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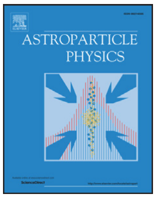

Evidence for correlations between fluctuations in ^{54}Mn decay rates and solar storms

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ABSTRACT

Following recent indications that several radioactive isotopes show fluctuating decay rates which may be influenced by solar activity, we present findings from a 2 year period of data collection on ^{54}Mn. Measurements were recorded hourly from a 1 μCi sample of ^{54}Mn monitored from January 2010–December 2011. A series of signal-detection algorithms determine regions of statistically significant fluctuations in decay behaviour from the expected exponential form. The 239 decay flags identified during this interval were compared to daily distributions of multiple solar indices, generated by NOAA, which are associated with heightened solar activity. The indices were filtered to provide a list of the 413 strongest events during a coincident period. We find that 49% of the strongest solar events are preceded by at least 1 decay flag within a 48 h interval, and 37% of decay flags are followed by a reported solar event within 48 h. These results are significant at the 0.9σ and 2.8σ levels respectively, based on a comparison to results obtained from a shuffle test, in which the decay measurements were randomly shuffled in time 10,000 times. We also present results from a simulation combining constructed data reflecting 10 sites which compared and filtered decay flags generated from all sites. The results indicate a potential 35% reduction in the false positive rate in going from 1 to 10 sites. By implication, the improved statistics attest to the benefit of analysing data from a larger number of geographically distributed sites in parallel.

1. Introduction

Anomalies in experimental data on nuclear decays have been reported recently by several groups studying a number of radioactive isotopes, and utilising a variety of different detectors (for recent summaries see Refs. [1–4]). These anomalies include annual periodicities in decay rates [5–10], presumably related to the annual variation in the Earth–Sun distance, sub-annual periodicities which may be related to solar rotation [11], a Rieger-like periodicity at 2.11 yr^{-1} [12], and shorter-lived anomalies as seen in ^{54}Mn count-rates coincident with an X-class solar flare [13]. Motivated by the latter observation, our group has developed a series of signal-detection algorithms (see Fig. 1) which employ several statistical tests to identify regions of statistically relevant deviations in the measured ^{54}Mn decay rate from the expected model, as described by the standard exponential decay law, $N(t) = N_o e^{-\lambda t}$. Here $N(t)$ is the number of atoms surviving at time t from an initial population N_o, and $\lambda = \ln(2)/T_{1/2}$ is the conventional decay parameter expressed in terms of the isotope half-life $T_{1/2}$. ^{54}Mn decays 100% via K-capture to an excited state of its daughter nucleus ^{54}Cr. A 2 × 2 Bicron NaI(Tl)crystal detector recorded the emission of the 834.8 keV γ-ray emitted during the de-excitation of ^{54}Cr to its ground state. The entire apparatus was shielded by lead bricks on all sides except at the base of the PMT tube to allow cables through. Apart from this shielding, the experiment was located within a windowless interior room where the temperature was monitored and maintained at 19.5(5) °C.

1.1. Signal processing algorithms

Fig. 1 outlines the flow of recorded measurements through the analysis process, where each algorithm acts independently and checks for atypical behaviour in specific features of the decay signal. The Two-sided Cumulative Sum (CUSUM2) checks for changes in the average level of an incoming signal and generates a *decay hit* when the cumulative sum of the number of decays exceeds a 2 standard deviation threshold from the expected mean [14,15]. The Geometric Moving Average (GMA) test introduces an exponential weighting

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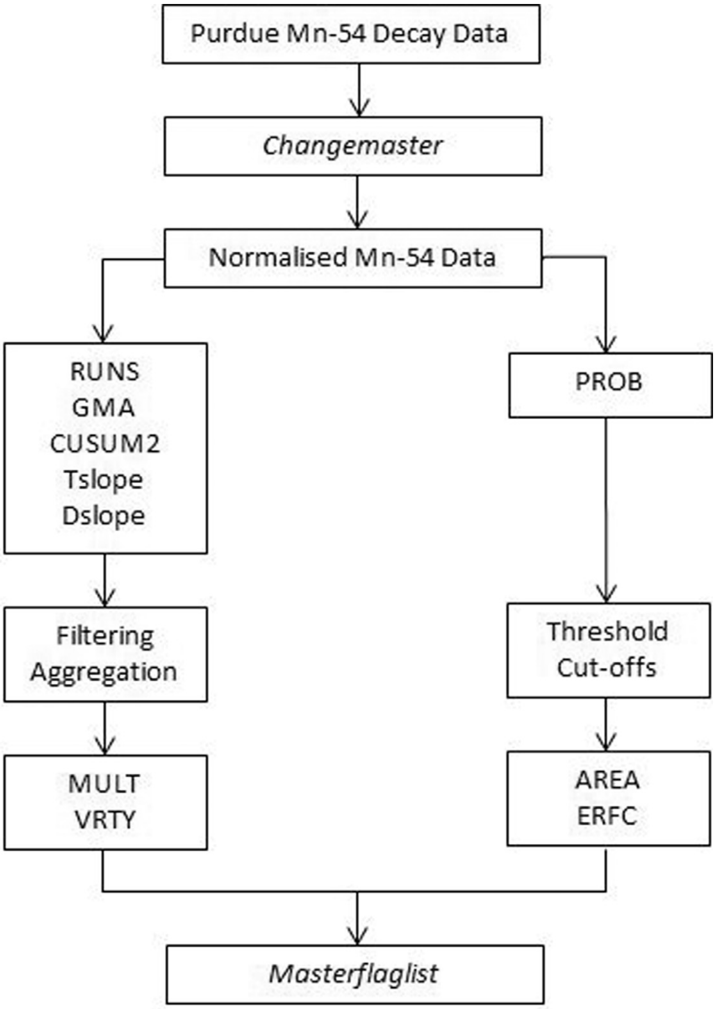

Fig. 1. Flow of decay data through detection algorithm. The program analyses normalised decay data for anomalies in the incoming signal. Using a variety of signal detection algorithms and cut-off thresholds, aggregated decay flags are listed in the text file *Masterflaglist*. See text for further details.

factor $W_i = \alpha(1-\alpha)^i$ to the data set, where α is a forgetting factor valued between 0 and 1. The data are weighted temporally with weights decreasing as a geometric progression from more recent observations to earlier ones [14,16]. The Runs test (RUNS) is adapted from the theory of runs [17] and analyzes the longevity of disturbances as a measure for triggering a hit. For instance, in an 8 h interval of data, a hit is generated if all of the following conditions are met: (a) a measurement x_i is found to be h_1 standard deviations from the expected value μ_o, (b) 2 of the previous 3 measurements $\{x_{i-2}, \ldots, x_i\}$ exceed the expected model by h_2 standard deviations, and (c) 7 of the prior 8 data points $\{x_{i-7}, \ldots, x_i\}$ show a positive increase from μ_o. If all three of these criteria are satisfied the Runs test will produce a hit indicating an 8 h interval of extended increase in the decay rate. In the following analysis $h_1 = 1.6$, $h_2 = 1$ and the data are normalised with $\mu_o = 0$. The D-slope (Dslope) and T-slope (Tslope) tests assume a monotonic exponential decrease as the expected model of decay, and compare the measured ^{54}Mn half-life within a sliding window to a larger time frame averaging the decay behaviour during that period. The T-slope test calculates the decay constant obtained from 2 days of measurements and triggers a hit when there is 30% discrepancy between this value and the decay constant describing a coincident 2 week region of data. The D-slope test works similarly with the addition of an adjustable inner window size, thus singling out regions of short-lived deviations in count rate as well as larger fluctuations in decay rates compared to the current rate. Finally, the F-probability test (PROB) is a customised analysis program which treats each active atom as an individual Bernoulli trial between each measurement. A prediction for each measurement is made using previous data points to project forward in time based on this model. See Appendix A for an outline of the F-probability test.

To reduce the number of false positives generated by randomly occurring outlying measurements, hits from each test are filtered to produce 4 different types of decay flags: Variety (VRTY), Multiplicity (MULT), Area (AREA), and Error Function (ERFC) flags. The VRTY and MULT flags are constructed by aggregating decay hits from the initial five signal processing algorithms. The occurrence of two or more hits of different types within a 48 h interval generates a VRTY flag. To prevent repetitive flagging of overlapping 48 h windows, the initial period is extended in 6 h increments to check for any further hits until either no new hits are found in the extended window or the window size reaches a maximum length of 72 h. All hits within this window are grouped into a single VRTY flag and the flag mean-time is calculated from an average of every included hit. The MULT flags are similarly generated when a minimum of 5 hits are triggered within an initial 48 h interval. Fig. 2 depicts a sample output of the VRTY and MULT flags from August 2011–October 2011. The AREA and ERFC flags are calculated independently using the PROB test. The multiple predictions made by the PROB test are used to generate a weighted average for the count rate. The difference between the measured counts and the averaged prediction expressed in standard deviations,