Final report

The Borexino experiment

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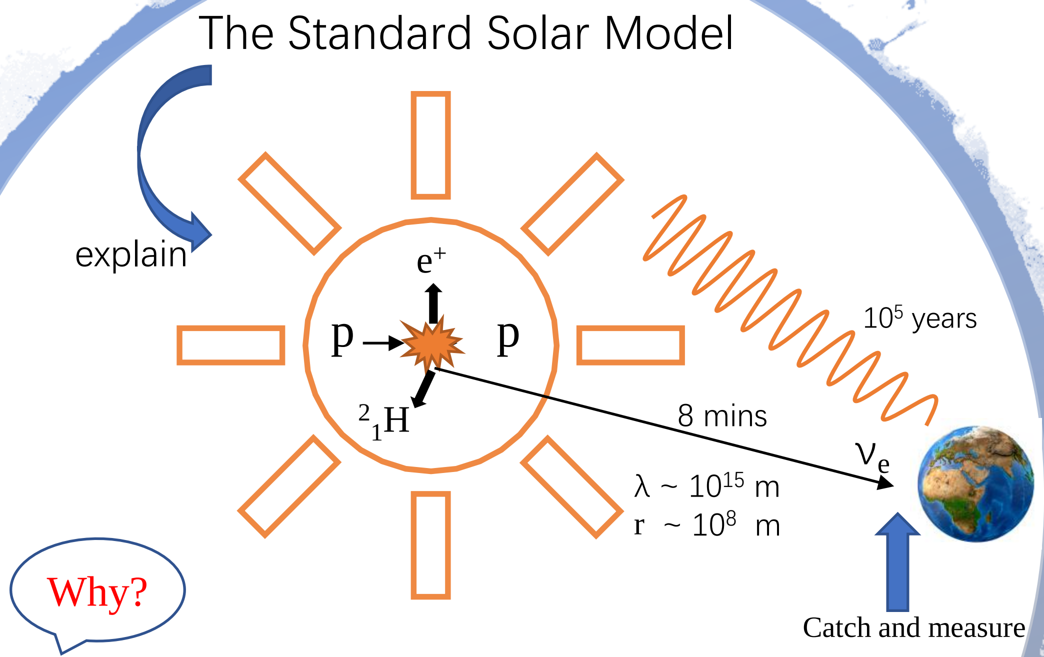
Slides outline

- Overview on solar neutrino
- Introduction to Borexino experiment
- p-p chain analysis
- Result and discussion
- Summary

➢ Overview on solar neutrino



In 1968, the number of neutrinos measured by American scientists was 1/3 less than that predicted by SSM theory.

→ Maybe unknown particle ? → Temperature ↓

→ Or 3 flavors mixing ?

Solar neutrino

- The sun can be seen as an extremely successful prototype of a self-sustaining thermonuclear reactor.
- Nuclear fusion reactions produce the solar energy.
- These reactions produce electron neutrinos called solar neutrinos.

In 2002, SNO Collaboration confirmed that oscillation led to the loss of neutrinos.

Physics goals

So, how to describe the solar nuclear fusion?

how much energy is generated directly from fusion?

how much energy is generated by carbon catalytic reactions?

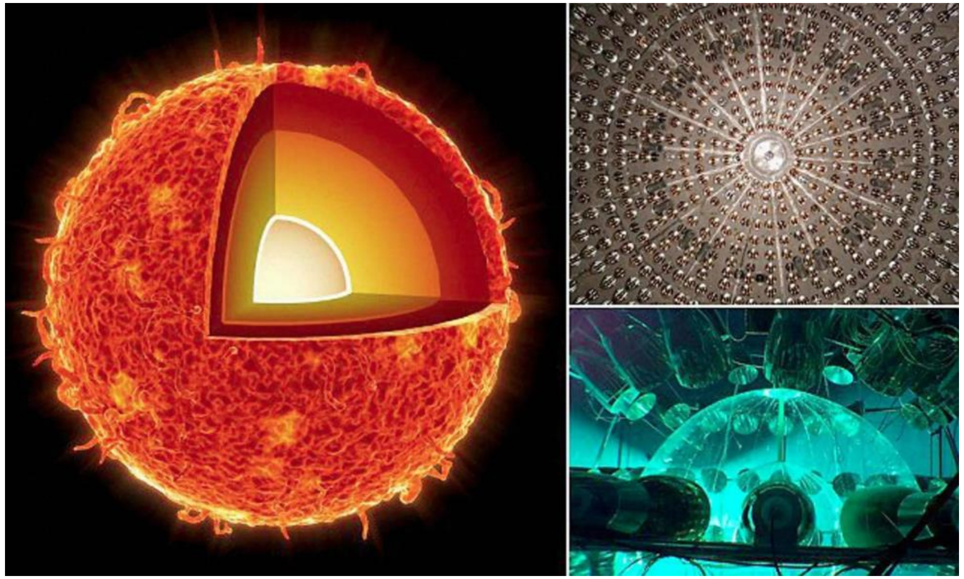
The Sun high metallicity(HZ) or low metallicity(LZ)?

To confirm the SSM

Borexino → *pp* chain

Borexino → CNO cycle

➢ Overview on Borexino experiment



Borexino experiment

- Borexino experiment is a real-time detector to measure low energy solar neutrinos fluxes.
- Borexino detector contains 100 ton of liquid scintillator. (underground 1400 m)
- Neutrinos are detected by means of electron scattering which can proceed via the charged and neutral current processes.

$$\nu_x + e^- \rightarrow \nu_x + e^-$$

Tips:

ν_e can interact via the charge and neutral current interactions.

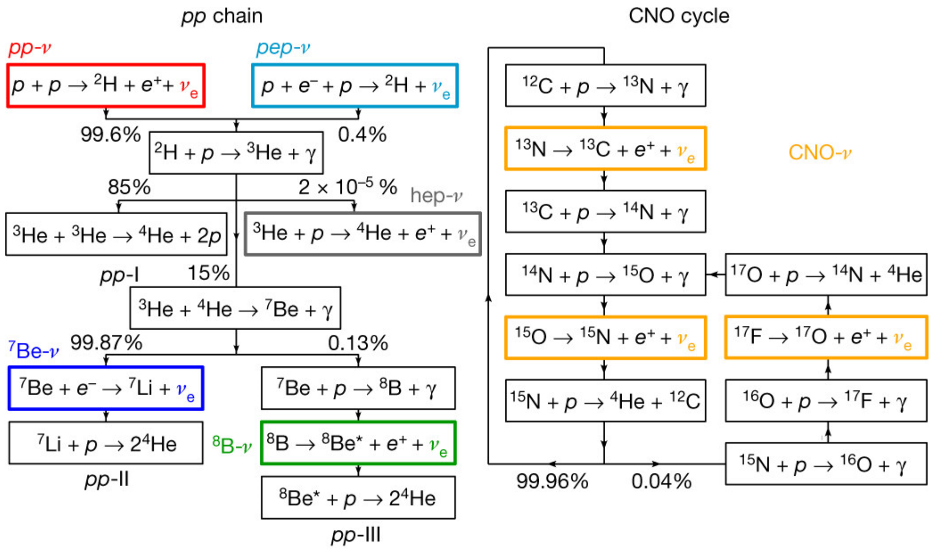
Other flavors neutrinos can only interact through neutral interactions.

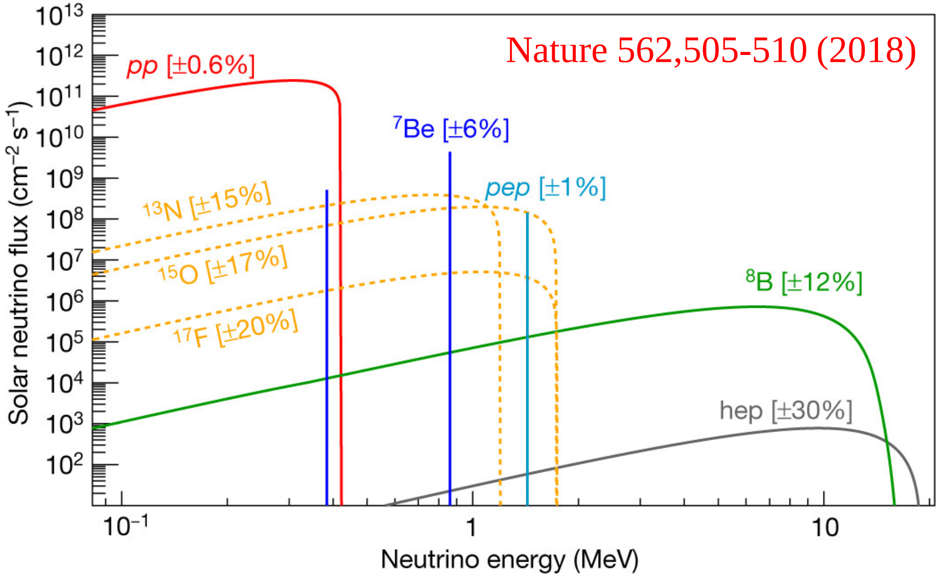
Neutrino scattering cross section

$$\frac{d\sigma}{dE} = \sigma_e \left\{ g_l^2 + g_r^2 \left(1 - \frac{E}{E_\nu}\right) - g_l\, g_r \frac{m_e c^2 E}{E_\nu^2} \right\}$$

$$\sigma = \frac{2G_F^2 m_e E_{max}}{\pi \hbar^4 c^2} \left\{ (g_l^2 + g_r^2) - \left(\frac{g_r^2}{E_\nu} + g_l\, g_r \frac{m_e c^2}{2E_\nu^2} \right) E_{max} + g_r^2 \frac{E_{max}^2}{3E_\nu^2} \right\} .$$

➢ p-p chain analysis



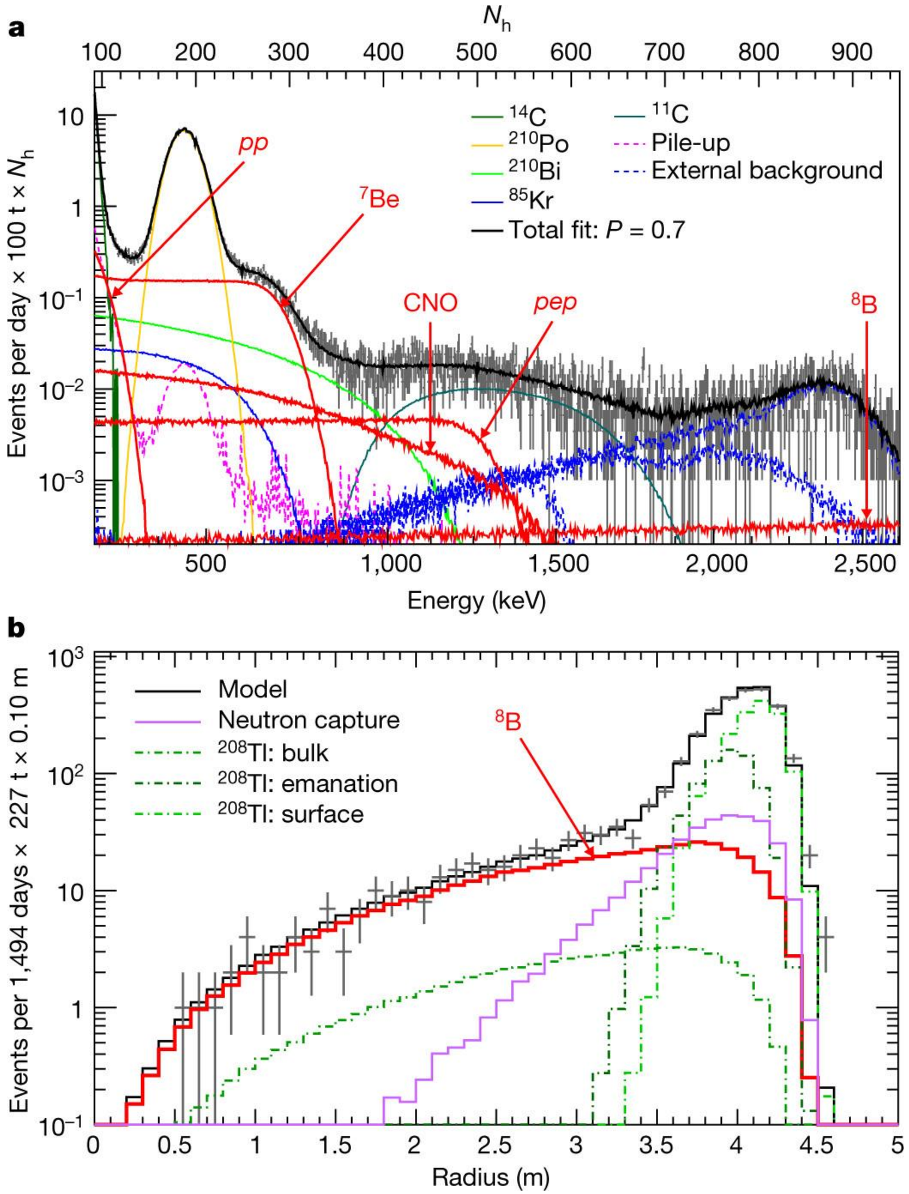


	Low-energy region(LER):	**High-energy region(HER):**	
Which neutrino signal	pp,^{7}Be and pep	^{8}B	
Energy region	0.19-2.93 MeV	3.2-5.7 MeV HER-I	5.7-16 MeV HER-II
bkg	gamma ray from ^{40}K, ^{214}Be and ^{208}Tl	gamma ray ^{208}Tl	
Actual selection	radius R < 2.8 m, vertical -1.8 m < z < 2.2 m (total 71.3 t of scintillator)	vertical z < 2.5 m (total 227.8 t)	entire scintillator volume (total 266 t)

event selection

- Use a different set of cuts in the three energy region to maximize the signal-to-background ratio.
- Reject cosmic muons surviving the mountain shield.
- Reduce the cosmogenic background.
- Select an optimal spatial region of the scintillator.

➢ p-p chain analysis



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LER fit:
the energy spectrum, the spatial and the pulse-shape estimator distributions

HER-I/II:
a fit of the radial distribution of events is performed to separate the ^{8}B neutrino signal (uniformly distributed in the scintillator) from the external background.

Background LER	Rate (Bq per 100 t)
^{14}C(0.156 MeV, β^-)	[40.0 ± 2.0]
Background LER	**Rate (counts per day per 100 t)**
^{85}Kr (0.687 MeV, β^-) (internal)	6.8 ± 1.8
^{210}Bi (1.16 MeV, β^-) (internal)	17.5 ± 1.9
^{11}C (1.02–1.98 MeV, β^+) (internal)	26.8 ± 0.2
^{210}Po (5.3 MeV, α) (internal)	260.0 ± 3.0
^{40}K (1.460 MeV, γ) (external)	1.0 ± 0.6
^{214}Bi (<1.764 MeV, γ) (external)	1.9 ± 0.3
^{208}Tl (2.614 MeV, γ) (external)	3.3 ± 0.1
Background HER-I	**Rate (counts per day per 227.8 t)**
μ, cosmogenics, ^{214}Bi (internal)	[$6.1^{+8.7}_{-3.1} \times 10^{-3}$]
(α, n) (external)	0.224 ± 0.078
^{208}Tl(5.0 MeV, β^-, γ) (internal)	[0.042 ± 0.008]
^{208}Tl(5.0 MeV, β^-, γ) (emanated)	0.469 ± 0.063
^{208}Tl(5.0 MeV, β^-, γ) (surface)	1.090 ± 0.046
Background HER-II	**Rate (counts per day per 266.0 t)**
μ, cosmogenics (internal)	[$3.8^{+14.6}_{-0.1} \times 10^{-3}$]
(α, n) (external)	0.239 ± 0.022

the absence of the *pep* reaction in the Sun is rejected with >5σ significance, enough to definitively claim discovery of solar *pep* neutrinos.

➢ Result and discussion

Borexino translate these measurements into the corresponding solar-neutrino fluxes using the known electron and μ/τ neutrino cross-sections and the flavor composition calculated according to the MSW-LMA paradigm.

Solar neutrino	Rate (counts per day per 100 t)	Flux ($cm^{-2}\ s^{-1}$)	Flux–SSM predictions ($cm^{-2}\ s^{-1}$)
pp	$134\pm10^{+6}_{-10}$	$(6.1\pm0.5^{+0.3}_{-0.5})\times10^{10}$	$5.98(1.0\pm0.006)\times10^{10}$ (HZ) $6.03(1.0\pm0.005)\times10^{10}$ (LZ)
^{7}Be	$48.3\pm1.1^{+0.4}_{-0.7}$	$(4.99\pm0.11^{+0.06}_{-0.08})\times10^{9}$	$4.93(1.0\pm0.06)\times10^{9}$ (HZ) $4.50(1.0\pm0.06)\times10^{9}$ (LZ)
pep (HZ)	$2.43\pm0.36^{+0.15}_{-0.22}$	$(1.27\pm0.19^{+0.08}_{-0.12})\times10^{8}$	$1.44(1.0\pm0.01)\times10^{8}$ (HZ) $1.46(1.0\pm0.009)\times10^{8}$ (LZ)
pep (LZ)	$2.65\pm0.36^{+0.15}_{-0.24}$	$(1.39\pm0.19^{+0.08}_{-0.13})\times10^{8}$	$1.44(1.0\pm0.01)\times10^{8}$ (HZ) $1.46(1.0\pm0.009)\times10^{8}$ (LZ)
$^{8}B_{HER\text{-}I}$	$0.136^{+0.013+0.003}_{-0.013-0.003}$	$(5.77^{+0.56+0.15}_{-0.56-0.15})\times10^{6}$	$5.46(1.0\pm0.12)\times10^{6}$ (HZ) $4.50(1.0\pm0.12)\times10^{6}$ (LZ)
$^{8}B_{HER\text{-}II}$	$0.087^{+0.080+0.005}_{-0.010-0.005}$	$(5.56^{+0.52+0.33}_{-0.64-0.33})\times10^{6}$	$5.46(1.0\pm0.12)\times10^{6}$ (HZ) $4.50(1.0\pm0.12)\times10^{6}$ (LZ)
$^{8}B_{HER}$	$0.223^{+0.015+0.006}_{-0.016-0.006}$	$(5.68^{+0.39+0.03}_{-0.41-0.03})\times10^{6}$	$5.46(1.0\pm0.12)\times10^{6}$ (HZ) $4.50(1.0\pm0.12)\times10^{6}$ (LZ)
CNO	<8.1 (95% C.L.)	$<7.9\times10^{8}$ (95% C.L.)	$4.88(1.0\pm0.11)\times10^{8}$ (HZ) $3.51(1.0\pm0.10)\times10^{8}$ (LZ)
hep	<0.002 (90% C.L.)	$<2.2\times10^{5}$ (90% C.L.)	$7.98(1.0\pm0.30)\times10^{3}$ (HZ) $8.25(1.0\pm0.12)\times10^{3}$ (LZ)

~8.20%

~17.58%

Likelihood ratio test

Assume that HZ is true, Borexino data disfavor LZ at 96.6%.

Calculate the power $P=(3.89^{+0.35}_{-0.42})\times10^{33} erg\cdot s^{-1}$

Well measured photon output $P=(3.846\pm0.015)\times10^{33} erg\cdot s^{-1}$

Confirm the energy origin

Summary

What did Borexino do

- Measure the complete p-p chain.
- Discovery of solar *pep* neutrinos
- Confirmed the solar energy originated from nuclear fusion
- Borexino result is in favor of HZ-SSM prediction.

Outlook Borexino further plan

Catch CNO neutrinos to confirm that if the Sun is HZ or LZ

Thanks!