The 6th World Multiconference on Systemics, Cybernetics and Informatics

July 14-18, 2002
Orlando, Florida, USA

PROCEEDINGS

Volume XVII

Industrial Systems and Engineering III

Organized by IIIS
International Institute of Informatics and Systemics

Member of the International Federation of Systems Research IFSR

EDITED BY
Nagib Callaos
Yigang He
Jorge A. Perez-Peraza

Heliospheric Observations:
Temporal profiles of GSEP events from EPHIN/SOHO Measurements.

L. del Peral, D. Rodríguez-Frías, R. Gómez-Herrero, J. Gutiérrez,
Departamento de Física. Universidad de Alcalá, 28871 Alcalá de Henares, SPAIN
J.Pérez-Peraza, E. Palomares
Instituto de Geofísica, UNAM 04510 - C.U., Coyoacán México D.F., MEXICO
A. Gallegos-Cruz
UPIICSA del IPN, Ciencias Básicas, Te 950, Iztacalco 08400, MEXICO

Abstract. This work is a preliminary study of 18 solar energetic particle (SEP) events detected by SOHO/EPHIN between 1996 and 2000. It has been separated in two parts: one for Impulsive events and this one for gradual SEP events. Temporal profiles of GSEP events have been parameterized to determinate differences among SEP events depending on the magnetic connection and Physical conditions of the interplanetary transport.

1 Introduction

Temporal evolution of energetic particle intensities during GSEP events observed at 1 AU is determined mainly from the injection at source and the interplanetary transport conditions (magnetic connection between the source and the observer and amount of scattering in the interplanetary medium). According to the "current paradigm" (Reames 1999), the extended intensity-time profiles of gradual events come from continued particle acceleration in spatially extended coronal/interplanetary shocks driven by fast CMEs. The amount of interplanetary scattering depends on the inherent conditions of interplanetary medium, but also may be affected by the event size, since very large gradual events may generate interplanetary magnetic field turbulence themselves (Mason et al, 1989).

2 Instrumentation and data selection

Temporal profiles presented here were observed with EPHIN instrument onboard SOHO spacecraft, located in an halo orbit around lagrangian point L1. The instrument is a stack of five cylindrical solid state detectors (see Müller-Mellin et al, 1995 for a detailed description), it points permanently in the nominal direction of the interplanetary magnetic field, 45° West from sun-spacecraft line. EPHIN provides counting rates of Hydrogen and helium isotopes in the energy range 4-53 MeV/n, and electrons between 0.25 and 10.3 MeV. Maximum temporal resolution is 1 minute. For this study we have selected counting rates in the lower energy channels: 4.3-7.8 MeV/n for Hydrogen and helium nuclei and 0.25-0.7 MeV for electrons. Pulse height analyzed data have also been examined to obtain $^3He/^4He$ ratios for the identification of impulsive events.

We have selected 18 SEPs events between July 1996 and August 2000. Seven events have been classified as impulsive (del Peral et al., "Heliospheric Observations: Temporal profiles of ISEP events from EPHIN/SOHO Measurements" on this proccedings). Nine events have been classified as gradual, all of them have associated CMEs and low $^3He/^4He$ ratios (^3He is not visible above background for most of them). We have checked solar wind data from MFI and SWE instruments onboard WIND spacecraft, and interplanetary shocks passages have been identified for six of these events in the four days following the CMEs. Five of the gradual events presented here show ion acceleration beyond 50 MeV/n, and they have been detected at ground level (GLEs). Finally, we have selected two events classified in the bibliography as mixed or hybrid events: July 9, 1996 (mixed-impulsive) and December 24, 1996 (mixed-gradual).

3 Data analysis

The fifth and sixth columns in Table 1 list the onset times for electrons and protons, determined using 5 minute averaged counting rates. The next four columns contain the parameters of the associated flare (location, Hα and X-ray classification, time of maximum in X-ray, and X-ray duration, obtained from Solar Geophysical Data). Columns 11-13 list the parameters of the associated CMEs (LASCO data): First appearance time in C2 coronagraph, estimated speed, and direction of propagation. Last column contains the passage times of IP shocks by the position of WIND spacecraft.

Using 30 minute averaged counting rates of electrons, protons and helium nuclei, we measured the time from the onset to the absolute maximum (T_r), the time from absolute maximum until the recovery of initial flux level (T_d), and the ratio R between the maximum differential flux and the differential flux at onset time. When the event is truncated by a subsequent one, T_d is only a lower limit. We also tried a parameterization of the profiles, fitting them to a pulse function:

$$j = j_0 + A\left[1-\exp\left(-\frac{t-t_0}{\tau_1}\right)\right]^P \exp\left(-\frac{t-t_0}{\tau_2}\right) \quad (1)$$

where, j_0 (ambient flux level) and t_0 (onset time) are fixed parameters, and A (amplitude), P (power), τ_1 and τ_2 (characteristic rise and decay times) are fitted parameters. We use this parameterization only to characterize

amplitude and rise and decay times, no attempt has been made to modelize interplanetary transport.
Table 2 lists the measured parameters Tr, Td, R and the fitted parameters τ_1, τ_2, A for electrons, protons and helium nuclei. Figure 1 shows the temporal profiles of four gradual and four impulsive events selected among the 18 events presented here.

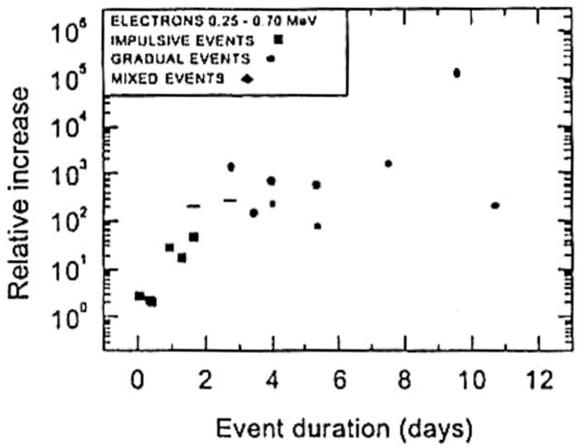

Fig. 1. Events durations versus relative increases for 0.25-0.70 MeV electrons.

4 Gradual solar energetic particle events

November 28, 1996
This SEP event presents a composition features typical of GSEP events, with coronal abundances of He He/p = 0.023), low abundances of ^{3}He (^{3}He/^{4}He<0.01). This SEP event is dominated by protons (e/p=6.7). There are some solar flares but the SEP event seems to be rela-ted to a CME observed at 16:50 UT of 970 km/s velocity with a driven shock arriving at the Earth at 00:33 UT of December 1, 1996, that should accelerate particles. The proton and Helium energy spectra have very similar spectral index, that means a common shock acceleration without a preferential acceleration.
On December 3, at 00:41 UT a second shock is arriving and an halo CME is detected at 15:35 UT with 613 km/s is observed by LASCO reaching the SOHO position at 12: UT of December 5.

December 24, 1996
The SEP event of December 24, 1996 has a very low abundance of Helium and low e/p ratio with a hard proton spectrum (γ_p=2.33) and no ^{3}He is found. It has not been observed a shock arriving at the SOHO position while a magnetic cloud in coincidence with the SEP event has been detected. This suggests us to classify this event as GSEP. The energy spectrum presents an index γ=2.33 in concordance with a shock with strength r=2.8.

April 1, 1997
This is another GSEP with low e/p and He/p ratios. It was East connected to the M1.9/1B solar flare on S25E16 location. The hard energy spectra, γ_p=1.95 and γ_{He}=2.46 with proton acceleration above 25 MeV. No shock has been detected and only 296 km/s CME was detected by LASCO.

A 3 % of Helium is ^{3}He. Therefore the event should be gradual although no shock is observed that produces particle acceleration.

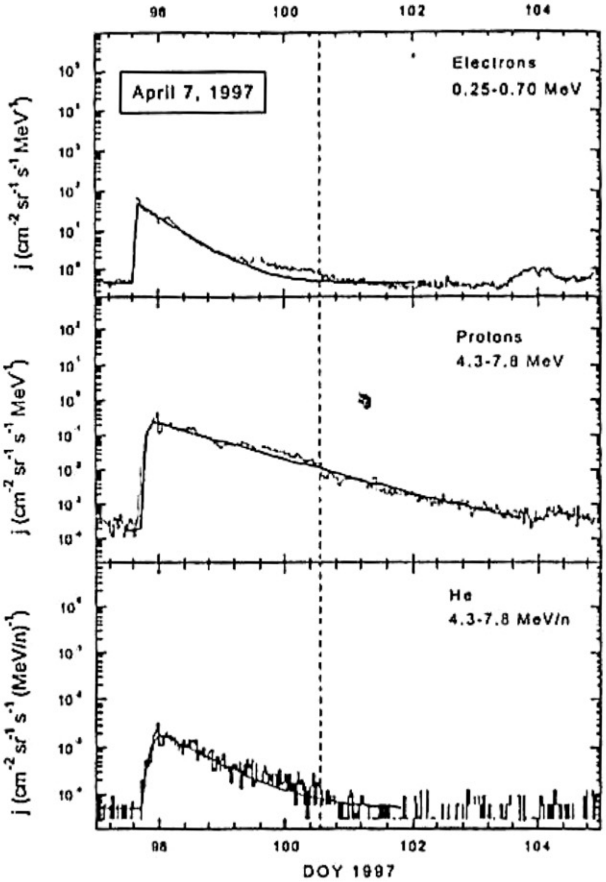

Fig.2. April 7, 1997 GSEP event temporal profiles.

April 7, 1997
This is a typical GSEP event associated with the C6.8/3N solar flare on S30E19, started at 13:50 UT of April 7. A shock, driven a 800 km/s fast CME observed at 14:27 UT by LASCO, arrived at 13:00 UT of November 10 and should accelerate particles with very similar spectral index, γ_p=2.65 and γ_{He}=2.85. Following the shock the leading edge of the CME was at 6:00 UT of April 11 up to the trailing edge at 19:00 UT. After the shock passage the spectral index remains constant for protons and Helium. Moreover low e/p, He/p and ^{3}He/^{4}He ratios were registered.

September 17, 1997
Associated with a M1.0/SF solar flare at the N21W84 location of the NOAA 8084 active region, at 17:45 UT, another ^{3}He-rich ISEP event was detected by SOHO/EPHIN. It presents a ^{3}He/^{4}He=0.18 ratio and high abundance of electrons, e/p=527, and Helium, He/p=0.155. A halo CME at 20:28 UT was observed by LASCO, drived by a shock. The CME passage account 261.0-263.S and seems not to contribute to the acceleration in the impulsive flare. SEP particles travel through a 350 km/s solar wind plasma during 1.13 AU, reaching 5 MeV protons to SOHO/EPHIN at 20:52 UT. The event is a joint of two events, and the second one is related to the solar flare of September 8, at 1:39 UT in the 8085 NOAA active region.

September 20, 1997
It is a GSEP event with some features typical of ISEP events. There is a solar flare (0087 B8.01) that may generate SEP 1 MeV electrons observed at 3:35 UT by EPHIN and 5 MeV protons observed at 13:43 UT. The electron to proton ratios are low. Coronal abundance He/p ratio was found but more ^{3}He than expected is this kind of events was detected. The passage of a CME with velocity between 264.9 km/s and 265.9 km/s is caused by a shock driven at 12:00 UT of DOY264. The spectrum index of Helium and protons is very similar. This lead us to the conclusion that the acceleration took place in the same conditions, with no preferencial acceleration mechanisms. The ^{3}He observed must be originated in the flare that was magnetically well conected.

September 24, 1997
This was a SEP event with a very hard proton spectra, γ_p=1.48. The e/p ratio and low abundances of helium and the absence of ^{3}He lead us to classify this event as GSEP. The problem is that no shock is found that could accelerate SEPs. On September 23 a halo CME could be responsible of the SEP generation. The CME had a 760 km/s speed and was observed at 22:02 UT. Thus when in the NOAA 8088 region a M5.9/1B solar flare starts at 2:43 UT on S31E19 location, the CME-driven shock was travelling through the interplanetary medium. This shock should accelerate particles generating the observed SEP population. The proton spectral index suggests a very strong shock with r=4.

November 4, 1997
This GSEP event is related to a X2.1/2B flare on the NOAA 8100 active region at 5:52 UT on S14W33 and a halo CME at 6:10 UT with driven shock that is reaching the Earth vicinity. The CME passage ocurrs during detection of SEP of November 6, 1997. The event shows coronal abundances with low e/p=25.9, ^{4}He/p=0.022 and ^{3}He/^{4}He <0.01 ratios, high energy particle generation (i.e. e>10 MeV, p and He >50 MeV/n). The event was detected at ground level by neutron monitor arrays. The electron, proton and helium energy spectra show the same temporal behaviour and values accounting for a same origin of the SEP. This GSEP event is west correlated showing a fast increase and an exponential decay in the temporal profile. The spectral index γ_p=2.02 indicates a strong shock of r=3.9 compresion ratio.

November 6, 1997
A second GSEP event was observed in the same NOAA active region, located on S18W63. The event is associated to a new X9.4/2B solar flare started at 11:49 UT of November 6, 1997. A fast CME was detected by LASCO at 12:10 UT of November 6. This CME was very fast and the spectral index of the SEP indicates a strong shock associated, with a r=2.3 compression factor. Particles of hundred of MeV/n were observed. The energy spectral index of protons and helium are closed indicating, as in the previous event, a shock acceleration of coronal material. The temporal profiles correspond to a well magnetically connected west event. The SEP composition are exactly the same of the previous event, only is appreciated more ^{3}He and electrons that can be explained by a better magnetic connection of the observer that can allow the observation of ^{3}He and electrons accelerated at the flare region. A more detailed description of this event can be found in Gómez-Herrero et al., 2002..

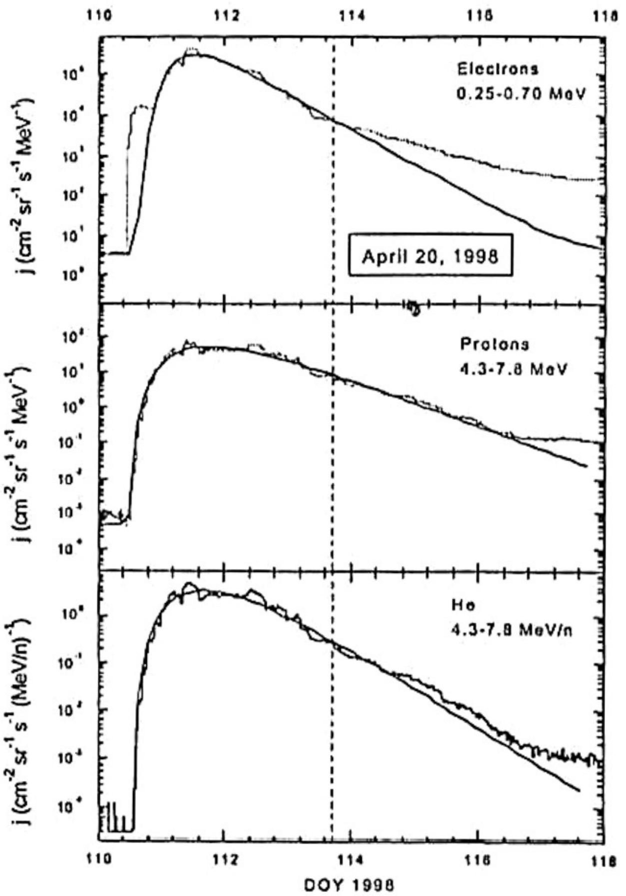

Fig.3. April 20, 1998 GSEP event temporal profiles 30 minutes averaged.

April 20, 1998
This is a typical GSEP event with high abundance of electrons and low He and ^{3}He abundances.The event is associated with a M1.4 solar flare in the NOAA 8194 active region at S43W90 location, detected in X-ray at 9:38 UT of April 20, 1998. A fast CME was detected by LASCO at 10:07 UT of April 20 with 1,638 km/s speed. The shock arrived at the SOHO position at 16:48 UT of April 24. The shock was strong generation very hard energy spectrum of SEP γ_p=1.16.

April 4, 2000
This GSEP event is associated with the C9.7/2F solar flare on the NOAA active region N16W66, starting X-ray emission at 15:41 UT. Fast halo CME was observed by LASCO C2 coronagraph at 16:32 UT with 984 km/s velocity generating observable interplanetary shocks that can be observed in Figure 4 marked. Two over imposed profiles can be appreciated in the electron temporal profiles.

June 6, 2000

This was a GSEP event with very strange temporal profile with very gradual increase in the flux and multiple particle injection evidence. It is associated to X2.3/3B solar flare located on the disk at N20E18 and related halo CME of 908 km/s velocity. X-ray emission start at 15:25 UT and first electrons arrive SOHO position at 16:48 UT and at 19:15 arrive first protons. The halo CME was observed by LASCO at 15:54 UT and the shock pass through SOHO position at 9:04 UT of June 8.

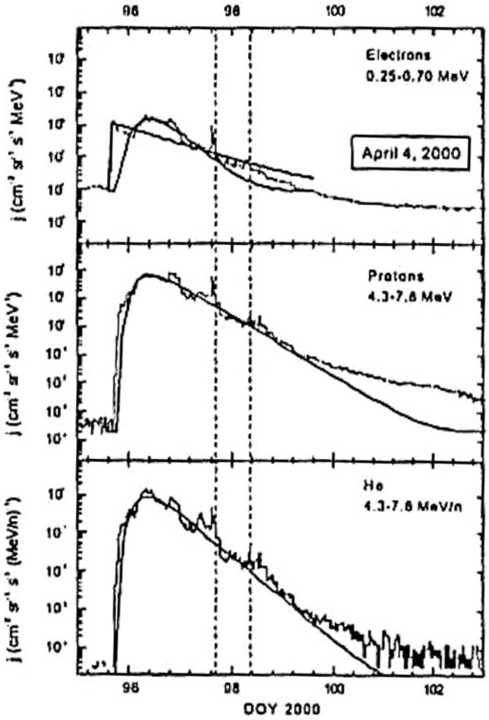

Fig. 4. April 4, 20002 GSEP event temporal profiles 30 minutes averaged.

6 Conclusions

Event duration and relative increase provide a good distinction between impulsive and gradual events. Relative increase factors in particle fluxes are less than 200 for impulsive events, and can reach more than 10^5 for gradual events. Figure 1 shows A versus T_d plot for electrons.

- Fitted parameter τ_1 provides a good characterization of the rise phase steeping, but there is not clear distinction between gradual and impulsive events. Gradual events tend to rise slower than impulsive ones, but there are gradual events with steep rise (May 27, 19970+).
- All the gradual events show a long diffusive decay phase ($\tau_2 > 0.4$ for H and He). The shape of the decay phase may be affected by interplanetary disturbances like shocks and magnetic clouds. Sometimes (e.g. June 6, 2000) shock passage can be appreciated as a peak in particle fluxes caused by particles trapped near the shock (energetic storm particles, ESP).
- Global shape of temporal profiles for gradual events are usually well explained on basis of the magnetic connection between the observer and the 'nose' of the shock where acceleration is strongest (Reames, 1999), which is optimal early in the event for west connected events, and later for east connected events. The extremely long rise times observed in some events (June 6, 2000) may be due to additional particle acceleration in shocks driven by a second CME (Kahler, 1993).

Some gradual events show a prompt peak followed by a secondary maximum or a plateau. This component might be accelerated in the flare but it only could be determined with a more detailed study.

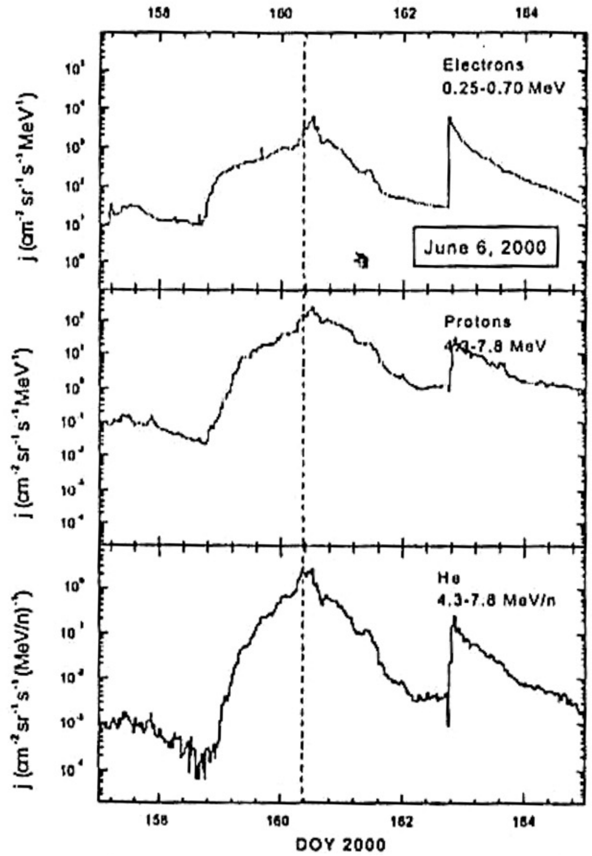

Fig. 5. June 6, 2000 GSEP event temporal profiles 30 minutes averaged.

Acknowledgements: We acknowledge the teams of WIND/MFI and WIND/SWE instruments for the use of KP data. The SOHO/LASCO CME lists used here are produced by a consortium of the Naval Res. Laboratory (USA), Max-Planck-Institut für Aeronomie (Germany), Lab. d'Astronomie (France), and the Univ. of Birmingham (UK). This work has been supported by the spanish Ministerio de Ciencia y Tecnología (MCYT) under project BXX2000-0784 and by the University of Alcalá under project E010/2001. SOHO is a project of international cooperation between ESA and NASA

References

Del Peral, L. Et al., *"Heliospheric observations: temporal profiles of ISEP evetns from EPHIN/SOHO measurements"* these proceedings 2002.

Gómez-Herrero, R. et al., *Astroparticle Physics, 17,* 1-12, 2002

Kahler, S.W., *J. of Geophys. Res., 98* 5607-5615, 1993

Kallenrode, M.B., Cliver E.W., and Wibberenz, G., *Astrophysical Journal, 391,* 370-379, 1992

Mason, G.M. et al, *Astrophysical Journal, 339,* 529-544, 1989

Müller Mellin, R. et al., *Solar Physics, 162,* 483-504, 1995.

Reames, D. V., *Space Science Reviews 90,* 413-491, 1999.

Table 1. Selected SEP events and associated flares and CMEs.

				Onset time		Flare				CME			
Event	Class	Date (m d, y)	Date (DOY)	~0.3 MeV electrons (hh:mm)	~6 MeV protons (hh:mm)	*Hα* Location	Hα/XR Class	Xray tmax (hh:mm)	Xray durat. (min)	C2 App. time (hh:mm)	Primary speed (Km/s)	Direction of propag.	IP Shocks passages DOY:hh:mm
1	MG	Dec. 24, 1996	359	13:22	15:00	-	-/C2.1	13:11	20	13:28	300	W	-
2	G	Apr. 1, 1997	91	>8:58	14:37	S25E16	1B/M1.9	13:48	36	15:18	296	E	-
3	G	Apr. 7, 1997	97	14:16	16:07	S30E19	3N/C6.8	14:07	29	14:27	830	Halo	100:13:00
4	G	Sep. 24, 1997	267	03:00	05:45	S31E19	1B/M5.9	02:48	9	02:51[a]	>300	SE	(274:01:00)
5	G	Nov. 4, 1997	308	06:14	08:35	S14W33	2B/X2.1	05:58	10	06:10	830	Halo	310:22:10
6	G	Nov. 6, 1997	310	12:12	15:30	S18W63	2B/X9.4	11:55	12	12:10	1560	W	313:10:00& 313 22:30
7	G	Apr. 20, 1998	110	10:25	11:00	S43W90	EPL/M1.4	10:21	100	10:07	1638	W	113:17:30
8	G	May. 27, 1999	147	10:55	11:51	-	-/C1.2	09:17	7	11:06	?	Halo	-
9	G	Apr. 4, 2000	95	15:21	16:50	N16W66	2F/C9.7	15:41	53	16:32	984	Halo	97:16:27& 98:09:16
10	G	Jun. 6, 2000[b]	158	16:48	19:15	N20E18	3B/X2.3	15:25	42	15:54	908	Halo	160:09:04

[a] Moreton wave observed by SOHO/EIT in NOAA AR 8088
[b] Very long rise time in particle fluxes. Evidence of multiple injection (X2.3 & X1.2 flares at 158:15:25 & 159:15:53 both of them accompanied by halo CMEs)

Table 2. Measured and fitted parameters of temporal profiles. (Tr, Td, τ_1, and τ_2 in days. A in $cm^{-2} sr^{-1} s^{-1} (MeV/n)^{-1}$, R adimensional)

	Electrons						protons						Helium					
Event	Tr	Td	R	τ1	τ2	A	Tr	Td	R	τ1	τ2	A	Tr	Td	R	τ1	τ2	*A*
1	0.06	1.68	197	0.002	0.222	155	0.44	3.50	1300	0.123	0.501	0.09	-	-	-	-	-	-
2	0.50	5.40	75.4	0.103	0.668	85.5	0.96	5.96	848	0.350	0.961	0.07	0.73	2.32	28.3	0.905	0.596	$2.1 \cdot 10^{-3}$
3	0.09	3.46	144	0.009	0.429	59.8	0.31	6.22	2529	0.051	0.843	0.34	0.27	2.64	70.1	0.092	0.616	$3.3 \cdot 10^{-3}$
4	0.11	10.7	199	0.009	0.435	55.3	0.21	7.48	162	0.173	0.980	0.02	-	-	-	-	-	-
5	0.07	2.78	1344	0.018	0.282	$1.5 \cdot 10^{4}$	0.23	2.70	450	0.030	1.557	9.32	0.23	2.70	$1.3 \cdot 10^{4}$	0.017	1.262	0.24
6	0.48	7.53	1509	0.105	0.434	$3.3 \cdot 10^{5}$	0.58	7.32	96.0	0.173	0.620	245	0.35	7.34	265	0.134	0.599	6.20
7	1.06	9.57	$1.3 \cdot 10^{5}$	0.366	0.493	$6.2 \cdot 10^{6}$	0.98	9.55	$2.5 \cdot 10^{5}$	0.929	0.659	1405	0.88	9.45	$1.6 \cdot 10^{5}$	1.115	0.523	153
8	0.06	5.35	541	0.002	0.169	1909	0.17	5.37	$2.7 \cdot 10^{4}$	0.007	0.535	2.49	0.06	4.83	286	0.005	1.165	$3.3 \cdot 10^{-3}$
9	0.71	4.03	221	$4 \cdot 10^{-4}$	0.897	1184	1.08	9.33	$4.2 \cdot 10^{5}$	0.238	0.411	653	0.64	5.31	$1.8 \cdot 10^{5}$	0.270	0.395	8.95
10	1.81	4.00	677	-	-	-	1.75	3.98	$1.1 \cdot 10^{4}$	-	-	-	1.56	3.79	$1.4 \cdot 10^{4}$	-	-	-