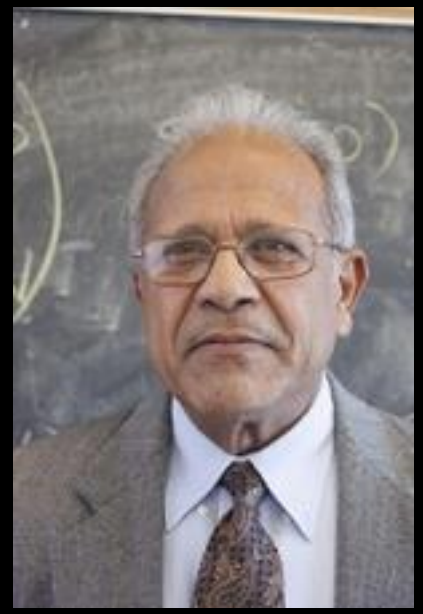
Stellar Limits on Light Scalars

[Some recent (and not-so-recent) work with Rabi]

Bhupal Dev

Washington University in St. Louis



Rabi-Fest

University of Maryland, College Park

October 21, 2022

Honor and Privilege to be Rabi's student (2007-12)

- **Post-Sphaleron Baryogenesis and Neutron-antineutron oscillation:** Babu, BD, Mohapatra, 0811.3411 (PRD '09). Set the foundation for 1303.6918 (PRD '13) – paper that Yuri loves so much.

- **Supersymmetric SO(10) GUT Phenomenology**
  - BD, Mohapatra, 0910.3924 (PRD '10) – one of my most cited papers
  - BD, Mohapatra, 1003.6102 (PRD '10)
  - BD, Mohapatra, Severson, 1107.2378 (PRD '11)
  - BD, Dutta, Mohapatra, Severson, 1202.4012 (PRD '12)

- **Leptogenesis:** Blanchet, BD, Mohapatra, 1010.1471 (PRD '10)

- **Dark Matter:** An, BD, Cai, Mohapatra, 1110.1366 (PRL '12)

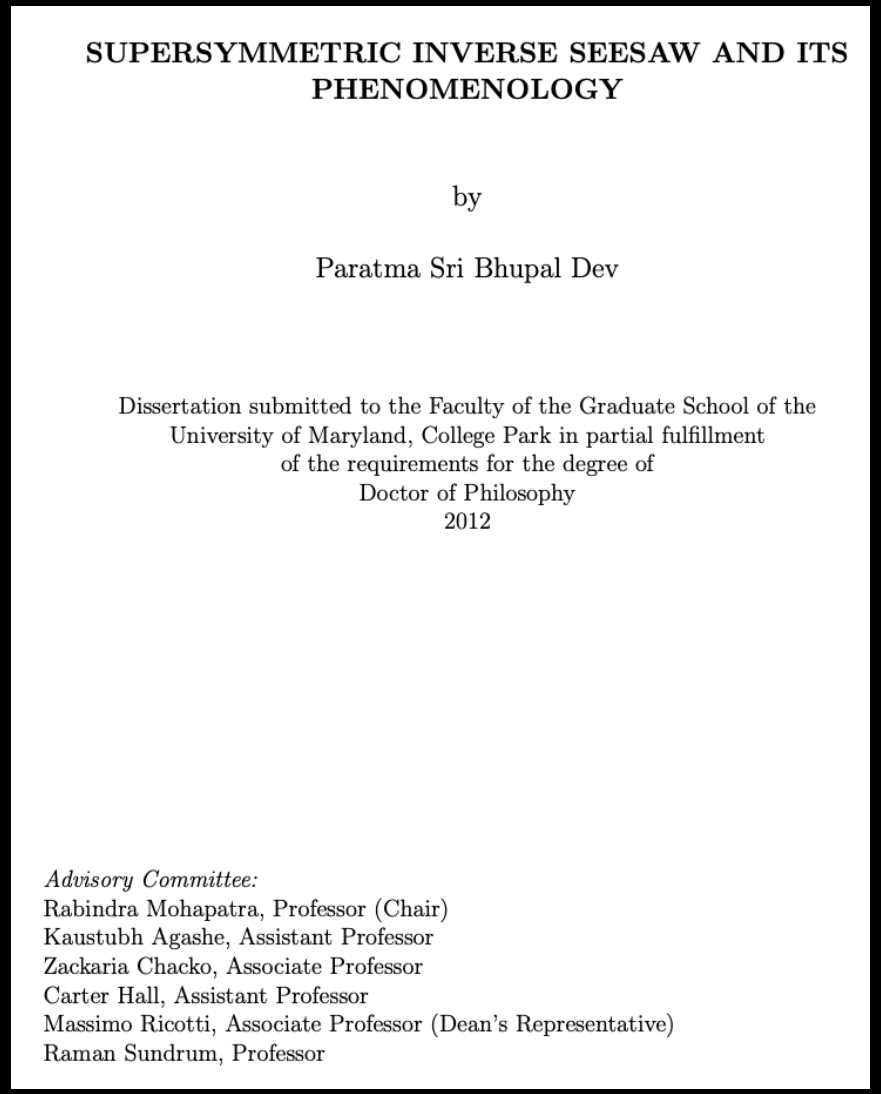
– one of Haipeng's favorites (see Xiangdong's talk)

- **Higgs Physics:** BD, Franceschini, Mohapatra, 1207.2756 (PRD '12)

-- my first experience with PYTHIA/Delphes

- **Collider Physics:** Chen, BD, 1112.6419 (PRD '12)

-- my first independent paper (with a TASI-mate)



SUPERSYMMETRIC INVERSE SEESAW AND ITS PHENOMENOLOGY

by

Paratma Sri Bhupal Dev

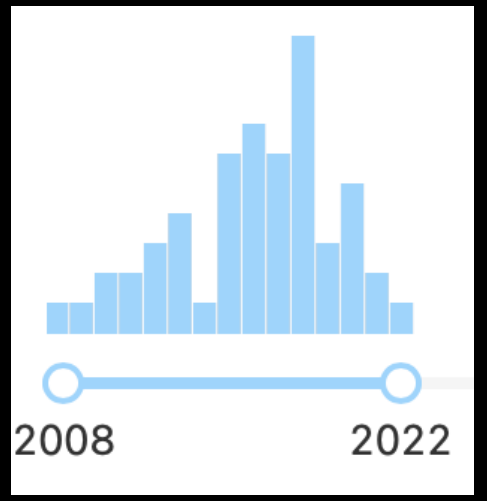
Dissertation submitted to the Faculty of the Graduate School of the University of Maryland, College Park in partial fulfillment of the requirements for the degree of Doctor of Philosophy
2012

Advisory Committee:
Rabindra Mohapatra, Professor (Chair)
Kaustubh Agashe, Assistant Professor
Zackaria Chacko, Associate Professor
Carter Hall, Assistant Professor
Massimo Ricotti, Associate Professor (Dean's Representative)
Raman Sundrum, Professor

My collaboration with Rabi has continued ever since

Will limit the rest of my talk to a couple of recent papers with Rabi and some follow-up work on astrophysical limits on light BSM physics.

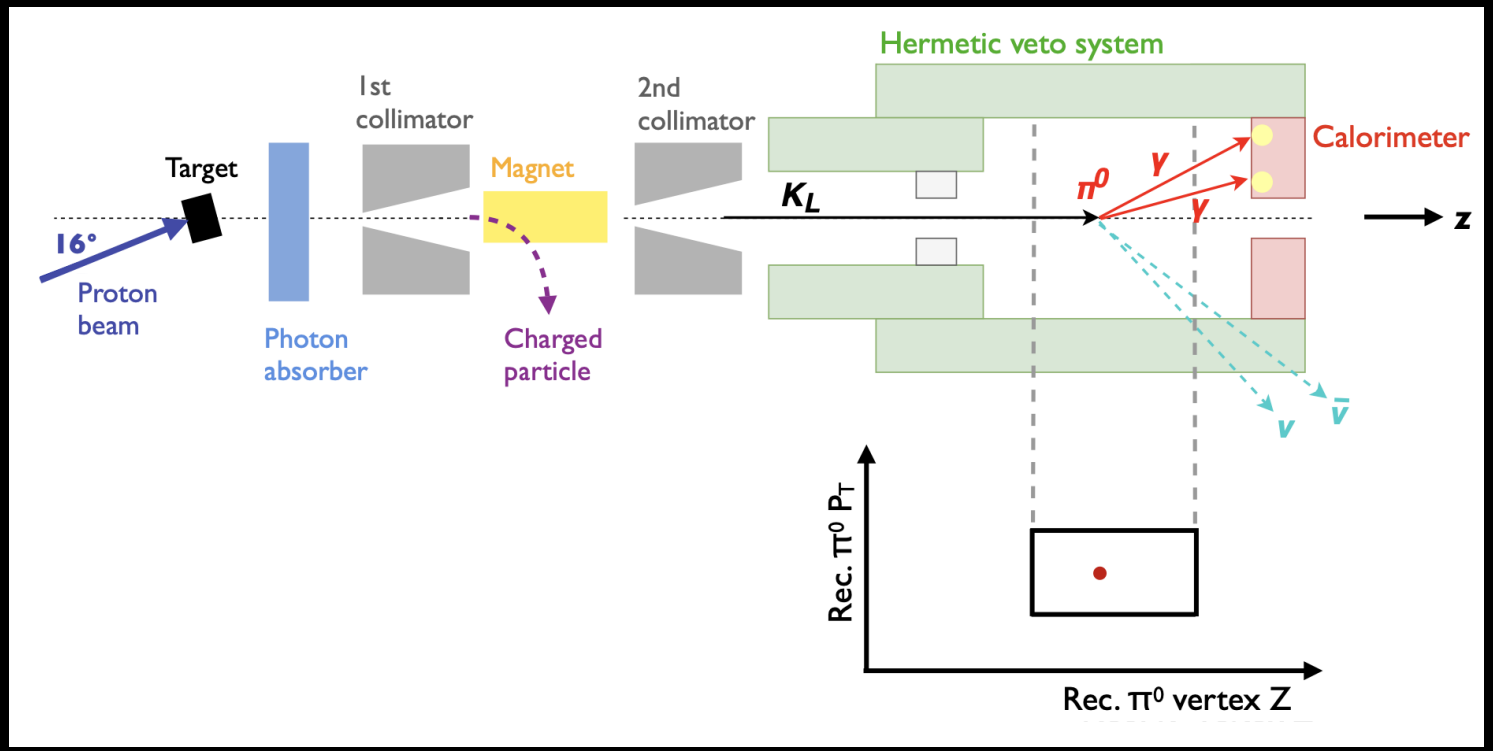
- BD, Mohapatra, Zhang, *Revisiting supernova constraints on a light CP-even scalar,* 2005.00490 (JCAP '20)
- BD, Mohapatra, Zhang, *Stellar limits on light CP-even scalar,* 2010.01124 (JCAP '21)
- BD, Harris, Fortin, Sinha, Zhang, *Light scalars in neutron star mergers*, 2111.05852 (JCAP '22)
- Balaji, BD, Silk, Zhang, *Improved stellar limits on a light CP-even scalar*, 2205.01669
- And ongoing work

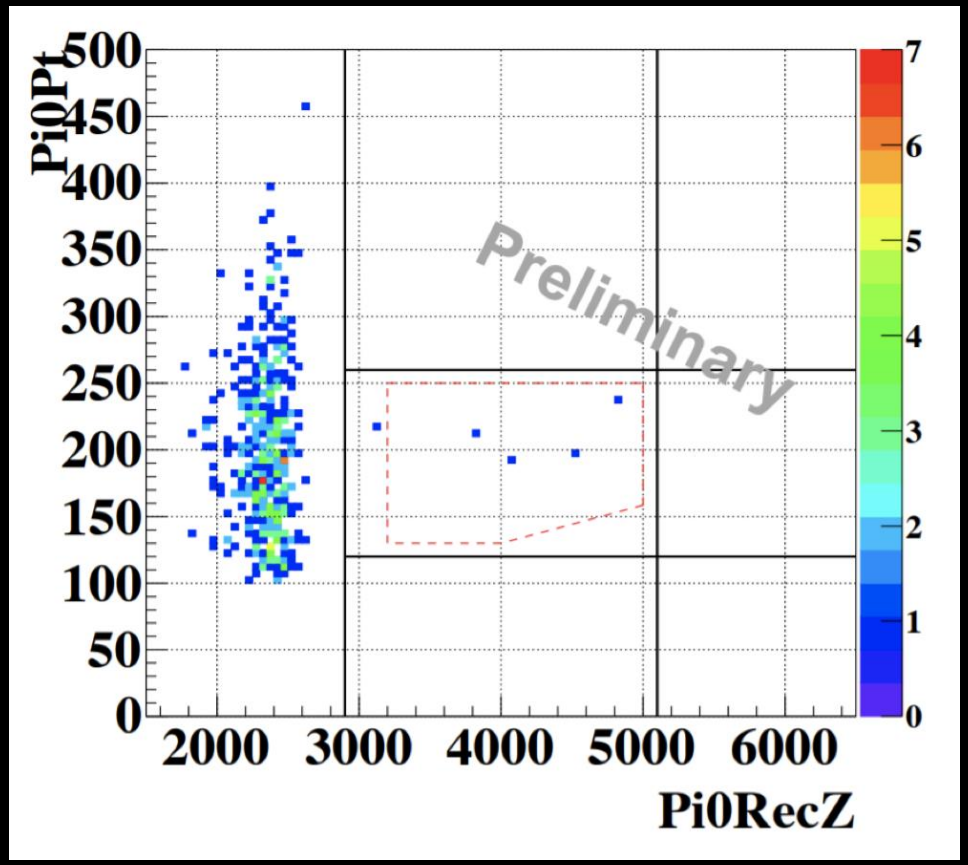


Yongchao Zhang
(former Rabi/Xiangdong student, our postdoc (2017-20).
Now Professor at Southeast Univ

This series of works started with something completely different:

KOTO Anomaly





3 events in the signal region vs SM expectation of 0.10±0.02.

Talk by Sinohara KAON 2019

New Physics? ☺

Light CP-even Scalar

$$K_L \to \pi^0 S\,, \quad S \to \text{invisible}$$

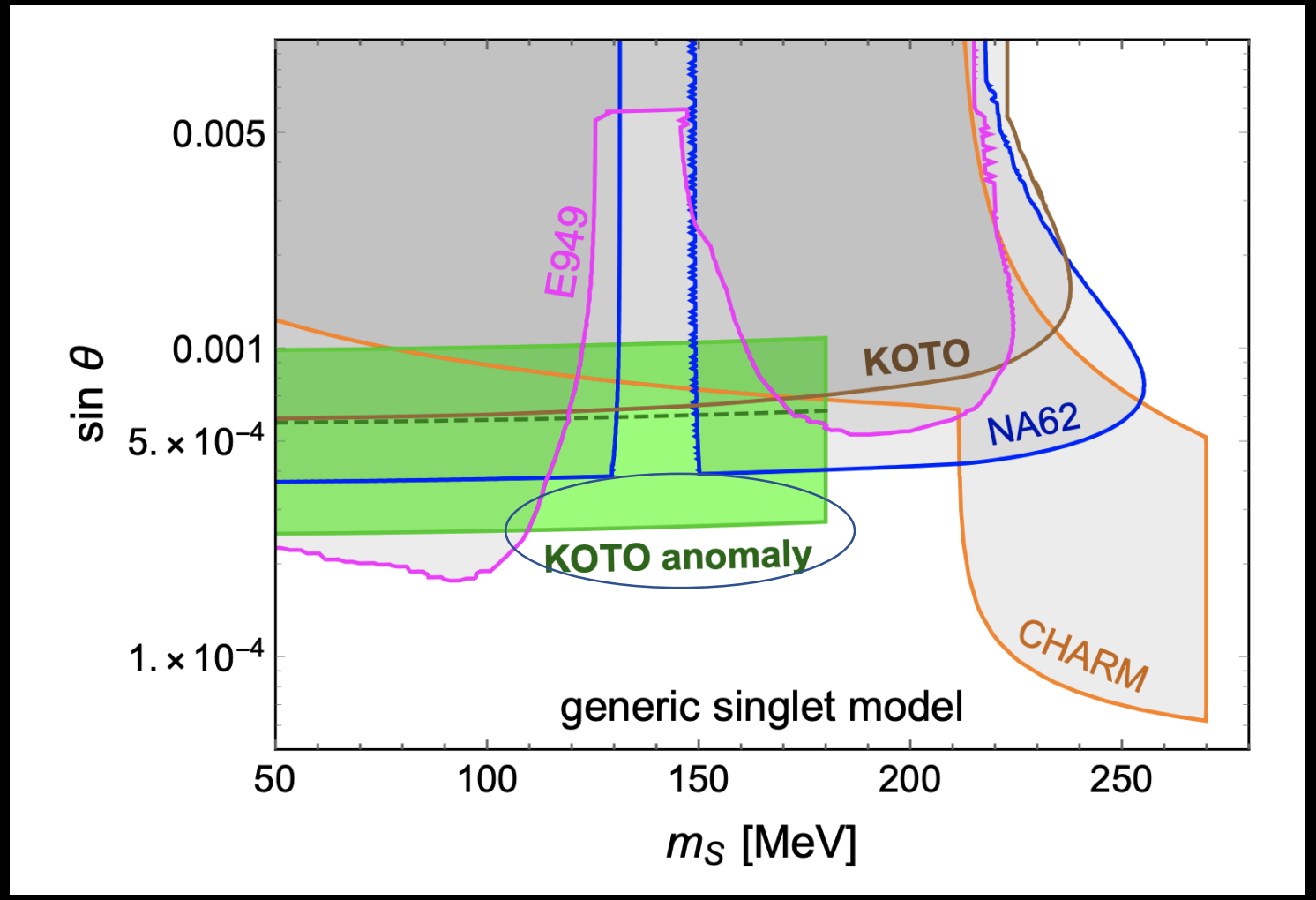
Not $K_L \to \pi^0 \nu\bar{\nu}$

What about the supernova constraint?

Soon realized that nobody had done a full calculation of SN1987A bound on *CP-even* scalar.

The existing literature just used the *NN* bremsstrahlung amplitude for *CP-odd* axions.

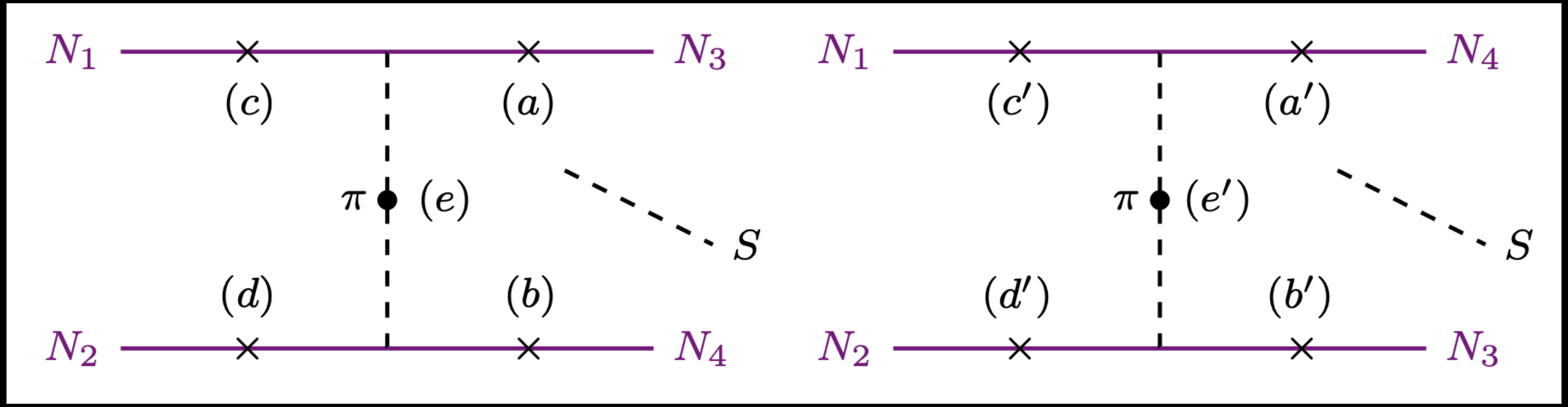
Isizuka, Yoshimura (PTEP '90);
Arndt, Fox, hep-ph/0207098 (JHEP '03);
Diener, Burgess, 1302.6486 (JHEP '13);
Krnjaic, 1512.04119 (PRD '16)



BD, Mohapatra, Zhang, 1911.12334 (PRD '20)

But there are two crucial differences between CP-even and CP-odd Cases!

BD, Mohapatra, Zhang, 2005.00490 (JCAP '20)

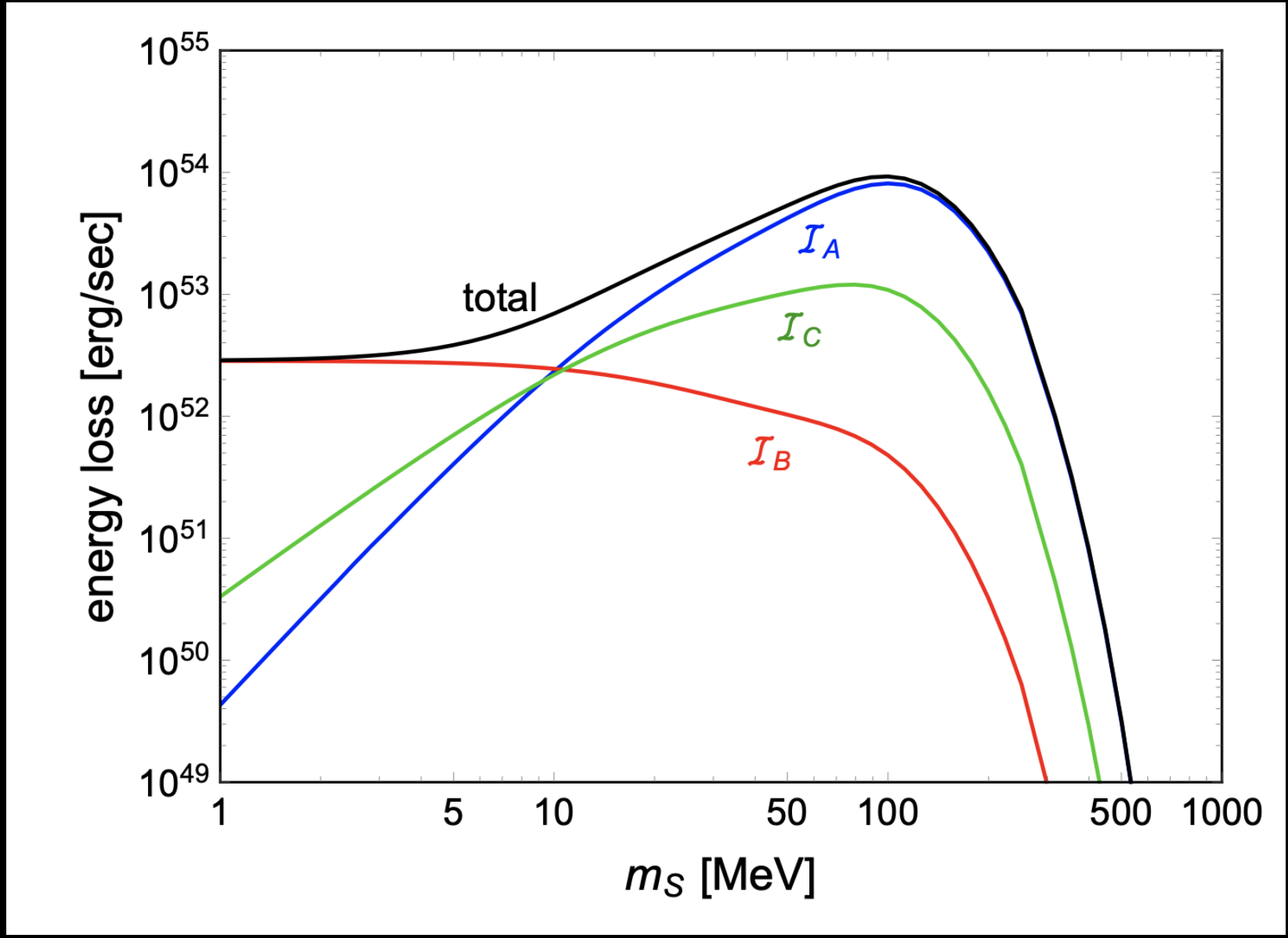


$$\mathcal{M}_a + \mathcal{M}_b + \mathcal{M}_c + \mathcal{M}_d \simeq 0\,,$$
$$\mathcal{M}_{a'} + \mathcal{M}_{b'} + \mathcal{M}_{c'} + \mathcal{M}_{d'} \simeq 0\,.$$

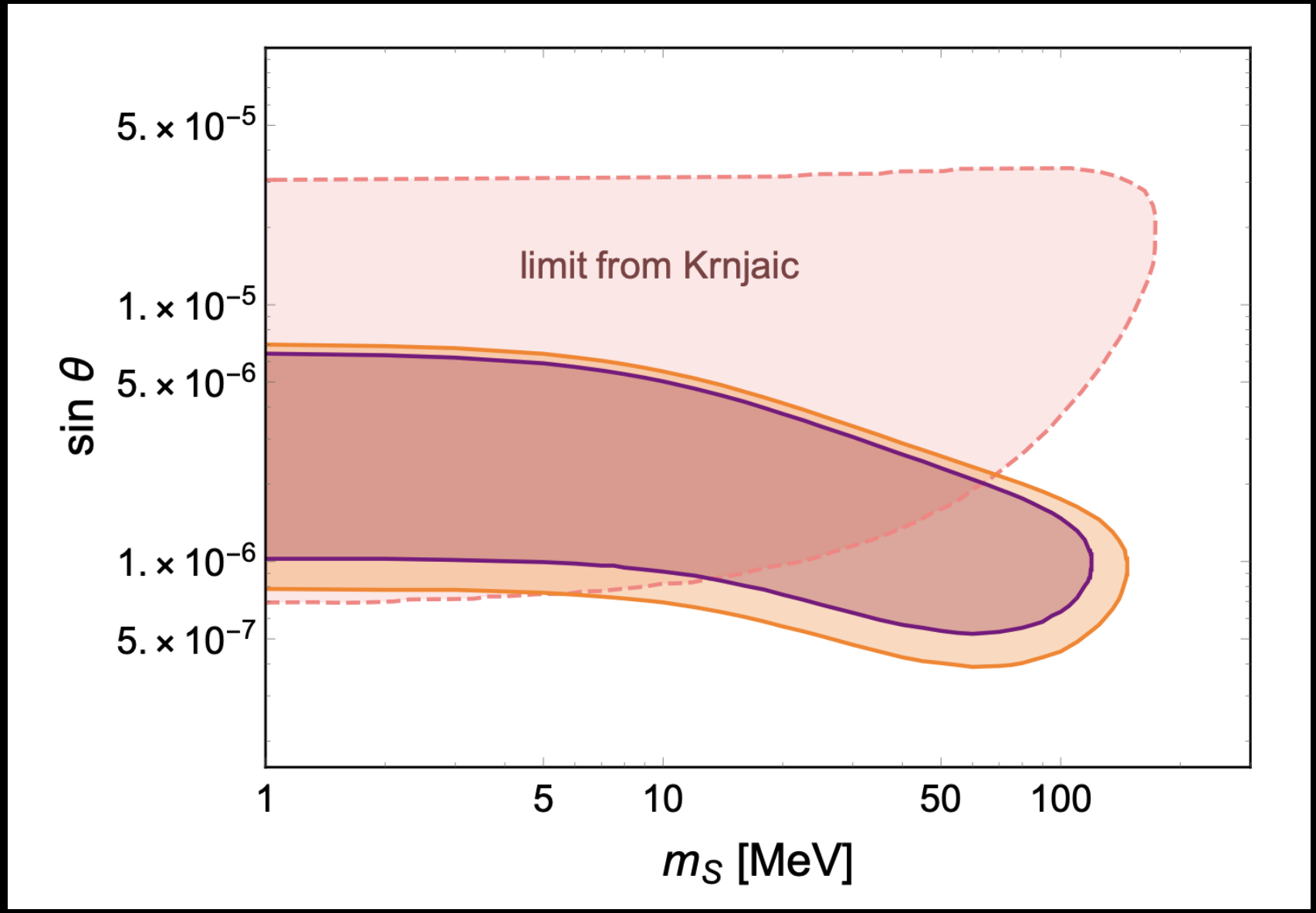
To the LO of $m_S^2/m_N E_S$

Coupling to pion mediator is important.
Absent in the CP-odd case.

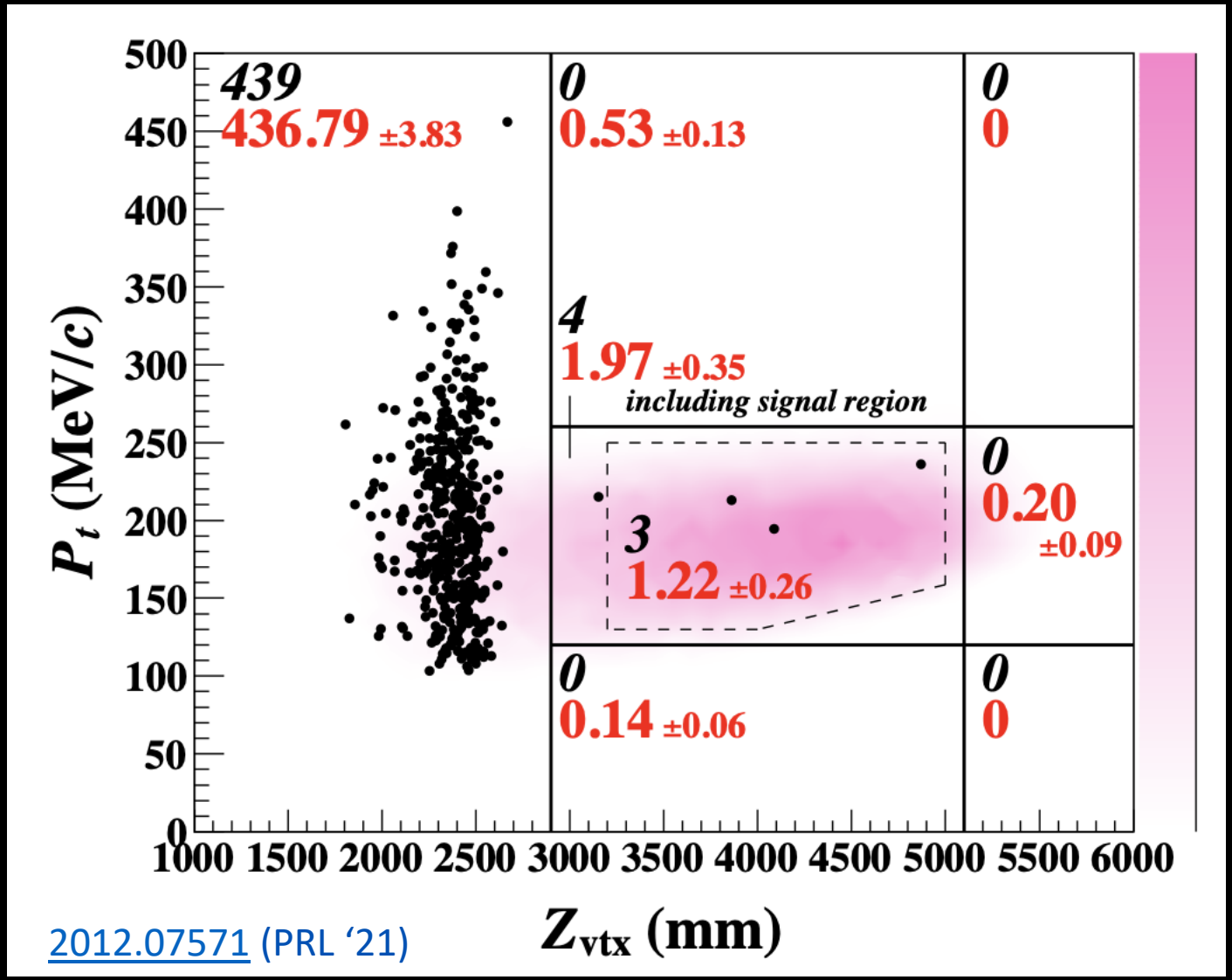
Comparison of Different Contributions



Updated SN1987A Bound on CP-even Scalar



Meanwhile, KOTO Anomaly Disappeared



2012.07571 (PRL '21)

More background than initial estimate.

Corresponding probability of observing 3 events is 13%.

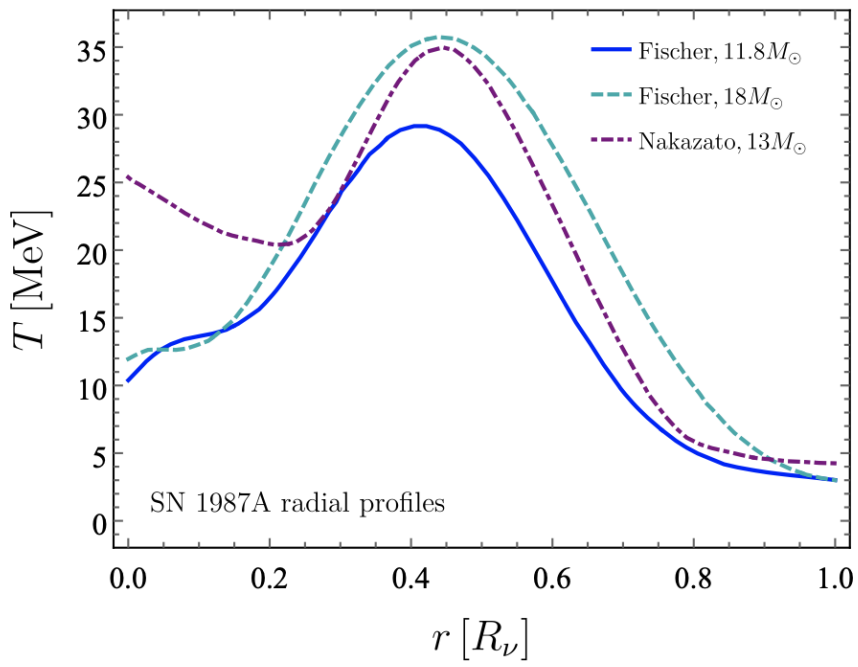
No New Physics yet (again).

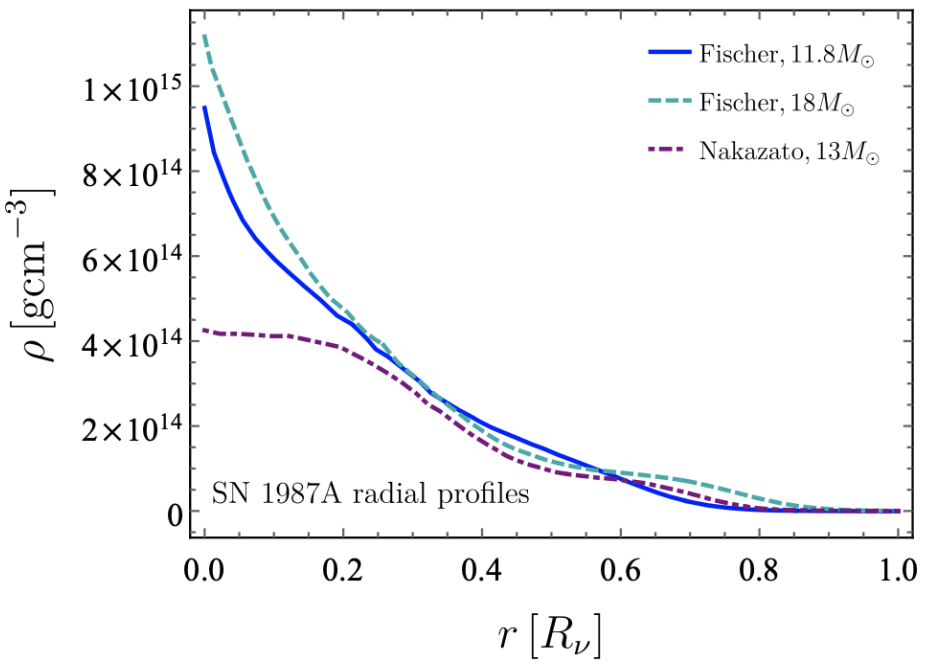
☹

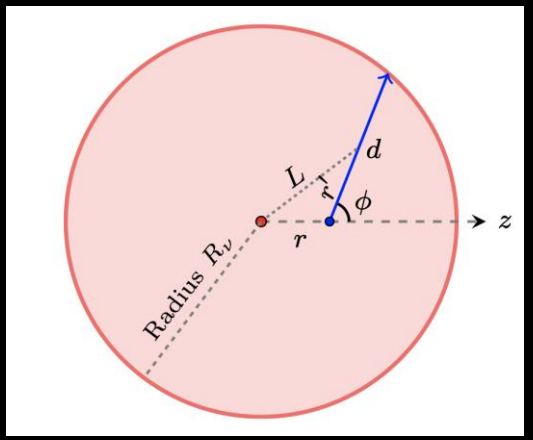
But still recalculating the supernova constraint was a useful exercise.

There is more to the Supernova story

Balaji, BD, Silk, Zhang, 2205.01669







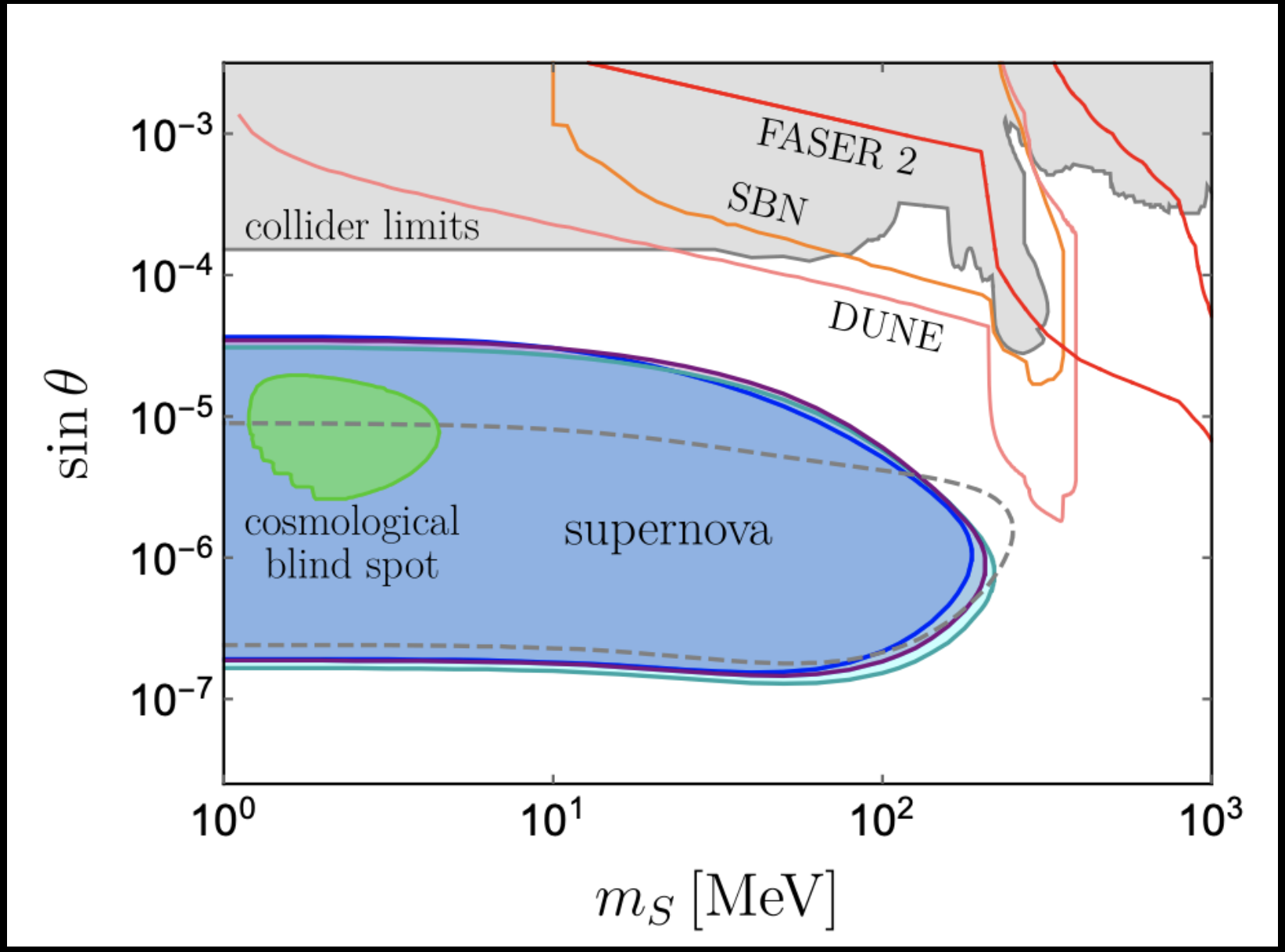
Geometry effect

Include the changing **temperature and density profile** effects.

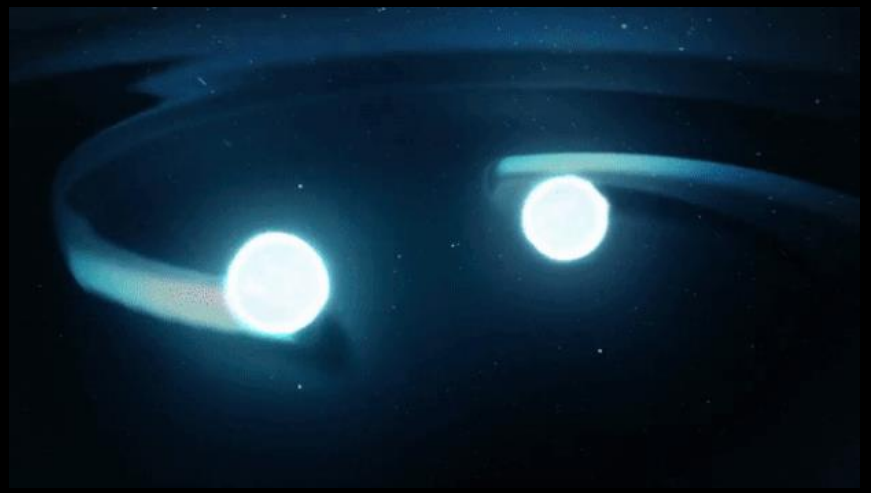
For axions, done in Chang, Essig, McDermott, 1611.03864 (JHEP '17)

was not included even for axions until a week before our work: Caputo,Raffelt, Vitagliano, 2204.11862 (JCAP '22)

Reupdated SN1987A Bound

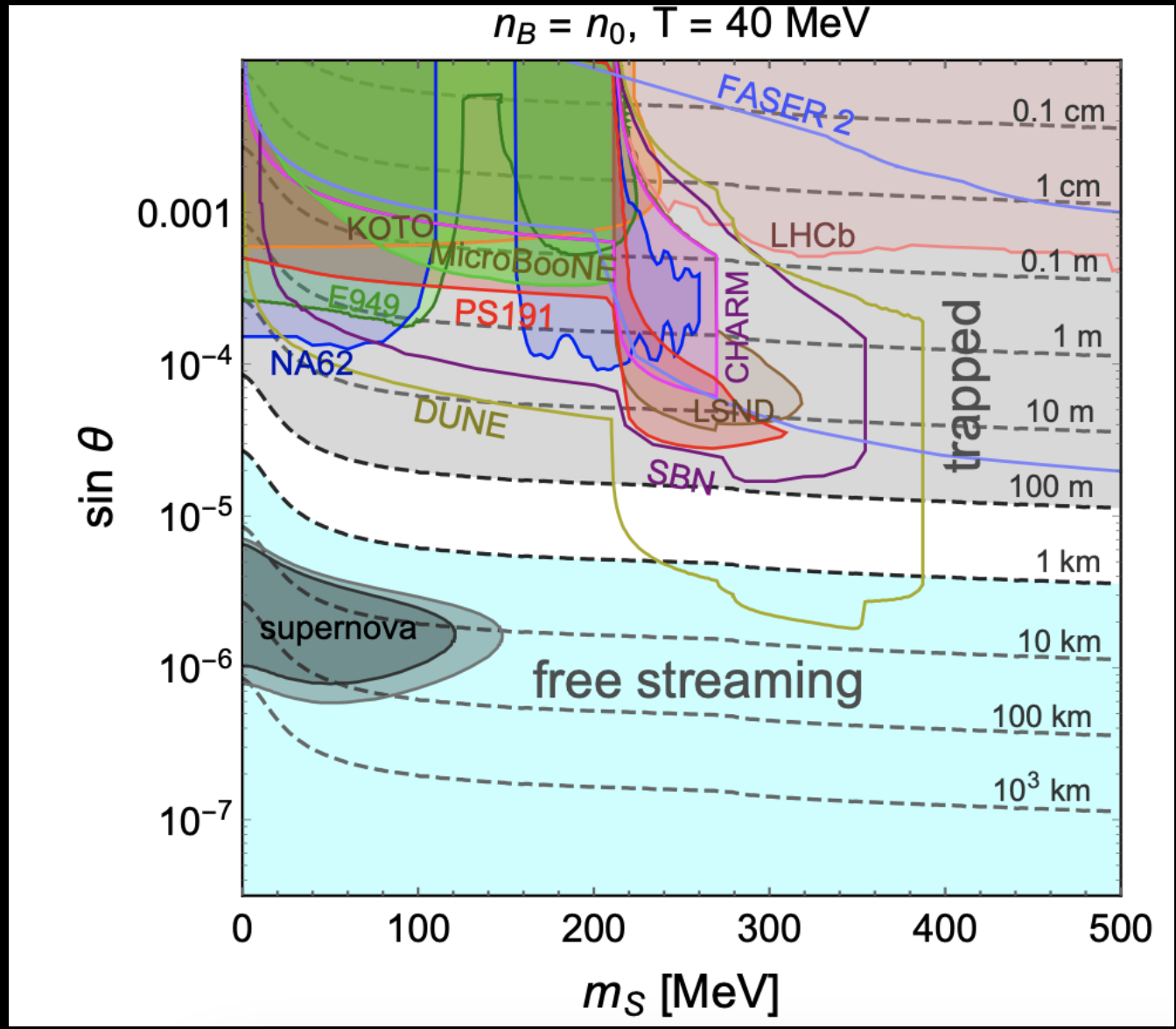


NS Mergers



From CBSNews

A New Multimesseger Window to BSM Physics



Axion: Harris, Fortin, Sinha, Alford, 2003.09768 (JCAP '21)

Dark photon: Diamond, Marques-Tavares, 2106.03879 (PRL '22)

BD, Harris, Fortin, Sinha, Zhang, 2111.05852 (JCAP '22)

How about other stellar structures?

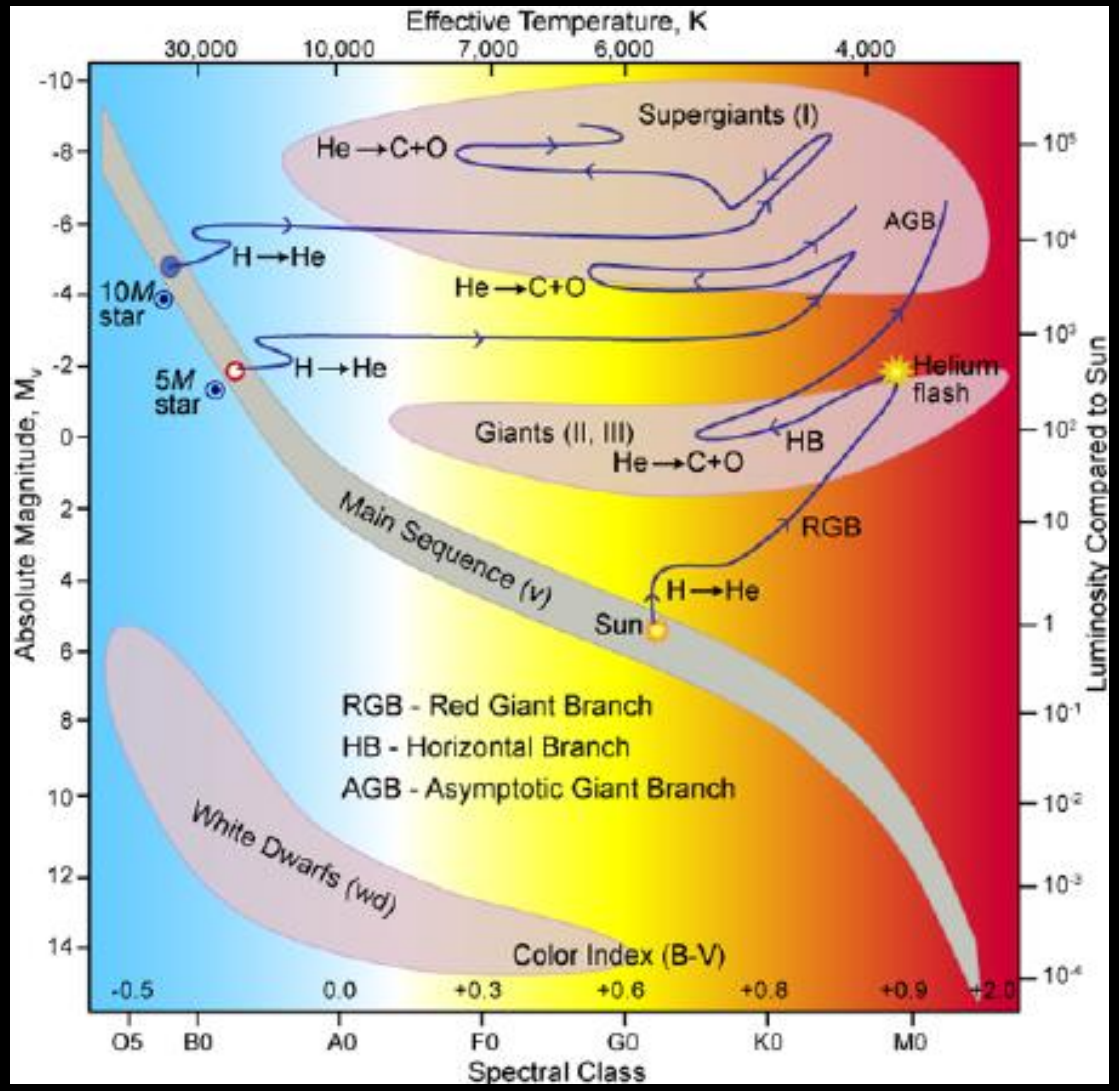
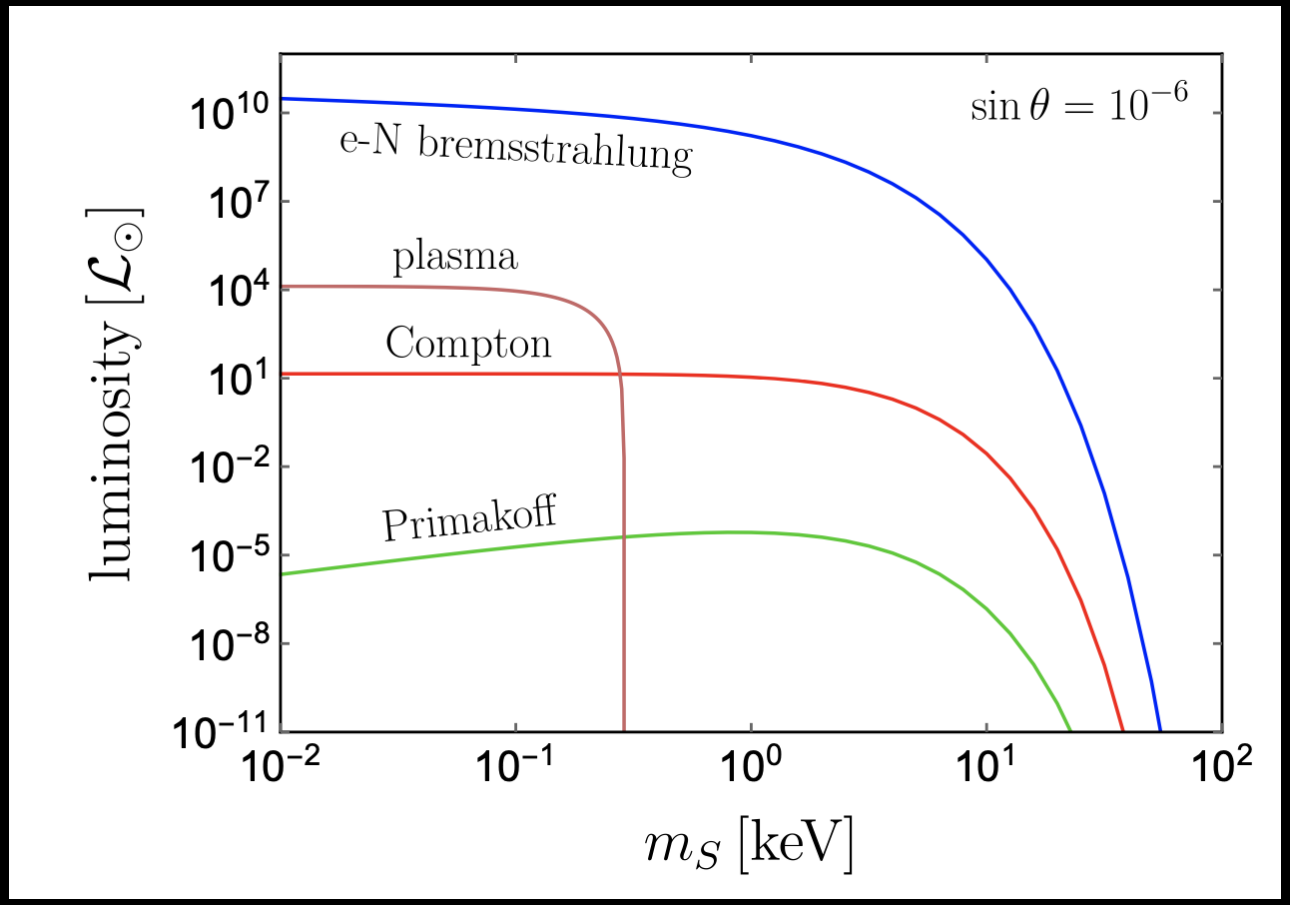


Figure from Robert Hollow



BD, Mohapatra, Zhang, 2010.01124 (JCAP '21);
Balaji, BD, Silk, Zhang, 2205.01669

Updated Stellar Limits

Star	Profile	Geometry	$\sin\theta$ range	m_S range
SN1987A	–	–	$2.4 \times 10^{-7} - 9.0 \times 10^{-6}$	< 249 MeV
	Fischer $11.8M_\odot$	✓	$1.5 \times 10^{-7} - 3.8 \times 10^{-5}$	< 187 MeV
	Fischer $18M_\odot$	✓	$1.3 \times 10^{-7} - 3.1 \times 10^{-5}$	< 219 MeV
	Nakazato $13M_\odot$	✓	$1.5 \times 10^{-7} - 3.6 \times 10^{-5}$	< 205 MeV
Sun	–	–	$7.4 \times 10^{-14} - 1.2 \times 10^{-3}$	< 40 keV
	standard solar model	✓	$1.5 \times 10^{-12} - 1$	< 45 keV
RGs	–	–	$5.3 \times 10^{-13} - 5.3 \times 10^{-3}$	< 384 keV
	–	✓	$5.3 \times 10^{-13} - 0.39$	< 392 keV
WDs	–	–	$2.8 \times 10^{-18} - 2.4 \times 10^{-6}$	< 283 keV
	–	✓	$2.8 \times 10^{-18} - 1.8 \times 10^{-4}$	< 290 keV

BD and HB stars to be included (ongoing)

Conclusion

- To quote Jim Gates, “If we had more people like Rabi, the world would have been a *much* better place”.
- Rabi is *the* best physicist, mentor, guide and collaborator I have interacted with so far.
- Looking forward to many more years of productive research with Rabi.
- Wish a very happy retirement life to Rabi and Manju Apa.

Photo Courtesy: Deepak Sathyan

Thank you.