Do radioactive decay rates depend on the distance between the Earth and the Sun?

Karsten Kossert and Ole Nähle

Physikalisch-Technische Bundesanstalt (PTB),
Department 6.1 “Radioactivity”

10th Patras Workshop on Axions, WIMPs and WISPs
CERN, Switzerland, 29th June – 4th July 2014

Overview

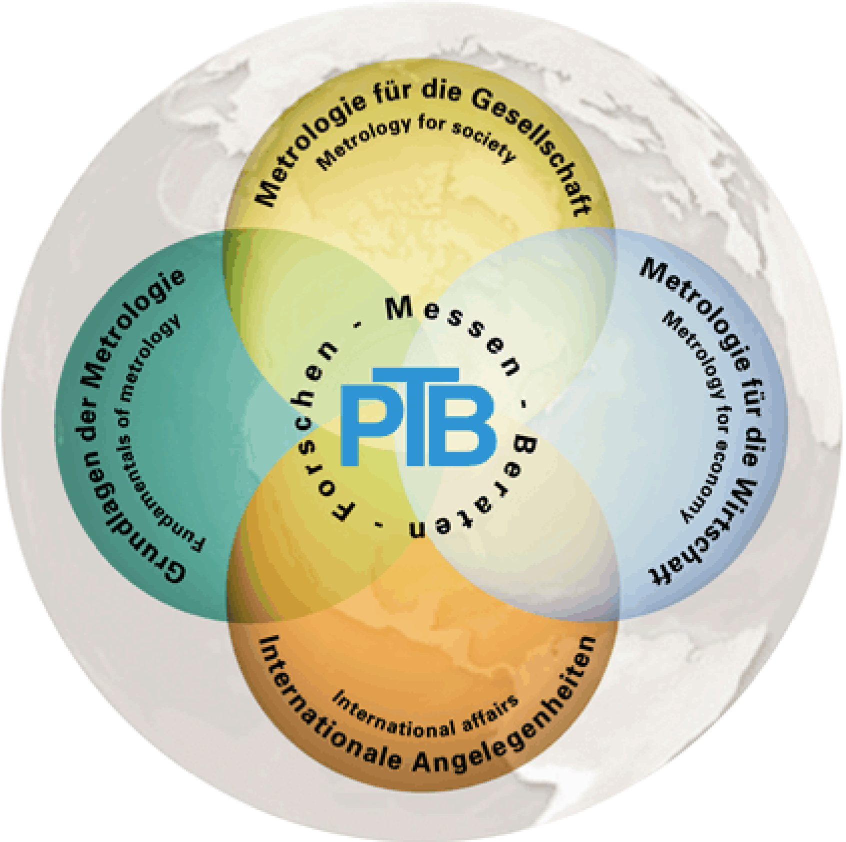
- About us
- Motivation
- ^{36}Cl and ^{90}Sr: New experiments at PTB
- Comments on a recent article by Sturrock et al.
- Conclusions

About us

The “unit of activity” working group

Business areas / Intentions

- Basics of metrology
  Activity standardizations (Becquerel), research: measurement and analysis techniques, nuclear and atomic data (e.g. half-lives)
- Metrology for economy (industry)
  Fabrication and provision of activity standards, calibration of sources from the customer, accreditation and consulting
- Metrology for the society
  Research, radiation protection (Rn-222, comparisons BfS), calibration of nuclides for medical applications, consulting
- International affairs
  Basics of Metrology, BIPM-, SIR-, CCRI-, ICRM-, EUROMET- and COOMET-comparisons, projects, conferences



Activity standards

Physikalisch-Technische Bundesanstalt
Braunschweig und Berlin

Kalibrierschein
Calibration certificate

Gegenstand: *Object:*	Aktivitätsnormal Activity standard
Hersteller: *Manufacturer:*	Physikalisch-Technische Bundesanstalt Fachbereich 6.1
Typ: *Type:*	Punktförmiges Präparat Point source
Kenn-Nummer: *Serial number:*	2004-1999
Auftraggeber: *Applicant:*	Firma Mustermann Mustermannstr. 15 12345 Musterhausen
Anzahl der Seiten: *Number of pages:*	4
Geschäftszeichen: *Reference number:*	PTB-6.11-999/99.2004
Kalibrierzeichen: *Calibration mark:*	PTB-6.11-2004-1999
Datum der Kalibrierung: *Date of calibration:*	26.01.2004

Im Auftrag *By order* — Braunschweig, 27.01.2004 — Bearbeiter: *Examiner:*

Siegel *Seal*

Kalibrierscheine ohne Unterschrift und Siegel haben keine Gültigkeit. Dieser Kalibrierschein darf nur unverändert weiterverbreitet werden. Auszüge bedürfen der Genehmigung der Physikalisch-Technischen Bundesanstalt.
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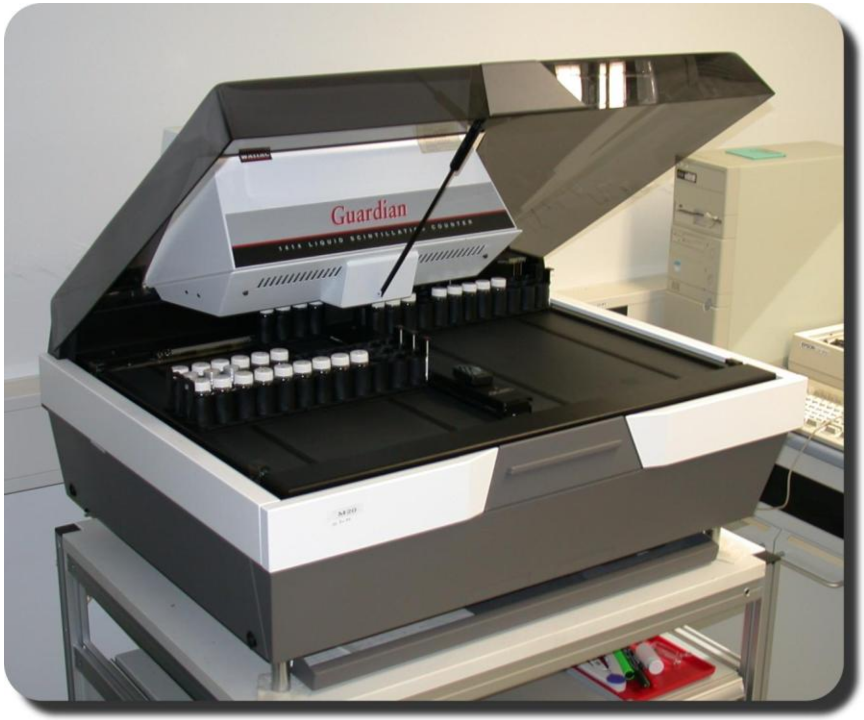
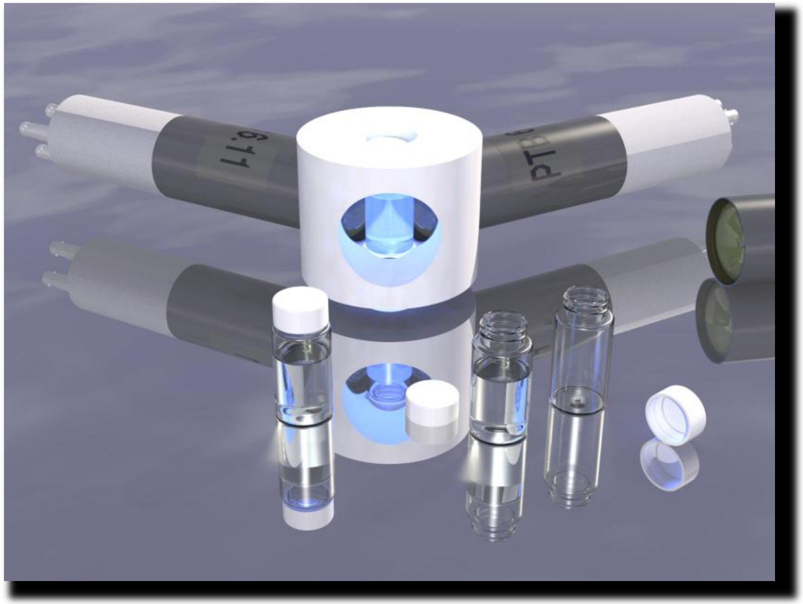
Activity determination with LSC

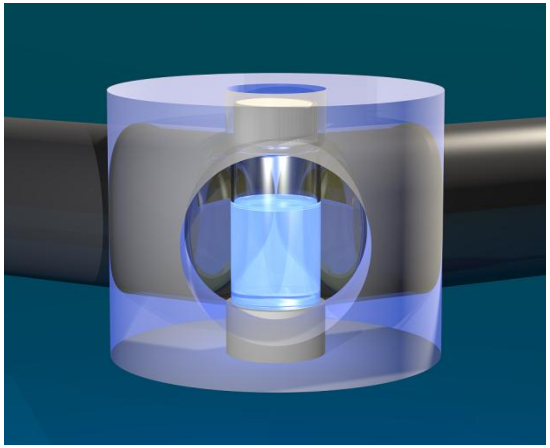




Important methods:

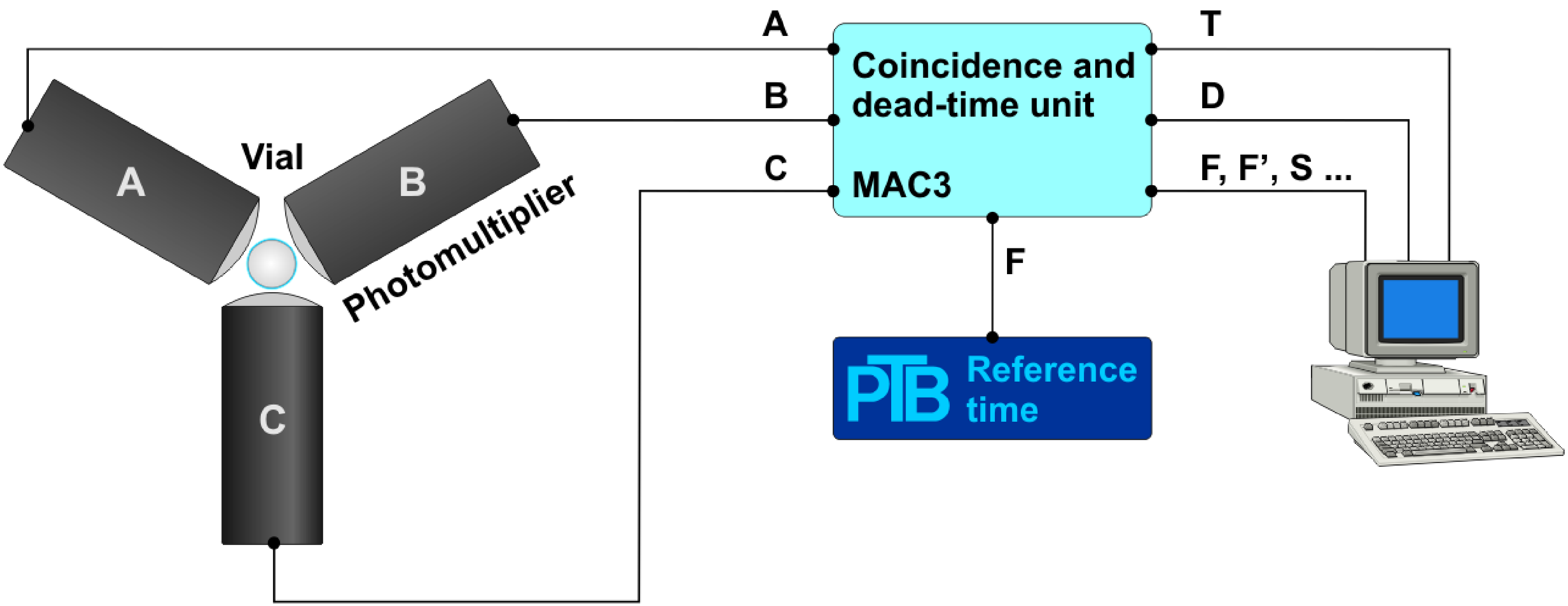
- CIEMAT/NIST
- TDCR

TDCR system



TDCR system of PTB

See, e.g. Nähle, Kossert, Cassette: Appl. Radiat. Isot. 68 (2010) 1534



The TDCR method

TDCR value:

$$\frac{R_T}{R_D} = \frac{\int_0^{E_{\max}} S(E)(1-e^{-\eta})^3 dE}{\int_0^{E_{\max}} S(E)((3(1-e^{-\eta})^2 - 2(1-e^{-\eta})^3))dE}$$

with

$$\eta = \frac{\nu}{3}\int_0^E \frac{AdE}{1+kB\frac{dE}{dx}}$$

If counting statistics is good enough the ratio of measured counting rates must agree with computed ratio

$$\frac{R_T}{R_D} = \frac{T}{D} = TDCR$$

For details see: Broda, Cassette, Kossert Metrologia 44 (2007) S36

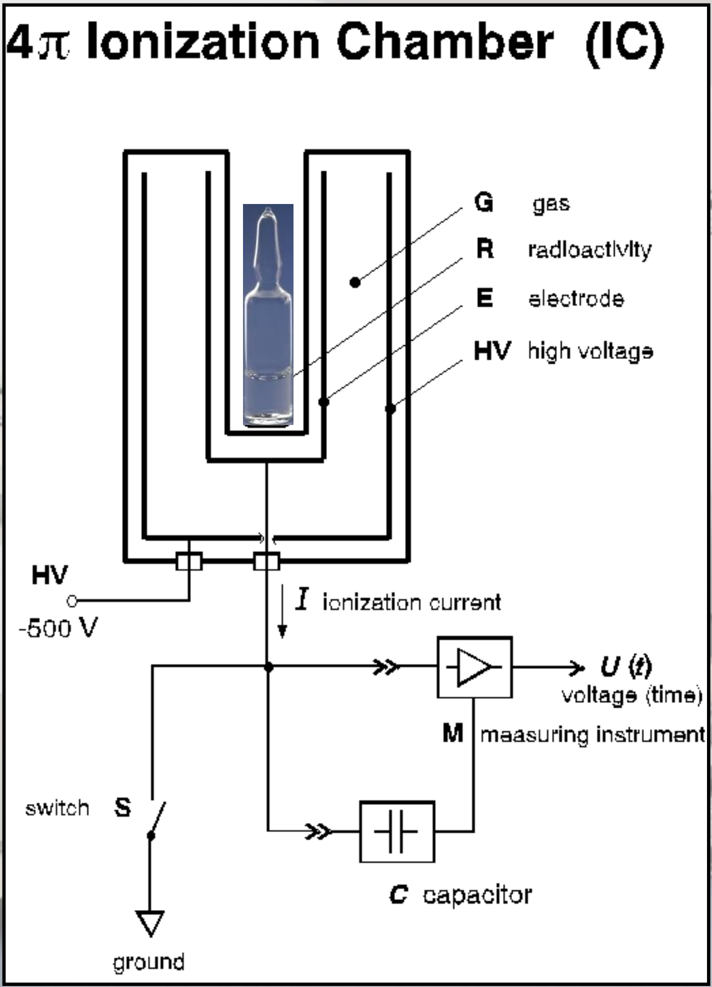
The TDCR method

The TDCR method is an <u>absolute method</u> (primary activity standardization), i.e.

- it does not require reference sources
- the method provides information on the counting efficiency and the activity
- timely variations of the counting efficiency are of minor importance, since the efficiency is known and taken into account (compensation).

Ionization chambers at PTB

Ionization chambers at PTB



Activity: $A = k_N \, C_{geom} m_{Ra\text{-}226} \, R_N \, / \, R_{Ra\text{-}226}$

- $k_N = 1/\varepsilon_N$ calibration factor
- C_{geom} geometry factor ; C_{geom}=1 for standard geometry
- $R_{Ra\text{-}226}$, $m_{Ra\text{-}226}$ instrument reading and mass* of Ra-226 reference source
- R_N instrument reading for nuclide under study*

* (corrected for background and decay)

Ionization chambers

Activity determination by means of ionization chambers is a <u>relative method</u> (secondary activity standardization), i.e.

- it requires reference sources for calibration
- the method provides no information on the detection efficiency

In addition, the detectors and electronics are known to be sensitive to changes of environmental conditions (e.g. temperature, air pressure and humidity). Changes of the efficiency manifest themselves in variations of the measured ionization currents. Thus, we measure sources against long-lived standard sources.

Motivation

Motivation

Since a few years, a group of scientists from the US claims to have found evidence for influence of solar neutrinos to the decay rates of radioactive isotopes.

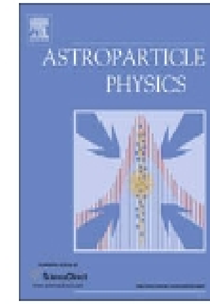
They started using ^{226}Ra data from PTB and ^{32}Si data from BNL and reported on correlations between the decay rates and the Earth-Sun distance.

Astroparticle Physics 32 (2009) 42–46

Contents lists available at ScienceDirect

Astroparticle Physics

journal homepage: www.elsevier.com/locate/astropart



Evidence of correlations between nuclear decay rates and Earth–Sun distance

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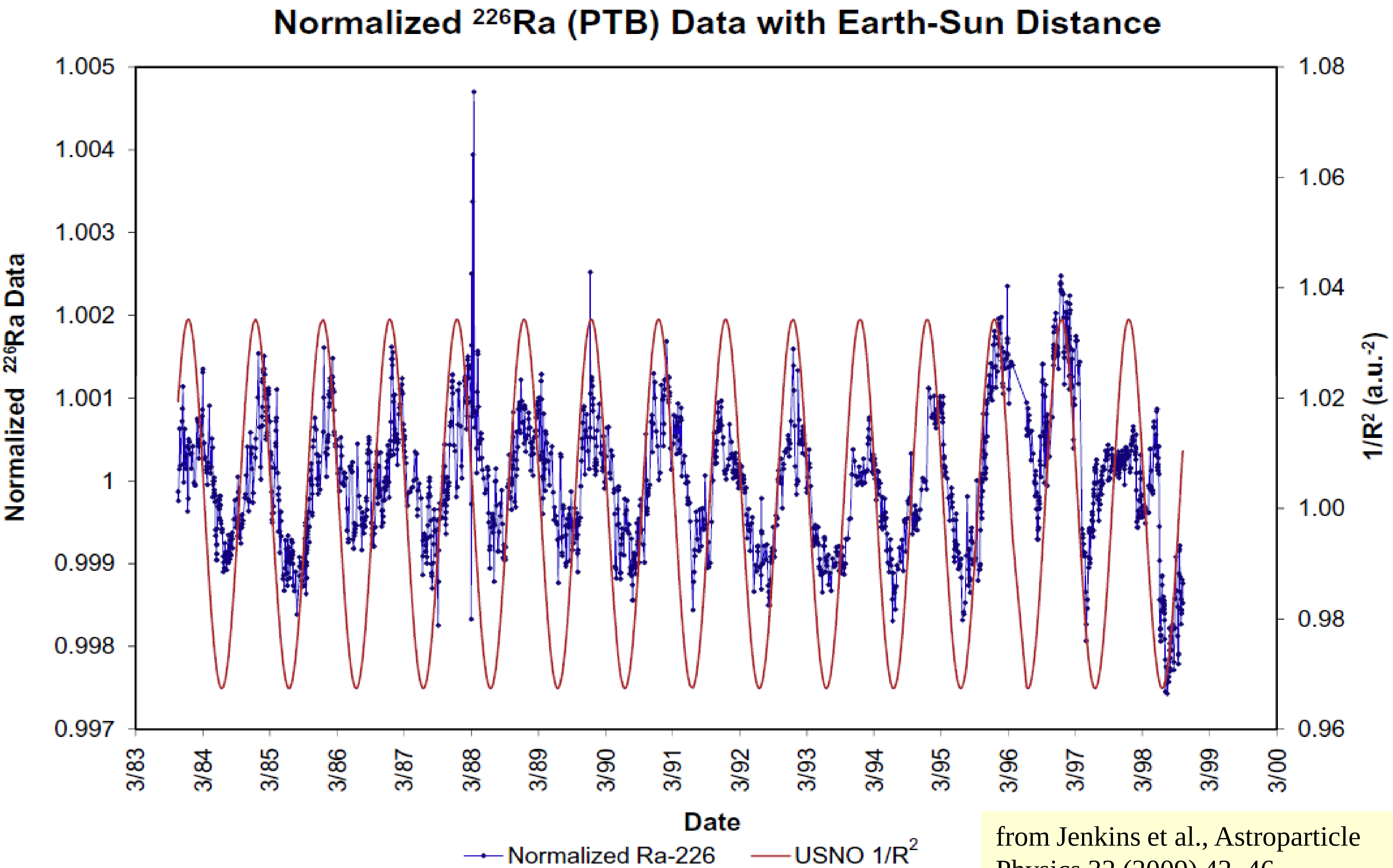
ABSTRACT

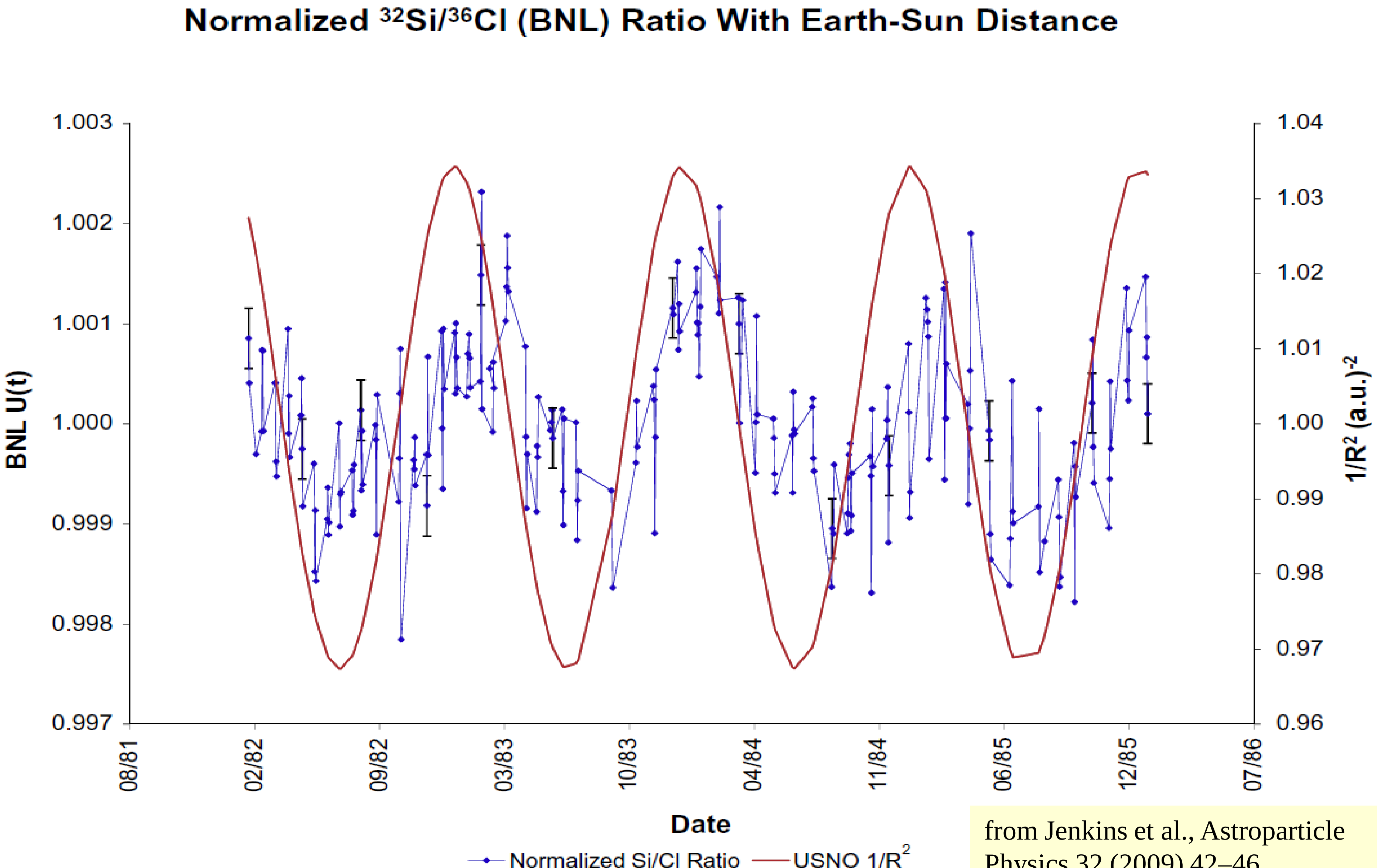
Unexplained periodic fluctuations in the decay rates of ^{32}Si and ^{226}Ra have been reported by groups at Brookhaven National Laboratory (^{32}Si), and at the Physikalisch–Technische–Bundesanstalt in Germany (^{226}Ra). We show from an analysis of the raw data in these experiments that the observed fluctuations are strongly correlated in time, not only with each other, but also with the time of year. We discuss both the possibility that these correlations arise from seasonal influences on the detection system, as well as the suggestion of an annual modulation of the decay rates themselves which vary with Earth–Sun distance.

Oscillations in instrument readings



from Jenkins et al., Astroparticle Physics 32 (2009) 42–46

Oscillations in instrument readings



from Jenkins et al., Astroparticle Physics 32 (2009) 42–46

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.

New physics?

arXiv:1106.1678v1 [nucl-ex] 8 Jun 2011:

ANALYSIS OF EXPERIMENTS EXHIBITING TIME-VARYING NUCLEAR DECAY RATES: SYSTEMATIC EFFECTS OR NEW PHYSICS?

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New physics?

arXiv:1106.1470v1 [nucl-ex] 7 Jun 2011:

EVIDENCE FOR TIME-VARYING NUCLEAR DECAY DATES: EXPERIMENTAL RESULTS AND THEIR IMPLICATIONS FOR NEW PHYSICS

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Unexplained annual variations in nuclear decay rates have been reported in recent years by a number of groups. We show that data from these experiments exhibit not only variations in time related to Earth-Sun distance, but also periodicities attributable to solar rotation. Additionally, anomalous decay rates coincident in time with a series of solar flares in December 2006 also point to a solar influence on nuclear decay rates. This influence could arise from some flavor of solar neutrinos, or through some other objects we call "neutrellos" which behave in some ways like neutrinos. The indication that neutrinos or neutrellos must interact weakly in the Sun implies that we may be able to use data on time-varying nuclear decay rates to probe the interior of the Sun, a technique which we may call "helioradiology".

New physics?

Sturrock et al., Astroparticle Physics 59 (2014) 47–58:

If further experiments and further analysis support the proposition that neutrinos are responsible for variations in beta-decay rates, one will face the theoretical issue of explaining this effect. Fischbach et al. have suggested that neutrinos interact with nuclei via a new potential, which may be a manifestation of a new boson [15].

Other studies

Several studies were made by other researchers.

Some of them found no evidence for a solar influence to the decay rates.

However, a clear disproof of the contentious theory is not given since most studies are based on secondary measurements (e.g. gamma-ray spectrometry). For such methods it is not possible to identify the reason of potential variations of counting rates.

Selected works:

De Meijer, Blaauw & Smit: "No evidence for antineutrinos significantly influencing exponential β^+ decay", Appl. Radiat. Isot. 69 (2011) 320.

Meier & Wieler: "No evidence for a decrease of nuclear decay rates with increasing heliocentric distance based on radiochronology of meteorites", Astropart. Phys. 55 (2014) 63.

^{36}Cl

^{36}Cl

Astroparticle Physics 37 (2012) 81–88

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journal homepage: www.elsevier.com/locate/astropart

Additional experimental evidence for a solar influence on nuclear decay rates

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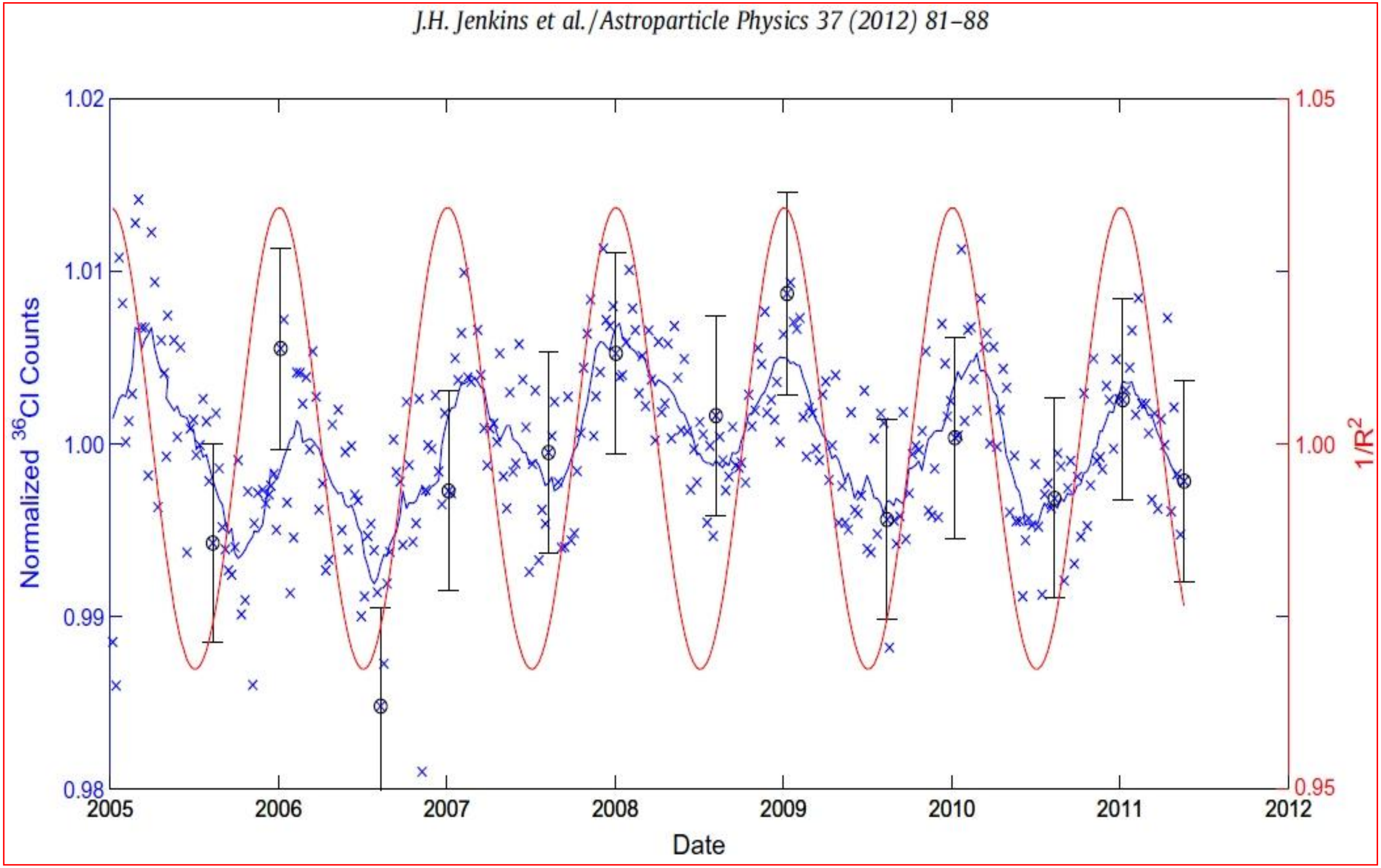
Beta decay
Solar influence

ABSTRACT

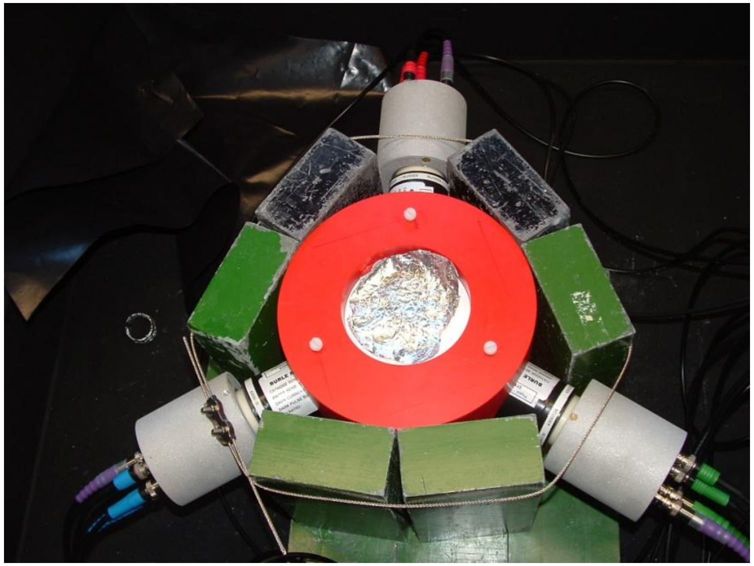
Additional experimental evidence is presented in support of the recent hypothesis that a possible solar influence could explain fluctuations observed in the measured decay rates of some isotopes. These data were obtained during routine weekly calibrations of an instrument used for radiological safety at The Ohio State University Research Reactor using ^{36}Cl. The detector system used was based on a Geiger–Müller gas detector, which is a robust detector system with very low susceptibility to environmental changes. A clear annual variation is evident in the data, with a maximum relative count rate observed in January/February, and a minimum relative count rate observed in July/August, for seven successive years from July 2005 to June 2011. This annual variation is not likely to have arisen from changes in the detector surroundings, as we show here.

^{36}Cl

GM counter measurements as OSURR

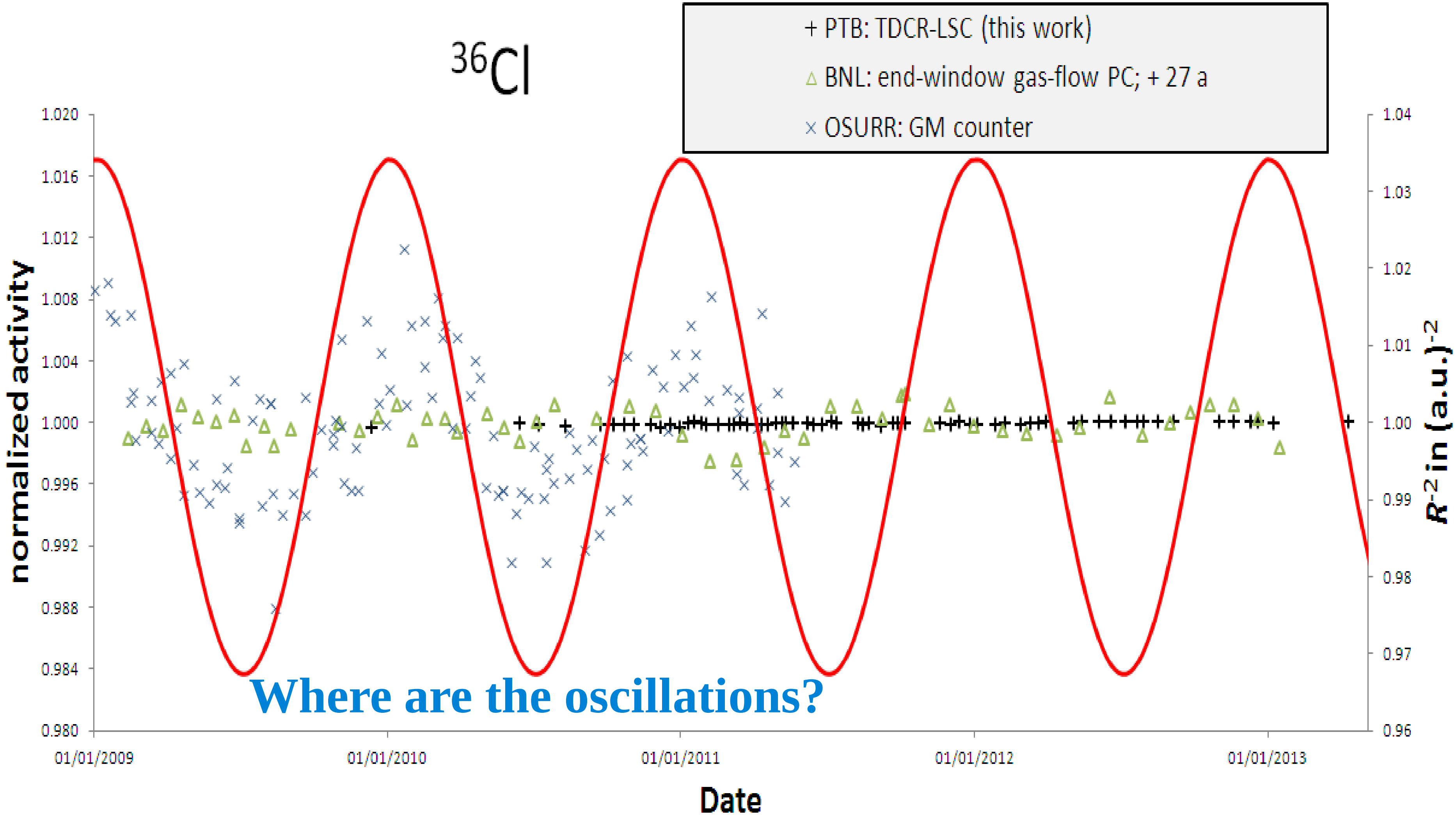


^{36}Cl measurements at PTB



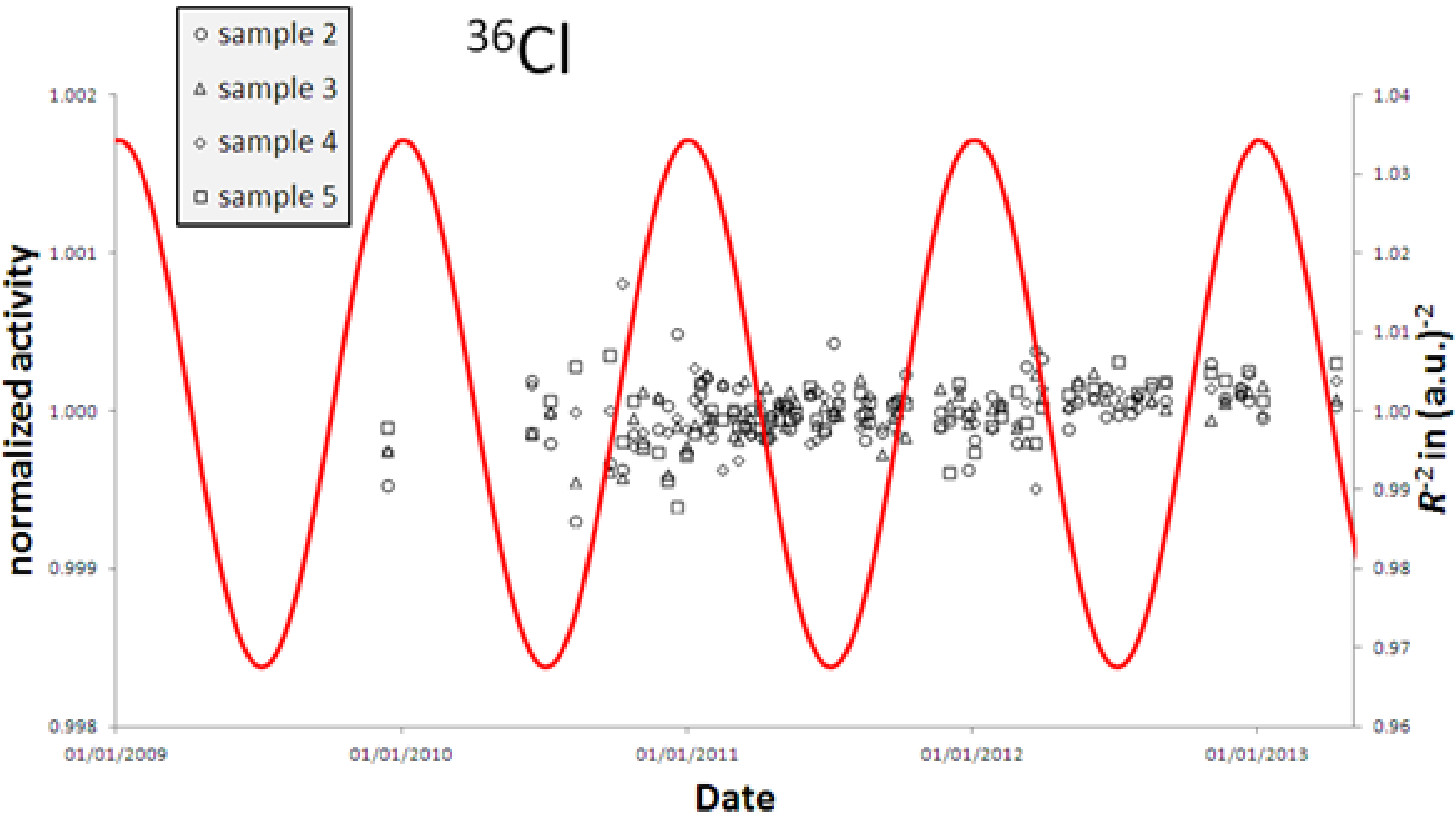
Start:	December 2009
Method:	TDCR
Advantages:	no self-absorption, potential deviations of the counting efficiency are compensated

Comparison: PTB – BNL - OSURR



from Kossert and Nähle,
Astroparticle Physics 55 (2014) 33–36

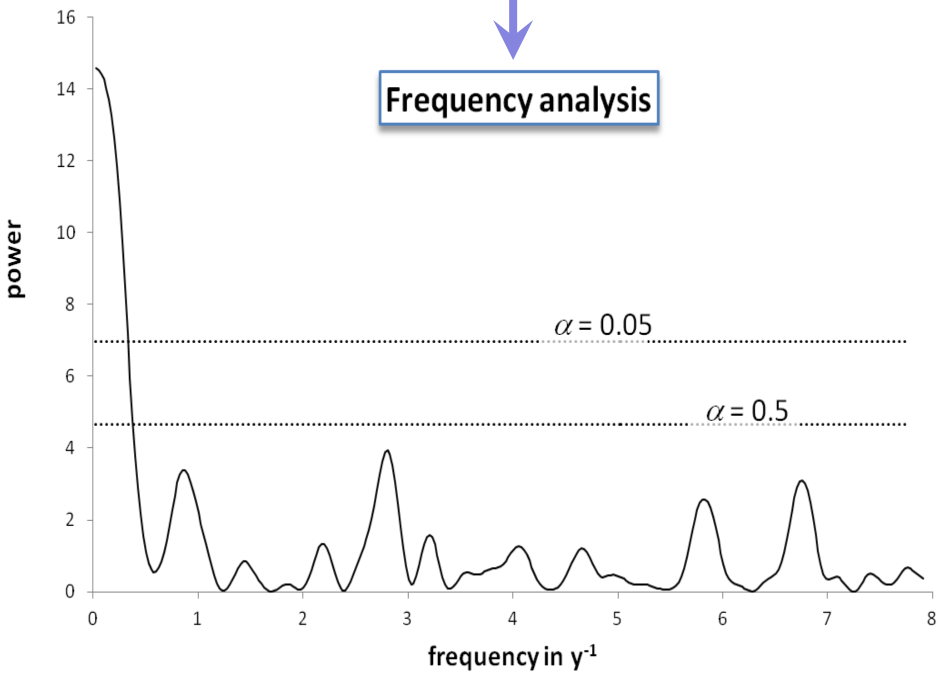
Where are the oscillations?



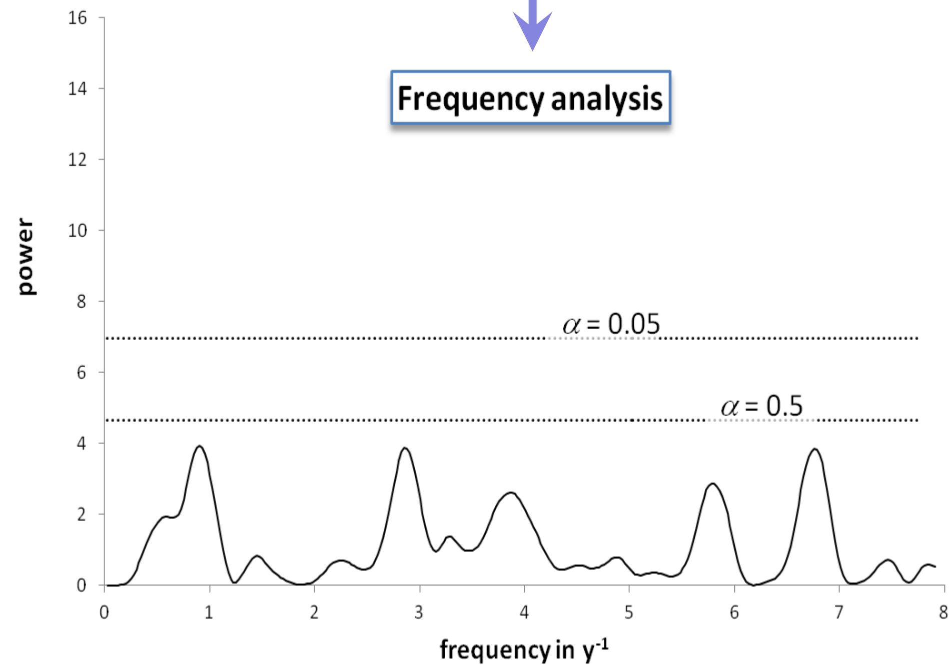
Slight increasing trend caused by colour quenching.

^{36}Cl: Lomb-Scargle frequency analysis

Activity without modification

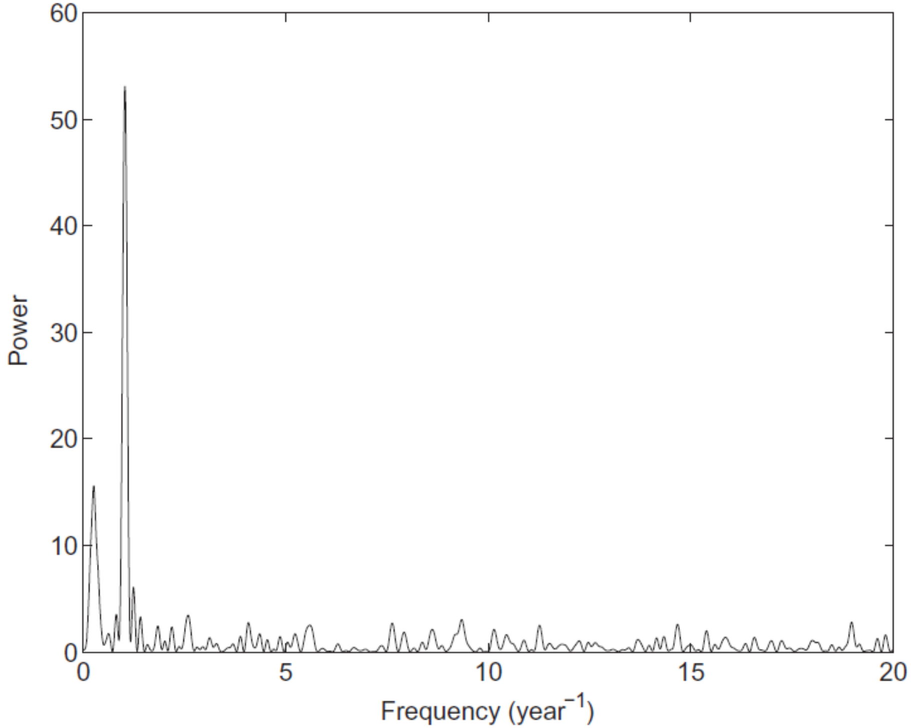


Activity after removal of linear trend due to colour quenching



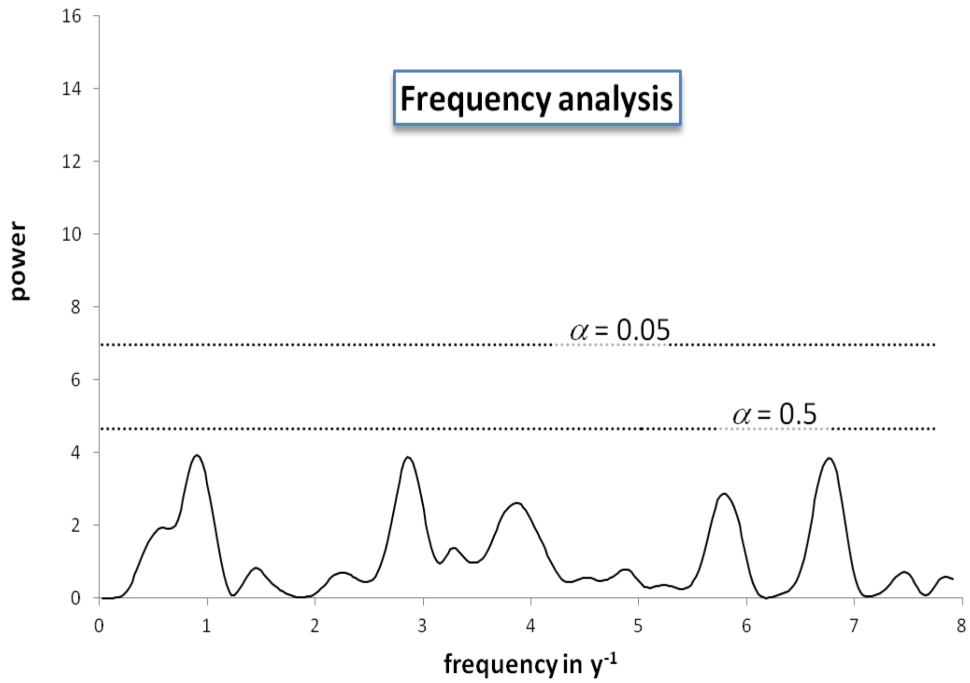
^{36}Cl: Lomb-Scargle frequency analysis

OSURR: GM counter



from Jenkins et al., Astroparticle Physics 37 (2012) 81–88

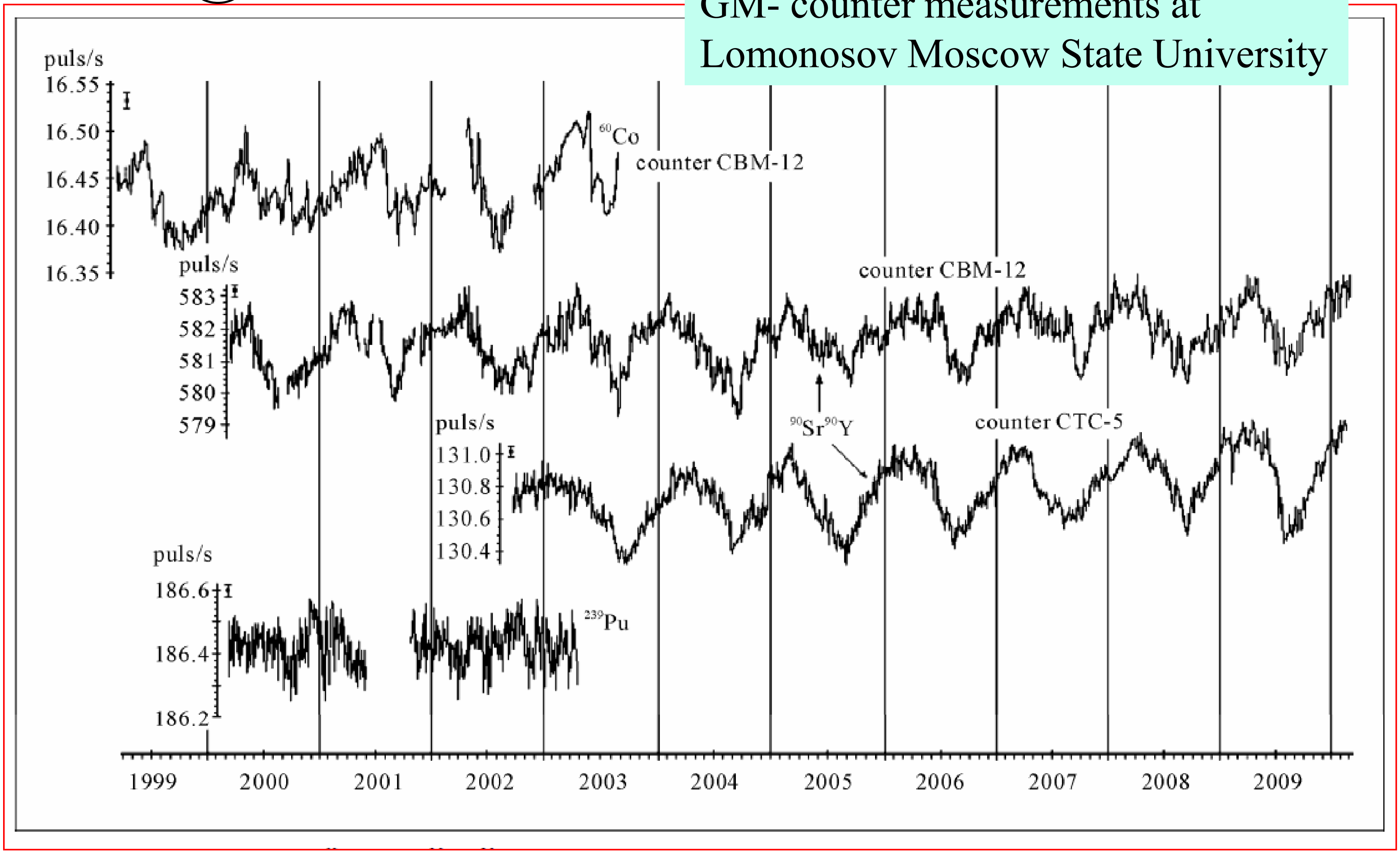
PTB: Liquid scintillation counting using the TDCR method



^{90}Sr

^{90}Sr @ LMSU

GM- counter measurements at Lomonosov Moscow State University



from Parkhomov, J. Mod. Phys., 2011, 2, 1310

^{90}Sr @ LMSU

from Parkhomov,
J. Mod. Phys., 2011, 2, 1310

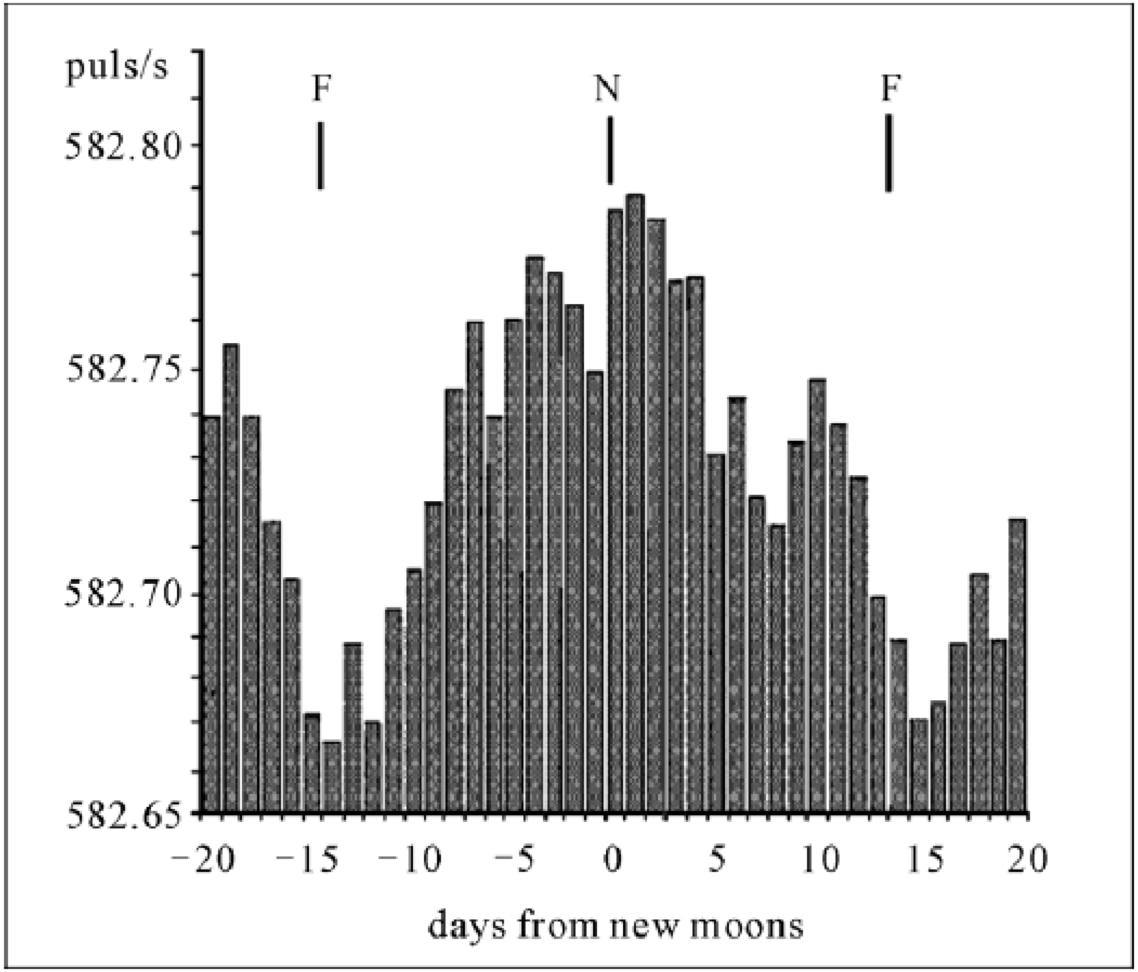
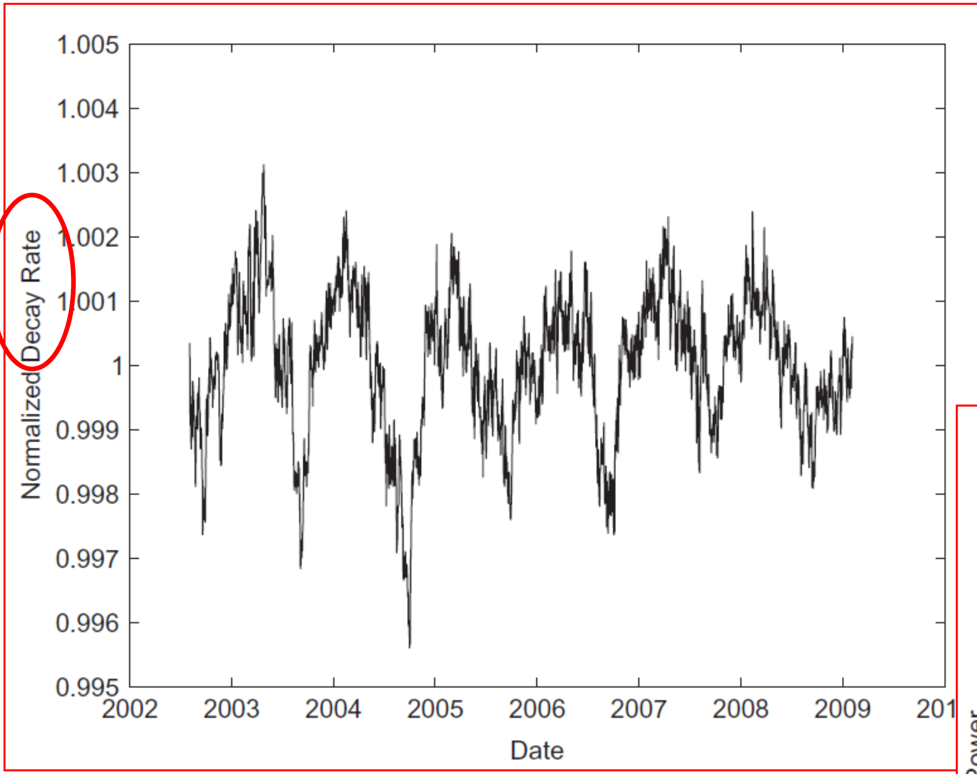
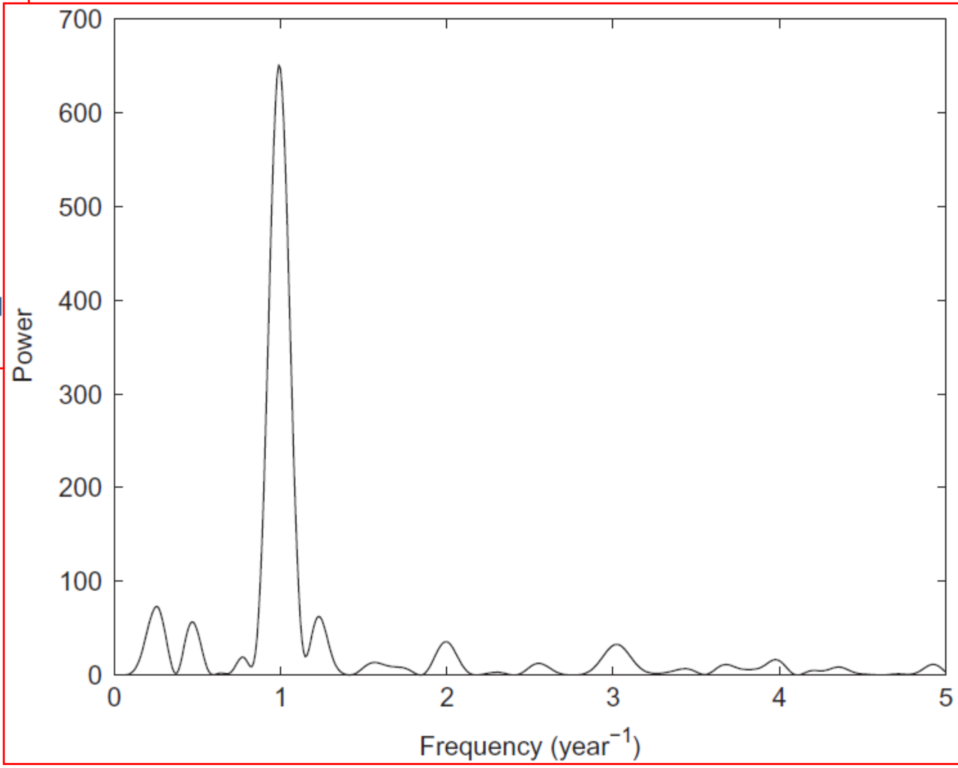


Figure 3. Averaging over cycles of the synodical Lunar month of the count rate data for ^{90}Sr-^{90}Y beta source, as registered by G-M counter between April 2000 and March 2007. Averaging covers 87 cycles. N—new Moon, F—full Moon [7,8].

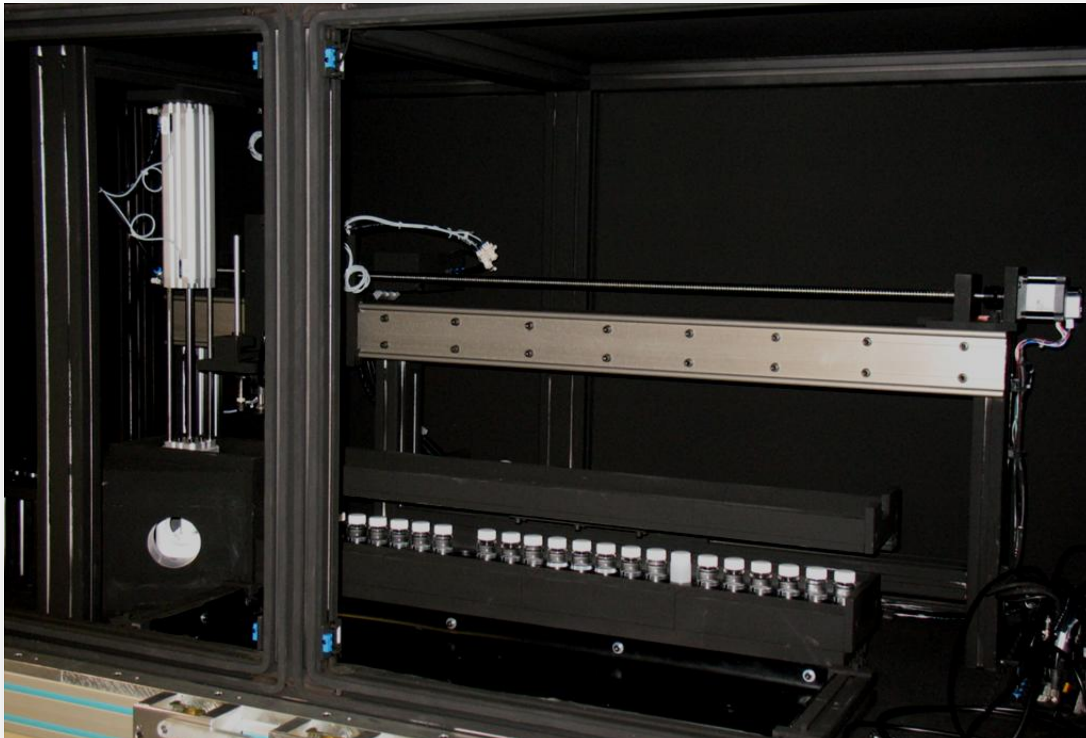
^{90}Sr @ LMSU





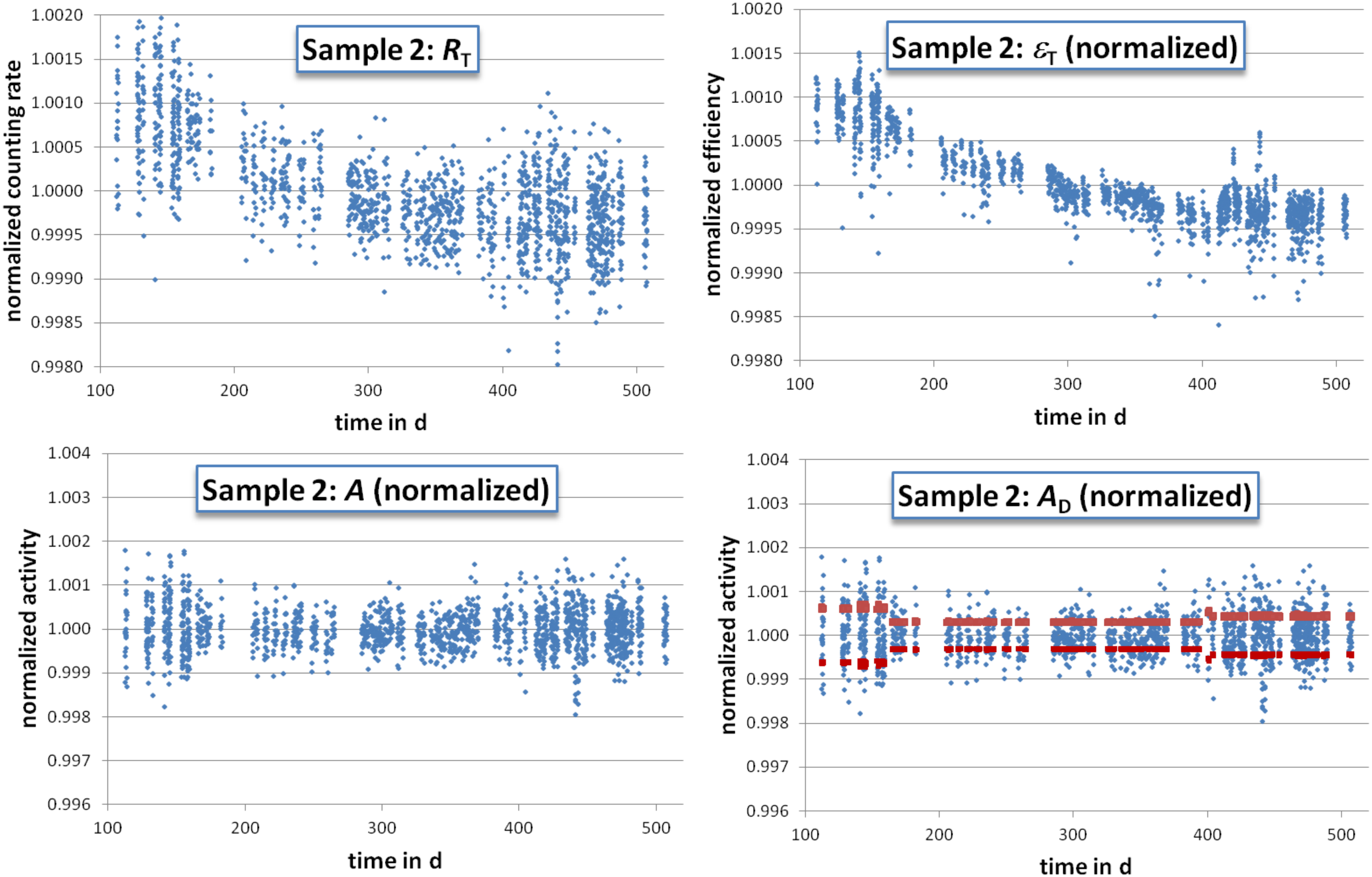
from Sturrock et al., Astroparticle Physics 35 (2012) 755

^{90}Sr measurements at PTB

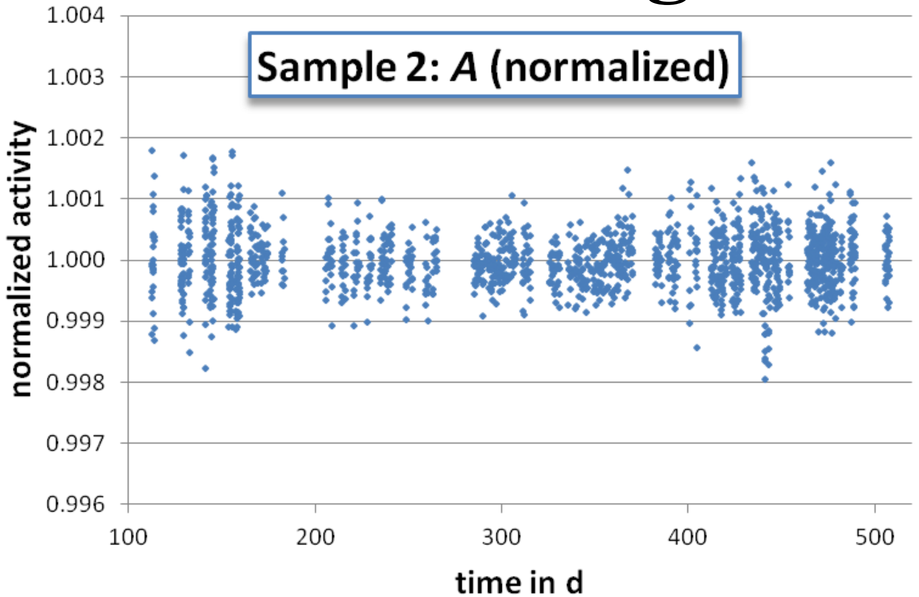


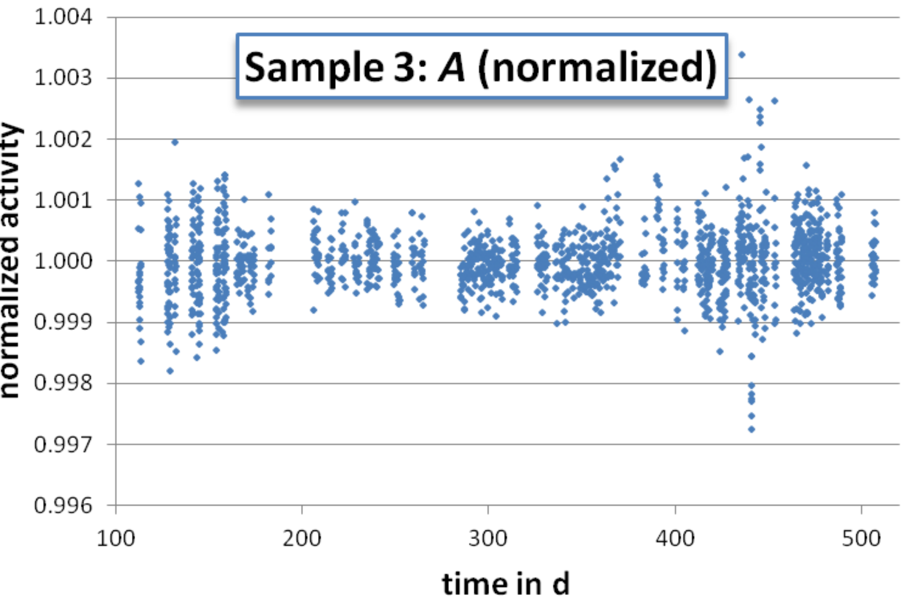
Start:	April 2013
End:	May 2014
Method:	TDCR using three ^{90}Sr samples and one background source
Advantages:	no self-absorption, potential deviations of the counting efficiency are compensated

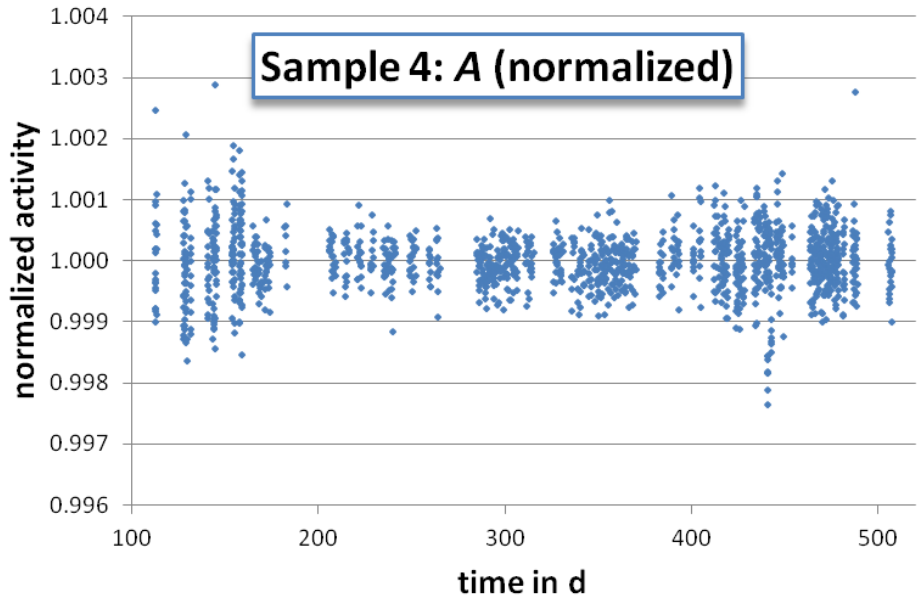
^{90}Sr measurements using TDCR



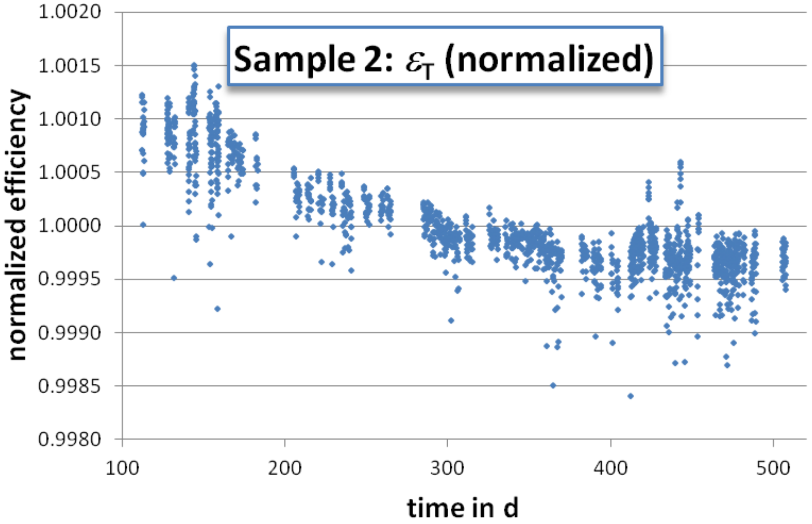
^{90}Sr measurements using TDCR

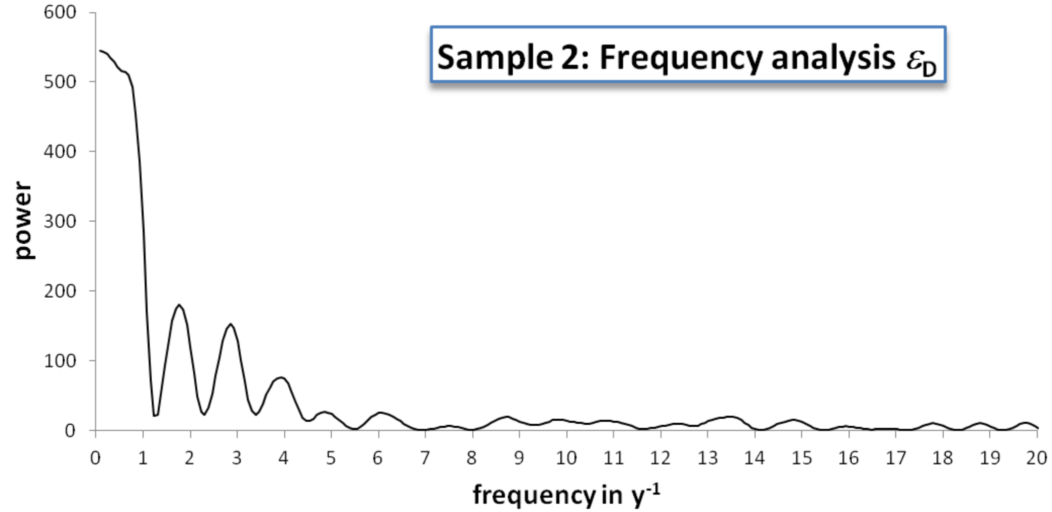


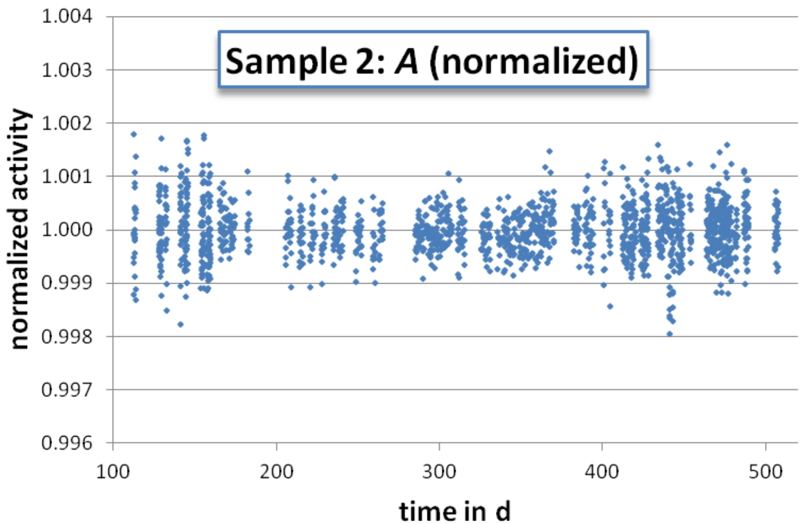


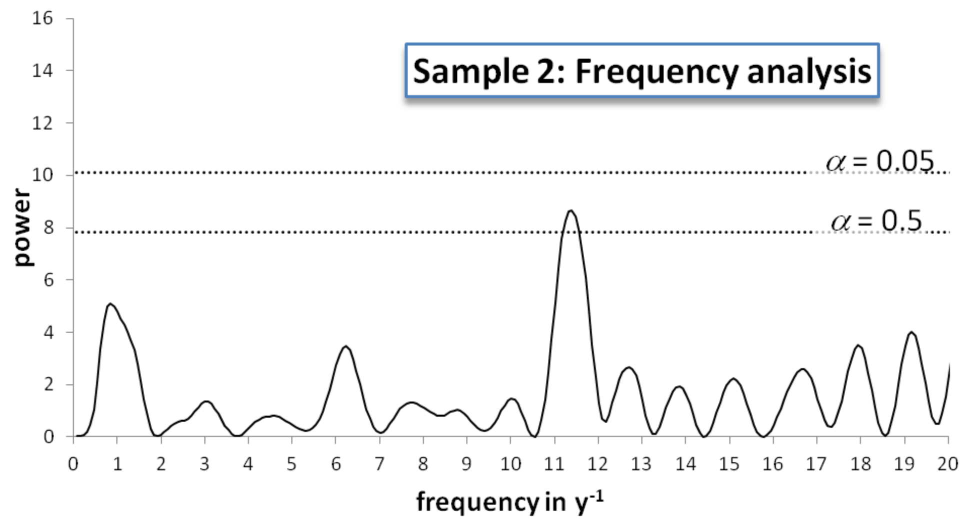


^{90}Sr measurements using TDCR

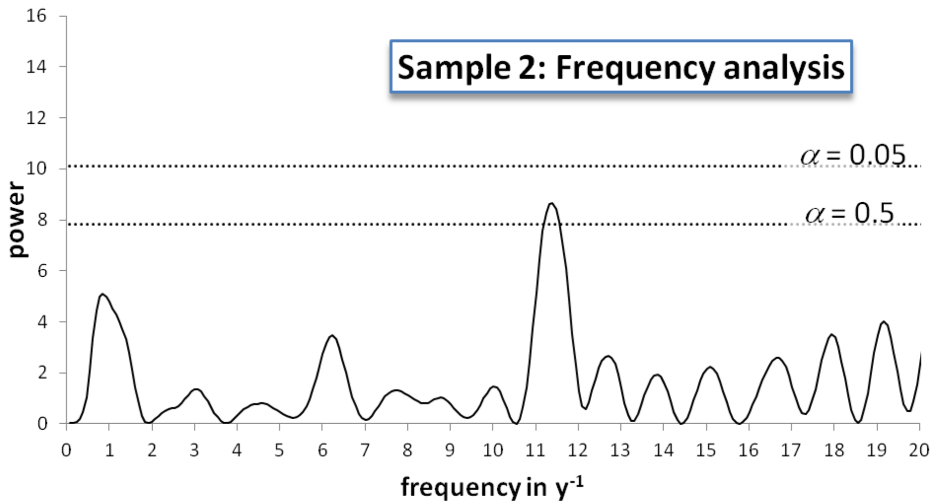


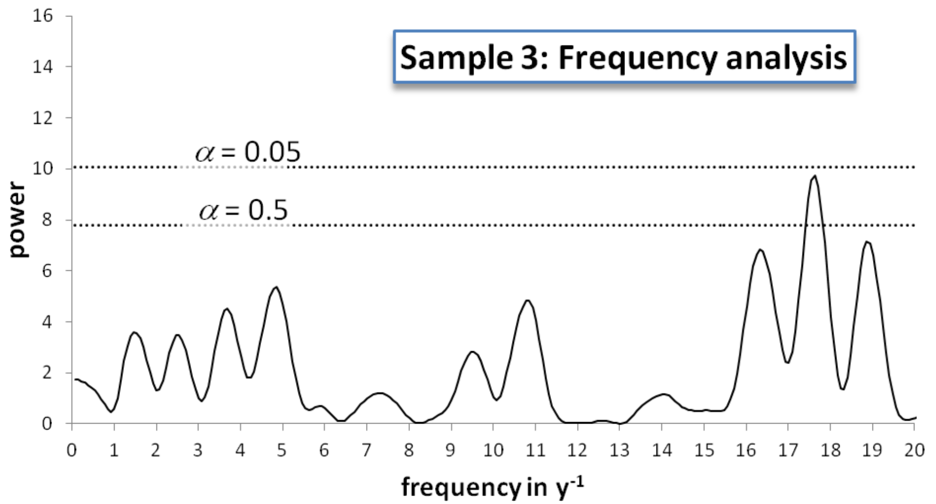


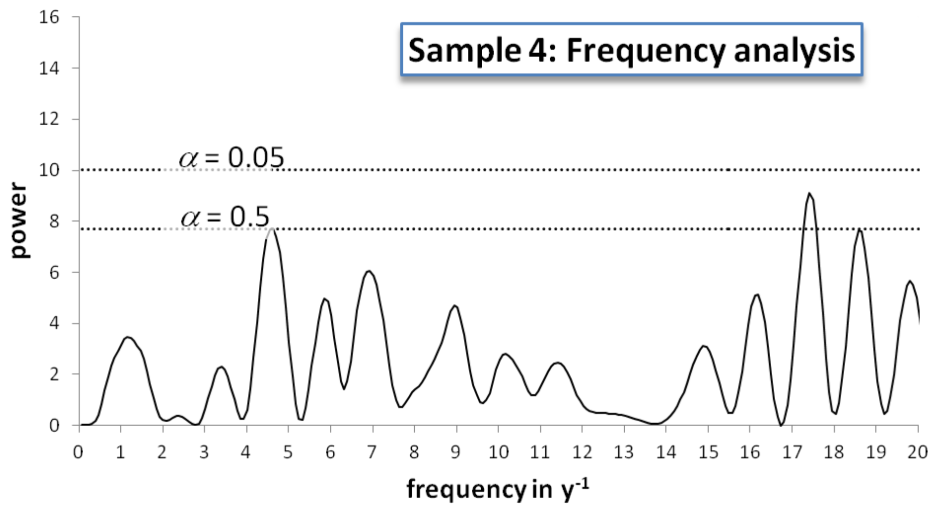




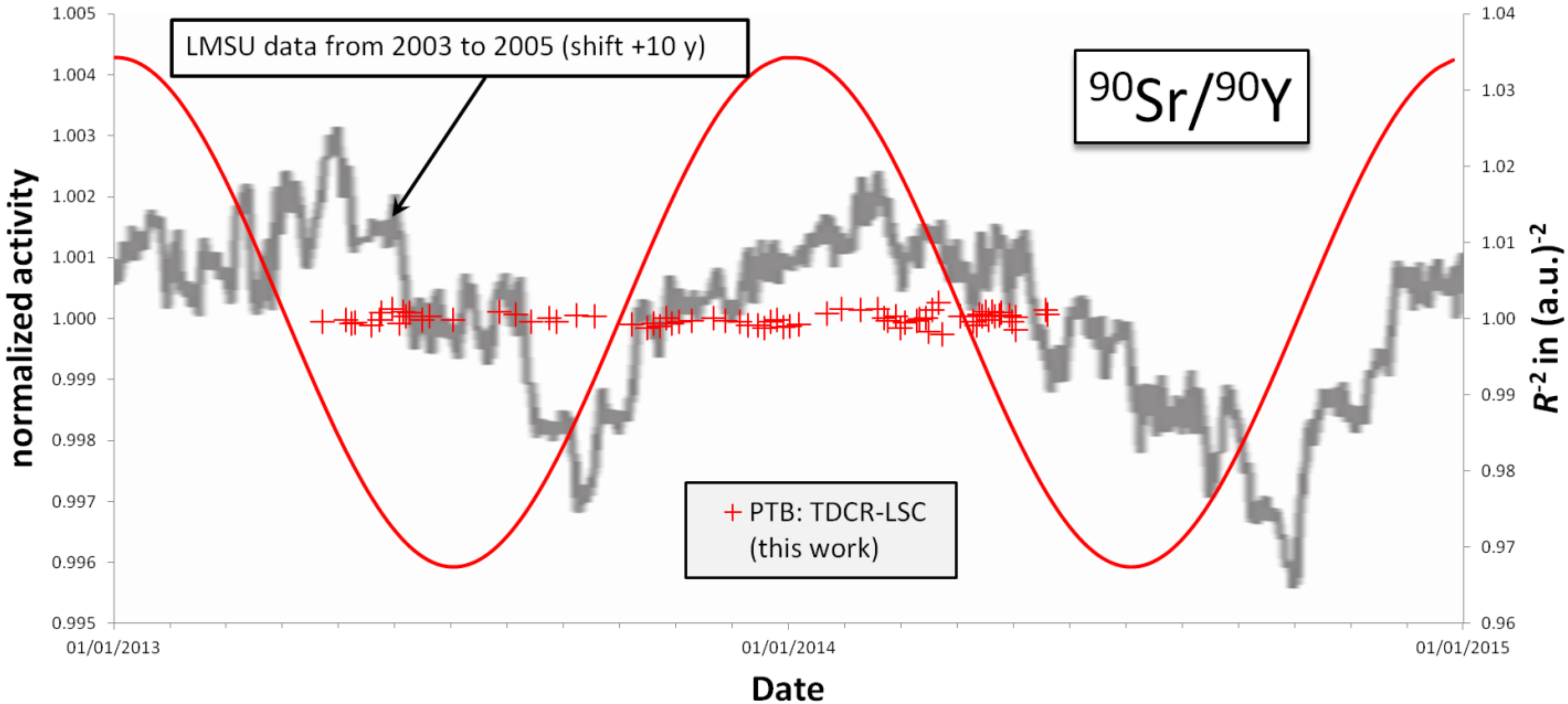
^{90}Sr measurements using TDCR







^{90}Sr measurements using TDCR



Comments on a recent article by Sturrock et al.

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Comparative study of beta-decay data for eight nuclides measured at the Physikalisch-Technische Bundesanstalt

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A B S T R A C T

We present the results of time-series analyses of data, kindly provided by the Physikalisch-Technische Bundesanstalt, concerning the beta-decays of Ag108, Ba133, Cs137, Eu152, Eu154, Kr85, Ra226, and Sr90. From measurements of the detector currents, we find evidence of annual oscillations (especially for Ra226), and for several solar r-mode oscillations. It is notable that the frequencies of these r-mode oscillations correspond to exactly the same sidereal rotation rate (12.08 $year^{-1}$) that we have previously identified in r-mode oscillations detected in both Mt Wilson solar diameter data and Lomonosov Moscow State University Sr90 beta-decay data. Ba133 is found to be anomalous in that current measurements for this nuclide have a much larger variation (by 4σ) than those of the other nuclides. It is interesting that analysis of variability measurements in the PTB files yields strong evidence for an oscillation for Ba133 but only weak evidence for Ra226.

12 pages with 49 funny coloured figures!

A new article

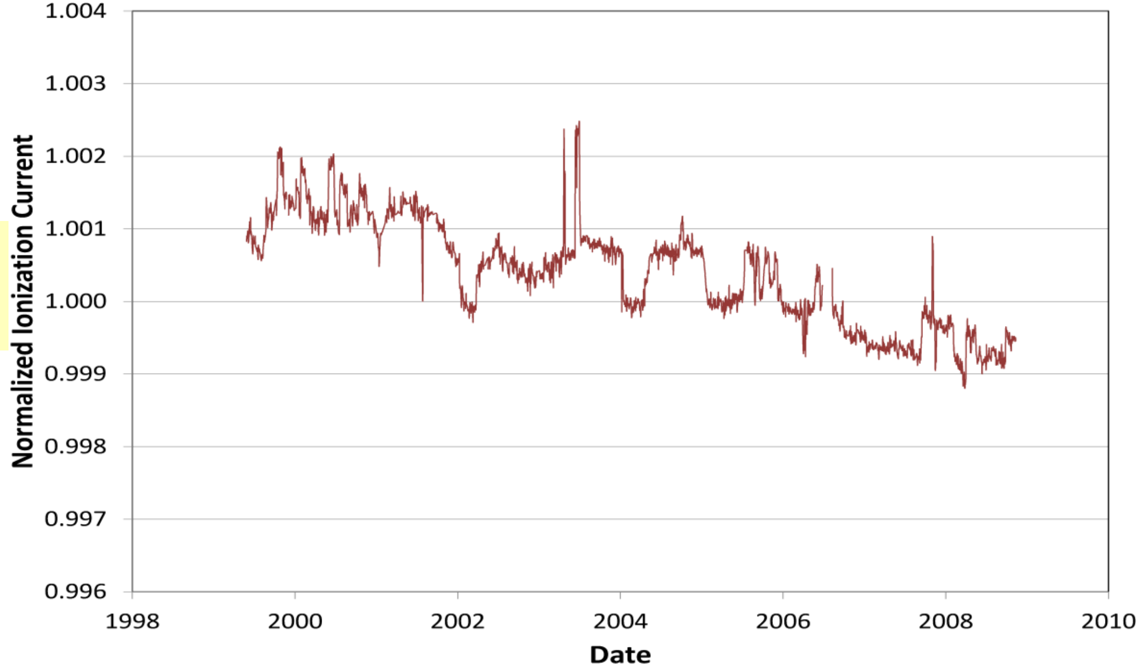
In a new article Sturrock et al. use further ionization chamber measurement data from our lab.

What we criticize:

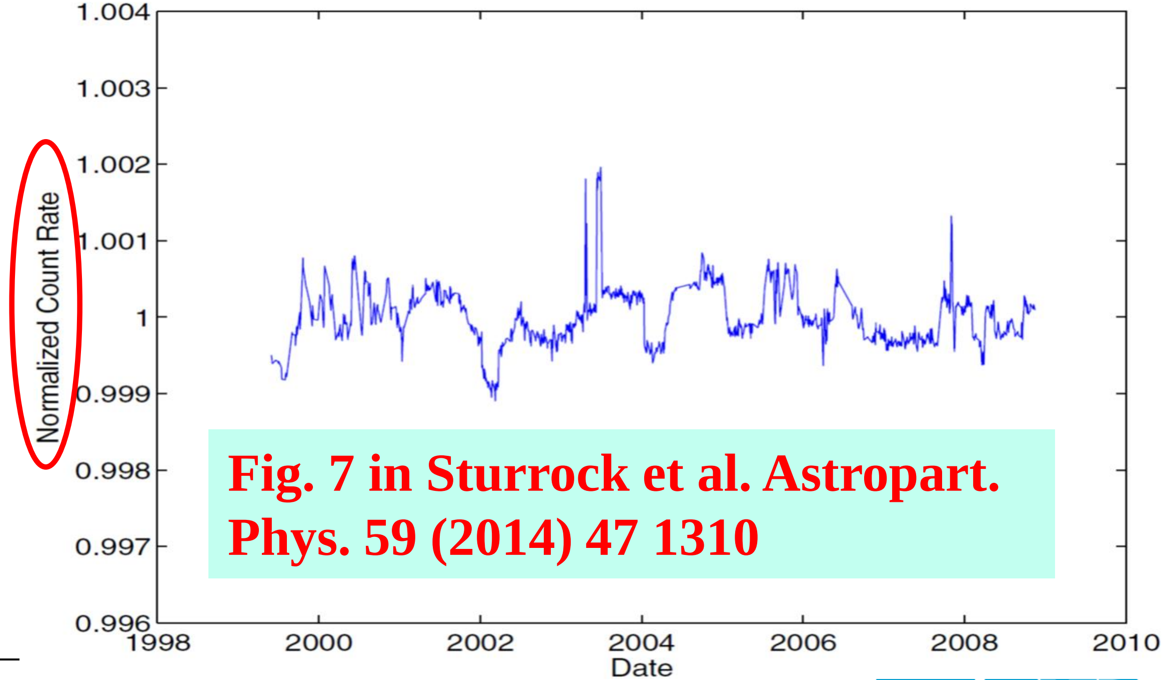
- They manipulate the original data by using arbitrary half-lives (which are not stated in their article)
- Again they equate instrument readings with decay rates.
- They ignore the influence of temperature, air pressure and humidity.
- Their analysis is ridiculous (e.g., they apply a frequency analysis to the "variability" of the data)
- They ignore the fact, that timely variations depend on the instrument. Thus, their articles are contradictory (see, e.g. their articles on
  ^{36}Cl (OSURR vs. BNL)
  ^{90}Sr (LMSU vs. PTB) and
  ^{226}Ra (PTB different chambers).

A new article

Normalized net ionization current obtained form a ^{226}Ra source.

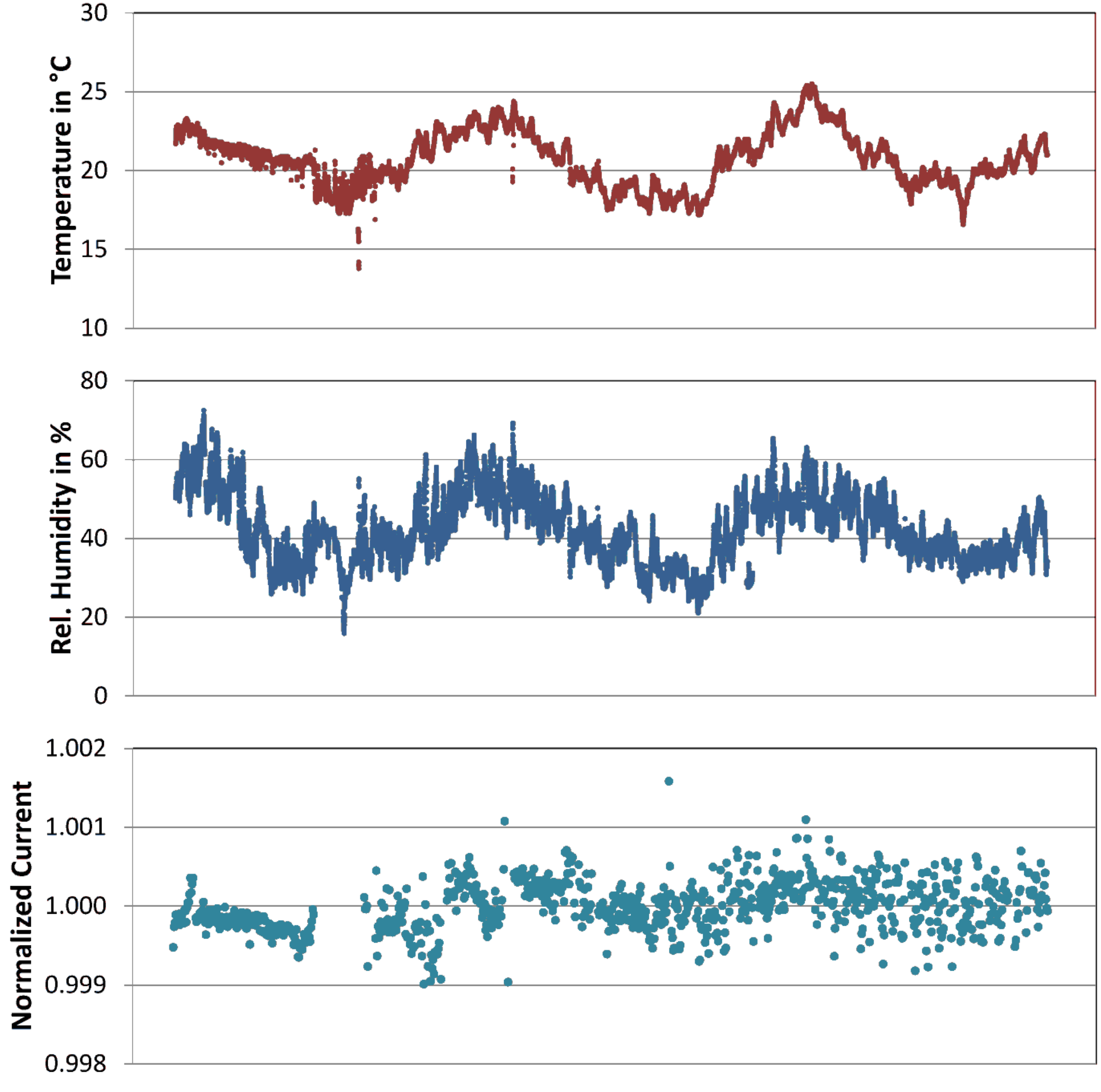


Data were manipulated using an arbitrary half-life.
We measure an ionization current but not a “count rate”.

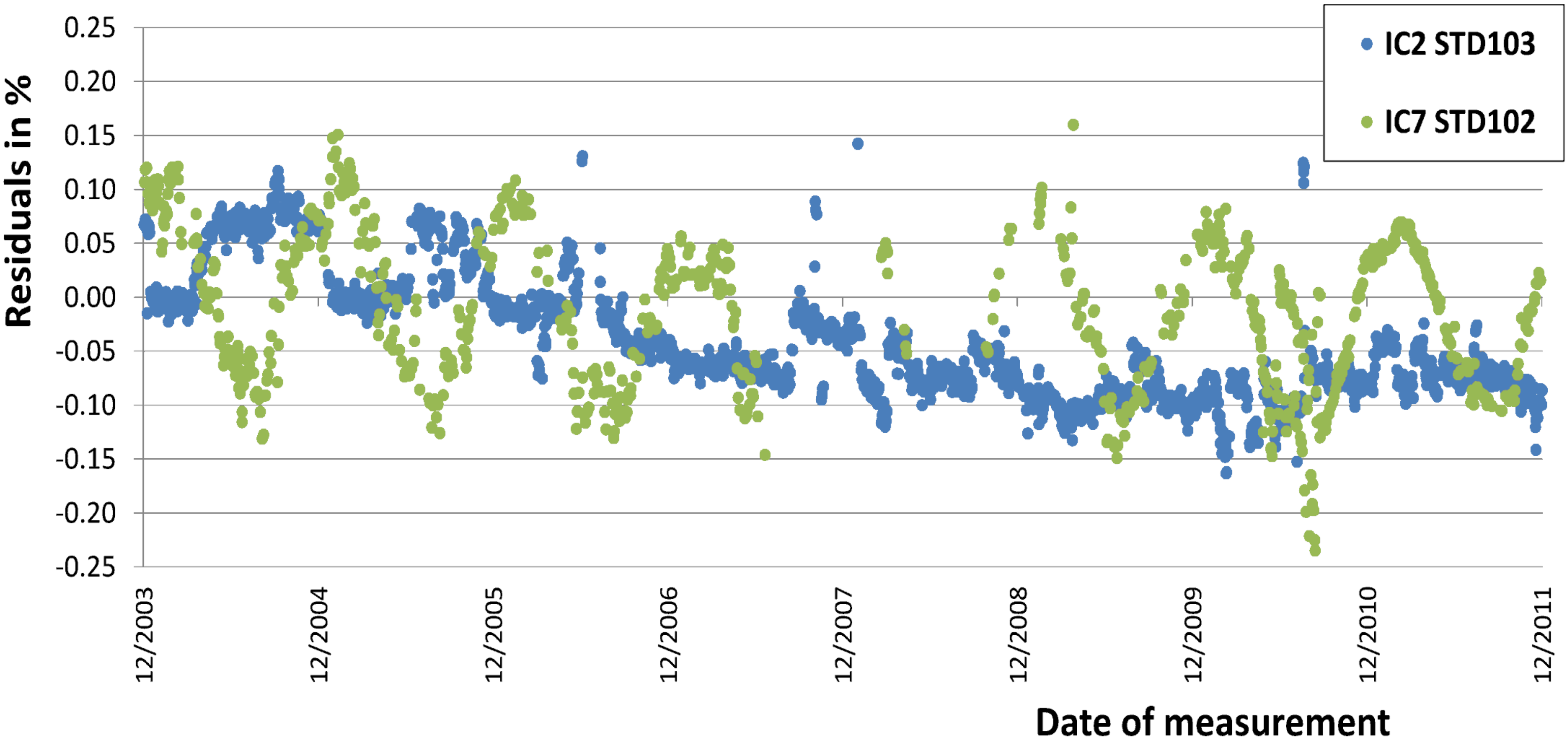


Other correlations

PTB data



Variations depend on the instrument



Comparison of two ^{226}Ra sources measured in different ionization chambers at PTB.

Conclusions: Due to the different characteristics of the two data sets we can exclude common timely variation of the decay rates as a reason for observed variations.

Conclusions

Conclusions (1)

Our TDCR results show no significant correlation between the radioactive decay rate and the time of the year.

Thus, we refute the findings from Sturrock, Fischbach, Jenkins et al.

Conclusions (2)

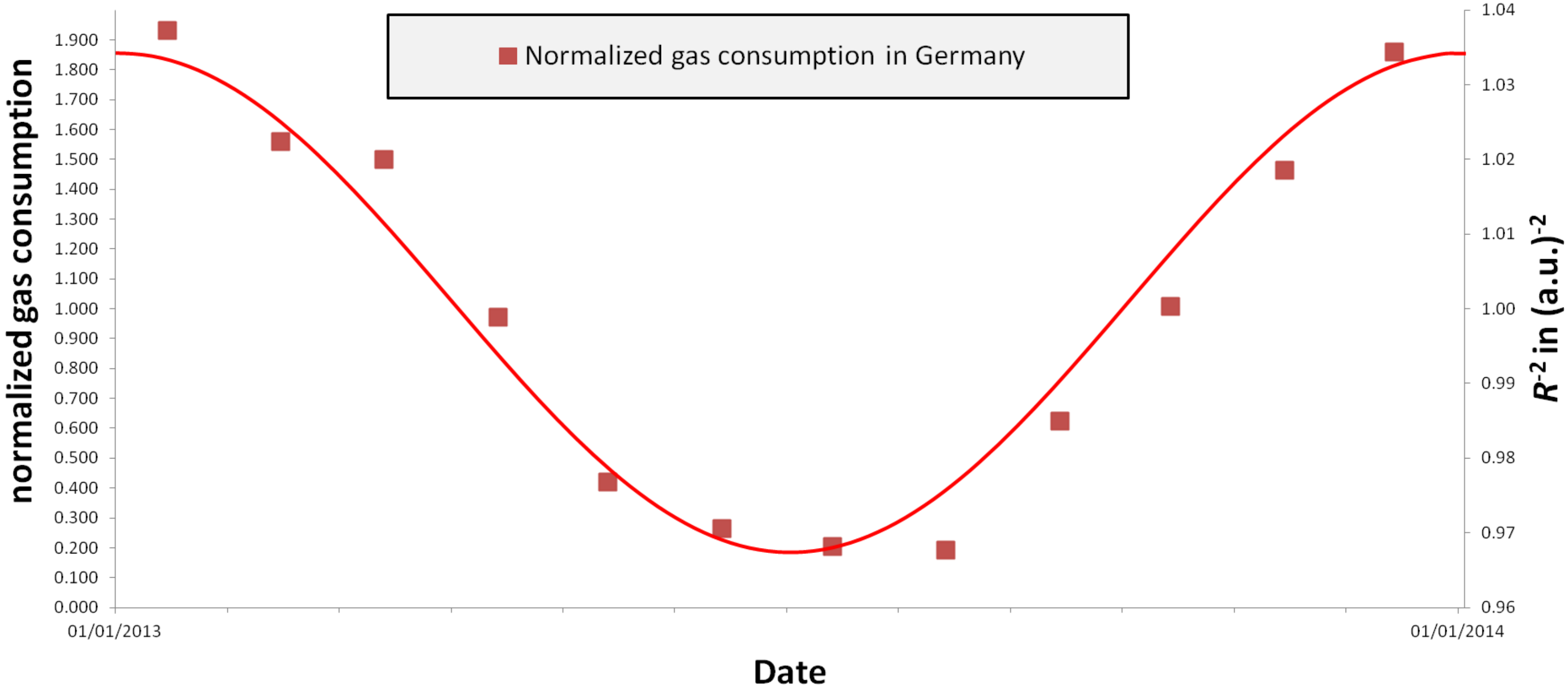
What are the faults made by Fischbach et al.?

1. They equate instrument readings (counting rates or ionization currents) with decay rates.
2. They ignore the fact that oscillations (in instrument readings) do not have the same frequency, phase and amplitude when using different counters.
3. They mainly use data from other researchers and do not know (and/or ignore) important details about experiments.
4. They use data from relative measurement methods which do not provide information about the detection efficiency.
5. They ignore the fact that a correlation in not a causality.

Correlation vs. causality

Other correlations / anti-correlations between the solar neutrino flux on Earth surface and

- Temperature
- Wind strength
- Number of committed suicides
- Ice cream consumption



Thank you very much for your attention