ASTRI Mini-Array
Science Requirements

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3.2	2021-04-01	Minor changes to the SII requirements
3.3	2021-04-10	SII Table added

List of Abbreviations:

ASTRI Astrophysics with Italian Replicating Technology Mirrors

CTA Cherenkov Telescope Array

MA Mini Array

SII Stellar Intensity Interferometry

IRF Instrument Response Function

FOV Field of view

PSF Point Spread Function

ACDC Astri Data Challenge

ZA Zenit Angle

Contents

1 Introduction

This document is aimed at providing a list of high-level scientific requirements as a reference for the development and commissioning of the ASTRI mini-array (MA) system.

In section 3 are reported the gamma-ray scientific requirements.

Requirements ASTRI-SCI-0010 to ASTRI-SCI-0090 concern the performance of the instrument. Requirements ASTRI-SCI-0010, ASTRI-SCI-0020 and ASTRI-SCI-0030 refer to the values reported in the ADCD1[1] set of instrument response functions (IRFs) [1] and obtained through Montecarlo simulations The sensitivity of the instrument can be evaluated using the results in the same set of IRFs. The sensitivity reported in ASTRI-SCI-0040 is the minimal flux of a point-like source detected with a significance of 5 sigmas following the standard Li&Ma method (equation 17 in [2]) This set of values are those required to obtain the scientific goals shown in the ASTRI white paper [3].
Requirements ASTRI-SCI-0060 and ASTRI-SCI-0070 are related to the pointing capabilities of the MA system. Requirements ASTRI-SCI-0100 to ASTRI-SCI-0140 are related to the knowledge of the instrument performance and they should be considered the "top level" goals of the calibration campaigns and constant monitoring of the instrument. Table 1 summarizes the gamma-ray scientific requirements and links them to the main ASTRI science topics.

The SII scientific requirements are reported in section 4 and summarized in Table 2

The requirements shall be valid in the energy range 1 - 200 TeV and in the ZA range 0-60 degrees (unless other energy and elevation range are explicitly indicated).
The requirements reported in this document are valid for the whole lifetime of the ASTRI MA project.

[1] see *https* : *//indico.ict.inaf.it/category/*99*/attachments/*3000*/*5841*/HowToDownload_ASTRI_MA_ACDC*1*_IRF.pdf*

2 Glossary

Differential Sensitivity

Definition : The Differential Sensitivity is the minimum detectable flux in five independent bins per decade in reconstructed energy. The required level of confidence in each bin is a five standard deviation (5 σ) statistical significance (calculated with equation 17 from Li&Ma 1983, ApJ 272, 317) and the presence of at least 10 excess events above background. Unless otherwise specified Reference Conditions should be assumed.

Energy Resolution

Definition : A measure of how well the array in a given configuration can reconstruct the energy of a primary particle/photon. Unless otherwise specified the primary should be assumed to be a gamma-ray. The energy resolution is defined such that 68% of events will have a true energy within this ΔE of their reconstructed/estimated energy. It is derived from simulations via the energy dispersion matrix, after all appropriate selection cuts.

Angular Resolution

Definition : A measure of how well the reconstructed direction of a primary gamma-ray corresponds to the true arrival direction. The angular resolution is defined as the opening angle of 68% containment for the angular distance to the true direction.

Point Spread Function

Definition : The point spread function (PSF) describes the imaging response to a point source. PSF(θ) is the fraction of events reconstructed with an offset, respect the true direction, less or equal to θ. The PSF depends on energy and off-axis angle.

Gamma-ray Field of View (FoV)

Definition : The Gamma-ray Field of View of the array is defined as twice the angular offset from the array pointing direction at which the differential point-source sensitivity (for a 50 hour exposure) is degraded by a factor of two. Note that the gamma-ray FoV is an energy- and analysis-dependent quantity.

Effective Collection Area

Definition : The energy-dependent effective collection area of the array is defined as the number of selected gamma-rays in a given observation time divided by the incident flux and observation time. Unless otherwise specified, the Effective Area should be assumed to include all quality and background rejection cuts, including angular cuts associated with a point-source analysis. Effective Area may be given as a function of either true or reconstructed primary energy.

Night Sky Background

Definition : Spectral form of the night sky background light assumed for calculations unless otherwise specified

Moonlight Reference Spectrum

Definition : Spectral form for the brightness of the night sky assumed for calculations under moonlight conditions.

Reference Gamma-ray Flux

Definition : The Reference Gamma-ray Flux at the top of the atmosphere is given by the expression dN/dE $= 2.83 \times 10^{-11}$ $(E/TeV)^{-2.62}$ TeV-1 s-1 cm-2 . Where E is the energy of primary gamma-rays. Point-like emission and an observation zenith angle of 20 degrees should be assumed unless otherwise indicated.

Reference Conditions

Definition : The standard set of conditions to be used for performance comparison using simulations (unless otherwise specified) is : 20 degree zenith angle observations. A night sky background flux of 0.24 photons/ns/sr/cm2 in the wavelength range from 300-650 nm (corresponding approximately to the extra-galactic night sky background level during astronomical darkness). An on-axis point-like source can be assumed unless otherwise specified.

3 ASTRI Mini-Array Gamma-ray Science Requirements

3.1 ASTRI-SCI-0010 - Gamma-ray Effective Area

The system (after all event selection cuts required to meet the sensitivity requirements) shall have an Effective Area, under Reference conditions, exceeding the curves given in figure below.

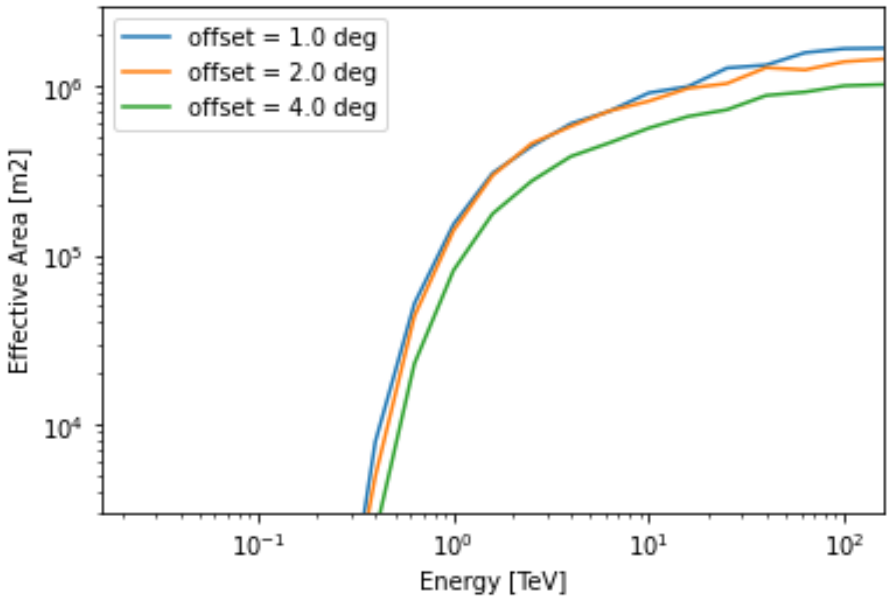

Figure 1: Astri effective area vs energy for few off-axis angles.

3.2 ASTRI-SCI-0020 - Gamma-ray Field of View

The Gamma-ray field of view FOV of the system shall have a diameter $>$ **6** degrees for all the gamma-ray energies in the range 1 - 200 TeV (see figure 3)

3.3 ASTRI-SCI-0030 - Gamma-ray Angular Resolution

The system shall meet the Angular Resolution given in the figure 2 at 20 degrees zenith angle and for the gamma-ray selection corresponding to the 50 h sensitivity requirement.

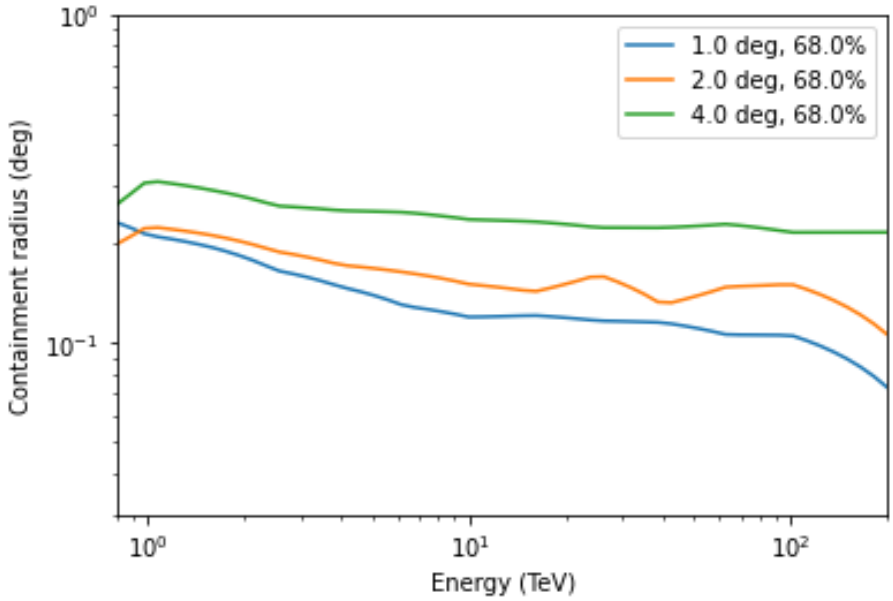

Figure 2: 68% containment radius as a function of energy for few off-axis angles.

3.4 ASTRI-SCI-0040 - Gamma-ray Sensitivity

The system shall allow the point-source Differential Sensitivity given in the figure below to be reached under Reference conditions Sensitivity is required in the energy range 1 - 200 TeV .

3.5 ASTRI-SCI-0050 - Gamma-ray Absolute Event Time

The absolute arrival time of on-axis Cherenkov light from a candidate γ-ray event at ground level shall be reconstructed to within 100 ns rms accuracy post-calibration.

3.6 ASTRI-SCI-0060 - Gamma-ray Source Localization

The rms space-angle systematic error on the localisation of a point-like source of gamma-rays (with the Reference Spectrum) with the system under standard observing conditions, shall be less than 15 arcseconds (per axis).

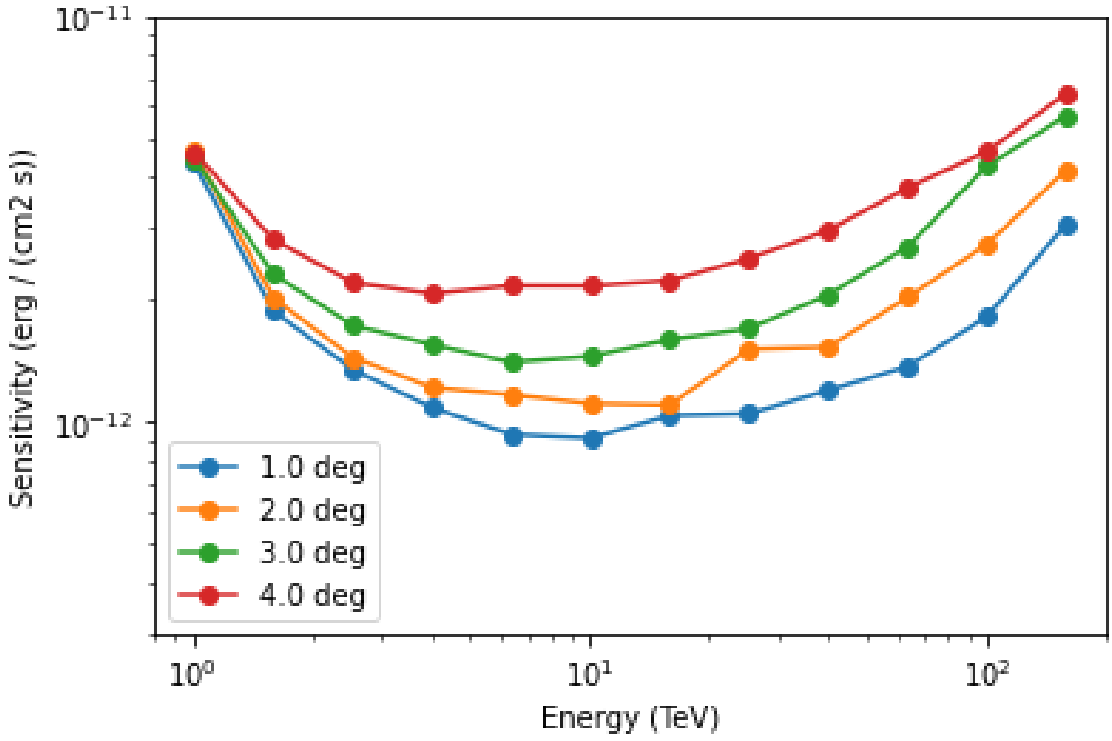

Figure 3: ASTRI MA differential sensitivity for 50 hours of observations and off-axis angles of 1, 2, 3 and 4 degrees.

3.7 ASTRI-SCI-0070 - Gamma-ray Observable Sky

The system as a whole shall be able to target any astrophysical object in the sky which has an elevation greater than 30 degrees.

3.8 ASTRI-SCI-0080 - Gamma-ray Telescope Deadtime

The fraction of the time that it is not possible to generate, receive or process triggers and/or data from an individual Telescope whilst in the observing state during observations shall be <6 %.

3.9 ASTRI-SCI-0090 - Gamma-ray Gamma-ray System Deadtime

The fraction of data lost during an observations (with telescopes on target) due to inefficiency in data collection, transport and storage, shall be less than 2 %.

3.10 ASTRI-SCI-0100 - Gamma-ray Effective Area Uncertainty

The contribution to the uncertainty on the effective collection area of the system arising from array level analysis and selection shall be less than 5% in the range 1 - 200 TeV , under Reference conditions, and over the gamma-ray field of view.

3.11 ASTRI-SCI-0110 - Gamma-ray Uncertainty on Trigger and Selection Efficiency

The contribution of the event triggering and selection process (at the level of individual telescopes) to the uncertainty on the effective collection area of the system shall be less than 8%

3.12 ASTRI-SCI-0120 - Gamma-ray Exposure Monitoring

The effective integrated exposure time associated with all ASTRI observations shall be known to at least 1% for timescales greater than 10 seconds.

3.13 ASTRI-SCI-0130 - Gamma-ray PSF Uncertainty

The uncertainty on the gamma-ray point spread function (PSF) shall not exceed 20% in the energy range 1 - 200 TeV , for data taken in standard observing conditions for any NSB level up to which sensitivity is required.

3.14 ASTRI-SCI-0140 - Gamma-ray Background Model Accuracy

The model for the residual background events in the field of view of every observation shall be accurate at a level of 2 % of the peak background , for all energies between 1 - 200 TeV , over the gamma-ray field of view.

Code	Name	Value	Science Topic
ASTRI-SCI-0010	Effective area (m^2)	@ 1 TeV : 1.52e5	Bl, FP
		@ 10 TeV : 9.11e5	PeV, Cr, Pwn
		@ 100 TeV : 1.66e6	PeV, Cr
ASTRI-SCI-0020	Field of view (deg)	6 (diameter)	PeV, Cr, Pwn
ASTRI-SCI-0030	Angular resolution (deg)	@ 1 TeV : 0.216	Bl, FP
		@ 10 TeV : 0.114	PeV, Cr, Pwn
		@ 100 TeV : 0.087	PeV, Cr
ASTRI-SCI-0040	Sensitivity (erg cm-2 s-1)	@ 1 TeV: 4.28e-12	Bl, FP
		@ 10 TeV : 9.55e-13	PeV, Cr, Pwn
		@ 100 TeV : 1.85e-12	PeV, Cr
ASTRI-SCI-0050	Absolute event time (ns)	100	Bl, FP
ASTRI-SCI-0060	Source localization	15 arcsec per axis	Bl, FP
ASTRI-SCI-0070	Observable sky	elevation > 30	PeV, Cr
ASTRI-SCI-0080	Telescope deadtime	$< 6\%$	PeV, Cr
ASTRI-SCI-0090	System deadtime	$< 2\%$	PeV, Cr
ASTRI-SCI-0100	Effective area uncertainty	$< 5\%$	PeV, Cr
ASTRI-SCI-0110	Uncert. on trigger and selection efficiency	$< 8\%$	PeV, Cr, Pwn
ASTRI-SCI-0120	Exposure uncertainty	$< 1\%$	PeV, Cr, Pwn
ASTRI-SCI-0130	PSF uncertainty	$< 20\%$	Bl, FP
ASTRI-SCI-0140	Background model accuracy	2% of the peak	PeV, Cr

Table 1: Summary of the gamma-ray science requirements, and related science topics (PeV : PeVatrons, Cr: Cosmic-Ray propagation, Pwn: Pulsar Wind Nebulae, Bl: Blazars, FP: Fundamental Physics)

4 ASTRI Mini-Array Stellar Intensity Interferometry Science Requirements

This set of requirements are needed to achieve the scientific goals for stellar intensity interferometry (SII) reported in the ASTRI white paper [3].

The requirements are valid in the elevation range 30-90 degrees, and for the whole lifetime of the ASTRI MA project.

4.1 ASTRI-SCI-0210 - Signal-to-noise ratio of a SII measurement

The acquisition and timing system of the instruments mounted on the Mini-array shall guarantee to achieve measurements of the correlation between any two telescopes with the signal-to-noise ratio and the exposure time reported (as a function of filter width) in Figure 4 left panel and right panel for stars with magnitude V=0 and V=2, respectively.

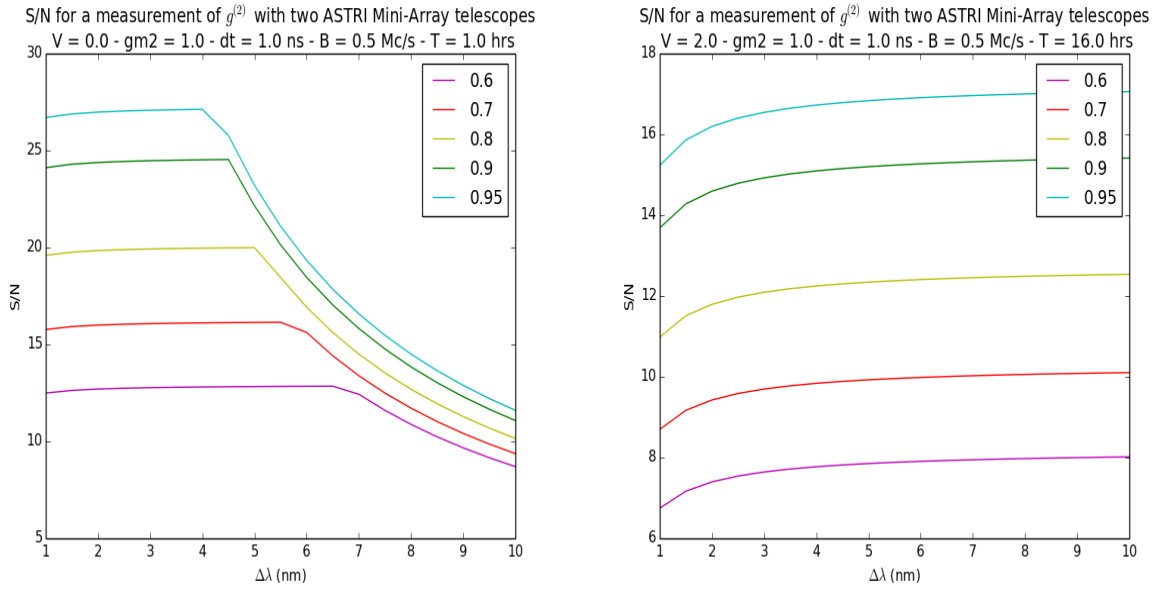

Figure 4: S/N ratio for a measurement of the discrete degree of coherence at zero delay with two ASTRI telescopes as a function of the narrow band filter width and for different values of the efficiency of the focal plane optics (from 0.6 to 0.95). Left: the star magnitude is V=0 and the exposure time is 1 hour. Right: the star magnitude is V=2 and the exposure time is 16 hours.

4.2 ASTRI-SCI-0220 - SII Timing accuracy

The acquisition and timing system of the instruments mounted on the Mini-array shall have the capability to sample the photon flux with a time bin of 1 ns and shall be able to detect each single photon event with a relative (among telescopes) time accuracy less than 0.5 ns over the whole duration of an observing run.

4.3 ASTRI-SCI-0230 - SII Observing Deadtime

The fraction of data lost during an observation (with telescopes on target) because of inefficiency in data collection, transfer and/or storage, shall be smaller than 10% per night.

Code	Name	Value	
ASTRI-SCI-0210	S/N of a SII measurement	see fig. 4, left panel	(for $m_V = 0$)
		see fig. 4, right panel	(for $m_V = 2$)
ASTRI-SCI-0220	SII Timing accuracy	1 ns	(time bin)
		<0.5 ns	(relative time accuracy among telescopes)
ASTRI-SCI-0230	SII Observing Deadtime	<10%	

Table 2: Summary of the Stellar Intensity Interferometry requirements.

References

[1] Pintore F., Giuliani A., Belfiore A. *et al.* (2020). *Scientific prospects for a mini-array of ASTRI telescopes: A γ-ray TeV data challenge*. Journal of High Energy Astrophysics, volume 26, pp. 83–94

[2] Li T.P. & Ma Y.Q. (1983). *Analysis methods for results in gamma-ray astronomy.*. ApJ, volume 272, pp. 317–324

[3] Vercellone S. & al (2021). *ASTRI Mini-Array Core Science at the Observatorio del Teide*. in preparation