*"Physics of Auroral Phenomena", Proc. XXXII Annual Seminar, Apatity, pp. 48 - 51, 2009*

Polar Geophysical Institute

# VISUAL LUMINOSITY EQUATORWARDS OF THE AURORAL OVAL DURING MAGNETIC STORMS

V.L. Zverev[1], Ya.I. Feldstein[2], V.G. Vorobjev[1]

[1]*Polar Geophysical Institute, Apatity, Russia, e-mail: zverev@pgia.ru*
[2]*Institute of Terrestrial Magnetism and Radiowave Propagation, Troitsk, Russia*

**Abstract.** The comparison between equatorial boundaries of auroral discrete forms (auroral oval) and diffuse auroral luminosity was carried out for periods of magnetic storms. Position of equatorial boundary of the night-side auroral oval depending on the value of the Dst index was taken from the paper by Starkov [1993]. The limit corrected geomagnetic latitude (CGL) of visual aurora locations was received on the basis of visoplots for IGY period [Auroral visoplots, 1964]. Twenty six magnetic storm events were used to determinate the equatorward boundary of visual auroral luminosity during Dst<-100 nT. When Dst changed from –100 nT to –400 nT the boundary of the visual auroral luminosity moves from about 51º to 44º CGL. According to visoplots the equatorward boundary of the visual auroral luminosity was found to be remove on about 7º to lower latitude from the equatorward boundary of the auroral oval in intervals of magnetic storms. The auroral luminosity was registered at all latitudes between its equatorward boundaries to the auroral oval. It means that during magnetic storm the equatorward boundary of visual luminosity according visoplots does not reflect the location of discrete auroral forms boundary. It is well known that a diffuse aurora equatorward of discrete auroral forms can intensify considerably in intervals of magnetic storms. This special type of the auroral luminosity at mid-latitudes in the forms of stretched diffuse areas is associated generally with the atomic oxygen 630.0 nm emission. In that way the lowest latitude of auroral luminosity on visoplots characterizes the equatorial boundary of diffuse auroras. The region of red diffuse luminosity spatially coincides with region of diffuse electron precipitation covering the region equatorward of the auroral oval up to latitudes of the main ionospheric trough. An electron energy flux and their average energy sharp decrease from oval to lower latitudes. It leads to decrease of the diffuse aurora intensity and respectively to the increase in the luminosity height at lower latitudes. The intensification of the 630.0 nm luminosity at mid-latitudes near of the main ionospheric trough was called as a stable auroral red arc (SAR-arcs). Between usual auroras and SAR-arcs does not exist the latitudinal gap. The latitudinal interval between the auroral oval and SAR-arcs is filled by auroral particle precipitations and diffuse luminosity.

## 1. Introduction

The spacious program of auroral visual observations was carried out during IGY. Only on USSR territory and adjacent countries the observations were realized in 620 points on weather stations and by astronomer-amateurs. Special emphasis was devoted to the observations on subarctic and mid-latitude regions where visual observations were main methods for registrations of auroras. Most of the observers were located on the land, but seamen and airmen also made valuable auroral observations. The results of observations at planetary network in encoded type in the shape of visoplots were published in [Annales IGY, 1964]. Below these data are used in analysis of the auroral luminosity distribution in intervals of magnetic storms.

## 2. The auroral oval and diffuse luminosity equatorward of the oval

It is well known that minimum latitude of the equatorial boundary of the auroral oval characterizes geocentric distance of the plasma sheet boundary for midnight sector of the magnetosphere tail [Starkov, 1993]. In intervals of magnetic storms the boundary is displaced to the equator, value of the displacement is defined by Dst index intensity. In Fig. 1 the points mark systematized by Starkov [1993] positions of the equatorial boundaries of the auroral oval (AO) depending on Dst index according to different researchers, including observations for period of IGY. The regression line obtained by the least square method is shown by dotted line in Fig. 1. The location of equatorial boundary of discrete auroral forms in corrected geomagnetic latitudes Φ' in dependence on Dst index can be expressed by equation: Φ' = 77.3º - 9.8 log |Dst| with correlation coefficient r= 0.92. The limits of equatorial positions of auroral luminosity at zenith by visual observations for IGY period are shown with crosses in Fig. 1 [Annales IGY, 1964].

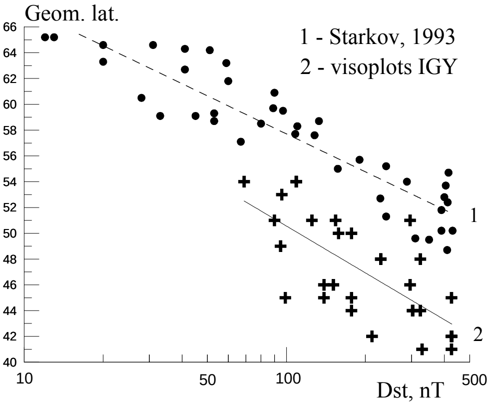

**Fig. 1**. Points - a position of the equatorial boundary of discrete auroral forms depending on Dst index [Starkov 1993], crosses - locations of auroral luminosity in zenith according to visoplots [Annales IGY, 1964].

The longitudinal sectors are represented in Fig. 2.

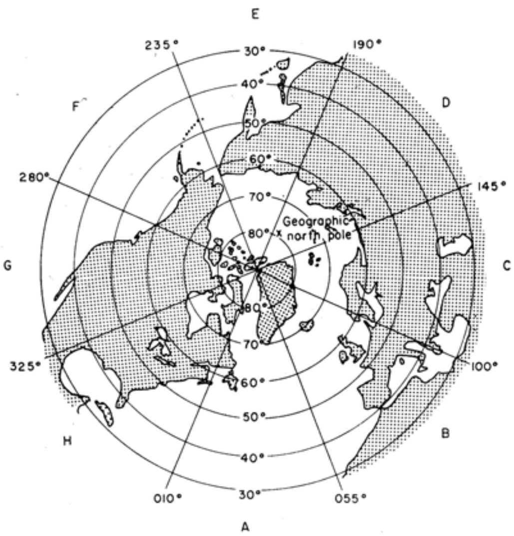


**Fig. 2.** Northern hemisphere sectors for auroral visoplots.

In Fig. 3 the example of visoplots for intensive magnetic storm on February 10-12, 1958 is shown (sectors F: Alaska; sector G: Canada, USA).

The vertical scale at the left side of Fig. 3 are the geomagnetic latitudes. The scale unit is 1º. The conditional indications used on visoplots [Annales IGY, 1964]: «if aurora was overhead in a particular zone at a particular time, this indicated by a black mark in the diagram. If the mark is a full square it implies that the observer actually saw the aurora overhead. If the mark is a vertical line, only partly filling the unit area, it implies that the observation was made from another zone, with a measurement of elevation which allowed an estimate that the aurora was overhead in the zone marked. In the visoplots made at WDC A (sectors F, G, H and A) an open circle indicates that the sky was clear of aurora overhead in that zone».

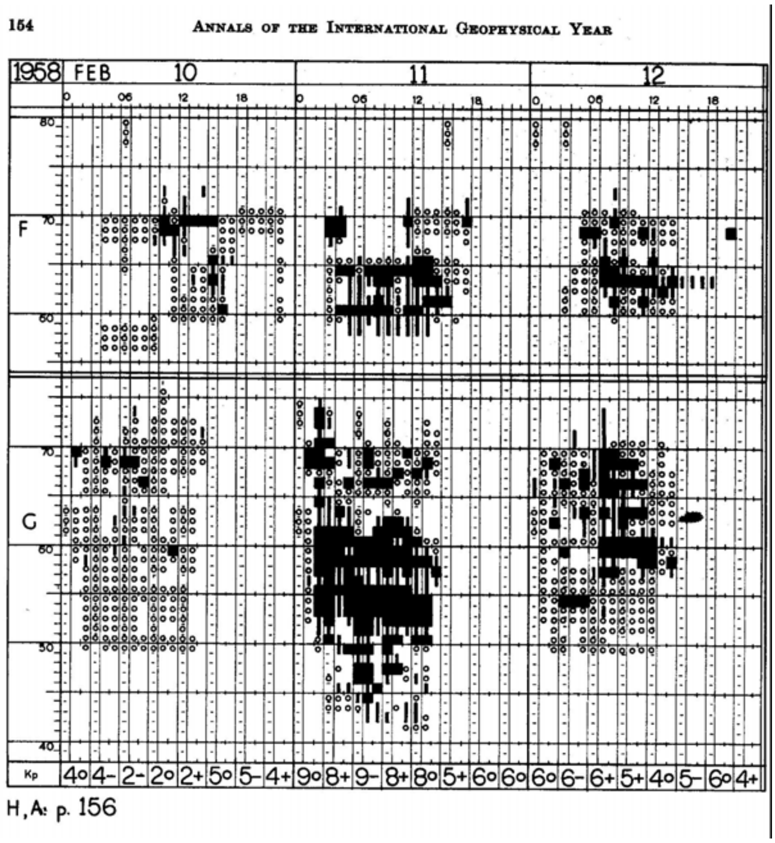


**Fig. 3**. Visoplots for 10 -12 February, 1958 in the intensive magnetic storm interval.

All intervals of the observations with Dst less than about -100 nT were used for analysis. The data covered mainly longitude sectors D (the East Siberia), G and H (the North-American continent). As for visoplots the geomagnetic coordinates were used, so that the correction was carried out for turning from Φ to Φ'. For each sector was used similar correction adjustment. The equation of regression, got by the least square method, is presented by solid line in Fig. 1: $\Phi' = 74.7^{o} - 12.05 \log |Dst|$, the correlation coefficient r=0.7. The regression line for visual luminosity equatorial boundary is shifted on ~7.5º southward from the boundary of the usual discrete aurorae region existence. This means that in intervals of magnetic storms the boundary of the visual auroral luminosity area appearance on visoplots in zenith reflects not equatorial boundary of the discrete auroras, but characterizes the diffuse luminosity situated at lower latitudes. When Dst changes from –100 nT up to –400 nT this boundary according to visoplots moves to equator on ~7º.

In the main phase of magnetic storm the intensity of diffuse luminosity sharply increases [Akasofu and Chapman, 1962]. As a result the diffuse luminosity was observed both by all-sky cameras and naked eye. As a consequence equatorial latitude of luminosity in zenith on visoplots marks not boundary of the discrete auroral forms as usually expected, but the boundary of the area with enough intensive diffuse luminosity. In particular this can corresponds to its equatorial boundary. This suggestion should be checked comparing position of the luminosity boundary on visoplots with equatorial boundary of diffuse luminosity determined independently. Such independent determination can serve the location of equatorial diffuse boundary of the auroral electron precipitations by DMSP satellite observations. Averaging of data in Fig. 1 for |Dst|<150 nT and |Dst|>300 nT gives the position of the visual luminosity boundary on Φ'= 49.5º for Dst= -120 nT and Φ'= 43.7º for Dst= -360 nT. It was shown [Vorobjev and Yagodkina, 2005] that the latitude of diffuse precipitation boundary was defined with sufficient accuracy using Dst and AL geomagnetic indexes. For the IGY period AL indexes are absent in WDC database, that makes the determination of the position of the aurora boundaries difficult. So comparison between the boundary positions is conducted by indirect way. We define the level of magnetospheric disturbance on AL index, under which the boundary of diffuse luminosity from the DMSP observations coincides with the limiting latitude of the luminosity on visoplots for 24 MLT. For Φ'= 49.5º under Dst = -120 nT one gets AL= -1070 nT, but for Φ'= 43.7º under Dst= -360 nT one obtains AL= -1170 nT. Such values of AL-index correspond to really observed in the main phases of the magnetic storms. The intensification of Dst on -240 nT and AL on -100 nT leads according to calculation to shift equatorward the diffuse precipitation boundary on 5.8º that comparable with shift of luminosity boundary displacement on visoplots at ~7º when Dst increases on -300 nT.

Thus both the position of diffuse precipitation boundary and the value of its equatorward displacement with increasing of the |Dst| correspond reasonably well to values for the limit of luminosity latitudes on visoplots.

## 3. Diffuse luminosity, electron precipitations and SAR- arcs

The area of diffuse electron precipitations spreads to the equator from the oval boundary up to latitudes of the main ionospheric trough. The electron spectrum in this area becomes harder with the latitude increase: from several eV on equatorial boundary to ~ 1 keV near the auroral oval, but the flux of electron energy monotonously increases from several fractions of erg/(cm$^2$ sec) to ~ 1 erg/(cm$^2$ sec) [Feldstein and Galperin, 1985]. Such electron precipitations are inevitably accompanied by the special type of diffuse luminosity, different from the auroral oval luminosity. Diffuse luminosity is situated at heights of 200-300 km and has an anomalous high ratio of emissions (OI) I630.0/I557.7 in contrast to luminosity observed in discrete forms of auroras. The emission (OI) 557.7 nm exists, but its intensity considerably lower in comparison with the red emission. It means that fluxes of soft electrons with the energy of several tens eV and less predominate.

The red diffuse luminosity appears equatorward of auroral oval as lengthy regions. The luminosity slowly weakens with decreasing of the latitude, its height and the ratio of I630.0/I557.7 increase. During magnetic storms the intensity of diffuse luminosity increases sharply. Existence of such extent diffuse red emission fields in the middle latitudes in intervals of the magnetic storms was mentioned by [Krasovsky, 1967]. From his analysis of the observations for the IGY period followed that on the USSR territory SAR-arcs did not appear, although patrol photometric and spectral observations occurred in the middle latitudes at IGY period and at the following years. Usually the sporadic increasing of the red diffuse emission took place in connection with magnetic disturbances. Due to the absence of SAR-arcs in interval IGY on USSR territory, Krasovsky [1967] did not avoid the temptation to identify them with vast fields of diffuse luminosity.

Till recently the existence of M-bands (Mid-latitude-bands) at the middle latitudes during magnetic storms is taken as a paradigm. Monochromatic increase of luminosity intensities in the red emission exists stable within M-bands. M-bands were later renamed to SAR-arcs. SAR-arcs are classified as special type of luminosity, with intensity and orientation are controlled by the geomagnetic field. The review to morphology and SAR-arcs dynamics is presented in [Roach and Roach, 1963]. According to standard notion, formation of SAR-arcs occurs in the magnetosphere near the plasmapause, as a result of the hot ion ring current interaction with cool plasma of the plasmasphere. The appearing electromagnetic waves heat up the cool electrons of the plasmasphere. Their flow along magnetic field lines to the ionosphere causes the luminosity in red emission at heights of ~ 400 km. Therefore SAR-arcs have a nature different from usual auroras situated at higher latitudes. The auroras in oval and diffuse luminosity equatorward the oval are conditioned by precipitations of energetic particles to the atmosphere from the magnetosphere plasma sheet as a result of earthward convection.

According to [Khorosheva, 1987] under strong magnetic storms limit latitudes of SAR-arcs were situated at Φ' ~ 40º (L~ 1.7), but the equatorward boundary of the usual auroras were not displaced lower than Φ' ~ 52º (L~ 2.7). Therefore these two types of luminosity are separated by latitude on ~ 12º, with the slot in intensities on the intermediate latitudes. SAR-arcs at the IGY period could not be observed by patrol spectroscopic observations on USSR territory due to very small probability of appearance of the intensive magnetic disturbances accompanying the appearance of SAR-arcs.

The typical event in the middle latitudes with appearance of SAR-arc was observed on February 11, 1958. The boundary of the auroral oval with intensive aurora was situated during storm maximum on Φ' = 52º (ascaplots of Aldan, East Siberia station), but SAR-arc was registered on Φ' = 40º (the stations in Japan) [Khorosheva, 1987]. This day at the middle latitudes the visual observations of the luminosity were made from evening up to the dawn hours of the local time, which are submitted for visoplots in sectors E (Chukotka, Kamchatka, Japan), G and H.

The limiting latitude of the luminosity in the evening sector is located at higher latitudes, than at midnight: in H sector on Φ' = 51º, but in G sector on Φ' = 48º, displacing up to Φ' = 43º by midnight (~8 UT). Therefore visoplots confirm the latitude displacements of the limiting latitudes of the luminosity, controlled by local time. Simultaneously they testify that luminosity at midnight exists in zenith in each degree of geomagnetic latitude northward from Φ' = 43º up to Φ' = 58º. Not confirmed is the existence of latitudinal gap between usual auroras and limiting latitude of diffuse luminosity, where SAR-arc is supposedly localized. The data of visual luminosity observations at midnight hours in interval of the given storm confirm existence of extended diffuse fields of luminosity at the middle latitudes, which fill all latitudes up to the auroral oval.

In the proposed above concept SAR-arcs are the effect of precipitation in the upper atmosphere of electrons, carried by earthward convection from magnetospheric plasma sheet in the tail [Nishida, 1980]. The convection velocity at the plasmapause is nearly zero, plasma drives around the plasmasphere. Such motion is accompanied near the plasmapause by the increasing of particles fluxes along magnetic field lines to the upper atmosphere. Near the plasmapause the energy of electrons is not big, so that the altitude of the luminosity is high enough. At the heights of ~ 400 km the density of neutral atmosphere is small leading to increase of the efficiency of 630.0 nm emission.

## 4. Summary

1 The intensity of diffuse luminosity equatorward of discrete auroral forms sharply increases during intervals of magnetic storms. The limiting latitude of auroral luminosity in zenith on visoplots characterizes the equatorial boundary of this luminosity.

2. According to visoplots in intervals of magnetic storms the luminosity is registered at all latitudes between limiting latitudes of auroral luminosity in zenith and the oval. The interval of latitudes between them is filled by diffuse luminosity, conditioned by the precipitation in upper atmosphere of auroral particles.

3. The region of diffuse luminosity coincides with the region of diffuse electron precipitations, spreading equatorward of the oval up to the latitude of the main ionospheric trough. The flux of electron energy and their energy decrease with the latitude diminution. This leads to the decrease of the diffuse luminosity intensity and increase of its height in lower latitudes.

4. The existence of SAR-arcs is caused by soft electron precipitation. The arcs are situated near the equatorial boundary of the diffuse electron precipitations. Such location of SAR-arcs is conditioned by both nature to large-scale convection of the plasma in the magnetosphere and character of aeronomic processes in upper atmosphere.

## References

Akasofu S.-I., Chapman S. A large change in the distribution of the auroras during the 11 February 1958 magnetic storm // J. Atmos. Terr. Phys. V. 24. P. 740-742. 1962.

Annals of the International Geophysical Year. V. XXIX. I.G.Y. Auroral visoplots. Ed. B. McInnes. Pergamon Press Ltd. 507 p. 1964.

Feldstein Y.I., Galperin Y.I. The auroral luminosity structure in the high-latitude upper atmosphere: its dynamics and relationship to the large-scale structure of the Earth`s magnetosphere // Rev. Geophys V. 23. № 3. P. 217-275.1985.

Khorosheva O.V. Magnetospheric disturbances and the associated dynamics of ionospheric electrojets, aurorae and plasmapause // Geomagnetism and aeronomy. V. 27. № 5. P. 804-811. 1987 (in Russian).

Krasovsky V.I. Aurorae // Geomagnetism and Aeronomy. V. 7. № 6. P. 945-957. 1967 (in Russian).

Nishida A. Geomagnetic diagnosis of magnetosphere. M.: Mir. 299 p. 1980.

Roach F.E., Roach J.R. Stable 6300 A auroral arcs in mid latitudes // Planet. Space Sci. V. 11. № 5. P. 523-545. 1963.

Starkov G.V. Planetary morphology of auroras // Magnetosphere-Ionosphere Physics: Brief reference book. Ed. Yu.P. Maltsev. St. Petersburg: The Science. 184 p. 1993 (in Russian).

Vorobjev V.G., Yagodkina O.I. Effects of magnetic activity on the global distribution of auroral precipitation zones // Geomagnetism and aeronomy. V. 45. № 4. P. 438-444. 2005 (in English).