EXPLORING THE MOST POWERFUL TRANSIENTS WITH THE NANCY GRACE ROMAN TELESCOPE

A. Cucchiara (College of Marin*)

IN HONOR TO A LONG LIST OF WOMEN (AND MEN) COLLEAGUES WHO HAVE SHAPED THIS FIELD OF RESEARCH

*Vera Rubin Observatory Transient and Variable Stars Science Collaboration
Justice Equity Diversity and Inclusion working group

LAND ACKNOWLEDGEMENT

We acknowledge that we are located on the un-ceded ancestral lands of the Hahamog'na tribe of the Tongva people who have stewards this land throughout the generations.

We honor with gratitude the land itself, and all of its ancestors: past, present, and emerging.

We thank them for their strength and resilience in protecting this land, and aspire to uphold our responsibilities according to their example.
We also support actions and policies that focus on the reparation of the arm caused to these lands and their ancestors.

**** WHY IS INDIGENOUS LAND ACKNOWLEDGMENT IMPORTANT?***

"It is important to understand the longstanding history that has brought you to reside on the land, and to seek to understand your place within that history. Land acknowledgements do not exist in a past tense, or historical context: colonialism is a current ongoing process, and we need to build our mindfulness of our present participation." Northwestern University

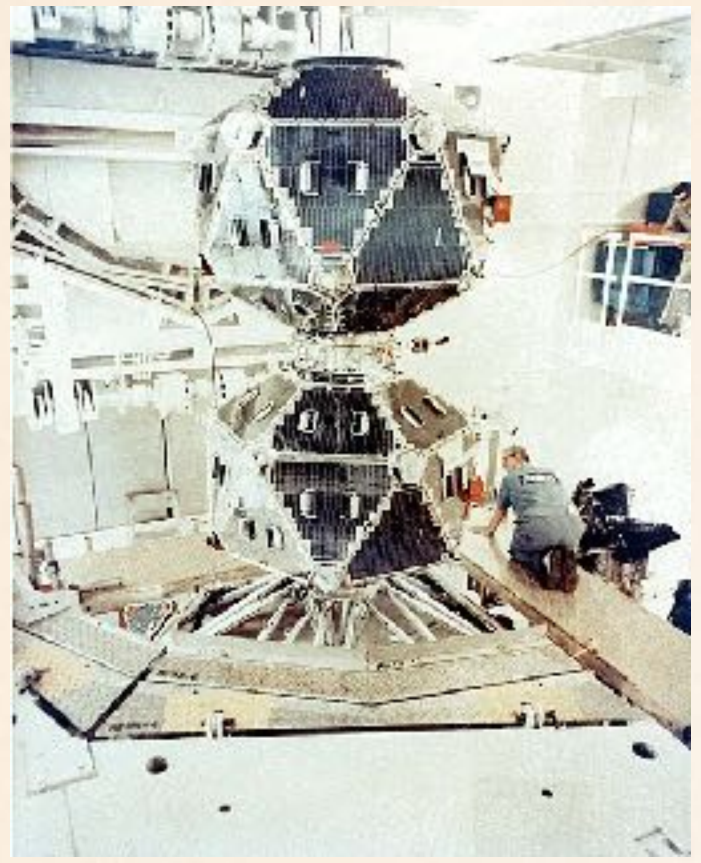
"When we talk about land, land is part of who we are. It's a mixture of our blood, our past, our current, and our future. We carry our ancestors in us, and they're around us. As you all do." Mary Lyons (Leech Lake Band of Ojibwe)

Other readings:
- https://www.cherokeephoenix.org/opinion/opinion-land-acknowledgments-fall-short-in-honoring-indigenous-people/article_cdf8233f-f107-5cb6-a9c5-e89823a10e2d.html
- https://www.cbc.ca/news/indigenous/land-acknowledgments-what-s-wrong-with-them-1.6217931

OUTLINE

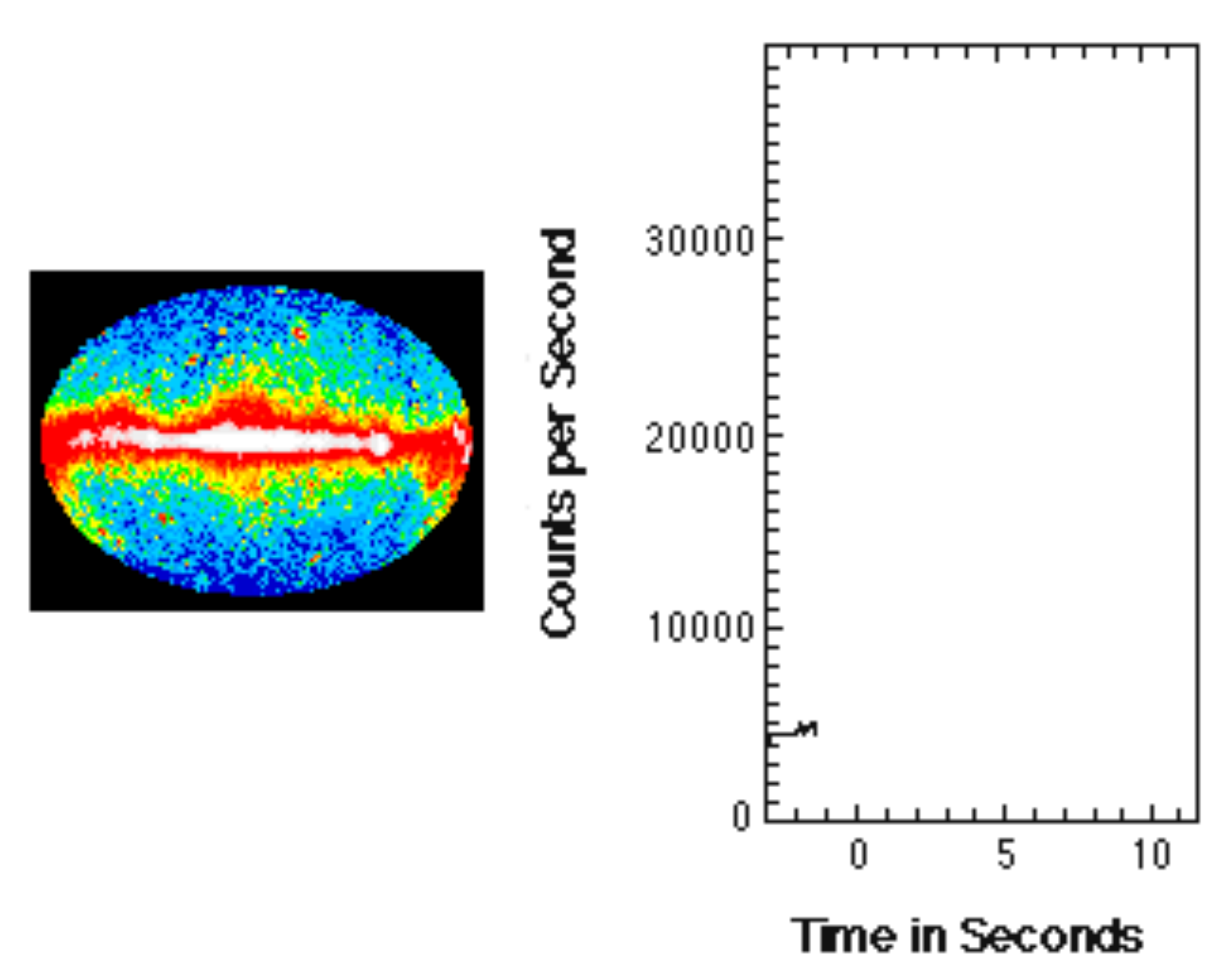
- A short introduction on Gamma Ray Bursts (GRB)
- GRB and Supernovae
- The search for the “first stars”
- Exploring the Star-formation Rate at z>7
- Short GRBs
- Kilonovae and Gravitational Waves
- Nancy Grace Roman Telescope - Reflections

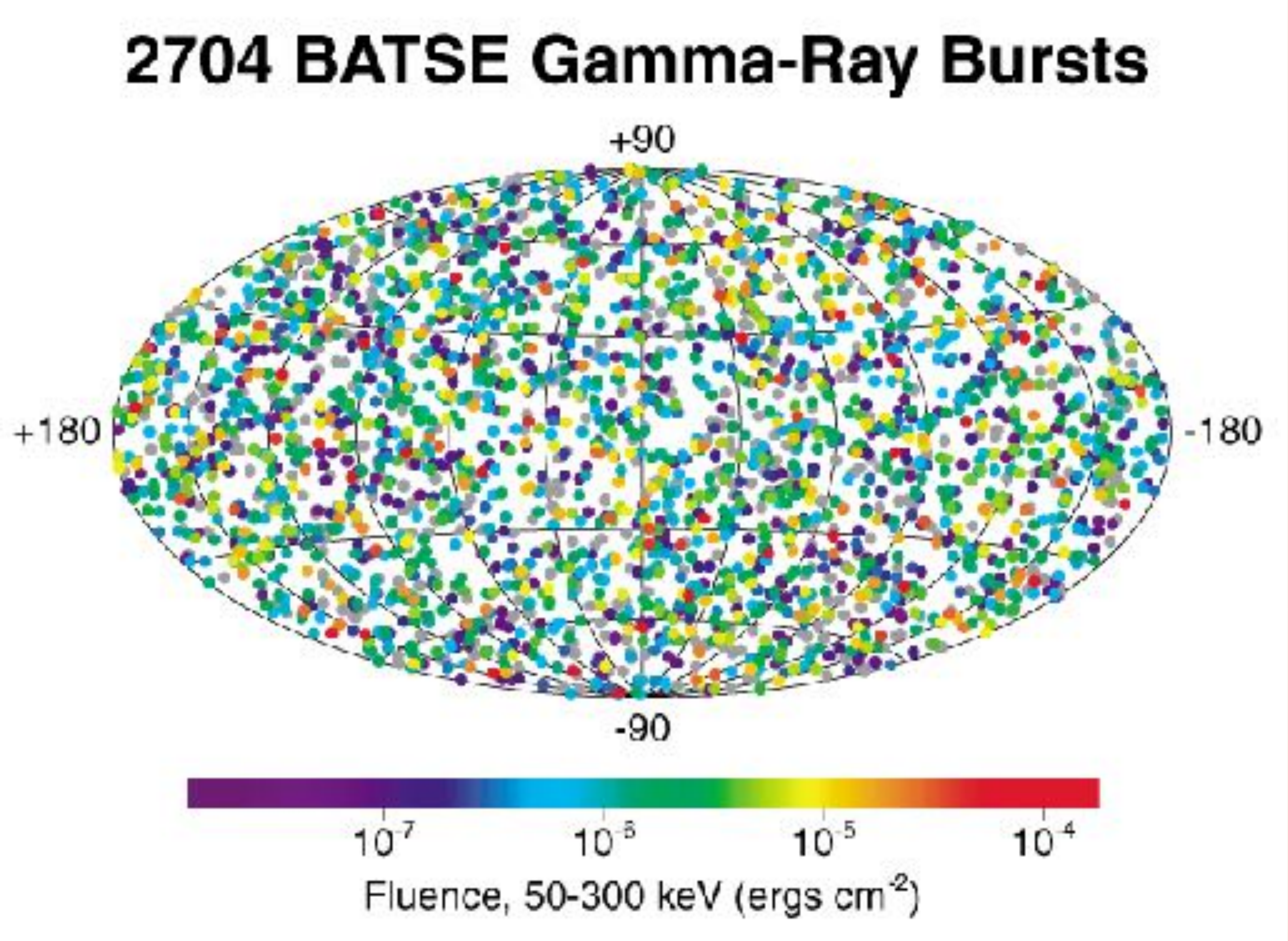
A QUICK HISTORY AND TAXONOMY OF GAMMA-RAY BURSTS



Gamma-ray burst were discovered serendipitously, by the VELA satellite, during the cold war period. They manifest themselves with a short pulse in the gamma-ray (hard X-ray) frequency range.

Thanks to the work done by the Compton Gamma-Ray Observatory (CGRO), we confirmed that they were of cosmological origin (vs. Galactic).





Follow-up observations from XMM-Newton, HST and Chandra allowed the identification of low-energy counterparts (X, Optical, and later Radio).

With the limited capabilities from space, the ground-based astronomical community began to invest in GRB follow-up efforts (from rapid observations, to robotic facilities).

A QUICK HISTORY AND TAXONOMY OF GAMMA-RAY BURSTS

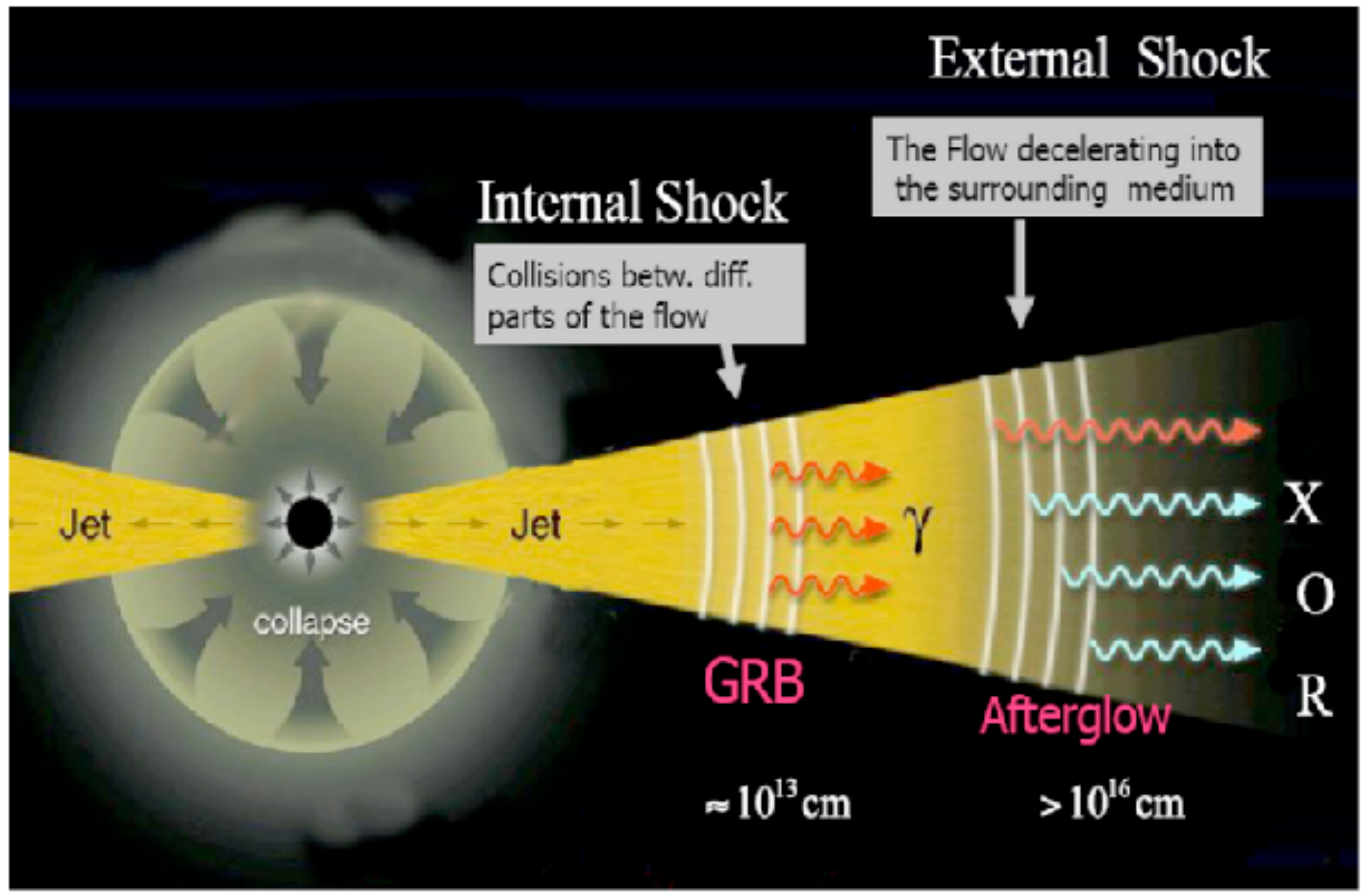
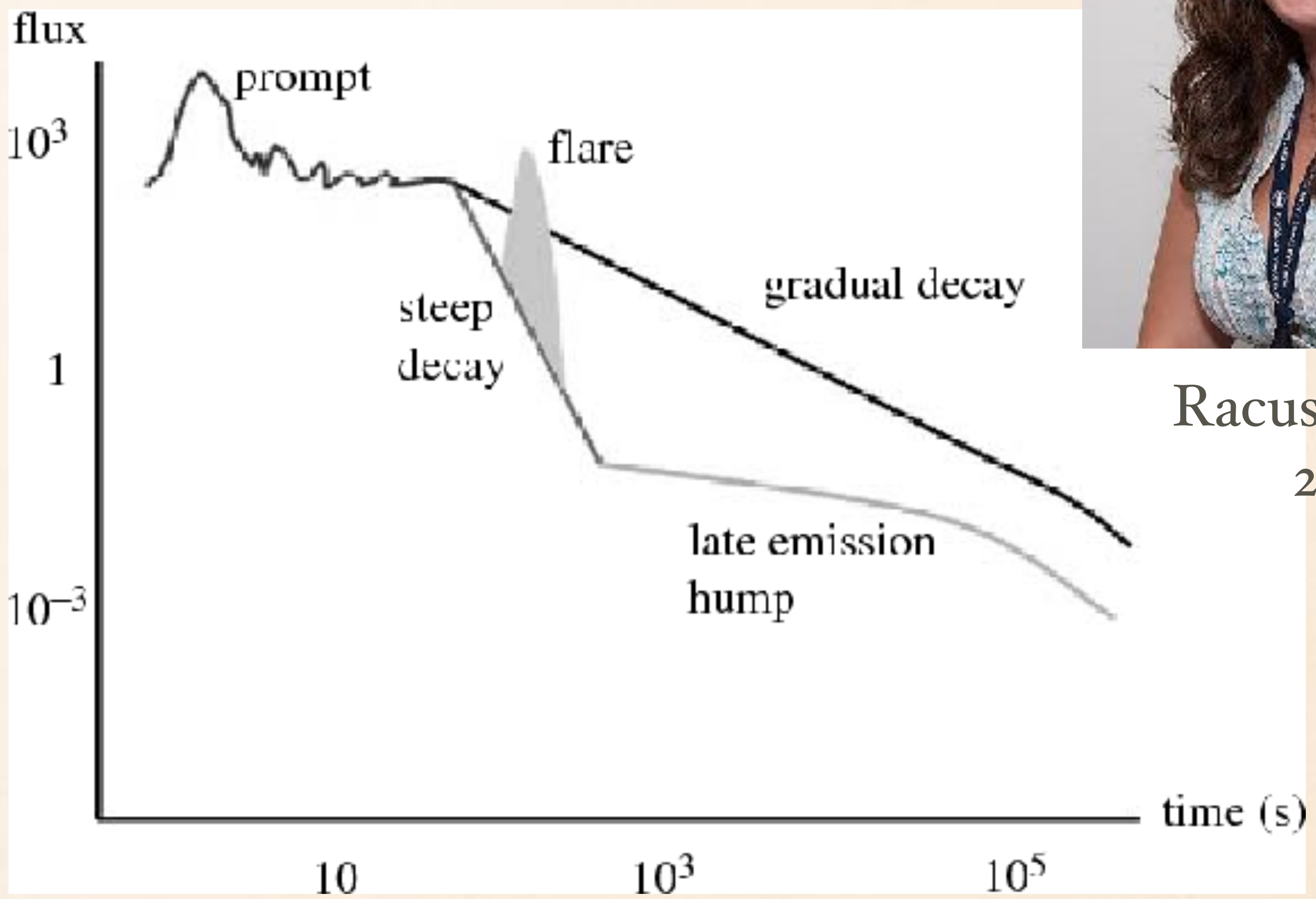


Illustration of the production of a GRB by a massive collapsing star.
http://arxiv.org/abs/astro-ph/0102255

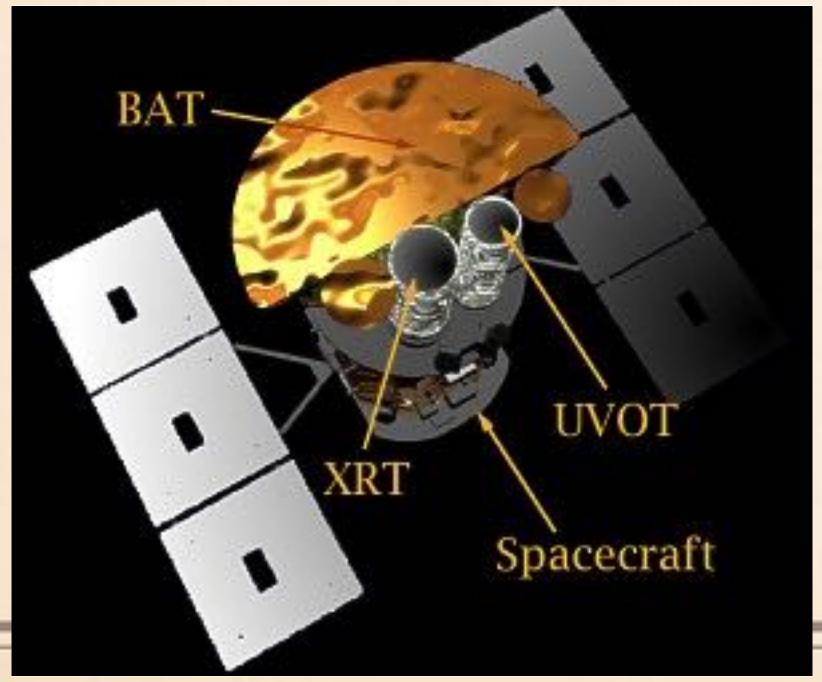
The prominent idea was a "central engine" generates a collimated jet of relativistic photons that interacts with the material (ISM) surrounding the progenitor creating an afterglow (low-energy).

Within the jet, shells collide and produce the prompt-emission (Gamma).
(Meszaros 2019 and reference therein)

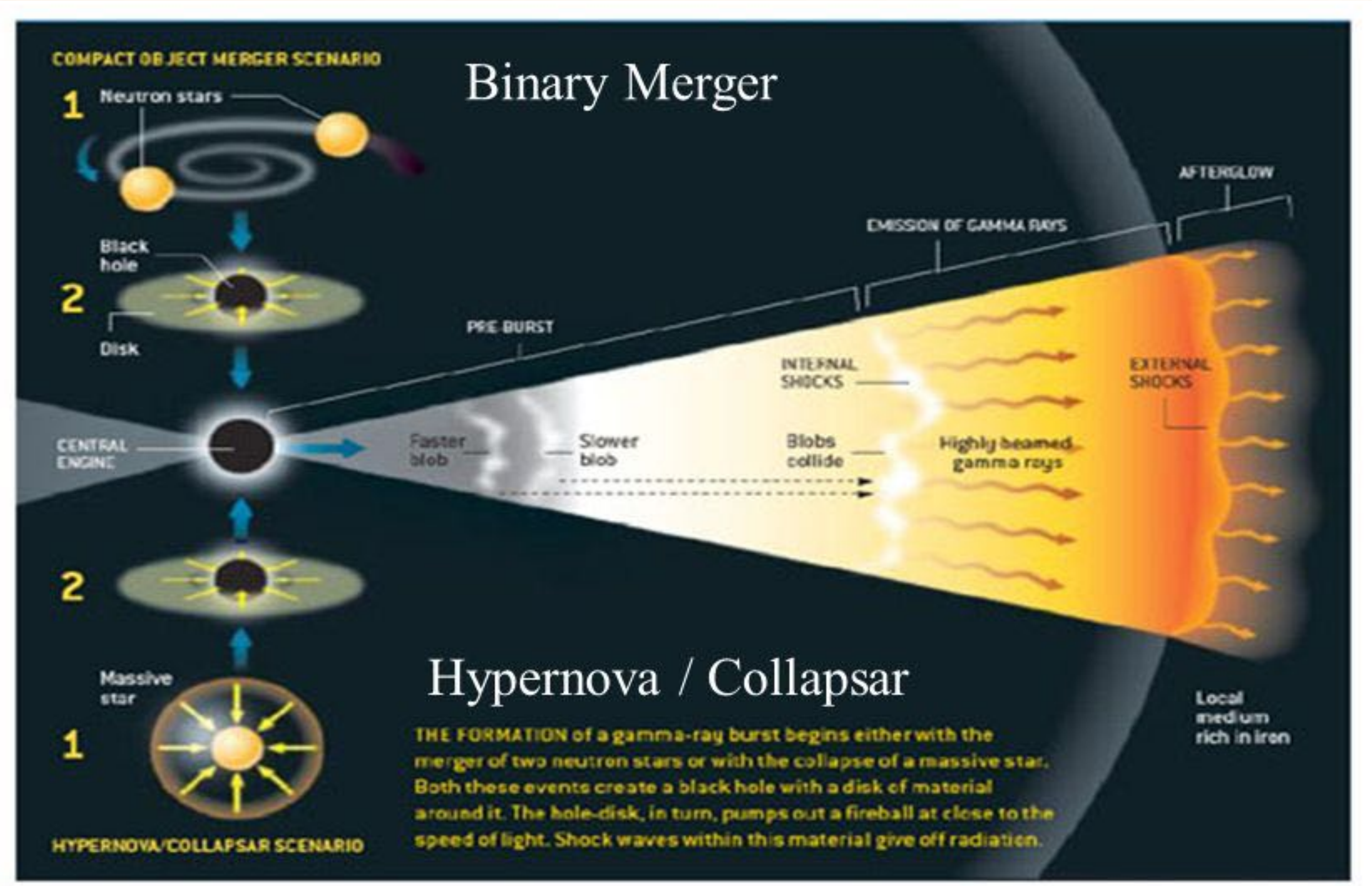
Racusin et. al. 2011



Thanks to 17 years of Swift and work done by many colleagues we now have a large dataset of X-ray afterglows that enables detailed studies of the central engine and the emission mechanisms.

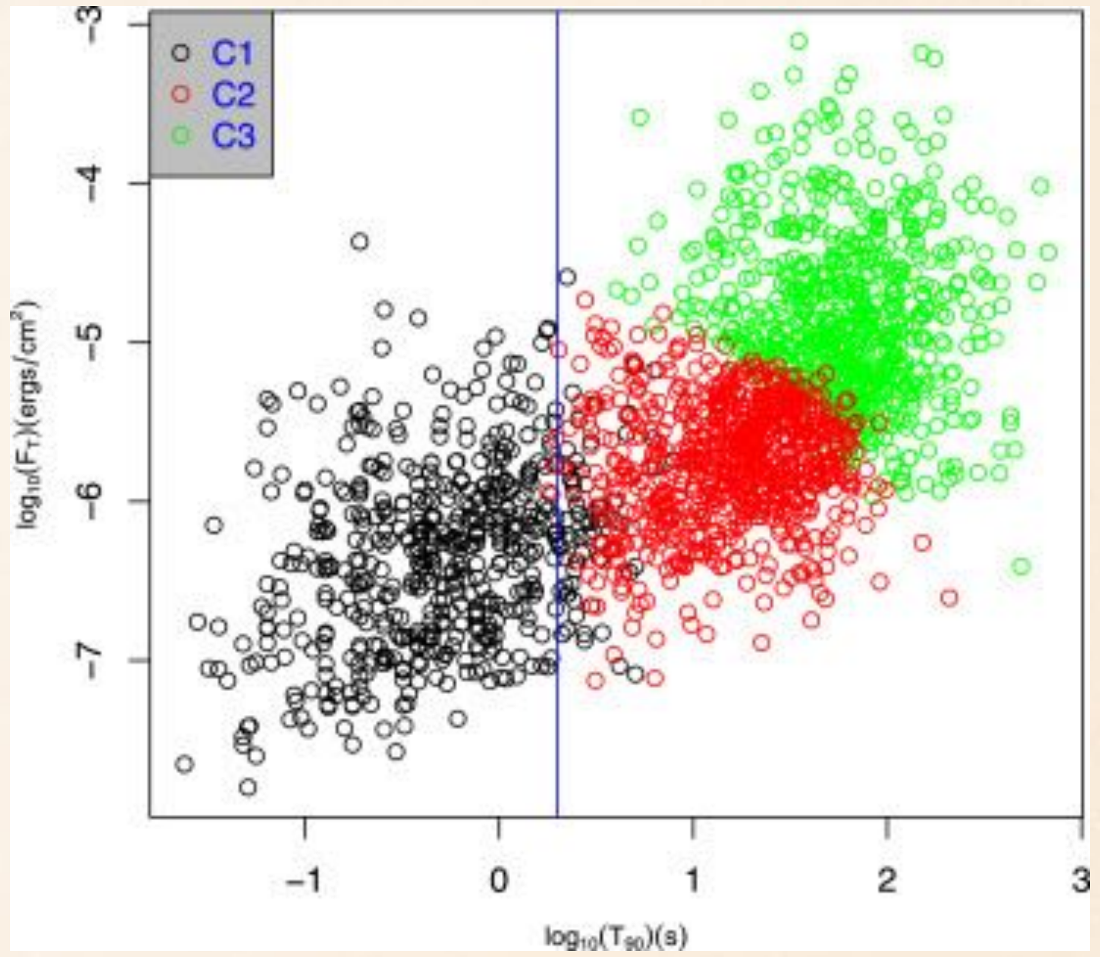


Page et. al. 2005



Based on the Gamma-ray data provided by BATSE (and later on by other satellites) we still divide GRBs in **Long** (prompt emission longer than 2s) and **Short** (<2s).

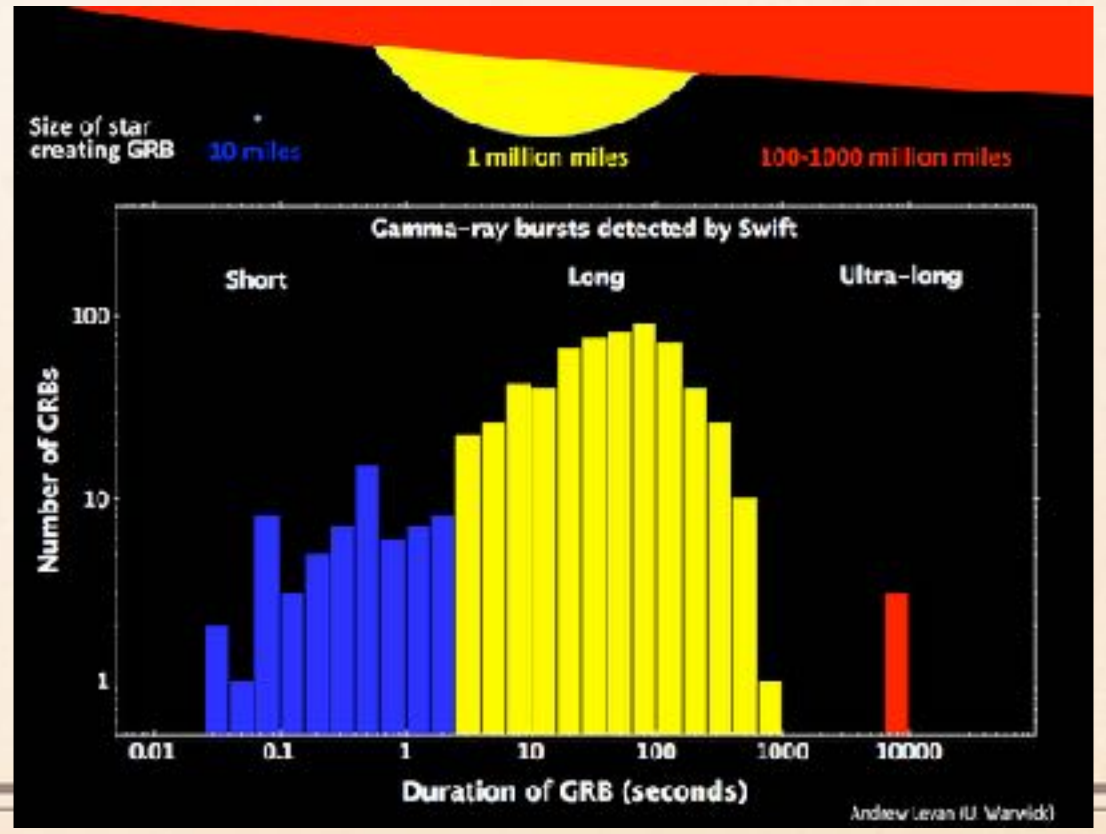
New statistical analysis suggests an **intermediate** class. (e.g. Soumita 2021)



We also have evidence of Ultra long GRBs, for which the prompt emission can last >1000s.

Long GRBs are produces by the collapse of very **massive stars** (>30 M).

Short-GRBs are the byproduct of **two compact object mergers** (and Gravitational Waver progenitors)

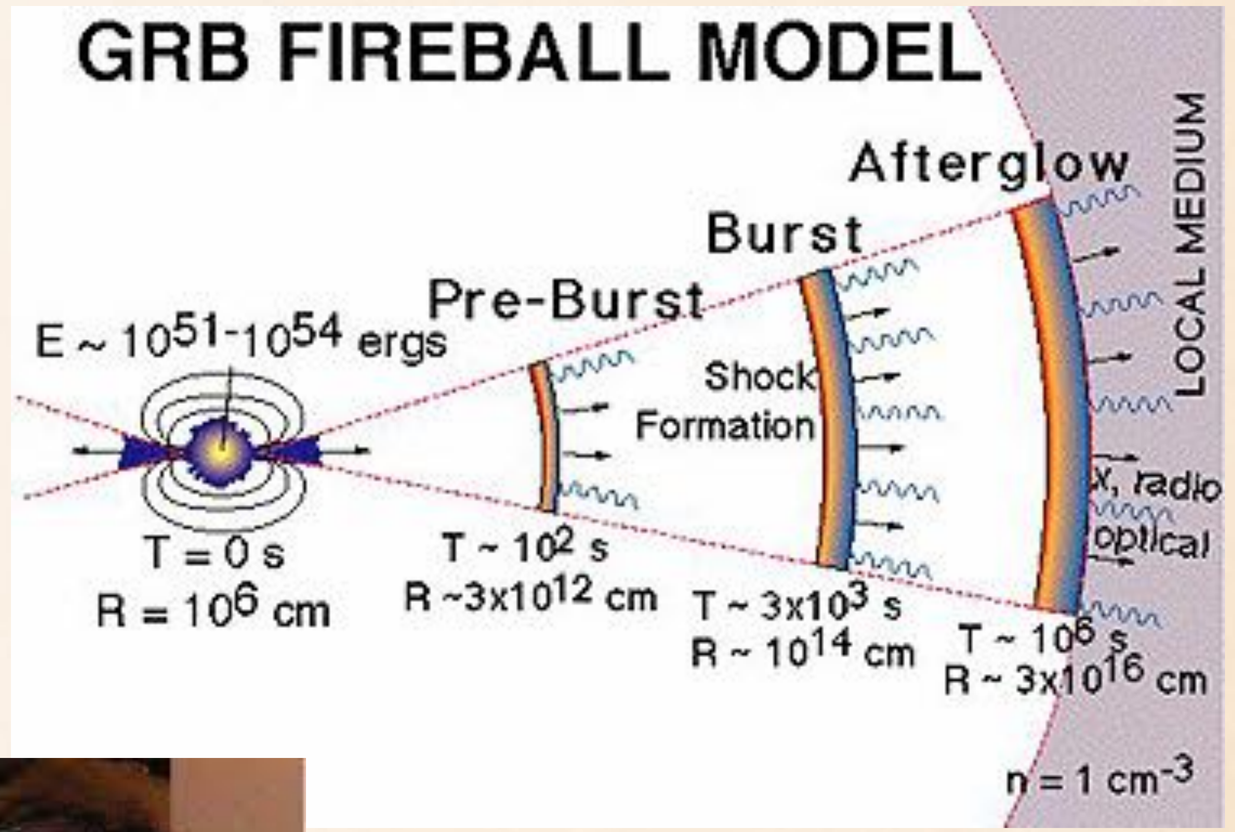


GRB SCIENCE IN A NUTSHELL

- Gamma ray bursts represent the most powerful explosions known in the Universe.
- Their interactions with the surrounding material (host galaxies) carries information on the chemical enrichment and history of the Universe.
- L-GRBs are cosmological objects (visible up to z > 20, PopIII stars?, Pair-Instability SN)
- S-GRBs are connected with the production of GW signals
- Represent the best tool for investigating the early stages of the Universe history, Star-formation and re-ionization epoch
- They are laboratories of dramatic conditions of stellar evolutions (magnetic field, shocks, compact objects equation of states, magnetar phases,...)

LONG GRBS: MAGNETARS, BLACK-HOLES, AND SUPERNOVAE

- The current standing model for long-GRB progenitors is a single massive star collapse
- The rapid, short living, gamma-ray emission is due to internal shocks colliding in relativistic motion (jetted)
- The ``afterglow" emission is produced by the interaction of the collimated jet with the surrounded ISM. Polarization is detected and carries information on the magnetic field.
- The presence of "flares" in the X-ray lightcurves, and the presence of pre-cursor in the prompt emission suggest a possible magnetar or continuously active central engine.
- A black-hole may be the end product of a long-GRB phenomenon
- Association of long-GRBs and Supernovae Ic also suggests a common origin




Maiorano et al. 2005

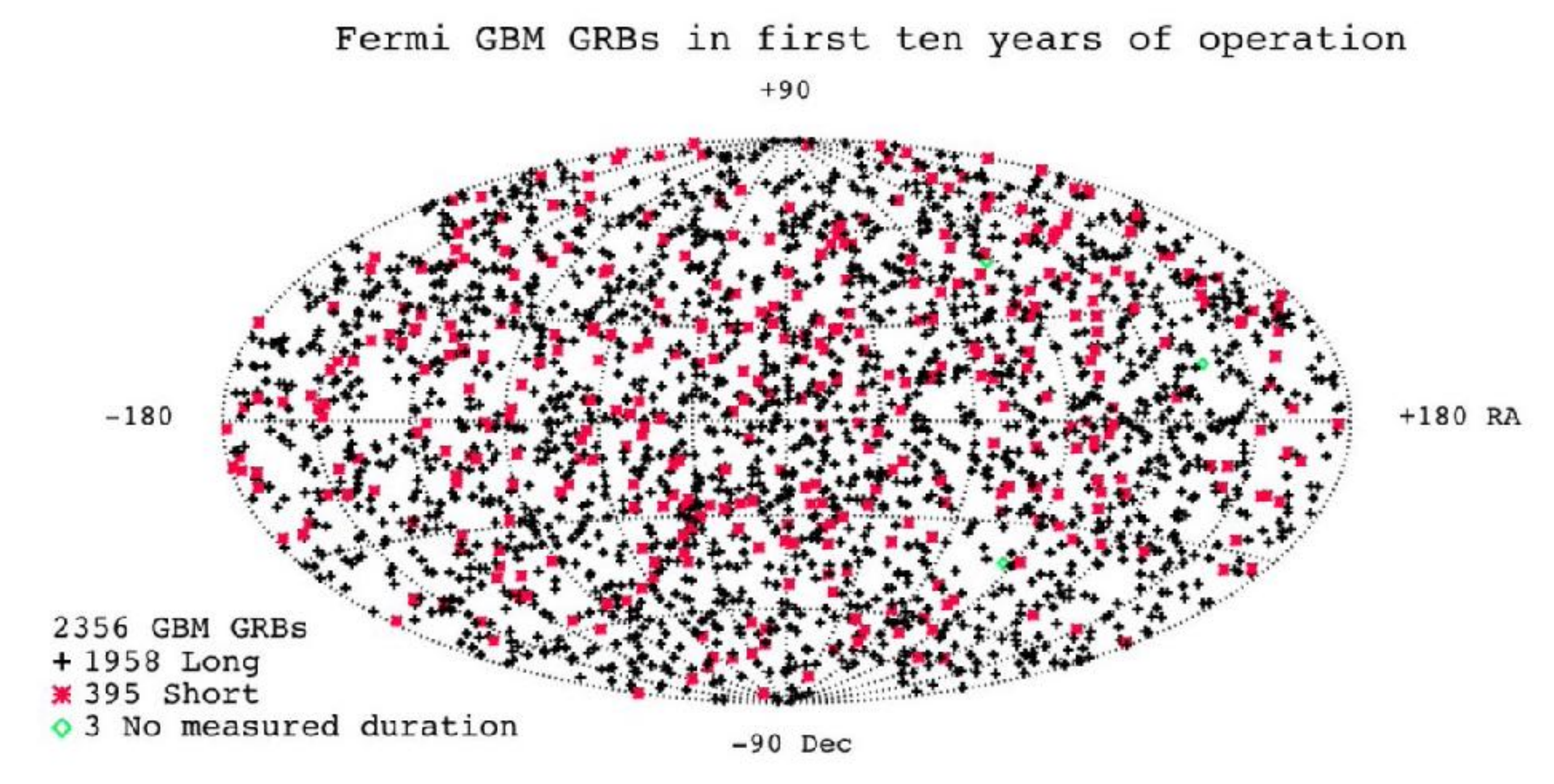

Rossi et al. 2002

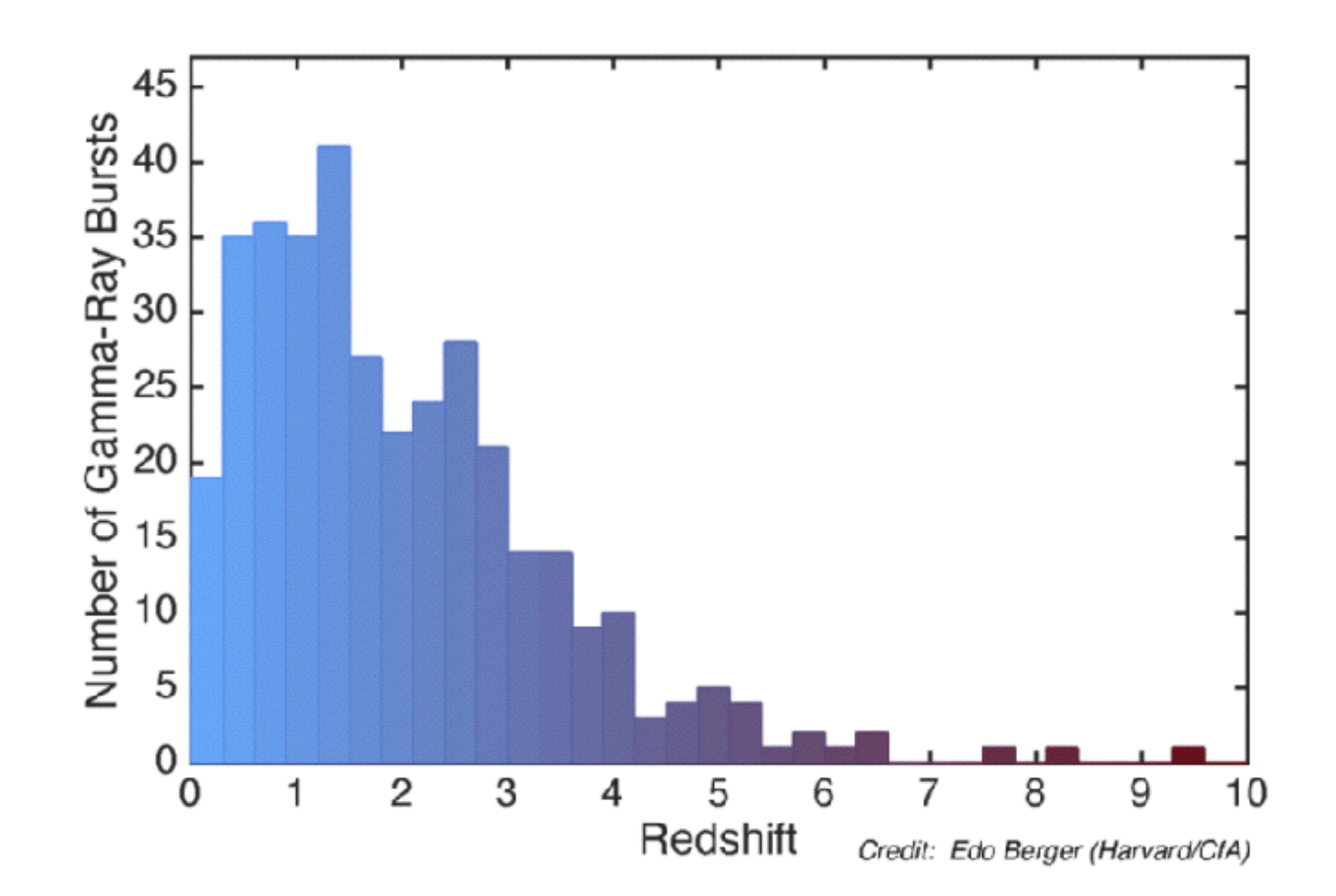

Soderberg et al. 2002


Modjaz et al. 2002


Margutti et al. 2002


Bernardini et al. 2002





Large field of view high-energy instruments in space, combined with adequate ground-based facilities are key to:

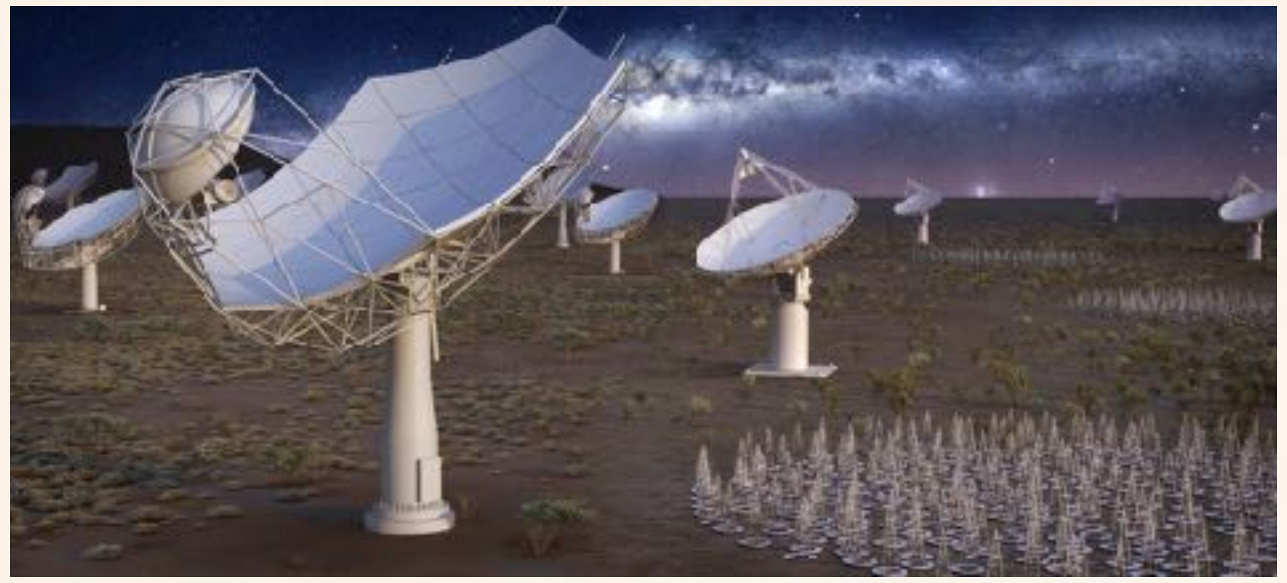
1. Rapidly identify the Long/Short GRB afterglows

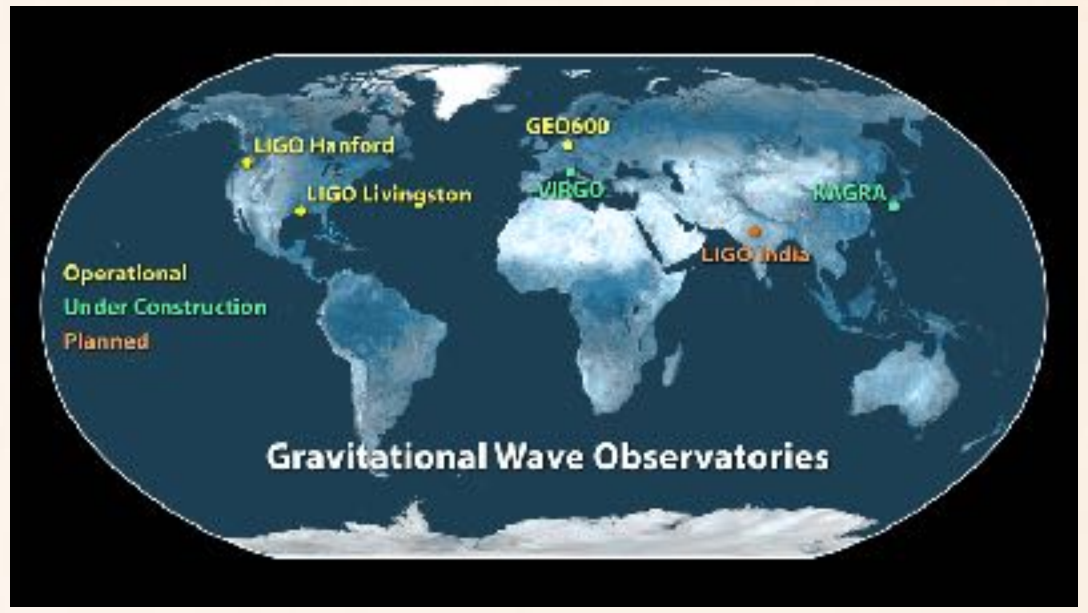
2. Obtain Redshift measurements

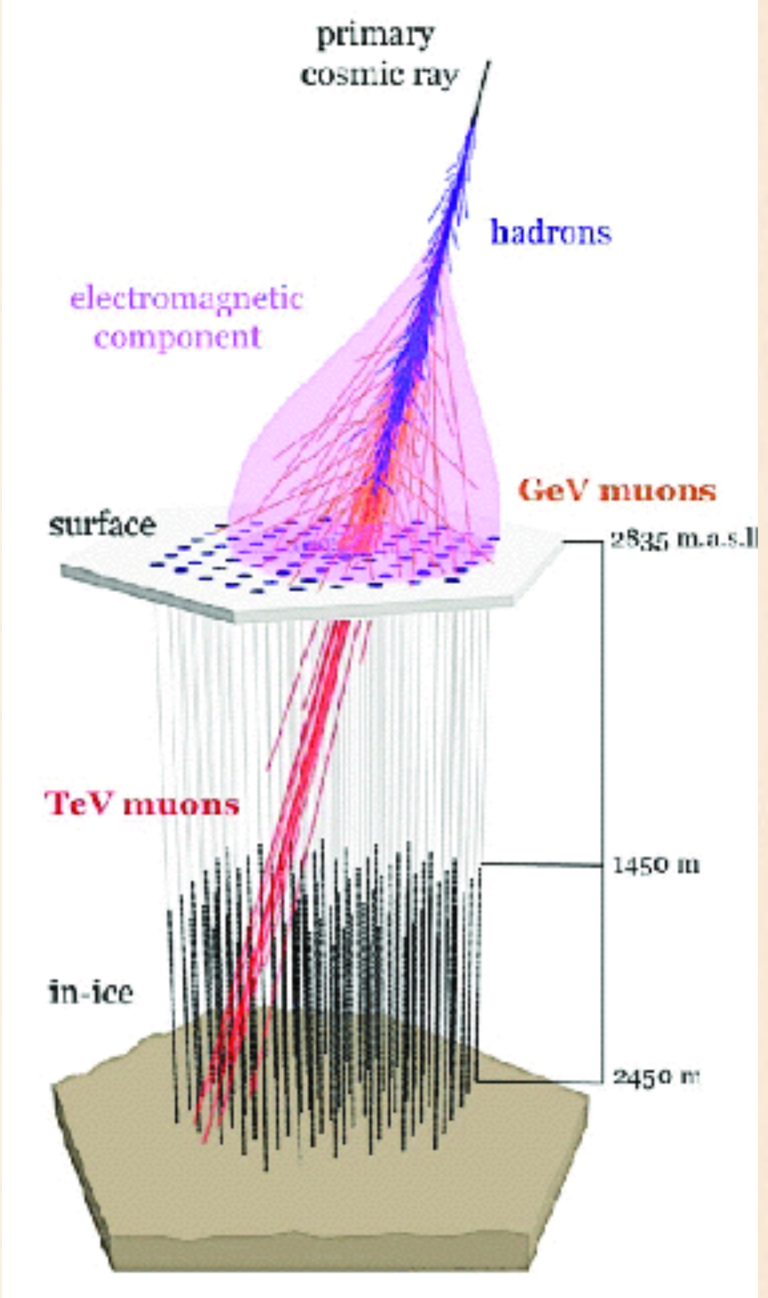
3. Collect key information about the progenitors itself, the host galaxy, and the ISM/IGM

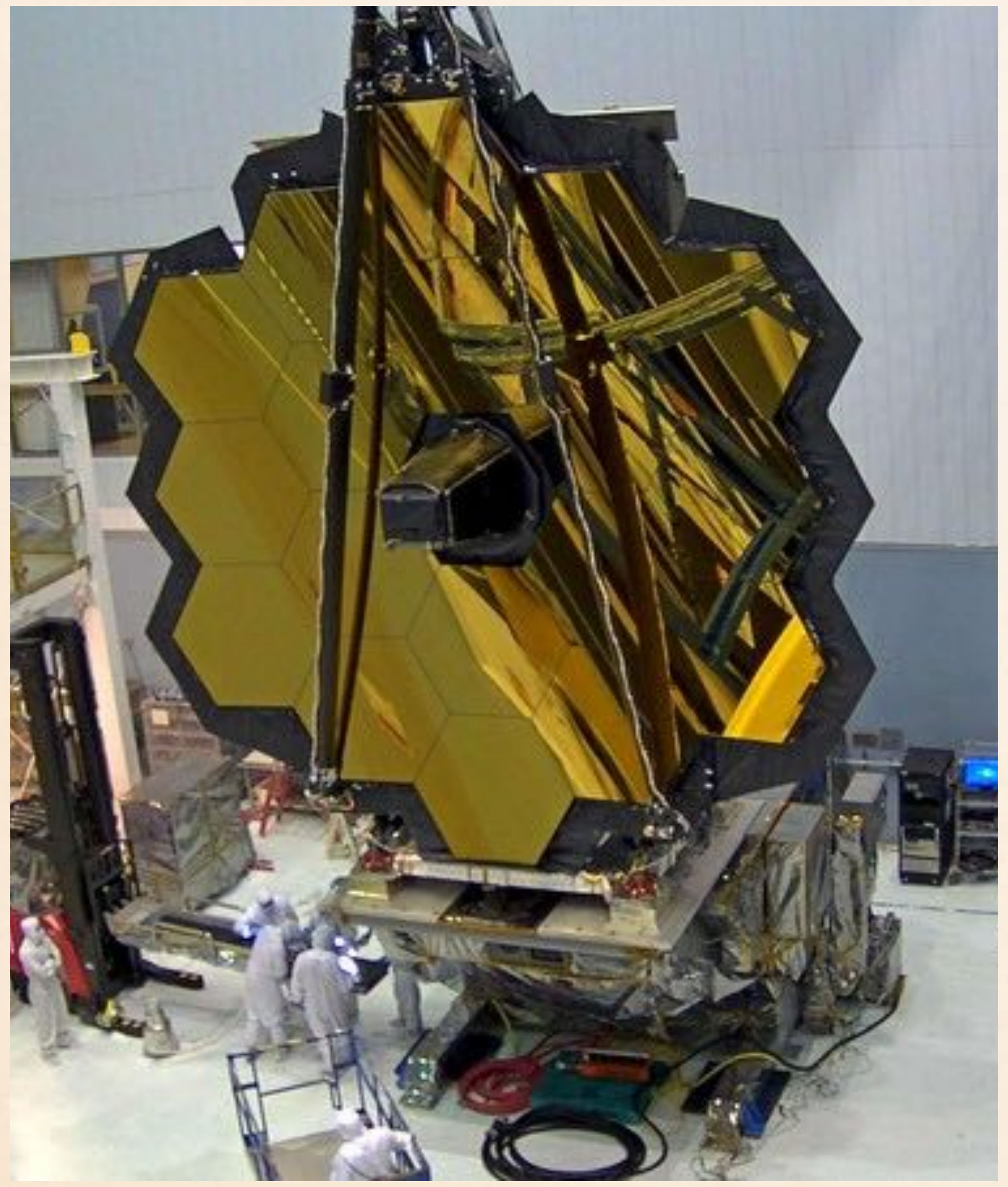
GETTING READY FOR GRB SEARCHES AND INVESTIGATION

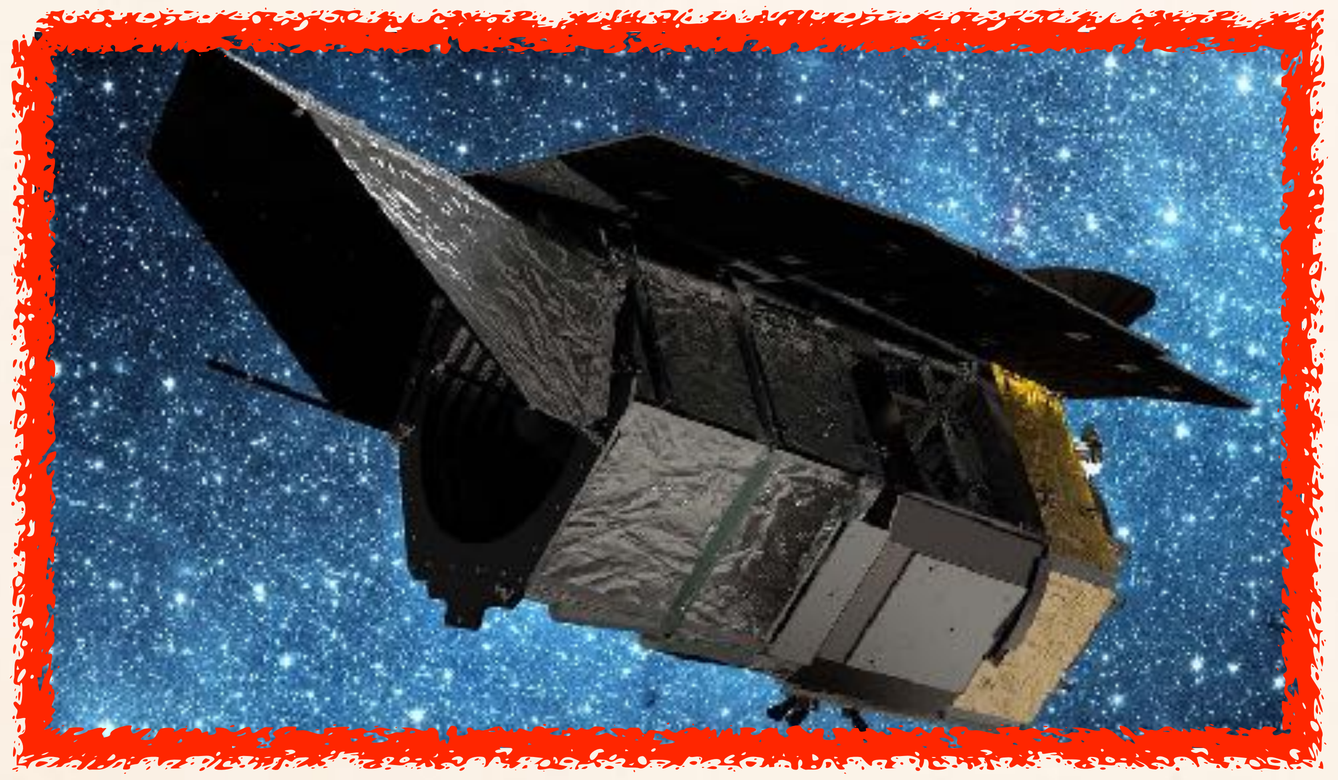
Roman will fly in 2026, joining an incredible suite of observatories apt to time-domain studies and multi-messenger astronomy.





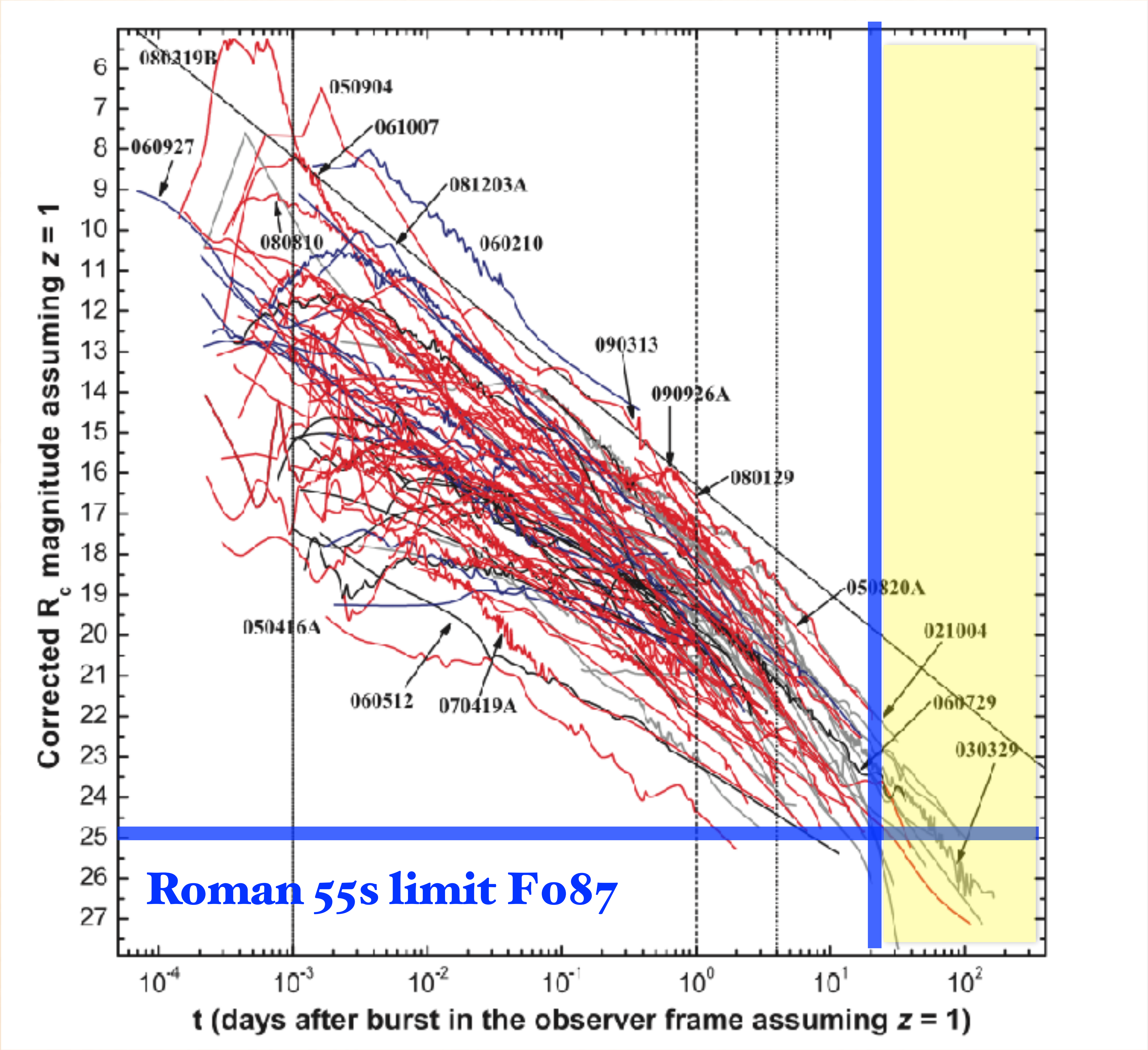






Synergy will be key to maximize
the science return from all these facilities and to properly follow-up
the most promising GRBs.

Lightcurves of long GRBs - Target of Opportunity program

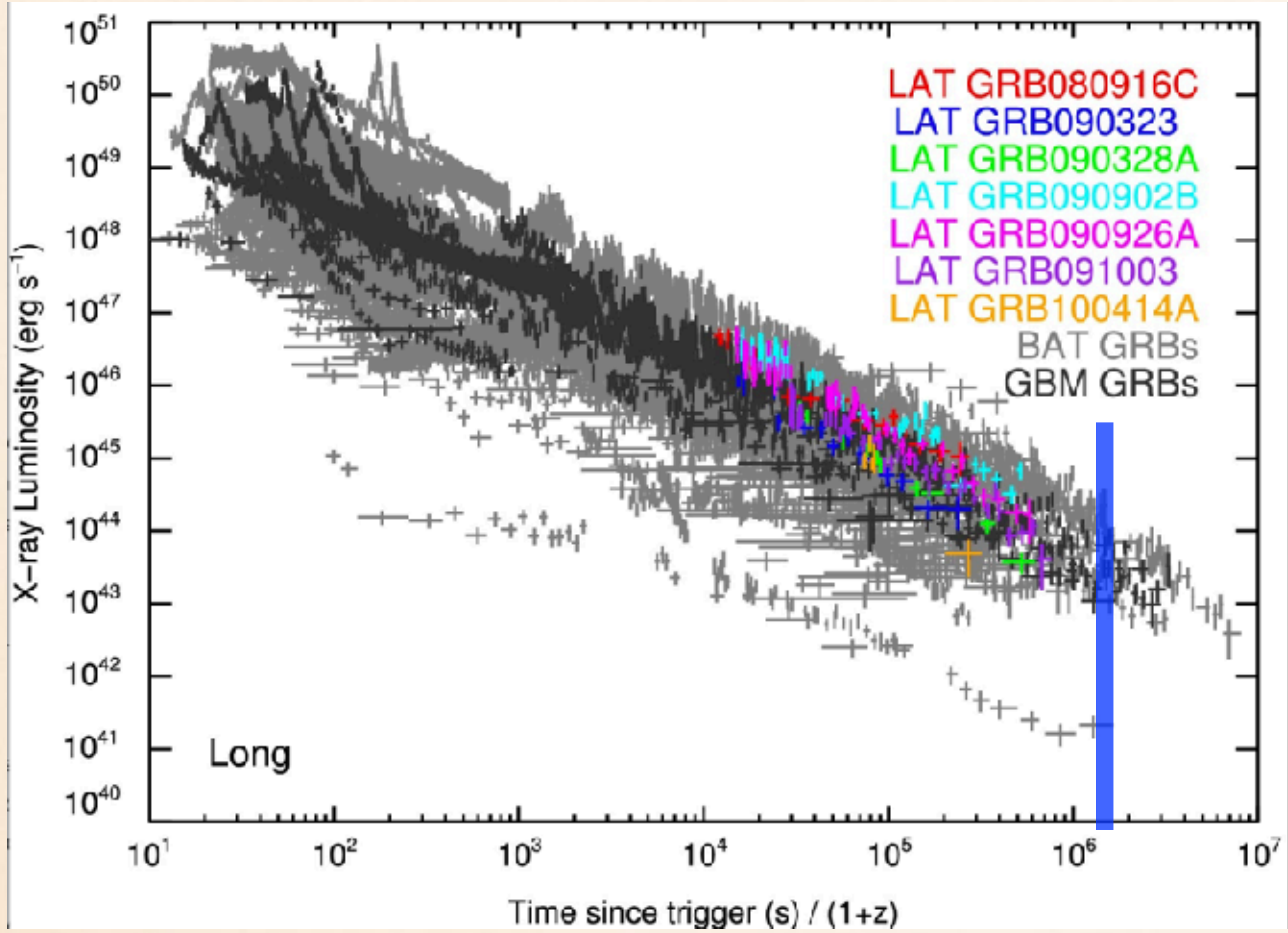


According to Summer 2020 Program-level requirement **Roman** should be able to slew to a point source within 2-weeks of notifying the Science operation center.

- LGRBs will be detectable in just 1 min (optical)
- LGRBs are brighter in the NIR
- GRISM spectroscopy will enable redshift measurements through broad features (DLA, Lyman break)

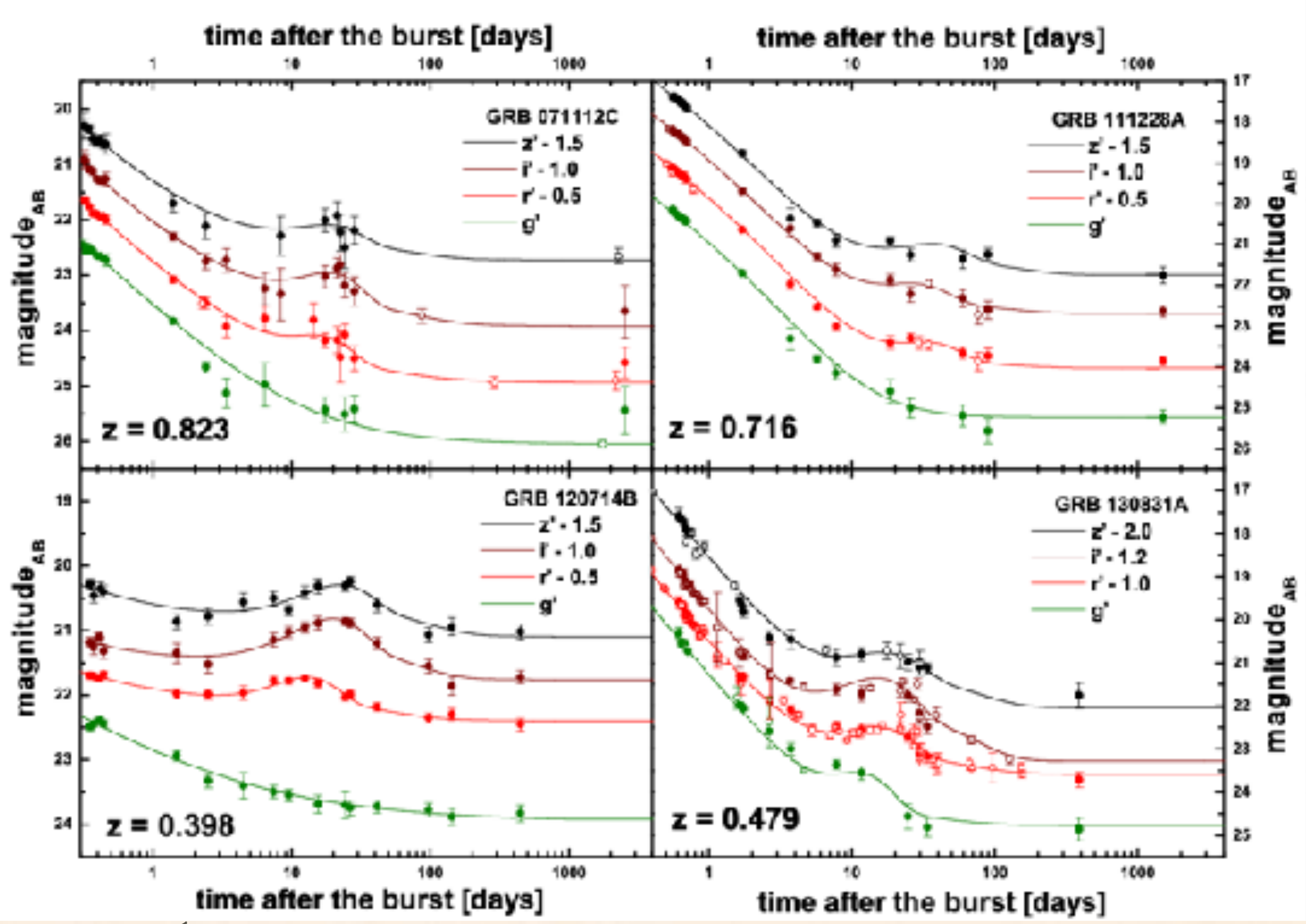
WHAT WILL WE LEARN?

We will explored a total new parameter space (NIR/Late time)

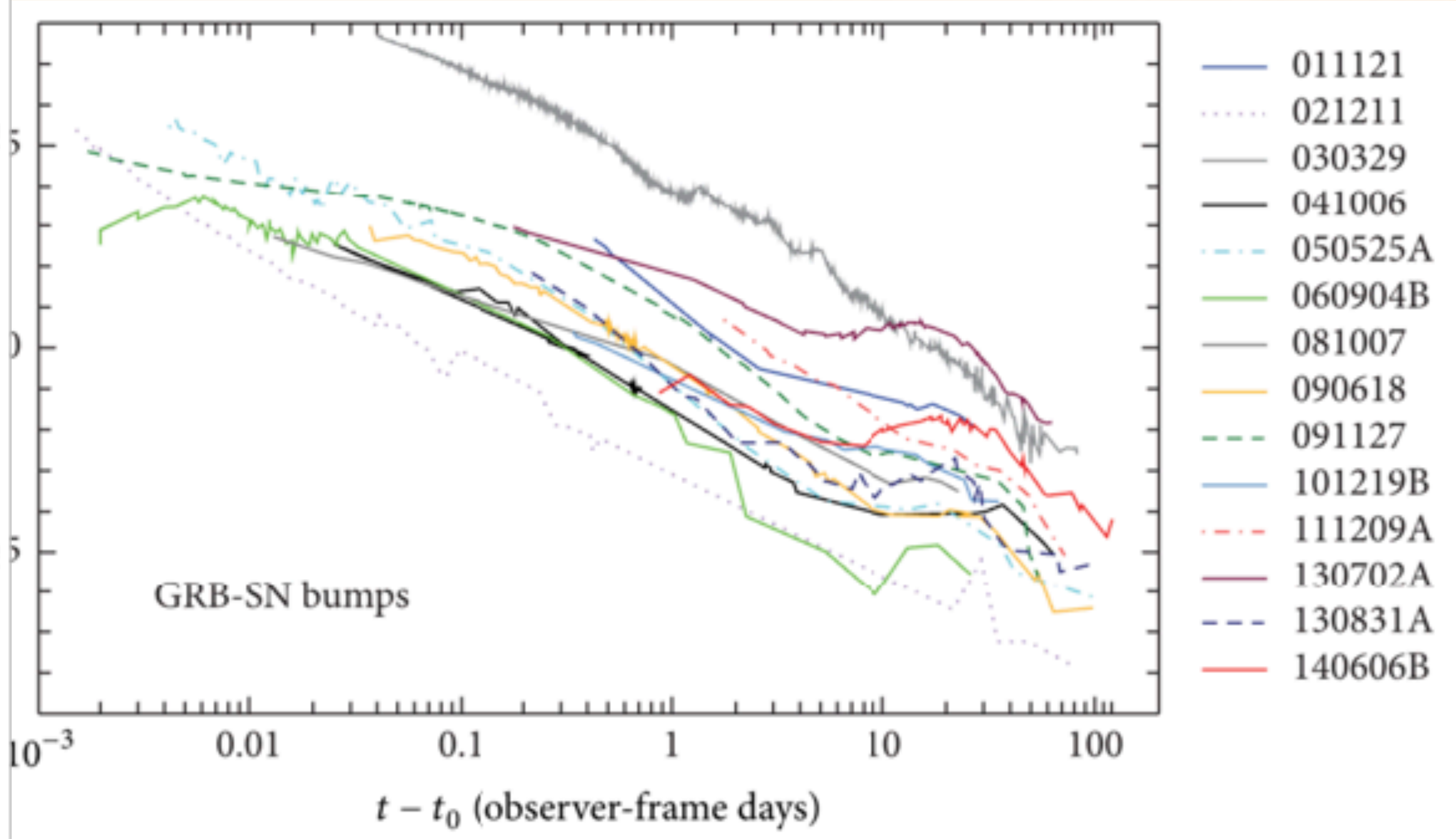


- We will be able to probe jet-breaks
- We will be able to study the un-obscured emission
- We will be able to determine redshifts
- We will determine Supernovae association

Zhu et al. 2015

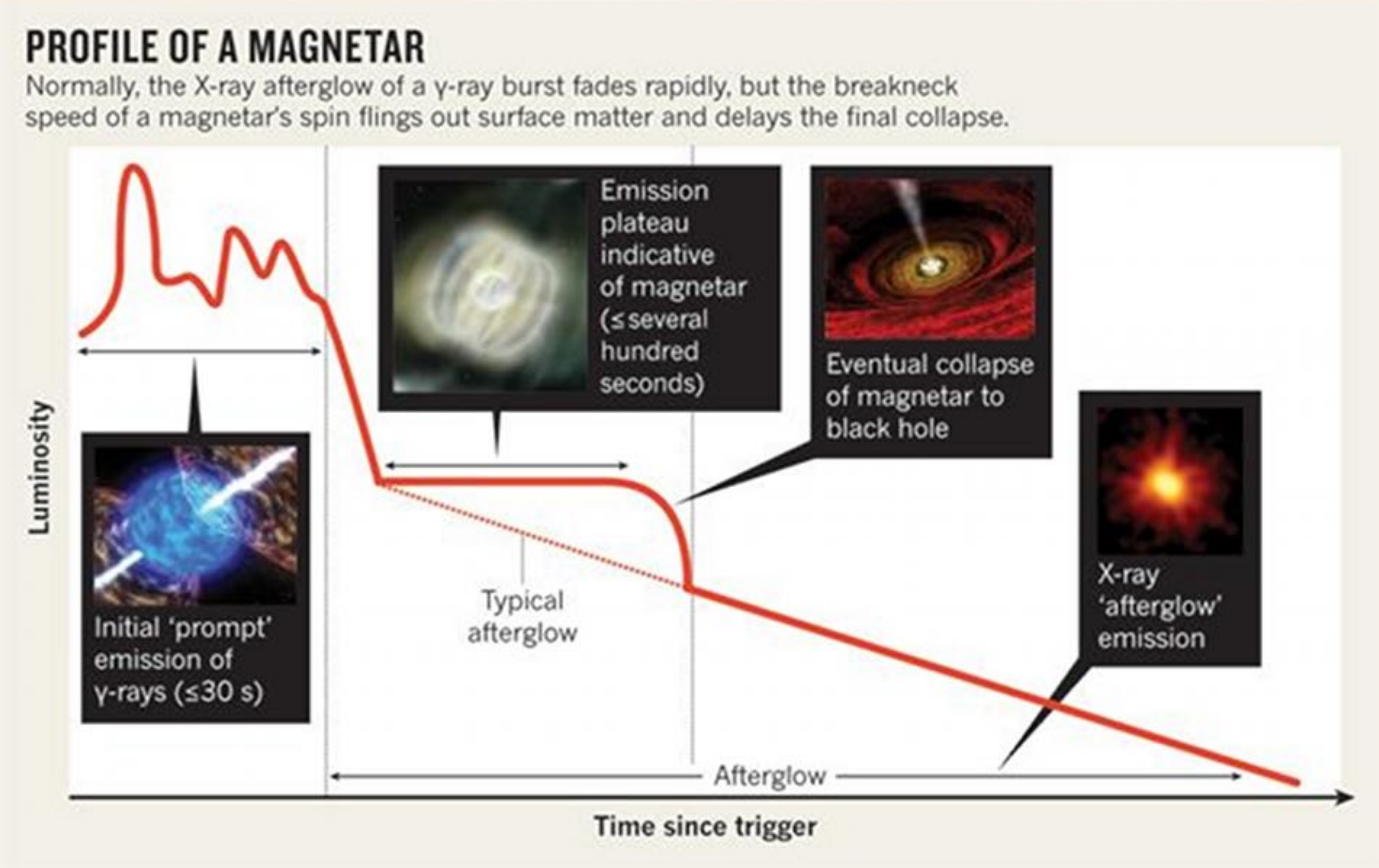


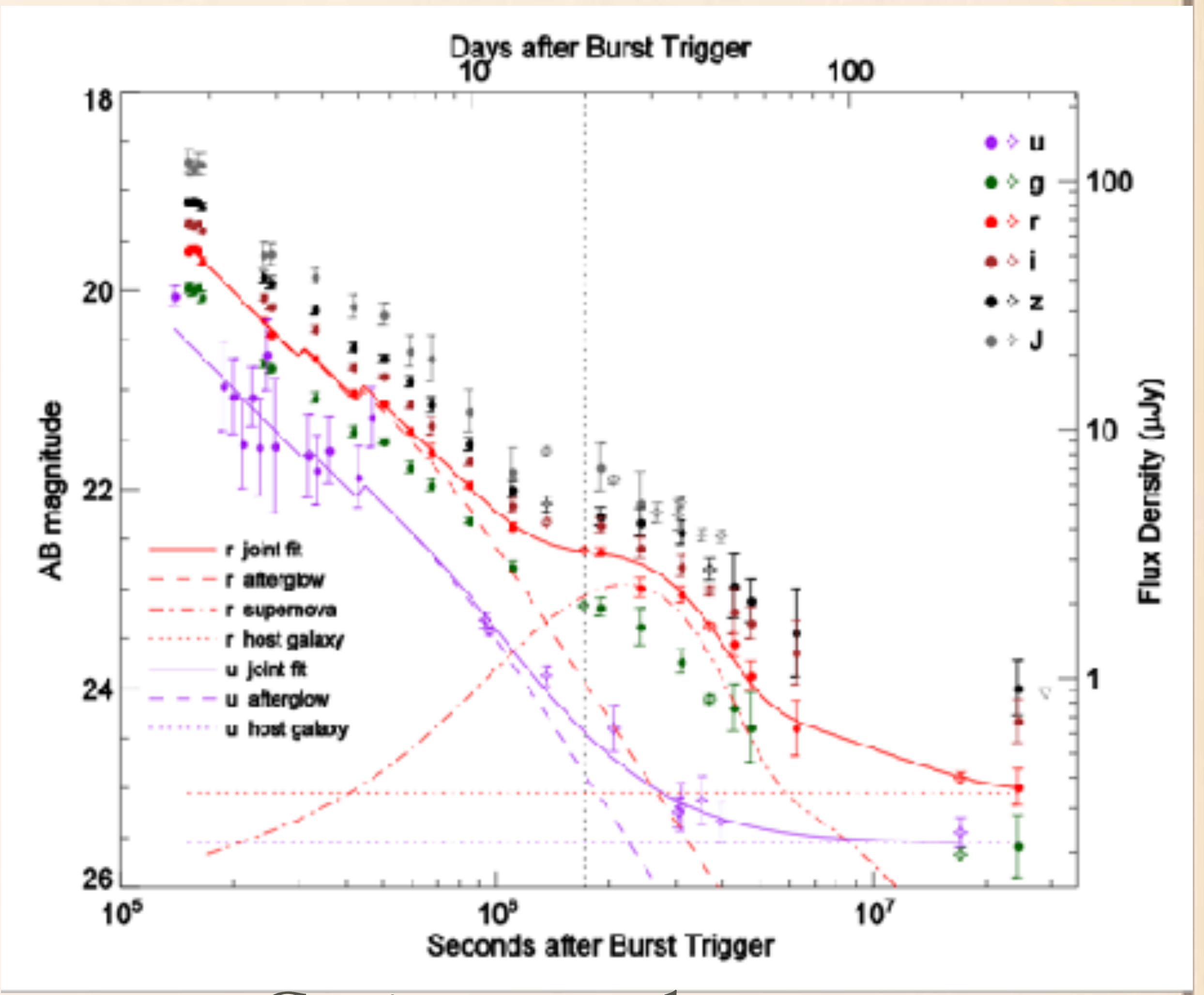
Klose+, 2019



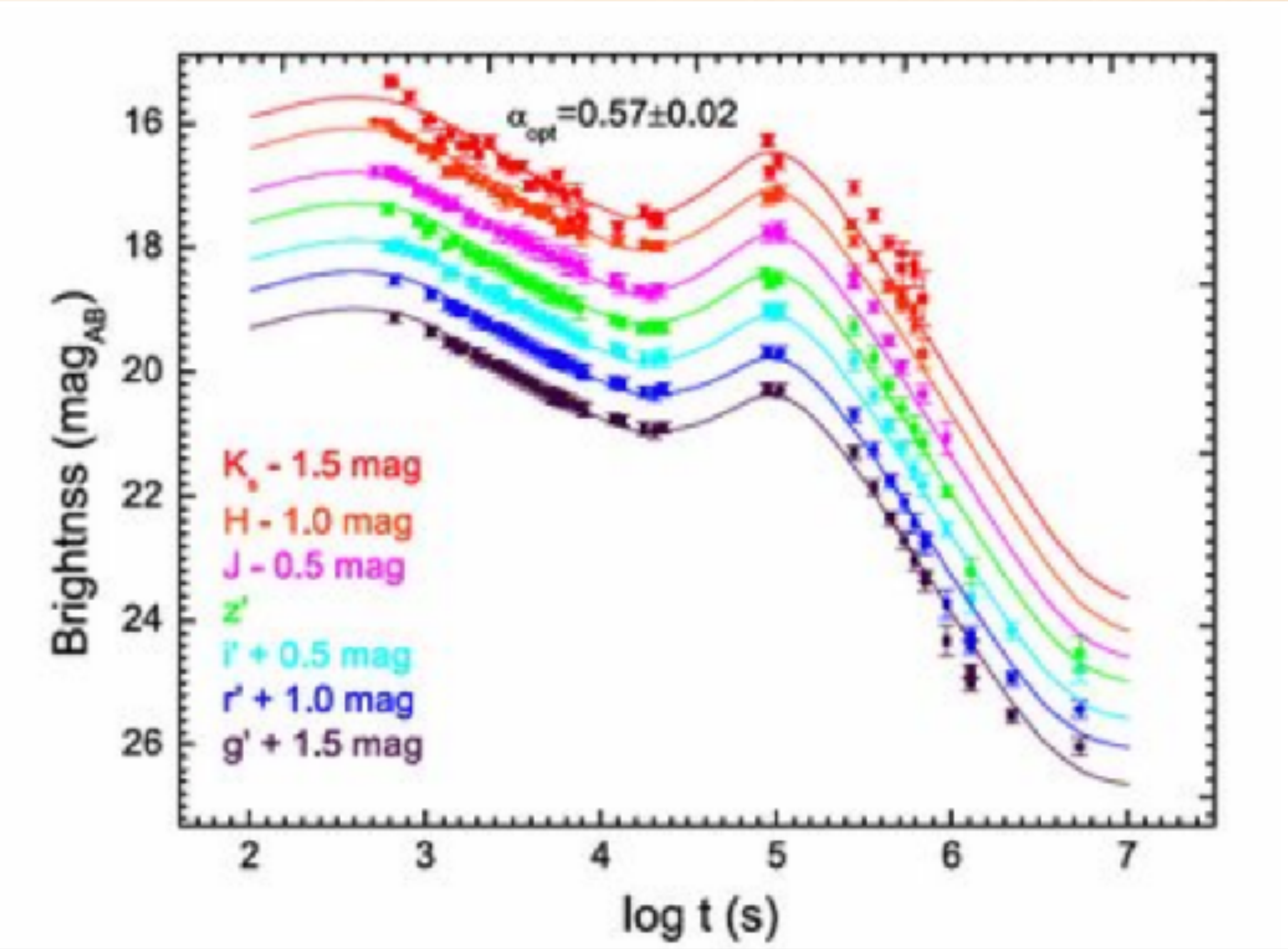
Cano+, 2017

MAGNETAR-POWERED GRB?





Greiner. et al. 2015

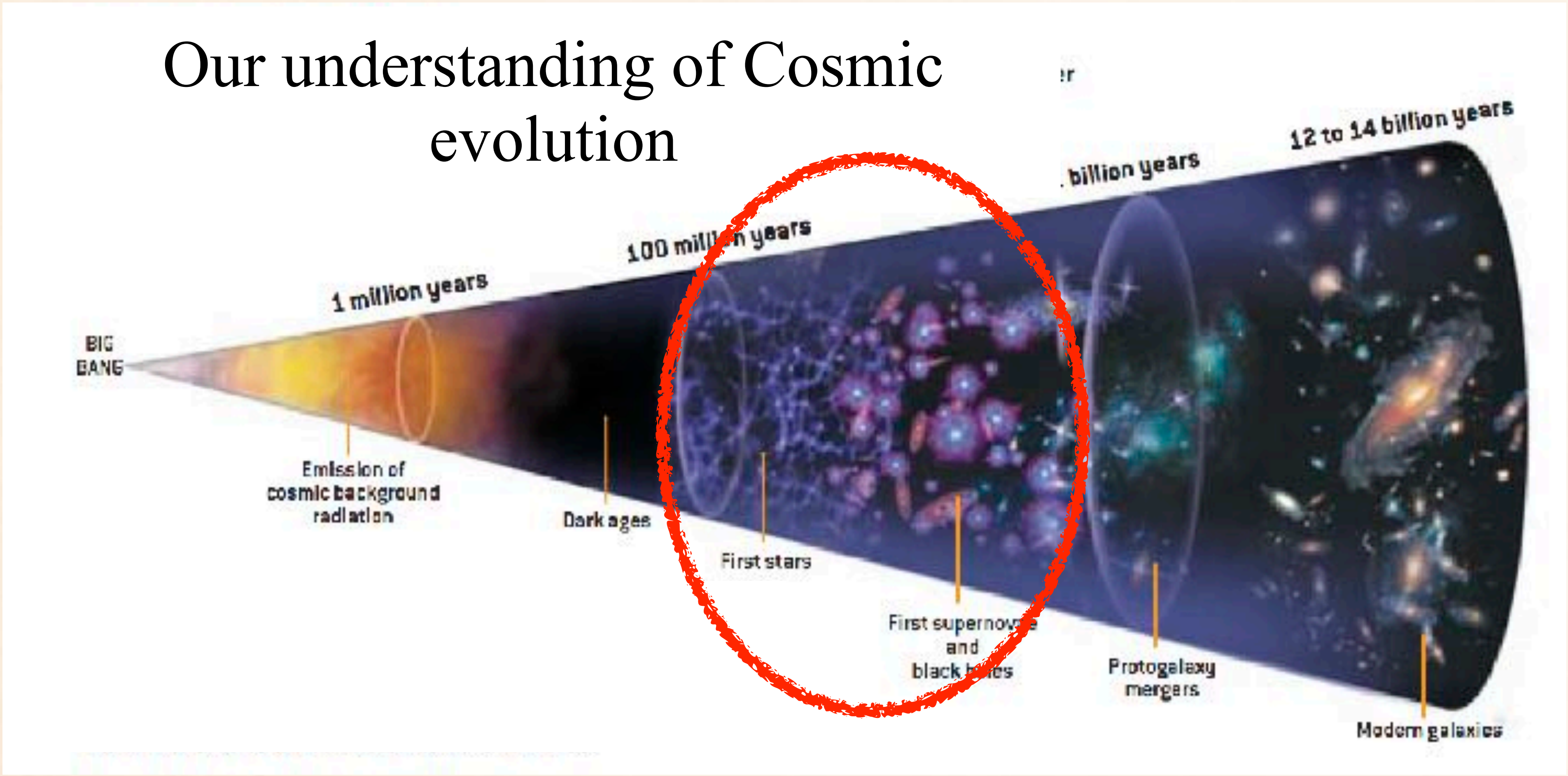


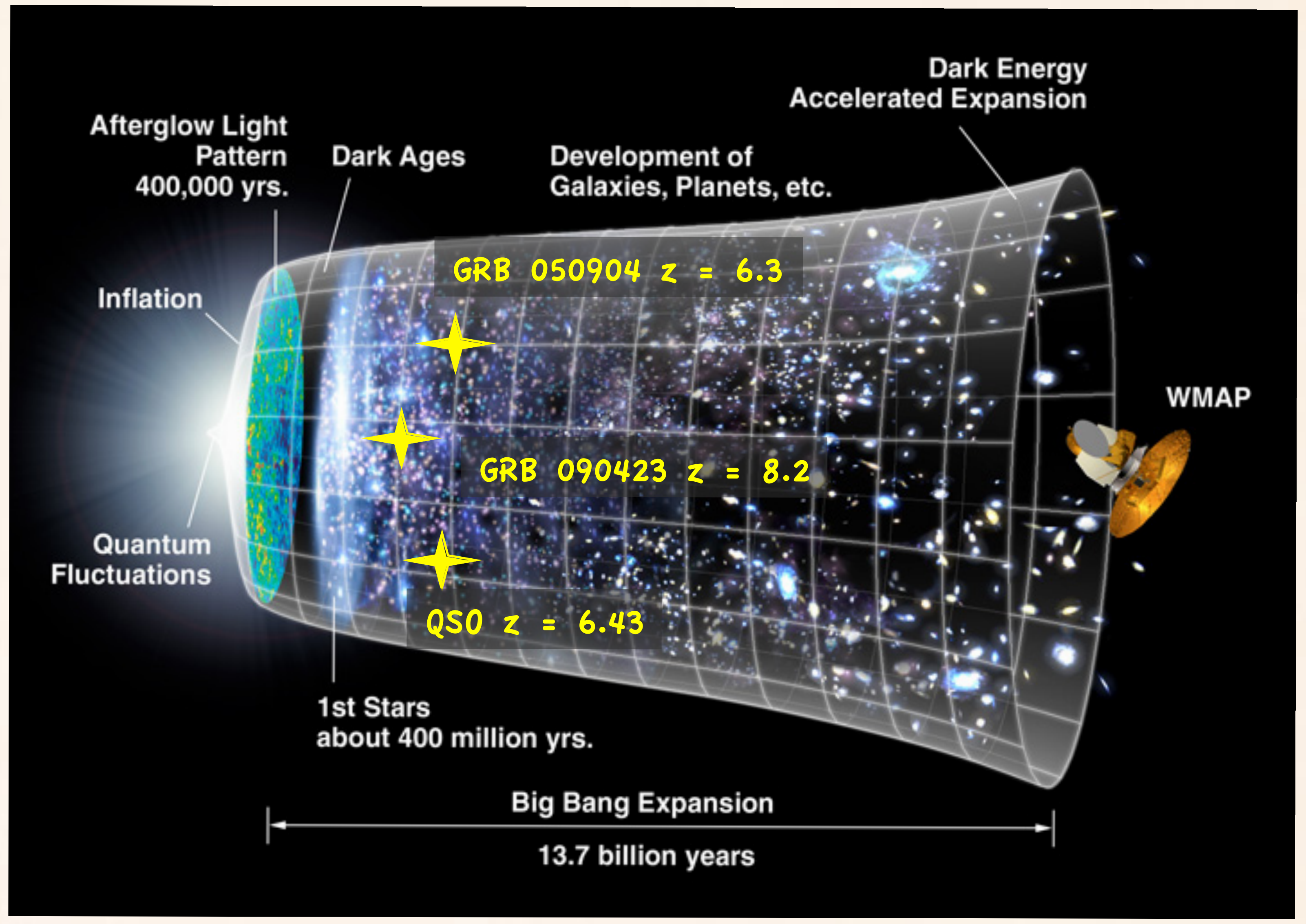
Yu. et al. 2020

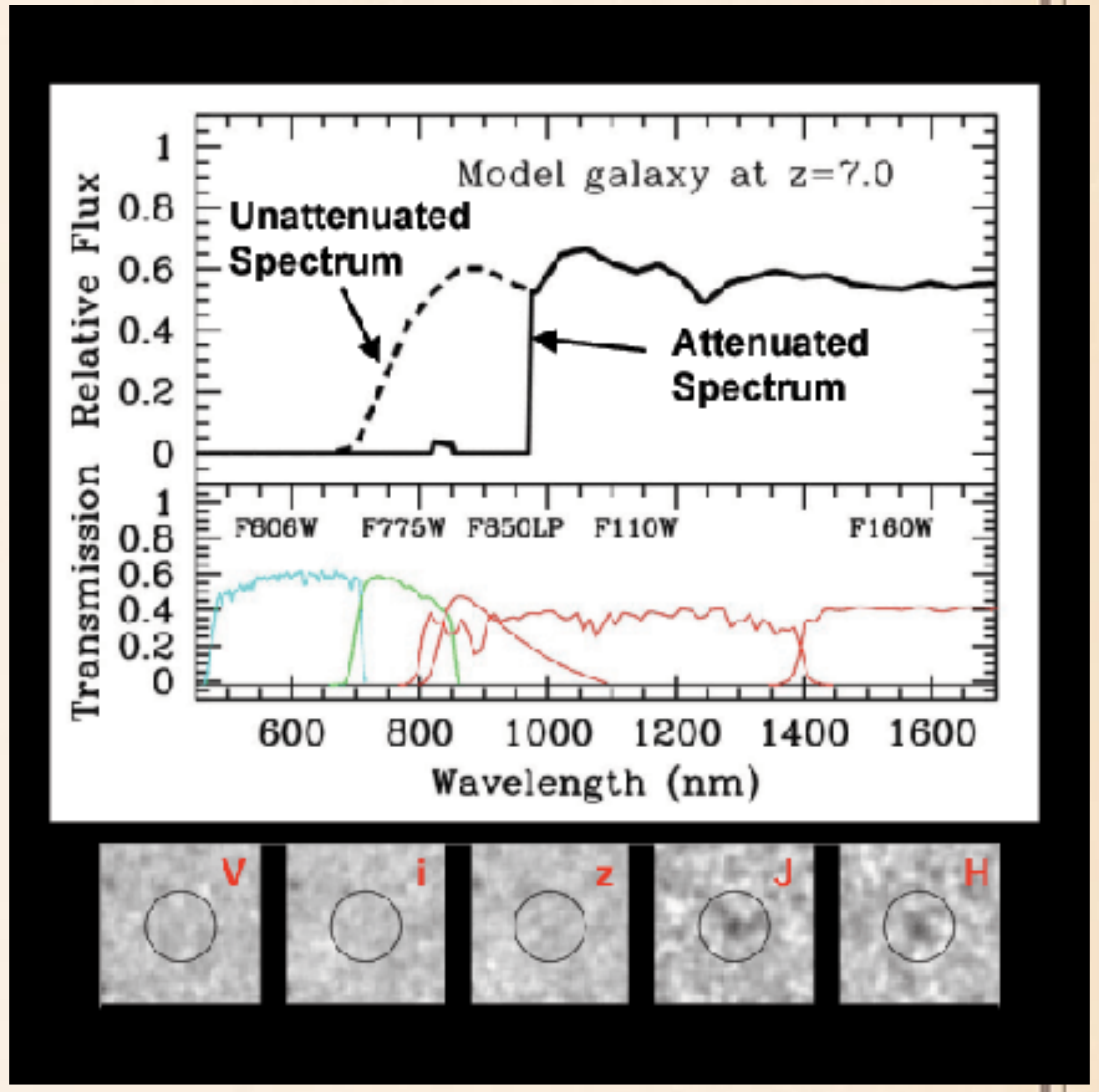
Roman will be able to disentangle the contribution of Magnetars (early) and SN (late) contributions

WHAT WILL WE LEARN?

Long GRBs at z>7 are our only chance to study massive star formation during re-ionization and re-ionization itself.



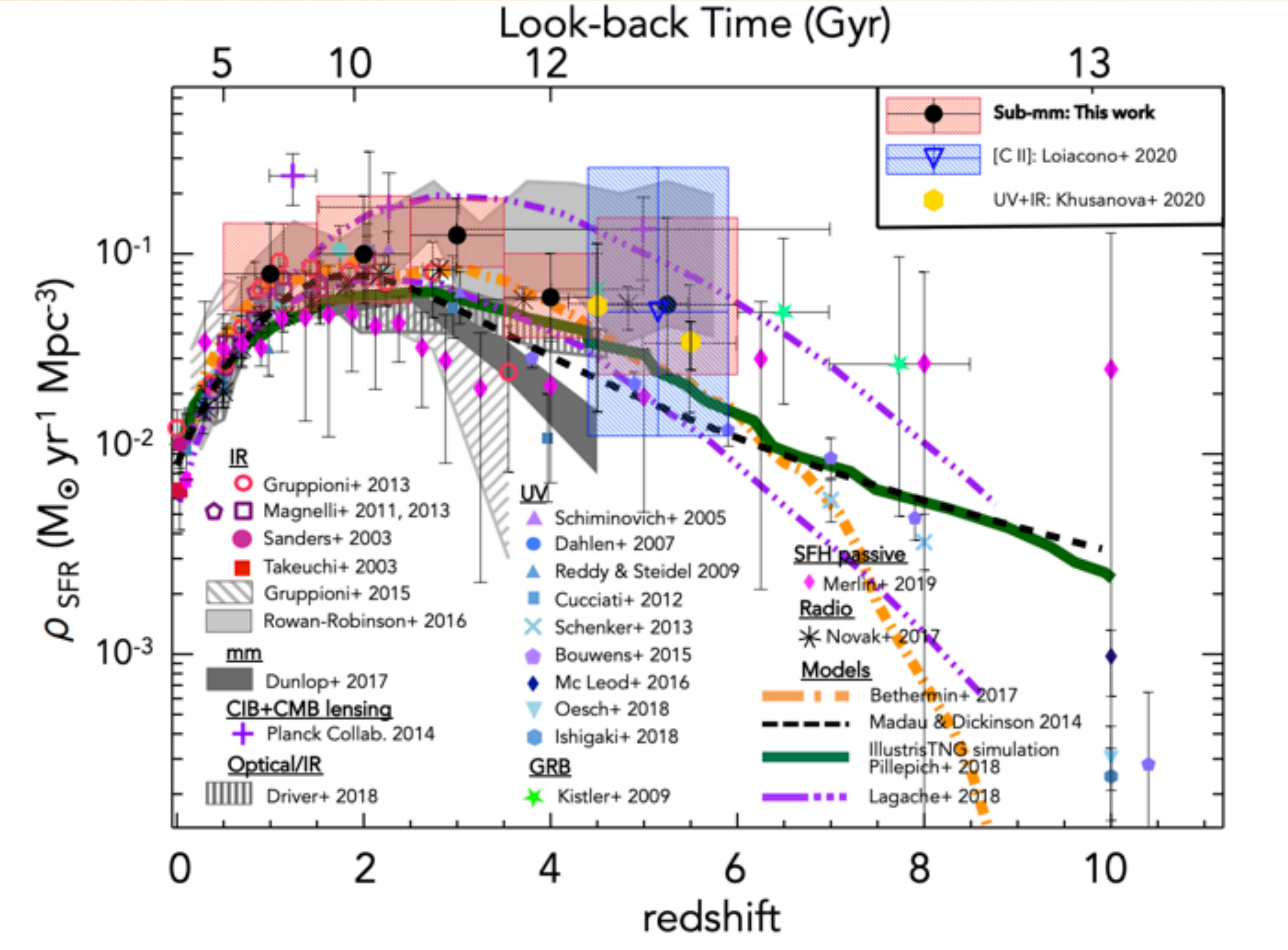




Credit: Charles Bowuens

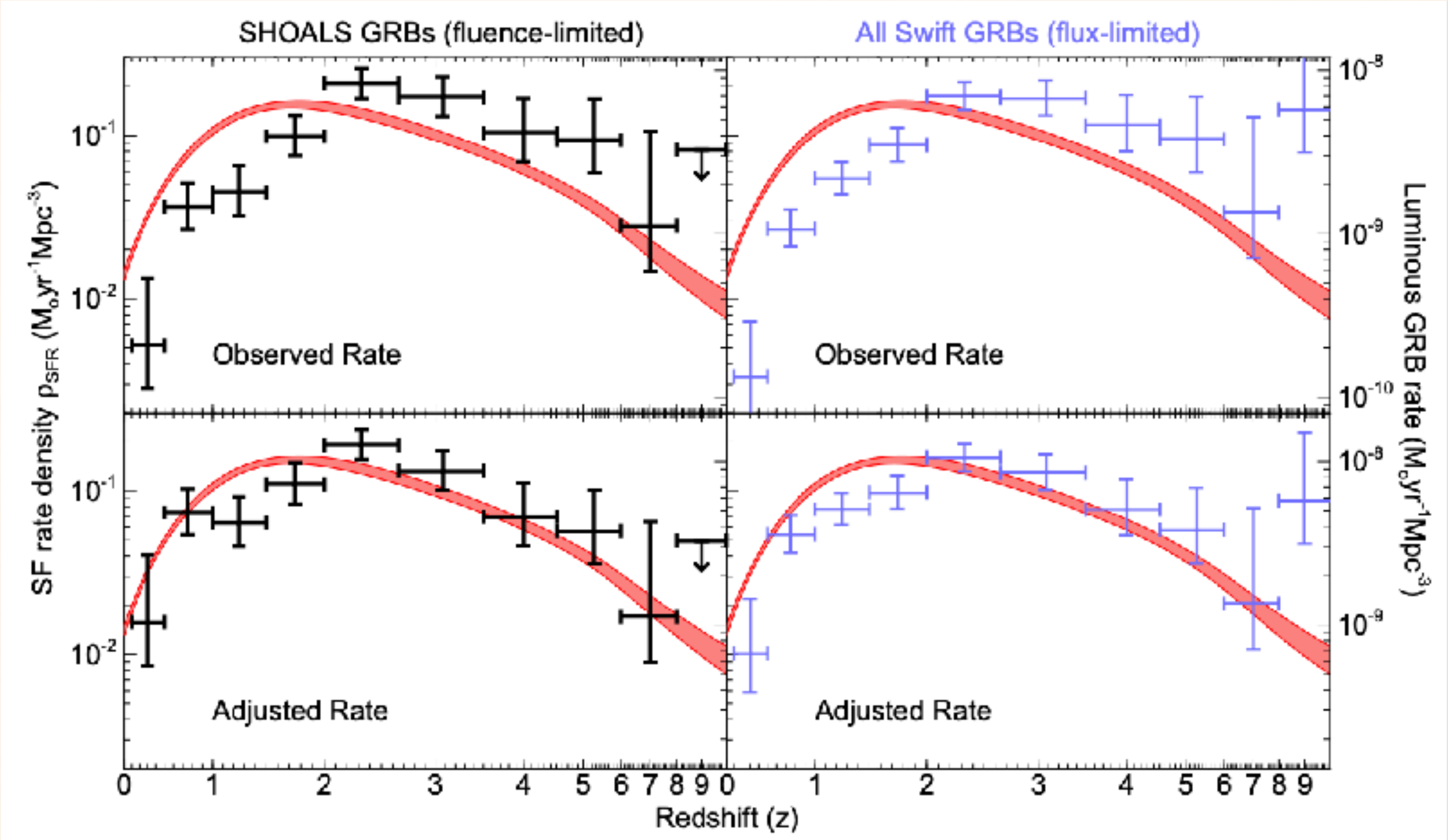
- Lyman-break technique will enable the confirmation of high-z GRBs
- GRISM (R~600) would be enough to detect broad features, like DLAs
- We will be able to assess the hydrogen neutral fraction and place constraints on the cosmic star-formation from GRBs

It is an exciting moment for Star-formation rate density studies, where GRBs and ground based (e.g. sub-mm) data gives puzzling discrepancies.



Gruppioni et al. 2020

GRB provide a great complementary tool to Galaxy surveys.

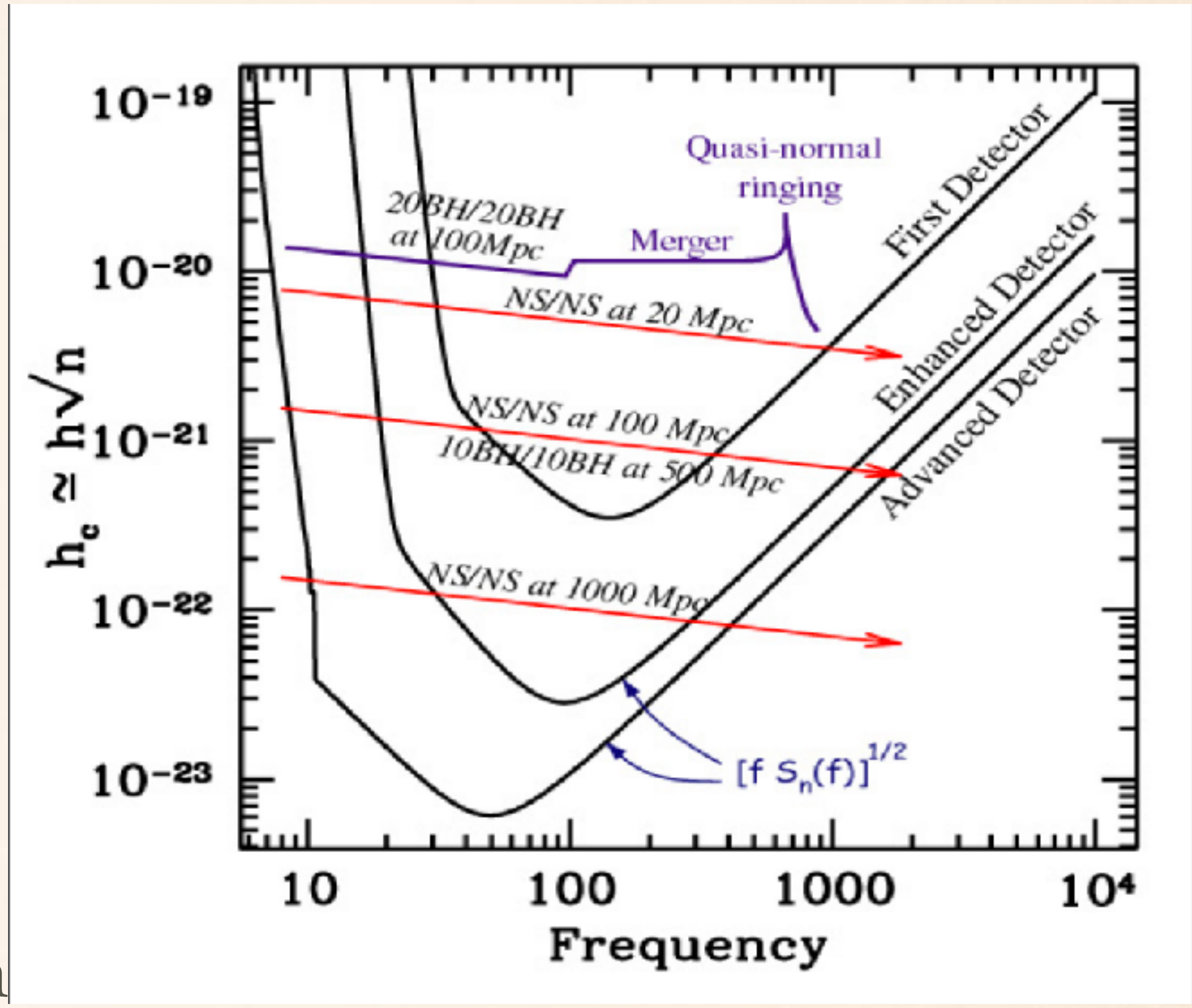


Perley et al. 2016

Roman will be complementary with JWST (e.g. ToO capability, observing constraints)

WHY WE CARE ABOUT SHORT-GRBS?

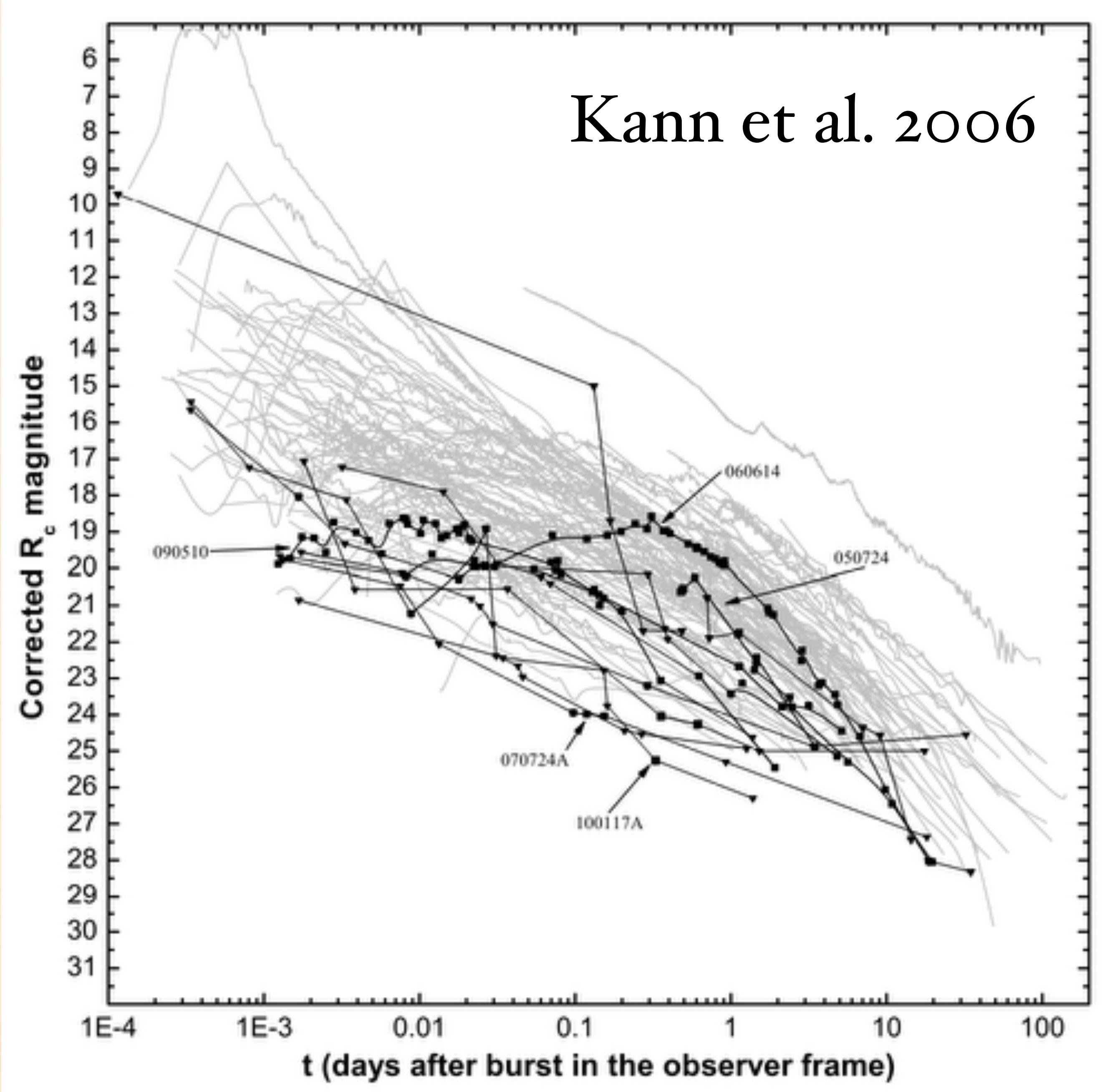
- SGRB Gamma-ray emission is short (<1-2 sec)
- Their emission is very faint (~10^{48}-10^{51} erg)
- So far z>0.122 (median 0.4)
- Hard to localize accurately (SGRB-Host association)
- They are produced by compact objects merger and produce their EM counterpart* (Kilonovae)
- They are associated with Gravitational Waves emission

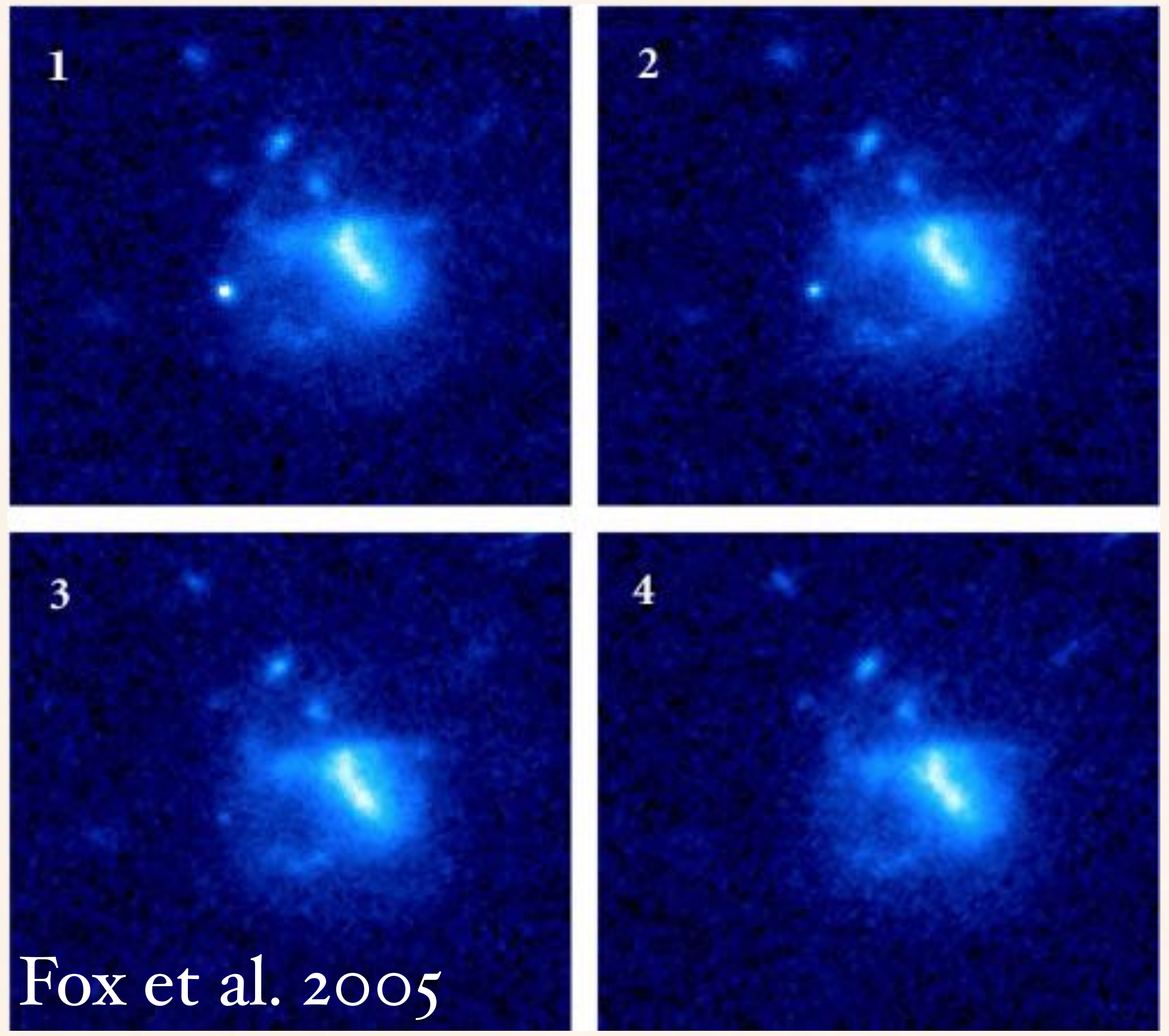


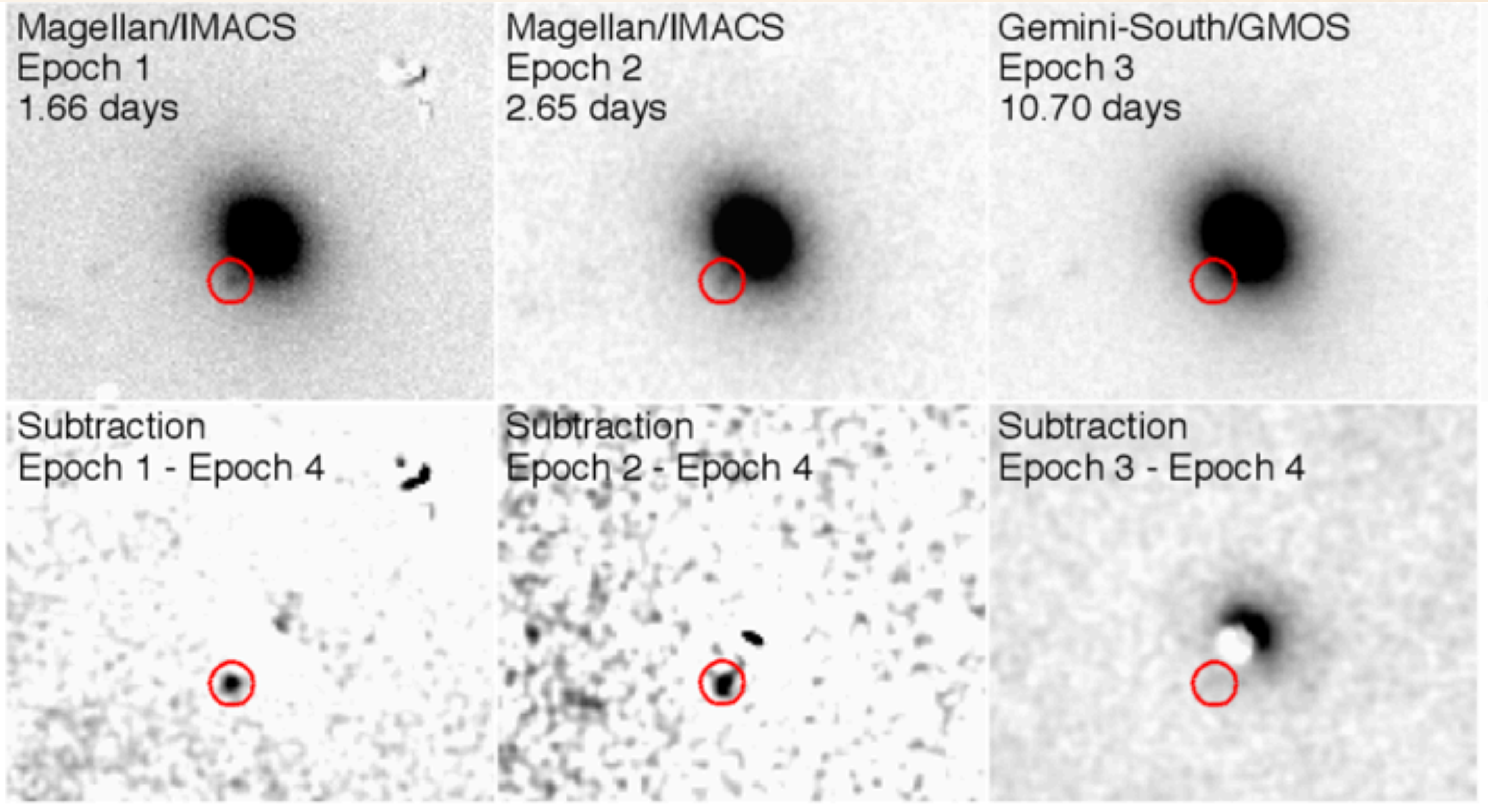
* Blinnikov et al. (1984); Paczynski (1986), Goodman (1986); Goodman, Dar & Nussinov (1987); Eichler et al. (1989) ; Narayan, Paczynski & Piran (1992); Paczynski (1991), Narayan, Paczynski & Piran (1992) Mochkovitch et al. (1993)

CHASING SHORT GRBS AND THEIR HOSTS

Due to the fast disappearing nature of the afterglow, the search for short GRBs and the adequate association with their hosts has been challenging.
Their intrinsic faintness compared to L-GRBs make even harder to follow-up.







Rastinejad, 2021

Nugent, 2022

Troja, 2010

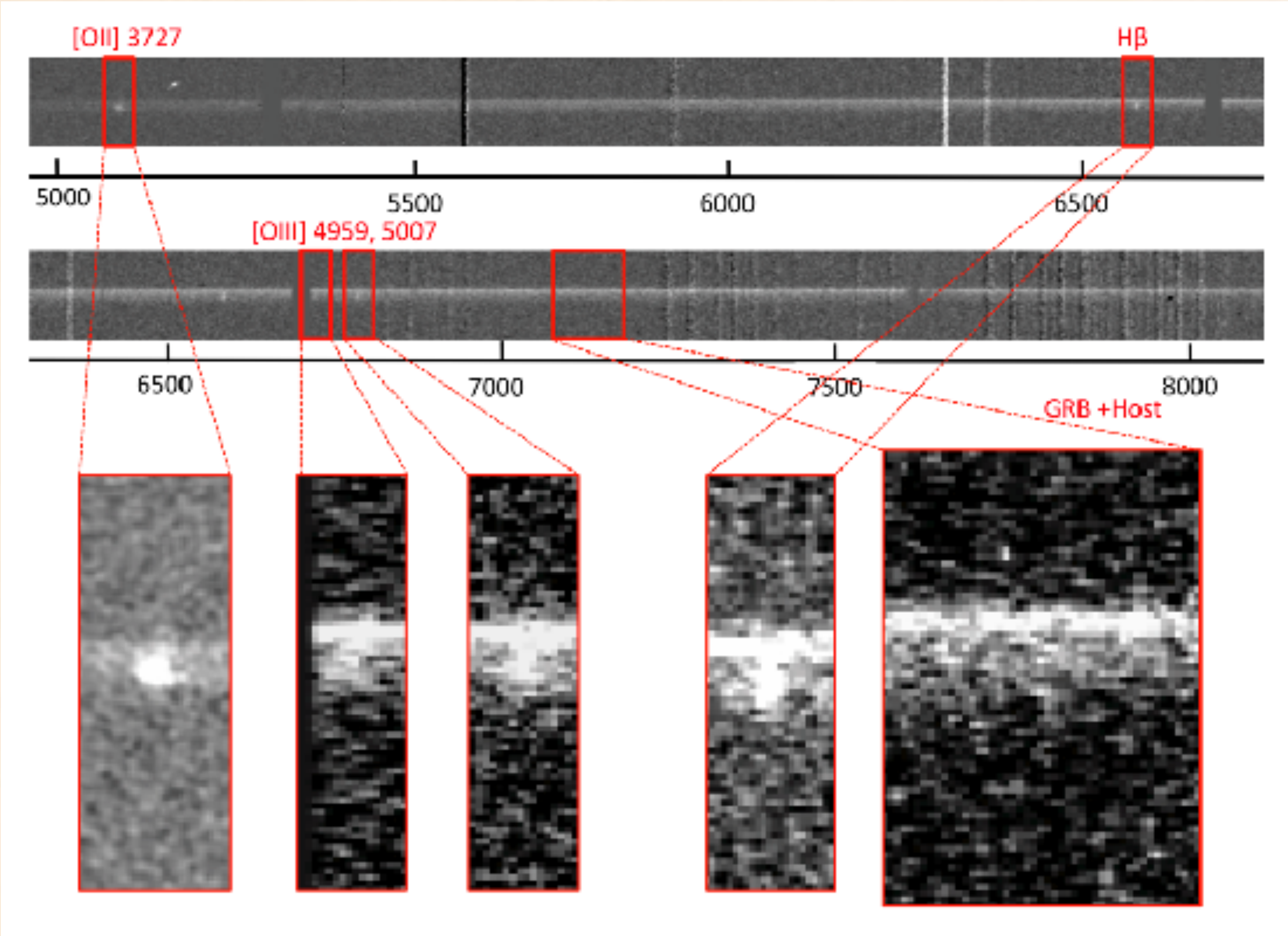
Peterson, 2019

Zauderer, 2012

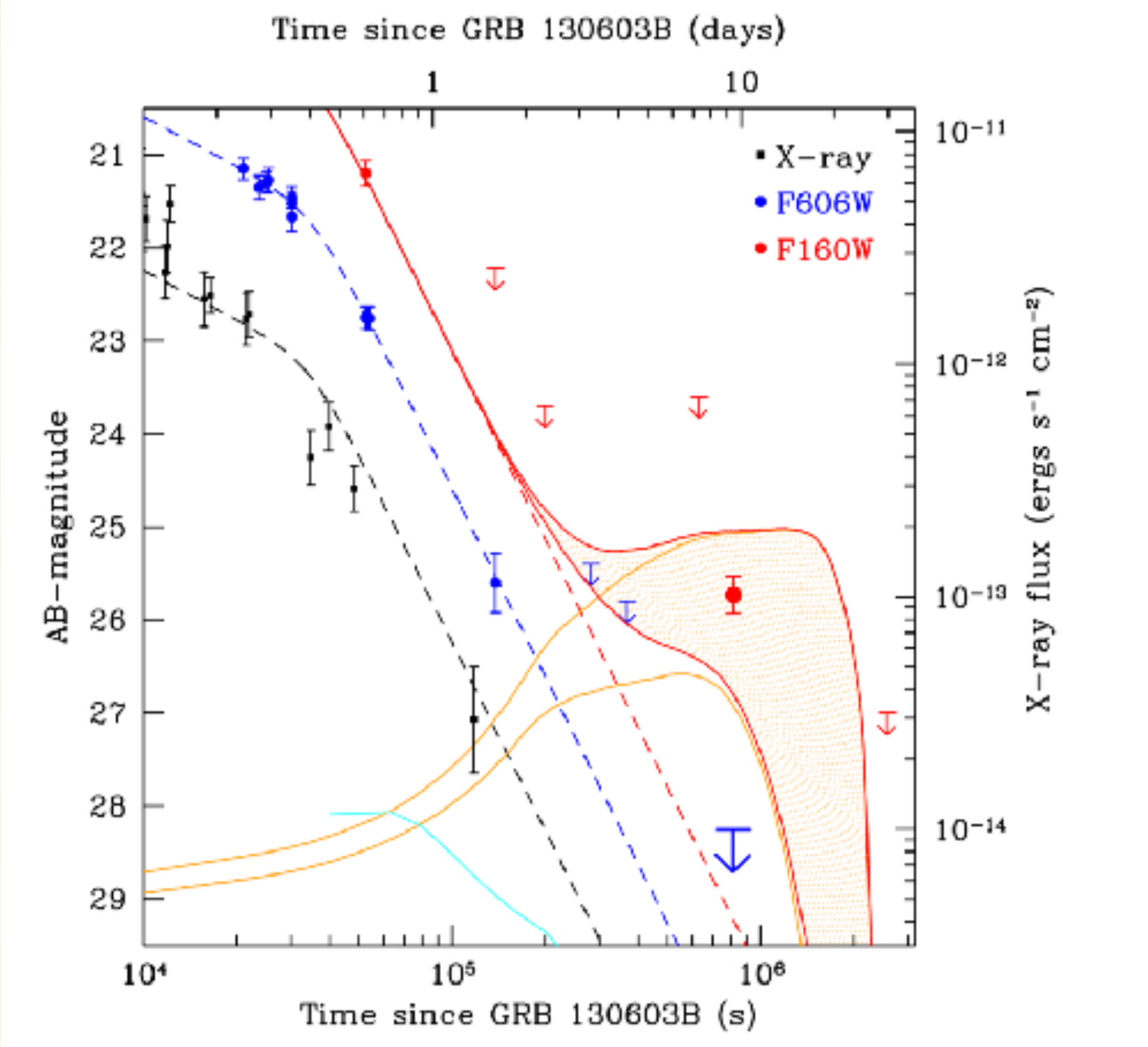
Levesque et al. 2012

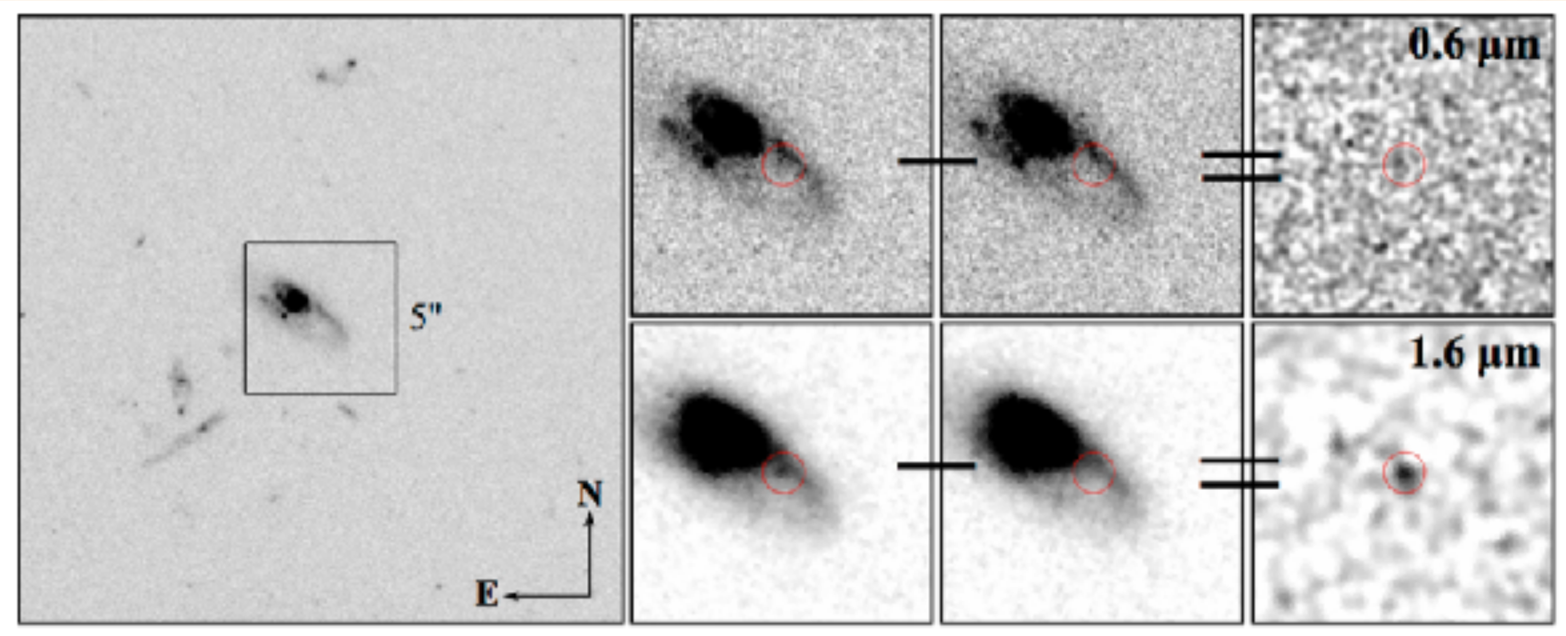
Fong et al. 2016

First short GRB spectrum



....then a "Kilonova"



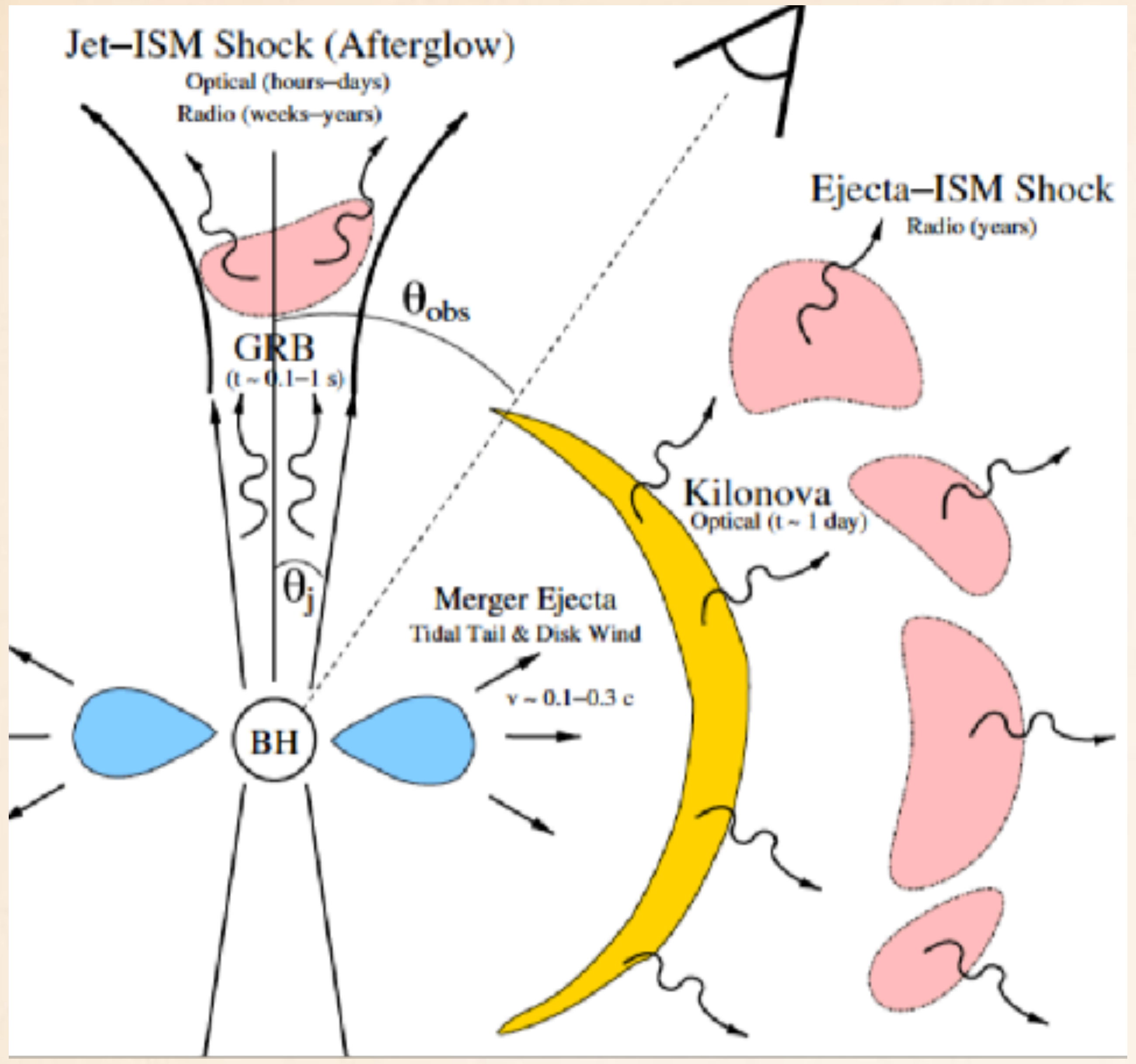


During the NS-NS merger the large amount of neutrons ignites the production of r-processed elements. The decay of such elements and their ejection during the merger produces a long-lived, red emission on the timescale of ~1-2 weeks.

GRB 130603B was the very first short-GRB for which we were able to obtain an optical spectrum. It was also the first one for which a Kilonova emission was detected

The required depth of the Kilonova emission can only be reached by **HST** (F606W and F160W above) or **ROMAN or JWST.**

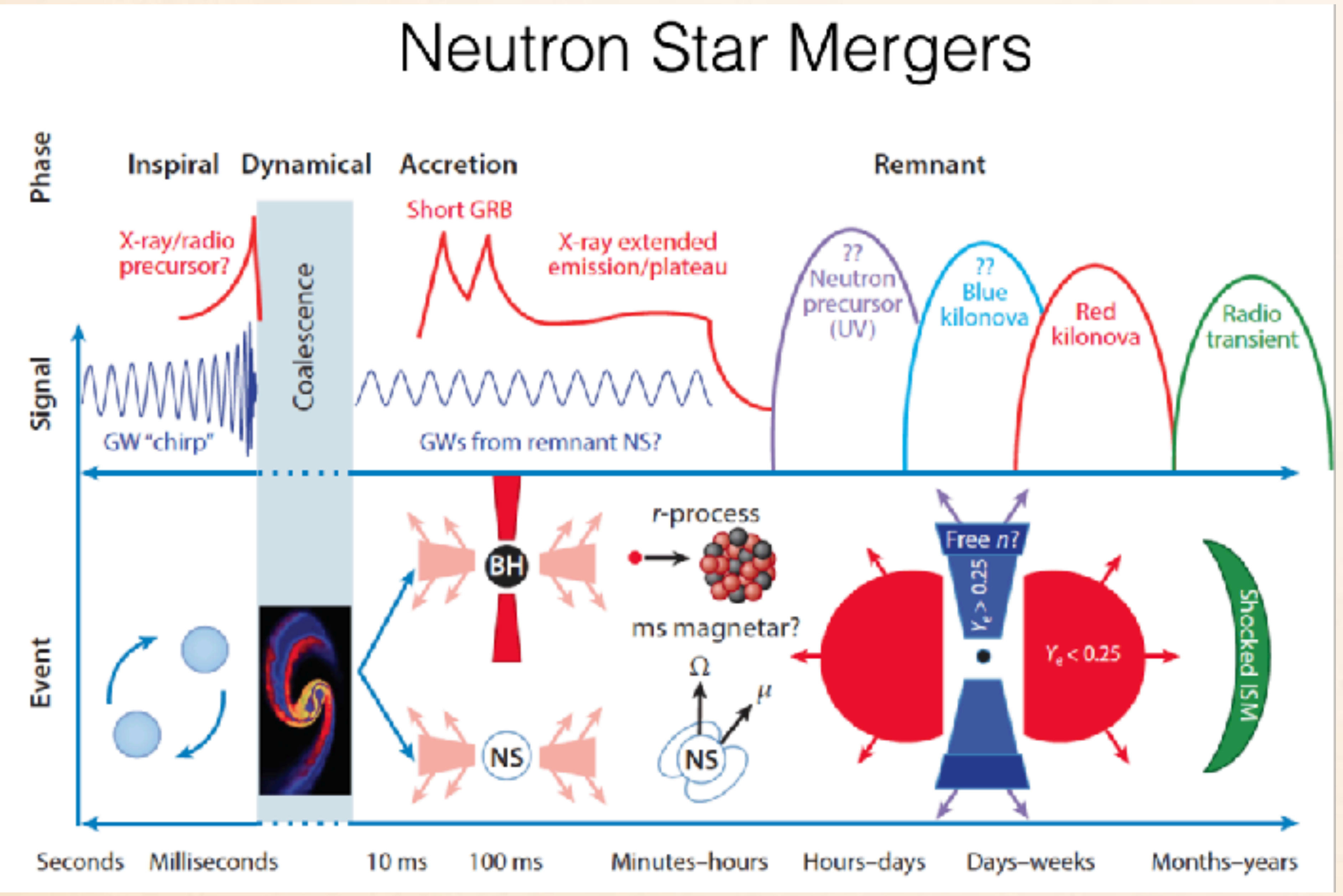
The Kilonova SED is very red (R-H=2.5) and **not due** to the synchrotron afterglow emission (e.g. X-ray). It is produced by r-processed elements synthesis.



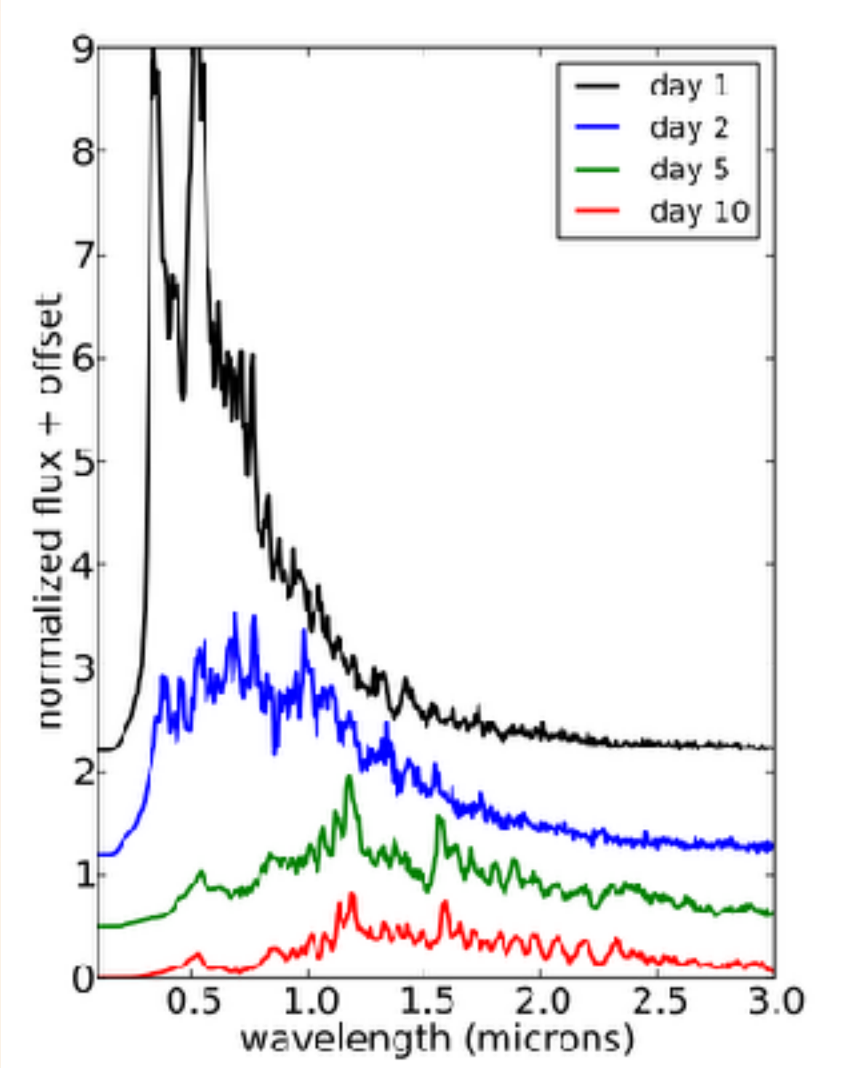
During the merging process a Kilonova emission was detected, due to the synthesis of r-process elements (Metzger+13, Kasen+13, +17).

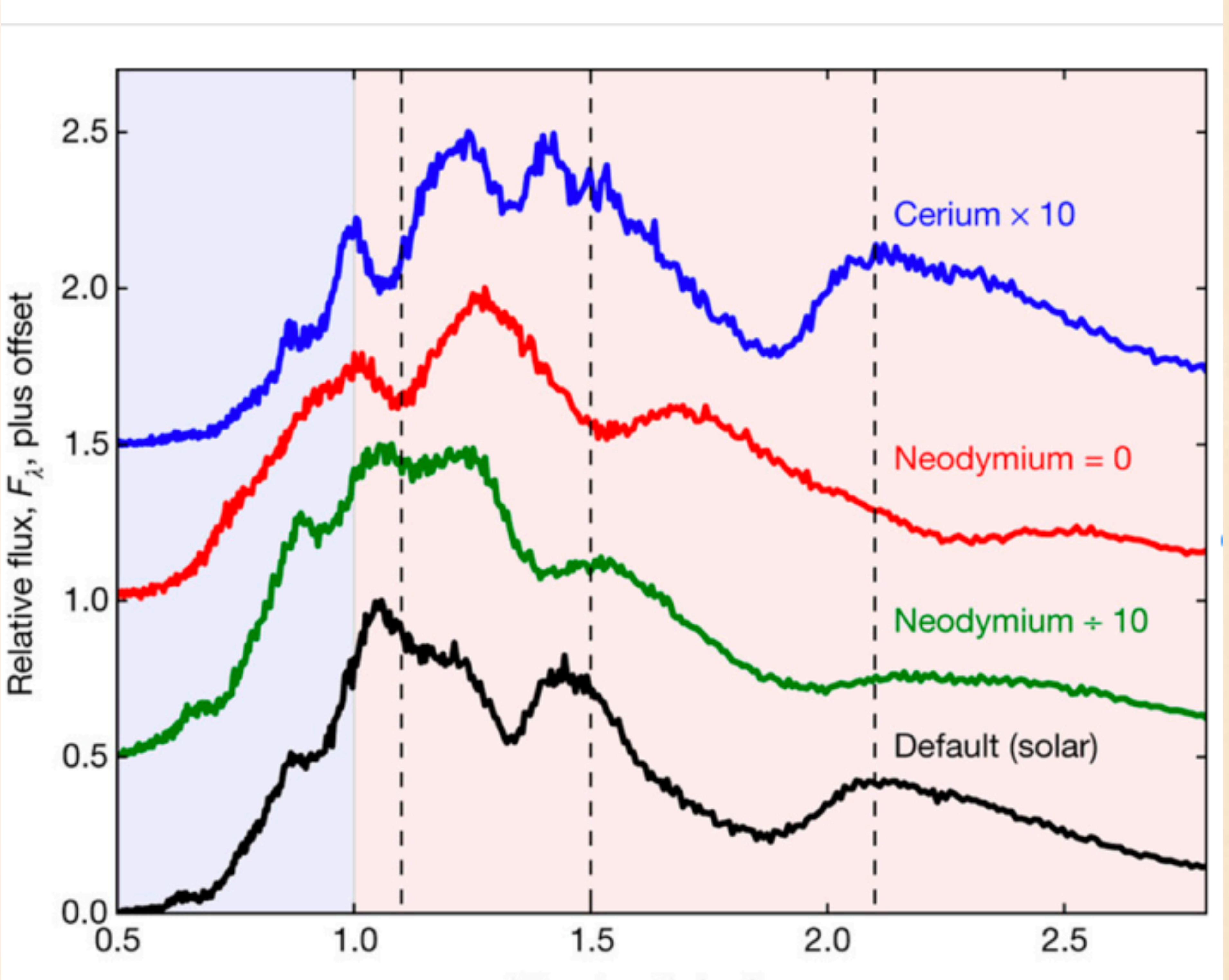
The KN is incredibly faint and can be hidden by the host galaxy or the GRB signature.

The next goal is to obtain a better spectrum of the Kilonova so we can test the theoretical spectrum of these NS-NS mergers.



Fernandez 2016

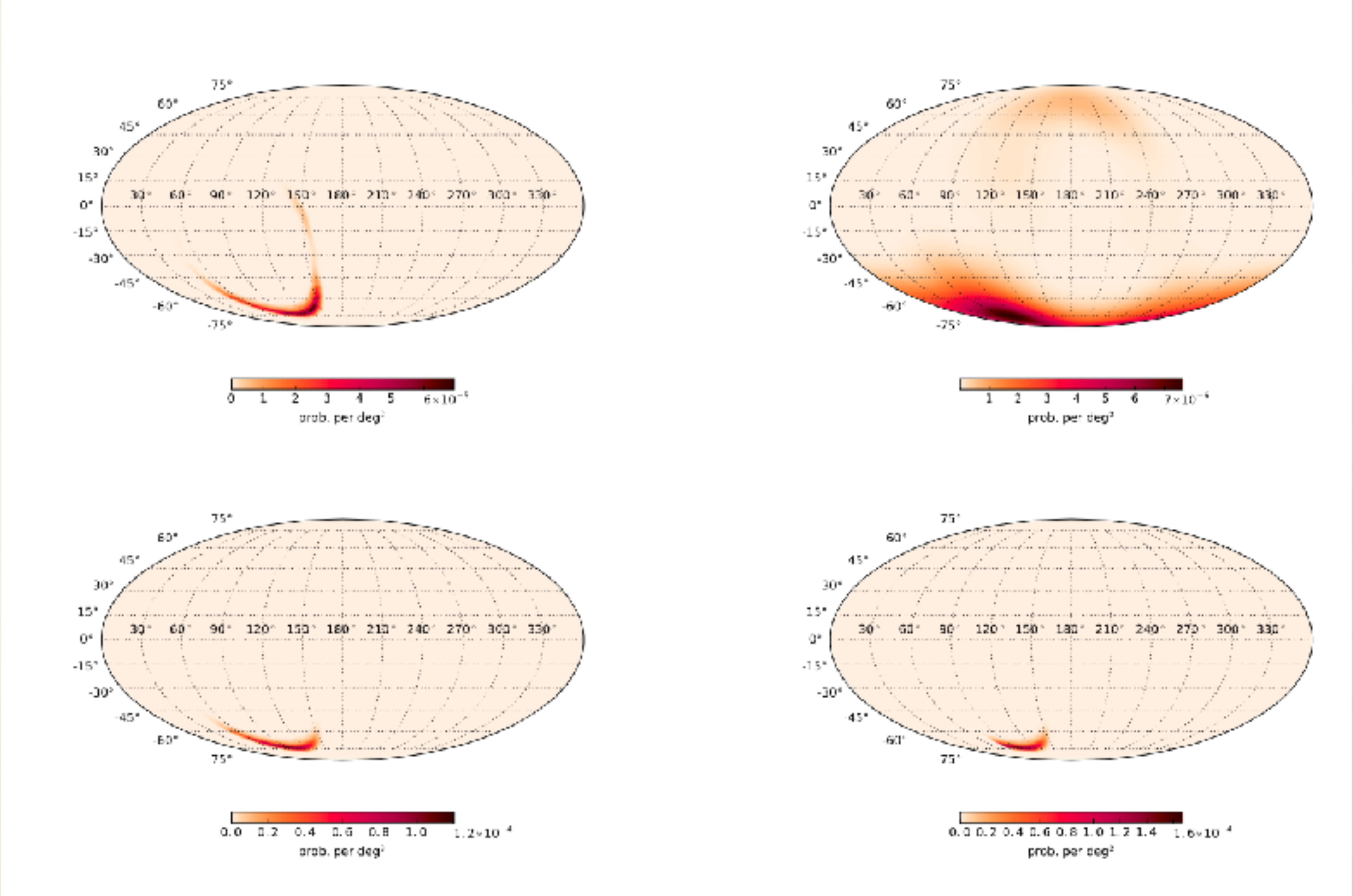


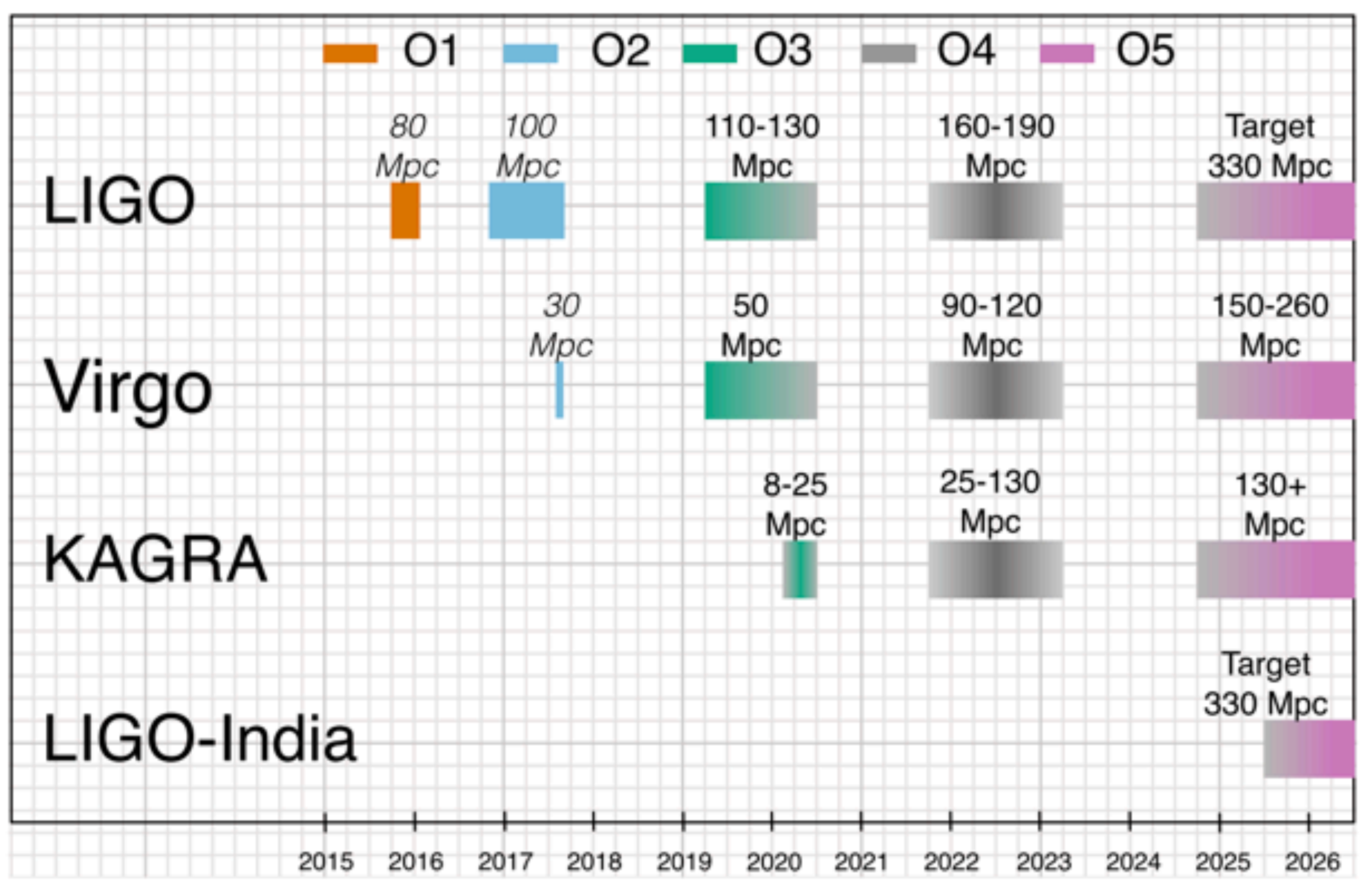


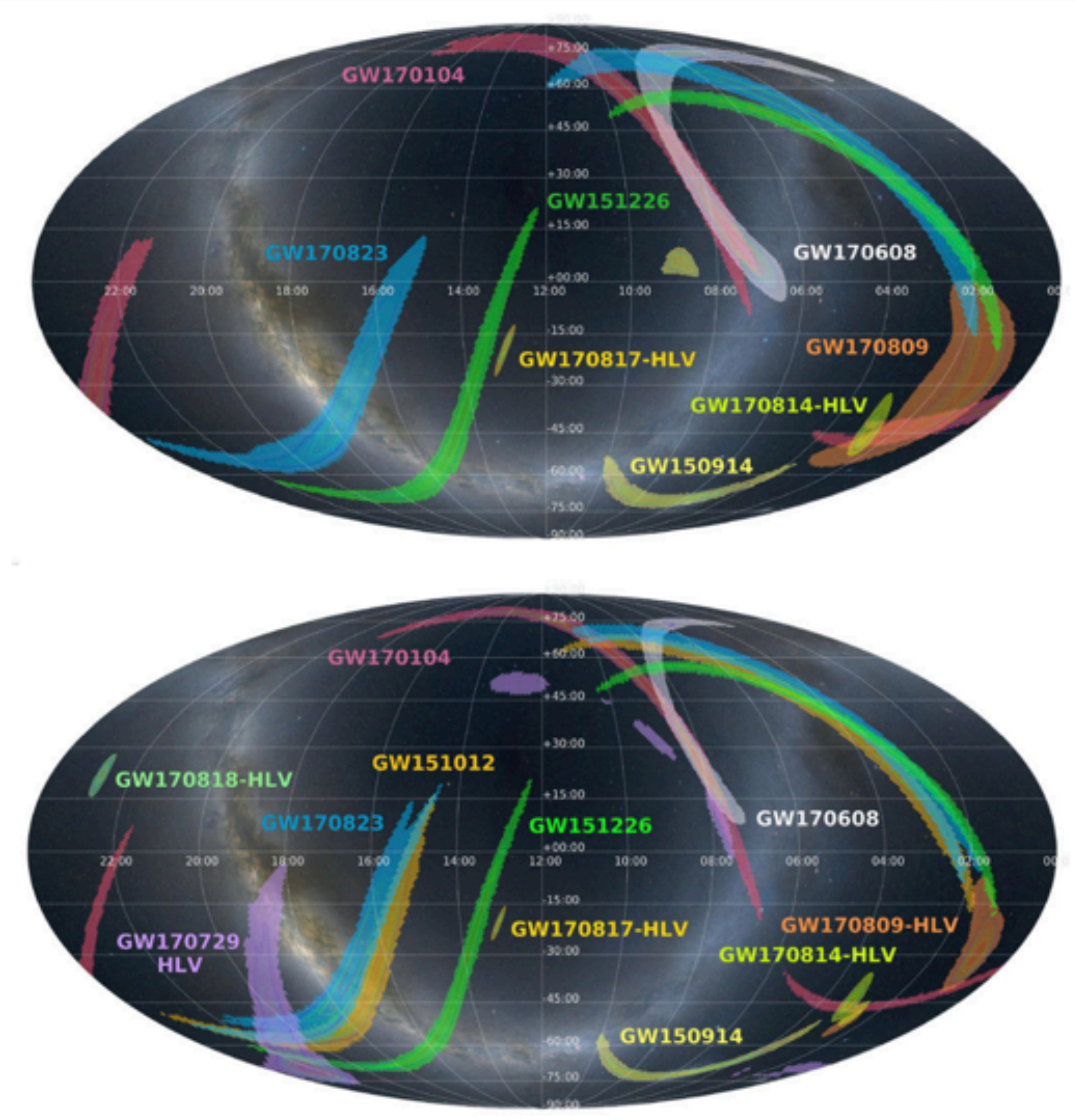
Roman will be able to disentangle these broad features

WHY WE CARE ABOUT SHORT-GRBS?

Because compact object mergers produce GW!







Accurate GW identification will enable **Roman** follow-up and tiling sequence that ultimately may provide the necessary photometric detection of BH-BH/NS-NS mergers

McEnery 2017

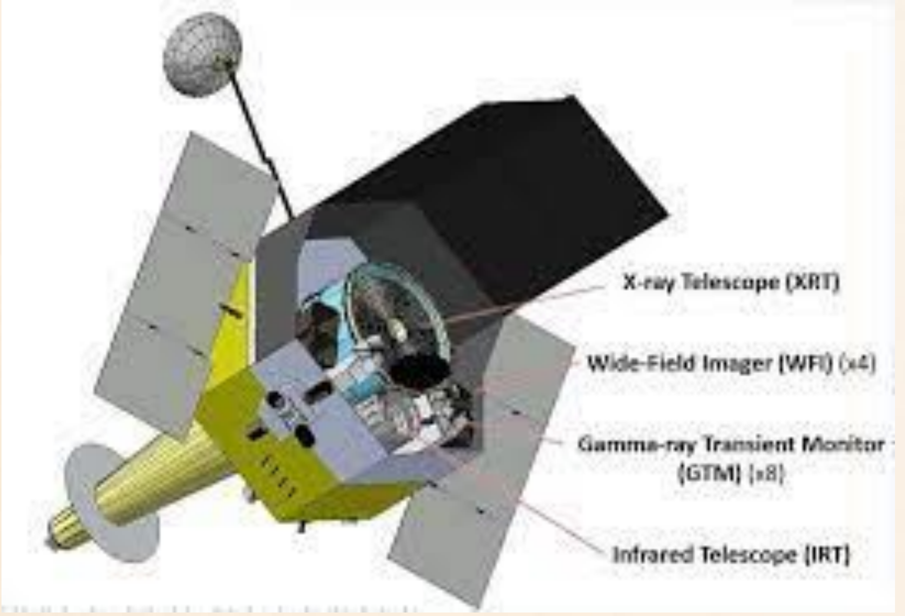
Connaughton+ 2016

Kasliwal+ 2019

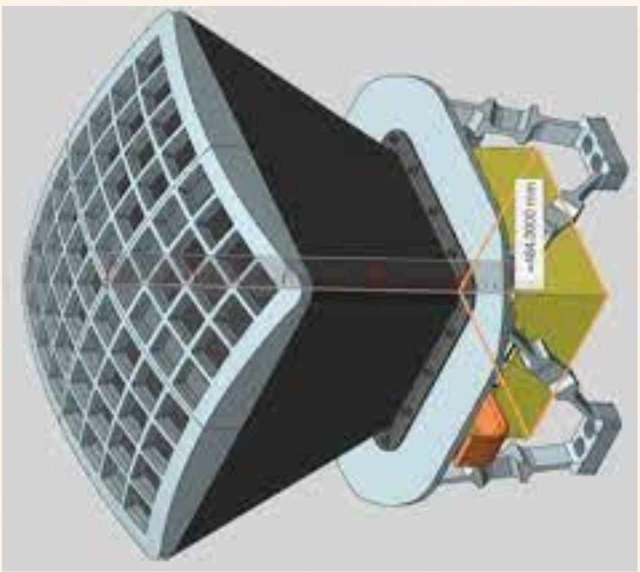
THE 2026 LANDSCAPE FOR GRB SCIENCE

Swift legacy and successes, thanks to the rapid slewing capabilities, the multiband feature, and gamma-ray sensitivity has provided us a leap in our understanding of GRBs, their role as beacons of re-ionization and GW progenitors. Even Fermi cannot provide sub-arcsec localization.

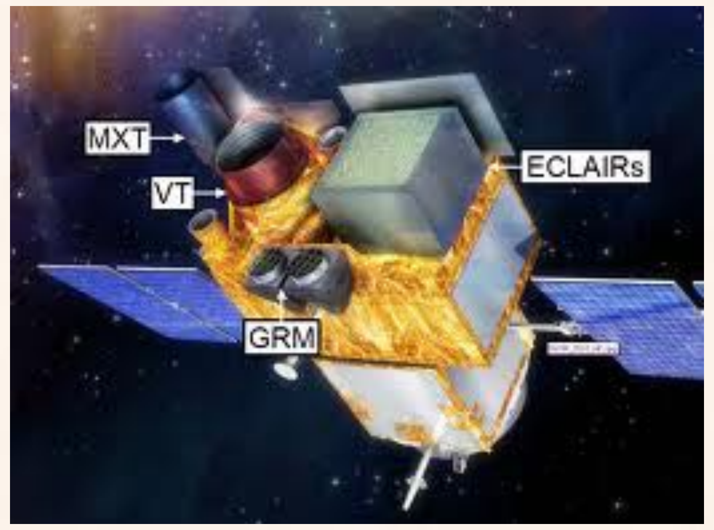
Nancy Grace Roman Telescope will require a multi-messenger approach, that includes space and ground based facilities as well as observing strategies (cadence, tiling) and adequate data processing.



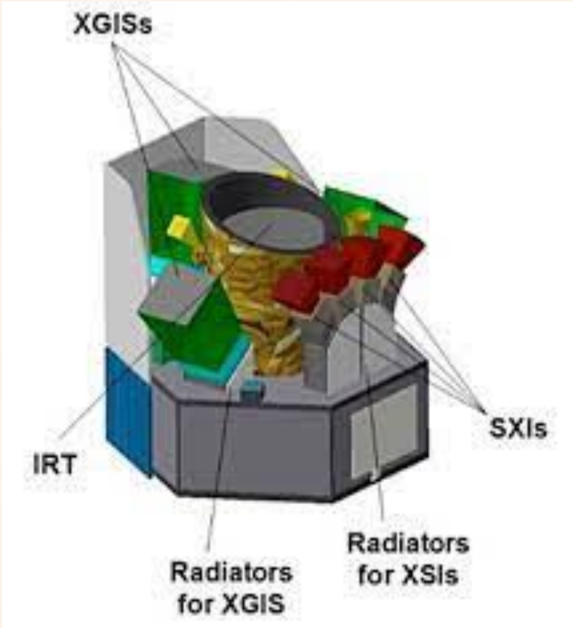
TAP



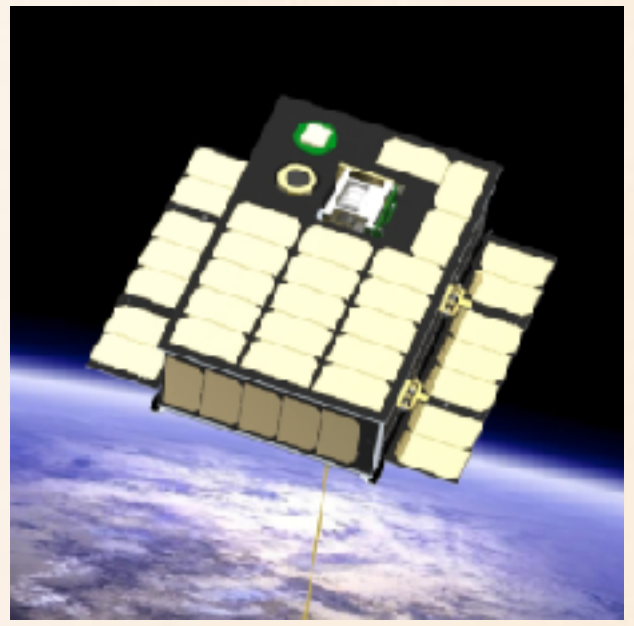
GAMOV



SVOM



THESEUS



Burstcube and Cubesats constellations

The creation of wide field of view optical/NIR robotic ground based observatory networks (e.g. GROWTH, LCO) will compensate the lack of quick and accurate localization from less sensitive gamma-ray instruments.

Adequate strategies and communication among facilities will enable **Roman** to provide novel insight on GRB science and pursuing new avenues to exploit GRBs probe of the COSMOS.

THE GOOD, THE BAD AND…THE FUTURE





Decadal 2020 recommendation: NASA, NSF, DOE, and professional societies should ensure that their scientific integrity policies address harassment and discrimination by individuals **as forms of research/ scientific misconduct.**

Roman telescope is an **opportunity** to avoid the mistakes of the past and truly **inspire** new generation of astronomers, more than Hubble or JWST.

While we plan and await to pursue our research with trepidation, we should be conscious that **equity and inclusion cannot be anymore separated by our actions and decisions**.

REFLECTIONS

- GRBs have provided incredible tools to explore the high-z Universe
- Long GRBs are tracers of SFRD, z>8 SNe, PopIII
- Short GRBs exploration in connection with GW and KN
- Roman will fly at the time where worldwide efforts to find fast transients like GRBs, so to compensate the lack of Swift/Fermi-like gamma-ray detectors.
- We can only succeed if we plan in advance on how to communicate and share discoveries rapidly (minute to hour) and process data
- Roman represents a true test and an opportunity to solidify some of the current effort to increase DEI efforts in our community.