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Prospects of the AMT single-dish science performance for monitoring gamma-ray blazars

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Blazars make up the largest fraction of *Fermi*-LAT-detected sources of high-energy gamma-ray emission. At the same time, their emission is known to be highly variable throughout the electromagnetic spectrum. With hints of their highest fractional variability in the radio regime being present at the highest radio frequencies, monitoring blazars at millimetre wavelengths will be one of the key science programmes of the Africa Millimetre Telescope (AMT).

Against this background, we study the expected science performance of the AMT based on a sample of 324 gamma-ray blazars with well-modelled spectral energy distributions, comparing three likely telescope sizes as well as the two possible locations.

We find that at 86 GHz, the performance of the AMT will not differ strongly amongst the telescope size and site options, while at 230 GHz and 345 GHz, a 13 m telescope will require 1.5 times the observation time of a 15 m telescope. A telescope close to the H.E.S.S. site will require 3 times (at 230 GHz) and 20 times (at 345 GHz) the observation time compared to a telescope on top of Mt. Gamsberg.

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1. Introduction

The Africa Millimetre Telescope (AMT) [1] is planned as an extension to the Event Horizon Telescope (EHT) network, which operates as a global Very Long Baseline Interferometry (VLBI) array and which has captured the first images of black hole shadows [2, 3], published in 2019 and 2022, respectively. The addition of the AMT will increase the available time windows for dynamical imaging with the EHT by 140% [4]. Beyond that, it will improve the robustness of the network. Although this science case is obviously a strong driver behind the development of the AMT, the EHT observing time per year is limited to less than two months, and from the beginning other science cases have been developed for the AMT, like flux monitoring of active galactic nuclei (AGN) [5] and transient science, which make use of the AMT as a single-dish telescope.

While initially planning to re-purpose the 15 m-diameter SEST telescope[6] for the AMT, meanwhile, a purpose-built telescope with a diameter of 13, 14, or 15 m is foreseen, optimized for the frequency range of 86–350 GHz and capable of observations down to 8 GHz. The front-end of the telescope is currently under development with support from the Dutch Research School for Astronomy, NOVA. Through a combination of dichroic mirrors, simultaneous observations in the following frequency ranges shall be possible [7]:

- ALMA Band 1: 31.3 – 45 GHz,
- ALMA Band 2: 67 – 90 GHz,
- ALMA Band 6: 211–275 GHz, and
- ALMA Band 7: 275–373 GHz.

Additionally, the development of a "low"-frequency receiver operating between 8 and 22 GHz is currently under discussion.

Two potential sites for the AMT have been identified within the Khomas highlands: one is close to the High Energy Stereoscopic System (H.E.S.S.) observatory site (as indicated in Figure 1), and the other is on top of Gamsberg Mountain. These sites are separated by a distance of approximately 30 km.

2. Blazar Monitoring

Blazars are AGN whose jets are closely aligned to our line of sight. They are known to emit throughout the electromagnetic spectrum from radio to gamma rays and exhibit rapid, strong variability, which is only partly correlated among different wavebands. To better understand these variability patterns, monitoring observations are essential. As the mm band is typically not suffering from synchrotron self-absorption within the source, such observations are more insightful for understanding the broadband spectral energy distribution of blazars. Furthermore, there are indications that the fractional variability of the radio emission of blazars correlates with frequency [9, 10]. [5] gives an overview of former and ongoing monitoring campaigns of blazars in the mm band, and motivates for a monitoring programme with the AMT.

Based on the CGRaBS all-sky catalogue of bright gamma-ray blazar candidates, [11] compiled multi-wavelength data of *Fermi*-LAT detected sources and systematically fitted a lepto-hadronic

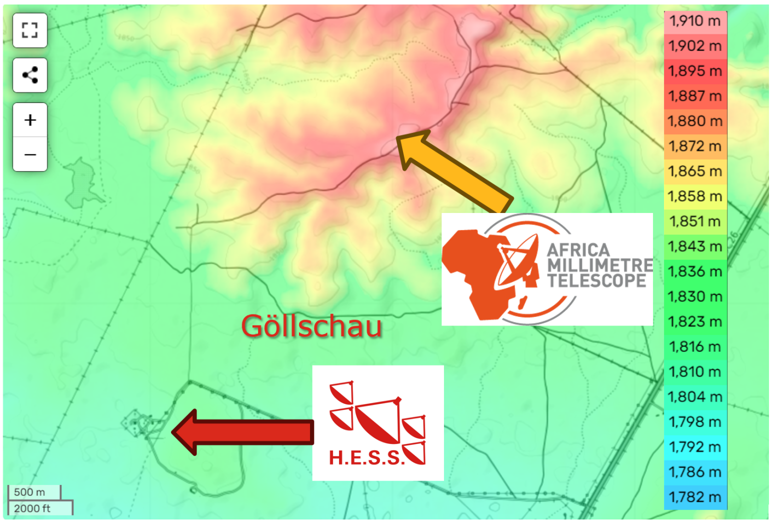

Figure 1: Relative location of the H.E.S.S. telescopes and the proposed site for the Africa Millimetre Telescope, both on Farm Göllschau in the Khomas Highlands of Namibia, on a topographical colour scale [8].

emission model to the resulting 324 sources. These best-fit spectral energy distributions (SEDs) form the basis of this study.

3. AMT Science Performance Estimation

For estimating the science performance of the AMT for monitoring gamma-ray blazars, we combine model flux densities derived from the best-fit SEDs of the source sample [11] with the atmospheric characteristics found at both sites [12].

The modelled source SEDs of [11] are evaluated at the AMT observing frequencies of 86 GHz, 230 GHz, and 345 GHz, using log–log interpolation where required. For lower frequencies, the impact of atmospheric conditions on observations, particularly on the differences between the two sites, will be marginal.

Based on the source catalogue mentioned above, we estimate the elevation angle of the culmination for each source during each week of the year for both sites and apply a cut-off of a minimum elevation angle at the culmination of 20°. By this, the size of the catalogue reduces from 324 to 270 sources.

Based on the work of [12], the weekly median values of precipitable water vapour (PWV) and ambient temperature T_{amb} were determined for both sites. PWV is the primary source of opacity at millimetre to submillimetre wavelengths. It is defined as the amount of water vapour in the atmospheric column above a location, equivalent to the amount of liquid precipitation that would result if all the water vapour in the column were condensed [13]. The yearly values are reported in Table 1.

From this, the observation time to reach 5 σ was estimated for each source, depending on the elevation angle at culmination and atmospheric opacity (derived from the PWV) for each week of the year. For this estimate, the following assumptions were made:

Table 1: Precipitable water vapour (PWV) measurements at the H.E.S.S. site and the Gamsberg Mountain as derived from GNSS station measurements. The values demarcate the median and upper and lower quartiles as reported in [12].

	PWV [mm]		
AMT site	25%	median	75%
H.E.S.S.	9.24	14.27	20.47
Gamsberg	5.07	9.25	14.40

- 8 GHz bandwidth of each receiver;
- ALMA receiver temperatures of 47 K, 136 K, and 219 K for band 2 (86 GHz), band 6 (230 GHz), and band 7 (345 GHz), respectively;
- aperture efficiency of the AMT of 75%, 70%, and 65% for band 2 (86 GHz), band 6 (230 GHz), and band 7 (345 GHz), respectively.

Figure 2 indicates the integration time in seconds to reach 5 σ for fluxes of each of the 270 sources in the main AMT frequency bands.

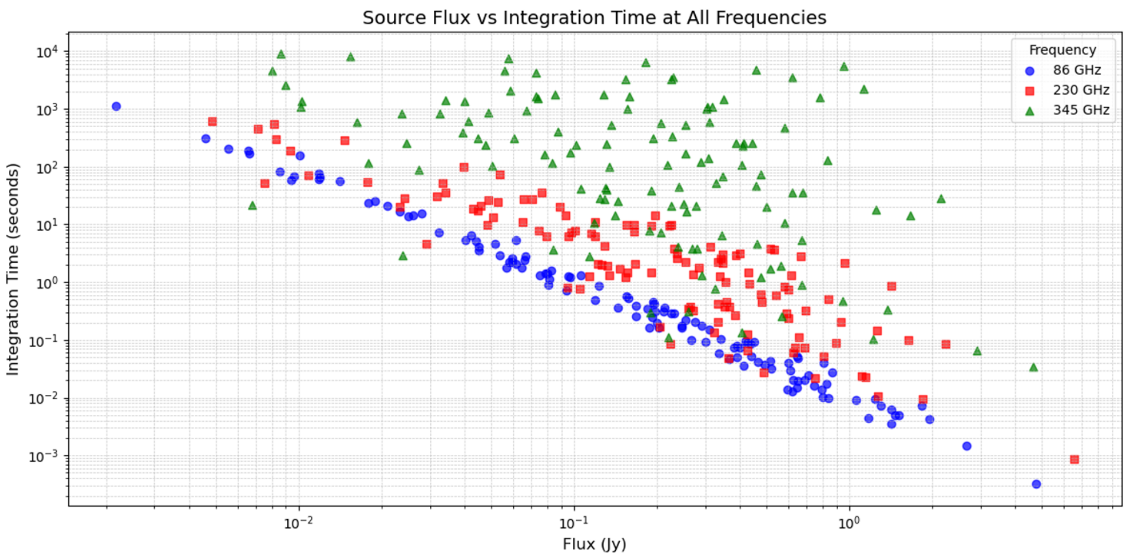

Figure 2: Estimated integration time in seconds to reach 5 σ for the modelled fluxes of the 270 sources from [5] for each of the main AMT frequencies.

Figure 3 presents the cumulative integration time in days to reach 5 σ for fluxes of the 270 sources in the main AMT frequency bands.

Assuming (arbitrarily) that a share of about 23% of the total observation time of the AMT will be devoted to monitoring of blazars means, there will be 138,462 s per week available for this. As all bands are to be observed simultaneously, the required observation time will be determined by the observation time at 345 GHz. Hence, sorting the sources by their required observation time at 345 GHz and filling the observation plan until 138 ks are reached gives an estimate of how many of

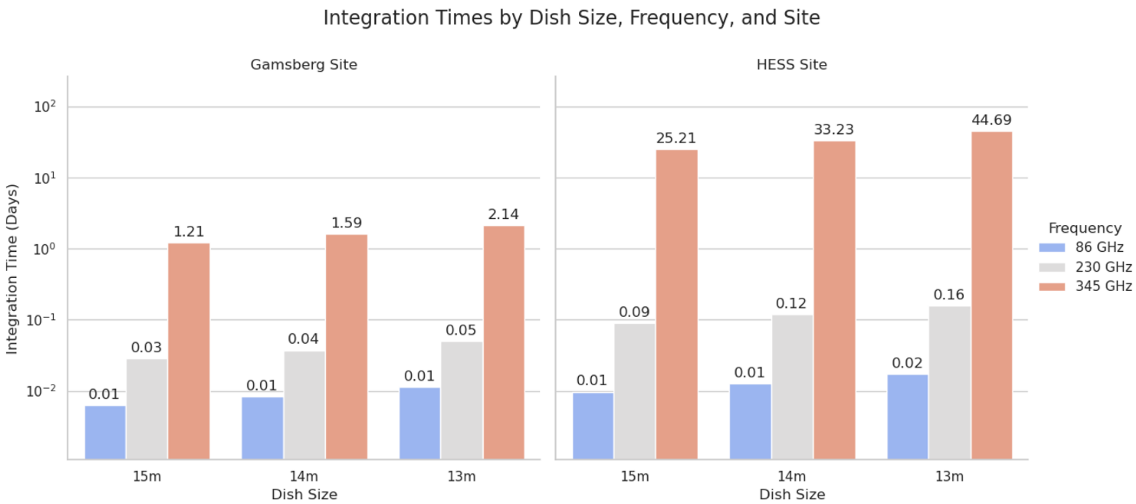

Figure 3: Estimated cumulative, "weekly" integration time in days to reach 5 σ for the modelled fluxes of the 270 sources from [5] for each of the main AMT frequencies, depending on telescope diameter and telescope site.

the 270 sources can be observed with a weekly cadence. Table 2 gives an overview of the number of observable sources and sample completeness for the two potential sites and the three main AMT frequencies (assuming a telescope diameter of 15 m).

Table 2: Estimates for number of observable sources and sample completeness per frequency band and for the two potential AMT sites, assuming a telescope diameter of 15 m.

AMT site	86 GHz	230 GHz	345 GHz
H.E.S.S.	237	179	61
	88.1%	66.3%	22.8%
Gamsberg	239	203	104
	88.5%	75.2%	38.5%

4. Conclusions

We have estimated the required observation time of 270 gamma-ray blazars with the AMT, depending on the weekly elevation angle at culmination and the weekly atmospheric conditions at the two proposed sites for the AMT and for the three main frequency bands of the AMT, namely 86 GHz, 230 GHz, and 345 GHz; all this for three potential telescope sizes of 13 m, 14 m, and 15 m. Unsurprisingly, the observation time differences at 86 GHz are only marginally dependent on the telescope size or the telescope site. At 230 GHz, a 13 m diameter telescope will require more than 1.5 times the time a 15 m diameter telescope will require, while the telescope will need 3 times as much observation time at the H.E.S.S. site, compared to the Gamsberg mountain (for the same telescope size). For 345 GHz, observations at the H.E.S.S. site will require about 20 times more observation time than at Mt. Gamsberg.

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