Comment on "The importance of auroral features in the search for substorm onset process" by Syun-Ichi Akasofu, A. T. Y. Lui, and C.-I. Meng

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[1] The paper by *Akasofu et al.* [2010, hereinafter Paper 1] gives an ambiguous interpretation of the auroral substorm observations. The authors consider their conclusion as a new result but it does not follow from the observations described in the paper. On the other hand, the phenomenon discussed was investigated earlier in papers not cited in Paper 1.

[2] The concept of auroral substorm was proposed by *Akasofu* [1964] for interpretation of the morphology and dynamics of auroras on the night side of the Earth (from 1800 to 0600 MLT). The change from quiet to disturbed conditions and back to the original state is a cyclic process. According to him each cycle consists of two phases: expansion phase ($0 < T < 30$ min) and recovery phase (30 min $< T <$ 2 h). The time $T = 0$ (or T_0) denotes the onset of a substorm and is the beginning of the expansion phase.

[3] For years in the 1950s, Y. Feldstein and G. Starkov were conducting aurora observations at the Arctic Observatory on the Dixon Island. Since the morphology and dynamics of the auroras observed fitted the Akasofu's concept, they supported it without reserve. *Akasofu* [2002, p. 59] notices "Many auroral scientists who have actually little experience in observing the aurora simply followed the experienced ones. Thus, it was hard to convince anyone about the validity of the concept of the auroral substorm. The only exception at that time was Feldstein, who strongly supported my finding."

[4] The original scheme of the auroral substorm was supplemented by *Akasofu* [1968, hereinafter Paper 2] with the distribution of auroras in the daytime sector obtained for substorm interval first by *Feldstein and Starkov* [1967a, 1967b]. The new scheme covering all MLT hours is represented in Paper 1, Figure 1 or *Akasofu* [2010, Figure 2]. This scheme of evolution of the auroral substorm has gained ample recognition in the scientific community. Often, it is erroneously referred to as the publication of 1964 (like it is in Paper 1, see *Akasofu* [2010, Figures 1 and 2]), while, in fact, it was published only by *Akasofu* [1968]. Perfection of two-phase auroral substorm model was continued later with supplement of the third phase (creation or growth phase) for interval $-60 < T < 0$ min by *Feldstein and Starkov* [1970] and *Starkov and Feldstein* [1971, hereinafter Paper 3]. The term growth phase was defined by *McPherron* [1970] based on magnetic field variations analyze and so far used for many phenomena before $T = 0$. For auroral activity before $T = 0$ we offered a term creation phase. The most distinct manifestation of this phase is an equatorward shift of auroral oval in evening and premidnight sectors before $T = 0$.

[5] Using *Akasofu*'s [1968] scheme as a working definition of the planetary dynamics of auroras in the substorm period, *Starkov et al.* [1971] analyzed ascafilms from Chelyuskin ($\Phi' = 71°.2$), Dixon ($\Phi' = 68°$), and Murmansk ($\Phi' = 65°.1$) stations for a large number of substorms. The criterion for the selection of substorms was the appearance of negative bay-like magnetic disturbances after the quiet background at premidnight hours. This selection technique leaves out pseudo equatorial motions of auroras in the evening sector due to propagation of the large-scale folding structure (WTS according to *Akasofu* [1964, 1968]). The result of the analysis was the scheme of evolution of an isolated auroral substorm consisting of three phases (creation, expansion, and recovery), which is represented in Figure 1 [*Feldstein and Starkov*, 1970; *Starkov and Feldstein*, 1971]. Below, we discuss the rightfulness of the new conclusion drawn by Akasofu et al. (Paper 1) and its compatibility with the schemes of the auroral substorm by Akasofu (Paper 2) and Feldstein and Starkov (Paper 3).

[6] Based on meridian scanning photometer (MSP) observations, *Akasofu et al.* [2010, paragraph 23] made a conclusion that "The equator half of the oval (EQ), not the whole oval, shifts equatorward prior to onset; this is a new result. The poleward arc(s) remains approximately in the same location. This is a new observation." MSP observations for the isolated substorm of 12 January 1997, which started after a few magnetically quiet hours, are shown in Figure 4a of Paper 1 to illustrate a typical case justifying such conclusion. The variations of AL index of geomagnetic activity represented in Figure 2 (left) agree with the classical scheme of a magnetic substorm proposed by *McPherron* [1970]: a slow decrease from −25 nT at 0630 UT to −100 nT at 0720 UT during the growth phase followed by a steep fall down to −700 nT (substorm commencement, T_0). In the evening sector of the auroral oval, there usually exist from one to three

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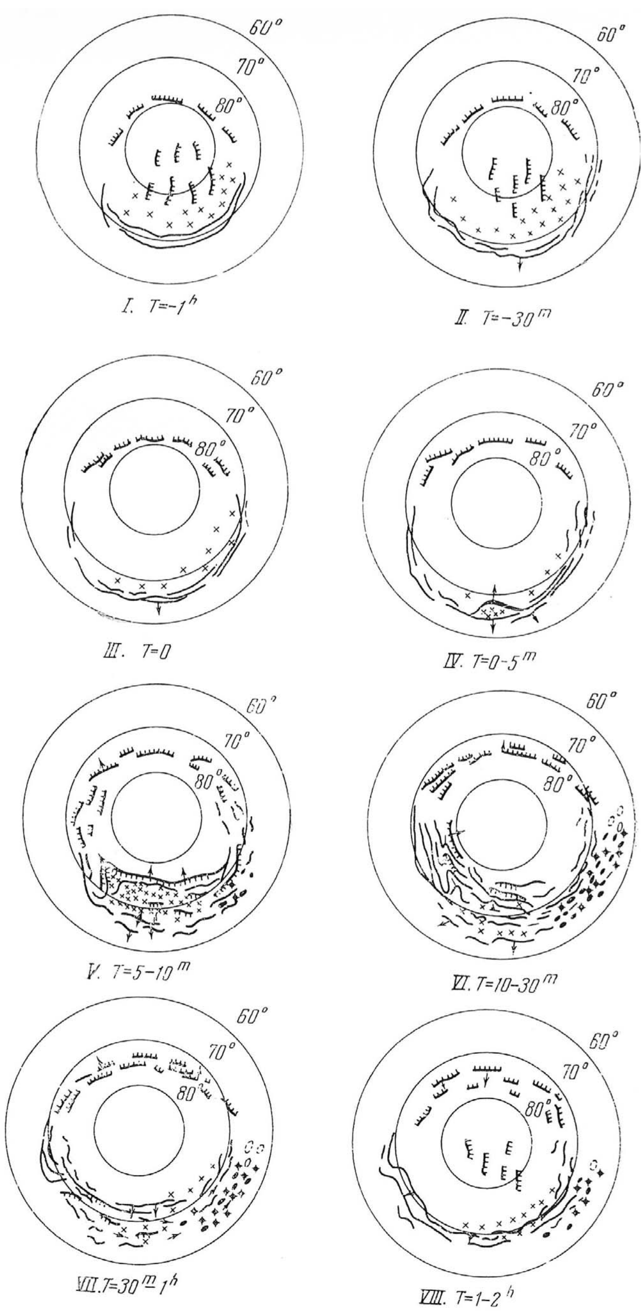

Figure 1. Spatial-temporal scheme of auroral substorm by [*Feldstein and Starkov* 1970]: I and II, creation phase; III, IV, V, and VI, expansion phase; VII и and VIII, recovery phase. Solid lines are homogeneous auroral forms, solid lines with hatches are ray forms, black ellipsis are pulsating forms, crosses are diffuse luminosity, connected with plasma sheet (central and boundary) in the magnetosphere tail, and crosses with points are diffuse luminosity, connected with eastward drifting in inner magnetosphere electrons.

auroral arcs. As is usually the case under relatively quiet geomagnetic conditions, the oval in Figure 4a of Paper 1 is represented by a single arc. Until the WTS passage at about 0810 UT, the arc is moving equatorward. It is not only the equatorial part that moves but the oval as a whole. According to the MSP data of Figure 4a, there was only very faint luminosity poleward of the arc, which remained in the poleward sky. It did not have the characteristics attributed to the poleward arc on the evening oval due to very low intensity and absence of auroral forms in luminosity.

[7] The other examples of the auroras dynamics by *Akasofu et al.* [2010, paragraph 12], from which "one can see more clearly the presence and independence of poleward arc(s) from EQ," are given in section 3 of Paper 1 (Figures 4b, 4c, and 4d). In these examples, the magnetic field is strongly disturbed, and the distribution of auroras in the evening sector is typical for the expansion phase, that is, largely, due to the WTS passage from the nighttime sector. We shall restrict our consideration to the event of 25 January 2003. The MSP data for this event are given in Figure 4b of Paper 1 and the AL index in Figure 2 (right). A few intensive substorms manifested in the evening auroras were recorded in the magnetic field during the time interval 0430 UT–0900 UT. The first substorm was accompanied by aurora enhancement at about 0500 UT. The onset of the next one at ~0545 UT resulted in a fast shift of the equatorial boundary of the oval to lower latitudes and its essential expansion. The sawtooth oscillations of the boundary position reflect the irregular nature of the magnetic disturbance. In this case, the equatorward motion occurs after the moment T_0, i.e., in the expansion phase. The high-latitude arc in Figure 4b of Paper 1 is part of the WTS, which has its poleward edge in the expansion phase located usually at even higher latitudes than the arc. The arc in Figure 4b keeps its latitude nearly constant, since it is located at the maximum zenith angles of the photometer near the poleward horizon of the observation point.

[8] The Poker Flat observations ($\Phi' \sim 65°$) are obviously unsuitable for unambiguously determining the morphology and structure of the substorm auroras on the poleward side of the oval, because the auroral bulge in the late evening sector extends as far as $\Phi' > 72°$, i.e., out of sight of MSP. So, the data from the stations located at $68° < \Phi' < 72°$ must be invoked. Such observations have been carried out since the 1970s on Chelyuskin and Dixon stations in the Eastern hemisphere and by the meridian chain of all-sky cameras in the Western hemisphere, and their results have been published, e.g., by *Starkov et al.* [1971], *Vorobjev et al.* [1976], *Zverev et al.* [1976] and by *Snyder and Akasofu* [1972], respectively. We shall dwell on the paper by *Snyder and Akasofu* [1972], which was written in coauthorship with the first author of the paper we are commenting here.

[9] The Alaskan meridian chain of station "scans" the polar sky once a day between geomagnetic latitudes of 60° and 80°. The paper presents for five selected periods in 1969–1970 the dynamic behavior of the auroral oval as delineated by the all-sky photographs (film). Substorm phases and moment T_0 were determined by all-sky camera (ASC), the magnetic records chain of stations and magnetic activity indices AL and AU. The substorms occurred at near-midnight hours. Among several features of auroral morphology presented by *Snyder and Akasofu* [1972] we quote the following:

[10] 1. Before the onset of an auroral substorm (till moment T_0) enhanced equatorward drift of 2 or 3 auroral forms occurs which constitutes evening-premidnight oval sector. All forms drift equatorward. There are no differences in drifts between equatorward and poleward halves of the

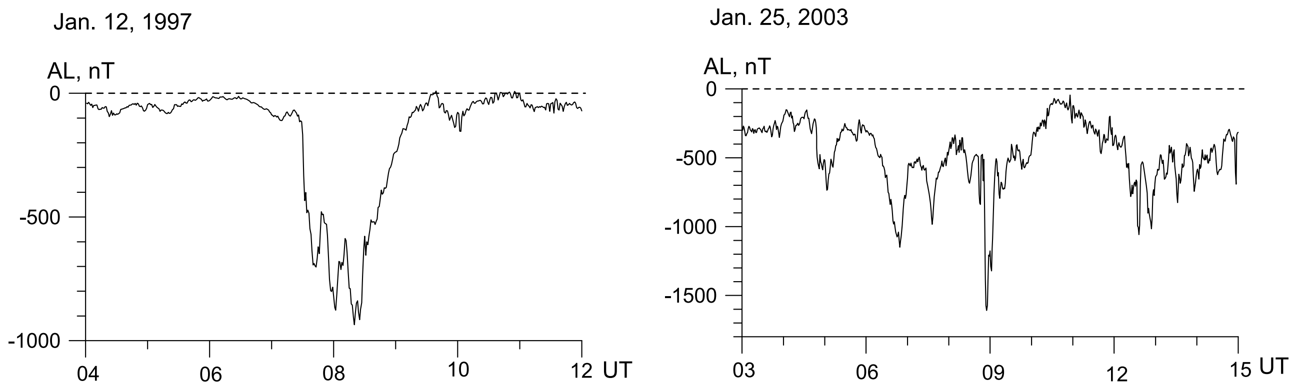

Figure 2. AL index variations: (left) 12 January 1997 and (right) January 25 2003.

oval. The speed of the equatorward auroral motions may be the same magnitude as the speed of the poleward expansion motions that occur after T_0. Equatorward drift motions of auroras are a common feature and therefore, according to opinion of authors, cannot be ground for existence of the growth phase;

[11] 2. At the time T_0 the sky poleward the oval becomes clear from auroral forms. Such a clearing, along with the equatorward drift motions, makes the oval thinner, so that, at the time T_0, it may be represented by a single arc;

[12] 3. The boundary of the auroral bulge in the near-midnight sector reaches the latitudes $\Phi' \sim 75°–77°$;

[13] 4. There are no unambiguous characteristic in the AU or AL indices that can be associated with the enhanced equatorward drift of auroras before the onset of an auroral substorm in the midnight sector. They note additionally that the method used to isolate the growth phase by *McPherron* [1970] relies on the data from insufficiently dense magnetic observatories network in the auroral zone, which makes the identification of the growth phase as a separate, independent phase of a substorm difficult.

[14] Thus, observations of the Alaskan meridian chain of stations did not reveal the division of the auroral oval prior to T_0 into the equatorial and poleward parts with different types of drift according to Paper 1. All arcs, that form the oval in the evening and premidnight sectors, drift in one direction, i.e., toward the equator. The drift velocity increases 1.5 h before T_0. It is strange enough that after a few decades of doubt about the existence of the creation (growth) phase as a typical part of the auroral substorm, the authors of Paper 1 explain it just like *Feldstein* [1974] did it 36 years ago as can be seen below:

[15] From Paper 1 [2010, paragraph 11]: "Note that the speed of this southward shift of EQ [equatorward half of the auroral oval] is much faster than the apparent shift of the oval because of its eccentricity with respect to the geomagnetic pole (1° in gm. latitude/1 hour)."

[16] From *Feldstein* [1974, p. 264]

> An abrupt increase in the equatorward drift velocity of auroral forms occur within 1.5 h prior to T = 0. Such increase in the velocity is due solely to the subsequent substorm, for the other days at the same hours of UT in the absence of substorms the equatorward drift velocity of the auroral form was considerably lower. A ~5° latitude shift of the luminosity region for a time of~1.5 h cannot be explained by the Earth's rotation beneath the oval.

[17] The velocities of the natural drift of arcs in different time sectors in three phases of a substorm were determined by *Vorobjev et al.* [1976]. The drift of discrete forms due to the Earth rotation under the auroral oval was excluded.

[18] Let us interpret the aurora dynamics before and after the beginning of the substorm active phase described in Paper 1 using the observations summed up in the substorm scheme shown in Figure 1. The scheme comprises the substorm creation (or, growth) phase (-1 h $< T < 0$), when during the minimum variation in the luminosity intensity the oval nighttime sector shift for a typical substorm by ~5° equatorward down to $\Phi \sim 65°$. This motion explains why, according to *Akasofu* [1968], the substorm starts at midnight at precisely this latitude. The model in Figure 1 allows us also to understand the particularities of luminosity distribution illustrated in Figure 4a of Paper 1 during the creation phase. The photometer records display a weak diffuse luminosity in the evening sector poleward of the discrete forms (oval), which is interpreted in Paper 1 as the poleward part of the oval. However, according to the model in Figure 1, a diffuse luminosity occurs in the creation phase poleward of the auroral oval arcs. It differs from the discrete forms in the auroral oval and cannot belong to the high-latitude part of the oval. These two types of the luminosity differ also by their relation to the plasma domains in the magnetosphere: the nighttime sector of the auroral oval is projected by the magnetic field lines onto the central plasma sheet in the magnetosphere tail, while the diffuse luminosity poleward of the oval is projected onto the plasma sheet boundary layer. The morphology of nighttime auroral luminosity, including diffuse aurora poleward of the auroral oval, its characteristics and connection with plasma structure of the magnetosphere is stated in the review by *Feldstein and Galperin* [1985].

[19] Model luminosity distribution shown in Figure 1 has a characteristic peculiarity: in the substorm active phase the structured forms are disintegrated in the central part of the oval. Such regions of diffuse glow are readily revealed as a dark area in MSP data (Figures 4b, 4c, and 4d of Paper 1) during the substorm expansion and recovery phases. This peculiarity is one of differences between substorm development schemes by *Akasofu et al.* [2010, Figure 1] and in Figure 1.

[20] Based on ASC observations of auroras *Akasofu et al.* [2010, paragraph 22] claim that "poleward arc(s) brightens

only after the initial brightening and shows only moderate activities." It follows from Figure 1 that, in the case of two arcs, A_E and A_P existing in the midnight sector, the time T_0 is associated with the equatorial arc (A_E) brightening and splitting (or appearance of a new arc immediately on its poleward side), and a fast poleward motion of its more intensive higher-latitude part. The weaker lower-latitude part remains in the old place. The initial poleward arc (A_P) does not take active part in the development of the auroral substorm and is absorbed by the poleward auroral bulge that originates from A_E. Among the poleward and equatorward arcs that are formed from the original A_E, the main role in the substorm evolution belongs to the poleward arc, which is at the high-latitude boundary of the bulge (of the auroral oval), while the equatorward arc, which is at the equatorward boundary of the oval, is less active (see Figures 2c and 2d of Paper 1).

[21] Main conclusions:

[22] 1. Paper 1 differs from the earlier paper by the same author [*Snyder and Akasofu*, 1972].

[23] 2. Conclusions of the earlier paper were based on observations covering simultaneously bigger longitude and latitude intervals (all-sky cameras), than MSP in Paper 1. The conclusions of the earlier paper were consistent with the results obtained by this comments author in 1970–1971 years.

[24] 3. We believe that Figure A of *Feldstein and Starkov* [1970] still holds as the most complete summary of the auroral substorm development.

[25] The scheme of evolution of the auroral substorm with two phases was proposed by *Akasofu* [1964] and was modified by *Feldstein and Starkov* [1970] and *Starkov and Feldstein* [1971], who introduced the third phase. Now, 40 years later, it's probably, high time to modify it again. Large aurora observations data, both from spacecraft and from ground are available now. The new auroral substorm scheme should incorporate and generalize them. We hope that the new scheme would be dated to the year of creation rather than the years of publication of the first (1964) or second (1970) versions.

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