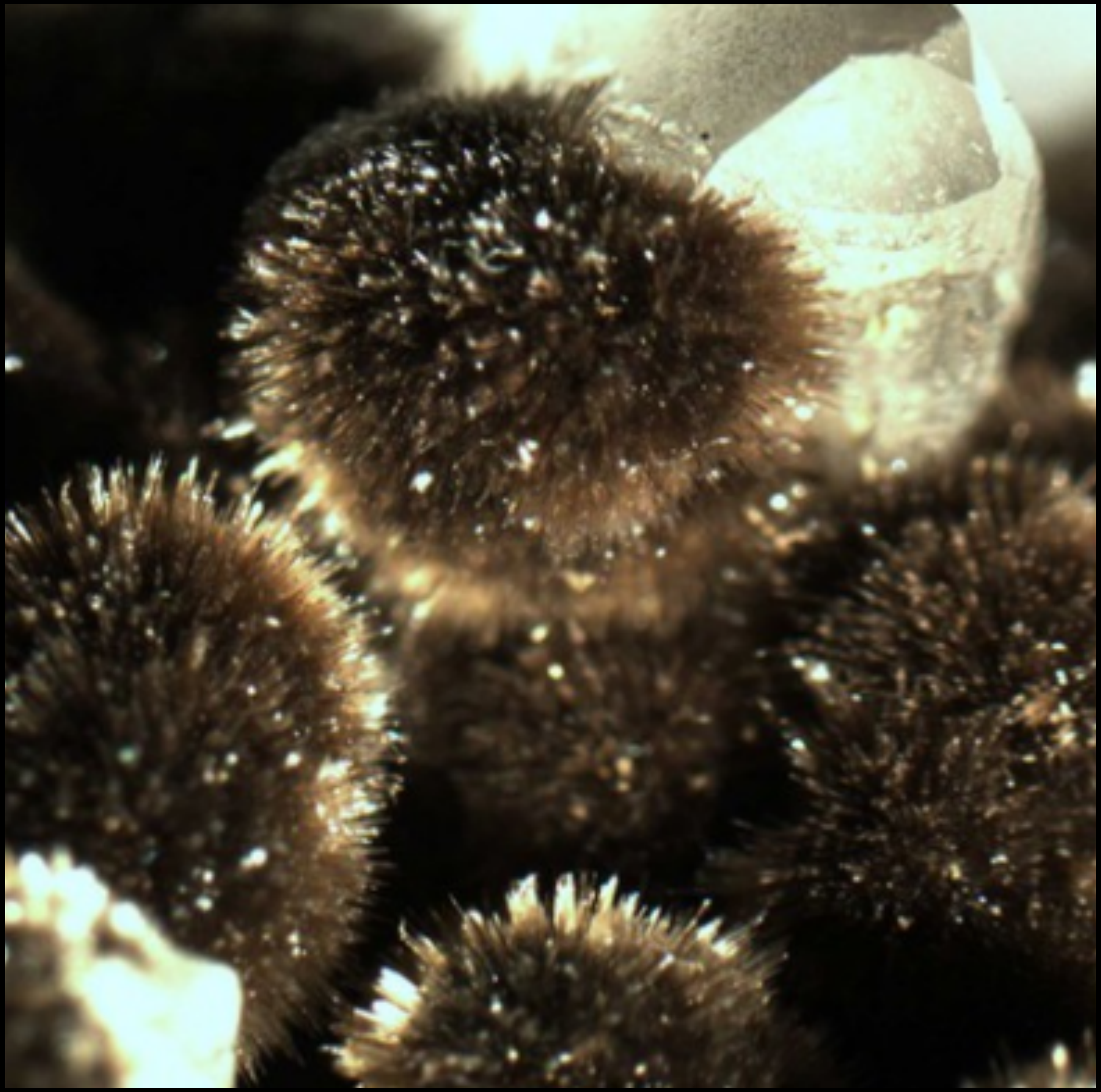
Measuring solar neutrinos over Gigayear timescales with Paleo Detectors

Natalia Tapia Arellano · University of Utah · MDνDM 24 · Jan 08-11

Outline

Contents



NCHWANINGITE

- Solar Neutrinos
- Paleo Detectors
- ν time evolution
- Results

Outline

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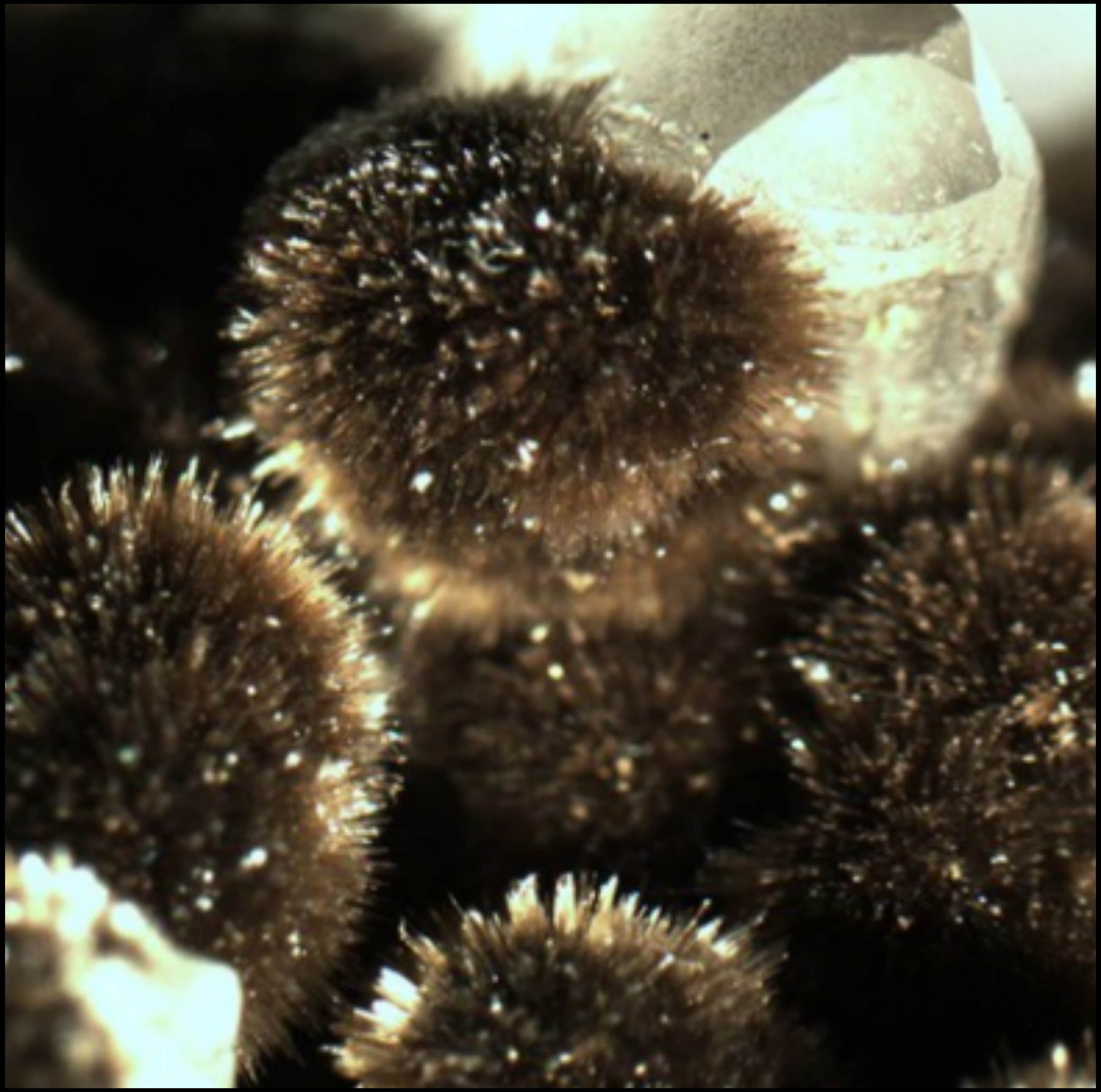
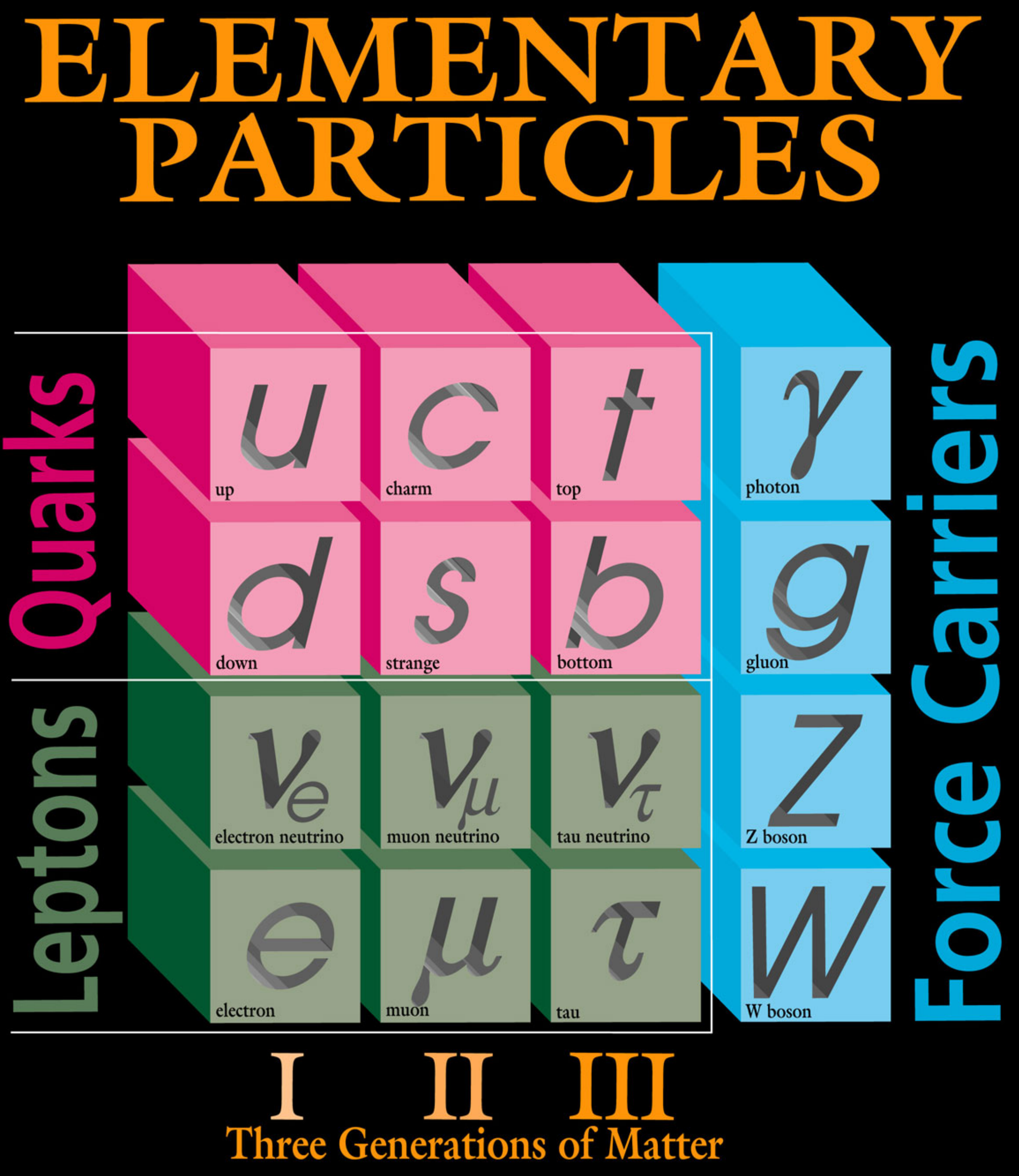


NCHWANINGITE

- Solar Neutrinos

Neutrinos

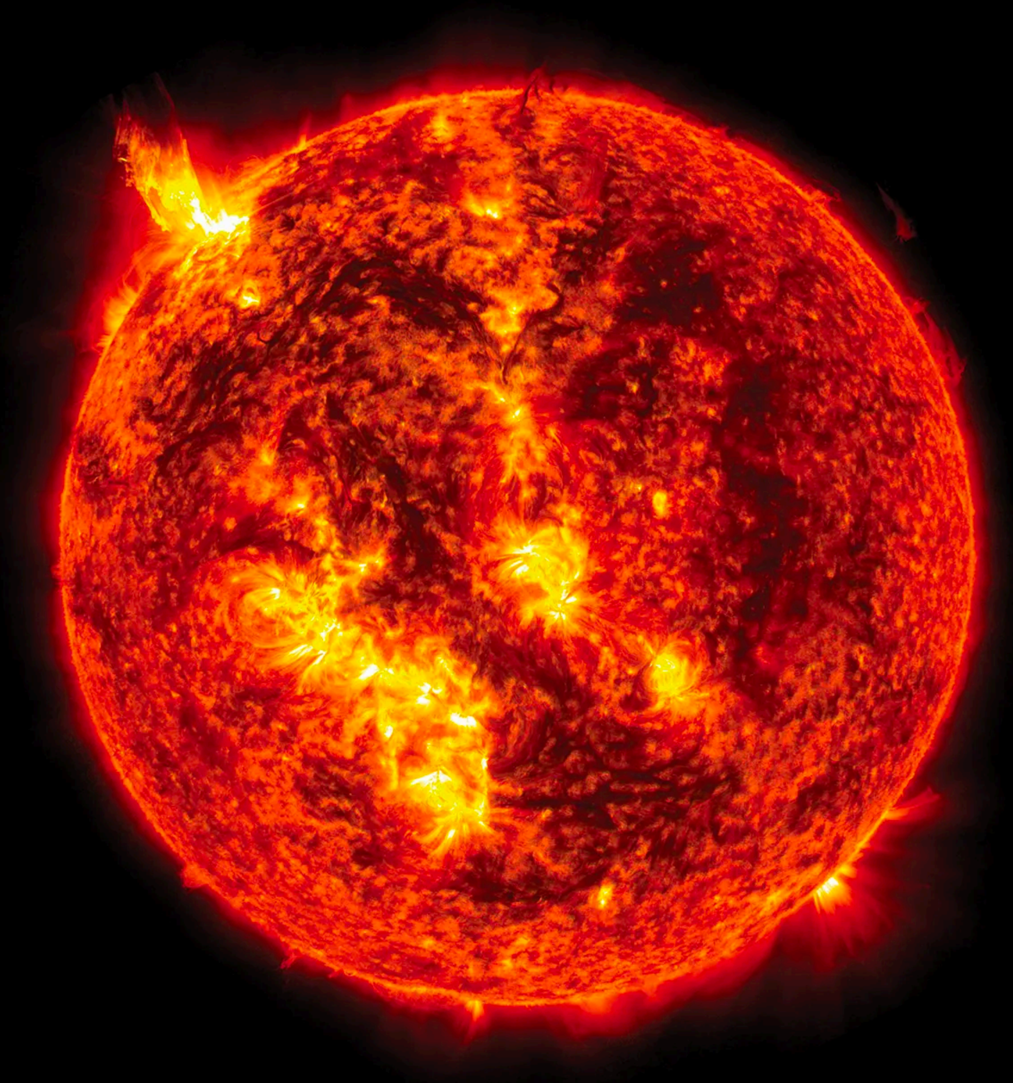
- Fundamental particle
- Abundant
- Three flavors
- Diverse sources
- Mystery
- Beyond SM



[Credit: All things neutrino, Fermilab]

Neutrinos: Solar Neutrinos

Solar Neutrino Problem



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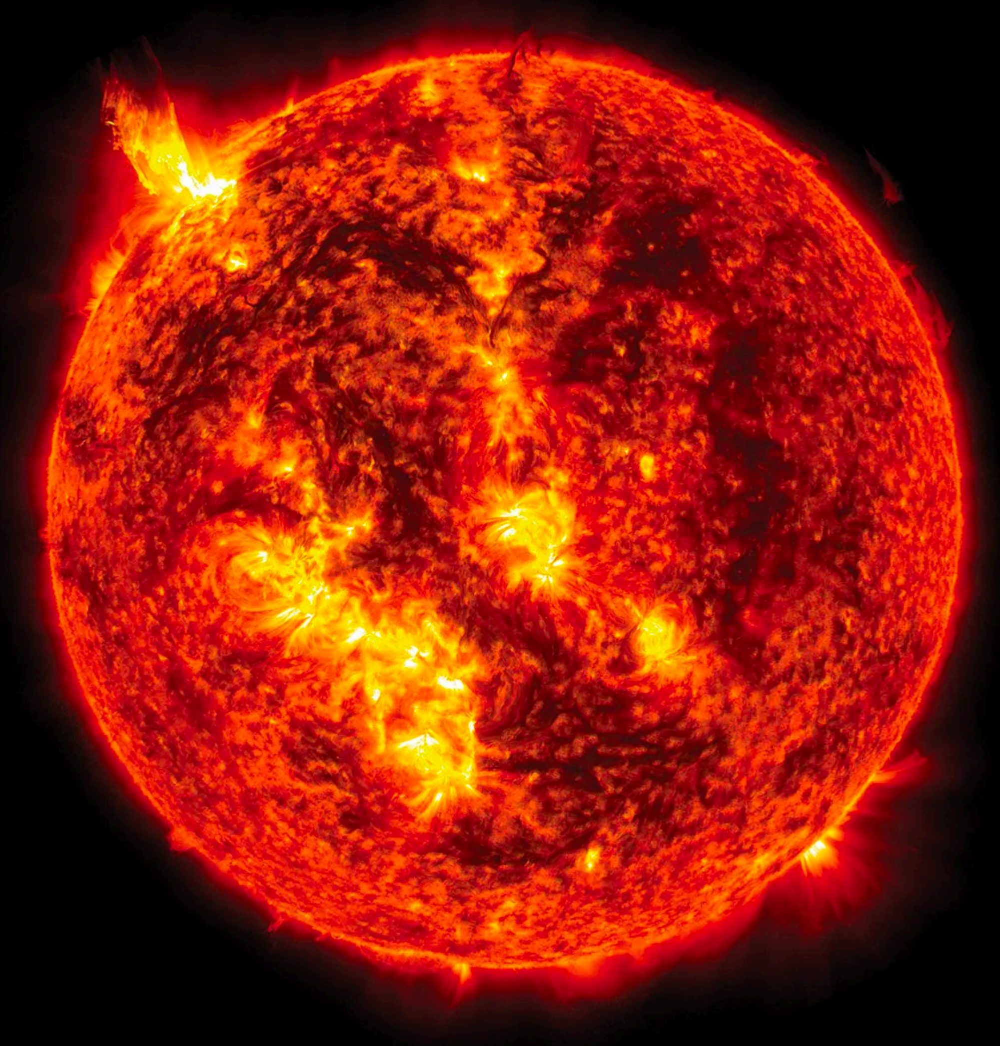

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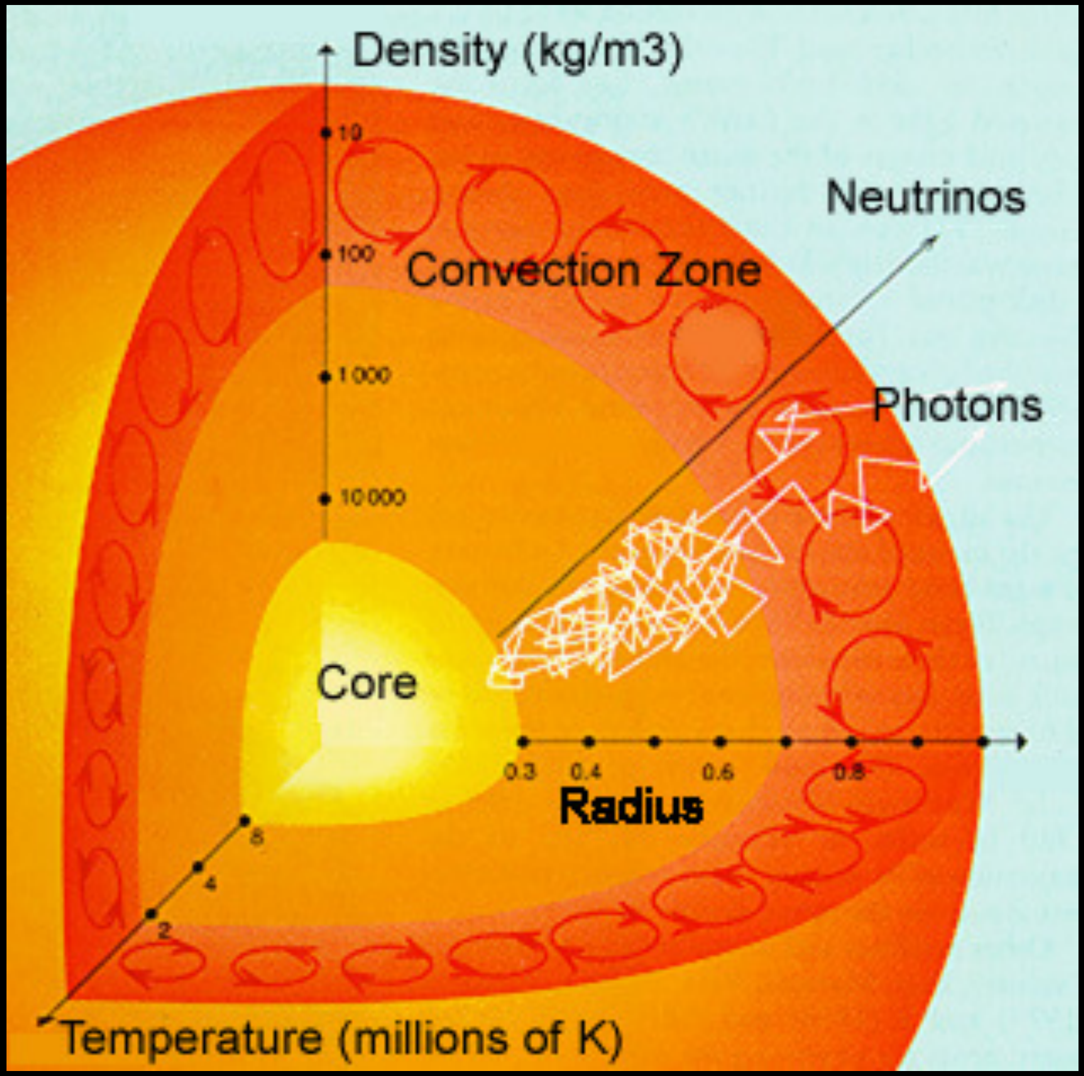
Neutrinos: Solar Neutrinos



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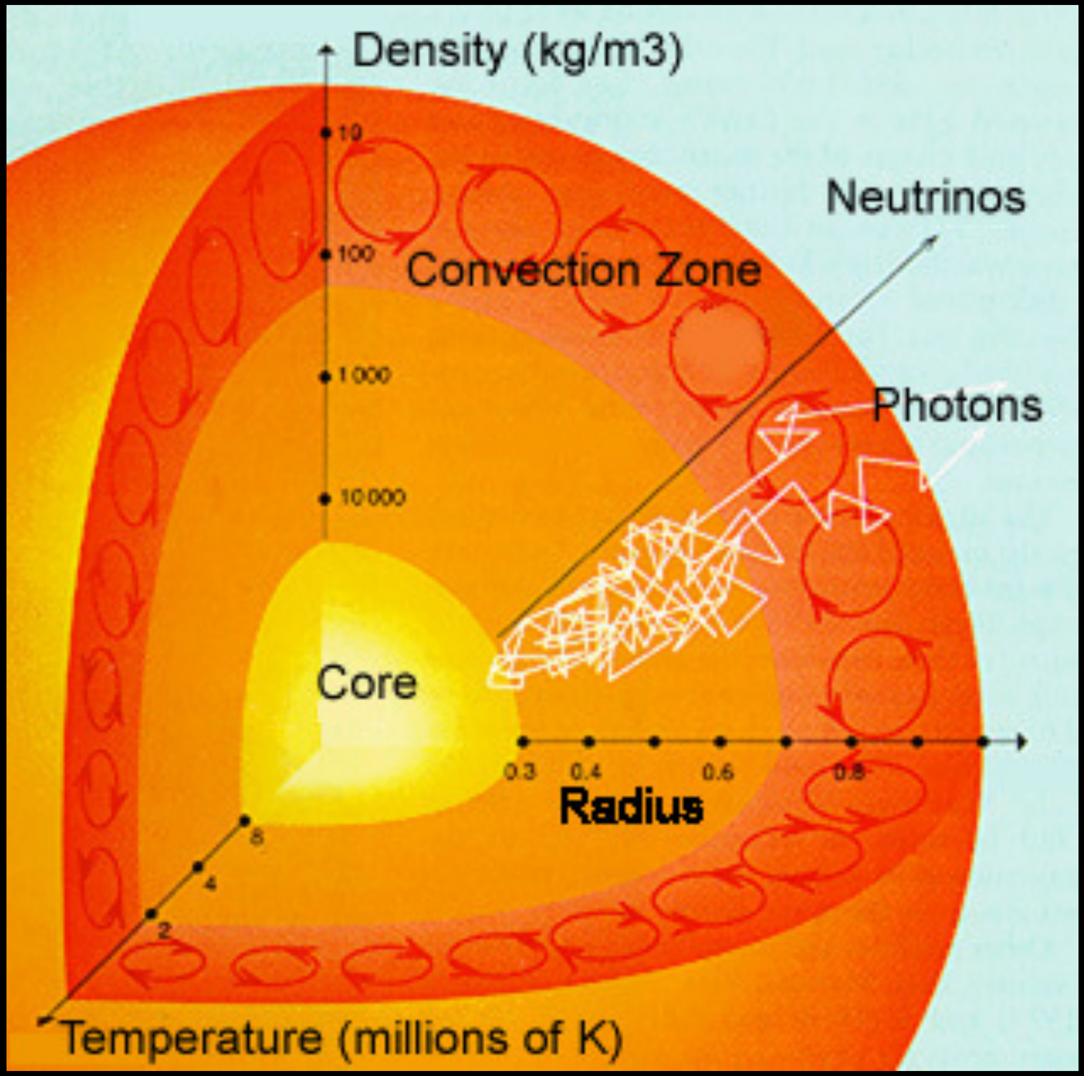

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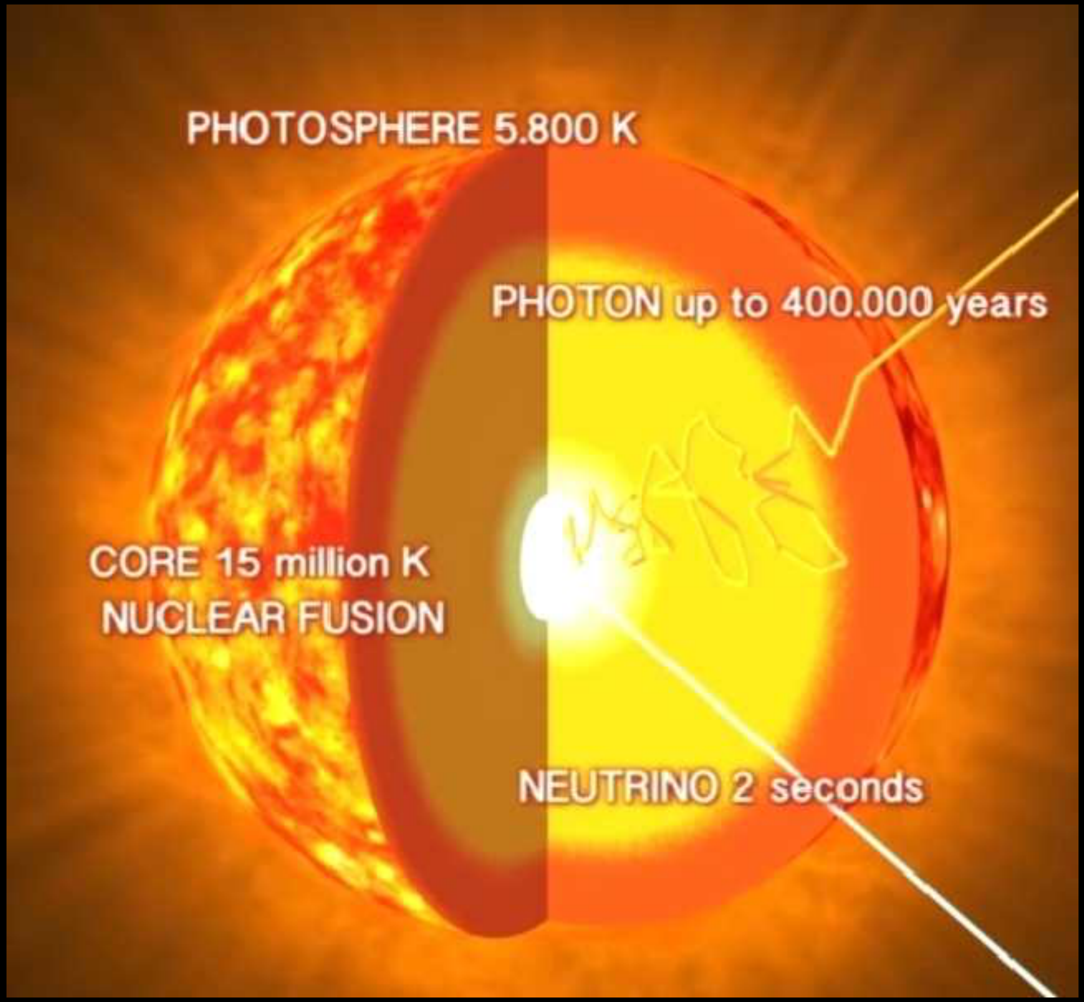

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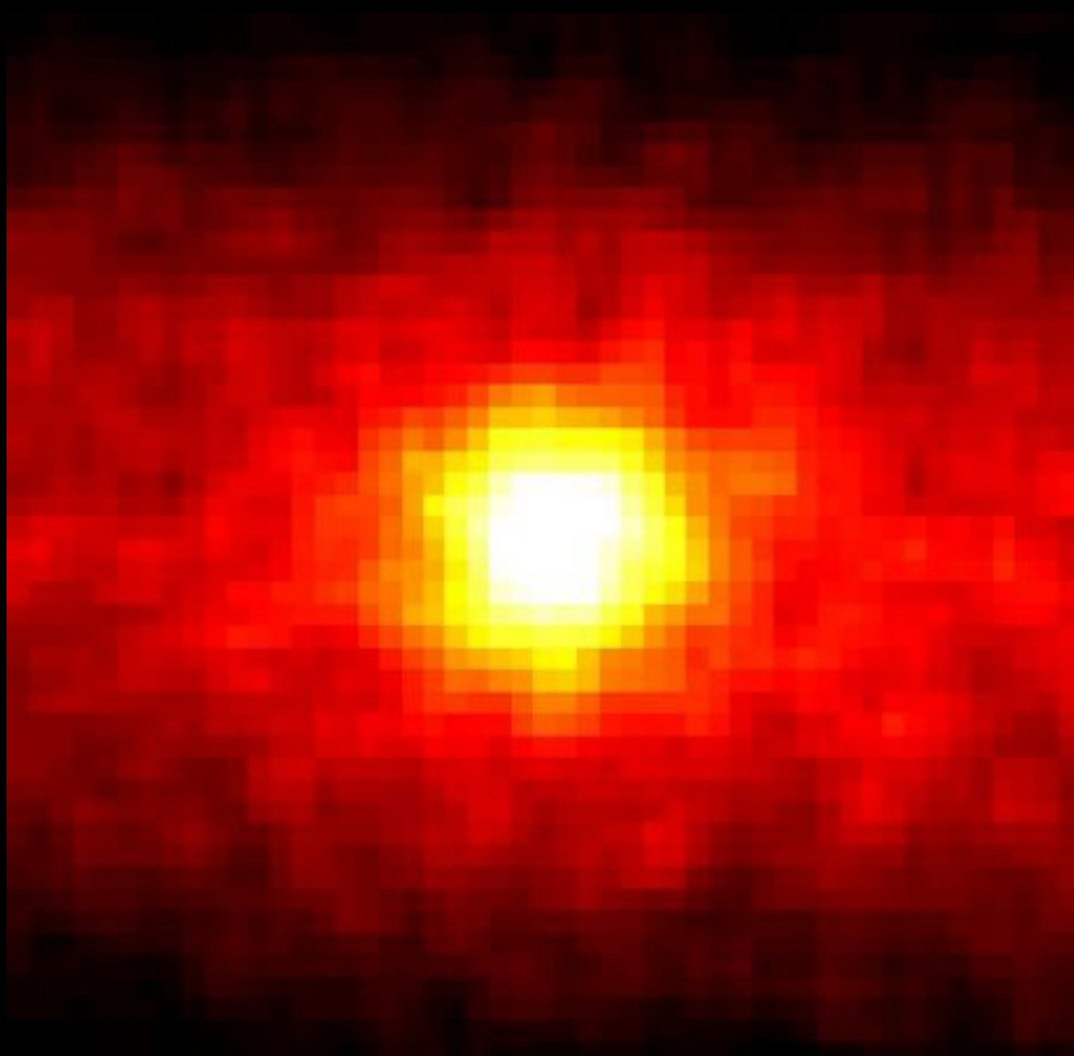

NASA: Astronomy Picture of the Day, 1998

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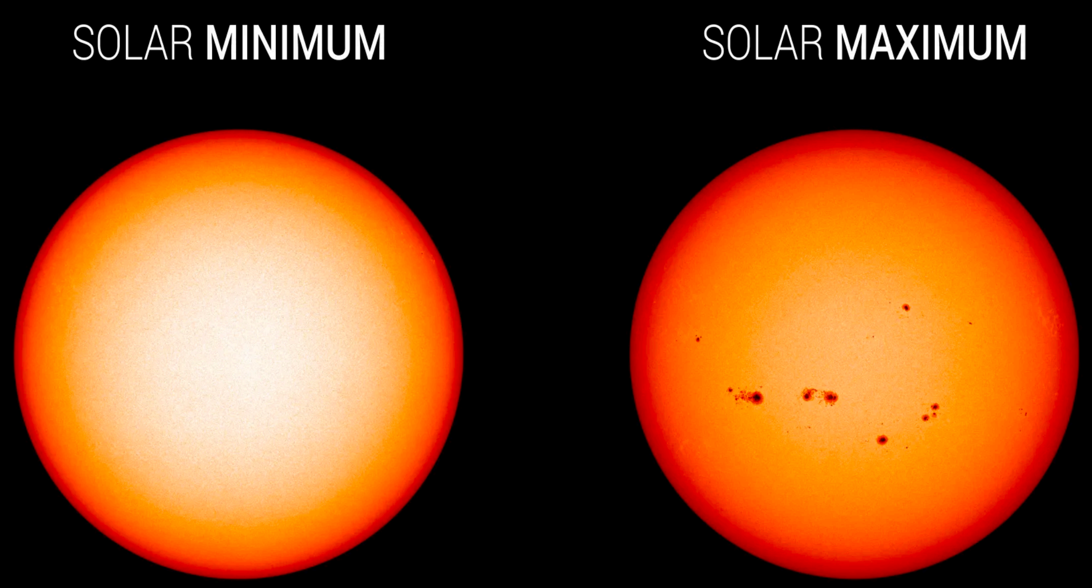

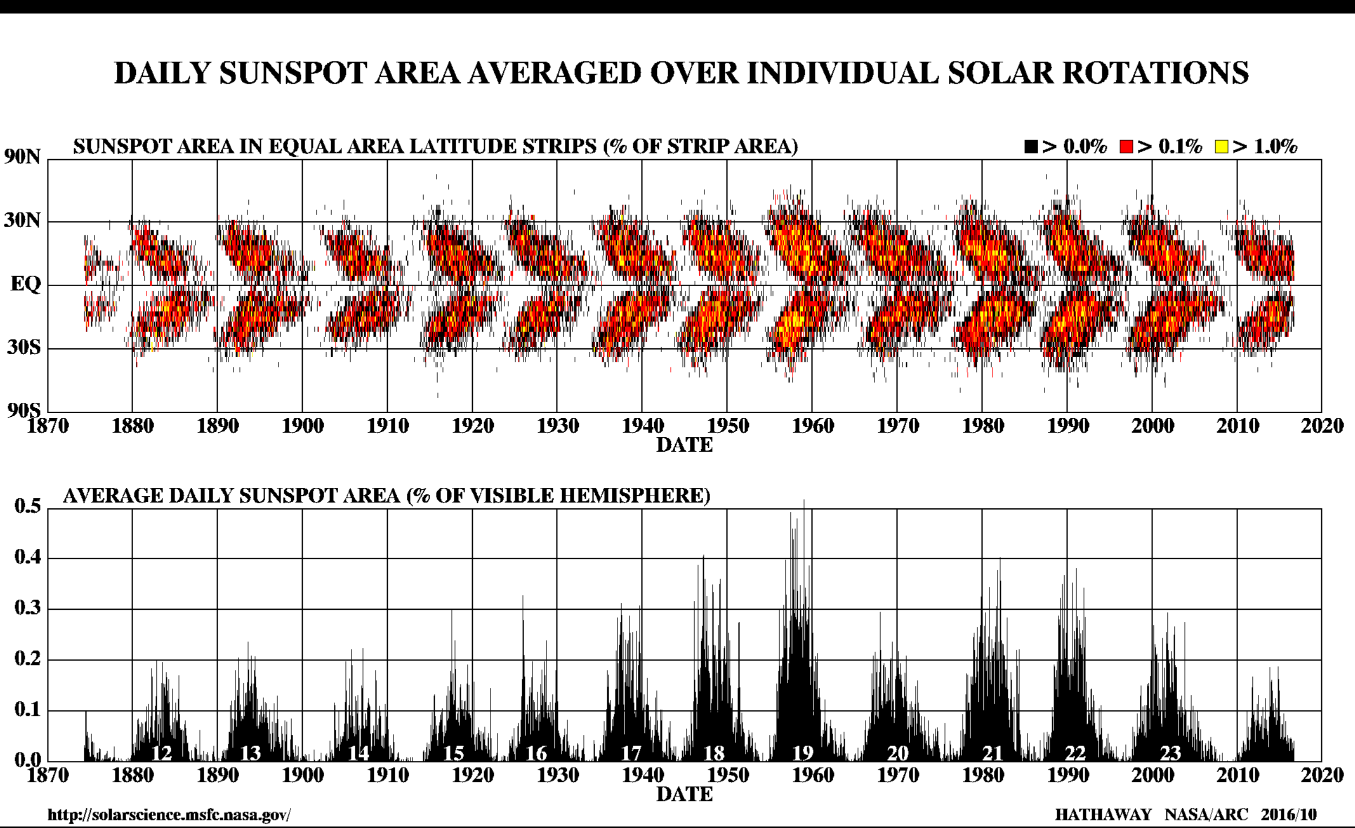

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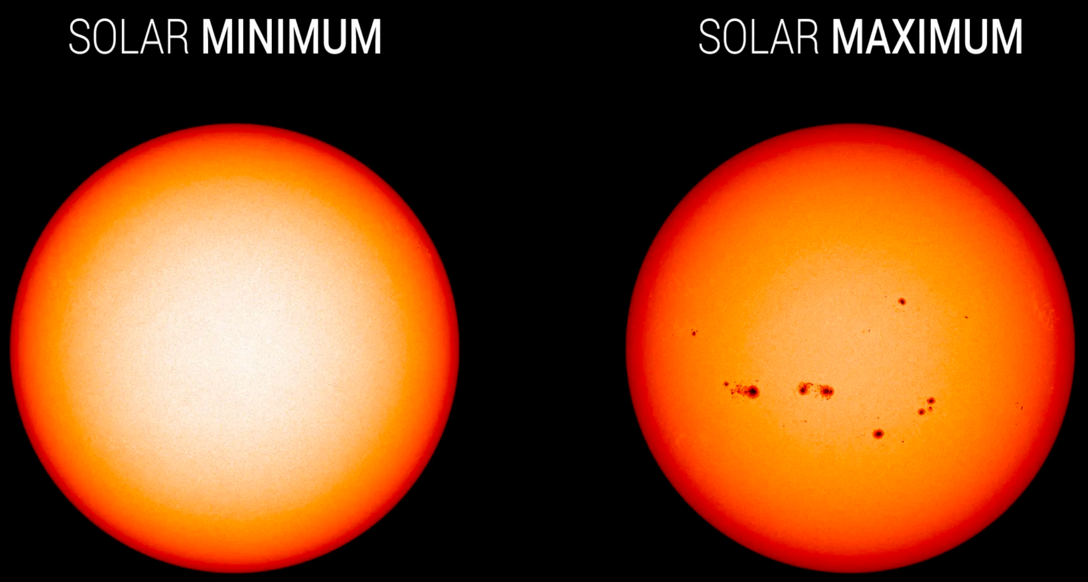

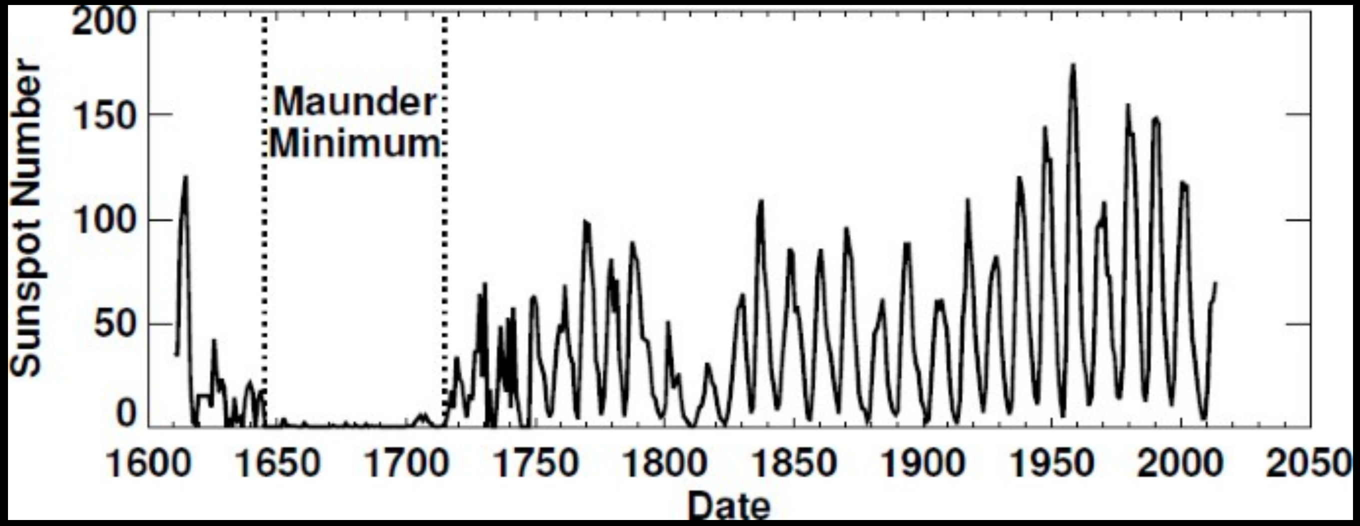

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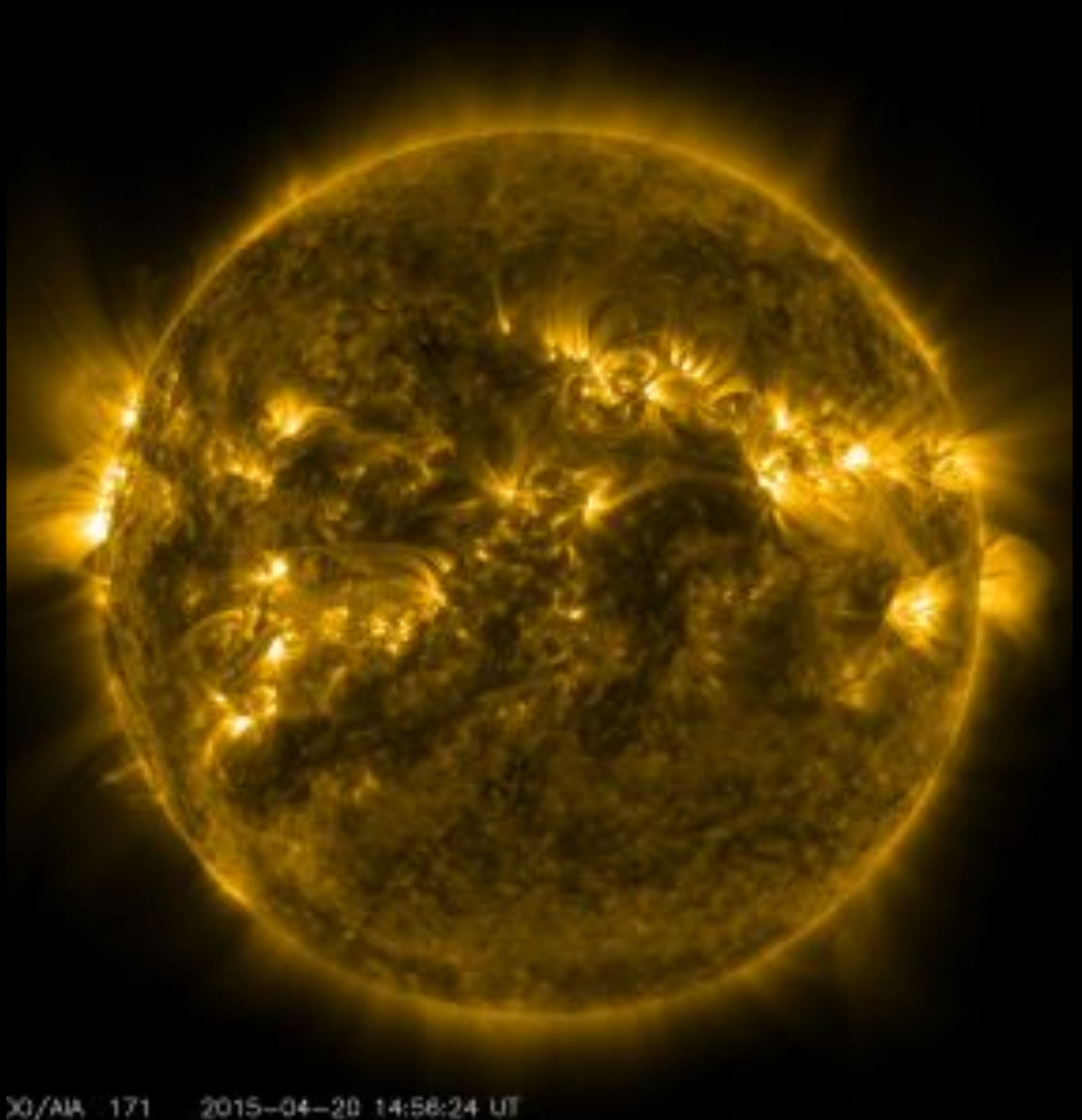
Solar Standard Model: Bahcall

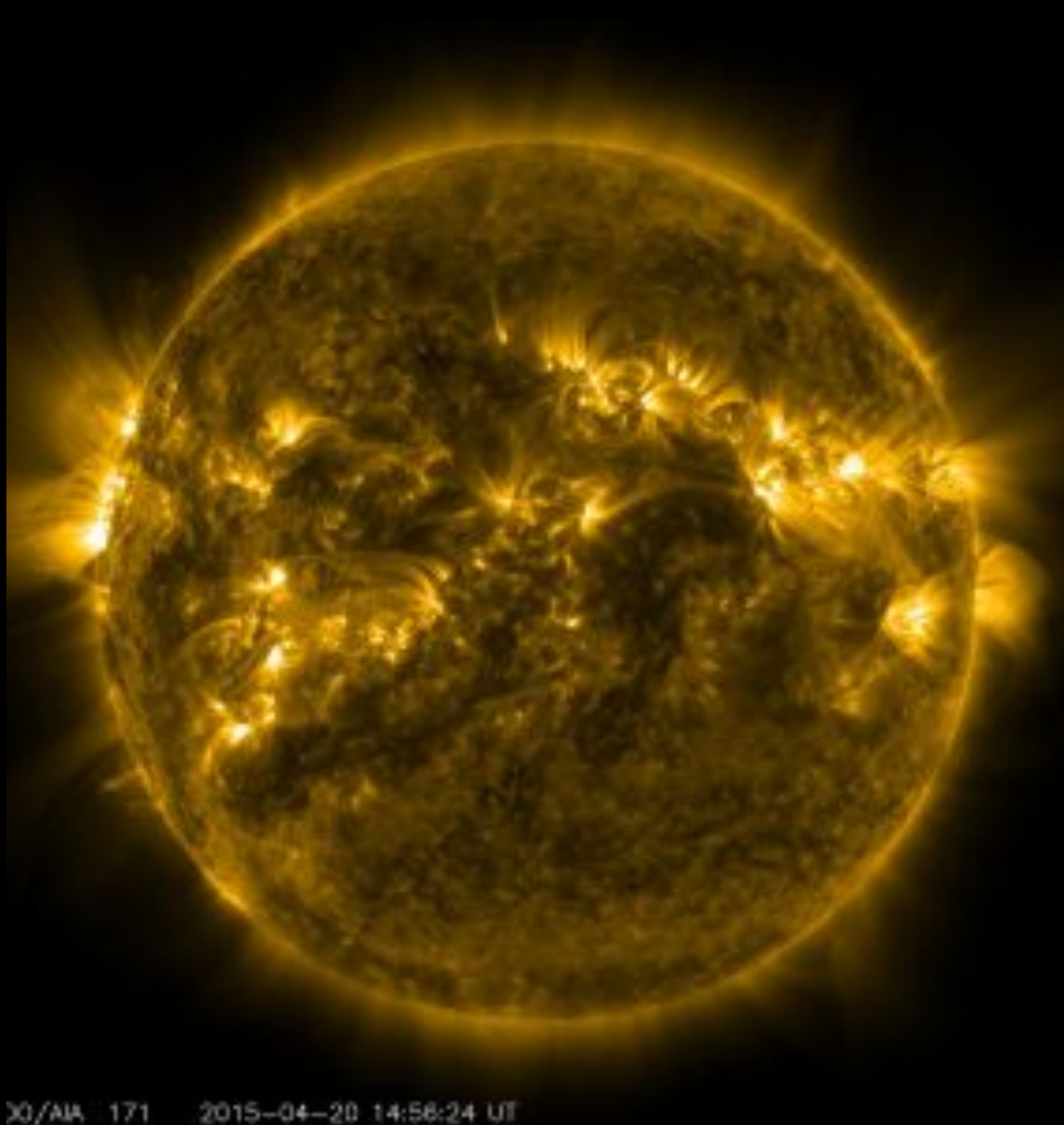
Understand and predict neutrino fluxes



Credit: NASA, Fermilab

- Fundamental tool to study Solar activity
- Prediction of fluxes, temperature, etc.
- Metallicity: Fraction of heavy element to hydrogen at the Surface.
- Testing SSM: studying pressure modes: Helioseismology

Solar Standard Model: Bahcall

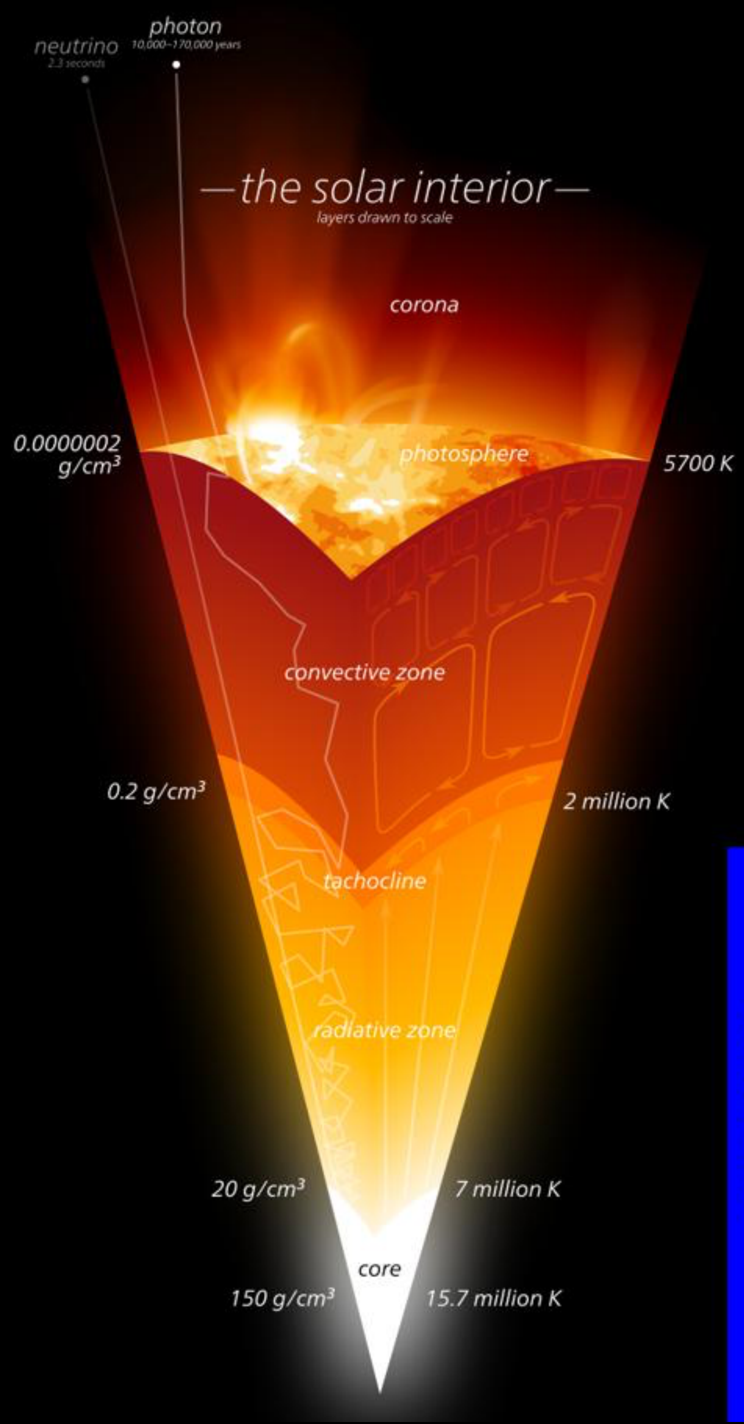


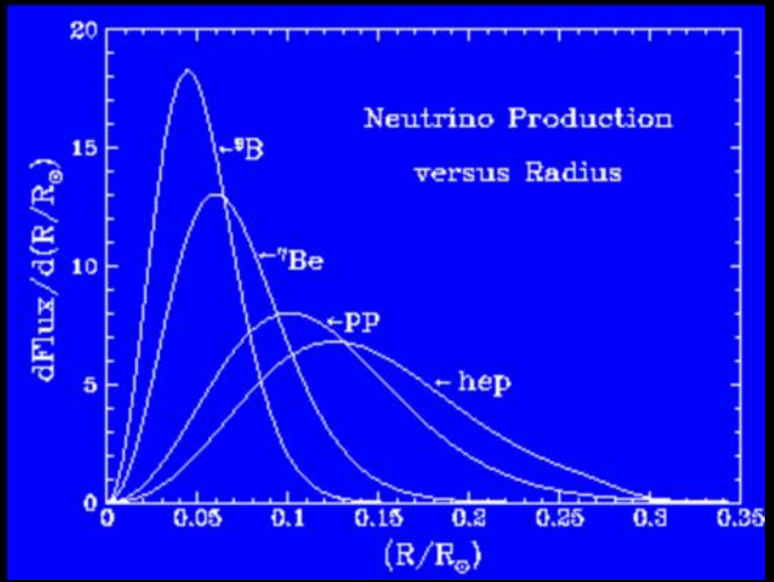
Credit: NASA, Fermilab

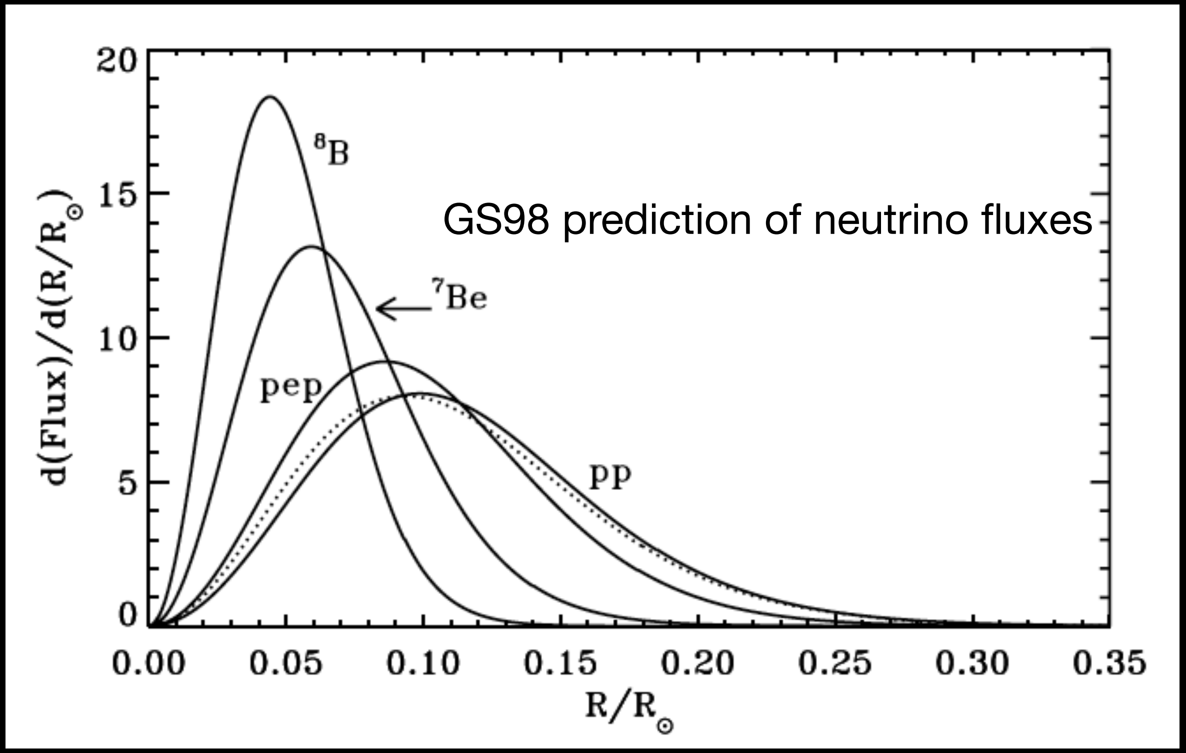
- Discrepancy in results from new SSM using different Sun's **Metallicity**
- Inconsistency between **photosphere abundances AGSS09** and **helioseismic data in GS98** sensitive to interior composition.
- **Standing paradox in Solar physics**

Luminosity function!

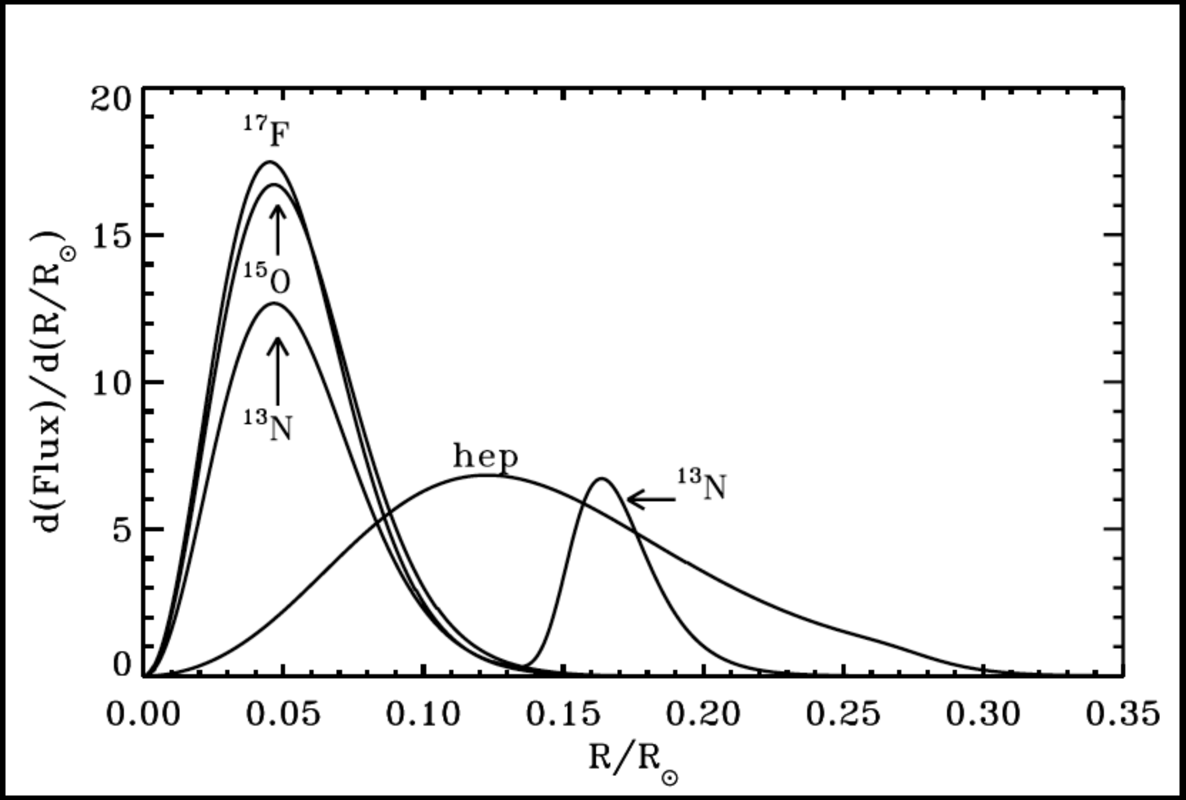
Solar luminosity and neutrino flux connected.

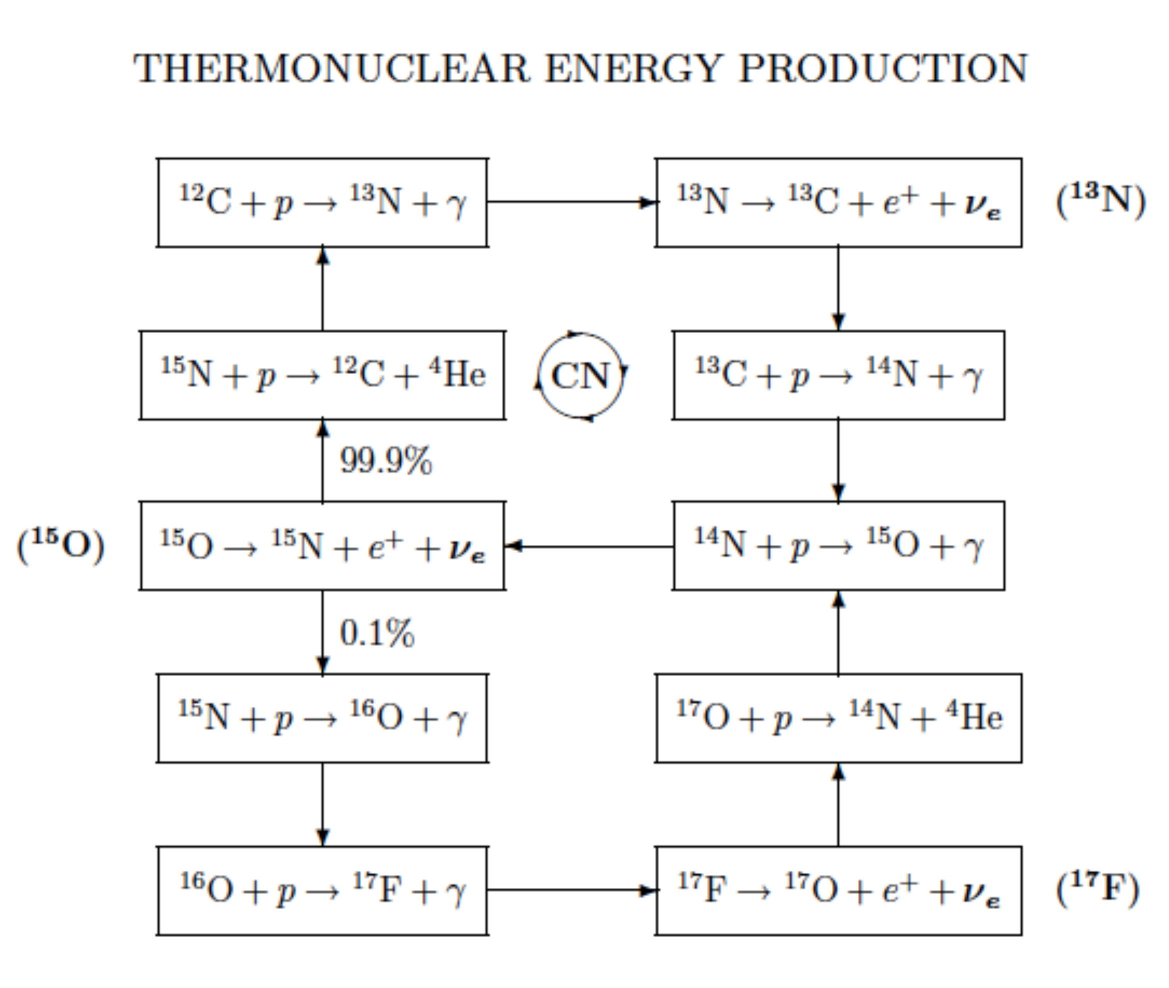






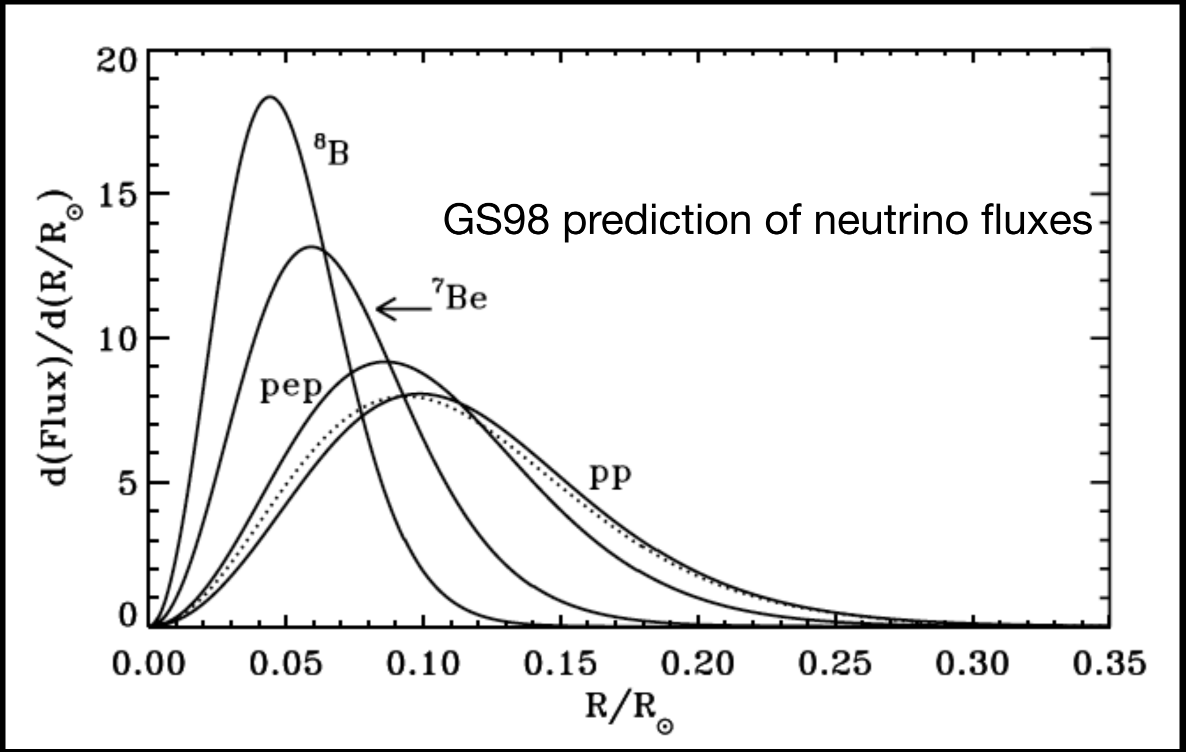
Distribution of the neutrino production in terms of radius for each neutrino flux, according to GS98





CNO (III) cycle of stellar thermonuclear reactions. Conversion from Hydrogen to Helium.

Giunti, Kim



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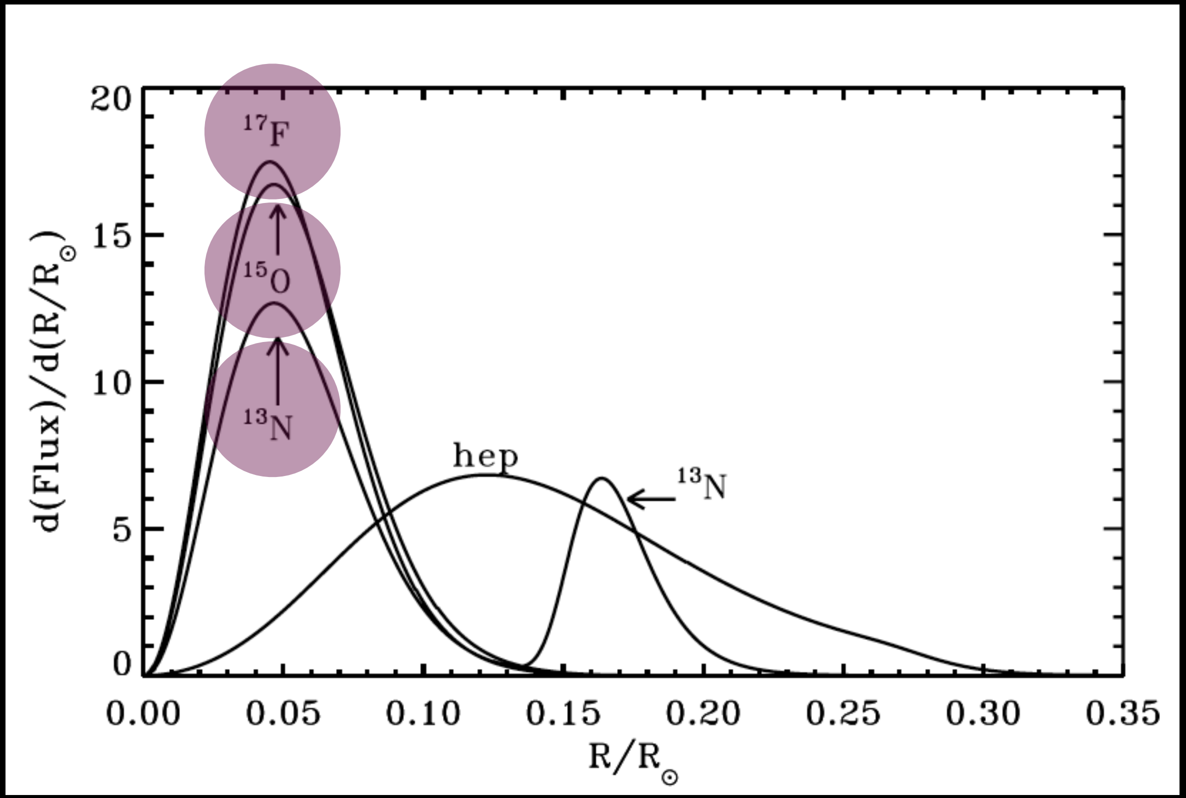

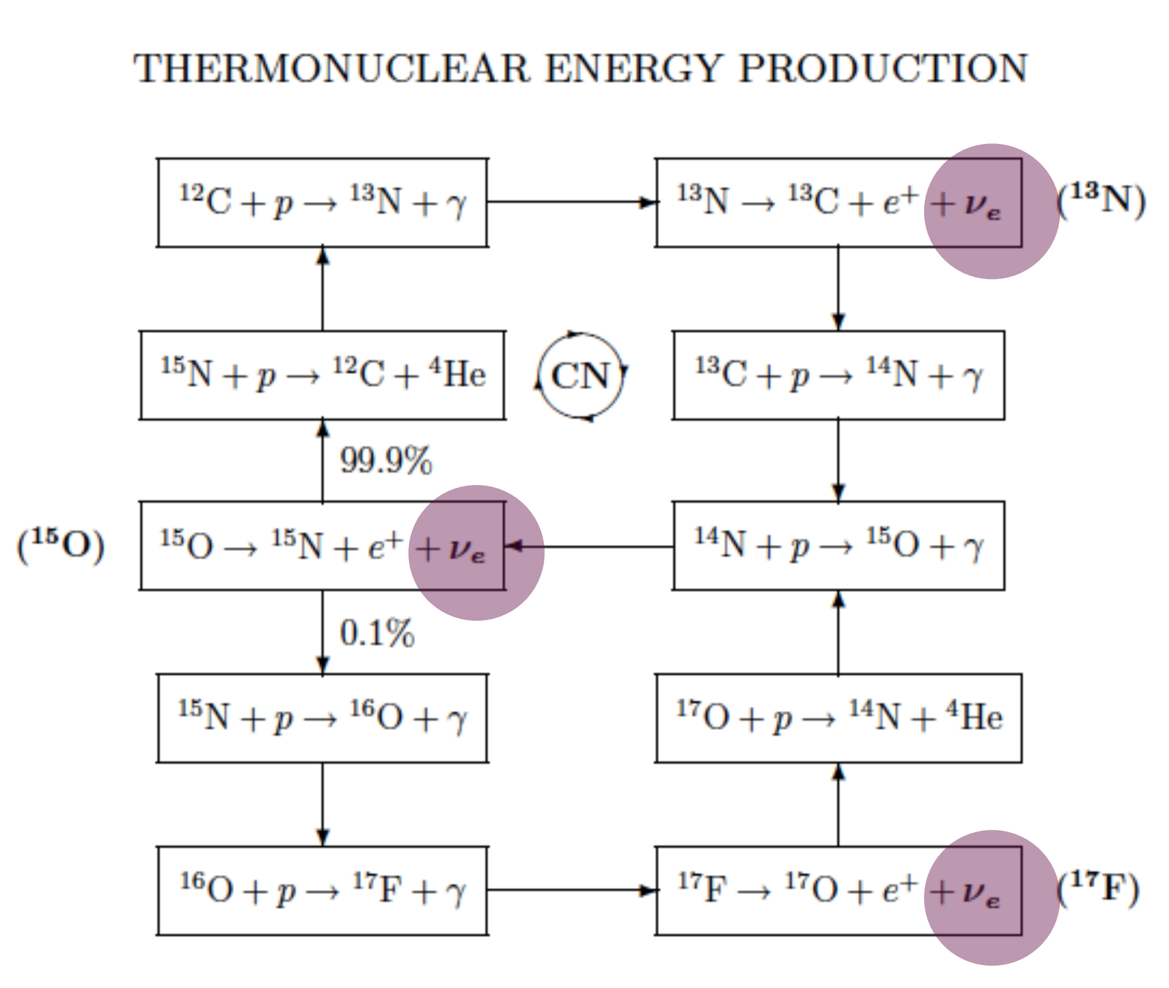

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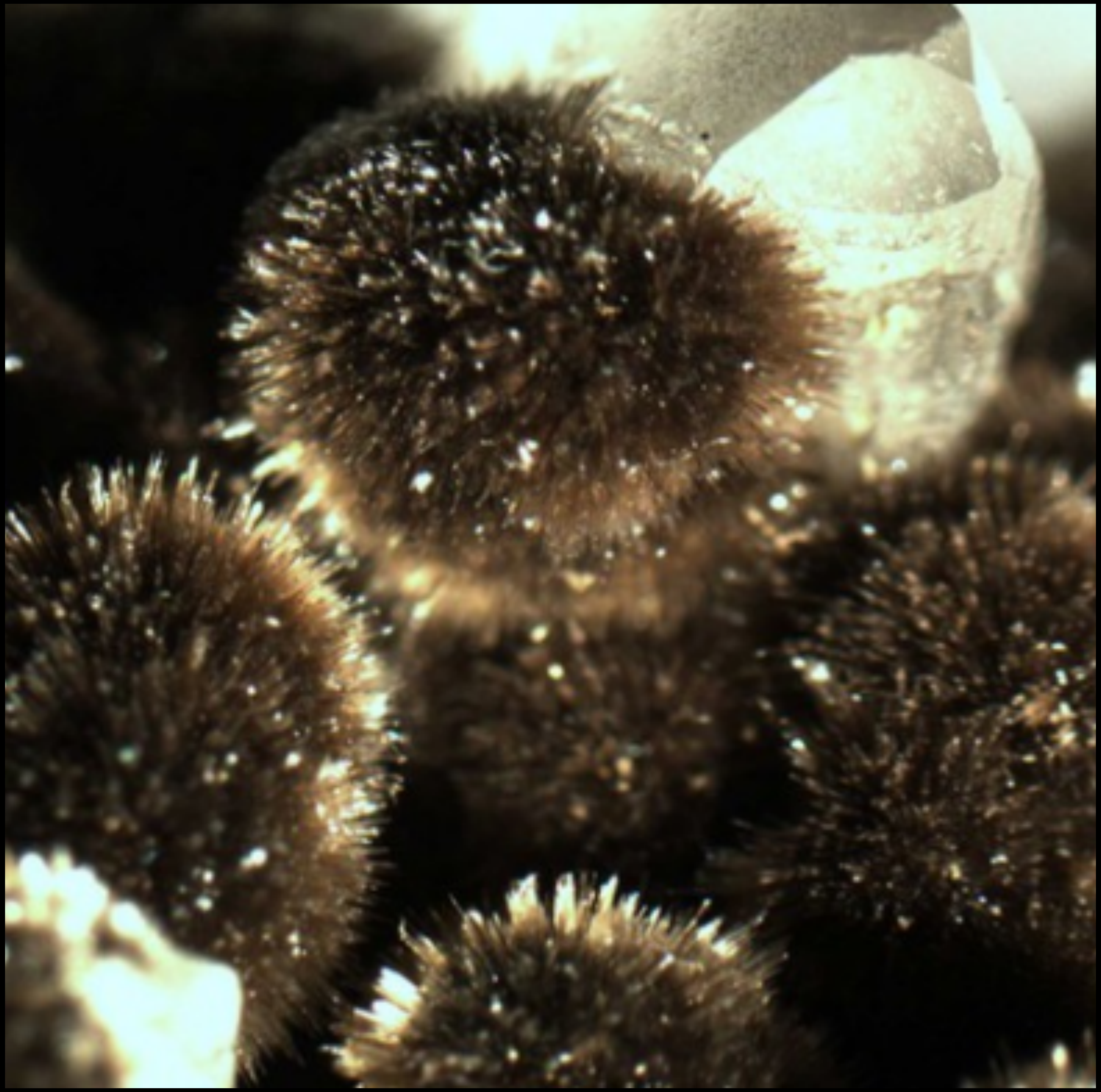


NCHWANINGITE

- Paleo Detectors

Paleo Detectors


- DM Searches
- Examine rocks!!


Billion year ~10^9 y

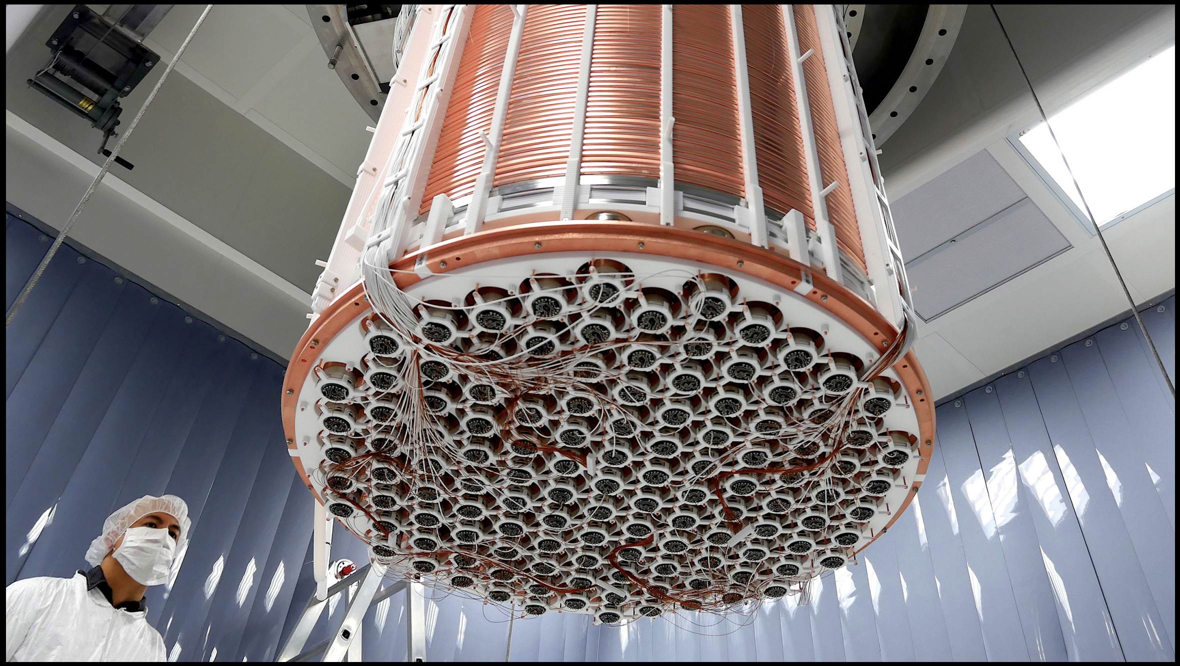

Exposure

ε = Target Mass * Integration Time

ε = 0.01 kg Myr

For Conventional Detectors

- 10 yr and 10^3 kg target mass



For Paleo Detectors:

- 1 Gyr old sample and O(10) mg of sample

[Xenon 1T: QM, 2020]

Outline

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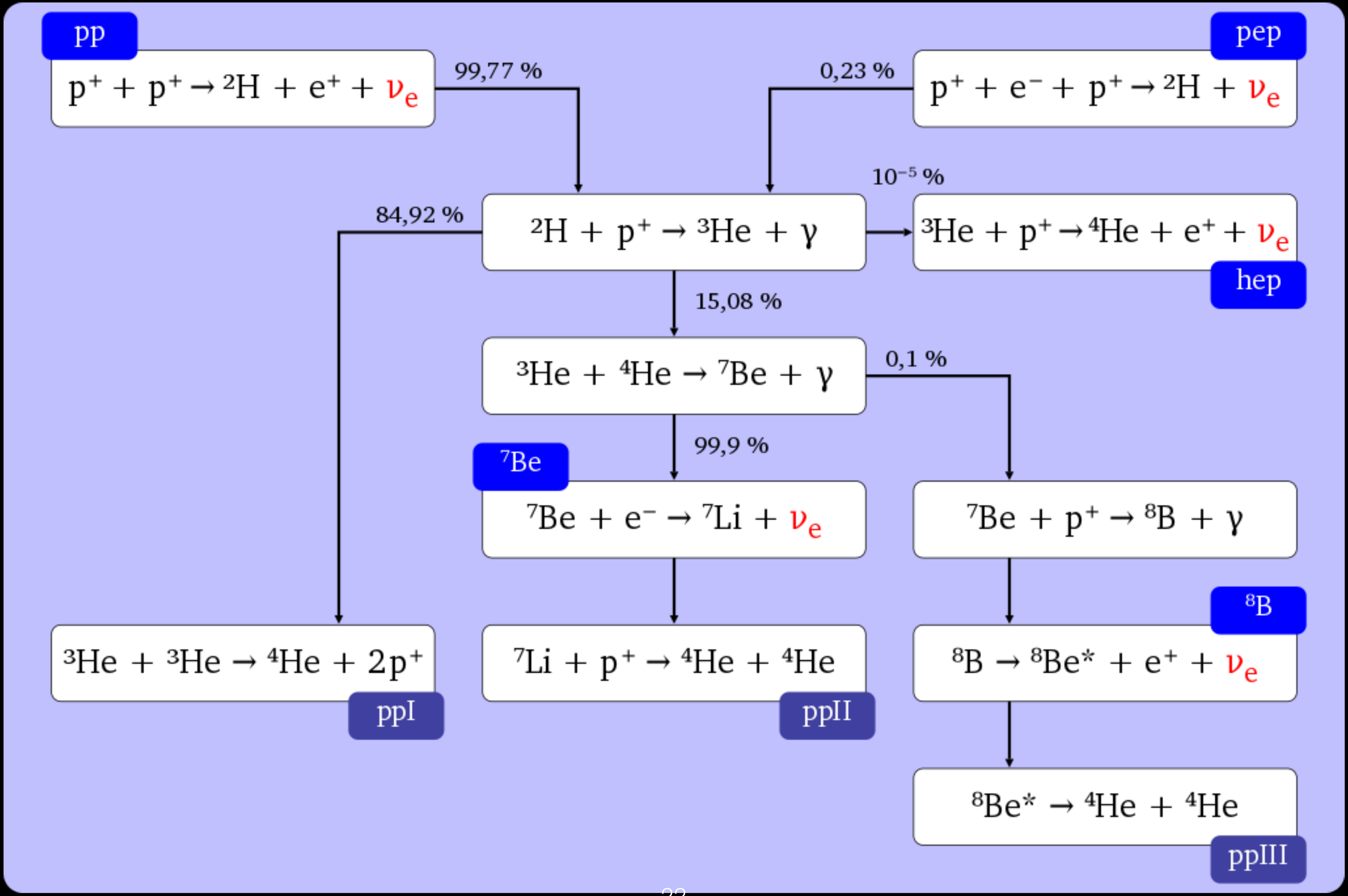
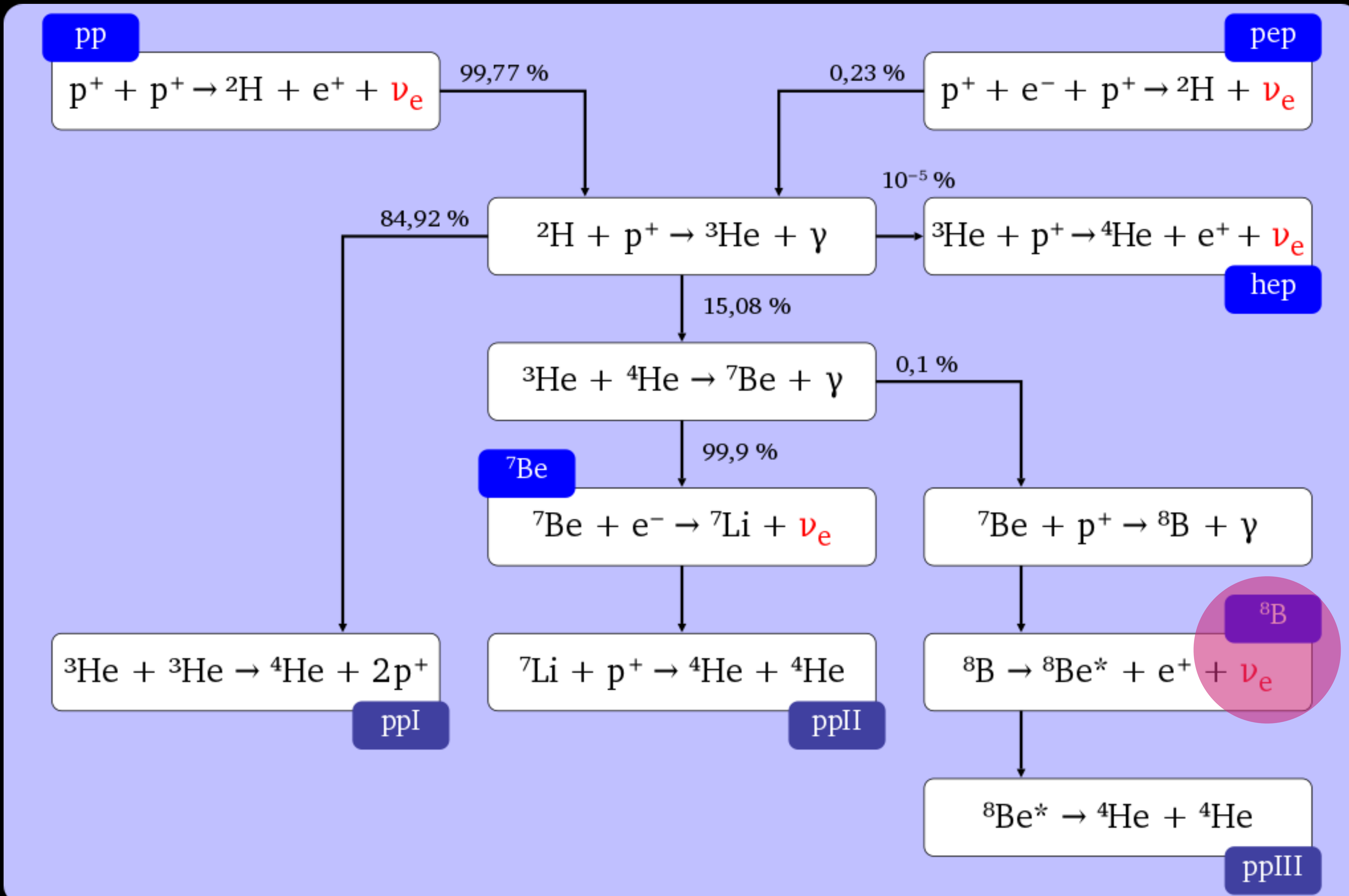
NCHWANINGITE

- ν time evolution

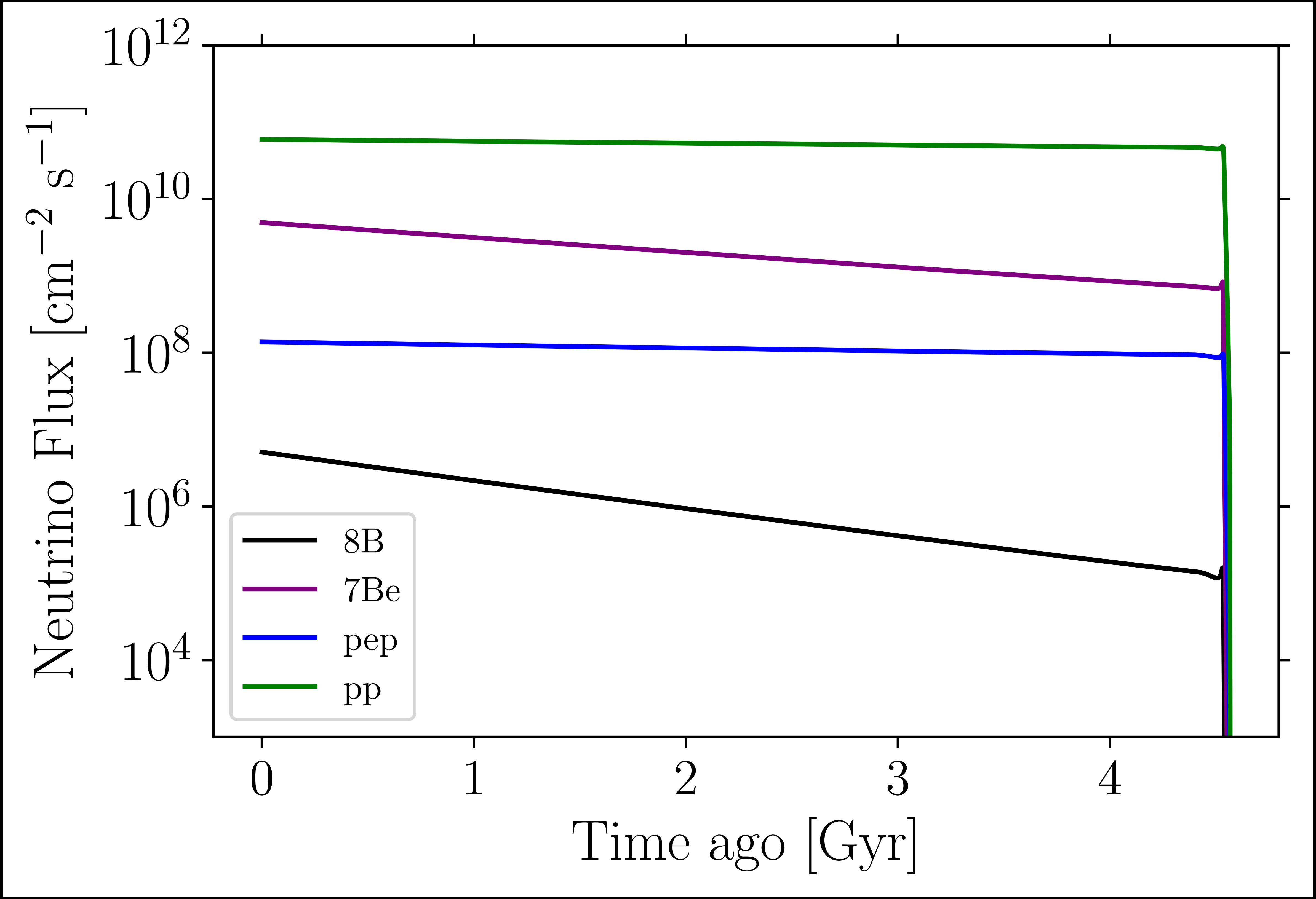
Chain production of 8B



Chain production of 8B

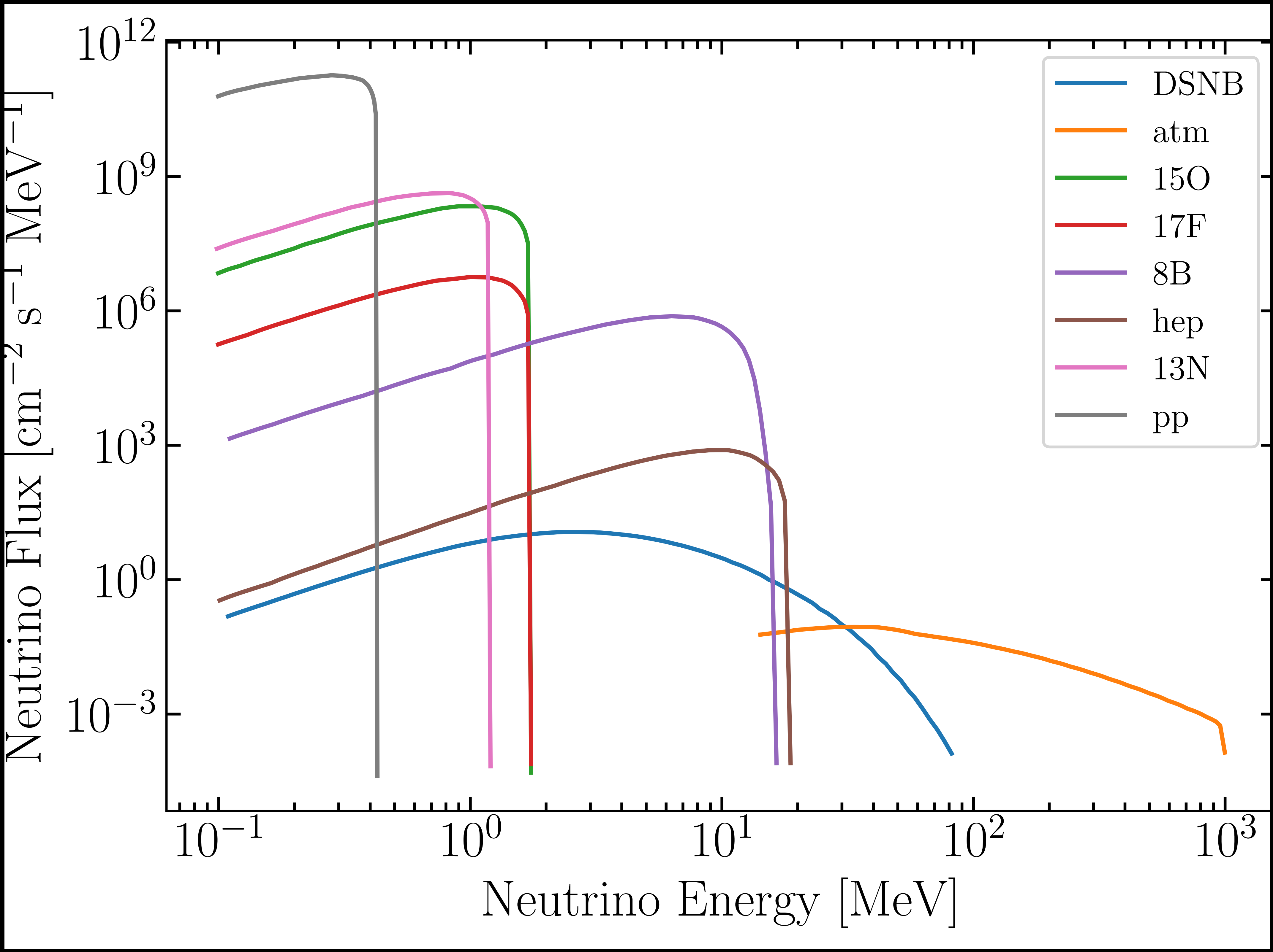


Time evolution of neutrinos



MESA: Modules for Experiments in Stellar Astrophysics

Energy Spectrum



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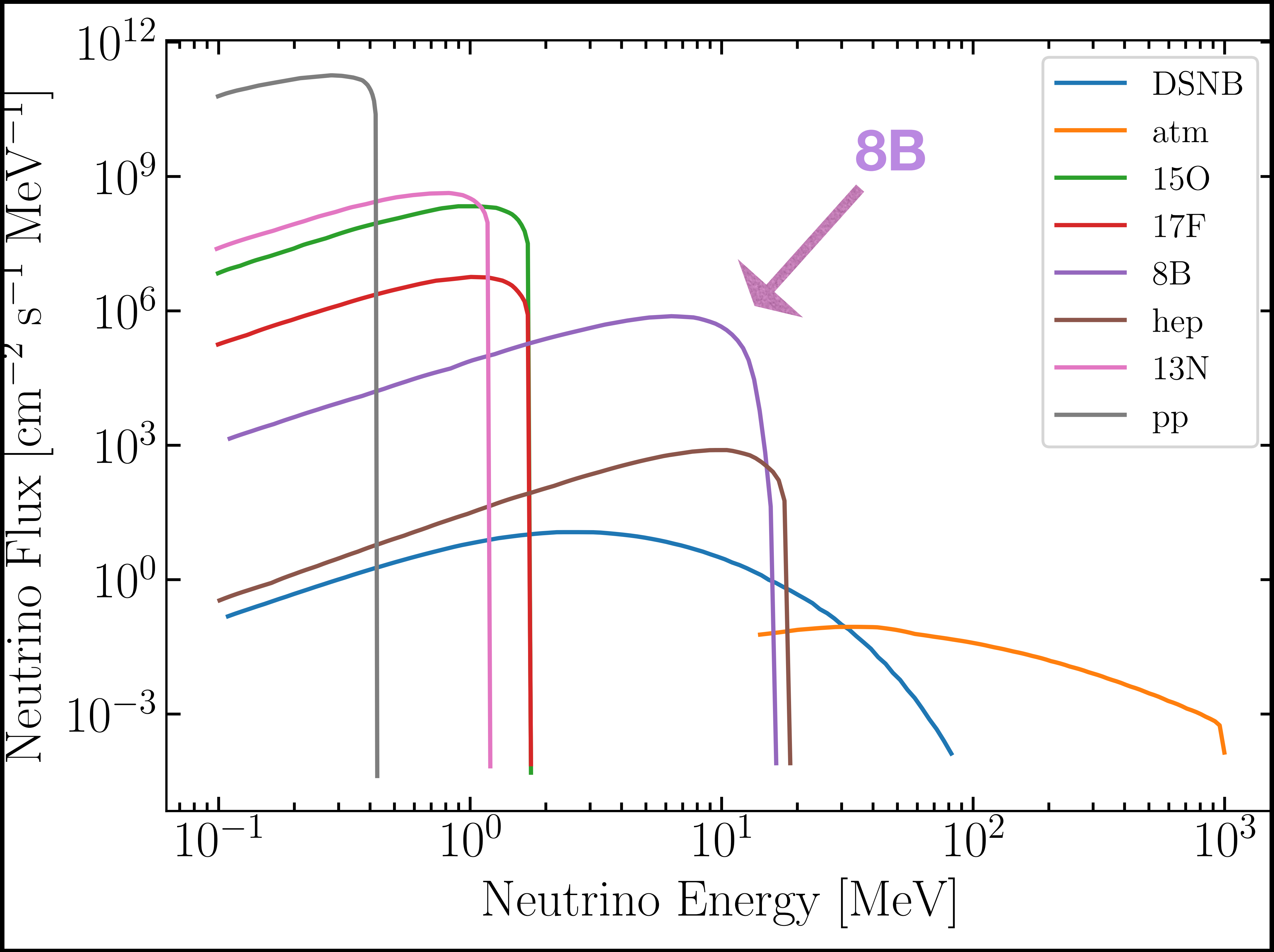
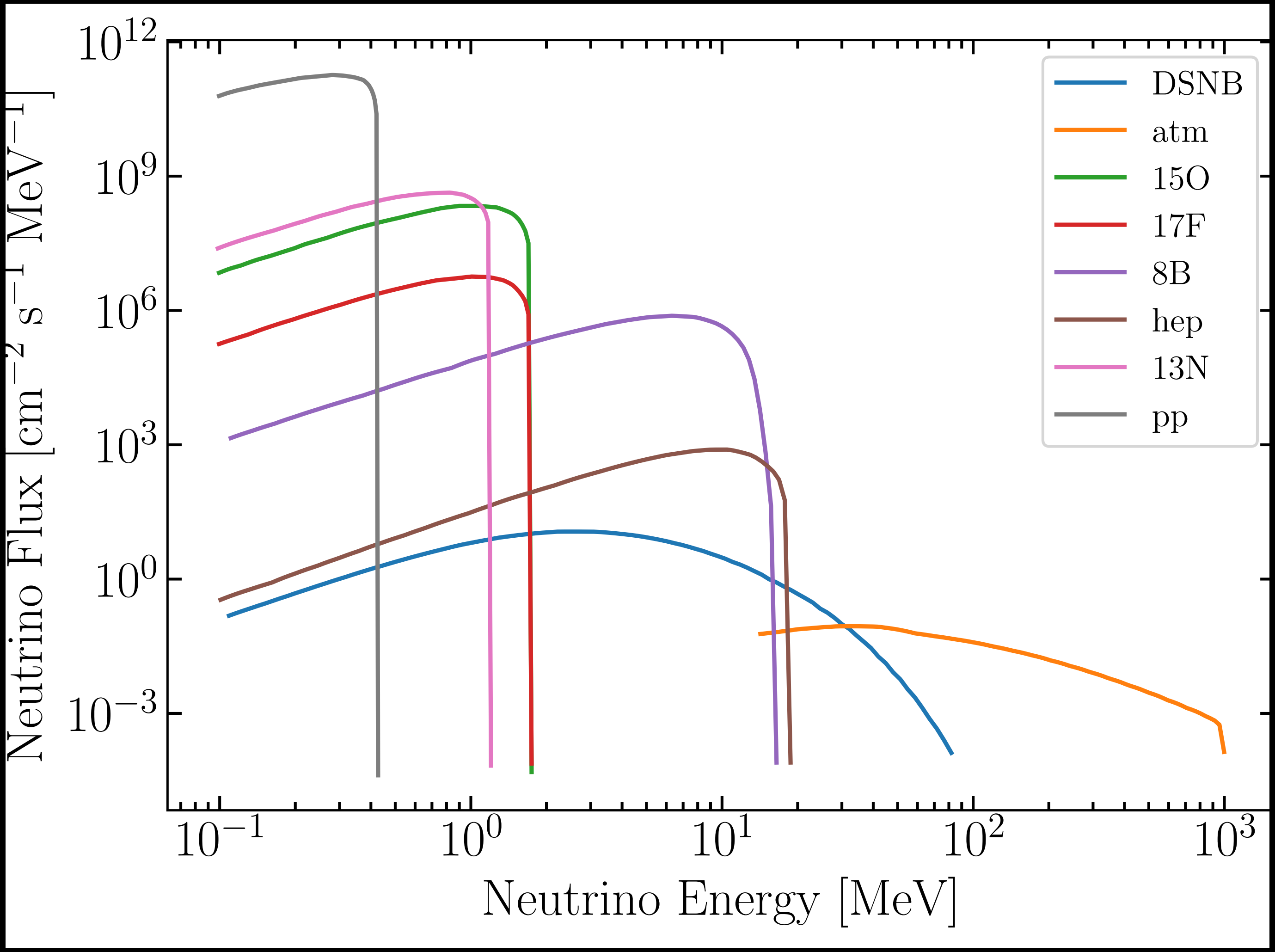


O' Hare

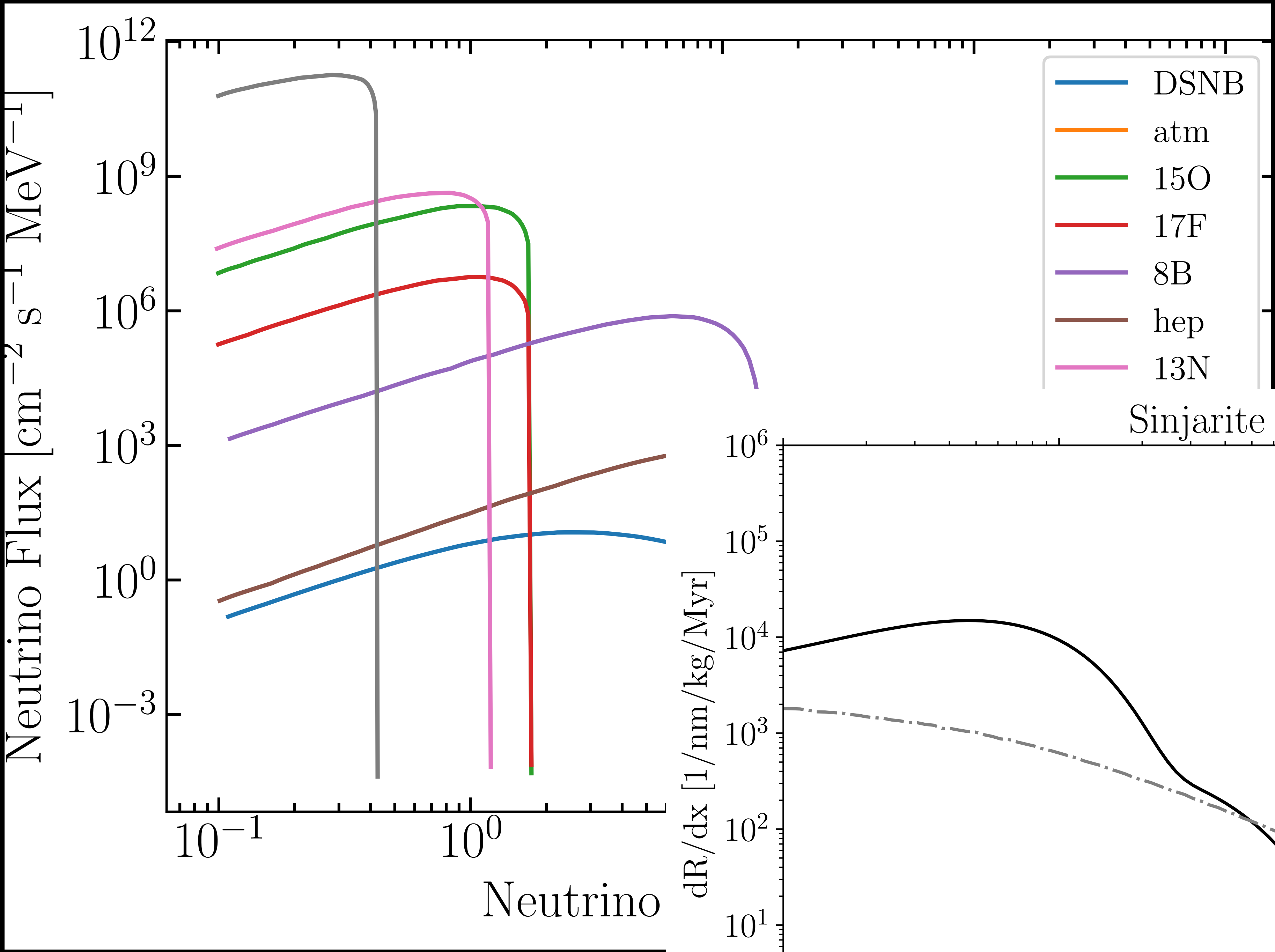
Tracks



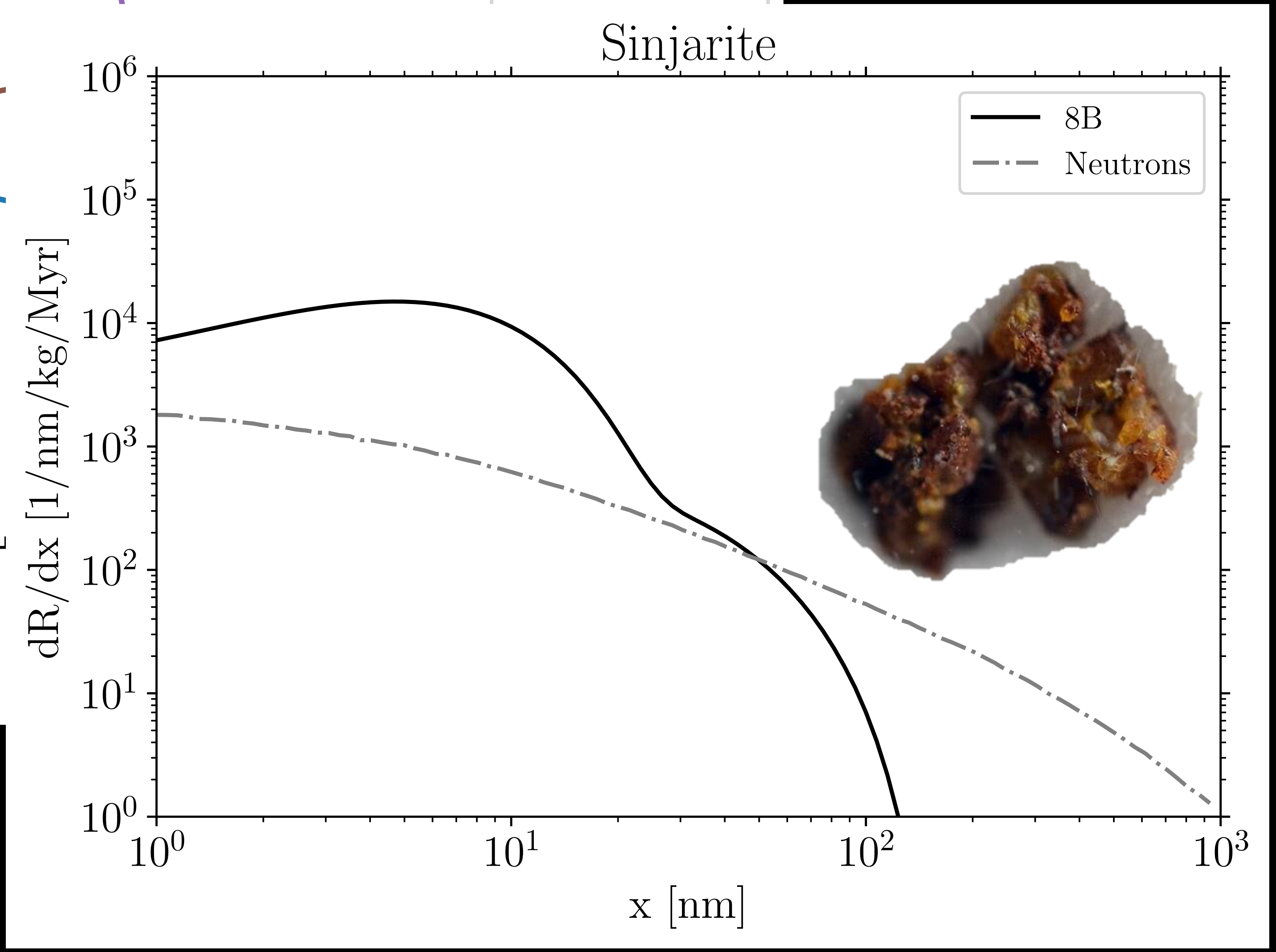
- Differential recoil spectrum per unit target mass induced by neutrinos

$$\left(\frac{dR}{dE_R}\right)_T = \frac{1}{m_T}\int_{E_\nu^{min}} dE_\nu \frac{d\sigma}{dE_R}\frac{d\Phi_\nu}{dE_\nu},$$

Tracks



Neutrino Flux [cm^{-2} s^{-1} MeV^{-1}]
Neutrino
DSNB
atm
15O
17F
8B
hep
13N



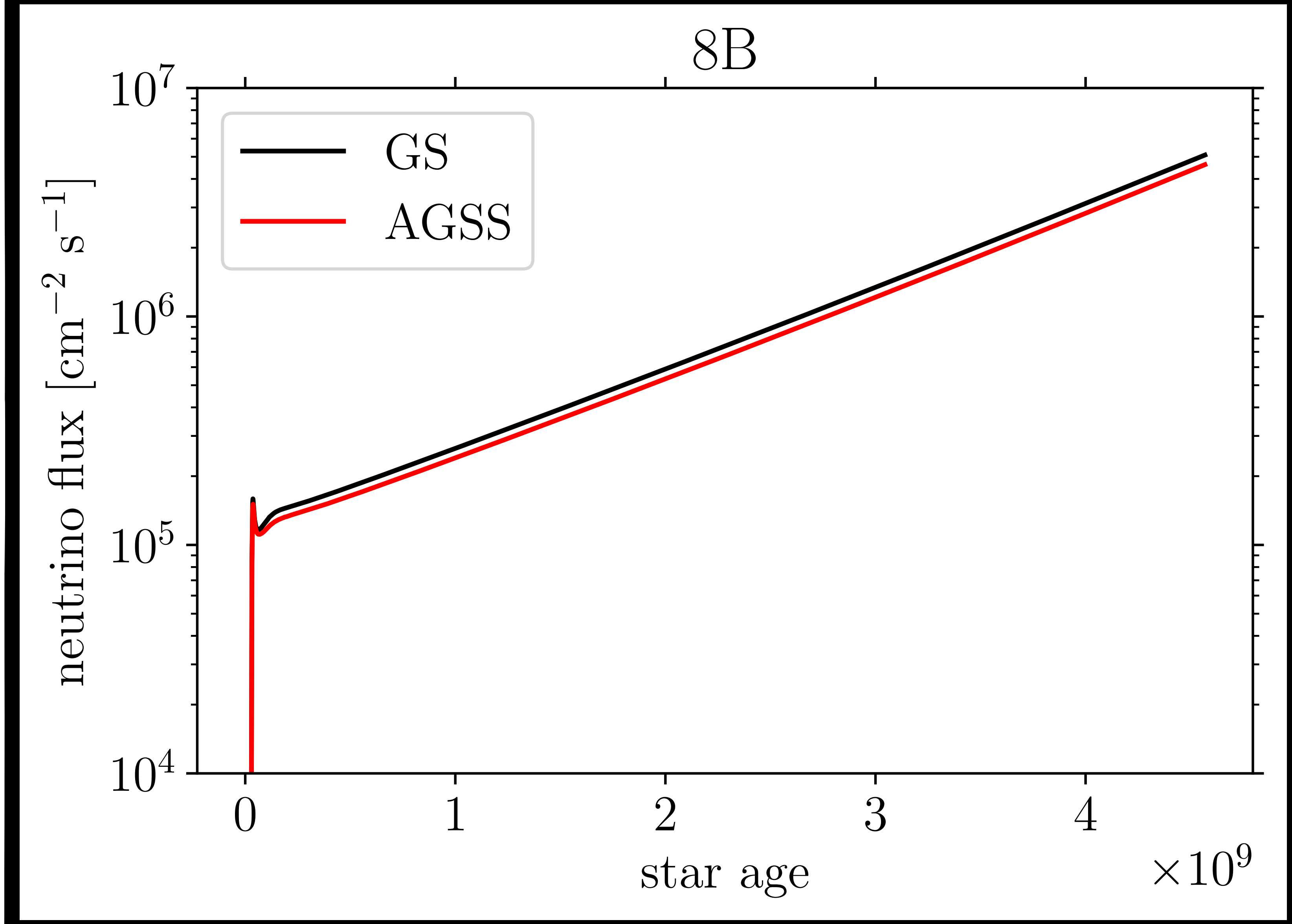
Sinjarite
dR/dx [1/nm/kg/Myr]
x [nm]
8B
Neutrons

Metallicity models

Metallicity Models:

- 8B Neutrinos strong dependence on Solar Core T°
- MESA code version r12115
- Z/X = 0.0229 for GS
- Z/X = 0.0181 for AGSS

8B : T^{24}



[MESA]

Metallicity models

Metallicity Models:

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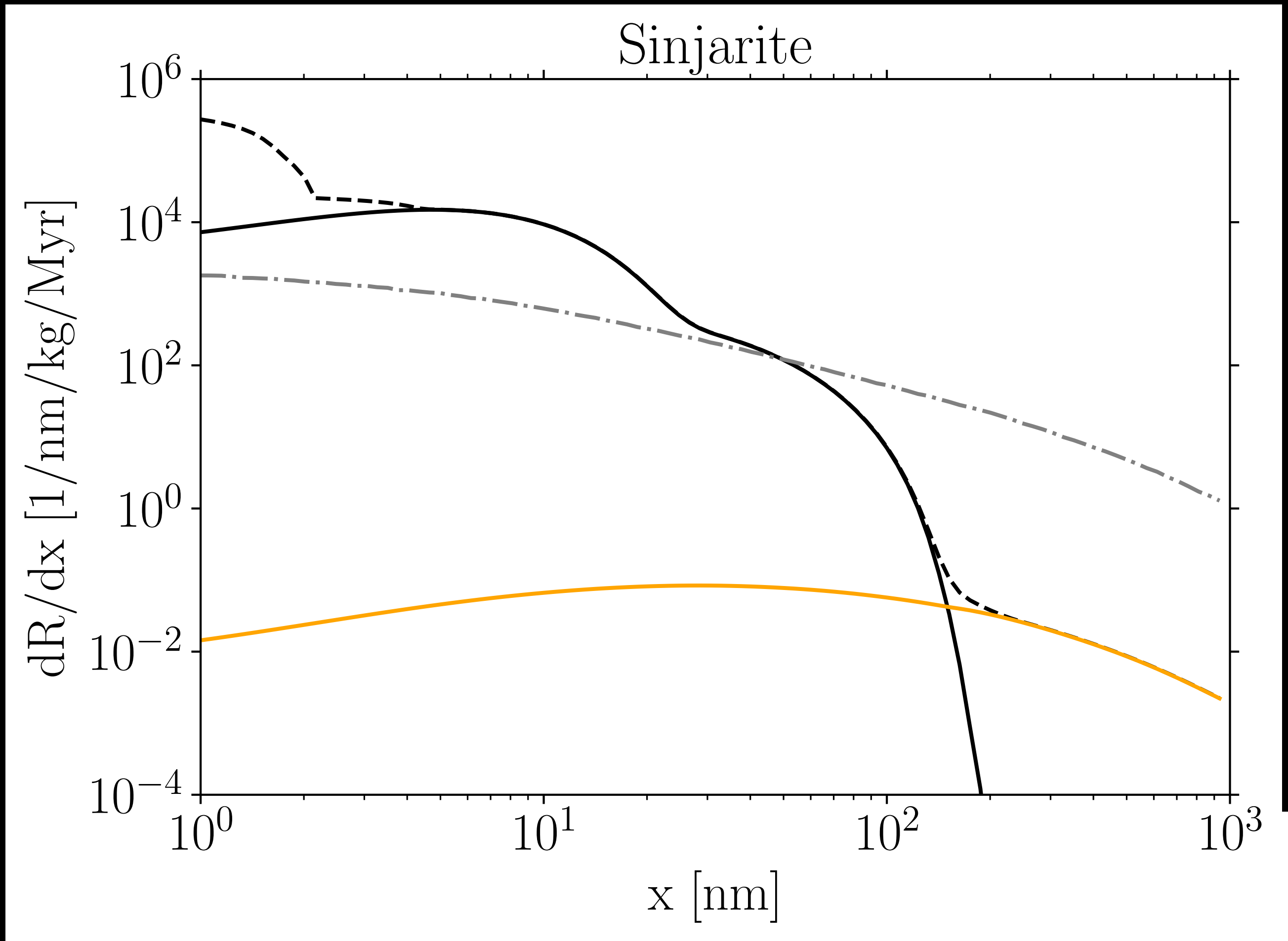
Channel	GS	AGSS	Measurement
$\Phi_{\rm pp}$	5.98	6.01	$6.05(1^{+0.003}_{-0.011})$
$\Phi_{^7\rm Be}$	4.95	4.71	$4.82(1^{+0.05}_{-0.04})$
$\Phi_{^8\rm B}$	5.09	4.62	$5.00(1 \pm 0.03)$
$\Phi_{\rm CNO}$	5.12	3.92	$7.0(1^{+0.43}_{-0.29})$

Solar neutrino fluxes at Earth, predicted by MESA and measured, in units of $cm^{-2}s^{-1}$.

They scale as: (pp) 10^{10}, (7Be) 10^{9}, (8B) 10^{6} and (CNO) 10^{8}



Marine Evaporite Materials

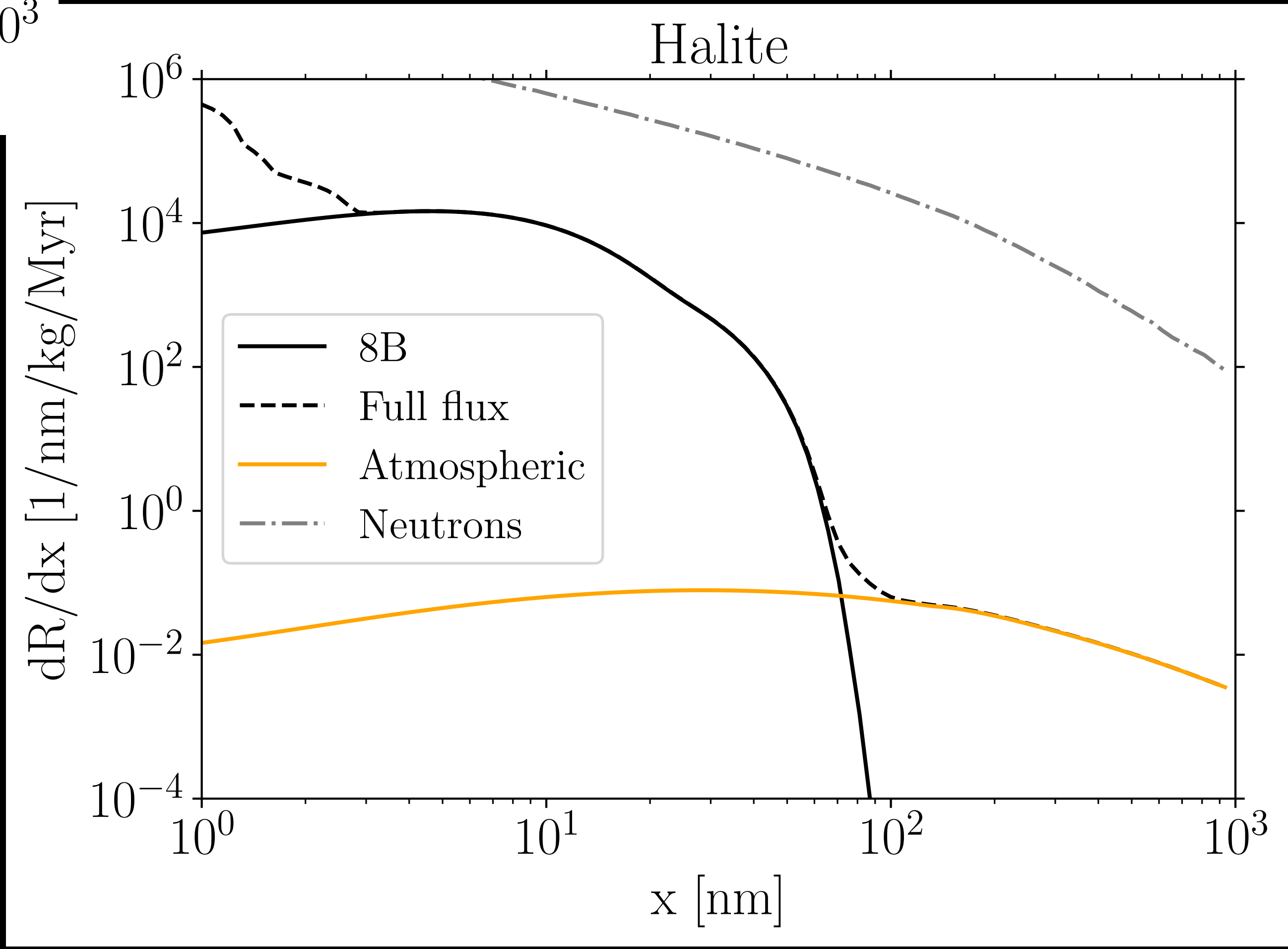
- We adopt Uranium concentrations of 0.01 parts per billion for MEs

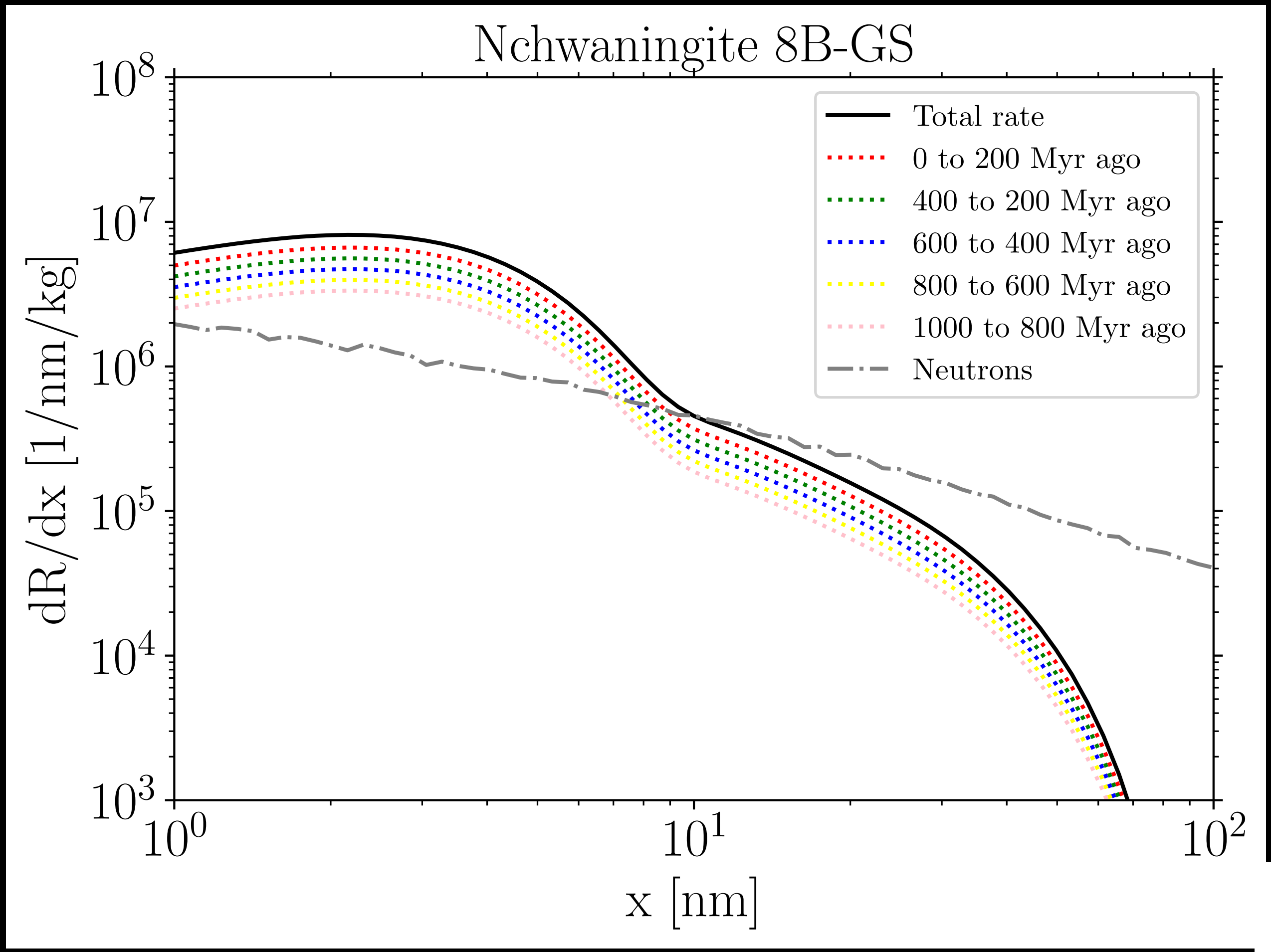
Sinjarite

$$CaCl_2 \cdot 2(H_2O)$$

Halite

$$NaCl$$





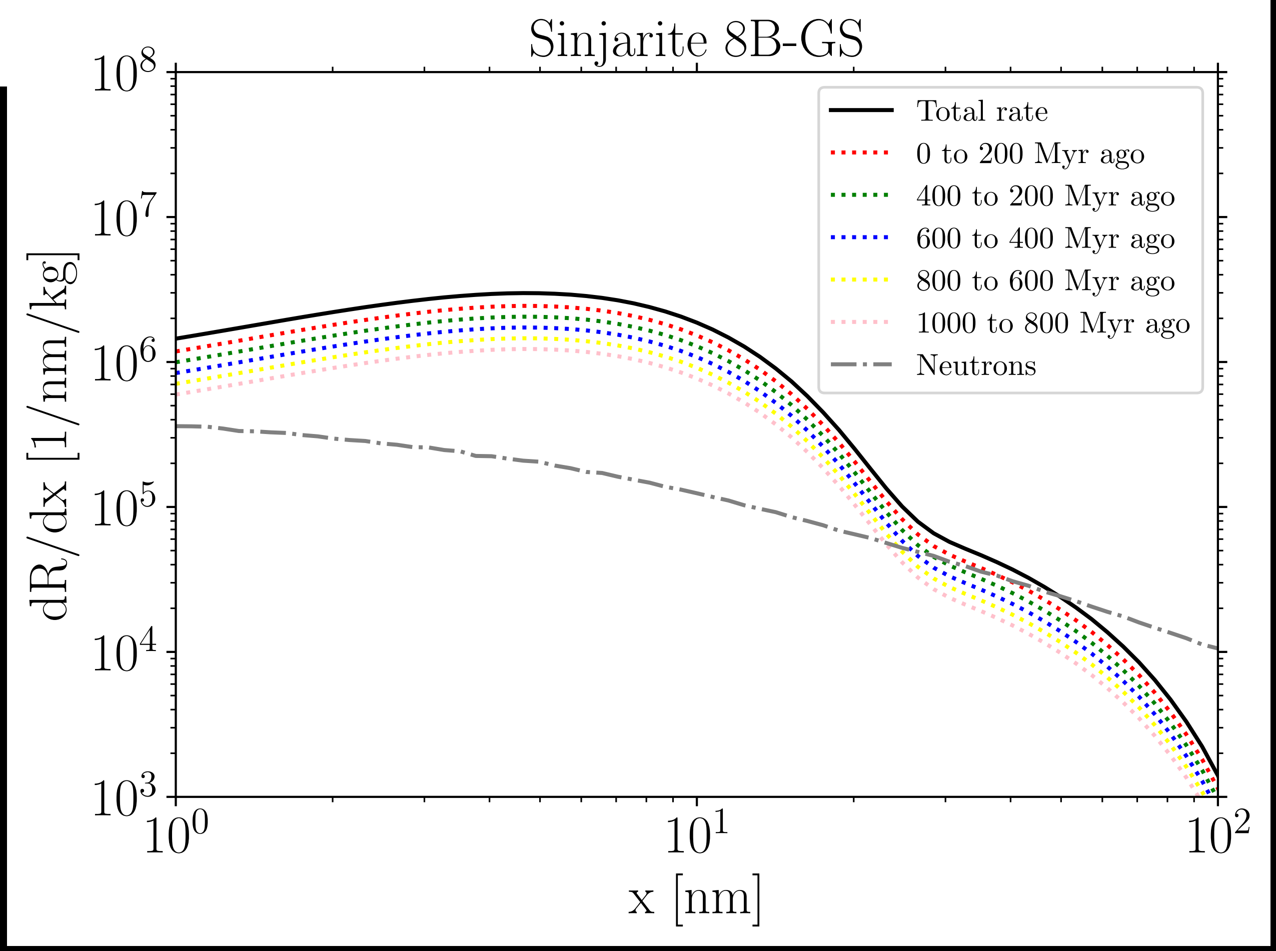
Backgrounds:

- Cosmogenic background are suppressed beyond 5 km depth rocks
- Neutron bkg: 10% uncertainty [sources-4A code]

Nchwaningite

UBR: arise from earth's mantle, 0.1 ppb concentration

$$Mn^{2+}SiO_3(OH) \cdot H_2O$$



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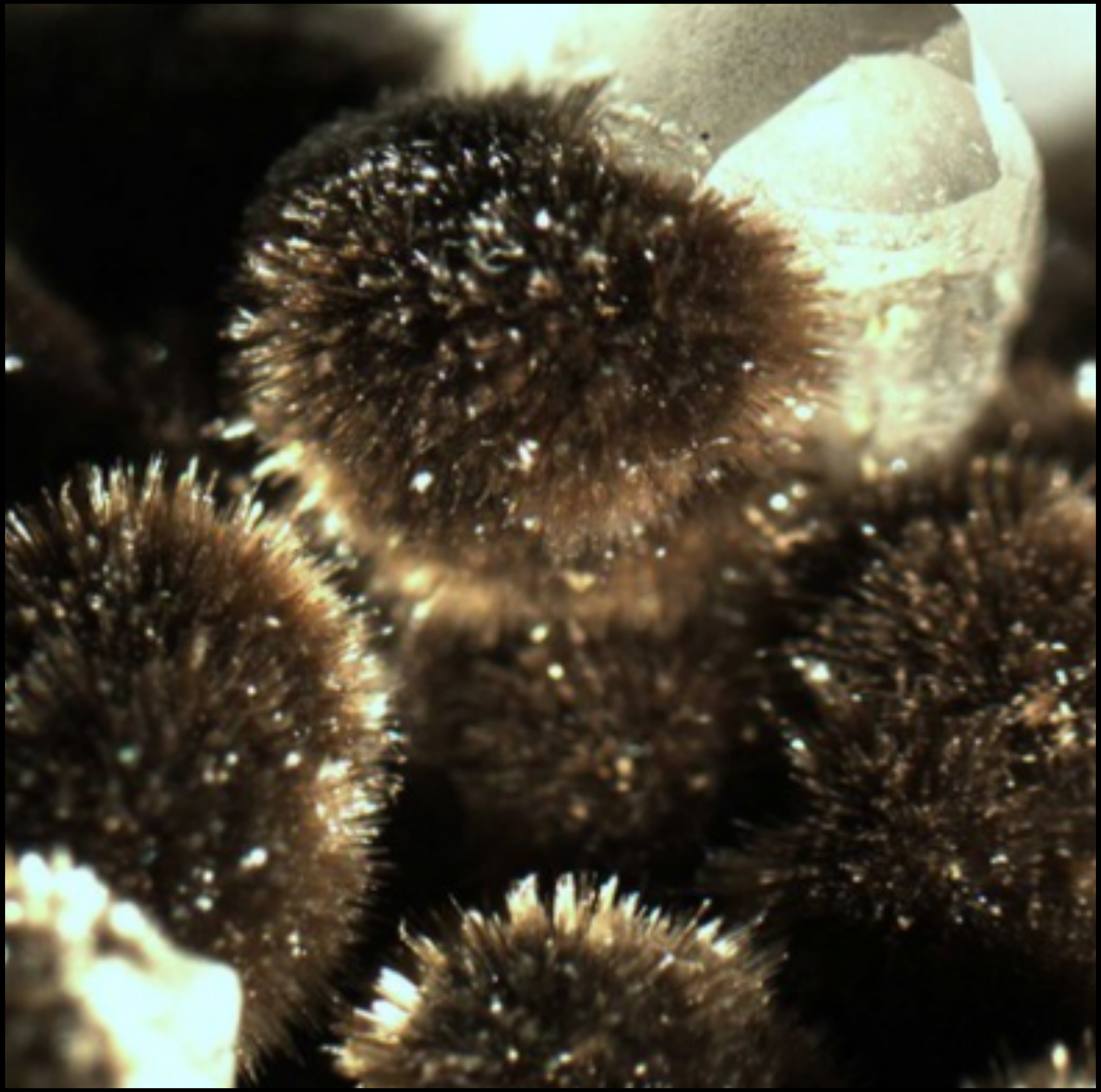


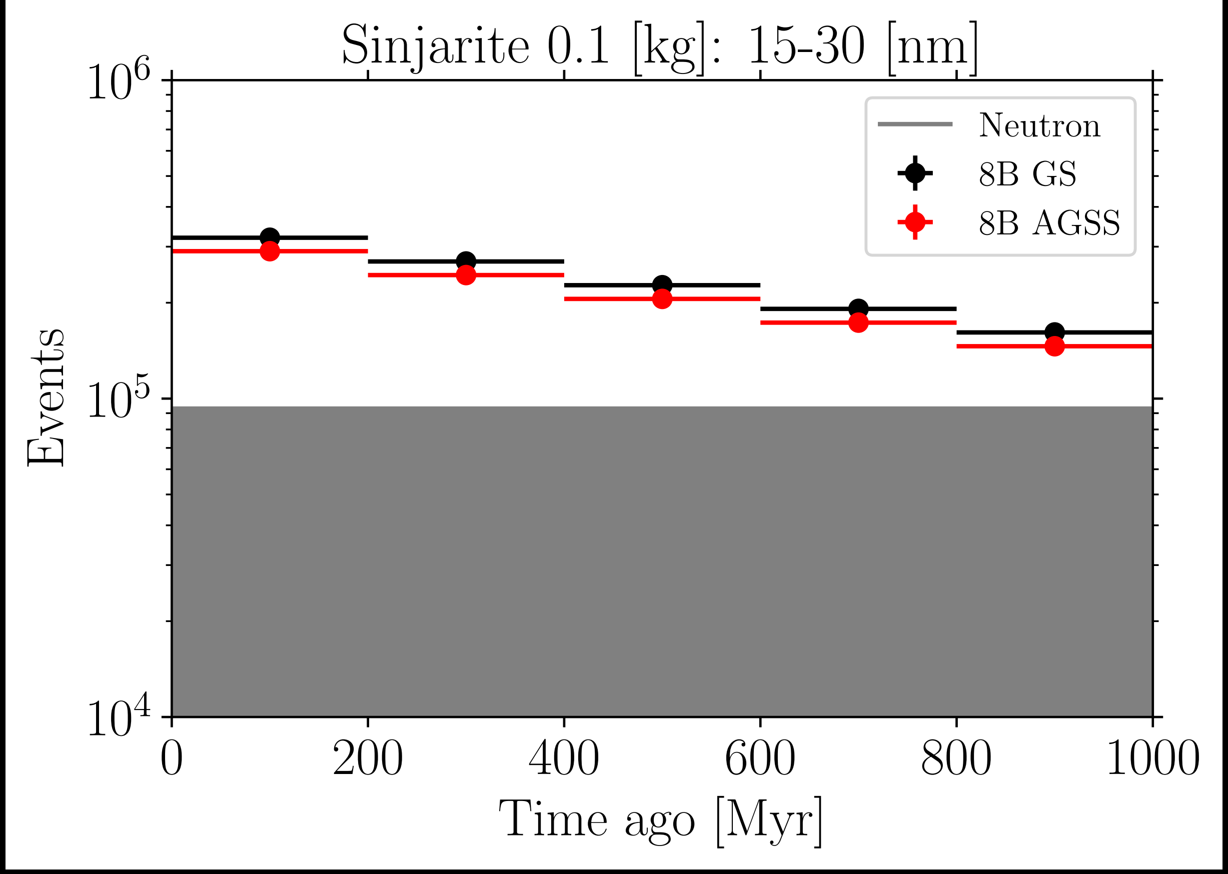
NCHWANINGITE

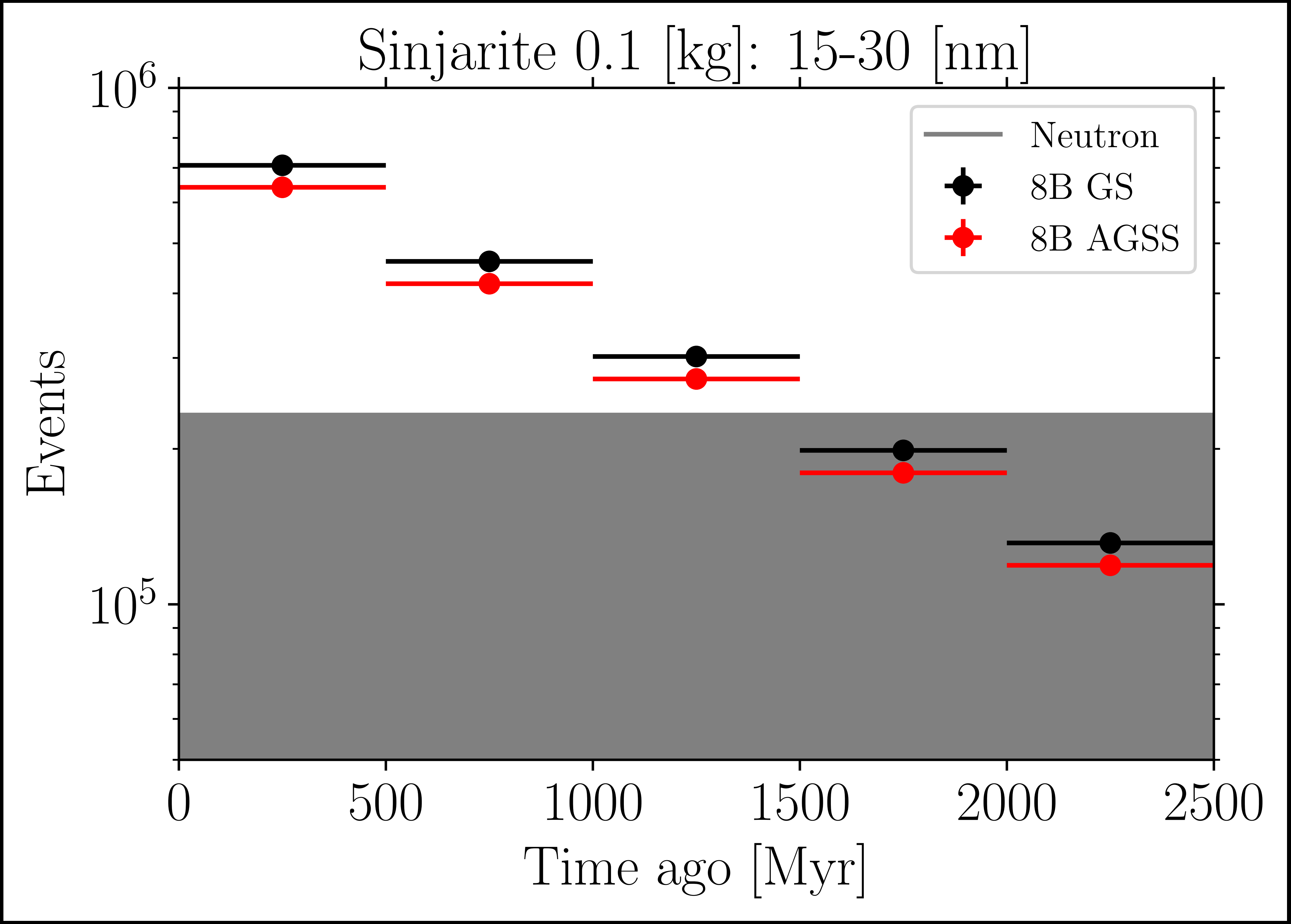
- Results

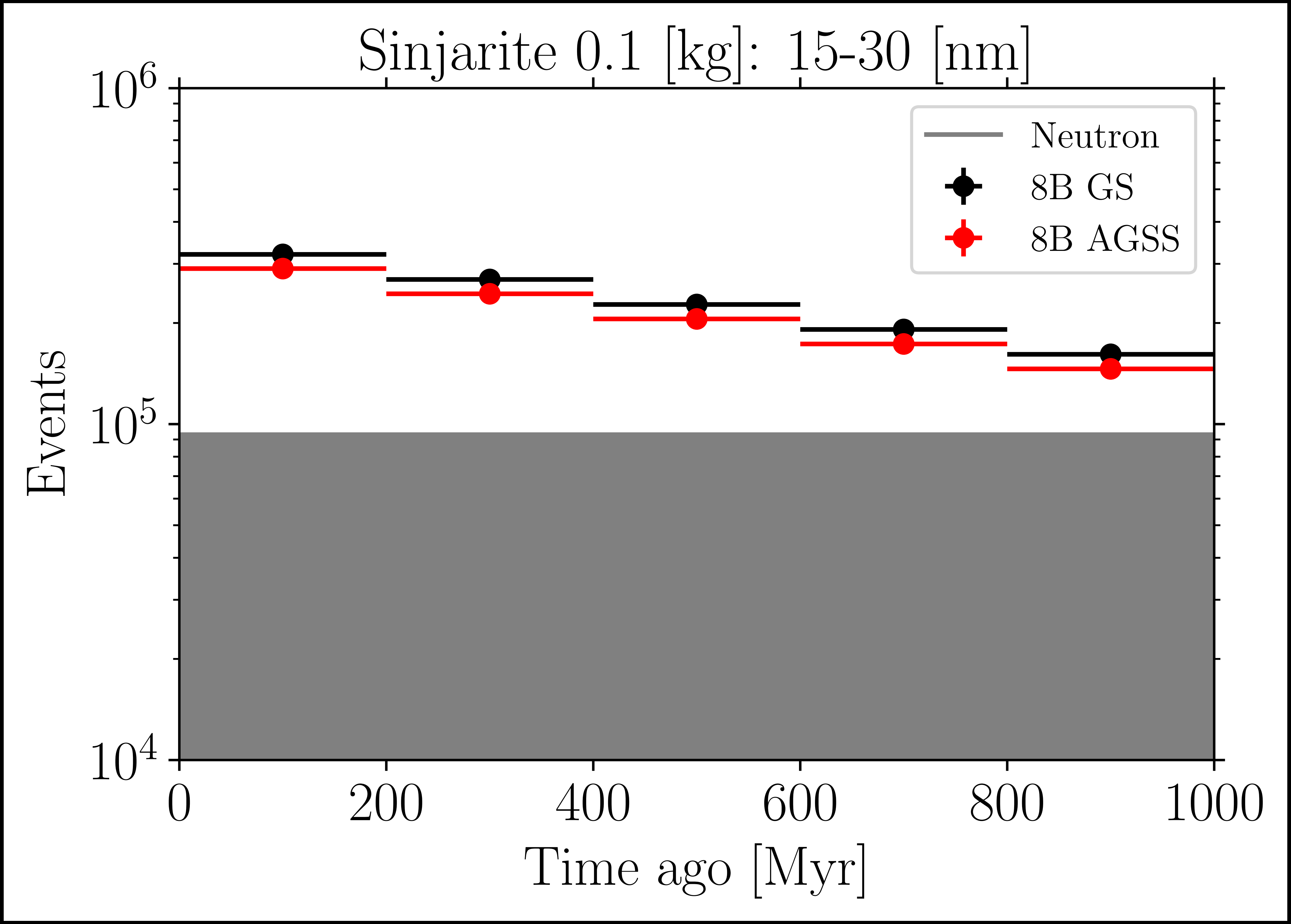
Results

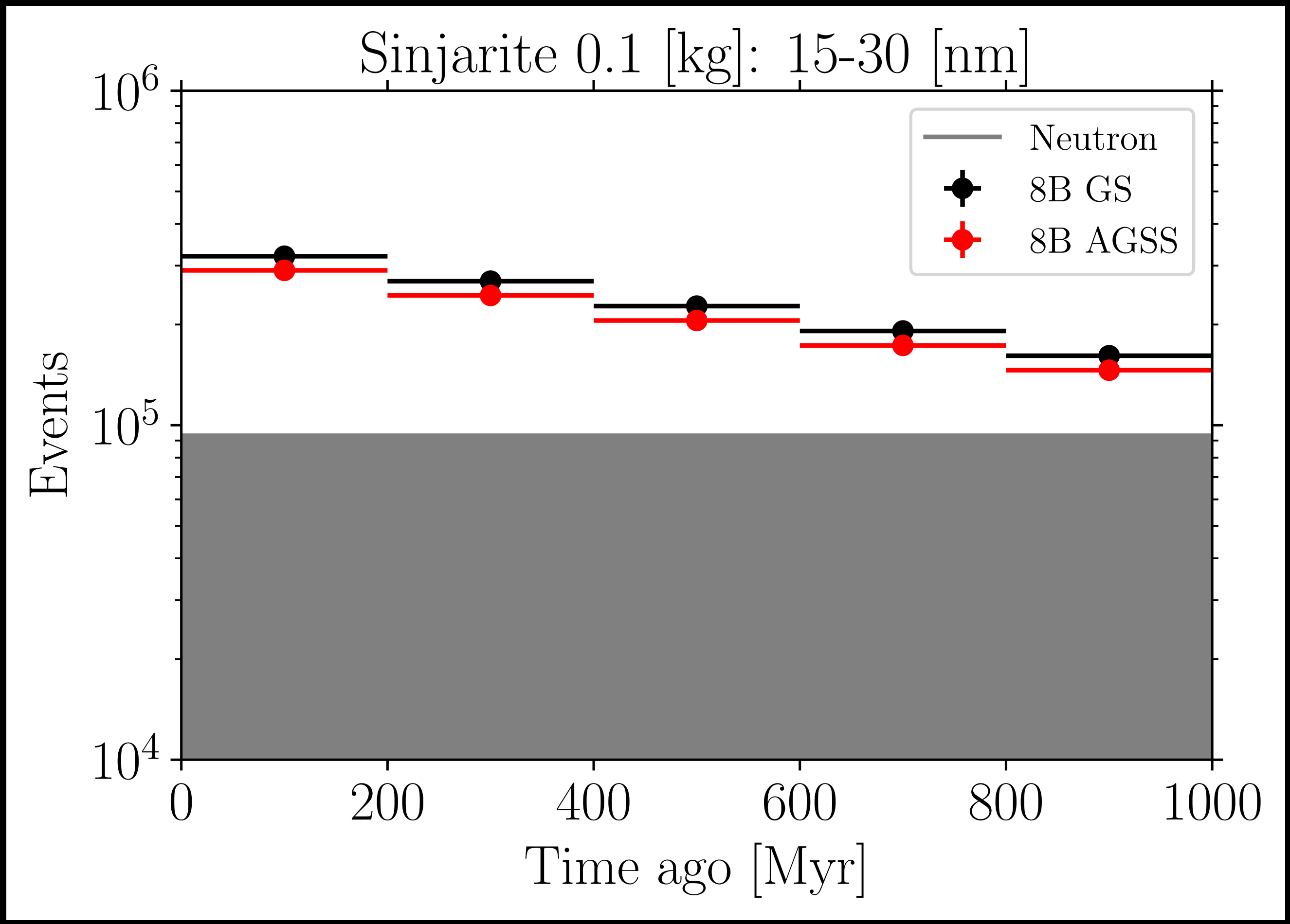
Different Scenarios

- We examined in details the track length range of 15-30 nm
- We use a sample mass of 0.1 kg
- Time window of time variation: 200 Myr and 500 Myr




Sinjarite 0.1 [kg]: 15-30 [nm]
Neutron
8B GS
8B AGSS
Events
10^6
10^5
0
500
1000
1500
2000
2500
Time ago [Myr]


Sinjarite 0.1 [kg]: 15-30 [nm]
Neutron
8B GS
8B AGSS
Events
10^6
10^5
10^4
0
200
400
600
800
1000
Time ago [Myr]

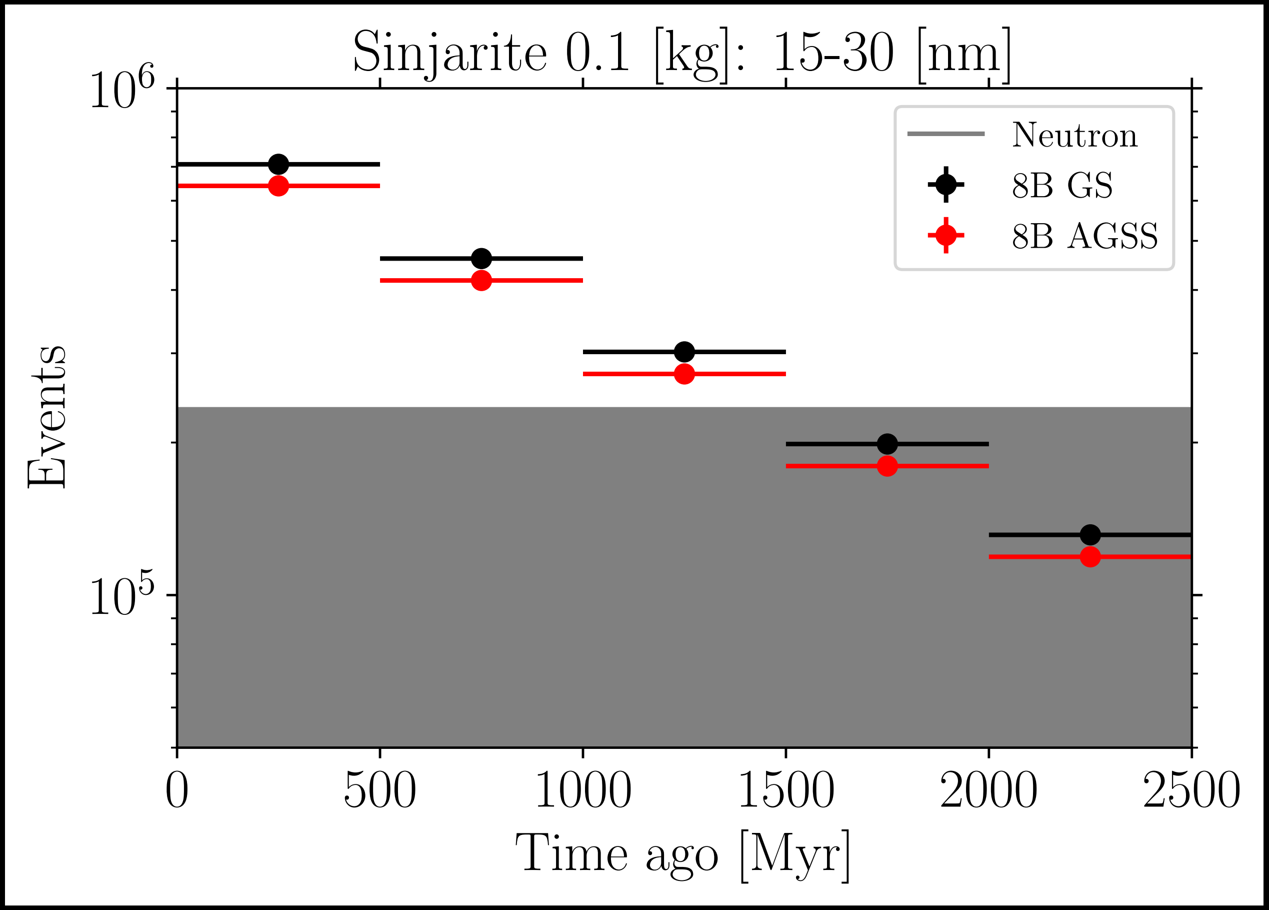


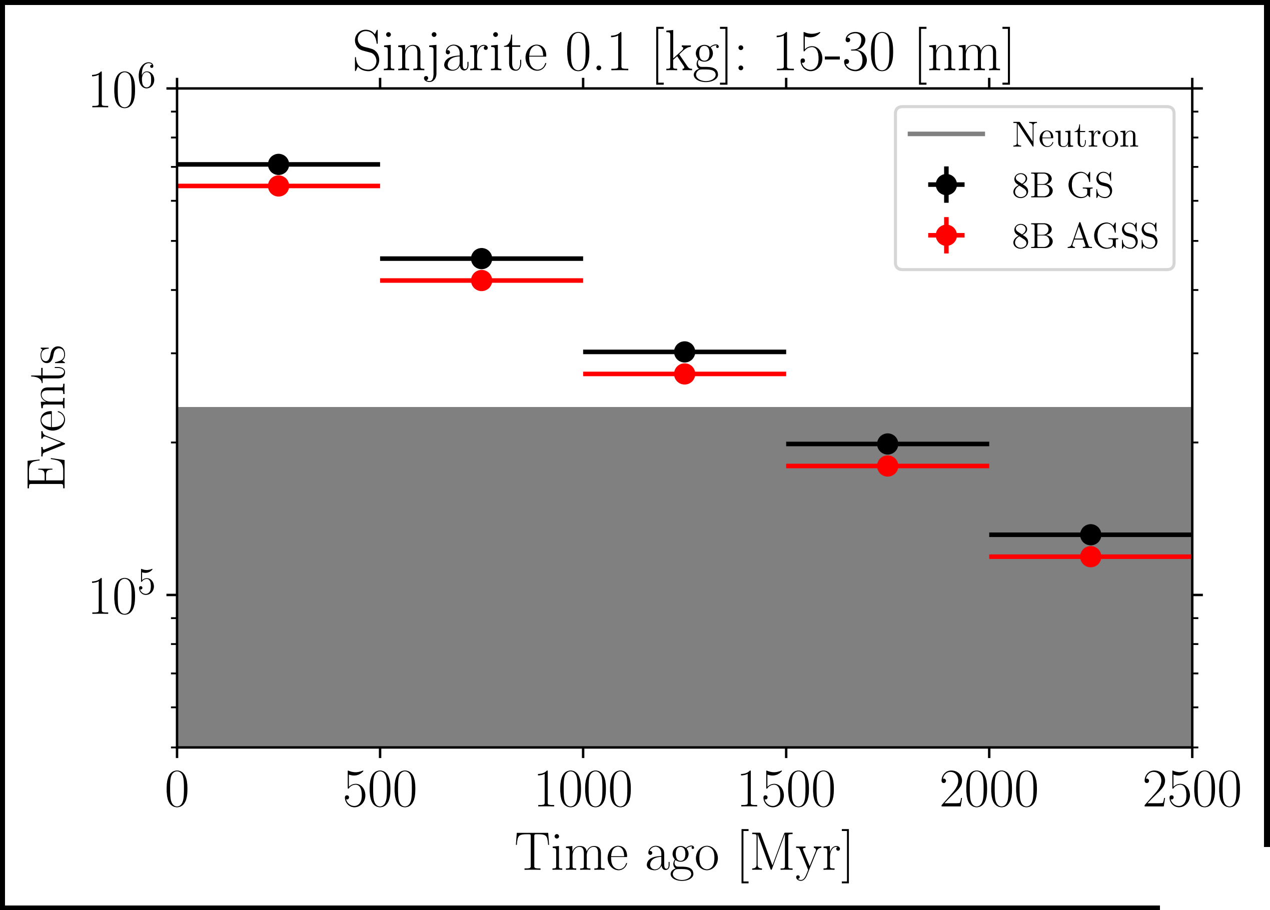
Track measure resolution:

- Small angle X-ray scattering can achieve 15 nm three dimensional spatial resolution

Rock dating

- Up to 1 Gyr with 10% uncertainty



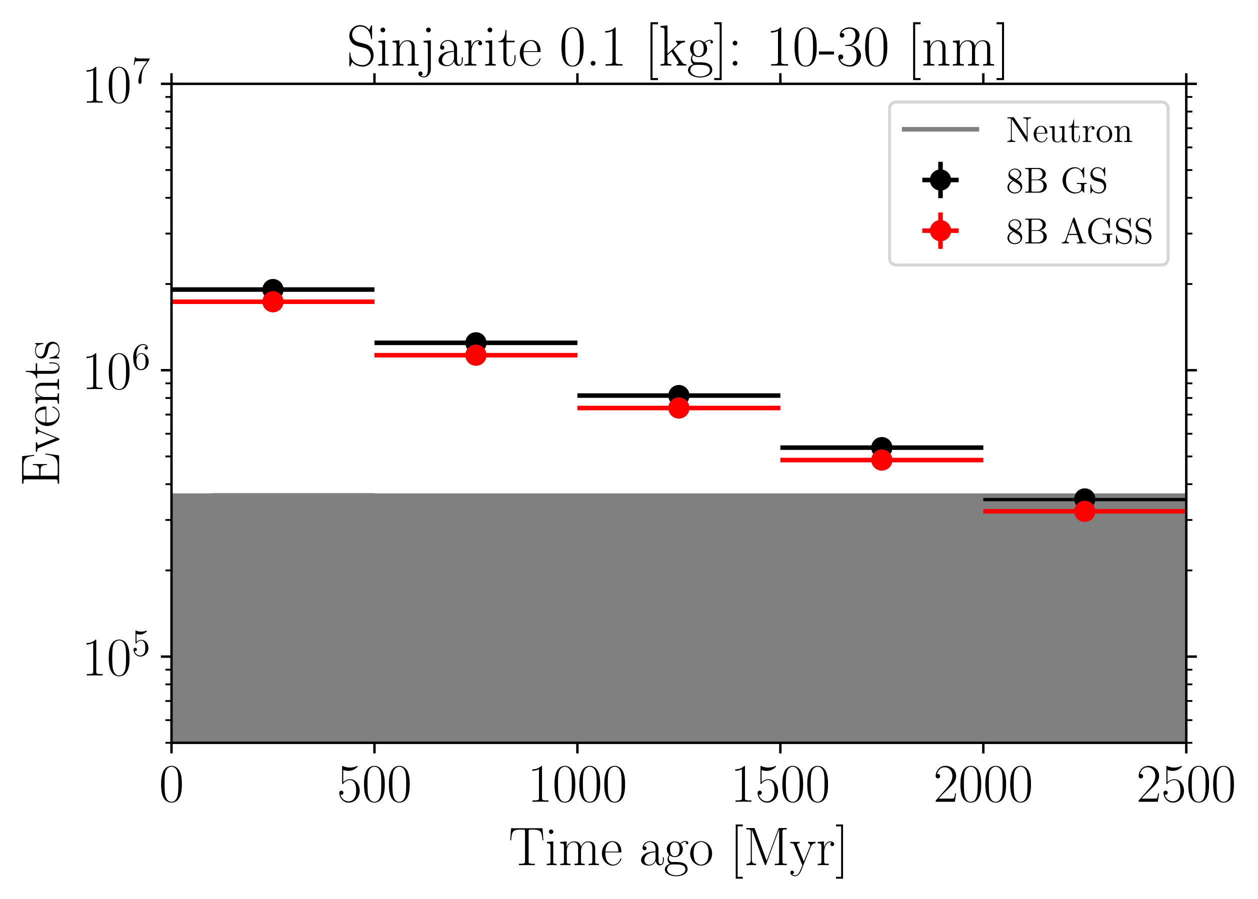


Metallicity sensitivity

- GS98 1Gyr: $(1.63 \pm 0.05) \times 10^6$
- AGSS09 1Gyr: $(1.52 \pm 0.05) \times 10^6$

- Background in a 10% uncertainty case

$(\sim 5) \times 10^5$



Summary

- Solar neutrinos help us understand the behavior of our local star.
- Solar Standard Models predict neutrino fluxes.
- Time variation of neutrinos can be recorded in paleo detectors, up to ~ 1 Gyr.
- Sinjarite would be the optimal material to probe Solar neutrinos and SSM

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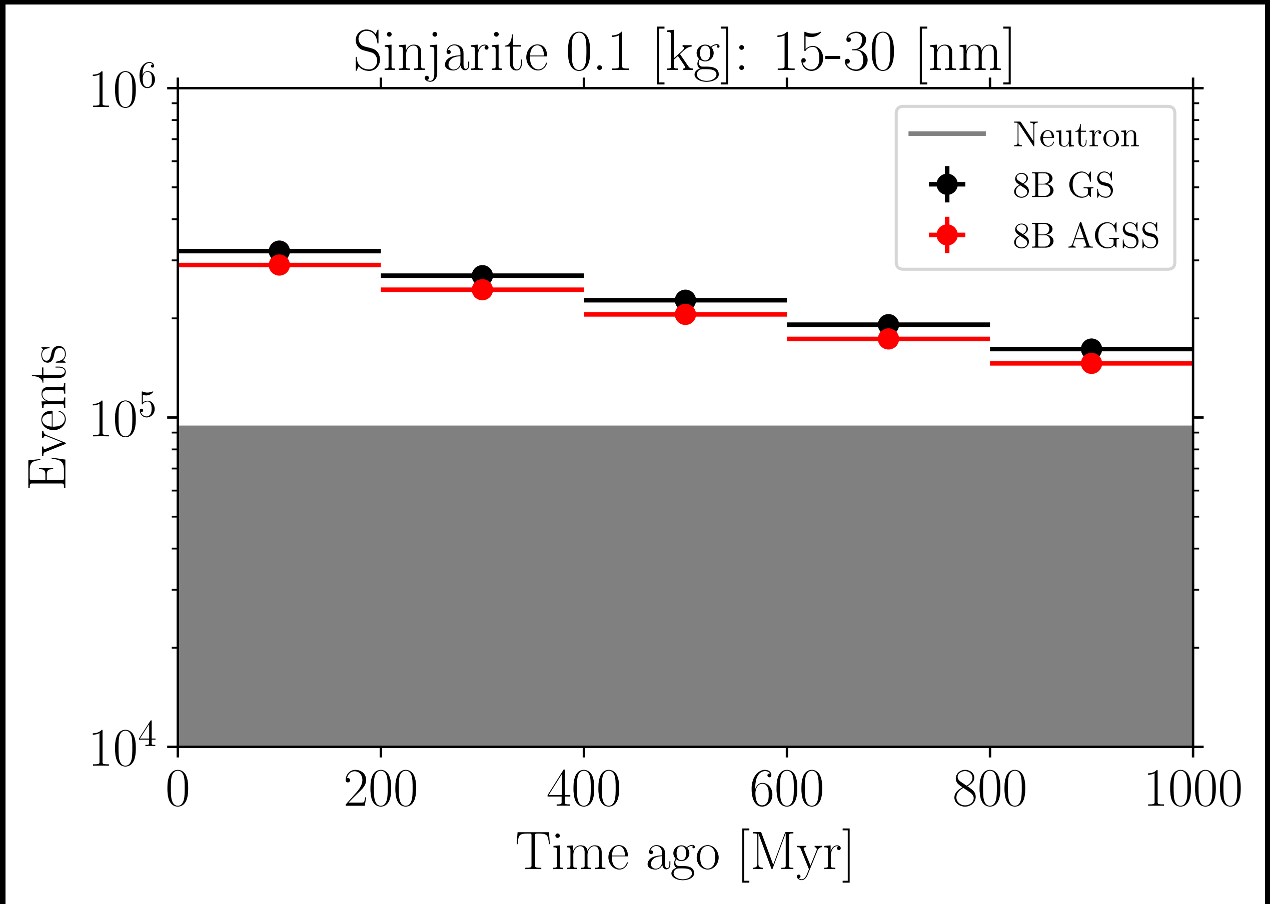
Thank you!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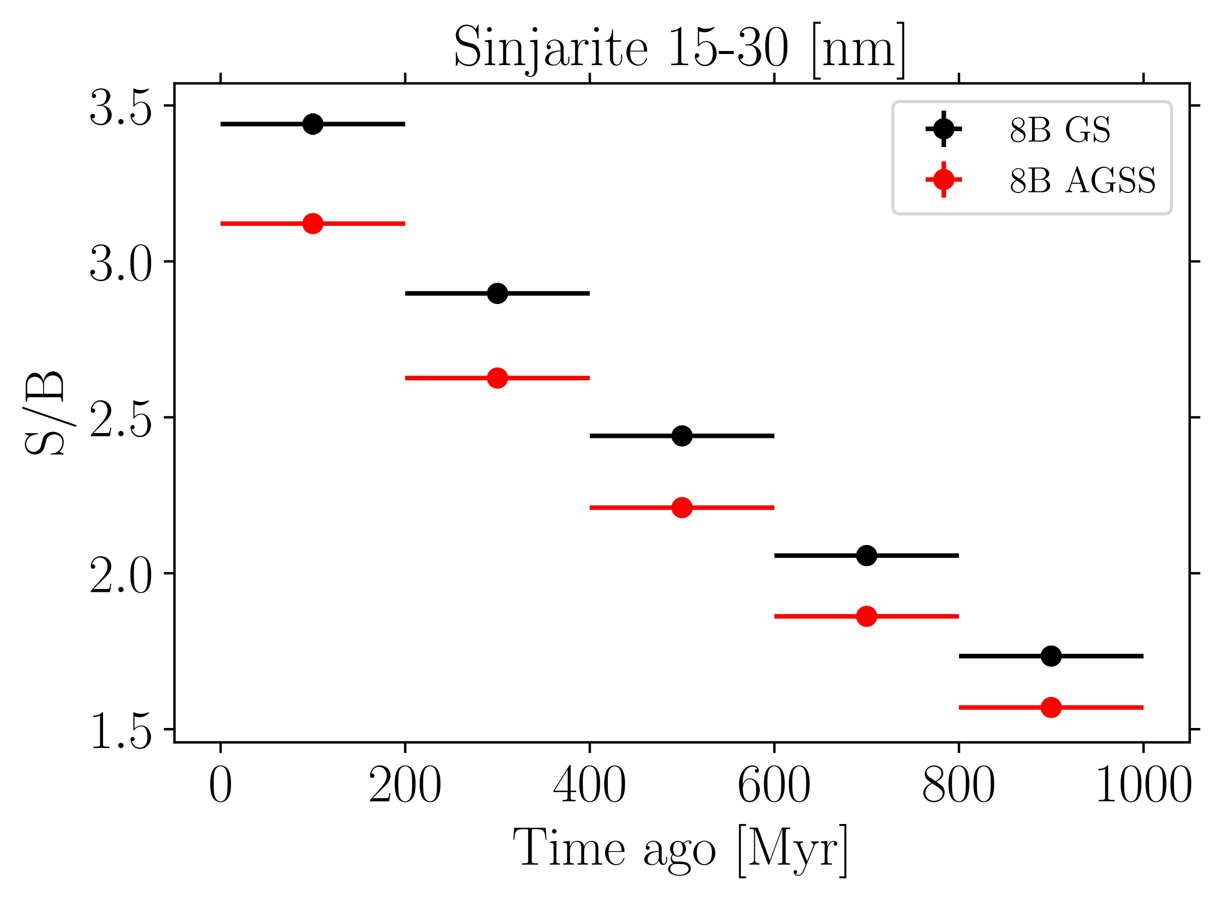
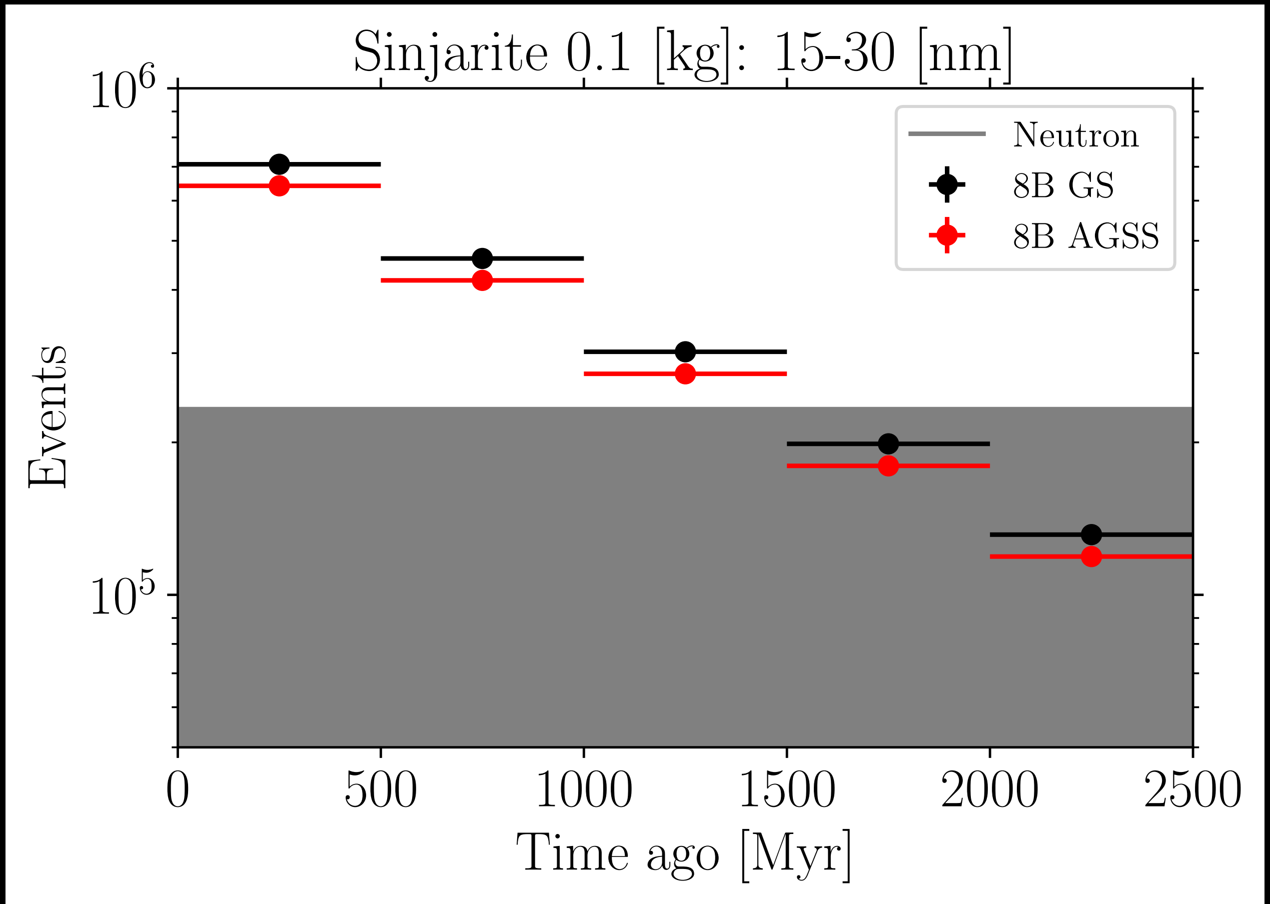

Sinjarite 15-30 [nm]
S/B
3.5
3.0
2.5
2.0
1.5
0
200
400
600
800
1000
Time ago [Myr]
8B GS
8B AGSS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8B GS
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10^6
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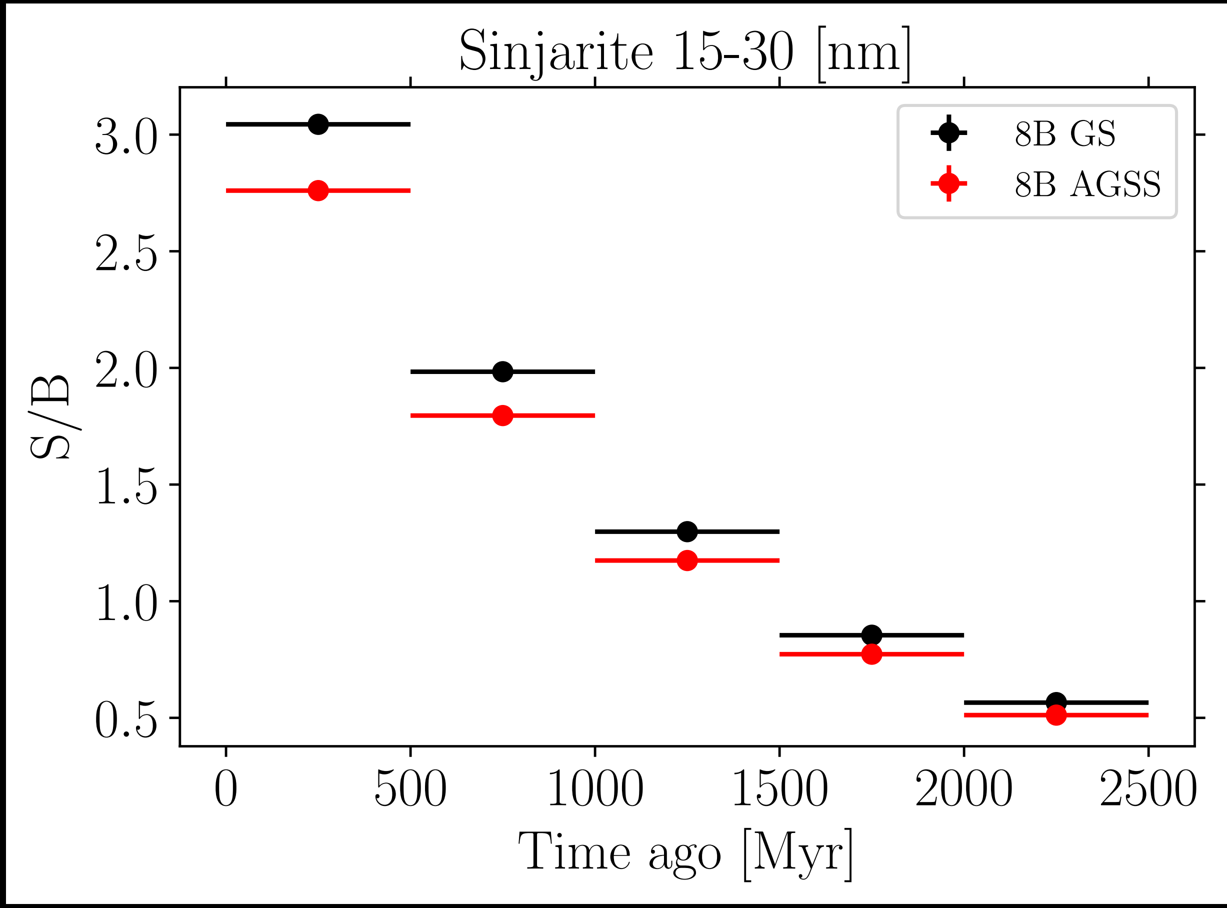
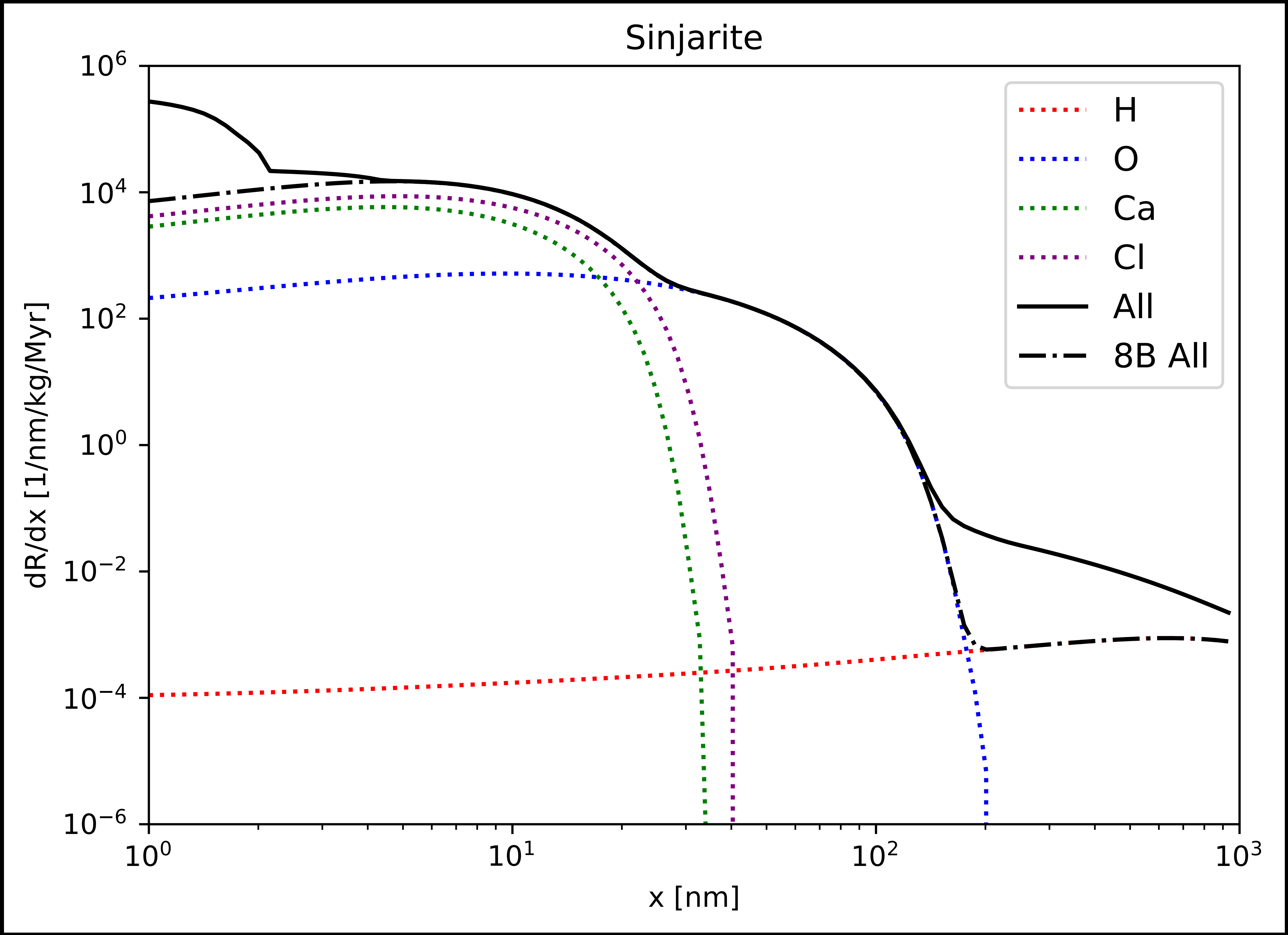
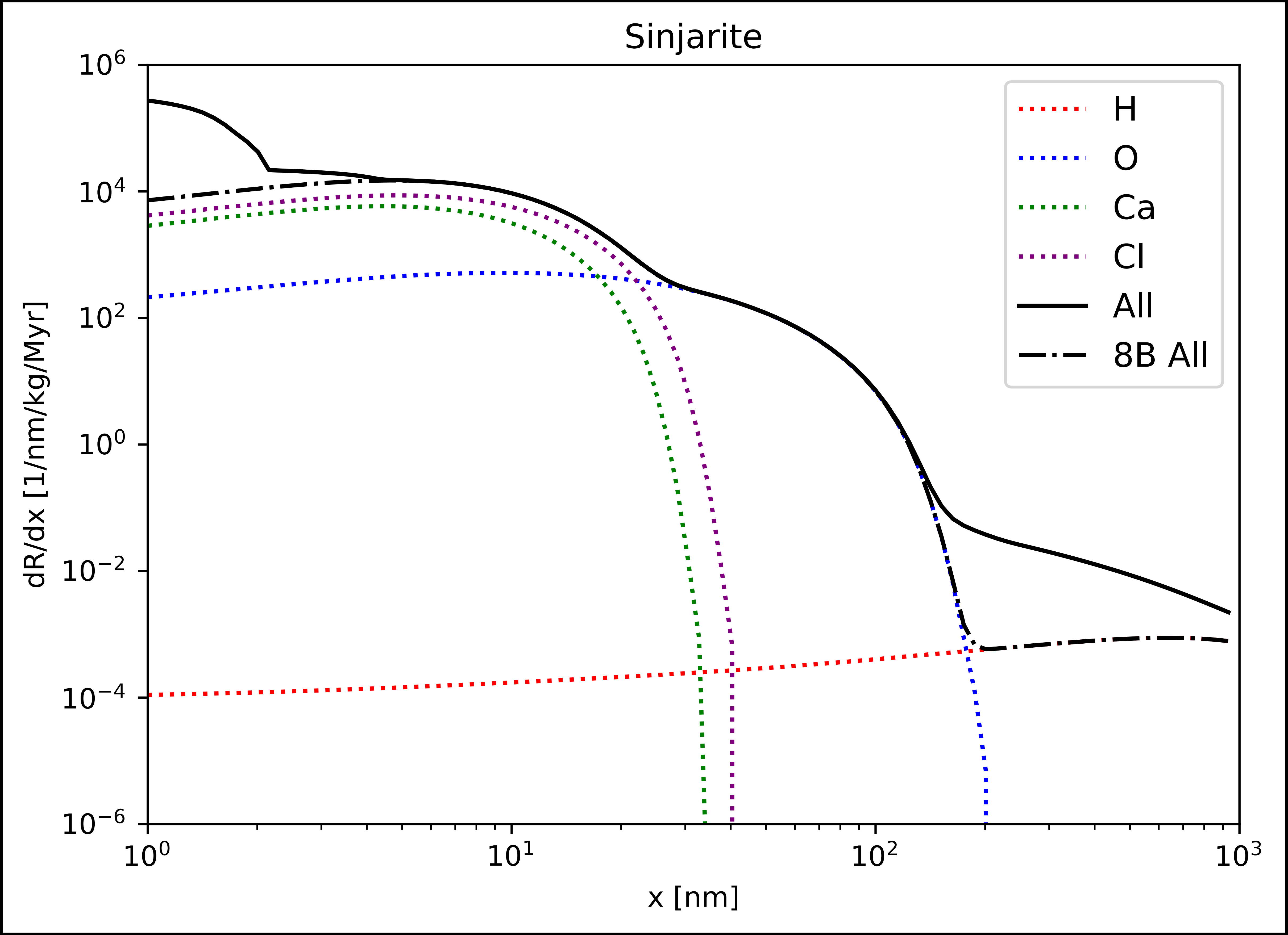
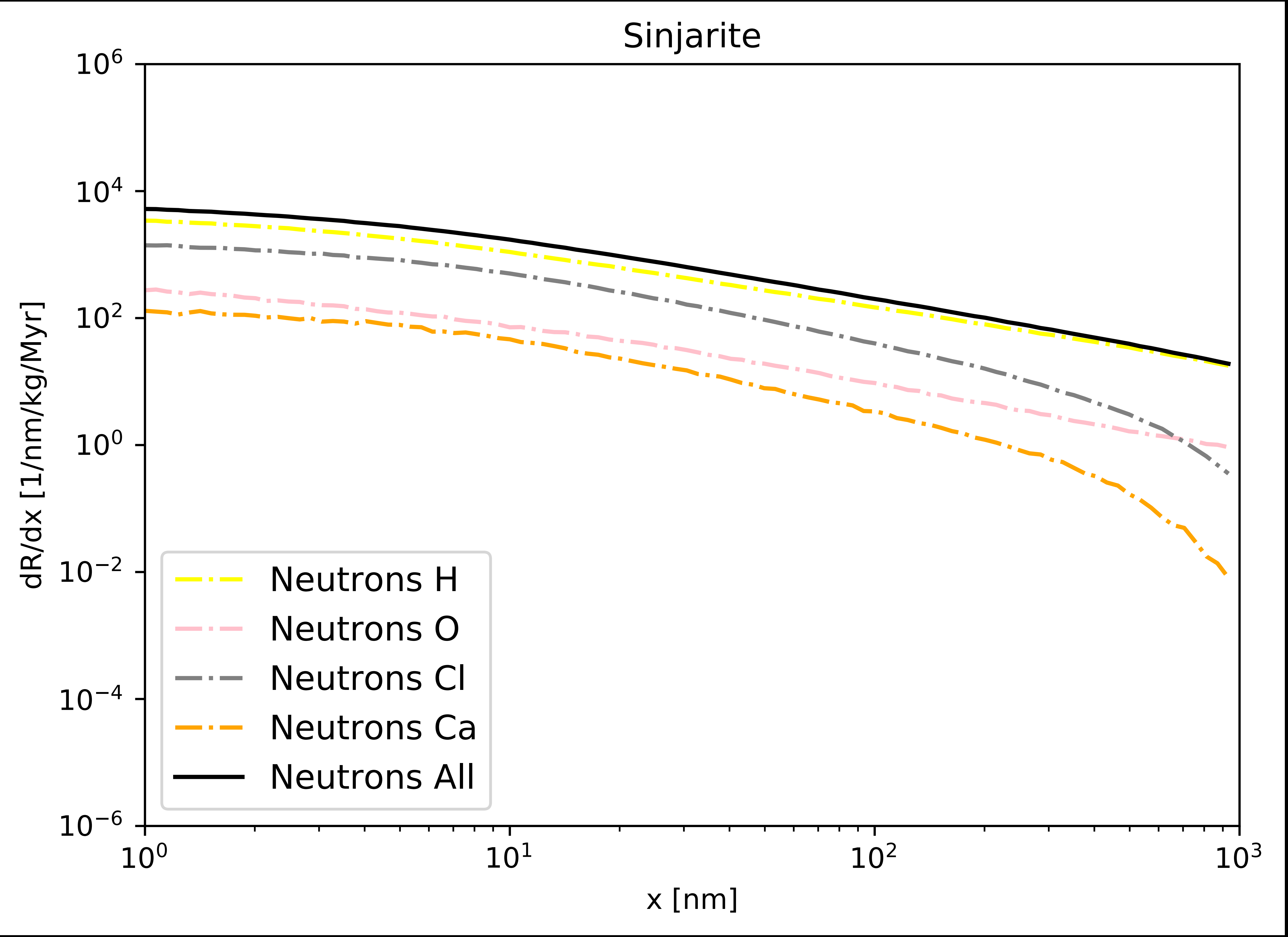

Sinjarite 15-30 [nm]
S/B
Time ago [Myr]
8B GS
8B AGSS
3.0
2.5
2.0
1.5
1.0
0.5
0
500
1000
1500
2000
2500

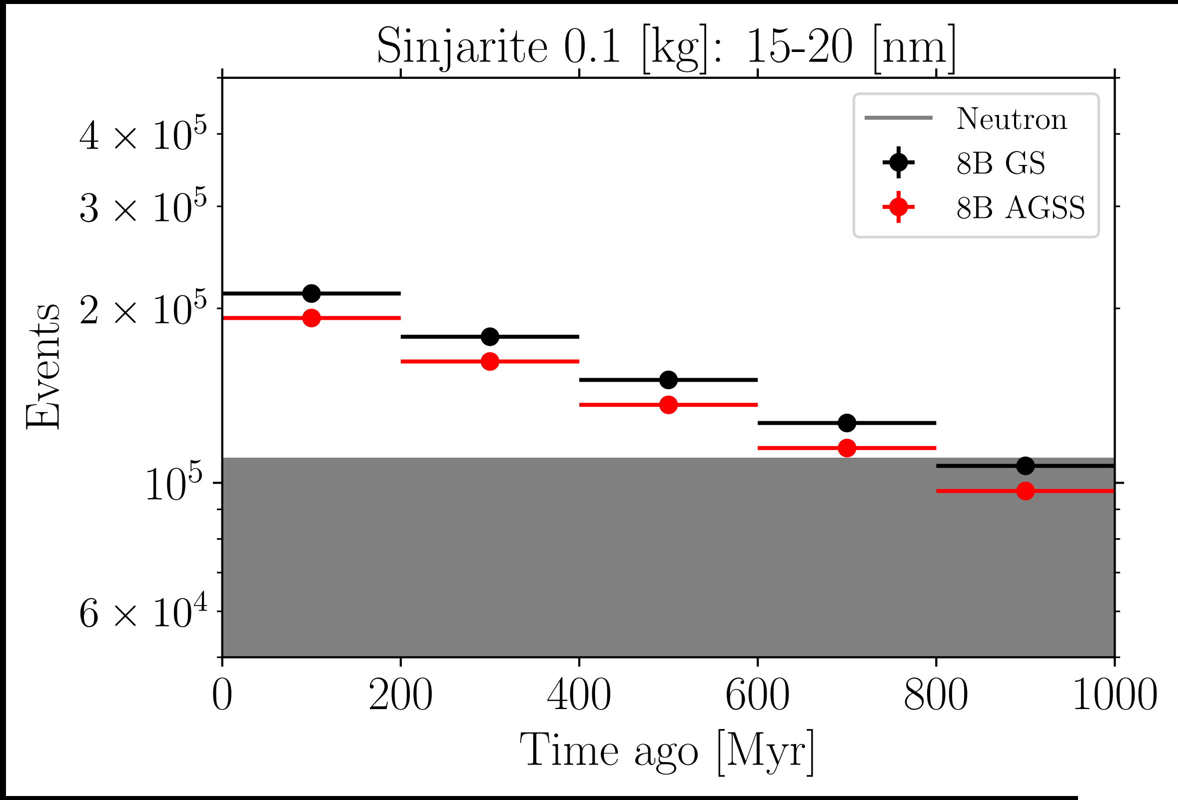

Sinjarite
dR/dx [1/nm/kg/Myr]
x [nm]
H
O
Ca
Cl
All
8B All

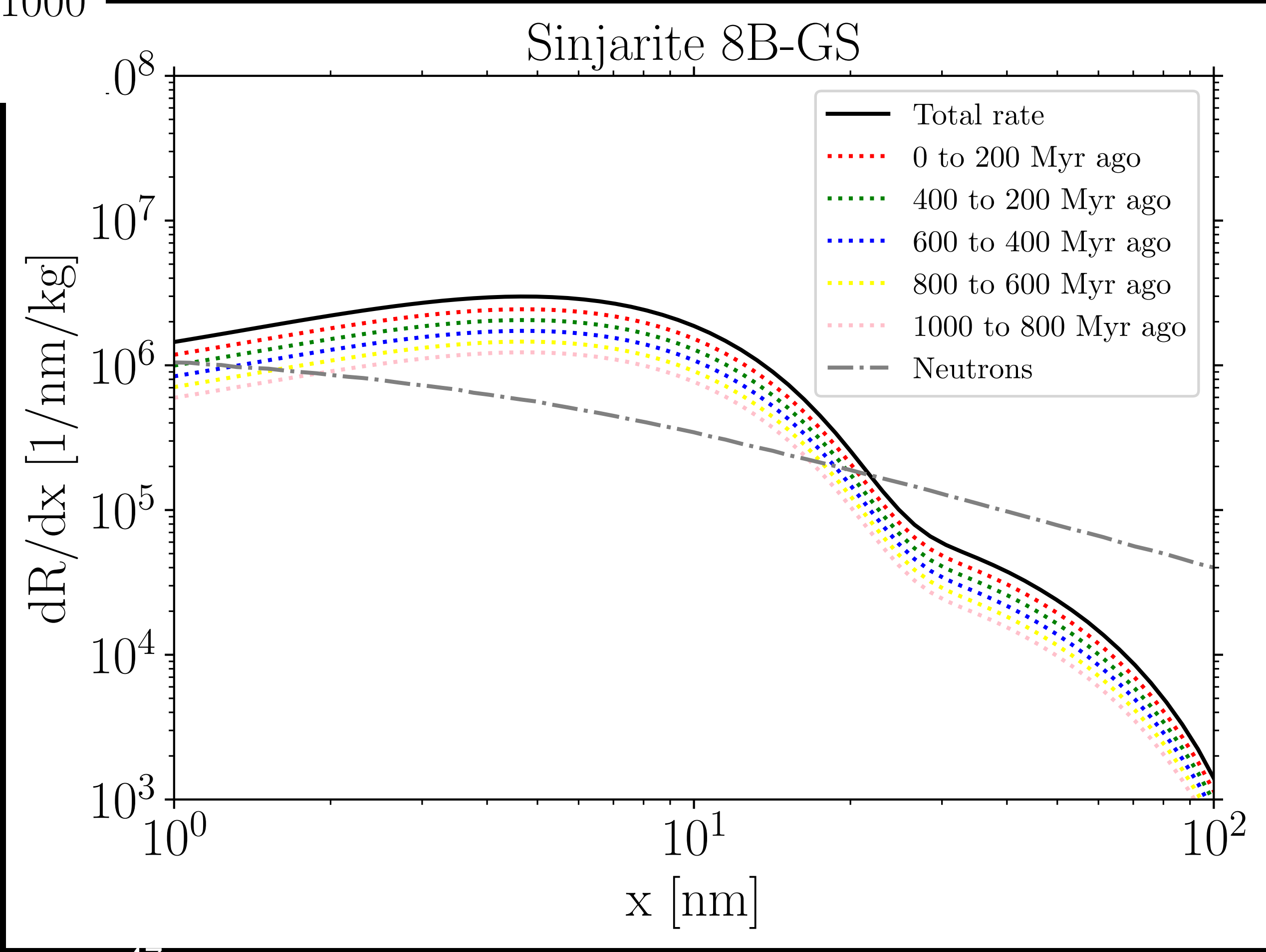

Sinjarite
dR/dx [1/nm/kg/Myr]
x [nm]
H
O
Ca
Cl
All
8B All
10^6
10^4
10^2
10^0
10^-2
10^-4
10^-6
10^0
10^1
10^2
10^3

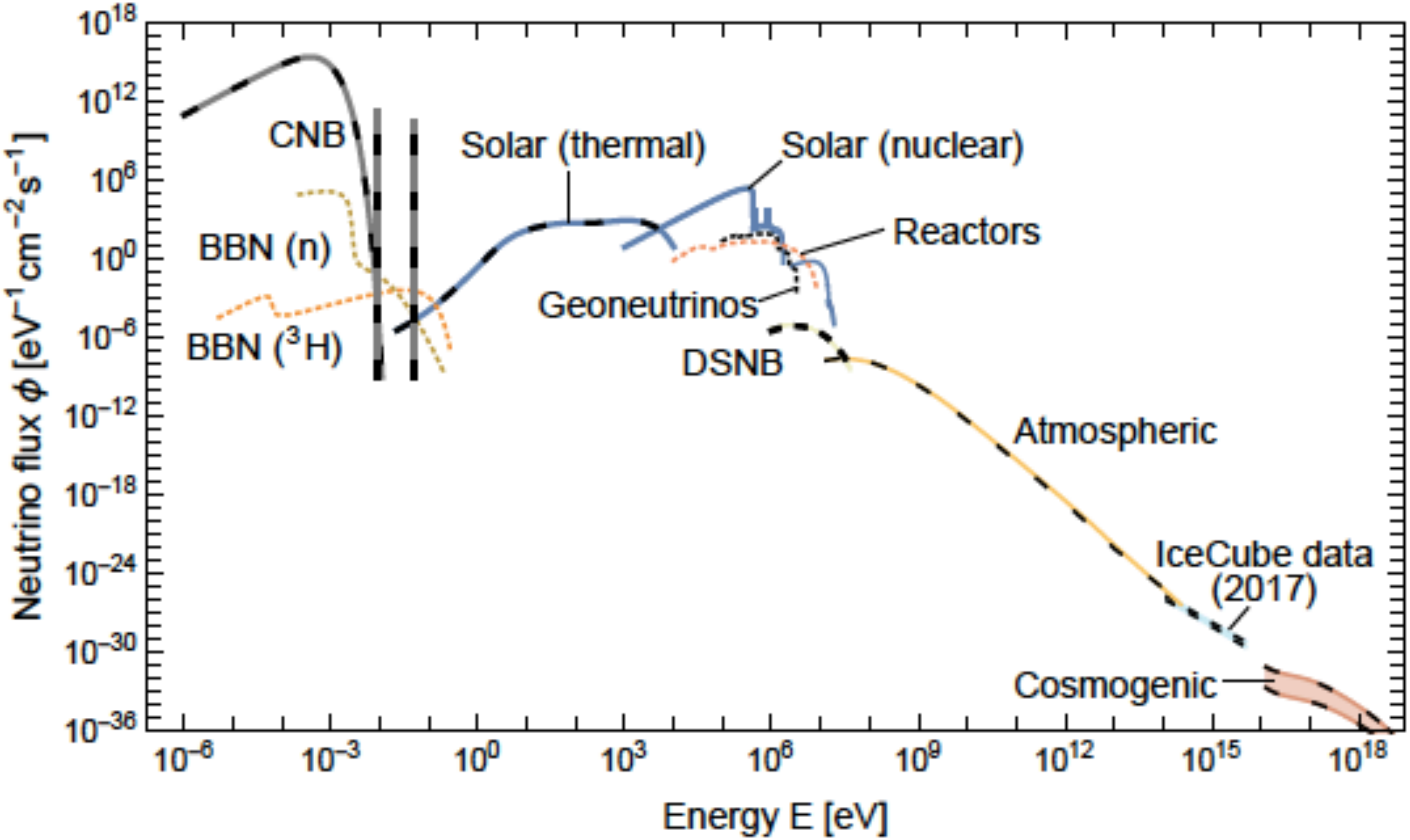


Sinjarite
dR/dx [1/nm/kg/Myr]
x [nm]
10^{6}
10^{4}
10^{2}
10^{0}
10^{-2}
10^{-4}
10^{-6}
10^{0}
10^{1}
10^{2}
10^{3}
Neutrons H
Neutrons O
Neutrons Cl
Neutrons Ca
Neutrons All

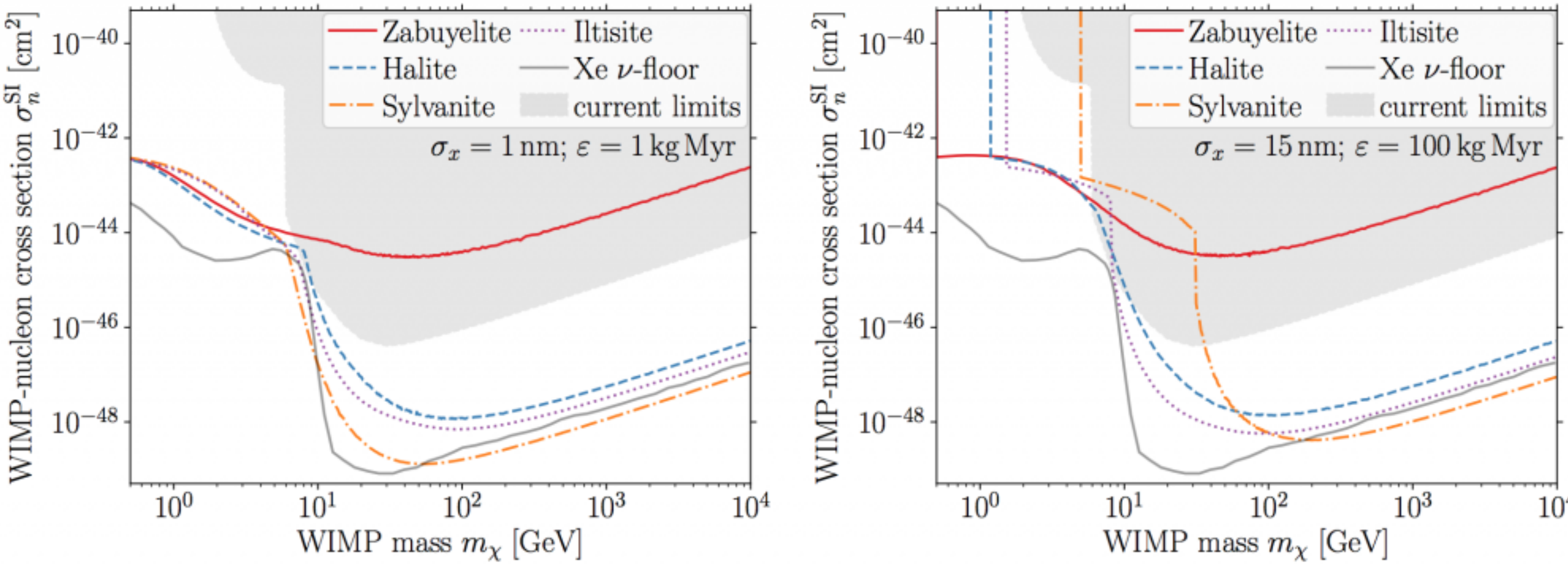
Including hydrogen

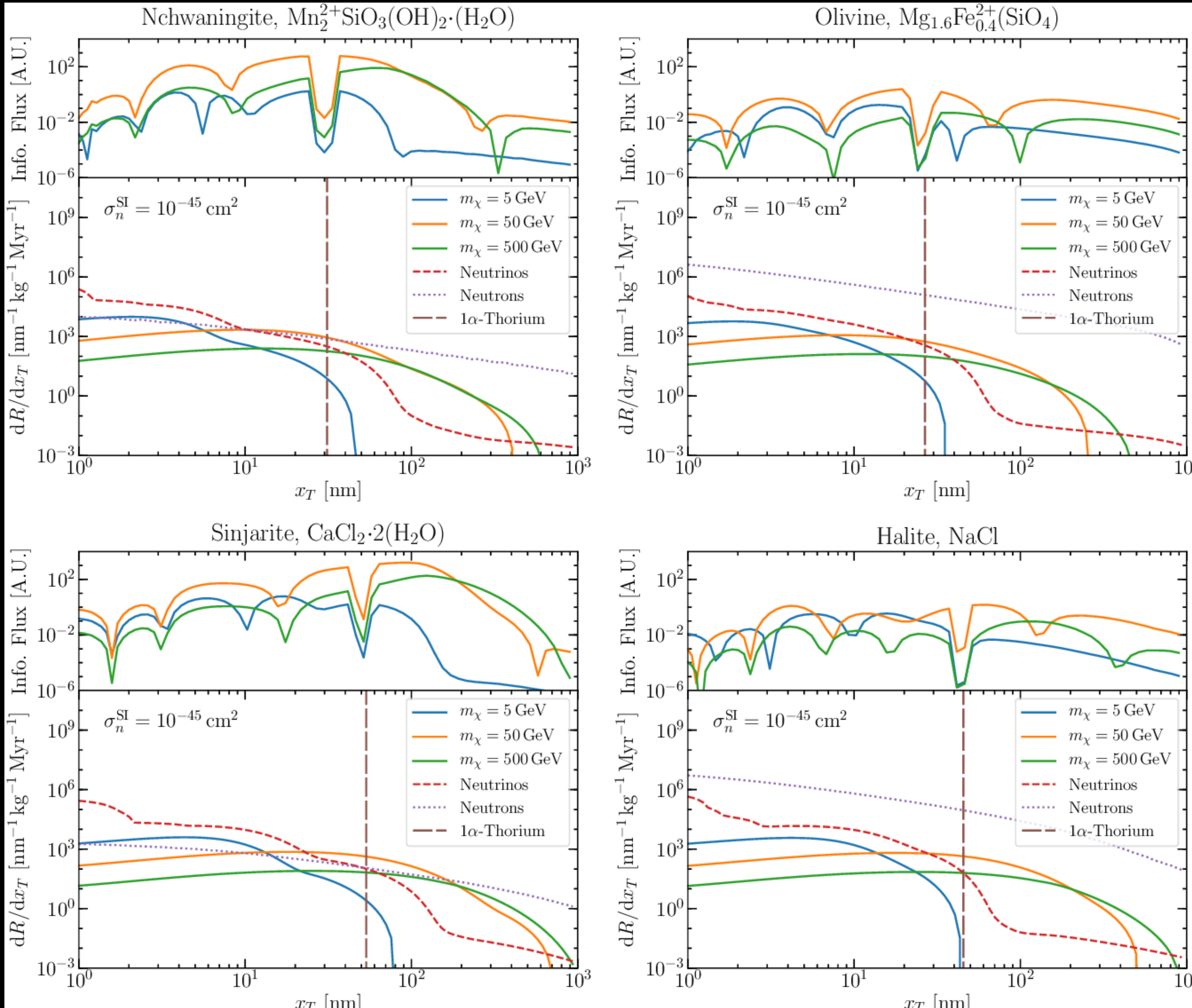






Vitagliano, Tamborra, Raffelt


Zabuyelite
Iltisite
Halite
Xe ν-floor
Sylvanite
current limits
$\sigma_x = 1\,\mathrm{nm}$; $\varepsilon = 1\,\mathrm{kg\,Myr}$
$\sigma_x = 15\,\mathrm{nm}$; $\varepsilon = 100\,\mathrm{kg\,Myr}$
WIMP-nucleon cross section σ_n^{SI} [cm^2]
WIMP mass m_χ [GeV]



Nchwaningite, $Mn_2^{2+}SiO_3(OH)_2\cdot(H_2O)$
Olivine, $Mg_{1.6}Fe_{0.4}^{2+}(SiO_4)$
Sinjarite, $CaCl_2\cdot 2(H_2O)$
Halite, NaCl
Info. Flux [A.U.]
10^2
10^{-2}
10^{-6}
$\sigma_n^{SI} = 10^{-45}\,cm^2$
$m_\chi = 5\,GeV$
$m_\chi = 50\,GeV$
$m_\chi = 500\,GeV$
Neutrinos
Neutrons
1α-Thorium
$dR/dx_T\ [nm^{-1}\,kg^{-1}\,Myr^{-1}]$
10^9
10^6
10^3
10^0
10^{-3}
x_T [nm]
10^0
10^1
10^2
10^3