Study for g-mode oscillations in the Sun using solar neutrino with Super-Kamiokande

Poster wall #35

Kamioka Observatory, ICRR, The University of Tokyo
*Yuuki Nakano for the Super-Kamiokande collaboration

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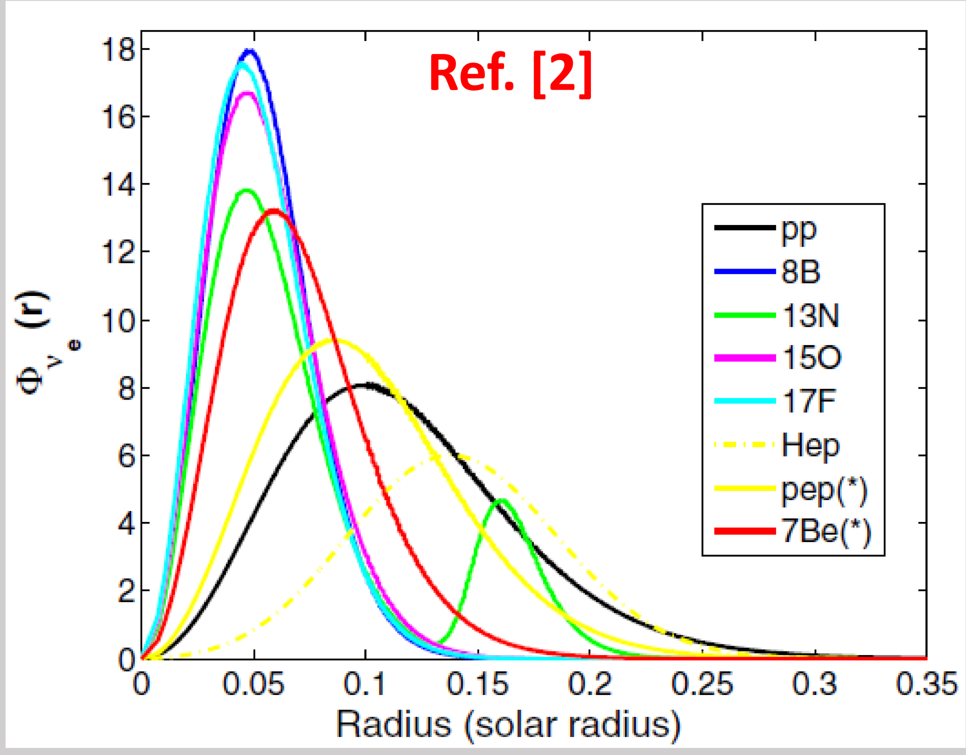
E-mail: ynakano@km.icrr.u-tokyo.ac.jp

1. Introduction



■ Standard Solar Model (SSM) [1].
- The SSM has been constructed by inputting several observation results assuming:
  (1) Spherically symmetric,
  (2) Hydrostatic equilibrium with no macroscopic motion except for the convection,
  (3) No mass loss, no mass accretion, no rotation and no magnetic field.
- The model well predicts the production and energy spectrum of solar neutrinos.

■ Periodic variations in the Sun.
- 11-years periodic change of the sunspot at the surface. This leads to the change of the magnetic field.
  → Some mechanisms propose conversions of neutrino ($\upsilon_L \rightarrow \upsilon_R$) if neutrino has a large magnetic moment [3-5].
- Solar oscillations around its equilibrium state because of the Sun's restoring force [6].
  → Acoustic oscillation (p-mode) due to compressibility [7-9] or gravity oscillation (g-mode) due to buoyancy [10].

2. G-mode oscillation and neutrino

■ Introduction about g-mode oscillations [11, 12].
- G-mode oscillations are described as spherical harmonics function.
- They may affect both electron density and temperature in the core of the Sun.
- These modes have not been detected because their amplitudes are low at the surface.
- Typical frequencies are about a few hours (~100-300 μHz) [11].

■ ^{8}B neutrino production rate.
- G-modes are trapped under the convective zone, where ^{8}B solar neutrino produced.
- Production rate depends on temperature. It is proportional to T^{24-25} (T~10^6 K) [13].
  → Its production rate is amplified by a factor of 170 [14].
  → It may affect the propagation of solar ν, MSW effect [15, 16], thus survival probability of νe [12].

Ref. [11]

n	l	ν (μHz)	Period (hr)	Energy[a] (ergs)	$\delta T/T$[a]
1	1	267.4	1.04	3.4×10^{31}	6.7×10^{-8}
1	2	297.1	0.94	2.1×10^{31}	4.4×10^{-8}
1	3	340.2	0.82	4.3×10^{31}	7.7×10^{-8}
2	1	193.0	1.44	1.3×10^{33}	4.6×10^{-7}
2	2	259.7	1.07	3.7×10^{31}	7.2×10^{-8}
2	3	299.2	0.93	4.4×10^{31}	8.8×10^{-8}
3	1	153.7	1.81	1.7×10^{33}	6.9×10^{-7}
3	2	224.0	1.24	8.7×10^{31}	1.3×10^{-7}
3	3	264.7	1.05	3.3×10^{31}	8.1×10^{-8}
4	1	128.3	2.17	1.7×10^{33}	7.4×10^{-7}
4	2	195.5	1.42	1.6×10^{32}	2.0×10^{-7}
4	3	240.5	1.15	2.9×10^{31}	7.4×10^{-8}
5	1	109.9	2.53	1.7×10^{33}	8.7×10^{-7}
5	2	171.8	1.62	3.1×10^{32}	3.1×10^{-7}
5	3	218.9	1.27	6.8×10^{31}	1.3×10^{-7}

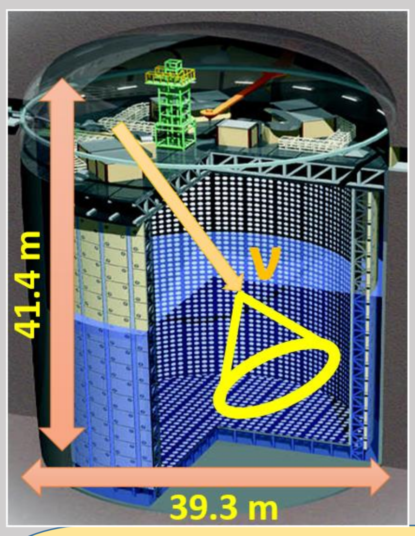
[a] Normalized to a velocity of 1 cm s^{-1} at the solar surface.

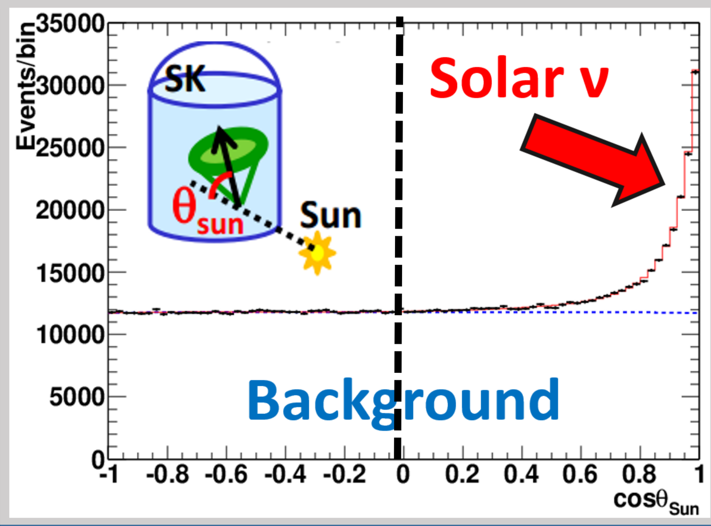
3. Super-Kamiokande & Methods

■ Super-Kamiokande [17] and solar neutrino observation [18-21].
- Cherenkov light produced via $\upsilon - e$ elastic scattering.

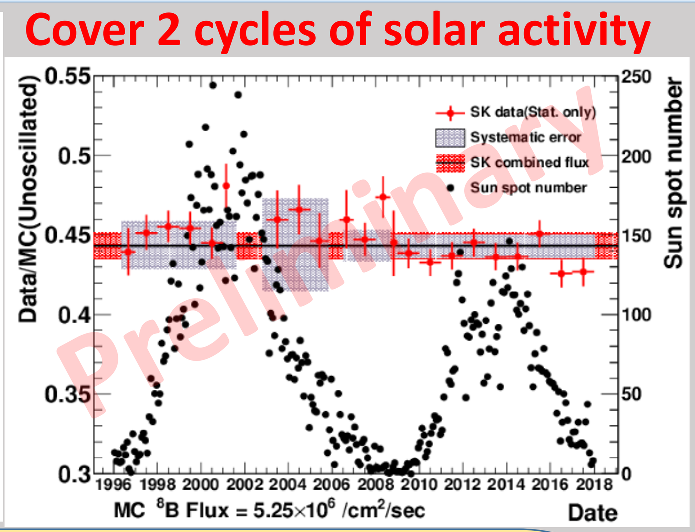
→ Recoil electrons preserve the direction of incident neutrinos.

■ Two methods to search for periodical signals.





Cover 2 cycles of solar activity



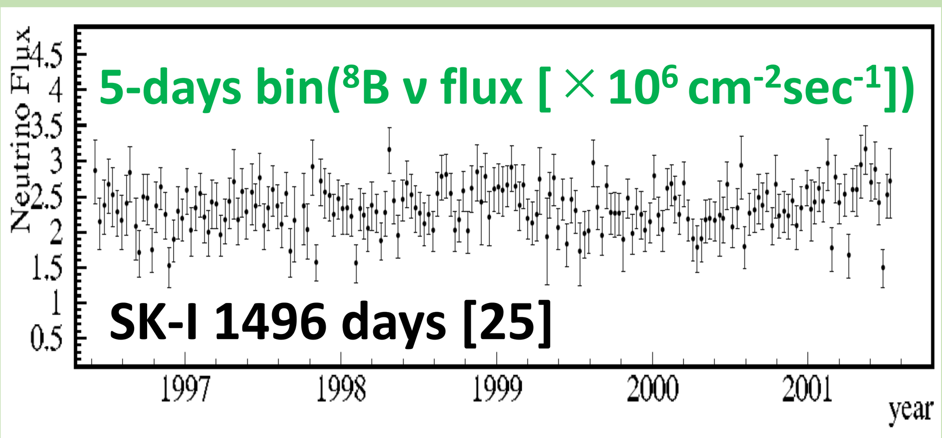
Generalized Lomb-Scargle method (Binned analysis)

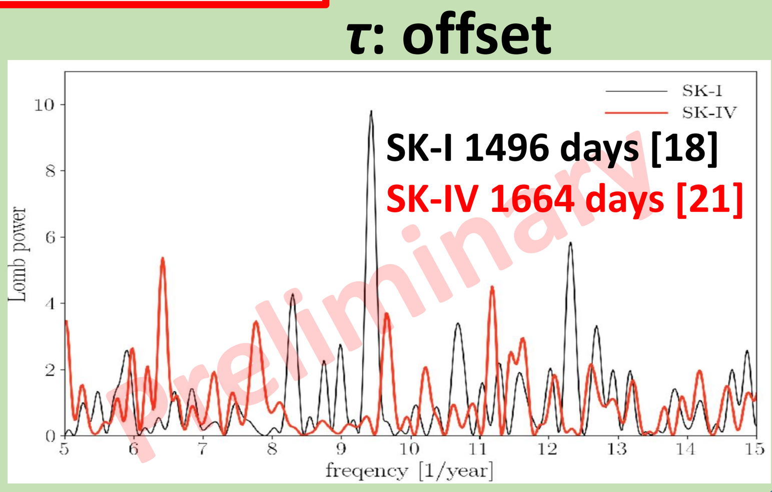
Search for periodic signals in uncontinuous data set [22-24].

$$\hat{p}(\omega) = \frac{1}{\sum_i y_i^2}\left\{\frac{\left[\sum_i y_i \cos\omega(t_i-\hat{\tau})\right]^2}{\sum_i \cos^2\omega(t_i-\hat{\tau})} + \frac{\left[\sum_i y_i \sin\omega(t_i-\hat{\tau})\right]^2}{\sum_i \sin^2\omega(t_i-\hat{\tau})}\right\}$$

y_i: flux of i-th bin
t_i: time of i-th bin
ω: angular frequency
τ: offset

5-days bin(^{8}B ν flux [× 10^6 cm^{-2}sec^{-1}])



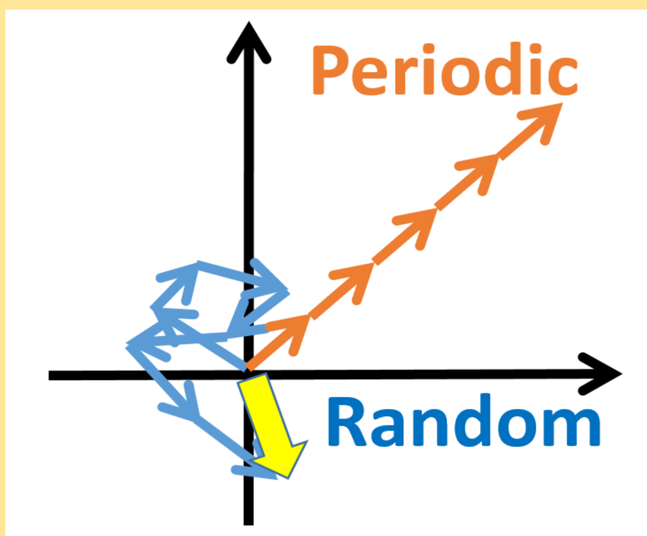


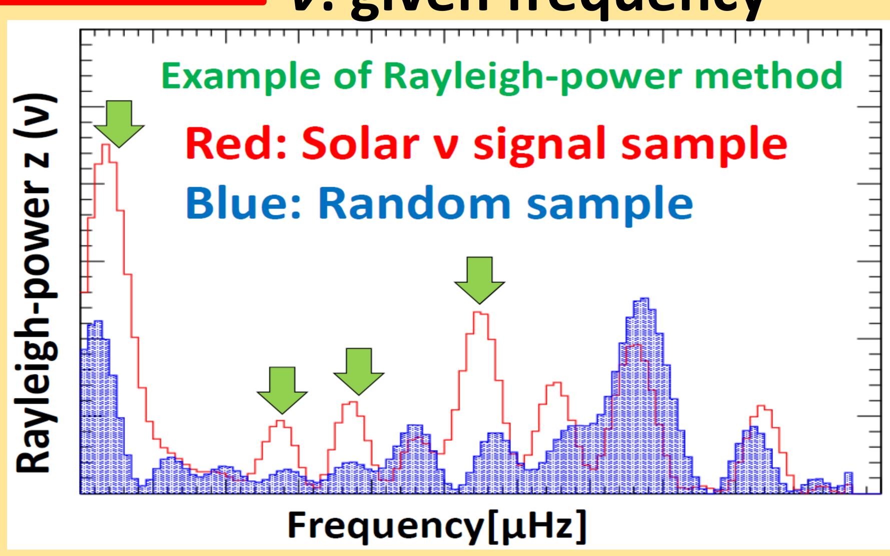
Rayleigh power method (Unbinned analysis)

Power spectrum considering timing of observed events [26, 27].

$$z(\nu) = \frac{1}{N} \times \left[\left(\sum_i^N \sin 2\pi\nu t_i\right)^2 + \left(\sum_i^N \cos 2\pi\nu t_i\right)^2\right]$$

N: number of total event
t_i: time of i-th event
ν: given frequency





4. Progress, Future prospect and Summary

■ Progress and future prospects
- Dead-time due to calibrations affects the sensitivity in Rayleigh power method.
- We have started to develop a randomly timed MC simulation considering operation-time/dead-time of SK.
- We will open the data soon after the MC production and compare with the former results from SNO collaboration [28-30].

■ Summary
- The SSM has been constructed for 50 years. However, the Sun oscillates around its equilibrium such as p-mode or g-mode.
- G-mode oscillation may amplify the solar ν production rate by a factor of 170 because of fluctuation of electron density.
- SK has a chance to search for g-mode oscillations by using its timing information of the observed solar ν.

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