THESEUS MOC & MOS

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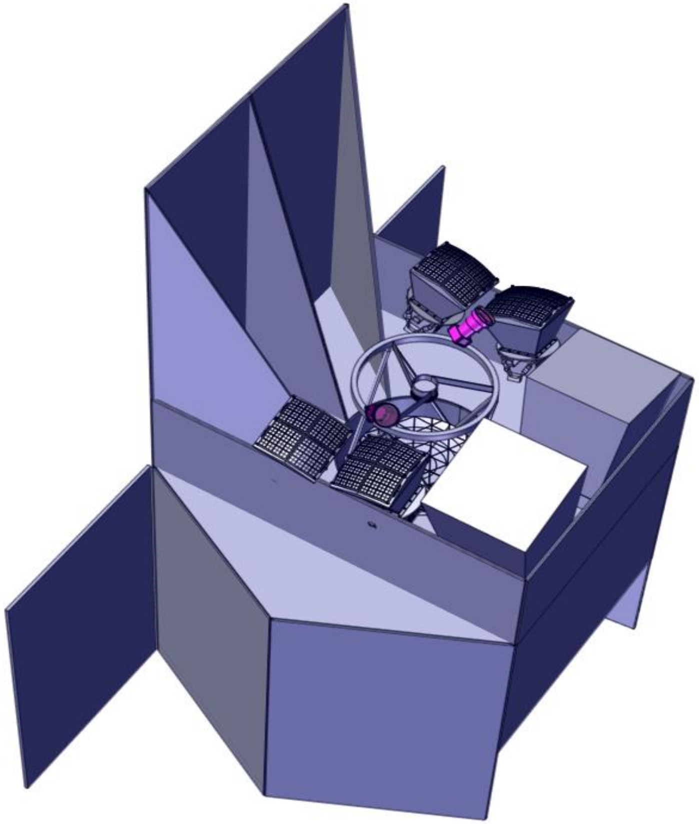

MOC – Mission Operation Concept document
(ESA document – collaborative effort with the consortium)

Details how the instruments and the mission itself will be operated, how they respond to triggers and ToOs, including the ground segment part. It lays down the main assumptions needed to size the spacecraft and the ground segment, taking into account the expected instrument observation modes and the resources needed for each mode. This includes also the triggering algorithms and the interactions between the instruments and the TBU, OBDH, DHUs.

MOS – Mission Observation Simulator
(ESA effort with inputs from the consortium)

It is a simulator of the THESEUS mission, based on a as-realistic-as-possible "sky model" assuming a GRB population as a function of redshift as well as ToO triggering sources and other transient/variable sources that THESEUS will be able to observe. It provides a simulated observational plan for the 3 years of mission operations including all "inefficiencies" related to the spacecraft and observational constraints, with the goal of demonstrating the feasibility of THESEUS core science objectives (with simplifying assumptions to be relaxed over time)

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Scientific Drivers

- Maximize detection, accurate location, mw characterization of GRBs at z>6 redshift
- Maximize detection, accurate (from arcmin to arcsec) location of short GRBs (as possible e.m. counterparts to GW signals)
- Maximize probability of detecting, accurately localizing (arcmin) and possibly characterizing soft X-ray and NIR emission associated to GW signals
- Monitoring of the sky from soft X-rays to gamma-rays, allowing detection and characterize of tens of variables / transients per year
- Optimizations and options: optimization of pointing strategy for follow-up from ground facilities (especially for high-z GRBs and e.m. counterparts of GW signals), optimization of X-ray survey coverage, guest observer program

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Observational strategy key criteria

- All core-science targets of THESEUS are randomly distributed in the sky and occur at random times -> no hard scientific constraints on sky region

- high degree of "autonomy" (follow-up from other facilities not formally critical for core science objectives) -> no hard scientific constraints on sky region

- Synergy with other main facilities of the near future is a strength, also substantially enlarging the interest and involvement of scientific community: preferences on sky region (e.g., low declination for follow-up from the ground especially of high-z GRBs and GW counterparts)

→ **Pointing strategy is being kept flexible and not fixed yet. An advanced mission simulator has proven that different pointing strategies options still allow THESEUS to fulfil its core science goals with wide margins**.

Observational modes

- **Survey mode**: pointing optimized for maximizing SXI and XGIS efficiency, as well as efficiency of possible follow-up observation with IRT; SXI and XGIS light curves and images continuously analysed by on-board s/w; possibly IRT pointed to sources of interest requiring small deviations from optimal pointing (GO program)

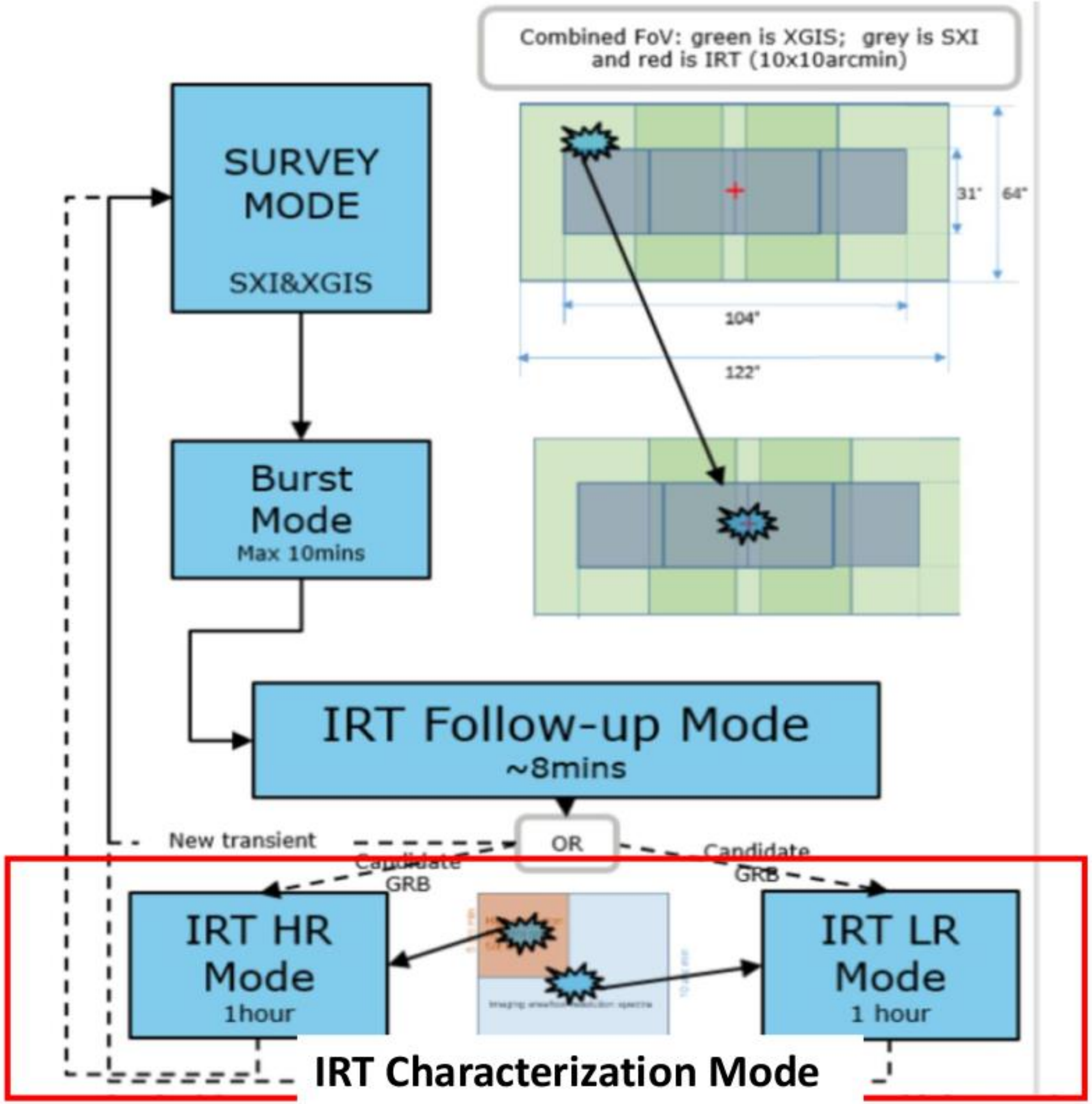
- **Burst mode**: SXI and XGIS set to “burst” mode; if OK for OBDH, slew is actually performed, with SXI and XGIS continuing acquiring data and IRT not observing

- **IRT follow-up mode**: when slew ended and satellite stabilized, start of the IRT observing sequence (either 12.5 min only or 12.5 min. + 1 hour, depending on if an afterglow candidate is found)

Observational modes (continues)

- **External trigger (TOO) mode**: requires 12 hours in working hours (goal 4 hours) to reach the spacecraft; may interrupt or no current follow-up observation depending on a "priority" flag; actual duration and possibility of being interrupted by on-board trigger will depend on a case by case and priority flag; it may be requested to search an IR / X-ray counterpart of, e.g., a GW / neutrino signal or GRB /transient of interest detected by other instrument or to study already identified X-ray / IR transient of high interest; IRT observation sequence depend on a case by case; SXI and XGIs as in survey mode. Limitation in response time for cost optimization rather than technical limitations (slew time is 0.1°/second, and could be better pending industrial studies confirmation). 3 per months planned for cost optimization, submitted to the Project Scientist at ESA by a dedicated THESEUS consortium team.

- **Guest Observer mode**: pointing to a source of interest with IRT or SXI selected through GO; IRT might be performing either imaging, or low-resolution spectroscopy, or high-resolution spectroscopy or a combination of these possibilities (depending on the specific requirements of the GO program proposal). Duration will vary from case to case; may be interrupted by on-board or external trigger.


Combined FoV: green is XGIS; grey is SXI and red is IRT (10x10arcmin)
SURVEY MODE
SXI&XGIS
31'
64'
104'
122'
Burst Mode
Max 10mins
IRT Follow-up Mode
~8mins
OR
New transient
Candidate GRB
Candidate GRB
IRT HR Mode
1hour
IRT LR Mode
1 hour
IRT Characterization Mode

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Consortium inputs to the MOS

- A GRB "sky model", in which the expected number of total GRBs in the all sky is provided according to the state-of-the-art knowledge about GRBs as a function of redshift. Flags are provided to show (calculate) if each GRB is detectable by the SXI (XGIS), as well as if its afterglow can be detected by the IRT.

- A list of variable / transient sources, derived from the INTEGRAL data analysis catalogue.

- Instruments response in a form suitable for being automatized within the MOS for all instruments (see next slide)

- Clarifications on assumptions based on feedback from the TSST and the scientific working groups

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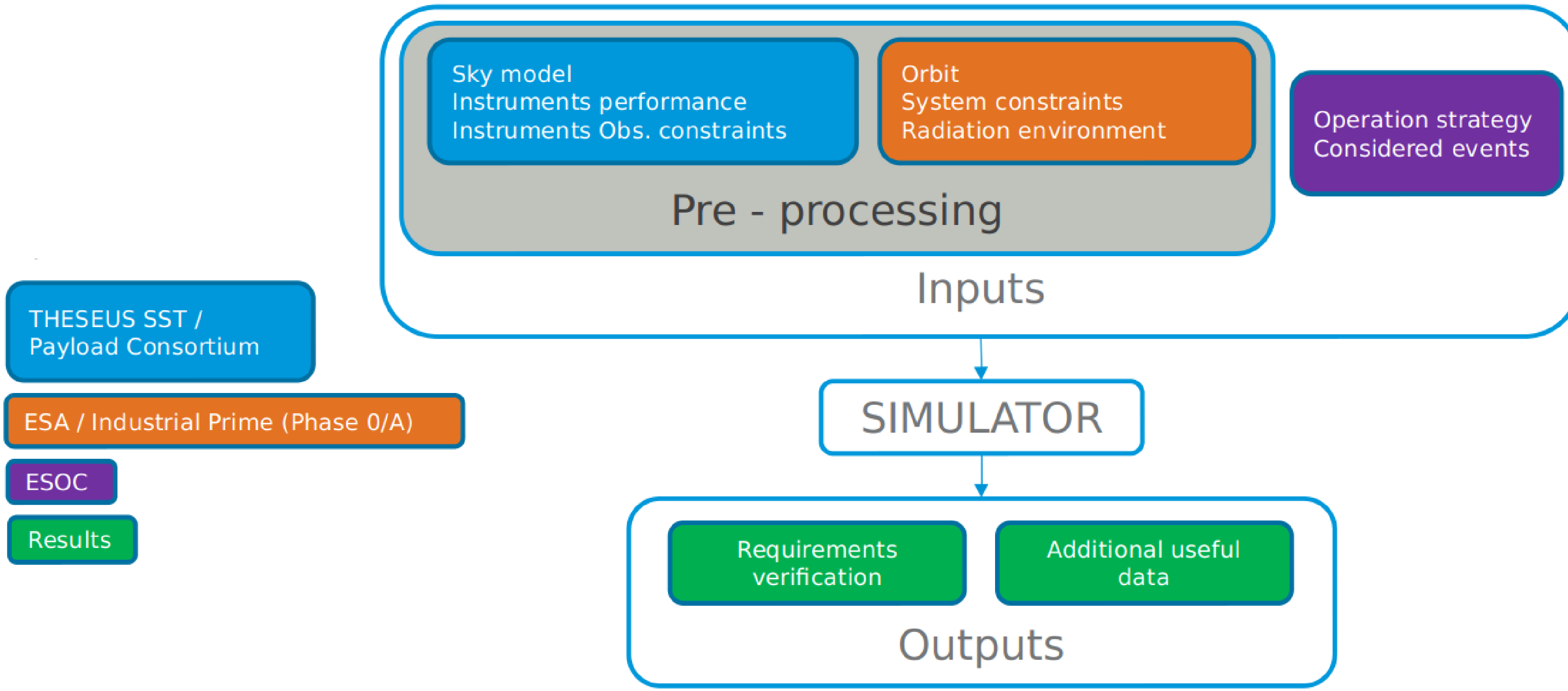

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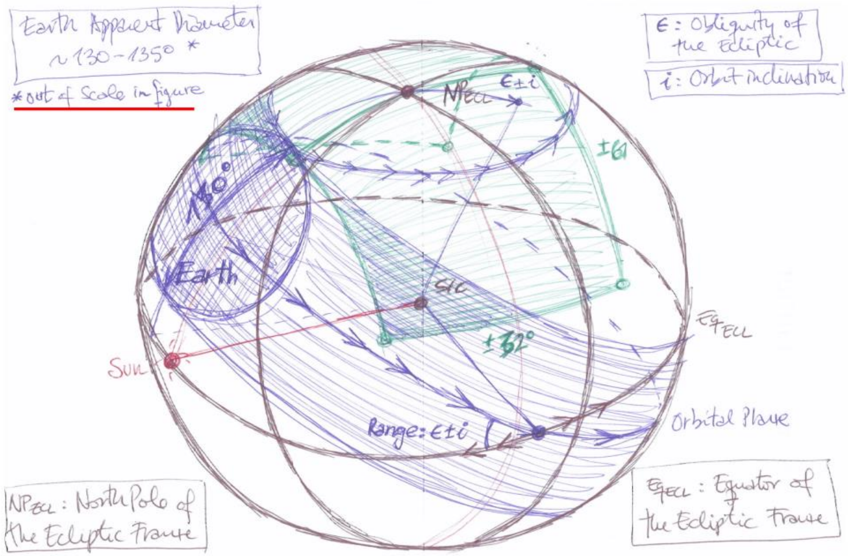

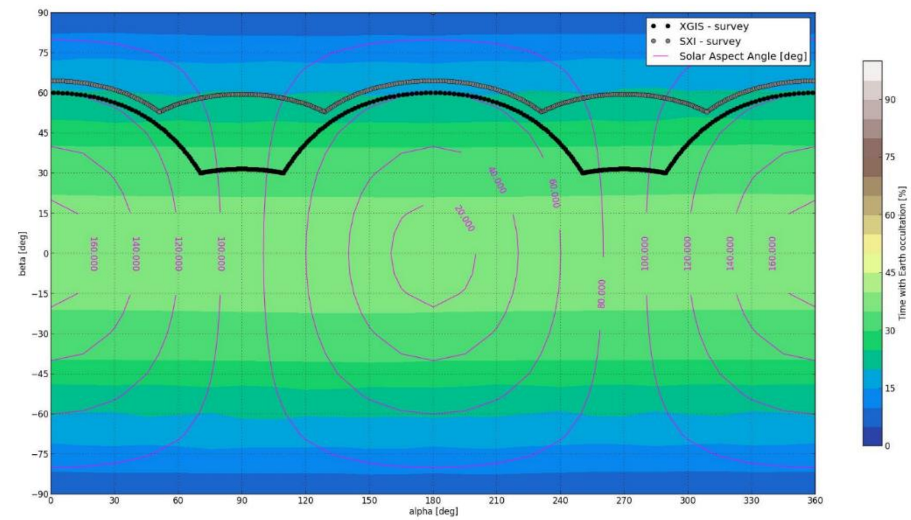

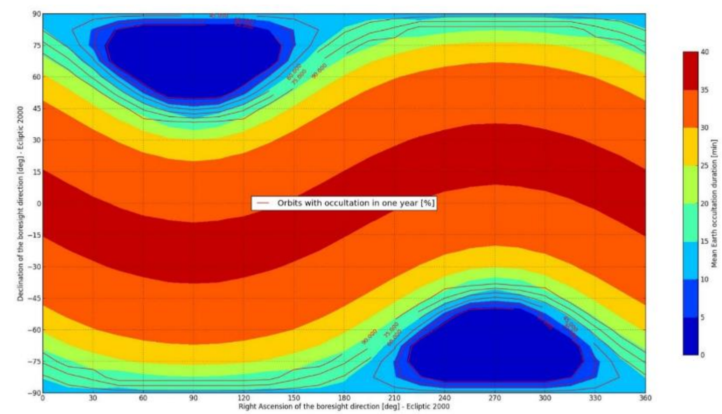

Initial planned pointing strategy: ecliptic poles to maximize the observational time available and thus the chance to detect GRBs

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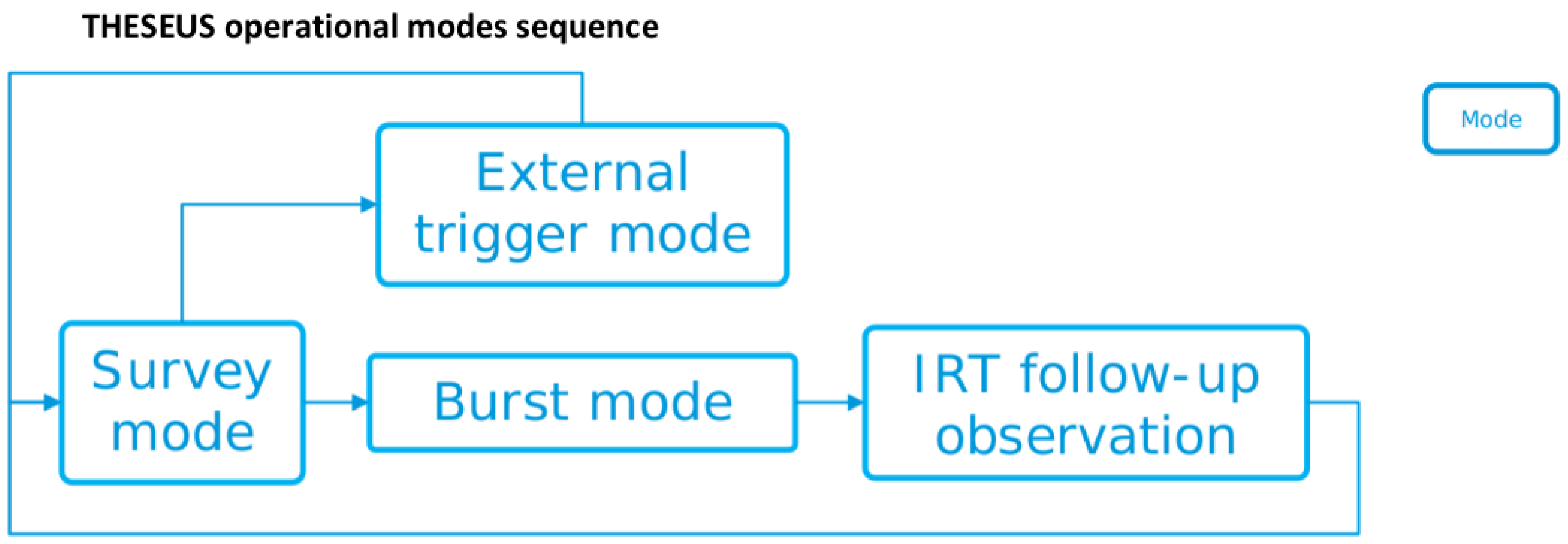

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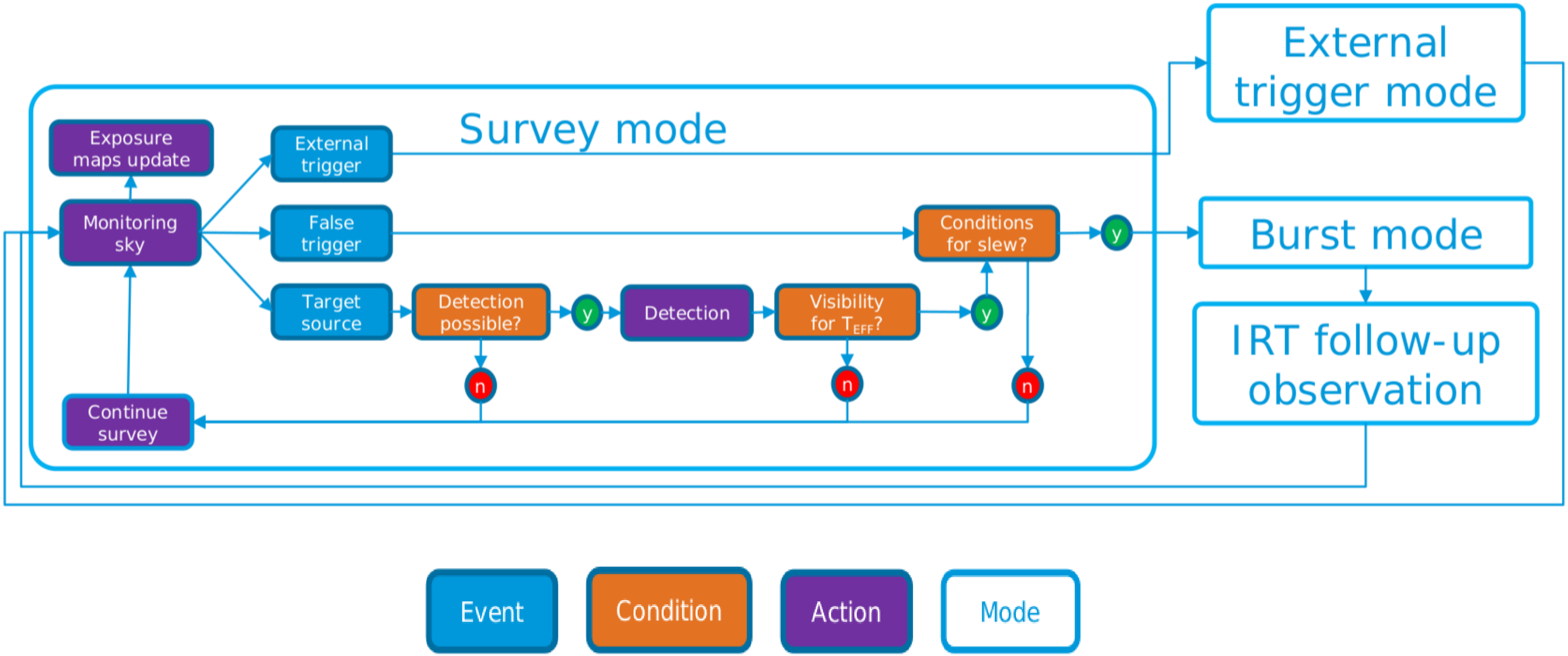

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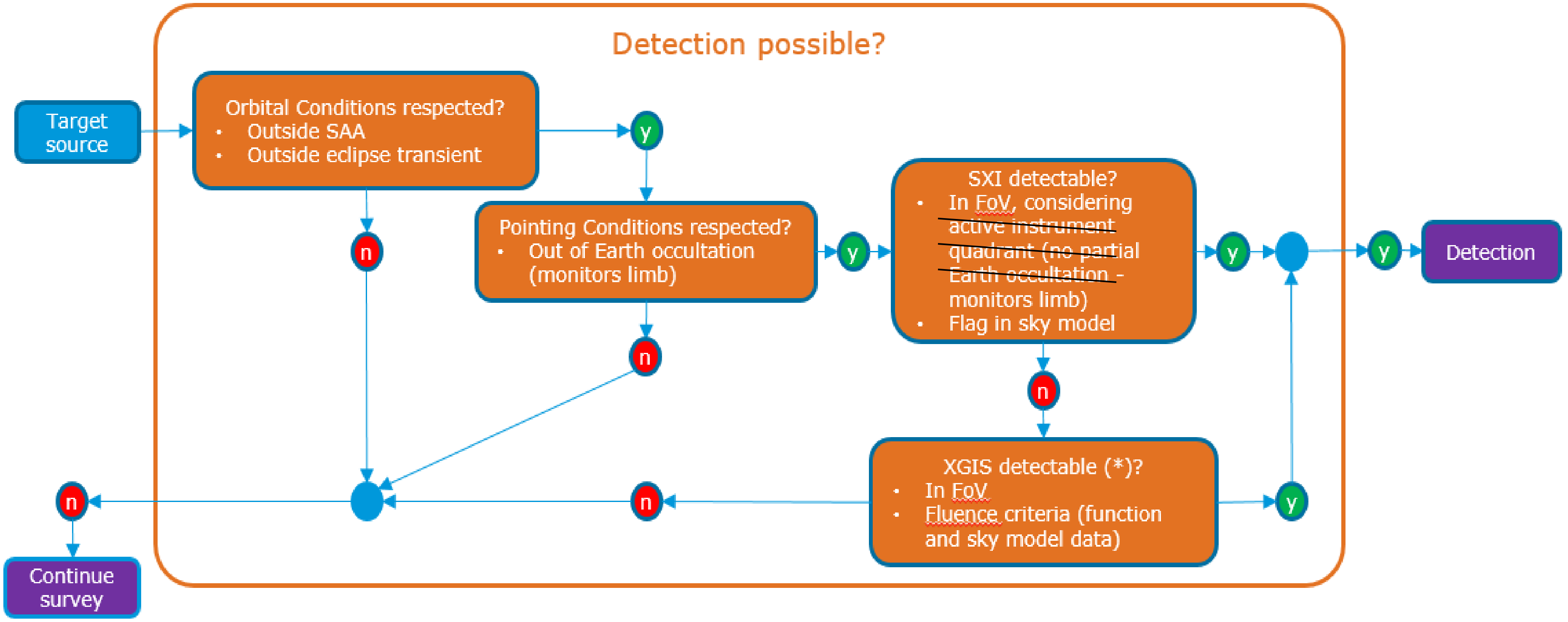
Operational constraints: Conditions for detection



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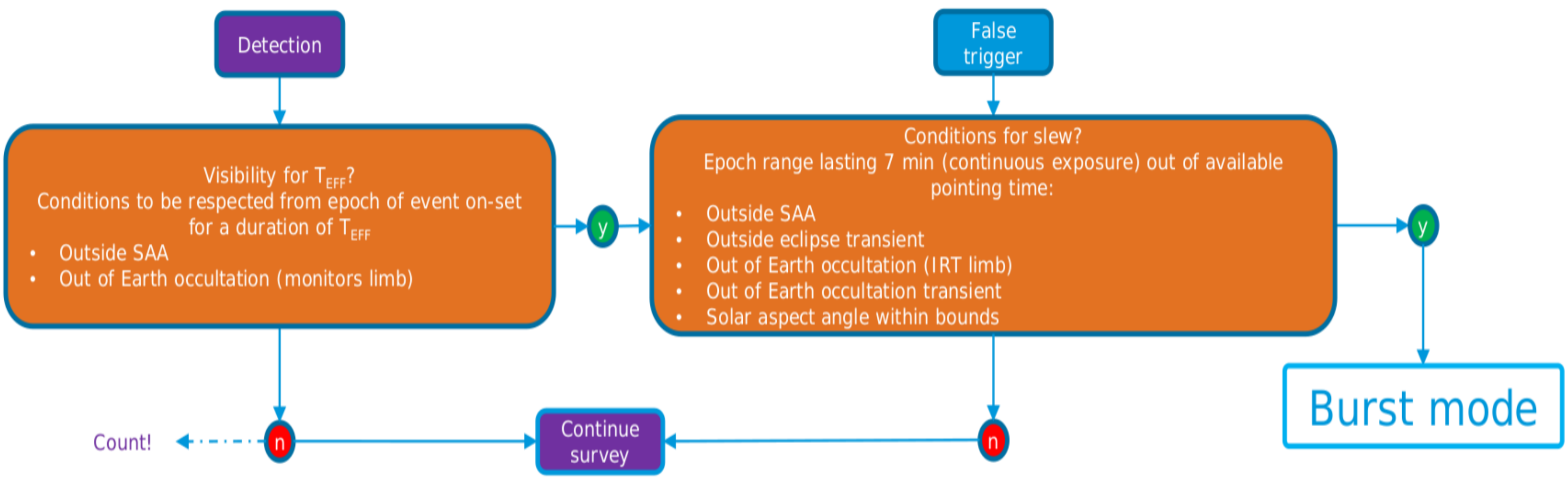
Operational constraints: burst duration visibility and conditions for slew.



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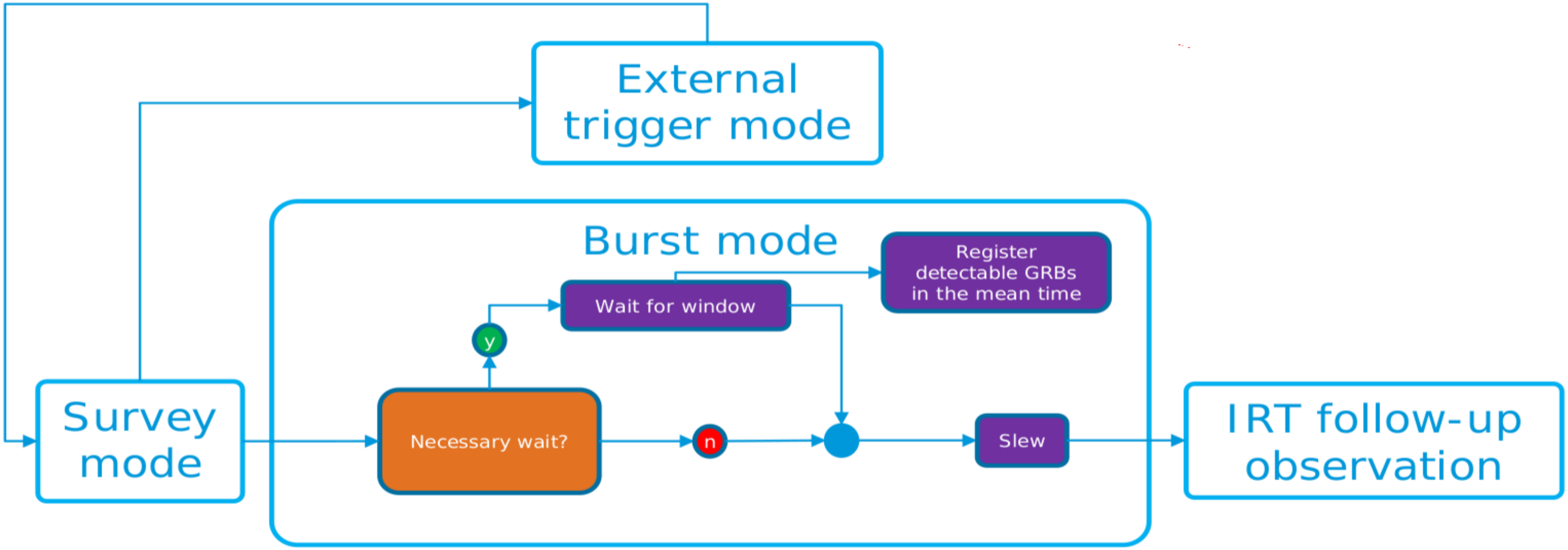
Burst mode



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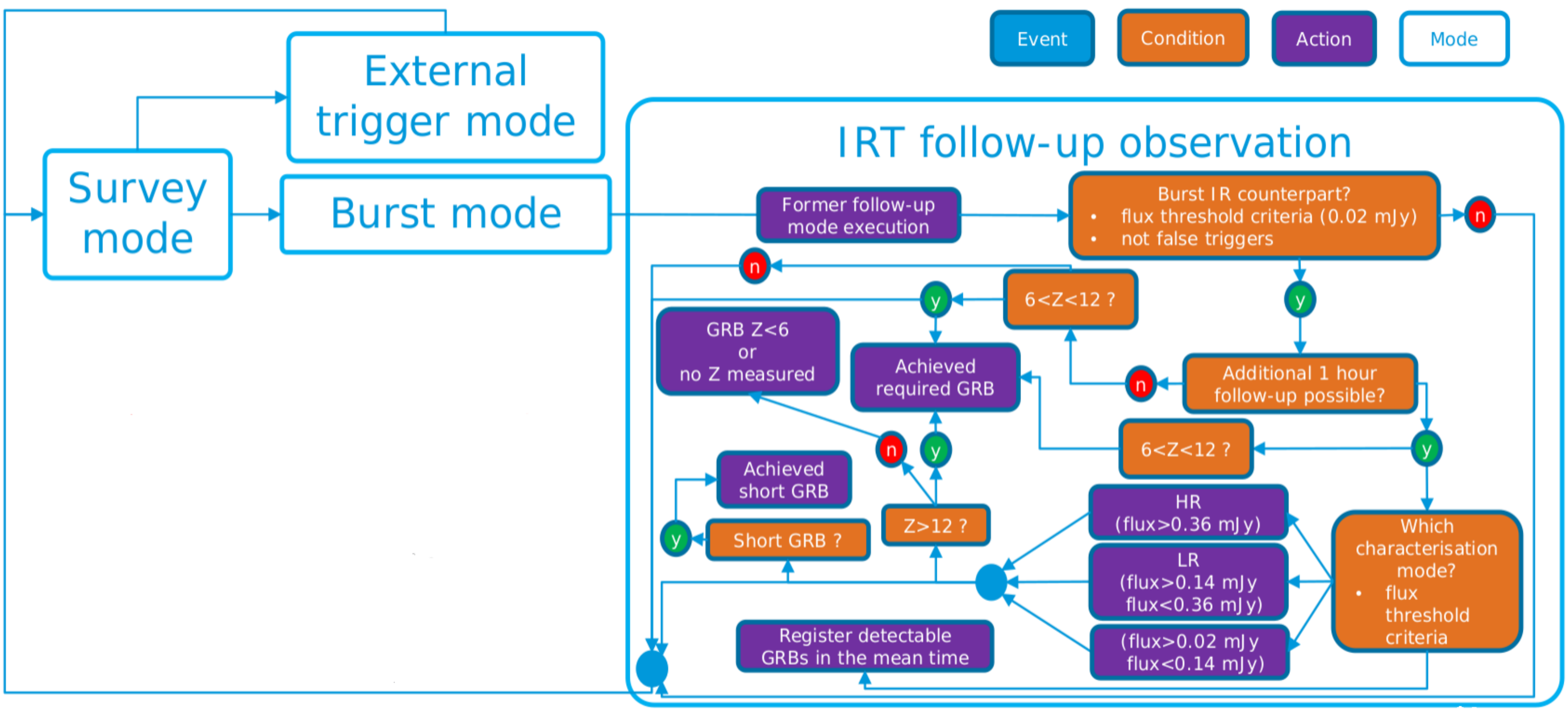
Follow-up mode

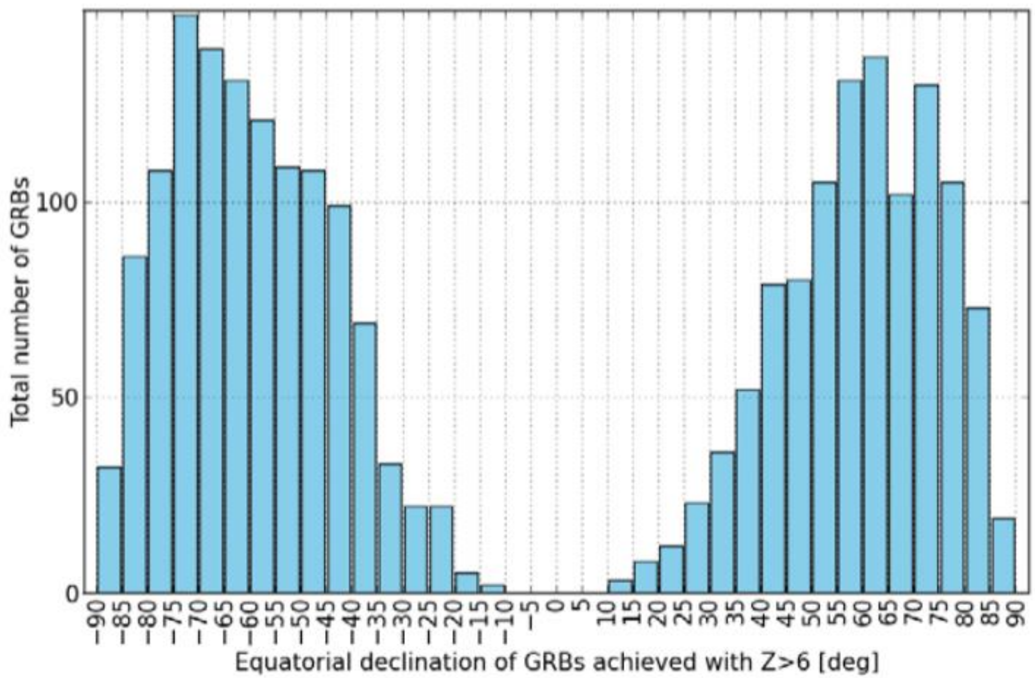


MOS – Mission Observation Simulator
Initially considered pointing strategy – Ecliptic poles

Main results	Average per science year	
	Absolute	Variation w.r.t. EP [%]
Detected target sources (false triggers excluded)	523.6	6.7%
detected only by SXI	218.0	2.2%
detected only by XGIS	124.6	16.3%
detected by both SXI and XGIS	181.0	6.4%
IRT follow-up mode executed (7 min continuous exposure out of 20/100 min, false triggers excluded)	438.9	6.2%
Detected by IRT (flux above 0.02 mJy)	282.6	4.8%
Further IRT characterisation performed (1 hour exposure)	282.4	4.8%
flux between 0.02 and 0.14 mJy	115.8	5.6%
flux between 0.14 and 0.36 mJy (LR mode)	49.0	4.9%
flux above 0.36 mJy (HR mode)	117.6	4.0%
Achieved required GRBs z>6	19.4	2.1%
Achieved required GRBs z>8	8.9	8.5%
Achieved short GRBs	11.7	10.4%

MOS – Mission Observation Simulator
Initially considered pointing strategy – Ecliptic poles

Declination range (absolute)	Fraction of achieved GRBs z>6
0-30	4.2 %
30-55	33.1 %
55-75	44.6 %
75-90	18.2 %



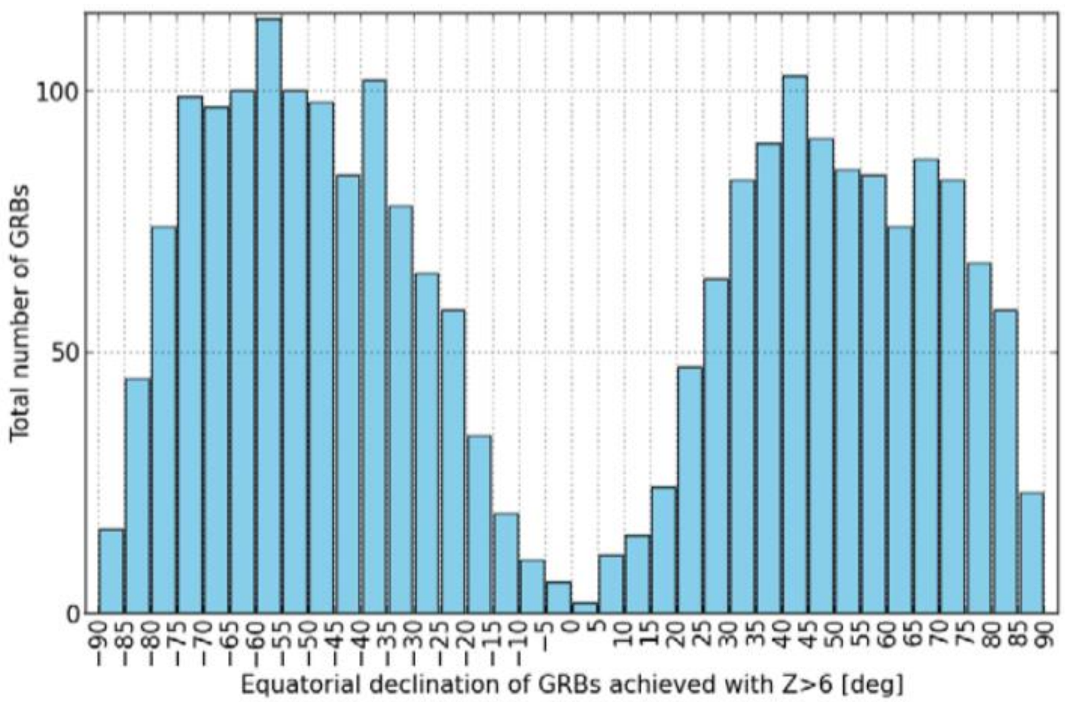
MOS – Mission Observation Simulator
Dynamic pointing strategy 1 – improving low declination detections for ground follow-up

Main results	Average per science year	
	Absolute	Variation w.r.t. EP [%]
Detected target sources (false triggers excluded)	504.8	2.9
detected only by SXI	217.6	2.0
detected only by XGIS	115.8	8.1
detected by both SXI and XGIS	171.5	0.8
IRT follow-up mode executed (7 min continuous exposure out of 20/100 min, false triggers excluded)	426.2	3.1
Detected by IRT (flux above 0.02 mJy)	280.7	4.1
Further IRT characterisation performed (1 hour exposure)	280.6	4.1
flux between 0.02 and 0.14 mJy	112.9	2.9
flux between 0.14 and 0.36 mJy (LR mode)	47.9	2.6
flux above 0.36 mJy (HR mode)	119.7	5.8
Achieved required GRBs z>6	19.1	0.5
Achieved required GRBs z>8	8.4	2.4
Achieved short GRBs	11.2	5.7

MOS – Mission Observation Simulator

Dynamic pointing strategy 1 – improving low declination detections for ground follow-up

Declination range (absolute)	Fraction of achieved GRBs z>6
0-30	15.5%
30-55	39.9%
55-75	32.2%
75-90	12.4%



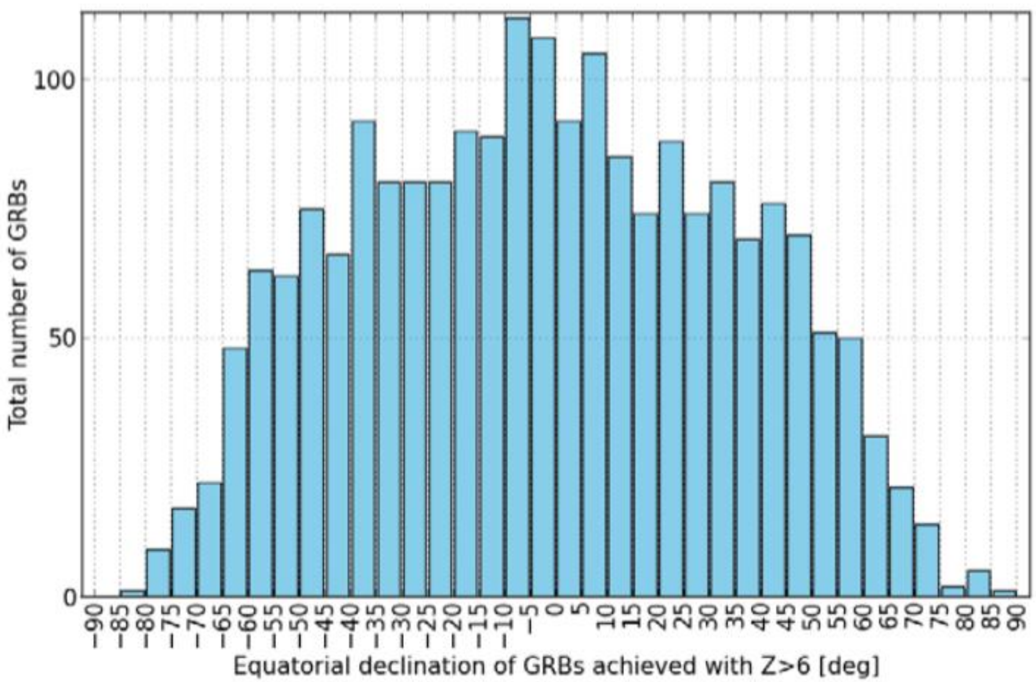
MOS – Mission Observation Simulator
Dynamic pointing strategy 2 – improving more and more low declination detections

Main results	Average per science year	
	Absolute	Variation w.r.t. EP [%]
Detected target sources (false triggers excluded)	482.4	-1.7
detected only by SXI	207.3	-2.8
detected only by XGIS	111.5	4.1
detected by both SXI and XGIS	163.7	-3.8
IRT follow-up mode executed (7 min continuous exposure out of 20/100 min, false triggers excluded)	400.9	-3.0
Detected by IRT (flux above 0.02 mJy)	263	-2.5
Further IRT characterisation performed (1 hour exposure)	262.8	-2.5
flux between 0.02 and 0.14 mJy	105.9	-3.5
flux between 0.14 and 0.36 mJy (LR mode)	44.3	-5.1
flux above 0.36 mJy (HR mode)	112.6	-0.4
Achieved required GRBs z>6	17.3	-8.9
Achieved required GRBs z>8	7.8	-4.9
Achieved short GRBs	10.4	-1.9

MOS – Mission Observation Simulator

Dynamic pointing strategy 2 – improving more and more low declination detections

Declination range (absolute)	Fraction of achieved GRBs z>6
0-30	51.7%
30-55	34.6%
55-75	12.8%
75-90	0.9%



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Note

- MOS has several conservative assumptions, compatible with the usual approach in phase A
- Revision of some assumptions/instrument performances ongoing. Numbers are not final
- Inherent artificial limitations: improvement of ~15-20% expected in “real life”
- MOS to prove the margins on fulfilling THESEUS core science goals. This is successful so far and different pointing strategies are tested to be feasible without impacting on the spacecraft design. Final choice is mainly science-driven but could not be needed already at this stage.