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COSMIC RAY ANOMALY AND THE LUNAR SAROS CYCLE

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Abstract

The power spectral density (frequency dependence of the variance) of the annual Stuiver radiocarbon record (Δ^{14}C) contains a major line with a 17.5 ± 0.5 (2σ) year period which is proposed to result from a hitherto unexpected forcing of the cosmic ray (CR) flux at the top of the atmosphere. The only known natural period with a corresponding value is the sidereal Saros cycle (Kaula, 1968), the retrograde period of rotation of the Moon's nodal plane; 18.5 years is the sidereal nodal regression period. It is proposed that the intersection of the Moon's downstream diamagnetic solar wind cavity with the Earth at the Saros period is the source of the apparent cosmic ray anomaly leading to this periodic change of Δ^{14}C ; arguably eclipsing and/or a low energy acceleration of the GCR could take place, though the evidence from the Fourier spectrum appears to favor acceleration.

1 Introduction:

We report the presence of a prominent $\sim 17.5 \pm 0.5$ (2σ) year period in the power spectral density of the annual radiocarbon variance (Δ^{14}C) and suggest a model for how this period is forced. Stuiver (1993) and Stuiver and Braziunas (1993) (noted hereafter for brevity as SB) earlier reported the maximum entropy spectrum while Stolov and Cameron (1964), and Rassbeck et al (1966) investigated possible solar wind–lunar effects on terrestrial parameters, but at generally shorter periods, e.g. the lunar orbital and solar rotational periods. (See also Michel et al, 1964). The annual radiocarbon record of Stuiver is from Pacific Northwest pine tree ring cellulose, the basic data from which the key result of this letter are drawn. Since tree ring cellulose takes up atmospheric CO_2 it incidentally provides a measure of the atmospheric radiocarbon concentration. But the tree ring record provides only an attenuated version of the atmospheric carbon (and radiocarbon) concentration, e.g. Craig, 1957; Houtermans et al, 1973. Attenuation factors vs. carbon dioxide atmospheric residence time are based on a simple two reservoir (atmosphere and ocean) system and accentuate short periods, in keeping with the well known extreme signal damping with increasing frequency. The simplified attenuation is computed here; the one oceanic reservoir approximation of a substantially more accurate reservoir model, including a multilayer ocean and sea floor sink, illustrates the corrected spectrum with sufficient accuracy for the present report.

2 Radiocarbon source

Radiocarbon is represented by a natural concentration of about 1 part in 10^{12} of natural carbon's 8 isotopes (Lederer et al, 1967) in the atmosphere in the form of carbon dioxide ($^{x}CO_2$) of which 6 isotopic versions are radioactive. The takeup of atmospheric carbon by the outermost growth ring of a tree ceases as this ring is blanketed by new growth. This termination of biotic respiration of a tree ring, followed by growth of a successive ring, provides a clock for dating biological matter. Variability of the atmospheric concentration of ^{14}C requires detailed calibration vs. tree ages for use as an archeological clock; it is a correspondingly promising tool in geophysics and solar physics. Radiocarbon production in the terrestrial atmosphere is the end stage of the interaction mostly of the protonic component of cosmic rays with the atmosphere. These are

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a low energy (p,n) reaction (35%) and spallation (65%) yielding neutron production (Damon, priv. comm), thermalization by scattering from atmospheric gases, and finally capture mainly by the exothermic nuclear reaction

$$^{1}n + ^{14}N(n,p) \rightarrow ^{14}C + \beta + \gamma \tag{1}$$

where ^{14}N is atmospheric. ^{14}C decays by

$$^{14}C \rightarrow ^{14}N + \bar{\nu} + \beta^{-} \tag{2}$$

where $\bar{\nu}$ is the antineutrino, β^{-} the electron, and ^{14}N is atmospheric.

3 Atmosphere–ocean exchange of CO_2

Because carbon is chemically very active, ^{14}C produced in the atmosphere is rapidly oxidized to CO_2; much of this is taken up by the oceans. More exactly, an exchange system between the atmosphere and different reservoirs in the world's oceans partitions the total terrestrial CO_2 along with the radiocarbon fraction. The takeup of radiocarbon by the oceans is, however, not simply a matter of CO_2 solubility, for the ocean buffers the process; carbonate and bicarbonate ions play a major role, but details of this are not especially relevant to this letter. The relatively long half life of ^{14}C causes the atmosphere to acts like a low pass frequency filter with periods ~ 10 years attenuated in amplitude by a factor of ~ 75 for standard ^{14}C attenuation models.

4 Power spectrum of Δ^{14}C

The major lines recovered from the periodogram (Fig. 3) are embodied by two clusters, centered at The attenuation–uncorrected spectrum (solid line) is strongly distorted by period–dependent reservoir attenuation. The attenuation–corrected PSD (dashed line) is shown for 25 year atmospheric residence time though the results are only weakly dependent on this parameter. PSD amplitudes are only qualitatively correct. Note the apparent anomalous sidelobe amplitude on the high frequency side of the 10 year cluster.

The attenuation–uncorrected spectrum (solid line) is strongly distorted by period–dependent reservoir attenuation. The attenuation–corrected PSD (dashed line) is shown for 25 year atmospheric residence time though the results are only weakly dependent on this parameter. PSD amplitudes are only qualitatively correct. Note the apparent anomalous sidelobe amplitude on the high frequency side of the 10 year cluster conjectured to be associated about 11 years and 17.5 year periods. This represents an increase in resolution from earlier decadal data, e.g. Sonett (1984); Damon and Sonett (1991). The MEM (maximum entropy) spectrum of SB show a major line at 16.9 years as well as a cluster about 11 years. The former we identify with the 17.5 year period taking account of the well known tendency for MEM to exhibit frequency instability. Major interest here is centered on the 17.50 ± 0.5 (2σ) year line with the 2σ error estimate based on a single frequency search using maximum likelihood. An additional test for the quality of the carbon PSD is by 'pattern recognition' where the effect of the addition of Gaussian noise in corrupting the data sequence is studied. Noise sequences with standard deviation increasing stepwise by 0.5 from 0.5 to 2.0 are added to the carbon annual data sequence from which then the PSD of each corrupted sequence is computed. The original carbon data standard deviation is 0.64

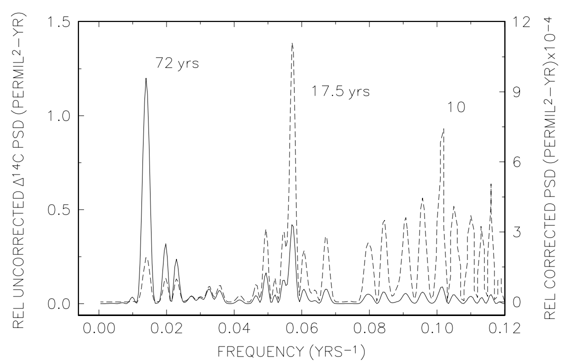

Figure 1: Periodogram of Stuiver and Braziunas annual record showing a major $\sim$ 72 year feature, probably Gleissberg (1944), and weaker lines at very approximately 50 and 45 years. The Saros line is at 17.5 years, while the cluster about 10 years us conjectured to be associated with the solar activity period.

($\sigma = 0.41$). From maximum likelihood calculations the corresponding signal/noise ratio is 3.8, from which the estimated Δ^{14}C noise standard deviation of the data is found to be 0.13. This value is much less than the value needed to significantly influence the data PSD pattern. The enigmatic '11' year cluster in Fig. 3 is almost certainly associated with the 11 year solar activity period and associated lines noted in the sunspot spectrum, e.g. Sonett (1982) but interpretation of the cluster is planned for publication elsewhere.

5 Nodal dynamics

The plane of the Moon's orbit rotates with a period of 17.5 years (synodic) retrograde with respect to the Earth's motion about the Sun. Thus the line of nodes (intersection of the Moon's orbit plane with the ecliptic) sweeps over the ecliptic once per Saros. Since the Saros period results from the intersection of the nodal line with the earth, it might be argued that the line of nodes should intersect the Earth twice per Saros period. But this narrowly restricted view ignores the problem of commensurability, i.e. that the line of nodes is synchronous (commensurate) over half a rotation with the earth but this is obviously not true as indicated by the Saros eclipse period which indicates that the line of nodes and the Earth arrive at a common point in space once per Saros. An additional suspected source of data might thought to be the periodogram of the monthly neutron monitor power spectral density (data from Pyle, 1994) which discloses a major association of variance with period in the neighborhoods of 17 years but which is imperfectly resolved because of the short length of the record.

Whether the strong line at 17.5 years (Saros) is associated with an increase or decrease in the CR is suggested by study of the phases of the Fourier components (Bracewell, 1978; Champeney, 1973) in the neighborhood of the 17.5 year line, but a search aimed at this has proven uncertain. A test for eclipsing, acceleration, or a combination will likely require direct measurements in space.

6 Perturbation source

The only heavenly body physically close to the Earth is the Moon. Can an association be surmised resulting in a change (increase or decrease) in the production of ^{14}C in the Earth's atmosphere, thus inferring a change in the incoming CR flux at the top of the atmosphere? A strong feature of the interaction of the Moon with the solar wind is a quasi–permanent hydromagnetic structure–the plasma cavity due to the target cross section of the moon in the solar wind–which streams off the Moon's antisolar hemisphere (Colburn et al, 1967; Siscoe et al, 1969; Lin, 1968; Dubinin et al, 1967). This cavity displays a characteristic diamagnetic signature arising form the differential solar wind plasma pressure accross the downstream lunar anto–solar cavity.

7 The gyro radius 'problem'

From considerations of nuclear interchange and Coulomb barriers, an addition to the atmospheric neutron sea is consistent with a low energy (but Mev) modification to the incoming CR flux, increasing the consequent production of neutrons in the atmosphere. The alternative of 'shadowing' by the diamagnetic cavity or Moon is also permissible. The gyro radii of the perturbed CR increment either for a minor accelerated or attenuated CR component are larger than the scale of the solar wind cavity structure. But the gyro radii problem is irrelevant to the production of a CR anomaly, for such a component has nothing to do with defining the cavity structure, i.e. the pressures defining the cavity are from the solar wind plasma. If the surmise is correct regarding the CR perturbation, then it is the local electric fields in association with the magnetic fields of the cavity which are invoked.

Using a solar wind Mach number of ~ 10 the expansion angle of the cavity is estimated to be ~ 0.1 radians. At a mean distance of the moon from the Earth of 4×10^5 km, the lateral dimension of the cavity at Earth is $\sim 4 \times 10^4$ km or about 60% of the magnetospheric span at 10 Earth radii. This structure is thus expected to interact fully with the magnetosphere once per 17.5 years, provided that it has not dissipated. For a solar wind magnetic field of $\sim 5\mu$-gauss, ρB $\sim 2 \times 10^4$ gauss-cm corresponding to a proton of ~ 1 Mev. Nuclear interactions for low Z isotopes are expected to range over a few Mev; the estimate here is barely consistent. As the orbital speed of the Moon is (O) 1 km-sec^{-1} and the width of the Moon's Mach cone at the distance of the Earth is (O) 760,000 km, the Earth's magnetosphere is exposed to the Moon's 'hydromagnetic' shadow a few hours every 18 years. As the neutron lifetime is 11.7 minutes, the atmospheric flux should decrease by about 3 e-folds during the immersion of the magnetosphere in the Mach cone. An enhancement dependent upon shock acceleration is observable on Earth only when the aforementioned alignment takes place. The effect upon the CR flux is either an increase at low energy where neutron and radiocarbon production increases are important or a decrease due to shadowing. If the diamagnetic cavity adds a small increment of energy to the low energy portion of the CR spectrum, the increase in the flux is slight, recalling that the mean atmospheric concentration of Δ^{14}C is only 1:10^{12}. The alternative conclusion of shadowing yields a correspondingly small decrease in the Δ^{14}C concentration.

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