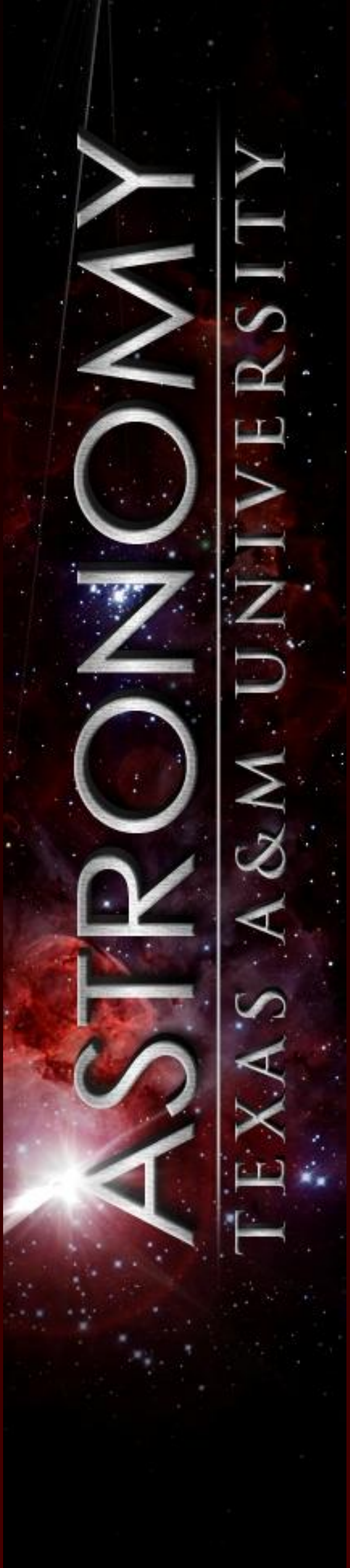

Searching for Gamma-Ray Emission from Rocky Bodies around Nearby Stars

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Abstract

Using the Fermi Large Area Telescope (LAT) we report on the utilization of the LAT to find evidence of particle cascades produced by cosmic ray interactions with surfaces of rocky bodies around nearby stars. In order to test the capabilities of Fermi as a tool to detect these bodies we pointed at α Lyr looking for signs of γ rays emitting off any asteroid-like bodies associated with the debris disk. Using an energy range of 100 MeV to 100 GeV the closest source to α Lyr's coordinates, we found, is unassociated with the star. Since no source was seen at these coordinates we concluded that the signal proposed to be there by these particle cascades is too faint to be detected by Fermi.

Introduction

The *Fermi* Large Area Telescope (LAT) is a space telescope conducting an all-sky gamma-ray survey. Below, Fig. 1, is the Fermi Gamma Ray picture of the sky. This photograph shows us what our sky looks like in gamma rays but also shows the innumerous amount of stellar objects to be studied in this spectrum.

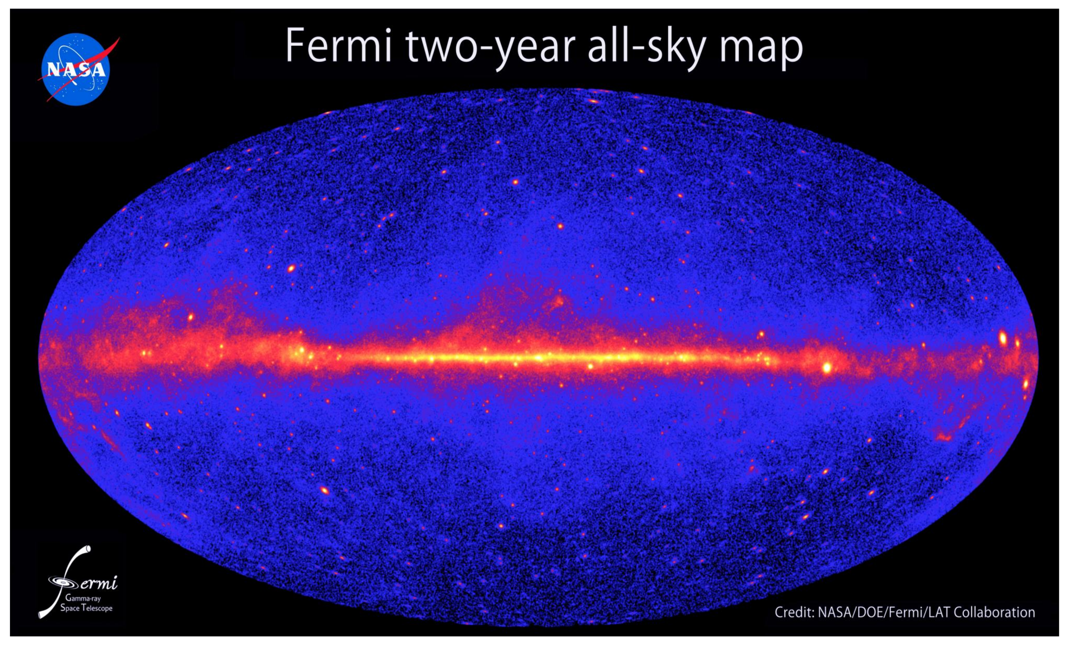

Figure 1. The NASA Fermi LAT 2 year all sky map depicting all sources and counts collected by the Fermi LAT over the course of the first two years of it's mission.

Apart from being used for efforts towards finding potential dark matter candidates such as WIMPs and completing our picture of the night sky, the LAT has also been used for many other useful purposes one of which was to find the moon (A. A. Abdo et al. 2012), an object that initially one would think to be invisible to a gamma ray telescope. As with all types of telescopes, scientist are continually trying to utilize, to their full potential, the telescopes we use to observe the night sky. Finding the moon, and potentially other rocky bodies within and outside of our solar system is one of these many attempts to fully take advantage of our tool's capabilities and finding the moon was a success. This was done by searching for particle cascades produced from incoming cosmic rays glancing slightly off of the surface of the moon, interacting with the lunar surface material and creating gamma-ray showers. These gamma rays are then observed and reduced to spectra that can be compared to predicted results and isolated from any background that would be present. Fig. 2 shows the spectra of the moon taken with Fermi[1].

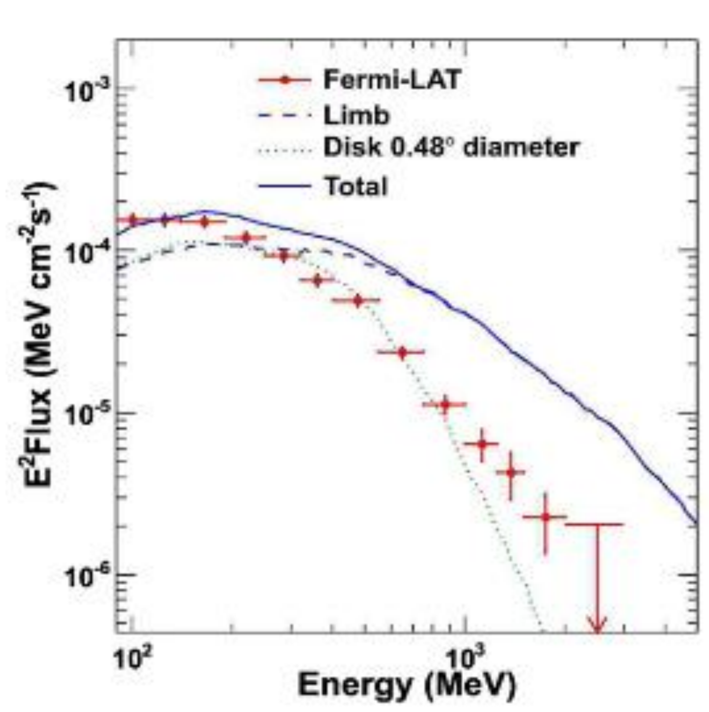

Figure 2[1]. The red circles are the 24 month observations made by Fermi LAT. Spectra of the Moon by the LAT is comprised of two components. The short dashed line and long dashed line show these components' spectra separated from each other. The blue solid line depicts a predicted total.

α Lyr's Debris Disk

In 1984 a cloud of debris was discovered to be surrounding α Lyr, also known as Vega, by the Infrared Astronomical Satellite (IRAS). Since then many reports have been written and published analyzing α Lyr and other stars in search of similar debris disks. Fig. 3 shows an infrared rendition of α Lyr's debris disk by David Wilner, Matt Holman and Marc Kuchner from the Harvard-Smithsonian Center for Astrophysics[2].

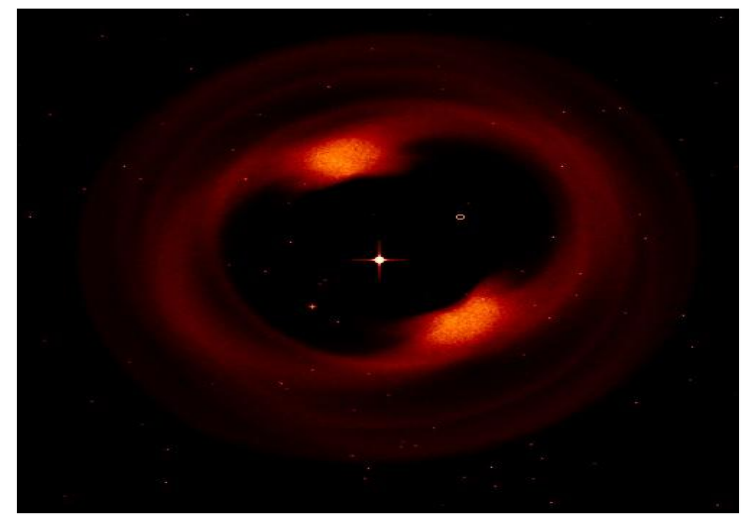

Figure 3. The center object is α Lyr and the red cloud surrounding it is the discovered debris disk.

Hoping to offer another tool to find and study these debris disks we use the principles of particle cascades used to find the moon and apply them to these disks. Looking at α Lyr we ran an Unbinned Analysis using the Fermi Science Tools Package v10r0p5. Below is a summarized procedure, in order, of running an unbinned analysis of a particular source.

Obtain Data --------------------------- The Fermi-LAT Data server can be queried by anyone wishing to analyze LAT data by simply inputting the RA and DEC of your source, the radius of interest (ROI), time interval of interest, and energy range of observed photons.

gtselect -------------------------------- First step in any analysis, gtselect cuts the data specifically as the user sees fit. The greatest use of which is to take the many event files downloaded from the LAT Data Server and, as a inputted list, cutting them into one filtered fits file.

gtmktime ---------------------------- The Fermi LAT team has included in their event files when good time intervals (GTI) occur. GTIs are periods where true observing was done when collecting photon data. Periods contrary to these would be during such moments as software updates or position recalibration wherein photons were observed but could potentially be contaminated by these particular events. gtmktime cuts the data removing the poor time intervals allowing for more accurate analysis.

gtltcube ------------------------------- Due to the LAT's method of photon detection, incoming gamma-ray collisions causing electron-positron pairs that are then analyzed to determine origin and energy of the detected gamma-ray, the angle of the source to the LAT's z-axis effects the intensity of the photons detected. Therefore, our analysis needs to know at specific times during live data collection what the sky position and inclination angle of the LAT was. This livetime cube is a three dimensional data cube containing that information.

gtexpmap ---------------------------- The exposure map created by this step is necessary to predict the number of photons contained and detected within the user set ROI for any diffuse components of our analysis.

make3FGLxml.py ------------------- This user contributed tool creates an input xml model that contains all sources from the 3FGL point source catalog from the Fermi LAT team at NASA that are within a certain number of degrees away from the ROI center. This model also allows the user to decide which sources parameters they would like to free when optimizing our likelihood data. The xml file also contains the isotropic diffuse model and galactic diffuse model used to filter the background from a source.

gtdiffrsp ------------------------------ The LAT data unbinned analysis is based on expected values and probability. The expected photon distribution is comprised of the source model expectations and the instrument response functions compensating for extreme angles of the source compared to the instruments z-axis. gtdiffrsp computes an integral of the diffuse models, isotropic and galactic, with the instrument response functions and adds the results to our event files in order to make our next computation faster.

gtlike ---------------------------------- gtlike is the core of the unbinned analysis. Taking in many of the previously created files from previously mentioned programs, gtlike creates a Test Statistic (TS) depending on the type of statistical distribution being used, determined by the program itself, and tries to maximize the TS depending on the parameters the user freed in their input xml file. gtlike uses a best fit model and then increases or decreases the freed parameters until the best possible values for each parameter has been found. These parameters include things such scale, index, and prefactor.

UpperLimits.py --------------------- In the case that you wish to put upper limit values on the amount of flux that could be found in a given area, this python script takes a likelihood object, also created in python similarly to gtlike and computes, based on TS values and the data from the event files, an upper limit for a given energy range at a given source.

Unbinned Analysis Results

After completing the previously described steps on the coordinates of α Lyr we present the following results. The primary result from our Likelihood analysis was the TS value we obtained from our unbinned analysis. We obtained a TS value of 0.875372. Typically a value of 25 or greater is necessary to claim a significant source exists at the coordinates.

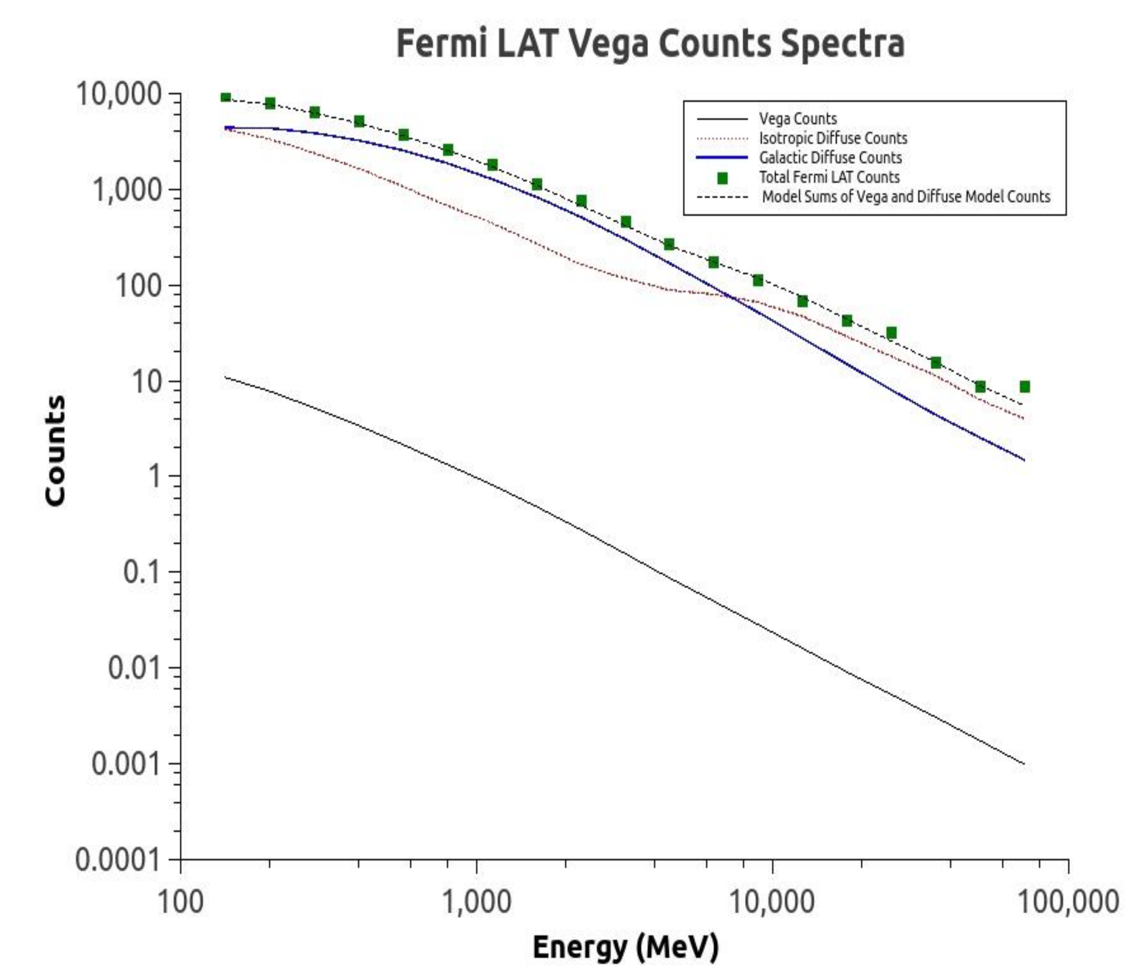

Figure 4. This plot compares the total photon counts that Fermi LAT took of the given region of our analysis with the individual counts of background sources and any spotted at Vega. The green dots represent the total photon counts, the blue solid line represents the counts attributed to the Galactic Diffuse background, the dotted red line represents the Isotropic Diffuse background counts, and lastly the solid black line represents the counts at Vega. The dashed black line is to confirm the counts detected by the LAT do indeed match the model sums of our sources.

Fig. 4 shows how most, if not almost all, the photon counts in our total observe counts from the LAT are contributed to the isotropic and galactic diffuse backgrounds. Very little, and sometimes no photons are contributed from Vega as a source.

Upper Limits

The idea of placing upper limits on the flux taken from a certain region helps us verify greater that we cannot see the debris disk surrounding α Lyr. By comparing the maximum flux as seen from our own moon to the maximum flux we can see from a particular region, if detectable, we can then put a limit on the amount of rocky bodies that have to be surrounding that source. However, in the case of Vega, simply not enough photons were detected to even reach a resulting upper limit for it's region. This finding, accompanied by our unbinned analysis results, allows us to come to these conclusions.

Conclusions

After completing a Unbinned Likelihood and Upper Limit analysis on α Lyr we can conclude that with 6 months worth of photon collection data that if a gamma ray source is present from particle cascades off of any rocky asteroid-like bodies surrounding Vega exists that it is too faint for the LAT to see. Within a 100 MeV to 100 GeV range we were unable to produce a sufficient TS value, 0.875372, at α Lyr's coordinates, suggesting that to Fermi, nothing is there. The insufficient photon counts within our search area prohibited an Upper Limit analysis on the entire range, along with several energy bins, to be carried out.

References

1 A. A. Abdo et al. "FERMI OBSERVATIONS OF γ-RAY EMISSION FROM THE MOON" 2012 ApJ 758:140

2 https://www.cfa.harvard.edu/COMPLETE/learn/debris_disks/debris.html, web, 2004

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