Prospects for detecting eV-scale sterile neutrinos from a galactic supernova

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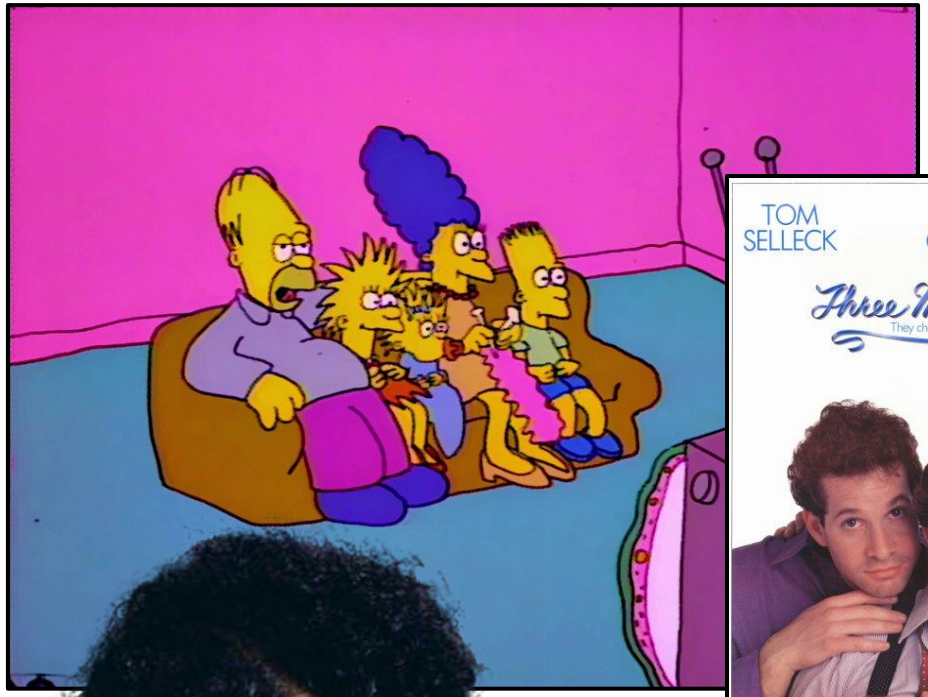
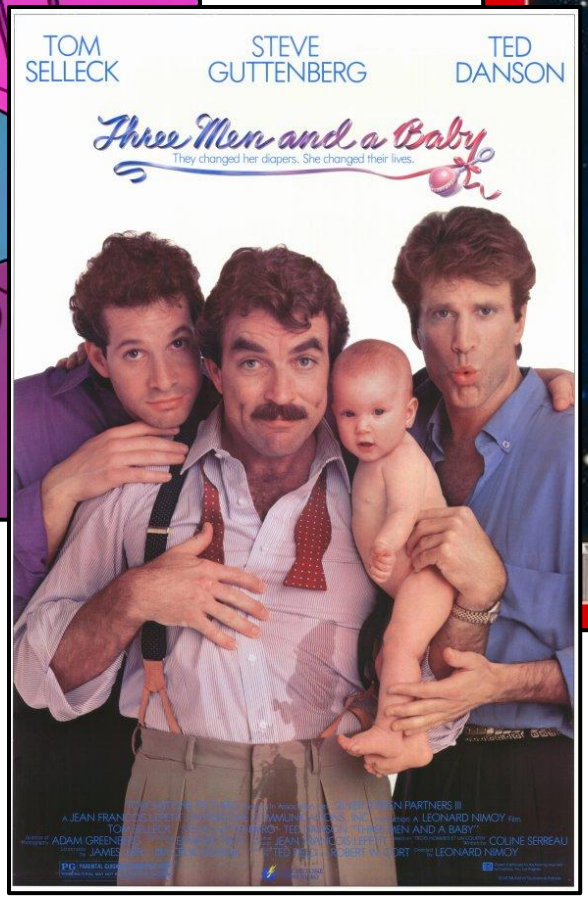
YTF, 2018

CORE-COLLAPSE SUPERNOVA

- $M \gtrsim 8\ M_{\odot}$
- $0.99\ U_G$ → neutrinos of all flavours
- 10^{57} neutrinos in ~ 10 seconds

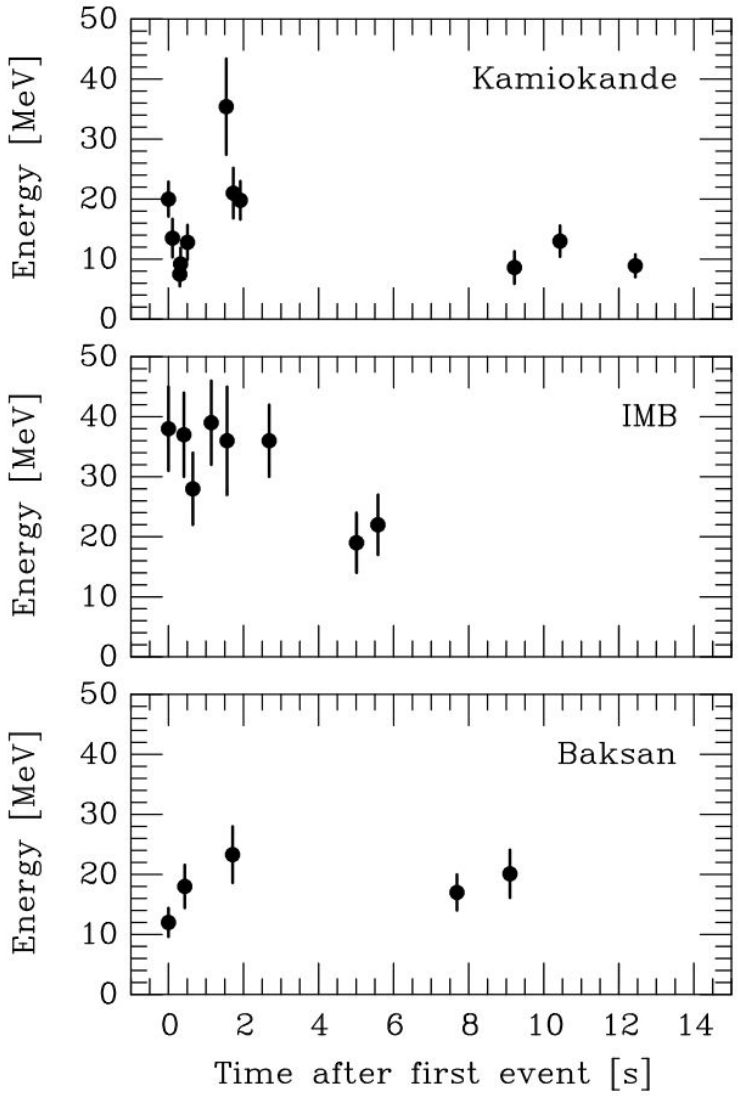
1987



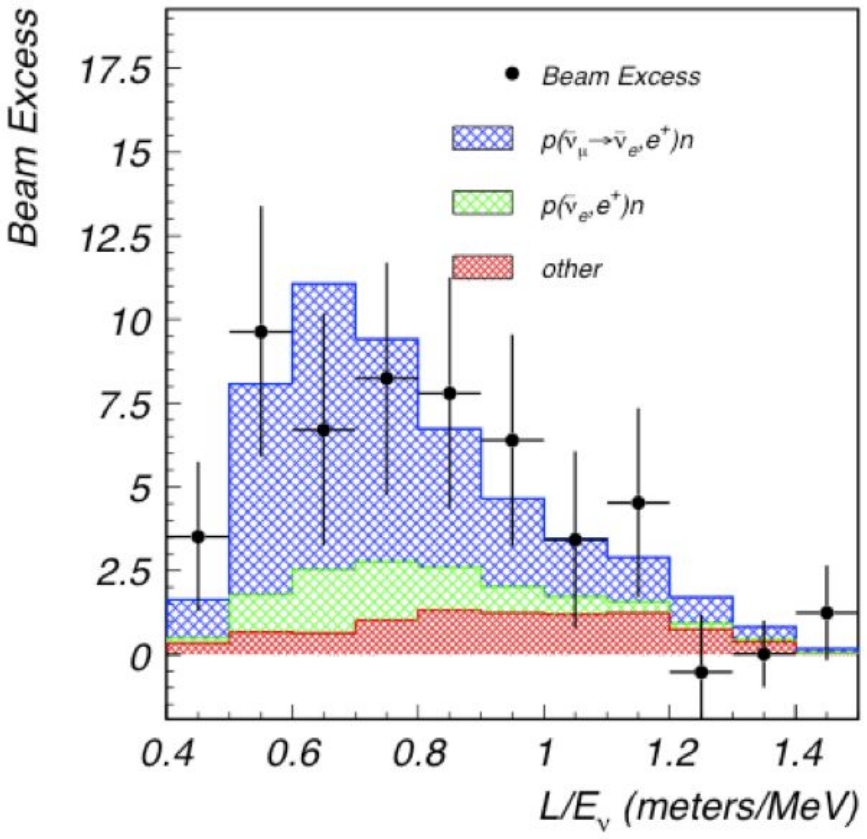

TOM SELLECK
STEVE GUTTENBERG
TED DANSON
Three Men and a Baby
They changed her diapers. She changed their lives.


MARCH 23, 1987
$1.95
TIME
ISRAEL
The Spy Case
Furor
BANG!
A Star Explodes, Providing New Clues
To the Nature of the Universe

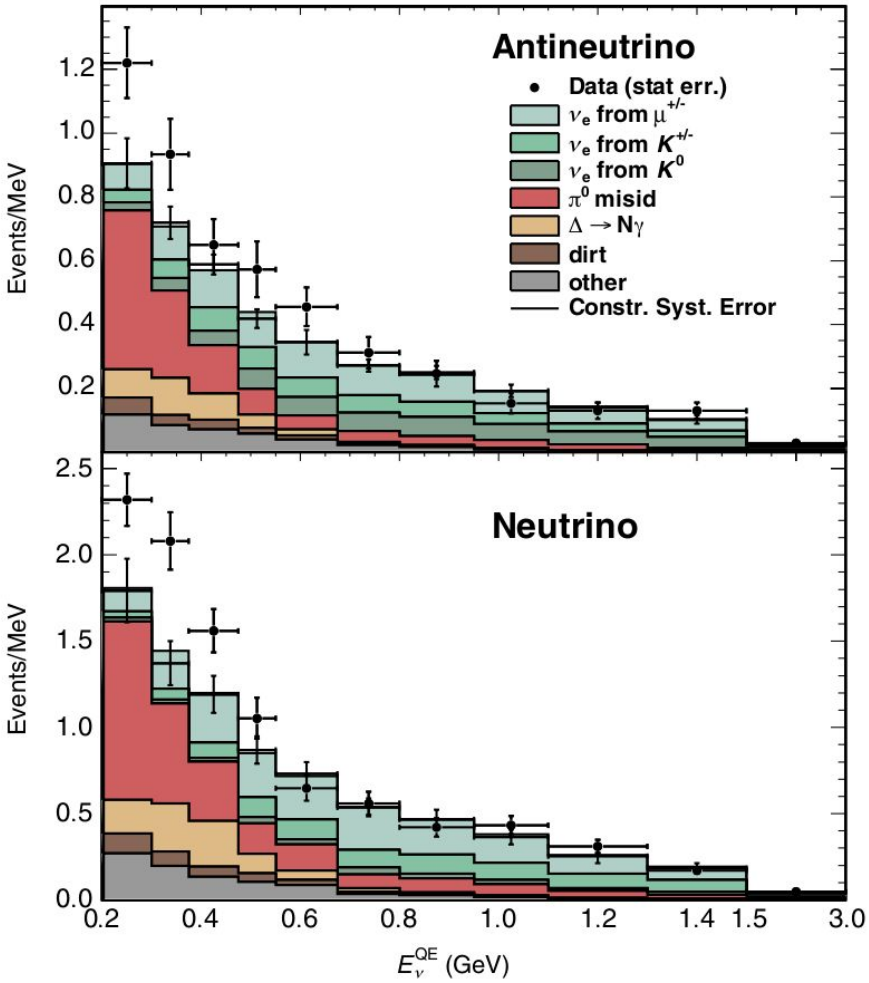
SN 1987A


Kamiokande
IMB
Baksan
Energy [MeV]
Energy [MeV]
Energy [MeV]
0
10
20
30
40
50
0
2
4
6
8
10
12
14
Time after first event [s]

SHORT BASELINE ANOMALIES



LSND

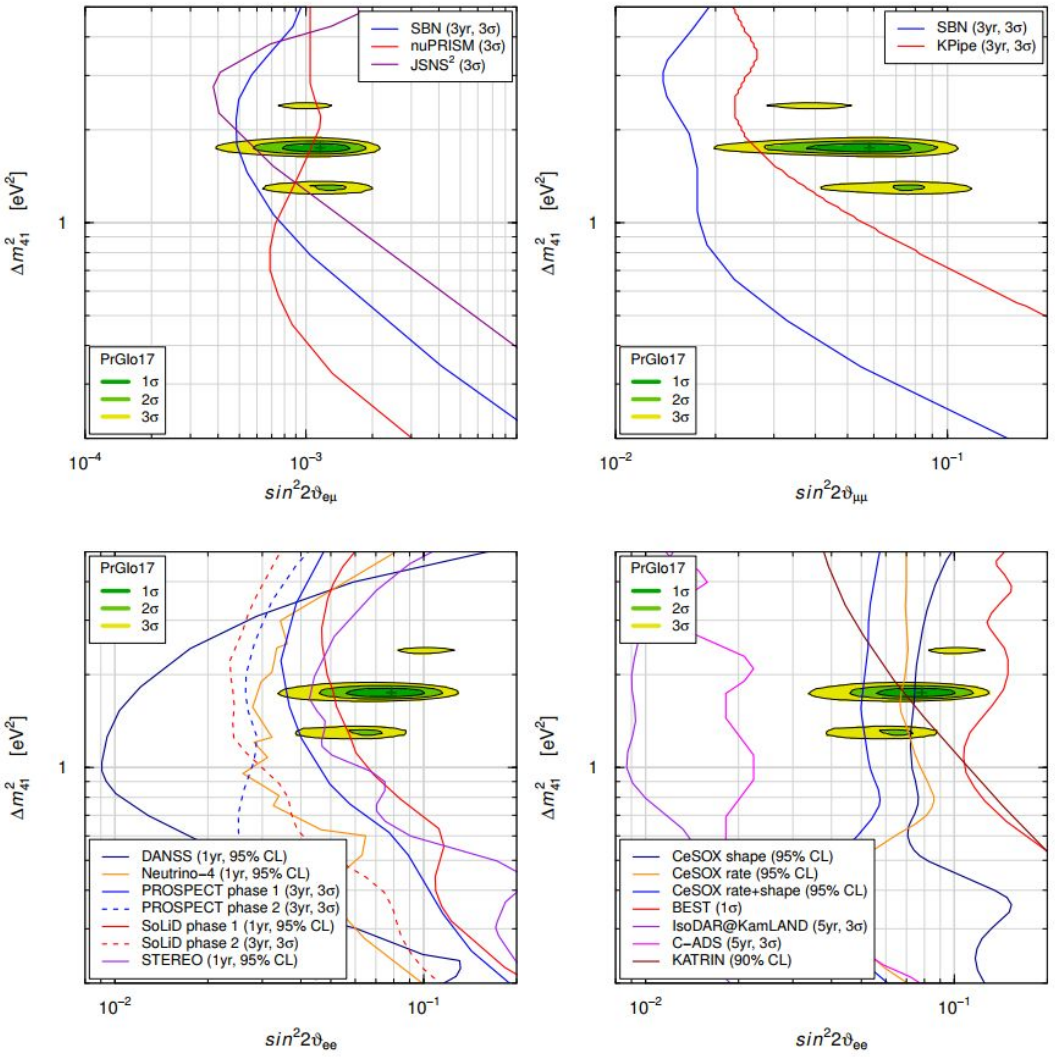


MiniBooNE

SHORT BASELINE ANOMALIES

- Anomalies not yet ruled out.

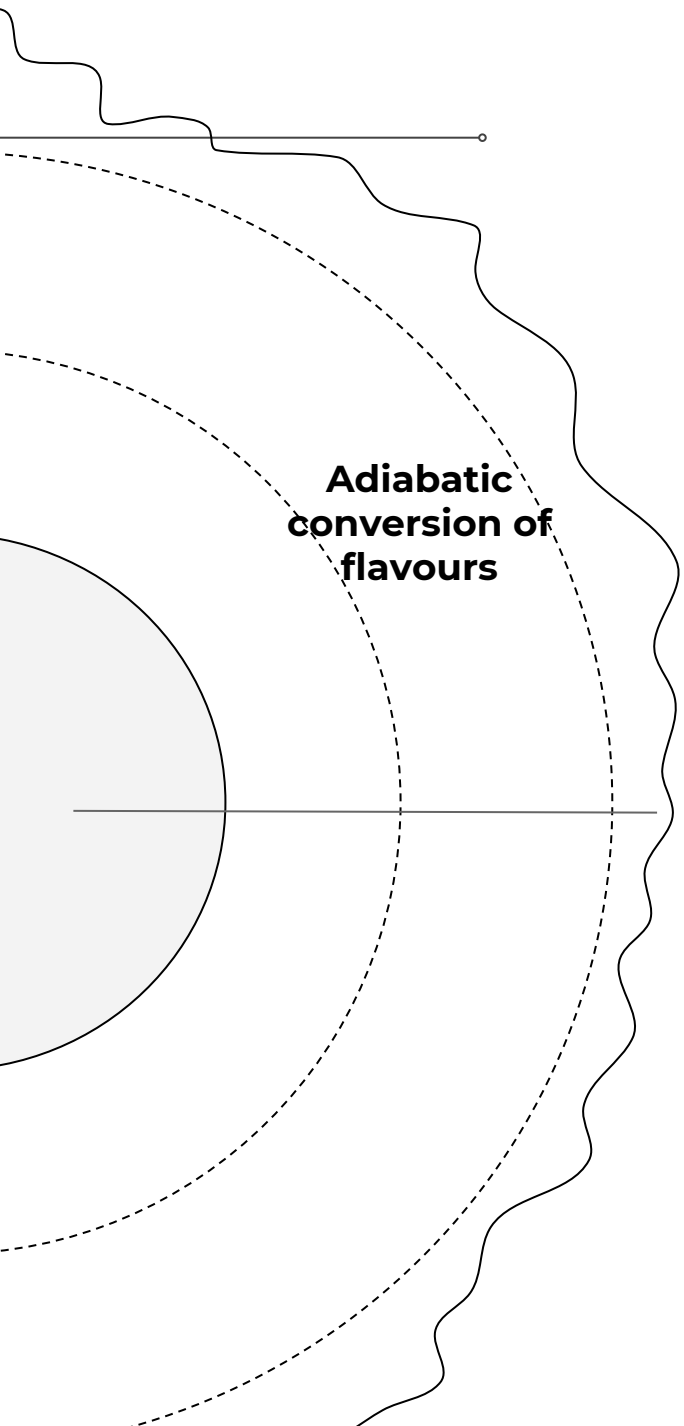
- Definitive answer in the next few years!



JHEP **06** (2017) 135, [arXiv:1703.00860]

CAN STERILE NEUTRINOS PRODUCE OBSERVABLE EFFECTS ON SUPERNOVAE FLUXES?

BASIC IDEA



Non-coherent propagation

Detection

SOLAR NEUTRINO PROBLEM

- Sun produces only electron neutrinos.

$$F_\nu = F_{\nu_e}$$

- Homestake experiment (1968):

$$F_{\mathrm{H}} \simeq \frac{1}{3} F_\nu$$

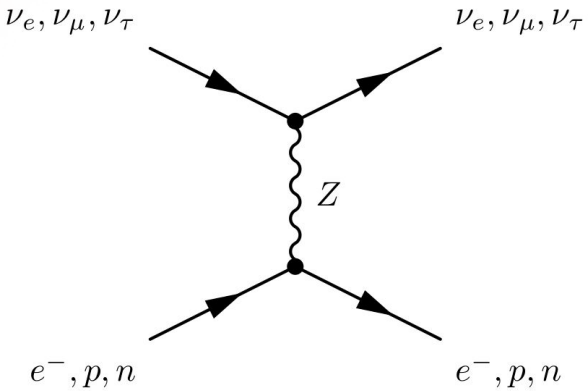
- SNO (2001):

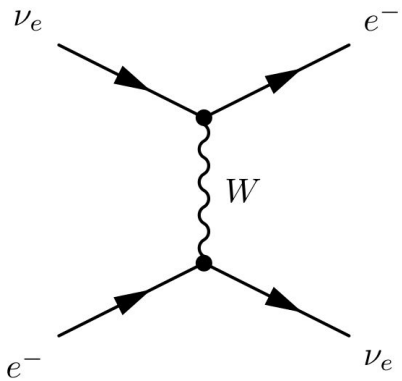
$$F_{\mathrm{SNO}} = F_\nu$$

$$\left.\frac{F_{\nu_e}}{F_\nu}\right|_{\mathrm{SNO}} \simeq \frac{1}{3}$$

ADIABATIC CONVERSION

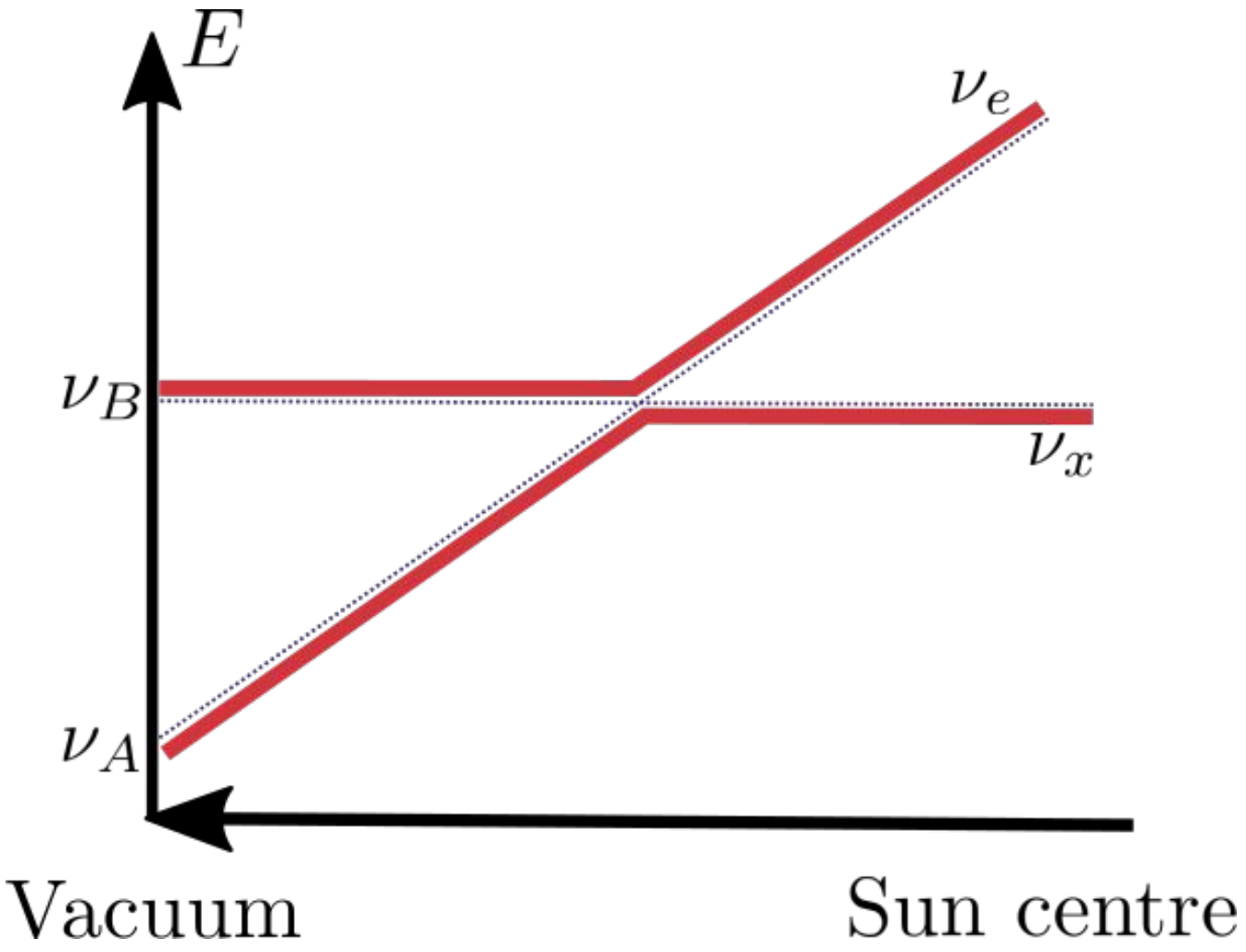
$$\nu_A = \nu_e \cos\theta + \nu_x \sin\theta$$
$$\nu_B = -\nu_e \sin\theta + \nu_x \cos\theta$$





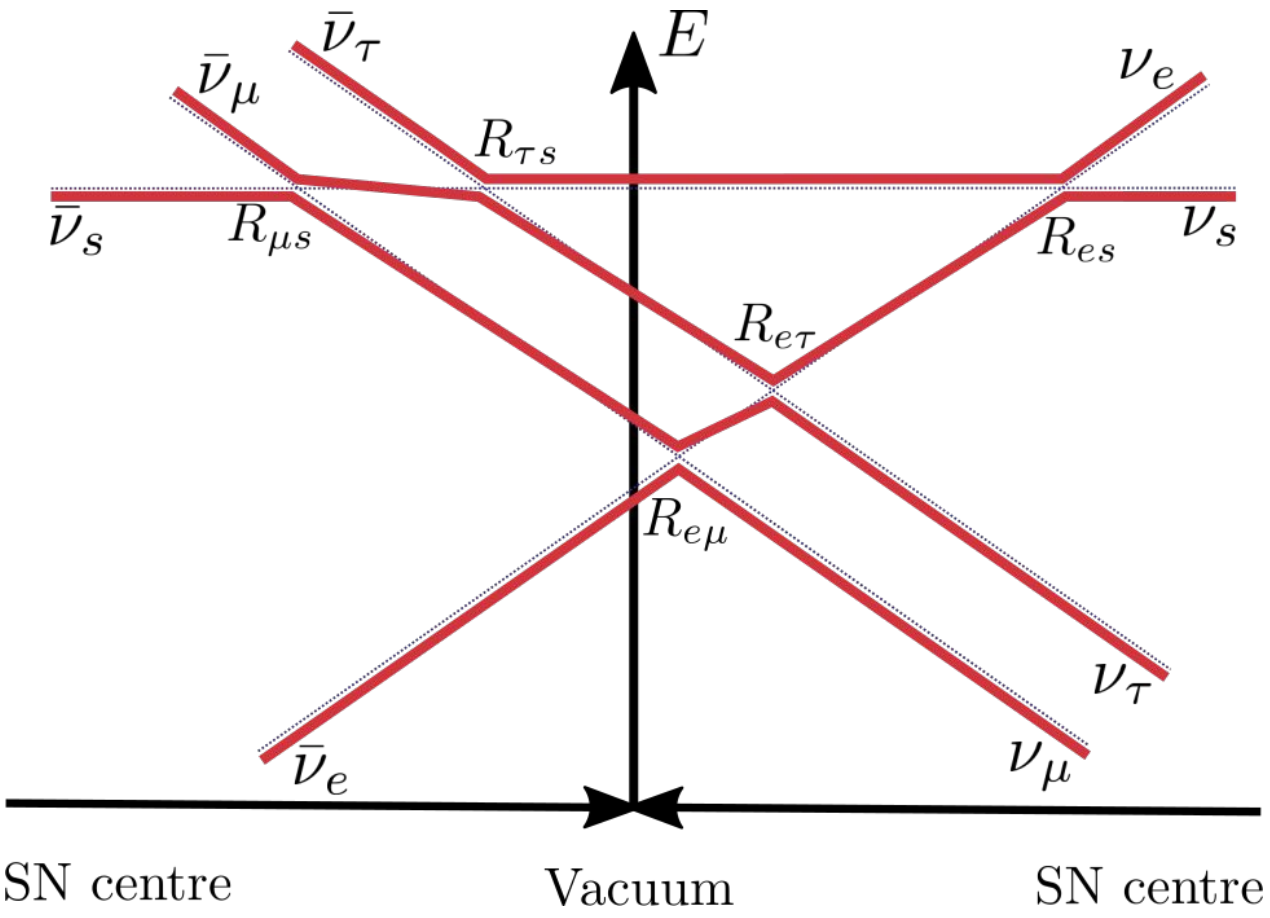
Production region: $\theta = \frac{\pi}{2} \quad \nu_e \simeq \nu_B$

ADIABATIC CONVERSION



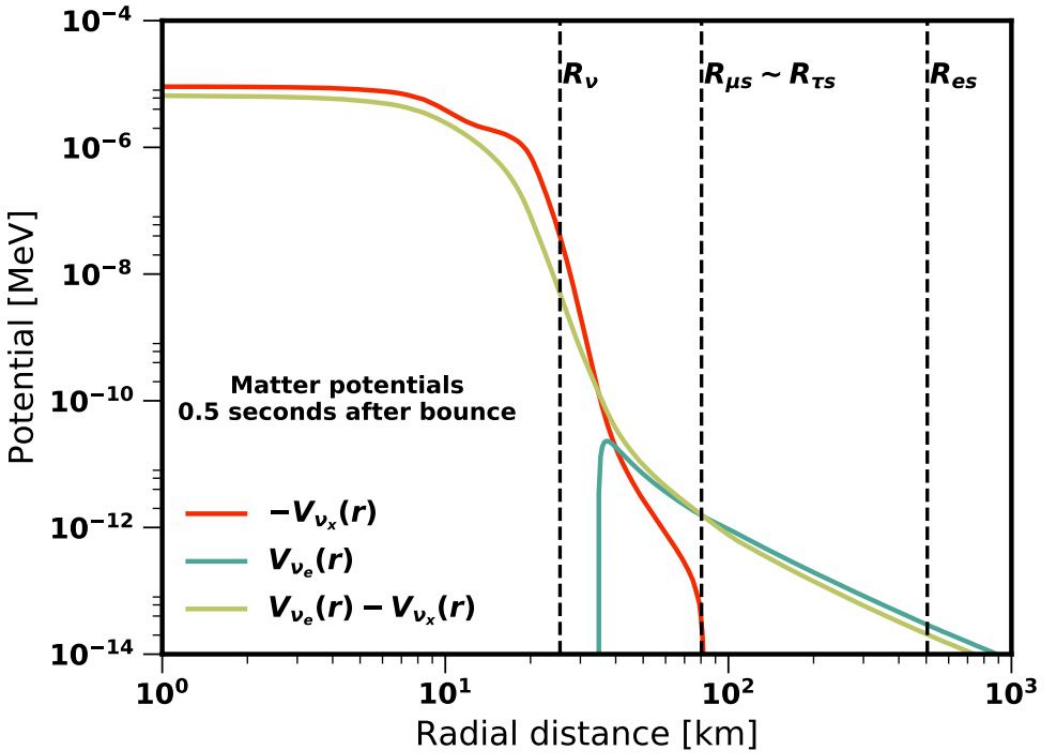
$$\nu_A \not\leftrightarrows \nu_B$$

3+1 NEUTRINOS IN A SUPERNOVA



SUPERNOVA SIMULATION

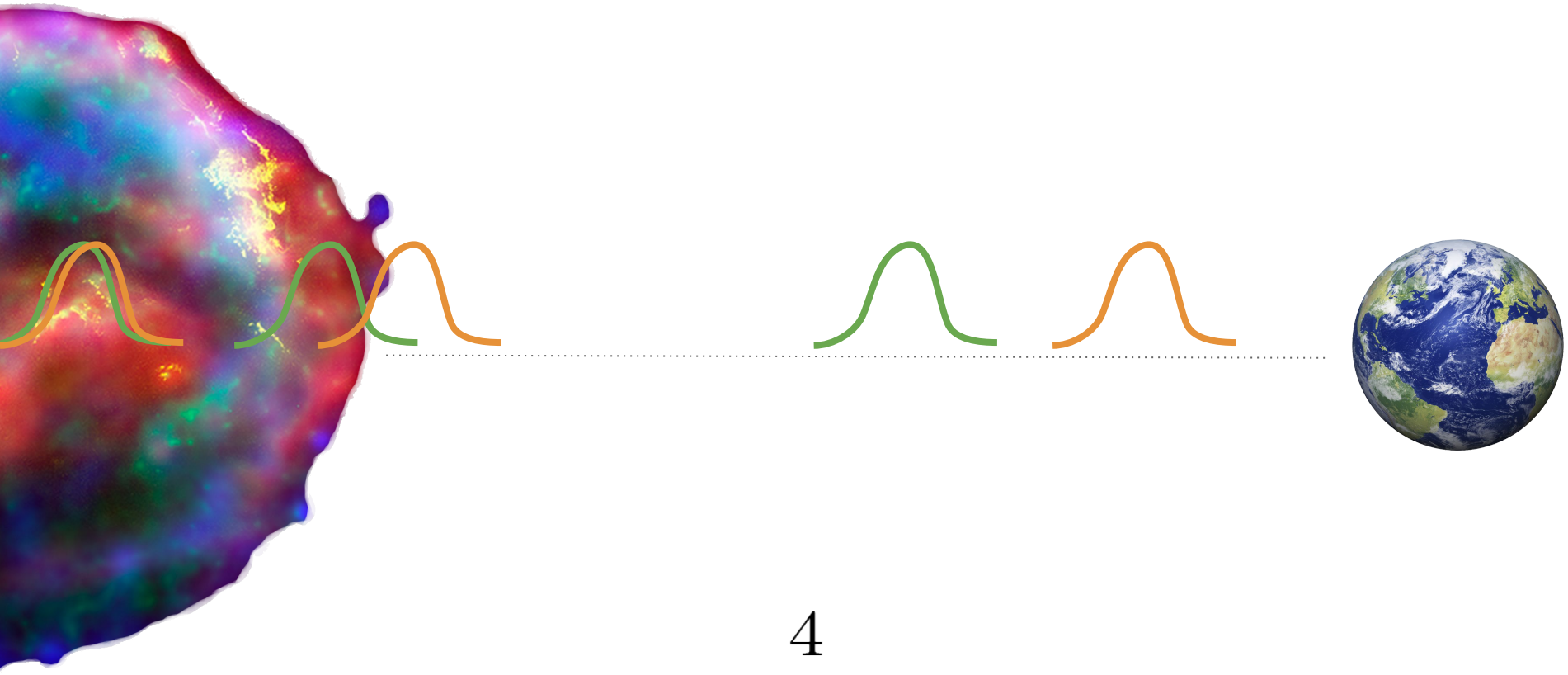
- Simulation of an 8.8 $M_\odot$ supernova by the Garching group*.



$$P_{\text{jumping}} = \exp\left[-\frac{\pi}{2}\frac{\tan 2\theta_0 |E_i - E_j|_{res}}{\left|\frac{1}{V}\frac{\partial V}{\partial r}\right|}\right]$$

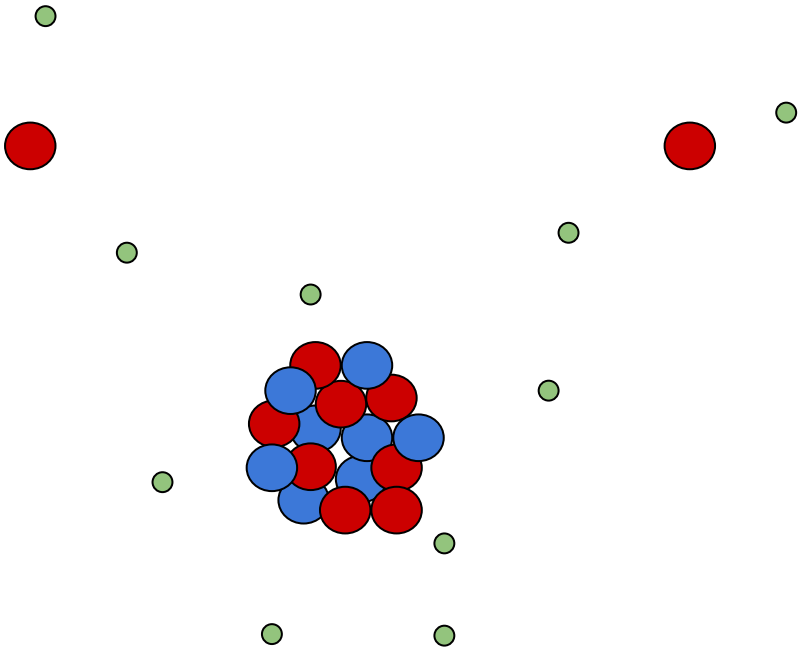
*Physical Review Letters **104** 251101

LOSS OF COHERENCE



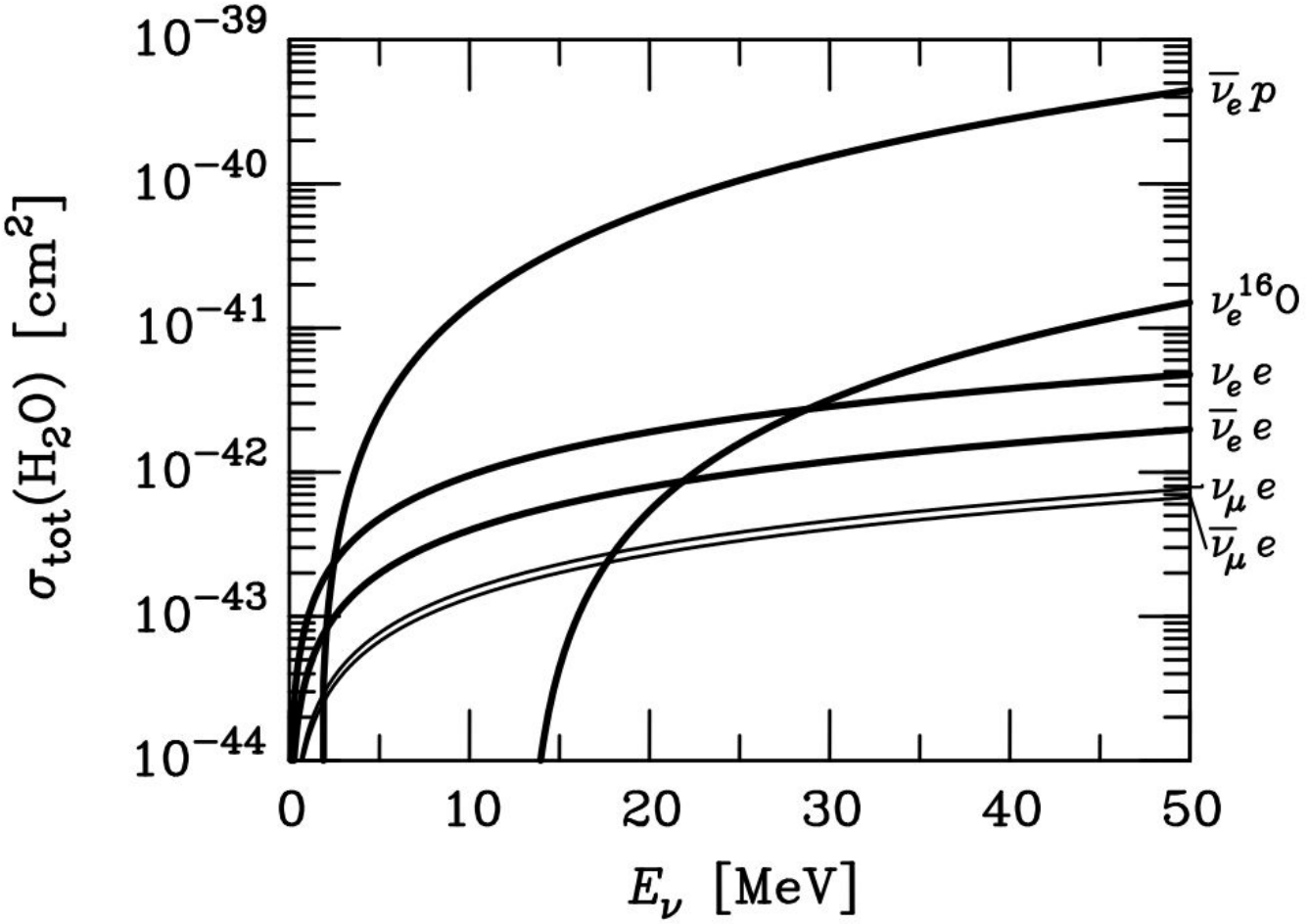
$$F_{\nu_\alpha} = \sum_{i=1}^{4} |U_{\alpha i}|^2 F_{\nu_i}$$

DETECTORS



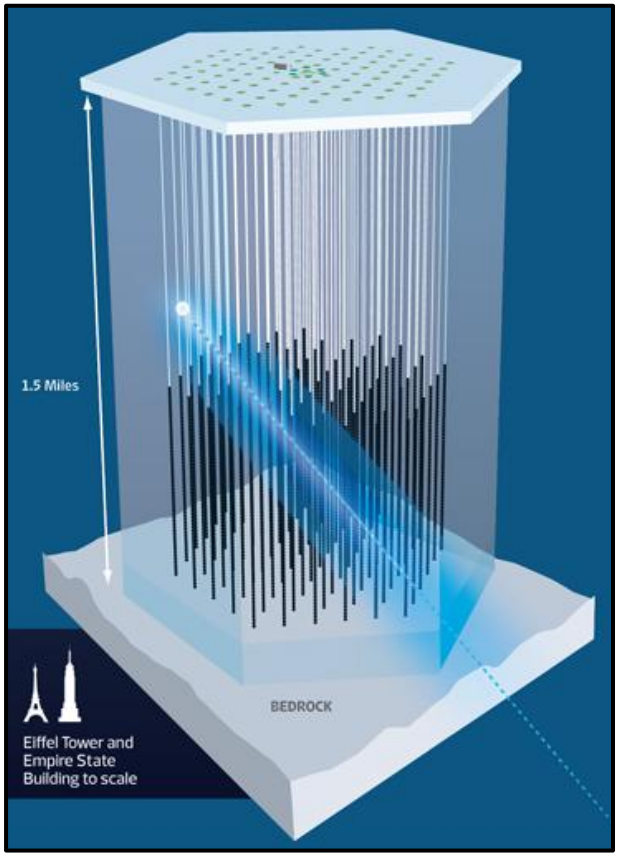
$$\nu + e^- \rightarrow \nu + e^-$$
$$\bar{\nu}_e + p \rightarrow n + e^+$$
$$\nu_e + {}^{16}\mathrm{O} \rightarrow {}^{16}\mathrm{F} + e^-$$

DETECTORS

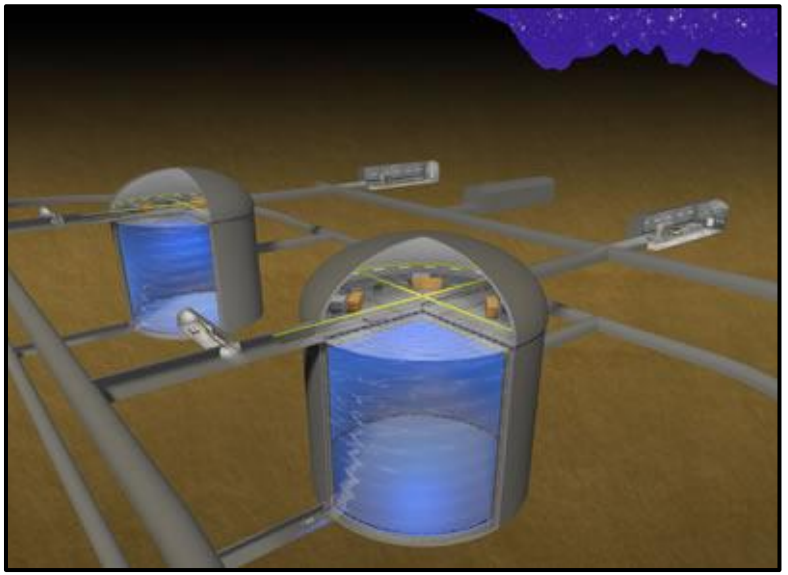


$$\bar{\nu}_e + p \rightarrow n + e^+$$

DETECTORS



IceCube



Hyper-Kamiokande

PARAMETERS

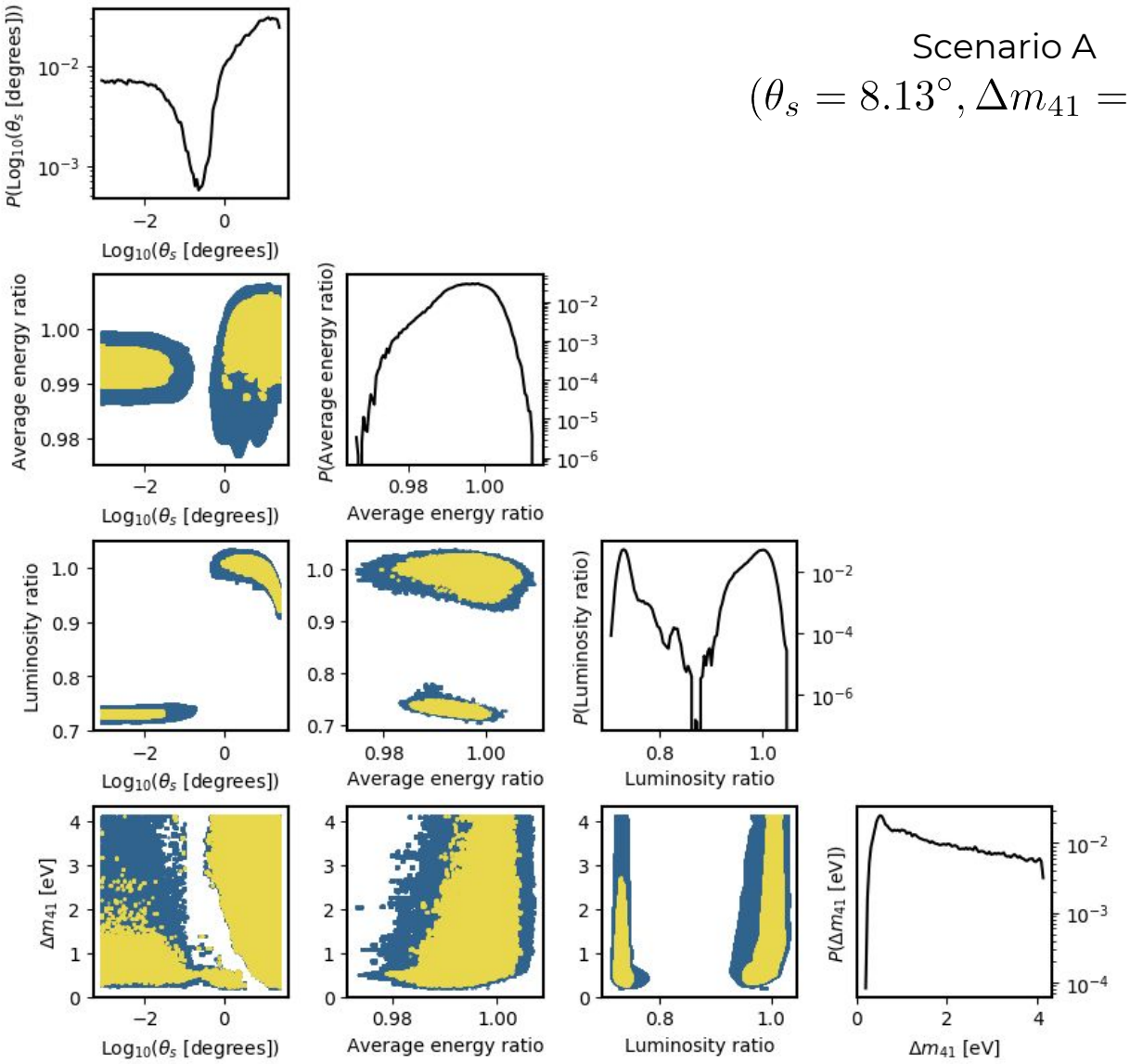
$$\theta_s = c_1 \times 8.13^\circ$$

$$\Delta m_{41} = c_2 \times 1.3\,\mathrm{eV}$$

$$\theta_{14} = \theta_{24} = \theta_{34} \equiv \theta_s$$

Scenario	c_1	c_2	Description
A	1	1	global fit to short baseline experiments
B	0.1	1	small active-sterile mixing angle
C	1	0.1	small mostly sterile state mass
D	0	-	no active-sterile mixing

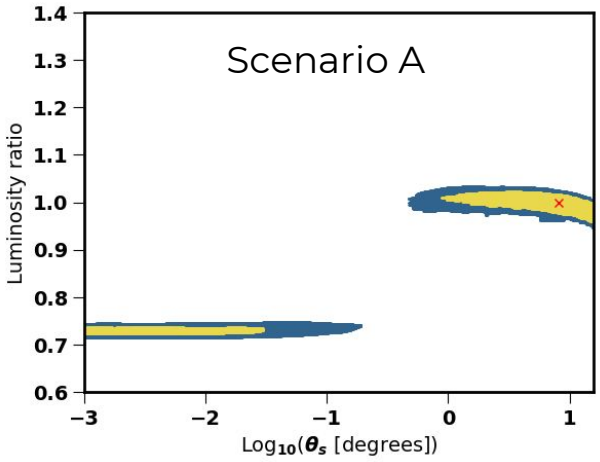
HYPER-KAMIOKANDE

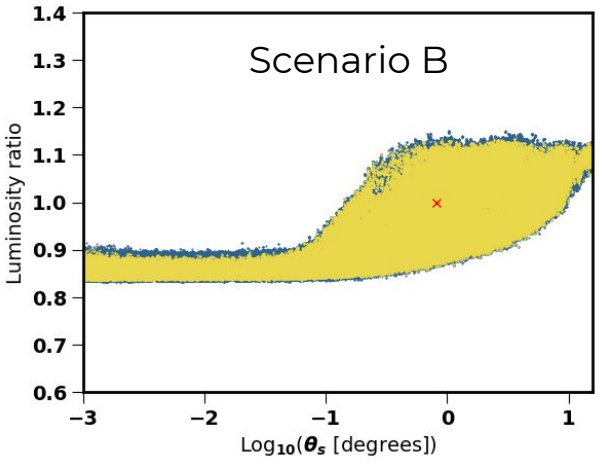


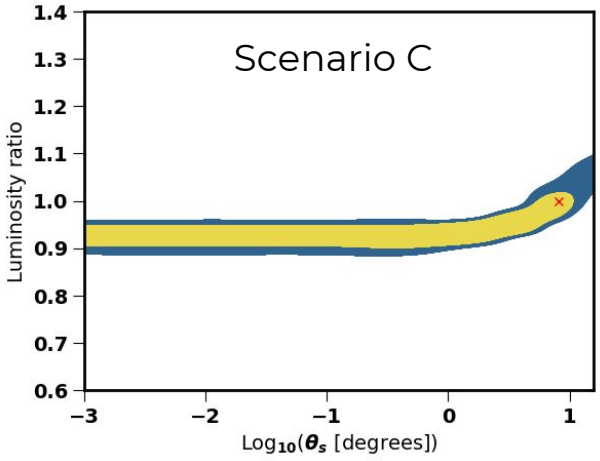
Scenario A

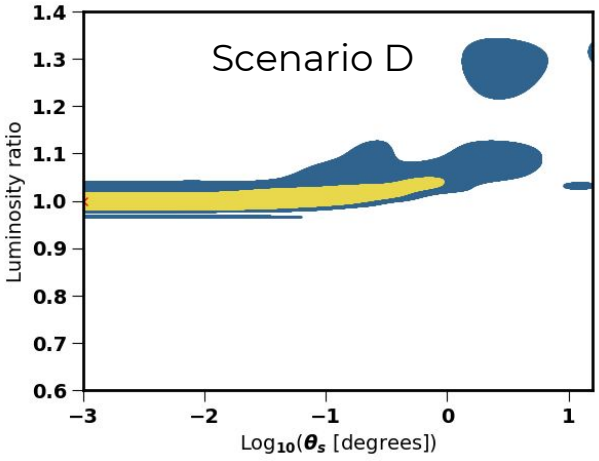
$(\theta_s = 8.13^\circ, \Delta m_{41} = 1.3\,\mathrm{eV})$

HYPER-KAMIOKANDE

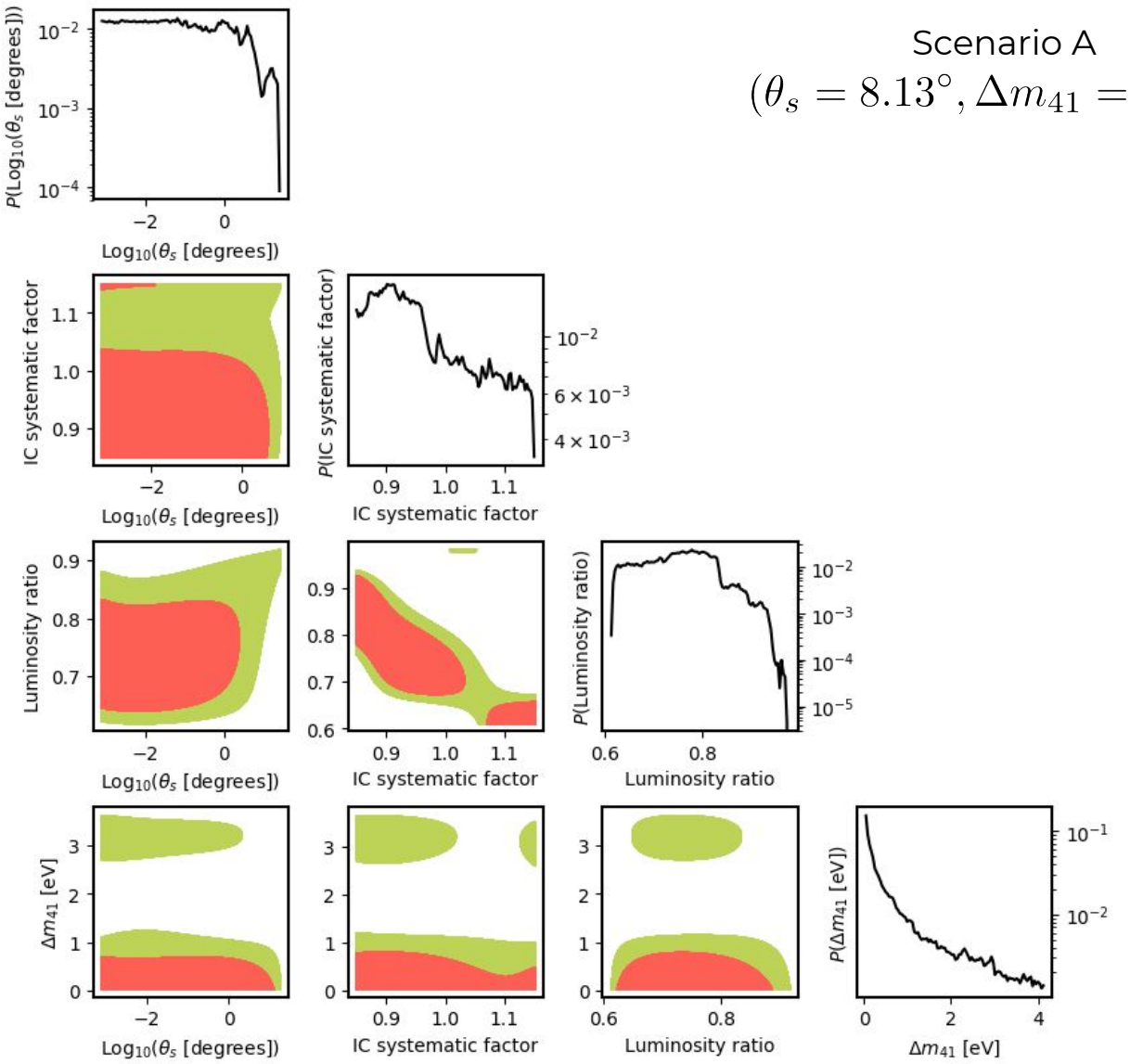








ICECUBE



Scenario A

$(\theta_s = 8.13^\circ, \Delta m_{41} = 1.3\,\mathrm{eV})$

SUMMARY

- **CAN STERILE NEUTRINOS PRODUCE OBSERVABLE EFFECTS ON SUPERNOVAE FLUXES?** Yes, they can.
- Without knowledge of the expected neutrino luminosity it is difficult to constrain the existence of sterile neutrinos.
- Without knowing whether sterile neutrinos exist and their properties, we cannot measure a supernova luminosity accurately.
- More details can be found on 1712.03836.

DETECTORS

Detector	Type	Mass (kt)	Location	Events	Status
Super-Kamiokande	H_2O	32	Japan	7,000	Running
LVD	C_nH_{2n}	1	Italy	300	Running
KamLAND	C_nH_{2n}	1	Japan	300	Running
Borexino	C_nH_{2n}	0.3	Italy	100	Running
IceCube	Long string	(600)	South Pole	(10^6)	Running
Baksan	C_nH_{2n}	0.33	Russia	50	Running
HALO	Pb	0.08	Canada	30	Running
Daya Bay	C_nH_{2n}	0.33	China	100	Running
NOνA*	C_nH_{2n}	15	USA	4,000	Running
MicroBooNE*	Ar	0.17	USA	17	Running
SNO+	C_nH_{2n}	0.8	Canada	300	Near future
DUNE	Ar	40	USA	3,000	Future
Hyper-Kamiokande	H_2O	374	Japan	75,000	Future
JUNO	C_nH_{2n}	20	China	6000	Future
RENO-50	C_nH_{2n}	18	Korea	5400	Future
PINGU	Long string	(600)	South Pole	(10^6)	Future

[arXiv:1707.06384]

TEMPERATURE