RevMexAA (Serie de Conferencias), **32**, 40–42 (2008)

SEARCHING FOR DISTANT BLAZARS WITH GLAST AND THE LARGE MILLIMETER TELESCOPE

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RESUMEN

El Gran Telescopio Milimétrico estudiará el universo a altos corrimientos al rojo, incluyendo la formación de las primeras galaxias masivas y sus núcleos activos. El GTM puede ser usado en conjunto con *GLAST* en la búsqueda de los blazares más distantes para explorar la época de formación de los primeros hoyos negros.

ABSTRACT

The Large Millimeter Telescope will study the high redshift Universe, including the formation of early massive galaxies and their active nuclei. LMT can be used together with *GLAST* to search for distant blazars and probe the epoch of black hole formation.

Key Words: BL Lacertae objects: general — galaxies: active — gamma rays: observations — submillimeter

1. INTRODUCTION

The study of distant blazars is of primordial importance to understand the formation of the first supermassive black holes in the Universe. While we have evidence that star formation was already in place in protogalaxies at $z \sim 6$, when the Universe was $\lesssim 1$ Gyr old and systems with up to 10^{12} $M_\odot$ were already assembled (Kashlinsky et al. 2007), it remains uncertain how long took the growth of massive black holes (BHs) in these systems. Studying and characterizing the most distant blazars, specially if found at $z \gtrsim 6$ is of basic importance to understand the evolution of early BH systems and their feedback to galaxy formation.

2. THE LARGE MILLIMETER TELESCOPE

The Large Millimeter Telescope –el Gran Telescopio Milimétrico (LMT/GTM)– will be a fine instrument for the study of the early Universe. LMT/GTM is a bi-national collaboration between the Instituto Nacional de Astrofísica, Óptica y Electrónica in Mexico and the University of Massachusetts at Amherst in the US teamed to build and operate a 50 meter aperture antenna for millimeter wave astronomy. The construction of LMT/GTM at the 4600 meter altitude site of Sierra Negra is nearing completion, with the telescope having been inaugurated by President Fox on November 22, 2006, with a 14 GHz observation of M87. The inner three rings of the surface, equivalent to a 30 m aperture, were installed for this occasion and are now been measured, tested and set, while the panels for the outer two rings are under construction. A first light a 3 mm is expected to occur around mid-2008. With a collective area of 2000 m^2 the LMT/GTM will be the largest single dish telescope in its frequency range, between 80 GHz and 350 GHz, while been located in one of the highest astronomical sites in the planet. LMT/GTM will have a resolution of 5 arcsec (λ/mm) and a field-of-view of 2×2 arcmin^2. With a slew capability of 1 degree per second on each axis (elevation, azimuth), LMT/GTM can become an important instrument for rapid observations of highly variable objects. LMT/GTM will be able to perform deep continuum maps, fine spectroscopy of extended sources and sensitive polarization measurements. And in the era of the Atacama Large Millimeter Array (ALMA), LMT/GTM been a prime instrument for mapping large extensions of the mm-wave sky, can become a perfect complementary partner, surveying and finding the best candidates for deep ALMA imaging.

3. ASTRONOMY WITH THE LMT INSTRUMENTATION

The science case of LMT/GTM departs from the study of cold bodies, naturally related to the formation of astronomical objects: the study of comets and Kuiper belt objects provides clues to the formation of our Solar System; the mapping of giant cold molecular clouds in the Milky Way and in nearby galaxies helps us understanding the similarities and differences between stellar systems. And, probably the most exciting case for the LMT/GTM,

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the study of dusty protogalaxies traces the star and galaxy formation history of the Universe. Aided by the negative K-correction of 30 to 60 K interstellar dust, LMT/GTM will be able to study the formation and evolution of dusty protogalaxies from the nearest systems up to $z \gtrsim 10$. The array cameras of LMT/GTM will be able to reach sub-mJy fluxes in seconds, exploiting their capabilities for making deep and extended maps. The requirements imposed by the scientific goals of the LMT project led to the instrumentation plan and development of the first generation LMT instruments, able to perform deep observations, high resolution spectroscopy and polarization measurements:

- SEQUOIA is a 32 element dual polarization heterodyne camera for line mapping around 3 mm, for high spectral and spatial resolution molecular mapping. The high performance of SEQUOIA has been thoroughly tested for some years at the FCRAO 14 meter mm telescope.
- AzTEC, the 144 bolometer camera of the LMT/GTM for continuum mapping, has recently been used in telescopes like the James Clerk Maxwell to produce deep maps like those of the GOODS-North field (Scott et al. 2007) and the field around the high redshift radio galaxy 4C41.17 (Hughes et al. 2007). Once mounted on the LMT/GTM, AzTEC will provide a sensitivity of 3 mJy $\sqrt{\mathrm{Hz}}$ at 1.1 mm per pixel and will be able to map 1 deg^2 as deep as 50 μJy (1σ) in 1000 hours or 300 deg^2 in 100 hours at 3 mJy (1σ) (Wilson et al. 2004).
- SPEED is a continuum camera made of four dual polarization frequency selective bolometers able to observe *simultaneously* the 2.1 mm, 1.4 mm, 1.1 mm and 0.8 mm bands. SPEED, described in detail by Wilson et al. (2003), will be the optimal instrument for multi-wavelength monitoring due to its sensitivities between 1.3 and 4.9 mJy Hz$^{-1/2}$ and optimal cross calibration between bands. SPEED will see its first light during 2008.
- The Redshift Receiver is a wide band spectrograph designed for redshift determinations based on detecting CO lines in its 75–100 GHz window – completely covered in single observations. The redshift receiver saw its first light in the 14 m FCRAO telescope in 2006.

4. MILLIMETER γ-RAY BLAZARS

The ubiquitousness of γ-ray emission among blazars was one of the most important discoveries of EGRET, the high energy γ-ray telescope on board of the *Compton Gamma Ray Observatory (CGRO)* (Gehrels et al. 1993). EGRET operated between 1991 and 2000, reporting in its 3^{rd} Catalog 271 celestial sources of photons with energies $E > 100$ MeV (Hartman et al. 1999). Of these, 66 were considered high confidence blazar identifications and 27 more were low confidence blazar identifications. In addition, there are 14 objects in the second EGRET catalog and its supplement (Thompson et al. 1995, 1996) not included in the 3EG catalog, some of which are potentially associated with blazars.

A precise assessment about the identification of extragalactic EGRET sources with flat spectrum radio loud sources was made by Mattox et al. (1997) for the 2EG catalog and its supplement. Later, Mattox, Hartman, & Reimer (2001) compared the 3EG catalog with the Green Bank 1.4 GHz and 4.85 GHz, and the PMN radio catalogs. These works quantified the likely association of individual γ-ray sources with known radio sources and served as basis for further studies. Halpern, Eracleous, & Mattox (2003) performed a redshift study of candidate γ-ray blazars, placing 2EG J1430+5356 at $z = 3.00$. This redshift was the largest for a blazar associated to a γ-ray source, which happens not to be in the 3EG catalog. Sowards-Emmerd, Romani, & Michelson (2003) made a detailed re-evaluation of the correlation between radio sources and EGRET sources for the Northern sky providing between 20 and 50 new associations, with redshifts potentially up to $z = 4$.

The generic relation between radio and γ-ray emission in blazars is interpreted through the scenario where both emissions arise in a relativistic jet along the axis of the accretion disk feeding the supermassive black hole. Particles are accelerated in shocks due to differential motions of fast moving ejected material catching with slower ejecta. Synchrotron emission from relativistic electrons shows from the radio up to the optical and UV, with a maximum in νF_ν typically at $\nu \sim 10^{12}$ GHz. The high energy component, due to either inverse Compton scattering by the same electrons or nuclear collisions of relativistic hadrons, shows from high energy X-rays up to GeV or TeV energies. As such, γ-ray blazars are inherently bright in the millimeter band. One particular example of a bright and highly variable such object is NRAO 530, whose 3 mm flare was reported by Bower et al. (1997).

The relation between these can be assessed through a comparison of the currently known millimeter and γ-ray sources. Four years ago Bennett et al. (2003) presented a catalog of 208 foreground sources observed by the *Wilkinson Microwave Anisotropy Probe (WMAP)*, a by product

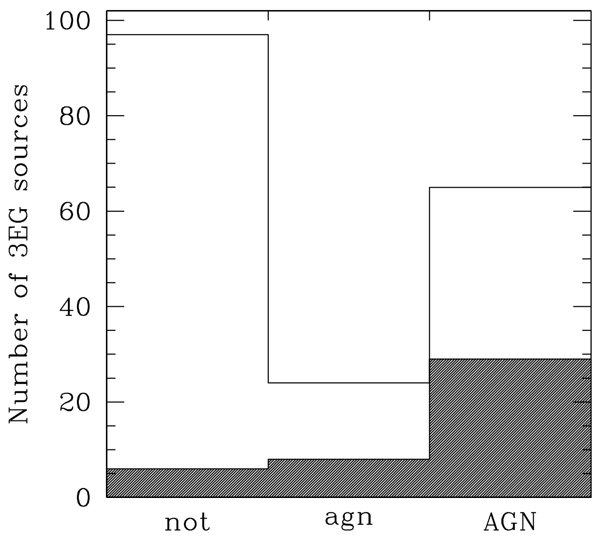

Fig. 1. The upper histogram is the number of sources in the Third EGRET catalog with latitude $|b| > 10°$ firmly (AGN) or weakly (AGN) associated to AGN and those not associated with AGN, compared to the subset of sources with positional match with a WMAP foreground source, indicated by the shaded histogram.

of their study of the Cosmic Microwave Background. These sources were detected in at least one of the K, Ka, Q, V and W bands, covering the 23 GHz–94 GHz interval. The *WMAP* catalog represents a shallow but complete survey of the sky, with the $|b| < 10°$ band excluded. Positional coincidences between the *WMAP* foreground sources and the 3EG Catalog are found for 43 sources – i.e. half of the known EGRET sources are found on a shallow mm-survey. Of these 29 are reported as high confidence and 8 as low confidence AGN in the EGRET catalog, with only 6 non AGN (Figure 1) – two of them, 3EG J1249–8330 and 3EG J1813–6419, identified by Mattox, Hartman, & Reimer (2001). Viewed from the inverse perspective, about 20% of the 208 *WMAP* foreground sources are detected as γ-ray sources down to the EGRET detection limit. The fraction increases considering the 94 GHz band, where 20 of 61 sources detected by *WMAP* are EGRET blazars. Even with mm fluxes at the Jy level, sources reach up to $z = 2.1$. An object like 3EG J0845+7049 can be detected by *GLAST* up to $z \simeq 7$; the 1.4 Jy flux detection in the 61 GHz band compared to the LMT/GTM sub-mJy possibilities at 3 mm makes this object detectable at arbitrarily large redshifts (beyond $z > 20$). Both LMT/GTM and *GLAST* have the capabilities to jointly detect the most distant blazars.

The main difficulty for LMT/GTM resides in the limited sky coverage, particularly compared to the amazing capability of *GLAST* to survey the entire sky in 3 hours. Given that the νF_ν mm-wave flux of the *GLAST* detection limit corresponds to about 60 mJy, one approach to search for distant blazars can be for LMT/GTM to perform very shallow surveys of extended regions searching for sources with fluxes of tens of mJy. Even in a snapshot these can be detected with enough signal to noise ratio to allow for future re-measurements in search of mm-wave variability. Any bright mm-wave high latitude source with such evidence can then be sought for in the *GLAST* data. The most extended survey one might consider could cover a few 1000 deg^2, up to 1 sr, with 5 to 10 mJy 1 σ noise at 1.4 mJy.

The opposite approach consists on an identification program based on mm-wave snapshots of unidentified weak *GLAST* sources. Given the expected positional accuracy for the γ ray sources of a few arcminutes, the full coverage of *GLAST* error boxes should be feasible in a few AzTEC images. Any bright potential counterpart can then be revisited for variability or observed with the redshift receiver in search of highly redshifted CO lines.

This work was supported by CONACyT research grant 42611.

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