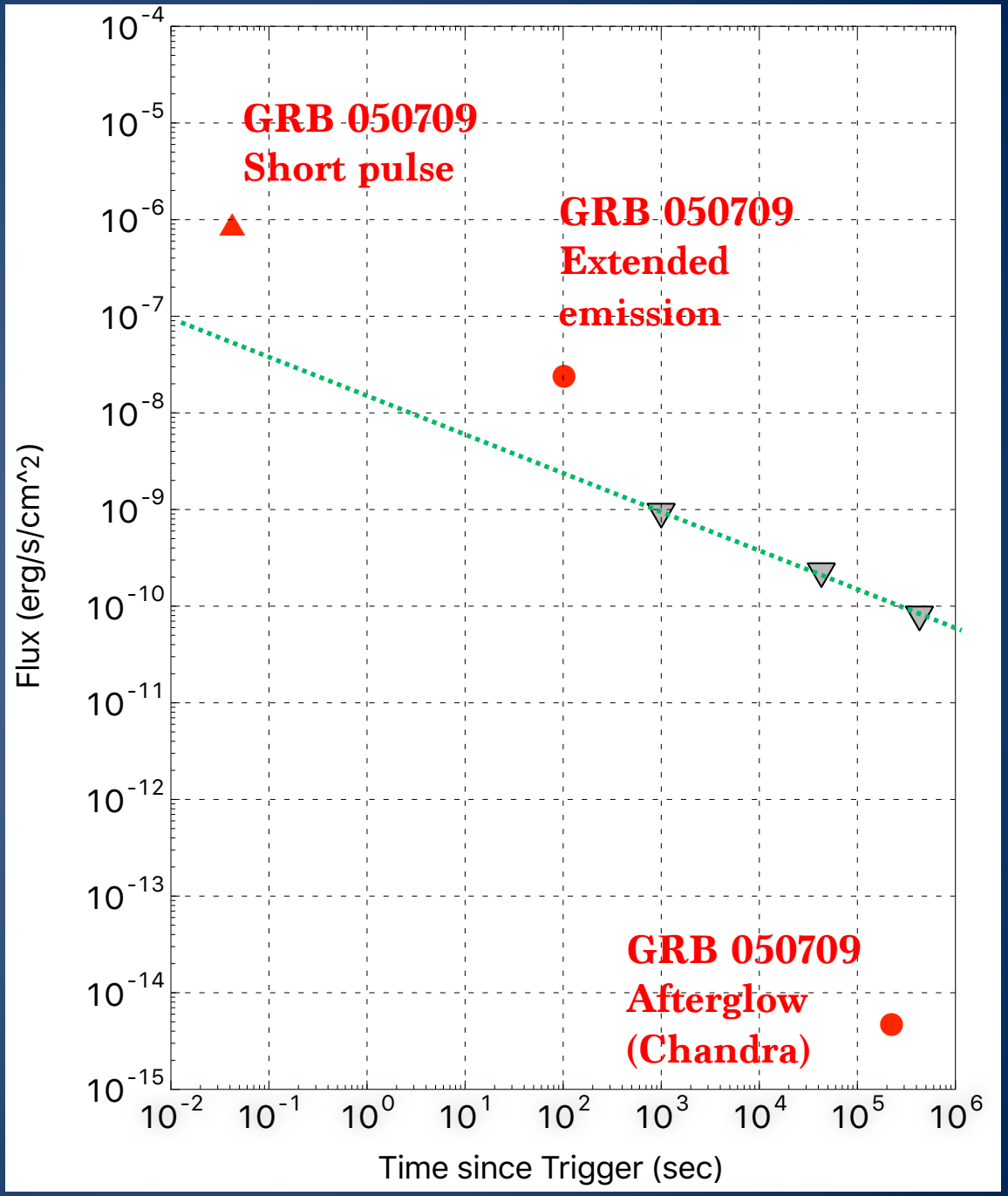
z=0.160

Dwarf irregular galaxy

SFR = 0.2 M_{sun}/yr

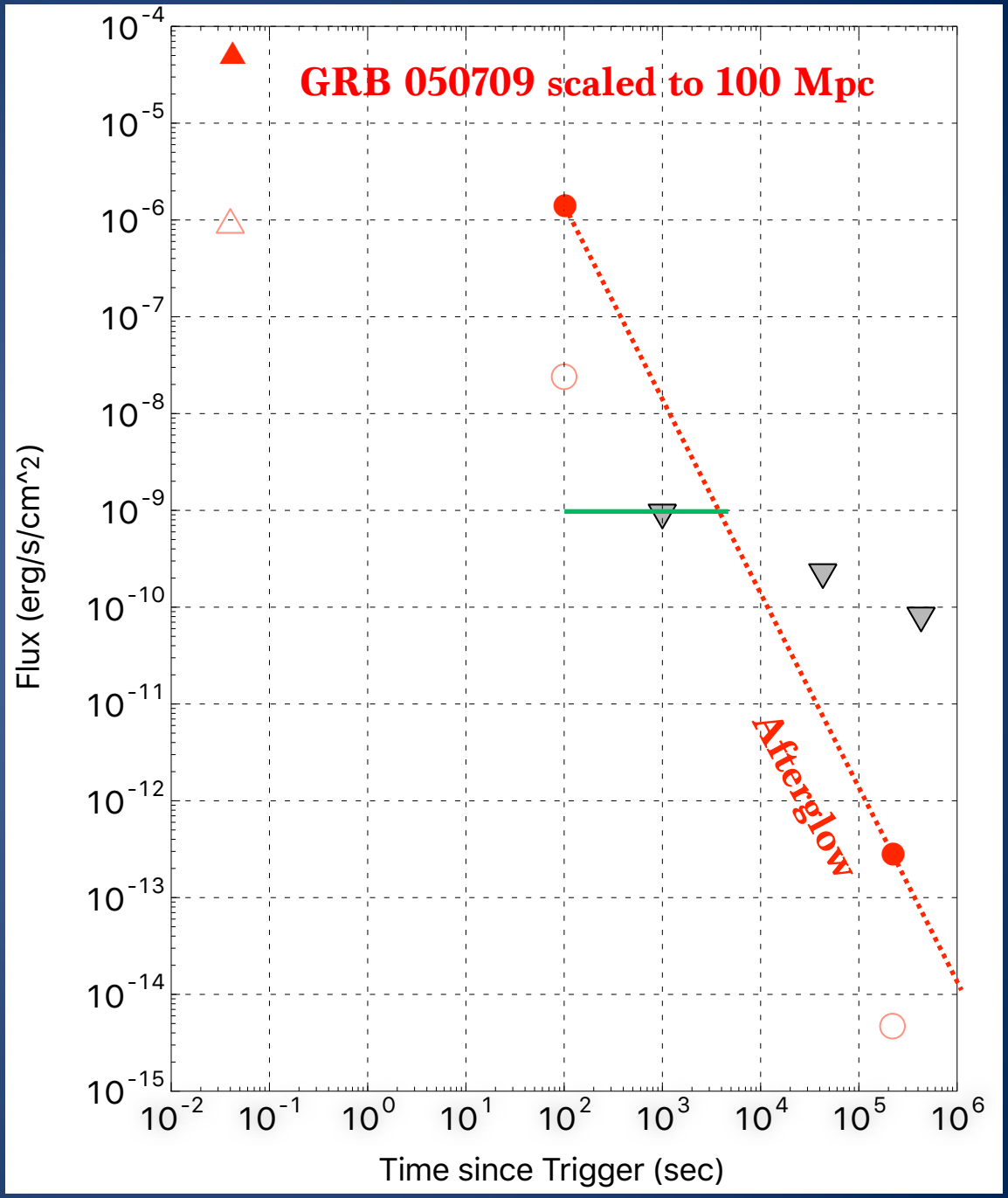
MAXI sensitivity for SGRB in GW range

MAXI could easily detect "short pulse" and "soft extended emission" of GRB 050709

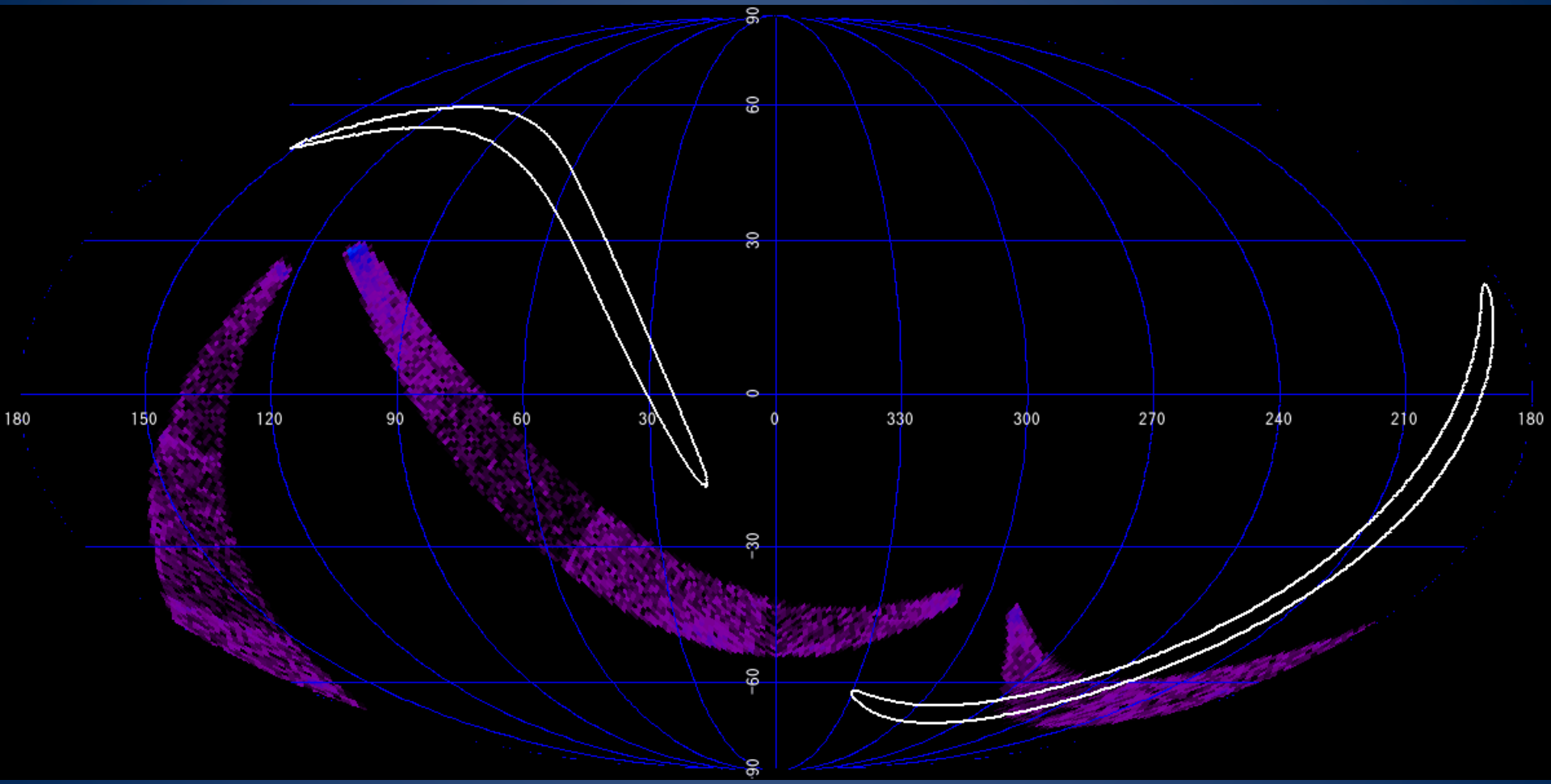


MAXI sensitivity for SGRB in GW range

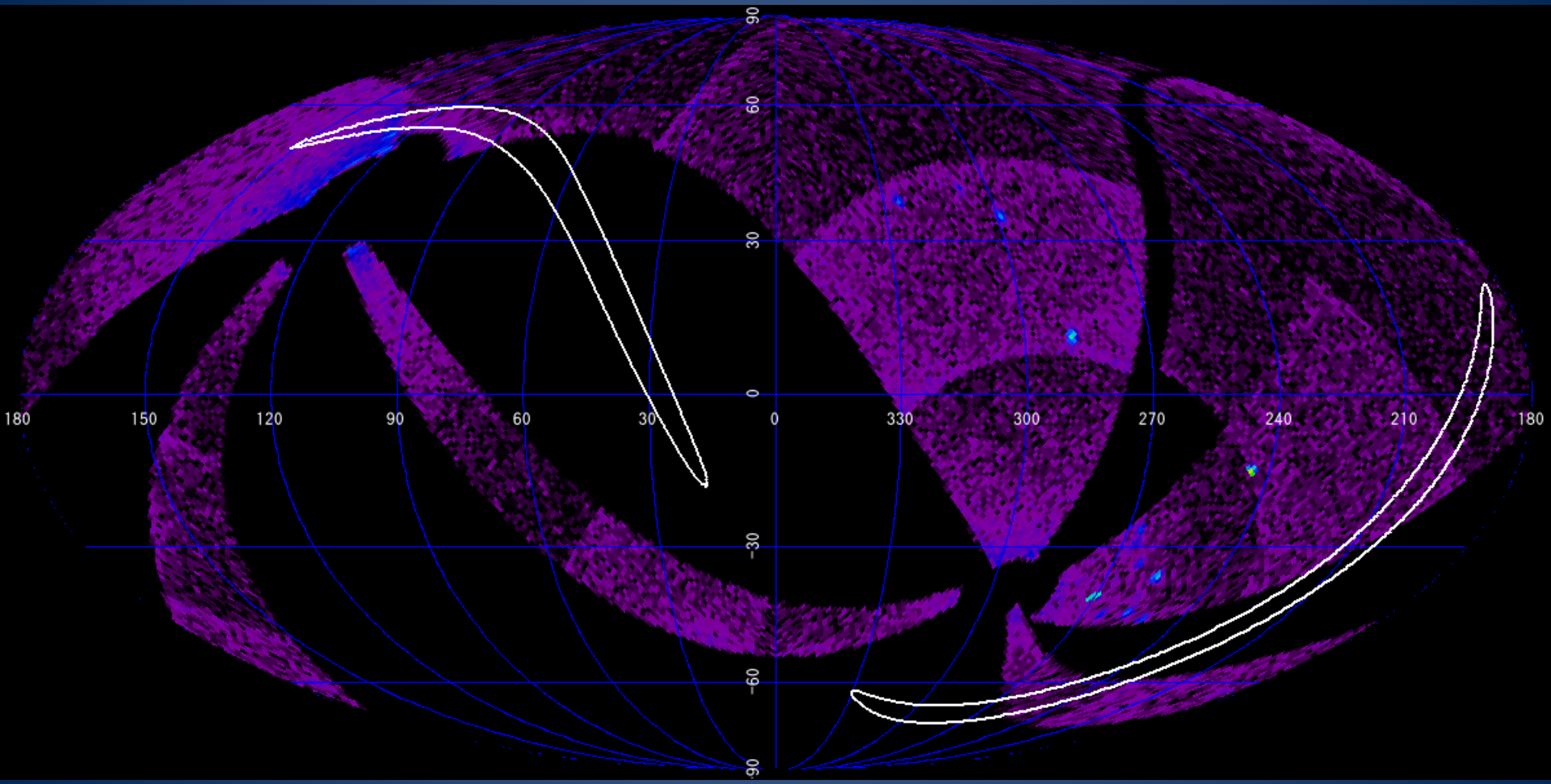
"Soft extended emission" or X-ray afterglow of a short GRB at LIGO O2 BNS range may be detected by MAXI in the following scan



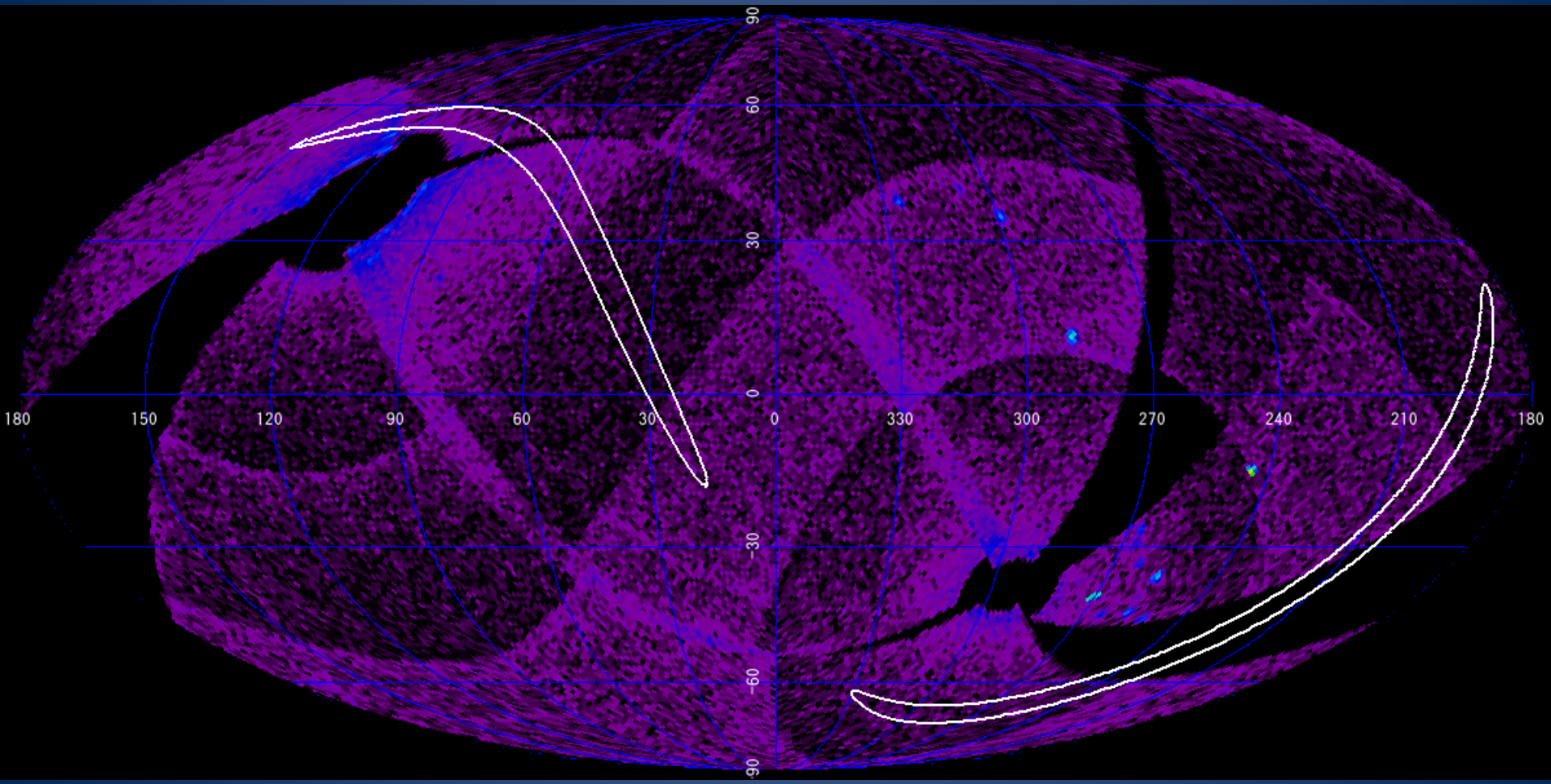
GW151226 0–4min



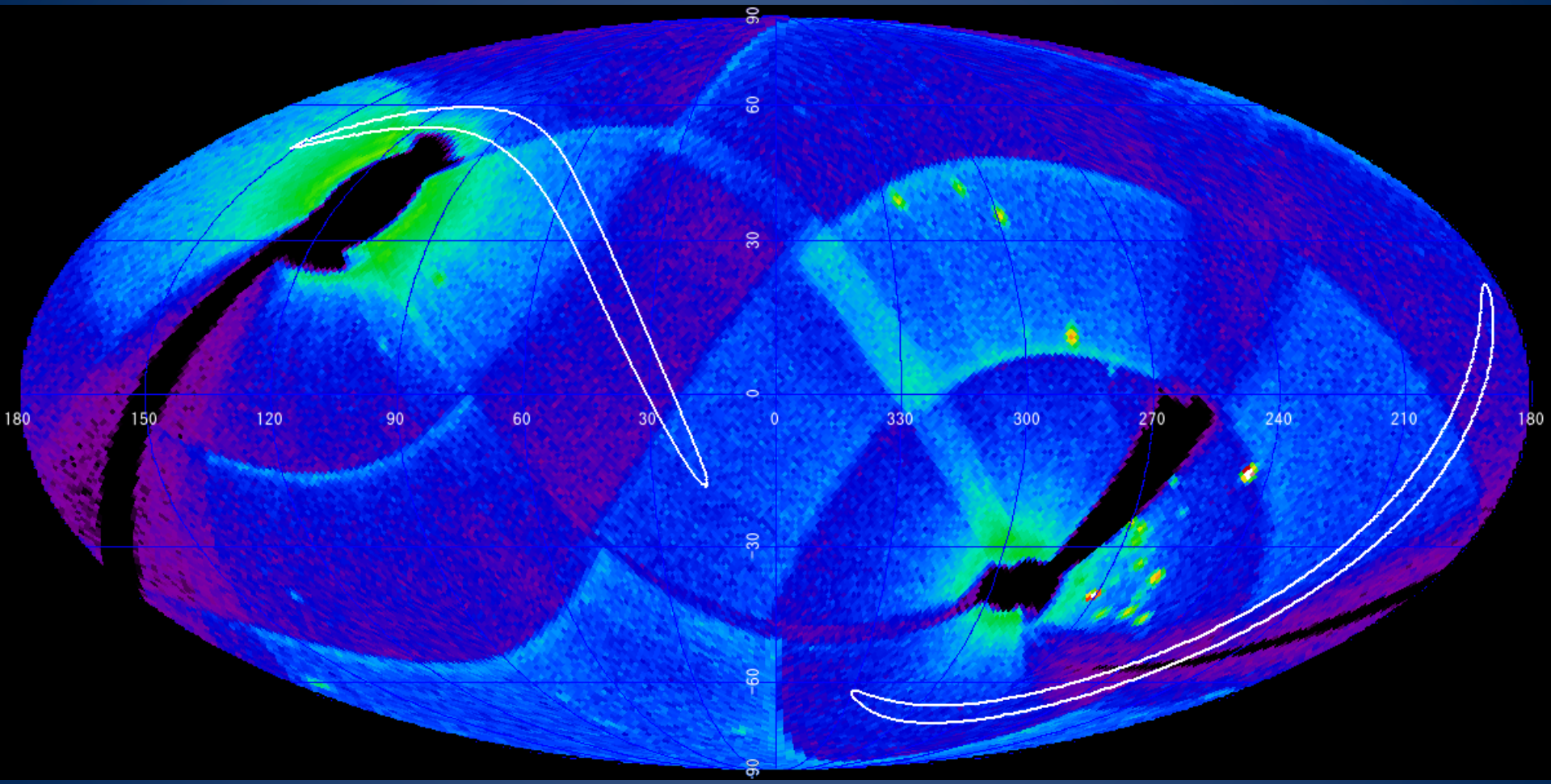
GW151226 0–60 min



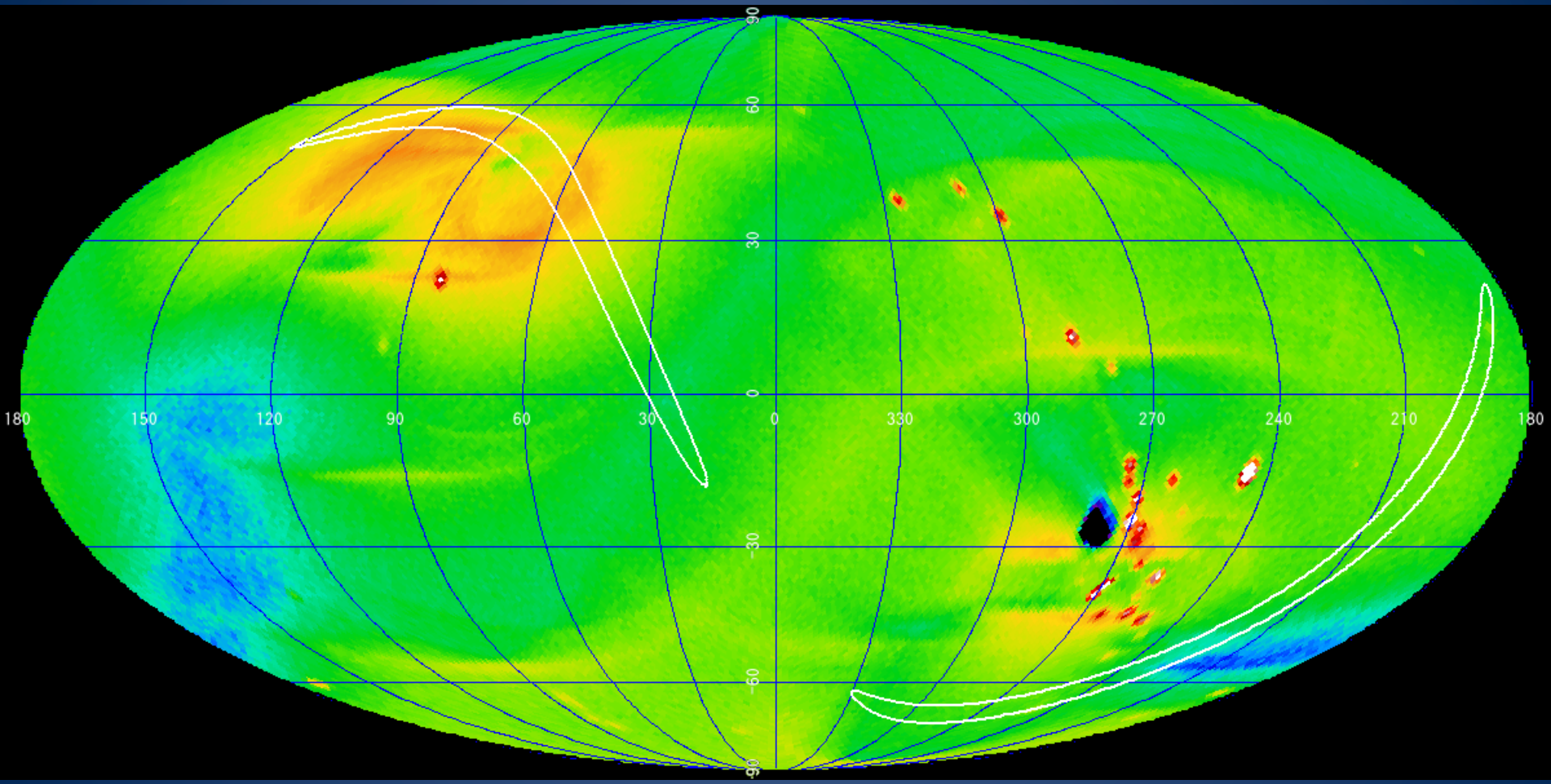
GW151226 one orbit



GW151226 one day



GW151226 10 days



Summary

- Soft X-ray band is unexplored for rapid transients, including possible counterparts of GW events.
- A large fraction of GW150914 region was covered in 1000s, yielding a flux upper limit ~10^{-10} erg s^{-1} cm^{-2}.
- MAXI can constrain the short GRB scenarios for DNS merger at <100 Mpc (O2 range)
- Instantaneous field of view of MAXI is 2% of the sky. iWF-MAXI (FoV >10% sky) has been proposed.