Detecting Sterile Neutrino Dark Matter at MeV Gamma-ray Observatories

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Collaborators: S. Fujiwara, T. Hayashi, Y. Watanabe

- ✓ Brief overview of Sterile neutrino dark matter
- ✓ Future MeV gamma-ray observatories, especially COSI
- ✓ Detecting the sterile neutrino dark matter at COSI

Sterile neutrino dark matter

O Standard Model (SM) + 2 Right-handed neutrinos

We can describe neutrino masses/mixings via the seesaw mech.

We can describe the baryon asymmetry of U. via Leptogenesis.

O Adding one more Right-handed neutrino

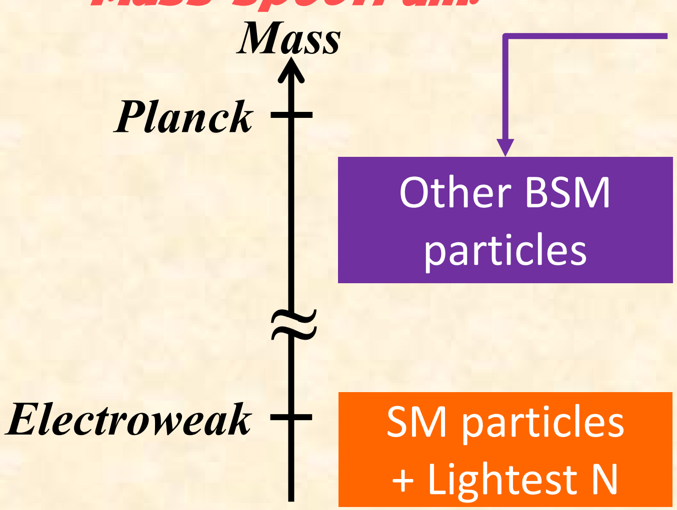
It can be a dark matter if its Yukawa int. is sufficiently small.

O The model promoting $U(1)_{B-L}$ to a gauge one in the SM

A R-neutrino is introduced in each generation to cancel the anomaly.

$$L = L_{SM} + L^{(K)}[N, Z', \Phi] + L^{(B-L)}[SM] + L^{(Y)}[N, \Phi] + L^{(Y)}[L, N, H] + V[\Phi, H].$$

Mass spectrum:



It is consistent with Seesaw & Leptogenesis!

This setup allows us to create the sterile neutrino dark matter in the early Univ.

$$\Omega_{\rm DM} h^2 \simeq 0.11 \times \left(\frac{m_N}{1\,{\rm MeV}}\right)\left(\frac{T_{\rm RH}}{10^{14}\,{\rm GeV}}\right)^3\left(\frac{10^{16}\,{\rm GeV}}{v_\Phi}\right)^4$$

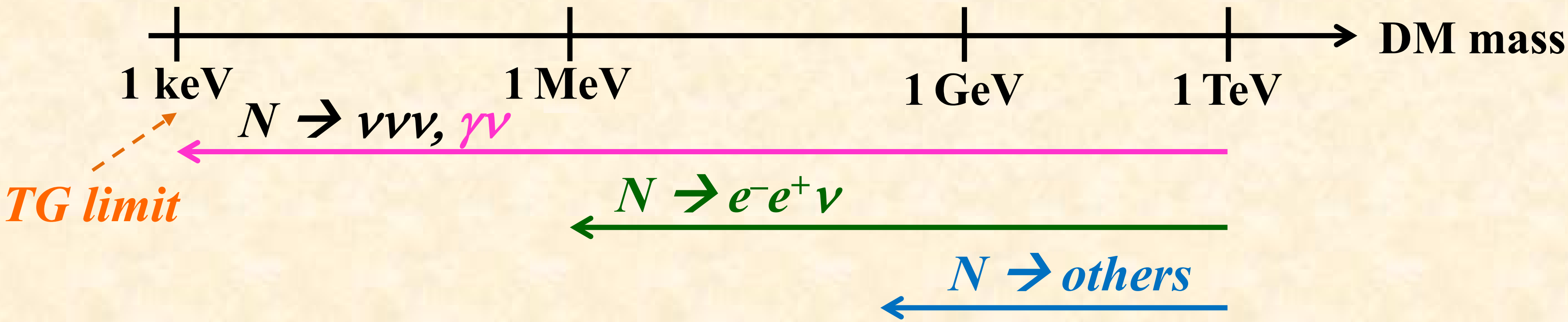
Freeze-in via SM+SM → Z' → N+N

Sterile neutrino dark matter

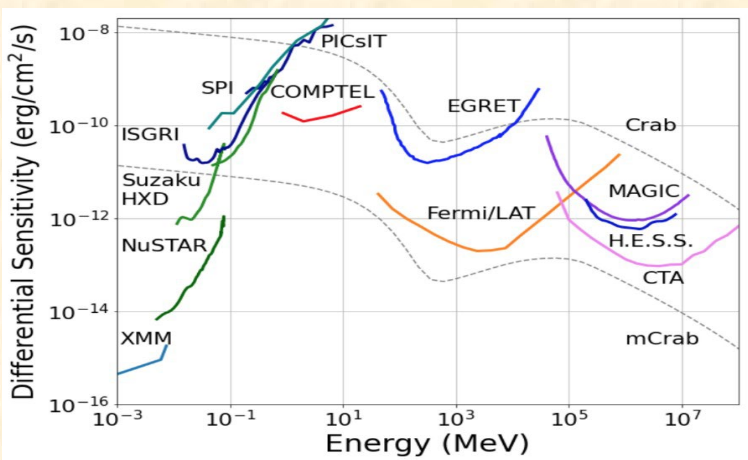
○ Detection of Sterile neutrino dark matter

Indirect detection via dark matter decay seems prominent.

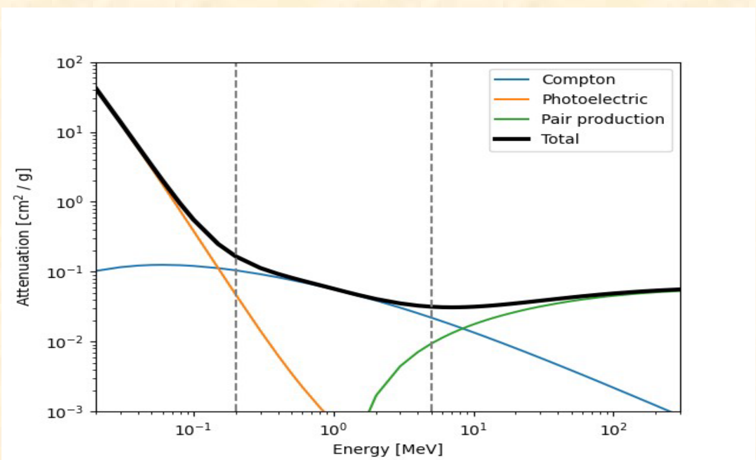
Decay channels:



The radiative decay mode is the most powerful for detection.



Sensitivity of photon signals



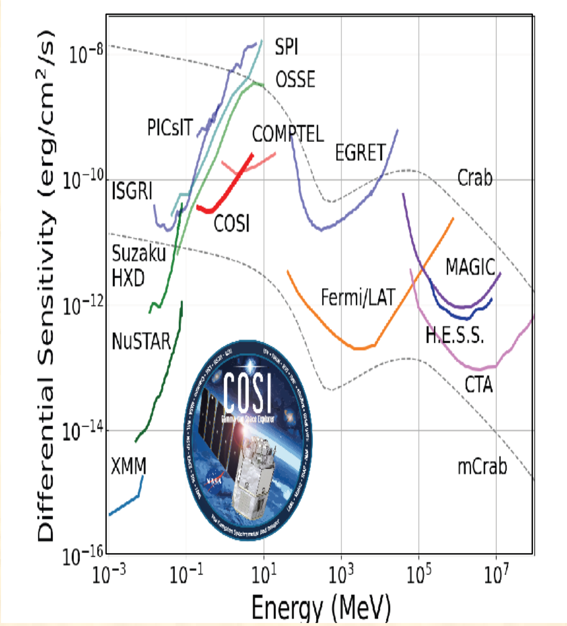
Fundamental photon interactions

Future MeV gamma-ray observatories

COSI A Gamma-ray Space Explorer = *Small Explorer (SMEX) Satellite of NASA (Planned launch in 2027).*

Detecting γ-rays in the 0.2-5 MeV energy range.

Characteristic	Requirement
Sky Coverage	• >25%-sky instantaneous FOV • 100%-sky each day
Energy Resolution* (FWHM)	• <1.2% @ 0.511 MeV • <0.8% at 1.157 MeV (^{44}Ti)
Narrow Line Sensitivity (2 yr, 3σ, point source)	[photons cm^{-2} s^{-1}] • 1.2x10^{-5} @ 0.511 MeV • 3.0x10^{-6} @ ^{26}Al, ^{60}Fe, and ^{44}Ti
Angular Resolution (FWHM)	• <4.1° @ 0.511 MeV • <2.1° @ 1.8 MeV (^{26}Al)



Although the sensitivity of COSI is not much better than that of past ones, its success would pave the way for more sensitive successors!!

Mission (Instrument)	Operation	Energy Range	Field of View	Energy Resolution
COSI	2027-	200 keV – 5 MeV	~10,000 deg^2	0.4-1.2% (>200 keV, est.)
CGRO (COMPTEL)	1991-2000	800 keV – 30 MeV	~3000 deg^2	5-10% (>1 MeV)
INTEGRAL (SPI)	2002-	25 keV – 8 MeV	~300 deg^2	0.2-1.6% (>100 keV)
NuSTAR	2012-	3-78 keV	0.05 deg^2	1.3-4.0% (>10 keV)

Future MeV gamma-ray observatories

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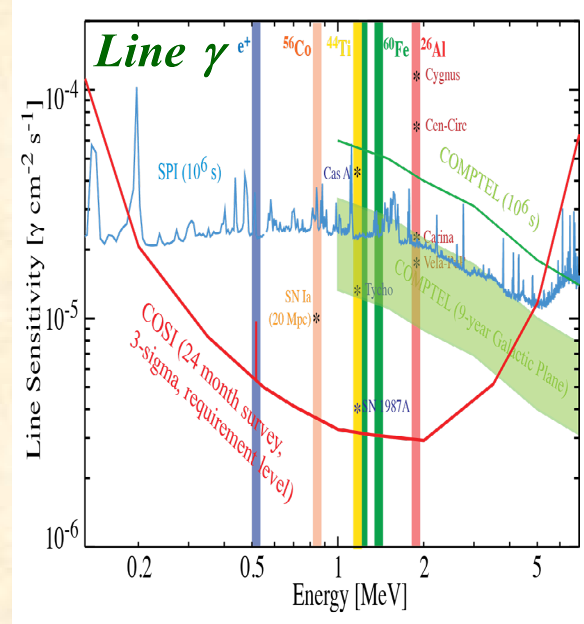

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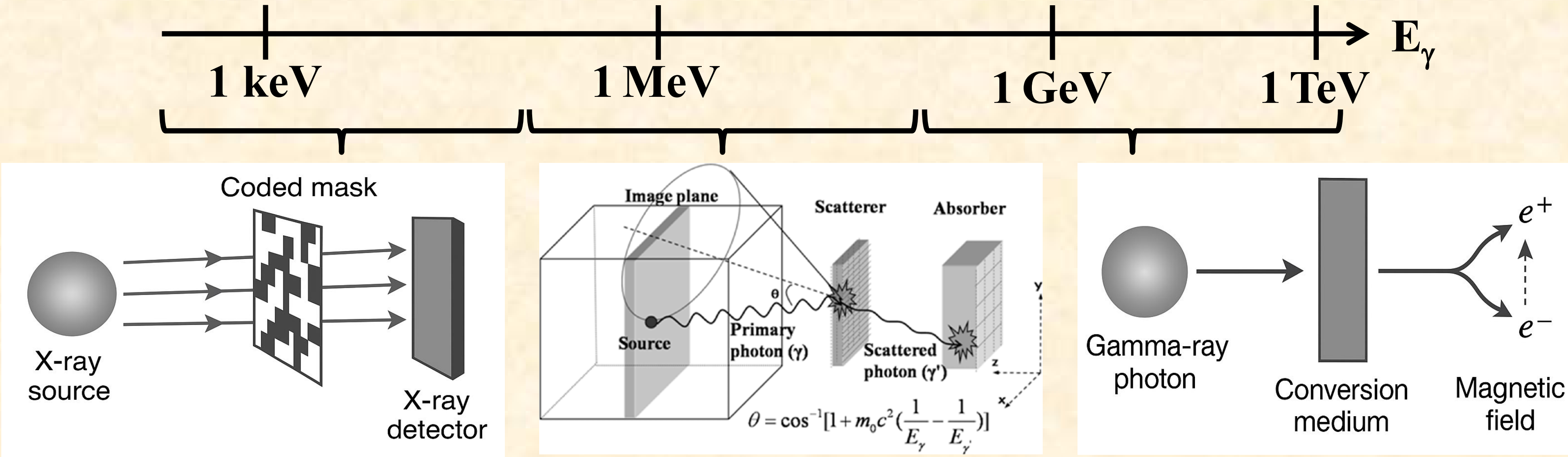
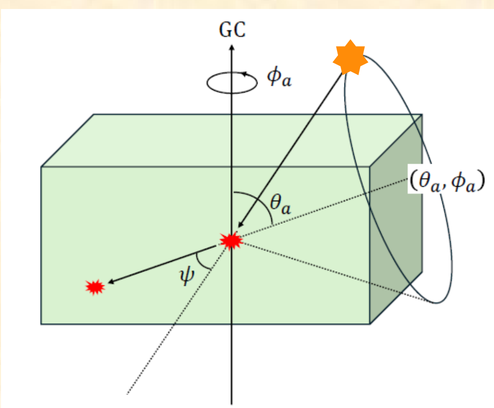
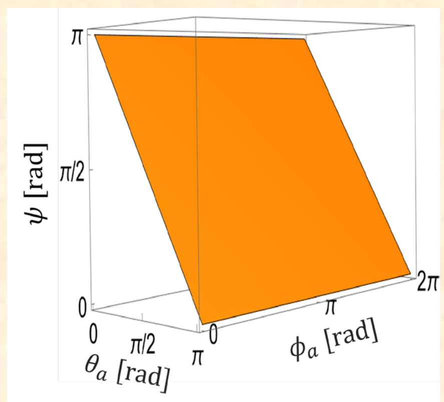
Large FoV & Excellent energy resolution

Future MeV gamma-ray observatories

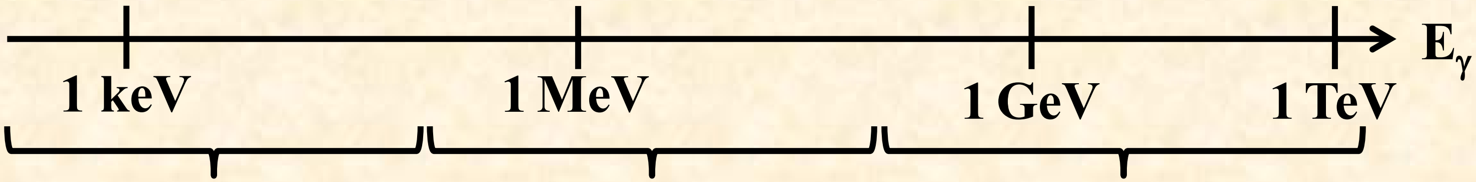


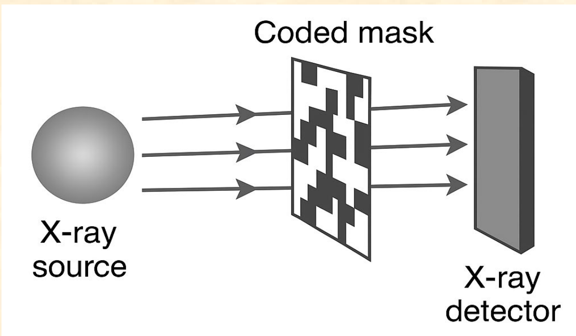


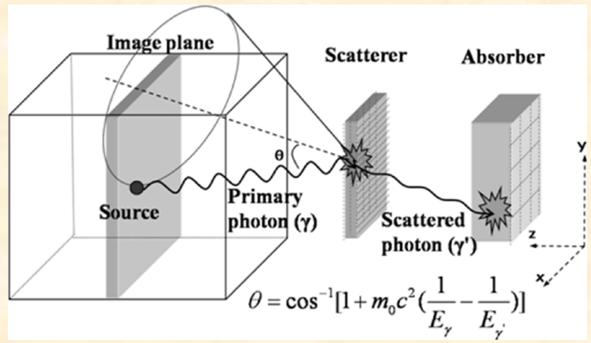


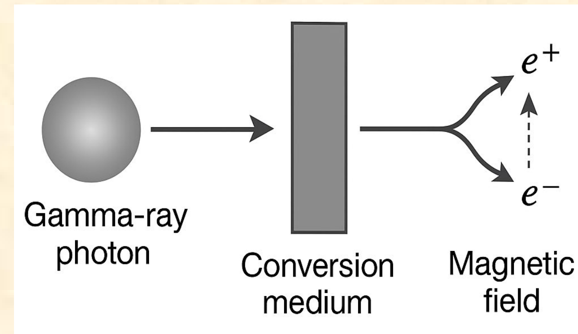
Each event is recorded in a Compton data space (θ_a, ϕ_a, ψ), with E_γ info.

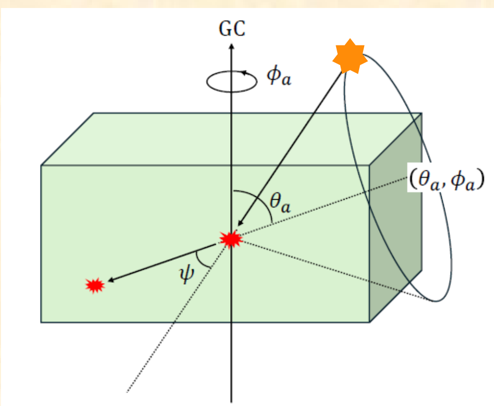
Future MeV gamma-ray observatories

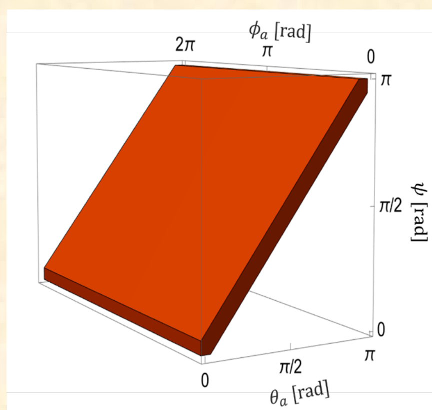


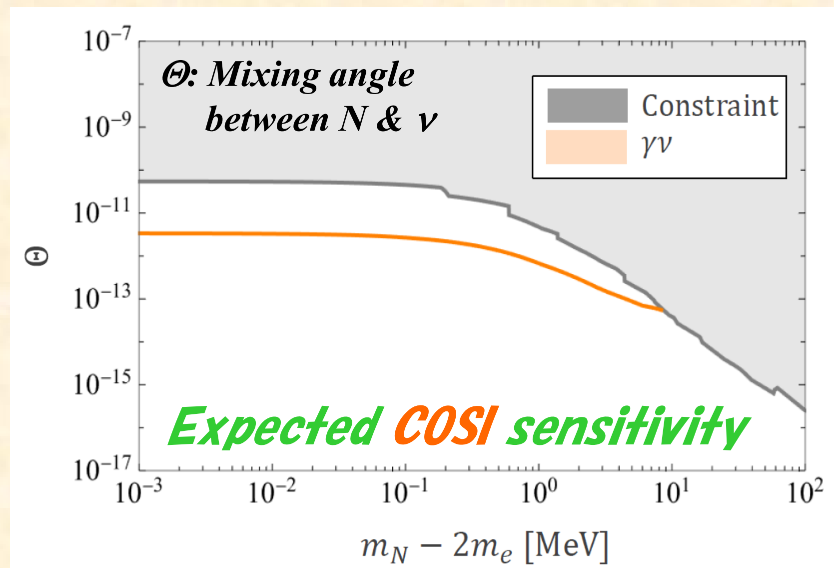












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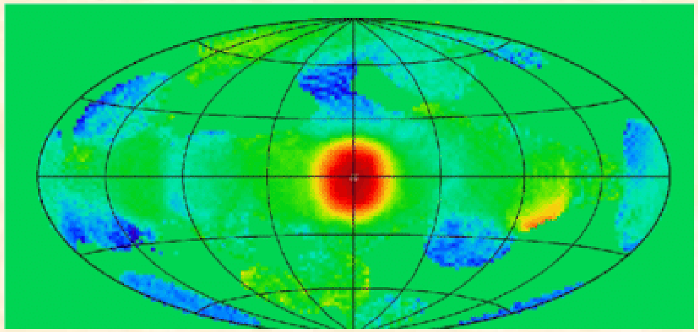
RoI: Galactic center region with a radius of 10 degrees. Sensitivity↑

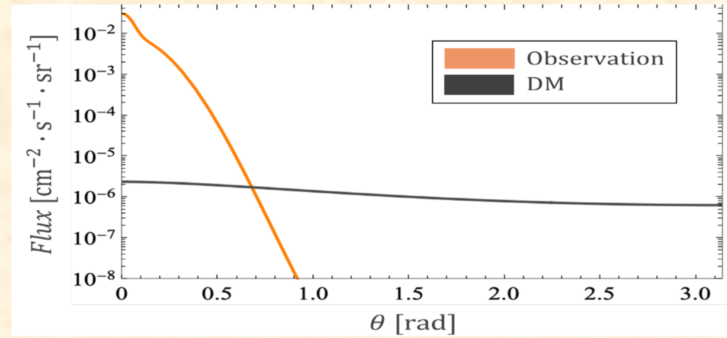
Future MeV gamma-ray observatories

O Another interesting MeV gamma-ray signal

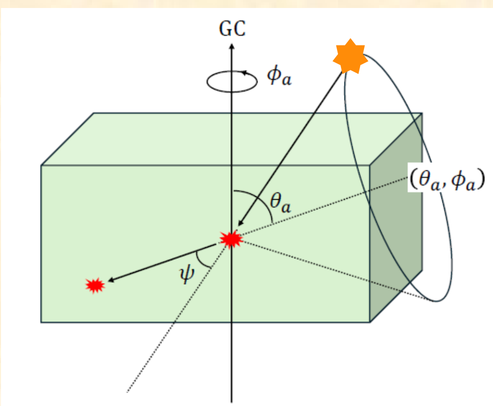
$N \to e^- e^+ \nu \to e^+$ is captured & forms Ps → 511 keV!

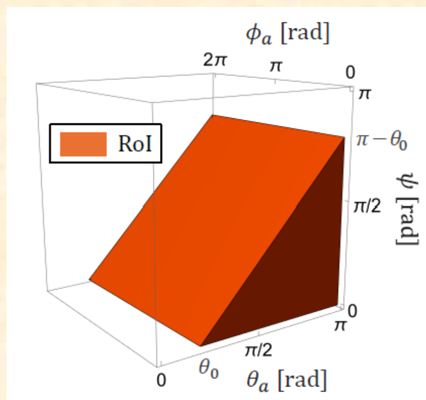


511 keV gamma was already observed.



Expected DM signal morphology





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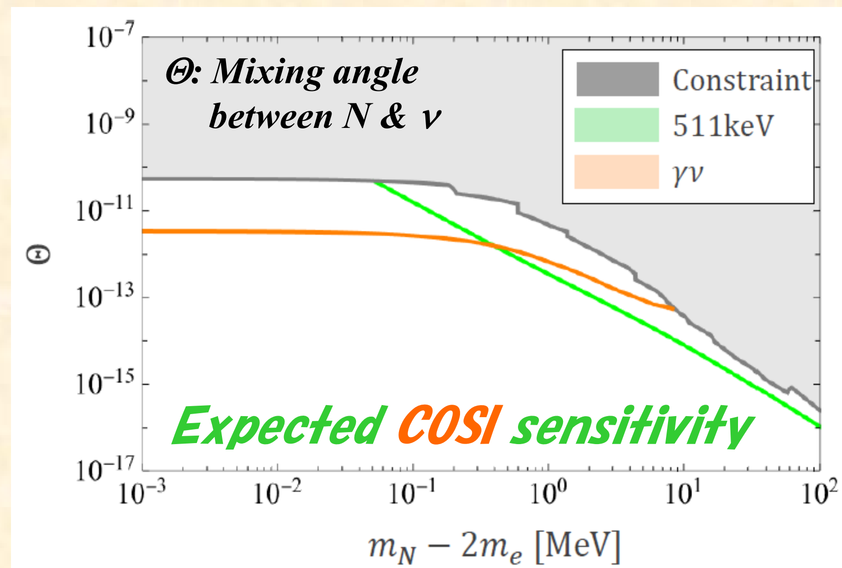
RoI: Regions outside Galactic bulge:



Higher mass region or two lines!

Summary

The detection of sterile neutrino dark matter at future MeV gamma-ray observatories has been discussed, with a particular focus on COSI.

- ✓ Sterile neutrino dark matter, namely the lightest right-handed neutrino, is one of the most popular dark matter candidates described within the minimal framework for neutrino mass and mixing generation, as well as for explaining the BAU.

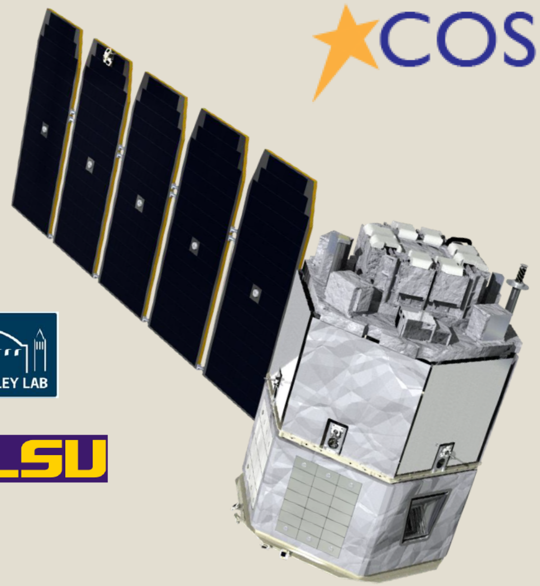
- ✓ Observing the photon signal from the process, $N \to \gamma\nu$, is the most prominent way to detect dark matter: however, the sensitivity in the MeV mass range is not as good as in other mass regions.

- ✓ Future MeV gamma-ray observatories, COSI and its successors, will address this issue and probe new parameter regions of the dark matter. In the MeV mass range, dark matter can also decay into an electron pair and a neutrino, producing a 511 KeV photon signal from positronium decay, which covers higher masses than the $N \to \gamma\nu$ channel. Furthermore, detecting both monochromatic signals would be a smoking-gun signature of sterile neutrino dark matter.

Backup 1

The COSI collaboration

University of California, Berkeley
University of California, San Diego
Naval Research Laboratory
Goddard Space Flight Center
Space Dynamics Laboratory
Northrop Grumman
Italian Space Agency (ASI)
German Aerospace Center (DLR)
French National Space Agency (CNES)

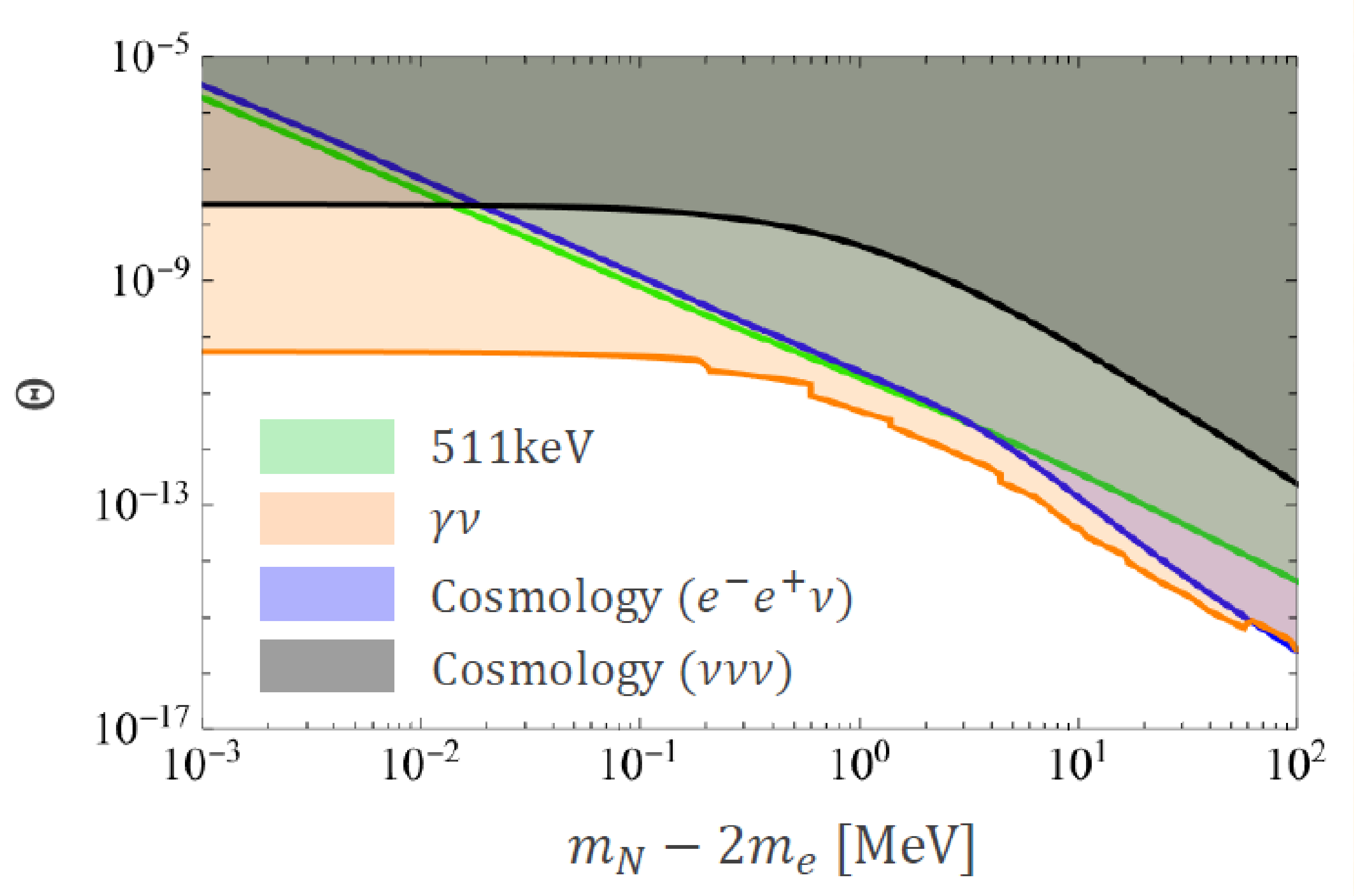


Institutions of Co-Investigators and Collaborators

- Clemson University
- Louisiana State University
- Los Alamos National Laboratory
- Lawrence Berkeley National Laboratory
- IRAP, France
- INAF, Italy
- Kavli IPMU and Nagoya University, Japan
- JMU/Würzburg and JGU/Mainz, Germany
- NTHU, Taiwan
- University of Hertfordshire, UK
- Centre for Space Research, North-West University, South Africa
- Deutsches Elektronen Synchrotron (DESY), Germany
- LAPTh-CNRS, France
- Yale University
- Michigan Technical University
- Washington University, St. Louis
- Marshall Space Flight Center
- Boston University
- IAA-CSIC, Spain
- Stanford University

Subgroup	Lead	Co-Leads
Positrons	Carolyn Kierans (GSFC)	Thomas Siegert (JMU, Germany)
Nucleosynthesis	Thomas Siegert (JMU, Germany)	Chris Fryer (LANL)
GRBs	Eric Burns (LSU)	Steve Boggs (UCSD), Dieter Hartmann (Clemson)
Galactic	Julien Malzac (IRAP, France)	Chris Karwin (GSFC)
Extragalactic	Marco Ajello (Clemson)	Fabrizio Tavecchio (INAF, Italy)
Dark Matter	Tad Takahashi (IPMU, Japan)	Fabrizio Tavecchio (INAF, Italy), Shigeki Mastumoto and Tom Melia (IPMU, Japan)

Backup 3



10^{-5}
10^{-9}
10^{-13}
10^{-17}
Θ
511keV
$\gamma\nu$
Cosmology ($e^-e^+\nu$)
Cosmology ($\nu\nu\nu$)
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
10^{2}
$m_N - 2m_e$ [MeV]