A System for Possible Early Warning of Disastrous Solar Flares

Jere Jenkins

Ephraim Fischbach

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RADIATIONS

FROM

RADIOACTIVE SUBSTANCES

by

SIR ERNEST RUTHERFORD, O.M., D.Sc., Ph.D., LL.D., F.R.S.

NOBEL LAUREATE

Cavendish Professor of Experimental Physics in the University of Cambridge

JAMES CHADWICK, Ph.D., F.R.S.

Fellow of Gonville and Caius College, Cambridge

and

C. D. ELLIS, Ph.D., F.R.S.

Fellow of Trinity College, Cambridge

Re-issue of the edition of 1930

CAMBRIDGE

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1951

CHAPTER VII

GENERAL PROPERTIES OF THE RADIATIONS

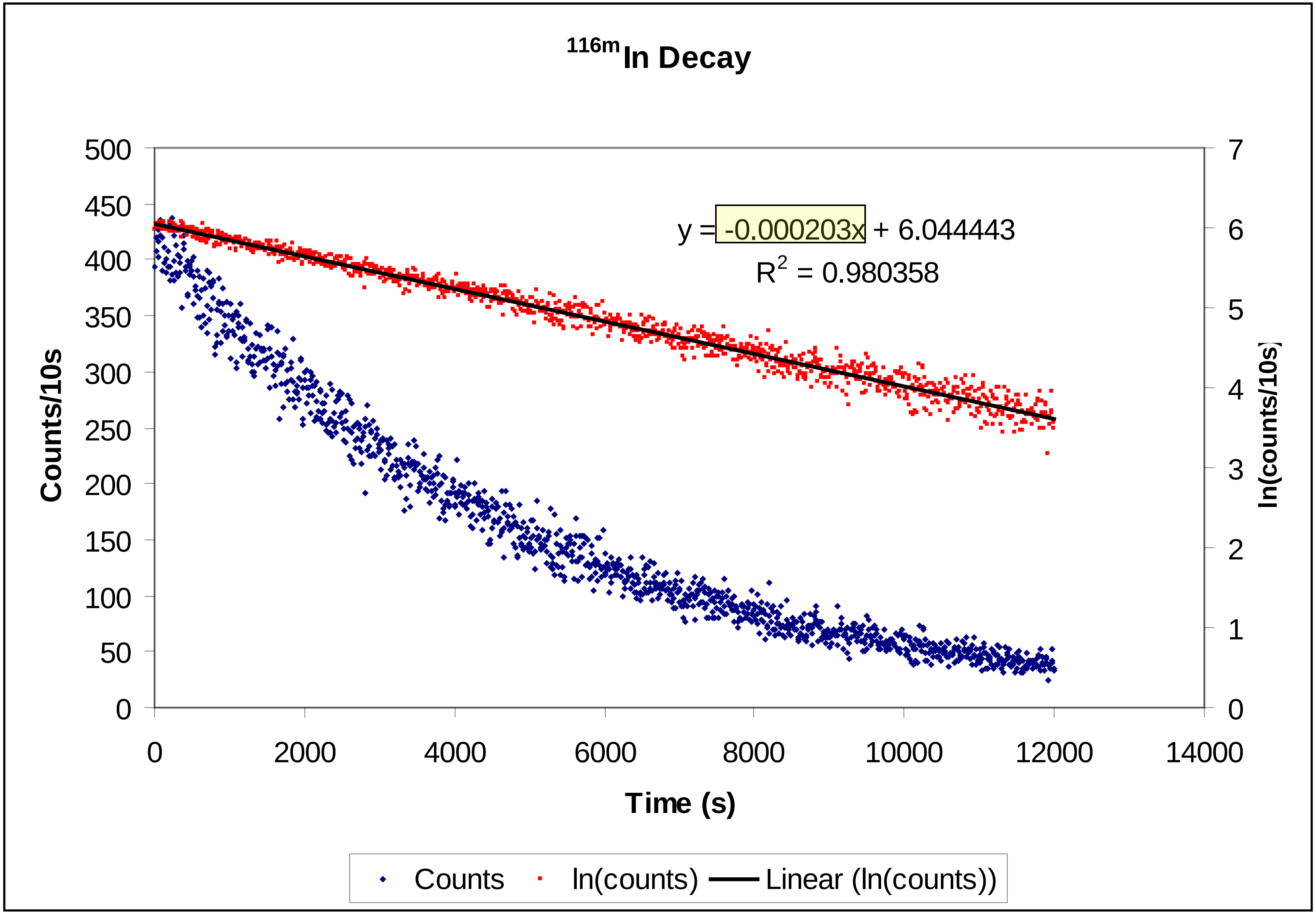
§ 34 a. Emission of α particles and probability variations. The rate of disintegration of all radioactive substances is expressed by a simple law, namely, that the number of atoms n breaking up per second is proportional to the number N of atoms present. Consequently $n = \lambda N$, where λ is a constant characteristic for a particular radioactive substance. The rate of transformation of an element has been found to be a constant under all conditions. It is unaltered by exposing the active matter to extremes of temperature or by change of its physical or chemical state. It is independent of the age of the active matter or its concentration. It is unaffected by exposure to strong magnetic fields. Hevesy has shown that the disintegration of the primary radioactive element uranium is unaltered by exposing it to the β and γ radiation from a strong source of radium, although these rays, of great individual energy, might be expected to penetrate the atomic nucleus.

Since the expulsion of an α or β particle results from an instability of the atomic nucleus, the failure to alter the rate of transformation shows that the stability of the atomic nucleus is not influenced to an appreciable extent by the forces at our command. This is not unexpected when we consider the enormous intensity of the forces, probably both electric and magnetic, which hold the charged parts of the nucleus together in such a minute volume.

E. v. Schweidler* showed that the exponential law of decay of the radioactive bodies could be deduced without any special hypotheses of the structure of the radioactive nuclei or of the mechanism of disintegration. He assumed only that the disintegration of an atom is subject to the laws of chance, and that the probability p that an atom of a certain type shall be transformed within a given interval of time Δ is independent of the time which has elapsed since the formation of the atom and is a constant which is the same for all atoms of the same type or radioactive product.

For very small values of the time interval Δ, the chance p of transformation will be proportional to the length of the interval. There-

* Schweidler, *Congrès Internat. Radiologie*, Liège, 1905.



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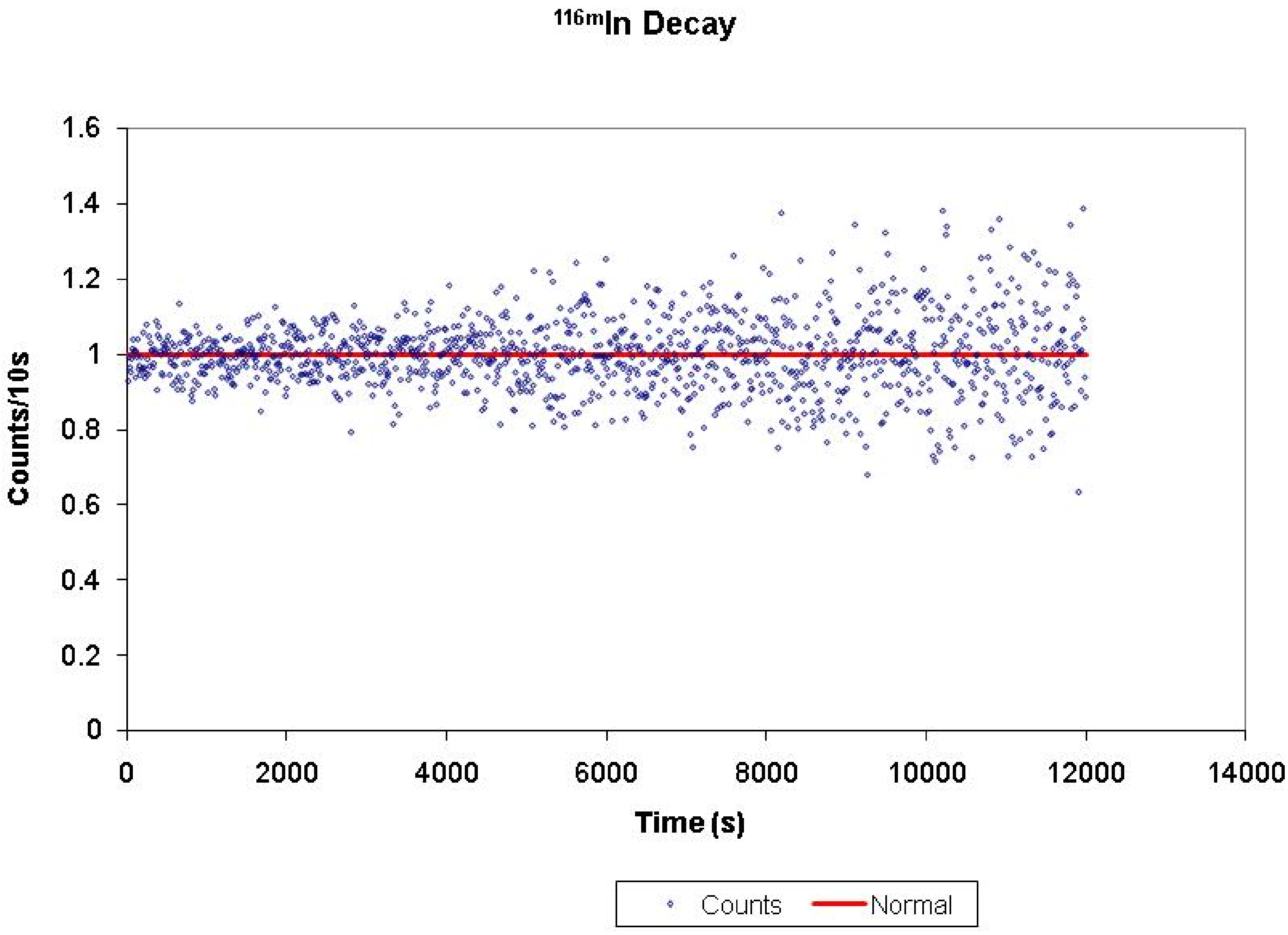

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Brookhaven National Laboratory

Measurement of ^{32}Si Half-life

David Alburger

Garman Harbottle

Eleanor Norton

168

Earth and Planetary Science Letters, 78 (1986) 168–176
Elsevier Science Publishers B.V., Amsterdam – Printed in The Netherlands

[6]

Half-life of ^{32}Si

D.E. Alburger, G. Harbottle and E.F. Norton

Brookhaven National Laboratory, Upton, NY 11973 (U.S.A.)

Received August 15, 1985; revised version received March 3, 1986

Beta rays from a ^{32}Si-^{32}P source, produced in 1968-69 via the $^{30}Si(t,p)^{32}Si$ reaction using a Van de Graaff beam at $E_t = 3.4$ MeV, were counted with an end-window gas-flow proportional counter system including an automatic precision sample changer. Comparison counts were taken on the β rays from a ^{36}Cl source. Measurements beginning February, 1982 were made at approximately 4-week intervals, each consisting of a total of 40 hours of counting on each sample. The decay rate was determined from the $^{32}Si/^{36}Cl$ ratio of counts. Small periodic annual deviations of the data points from an exponential decay curve were observed, but are of uncertain origin and had no significant effect on the result. Based on the analysis of 53 points taken in 48 months, the value $T_{1/2} = 172(4)$ yr is adopted for the half-life of ^{32}Si. This result is substantially greater than two previously reported measurements of 108(18) yr and 101(18) yr but is lower than values based on geophysical evidence.

D.E. Alburger, G. Harbottle, E.F. Norton, Earth and Planetary Science Letters 78 (1986) 168.

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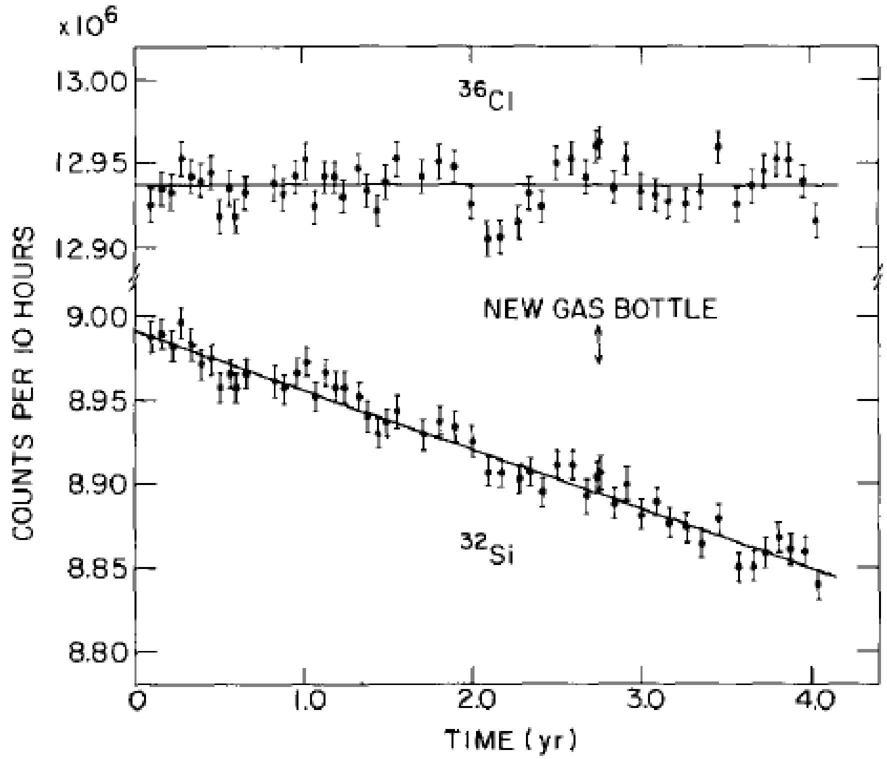

Fig. 3. Lower part, ^{32}Si singles counting rate measured over a period of 48 months; upper part, corresponding ^{36}Cl singles counting rate. Points are counts per 10 hr on each sample, averaged from 4 runs. Error bars are (arbitrarily) three times the statistical uncertainties. The solid curve shown for ^{32}Si is an exponential computer fit, although the ordinate is linear for convenience in plotting. The upper horizontal line is the average of all ^{36}Cl points. The results of the fit to the ^{32}Si data are $T_{1/2} = 173.8$ yr with an uncertainty of 4.8 yr and a standard deviation of 1.7 yr.

D.E. Alburger, G. Harbottle, E.F. Norton, Earth and Planetary Science Letters 78 (1986) 168.

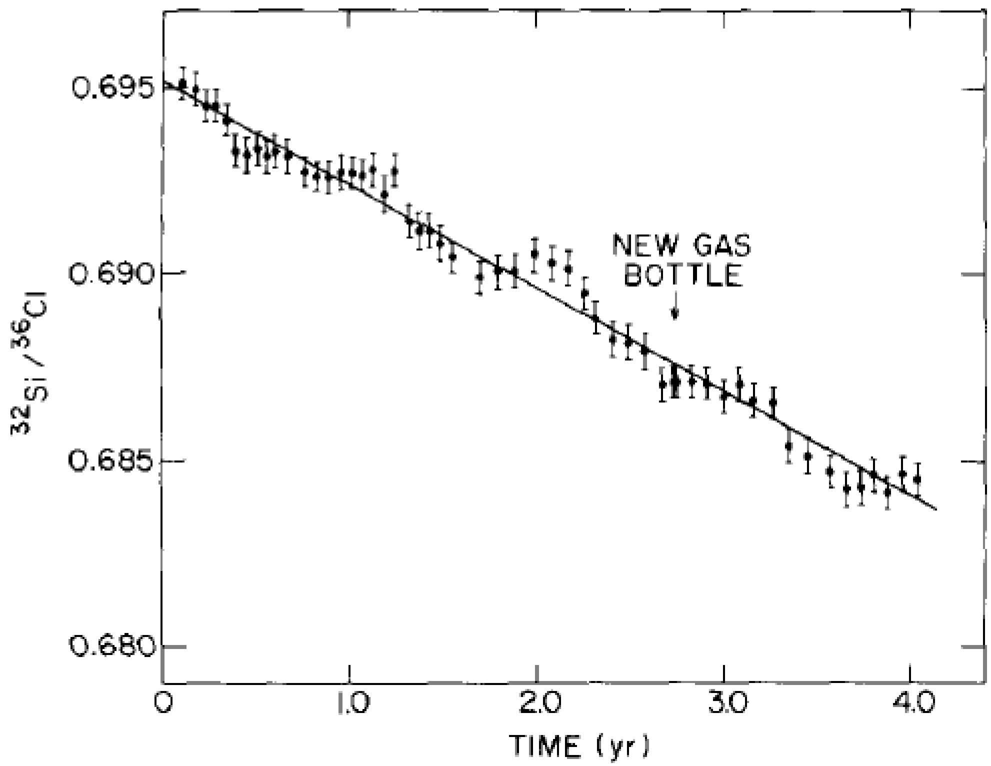

Fig. 2. Ratio of $^{32}Si/^{36}Cl$ counts measured for 53 points over a period of 48 months. Points are averages of 4 runs, each with 10 hr on each sample. Error bars are (arbitrarily) three times the statistical uncertainties and the solid line is an exponential computer fit, although the ordinate is linear for convenience in plotting. The results of the fit are $T_{1/2} = 171.6$ yr with an uncertainty of 3.3 yr and a standard deviation of 3.2 yr.

D.E. Alburger, G. Harbottle, E.F. Norton, Earth and Planetary Science Letters 78 (1986) 168.

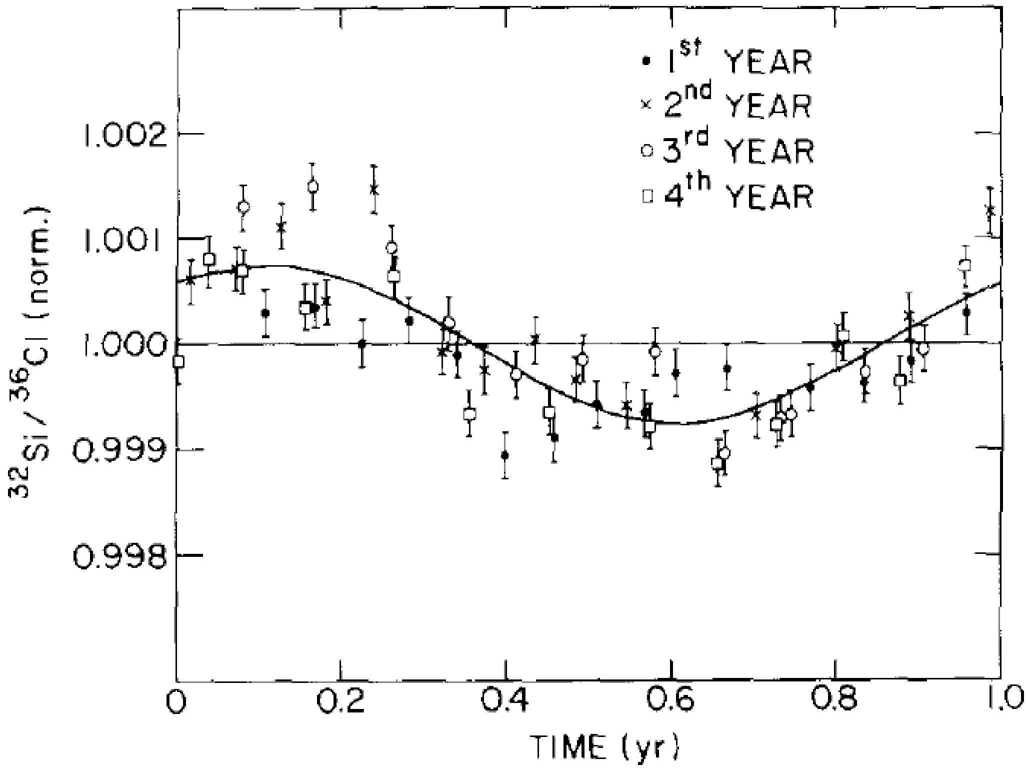

Fig. 4. Points from Fig. 2 corrected for decay using $T_{1/2} = 172$ yr, normalized to 1.000 for the average of all points, and plotted with four 12-month groups superposed. Error bars are statistical uncertainties and $T = 0$ is January 1. A clear annual effect is evident and an arbitrary sine function fit gives an amplitude of 3.4 standard deviations, a maximum on February 9, and a minimum on August 6.

D.E. Alburger, G. Harbottle, E.F. Norton, Earth and Planetary Science Letters 78 (1986) 168.

Physikalisch-Technische Bundesanstalt (PTB)

Europium Half-lives and Long Term Detector Stability

Helmut Siegert
Heinrich Schrader
Ulrich Schötzig

Pergamon

Appl. Radiat. Isot. Vol. 49, No. 9–11, pp. 1397–1401, 1998

0969-8043/98 $19.00 + 0.00

PII: S0969-8043(97)10082-3

Half-life Measurements of Europium Radionuclides and the Long-term Stability of Detectors

HELMUT SIEGERT, HEINRICH SCHRADER* and ULRICH SCHÖTZIG

Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, D-38116 Braunschweig, Germany

H. Siegert, H. Schrader, U. Schoetzig, Applied Radiation and Isotopes 49 (1998) 1397.

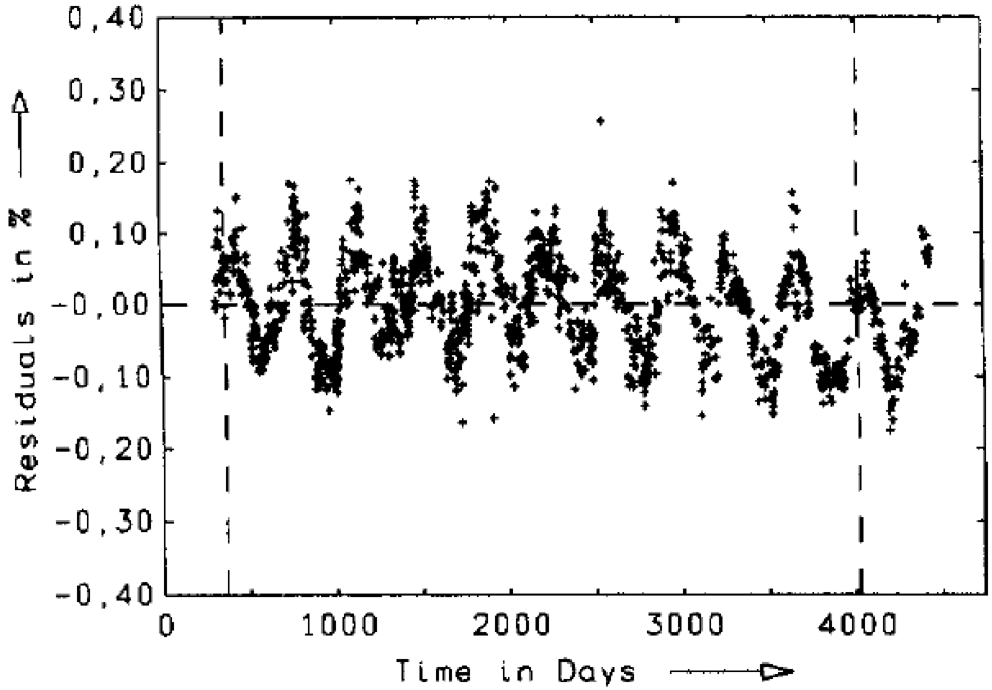

Fig. 1. Residuals of the ionization chamber measurement data of ^{226}Ra as a function of time from a fit with an exponential decay function. A datum point is an average value and contains about 30 individual measurements of current taken over about 3 days and corrected for background. The vertical dotted lines are positioned at 1st January at an interval of 10 years.

H. Siegert, H. Schrader, U. Schötzig, Applied Radiation and Isotopes 49 (1998) 1397.

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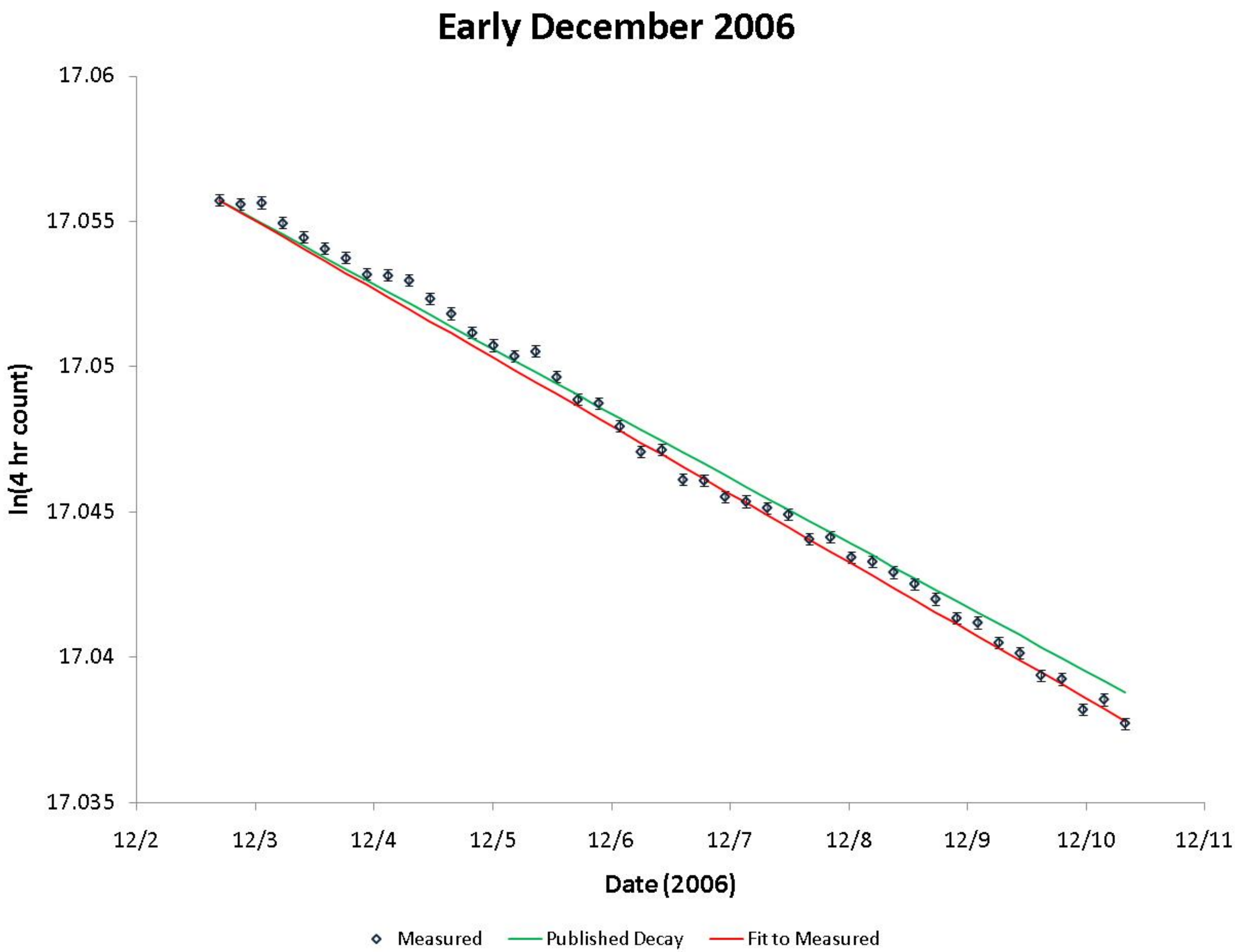

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FOX NEWS.com

Solar Flare Forces Shuttle Astronauts to Seek Shelter From Radiation

Wednesday, December 13, 2006

FOX NEWS

Astronauts scampered to shielded areas of the international space station and space shuttle Discovery Tuesday night to protect themselves from possibly being exposed to high levels of radiation from an unusually large solar flare, NASA said.

Activity aboard Discovery and the space station was interrupted when the solar flare erupted late Tuesday, as two astronauts were finishing the first spacewalk of the current shuttle mission.

Space.com categorized it as an X-3 flare, in the most dangerous category. Such storms are fairly common when the Sun is at its most active, but they are rare during the current low point in the 11-year cycle of solar activity.

• Click here to visit FOXNews.com's Space Center.

NASA spokesman Bill Jeffs told FOXNews.com that crew members slept overnight in "heavily shielded areas" of their respective craft — such as airlocks and the Destiny science lab aboard the space station — as a precautionary measure.

"That move was made to avoid having to wake the crew during their sleep period," NASA spokesman John Ira Petty told Space.com. "It was never a danger to the crew."

FOX NEWS.com

Severe Geomagnetic Storm Expected From Tuesday's Solar Flare

Thursday , December 14, 2006

By Robert Roy Britt

SPACE.com

Space weather forecasters revised their predictions f storminess Wednesday after a major flare erupted o the Sun overnight, threatening damage to communication systems and power grids while offeri up the wonder of the Northern Lights.

"We're looking for very strong, severe geomagnetic storming" to begin probably around mid-day Thursda Joe Kunches, lead forecaster at the NOAA Space Environment Center, told SPACE.com.

The storm is expected to generate aurora or Norther Lights as far south as the northern United States Thursday night.

• Click here to visit FOXNews.com's Space Center.

Astronauts aboard the International Space Station are not expected to be put at additional risk, Kunche said.

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31-May-2008

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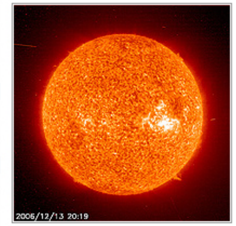


SOHO image of storm on Sun, 13 December 2006

ESA mission controllers react to solar flare

15 December 2006

An energetic storm on the Sun has forced ESA mission controllers to react to anomalies or take action to avoid damage to spacecraft. Several missions, including Integral, Cluster and Envisat, felt the storm's effects, highlighting the need for ESA's ongoing development of space weather forecasting tools.

The joint ESA/NASA spacecraft SOHO (Solar & Heliospheric Observatory) imaged a large solar flare on 13 December that led to an energetic solar radiation storm.

The LASCO (Large Angle and Spectrometric Coronagraph Experiment) instrument on board SOHO detected a powerful coronal mass ejection (CME) generated by the storm; the CME - a stream of fast-moving atomic particles - was directed towards Earth. The flare also generated X-rays.

The ejection arrived at Earth 14 December between 13:00-19:00 CET (12:00-18:00 UTC), where it gave rise to a strong geomagnetic storm; initial edges of the ejection were detected as early as 04:00 CET (03:00 UTC) on 13 December.

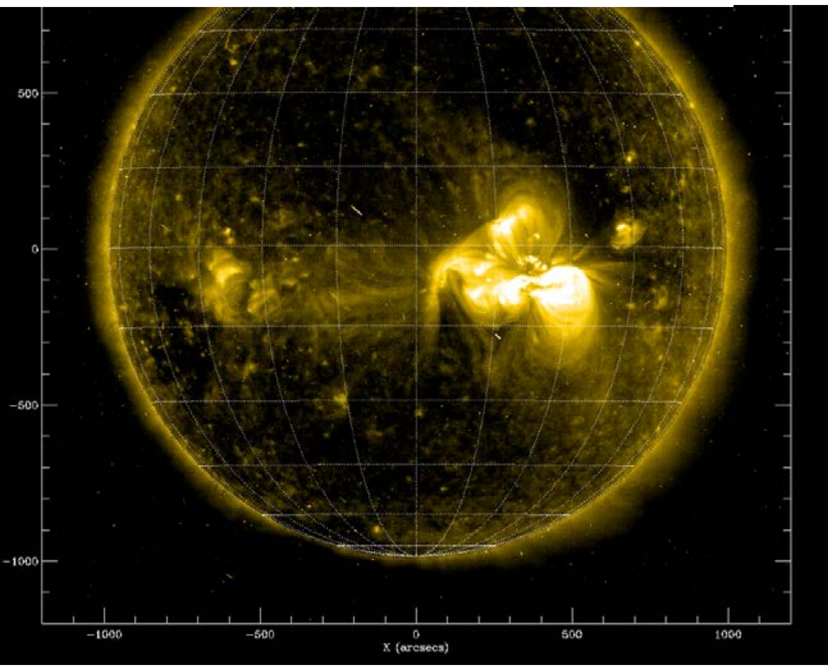
Artist's impression of the SOHO spacecraft

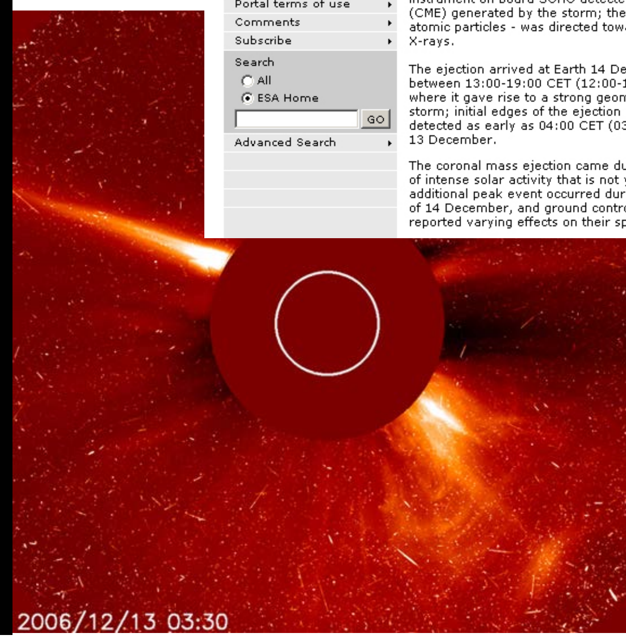
The coronal mass ejection came during a week of intense solar activity that is not yet over. An additional peak event occurred during the night of 14 December, and ground controllers on several ESA missions have reported varying effects on their spacecraft.

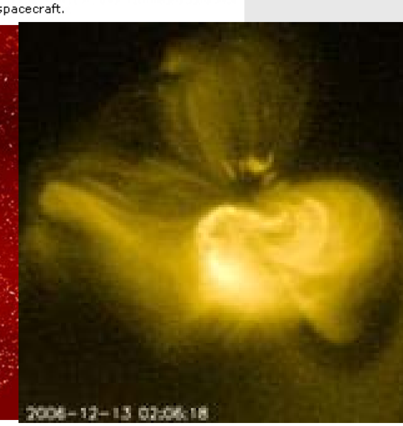
Spacecraft Operations

More news
- NOAA tracking space weather event
- See Mercury's silhouette with SOHO
- European expertise helps to view the Sun in a new way

Related links
- SOHO and space weather
- ESA Space Weather
- Coronal Mass Ejections
- Envisat overview
- Cluster overview
- Integral
- SEISOP Fact Sheet (PDF)







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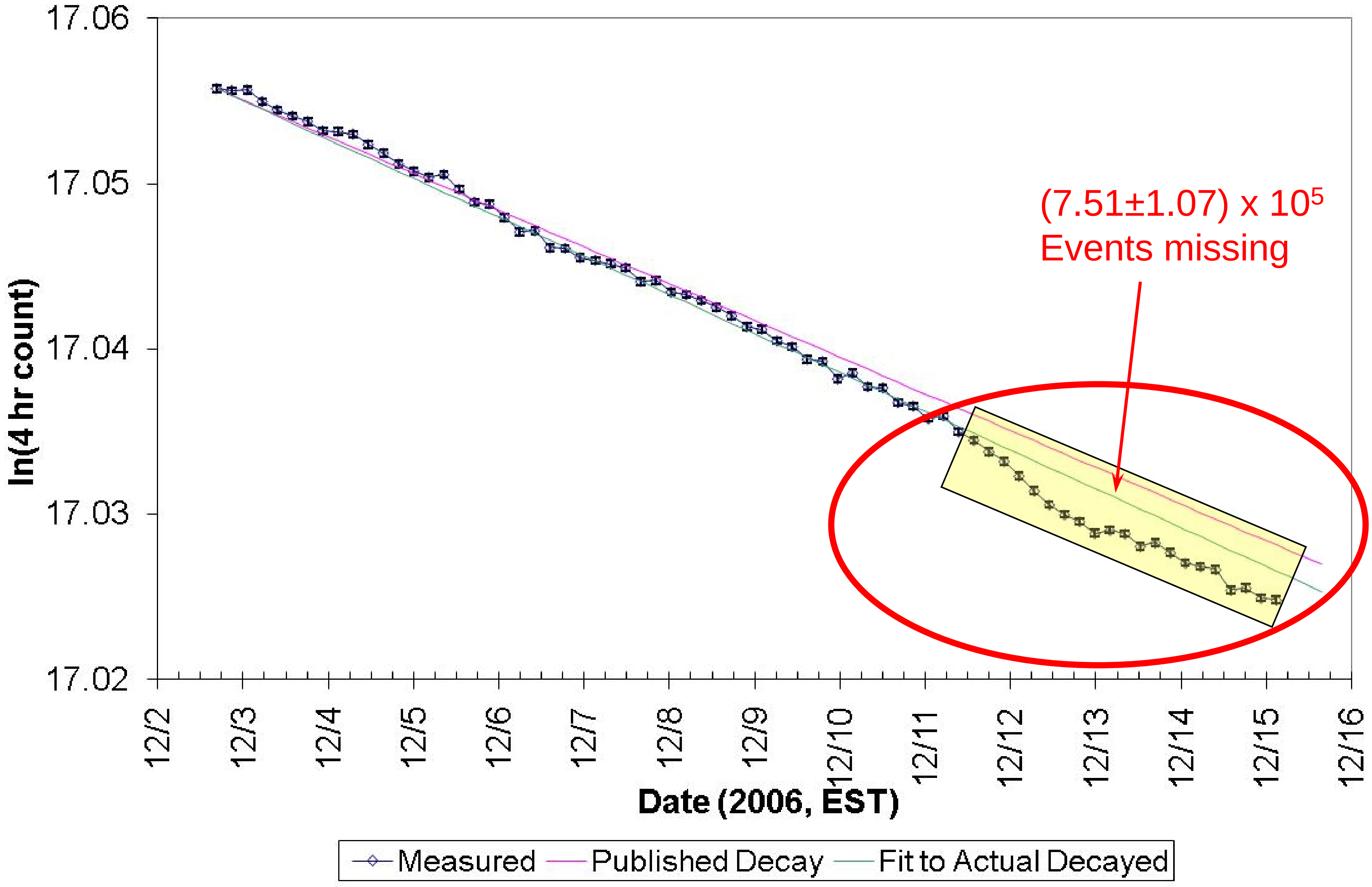
Mn-54 4 Hr Counts, Published, Fit and Actual Data



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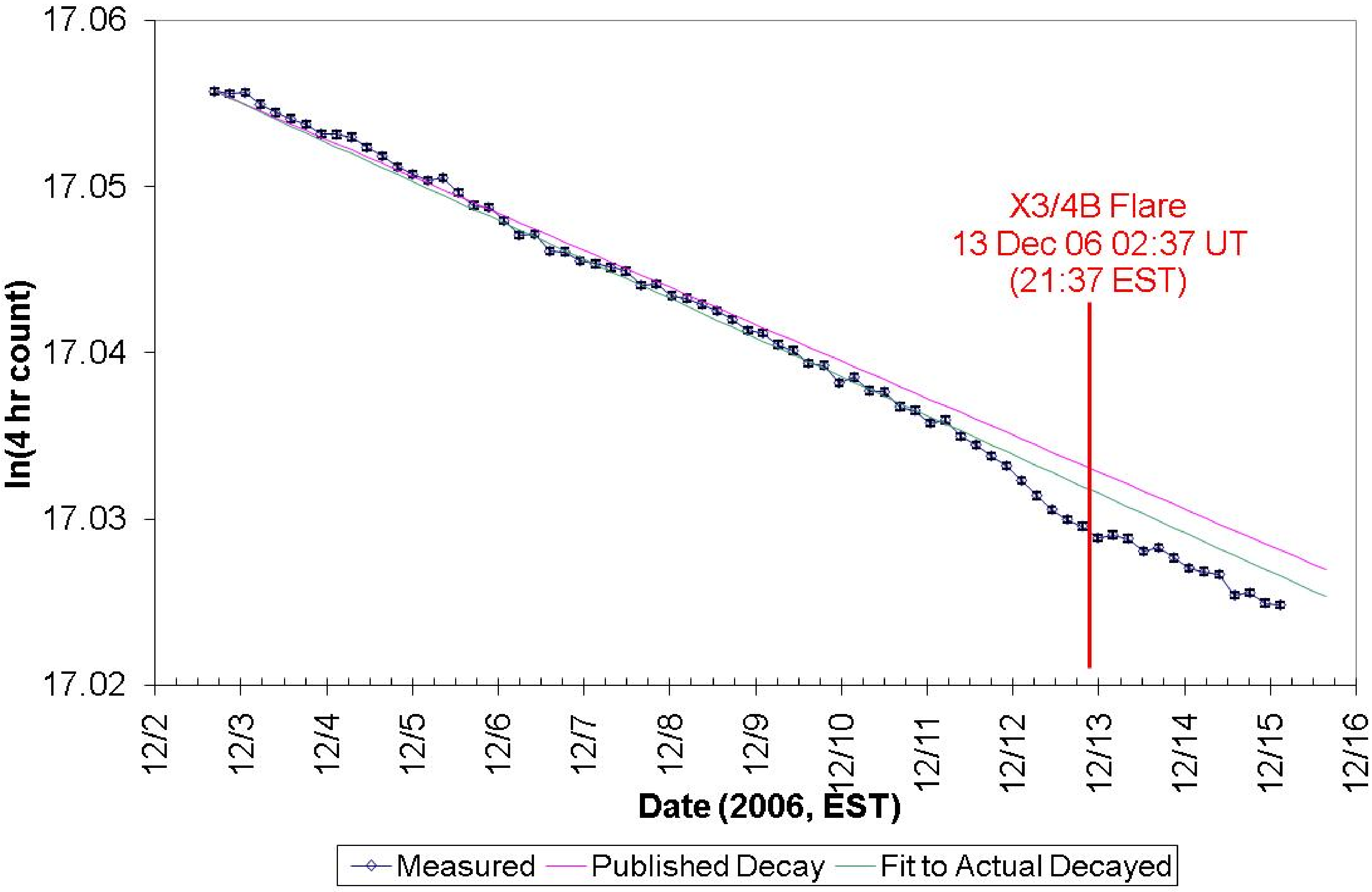
Mn-54 4 Hr Counts, Published, Fit and Actual Data



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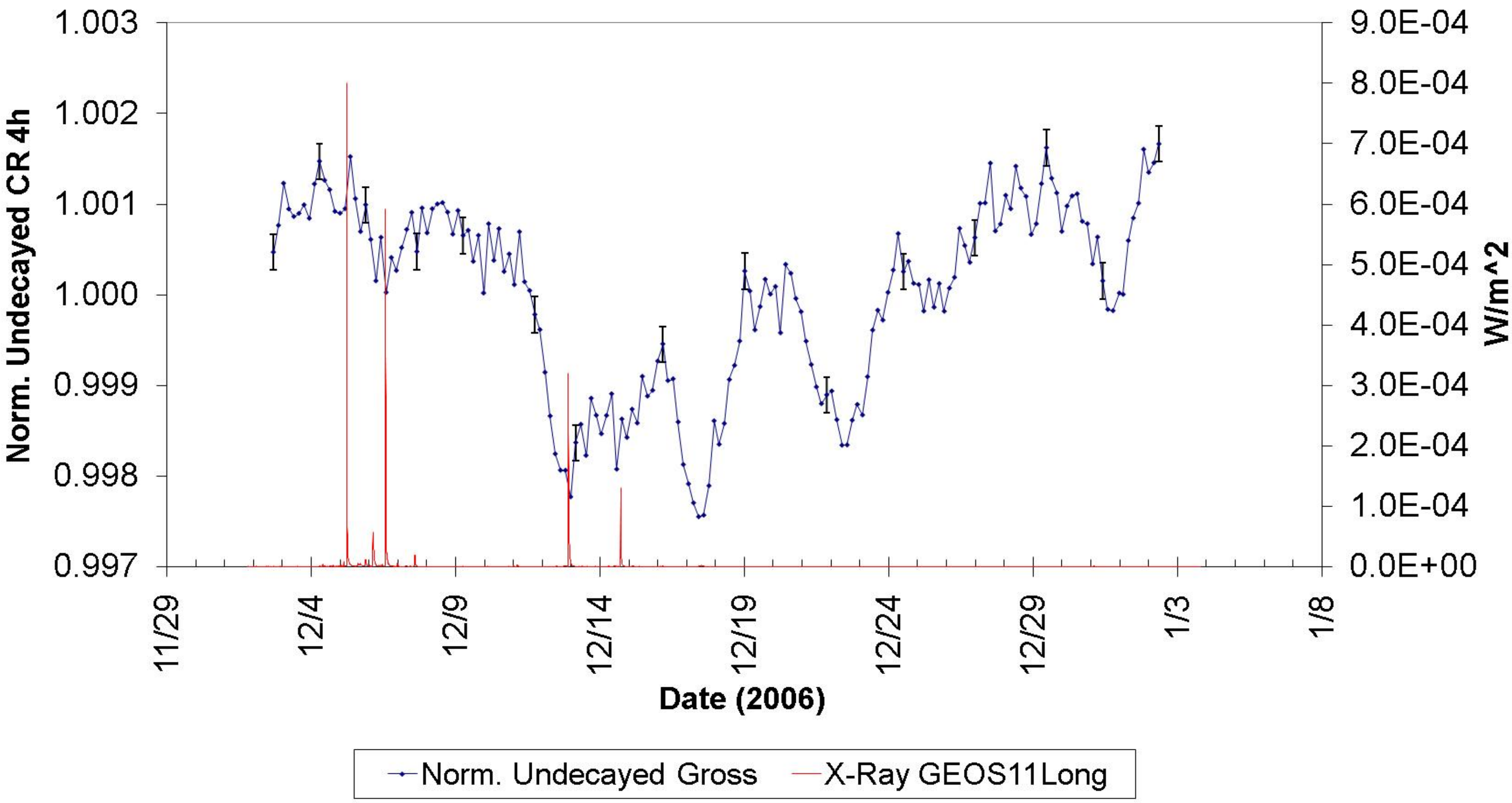
Physics 167 Mn-54 Consecutive 4 hr Counts Normalized with Linear GEOS11 x-ray Data



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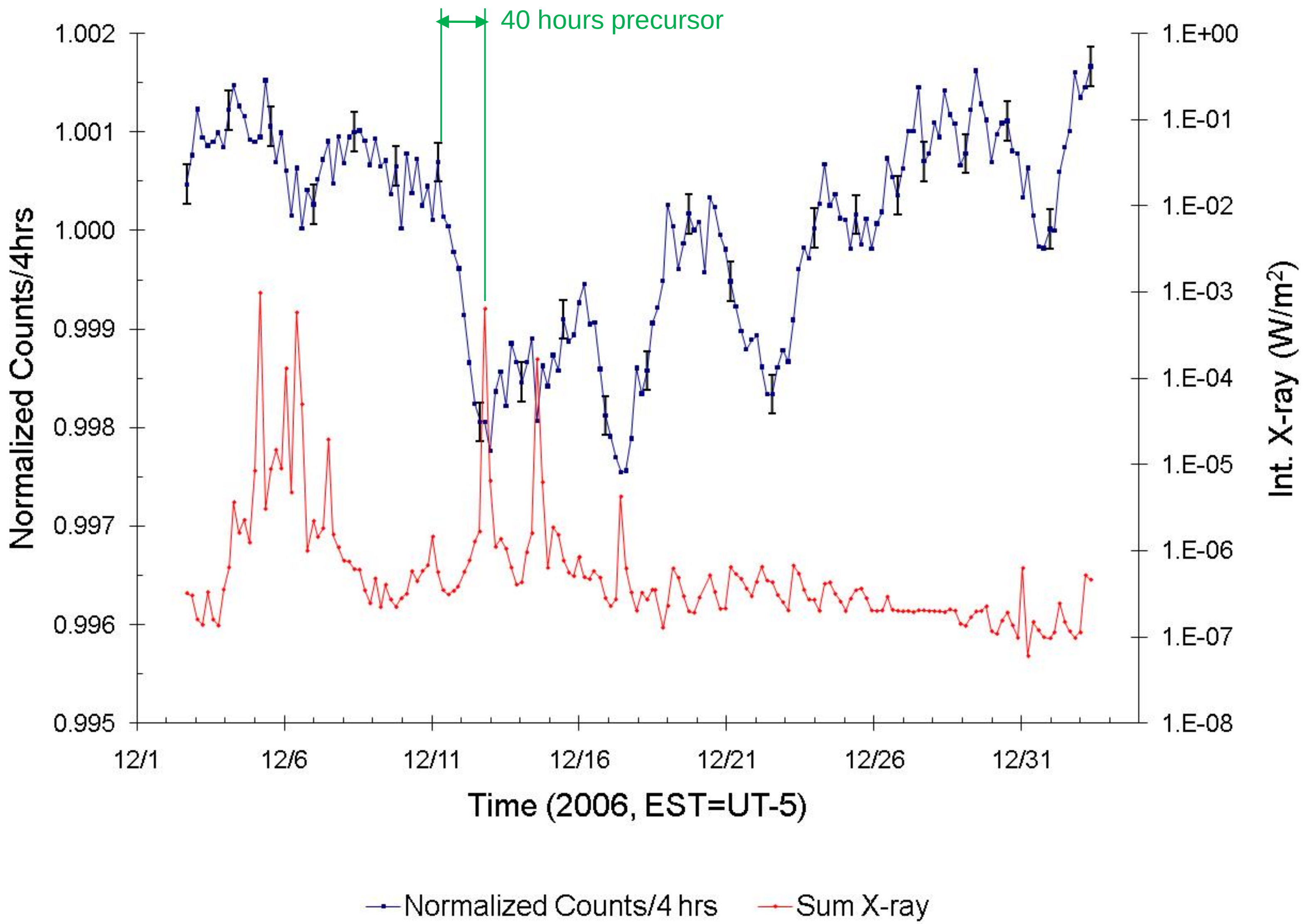
December ^{54}Mn Decay Data with Integral GOES-11 X-rays



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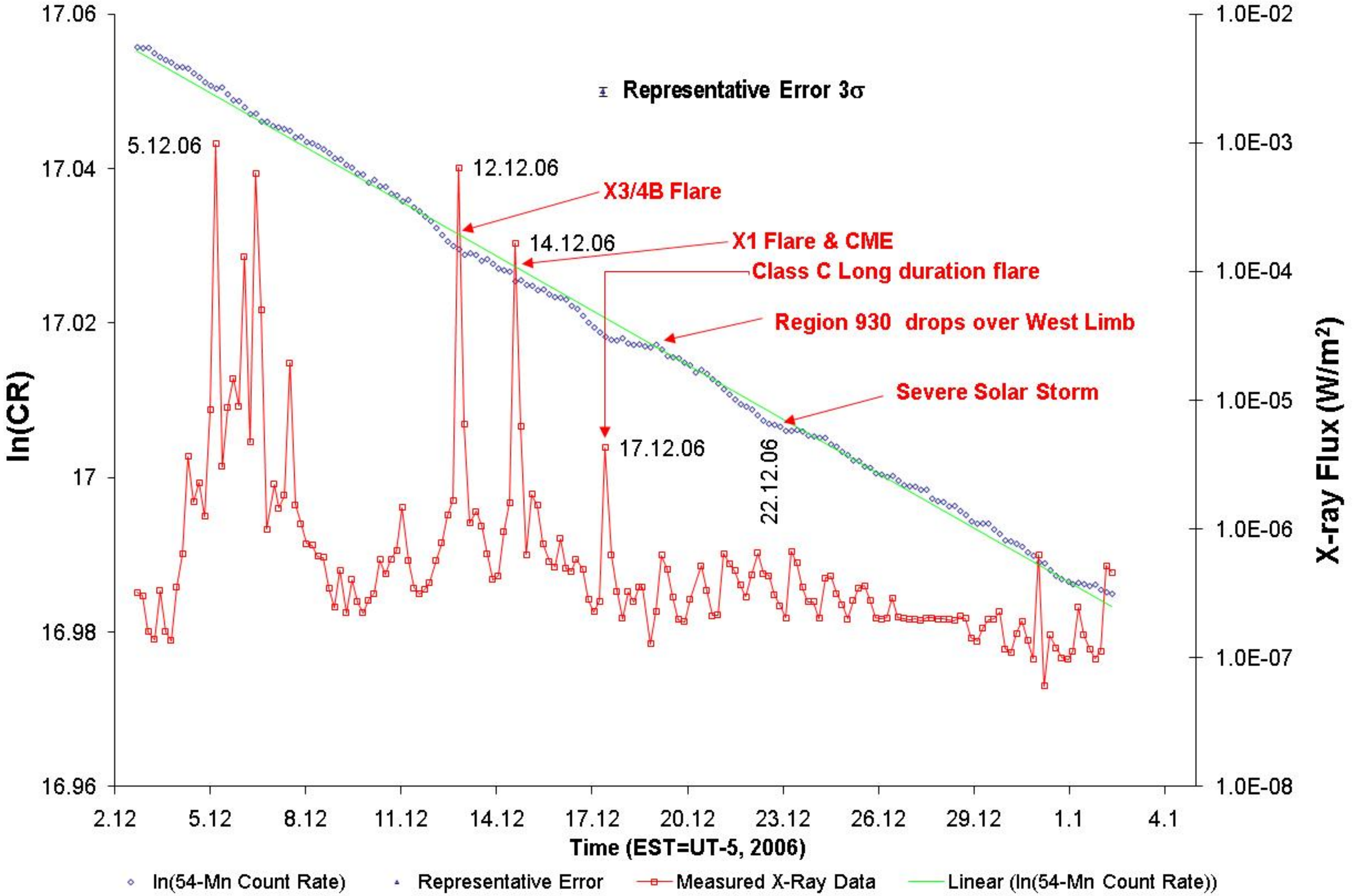
Logarithmic Decay of ^{54}Mn with Integral X-ray Flux



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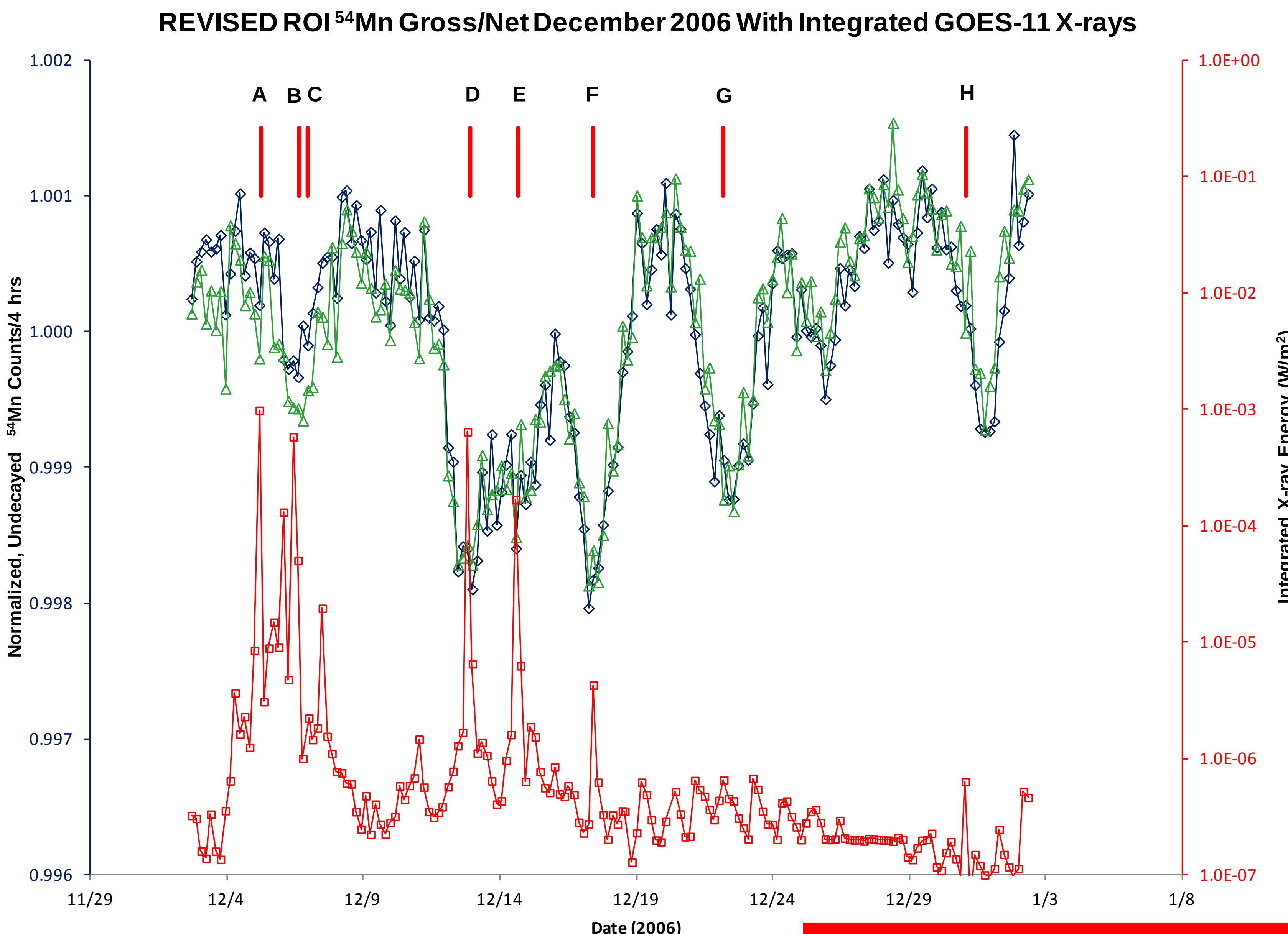

For the letter key, see following page.

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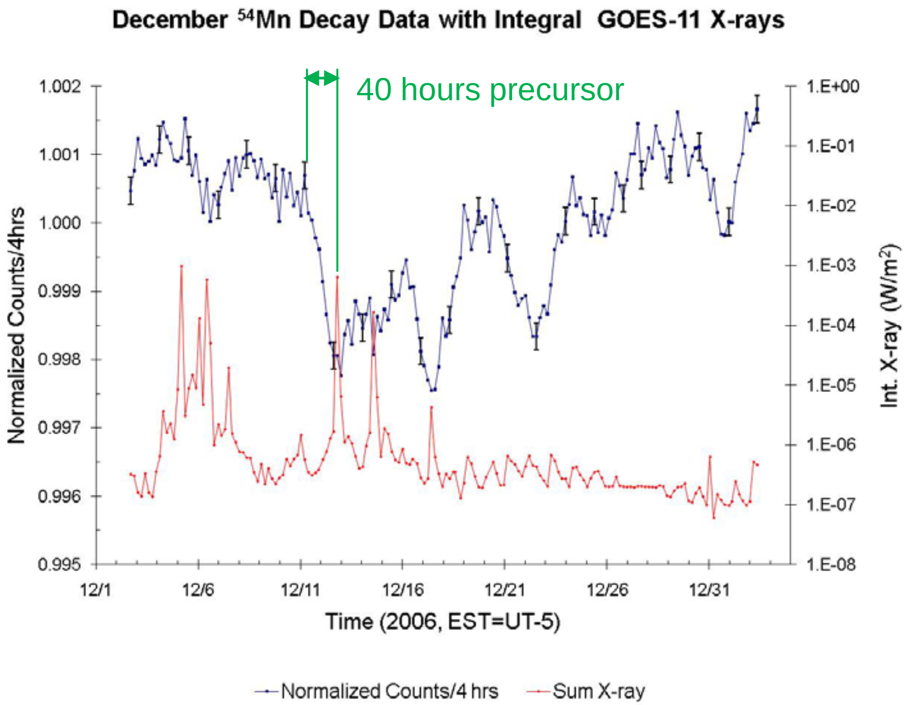
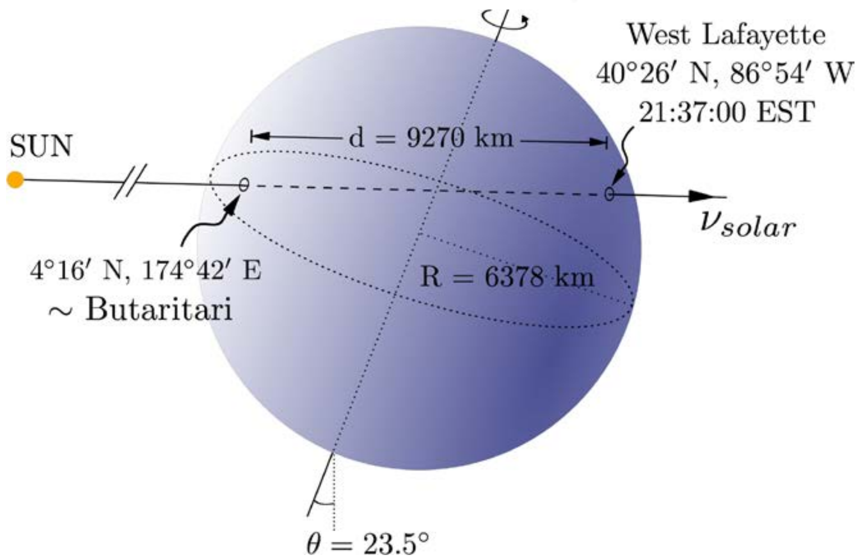
December 2006

Tag	EName	Start	Stop	Peak	GOES Class	Derived Position (SXI-GOES12 or EIT High Cadence Wavelength)
	gev_20061205_0745	2006/12/05 07:45:00	08:06:00	08:03:00	M1.8	S05E71 (930)
	gev_20061205_0907	2006/12/05 09:07:00	09:14:00	09:11:00	C1.5	S06E71 (930)
A	gev_20061205_1018	2006/12/05 10:18:00	10:45:00	10:35:00	X9.0	S06E59 (930)
	gev_20061206_0130	2006/12/06 01:30:00	03:15:00	02:20:00	M1.3	S06E67 (930)
	gev_20061206_0802	2006/12/06 08:02:00	09:03:00	08:23:00	M6.0	S02E65 (930)
B	gev_20061206_1829	2006/12/06 18:29:00	19:00:00	18:47:00	X6.5	S05E57 (930)
C	gev_20061206_2014	2006/12/06 20:14:00	20:22:00	20:19:00	M3.5	S03E55 (930)
	gev_20061207_0427	2006/12/07 04:27:00	05:20:00	04:45:00	C6.1	S05E51 (930)
D	gev_20061213_0214	2006/12/13 02:14:00	02:57:00	02:40:00	X3.4	S07W22 (930)
	gev_20061214_1636	2006/12/14 16:36:00	16:59:00	16:49:00	C1.2	S08W39 (930)
E	gev_20061214_2107	2006/12/14 21:07:00	22:26:00	22:15:00	X1.5	S06W46 (930)
F	gev_20061217_1447	2006/12/17 14:47:00	18:37:00	17:09:00	C2.1	S07W89 (930)
	gev_20061222_0345	2006/12/22 03:45:00	03:59:00	03:51:00	A2.2	S09E89
G	gev_20061222_0449	2006/12/22 04:49:00	05:19:00	04:56:00	A5.7	N13E16
H	gev_20061231_0706	2006/12/31 07:06:00	07:39:00	07:17:00	C1.3	S01E75 (933)

- Flare intensity denoted by letter class, A, B, C, M, X (least to greatest).
- Letter tags denote markers in plot on previous page.





Why neutrinos?

- Minimum in relative count rate occurred at night, coincident with the timing of the flare (21:37 EST)
- Measured decay rate was trending down for ~40 hours (1.67 Earth rotations).
- This implies that the probable agent could pass through the Earth unimpeded. The only known particle emitted by the Sun that can do that is the neutrino.

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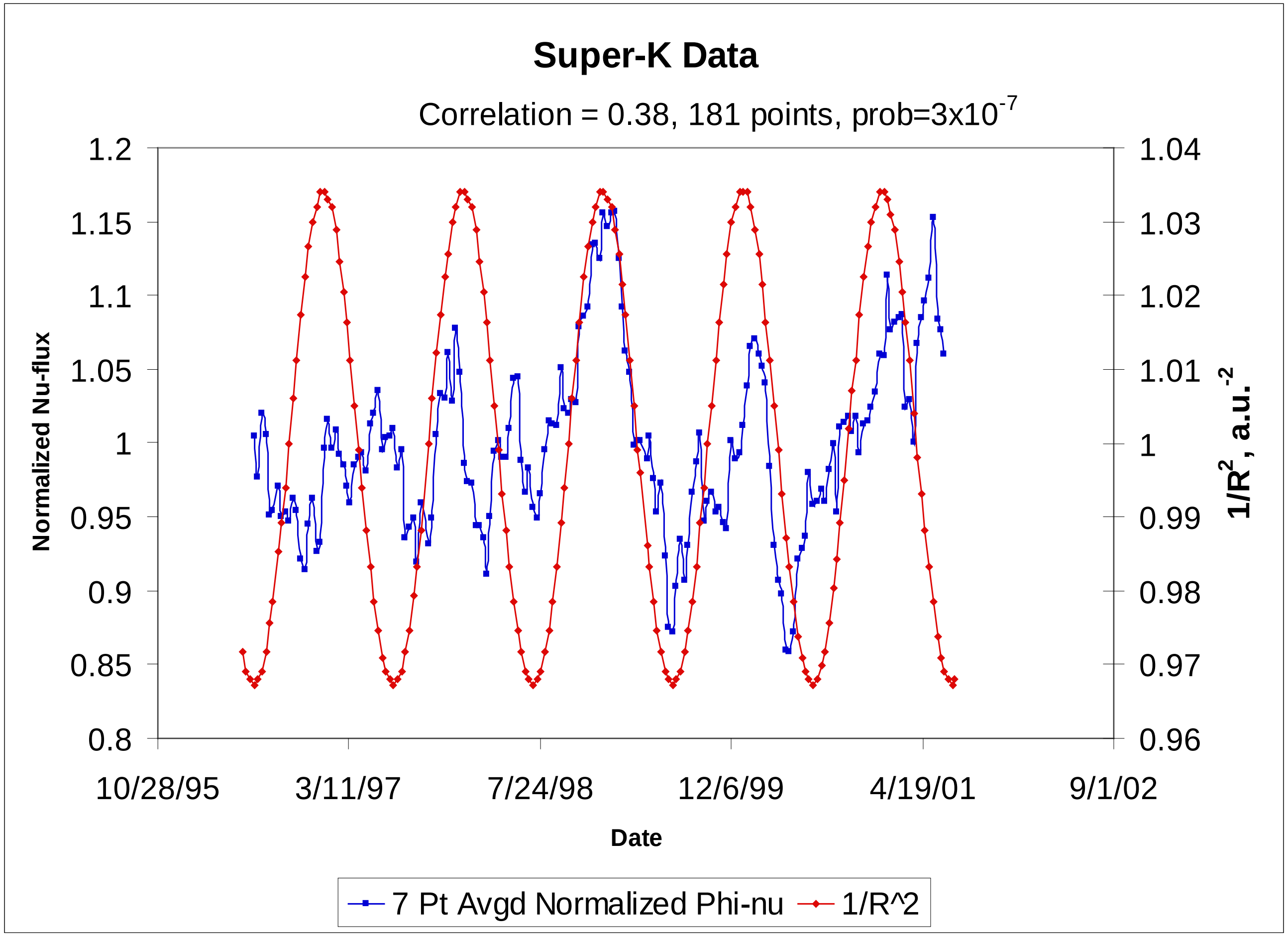
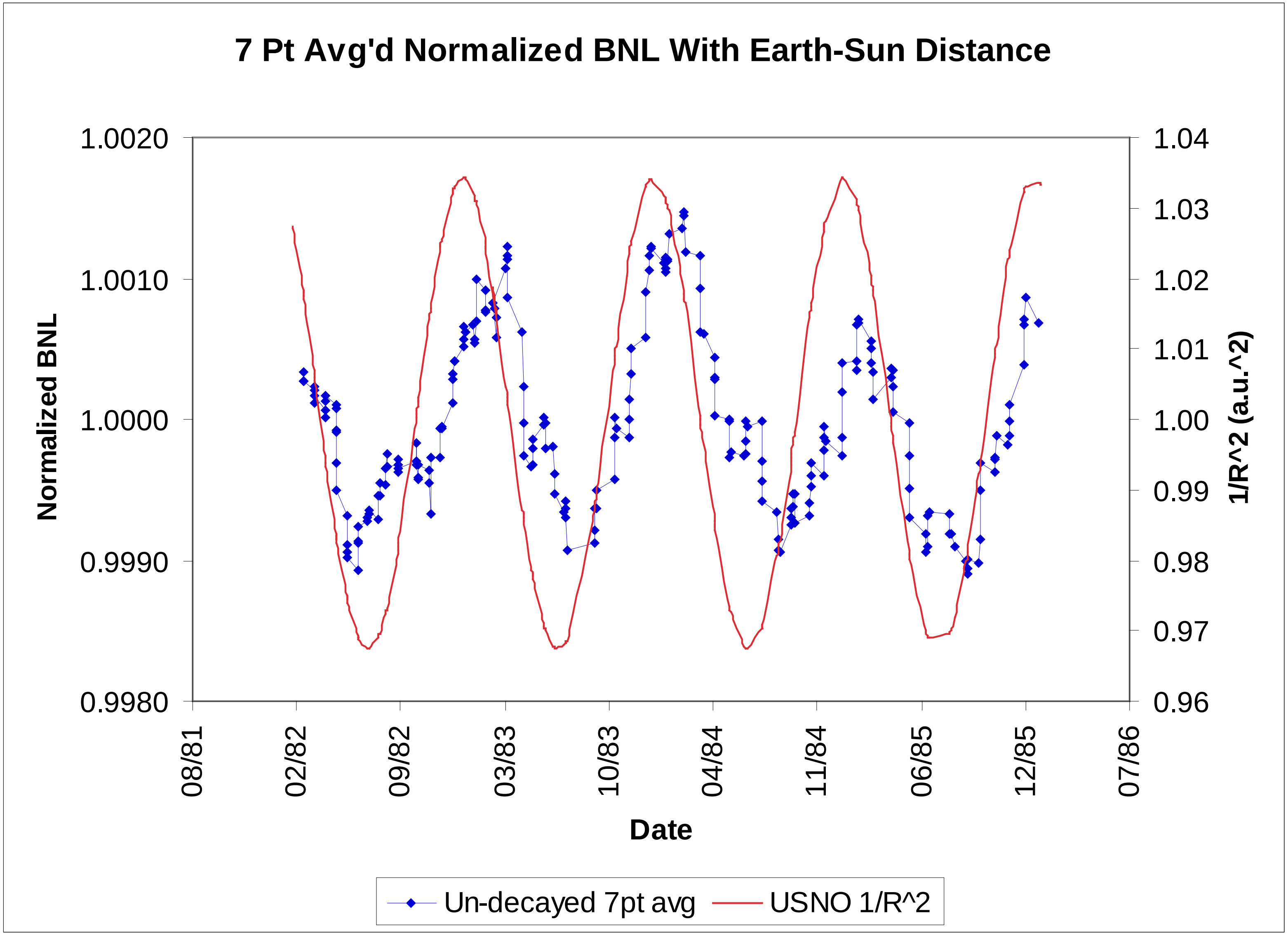
Solar Neutrinos?



Data from Yoo, et al., Phys Rev D **68**, 092002 (2003)



Pearson Correlation Coefficient *r*=0.66, *N*=233, Prob=1.0x10^{-31}

Data from: Alburger, et al., Earth and Planet. Sci. Lett., **78**, (1986) 168-176

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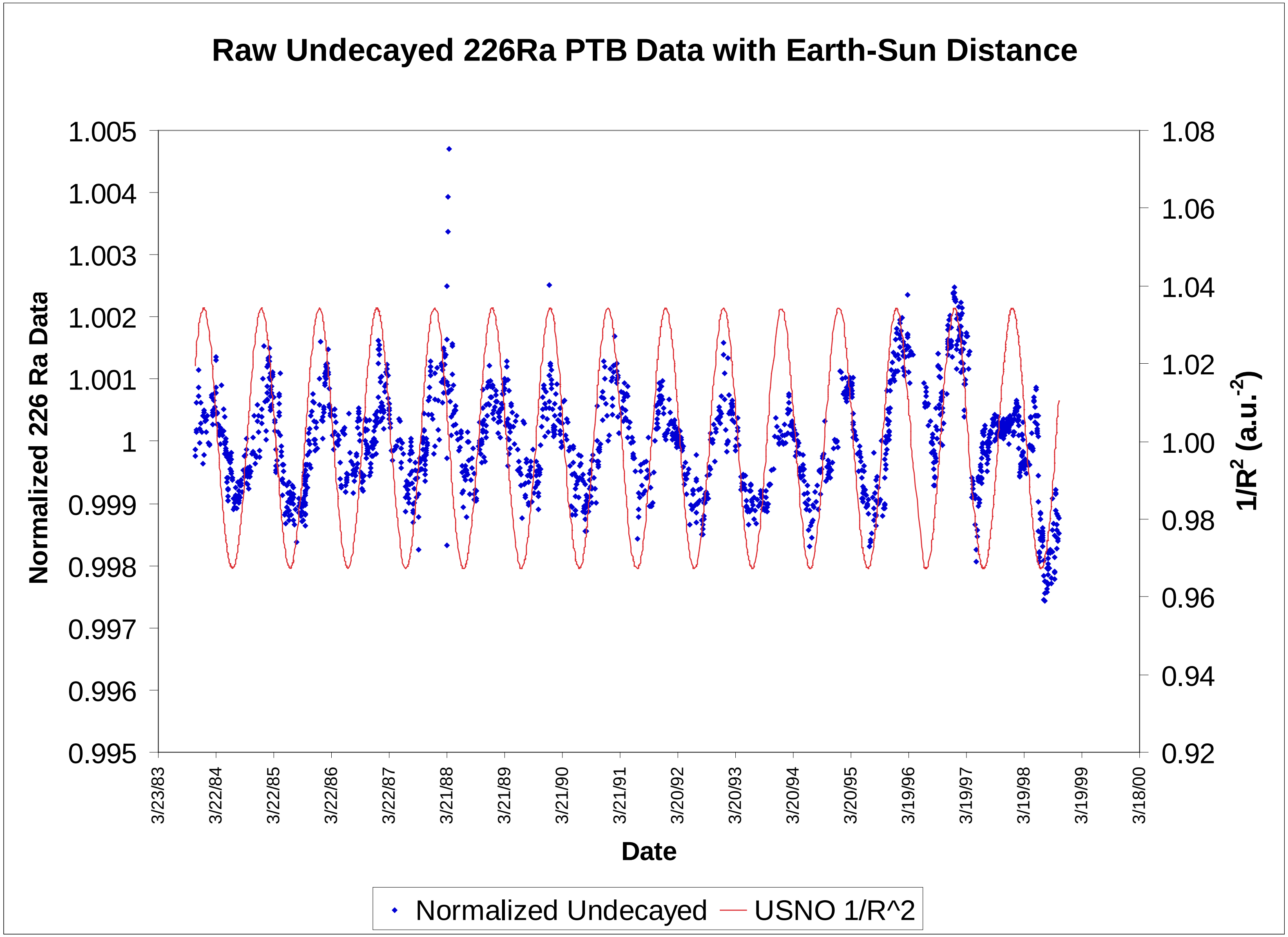

Pearson Correlation Coefficient *r*=0.62, *N*=1974, Prob=5.13x10^{-210}

Data from Siegert, et al., Appl. Radiat. Isot. **49**, 1397 (1998) Fig. 1

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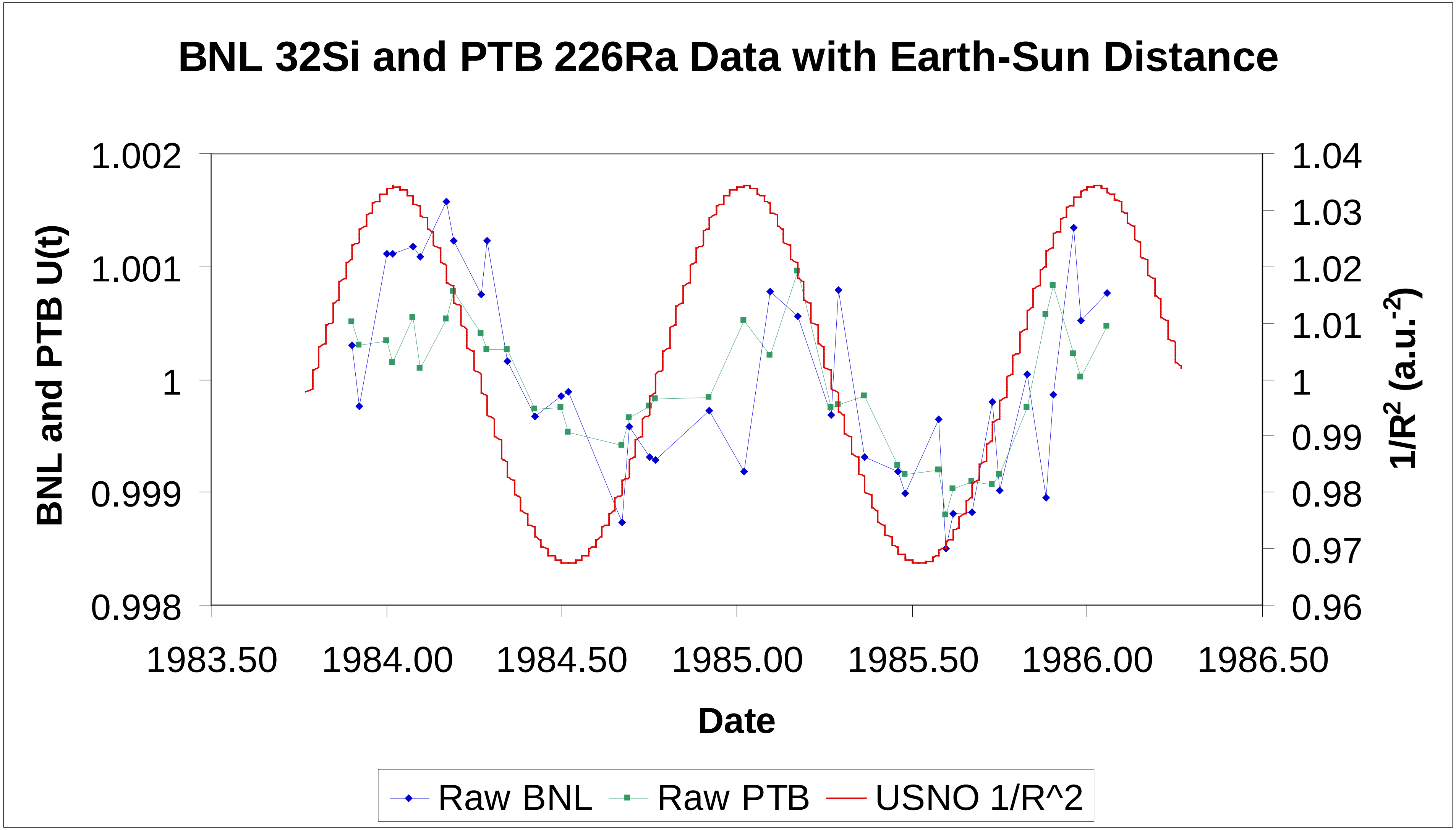

Pearson Correlation Coefficient r=0.66, N=39, Prob=5.8×10^{-6}

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Tritium

$$\frac{\dot{N}(t)}{\dot{N}(0)} - 1$$

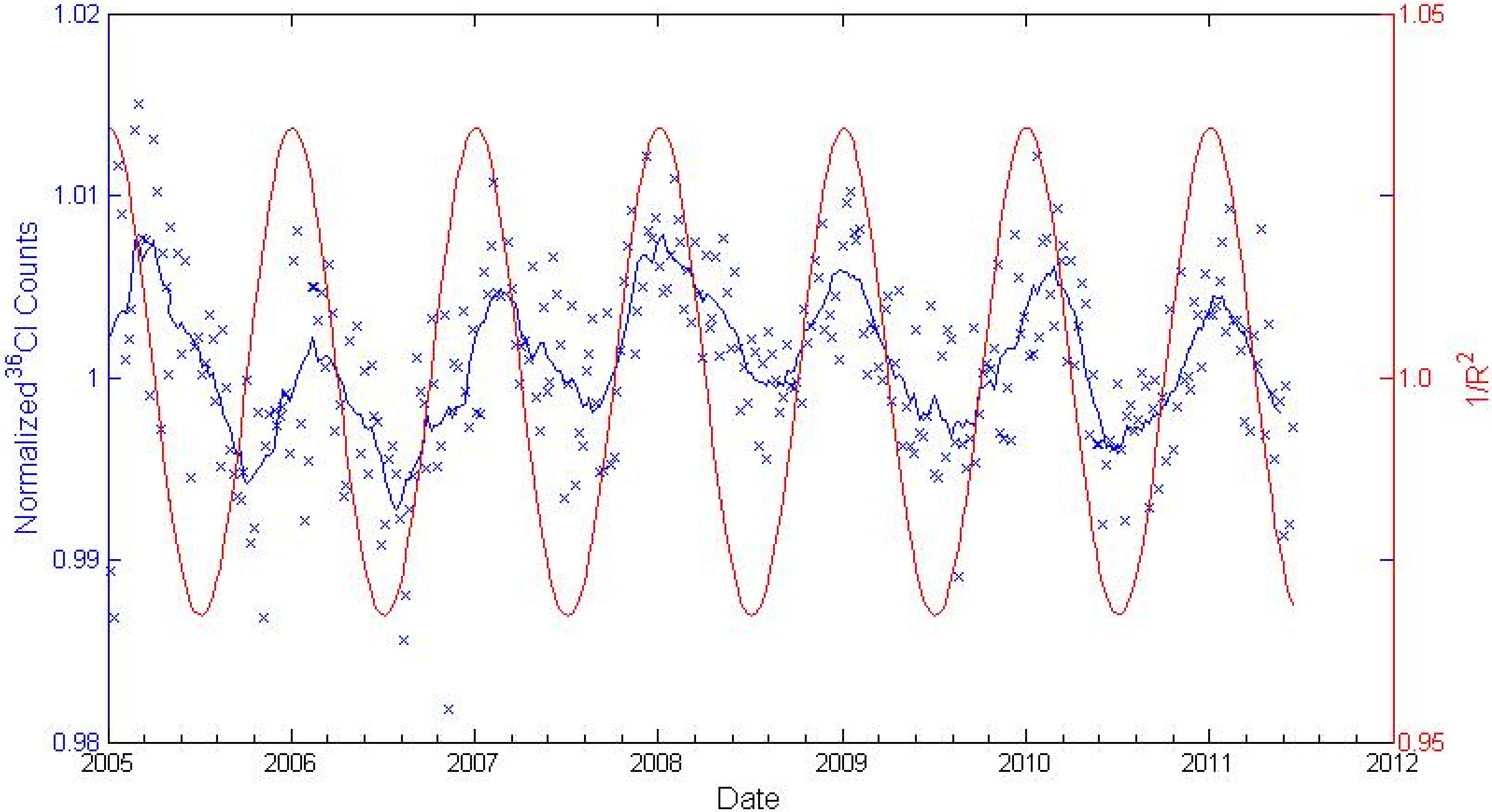
t (days)

t = 0 = 1 Jan. 1980

$$\text{Amplitude}(t) = (0.37\%)\cos\left(\frac{2\pi t}{1\text{ year}} - \phi\right) \qquad \phi \sim \text{ Feb. 15}$$

Reference: E. D. Falkenberg, Apeiron **8** (2), 32 (2001)

OSURR Cl-36



1.02
1.01
1
0.99
0.98
Normalized ^{36}Cl Counts
1.05
1.0
0.95
$1/R^2$
2005
2006
2007
2008
2009
2010
2011
2012
Date

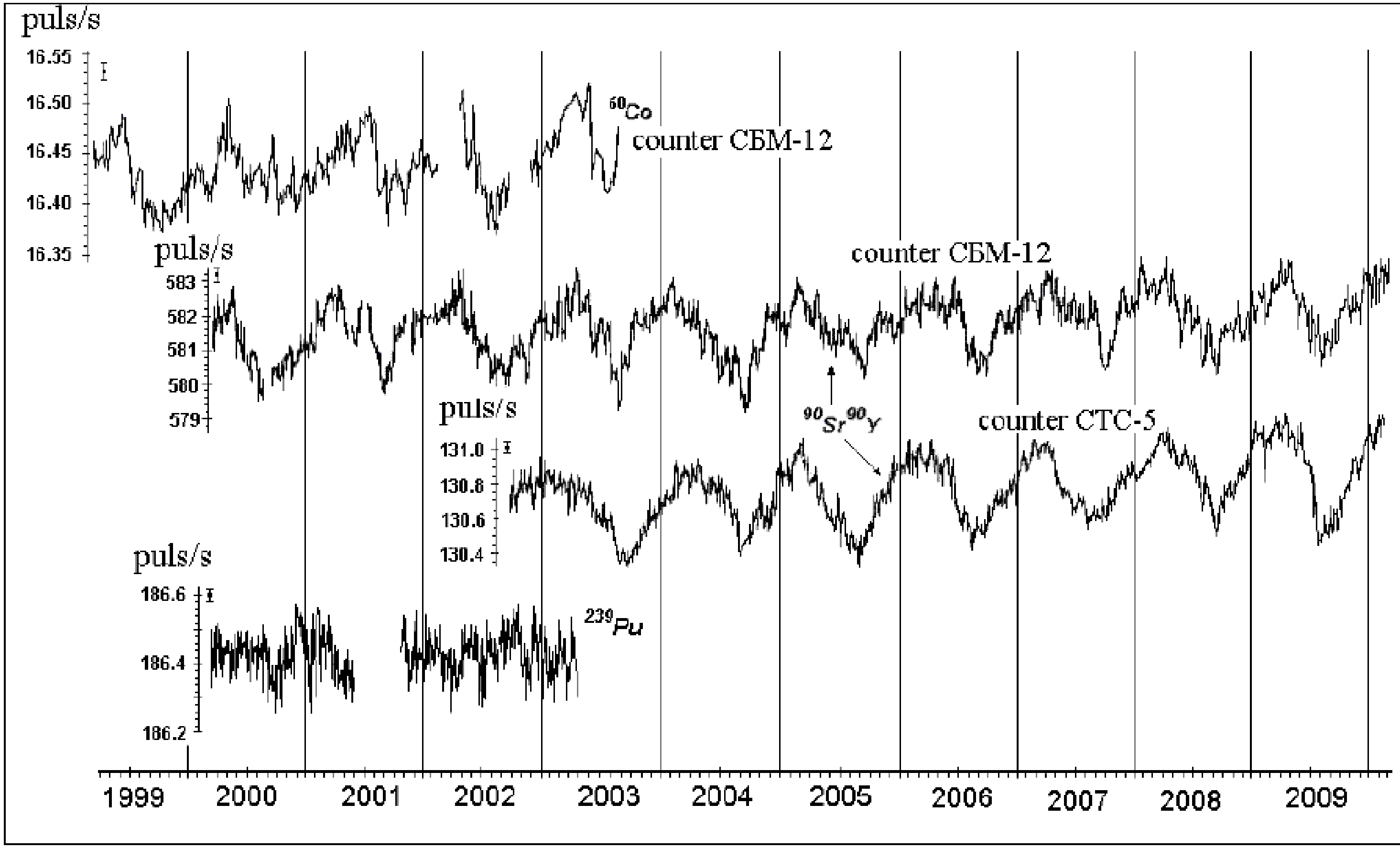


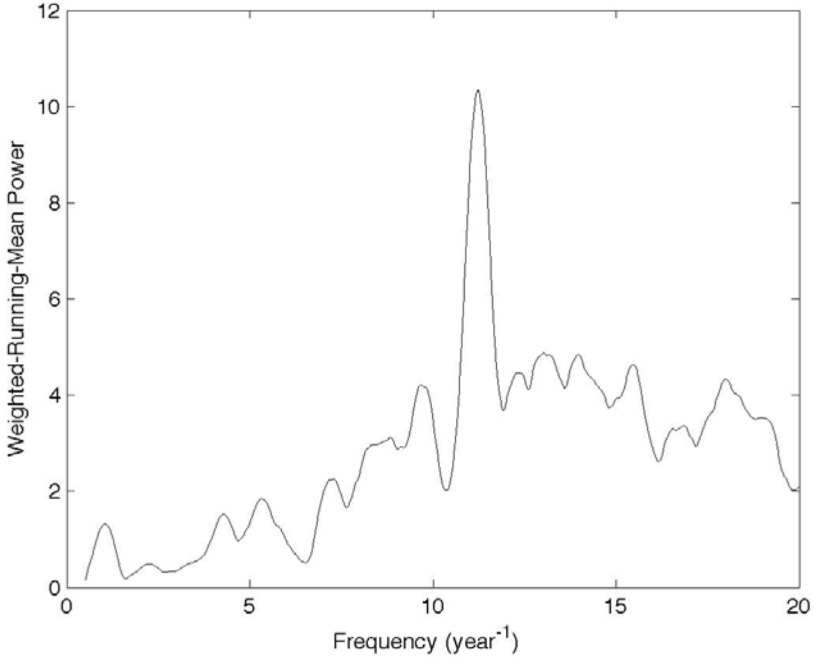
Fig. 1. Count rate of the ^{60}Co and ^{90}Sr-^{90}Y β sources, measured by G-M counters, adjusted for a drop of activity with half-lifes 5,27 and 28,6 years, and count rate of the ^{239}Pu α source, measured by the silicon detector [3, 5].

Parkhomov, A.G., Researches of alpha and beta radioactivity at long-term observations, arXiv:1004.1761v1 [physics.gen-ph], (2010)

Further Evidence

Sub-annual periodicities

BNL/PTB Solar Core Period



- The joint power spectrum formed from the weighted-running-mean BNL and PTB power spectra.
- The peak is found at 11.23 year^{-1} with J=10.34.

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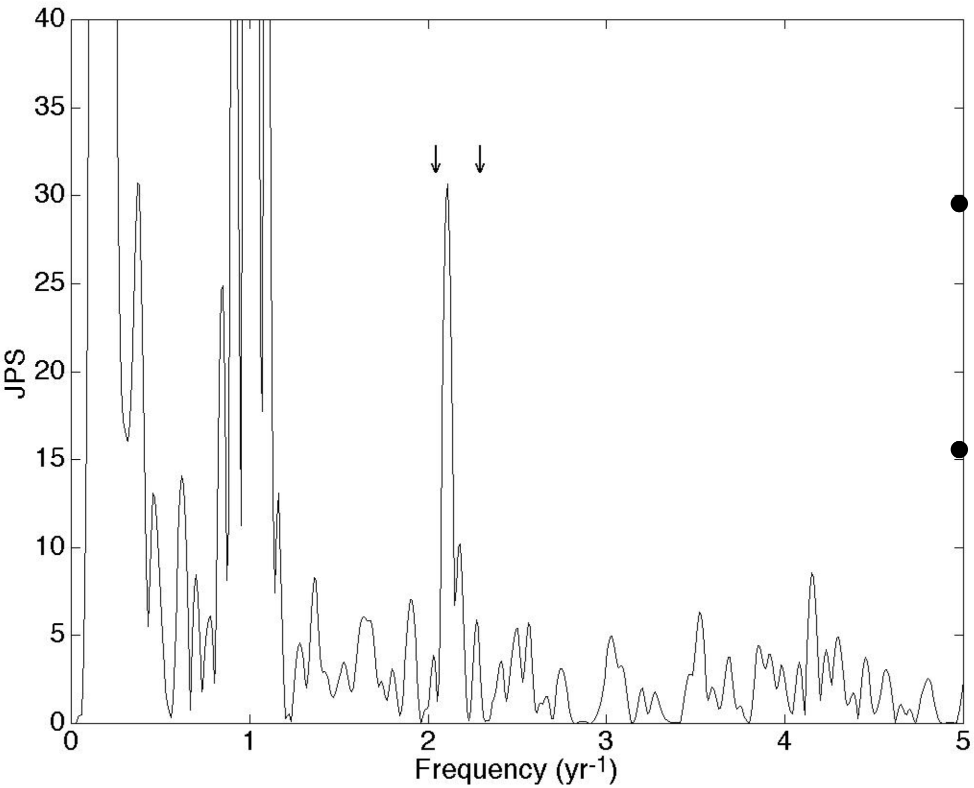
Joint Power Statistic (Rieger)



- The joint power statistic using the BNL and PTB power spectra.
- The arrows indicate the search band 2.00 yr^{-1} to 2.25 yr^{-1}.
- The peak is found at **2.11 yr^{-1}** with joint power statistic **J = 30.65**.

Table 1 Some experiments where time-dependent decay rates have been observed.

Isotope	Decay Type	Detector Type	Radiation Measured	1 yr^{-1}	2.11 yr^{-1}	11-13 yr^{-1}	365 yr^{-1}	Other
^{3}H	β^-	Photodiodes	β^-	X				
^{3}H	β^-	Liq. Scint.	β^-	X		X	X	
^{3}H	β^-	Liq. Scint.	β^-			X		
^{3}H	β^-	Sol. St. (Si)	β^-		X			
$^{22}Na/^{44}Ti$	β^+, κ	Sol. St. (Ge)	γ	X				
^{36}Cl	β^-	Prop. (gas)	β^-	X	X	X		
^{36}Cl	β^-	G-M (gas)	β^-	X				
^{54}Mn	κ	Scint.	γ					X
^{54}Mn	κ	Scint.	γ	X				
^{56}Mn	β^-	Scint.	γ	X				
^{60}Co	β^-	G-M (gas)	β^-, γ	X				
^{60}Co	β^-	Scint.	γ			X	X	
^{85}Kr	β^-	IC (gas)	γ	X				
$^{90}Sr/^{90}Y$	β^-	G-M (gas)	β^-	X		X		
^{108m}Ag	κ	I-C (gas)	γ	X				
^{133}Ba	β^-	I-C (gas)	γ	X				
^{137}Cs	β^-	Scint.	γ			X	X	
^{152}Eu	β^-, κ	Sol. St. (Ge)	γ	X				
^{152}Eu	β^-, κ	I-C (gas)	γ	X				
^{154}Eu	β^-, κ	I-C (gas)	γ	X				
^{222}Rn	α, β^-	Scint.	γ	X	X	X		
^{226}Ra	α, β^-	I-C (gas)	γ	X	X	X		
^{239}Pu	β^-	Sol. St. (Si)	α	X		X	X	

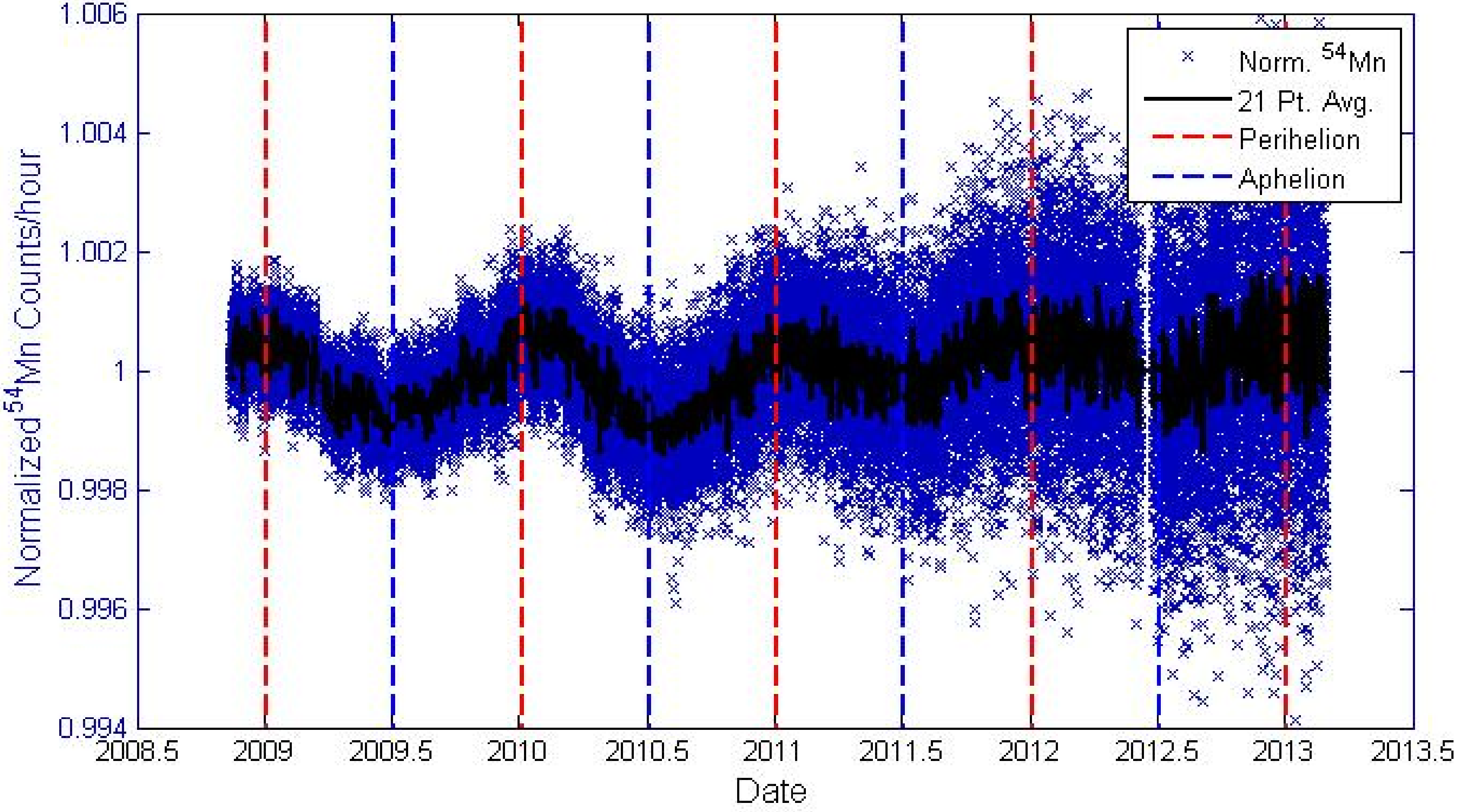
From: Jenkins, J.H., et al., Concerning the Time Dependence of the Decay Rate of 137Cs. Physics Letters B, 2012(Under Review).

Table 1
Experiments where time-dependent decay rates have been observed.

Isotope	Decay type	Detector type	Radiation measured	Effect observed	Reference
^{3}H	β^-	Photodiodes	β^-	Periodicity: 1 yr^{-1}	Falkenberg (2001)
^{3}H	β^-	Liquid scintillator	β^-	Periodicity: 1/d, 12.1 yr^{-1}, 1 yr^{-1}	Shnoll et al. (1998)
^{3}H	β^-	Liquid scintillator	β^-	Periodicity: ~12.5 yr^{-1}	Veprev and Muromtsev (2012)
^{3}H	β^-	Solid state (Si)	β^-	Periodicity: ~2 yr^{-1}	Lobashev et al. (1999)
$^{22}Na/^{44}Ti$[a]	β^+,κ	Solid state (Ge)	γ	Periodicity: 1 yr^{-1}	O'Keefe (in preparation)
^{36}Cl	β^-	Proportional	β^-	Periodicity: 1 yr^{-1}, 11.7 yr^{-1}, 2.1 yr^{-1}	Jenkins et al. (2009) and Sturrock et al. (2010a, 2011a)
^{36}Cl	β^-	Geiger–Müller	β^-	Periodicity: 1 yr^{-1}	Jenkins et al. (2012)
^{54}Mn	κ	Scintillation	γ	Short term decrease during solar flare	Jenkins and Fischbach (2009)
^{54}Mn	κ	Scintillation	γ	Periodicity: 1 yr^{-1}	Jenkins et al. (2011)
^{56}Mn	β^-	Scintillation	γ	Periodicity: 1 yr^{-1}	Ellis (1990)
^{60}Co	β^-	Geiger–Müller	β^-,γ	Periodicity: 1 yr^{-1}	Parkhomov (2010a,b)
^{60}Co	β^-	Scintillation	γ	Periodicity: 1/d, 12.1 yr^{-1}	Baurov et al. (2007)
^{85}Kr	β^-	Ion chamber	γ	Periodicity: 1 yr^{-1}	Schrader (2010)
$^{90}Sr/^{90}Y$	β^-	Geiger–Müller	β^-	Periodicity: 1 yr^{-1}, 11.7 yr^{-1}	Parkhomov (2010a,b) and Sturrock et al. (2012)
^{108m}Ag	κ	Ion chamber	γ	Periodicity: 1 yr^{-1}	Schrader (2010)
^{133}Ba	β^-	Ion chamber	γ	Periodicity: 1 yr^{-1}	This work
^{137}Cs	β^-	Scintillation	γ	Periodicity: 1 d^{-1}, 12.1 yr^{-1}	Baurov et al. (2007)
^{152}Eu	β^-,κ	Solid state (Ge)	γ[b]	Periodicity: 1 yr^{-1}	Siegert et al. (1998)
^{152}Eu	β^-,κ	Ion chamber	γ	Periodicity: 1 yr^{-1}	Schrader (2010)
^{154}Eu	β^-,κ	Ion chamber	γ	Periodicity: 1 yr^{-1}	Schrader (2010)
^{222}Rn[c]	α,β^-	Scintillation	γ	Periodicity: 1 yr^{-1}, 11.7 yr^{-1}, 2.1 yr^{-1}	Steinitz et al. (2011) and Sturrock et al. (2012)
^{226}Ra[c]	α,β^-	Ion chamber	γ	Periodicity: 1 yr^{-1}, 11.7 yr^{-1}, 2.1 yr^{-1}	Jenkins et al. (2009) and Sturrock et al. (2010b, 2011a)
^{239}Pu	β^-	Solid state	α	Periodicity: 1/d, 13.5 yr^{-1}, 1 yr^{-1}	Shnoll et al. (1998)

[a] Only the count rate ratio data were available.
[b] Only the κ photon was measured.
[c] Decay chain includes several primarily β-decaying daughters which also emit photons.

^{54}Mn Decays 2008-2013



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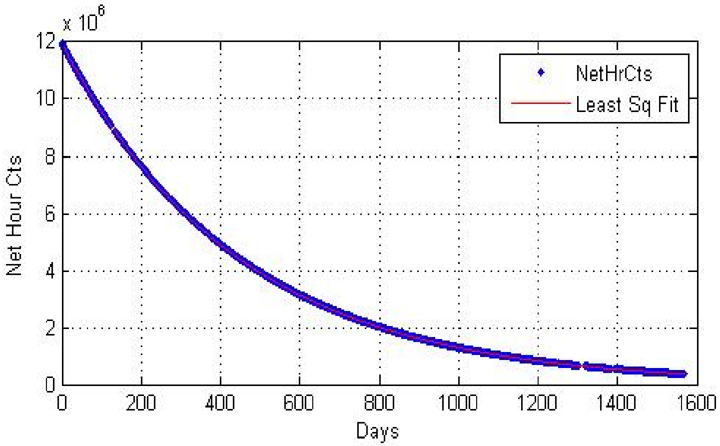
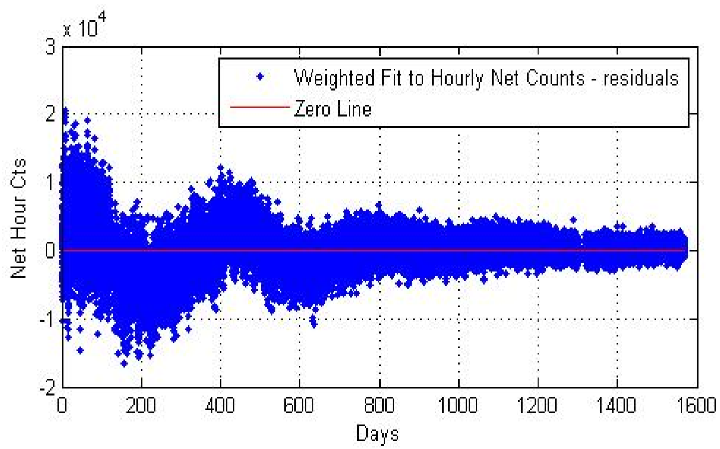
Jenkins, Fischbach, et al.
10th ESWW, Antwerpen, Belgium

^{54}Mn Half-life (2008-2013)





- Literature value (NNDC, 2013): **$T_{1/2}$ = 312.12(6) days**
- Detail (Net counts):
  - **34,442** 1-hour counts
  - **1568.8** days (5.03 half-lives),
  - **1.11×10^{11}** events detected in full energy peak.
- **Weighted linear fit: $T_{1/2}$ = 311.662(1) days**, χ^2/d.o.f. = 1.66
- **Weighted exponential fit:** General model
  Exp1: f(x) = a*exp(b*x)
  - Coefficients (with 95% confidence bounds):
    - a = 1.196e+07 (1.196e+07, 1.196e+07)
    - **b = -0.002224 (-0.002224, -0.002224)**
      $T_{1/2}$ =311.667(1) days
    - Goodness of fit:
      - SSE: 1.707e+008
      - R-square: 1.00000
      - Adjusted R-square: 1.00000
      - RMSE: 70.4

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Preliminary Results

- Data from 1/3/10-12/9/11
- NOAA identifies 12033 solar events for the same period
- Our tests produced 256 decay flags
- Looking at the 413 strongest events, we find that 37% of the decay flags were followed by a stong solar event within 24 hours
- 50% of the solar events were preceded by at least one decay flag

Publications to date

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- **Jenkins, J.H., et al., *Evidence of Correlations Between Nuclear Decay Rates and Earth-Sun Distance.* Astroparticle Physics, 2009. 32(1): p. 42-46. [**DOI: **10.1016/j.astropartphys.2009.05.004]**
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Questions?