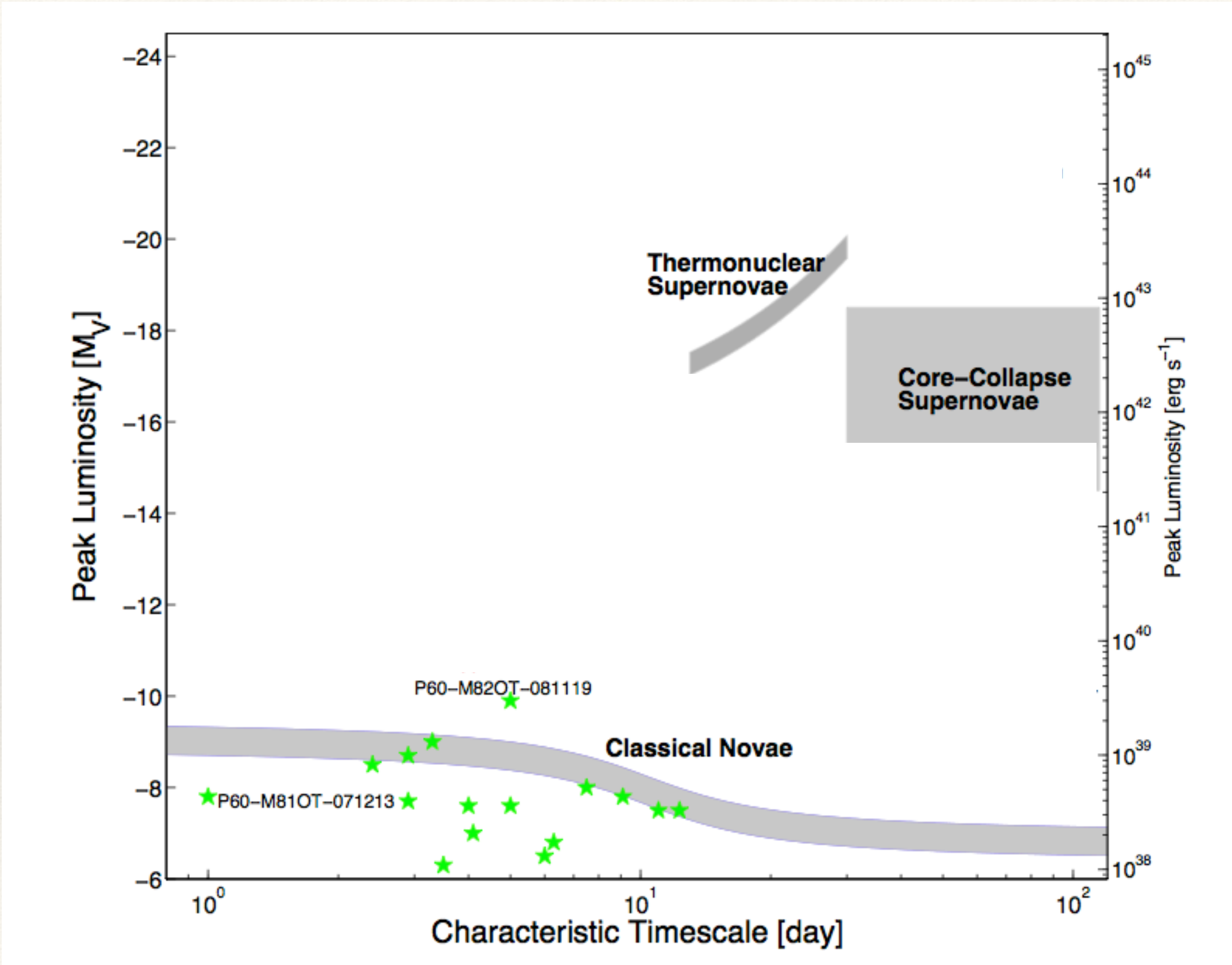
Next-generation of optical facilities in the multi-messenger era: the SOXS case

Enrico Cappellaro on behalf of

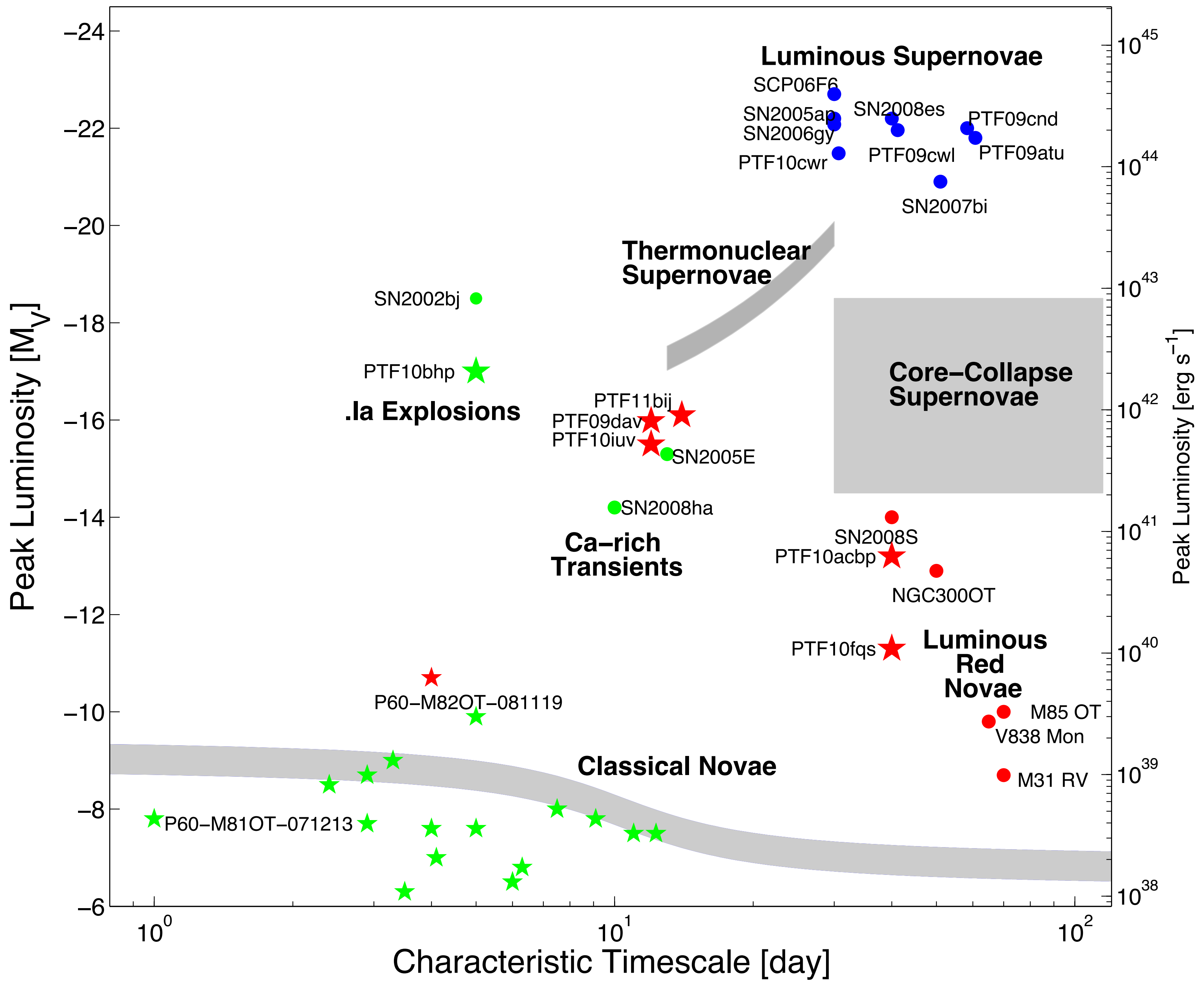
Sergio Campana
INAF - Osservatorio astronomico di Brera

Transients < 2000

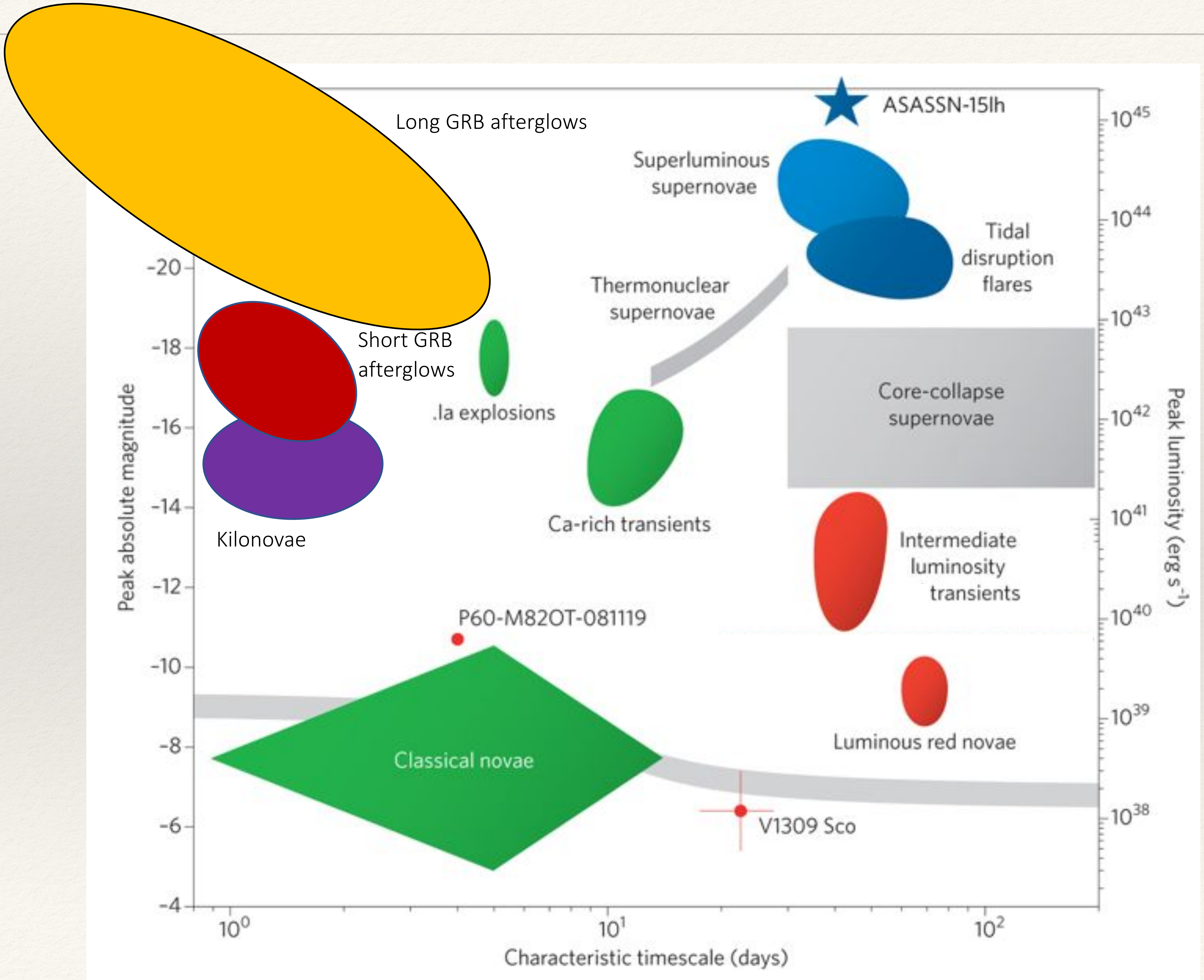


adapted from Kulkarni 2012

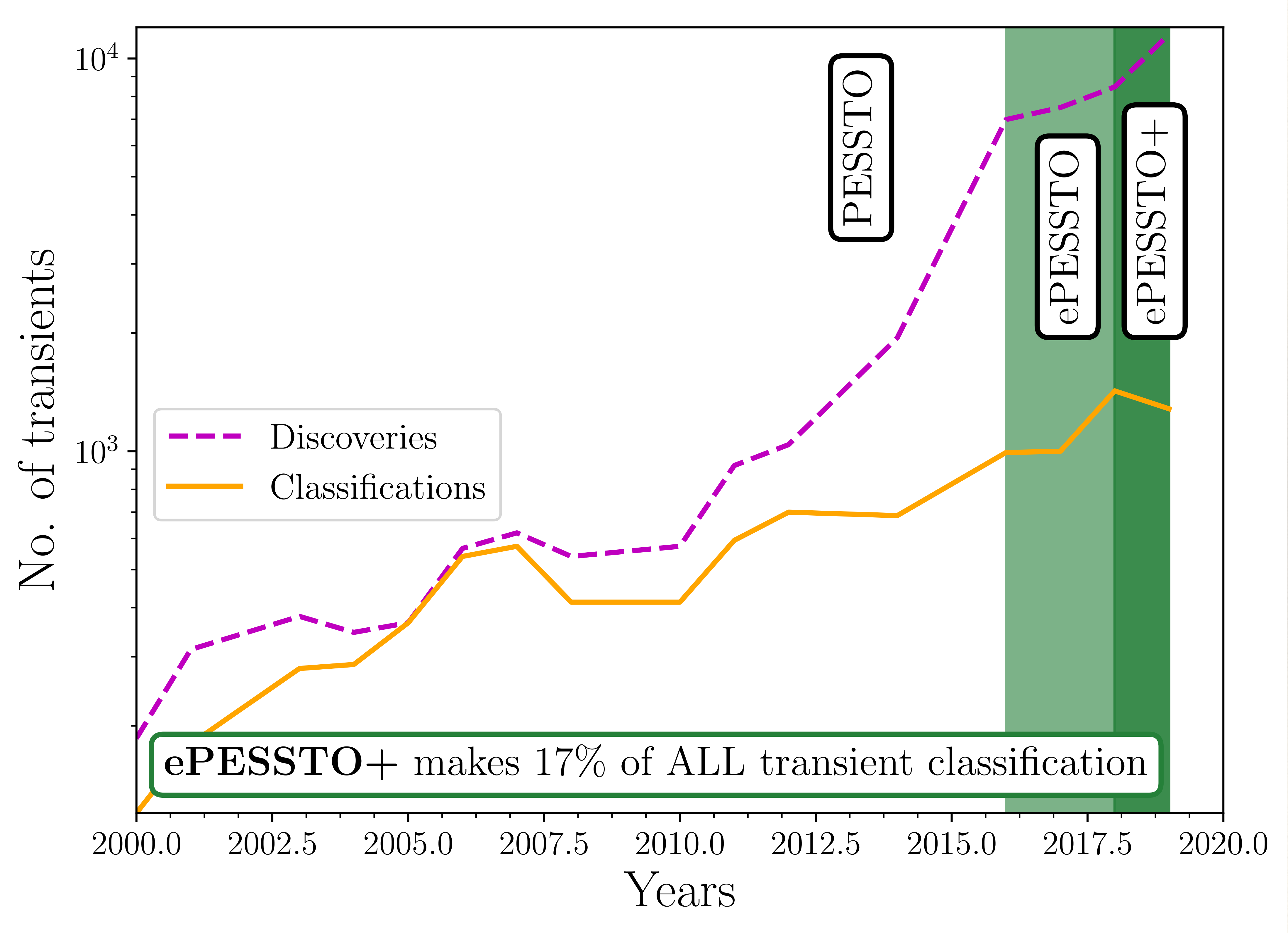
Transients > 2000



Current transients' view

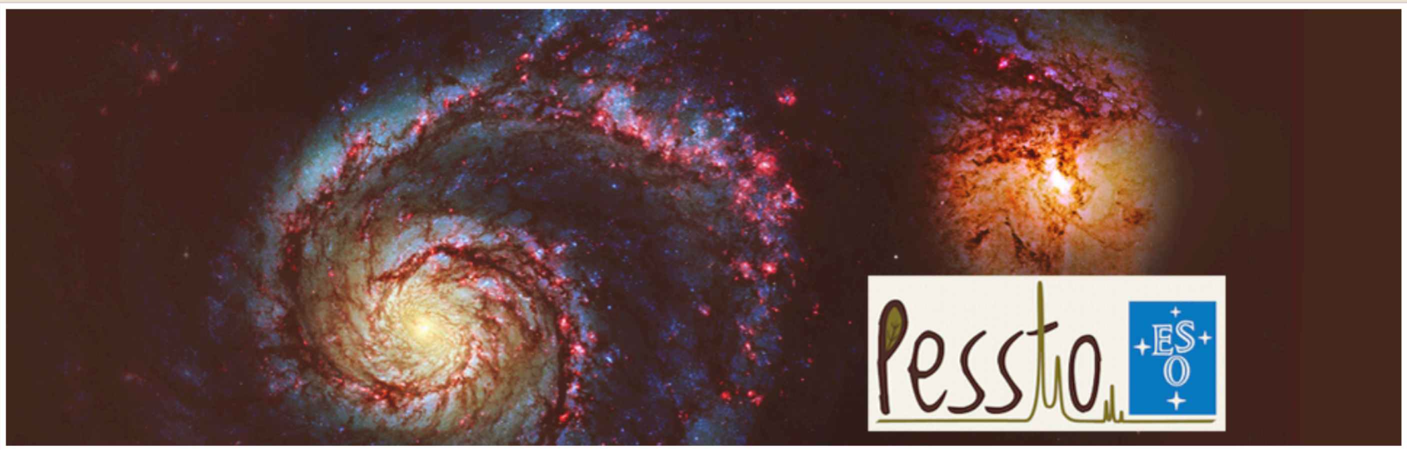


THE problem



PESSTO
ePESSTO
ePESSTO+
Discoveries
Classifications
No. of transients
10^4
10^3
ePESSTO+ makes 17% of ALL transient classification
2000.0
2002.5
2005.0
2007.5
2010.0
2012.5
2015.0
2017.5
2020.0
Years

The current answer



1388 transients classified by PESSTO so far

486 transients are being followed by PESSTO

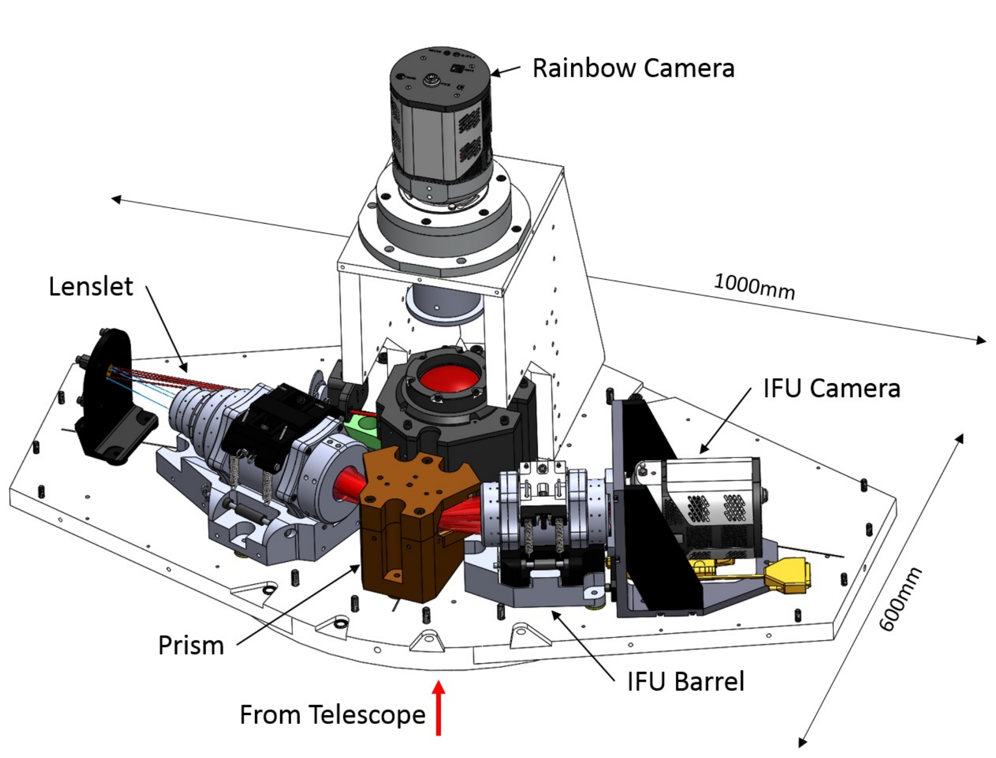
90 nights/year at the ESO/NTT in La Silla

~30% of ePESSTO+ observing time in classification activities

resolution ~500

17% of overall classifications

ZTF/SEDM



resolution ~100

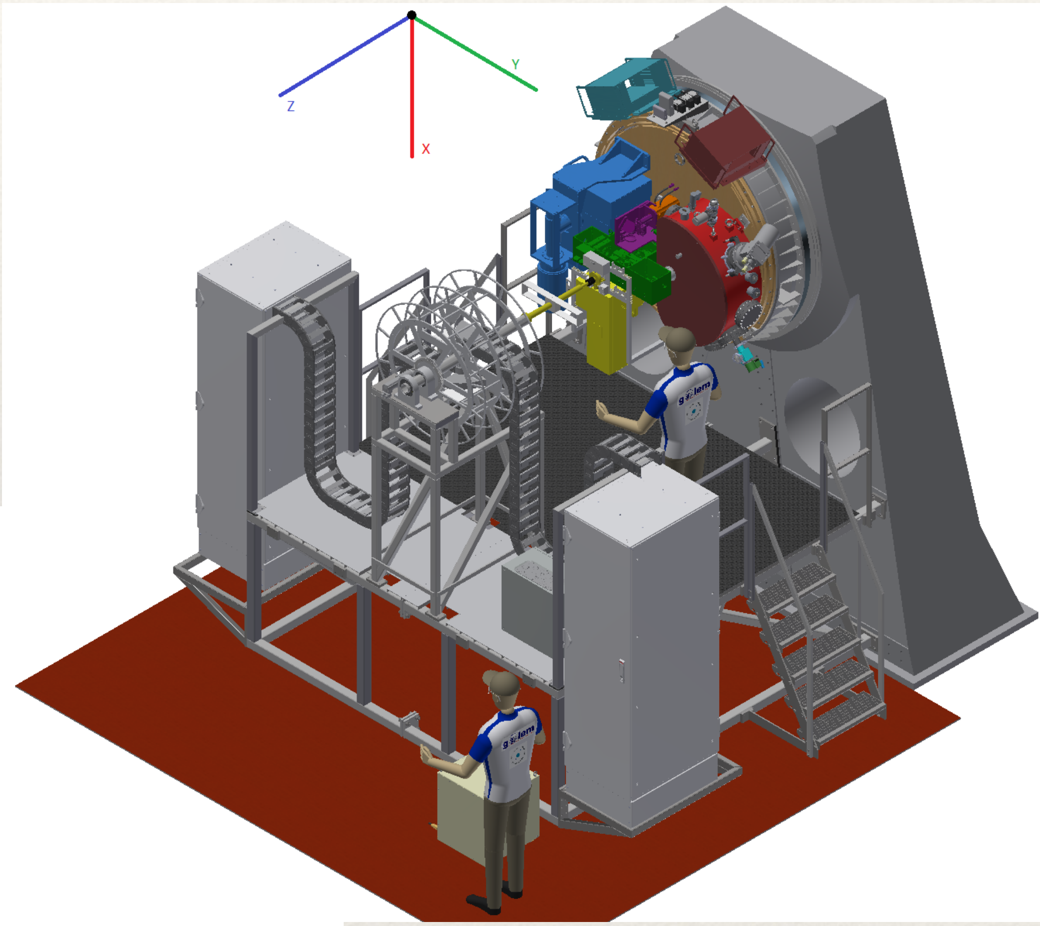
46% of overall classifications

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 R_{AB}~20.5

מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE
Queen's University Belfast
INSTITUTO MILENIO DE ASTROFÍSICA
Turun yliopisto
University of Turku
ISTITUTO NAZIONALE DI ASTROFISICA INAF
Niels Bohr Institutet
TEL AVIV UNIVERSITY

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 UV-VIS arm

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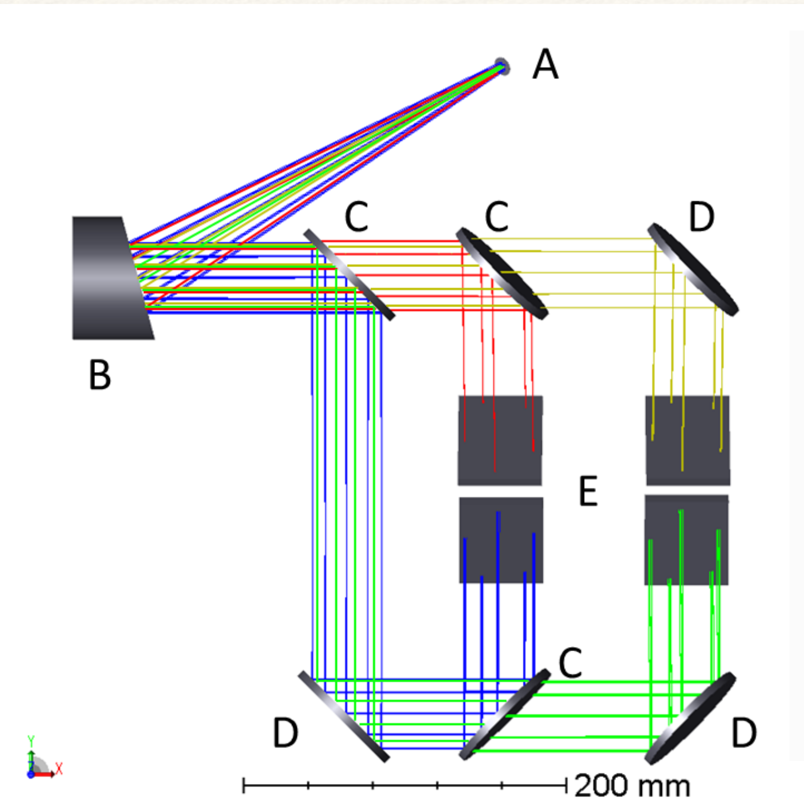
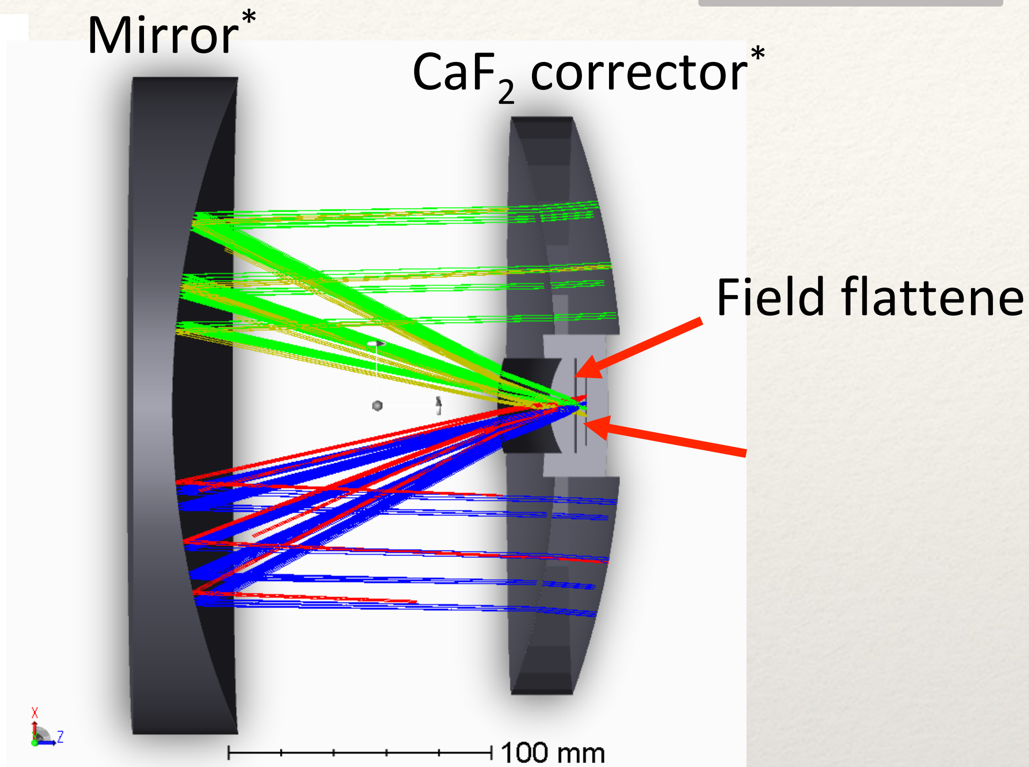
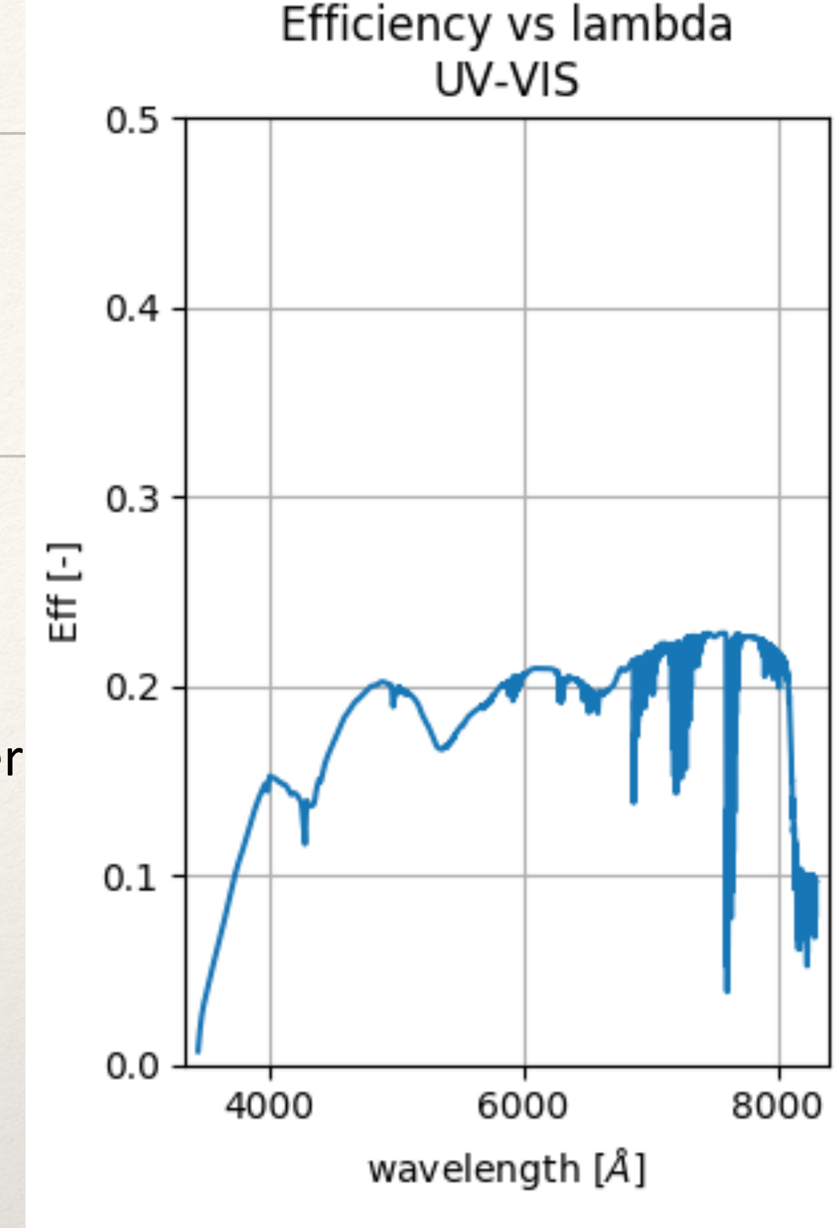
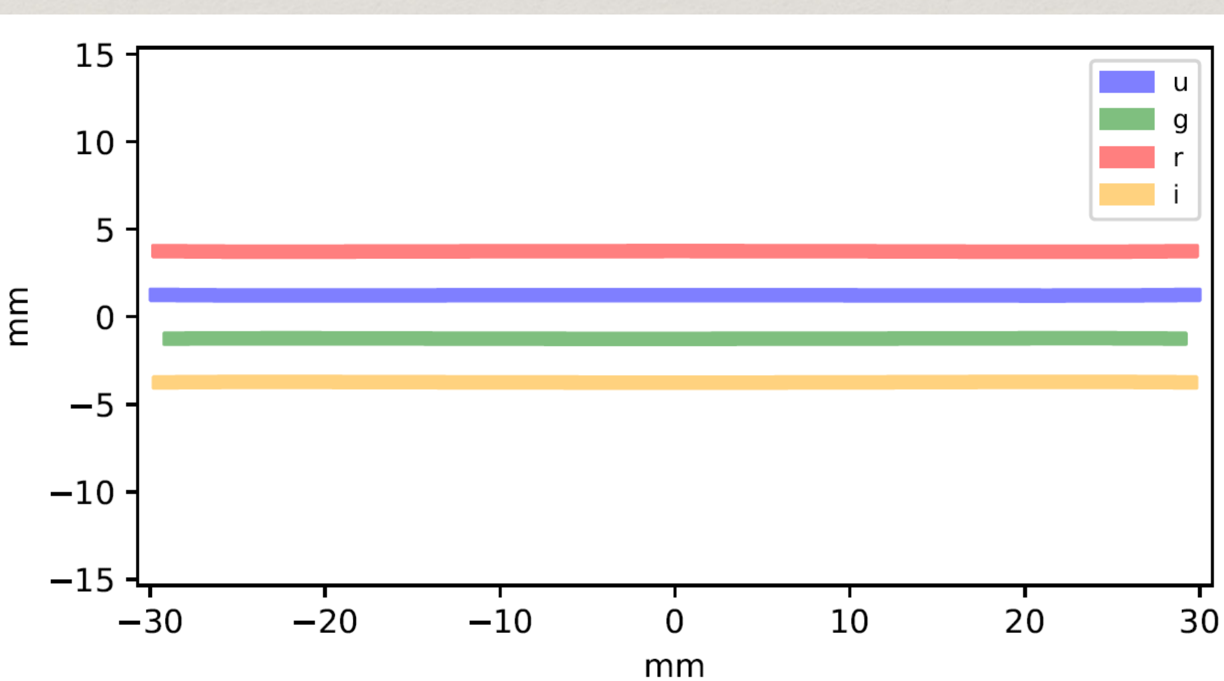
WEIZMANN INSTITUTE OF SCIENCE

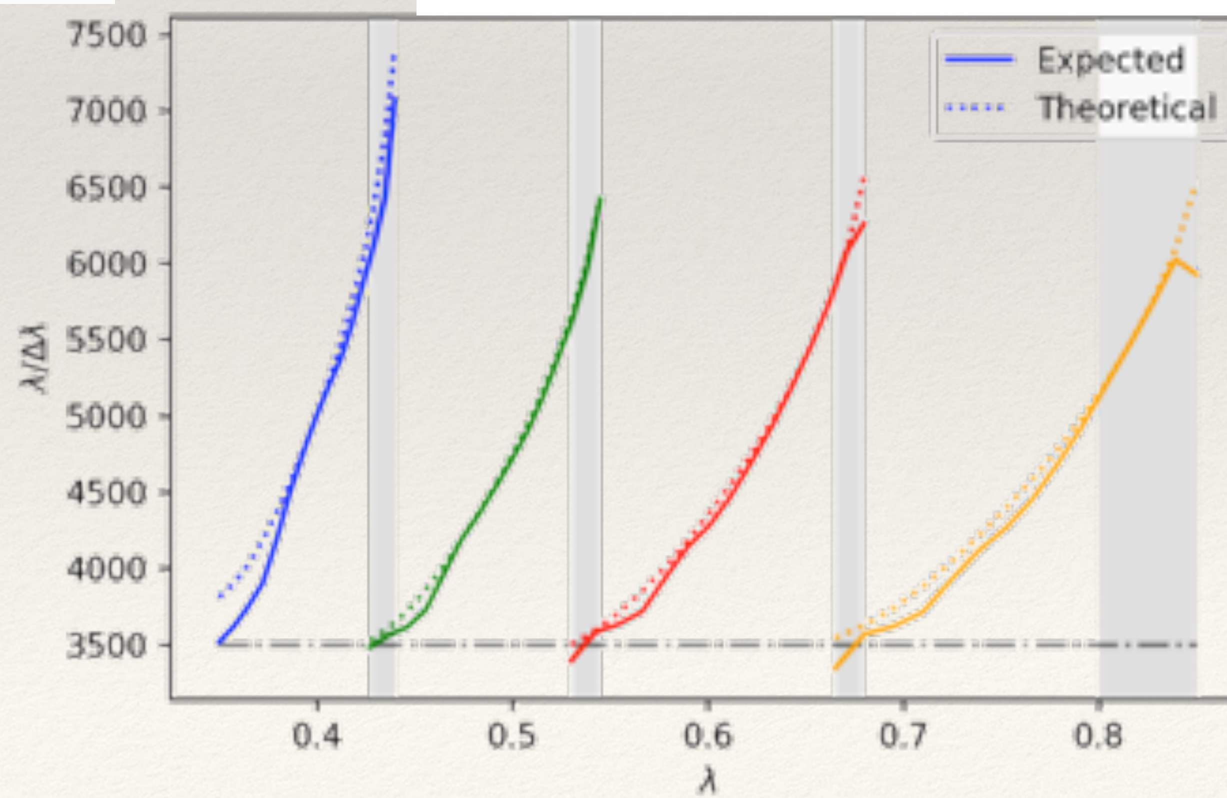
*Aspheric



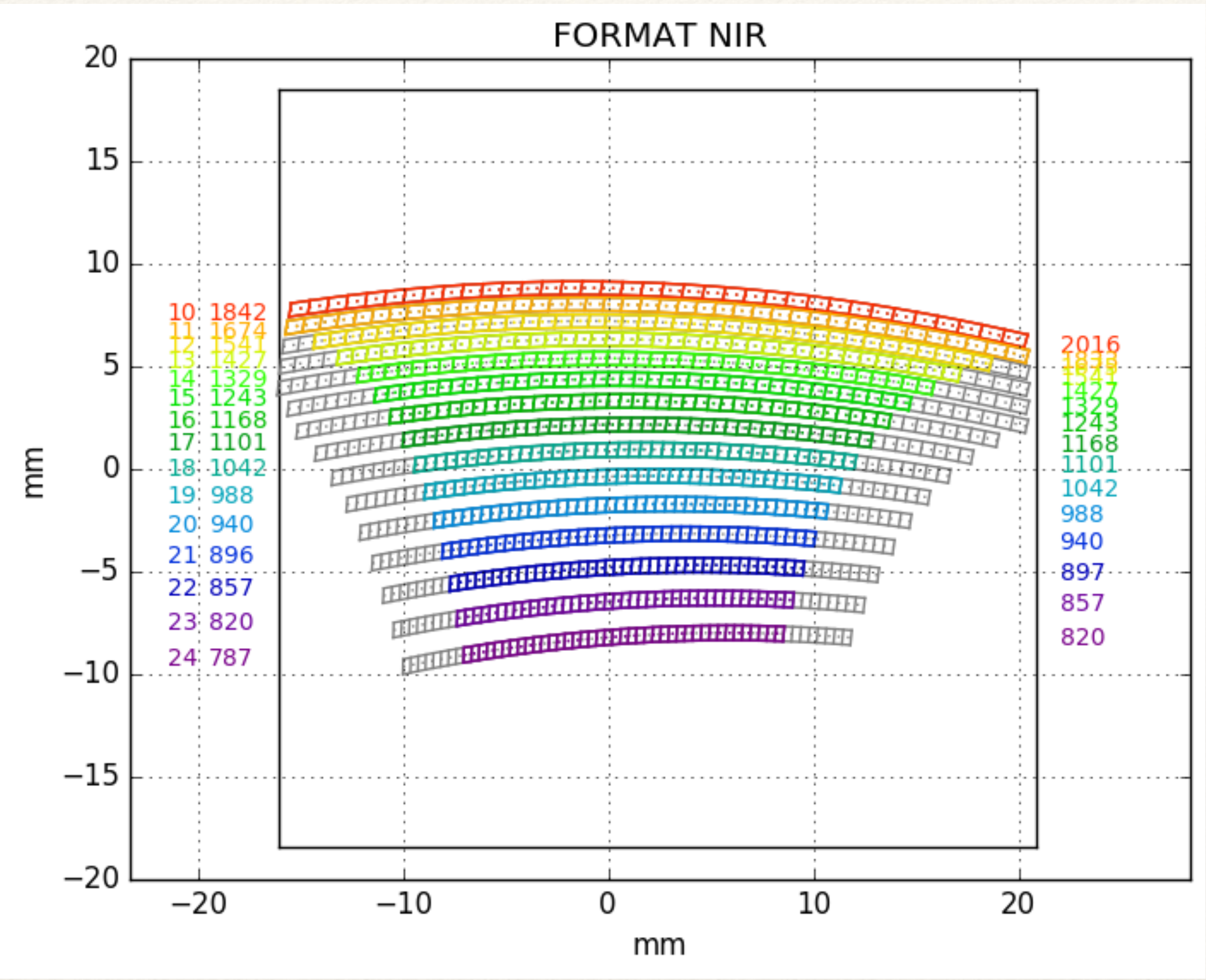


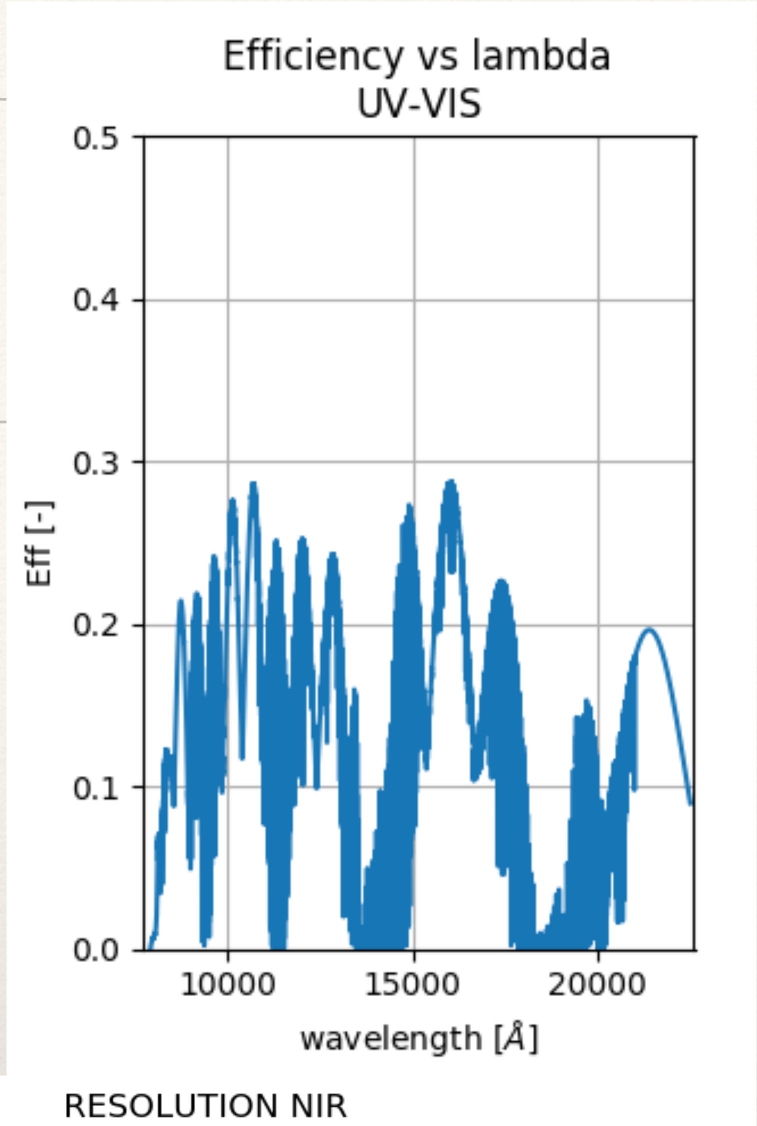


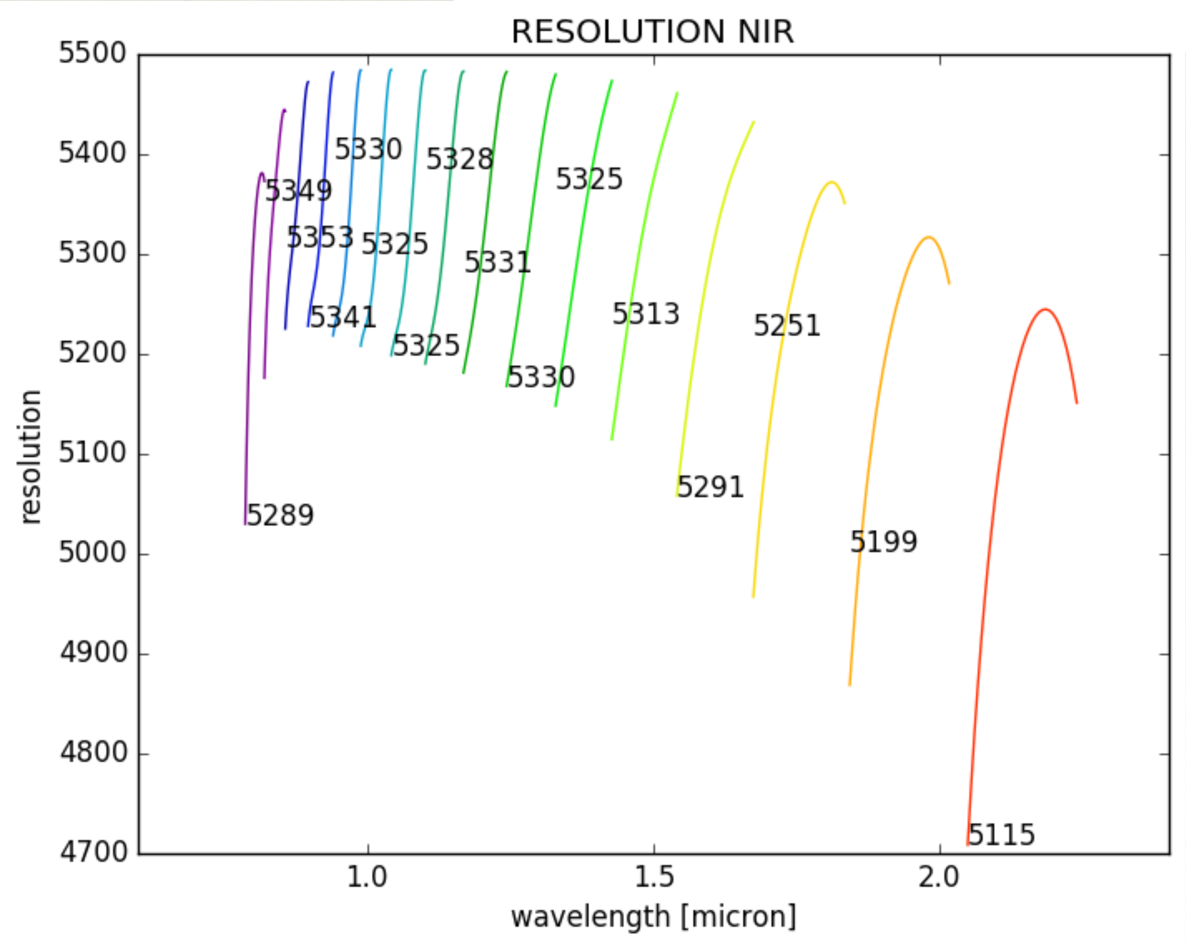




SOXS NIR arm


FORMAT NIR
mm
10 1842
14 1329
15 1243
16 1168
17 1101
18 1042
19 988
20 940
21 896
22 857
23 820
24 787
2016
1168
1101
1042
988
940
897
857
820


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

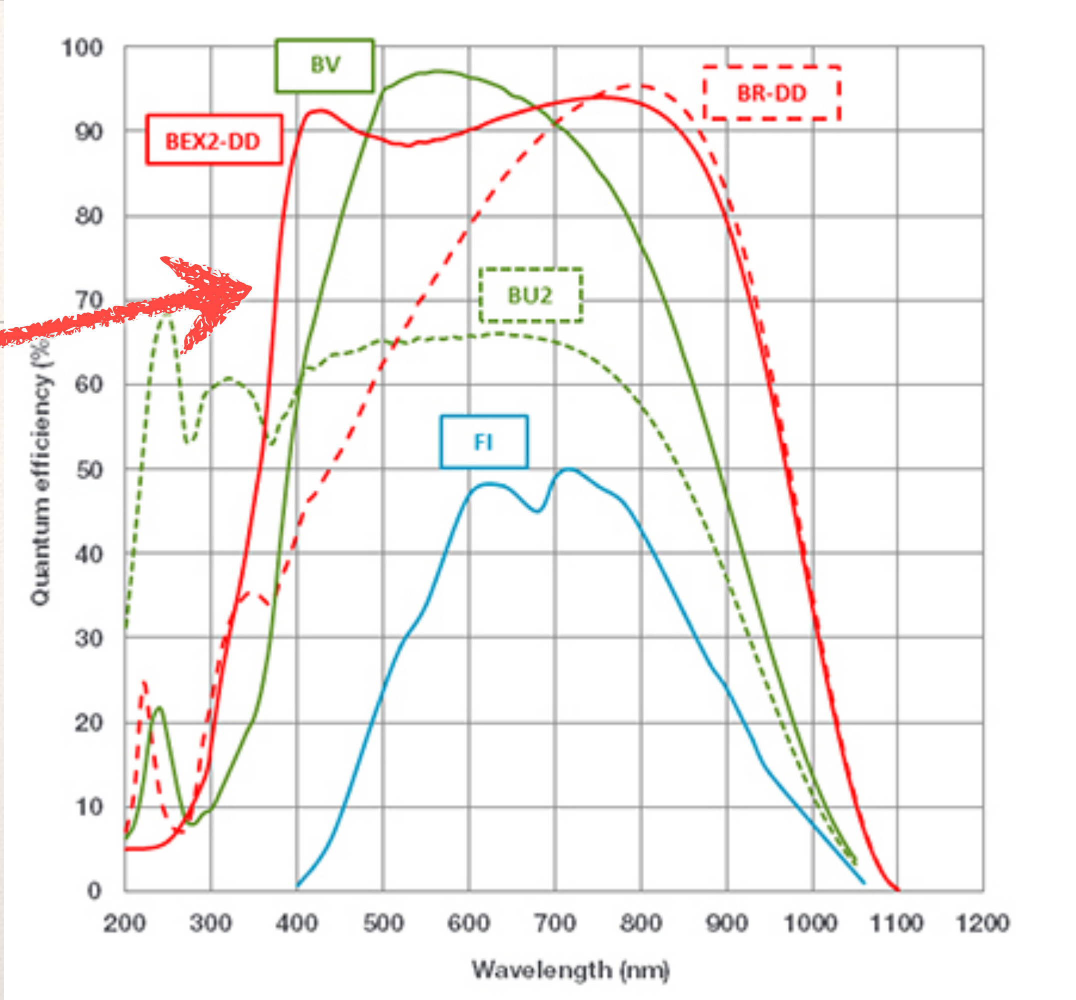

RESOLUTION NIR
resolution
wavelength [micron]
5330
5328
5325
5349
5353
5325
5331
5341
5313
5251
5325
5330
5291
5289
5199
5115

Acquisition Camera

	Value
Field of View (FOV)	3.5 arcmin x 3.5 arcmin
Detector wavelength range	Up to 1.0-1.1micron, with QE>20%
Filters	u, g, r, i, z, y (LSST) and V (Johnson)
Image quality	Scale < 1 arcsec/pixel
Detector format	1k x 1k optimized for NIR QE
Pixel size	13 micron
Frame Rate	High Frame rate (up to 5MHz)
Readout noise	Low read out noise (3.0e-)
Volume	600mm x 340mm x 393 mm
Back focal plane	500mm
Position	Close to the Nasmyth flange/ at least 110mm from the optical axis
Design	*Based on Xshooter A&G*

Acquisition Camera

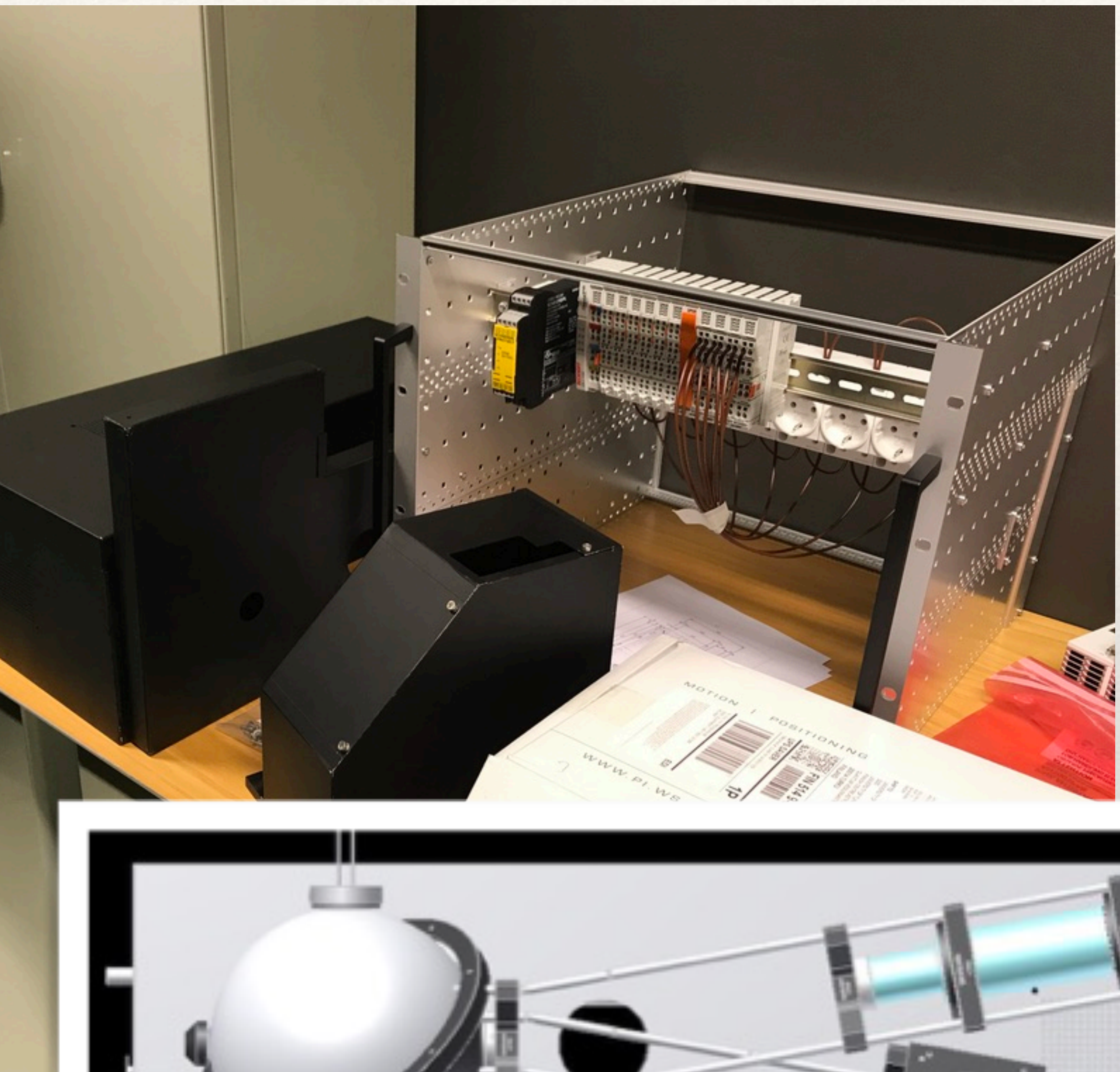
- Andor iKon M-934
- CCD sensor BEX2-DD (Broad band coverage and higher NIR-QE)

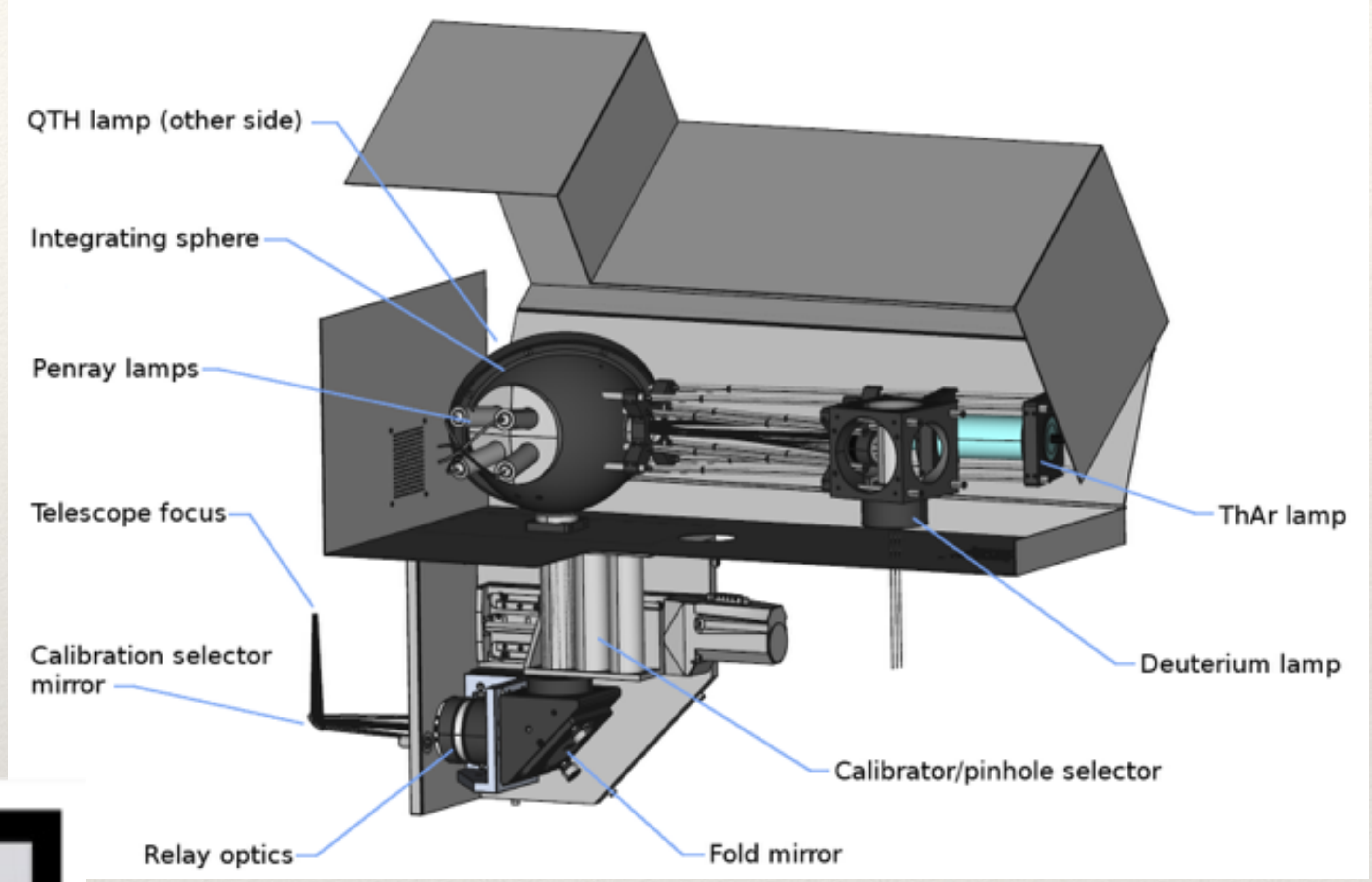


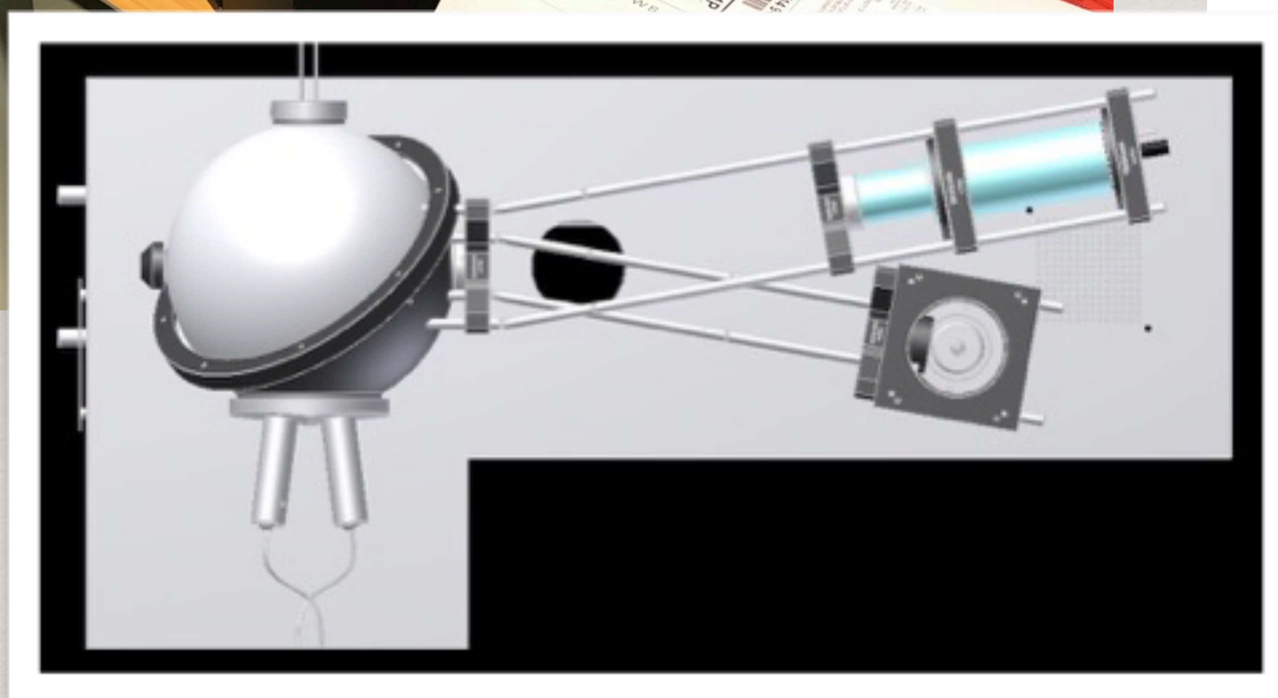
LSST Band (Wav)	1 sec	2 sec	3 sec	5 sec	10 sec	15 sec	20 sec
u’ (355.7nm)	15.9	16.7	17.5	17.7	18.4	18.7	19.1
g’ (482.5nm)	18.2	18.9	19.4	19.8	20.5	20.8	21.0
r’ (626.1nm)	18.0	18.6	19.0	19.5	20.0	20.3	20.4
I’ (767.2nm)	16.4	17.1	17.5	17.9	18.4	18.6	18.8
z’ (909.7nm)	15.3	15.9	16.2	16.5	16.9	17.2	17.4

VIMOS Band (Wav)	1 sec	2 sec	3 sec	5 sec	10 sec	15 sec	20 sec
V (550nm)	19.5	20.1	20.5	21.0	21.5	21.8	21.9

Calibration Unit





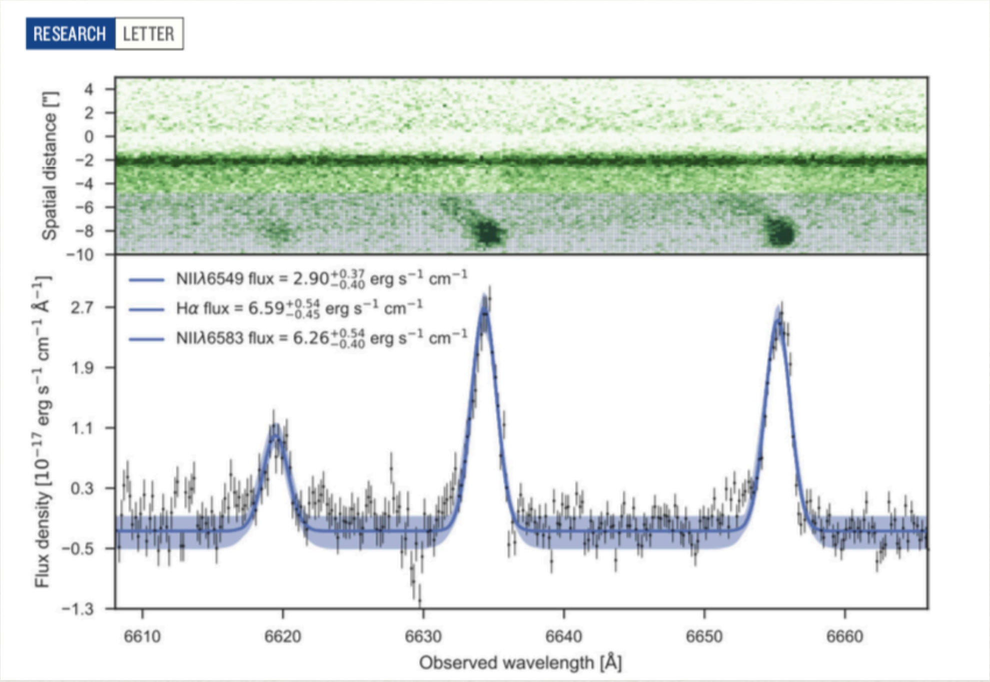


- QTH, penrays, each uses 1 port
- D2 + ThAr occupy 1 port
- —> COTS 4-port sphere (Labsphere)
- cable feedthrough at bottom side, ventilation grills
- cover + hinge for easy lamp access, with interlock

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)



- 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

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

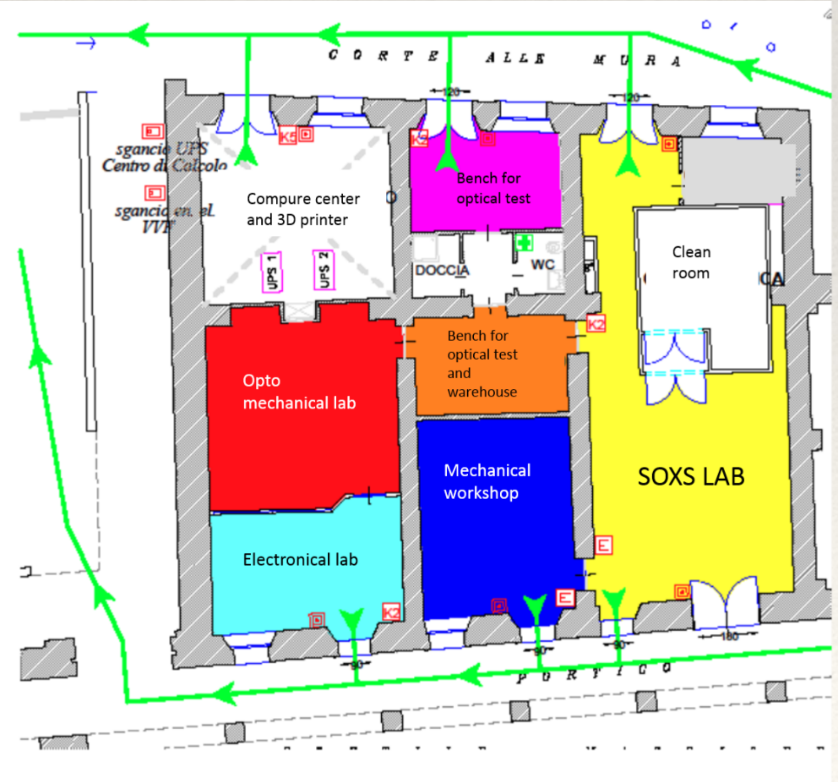
SoXS pipeline will be public

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	02/2021	27 months
Commissioning & PAC (Chile)	03/2021	09/2021	7 months
Operations	2021	2026	

Building SOXS

1. Procurement + SOW
2. Pre sub-system integration = tests on components + facilities
3. Sub-system integration and tests
4. Assembly Readiness Review
5. European System integration and tests
6. System integration and tests @ NTT

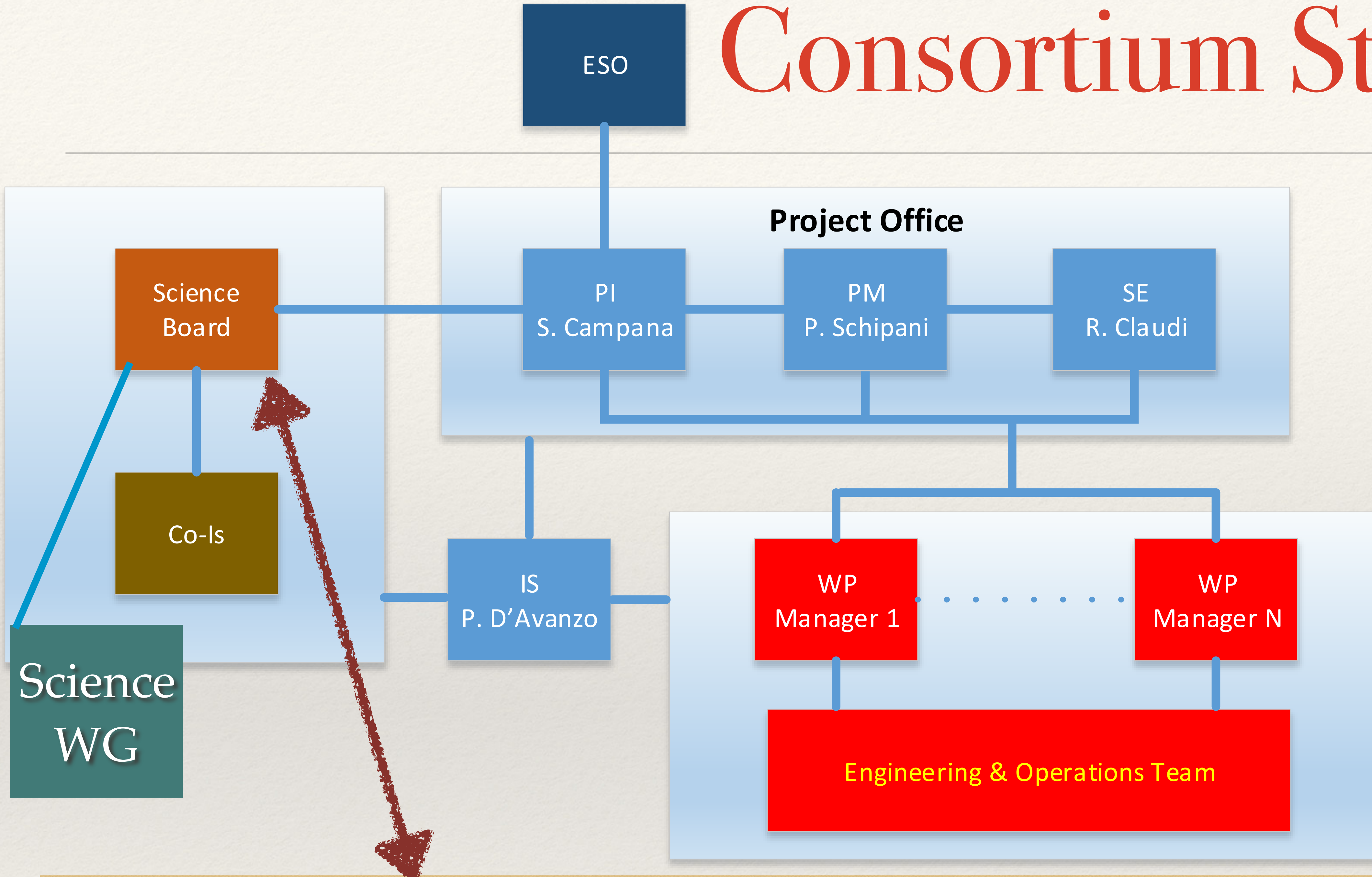


Cui protest?

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

Consortium Structure



- E. Cappellaro (INAF-OAPadova) - Italy
- M. Della Valle (INAF-OANapoli) - Italy
- A. Gal-Yam (Weizmann) – Israel
- S. Smartt (Univ. Belfast) – UK
- I. Arcavi (Tel Aviv University) – Israel
- S. Mattila (FINCA) – Finland
- M. Stritzinger (Aarhus U.) – Denmark
- S. Campana (INAF-OABrera) - Italy

Responsibilities

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

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

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

FINCA ~7% (Calibration Unit)

MAS ~6% (Acquisition camera)

Tel Aviv University ~4%

DAWN & Aarhus Univ. ~2%

SOXS peculiarities

SOXS is an instrument dedicated to the study of transient and variable sources. Some of them are predictable (eclipses, transits, periodic variability), some others have long reaction times (from days to weeks, SN, blazar variability monitoring, binary X-ray transients), but other need fast reaction times, within one night or less.

SOXS will therefore be based on 180n/yr of Target of Opportunity (ToO) observations!

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.

Mountain operations

After an initial period of training (of people) and instrument (set up and debug), no SOXS scientists will be in La Silla (unless for limited periods).

SOXS people
- will prepare the night schedule in advance
- one scientist will remain on-call for problems and for **changing** the schedule in case of unforeseen fast-track events

ESO people
- observations are carried out by the night operator at the NTT telescope

Data management

Data will be first processed on the mountain with the SOXS pipeline and simultaneously transferred to the ESO archive in Garching (10 min). Data processing should be very quick. Quick look on the mountain.

Standard 2D & 1D spectra will be available.

SOXS people will look only at SOXS Consortium data.

Data will be fully compliant with ESO standard.

Data reduction pipeline will be public.

Data policy

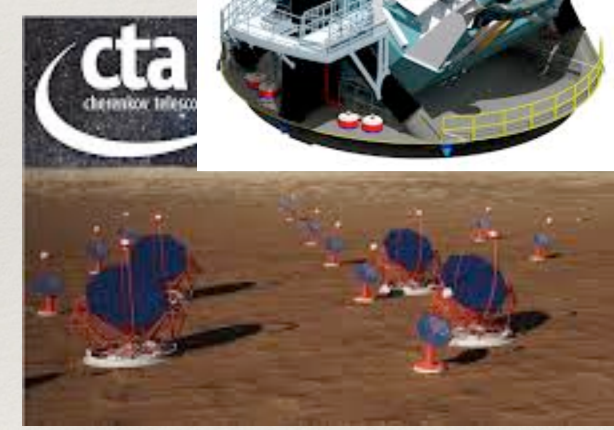
SOXS-GTO sources selected with <u>clear triggering criteria</u>, Criteria will be made public before the start of the operations (and updated every 6 months).

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

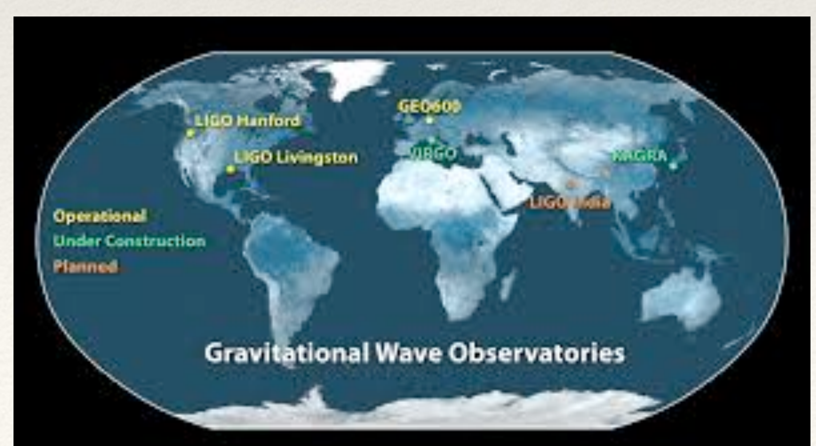
SOXS will also take classification spectra of sources from optical surveys (up to 25% of SoXS GTO observing time).
These data can be claimed by the SOXS Consortium within 3 days, if they fall under a GTO proposal (and will then remain private for 12 months). Otherwise classification data are public.

Why do we need SOXS

Current & new optical survey: ASAS-SN, ATLAS, DES, ZTF, LSST, …
Space optical missions: Gaia, EUCLID, …
Space high-energy missions: Swift, Fermi, eROSITA, SVOM, …
Radio new facilities: MeerKAT, SKA, …
VHE: MAGIC, HESS, CTA
Messengers: LIGO-Virgo, KM3Net, ANTARES, …



SOXS@NTT will have 180 n/yr (for 5 yr)
~3,000 - 4,000 spectra/yr



ANTARES

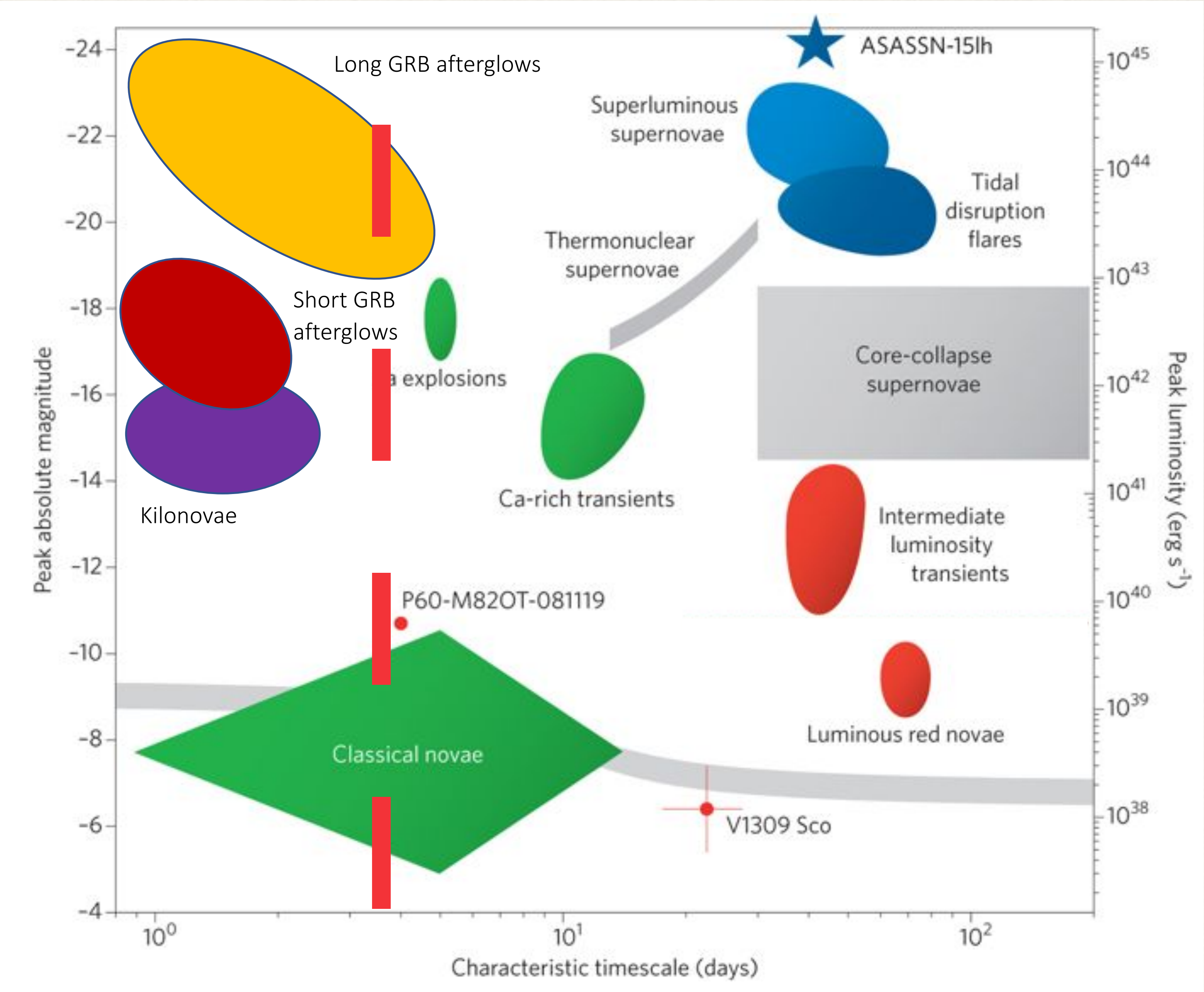
SVOM

SKA
SQUARE KILOMETRE ARRAY

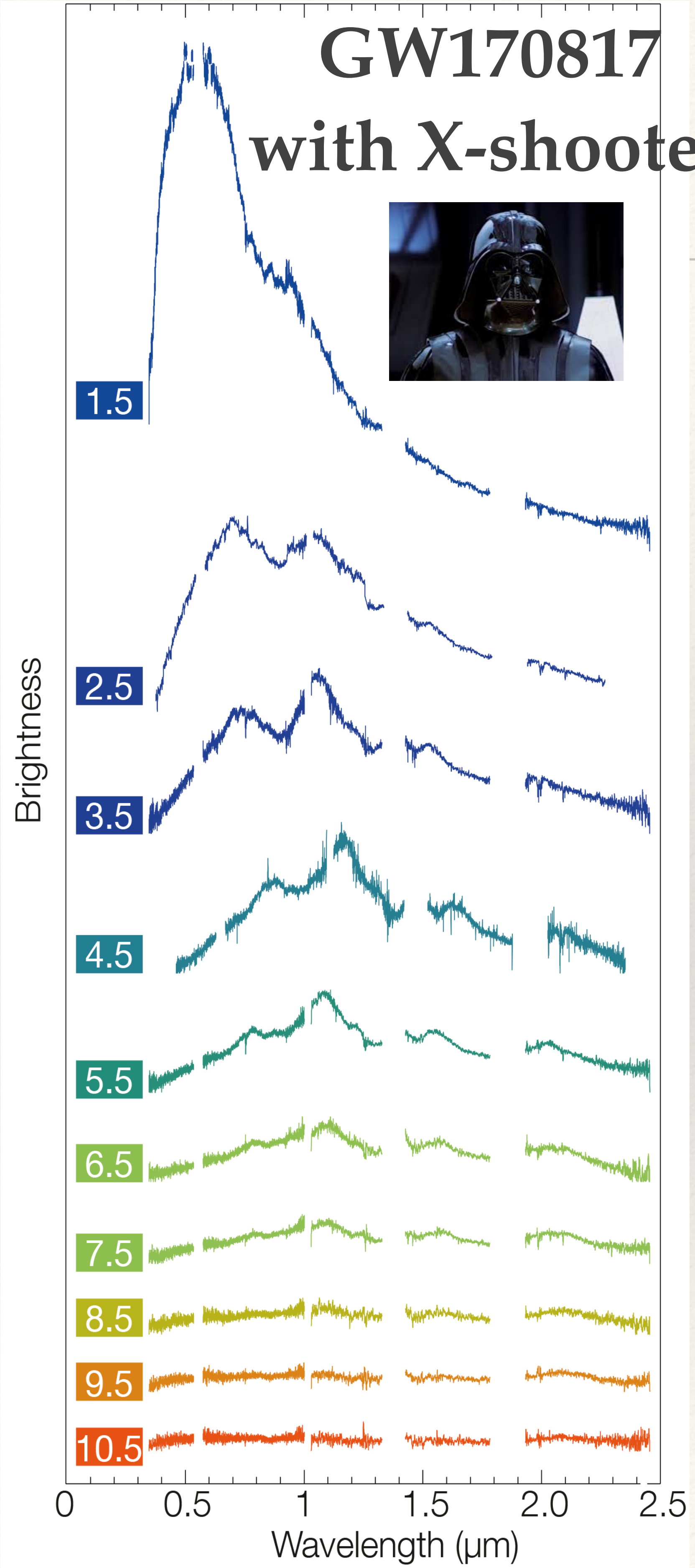
SOXS Science cases

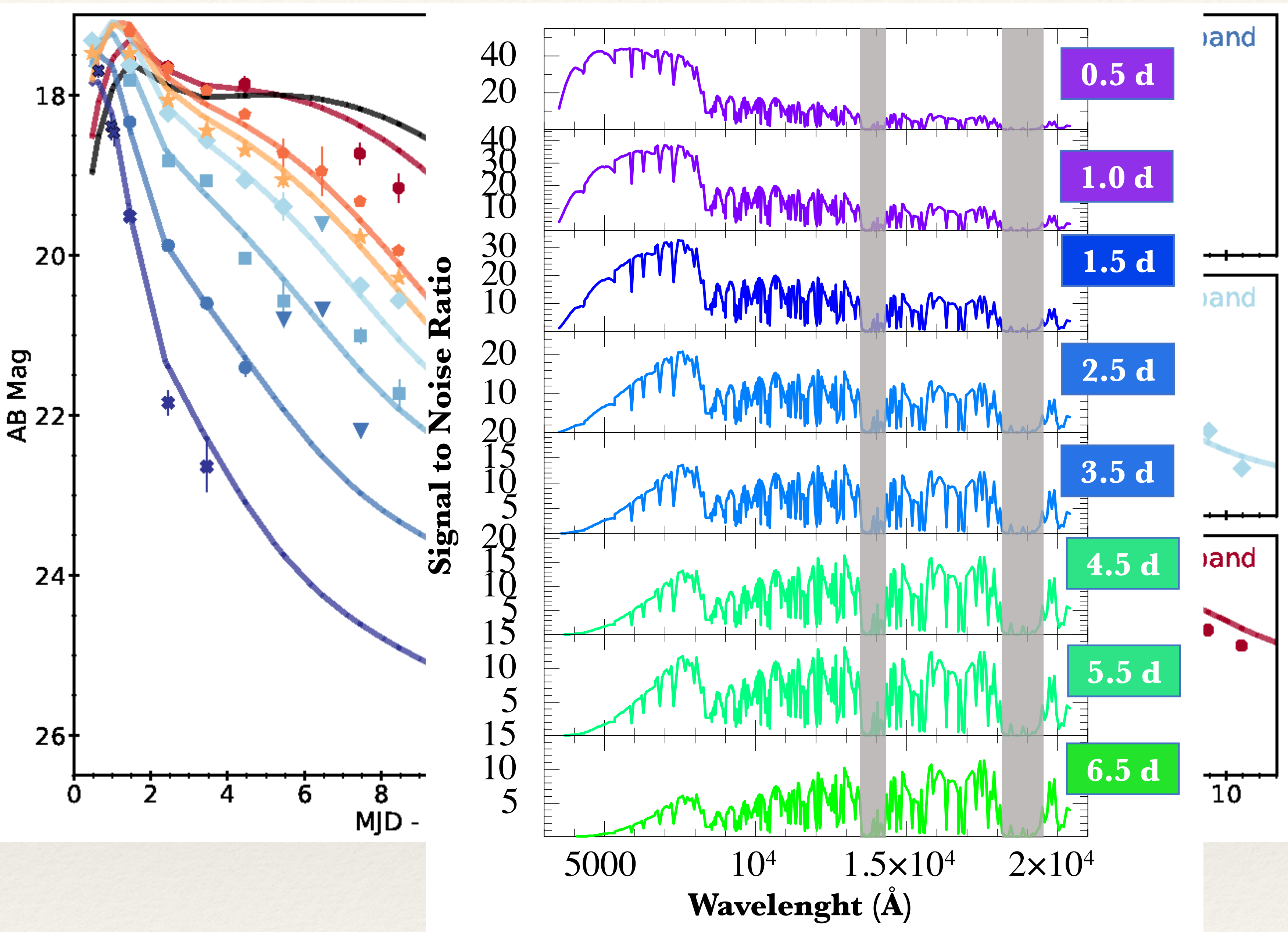
- Classification (service)
- **SN (all flavours)**
- **GW & ν**
- **TDE & Nuclear transients**
- **GRB & FRB**
- X-ray binaries & magnetars
- Novae & WDs
- Asteroids & Comets
- Young Stellar Objects & Stars
- Blazars & AGN
- Unknown

- **Rapid follow-up**
- **Dense monitoring**



SOXS for GW sources

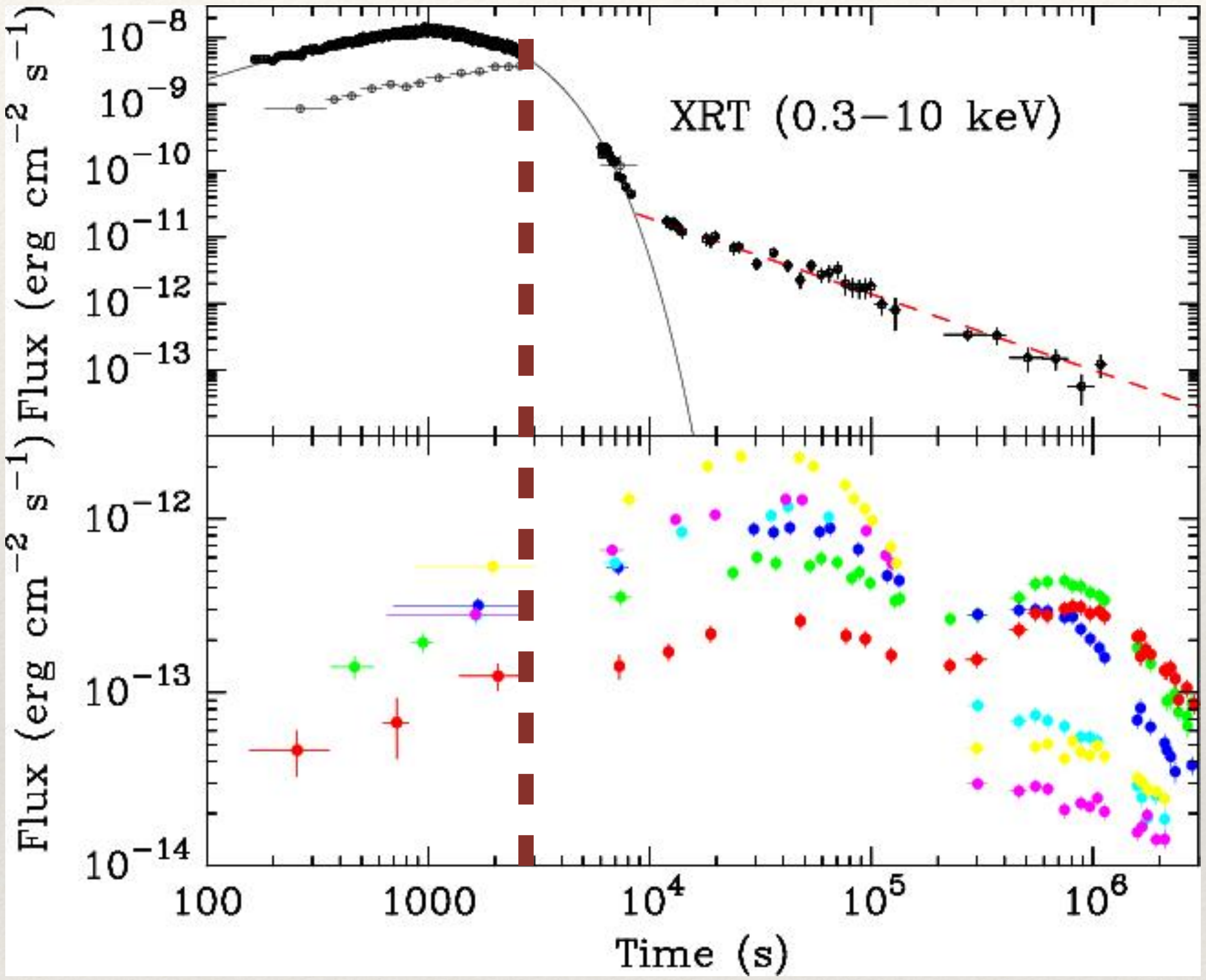




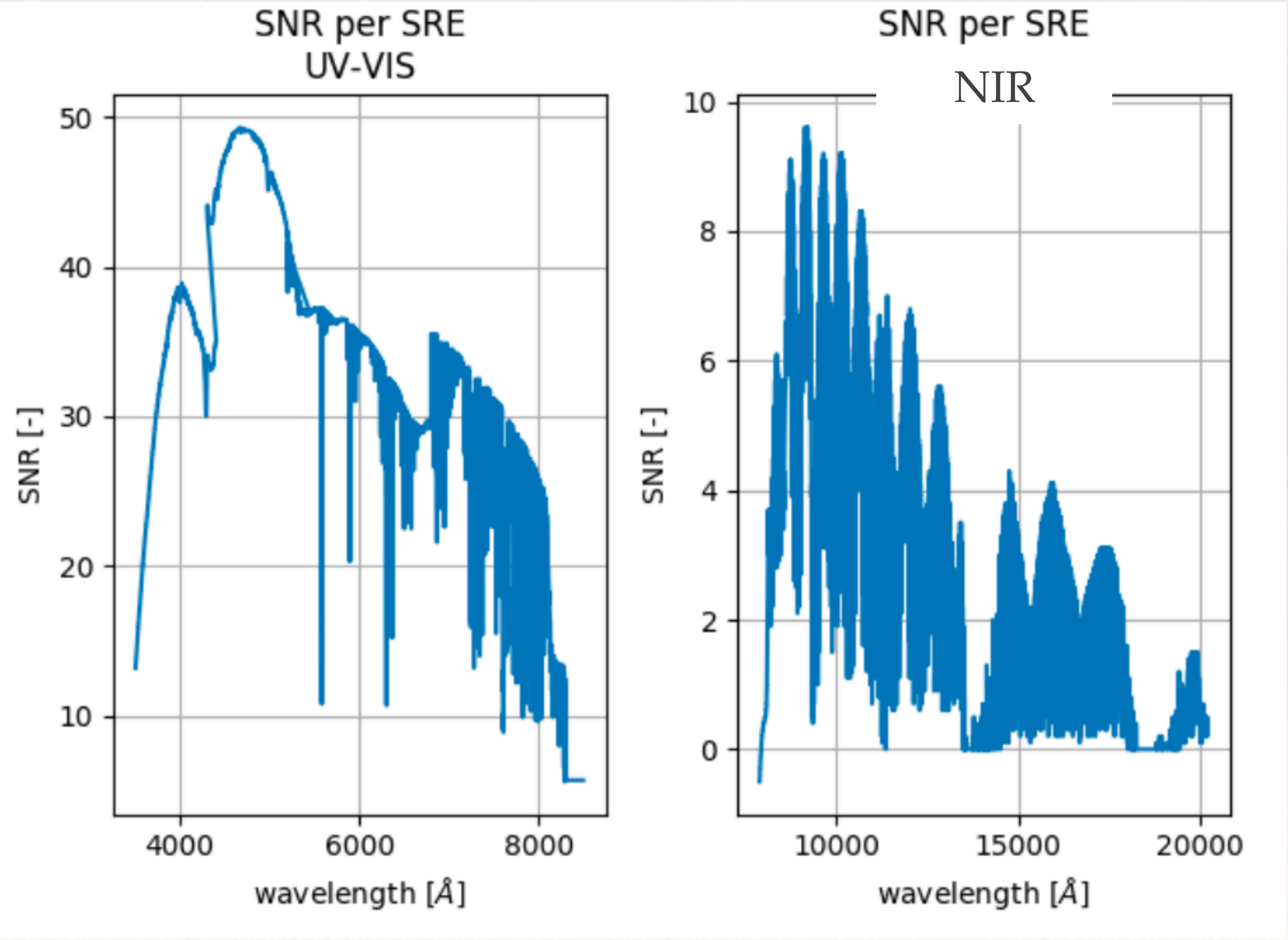
Preliminary SoXS ETC

http://192.167.38.34/

Shock break out



GRB 060218 / SN2006aj



Summary

- SoXS @ NTT from 2021 (5yr)
- Medium resolution (~4,500)
- Broad-band (350-2000 nm)
- Photometry ugrizY (3.5'x3.5')
- 180 n/yr for 5 years
- Possibility to trigger every night
- Fast reaction, 10min on source
- GTO is fully dedicated to transient and variable sources (~18,000 pointed observations of transients)

Thanks