

A Joint Radio and Gamma-ray Monitoring Survey of Southern Hemisphere Sources

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Abstract

The Large Area Telescope on the Fermi Gamma-ray Space Telescope, launched in June 2008, is expected to conduct an almost continuous survey of the entire gamma-ray sky until 2018. We propose a joint radio and gamma-ray monitoring survey of the entire southern hemisphere sky, to detect and investigate the broad multi-wavelength properties and behaviour of galactic and extra-galactic sources which are detected to vary in either of these energy ranges over timescales of about 1 week or longer. For ASKAP, we propose a continuous, moderate angular resolution radio continuum survey of the southern hemisphere. The LAT, when Fermi is operating in sky survey mode, observes the entire sky several times per day. ASKAP has the capability to cover the entire hemisphere with a cadence of less than one week, and a goal for our proposal would be to better match the cadence of the LAT survey by performing ASKAP surveys once per day.

This joint broadband monitoring campaign will provide an opportunity for improved source identification for gamma-ray detected variable sources over the entire southern hemisphere, and probe the evolution of variable relativistic outflows in a comprehensive sample of extragalactic gamma-ray loud blazars, flat-spectrum radio quasars and other AGN, and galactic compact objects such as micro-quasars. In addition, interesting regions such as the galactic center will be routinely monitored as part of this survey. The presence of broadband variability will enable the selection of interesting objects to trigger other more detailed observations at other wavelengths.

Expected Science Outcomes

The Fermi Gamma-ray Space Telescope, launched in June 2008, has a planned lifetime of 5 years, with a goal of 10 years, and has successfully started its first year sky survey with the LAT instrument in early August 2008. The LAT observes gamma-rays in the energy range from 20 MeV to more than 300 GeV. The design, operation and performance of the LAT instrument on Fermi are described in Abdo *et al* (2009). The LAT performance is significantly better than the previous generation EGRET instrument, with a typical point source sensitivity (5σ) of 3×10^{-9} photons $\text{cm}^{-2} \text{s}^{-1}$ ($E > 100$ MeV) from the first year survey.

During the survey mission, the LAT observes the entire sky every 2 orbits by observing an alternate hemisphere of the sky each orbit. With an orbital period of 96 minutes, the LAT thus observes the entire sky several times per day. The capability of the Fermi mission to systematically survey the sky in time is a forerunner to similar capabilities in future telescopes such as PanSTARRS and LSST at optical wavelengths, and ASKAP at radio wavelengths. With operations expected through 2018, the Fermi sky survey will overlap with ASKAP operations for several years.

The extragalactic sources expected to be detected by the LAT are largely blazars and flat spectrum radio quasars, which are known to be variable on all timescales down to minutes. Likewise LAT will detect variable galactic sources, for example micro-quasars such as LS I +61 303 and LS 5039. The LAT has observed sources varying significantly on timescales as short as several hours (Foschini *et al* 2008). Our proposed joint survey, which could be performed with a repeated observation cadence as fast as 1 day with ASKAP, will both enhance the science return of both the Fermi mission and complement ASKAP survey schemes which address slower timescales. The joint radio and gamma-ray survey will provide much better data on the short (~1 day) timescale broadband variability characteristics of both galactic and extragalactic sources, which can be further exploited and expanded by triggering observations at other wavelengths to reveal the physics of the compact and relativistic emission regions in these sources. In addition, the potential exists for discovering new types of transient sources and behaviour.

While the LAT has better angular resolution than EGRET, source identification will remain an important issue with the LAT as it was with EGRET, where a large fraction of EGRET sources remain unidentified. The LAT has an energy-dependent angular resolution, with 68% energy containment of less than 1 degree at 1 GeV, and with source localization typically of a few arcminutes for bright sources. Correlated source variability at radio and gamma-ray wavelengths will provide a means to improve source identification, by exploiting the superior angular resolution available through ASKAP, and enable more detailed follow-up observations, using e.g. the ATNF ATCA and LBA.

Existing ATNF observing programs using the ATCA, such as C1730 and C1749, demonstrate the value of joint gamma-ray and radio surveys. These programs are already being updated from being based on EGRET-era gamma-ray source information to Fermi-era information. In addition, NAPA observing programs for the ATCA are being proposed to study the multi-wavelength properties of transient gamma-ray sources, which are based on day timescale Fermi-detected transient sources. These current programs will provide a great deal of experience in refining the joint observing strategies and defining data processing and analysis needs for an ASKAP-era survey.

This helps ASKAP satisfy two of its top 4 science priorities as defined in the ATNF Science Priorities for 2010-2015 (Ball *et al.* 2008):

- The characterization of the radio transient sky through detection and monitoring (including VLBI) of transient and variable sources
- Determining the evolution, formation and population of galaxies across cosmic time via high resolution, confusion limited, continuum surveys

Technical Details

During the Fermi mission, the LAT Collaboration performs automated science processing of LAT data, including regular point source detection and reporting at time intervals of 6 hours, 1 day and 1 week for the entire sky. The transport of LAT data from spacecraft to ground plus the subsequent ground

processing typically requires about 10-12 hours of time. The LAT collaboration releases information promptly on sources which flare above $2 \times 10^{-6} \text{ ph cm}^{-2} \text{ s}^{-1}$ ($E > 100 \text{ MeV}$). The LAT 5σ sensitivity on a 1 day timescale, matched to our timescale goal for the ASKAP survey, is a few times $10^{-7} \text{ photons cm}^{-2} \text{ s}^{-1}$ ($E > 100 \text{ MeV}$), and the LAT could identify varying sources at a rate of a few per week at that level. Source localization in the LAT data at such flux levels is typically about 10 arcminutes (95% confidence radial position error).

At the end of the first year survey, the LAT Collaboration (Peter Michelson, PI) will release a gamma-ray source catalog for the entire sky, together with a model for the diffuse gamma-ray emission from the galaxy. At that time, the LAT photon data for the first year of the Fermi mission will also be made public. Beyond the first year, LAT photon data will be made public immediately after processing through the LAT Instrument Science Operations Center and subsequent delivery to NASA's Fermi Science Support Center. While the Fermi observatory is opened to a guest investigator program in the second year and beyond of the mission, which may include non-survey observing, it is expected that survey observing will be used for the majority of the mission. In addition to the source catalog released after the first year sky survey, the LAT collaboration will release updated gamma-ray source catalogs at the end of the second and fifth years of the mission.

Proposed ASKAP survey parameters and associated notes.

- Angular resolution: 10-20 arcsec. This provides significantly better angular resolution and hence source localization than the (several arcminute) LAT source localization accuracy for bright transient sources. This allows sufficient angular resolution for correlating against known source catalogs to identify the LAT source, and is sufficient for planning follow-up observations of interesting objects with other telescope.
- Continuum survey, 300 MHz bandwidth; as high as possible for maximum sensitivity.
- Observing frequency: 1.4 GHz, for comparison to previous observations and source catalogs
- Survey speed: Would need to approach $10^3 \text{ deg}^2 \text{ hr}^{-1}$. This speed is needed to complete a hemisphere survey in 24 hours. The corresponding source sensitivity would be about $300 \mu\text{Jy beam}^{-1}$ (1σ), extrapolating from the ASKAP performance tables.
- Sky coverage: Daily observation of the entire sky south of declination 0° . As an option, since the ASKAP will be capable of observing at declinations up to $+45^\circ \text{ N}$, the survey could be extended well into the northern hemisphere, if the survey speed allows this, to further increase the overlap with the Fermi all-sky data.
- Survey strategy: Repeated meridional stripes in alternating north and south directions. Details are TBD.
- Radio data processing: routine data processing would consist of differencing daily data against a known constant, or at least template, continuum radio sky, to detect both radio flux increases and decreases relative to the reference sky. The template continuum radio sky could be a product of other more detailed sky surveys performed with ASKAP, or could be self-derived from stacking and averaging the daily surveys.
- Data products: daily lists of variable sources with associated properties. Thresholding would be applied to these products to derive triggers for detailed follow-up observations.
- Other relevant details for technical assessment:
 - Will require availability of other radio telescopes, e.g. ATCA and LBA, for prompt follow-up of interesting sources. Triggering of follow-up observations, based on Fermi transient detections, would be not more than a few per month.
 - This joint gamma-ray radio survey can start during the ASKAP BETA phase and benefit from an extra year or more of the Fermi mission to obtain joint results, as well as

develop and commission this survey as ASKAP itself is developed and commissioned. By the time that ASKAP commissioning starts, the Fermi survey and associated data processing will be fully mature, with the potential to contribute to the definition and design of ASKAP data processing.

Concept Design and Commissioning Contribution

The listed investigators will provide their own contributions and expertise to this joint survey. In addition the investigators from the LAT collaboration can guide resources and effort from within the collaboration to ensure LAT results and analyses meet the joint survey needs and objectives.

The roles and responsibilities of the investigators are as follows:

- Cameron: Manage automated processing of Fermi LAT data in SLAC processing facilities to generate automated science data products from LAT, suitable for matching/merging with ASKAP data products.
- Edwards: ASKAP data analysis and VLBI and ATCA follow-up observations
- Ekers: ASKAP survey and processing strategy.
- Macquart: ASKAP data analysis and VLBI and ATCA follow-up observations.
- Michelson: LAT Principal Investigator and LAT collaboration spokesperson.
- Murphy: ASKAP data processing; variables and transients analysis.
- Romani: Lead efforts within LAT AGN and galactic source science groups of the LAT collaboration. Provide blazar and FSRQ source catalog expertise.
- Sadler: ASKAP data analysis, source identification and radio/optical follow-up
- Tingay: ASKAP data analysis and VLBI and ATCA follow-up observations.