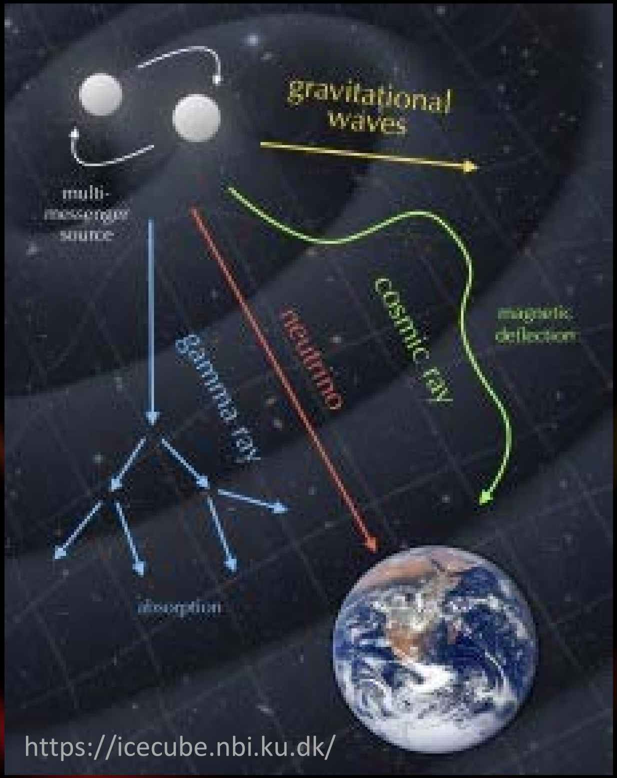
Rapid-Response Radio Telescopes in the Era of Multi-Messenger Astrophysics

ICRAR

International Centre for Radio Astronomy Research



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26 March 2019

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Curtin University

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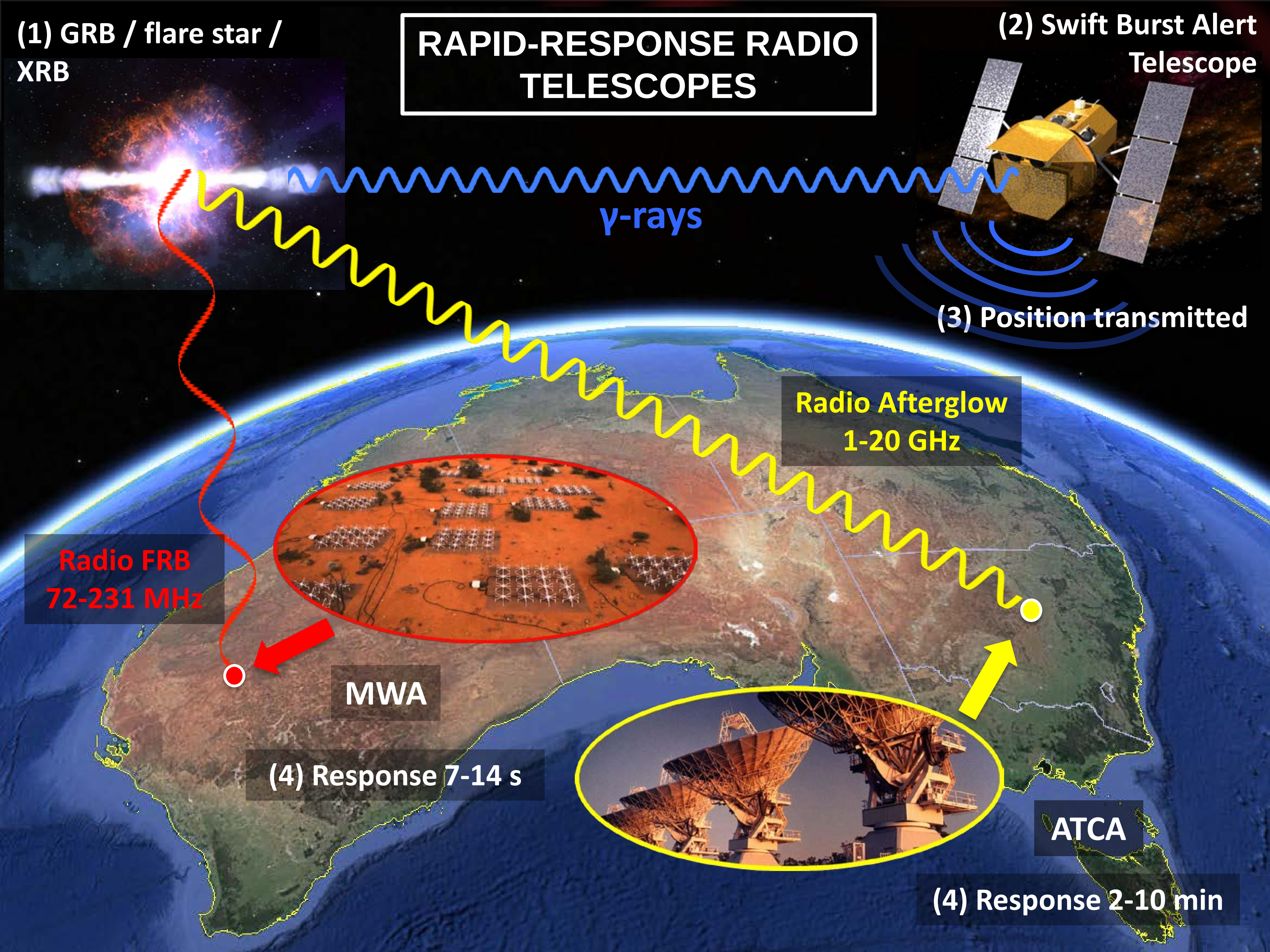
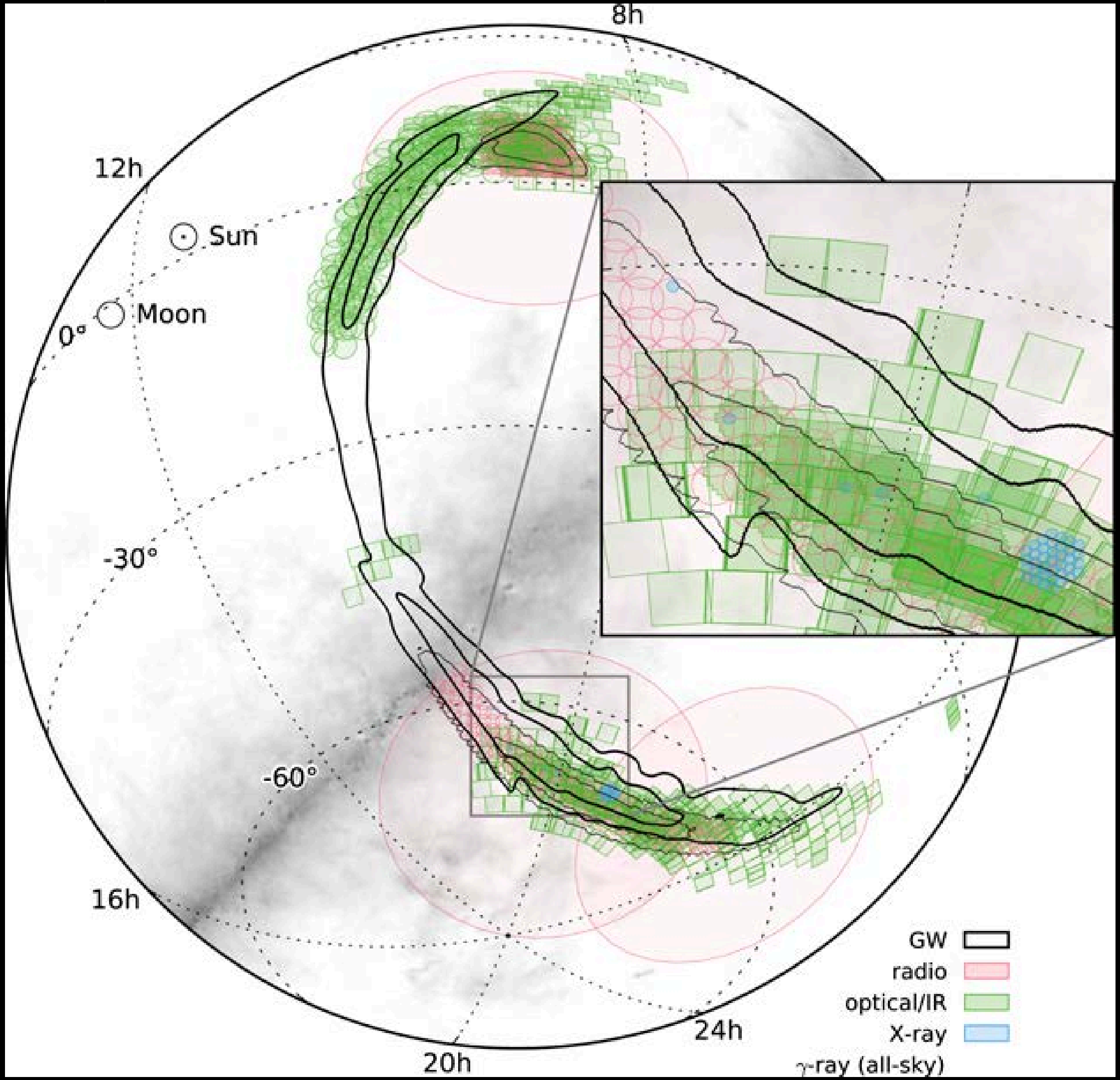


RAPID-RESPONSE RADIO TELESCOPES
(1) GRB / flare star / XRB
(2) Swift Burst Alert Telescope
γ-rays
(3) Position transmitted
Radio Afterglow 1-20 GHz
Radio FRB 72-231 MHz
MWA
(4) Response 7-14 s
ATCA
(4) Response 2-10 min

Radio triggering & Multi-messenger science



Abbott et al. (2016), ApJL, 826, L13

Radio benefits:

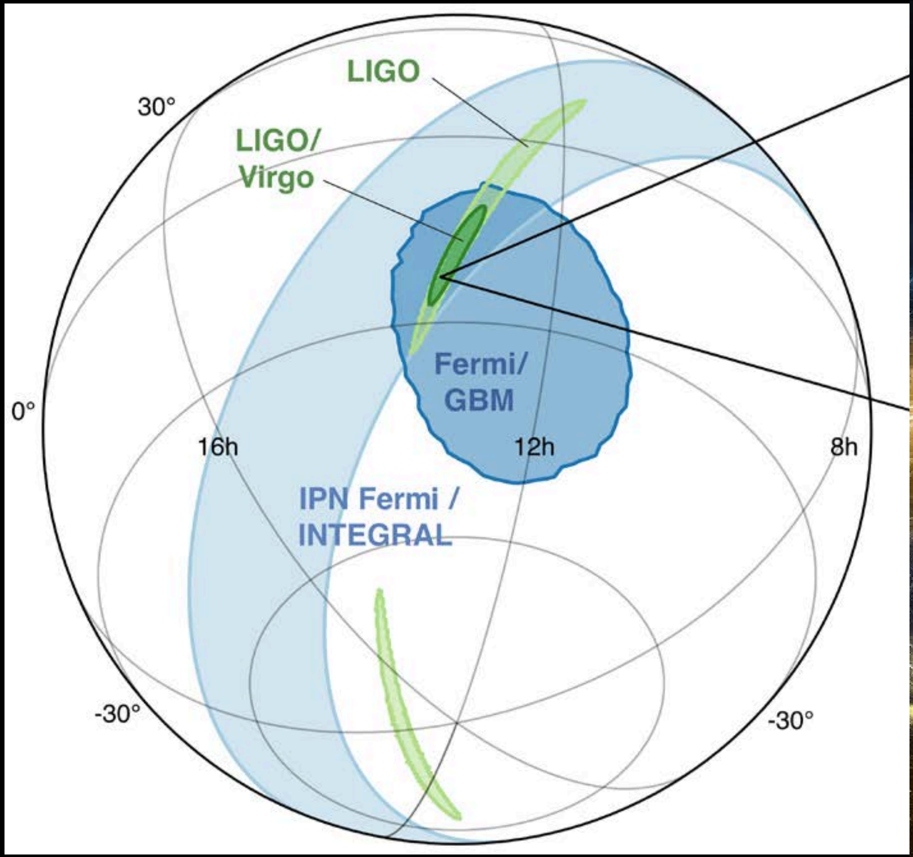
- Quiet transient sky
- Large field-of-view
  Australia is primed
  - MWA ~1000 deg^2
  - ASKAP ~30 deg^2

However!

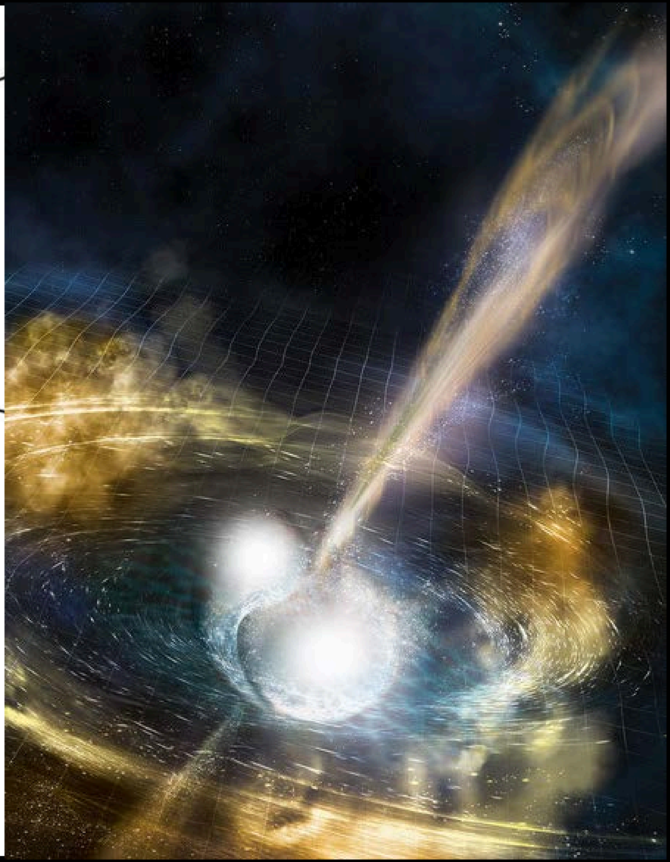
- Radio transients are faint!
- We don’t know the luminosity or timescales of GW/neutrino/cosmic rays/TeV counterparts

GW170817: The short GRB link

Short Gamma-ray Bursts (SGRBs): GW events pointed at Earth
Swift BAT: 1-4’ (1/6 sky), Fermi GBM: <10 deg^2 (50% sky)



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


NSF/LIGO/Sonoma State Uni/ A. Simonnet

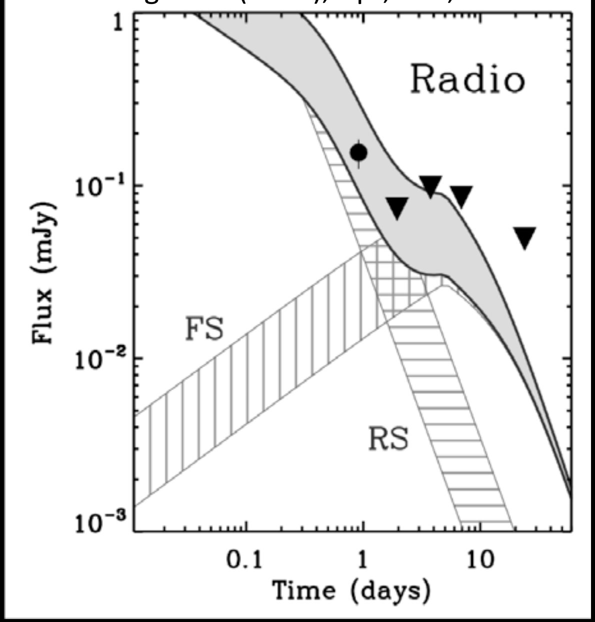
Early-time temporal and brightness properties of BNS mergers

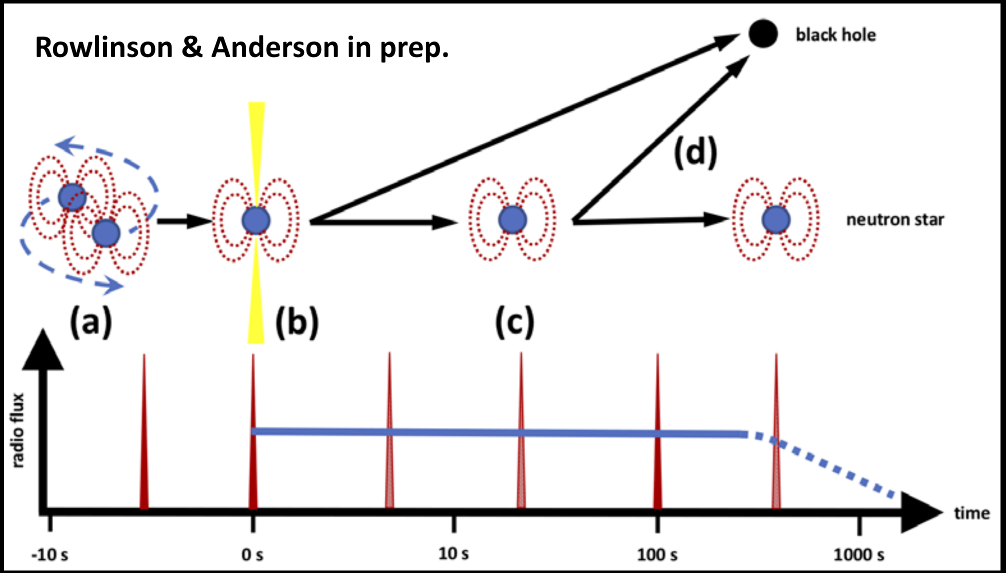
Merger early-time radio predictions

Prompt

- Theories link FRBs to mergers
- FRB rate now much lower and matches merger rates!
- Merger models and products
- EoS of nuclear matter

Soderberg et al. (2006), ApJ, 650, 261





Incoherent (synchrotron)

- Only 5 SGRBs radio detected
- 4 SGRB faded < 2 days
- Reverse shock flare?
- Constrain energy budget, B field, CSM density, outflow structure

MWA triggering – Prompt signals

Upgraded rapid-response

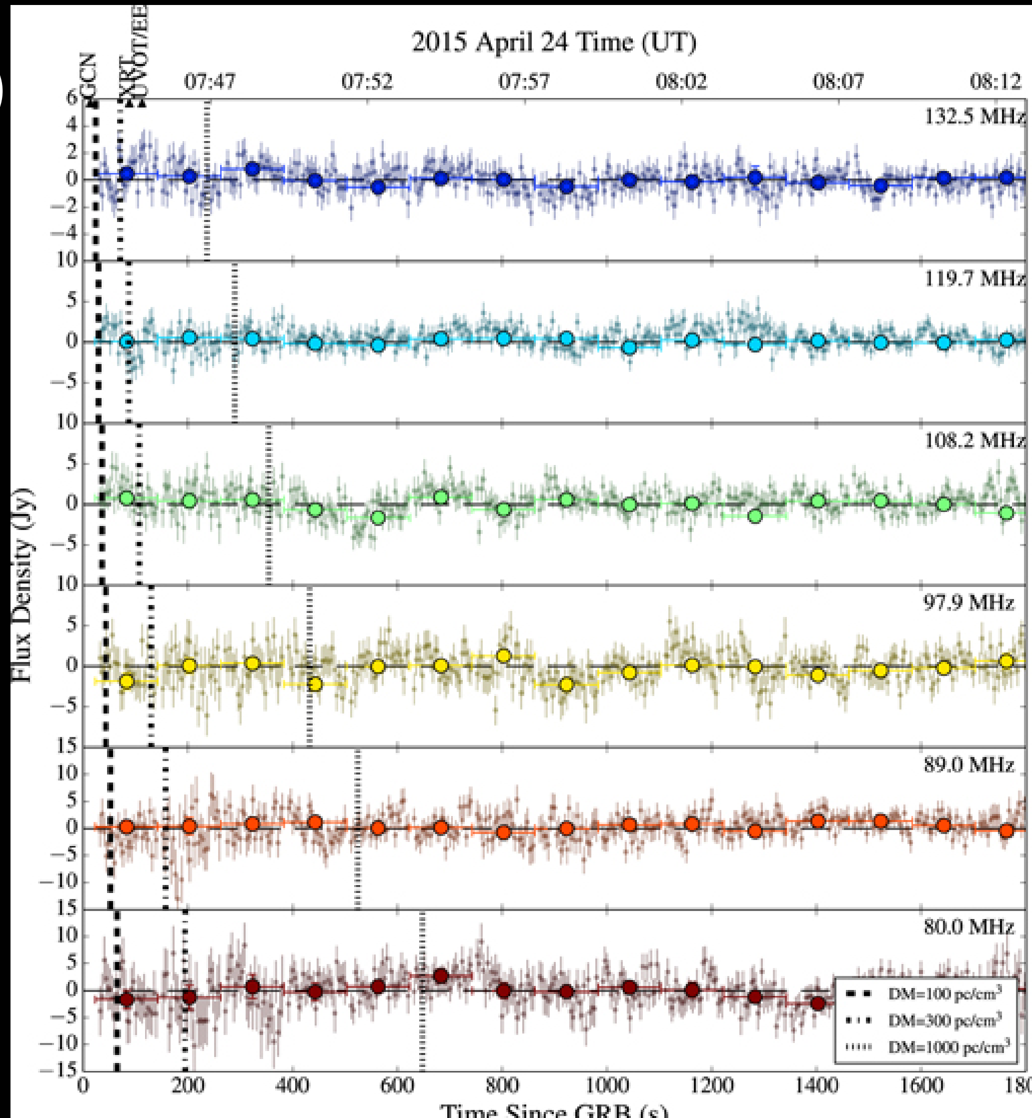
- Trigger- VOEvents (Swift/Fermi)
- 6-14 seconds
- 30 mins, 0.5 s/40 kHz
- High time sampling – Voltage Capture System
- Position updates
- Swift and Fermi GRBs

Low frequency advantage ➔ Dispersion Delay

- Z~0.7 (average SGRBs)
  - 100s arrival delay
  - 30s to cross 30 MHz band

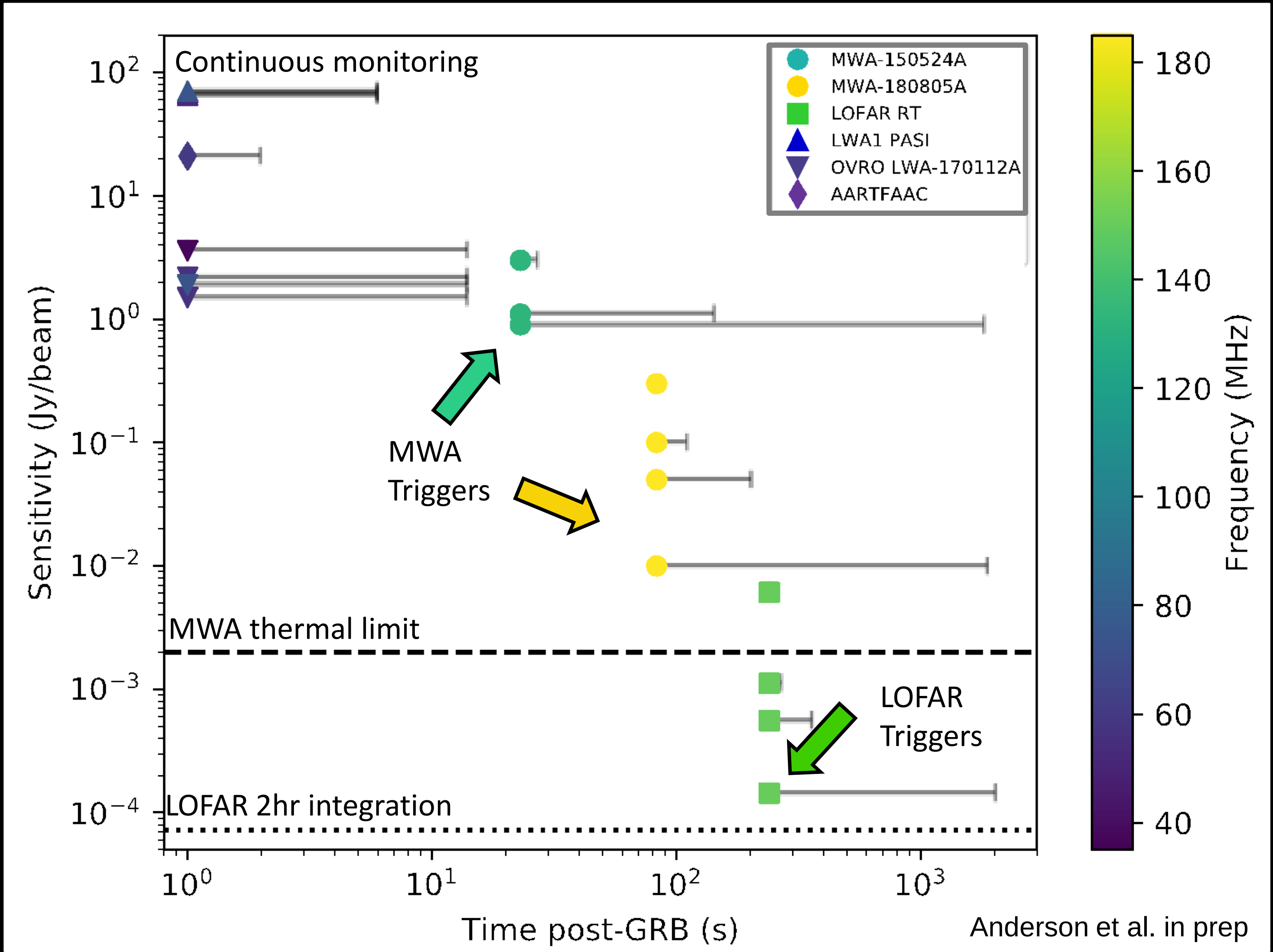
Old MWA rapid-response mode

- GRB 150424A
- 23s – 30 mins (4s, 2, 30 min)
- 3 Jy limit (3σ) 4s timescales



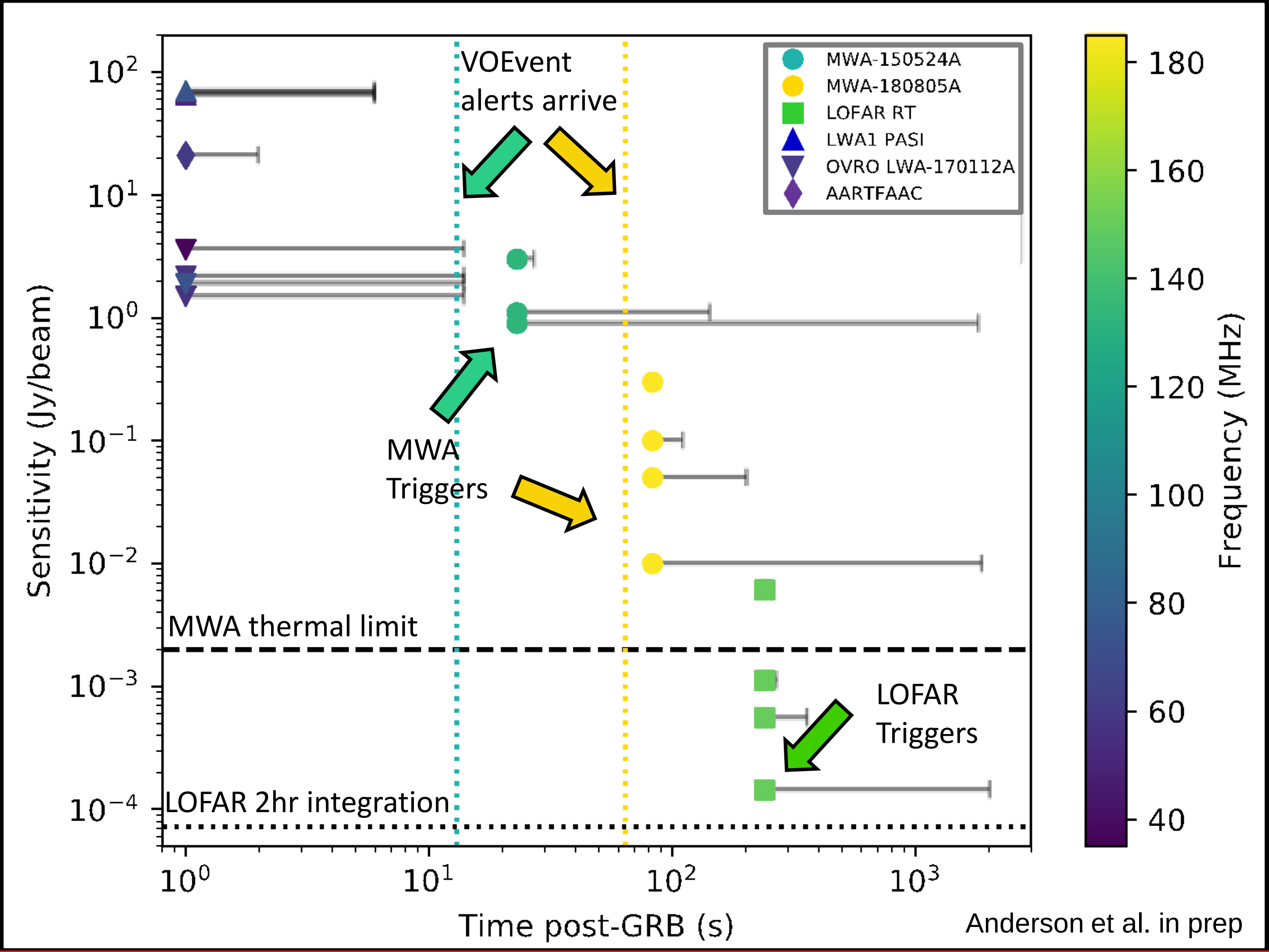
Kaplan et al. (2015), ApJL, 814, L25

Automated transient capabilities of low frequency telescopes



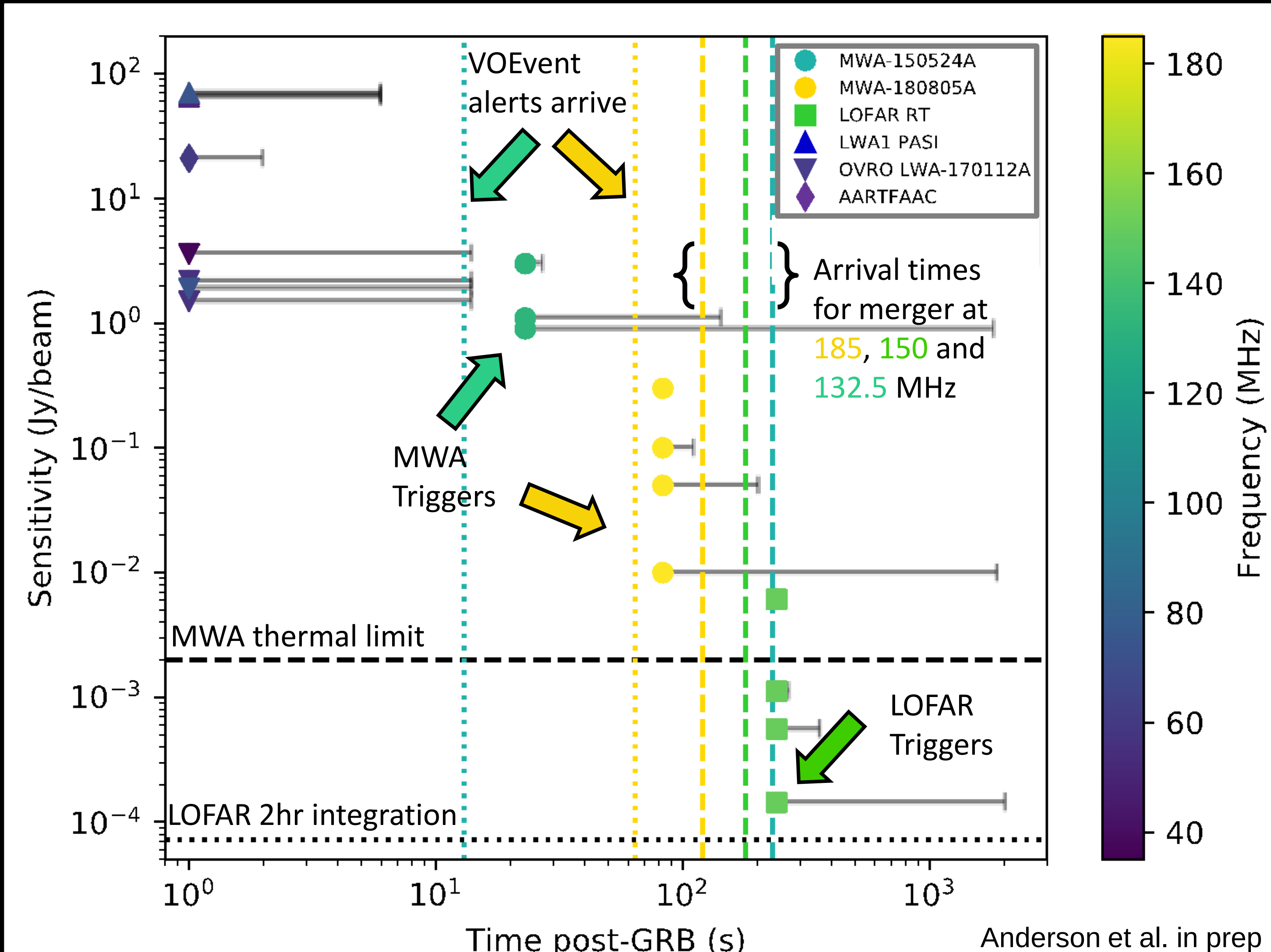
Anderson et al. in prep

Automated transient capabilities of low frequency telescopes

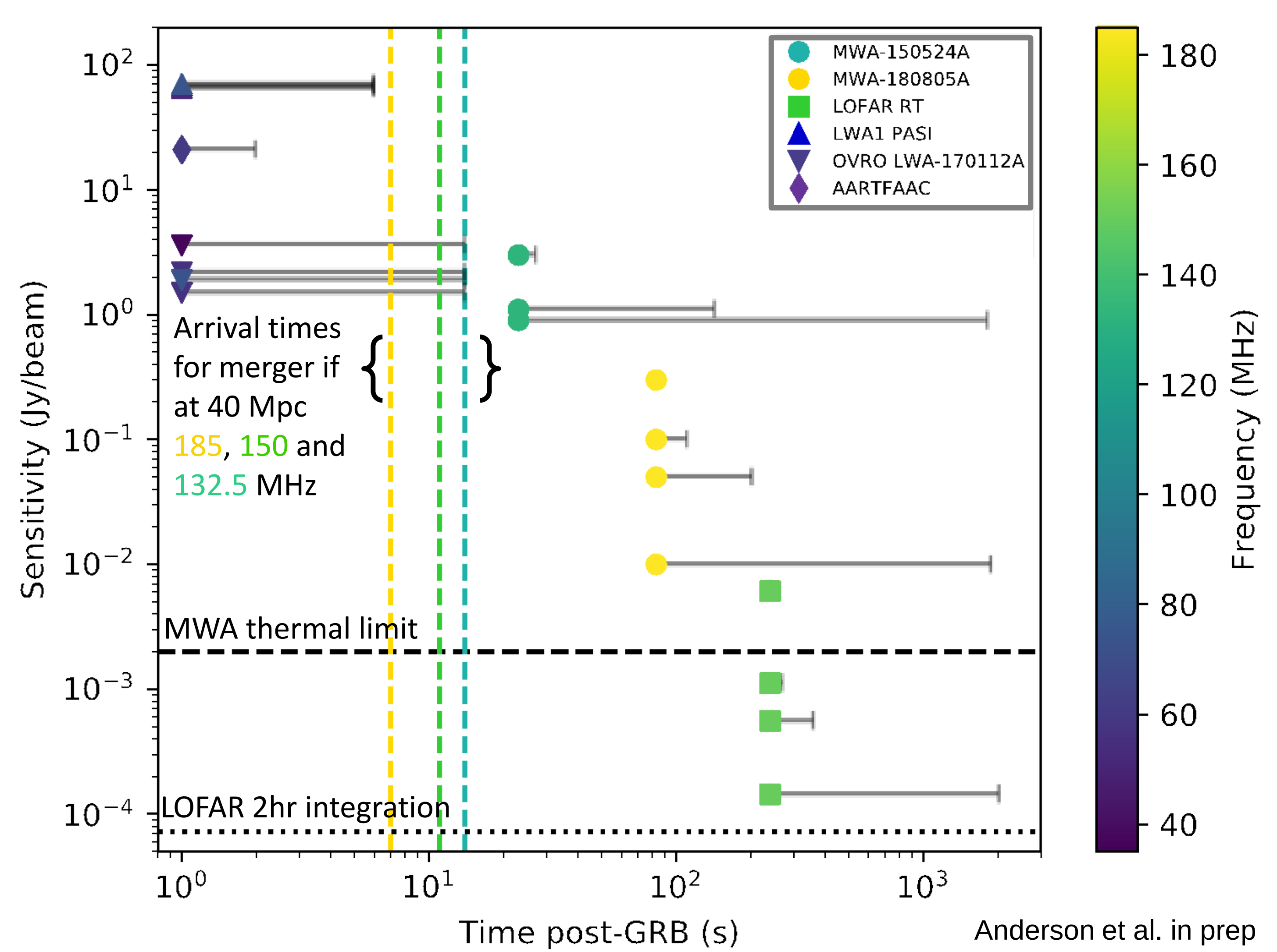


Comparisons to MWA

MWA is the most sensitive at early-times



What about Gravitational Wave Events?



Anderson et al. in prep

ATCA rapid-response - Synchrotron emission

- VOEvent triggers on SGRBs and flare stars

https://github.com/mebell/vo_atca

SGRBs – Swift-BAT, flare stars – Swift-BAT, MAXI

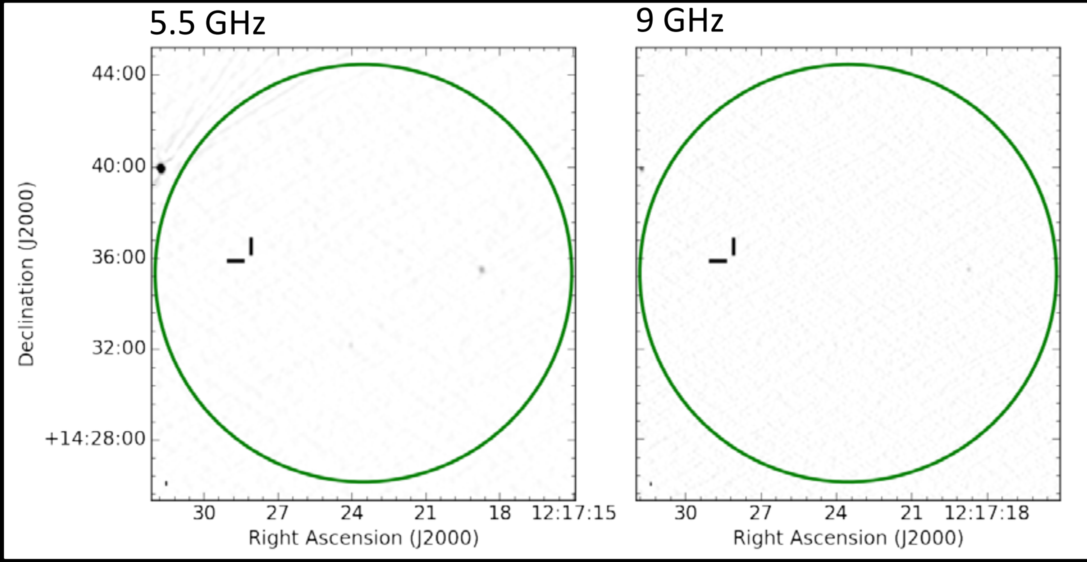
- Active since April 2017:
- First successful SGRB trigger Dec 2018
- First successful flare star trigger Jan 2019

Table 1: Unsuccessful ATCA override triggers

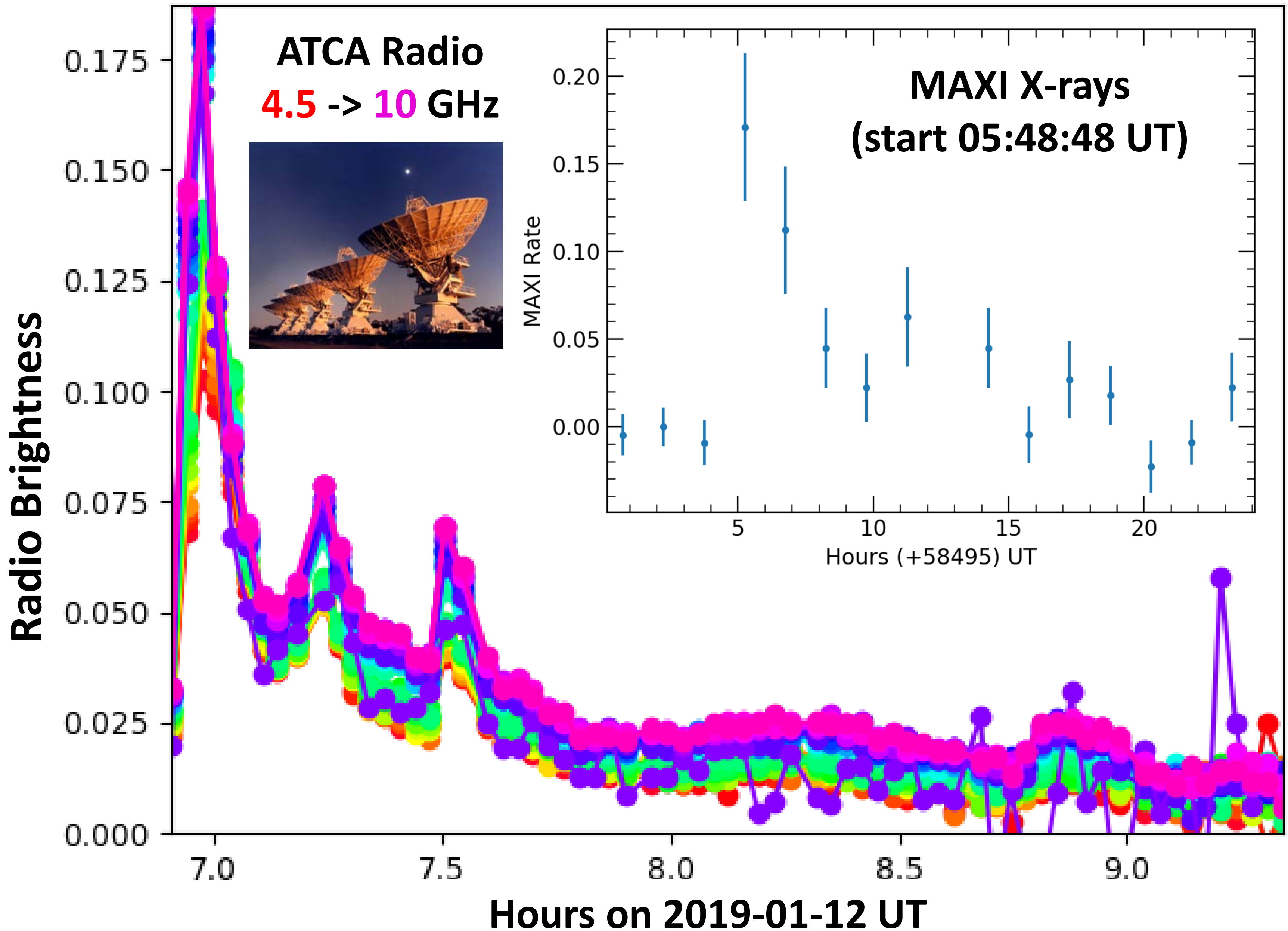
Reason	SGRB	LGRB	Other
Observatory software	2	1	0
VOEvent parsing	1	0	0
Maintenance/reconfiguration	1	0	0
VLBI	1	1	0
Correlator mode	0	2	1
Total	5	4	1

Right: SGRB 181123B

- 12.5 hr post-burst (when source rose)
- 8.5 hours at 5.5 and 9 GHz
- No detection – 3σ limits 66 and 69 μJy



ATCA Triggering: Flare star – AT Mic

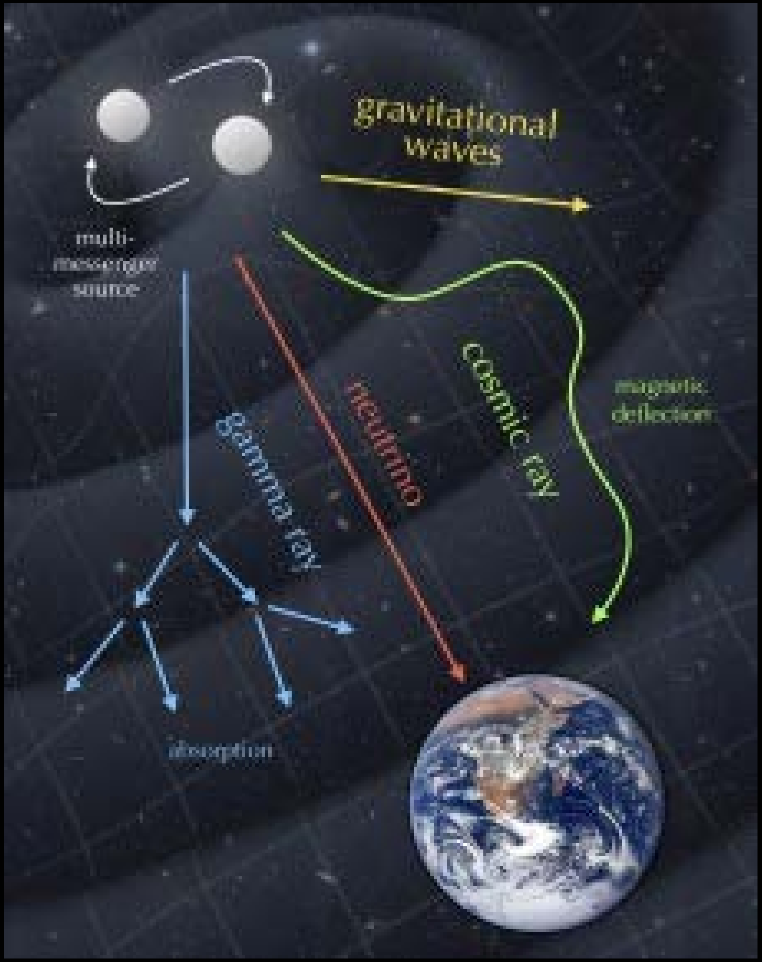


Observation Interruption

We want to interrupt your observing program….

However!

- These are rare events (~10 SGRBs/semester)
- While you loose 30 mins to 12hrs of data ➔ we gain a whole project!
- Observations can be rescheduled
- Enabling science that would otherwise not be possible!



https://icecube.nbi.ku.dk/

Override Triggering Logic

All proposals are scored by the TAC

Provided:

- Triggering program score > minimum project score on schedule
- Triggering program < make up time available
- Current program not time critical (transients, observing campaign)

TAC has ranked program at the same priority as scheduled projects

➔ Trigger overrides current program regardless of score

Used by the Australia Telescopes Compact Array

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Used by the Australia Telescopes Compact Array

OR

Submitted proposals must include a statement regarding their INTERRUPTIBILITY

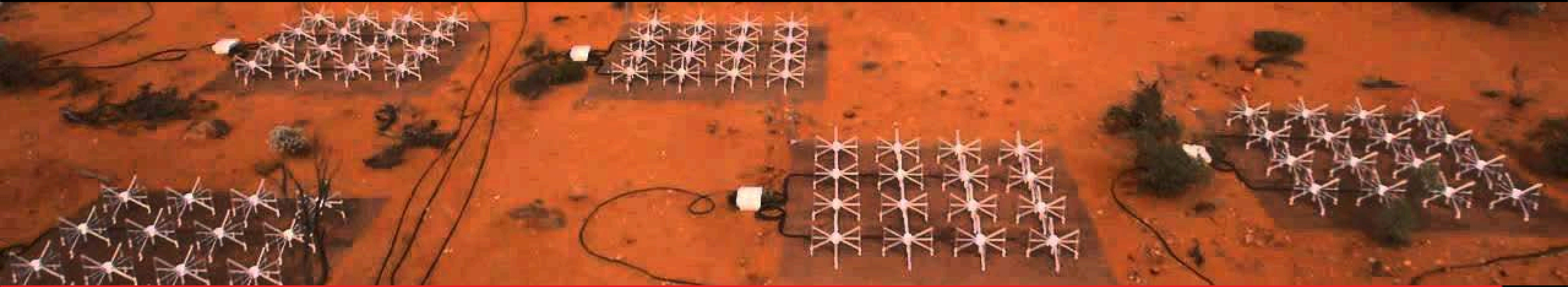
Use by the Murchison Widefield Array

Conclusions

- ATCA and MWA have new/updated rapid-response mode
  - Available to all observers!
  - Many potential multi-messenger science cases
- If you are interested then talk to me: gemma.anderson@curtin.edu.au

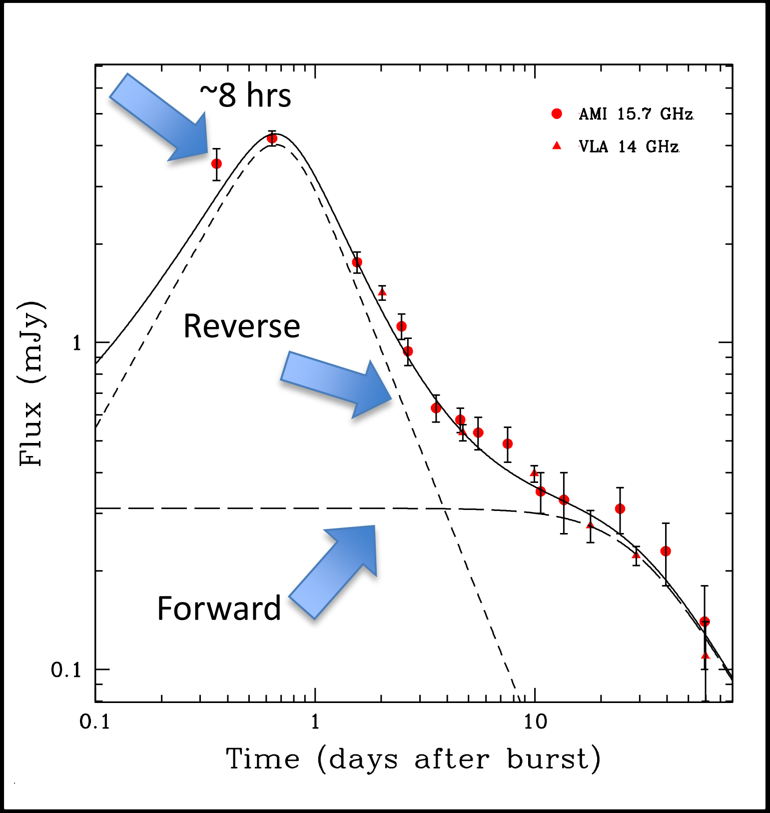
  Also see: VOEvent trigger parsing code on GitHub/MWATelescope/mwa_trigger & /mebell/vo_atca

- Science return for radio triggering is high compared to interruption time.
- TAC scores of triggering programs > minimum scheduled programs ➔ TAC thinks it should be observed



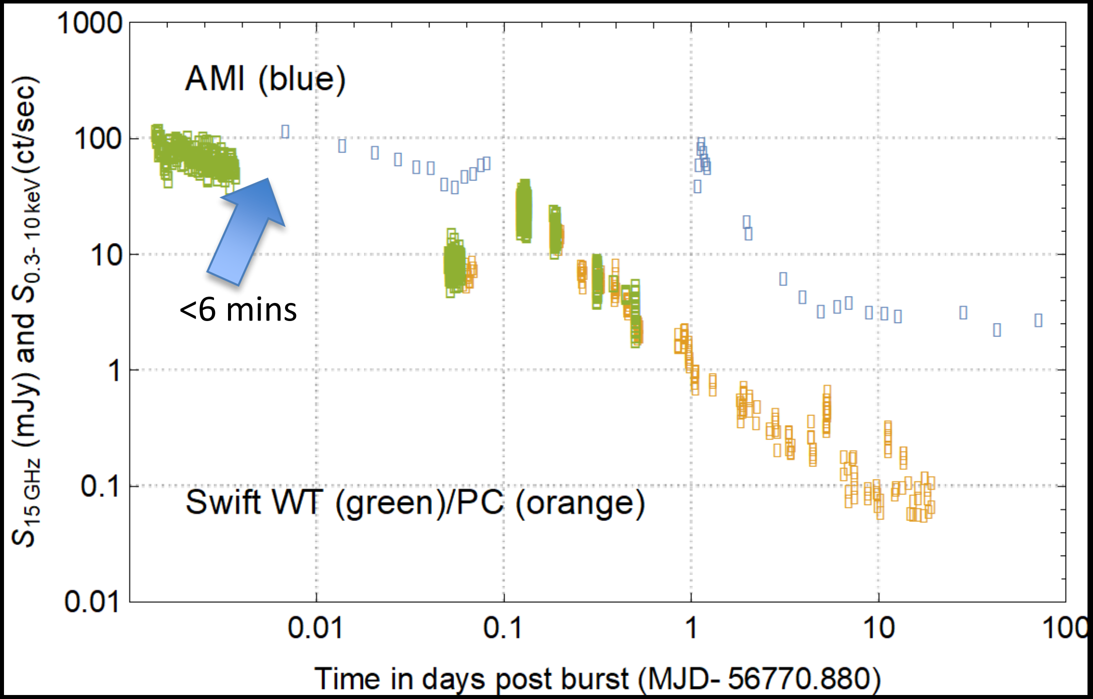
TRIGGERING: AMI results

GRB 130427A: Radio REVERSE SHOCK detection

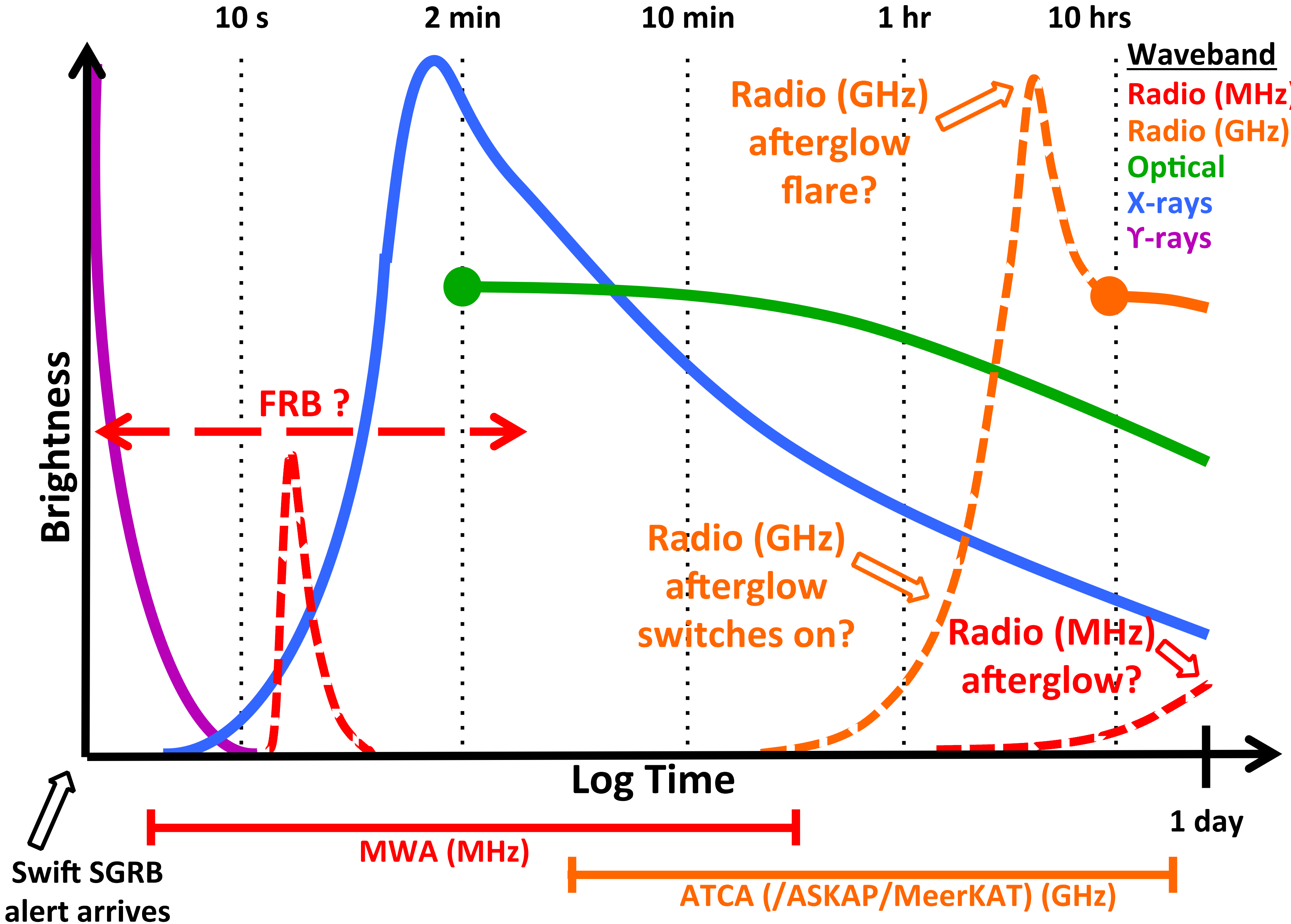


Anderson et al. (2014), MNRAS, 440, 2059

DG CVn (rapidly-rotation M dwarf): Associated radio flare with ϒ-ray superflare



Fender, Anderson et al. (2015), MNRAS, 446, L66


10 s
2 min
10 min
1 hr
10 hrs
Waveband
Radio (MHz)
Radio (GHz)
Optical
X-rays
ϒ-rays
Radio (GHz) afterglow flare?
FRB ?
Brightness
Radio (GHz) afterglow switches on?
Radio (MHz) afterglow?
Log Time
1 day
Swift SGRB alert arrives
MWA (MHz)
ATCA (/ASKAP/MeerKAT) (GHz)

MWA rapid-response mode performance

GRB 180805A – Swift 851829

RA = 11:10:07, Dec = -45:19:50 (3 arcmin uncertainty)

Time on 2018-08-05 (UT)	Latency (s)	Event
09:04:49	0	*Swift*-BAT detected SGRB 180805A
09:05:53	64	*Swift* VOEvent alert notice circulated
09:05:54	65	Comet VOEvent-broker received VOEvent and queued for handler processing
09:05:56	67	VOEvent queueing complete
09:05:56.8	67.8	MWA *Swift-Fermi* VOEvent handler processes VOEvent
09:05:57.1	68.1	MWA *Swift-Fermi* VOEvent handler triggers observation
09:06:08	79	MWA is on target
09:06:12	83	MWA begins observations of SGRB 180805A

Fixed! (65–67 s)

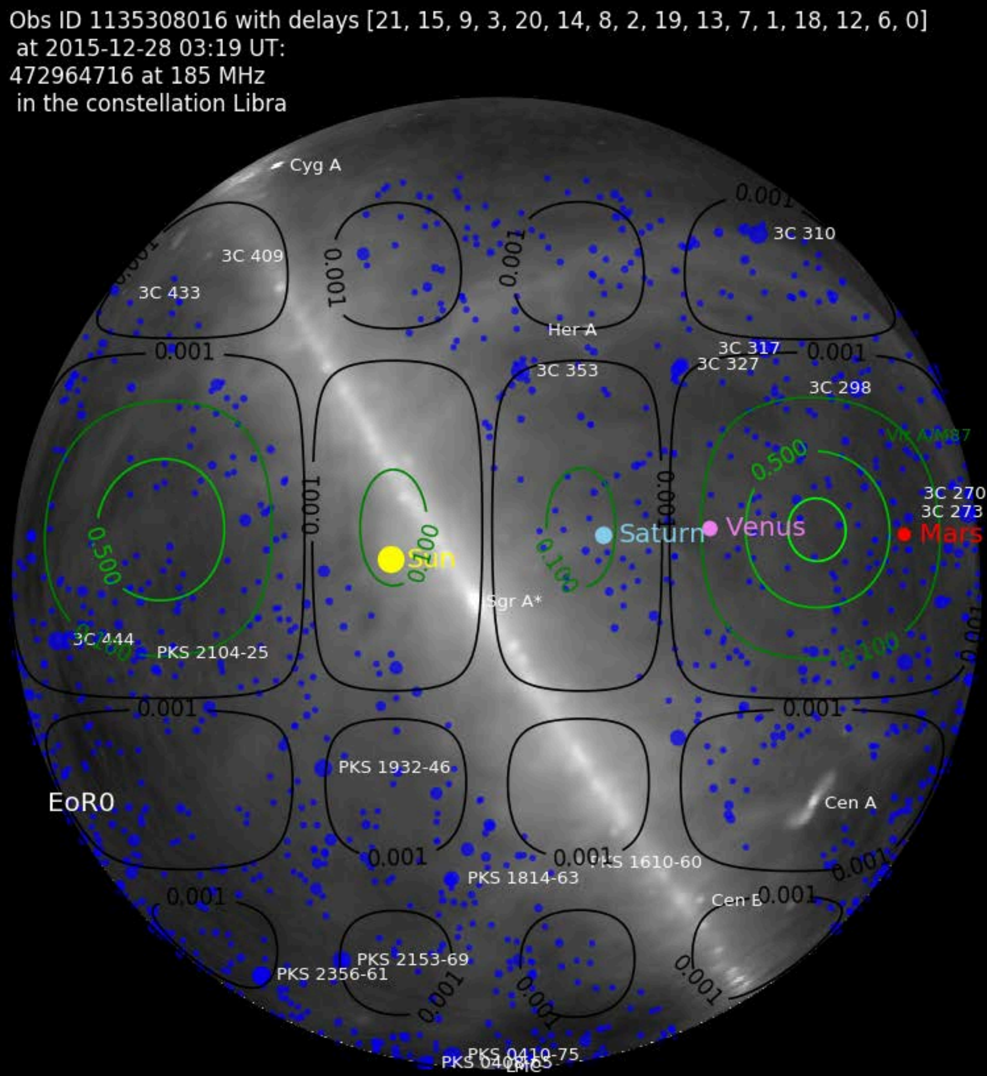
11s: Correlator limited (68.1–79 s)

- Hard limits associated with the hardware
- Continued work to reduce latency
  - 2-3 s delay between VOEvent arrival and it being pushed to the handler
- MWA is not the limiting factor!

Upgraded MWA rapid-response mode

Swift & Fermi GRBs

- Response 6-14s
- MWA covers Fermi position error (1-10 deg)
- Triggers if source in sky
- 30 mins, 0.5 s/40 kHz
- High time sampling – Voltage Capture System
- Position update
- Sun or bright source suppression in sidelobe null

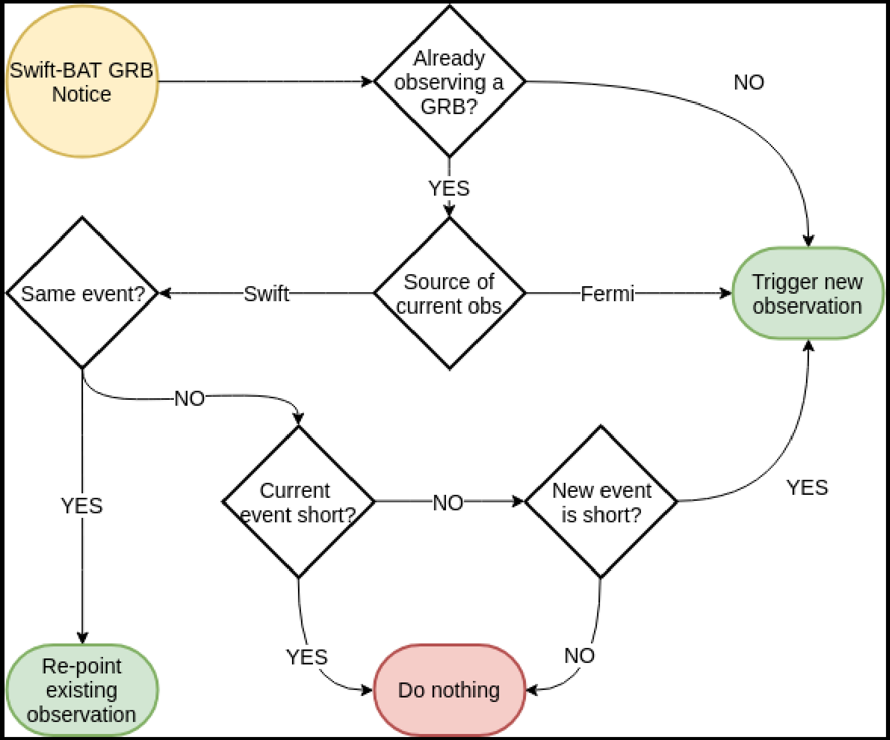


Upgraded MWA rapid-response mode

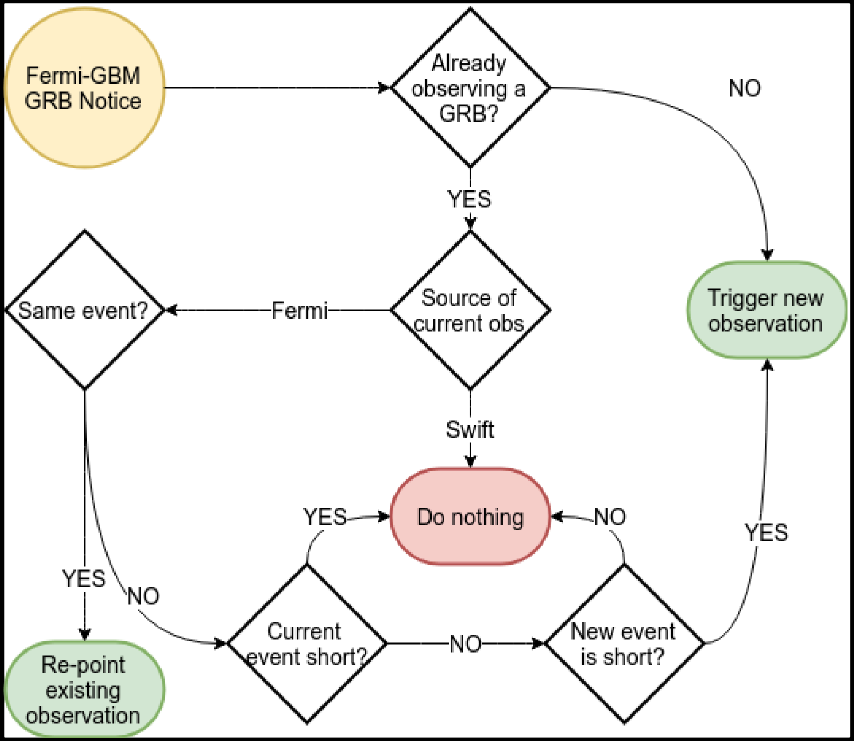
VOEvent parsing (transient alert distribution standard)

All GRBs – Swift-BAT, SGRBs – Fermi, flare stars – Swift-BAT, MAXI

Swift GRB Triggers



Fermi GRB Triggers



4 Pi Sky VOEvent Broker (used by AMI): https://4pisky.org/voevents/

Front-end service and VOEvent parser:

https://github.com/MWATelescope/mwa_trigger

Anderson, Hancock, et al. PASA, submitted