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K. KUDELA, S. PINTER

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ADVANCES IN CORONAL PROPAGATION OF SOLAR PARTICLES

J. Pérez-Peraza

Instituto de Geofísica, UNAM, 04510 - C. U. MEXICO 20, D. F.

I.- INTRODUCTION. It is well known that the study of the transport of solar particles is not only related to the knowledge of the phenomenon itself, but may infer also in the study of the dynamics of charged particle motion through electromagnetic fields, and in the knowledge of the traversed coronal and interplanetary magnetic field configurations.

For studying solar particle transport, we dispose of observational elements that make possible to locate the site, and time of solar particle production, in association with solar flares or specific active centers on the solar disk, as well as the time, the location and their arrival directions when they are detected, either at earth or in spacecrafts. What it is not subject to direct observations is what happens between their generation and detection. In fact all observational characteristics of solar particle events, such as time-intensity profiles, longitudinal distributions, anisotropies and energy spectra, as we see at the point of observation is a combination of processes of different nature taking place since their production till their detection. However, it is not easy to know exactly the number of processes involved in particle transport, nor the relative role of each one, at least we could perform enough specific observations of different kind in order to separate the effects of each involved process. Though solar particles leaving the source environment need to travel through two different magnetic field topologies, those of the corona and the interplanetary space, primary works were directed to particle transport through the interplanetary magnetic field, under the assumption of impulsive ejection of particles from the source to the base of the interplanetary magnetic field lines, such that, particle profiles, anisotropies, longitudinal distributions and modulation of the energy spectrum, were exclusively determined by interplanetary transport. At present, it is realized that gradual particle release and particle control by coronal magnetic fields may become of fundamental importance in quite a high number of solar particle events. In particular, there appears now to be an established consensus, that the azimuthal distribution of solar particles relative to the flare-observator connecting field line takes place mainly in the corona, and not during interplanetary transport.

The aim of this invited talk is to give a sumary of the main advances in connection with the phenomenon of coronal transport of solar particles. Due to the lack of elements for absolute discrimination among different effects I will designate, in an arbitrary form, for coronal transport all processes involved during coronal particle propagation, eventual stages of particle storage and particle escape into the interplanetary space.

II.- CORONAL VERSUS INTERPLANETARY PROPAGATION FOR AZIMUTHAL PARTICLE TRANSPORT.

Measurements of magnetic field irregularities allow to determine the relative size of the parallel $\kappa_{\parallel}$ and perpendicular $\kappa_{\perp}$ diffusion coefficients for particle transport in the interplanetary space, however, these measurements are not always enough confidents to decide about the ratio $(\kappa_{\parallel}/\kappa_{\perp})$, and in addition, there is still some contoversy about the validity of the employed theory to calculate the coefficients from magnetic field fluctuations. Nevertheless, from other kind of sources, it has been concluded that interplanetary propagation is basically carried out the long of the magnetic field lines, through a diffusive-type transport in the interplanetary magnetic field irregularities (e.g. Coleman, 1966), where the transversal diffusion coefficient to the mean interplanetary magnetic field is quite smaller in relation to the parallel diffusion coefficient $(\kappa_{\parallel}/\kappa_{\perp} << 1)$. This assumption is based on the followinging features:

1. Strong anisotropy (50-100)% in the initial phase of solar particle events aligned with the sun-observator field line of connection (e.g. O'Gallagher and Simpson, 1966; McCracken et al 1967; McCracken and Kao, 1970; Rao et al., 1971). This feature is observed in high energy protons (Duggal et al. 1971) and in electrons (e.g. Allum et al., 1971). In the case of low energy protons, anisotropy may last some days up to the end of events (Krimigis et al., 1971).
2. In order that solar corrotating events may subsist for several rotations (e.g. Mc Donald and Desai, 1971), it is needed that $\kappa_{\perp} << \kappa_{\parallel}$, otherwise the flux would be azimuthaly dispersed and lost (McKibben, 1973).
3. The strong temporal difference between the onset arrival times of particle fluxes observed in different spacecrafts, placed very close of each other, indicating that transport is performed within "magnetic flux tubes", in a very independent form between adyacent flux tubes, and implying that the properties of fluxes only depend on the way they were injected onto the root of the interplanetary field lines (Krimigis et al., 1971).
4. The aleatory motion of interplanetary field lines (Jokipii and Parker, 1969), is not enough efficient to produce azimuthal dispersion of flare particles, and can only explain small changes in the direction of the anisotropy (Roelof and Krimigis, 1973).
5. Cross-field diffusion may play only a minor role in transporting particles from one field line to the next one in Long-Lived-events (Gold et al., 1977).

On the other hand, there are many solar particle events observed at earth, which are associated to solar flares in all the visible and invisible solar disk, indicating that very often the acceleration region is very far away of the root of the sun-earth connecting field line located at 60° W (Bukata et al, 1972). So particles need to undergo considerable azimuthal dispersion to reach the base or that field lines, if particles have to be seen at earth. Since this propagation in heliolongitud cannot take place in the interplanetary space, for the above arguments, the longitudinal shifts must occur before the bulk of particle escape into the interplanetary space (where their propagation is basically of unidimensional character in the direction of the magnetic field).

Convencing evidence has been provided by Reinhard and Wibberenz (1974) and Roelof (1973), that azimuthal transport of solar particles takes place in the solar corona as opposed to perpendicular diffusion in the interplanetary space. Some inferences supporting coronal transport before particle escape, though model-dependents, are however interesting to be mentioned:

1. The observational intensity profiles of low energy particles at 1 A.U. are better reproduced by theoretical profiles, if injection is assumed to be finite in time (like storage or azimuthal propagation in the corona) instead of impulsive liberation into the interplanetary space (e.g. Feit, 1973; Gombosi et al., 1979).
2. Exponential decay of fluxes in the last phases of events may be explained without assuming an escape frontier, or, a fast variation with radial distance of the diffusion coefficient, if a temporal profil simulating coronal propagation and continuos leakage is superposed to interplanetary propagation (Wibberenz and Reinhard, 1975).
3. Amata et al., (1975) have noted that in some events, associated to flares very near the sun-observator field line of conection, there is a delay in the arrival of particles, what can be understood if particles are first distributed in the corona and then injected into the interplanetary space.
4. By means of the potential approximation, Newkirk (1973) made calculations of the magnetic field topology of some solar flares for which magnetic field had been measure, and then compare the longitudinal extension of the open magnetic field line configurations associated to a certain surface or injection, for those flares that produced particle events, with the extension of the longitud of detection, and he found no agreement, but the detection range of longitudes is wider. This argues in favour of coronal azimuthal transport.
5. A compton-Getting transformation to determine the anisotropy in the co-moving frame, from that the observed in the spacecraft frame, reveals a long lasting residual anistotropy in the co-moving frame, with protons streaming from the sun, what was used to argue against impulsive ejection in some events (e.g. October 1972) (Gold et al, 1975).

Once that the existence of a certain amount of solar particle propagation in the solar atmosphere is established, it is necessary to know the properties of such propagation in order to develop physical models for interpreting observational data. The first studies of longitudinal displacements were carried out without paying much importance to the place where such dispersion occurred, but rather limited to measure azimuthal gradients and temporal evolution of events from different heliolongitudes of detection; however the conception of two stages of propagation (coronal and interplanetary) had been considered long ago by Lüst and Simpson (1957) in association with the particle event of February 23, 1956.

III. OBSERVATIONAL PROPERTIES OF CORONAL PROPAGATION. To separate coronal of interplanetary transport and establish the properties of azimuthal transport, observations have been carried out in two different forms:

1. Observations from one unique point in the Interplanetary Space (the earth for instance) of several flare particle events taking place at different sites through the Solar disk.
2. Observations of individual particle events simultaneously, with several spacecrafts located at different heliolongitudes and helioradii (e.g. Kunow et al., 1981; McGuire et al., 1983a; Lockwood and Debrunner, 1984).

The statistical study of these data furnish the most common behavior of particle coronal propagation. It is worth to mention that transport of flare particles in the solar corona is not only azimuthaly but also radially, however the kind of information that we can draw from data is not enough to evidence the characteristics of such a radial propagation. Primary work in this direction with multiple spacecraft observations (McGuire et al., 1983a) seems to indicate that the magnitud of any radial effect is small compared to the longitudinal effects. Obviously the observational information concerns the last step of coronal propagation, when particles are liberated, but what happen between the time of acceleration and the time of escape remains masked to direct observations, and we only observe the final effects. Even the data obtained from this last step is not of absolute precisness, because the limitations of corrective techniques for interplanetary effects; that is, the time-dependet azimuthal distribution of particles at the time of coronal liberation, may in principle be deduced from the time-intensity profiles measured in different longitudes at the level of the earth orbit, after substracting effects of interplanetary propagation. However, in that case it is necessary to make certains suppositions about interplanetary propagation, and so the obtained results depend on the validity of the adopted model. The most common technique has been the mapping of the measured fluxes back to the sun, by simple proyection of particle intensity the long of the magnetic field line, connecting the observator with the solar corona. To do so, it is assumed what we have previously emphasized, that interplanetary propagation is basically the long of the magnetic field lines. However, here again it is needfull to adopt a model for the interplanetary magnetic field; generally it is assumed the Extrapolation Quasi Radial Hiper-velocity model of Notle and Roelof (1973), with account of time-dependent solar wind velocities. The mapping method was first used by Bukata et al.,(1972); Roelof and Krimigis (1973); Gold et al., (1973). In particular, the later authors were able to isolate spatial and temporal variations. Using multispacecraft observations at four different heliolongitudes, Bukata et al.(1972) studied the particle events of March-April 1969 and found that flare particles were detected over the 360° of heliolongitud with a strong influence of azimuthal gradients on the temporal evolution of fluxes. By mapping back fluxes to the sun, they were able to locate the flare site of events occured on the hidden hemisphere of the sun, under the assumption that the point of major emission should concur with the flare position. This however is not always true, since it has been seen that in some events, the major flux intensity is injected in a far longitud from the source flare (Gold et al. 1977). In addition this mapping technique is mainly valid in the initial phase of events, when particles arrive with very few dispersions through the irregularities of the field, in the magnetic flux tubes of their propagation; for later times it is rather valid for very high energy particles, or even low energy particles if the spacecraft are very near to the sun, as for instances the Helios spacecrafts (Kunow et al, 1977), in which case interplanetary propagation plays a minor role. Nevertheless in spite of the limitations of observational techniques, it has been possible to deduce the following properties of coronal transport:

(a) The onset time of the event and the time of peak intensity increase (or at least remain constant) with the azimuthal separation between the observant and the flare site (Fan et al., 1968; Reinhard and Wibberenz, 1974; Van Hollebeke et al., 1975; Ma Sung et al., 1975; Datlowe, 1975; Mc Kibben, 1972; Simnett, 1971, 1972; Barouch et al., 1971; Sakurai, 1971; Lanzerotti, 1973).

(b) The time-intensity profile widens with the longitudinal separation between the observant and the flare site (e.g. Reinhard and Wibberenz, 1974), and the maximum intensity is greatly reduced (McCracken et al., 1967; McCracken and Rao, 1970, Van Hollebeke et al., 1975).

(c) The azimuthal distribution of flare particles tends toward uniformity for long times during the decay phase of events (e.g. McCracken et al., 1971; McKibben, 1972).

(d) Azimuthal coronal transport takes place at two different rates: a fast propagation process, covering in one hour a longitudinal extension of about 60° - 100° around the flare site, the so called fast propagation region (FPR), with an average velocity of < 50°/hr >, and a slower propagation process, outside of the FPR, where transport is performed at a rate of (24°-93°)/day (Fan et al., 1968; Duggal and Pomerantz, 1973; Reinhard and Wibberenz, 1973, 1974; Ma Sung et al., 1971; Duggal, 1975). Similar results were found by Anderson and Lin (1966) and Lin (1970) in relation with non-relativistics electrons.

(e) On statistical grounds, the azimuthal propagation of low energy particles is both rigidity and energy independent (McKibben, 1972; Lanzerotti, 1973; Reinhard and Wibberenz, 1973; Ma Sung et al., 1975; Roelof et al., 1975; Gold et al., 1977; Perron et al., 1978; Combosi et al., 1979). A fine structure of the azimuthal propagation behevior shows that the traveling time, over a certain longitudinal distance is slightly velocity-dependent, as $v^{-0.55}$ (Ma. Sung, 1977) and practically rigidity-independent, $R^{-0.07}$, (Ma Sung and Earl, 1978). On the other hand, azimuthal transport of high energy protons (> 100 MeV) tends to behave in energy and rigidity dependent manner (Bazilevskaya and

Vashenyuk, 1979, 1981; Kecskemety et al., 1981). There are however other results supporting that coronal tranport of low energy particles may show a stronger velocity dependence, or even an energy or rigidity behavior: for instance, in association with coronal diffusion coefficients (e.g. Gombosi et al., 1977; Kunow et al., 1981; Lockwood and Debrunner, 1984), or in relation with variations of the spectral index as a function of longitudinal distance (Mc Cracken et al., 1971; Van Hollebeke et al., 1975; Conlon et al., 1979). Nevertheless, such an eventual behavior might be attributed to the last steps of coronal transport. i.e., particle escape, or, propagation out of the FPR. Therefore, what can be drawn from the general consensus is the following:

(1) For observational points connected with field lines near the flare site, such that only interplanetary propagation is important, the phenomenon of velocity dispersion is observed ($vt_m \sim 8.3$ A.U., where t_m is the time of maximun intensity).

(2) For observational points connected to the sun far from the flare site, vt_m is not a constant, but increases with particle velocity.

(f) The azimuthal propagation is controled to a certain extent by the unipolar field sectors of the large-scale photospheric field. Particle fluxes crossing two sectors of opposite polarity are strongly modulated: flux intensity decreases and the onset and peak time increase. This has been observed in low energy particles (Gold et al., 1973; Roelof and Krimigis, 1973; Roelof et al., 1975; Gold and Roelof, 1979; Reinhard, 1975; Kunow et al., 1977; Reinhard et al., 1977) as well as in high energy particles (Vashenyuk et al., 1977). The frontiers of unipolar sectors seem to be associated to the coronal extensions of chromospheric neutral lines, or, the dark filaments of the low corona. Unipolar sectors behave as extended regions of preferential liberation (Reinhard et al., 1977), and determine large azimuthal gradients among them. Van Hollebeke et al., 1975 infered preferred-connection longitudes of ∼ 60° of extension, in agreement with the average dimension of chromospheric unipolar region (Mc Intosh, 1972).

(g) Besides property (c), the point of peak intensity moves in longitud to the west, out of the flare site, up to same definite distance (e.g. ∼ 100° for the april 10, 1969 event) where there is no more displacement, as if there were a localized zone of preferential liberation, or, a strong magnetic barrier: in some events, the major intensity may be injected at a different longitud of that of the flare site (Keath et al., 1971; Reinhard and Wibberenz, 1973; Gold et al., 1977; Reinhard et al., 1977)

These seven properties are more or less common to most of solar flare particle events. Obviously, the first three look like typical properties of diffusive transport, though the time of maximum intensity increases linearly with azimuthal distance, instead of a quadratic increase as it is expected from pure diffusion (Reinhard and Wibberenz, 1973). There are however other features that seem not to be general properties of coronal transport, but rather peculiar properties of some specific particle events, or alternatively, there is no consensus because the dispersions of results without a definite tendency.

(h) The spectral index γ, of the power low energy spectra, at energies higher than ∿ 15 MeV, increases with azimuthal distance in the initial phase of events (Van Hollebeke et al., 1975; Conlon et al., 1979), whereas in others γ remains constant (McKibben, 1972; Perron et al., 1978) bur it may decreases with longitudinal distance during the decay phase of some events (McCracken et al., 1971). In Fig. 1, this property has been schematized. This is a highly controversial point where the effects of azimuthal displacement are hardly separable from those of coronal particle escape, or even from energy degradation during particle storage, or, an eventual participation of continuous acceleration with a spatial and temporal dependent source strength. At any event, this property seems to be ineluctably associated with properties (d),(e), (g) and the diffusive behavior during coronal transport.

(i) McKibben, (1972) reported two phases of particle decay in some events, where the time-decay constant abruptly increased for a factor of 2 - 3 from one phase to the other. Strong azimuthal gradients were observed in the first phase, and low longitudinal gradients with longer time decay occured in the second phase. The abrup transition were simultaneously observed at two spacecrafts very separated in heliolongitud. Particles of the second component were uniformely distributed in longitud, whereas the first component are rather concentrated to a shorter longitudinal emission extension.

(j) In some events particle emission last longer than the needed time for propagation if particles were simply advancing azimuthally while escaping, and emission may even prolong for several days after the flare. Particle storage has been evoked for interpreting this delay (e.g. Simnet and Holt, 1971; Benz and Gold, 1971; Zeldovich et al., 1977, Helios group, 1979). This is supported by radio-waves and X-rays emissions (e.g. Lin, 1970; Simnet, 1971). However, for the survival of low energy particles against collisional losses, a continuos acceleration process must be operating along with particle storage (Krimigis, 1973; Roelof and Krimigis, 1973; McDonald and Desai, 1971).

(k) At least in the particular case of corrotating solar particle events, where a regimen of continuos emission is established, the time decay of low energy particles is longer than for high energy particles, indicating that azimuthal gradients are higher for low energy than for high energy particles (Rao, et al., 1971).

Finally, another restriction that should be considered in modelating coronal transport, is the occasional occurence of a preliminary peak in the intensity-time profile of nonrelativistic protons, before the peak of the bulk of the flare particle radiation (personal communication of the GSFC group, 1978). This seems indicate that particles are impulsively liberated in a step of different nature of the subsequent gradual escape.

To conclude the description of the observational points that a suitable model of azimuthal transport of solar flare particles should be able to explain, let emphasize again that it is not yet possible to categorically determine which are the characteristics of the longitudinal injection profiles that depend on the process of longitudinal propagation, or, on the escape mechanism. For instance, the azimuthal gradients may be used as indicators of the magnetic field structure, since particle escape is controled by the magnetic field: the points of major detection of particles would be indicative that the coronal magnetic field have open field lines in the connection site with the observant, whereas minor particle fluxes should be injected from magnetic structures with closed field lines, where particle escape is more difficult. Alternatively, the site where the flux is weak could have open field line configuration, but the number of particles arriving to that point may be small due to particular conditions of propagation since the place of production, such as the crossing of a neutral sheet separating two sectors of opposite polarity. Therefore, it is not easy to know if the delay in particle escape, or, the low particle intensity in some point is due to the mechanism of propagation, or, the mechanism of escape, by measuring only the longitudinal distribution of particle fluxes, since as it was already mentioned, by maping the observational fluxes back to the sun, to obtain the longitudinal injection profiles, it is only obtained information about the last step of coronal transport, but the involved intermediate processes rest masked.

IV. MODELATION OF SOLAR FLARE PARTICLE CORONAL TRANSPORT. With regard to the modelation of coronal transport, models should be able to explain both qualitatively and quantitatively observational features: for one side to describe the physical processes involved in coronal transport, and on the other hand, to give an adequate mathematical description of the effect of these processes on the particle fluxes, such that the quantitative prediction could be compared with observations. At present there is not model able to satisfacorely cover both aspects, and to give a global description of the observational features listed in section III. Due to the lack of knowledge about all the processes taking place since particle production till their detection, several proposals for coronal transport have been given in a free manner in the literature, that cannot be definitively approved or disapproved: in fact, observational effects seem not to be of general nature, but rather to change from event to event, and even among those properties that may be think that are of more general character, there is still a quite amount of controversyaround them, according to different authors. So, this leads to such a situation that many models at present have been developed with the aim of explaining particle transport for one particular solar event, or ,specific kind of a serie of peculiar events. However, it seems to me that the adequate methodology to understand solar particle transport is to develop first a global description of the physics involved in the overall phenomenon of particle transport, and then from such a global model try to understand the intrinsic peculiarities of specific particle events.

Historically, the first models for coronal transport were developed in a quantitative manner: by solving transport equations the basic parameters of each models are matched such to reproduce the observational time-intensity and anisotropy profiles, with the aim of deducing the general features of the transport processes. The common feature of those models is that they are adressed to give account of the shift of the times of onset and maximum intensity with longitudinal distance, as well as the widening of the profile with azimuthal separation, the trend toward uniformity of longitudinal distributions for long times and the exponential decay of flux intensity in the late phase of particle events. The most basic assumptions usually employed consist of an initial diffusive propagation in the corona, characterized by a diffusion coefficient and an escape time, followed by a second step of diffusion along the interplanetary field lines. Some of them have included other effects at the coronal level, such as particle energy losses, collective motions, particle acceleration and disturbances by shock waves and solar wind streams. In fact those original models, did not take into account modern observations, such as the existence of a FPR, and the energy and rigidity independent nature of the transport process of the major component of solar particles (< 100 MeV) as well an the very slight velocity dependence of the transport process. On the other hand, most of recent models are rather of qualitative nature and mainly adressed to describe the involved physical processes for explaining these new observational properties, (d) and (e), and consequently, very often they do not generate results of particle fluxes that may be compared with observations.

A. Precursor Models. Sekido and Murakami (1955) proposed the existence of two different magnetic field configurations where particles were confined. The first one, was a sphere around de Sun of $\sim 100\ R_\odot$ of radii, where particles were dispersed and then emitted from any point of the sphere surface into the extern magnetic field, that would be weaker but of largest extension. In this way, the first stage would distribute particles independently of the flare position. Lüst and Simpson (1957) suggested in connection with the February 23, 1956, event, a diffusion region around the Sun ($\sim 30\ R_\odot$), that they called the solar envelope, where there was much more diffusion than outside it. Once particles escape from that envelope, propagation was more "free" the long of a preferential direction, determined for the magnetic field line where they leave the envelope. In this way they interpret the strong anisotropy degree of that particular event. In fact, these precursor models, that introduce particle propagation around the sun, were not specifically adressed to explain azimuthal transport observations.

B. Models Based on a Transport Equation (quantitative results comparable to observational data).

1. Reid, (1964), developed a two dimensional model where flare particles undergo isotropic diffusion in a very narrow layer ($< 1R_{\theta}$) before escaping into magnetic flux tubes of the interplanetary space, where there is practically no more dispersion, such that the observed time profil at the earth orbit represents the nomber of injected particles from the solar atmosphere, without any modification for interplanetary transport. For the September 28, 1961 event, this model is able to describe the early phase of the event. For long times, interplanetary propagation played an important role. The model may explain properties (a),(b),(c) and (g), of secction III.

2. Axford, (1965), superpose to the coronal diffusion model of Reid and anisotropic interplanetary diffusion of the type proposed by Krimigis (1965), where only parallel propagation to the magnetic field is considered. By adjusting five parameters he is able to produce fits to the data of Bryant et al., (1962). The model is able to reproduce observational properties (a), (b) and (c).

   The main difference between models (1) and (2) is that the time evolution of particle intensity is of different nature: in the model of Reid, the profile is determined by the change of connection longitudes between the sun and the observant, as the sun is rotating, whereas in the Axford model the interplanetary diffusion is predominant, such that particle gradients take place in a same flux tube. Though the coronal diffusion coefficients do not depend in explicit form of particle velocity, however a small dependence is introduced by using slighthy differente values, for different energy ranges. So these models do not contradic property (e).

3. Burlaga, (1970), quentified the scenario of Lüst and Simpson (1957) in an unidimensional model where the concentration of dispersion centers is higher near the Sun than in the interplanetary space. However, since propagation is basicaly in the radial direction, it does not account for any kind of azimuthal particle motion.

4. Englade, (1971), considered along with particle diffusion, collisional energy losses during particle stay in the corona. Here it is assumed an explicit energy dependence of the diffusion coefficient ($\kappa \sim E^q$) and of the escape rate ($\beta \sim E^q$). For the late phase of the event the coronal injection profiles are superposed to diffusive interplanetary transport, including convection and adiabatic deceleration. For the initial phase, impulsive injection is considered. No comparisions are made with observational data of specific events, but it is adressed to reproduce the several features of the time profiles, energy spec-

tra and anisotropies observed at the earth orbit. With the consideration of coronal energy losses it is attempted to explain the decrease of the spectral index of low energy particles in the initial phase of events, that cannot be explained by velocity dispersion. This model explains observational properties (a), (b), and (c), though it does not contradict the others features. In particular the energy independence of coronal transport may be imposed by setting $q \approx o$.

5. Reinhard and Wibberenz, (1973, 1974); Reinhard and Roelof (1973) developed a two dimensional model for solar particle transport outside of the FPR. Based on the fact that the maximum intensity of the flare particles it is often not observed at the flare site, they deduce a deterministic process (longitudinal drift at a rate of 1°-4°/h) acting along with an stochastic process (longitudinal diffusion parallel to the solar equator), which is generally observed by the fact that time intensite profiles of eastern hemisphere events are much wider than those of western hemisphere events. By assuming impulsive injection through a region of preferential longitudes of release of about 60° of extension, the solution of the transport equation becomes dependent of two basic parameters, the longitudinal drift time τ_E and a characteristic diffusion time τ_D, that are determined by the onset time and the time of maximum intensity of the coronal injection profiles, at the connection longitud with the observant. From the analysis of 50 proton events, they found that, in average, particle drift dominates diffusion in particle transport. By introducing long lasting injection (Wibberenz and Reinhard, 1975) with a characteristic escape time τ_L, they are able to explain whetherit can be observed or not, flare particle events that take place far of the connection longitud with the observant, in terms of the relative importance of τ_L and τ_E: when τ_L is longer than τ_E, particle lost is relatively small and the peak intensity will move far by coronal drift, whereas when $\tau_E > \tau_L$, the particle lost becomes so important, that no particle observations are expected at observational points far from the flare site. The interplanetary profiles are obtained by convolution with the solution of the model of Krimigis (1965), and it is shown that the exponential decay shape of the time intensity profile is explained by finite energy-independent solar injection. So, this model predicts energy independent coronal transport on basis to the average values of the model parameters ($\tau_E = 0.56$ h/deg, $\tau_D = 0.22$ h/deg^2 . $\tau_L = 23$ h). Any velocity dispersion appears from the interplanetary diffusion coefficient ($\kappa \sim v$). Therefore, in addition of explaining the exponential decay of flare particle events, this model is consistent with properties (a), (b), (c), (g) and potentially (e), though does

not consider the small velocity dependence of low energy particles and energy dependence of high energy protons. Also, there are not explicit assumptions concerning the transport process in the FPR, across the first ∿ 60° of longitudinal transport, after which the drift and diffusion processes are considered.

6. Ng and Gleeson, (1976), develop a model for coronal diffusion based on the model of Reid (1964), that they solve in spherical coordinates for an impulsive injection. As in the model of Reid, they also consider corrotation of the magnetic flux tubes, such that particles are distributed among different flux tubes. This model predicts energy-independent transport of low energy particles, because the coronal diffusion coefficient and the escape rate are both energy-independents. It leaves open the possibility of a phenomenological incorporation of the FPR within the quantitative description. The coronal injection profile is taken as a frontier condition for an unidimensional interplanetary process, with consideration of corrotation of field lines, convection and adiabatic deceleration. The predicted intensity decay is much slower than in the model of Reid, what is closer of the observational behavior. This model is able to explain features (a), (b), (c) and potentially (d) and (e).

   Another derivation of the model of Reid (1964) was developed by Kunow et al., (1981), which is convoluted with the interplanetary model of Owens (1979), and that is able to reproduce properties (a), (b), (c) for low energy particles, though a divergence with observational data is obtained for the lates time of events.

7. Bazilevskaya and Vashenyuk, (1979, 1981), developed an analysis of the inyection function of high energy protons ($\gtrsim$ 100 MeV) into the interplanetary space on basis to the following assumptions: flare particles fill an acceleration volume of ∿ 60°-60° of longitudinal extension, while escaping exponentialy to the interplanetary space, following a faster propagation step to the foots of the interplanetary field lines, than it is predicted by coronal diffusion. The escape and the fast propagation processe are energy dependents. For comparisons with observational time intensity and anisotropy profiles, the exponential injection function is convoluted with the formulation for interplanetary transport of Schulze et al., (1977). So the main result of this analysis is, that almost the entire coronal transit time of high energy particles is related to the escape, independently of solar longitud, from a volume of about the same size of that of the FPR.

   This result make think in a similar situation of that of low energy particle transport to the correction longitudes which are near the flare site: i.e., those particles that are injected without undergoing the slow second step of coronal propagation, but only the fast first step. The difference with that situation is that escape of high energy protons show a definite energy-dependence.

8. McGuire et al., (1983b), developed a model which includes coronal diffusion, exponential escape and initial acceleration of local coronal particles over a finite width $\Phi_o \approx 10°-30°$, centered about the flare site. The initial distribution is a Gaussian of width Φ_o that broadens with time at a rate that depends on the amount of diffusion, and drop in intensity at a rate that depends on the e- folding escape time. Particle distribution remains Gaussian, as far as the diffusion coefficient and escape time are not functions of longitude. Coronal injection profiles are convoluted with the addition of corrotation effects. The effect of corrotation is translated in an asymetry of the predicted profils about the flare site, in agreement with observational data. The estimated coronal diffusion coefficients and escape time are energy-independent. This model is able to explain properties (a), (b), (c), and (d).

9. Lockwood and Debrunner, (1983, 1984), studied the May 7, 1978 flare particle event, by means of two dimensional model of coronal transport, of the type of those of Reid and Axford previously mentioned. Given the high degree of anisotropy of the event, it assumed that the detected profiles within the first our of the event represent closely the solar injection profiles, even at energies as low as 50 MeV, such that by tracing back the observed fluxes to the Sun they describe the coronal particle time profiles. Data from two spacecrafts were employed in this study: one at the earth orbit, (IMP), which connecting line to the Sun is longitudinaly separated by 15.7° from the flare site, and other very near the Sun (Helios), which connecting line is separated by the opposite side, 32°, from the flare site. Though the rate of transport is not explicitely calculated, to deduce if there are two different propagation processes, however, the fact that the measure fluxes are very differents at 15.7°, in one side of the flare, to the fluxes at 32° on the other side, leads to conclude that the fast propagation region cannot extend more of $\pm$ 25° from the flare. At any event, only one kind of coronal transport process is considered, characterized for a velocity dependent ($E^{0.5}$) diffusion coefficient between 30 and 350 MeV, and an average constant value for the escape rate. In this way a velocity-dependent coronal transport is predicted even for low energies. The behavior of these two basic parameters of the model are obtained by fitting the deduced coronal profiles with the calculations. This model is able to explain features (a), (b), and (c).

It is interesting to note that if the FPR for this event would extend symmetricaly $\sim \pm 25°$, therefore the difference between the observed fluxes in Helios from those of IMP, could be interpreted in terms that the particle fluxes seen in Helios have undergone two steps, of coronal propagation, the 2nd one with a slower rate of transport, out of the FPR, whereas particles seen at IMP have only undergone propagation within the FPR.

The common feature of these nine prototypes of coronal transport models is that they do not furnish a physical scenario for the phenomenon ,and scarcely specify the physical processes and coronal structures that give place to particle diffusion, drift, escape and eventual acceleration, but they generally reduce to determine the values of the parameters of those processes, by adjusting predictions with observational data. It is currently assumed in Astrophysics that a complet, model should include a physical scenario and a mathematical description that reproduces suitably the observational features.

C. Coronal Transport Models Based on Physical Scenarios. Most of the models that attempt to give an explanation to the physical process are of qualitative nature, and limited to some specific properties of coronal transport; for instance, the first proposed models did not take into account the rigidity and energy-independent behavior of low energy particle transport. Among the several models, it can be mentioned the following proposals:

1. The open magnetic field topology models of Fan, Ling and Wang: Fan et al., (1968) proposed a FPR of 100° of extension for protons of 13-70 MeV associated with an open Fan-Shaped topology over the active region of the flare, whose field lines are connected to the interplanetary field. Within that extended FPR, particles would undergo such a peculiar anisotropic diffusion process, that the onset and peak intensity times are practically independent of longitud of the flare, according to observations. Lin (1970) attempted to explain the rapid acces of flare electrons to the wide range of longitudes, by means of an extended source that may be associated with shock wave acceleration. The occuped region by the shock waves would be sourounded by field lines directly connected to the interplanetary field. This open extended region was denominated the open cone of propagation, such that impulsive electron events would proceed from this region. A similar idea was extended by Wang (1972) in the sense that open field lines should allow for electron escape from a very wide region in longitud. In all those proposals propagation inside and outside the region of rapid acces to the interplanetary medium, would be energy-dependent. These models may explain property (d), though before a flare takes place, it is more common to find closed magnetic field configurations, than open field topologies, which are more often created after the flare, by the abrupt heating of solar plasma.

2. The coronal transport model for prompt events of McCracken and Rao (1970): the studies of solar flare particle events of McCracken and Rao established that azimuthal gradients in delayed events were considerable higher than in prompt events. This leads to these authors to the assumption that azimuthal transport were less important in delayed than, in prompt events.

So, they develop a diffusion model for prompt events in a thin layer $0.5R_\theta$ above the photosphere, where the magnetic field is commonly highly disturbed by the same flux of magnetohydrodinamic waves that dissipate heat into the corona. So particles diffuse transversaly through the magnetic irregularities induced by the MHD waves. Above that layer, magnetic fields are more ordered, azimuthal diffusion becomes negligible and transport is basically in the radial direction. It may be noted that this model fits the mathematical description of the phenomenon given by Reid (1964) and Axford (1965), however, this kind of particle diffusion is energy and rigidity dependent, through properties (a) to (c) could be explained.

3. The two emission-phase models of Simnet and McKibben: Simnet, (1971, 1972) proposed that flare protons and relativistic electrons are emitted in two components, a prompt and a delayed. It is assumed in this model that when a flare takes place, the coronal magnetic field is disturbed by the heated plasma that escapes from the magnetic field influence toward the interplanetary space. The irregularities produced from that disturb may act as scatter centers of the flare accelerated particles. Behind that plasma there is an hydromagnetic shock wave that keeps the accelerated particles behind the shock front, until a high for above of $3R_\theta$ where particles begin to escape, to give rise to the prompt component. Particles that were produced in the flare after the shock wave have sweeped the region $\leq 3R_\theta$, remain confined in the strong magnetic fields of the low corona, where they diffuse in the longitudinal direction, to reach the extern corona and interplanetary medium. This component would produce the delayed component, and may even create in some events a corrotating regimen, as in often seen with particles of low energy. For explaining the emission of low energy particles in some events, before the bulk of flare particles, Simnet assumed that previous a flare, there is a population of trapped energetic particles produced in precedent solar flares. So, when a new flare occurs, some of them are liberated, and others remain confined within the active region, where they are accelerated by the flare process to very high energies. Among the liberated particles, in some cases, only low energy electrons would be detected previously to the bulk of flare particles, due that the velocity of electrons is higher than that of protonsof the same energy, so the low energy protons would mix with the main flare particles and would arrive to the detection point by the same time. To support his hiphotesis, Simnet (1972) points out that the first event following a period of low solar activity,very often does not present a very high energy component,because there were not trapped particles previously accelerated.

For explainning property (i), McKibben (1973) proposed that when particles are accelerated in the flare process, some of them may were similarly efficient for all particles.

5. Gold et al., (1977) gave a qualitative proposal for explaining the shift in longitud of the peak intensity of April 10, 1969 event. They suggest that the hot plasma which is ejected by the flare, blows open the field lines over the flare site allowing for the escape of the energetic particles and even emission of enhanced solar wind. Since the flare is within an active center, the magnetic field is quite strong, so that after a short time it closes, avoiding easy escape to those particles that are being produced in the flare after the closure. Therefore, particles need propagage in longitud while they are gradually liberated. In their way, they find localized regions of weak field or with open field lines, where they escape esasily, giving rise to the shift of the peak intensity. At a distance of about 100° there is one of such regions beyond the which particle transport becomes strongly restricted, such that particles end for escape at that site. This model explains properties (b) and (g).

- Since in a static magnetic field the higher the particle energy the faster the propagation is, the only option that does not depend on particle energy is the drift by an electric field: however, if there were an azimuthal electric field through the solar plasma, also thermal particles would move in absence of flares, at least that such electric fields appear around the site of flare ocurrence, and disappear some time after the flare. On the other hand, for a diffusion process to be independent of particle velocity, the mean free path, λ, must behave as $\lambda \alpha v^{-1}$; therefore, though the above possibilities cannot be completely rejected, it seems scarcely probable that static magnetic fields may explain property (e). The most promising possibility for that goal is to evoke the dynamical behavior of solar magnetic fields; i.e. that the magnetic fields themselves, move carrying with them particles of all energies, at the same rate. The following models were developed in that direction -.

6. The bird-cage model of Newkirk and Wentzel: by analogy with bird cages, it is assumed a row of cages with no direct connection among them, that is, with closed doors. In the central cage there are enclosed birds of all kinds; suddenly the doors of both sides are open, allowing the birds to go into the lateral cages, whose contiguos doors are open, but their doors of the opposite side remain closed. When the slower birds have entered into those cages, their open doors close and the doors of the other extreme become open, such that birds go into the next cages and, so on. A single cage is never connected for both sides, but only one at a time. In this way all kinds of birds will travel the long of the row at the same effective velocity. Now, if instead of birds and cages we have energetic particles and magnetic archs, and since the archs roots are in stochastic motion due to photospheric motion, Newkirk and Wentzel, (1978), proposed that when the roots of two magnetic archs get in touch,

there is a topological inestability that leads to field line reconnection, allowing the interchange of particles between the two archs during a short time, before, they separate again. The restrictions of such a transport are that the particle transmittal time must be shorter than the reconnection time, and the last one must be shorter than the diffusion time for the stochastic process that may bring them in touch, in order that no more of two archs might be simultaneously connected. In this way the transport process is highly efficient, with a propagation velocity which is energy-independent. During this transport process, particles may escape by gradient and curvature drifts that depend on the particle energy, but this energy-dependent escape is limited by a threshold in energy, imposed by the diameters of the archs, below the which particles cannot drift within their remain time in a single arch. So, this model is able to explain property (e) for both low and high energy particles, if the diameter of the archs is of the order of 10^{10}cm. However, it seems difficult to realize that the required conditions may fortuitously be satisfied in every solar particle event: a high number of magnetic flux tubes simultaneously present over a large longitudinal extension, that reconnections continuosly take place and only two arch at each time.

7. The magnetic bottle model of Schatten and Mullan: based on the fact that magnetic bottles expanding with velocities of several hundreds of km/s seems to be a general phenomenon associated to solar flares (e.g., Sakurai, 1965, 1973; Schatten, 1970), which azimuthal expansion may be infered from the Moreton wave associated to burst of type-II, Schatten and Mullan, (1977), proposed a two-step coronal transport model, where the dynamical behavior of the magnetic field during the first step produces similar azimuthal transport for particles of all energies. Therefore, when a flare takes place in the closed magnetic field configuration of active centers, the field lines are pushed out of that region, because the kinetic energy of the superheated ejected plasma is higher than the magnetic energy. The flare accelerated particles remain trapped in the top of the expanding bottle, while bouncing in the photospheric roots of the field lines. The external plasma of the expanding bottle is compressed as the bottle expands more and more, whereas the internal plasma becomes less and less dense. In this way, an instability of the Raleigh-Taylor type appears, due to the gravity force, that produces interchange between the external and the internal plasma. The external field lines become deformed allowing particle escape, whereas the internal field lines undergo reconnection by the topological instability, with the subsecuent escape of particles. Particles of energy E > 3 GeV may drift out of the bottle before its opening. The onset time for the trigger of the Raleigh-Taylor instability is of the order of (10-1000)s and for the bottle to be completely open it takes about (100-2000)s more, such that all particles are convected with the same expansion velocities for an

interval of ∿ (5-50) min (averane of 10^3s) before their release. According to the model, there are two population of energetic particles, the first one is trapped inside the bottle for a finite time, while continuosly accelerated to balance adiabatic losses, and it is liberated at the bottle opening; the second population is accelerated in the very reconnection process, during the bottle openino. The relativistic electrons associated with type IV emission would be accelerated in this last process. The occurence of a particle event depends on whether the conditions are given or not for the bottle opening, which in turn depends on whether the duration of the flare induced coronal shock are larger or not that the Raleigh-Taylor instability grow time. Therefore, when the bottle opens and particles leave this kind of FPR, at the level of the top of the bottle, some of them escape directly into the interplanetary space and others undergo a 2nd step of coronal transport outside of the FPR. For this last step, Mullan and Schatten (1979) propose that particles travel through the large scale coronal field with a superposition of scatter centers, that they identify with the network of brillant points that are seen in X-rays through all the solar disk, and that presumably represent localized enhancements of magnetic field. They carried out numerical calculations of particle trajectories in this static magnetic field, and found that the transport is performed by azimuthal drift guided by the general solar magnetic field, and diffusion through the assumed network of scatter centers, as proposed previously by Reinhard and Wibberenz, (1973); but whereas in the previous model the transport is velocity-independent and energy-independent, here both the drift rate and the diffusion coefficient are energy-independents but velocity-dependents. Diffusion dominates at low energies and drift becomes dominating at high energies. So, the propagation time of low energy particles since acceleration until particle escape is composed of two parts, $t \sim t_o + A/\bar{\beta}$, where the first term represents the time that particles remain in the bottle, and the second one the diffusion time, such that the composition gives a weaker velocity dependence than v^{-1}, as was found by Ma Sung (1977). This model is able to explain properties (a), (b), (c), (d) and (e) in a qualitative manner. It is predicted that the drift motion change of direction with the solar cycle. The predicted time scale of this model has been critizised by Cliver et al., (1982), and further consistently answered by Mullan, (1983).

Finally, it must be pointed out that given the degree of incertitude with respect to some of the listed coronal transport properties and that we are not yet able to unambiguosly separate propagation effects from escape effects, it is not possible to judge a given model in the adequate form, that allows to prove or disapprove it in a definitive manner. Nevertheless, with the aim of going deep into the study of coronal transport, we have developed a model based in several emission phases, that we have tried to describe as quantitatively as possible.

V. THE MULTI-EMISSION PHASE MODEL OF PARTICLE CORONAL TRANSPORT.

Taking properties (d) and (e) as depart plataform, we assume that the coronal magnetic field must play an active role in the transport of solar flare particles; i.e., the fields must be dynamics, otherwise if static magnetic fields were prevalent anywhere, the coronal injection profiles would present a characteristic velocity dispersion, energy and rigidity dependence, that is not observed in the main particle population ($\leq$ 100 MeV). With dynamic fields, it is possible to search for situations where all kind of particles be constrained to a similar transport; but because according property (e) there is a slight dependence on velocity in the transport process, it is probably that dynamics fields be no present through all the traversed regions, since particle acceleration till particle injection into the interplanetary space. A possibility is that propagation, may be of different nature through different coronal regions: we know from property (d) that particle transport within the FPR is carried out with a different rate than outside that region. Since most of observable events are associated with flares whose connections with the observator are located within the range of longitudes of the FPR, and the energy and rigidity independence is observed in most of particle events, it is usually assumed that the velocity independent transport is a property of the FPR, whereas the slight velocity dependence of low energy particles is acquired out of that region. Furthermore, since properties (a), (b), (c) look like the result of a diffusive-like-process, and according to property (g) the peak intensity may shift in heliographic longitud from the flare site, it seems natural to infer that any velocity-dependent process occurs out of the FPR, Therefore, following Schatten and Mullan, (1977), we assume that transport in the FPR is performed in association with a dynamic magnetic field where the particles are constrained, and on the other hand, according to Reinhard and Wibberenz, (1974), that the transport outside the FPR is dominated by drifts and diffusion. It is attempted here to give a global model for explaining general features of coronal transport, instead of the particular behavior of solar particles in an specific solar flare event.

A. Qualitative description of the involved physical processes. The temporal and spatial sequence of different emissions during a Solar Flare have driven to a widely accepted description of the flare phenomenon in four main steps: the pre-flare phase, the impulsive phase, the flash phase and the main phase (e.g. Priest, 1981). The microwave impulsive burst and hard-X-rays are evidences of energetic electron production during the impulsive phase. On the other hand, there are inferences that high energy protons (even Multi-GeV protons) are already present in flare regions at the begining of the flash phase (Chupp and Forrest, 1982), and that the injection of protons of (4-80) MeV may be instantaneous within the time scale of the flash phase (e.g. Ma Sung et al., 1975). Therefore, it seems that a first acceleration stage takes place during the impulsive phase, by a deterministic acceleration process.

According to Pérez-Peraza et al., (1977, 1978), if the impulsive process is associated with neutral current sheet acceleration, multi-GeV protons can be obtained in some seconds. Therefore, we assume that the flare process is initiated most of times in a closed magnetic field configuration: the flare energy is so large, that within the time scale of the impulsive phase the energy density of the plasma and accelerated particles may be higher than the magnetic energy density ($\beta \geq 1$). According statistical studies of Hudson (1978) and Belovskii and Ochelkov (1980), $\beta \geq 1$ is the situation in quite a high number of solar flares. Under this situation, it is enough than $\beta > 0.1 - 0.3$, for the magnetic trap to be destructed by the effect of an MHD-instability, or, due to the absence of equilibrium (e.g. Parker and Stewart, 1967; Meerson and Sasarov, 1981). In this case, an appreciable amount of plasma with energetic particles and frozen-in magnetic fields is ejected from the magnetic trap on a time scale, $\tau_{tr} = L/V_a$, where L is the characteristic size of the trap and V_a the Alfvén velocity. Therefore, if the flare region is found, for instance, at a height of (0.005 - 0.05) R_θ above the solar surface, and has on average longitudinal size ∿ 10°, it means $L \sim 10^{10}$ cm, in such a way that assuming hydromagnetic motions of ∿ (1000 - 2000)km/s it is obtained $\tau_{tr} \sim$ (50-100) s, which is just of the order of the time scale of the impulsive phase. After that time, the field lines may close again, since magnetic field strength is usually very high in those active centers. The particle release in this phase, while depending on the energy density of the accelerated particles, is independent of their energy. Later, in the course of the flash and main phases of the flare, more hot plasma of very high conductivity is created, such that the frozen plasma and field expand outward as the kinetic pressure in the interior of the closed loops increases. Now, the conditions are such that $\beta < 0.1 - 03$, in which case according to Meerson and Sasarov, (1981), the magnetically trapped particles excite strong Alfvén wave turbulence of small transverse scale. According Pérez-Peraza, (1975), small scale turbulence of linear dimensions ∿ (1 - 10) Km may account for effective stochastic acceleration up to some GeV, in a time scale of about ∿ 20s, if this second acceleration stage has place at chromospheric levels. If the second step has place at the coronal level, according to Mullan (1976, 1983) a high pressure piston is formed which drives a shock within the closed field configuration: magnetized turbulent cells of scale size of ∿ 100 Km remain bounded in the wake of the "bottled up" shock wave. Since the shock wave velocity is higher than the expansion velocity of the magnetic bottle, the statistical Fermi acceleration overcome the 1st order Fermi process (adiabatic losses) due to the expansion of the bottle; this 2n acceleration stage initiated in the flash phase prolongs until the shock wave dissapears, or, the coinfinement of particles in the bottle is no longer effective. Though there is a time interval between the onset of the first acceleration and the onset of the second acceleration stages, however, it may be cases where they are almost continous, or, even a superposition of both stages may ocurr; i.e. the 2nd stage may have initiated before the end of the first one. In the case that the flare magnetic configuration is broken in the impulsive phase, some of the energetic particles are impulsively ejected into the interplanetary space and others remain in the environment of the active region. In this way, at the beginning of the particle event there is a strong anisotropy aligned with the interplanetary field lines, that are connected to the heliographic longitudes of the cone which is displayed by the open lines, i. e. the azimuthal distribution is determined by the extension of the fan-type-cone of open lines. The accelerated electrons reach lower energies than protons because they are strongly decelerated in the source medium. In fact, while protons only lose energy by collisional losses and energy degradation by p-p collisions, electrons lose energy by collisional losses, gyrosincrotron, Bremstrahlung and Compton inverse effect; however, for a given energy, electrons arrive faster to the detection point than protons, because their higher velocities. It is predicted in the case of occurence of this first emission phase, that the maximum peak intensity will be seen at the flare site, even if the peak intensity shifts later during a later emission phase. The energy spectrum of electrons will show a definite change of slope at a certain energy ($\sim$ 100 KeV) in some events indicating two different populations; those of the primary process accelerated in a dense medim, and those of the secondary acceleration in a less restricting medium. For protons the change of slope may take place at some MeV, however, the break in the spectrum is not very hard because low energy protons of the first emission mix with the first released protons of the 2nd emission in the connecting longitudes with the flare site, arriving by the same time at the observation point.

In the case that the flare conditions are such that the magnetic trap is not destructed in the impulsive phase (β < 0.1-03), the population of the first acceleration process mix within the loop with the population of the secondary acceleration, remaining confined in the expanding magnetic bottle, in which case not a noticeable change in slope is predicted in particle spectra, and the maximum peak intensity will not necessarily occur at the flare site. In such a case it is not expected an early flux of low energy electrons. Obviously, in the case that the conditions for the opening of the expanding bottle are not remplished as discussed by Mullan (1983), only the impulsive component emitted during the impulsive phase will be observed, as an event with a small emission cone; in addition, if also the conditions of the break down of the primary source configuration during the impulsive phase were not given, no particle event is expected.

A.1. Velocity Independent Transport of Low Energy Particles in the FPR.

Among the particles that are impulsively ejected in the first emission phase, we said before that some of them reach directly the interplanetary field lines, and so, only interplanetary propagation is important, and others remain trapped in the local fields where they may be reaccelerated to high energies during the 2nd acceleration stage, in the course of the flash and main flare phases. The stored particles and the new accelerated component in the expanding bottle might be scattered by Alfvén wave turbulence and precipitate into the dense atmospheric layers as a consequence of the cyclotron instability (Kennel and Petschek, 1966). This instability arises due to anisotropy of longitudinal and transverse pressures of high energy particles with respect to the magnetic field in the bottle. However, according to Meerson and Rogachevskii, (1983), particle precipitation does not occur if the characteristic life time of particles in the trap is longer than the wave-passage time ($\tau_\omega = h/V_a$), where h is the height of the arch, i.e., that the characteristic time of particle diffusion be longer than τ_ω, in which case particles remain stored for long time, and do not precipitate into dense regions. The conditions for storage is reduced to $\beta < \beta_*$, where β_* is a value that increases with distance from the photosphere. Since β decreases with height above the photosphere, as the internal density decreases with the expansion of the bottle, it entails that as the bottle expands particles have less probability of being lost in the dense layers of the solar atmosphere.

The longitudinal and radial expansion of the magnetic bottle, as well as the subsequent opening by a Raleigh-Taylor instability, followed by field line reconnection have been widely described by Schatten and Mullan, (1977), and Mullan, (1983). Such an expansion produces the convective particle transport in an independent manner of energy and rigidity: however, particles of $E \geq 100$ MeV may ocasionlly escape of the trap by drifts from magnetic field gradient and curvature, which are velocity-dependents, $V_d = (\gamma_L mc/qR_c H)(v_\parallel^2 + v_\perp^2/2)$, where m, q and γ_L are the particle mass, charge and Lorentz factor resrespectively, R_c is the radius of the bottle, H is the fields strength $v_\parallel$ and $v_\perp$ are the parallel and perpendicular components of particle velocity to the magnetic field. Combining $v_\parallel$ and $v_\perp$ into an effective total velocity v, we have for 100 MeV protons $v = 1.285 \times 10^{10}$ cm/s. According to Mullan, (1983), the radius of the bottle at the time of opening is (0.05 - 0.5) R_θ, so, it can be shown that high energy particles may drift before that opening: for instance, if we take $R_c = 0.01$ for the case that the bottle opens at 0.05 R_θ and $R_c = 0.1$ when it opens at 0.5 R_θ, we have that 100 MeV protons escape after t = (0.5 - 5) min if H = (1-10) gauss respectively in the first case, and H = (0.1 -1) gauss in the second case. When the bottle is near its opening $R_c \sim$ (0.05 - 05) R_θ, particles are still able to escape by drifts after a time of about 13 min. (if the bottle has not open yet), when the fields are of 1 gauss and 0.1 gauss respectively. Therefore, it is expected that particle escape of high energy protons be definitively energy-dependent, in some particle events. Meanwhile, the net transport of the bulk of particles is that of the expanding region with a relatively high velocity. At the end of the convective motion, particles have completely filled the top of that FPR, such that when the bottle opens, the next transport step initiates at the coronal level of the bottle opening, for those particles that do not escape directly.

A.2. Velocity-dependent Transport out of the FPR. Once partic leave the bottle, transport is accomplished by drifts and diffusion, while particles escape as they found preferential sites of open field lines, according to the field topology behavior in each particular event. The basic motion of particles is along the north-south general magnetic field of the Sun; so, the gradient and curvature drifts of particles traveling along that field are in the azimuthal direction, depending on the charge, mass and velocity of particles. For the diffusion process, it must be realized that alternatively of the possible static scatter centers associated with X-rays bright points, also the flare disturbance may affect the solar corona at heights so extended as 1 R_θ; so, the coronal magnetic fields are disturbed, at least for some time after the flare, and such irregularities may act as diffusion centers, making possible the azimuthal transport in addition to drifts. However, at heights far above 1 R_θ, the fields must be more ordered and transversal diffusion may be negligeable in relation to radial motion. Therefore, the propagation region is composed of a background of ordered magnetic fields, superposed of magnetic irregularities of all scale sizes. According to Parker, (1963), particle transport in disorder fields is described by means of two transport geometries, the thick and thin geometries if the particle gyroradii are smaller, or, larger respectively than the average size of field irregularities, and a drift geometry in ordered magnetic fields. The diffusion coefficients in thick and thin geometries and the drift rate may be generalized in the following expression

$$(q^*/A)R^L \sim (Z/q^*)\beta^L$$

where L = 1, 2 an 3 correspond to the thick, drift and thin geometries respectively. R is the magnetic rigidity, A an Z are the atomic mass and atomic number, $q^* \sim Z\,[1 - \exp(-130\,\beta/Z^{0.66})]$ is the particle effective charge and β is the particle velocity in terms of the light velocity. Assuming that the average magnetic field strenght of the field concentrations at $\sim 1\ R_\theta$ is of 10 gauss (or $\sim$ 1 gauss), and their diameter of $\sim$ 1.3 Km (or $\sim$ 13 Km), therefore protons with energies lower than $\sim$ 100 MeV move in a thick geometry ($\kappa_1 \sim \beta$), whereas protons of $E \gtrsim 100$ MeV move in a thin geometry ($\kappa_3 \sim \beta^3$). According to observational properties (a), (b), (c), the azimuthal transport shows a typical behavior of diffusive propagation. However, if azimuthal transport were exclusively accomplished by diffusion, the traveling time would present a velocity dependence of the form $t \sim 1/v$; on the other hand, according to property (g) a colective motion of particles fluxes seems to be superposed with diffusion, producing a shift of the peak flux. Assuming that a drift of particle fluxes may be infered from that coherent shift, as proposed by Reinhard and Wibberenz, (1973), therefore the transport time in the LPR, since particles leave the magnetic bottle until they escape, can be written as the sum of the two following components:

low energy protons: $t_{LPR} = t_{thick} + t_{dr.} \sim \beta^{-1}+\beta^{-2} \sim \beta^{-1}$

high energy protons: $t_{LPR} = t_{thin} + t_{dr.} \sim \beta^{-3}+\beta^{-2} \sim \beta^{-2}$

which is similar to the conclusion of Mullan and Schatten (1979): diffusion with a velocity-independent mean free path is dominant at low energies, whereas drifts are the dominant transport processes at high energies, that is, high energy protons are transported to longer distances from the flare site than low energy protons. The superposition of diffusion and drift of low energy protons gives, as we have seen, a velocity-dependence of the form $t \sim v^{-1}$, however, according to property (e) their velocity dependence during coronal transport is of the form $t \sim v^{-0.55}$. Nevertheless, this may be conciliated from our preliminary assumption, that transport in the FPR is velocity-independent such that the resultant velocity dependence from the combination of both propagation regions is

$$t_{\psi} = t_{FPR}+t_{LPR} \sim \text{const.}+(v^{-p}+v^{-1}) \sim v^{-q} \text{ with } (0<q<1) \text{ and } (1<P\leq 2)$$

which is just what is claimed in property (e) for low energy protons. This is illustrated in Figure 2. For high energy protons we have

$$t_{\psi} = t_{FPR} + t_{LPR} \sim \text{const.} + v^{-2} \sim v^{-p} \text{ with } (1<p\leq 2)$$

Therefore, azimuthal transport of high energy protons is quasi-energy and rigidity dependent, because for a given field geometry the drift velocity scales as $V_d \sim (\gamma_L c/q)\, m\, v^p$.

It is worth to mention the general features of the spectral shape behavior as described in property (h): in some events when there is the first emission phase of narrow emission cone, particles of all energies are concentrated in that cone around the flare site, in such a way that there are relatively more high energy particles within the corresponding narrow cone of detection, than some minutes later, when the magnetic bottle opens and high energy particles are found distributed over a much more wider emission cone, of at least the longitudinal extension of the opened bottle. For this reason there are relatively less high energy particles far of the flare site in the initial phase of particle events. In addition, there is the fact that protons of E > 100 MeV have occasionally escaped in an energy-dependent manner before the bottle opens. Furthermore, it may be expected a high concentration of low energy particles during the 2nd acceleration stage in the bottle due to adiabatic losses. These are the predicted reasons why the energy spectrum becomes steeper with longitudinal distance from the flare site. However, in events where there is not first emission phase, it is not expected a noticeable increase of the spectral index with azimuthal distance, in the initial phase of the particle event, at least for energies lower than 100 MeV. In the decay phase of the event, the decrease of the spectral index with distance from the flare is due to the drift effect that takes preferentially the high energy protons to long distance, such that after long times there are more high energy particles far from the flare than around the FPR where they were liberated.

Propagation out of the FPR is not completely uniform through all the solar disk, but the fluxes are modified when particles pass from a region of a given magnetic polarity to a region of opposite polarity. In fact, according the description of Svalgard et al. (1974) of the coronal magnetic field structure over sector boundaries, there is a neutral current sheet lying along the sector boundary. Therefore, the diffusion coefficient and drift rate are modified when particle fluxes reach a sector boundary due to a drift-like-process along the neutral sheet, similar to the process suggested by Fisk and Schatten (1972).

B. Quantitative Predictions of the Model. Assuming that the propagation of the impulsively ejected particles, in the first emission phase, during the impulsive phase of the flare, is purely interplanetary propagation, therefore, we will concentrate in the second emission phase, when particles undergo azimuthal coronal transport. We have already mentioned that velocity-independent transport in the FPR is associated with a convective process produced by flare phenomena, such as an expanding magnetic loop, or alternatively, with the expulsion of an hydromagnetic shock (the flare blast wave) keeping particles under acceleration behind the front shock, until it reaches a height of (0.5 - 1) R_θ, where there is not any more a very high concentration of closed magnetic field archs, and where changes in the thermodinamical parameters, and thus in the conductivity, may lead to the defreezing of field lines, and liberation of the constrained energetic particles. Meanwhile, the net transport of all particles is that of the expanding region; so, we assume a convective like process where particles propagate coherently at a definite velocity V_c. The evolution of the number density of particles at a point X and time t within the FPR is expressed in unidimensional coordinates, by the condition of particle conservation (Pérez-Peraza and Martinell, 1981).

$$\frac{\partial N}{\partial t} = -V_c \frac{\partial N}{\partial X} \qquad (1)$$

for the task of mathematical simplicity we have neglected collisional and adiabatic losses, as well as the 2nd acceleration process rate, under the rough assumption, that there is an equilibrium between energy gains and losses. We also assume that eq. (1) concerns mainly the bulk of flare particles ($\leq$ 100 MeV), because for higher energies and additional term for the energy-dependent escape rate should be included. A similar analysis in spherical coordinates has been previously developed by Martinell and Pérez-Peraza (1981). The solution of eq. (1) gives a coherent pulse of particles in azimuthal direction X of the form

$$N\ (X,\ t) = \frac{N_a}{X_o}\ \delta\ (X - X_f - V_c t) \tag{2}$$

where N_a is the number of accelerated particles, X_o the FPR extension and X_f the flare extension assumed symetric with respect to a localized origin. Since the coherent motion takes place in all directions, the convected energetic particle flux distributes uniformely all over the top of the FPR, so that the initial conditions for transport outside the FPR are

$$N(X,0) = \begin{cases} N_a/X_o & -X_o/2 \leq X \leq X_o/2 \\ 0 & |X| > \pm\ X_o/2 \end{cases} \tag{3}$$

Once particles abandon the FPR volume, they are conveyed by diffusion with a diffusion coefficient K_ℓ, and by drift at a velocity V_d, and are lost into the interplanetary space at a rate Γ (e.g. Reinhard and Roelof, 1973). The corresponding transport equation, neglecting energy losses, corrotation and flux depletions for changes through different unipolar magnetic sectors is

$$\frac{\partial N}{\partial t} = K_\ell \frac{\partial^2 N}{\partial X^2} - V_d \frac{\partial N}{\partial X} - \Gamma N \tag{4}$$

It must be pointed out that eq. (4) also applies to the heliographic longitudes located over the top of the FPR; the difference with eq. (1) is that they operate at different heights in the corona and at different times. The analytic solution of eq. (4) is

$$N(X,t) = 2.5\ N_a \exp\left(-\Gamma t - \frac{(X-V_d t)^2-(X_o/2)^2}{8K_\ell t}\right)\left\{\exp\left[\frac{(X-V_d t)X_o/2}{4K_\ell t} + \frac{(X-V_d t-X_o/2)^2}{8K_\ell t}\right] \mathrm{erf}\left(\frac{X-V_d t-X_o/2}{(4K_\ell t)}\right) - \exp\left[-\frac{(X-V_d t+X_o/2)}{4K_\ell t} + \frac{(X-V_d t+X_o/2)^2}{8K_\ell t}\right] \mathrm{erf}\left(\frac{X-V_d t+X_o/2}{(4K_\ell t)^{0.5}}\right)\right\} \tag{5}$$

It can be appreciated from eqs. (3) and (4) that the solution (5) does not depend on the convective velocity V_c and the source location X_f. Assuming that the FPR liberates the flare particles at a height of

0.8 R_Θ above the solar surface, we have translated the linear coordinates into angular coordinates by the relationship $\Psi = (X/1.8\ R_\Theta)57.295$. In accordance with previous studies of coronal transport, we have assumed a coronal drift velocity $V_d = 4X10^{6}$cm/s, $\kappa_\ell = 2X10^{17}$cm^2/s for protons of $E \gtrsim 50$ MeV and $V_d = 4X10^{5}$cm/s, $\kappa_\ell = 2X10^{16}$cm^2/s for protons of $E < 50$ MeV. For the loss rate we used $\Gamma = 3600\ s^{-1}$, but the model is weakly sensitive to variations of Γ within a factor of 100. The results shown on the next figures are given in terms of $N(X, t)/N_a$. Fig. 3 shows the azimuthal distribution of particles in the corona given by eq. (5): on the upper panel we considered high energy protons and a FPR extension $\Psi_o = 92°$, while the low panel corresponds to low energy protons and $\Psi_o = 60°$. It can be noted that according to property (c), the angular distribution tend to be uniform for very long times, as well as certain shift of the peak intensity out of the flare site (normalized at $\Psi = 0°$) as indicated by property (g): this East-West drift is seen in panel (a), for high energy protons and relatively large times, however the shift is less noticeable at low energies, indicating how the relative importance between drift and diffusion changes with velocity. On Fig. 4 it is shown the coronal injection time profiles of high energy protons, for two different heliographic longitudes; one above the FPR, and the other just outside of the FPR extension, for $\Psi_o = 92°$. It can be appreciated that in the LPR, at a longitud $\Psi = 50.4°$, the intensity-time profile is typical of the diffusive-type, whereas above the FPR, just at the center of the flare site, $\Psi = 0$, the profile is quite different. Also it may be noted that according to property (a) the peak intensity is shifted to longer times with azimuthal distance; according to property (b) the profile widens with separation from the flare site, and according to property (c) the intensity tends to be equal at both locations for large times. Fig. 5, shows a similar behavior of the coronal injection profiles of high energy protons for a FPR extension $\Psi_o = 100°$, and two different locations, one of them within the FPR at $\Psi = 40°$, and the other outside the FPR at $\Psi = 55°$. Therefore, these results represent particle distributions reaching the roots of the interplanetary field lines, but not the observed fluxes. To reproduce the observational fluxes at the earth orbit, we must incorporate interplanetary effects. Since interplanetary transport is along field lines, the longitudinal distributions at the escape from the corona remain basically unaltered. So, with the aim of illustrating the translation of the injection profiles at the level of the earth orbit, we have chosen the simplest diffusion description along magnetic flux tubes, with a constant magnetic diffusion coefficient K: according to Parker (1963), particles that are impulsively ejected from the Sun, distribute in the interplanetary space in the following form

$$U\ (r,\ t) = \frac{N}{(4\pi Kt)^{3/2}}\ \exp\ (-r^2/4Kt) \qquad (6)$$

where N is the number of impulsively ejected particles and r = 1.2 A.U. is the distance from the upper corona along an interplanetary field line. When ejection is not impulsive, but gradual, the observed time profile is obtained from the convolution of eq. (6) with the injection profile given by eq. (5). So, the observed particle profile is

$$W\ (r, \Psi, t) = \int_0^t N(\Psi,\ t - \tau)\ U\ (r, \tau) dt \qquad (7)$$

where τ is the interplanetary travel time, and $t - \tau$ the coronal travel time. Taking $K = 5 \times 10^{21} cm^2/s$, we show in Fig. 6, the results of this convolution, for the two profiles of Fig. 4. Similarly in Fig. 7, it is shown the convolution for the profile of Fig. 5, (for a location $\Psi = 55°$, with $\Psi_0 = 100°$). In both figures we have plotted for comparaison the profile of pure interplanetary propagation, as if particles were impulsively injected. It should be appreciated that though the shape of the coronal profiles are lost (what is more noticeable for longitudes located within the FPR, at $\Psi = 0°$ for instance), however, the shifts of the onset, the peak intensity and the broadening of the profile with azimuthal separation, i.e., properties (a), (b) and (c) are conserved through interplanetary propagation, and are larger relative to impulsive ejection: similar results are obtained with low energy protons, but with a delay in time scales. Obviously, for particles of the first emission phase, during the flare impulsive phase, eq. (7) represents their time-intensity profile.

B.1. Prompt Particle Fluxes. If we adopt the magnetic bottle model of Schatten and Mullan, (1977), we can predict according to the property mentioned at the end of the list of chapter III, the presence of prompt particles before the flare particles can escape of the bottle. We have said before, that only protons of E > 100 MeV may occasionaly drift out of the expanding bottle, before its opening, when some restricted conditions are remplished. As it was stated by Mullan, (1983), the release of the flare population takes between 5-50 min, with a most probably value around ∿ 10^3s. Therefore, according to our model, the low energy proton population (< 100 MeV) which is ocassionally seen in the interplanetary space before the bulk of flare particles, cannot be flare particles. For explaining their origin, we propose the following phenomena (Pérez-Peraza and Martinell, 1981): the expanding magnetic bottle finds itself within an active region of complex magnetic structure, populated of magnetic archs. So, during its expansion it can get in touch with adyacent field lines of opposite polarity, forming a neutral point that rapidly evolves in a neutral current sheet as the bottle expands (Fig. 8). In this sheet, the long of which there is an electric current, a tearing-mode instability may be developed due to the fact that, though the coronal plasma conductivity is very high, it is not infinite: magnetic field lines around the neutral sheet are reconnected, transfering their energy excess to the local thermal particles. So, according to Furth et al., (1963) the grow rate of the instability is given as $\omega = (fc^2/4\P\sigma^2)(2s/q\alpha)^{2/5}s^{-1}$, where f takes a value between 0 and 1, $\alpha = \kappa a \sim 0.2$, where κ is the wave number and a is the width of the neutral current sheet, σ is the coronal conductivity, $s = (4\P/\rho)^{0.5}(\sigma H/c^2)$, with ρ the plasma density, H the field strenght and c the light velocity. Taking $H = 3$ gauss, $\sigma = 10^{16}\ s^{-1}$ and $\rho = 1.6 \times 10^{-16}$ gr/cm^3, as typical coronal values below $\sim 1\ R_\theta$, the grow rate becomes $\omega = 2.77 \times 10^5\ a^{-8/5}\ s^{-1}$. Now, assuming an expansion velocity of the form $V_c = V_o e^{-t/t_e}$, the current sheet width decreases as $a = d\ e^{-t/t_e}$, where d is the initial width of the sheet, $t_e = d/V_o$ is the esponential compression time and V_o is the bottle velocity when the archs get together. For calculations, we make the following assumptions: since a certain time interval has elapsed when the expanding bottle finds a magnetic loop of opposite polarity, the velocity V_o must be lower than the initial expansion velocity; lets take $V_o = 1000$ Km/s, so, in Fig. 9, we have plotted the grow time for the instability, ω^{-1}, versus the evolution of the width a for two reasonable values of the initial sheet width d, 0.01 R_θ and 0.02 R_θ. The intersection of each of these curves gives the grow time and the width of the neutral sheet corresponding to those times. It can be seen that these turn to be $t = 31.5$ s with $a = 2.19 \times 10^4$ cm and $t = 64.5$ s with $a = 3.41 \times 10^4$ cm for the specific initial conditions respectively. To these times we need to add the time elapsed since the expansion of the bottle till the formation of the neutral sheet; as we said before, the magnetic loops that may interact with the expanding bottle must find in the same active region. Consecuently, their distance to the magnetic bottle cannot be larger than the dimensions of the active regions, which are typically of the order of 0.1 R_θ, thus, the time that the bottle last to reach a magnetic arch, if the initial expansion velocity is $\sim$ 1200 Km/s is at the most of the order $t = 0.1\ R_\theta/1200$ Km/s $= 1$ min. Therefore, we obtain that a particle population may be accelerated out of the flare site after (1.5 - 2) minutes of the initial magnetic bottle expansion, which are clearly shorter times than the liberation times from the bottle (5 - 50 min).

The electric field produced by the change of magnetic field structure around the neutral layer appears from the Faraday law as $\varepsilon = \omega HL/c$, where L is the length scale of the electric field, ω^{-1} is the time for change of the magnetic field structure, that can be considered as the grow time for the instability. Taking the length of the neutral sheet of 0.05 R_θ, so, since the electric field appears in the parallel direction to the neutral sheet, we can consider this length, as the scale L. Therefore, for a magnetic field $H \simeq 1$ gauss around the neutral sheet, we have $\varepsilon = 3.7 \times 10^{-3}$ statvolt/cm for $\omega^{-1} = 31.5$ s and $\varepsilon = 1.8 \times 10^{-3}$ statvolt/cm for $\omega^{-1} = 64.5$ s. The obtained energy from this dissipation magnetic energy process, in the volume L^2a of the neutral sheet are 1.46×10^{17} ergs and 5.38×10^{16} ergs respectively. Clearly, this liberated energy is at least 10^{-13} times lower than the liberated energy in the flare, but is enough for producing a bunch of particles of energies as high as $\varepsilon_{max} = e\varepsilon L = 3.7$ GeV and 1.81 GeV respectively. Some of these accelerated particles are impulsively ejected, and others may undergo azimuthal propagation.

It should be noted that we have refered to three different emission phases within the frame of this model: the impulsive phase of primary flare particles, the emission of stochastically accelerated particles, and the emission of prompt particles out of the flare magnetic bottle. We should mention, according to Mullan, (1983), an additional particle emission, up in the corona, from acceleration in the reconnection processes during the bottle opening, giving rise to relativistic electrons.

Now, let sumarize the model by making a balance of our results: by evoking the dynamical behavior of the flare magnetized plasma, it is explained property (d) for a FPR, where particles are convected at the expansion rate of the magnetic structure, with an average velocity that may varie from event to event: for instance, if the average expansion velocity is of 10^3 Km/s and opens at 1 R_θ above the solar surface, the rate is $\sim < 150°/h >$, whereas if $< V_c > = 350$ Km/h and opens at 0.8 R_θ, the transport rate is $\sim < 60°/h >$. In this form it is satisfied property (e) of velocity and energy independence of low energy particles, whereas high energy particles drift from the confining structure with a velocity-dependent rate. Particle transport of low energy particles out of the FPR is dominated by a diffusive thick geometry, introducing a slight velocity-dependence, while high energy particle behavior is energy-dependent through a drift-type-transport. The strong anisotropy observed in some events in the initial phase of events, is explained by the impulsive ejection of particles during a first emission phase taking place during the flare impulsive phase. This allows also to explain the arrival of low energy electrons before protons of the same energy, because the later mix with the population of the secondary acceleration stage which are liberated several minutes later. On the other hand, the location of the maximum peak intensity in many events over the flare site is also a consecuence of the impulsive emission phase. The absence of this first emission phase favourizes an occasional shift of the maximum peak intensity to other preferential liberation regions, and the observation of a wide cone of anisotropy at the begining of the event, instead of a marrow one, as in the case previously mentioned. The increase of the slope with azimuthal distance in the initial phase of some particle events, or its constancy in other events depends on whether the first emission phase takes or not place. The characteristic change of slope in particle energy spectra (around 100 KeV for electrons) indicates the occurence of the first and second emission of solar flare particles. The spectral slope decrease with longitud, in the decay phase of events, is attributed to preferential drift of high energy particles relative to low energy particles. Property (f) concerning the modulation of particles fluxes when they traver form one unipolar sector to another of opposite polarity is only described qualitatively in terms of fluctuations of κ_ℓ and V_d, when particles find quasi-equilibrium neutral sheets (very low rate of field line diffusion)that do not generate intense accelerating electric fields, but only act as particle propagation modulators: in order to quantify this effect, it should be included in the calculations some reliable perturbations on the two propagation parameters, i.e., the drift velocity and the diffusion coefficient.

Observational features (a), (b), (c) and (g) have been quantitatively reproduced by means of transport equations within the frame of the model. The eventual presence of prompt protons, of all energies, before the bulk of flare particles has been quantitatively predicted by an additional emission phase in a conpressed coronal neutral sheet. Relativistic electrons associated to type-IV bursts may appear from reconnection processes during the bottle opening (Mullan, 1983).

Perspectives for going deep into the understanding of solar particle azimuthal transport are undoubtedly associated with futur multi-spacecraft observations, making possible a fine structure in the temporal and spatial behavior of particle fluxes, azimuthal and radial effects, for different solar ions and electrons, simultaneously with other flare emissions and measurements of magnetic fields, solar wind and local physical parameters. This will allow for a better discrimination between particle coronal propagation and escape from the coronal magnetic fields. In particular, the "out of the ecliptic" spaceprobe experiments will bring new lights in the phenomena of coronal transport of flare particles. From the theoretical point of view, it is interesting to search for specific functions of the escape rate, $\Gamma(\Psi)$, that allows, at least, for preferential liberation at some definite longitudes and escape inhibition at other longitudes, while it is not yet established a plausible time and velocity dependence of the escape process. This may be done, in principle, by new detailed numerical calculations of particle trajectories in a suitable coronal magnetic field topology. This, however, needs of further information about the behavior and evolution of magnetic fields in the course of a solar event. Very outstanding advances may be expected in the determination of the complete coronal vector magnetic field from the simultaneous application of the Hanle effect for two emission lines, that makes possible to determine in an unambiguos manner the three components of the field, as any other method can give until present (e.g. Bommier et al., 1981).

Finally, I would like to point out, that in spite of the eventual falacies of the proposed model in confrontation with specific solar particle events, the main goal of such a proposal is to emphasize the importance of the particle multi-emission phase character of the flare phenomenon, though the number of phases and their relative importance may vary from event to event.

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Fig. 1

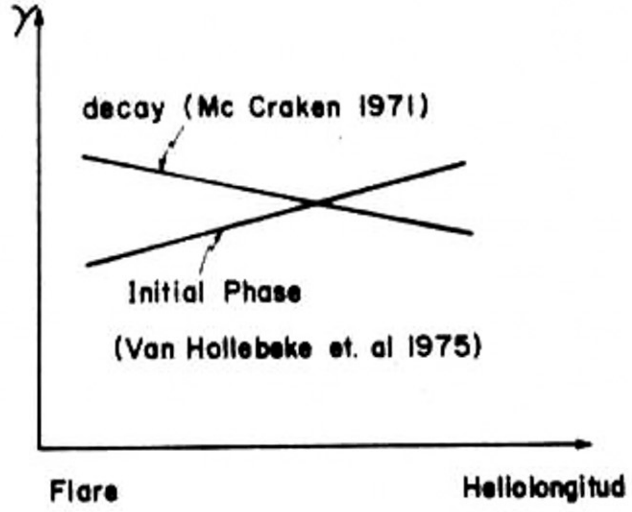
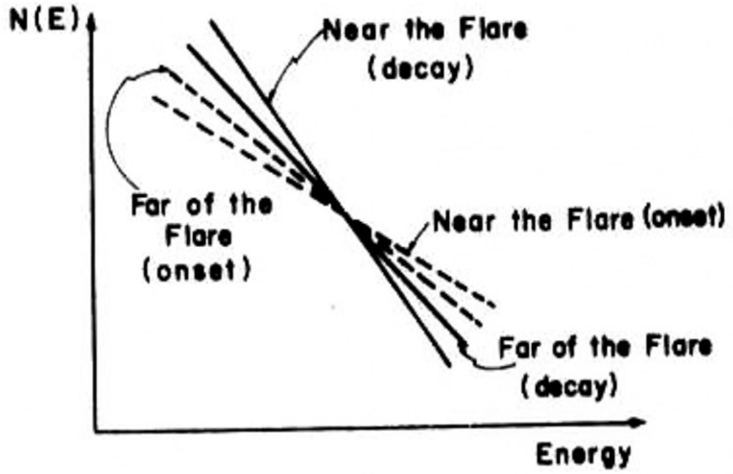
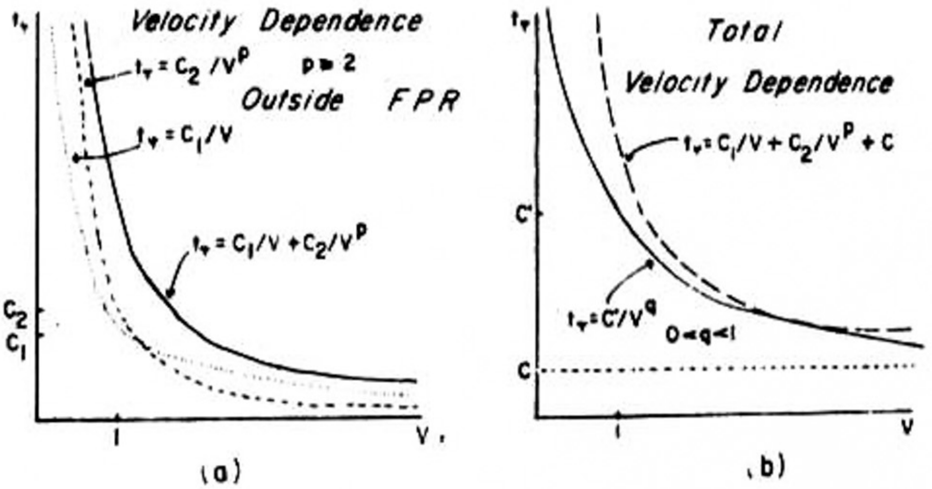

γ
decay (Mc Craken 1971)
Initial Phase
(Van Hollebeke et. al 1975)
Flare
Heliolongitud

Fig. 2


N(E)
Near the Flare
(decay)
Far of the
Flare
(onset)
Near the Flare (onset)
Far of the Flare
(decay)
Energy


t_v
Velocity Dependence
$t_v = C_2/V^p$ $p = 2$
Outside FPR
$t_v = C_1/V$
$t_v = C_1/V + C_2/V^p$
C_2
C_1
1
V
t_v
Total
Velocity Dependence
$t_v = C_1/V + C_2/V^p + C$
C'
$t_v = C'/V^q$
$0 < q < 1$
C
1
V

(a)

(b)

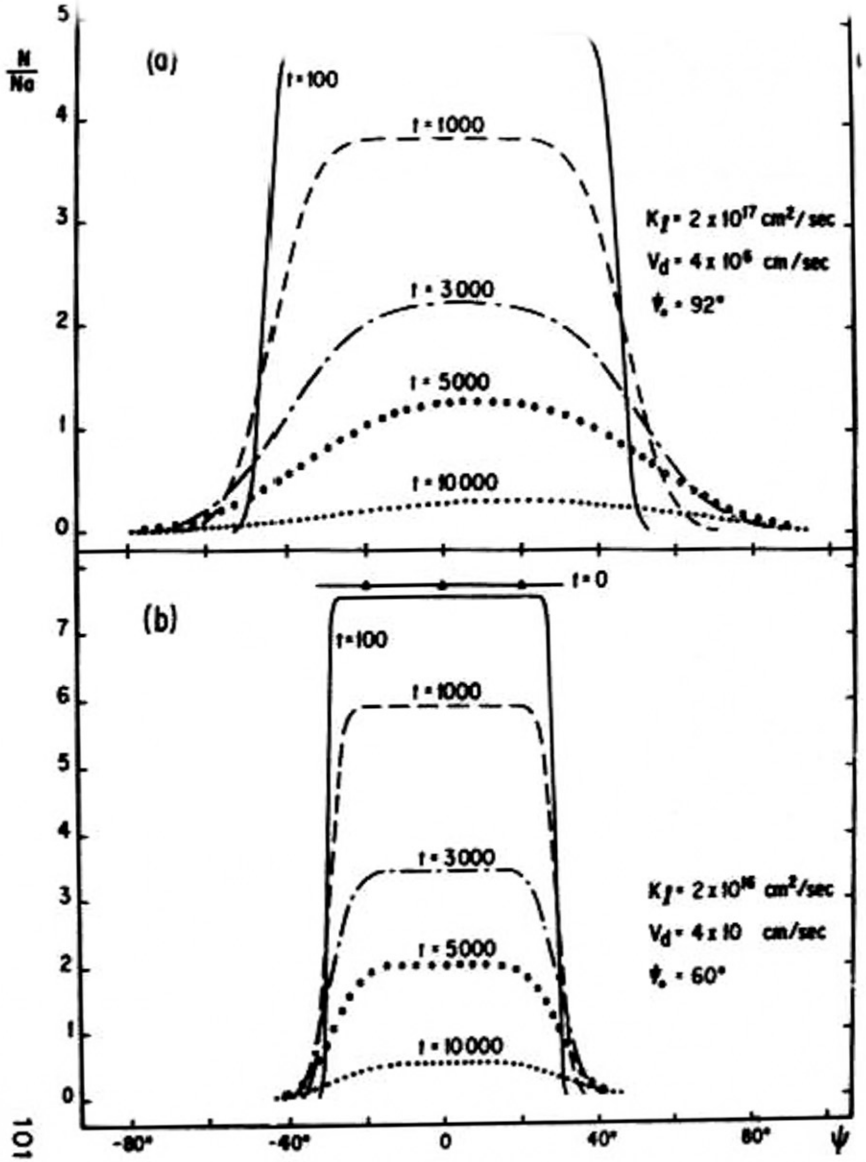

N/Na
(a)
t = 100
t = 1000
t = 3000
t = 5000
t = 10000
K_ℓ = 2 x 10^17 cm²/sec
V_d = 4 x 10^6 cm/sec
ψ₀ = 92°
(b)
t = 0
t = 100
t = 1000
t = 3000
t = 5000
t = 10000
K_ℓ = 2 x 10^16 cm²/sec
V_d = 4 x 10 cm/sec
ψ₀ = 60°
0
1
2
3
4
5
6
7
-80°
-40°
0
40°
80°
ψ

Fig. 3

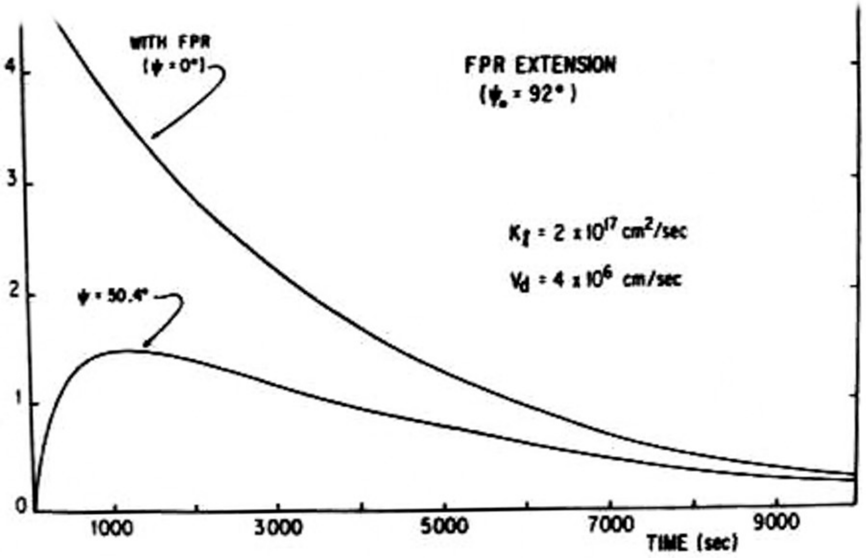

WITH FPR
(ψ = 0°)
ψ = 50.4°
FPR EXTENSION
(ψ₀ = 92°)
K_ℓ = 2 x 10^17 cm²/sec
V_d = 4 x 10^6 cm/sec
0
1
2
3
4
1000
3000
5000
7000
9000
TIME (sec)

Fig. 4

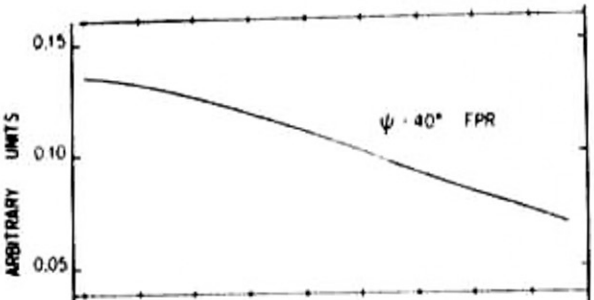

0.15
0.10
0.05
ARBITRARY UNITS
ψ = 40° FPR

Fig. 5

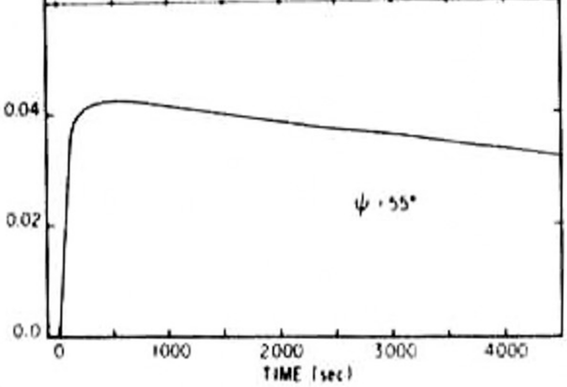
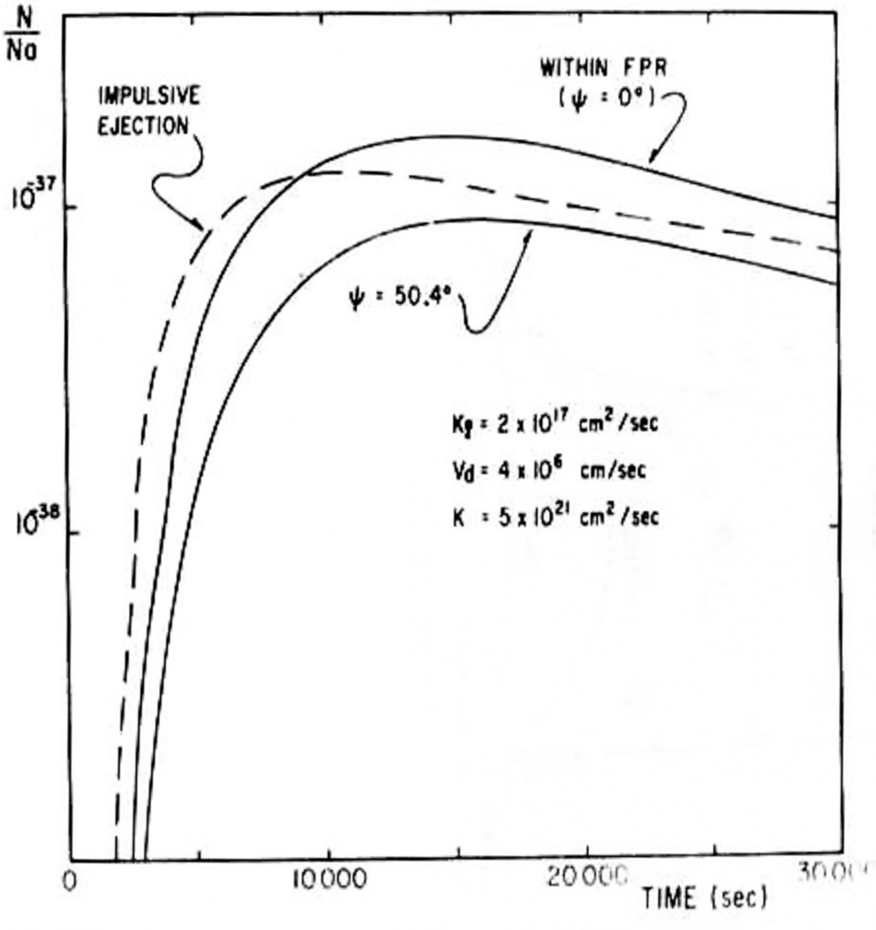
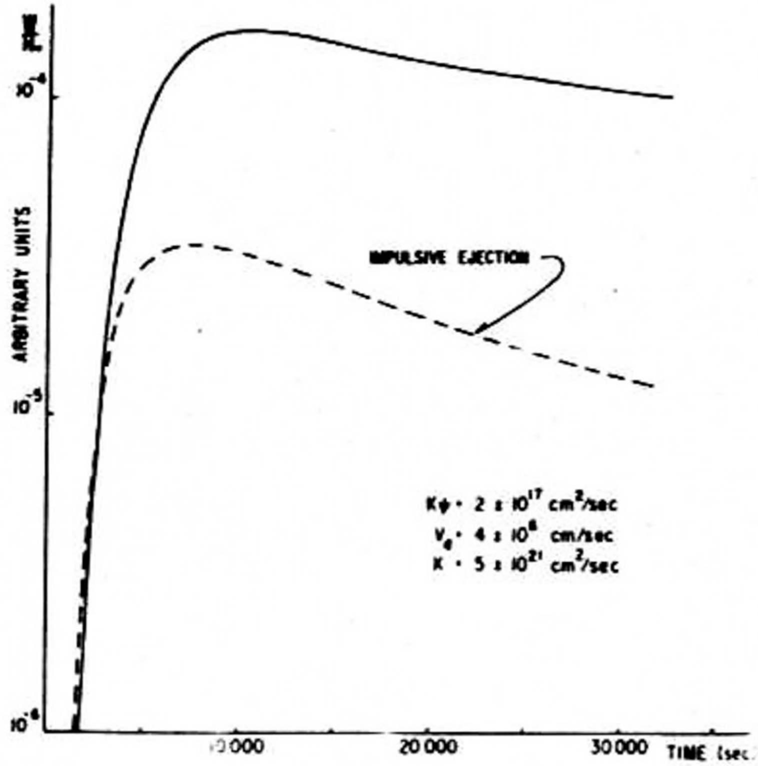
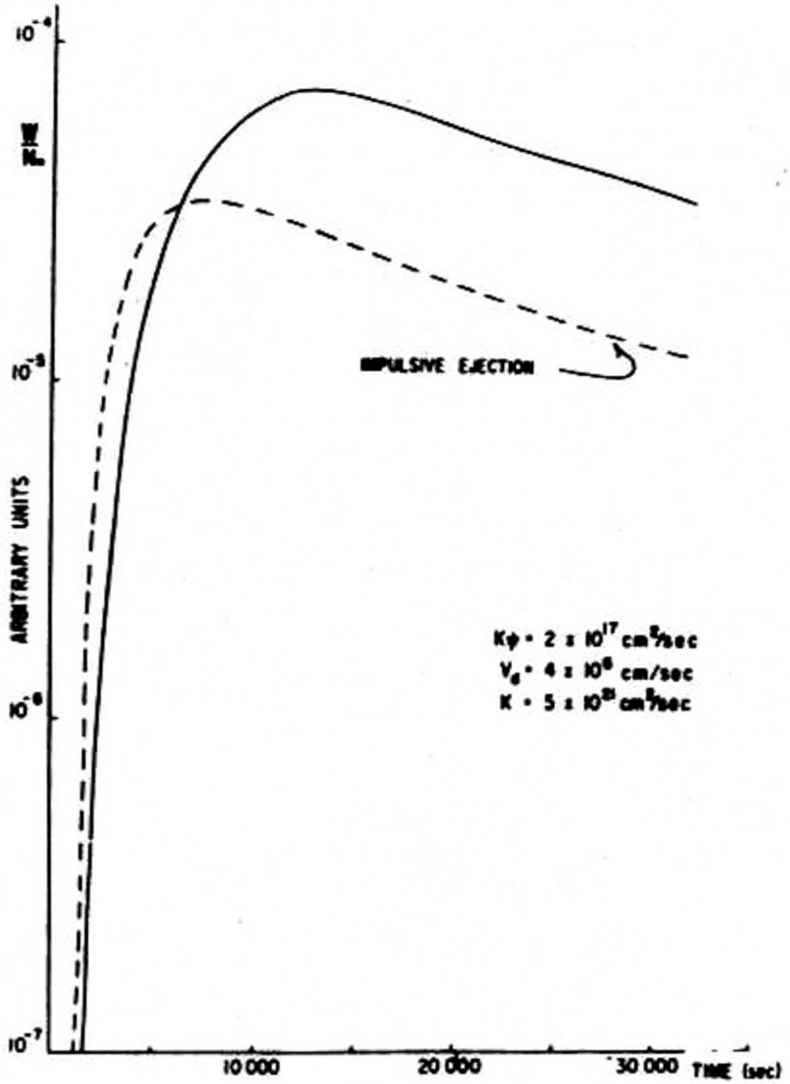

0.04
0.02
0.0
ψ = 55°
0
1000
2000
3000
4000
TIME (sec)

Fig. 6


$\frac{N}{No}$
IMPULSIVE EJECTION
WITHIN FPR ($\psi = 0°$)
10^{-37}
$\psi = 50.4°$
$K_\theta = 2 \times 10^{17}$ cm^2/sec
$V_d = 4 \times 10^{6}$ cm/sec
$K = 5 \times 10^{21}$ cm^2/sec
10^{-38}
0
10000
20000
TIME (sec)


10^{-4}
ARBITRARY UNITS
10^{-5}
10^{-6}
IMPULSIVE EJECTION
$K_\phi = 2 \times 10^{17}$ cm^2/sec
$V_d = 4 \times 10^{8}$ cm/sec
$K = 5 \times 10^{21}$ cm^2/sec
10 000
20 000
30 000
TIME (sec)

Ψ = 40°


10^{-4}
ARBITRARY UNITS
10^{-5}
10^{-6}
10^{-7}
IMPULSIVE EJECTION
$K_\phi = 2 \times 10^{17}$ cm^2/sec
$V_d = 4 \times 10^{8}$ cm/sec
$K = 5 \times 10^{21}$ cm^2/sec
10 000
20 000
30 000
TIME (sec)

Ψ = 55°

Fig. 7

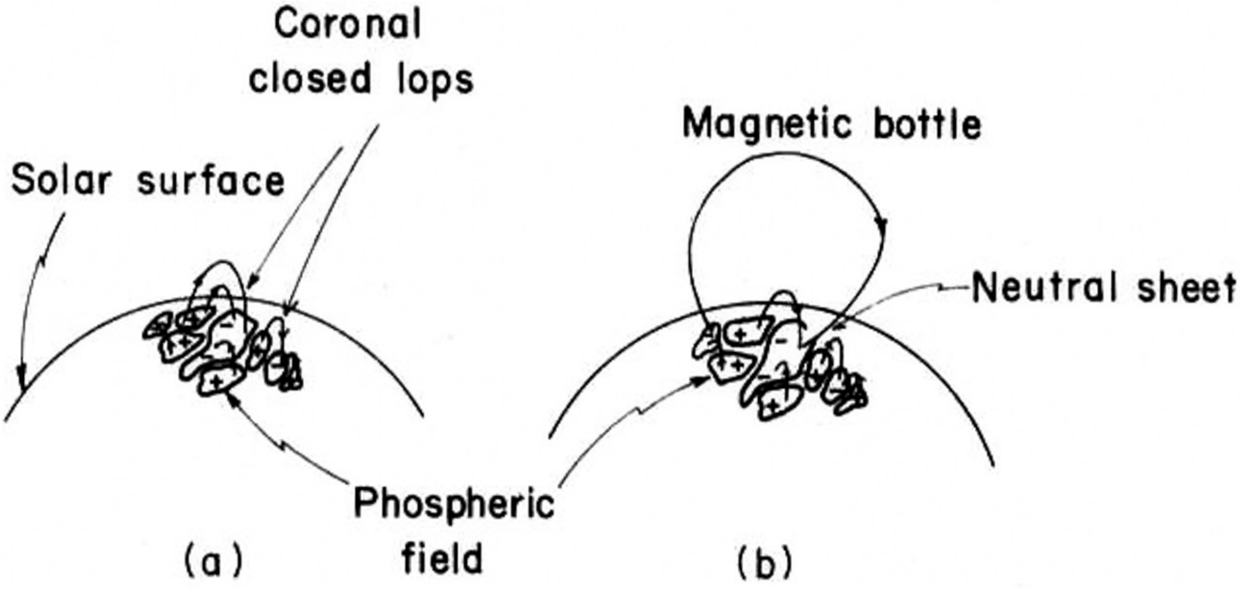

Coronal
closed lops
Solar surface
Magnetic bottle
Neutral sheet
Phospheric
field
(a)
(b)
+
-

Fig. 8

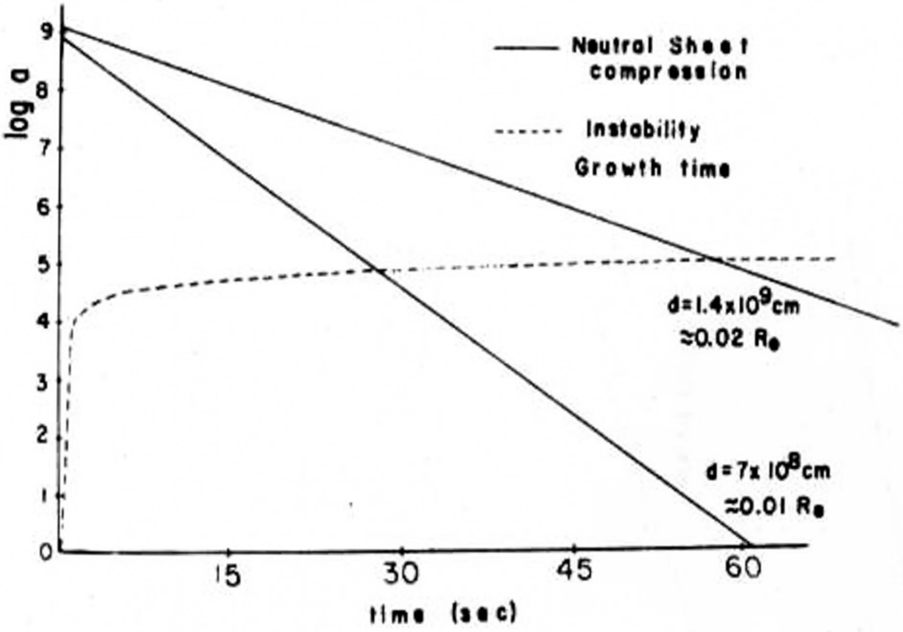

log a
9
8
7
6
5
4
3
2
1
0
15
30
45
60
time (sec)
Neutral Sheet compression
Instability
Growth time
d=1.4x10^9cm
≈0.02 R☉
d=7x 10^8cm
≈0.01 R☉

Fig. 9