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Experimental study of Variation of Secondary Cosmic Gamma Ray Flux and Energy during Partial Solar Eclipse of 4th January 2011 at Udaipur, India

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Abstract

The partial solar eclipse at Udaipur (24^0 34' 16.14"N, 73^0 41' 30.22"E), India was experimentally observed on 4th January 2011. A cadence of data was collected using ground based NaI (Tl) Scintillation detector. The analyzed data reveal significant variation in secondary cosmic gamma ray (SCGR) flux and energy. The measured maximum drop in SCGR flux during the partial solar eclipse was about 15 %. This was found well in agreement with what the earlier studies reported during solar eclipse. But unlike earlier findings, we observed an additional peak in the energy spectrum of SCGR flux in the energy range extending from 650.73 keV to 666.51 keV and variation of amplitude in the range of 21% -30% during the progress of solar eclipse. These results of variation of SCGR flux can be explained on the basis of well established shadowing effect of the moon. During maximum eclipse, the galactic cosmic radiations (GCR) and solar energetic particles (SEP) reaching towards the earth atmosphere are obstructed by the moon. However the variation of energy and amplitude of an additional peak observed in SCGR spectrum can be attributed to the gamma ray emission from the moon's surface near its limb by hard hitting of SEP and bent GCR under the influence of strong magnetic field of the sun and the interplanetary magnetic field.

Keywords: Solar eclipse, solar magnetic field, interplanetary magnetic field, bending of primary cosmic ray and solar energetic particle, shadowing effect by moon, high energy gamma ray emission from moon surface near moon's limb.

Introduction

Experimentally explicated cosmic rays are inherent high-energy charged particles that travel at nearly the speed of light and isotropically strike the earth from all directions. Being sure of the experimental outcomes these are nuclei of atoms ranging from the lightest to the heaviest elements in the periodic table[1]. About 89% of these nuclei are of hydrogen (protons), 10% of helium, and about 1% of others heavier elements. Cosmic rays include high-energy electrons, positrons, and other subatomic particles which originate in sources outside the solar system, distributed throughout the Milky Way galaxy. The common heavier elements (such as carbon, oxygen, magnesium, silicon, and iron) are present in the same relative abundance as in the solar system. Nevertheless there are important differences in elemental and isotopic composition that provide information about the origin and history of galactic cosmic rays (GCR). The term, isotropic cosmic ray has also come to address other classes of energetic particles that are associated with energetic events on the sun, also known as solar energetic particles (SEP) and are accelerated in interplanetary space. Presently GCR and SEP have become important components to probe the high energy astronomy.

In order to unveil the hidden secrets of high energy astronomy, technical advances, over more than half century, have been so great that we could achieve objective to pinpoint how astronomical observations and physical concepts interact. For this purpose, a large number of experimental studies to procure good quality data of GCR and SEP have been made. Albeit acquisition of short wavelength data on ground as well as in space is not an easy task, but data are being obtained efficiently with the help of advanced technologies by astronomers, for all celestial events occurring at various points of time. However due to these events, it is found that the characteristics of GCR and SEP are modulated and manifested in the ground based spectrum observed for the terrestrial secondary cosmic gamma rays (SCGR) flux. These SCGR signals carrying the signatures of modulated GCR and SEP are measured by efficient scintillation detectors. Several experimental studies of solar eclipse (one of the most popular celestial event) have been carried out to understand the interactions of GCR and SEP with interplanetary magnetic field, strong magnetic and gravitational field of the sun, as well as their correlations with shadowing effect of the moon and high energy emission of gamma ray from the moon's surface[2,3]. The comparative changes in the observed spectra of SCGR, if detected any, should have direct attribution to the characteristic variations what intruded in the modulated GCR and SEP by celestial events.

In daytime, during total solar eclipse, the new moon passes directly between the sun and the earth and casts a dark umbral narrow shadow, known as path of totality, across the earth. Continuously at all places within the path of totality, throughout the course of transit of the moon, the corona of the sun comes into view with the dark disk of the moon totally obscuring the bright photosphere of the sun. Outside the path of totality, in the moon's partial shadow (the penumbra), some portion of the sun's bright disk remains visible and we observe there what is called, partial solar eclipse. During a partial solar eclipse only the penumbra touches the earth. On 4th January 2011 a partial solar eclipse was witnessed over Europe, Arabian Peninsula, North Africa and Western Asia including northern and western parts of India as shown in figure-1. The present study was conducted on January 4,2011 in India at Udaipur, Rajasthan, where the first contact P1 began at 11:40:11.3 IST, the fourth contact P4 ended at 16:00:53 IST and the maximum partial eclipse occurred at 14:20:00 IST. The sun was obscured about 10% by the moon. The geometric coordinates of the sun and the moon at maximum eclipse were R.A. = 18h59m14.9s, Dec. = -22^0 44'21.1'', S.D. = $00^0$16'15.9", H.P. = $00^0$00'8.9" and R.A.= 18h58m23.85 Dec.= -$21^0$46'01.2", S.D = $00^0$15'18.1", H.P. = $00^0$56'09.6" res. The eclipse magnitude recorded at above geometric coordinates was 0.8578 with gamma=1.0626, Saros series =151, member = 14 of 72.

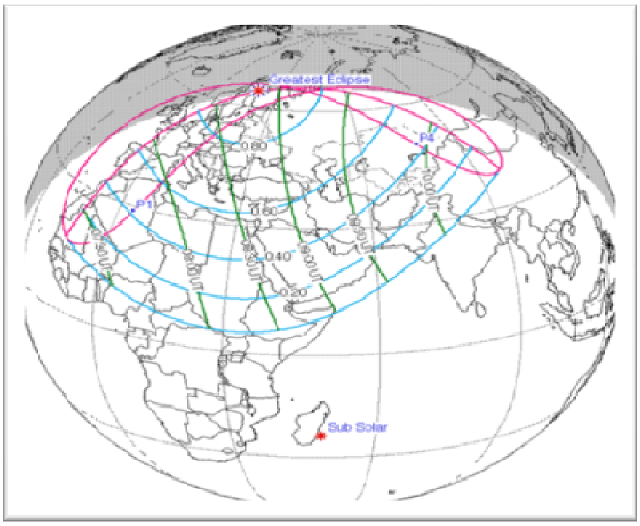

Figure-1
4th January 2011 a partial solar eclipse

Solar eclipse: Varying cosmic flux: The total solar eclipses sweep narrow umbral shadow of air column diameter (~ 10 km) with concentric several kilometers (~ 100 km diameter air column) wide penumbral column of atmosphere in which GCR and SEP flux interact and produce SCGR. Thus in all experimental studies, the spectra of SCGR taken on ground, reveal all the information whatever conveyed by the modulated SEP and GCR in the earth atmosphere. During the total Solar eclipse of 24th October 1995 at Diamond Harbour, Bhattcharya et al.[4] reported ~25% intensity drop of observed SCGR in the energy range of 2.5-3 MeV. Chintalapudi et al.[5] observed a sharp dip of 9% in SCGR and 10% in X ray. Kandemir G. et al.[6] showed the sudden drop of 11% for low energy SCGR during the partial solar eclipse on 11th August 1999, whereas Nayak. et al.[7] studied the total solar eclipse on 1st August 2008 at Novosibirsk, Russia and observed ~ 4% decrease in SCGR flux. Bhaskar et al.[8] also observed maximum drop of SCGR flux in the energy range of 1.0 MeV - 1.5 MeV of about 21% during annular eclipse on 15th January 2010 at Rameswaram, India.

In order to investigate the changes in SCGR spectrum during partial solar eclipse, we planned the experimental study on 4th January 2011 employing scintillation counter at Udaipur, India. During this event, there was a partial shadow due to dark disk of the moon of about 10% over the bright sun, which caused about 15% drop in SCGR flux as discussed in section-4).

Secondary cosmic gamma rays: Variation of energy during the progress of solar eclipse: Isotropic cosmic rays propagate through interplanetary space before arriving on the earth atmosphere[9] bends under the influence of solar and interplanetary magnetic field[10]. In cartoon figure- 2, continuous arrows represent GCR whereas dashed arrows SEP. GCRs are isotropically incident on the upper part of the earth atmosphere but they appear to be convergent from the side of the sun due to the bending under the influence of strong magnetic and gravitational fields of the sun and interplanetary magnetic field as shown in figure-2(a). The bending of cosmic rays was first suggested by Clark[10] and later several other groups (Alexandreas et al., ; Borione et al.,; Pomarede, D. et al.,)[11-13]. Bending of cosmic flux specifically becomes important when the moon is in the line joining the centers of the sun and the earth during the solar eclipse[14, 15]. The exposures of the bent GCR and SEP on the white upper half moon produce X-rays (figure-2(b)).This was proved later by the moon's X – ray image which was taken by ROSAT satellite on June 20, 1990. It suggested that the moon reflected X- ray from the sun and just as it did for visible light. However it was more surprising when observation of the moon was taken in the short wavelength i.e. it was found still brighter in gamma rays than what it was in the X-rays. The gamma ray image (a composite of 8 exposures taken during 1991-1994) of the moon was revealed by EGRET aboard the CGRO satellite**.** It further indicated that high energy cosmic rays continuously collided with the lunar surface that excited the particles on the moon surface and as a result generated gamma rays. This process is similar to the interaction what undergoes on the earth in particle accelerators.

The strong impact of SEP and bent GCR flux on half moon exposed to the sun and the moon limbs may emit high energy gamma rays in the range of several hundred keV to MeV as depicted in figure-2(b) by small oblique arrows from both sides of the moon limbs[16,2,3]. They accompanied by SEP and bent GCR enter in the earth atmosphere and generate their signatures in the spectrum of the SCGRs flux which can be detected using appropriate detector on ground[17,18]. During the progress of the solar eclipse, to investigate how the presence of the moon plays its role in producing variation in energy and flux of gamma rays, we conducted the present study, and observed energy variation using a scintillation detector as described in the subsequent section- 4.

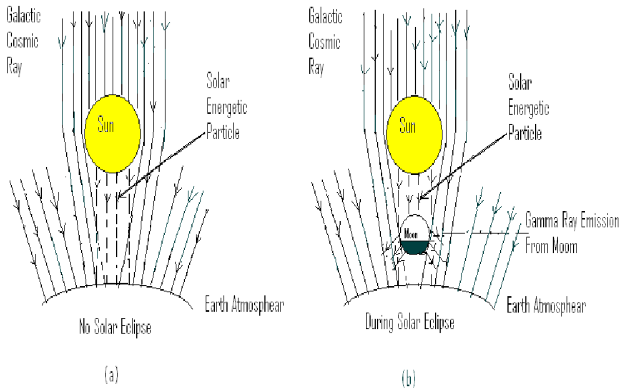

Figure-2
(a) GCR, SEP bend under the influence of strong magnetic, gravitational fields of the sun and interplanetary magnetic field (b) High energy gamma rays emission from moon limbs in the range of several hundred keV to MeV

Methodology

Experimental Set-up and Observations: **S**cintillation detector Model 802 (make: Canberra Genie 2000) was employed to detect SCGR produced by the SEP and GCR during partial solar eclipse in the energy range of 2 keV to 2048 keV [Figure-3**]**. The SCGR were incident on a NaI (Tl) crystal 50 mm thick and 44.5 mm in diameter optically coupled with photo multiplier tube (PMT) Model 2007P. The integral line was connected to a high tension voltage supply model 3102D of 1100 Volts DC. The negative signal of about 0.5 Volts was amplified to 5 Volts positive pulse using negative polarity of spectroscopic amplifier Model 2022. The signal was fed to multi channel analyzer for acquisition and analysis. It has multi channel Buffer of all 1024 energy channels. The entire integrated assembly was put into 2.5 inches lead shield with small opening allowing the pointed secondary gamma rays along the line of site of the partial solar eclipse and disallowing the earth radioactivity background. This counter system (figure-30) was used to collect the counts as a function of time. The scintillation detector was kept on the terrace of computer centre of Mohan Lal Sukhadia University, Udaipur (India). The data files were stored in computer of every half an hour duration from 13.00 IST to 16.00 IST on pre eclipse normal day 2nd January as well as on post eclipse day 6th January 2011 and also on partial eclipse day 4th January 2011 from 13.00 IST to 16.30 IST. Maximum eclipse period was 14.20 IST. The energy calibration was observed to be 2.0 keV per channel using standard radioactive sources Cs^{137}.

Results and Discussion

Analysis and Results: Figure-4 shows the total integrated counts over the half an hour of SCGR flux as a function of time of progress of the partial solar eclipse. During the course of time of the 4th January eclipse day the observed integrated counts were between 61000-62000 but at the time of maximum eclipse there was a drop of integrated counts to 52524 i.e. about 15 % decrease in the counts of SCGR flux. The result clearly shows the shadowing effect of the moon during maximum time of eclipse.

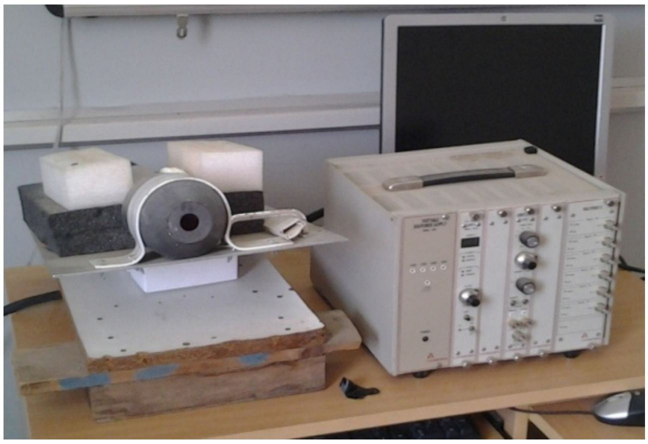

Figure-3
Scintillation detector counter system

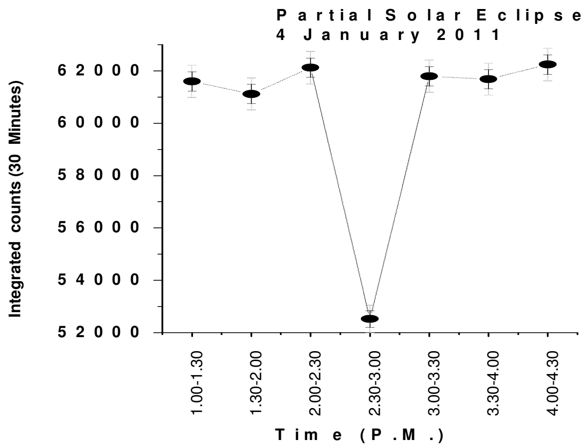

Figure-4
Total integrated counts over the half an hour of SCGR flux as a function of time

The time dependent energy spectra of SCGR flux detectable on the ground are a result of interaction of incident cosmic ray with atmosphere of the earth. As depicted in the panels of figure-5, the energy spectrum of SCGR flux on pre eclipse day (2nd January), partial eclipse day (4th January) and post eclipse day (6th January 2011) in the energy range between 200 keV – 1600 keV were taken. The first, second and third panels of energy spectrum from left to right were observed during the period from 1-4 P.M. of duration of half an hour data files. In both panels of energy spectra of pre and post eclipse days, there is no specific peak but on partial eclipse day 4th January there is a clear additional specific peak in the energy range of 600 keV to 700 keV.

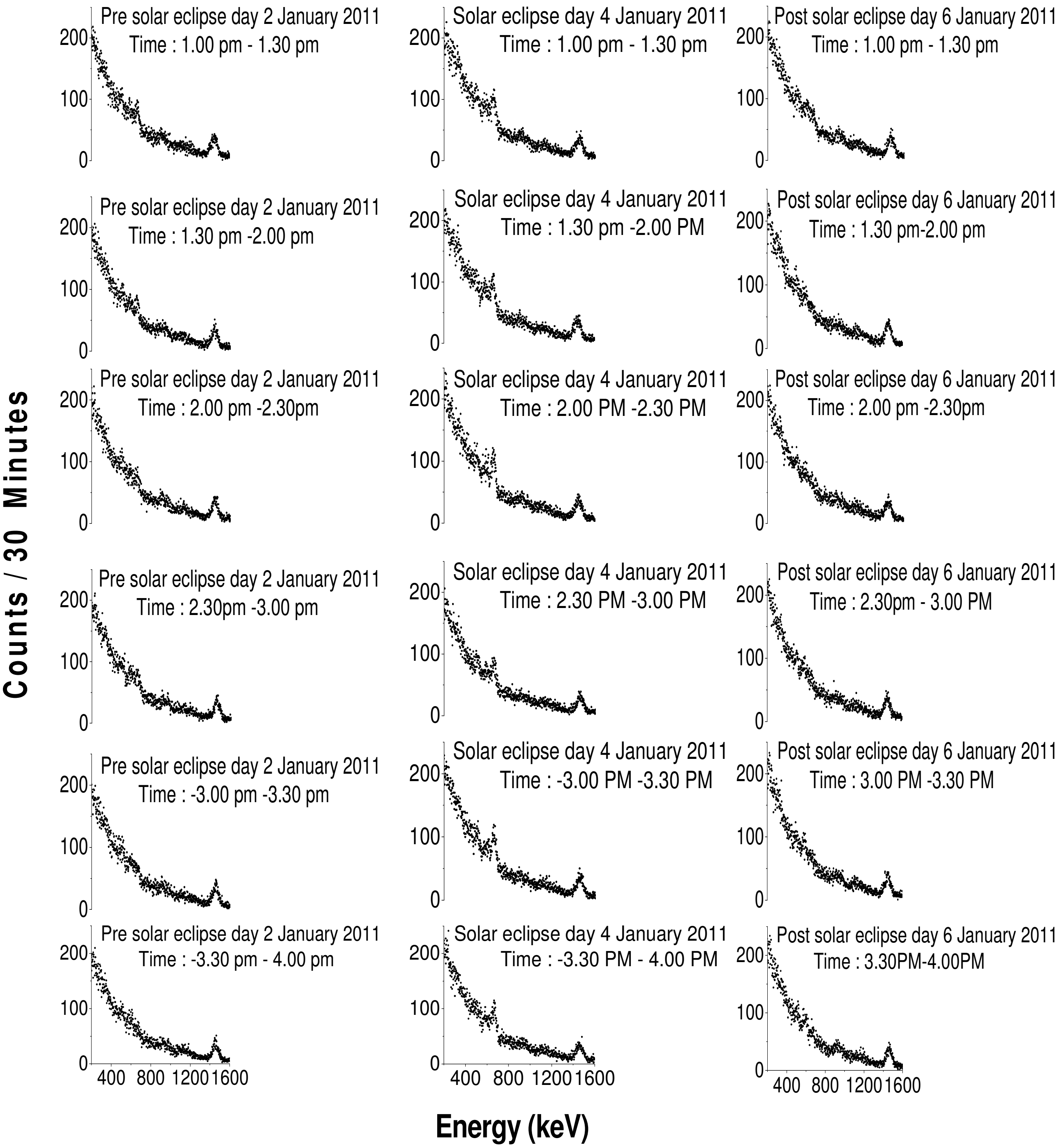

Figure 5

Panels of energy spectrum of SCGR flux on pre eclipse day (2nd January), partial eclipse day (4th January) and post eclipse day (6th January 2011)

To confirm this additional specific peak in spectrum we used the counts ratio technique. We took ratios of data between eclipse day 4th and normal days 2nd, 6th January2011. First we tried the count ratios between two normal days (2nd and 6th January) data files from time 1P.M. to 1.30 P.M., 2.00P.M. to 2.30 P.M. and 3.30 P.M. to 4.00 P.M. to search for the existence of additional peak as shown in figure-6. Right panel shows no such peak in the spectrum between energies 200keV to 1600keV during normal days. It enabled us to conclude for the absence of the peak.

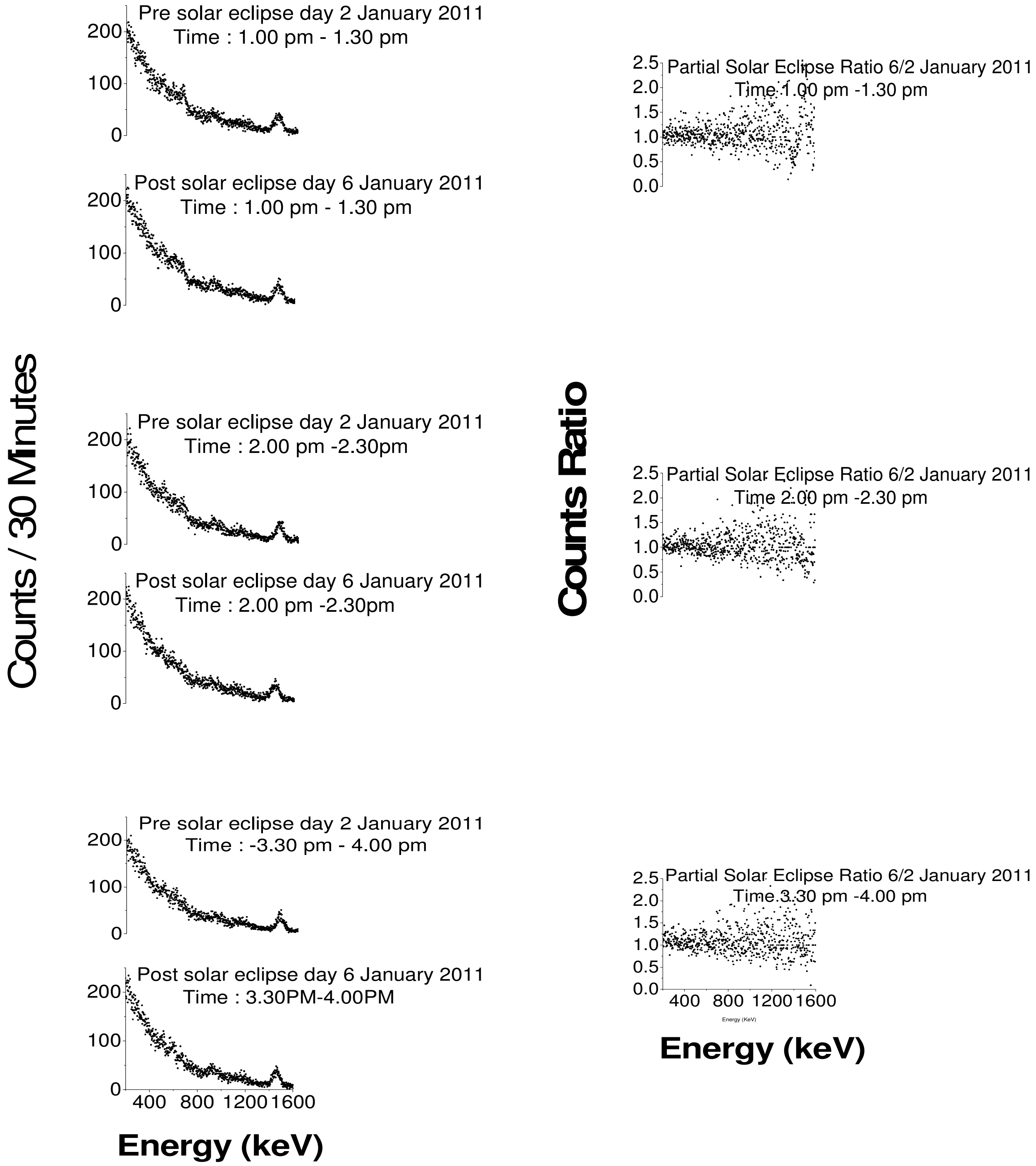

Figure-6
Panels of energy spectrum of SCGR flux on pre eclipse day (2nd January), and post eclipse day (6th January 2011) and count ratios between two normal days (2nd and 6th January) from time 1P.M. to 1.30 P.M., 2.00P.M. to 2.30 P.M. and 3.30 P.M. to 4.00 P.M.

Further, we took count ratios of data between eclipse day 4th January and other two days 2nd and 6th January in the same time scale of half an hour from 1 P.M. to 4 P.M. Figure-7 shows significant peak of SCGR between energy ranges 600 keV to 700 keV. This becomes much clear with the progress of the eclipse.

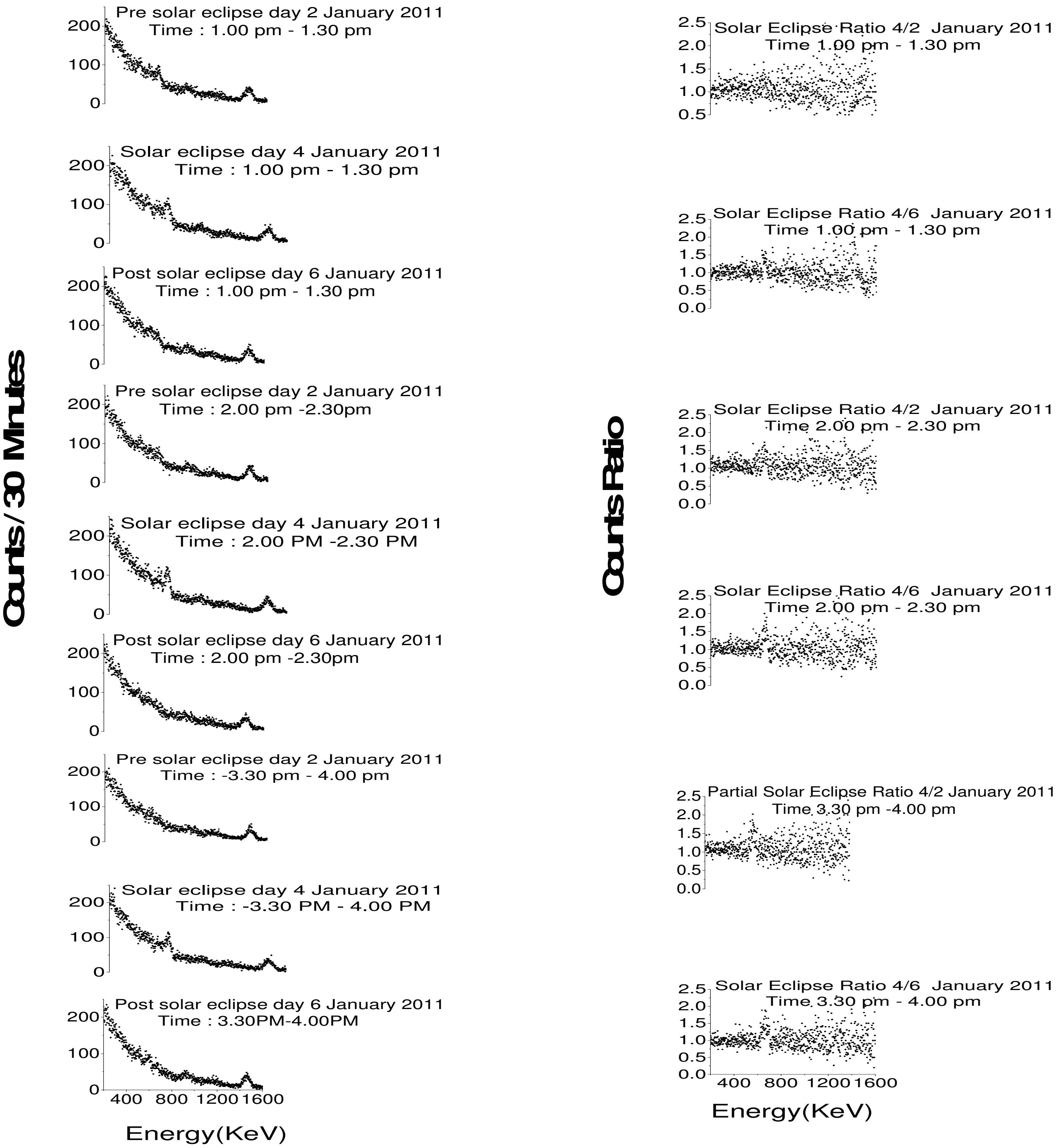

Figure-7

Panels of energy spectrum of SCGR flux on pre eclipse day (2nd January), partial eclipse day (4th January) and post eclipse day (6th January 2011) and count ratios between partial eclipse day (4th January) with Pre eclipse day, post eclipse day (2nd and 6th January 2011) from time 1P.M. to 1.30 P.M., 2.00P.M. to 2.30 P.M. and 3.30 P.M. to 4.00 P.M.

Right panel of figure-7 shows existence of the specific peak with the progress of partial solar eclipse and goes on becoming clearer from 1.30P.M. to 4 P.M. In order to understand the characteristics and energy- variation of SCGR peak in the energy range of 600 keV to 700 keV, we fitted Lorentz peak in the data as shown in figure-8.

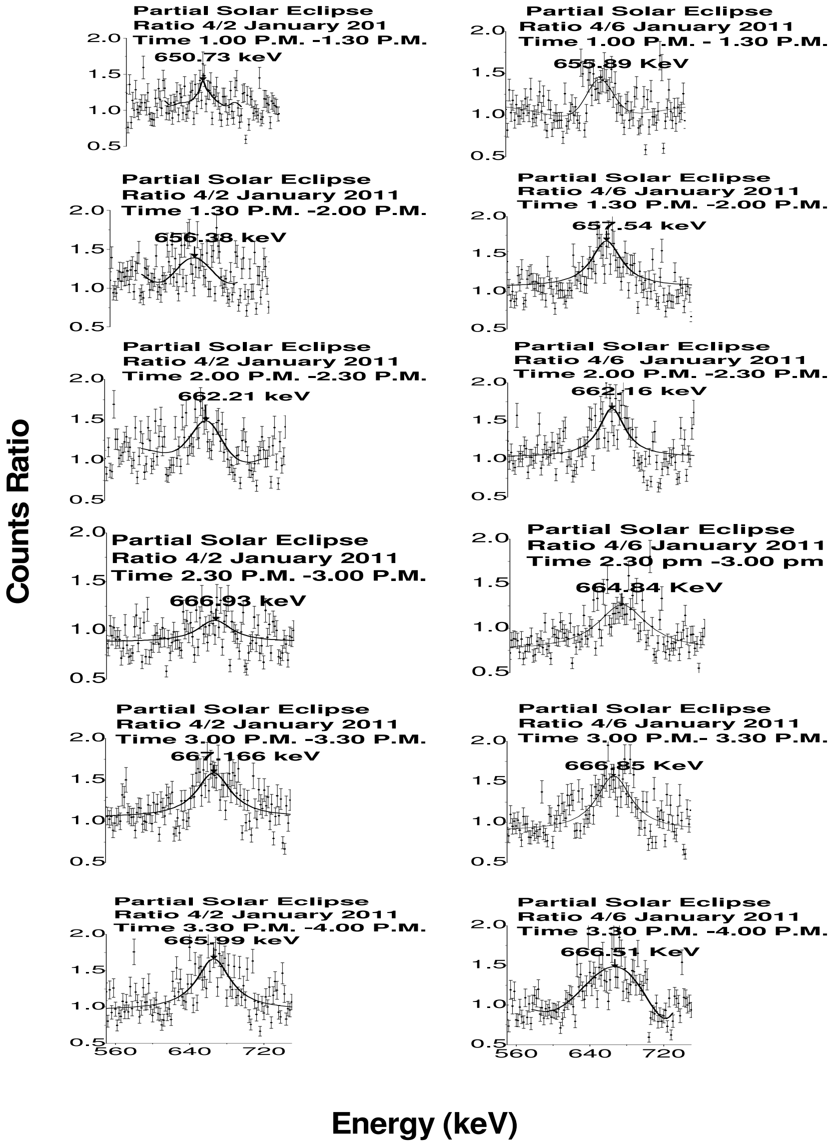

Figure-8
Panels of SCGR specific peak in the energy range of 600 keV to 700 keV with the progress of partial solar eclipse from 1.30P.M. to 4 P.M.

Although a few initial fittings of the data (top of left panel) were difficult but for the rest of the data Lorentz peak was fitted with Chi- square value of about 0.03. The time dependent energy spectrum analysis clearly shows that with the progress of the eclipse, the energy of the observed peak vary consistently from 650.73 keV to 666.51 keV on eclipse day with respect to pre eclipse day 2nd January and for post eclipse day 6th January. As shown in figure-9, the variation in peak energy is about 2.5%, which is noticeable and may be more important issue to resolve in the next study on solar eclipse.

The above results confirm that bending of cosmic flux becomes significant besides the often observed shadows from the sun and the moon when the moon is in the line joining the centers of the sun and the earth at time of the Total Solar Eclipse (TSE). During the progress of the solar eclipse, the intrusion of the moon is likely to produce variation in energy of cosmic ray flux [16, 2, 3]. In fact it may be attributed to strong impact of primary SEP and bent GCR flux on the moon limbs which produce high energy gamma ray emissions in the range of several hundred keV to MeV i.e. between the observed values of 650.73 keV and

666.51 keV. We observed peak amplitude as function of time as plotted in figure-10. It points that at the time of maximum partial eclipse, amplitude of peak decreased to 21% -30% which is significant and supports shadowing effect.

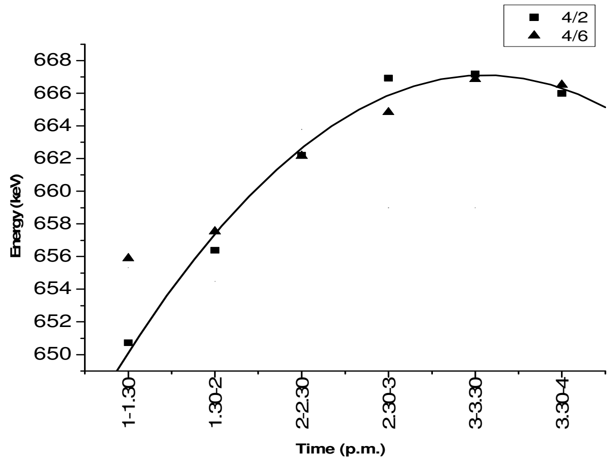

Figure-9
The variation in SCGR specific peak energy in the range of 600 keV to 700 keV with the progress of partial solar eclipse from 1.30P.M. to 4 P.M.

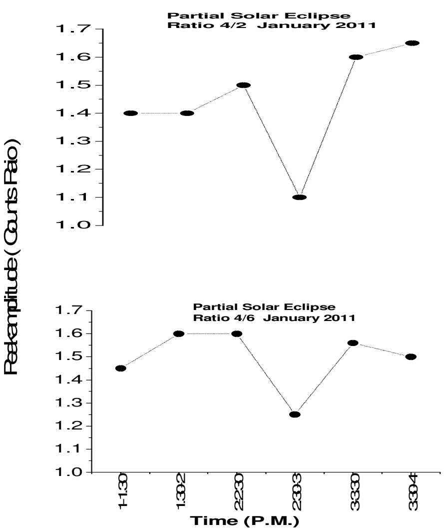

Figure-10
SCGR specific peak amplitude variation as function of time energy in the range of 600 keV to 700 keV

Before and after the maximum eclipse time, peak amplitude varied between 1.4 and 1.6; at the time of maximum eclipse it decreased up to 1.1 to 1.2. It proved blocking of flux and moon's shadow effect in good agreement with the earlier studies done during the progress of eclipse.

Discussions: The observed results of the present study for the variation in SCGR flux, as well as the energy and amplitude of specific energy peak can be understood by the following arguments: i. The moon appears to act like a big celestial umbrella to stop incident cosmic flux along the path of maximum of solar eclipse. As the eclipse progresses the shadow effect of the moon becomes significant at the time of maximum of eclipse. It cuts radiation flux causing drop in the counts of SCGR flux figure- 4 and figure-10. These results are well consistent with the earlier studies. ii. Unlike the earlier studies, the clear additional specific peak appearance in SCGR spectrum during the solar eclipse is a unique finding of this study [figure-5 and figure-7]. It may be attributed to emission of gamma rays from the moon's limbs after hard hitting of SEP and bent GCR figure-2. These gamma rays from the moon accompany with the incident GCR, SEP and enter in the earth atmosphere. These produce variation in energy of SCGR specific peak between 600 keV to 700 keV. The detected energy variation of specific peak is albeit small (about 2.5%) but its amplitude variation (figure-10) is significant (about 21-30%). This is a new observation first time reported in the present study during partial solar eclipse and may be examined in detail with more statistics in the next total solar eclipse.

Conclusion

From Above points (1) and (2) we can understand that as the eclipse progresses the shadow effect of the moon becomes significant and at the time of maximum of eclipse, it cuts radiation flux causing drop in the counts of SCGR and unusual variation in energy of SCGR specific peak between 600 keV to 700 keV.

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