Variations in the Neutron Time Delay Distribution at the Princess Sirindhorn Neutron Monitor

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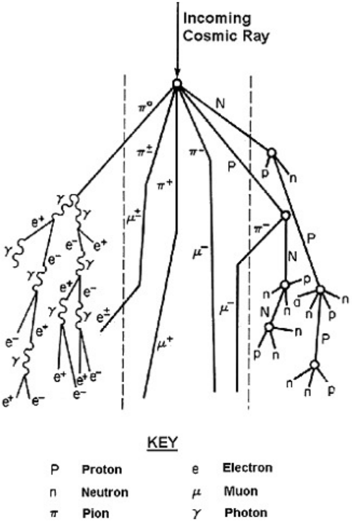
Outline

Cosmic Rays and Space Weather

- Galactic cosmic rays with $E \sim$ tens of GeV
  - Have high speeds, long mean free paths
  - Are affected by interplanetary structures related to solar activity
  - Can be used for remotely "probing" near-Earth space $\Longrightarrow$ space weather forecasting
- For example:
  - Effects of solar wind structures (high speed solar wind streams, CIRs) at or near Earth seen in cosmic ray anisotropies [Yeeram et al, in preparation]
  - Loss cones prior to Forbush decreases [Leerungnavarat et al 2003]

Cosmic Ray Detection

- Cosmic rays produce cascades of secondary particles on Earth's atmosphere
- If energetic enough, secondary particles reach ground level
- Neutron monitors measure atmospheric neutrons from cosmic ray cascades
  - Sensitive to air mass: P correction



Neutron Monitors

- Neutron monitors are designed to monitor number of cosmic rays
- Originally not designed to measure cosmic ray energy
- Multi-station measurements can give spectral information
- What can be done with a single station?

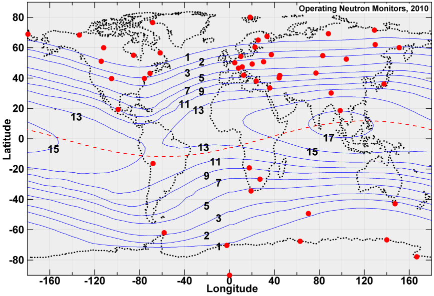


Figure: Neutron monitor locations and vertical cutoff rigidity contours. Credit: R. Pyle

The Princess Sirindhorn Neutron Monitor (PSNM)

- PSNM operates since late 2007
- Location: Doi Inthanon, Chiang Mai province
- Altitude: 2565 m over sea level
- World's highest cosmic ray cutoff rigidity (pc/q) for a fixed station, 16.8 GV

PSNM is a standard 18-NM64:

- 18 proportional counter tubes ($^{10}\mathrm{BF}_3$ gas)
- 30 tons of Pb as neutron producer
- Polyethylene neutron reflector and moderators

One atmospheric neutron interacts with a Pb nucleus producing more neutrons, which are moderated by the polyethylene and finally detected in the proportional counters through

$$\mathrm{n} + {}^{10}\mathrm{B} \longrightarrow {}^{4}\mathrm{He} + {}^{7}\mathrm{Li}^{*}.$$

Time delays

The electronics in PSNM's data acquisition system records time delays between successive neutron counts

- Long time delays: counts from independent atmospheric neutrons
- Short time delays: mostly from neutrons produced from the same Pb nucleus $\Longrightarrow$ information about cosmic ray energy
  - Cosmic rays with higher energy produce higher energy atmospheric neutrons
  - Neutrons with higher energy produce larger numbers of neutrons in the Pb
  - Multiple neutrons produced together in the Pb show short time delays
- But some are just chance coincidences!

Chance coincidences

$R(t)$ is the probability of time delay $\geq t$ for a neutron count in one counter tube

- $n(t)$ is the probability density function: $n(t) \equiv -\mathrm{d}R/\mathrm{d}t$
- α is the probability per unit time of having a new count

If all the counts were independent:

$$\frac{\mathrm{d}R}{\mathrm{d}t} = -\alpha R, \quad \text{or} \quad \frac{\mathrm{d}}{\mathrm{d}t} \ln R = -\alpha, \quad \text{so} \quad R = \mathrm{e}^{-\alpha t}$$

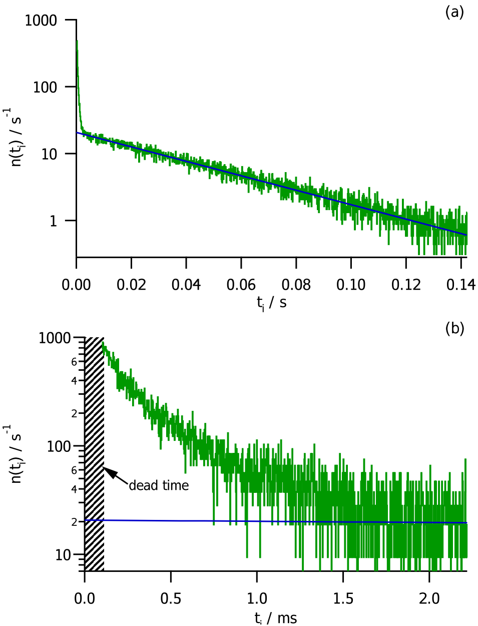
and

$$n = \alpha\, \mathrm{e}^{-\alpha t}$$

$\Longrightarrow$ a straight line in a log-linear plot of $n(t)$

Example of $n(t)$ at one counter tube recorded during one hour

- Long time delays (a) show the exponential distribution typical of unrelated events
- Short time delays (b) deviate substantially from the exponential (blue line).



Following counts

Short time delays are dominated by counts of neutrons produced from the same Pb nucleus $\Longrightarrow$ "following" counts

- Total distribution is not the sum of follower distribution and chance coincidences: distributions are not independent!
- Distribution of chance coincidences gets affected by followers, and vice versa

The "conventional" way to estimate following counts:

- Number of counts during a short time window: multiplicity
- Contaminated by chance coincidences

Leader fraction

If $\beta(t)$ is the probability per unit time of a following count with delay t since the previous count from the same production event, then

$$\frac{\mathrm{d}R}{\mathrm{d}t} = -R\,(\alpha + \beta(t))\,, \quad \text{or} \quad \frac{\mathrm{d}}{\mathrm{d}t}\ln R = -\,(\alpha + \beta(t))\,, \quad \text{so} \quad R = \mathrm{e}^{-\alpha t}\mathrm{e}^{-\int_0^t \beta(t')\,\mathrm{d}t'}$$

We define the nuclear part of $R(t)$ as:

$$R_\mathrm{n}(t) \equiv \mathrm{e}^{-\int_0^t \beta(t')\,\mathrm{d}t'}$$

Then

$$n = \alpha\,\mathrm{e}^{-\alpha t} R_\mathrm{n} - \mathrm{e}^{-\alpha t}\frac{\mathrm{d}R_\mathrm{n}}{\mathrm{d}t}$$

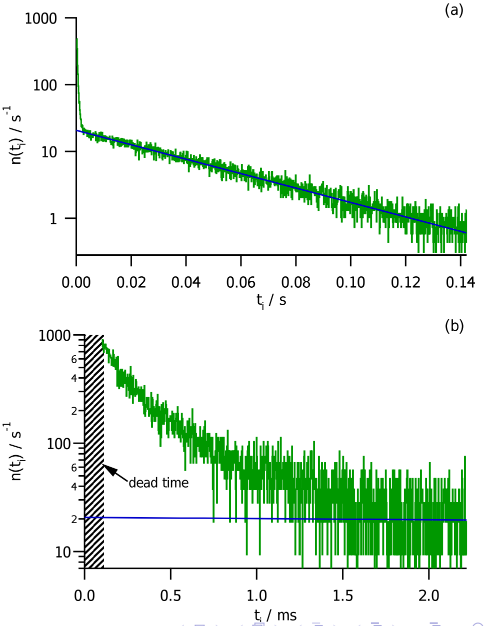
For long time delays, $\mathrm{d}R_\mathrm{n}/\mathrm{d}t \simeq 0$ and $R_\mathrm{n} \simeq$ constant: $R_\mathrm{n} \simeq R_\mathrm{n}(\infty) \equiv L$
$\Longrightarrow$ leader fraction, and

$$n \simeq \alpha\,L\,\mathrm{e}^{-\alpha t}$$

L is the probability for a neutron count to be the leader in a "multiple count"

- L is larger when multiplicity is smaller
- It may contain information about cosmic ray energy
- Free from effects of chance coincidences

Fitting the exponential tail in the data (a) to $n \simeq \alpha L \, \mathrm{e}^{-\alpha t}$ we can estimate both α and L.



Corrections to the equation

- The electronics have a dead time $t_{\text{dead}} \simeq 0.1\,\mathrm{ms}$ (time delays shorter than t_{dead} are not recorded)
- There is an electronics overflow at $t_{\text{overflow}} \simeq 142\,\mathrm{ms}$ (time delays longer than t_{overflow} are recorded modulo t_{overflow})

Both effects vary with α. We include the corrections in order to estimate L more accurately:

$$n \simeq \alpha\, L\, \mathrm{e}^{\alpha t_{\text{dead}}} \left[1 + \frac{1}{\mathrm{e}^{\alpha t_{\text{overflow}}} - 1}\right] \mathrm{e}^{-\alpha t}.$$

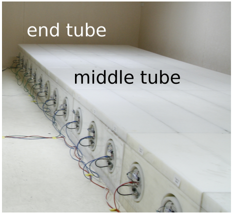
Analysis of temporal variations of L

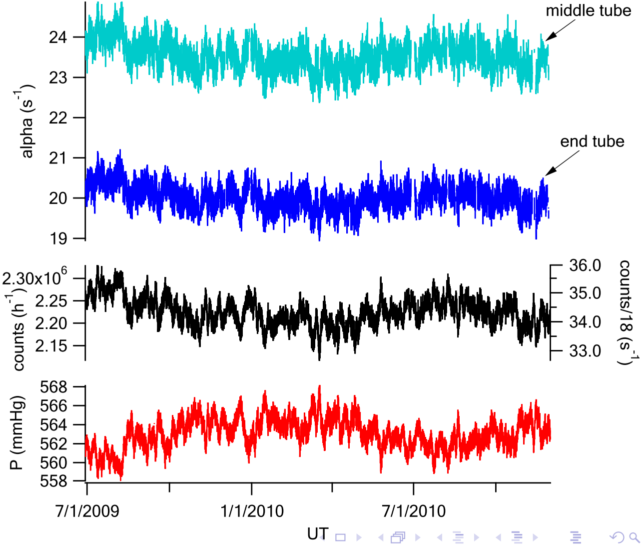
We estimate α and then L from fit to exponential tail of time delay distributions at PSNM

- Hourly-averaged distributions
- 18 months of data (July 2009–January 2011)
- Individual counter tubes

Variations of α

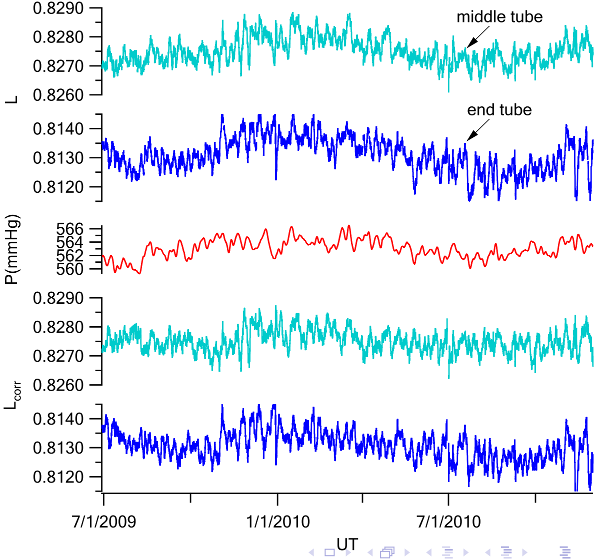
- α related to uncorrected count rate $\Longrightarrow$ atm. pressure





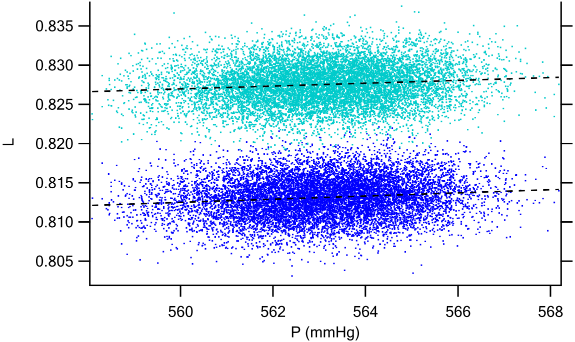
Variations of L

- L should be free from the effect of chance coincidences
- L is quite constant for each tube
- L is lower for the end tubes: reflection at the sides



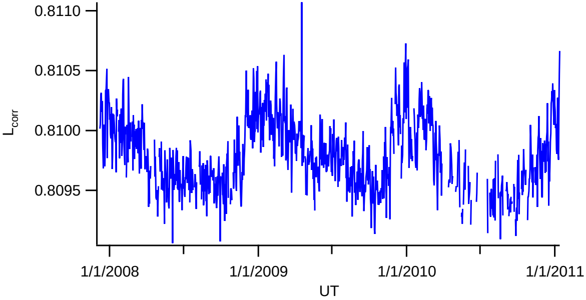
Variations of L

- Small but clear correlation with atm. pressure
- At high P (larger air mass) multiplicity is smaller so L is larger
- Correcting for this trend still leaves a seasonal variation
- Maybe related to atmospheric structure?



Variations of L

- Seasonal variations confirmed using daily histograms for 3 years



Conclusions

- We analyze neutron time delay distributions for the PSNM
- We find time variations in the leader fraction L
  - Related to true neutron multiplicity
  - Not contaminated by chance coincidences
- In the present study, variations may be atmospheric

Thank you for your attention