TDAMM Observing Plan/Strategy for Magnetars

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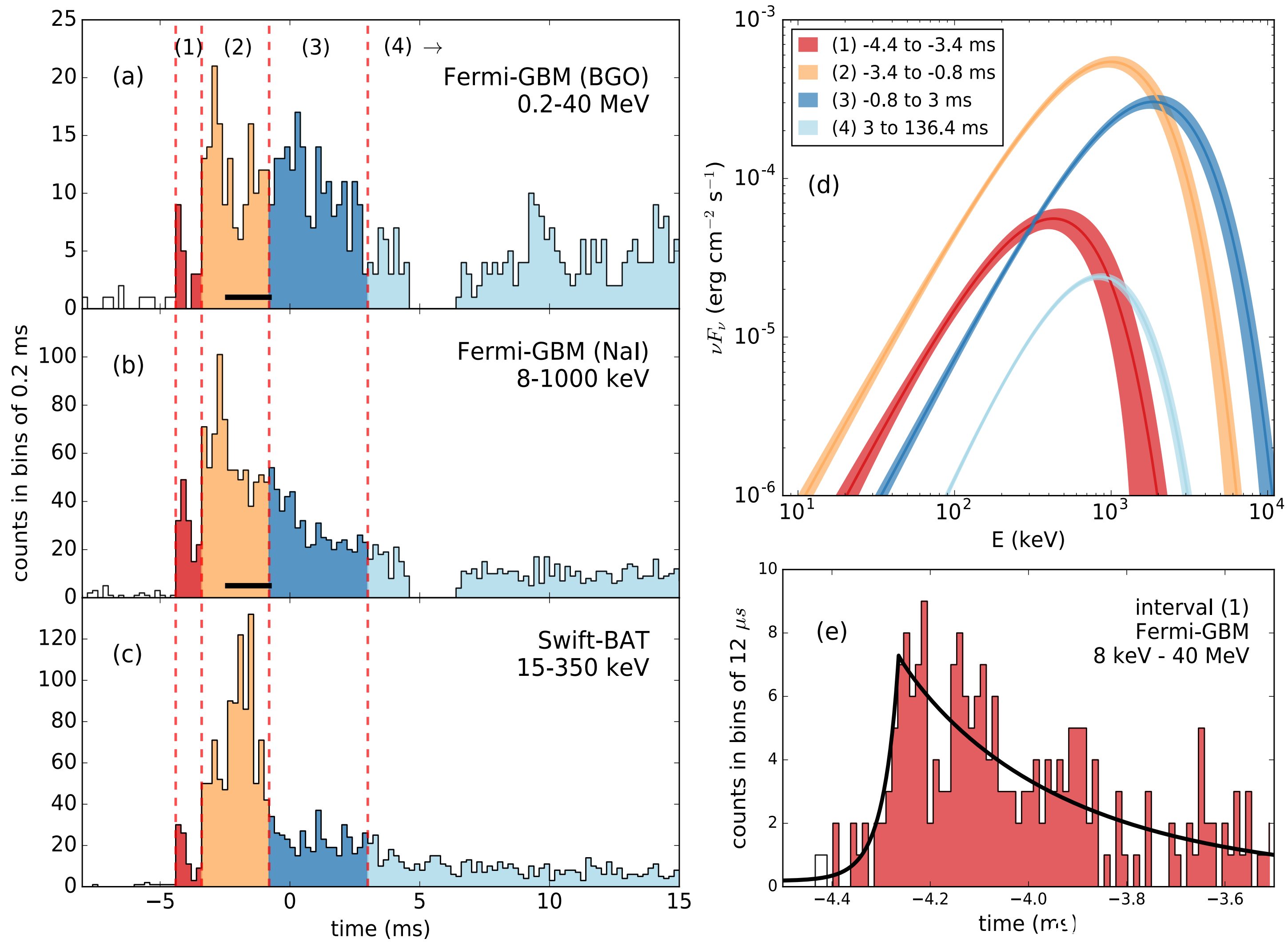
Magnetar Overview

- Transient activity of magnetars provides a zoo of phenomenology to test fundamental physics under extreme conditions using one of most exotic objects in the universe.
- Focal tests are for strong magnetic field QED:
  - quantum vacuum birefringence (X rays) and magnetic photon splitting (soft gamma rays)
- Constraining the magnetar equation of state at supra-nuclear densities is a core goal:
  - probes nucleon superconductivity and superfluidity.
- Seek possible gravitational waves accompanying structural rearrangements that may also spawn transient r-processes nucleosynthesis.

Magnetar Giant Flares (MGFs)

- The most powerful signal emitted by magnetars, with $L \sim 10^{45}$ - 10^{47} erg/sec at peak.
- Expected event rates are 3.8×10^5 /Gpc/year (Burns et al 2021, Trigg et al 2025, in prep).
  - Rate within ~5 Mpc is ~1/few years;
  - Milky Way rate is one every 2 decades .
- Initial pulse is of ~ms peak timescales.
- Galactic events will see oscillatory X-ray tails for a few hundred seconds, and any nuclear gamma-ray emission for a few thousand seconds.
- The nucleosynthesis may power a nova brevis visible in Galactic and possibly extragalactic events.

GRB 200415A: *Fermi*-GBM and *Swift*-BAT



Comptonized spectrum throughout, non-thermal.

Further Details: O.J. Roberts et al., Nature: http://doi.org/10.1038/s41586-020-03077-8

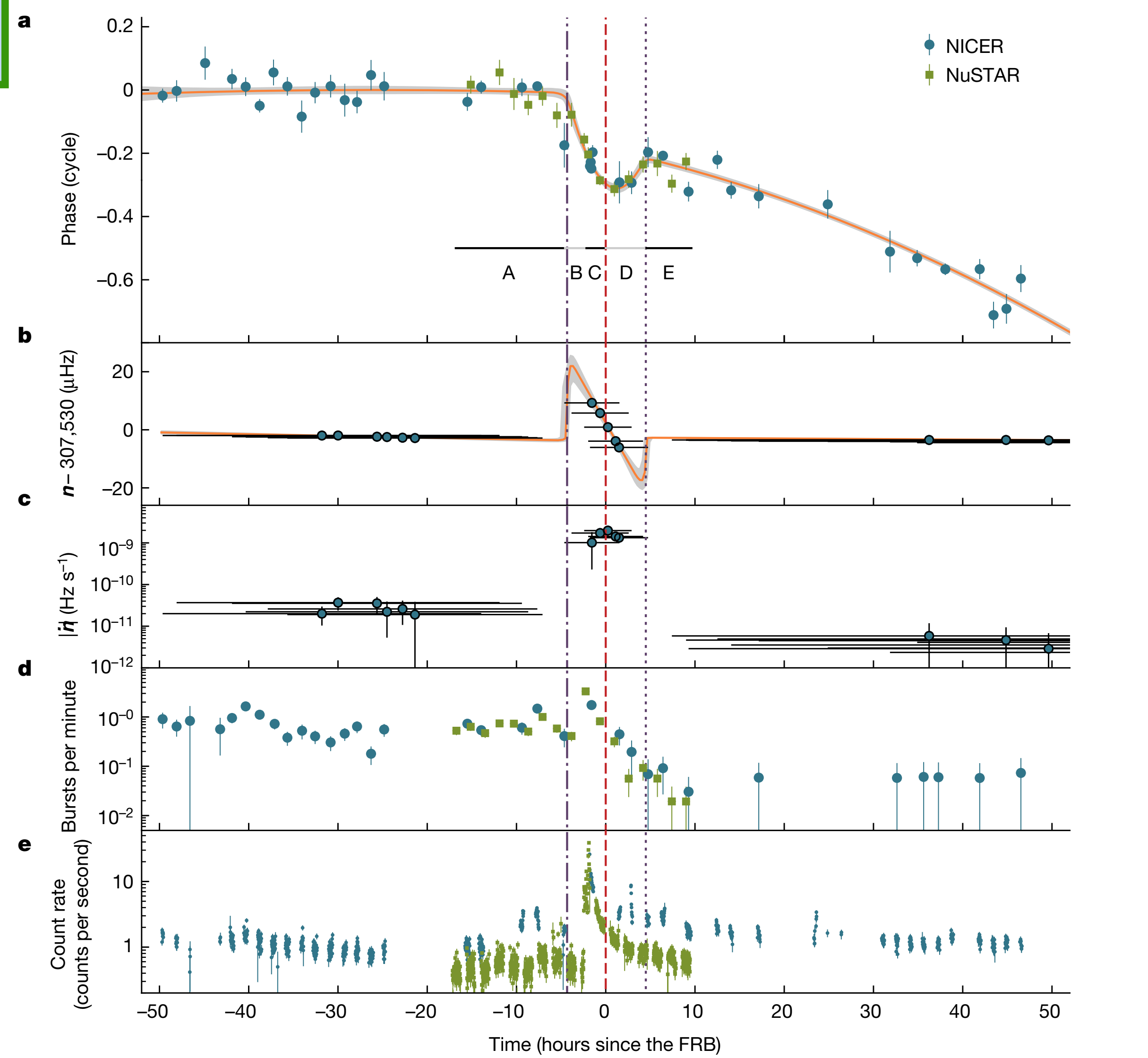
Magnetar State Changes

- Onset of magnetar flaring states with energetic bursting (hard X-ray) and persistent (soft and hard X-ray) emission occurs once every few years.
- Pulsed radio emission arises every few years.
- FRB/magnetar-burst joint detection - rate of up to one per year when a given magnetar is active:
  - e.g. SGR 1935 has given ~4 in the past 5 years, but other magnetars are quiet.
- Glitches, spin-down glitches, extreme timing anomalies occur once every few years;
  - are they tightly coupled to FRBs and MGFs?
- What is needed?: high cadence radio/X-ray/gamma-ray monitoring of the temporal evolution of the magnetar.

SGR J1935+2154 Double Glitch

C.-P. Hu et al. Nature **626**, 500 (2024).
See also Younes et al. (Nat Astron 2023).

- Two strong glitches seen in **October 2022** from SGR J1935+2154.
- In between there was an FRB, and a strong spin-down epoch, nominally from a strong wind emanating from the magnetic pole.
- Net mass loss is large.
- Slow release implies energy density orders of magnitude less than for MGF => radiatively weak in hard X-rays.



Lessons Learned from the Past

- Case Study: 2004 Galactic giant flare from SGR 1806-20
- What worked well:
  - The reports of the unusually active state led to monitoring before, during, and after the giant flare. This included contemporaneous radio observations.
- What could be improved:
  - The identification of the giant flare was not done for 2 days.
  - There were no rapid follow-up in key wavelengths including UV and optical (landscape is different now).
  - Arcsecond scale gamma-ray localizations
- Key facilities in future include IPN.

Lessons Learned ctd.

- Case Study: 2023 giant flare from M82
- What worked well:
  - Quick identification that the short burst came from a nearby star-forming galaxy and was likely a giant flare.
- What could be improved:
  - Automated identification for likely events.
- Role of Specific Facilities: INTEGRAL's individual capability for ~arcminute localizations drove this.

Lessons Learned ctd.

- Case Study: SGR 1935 X-ray bursts + FRBs
- What worked well:
  - Early identification that FRBs and X ray bursts were associated.
- What could be improved:
  - Automated identification for likely events.
- Role of Specific Facilities: INTEGRAL, Konus-Wind, Fermi-GBM, CHIME, FAST, Insight-HXMT, NICER, NuSTAR

Recommended Observing Timelines

- Giant flares:
  - T0 + 1 minute: hard X-ray observations to capture tail emission;
  - T0 + 15 minutes - hours: UV/optical spectroscopy and imaging to capture nucleosynthetic nova brevis;
  - T0 + 0.5 days - weeks: multi-epoch coverage across X-ray / radio/gamma-ray in order to monitor the temporal evolution of the magnetar, and look for nebula emission.

- Persistent emission and bursting state changes:
  - T0 + 0.5 days - weeks: Multi-epoch coverage across X-ray / radio in order to monitor temporal changes, including glitches;
  - Seek fast radio bursts (FRBs) and pulsed radio episodes.

Community Coordination Needs

- Space missions, ground-based observatories, coordination networks need to be alerted.
- Preferred alert channels: GCN
- MGFs: need automated identification of MGF candidates with classification probabilities and localizations.
- Magnetar FRBs and GWs: need automated association of events and immediate alerts.

Open Questions/Discussion Points

- What parameter space remains under-explored for magnetars?:
  - No robust observation of nova brevis signals;
  - No observations of GW or neutrinos from magnetars.
  - How do we build upon the IXPE success story for persistent signals and measure hard X-ray polarization in magnetars?
- Are there new facilities coming online that will improve follow-up?
  - Rubin, ULTRASAT, UVEX, COSI, Km3Net, KAGRA
- What are the biggest limitations in current strategies?
  - Lack of investment in automated infrastructure;
  - Lack of systematic tracking of current states of magnetars.