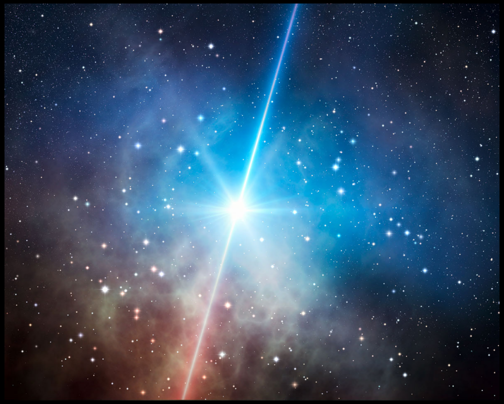
Rapid radio follow-up of high-energy astrophysical events



ESO

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The 2nd Pietro Baracchi Conference

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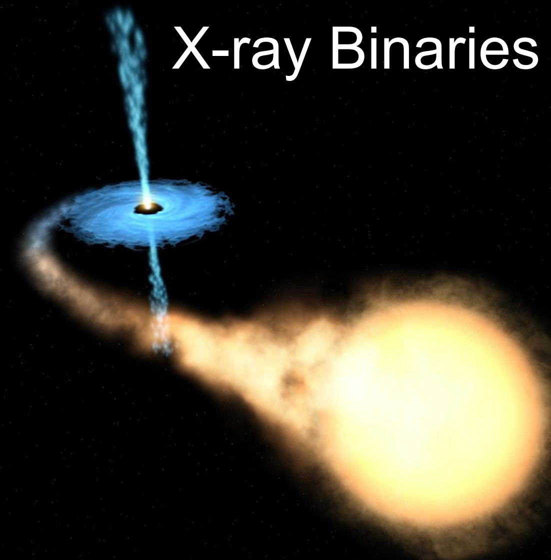
ICRAR
International Centre for Radio Astronomy Research

Curtin University · The University of Western Australia · Government of Western Australia, Department of the Premier and Cabinet, Office of Science

Radio Transients

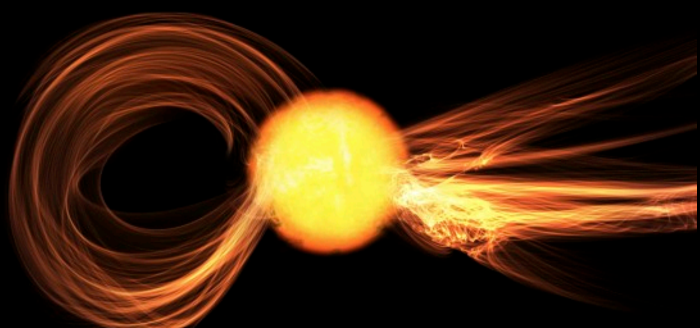
Supernovae

X-ray Binaries



Gamma-ray Bursts

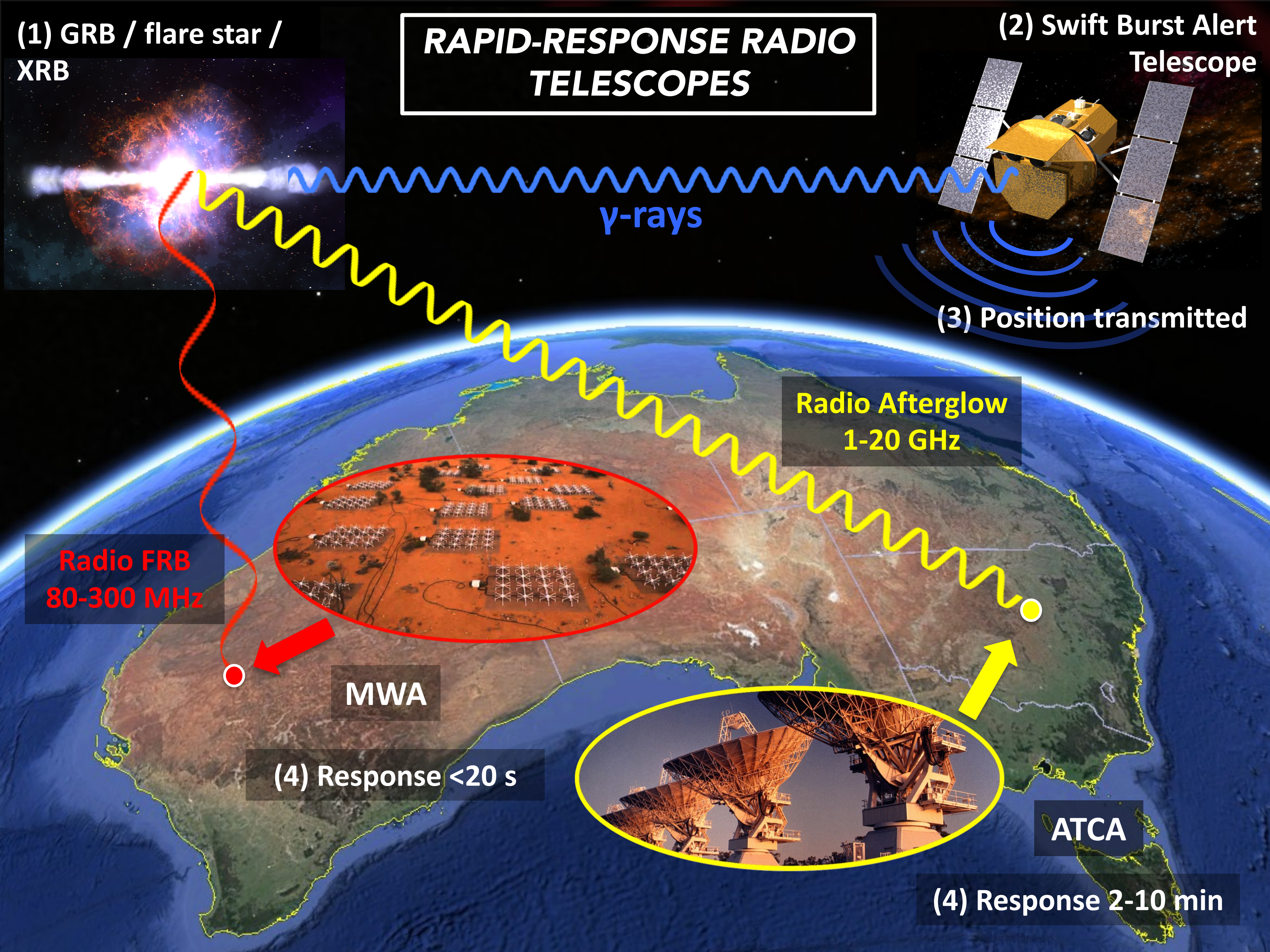
Flare Stars



Tidal disruption Events

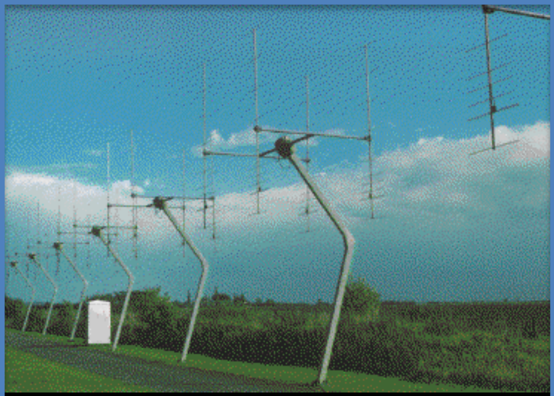
All require rapid and automatic radio triggering!

Getty



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 80-300 MHz
MWA
(4) Response <20 s
ATCA
(4) Response 2-10 min

Radio triggering history



Cambridge: 1990's
151 MHz, BATSE GRBs
e.g. Green et al. (1995)

Mt Pleasant (2011-2012)
2.3 GHz, 5 Swift GRBs
Palaniswamy et al. (2014)

Parkes 12m dish
(2010-2011)
1.4 GHz
9 Swift GRBs
Bannister et al. (2012)

Current radio triggering experiments

AMI (2012 -), 14-18 GHz
Response > 2min
SWIFT GRBs, flare stars, XRBs, magnetars
Staley et al. (2013)

ATCA (2017 -) 1-20 GHz,
Response < 10 min
Swift GRBs, Swift/MAXI flare stars
e.g. Anderson et al. (2018), GCN

Murchison Widefield Array

Low Frequency Array

LOFAR (2018 -) 3-5 min
HBA: 120-168 MHz
Swift GRBs, aLIGO/Virgo GWs
e.g. Rowlinson et al. (2019)

MWA (2014 -) <20s
80-133 MHz
Swift/Fermi GRBs, flare stars, aLIGO/Virgo GWs
e.g. Kaplan et al. (2015)

Status of Australian Radio Telescope's rapid-response modes

Australia Telescope Compact Array

- ToO overrides all active programs if:

Proposal score > minimum schedule score

- <10 min response time
- Override all correlator modes (1-20 GHz)
- VOEvent triggers on SGRBs and flare stars

https://github.com/mebell/vo_atca

Used AMI - 4 Pi Sky VOEvent Broker:

https://4pisky.org/voevents/

SGRBs – Swift-BAT and

Flare Stars – Swift-BAT, MAXI

- Active since April 2017:
- First successful SGRB trigger Dec 2018 (Anderson et al. in prep)
- First successful flare star trigger Jan 2019

Table 1: Unsuccessful ATCA override triggers

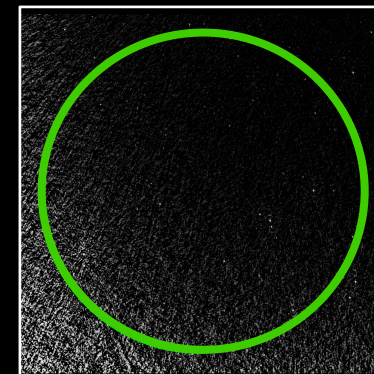
Reason	SGRB	LGRB	Other
Observatory software	2	1	0
VOEvent parsing	1	0	0
Maintenance/reconfiguration	1	0	0
VLBI	1	1	0
Correlator mode	0	2	1
Total	5	4	1

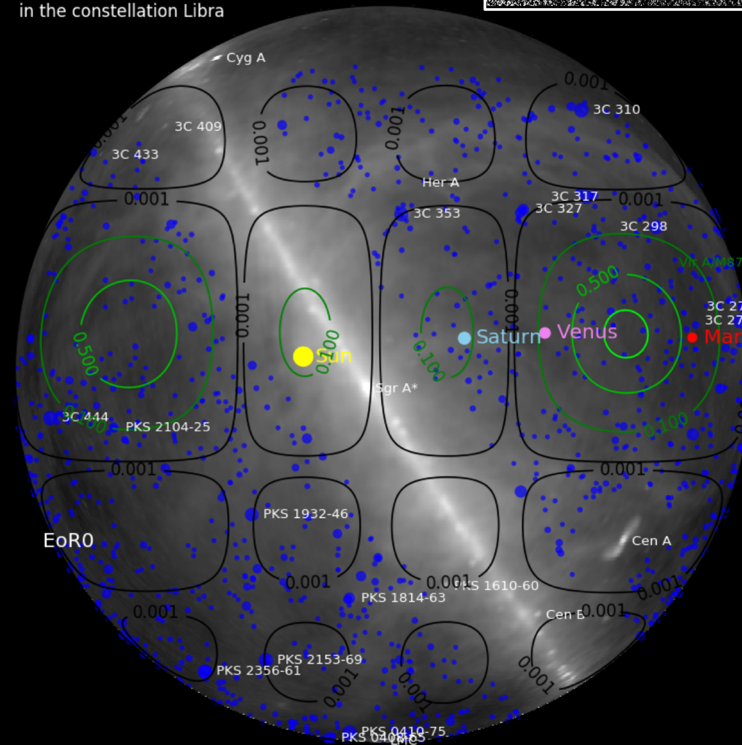
ICRAR

Status of Australian Radio Telescope's rapid-response modes

Murchison Widefield Array

- Upgraded Aug 2018
- Front-end service and VOEvent parser: https://github.com/MWATelescope/mwa_trigger
- ToO override depending on active program's interruptability
- Observations begin (6-14s) <20s
- 30 mins, 0.5s/10 kHz
- Voltage Capture System (VCS)





SGRBs – Swift-BAT and Fermi-GBM
LGRBs – Swift-BAT
Flare Stars – Swift-BAT, MAXI

- Fermi position update repointing
- Sun suppression

Hancock, Anderson et al. (2019), PASA accepted, arXiv:1910.02387

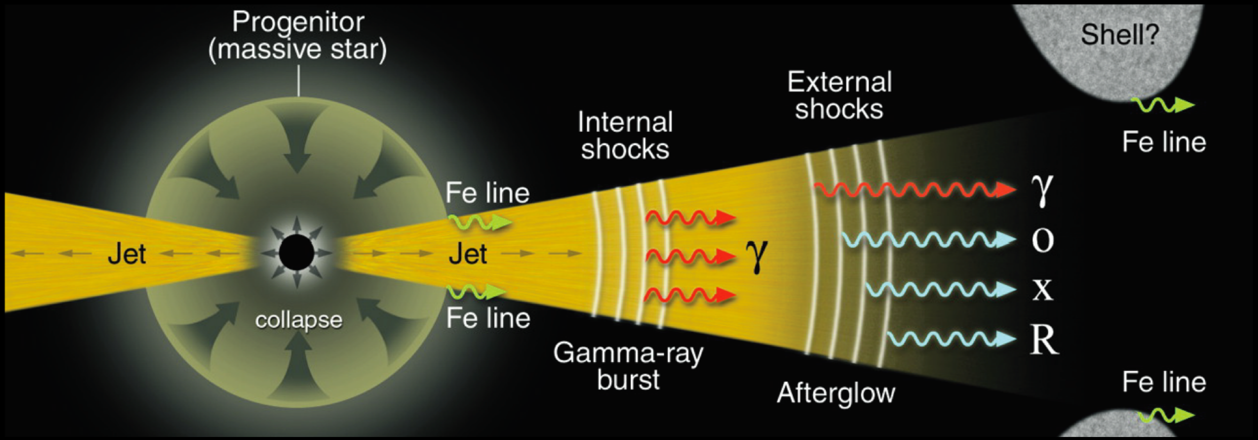
High frequency (GHz) Science Case

Incoherent (synchrotron) transients

Gamma-ray bursts rapid-triggering

Spectrum and light curve modelling (radio)

- SSA peak -> minimum energy
- B field and internal energy f(source size)
- Probe circumburst medium

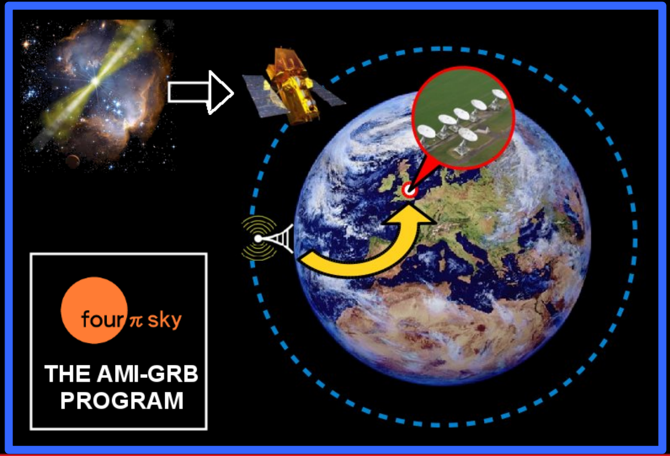


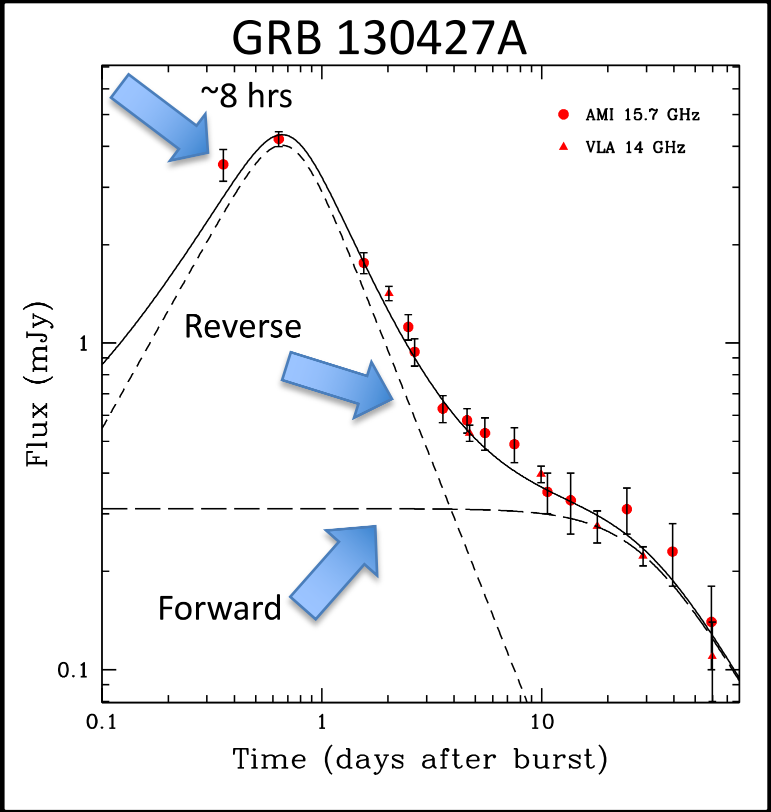
High frequency (GHz) Science Case

Incoherent (synchrotron) transients

Gamma-ray bursts rapid-triggering

Test Fireball model – REVERSE shock detection





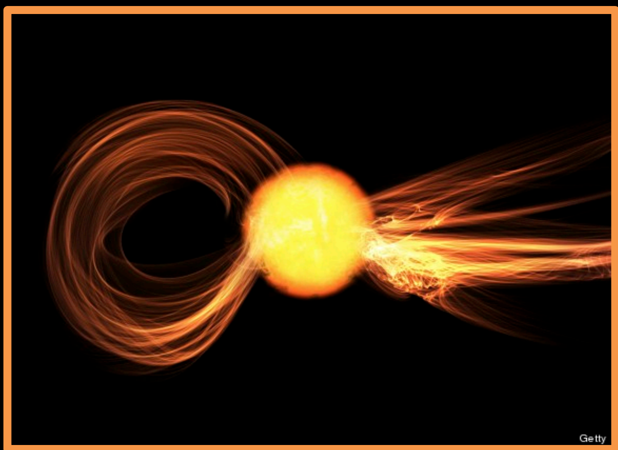
Anderson et al. (2014), MNRAS, 440, 2059

High frequency (GHz) Science Case

Incoherent (synchrotron) transients

Flare stars (rapidly rotating M dwarfs and RS CVn)

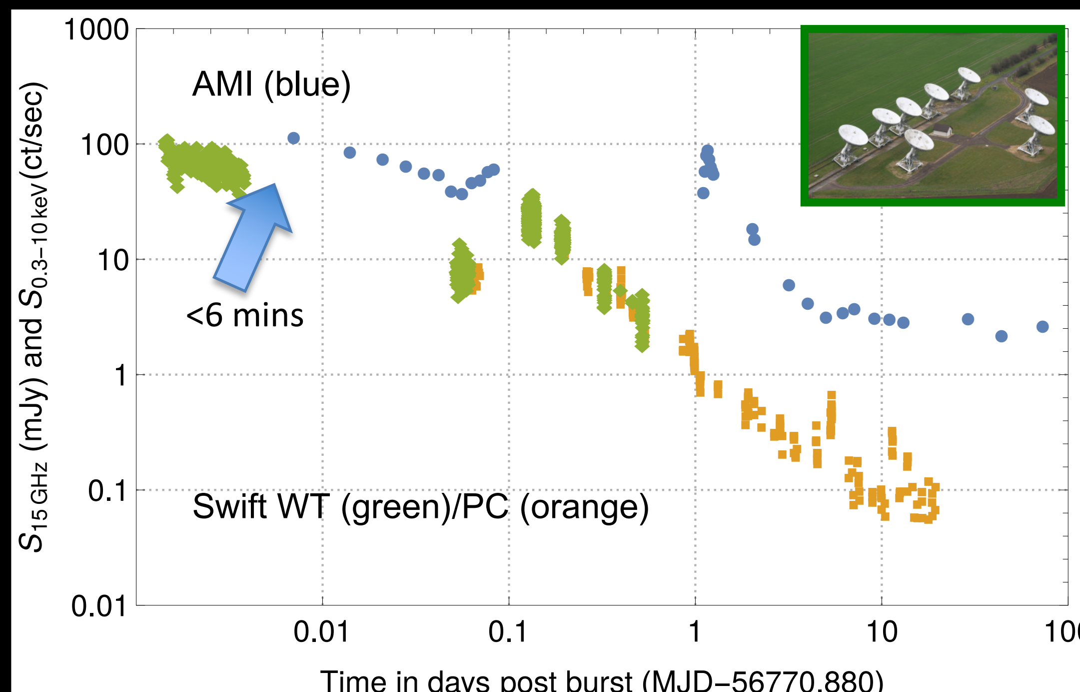
X-ray/Gamma-ray superflare -> giant gyrosychrotron radio flare



Radio studies

- Probe electron population
- Brightness temperature
- KE and B field
- Gyrosynchrotron >5 GHz
- Circularly polarised coherent flares < 5GHz

DG CVn (rapidly-rotation M dwarf)



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

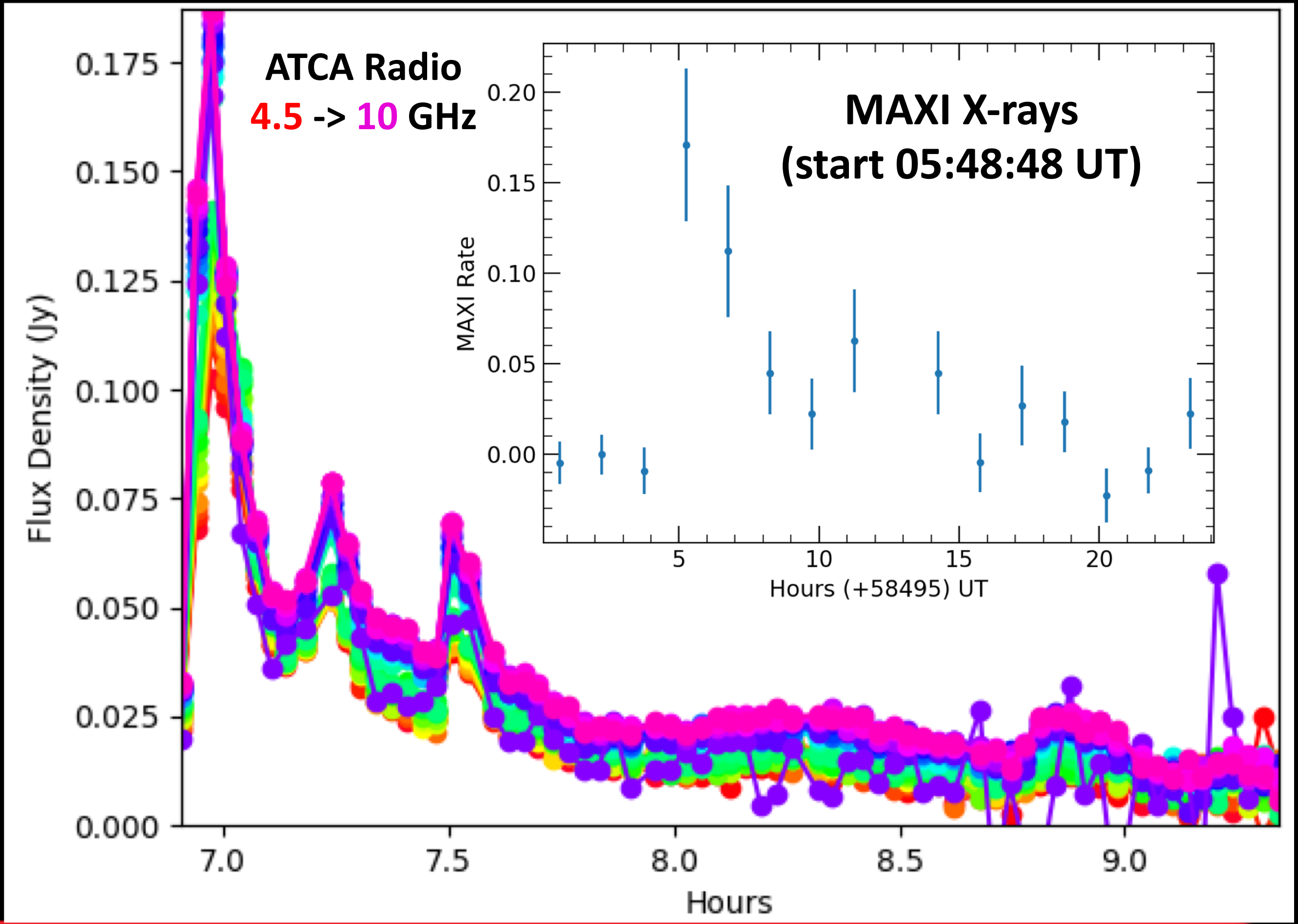
High frequency (GHz) Science Case

Incoherent (synchrotron transients)

Flare stars (rapidly rotating M dwarfs and RS CVn)

X-ray/Gamma-ray superflare -> giant gyrosychrotron radio flare

AT Mic: ATCA trigger on MAXI-detected flare

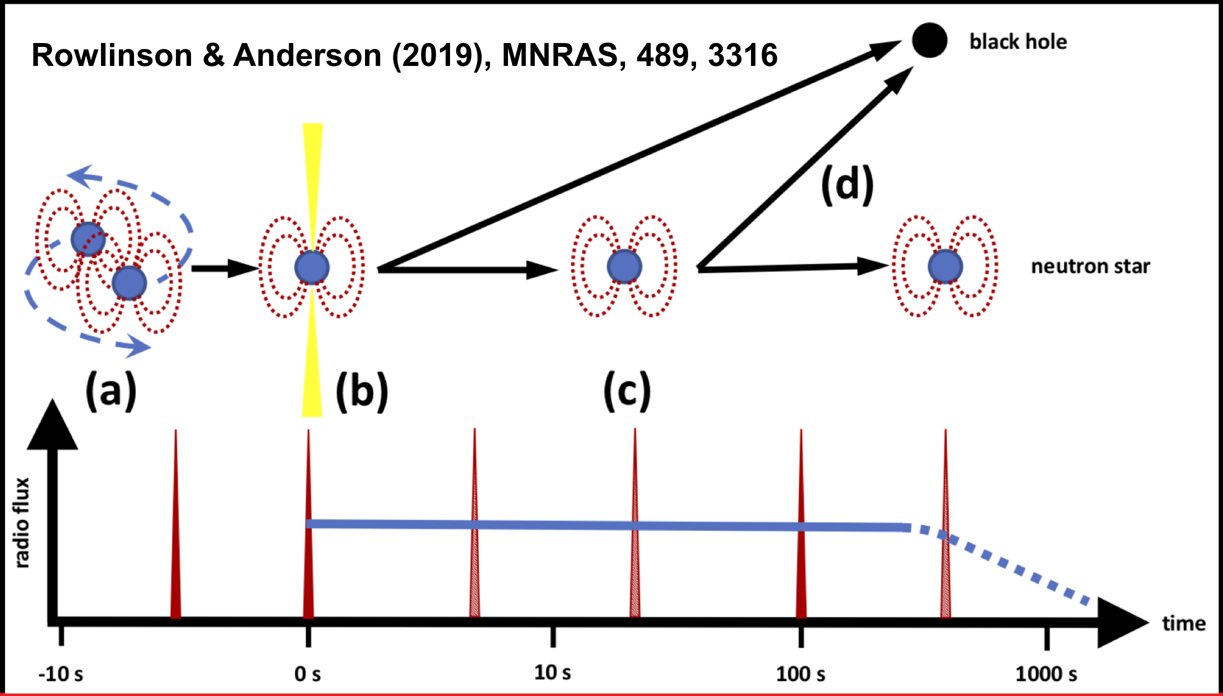


Anderson et al. in prep

Low frequency (MHz) Science Case

Gamma-ray Bursts (GRB) – Prompt emission

- X-ray studies – late-time energy injection: magnetar?
- Theories link coherent prompt (FRB-like) or persistent (dipole radiation) emission
- Models SGRBs (aka BNS GW mergers) and LGRBs
- Merger products - EoS of nuclear matter



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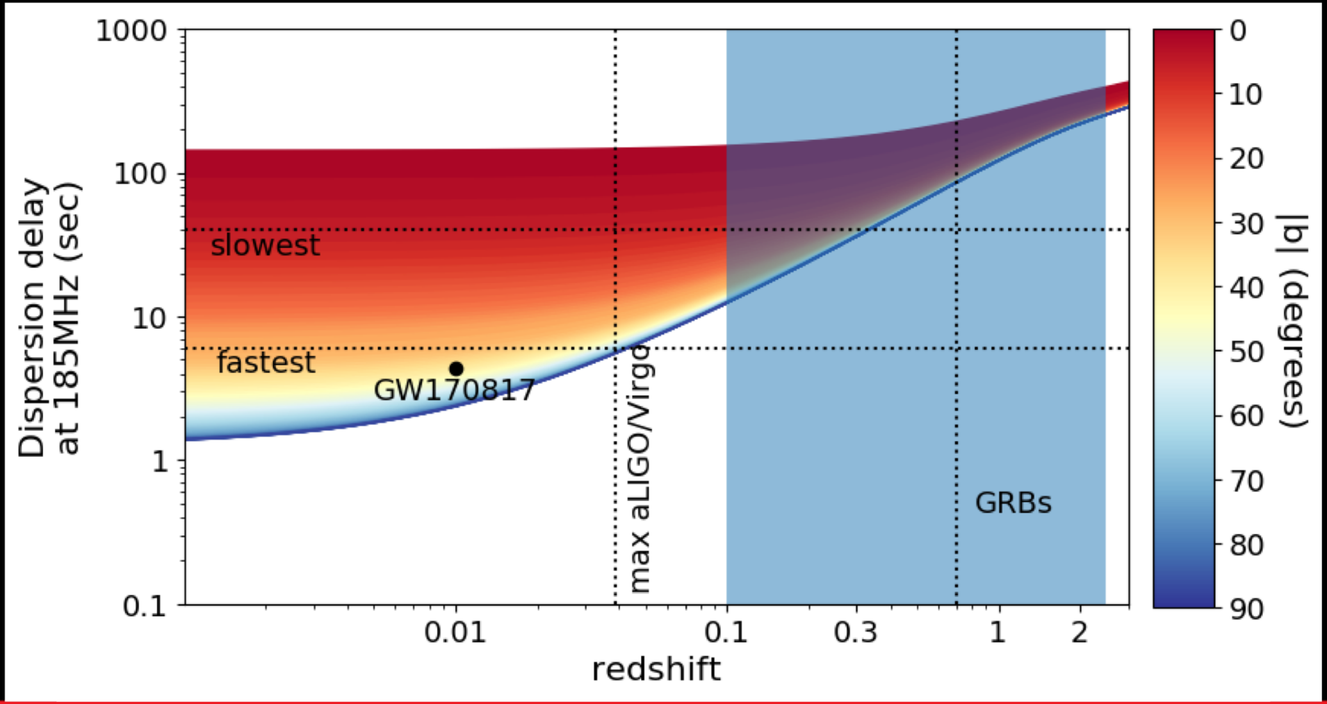
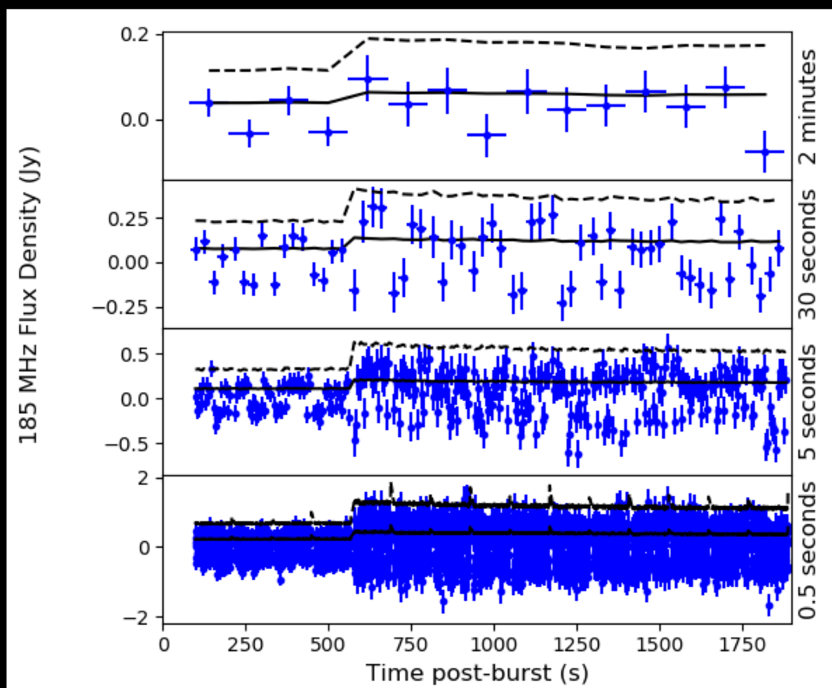


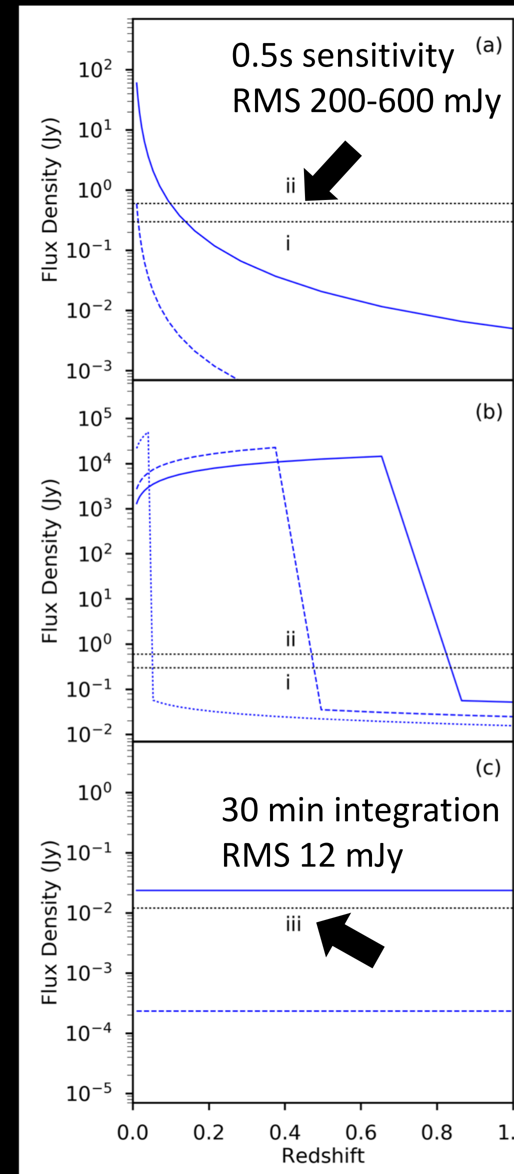
Low frequency (MHz) Science Case

Short Gamma-ray Bursts (SGRB)

MWA trigger on SGRB 180805A

- Response 19s post-VOEvent
- Recording 83s post-burst
- Limits 0.5s, 5s, 30s, 2min, 30s





- Flux predictions based on magnetar model
- Image dedispersion to come

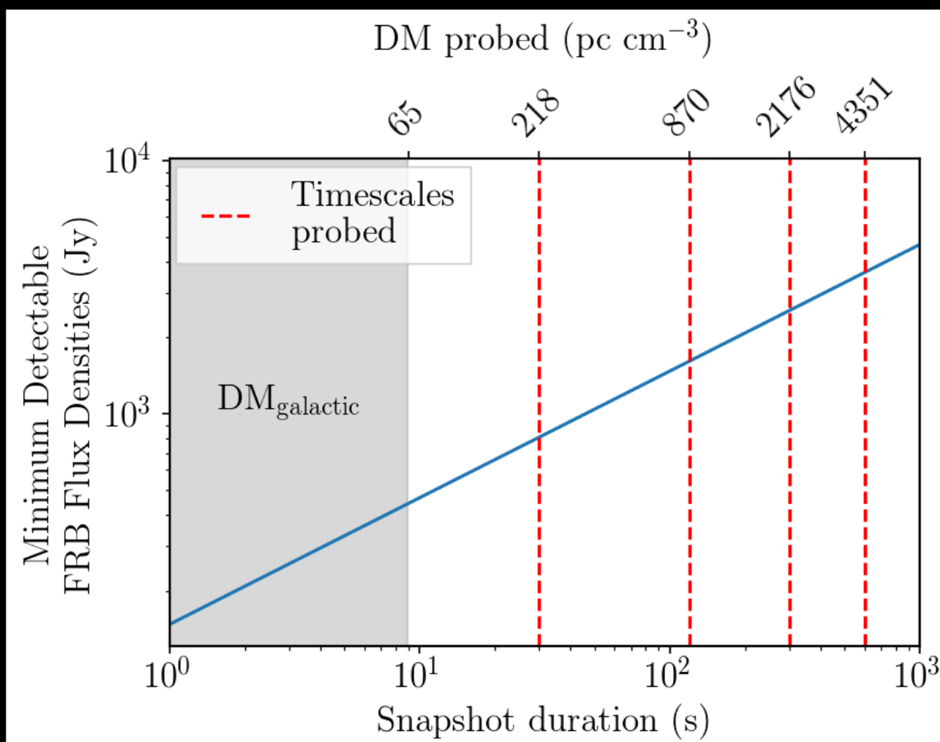
Anderson et al. in prep! Watch this space!

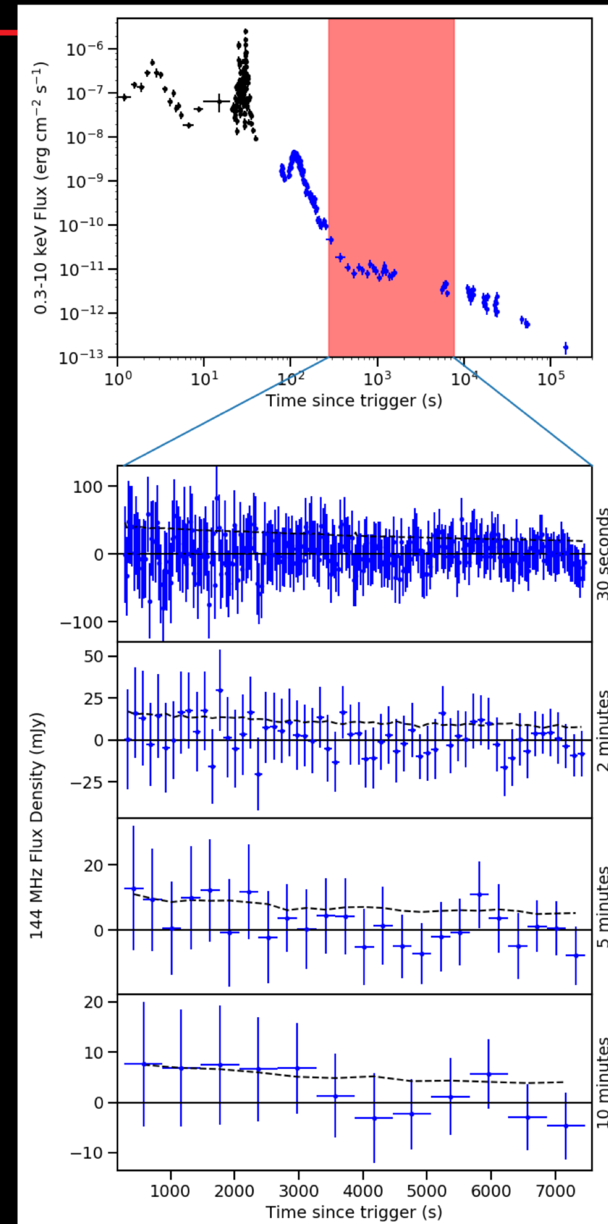
Low frequency (MHz) Science Case

Long Gamma-ray Bursts (LGRB)

LOFAR trigger on LGRB 180706A

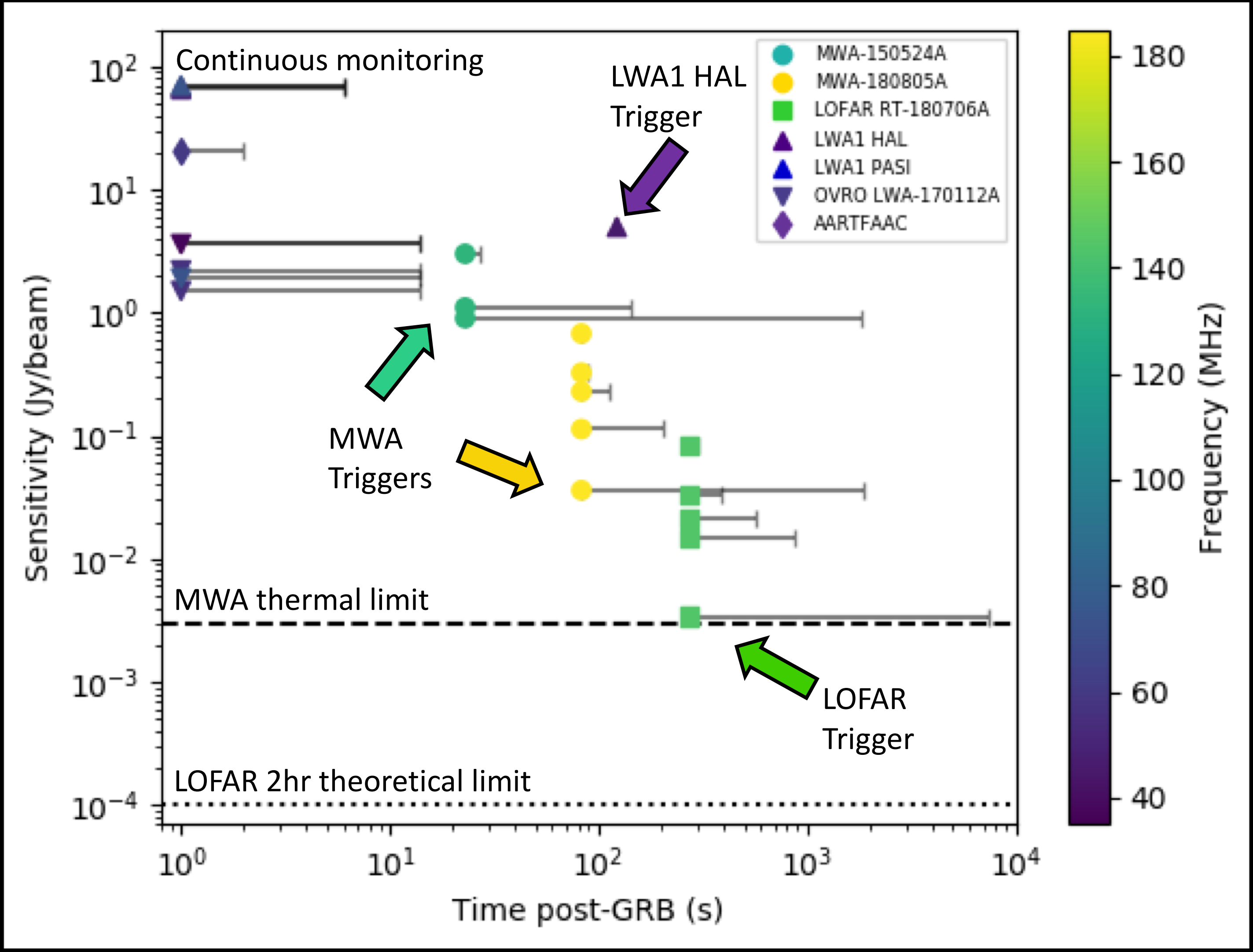
- 4.5 min response
- Limits 30s, 2m, 5m, 10m, 2hr
- Most sensitive limit 1.7mJy/beam (3σ)



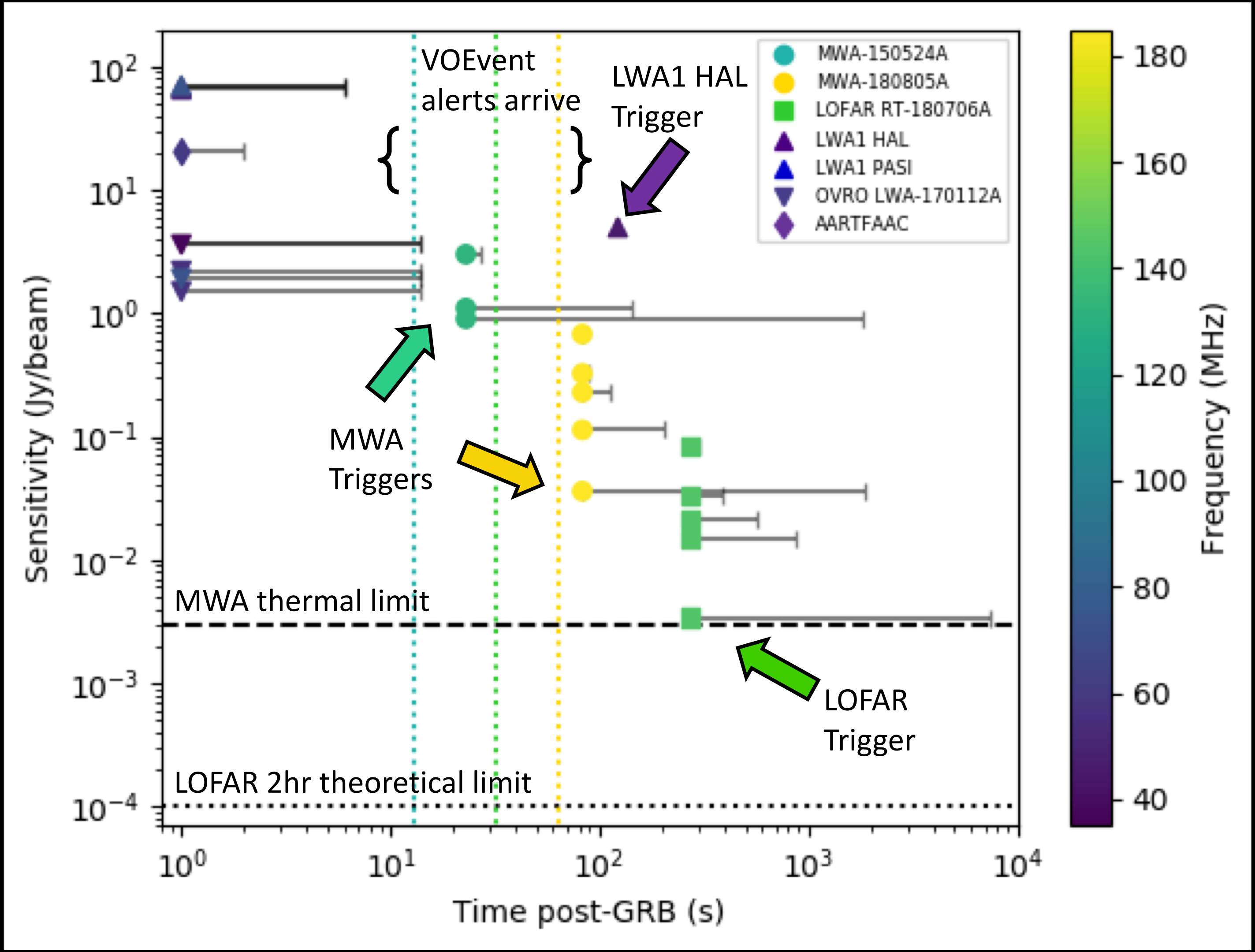


Rowlinson et al. (2019), MNRAS accepted, arXiv:1909.02958

Automated transient capabilities of low frequency telescopes



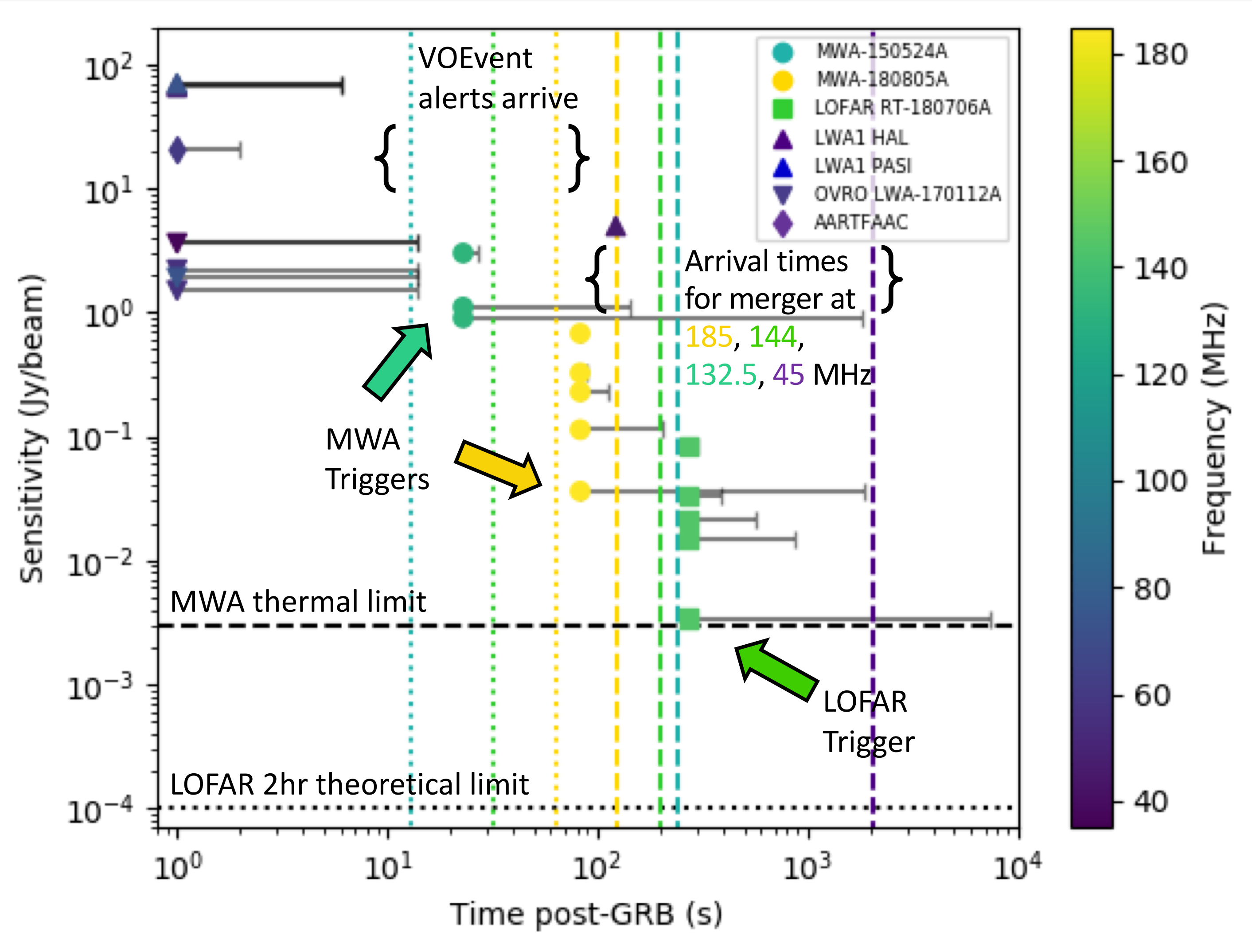
Automated transient capabilities of low frequency telescopes



Anderson et al. in prep

Comparisons to MWA

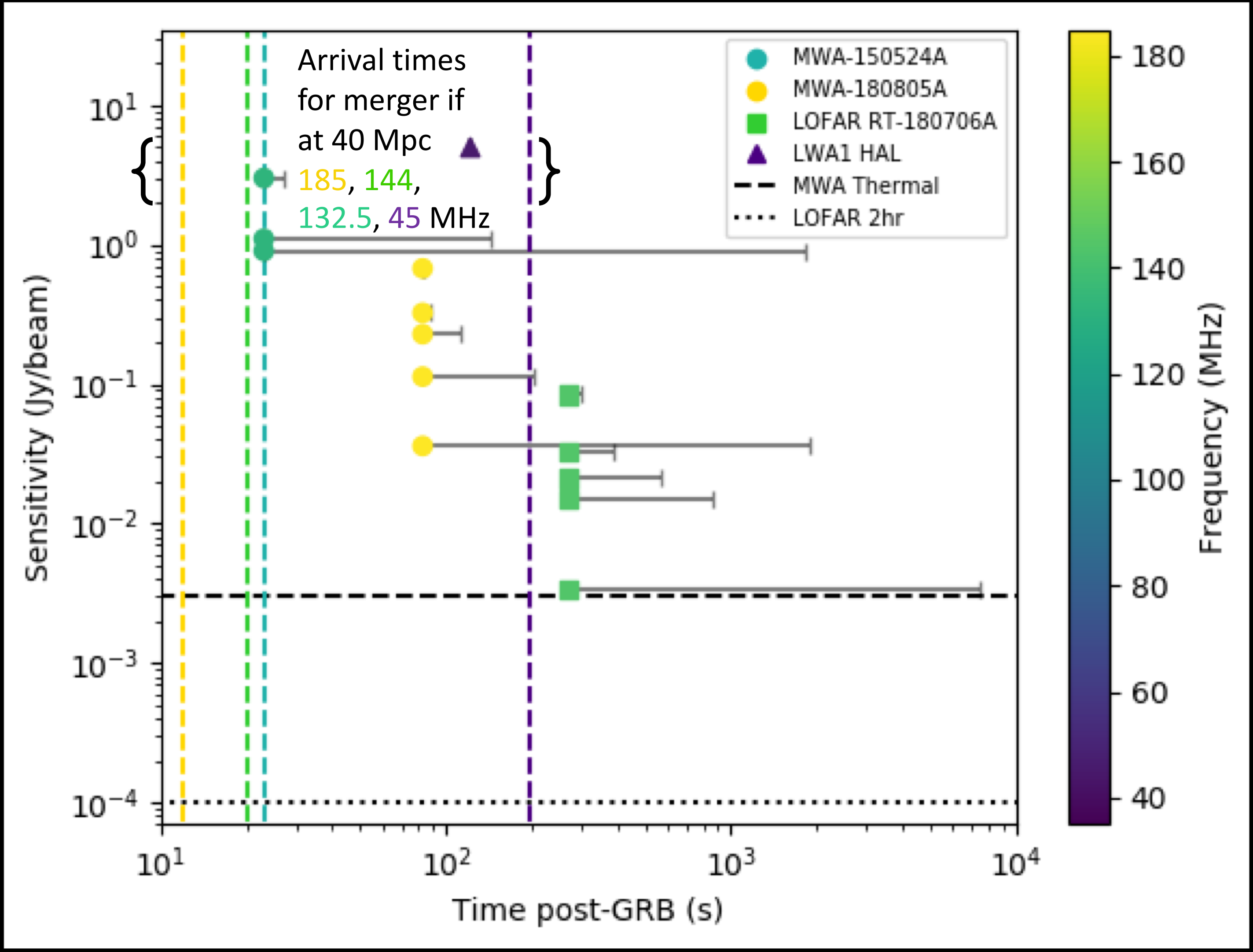
MWA is the most sensitive at early-times



Anderson et al. in prep

What about Gravitational Wave Events?

GW170817 – 40 Mpc



Anderson et al. in prep

Conclusions

- Australian telescopes with active rapid-response modes: Available to all observers!
  - ATCA – largest frequency coverage, polarisation, sensitivity
  - MWA – Fastest response time, good sensitivty
- High frequency (GHz) science case
  - GRB shock physics
  - Stellar flare physics
- Low frequency (MHz) science case
  - GRBs – search for prompt, coherent (FRB-like) radio signals
    - Dispersion delayed
    - Equation of state of nuclear matter