Shock breakout and relativistic supernovae

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Plan

- Shock breakout: new instruments and strategies
- Where are the supernova missing a GRB?
- Can we identify chocked jets?
- A continuum in SN - relativistic SN - llGRBs - GRBs, and what are FBOTs?
- Where are the companions?

How can we follow-up SBOs?

Instruments?

Alerts?

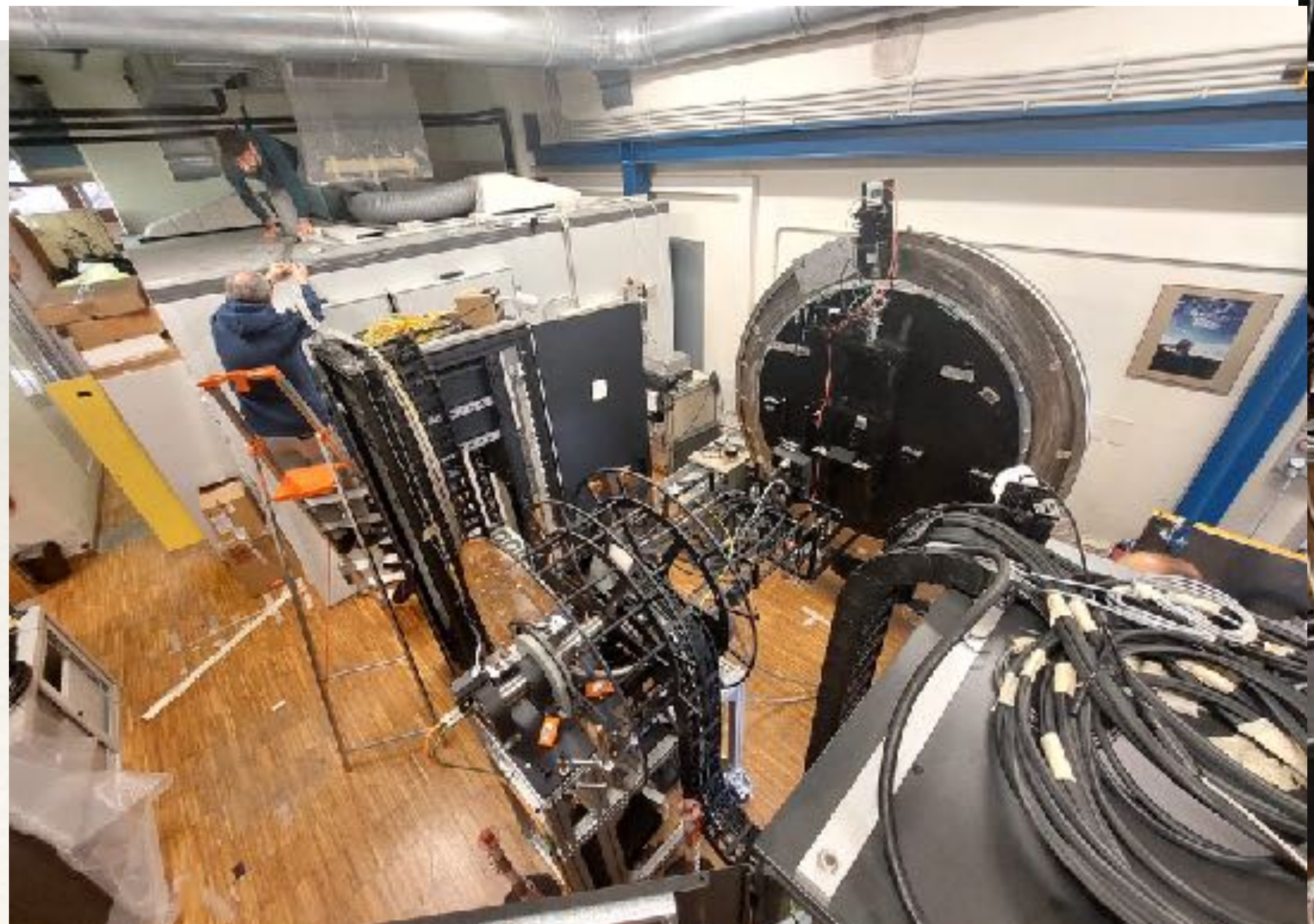
Strategies?

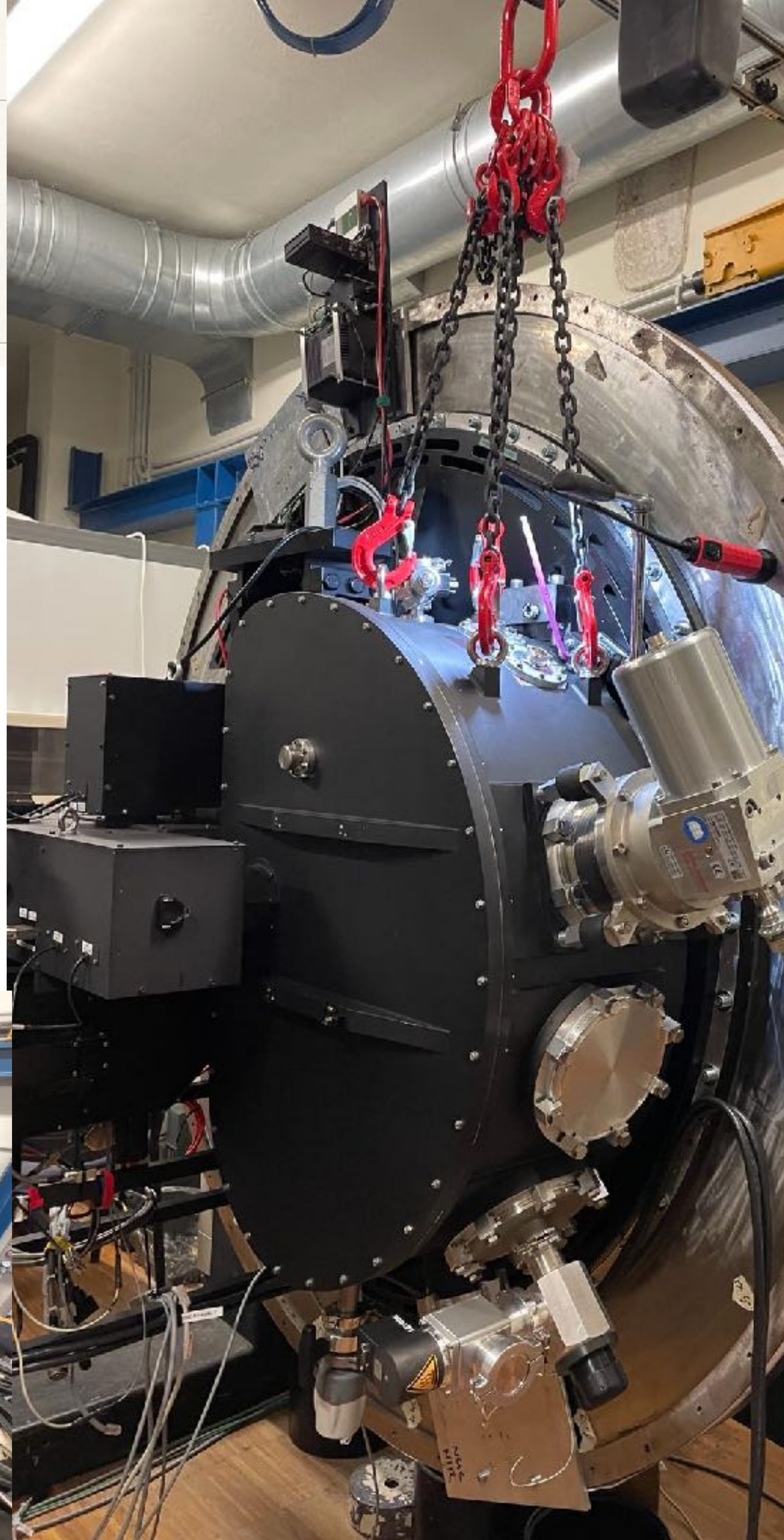
SOXS in a nutshell

Main characteristics

- Single-object
- 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 for $R_{AB}\sim20.5$

SOXS @ NTT/ESO 4m





Responsibilities

INAF ~ 49% (CP, NIR-arm, integration, management, etc.)

Wiezmann ~24% (UV-VIS arm optics and mechanics)

QUB ~8% (reduction pipeline, bought UV-VIS-CCD)

FINCA ~7% (Calibration Unit)

MAS ~6% (Acquisition camera)

Tel Aviv University ~4%

DAWN & Aarhus Univ. ~2%

First light fall 2024

Preliminary GTO/Delta call Spring 2025

Official start GTO October 2025

Kulkarni's comparison

Instrument efficiencies

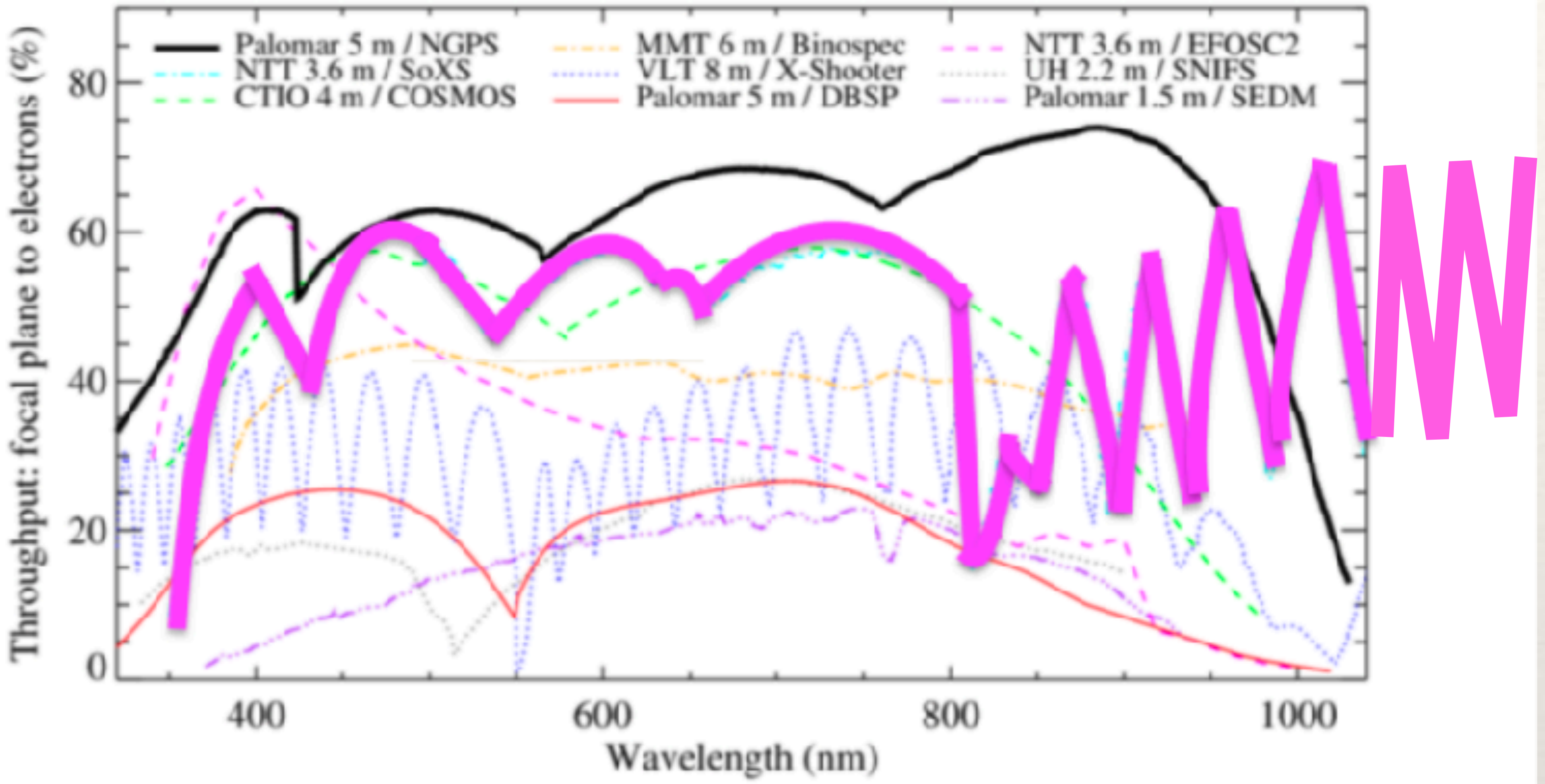


Figure 5. The throughput from the focal plan to photoelectrons of the Next Generation Palomar Spectrograph (NGPS; solid line). The throughput for other spectrographs varies between this measure to "from sky to photoelectrons". References: Son of X-Shooter (SoXS, Claudi et al. 2018, M. Genoni, pers. comm.), 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

Imaging & Acquisition camera

Preliminary ETC for the imaging with the SOXS acquisition camera

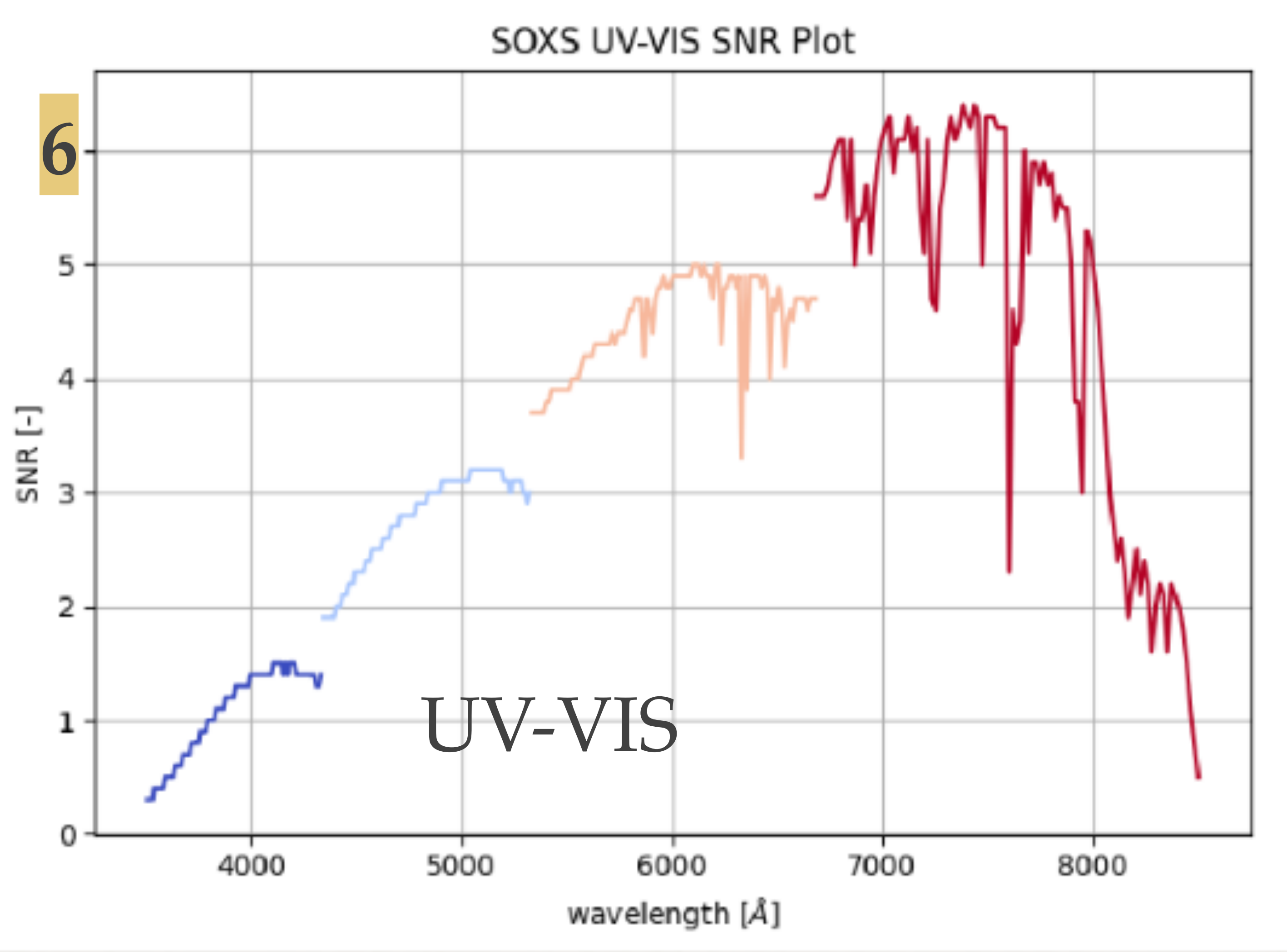
Performances comparable to EFOSC2, slightly worse in the blue-red filters, better in the reddest filters

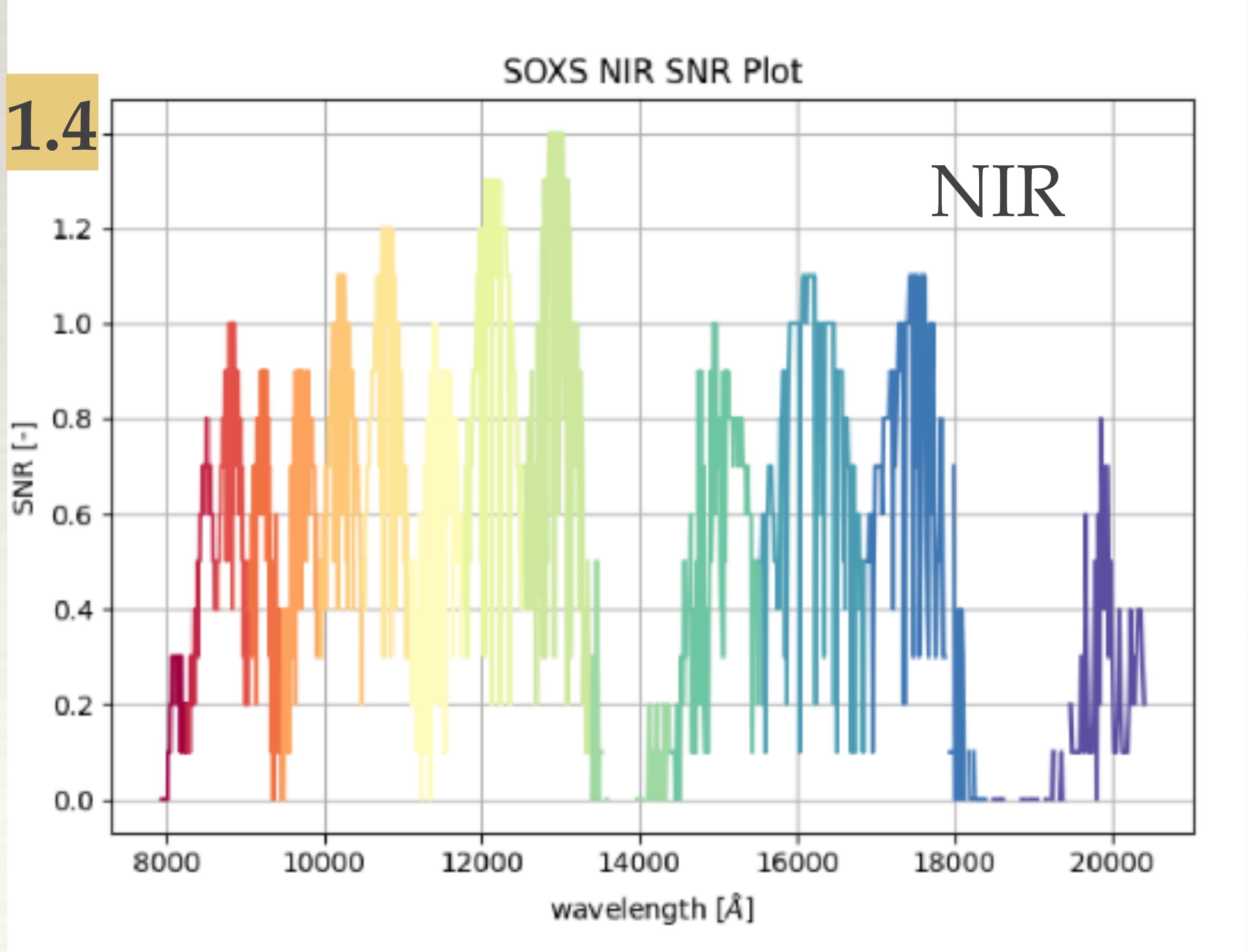
Single exposure 1500s, 0d Moon, 1.2 airmass, 1'' seeing, BB=5600K, mag_AB=24.5

	SOXS	EFOSC2
V	4.2	10.0
g	4.1	9.8
r	6.2	10.0
i	5.7	6.1
z	4.0	3.1

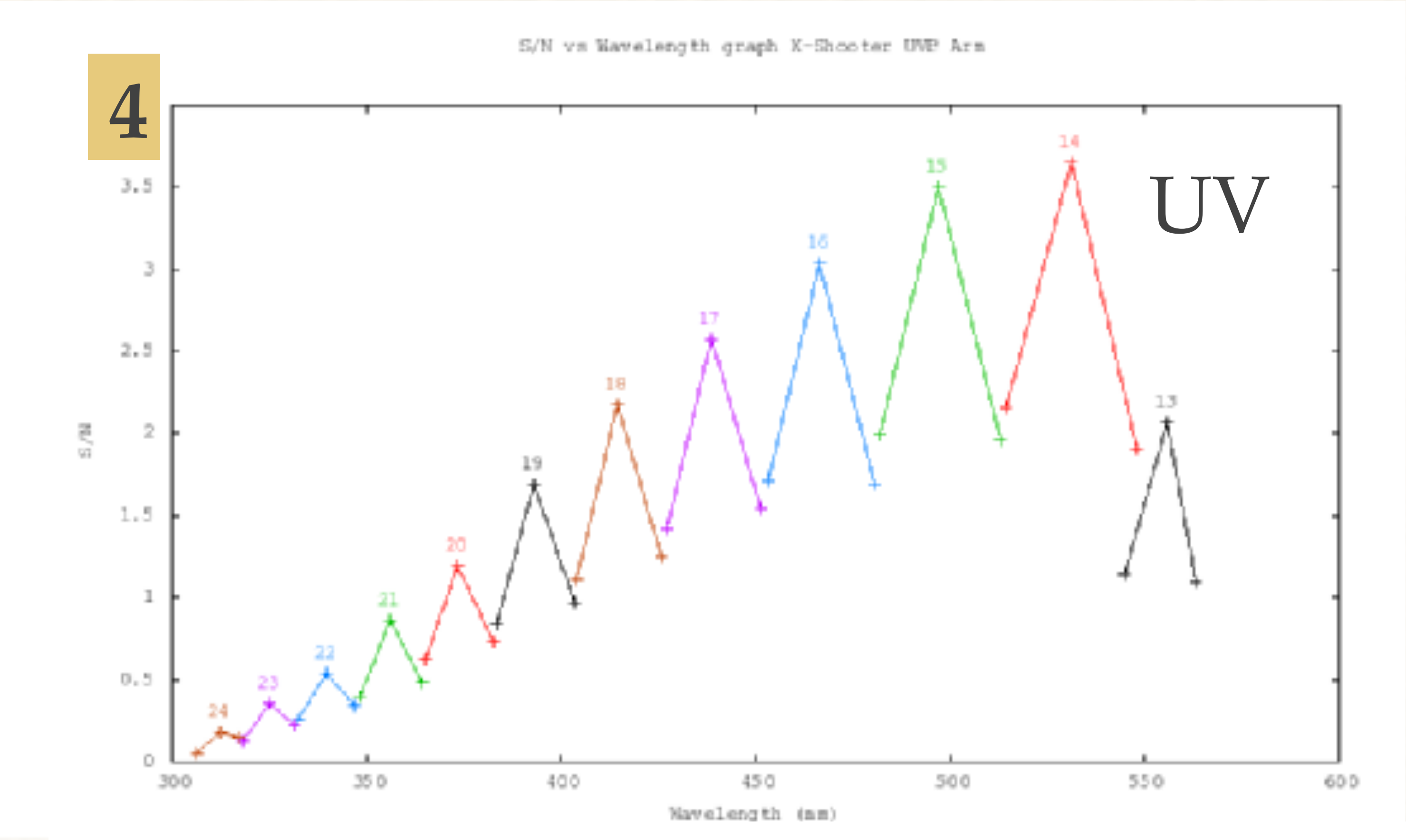
Four 900s exposures, 0d Moon, 1.2 airmass, 1” seeing, PWV=30 BB=5600K, Rmag_AB=21.5

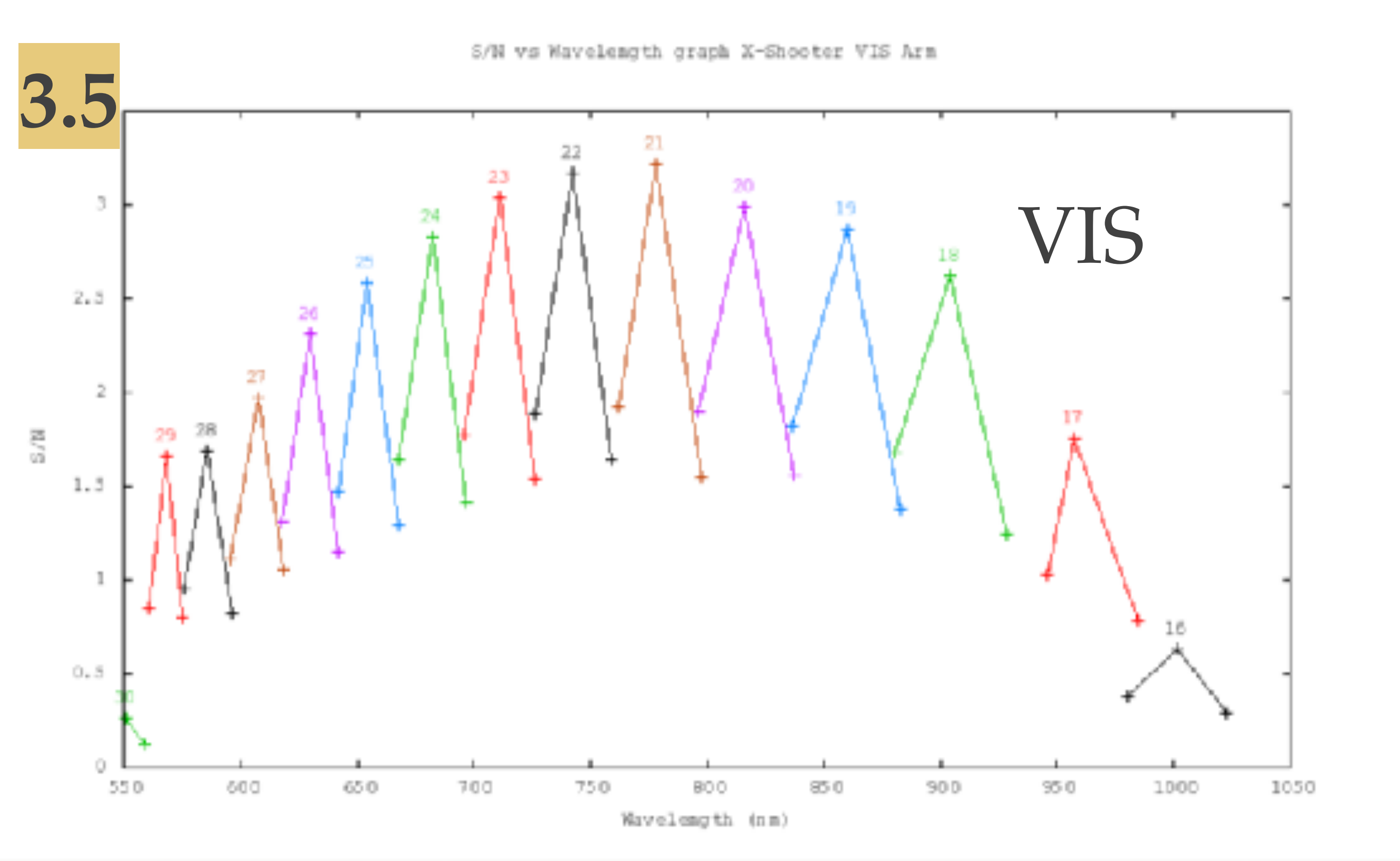
SOXS vs. X-shooter

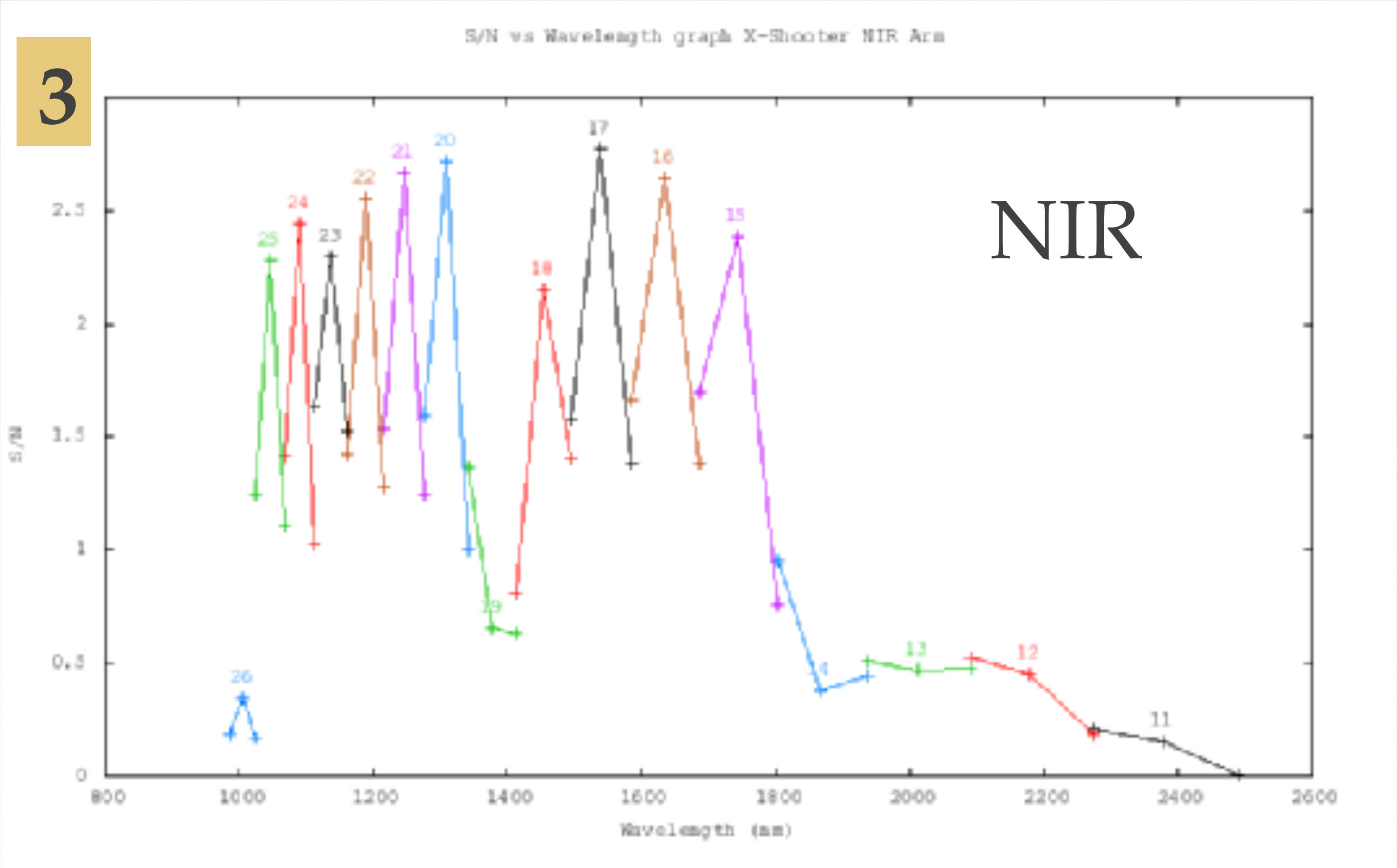




SNR per resolution element







SOXS GTO

- 180 n/yr for 5 yr
- Bad weather shared with ESO
- Time: 8.5 hr * 0.75 eff * 0.9 good *180 n/yr ~ 1000 hr/yr
- SOXS GTO fully dedicated to Target of Opportunity observations for transient and variable sources, very limited time for long term monitoring of variable sources

Operations

SOXS DUTIES

- prepare the overall night schedule in advance
- one scientist will remain on-call for problems and for **changing** the schedule in case of unforeseen fast-track events
- remain on call in case of (rare) instrument problems or more general problems
- help ESO users in case of need (helpdesk during working hours)
- classify “classification targets”
- light quality control

How can we optimise SBO (and other, e.g. FBOT) searches?

Relativistic SNe

- Long GRB collimation angle θ~5-10°
- 1/(1-cos θ) ~ 65-260
- For 1 long GRB we should expect 65-260 SNe for which we do not see the GRB
- Where are these SNe?

Rates

Ho 2020

CC SN	$7.05 \pm 1.57 \times 10^{-5}\ \mathrm{yr^{-1}\ Mpc^{-3}}$	
... SN II	$4.47 \pm 1.39 \times 10^{-5}\ \mathrm{yr^{-1}\ Mpc^{-3}}$	[1]
... SN Ibc	$2.58 \pm 0.72 \times 10^{-5}\ \mathrm{yr^{-1}\ Mpc^{-3}}$	[1]
Ic-BL SN	$3.6 \pm 1.4 \times 10^{-6}\ \mathrm{yr^{-1}\ Mpc^{-3}}$	
	$2.6^{+3.1}_{-2.6} \times 10^{-6}\ \mathrm{yr^{-1}\ Mpc^{-3}}$	
... Frac. of Ibc SN that are Ic	0.69 ± 0.09	[2]
... Frac. of Ic SN that are Ic-BL	0.21 ± 0.05	[2]
... Frac. of CC SNe that are Ic-BL	$0.037^{+0.029}_{-0.037}$	[3]
LLGRB	$\mathcal{R}_{\mathrm{obs}} = 2.3^{+4.9}_{-1.9} \times 10^{-7}\ \mathrm{yr^{-1}\ Mpc^{-3}}$	[4]
	$\mathcal{R}_{\mathrm{obs}} = 3.3^{+3.5}_{-1.8} \times 10^{-7}\ \mathrm{yr^{-1}\ Mpc^{-3}}$	[5]

[1] Li et al. (2011), [2] Kelly and Kirshner (2012), [3] Shivvers et al. (2016), [4] Soderberg et al. (2006b), [5] Liang et al. (2007),

1 GRB = 112 Ibc

1 GRB = 75 Ic

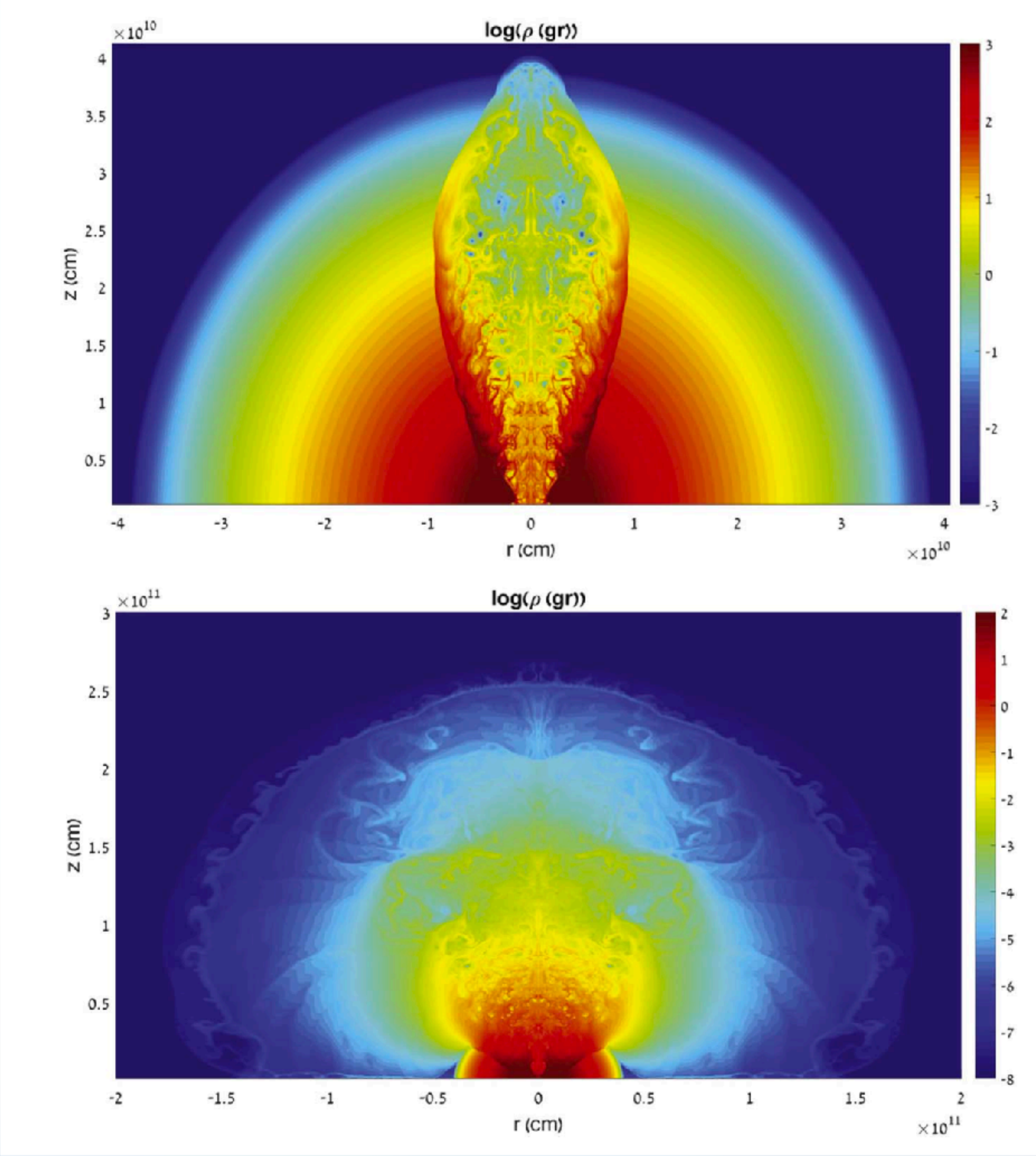
1 GRB = 16 Ic-BL

Long GRBs are usually associated with SN Ic

Only for (the SBO) XRF080109=SN2008D Ib-> Ic

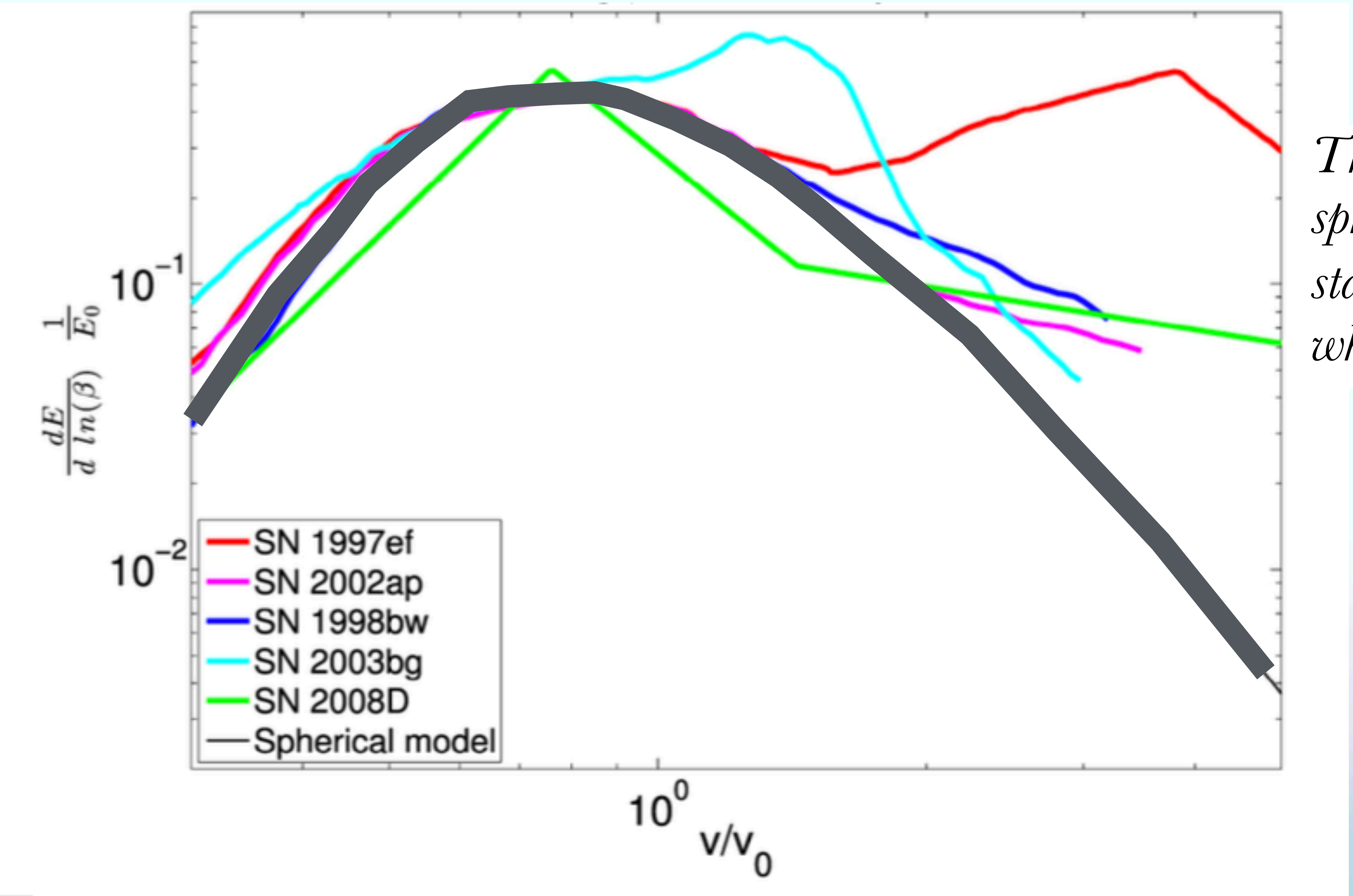
Are all Sn Ibc connected to GRBs?

Chocked jets



Piran et al. 2019

Can we detect chocked jets?

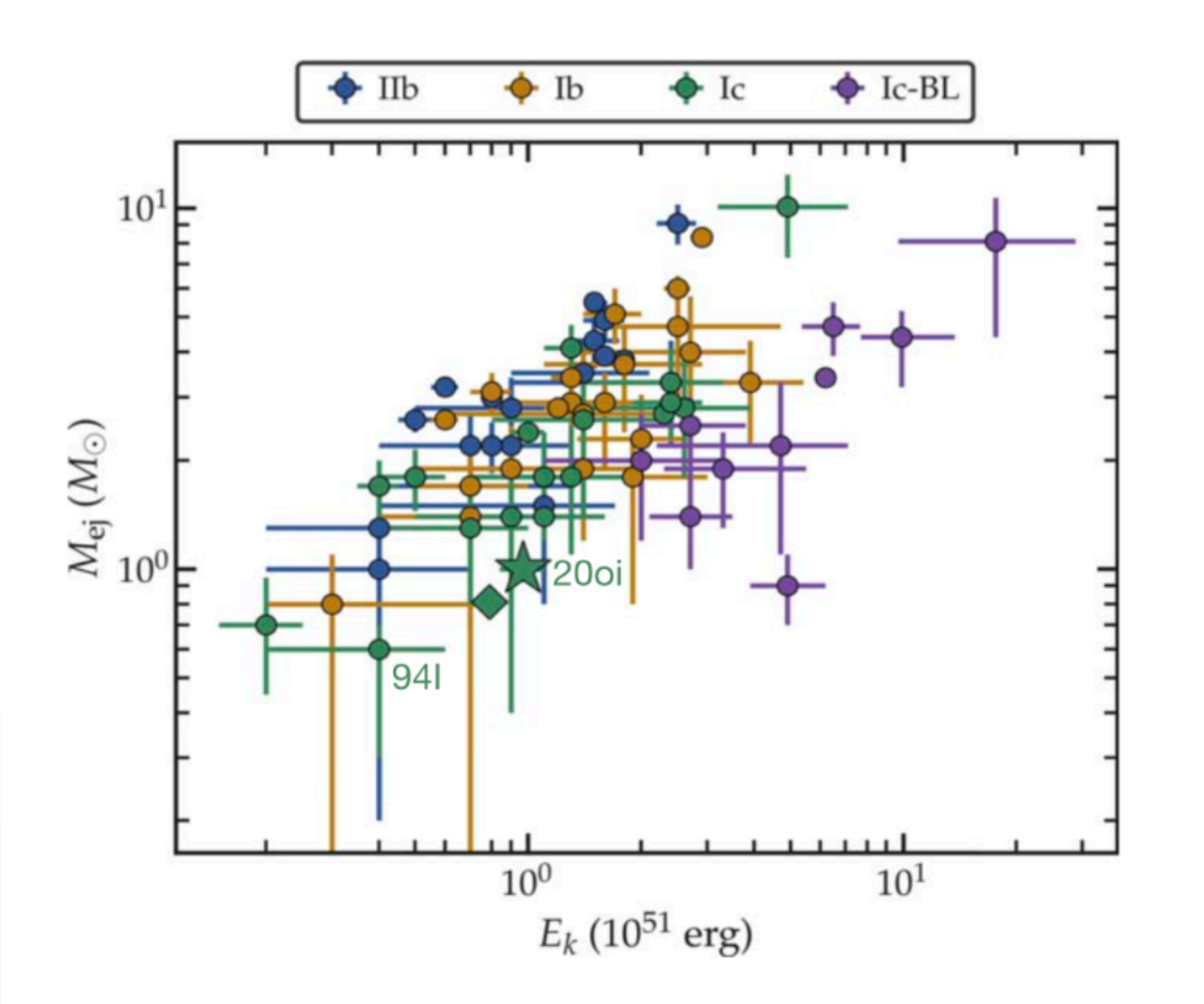


The black line shows the distribution for a spherical explosion of a progenitor with a standard density profile $\rho(r) \propto (R* - r)3$, where $R*$ is the stellar radius.

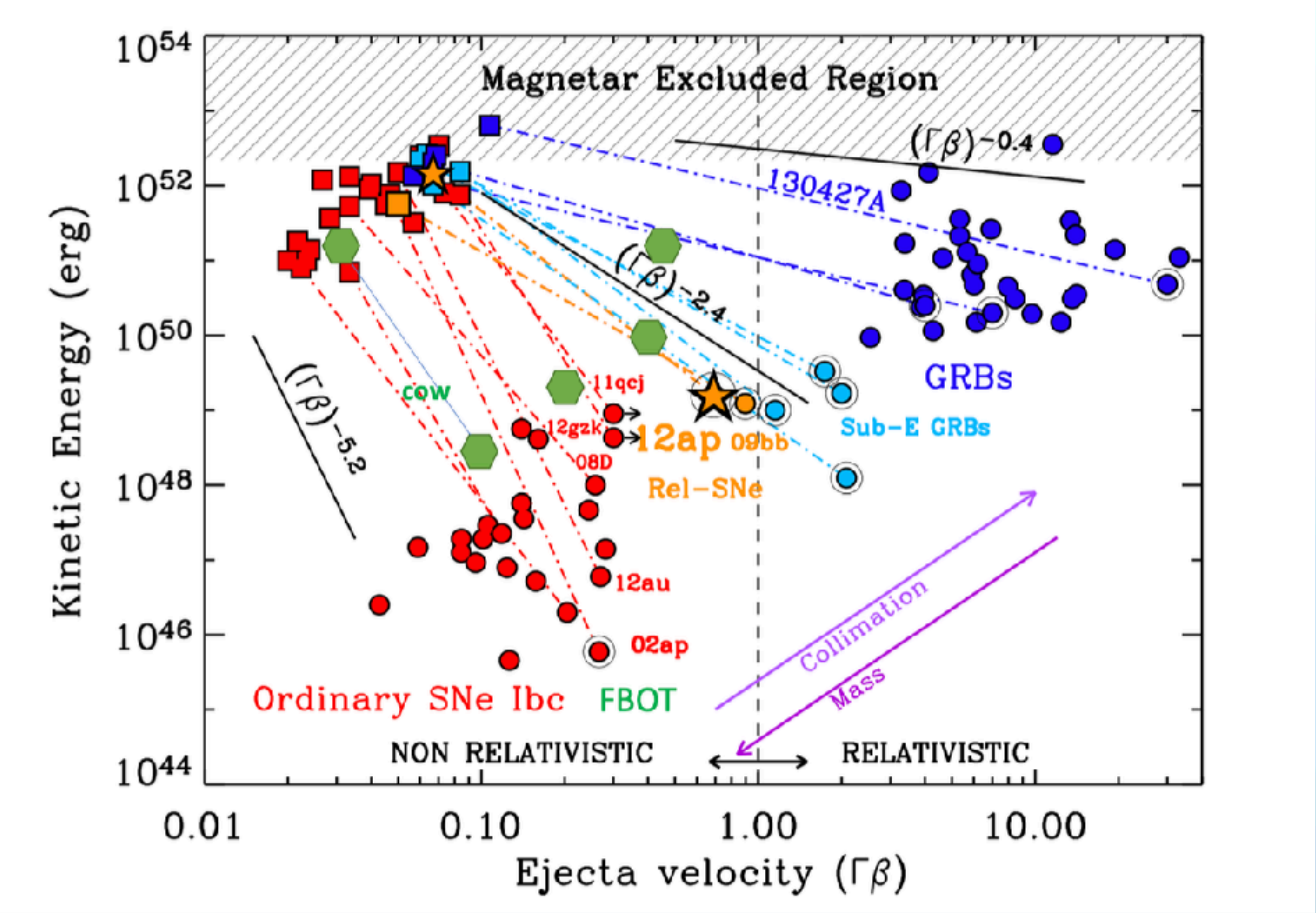
Ehud!

$v0 = \sqrt{2Ekin/Mej}$

A continuum in the central engine powered SN population



Gagliano et al. 2022

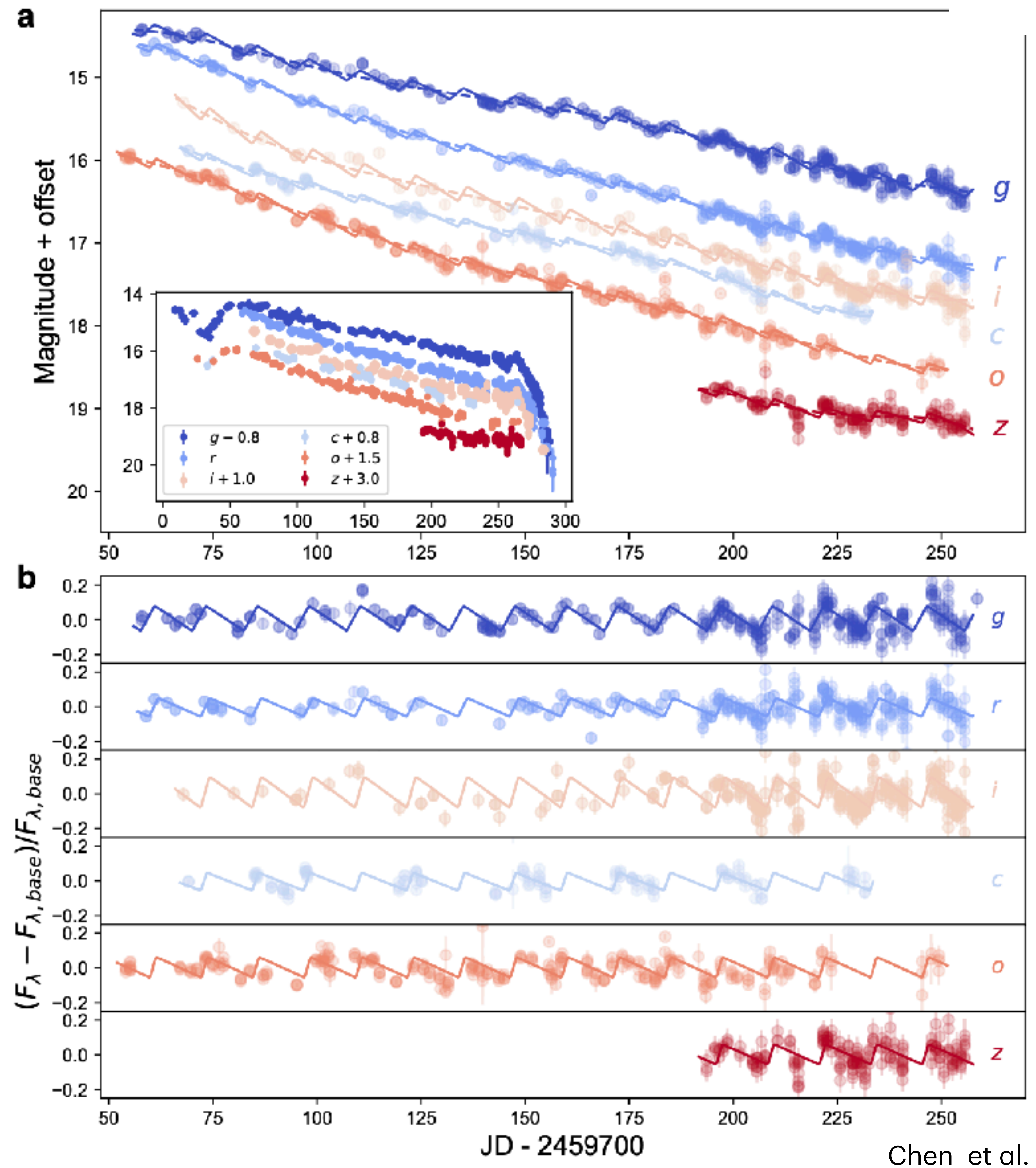


Margutti et al. 2014

Companions?

What is the fraction of stars in binaries?

The average binary fraction is 0.42 ± 0.01 for the whole sample. Thin-disk stars are found to have a binary fraction of 0.39 ± 0.02, thick-disk stars have a higher one of 0.49 ± 0.02, while inner halo stars possibly have the highest binary fraction. 1 dic 2021



Chen et al. 2024

Where are the signatures

of a companion in all the other SNe?