The future of rapid spectroscopy, from GW sources and GRBs

Sergio Campana
INAF - Osservatorio astronomico di Brera

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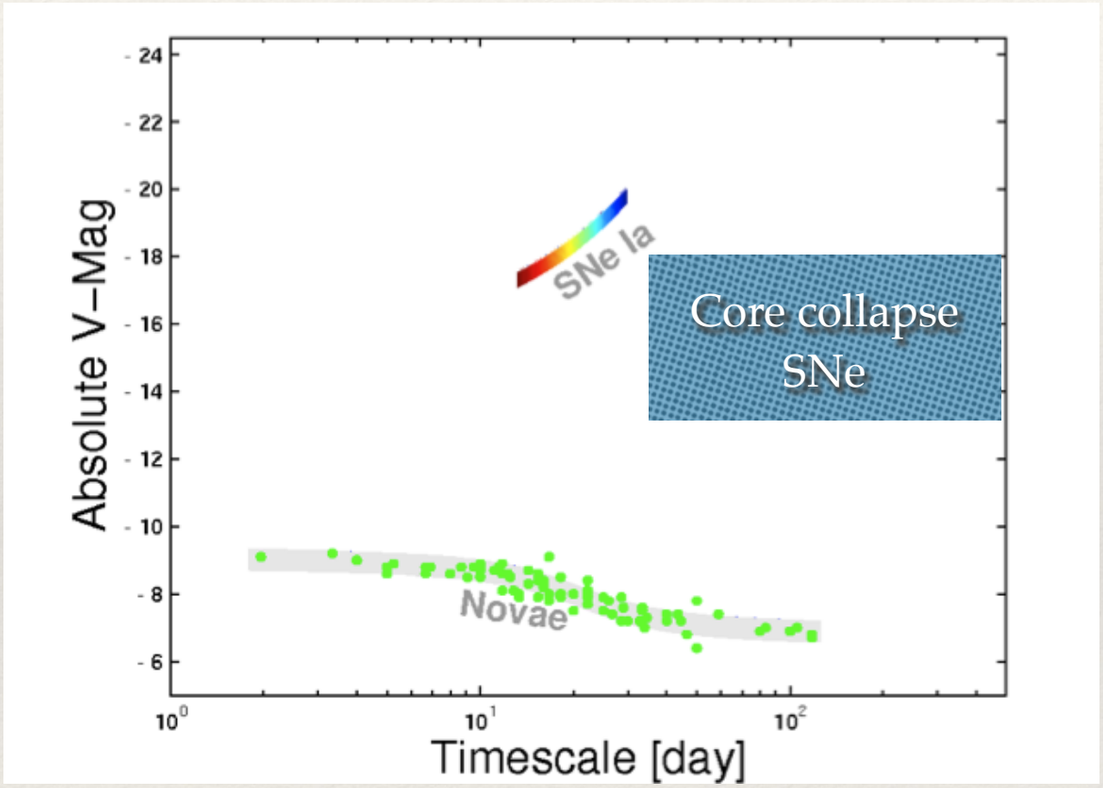
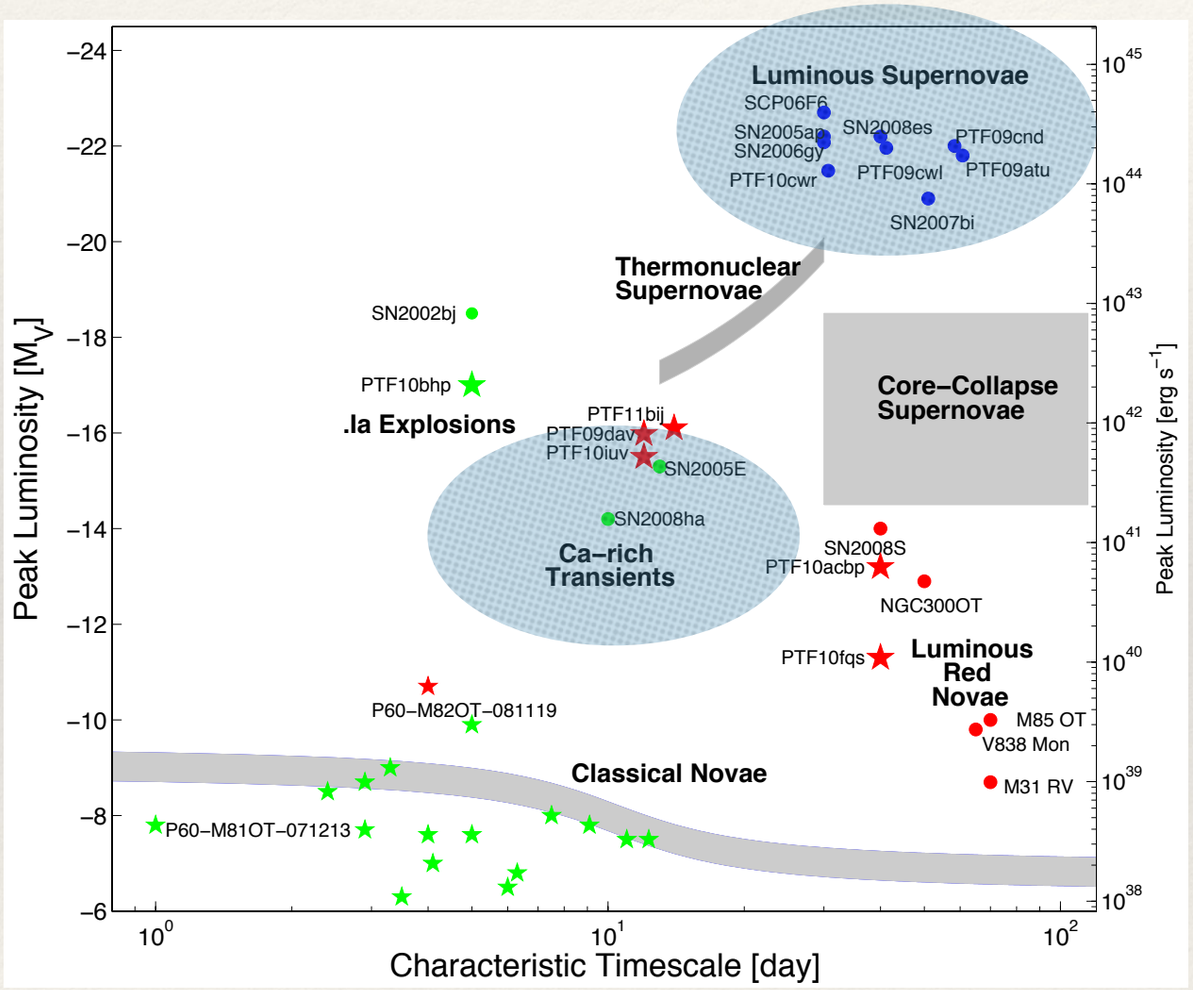
OSSERVATORIO ASTRONOMICO DI BRERA

The beginning



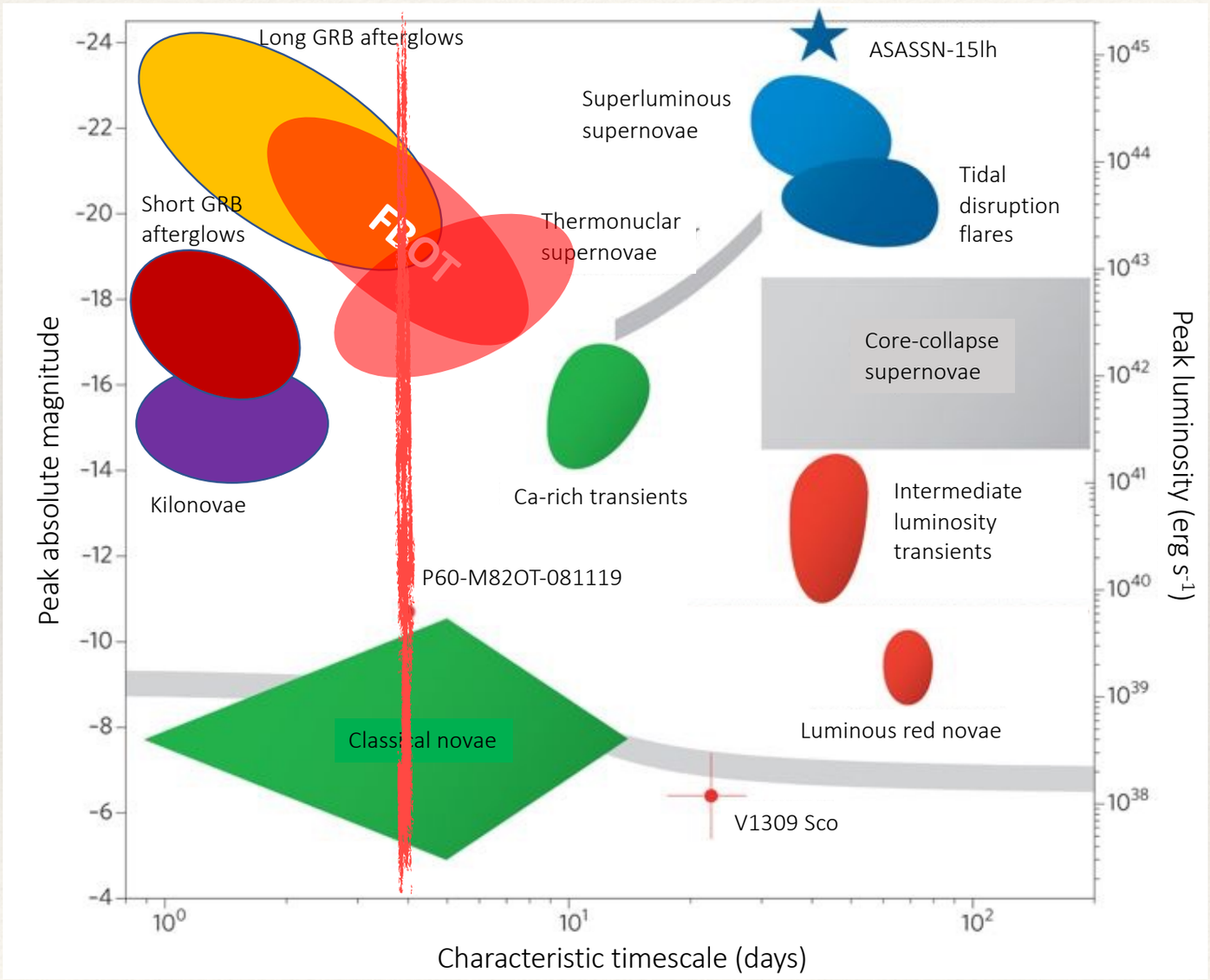
Transient astronomy at the Zwicky's time (~1930)

First time-domain optical surveys



Catalina
QUEST
PTF
Skymapper
Pan-STARRS

Nowadays



Wide-angle,
high-cadence surveys

ZTF
ATLAS
ASASN-SN

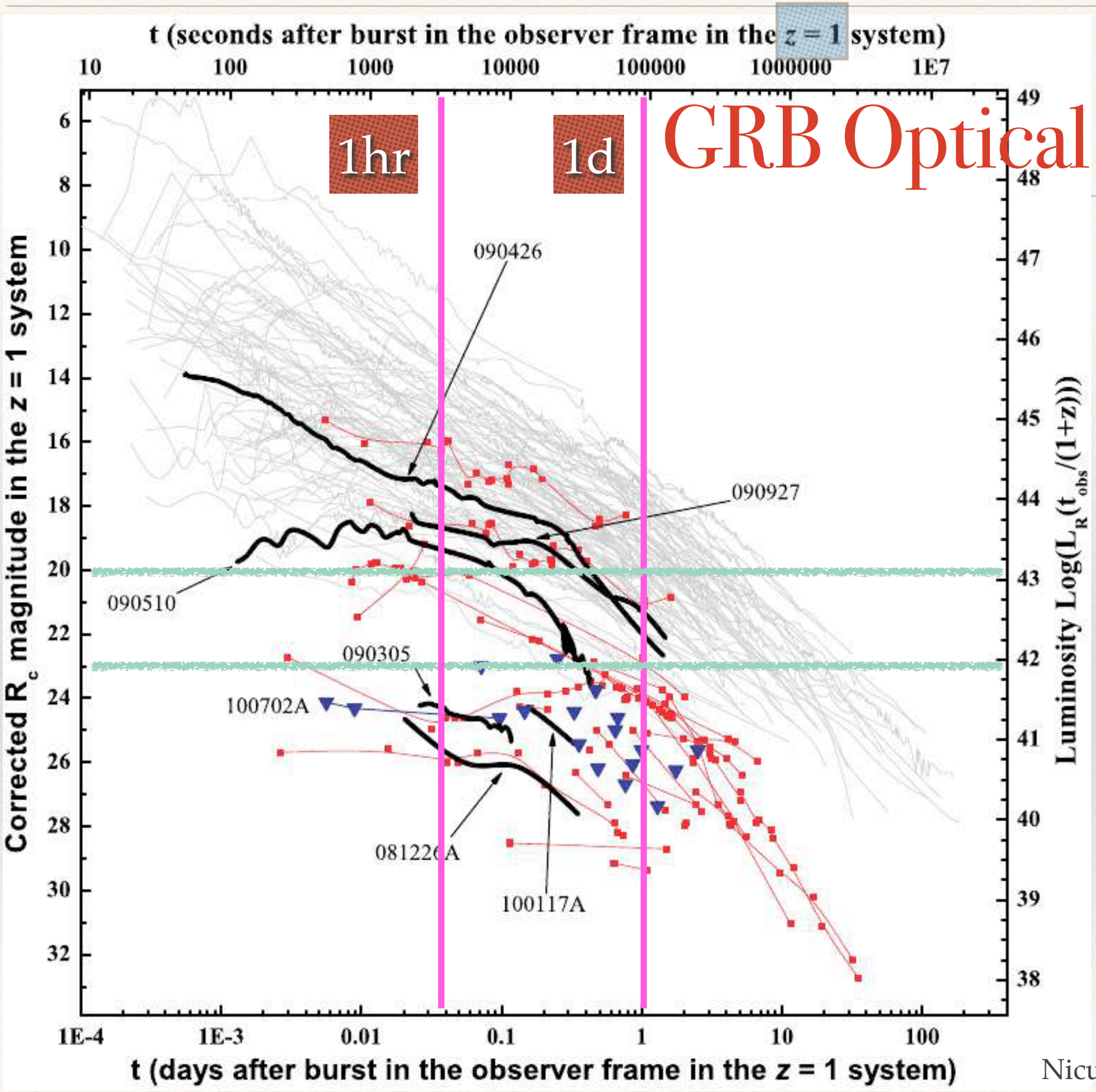
…

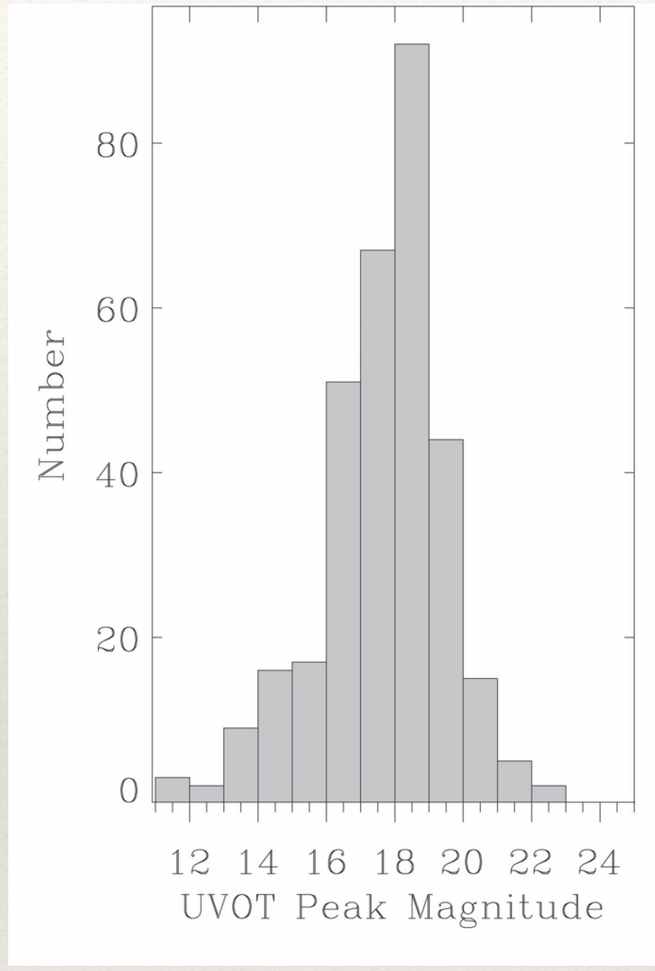
ULTRASAT
Rubin/LSST

The case for fast-evolving transients

- Long-duration GRBs (collapse of massive stars, with a jet pointing toward us) & Shock breakout
- Short-duration GRBs (merger of NS-NS binary systems -or NS-BH- with a jet pointing toward us)
- GW-kilonovae (merger of NS-NS binary systems -or NS-BH- signalled by GW emission)
- FBOT (fast blue optical transients)

GRB Optical light curves



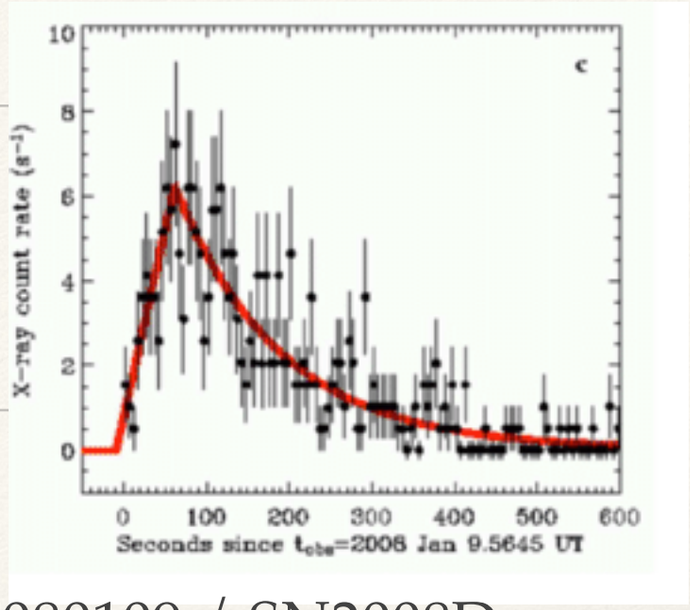


Roming et al. 2019

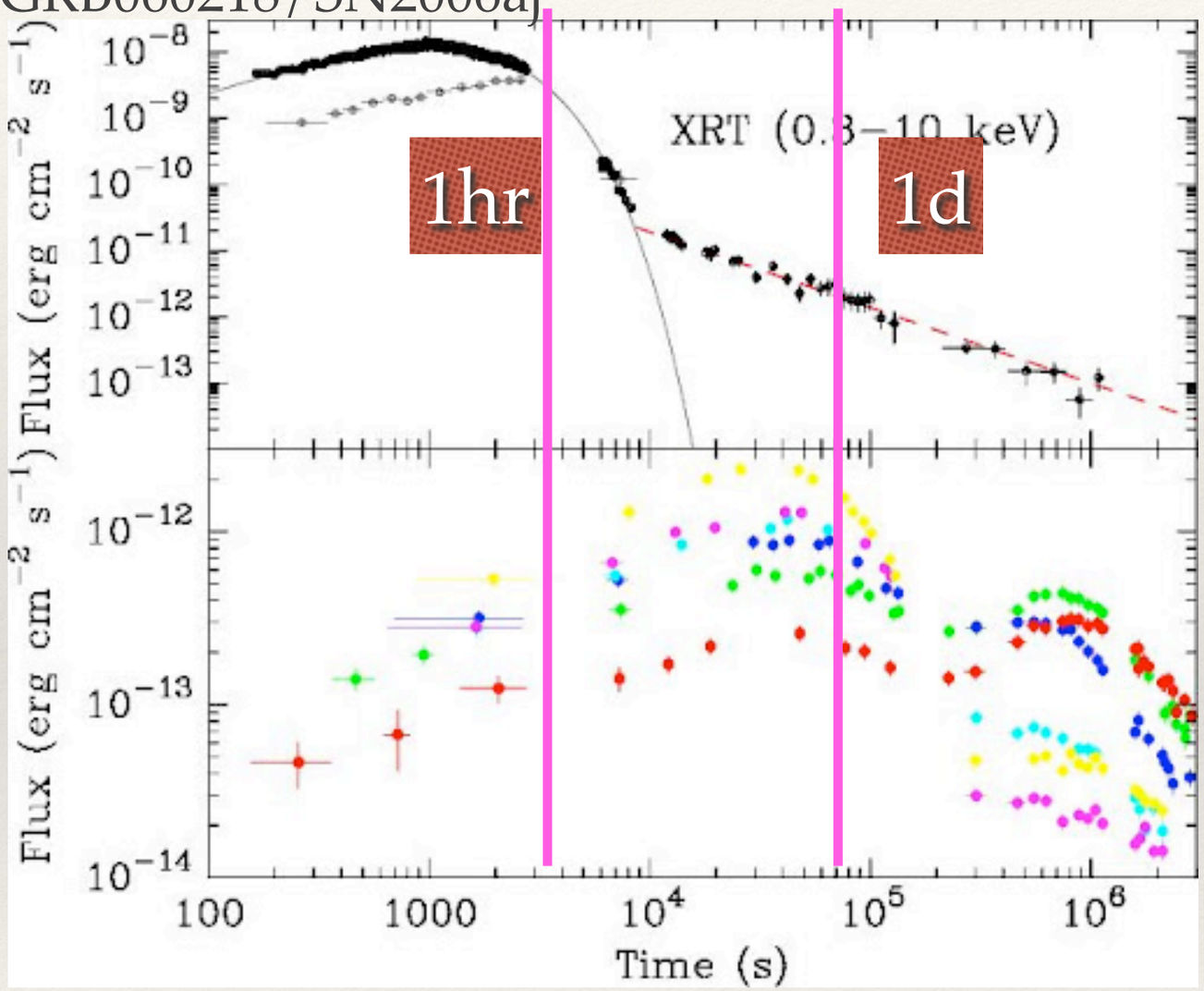
Kann et al. 2010

Nicuesa Guelbenzu et al. 2012

Shock BreakOut

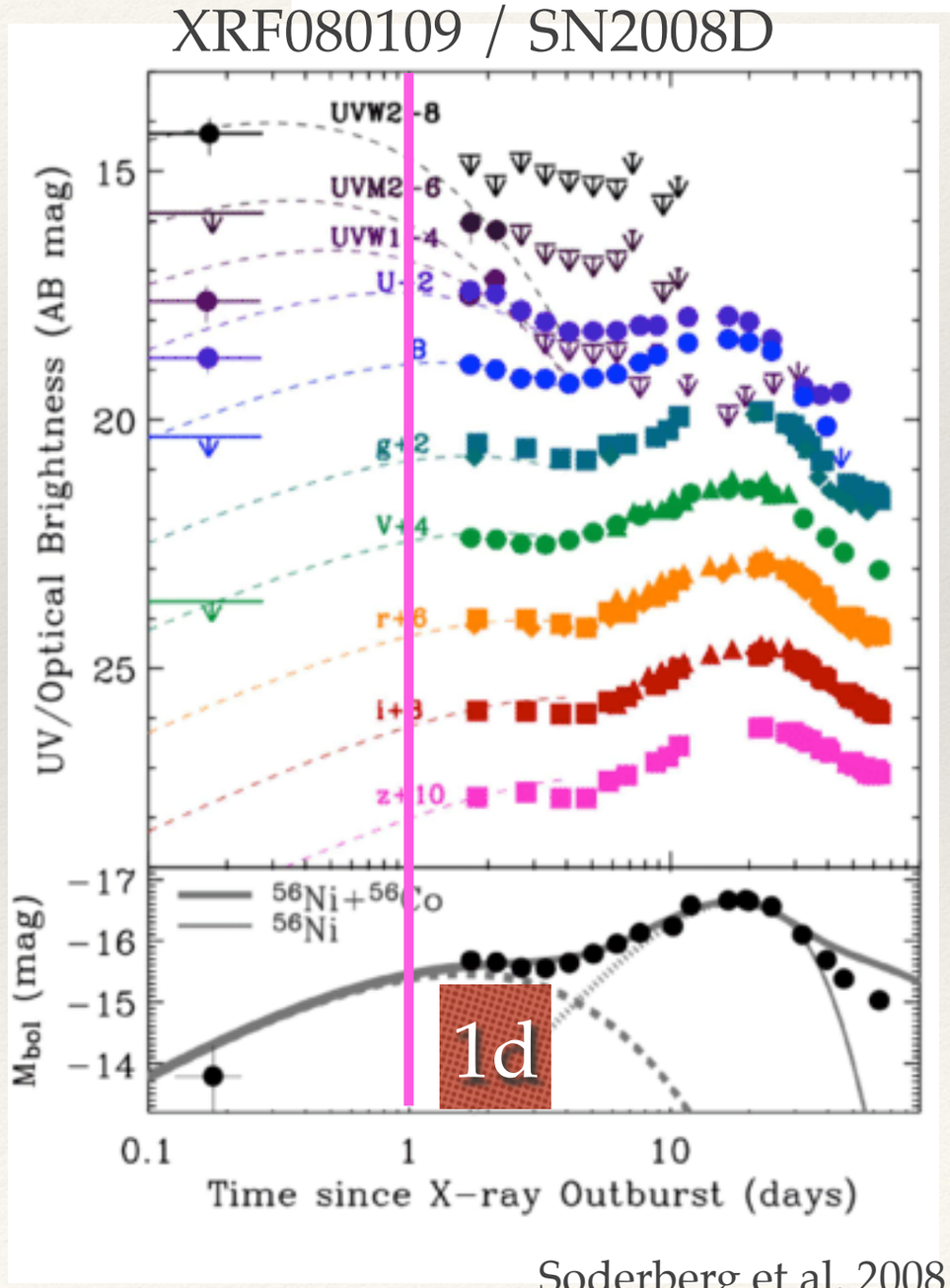


GRB060218/SN2006aj



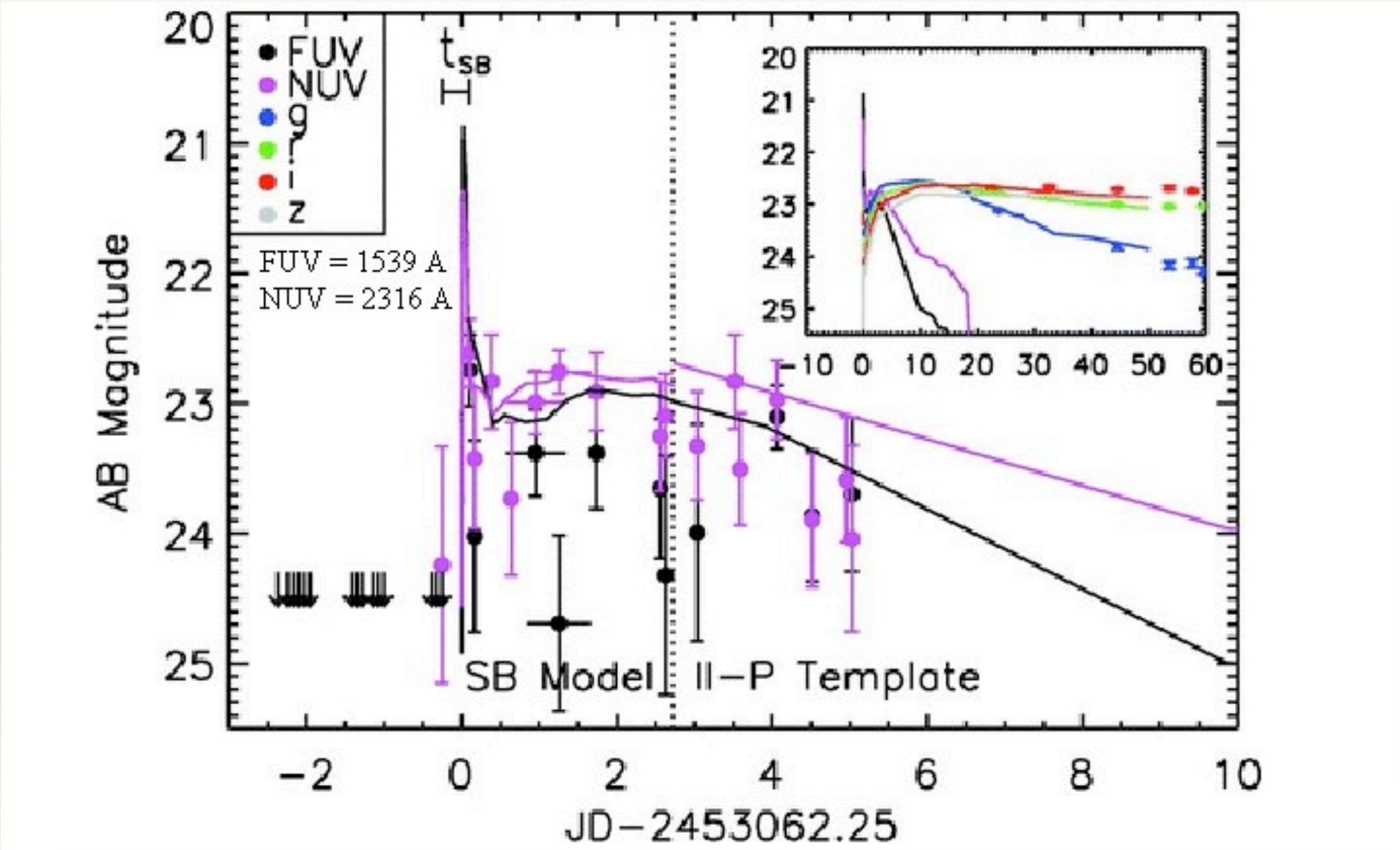
Campana et al. 2006

XRF080109 / SN2008D



Soderberg et al. 2008

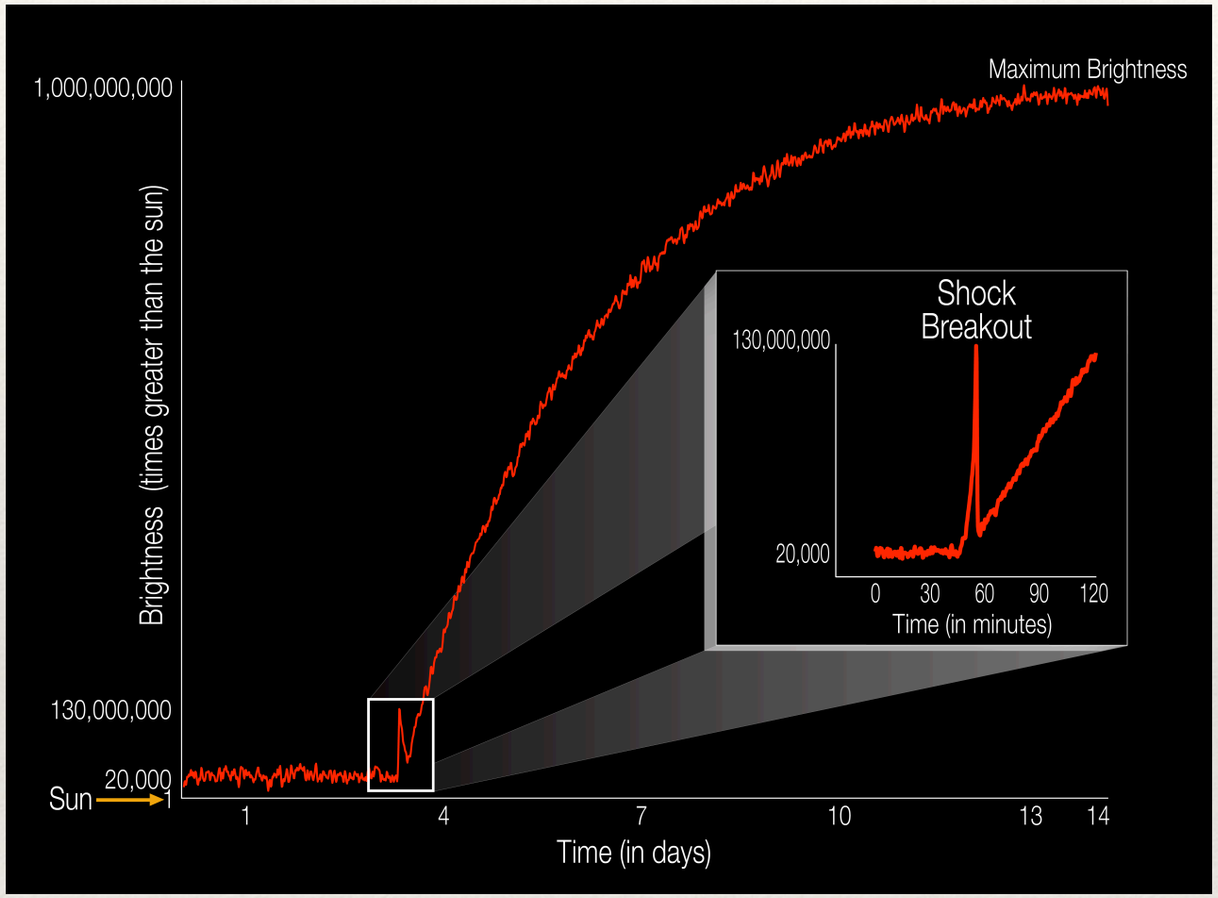
SBO cooling tails in UV



Gezari et al. 2008

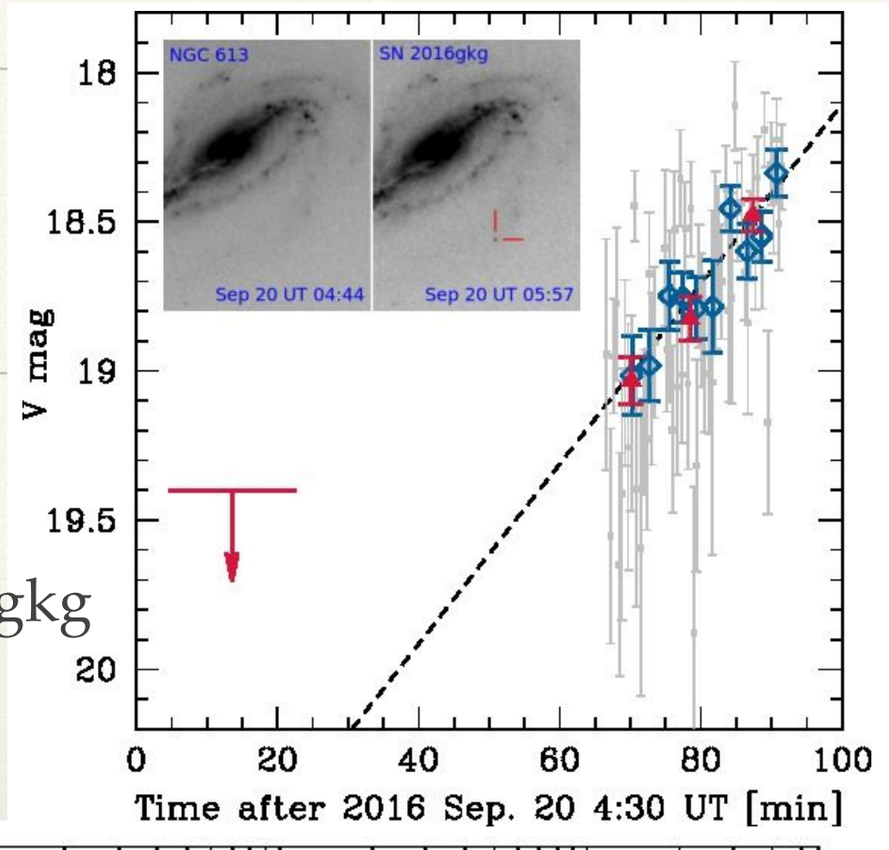
More recent SBOs

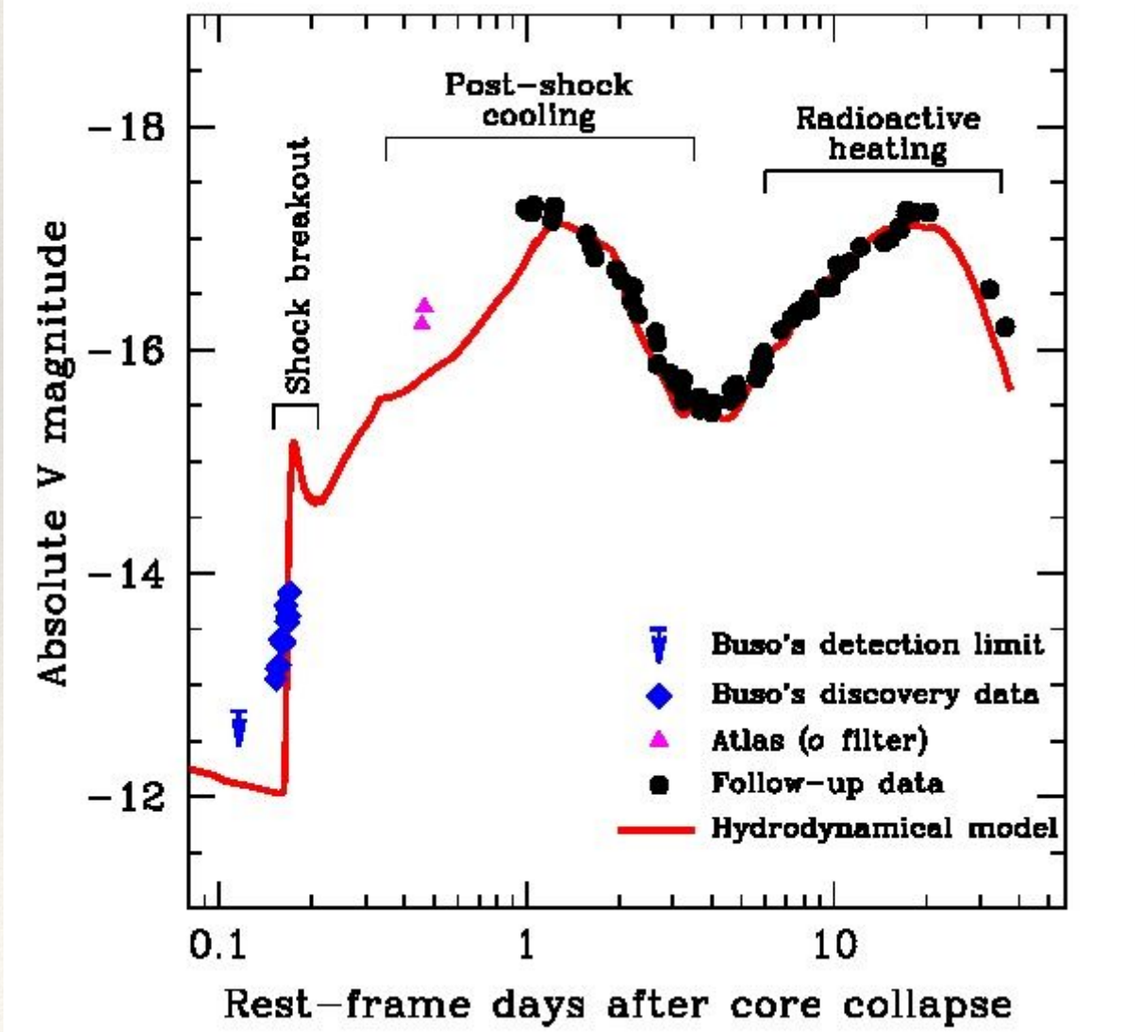
KSN2011d



Garnavitch et al. 2011

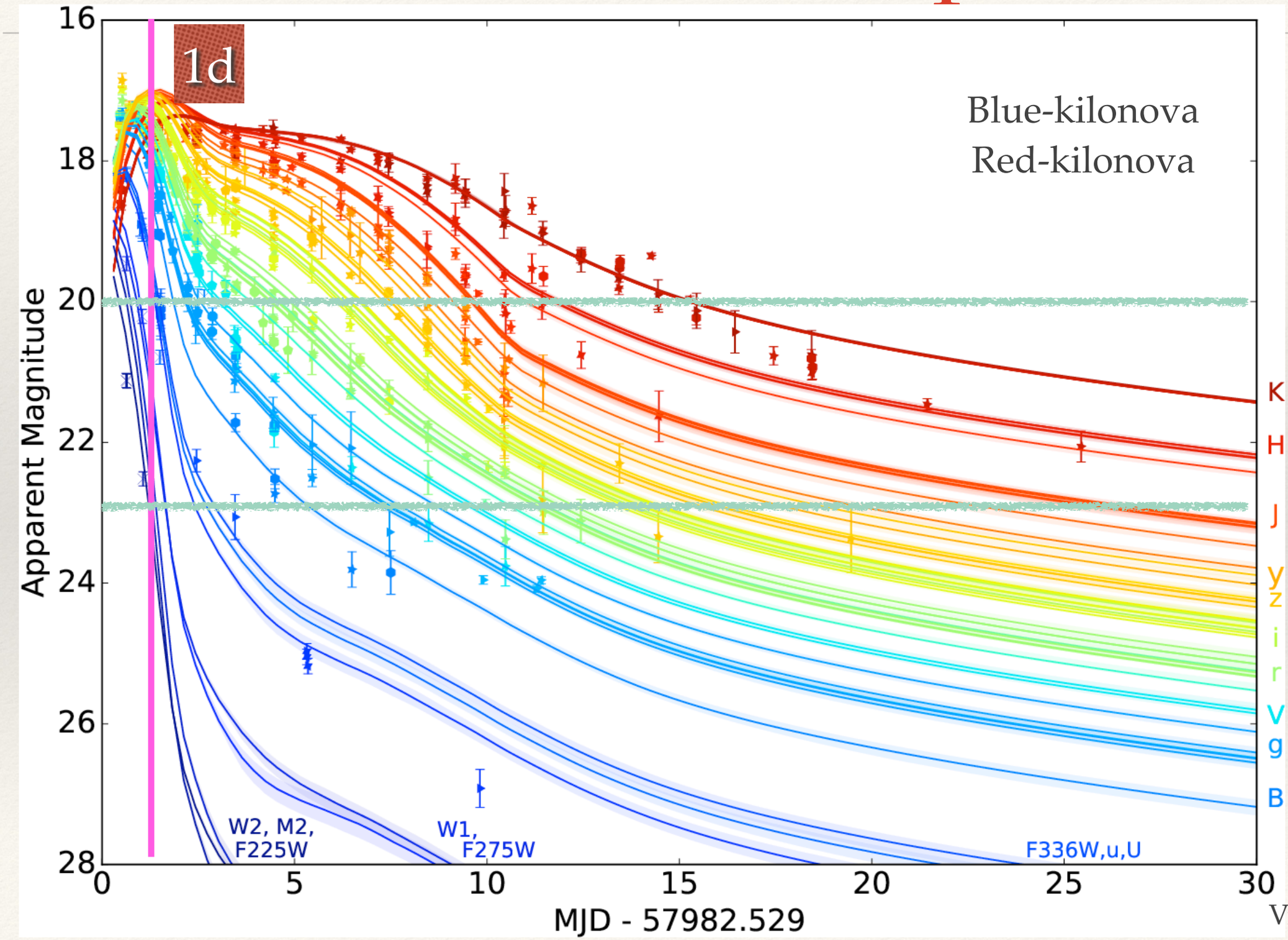
SN2016gkg





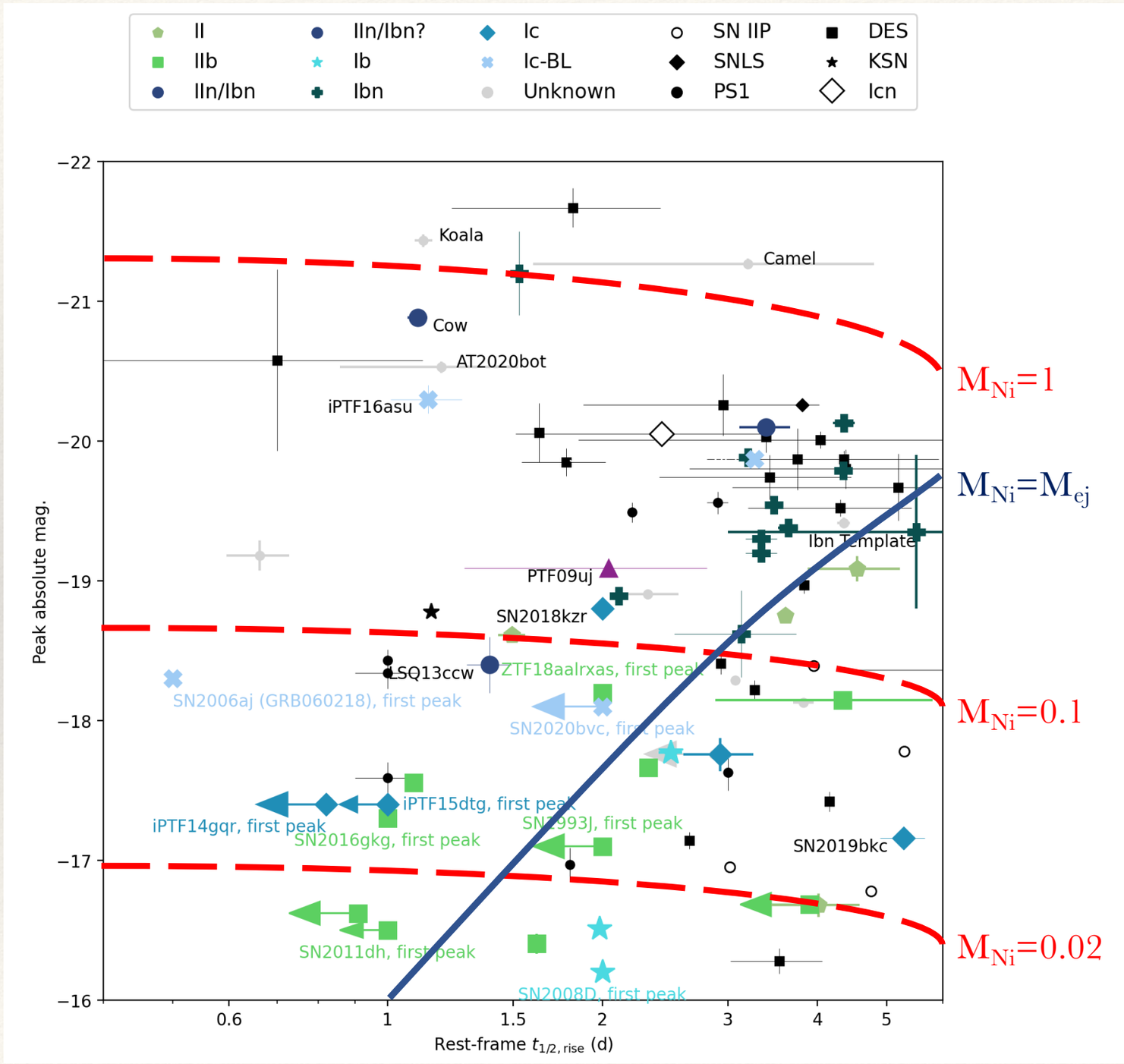
Bersten et al. 2018

GW170817: UV-optical-nIR



Villar et al. 2017

Fast Blue Optical Transients



Ho et al. 2021 (adapted)

FBOT

What are they?

- SNe (or failed SNe) of massive stripped stars
  (e.g. Drout+ 2013, Tauris+ 2013, 2015, Kleiser & Kasen 2014, Kazumi & Quataert 2015, Suwa+ 2015…)

- Breakout of a SN shock from a dense wind or extended progenitor
  (e.g. Ofek+ 2010, Drout+ 2014, Pastorello+ 2015, Shivvers+ 2016, Arcavi+ 2017, Tanaka+ 2016, Rest+ 2018)

- Cooling envelope emission from radially extended red supergiants
  (e.g. Drout+ 2014, Tanaka+ 2016)

?

- Prolonged energy injection from:
  - Millisecond magnetar (e.g. Gao+ 2013, Yu+ 2013, Metzger & Piro 2014, Hotokezaka+ 2017)
  - Accreting neutron star (e.g. Margalit & Metzger 2016)
  - Accreting black hole (e.g. Kashiyama & Quataert 2015, Strubbe & Quataert 2009, Cenko+ 2012)

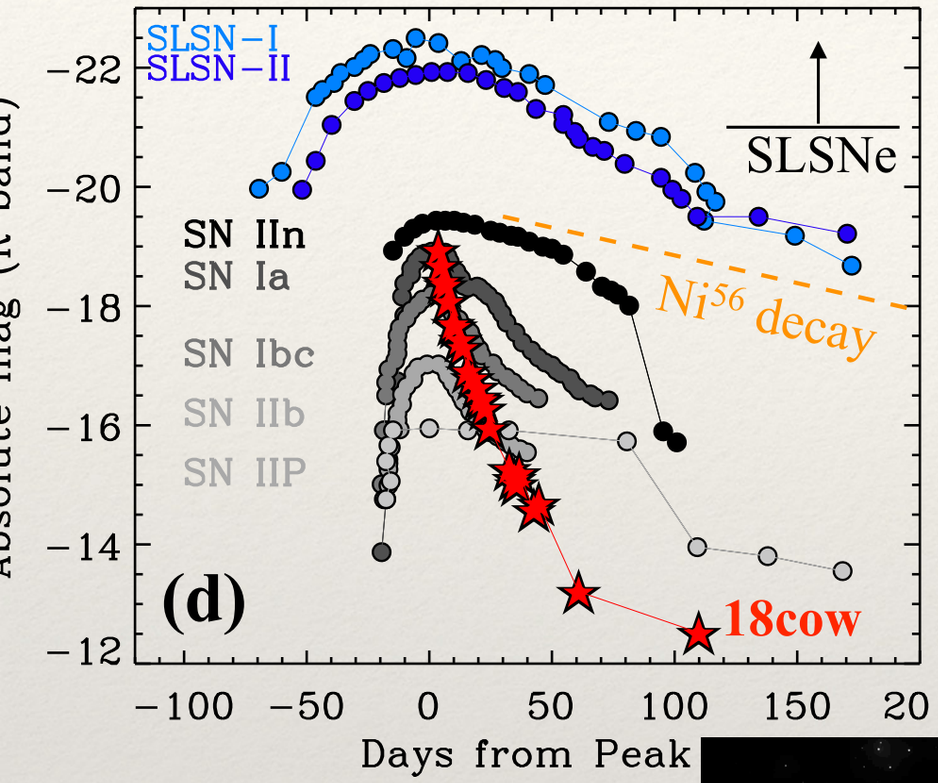
- Detonation of a helium shell on a white dwarf (e.g. Shen+ 2010, Perets+ 2010)

- Shockwave afterglows from GRBs (Cenko+ 2013, 2015, Stalder+ 2017; Bhalerao+ 2017)

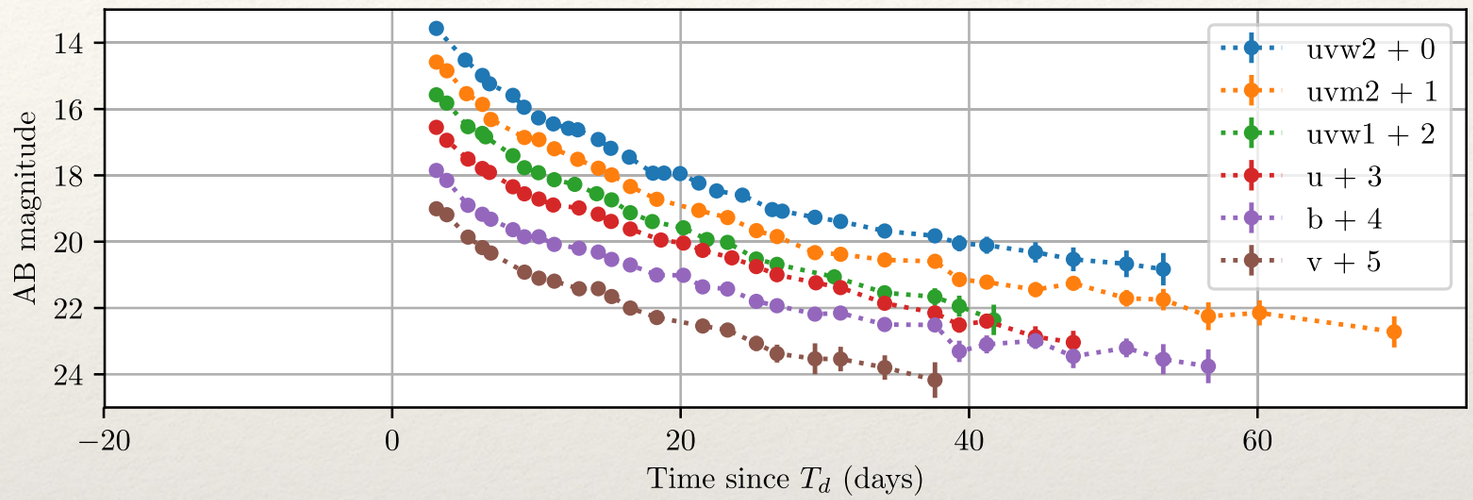
2

from Coppejans talk

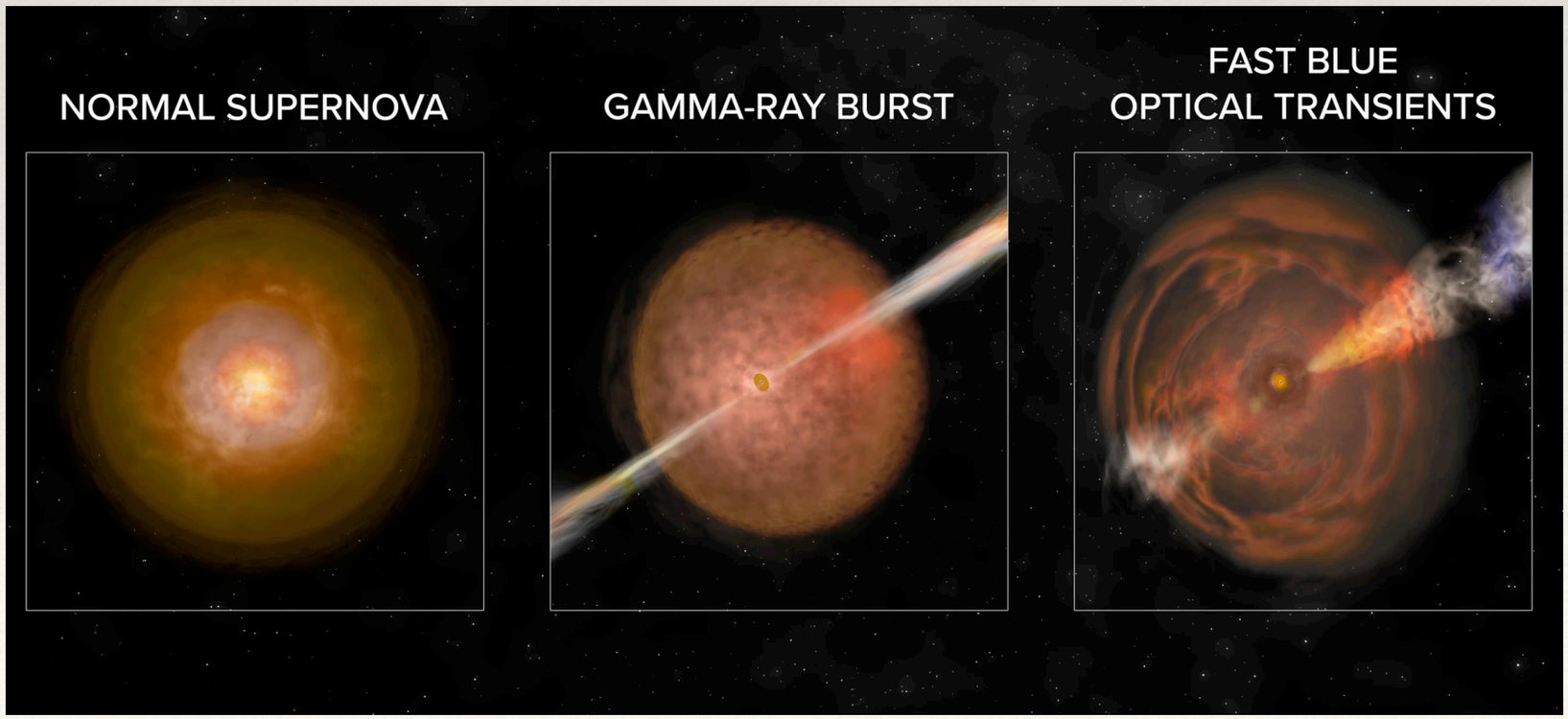
The Cow at optical wavelenghts



Margutti et al. 2019



Kuin et al. 2019

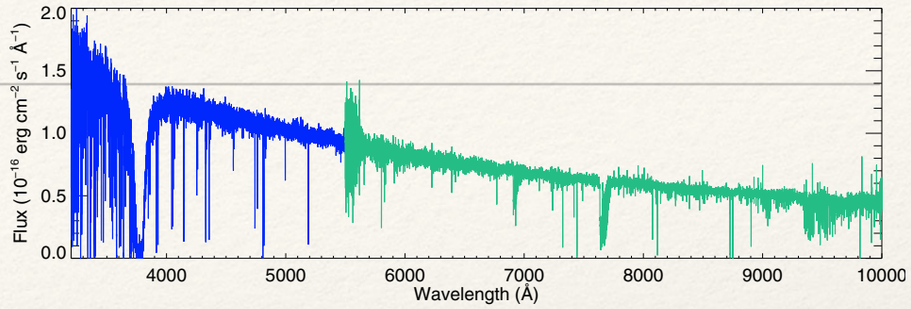


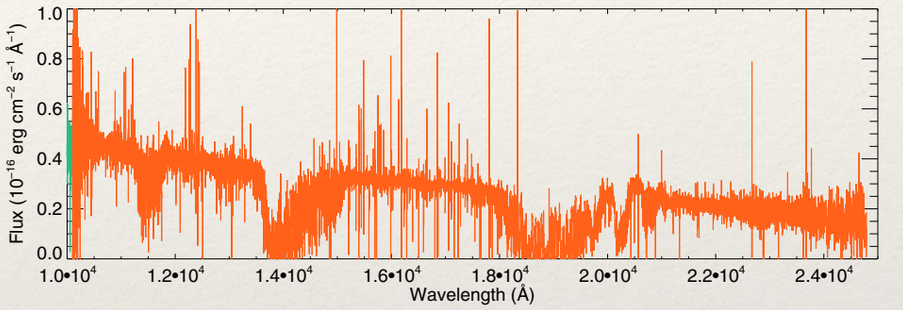
Coppejans et al. 2021

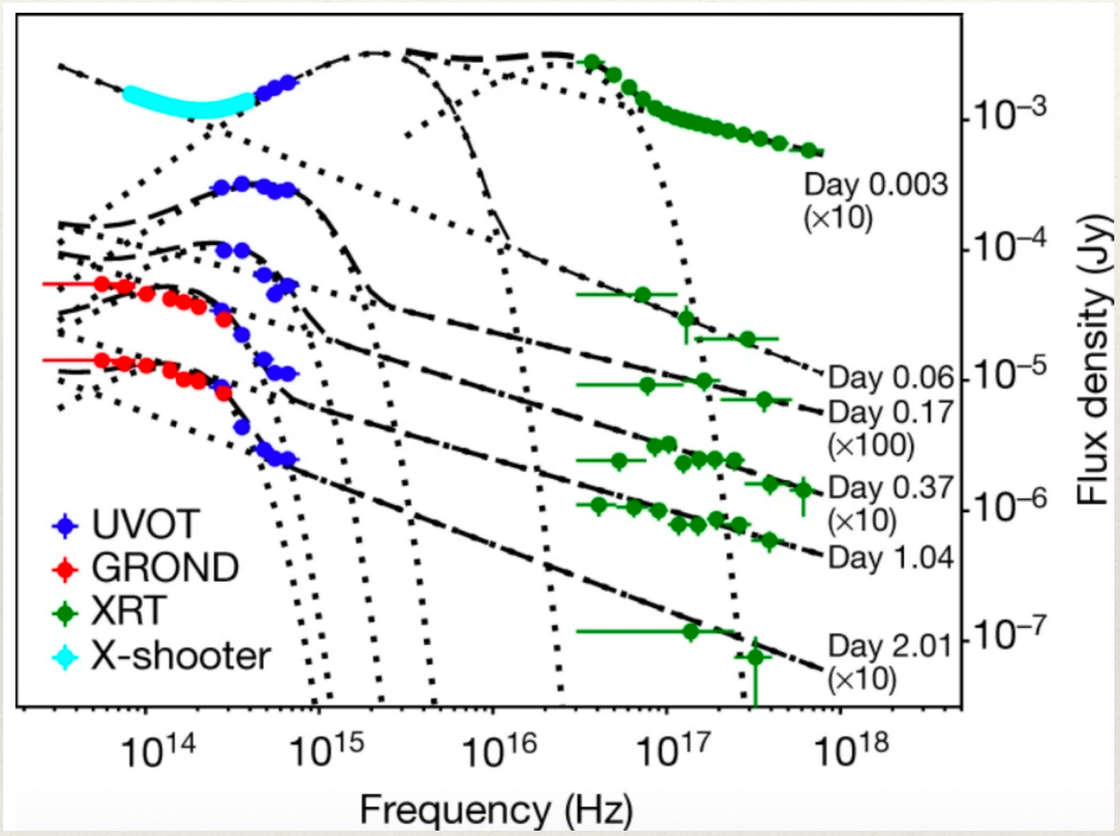
…and finally the spectra

Long GRBs

normally just a few absorption lines from the ISM and sometimes emission lines from the host

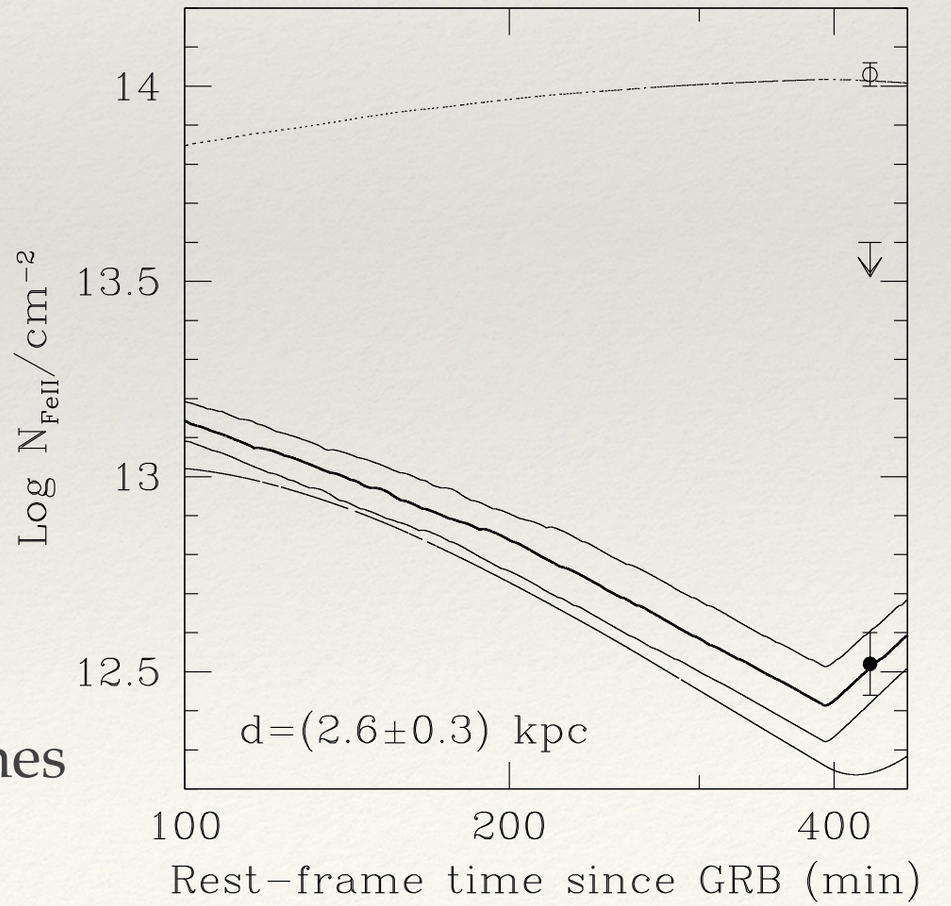






Early observations found evidence for a cocoon in a closely GRB-SN

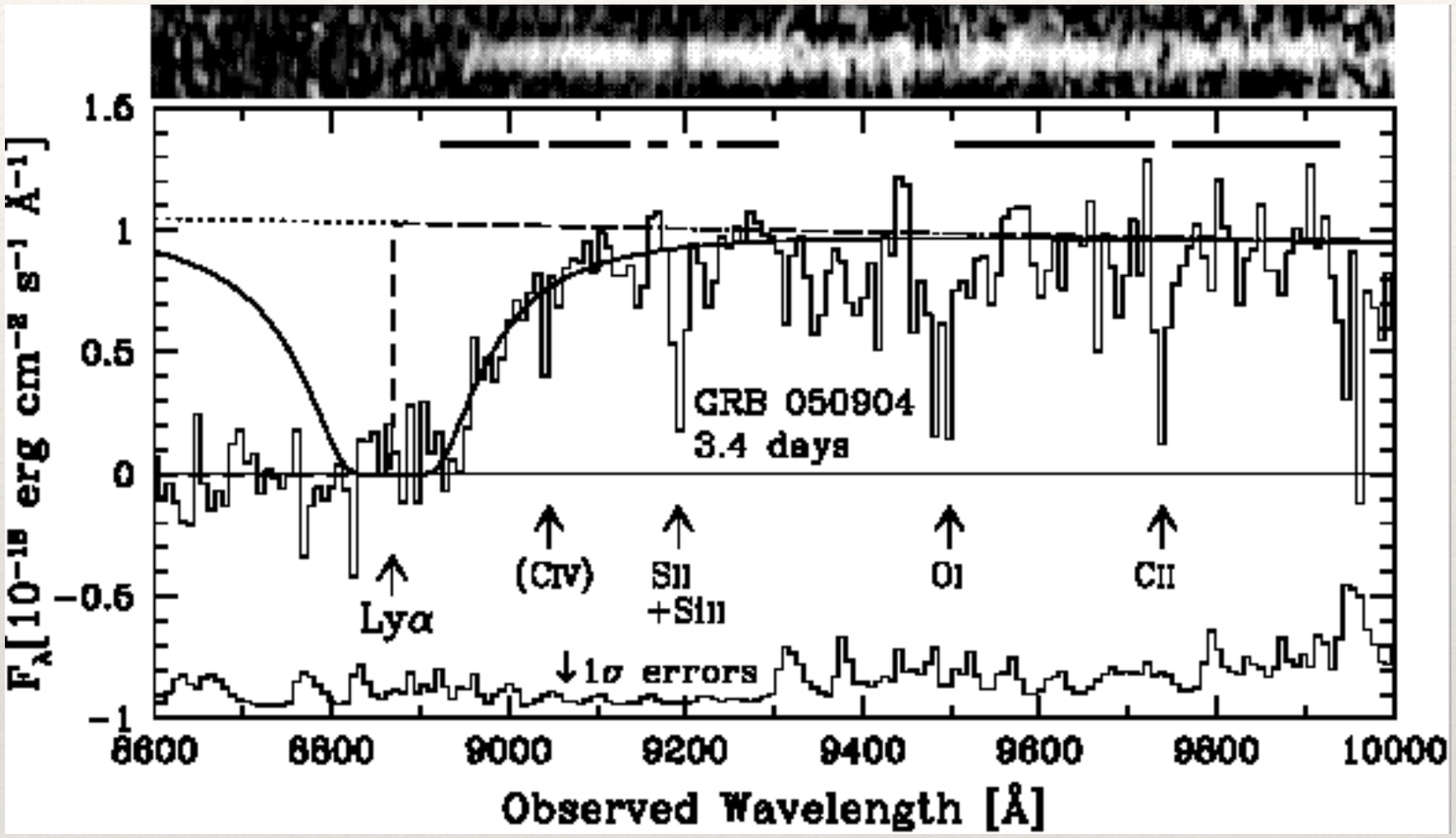
Izzo et al. 2019



Fine structures lines

D'Elia et al. 2010

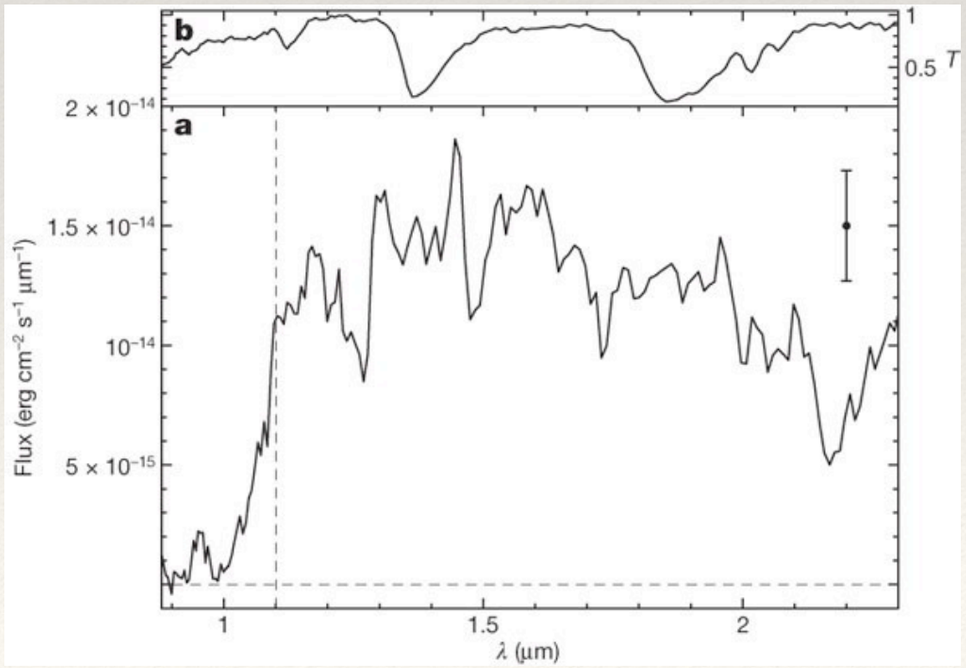
and if you are lucky .. high-z GRB



Totani et al. 2006

GRB050904 @ Subaru z=6.3

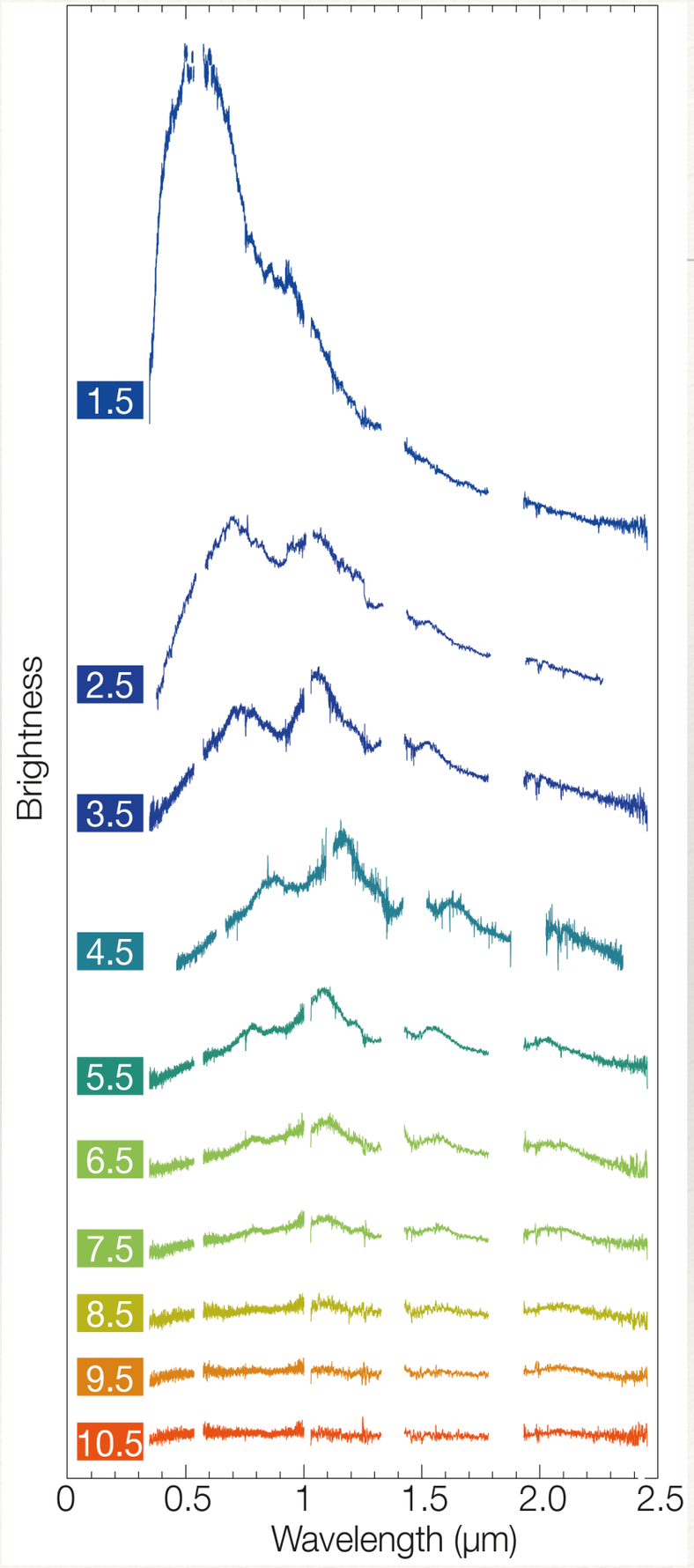
GRB090423 @ TNG z=8.2



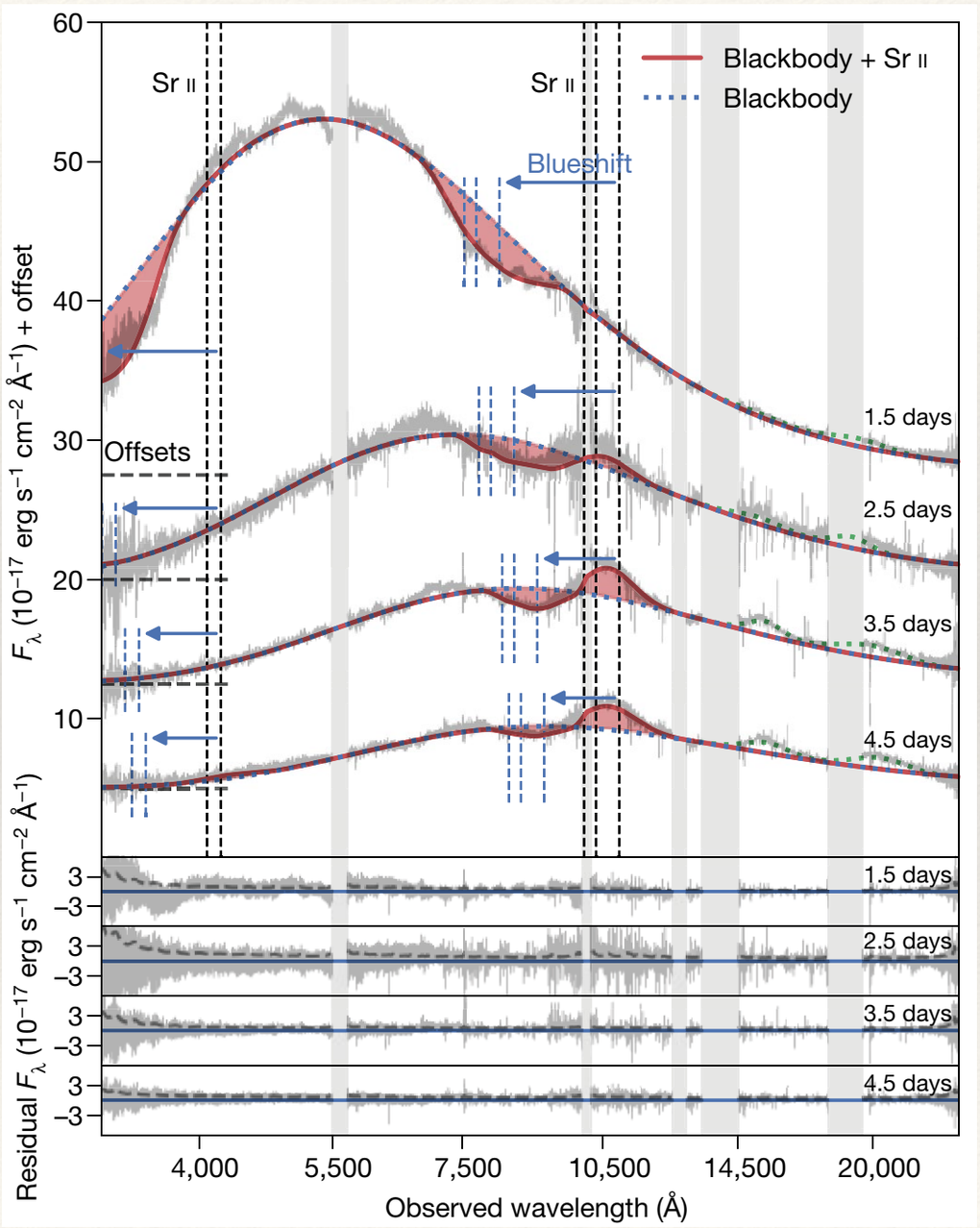
Salvaterra et al. 2009

Short GRB & SBO

GW spectra

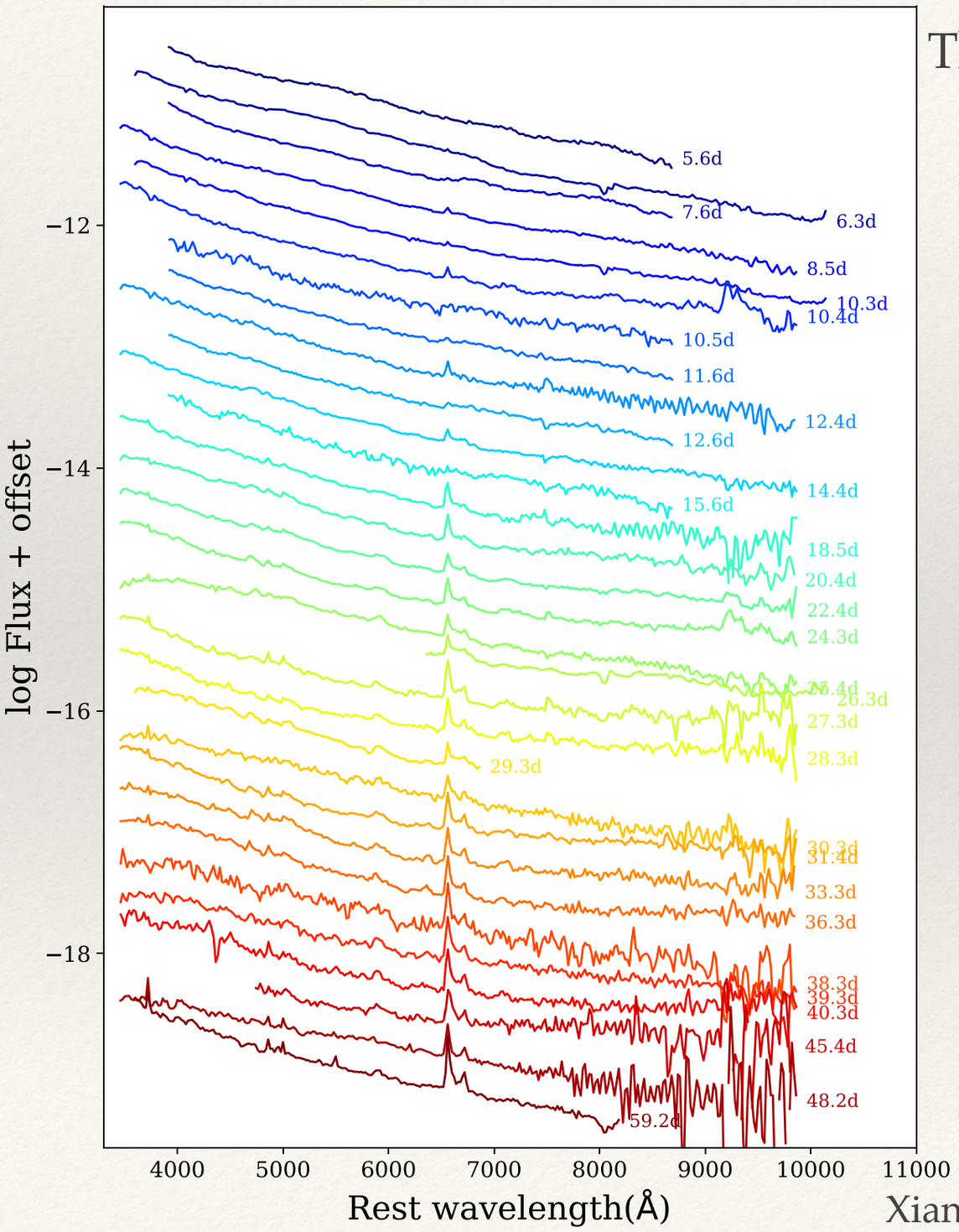


Pian, D'Avanzo et al. 2017
Smartt et al. 2017



Watson et al. 2019

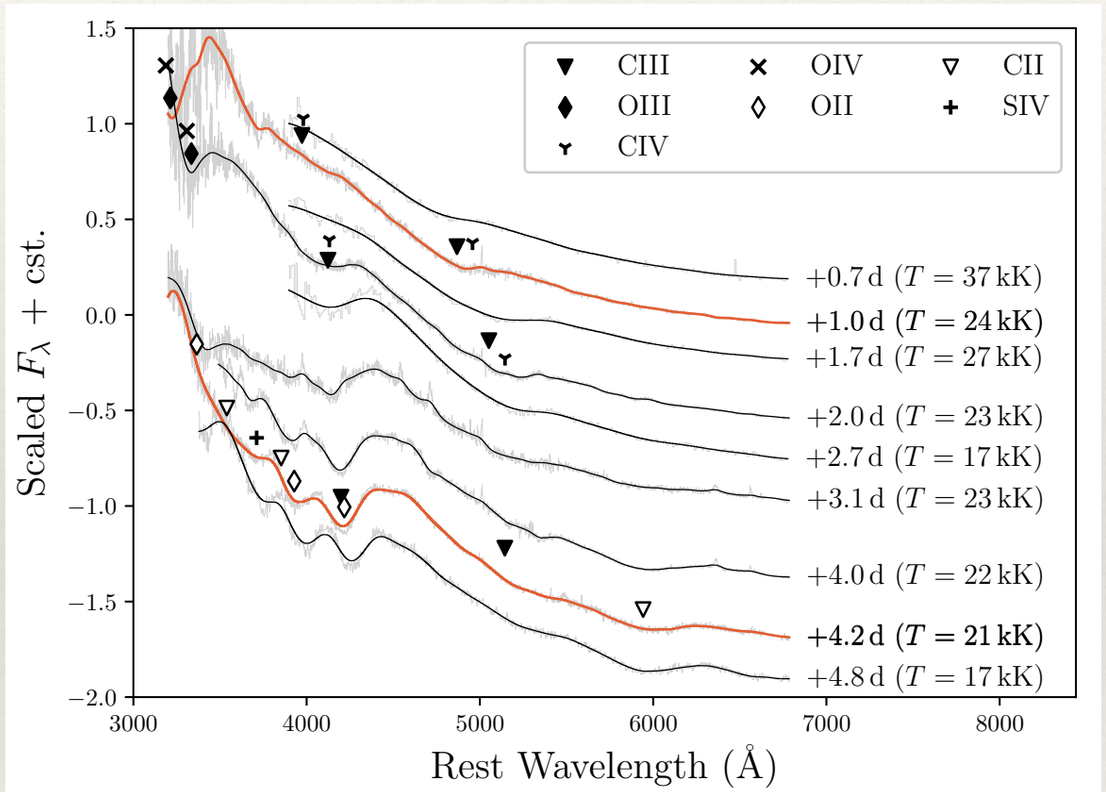
FBOT spectra



The cow

Xiang et al. 2021

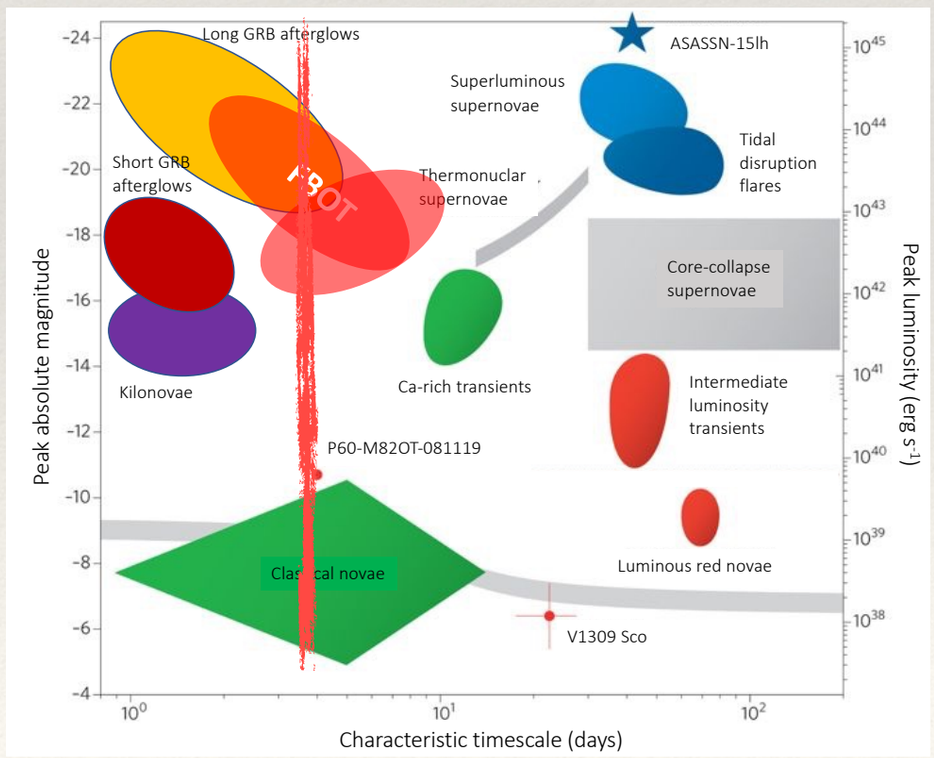
SN2018gep Type Ic-BL



Ho et al. 2019

How can we improve in the near future?

- On one side we will soon have ULTRASAT and Rubin/LSST
- How can we exploit their alerts in the best way?



ESO/VLT

At ESO/Paranal the Rapid Response Mode (RRM) is active to be on source in ~10min

	Imaging	Spectroscopy
La Silla	EFOSC2 SUSI WFI SOFI	EFOSC2 HARPS FEROS SOFI
Paranal UT1	FORS2	FORS2 KMOS
Paranal UT2	VISIR	UVES UVES-FLAMES GIRAFFE VISIR
Paranal UT3	SPHERE-IRDIS SPHERE-ZIMPOL	X-SHOOTER SPHERE-IFS CRIRES
Paranal UT4	HAWK-I	MUSE
Paranal ICCF		ESPRESSO
Paranal VISTA	VIRCAM	4MOST
Paranal VST	OmegaCAM	
ELT	ELT	ELT
VLTI	GRAVITY MATISSE VisCalc CalVin	

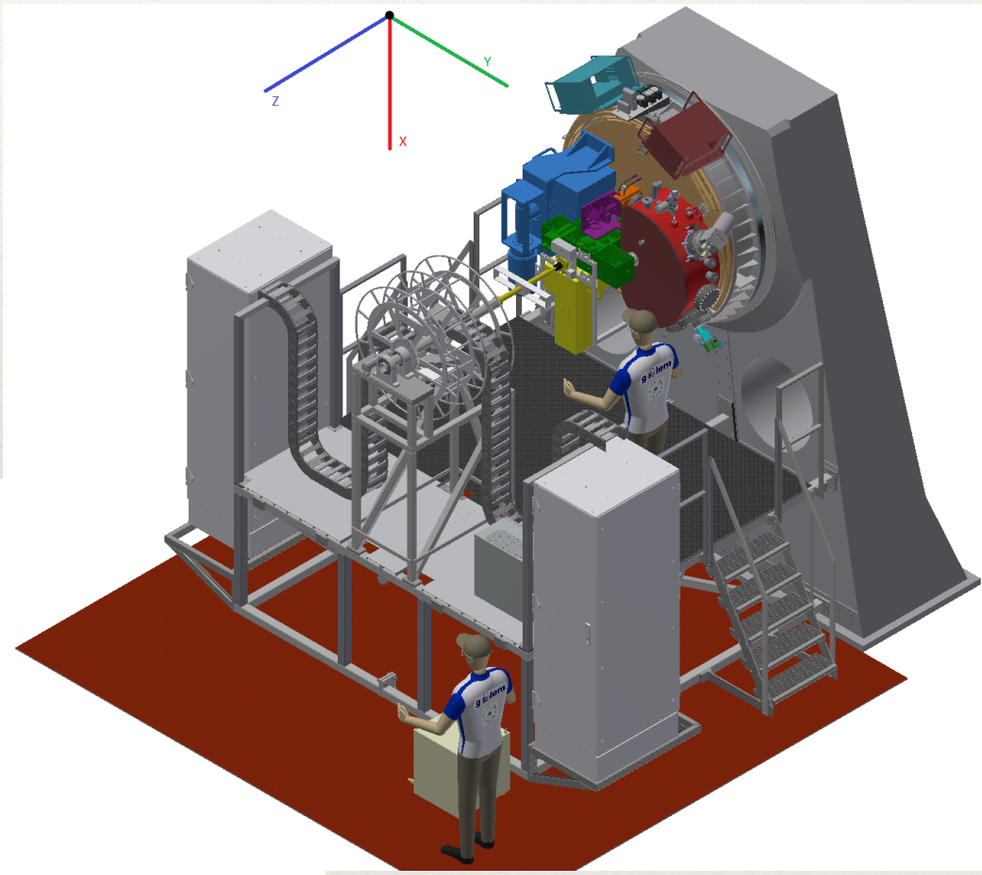
- Approved time
- Instrument mounted
- Have not finished the observing time

SOXS

ESO call for new instruments at NTT (06/2014)

Proposal submission (02/2015)

SOXS selected by ESO (05/2015) out of 19



Main characteristics

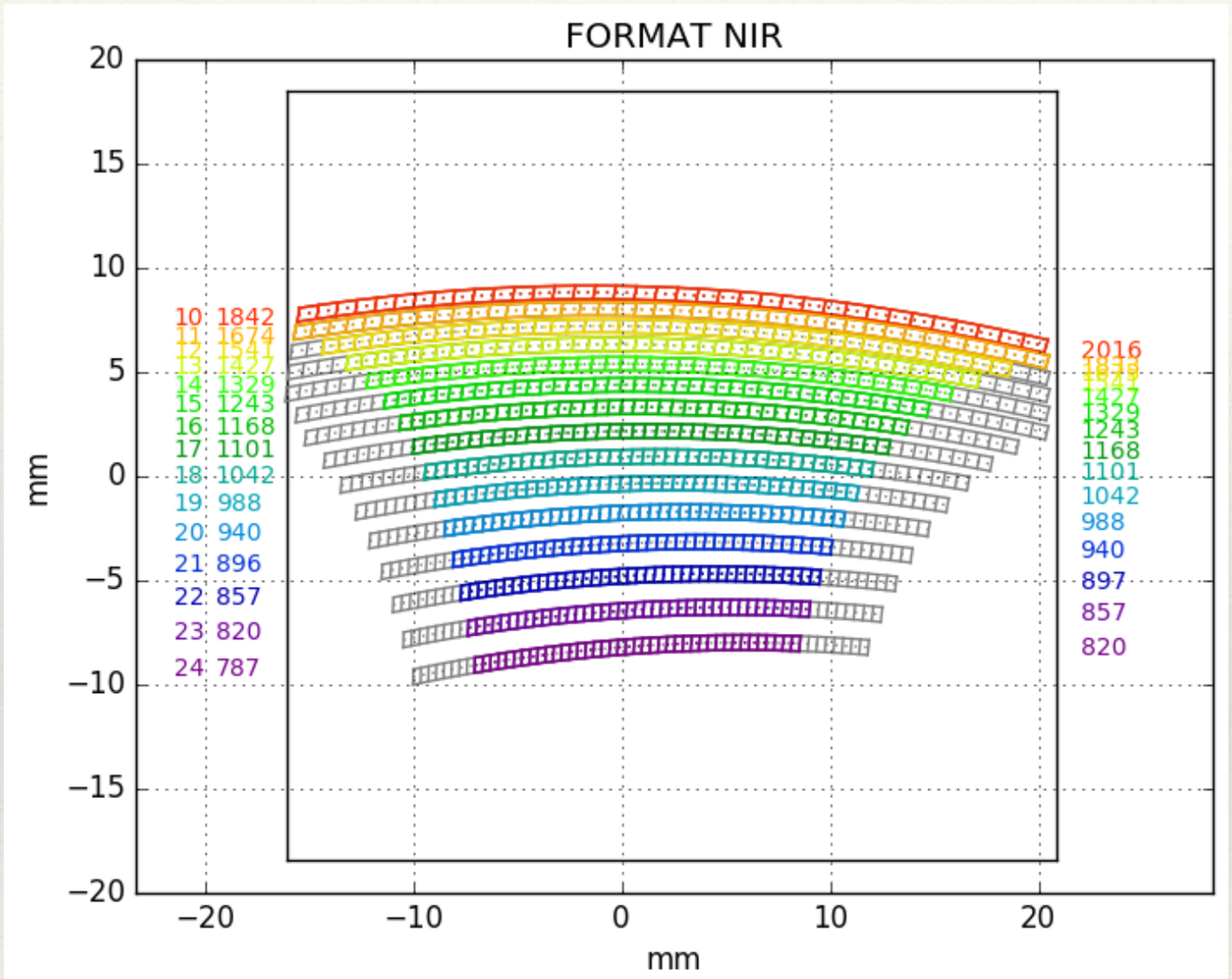
- Broad band spectrograph 350-2000 nm
- R~4,500 (4,000-6,000)
- Two arms (UV-VIS + NIR) 350-850 nm + 800-2000 nm
- Acquisition camera to perform photometry ugrizY (3.5'x3.5', 0.2" pixel)
- S/N~10 spectrum - 1 hr exposure $\mathbf{R_{AB}}$**~20.5**

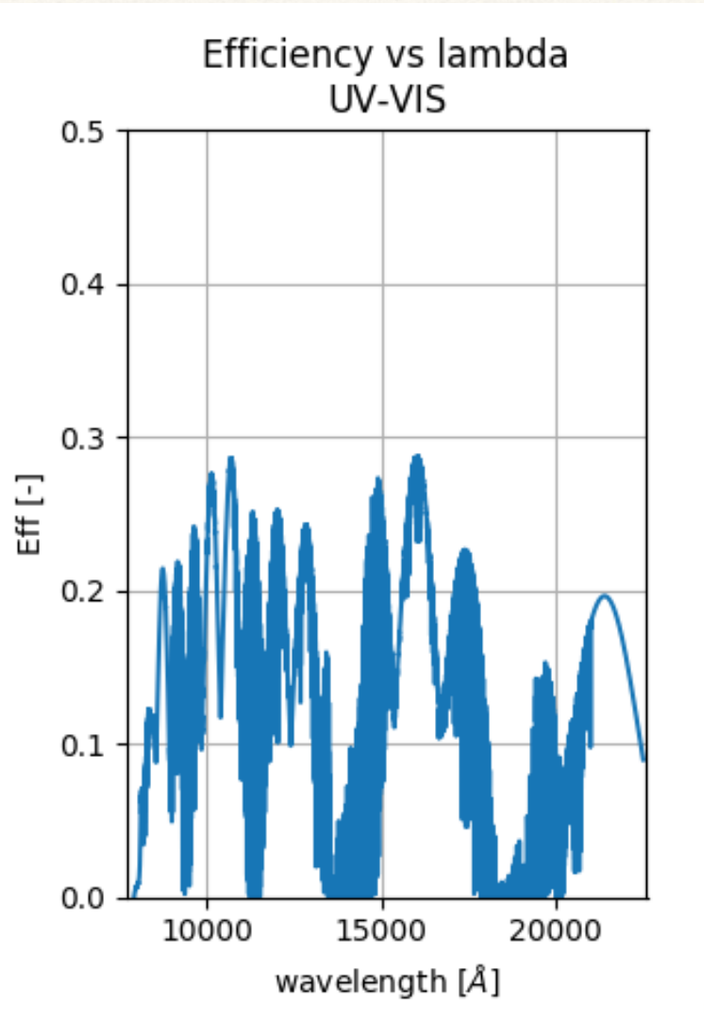
SoXS Consortium

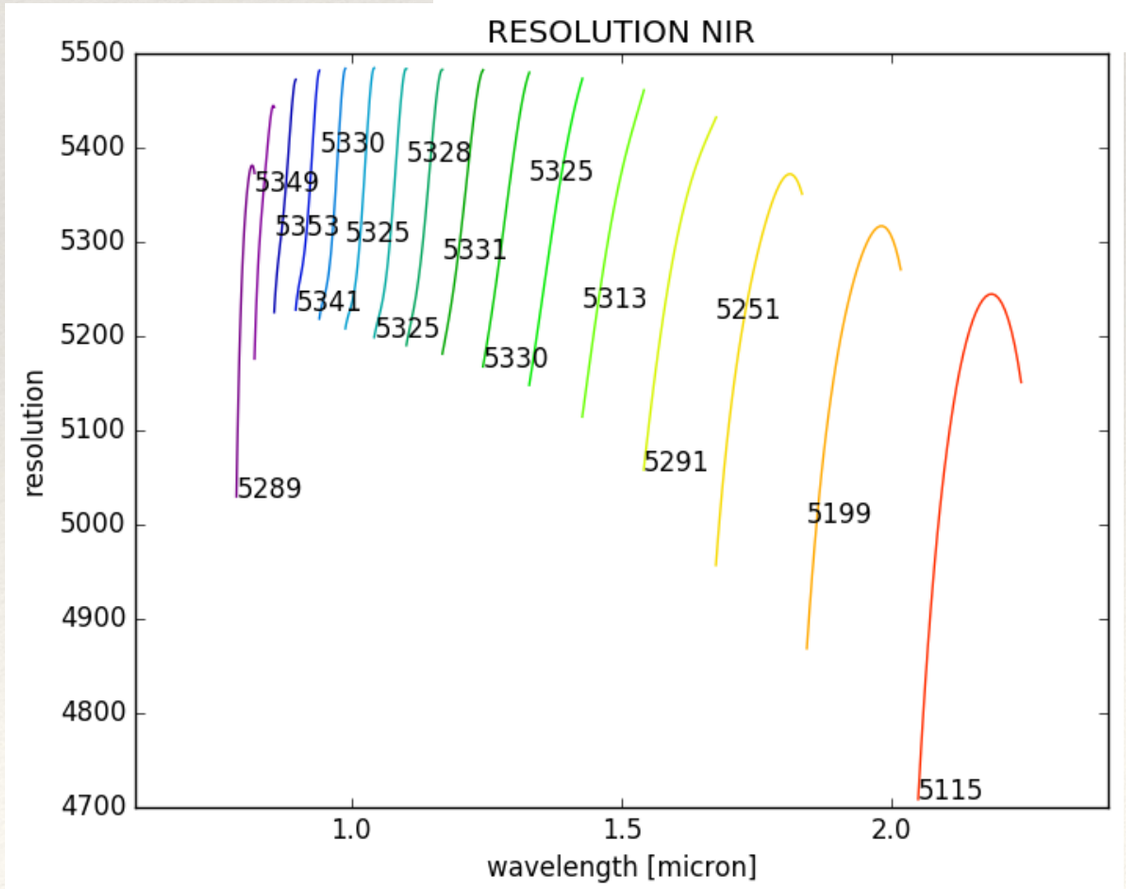
Institutes from 6 Countries

- Common Path, NIR Spectrograph, Control Software & Electronics, Vacuum and Cryogenics, Detectors control (INAF)
- UV/VIS Spectrograph (Weizmann)
- Acquisition Camera (Millennium Institute of Astrophysics - MAS)
- Calibration Unit (Turku University)
- Data Reduction (Queen's Un. Belfast)
- Tel Aviv University
- Neils Bohr Institute & Aarhus Univ.

SoXS NIR arm


FORMAT NIR
mm
mm
10 1842
11 1674
12 1541
13 1427
14 1329
15 1243
16 1168
17 1101
18 1042
19 988
20 940
21 896
22 857
23 820
24 787
2016
1873
1747
1427
1329
1243
1168
1101
1042
988
940
897
857
820

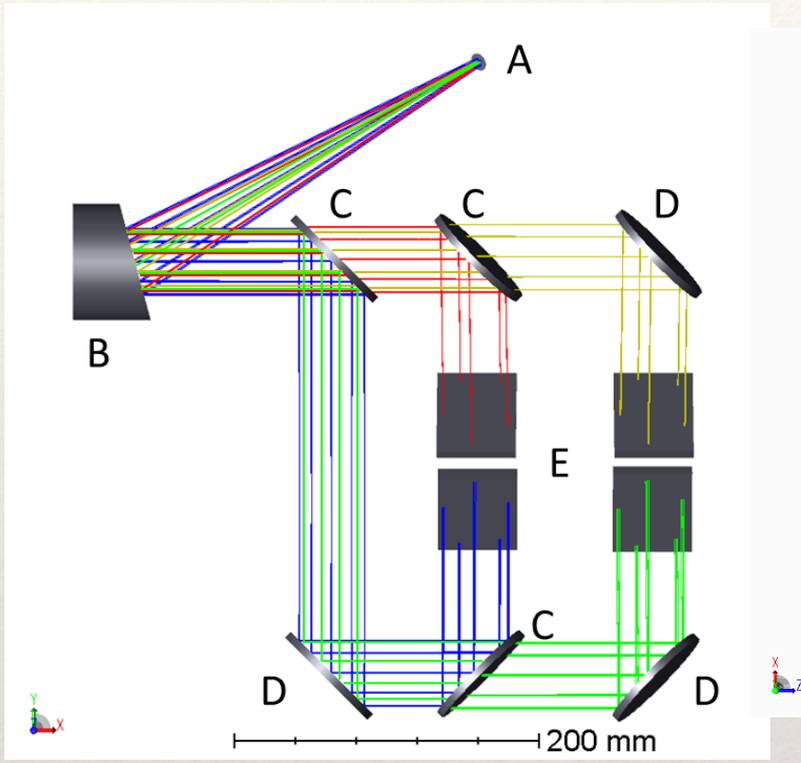

Efficiency vs lambda
UV-VIS
Eff [-]
wavelength [Å]

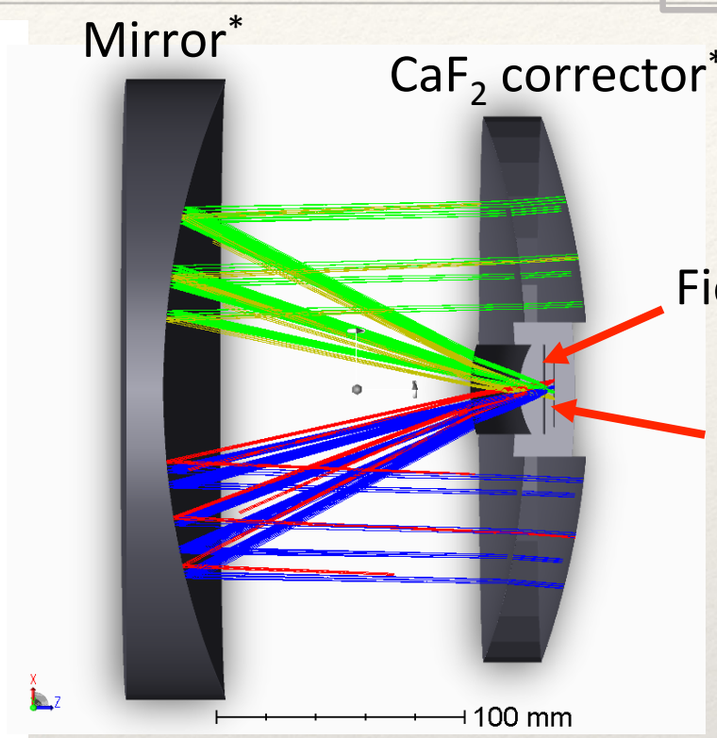

RESOLUTION NIR
resolution
wavelength [micron]
5289
5349
5353
5341
5330
5325
5328
5325
5331
5330
5325
5313
5291
5251
5199
5115

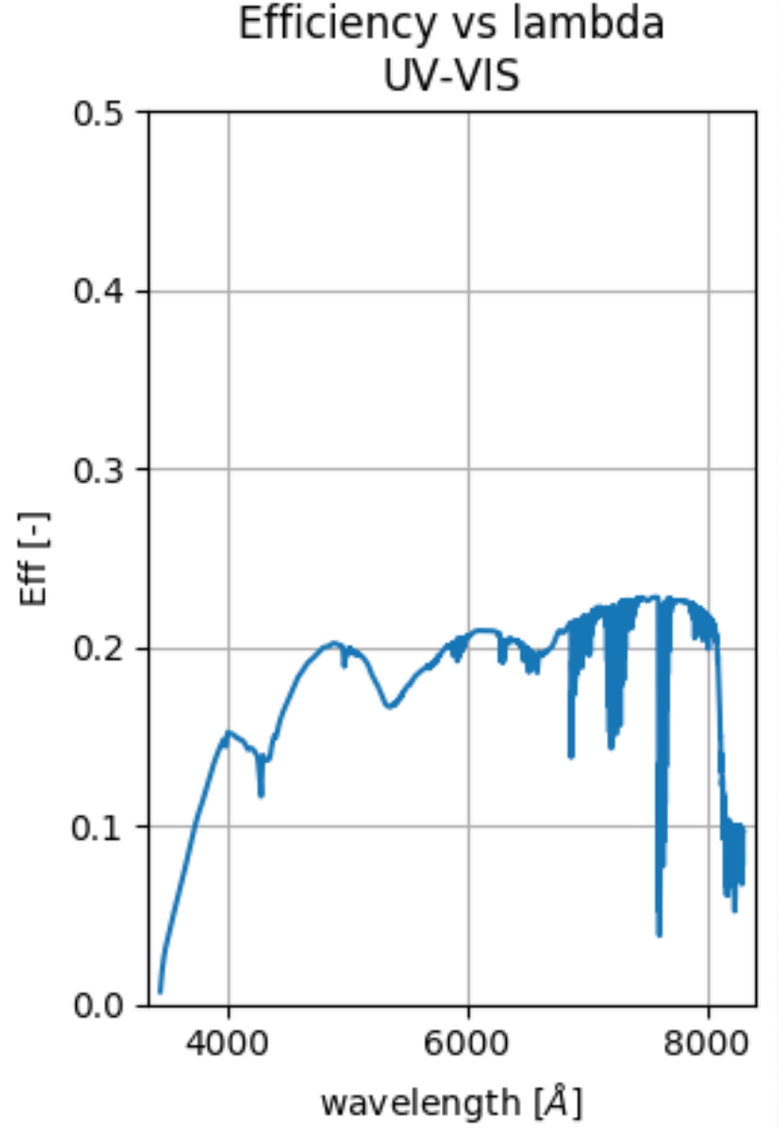
SoXS UV-VIS arm

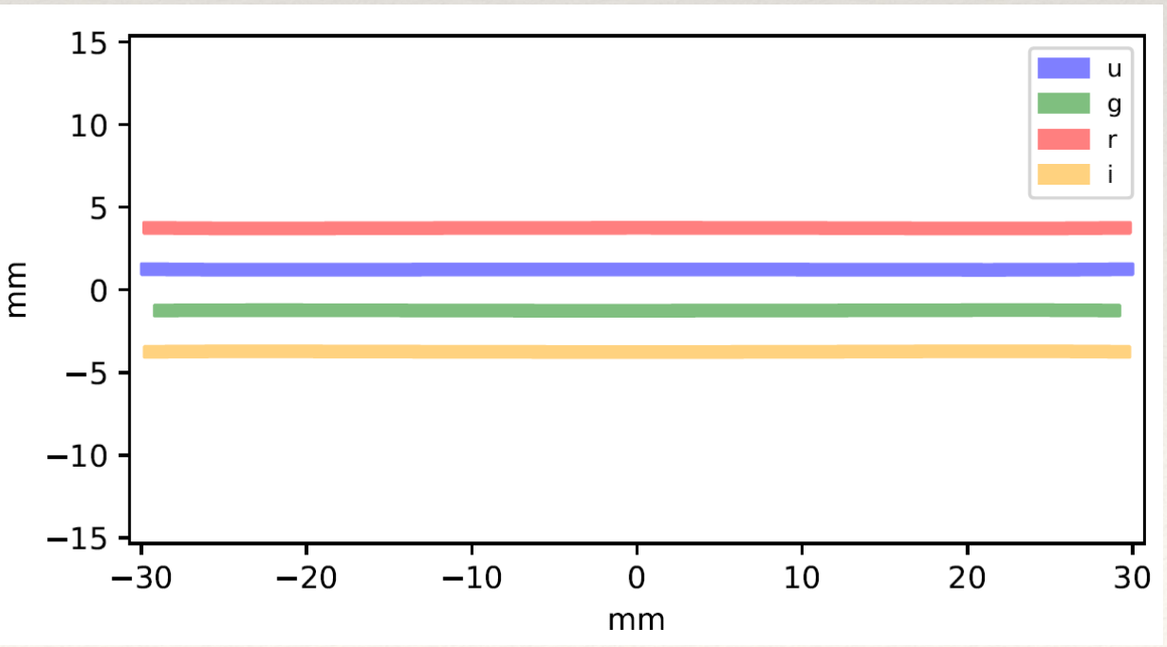
מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

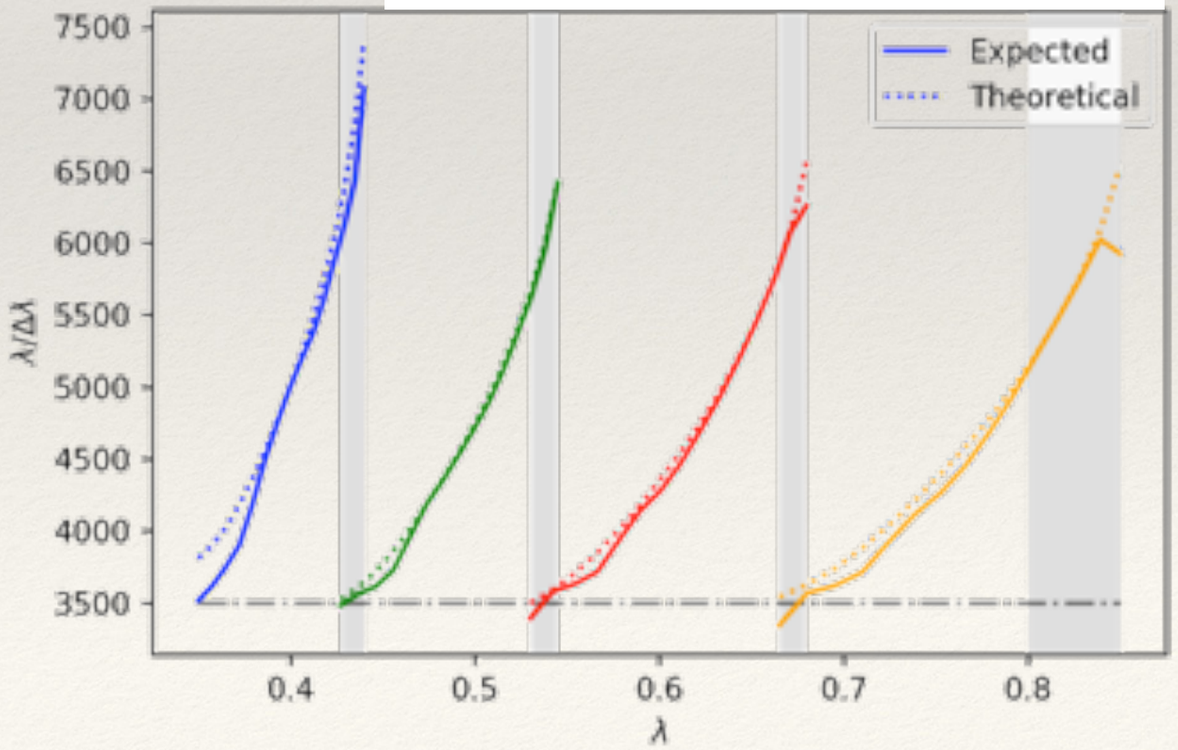
*Aspheric











Kulkarni's comparison

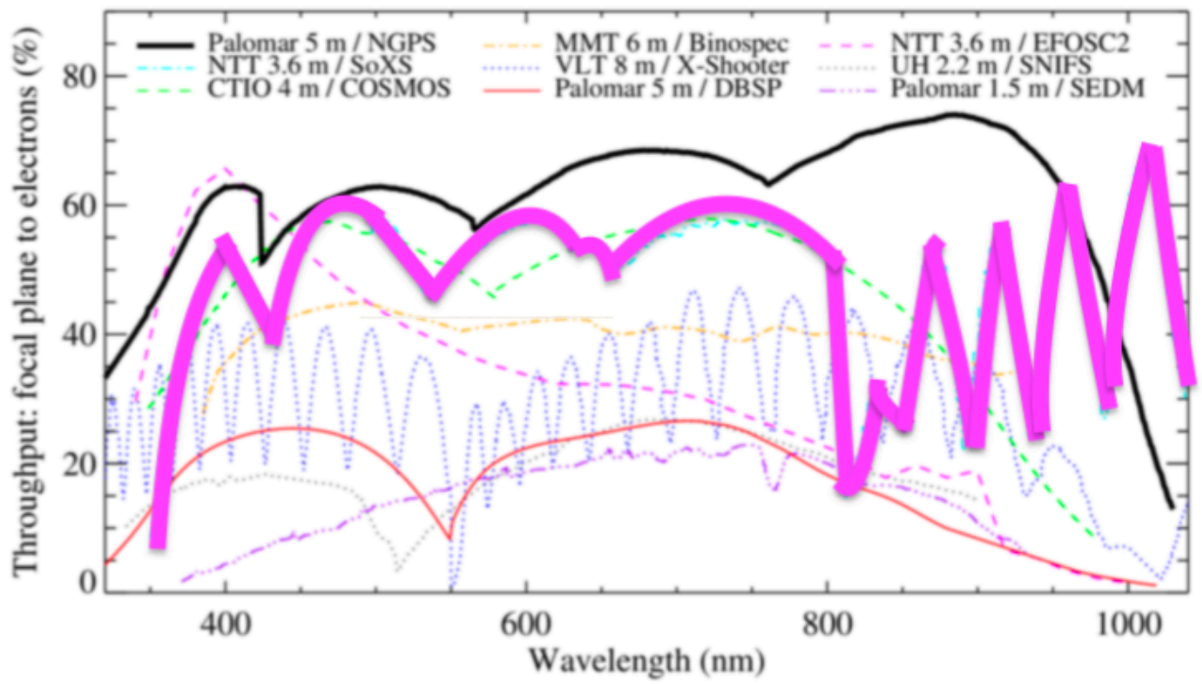


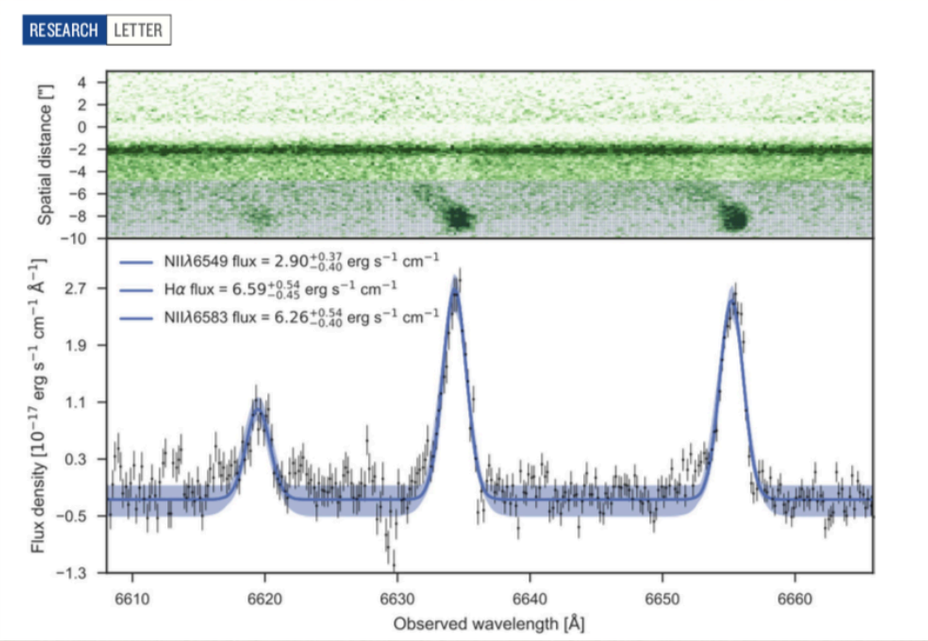
Figure 5. The throughput from the focal plan to photoelectrons of the Next Generation Palomar Spectrograph (NGPS; solid line). The throughput for other spectrographs varies between this measure to "from sky to photoelectrons". References: Son of X-Shooter (SoXS, Claudi et al. 2018, M. Genoni, pers. comm.), COSMOS (Martini et al. 2014), Binospec (Fabricant et al. 2019), X-Shooter (Vernet et al. 2011), DBSP (Oke & Gunn 1982), EFOSC2, which is part of PESSTO (Smartt et al. 2015), SNIFS (Lantz et al. 2004; Lombardo et al. 2017), and SEDM (Blagorodnova et al. 2018). Figure supplied by E. Kirby.

https://arxiv.org/abs/2004.03511

SoXS pipeline

Queen's University Belfast

- Pixel detrending – bias, flat, dark, linearity corrections (dark only for NIR)
- Produce 2D distortion corrected, orders merged pre-extraction spectrum for each arm (rectification)



Very quick. Data reduction in near-real time. No need for a quicklook.

- X-shooter like reduction recipes and data products
- But faster production of science ready products

Pipeline also for the acquisition camera data; astrometric and photometric corrections with Pan-STARSS

SoXS pipeline will be public

SoXS timeline & operations

Project Phase	Start	End	Duration
Preliminary Design	08/2016	07/2017	12 months
Final Design	08/2017	10/2018	14 months
MAIT & PAE	11/2018	05/2022	
Commissioning & PAC (Chile)	09/2022	03/2023	
Operations	2023	2027	

SOXS Consortium time 180 night/yr for 5 years at the NTT

All SOXS Consortium observing time is dedicated to observation of transient and variable sources

Integrated approach

SOXS Consortium will manage the entire schedule including ‘SOXS’ time and ‘ESO’ time.

Schedule day-by-day, optimising for into account the Moon, airmass, seeing, water vapour, sky brightness, wind direction constraints. One SoXS scientist always on duty. Possibility to change the observing schedule on the fly.

Overall balance among ESO and SOXS time in terms of dark-grey-bright time, water vapour, seeing, etc.

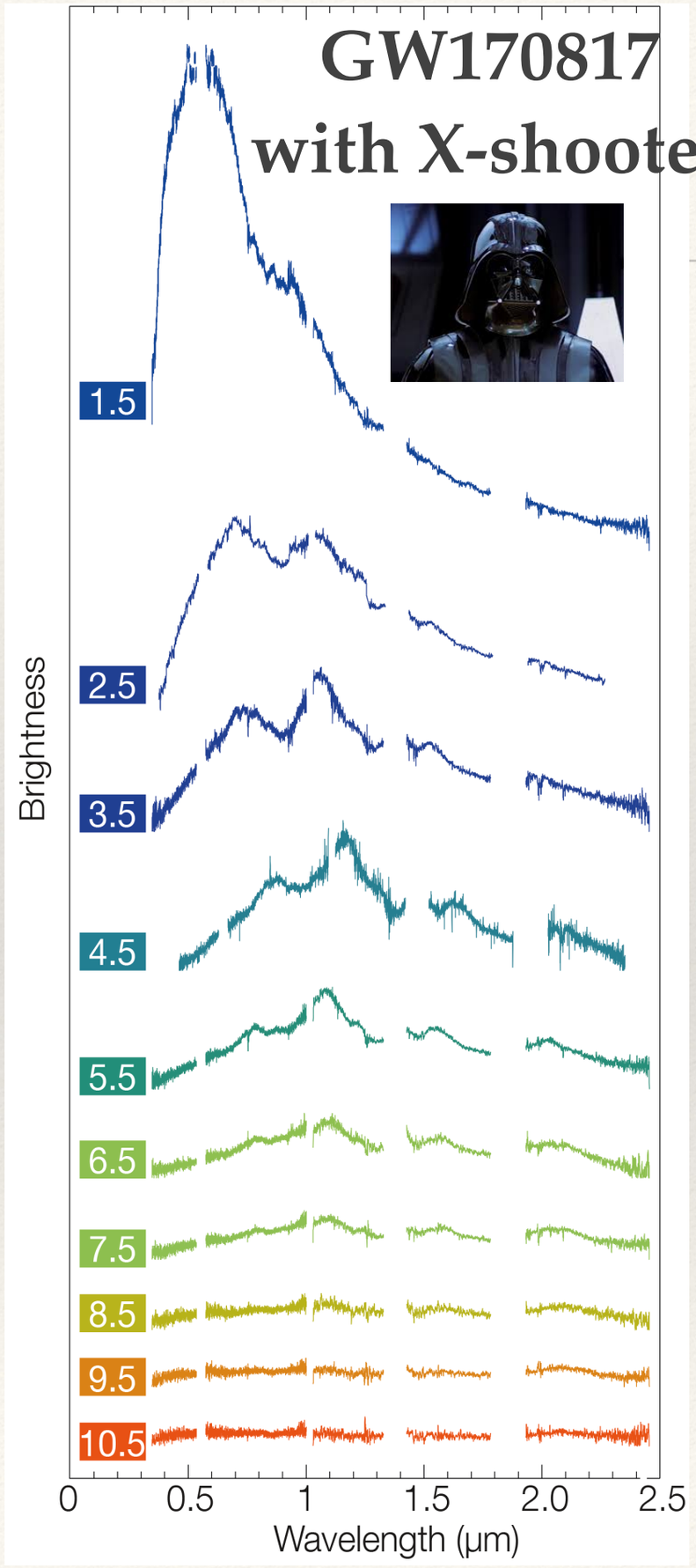
Data policy

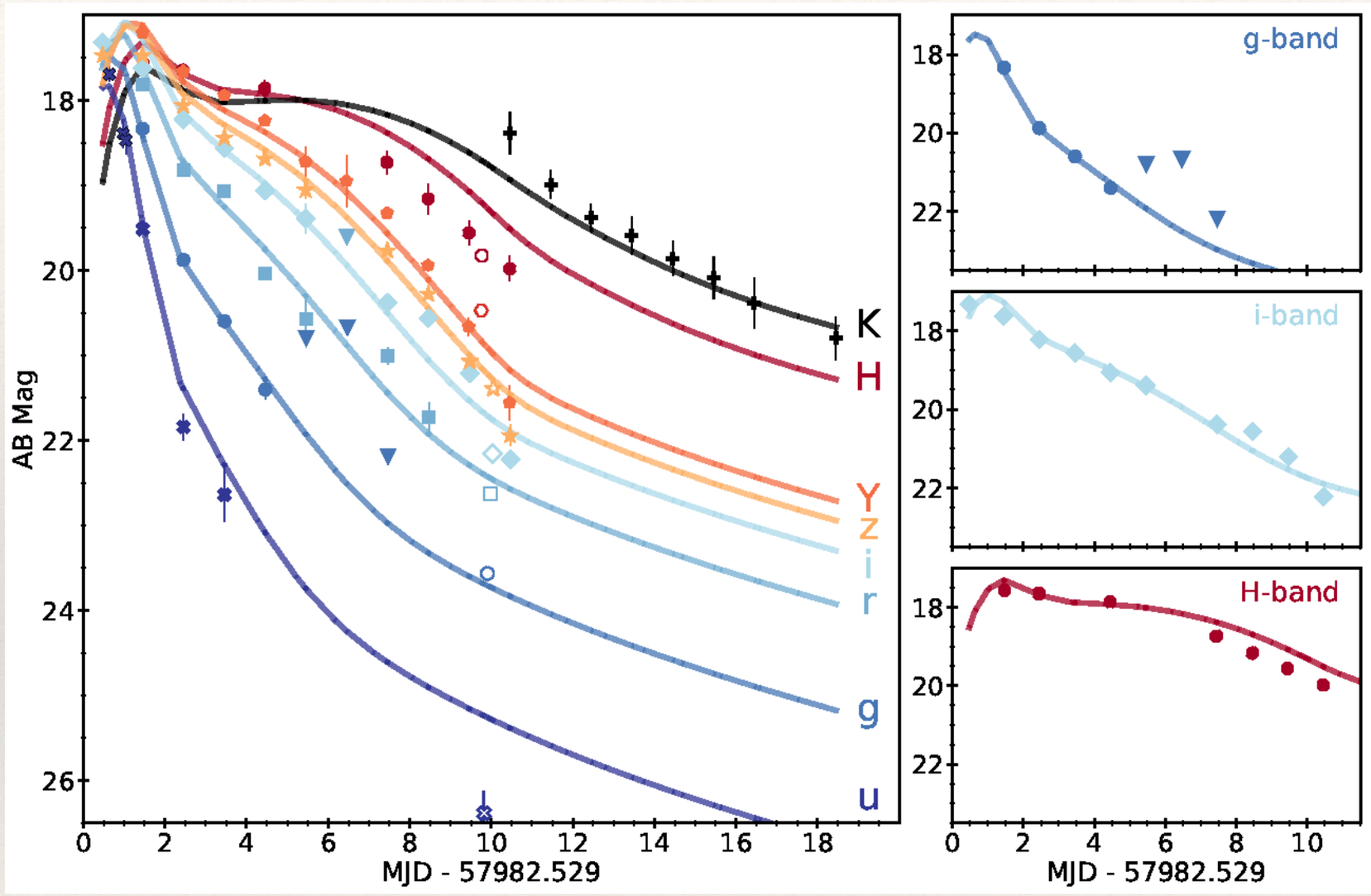
SOXS-GTO sources selected with clear triggering criteria, criteria will be made public before the start of the operations (and updated every 6 months).

Consortium GTO data will remain private for 12 months (or when data are published).

SOXS will also take classification spectra of sources from optical surveys (up to 25% of SoXS GTO observing time).
These data can be claimed by the SOXS Consortium within 3 days, if they fall under a GTO proposal (and will then remain private for 12 months). Otherwise classification data are public.

SoXS for GW sources

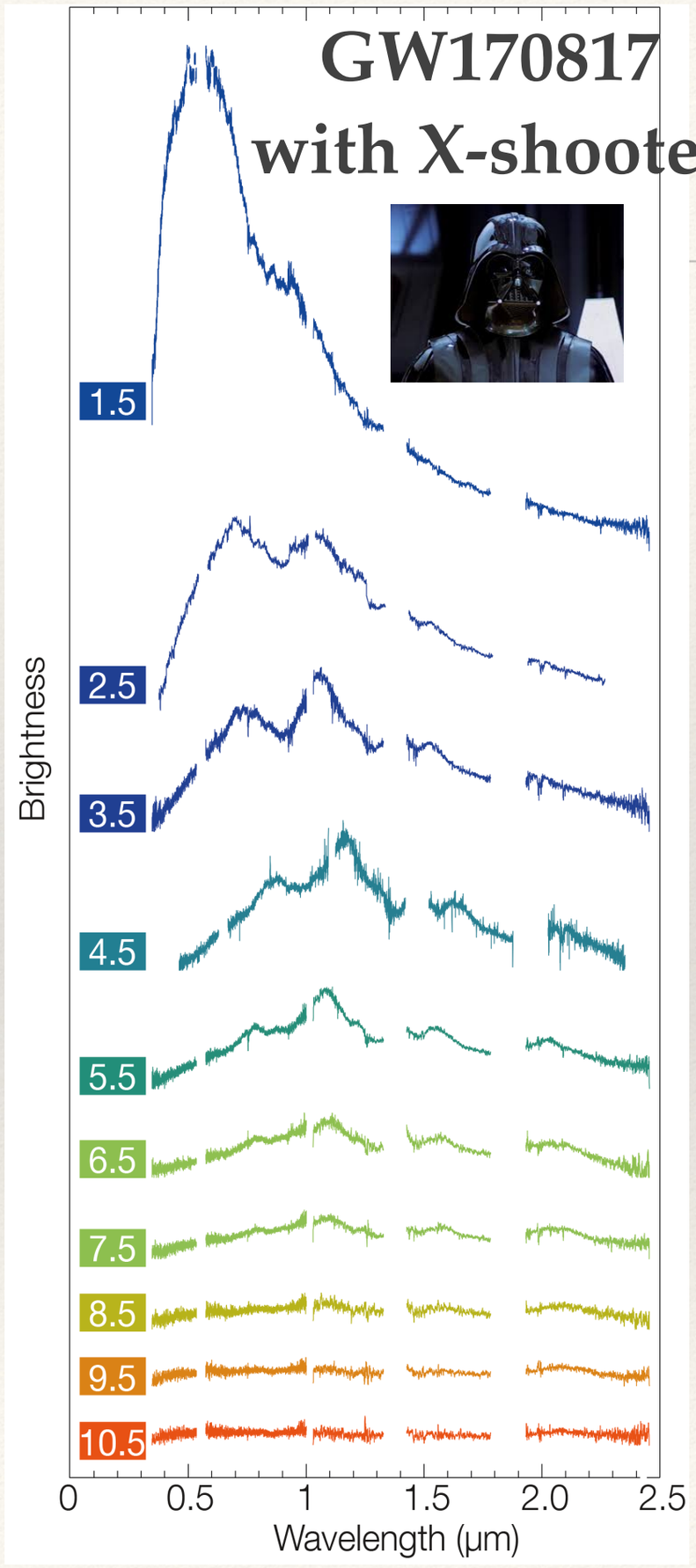


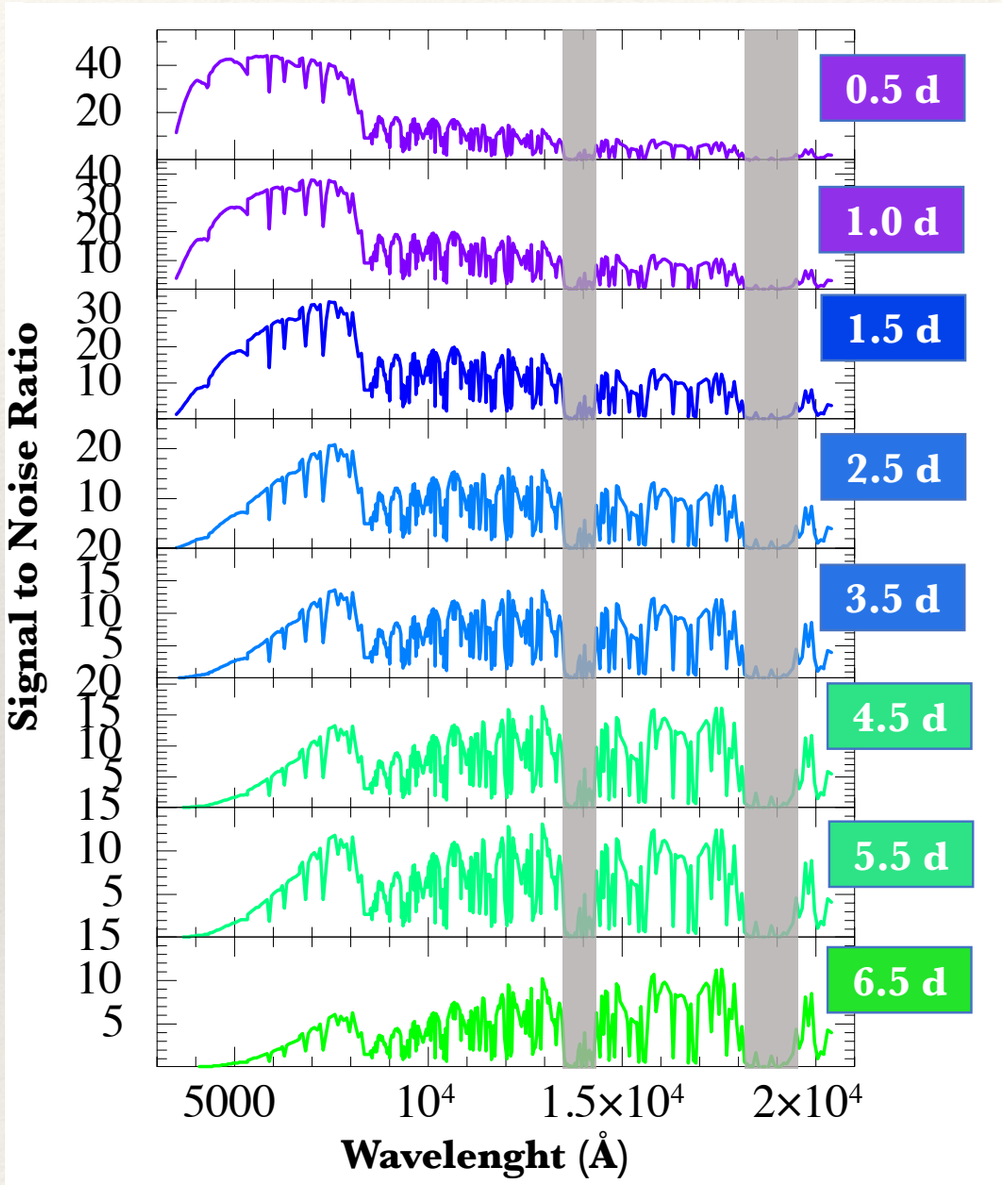


Preliminary SoXS ETC

http://192.167.38.34/

SoXS for GW sources

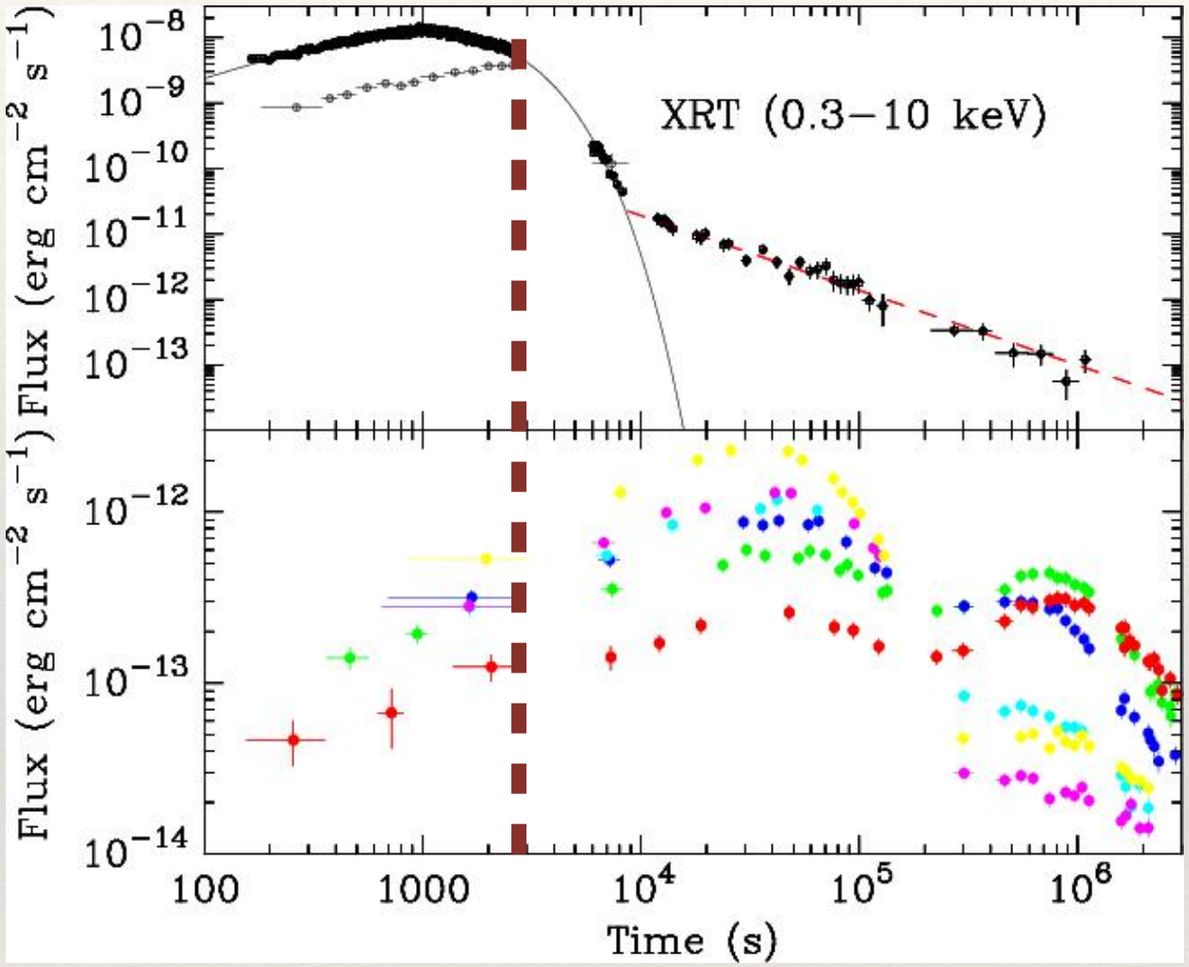




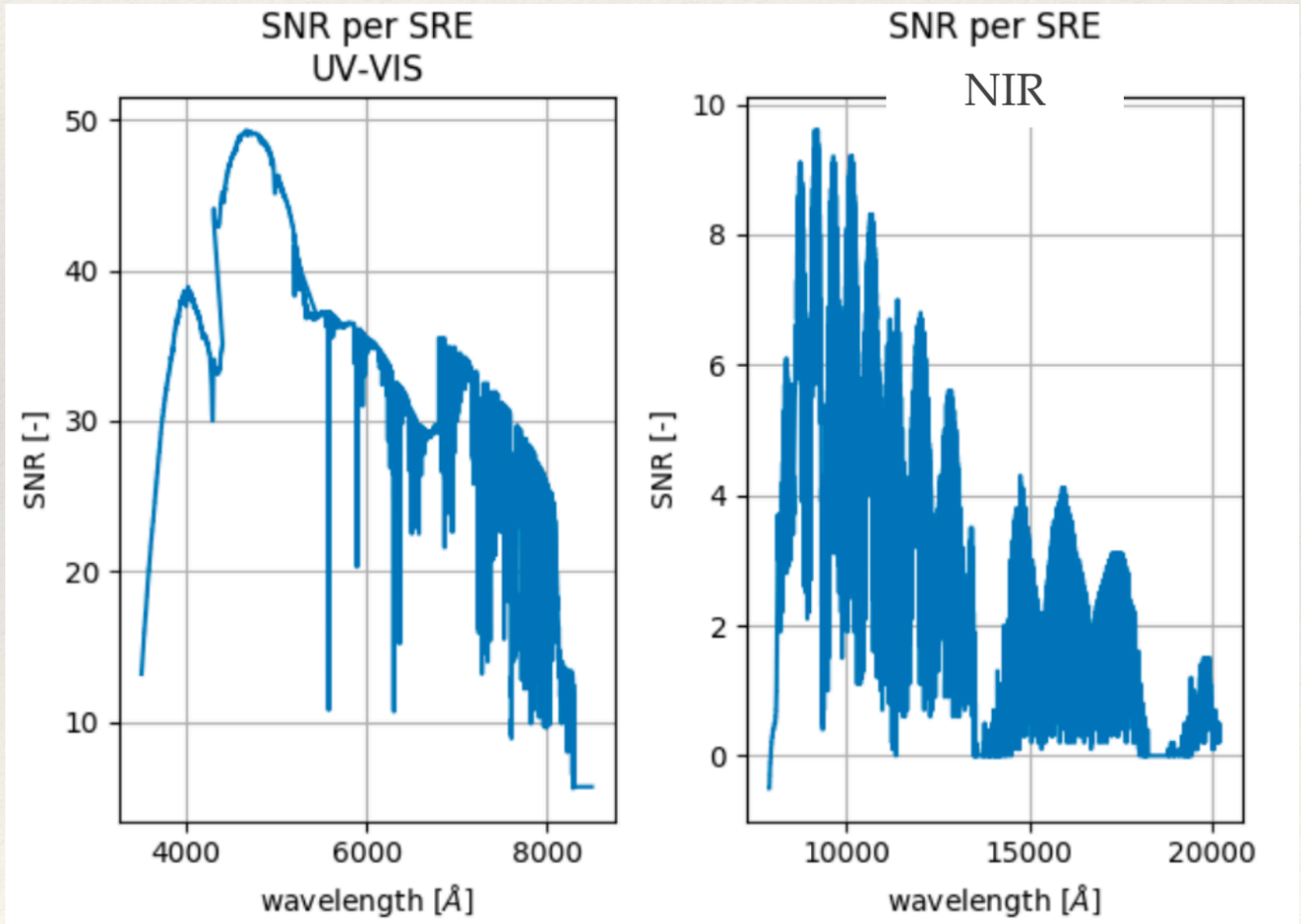
Preliminary SoXS ETC

http://192.167.38.34/

Shock break out



GRB 060218



Summary

Fast Evolving Extra-galactic Transients (FEET)

- LGRB
- SGRB
- GW
- SBO
- FBOT

A new era is starting with Rubin/LSST and ULTRASAT

- Complement photometry from ground
- Fast repointing of Swift for X-rays
- Fast optical spectroscopy (SOXS & VLT/RRM)
- Synergies between ULTRASAT and SOXS

Thanks