The Critical Seconds - Minutes EM Response Time for TDAMM Science

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TDAMM Motivations

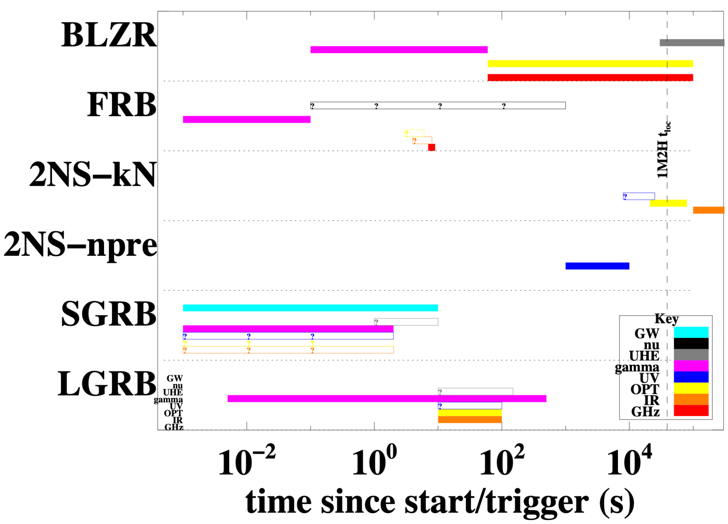
The decadal survey TDAMM section reflects curiosity and excitement over two very big events: First, detection of **GW/SGRB170817**; we have one ID for a NS-NS GW event, but soon we may have dozens / yr. We must be ready to extract science on NS structure, explosion physics, and formation of elements. Second, the coming flood of time domain data: ZTF has already begun, and Rubin will soon produce half-sky surveys every 2 days, a flood of transients on $\gtrsim$ day timescale. But **other important transients have timescale ~sec. !**

What about shorter time scales? –Important science!

The purpose here is to remind NASA and community of importance of much shorter timescale phenomena and science. Doing this science properly (simultaneous, multi-wavelength or multi-band; MW) requires measurements on these difficult time scales, therefore significant work and investment (e.g. multi-band cameras, fast-pointing) from NASA and community are required.

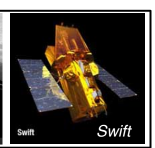
Shorter Time Scales

The figure below shows **just a few** different events/bands requiring fast cadence monitoring a single source, or large areas, or **fast response** to fast triggers, such as Swift BAT triggers, **down to < 1 s.** GW170817 was localized in 11hr –a far longer time scale than any of the events here.



BLZR = BLAZARs; FRB = Fast Radio Bursts, 2NS-kN= NS-NS coalesence kilonova; 2NS-npre = NS-NS neutron precursor[1], SGRB = Short Gamma-ray Burst (incl. GW signal), prompt emission only. LGRB=Long GRB, prompt emission only. Key: GW= gravity wave; nu = neutrino; UHE = any > 100 GeV. Colored rectangles give the rough time scales of bright emission. Open rectangles with question marks = expected emission that is not ruled out, or searched for at all. (Note FRB dispersion puts radio 8 s behind gamma-rays.)

Examples of active fast-response follow-up instruments: NUTTelA-TAO[2] (70 cm; $t_{respond}$<12s, simultaneous g',r',i'), MASTER-NET[3] (40 cm; $t_{respond}\gtrsim$30s, single band), *Swift* (30 cm (space); $t_{respond}$>60s, single band).



References: 1) Metzger, B. D., et al. 2015, MNRAS, 446,1115; 2) Grossan, B. & Maksut, Z. 2020, SPIE 11447, 114479; 3) Lipunov et al., 2010, Adv. Astr, 2010, 30L 4) Shen, R.-F., & Zhang, B. 2009, MNRAS, 398, 1936; 5) Grossan, Kumar, Smoot, 2019, JHEA 23, 14; 6) Metzger, Fang, Margalit 2020, ApJL, 902, 22; 7) Kadler et al. 2016, Nature Physics 12, 807; 8) Acciari et al. 2021, MNRAS 507, 1528.

Shorter Time Scale Science – Electro-Magnetic (EM) Signals

LGRB – Prompt emission mechanism unknown. Measurement of the optical spectral slope during prompt emission, within ~ 10's of s after the γ-ray trigger, will falsify or verify the prevailing emission mechanism theory, a "hard conclusion" (4,5). Requires purpose-built fast-response **simultaneous** (filter wheels too slow) **multi-band** instrument, and extend/replace *Swift*.

SGRB – Prompt emission mechanism unknown; (time-) extended emission nature unknown; GW source studies just begun. As above, the prompt emission mechanism remains unknown, but requires <1 s timescale optical slope measurement (e.g. a sensitive, wide-field, multi-band, all-time monitor; but none exist).

NS-NS kilonova – only one, and no EM < 11 hours. Estimates of *even earlier* UVOIR require space UV, MW (multi-wavelength or -band to measure Temp.), rapid response.

NS-NS neutron precursor – Bright UV emission starting 10^3 s, earlier than from kilonova, is predicted due to free neutron decay heating of ejecta[1]; important for relativistic calculation, NS structure science. Requires space MW UV, rapid response.

FRB – FRB20200428 / SGR200428 detected in both radio and X-ray. Emission mechanism unknown. potential IR or mid-IR measurement of extinguished galactic sources with wide-field, sub-s cadence sky monitor, perhaps with very-rapid response. Possible ν signal[4].

Multi-messenger science: Fast EM response value

MM capabilities now impressive; however, localizations are large and IDs suffer from high false probability. Ice Cube regularly issues alerts of ν detections, some with position + time coincidence with HAWC (high energy γ-rays); the high rate of non-astrophysical νs, up to 50% false alarm rate on some alerts, makes source ID difficult. Short time, coincident flares detected in high-resolution UVOIR instruments would greatly improve ID confidence. *No high-speed localization and follow-up system exists.*

Fast-response localization and counterpart searches, wide-field full-time monitors, would greatly reduce the time window of these searches, increasing ID confidence.

BLAZARs – PKS 1424-418 was identified as the source of a PeV ν in Ice Cube[7] IC35; at these energies, atmospheric events rare. The source's "flare state" was a supporting evidence, but it had been flaring for ~ year, an extremely poor time coincidence.

FRBs – ν flares are an important prediction[6] of the baryon-loaded shock scenario for poorly understood FRB event (note: only close events detectable).

Note UHE$\gtrsim$ 100 GeV EM IDs would also benefit from coincident detection of UVOIR (or other high-resolution instruments). Consider UHE **BLAZAR Flares**– e.g. TXS1515-273 E>400 GeV[8].

Recommendations

- **Enable ~second delay follow-up, always**, for simultaneous MW science enhancement. *Can you speed up localizations?* Can you automate your transient alerts? *Did you invest in fast communications?*
  – *NASA Panels take note: if proposed instrument could detect a transient, ask what the PI did to provide for MW follow-up.*
  -TDRSS oversubscribed? NASA should explore commercial options.
- **Invest in fast-response multi-wave follow-up.** Little NASA, NSF investment in new instruments. Simultaneous MW especially lacking.
- **Invest in better localizations, always.** More science always comes from MW follow-up. For any proposed instrument, ask the cost of improving σ_{posn} by factors of 2, or 10. Balance PI vision and community MW follow-up.
- **New Tech: Fast follow-up spectra** (?Fast phot2spec transition? Ultra-Wide field IFUs?)
- ***Next-Gen Swift:*** I propose an immediate effort to replace Swift with < 20 s response, I-U multi-channel simultaneous capability. SVOM is a marginal substitute for true simultaneous MW transient measurements, without IR, and localizations and event rates inferior to *Swift*, which will not work forever.

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