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Key Points:

- We make a review of the observational spectra of the GLE of May 17, 2012, noting that there is some dispersion due to the different techniques used in its derivation
- We observe that certain authors discern two different components of the spectrum: a promt one and a delayed one
- Cofrontation of these results with the theoretical spectra published previously leads to a plausible scenario of the source phenomena; we propose a set of parameters characterizing the source and acceleration process

Supporting Information:

- Supporting Information S1

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Source Energy Spectrum of the 17 May 2012 GLE

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Abstract Among the several GLEs (ground level enhancements) that have presumptuously occurred in the period 2012–2015, the 17 May 2012 is that which is more widely accepted to be a GLE, in view of the high number of high-latitude neutron monitor stations that have registered it. In spite of the small amplitude, it was more prominent of the predicted GLE's of the present decade (Pérez-Peraza & Juárez-Zuñiga, 2015, https://doi.org/10.1088/0004-637X/803/1/27). However, the lack of latitude effect makes it difficult to study the characteristics of this event in the high-energy extreme of the spectrum. Nevertheless, several outstanding works have been able to derive observational spectra at the top of the Earth atmosphere for this peculiar GLE. Some of these works find that the flow of protons is characterized by two components. Quite a great number of works have been published in relation with observational features obtained with different instrumentation, but the source phenomena, regarding the generation processes and source physical parameters, have not been scrutinized. The main goal of this work is to look at such aspects by means of the confrontation of the different approaches of the observational spectra with our analytical theoretical spectra based on stochastic acceleration and electric field acceleration from reconnection processes. In this way, we derive a set of parameters which characterize the sources of these two GLE components, leading us to propose possible scenarios for the generation of particles in this particular GLE event.

1. Introduction

The importance of the study of relativistic solar particles that produce the so-called GLEs (ground level enhancements) has been highlighted long ago in the literature (e.g., Miroshnichenko & Pérez-Peraza, 2008; Miroshnichenko, 2014) emphasizing solar phenomena features and terrestrial effects. It is assumed that the time profile of particles gives information about the interplanetary transport processes and structure of the interplanetary magnetic field, whereas the energy spectrum gives information about the source phenomena: involved processes (acceleration and deceleration processes), plasma parameters magnetic field strength (B), density (n), temperature (T) and so on. Usually, the confrontation of timing synchronization between electromagnetic flare emissions with those of energetic particles and coronal mass ejections (CME) is the method utilized to explore the physical conditions and processes taking place in the sources of particle generation. This synchronization method has been exhaustively exemplified by Malandraki et al. (2012) in connection with the SEPServer project for the case of the 13 July 2005 event. Besides, by means of the HESPERIA HORIZON 2020 project the first inversion of the neutron monitor (NM) observations has been carried out that infers directly the release timescales of relativistic Solar Energetic Particles (SEPs) at or near the Sun (Malandraki et al., 2015). Recently, the Fermi-LAT collaboration (Ackermann et al., 2017) proposes that $>$10-GeV protons (accelerated in the CME environment) produce $>$100-MeV gamma rays which correlates by the interaction of $>$10-GeV protons in a thick target photospheric source away from the original flare site and the hard X-ray emission. In the particular case of the GLE71 (17 May 2012) several outstanding synchronization between particles and electromagnetic radiation studies have been done (e.g., Battarbee et al., 2017; Li et al., 2013).

Another method to infer about the source physical parameters and the kind of acceleration mechanisms involved in the phenomenon is by means of the confrontation of the observational and theoretical particle energy spectra (Pérez Peraza et al., 2011; Pérez-Peraza et al., 2006, 2008, 2009; Miroshnichenko et al., 2009). Based on this last alternative, in this work, we attempt here to determine the physical parameters and acceleration processes at the source of the 17 May 2012 GLE. This leads us to build possible scenarios for the particle generation process.

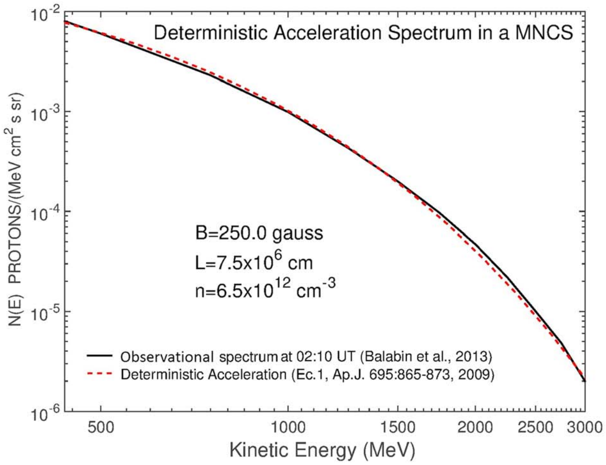
Among the descriptions for describing particle spectra of GLE at the top of the Earth atmosphere, a number of proposals can be found in the literature: an exponential over rigidity (e.g., Freier & Weber, 1963; Lockwood et al., 1974), a power law with an exponential roll-off (e.g., Ellison & Ramaty, 1985), or alternatively the so-called Band function (Band et al., 1993) based on a suitable model to parameterize the event-integrated fluence (Tylka & Dietrich, 2009); this approach describes the integral rigidity spectrum by a double power law in rigidity with a smooth exponential junction in between (Usoskin et al., 2011). Some of these propositions describe nicely the observational data for some particular GLE, though according to some authors (e.g., Bombardieri et al., 2006, 2007, 2008; Shea & Smart, 2012) these simple approximations often do not work well, especially for high energies above several GeV. Nevertheless, whatever the approach, the observational spectra obtained at the Earth level give scarce information about the source phenomena at the Sun level. This is due to the fact that, in general, the spectrum at the top of the atmosphere is not necessarily the same than the one at the source.

The reconstruction of solar cosmic rays spectra at the source from observations at the top of the Earth atmosphere is a complicated problem, since the spectrum goes considerable modulation along the way from the source to the Earth; the observed time profile is a superposition of the effects of particle azimuthal propagation in the solar corona and modulation during their transport in the interplanetary space. Because of the stochastic nature of the solar and interplanetary magnetic fields, the inverse problem of Solar Cosmic Rays (SCR) propagation, that is, the reconstruction of their characteristic near the roots of the interplanetary field lines at the high corona cannot be solved exactly. It can only be done under certain model approximations (e.g., Miroshnichenko & Sorokin, 1985, 1986, 1987a, 1987b, 1989): one must assume that the demodulated spectrum for interplanetary transport corresponds approximately to the spectrum only when the emitted particles from the upper corona occur near the longitude of the Sun-Earth connection ($\theta \approx 60°$W). For further demodulation of the spectrum, after the interplanetary demodulation obtained up to the top of the solar corona field lines, one must allow for the azimuthal transport of particles in the magnetic fields of the solar corona as proposed originally by Reinhard and Wibberenz (1973, 1974), Wibberenz and Reinhard (1975), Schatten and Mullan (1977), Martinell and Pérez-Peraza (1981), Pérez-Peraza and Martinell (1981) and Pérez-Peraza et al. (1985) and reviewed in Pérez-Peraza (1986). This method proposes two coronal regions of particle transport (in the ecliptic plane), a fast propagation region and a slow propagation region. According to Álvarez-Madrigal et al. (1986), in their conclusion no. 4, if the fast propagation region contains the solar longitude of connection between the Earth and the Sun, then the observed spectrum and the full demodulated spectrum (spectrum of the source) practically coincide. On the other hand, it is well known that Forman et al. (1986) have developed a method to derive the observational energy spectrum on the basis of the fluences at the *time of maximum intensity* at each particle energy, usually known as the TOM method. These authors pointed out that this method is suitable for very high energy particles, when the source is in the well-connected region of the Sun (55°W–88°W), to avoid effects of coronal and interplanetary transport. This assumption allows estimating suitable integral energy spectra of several GLE that have taken place since 23 February 1956 (Miroshnichenko, 1994, 1996, 2001). Therefore, taking into account that under those particular conditions the source spectrum can be approximated to the observational one, we have proceeded to study the source processes by solving the Vlasov equation (collisionless Boltzman equation) in the frame of the quasi-linear theory; such equation leads us to a Fokker Planck kind equation in energy space, which we have analytically solved by means of the WKBJ method (Gallegos-Cruz & Pérez-Peraza, 1995, hereafter G-P, Ap.J. 1995), through all the energy range, from suprathermal to ultrarelativistic energies. It is in this way that considering the observational spectra as a proxy of the source spectra, we have proceeded, in the past, to the confrontation of the theoretical spectra with the observational one for several GLE (Bombardieri et al., 2006, 2007; Pérez-Peraza et al., 2006, 2008, 2009; Vashenyuk et al., 2006).

In the particular case of the GLE in consideration, the GLE71, which has presented at least two different components (what may be interpreted as two different sources), we have assumed that most of the observational spectra given by different authors were measured around the TOM. Besides, since the responsible flare was located at 13°N, 83°W, it can be considered that it is within the fast propagation region of the corona, allowing us to consider the observational spectrum as a proxy of the source spectrum.

2. Energy Spectrum of the 17 May 2017

On 17 May 2012 took place a peculiar GLE that has been conventionally designated as GLE71. As mentioned above, determination of the observational energy spectra of GLE has been done historically by several



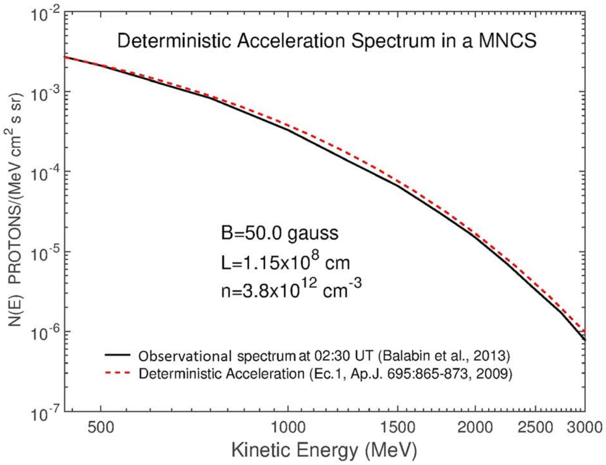


Figure 1. Confrontation of the observational spectra at 02:10 and 02:30 universal time (UT) (Balabin et al., 2013) versus theoretical spectra with deterministic acceleration in a magnetic neutral current sheet (MNCS).

different methods. The standard conventional method is based on a given spectral function, specific yield functions, pitch angle distribution, asymptotic cones, an inversion method, and so on (see, e.g., Miroshnichenko, 2014). This method usually requires data of NM stations well distributed in latitude, which is not precisely the case of GLE71.

The event was mainly observed in high-latitude polar NM and some few stations at lower latitudes with geomagnetic cutoff <3 GV. It was an event of small intensity and highly anisotropic: the maximal enhancement (~25% according to 5-min data) was registered at the South Pole station. Particles of $E < 433$ MeV were recorded by several spacecraft, for example, Geostationary Operational Environmental Satellite (GOES) and Anomalous Long Term Effects in Astronauts (ALTEA) (e.g., Berrilli et al., 2014). The observational characteristics of the associated flare and electromagnetic emissions have been widely described by many authors (e.g., Augusto et al., 2013; Firoz et al., 2014; Heber et al., 2013; Li et al., 2013; Papaioannou et al., 2014).

Studies of the observational spectrum have been done by Kuwabara et al. (2012), Balabin et al. (2013), Plainaki et al. (2014), Mishev et al. (2014), and Asvestari et al. (2017). For the confrontation of our theoretical spectra (G-P, Ap.J. 1995) and the observational spectra of the several authors, previously mentioned, we have limited the span in kinetic energy of protons up to the top of the observational fluences by the NM stations. Then, we begin with the spectra given by Balabin et al. (2013) derived for three different times; though their results are presented up to 7 GeV, we have only considered them up to the observed top by NM stations, that is, near 3 GeV. Our best fit of their spectrum is by assuming *deterministic acceleration* from a *magnetic neutral current sheet* (*MNCS*). In Figure 1 we show such adjustment, at times 02:10 and 02:30, with equation (4) in the supporting information (corresponding to equation (1) in Pérez-Peraza et al., 2009). The obtained source parameters point toward an expanding chromospheric MNCS, which is lengthening as acceleration is taking place in the first phase of the event. It could be considered that such spectra correspond to the so-called prompt component (PC; e.g., Vashenyuk et al., 2006, 2008); however, the authors do not give such specification nor a spectrum later than 02:30 that could be considered as a *delayed component* (DC).

Another observational spectrum, the first published one of the GLE71 (to our knowledge), was given by Kuwabara et al. (2012). This was done on the basis of the data of the large Antarctic installation (South Pole monitors), the IceTop Cherenkov detector, the NM64 NM, and the Polar Bare NM. They use a standard-kind model to derive the energy spectrum. Figure 2 shows their derived spectrum between 02:35 and 03:35 UT. We have adjusted their curve with a *time-dependent spectrum* from *stochastic acceleration* and *injection* from a preacceleration stage, fed by a *monoenergetic* fluence of protons of $E_0 = 1$ MeV (from the top of a plasma thermal distribution at about 10^7 K) while being decelerated by *adiabatic* losses. The employed spectrum is given in the supporting information as equation (1) (corresponding to equation (41) in G-P, Ap.J. 1995), where we have added adiabatic energy losses during acceleration in the expanding structures of the source up to the moment that particles escape to the interplanetary space. This is the best fit of the reported spectrum, among the several different scenarios studied in G-P, Ap.J. 1995.

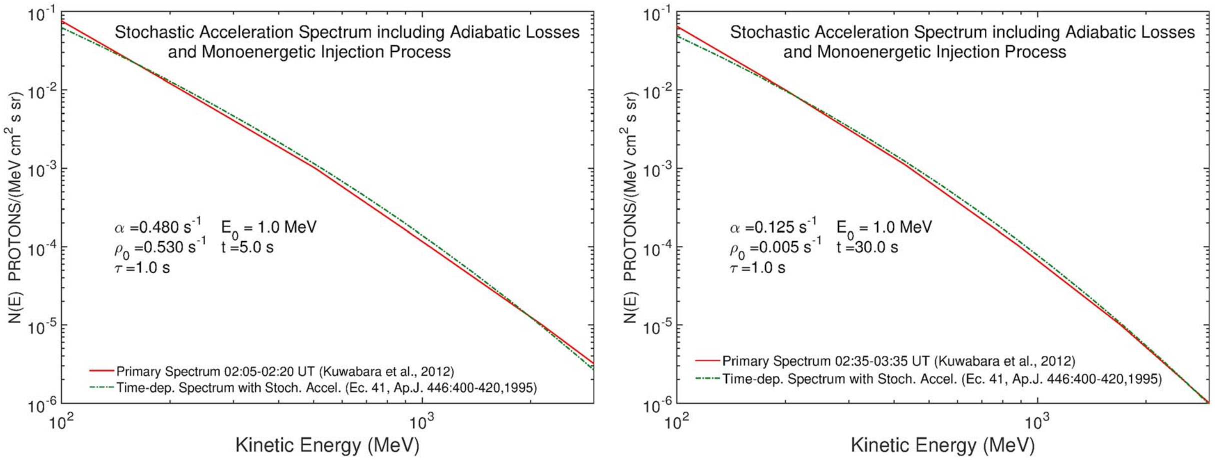


Figure 2. Confrontation of the observational spectra (Kuwabara et al., 2012) at 02:05–02:20 UT (left panel) and 02:35–03:35 UT (right panel) versus theoretical time-dependent spectra with stochastic acceleration.

Another outstanding analysis was carried out by Plainaki et al. (2014), based on their model NMBANGLE PPOLA that allows them the use of a number of stations that apparently did not register the GLE. Their work leads to two different *episodes* in the event: an initial one (prior to the arrival of the bulk of particles to NM stations), where the spectrum is rather of soft nature, and on the other hand, there is a second episode composed by particles with harder spectrum. They interpret these two phases as a possibility of the existence of two acceleration processes. Figure 3 shows our fit to the soft component just at the beginning of the event when particles belong rather to the SPE component, but high-energy protons scarcely have arrived at ground level (01:45 UT). The best fit is obtained assuming stochastic acceleration with monoenergetic injection and adiabatic energy losses in a relatively fast process at the source. Figure 3 also shows the fit of our source spectrum to their observational harder spectrum as measured by those authors at 03:05 UT. Our fitting of the spectrum at 03:05 points toward acceleration in a second episode of the event. We obtain that the best description is by stochastic acceleration with monoenergetic injection of 1-MeV protons, while particles are losing energy at the source by adiabatic deceleration. Both fittings in Figure 3 were obtained with equation (1) in the supporting information (corresponding to Equation (41) in G-P, Ap.J. 1995).

Besides, Mishev et al. (2014) develop an original method to determine the energy spectrum of the GLE71 that turns out to be quasi-independent of the latitude of NM stations. To derive a suitable spectrum the authors drew on low-latitude stations that seemingly have not recorded the GLE71. The method is based on a modern conception of the standard-kind method with a new yield function and inversion method. In fact, they

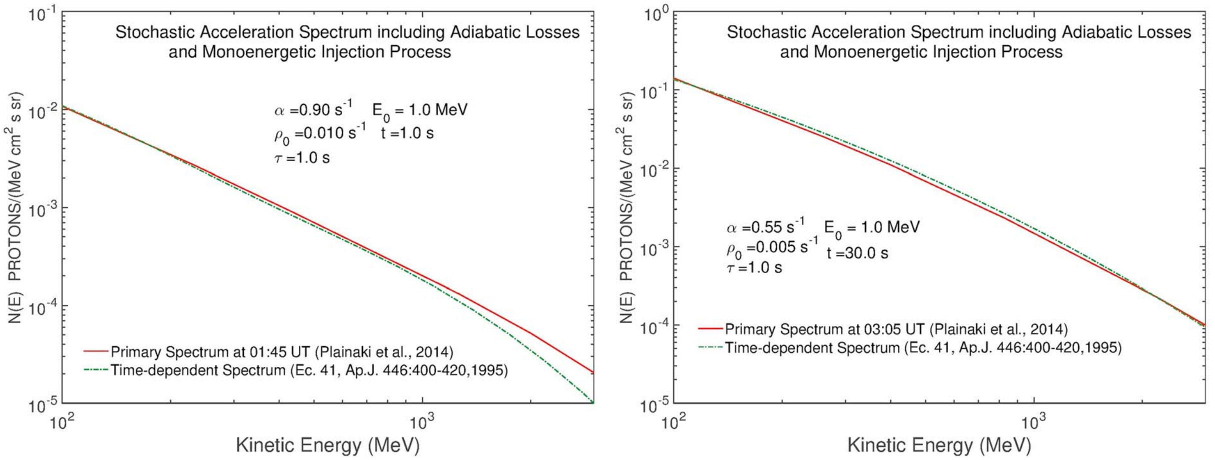


Figure 3. Confrontation of the observational spectra (Plainaki et al., 2014) at 01:45 UT (left panel) and 03:35 UT (right panel) versus theoretical time-dependent spectra with stochastic acceleration.

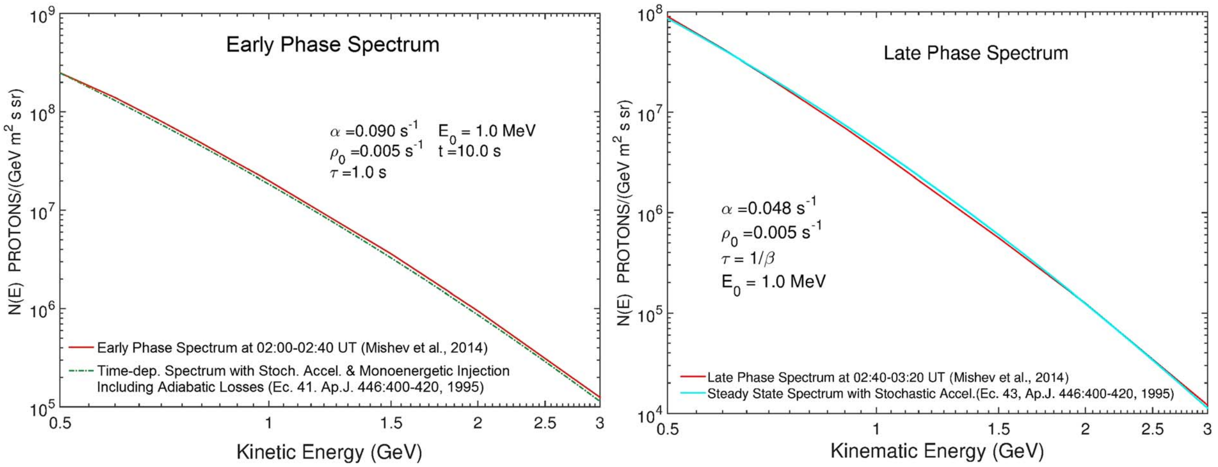


Figure 4. Confrontation of the observational early phase (02:00–02:40 UT) and late phase (02:40–0320 UT; Figure 5 in Mishev et al., 2014) versus theoretical time-dependent and steady state spectra, respectively.

distinctly showed the presence of an "early" phase and a "late" phase in the ground NM data during the GLE71, which in some measure could be considered as equivalent to the PC and DC that were put in evidence long ago by the group of *Apatity* (e.g., Miroshnichenko et al., 1990; Vashenyuk et al., 1991, 1994, 1997, 2002, 2006, 2008, Vashenyuk, Balabin, et al., 2007, Vashenyuk, Miroshnichenko, et al., 2007). Their early phase is illustrated in Figure 4, corresponding to the angle-averaged integrated fluency from 02:00 to 02:40 UT. This can be suitable reproduced by means of the time-dependent spectrum from stochastic acceleration after 10 s, with monoenergetic injection of 1-MeV protons while undergoing adiabatic energy losses (equation (1) in the supporting information, corresponding to equation (41) in G-P, Ap.J. 1995). In Figure 4 is also shown the angle-averaged integrated fluency in the time interval 02:40–03:20 UT (Mishev et al., 2014). For this time interval the best description of the spectrum is obtained with the *steady state spectrum* from stochastic acceleration and monoenergetic injection, given in equation (3) of the supporting information (corresponding to equation (43) in G-P, Ap.J. 1995), where it is assumed that particle escape is inversely proportional to the velocity of the particles. In Figure 5 we show the observational spectra at specific times during the so-called late phase 02:40 and 03:10 UT. These can be reproduced with our source time-dependent spectrum from stochastic acceleration and monoenergetic injection while losing energy by adiabatic losses (equation (1) in the supporting information). It can be seen that the source spectrum, in our time-dependent approach (at two different acceleration times, 10 and 30 s), fits quite correctly the observational spectra for the two times, 02:40 and 03:10 UT. The closeness in Figure 5 between the theoretical spectrum with the observational one might indicate that even if the steady state was not yet reached, it was very near to be reached after

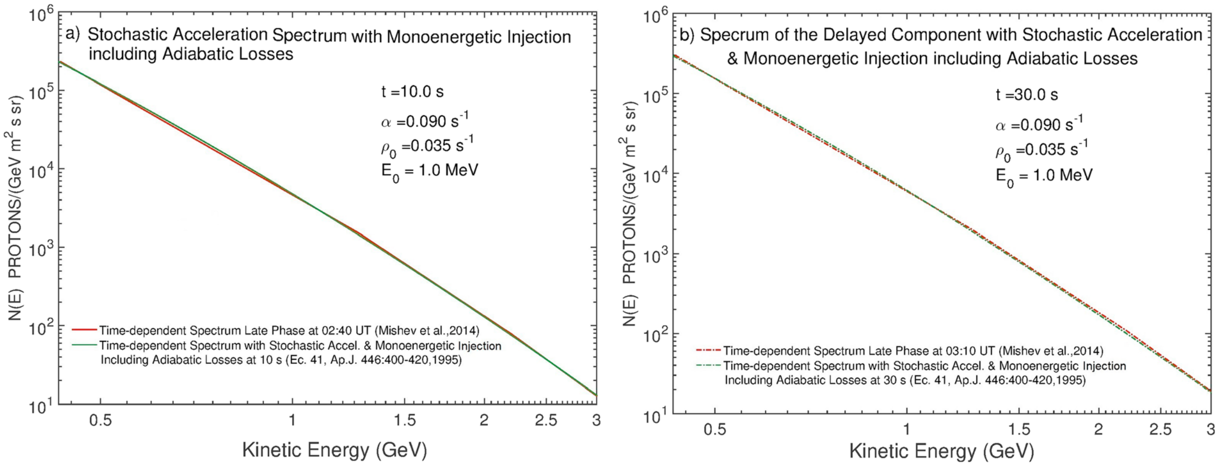


Figure 5. Confrontation of the observational late phase (02:40 and 03:10 UT; Figure 4 in Mishev et al., 2014) versus theoretical time-dependent spectra.

10 s in the source (translated to the Earth level in a time interval, 02:40–03:20 UT): according to Figures 4 and 5b such steady state situation took place at an acceleration time just above 30 s, which at the Earth level occurred between 03:10 and 03:20 UT.

Recently, Asvestari et al. (2017) give a spectrum of the GL71 on the basis of the PAMELA data that differs from the GOES + NM data only at $E > 1$ GeV. The authors do no mention the specific time of their differential spectrum neither comment on different acceleration stages; it should be noted that the fluence is not per time unit and differs by several orders of magnitude with respect to the other authors. In Figure 6, it is shown that in this case the best fit to their spectrum is given with deterministic acceleration in a reconnection process of a MNCS (equation (4) in the supporting information, corresponding to equation (1) in Pérez-Peraza et al., 2009).

Regarding Figure 7, it has been argued by Li et al. (2013) that in practice, due to the limited latitude effect and to the extreme low intensity at high energies ~ 3×10^{-4} pfu (cm^{-2}·s^{-1}·sr^{-1}) of GLE71, no confident energy spectrum can be determined in the high-energy portion by the standard model, just in agreement with Bütikofer & Flückiger (2013). In order to avoid high controversies around the NM counting rates that appear due to statistical fluctuations, instead of the standard model used by most authors, Li et al. (2013) drew on the TOM method using data of five NM stations. They derived a spectrum that fits correctly the low-energy portion from GOES-13. The black curve in Figure 7 shows the derived TOM spectrum including data at low energies. It should be noted that in contrast to other authors, they give an integral spectrum instead of a differential one, so instead of converting their spectrum to the differential form, we have chosen to integrate our equations (1)–(3) of the supporting information. In this case, our study indicates that above 400 MeV very good fittings may be obtained with the steady state spectrum from stochastic acceleration with monoenergetic injection and adiabatic losses (equations (2) and (3) of the supporting information, corresponding to equations (42) and (43) in G-P, Ap.J. 1995) and even with the time-dependent spectrum (equation (1) in the supporting information). However, at lower energies we cannot reproduce the observational spectrum, which can be attributed, at least, to two main causes: (1) Forman et al. (1986) precluded the TOM method for low-energy particles, because it is less reliable not only due to transport effects but also because particles are more subject to convection and adiabatic deceleration, so the spectrum becomes flatter than the spectrum at the Sun; (2) the low-energy portion of the spectrum is produced by another stage of acceleration, most probable due to shock wave acceleration as argued by Li et al. (2013). This second option could be also consistent with the series of works of Bombardieri et al. (2006, 2007, 2008) who have shown that shock wave acceleration is rather effective for the nonrelativistic range, but at high energies the spectrum is broken undergoing an exponential cutoff. The result is then a significant softening of the particle spectrum and decrease of their maximum energy. Those works are in agreement with our claim in the present work, regarding the predominance of stochastic acceleration. Under these circumstances the logical scenario could be a prompt acceleration phase by reconnection in a MNCS and shock wave acceleration and a delayed stage by stochastic acceleration.

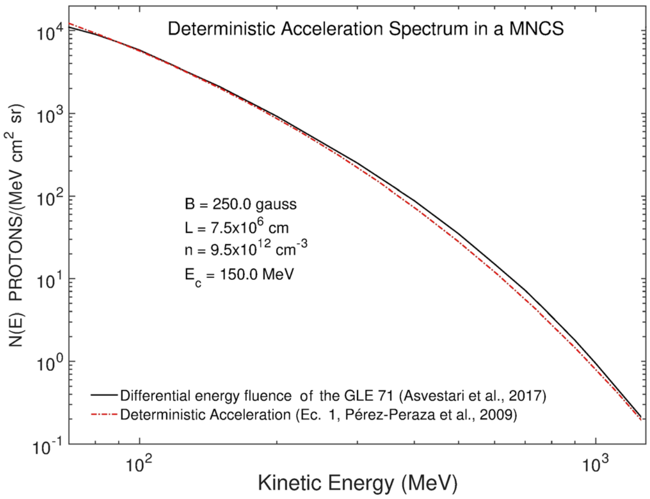


Figure 6. Confrontation of the observational spectra (Asvestari et al., 2017) versus theoretical spectra with deterministic acceleration in a magnetic neutral current sheet (MNCS).

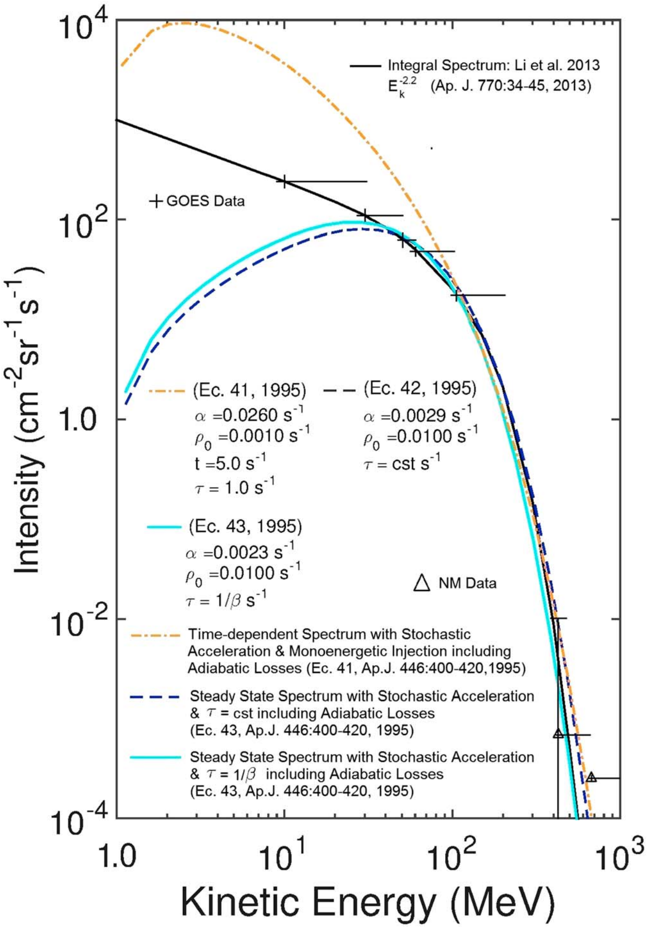


Figure 7. Confrontation of the observational spectrum (Li et al., 2013) versus theoretical time-dependent and steady state spectra.

3. Discussion

The GLE of 17 May 2012 was very peculiar from the point of view that was relatively small, showing a spectrum at $E < 433$ MeV of relatively soft nature, changing to a hard one as the time elapses. There is a consensus that the lack of a latitude effect of nonpolar MN stations inhibits the standard model to derive the observational spectrum at $E > 433$ MeV. However, there is no doubt that a number of stations have registered a counting rate increase at the time of the event, originated in a class 5.1 flare that took place at about 01:25 UT. Such increase was registered also for some nonpolar stations, though on the basis of statistical fluctuations they have been disregarded by Li et al. (2013), what led those authors to derive a spectrum on the basis of the TOM model (Forman et al., 1986). Nevertheless, ignoring those statistical constraints, a number of authors derived the spectrum on the basis of different variants of the conventional standard model. The observational spectrum tends to show two different behaviors: a rather flat spectrum from 01:45 to 02:30 UT that we have identified as a PC and a steeper spectrum that we designate here as a DC. These connotations may be identified with the early and late phases of Mishev et al. (2014) and the acceleration episodes of Plainaki et al. (2014).

As we mention in section 1, the phenomena that take place at the sources of solar energetic particles can be inferred from the timing synchronization between the several electromagnetic flare emissions and CME. Another option is by means of energetic particles on the basis of the confrontation of observational spectra with theoretical source spectra. In the present work we attempt to infer about the source phenomena by this last option, that is, by fitting observational spectra with our theoretical spectra developed in Pérez-Peraza et al. (1977), Gallegos-Cruz and Pérez-Peraza (1995), and Pérez-Peraza et al. (2009). Such confrontation leads us to infer about plausible scenarios of particle generation in this peculiar GLE. The restriction of this method is that observational spectra, even at high energies, are not strictly representative of the source spectra. In fact, the closest translation is when the source is in the Sun-Earth connection (~55°–88°); particles traveling out of that cone never reach Earth, so then the registered fluence is lower than that at the source level. Furthermore, there are effects of coronal azimuthal and interplanetary transport, as well as adiabatic and collisional energy losses in and out of the source (probably behind the expanding shock wave). If the source magnetic structure is momentarily closed, even the most energetic particles may be modulated by collisional energy losses before they escape to the interplanetary medium. Given the involved flare location, for the particular event, the GLE71, we have considered here the observational spectrum as a proxy of the source spectrum. The confrontation of theoretical source spectra with the observational one gives us an approximate conception of the scenarios of production, which is the involved acceleration and energy loss processes and the plausible source parameters.

We found that two main acceleration mechanisms are potentially involved: (1) a deterministic process by direct electric field acceleration from reconnection in a MNCS (the presence of reconnection processes during flare activity has been often discussed in the literature since at list from 1953; see, e.g., the excellent review by Cargill, 2013) and (2) a stochastic process by local magnetohydrodynamic turbulence in the flare body and/or turbulence generated behind the shock generated in the CME associated to the flare, when the preceding CME can provide enough enhanced turbulence to feed a particle population ahead the main CME-driven shock.

Regarding the source parameters, it should be emphasized that taking into account, there is not a unique observational spectrum, but there exist a great dispersion of results for the GLE71, even at similar record times, so one can only determine a range of the most probable source parameters. The results obtained here from stochastic acceleration point toward an acceleration efficiency in the range $\alpha = 0.9–0.0023$ s^{-1} and the deceleration efficiency by adiabatic losses $\rho = 0.01–0.001$ s^{-1}, and the best description of the spectrum is obtained for acceleration times in the range $t \approx 1–30$ s and for monoenergetic injection the best value is $E_0 = 1$ MeV. For the deterministic acceleration process by reconnection in a MNCS the values of the magnetic field strength are in the interval $B = 250–50$ Gauss, the density $n = 9.5 \times 10^{12}$ to 6.5×10^{12} cm^{-3} and the length of the neutral sheet $L = 7.5\times 10^{6}$ to 1.15×10^{8} cm. Such a dispersion of the physical parameters can be understood from the fact that the observational spectra given by different authors have been done using different approaches of the standard model: different sets of NM stations, different yield functions, different considerations about time evolution of pitch angle distributions and functions of asymptotic cones, and different flux intensity with different spectral indices, so that their

Table 1
Source Parameters Derived From the Best Fittings in Figures 1–7

Author	Spectrum	UT	Fit	α (s^{-1})	ρ_0 (s^{-1})	E_0 (MeV)	τ (s)	t (s)	B (gauss)	L (cm)	n (cm^{-3})	Injection
Kuwabara et al. (2012)	Time-dependent stochastic acceleration	02:05–02:20	Ec. 41, Ap.J. 446,1995	0.48	0.53	1.0	1.0	5.0				Monoenergetic
Kuwabara et al. (2012)	Time-dependent stochastic acceleration	02:35–03:35	Ec. 41, Ap.J. 446,1995	0.125	0.005	1.0	1.0	30.0				Monoenergetic
Li et al. (2013)	Time-dependent stochastic acceleration		Ec. 41, Ap.J. 446,1995	0.026	0.001	1.0	1.0	5.0				Monoenergetic
Li et al. (2013)	Steady state stochastic acceleration		Ec. 42, Ap.J. 446,1995	0.0029	0.01	1.0	1.0					Monoenergetic
Li et al. (2013)	Steady state stochastic acceleration		Ec. 43, Ap.J. 446,1995	0.0023	0.01	1.0	$1/\beta$					Monoenergetic
Balabin et al. (2013)	Deterministic acceleration	2:10	Ec. 01, Ap.J. 695,2009						250.0	7.50E+06	6.50E+12	
Balabin et al. (2013)	Deterministic acceleration	2:30	Ec. 01, Ap.J. 695,2009						50.0	1.15E+08	3.80E+12	
Plainaki et al. (2014)	Time-dependent stochastic acceleration	1:45	Ec. 41, Ap.J. 446,1995	0.9	0.1	1.0	1.0	1.0				Monoenergetic
Plainaki et al. (2014)	Time-dependent stochastic acceleration	3:05	Ec. 41, Ap.J. 446,1995	0.55	0.005	1.0	1.0	30.0				Monoenergetic
Mishev et al. (2014), early phase	Time-dependent stochastic acceleration	02:00–02:40	Ec. 41, Ap.J. 446,1995	0.09	0.005	1.0	1.0	10.0				Monoenergetic
Mishev et al. (2014), early phase	Steady state stochastic acceleration	02:40–03:20	Ec. 43, Ap.J. 446,1995	0.048	0.005		$1/\beta$					Monoenergetic
Mishev et al. (2014), early phase	Time-dependent stochastic acceleration	2:40	Ec. 41, Ap.J. 446,1995	0.09	0.035	1.0	1.0	10.0				Monoenergetic
Mishev et al. (2014), early phase	Time-dependent stochastic acceleration	3:10	Ec. 41, Ap.J. 446,1995	0.09	0.035	1.0	1.0	30.0				Monoenergetic
Asvestari et al. (2017)	Deterministic acceleration		Ec. 01, Ap.J. 695,2009						250.0	7.50E+06	9.50E+12	

Note. UT = universal time.

fluences and spectral indices change from author to author. It is obvious that under such circumstances, it is not feasible to have a protocol to derive observational spectra of energetic solar particles; all what we can hope is that they only differ no more of an order of magnitude. Nevertheless, it should be noted that the source parameters obtained here are within the conventional range of chromospheric and coronal solar flares values. Note that in the particular case of the spectrum of Balabin et al. (2013) at 02:10 UT and that of Asvestari et al. (2017), even if the fluence scales are different, it can be seen in Table 1 that the obtained source parameters are the same.

4. Conclusions

We have explored the sources of particles during GLE of 17 May 2017 on the basis of the spectra given by different authors, under different approaches of the standard model, and on the TOM model. In spite that authors present their results in different scale units, most of them agree, within a factor around 10 in their observed fluences, with the exception of Asvestari et al. (2017). This agreement is very important considering that one of the main goals of authors in calculating energy spectra is that the specialized community may draw inference about the source phenomena.

The main results of this work to highlight are the set of source parameters of particle generation and the involved acceleration processes driving to plausible scenario(s) during the GLE71. It is precisely the confrontation of theoretical source spectra with the observational spectra that gives us an approximate conception of the scenarios of production. The analysis of the spectra leads us to consider the presence of two different particle components during the GLE71, conspicuously the works of Kuwabara et al. (2012) and Mishev et al. (2014), with their early and late phases, and Plainaki et al. (2014), with the so-called episodes. Here we have designated those two components as the PC and DC. These two components may indicate the occurrence of two different acceleration processes or a unique acceleration mechanism in two different acceleration stages. Due to the dispersion of results of different authors, strictly one could conceive different scenarios according to different observational spectra. However, here we opt for proposing a general picture of particle generation phenomena which leads us to conclude that among all the scenarios that were able to occur during particle generation in the GL71, those invoking two acceleration stages with different acceleration mechanism are the more likely to occur. The exceptions are the results presented by Balabin et al. (2013) and Asvestari et al. (2017), which apparently only found one single acceleration stage that we have adjusted by means of the deterministic acceleration.

The fact that in our results the magnetic field B and local density n decrease as time elapses whereas the length of the sheet L increases with time leads us to propose a tentative scenario where particles of the PC are accelerated by an impulsive and fast deterministic process, whereas the DC is produced in the source and its environment by stochastic acceleration due to the local turbulence and/or the turbulence generated by the plasma expansion behind the shock wave, while losing energy by adiabatic losses, up to the moment when the "expanding magnetic bottle" opens, allowing particles to escape to the interplanetary medium. Meanwhile, the prompt particle component is produced in a concomitant MNCS. It should be noted that, according to the theoretical spectra from stochastic acceleration, at 03:40 the steady state seems to have been reached, and consequently, under this situation the acceleration efficiency tends to be much lower than at early times (Figure 4). The fact that some spectra cannot be nicely reproduced with our theoretical spectra, that is (Kuwabara et al., 2012), in the lapse 02:05–02:20 UT (Plainaki et al., 2014), before 03:05 (Figure 4), as well as the angle average spectrum of the early phase of Mishev et al. (2014) during the lapse 02:00–02:40 UT, and (Li et al., 2013) at low energies may be indicative of the possible contribution of shock wave acceleration. It should be mentioned that modern literature favors shock wave acceleration due to the frequent presence of a CME; for the GLE71 Li et al. (2013) invoke shock wave acceleration, though we think that their work is rather of qualitative nature, in contrast with our present work. Within the frame of our scenario, pure shock acceleration does not play the mayor role for accelerating particles up to GLE energies. Our present study supports rather the results of Bombardieri et al. (2006, 2007, 2008), though it is likely that shock wave acceleration has contributed to the generation of particles registered by GEOS-13 at $E < 433$ MeV. Whatever the reason of our fail to reproduce adequately the above mentioned spectra, it must be considered that the derived spectra by several authors disagree among them not only within a factor around 10 in the magnitude of the fluency but also in the slope of their spectra.

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