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Improved limits on sterile neutrino dark matter from full-sky observations by the Fermi-GBM

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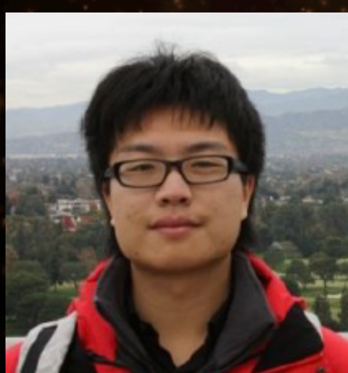
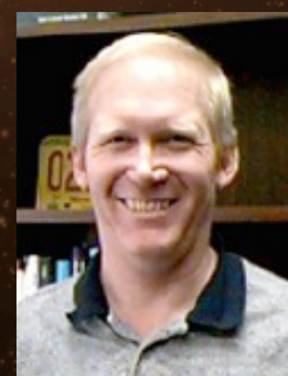




Kenny Ng (Ohio State)

Jennifer Siegal-Gaskins (GRAPPA)

Rob Preece (Alabama)

Miles Smith (JPL)

Sterile neutrino dark matter

Particle motivations:

Sterile neutrino (ν_s) arises in many explanations of non-zero neutrino mass

ν_s are not completely "sterile" : they mix with active neutrinos

→ They can be generated in the early Universe

→ They are stable, and can be DM

Dodelson & Widrow (1994)
Shi & Fuller (1999)

Note: ν_s DM may be HOT, WARM, or COLD depending on how they are generated.

Astrophysical hints:

CDM has constantly been challenged by observation on sub-Galactic scales

- Density profile
- Missing Satellites
- Too-big-to-fail

Klypin et al (1999)
Moore et al (1999)
Boylan-Kolchin et al (2011)

One possible solution to these issues is a departure from the CDM paradigm, e.g., sterile neutrino warm DM.

Lovell et al (2012), Anderhalden et al (2012), Schneider et al (2013)

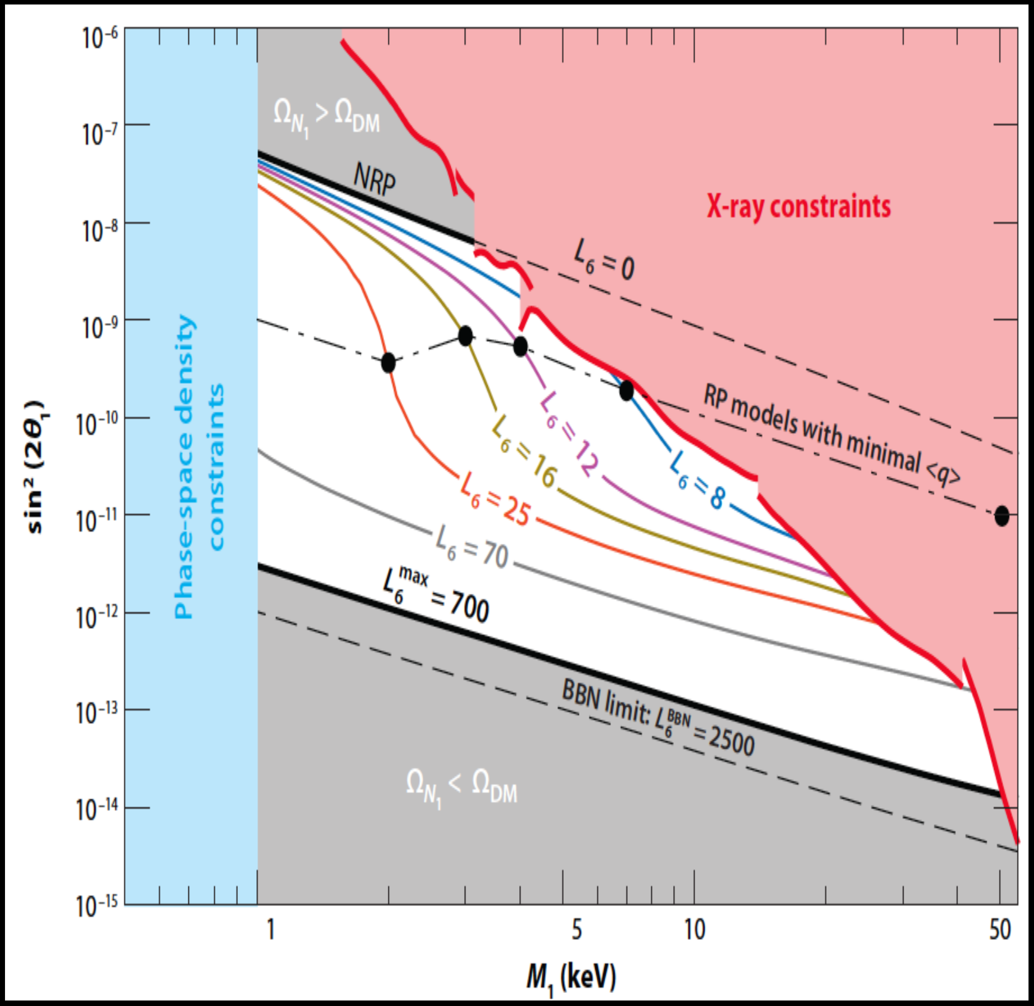
Sterile neutrino DM searches

X-ray: ν_s radiatively decay to active neutrinos + photon, producing a X-ray line signal

Phase-space density: ν_s cannot be confined to arbitrary high densities

BBN: too much lepton asymmetry disrupts ^{4}He abundance

Small-scale structure: ν_s suppress power on small scales, affecting e.g., Lyman-a power, satellite counts, etc…



Review papers: Boyarsky et al (2009)
Kusenko (2009)

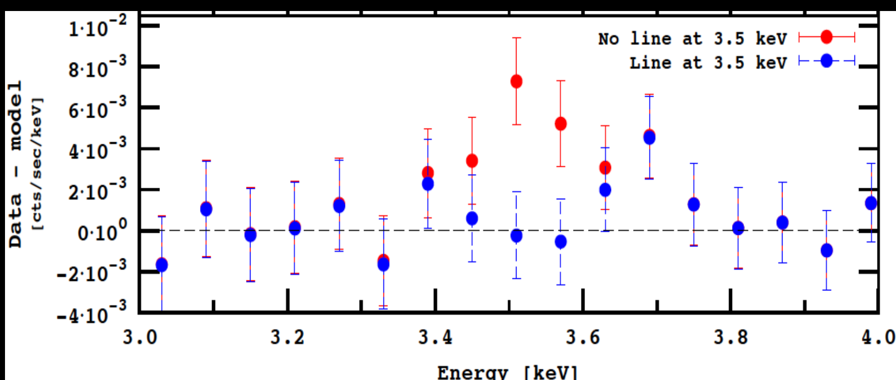
A window of parameter space remains!

Recent news: anomalous 3.5 keV line

Anomalous X-ray line observed by multiple groups.

- Seen by multiple satellites: XMM-Newton, Chandra
- Seen in multiple sources: stacked galaxy clusters, Perseus cluster, M31, and the Milky Way
- The signal is consistently redshifted
- Formal significance: 4~5σ

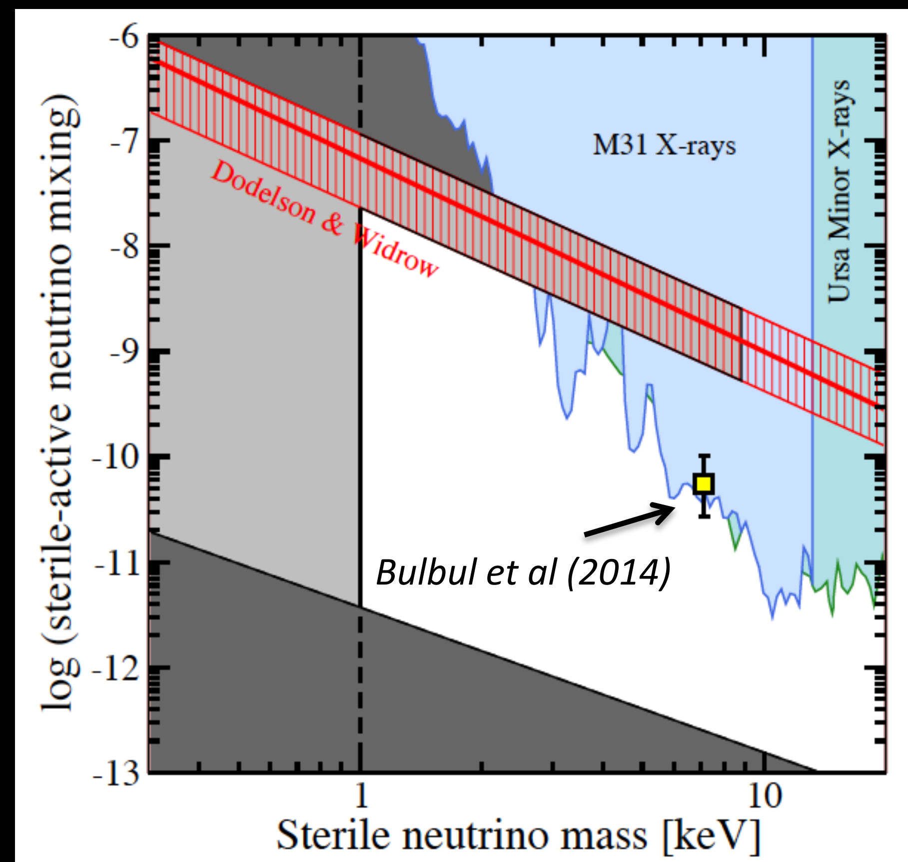
Bulbul et al (2014), Boyarsky et al (2014)



- Many BSM interpretations

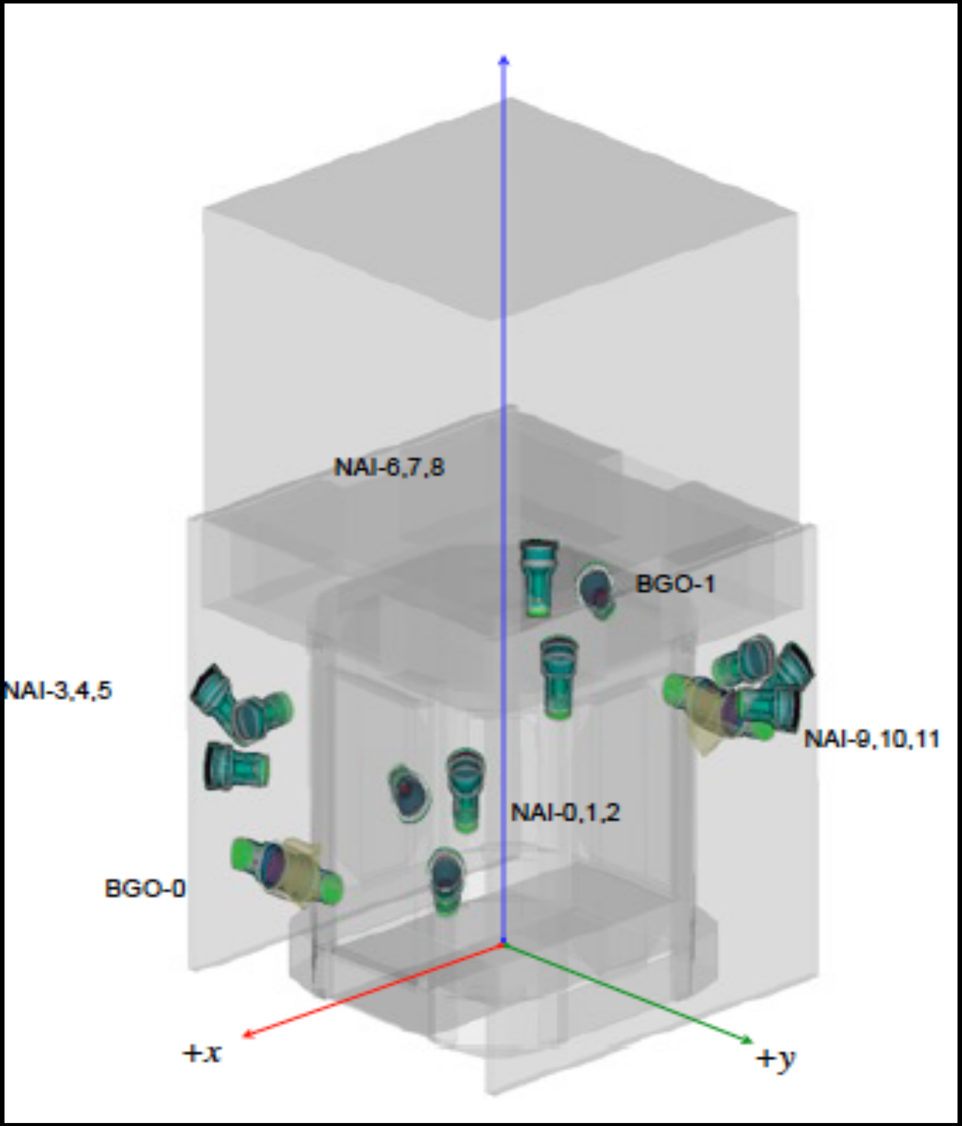
Debate on analysis and searches

Riemer-Sorensen (2014), Jeltema & Profumo (2014), Bulbul et al (2014b), Boyarsky et al (2014b)



Horiuchi et al (2014)

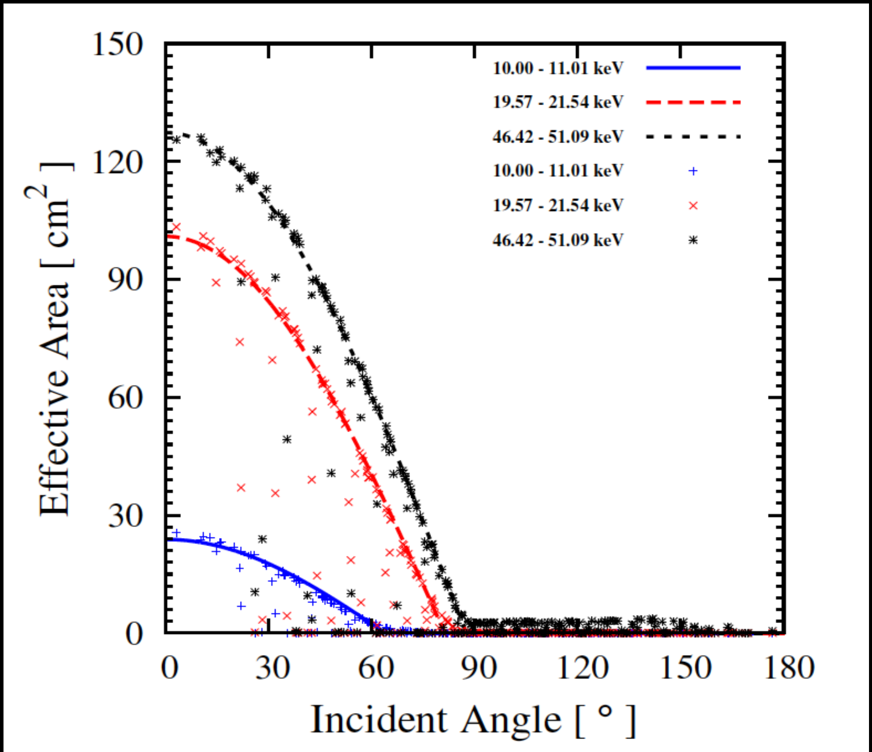
Fermi Gamma-ray burst monitor

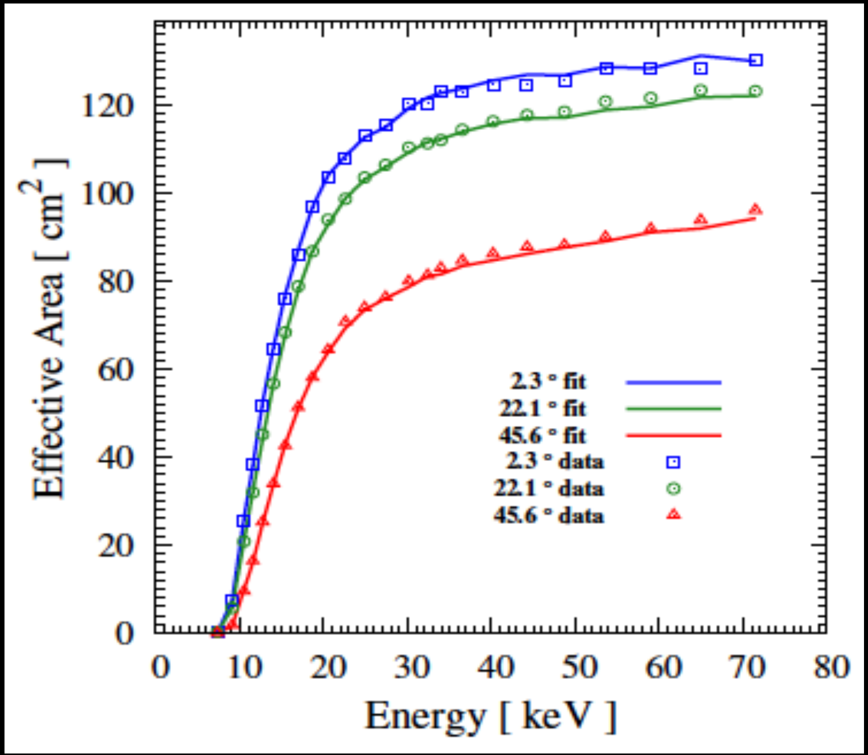


Gamma-ray burst monitor (GBM):

- 12 NaI (8-1000 keV) detectors
- 2 BGO (0.15-40 MeV) detectors
- Observes the entire unocculted sky
- Among the NaI detectors, det-0 and det-6 point within ~20deg of LAT pointing direction

GBM capabilities





- FoV: very large, almost half the sky observed per NaI detector ☺
- Effective area: some obstructions but stable and good size area
- Energy resolution: order ~10%
- Angular resolution: no angular information on an individual photon basis ☹
- Energy range: probes an energy window above traditional X-ray satellites (*Chandra, Suzaku, XMM*) and below *INTEGRAL* ☺ [Last probed by HEAO-1 in 1970s]

Gruber et al 1999, Boyarsky et al 2006

Analysis tools

Tools: Since there are no public GBM "tools," we built our own:

1. To simulate the *count rate* as a function of Galactic coordinate and energy based on an input source model
2. To extract the *count rate* in a specific GBM detector as a function of Galactic pointing direction and energy (accounts for the actual Fermi pointing history)

1. Sterile neutrino decay signal

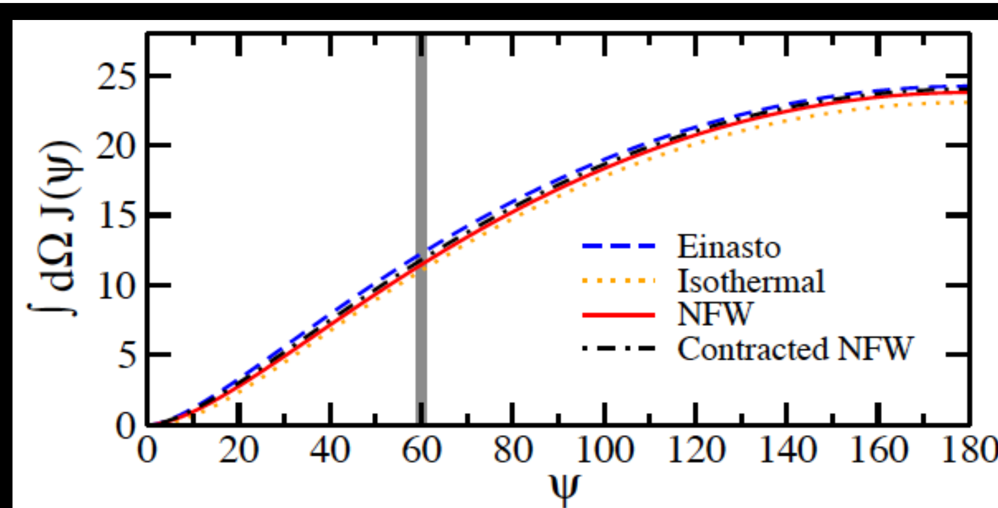
$$\frac{d\nu_{i,j}}{dT_j} = \int_{E_i^{\rm min}}^{E_i^{\rm max}} dE \int_{2\pi} d\Omega(\theta) \int d\tilde{E} \left\{ \mathcal{I}(\psi,\tilde{E})\, G\left(E,\tilde{E}\right) A_{\rm eff}(\tilde{E},\theta) \right\}$$

← Count rate in energy bin *i* and pixel *j*

Source photon intensity: we include the extragalactic contribution which can be comparable to the Galactic contribution for large FoVs.

$$= \frac{\rho_\odot R_\odot}{4\pi m_s \tau_s} \left(\mathcal{J}(\psi)\frac{dN}{dE} + R_{\rm EG} \int \frac{dz}{h(z)} \frac{dN}{dE'} \right)$$

➔: the Milky Way signal is relatively stable to DM profile assumptions.



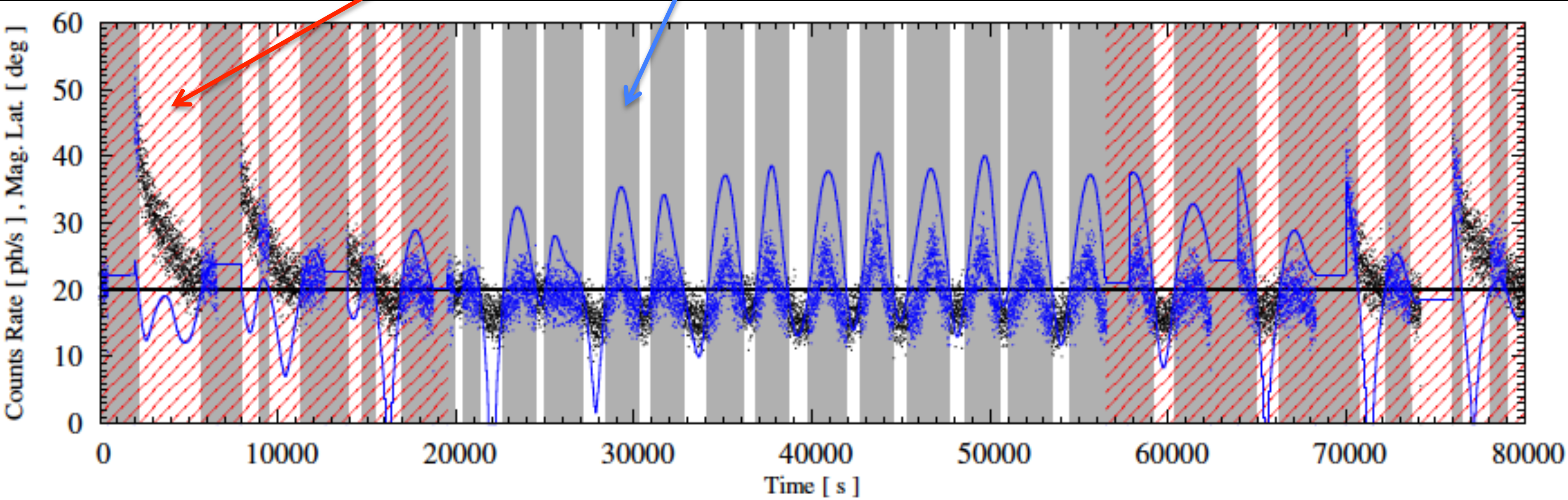
G(E,E): approximate the energy response as a Gaussian

Data reduction pipeline

Data: 3 years worth of data (AUG2008–DEC2012), CSPEC (128 Ebins, 4sec), we

- Use only one NaI detector (det-0, pointing closest to the LAT zenith)
- Use good time intervals based on LAT survey mode
- Apply additional Earth cuts (since NaI is not aligned with LAT)
- Apply additional transient source cuts (GRBs, solar flares, etc)
- Apply additional SAA & geomagnetic latitude cuts

Approximately ~53 days worth of data remaining after cuts



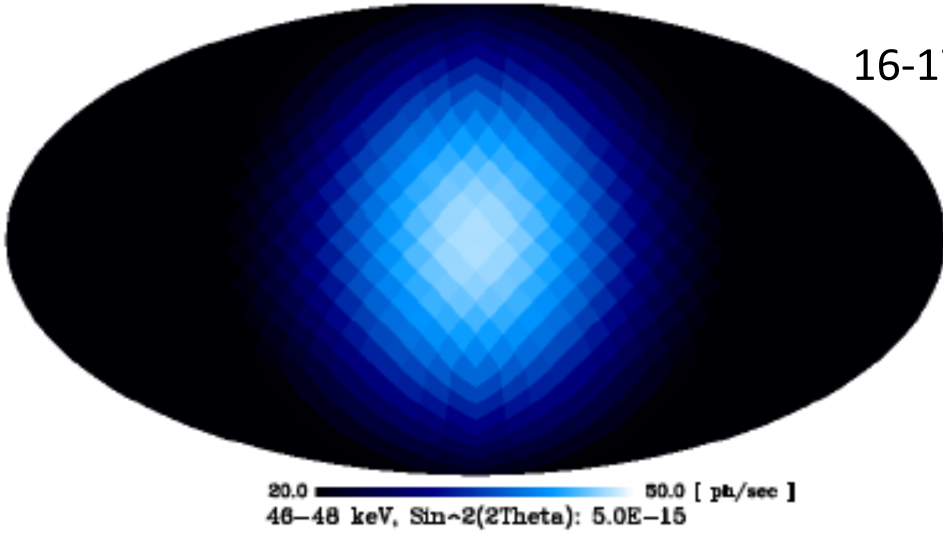
Ng et al (in prep)

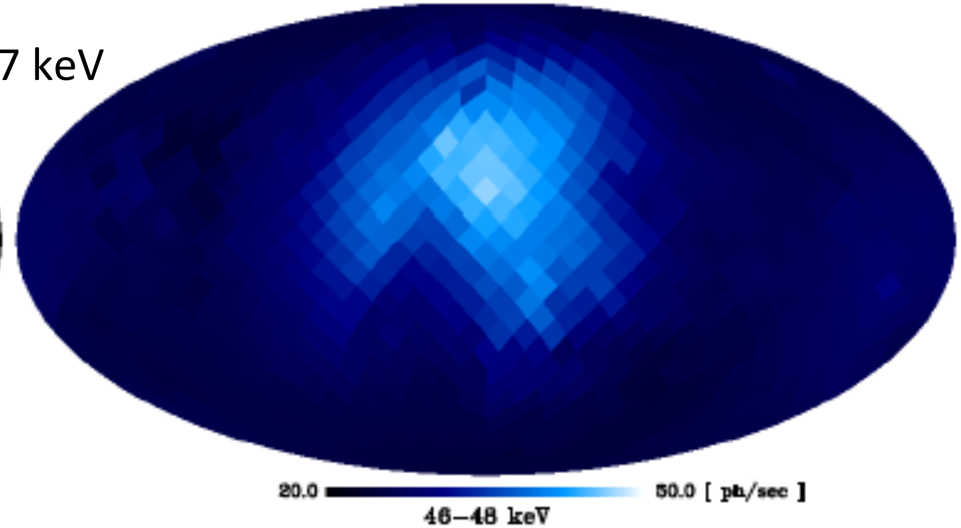
All-sky count rate maps

Simulate DM maps

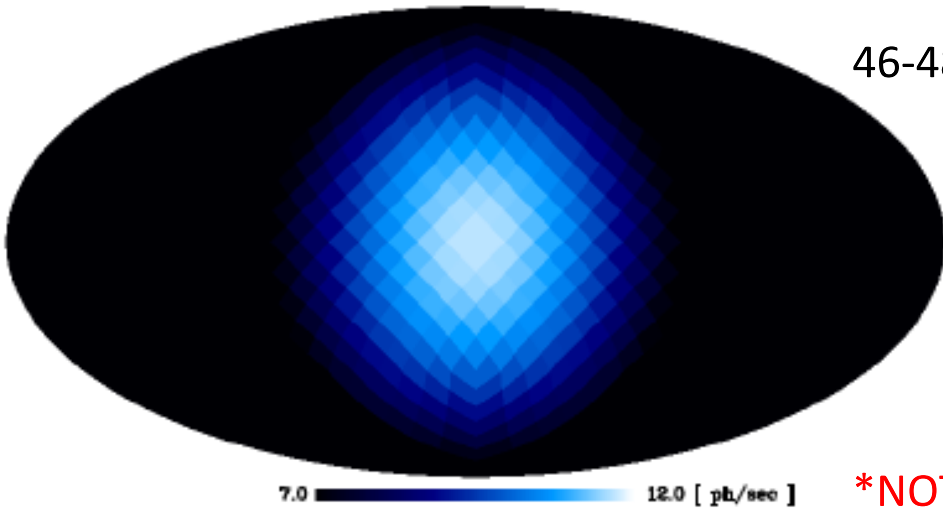
Data after cuts

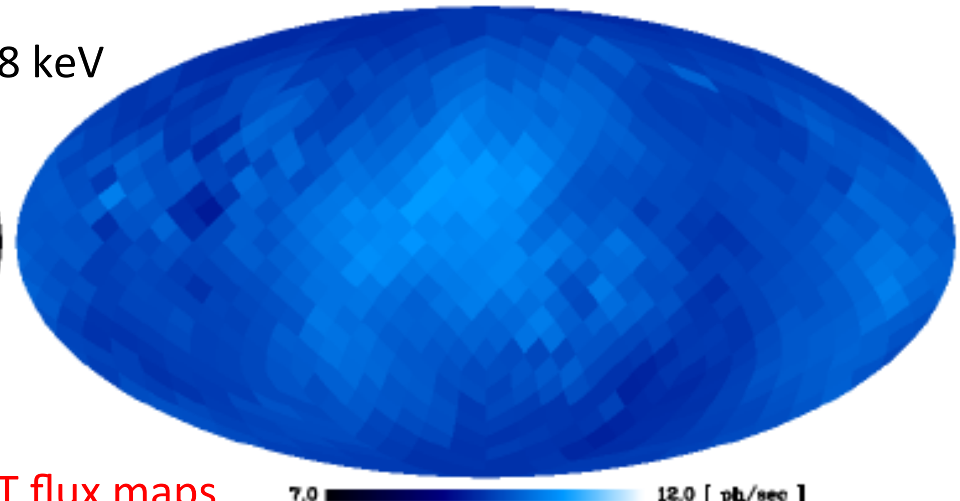
16-17 keV





46-48 keV





*NOT flux maps

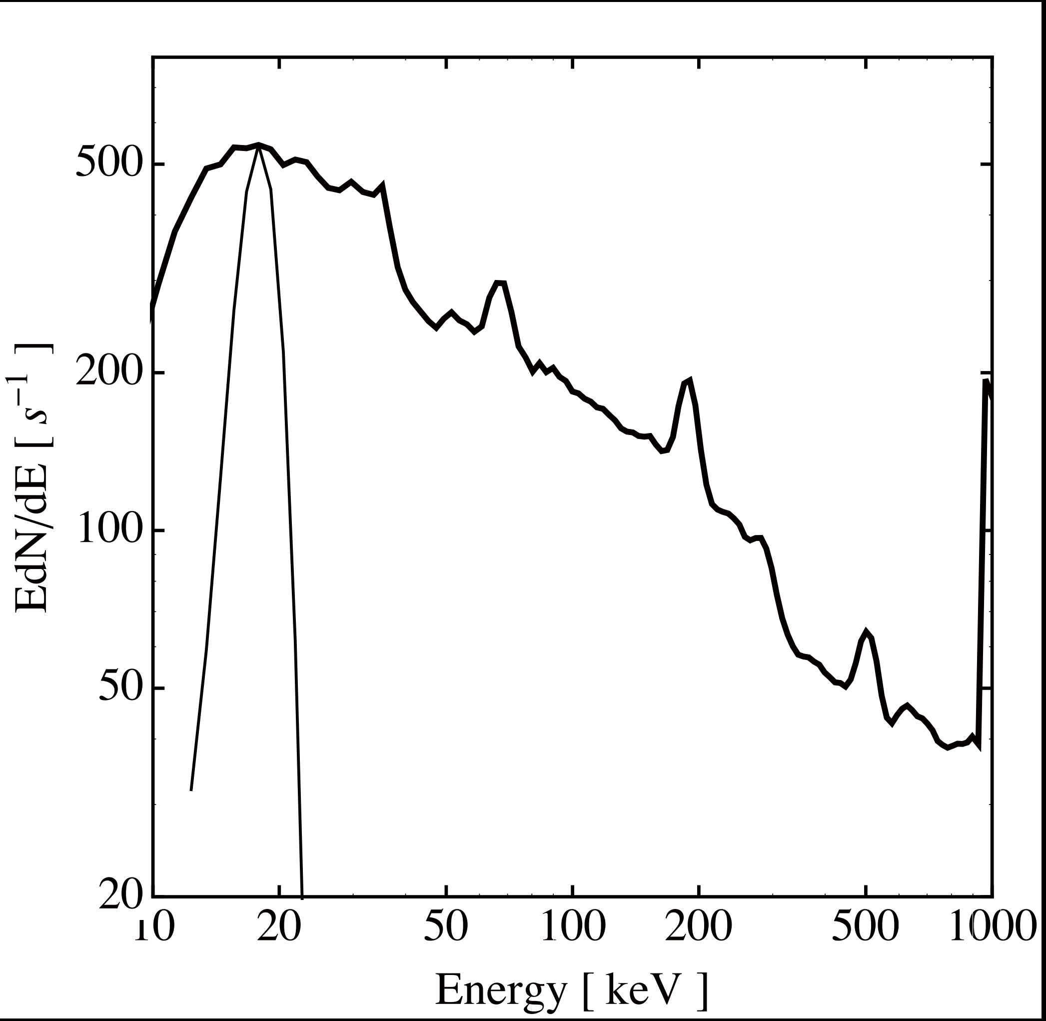
Bulk counting limit

Count rate spectrum:

- Dominated by backgrounds
- Instrumental lines

Conservative limit:

- Require signal to be smaller than total count



Ng et al (in prep)

Power-law background modeling

Model:

Model the background as a power-law with single index over small energy windows

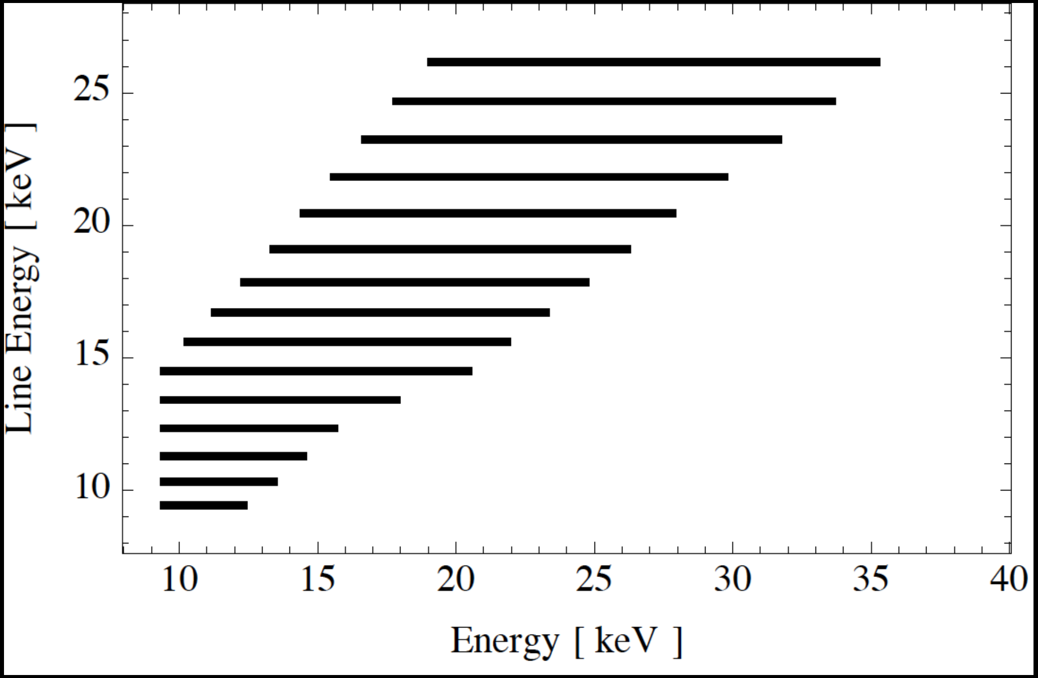
- Add 5% A_{eff} systematic uncertainty
- Check the power-law gives a good fit to the data

Profile likelihood

- Model the data as a line signal (at a fixed energy) plus background, i.e., total of 3 free parameters

Running energy window:

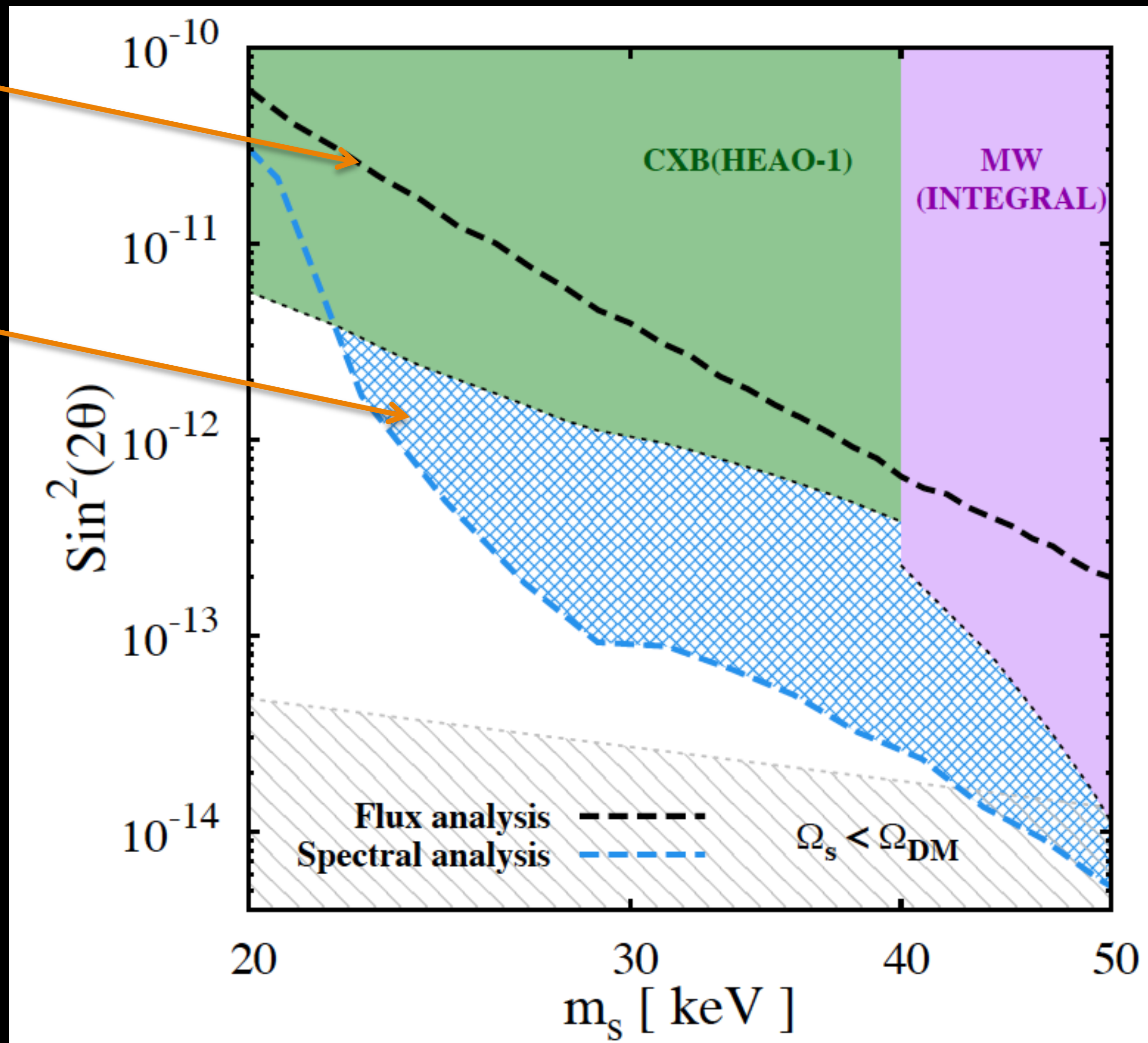
Typically ±5 energy bins around the bin of line energy (larger than the line width).



New limits on sterile neutrino mixing

Bulk counting limit:
Unsurprisingly, does not give a strong limit.

Spectral analysis limit:
Simplest background modeling already gives competitive limits!



Ng et al (in prep)

Summary

GBM data covers an interesting energy range for sterile neutrino dark matter searches (10-25 keV). The large FoV and energy resolution make this data competitive.

We have developed data reduction tools that minimize detector background events, and tools to simulate count rates from flux maps

Resulting limits on sterile neutrino dark matter are competitive (last probed in 1999)

Significant scope for improving our simple analysis exists:

- On-off region differencing at higher energies
- Astrophysical modeling at low nergies
- Techniques for obtaining angular information (e.g., occultation techniques)

e.g., Wilson-Hodge et al 2012