Seasonal variations of Saturn's auroral acceleration region deduced from spectra of auroral radio emissions

T. Kimura[1], L. Lamy[2], C. Tao[1], S. Badman[1], B. Cecconi[2], P. Zarka[2], A. Morioka[3], Y. Miyoshi[4], Y. Kasaba[3], D. Maruno[3] and M. Fujimoto[1]

1: ISAS, JAXA, 2: Paris Observatory, 3: Tohoku University, 4: Solar Terrestrial Environment Laboratory, Nagoya University

Multi-instrumental survey of Saturn's magnetosphere by Cassini indicated that auroral radio emissions (Saturnian Kilometric Radiation, SKR), aurorae in UV and IR wavelengths and Energetic Neutral Atoms (ENA) from the inner magnetosphere have periodic behavior around the Saturn's rotational period [e.g., Kurth et al., 2008; Mitchell et al., 2009; Nichols et al., 2010]. Remote sensing of SKR over more than 7 years discovered that the periodicity is asymmetric between the northern and southern hemisphere and varies depending on seasons [Gurnett et al., 2010]. Perturbations of magnetic field in the polar and equatorial region were also found to be rotationally periodic with the north-south asymmetry and seasonal variations, suggestive of the north-south asymmetric current system of the magnetosphere-ionosphere coupling process corotating at different periods [e.g., Andrews et al., 2010]. These phenomena suggest the magnetosphere-ionosphere coupling process and associated energy dissipation process (aurora & SKR) are dynamically dependent on rotations and long-term conditions of magnetosphere/ionosphere.

To reveal the global view of this M-I coupling process, this study investigated seasonal variations Saturn's auroral acceleration region, which is the interface between the ionosphere and magnetosphere, based on a sufficient data volume of SKR observed by Cassini's wave experiment. Morioka et al. [in press] investigated spatial distribution of the auroral acceleration region along polar magnetic field line based on spectra of the terrestrial auroral kilometric radiation (AKR). Spectra of planetary radio emissions allow us to deduce spatial distribution of auroral acceleration region where energetic electrons excite radio emissions at a frequency near the local cyclotron frequency via the Cyclotron Maser Instability [Wu and Lee 1979].

Applying this approach to Saturn, we deduced height distribution of auroral acceleration region in the northern and southern hemisphere from SKR spectra over 7 years from 2004 to 2010. It was found that the southern (summer) SKR spectral density is 10db greater at the peak altitude (~0.9Rs) in average and harder in height direction than those in the northern (winter) hemisphere. In addition, southern and northern spectral densities become comparable with each other around the equinox. These results suggest stronger field aligned acceleration and current in the southern hemisphere than north depending on seasons. The main auroral oval in IR is similarly stronger in the southern hemisphere than north during southern summer [Badman et al. 2011]. Badman et al. [2011] suggested that greater conductivity in the southern polar ionosphere could result in greater precipitating electron flux and/or Joule heating which are responsible for the stronger southern auroral emissions in IR. The north-south asymmetric acceleration region deduced from SKR will be further compared with ionospheric and magnetospheric parameters (e.g., electron density, temperature, conductivity). Finally, comparative discussions of M-I coupling process between Saturn and Earth will also be presented.

Symposium on Planetary Science 2012 Poster-1

Seasonal variations of Saturn's auroral acceleration region deduced from spectra of auroral radio emissions

T. Kimura[1] with
L. Lamy[2], C. Tao[1], S. V. Badman[1], B. Cecconi[2], P. Zarka[2], A. Morioka[3], Y. Miyoshi[4], Y. Kasaba[3], D. Maruno[3] and M. Fujimoto[1]
1: ISAS, JAXA, 2: Paris Observatory, 3: Tohoku University,
4: Solar Terrestrial Environment Laboratory, Nagoya University

1

Saturn's M-I coupling process

- Steady state: M-I coupling current is driven by sub-corotation of magnetospheric plasma at Saturn and Jupiter [e.g., Cowley and Bunce 2003, 2004]

field-aligned current above polar ionosphere

$$j_{\parallel i}(\theta) = -\frac{n_r}{2\pi R_i^2(\theta)\sin\theta}\left(\frac{B_i}{B_{i_n}}\right)\frac{dI_{hP}}{d\theta}$$

ionospheric Pedersen current

$$I_{hP}(\theta) = 2\pi\Sigma_P^*\Omega_S B_{ip} R_i^2(\theta)\sin^2\theta\left(1-\frac{\omega}{\Omega_S}\right)\left(\frac{B_i^2}{B_{ip}\,|B_{i_n}|}\right)$$

sub-corotational term

ω : angular velocity of magnetospheric shell

Ω_s: angular velocity of Saturn's rotation

Σ_p^* : effective height integrated Pedersen conductivity

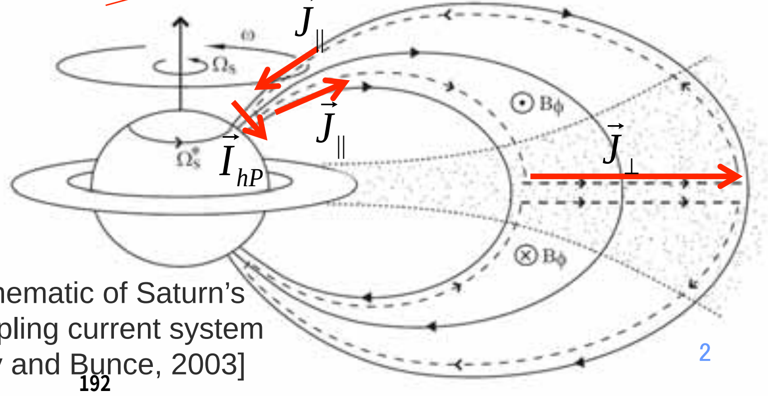


Fig. Schematic of Saturn's M-I coupling current system [Cowley and Bunce, 2003]

2

Dynamic and asymmetric coupling

- Periodic enhancement of Saturnian Kilometric Radiation (SKR) near planetary rotation period [e.g., Desch and Kaiser, 1981; Gurnett et al., 2007, 2010]
- Rotationally periodic intensification of dawn aurora and ENA in the inner magnetosphere [Nichols et al., 2010; Badman et al.]
- Seasonal variation and north-south asymmetry of aurora and radio [Gurnett et al., 2010; Badman et al., 2011]

Rotationally and seasonally dynamic M-I coupling process at Saturn

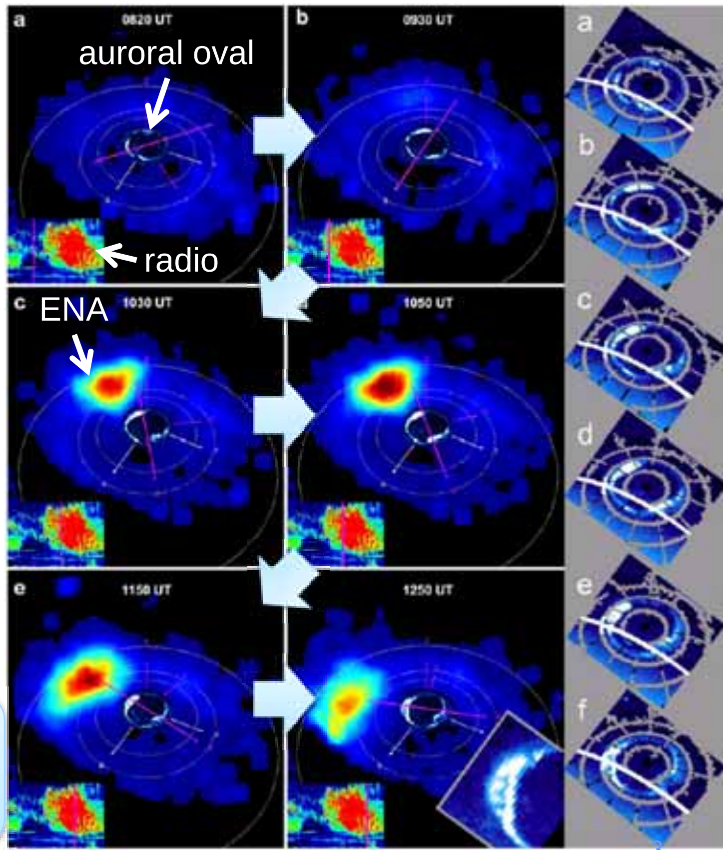
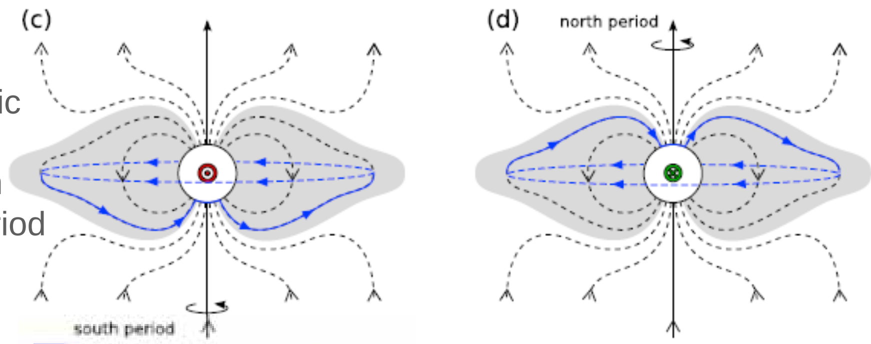


Fig. Periodic aurora, radio and ENA [Mitchell et al., 2009]

Problems

- Who drives periodic aurora, radio and magnetic field?
- Who drives N-S asymmetric aurora, radio and magnetic field?
- What is the cause of their seasonal variation?
- How M-I coupling process is dynamically driven with above manners?

Fig. M-I coupling current system for Saturn's periodic phenomena deduced from magnetic field perturbation near planetary rotation period [Andrews et al., 2010]



Purpose

- Elucidate seasonal variation of auroral acceleration region based on continuous SKR spectral observations by Cassini
- Discuss about seasonal variation of M-I coupling process comparing with Earth

Approach

- Frequency spectra of auroral radio emissions excited from auroral electrons

=>Altitudinal spread and intensity of radio source region

=>Altitudinal spread and intensity of auroral acceleration

[e.g., Morioka et al., 2012]

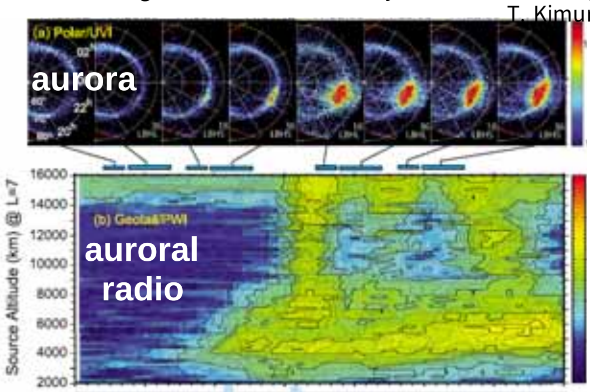


Fig. Altitudinal evolution of Earth's auroral acceleration region deduce from Earth's auroral radio [Morioka et al., 2012]

Datasets

- Cassini/Radio and Plasma Wave Investigation/HFR
- Flux density data in LH and RH circular polarizations

Spec	Value
Frequency range	3.5-1500kHz
Frequency resolution at 3.5-325 kHz	log-spaced 24 channels df/f ~ 20%
Frequency resolution at 350-1500 kHz	linearly spaced 24 channels df = 50kHz
Time resolution	3min
Period (Southern summer)	2004DOY001-2010DOY193

5

Methods and assumptions

1. Identify SKR event under the selection criteria

2. Get mean spectra with 1hr resolution, separating northern and southern component based on wave polarization

3. Find the source altitude where SKR spectral frequency is equal to polar local cyclotron frequency

4. Plot the normalized flux density of the spectra at the source altitude

- Spectral frequency of SKR *f* = local cyclotron frequency *fc* at source region
- Remove visibility effects [Lamy et al, 2009] based on S/C position

Data selection criteria:

1.S/C Lat: -30deg to +30deg
2.S/C LT: 08+/-6 hr [Lamy et al., 2008a]
3.S/C radial distance: 10Rs to 100Rs
4. Φ_{SKR} (rotational phase) : -45° to 45° (Φ_{SKR} =0° at SKR maxima)

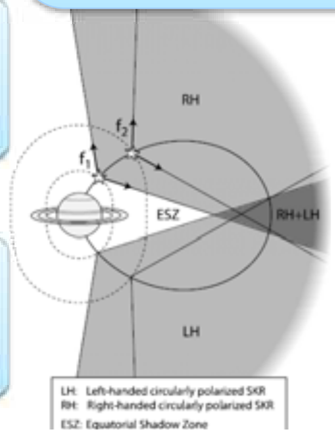


Fig. Schematic of SKR beaming [Lamy et al., 2008]

6

Result-Southern SKR

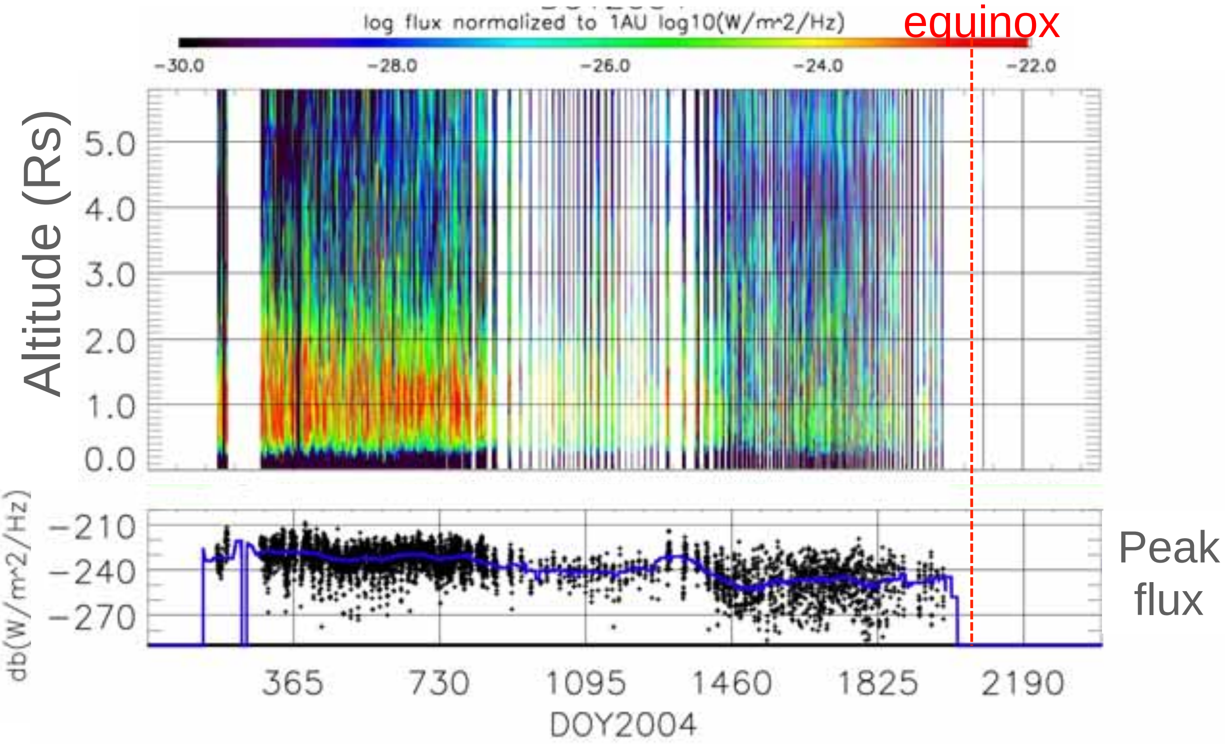


Fig. (top) Altitude-time diagram showing altitudinal expand of auroral acceleration deduced from SKR and (bottom) peak flux of SKR as a function of time

Median spectra - south

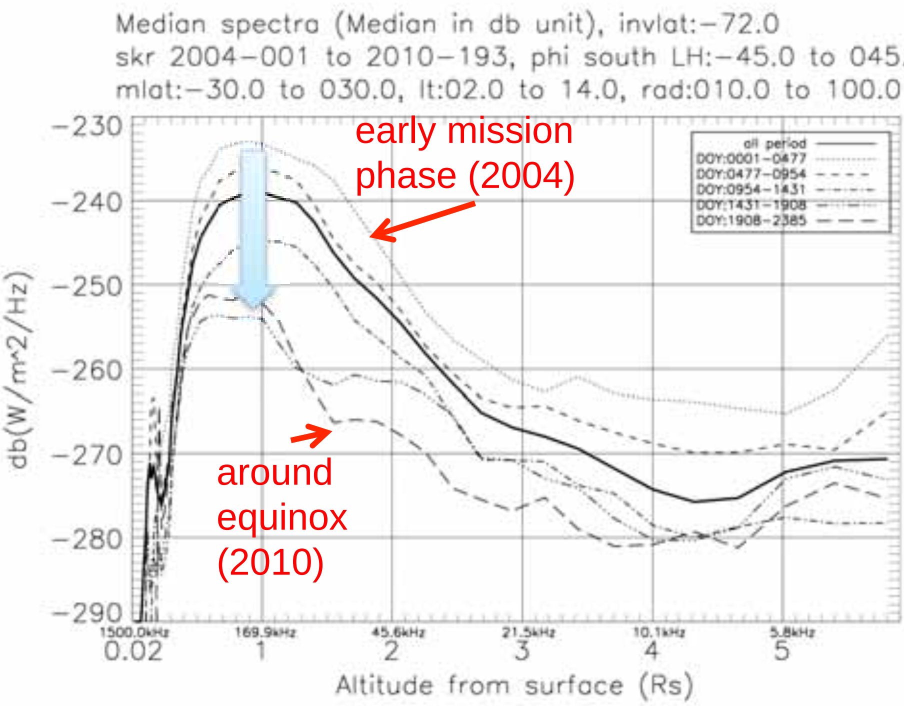


Fig. Median spectra of SKR for each period (see legend)

Southern SKR spectra has long-term variations: stronger during summer and gradually decreasing with the equinox approaching

Altitudinal spread-south

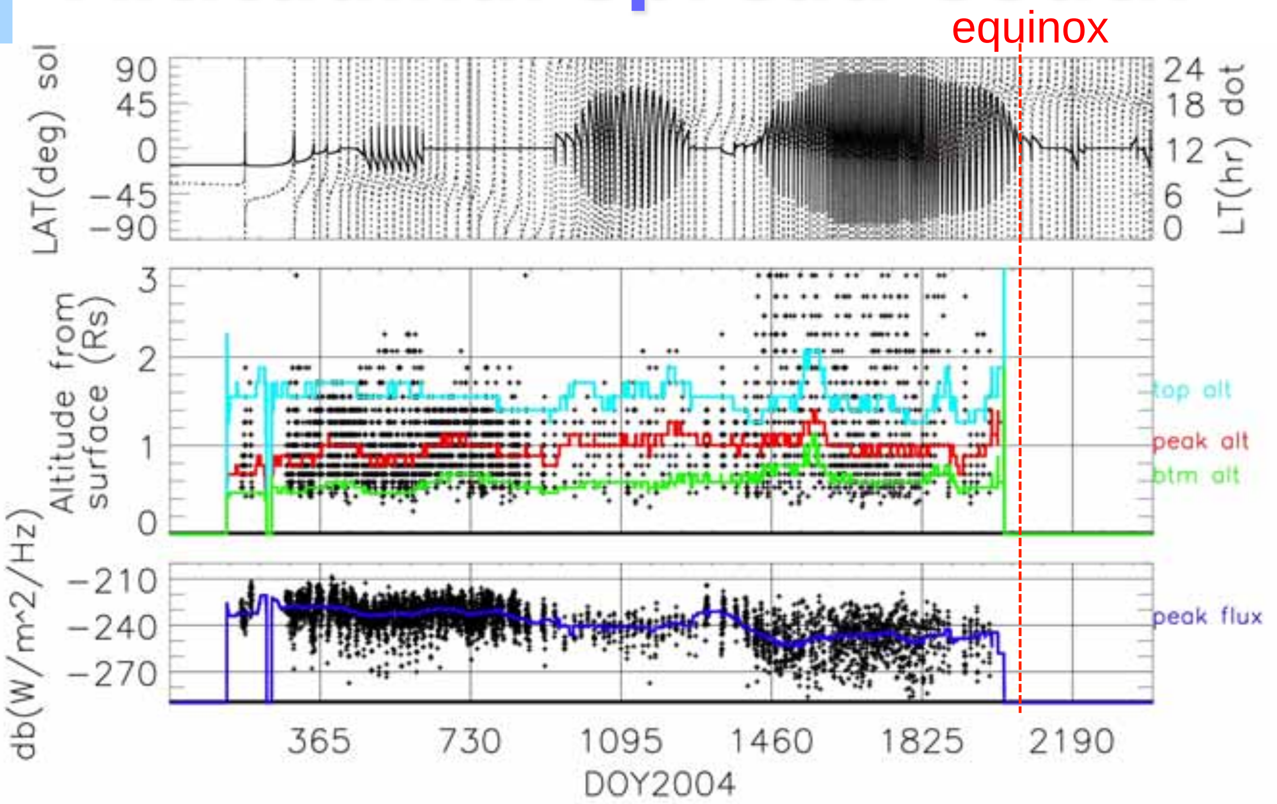


Fig. Top, bottom, peak flux altitude and peak flux as functions of time.

Peak flux & altitudinal spread - south

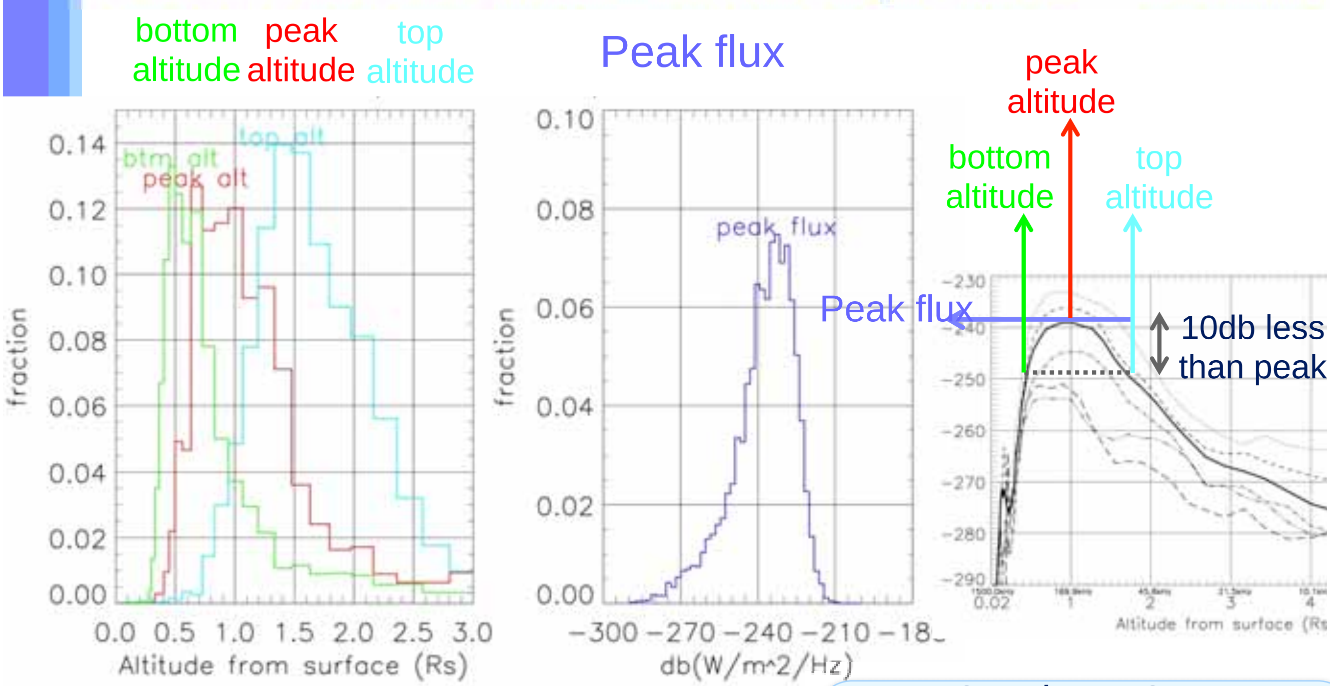
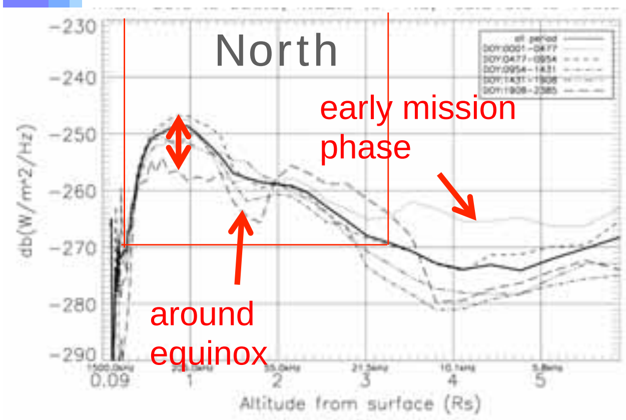


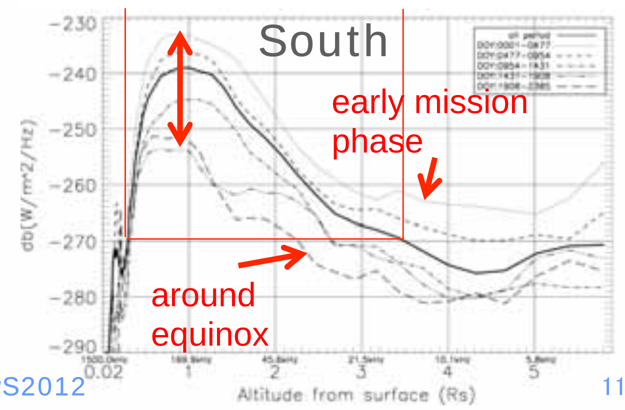
Fig. Statistical distribution of peak flux, top, bottom and peak altitude derived from SKR spectra.

Southern SKR
- Peak flux: -230db
- Top altitude: ~1.4Rs
- Peak altitude: ~0.9Rs
- Bottom altitude: ~0.5Rs

N-S asymmetry

- Flux density:
  - south (summer):
    - seasonally variable
    - decreasing with the equinox approaching.
    - Mean spectrum over the entire period (solid) is 10db larger than north at peak.
  - north (winter):
    - Seasonally more stable
    - comparable with south around the equinox
- Peak, spread & gradient:
  - south (summer):
    - peak~0.9Rs (from planet surface)
    - grad & spread: hard, 0.3-3.5Rs (above -270dB)
  - north (winter):
    - peak~0.9Rs
    - grad & spread: soft, 0.3-3.4Rs (above -270dB)

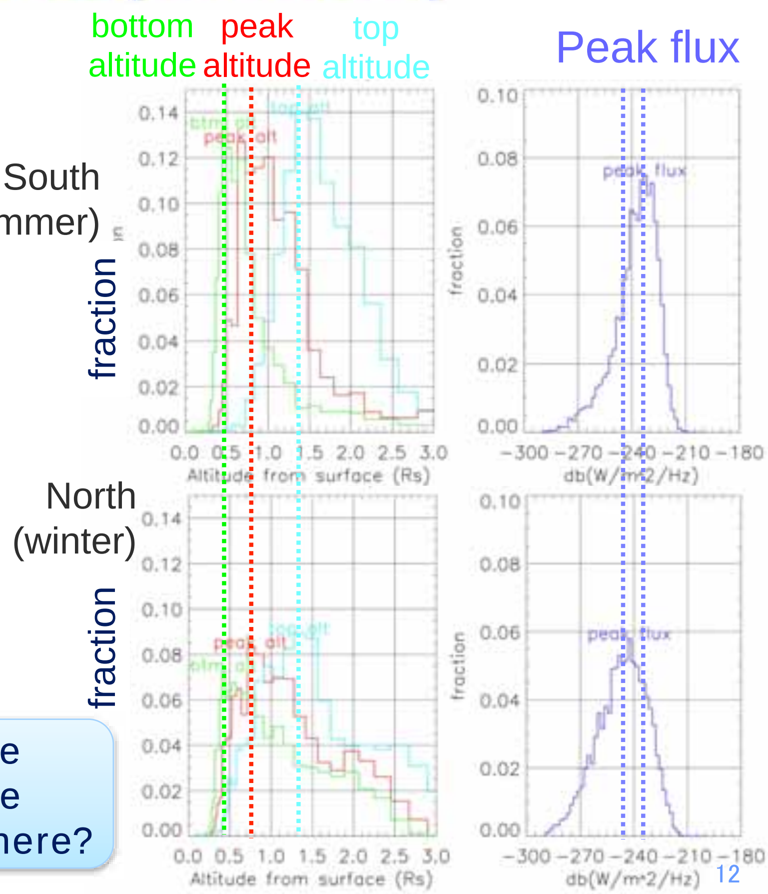




SPS2012 11

N-S asymmetry

- Altitudinal spread:
  - North&South: modes are seasonally stable
    - bottom:~0.5Rs
    - peak:~0.9Rs
    - top: ~1.4Rs
  - South: narrower spread
  - North: spreading to higher altitudes
- Peak flux
  - South: 10-15db greater than north



stronger and more stable acceleration region in the southern (summer) hemisphere?

12

Comparison with Earth

- Intense AKR emission in the winter hemisphere [Kumamoto et al., 1998]
- Seasonal variation of AKR depending on both plasmasheet (temperature, density) and ionosphere (density) [Morioka et al., 2012]
  - altitudinal spread
  - peak flux
  - phase dependence (breakup and off-breakup)

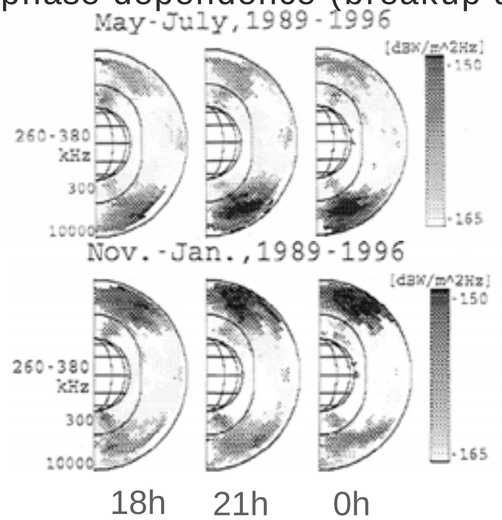


Fig. Meridional distribution of AKR intensity in each season [Kumamoto et al., 1998]

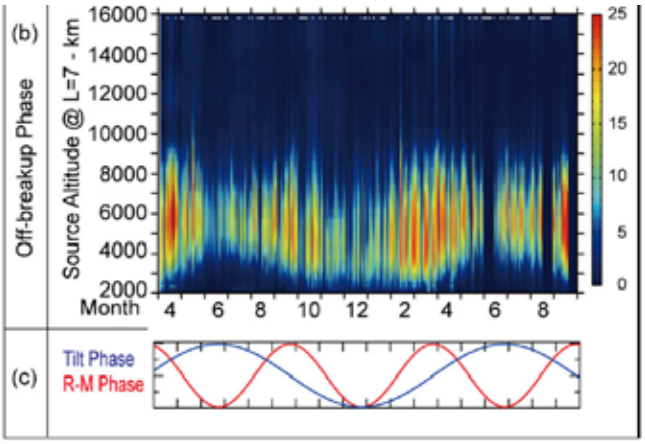


Fig. Altitude-time diagram of AKR for off-breakup phase [Morioka et al., 2012]

AKR vs Magnetosphere-Earth

- positive correlation between
  - Russell-McPherron effect
  - m'spheric T_e
  - AE index
  - AKR peak power
  - AKR top altitude
- positive correlation between
  - i'spheric scale height
  - AKR peak power altitude
  - AKR bottom altitude

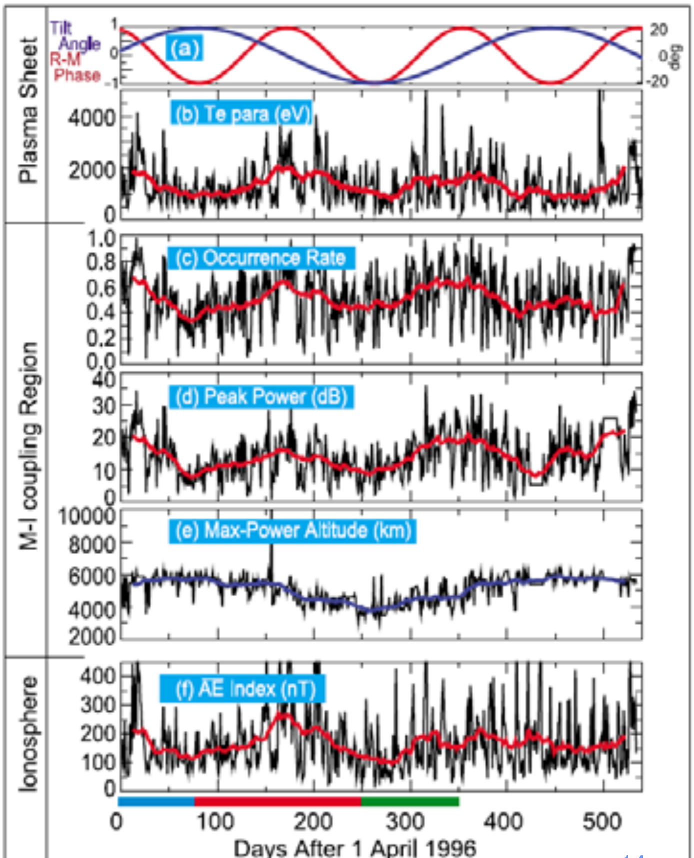


Fig. Time series of magnetospheric parameters and AKR for off-breakup phase [Morioka et al., 2012]

Earth vs Saturn

	AKR at Earth (Morioka et al., 2012)	SKR at Saturn (this study)
Peak power, P_p	•Positively correlated with T_e & N_e at m'sphere •Russell-McPherron effect :greater around equinox	•Grater during summer =>Insignificant R-M effect? Strong J_|| by higher conductivity effect in sunlit hemisphere or other unknowns?
Top altitude, H_t	•Positively correlated with T_e & N_e at m'sphere •R-M effect: higher around equinox	•Seasonally constant =>Insignificant R-M effect?
Bottom altitude, H_b	•positively correlated with N_e at upper i'sphere •Scale height effect: higher during summer	•Seasonally constant =>Insignificant i'spheric scale height effect?
Maximum power altitude, H_max	•positively correlated with N_e at upper i'sphere •Scale height effect: higher during summer	•Seasonally constant =>Insignificant i'spheric scale height effect?

15

Comparison with Saturn's aurora

- Conductivity dependence $I_{IR} \propto \Sigma_P^* \sqrt{B_i}$, $\frac{Q_{JS}}{Q_{JN}} \propto \frac{\Sigma_{PS}^*}{\Sigma_{PN}^*}$,
  - IR aurora during southern summer [Badman et al. 2011]
- Ionospheric field strength dependence
  - equinoctial UV aurora [Nichols et al. 2009] $P_{UV} \propto \Sigma_P^{*2} B_i$.

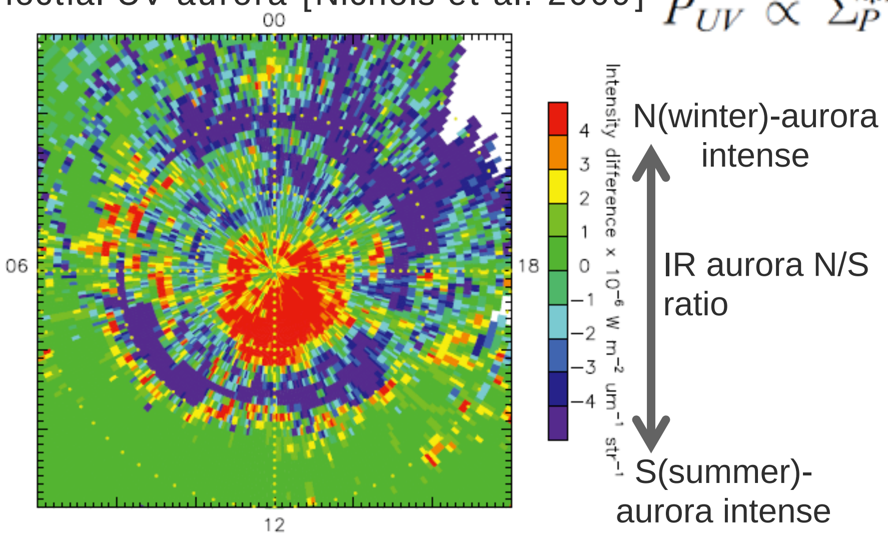


Fig. Polar plot showing north-south ratio of Saturn's IR aurora [Badman et al. 2011]

SKR has similar characteristics to IR aurora.
Polar ionospheric conductivity controls J_||?

16

Outstanding questions

- Correspondence to solar wind / magnetospheric / ionospheric conditions:
  - Solar wind [e.g., Badman et al., 2008]
  - N-S asymmetric auroral emissions [e.g., Badman et al., 2011; Nichols et al, 2009]
    - conductivity?
    - magnetic mirror ratio between polar and equatorial region [e.g., Ray et al., 2010]?
    - ionospheric field strength?
  - Plasma density and temperature [Sergis et al., 2011]
  - Corotational lag
  - equatorial partial ring current [e.g., Brandt et al., 2010]
  - Polar in-situ FAC [e.g., Talboys et al., 2011]
- Visibility effect (beaming effect of SKR)
  - Variations in spectra still include visibility effect?
    - S/C LT dependence
    - S/C LAT dependence

Summary

- Altitudinal spread of Saturn’s auroral acceleration region was deduced from SKR
- Stronger southern summer component was found
- Suggestive of different M-I coupling process to Earth
- Seasonal variation of Saturn’s M-I coupling process is controlled by polar ionospheric conductivity or other unknowns?
- Future work: comparison of SKR spectra with
  - magnetospheric condition
  - polar ionospheric condition
  - solar wind variation
  - visibility (apparent variation due to radio beaming)