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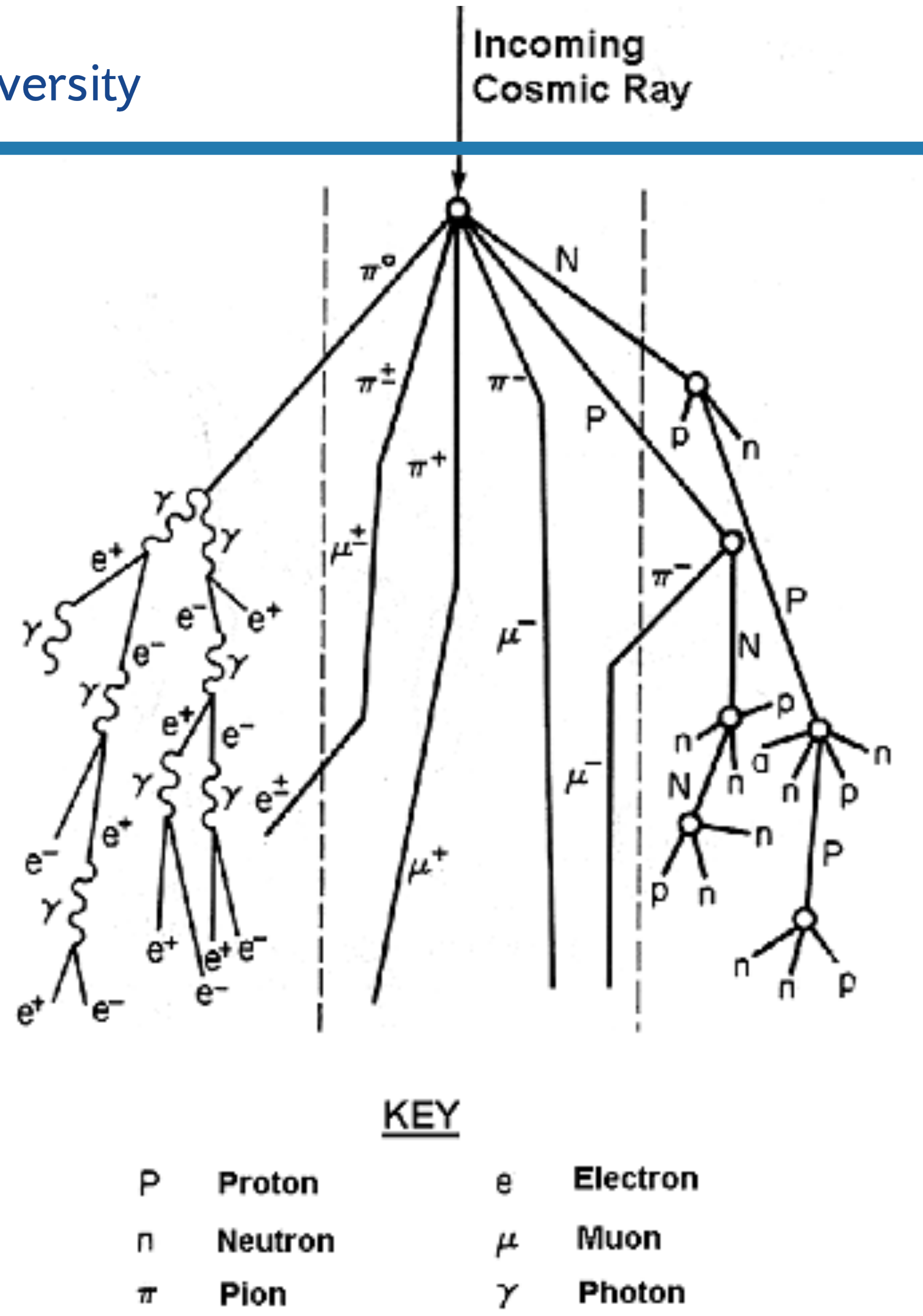
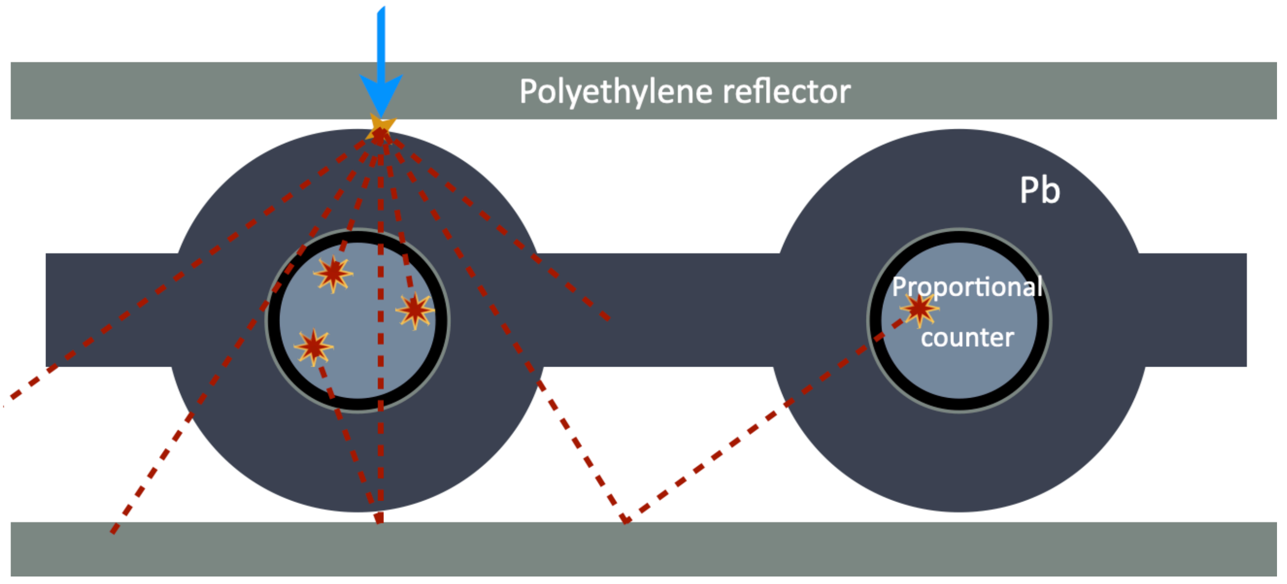
"Time-Delay Measurements from Antarctic Neutron Monitor Stations Indicate Weak Spectral Change during 27-day Variations"

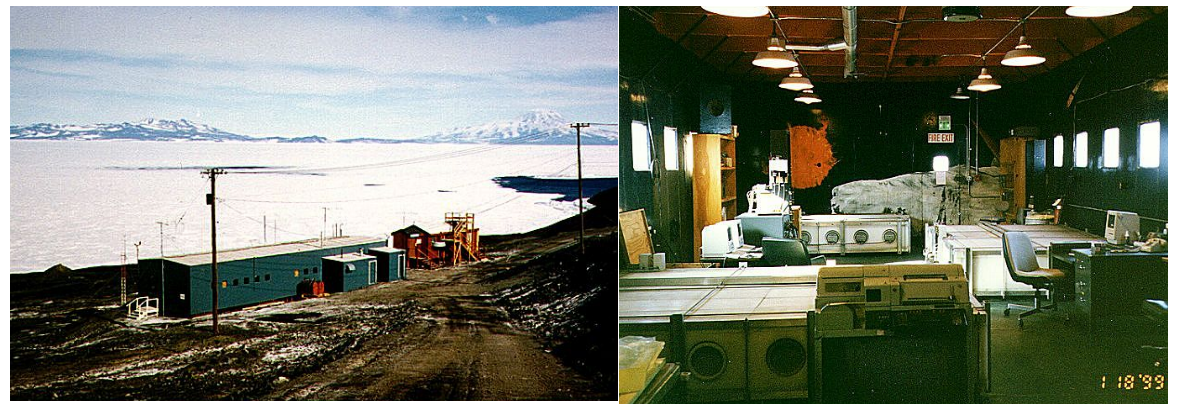
ANTARCTIC NEUTRON MONITOR STATIONS





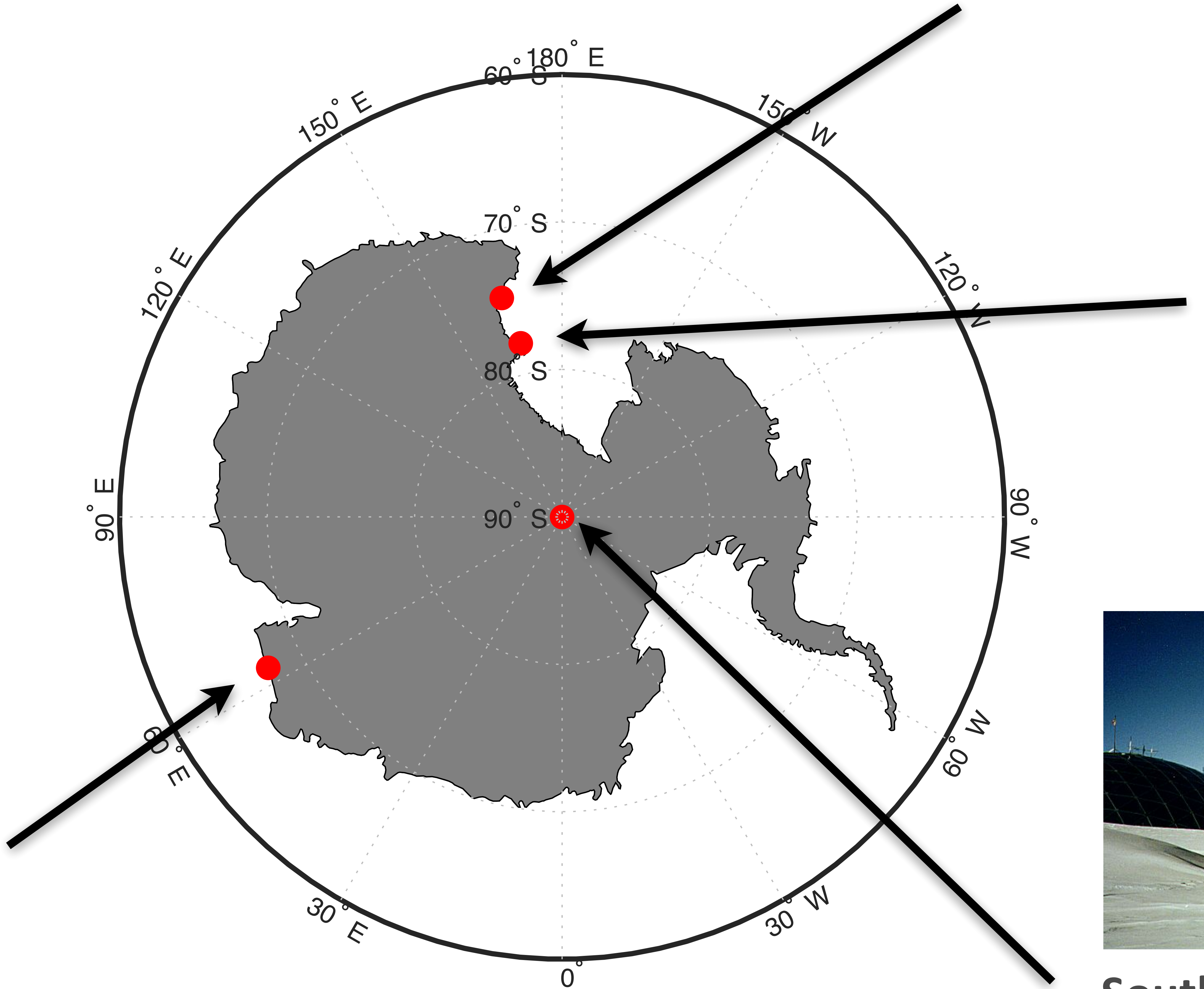
Jang Bogo Station (JB):

- 6 tubes (Dec 2015 to Jan. 2019)
- 18 tubes with 11 tubes special electronics (Jan. 2019)



McMurdo Station:

- 11 tubes with 6 tubes special electronics (Dec. 2015 to Jan. 2017)



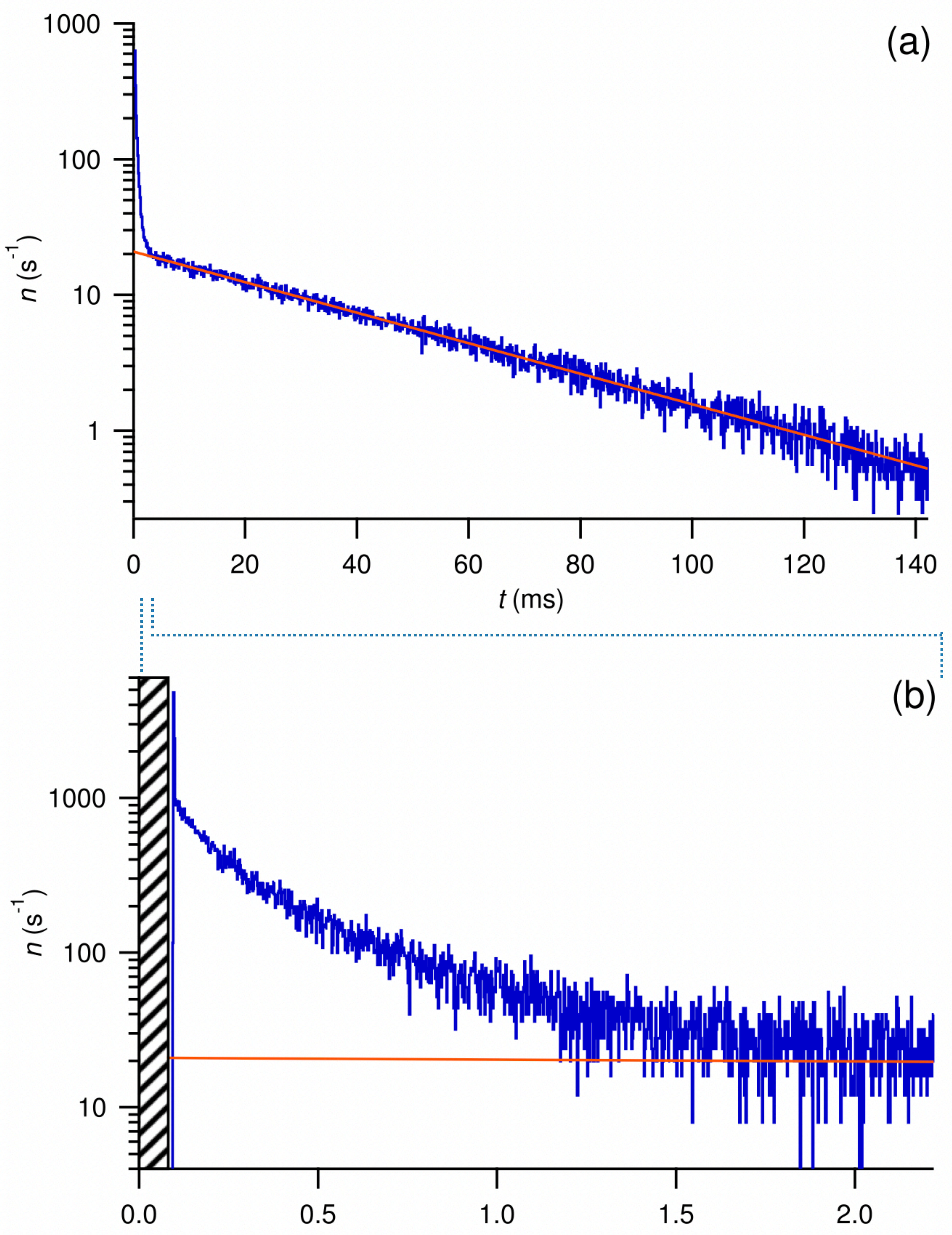
Mawson station (MW):

- 18 tubes (Feb. 2020)

South Pole Station (SP):

- 3 tubes (Mar. 2015)

TIME-DELAY HISTOGRAM



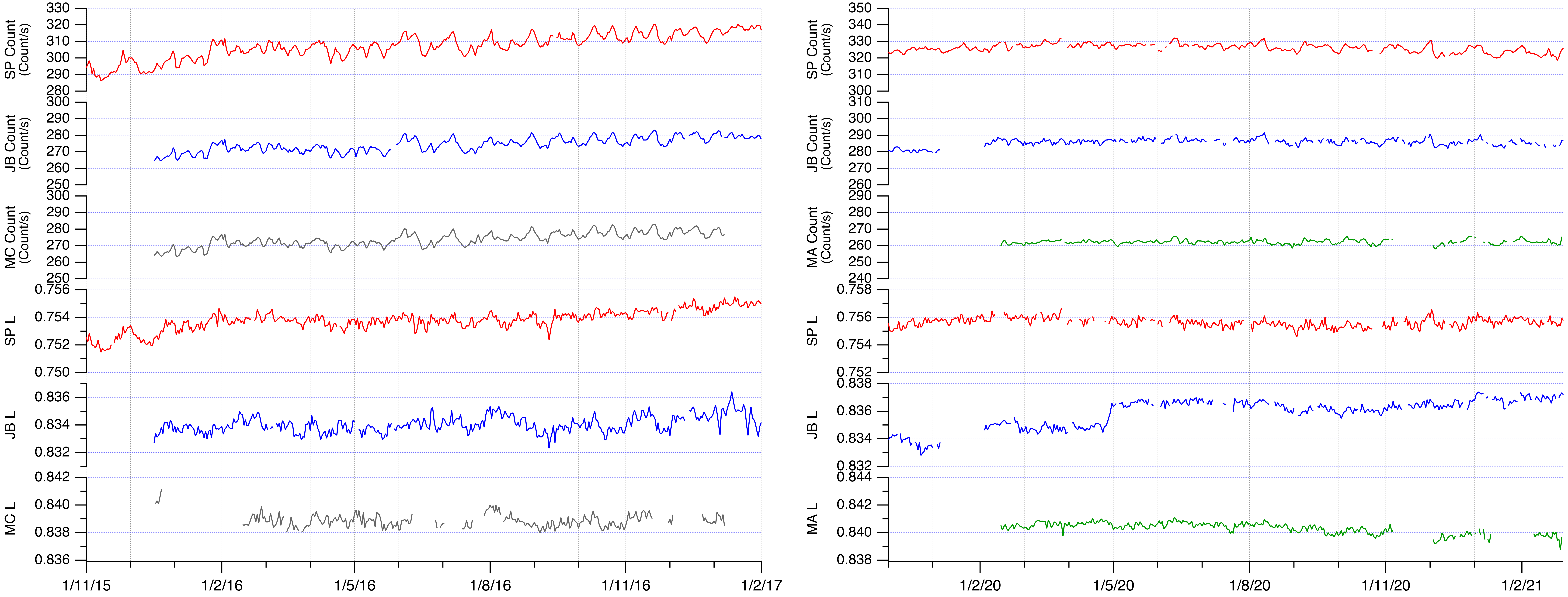
Ruffolo et al., 2016

- The electronics records time delays between successive neutron counts, on count to the next count
  - Long time delays: counts from independent atmospheric neutrons, unrelated events
  - Short time delays: mostly from neutrons produced from the same Pb nucleus
- Ruffolo et al., 2016 calculated *L* from the time delays histograms
- *L* from histograms of time delay related to cosmic ray spectral index.

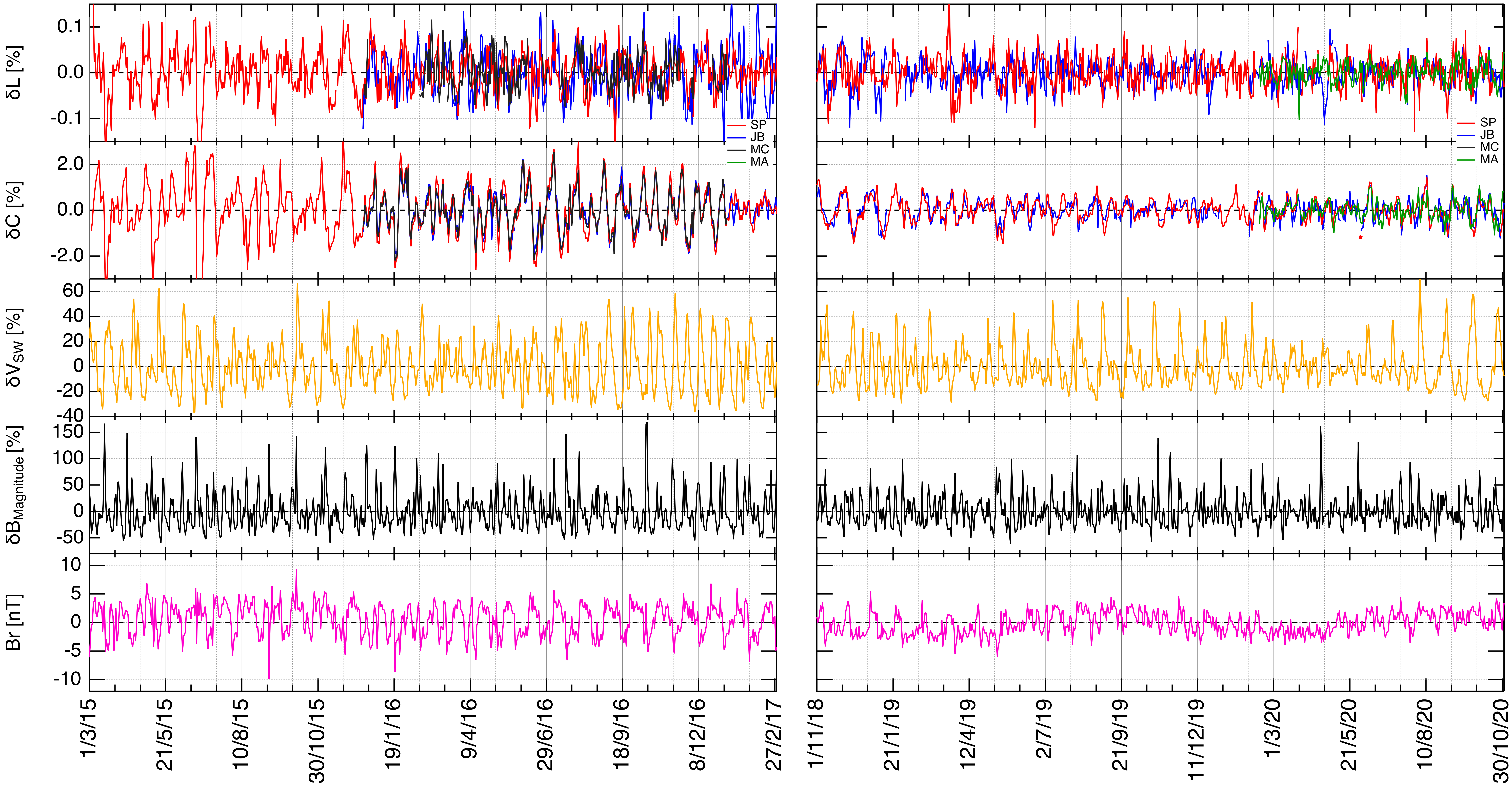
***L* = "leader fraction" (inverse multiplicity)**

COMPARISON OF COUNT RATE *C* LEADER FRACTION *L*

FROM SP, JB, MC, AND MA STATIONS



DETRENDED DAILY AVERAGE FROM 27-DAY AVERAGE

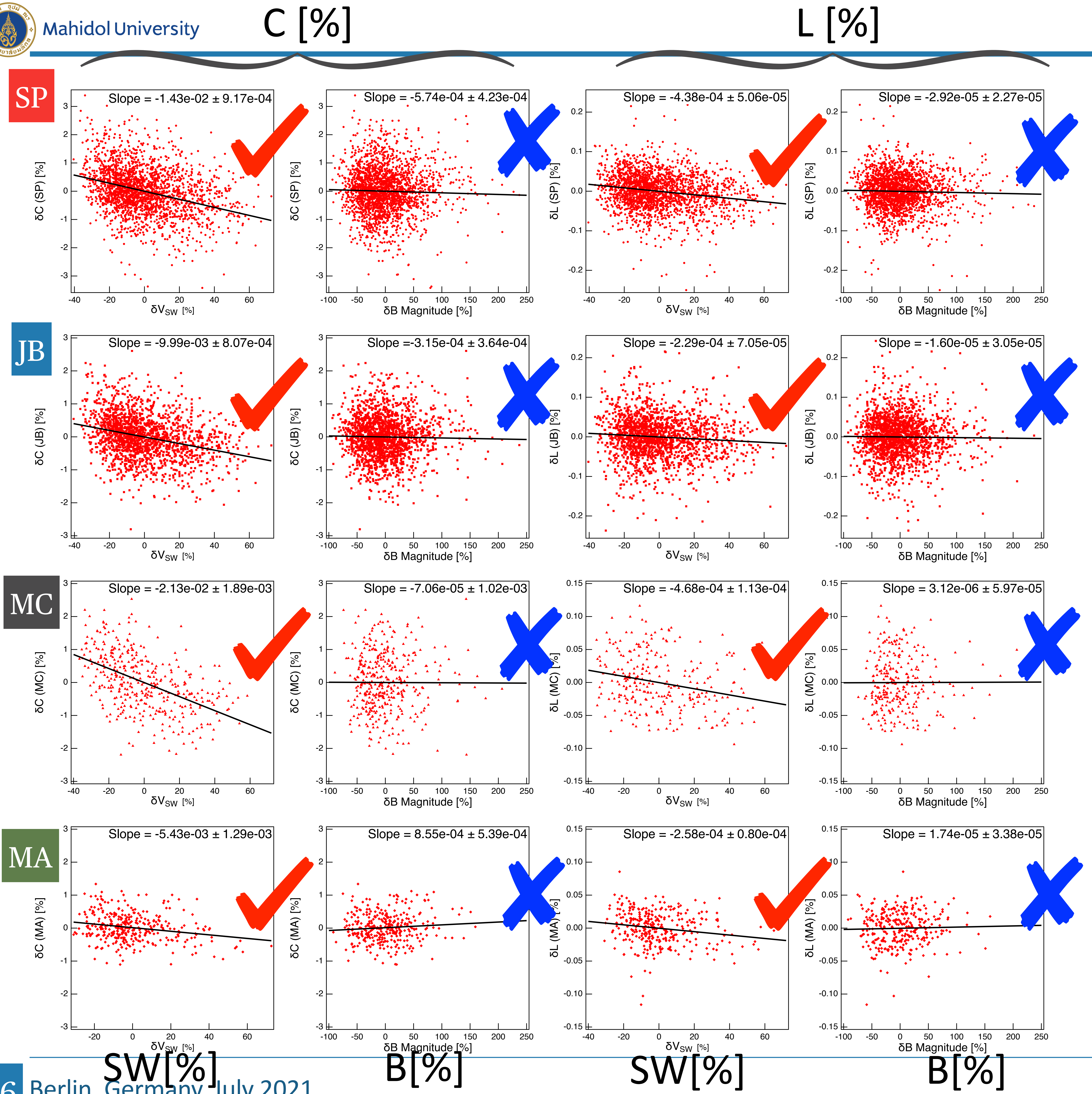


$$\delta I = \frac{x - \bar{x}}{\bar{x}} \times 100\%$$

x is daily average

$\bar{x}$ is 27-day running average

CORRELATION C AND L WITH SOLAR PARAMETERS

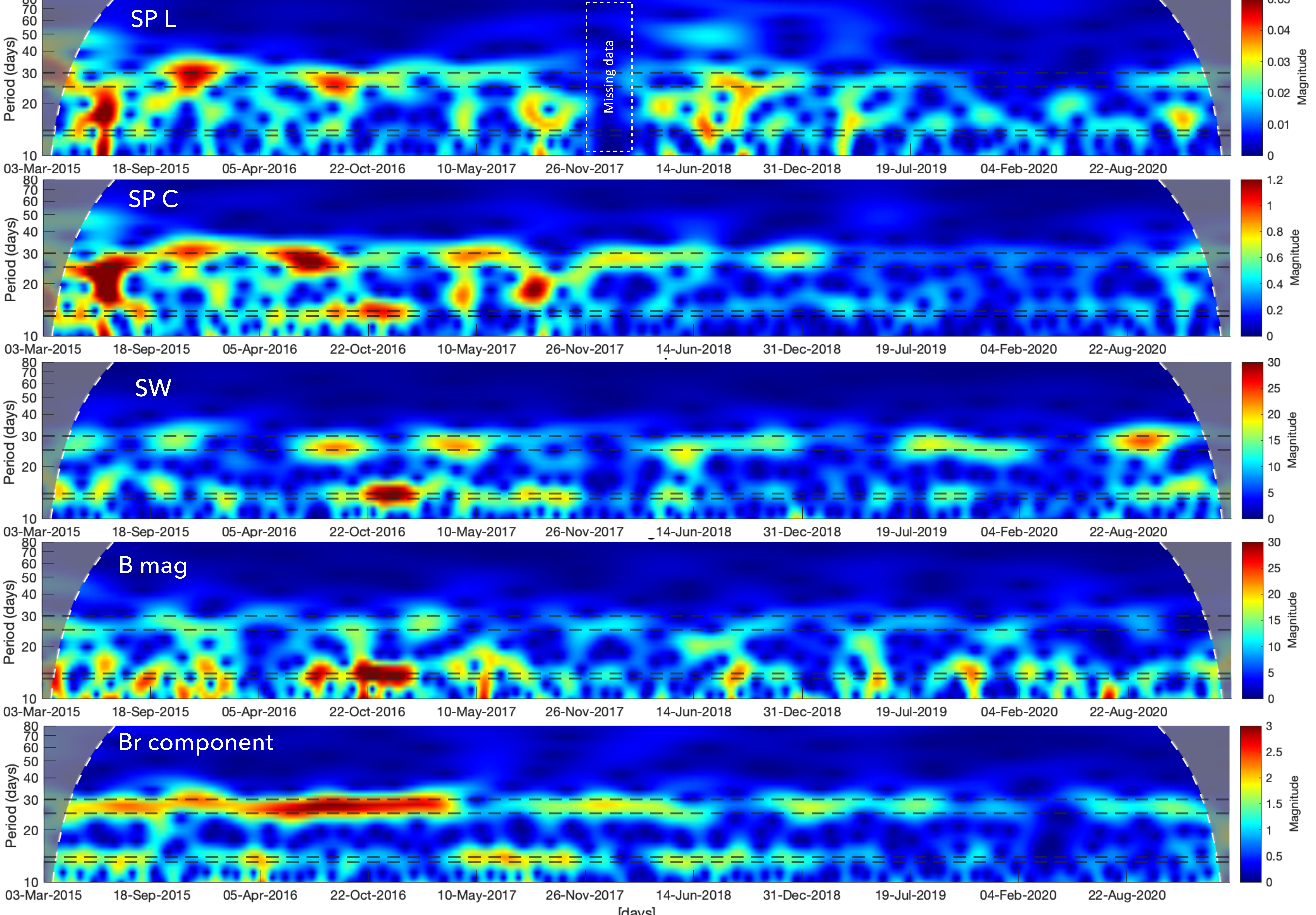


- Significant correlation -> linear slope greater than 2 sigma
- *C* and *L* are negative correlation with solar wind velocity
- No significant correlation between devotion from B magnitude relative to *C* and *L*
- *L* is a much weaker correlation with solar wind velocity than *C*

- SP: Mar 2015 - Feb 2021
- JB: Dec 2015 - Feb 2021
- MC: Dec 2015 - Jan 2017
- MA: Feb 2020 - Feb 2021

WAVELET ANALYSIS

- *C* see:
  - two significant signal with periodicity of 27-day and 13-day
  - Mostly similar to solar wind
- *L* see:
  - correlated with C in 27-day periodic
  - but much weaker in periodic of 13-day.
- So, the spectral variation is only 27-day period not a harmonic



SUMMARY

- Using time-delay histograms from single NM station to calculate "leader fraction *L*" can be use to observe cosmic rays spectral variations
- Comparative analysis of L for 4 Antarctic NM stations, SP, MC, JB, and MW, variation in L tracking with C very well.
- The 27-day variation in *L* was weaker than GCR count rate *C*
- The 27-day variation in L and C are significant correlated with solar wind speed (SW) and not with magnetic field magnitude
- Both *C* and *L* were observed anticorrelation with SW but *L* is a much weaker correlation than *C*
- Wavelet analysis results:
  - *C* are strong two significance signals with periodicity of 27-day and 13-day similar to solar wind speed.
  - *L* showed no visible periodicity at half of the solar rotation period. So, the spectral variation is only 27-day period, not a harmonic


Thank You

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MONITORING SHORT-TERM COSMIC-RAY SPECTRAL VARIATIONS USING NEUTRON MONITOR TIME-DELAY MEASUREMENTS

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Let α be the probability of a chance coincidence per unit time. If all the neutron counts arrived independently with random arrival times, and the dead times in the electronics were negligible, we would have

$$\frac{dR}{dt} = -\alpha R$$
$$\frac{d}{dt}\ln R = -\alpha, \qquad (1)$$

We can define the multiplicity contribution to R as

$$R_n(t) \equiv e^{-\int_{t_d}^{t}\beta(t')dt'}. \qquad (4)$$

$$n(t) = -\frac{dR}{dt} = \left(\alpha R_n - \frac{dR_n}{dt}\right)e^{-\alpha(t-t_d)}. \qquad (5)$$

At $t > t_n$, we have $dR_n/dt = 0$ and $R_n(t) = L$, so we use

$$n = \alpha L\, e^{-\alpha(t-t_d)}. \qquad (t > t_n) \qquad (6)$$

The time-delay histograms can be very well fit by an exponential at long time delays, and now we see that such a fit can be used to estimate not only a chance coincidence probability α for each histogram, but also the parameter L related to multiple neutron production in the lead.

In greater detail, the first technique for determining L from a given time-delay histogram should also take into account the overflow time $t_o = 142$ ms in the electronic recording system. Then the recorded probability density $\tilde{n}(t)$ is given by

$$\tilde{n}(t) = n(t) + n(t + t_o) + n(t + 2t_o) + ... \qquad (7)$$

For $t > t_n$, we use

$$\tilde{n}(t) = \alpha L \sum_{k=0}^{\infty} e^{-\alpha(t+kt_o-t_d)}$$
$$= \frac{\alpha L\, e^{\alpha t_d}}{1 - e^{-\alpha t_o}} e^{-\alpha t}. \qquad (t > t_n) \qquad (8)$$

The long-time histogram is fit to an exponential form $\tilde{n}(t) = Ae^{-\alpha t}$ using a maximum likelihood method that accounts for the Poisson distribution in the observed $\tilde{n}$ for each time bin t. We then determine L from the fit parameters using

$$L = \frac{1 - e^{-\alpha t_o}}{\alpha\, e^{\alpha t_d}} A. \qquad (9)$$

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Tracking Cosmic-Ray Spectral Variation during 2007–2018 Using Neutron Monitor Time-delay Measurements

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Abstract

The energy spectrum of Galactic cosmic-ray (GCR) ions at Earth varies with solar activity as these ions cross the heliosphere. Thus, this "solar modulation" of GCRs provides remote sensing of heliospheric conditions throughout the ~11 yr sunspot cycle and ~22 yr solar magnetic cycle. A neutron monitor (NM) is a stable ground-based detector that measures cosmic-ray rate variations above a geomagnetic or atmospheric cutoff rigidity with high precision (~0.1%) over such timescales. Furthermore, we developed electronics and analysis techniques to indicate variations in the cosmic-ray spectral index using neutron time-delay data from a single station. Here we study solar modulation using neutron time-delay histograms from two high-altitude NM stations: (1) the Princess Sirindhorn Neutron Monitor at Doi Inthanon, Thailand, with the world's highest vertical geomagnetic cutoff rigidity, 16.7 GV, from 2007 December to 2018 April; and (2) the South Pole NM, with an atmosphere-limited cutoff of ~1 GV, from 2013 December to 2018 April. From these histograms, we extract the leader fraction *L*, i.e., inverse neutron multiplicity, as a proxy of a GCR spectral index above the cutoff. After correction for pressure and precipitable water vapor variations, we find that *L* roughly correlates with the count rate but also exhibits hysteresis, implying a change in spectral shape after a solar magnetic polarity reversal. Spectral variations due to Forbush decreases, 27 day variations, and a ground-level enhancement are also indicated. These methods enhance the high-precision GCR spectral information from the worldwide NM network and extend it to higher rigidity.

Unified Astronomy Thesaurus concepts: Cosmic rays (329); Solar-terrestrial interactions (1473); Solar cycle (1487)

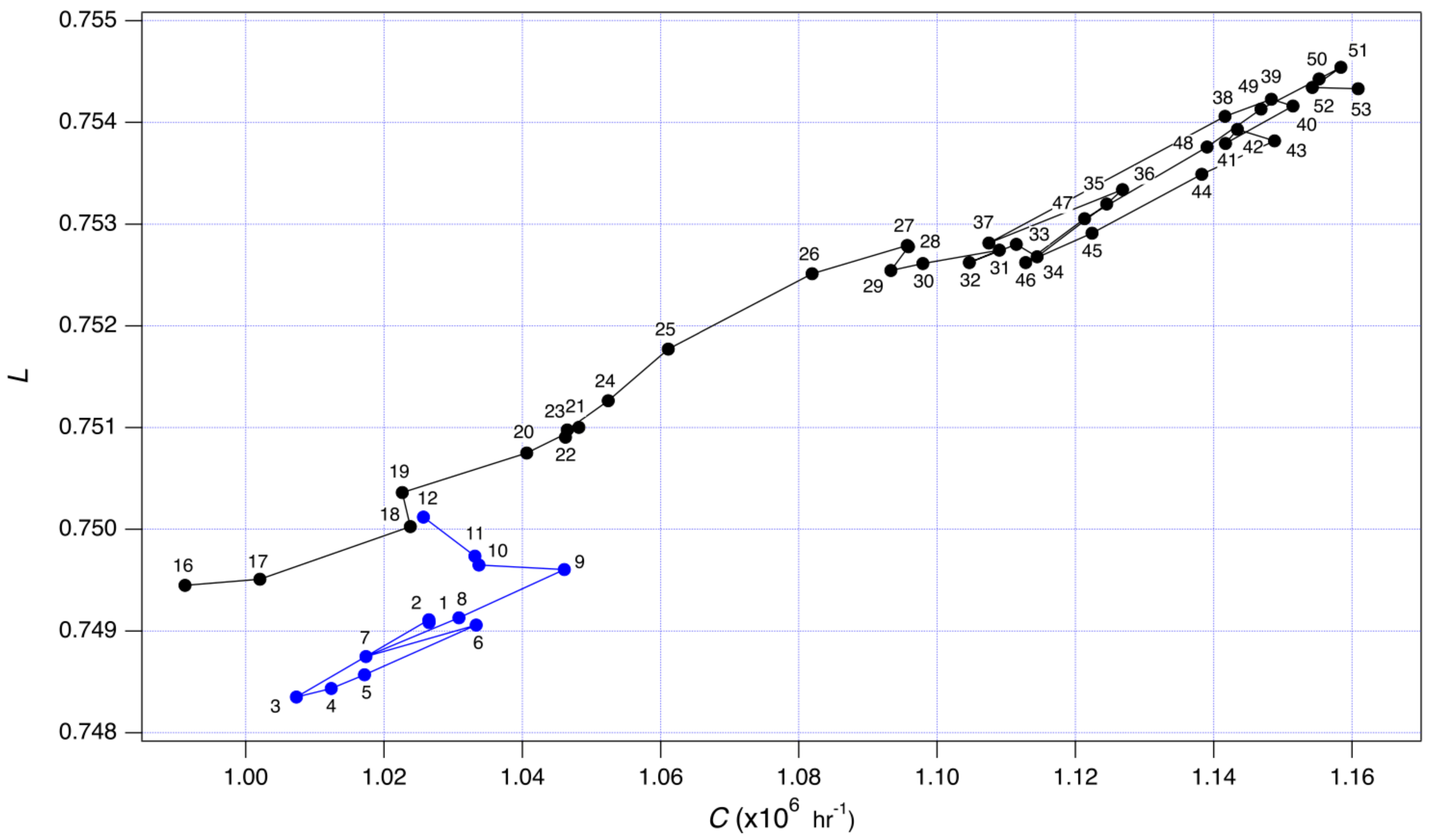

Figure 7. Monthly averages of the leader fraction *L* vs. count rate *C* from Figure 5 for the 3 × 1NM64 at the South Pole during 2013 December–2018 April. Labels indicate the order of monthly data points, starting at 1 for 2013 December and ending at 53 for 2018 April. Blue indicates an uncertain normalization of the data from 2013 December to 2014 November relative to the later data, which show a nearly linear relationship between *L* and *C* for a half-cycle of solar modulation.