IUGONET
超高層大気長期変動の全球地上ネットワーク観測・研究
Inter-university Upper atmosphere Global Observation NETwork
Metadata DB for Upper Atmosphere

SPEDASを用いた オメガバンドオーロラとPs6地磁気脈動の解析

佐藤夏雄（極地研）、門倉昭（極地研）、田中良昌（極地研）、堀智昭（STE研）、行松彰（極地研）

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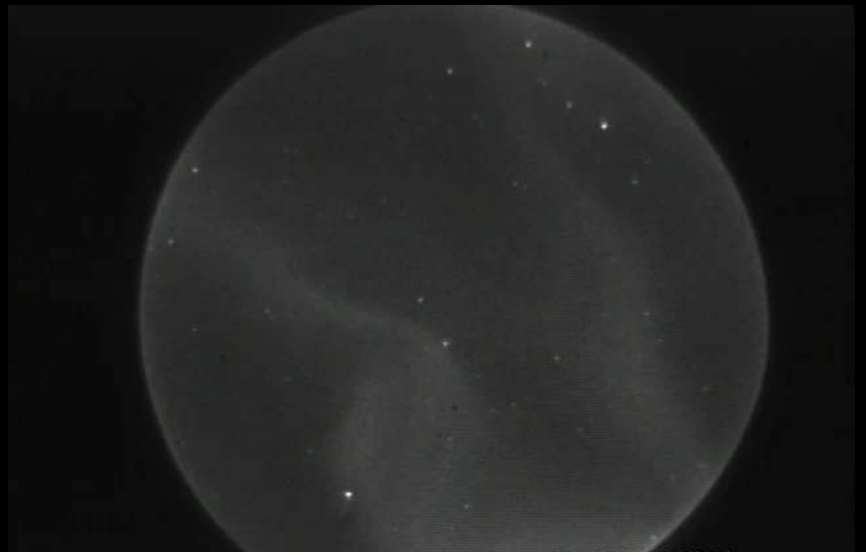
Pulsating Auroras (PsA): Brief review

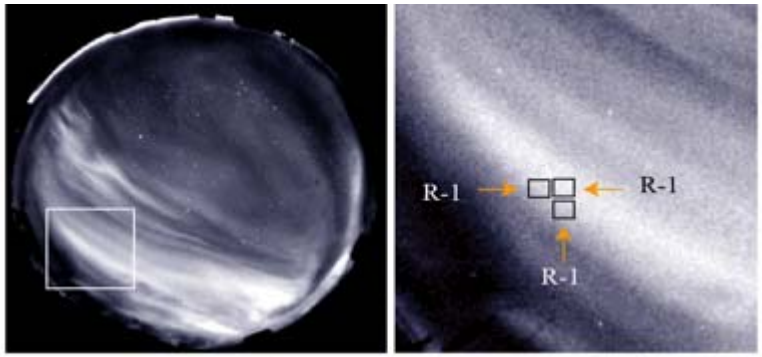
- PsA are observed universally during the recovery phase of substorms in the auroral and sub-auroral zones.
- Activities are more prominent in the postmidnight to morning side.
- Main period is ranges from a few seconds to a few tens of second.
- Higher frequency internal modulations of ~3 Hz or faster are often
- Shapes are irregular patches, E-W bands, omega-band structure.
- Energies of modulated electron fluxes are a few keV to 100 keV

Mechanism is still Open discussion

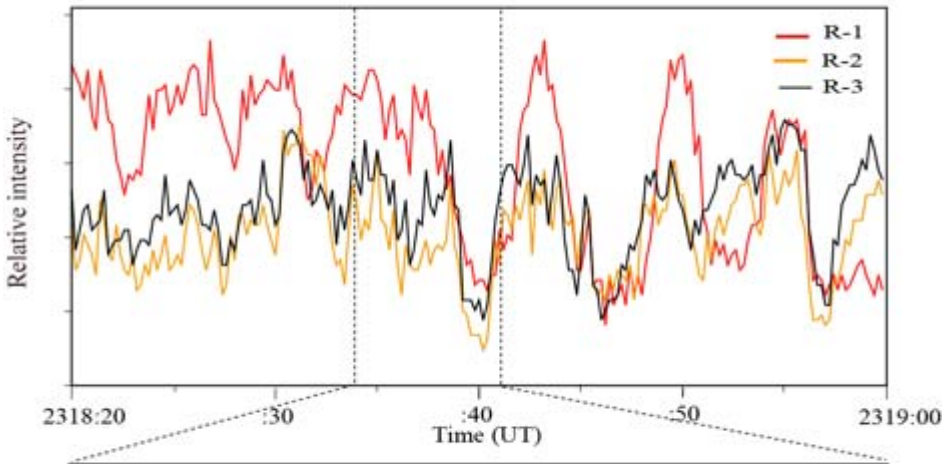


Example of Pulsating Auroras observed at Syowa TV

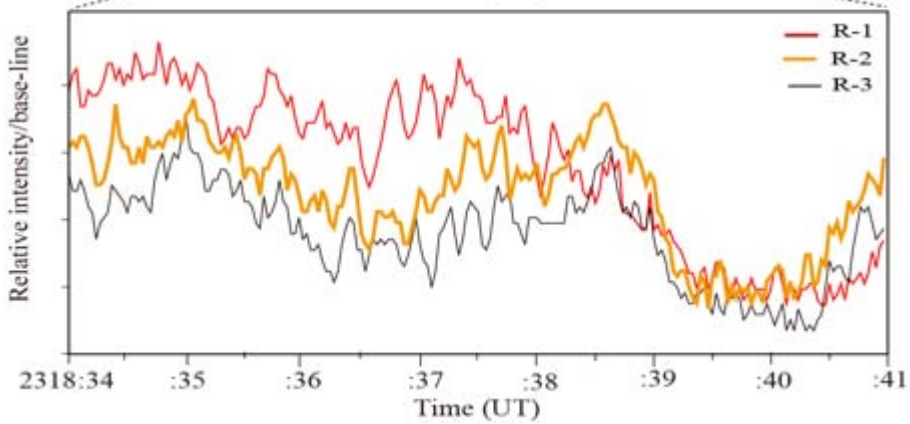
All-sky TV camera



~6 sec main period modulation



~3Hz higher frequency internal modulation



Pulsating Auroras (PsA): Open Questions

Questions

Fundamental characteristics

☆ON-OFF modulation（tens of second and a few Hz）

☆ Formation of shapes（Patch, E-W band, Omega band）

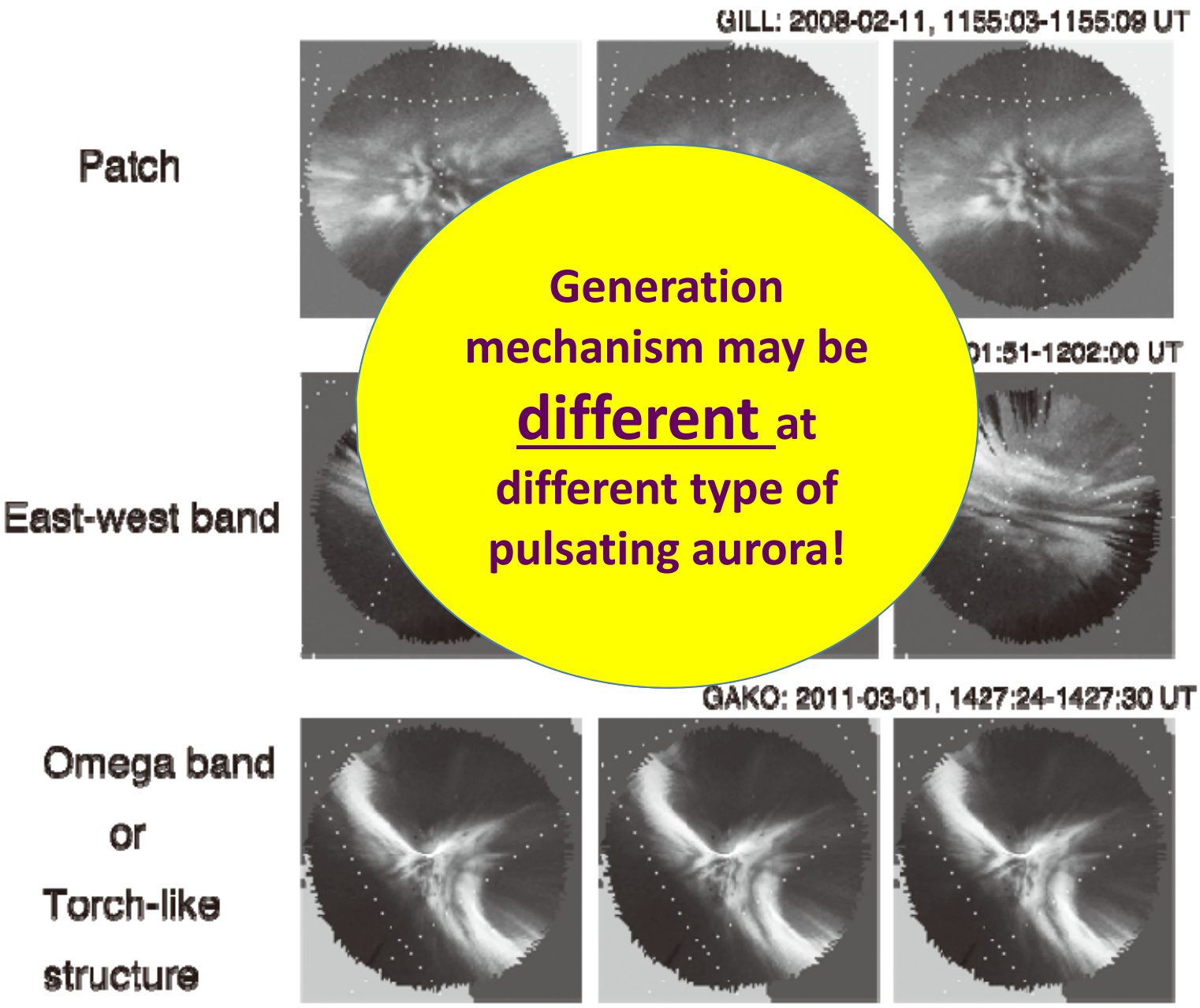
☆ Movement（Standing, Poleward movement）

Generation Mechanism?

☆Pitch-angle scattering via wave-particle interaction *(Standard model)*

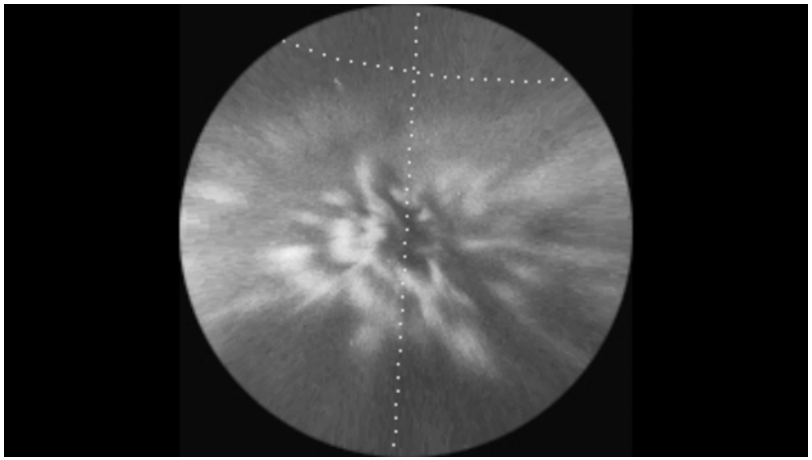
☆DC electric field modulation? *(Sato et al., 2004)*

Type/Classification of PsA

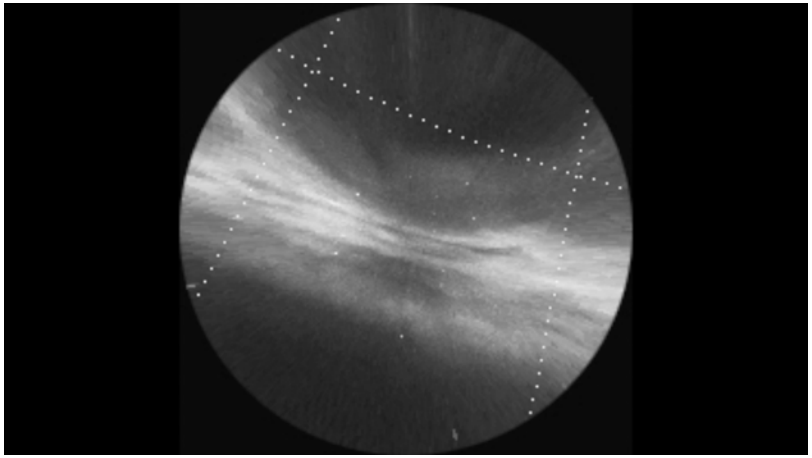


Generation mechanism may be <u>different</u> at different type of pulsating aurora!

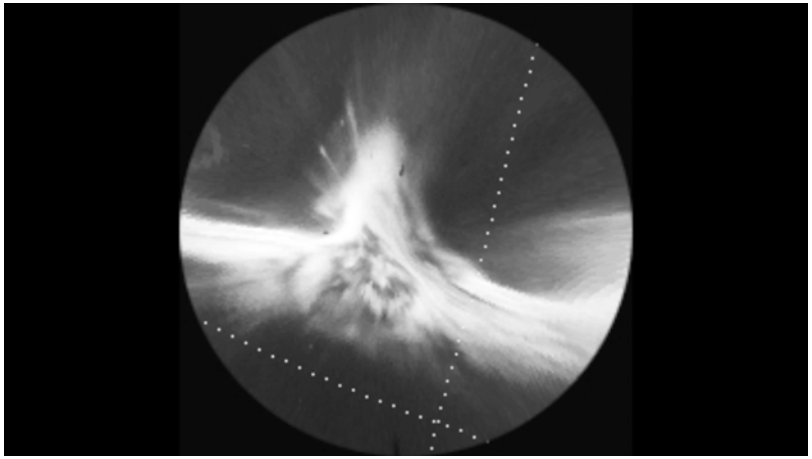
Patch



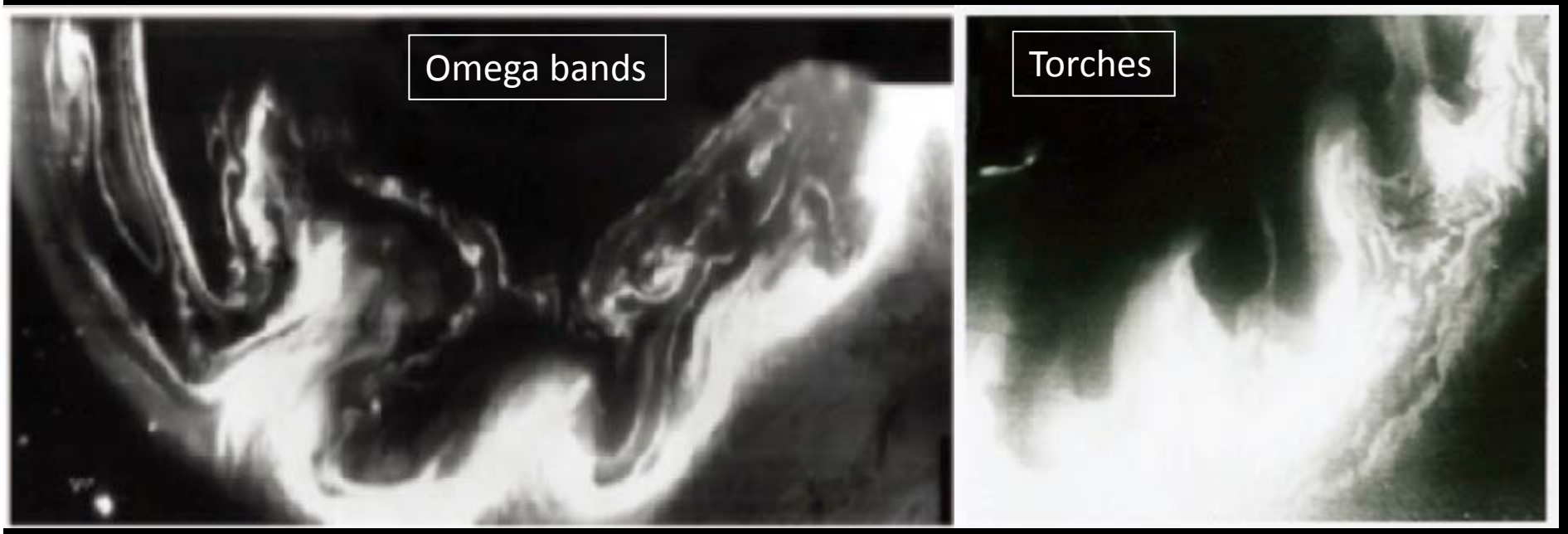
E-W band



Omega band
or
Torch-like structure



Omega bands/Torch-like structure



from DMSP spacecraft

Brief review of Omega bands/Torches

Observation signature

- Shapes are which resembles an inverted Greek letter Ω.
- Scale sizes are 400-1000 km
- Occurrence local time is midnight to early morning
- Substorm recovery phase
- Eastward drift with speed of 0.2-4 km/sec
- Psc6 magnetic pulsation with period of 5-40 min
- Fine structure consists with Pulsating aurora

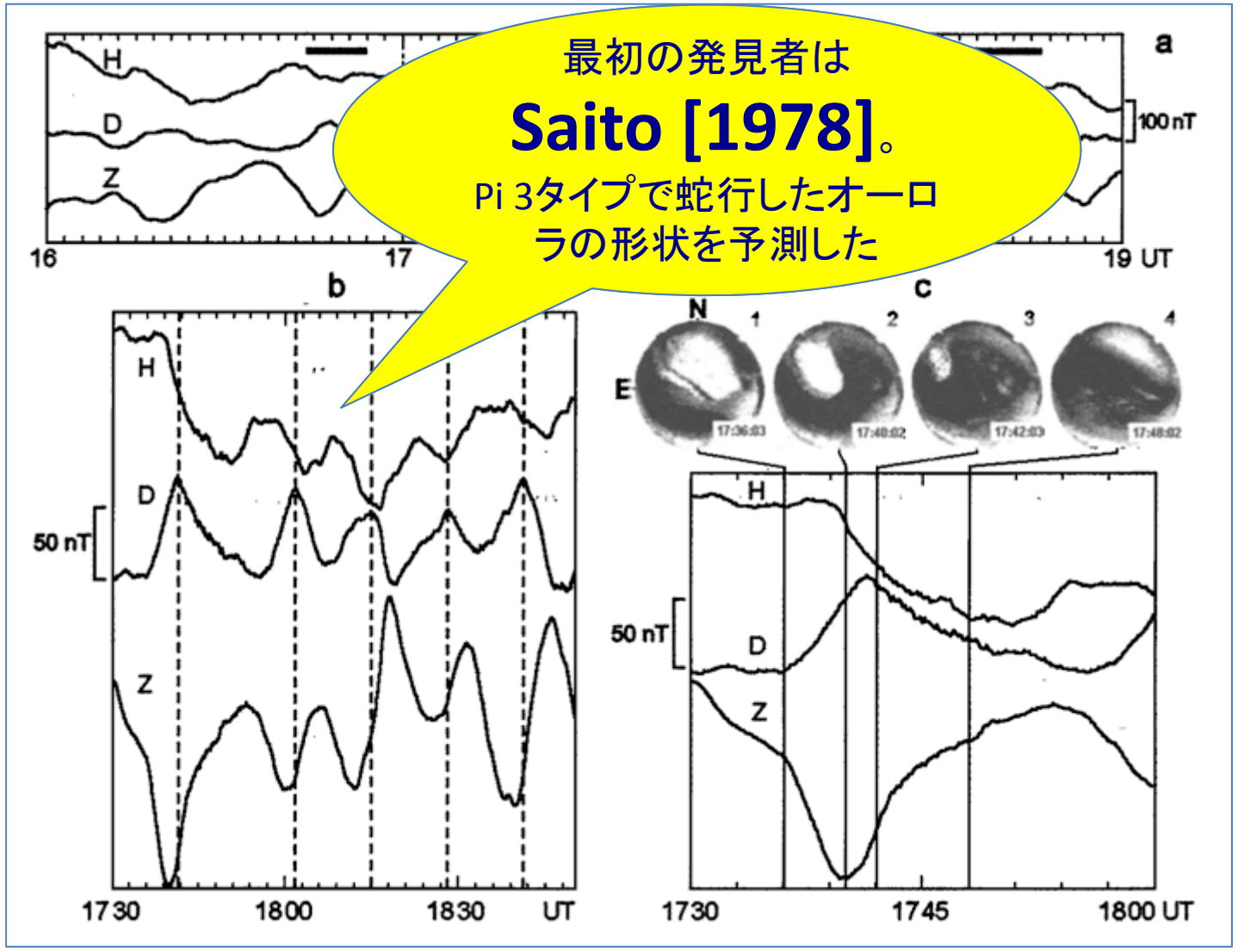
Generation mechanism (?)

There is no commonly accepted understandings of the formation mechanism of omega band aurora

1. KH instability (Rostoker and Samson:1984)
2. Rayleigh-Taylor (Interchange) instability (Yamamoto:1997)
3. M-I coupling instability (Lyatsky and Maltsev: 1984)
4. Field-aligned electric field (Jorgensen etal. :1999)

Omega band aurora and Ps6 magnetic pulsation

Solovyev et al., 1999.JGR



Brief review of Omega bands/Torches

Observation signature

- Shapes are which resembles an inverted Greek letter Ω.
- Scale sizes are 400-1000 km
- Occurrence local time is midnight to early morning
- Substorm recovery phase
- Eastward drift with speed of 0.2-4 km/sec
-Retaining their shapes for several minutes
-Psc6 magnetic pulsation with period of 5-40 min
- Fine structure consists with Pulsating aurora

Generation mechanism (?)

There is no commonly accepted understandings of the formation mechanism of omega band aurora

1. KH instability (Rostoker and Samson:1984)
2. Rayleigh-Taylor (Interchange) instability (Yamamoto:1997)
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4. Field-aligned electric field (Jorgensen etal. :1999)

2011.03.01
Omega band Pulsating Aurora
observed at Sanikiluaq (SNKQ) in Canada and THEMIS-D and E spacecraft

Sato et al., 2015. JGR

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Journal of Geophysical Research: Space Physics

RESEARCH ARTICLE

10.1002/2015JA021382

Special Section:
Pulsating Aurora and Related Magnetospheric Phenomena

Omega band pulsating auroras observed onboard THEMIS spacecraft and on the ground

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Key Points:
- Optical signature of omega band pulsating aurora
- Simultaneous observation at TH on the ground and onboard THEMIS satellites
- DC electric field showed the same as the pulsating aurora

Supporting Information:
- Text S1
- Movie S1
- Movie S2

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Citation:
Sato, N., A. Kadokura, Y. Tanaka, T. Nishiyama, T. Hori, and A. S. Yukimatu (2015), Omega band pulsating auroras observed onboard THEMIS spacecraft and on the ground, *J. Geophys. Res. Space Physics*, *120*, doi:10.1002/2015JA021382.

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Abstract We examined a fortuitous case of an omega band pulsating aurora observed simultaneously on the ground at Sanikiluaq in Canada and onboard the Time History of Events and Macroscale Interactions during Substorms (THEMIS) spacecraft on 1 March 2011. We observed almost the entire process of the generation of the omega band aurora from the initial growth to the declining through expansion period. The omega band aurora grew from a faint seed, not via distortion of a preexisting east-west band aurora. The size of the omega band aurora was ~100 km in the north-south direction and ~200 km in the east-west direction. The mesoscale omega band aurora consisted of more than 15 patches of small-scale auroras and contained an intense pulsating aurora with a recurrent period of ~9–12 s and a poleward moving form. The footprints of the THEMIS D and THEMIS E spacecraft crossed the poleward part of the omega band aurora. THEMIS D observed significant signatures in the electron flux of the loss cone particles at the time when the spacecraft crossed the omega band aurora. In particular, it was found that the *Y* and *Z* components of the DC electric field intensity, especially the *Z* component, modulated with almost the same period as that of the optical pulsating auroras. The electrostatic low frequency waves of less than 50 Hz showed quasiperiodic intensity variations similar to those of the DC electric field. These observations suggest that DC electric field variation and low-frequency electrostatic waves may play important roles in the driving mechanism of omega band pulsating auroras.

1. Introduction

Pulsating auroras are common phenomena that are observed universally during the recovery phase of substorms in the auroral and subauroral zones [*Akasofu*, 1968; *Oguti and Watanabe*, 1976]. Most of the known characteristics of pulsating auroras have been described by *Johnstone* [1983], *Davidson* [1990], *Nemzek et al.* [1995], and recently by *Lessard* [2012]. Here we briefly summarize the basic characteristics of pulsating auroras that may relate to this study. They exhibit typical periods of a few seconds to a few tens of seconds [*Johnstone*, 1978; *Yamamoto*, 1988]. Rapid ~3 Hz or faster modulations are often observed in the pulsation structure [*Royrvik and Davis*, 1977; *Sandahl et al.*, 1980; *Winckler and Nemzek*, 1993; *Sato et al.*, 2004; *Kataoka et al.*, 2012; *Nishiyama et al.*, 2012, 2014].

Rocket measurements have demonstrated that modulated electron fluxes from as low as a few keV to 100 keV are responsible for these phenomena [e.g., *Sandahl et al.*, 1980; *McEwen et al.*, 1981]. Recently, spacecraft measurements by GOES 13, which is located near the equatorial plane in the magnetosphere, demonstrated that modulations were more prominent in the 30–50 keV channel but were also observed in the 50–100 keV channel [*Jaynes et al.*, 2013].

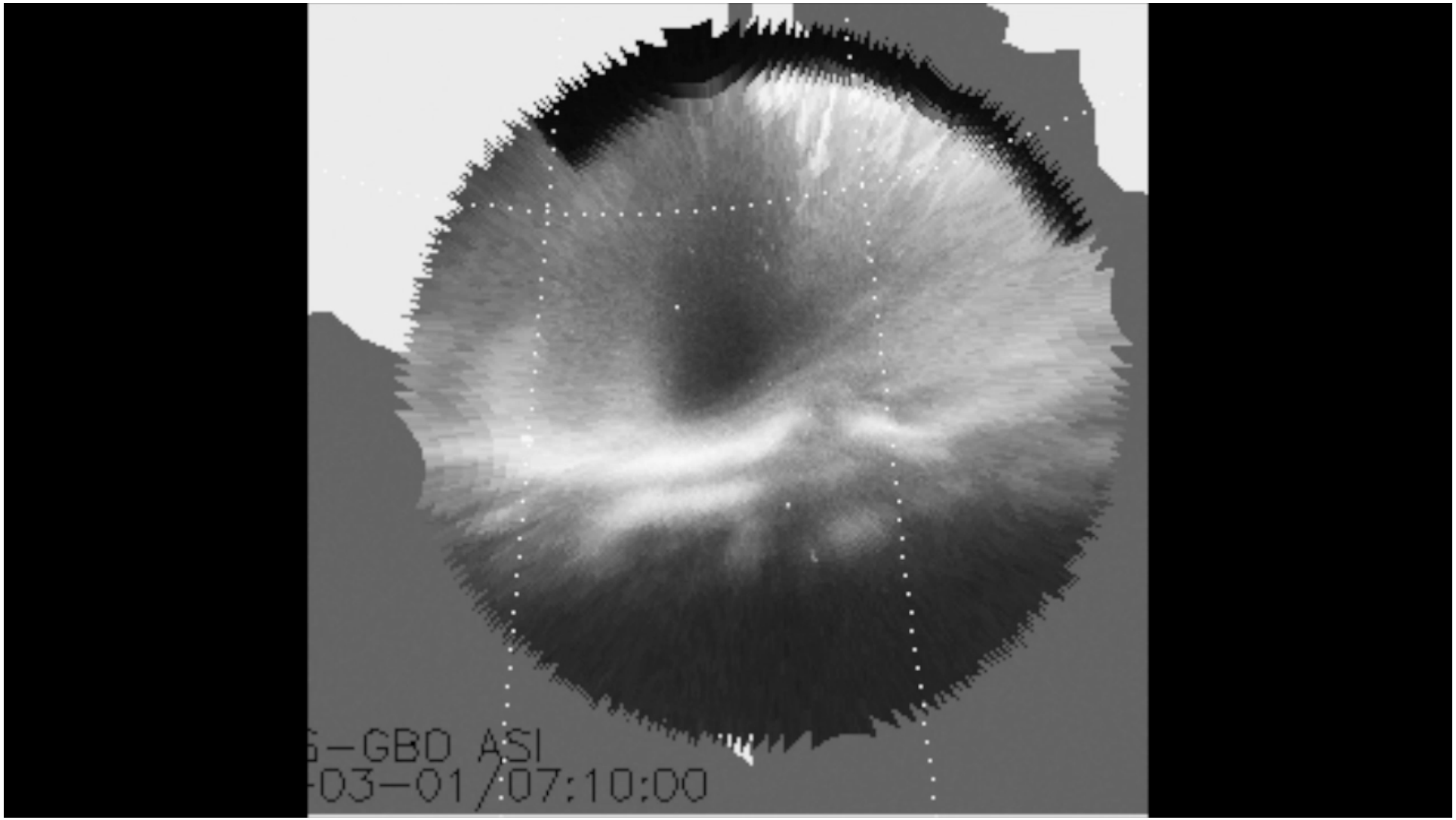
2015_JGR special issue on "Pulsating Aurora and Related Magnetospheric Phenomena"

"Omega band pulsating auroras observed onboard THEMIS spacecraft and on the ground"

by Natsuo Sato, Akira Kadokura, Yoshimasa Tanaka, Takanori Nishiyama, Tomoaki Hori, Sessai A. Yukimatu

NiPR National Institute of Polar Research

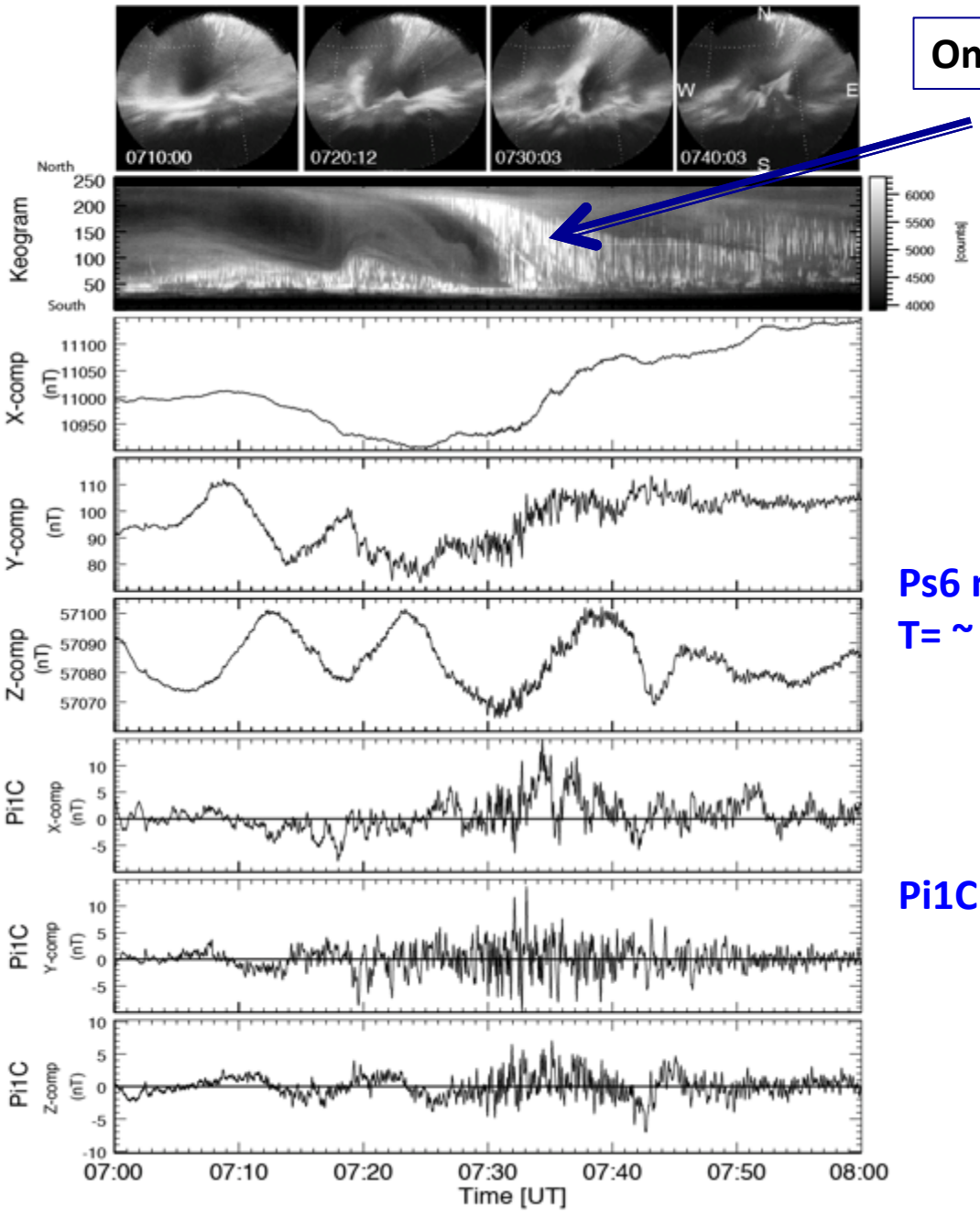
Movie: Life cycle of Omega band aurora



Signatures of Omega band aurora on the ground

All-sky image

Keogram



Omega band aurora

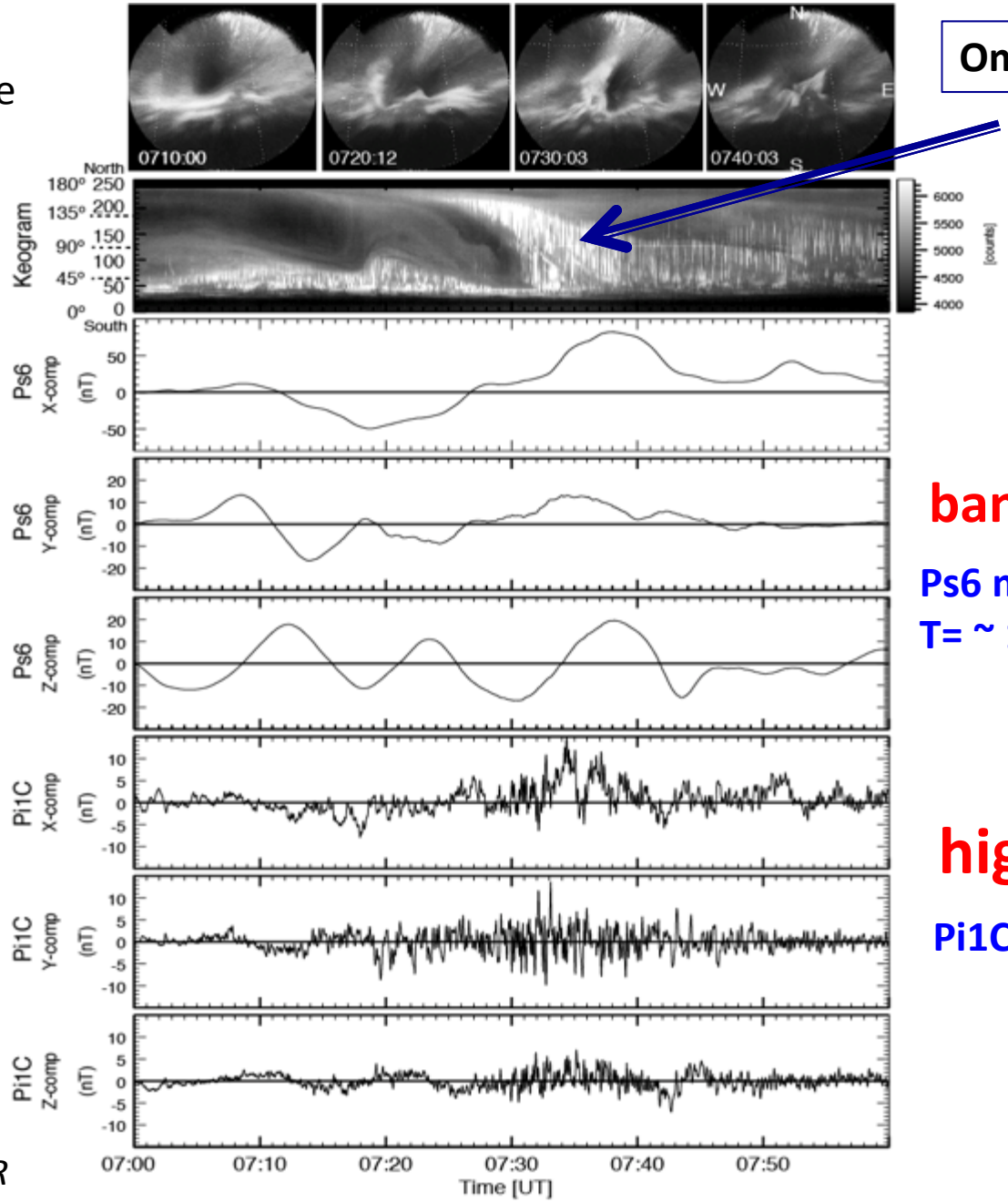
Ps6 magnetic pulsations
T= ~ 10-20 min

Pi1C magnetic pulsations

Signatures of Omega band aurora on the ground

All-sky image

Keogram



Omega band aurora

band-pass filter

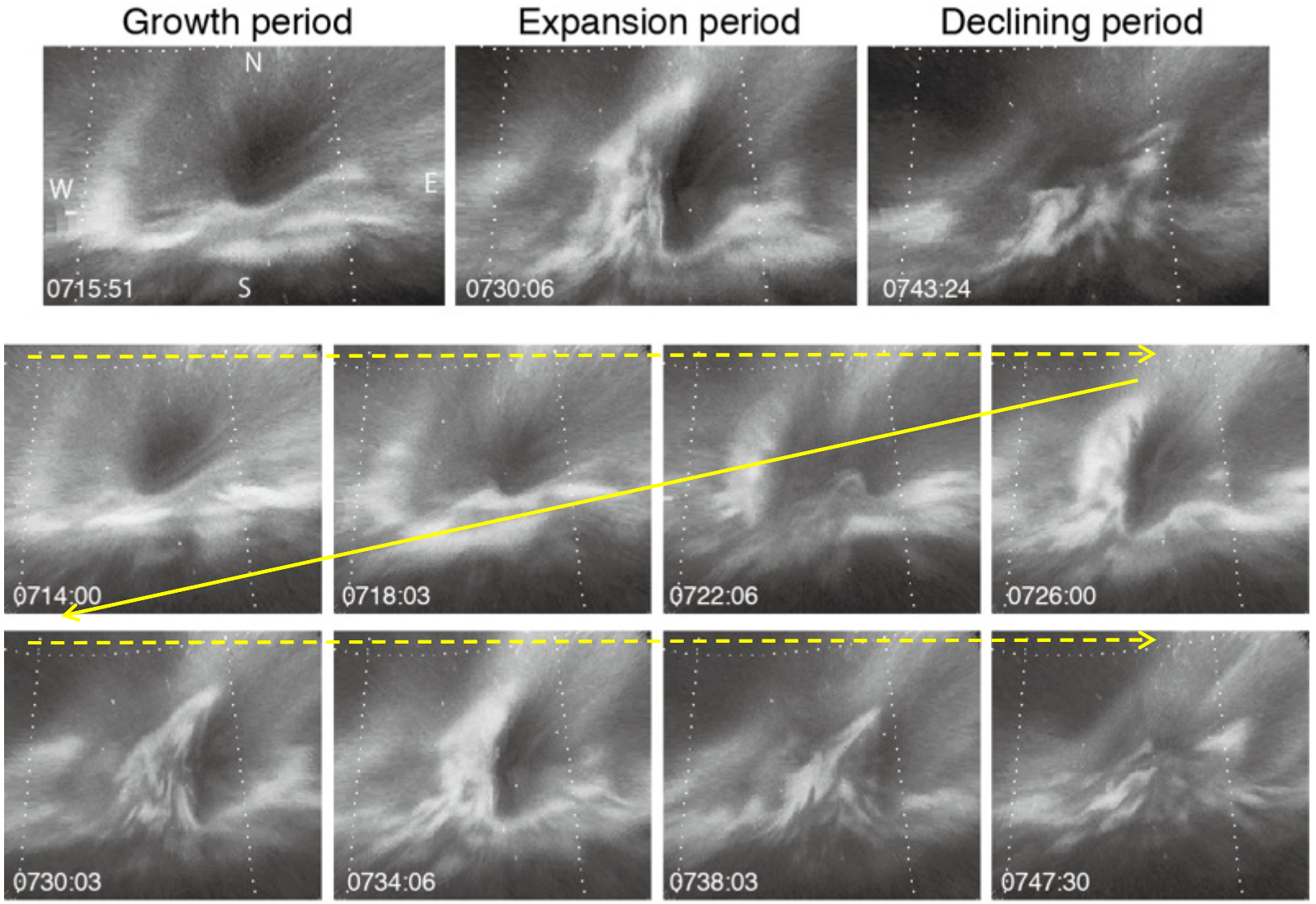
Ps6 magnetic pulsations
T= ~ 10-20 min

high-pass filter

Pi1C magnetic pulsations

Sato et al., 2015. JGR

Life cycle of Omega band aurora

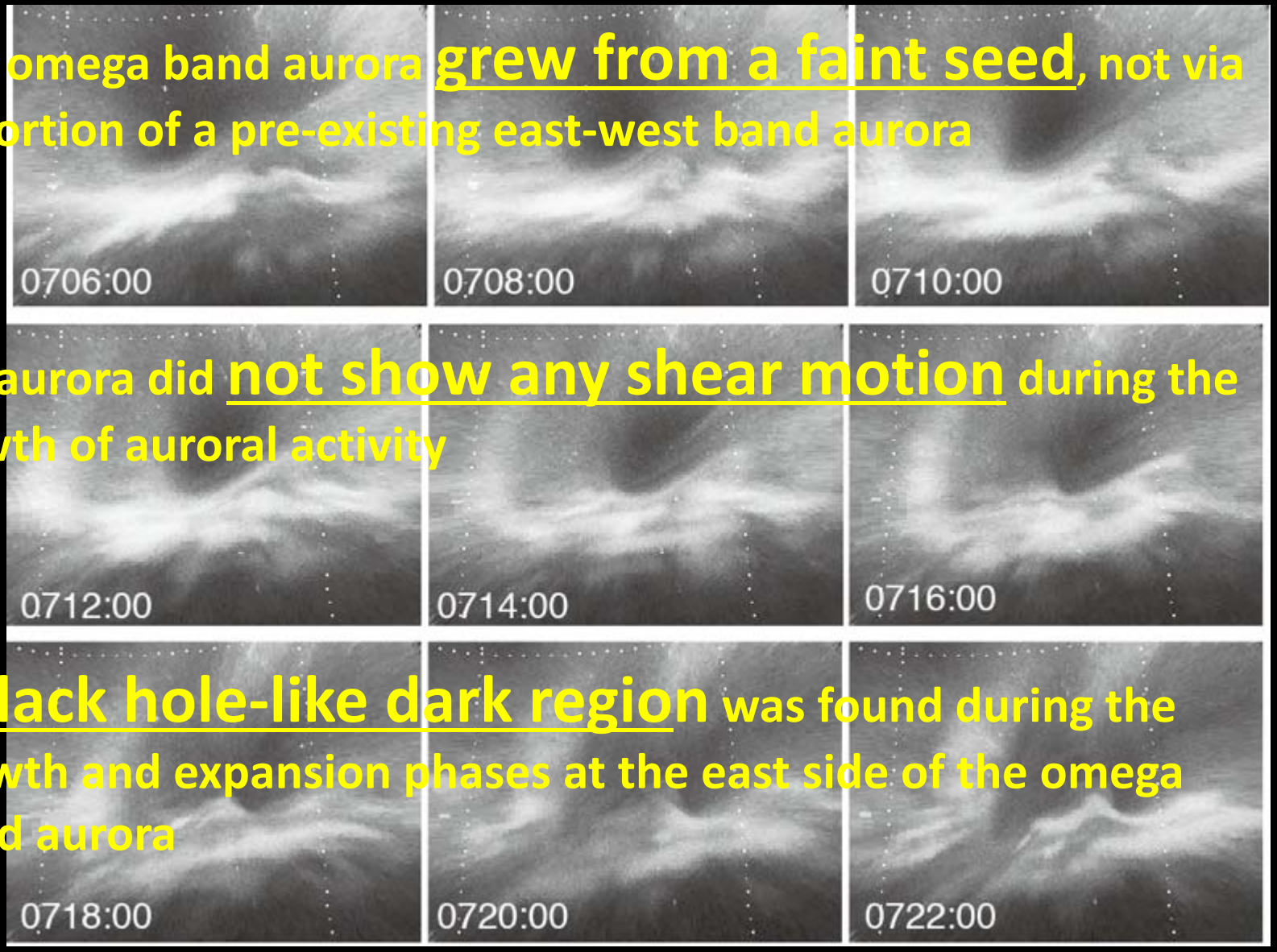


Growth of Omega band PsA

The omega band aurora **grew from a faint seed**, not via distortion of a pre-existing east-west band aurora

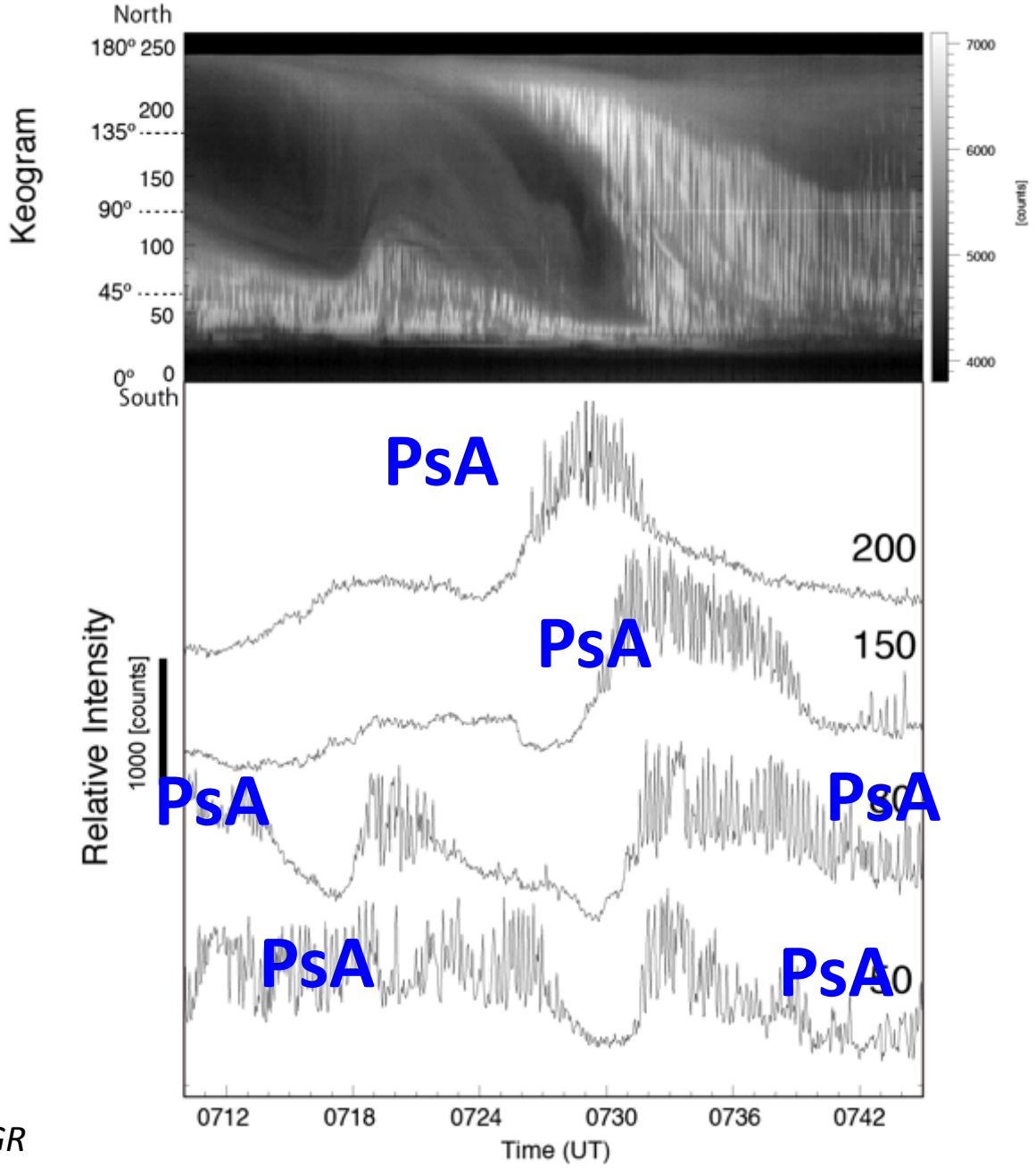
The aurora did **not show any shear motion** during the growth of auroral activity

A **black hole-like dark region** was found during the growth and expansion phases at the east side of the omega band aurora



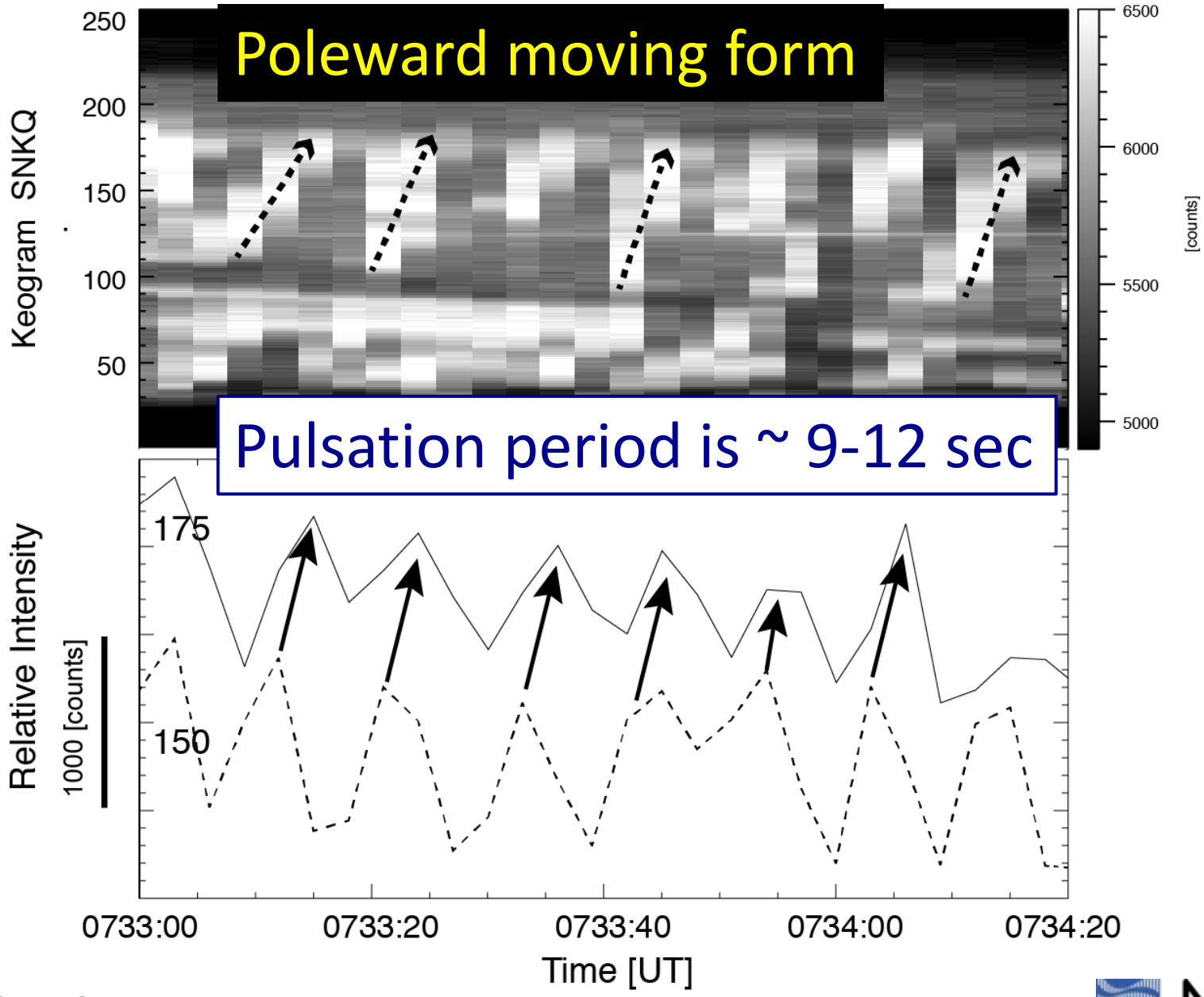
Sato et al., 2015. JGR

Omega band Pulsating Auroras



Sato et al., 2015. JGR

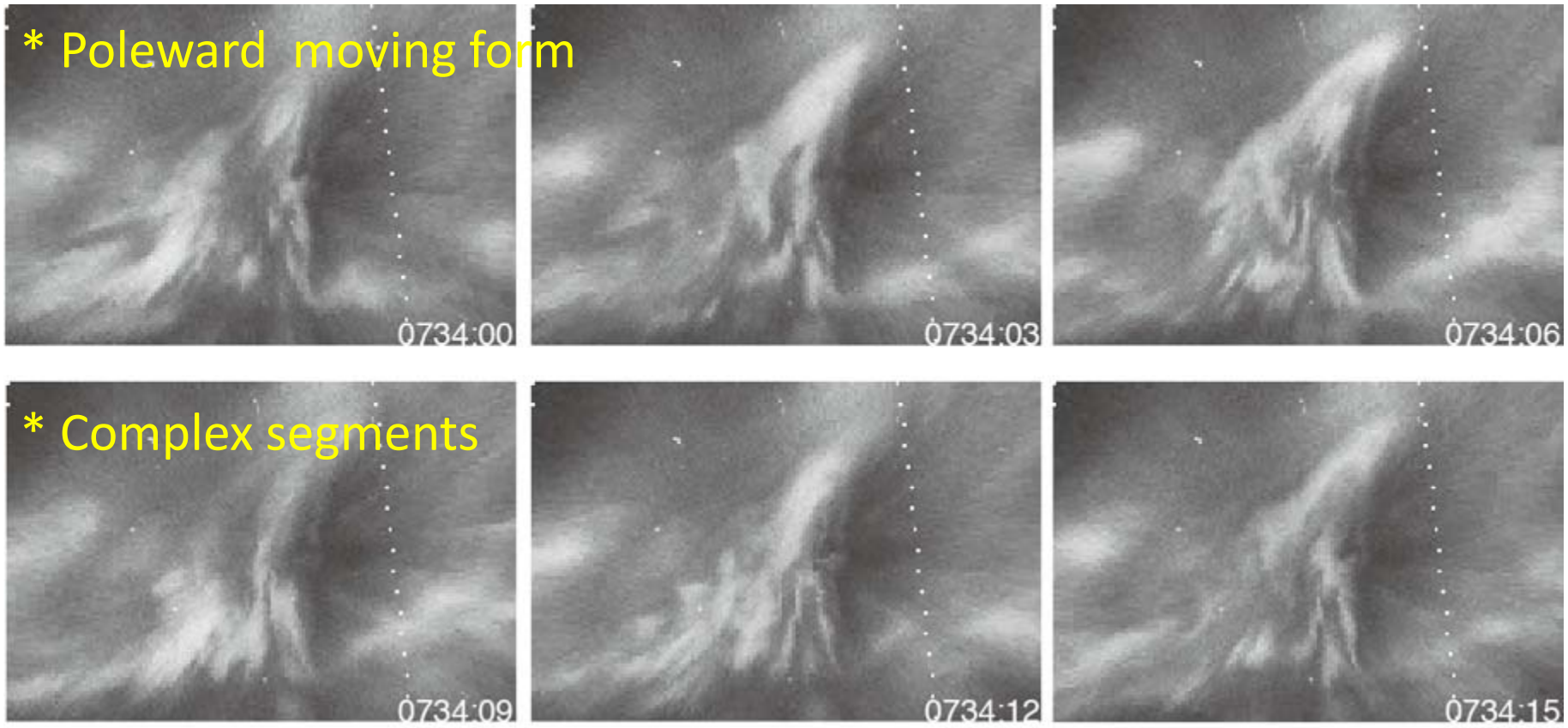
Omega band Pulsating Auroras



Sato et al., 2015. JGR

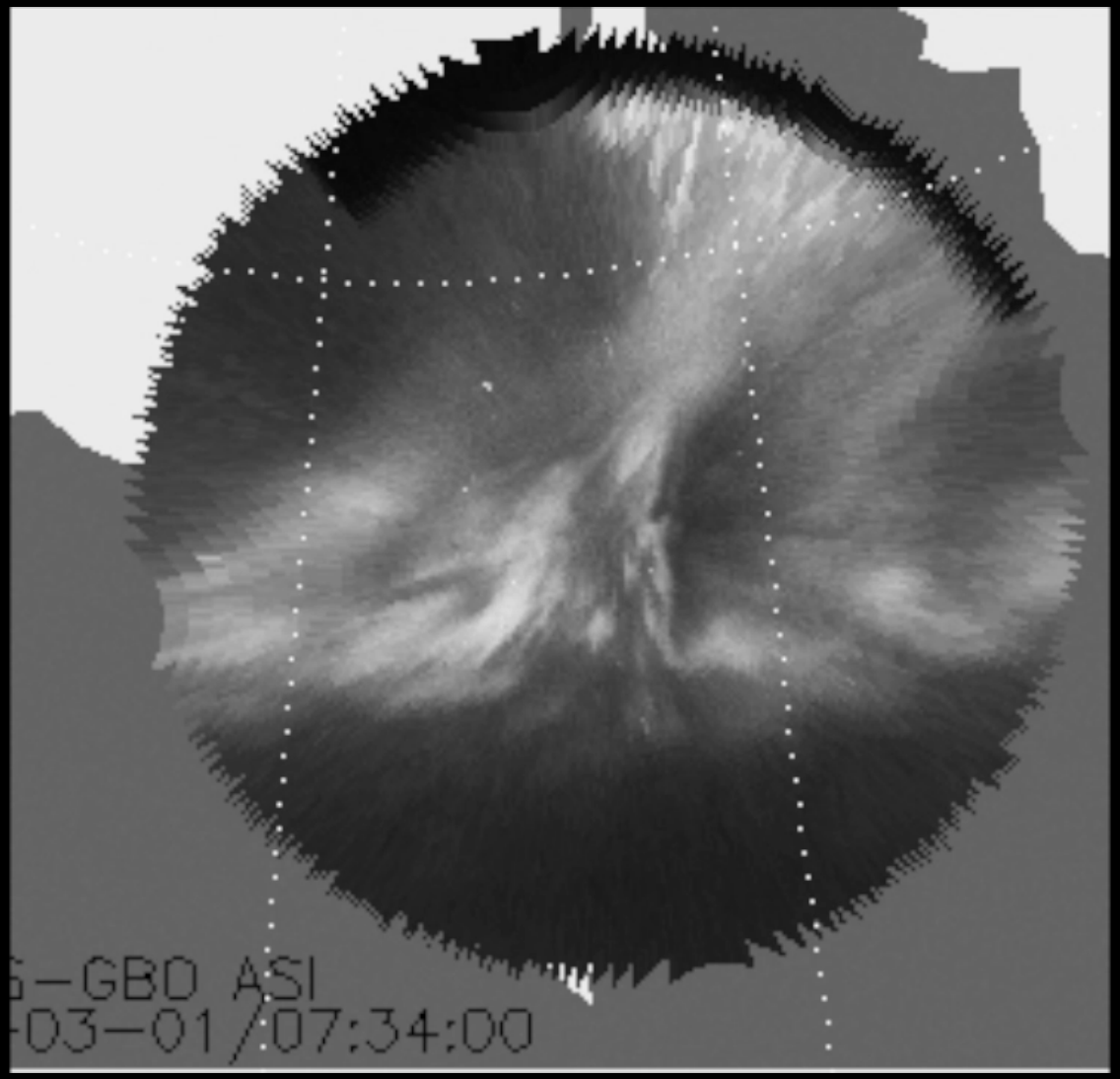
Expansion/Maximum period of Omega band aurora

every 3 second data

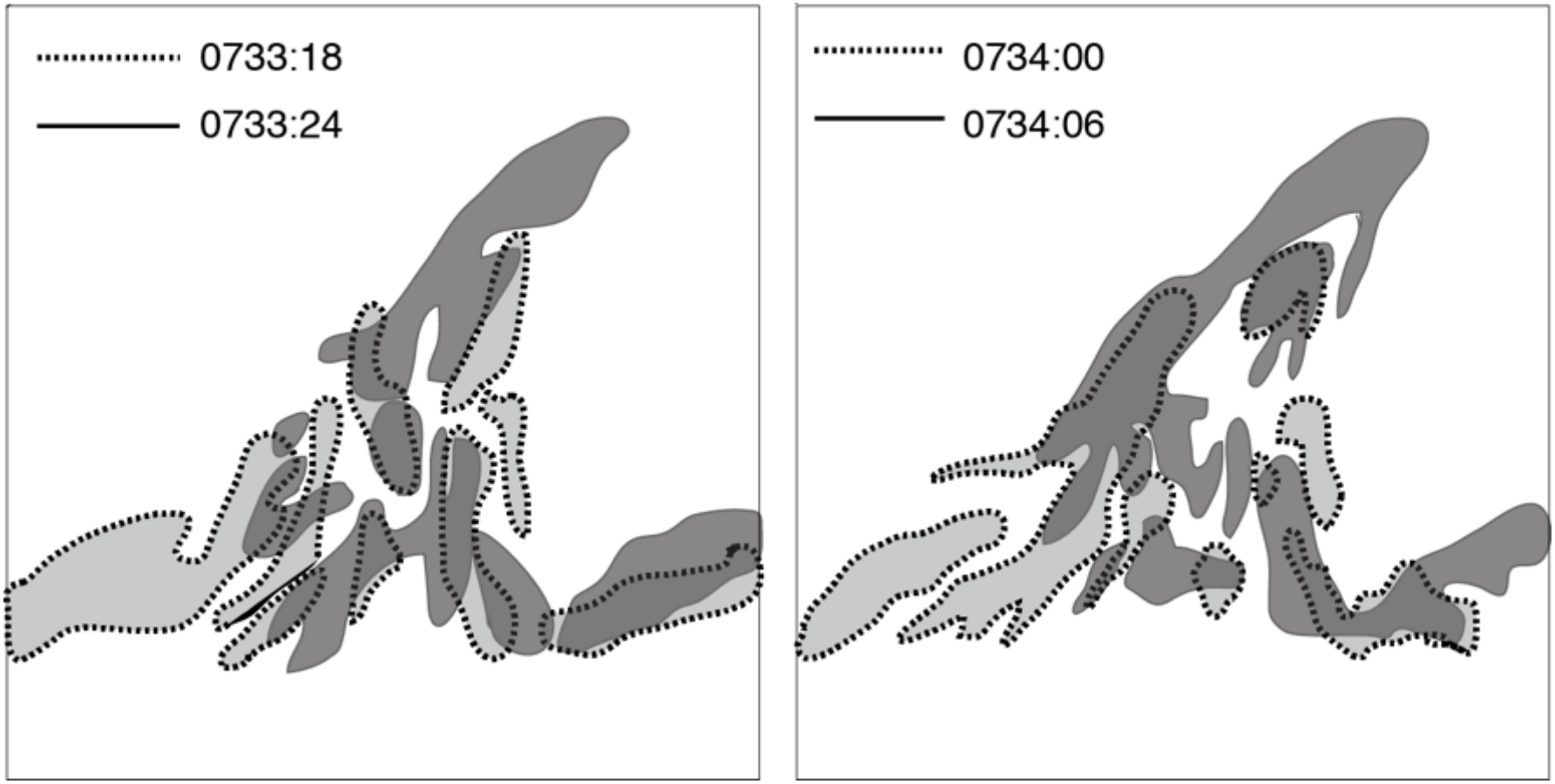


Sato et al., 2015. JGR

Movie: Expansion/Maximum period of Omega band Pulsating Aurora



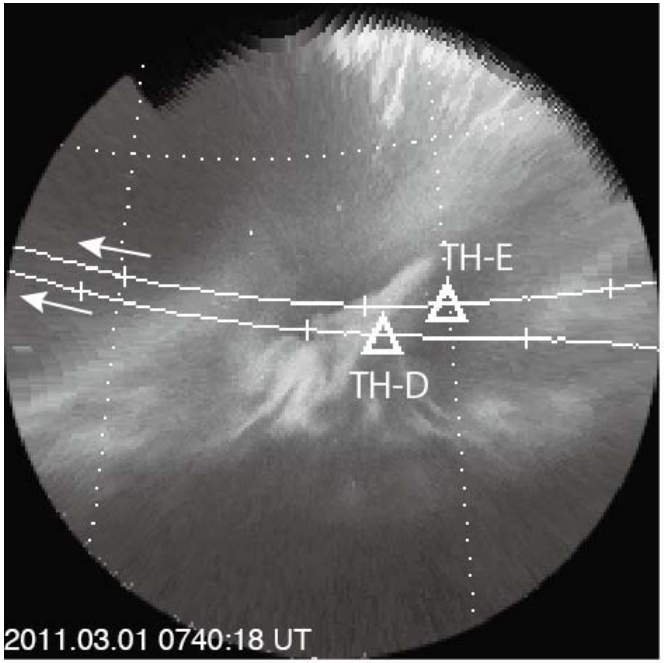
Expansion/Maximum period of Omega band Pulsating Aurora



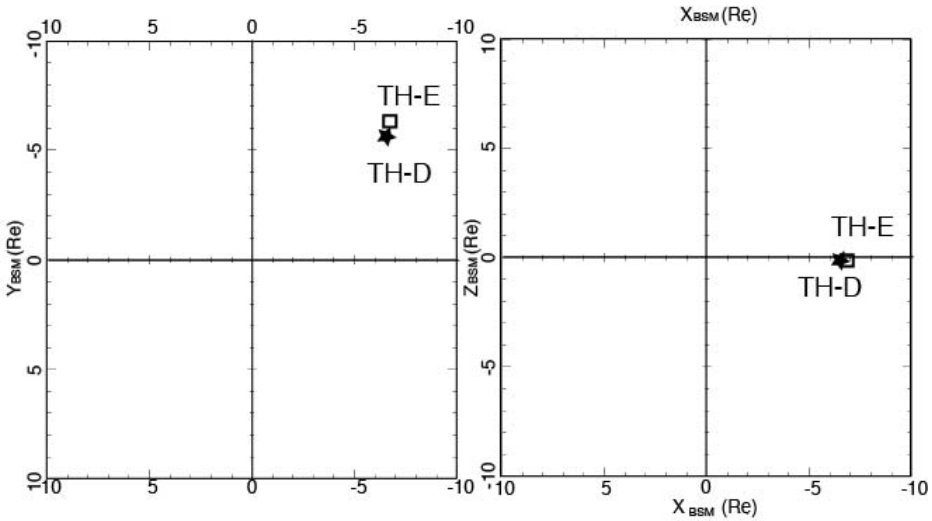
Sato et al., 2015. JGR

THEMIS satellite observation of Omega band aurora

footprint



orbit



T96 model using following parameters: Dst, solar wind pressure, IMF, By, and Bz were +20.0 nT, 7.0 nPa, 2.0 nT, and 7.5 nT.

Sato et al., 2015. JGR

THEMIS-D and E satellite observation

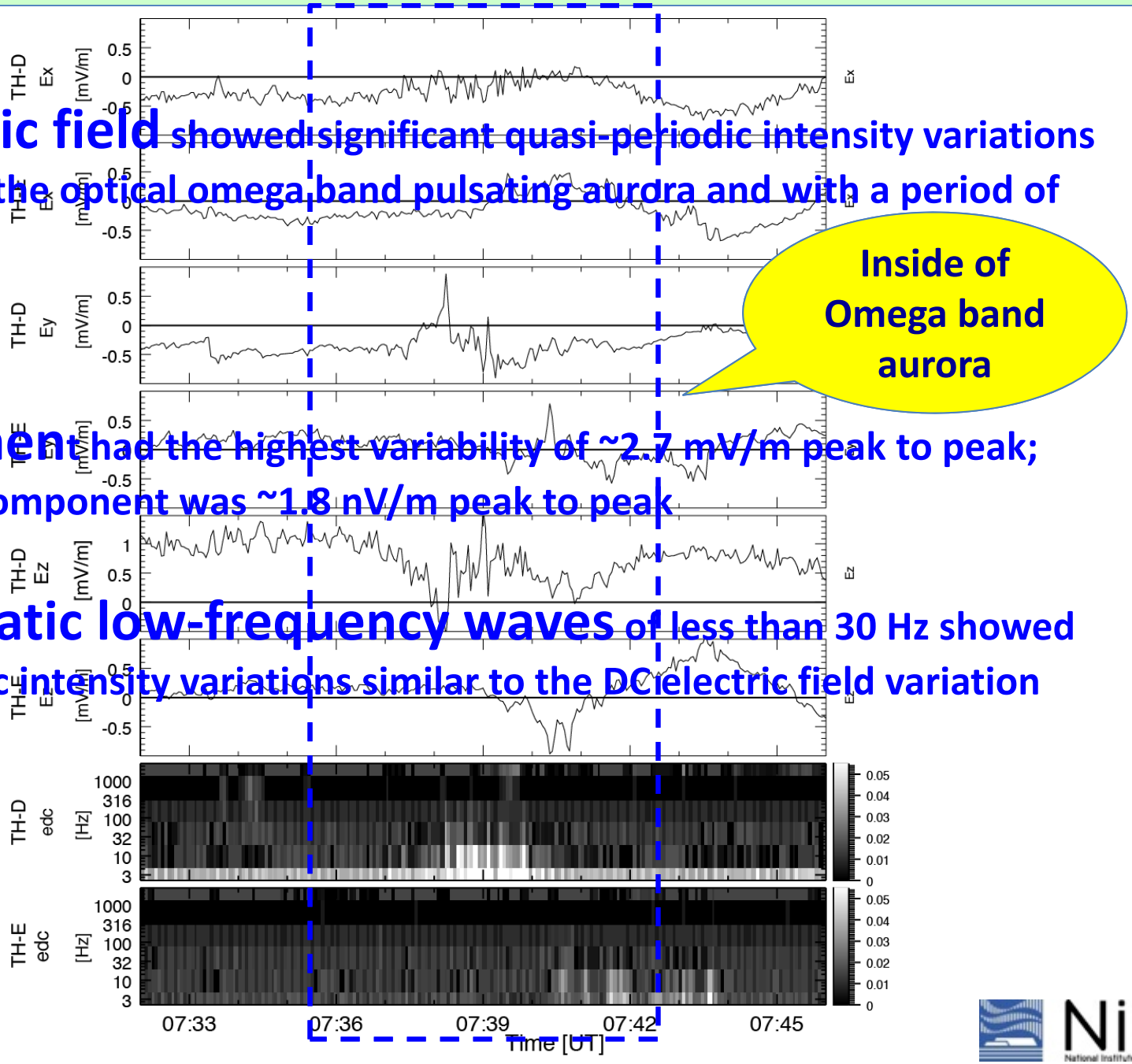
* **DC electric field** showed significant quasi-periodic intensity variations together with the optical omega band pulsating aurora and with a period of about 15-20 s

*Z component had the highest variability of ~2.7 mV/m peak to peak; that of the Y component was ~1.8 nV/m peak to peak

*Electrostatic low-frequency waves of less than 30 Hz showed quasi-periodic intensity variations similar to the DC electric field variation

Electric field

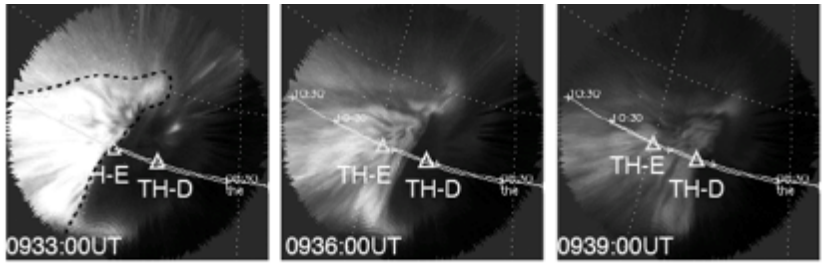
ELF wave



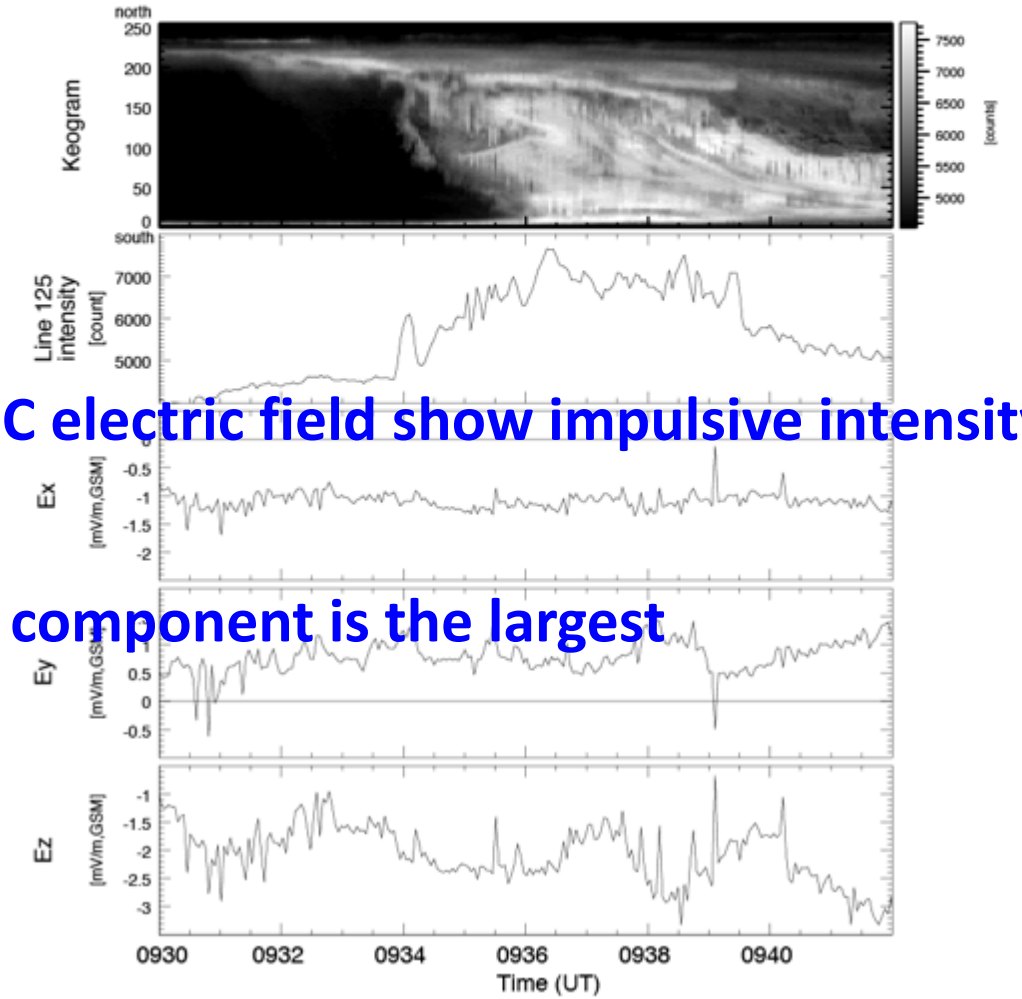
Sato et al., 2015. JGR

Another example of Omega band PsA: 2009-02-27 event

2009.02.27 event



All-sky image



FSMI

*DC electric field show impulsive intensity variations

*Z component is the largest

Electric field

THEMIS-E

Sato et al., 2015. JGR

2-2. Event survey from THEMIS ASI network

＊Total number
＊MLT dependence

How to find Omega event from THEMIS summary plots?

THEMIS: Coordinated space and ground observation

THEMIS: Coordinated All-sky imager network

2011.03.01.0736:06UT

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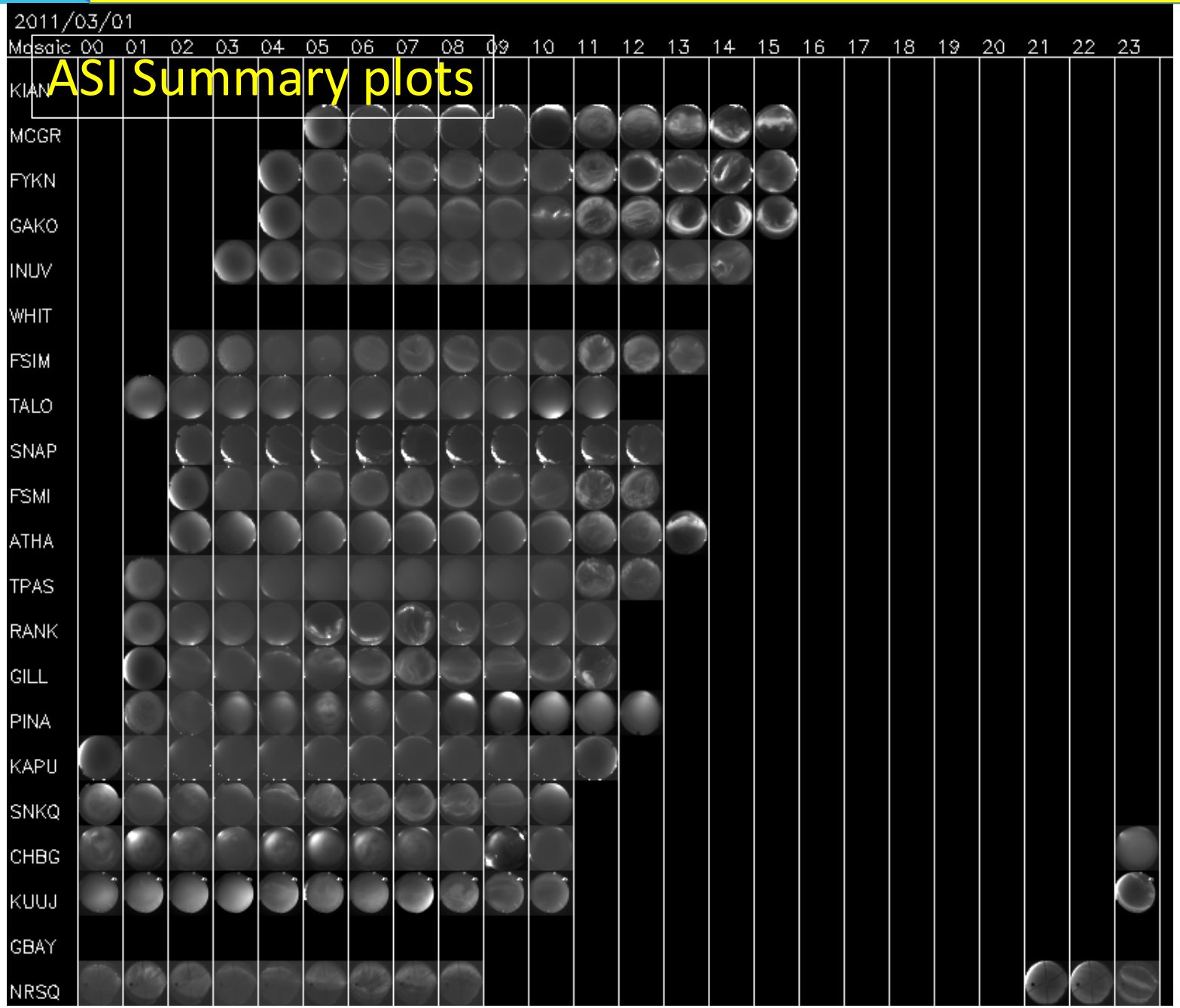
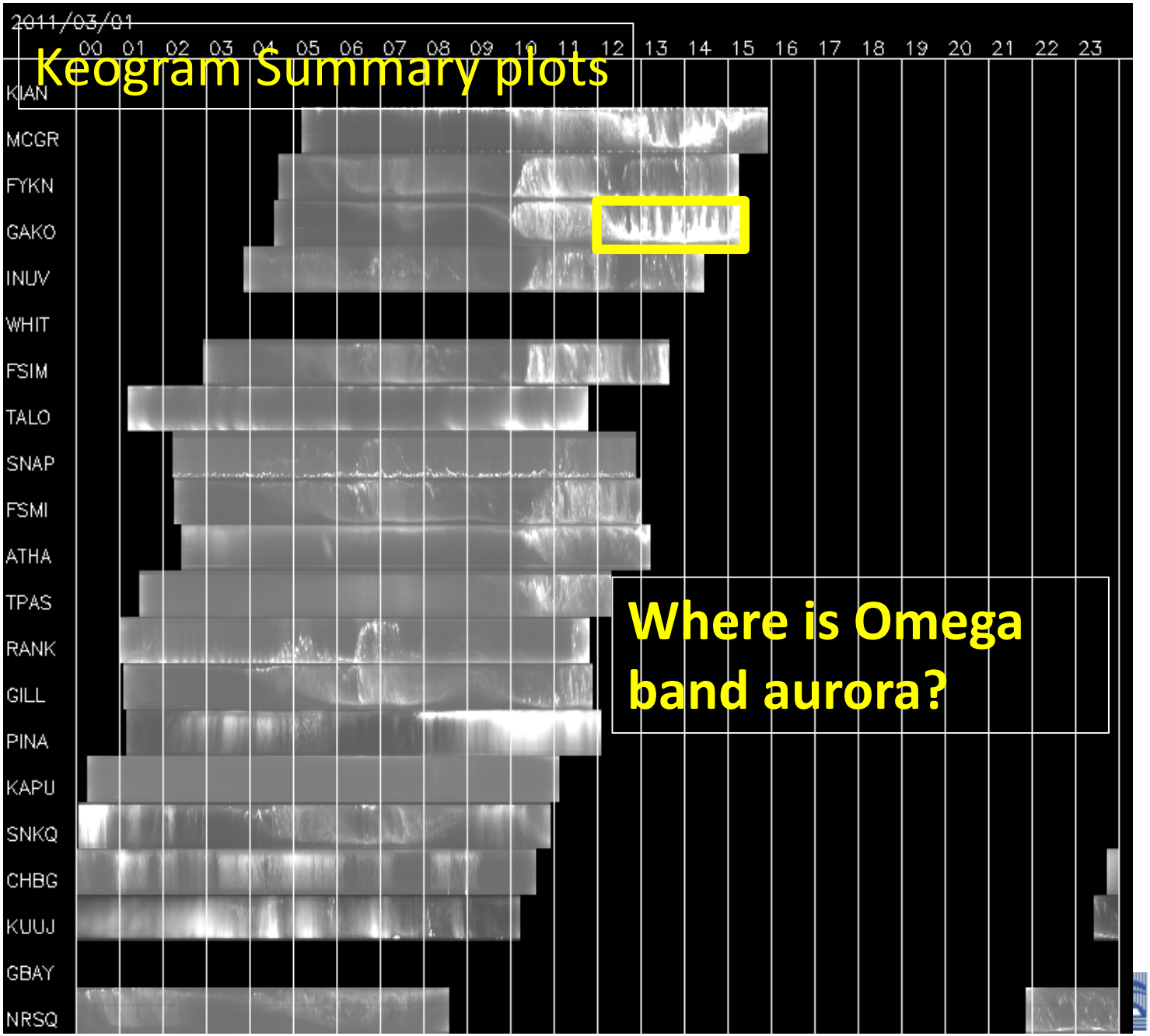
THEMIS: Coordinated All-sky imager network

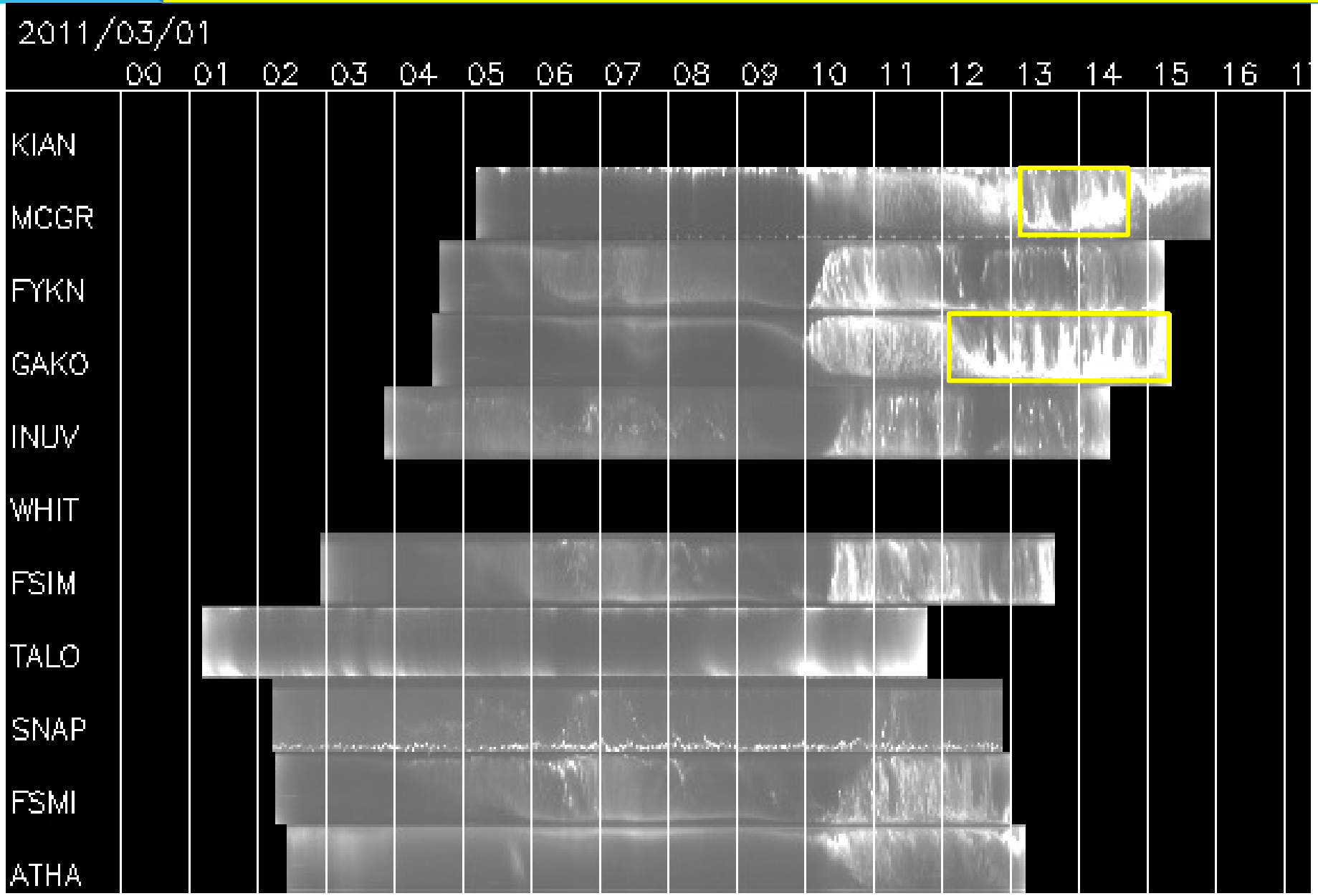


ASI Summary plots

THEMIS: Coordinated All-sky imager network

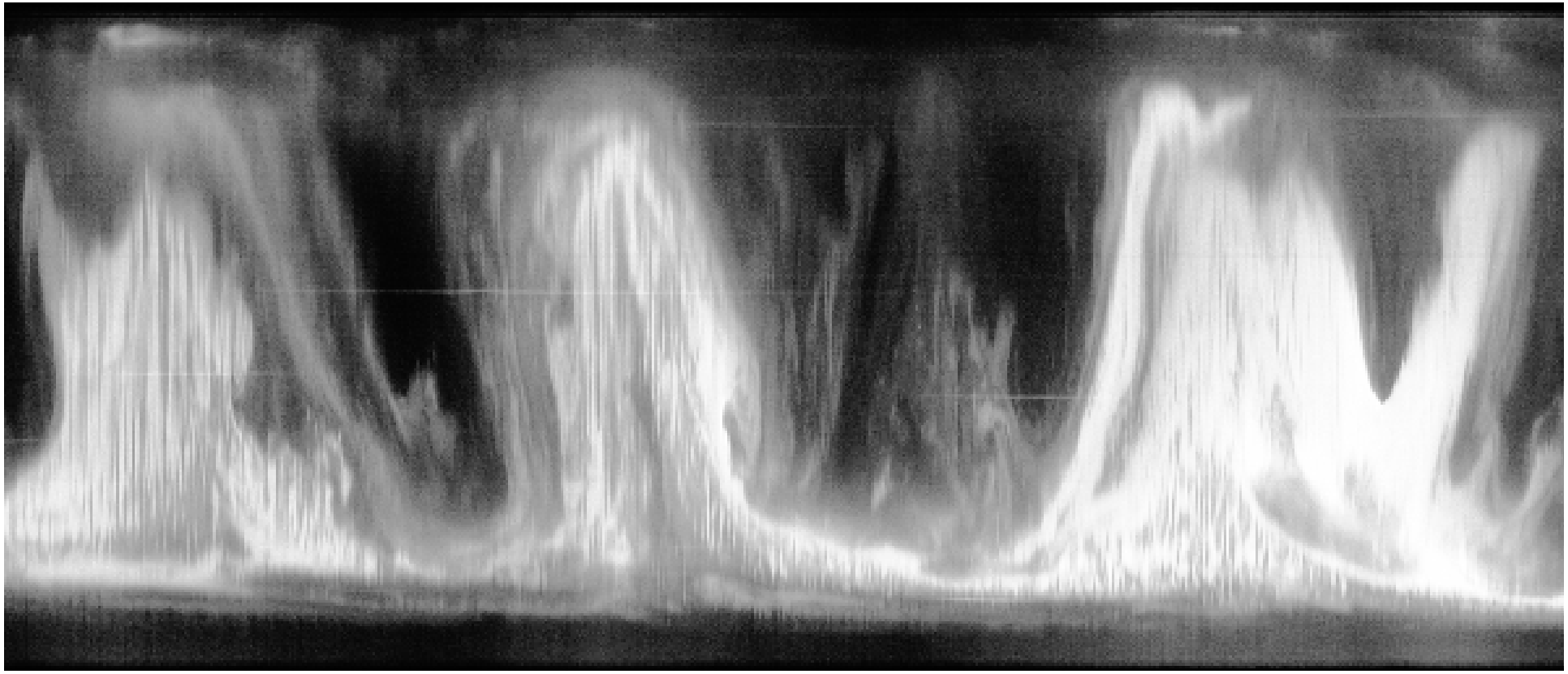


THEMIS: Coordinated All-sky imager network



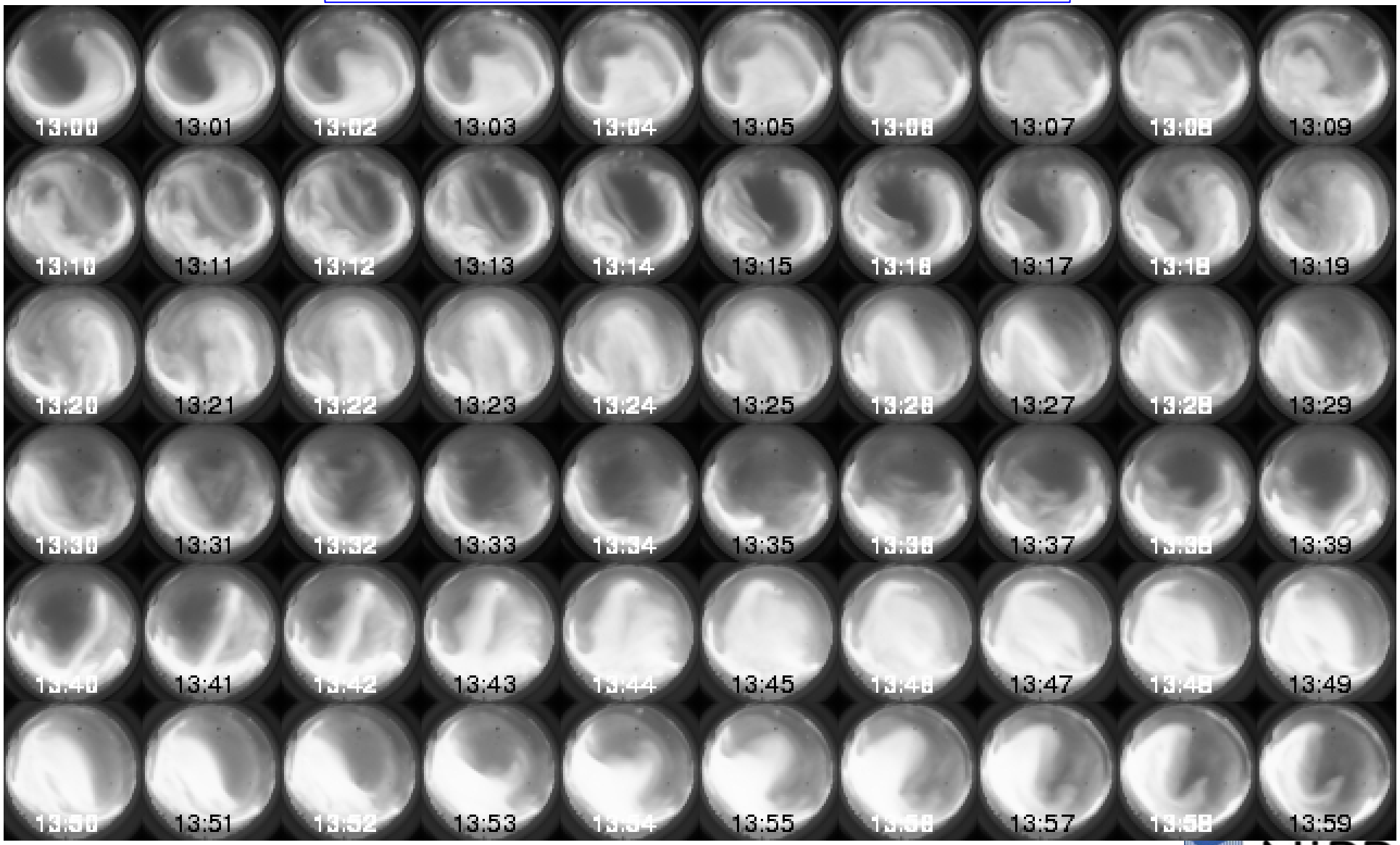
THEMIS: Coordinated All-sky imager network

20110301_13-14_gako-keogram.pgm



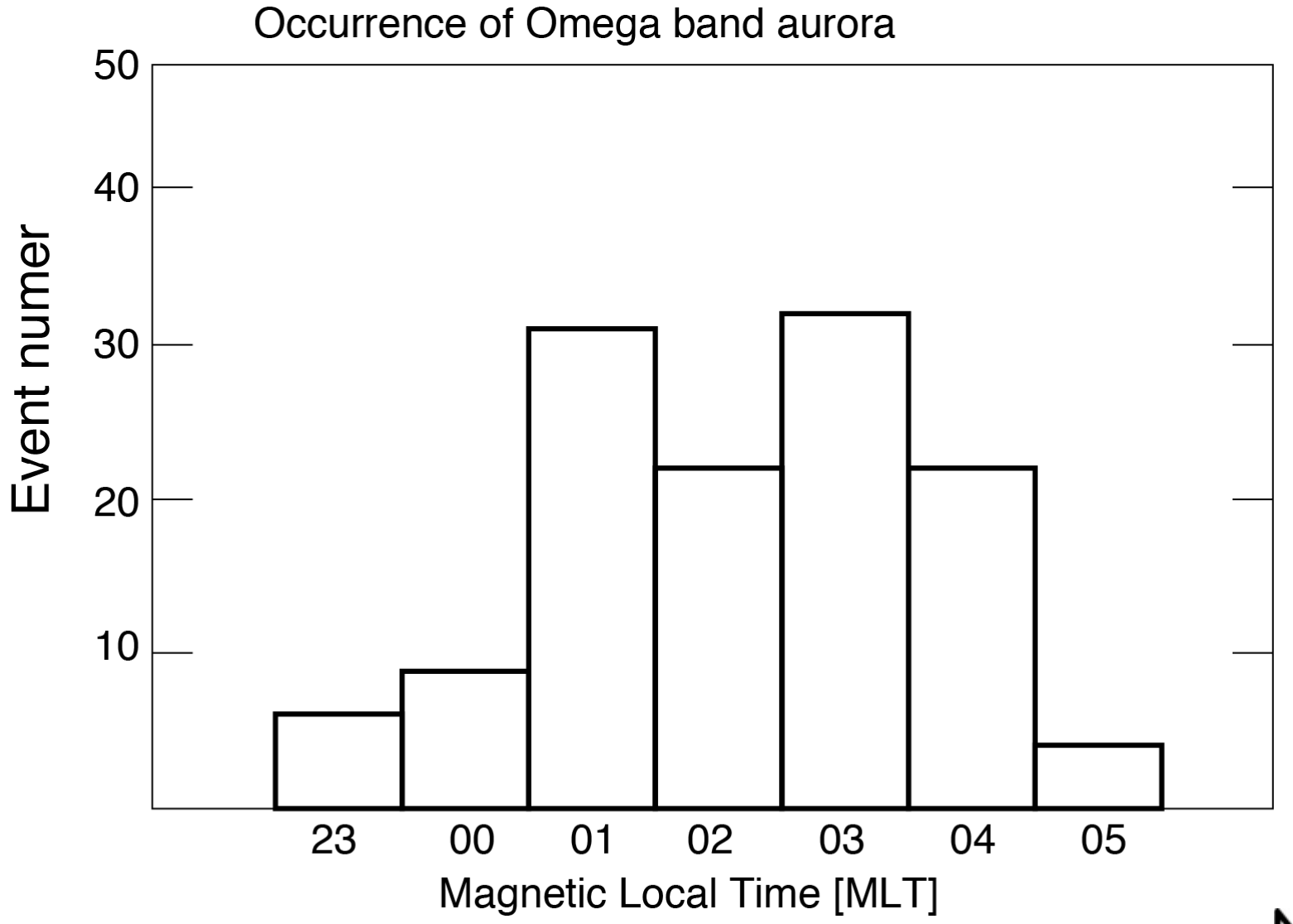
THEMIS: Coordinated All-sky imager network

20110301_13-14_gako-montage.pgm



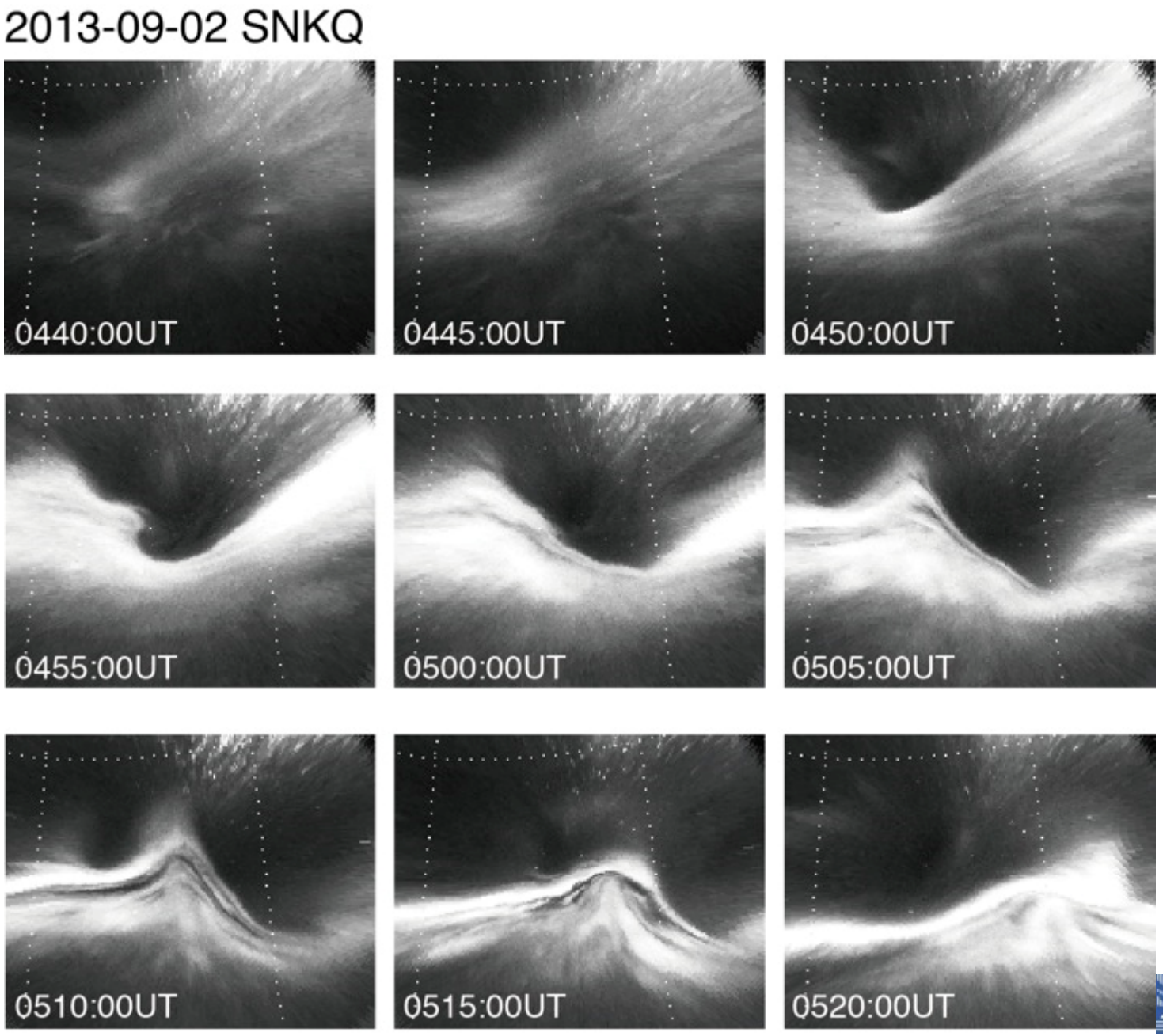
Magnetic local time (MLT) dependence of Omega aurora

2008～2014 **Total Event Number : ~ 150**

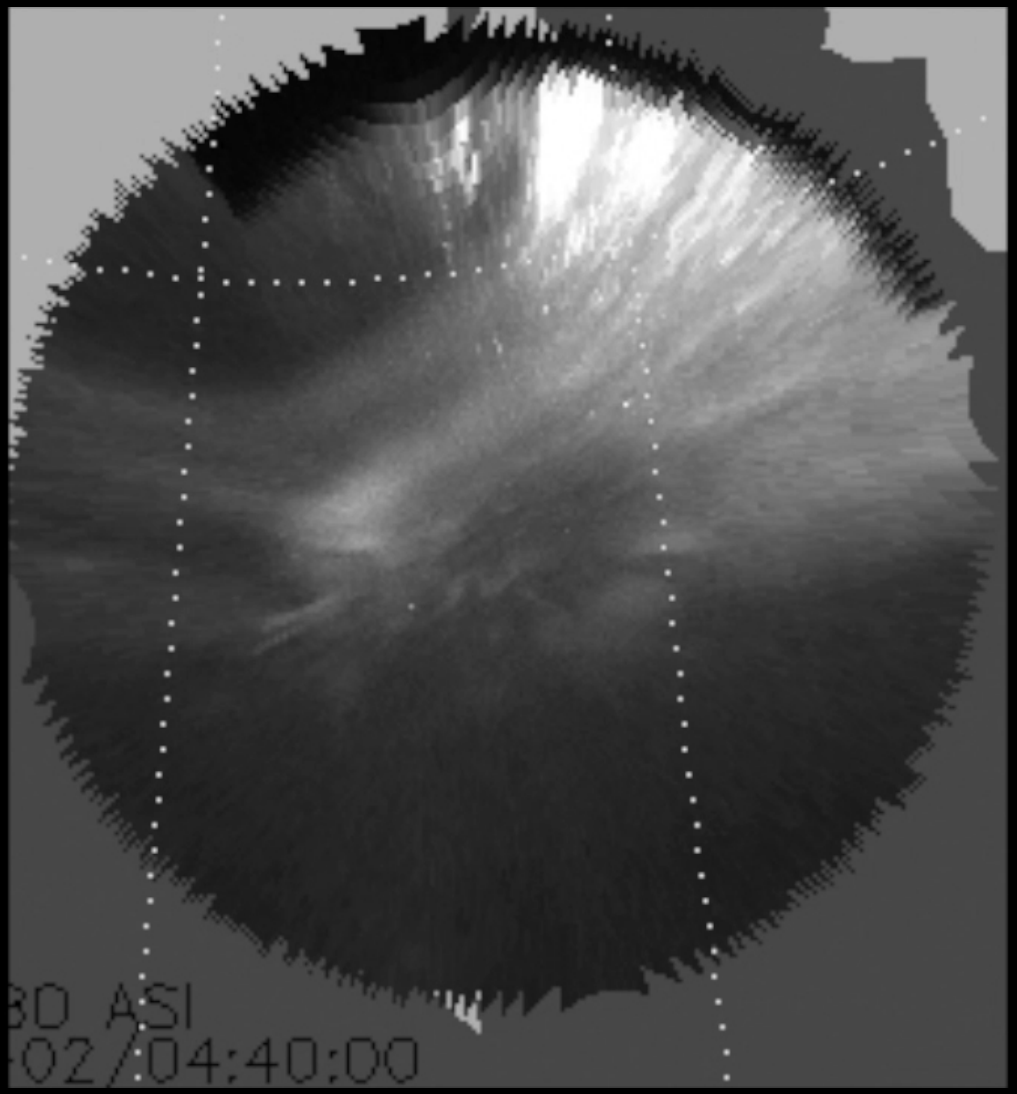


2013.09.02
Omega band Pulsating Aurora
observed at Sanikiluaq (SNKQ) in Canada

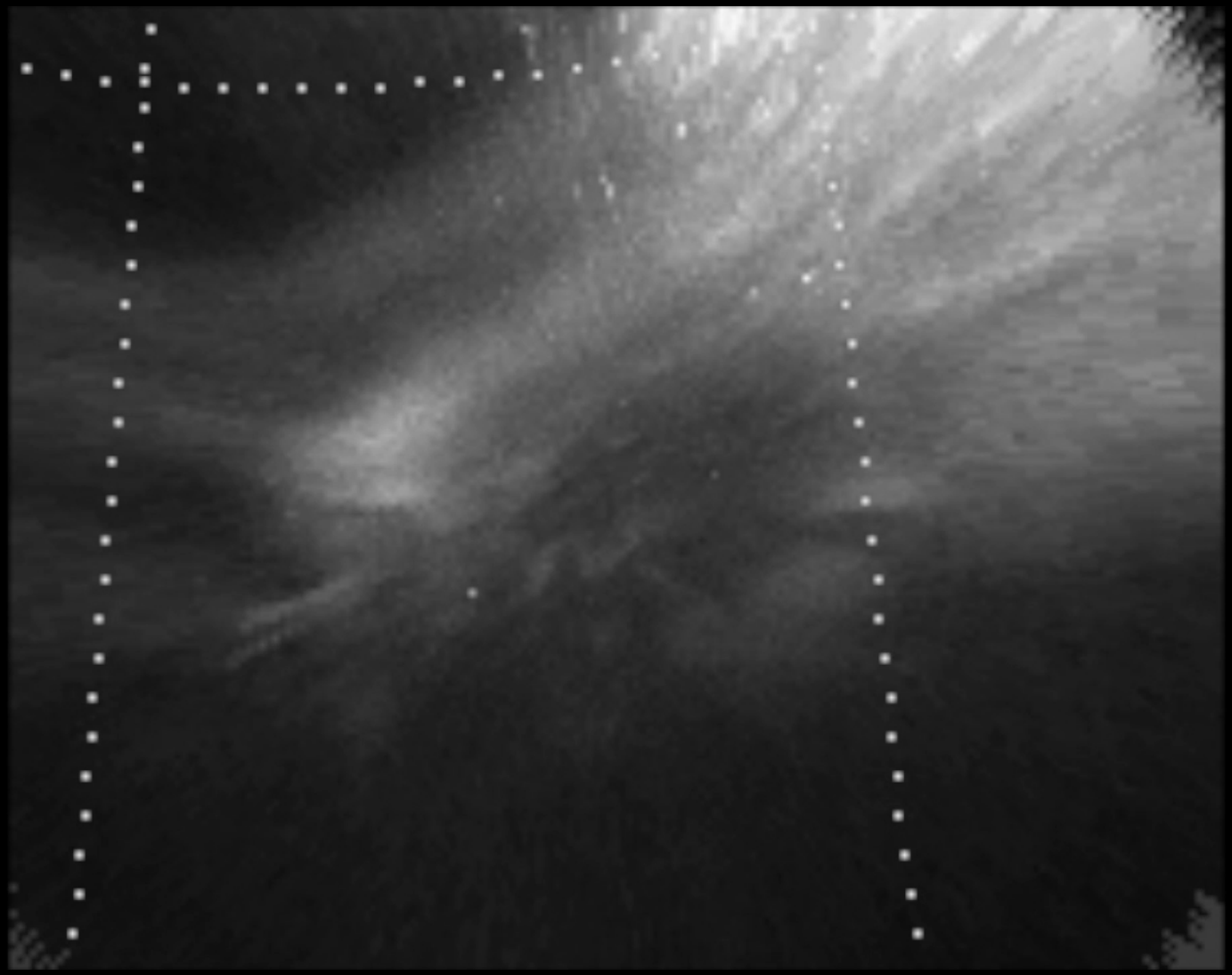
2013.09.02_ SNKQ event



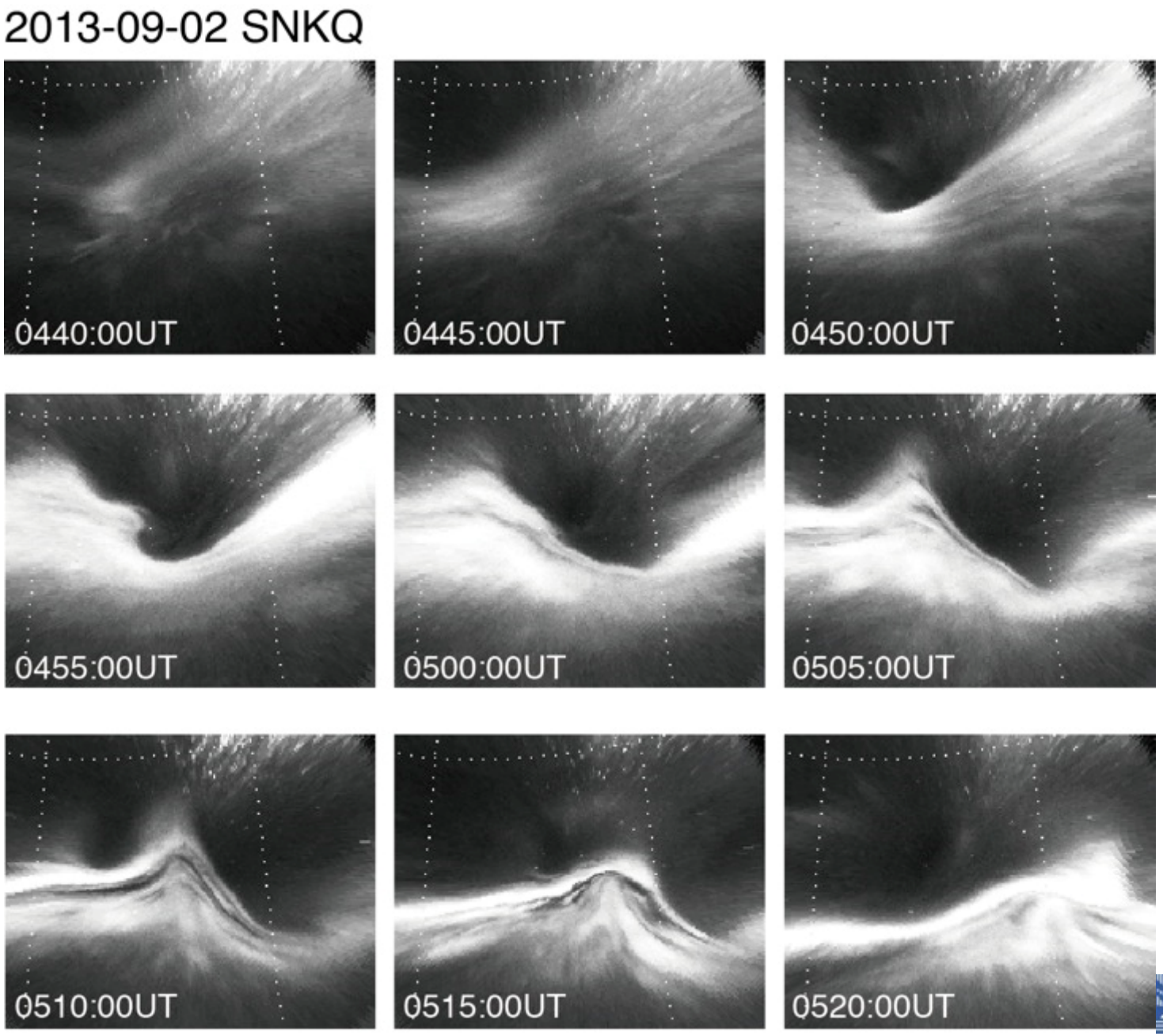
2013.09.02 Omega band aurora at SNKQ



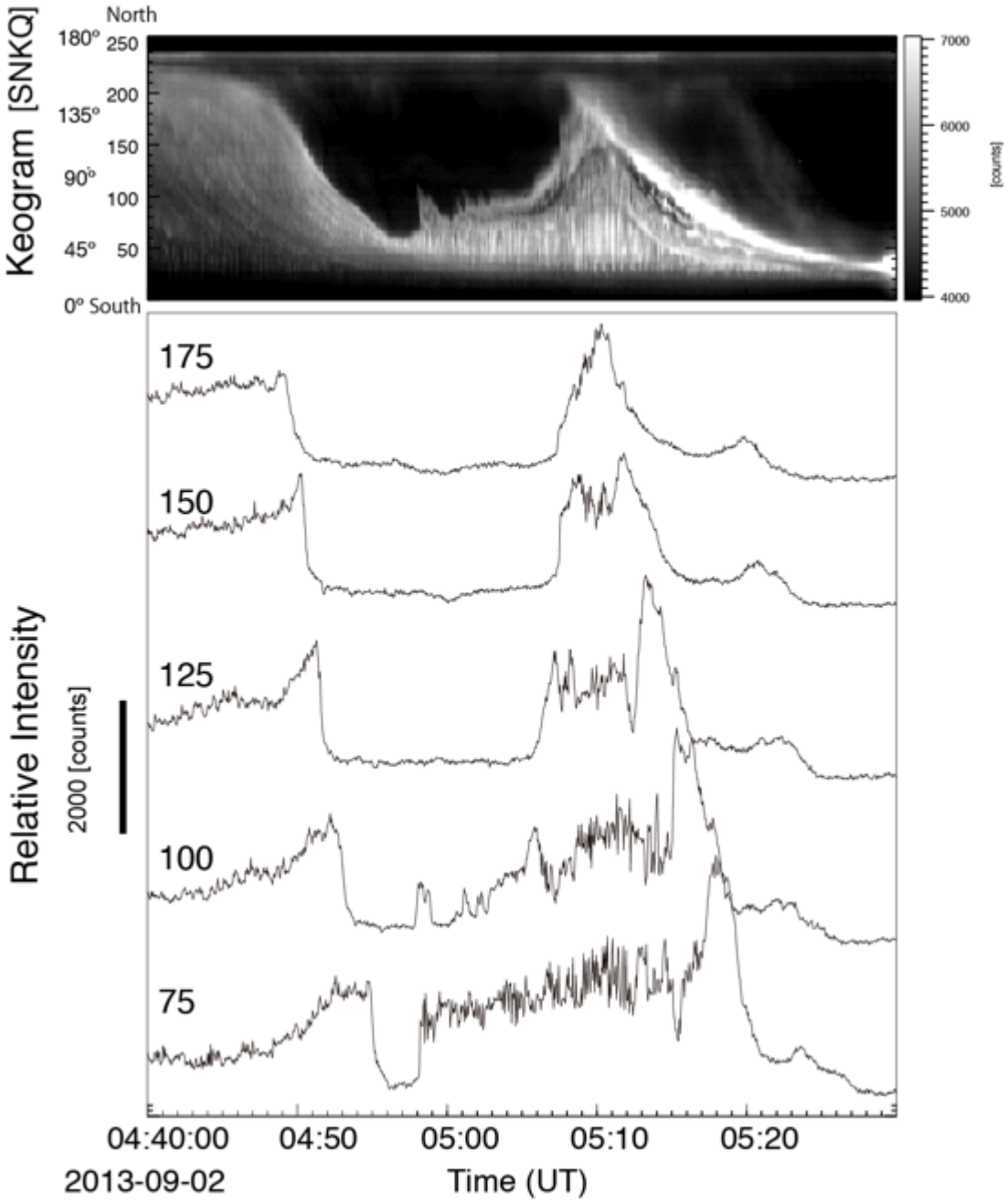
2013.09.02 Omega band aurora at SNKQ



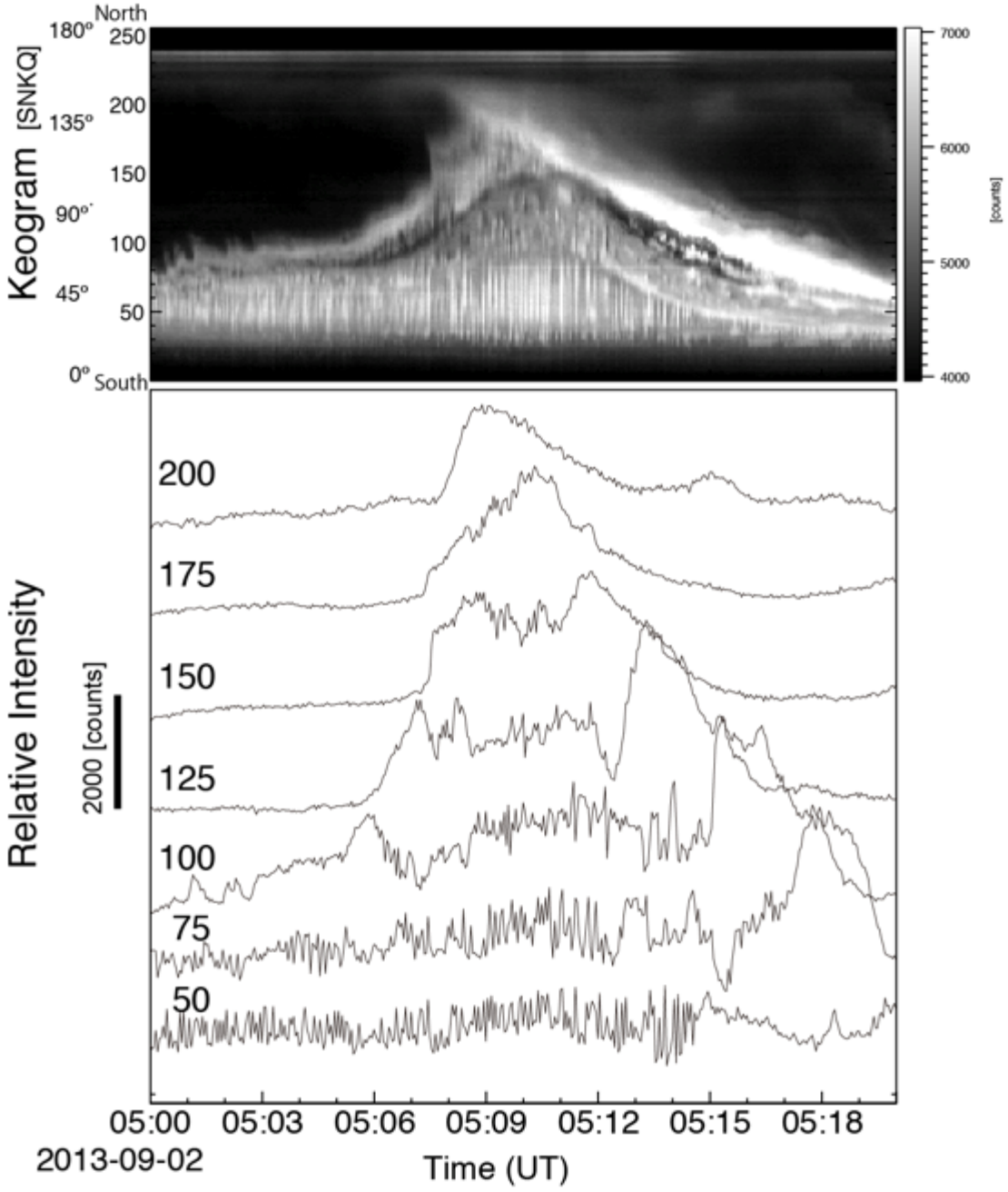
2013.09.02 Omega band aurora at SNKQ



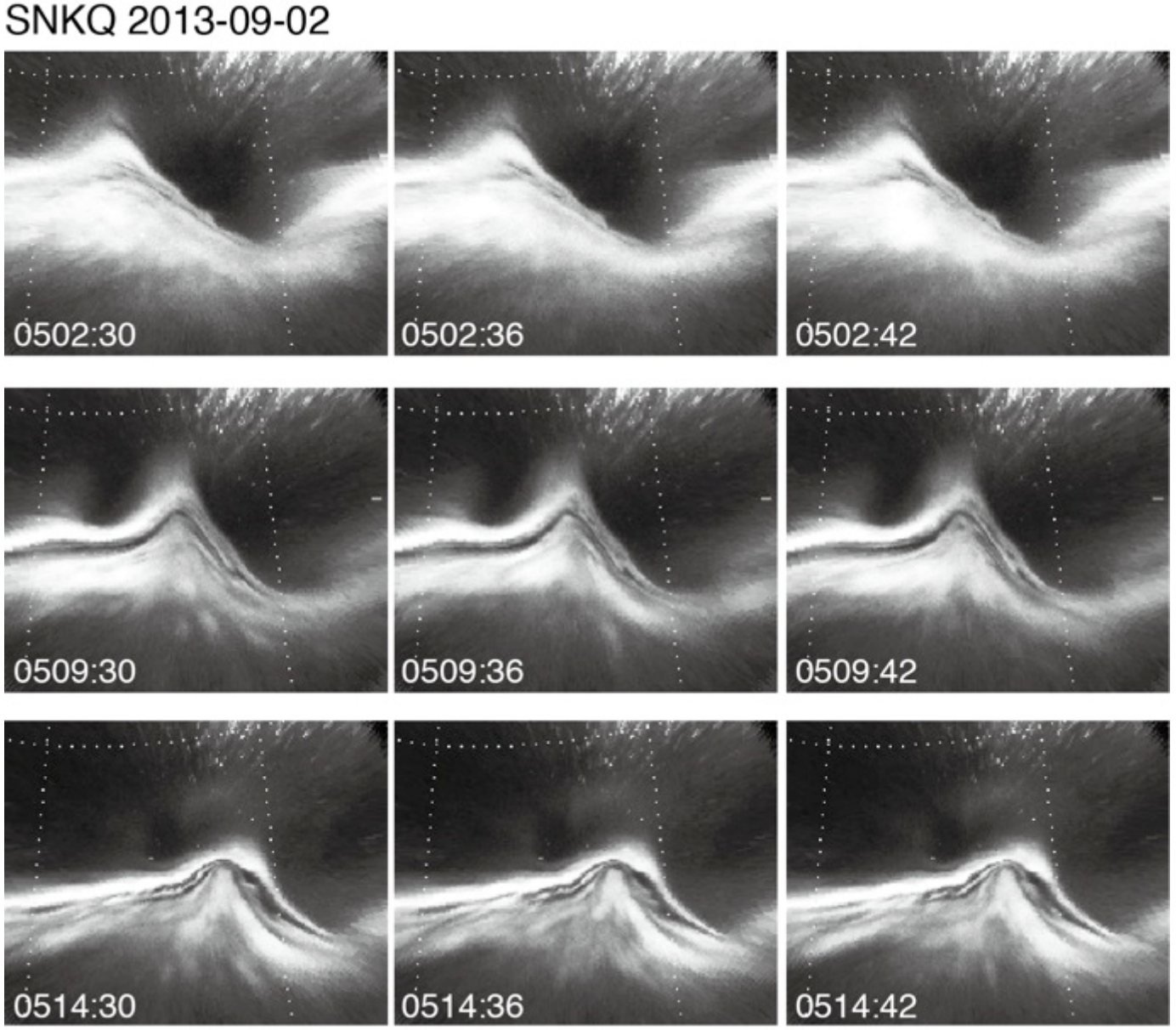
2013.09.02 Omega band aurora at SNKQ



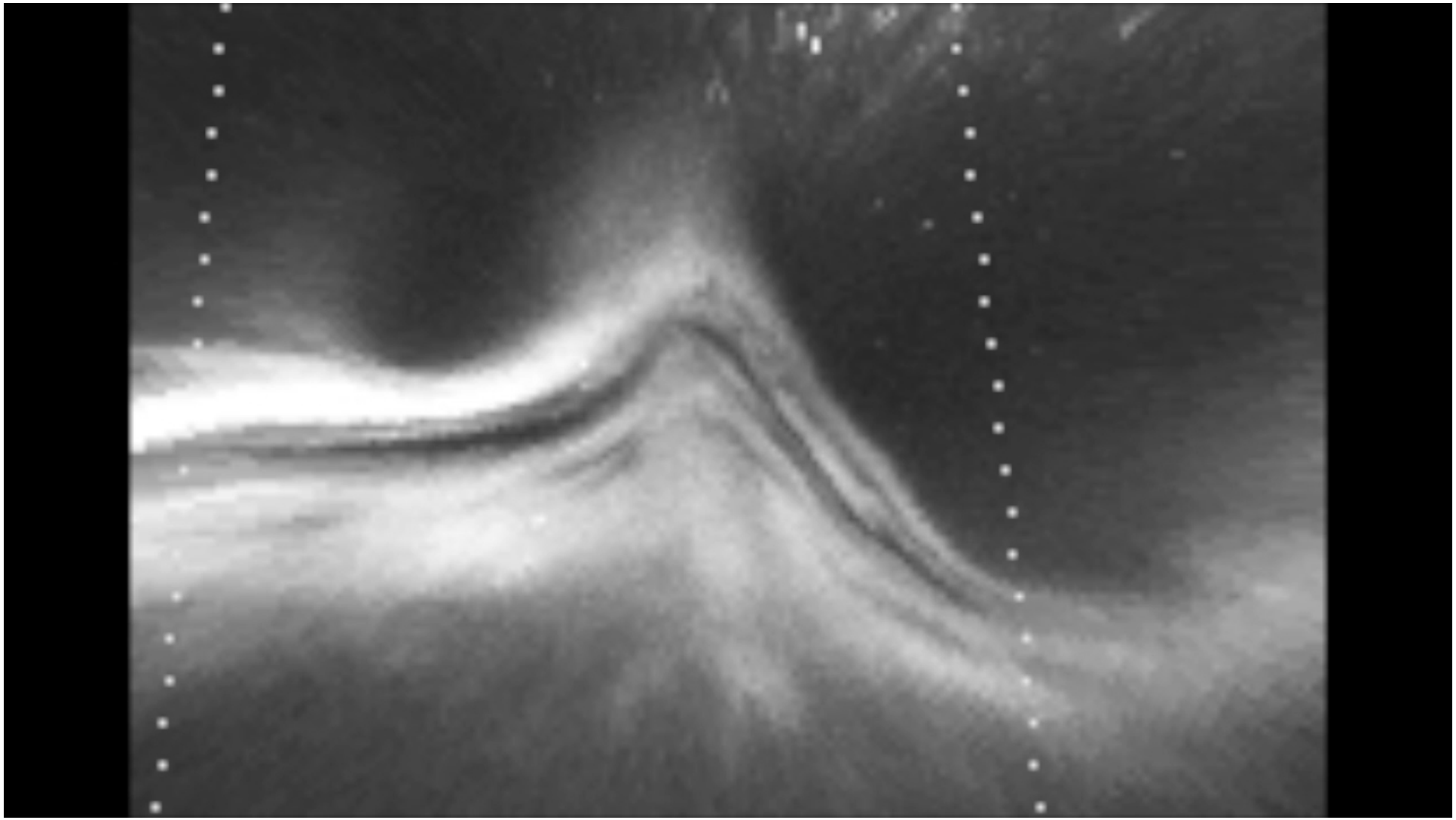
2013.09.02 Omega band aurora at SNKQ



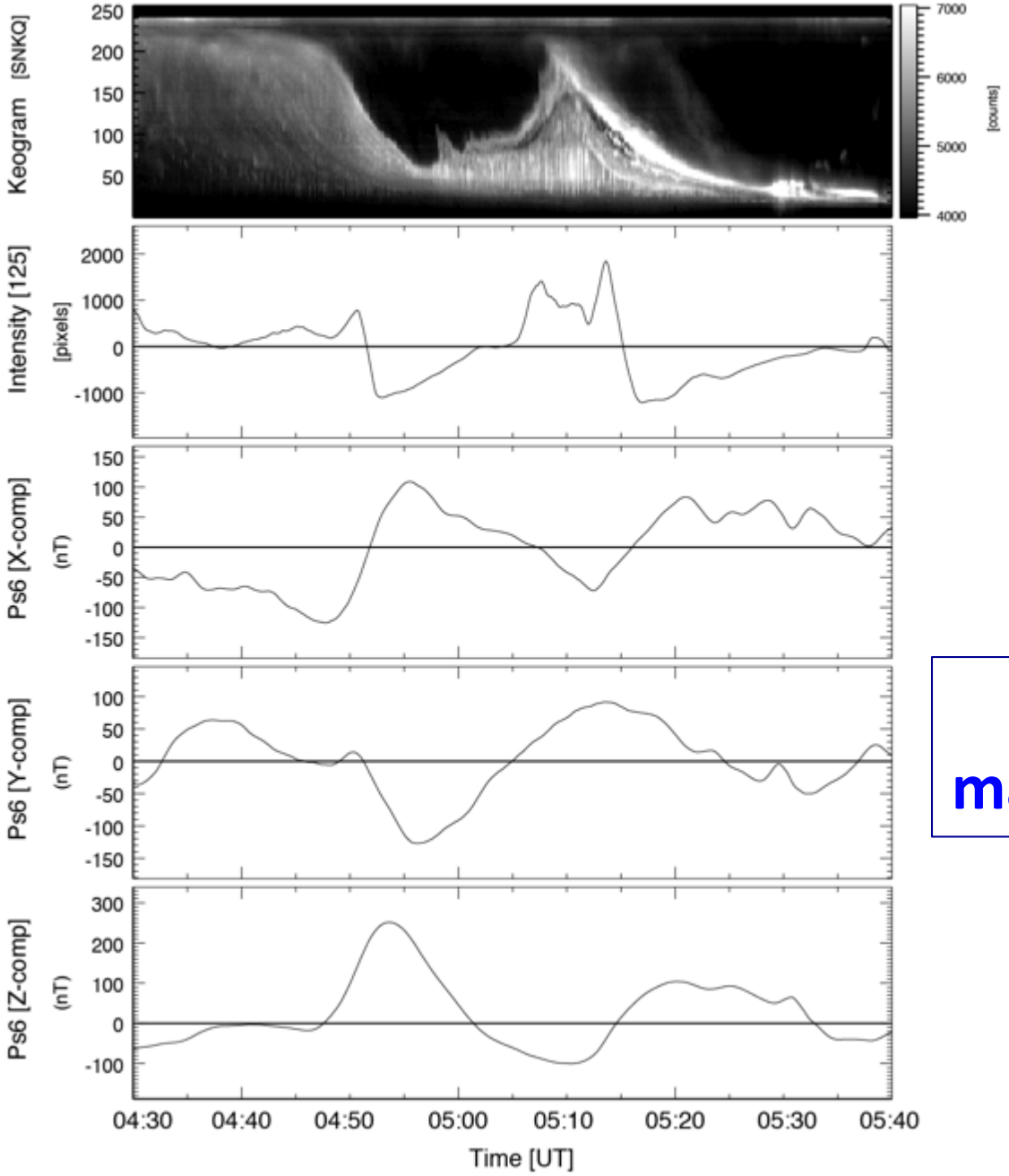
2013.09.02 Omega band aurora at SNKQ



2013.09.02 Omega band aurora at SNKQ



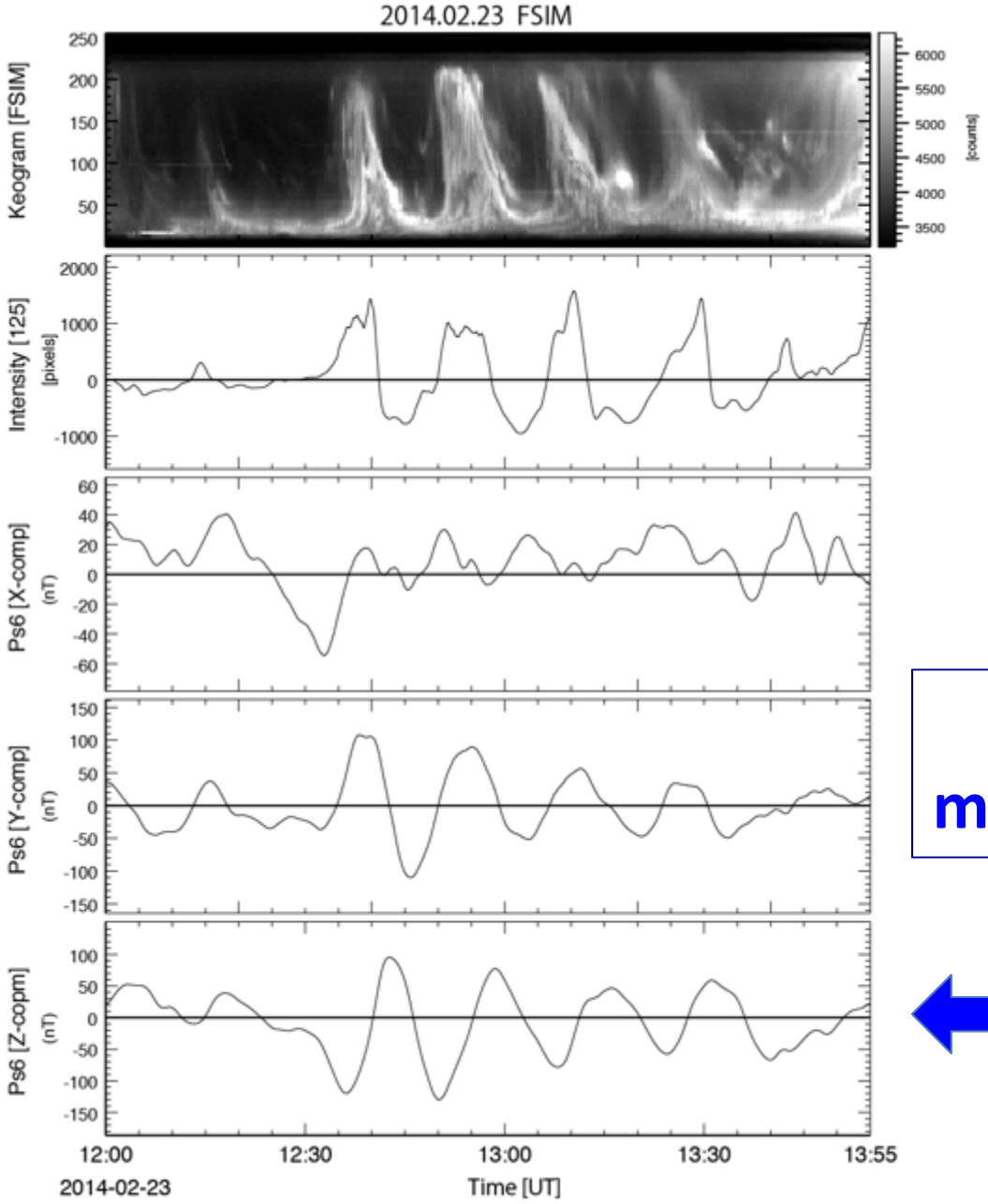
Omega band aurora and Ps6 magnetic pulsation at SNKQ



Ps6
magnetic pulsation

2014.02.23
Omega band Pulsating Aurora
observed at Fort Simpson (FSIM) in Canada

Omega band aurora and Ps6 magnetic pulsation

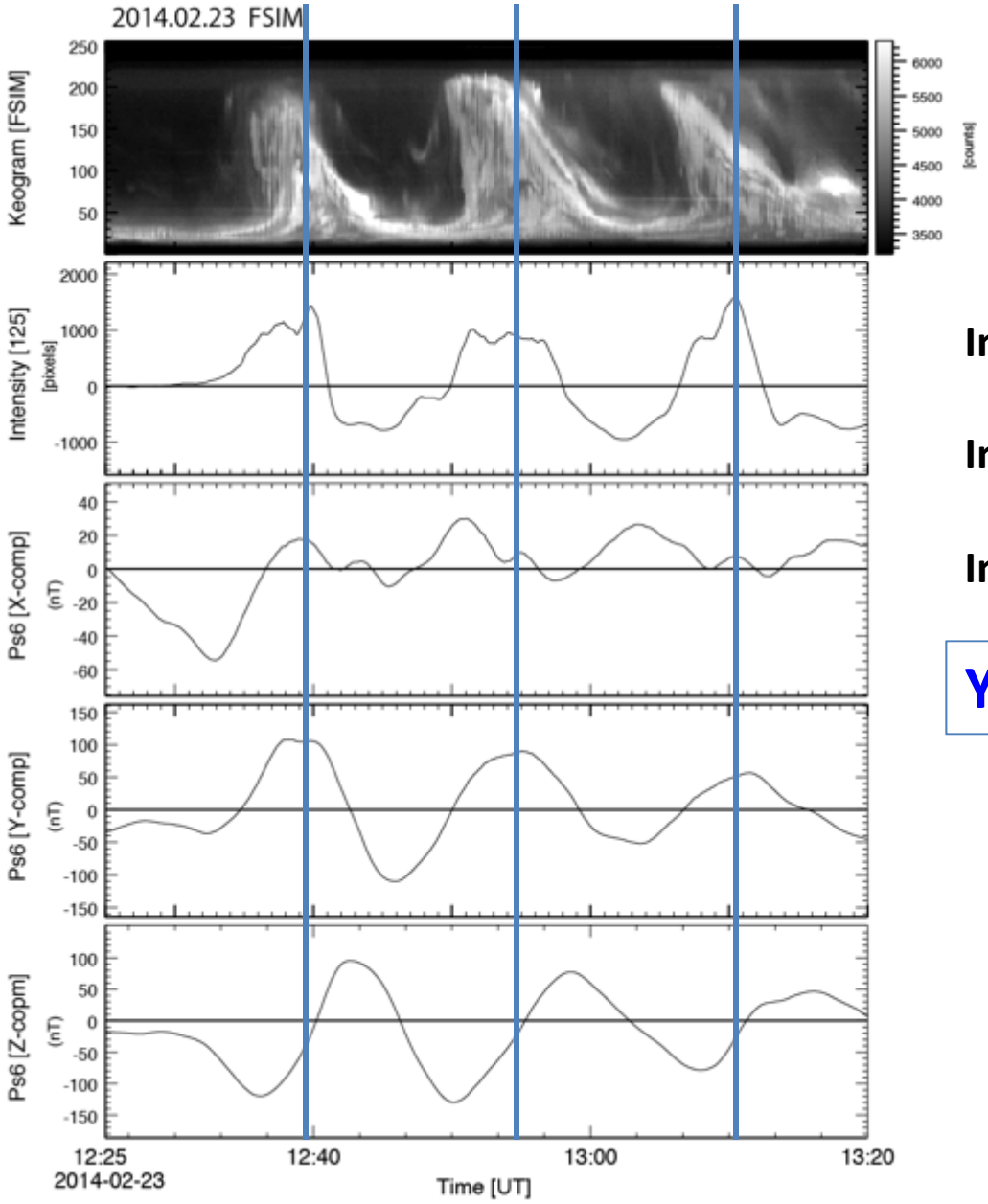


Ps6
magnetic pulsation

Pi3 Saito 1973

NiPR
National Institute of Polar Research

Omega band aurora and Ps6 magnetic pulsation



Intensity- X comp => ??

Intensity- Y comp => In phase

Intensity- Z comp => 90° delay

Y-com/max= Z-comp /zero

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National Institute of Polar Research

2011.03.01

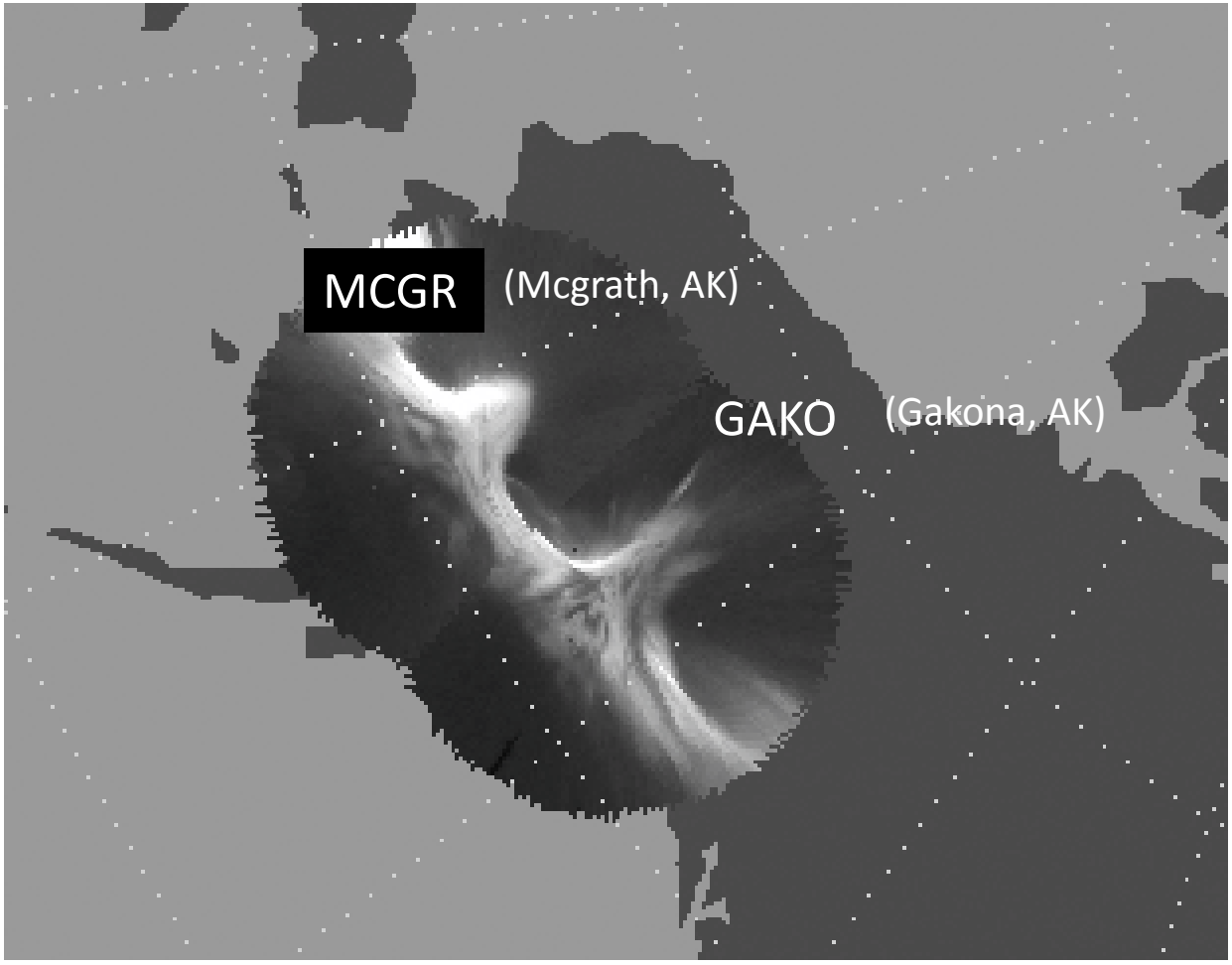
Omega band event

observed at Mcgrath and Gakona in Alaska

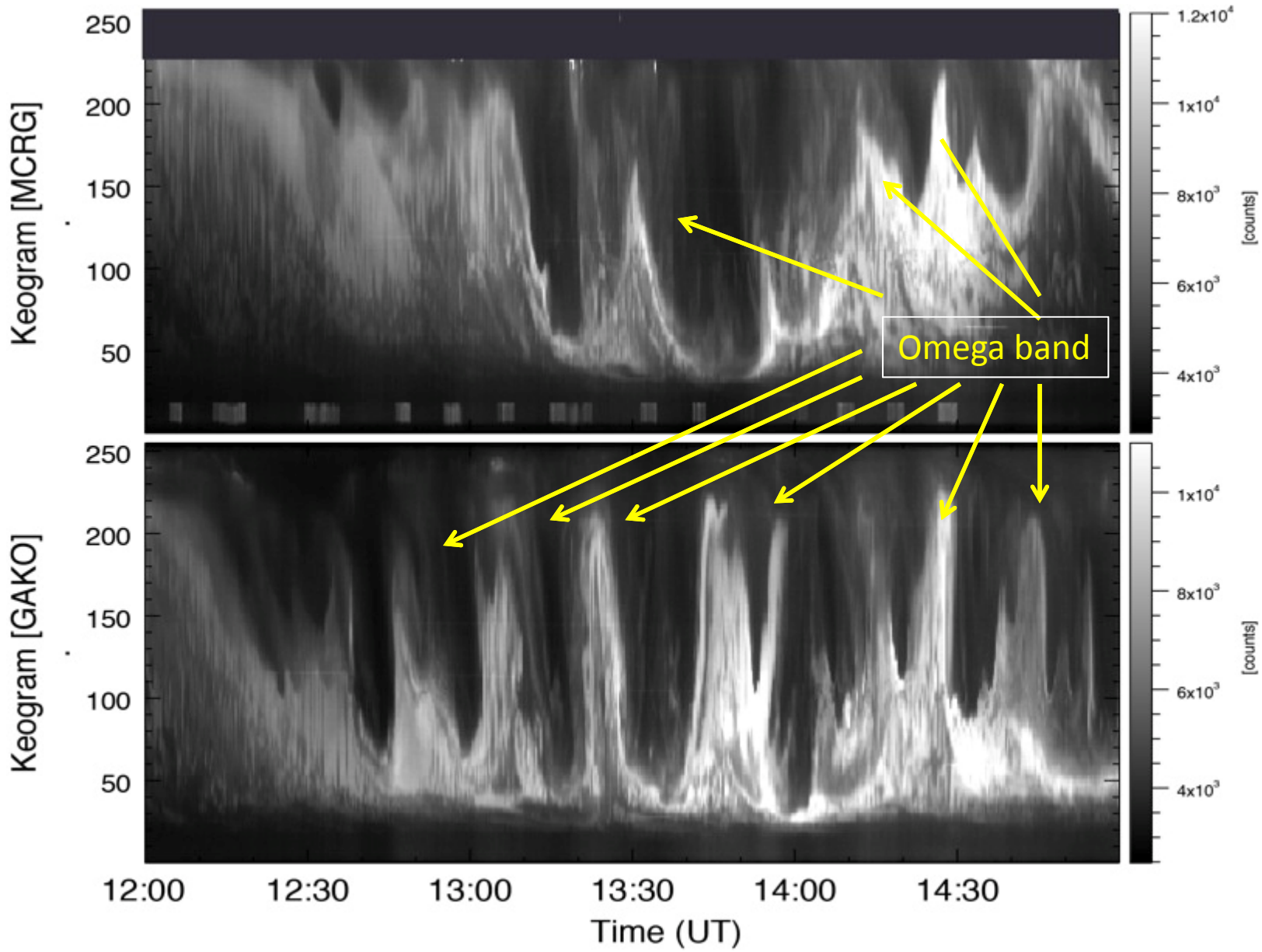
Omega band event on March 1, 2011

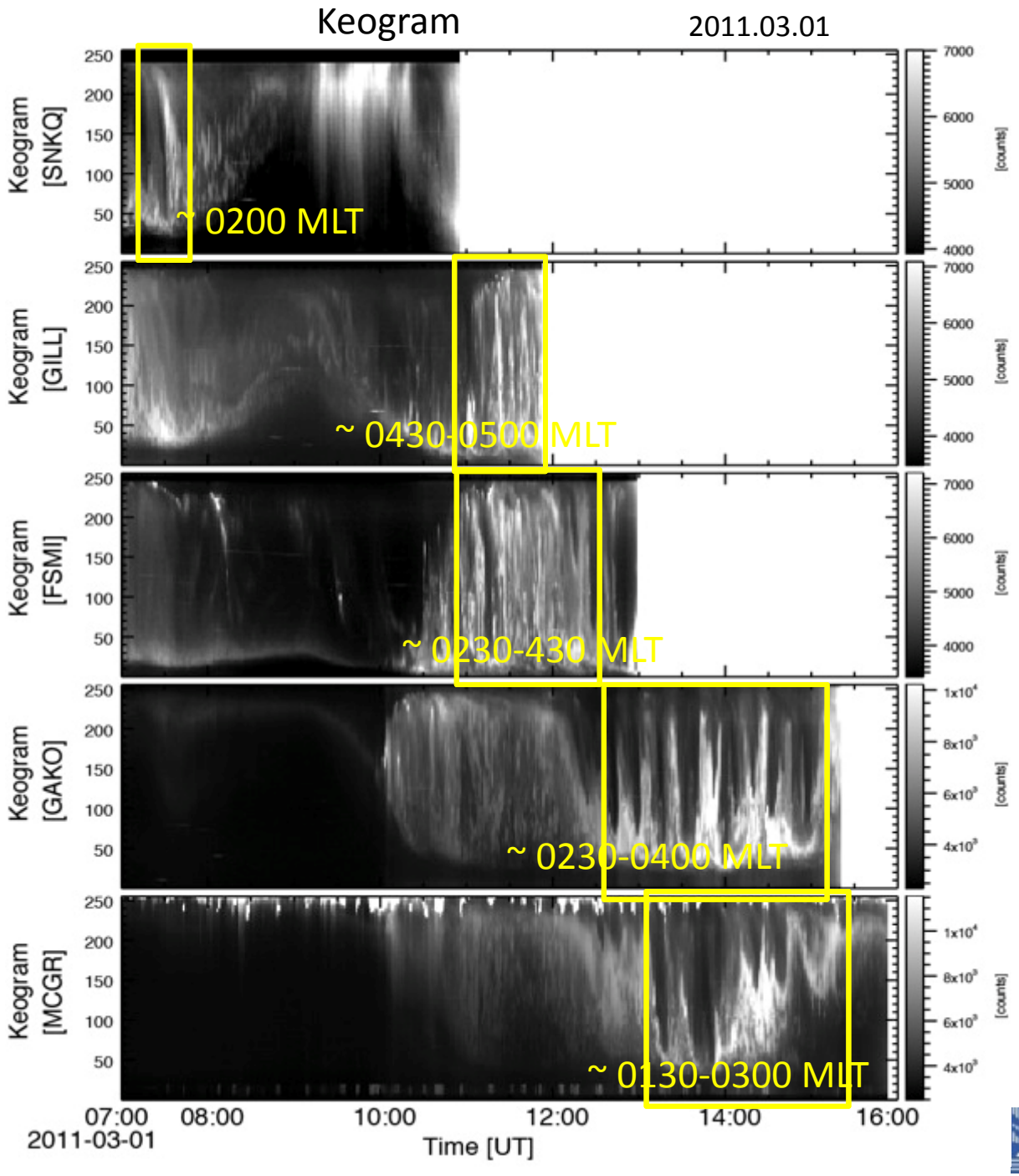
Very active Omega band event

- March 1, 2011 event

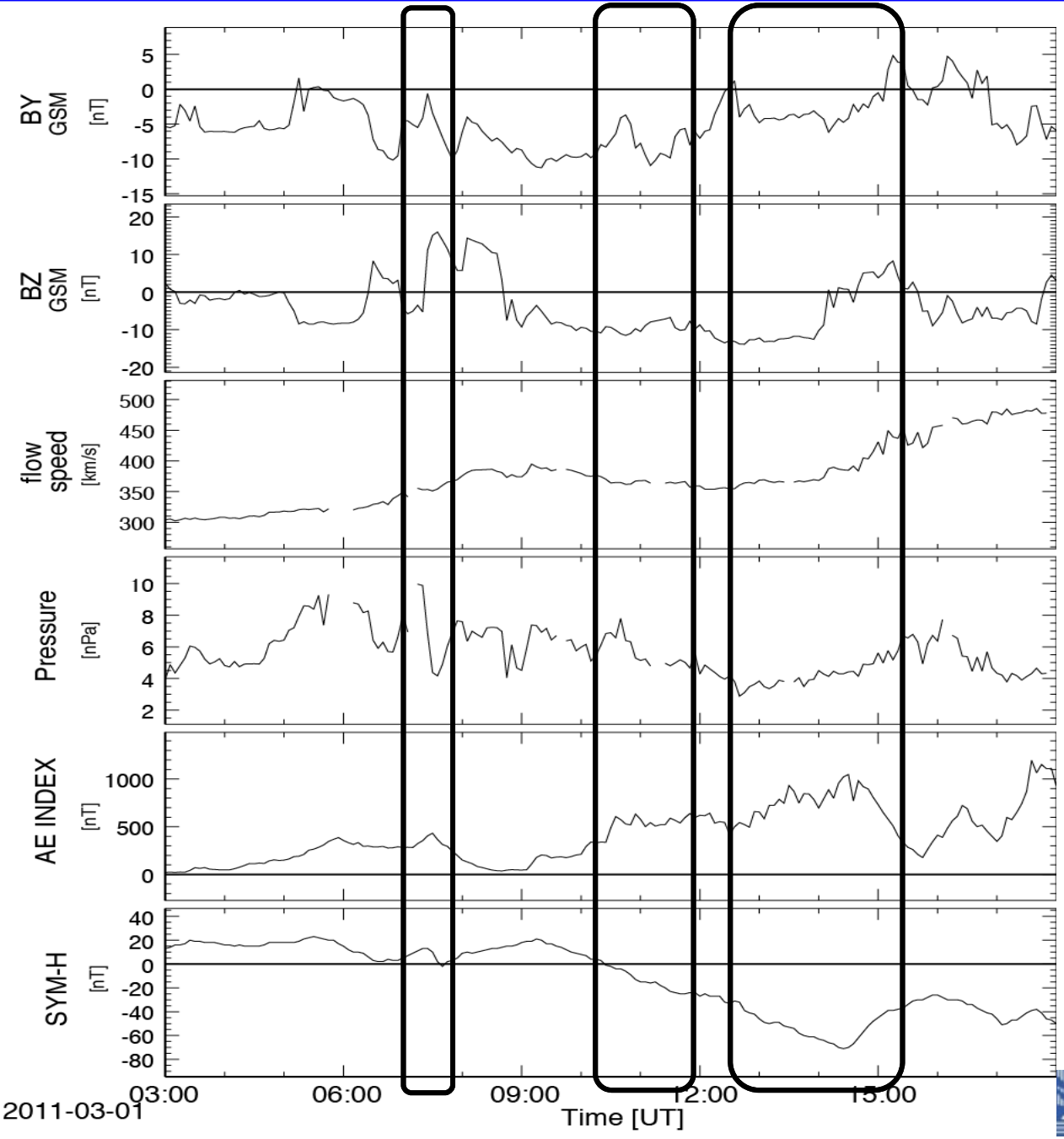


Omega band aurorsa at MCRG and GAKO

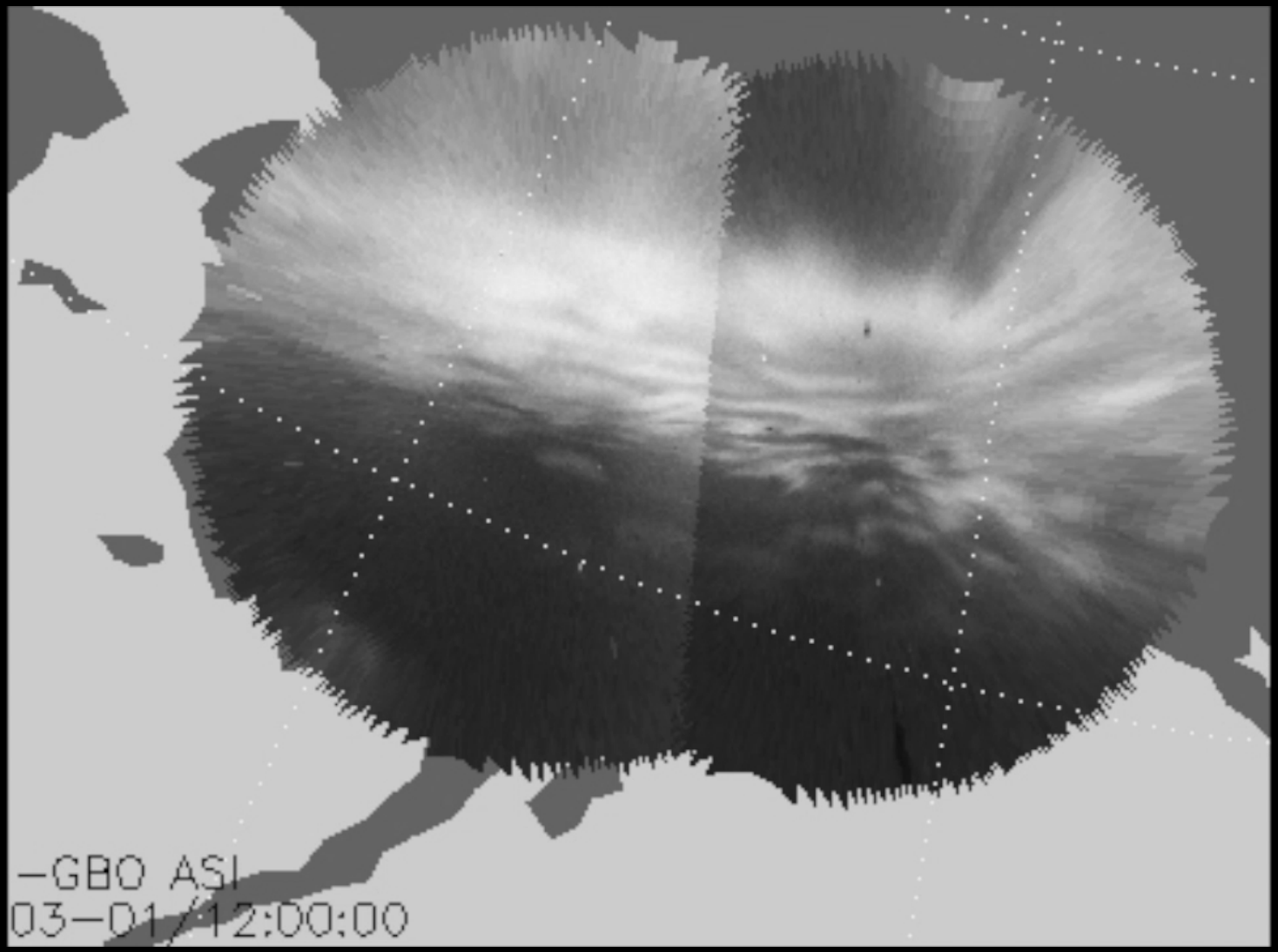



Keogram
2011.03.01
Keogram [SNKQ]
~ 0200 MLT
Keogram [GILL]
~ 0430-0500 MLT
Keogram [FSMI]
~ 0230-430 MLT
Keogram [GAKO]
~ 0230-0400 MLT
Keogram [MCGR]
~ 0130-0300 MLT
[counts]
07:00
08:00
10:00
12:00
14:00
16:00
2011-03-01
Time [UT]

Omega band event on March 1, 2011

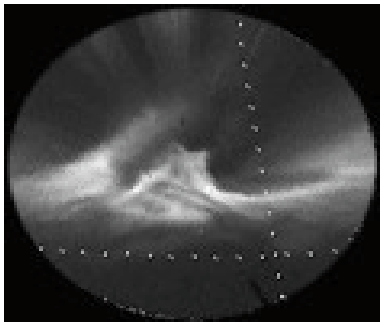


Movie of Omega band observed at MCGR/GAKO



Growth signature of Omega band aurora

Growth of Omega band Pulsating Aurora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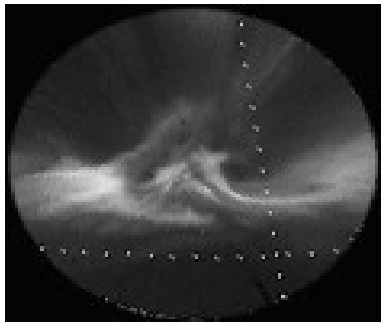
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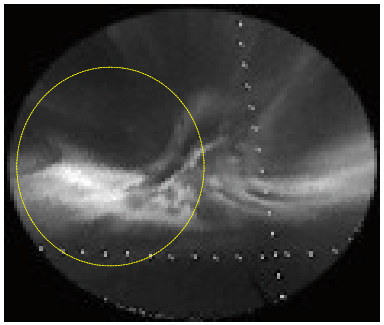
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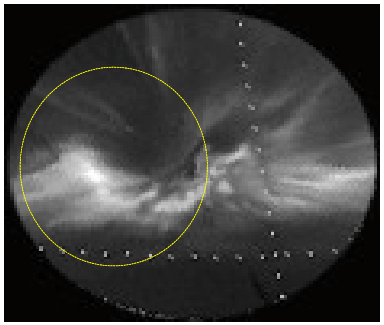
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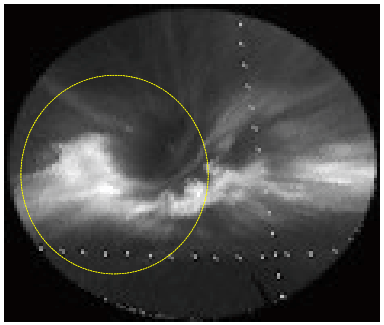
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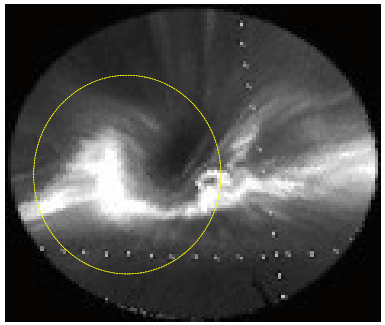
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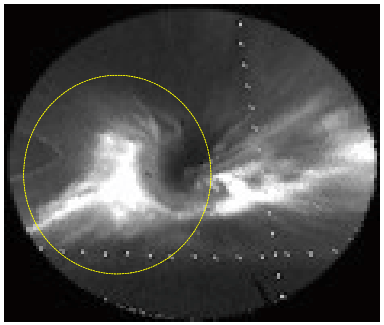
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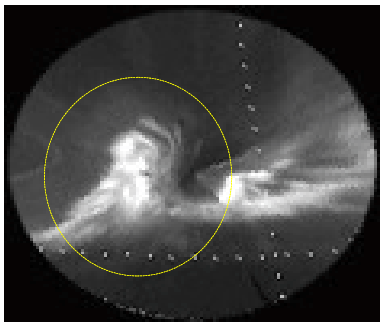
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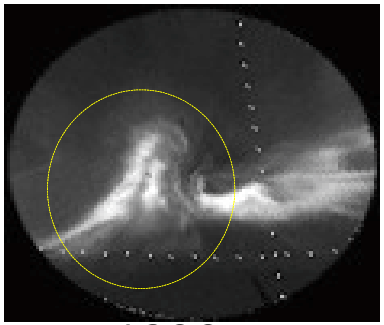
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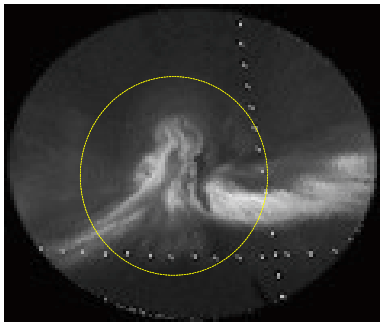
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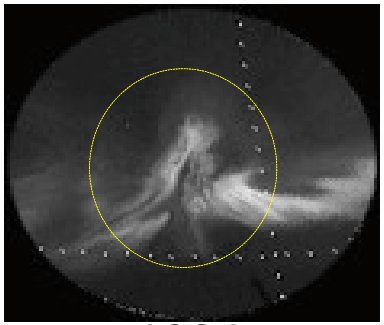
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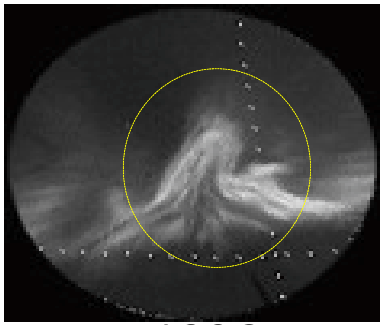
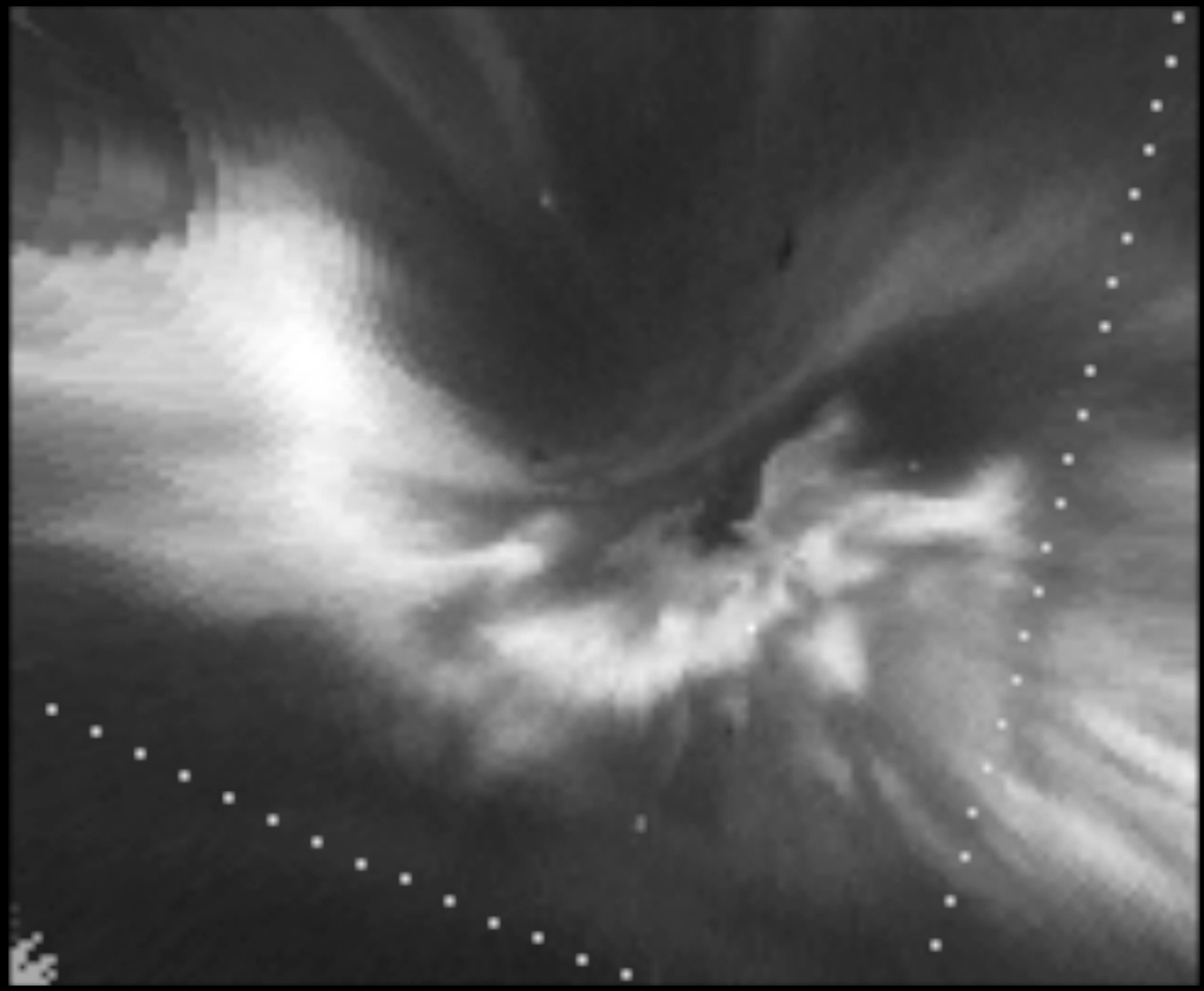
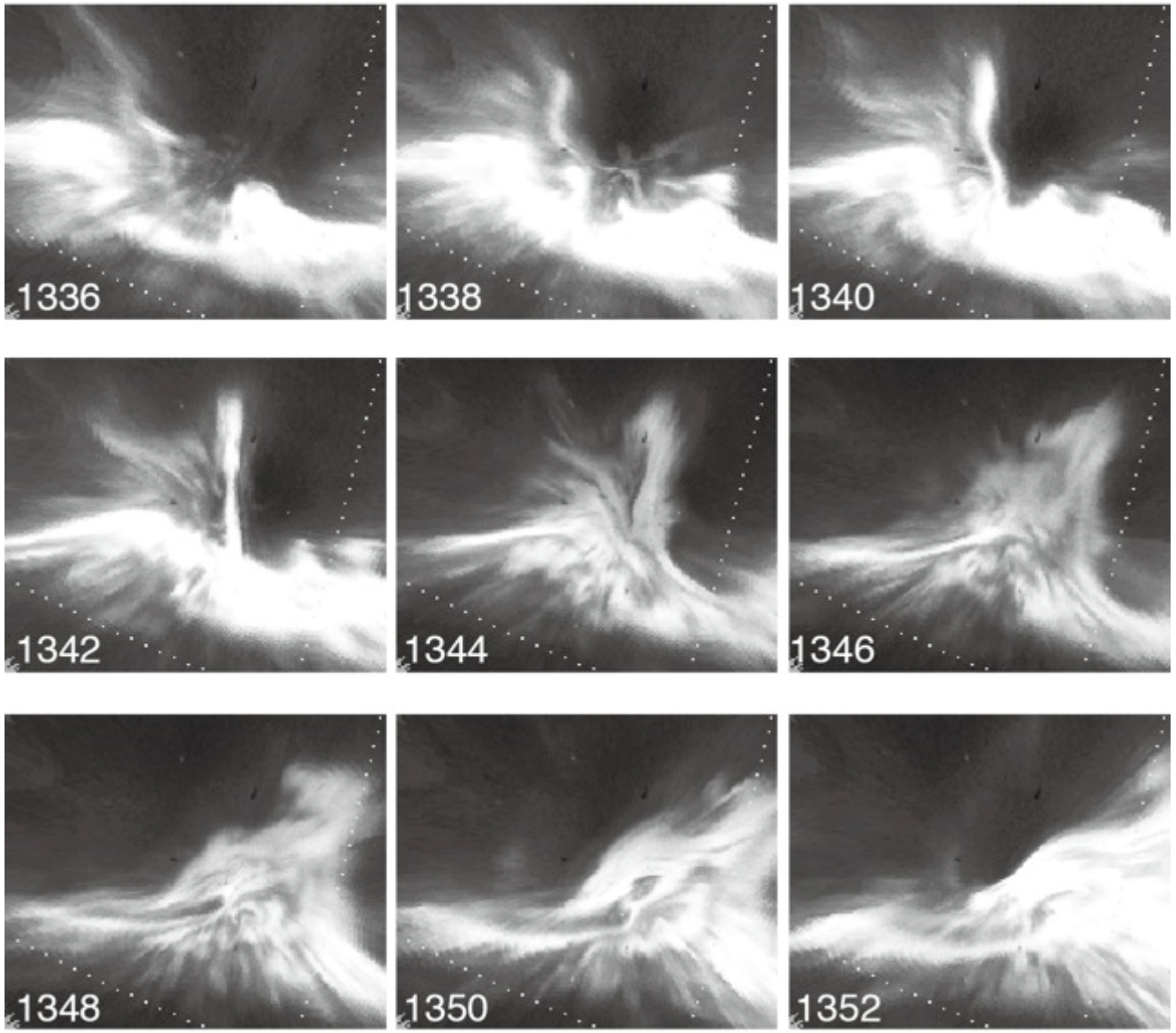

1326

Omega bands observed at GAKO

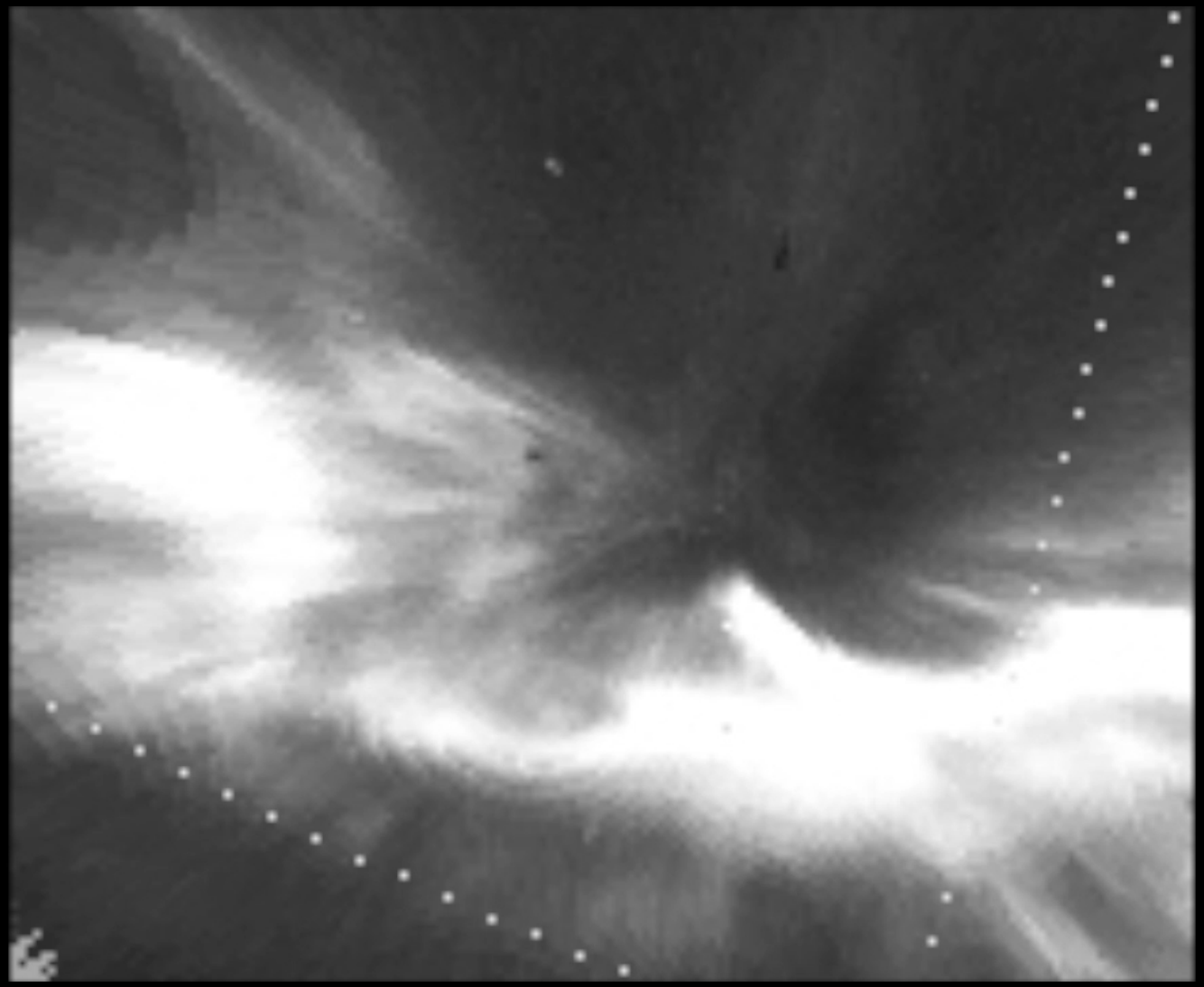


Growth of Omega band Pulsating Aurora

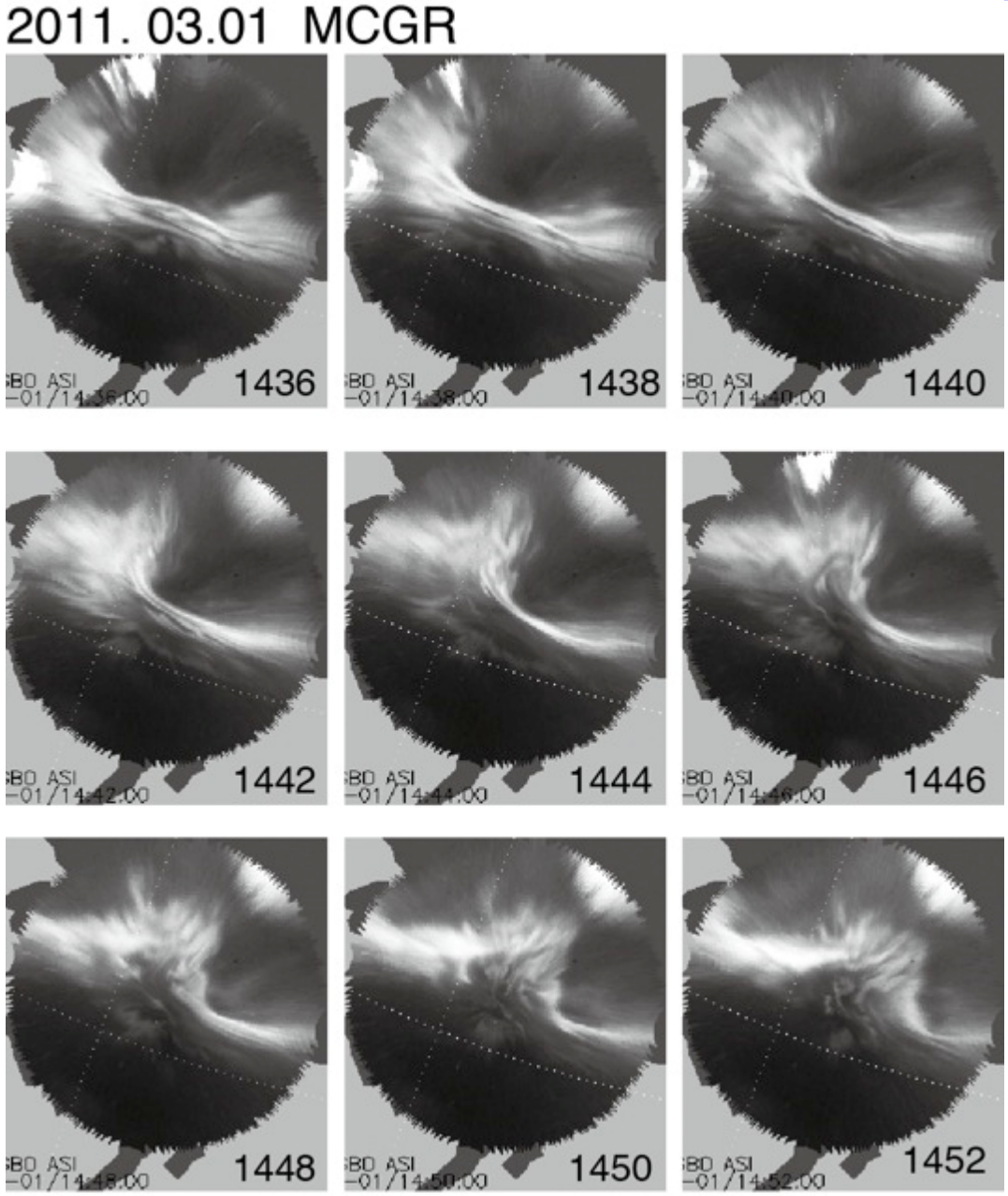
GAKO 2011.03.01



Omega bands observed at GAKO

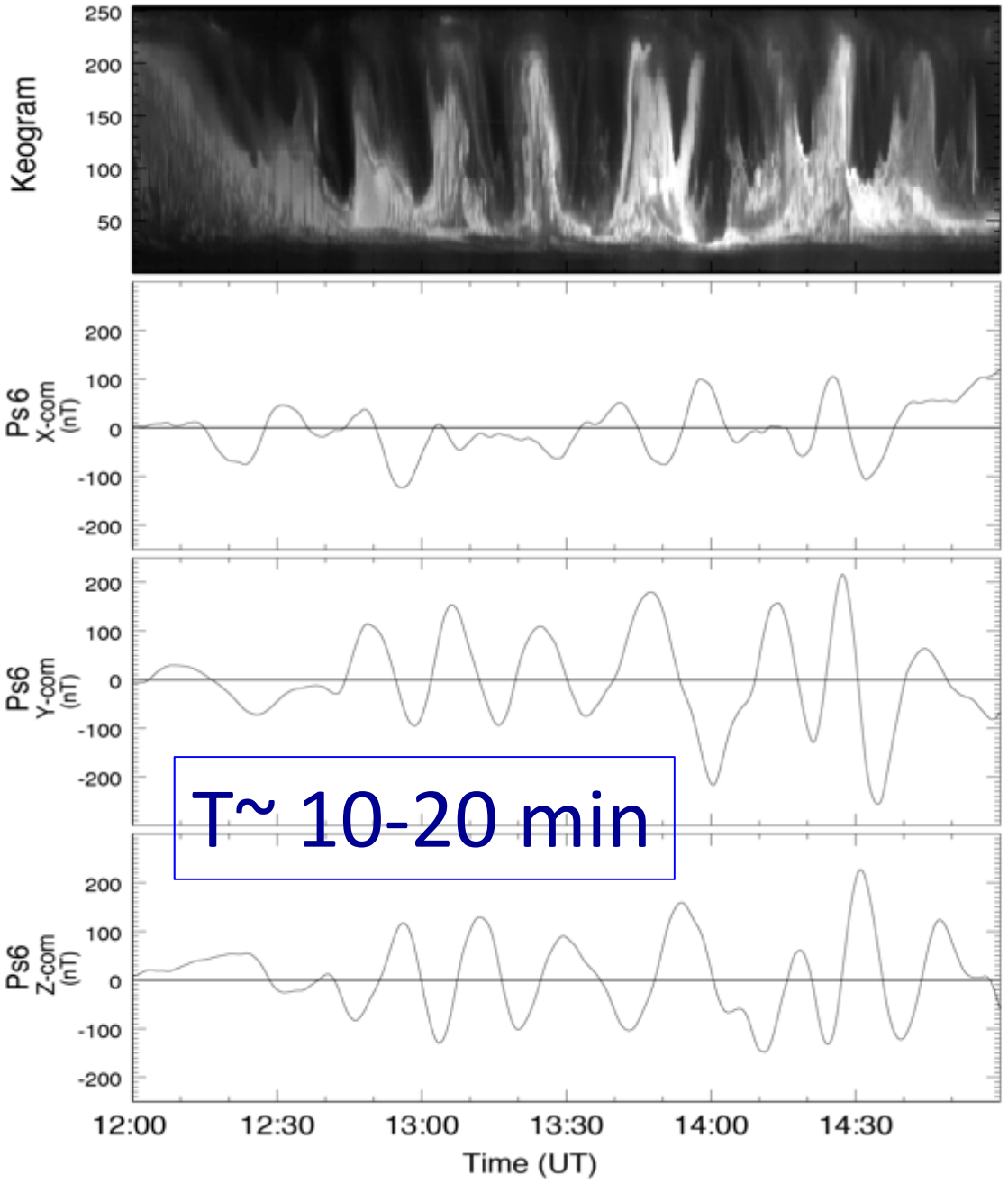


Growth of Omega band Pulsating Aurora



Relation between Omega band auroras and Ps6 Magnetic pulsations

Omega band aurora and Ps6 magnetic pulsation



Keogram (GAKO)

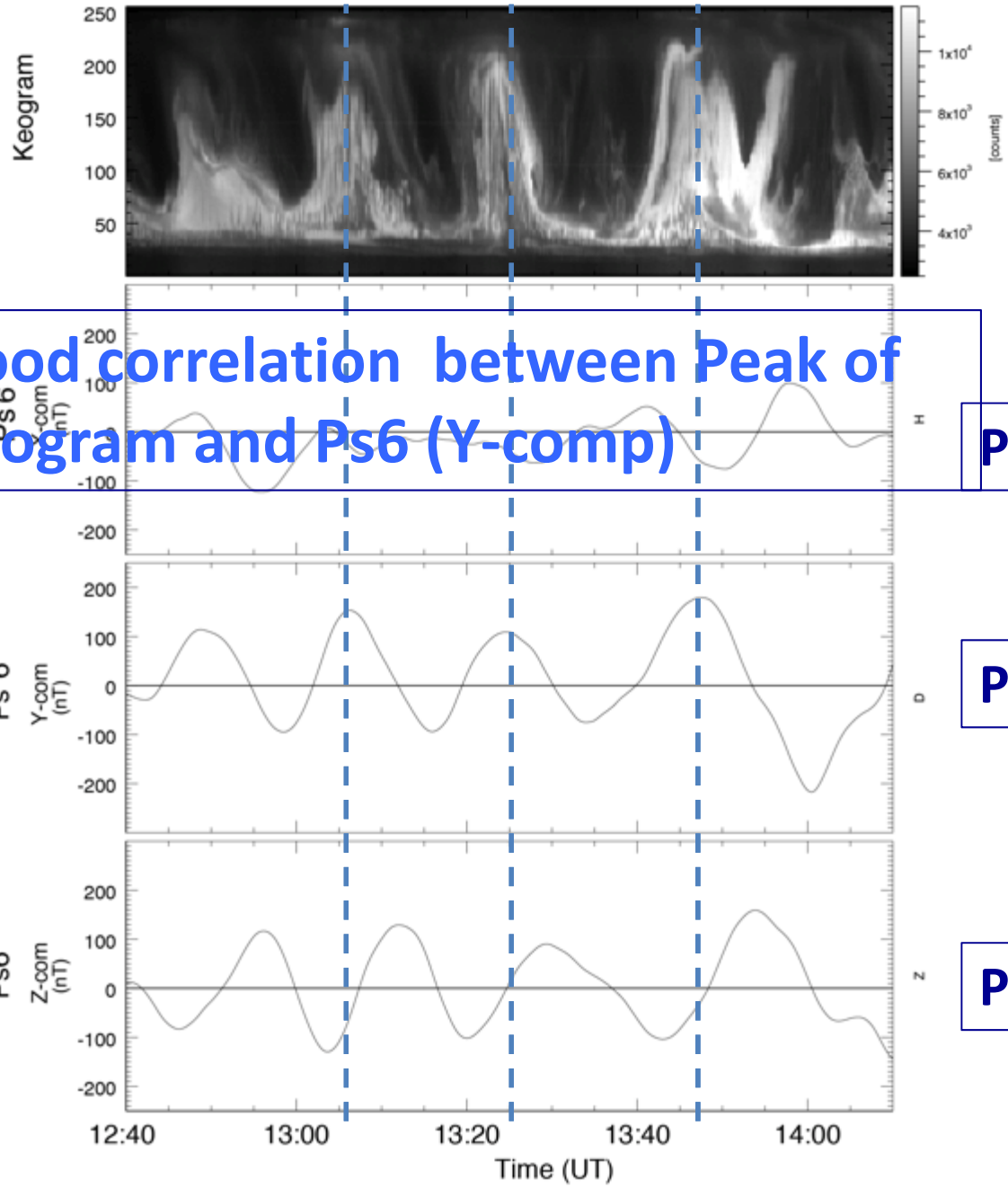
Ps6 (X-comp)

Ps6 (Y-comp)

T~ 10-20 min

Ps6 (Z-comp)

Omega band aurora and Ps6 magnetic pulsation



Keogram (GAKO)

Good correlation between Peak of Keogram and Ps6 (Y-comp)

Ps6 (X-comp)

Ps6 (Y-comp)

Ps6 (Z-comp)

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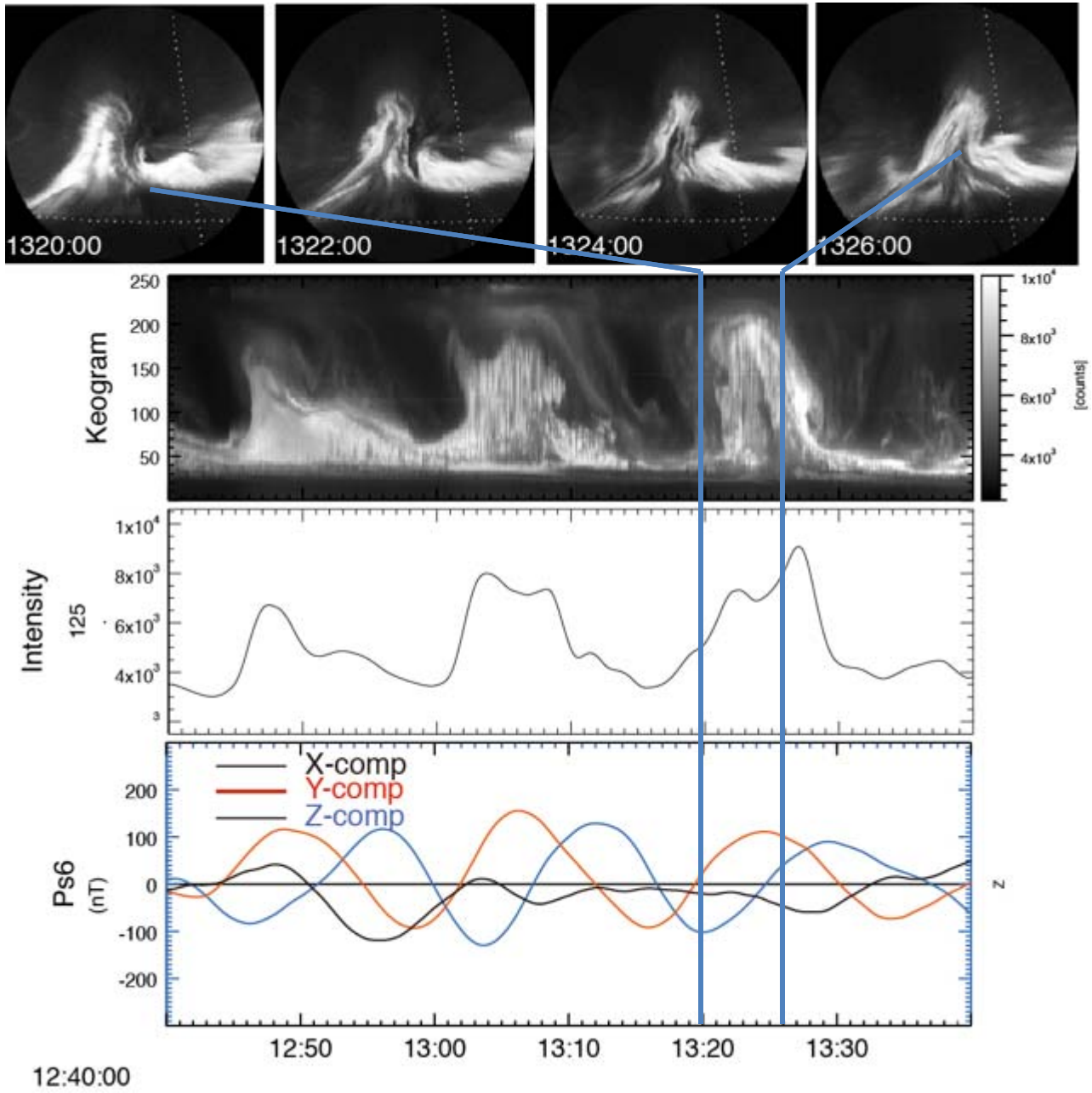
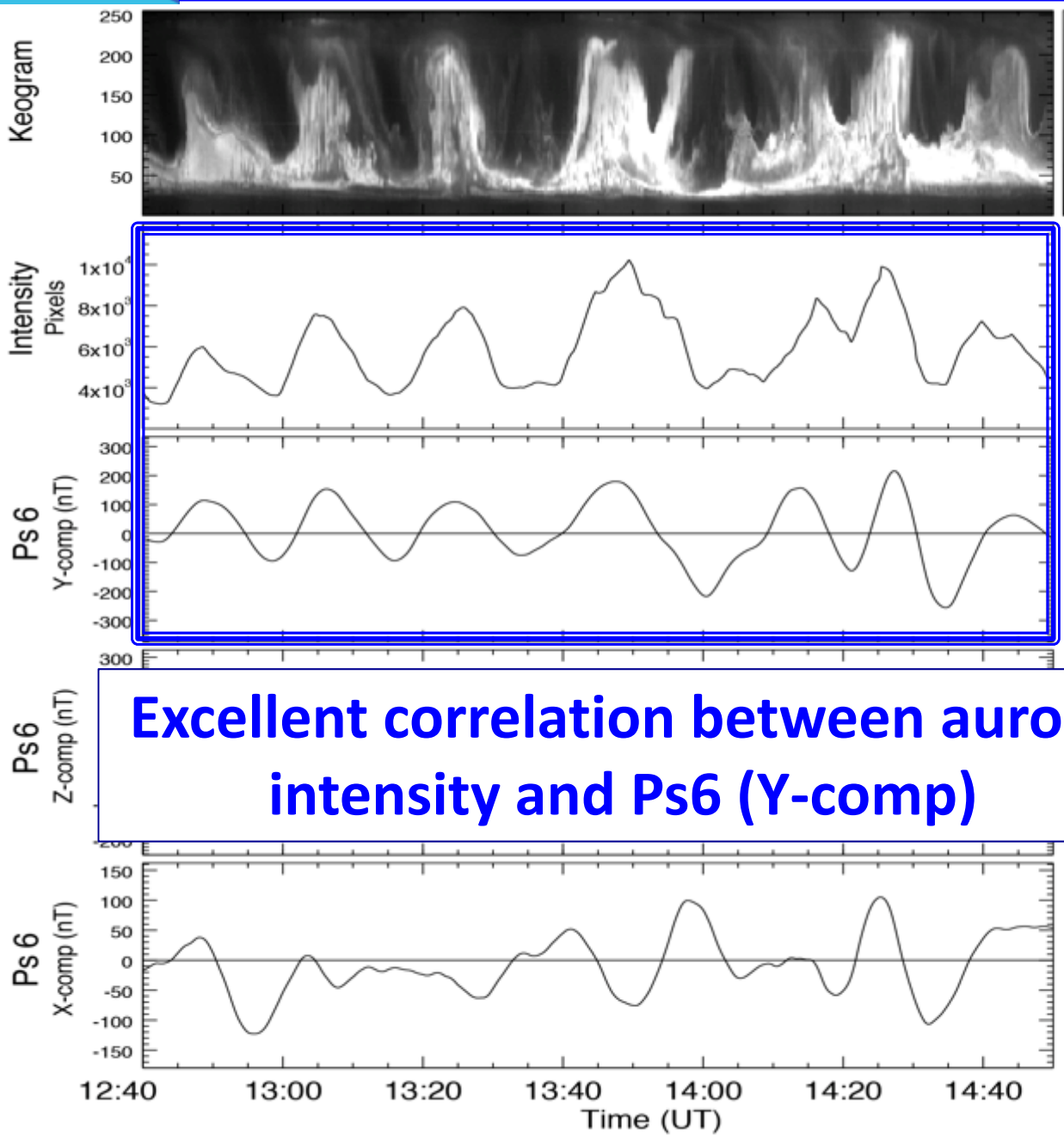

1320:00
1322:00
1324:00
1326:00
Keogram
250
200
150
100
50
1x10^4
8x10^3
6x10^3
4x10^3
[counts]
Intensity
125
1x10^4
8x10^3
6x10^3
4x10^3
X-comp
Y-comp
Z-comp
Ps6
(nT)
200
100
0
-100
-200
Z
12:50
13:00
13:10
13:20
13:30
12:40:00

Omega band aurora and Ps6 magnetic pulsation



Keogram (GAKO)

Aurora intensity at Zenith

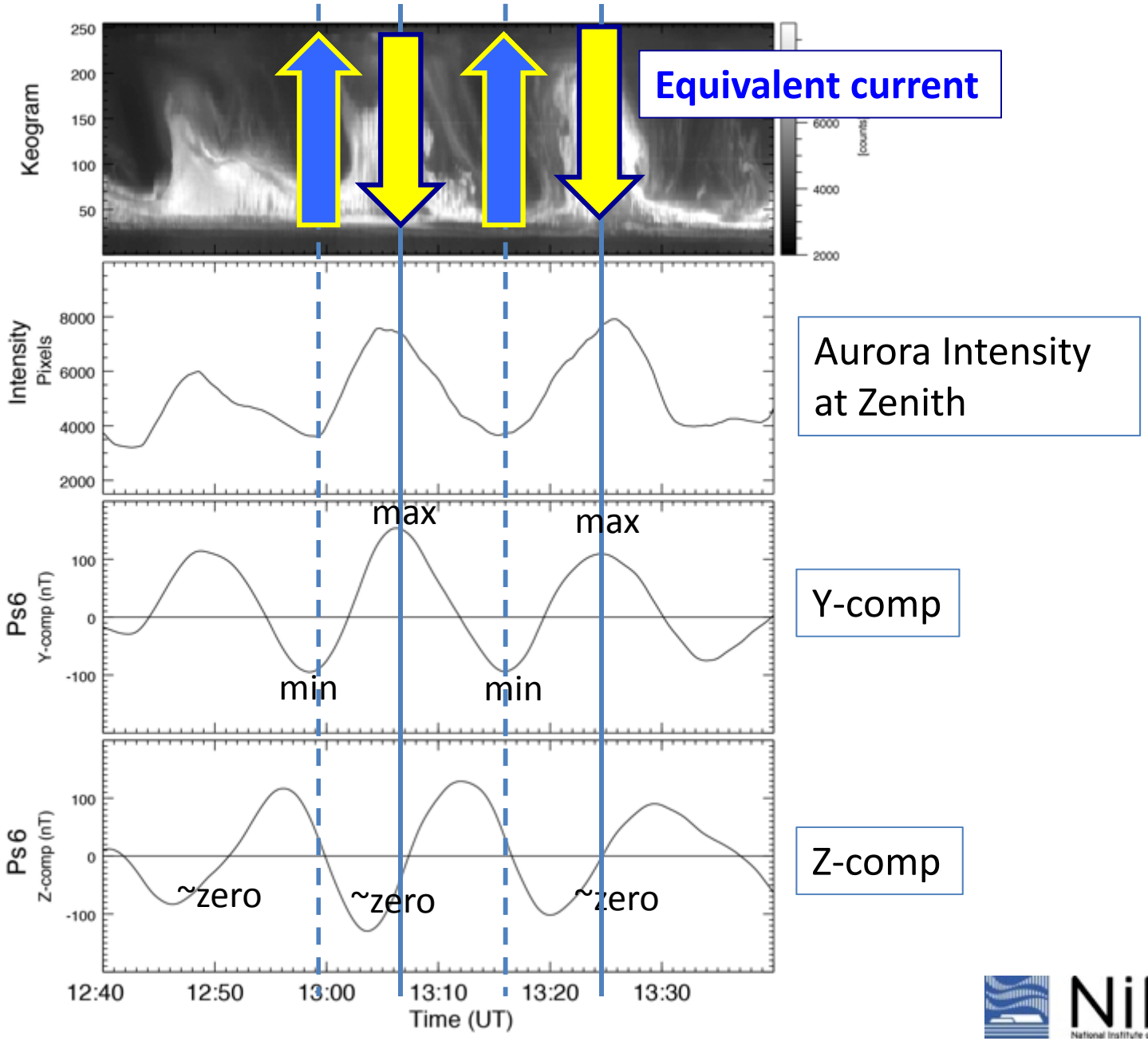
Ps6 (Y-comp)

Excellent correlation between aurora intensity and Ps6 (Y-comp)

s6 (Z-comp)

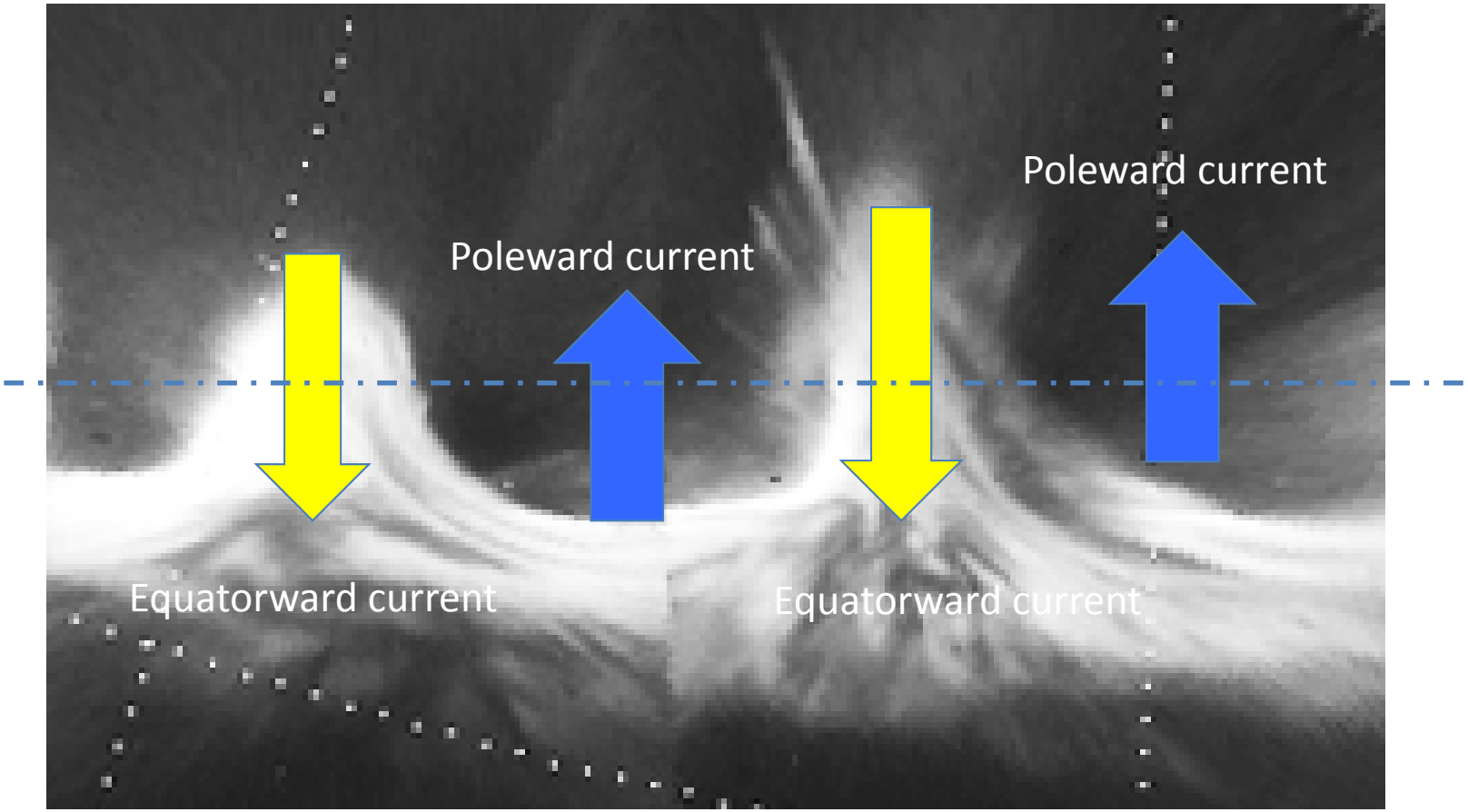
Ps6 (X-comp)

Omega band aurora and Ps6 magnetic pulsation



Omega band aurora and Ps6 magnetic pulsation

Equivalent current



Omega band aurora and field-aligned current

Opgenooth et al., 1983.JGR

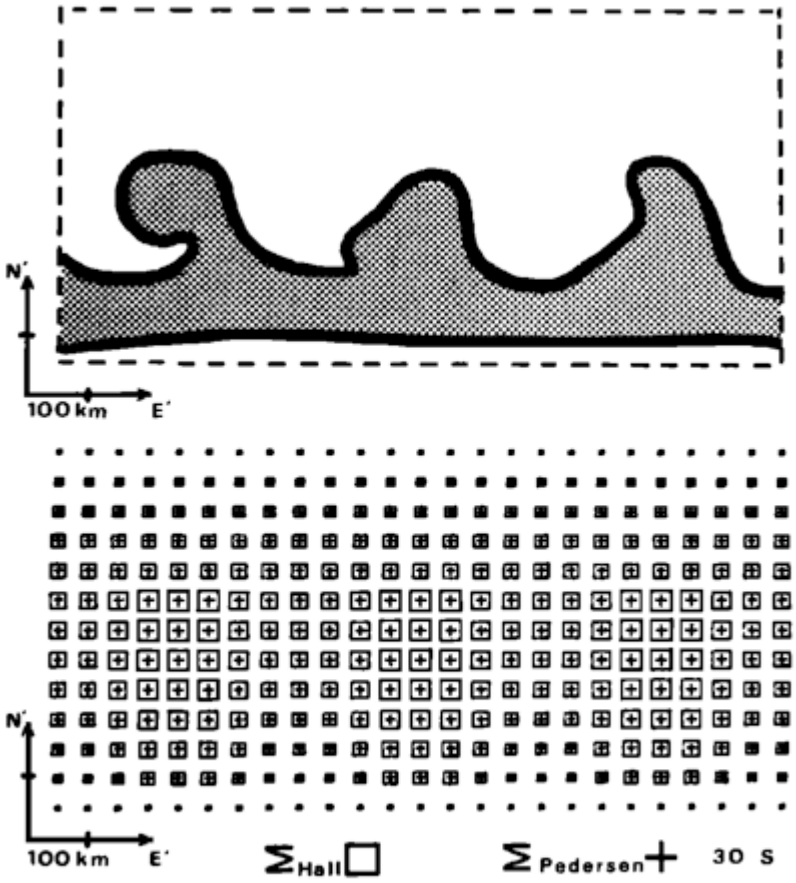


Fig.11b. Inhomogeneous model conductivity distribution (lower panel) associated with the auroral forms (upper panel).

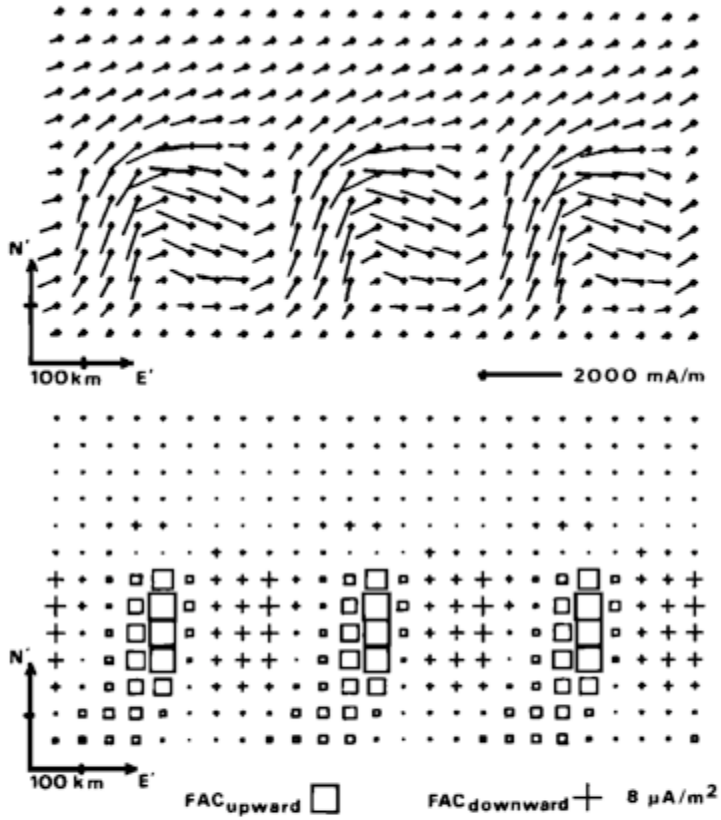


Fig.11c. Three-dimensional current system associated with the auroral forms. (upper panel) Height-integrated horizontal ionospheric current flow according to the electric field and conductivity distributions in Figures 11a and 11b. (lower panel) Field-aligned current flow as determined from the divergence of the horizontal current in the upper panel.

2011.03.01

Omega band event

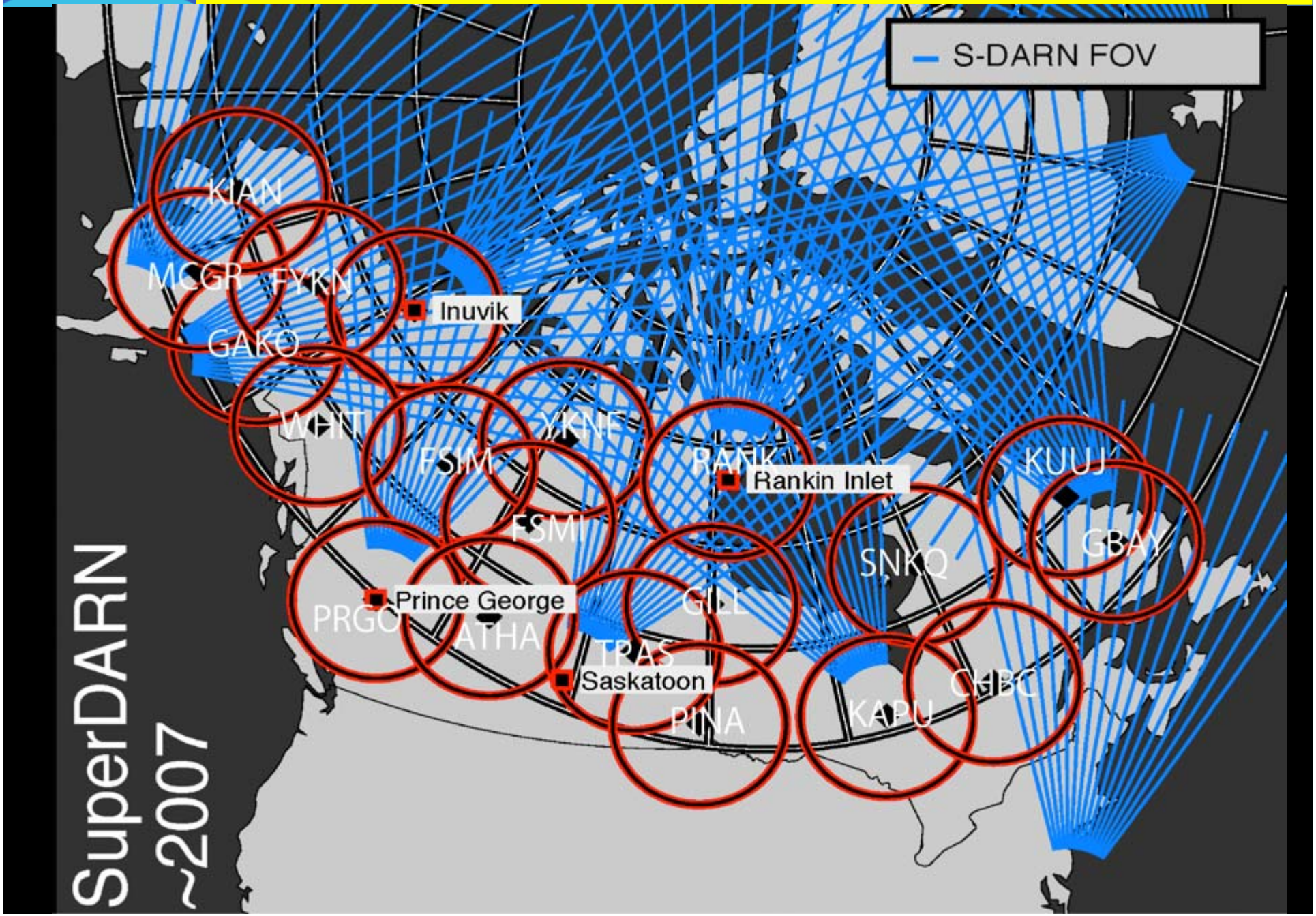
observed at Mcgrath and Gakona in Alaska

compared with

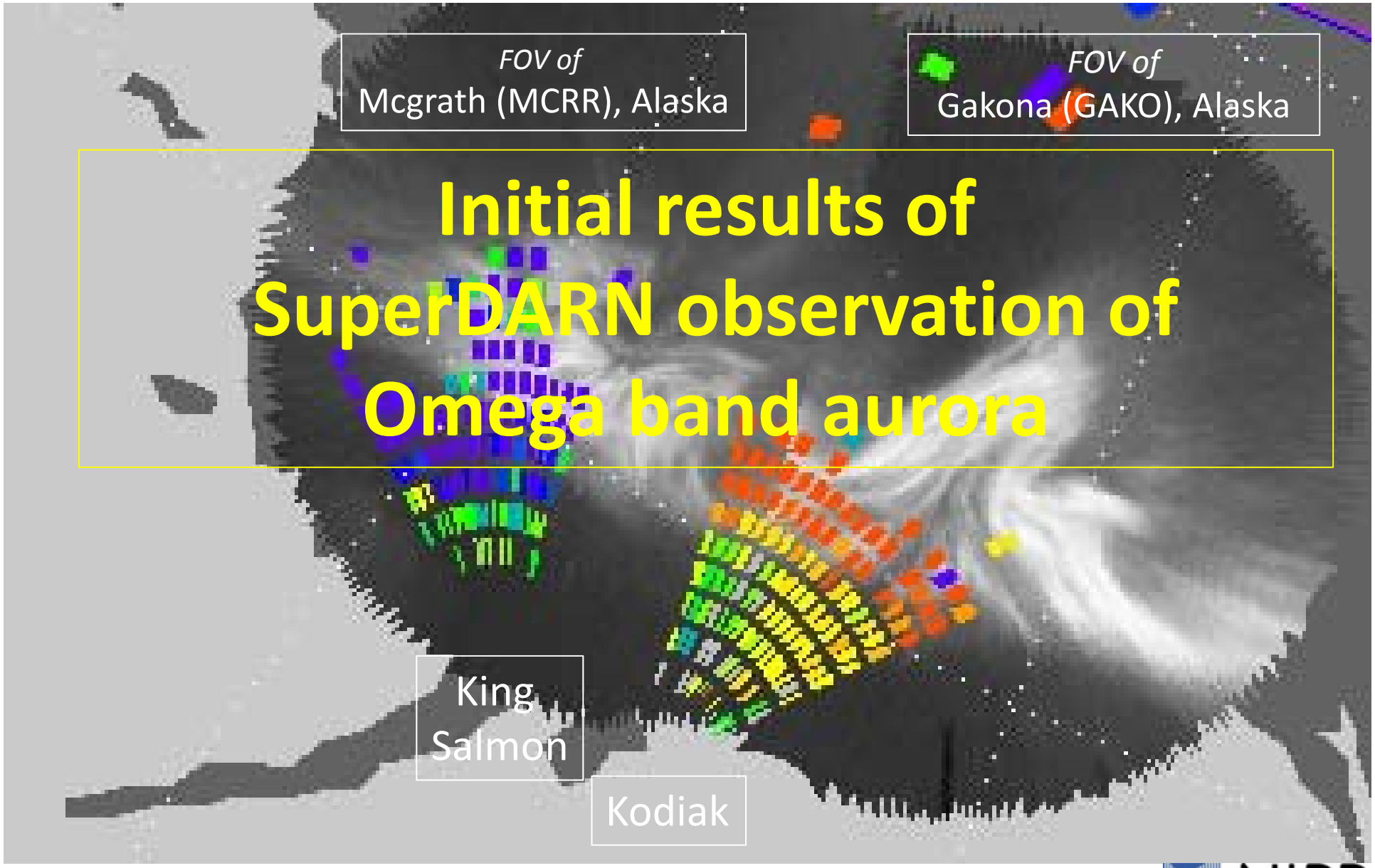
SuperDARN radars at

Kodiak and King Salmon

THEMIS all-sky camera network and SuperDARN

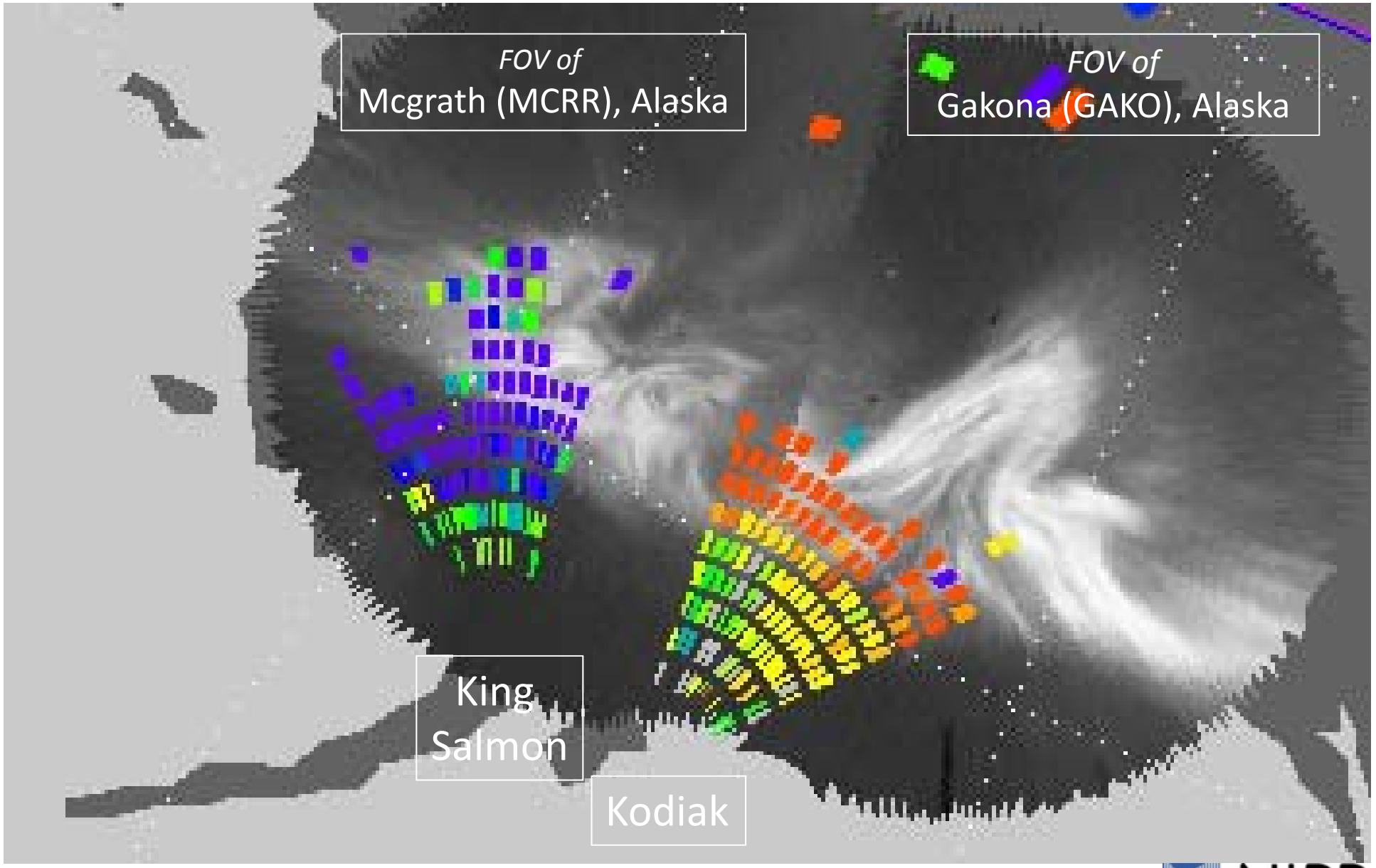


SD observation of Omega band aurora

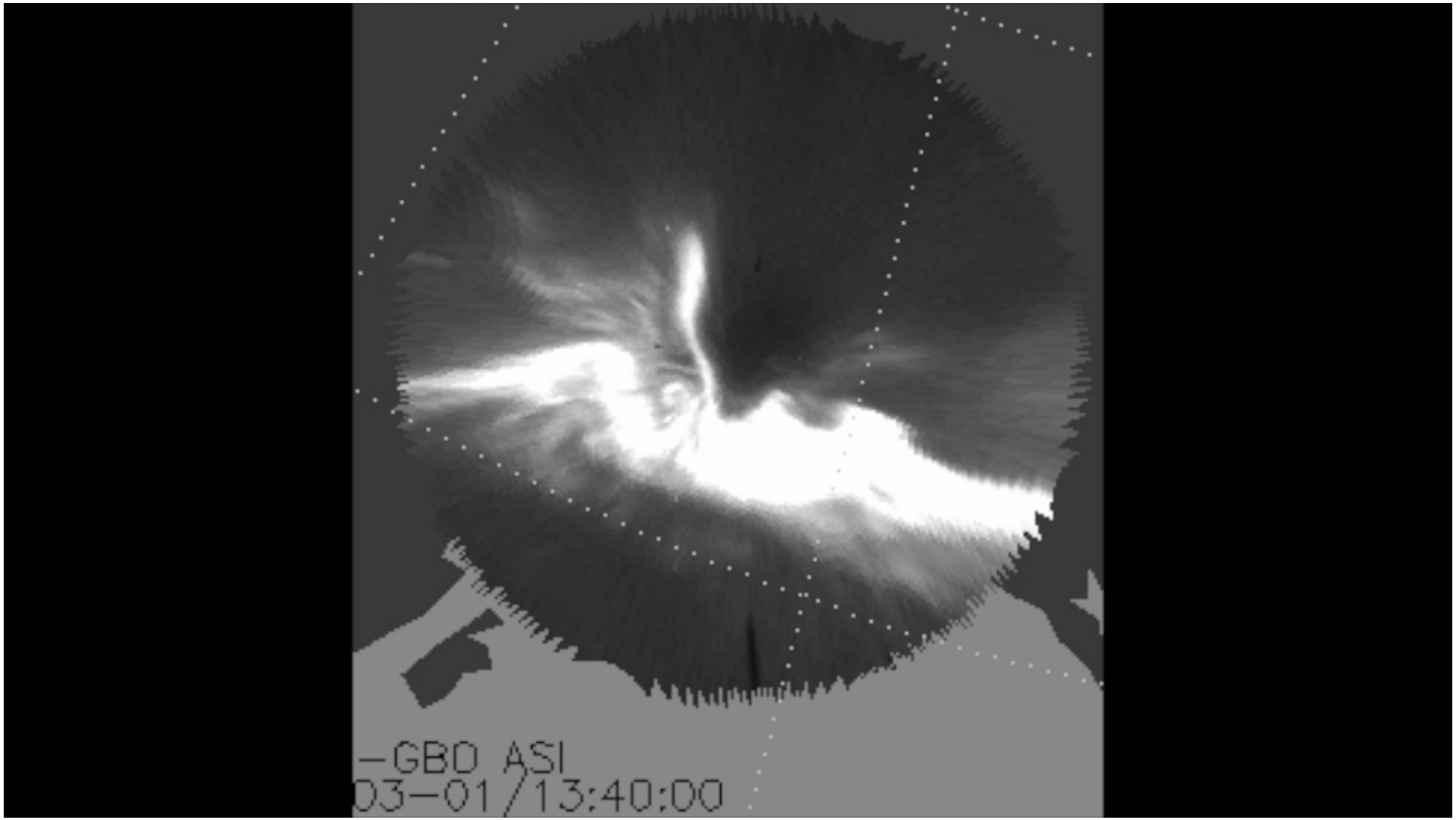


Initial results of SuperDARN observation of Omega band aurora

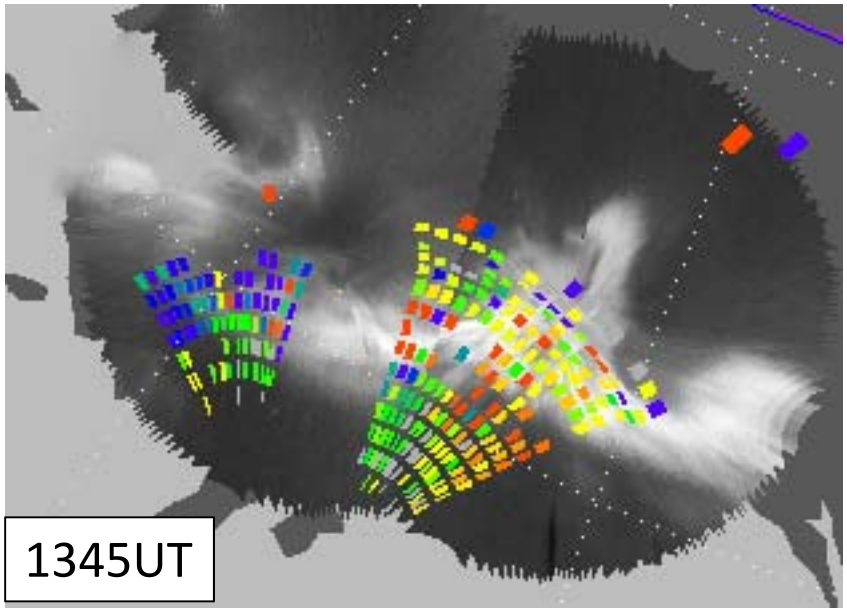
SD observation and Omega band aurora

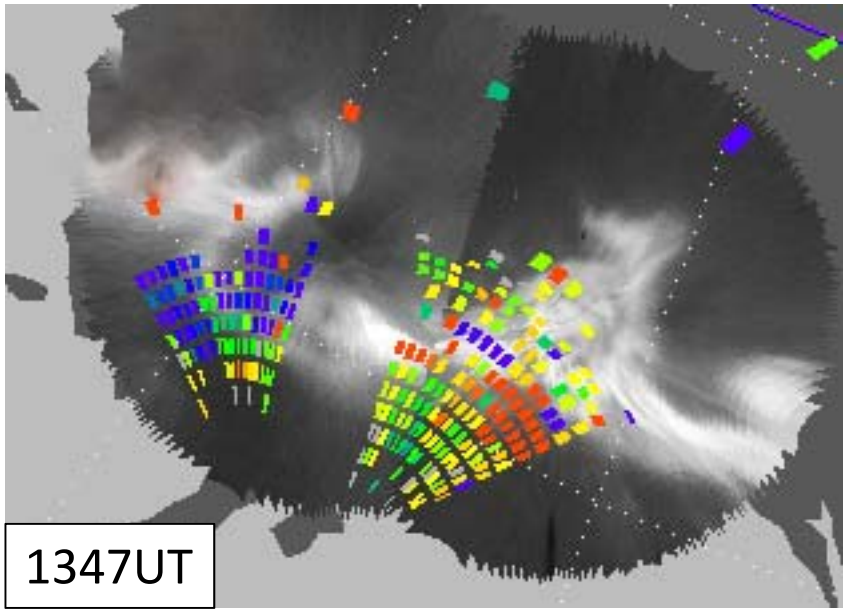


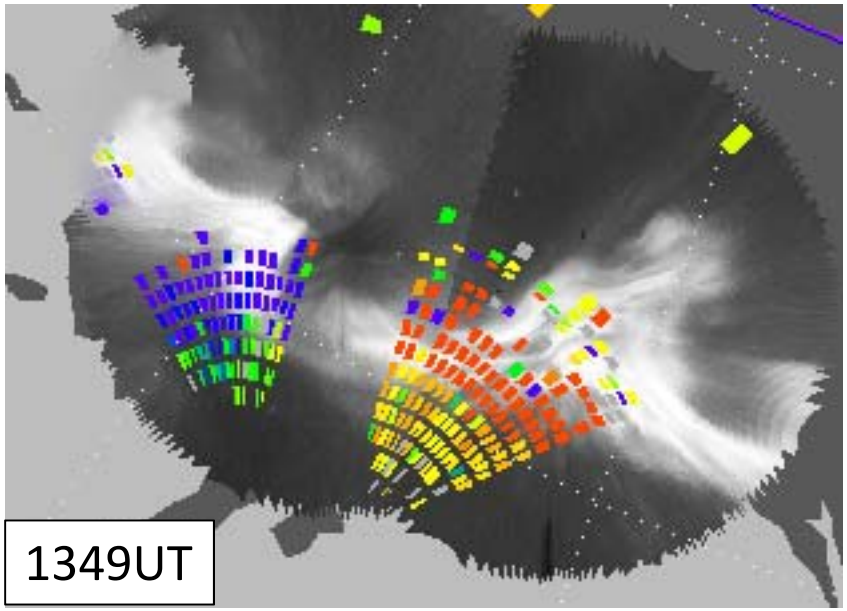
Event (1)

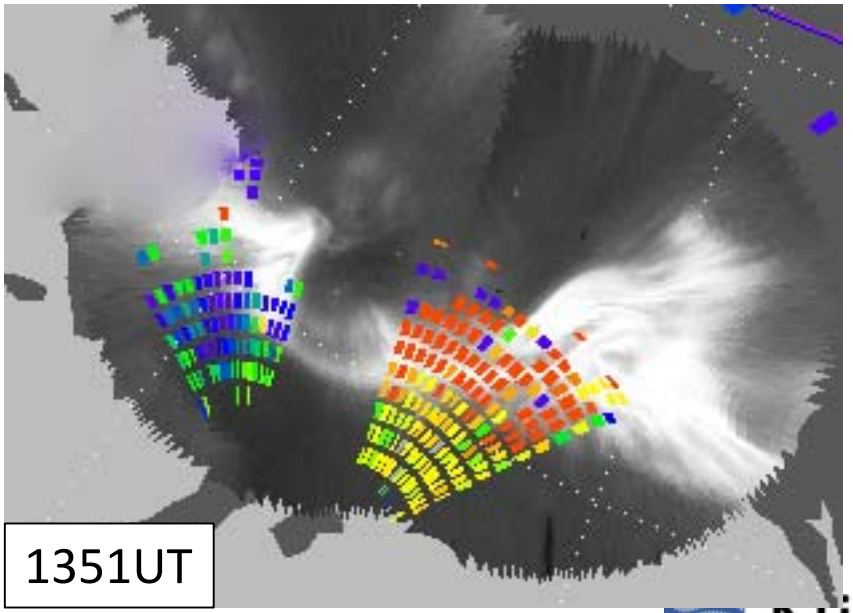


Omega band aurora and Convection by SD

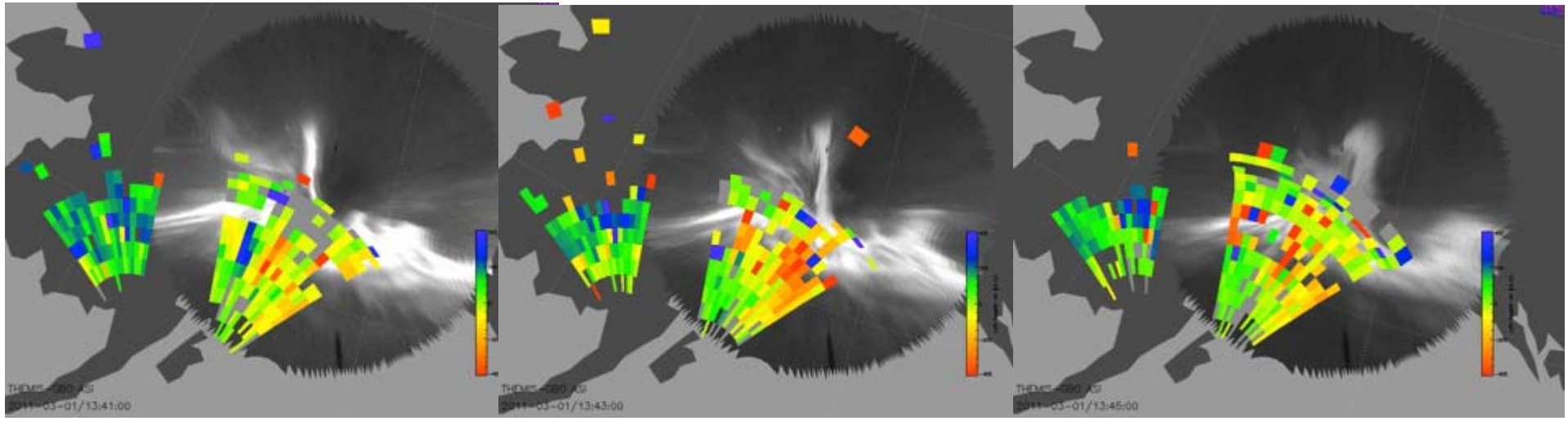




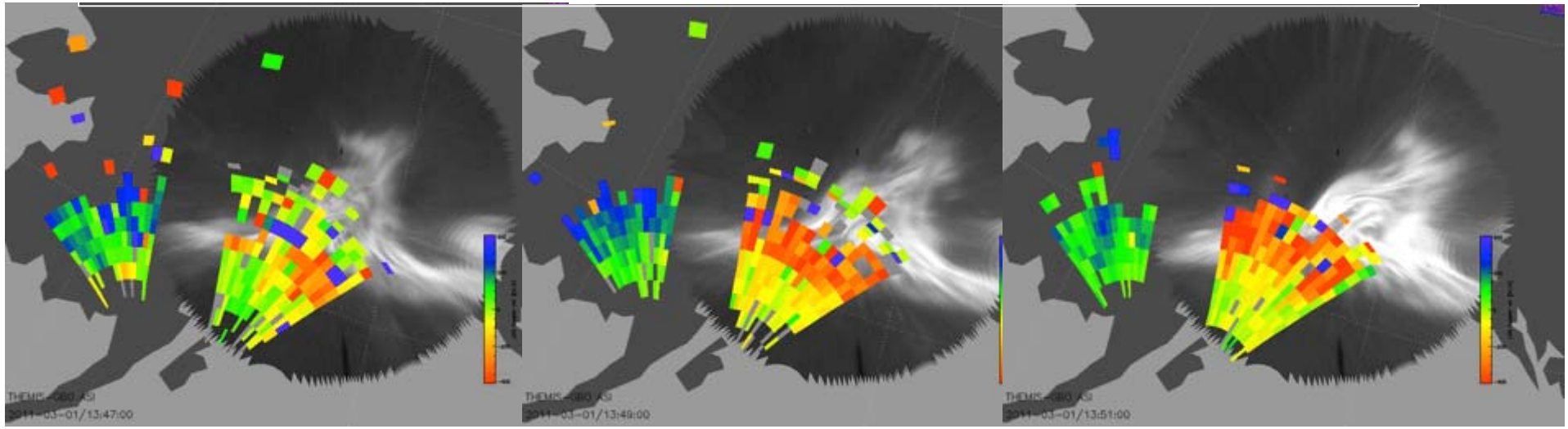




Omega band aurora and Convection by SD

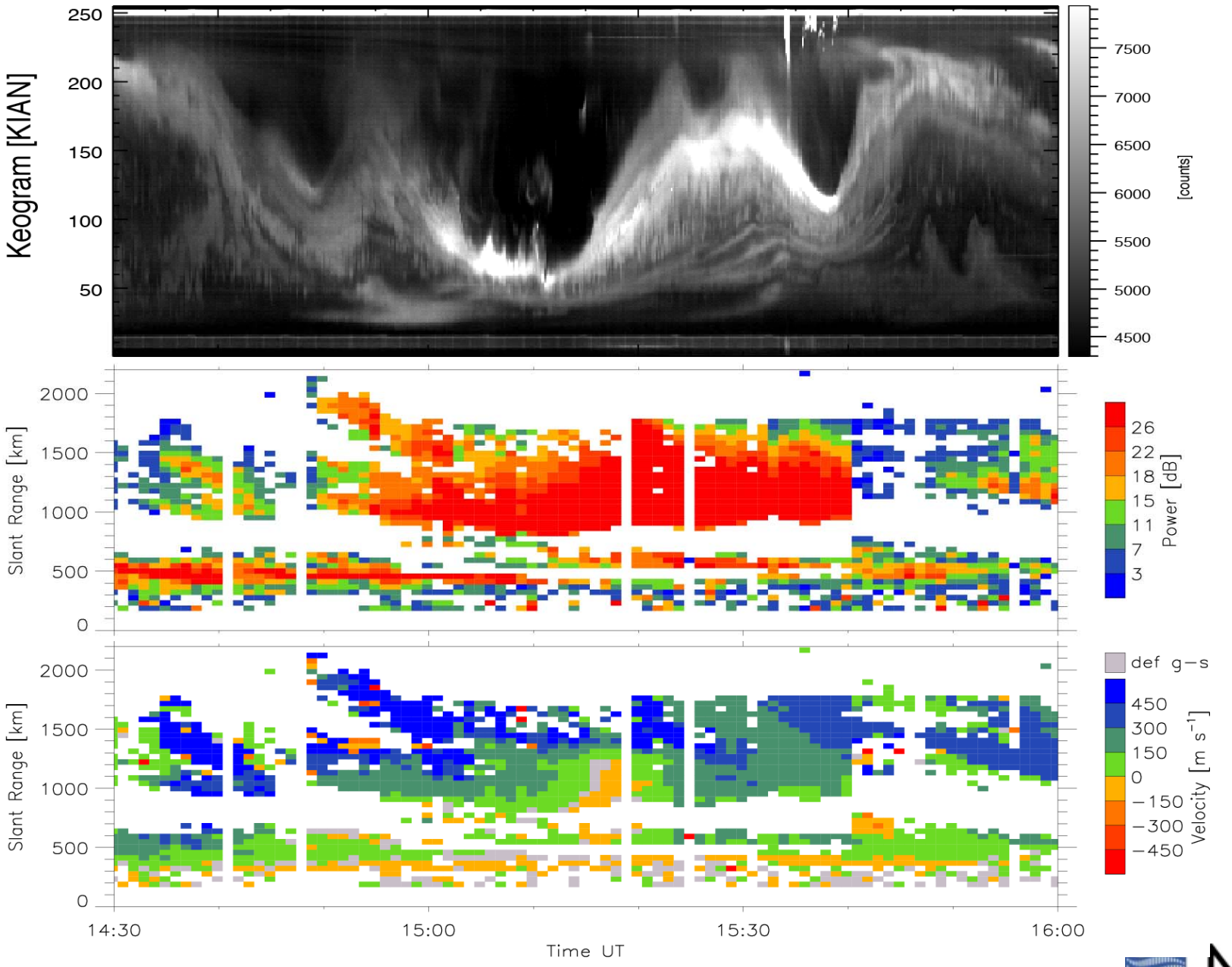


Electric field enhanced when Omega band aurora enhanced



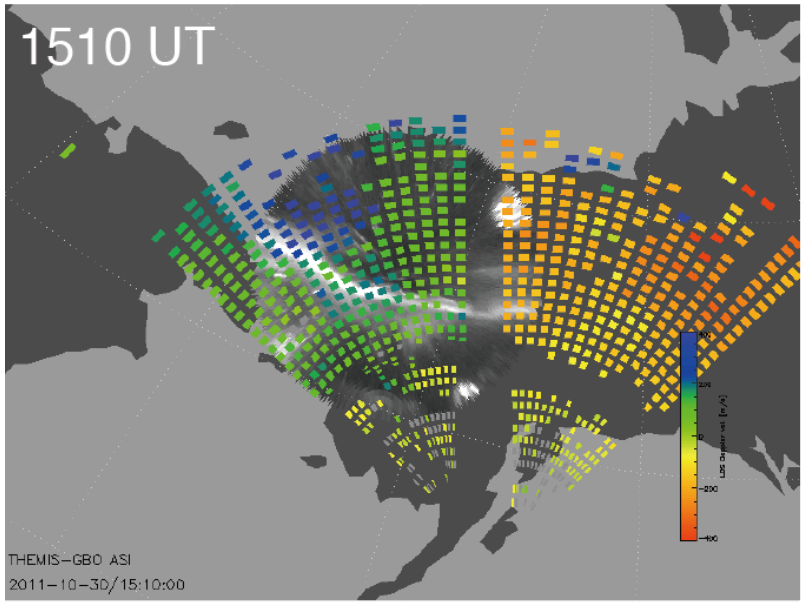
2011.10.30
Omega band event
observed at Kiana in Alaska
compared with
SuperDARN radars at
Kodiak and King Salmon

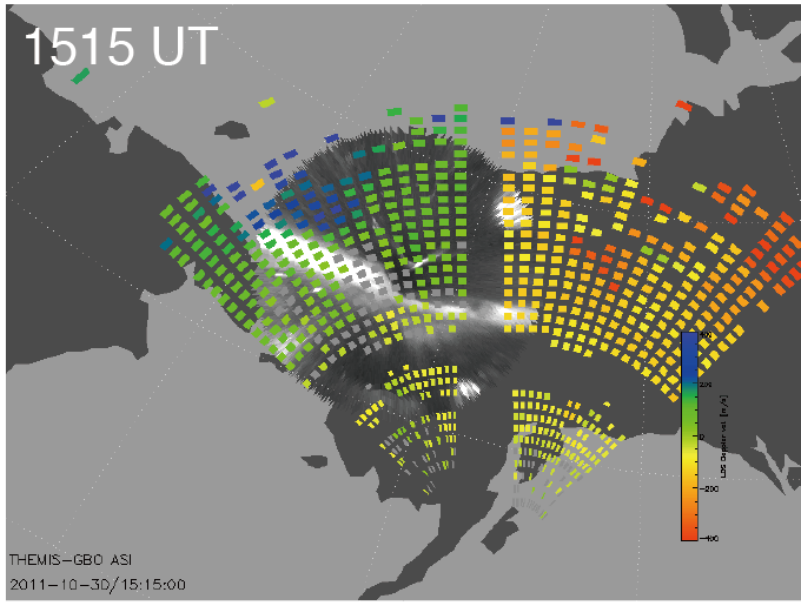
Omega band aurora and Convection by SD

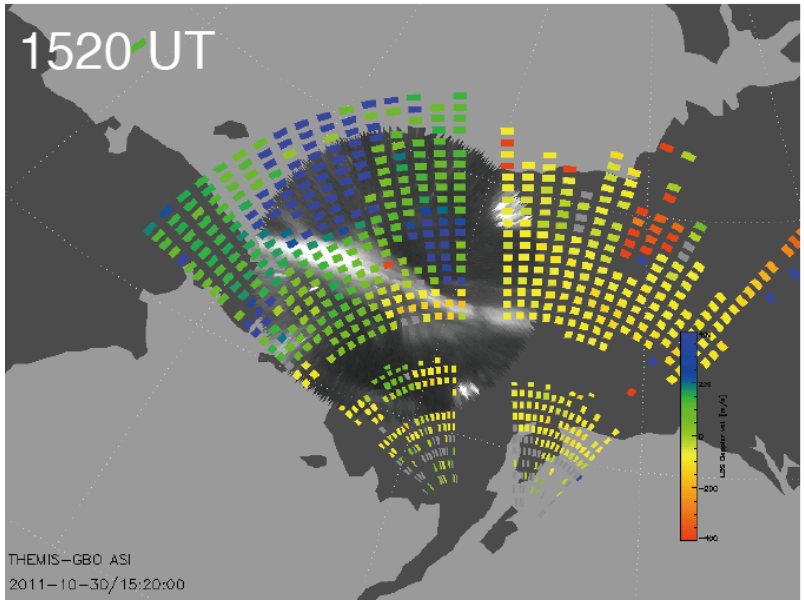


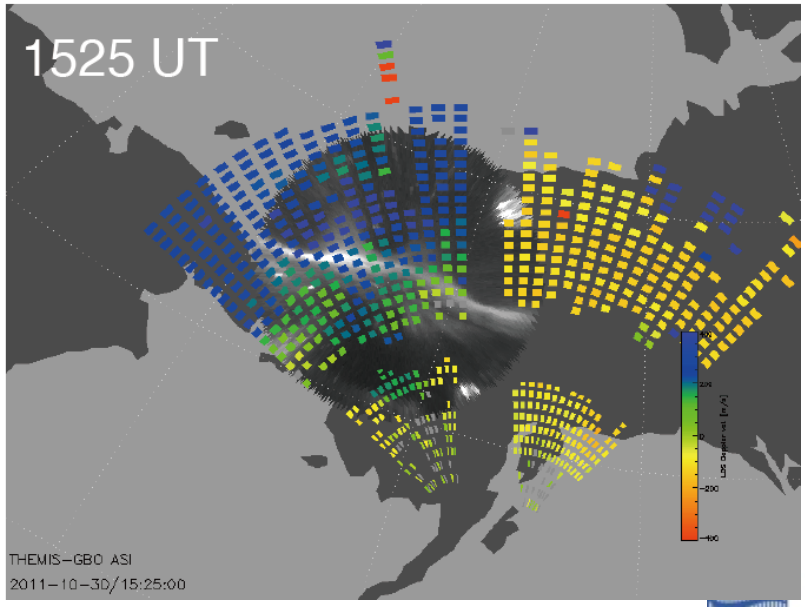
Omega band aurora and Convection by SD

2011.10.30 King Salmon



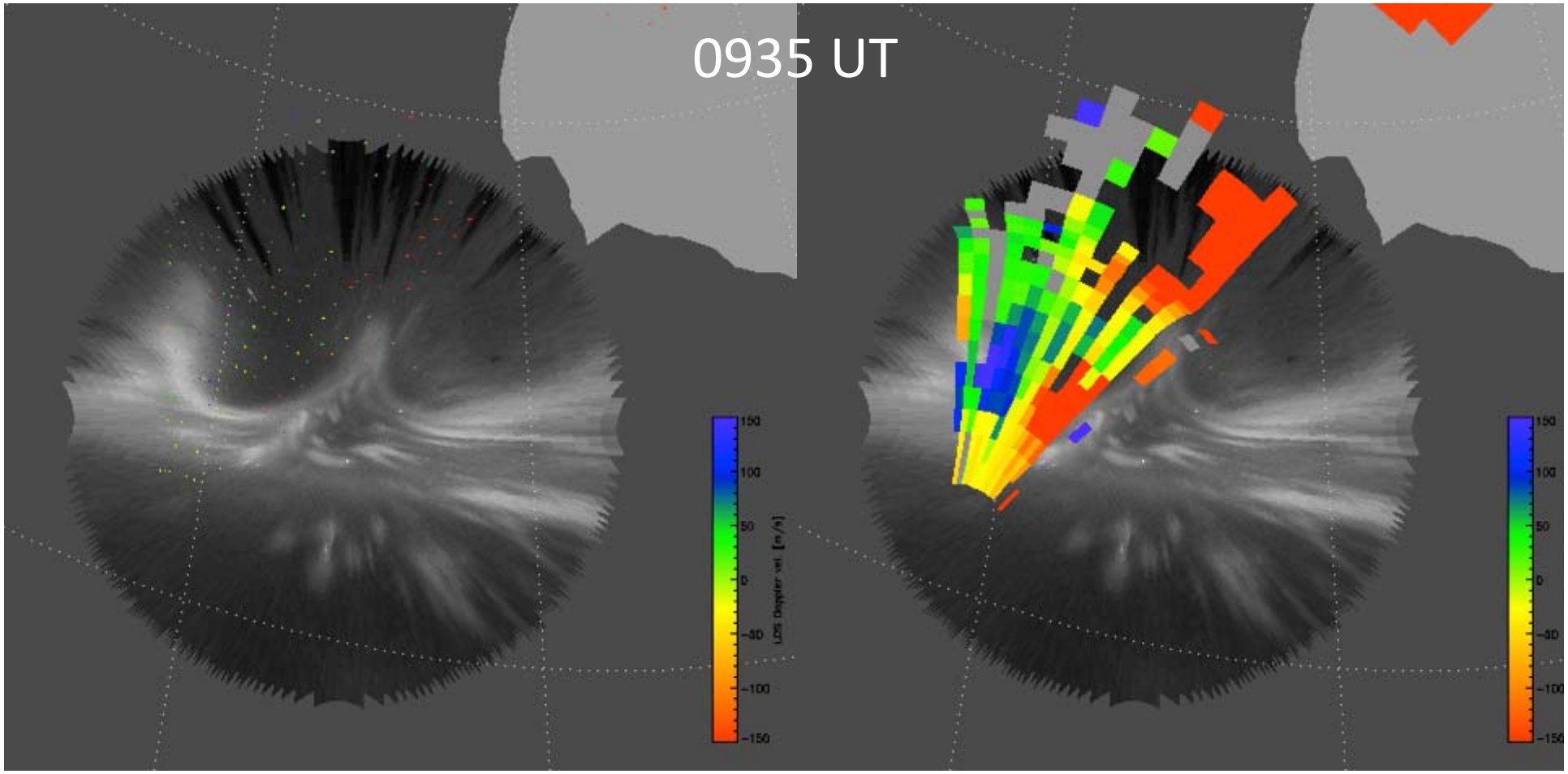




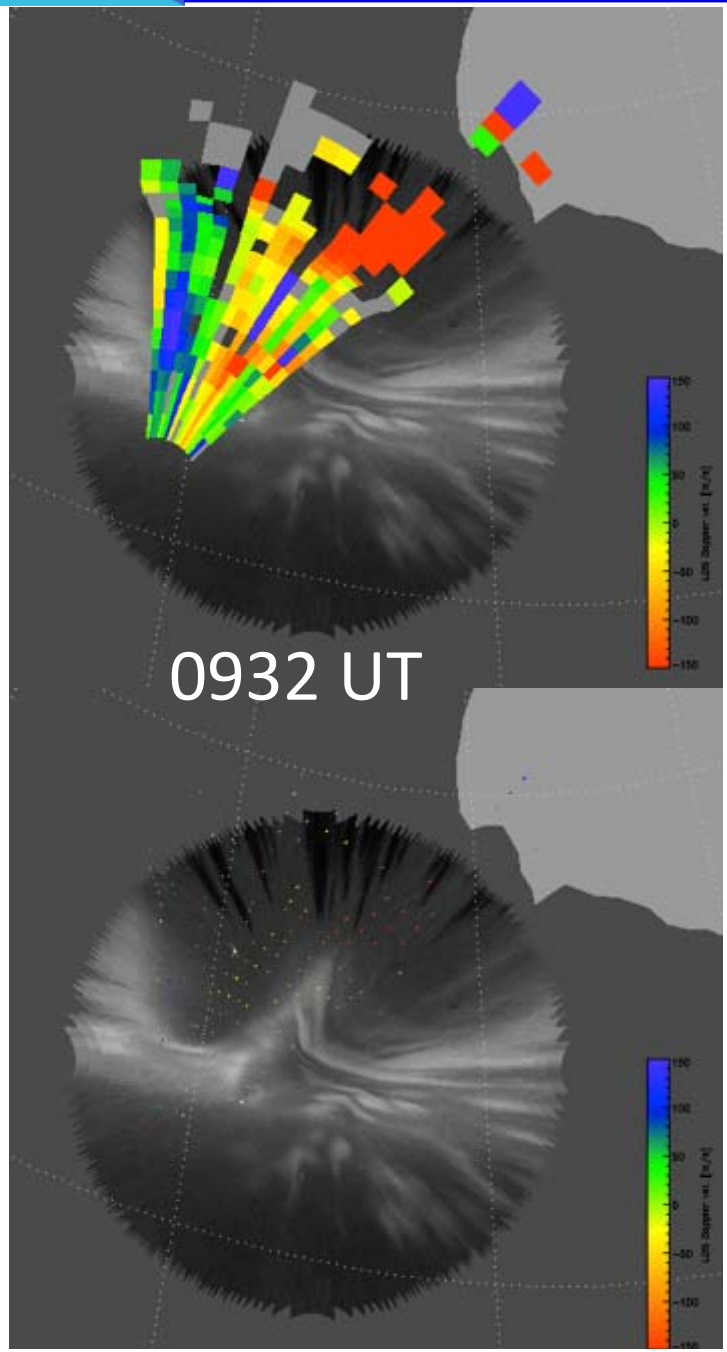


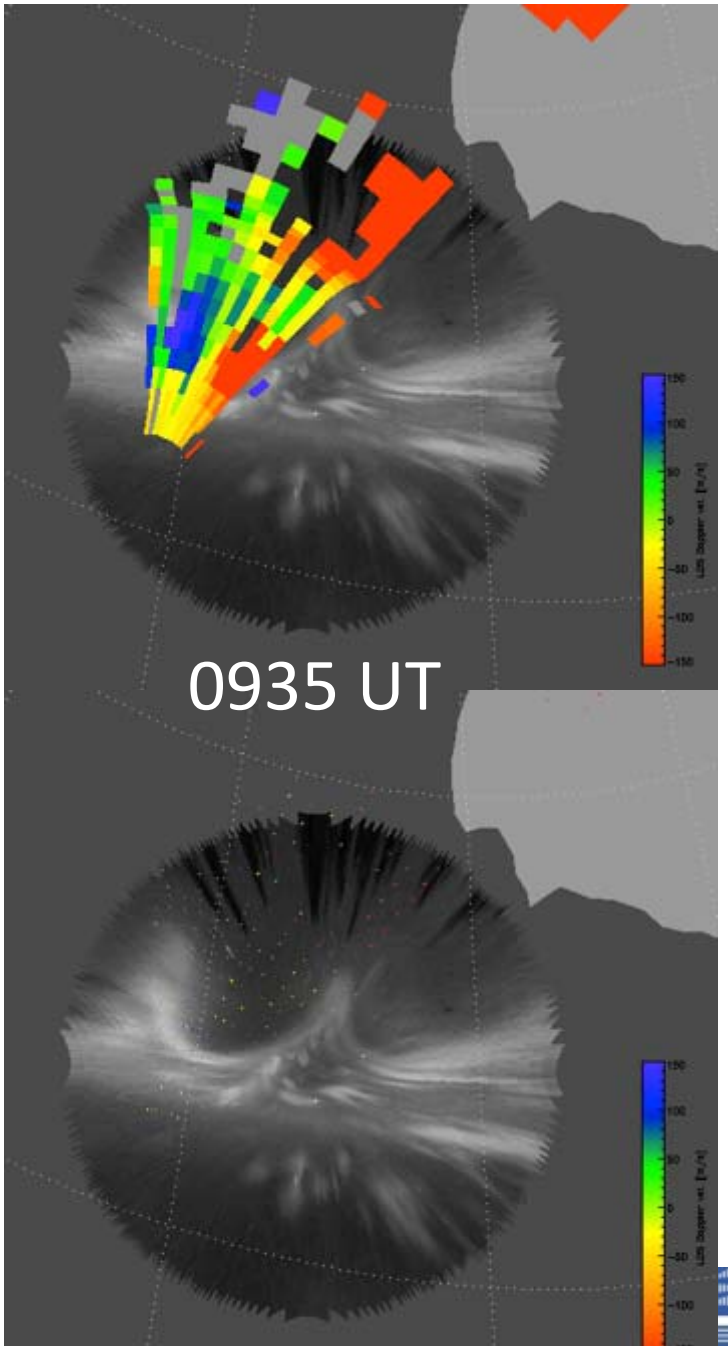
Omega band aurora and Convection by SD

2008.03.09 Saskatoon SD/Gill ASI



Omega band aurora and Convection by SD





Summary and Conclusion (1)

(1): Optical signature on the ground

A torch-like structure omega band pulsating aurora was observed simultaneously on the ground and onboard the THEMIS spacecraft.

*The omega band aurora **grew from a faint seed, not via distortion** of a pre-existing east-west band aurora.

*The aurora did **not show any shear motion** during the growth of auroral activity.

*The aurora drifted eastward with a speed of ~0.25 km/s.

***A black hole-like dark region** was found during the growth and expansion phases at the east side of the omega band aurora.

*The meso-scale omega band aurora **consisted of more than 15 patches** of complex-shaped small-scale auroras.

*Each patch showed an intense pulsating aurora with a recurrent period of ~9-12 s and a **poleward-moving form**.

Summary and Conclusion (2)

(2) Omega band aurora and Ps6 magnetic pulsation

*Ps6 (Y) and aurora intensity showed one to one correlation
*Ps6 (Y) became maximum when omega aurora arrived at the zenith
*Ps6 (Y) became minimum when black hole-like dark region arrive at zenith
*Ps6 (Z) became zero when both of Ps6 (Y) became maximum and minimum

(3) Equivalent Current of Ps6 magnetic field

*Equator current is associated with omega band aurora
*Poleward current is associated with the back hole-like dark region
*That is, Ps6 magnetic pulsations occurred in association with the temporal and spatial variation of Omega band aurora

(4) Initial result of SuperDARN radar

*Electric field intensity enhanced when Omega band aurora enhanced
*We need further work!

Future work

(1): Generation signature of Omega band aurora

- Statistical signatures with relation to IMF
- Initial optical signature of growth of aurora
- SuperDARN
- NIPR Data (Syowa: unmanned magnetometer), Iceland, Tromso (EISCAT)
- Survey of simultaneous events of Satellite and on the ground

(2): Catalogues (Photo and Movie

- Pulsating aurora
- Omega band aurora

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