A review of multiple-onset substorm studies enlightened by Prof. Russell

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Outline

• Introduction
  A list of published multiple-onset substorm studies enlightened by Prof. Chris Russell
• Three phases of multiple-onset substorm studies
  “Growth” phase: Mapping consecutive onsets of ground Pi2s to the incident IMF
  “Expansion” phase: Using CANOPUS-MPA, GOES data, Polar UVI images and LANL energetic electron injections for verification
  “Recovery” phase: Using THEMIS data to justify the cause of quiet-time Pi2s to be the same as substorm-time ones
• Summary and conclusion
• Acknowledgments
Introduction

Pi2 pulsations, in a period of 40 to 150 seconds (6-25 mHz), impulsive and damped oscillations of geomagnetic fields, associated with substorm onset [Saito, 1969; Baumjohann and Glassmeier, 1984; Yumoto, 1986; Olson, 1999, and references therein].

A group of Pi2s generally occurred successively during substorm onsets [see review by Saito, 1969].
A substorm often has two Pi2s and two individual “bays” in the horizontal component of the magnetic field denoted as the trigger bay and the main bay respectively. [Rostoker, 1968]
Some evidence of multiple onsets accompanied by Pi2s in a magnetospheric substorm. [e.g., Kisabeth and Rostoker, 1971; Clauer and McPherron, 1974]

What causes the occurrence of successive Pi2 pulsations during a magnetospheric substorm is still not well determined.
Mishin et al. [2000, 2001] pointed out two distinct onsets in a magnetospheric substorm of which the first occurs at low latitudes and the second at higher latitudes.

To explain their observations, Russell [2000] extended the near-Earth neutral point model by Russell and McPherron [1973] with emphasis on the role of the distant neutral point.

In the model, the interplay between near-Earth and distant neutral points in the magnetotail creates two onsets, one when reconnection at the near-Earth neutral point first begins on closed field lines within the plasma sheet, and one when at the near-Earth neutral point reaches the open flux of the tail lobes.

The timing of the second substorm onset should be controlled by the distant neutral point that in turn is controlled by the northward turning of the IMF.

During a magnetospheric substorm, there can be at least two Pi2 bursts in space as well as on the ground as the incident IMF initially becomes southward for a period time and later northward.

Thus, it is an important topic to testify the Russell [2000] model with both ground- and space – based observations.
Two-neutral-point substorm model for the IMF variation of north-to-south and then north [Russell, 2000]
A list of published substorm studies enlightened by Prof. Chris Russell

“Growth” phase: Mapping Pi2 onsets at SMALL, IGPP/LANL and CPMN to the IMF sensed by ACE and Wind [Cheng et al., 2002a; 2002b; 2004]
The southward IMF flux before the burst #1 onset

\[ \Phi = KV_X B_S \Delta t DM \]

\( \Delta t \): the time interval between southward IMF turning and the burst #1 onset.

\( V_X \): the average magnitude of the \( x \) component of solar wind velocity.

\( B_S \): the average magnitude of the southward IMF.

\( K \): assumed to be 10\%, the percentage of the southward IMF flux incident on the magnetosphere.

\( DM \): assumed to be 30 \( R_e \), the nominal width of the magnetosphere.

\( t_{12} \): the time interval between the burst #1 onset and the burst #2 onset.
Sketch of substorm current wedge from *McPherron et al.* [1973]

Six source mechanisms for nightside Pi2s [see Yumoto, 2001]

- High-lat. Pi 2: The bouncing of the transient FAC between the plasmasheet and the ionosphere.
- Substorm Current Wedge oscillation.
- Mid-lat. Pi 2: Surface wave at the plasmapause.
- Low-lat. Pi 2: Cavity wave in the inner magnetosphere.
Magnetospheric/plasmaspheric cavity resonance modes [Cheng et al., EPS, 1998, 2000]

\[ ma=0, ka=0.2\pi, p=5, q=5.1, R=9 \]

\( H \) comp.
“Expansion” phase: Using CANOPUS, GOES, Polar and LANL data for verification [Cheng et al., 2005]
“Recovery” phase: Using THEMIS data to justify the cause of quiet-time Pi2s to be the same as substorm-time ones [Cheng et al., 2009a; 2009b; 2011]
Fig. 1 in *Lester et al.* [1984]  
Reproduced from *Pashin et al.* [1982]

CCW polarization

Current line

Current sheet
A case study of two double-onset substorms [Cheng et al., 2011]
Summary and conclusion

According to Baker et al. [1996], substorm characteristic features in the near-Earth nightside magnetosphere mainly include bursty bulk flows (BBFs) or fast flows, formation of the current wedge, auroral breakups, magnetic bays at high latitudes, Pi2 pulsations.

These features can be found in our multiple-onset substorm events in the “expansion” and “recovery” phase.

The mapping of ground Pi2 pulsations onset timing to the solar wind observation just in front of Earth’s magnetopause shows that both bursts appear under a variation cycle of north to south and then north.

The second Pi2 burst can occurs after a time that is correlated with the amount of southward IMF convected to the magnetopause.
The second Pi2 onset can signal that reconnection reaches the tail lobes after the IMF returns to a northward value.

Wavelet transformations of $H$ and $D$ components at high latitude show first high frequency and then lower one bearing the spectral characteristics of double-onset substorm triggered by northward turning. But at low latitudes, their dominant frequency seems to close to each other.

Waveform comparisons show that Pi2 can result from a combination of fast magnetospheric and plasmaspheric cavity resonances due to braking earthward fast flows. In addition, they can result from coupling to field line resonances.

The source mechanism of Pi2s at times of weak geomagnetic activity can be the same as during substorms.

*Hence, the two-neutral-point model by Russell [2000] can explain the occurrence of multiple-onset substorms due to magnetic reconnection in the near-Earth region and the distant-Earth one respectively under IMF variations.*
Acknowledgments

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Thank you for your attention.

Happy 70th birthday to Chris !