Probing the debris disks of nearby stars with the *Fermi* Gamma-ray Space Telescope

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Abstract

Many nearby stars are known to host circumstellar debris disks, similar to our Sun's asteroid and Kuiper belts, that are believed to be the birthplace of extrasolar planets. The asteroids in these debris disks emit gamma radiation resulting from interactions with cosmic rays from their host star, as previously observed from measurements of the gamma ray albedo of the Moon. We present the results of applying a point source analysis to four of these nearby debris disks using the past nearly-eight years of data taken by the *Fermi* Gamma-ray Space Telescope. Through this analysis, we obtain upper limits on the gamma ray flux from these debris disks that provide constraints on the physical parameters of the disk.

Introduction

Debris disks – disks of planetesimals and dust – are known to encircle a sizeable fraction of main-sequence stars. The dust in these disks, formed by collisions between larger asteroids, re-emits light from its star that has been observed directly in the infrared, most recently with the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile. Additionally, interactions between cosmic rays and rock within the asteroids produce gamma rays, an effect that has been measured and modeled for the Moon. We present complementary results to recent infrared studies that use high-energy gamma observations from NASA's *Fermi* Gamma-ray Space Telescope. From these results we are able to obtain upper limits on the source flux that constrain the size of the asteroids in our simplified model.

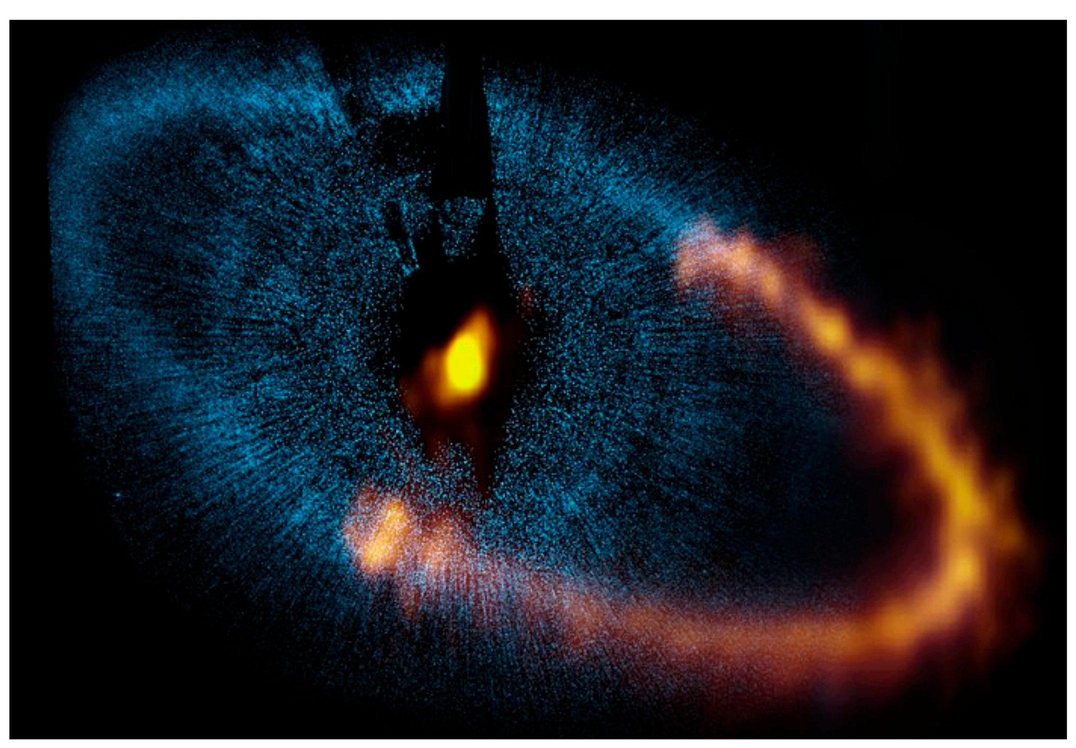

Figure 1. Debris disk around Fomalhaut. The superimposed blue image is a previous picture from the HST. Credit: ALMA (ESO/NAOJ/NRAO). Visible light image: the NASA/ESA Hubble Space Telescope.

Data Analysis

For each of four known nearby debris disks, we obtained the newest *Fermi*-LAT Pass-8 data that includes improved event reconstruction, a wider energy range, better energy measurements, and a significantly increased effective area. Our data spanned the past seven years and eleven months with a radius of 30° around the candidate source. The resulting counts maps for each source are presented in Figure 2.

Once this data was obtained, we applied the recommended quality cuts and additional time and spatial cuts based on the type of analysis – binning events by energy vs. treating each event individually. Our input source model included all sources within 10° outside of the region of interest (due to the high point-spread function of the instrument) from Fermi's primary 3FGL source catalog of over 3000 verified sources. From there, we used the Fermi Analysis Tools' likelihood maximizing function to fit freed parameters (freeing only the diffuse backgrounds or additionally freeing sources within 5° of center) in the source model and remove sources that were not well supported by our data.

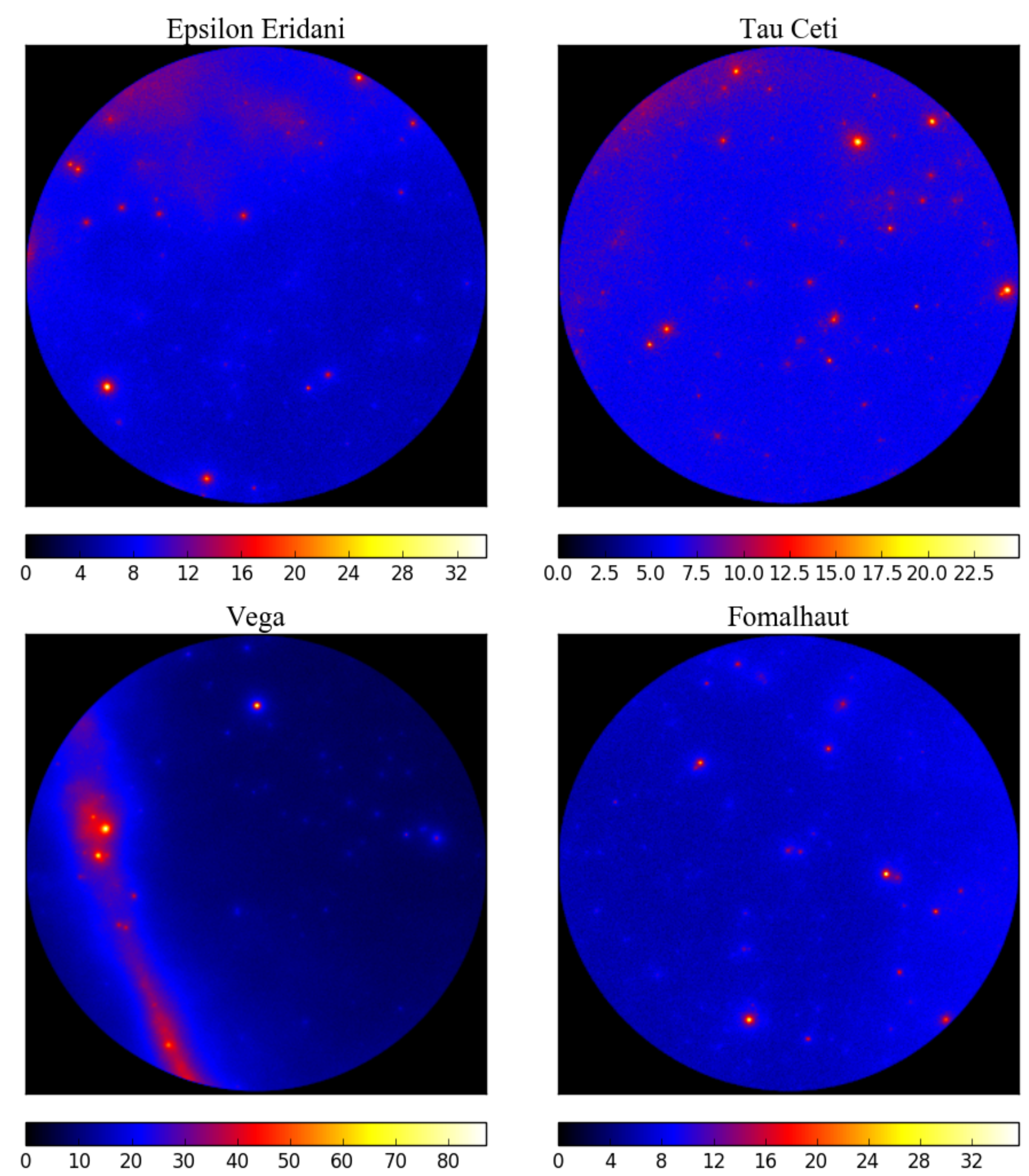

Figure 2. Counts map for each region of interest. Images are on a square-root scale.

Results

Table 1 summarizes the results from the point source analysis in each region. The fitting procedure returns a test statistic (TS) that is indicative of how much support a model source has from the data, and is approximately equal to the square of the detection significance for that source. Each of our sources has a TS below the threshold value of 25, so rather than claim to have detected the gamma signature from these debris disks we instead provide reasonable upper limits on the emitted flux.

		Unbinned Analysis		Binned Analysis	
Source	Model	TS	Upper limit	TS	Upper limit
Epsilon Eridani	BKGD	2.26	1.83×10^{-8}	16.9	8.42×10^{-9}
	5DEG	2.23	1.73×10^{-8}	11.9	7.54×10^{-9}
Tau Ceti	BKGD	-0.04	2.75×10^{-9}	-0.31	4.74×10^{-10}
	5DEG	-0.02	4.70×10^{-9}	-0.07	1.28×10^{-9}
Vega	BKGD	-0.03	3.81×10^{-9}	0.02	2.78×10^{-9}
	5DEG	-0.01	1.00×10^{-8}	11.3	9.45×10^{-9}
Fomalhaut	BKGD	50.1	4.87×10^{-8}	-0.51	3.11×10^{-10}
	5DEG	2.18	1.71×10^{-8}	-0.04	1.99×10^{-9}

Table 1. Summary of point source analyses. Upper limits are given in [ph cm^{-2} s^{-1}].

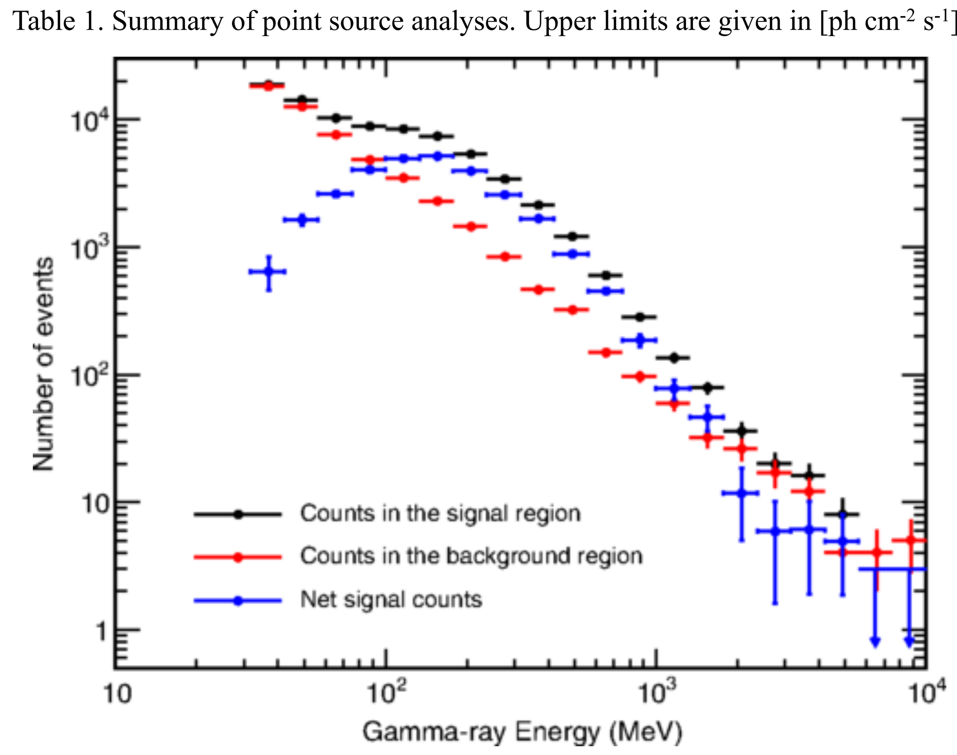

Figure 3. Measurement of the gamma ray spectrum of the Moon from Ackermann et al. (2016).

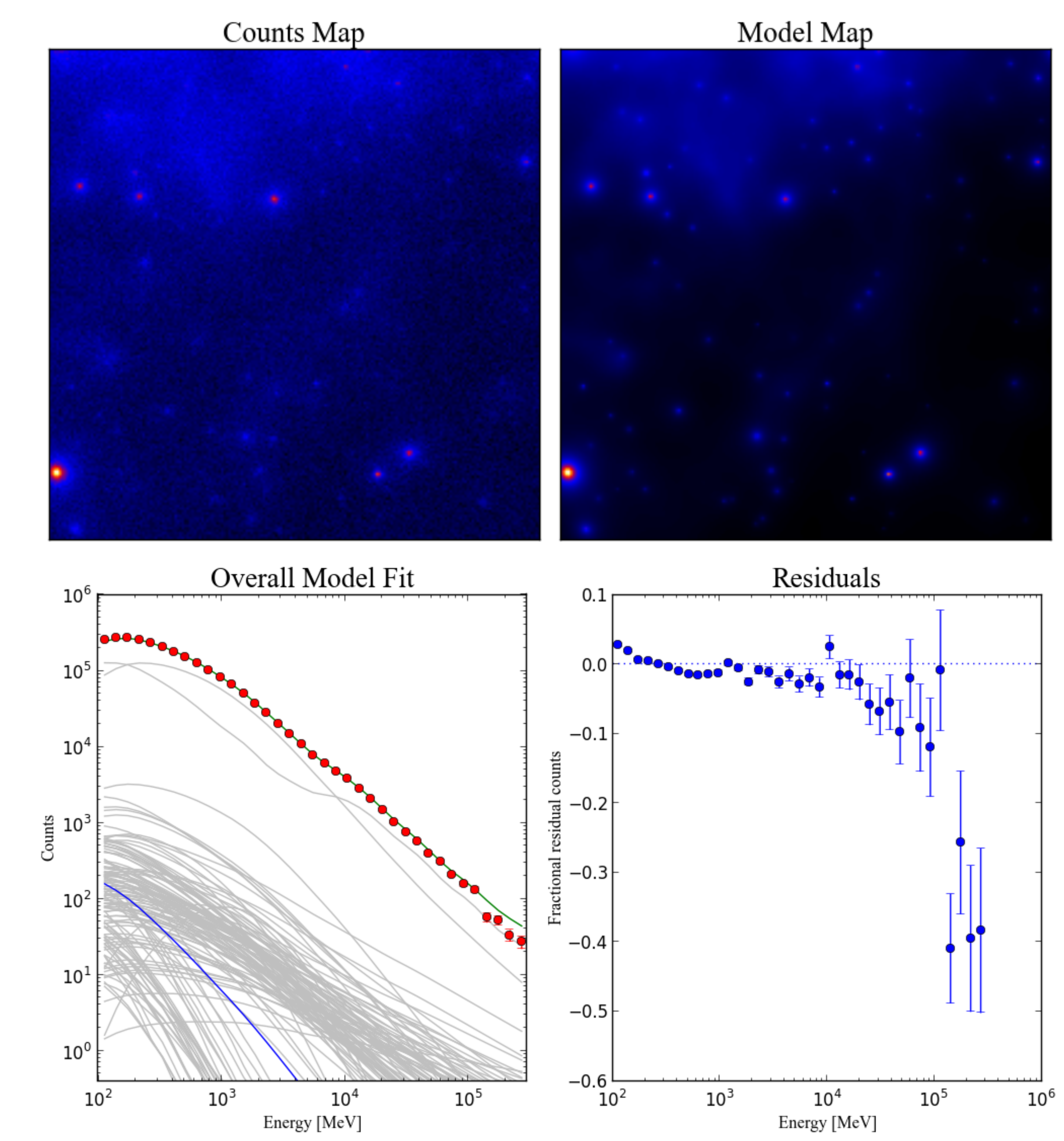

Figure 4. Example fitting for Epsilon Eridani.

Modeling the System

As a basic model of the debris disk, imagine the disk of a certain mass (ranging from 1–10 solar masses) that is constructed of uniform density spheres of the same radius. Each of these asteroids has an emission spectrum similar to that of the Moon (Fig. 3) and scaled to the size of the asteroid. The upper limits obtained from the point source analyses then correspond to lower limits on the radius of these bodies.

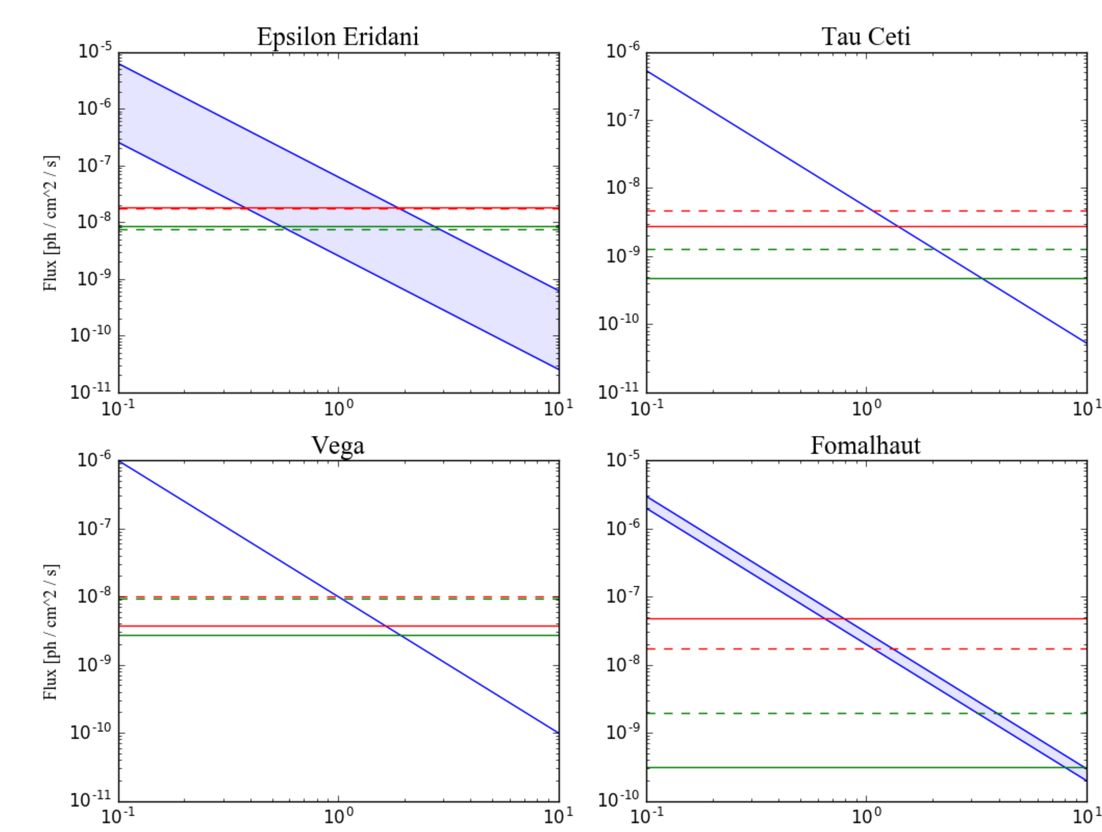

Figure 5. Theoretical fluxes for a given asteroid body radius, along with the upper limits obtained by Table 1. The intersections give the lower limits on the radius. Red vs. green indicates unbinned vs. binned, while solid vs. dashed indicates BKGD vs. 5DEG models.

Conclusions

We have presented the results of applying a point source analysis to the past eight years of *Fermi*-LAT improved Pass 8 data for four nearby stars that are known to host circumstellar debris disks. Though we cannot report detection of these disks with statistical certainty, we do provide reasonable upper limits on the gamma ray flux from these debris disks. From there, we apply a simple model to obtain lower limits on the radius of the asteroids in these debris disks. These lower limits can now be used in future models and simulations to understand the processes that lead to dust formation and possible planets formed in these stellar systems.

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References

Ackermann et al. (2016). *Phys. Rev. D, 93*, 082001.