Constraints on Sterile Neutrino Dark Matter Candidate Mass by the *Fermi* Gamma-ray Burst Monitor

Rob Preece
The University of Alabama in Huntsville
Space Science Department

in collaboration with

Jennifer Gaskins
GRAPPA, University of Amsterdam

Shunsaku Horiuchi
(Virginia Tech)
Miles Smith
(Penn State)
Kenny Chun Yu Ng
(Ohio State University)
The Gamma-ray Burst Monitor (GBM)

- 12 sodium iodide (NaI) detectors (8 - 1000 keV, in 128 energy bins)
- 2 bismuth germanate (BGO) detectors (150 keV - 40 MeV)
- GBM observes the entire unocculted sky
- Versatile:
  - GRBs
  - Low energy Galactic sources
  - Pulsar timing
  - TGFs
- Why not Dark Matter?
Indirect searches for sterile neutrinos

- Sterile neutrinos can radiatively decay to active neutrinos, producing a photon line signal at half the sterile neutrino mass.
- X-ray telescopes can search for spectral lines from keV neutrinos.
- (Model-dependent) constraints also obtained from Lyman alpha measurements (probing clustering in the early universe) and the dark matter abundance.
- A window of parameter space remains...

Abazajian, Fuller, & Tucker 2001
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\[
\sin^2(2\theta) = \begin{cases} 
10^{-12} & \text{for } m_s > 10^2 \text{ keV} \\
10^{-11} & \text{for } m_s < 10^2 \text{ keV} 
\end{cases}
\]

The Gamma-ray Burst Monitor (GBM)

detectors 0 and 6 point within ~ 20 deg of LAT pointing direction, but the spacecraft blocks part of their field of view.

we use detector 7 which has good sky coverage (points near LAT pointing direction) but minimal problems with spacecraft blockage.
• effective area defines the relevant FOV

• at low energies, effective area is close to 0 at incidence angles $\gtrapprox 90$ deg (note that effective area is non-negligible over half the sky!)

• effective area increases rapidly up to $\sim 30$ keV
Dark matter decay signal

"FOV" of a GBM detector

angle from GC
Arrival direction analysis tools for GBM

- not possible to correctly calculate a flux within a limited region-of-interest (ROI) due to lack of individual photon tracking and extremely broad “FOV” of GBM detectors

- we created a suite of tools for directional analysis of GBM data, including:
  - a tool to calculate the count rate in a specified NaI detector as a function of Galactic pointing direction based on actual pointing and livetime history of Fermi; uses public Fermi data files (GBM CSPEC files and LAT FT2 files)
  - a tool to simulate NaI counts data from an input source model; accounts for NaI effective area as a function of inclination angle and photon energy
  - the count rate in a specified NaI detector as a function of Galactic pointing direction can be predicted for a theoretical model
The X-ray sky as seen by ROSAT

c) 1.5 keV (R67)

Image Credit: Snowden et al. 1997
The X-ray sky as seen by GBM

GBM count rate in detector pointing direction
(10 keV < E < 11 keV, NaI detector 7, Galactic coordinates)

NB: not a flux map

(excluding data time intervals with GRBs, transients, SAA, and after magnetic latitude cut)
The X-ray sky as seen by GBM

10-11 keV

16-17 keV

40-42 keV

at higher energies, instrumental backgrounds dominate over astrophysical signals
Simulated DM decay signal

GBM count rate in detector pointing direction
(NaI detector 7, Galactic coordinates)

**NB:** not a flux map

(excluding data time intervals with GRBs, transients, SAA, and after magnetic latitude cut)
Flux analysis

- require that the dark matter signal doesn’t exceed the total measured count rate in the energy bin of the line, in the selected ROI
- most robust / conservative limits
- note that we have several background lines! (some of which we know the origin!)

Count rate spectrum

ROI = 60 deg around GC

\[ E^2 \frac{dN}{dE dt} \text{ [keV s}^{-1}] \]

20 keV line
Spectral analysis

- choose a window around each line energy (larger than observed line signal width)
- model spectrum as line signal (at fixed energy) + power law
- model parameters are the signal and background normalizations and the power-law index
New constraints from GBM analysis

\[ \sin^2(2\theta) \]

\[ m_s [\text{keV}] \]

- CXB(HEAO-1)
- MW (INTEGRAL)
- Flux analysis
- Spectral analysis
- \( \Omega_s < \Omega_{DM} \)
Summary

- tools to use angular information in GBM data have been developed and applied in the context of a search for lines from sterile neutrino dark matter
- constraints from GBM data exclude new regions of sterile neutrino dark matter parameter space
Data selection for dark matter line search

- used data from NaI detector 0 (~20 deg offset from LAT pointing direction, minimal Earth limb contamination)

- selected good time intervals (GTIs):
  - exclude any orbits which pass through SAA (activation effects lead to heightened backgrounds for some time after Fermi has exited the SAA)
  - select times when LAT is in normal survey mode and LAT rocking angle < 52 deg
  - remove times when GRBs and transients are detected by GBM
  - pre-cut livetime ~$10^8$ sec (~3 years), total livetime in GTIs = $2.85 \times 10^7$ sec

- chose pointing directions within 30 deg of the Galactic Center
  - livetime in ROI = $1.7 \times 10^6$ sec
  - average counts in ROI in a single energy bin = $4 \times 10^7$ counts
The Fermi Gamma-ray Space Telescope

Credit: NASA/General Dynamics
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Bulk counting analysis limits

$\sin^2(2\theta)$ vs $m_s$ [keV]

- INTEGRAL
- MW (HEAO-1)
- Ursa Minor
- Bulk analysis

$\Omega_s < \Omega_{DM}$

Ly-α

PRELIMINARY

30 deg ROI