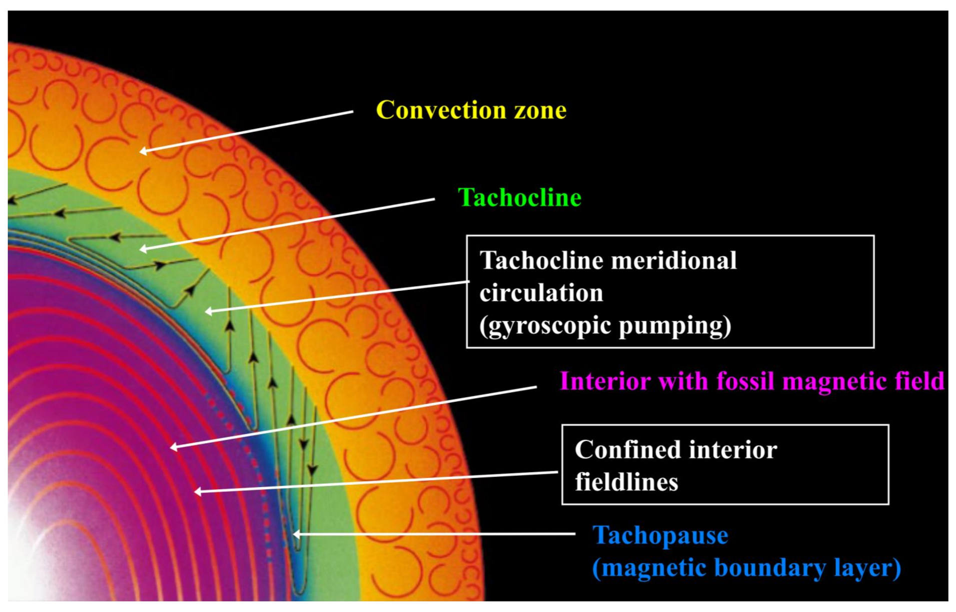
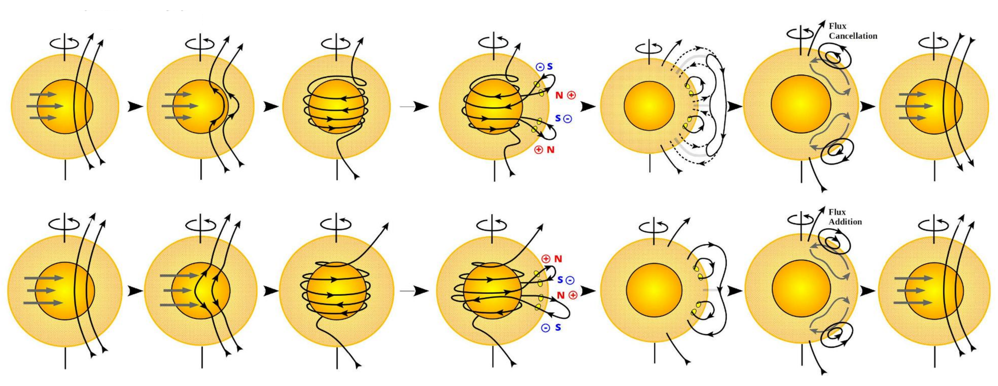
Search for Periodic Time Variations of the Solar ^{8}B Neutrino Flux Between 1996 and 2018 in Super-Kamiokande

Jeong Yeol Yang (Seoul National University)

NuFACT 2023
The 24th International Workshop on Neutrinos from Accelerators
August 21 ~ 26, 2023 at Seoul National University, Seoul, Korea

Motivation



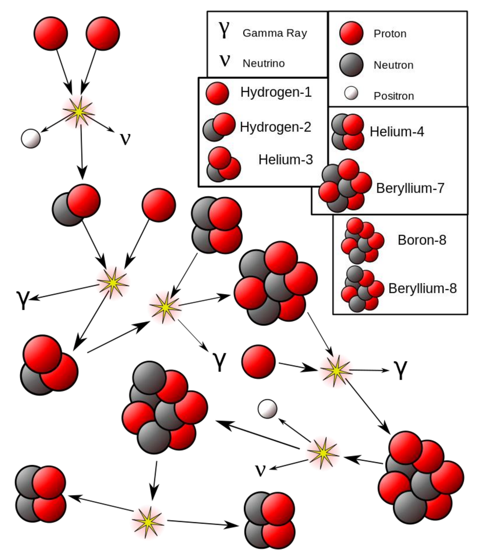


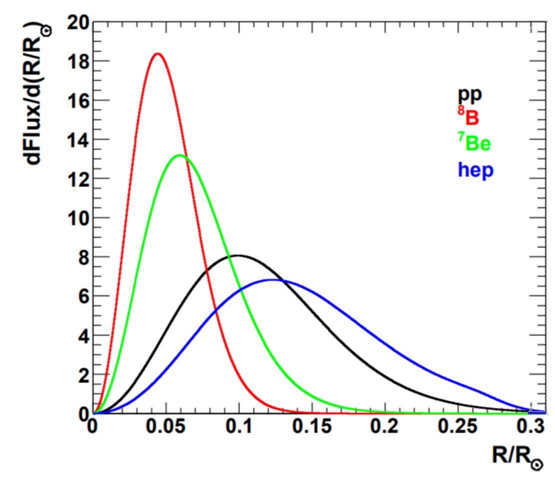
Impact of anti-solar differential rotation in mean-field solar-type dynamos (Q. Noraz et al. 2021 Nov 11, Solar Physics)

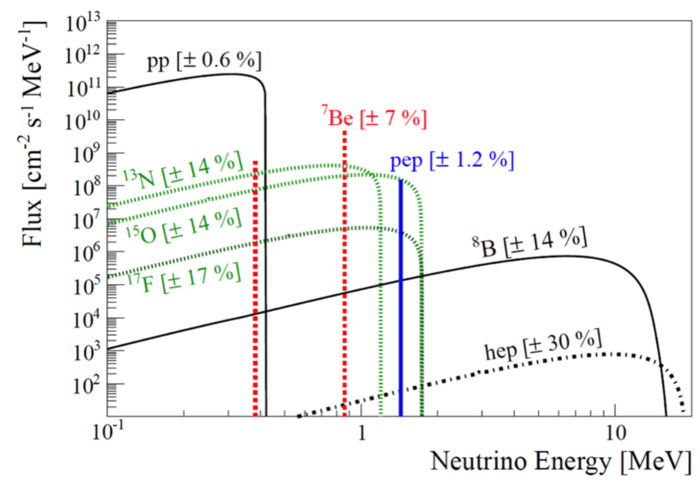
1. LMA solution
   – $1/r^2$ annual modulation
2. Flux dependence of core temperature

   $\Phi_{solar\ ^8B\ \nu} \propto T^{25}$ (PRD, 53:4202, 1996)
3. Friction in tachocline
   – Related with the sunspot
   – Strong magnetic field
4. Magnetic field flips flavor and spin of ν called resonant spin flavor precession
   – Additional disappearance
   – Periodicity of flux modulation

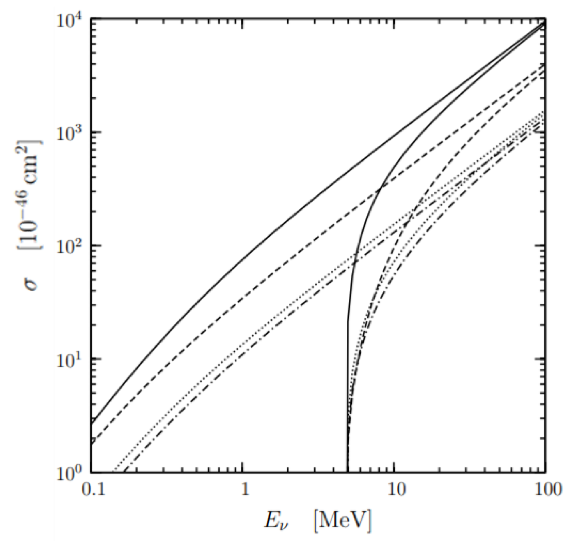
Solar neutrino at SK





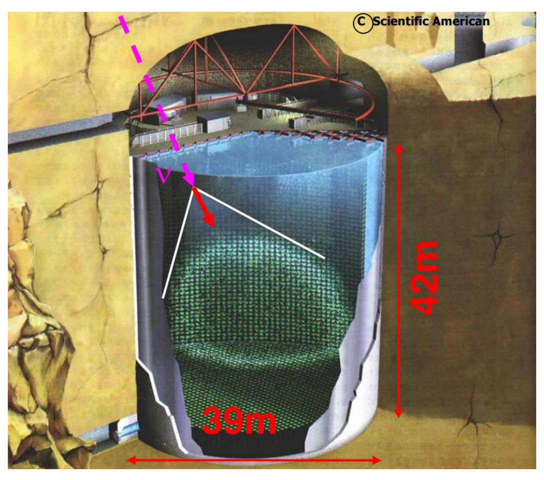


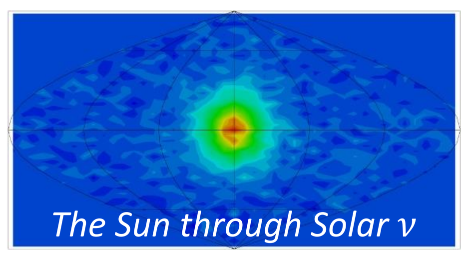
Solid: $\nu_e + e \to \nu_e + e$
Dotted: $\nu_\mu + e \to \nu_\mu + e$
Upper: No threshold
Lower: 4.74MeV threshold



1. Neutrino from 8B(99.8%) and hep(0.2%)
2. Most neutrino made in core (<0.3R_sun)
3. During escaping the Sun, ν_{solar}
   – MSW effect inside of the Sun
   – Coincide 2nd mass eigenstate
4. Measure elastic scattering electron/muon neutrino event at SK
   – $\nu_e + e \to \nu_e + e\ (Z, W)$ / $\nu_\mu + e \to \nu_\mu + e\ (Z)$

Super-Kamiokande (SK)

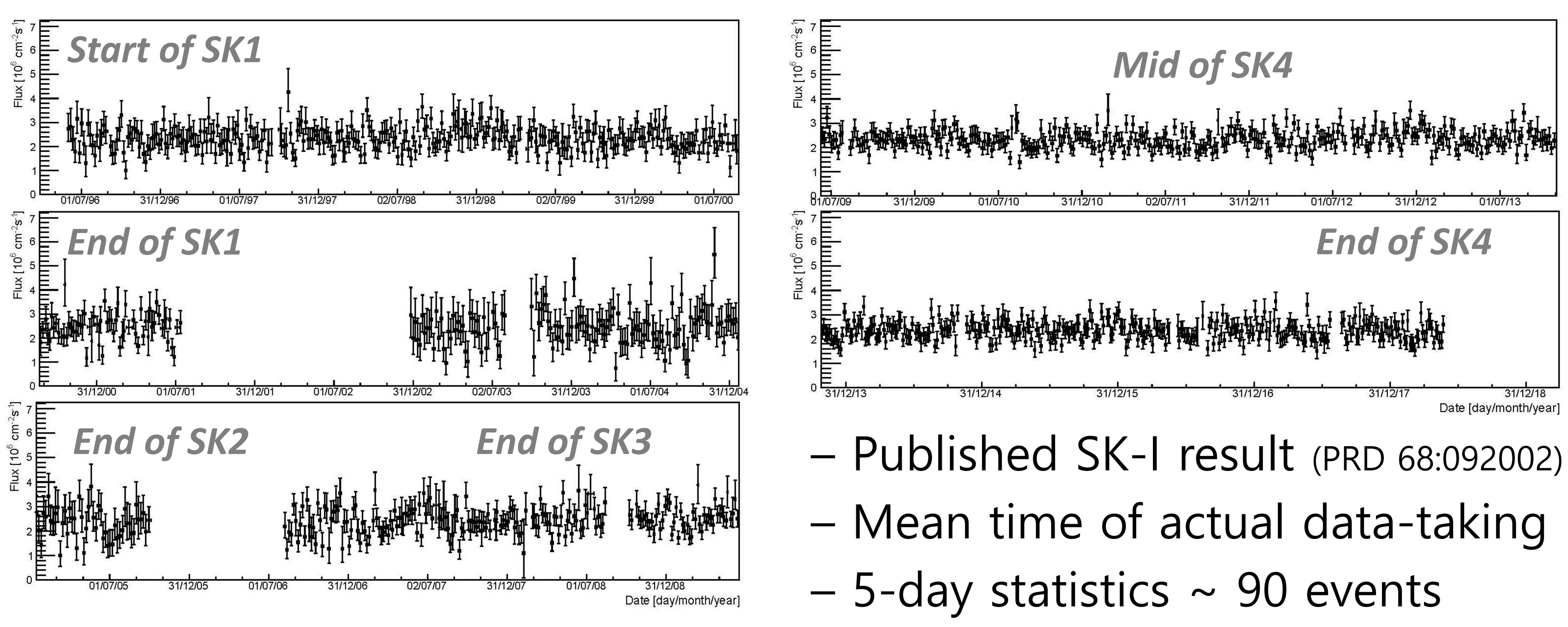




1. Water cherenkov detector
2. Water 50ktons (22.5ktons fid.)
3. 1,000m underground
4. Inner-Detector : 11,146 50cm PMTs (40%)
5. Outer-Detector : 1,885 20cm PMTs

SK Phase	Start date ~ End date	Live days	Energy range [MeV]	Flux (ϕ_ν)+(stat.)+(sys.) [10^6cm^{-2}s^{-1}]
SK-I	1996-05-31 ~ 2001-07-15	1495.7	4.49~19.5	$2.35 \pm 0.02 \pm 0.08$
SK-II	2002-12-10 ~ 2005-10-06	791.9	6.49~19.5	$2.38 \pm 0.05 ^{+0.16}_{-0.15}$
SK-III	2006-05-23 ~ 2008-08-17	548.5	4.49~19.5	$2.32 \pm 0.04 \pm 0.05$
SK-IV	2008-09-15 ~ 2018-05-30	2967.7	4.49~19.5	$2.31 \pm 0.014 \pm 0.040$

Search for Periodicity



– Published SK-I result (PRD 68:092002)
– Mean time of actual data-taking
– 5-day statistics ~ 90 events

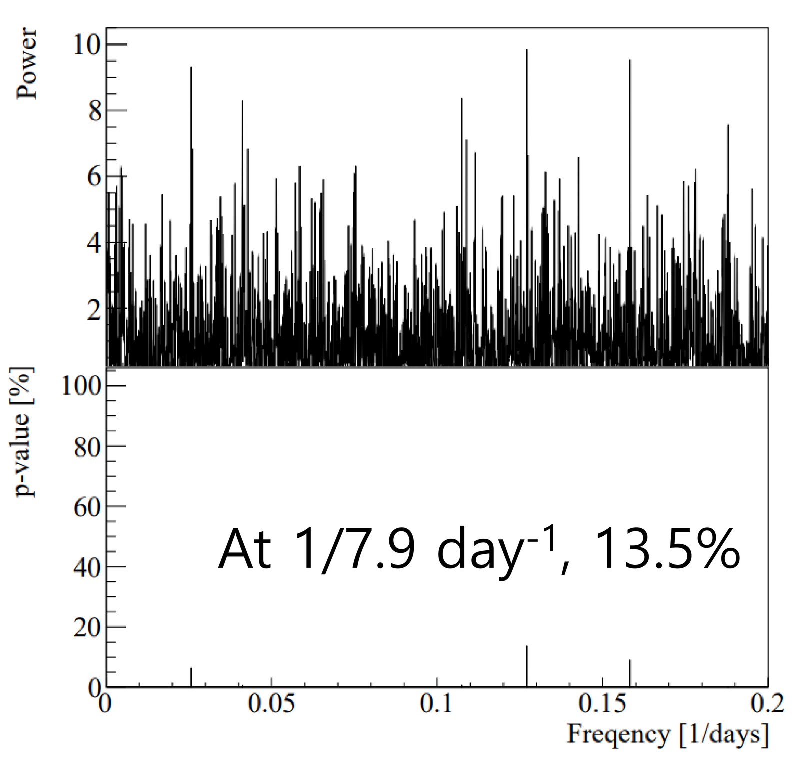


FIG. 2. Power distribution of likelihood method (top) and p-value (bottom) for $1/R^2$*corrected* 5-day interval solar neutrino data.

1. Average flux g_0 with statistical asymmetric error (σ_r)
2. Minimize $-ln\ L$.

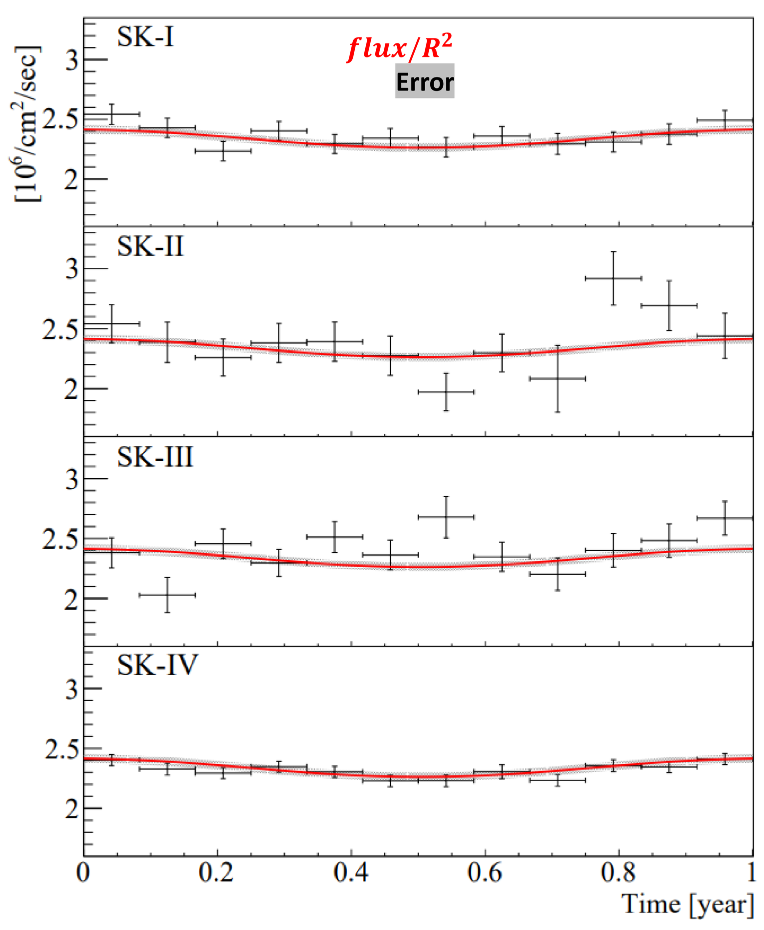
$$-lnL(r; A, B) = \frac{1}{2}\Sigma_r \left(\frac{D_r - g(r)}{\sigma_r}\right)^2$$

$$g(t_i, t_f) = g_0(t_i, t_f) + \frac{1}{\Delta t}\int_{t_i}^{t_f} Acos(\omega t) + Bsin(\omega t)\, dt$$

3. Power $= ln\left(\frac{L(g(A,B))}{L(g_0)}\right)$
4. For p-value, generate 10,000 MC samples for g_0 with asym. error.

→No significant periodicity for >5days

Annual modulation



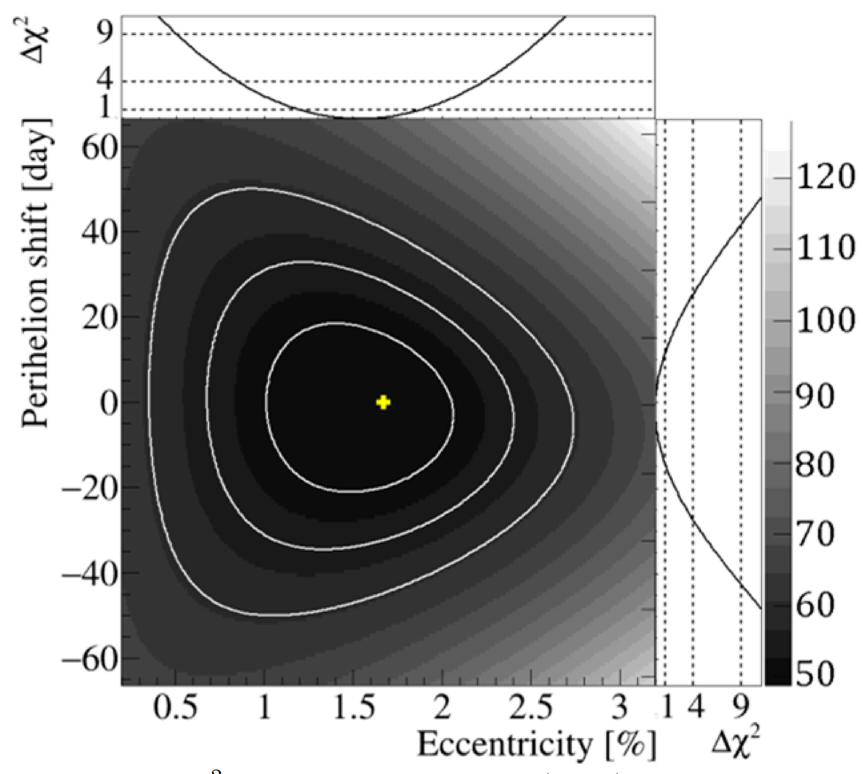
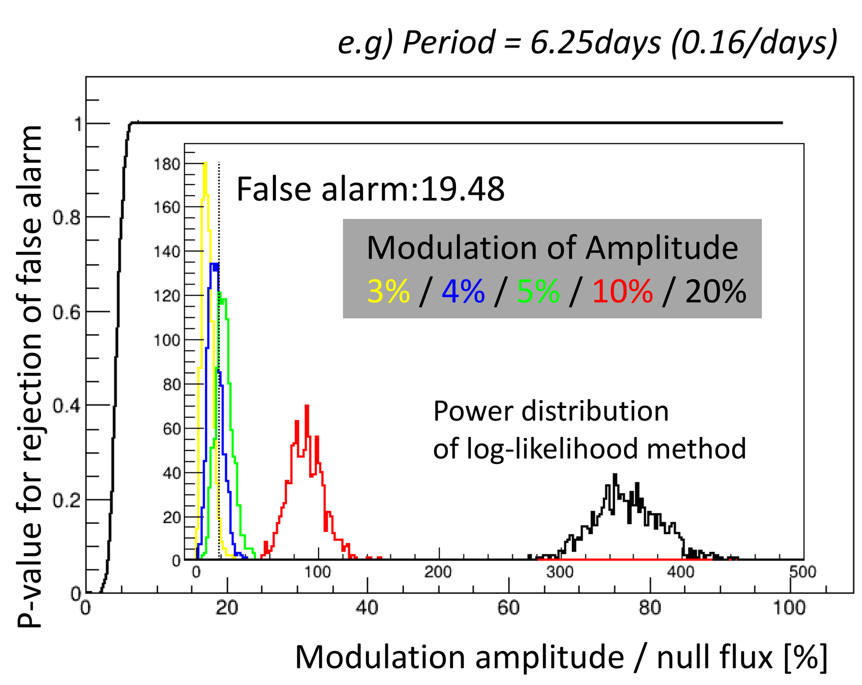


FIG. 5. $\Delta\chi^2$ for Kepler constants (ϵ, t_p) with contours $\Delta\chi^2$=2.3, 6.18, 11.83; $\epsilon = 1.53 \pm 0.35\%$ (known as 1.67%), $\delta t_{peri} = -1.5 \pm 13.5$ days shifted from Jan 3rd with minimum $\chi^2/NDF = 48.74/(48-3)$.

1. The seasonal variation of the solar neutrino flux for SK-I/II/III/IV.
2. Best fit flux at 1 AU $f = (2.335 \pm 0.036) \times 10^6 cm^{-2} s^{-1}$
3. Kepler constants in measurement are consistent to the expected.

Sensitivity

1. $1/R^2$ corrected 5-day data
2. Simulated 1,000 MC signals
3. Amplitude / null flux : 1-99%
4. Frequency : 1000 cases
5. Use asymmetric stat. error



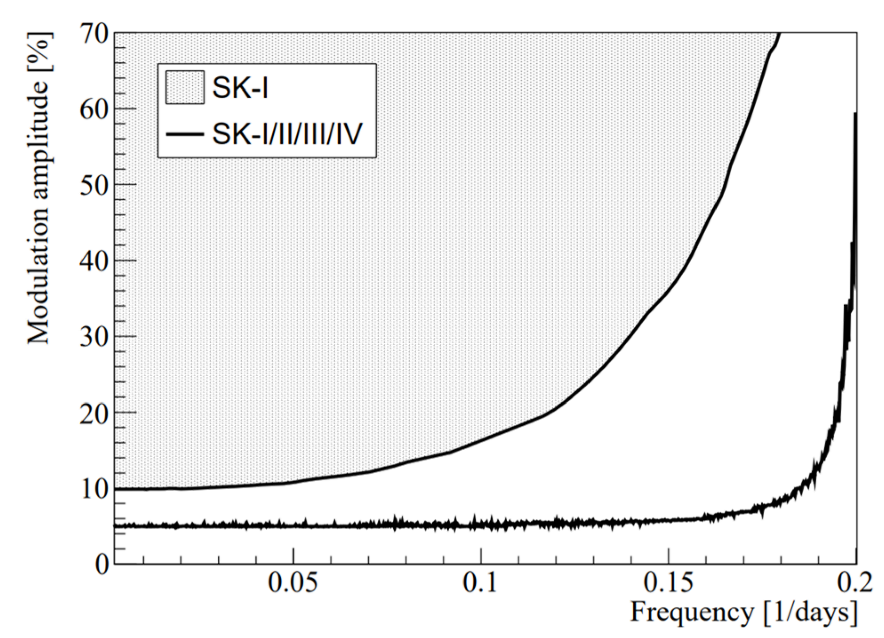


FIG. 3. A search sensitivity of solar neutrino modulation amplitude for each frequency with CL 95%. The shaded area is ruled out using SK-I solar neutrino data. The solid curve shows this analysis results.

Rule out the solar modulation amplitude greater than 5.1%
→ Significant improvement compared to SK-I results

Summary

1. Measure Solar neutrino flux using SK-I/II/III/IV data.
2. Confirm the annual modulation with measurement of Kepler constants as expected.
3. For the periodicity longer than 5-day interval, we do not find significant peak.
4. We can rule out the modulation of 5.1% amplitude or larger amplitude (period > 6.25 day).