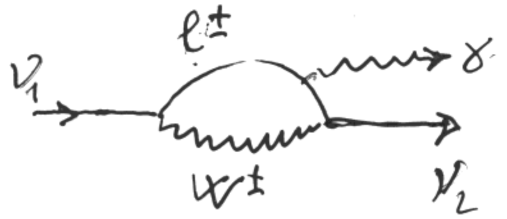
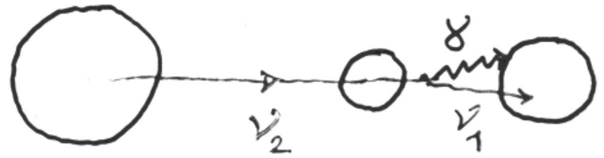
SEARCH FOR RADIATIVE DECAYS OF SOLAR ν's DURING A SOLAR ECLIPSE



MASIERO, SCIAMA P.L.B259('91)323



SUN MOON EARTH

1° PLB397 ('97) 143
2°. hep/ex-0011048

1999 ECLIPSE IN ROMANIA

BAD WEATHER – BUT VIDEOCAMERA IMAGES FROM TV STATION

1. DIGITIZE AND SUM IMAGES
2. OBSERVE MOON IN LIGHT FROM EARTH
3. SUBRACT IMAGE OF MOON
4. WAVELET DECOMPOSITION
5. REMOVE DIFFRACTION ? NORMALIZATION?

FINAL IMAGES IN 3 COLOURS + SUM (WHITE)

LIMITS ON $\tau_{\nu_2} \sim 10^6$ sec IN EARTH FRAME

2001 ECLIPSE IN ZAMBIA

CELESTRON + WEBCAM

TELELENS + DIGITAL CAMERA

DIGITAL VIDEOCAMERA

---- FROM AMATEUR ASTRONOMERS

ANALYSES IN PROGRESS

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VENEZIA 2001

DFUB 2000/19
Bologna, January 29, 2001

Limits on radiative decays of solar neutrinos from a measurement during a solar eclipse.

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ABSTRACT

A search for possible radiative decays of solar neutrinos with emission of photons in the visible range was performed during the total solar eclipse of August 11, 1999. Due to very bad weather conditions our two telescopes were unable to collect useful data; fortunately we obtained several video camera images from a local TV station. An analysis of the digitised images is presented and limits on the lifetime for radiative decay are discussed.

1. Introduction

It is generally agreed that most probably neutrinos have non–zero masses. This belief is based primarely on the evidence/indication for neutrino oscillations from data on solar and atmospheric neutrinos.

Neutrino oscillations are possible if the flavour eigenstates are not pure mass eigenstates, e.g.:

$$|\nu_e>=|\nu_1>\cos\theta+|\nu_2>\sin\theta \qquad (1)$$

where $m_{\nu_2} > m_{\nu_1}$ and θ is the mixing angle.

Since few years there is evidence that the number of solar neutrinos arriving on Earth is considerably smaller than what is expected on the basis of the "Standard Solar Model" and of the "Standard Model" of particle physics, where neutrinos are massless (see e.g. [1]). One possible explanation of these experimental results involves neutrino oscillations, either in vacuum with $\Delta m^2_{sun} = m^2_{\nu_2} - m^2_{\nu_1} \sim 10^{-10}$ eV^2 (as originally discussed in [2, 3]) or resonant matter oscillations $\Delta m^2_{MSW} \sim 10^{-5}$ eV^2 [4, 5].

Recent results from Super-Kamiokande [6], MACRO [7] and Soudan2 [8] experiments on atmospheric neutrinos support the hypothesis of neutrino oscillations (in particular $\nu_\mu \to \nu_\tau$) with large mixing ($\sin^2 2\theta > 0.8$) and $\Delta m^2_{atm} \simeq 3 \times 10^{-3}$ eV^2.

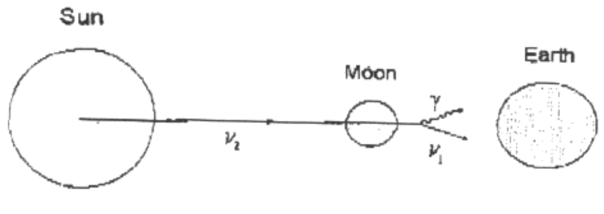

Figure 1: Sketch of the principle of the experiment to detect radiative neutrino decays during a solar eclipse (the emission angles of the photon and of the neutrino are enlarged).

Another indication in favor of neutrino oscillations with a third energy scale $\Delta m^2_{LSND} \simeq 1$ eV^2 is reported in [9].

The above observations appear to be the first indications for new physics beyond the "Standard Model", and any model that generates neutrino masses must contain a natural mechanism that explains their values and the relation to the masses of their corresponding charged leptons.

Different scenarios have been proposed to explain all the observations, including the results with neutrinos from reactors and accelerators [10, 11, 12].

If neutrinos do have masses, then the heavier neutrinos could decay into the lighter ones. For neutrinos with masses of few eV the only decay modes kinematically allowed are radiative decays of the type $\nu_i \rightarrow \nu_j + \gamma$ (where lepton flavour would be violated).

Upper bounds on the lifetimes of such decays are based on astrophysical non–observation of the final state γ rays. Limits were obtained from measurements of X and γ ray fluxes from the Sun [13] and SN 1987A [14, 15].

In the case of neutrinos with nearly degenerated masses, of the order of the eV, the emitted photon can be in the visible or ultraviolet bands [16, 17, 18]. A first tentative to detect such photons, using the Sun as a source, was made during the total solar eclipse of October 24, 1995 [18].

Direct visible photons from the Sun come at a rate of some 10^{17} cm^{-2} s^{-1}; this makes a direct search for photons from solar neutrino decays impossible. To perform a measurement one must take advantage of a total solar eclipse, which cuts by at least 8 orders of magnitude the direct photon flux. By looking with a telescope at the dark disk of the Moon one can search for photons emitted by neutrinos decaying during their 380000 km flight path from the Moon to the Earth, Fig. 1.

In this paper we describe the methodology employed for such a search and give limits obtained from a preliminary measurement performed during the total solar eclipse of 11 August, 1999.

2. Kinematics of radiative decays

We assume the existence of a possible neutrino radiative decay, $\nu_2 \rightarrow \nu_1 + \gamma$, where $m_{\nu_2} > m_{\nu_1}$ and ν_1, ν_2 are neutrino mass eigenstates.

The energy of the emitted photon in the earth reference laboratory system is

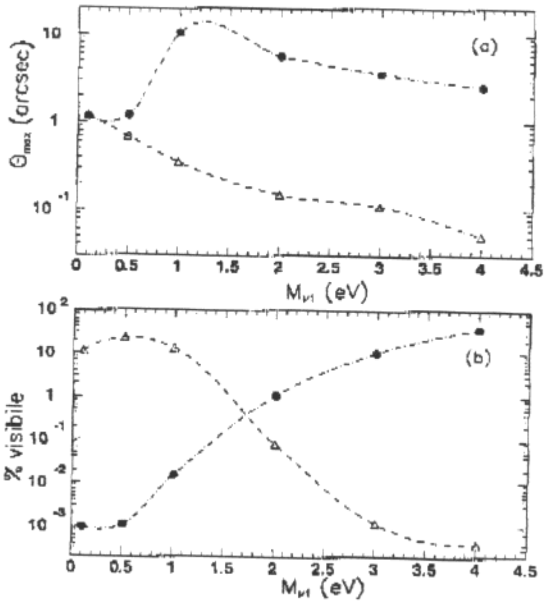

Figure 2: (a) Expected maximum angle of emission of visible photons from radiative solar neutrino decays as function of the ν_1 mass. (b) Percentage of visible photons for different ν_1 mass values. The open triangles correspond to the Super Kamiokande solution with $\Delta m^2 = 6 \times 10^{-6}$ eV^2 and $\sin^2 2\theta = 4 \times 10^{-3}$; the black points correspond to the solution with $\Delta m^2 = 2 \times 10^{-4}$ eV^2 and $\sin^2 2\theta = 0.71$.

$$E_{lab} = E_{cm}\gamma_\nu \left(1 + \beta_\nu \cos\theta^*\right) \tag{2}$$

where E_ν and $\gamma_\nu = \frac{E_\nu}{m_{\nu_2}} = (1-\beta_\nu^2)^{-\frac{1}{2}}$ are in the lab. frame, and θ^* and E_{cm} are the photon emission angle and the energy of the emitted photon in the decaying neutrino rest frame.

For radiative neutrino decays the general expression for the angular distribution of the emitted photons in the rest frame of the parent neutrino is [19]

$$\frac{dN}{d\cos\theta^*} = \frac{1}{2}\left(1 - \alpha\cos\theta^*\right) \tag{3}$$

where the α parameter is equal to -1, +1, for left-handed and right-handed Dirac neutrinos, respectively, and 0 for Majorana neutrinos.

In order to estimate the expected number of photons in the visible range and the maximum angle of emission of visible photons from radiative solar neutrino decays we performed Monte Carlo simulations for neutrino masses in the range 0.1 − 4 eV and two different scenarios of the Sun diameter (~ 12 arcsec); the maximum emission angles for visible photons, with respect to the initial neutrino flight direction, would always be limited to few arcsec (see Fig. 2).

5. Estimate of the lifetime sensitivity

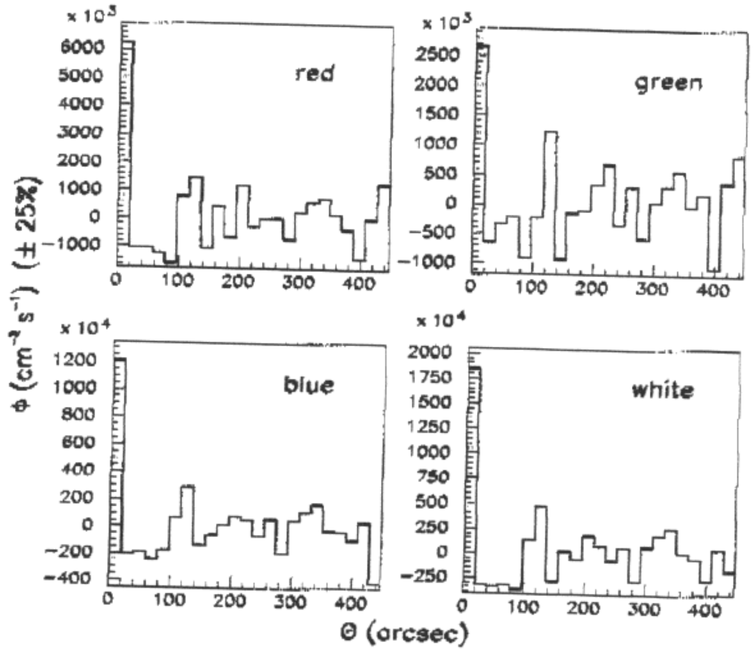

Figure 4: Average residual light fluxes, after moon subtraction and wavelet decomposition, in the red, blue, green channels and summed (white) expressed in photons cm^{-2} s^{-1} as a function of the angular distance from the center of the Moon disk expressed in arcsec.

In order to estimate the lifetime of ν_2 (see Eq. 5) we need to determine the flux of visible photons from $\nu_2 \rightarrow \nu_1 + \gamma$ decay. We performed a wavelet decomposition on the image after subtraction in all color channels.

The wavelet analysis is generally used in order to restore the image and to eliminate spurious signals. We were interested in what is usually considered as "noise"; thus we did not use the terms of wavelet decomposition but we used the residues; in particular we used the fourth order residuals of a wavelet decomposition in the Haar basis [24]; the fourth order is the highest usable order because the subtracted image has dimensions 32×32 pixels [1].

Fig. 4 shows the residuals light signal Φ, after wavelet decomposition, in the red, green, blue and white channels as a function of the distance from the center of the Moon disk. At the beginning of our analysis the 4^{th} order residual flux of the wavelet decomposition was expressed in Acquisition Digital Units (ADU). We made a conversion from ADU to photon flux units

[1] We recall that if the original image has 32×32 pixels, the 1^{th} order image has 2×2 pixels, ..., the 4^{th} order image has 16×16 pixels.

m_{ν_1} (eV)	Δm^2 (eV)^2	$\sin^2 2\theta$	τ (s) Earth sys.	τ_0 (s) proper time
0.1	6×10^{-6}	4×10^{-3}	5.9×10^{3}	1.8×10^{-3}
0.5	6×10^{-6}	4×10^{-3}	1.2×10^{4}	1.9×10^{-2}
1	6×10^{-6}	4×10^{-3}	6.9×10^{3}	2.1×10^{-2}
1	2×10^{-4}	0.71	1.6×10^{3}	5.0×10^{-3}
2	2×10^{-4}	0.71	1.3×10^{5}	0.8
3	2×10^{-4}	0.71	1.3×10^{6}	12.0
4	2×10^{-4}	0.71	4.7×10^{6}	57.8

Table 1: Preliminary lifetime lower limits for a possible radiative decay of solar neutrinos, obtained from the 1999 total eclipse images. The limits are given as a function of m_{ν_1}, Δm^2 and $\sin^2 2\theta$. In the first three columns are given the oscillation parameters used to obtain the limits presented in the last two columns.

pixel a flux $\Phi_\gamma^r = 7.4 \times 10^6$ cm^{-2} s^{-1} in the red channel and $\Phi_\gamma^b = 1.4 \times 10^7$ cm^{-2} s^{-1} in the blue one.

We ascribe to the Poisson spot all the signal in the red channel; thus in the blue channel we obtain a residual photon flux of about $\sim 7\%$ of the signal.

We assume that the relative contribution to the overall decay signal in the white light may be taken as the average of the signals at the two extremities of the visible spectrum, that is 3.5% of the white maximum, thus $\Phi_\gamma^w = 7.4 \times 10^5$ cm^{-2} s^{-1}.

Preliminary results on the limits of the ν_2 lifetime, with respect to its radiative decay in the earth reference system, may be computed from

$$\Phi_\gamma^w = \epsilon \Phi_\nu \sin^2 2\theta \left(1 - e^{\frac{t_{M\to E}}{\tau}}\right) e^{\frac{t_{S\to M}}{\tau}} \tag{5}$$

where $\Phi_\nu = 8.56 \times 10^{10}$ cm^2 s^{-1} is the solar neutrino flux at the Earth computed from the Solar Standard Model, ϵ is the Monte Carlo branching fraction of visible photons produced in the radiative decay (see Fig. 2), θ is the neutrino mixing angle, $t_{S\to M}$ and $t_{M\to E}$ are the average flight times of solar neutrinos (assuming an average energy of about 325 eV) from the Sun to the Moon and from the Moon to the Earth, respectively.

The obtained preliminary lifetime lower limits on a possible radiative decay of solar neutrinos are given in Table 1. The limits are given as function of m_1, Δm^2 and $\sin^2 2\theta$.

The data did not allow to obtain lifetime limits for all mass–Δm^2 combinations. This suggests an underestimation of the contribution of the Poisson spot and of other background sources; thus the lifetime limits in Tab. 1 are conservative lower limits.

6. Conclusions

The analysis of the digitised images measured by a video camera used during the total solar eclipse of August 11, 1999 gave us the opportunity to test our data reduction software and also lead to some interesting results:

a) we evidenced the presence in our data of the Moon image in the light reflected from the Earth;

Large-scale diffraction patterns from circular objects

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The diffraction of light by a U.S. penny and an aperture of the same size with the light source and viewing screen 20 m from the objects has been investigated quantitatively. It was found that the diffraction by these relatively large objects involving such unusually long light paths could be adequately described by the scalar theory of Kirchhoff in the specialized form due to Lommel. Differences noted between the theory and the measurements are discussed with probable causes indicated.

I. INTRODUCTION

A. The problem

The diffraction pattern of a penny on a screen about 20 m away from the penny is a captivating sight. A photograph (Fig. 1) cannot show the phenomenon with the detail and illuminance range seen directly by the eye but at least it can indicate the general nature of the effect. An aperture of the same size produces an equally intriguing pattern. They have been used here to gain the attention and interest of not only those already inclined toward physics, but also of those in general education classes and various visitors. The curiosity aroused in the viewer about the cause of the many circles and bands of light can be partially satisfied by vague references to the wave nature of light, while for the physicist much more satisfaction is possible by a quantitative comparison of what is seen with what can be calculated using a mathematical theory of light.

This paper presents such a comparison, taking for the theory of light the scalar theory of Kirchhoff[1] which is based on the work of Fresnel and Huygens. The successful predictions of this theory have long been appreciated and it is widely taught and used today.[2] The formulation of the theory is in terms of a scalar function which was originally interpreted as the amplitude of a transverse vibration of an ether.

Some related work[3–12] of this nature includes many more interesting diffraction patterns. The comparison[13] most nearly like the present one used diffracting objects less than ¼ the size of a penny and showed computed in-

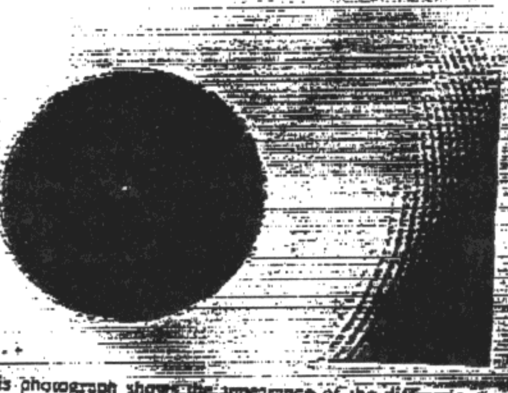
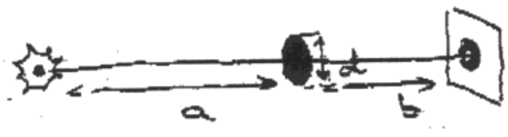


Fig. 1. This photograph shows the appearance of the diffraction pattern due to a penny on a screen which is 20 m from the penny. The source of light is also 20 m from the penny. The Poisson spot is clearly shown in the center of the circular pattern and the distance from this spot to the farthest edge of the photograph is about 5 cm.



if $d \gg \lambda$; $(a+b) \gg d$

↓

The Fresnel diffraction

(Poisson spot)

$I_{spot} \sim I_0$

$I_{spot} = I_0$ for pointlike sources

$I_{spot} = \frac{1}{4} I_0$ for plane waves

but ↑ not true...

assuming

$I_{spot}(\lambda) = k I_0(\lambda)$

one could eliminate the contribution of the Poisson spot!