Gamma-Ray Astronomy in the Context of Multi-Wavelength Astronomy and Multi-Messenger Astrophysics

Submission to the ASFAP Working Group "Astrophysics & Cosmology"

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Gamma-ray astronomy is one of the three pillars of the South African multi-wavelength strategy, together with radio and optical astronomy. Southern Africa hosts some of the world's leading multi-wavelength facilities, in particular MeerKAT in the Karoo area of South Africa, which will expand into the Square Kilometre Array (SKA) mid-frequency array over the next decade, the Southern African Large Telescope (SALT) near Sutherland, South Africa, which is the largest single optical telescope in the Southern Hemisphere, and the High Energy Stereoscopic System (H.E.S.S. - see dedicated LoI submitted by the University of Namibia) near Windhoek, Namibia, which is the world's largest ground-based gamma-ray observatory.

Astrophysical sources of gamma rays trace the sites of the most extreme particle acceleration in the Universe, often associated with violent, explosive events. As such, they are often variable on a variety of time scales, from years and months down to minutes or even seconds. They include the remnants of supernova explosions of massive stars (supernova remnants [SNRs] and neutron stars / pulsars), binary systems consisting of neutron stars or black holes and regular stars, active galactic nuclei (AGN), powered by mass accretion onto supermassive black holes, ejecting collimated outflows (jets) of ultra-relativistic material, and gamma-ray bursts (GRBs), among others. GRBs have only very recently (2018) been detected as sources of very-high-energy gamma rays (VHE: $E > 100$ GeV) [3,4], observable by ground-based Cherenkov telescopes, such as H.E.S.S. They are also the first true multi-messenger sources, with the detection of a gravitational-wave event (GW170817) due to the merger of two neutron stars, associated with a short GRB (GRB170817A) [1].

The production of VHE gamma rays requires the efficient acceleration of particles to at least TeV energies, and there are indications that some Galactic gamma-ray sources (such as SNRs) are capable of accelerating protons or heavier nuclei to PeV energies. They are therefore the likely sources of cosmic rays (CRs) up to the knee in the CR spectrum at E ~ 3 PeV. Protons of PeV energies inevitably also produce neutrinos through the decay of charged pions produced in proton-photon or proton-proton interactions with photons or gas in or near their acceleration site. The tentative association of several AGN with VHE neutrinos detected by the IceCube neutrino detector at the South Pole (the most prominent example being the blazar TXS 0506+056 associated with the neutrino event IceCube-170922A [2] as well as a flare of neutrinos in 2014-15) has recently ushered in another facet of multi-messenger astronomy.

While activities in gamma-ray and associated multi-wavelength as well as multi-messenger astrophysics on the African continent is concentrated in Southern Africa, where activities of about 100 permanent staff, postdocs and students in South Africa and Namibia are co-ordinated through the South African Gamma-Ray Astronomy Programme (SA-GAMMA), research groups active in this field also exist in Ethiopia, Rwanda, Nigeria, and several other African countries. African researchers engaged in gamma-ray and multi-messenger astrophysics are involved in multi-wavelength studies of high-energy astrophysical sources using H.E.S.S., the *Fermi* Gamma-Ray Space Telescope, SALT and other ground-based optical telescope on the African continent, the MeerKAT radio telescope and the Event Horizon Telescope (EHT), to which the proposed Africa Millimetre Telescope (AMT) is anticipated to make a significant addition (see dedicated LoI submitted by the University of Namibia). There is also significant African participation in the IceCube neutrino detector at the South Pole and the km^3 Neutrino Telescope (KM3NeT), currently under construction in the Mediterranean Sea, as well as the Cherenkov Telescope Array (CTA), the next-generation ground-based gamma-ray observatory, which has just recently entered its construction phase, with Cherenkov telescope arrays in Chile and Spain. In addition to these observational aspects, significant efforts are also going into theoretical investigations and numerical simulations. These as well as the analysis of observational data require significant computational resources, which are currently available only in a few African institutions.

Astrophysical gamma-ray sources are inherently multi-wavelength sources, and their study often requires co-ordinated observations across the electromagnetic spectrum, from radio to gamma-rays, due to their often unpredictable multi-wavelength variability. The multitude of multi-wavelength astronomy facilities and their favourable geographic location (clear, dark skies, and a location in the Southern Hemisphere, with a privileged view of the central regions of our Milky Way) and the wide range of multi-wavelength and multi-messenger investigations in which African researchers are actively involved (detailed descriptions will be provided in a white paper), provides excellent opportunities for Africa to take on a driving role in the field of multi-wavelength and multi-messenger astrophysics, which is currently in its infancy.

References:

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