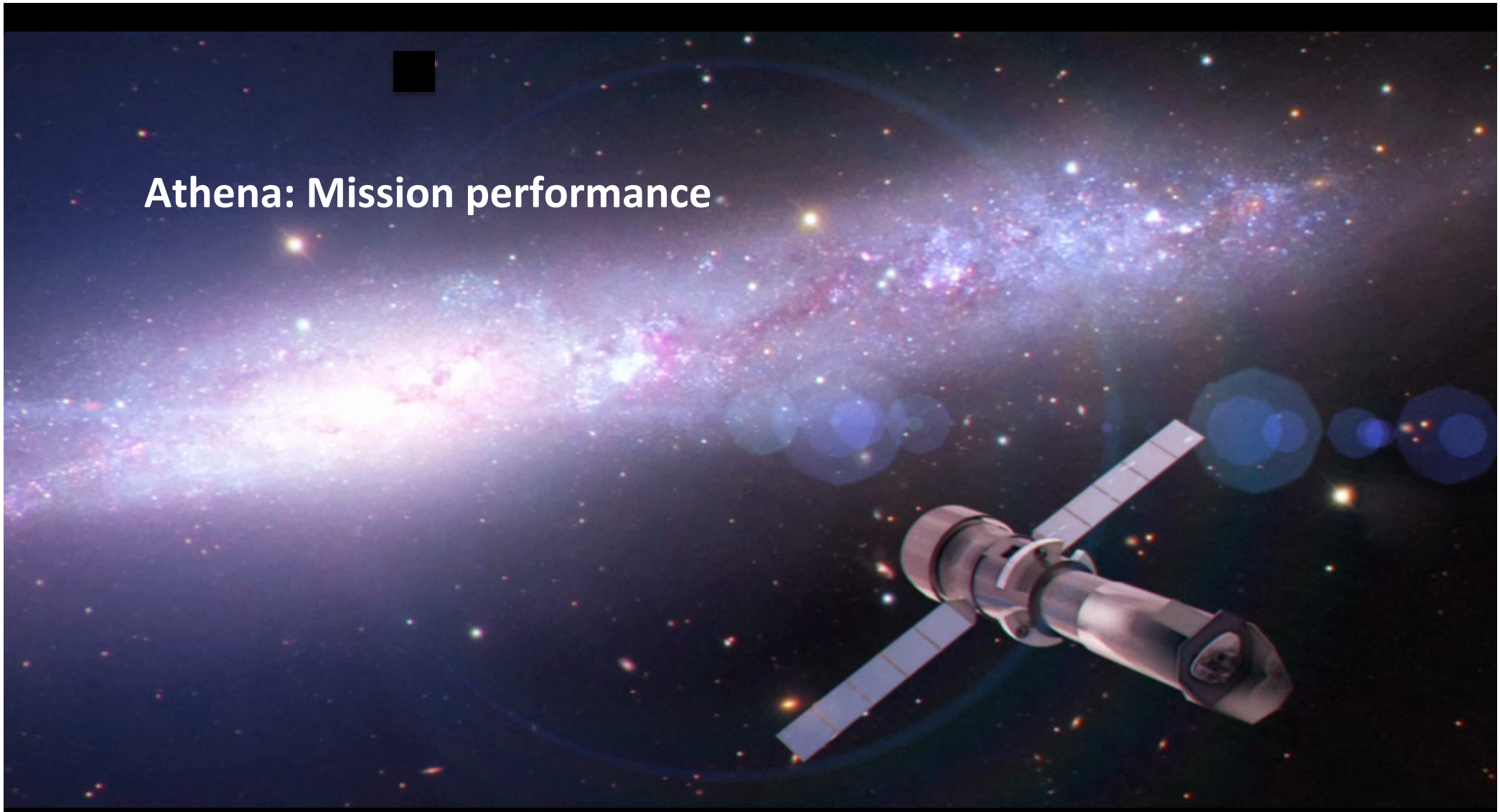
Athena: Mission performance



Jan-Willem den Herder (SRON), Luigi Piro (INAF) and Arne Rau (MPE)
on behalf of the Mission Performance Working Group

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- Science requirements
- Mock observation plan
- End-to-end simulations
- Target of Opportunities
- Science Ground Segment

Science requirements
(SWG, ASST)

- level 0: top level goals
- Level 1: quantified science objectives
- Level 2a: mission requirements (not assuming a particular missions design)
- Level 2b/2c: mission/instrument requirements derived from level 2a for a given design)

Level 0 requirements

The Hot Universe: Determine how and when large-scale hot gas structures form in the Universe and track their evolution from the formation epoch to the present day.

The Energetic Universe: Perform a complete census of black hole growth in the Universe, determine the physical processes responsible for that growth and its influence on larger scales, and trace these and other energetic and transient phenomena to the earliest cosmic epochs.

Observatory and Discovery Science: provide a unique contribution to astrophysics in the 2030s by exploring high energy phenomena in all astrophysical contexts, including those yet to be discovered.

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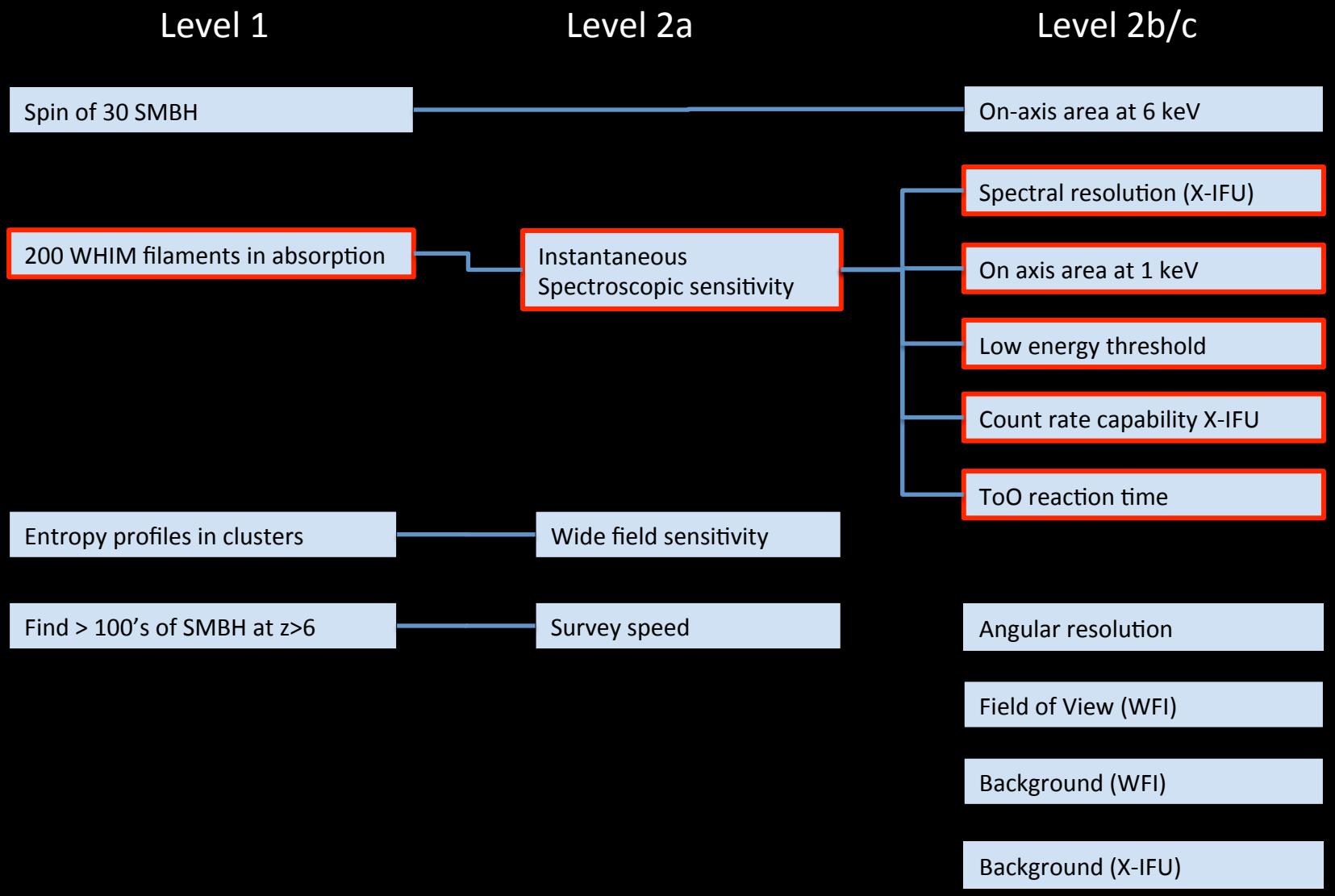
An Example of flowdown:



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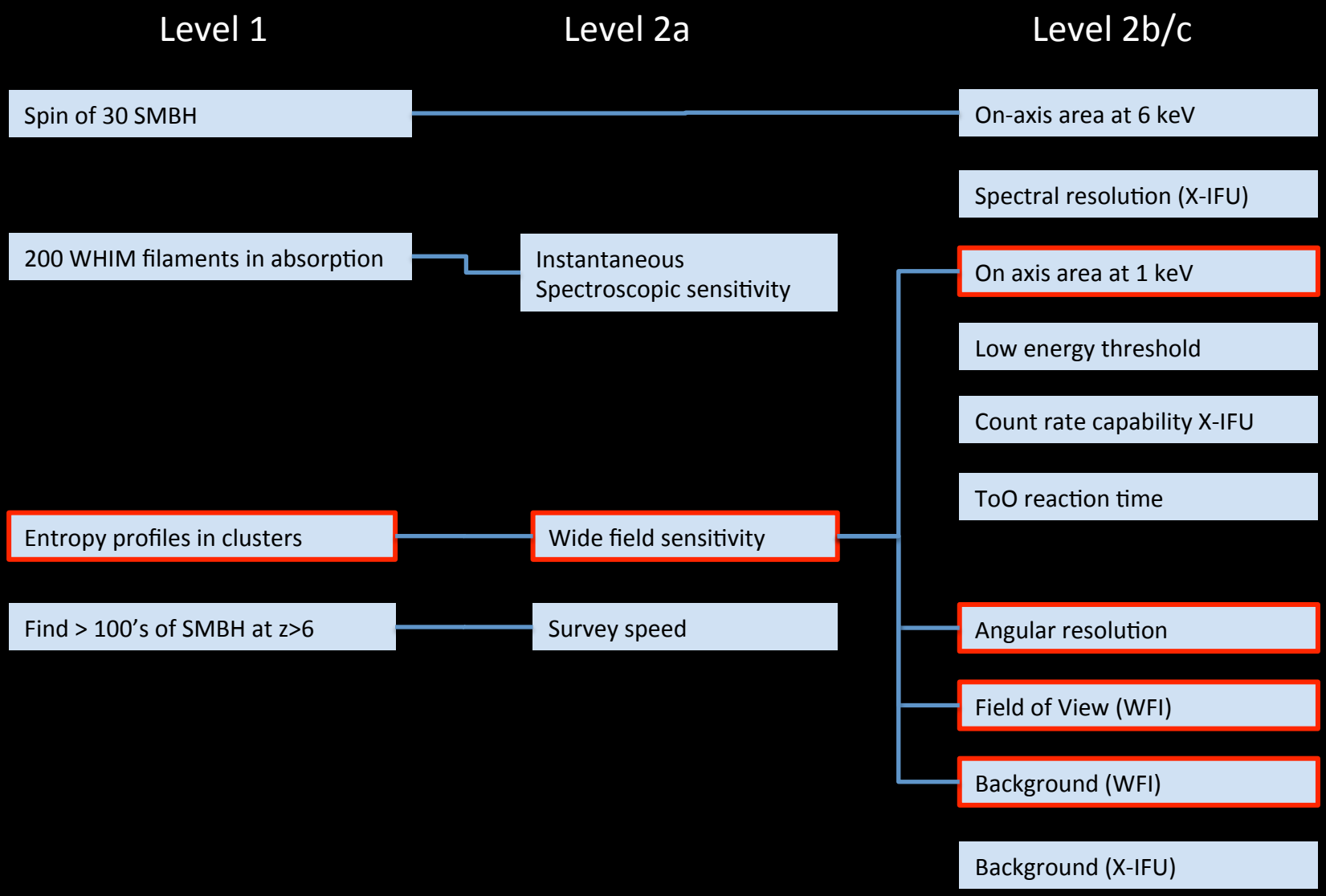
Level 1
Level 2a
Level 2b/c
Spin of 30 SMBH
200 WHIM filaments in absorption
Instantaneous Spectroscopic sensitivity
Entropy profiles in clusters
Wide field sensitivity
Find > 100's of SMBH at z>6
Survey speed
On-axis area at 6 keV
Spectral resolution (X-IFU)
On axis area at 1 keV
Low energy threshold
Count rate capability X-IFU
ToO reaction time
Angular resolution
Field of View (WFI)
Background (WFI)
Background (X-IFU)

Level 1 requirement: an example
(total 35)

- R-SCIOBJ-122

- Athena shall constrain supernova yields by measuring the abundances and distribution of rarer metals (e.g., Al, Cl, Mn, Co) in clusters of galaxies from the core to ~virial radius locally (5 s detection). In distant clusters, Athena shall constrain the SNIa/SNcc ratio-via relative abundances of more abundant metals (i.e., O, Si, Fe), and study their evolution in redshift and mass, as well as differences between distributions in core and up to ~R_{500} (5 s detection).

- Metal production and dispersal in cluster hot gas out to z=2. Observe 10 local clusters and 10 clusters per redshift bin per mass bin out to z~2. Total 100 clusters.

Level 2a requirements: ongoing work

- Point source sensitivity (combination of area, angular resolution, background, integration time, energy resolution)
  - 7.2 10^{-17} erg/cm^2/s (in 60 ks observations over 52 deg^2)
  - 2.4 10^{-17} erg/cm^2/s (in 1 Ms observations over 2.4 deg^2)
- Survey speed (combination of area, angular resolution over field of view, field of view, background)
- Positional accuracy (satellite alignment, stability, pointing accuracy and reconstruction)

Level 2b/2c requirements

(implementation dependent, goals also defined, > 70)

- SCI-EA-R-05

- Athena shall perform Narrow Field observations with an effective area at the target of at least 0.23 m^2 at 6 keV

- Translates into mirror effective area and instrument QE (and knowledge about pointing)

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What to remember?

Parameter	value	enables (driving science goals)
Effective area at 1 keV	2 m^2	Early groups, cluster entropy and metal evolution, WHIM, high redshift AGN, census AGN, first generation of stars
Effective area at 6 keV	0.25 m^2	Cluster energetics (gas bulk motions and turbulence), AGN winds & outflows, SMBH & GBH spins
PSF HEW (< 8 keV)	5'' on axis, 10'' off axis	High z AGN, census of AGN, early groups, AGN feedback on cluster scales
X-IFU spectral resolution	2.5 eV	WHIM, cluster hot gas energetics and AGN feedback on cluster scales, energetics of AGN outflows at z~1-4
X-IFU FoV	5' diameter	Metal production & dispersal, cluster energetics, WHIM
X-IFU background	< 5 10^{-3} counts/s/cm^2/keV (75%)	Cluster energetics & AGN feedback on cluster scales, metal production & dispersal
WFI spectral resolution	<150 eV @ 6keV	GBH spin, reverberation mapping
WFI FoV	40' x 40'	High-z AGN, census AGN, early groups, cluster entropy

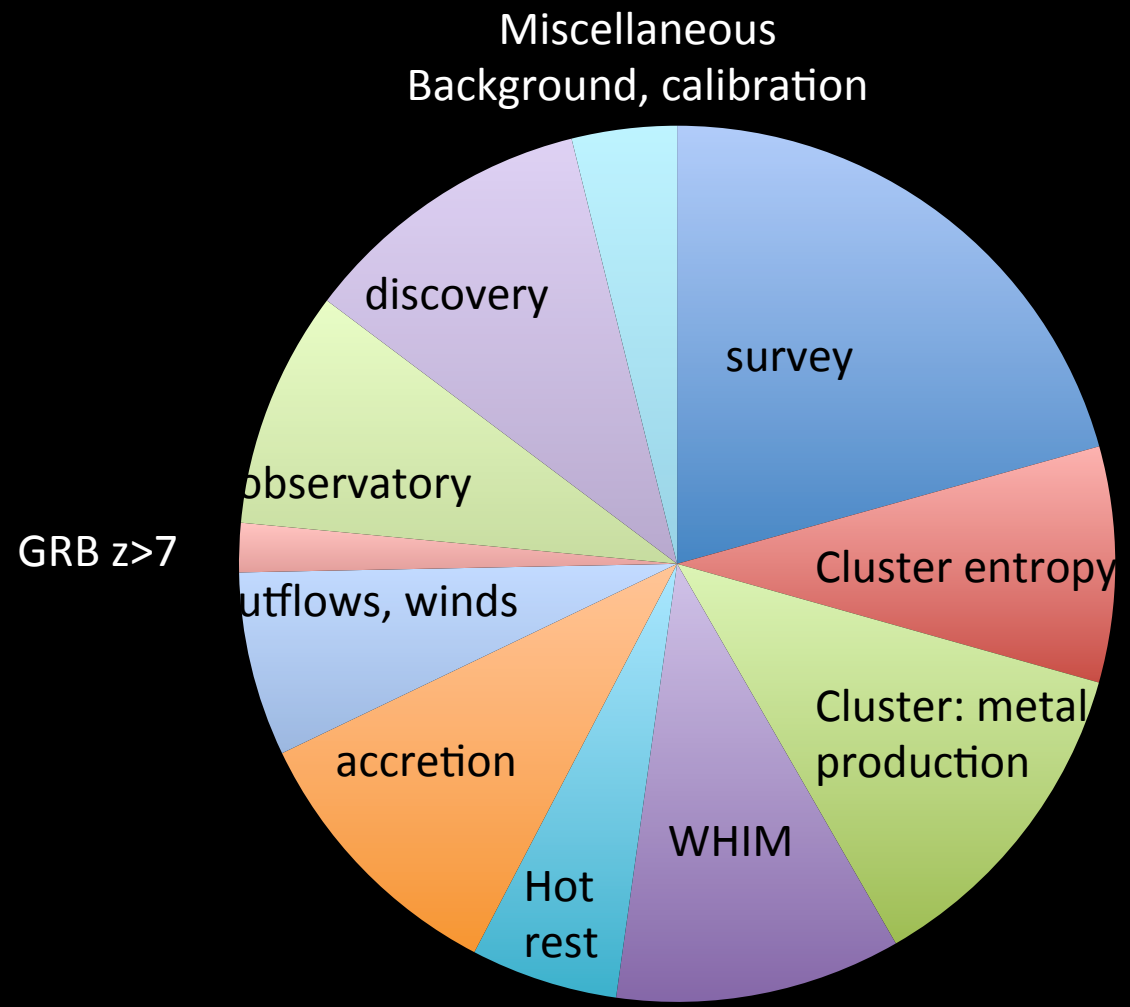
Mock Observing Plan

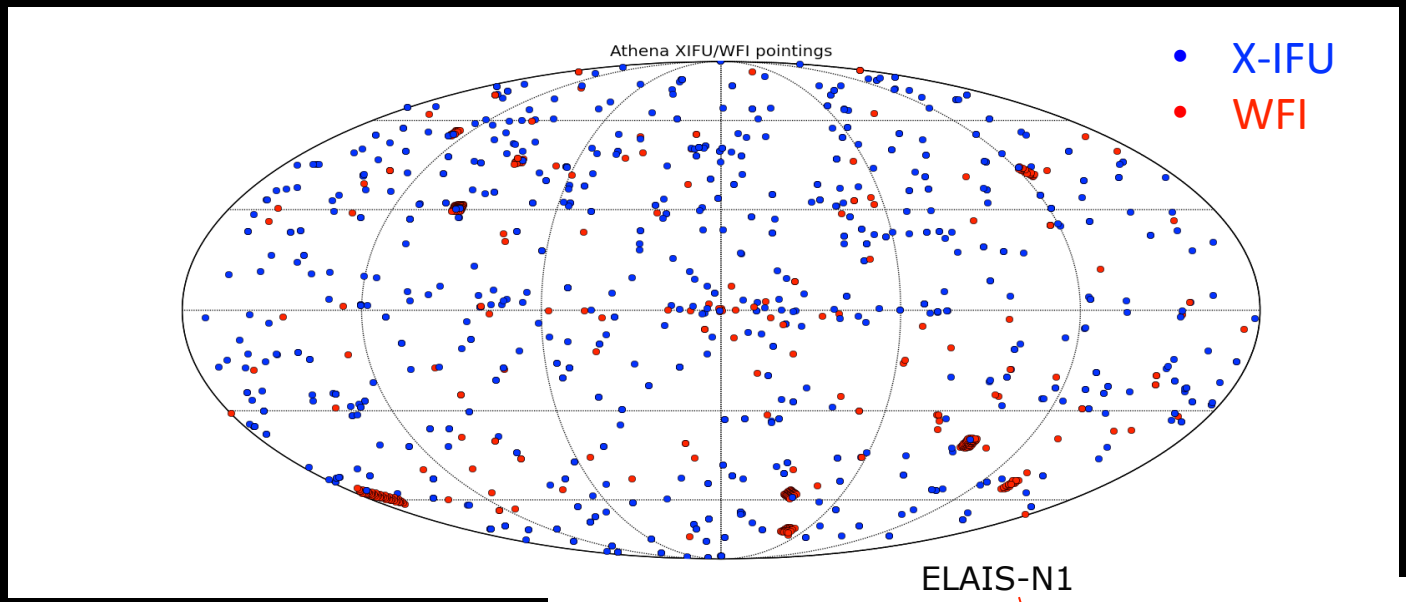
(SWGs, de Plaa)

- Does not define what Athena will measure in 2028 and beyond
- Is used to scale the mission (e.g. consumables, optimization of pointings, telemetry, split between X-IFU time and WFI, etc)
- Is used to verify that we can do the science of the white paper in the mission life time
- Current version has not yet prioritized observations: full 5 year is needed with 1 year of observatory/discovery science

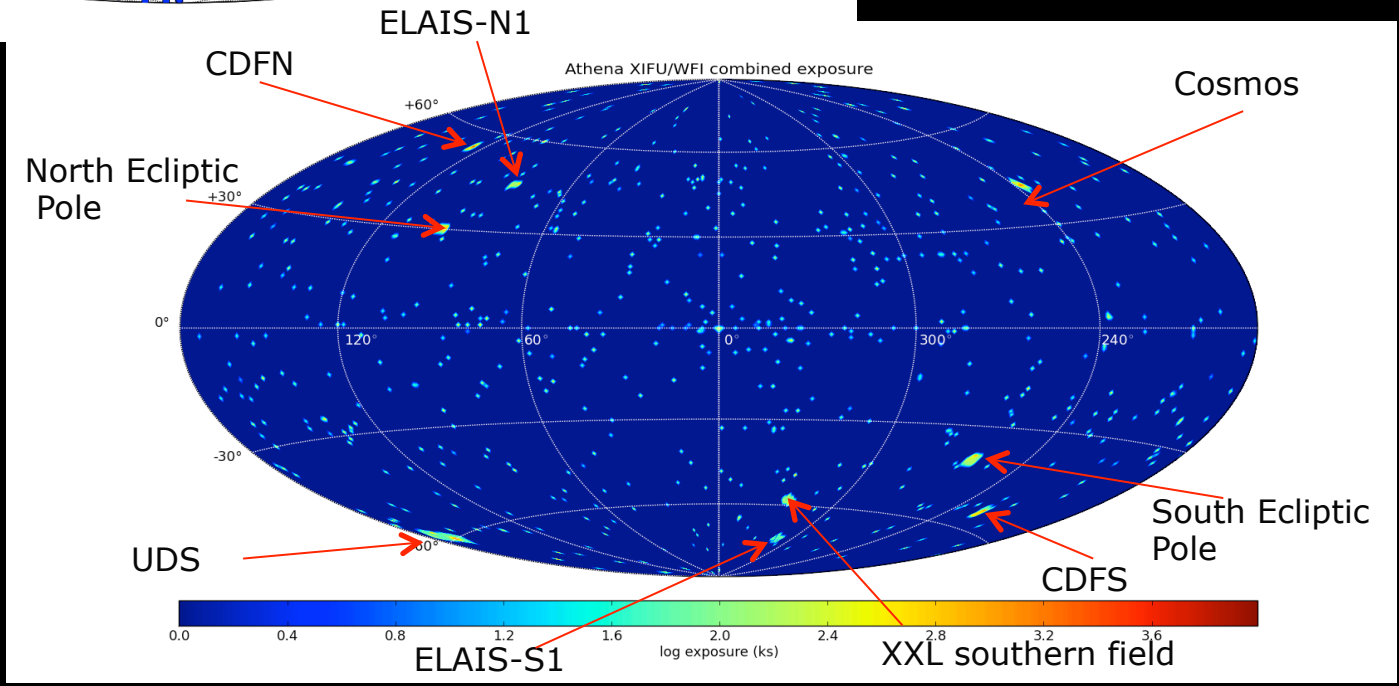
Some results

- Current distribution for 85% observing efficiency and 2m^2 area
- X-IFU: 57%, WFI: 43%
- 100 fast slews in 5 year





exposure



North Ecliptic Pole

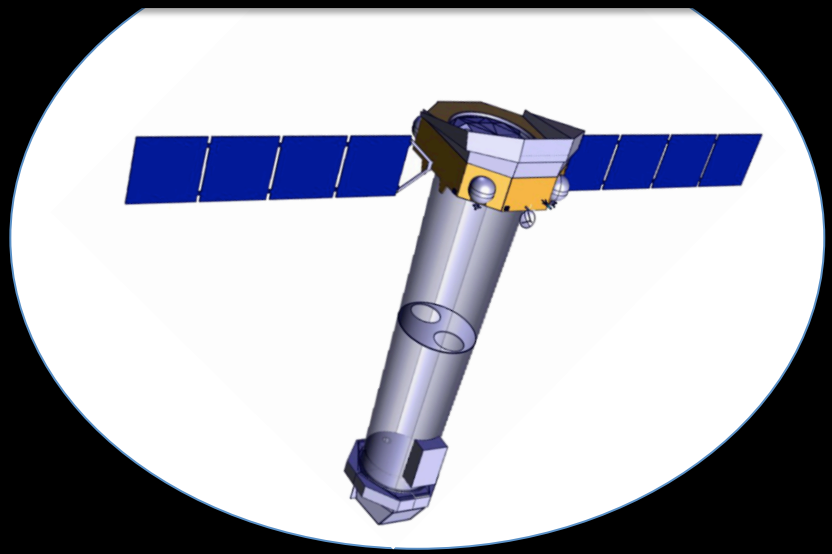
End-to-End simulations

(Wilms, Peille and E2E panel)

Provides realistic simulation of Athena mission:

- Detailed astrophysical source model allowing **M**onte Carlo simulations of photons
- Realistic (but parameterized) response of the optics (ARF, PSF)
- Physics based instrument response including Simulations of onboard electronics and event processing

Unique capability : sources with slight/moderate pile-up (> 1 mCrab), extended sources and proper treatment gaps, charge splitting etc.; fast timing



Generic for many missions (**SRG/**eROSITA, Athena, XMM, ARCUS, ….)

See also poster 12.5, 12.10 and 12.14

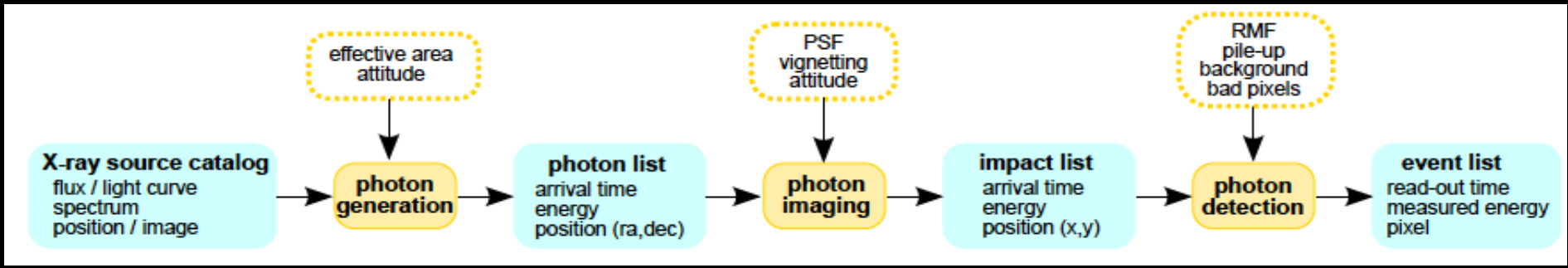
Simulator: SIXTE

Source model
- Catalogs
- Source specification (spectra, positions, light curves, spatial extend, MHD simulations, …

Uses SIMPUT formats

Telescope model
- Pointing
- ARF
- Vignetting
- PSF

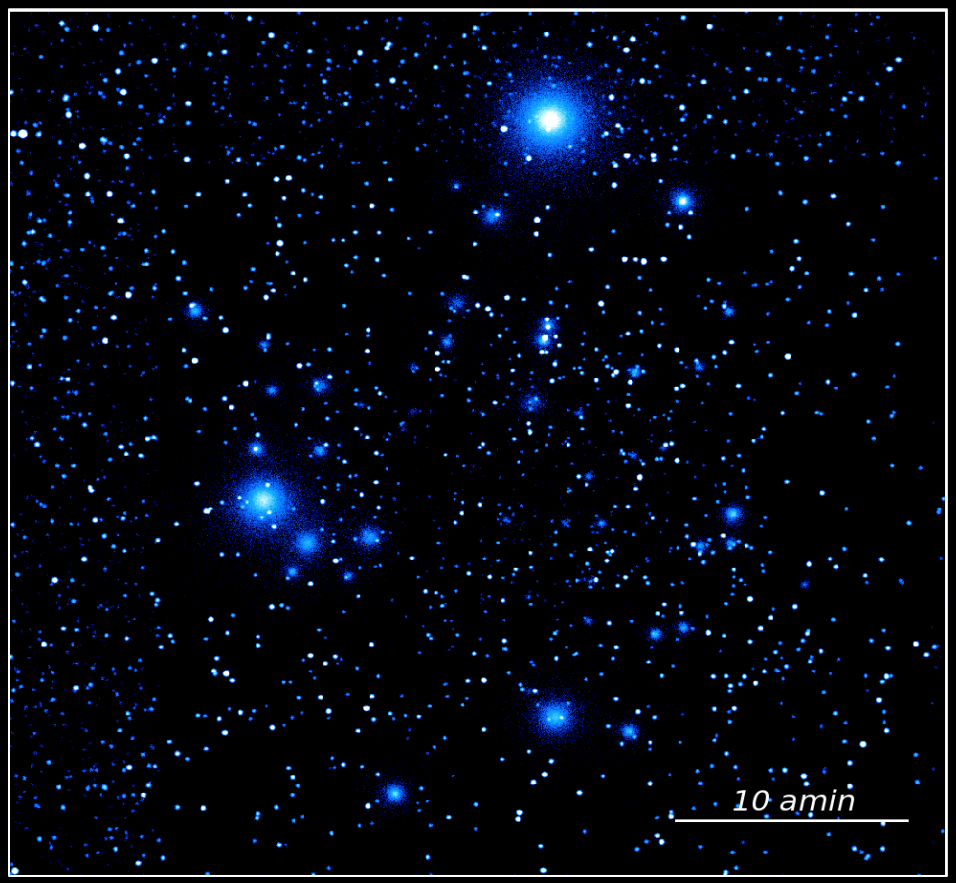
Instrument model
- RMF or physics simulation
- Pile-up
- Pixel-to-pixel variations
- Cross talk
- Background
- readout



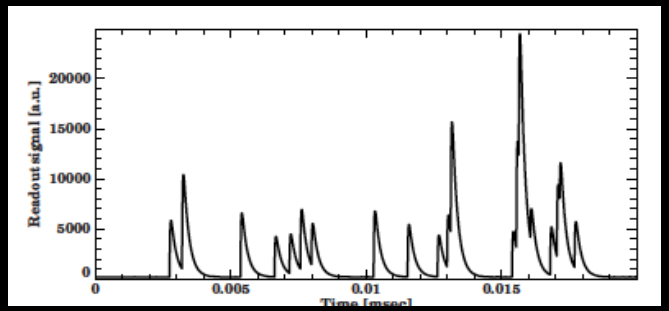
Some results

see: www.sternwarte.uni-erlangen.de/research/sixte

100ks WFI deep field (incl. dithering)



Event profiles X-IFU



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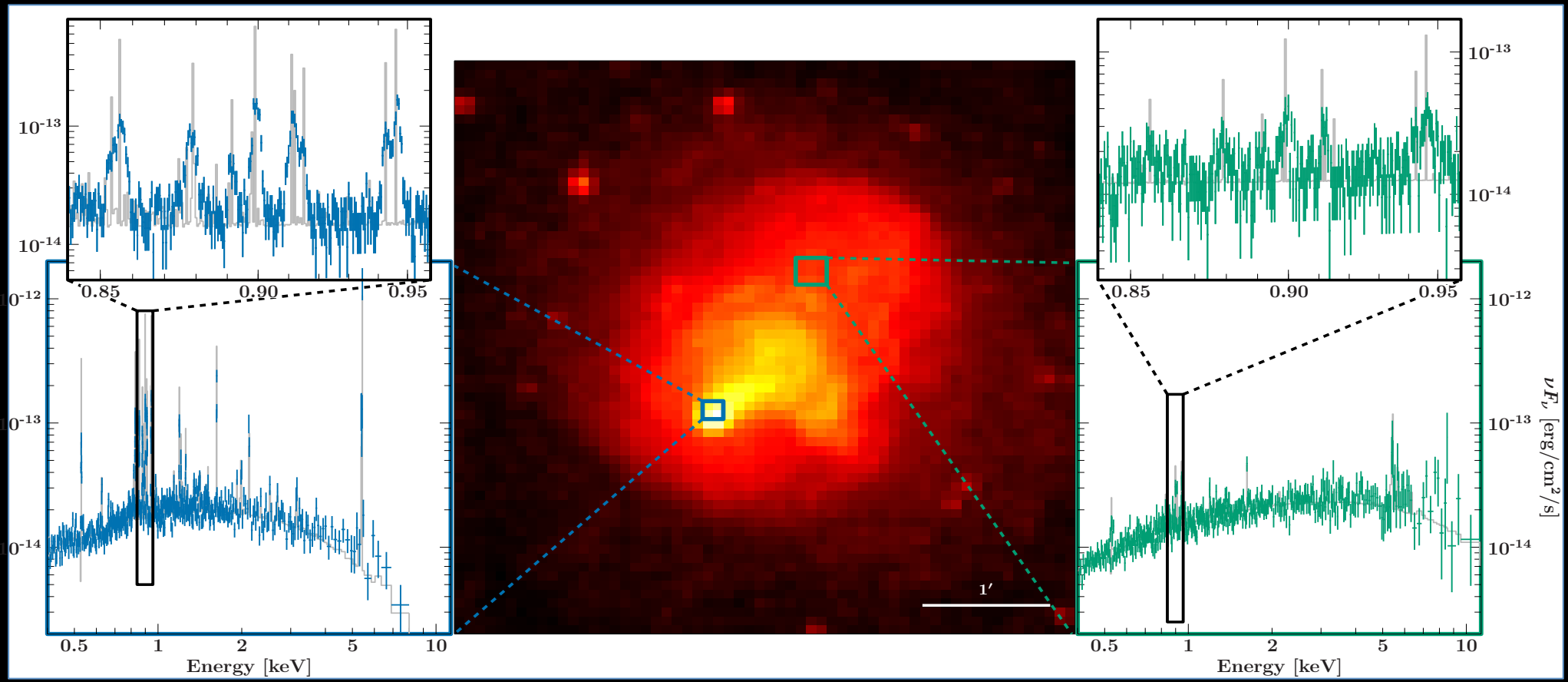
(Chandra image and T map, 100 ks)



Target of Opportunity

(Troja, Basa, Ayre, Ferreira)

- Key for part of the core science (WHIM and GRB at high red-shift)
- Need for external trigger (no all-sky monitor on Athena) with accurate positions (< 5'' for strong GRBs) to enable the observation with the high-countrate capability of the X-IFU
- Need for fast response time (less than 4 hours (goal 2) for 40% of the bursts going off in the whole sky)

- No autonomous control by satellite itself: trigger from the ground after (a) approval by project scientist and (b) validation of operations engineer

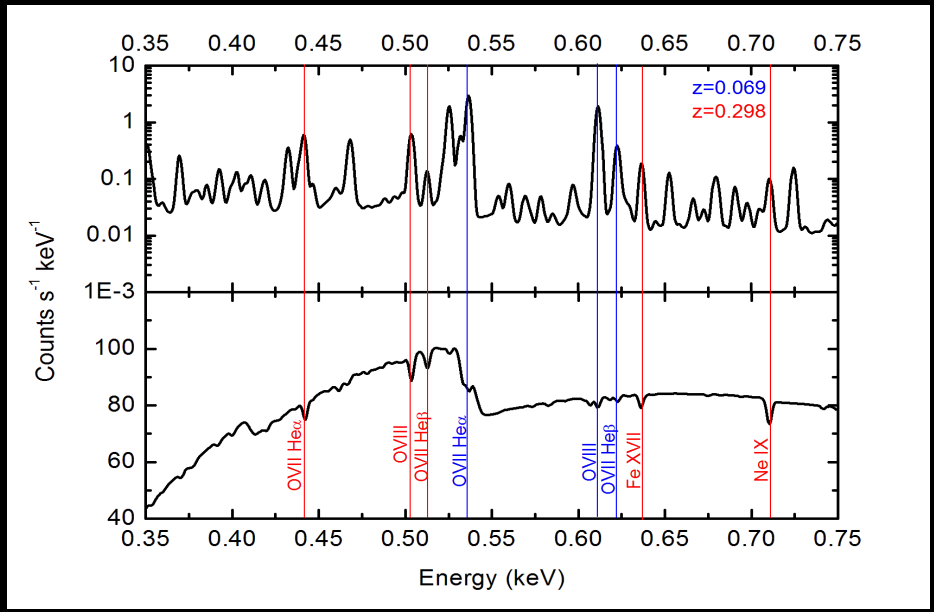
See also poster 12.7

Core science

(but other science will also benefit)

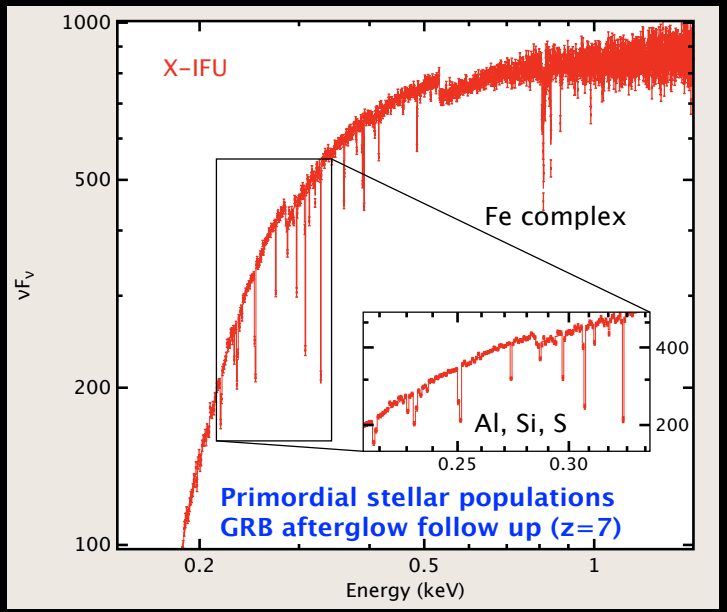
Detection of WHIM filaments

using GRB as backlight



Characterize first generation of stars

by determination of abundances in medium around high redshifted GRBs (z>7)



Response time components

- 50 ks X-IFU observations (with 100 ks feasible uninterrupted observing times)
- Need for semi-continuous uplink (covered)

- Need for 24/7 coverage for ToOs
- Fast decision and commanding (from home) by project scientist and support tools need to be available (e.g. position known, GRB intensity, N_H, visibility, etc.)
- Decide beforehand if ToO can be considered or planned (time critical) observations will not be interrupted
- Optimize (simplify) commanding of X-IFU (single/few commands only to start observations considering re-cycle time)

- XMM: 5 hours feasible, 4 hours hard

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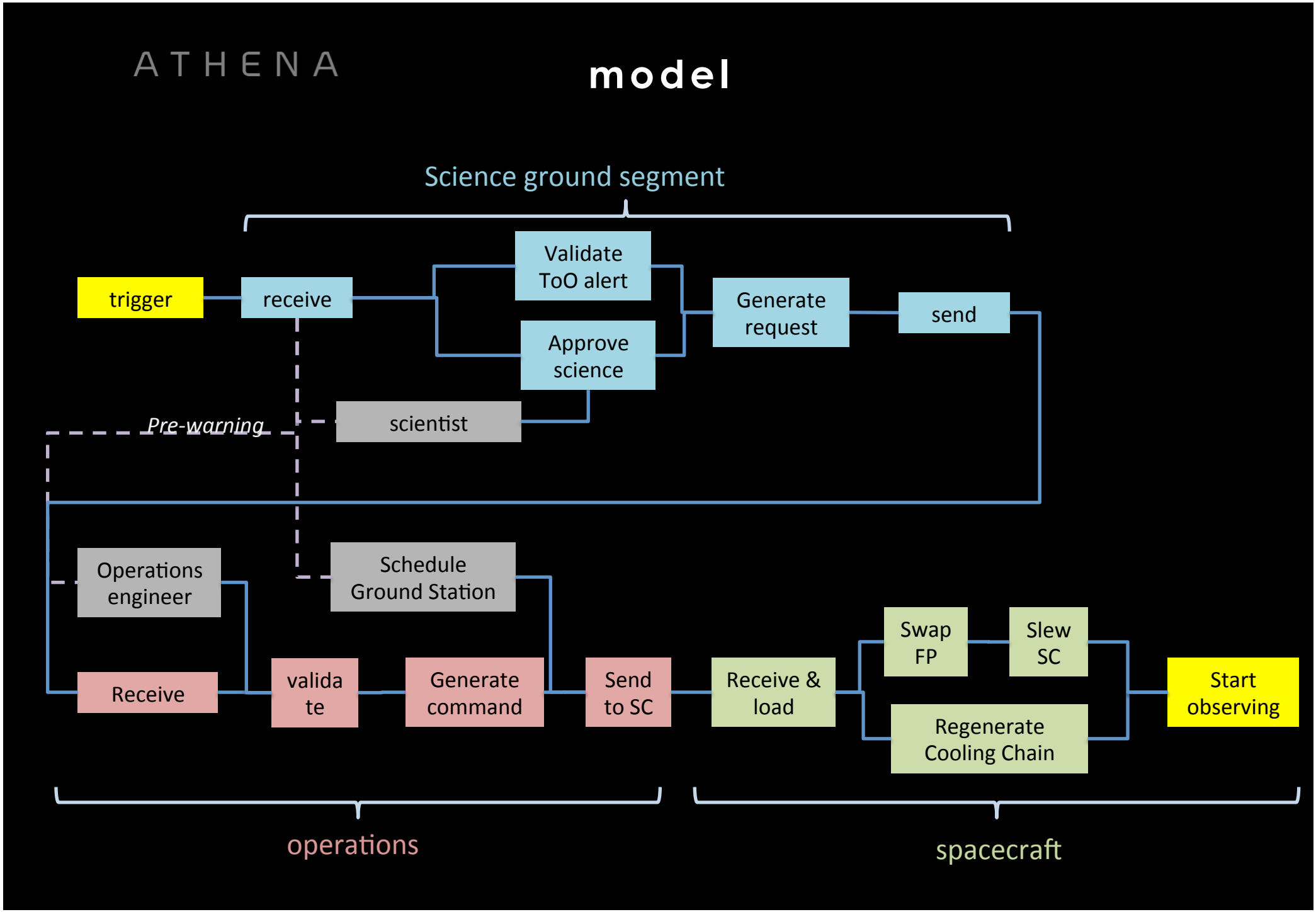
model



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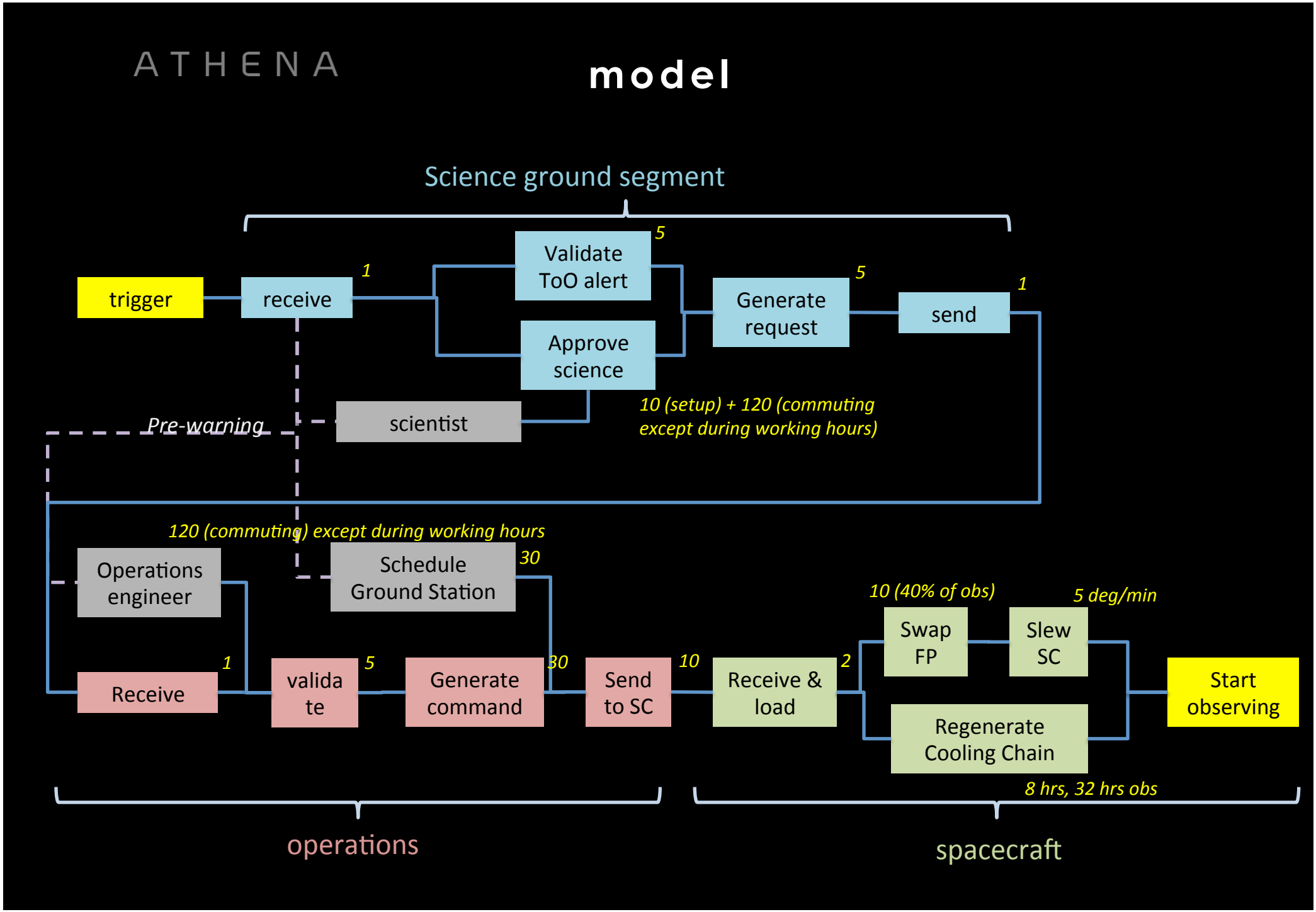
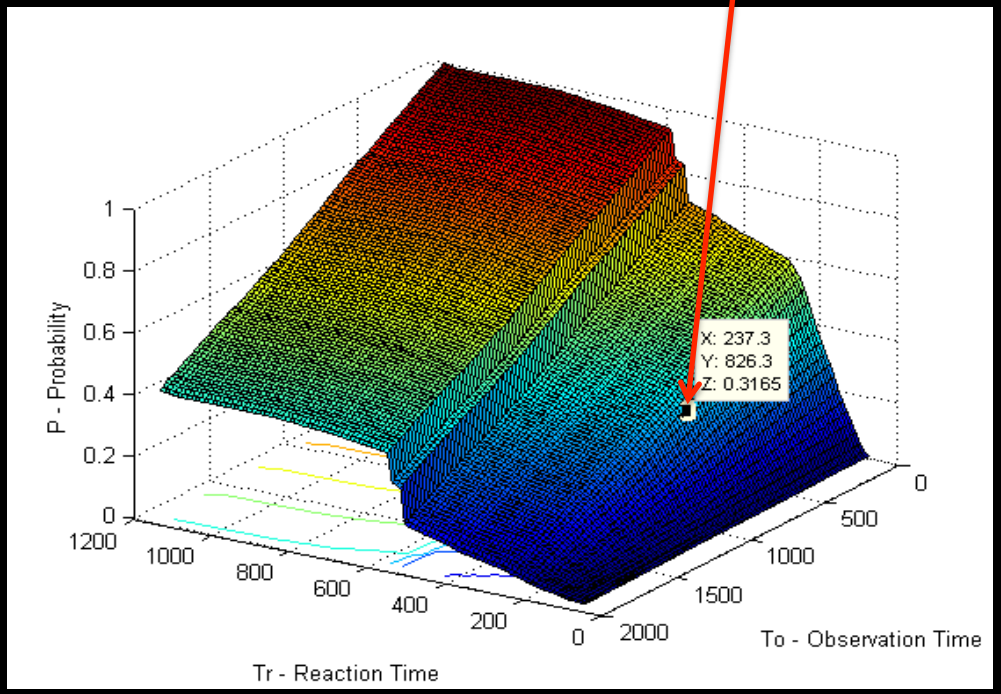
model

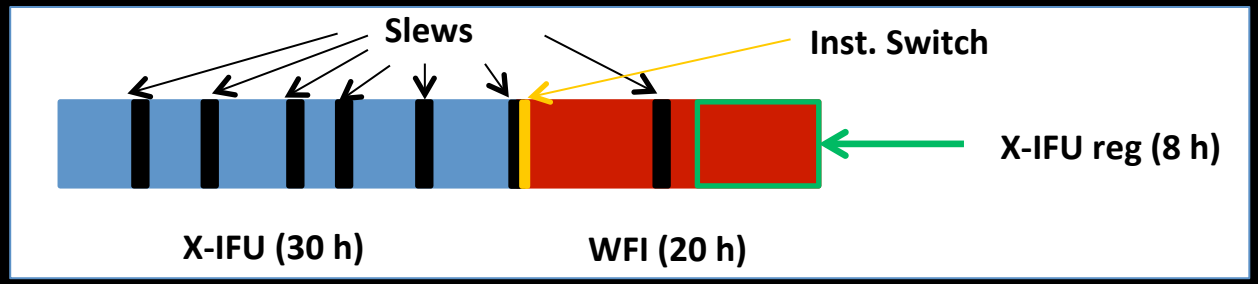


Result

- **X-IFU r**egeneration time dominates this estimate (see later)
- Commuting time has also clear impact



Result



X-IFU (12 h) *WFI (8 h)*

Model	Probability	Comment
Requirement (50 ks X-IFU 4 hours after ToO	80% for 50% FoR 67% for 60% FoR	
Baseline (see note)	32%	Driven by cooling chain (8 hours regeneration, 32 hours observation time, 2 hour commuting limits fast response time outside working hours
Intermediate **(see notes)**	53%	Start regeneration so there is 50 ks observing time left
Best	59%	Perform WFI observations during regeneration matching 40% WFI observing time. However, increase of observations (46%), total slew

Target of Opportunity summary

Further improvements under study

- Partial regeneration of the X-IFU (likely and very efficient)
- Realistic estimates for availability of operators (120 min)

For feasible improvements increase of number of observations and slews can be used to reach the required level (but has impact on observing efficiency)

In all cases we need a good trigger including accurate position and red-shift (and Athena will not have the capability)

Science Ground Segment

(Watson, Webb and SGS panel, ongoing discussions)

- ESA proposes to organize the science ground segment based on the Herschel model (strong instrument centers):
- Mission Operations: ESA
- Science Operations including archiving + AO ESA
- Instrument support + instrument calibration instrument teams

- Data processing + processing environment different emphasis feasible
  - science data center with some central functions (XMM-like)
  - Science data centers in instrument teams and central functions by ESA (Herschel like)

- Ongoing discussions about these options (do we miss some functionality, advantages/ disadvantages and is the funding available)

Summary

- Solid flow down from science to instrument requirements and mock observing plan ongoing
- Advanced end-to-end analysis tools under development and already operational
- Target of Opportunity response time understood but optimization is important for part of the science
- Organization of Science Ground Segment ongoing but does not affect mission design
- Only 13 years + 4 months till launch, the clock is ticking

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The Athena Mission Performance Working Group

Science Ground Segment: Watson, Webb, Fiore, Adami, Guennou, Reiprich, Page, Evans, Bozzo, Motch, Santangelo, Traulsen, Ehle, Randall, Akylas, de la Calle, Bulgarelli, Natalucci, Terada, Ceballos, Surace, Wilms, Zolotukhin, Corcoran, D'Elia, Ebisawa, Ibarra, Juda, Lamer, Paltani, Pittori Mazzotta

Background: Molendi, Laurent, Gastaldello, Ghizzardi, Pointecouteau, Pratt, Rossetti, Marelli, Eckert, Spiga, De Grandi, Biasotti, Ceriale, De Gerone, Gatti, Pizzigoni, Moretti, Corsini, Tsuru, De Luca, Novara, La Palombara, Tiengo, Bulgarelli, Freyberg, Gualtieri, Lotti, Miniussi, Peille, Perinati, Belfiore, Cea, Chipaux, Cusumano, Eraerds, Fioretti, Gottardi, Hoshino, Jacquey, Kilbourne, Kohmura, La Parola, Laurenza, Macculi, Mineo, Pajot, Uslenghi, Dadina, Mereghetti

Inter-Calibration: Sembay, Pajot, Burwitz, Pointecouteau, Nevalainen, Yamada, Godet, Audard, Fiocchi, Plucinsky, Natalucci, Terada, Gualtieri, Lotti, Miniussi, Laurent, Barbera, Carpano, Balman, Eckart, Meidinger, Nakajima, Pareschi, Pelliciari, van der Kuur, Wilms, Peille

End-to-end simulations: Wilms, Peille, Rozanska, Biffi, Rasia, Aird, Georgakakis, Peroux, Samuel, Clerc, Dauser, Ceballos, Surace, Ptak, Perinati, Barbera, Carpano, Bachetti, Bandler, Brandt, Cobo Martin, den Hartog,. Gardiol, Prele, Smith, de Plaa, Smith

Advanced analysis tools: Haberl, Fiore, Fiore, , Ettori, Sanders, Piconcelli, Costantini, Kallma, Chakravorty, Manousakis, Wise, De Marco, Orio, Dennerl, Ducret, Turck-Chieze, Vastel, de Avillez, Watson, Zolotukhin, Brown, Caux, Chiappetti, Foster, Fruscione, Hell, Kashyap, Leutenegger, Martin-Carrillo, Perri, Porter, Puccetti, Sartore, Walter, Bourdin, Zappacosta, Mazzotta, Del Zanna

Targets of Opportunity: Basa, Troja, Salvaterra, Campana, Gogus, Evans, Tashiro, Amati, Covino, D'Avanzo, De Pasquale, Fox, Ghirlanda, Götz, Hanlon, Kawai, Kouveliotou, O'Brien, Schady, Starling, Tanvir, Bernardini, Melandri, von Kienlin

ESA team: Mark Ayre, Dave Lumb, Jos de Bruyne, Ivo Ferreira, Martin Linder, Peter Verhoeve