Examination of the Odd Mode Model of Pi 2 Based on an Analysis of ULF Signals Received at Syowa Station

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昭和基地の ULF 波動解析に基づく Pi 2 型磁気脈動に関する Odd Mode モデルの検証

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要旨．昭和基地の資料を解析して得られた，hissagram (high-speed spectrum analyzer で得られた dynamic spectrogram) と auroragram と magnetogram との比較から，Pi 2 型地磁気脈動は，磁気圏嵐の開始機構と密接に関係していることが確認された．昭和基地で磁気テープレコーダーに録音された ULF 波動を speed-up ratio～2×10^4 で再生し，HISSA にかけて得られた hissagram の中にも，Pi 2 成分が明らかに含まれていることが見出された．

このような解析結果を今までの解析結果と共に総合的に解釈すると，真夜中子午線付近の南北 auroral oval をつなぐ磁力線に沿う，基本 1 次 mode の Alfvén 波が Pi 2 として地上で観測されるという Pi 2 の odd mode model が，最も promising であると考えられる．磁気圏嵐開始時に磁気圏尾部の形状が，tail-like から dipole-like に急激に変形する速度は今まで定量的に明らかにされていなかったが，上記 odd mode model が正しいとすると，この変形はわずか 0.5–4 分の間に起こると考えられる．

Abstract: A correlation analysis of hissagram, auroragram, and magnetogram obtained from the Syowa Station data implies that magnetic Pi 2 pulsation is closely related to the onset mechanism of magnetospheric substorm. Even at the polar station, Syowa, the Pi 2 component is clearly detected on hissagrams which are obtained by reproducing the original ULF signals by an FM tape recorder with a speed-up ratio of as much as 2×10^4. Based on summarized morphological characteristics of Pi 2, we confirmed the odd mode model of Pi 2 that the fundamental odd mode Alfvén wave along a field line anchored in the midnight auroral oval is observed on the earth's surface as Pi 2. A rapid changing of the tail field configuration at the time of substorm onset is suggested.

1. Introduction

A magnetospheric substorm accompanies various kinds of substorm signatures. Among the signatures, Pi 2-type magnetic pulsation is one of the best indicators of the

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onset of the substorm as shown in Fig. 1, where a substorm event observed at Syowa Station is expressed by a hissagram, an auroragram, and a magnetogram, and is compared with the event observed at both a low-latitude station and the conjugate station.

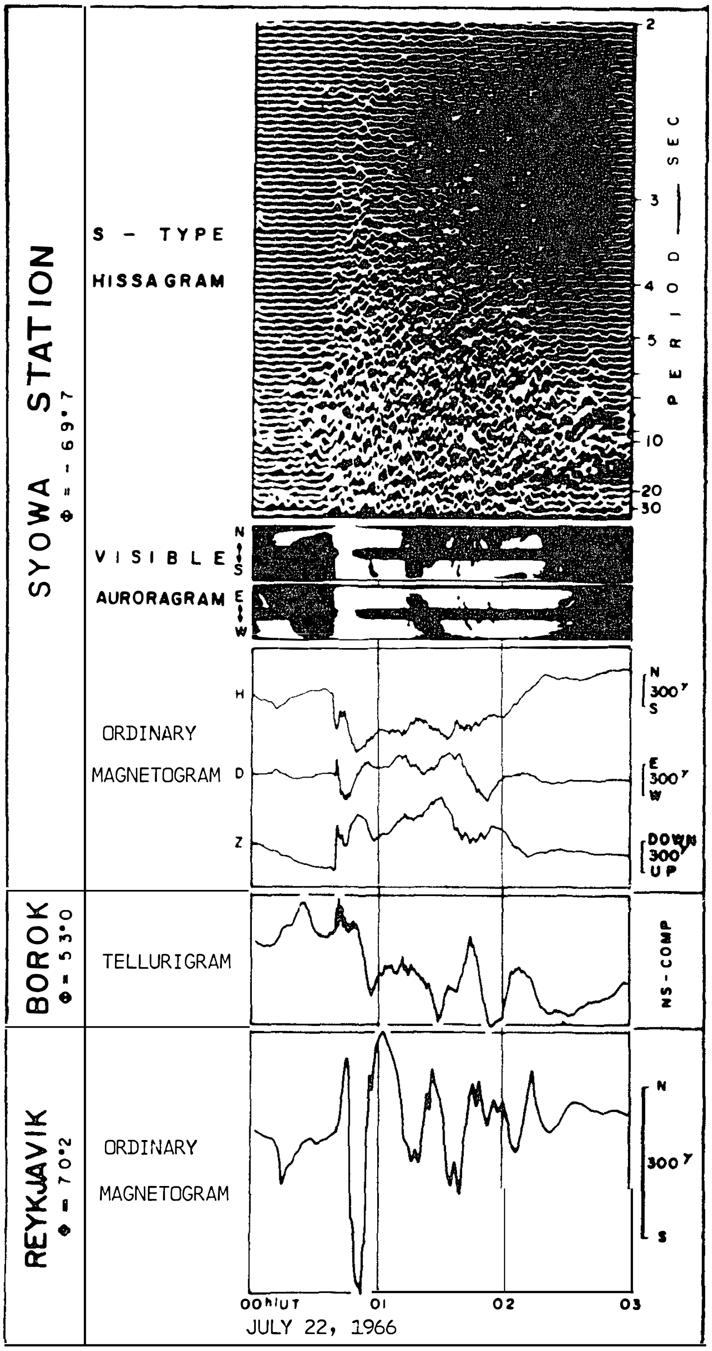

Fig 1　Hissagram, auroragram, and magnetogram for Syowa Station are compared with tellurigram at Borok and ordinary magnetogram at Reykjavik. See the simultaneous onset of ULF-, auroral-, and magnetic-substorms at the polar conjugate stations and the mid-latitude station.

The purpose of this paper is to show how the Pi 2-type pulsation is essentially related to the onset mechanism of substorm

2. Main Morphological Features

ULF signals registered at Syowa Station on magnetic tapes are reproduced by another data recorder with a speed-up ratio of 10^4 times of the recording speed (SAITO *et al.*, 1980) and displayed by hissagrams with a high-speed spectrum analyzer (HISSA)

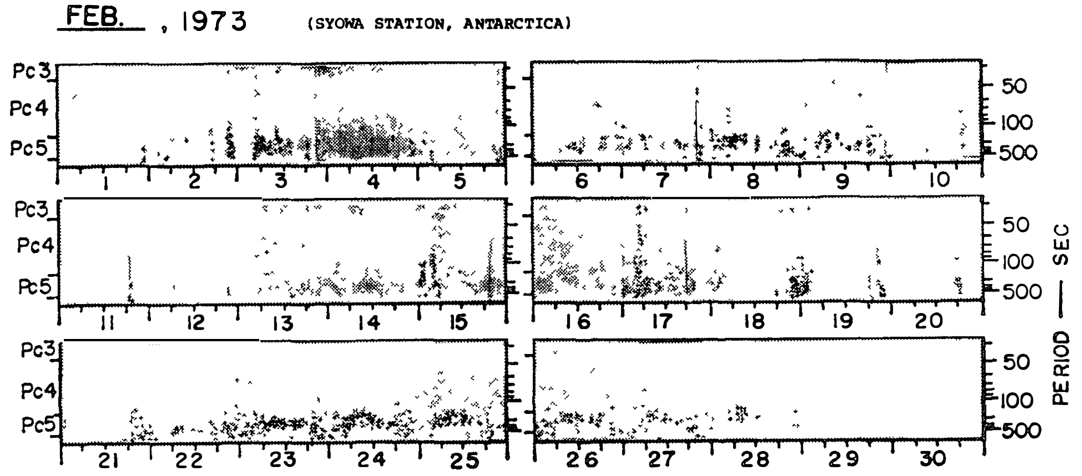

Fig 2 Hissagrams of ULF waves observed at Syowa Station during 1–28 February, 1973

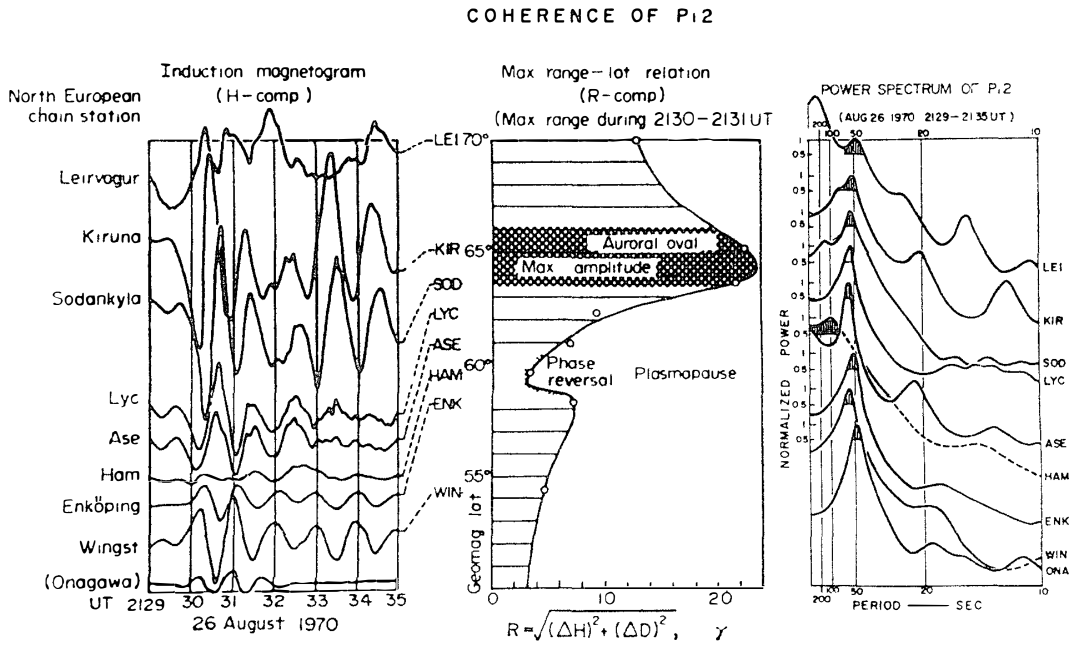

Fig 3 Coherence of Pi 2 observed over the whole dark hemisphere from high latitudes to low latitudes

at Tohoku University (SAITO, 1976). Fig. 2 shows one of the hissagrams, where Pi events are expressed by burst-like vertical lines during every nighttime. A detailed survey of the vertical lines reveals that the lines involve the Pi 2 component even in the auroral-zone station, Syowa. We can find that the Pi 2 component is concurrently observed over the whole dark hemisphere from high latitudes to low latitudes as shown in Fig. 3.

Table 1. Summary of morphological features of Pi 2

Item	Observed fact	Model
ΔB_Z in distant tail	Southward turning→Generation of Pi 2	Formation of X-type neutral line in the magnetotail
Onset time of Pi 2	=Substorm onset =Sudden brightening of equator edge of auroral arc	Arrival of precipitating particles onto the auroral oval
Pi spectrum on oval	Existence of the Pi 2 component	Transient torsional standing oscillation of dipole-like field-line anchoring on the auroral ovals near the midnight meridian
Latitudinal dependence of Pi 2 amplitude	Primary maximum at auroral oval	
Conjugacy of Pi 2	Coincidence of onset time, spectral pattern, *etc*	
Polarization of Pi 2	Fundamental mode	
Substorm magnitude (M)	Small M→large $\Phi_{Pi\,2}$ and large $T_{Pi\,2}$ (mini-substorm)	

These important morphological features are summarized in Table 1 together with other features that were revealed in other studies (*e.g.*, SAITO *et al.*, 1976a, b, 1980; KUWASHIMA and SAITO, 1980). The table implies an appropriateness of the odd mode model that the fundamental odd mode Alfvén wave along a field line anchored in the midnight auroral oval is observed on the earth's surface as the Pi 2-type pulsation.

3. Pi 2 Model

A question arises from the model derived in the previous section that the period expected from the model might be too longer than the observed one, because the field line anchored in the oval must be connected, at the very moment of the substorm onset, to the region of X-type neutral line formation at as far as $X=-15R_E$ (SAITO *et al.*, 1976b). Fig. 4 shows the answer schematically: The energetic plasma generated by the sudden formation of the X-type neutral line starts from the annihilation region with the Alfvén speed along the field line No. 0. When both the plasma and the Alfvén wave arrive simultaneously at the polar ionosphere, both auroral substorm and ULF substorm are observed to start by the ground-based observer. During the starting and the arrival of the Alfvén wave, the field line must be changed from the tail-like one to

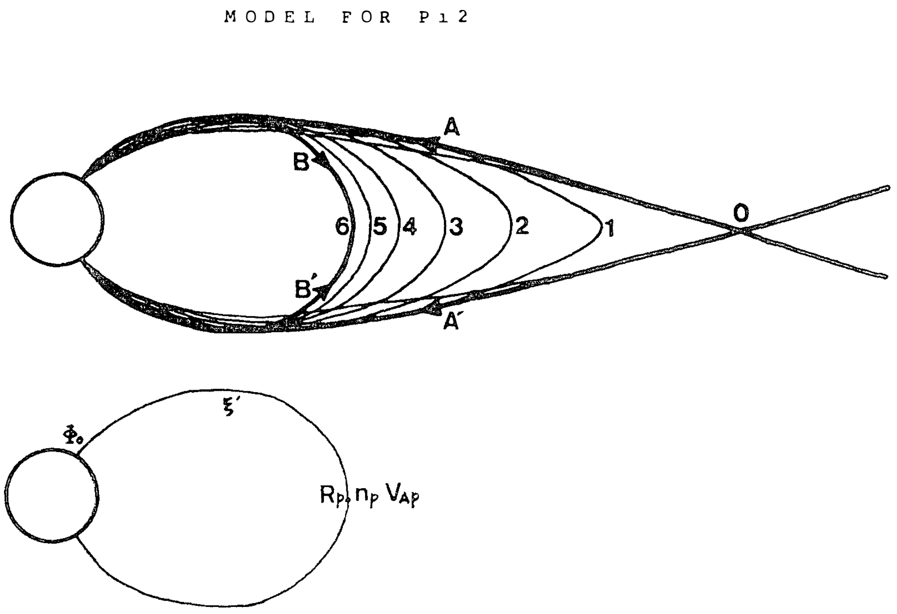

Fig. 4. Schematic model for Pi 2. The field line configuration is considered to change from the tail-like one at the time of sudden formation of the X-type neutral line to the dipole-like one at the arrival time of the Alfvén wave.

the dipole-like one from No. 0 through Nos. 1, 2, 3, 4, 5, to No. 6. The arriving Alfvén wave is then reflected back by the conducting ionosphere along the field line No. 6 and makes a fundamental odd mode standing oscillation between the northern and the southern polar ionospheres. The temporal oscillation is observed to be Pi 2 on the ground (SAITO, 1979). Importance is that when the X-type neutral line is formed, the information on the formation is not yet conveyed to the ground-based observer and the field line is still tail-like, and that when the information is conveyed to the ground, the field line becomes dipole-like. Hence, in order to confirm this odd mode model (which is identical to the plasma sheet model, SAITO, 1980), we may compare the calculated period expected from this model with the observed period.

The compared result is summarized in Table 2, where the used values of Φ_0, R_P, n_P, and ξ' are also tabulated for representative magnitude of substorm.

Table 2. Comparison of the observed Pi 2 period with the calculated period derived from the Pi 2 model for four representative latitudes.

Φ_0	R_P (R_E)	n_P (cm^{-3})	ξ'	T_{calc} (s)	T_{obs} (s)
63°	6.3	2	1.1	55	57
65°	6.8	2	1.1	76	77
69°	8.0	2	1.2	164	160
71°	9.3	2	1.2	307	300

4. Discussion and Conclusion

The striking coincidence between the observation (T_{obs}) and the expectation (T_{calc}) as seen in Table 2 means that the odd mode model is appropriate and that the field line configuration changes from tail-like to dipole-like is as fast as expected from this model. The interval of the change is estimated to be only 0.5–4 minutes (Saito *et al.*, 1979).

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