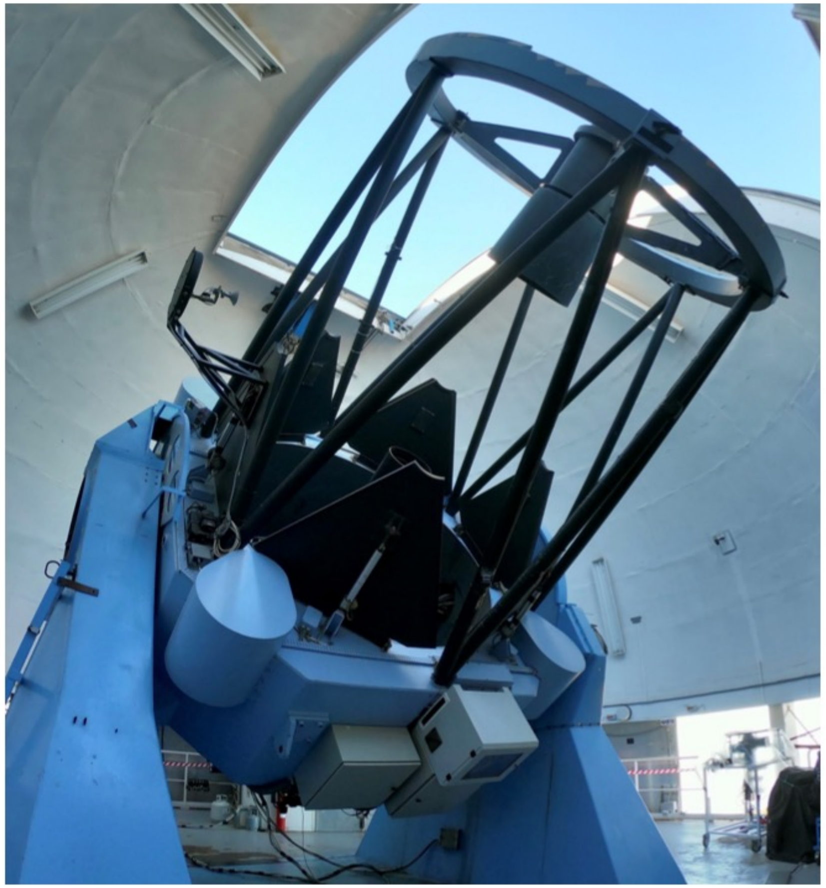
Follow-up with (larger) telescopes



NOT Transient Explorer (NTE)

A new instrument for the Nordic Optical Telescope

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SVOM Burst Advocates Workshop
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ASTRONOMY AND ASTROPHYSICS

Letter to the Editor

VLT identification of the optical afterglow of the gamma-ray burst GRB 000131 at $z = 4.50^{\star}$

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Abstract. We report the discovery of the gamma-ray burst GRB 000131 and its optical afterglow. The optical identification was made with the VLT 84 hours after the burst following a BATSE detection and an Inter Planetary Network localization. GRB 000131 was a bright, long-duration GRB, with an apparent precursor signal 62 s prior to trigger. The afterglow was detected in ESO VLT, NTT, and DK1.54m follow-up observations. Broad-band and spectroscopic observations of the spectral energy distribution reveals a sharp break at optical wavelengths which is interpreted as a Lyα absorption edge at 6700 Å. This places GRB 000131 at a redshift of 4.500 ± 0.015. The inferred isotropic energy release in gamma rays alone was $\sim 10^{54}$ erg (depending on the assumed cosmology). The rapid power-law

Main responsible

Niels Bohr Institute
University of Copenhagen
Denmark

Nordic Optical Telescope
University of Aarhus/
University of Turku
Spain

Key partners

Optical Imager Mechanics
Department of Physics and Astronomy
University of Aarhus
Denmark

Optical and Infrared Imagers
Finnish Centre for Astronomy with ESO
University of Turku
Finland

Polarimetric mode
Planetary-system research, Department of Physics
University of Helsinki
Finland

Rapid response mode
The Centre for Astrophysics and Cosmology
The Science Institute
University of Iceland, Iceland

Optical and Infrared Imagers
The Oscar Klein centre.
Stockholm University
Sweden

Camera Optics and Spectrograph Vessel
Osservatorio Astronomico di Brera
Istituto Nazionale di Astrofisica
Milan, Italy

Infrared Imager Mechanics
Laboratoire d'Astrophysique de Marseille
Marseille, France

Infrared detectors
Max Planck Institute for Astronomy
Heidelberg, Germany

Optical and Infrared Imagers
The Key Laboratory of Space Astronomy and Technology
National Astronomical Observatories, Chinese Academy of Sciences
Beijing, China

Atmospheric Dispersion Corrector
Department of Particle Physics and Astrophysics
Weizmann Institute for Science
Tel Aviv, Israel

NTE Team

Niels Bohr Institute

Michael I. Andersen – Systems engineer

Lise Christensen – Pipeline responsible

Niels Michaelsen – Mechanics

Bo Milvang-Jensen – Pipeline development

Anton N. Sørensen – Calibration and AIT

Joonas K. M. Viuho – Motors and control

Dennis Wistisen - Mechanics

Johan P.U Fynbo – Principle investigator

Nordic Optical Telescope

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Jacob W. Clasen – Project Manager

Graham C. Cox – Detector systems

Anlaug Djupvik – Astronomer, IR applications

Carlos Perez – Mechanics

Tapio Pursimo – Astronomer, imaging

John Telting – Astronomer, spectroscopy

Partner institutes

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LAM, France

Stefano Covino – Head of science team
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Anders S. Damgaard - VIS Imager mechanics
University of Aarhus, Denmark

Kasper E. Heinz – Instrument scientist, pipeline
University of Iceland, Iceland

Vitaly Neustreov – Imaging pipeline
FINCA/University of Oulu, Finland

Marco Riva – Spectrograph camera optics
INAF Brera, Italy

NTE - Motivation

- High demand for low- to mid-resolution high-efficiency spectroscopy
- X-shooter is one of the most popular VLT instruments
  - New instruments: SOXS (NTT), SCORPIO (GEMINI), GATOS (GTC)
- Larger telescopes are slower + more competitive
- Smaller telescopes have an advantage in transient follow-up due to faster slew time *if they can acquire the target rapidly*
- New transient finding facilities coming online
  - Rubin observatory /LSST
  - Ever increasing likelihood for transient discovery

NTE – ultra quick summary

- Two arm imager :

  Images in filters from U- to optical- and near-IR

  Simultaneous images in optical and near (1 filter each)

- Two arm spectrograph :

  Mid-resolution, R ~ 4000,

  cross-dispersed, echelle

  Spectral range 320 nm – 2200 nm

  Full spectral range in each exposure

NTE - Motivation

First light in 2024

Reaction time

- Rapid Response Mode for fast transient reaction   (<2 minutes)
- Real-time extraction of spectra

Main focus of GRB follow-up

- Complete sample (follow-up everything) important to chatacterise a new GRB satellite parameter space
- Early follow-up
- Dusty, reddened GRBs
- High-z events

Main science cases

Transients

1. GRB follow-up studies
2. Optical counterparts of gravitational wave sources
3. Fast radio-bursts and their host galaxies
4. Type Ia supernovae
5. Follow-up of core-collapse supernovae
6. New/Unknown Transients

Non-transients

7. Active galactic nuclei and their host galaxies
8. Cosmology and Black Hole Accretion Physics with AGN
9. Follow-up studies of targets selected in wide-field, multiband surveys
10. Polarimetry of solar system sources
11. The Solar System
12. Ground-based studies of exoplanet atmospheres

Guaranteed time on NTE

Available telescope time

- ~500 nights over ~10 years for *all science cases* and all GTO teams
- 80 nights (800 hours) over 10 years for **SVOM+NTE follow-up**

  (Could be more than this due to common science interests (J. Fynbo)
- *Follow-up team: TBD* Fynbo + Christensen

  +2 project-hired post-doc/ students in Copenhagen

  + SVOM team follow-up group ?

- Typical time spent on GRB at the NOT now : ~10 nights / semester

GRB follow-up

Localizing the GRB counterpart

- Long, + short GRBs

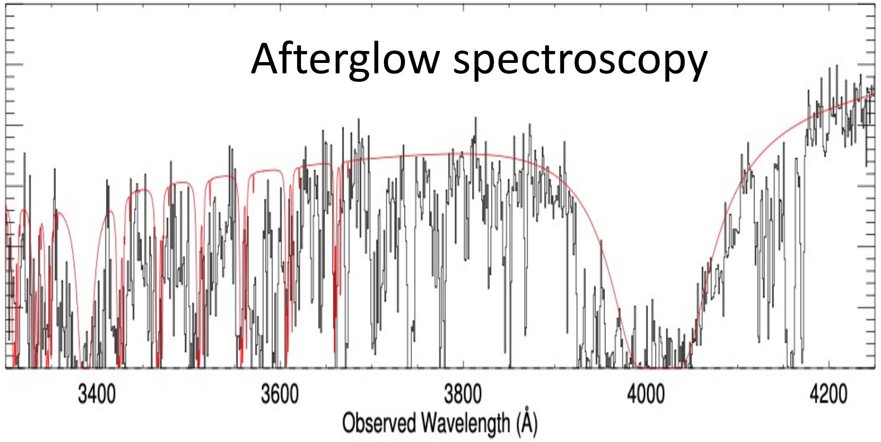
Characterization of the counterpart

- Short-GRB – kilonova connection
- Long-GRB – first star explosion, inter-stellar medium, dust bias

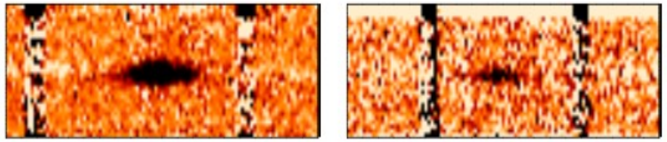
Physical analysis

- GRBs as probes of star-formation (GRB-SN connection)
- Dust, extinction curves
- Chemical enrichment in the 'dark ages', z > 6

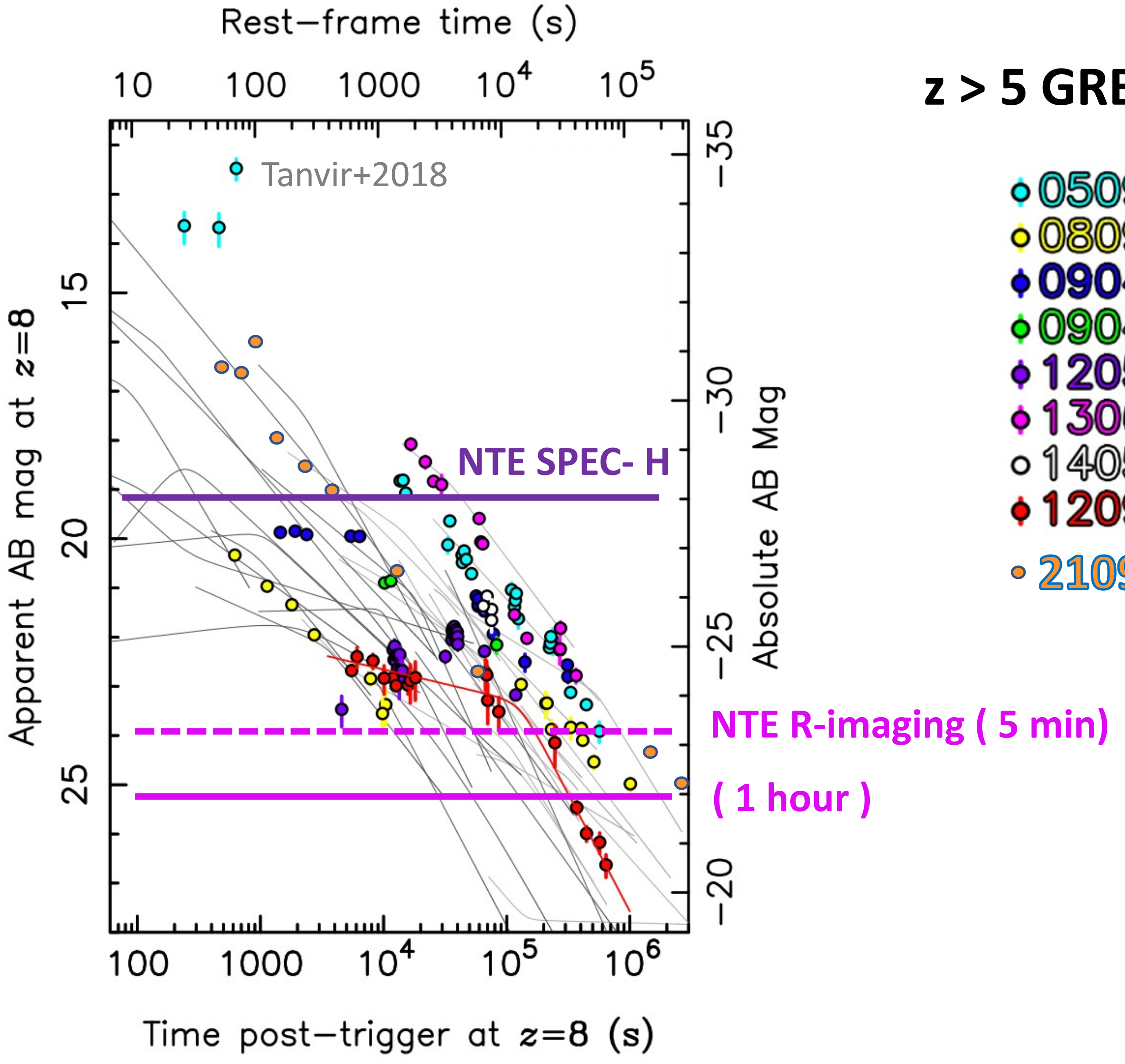
Afterglow spectroscopy



Host galaxy emission-lines
Ha, Hb, [OII], [OIII],…



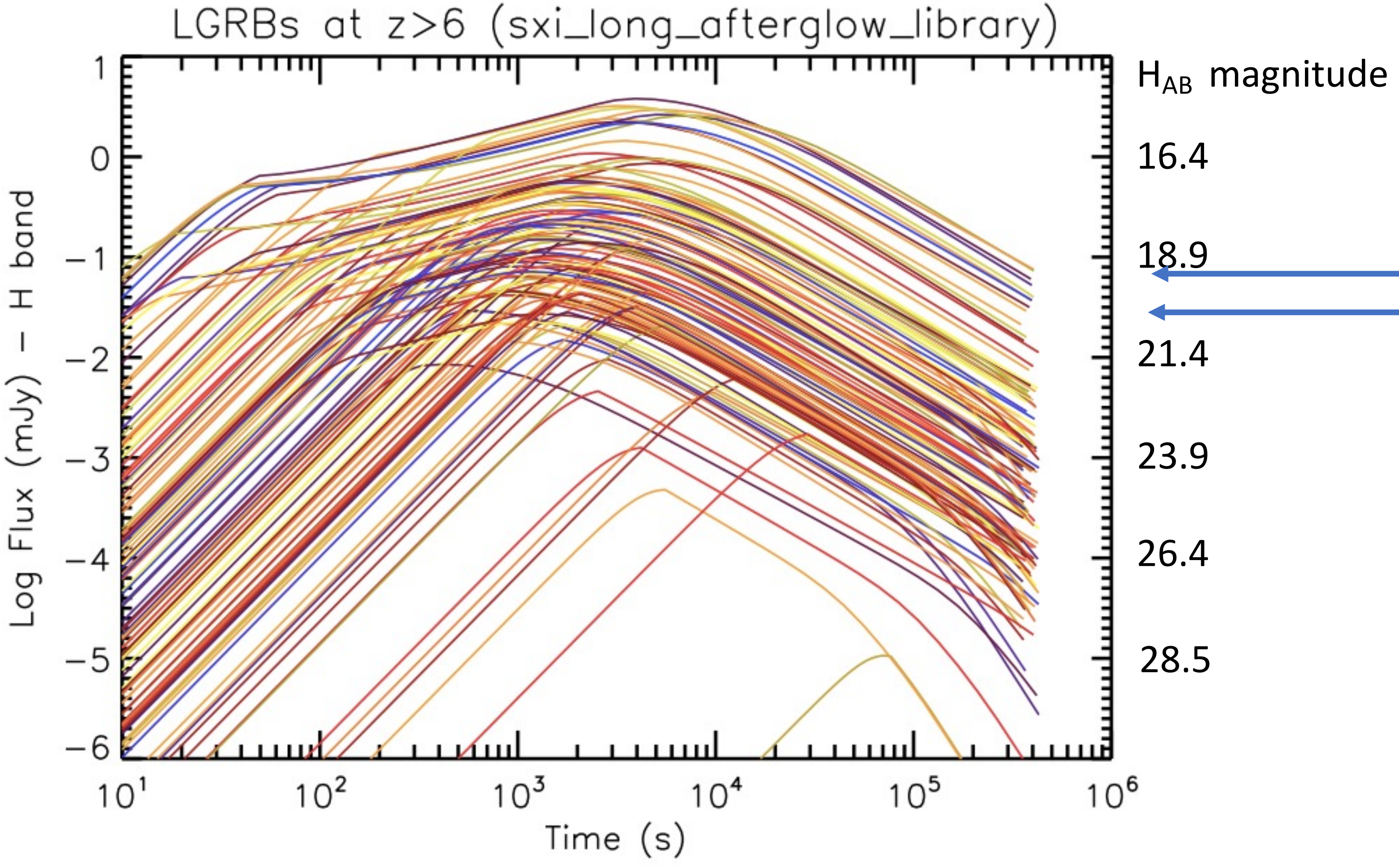
Infrared afterglow light curves projected to z=8



z > 5 GRBs:

- 050904
- 080913
- 090423
- 090429B
- 120521C
- 130606A
- 140515A
- 120923A
- 210905A (Rossi+22)

H band light curves of 113 Long GRBs at z>6 (Ghirlanda etal.).



NTE spectroscopic limits:
H = 19.2 mag
R = 20.7 mag

S/N = 10/spectral bin
t_exp = 3600 s

Le Floc'h

GW source follow-up

Localizing the GW counterpart

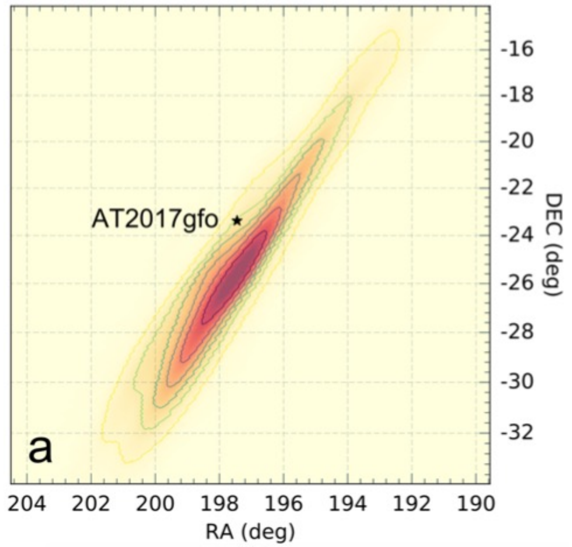
- Sources may be reddened
- Imaging in VIS + NIR
- Binary neutron star merger counterparts follow mass -> not necessary to monitor 10 - 100 sqr deg.

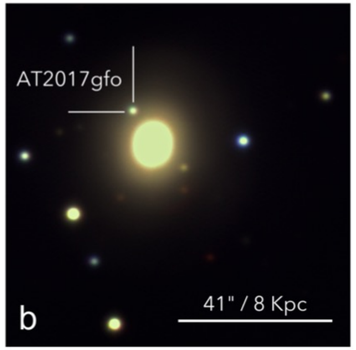
Characterization of the counterpart

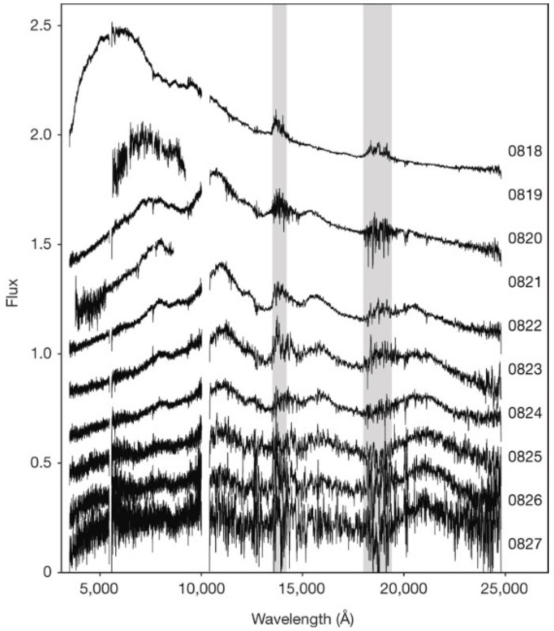
- Lightcurve
- Spectrophotometry

Physical analysis

- r-process elements
- Temperature, expansion velocity
- Explosion energy, ejected mass, geometry







Fast radio bursts and their host galaxies

Theoretical origins

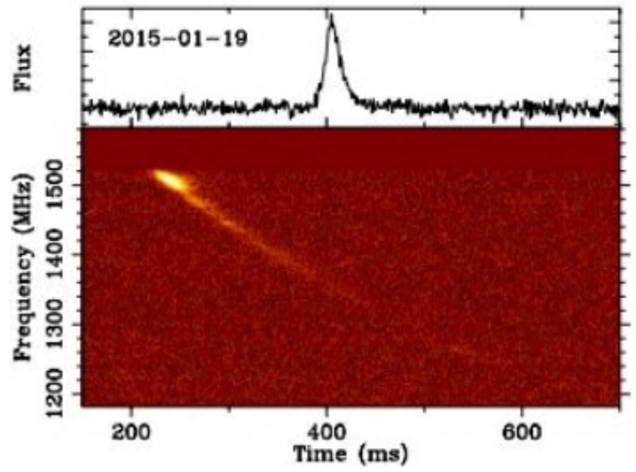
- compact object mergers or collapse
- exotic AGN activity
- Super-pulses from magnetars

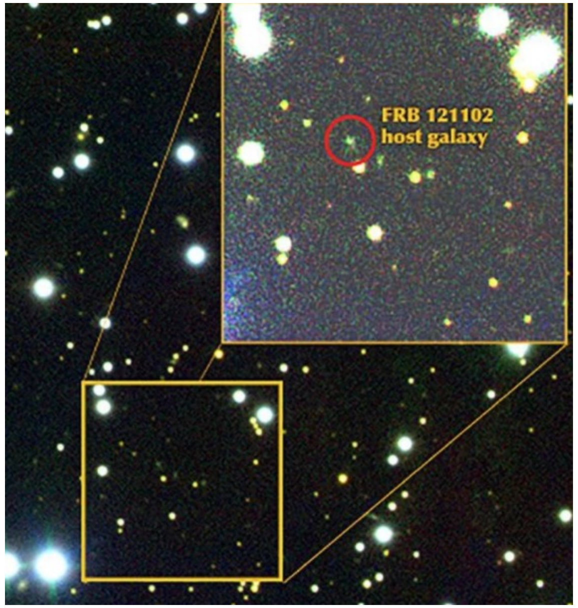
Triggered by major radio-facilities

- ASKAP , CHIME , MeerKAT (soon)

Physics

- Two classes: repeating, single events
- Host galaxy characterization , Redshift determination
- sweep in time/frequency space -> dispersion measure DM = $\int n_e \, ds$
- DM-z relation to probe the baryons in the WHIM





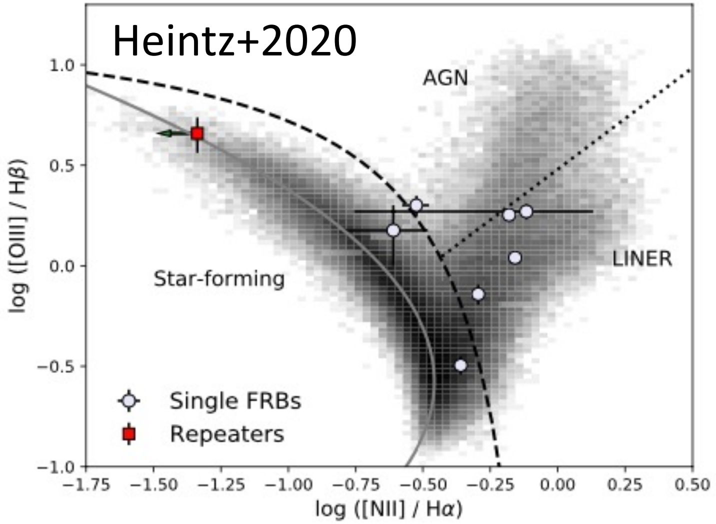
Fast radio bursts and their host galaxies

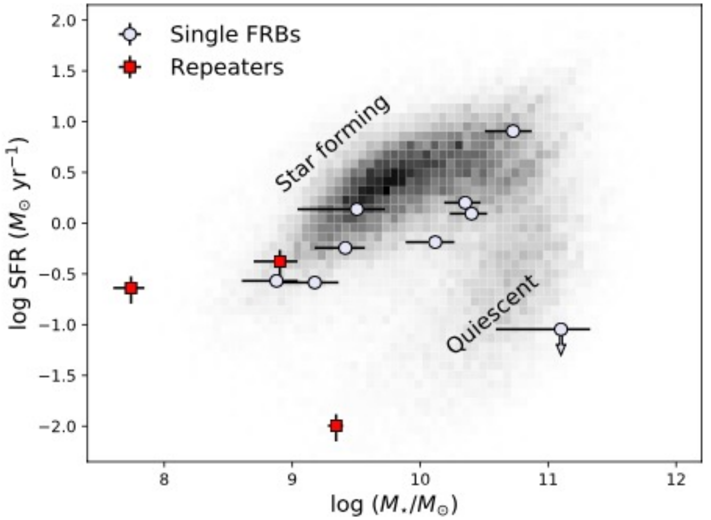
Requirements

- Rapid observations to locate potential optical+ near-IR counterparts

Science goals

- Host galaxy characterization
- Progenitor linked to host-galaxy stellar populations ?
- Spectroscopy of host: Redshifts (z= 0 - 3), emission lines + characteristics





New/Unknown Transients

New domain in phase-space

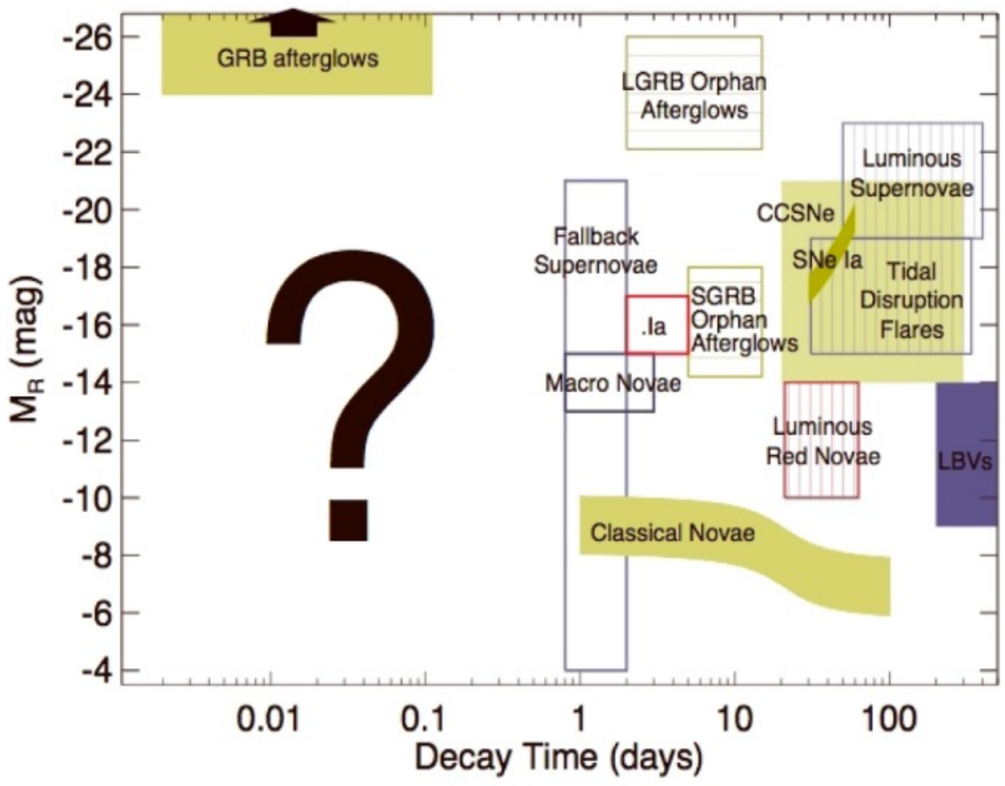
- Early follow-up
- Near-infrared discovery space

New transient types

- Empty boxes : theoretical predictions
- Orphan GRB afterglows : not yet detected

Science goals

- Localization
- Redshift determination
- Wide – λ characterization



LSST Science Book v. 2.0

NTE Design Concept

- ➢ VIS + NIR imager - 6’x6’ FoV
- ➢ VIS + NIR single slit spectrograph R~4000
- ➢ U- to K-band imaging and spectroscopy from 330-2400 nm
- ➢ Independent operation of VIS and NIR arms both in imaging and spectroscopy
- ➢ Fast to re-configure
- ➢ fast telescope slew time

NTE - imaging

- Simultaneous VIS and NIR imaging (one filter each)
- 6’x6’ FoV
- Permanently mounted filters

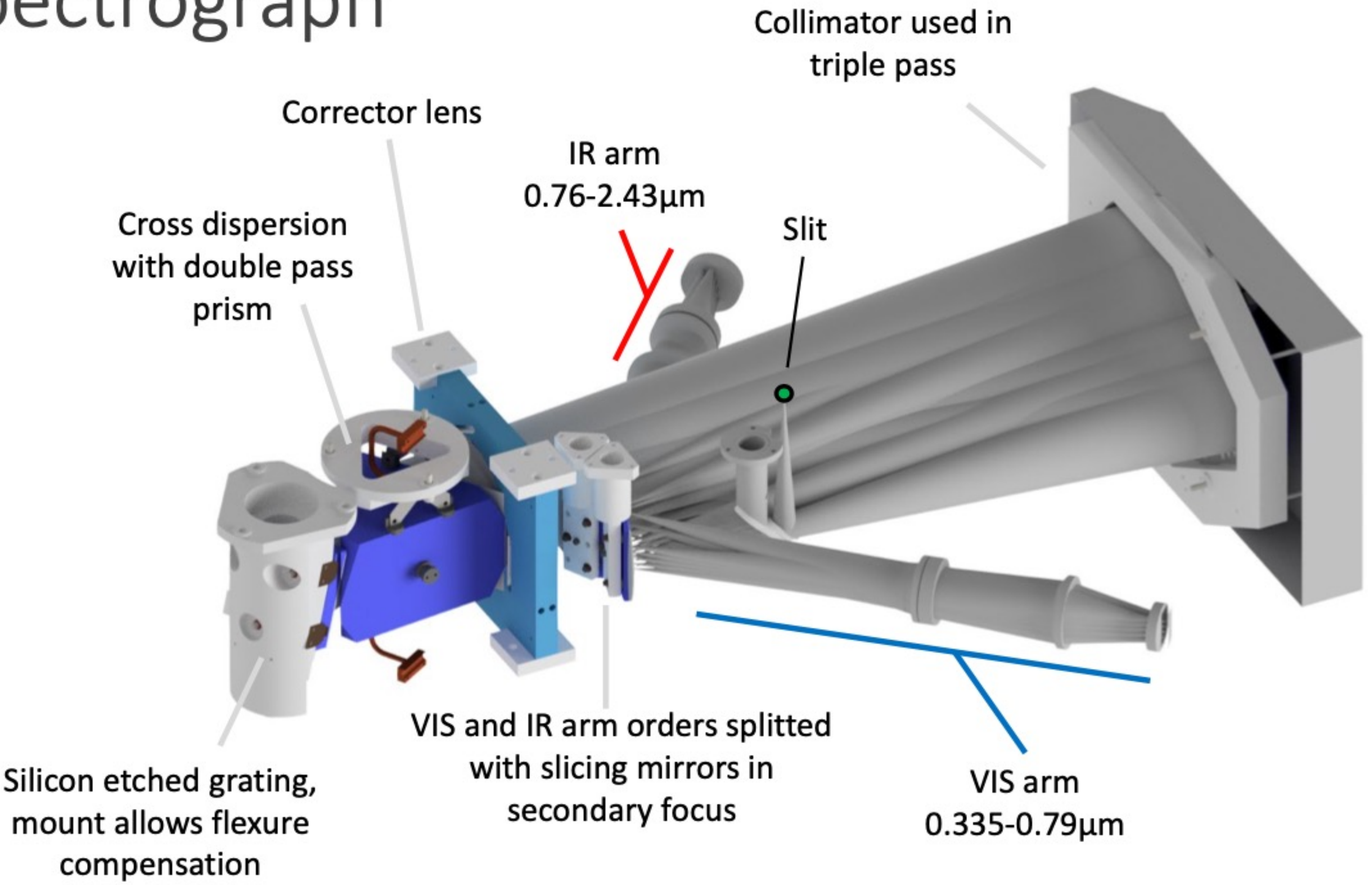
VIS imager
Bessel and SDSS filter set

Limiting magnitudes (1h, S/N=5)
U=25.0
B=26.2
V=26.8
R=25.2
I=24.4

NIR imager
VISTA-like filter sets : I Z J H K_s

Limiting magnitudes (1h, S/N=5, AB)
Y=23.4
J=22.9
H=22.6
K=22.4

Spectrograph



Spectrograph - specifications

	VIS arm	NIR arm
Slit widths	0.8” / 1.0” / 1.2” / 1.5” / 1.7” / 2.0” / 5.0”	
Grating groove frequency	91.5l/mm	
Grating blaze angle	17.5°	
Beam diameter	70mm	
Minimum order separation	27”	
Wavelength coverage	335nm-790nm	0.76-2.43µm
Spectral orders	21 – 8	7 – 3
Camera F-ratio	f/3.0	f/3.6
Pixel scale	0.38”-0.42”	0.42”-0.50”
Resolution	~ 4000	~ 4000

Follow-up strategy

Observing sequence :

Imaging -> detect new source -> Follow-up spectroscopy (bright target)
-> Deeper imaging (fainter target)

Imaging filter sequence (TBD)
Optimal combination of VIS and NIR filter (TBD)

Automatic, autonomous detection :

1. new VIS source in image from GAIA catalog comparison (mag ~ 20)
2. new NIR source in images : Reference near-IR source catalog ?
   (2MASS is not deep)
3. optical-NIR dropout source
4. Variable source

Spectroscopy - acquisition

Target acquisition methods

1) with **acquisition** camera
   - Direct
   - Blind offset
2) with **optical** imager
   - Direct
   - Blind offset
3) with **NIR** imager
   - Direct
   - Blind offset

Observing modes:

1) Stare-mode spectrum
2) Nodding along the slit spectrum
3) Generic offset spectrum
4) Fixed sky offset spectrum (offset from target to sky)

Science operation

Observing modes

Queue mode in 50% of the time (covering transients)

Visitor obs. for 50% (non-transient science)

Transient triggering

Target of Opportunity (ToO) : range of trigger times (1-x days)

Rapid response mode (RRM) : response times of < hours
aimed for urgent (and rare) cases

Target of Oportunity (ToO) at the NOT

Regulations for ToOs at NOT

- Programmes approved by OPC, with a fixed number of alerts per period
- PI is authorized to contact NOT observer directly
- ToOs typically limited duration of up to 3 hours per trigger
- Can interrupt observations during almost any runs (except Spanish time)
  - > define **override priorities**

RRM at the NOT

Motivation

- Observe transients as quickly as possible
- GRB afterglows fade quickly:

  R(mag) = 16 at t = 5 min

  R(mag) = 19 at t = 30 min

Implementation plan at NOT

Planning

- PI granted RRM mode
- PI creates Observing Blocks (OBs) in the NOT system. OBs can be triggered automatically and <u>remotely</u>

At the NOT

- Verification that (the person who) triggers is allowed
- Automatic stop of ongoing observations
- Automatic execution of OB

Faster reaction-time than at the VLT; <u>NOT re-points faster</u>

Criteria for triggering NOT observation

Criteria based on VLT follow up of *Swift* - GRBs

(**FORS**: Fynbo+2009; **X-shooter**: Selsing+2019)

1) Observed duration T90 > 2 s
2) XRT started observing < 10 min after the GRB + XRT afterglow position distributed in < 12 hr
3) Small foreground Galactic extinction: AV < 0.5 mag
4) Favourable declination: $-70^{\circ} < \delta < 70^{\circ}$
5) Visible from Paranal for at least 60 min, 30° above the horizon, with the Sun below -12°
6) Sun-to-field distance larger than 55°
7) No bright, nearby stars

Follow-up strategies at the **VLT** :

Stargate collaboration : merging of different GRB programs:

- GRB redshift program (PI Fynbo), complete sample
  (redshift distribution; metallicities, dust, HI)

- High-redshift program (Pis: Tanvir, Greiner)
  as above, but focused on high-z GRBs

- Two high-resolution spectroscopy programs (PIs: D'Elia, Ledoux)
  Metallicity in exquisite detail; line variability; uses RRM

- Two short GRB / KN programs (PIs: D'Avanzo, Levan)
  Origin of short GRBs; main goal: KN search; also includes host galaxies

- Polarimetry program (PIs: Covino, Wiersema):
  Requires an optically bright event. Focus on the jet physics. Capitalizes on RRM.

- Excluded: GRB / SN follow-up (PI: Pian).

Triggering the **VLT** :

Target of opportunity (ToO)

Most common way of triggering (manual)
Reaction time at least 30 minutes
Overrides service mode, but requires permission to override visitors
Trigger configuration can be modified

Rapid response mode (RRM)

Very rare (1-2 per year)
Automatic override of current observation
Since 2021, instrument changes are allowed
Overrides both service and visitor mode
Set of prearranged, fixed observations – only coordinates can be changed

RRM at the VLT : FORS2, UVES, X-shooter, Sphere, Hawk-I, MUSE

Method

1. User sends a trigger via web-page interface to trigger a *known OB*
2. Converted to an ASCII file that is sent to an *ftp server* at the VLT mountain
3. A programme at the telescope is *continuously monitoring* the ftp directory
4. If a *trigger is valid:*
   - ongoing observation stops – with no user interaction
   - (new) instrument is selected
   - Telescope presets
   - Observations stars

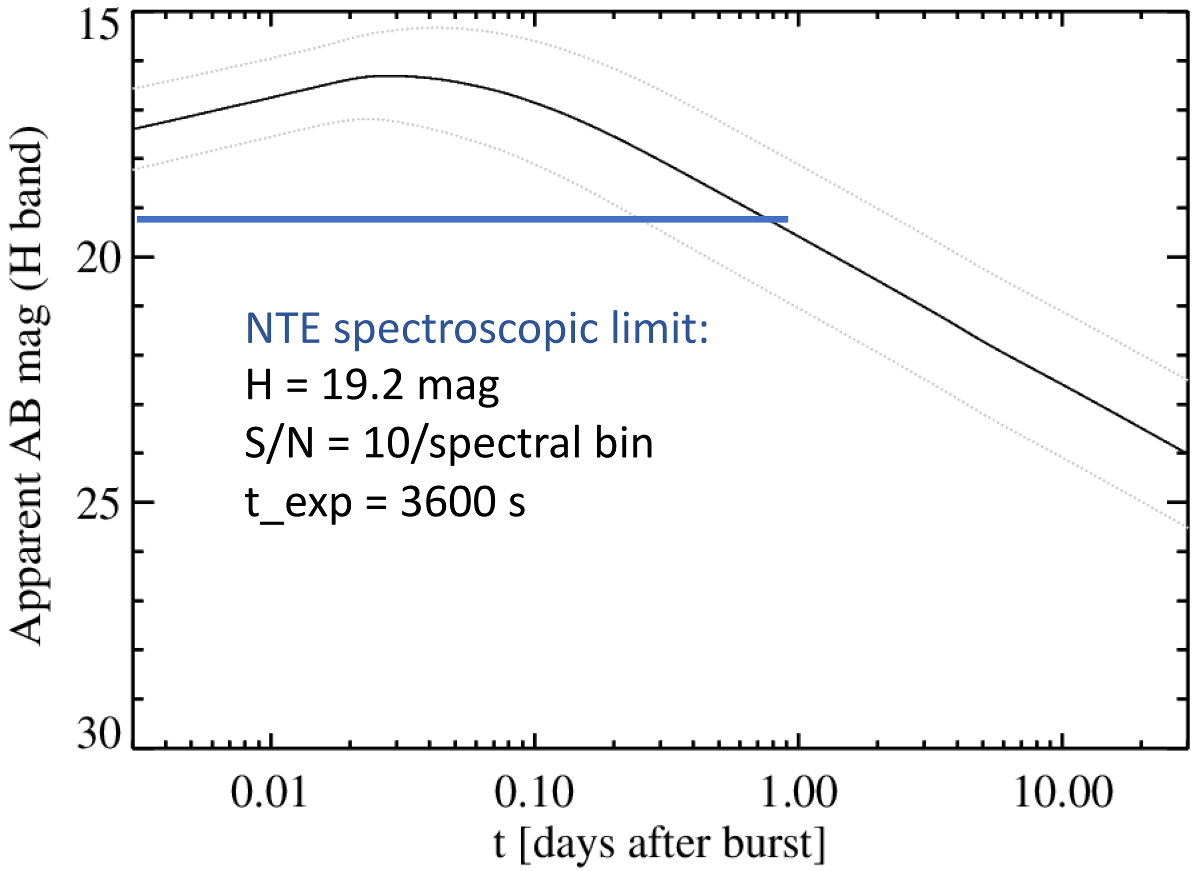
Other considerations (VLT specific)

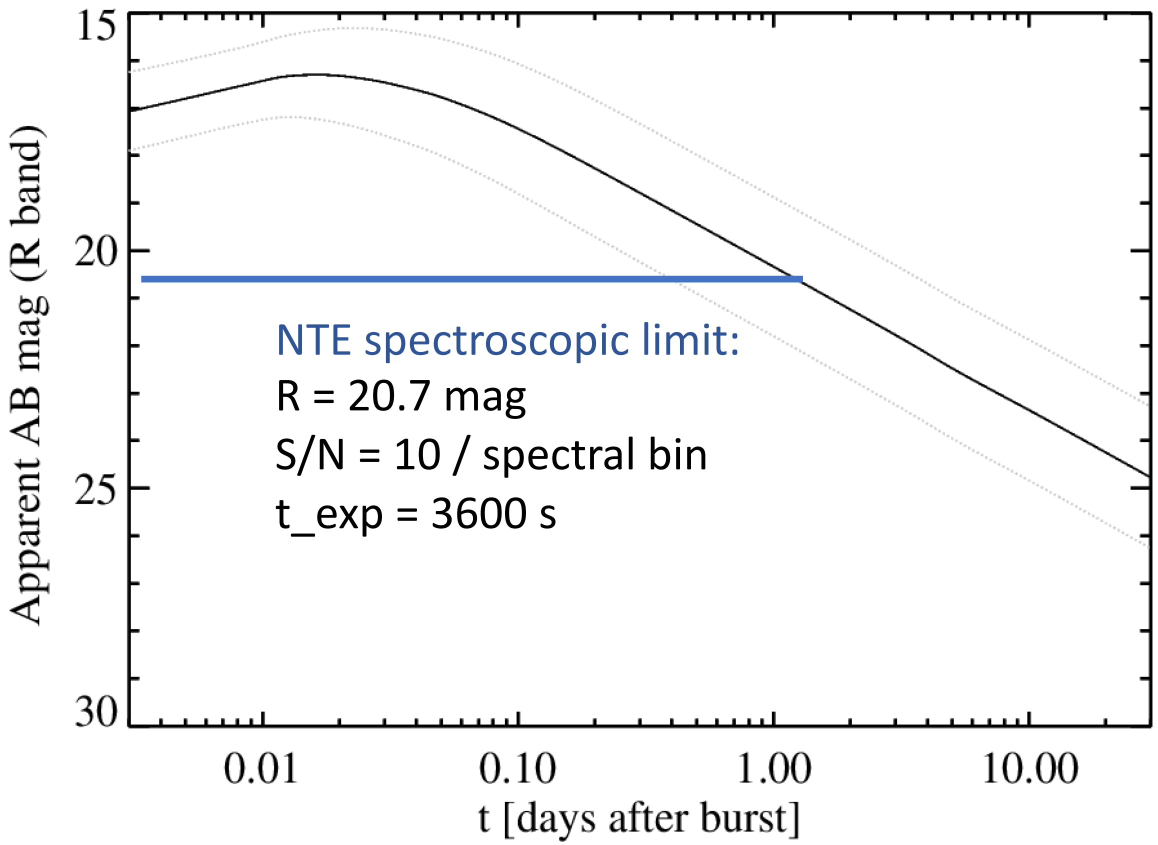
- An observer *may be allowed to reject trigger* within a minute
- RRM mode *may be deactivated* at night
- RRM valid for 4 hours
- Validity can be a problem if the ASCII file is not 100% correct -> low RRM trigger success-rate
- Time accounting after OB execution

Summary : SVOM + NTE

- *NTE will be ideal* for following up transients and GRBs discovered with SVOM
- Fast reaction, automatic detection of new sources
- Fast processing of imaging and spectroscopy data
- 80 nights GTO time with SVOM
- *Learn to use SVOM BA tools* (VT/ XMT position + photometry)
  - Optimize follow-up
  - Define NTE data delivery products (ingest NTE data into archives ?)
  - Follow-up observing team to be formed

Average light curve 6>z>12





Kilonova follow up