The Swift Mission as High-z Explorer: GRBs as Legacy for TMT

Antonino Cucchiara
(NPP Fellow - NASA/GSFC)

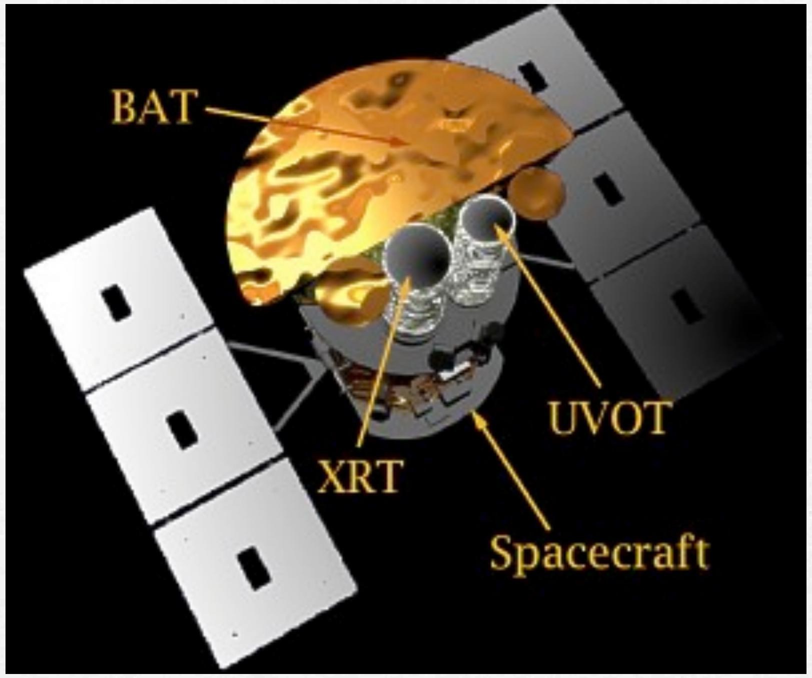
Outline

- The Swift mission
- "10" years of science
- Time-domain Astronomy
- The Early Universe
- The future: from Space to Earth

Swift mission

Swift revolutionized spacecrafts technology for transients studies (2 yr nominal mission):

- Fast slewing (minutes)
- Flexible observations (ToO)
- Multiband capabilities



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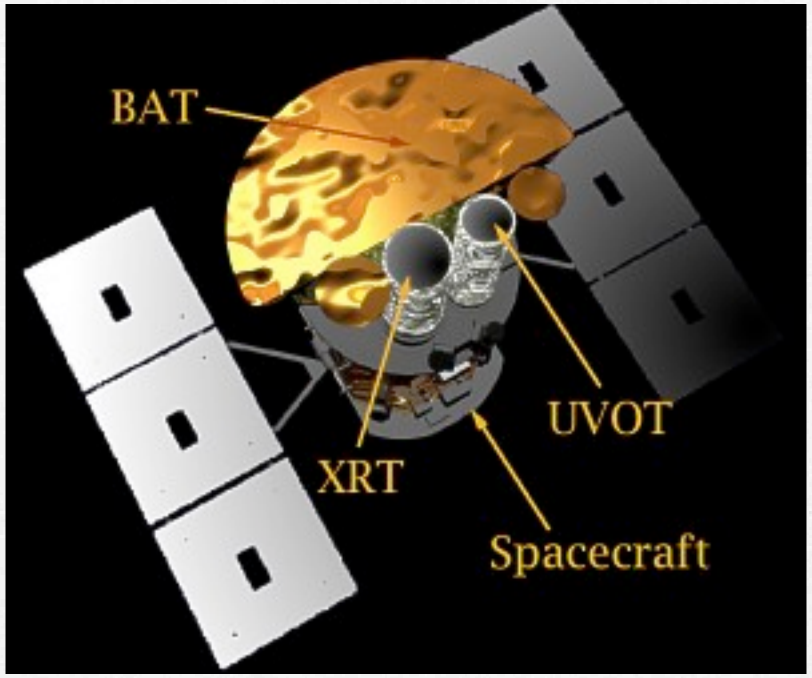

BAT:

- Coded Mask detector for Hard X-ray (50-350 keV)
- 1.4 sr sky coverage

XRT:

- Photon counting device for soft X-ray (0.5-10 keV)
- 23x23 arcmin FOV
- Multiple observing modes

UVOT

- Optical/UV telescope
- 17x17 arcmin FOV
- Grisms/6filters

More than a GRB mission

Swift has become more versatile then its "big brothers" (Senior review 2014), adding "new" science at every GI cycle.

- GRB mysteries (Long, Short, High-z, GW, Neutrinos,...)
- Supernovae
- AGN, BL-Lacs, ...
- SGRs, AXP, XRF, FRB, other compact objects
- Cataclysmic variables
- Comets, Galaxies, Tidal disruption events...

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- Cataclysmic variables, symbiotic stars,...
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Swift and Friends

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- Swift triggered on known and unknown transient phenomena
  - Rapid-response by robotic telescopes enabled longer wavelength coverage, spectroscopic follow-up of bright events
  - Rapid response with 8/10m telescopes enabled high spacial resolution of unusual phenomena and obs. of faint targets
  - Radio, sub-mm and mm observations.

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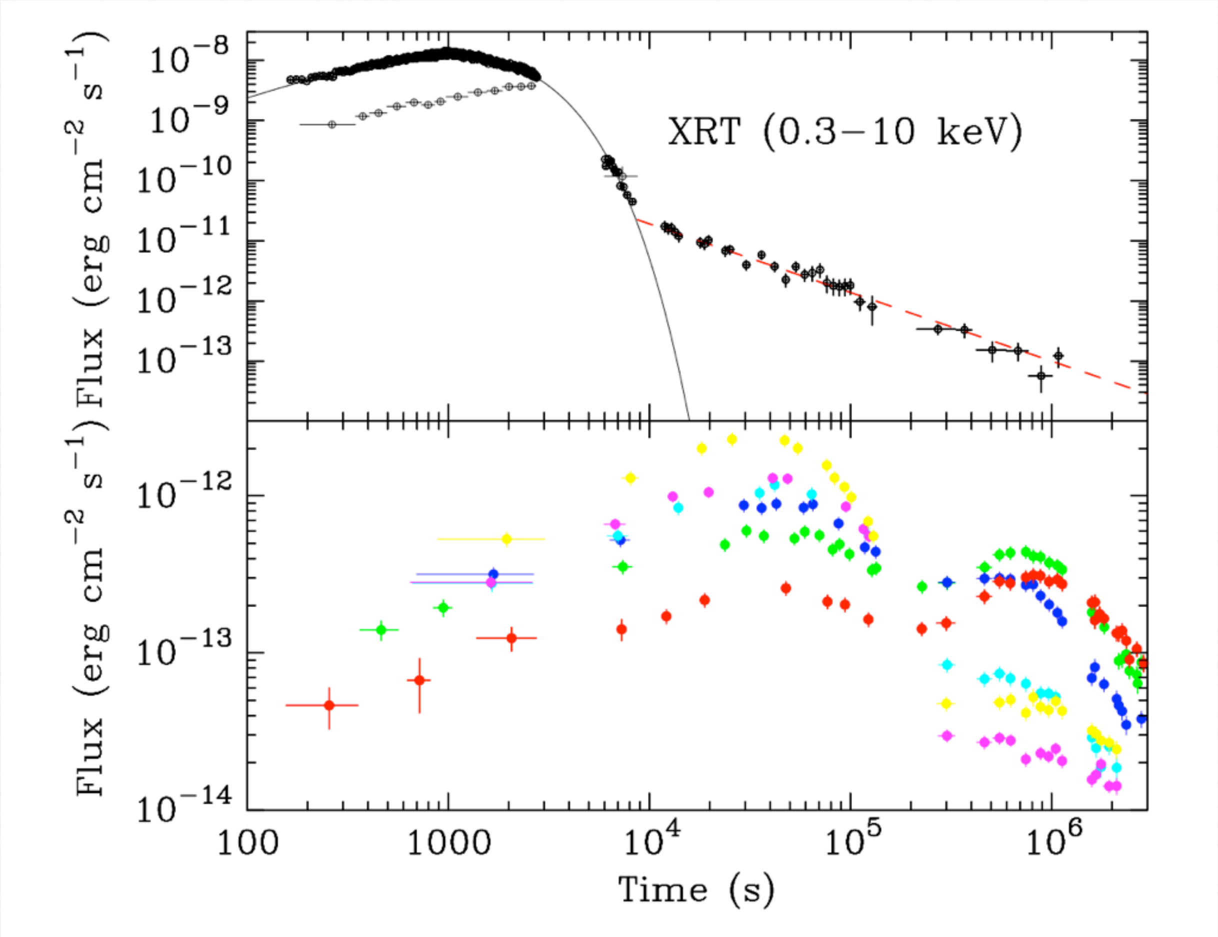
  - Radio, sub-mm and mm observations.
- Ground-based discoveries have found a great ally in Swift (ToOs)
  - X-ray/UV rapid response on ground discoveries (SNe, CV, SGR)
  - Temporal coverage during "day time"
  - Coordinated Multiwavelength Observations

Time-Domain Science

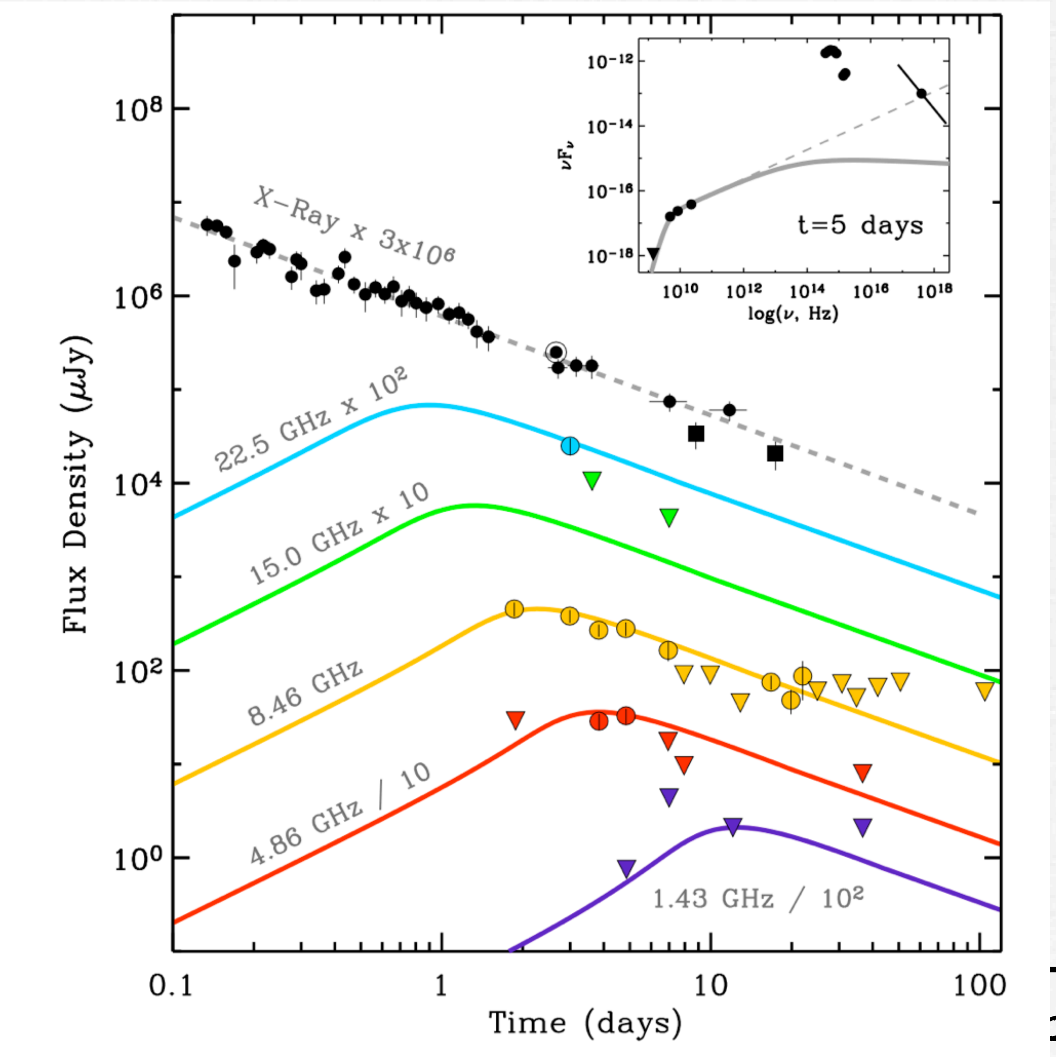
Swift has pioneered the 2010 Decadal Survey recommendations regarding Time-domain Astronomy

GRB 060218/SN2006AJ

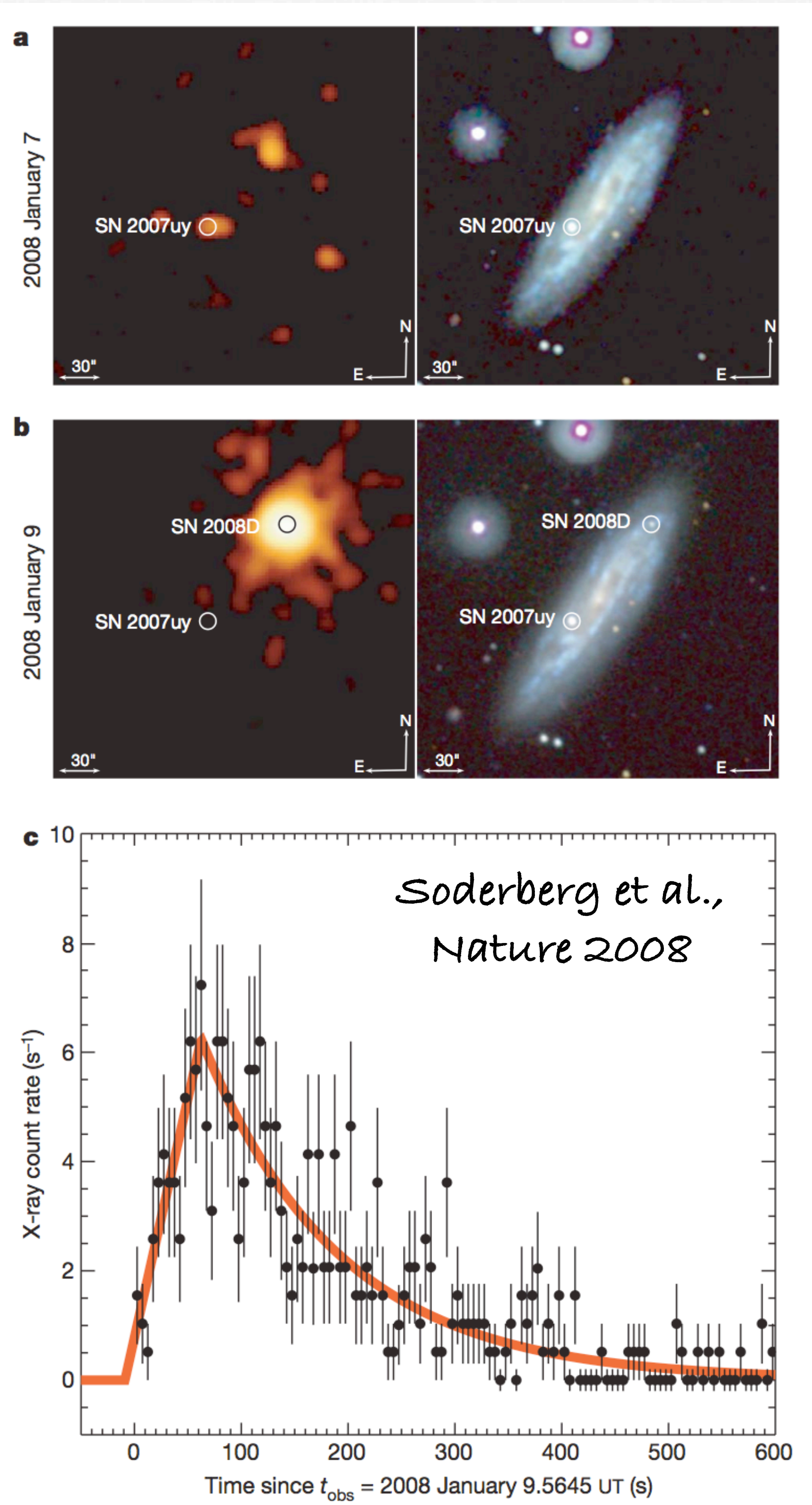


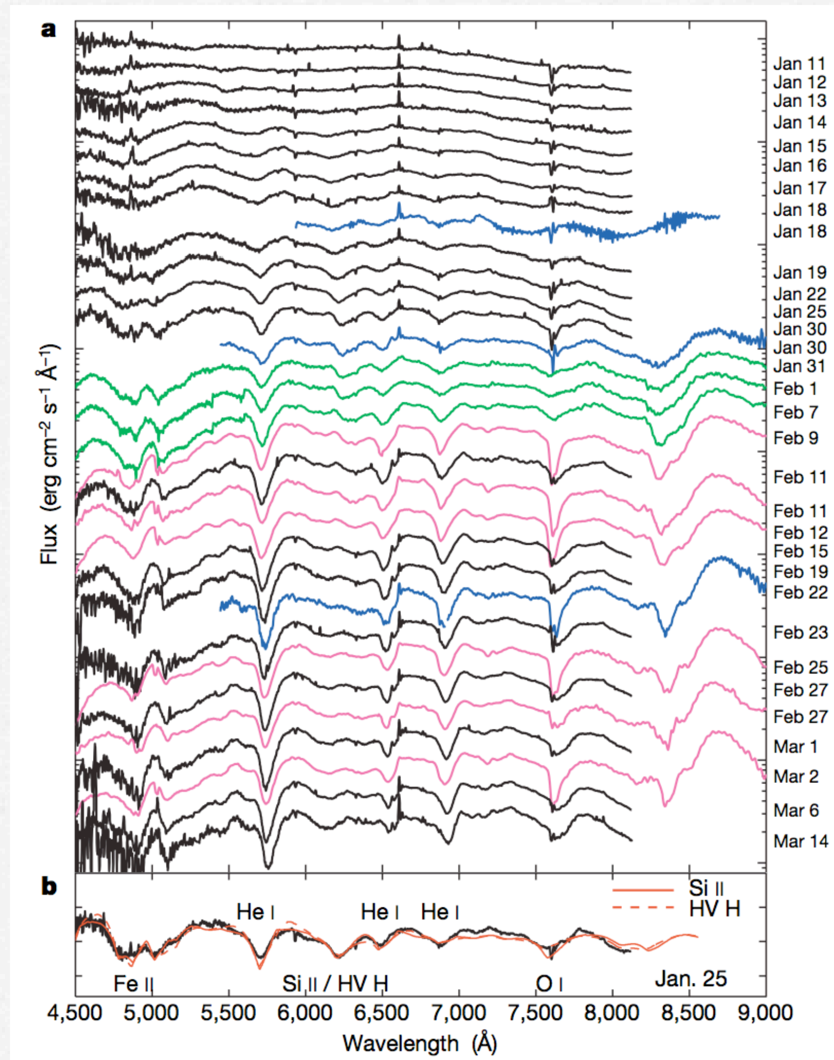
First XRF/SN Shock-breakout
(Campana et al., Nature 2006)

Relativistic ejecta studies (radio)
(Soderberg et al., Nature 2006)



Time-Domain Science





SN2008D serendipitous discovery of the first ever detected X-ray emission from SNe.

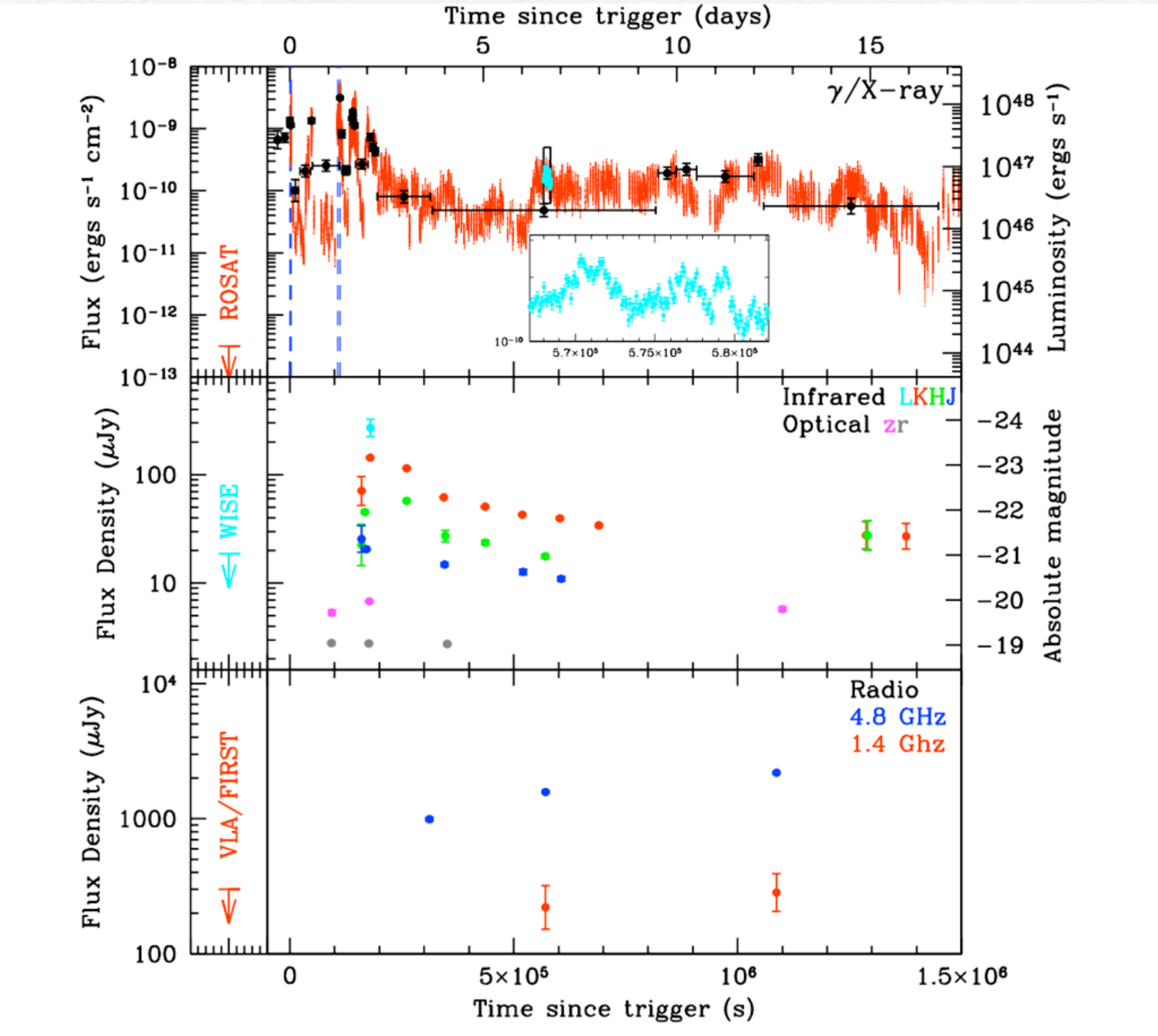
Future Surveys may help in this (eROSITA)

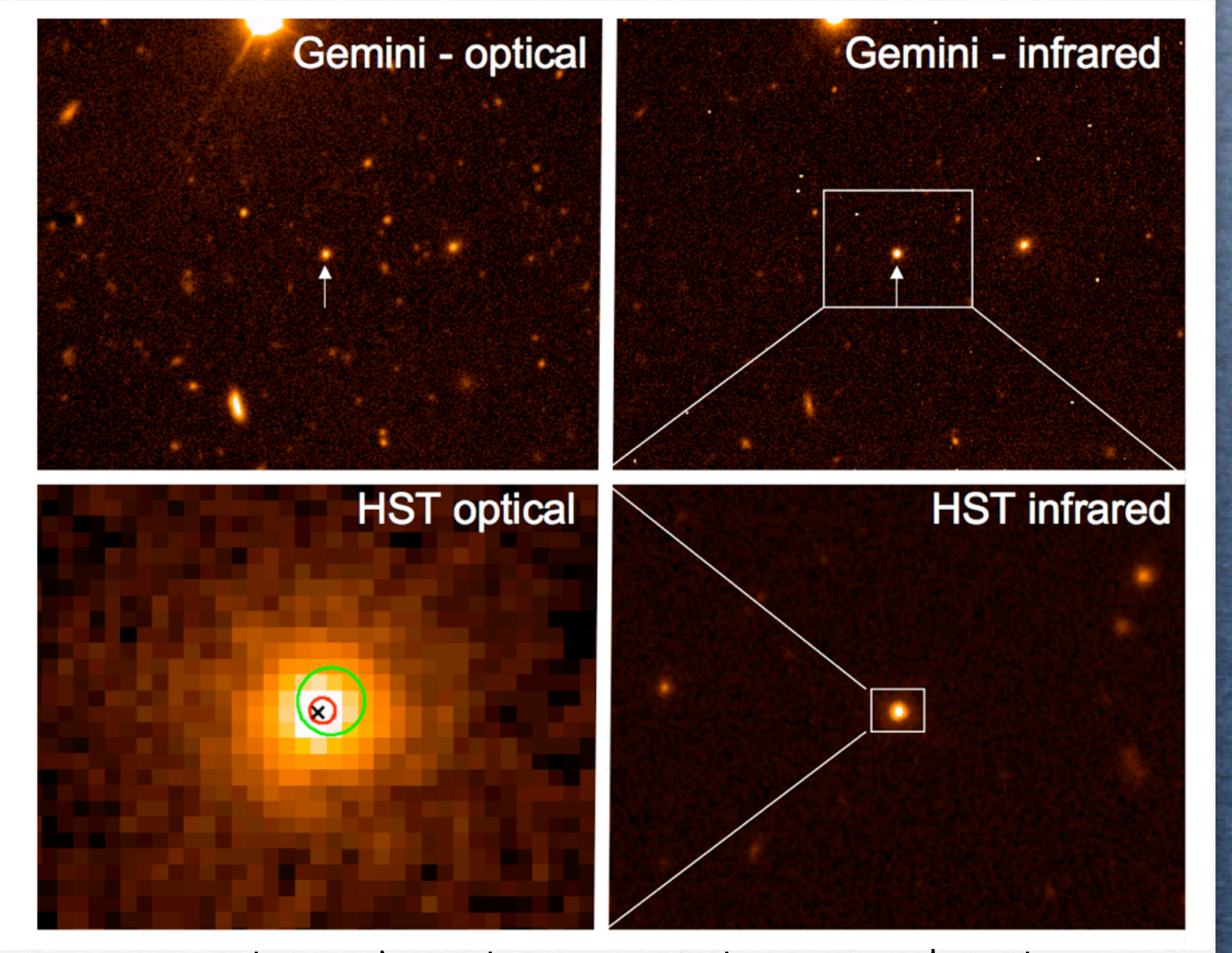
SN2008 shows how important is the contribution of ground-based follow-up at late time, when the SN is faint.

Also, the NIR coverage will break the ground for high-z SN studies.

Time-Domain Science

First Tidal disruption event, Swift J1644 (z=0.35)





Levan+11, Bloom+11, Berger+12, Zauderer+13

The spacial resolution, the NIR coverage, and imaging sensitivity of TMT will be key for studying the NIR emission from the accretion disk or the Jet (high A_V).

Time-Domain Science

What's the lesson?

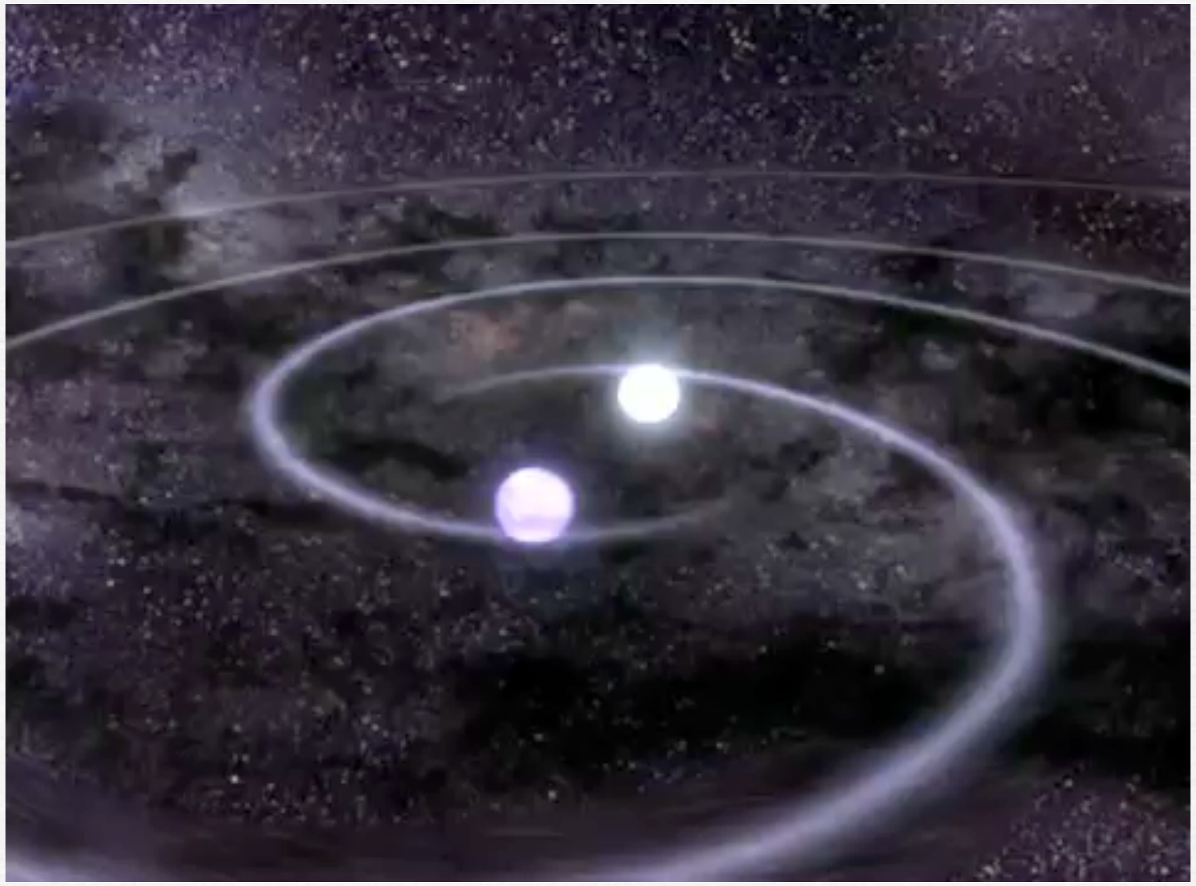
All this science could not have been done
without the connection between Swift and the ground based community

Where from here?

- TMT will allow the discovery and follow-up of higher-z SNe
- TMT will be able to observe inner layers of SNe explosions
- TMT will enable the spectrscopic observation of fainter objects
- TMT will have spatial resolution such to identify the location of TDE and their products

Short-GRBs and GW

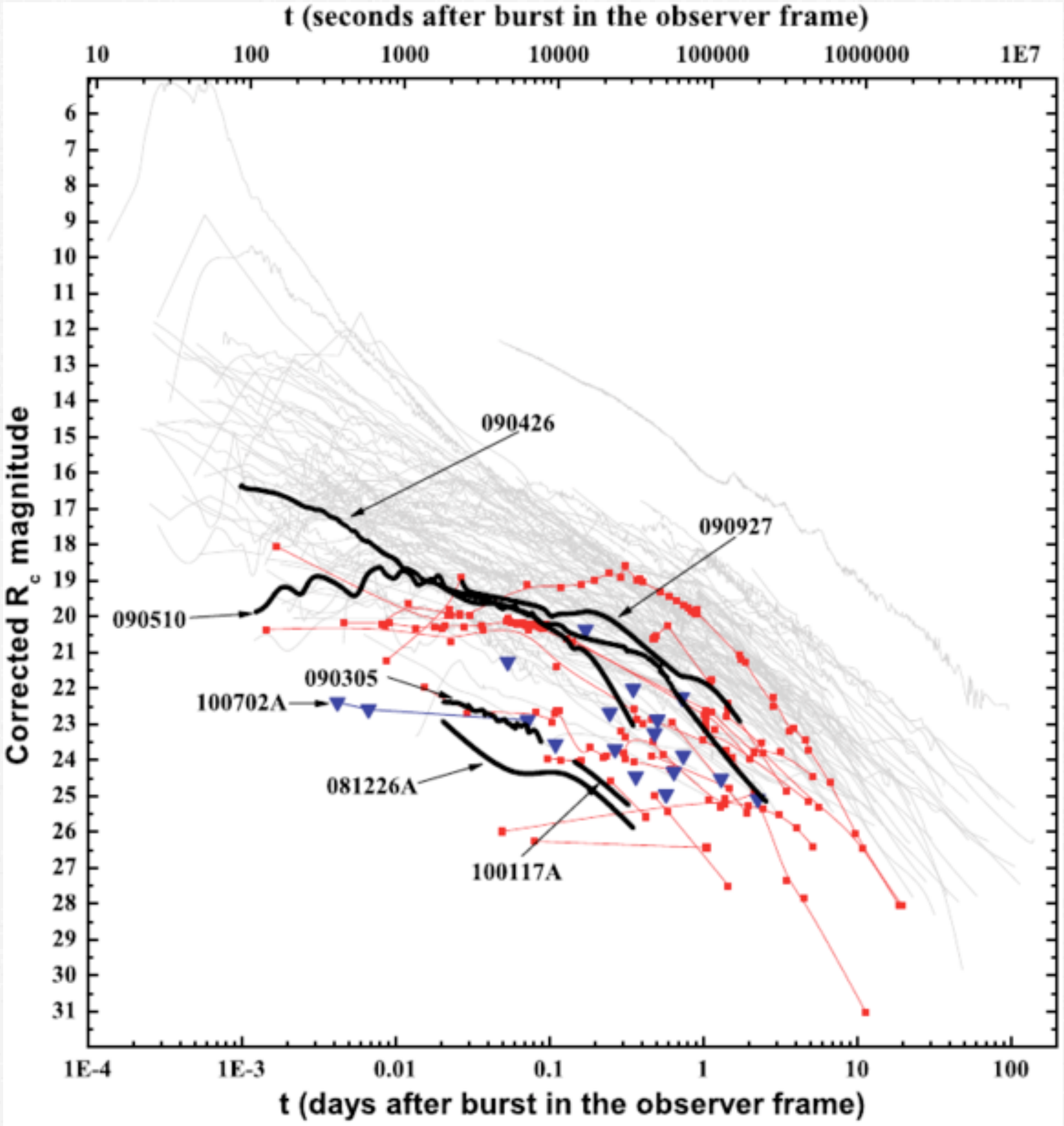
The Decadal Survey 2010 has ALSO indicated Gravitational Wave Astronomy as one of the priorities



The coalescence process of two compact objects (NS-NS,NS-BH) can produce a short Gamma-ray Burst and generate a detectable GW signal.

Short-GRBs and GW

- SGRB are rare (6% of all GRBs)
- Short GRBs are usually fainter than L-GRBs
- Very few have optical/spectroscopic follow-up
- Redshift is determined from “Hosts”



Kann+11

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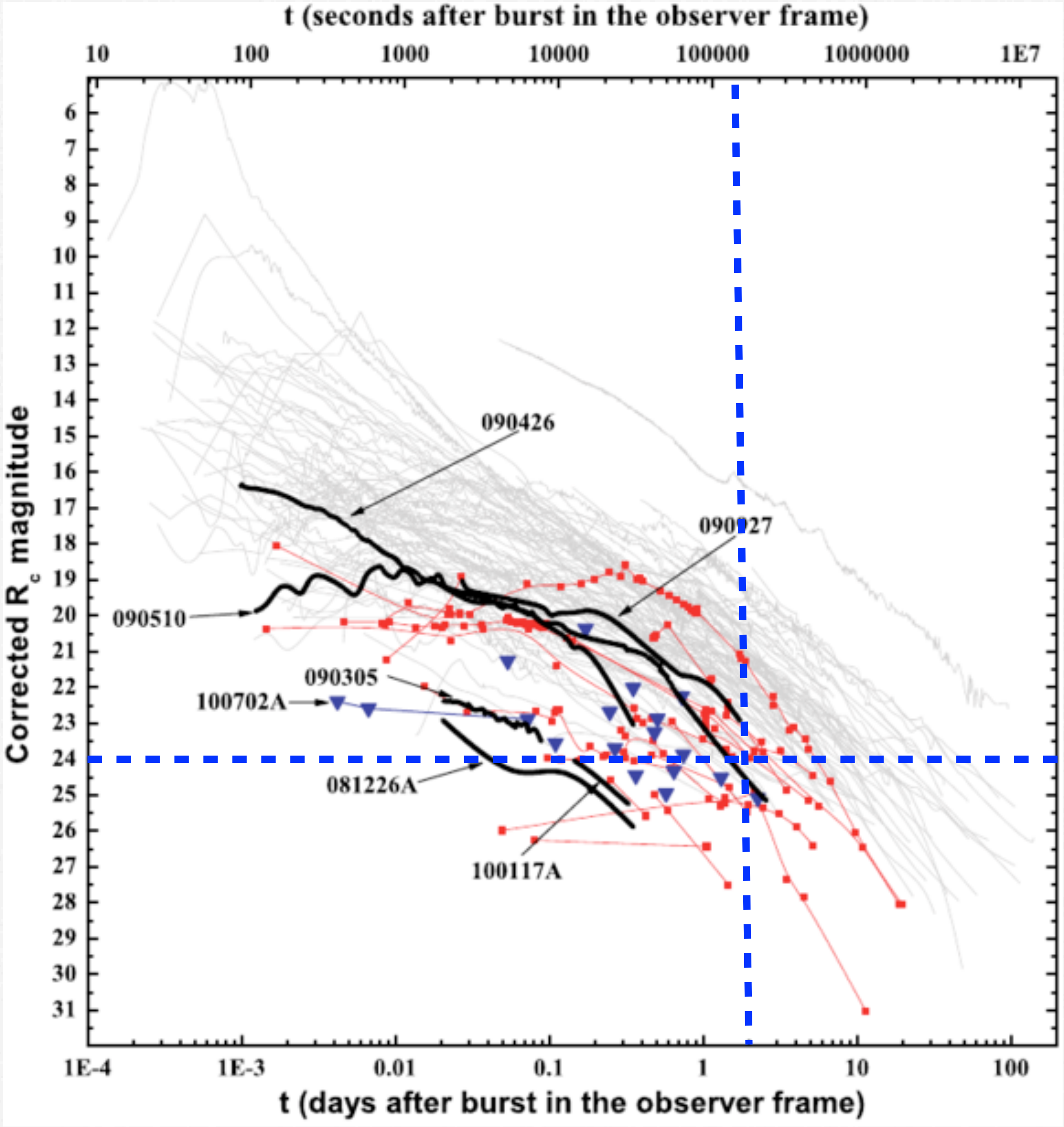

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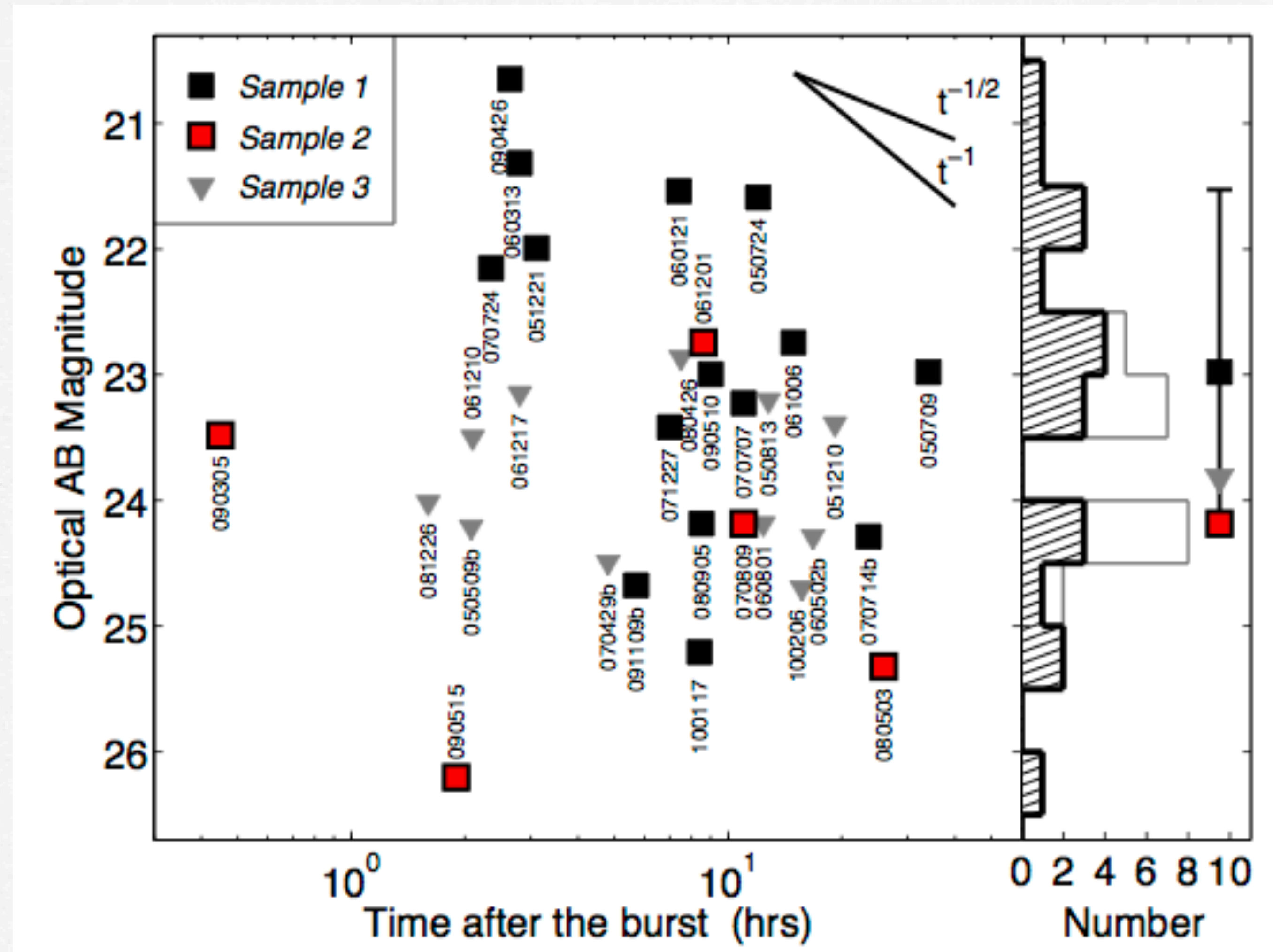


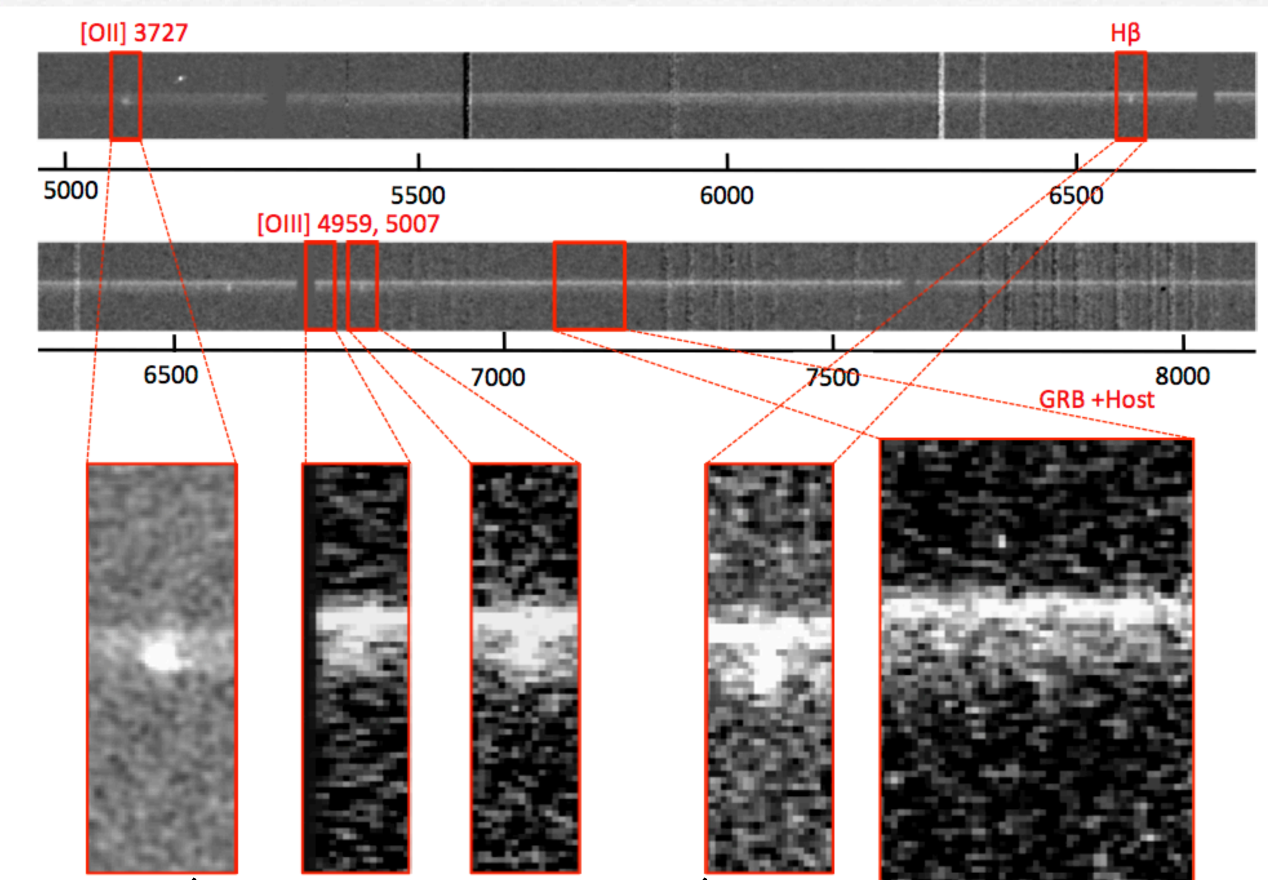
Then GRB 130603B occurred...

berger+10

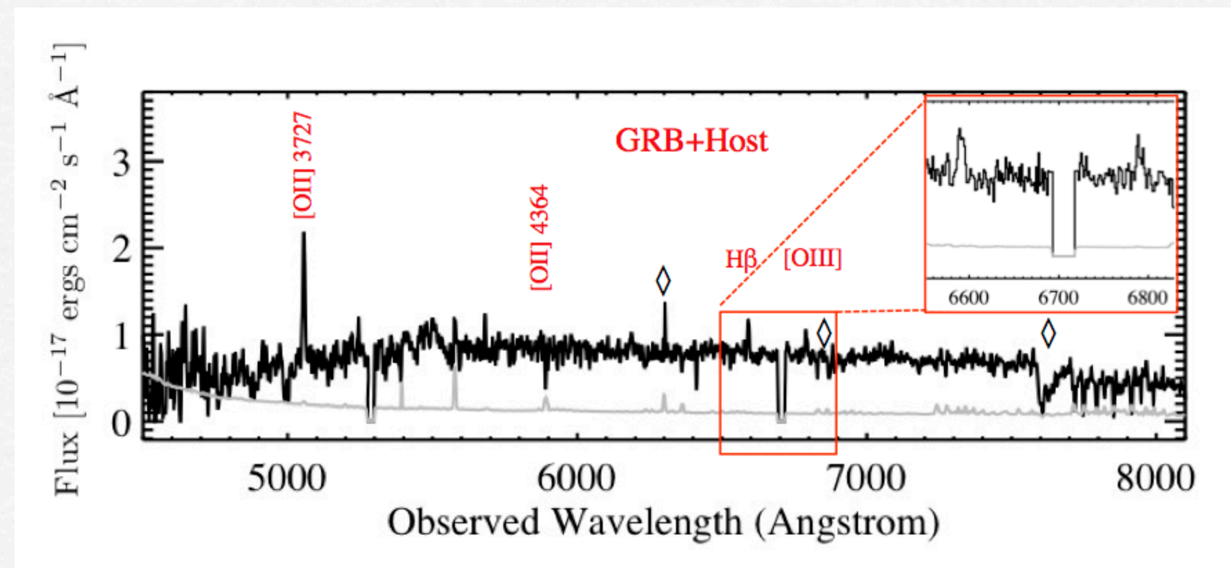
Short-GRBs and GW

GRB 130603B is the best SGRB for which spectroscopy of the afterglow was obtained, allowing firm determination of the redshift ($z=0.356$).

Also the properties of the host and GRB explosion site were determined.



Cucchiara+13, De Ugarte-Postigo+13



Host Properties

SFR ~ 1.84 $M_\odot$/yr

12+log(O/H) ~ 8.4

Mass = $5\times10^9\ M_\odot$

M_B = -20.96 (~L^*)

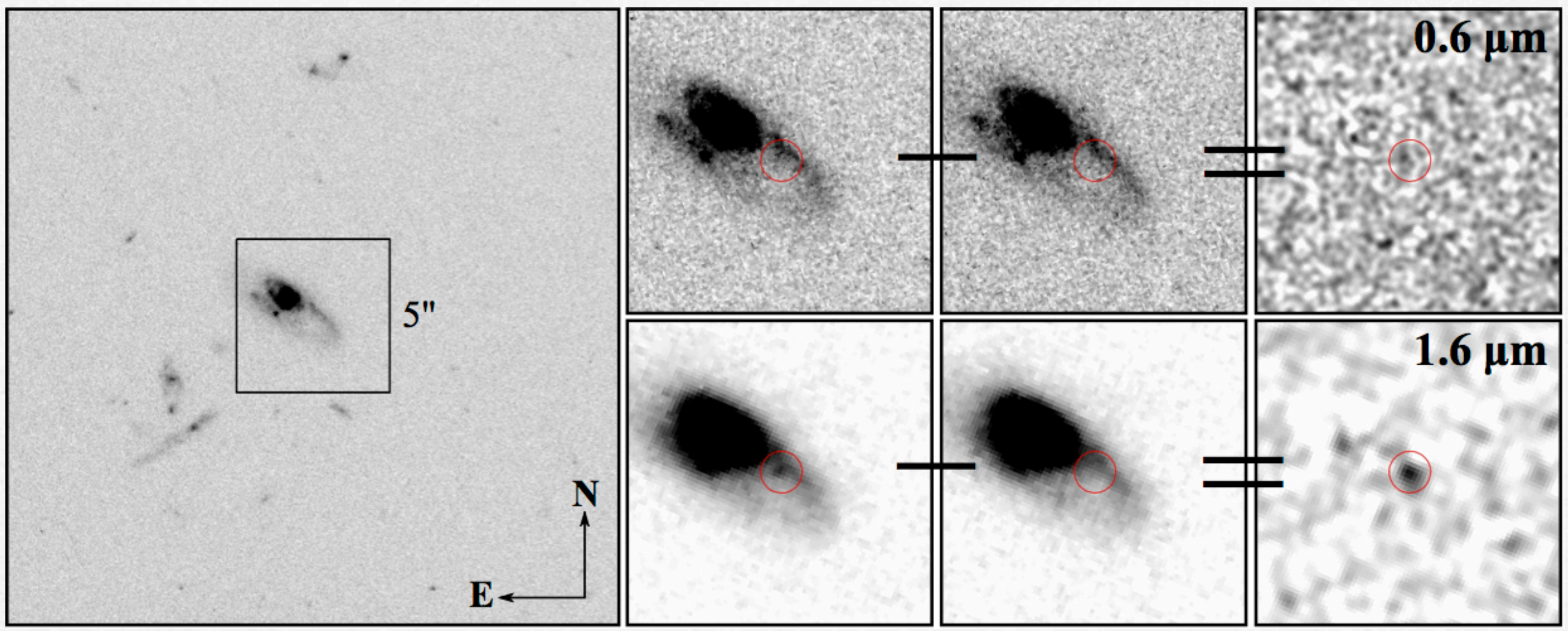
GRB location Properties

SFR < 0.4 $M_\odot$/yr

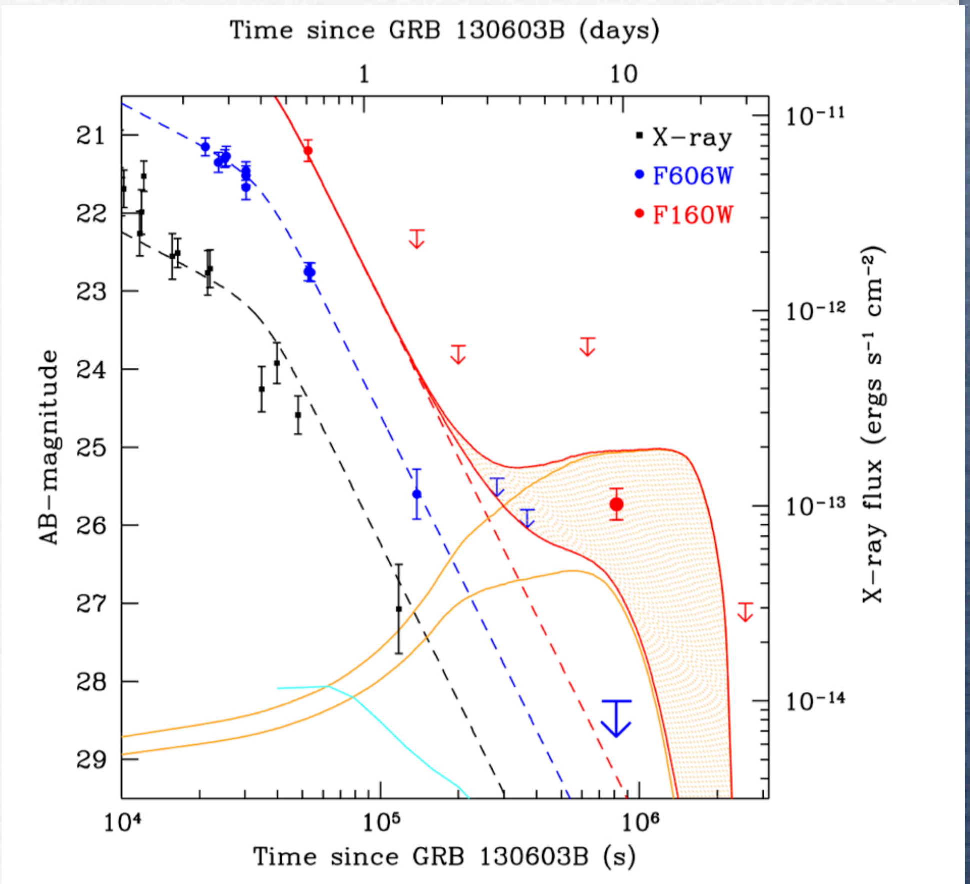
But surprise surprise...

Short-GRBs and GW

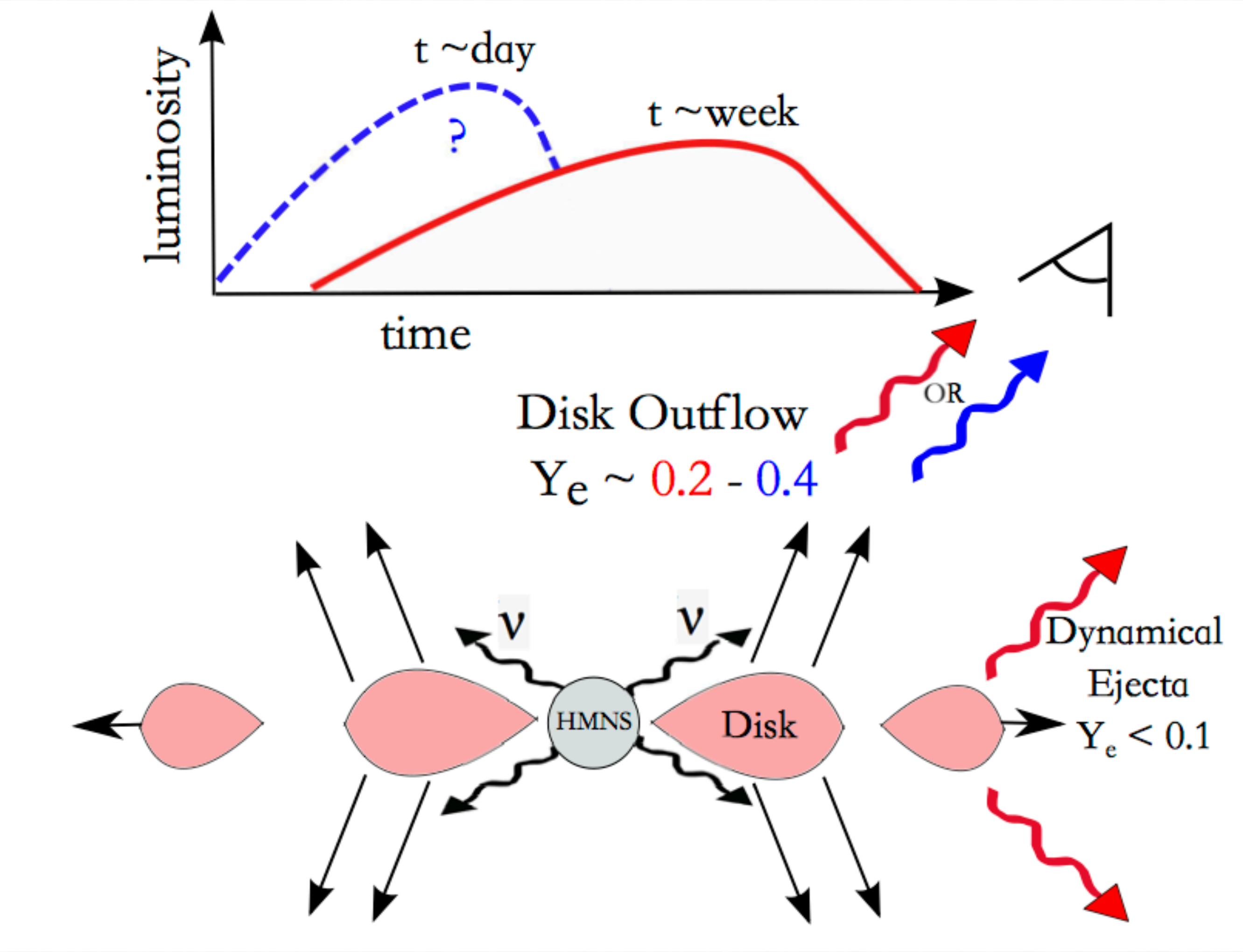
r-Process supernova ("Kilonova") signature was detected



Tanvir+13, Berger+13



- Emission in the NIR only, above the extrapolation from the early lightcurve was interpreted as produced by the torus surrounding the coalescent binary.
- Large amount of neutron-rich elements suppress optical emission.
- Time scale (~1 week) was consistent with the "kilonova" models.



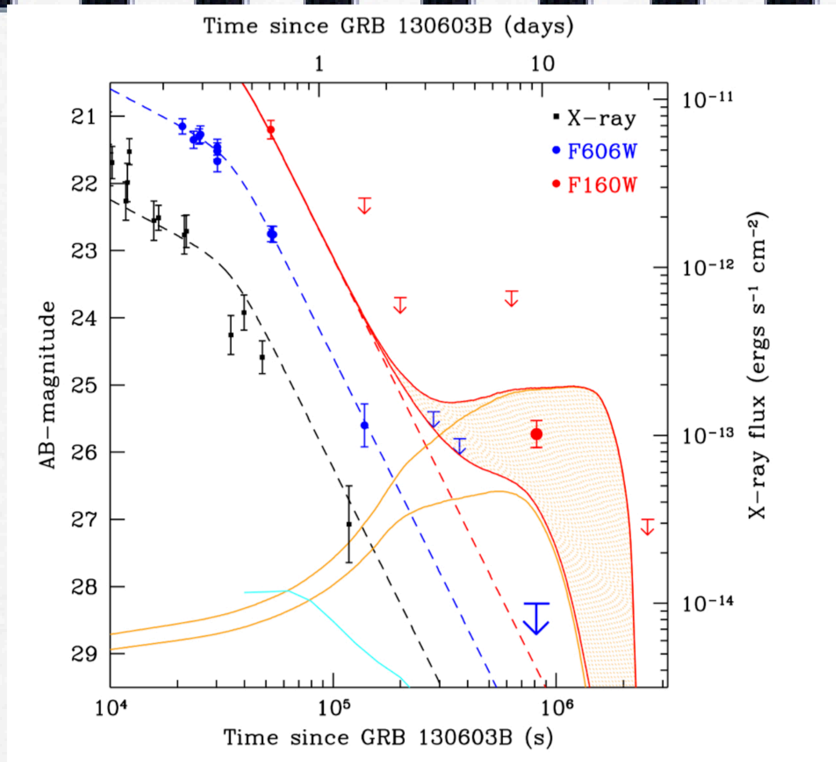
Metzger+14

The idea is that during the coalescence process a torus neutron rich is produced and r-process elements is strong. These elements have high-opacity, suppressing the optical emission, while the NIR emerges.

Time scale (~1 week) was consistent with the "kilonova" models.

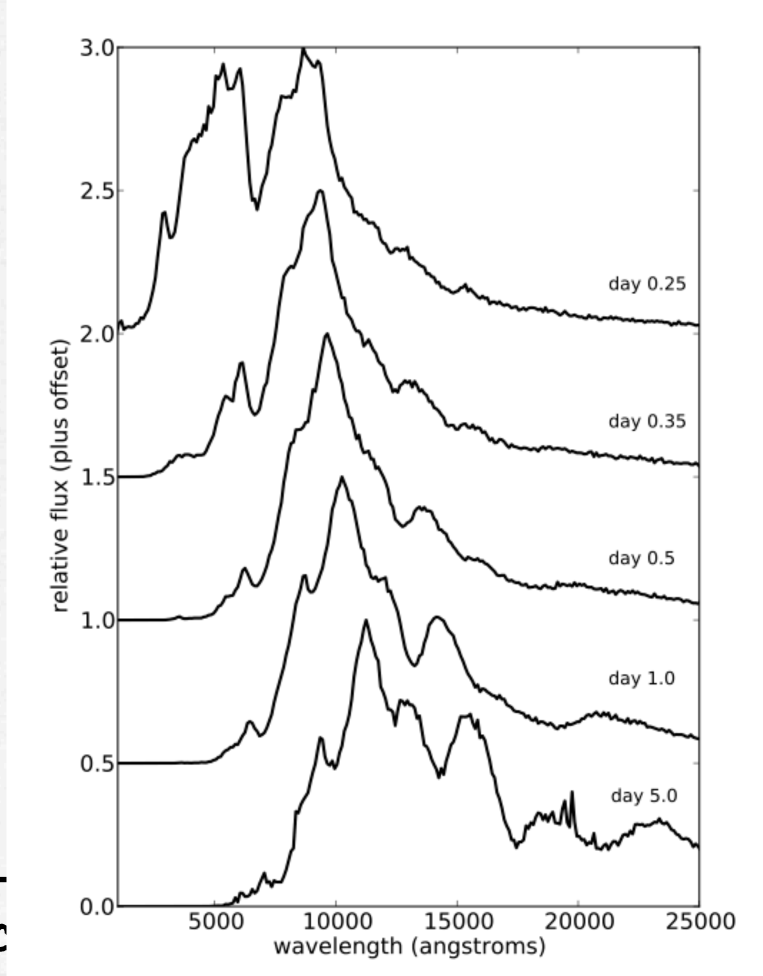
TMT will be able to constrain the lightcurve of these events via simple imaging campaigns. (~week timescale)

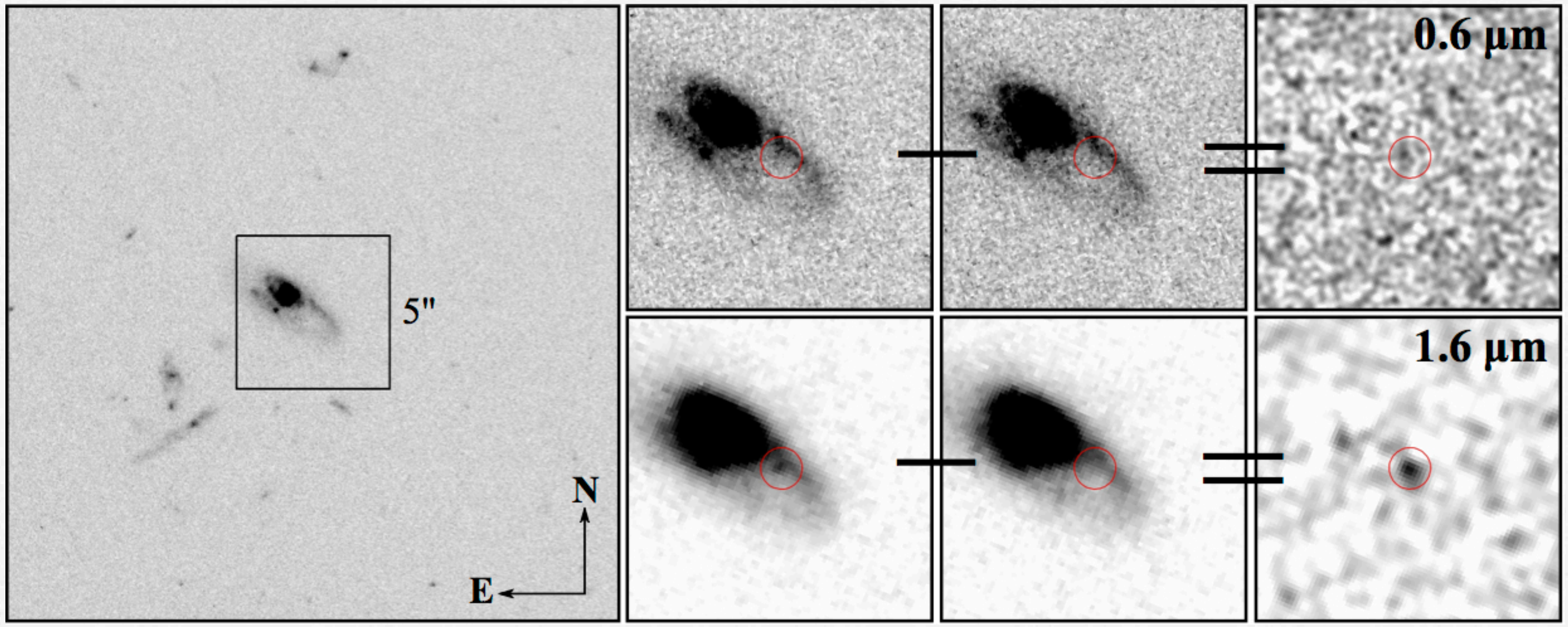
Tanvir+13

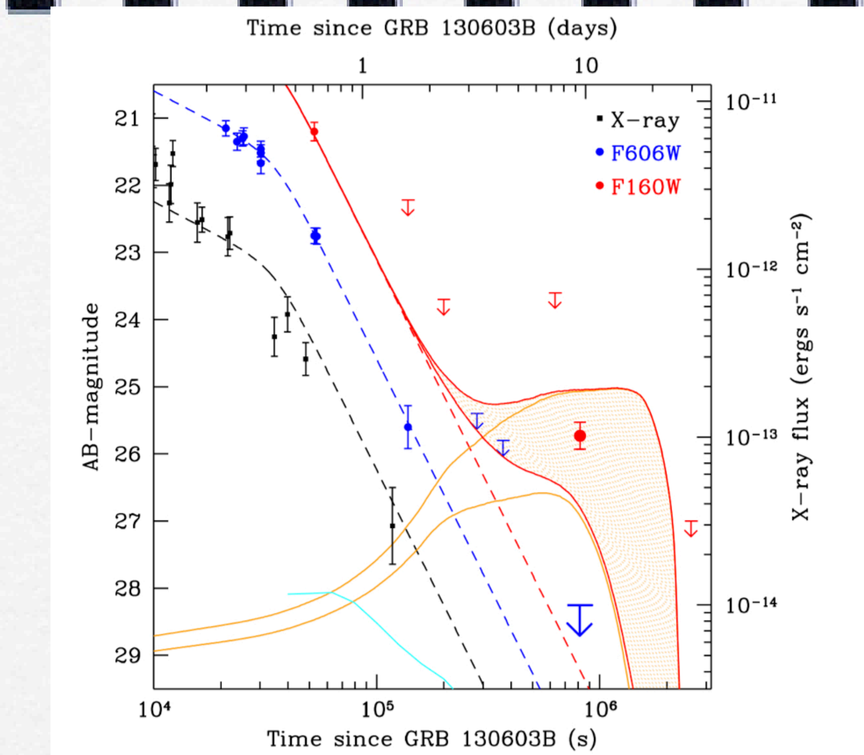


TMT +IRIS will provide spectroscopic follow-up at late time, investigating the presence/absence of r-process material in the ejecta. Models are still crude, but prediction are within IRIS capabilities.

Kasen+13





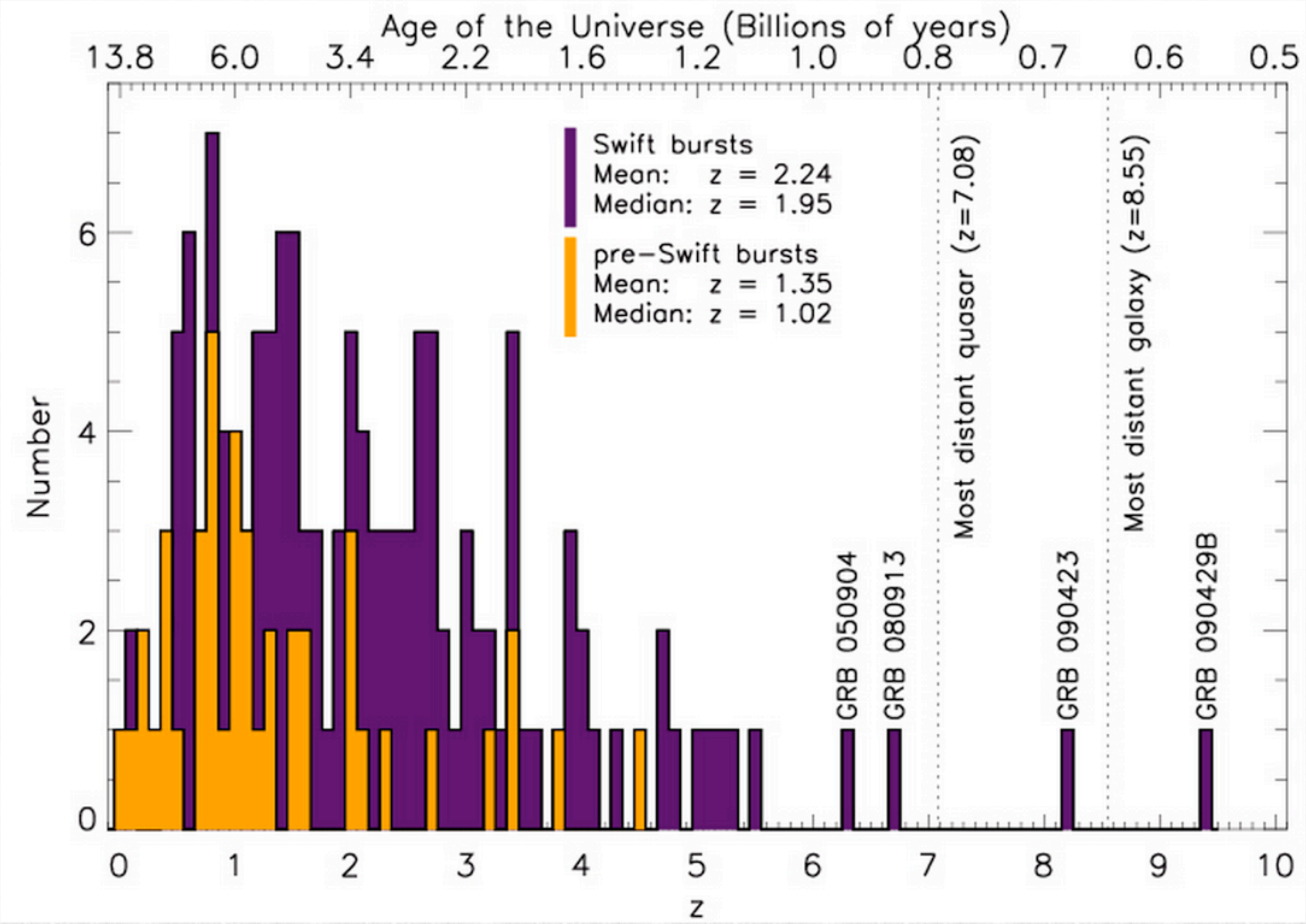


Tanvir+13

TMT contribution

- The secure identification of SGRBs and its hosts
- Characterize progenitor's environment
- Properties of the coalescent massive binary (kilonova) will provide fundamental pieces of the puzzle of our understanding of GW progenitors.
- TMT will also help solving the "kick" of these objects

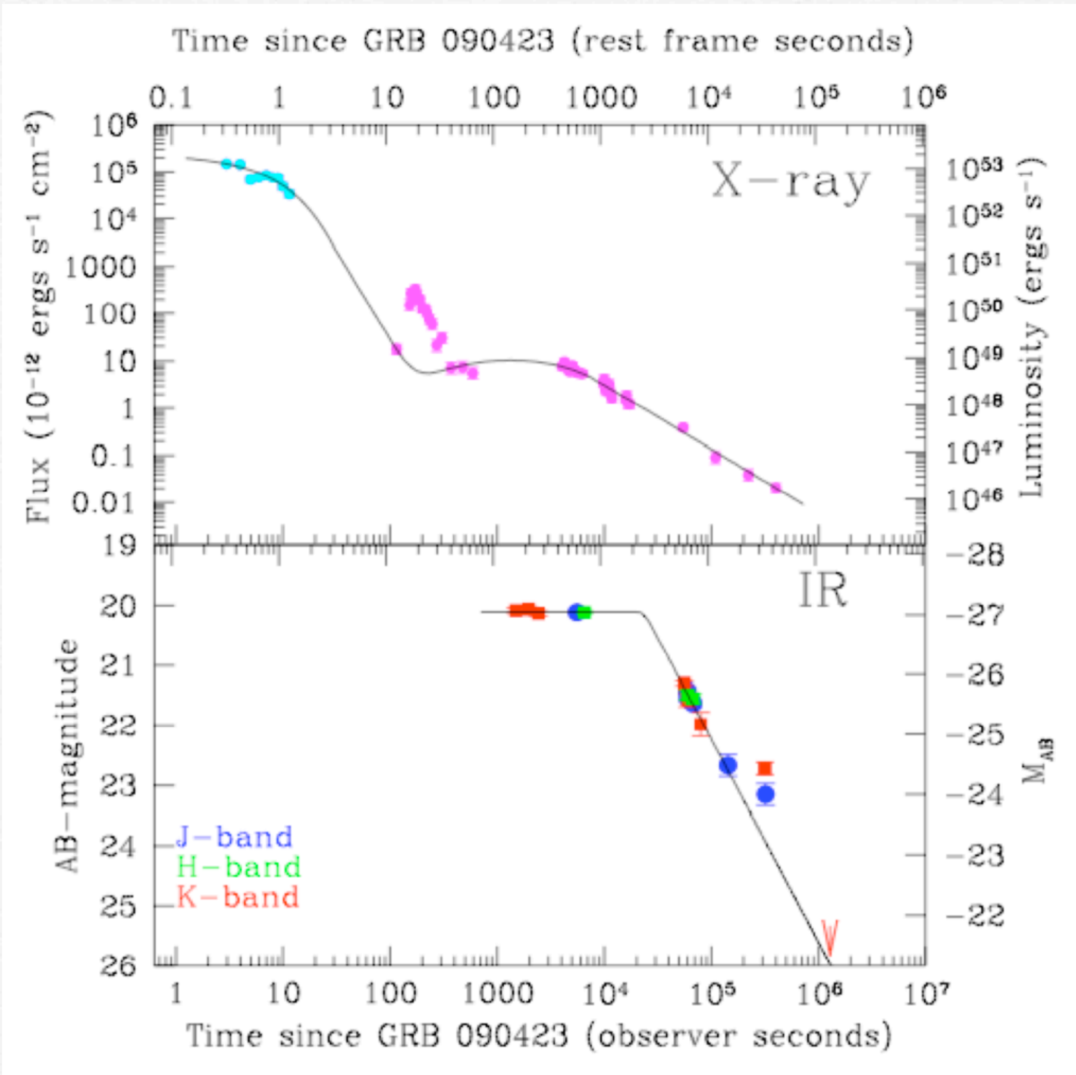
Long-GRBs

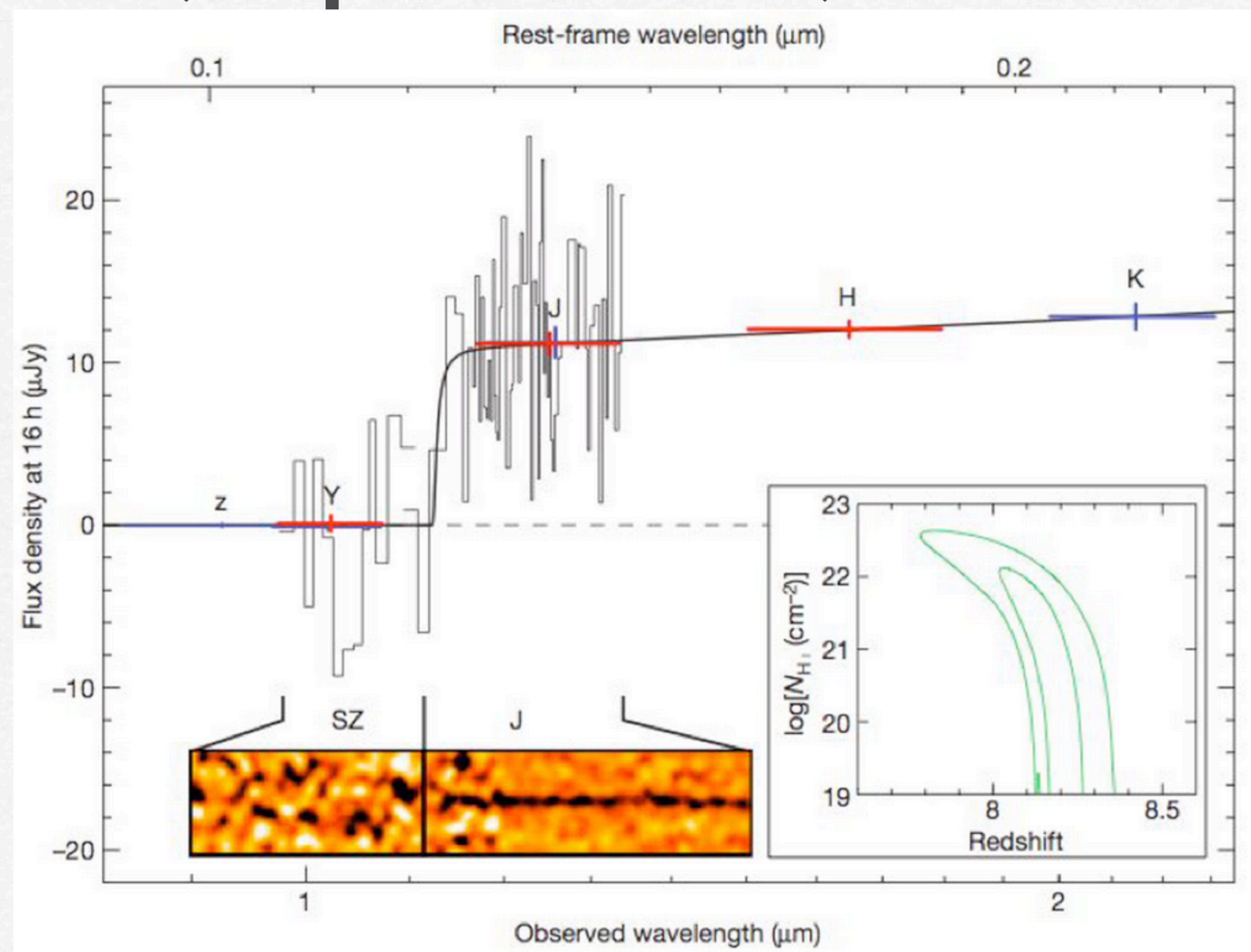


The majority of GRB detected by Swift (100/yr) belongs to the “long” class.

- They are the brightest in the Gamma-ray regime
- The likely progenitor are massive compact objects (like PopIII, PopII.1)
- They pinpoint the location of the first Galaxies
- The are the best tools to investigate the cosmic chemical enrichment

GRB 090423(z_{spec}=8.2)



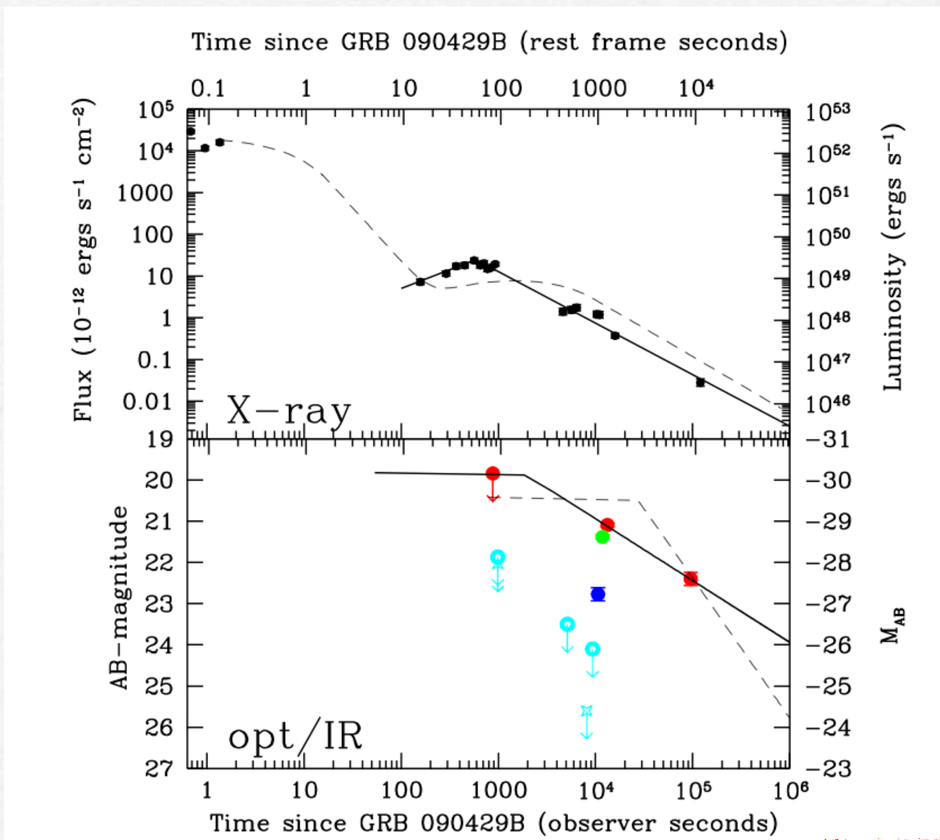


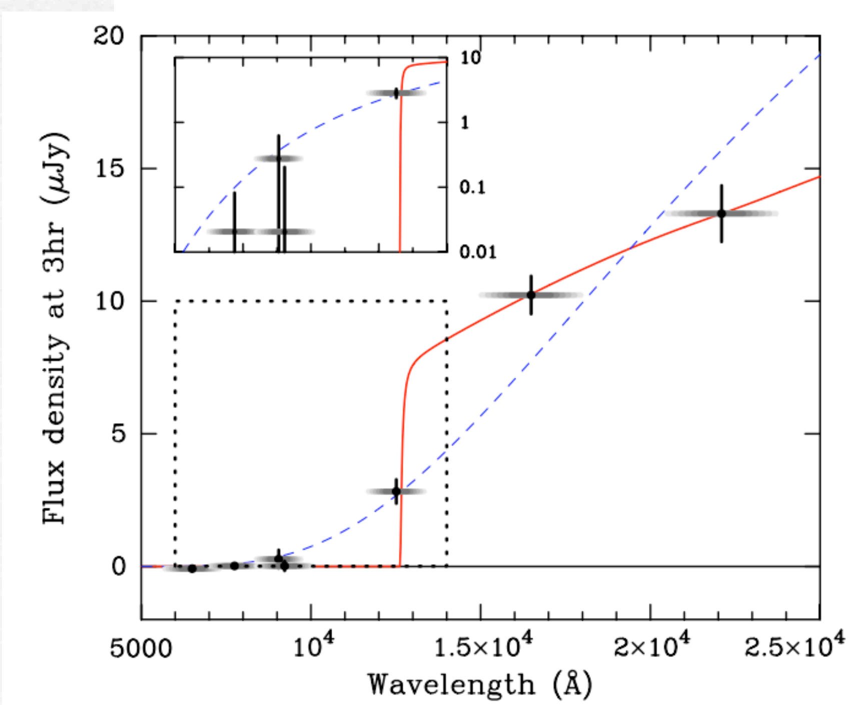
GRB 090423 was H=22 at T+1d

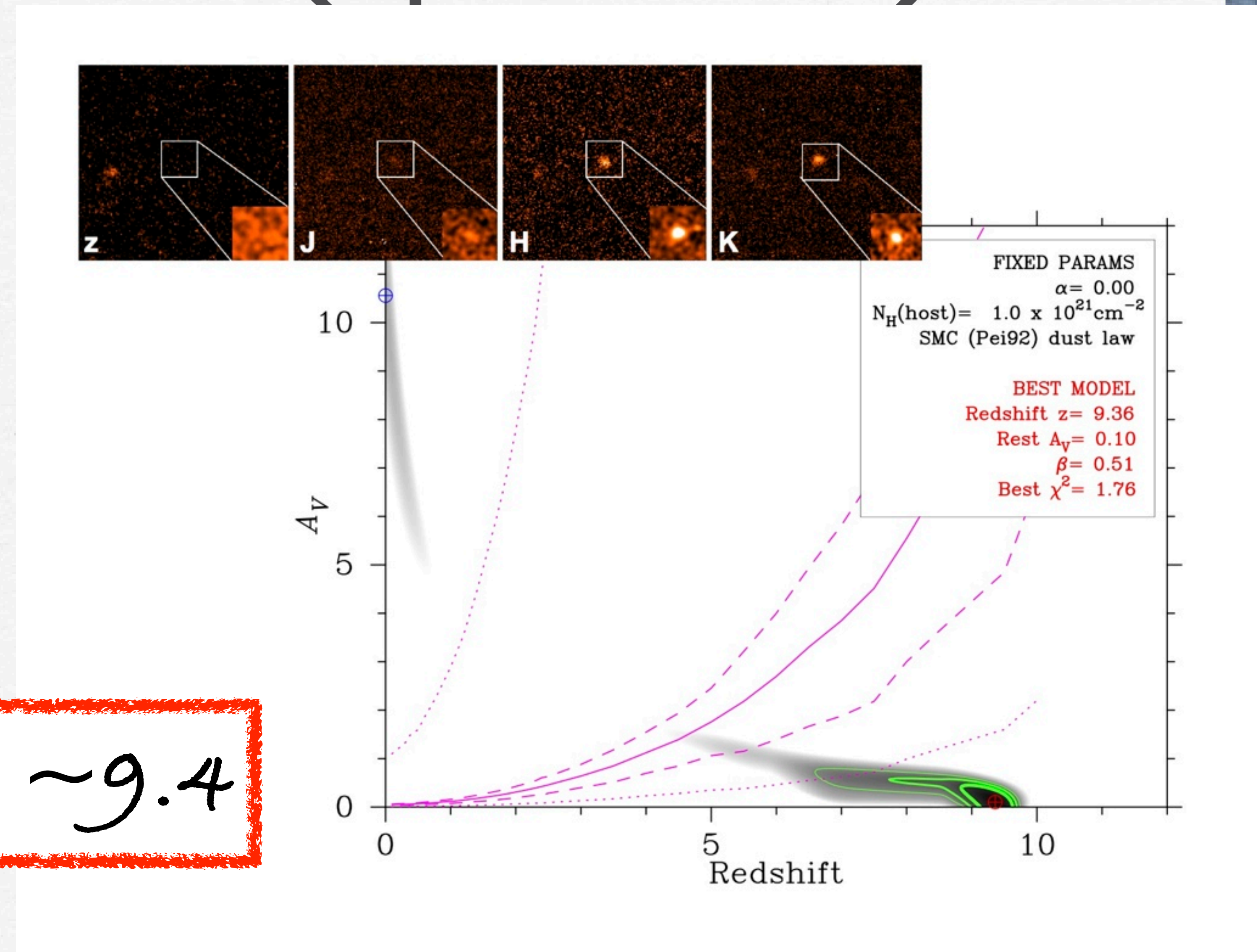
Spectroscopy was obtained at T+2d (low S/N)

TMT would be able to observe and obtain high-S/N spectrum even 3 days after the GRB discovery

GRB 090429B (z_{phot}~9.4)







z_{phot} ~9.4

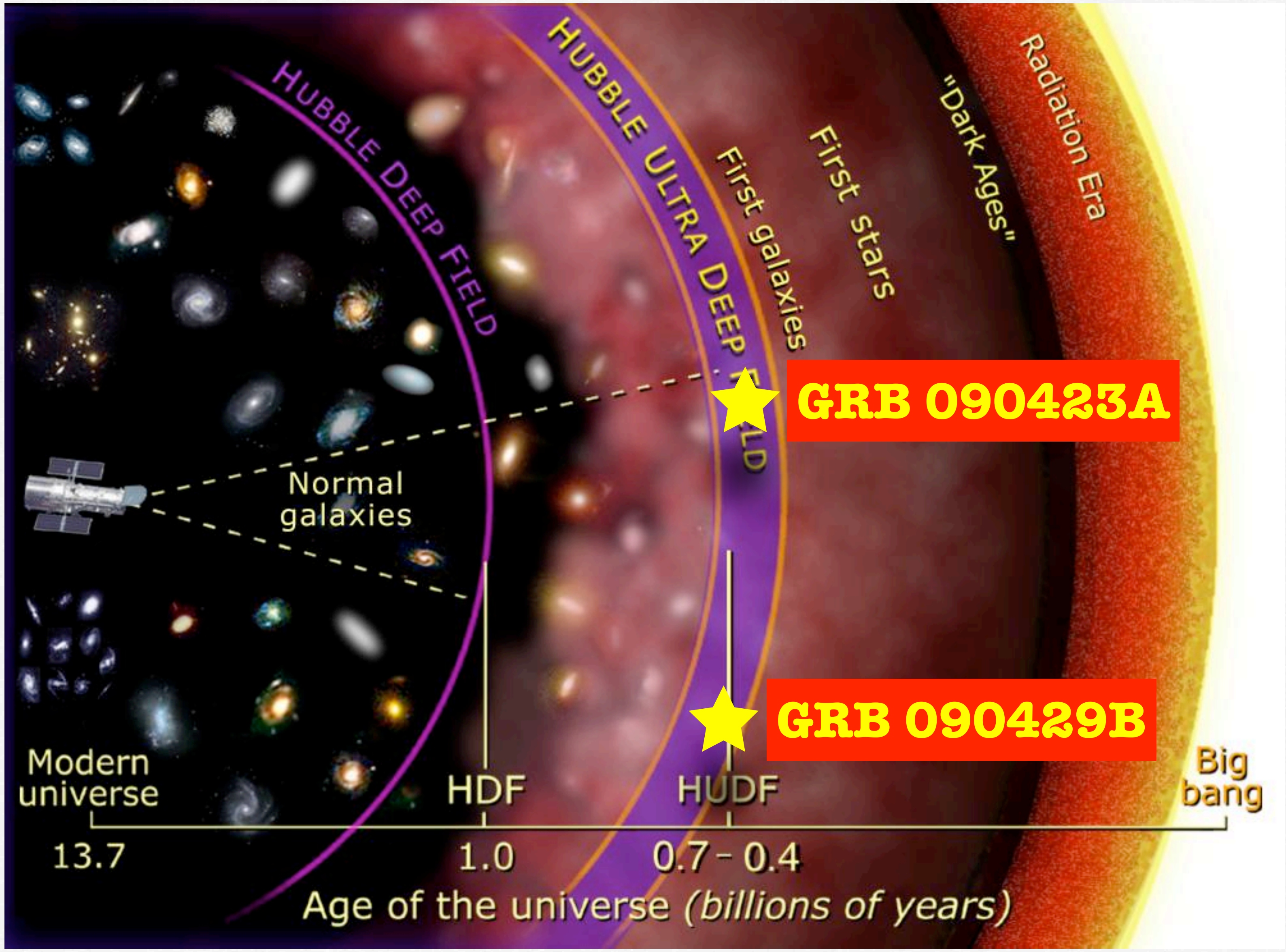
GRB 090429B was K=22.5 at T+2d

Spectroscopy was not obtainable due to observing constraints and "science choice" (a.k.a. 090423)

Summary in one slide...

Summary in one slide...

GRBs (7 days) vs. HST (20+ years)



Summary in one slide...

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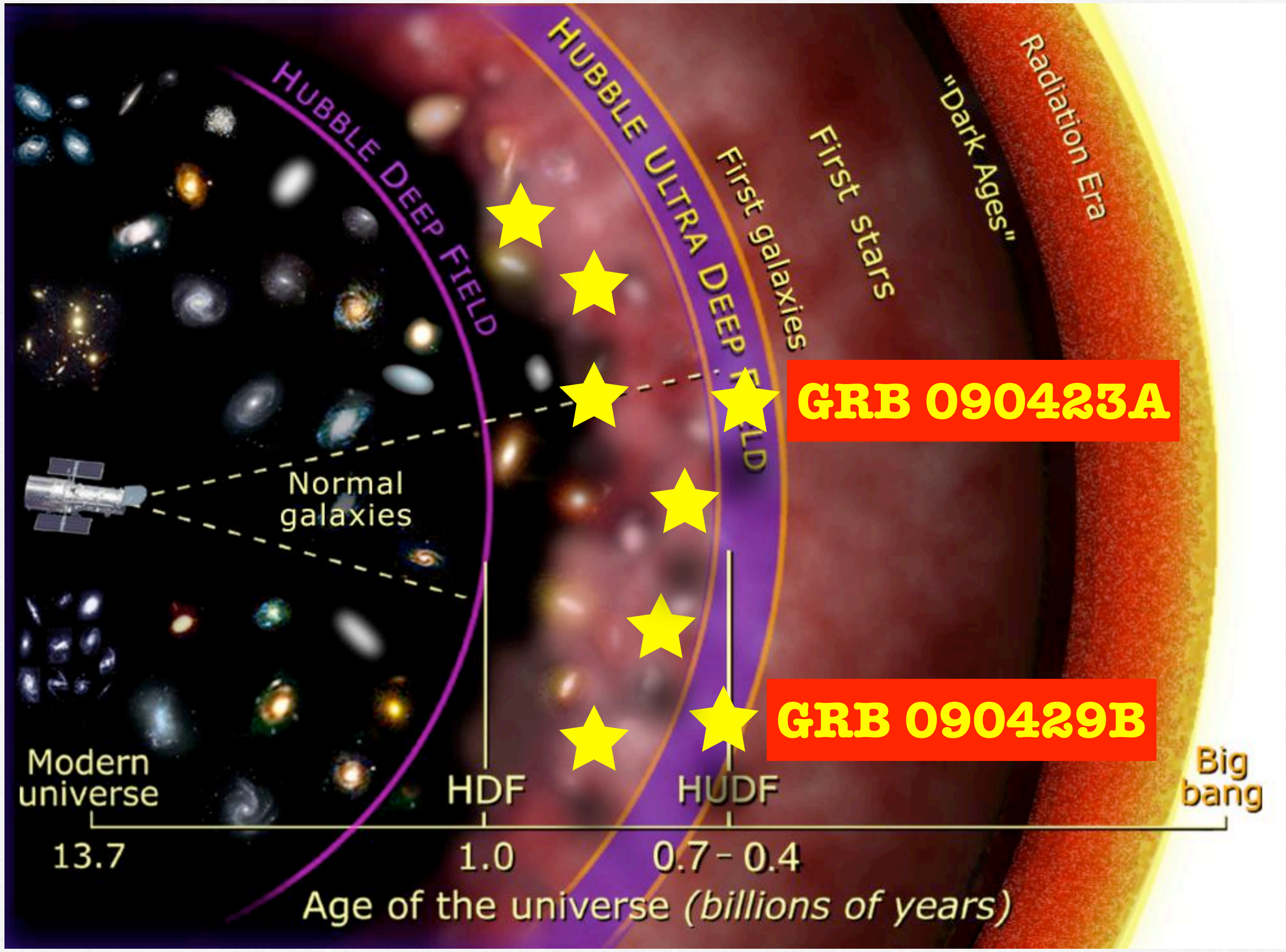
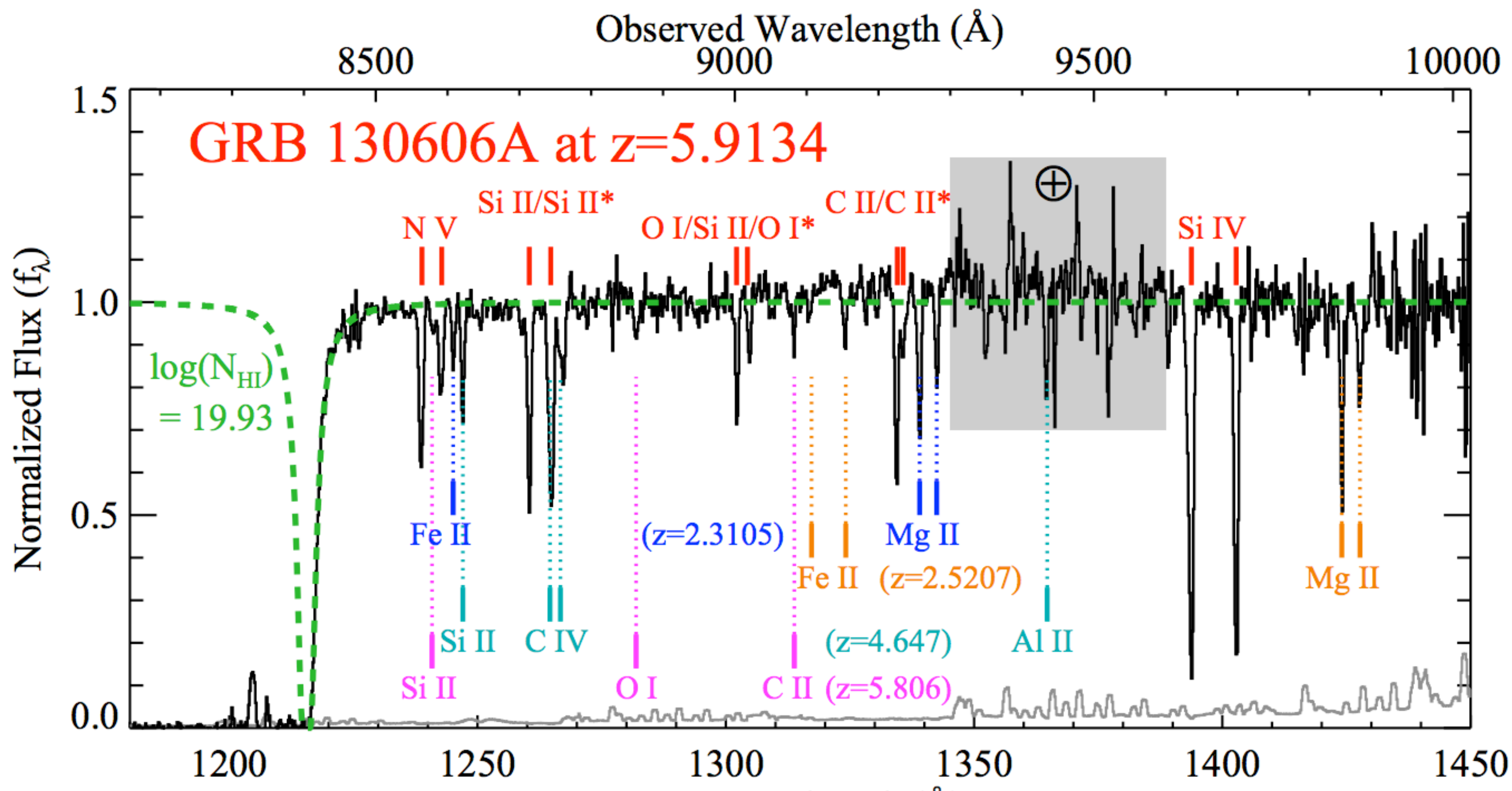


Will GRBs “really” show us the final frontier?

The chemistry of the early Universe:

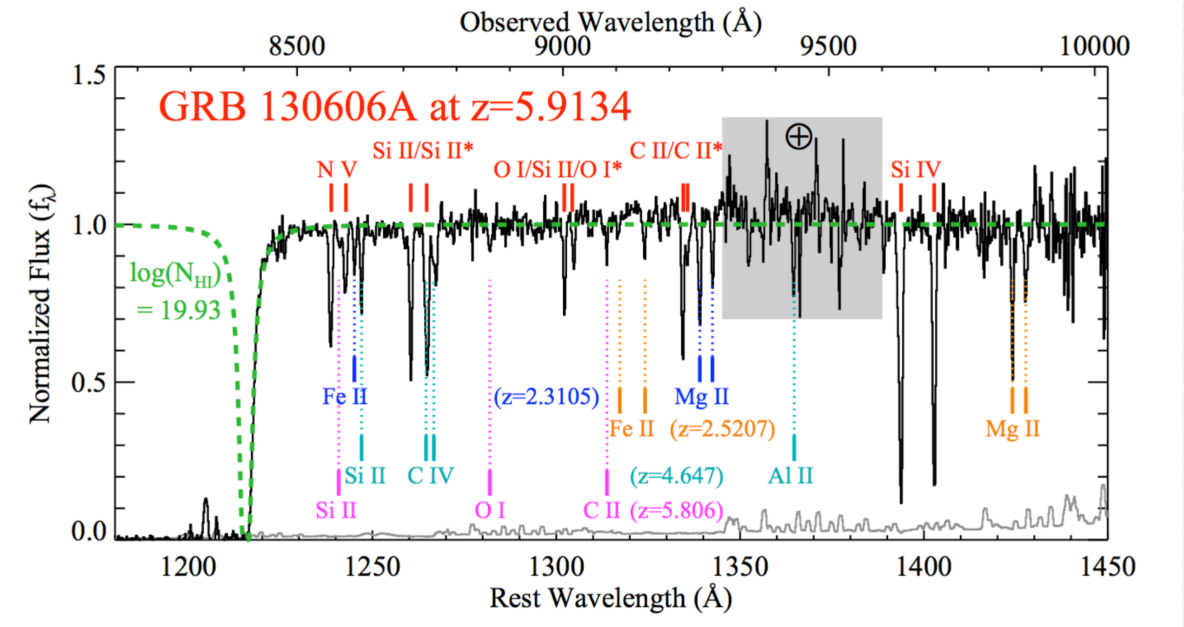


Chornock+13

...Yes!

GRB 130606A allows:

- ☐ Clear redshift determination
- ☐ HI column density of the Host
- ☐ f_{esc} measurement through the Lyα forest
- ☐ Identification of multiple intervening systems



But the GMOS resolution is too low (R~1200) b/c line blending (saturation effects prevent to estimate accurate metal abundances)

Even JWST/NIRSPEC may not be the "best option"

TMT/IRIS could observe z=8-10 GRBs within 2 days of the explosion and obtain higher Resolution spectroscopy!!!

The cosmic metal budget

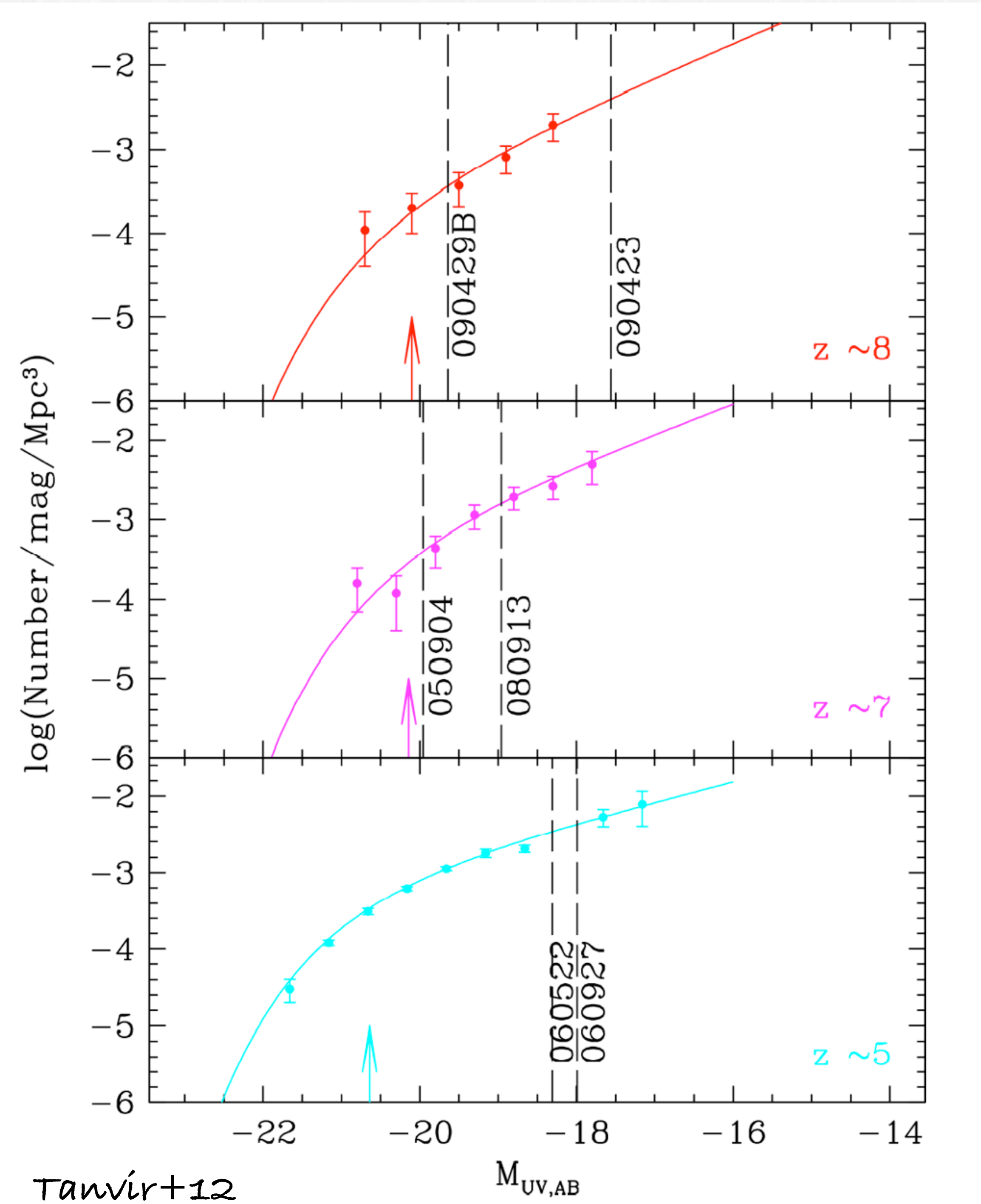
Cucchiara+14 in prep.

Comparing a sample of GRB-DLAs with QSO-DLA metallicity we see that GRB-DLA trace much more mature, metal rich environment.

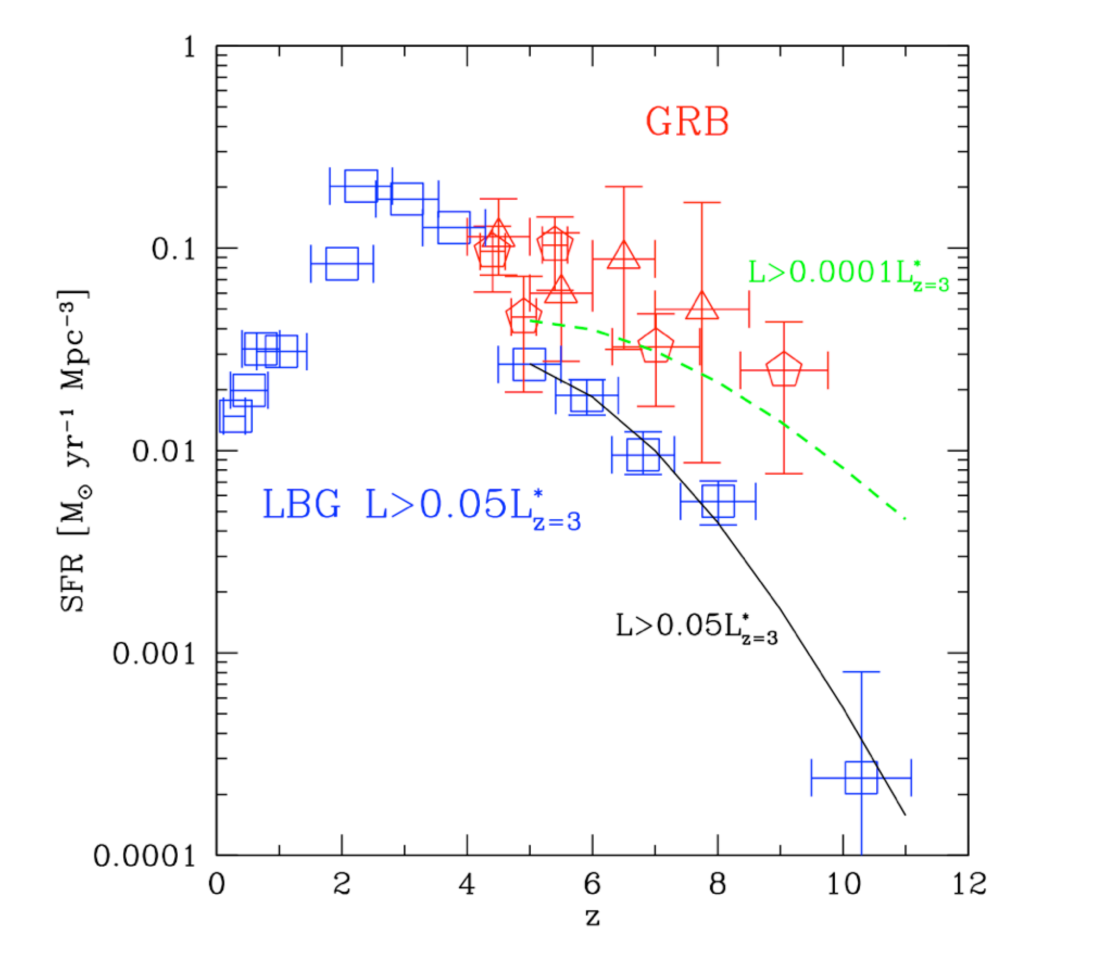
The primordial metallicity can be traced ONLY by GRB absorption spectra.

What else? Well, the usual

GRB probes small, faint galaxies, those elusive onew missed by HUDF (?)



Tanvir+12



Trenti+12 (see also Robertson+12, Oesch+13, Bouwens+13,+14)

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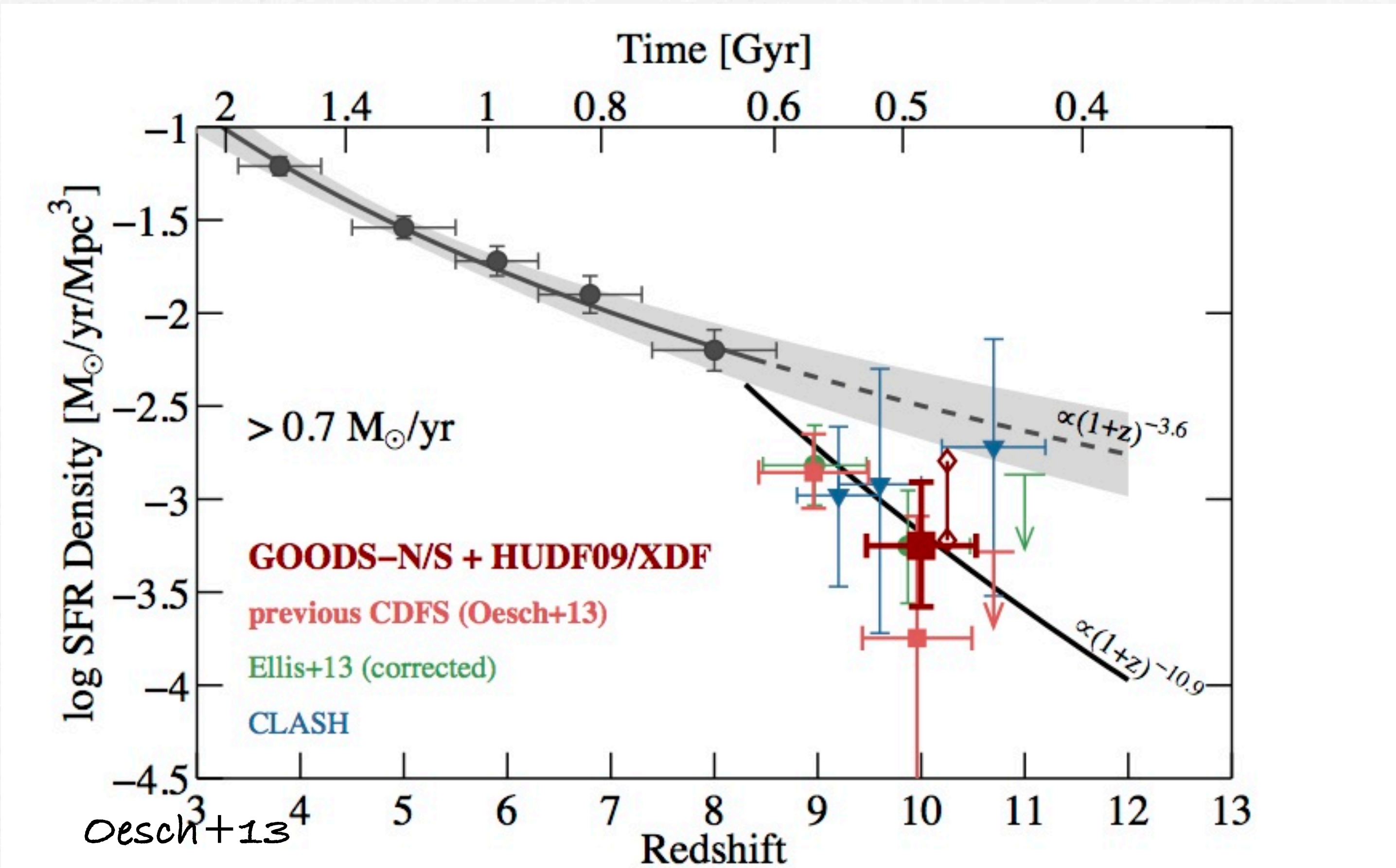
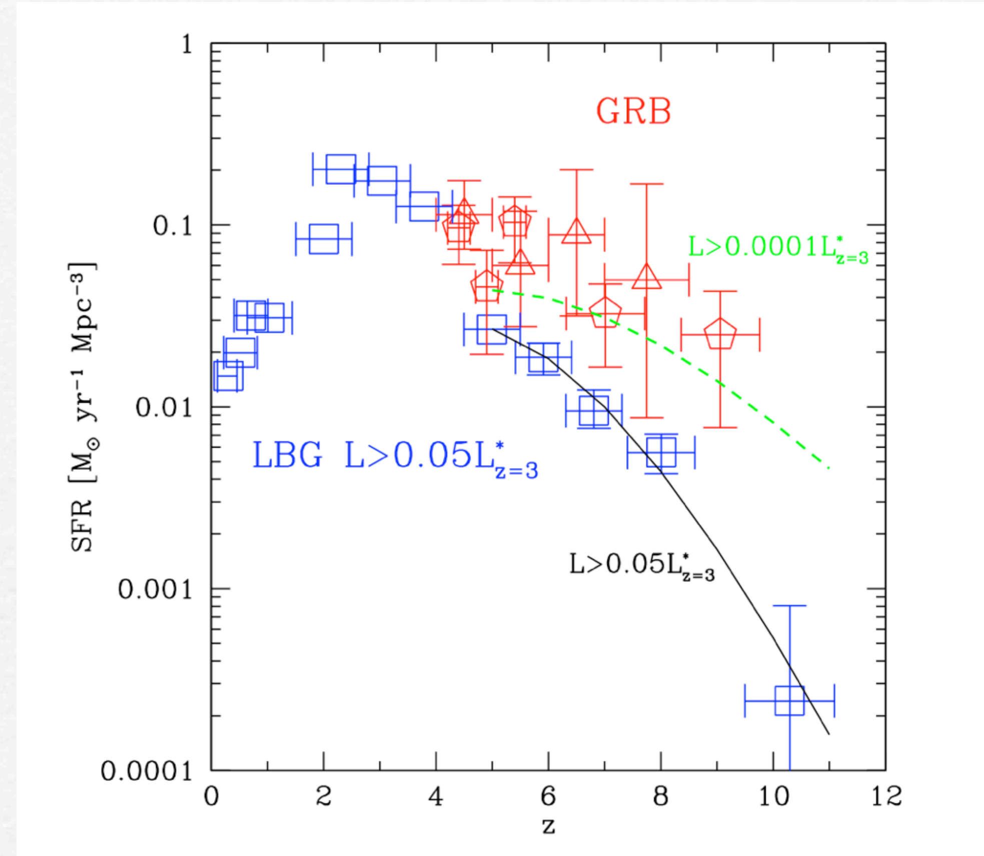


Oesch+13



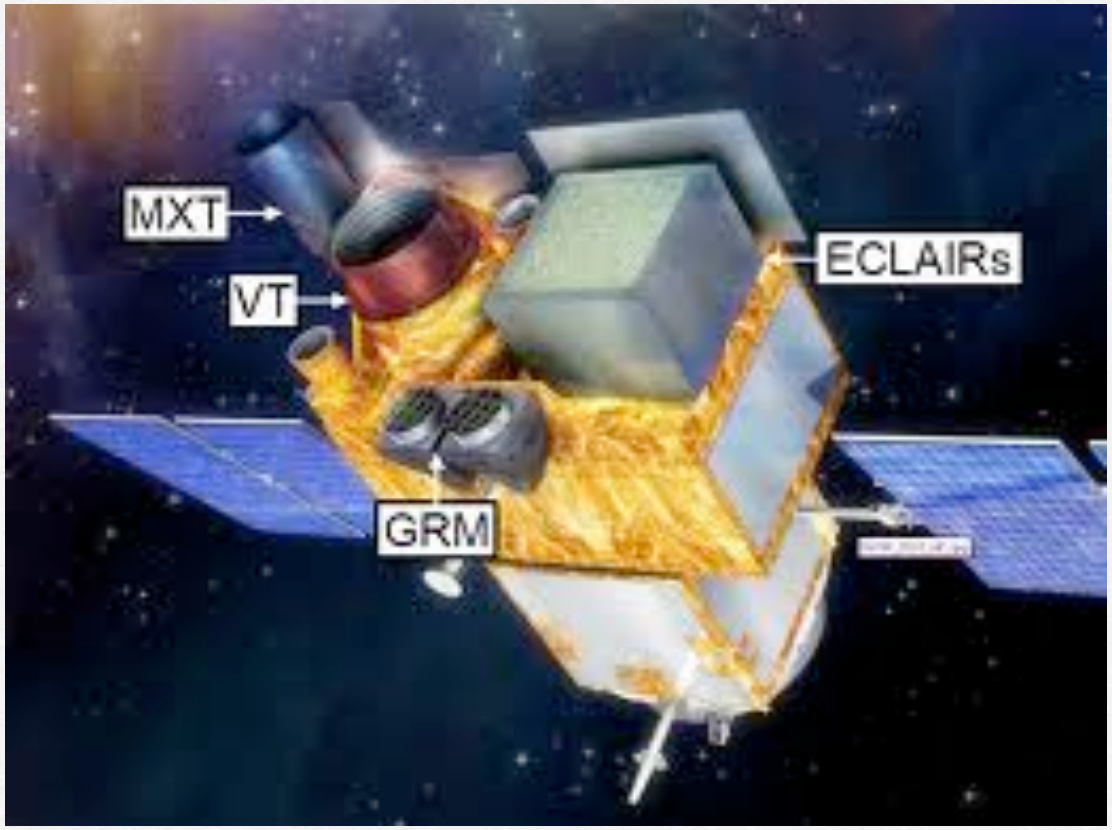
Trenti+12 (see also Robertson+12, Oesch+13, Bouwens+13,+14)

Lot of work needs to be done, but TMT can be "guided" towards those elusive galaxies as traced by GRBs, that may holds the first beacon of Star-Formation

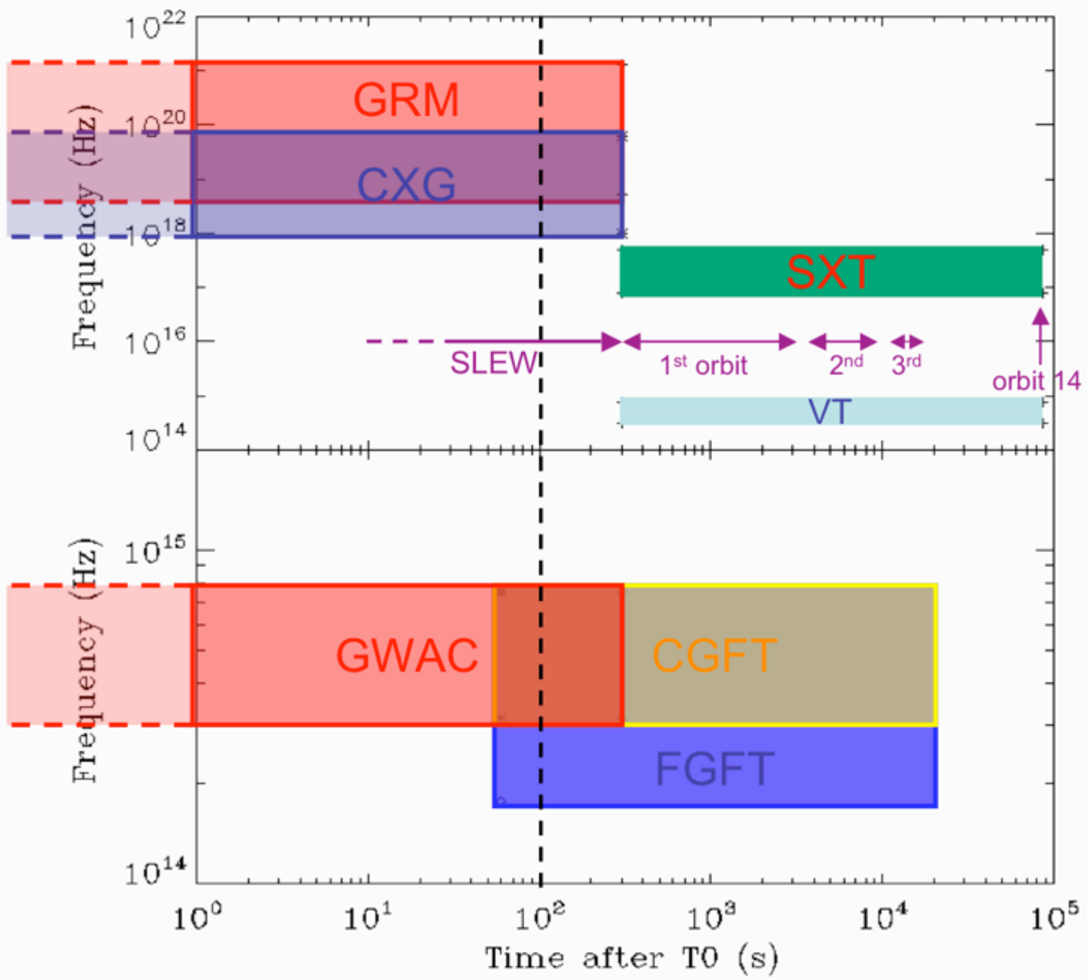
The 2020 new-horizon

- Future after Swift: SVOM (2018)
- Future after Hubble: JWST (2018)
- Future of Survey: WFIRST (2022)
- Future of time domain: LSST (2022), ZTF (2016)
- Future of 30-m telescopes: TMT/GMT (2024)

SVOM mission (FRA-CHI)



Launch in 2017

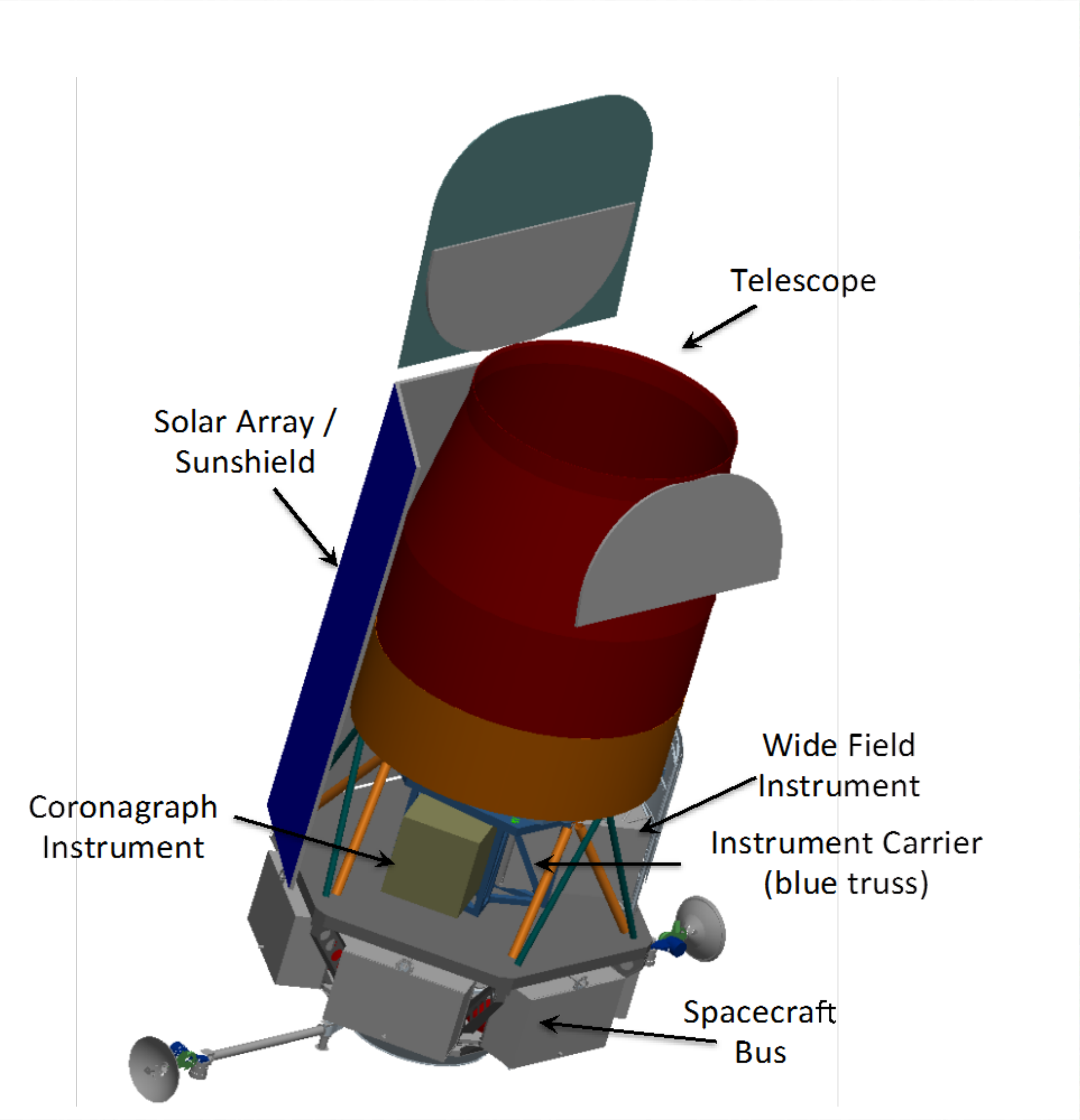


- Promise to detect 80 GRB/yr
- Swift Sensitivity
- Lower X-ray energy band

WFIRST (see Dan Stern's talk)

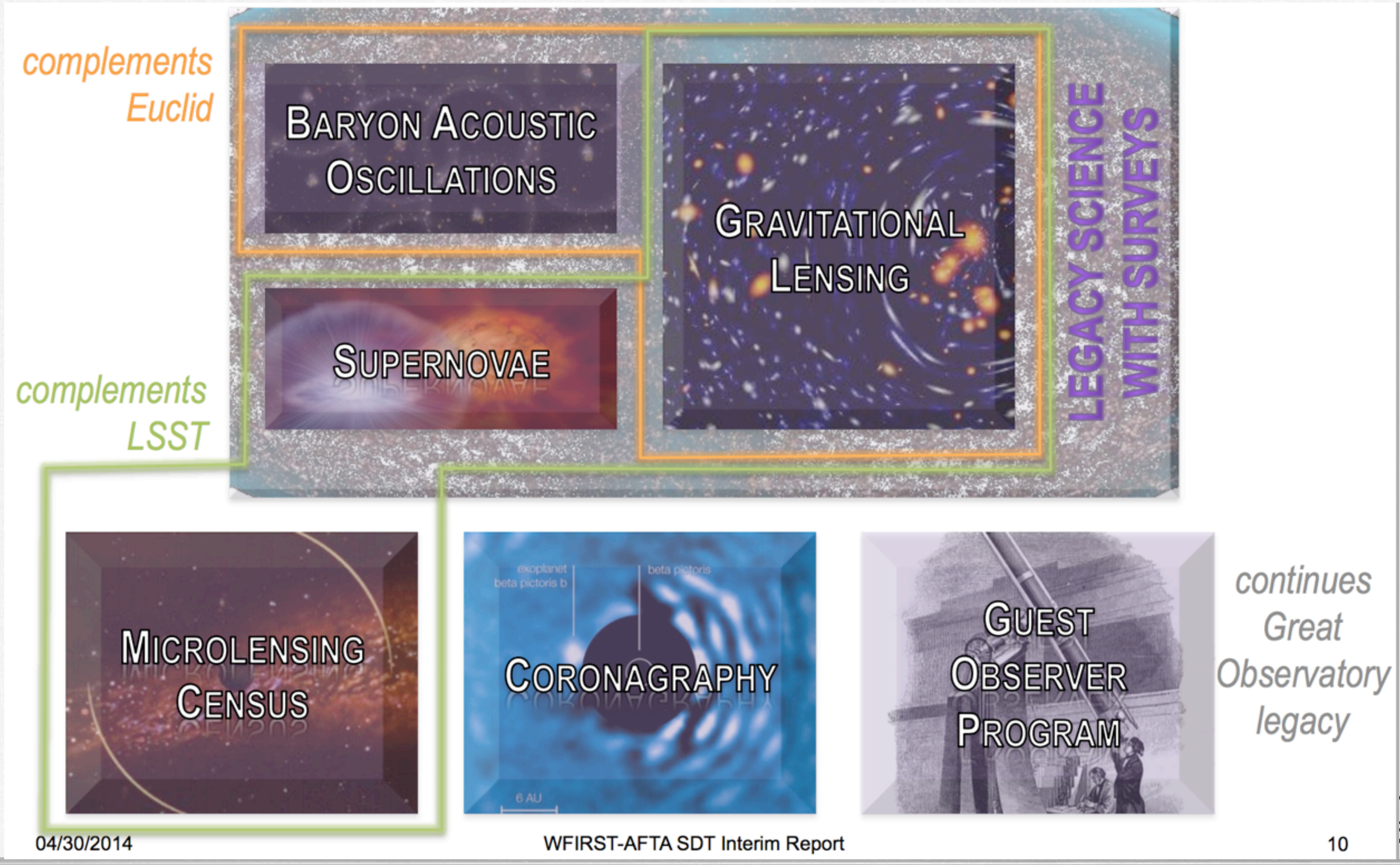
Thw Wide Field Infra-Red Survey Telescope

- 2.4 meter telescope
- WFC3/IR spatial resolution over x200 the FOV
- Coronograph (exo-planet direct imaging)
- GRISM spectroscopy (0.6-2.0 micron)
- IFU spectroscopy (R~100)
- Guest-Investigator program (1.5/5 yr)



WFIRST

http://wfirst.gsfc.nasa.gov/



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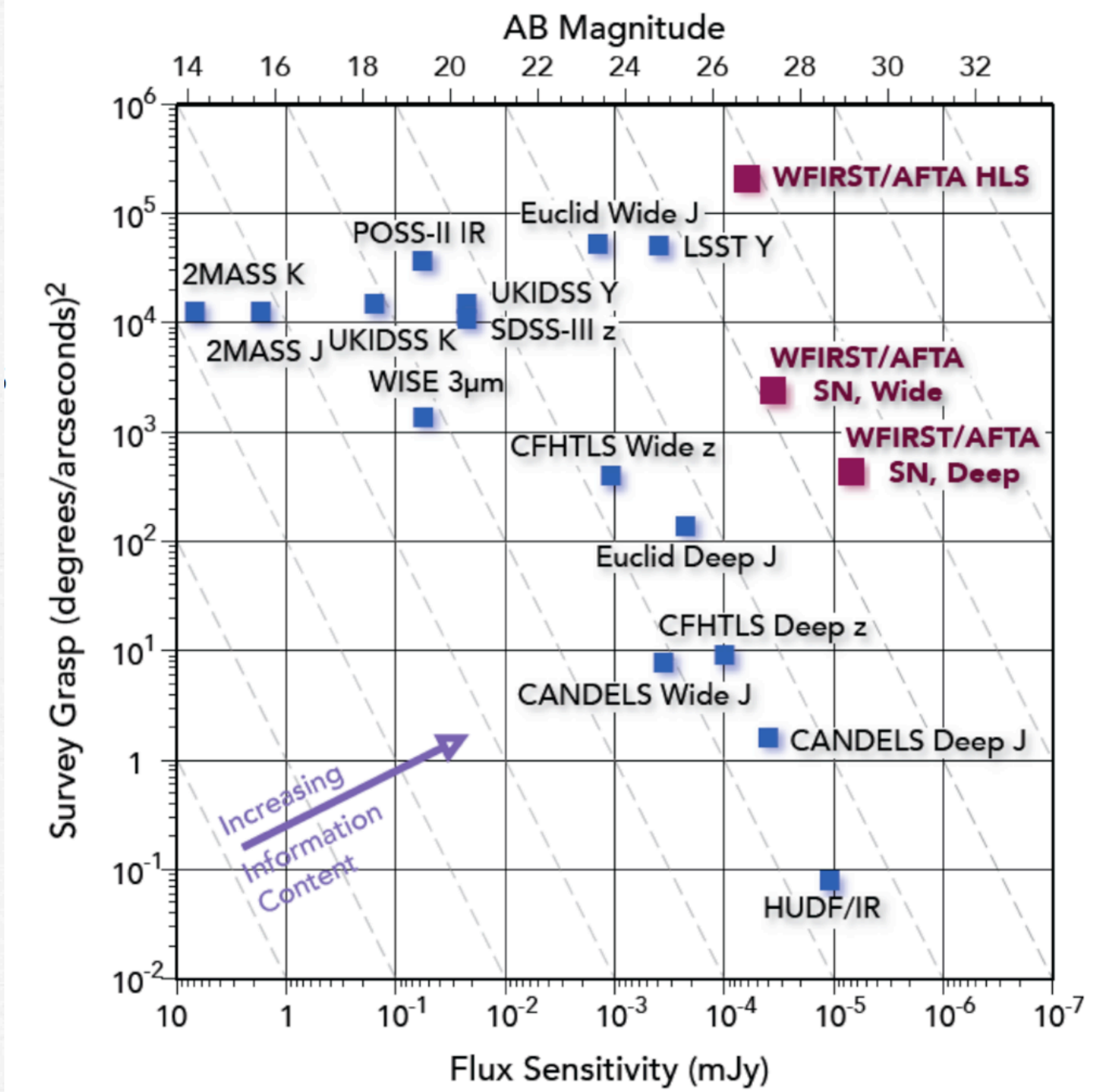


Near Infrared Surveys

Summary

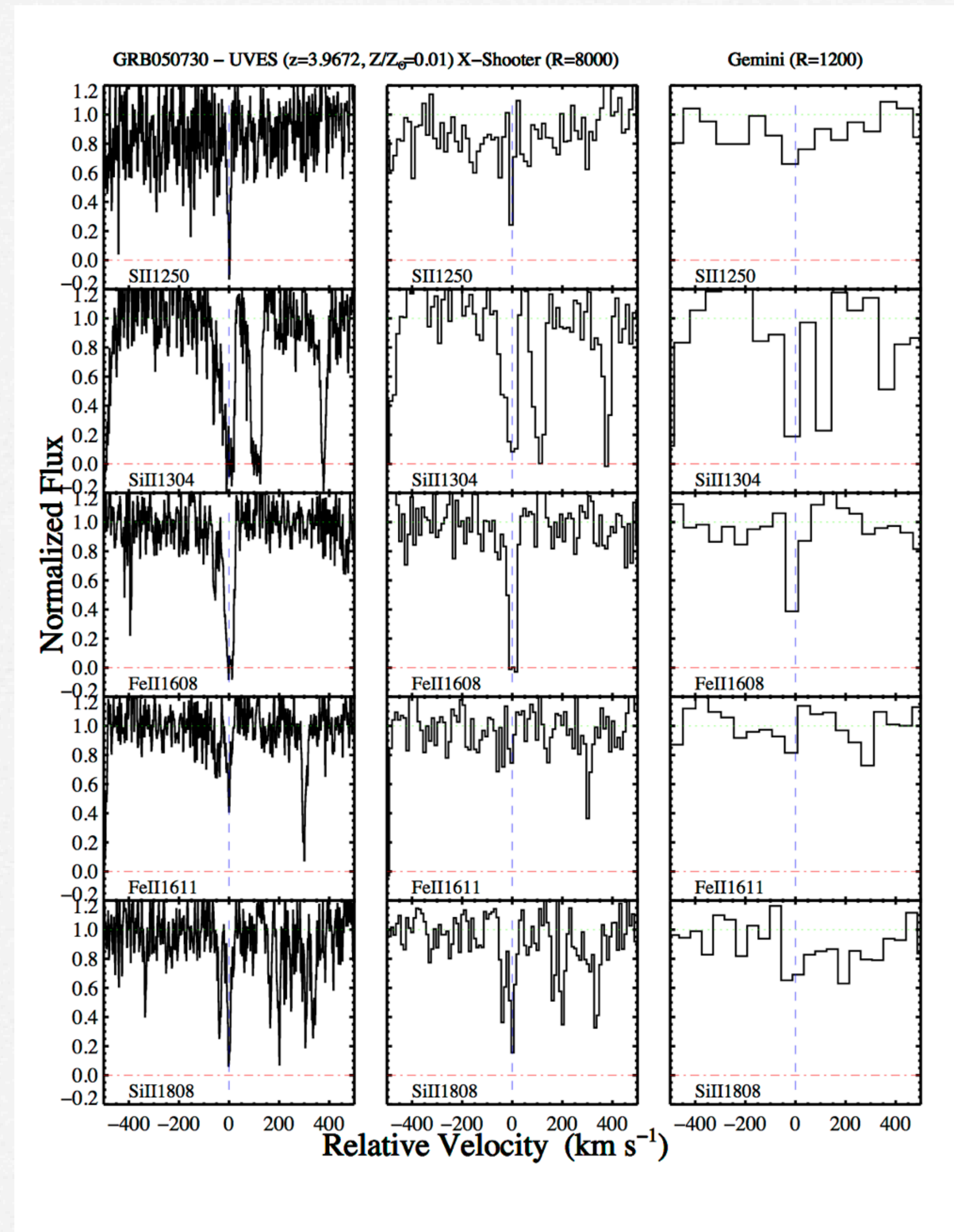
- TMT NIR will observe SN shock breakout of core-collapse SNe at high-z
- TMT will provide unique spatial/spectral probes of Tidal-disruption events
- Short-GRBs/Kilonovae will be "easy": fundamental for GW electromagnetic counterparts characterization
- Long-GRBs/Hosts at z>6: PopIII stars, PI-SN, metallicity measurements of high-z galaxies (rapid spectroscopy)
- Ly-α escape fraction f_{esc}, neutral hydrogen fraction n_{HI}
- Nail down the SFRD beyond JWST capabilities

"High" spectral resolution requirement

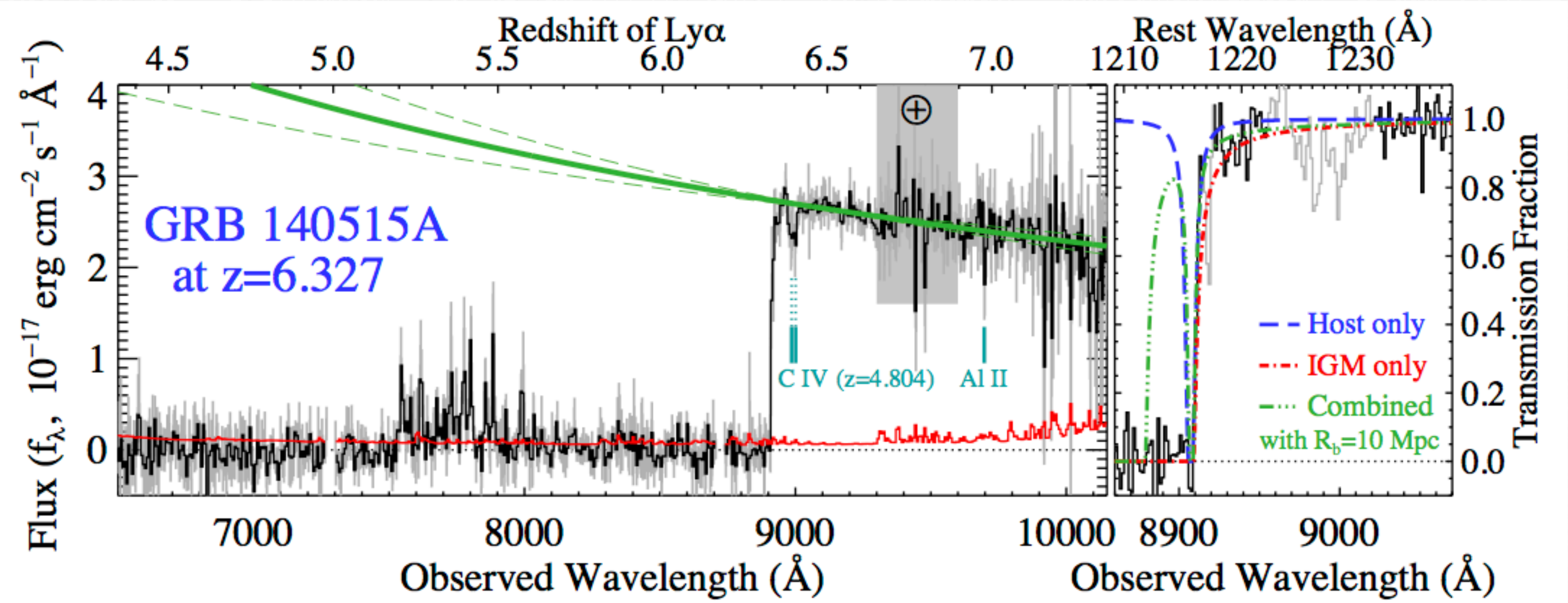
In order to derive metal abundances we use wake lines

Resolution < 6000 is not good enough

- ☐ Saturation of strong lines
- ☐ Blending with multiple components
- ☐ Blending with other host lines
- ☐ Blending with other systems

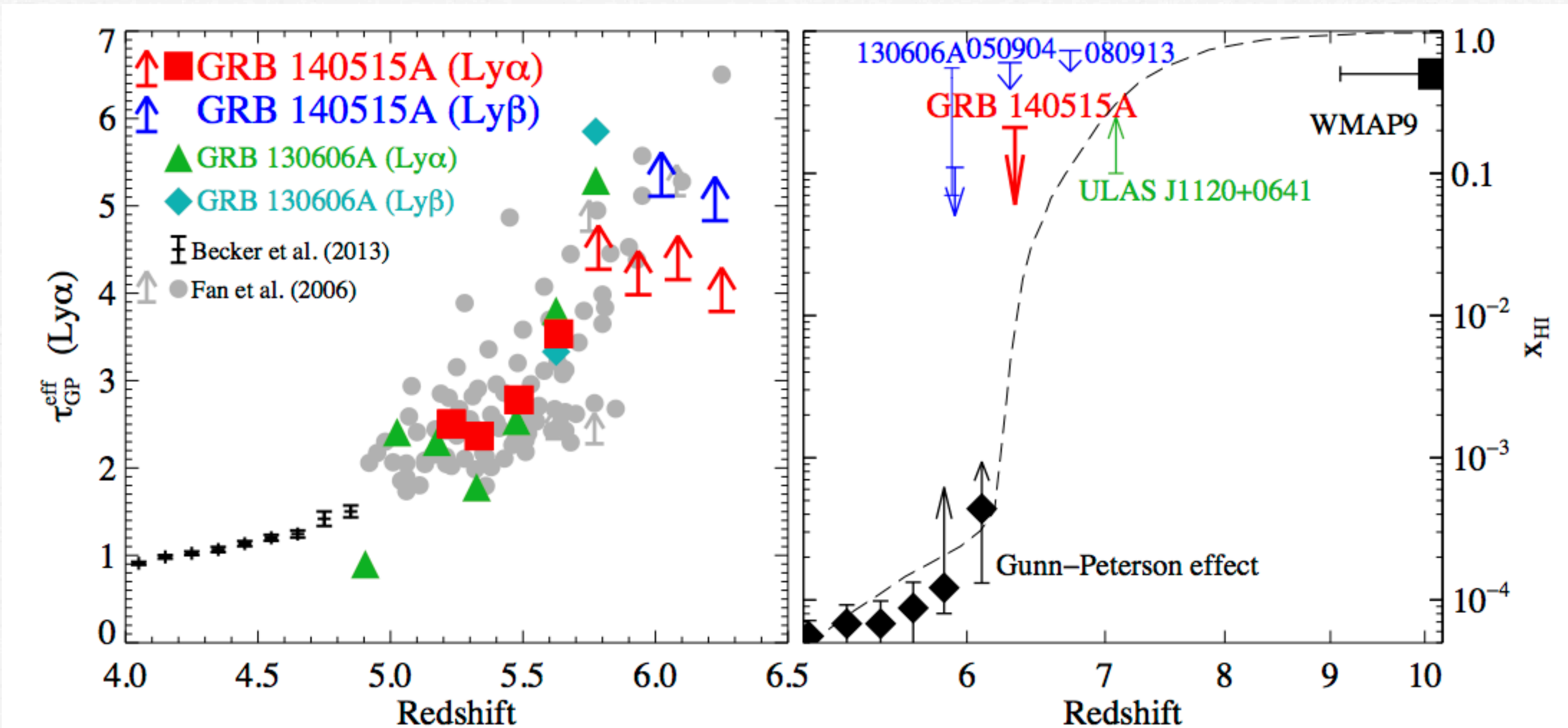


A not so lucky case



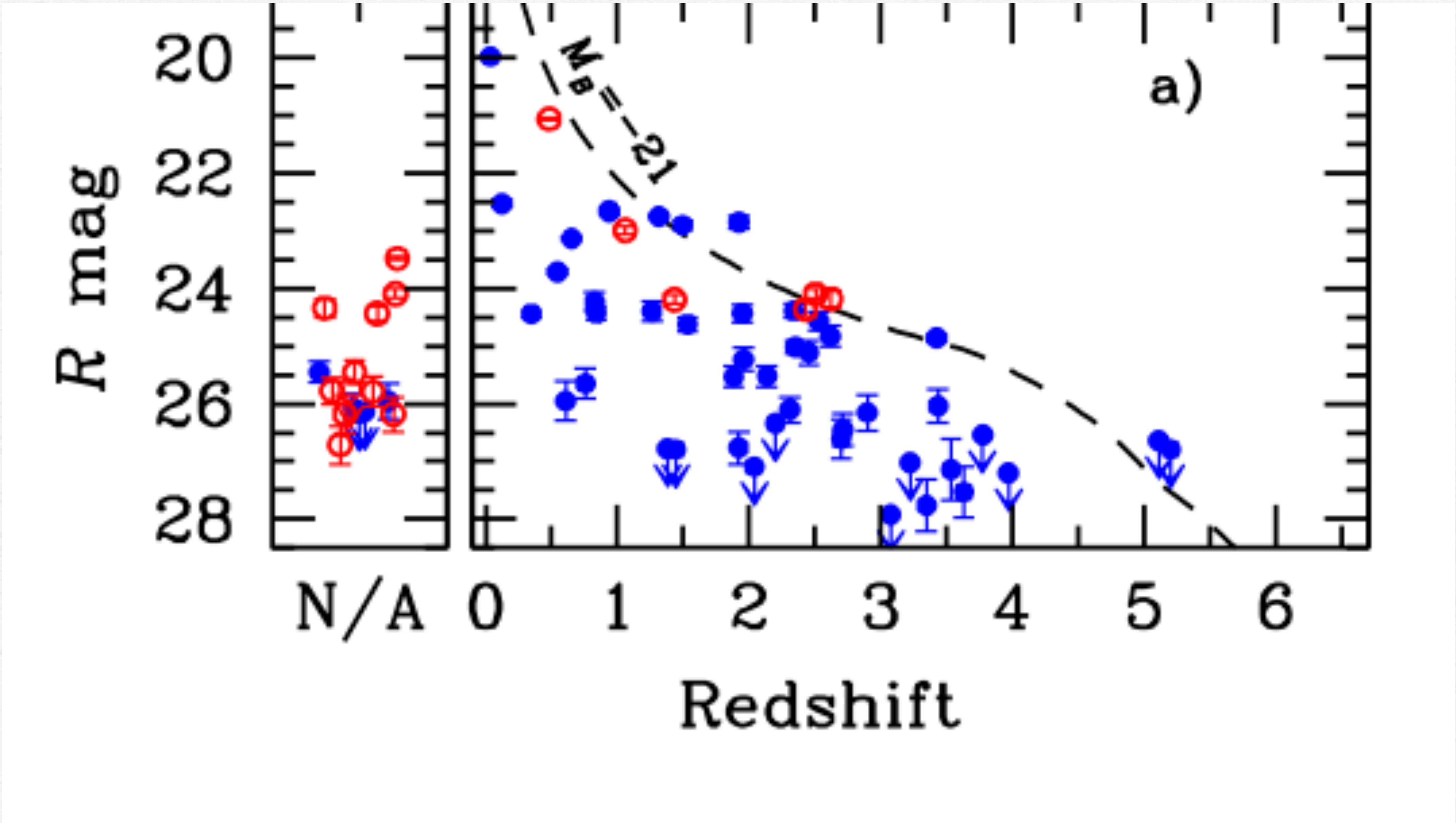
Chornock+14

Neutral hydrogen fraction



Chornock+14

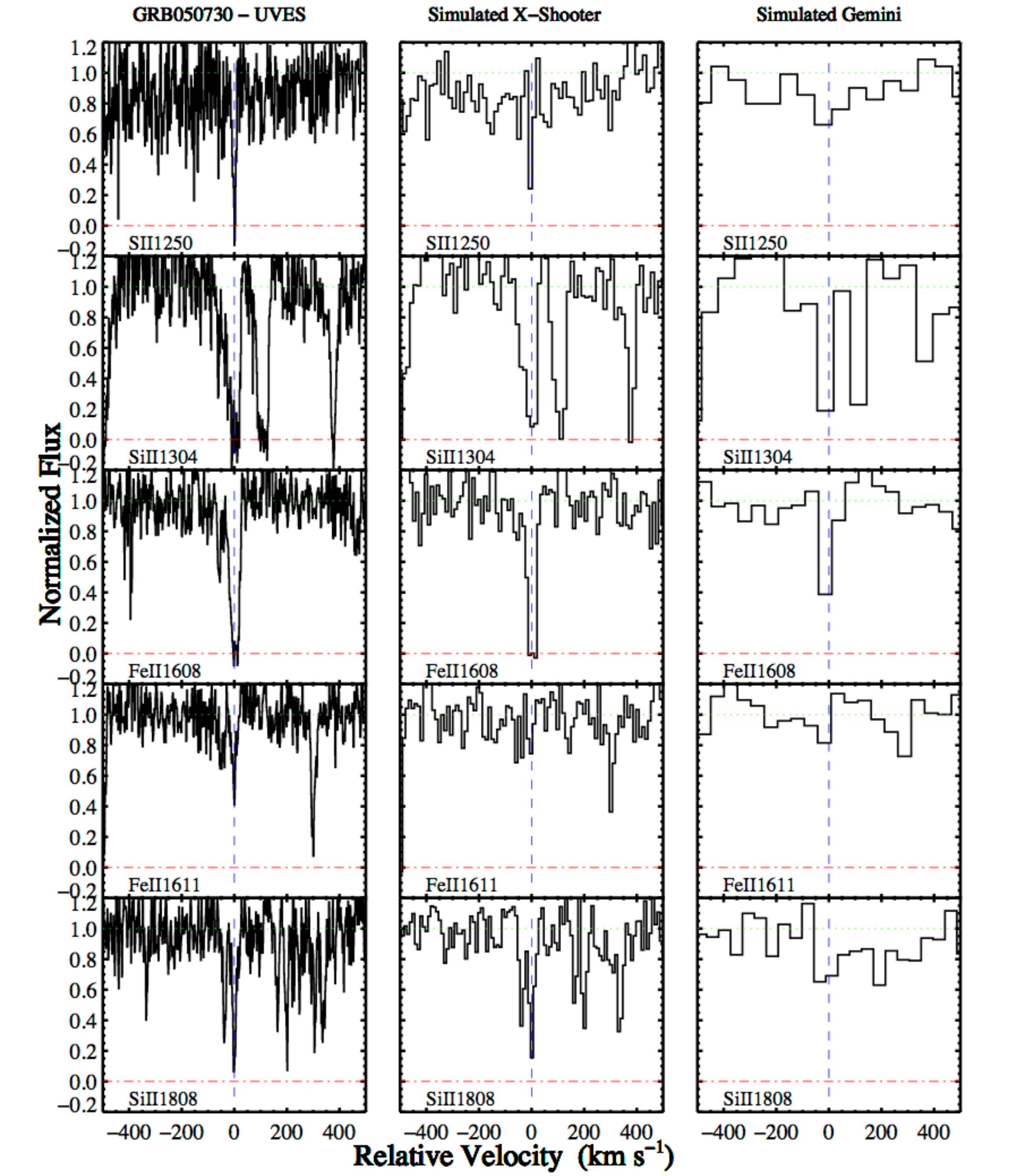
Hosts luminosity

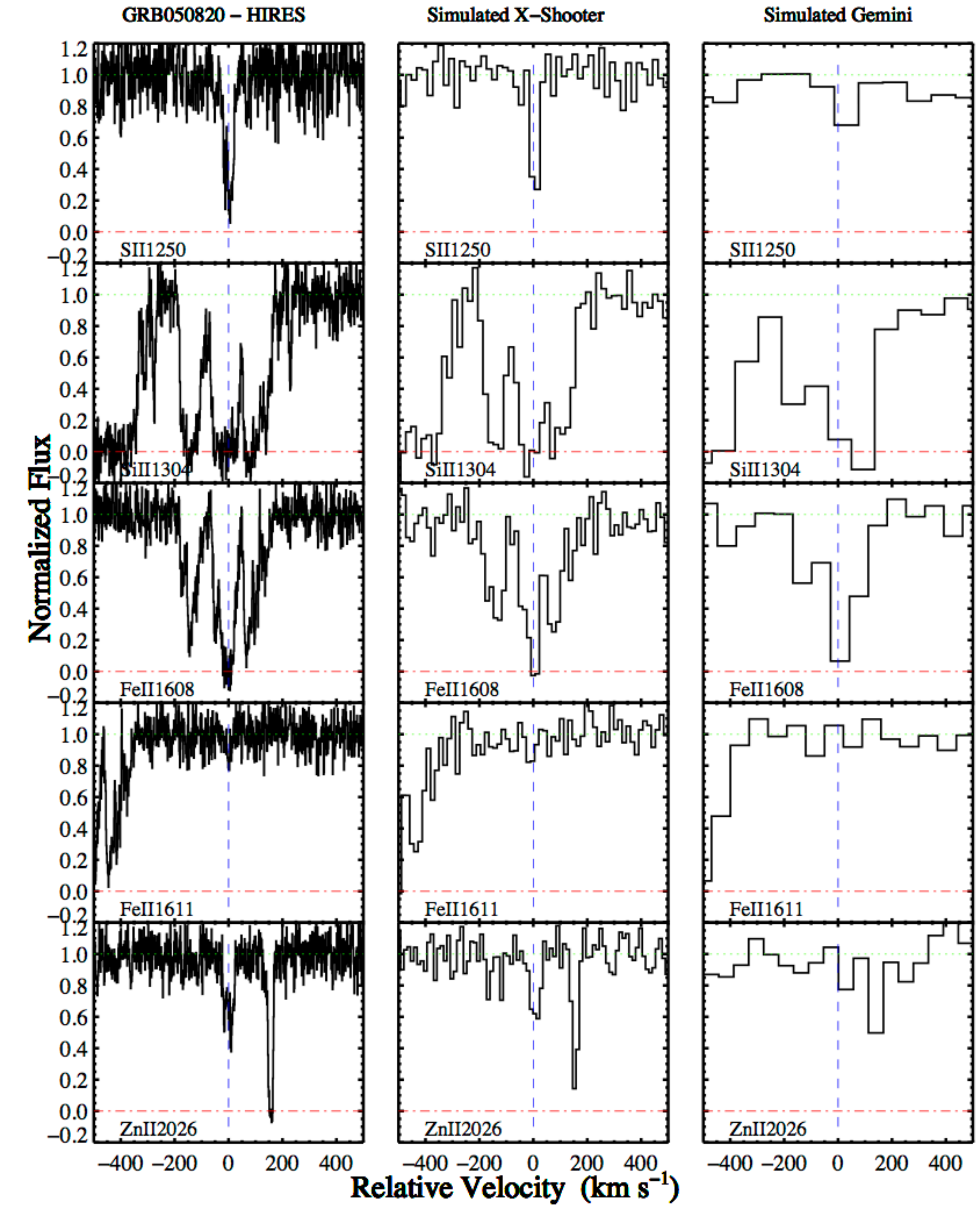


Hjorth+12

Resolution

Cucchiara+14 in prep





GRB 050730 (z=3.97) has Z/Z_{sun}=0.01

GRB 050820 (z=2.62) has Z/Z_{sun}=0.12