Constraints on Sterile Neutrino Dark Matter from the Fermi Gamma-ray Burst Monitor

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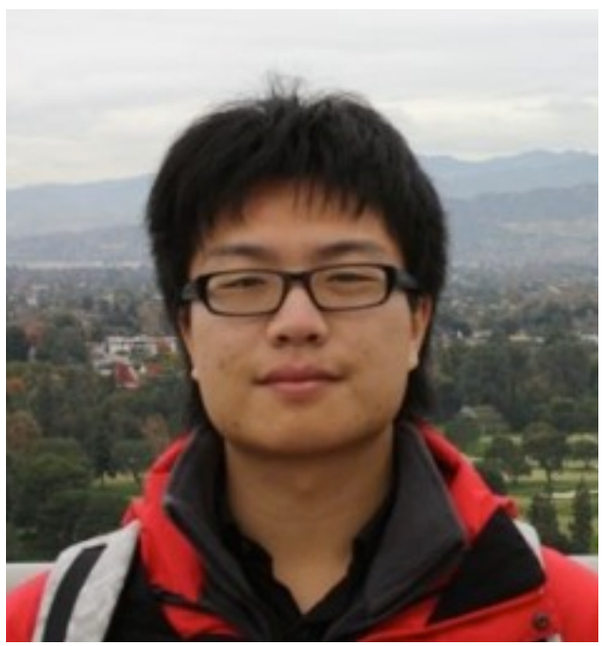

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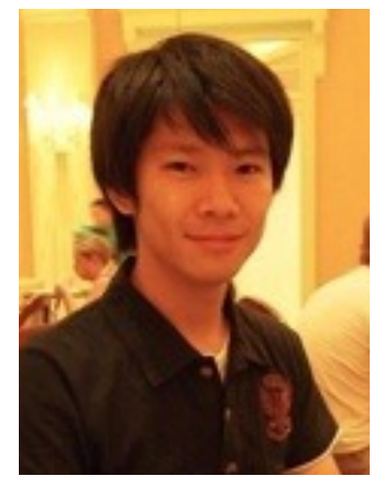

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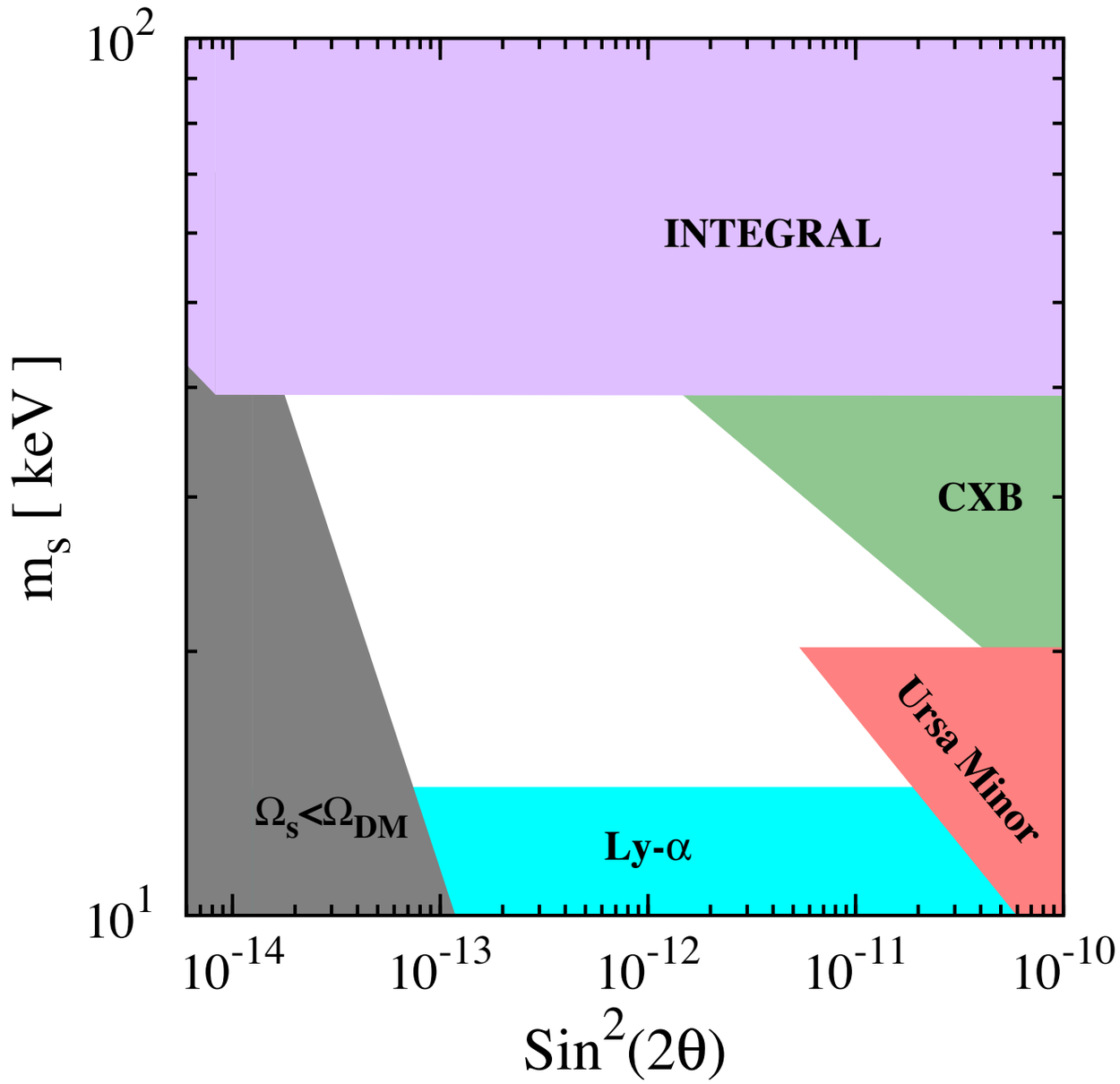
Indirect searches for sterile neutrinos

- 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
- constraints also obtained from Lyman alpha measurements (probing clustering in the early universe) and the dark matter abundance
- a window of parameter space remains...



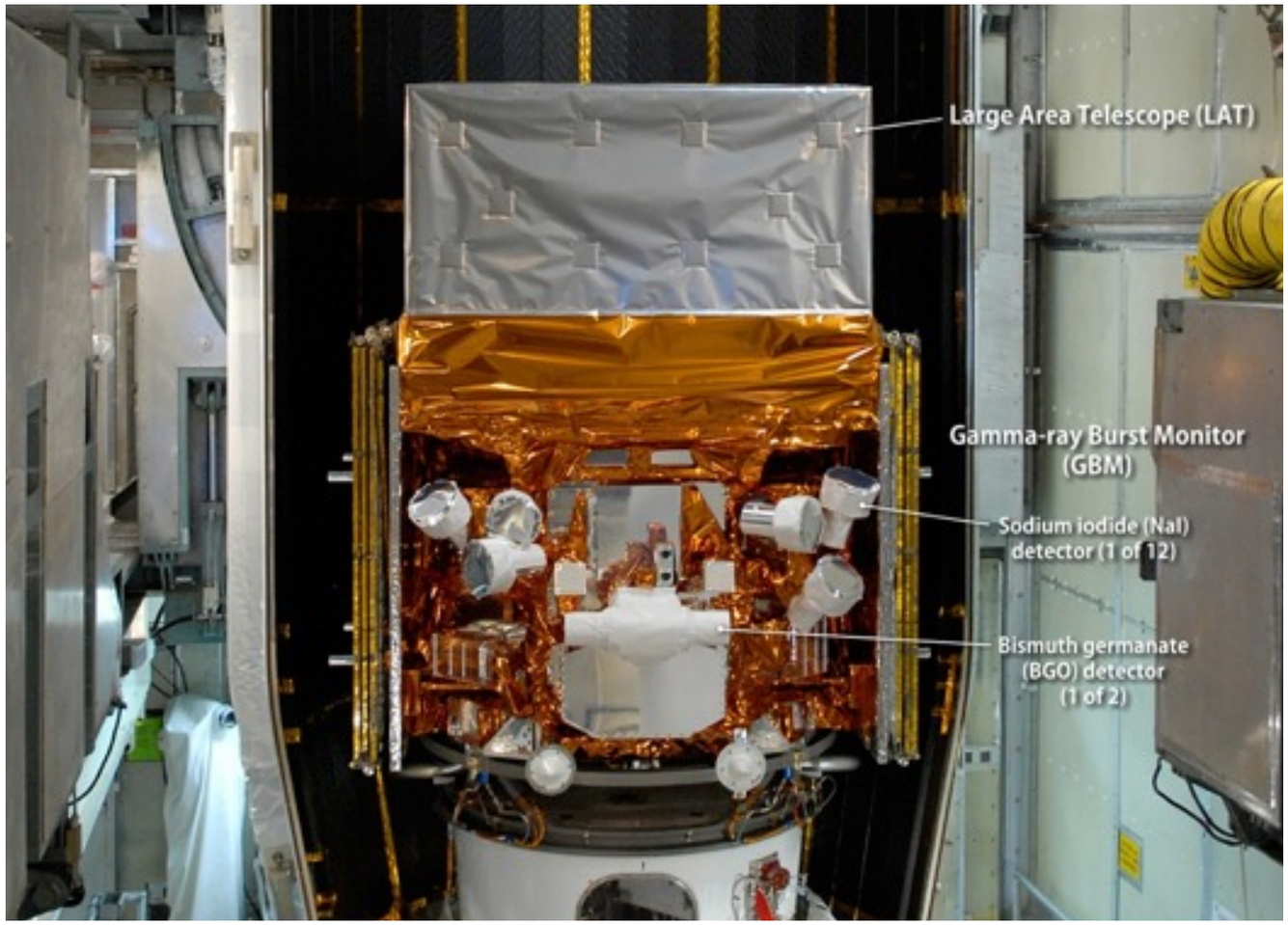
DM abundance: Boyarsky et al. 2009; Lyman alpha: Seljak et al. 2006; INTEGRAL X-ray: Yuksel et al. 2008; CXB: Boyarsky et al. 2006; Ursa Minor X-ray: Loewenstein et al. 2009

The Fermi Gamma-ray Space Telescope

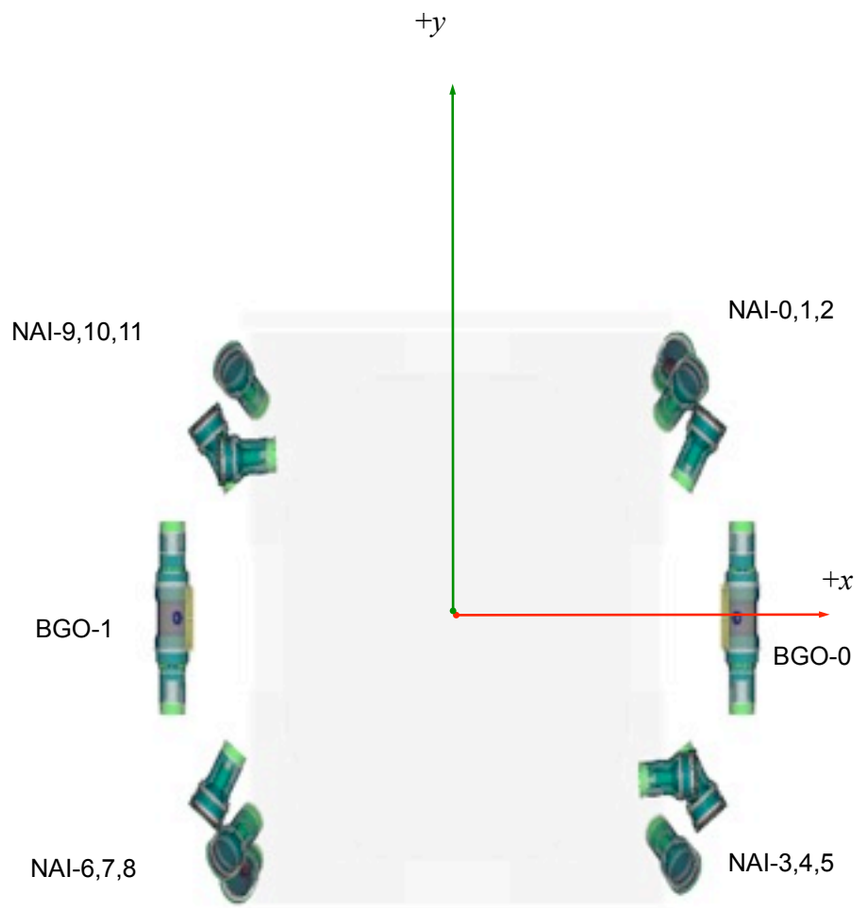
Credit: NASA/General Dynamics

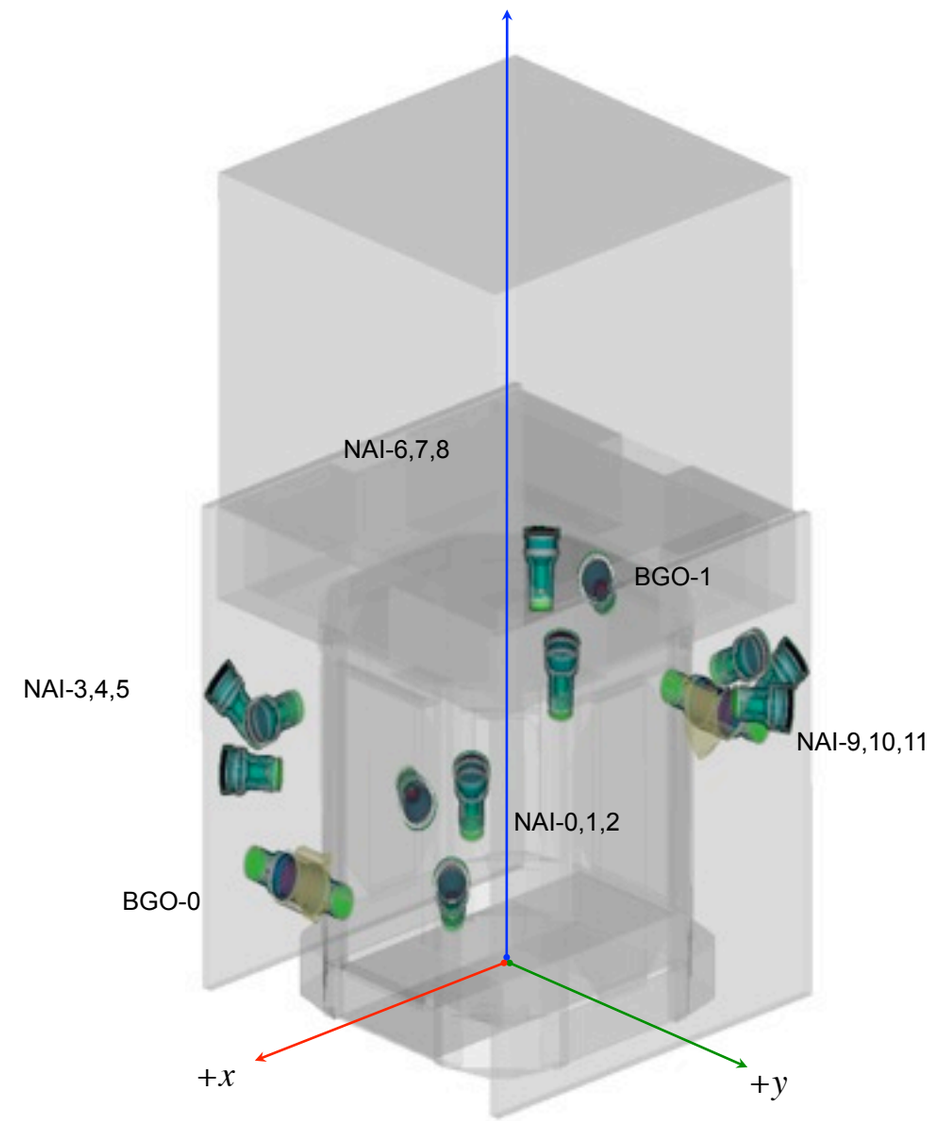
The Gamma-ray Burst Monitor (GBM)

- 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



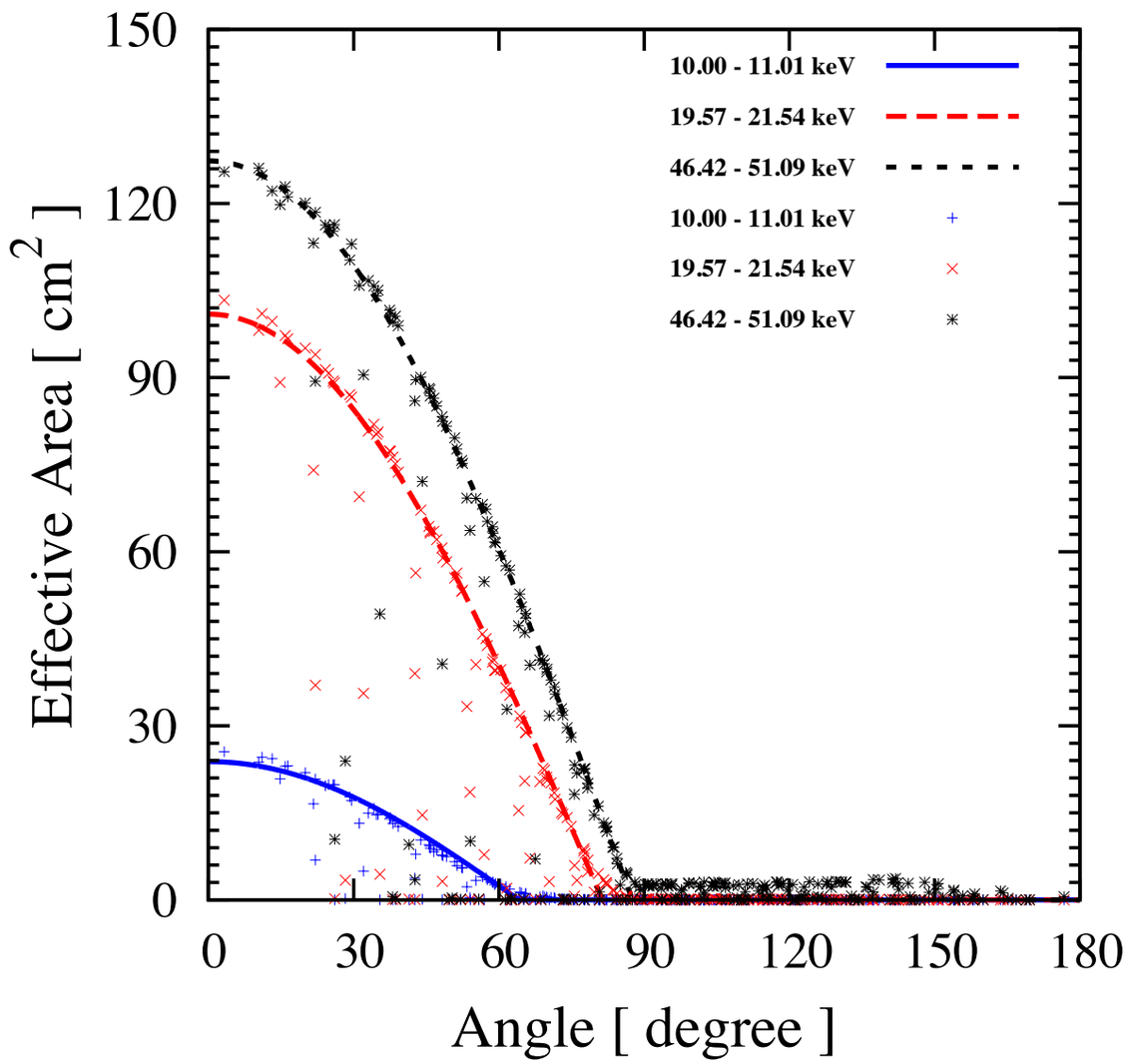
The Gamma-ray Burst Monitor (GBM)

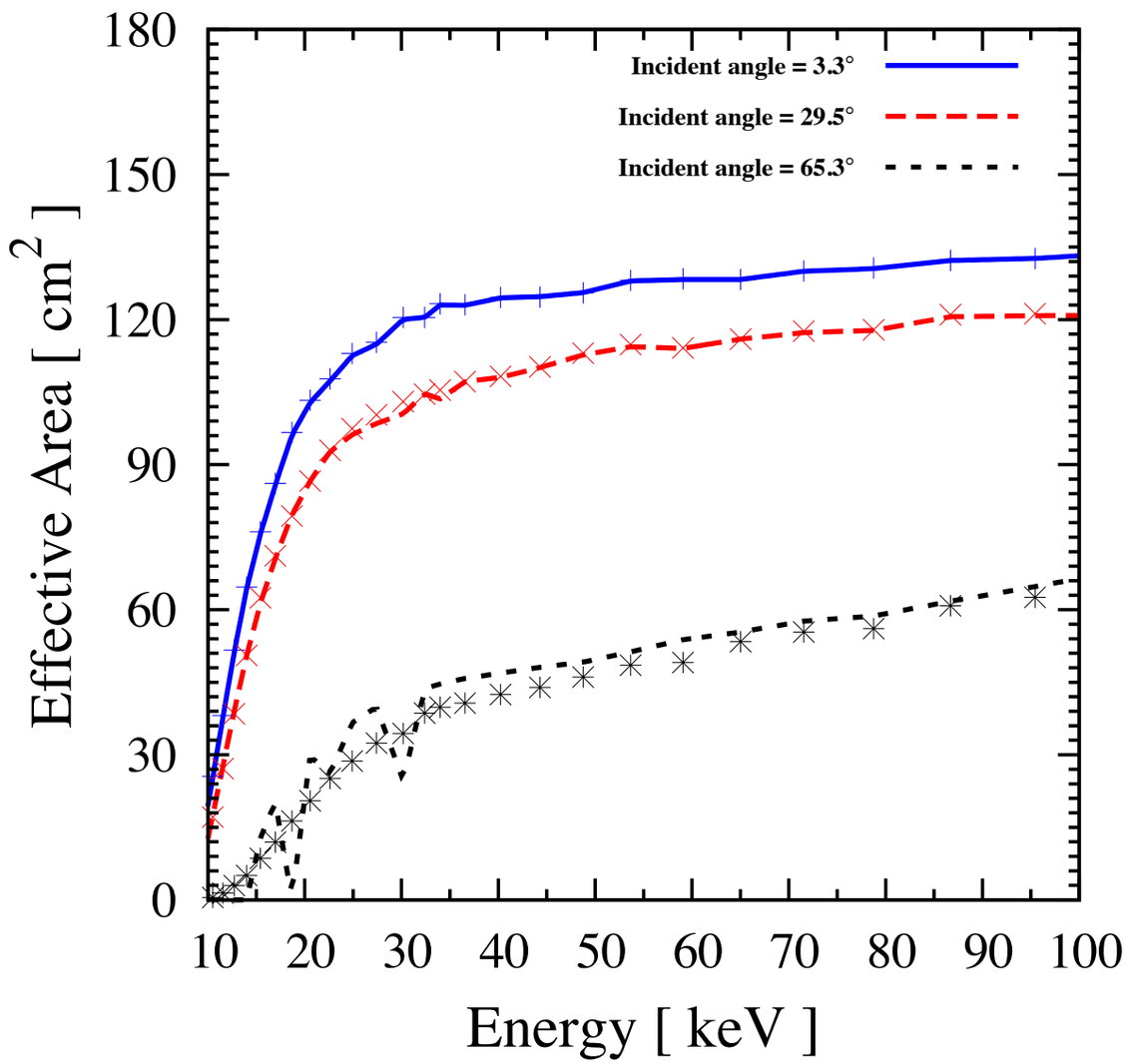




detectors 0 and 6 point within ~ 20 deg of LAT pointing direction

NaI detector effective area





- effective area defines the relevant FOV
- at low energies, effective area is close to 0 at incidence angles ≳ 90 deg (note that effective area is non-negligible over half the sky!)
- at higher energies (not shown), effective area is not quite zero at angles > 90 deg
- effective area increases rapidly up to ~30 keV

Why GBM?

- difficult to use spatial information to understand and/ or exclude sources of background...
- but not impossible
- data covers the whole sky, and lots already available
- VERY LARGE STATISTICS!

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

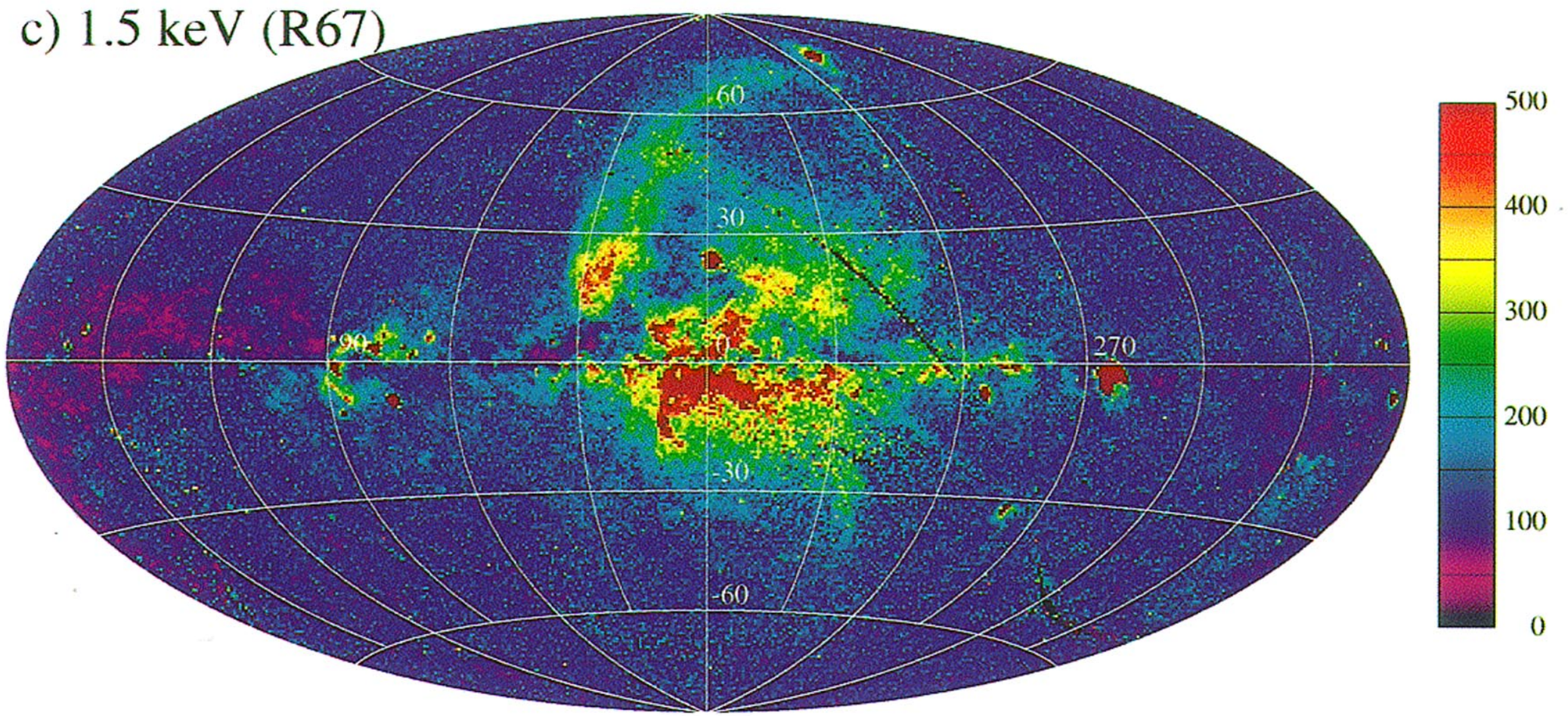
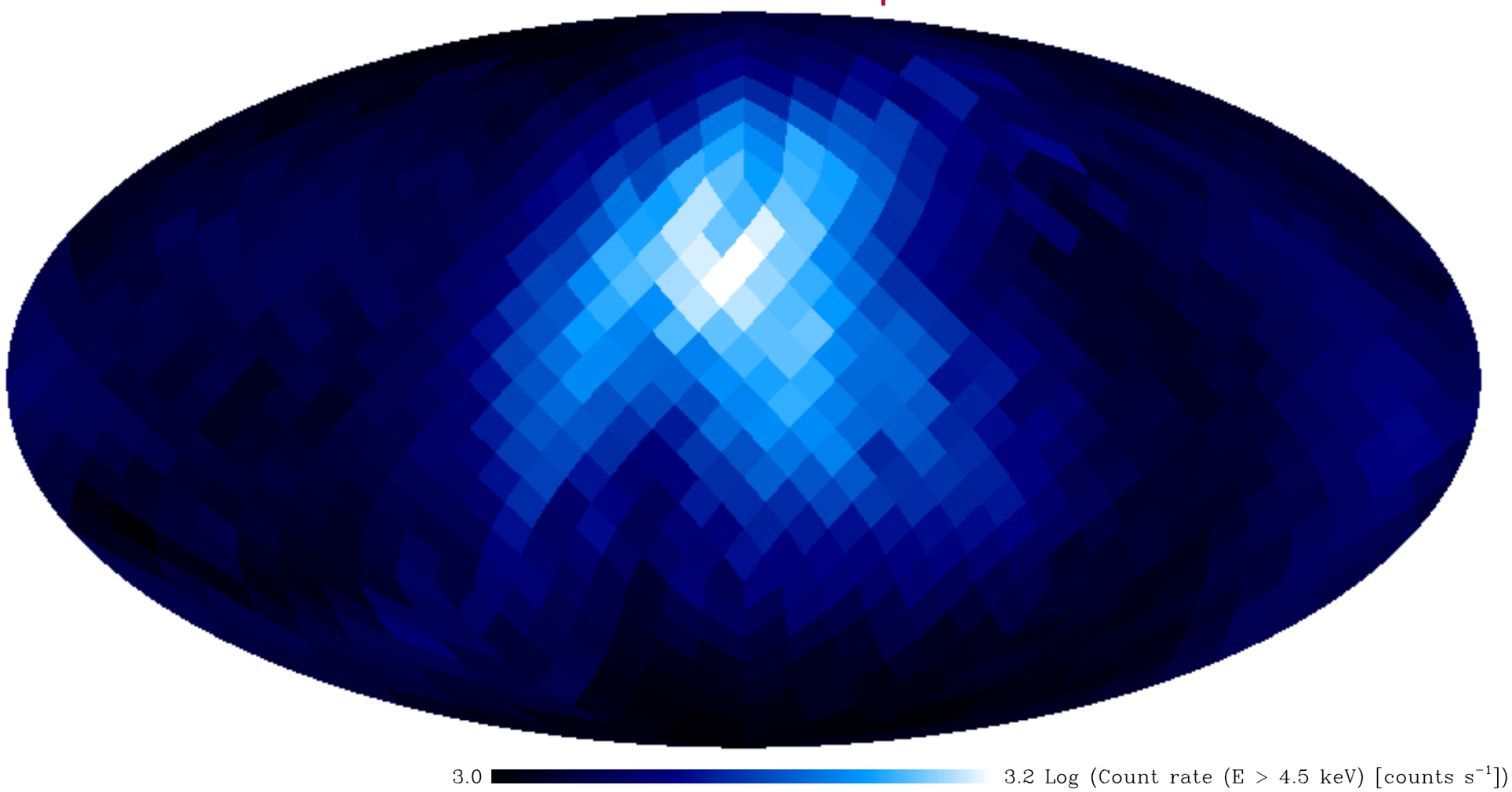


Image Credit: Snowden et al. 1997

The X-ray sky as seen by GBM

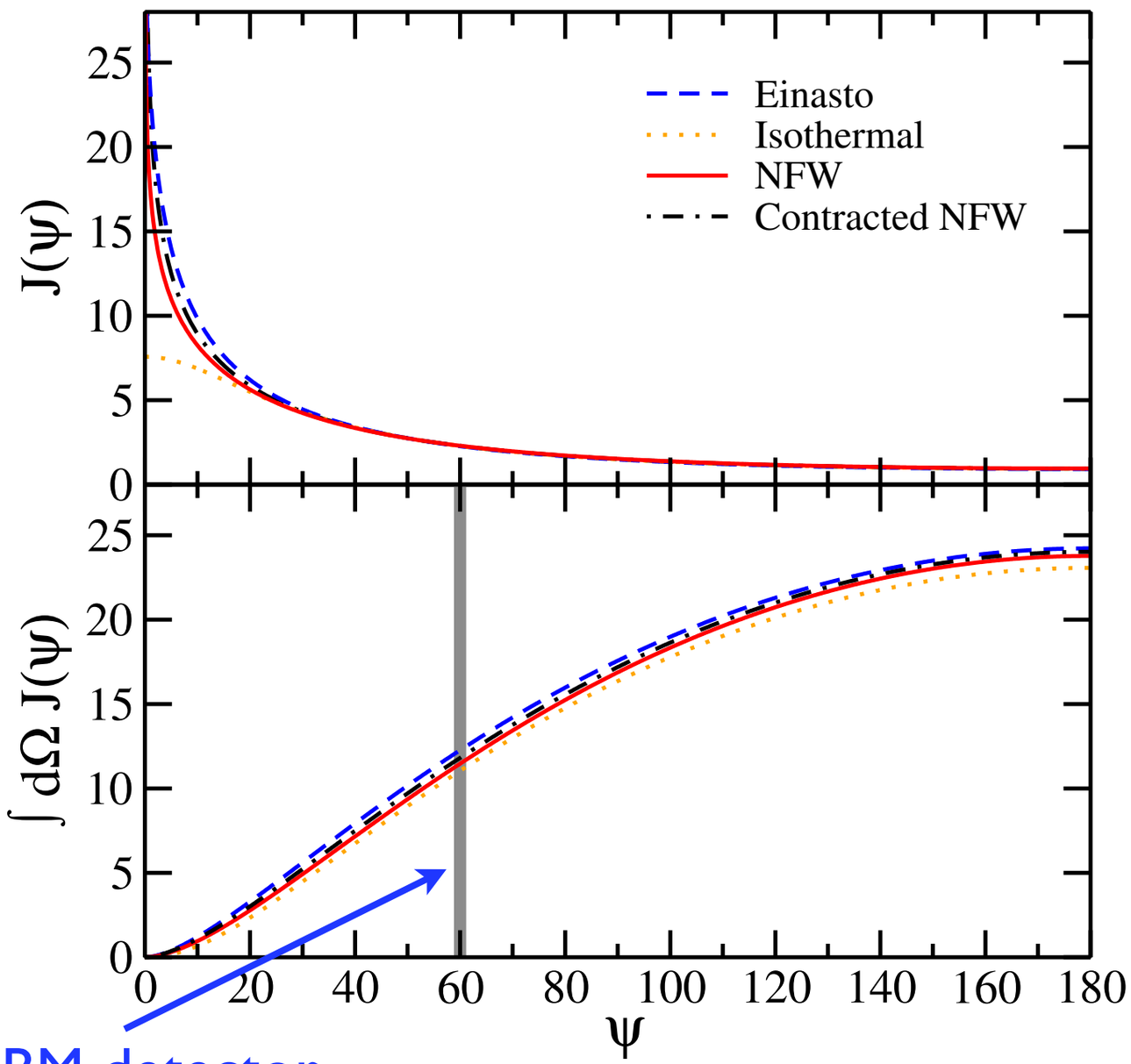
GBM count rate in detector pointing direction
(E > 4.5 keV, NaI detector 0, Galactic coordinates)

NB: not a flux map



(excluding data time intervals with GRBs, transients, SAA)

Dark matter decay signal



"FOV" of a GBM detector

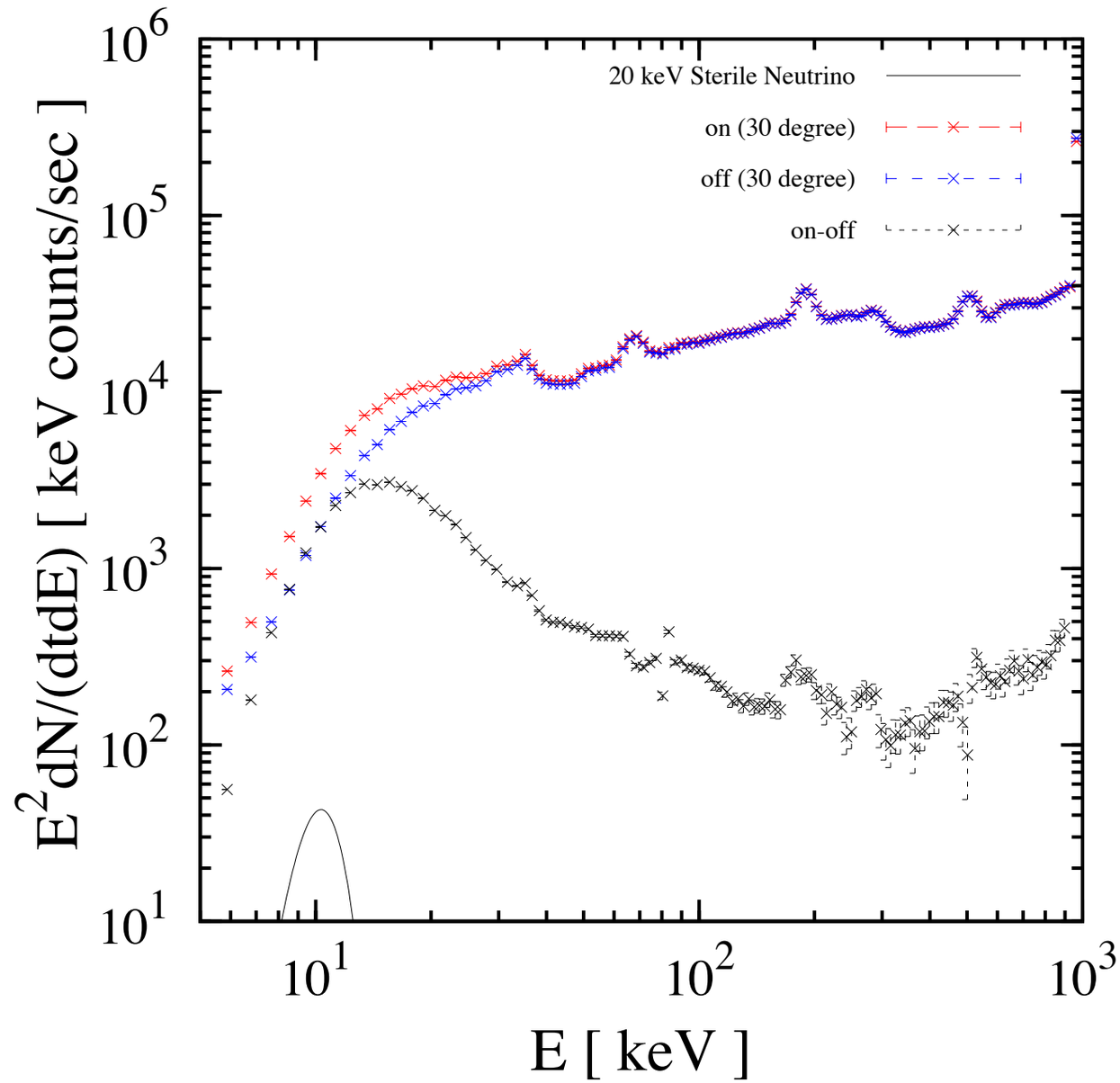
angle from GC

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 = 2.85×10^7 sec
- chose pointing directions within 30 deg of the Galactic Center
  - livetime in ROI = 1.7×10^6 sec
  - average counts in ROI in a single energy bin = 4×10^7 counts

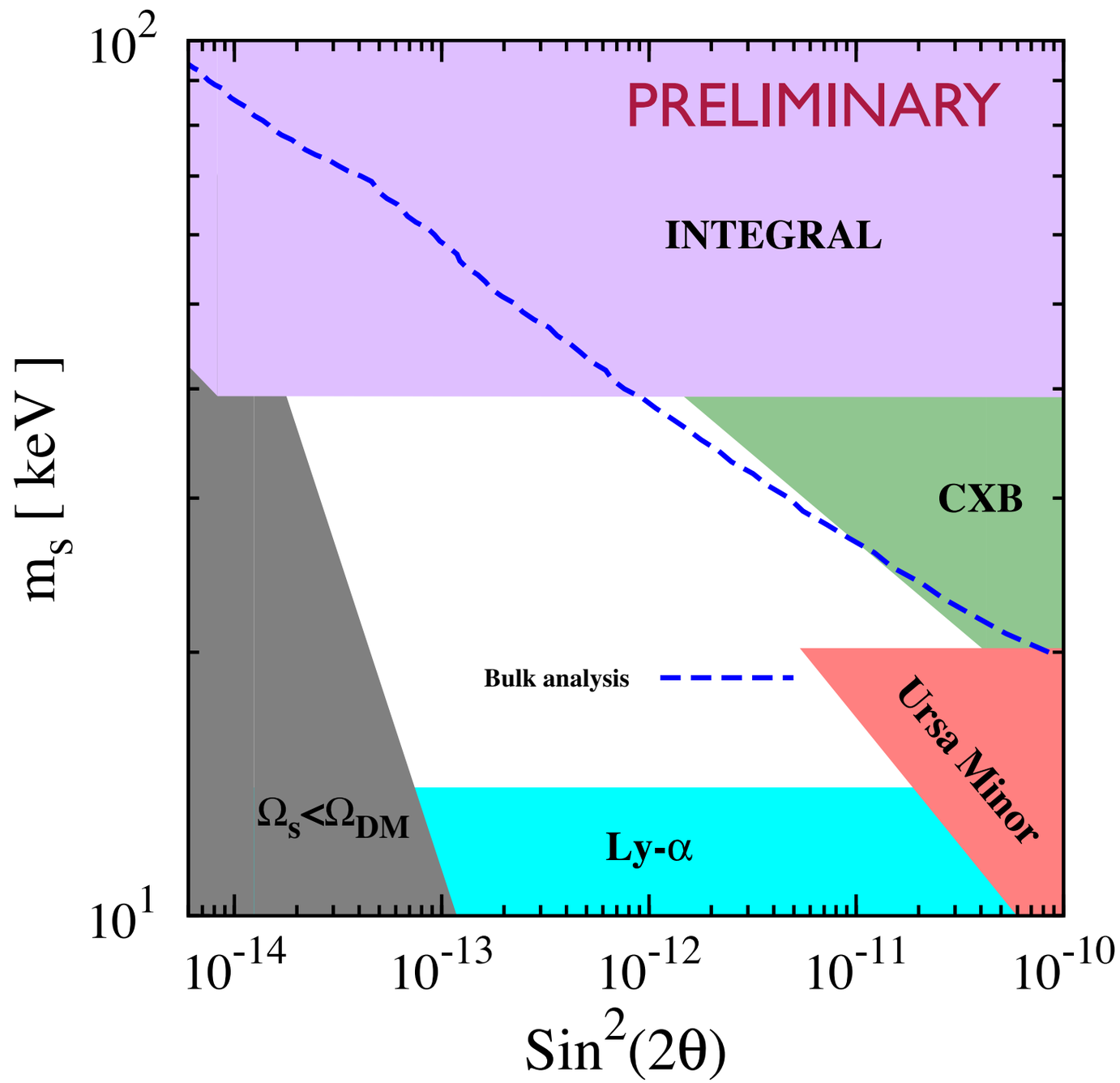
Bulk counting analysis

- 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



Bulk counting analysis limits

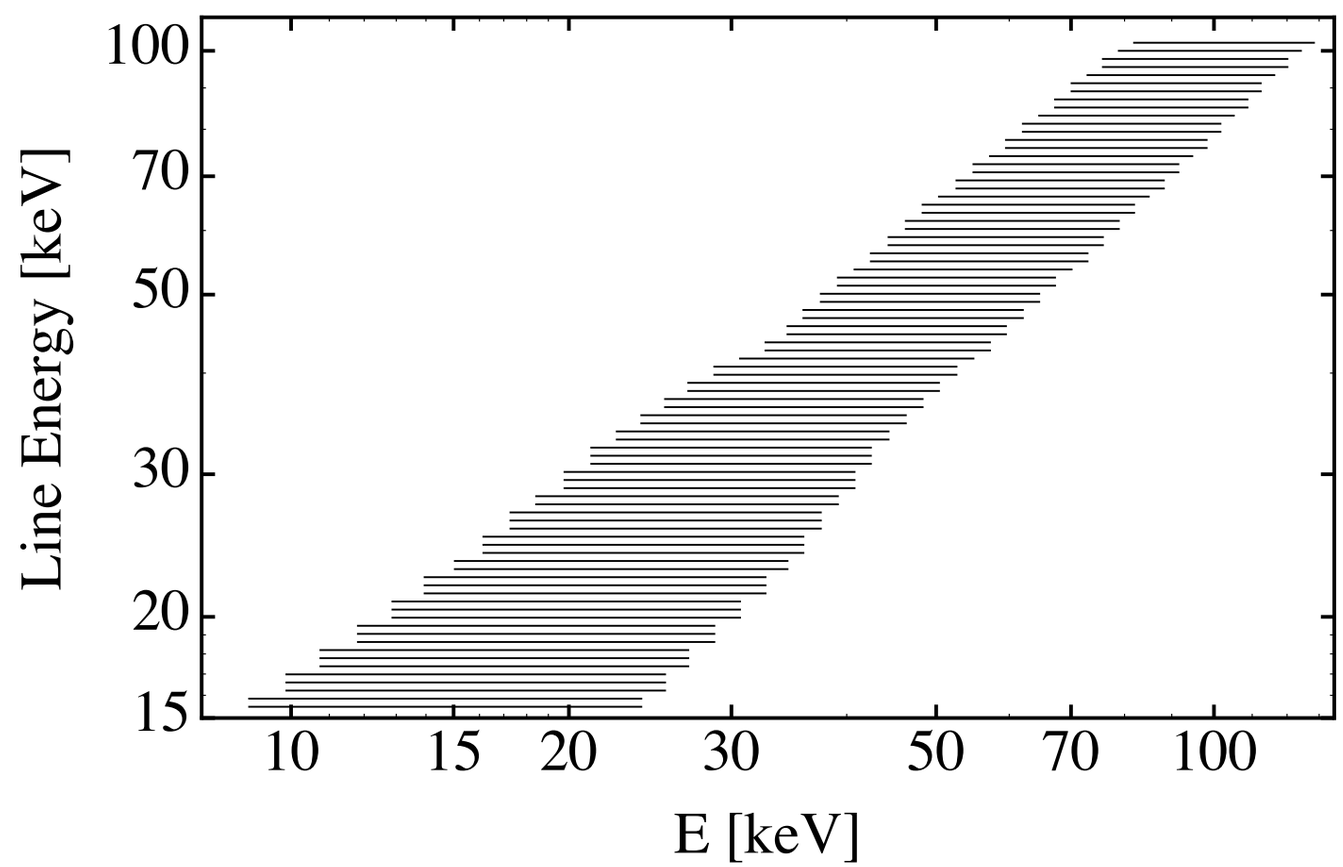
"on" region



Spectral analysis

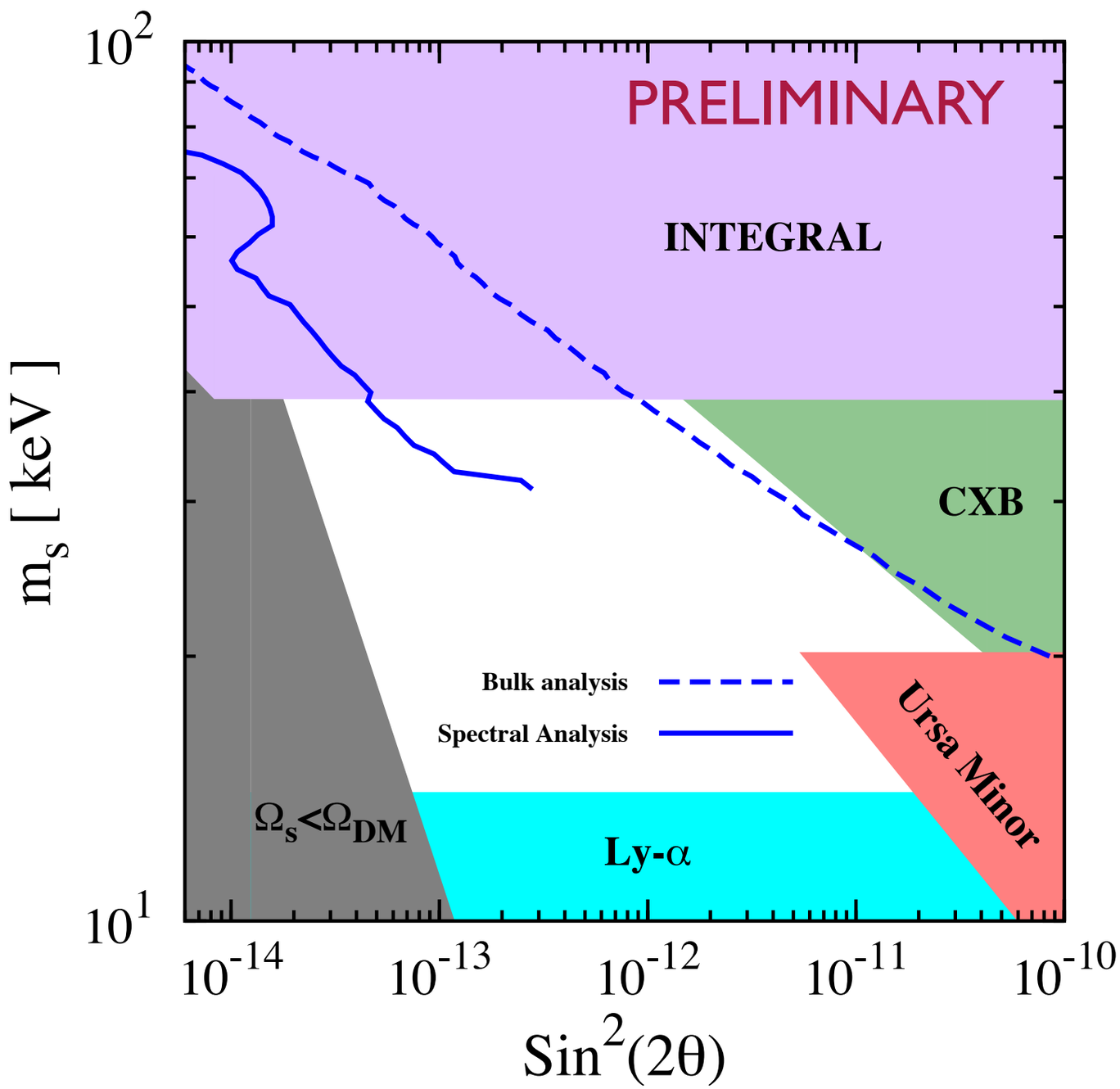
- model spectrum as line signal (at fixed energy) + power law
- model parameters are the signal and background normalizations and the power-law index
- choose a window around each line energy (larger than observed line signal width)
- approximate GBM energy response as a Gaussian

Energy windows



window = ± 6 energy bins around bin of line energy

Spectral analysis limits



Summary

- GBM data covers an interesting energy range for sterile neutrino dark matter line searches; large statistics make this data set competitive
- 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
    - more sophisticated techniques for obtaining angular information (e.g., occultation studies) may be possible and could enable more sensitive searches
- preliminary constraints exclude new regions of sterile neutrino dark matter parameter space
    - working on extending search to lower energies and incorporating other search methods to more effectively handle backgrounds (e.g., on-off region subtraction)
    - morphology-based approach using all-sky angular information under development