Tracking Gamma-Ray Emitting Active Galactic Nuclei with Austral Milliarcsecond Interferometry

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Abstract

We propose observations and coordination support from the IVS in an ongoing Southern Hemisphere monitoring program of compact extragalactic-jet sources, conducted in the framework of multiwavelength observations with the new NASA γ-ray mission GLAST. Our program TANAMI (Tracking Active galactic Nuclei with Austral Milliarcsecond Interferometry) is currently being conducted with the LBA, with 8.4 GHz observations of a large sample of sources every two months. TANAMIs scientific goals are closely related to questions about the stability of the international celestial reference frame (ICRF), by searching for the origin of the γ-ray emission in AGN jets and attempting to measure the positional offsets between these presumably more nuclear sites of γ-ray production and the compact radio cores that form the ICRF. In particular, variability studies of these offsets between the γ-ray and radio cores can be used to probe the stability of the ICRF. The accuracy of our measurements would benefit substantially from the participation of the two IVS stations TIGO and O'Higgins.

Scientific Justification

One of the most important results in research on active galactic nuclei (AGN) over the past two decades was made by the *Compton Gamma Ray Observatory* with its main instrument EGRET: that blazars are bright γ-ray emitters (e.g., Dondi & Ghisellini 1995, MNRAS, 273, 583). These sources represent the subset of AGN that are radio loud and whose powerful relativistic jets are pointed close to the line of sight of the observer so that they are observationally dominated by bright, compact radio cores even on sub-milliarcsecond scales. Currently a number of models for the γ-ray emission are proposed, including a Compton upscattering of low frequency radiation by the same electrons responsible for the synchrotron emission that dominates the radio band. Most theoretical models predict that the γ-ray emission is produced in the innermost region of the jets, very close to the black holes at the true center of the system, while the radio emission is produced further downstream. VLBI resolves the powerful relativistic outflows that produce the bright radio synchrotron emission, and which represent unique laboratories for studying a variety of physical processes associated with special and general relativity, high energy particle acceleration, and magnetohydrodynamics.

A milestone for our understanding of blazar-jet structure and the connection between the low- and high-energy ends of blazar SEDs has been reached with the successful launch of the Gamma-ray Large Area Space Telescope (GLAST) satellite (Gehrels, N., & Michelson, P. 1999 APh, 11, 277). The main instrument on GLAST, the Large Area Telescope (LAT), has broader energy coverage (20 MeV – 300 GeV), better resolution, a wider field of view and a sensitivity superior to EGRET. GLAST will continuously collect γ-ray data for each position on the sky. With proper VLBI observing programs in place, we can address the most crucial questions that EGRET left us with:

- Where are the γ-rays produced in blazar jets with respect to the compact radio cores that form the International Celestial Reference Frame (ICRF)? Are the two regions co-spatial and if not, how stable are their relative positional offsets? Superluminal jet components and standing recollimation shocks are possible alternative sites of origin of the γ-ray emission.
- How do high-energy variability patterns relate to intrinsic jet parameters like jet speeds, Doppler factors, opening and inclination angles, magnetic field strengths and gradients?

- Are radio and γ-ray emission beamed with the same Lorentz factor? What are the implications for the structure of jets and the positional stability of the radio cores and the ICRF?

In the northern sky, the VLBA monitoring program MOJAVE (e.g., Lister & Homan 2005, AJ 130, 1389) has long been in place and has recently been optimized to yield best possible synergy with GLAST. Our team has set up an analogous VLBI monitoring program for radio- and γ- bright AGN of the less-well studied southern sky: TANAMI – Tracking Active galactic Nuclei with Austral Milliarcsecond Interferometry (Kadler et al. 2008, AAS Meeting #211, #04.13). TANAMI is the only large VLBI monitoring program targeting bright AGN south of declination -30°. It is being conducted at 8.4 and 22 GHz GHz with the LBA (Long Baseline Array; typically enhanced by the NASA/DSN Tidbinbilla DSS-43 antenna and Hartebeesthoek antenna). **With this proposal, we propose the participation of additional IVS antennas in the 8.4 GHz TANAMI observations. In particular the TIGO antenna in Chile and the O'Higgins antenna, when available during the Antarctic summer, would dramatically improve our *(u,v)*-coverage and our ability to image and trace VLBI jet structure.**

One of the major science goals of TANAMI is to pin point the location of origin of the gamma-ray emission in AGN jets with respect to the positions of the radio cores and with sub-milliarcsecond accuracy. To address this issue, we will monitor the parsec-scale structure of our target sources parallel to monitoring their gamma-ray light curves and spectra with GLAST. We will cross-correlate gamma-ray flares with the ejection of new VLVI jet components and measure the time delay between the onset of the gamma-ray flare and the time when the new jet component travels through the $\tau = 1$ surface (the radio core). On the long time scales of > 5 years for which both the GLAST mission and the TANAMI program are set up for, it will be possible to measure such time delays for a large sample and even multiple ones for the most active and fastest sources. If the gamma-ray emission is indeed produced much closer to the tue central engine, as predicted by most theoretical models, these measurements will implicitly reveal information about the stability of the ICRF. TANAMI is the only program to yield this information for the elusive southern part of the radio–gamma sky.

Immediate Goals:

The TANAMI program is supported by an ATCA project (PI: Tingay) for flux density monitoring between 20 cm and 7 mm, with largely overlapping target lists[1] and by bi-monthly multifrequency radio spectral monitoring with the Hobart and Ceduna radio telescopes at 2.3, 6.7, and 8.4GHz (PI: J. Lovell). In combination with these long-term flux-density spectral monitoring data, our LBA observations allow us to address the following issues:

- Relativistic Jet Kinematics: Multi-epoch VLBI observations continue to provide the only direct evidence for and measure of relativistic motion in AGN jets. They provide important constraints for numerical jet simulations and tests of the relativistic-beam model (e.g., Cohen et al. 2007, ApJ, 658, 232). By fitting Gaussian components to features within the jet, we are be able to track their trajectories. Back extrapolation of component trajectories gives us ejection epochs to compare directly with radio flux-density source light curves and GLAST-measured γ-ray light curves.

- Spectra: We obtain spectral indices of the cores and the brightest jet features of our sources by observing at 8 and 22 GHz. The dual-frequency approach enables us to address important questions about the emission and absorption processes at work, e.g., via studying the core shift between both frequencies (Lobanov 1998, A&A 330, L79) and the spectral indices of the cores and individual jet features. The *Swift* team (PI: N. Gehrels) will provide coordinated observations with the UVOT, XRT and BAT instruments onboard the *Swift* satellite (Gehrels et al. 2004, ApJ, 611,

[1] ATCA observations extend to declinations north of $-30°$, to support planned VLBA programs, while the LBA observations will concentrate fully on targets not accessible by the VLBA.

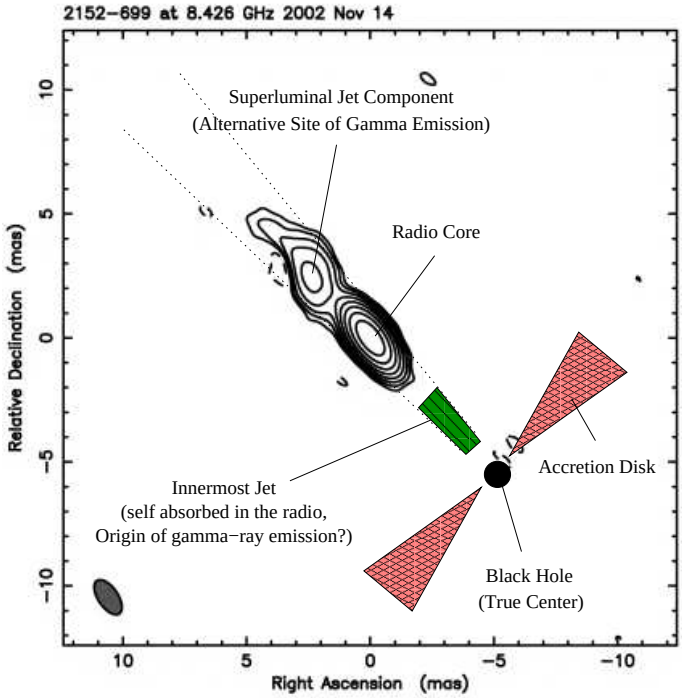

Figure 1: Sketch of an AGN, showing the ICRF-measured radio core downstream from the true center of the system and the putative site of the γ-ray emission in the innermost jet, close to the central black hole. Measuring the currently unknown offset of the radio core (exaggerated in this sketch) and its positional stability is one of the major science goals of TANAMI.

1005) to complete the broadband SEDs of our sources between the radio and γ-ray bands with optical/UV/X-ray data. Complementary near-infrared/optical measurements are guaranteed by the REM team (`www.rem.inaf.it`). SED modeling in combination with jet-speed measurements will allow us to investigate the relation between the Doppler-boosting parameters for the radio and γ-ray emitting regions of the jets.

- Outbursts and Flaring: We will measure the time delays between radio and γ-ray emission outbursts. These delays are used to calculate how far from the core the γ-ray emission originated, thus identifying the site of γ-ray emission. The obvious candidates are the compact jet cores, but it has also been suggested that the γ-rays may originate in superluminal jet components (Jorstad et al. 2001, ApJ, 556, 738) or even in standing recollimation shocks (D'Arcangelo et al. 2007, ApJ, 659, L107).

Proposed IVS Observations to Enhance the TANAMI Program

IVS Ressources Requested: We request the participation of two IVS stations in TANAMI observations: TIGO and O'Higgins (GARS), if possible during the Antarctic summer. We propose to conduct these observations as part of the IVS R&D (research and development) program. We request 8.4 GHz observations at six epochs at approximately two-month intervals with 24 hours of time at each epoch, for a total of 144 hours of observing time, for one year. We note that the IVS station in Hartebeesthoek is routinely observing together with the LBA and that no additional IVS observing time for this station is needed. As the LBA will coordinate the Hartebeesthoek station time, this will reduce the coordination efforts for the IVS to the TIGO and O'Higgins antennas (priv. communication: D. Behrend, IVS Coordinating Center). The LBA schedule for the next TANAMI run is typically prepared about two to three months in advance. Our TANAMI team member Phil Edwards, who is the LBA scheduler, would contact the IVS coordination office at this point to plan

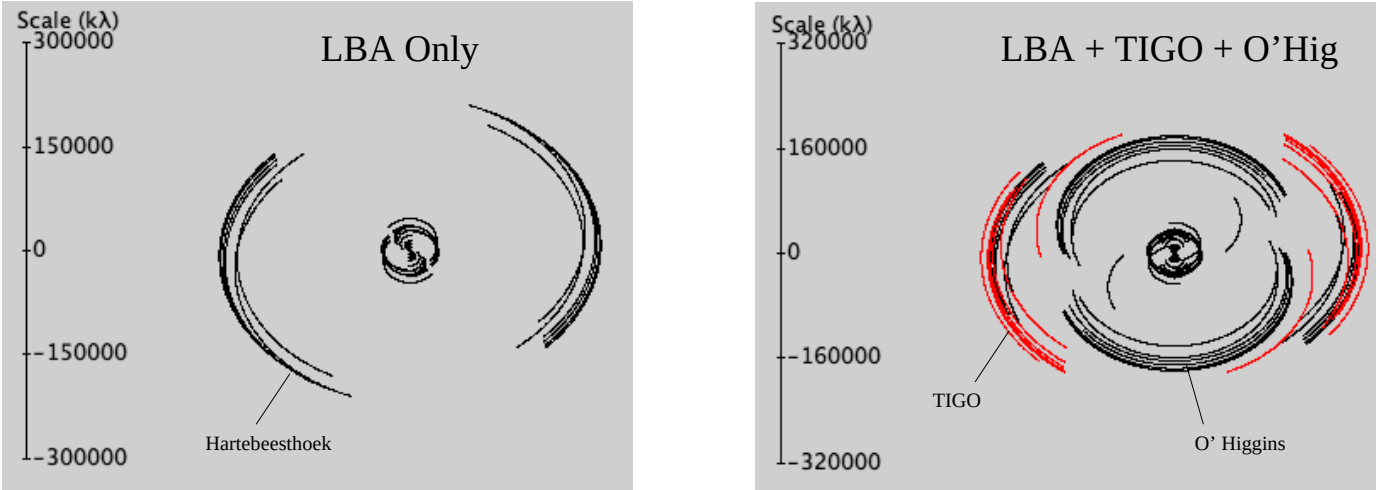

Figure 2: (u, v)-plots demonstrating the dramatic improvement of our VLBI array by the inclusion of the two requested IVS antennas TIGO and O'Higgins. Left: (u, v)-coverage for our current array, including Hartebeeshoek. Right: Our enhanced LBA+IVS array. TIGO improves significantly the sampling at the longest baselines while O'Higgins fills in the wide gap between the australian and trans-oceanic baselines. stations.

the forthcoming observations. In each observing run, about 20 sources are observed at 256 Mbps. The data will be recorded on MkV 8-pack hard drive modules and correlated at the Curtin Univ. Tech. software correlator. We will provide four 6 TB disk packs for use within the IVS disk pool. We also request the IVS to coordinate the shipping and handling of the disk packs between O'Higgins and TIGO and the correlator for our program. We do not request any proprietary data rights period from the IVS and we plan to make the combined and calibrated LBA+IVS data publically available from our project website in a timely fashion.

Target list and Cadence: We propose to observe a sample of bright, flat-spectrum AGN with bright compact radio cores and additional extended emission, located south of declination -30 degrees (most sources are well above 1 Jy). For most of the jets in our sample, the jet speeds and characteristic component separations are not yet known, so that we require three initial epochs with spacings from two to four months to determine their proper cadences. Once we have determined the right cadence for an individual source, we will adjust the sampling for the follow-up observing program. Eventually, this strategy will allow us to monitor ~ 120 sources per year.

We have selected our initial sample based on previous γ-ray detections by EGRET and on radio flux density and luminosity. The MOJAVE program has shown that bright γ-ray emission seems to correlate with fast jets and that the fastest jets are found in the highest-luminosity objects (Kellermann et al. 2004, ApJ, 609, 539; Cohen et al. 2007, ApJ, 658, 232). Following this strategy, we selected the 21 highest-luminosity AGN jets from the literature (including the ATNF/USNO data base) in addition to the 19 high-probability EGRET identified blazars of the southern sky. Observations of this initial sample have begun in November 2007.

Frequencies Requested: We are requesting IVS observations at 8.4 GHz. Imaging observations at 8.4 GHz yield the best image fidelity and thus the most detailed structural information with this array. We have considerable experience of imaging at this frequency including the USNO/ATNF ICRF imaging program that has successfully imaged most existing and some potential Southern Hemisphere ICRF sources (Ojha et al. 2004, AJ, 127, 3609; Ojha et al. 2005, AJ, 130, 2529). This frequency is also high enough to provide good resolution and low enough to avoid missing extended structure that often has a steep-spectrum. Atmospheric opacity effects are also negligible at this frequency.

Simultaneous Broadband SED Observations and Public Data Access: From mid/late 2008, GLAST will continuously collect γ-ray light curves and spectra for all of our sources using its

main instrument LAT. *Swift* observations will start with the beginning of GLAST operations and will be performed as fill-in or ToO observations. All *Swift* ToO data are public. After the end of the one-year GLAST/LAT proprietary data period, the LAT team will make all their data publically available, as well[2]. At that time, we will provide combined radio through γ-ray SED data together with calibrated LBA+IVS data for the TANAMI sample on our project website.

[2]If necessary, the GLAST/LAT affiliated scientists in our team (MK, RO, NG, JM, GT, DT, JAZ) would have the opportunity to access these data even during year 1.