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European Space Research
and Technology Centre
Keplerlaan 1
2201 AZ Noordwijk
The Netherlands
T +31 (0)71 565 6565
F +31 (0)71 565 6040
www.esa.int

Requirement Document / Specification (System, Subsystem, Unit, Equipment level)

Athena Science Requirements Document

European Space Agency
Agence spatiale européenne

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APPROVAL

Title Athena Science Requirements Document	
Issue Number 2	**Revision Number** 3
Author David Lumb, J-W den Herder and Matteo Guainazzi for Athena Science Team	**Date** 8/1/2019
Approved By	**Date of Approval**
Athena Science Study Team	**28/9/2018 (ASST#18)**

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Note: Many contributions from the Athena Topical Panels, especially coordinated by Arne Rau and by the Athena Performance Scientist Jos de Bruijne, all of whom are thanked

CHANGE LOG

Reason for change	Issue Nr.	Revision Number	Date
Updated background L2b/c requirements	2	3	8/1/2019
7/10 keV effective area requirements correction	2	2	10/9/2018
Typo corrected in 2a-020 (exponent sign)	2	1.2	4/9/2018
Typos corrected in SCI-CTR-R-020 and -021	2	1.1	17/07/2018
2a-020 + editorial review by the WFI PS + removal calibration requirements + detailed review of WFI and X-IFU requirement in preparation of IPRR (approved by ASST#17)	2	1	10/07/2018
Parent requirements of SCI-EA-R-050 updated	2	0.1	22/11/2017
Requirements consistent with the CORE mission profile	2	0.0	15/11/2017
Changes agreed at ASST#11: surface brightness sensitivity requirements, count rate capability of extended sources	1	6.0	14/3/2017
More precisely defined surface brightness requirement and some typo's	1	5	3/8/2016
Minor update for optical load of the wide field instrument	1	4	28/7/2016
Major update following discussions in the ASST meeting #10 and some further clarifications	1	3	25/7/2016
Updates from Topical Panels Partly responding to request for clarifications from ESA	1	2	1/6/2016
Editorial	1	1	7/3/2016
Major update from ASST	1	0	18/1/2016

CHANGE RECORD

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Issue Number 1	Revision Number 5		
Reason for change	**Date**	**Pages**	**Paragraph(s)**
TOO Quick Look requirement changed to goal, and previous goal removed		52	
Modified text regarding moving bodies and preferred to remove duplication with 2a_103		51	
Clarify the use of background monitoring when not in focal point		47	
Removed incorrectly duplicated background requirements for focused point source light		46	
Quiescent background conditions changed to 80% of time for X-IFU		44	
Quiescent background conditions changed to 60% of time for WFI		43	
Change definition of requirement CTR-R-070 & 080		43	
Changed duplicate numbered requirement		39	
Remove duplicated requirement		35	
Modified requirement at 10keV		34	
Requirement dropped as WFI will not be operated without filter, due to contamination mitigation procedures		32	
Moved X-IFU area requirements to 2a		31	
Removed obsolete requirements on energy range		30	
2a-103: Not core science – leave as a 2b/2c and avoid duplication SCI-POI-G-040	1/6/2015	27	
Data latency requirement retired to 2b/2c level only	1/6/2015	26	
Added new requirement on 0.3keV effective area for X-IFU	1/6/2015	23	
Confirmed a 2sigma formulation for Absolute Pointing Knowledge Accuracy	1/6/2015	22	
Table 7.4 deleted	1/6/2015	19	7
Introductory bullets updated	1/6/2015	13	7
Revision from SWG 3. Merge Requirements 332/325. Update 336	1/6/2016	10-11 Table 6.1	6
Editorial	1/6/2016	6	Introductory text
Major update from ASST	18/1/2016	All	
Issue Number 1	**Revision Number 3**		
Reason for change	**Date**	**Pages**	**Paragraph(s)**
Specified explicitly which requirements are still subject of further analysis (in addition to the calibration requirements listed in the previous version	25/7/2016	7	4

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Specified that surface brightness sensitivity off-axis has been calculated for an area of 220 arcmin2	25/7/2016	21	2a-022
Specified 6 arcsec imaging quality for X-IFU (driven by relevant spatial scales of voids in clusters and/or shocks in e.g. SNR	25/7/2016	22	2a-031
Updated weak line sensitivity to 0.075 eV but this numbers needs to be checked	25/7/2016	23	2a-060
Specified instruments for which relative time accuracy and count rate capability apply	25/7/2016	25	2a-091 and 2a-100
Specified that Aeff calibration accuracy should be 8% (TBC)	25/7/2016	33	SCI-EA-R-140
Changed defocussing goal into a defocussing requirement	25/7/2016	35	SCI-ANR-R-012
Specified 1% dead time knowledge accuracy for high spectral resolution instrument	25/7/2016	38	SCI-TMR-R-050
Introduced requirements for particle diverter (protons only)	25/7/2016	43	SCI-BCK-R-070, 080
Updated requirements for X-ray backgrounds and straylight baffle	25/7/2016	43	SCI-BCK-R-110, 120, 130
Issue Number 1	**Revision Number 4**		
Reason for change	**Date**	**Pages**	**Paragraph(s)**
Provided a consistent definition of the need for optical suppression in the wide field imager instrument (transferred from level 2a to a level 2c requirement	28/7/2016	26	Level 2a-102: optical brightness and SCI-BKG-R-170
Issue Number 1	**Revision Number 5**		
Reason for change	**Date**	**Pages**	**Paragraph(s)**
Clarified some inconsistencies between table 7.1 and the listed requirements: S/N for velocities is 5, relative flux calibration between 0.5-2 and 2-10, and defined optical load (instead of other)	8/9/2016	17	7.1
Corrected units and values for the GRASP requirement	8/9/2016	20	2a-011 and 2a-012
Updated surface brightness requirements	8/9/2016	21	2a-020, 21, 22, 23
Corrected positional accuracy requirement (1 arcsec/3 sigma)	8/9/2016	22	2a-030
Issue Number 1	**Revision Number 6.0**		
Reason for change	**Date**	**Pages**	**Paragraph(s)**
Removed “b” effective area sensitivity requirements	14/3/2017	31-32	SCI-EA-R-050b, SCI-EA-R-060b, SCI-EA-R-070b, SCI-EA-R-081b, SCI-EA-R-090b, SCI-EA-R-100b, SCI-EA-R-110b,

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			SCI-EA-R-120b, SCI-EA-R-130b
Updated requirement on count rate capability for extended sources: 0.02 → 0.01 erg.s^{-1}.cm^{-2}.sr^{-1}, 90 → 80%	14/3/2017	41	SCI-CTR-R-080
Updated requirement on the maximum stray light count rate: 10% → 27%	14/3/2017	43	SCI-BKG-R-110
Issue Number 2	**Revision Number 0.0**		
Reason for change	**Date**	**Pages**	**Paragraph(s)**
Throughout the whole document	15/11/2017	All	All
Issue Number 2	**Revision Number 0.1**		
Reason for change	**Date**	**Pages**	**Paragraph(s)**
Number of AGN for which UFO monitoring is envisaged corrected (R-SCIOBJ-231)	22/11/2017	13	R-SCIOBJ-231
Parent requirements for SCI-EA-R-050	22/11/2017	28	SCI-EA-R-050
Issue Number 2	**Revision Number 1**		
Reason for change	**Date**	**Pages**	**Paragraph(s)**
Value for surface brightness requirement	21/12/2017	21	2a-020
Editorial revision	21/12/2017	All	All
Change of units for SCI-CTR-R-020, 021, 030	5/2/2018	36	SCI-CTR-R-020, 021, 030
Calibration-related requirements moved to the Calibration Requirement Document to avoid duplications	23/2/2018	Sect.8	SCI-BKG-R-030, SCI-BKG-G-030, SCI-BKG-R-031, SCI-BKG-R-060, SCI-BKG-R-130, SCI-EA-R-140, SCI-EA-R-141, SCI-EA-R-150, SCI-EA-R-160, SCI-SPR-R-020, SCI-SPR-R-050, SCI-TMR-R-050
Rates adapted to the expected WFI Crab counts with the 15-row mirror	13/6/2018	36	SCI-CTR-R-020, SCI-CTR-R-021
Formulation of SCI-CTR-R-030 changed to clarify that it is not inconsistent with SCI-OBS-R-020	13/6/2018	36	SCI-CTR-R-030
Change of SCI-AST-R-010 to accommodate a request by the ESA Study Team (cost-saving measure)	13/6/2018	43	SCI-AST-R-010
Change of SCI-CTR-R-080 value (and units) to correspond to the flux of the core of the Perseus Cluster (the old formulation is now a goal)	13/6/2018	39	SCI-CTR-R-080
Energy range of SCI-SPR-R-010 extended to ≤7 keV	13/6/2018	34	SCI-SPR-R-010
Change of SCI-SPR-G-010 to 2 eV (1.5 eV considered unattainable by the X-IFU Team)	13/6/2018	34	SCI-SPR-G-010

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New 2c requirement on the X-IFU energy resolution at 10 keV	13/6/2018	34	SCI-SPR-R-015
Change in the formulation of timing requirements to solve ambiguities	13/6/2018	26, 36	2a-090/091, SCI-TMR-R-010/015/020/030
Relaxation of effective area absolute calibration requirements (10% → 12%)	13/6/2018	25	2a-081
New requirements on X-IFU QE at 10 keV (>50%)	2/7/2018	31	SCI-EA-R-075
Issue Number 2	**Revision Number 1.1**		
Reason for change	**Date**	**Pages**	**Paragraph(s)**
Typos corrected in SCI-CTR-R-020 and -021	17/7/2018	37-38	SCI-CTR-R-020, SCI-CTR-R-021
Issue Number 2	**Revision Number 1.2**		
Reason for change	**Date**	**Pages**	**Paragraph(s)**
Typo corrected in 2a-020 (exponent sign)	4/9/2018	22	2a-020
Issue Number 2	**Revision Number 2**		
Reason for change	**Date**	**Pages**	**Paragraph(s)**
7/10 keV effective area requirements corrected as per [RD12].	10/9/2018	21 23 23 30 31 31 31	2a-012 2a-041 2a-042 SCI-EA-R-070 SCI-EA-R-100 SCI-EA-R-110 SCI-EA-R-120
Issue Number 2	**Revision Number 3**		
Reason for change	**Date**	**Pages**	**Paragraph(s)**
Update of background-related L2b/c requirements	8/1/2019	28	SCI-BKG-R-010 SCI-BKG-G-010 SCI-BKG-R-020 SCI-BKG-G-020 SCI-BKG-R-240
Typo corrected in R-SCIOBJ-111	8/1/2019	13	R-SCIOBJ-111
Outdated reference to X-IFU in SCI-POI-R-030 removed	8/1/2019	28	SCI-POI-R-030

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Name/Organisational Unit
Athena Study Manager
ESA Coordination Office

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X-IFU Principal Investigator
WFI Principal Investigator

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1 ACRONYMS

ADC	Analogue to Digital Conversion
AGN	Active Galactic Nucle(us)i
BH	Black Hole
CORE	Cost-Oriented Reprogramming Exercise
DDF	Design Definition File
DJF	Design Justification File
DOORS	Dynamic Object Oriented Requirements System
EoL	End of Life
EoS	Equation of State
FOV	Field of View
FRII	Faranoff-Riley -class II radio galaxy
FWHM	Full Width at Half Maximum
GRB	Gamma Ray Burst
HEW	Half Energy Width
ICM	Inter Cluster Medium
IMF	Initial Mass Function
ISM	Interstellar Medium
L_{bol}	Bolometric Luminosity
L_{edd}	Eddington Luminosity
LDA	Large Detector Array
MOP	Mock Observing Plan
NS	Neutron Star
PSF	Point Spread Function
QSO	Quasi-Stellar Object
R_{500}	Radius where density =500x critical
SMBH	Supermassive Black Hole
SN	Supernova
TBC	To Be Confirmed
TBD	To Be Determined
TDB	Barycentric Dynamical Time
TDE	Tidal Disruption Events
ToO	Target of Opportunity
ULX	Ultra-Luminous X-ray Source
UTC	Coordinated Universal Time
WFI	Wide Field Imager
WHIM	Warm-Hot Intergalactic Medium
XDIN	X-ray Dim Isolated Neutron Star
XIFU	X-ray Integral Field Unit

2 REFERENCE DOCUMENTS

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[RD1] 2013arXiv1306.2307N	June 2013	The Hot and Energetic Universe: A White Paper presenting the science theme motivating the Athena+ mission and all references to the supporting white papers
[RD2] n/a	April 2014	Athena: The Advanced Telescope for High Energy Astrophysics (mission proposal to ESA)
[RD3] n/a	15 May 2015	Athena Science Impact Assessment
[RD4] ECAP-ATHENA_WFI-RSP20150326	26 March 2015	Athena WFI response files
[RD5] ECAP-ATHENA-XIFU-RSP20150327	27 March 2015	Athena X-IFU response files
[RD6] SWG1.2-TN-0003	25 October 2015	The effect of the WFI background on Athena measurements in cluster outskirts
[RD7] WFI-BSR-04-draft	21 May 2015	Bright source Performance of the Athena WFI
[RD8] ESA-ATH-SP-2016-001	8 February 2017	Athena Calibration Requirements
[RD9] XIFU-SRD-OT-1-IRAP	8 November 2017	Science requirement clarification
[RD10] SWG1.2-TN-0002	11 November 2015	Note on L2a science requirements
[RD11] SRON-ATH-PL-2014-001	V.4.0	Athena mock observation plan
[RD12] ESA-ATHENA-ESTEC-SCI-TN-0002	10 September 2018	On the Athena effective area science requirements at 7 and 10 keV

3 APPLICABLE DOCUMENT

[AD1] http://sci.esa.int/ssc_report	October 2013	Report of the senior survey committee on the selection of the science themes for the L2 and L3 Launch opportunities in the cosmic vision programme

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4 INTRODUCTION

In this Science Requirements Document the top-level goals as described in the Hot and Energetic Universe White Paper ([RD1]) amended by the recommendations of the Senior Survey Committee ([AD1]) are translated into quantified science objectives (level 1). These science objectives are subsequently converted into mission requirements (level 2a) that are largely independent of the actual mission concept. These are than translated into level 2b requirements that are specific for the proposed mission concept. Additional mission requirements which are not related to the level 1 science objectives are defined as level 2c. It should be noted that different implementations for a level 2a requirement could be realized (e.g. the same point source sensitivity can be achieved by a different combination of effective area, angular resolution, particle induced background, and observing time).

In the current version of the SciRD we provide:

- *consolidated science goals* (L0)

- *science objectives* (L1) including required accuracies and sample sizes

- *science requirements* (level 2a) are performance specifications to achieve the science given in the L1 objectives without specifying the actual mission concept (e.g. sensitivities are given but not how they are achieved).

- *derived science requirements* (level 2b/2c). This list is largely dependent on the selected implementation of the mission in the mission proposal [RD2]. Level 2b follow directly from the level 2a. Level 2c is added to have top level reference requirements for non-driving parameters which are not directly following from level 2a (e.g. raster scan where an area is given for reference).

Some outstanding issues were identified which have not yet been fully settled (but have no or limited effect on the system design of the mission). Apart of some parameters that need firm confirmation (given as TBC) these issues include:

- Precise calibration accuracy requirements are under study. Values provided herein should be taken as reasonable estimates.
- All background requirements (including the performance of the particle diverter, see below) may need to be updated following the AREMBES activities

5 LEVEL 0 REQUIREMENTS

The level 0 requirements are based on the “Hot and Energetic Universe” White Paper [RD1], the report of the Senior Survey Committee [RD3] and the Athena Mission Proposal [RD2] and are summarized in Table 5-1.

Top level goal	Definition
The Hot Universe:	Determine how and when large-scale hot gas structures formed 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.

Table 5-1 Level 0 Requirements (top level scientific goals)

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6 LEVEL 1 REQUIREMENTS

The level 1 requirements (a.k.a. "science objectives") are given in the White Paper for the hot and energetic Universe [RD1] and in the mission proposal [RD2] and listed in the Table 6-1 below. Compared with the white paper and the mission proposal the listed science requirements are, where possible, quantified and use homogeneous sample sizes:

- *All results, detections etc. are to be established at the 5σ level, or equivalent*
- *A minimum of 10 objects per bin is required, when splitting samples as a function of parameters such as redshift or luminosity*
- *A minimum of 25 objects is required when attempting to establish a trend within a sample ag*ainst a given parameter (e.g. luminosity, redshift, mass)

It should be noted, however, that for good reasons not in all cases these guidelines are followed: (a) the number of solar system bodies is limited, (b) the number of desired WHIM filaments defines the number of systems to be measured in absorption and (c) only for a fraction of this follow up measurements in emission makes sense. This applies to more science objectives.

Table 6-1 Athena Science Objectives

reference and short description	Requirement (science objective)	Quantification
The Hot Universe		
R-SCIOBJ-111 First groups	Athena shall find distant evolved groups of galaxies with hot gaseous atmospheres at z>2 with M_{500}>5x10[13] M_{Sun}, of which at least 10 shall have global gas temperature estimates.	10 galaxy groups with gas temperature at z>2 to investigate L-T relation.
R-SCIOBJ-112 Cluster bulk motions and turbulence	Athena shall measure how gravitational energy is dissipated into bulk motions and gas turbulence in the galaxy cluster population, by achieving a 5σ detection of these quantities in a sample of 10 massive clusters.	Kinetic energy dissipated from gravitational assembly in 10 galaxy clusters in the nearby Universe.
R-SCIOBJ-121 Cluster entropy profile evolution	Athena shall determine the evolution of the gas thermodynamics during hierarchical gravitational collapse as a function of cosmic epoch by measuring the structural properties (e.g. the entropy profiles) of a limited sample of high mass clusters. The measurements shall be achieved out to R_{500} up to z~2, with an uncertainty <25% (at R_{500} at z=2). Athena shall also resolve the accretion regions (R_{500} to R_{200}) in a limited number of high mass local (z <0.5) objects. Furthermore, Athena shall measure the evolution of the scaling relations between bulk properties of the hot gas (e.g., the L_x-T relation) out to at a redshift of 2, to a precision of <25%.	Cosmic history of the injection of entropy in cluster hot gas at 0<z<2. Investigate 10 clusters in each of 4 redshift bins (total 40 clusters)
R-SCIOBJ-122 Cluster chemical evolution	Athena shall explore the production and circulation of metals in the deep potential wells of massive galaxy clusters across time. Metal production will be estimated from the abundances of the most common elements (e.g. O, Si, S, Fe — at 5σ) and their relative number will be related to the number of time-integrated SNIa and SNcc products. The measurements (5σ) of trace elements (e.g., Al, Cl, Mn, Co) shall allow constraints to be put on initial metallicity of the SNIa progenitors. These measurements will be spatially resolved at up to R500 and the evolution derived over 10 Gyr of cosmic time (0<z<2) for the most massive clusters.	Metal production and dispersal in cluster hot gas out to z=2. Observe 10 clusters in each of 3 redshift bins out to z~2 (total 30 clusters).

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R-SCIOBJ-131 Physics of cluster feedback	Athena shall measure the energy stored dynamically and thermally in the hot gas around the bubbles in a statistical sample of clusters, selected to cover a range in jet power, by achieving a 5σ detection of bulk motion and turbulence induced through AGN feedback and allow measurements of the spatially-resolved velocity structure in the best-studied systems.	Statistical sample of 25 objects is designed to cover a range in central AGN jet power, with a tiered strategy allowing spatially resolved studies of the velocity structure in the feedback region with the deepest observations, and at least a single detection of velocity structure otherwise.
R-SCIOBJ-132 Feedback-induced cluster ripples	Athena shall determine the occurrence and impact of AGN feedback phenomena by searching for ripples in surface brightness in the inner 5 arc-minutes of a statistical sample of clusters, selected by central AGN power.	Detection of ripples in cluster gas created by AGN jet activity, in a statistical sample of 25 clusters.
R-SCIOBJ-133 Heating/cooling balance in cluster feedback	Athena shall determine the gas that fuels the AGN jet to balance the gas cooling rate by measuring how much gas is at each temperature in cluster cores using temperature-sensitive line ratios in a representative sample of nearby clusters.	Heating-cooling balance in hot gas of 10 cluster cooling cores.
R-SCIOBJ-134 Shock speeds of radio lobes in clusters	Athena shall determine the shock speeds of expanding radio lobes in a representative sample of nearby powerful (FRII) radio galaxies by distinguishing the gas temperature in shocked and undisturbed regions to >3σ level, to determine the population-wide impact and evolution of jet feedback in poor environments.	Shock speeds of expanding radio lobes in 10 clusters around radio galaxies for 2 source size and 2 radio power bins[1].
R-SCIOBJ-141 Missing Baryons	Athena shall measure the local cosmological baryon density in the WHIM to better than 10% and constrain structure formation models in the low-density regime by measuring the redshift distribution and physical parameters of 200 filaments against bright background sources, selected to probe various cosmic densities; and by performing a statistical analysis of the emission lines of heavy elements in a representative sky region and high-probability targets.	Detect 200 WHIM filaments in absorption, 100 towards BLLacs and 100 towards bright GRB afterglows to sample the WHIM up to z=1.
R-SCIOBJ-142 WHIM in emission	Athena shall detect WHIM filaments in emission associated to absorption detected against 7 GRBs, after they faded away, as well as 2 filaments.	Detect emission of WHIM filaments associated with systems detected in absorption detected against 7 GRB afterglows. Determine metal abundances from emission lines in filaments along 2 selected regions (A222 and COSMOS).
Energetic Universe		
R-SCIOBJ-211 High redshift SMBH	Athena shall determine the nature of the seeds of the earliest growing SMBH (z>6), characterize the processes that dominated their early growth and investigate the influence of accreting SMBH on the formation of galaxies. Populate the L_X-z plane at high redshift, specifically: identify >160 AGN at z>6.	Detect 10 AGN with $10^{43.0} < L_x < 10^{43.5}$ erg/s at z=6-7 and 10 AGN with $10^{44.0} < L_x < 10^{44.5}$ erg/s at z=7-8.

[1] The 178 MHz radio luminosity is 5 10^{24} – 10^{27} $WHz^{-1}sr^{-1}$ with a boundary of 3 10^{25} $WHz^{-1}sr^{-1}$ and the range in the source size is 50 – 1000 kpc with a boundary at 350 kpc giving equal numbers (but this will be updated based on future surveys)

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R-SCIOBJ-221 Complete AGN census	Athena shall determine the accretion energy density in the Universe, by measuring the X-ray luminosity function and obscuration properties of the AGN population with at least 10 Compton thick AGN per luminosity bin (0.5dex) and redshift bins (Δz=1) up to redshift z~3.	Spectral characterization of at least 10 Compton-Thick AGN with $10^{44.4}$<L_x<$10^{44.9}$ erg/s per unit z at z~3. Map obscured AGN/galaxy co-evolution.
R-SCIOBJ-222 Census of AGN outflows at z=1-3	Athena shall determine the incidence of strong and ionized absorbers, implying the presence of outflows, among the population of luminous AGN from z=1 to z=3.	Detect at least 10 warm absorbers in AGN with 10^{44}<L_x<$10^{44.5}$ at z=1-3.
R-SCIOBJ-223 Mechanical energy of AGN outflows at z=1-3	Athena shall measure the mechanical energy of moderately ionized outflows in L_X>L* AGN at z=1-3.0, spanning a broad range of column densities and ionization parameters.	Measure the mechanical energy of outflows in luminous AGN at z=1-3, 10 per 2 luminosity bins and per 2 redshift bin of Δz=1 .
R-SCIOBJ-224 Ultra-fast outflows at z=1-4	Athena shall determine the incidence, duty cycle and energetics of transient Ultra-Fast Outflows (UFOs) in QSOs from z=1 to z=4.	Frequency and mechanical energy of UFOs at z=1-4.
R-SCIOBJ-231 AGN outflows in local Universe	Athena shall measure the kinetic energy in nearby AGN outflows and understand how accretion disks around SMBH launch winds and outflows.	Wind energetics in 25 nearby AGN out of 70. Wind launch physics from time resolved spectroscopy of 10 AGN.
R-SCIOBJ-232 Feedback in local AGN and star forming galaxies	Athena shall test stellar feedback models (particularly starburst super winds) and their dependence on galactic parameters such as star-formation rate, galaxy type and morphology, and star formation history, as well as the presence of a low-luminosity AGN	Gas, metal and energy output from AGN and Starbursts in 10 Starburst and (U)LIRGs.
R-SCIOBJ-241 AGN reverberation mapping	Athena shall determine the geometry of the hot corona-accretion disk system and constrain the origin of the hot corona in AGN.	Reverberation mapping of 4 bright local AGN with established lags.
R-SCIOBJ-242 AGN spin census	Athena shall determine the SMBH spin distribution in the local Universe as a probe of the growth process (mergers versus accretion, chaotic versus standard accretion).	Spin distribution (histogram) of 25 nearby SMBH.
R-SCIOBJ-251 GBH and NS spins and winds	Athena shall observe 10 stellar-mass black holes and 10 neutron stars X-ray binaries in order to measure black hole spins, constrain neutron star radii, detect winds and outflows, and study the accretion disk and coronal physics.	(a) Measure spins of 10 Galactic BHs and 10 NS through various methods and probe their accretion geometry and jet properties through reverberation mapping. (b) Measure winds in the same 10 Galactic BHs and 10 NS.
R-SCIOBJ-252 Black hole accretion at the highest and lowest rate	Athena shall observe 25 ULXs (high accretion rates) in order to understand the geometries that enable super-Eddington accretion, and sub-population within the ULX class. Athena shall observe SgrA* (low accretion rate) in the longest continuous segment possible in order to obtain an excellent spectrum of the quiescent flux level and to maximize the chance of catching a flare event for comparison	Accretion properties 25 ULX spanning the 39<log(L_x)<41 range, accurate determination of the SgrA* quiescent flux.
R-SCIOBJ-261 High z GRBs	Athena shall probe the first generation of stars, the formation of the first black holes, the dissemination of the first metals and the primordial IMF. Determine the elemental abundances of the medium around high-z GRBs by deriving relative elemental abundances distinctive of primeval (Pop III) explosions versus evolved stellar populations in the spectrum of GRB afterglows.	Probe ISM of z>7 galaxies by ToO observations of 25 GRB afterglows.

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R-SCIOBJ-262 TDEs	Athena shall study the nature of stellar disruption and the subsequent surge in accretion onto SMBHs during TDEs in order to probe the dynamics of tidal shearing in the proximity of the event horizon, characterize the orbital and physical evolution of the debris, probe the likelihood of disruption for a given stellar population, and gain insight into the effects of rapid accretion rate changes in AGN systems.	Probe 5 TDEs by ToO observations.

In the section of the table for the Observatory science the expected sample size for the MOP is usually excluded as this will be decided closer to the mission launch. In the description of the MOP some sample sizes, based on our current understanding will be used.

Observatory science		
R-SCIOBJ-311 Planetary X-ray spectroscopy	Athena shall perform spectral mapping of targets in the Jupiter system, of Mars' exosphere and of five comets when they are close to the Sun. Athena shall search for evidence of X-ray aurorae on Saturn and for X-ray emission from Uranus.	Auroral and exosphere X-ray emissions of solar system bodies (planets and moons) and cometary tails and their interaction with Solar Wind.
R-SCIOBJ-312 Stellar activity in exoplanet systems	Athena shall detect and characterize X-ray transits in two exoplanet systems and study the Star-Planet Interactions (SPIs) in two exoplanet targets	Effects of stellar magnetic activity of exoplanets.
R-SCIOBJ-322 Colliding winds in binaries	Athena shall map the hot gas distribution in the wind interaction zone of binary systems where the winds from both components collide by phase-resolved spectroscopy.	Wind interactions in binaries through phase-resolved spectroscopy in 5 massive binaries.
R-SCIOBJ-323 Magnetospheric accretion in low mass stars	Athena shall explore, in a few prototypical sources, magnetospheric accretion and plasma dynamics onto the photosphere and corona of young low-mass stars and brown dwarfs both in the field and selected star-forming regions by measuring time-series of high-resolution spectra to probe line-intensity variability from the accretion shock and post-shock plasmas, and the stellar corona.	Magnetospheric phenomena and/or accretion in nearby field M Stars, late-type PMS stars and BDs, and magnetospheric accretion phenomena and circumstellar disk interactions in YSOs in selected nearby SFRs.
R-SCIOBJ-324 Magnetic activity in ultra-cool dwarfs	Athena shall measure magnetic activity in a few prototypical late M stars and ultra-cool dwarf stars by assessing and monitoring their X-ray luminosity and temperature and looking for the occurrence of flares.	Magnetic activity in ultra-cool dwarf stars.
R-SCIOBJ-325 Mass loss in massive stars	Athena shall determine the geometry, porosity and mass-loss rate of stellar winds of isolated massive stars, especially in the presence of magnetic fields, for a sample of Galactic massive stars. Time resolved spectral analysis of X-ray emission from a sample of high mass X-ray binaries hosting supergiant companions will provide an independent and representative probe of massive star wind properties	Characterize the mass-loss and winds in a sample of early type stars and in HMXBs.
	Athena shall also study the metallicity dependence of stellar wind mass-loss via the observation of X-ray emission from populations of massive stars in galaxies of the Local Group.	Measure the X-ray spectra of selected OB associations (each containing at least 10 massive stars) in 3 different Local Group galaxies with different metallicity.
R-SCIOBJ-331 EoS of ultradense matter	Athena shall provide a representative measurement of the neutron star mass and radius by obtaining X-ray spectra of quiescent low mass X-ray binaries with a good distance estimate.	Equation of state of dense matter from observations of LMXBs.

R-SCIOBJ-333 Masses of accreting white dwarfs	Athena shall determine the mass of accreting white dwarfs in two of the most representative cataclysmic binaries within 15% accuracy, resolve the accretion regions in 3 representative sources to probe the magneto-ionospheric or inner disk interaction regions, and constrain also processes of their energy release (e.g. hydrodynamic accretion models).	Determine mass of accreting white dwarfs.
R-SCIOBJ-334 magnetars	Athena shall constrain the geometry surface magnetic field of 2 representative magnetars and 1 XDINs by detecting energy and phase-dependent proton cyclotron lines, together with their harmonics, resulting from resonant scattering of the neutron star emission in the presence of magnetic structures close to its surface.	Characterize geometry of magnetars and XDINs.
S-SCIOBJ-335 PWN	Athena shall provide insight about transport and particle acceleration mechanisms and the magnetization of ultra-relativistic plasmas, together with the progenitors and energetics of supernova explosions making pulsar-wind nebulae, through observations of a sample of extended and relatively bright PWNe.	Constrain particle acceleration by the study of PWN.
S-SCIOBJ-336 Novae	Athena shall provide a representative measurement the chemical composition of Novae ejecta, testing SN type Ia progenitor scenarios via the single-degenerate channel and determining the corresponding chemical enrichment of the Galaxy. Athena shall further determine high-resolution spectra of the faint, soft, diffuse X-ray emission from planetary nebulae (PNe) to accurately determine their interior plasma abundances and temperatures, and to constrain the wind interaction processes that generate PNe hot bubbles.	Observe 1 nova going off during Athena mission.
S-SCIOBJ-337 double degenerate binaries	Athena shall provide insight about different evolutionary scenarios for double degenerate binaries and identify the most promising gravitational wave sources and Type Ia Supernova progenitors among these systems.	Observe double degenerate systems and one type Ia supernova at distance <25 Mpc.
R-SCIOBJ-338 SN	Athena shall gain insight in BH birth through observations of Supernovae.	BH birth through 5 SN.
R-SCIOBJ-341 Chemistry of the cold ISM	Athena shall determine the chemistry of the cold interstellar medium through X-IFU observation of X-ray-absorption fine-structure features due to absorption by interstellar matter.	Chemical composition of cold ISM through absorption spectroscopy.
R-SCIOBJ-342 Dust scattering haloes	Athena shall constrain dust models from the dust size distribution and dust composition through imaging and spectroscopy of dust scattering halos.	Dust models and particle distribution through scattering halos.
R-SCIOBJ-343 Physics of the warm and hot ISM	Athena shall determine the chemical composition, the heating and the dynamics of the warm and hot gas of the interstellar medium in nearby galaxies.	Characterize warm and hot ISM in nearby galaxies.
R-SCIOBJ-344 Mapping of SNR	Athena shall constrain SN1a and core-collapse explosion models and the shock dynamics by 3d determination of kinematics, ionization state and abundances of young galactic supernova remnants. .	3D mapping of SNR from SN1a and core-collapse SN.
R-SCIOBJ-399 Discovery Science	The Athena mission shall make available an additional observing time beyond that needed for the above goals to enable proposer-driven observations of high energy phenomena which cannot currently be formulated, because e.g. they are based on new discoveries by future multi-wavelength or multi-messenger facilities, or Athena itself.	Athena should be able to respond to scientific challenges triggered by new developments, including new multi-wavelength or other messenger observations.

7 LEVEL 2A REQUIREMENTS

Based on these science cases level 2a requirements have been defined. Clearly some of the science objectives have driven these requirements and these can be summarized as follows:

- *Point source sensitivity (on and off-axis)*: the point sensitivity requirement is largely driven by the desire to measure the injection of entropy in cluster hot gas up to R_{500} in nearby clusters and the detection of high redshift AGNs in the survey using the wide field imaging capability of Athena.

- *Effective area*: this impacts on sensitivity but is driven directly by the need to collect sufficient photons in a given integration time. For GRB afterglows - also used as backlight for the WHIM studies - the integration time is directly related to the expected elapsed time between the GRB explosion and the moment of data acquisition (with the X-IFU), so the signal-to-noise ratio for a given GRB flux then depends only on the effective area. In other cases the requirement is to measure time variations on a fixed timescale related to the properties of the source (reverberation mapping, accretion phenomena, among others).

- *Spatial Resolution:* this also impacts strongly on point source sensitivity but is also required to separate source features e.g. cavities, shocks and ripples in clusters of galaxies.

- *Spectral resolution and energy scale accuracy*: this is largely driven by the ability to measure velocities and velocity broadening with the high spectral resolution instrument. These include bulk motions in clusters of galaxies and wind energetics in nearby AGN.

- *The Target of Opportunity time*: this is mostly driven by the need to collect sufficient photons for rapidly fading events such as GRBs.

- *Count rate capability and time resolution:* required to make observations of the brightest sources, for example for reverberation mapping and spin determination of bright X-ray binaries.

- *Weak line sensitivity*: depends on energy resolution, effective area and the requirements are driven by WHIM, metallicity studies (rare elements).

In the subsequent sections, we provide the level 2a definitions, a reference to the appropriate table and the dependencies between the level 2a and level 2b requirements (where relevant for optimizations of the mission design). Note that calibration requirements are tentative

7.1 Level 2a definitions:

In this section, we give the definition of the level 2a requirements including the relevant units

Table 7-1 Definitions for science requirements parameters

Requirement number	Parameter	Definition	Units
2a-001	point source sensitivity on axis (0.5-2 keV)	0.5-2 keV flux of point source detectable at 5 sigma in 100 ks (or 450 ks if specified)	erg/cm²/s
2a-003	point source sensitivity at 15 arcmin radius (0.5-2 keV)	0.5-2 keV flux of point source detectable at 5 sigma in 100 ks at a radius of 15 arcmin	erg/cm²/s
2a-011	GRASP at 1 keV	effective area times solid angle at 1 keV over full detector	m²deg²
2a-012	GRASP at 7 keV	effective area times solid angle at 7 keV over full detector	m²deg²
2a-020	surface brightness sensitivity (0.5-2 keV)	0.5-2 keV flux per arcmin² detectable in 100 ks (5 sigma)	erg/cm²/s/arcmin²
2a-021	surface brightness sensitivity (5-7 keV)	5-7 keV flux per arcmin² detectable in 100 ks (5 sigma)	erg/cm²/s/arcmin²
2a-030	positional accuracy	absolute positional error after world-coordinate system reconstruction (3σ)	arcsec
2a-031	angular resolution	HEW for 0.5 - 2 keV	arcsec
2a-040	effective area at 1 keV	On-axis effective area (telescope + instruments)	m²
2a-041	effective area at 7 keV	On-axis effective area (telescope + instruments)	m²
2a-043	effective area at 0.3 keV	On-axis effective area (telescope + instruments)	m²
2a-042	effective area at 10 keV	On-axis effective area (telescope + instruments)	m²
2a-050	velocity resolution at 1 keV	error on turbulent velocity for a bright line (S/N >5)	km/s
2a-051	velocity resolution at 7 keV	error on turbulent velocity for a bright line (S/N >5)	km/s
2a-052	energy scale accuracy	Accuracy with which an energy can be reconstructed	eV
2a-060	weak line sensitivity at 1 keV	5 σ detectable equivalent width of unresolved emission/ absorption line at 1 keV against bright continuum	EW in eV
2a-061	weak line sensitivity at high energy (>7 keV)	5 σ detectable equivalent width of an unresolved emission or absorption line at indicated high energy against a bright continuum	EW in eV
2a-070	ToO trigger efficiency	Fraction of the time that a ToO trigger in a random position of the sky results in a successful X-IFU observation.	Fraction
2a-071	ToO fluence capability at high spectral resolution	Minimum fluence to be measured by X-IFU in a GRB ToO observation.	erg/cm²
2a-080	absolute temperature calibration	Accuracy of temperature measurements from X-ray spectra	Percentage
2a-081	absolute flux calibration uncertainty	Maximum on-axis calibration error (rms) in 0.5-2 keV and 2-10 keV	Percentage
2a-082	relative flux uncertainty as function of energy	Maximum on-axis relative calibration error (rms) in 0.5 – 2 keV and 2-10 keV energy bands	Percentage

2a-090	absolute time accuracy	Maximum difference of internal clock with respect to universal system	Microseconds
2a-091	relative time accuracy	Maximum rms internal clock error to detected events	Microseconds
2a-100	count rate capability	Maximum count rate in an instrument where science goals can be achieved with nominal performance, or degraded performance as specified in the required definition	erg/cm²/s
2a-102	optical load	Maximum visible magnitude that can be observed with no more than 10% energy resolution degradation at 7keV	m_v

7.2 Level 2a performance parameters dependencies

In this section we summarize the relations between level 2a requirements and level 2b requirements where relevant

Table 7-2 Definition of science parameters

Parameter	Definition
SNR	Signal-to-noise ratio
A_{eff}	Effective area (cm^2)
t	Exposure time (s)
B_c	Background counts spectrum (counts keV^{-1})
b	Background counts per solid angle (counts $arcmin^{-2}$)
p	PSF area or beam ($arcmin^2$)
FOV	Field of view ($arcmin^{-2}$)
Ω	Solid angle ($arcmin^{-2}$)
F_b	Background surface brightness (erg cm^{-2} s^{-1} $arcmin^{-2}$)
F_c	Continuum surface brightness (erg cm^{-2} s^{-1} $arcmin^{-2}$)
E_{ph}	Line photon energy (keV)
c	Speed of Light (cm s^{-1})
σ	Turbulent velocity R.M.S. (km s^{-1})
$\Delta\sigma_{sys}$	Systematic limit of turbulent velocity (km s^{-1})
F_p	Point source sensitivity
ΔE	Energy resolution
δE	energy scale accuracy

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Table 7-3 dependencies of level 2a requirements

Parameter	Units	Relation
Point source sensitivity (F_p)	erg/cm²/s in 100 ks	$F_p = 1.602 \cdot 10^{-9}\,\overline{E}\,\frac{SNR^2}{2A_{eff}t}\left(1+\sqrt{1+\frac{4bp}{SNR^2}}\right)$, where $b = \int_{0.5keV}^{2.0keV} B_c(E)\,dE$ is the number of background counts. $\overline{E}$ is the average energy in the spectrum. For the 0.5-2.0 keV band ~1keV is a reasonable number.
GRASP (1 and 7 keV)	m² deg²	$G = A_{eff}$ x FOV (Notes: units are m² and deg²)
Surface brightness	erg/cm²/s/ arcmin²	$F_s = 1.602 \cdot 10^{-9}\,\overline{E}\,\frac{SNR^2}{2A_{eff}t\Omega}\left(1+\sqrt{1+\frac{4b_s}{SNR^2}}\right)$, where $b_s = \frac{\int_{0.5keV}^{2.0keV} B_c(E)\,dE}{\Omega}$
Spectral line sensitivity (1 and 6 keV)	erg cm⁻² s⁻¹ arcmin⁻²	$F_l = 1.602 \cdot 10^{-9} E_{ph}\frac{SNR^2}{2At\Omega}\left(1+\sqrt{1+\frac{4At\Omega}{SNR^2}\Delta E\left(F_c+F_b\right)}\right)$
Velocity resolution (1 or 7 keV)	km/s $\Delta\sigma_v = \frac{c^2\Delta E^2}{7.84\sigma_v E_{ph}^2\sqrt{F_l At}}\sqrt{1+\frac{\Delta E\left(F_c+F_b\right)}{F_l}}$	$\Delta v \cong c\frac{\Delta E}{E}$
Energy scale accuracy	eV	$\delta v = c\frac{\delta E}{E}$

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The level 2a requirements below describe the science performance of the mission without assuming a particular realization of the mission. They are directly related to the level 1 requirements. (see separate excel file). For each requirement below, if a parent requirement is identified as particularly driving, the number is highlighted in red.

2a-001 Point source sensitivity (On-axis)

	Value	Units	Condition or Instrument	Parent Requirements
Definition	0.5-2 keV flux of point source detectable at 5σ			
Requirement	**2.4 10^{-17} in 450 ks** **10^{-15} in 100 ks ([RD10])**	**erg cm^{-2} s^{-1}**	In WFI In X-IFU	111, 112, 121, 122, 134, 323, 324, 325

Comments: 5 σ is set for homogeneity across all Athena objectives. The exposure time of 100 ks is a reasonable reference value but can vary between observations

2a-003 Point source sensitivity (Off-axis)

	Value	Units	Condition or Instrument	Parent Requirements
Definition	0.5-2 keV flux of point source detectable at 5σ at a field radius of 15 arcmin			
Requirement	**2.4 10^{-17} in 450 ks**	**erg cm^{-2} s^{-1}**	In WFI	111, 122, 211, 221, 222, 224

Comments: Reference angle ensures the definition covers at least half the available solid angle, and a large proportion of PSF variation with field angle. The reference observing times chosen as representative for wide field survey strategies.

~~2a-010 Survey Speed~~

Dropped (already covered by Grasp and point source sensitivity)

2a-011 Grasp at 1 keV

	Value	Units	Condition or Instrument	Parent Requirements
Definition	Integrated area times solid angle at 1 keV over full detector			
Requirement	**0.268**	**m^2 deg^2**	WFI (*dropped* for the X-IFU as of SciRDv2.0 as this is already covered by effective area and FoV)	111, 221, 222, 224

2a-012 Grasp at 7 keV

	Value	Units	Condition or Instrument	Parent Requirements
Definition	Integrated area times solid angle at 7 keV over full detector			
Requirement	**0.014**	**m^2 deg^2**	WFI at 7 keV (*dropped* for the X-IFU as of SciRDv2.0)	111, 142, 221, 222, 224

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2a-020 Surface brightness sensitivity (wide field)

	Value	Units	Condition or Instrument	Parent Requirements
Definition	Athena shall perform wide-field observations with a surface brightness sensitivity of at least 8x10^{16} erg/s/cm^2/arcmin^2 in 100 ks in the 0.5-2 keV energy band out to a field radius of 15 arc minutes.			
Requirement	**8x10^{-16}**	**erg cm^{-2} s^{-1} arcmin^{-2}**	In WFI 0.5-2 keV	111, 132, 134

2a-021 Surface brightness sensitivity (wide field)

	Value	Units	Condition or Instrument	Parent Requirements
Definition	5- 7 keV flux per arcmin^2 detectable in 100 ks (5 sigma). It assumes a 100 ks integration, either within an annulus cantered on-axis with inner radius of 17.77' and outer radius of 19.6', or integrated within a circle of 5' radius centred on-axis			
Requirement	**6.2x10^{-16}**	**erg cm^{-2} s^{-1} arcmin^{-2}**	In WFI 5 – 7 keV	121, 122, 132, 134

2a-030 Positional accuracy

	Value	Units	Condition or Instrument	Parent Requirements
Definition	Absolute source location positional error after reconstruction (3 sigma)			
Requirement	**1.0** **2.5**	**arcseconds**	WFI X-IFU	111, 122, 211, 221, 261, 262, 323

Comments: a maximum off-axis distance of 20 arc minutes can be assumed and needs to be achieved in a majority of the cases applying post-fact reconstruction.

2a–031 Angular Resolution

	Value	Units	Condition or Instrument	Parent Requirements
Definition	Half Energy Width (i.e. radius containing half detected photons)			
Requirement	**5** **6** **5 (goal X-IFU)**	**arcseconds**	0.5 – 2 keV WFI 0.5 – 2 keV X-IFU	122, 131, 132, 134, 141, 142, 252

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Comment: XIFU resolution accepted to be worse than WFI according to pixel sizes and most XIFU science is "aperture spectrophotometry" not imaging. A goal of 5 arcsec is maintained for the X-IFU as well. The HEW is driven by spatial scales of sources, confusion limit and discrimination of point sources

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2a–040 On-axis Effective Area at 1keV

	Value	Units	Condition or Instrument	Parent Requirements
Definition	Total collecting area of combination of mirror and instrument following all loss factors at EoL			
Requirement	**1.25** **1.05**	**m ^{2}**	WFI X-IFU	141, 241, 242, 251, 252, 261, 323

2a–041 On-axis Effective Area at 7keV

	Value	Units	Condition or Instrument	Parent Requirements
Definition	Total collecting area of combination of mirror and instrument following all loss factors at EoL			
Requirement	**0.153** **0.136**	**m ^{2}**	WFI X-IFU	121, 221 (WFI), 112, 231, 241, 251 (X-IFU)

2a–042 On-axis Effective Area at 10keV

	Value	Units	Condition or Instrument	Parent Requirements
Definition	Total collecting area of combination of mirror and instrument following all loss factors at EoL			
Requirement	**0.034**	**m ^{2}**	WFI	242

2a – 043 On-axis Effective Area in the soft band [0.2 keV (WFI)/0.35 keV (X-IFU)]

	Value	Units	Condition or Instrument	Parent Requirements
Definition	Total collecting area of combination of mirror and instrument following all loss factors at EoL			
Requirement	**0.069** **0.105 (TBC)**	**m ^{2}**	WFI (0.2 keV) X-IFU (0.35 keV)	111, 121, 211, 221, 222, 224 (WFI), 141, 142, 261 (X-IFU)

2a-050 Velocity resolution at 1 keV

	Value	Units	Condition or Instrument	Parent Requirements
Definition	Minimum detectable velocity shift between two unresolved lines with signal to noise ratio of 5 at 1 keV in a given observation, enabling the measurement of their respective fluxes			

Requirement	**100**	**km s^{-1}**	X-IFU	112, 131, 141, 142, 223, 231, 232, 261, 262, 332

Comments: Ability to resolve lines at soft energy, particularly OVII triplet but note the energy of this triplet is not exactly 1keV

2a-051 Velocity resolution at 7 keV

	Value	Units	Condition or Instrument	Parent Requirements
Definition	Minimum detectable velocity shift between two unresolved lines with signal to noise ratio of 5 at 7 keV in a given observation, enabling the measurement of their respective fluxes			
Requirement	**20**	**km s^{-1}**	X-IFU	112, 131, 232, 242, 251, 261, 262, 322, 323

Comments: Ability to resolve lines around Iron lines but note their energy is not exactly 7 keV

2a-052 Absolute energy scale accuracy

	Value	Units	Condition or Instrument	Parent Requirements
Definition	Maximum r.m.s. variation in km/s of the absolute energy scale calibration with respect to an external velocity frame $\Delta E = vE/c$			
Requirement	**0.4**	**eV**	X-IFU	112, 122, 131, 141, 142, 231, 232, 261, 262, 322

Comments: Necessary to put together velocity mosaics

2a-060 Weak line sensitivity at 1 keV

	Value	Units	Condition or Instrument	Parent Requirements
Definition	5σ detectable equivalent width of an unresolved emission or absorption line at 1 keV against a bright continuum (assuming a 0.5 mCrab source in the 2-10 keV band, and an exposure time of 50 ks)			
Requirement	**0.18**	**eV equivalent width**	X-IFU in 50 ks against a point source with a 0.5 mCrab flux in the 2-10 keV energy band ($F_{2\text{-}10\ keV} = 1\times10^{-11}$ cgs for $\Gamma = 1.8$)	133, 141, 223, 231, 261

Comments: Driven by calibration uncertainties and systematics.

2a-061 Weak line sensitivity at 7 keV

	Value	Units	Condition or Instrument	Parent Requirements

Definition	5σ detectable equivalent width of an unresolved emission or absorption line at 7 keV against a bright continuum			
Requirement	**10**	**eV equivalent width**	X-IFU: in 50 ks against a point source with 3.5×10^{-5} photons keV^{-1} cm^{-2} s^{-1} at 8 keV (corresponding to a continuum flux of F_{2-10} keV = 5×10^{-12} cgs for $\Gamma = 1.8$)	122, 231

Comments: Driven by calibration uncertainties and systematics.

2a-070 ToO trigger efficiency

	Value	Units	Condition or Instrument	Parent Requirements
Definition	Fraction of the times that a ToO triggers in a random position of the high-latitude sky (|b|>20 degrees) resulting in a successful observation			
Requirement	**0.5**	**Fraction**	X-IFU	141, 252, 261, 262

Comments: This does not specify how long does it take to get there, which is secured by the ToO fluence capability.

2a-071 ToO fluence capabilities

	Value	Units	Condition or Instrument	Parent Requirements
Definition	Minimum fluence to be measured by the X-IFU in a successfully observed GRB afterglow ToO			
Requirement	**0.7×10^{-6}**	**erg cm^{-2}**	X-IFU. Characterized by a typical GRB decay profile to 10 mCrab flux after 4 hours	141, 261

2a-080 Absolute temperature/metallicity calibration uncertainty

	Value	Units	Condition or Instrument	Parent Requirements
Definition	Fractional temperature uncertainty at a reference temperature			
Requirement	**4 (TBC)**	**%**	Reference temperature of 5 keV (TBC) at redshift z=0.5, abundance Z=0.3 solar (assuming also a reference spectral model, e.g. APEC with Anders & Grevesse (1989) abundances	111, 112, 121, 122, 134, 232

2a-081 Absolute flux calibration uncertainty

	Value	Units	Condition or Instrument	Parent Requirements
Definition	Maximum on-axis calibration error (rms) in 0.5-2 keV and 2-10 keV			
Requirement	**12 (TBC)** **4 (TBC)**	**%**	At beginning of life Relative change in orbit	111, 121, 221, 251, 252, 261, 262

Comments: ensures we know the luminosity of objects, and, e.g., gas density profile of clusters.

2a-082 Relative flux calibration uncertainty as function of energy

	Value	Units	Condition or Instrument	Parent Requirements
Definition	Maximum relative calibration error (r.m.s.) across a range of energies (0.5 to 2, and 2 to 10 keV)			
Requirement	**5 (TBC)**	**%**	At beginning of life and also any relative change in orbit	121, 132, 134, 221, 251, 252, 261, 262

Comments: This definition covers the broad band calibration but needs to be specified for small scale spectral ranges for X-IFU science (e.g. EXAFS signatures).

2a-090 Absolute Time Accuracy

	Value	Units	Condition or Instrument	Parent Requirements
Definition	Maximum difference (3σ) between the event arrival time and the registered event datum expressed in a universal timing system at the solar system barycenter			
Requirement	**50**	**μsec**	After including all space and ground segment (delays) corrections.	251

Comments: includes orbit determination to derive solar system barycenter correction

2a-091 Relative Time Accuracy

	Value	Units	Condition or Instrument	Parent Requirements
Definition	Required precision (rms, 1σ) of the time-tagging of detected events			
Requirement	**10**	**μsec**	X-IFU	251

2a-100 Count Rate Capability

	Value	Units	Condition or Instrument	Parent Requirements
Definition	Maximum count rate in an instrument where the science goals can still be achieved			
Requirement	**1** **10^{-3} (10^{-2}: goal)**	**Crab**	WFI FD with >80% throughput X-IFU: for this level a point source should give 80% high resolution events (2.5 eV)	141, 251, 252, 262, 341, 343

2a-102 Optical Brightness

	Value	Units	Condition or Instrument	Parent Requirements
Definition	Maximum visible magnitude that can be observed with no more than 10% energy resolution degradation at 7keV			
Requirement	**2**	**m_v**	X-IFU with selectable filter	311, 322, 325

8 LEVEL 2B/C REQUIREMENTS

The given level 2b and 2c requirements are related to the implementation of the Athena mission as proposed in the mission proposal. Some other optimizations could realize the same (or similar) science objectives (e.g. there is a trade between effective area, angular resolution, spectral resolution and ToO response time for various of the science objectives). Clearly some requirements are less far advanced. This is in particular true for:

- the accuracies with which the various parameters need to be calibrated
- the requirements and estimates for the background

The accuracy of the calibration parameters do not directly impact the design, the background requirements are under study as there is a limited set of data for L2 but different instrumental options have been identified to reach these levels.

L2c are requirements needed to complete the mission/instrument description, and shall not be considered as drivers of the mission or instrument design.

Below we first give the meaning of the various columns:

- *Object identifier:* unique identifier of the requirement in the DOORS database
- *Original identifier*: original identifier of the requirement (as of v.2.2 and earlier of this document)
- *Description*: description of the requirement
- *Comment*: on the condition for which the requirement applies (high spectral resolution, wide field, fast chip, other conditions)
- *Justification:* justification of the requirement. Where relevant a reference is made to an external document for additional details.
- *Level 1 parent:* identification which science objectives are most directly affected by the given parameter where it should be noted that some capability (area) is important for all science we list only the more driving science objectives
- *Level 2a parent*: same as for the SciOBJ
- *Owner:* subsystem which should ensure the requirement (X-IFU, WFI, ESA for the other parts but this may be more explicitly defined by ESA [e.g. ground segment, satellite, launcher etc.])
- *Author:* originator of the requirement

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<#>5 = very confident (accurate to better than 10%); ¶
<#>4 = confident (accurate to better than 25%); ¶
<#>3 = average (better than factor 2), ¶
<#>2 = limited confidence (factor 10) and ¶
<#>1 = poor (factor >> 10). ¶
<#>Note that this is somewhat arbitrary and for some requirements limited confidence might still be acceptable (e.g. straylight at the entrance of the detectors could be sufficient to have specified with an accuracy of a factor 10)
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- L2: specification level 2b if it is traced down from level 1 or level 2a. Level 2c requirements are added to complete the mission concept but are not driving and some may be transferred to the instrument requirement documents.

For the purpose of these requirements the Crab is defined as the XSPEC model powerlaw*tbabs (Γ=2.1, Norm=9.5 pho/cm^2/s/keV, N_H=0.4 10^{22} cm^{-2}).

These requirements are consistent with the performance of the instruments (response matrices have been used in verification of the science objectives and the definition of the Mock Observing Plan for the original mission proposal and have been scaled accordingly for the smaller effective area). These response matrices are based on an inner radius of 25 cm, an outer radius of 1.19 m, a rib spacing of 2.3 mm and a factor of 0.9 to correct for alignment errors and contamination. It shall be noted that the responses have been recalculated for the CORE exercise, even if the mirror configuration is similar to that of the ASIE ([RD4]). Details are given in [RD5] and [RD6]. The WFI response matrices without external filter have not been used as it is assumed that except for special cases, its external filter will be the nominal operational mode as it reduced the contamination.

As of version 2.3 of this document, L2b/c requirements are stored in a database under configuration control (DOORS). The list of requirements applicable to a given version of the SciRD are listed in a spreadsheed attached to the PDF (file name: `Athena_SciRD_vX.Y_L2bc_DOORS.xlsx`, where X.Y is the SciRD version)

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9 DEFINITIONS

9.1 Collected Definitions

Half Energy Width – the diameter (or equivalent in two dimensions of asymmetric PSF) containing half the X-ray photons from a point source

Effective Area – the collecting area at an instantaneous X-ray energy, E, [$Aeff$ (E)] of the Athena system is a product of the Effective Area provided to the focal plane by the SC [$Aeff\_SC$(E)] and the QE of the instrument [Q_{inst}(E)]. The former includes all losses such as vignetting due to pointing and mis-alignment, the latter including all effects at instrument-level including filters, dead spaces and event processing selections.

Relative Effective Area – the change in effective area between two energy ranges

Absolute Time – a time datum referred to the detection of an event in a detector in UTC (or synchronously running system such as TAI). It shall be assumed that the space and ground segments secure necessary conversions to alternate standard systems such as TDB Barycentric Dynamical Time

mCrab Flux – a convenient conversion between the flux in an energy band for a Crab-like reference spectrum, and the X-ray count rate is frequently used. Assuming a power-law with photon index Γ=2 and an absorbing column of 3×10^{21} cm^{-2}, 1 mCrab is ~2 10^{-11} erg/cm^2/s.

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