The next decade of GRB science: Swift legacy

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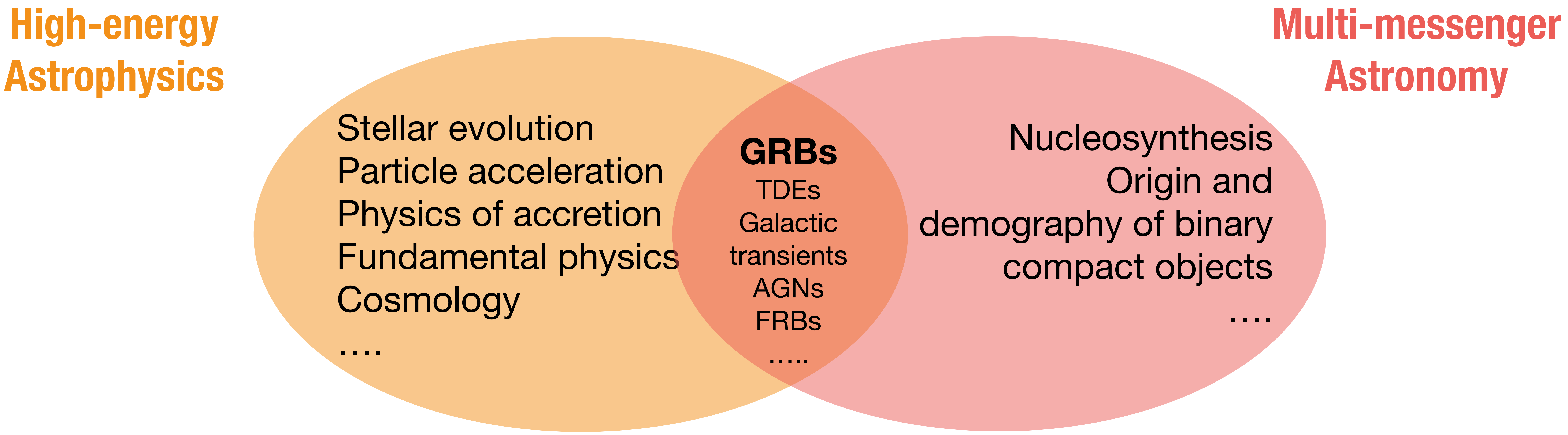
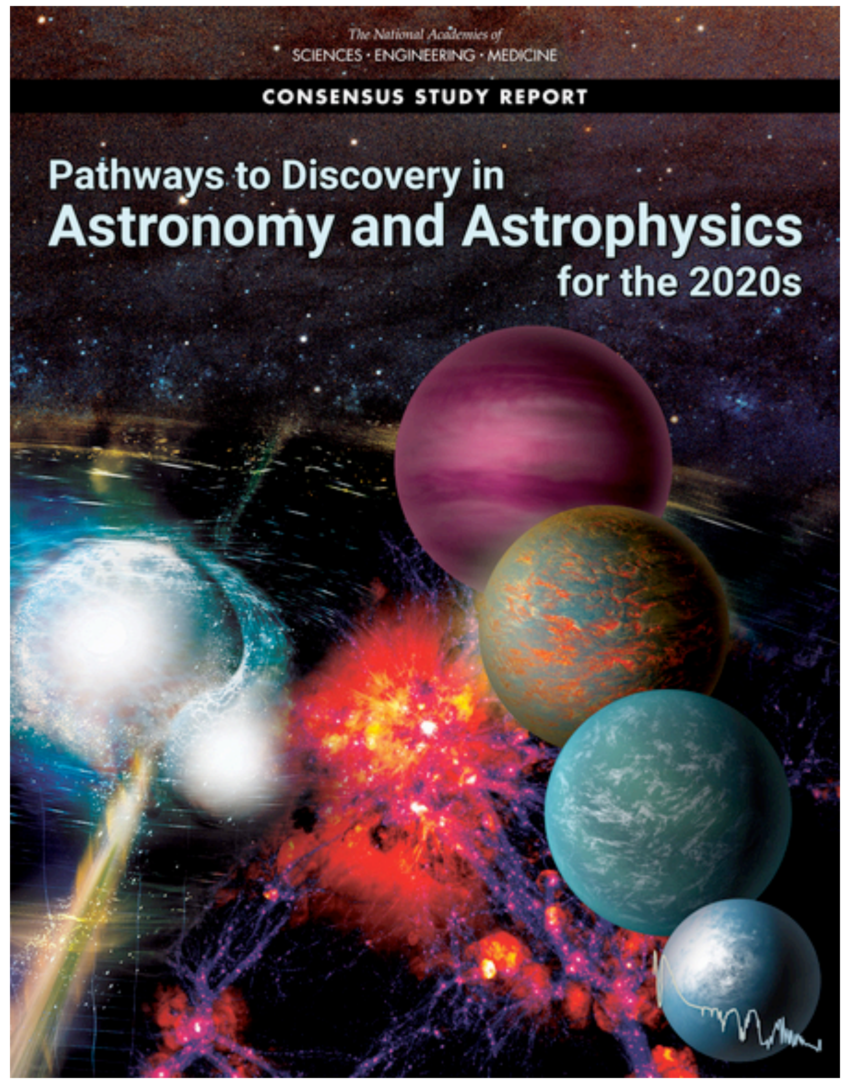
What do we expect for the next decade?





"*Pathways to discovery in Astronomy and Astrophysics for the 2020s*" (NASA decadal survey, 2023):

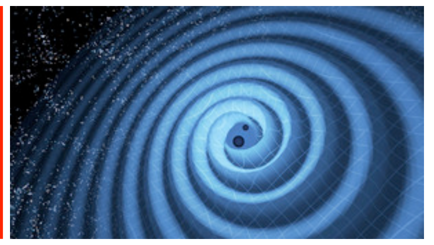
- The study of **transient and multi-messenger Universe is a recognized priority** for the next decade and beyond
- The role of **small and medium-size missions is fundamental** to discover and characterize new transients
- New space missions shall account for the **diversity of high-energy transients, in terms of time and energy scales**

https://nap.nationalacademies.org/catalog/26141/pathways-to-discovery-in-astronomy-and-astrophysics-for-the-2020s

Small and medium size missions in GRB science

Past breakthrough

BIRTH OF THE MULTI-MESSENGER ASTRONOMY WITH GWs



INTEGRAL
- Short GRBs and GW

1970 | 1980 | 1990 | 2000 | 2010 | 2020 | years

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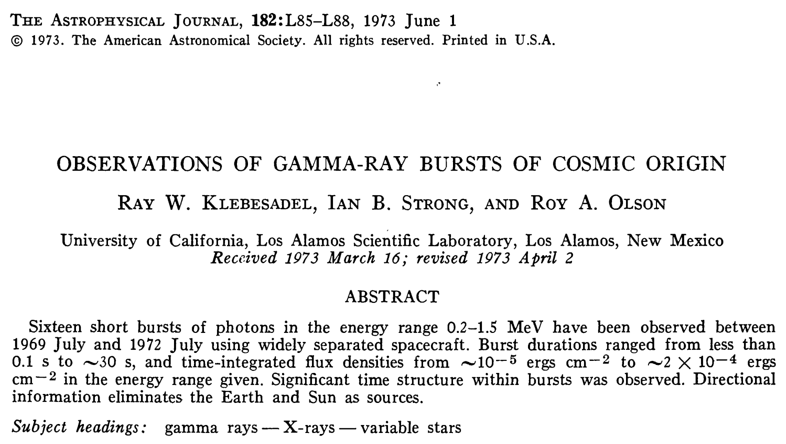
Announcement of the discovery by the Vela satellites


THE ASTROPHYSICAL JOURNAL, **182:**L85–L88, 1973 June 1
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OBSERVATIONS OF GAMMA-RAY BURSTS OF COSMIC ORIGIN

RAY W. KLEBESADEL, IAN B. STRONG, AND ROY A. OLSON

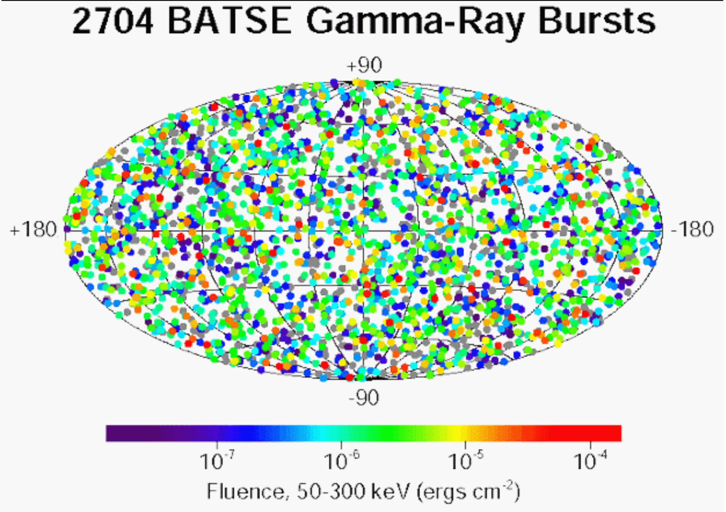
University of California, Los Alamos Scientific Laboratory, Los Alamos, New Mexico
Received 1973 March 16; revised 1973 April 2

ABSTRACT

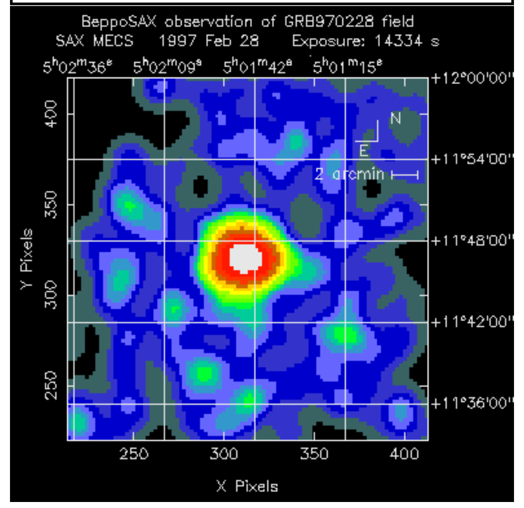
Sixteen short bursts of photons in the energy range 0.2–1.5 MeV have been observed between 1969 July and 1972 July using widely separated spacecraft. Burst durations ranged from less than 0.1 s to $\sim$30 s, and time-integrated flux densities from $\sim 10^{-5}$ ergs cm^{-2} to $\sim 2 \times 10^{-4}$ ergs cm^{-2} in the energy range given. Significant time structure within bursts was observed. Directional information eliminates the Earth and Sun as sources.

Subject headings: gamma rays — X-rays — variable stars

CGRO/BATSE
- Extragalactic origin
- Short and long
- Prompt emission spectrum



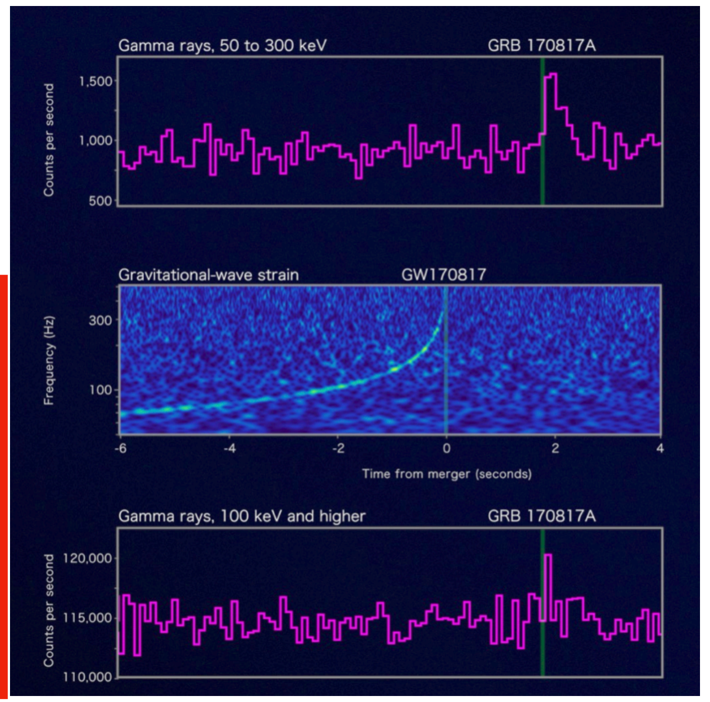
BeppoSAX
- Long GRBs afterglow and redshift
- Long GRBs and SNe



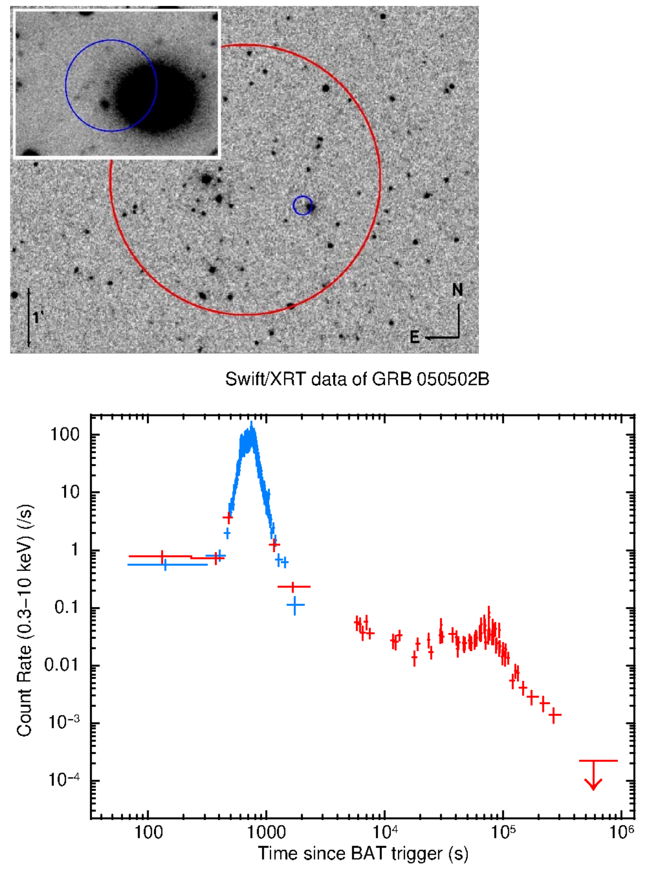
HETE II
- XRR/XRF
- Short GRB afterglow

Agile

Fermi
- Prompt emission at high-energy
- Short GRBs and GW



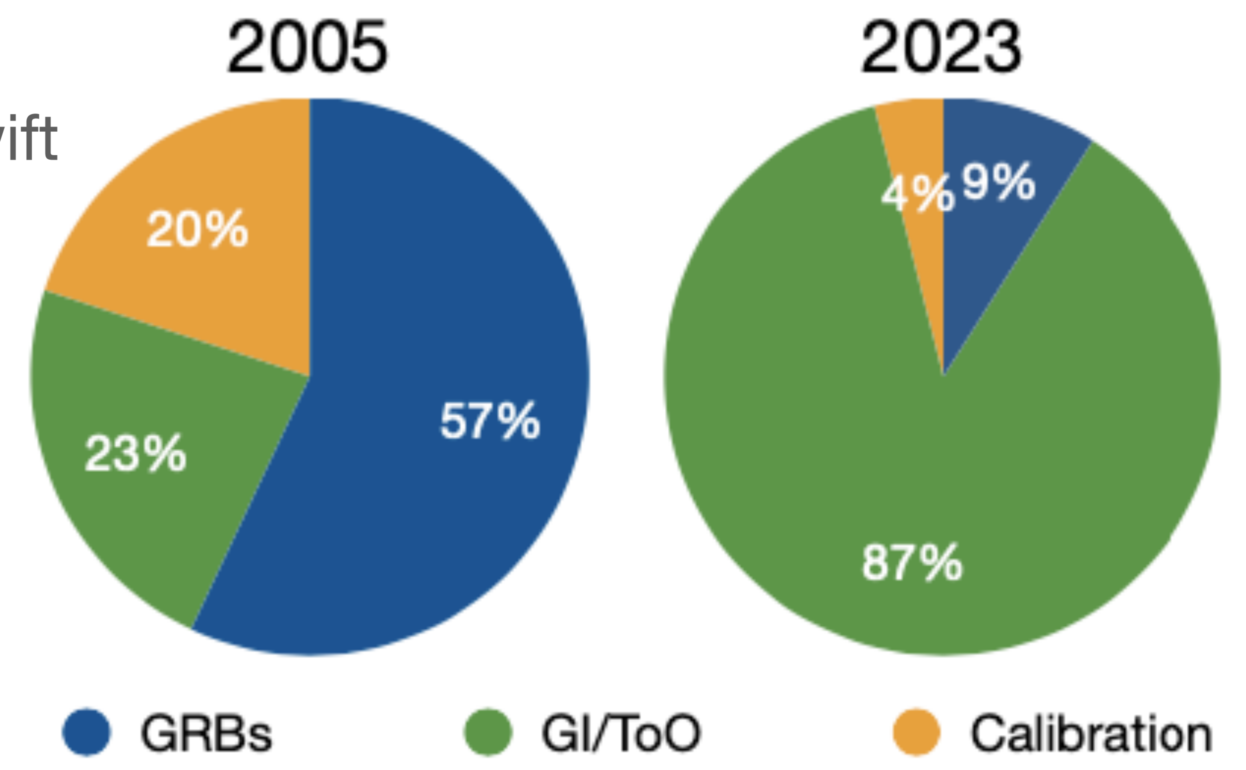
Swift
- Short GRBs afterglow and redshift (and progenitors)
- Early X-ray emission (plateaus and flares)
- UV kilonova

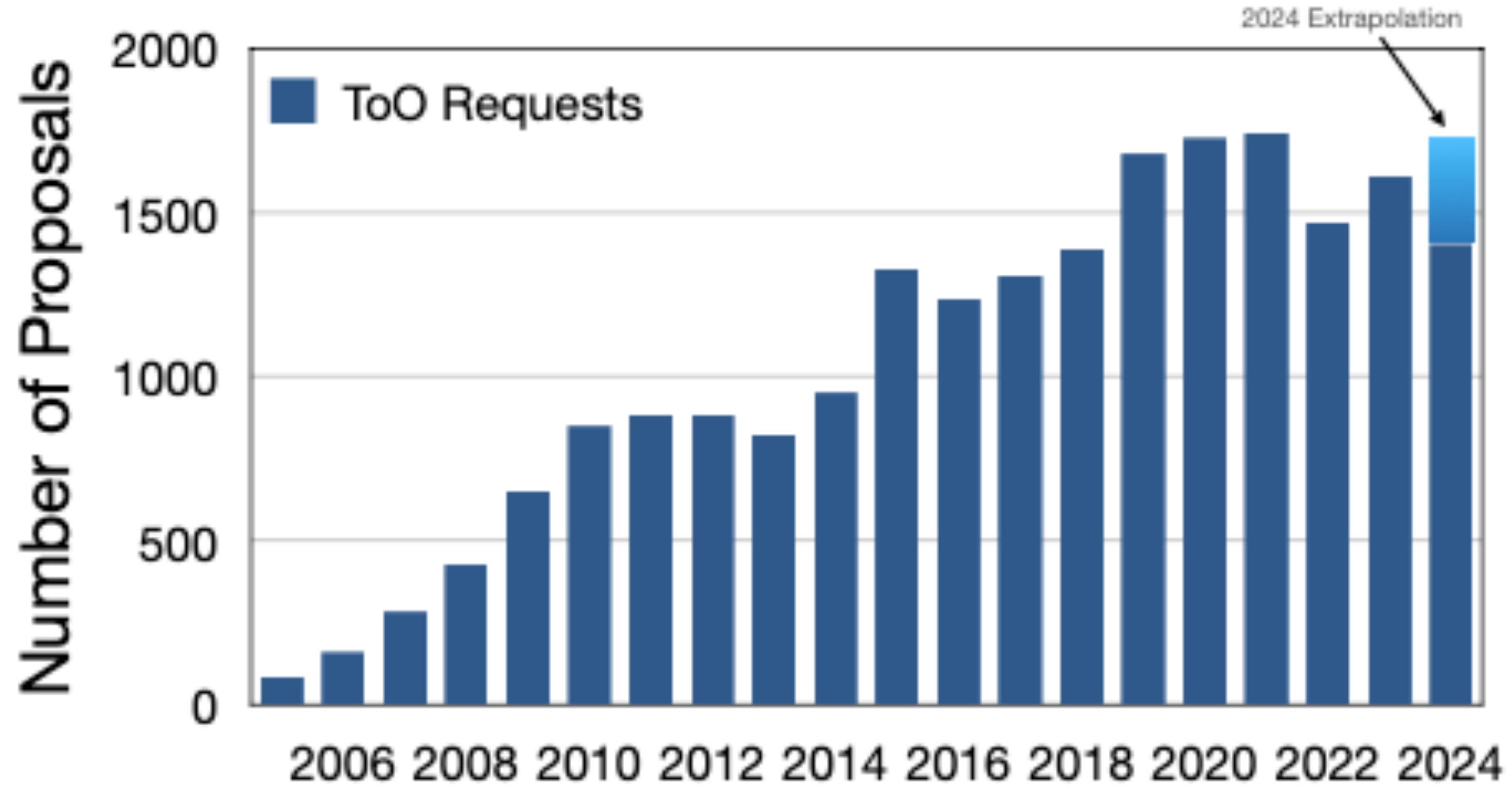


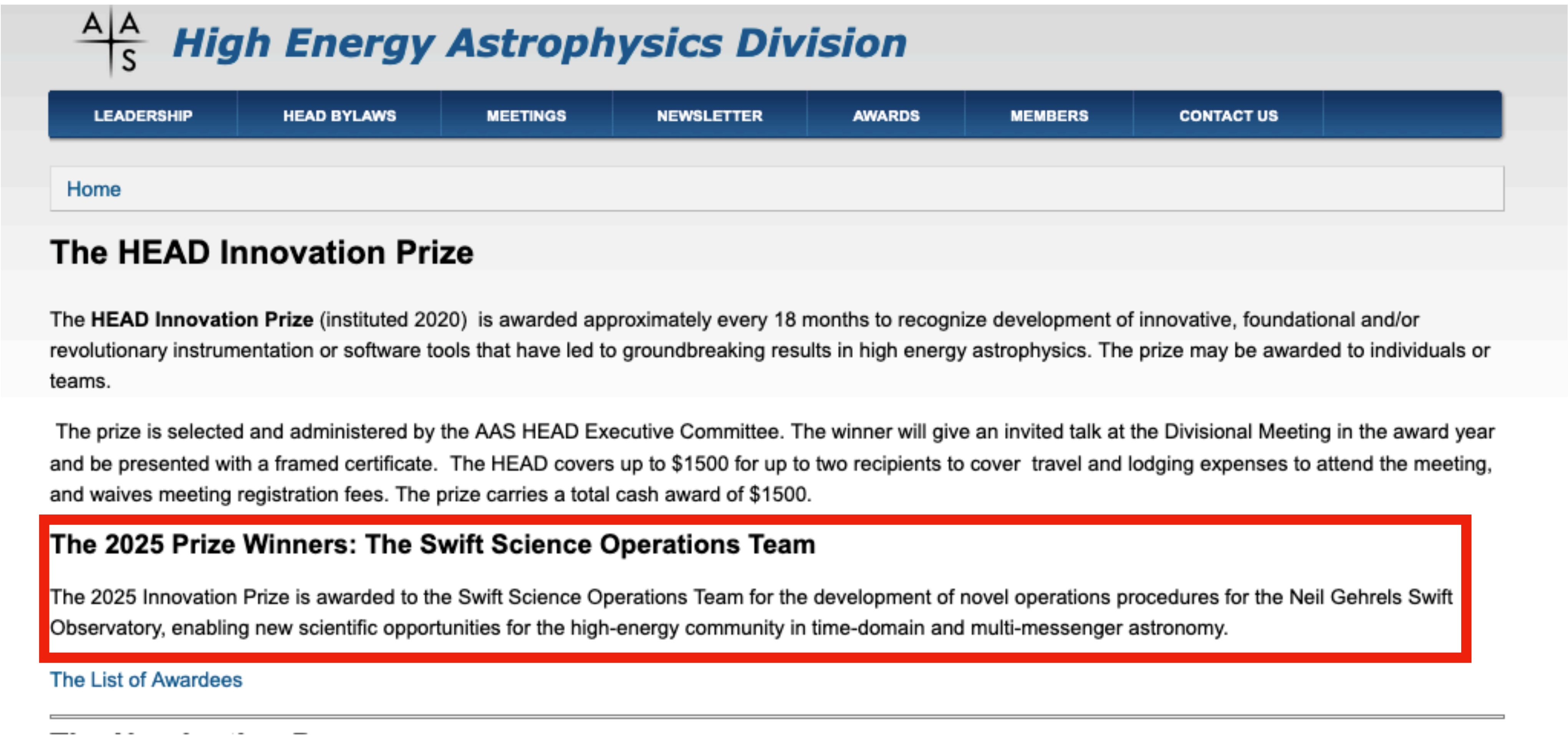
What makes Swift unique

- Prompt transients follow-up
  - Fast repointing
  - Flexibility of the schedule: e.g. continuous commanding, coordination with external facilities, increase of the number of ToOs
- Multi-wavelength monitoring
  - X-ray telescope that is still the state of the art
  - UV telescope + multi-color
- Synergies
  - Within its instruments
  - With external facilities (NuSTAR, Fermi, NICER, TESS, HST, Chandra and XMM-Newton, JWST, IXPE, ….)

How Swift observing strategy and number of ToOs evolved during the years (from 2025 Swift Senior Review)







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The HEAD Innovation Prize

The **HEAD Innovation Prize** (instituted 2020) is awarded approximately every 18 months to recognize development of innovative, foundational and/or revolutionary instrumentation or software tools that have led to groundbreaking results in high energy astrophysics. The prize may be awarded to individuals or teams.

The prize is selected and administered by the AAS HEAD Executive Committee. The winner will give an invited talk at the Divisional Meeting in the award year and be presented with a framed certificate. The HEAD covers up to $1500 for up to two recipients to cover travel and lodging expenses to attend the meeting, and waives meeting registration fees. The prize carries a total cash award of $1500.

The 2025 Prize Winners: The Swift Science Operations Team

The 2025 Innovation Prize is awarded to the Swift Science Operations Team for the development of novel operations procedures for the Neil Gehrels Swift Observatory, enabling new scientific opportunities for the high-energy community in time-domain and multi-messenger astronomy.

The List of Awardees

Swift transformed responding to the community's needs and the evolving TDAMM landscape (see J. Kennea's talk):

- team pioneering new operational processes
- observation requests and data all publicly accessible

After 20 years, Swift is essentially a brand new mission

What makes Swift unique

- Prompt transients follow-up
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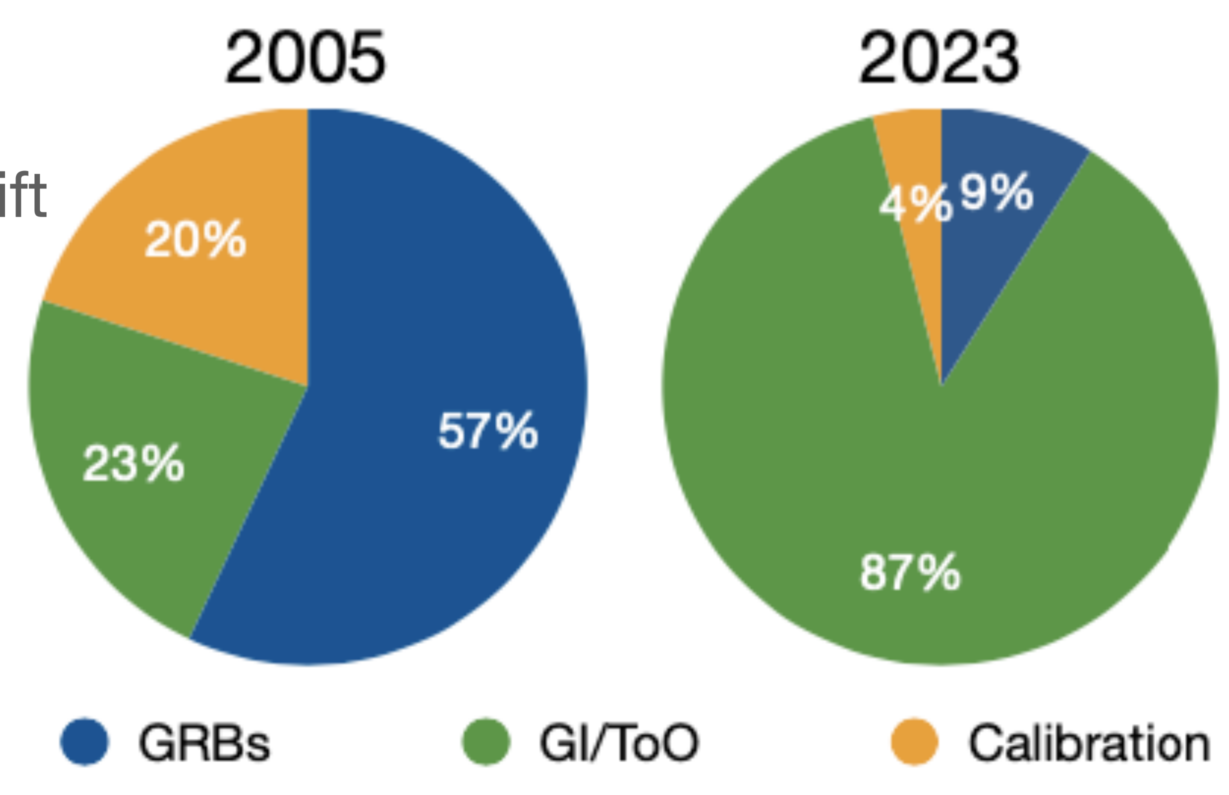

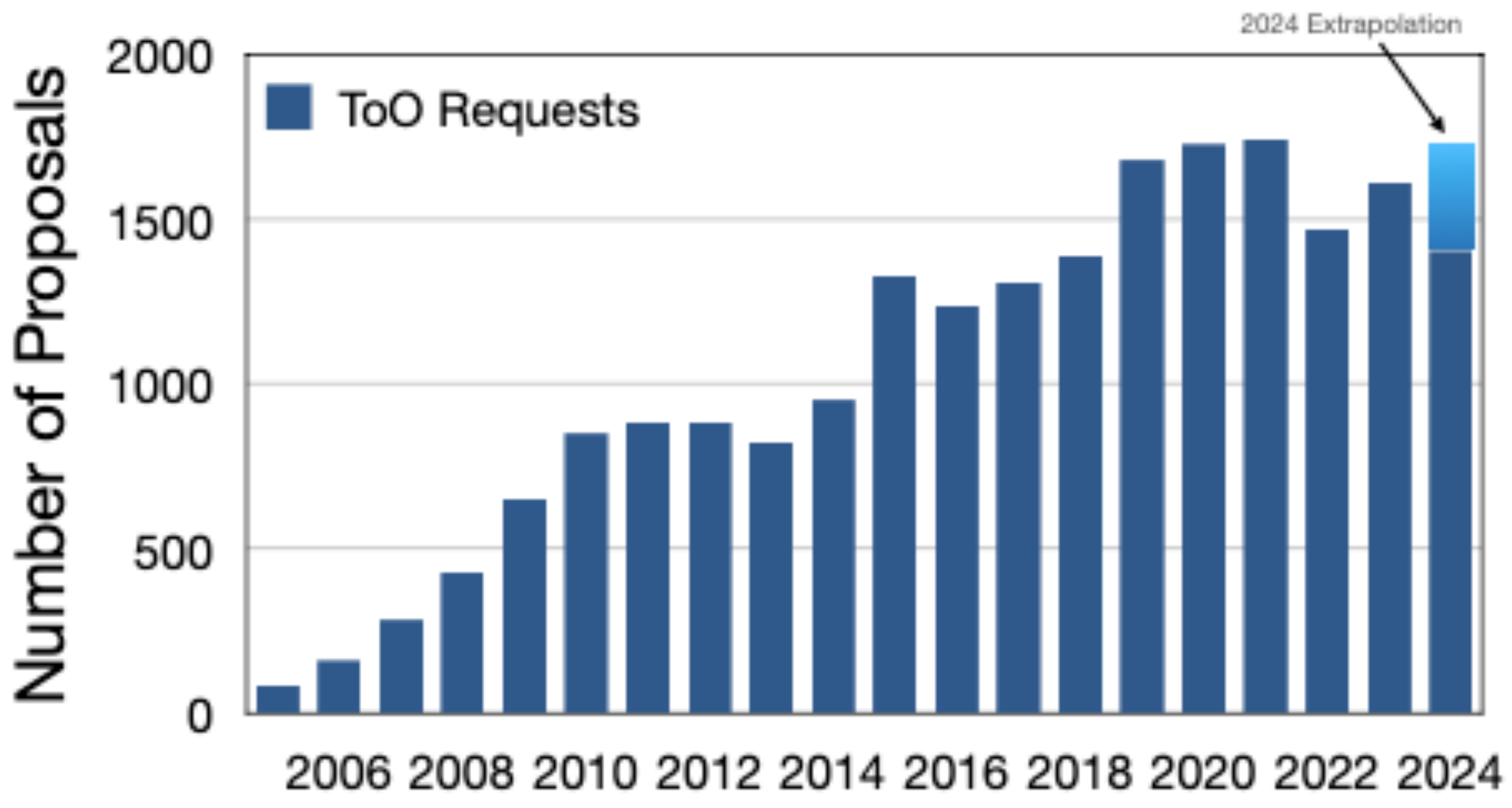

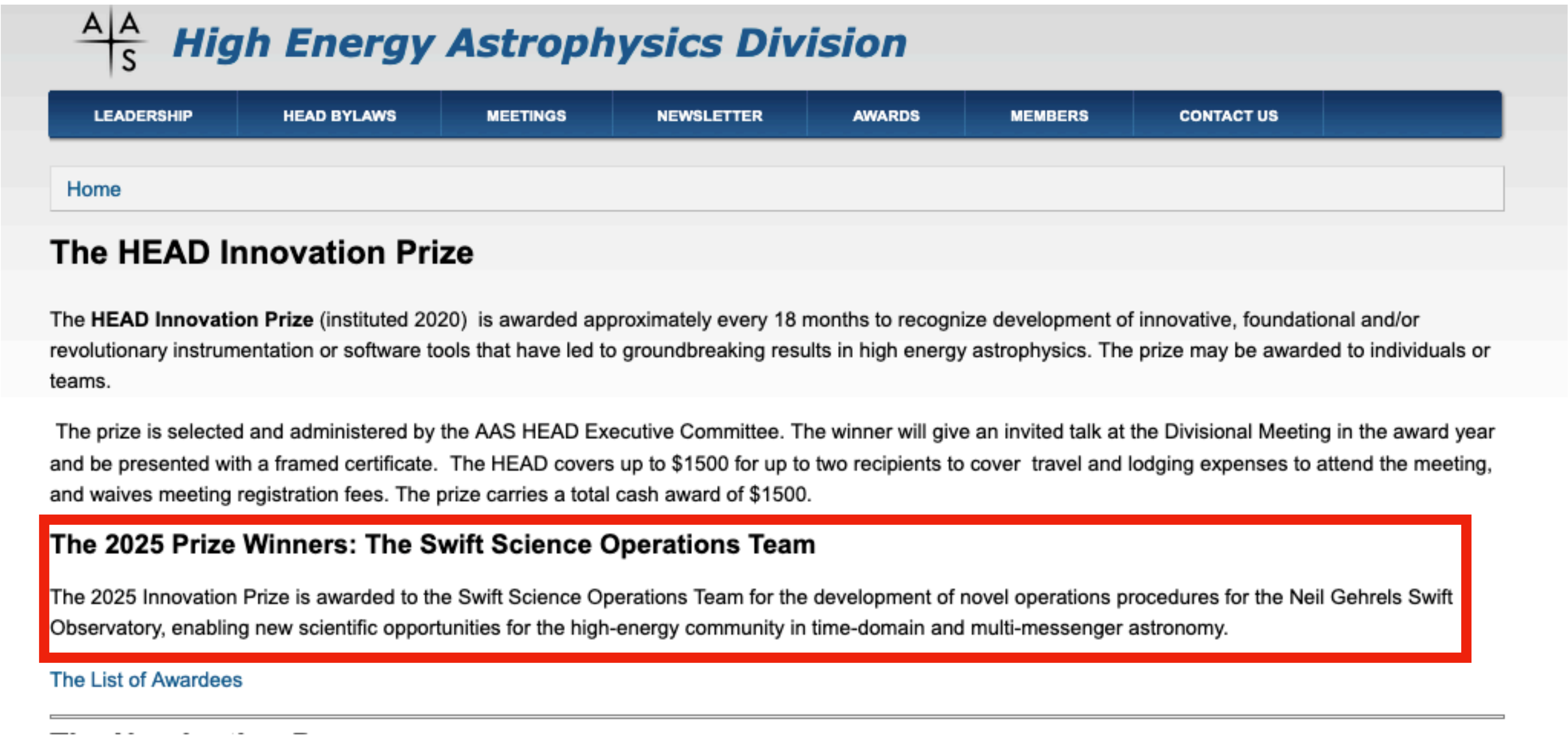
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Swift transformed responding to the community's needs and the evolving TDA

- team pionee
- observation

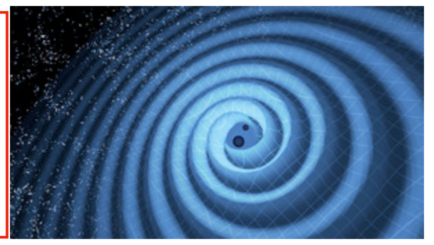
20% of participants to the conference are PhD students!

After 20 years, Swift is essentially a brand new mission

Small and medium size missions in GRB science

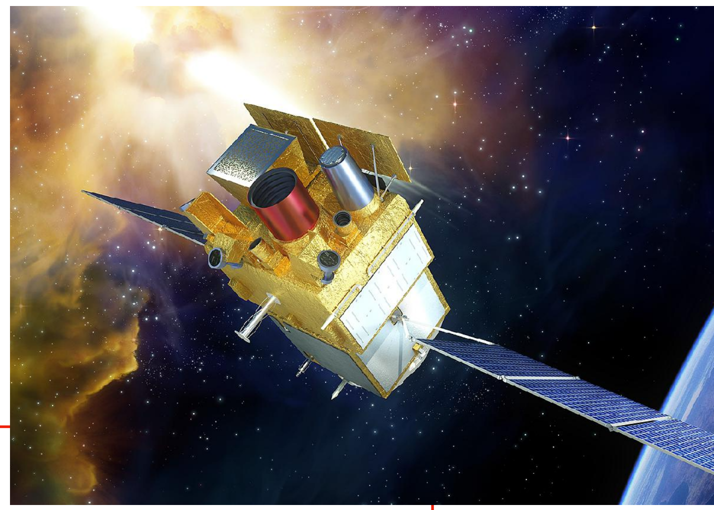
Present status

BIRTH OF THE MULTI-MESSENGER ASTRONOMY WITH GWs



2010 2020 2030 years

170817



Swift

Fermi

Einstein Probe
(see W. Yuan's talk)

- CAS with ESA and MPE
- 2 X-ray telescopes on board
  - Large FoV lobster-eye optics (WXT)
  - Sensitive X-ray telescope (FXT)

➡Monitor the X-ray sky and discover cosmic variable objects and transient phenomena shining in X-rays

SVOM
(see B. Cordier's and F. Daigne's talks)

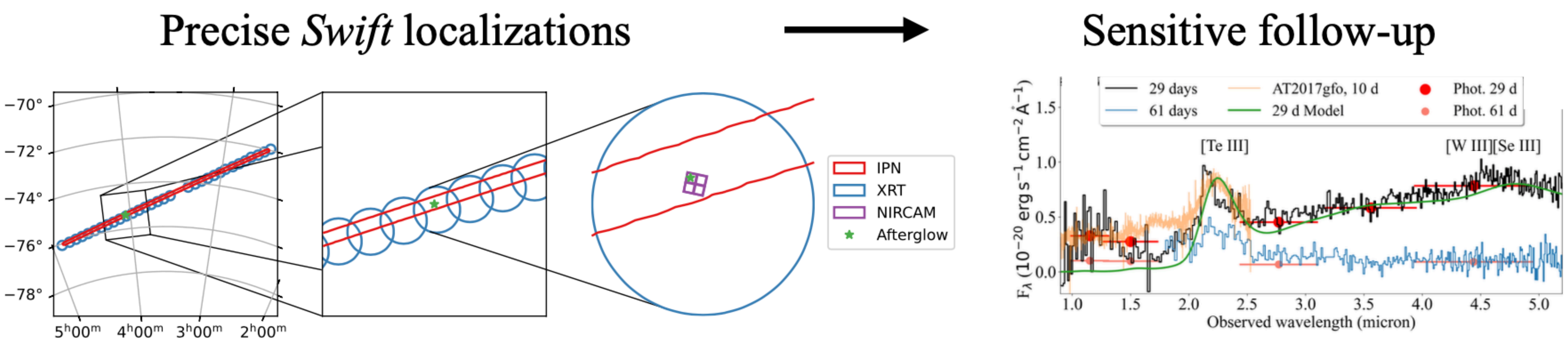
- CAS and CNES
- 4 instruments on-board
  - Large FoV: hard X-rays coded mask (ECLAIRs) + gamma-ray monitor (GRM)
  - Narrow FoV: lobster-eye X-ray telescope (MXT) + optical telescope (VT)
- Ground segment of 2 dedicated robotic telescopes and 1 optical monitor

➡Discovery and multi-wavelength follow-up of GRBs and other transients, high fraction of redshift expected

➡Open observatory via GO programs, including ToOs

Open questions and challenges in GRB science

Progenitors, central engine and jet structure



From precise Swift/XRT localization to sensitive follow-up: the example of GRB 230307A; from 2025 Swift Senior Review, Levan et al. (2024)

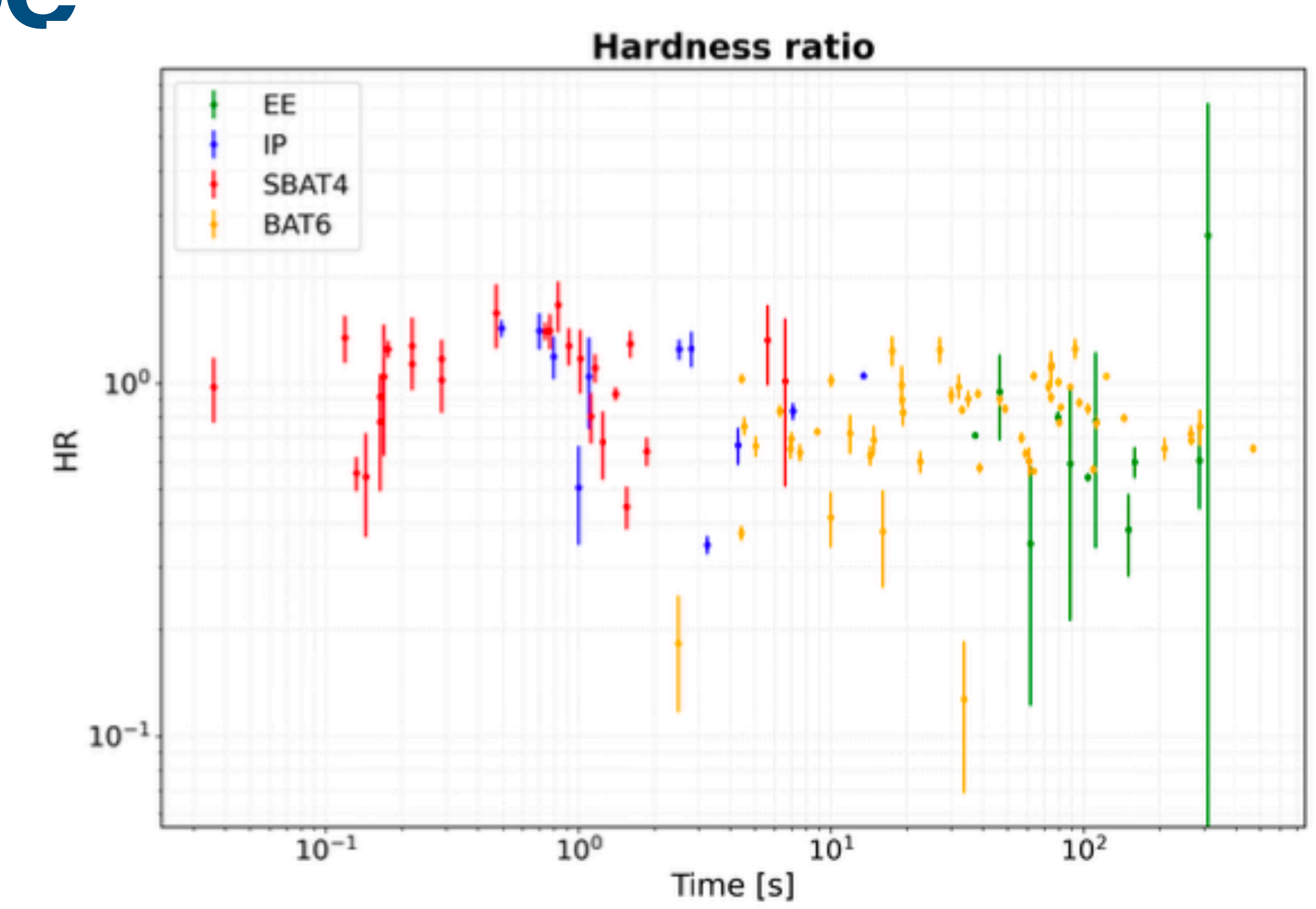
- **Long/short dichotomy** recently challenged by observations of long GRBs from BNS mergers (e.g. GRB 230307A - long with KN discovered by JWST, see also A. Levan's talk):

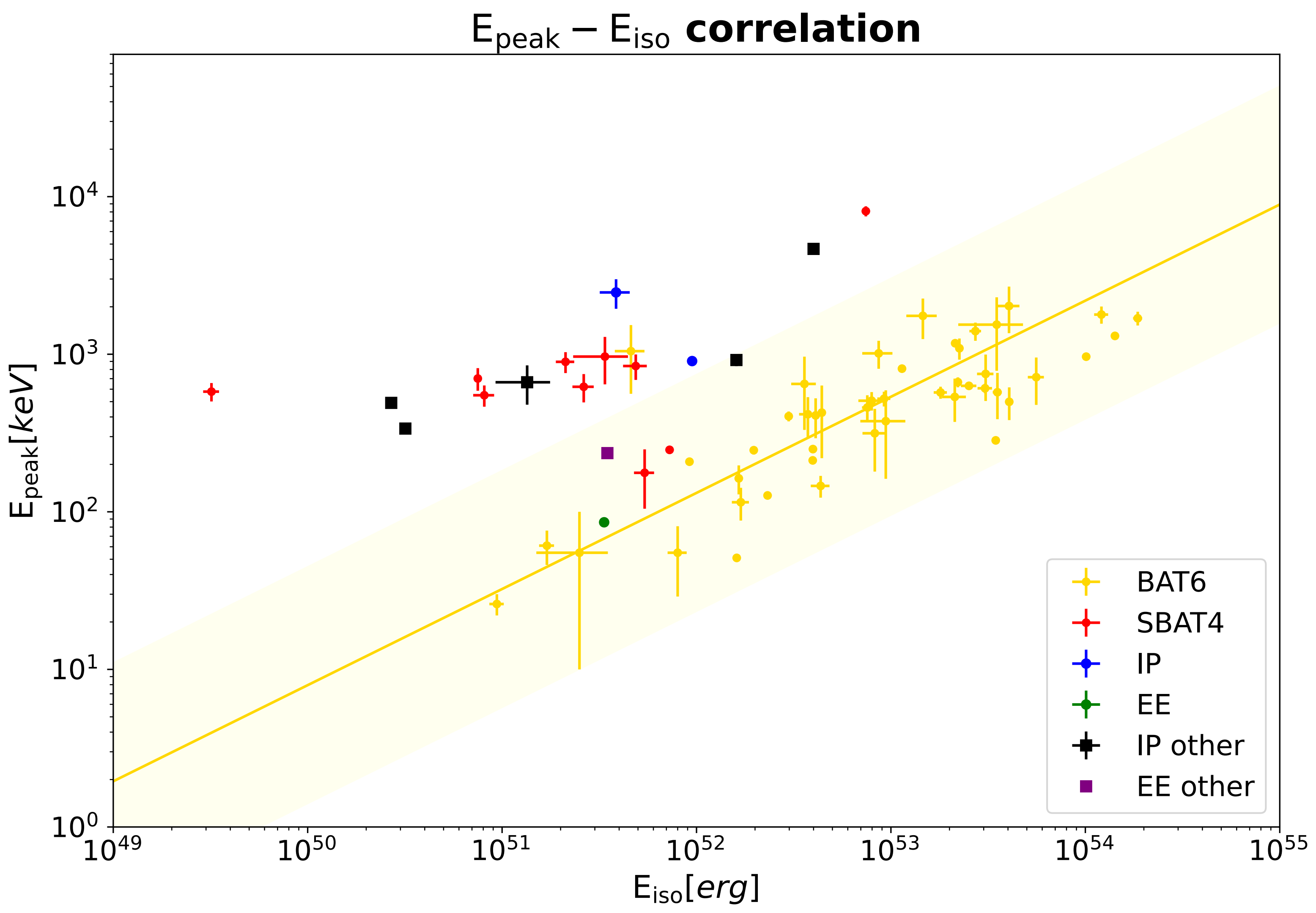
➡ Need to **pinpoint GRB locations** to spot SNe-KNe

✴ **Swift, SVOM, EP** provide accurate localization (arcmin to arcsec) and rapid dissemination

➡ Investigate the population of **short GRBs with extended emission**:

✴ **SVOM/ECLAIRs+GRM** (4 keV to 5 MeV) further deepens our knowledge of this class





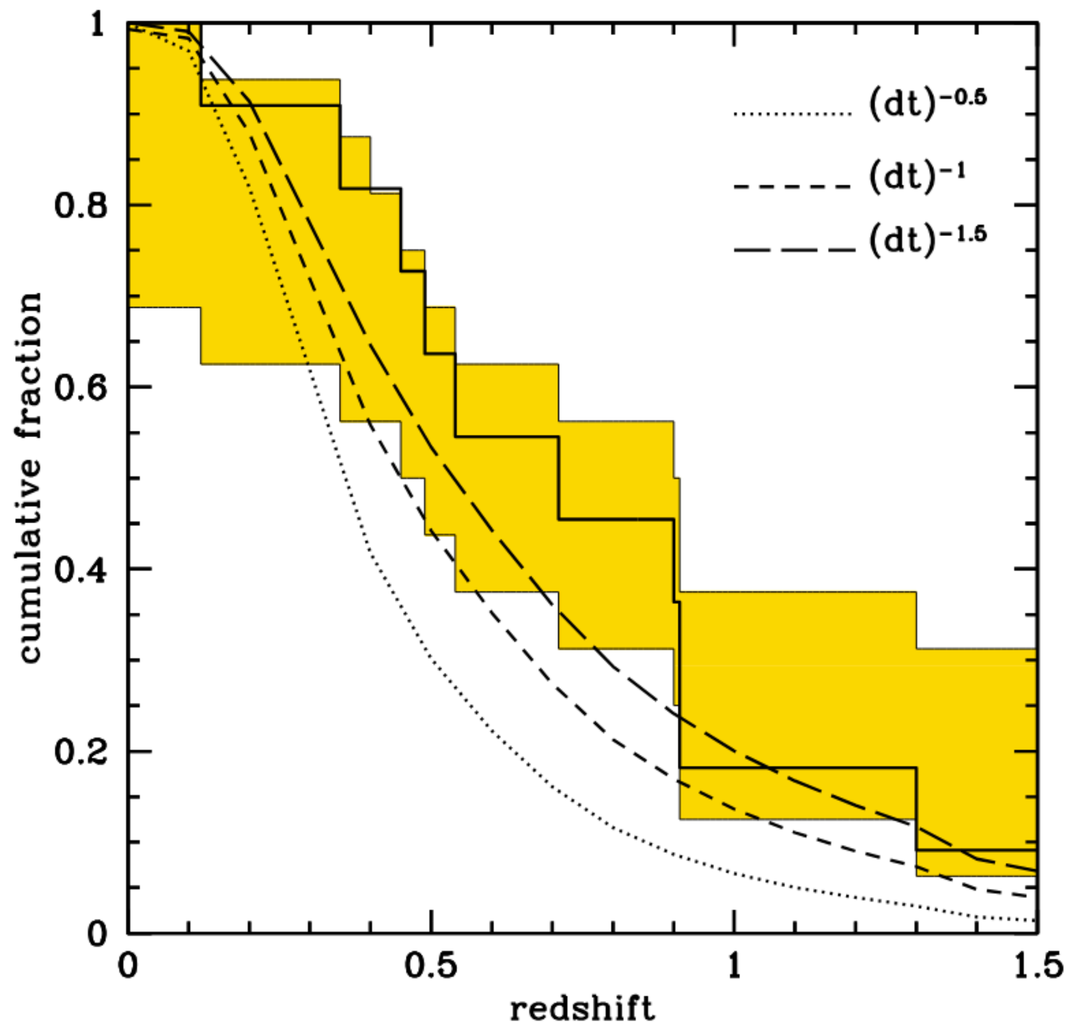
Short GRBs with EE compared with short and long from complete samples of Swift GRBs: the HR vs. T90 and the Epk-Eiso plane, see M. Dinatolo's poster

Open questions and challenges in GRB science

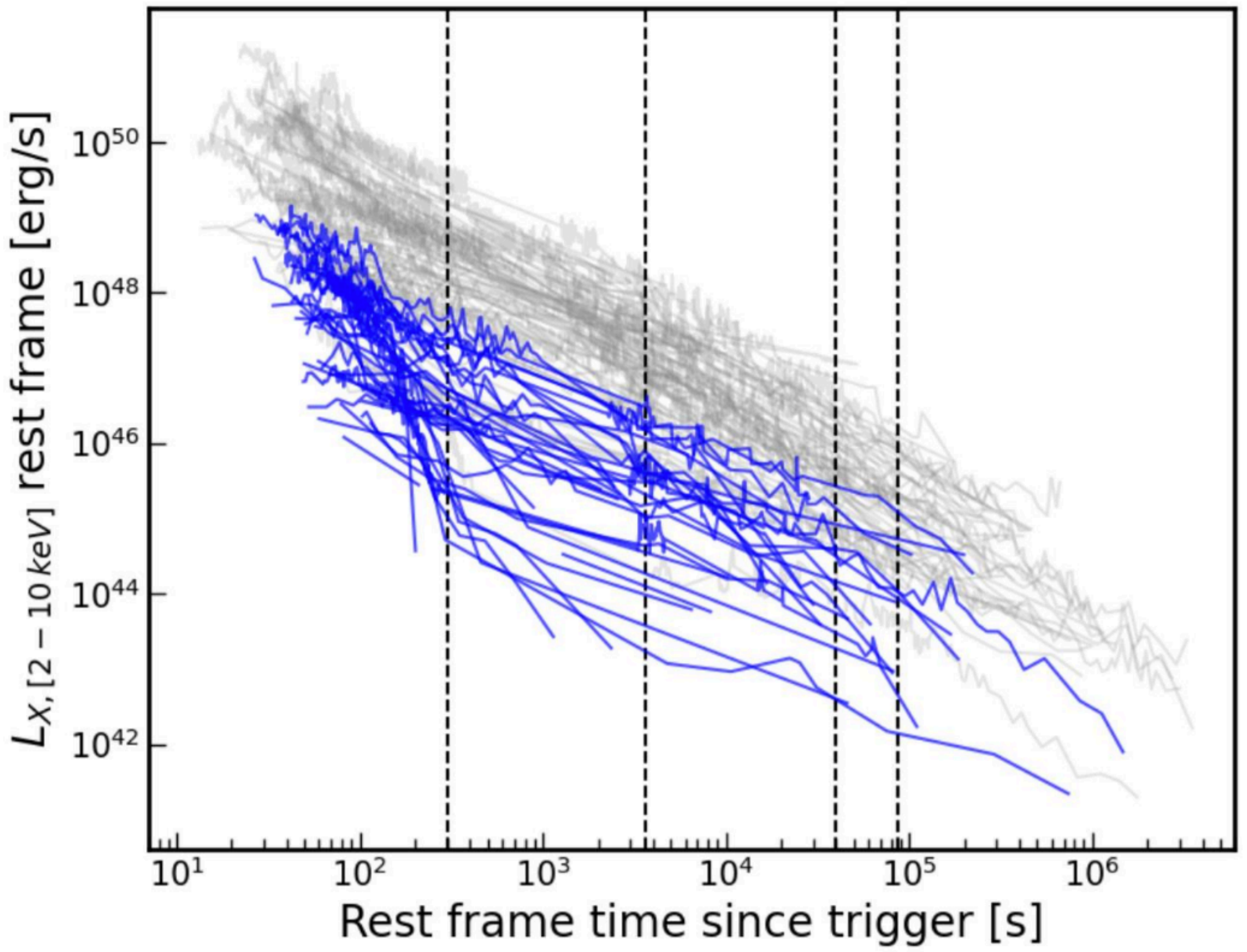
Progenitors, central engine and jet structure

- Given the current lack of GW triggers from BNS mergers, **observations of short GRBs are still the best mean to study the BNS-GRB connection**:
  - ➡ Refine the estimates of the **volumetric rate of short GRBs**
    - ✳ **Swift, SVOM** provide discovery, localization and multi-wavelength follow up of short GRBs, enabling redshift measurements -> building samples for **population studies**
    - ✳ Driven by MM science case, **Swift** put in place new techniques that are now of broader usage as **BAT-GUANO**: provide arcmin localization for short GRBs from external facilities (see J. DeLauney's talk)

- Our current understanding of the **jet structure** is essentially based on one event (GRB170817A): need for improvement in our capability to recognize **orphan afterglows in optical (from ZTF to Rubin) and radio (SKA) surveys** to get direct look to the jet structure and consequently of true rates for both short and long GRBs (see G. Srinivasaragavan's talk)



Redshift distribution of a complete sample of Swift short GRBs, from D'Avanzo et al. (2014)

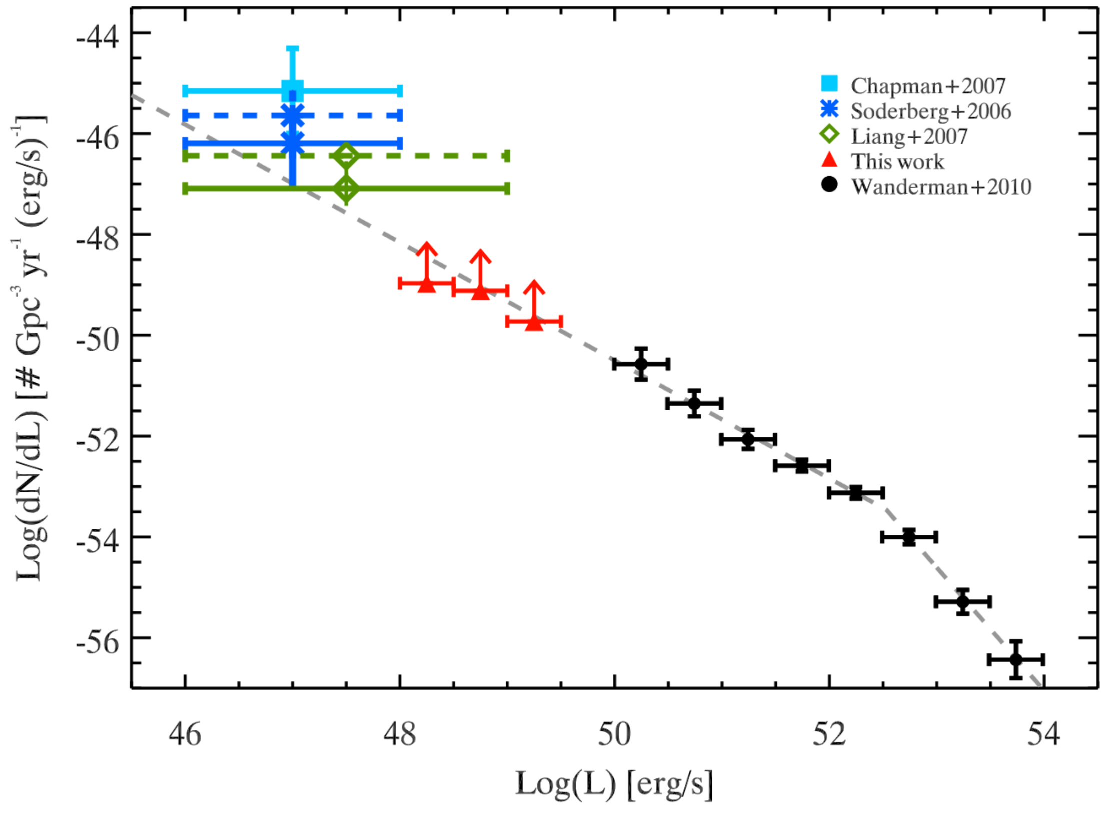


X-ray luminosity of complete samples of Swift short (blue) and long (grey) GRBs, see R. Brivio and M. Ferro's talks

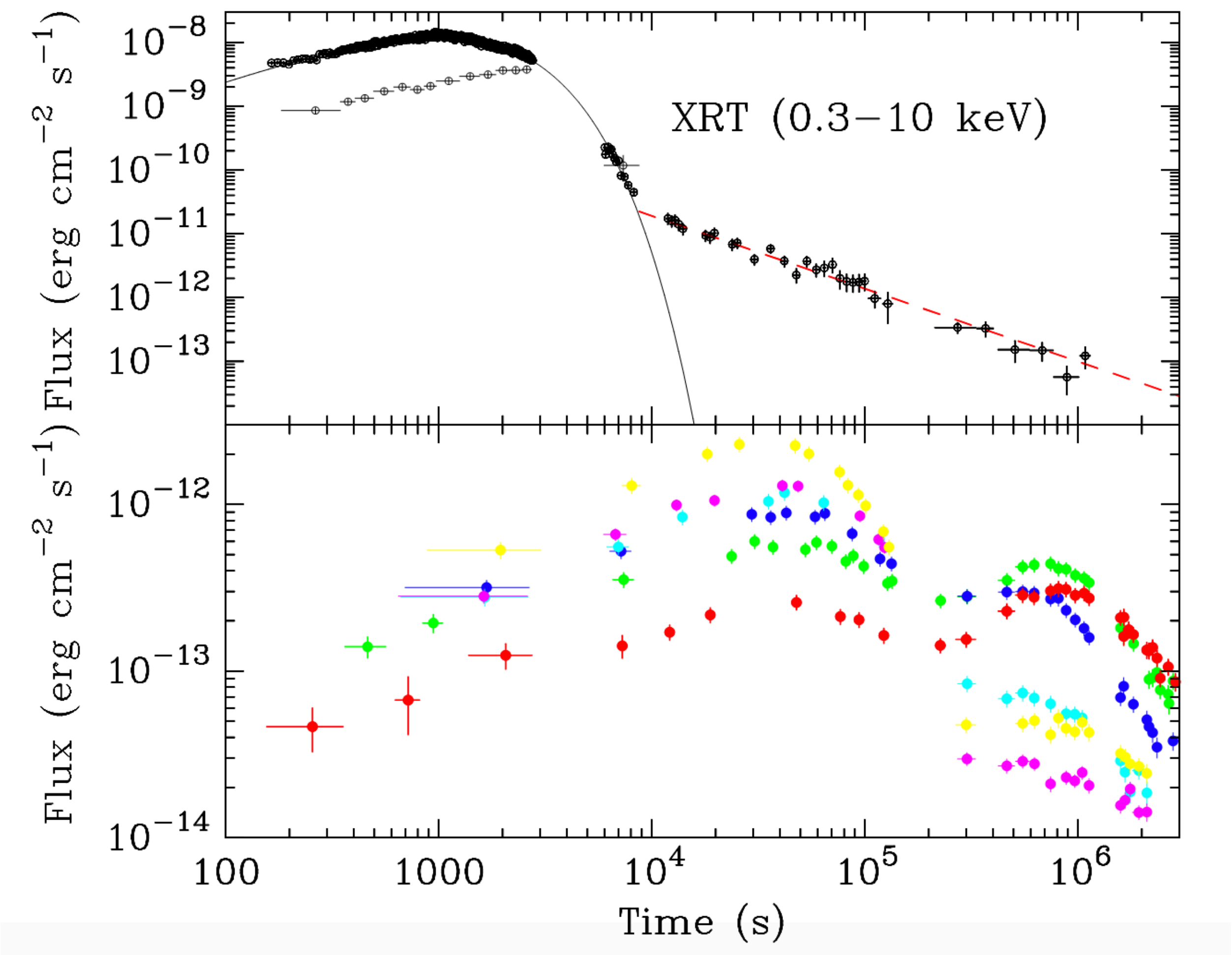
Open questions and challenges in GRB science

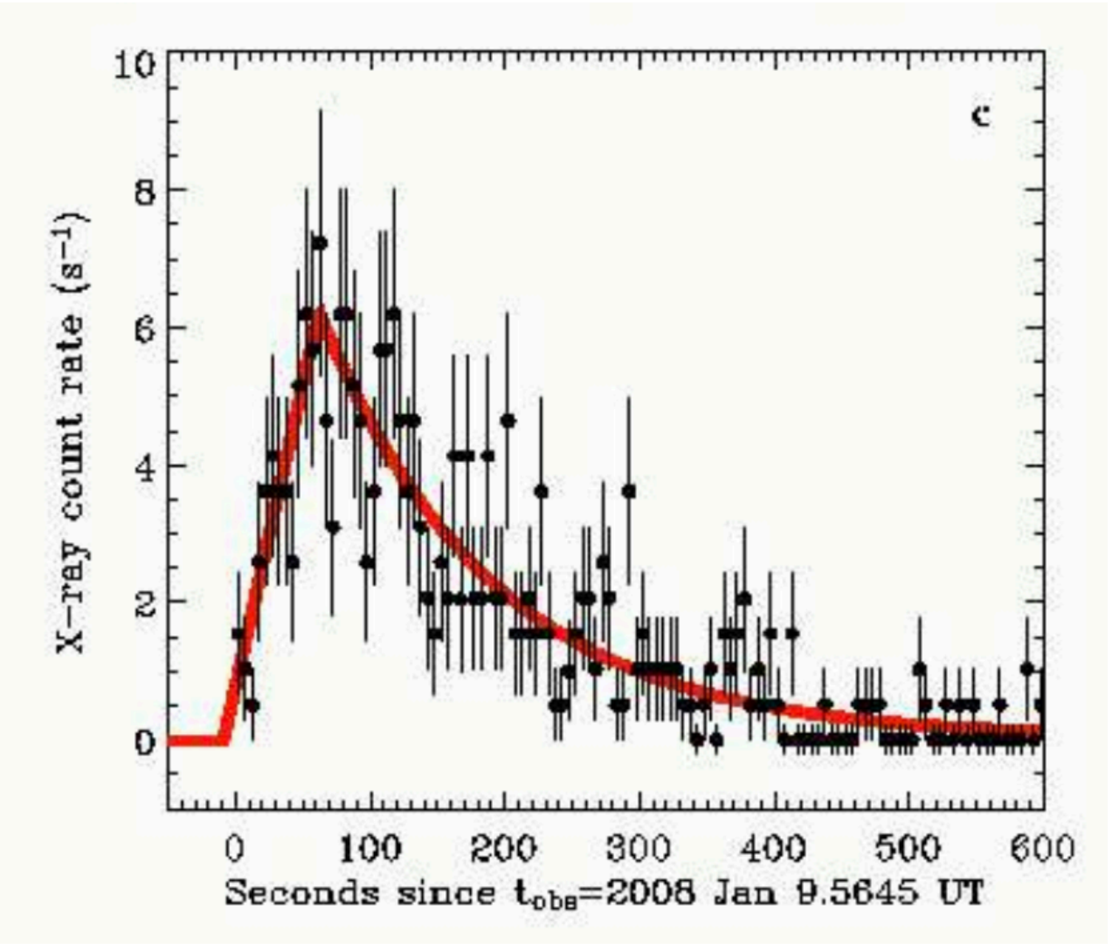
Progenitors, central engine and jet structure

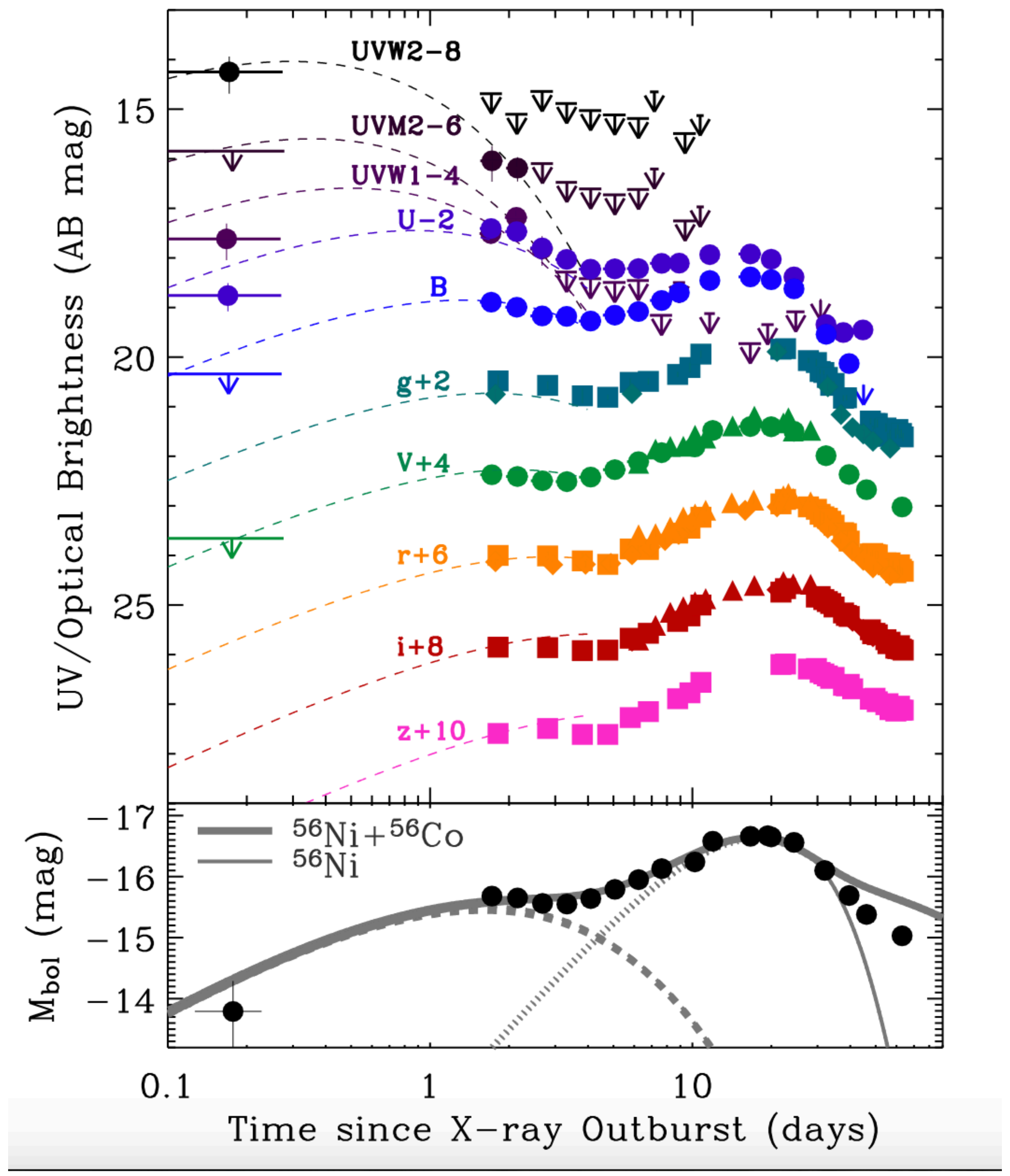
- **Poorly explored families of GRB**, as XRR, XRF, low-luminosity, ultra-long -> GRBs in a more **general scenario of explosive events**, possible clues on secret ingredients needed to produce a GRB
  - ✳ **EP, SVOM** already proved to be game changer on this topic thanks to their **sensitive instruments @soft X-rays with large FoV**
  - ✳ **SVOM** energy range extends to MeV (GRM): further help to **classify the events**
  - ✳ With ***Continuous commanding*** (autonomous, ultra-rapid ToO uplinks), **Swift** complements the observation of **SVOM, EP** transients



Luminosity function of long GRBs, from Pescalli et al. (2015). See G. Ghirlanda's talk







GRB060218 (left, from Campana et al. 2006) and XRO080109 (top, from Soderberg et al. 2008), two examples of Swift contribution to the field

Open questions and challenges in GRB science

GRBs as probes

- **Nucleosynthesis of heavy elements (Kilonovae)**

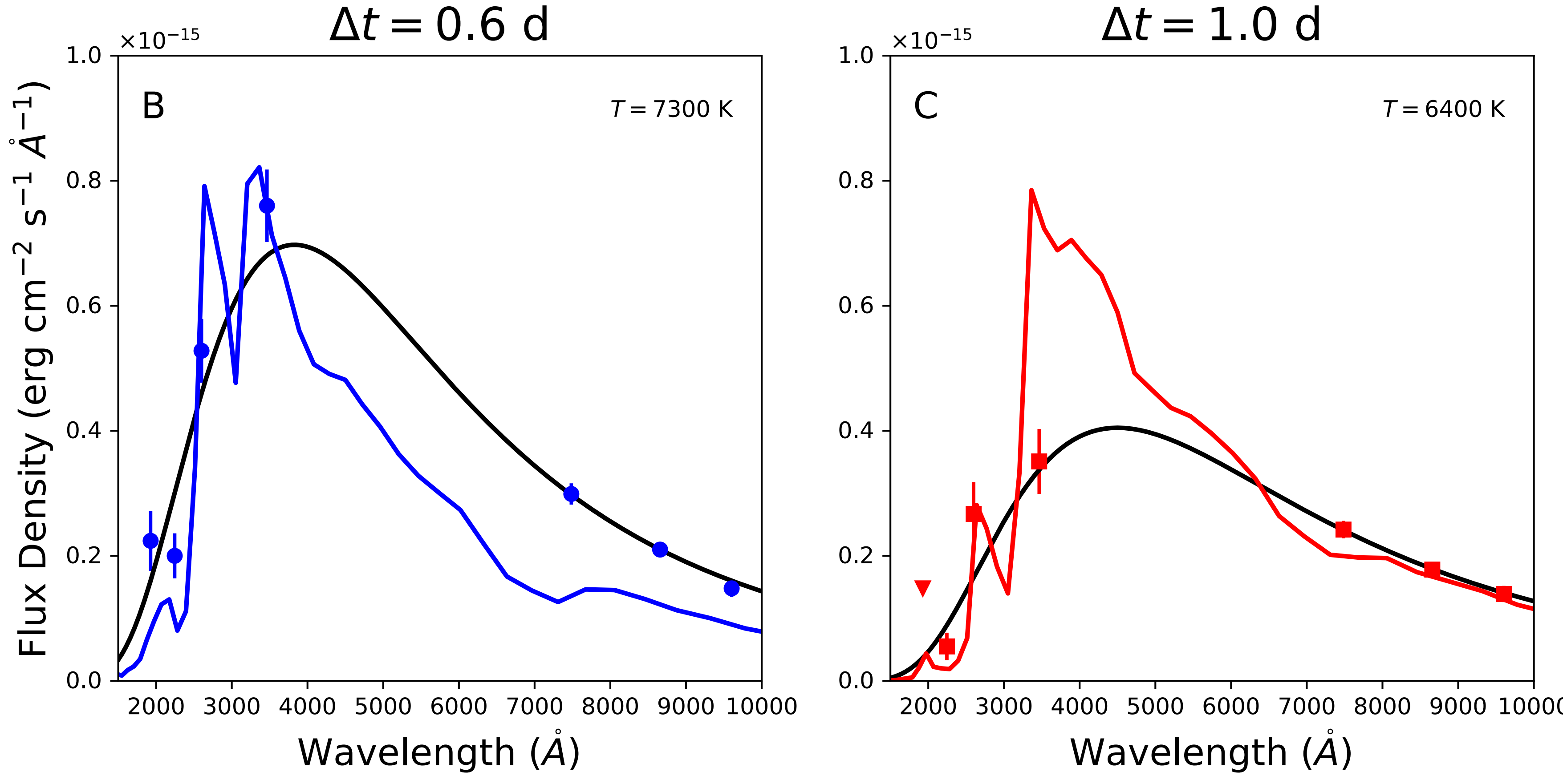
  ➡ **short GRBs are still the best place to search for KNe** (see J. Rastinejad talk)

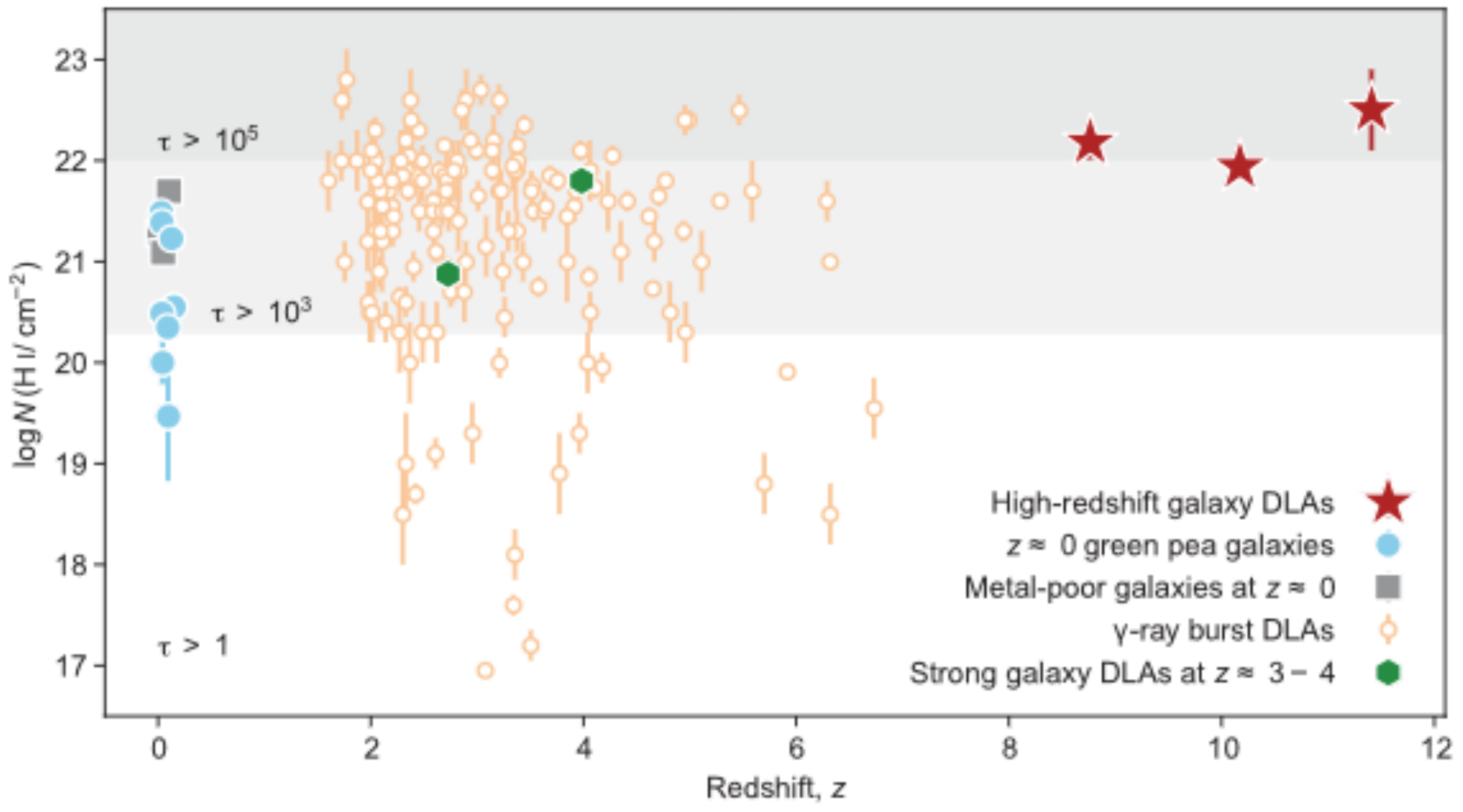
  ✴ **Swift/UVOT** is unique to spot the blue kilonova

  ✴ In the near future, wide FoV facilities to discover KNe in UV and IR, either serendipitously or associated to GW events (ULTRASAT, Roman)

Arcavi (2018), Andreoni et al. (2023)

The KN AT2017gfo associated to GW170807/ GRB170817A, observed by UVOT, from Evans et al. (2017)





NHI vs redshift for the high-z galaxies observed by JWST compared to the GRB host galaxies, from Heintz et al. (2024)

- **Universe in the epoch of reionization**

  ➡ High-z GRBs pinpoint very faint galaxies allowing to determine their properties, but also the effect of re-ionization on the intergalactic medium (see A. Saccardi's talk)

  ✴ **Swift** GRB hosts provide a natural comparison source for the star-forming galaxies discovered in the early Universe by JWST

  ✴ **SVOM, EP** even more suited to discover high-z GRBs thanks to the sensitivity @soft X-rays

The future after Swift

- What happens after Swift, SVOM and EP? Possibly **THESEUS** (see L. Amati's talk), but we risk to have a long gap. Cubesats might be an easy and “light" way to provide triggers (see e.g. HERMES)
- With the third generation interferometers (ET, CE), in 20 years were might have one GW signal for each short GRB. But who will observe those short GRBs?

How to cover the long gap? How to maintain the field alive?

Need to rethink how we do science in the field

- Take advantage of the big facilities and on the large number of transients that will be discovered. But how to classify transients (SOXS, see S. Campana's talk)?
- For a panchromatic view of transients, need to combine different facilities
- Need for public data and alerts (both lesson learnt from Swift)
- Need to develop need approaches to treat data (machine learning?)