On earthward penetration of near-tail disturbance as observed by THEMIS spacecraft

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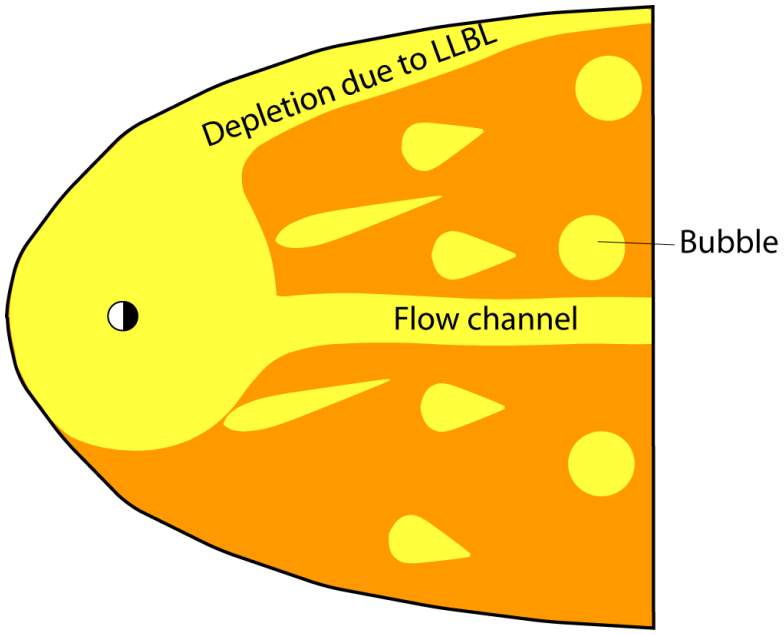
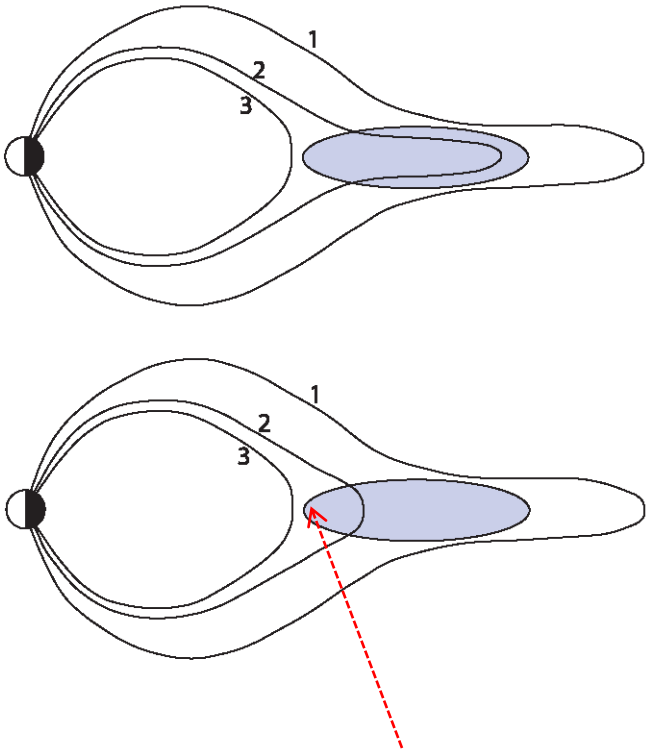
Introduction



Taken from Dick Wolf (2010, ICS – 10)

- Currently prevailing convection scenario by bubble
- Bubbles: defined to have lower $pV^{5/3}$ values than the surroundings and thus propagate earthward by a successive interchange process [e.g., *Chen and Wolf*, 1993, 1999; *Birn et al.*, 2004; *Wolf et al.*, 2009, 2012].
- Can bring particles inward with energization
  - In addition to possibly resolving the pressure imbalance problem

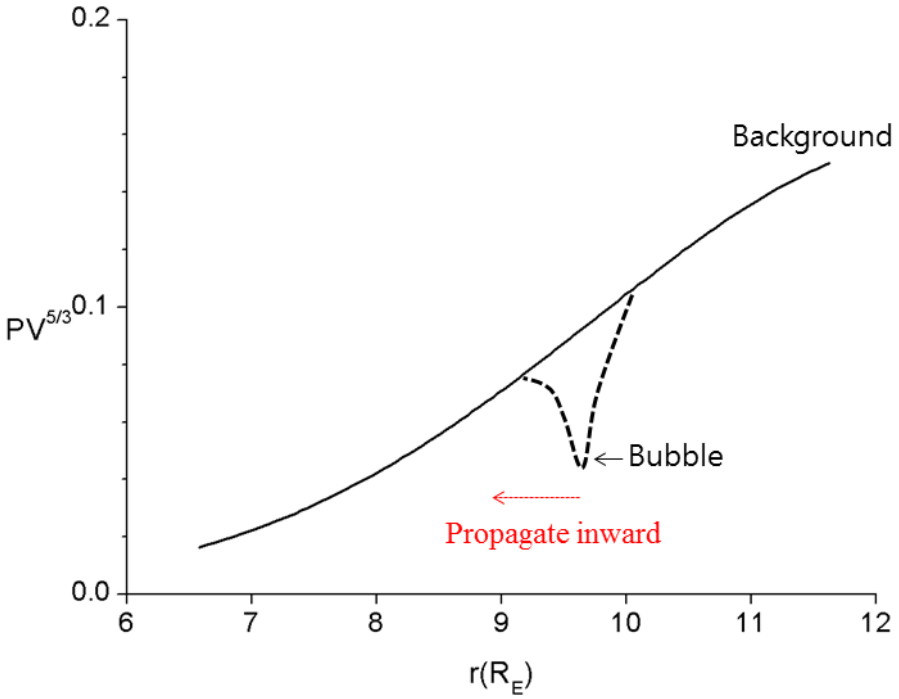
Introduction (Cont'd)



- In addition, *Wolf et al*. [2009] propose an idea that the current disruption close to the Earth (possibly by an internal instability), leading to dipolarization, can result in a local region with a reduced $pV^{5/3}$, hence a bubble.

Geometrically rounder B
→ Thus reduction in V (flux tube volume) between 2 and 3

Introduction (Cont'd)



- Therefore, in our view, sometimes the near-tail space close to the Earth can be locally supplied with bubbles of earthward penetrating flows from the down tail, and at other times it can by itself generate instability-induced bubbles through dipolarization.
- No matter what their origin is, these bubbles can propagate inward.

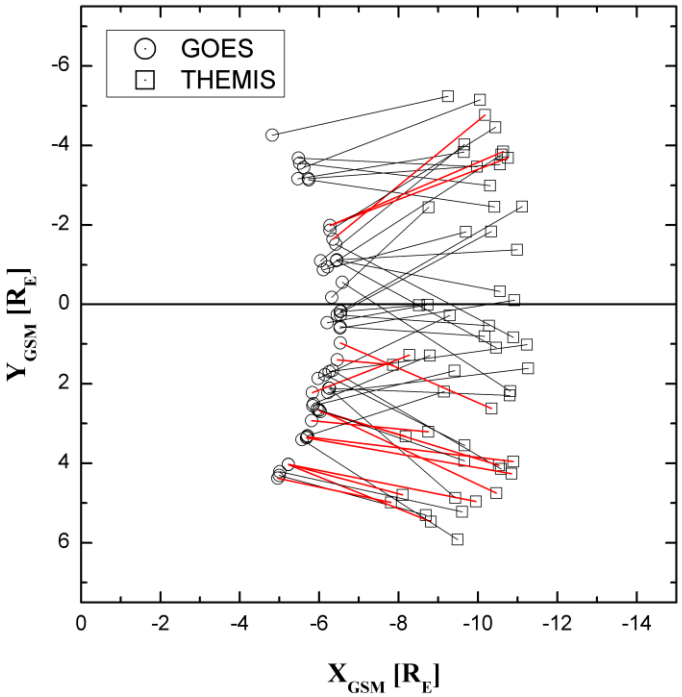
Introduction (Cont'd)

- Then, "How deep can such a bubble penetrate earthward?" or "What is the final phase of its evolution close to the earth?".
- These questions are relevant to the following issues.
  ① Substorm/storm dipolarization does sometimes occur at geosynchronous orbit and it is a question whether geosynch dipolarization is due to penetration of near-tail dipolarization and flow [*Ohtani et al*., 2006; *Takada et al*., 2006; *Dubyagin et al*., 2011].
  ② The region between the geosynchronous altitude and the near-tail (X ~ -8 to -12 R_E) is critically related to the auroral substorm onset latitude, and thus complete understanding of the dynamics in this intermediate region is important.
  ③ The bubble penetration concept may explain how tail energetic particles are injected into the ring current region [*Lemon et al*., 2004; *Zhang et al*., 2008; *Yang et al*., 2011] – and thus likely source of seed electrons for radiation belt energetic electrons.

A simple, straightforward work done here

- We examine the issue of bubble plasma penetration using multi-satellite observations and the $pV^{5/3}$ parameter. [Flux tube volume V is calculated from *Wolf et al*. (2006)]
- We use the three inner tail probes of the THEMIS mission, P3 (TH-D), P4 (TH-E), and P5 (TH-A), to identify dipolarization and its associated bubble close to the Earth (r ~ 7 to 12 R_E).
- We compare "tail bubbles" with geosynch magnetic response (at GOES).
- We then examine how deep the near-Earth "tail bubble" can penetrate earthward and determine the critical factor that is most responsible for it.
- Throughout this paper, we use the terminology "tail bubble" to refer to a local region or interval with a reduced $pV^{5/3}$ associated with dipolarization at r ~ 7 to 12 R_E.

Event selection

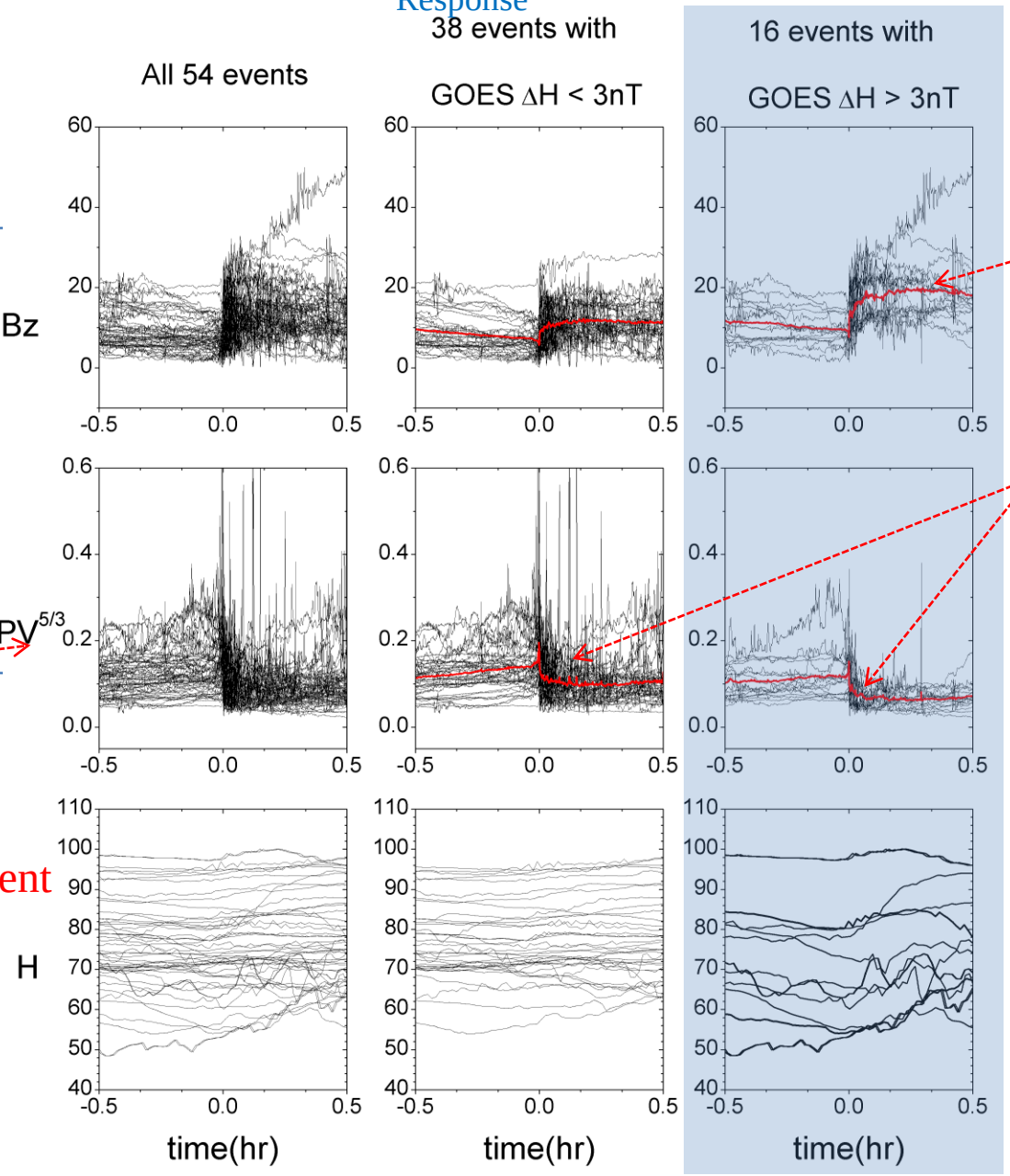


- Identified bubbles based on dipolarization events from THEMIS observations at r ~ 7 to 12 R_E.
- Selected the cases where THEMIS - GOES are approximately aligned with each other

  (MLT difference < ~1 hr)
- Total of 54 events from 2007-2008
- The solid lines connect both spacecraft for each pair
- Red lines: Events where GOES disturbance is seen around the time of THEMIS bubble observations.

No Geosynch Response

Geosynch Response Events

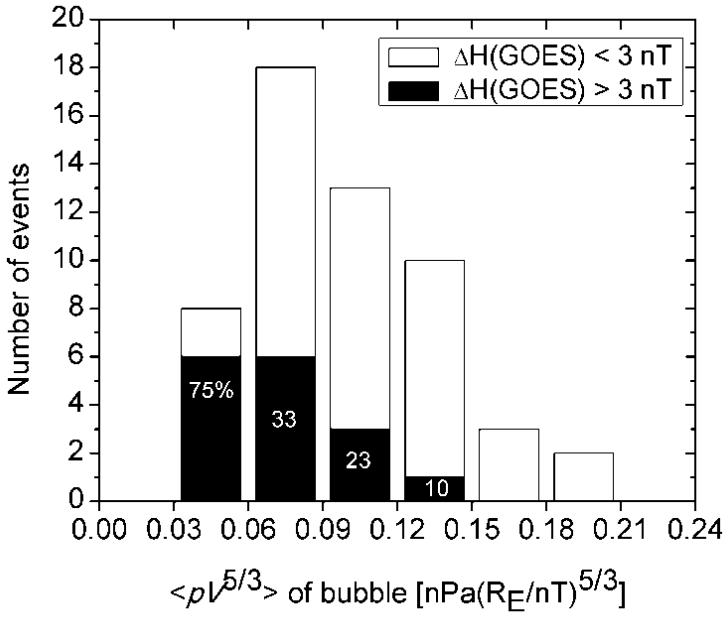


Dipolarization at THEMIS

V from Wolf et al

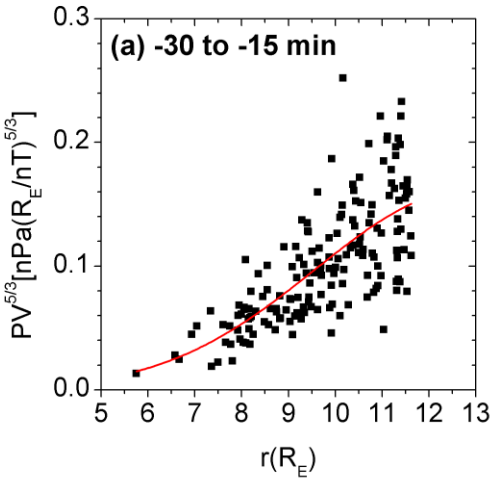
Vertical component of **B** at GOES

- Larger Bz-increase
- Bubble: reduction in $PV^{5/3}$ at near tail (THEMIS)
- H component response at GOES: pronounced for more $PV^{5/3}$ -depleted tail bubble

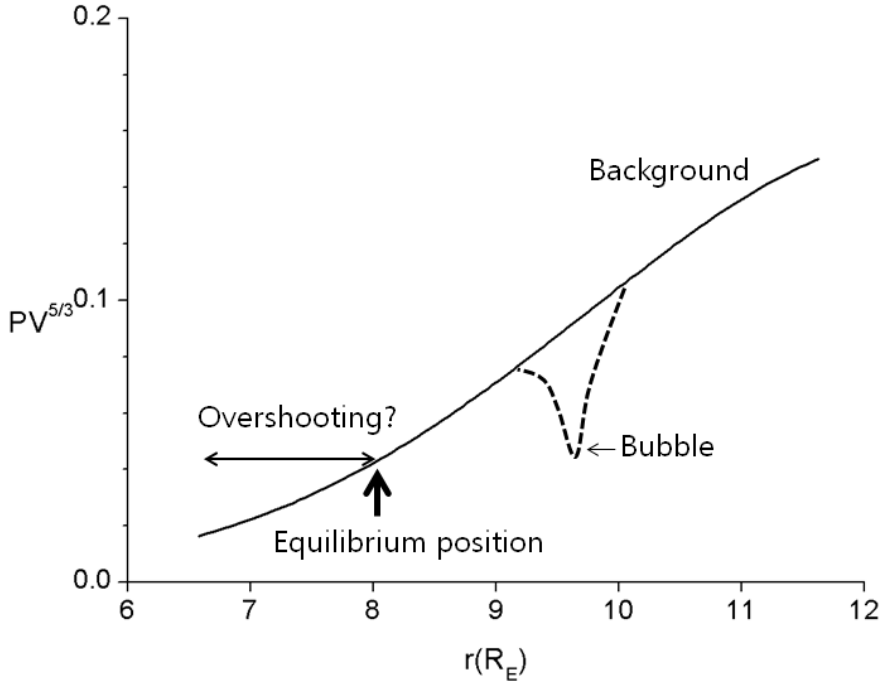


- The probability for geosynchronous response ($\Delta H > 3$ nT) increases for lower values of $pV^{5/3}$ of tail bubbles.
- Thus, $pV^{5/3}$ of tail bubbles is a critical factor related to geosynchronous disturbance.
- More precisely, it is the $pV^{5/3}$ of tail bubbles relative to the radial profile of the background $pV^{5/3}$ that determines the extent of the bubble penetration inward.
- Then the question is "what is the background $pV^{5/3}$ profile that a tail bubble is supposed to see while propagating earthward?"

Determination of Background $pV^{5/3}$ Profile



- An observational determination of the background $pV^{5/3}$ profile for a single event is impossible
- We have estimated $pV^{5/3}$ statistically.
  - Assumed that the region r ~ 6-12 R_E suffers from growth phase stretching during the times before tail bubbles are created
  - Identified 167 dipolarization events, estimated $pV^{5/3}$ during growth phase and superposed them.
- We assume that this approximately represents a background $pV^{5/3}$ profile before localized bubbles are created or arrive at a specific tail location.



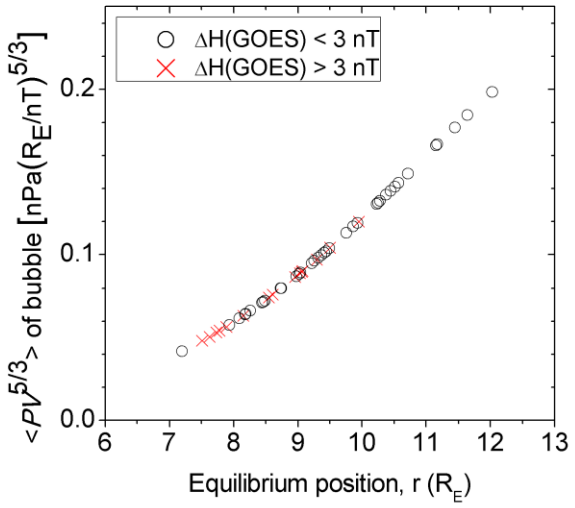
A schematic of $pV^{5/3}$ for the background and a bubble in the near-Earth tail region.

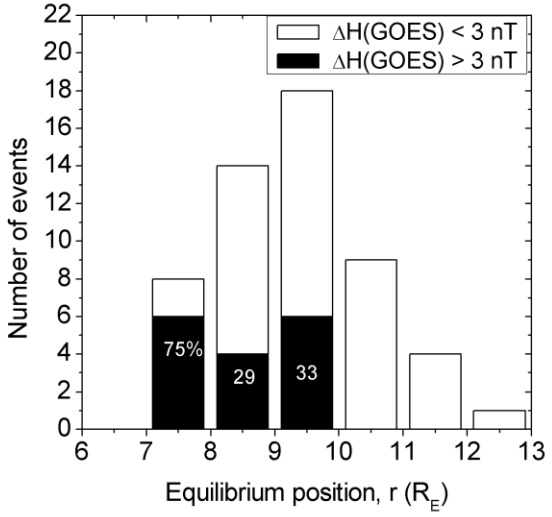
• An earthward moving bubble will meet an "equilibrium" point where its $pV^{5/3}$ is equal to that of the background.

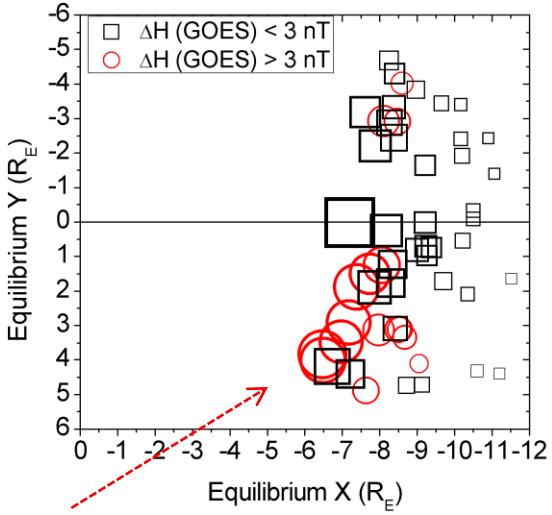
• Overshooting may be possible followed by oscillations around the equilibrium position and finally stop at an equilibrium position [*Chen and Wolf* ,1999; *Panov et al*., 2010; *Wolf et al*., 2012].

• Using the statistically determined background $pV^{5/3}$ profile, we determined expected equilibrium positions for bubbles observed at tail by THEMIS

Expected equilibrium positions for tail bubbles







The size of the symbols:

inversely proportional to $pV^{5/3}$ of the bubbles.

- The equilibrium positions are closer to the Earth for the events showing disturbance at geosynchronous orbit.
- If the bubble equilibrium position < 8 R_E, then the probability for causing (or expecting) geosynchronous disturbance is 75%.

Dilemma: The estimated equilibrium positions are still outside geosynchronous altitude for all of the events (r > 7.5 R_E for most of the events), while we do have 16 events showing geosynchronous disturbance.

Uncertainties in $pV^{5/3}$, but a possible resolution

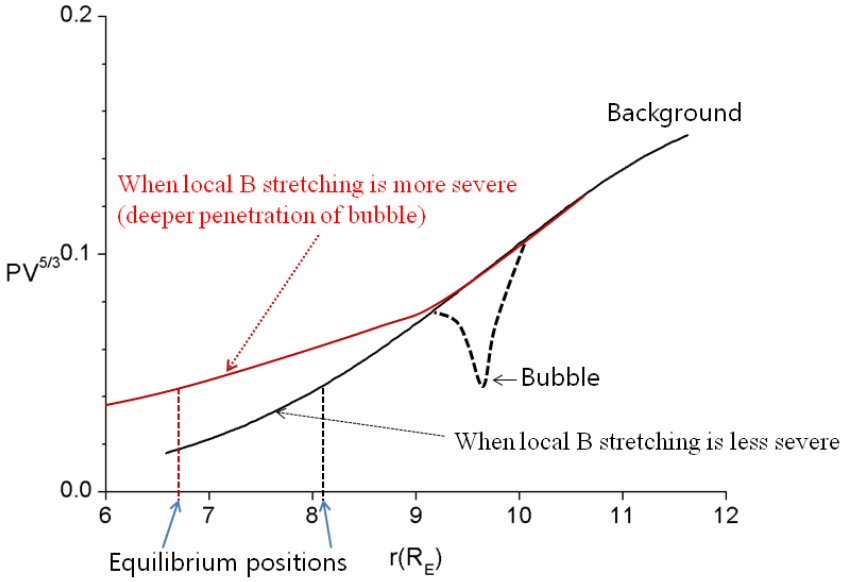
- The *Wolf et al*. formula is of limited use
  - overestimation in presence of high plasma flow
- The actual background profiles of $pV^{5/3}$ can differ from event to event (differing from our statistical profile).
- We never know for sure if spacecraft does observe the central part of the bubble flow that has the lowest $pV^{5/3}$.
- All these can affect penetration depth

- Nevertheless, a reasonable resolution is overshooting that may provide extra penetration close to geosynch.

Non-storm time vs. Storm time

- Our studied THEMIS events are all from non-storm times
  - Events identified from 2007-2008
- During storm times,
  - geosynchronous dipolarization is more often seen
  - reasonable to expect more $pV^{5/3}$ depleted tail bubbles (so deeper penetration)
    - Rice Convection Model simulations [*Lemon et al*., 2004; *Zhang et al*., 2008].
  - Therefore, a broader range of the bubbles' $pV^{5/3}$ values… which is useful for quantitatively a more precise answer.

Non-storm time vs. Storm time (Cont'd)



- During storm times,
  - The magnetic field lines near geosynch are excessively and "locally (in radial direction)" stretched? … to the point that the flux tube volume becomes large at that local region, which makes the $pV^{5/3}$ profile decrease earthward at a less steep rate.
  - This would allow for a more inward penetration of a tail bubble with a given $pV^{5/3}$.
  - Need a comprehensive determination of background $pV^{5/3}$ during storm times

RBSP-GOES-THEMIS coordinated observations are very promising during the up-coming solar max for this purpose!

Conclusions

- We find that the degree of bubble plasma penetration is strongly controlled by its $pV^{5/3}$ value relative to that of the background.
  - Based on the THEMIS and GOES observations in 2007-2008, the probability of bubble penetration effect on geosynchronous disturbance is higher for tail bubbles with a lower $pV^{5/3}$.
- But we also find that bubble penetration requires an additional physics such as overshooting of bubble flow to explain geosynchronous response.
- Also, additional observations/technique are needed for a precise determination of the background $pV^{5/3}$ profile covering geosynch to the near-tail.
- Bubble penetration should be more effective under storm time conditions.
  - **Coordinated observations of THEMIS and RBSP** around the up-coming solar maximum.