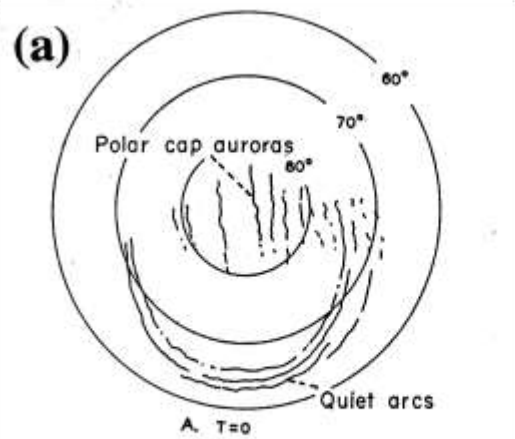
オーロラサブストーム

～何が説明されるべきか

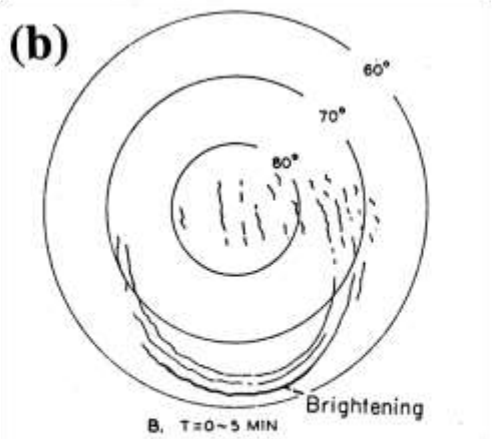
門倉 昭

Classical Morphology

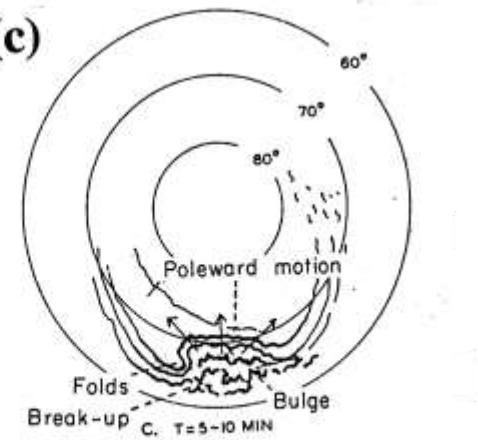
Akasofu, S.-I., The development of the auroral substorm, *Planet. Space Sci., 12*, 273-282, 1964.



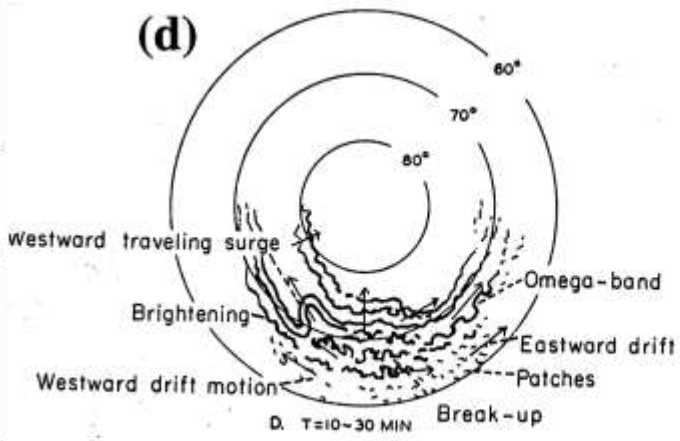
Quiet Phase (T=0)



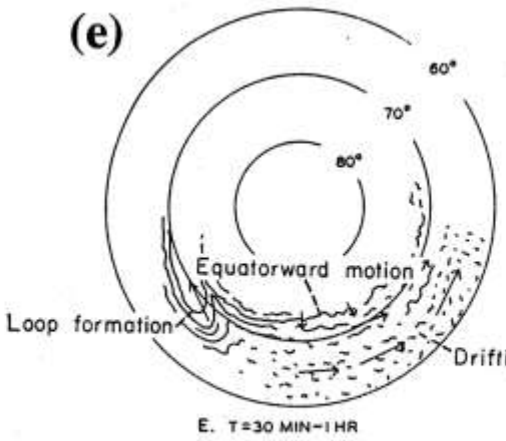
Expansive Phase (T=0~5 min)



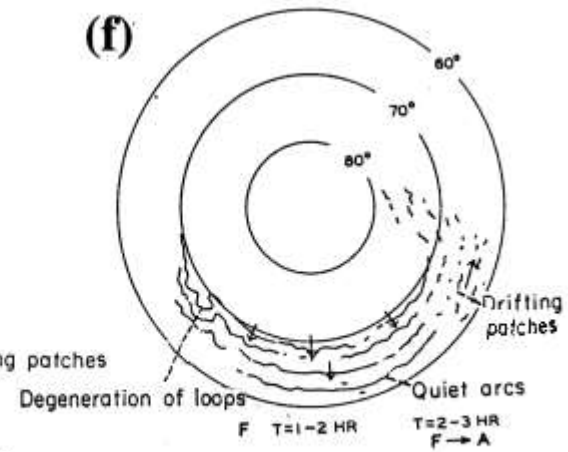
Expansive Phase (T=5~10 min)



Expansive Phase (T=10~30 min)



Recovery Phase (T=30~60 min)



Recovery Phase (T=1~2 hour)

Classical Morphology に対する追加、修正

- Diffuse Aurora の発見 （ISIS-2衛星, Lui and Anger, *Planet. Space Sci., 21*, 799-809, 1973 ）

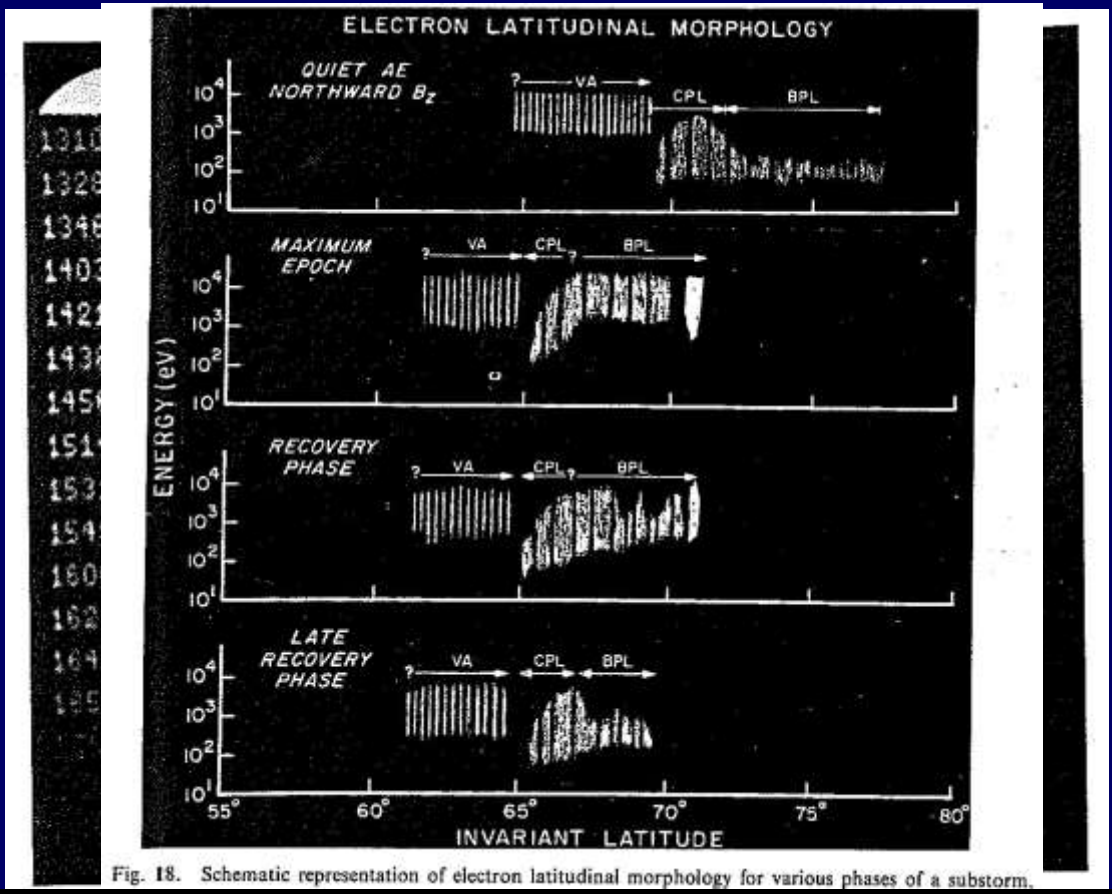
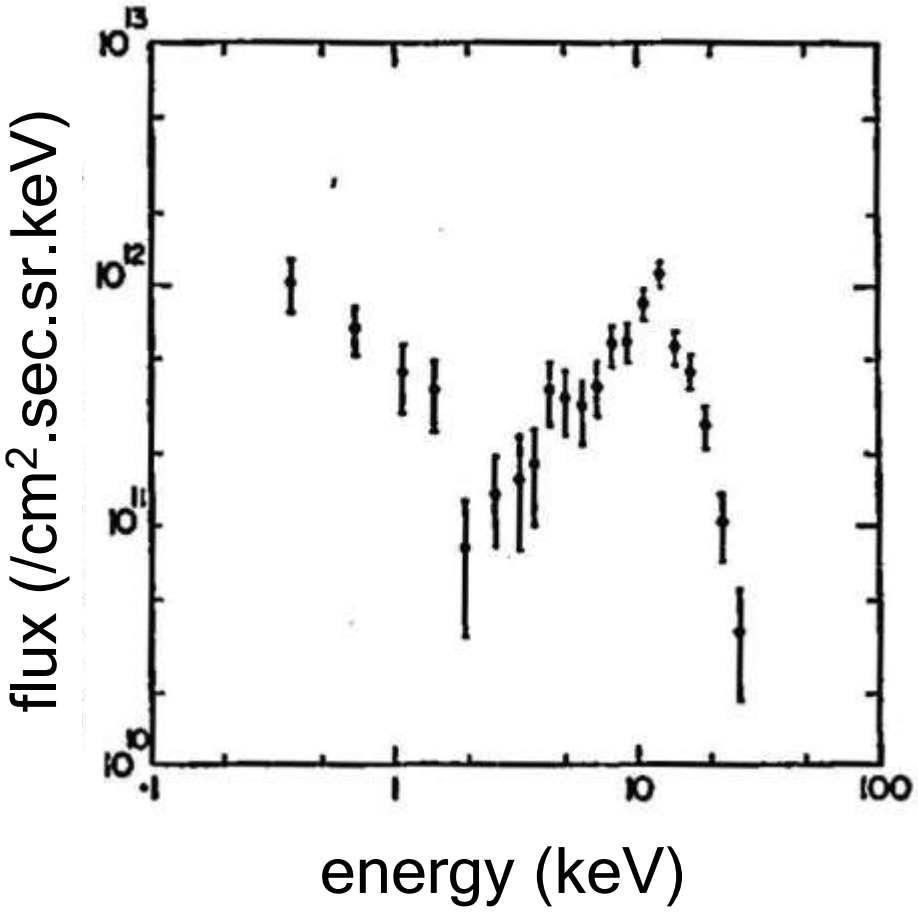
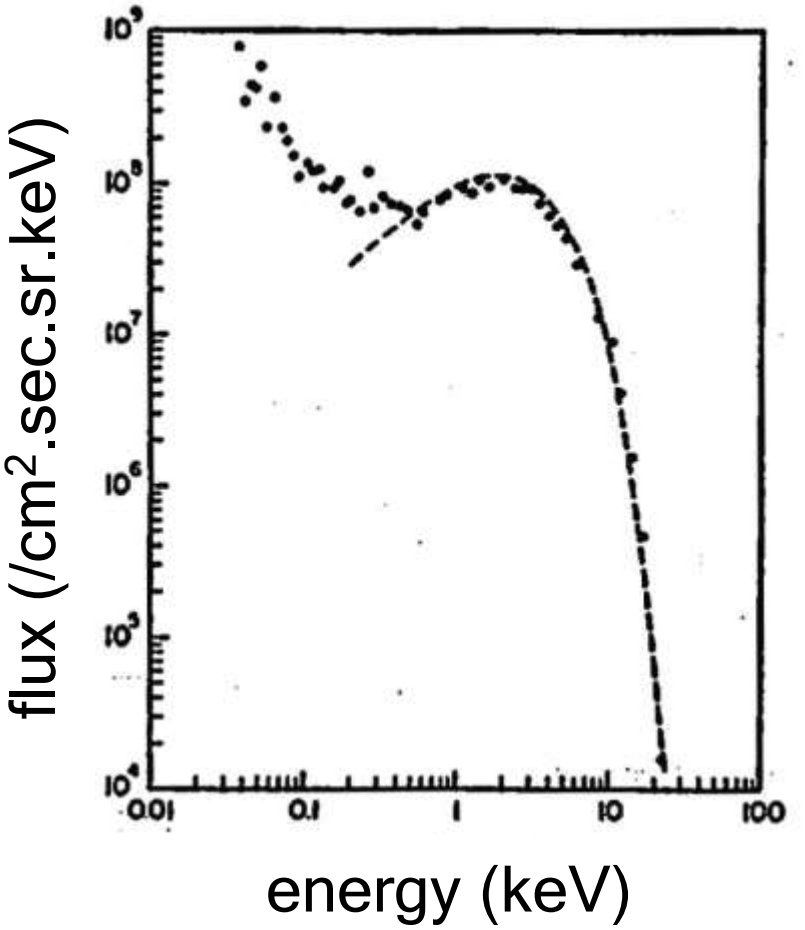


Fig. 18. Schematic representation of electron latitudinal morphology for various phases of a substorm.

These two characteristics of the precipitating electrons are categorized by *Winningham et al.* [1975] as the CPS (central plasma sheet) and BPS (boundary plasma sheet), respectively.

Energy spectrum of auroral electrons





Discrete Aurora
Accelerated mono-energetic peak

Diffuse Aurora
Maxwell distribution

Classical Morphology に対する追加、修正

Proton Aurora Substorm

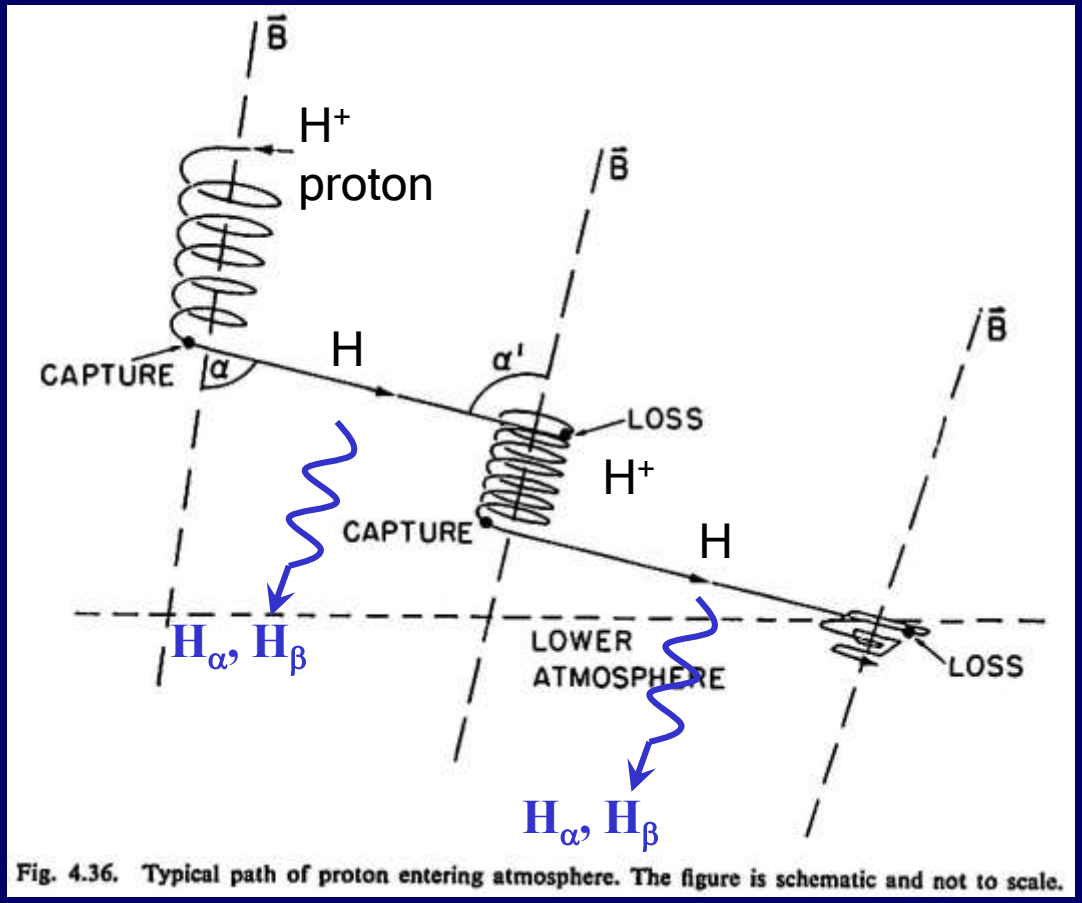
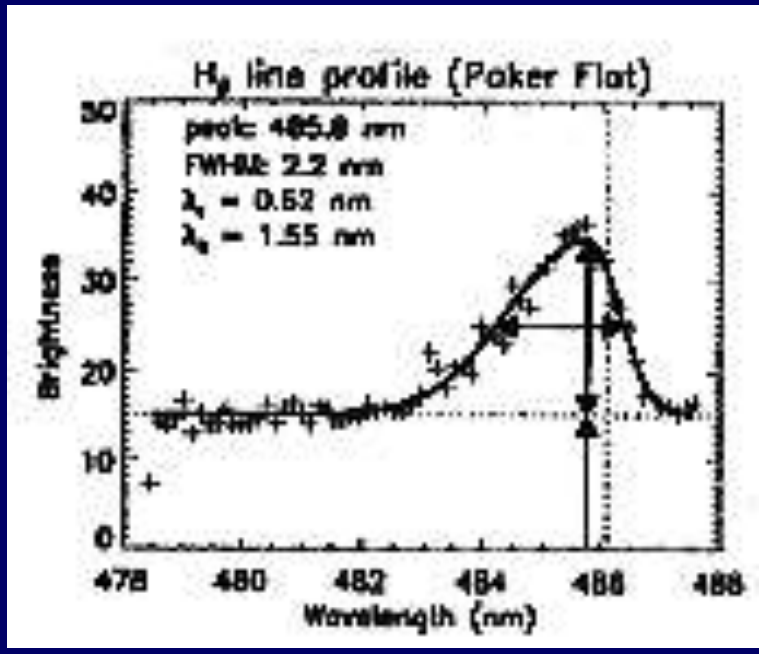


Fig. 4.36. Typical path of proton entering atmosphere. The figure is schematic and not to scale.



Spatially spread ⇒ diffuse type

Doppler broadening and shifting

Classical Morphology に対する追加、修正

- Proton Aurora Substorm（*Montbriand* (1971), *Fukunishi* (1975)）

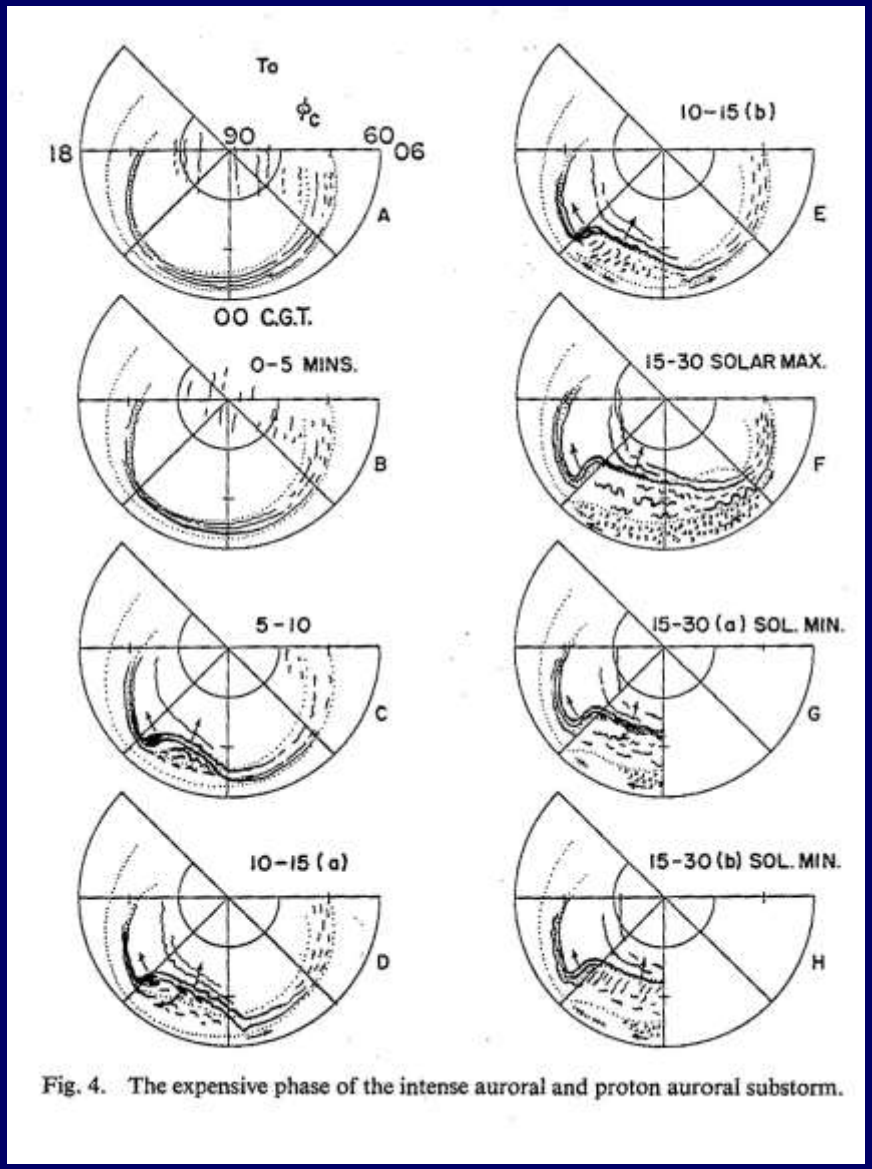


Fig. 4. The expensive phase of the intense auroral and proton auroral substorm.

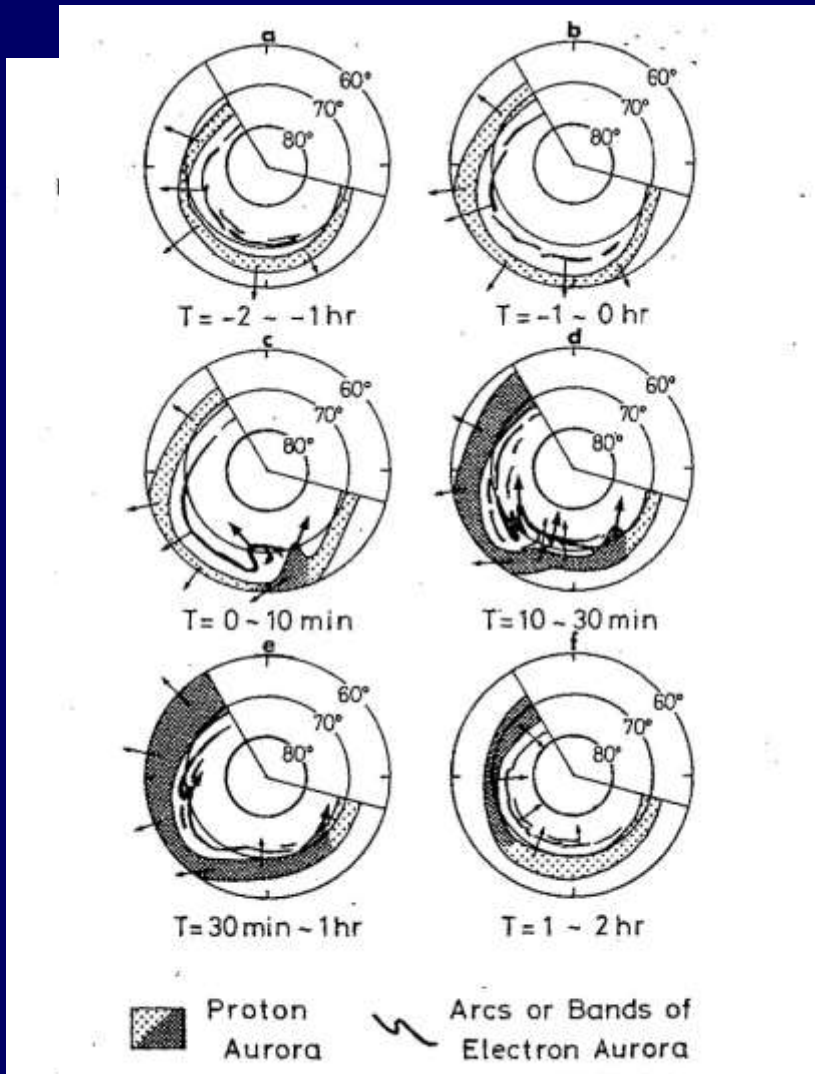


Fig. 23. Schematic diagrams showing the worldwide development of proton and electron auroral substorms; $T = 0$ is the onset time of the expansion phase. The notation is the same as that in Figure 21.

Classical Morphology に対する追加、修正

- Proton Aurora Substorm（*Oguti* (1973)）

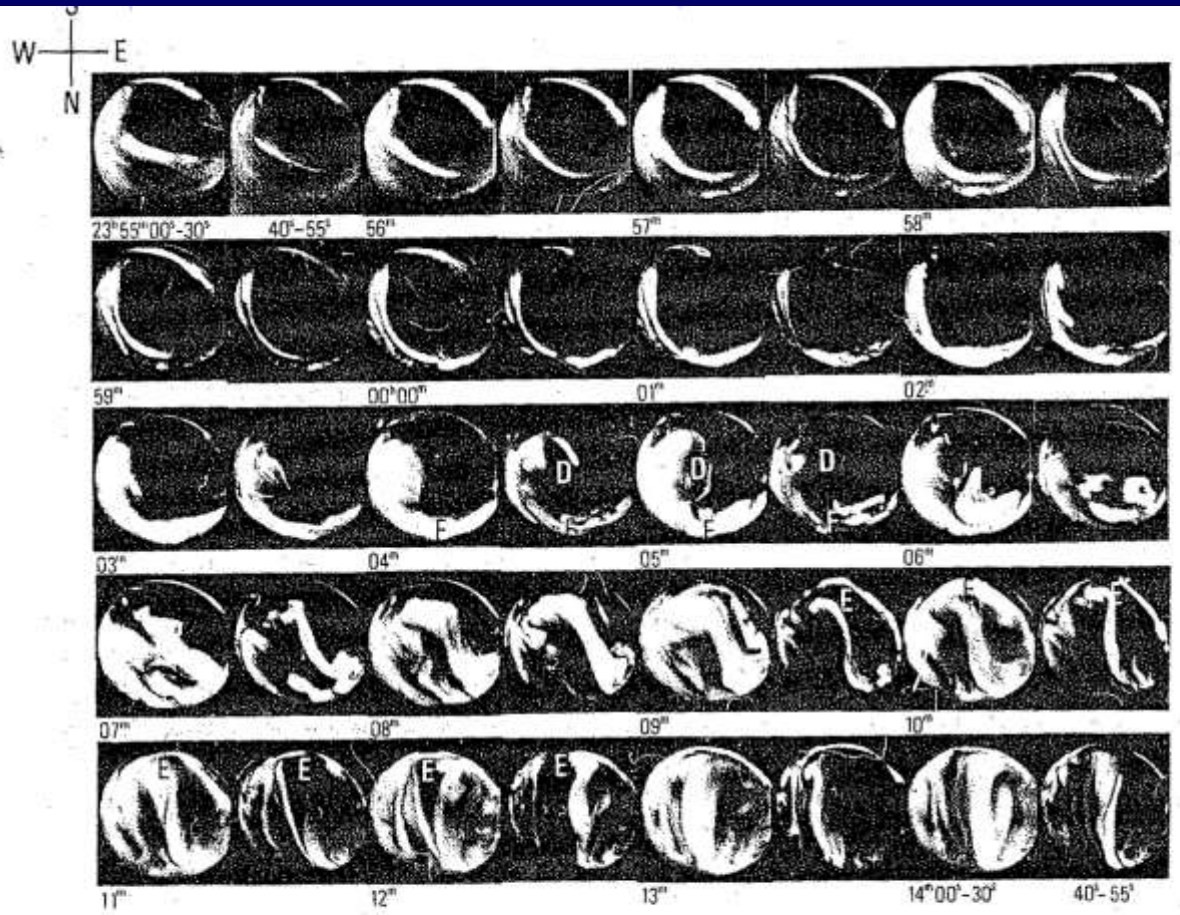


Fig. 2a.

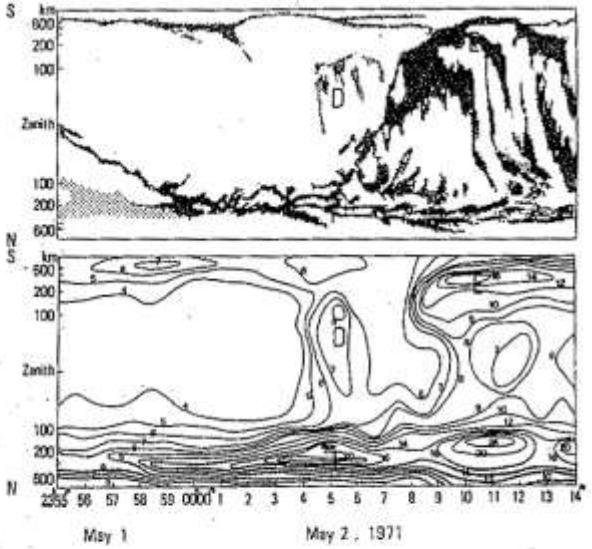


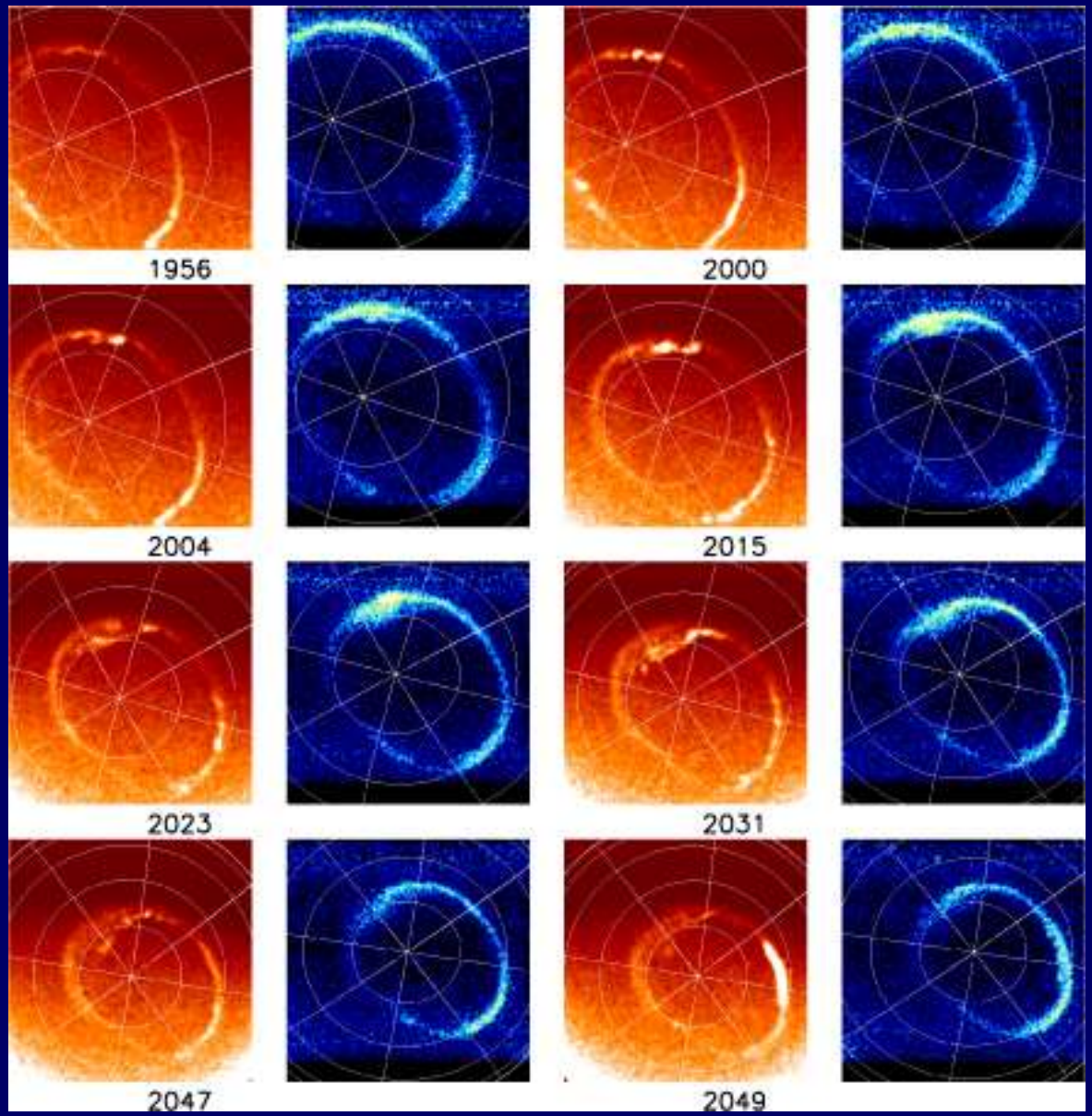
Fig. 2b.

OGUTI: LETTER

Fig. 2. Development of the electron aurora and hydrogen emission during the auroral breakup of May 1–2, 1971. (*a*) All-sky camera photographs. (*b*) Meridian-time display of the electron aurora (top), and meridian-time display of the hydrogen emission (bottom).

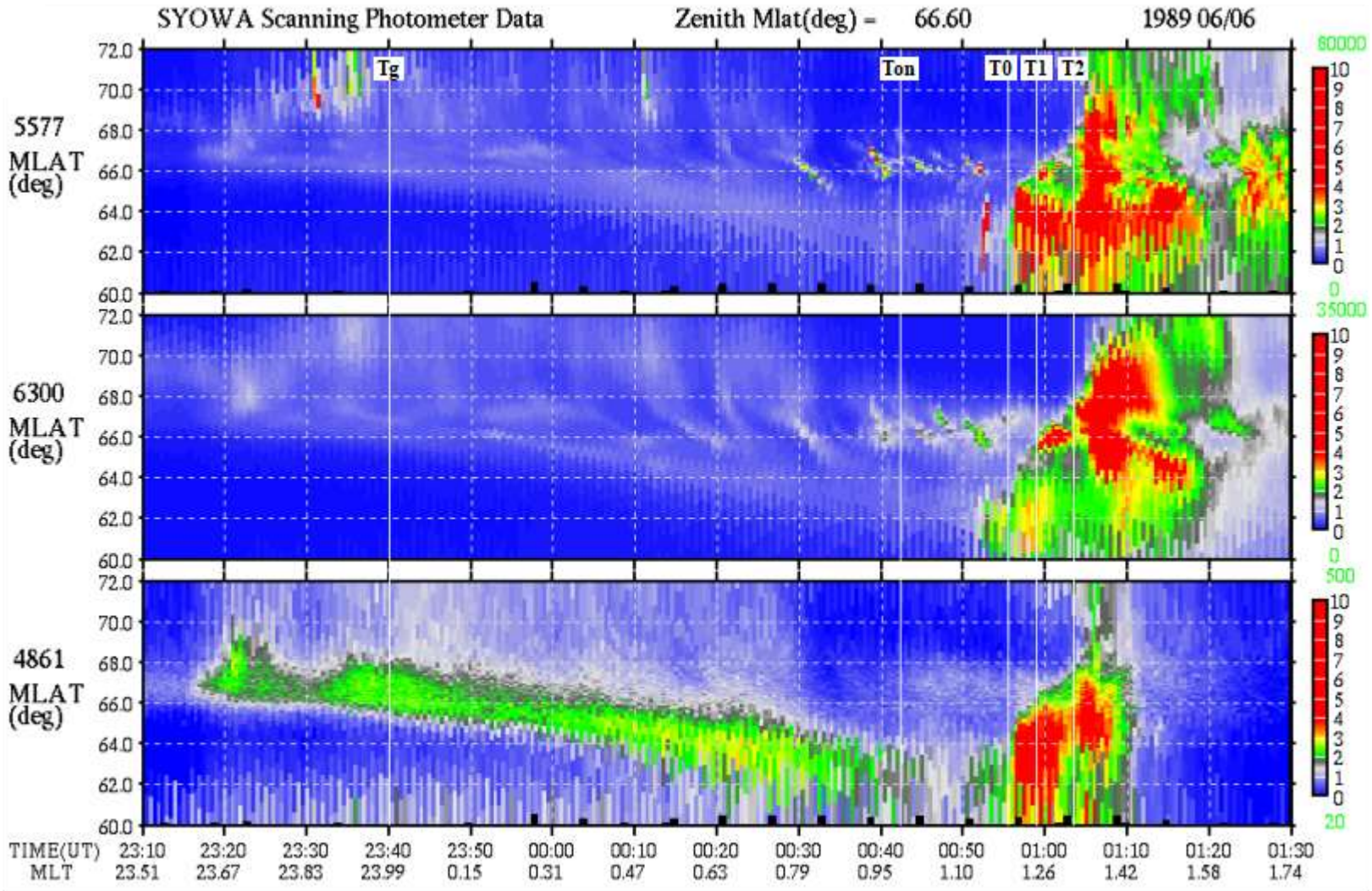
Classical Morphology に対する追加、修正

- Proton Aurora Substorm（IMAGE衛星、*Mende et al.* (2001)）



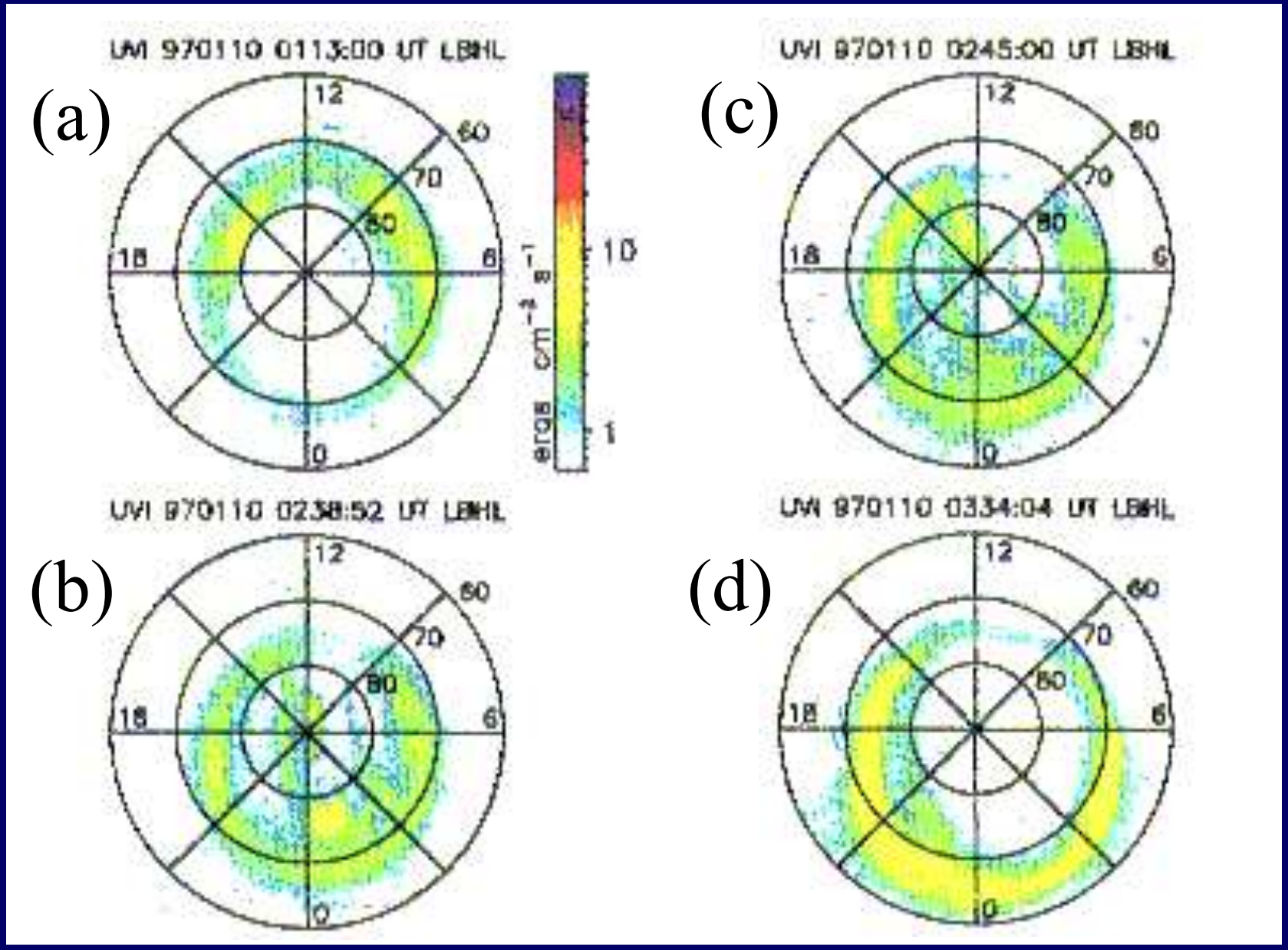
Classical Morphology に対する追加、修正

- Growth Phase



Classical Morphology に対する追加、修正

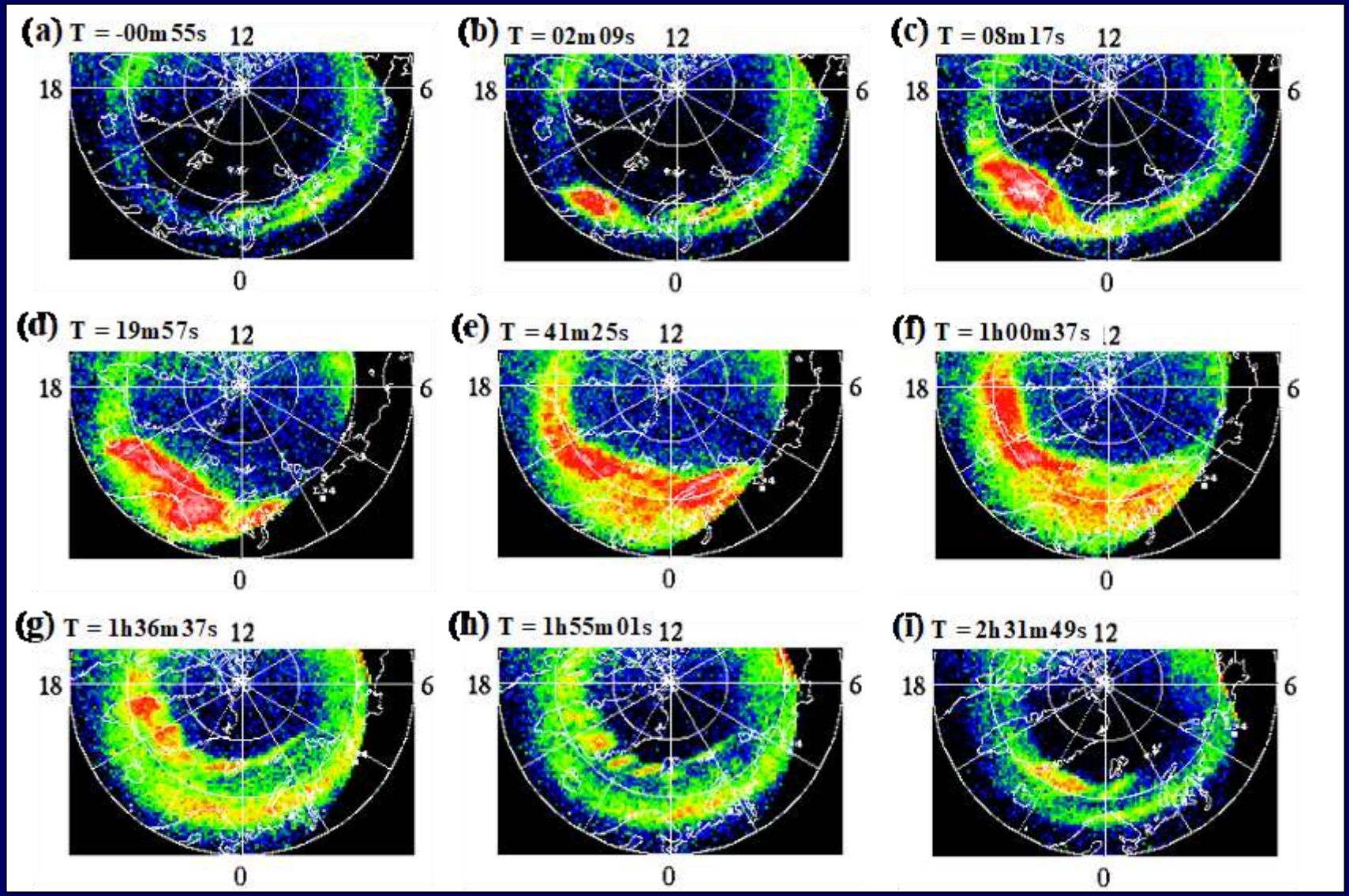
- Growth Phase　　*Brittnacher et al.* (1999)　(POLAR UVI)



Classical Morphology に対する追加、修正

- Premidnight preference & localization of onset region
- Double oval configuration during the recovery phase

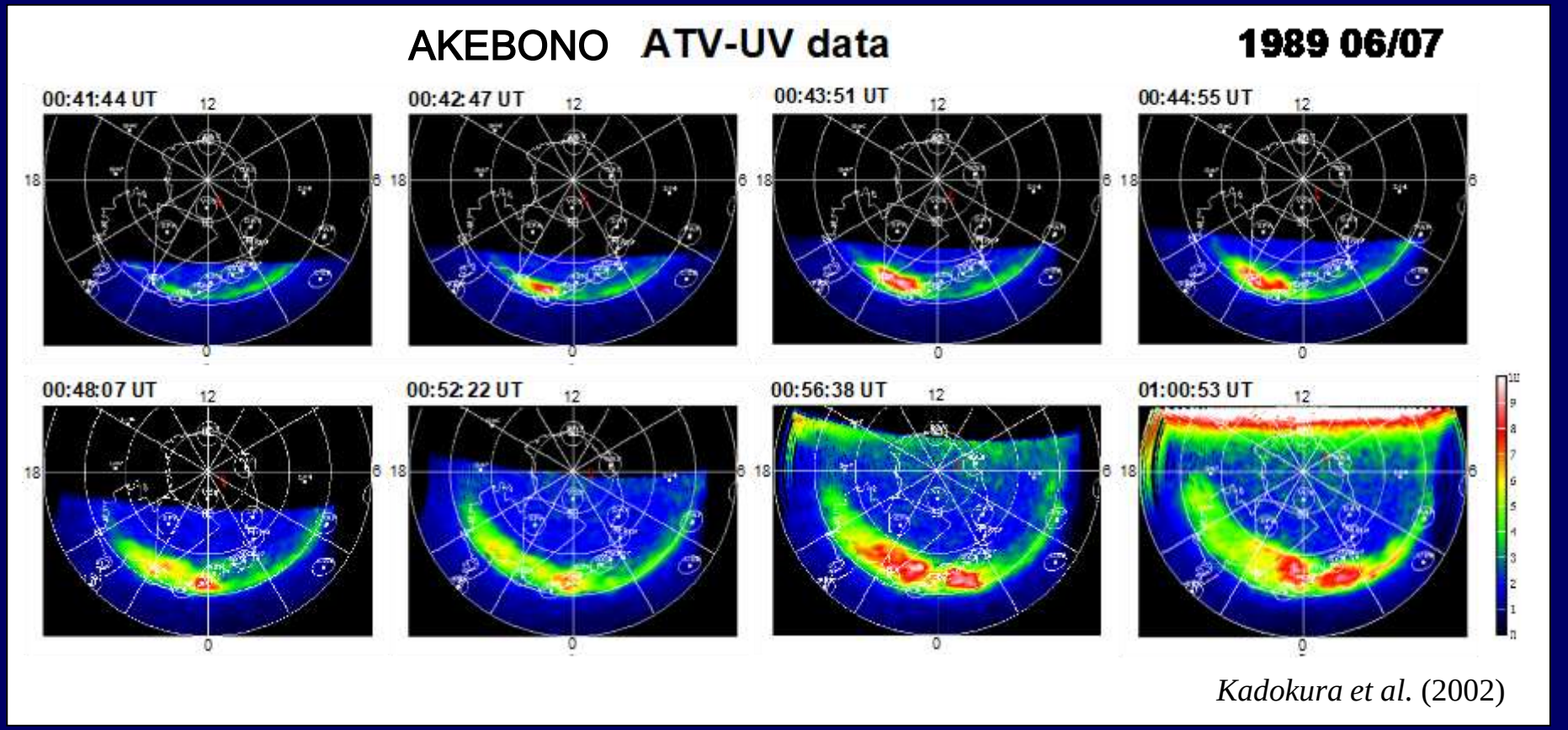
POLAR UVI (1997)



Classical Morphology に対する追加、修正

- Premidnight preference & localization of onset region

Elphinstone et al. (1995) for VIKING 80 events
Average location : 22.9±1.2 hr MLT and 65.9±3.5 deg CGMLAT
Spatial extent : about 1 hr MLT



Kadokura et al. (2002)

Classical Morphology に対する追加、修正

- Premidnight preference of onset region

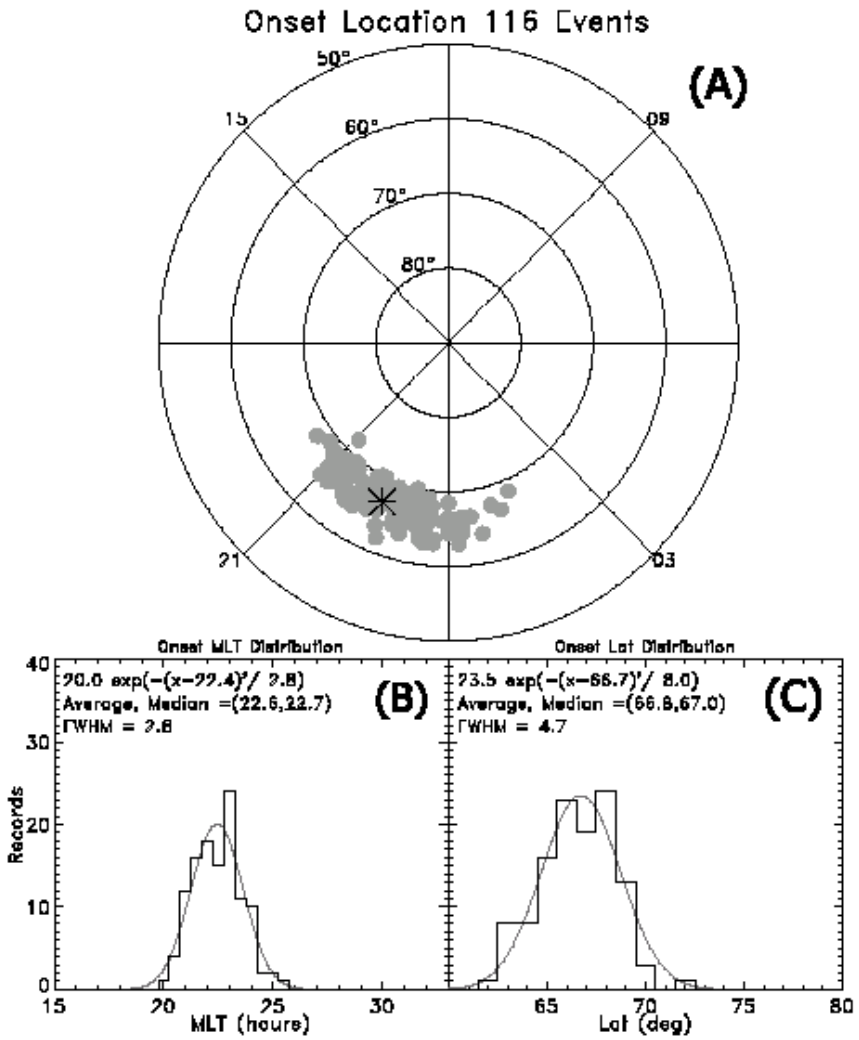


Figure 6. (a) The distribution of onset locations in MLT/ILat. with the average marked as an asterisk. (b and c) The distribution as histograms in MLT and ILat, respectively, of the onset locations. Gaussian curves are fitted to the data, with the equation, average, median, and full-width at half-maximum included.

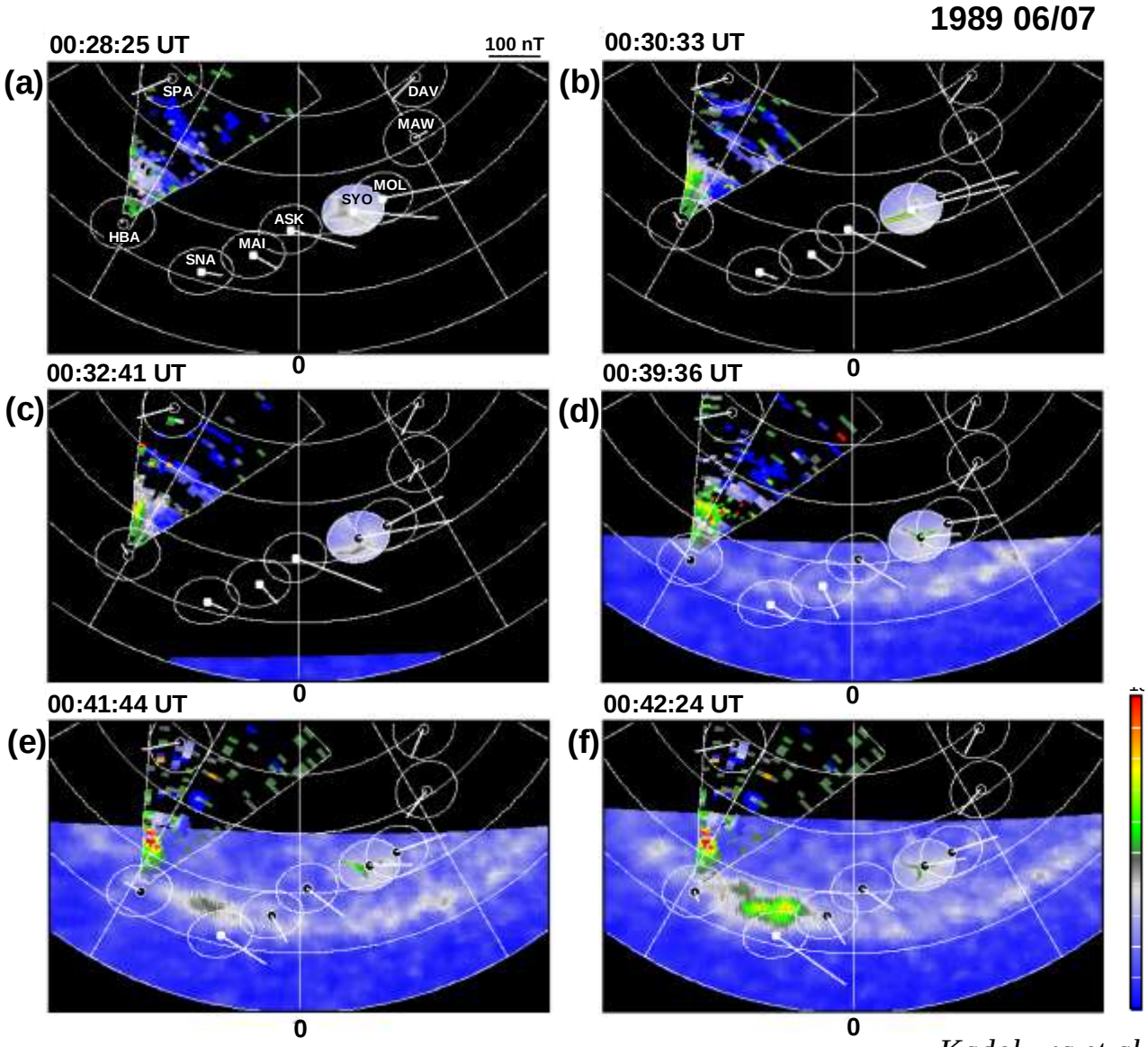
POLAR
VIS Earth camera

Gjerloev et al.
(JGR, 112, 2007)

Classical Morphology に対する追加、修正

- Premidnight preference & localization of onset region

AKEBONO ATV-UV



Kadokura et al. (2002)

Relationship between onset location and convection

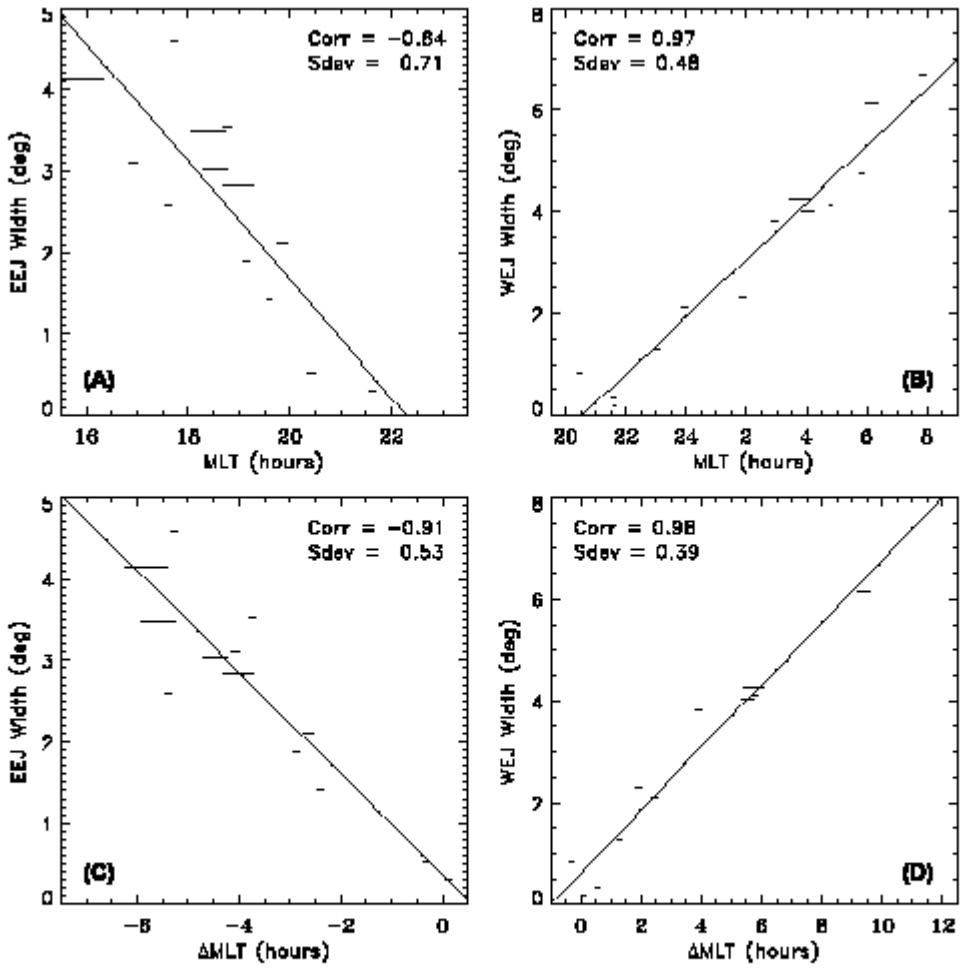
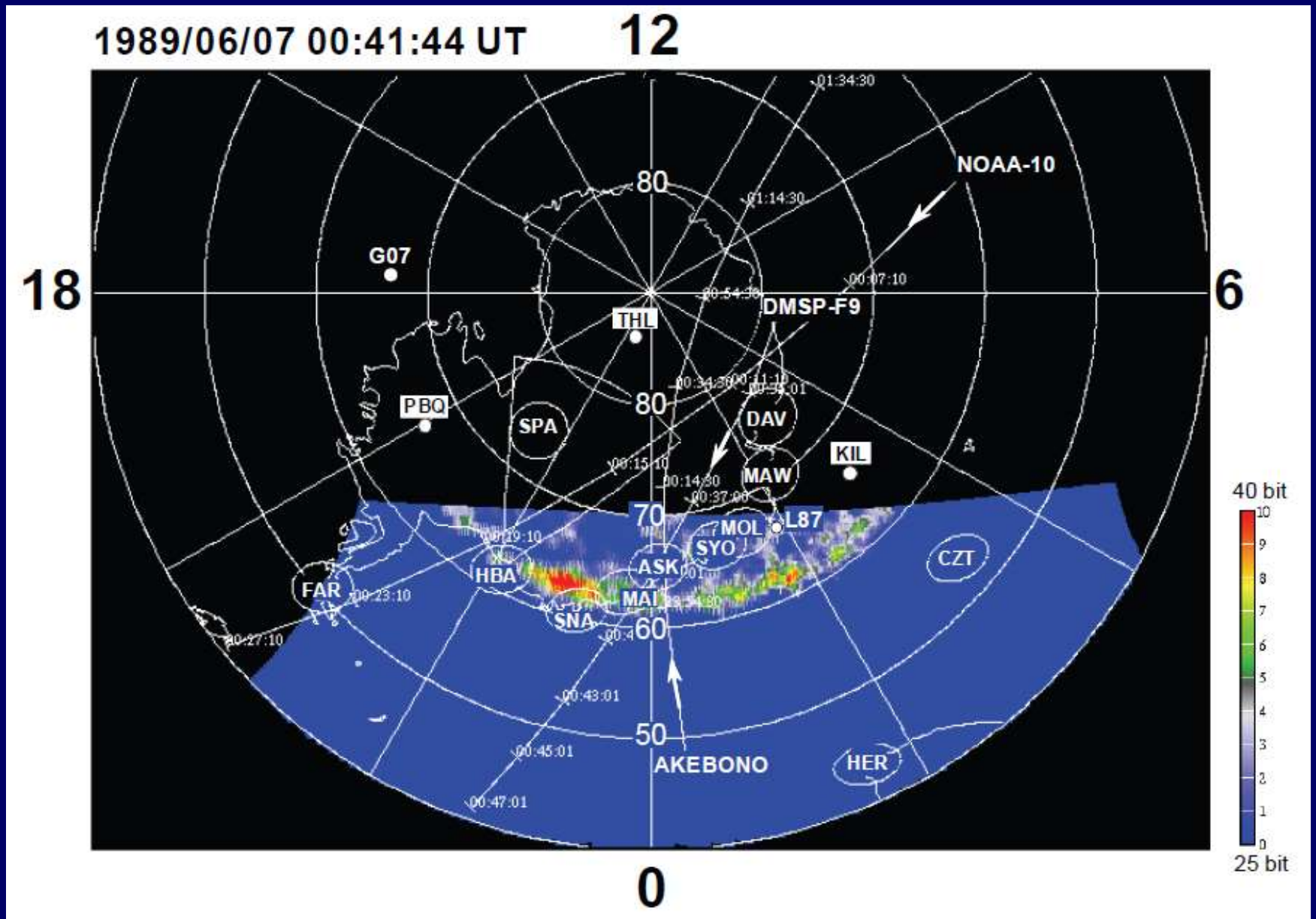


Figure 4. Latitudinal width of the auroral electrojets during the growth phase of classical bulge-type auroral substorms. Top panels (A and B) show the widths as a function of MLT while the bottom panels (C and D) show the widths as a function of the MLT distance to the future optical onset location. Zero MLT indicates the location of the future substorm onset. Corr and Sdev indicate the linear Pearson correlation coefficient and the standard deviation, respectively.

DE-1 & DE-2

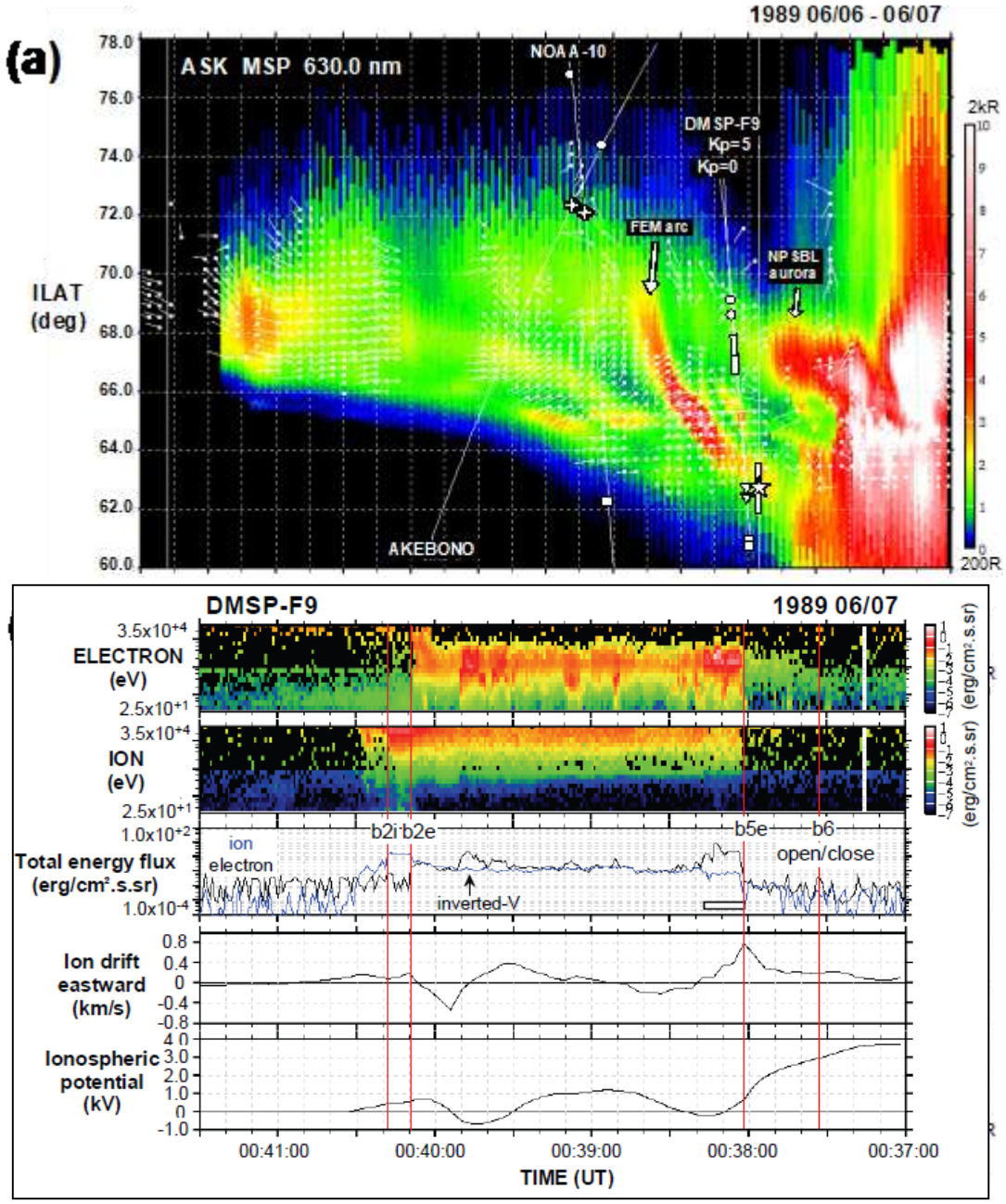
Gjerloev et al. (GRL, 30, 2003)

Onset location & Onset Arc



Kadokura et al. (2002)

Onset location & Onset Arc

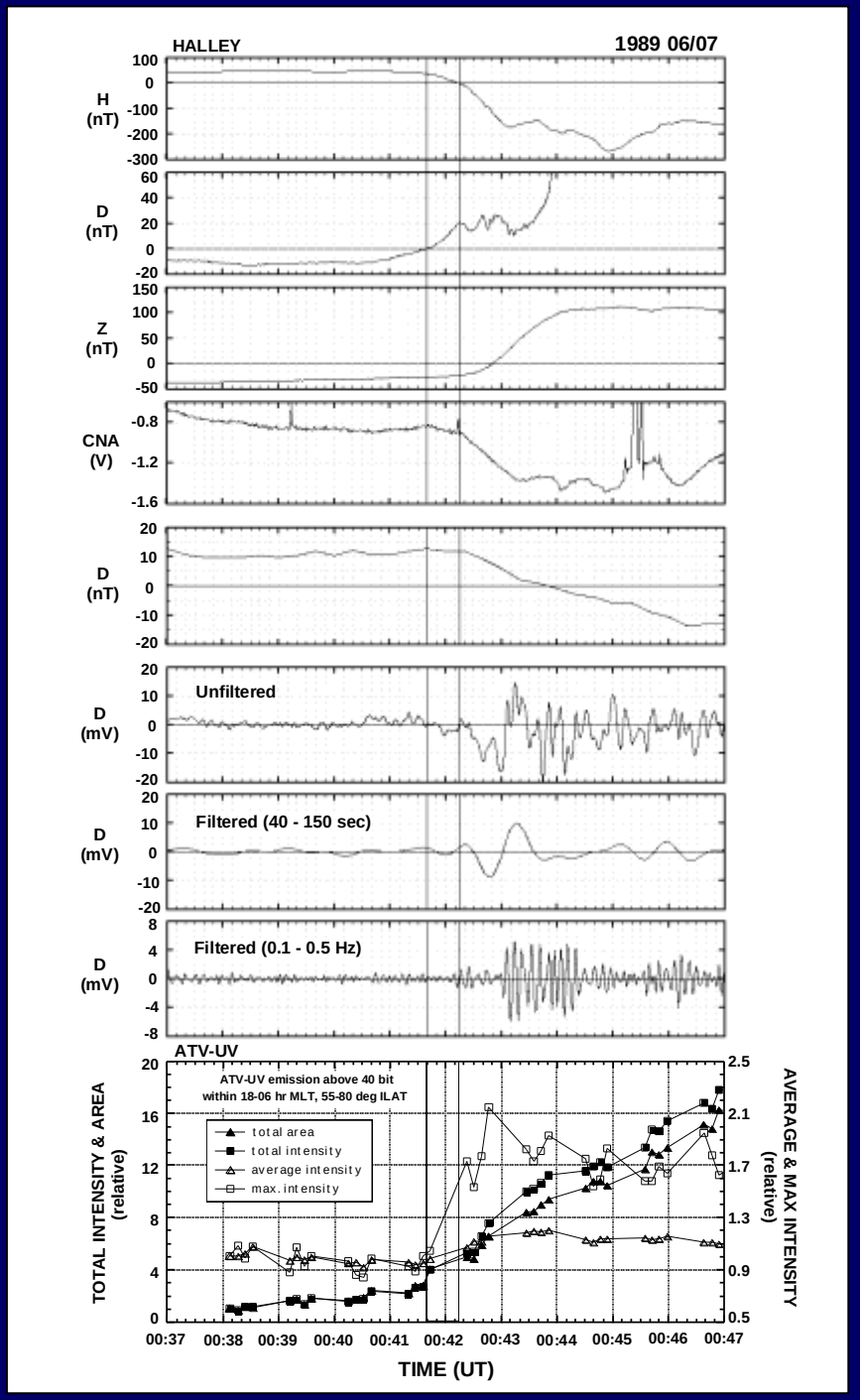


Kadokura et al. (2002)

Precursor phenomena & Explosiveness

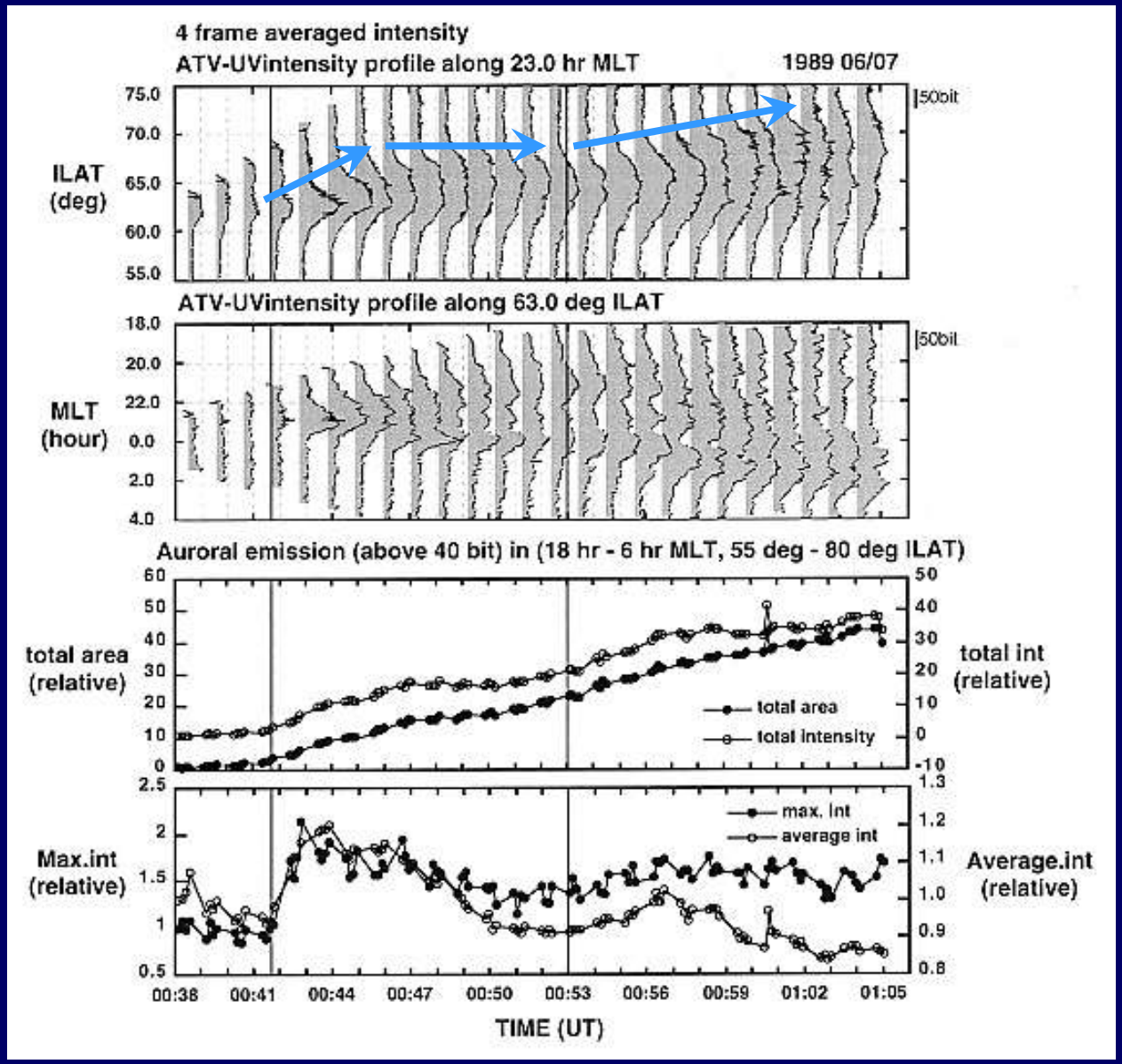
- Auroral fading
  (e.g. *Kauristie et al.* (1997))
- AAF (Azimuthally spaced Auroral Forms)
  (*Elphinstone et al.*, 1995)
- Enhancement of equivalent current
  (e.g. *Kawasaki and Rostoker*, 1979)

Kadokura et al. (2002)

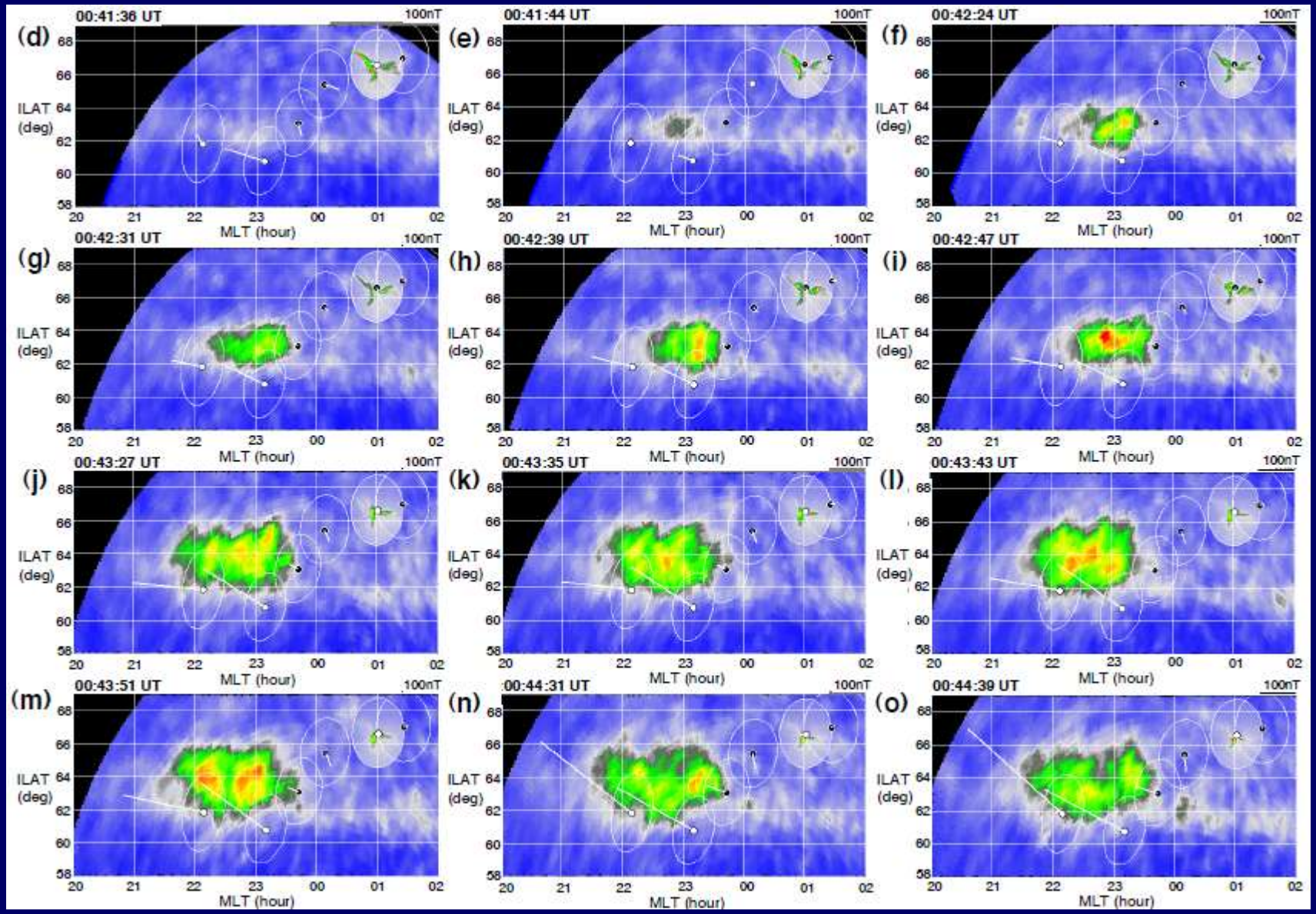


Classical Morphology に対する追加、修正

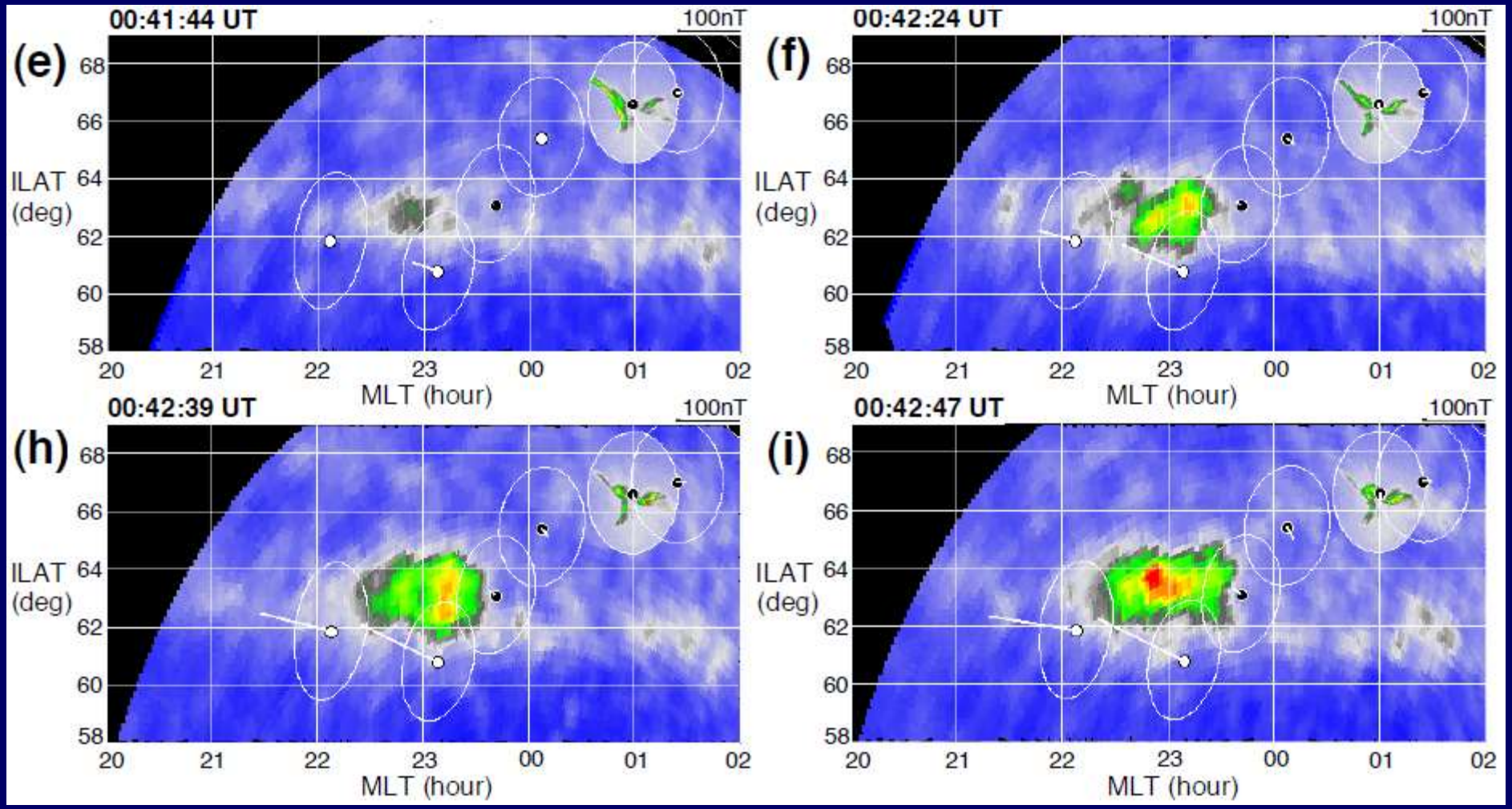
- Stepwise evolution during the expansion phase



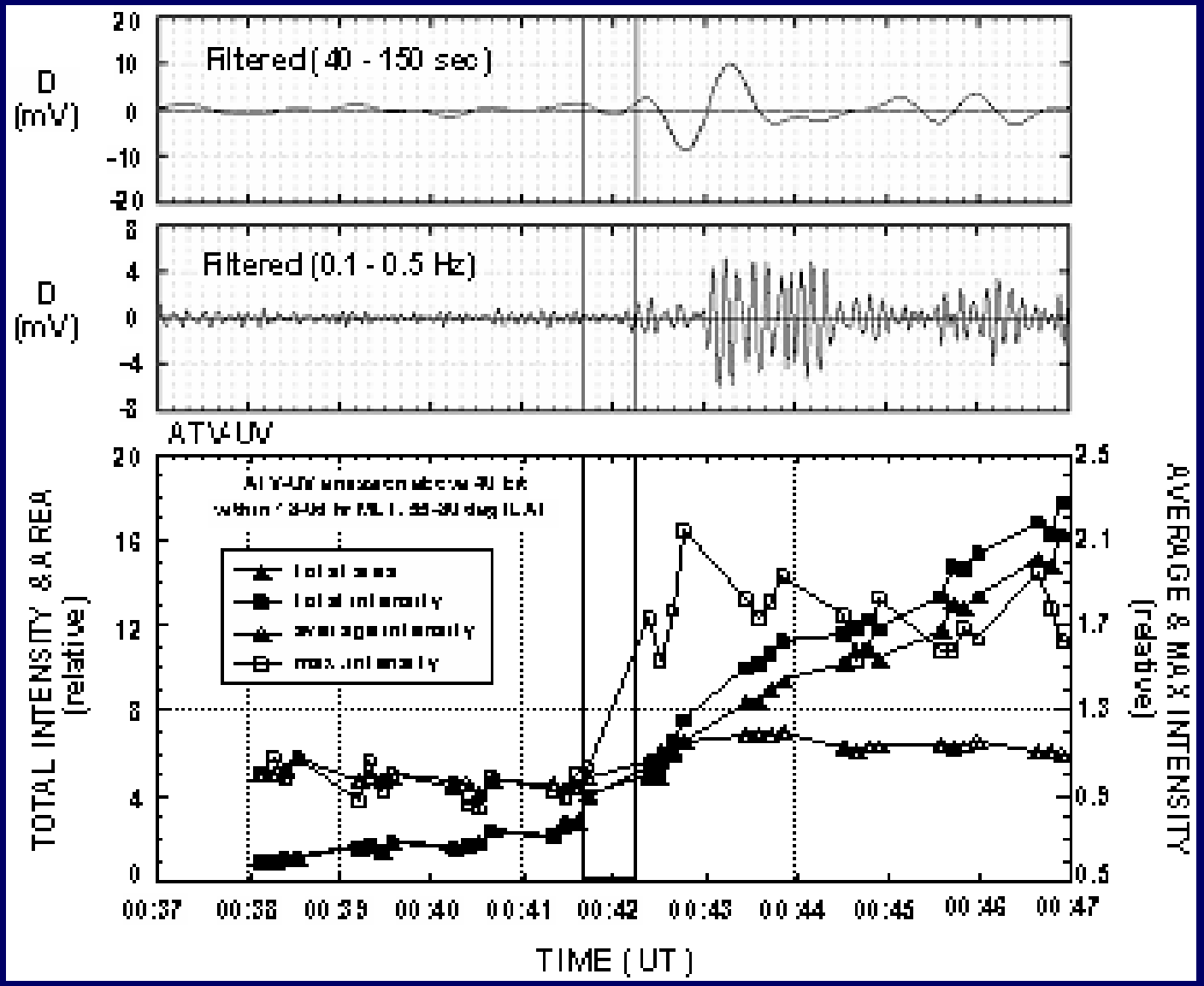
Stage-1: Rapid poleward expansion



Breakup region ≠ Negative potential center

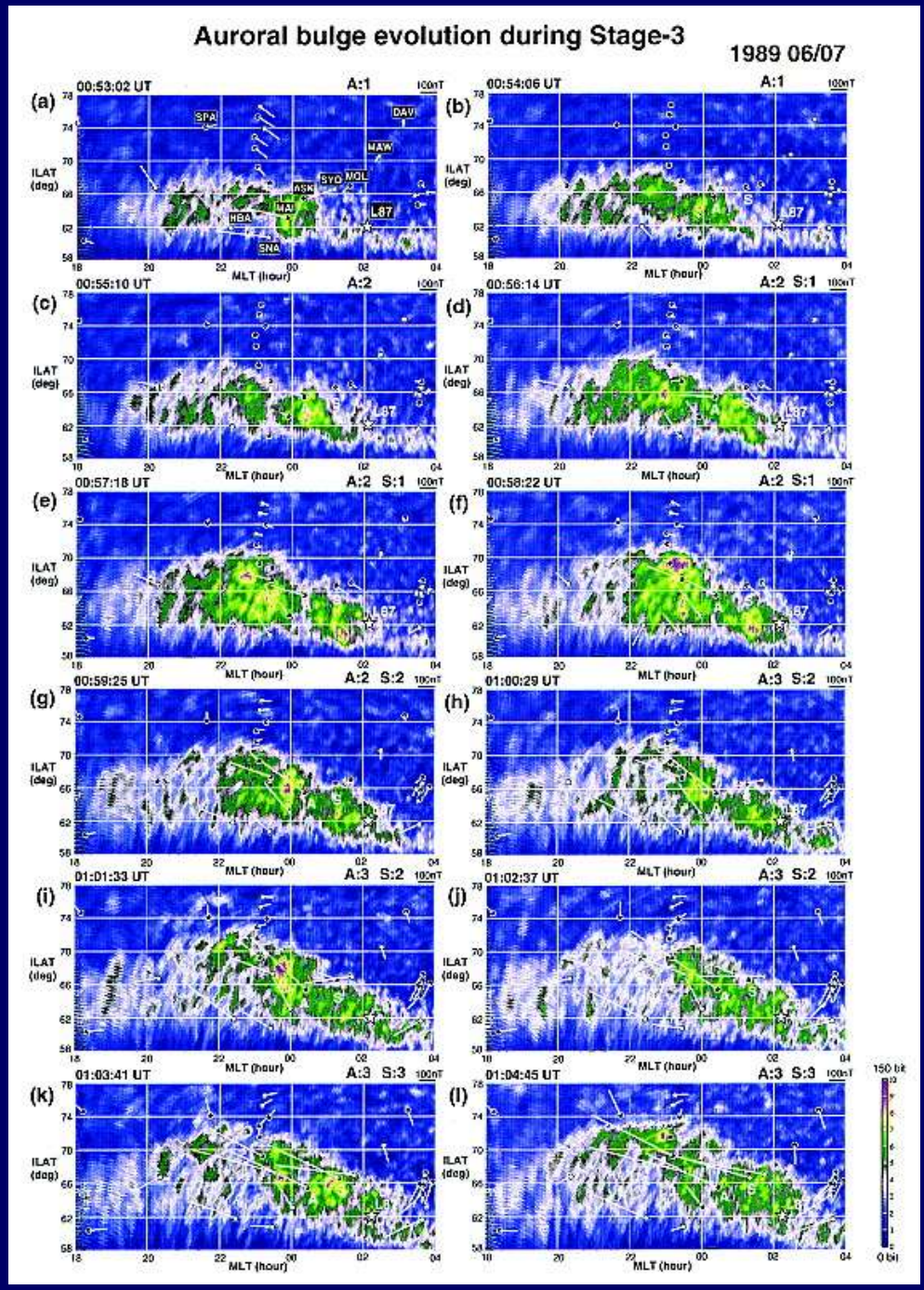


Stage-1: Pure Pi2 wave form



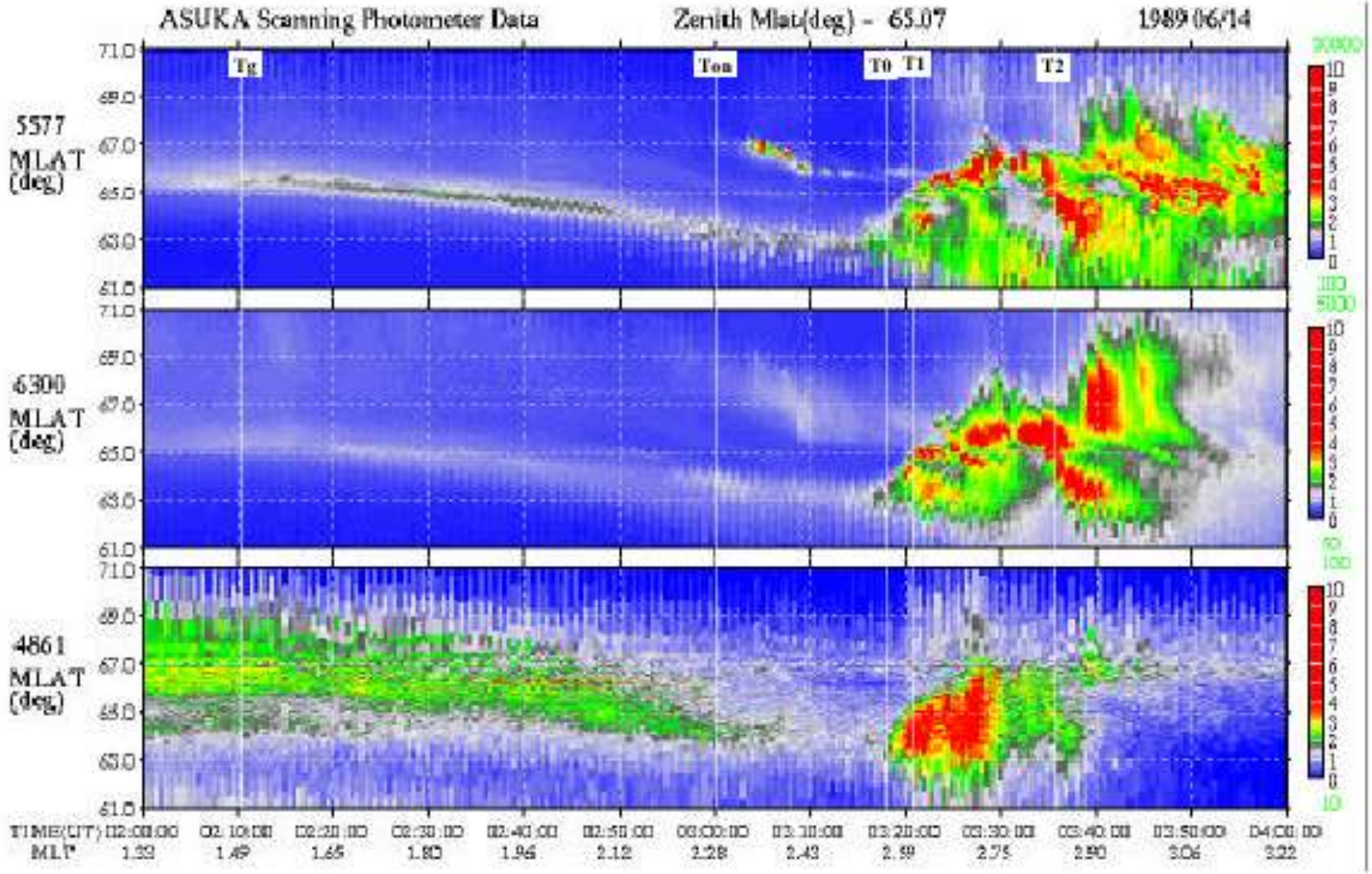
Stage-3

Re-activation of the further expansion



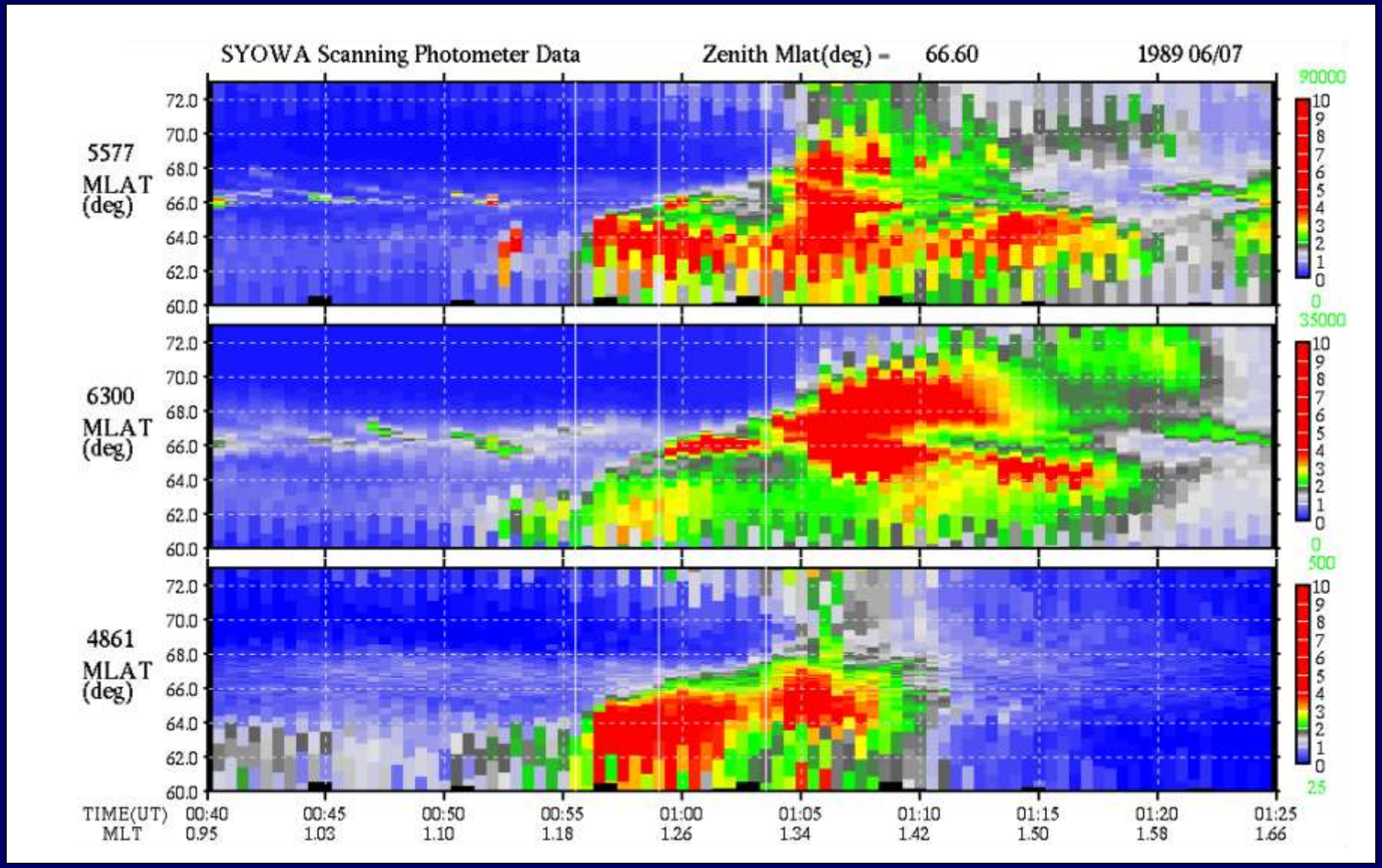
Classical Morphology に対する追加、修正

- Stepwise evolution during the expansion phase



Classical Morphology に対する追加、修正

- Stepwise evolution during the expansion phase



N-S aurora

Nakamura et al. (1993)

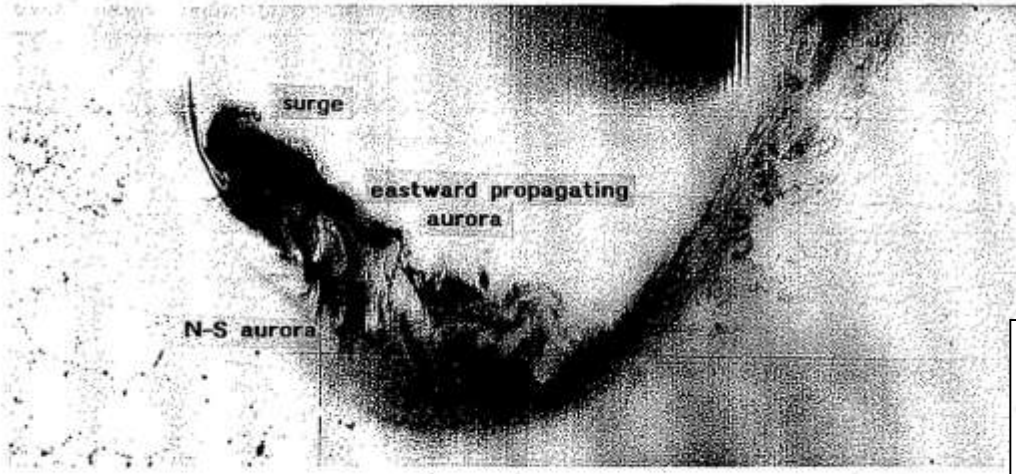


Fig. 2. DMSP auroral image of a bulge including characteristic auroral structures: the surge, the N-S aurora, a
propagating aurora.

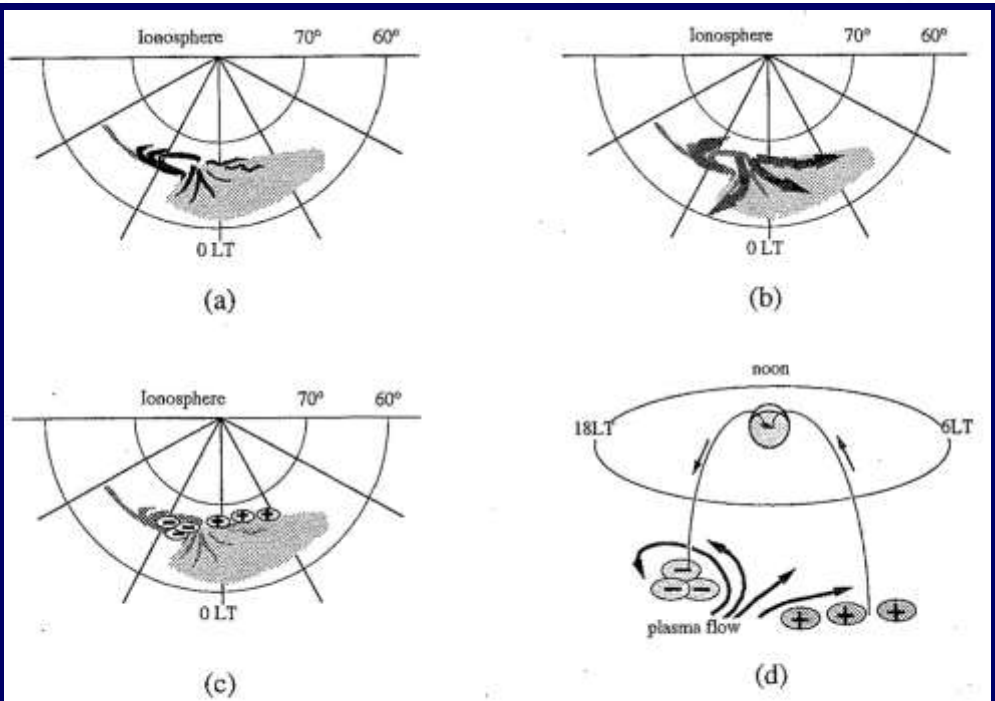


Fig. 11. (*a*) A schematic representation of the bulge at the maximum epoch. (*b*) The direction of the expansion of each aurora within the bulge. (*c*) The location of the expected space charges in the magnetosphere transferred onto the ionosphere, which could be expected from the evolution of the aurora. (*d*) The expected plasma flow in the magnetosphere associated with the auroral expansion.

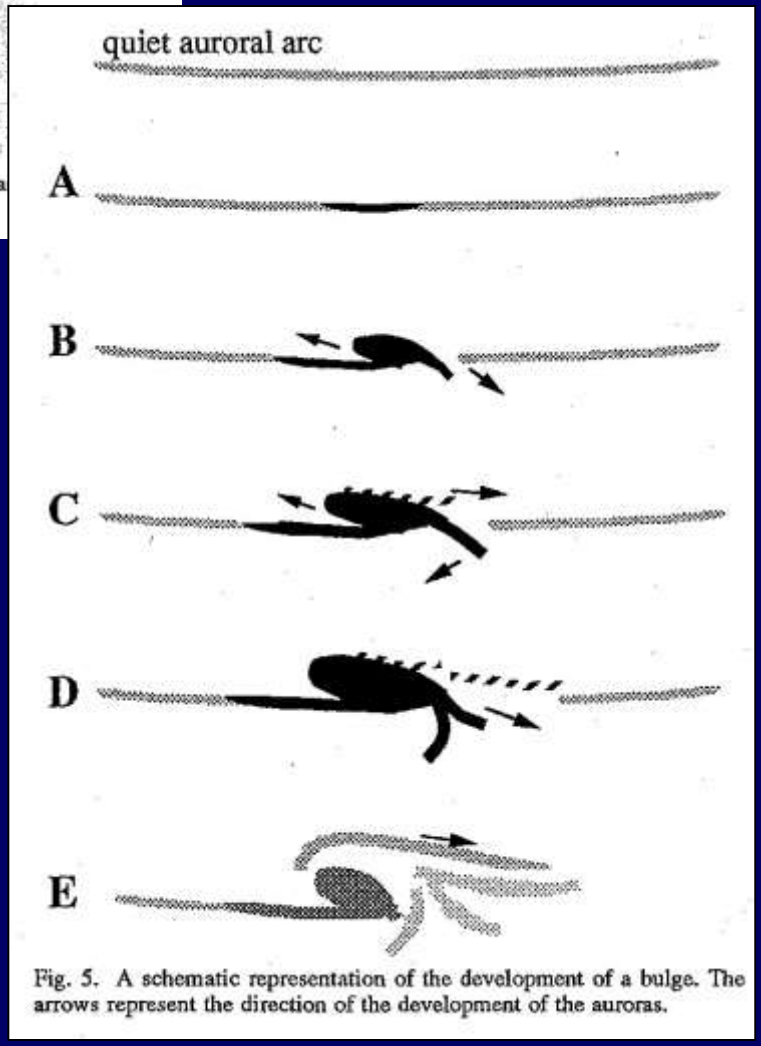
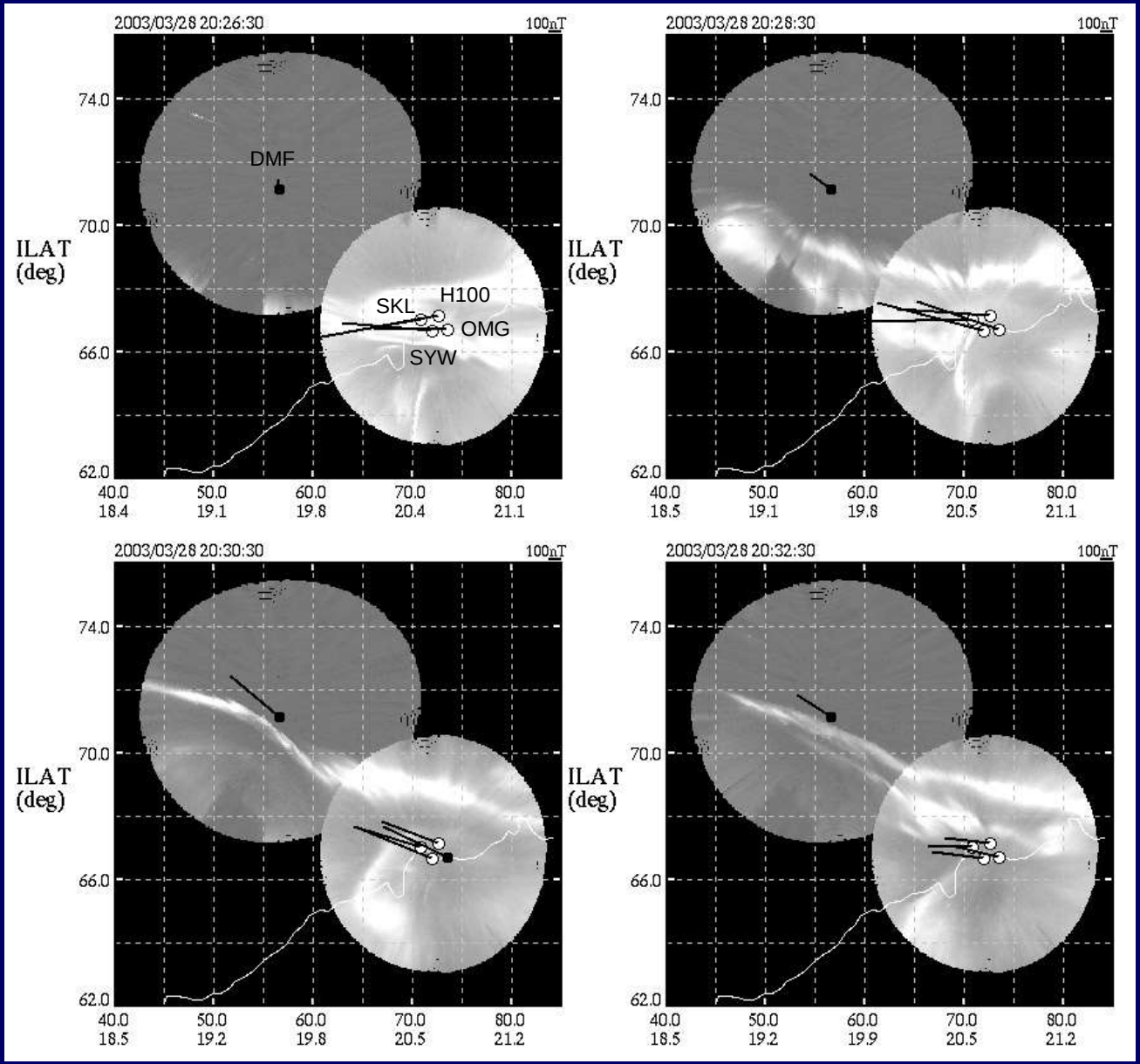


Fig. 5. A schematic representation of the development of a bulge. The arrows represent the direction of the development of the auroras.

Relationship between WTS and N-S aurora



Kadokura et al. (2008)

N-S aurora

Henderson et al. (1998)

Auroral Streamer

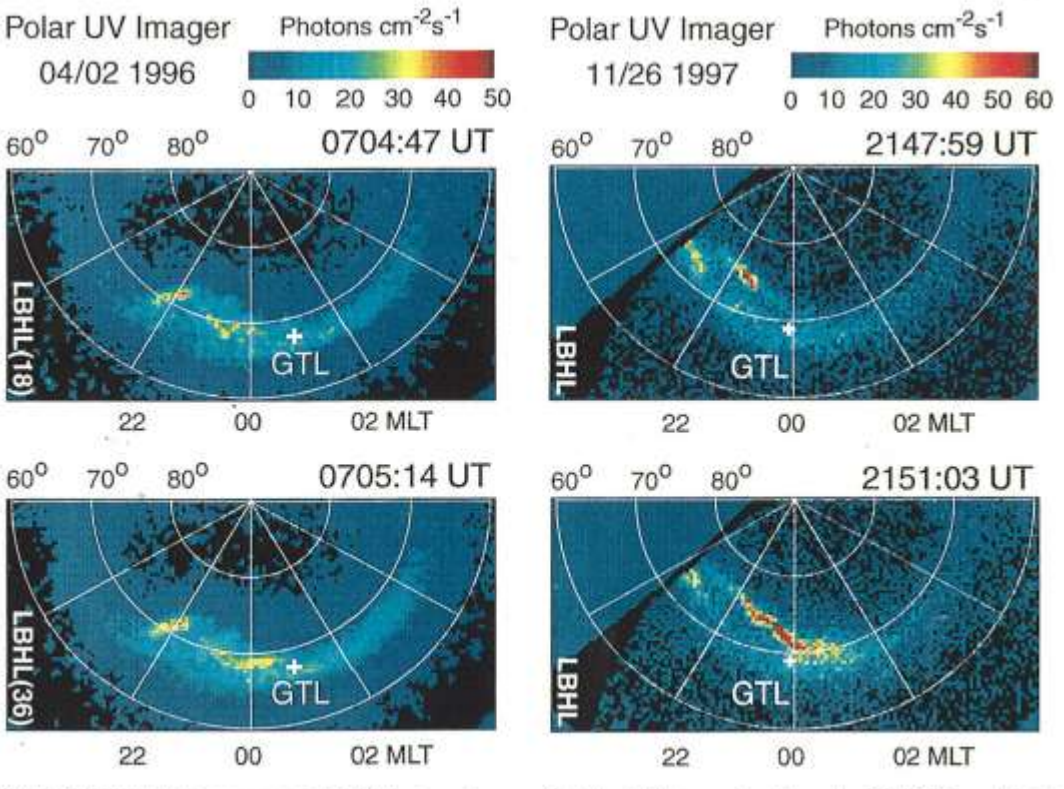


Plate 1. Selected UVI images on April 2, 1996, shown in geomagnetic coordinates. The foot point of Geotail is marked in the figure.

Plate 2. UVI images for November 26, 1997, event in the same format as Plate 1.

Nakamura et al. (2001)

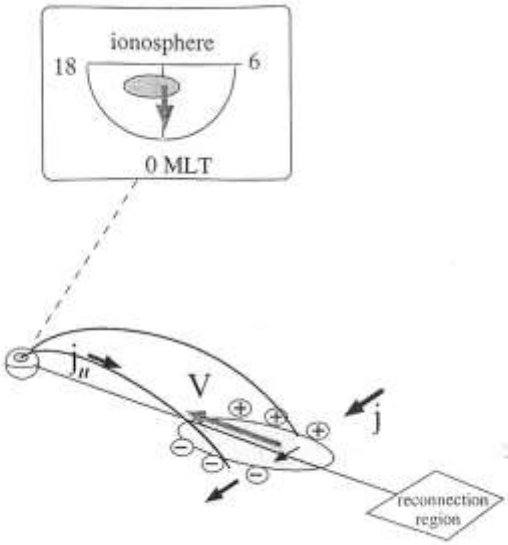
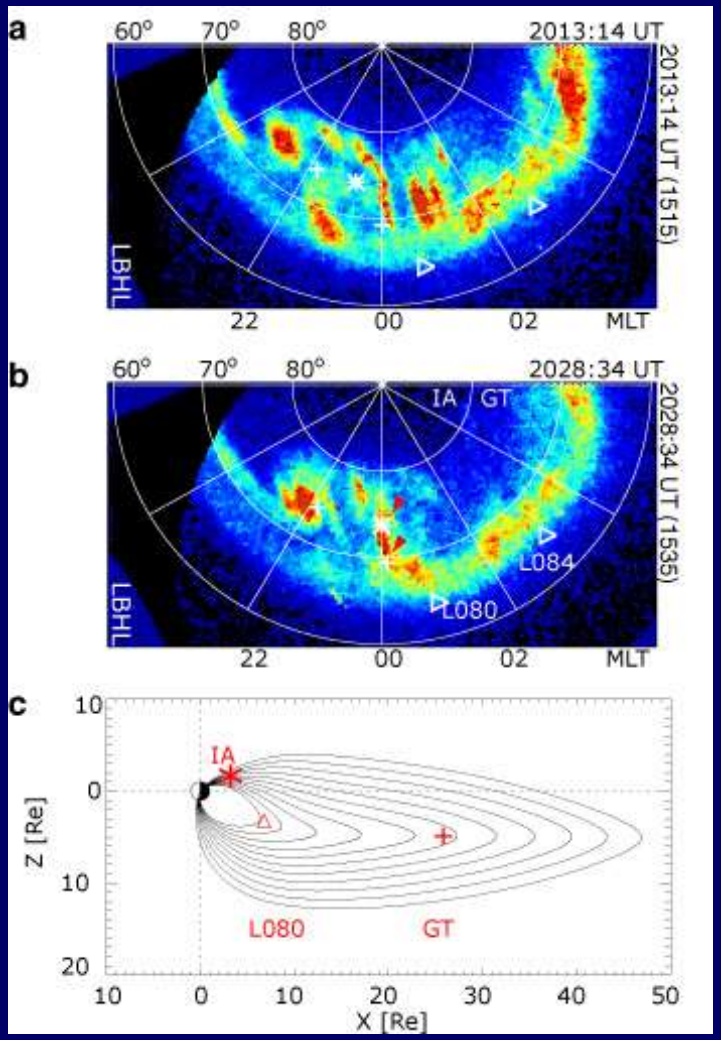
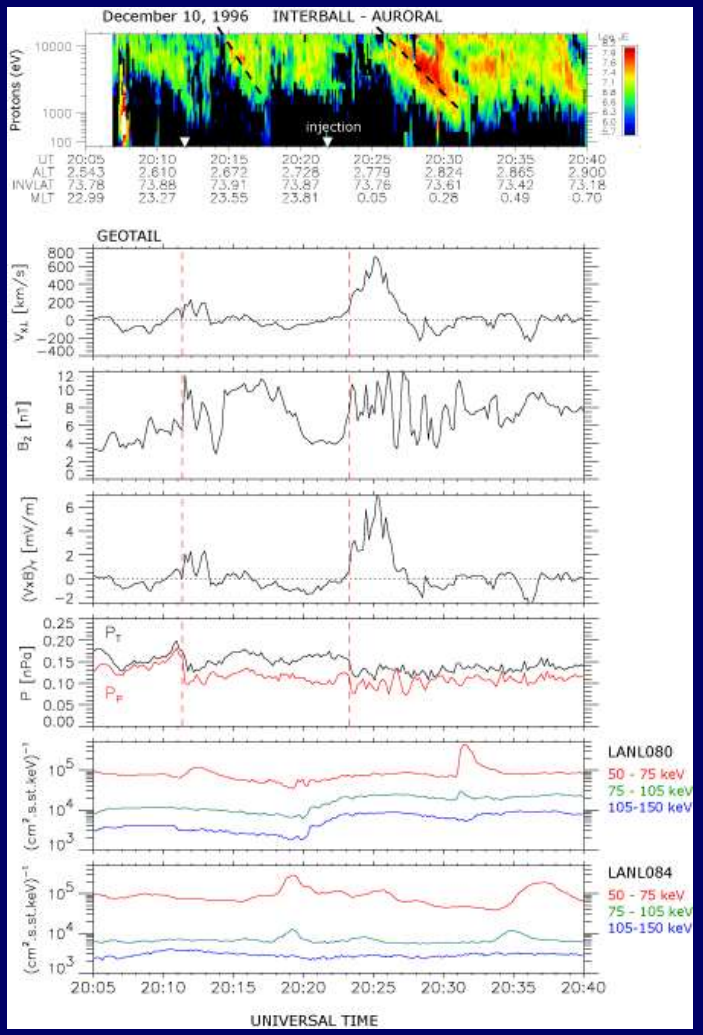


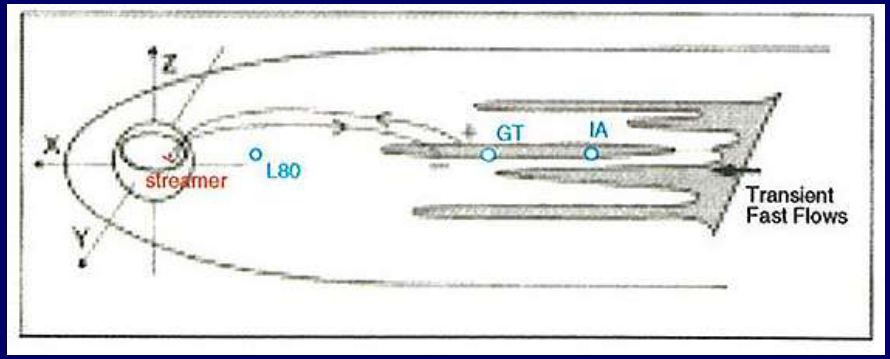
Figure 7. Illustration showing the relationship between aurora and plasma bubble in ionosphere and in magnetosphere. Expansion aurora is centered west of the flow burst.

Auroral Streamer

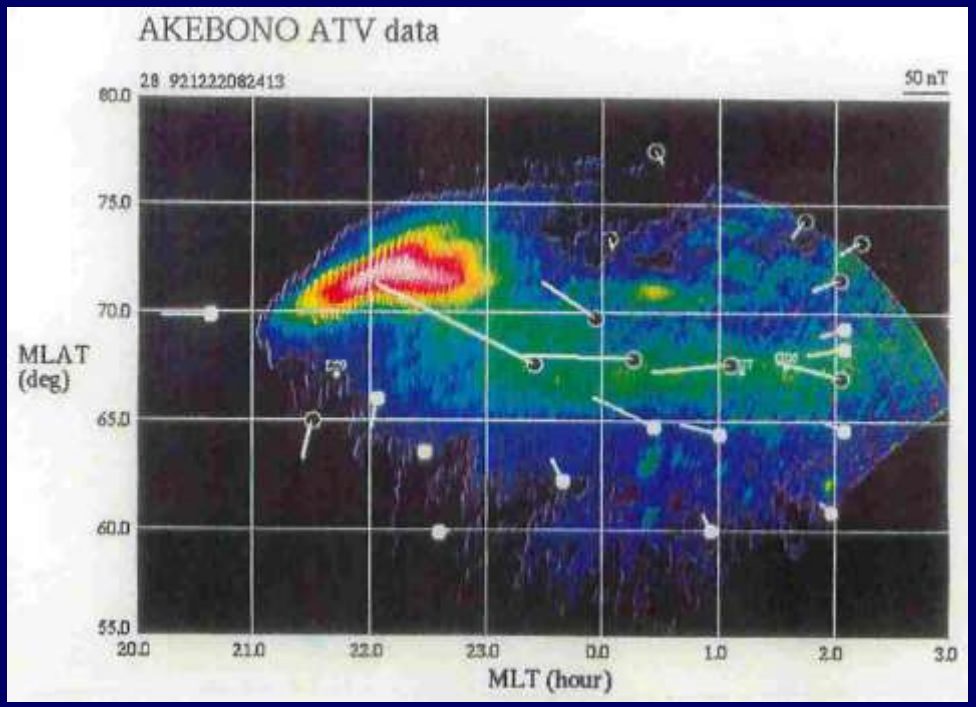
Sergeev et al. (2000)

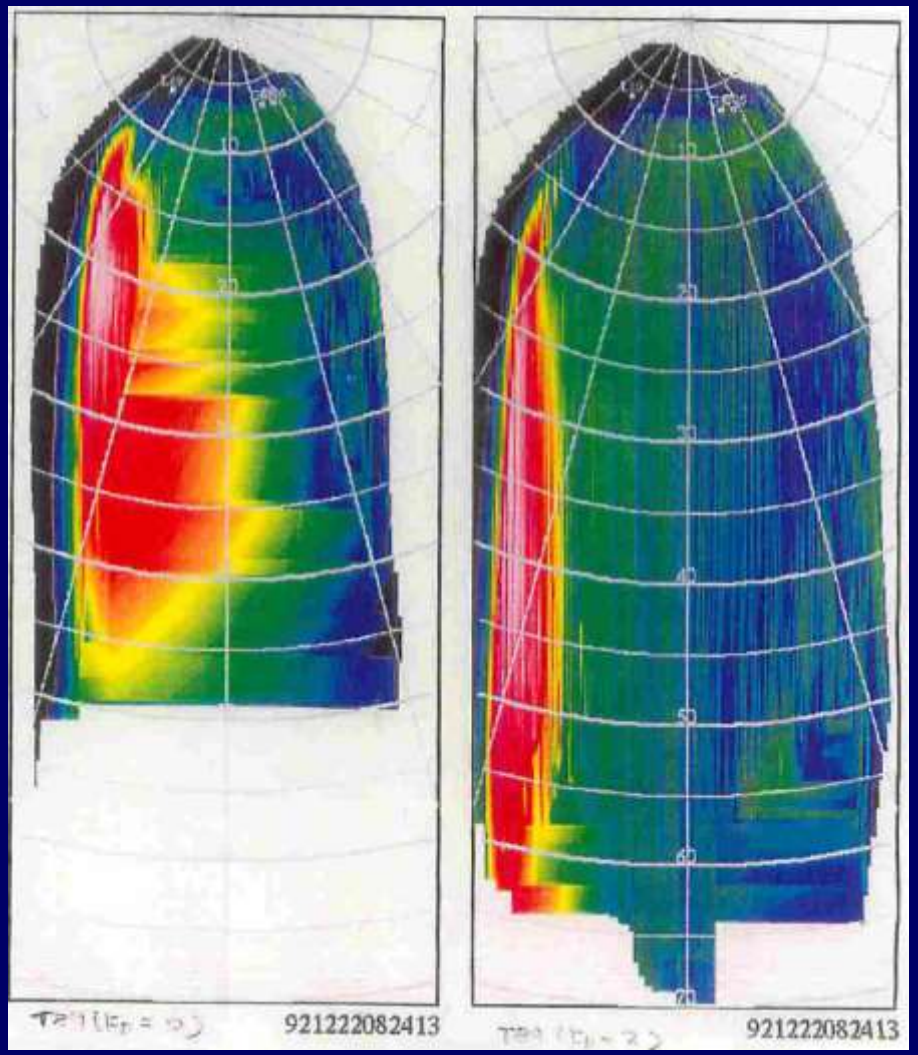






Plasma sheet projection

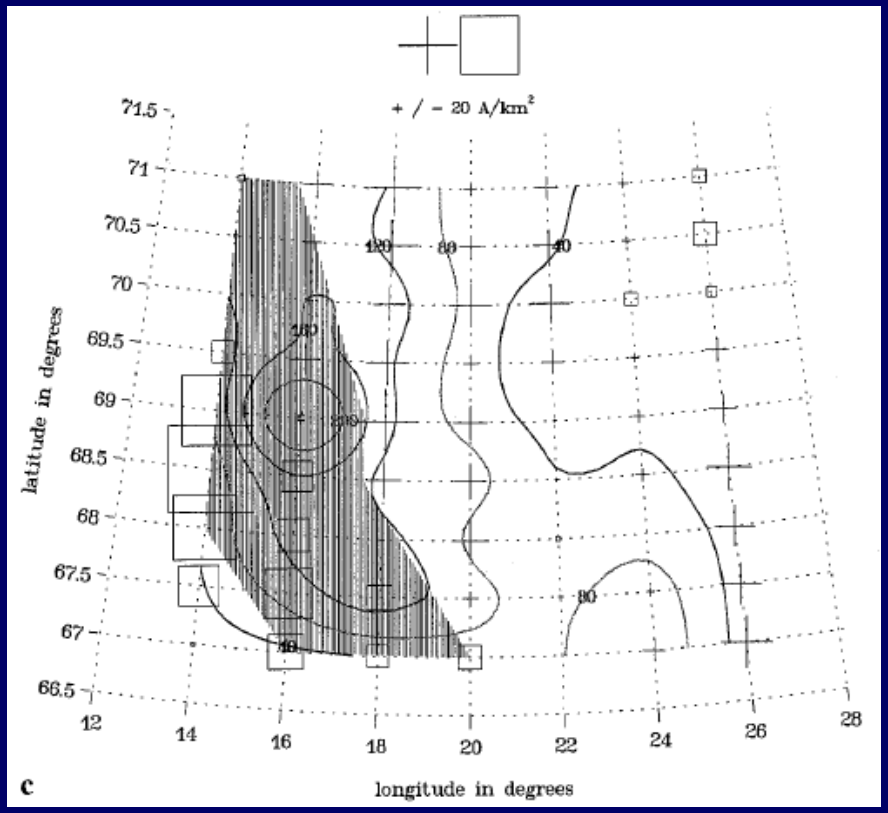




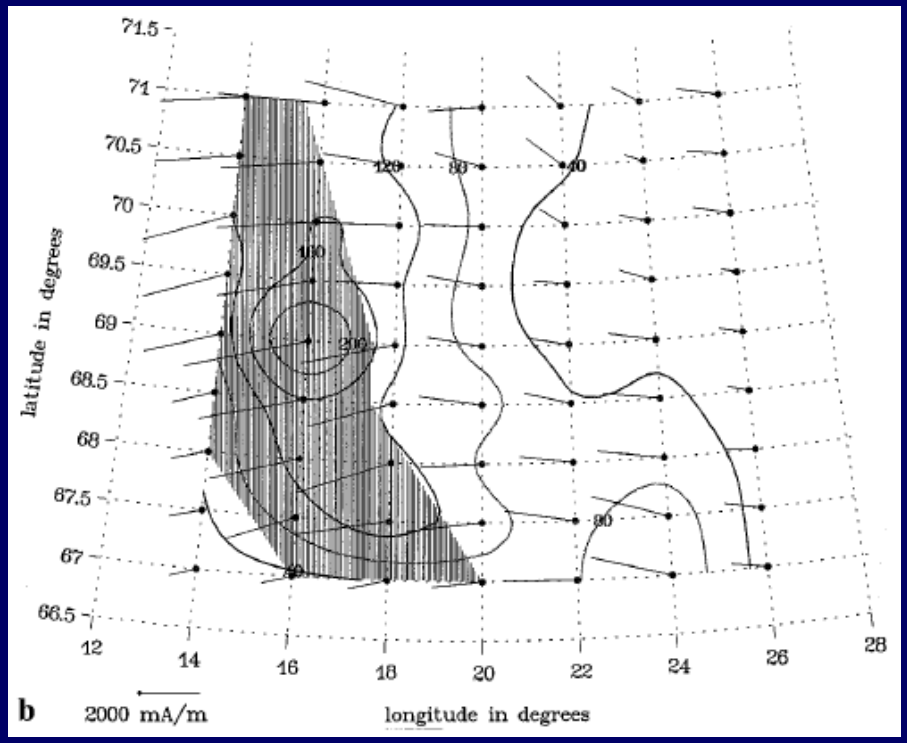
T89(Kp=0)

T89(Kp=2)

Aurora ≠ Intense upward Field-aligned current



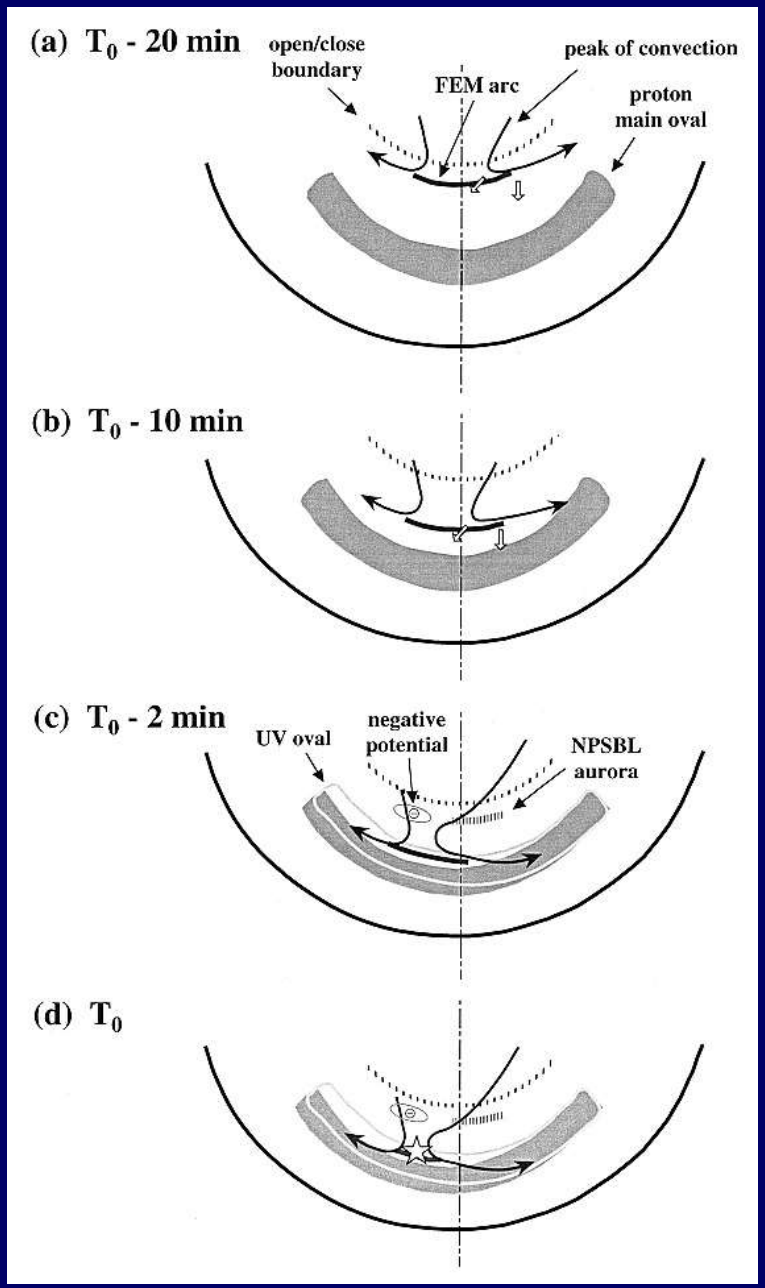
Field-aligned current

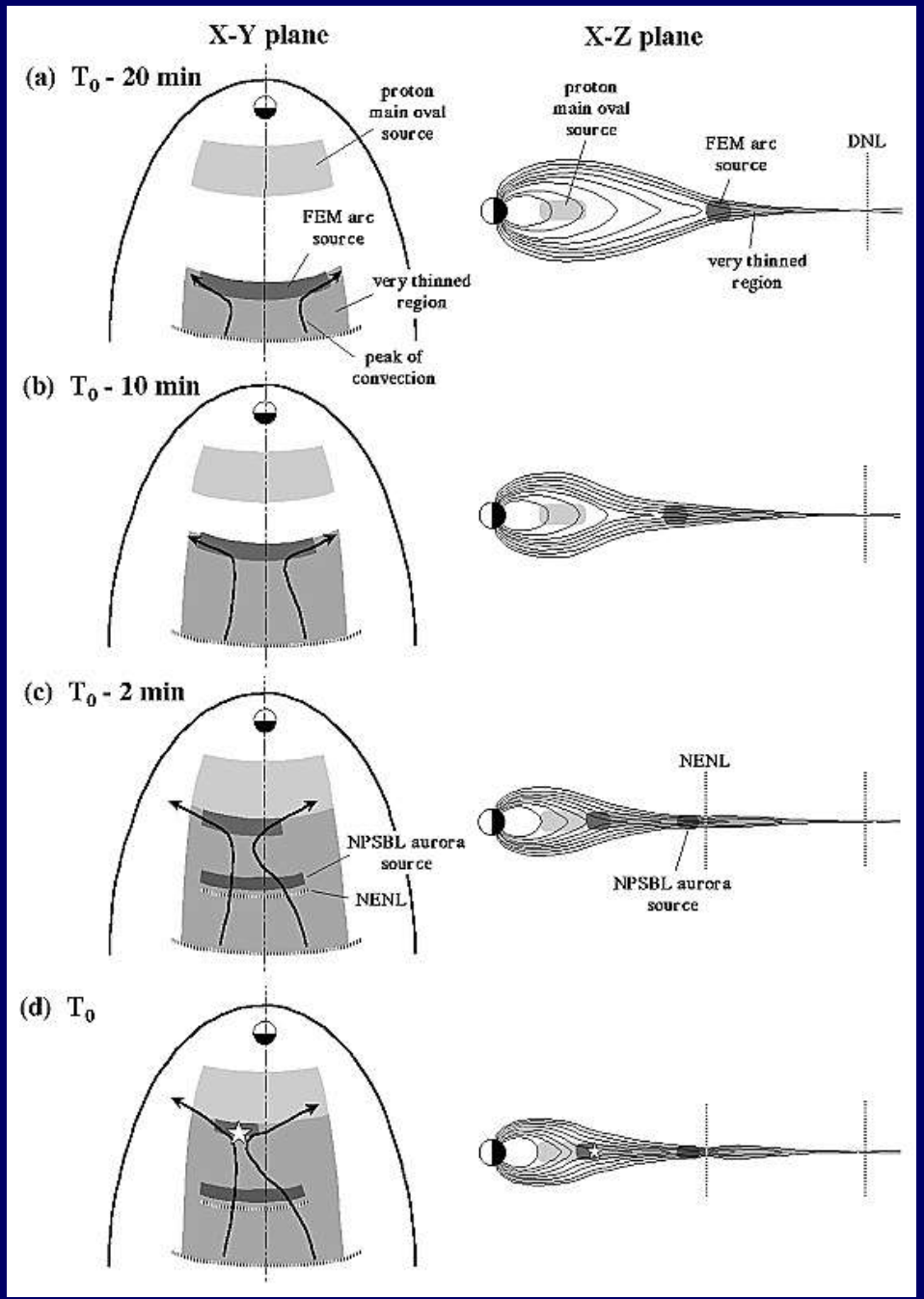


Ionospheric current

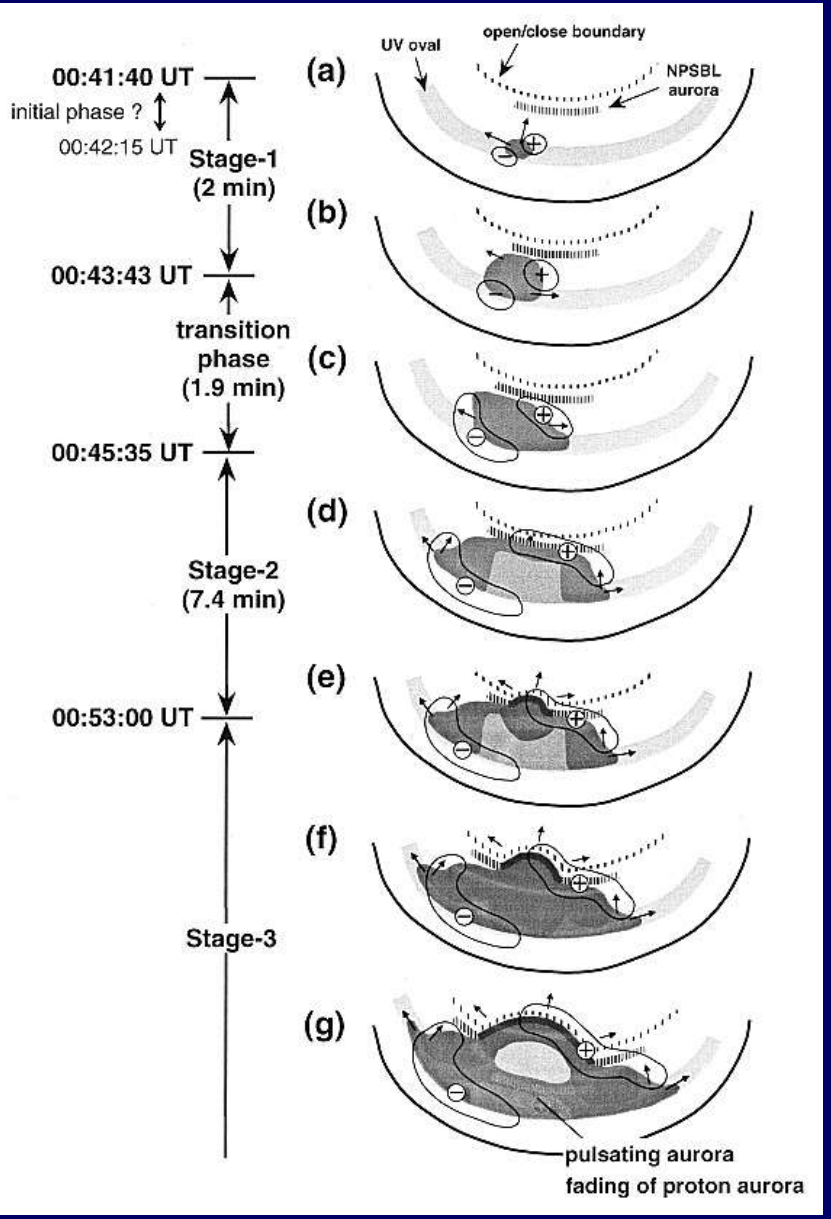
O. Amm et al. (Ann. Geophys., 17, 1385, 1999)

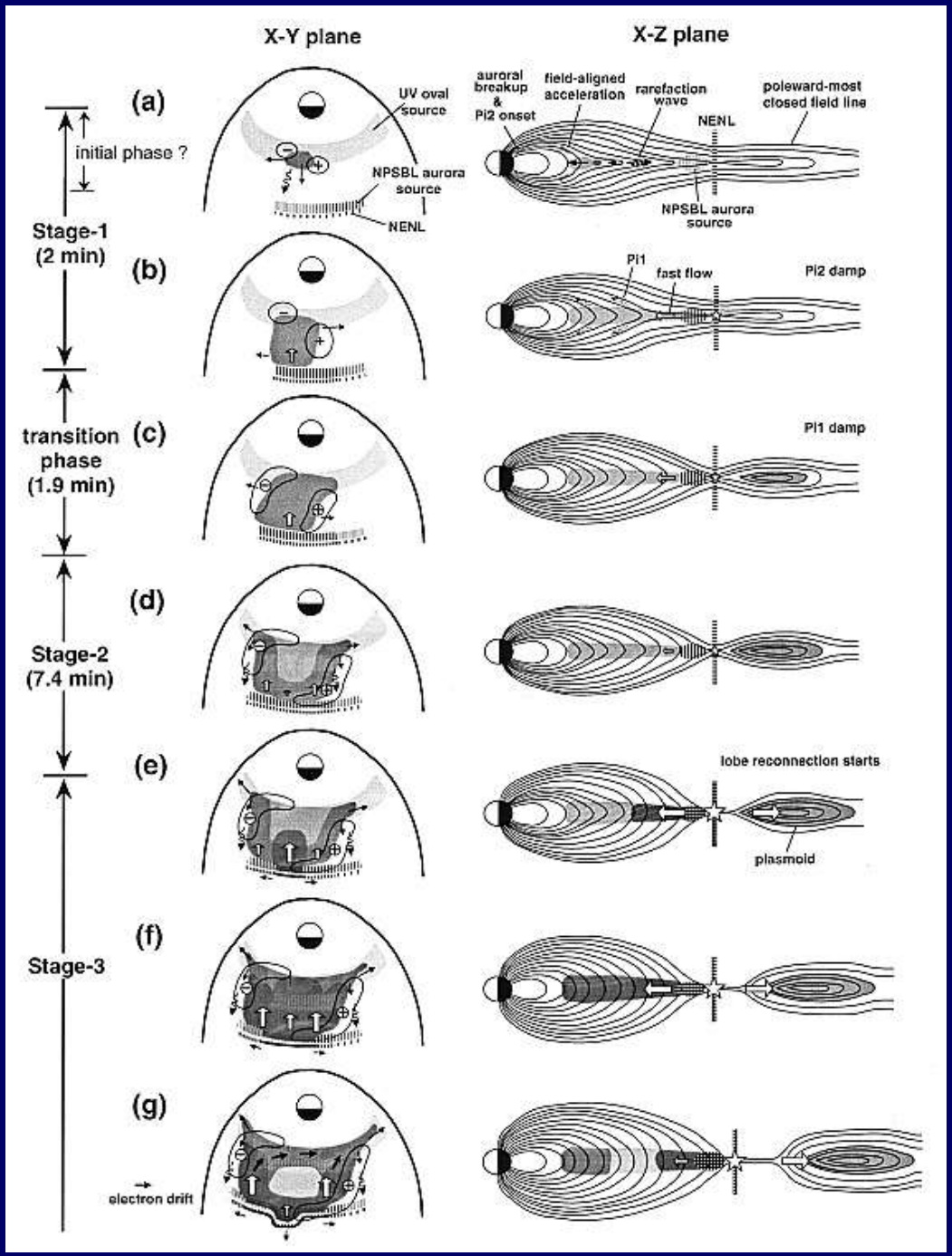
Growth Phase





Expansion Phase





オーロラサブストーム　～何が説明されるべきか

① Source mechanism of the onset arc, and its relationship with the onset mechanism

② Onset mechanism

③ Premidnight preference of the onset region

④ Localization of the onset region

⑤ Explosiveness of the onset phenomena

⑥ Causal relationship between the various onset signatures:

NENL formation, CD, dipolarization, injection, Pi2, Pi1B, SCW, DP1 current system, and the auroral brightening

⑦ Causal relationship between the phenomena during the expansion phase and the recovery phase:

NENL activity, CD, dipolarization, injection, Pi2, Pi1, SCW, DP1 current system, and the auroral bulge evolution, N-S aurora, Pulsating aurora