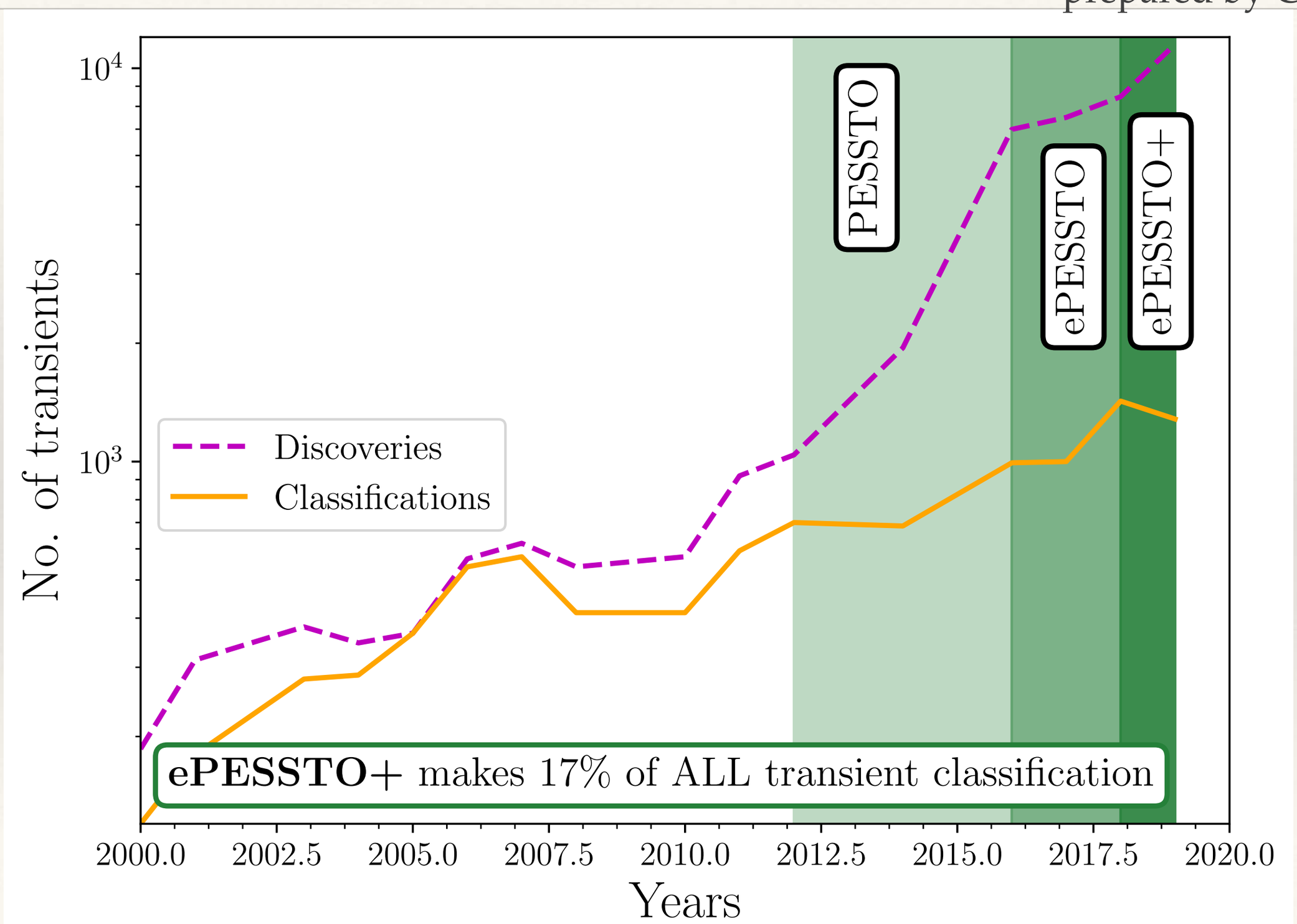
SOXS and the future landscape of instrumentation at ESO for transients, mergers and afterglows

Sergio Campana
INAF - Osservatorio astronomico di Brera

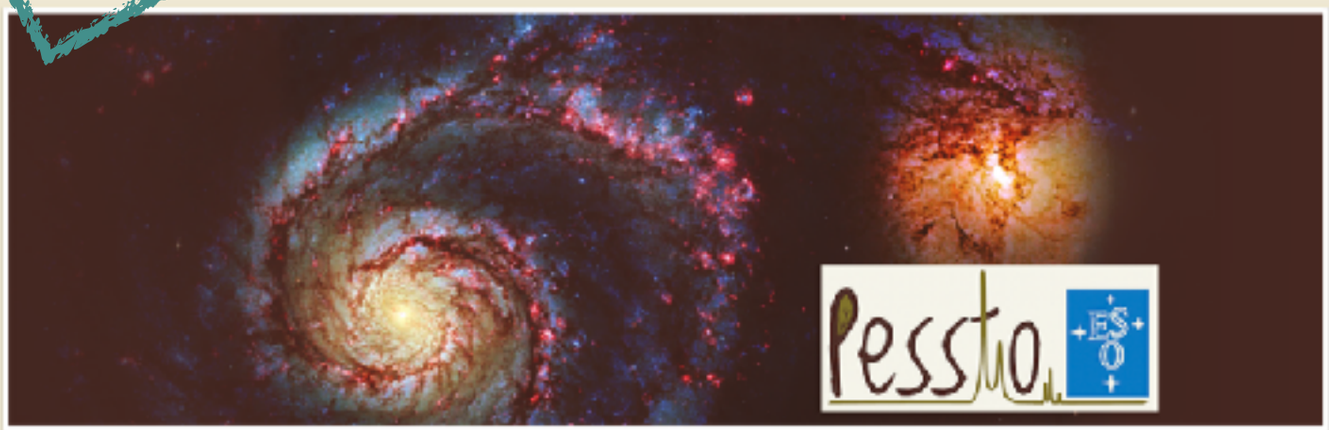
THE problem

from Janet's presentation
prepared by Cosimo



Chen's talk

The current answer



1388 transients classified by PESSTO so far

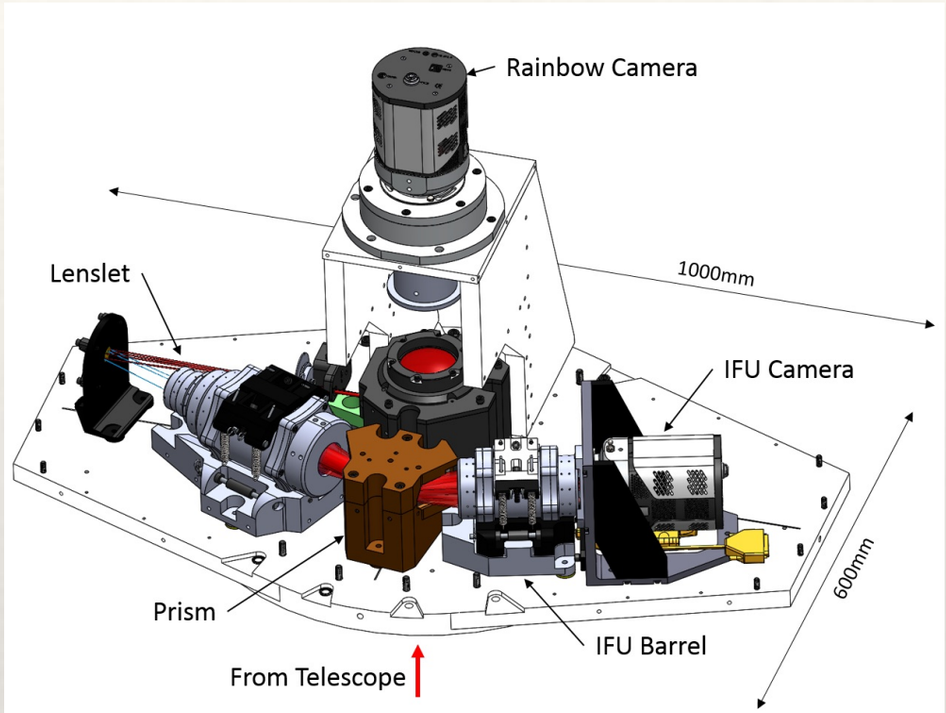
486 transients are being followed by PESSTO

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

~30% of ePESSTO+ observing time in classification activities

16% of overall classifications

SEDM



46% of overall classifications

Neill's and Rigault's talks

La Silla instruments

No instrument dedicated to transients in Paranal.

Several instrument dedicated to single science topics in La Silla but none to spectroscopic follow-up of transient sources.

Planets

- HARPS
- Euler
- MASCARA
- TRAPPIST
- 1.54 Danish

Photometry

- REM
- TAROT
- GROND

Transients surveys - photometry

- Blackgem
- La Silla QUEST

ESO new instruments

Instruments and Infrastructure in Development

Design Phase	Manufacture, Assembly Integration and Testing	Commissioning	Upgrades	Infrastructure
ERIS (VLT)	MATISSE (VLTI)		VISIR (VLT)	AOF-GALACSI (MUSE)
MOONS (VLT)	NIRPS (La Silla 3.6m)	GRAVITY (VLTI)	CRIRES+ (VLT)	AOF-GRAAL (HAWK-I)
4MOST (VISTA)	ESPRESSO (VLT)			AOF-DSM
SoXS (NTT)				AOF-4LGSF
MAVIS (VLT)				VLTI

Image reconstruction

Radial velocity (10 cm s^{-1})

Radial velocity NIR

Astrometry

ESO new instruments

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4MOST (VISTA)	ESPRESSO (VLT)			AOF-DSM
SoXS (NTT)				AOF-4LGSF
MAVIS (VLT)				VLTI

AO imaging infrared

1000-fibers over 25arcmin FOV

AO imaging visible

ELT > 2025

4MOST

Table 1. 4MOST key instrument specifications.

Instrument parameter	Design value
Field of view (hexagon)	~ 4.2 square degrees (Ø = 2.6 degrees)
Accessible sky (zenith angle < 55 degrees)	> 30 000 square degrees
Expected on-target fibre-hours per year	LRS: > 3 200 000 h yr^{-1}, HRS > 1 600 000 h yr^{-1}
Multiplex fibre positioner	2436
Low-Resolution Spectrographs LRS (× 2)	
Resolution	<*R*> = 6500
Number of fibres	812 fibres
Passband	3700–9500 Å
Velocity accuracy	< 1 km s^{-1}
Mean sensitivity 6 × 20 min, mean seeing, new moon, S/N = 10 $Å^{-1}$ (AB-magnitude)	4000 Å: 20.2, 5000 Å: 20.4, 6000 Å: 20.4, 7000 Å: 20.2, 8000 Å: 20.2, 9000 Å: 19.8
High-Resolution Spectrograph HRS (× 1)	
Resolution	<*R*> = 20 000
Number of fibres	812 fibres
Passband	3926–4355, 5160–5730, 6100–6790 Å
Velocity accuracy	< 1 km s^{-1}
Mean sensitivity 6 × 20 min, mean seeing, 80% moon, S/N = 100 $Å^{-1}$ (AB-magnitude)	4200 Å: 15.7, 5400 Å: 15.8, 6500 Å: 15.8
Smallest target separation	15 arcseconds on any side
# of fibres in random Ø = 2 arcminute circle	≥ 3
Fibre diameter	Ø = 1.45 arcseconds

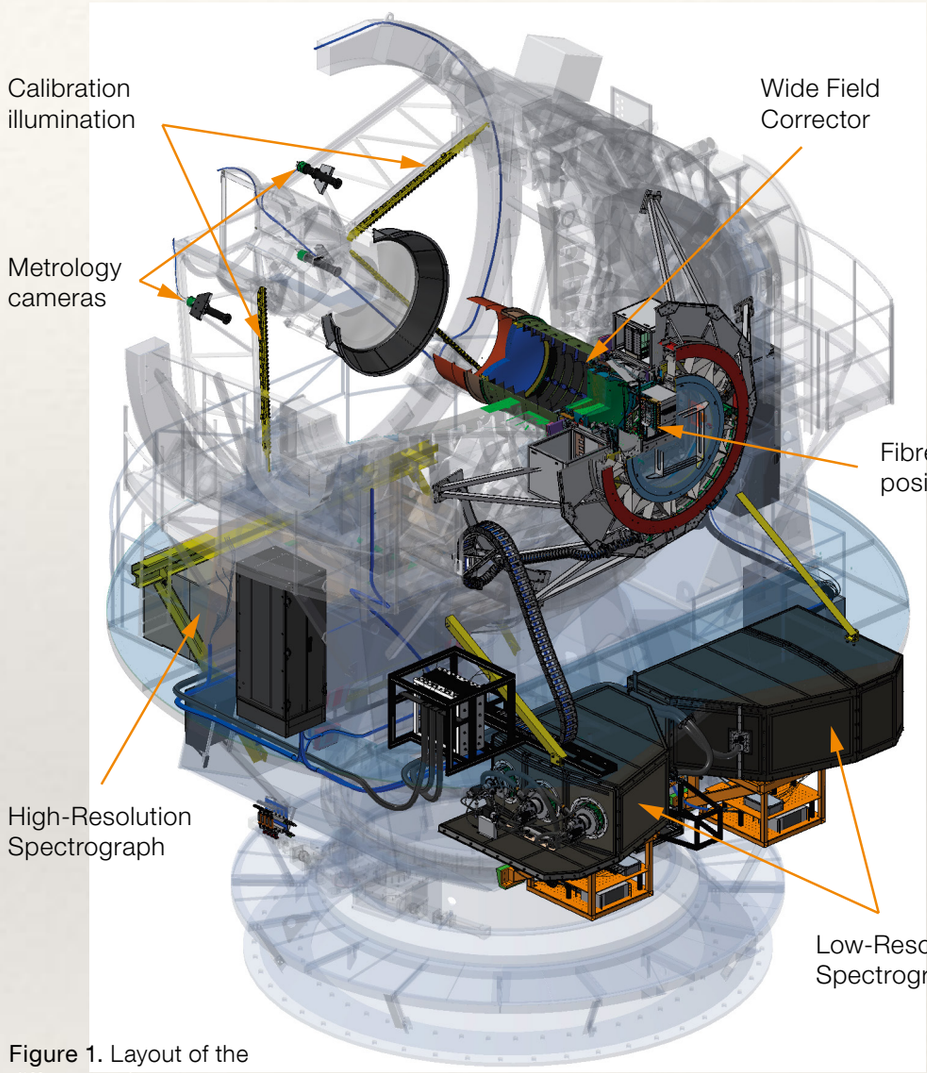


Figure 1. Layout of the different subsystems of 4MOST on the VISTA telescope.

Integration July 2021
PAE February 2022
PAC November 2022

VISTA 4m telescope @ Paranal

4MOST Builders' Consortium

Table 3. 4MOST Consortium institutes and their main roles in the Project.

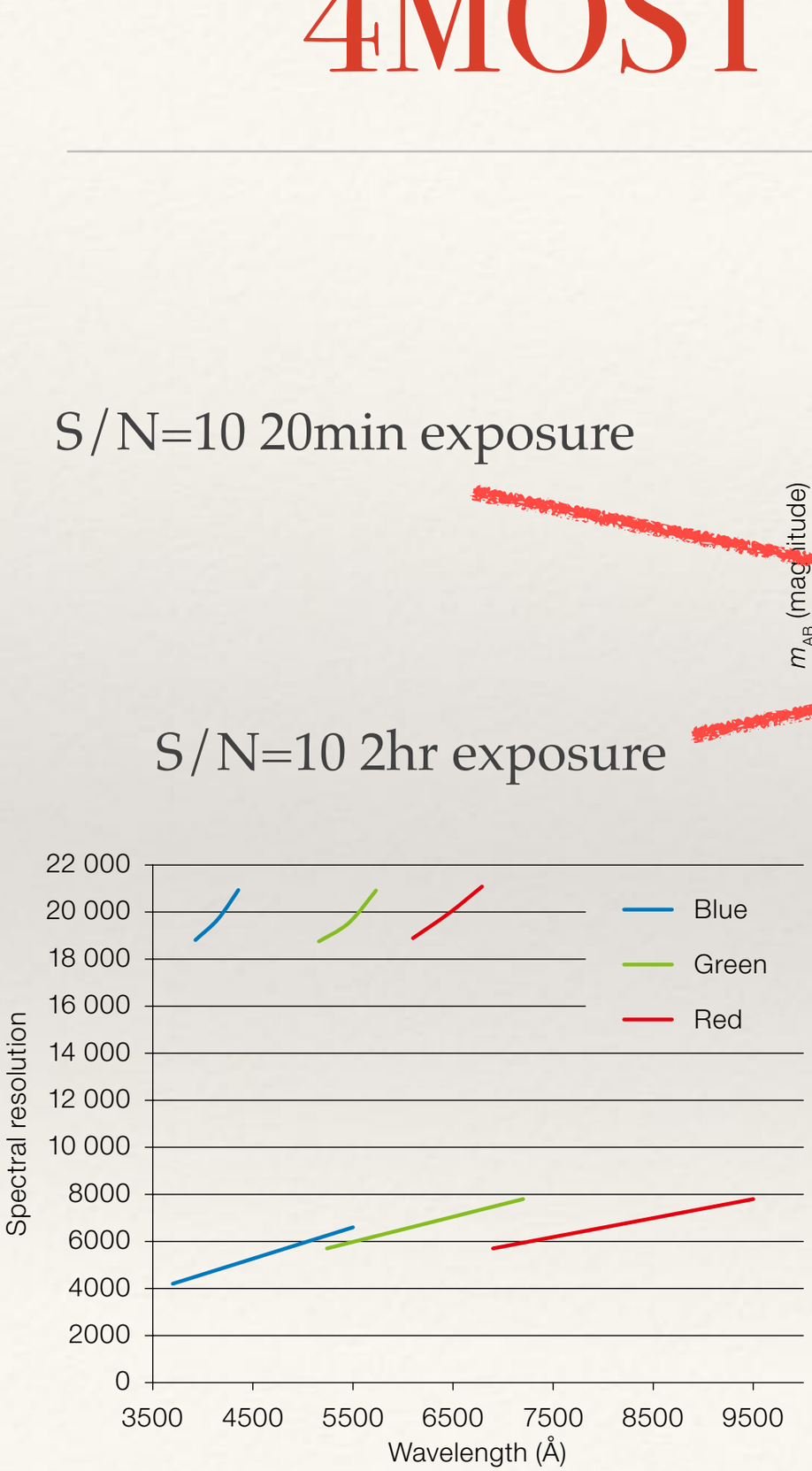
Institute	Instrument responsibility	Science lead responsibility
Leibniz-Institut für Astrophysik Potsdam (AIP)	Management and system engineering, telescope interface (including WFC), metrology, fibre system, instrument control software, System AIV and commissioning	Milky Way Disc and Bulge LR Survey, Cosmology Redshift Survey, Magellanic Clouds Survey
Australian Astronomical Optics – Macquarie (AAO)	Fibre positioner	Galaxy Evolution Survey
Centre de Recherche Astrophysique de Lyon (CRAL)	Low-Resolution spectrographs	Cosmology Redshift Survey
European Southern Observatory (ESO)	Detectors system	
Institute of Astronomy, Cambridge (IoA)	Data management system	Milky Way Halo LR Survey
Max-Planck-Institut für Astronomie (MPIA)	Instrument control system hardware	Milky Way Disc and Bulge HR Survey
Max-Planck-Institut für extraterrestrische Physik (MPE)	Science operations system	Galaxy Clusters Survey, AGN Survey
Zentrum für Astronomie der Universität Heidelberg (ZAH)	High-Resolution spectrograph, Instrument control system software	Milky Way Halo HR Survey
NOVA/ASTRON Dwingeloo	Calibration system	
Rijksuniversiteit Groningen (RuG)		Milky Way Halo LR Survey
Lund University (Lund)		Milky Way Disc and Bulge HR Survey
Uppsala universitet (UU)		
Universität Hamburg (UHH)		Galaxy Evolution Survey
University of Western Australia (UWA)		
École polytechnique fédérale de Lausanne (EPFL)		Cosmology Redshift Survey

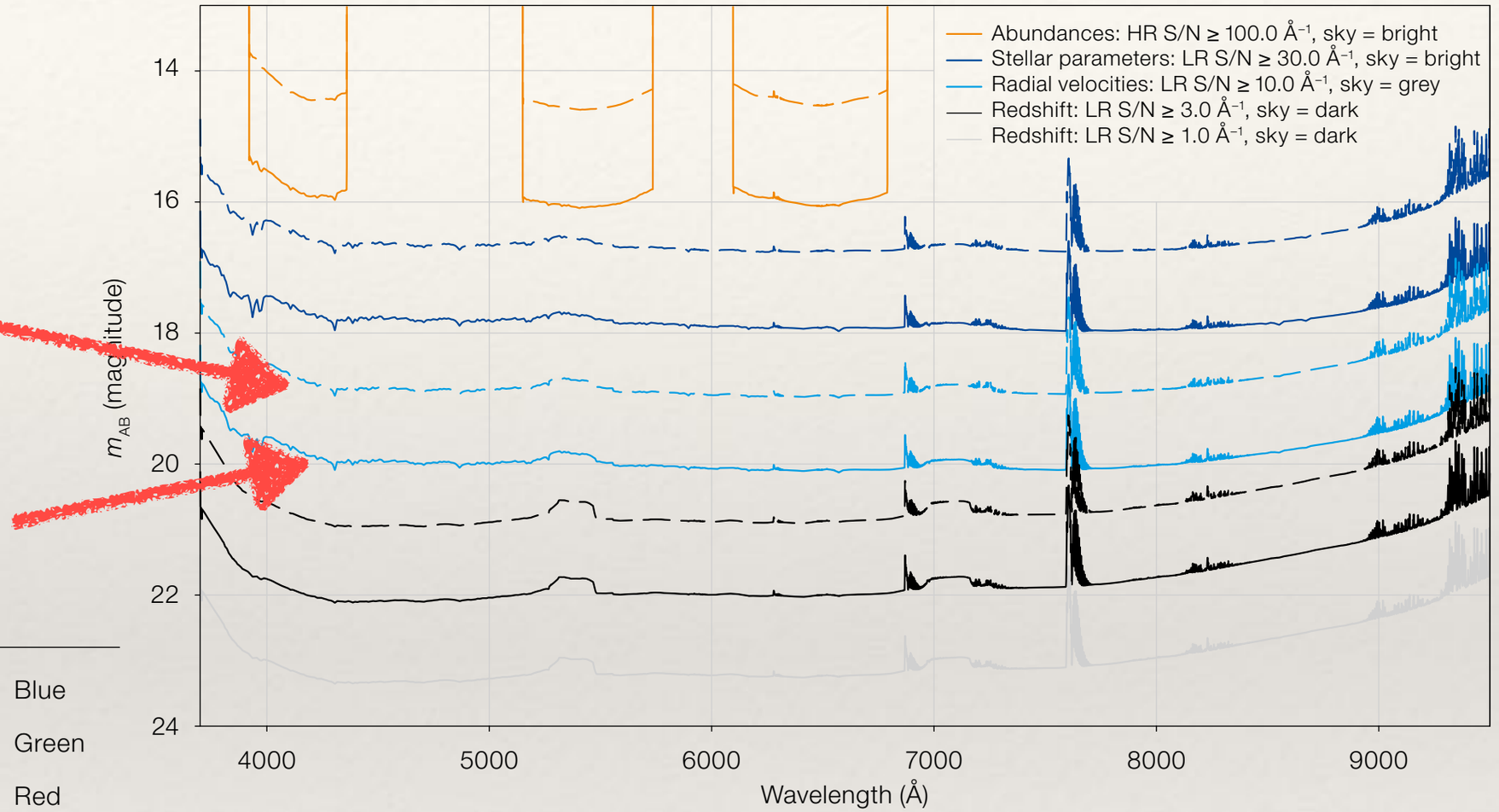
Principal Investigator
Roelof de Jong
Leibniz-Institut für Astrophysik Potsdam (AIP)

4MOST resolution and S/N

S/N=10 20min exposure

S/N=10 2hr exposure





Survey 10: TiDES

Summary: TiDES – 4MOST + Transients

- What is the science?
  - SN Ia cosmology (*inc. first LSST SN Ia cosmology*)
  - SN and transient physics
  - AGN reverberation mapping

- Why 4MOST?
  - Can provide the massive spectroscopic follow-up needed
  - Similar sky coverage to major time-domain surveys
  - Similar timeline to LSST

see next talk by Elizabeth Swann

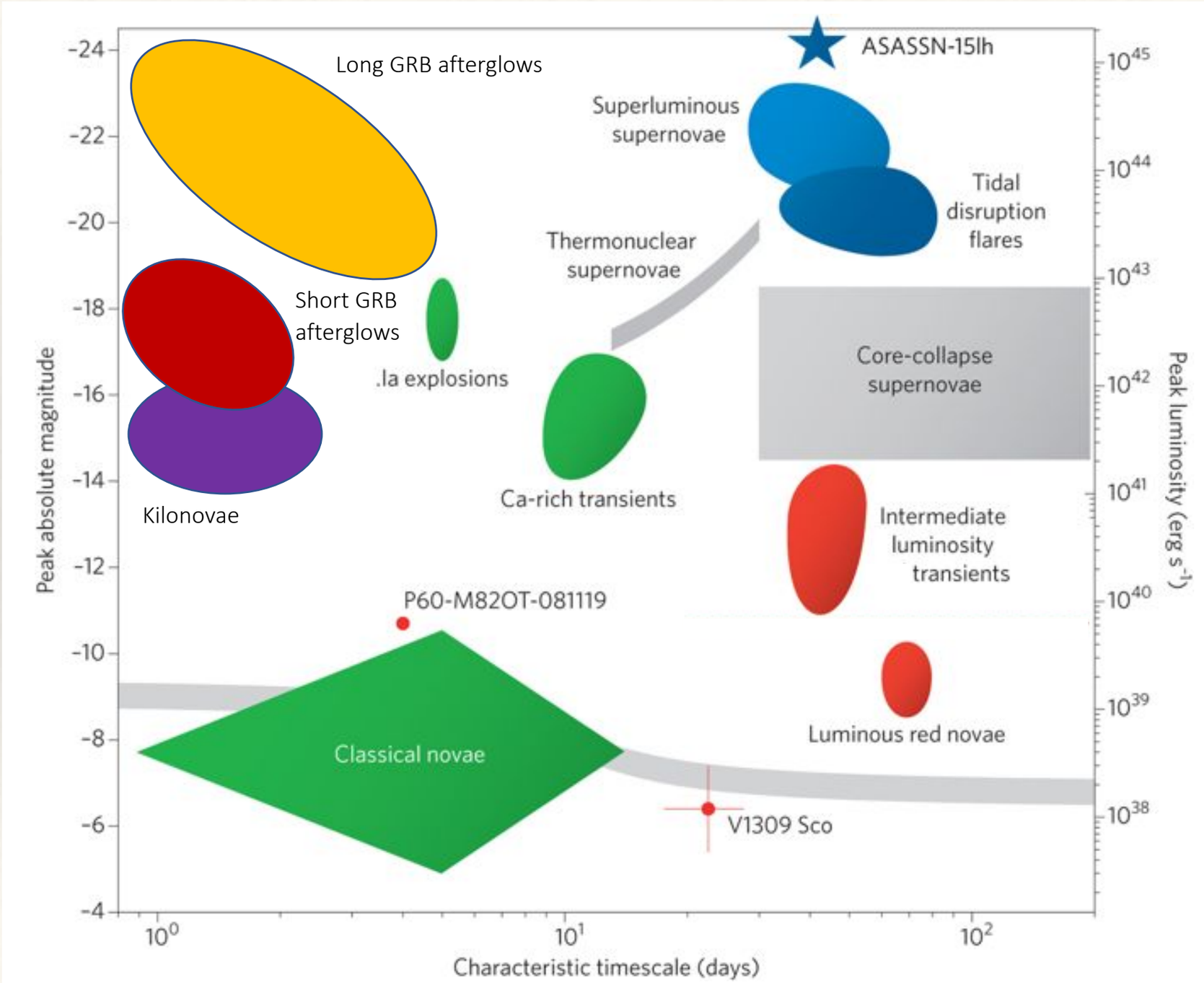
4MOST limitations on transients

Cadence, variables, transients

- *4MOST does not allow for timed observations!*
  - The survey nature clashes with individual target needs
- We expect to have a limited set of deep/repeat fields that will be observed with a certain cadence (~once every 2 weeks)
- Some areas may be re-observed on purpose with a minimum amount of time in between (~12 months) to check for variability (e.g., radial velocity binaries)
- Other contiguous areas will be completed as quickly as possible to measure large scale spatial structures
- We may adapt some of the cadence strategy to mimic/follow LSST (e.g., rolling Dec cadence)
- A small fraction of transients may be added on ~weekly time scale to be observed in the coming weeks
  - This will not drive the pointing of the telescope significantly; transients will be observed wherever observations are scheduled

from de Jong's presentation at ESO

Fast (<2-4 d) transients & dense monitoring campaigns



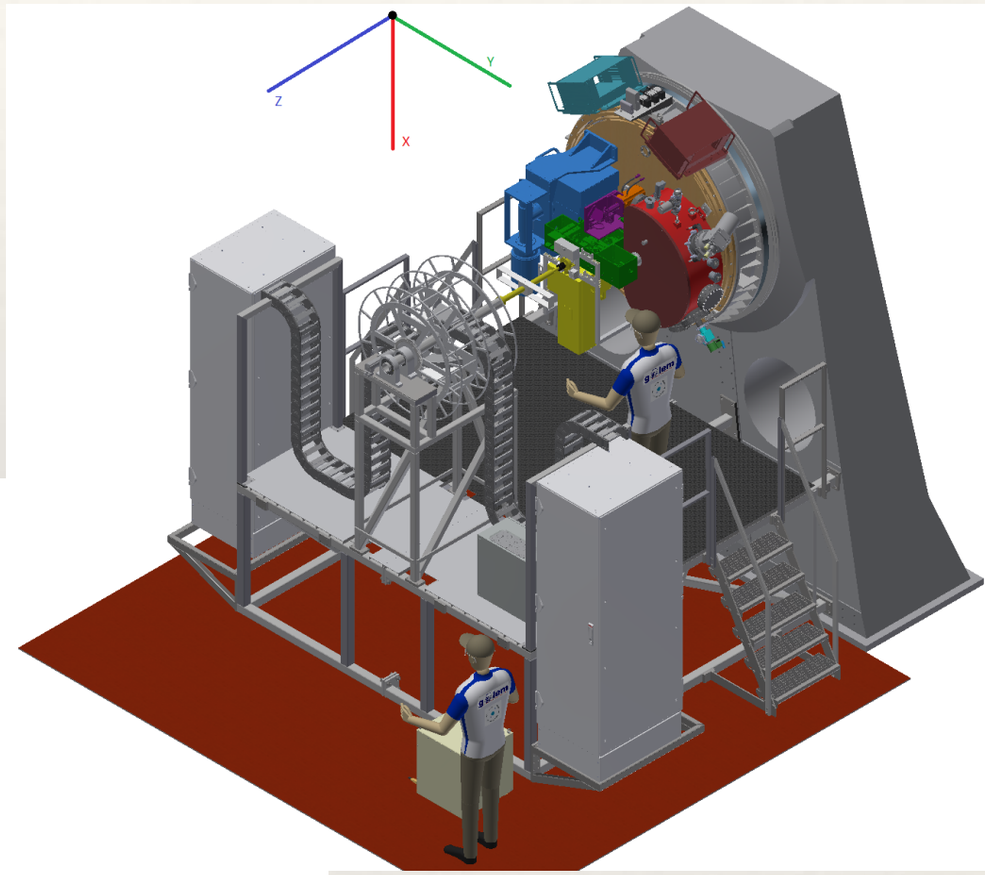
Detection & Follow-up

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

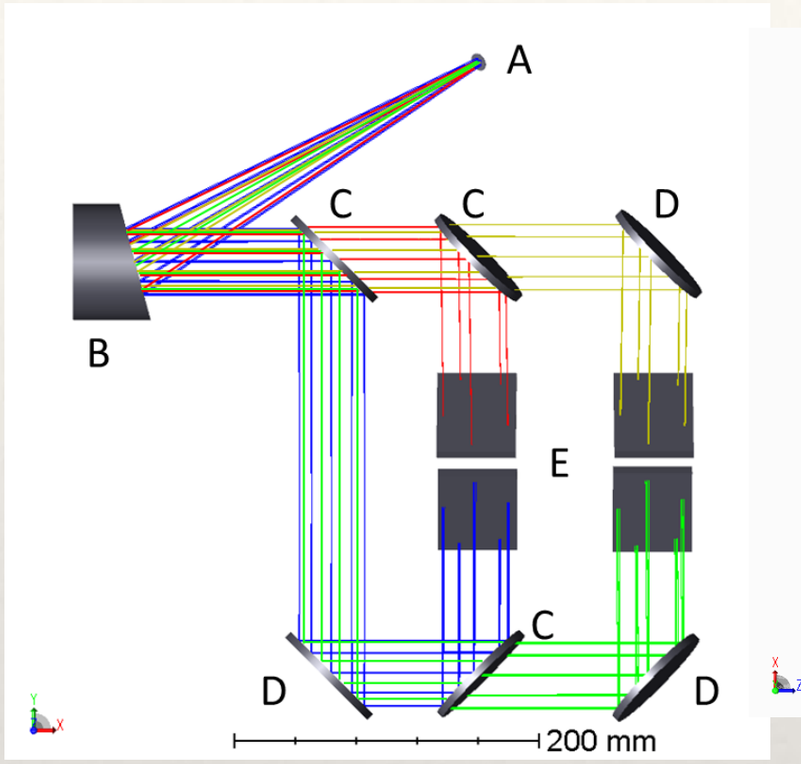
Institutes from 6 Countries

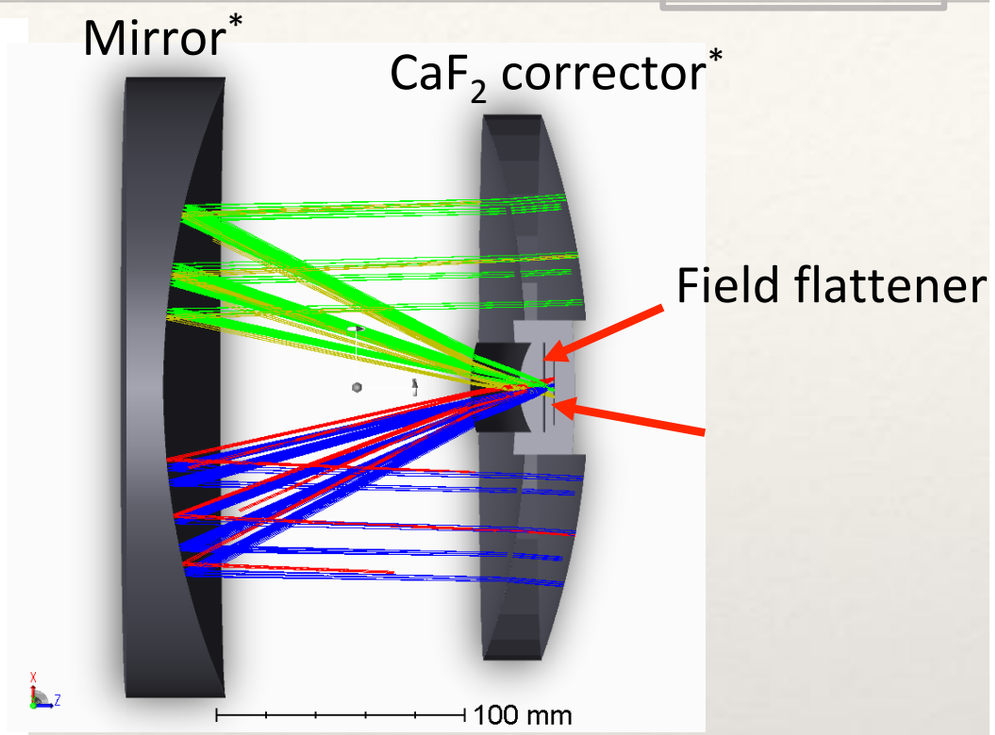
- Common Path, NIR Spectrograph, Control Software & Electronics, Vacuum and Cryogenics, Detectors control (INAF)
- UV/VIS Spectrograph (Weizmann)
- Acquisition Camera (Millennium Institute of Astrophysics - MAS)
- Calibration Unit (Turku University)
- Data Reduction (Queen's Un. Belfast)
- Tel Aviv University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

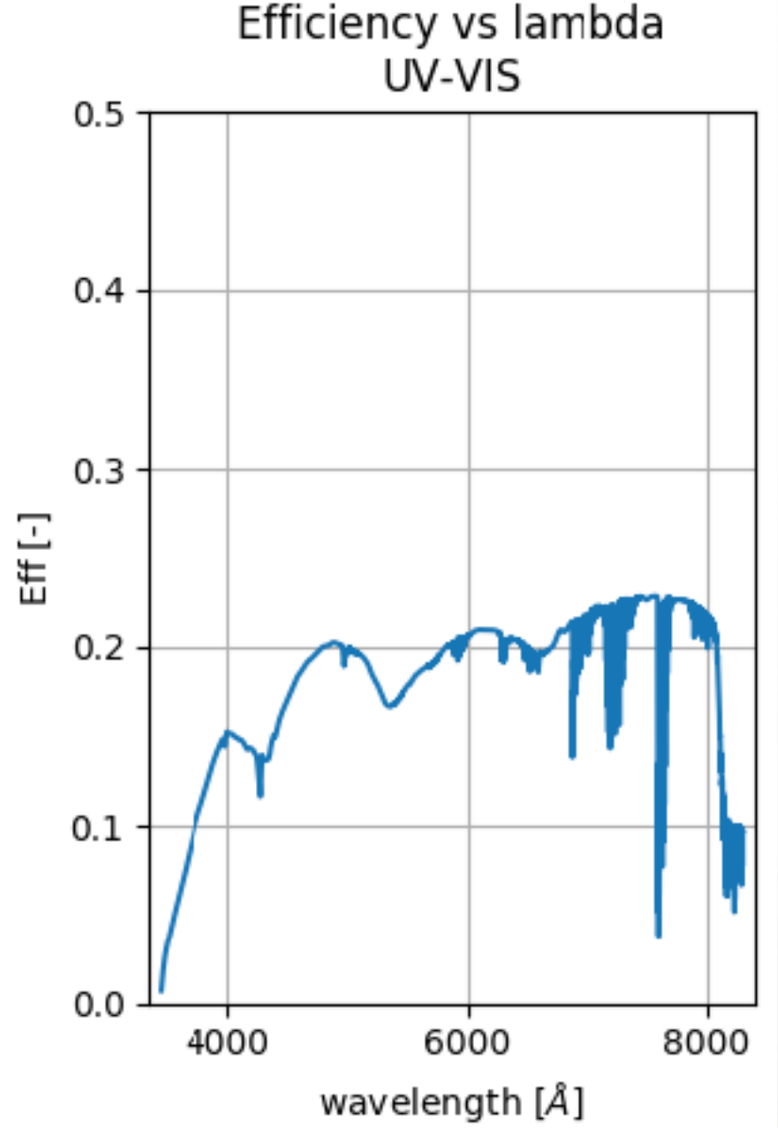
SoXS UV-VIS arm

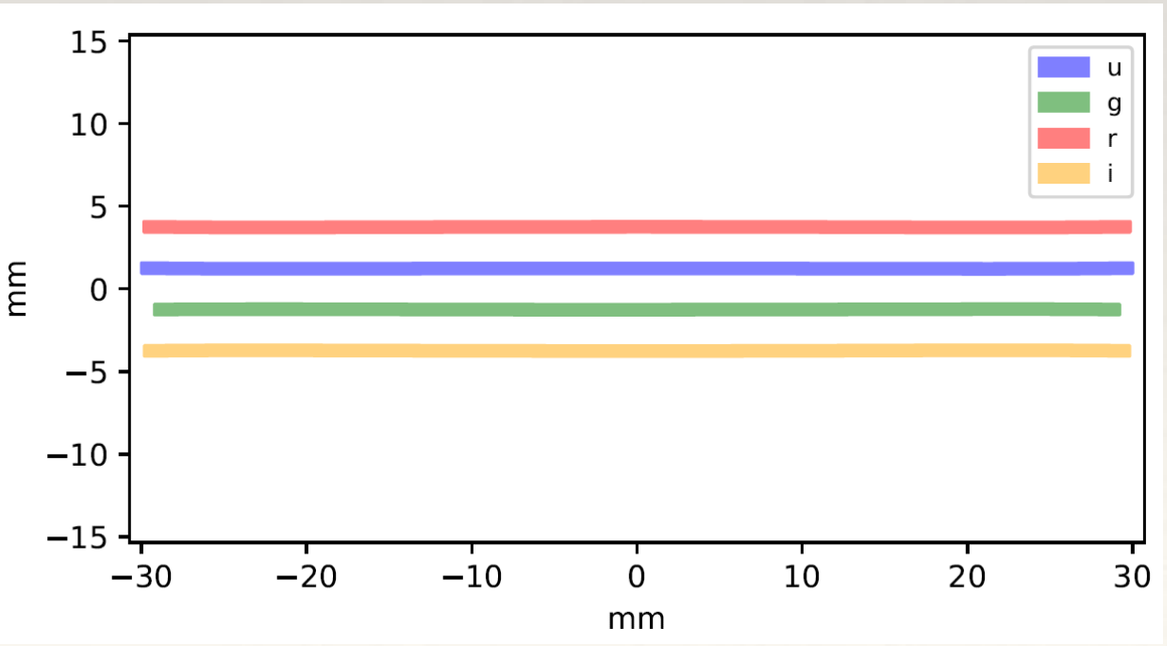
מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

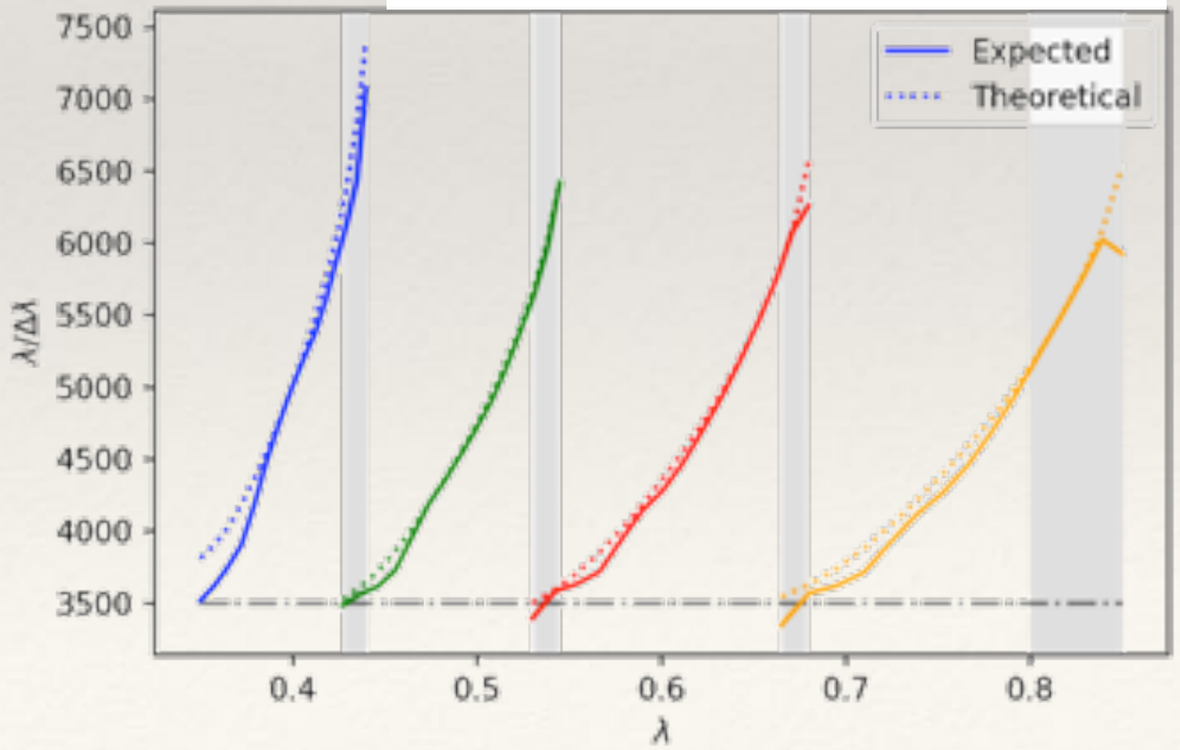
*Aspheric



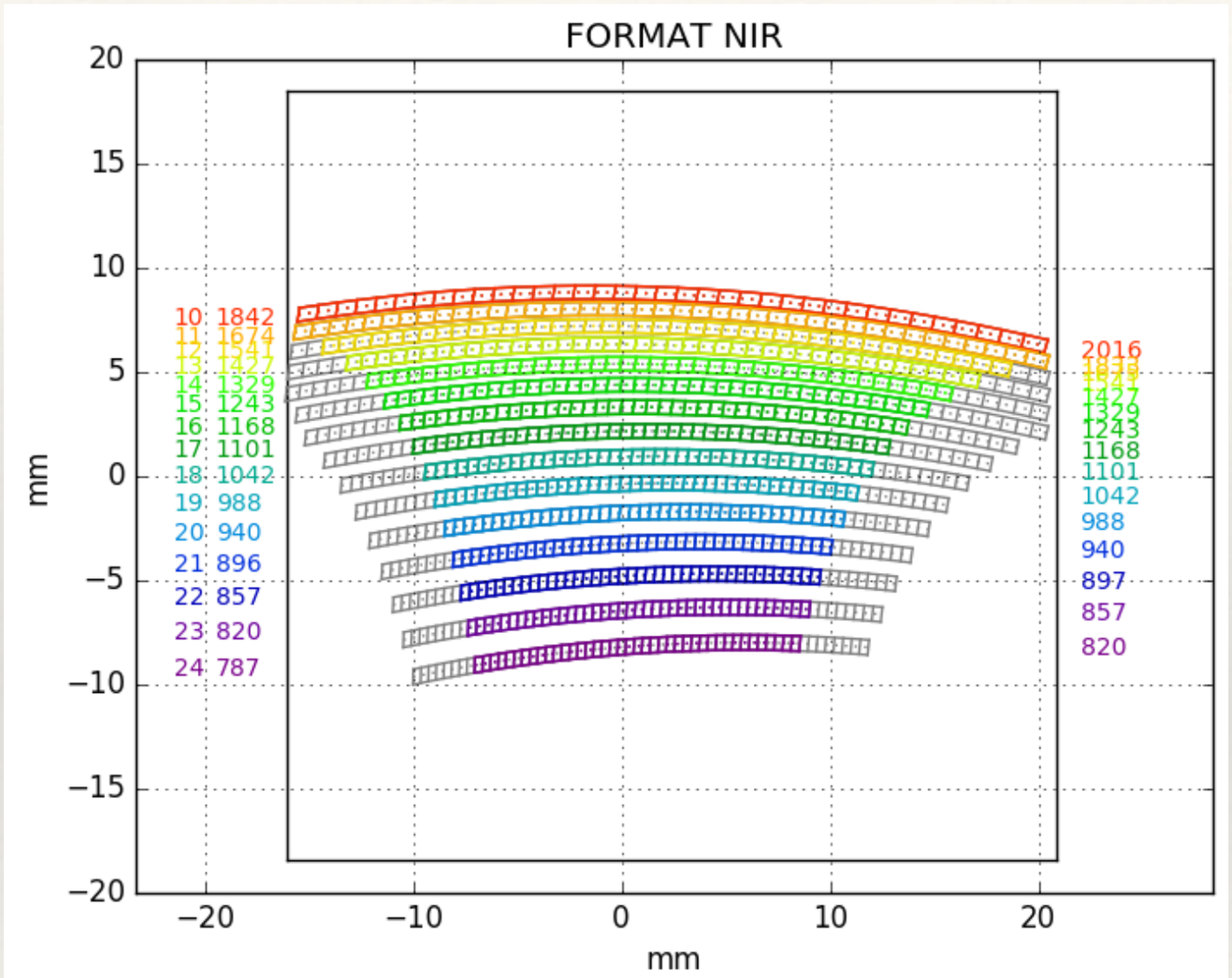


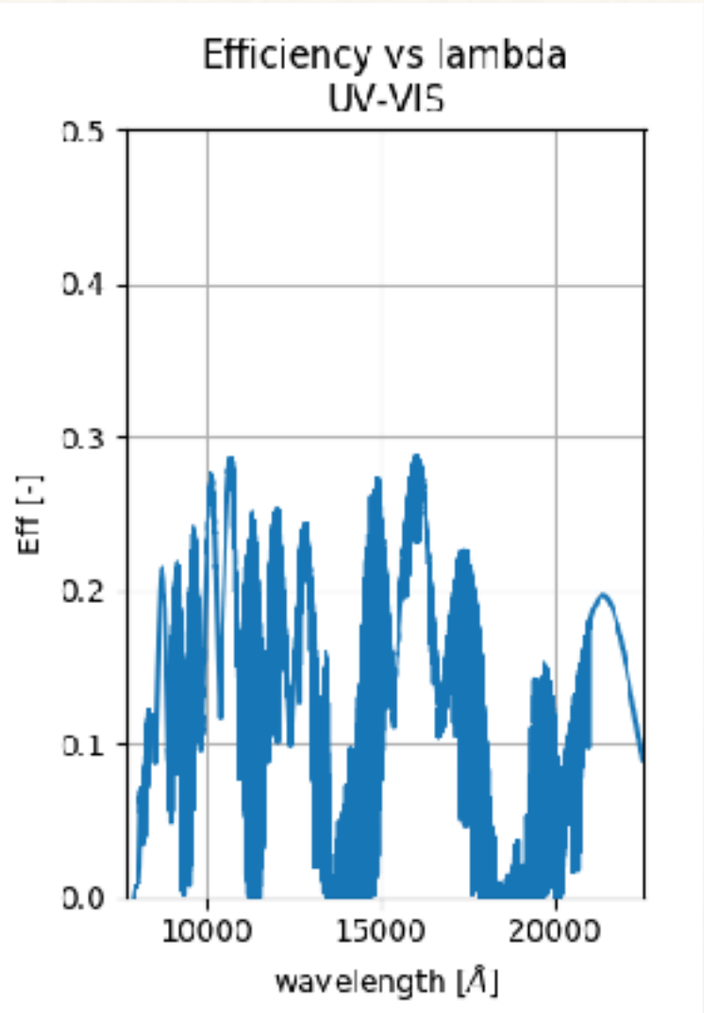


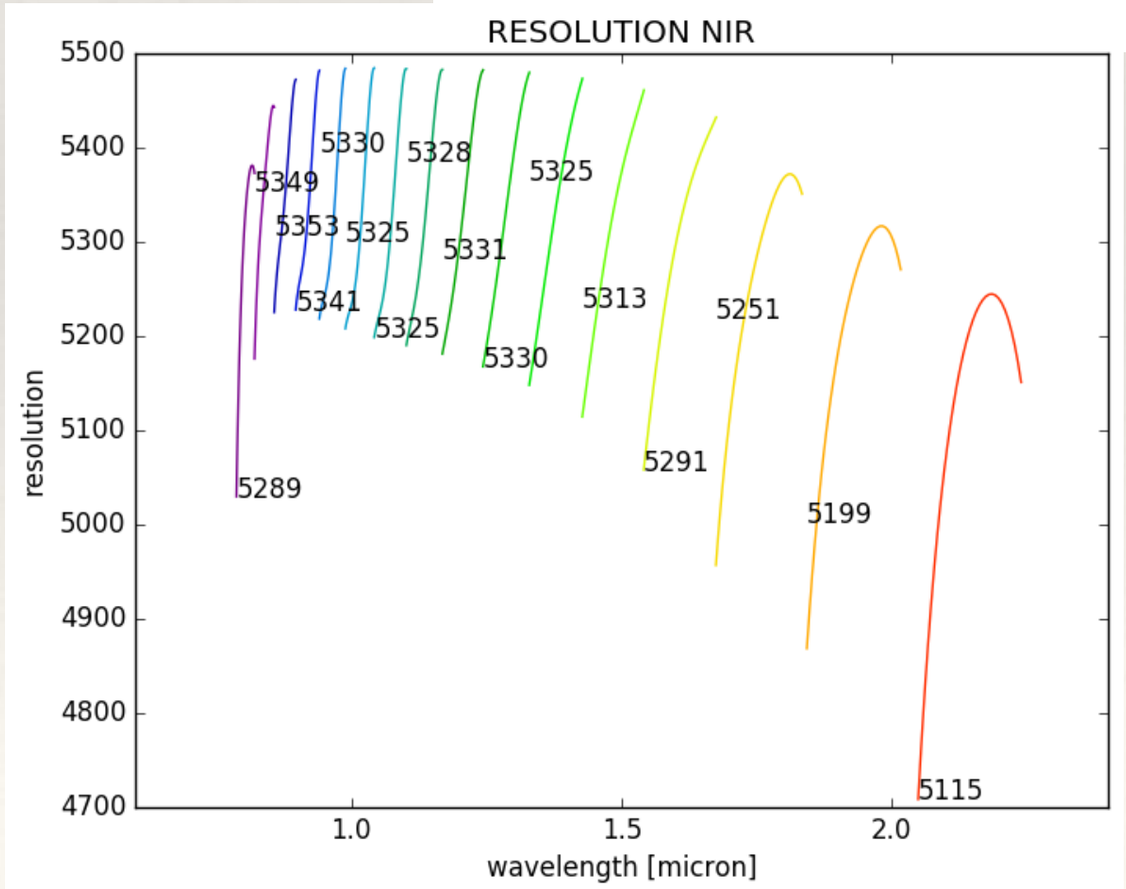




SoXS NIR arm

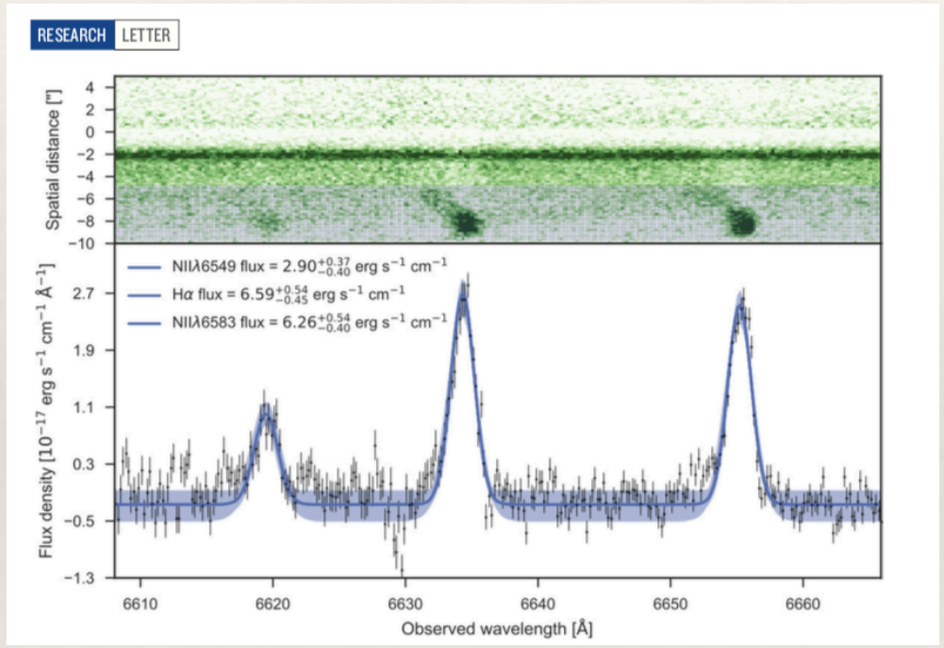

FORMAT NIR
mm
mm
10 1842
11 1674
12 1541
13 1427
14 1329
15 1243
16 1168
17 1101
18 1042
19 988
20 940
21 896
22 857
23 820
24 787
2016
1674
1541
1427
1329
1243
1168
1101
1042
988
940
897
857
820


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 pipeline

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

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

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.

Data policy

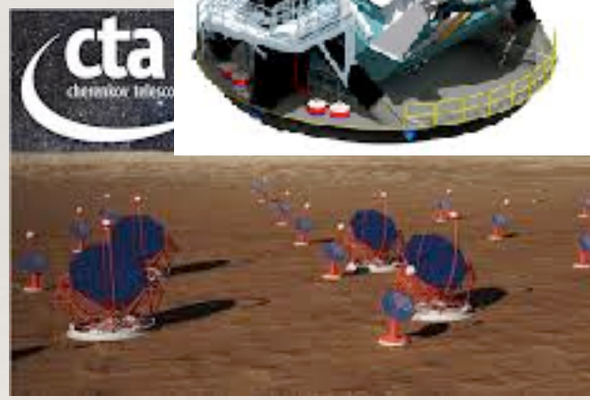
SOXS-GTO sources selected with clear triggering criteria, criteria will be made public before the start of the operations (and updated every 6 months).

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

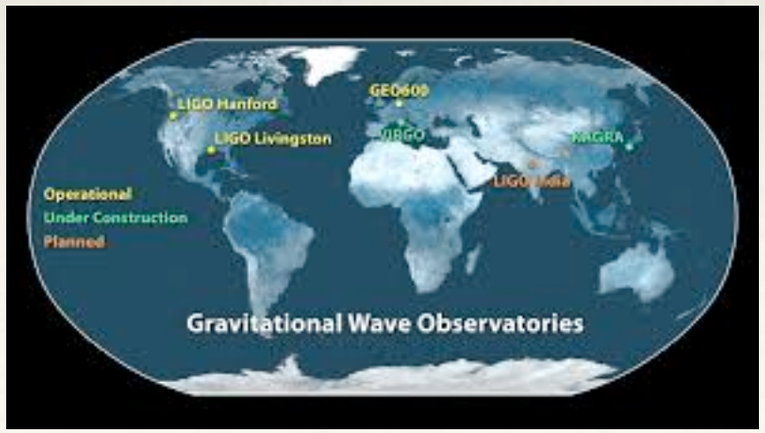
SOXS will also take classification spectra of sources from optical surveys (up to 25% of SoXS GTO observing time).
These data can be claimed by the SOXS Consortium within 3 days, if they fall under a GTO proposal (and will then remain private for 12 months). Otherwise classification data are public.

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, …



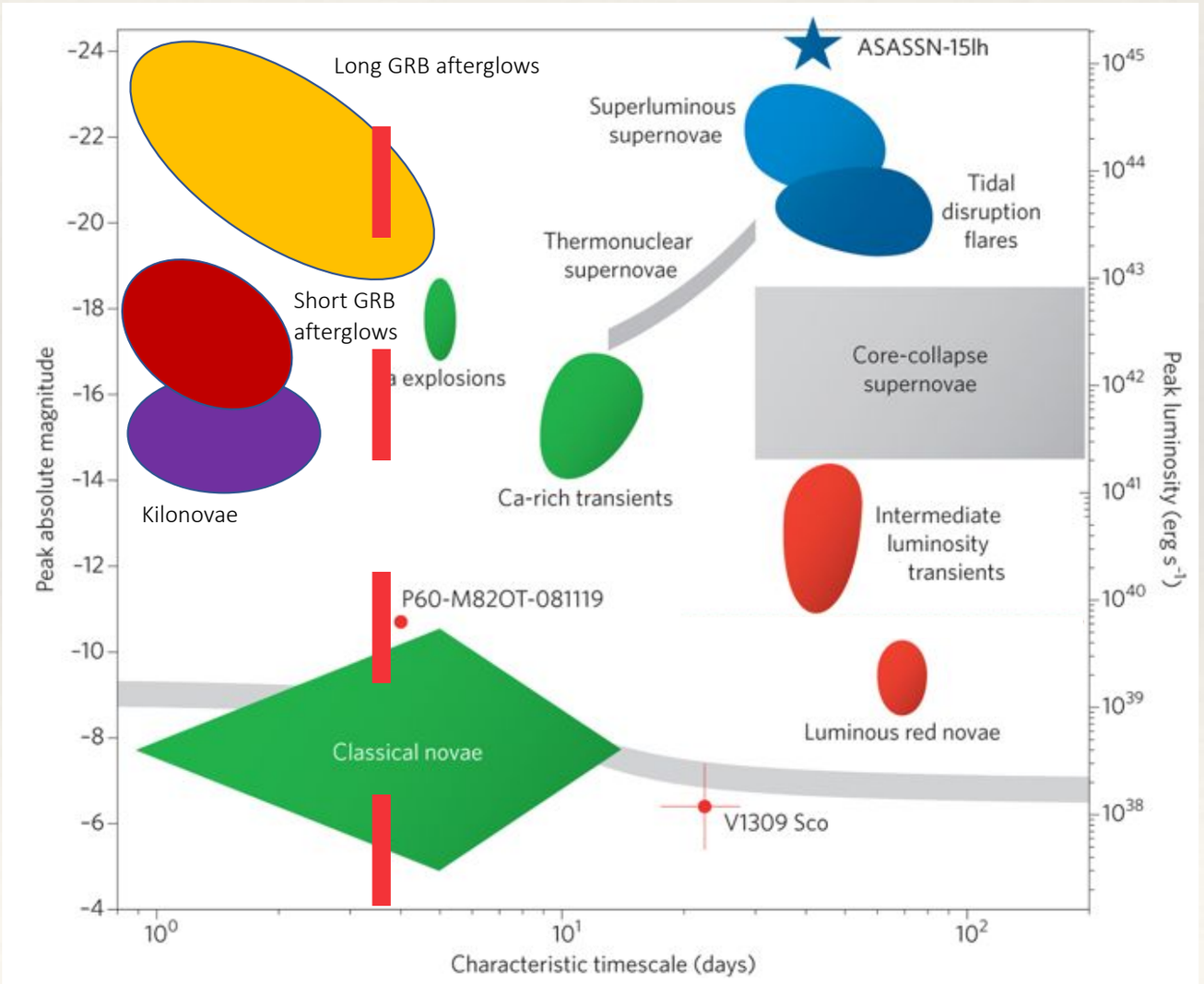
SOXS@NTT will have 180 n/yr (for 5 yr)
~3,000 - 4,000 spectra/yr



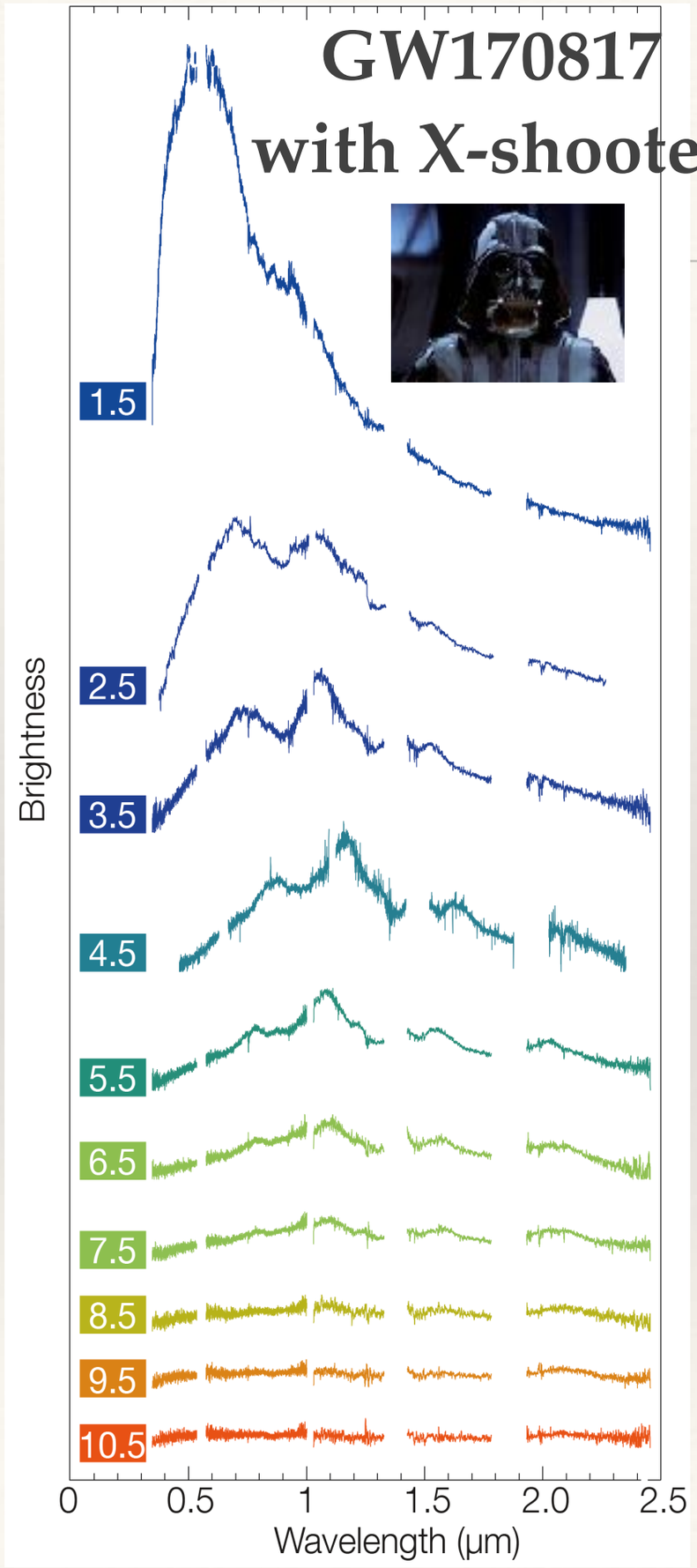
SoXS Science cases

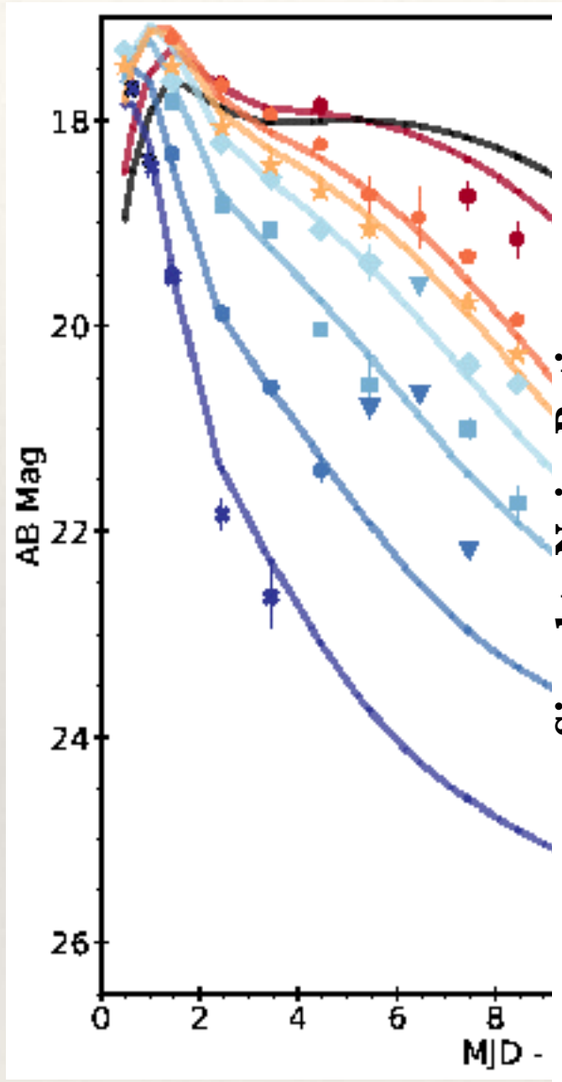
- Classification (service)
- **SN (all flavours)**
- **GW & ν**
- **TDE & Nuclear transients**
- **GRB & FRB**
- X-ray binaries & magnetars
- Novae & WDs
- Asteroids & Comets
- Young Stellar Objects & Stars
- Blazars & AGN
- Unknown

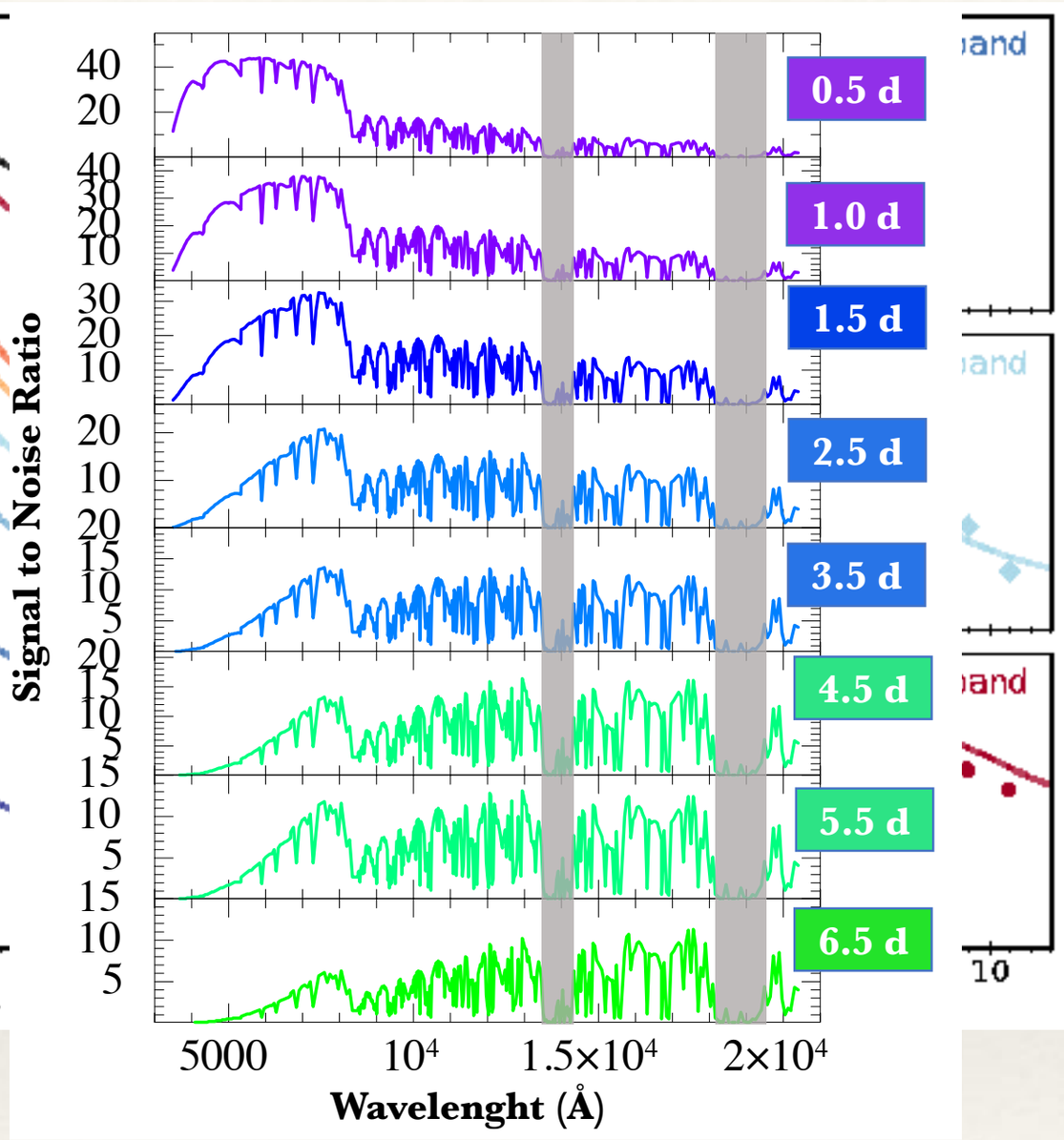
- **Rapid follow-up**
- **Dense monitoring**



SoXS for GW sources



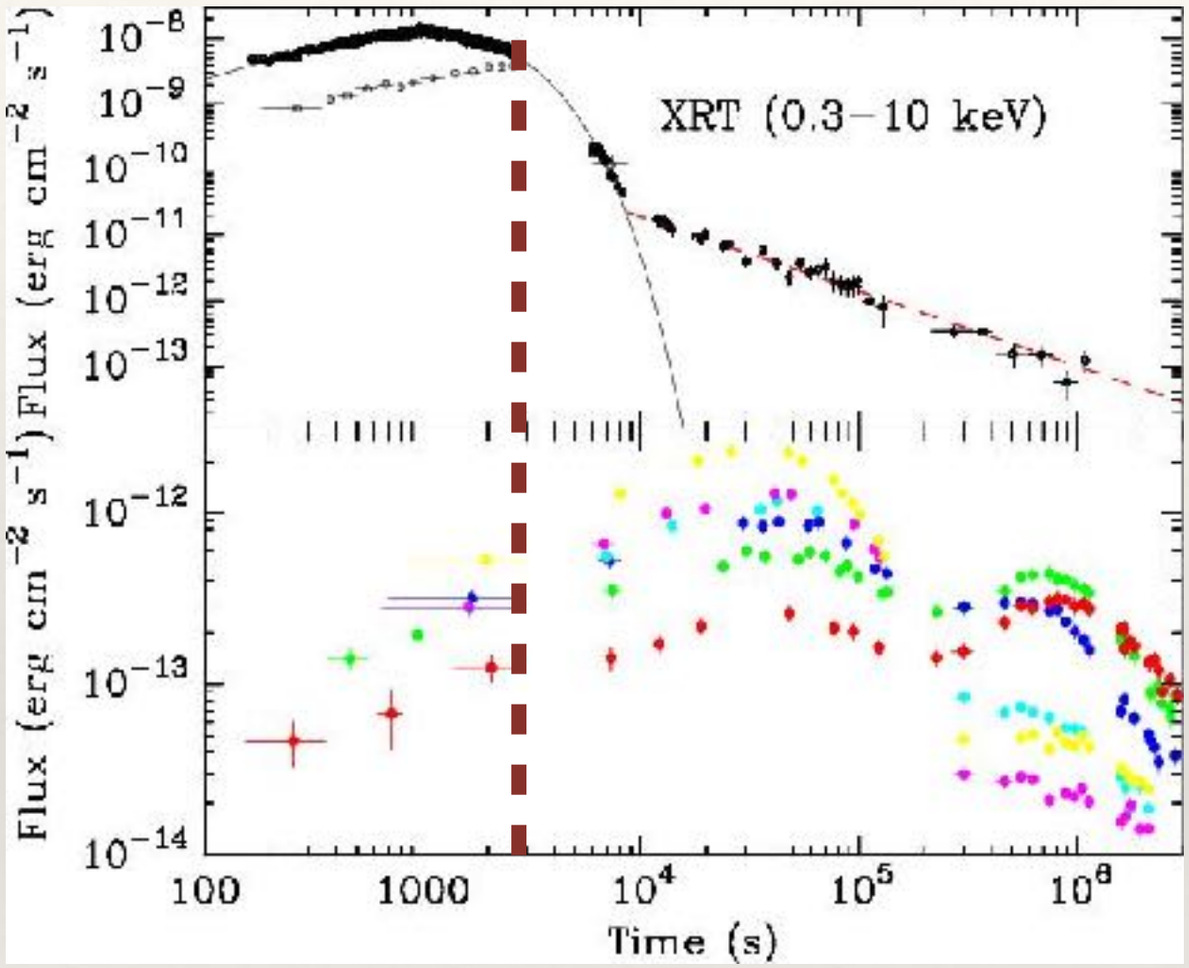




Preliminary SoXS ETC

http://192.167.38.34/

Shock break out



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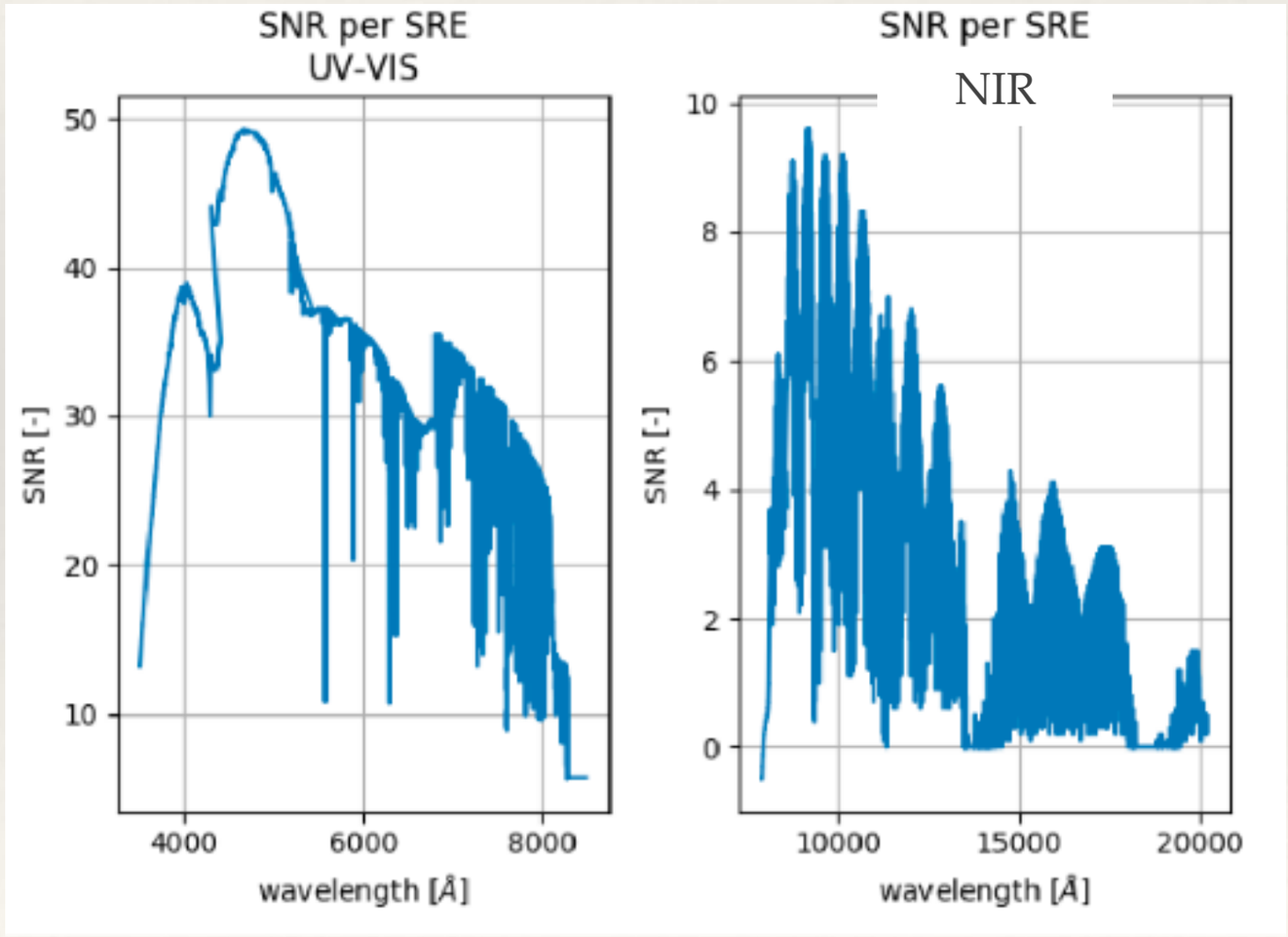

Summary

- *4MOST @ VISTA from 2022 (5yr)*
- *Medium resolution (~6,500) or high resolution (~20,000)*
- *370-950 nm*
- *4.2 deg2 FOV, 812 +812 fibers*
- *No photometry*
- *Limited triggering capabilities*
- *No fast reaction*
- *Cover transients within LSST fields within ~1week*
- *TiDES dedicated program for 30,000 observations of transients*

- *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