

Modes and Timescales of Magnetotail Transport

Or

Why, after 3 1/2 decades of research and 9 ICS conferences,
is “What is a substorm?” still an open question?

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2008 GEM Student Sponsored Tutorial

Motivation #1: ICS-9, Seggau, Austria

- 45 minute discussion: “What is a substorm?”
- Jimmy Raeder: “If you can’t quantify a substorm, you don’t know what it is”



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“[...] the community is more interested in traveling than in working, especially since the same ideas about substorm processes are being debated today as were being debated twenty years ago. One cynic has even suggested a conspiracy theory of substorms, that the principals have agreed not to solve the problem in order to keep the field alive.” - Chris Russell, 1994.



Motivation #2: Bob McPherron, GEM, 1997

ISSUES IN SUBSTORM ONSET TIMING

WHAT is a substorm?

What is an onset?

Multiple onset or multiple substorms?

What are signatures of substorm onset?

Can we cluster onset events into higher order structures?

If so, which is the cluster's "Main Onset"?

What operational procedure is used for each signature?

What is the accuracy of the measure?

What are the systematic errors of the procedure?

How do we associate possible onset features?

How do we gauge the statistical significance of possible associations?

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Outline

- The uses and abuses of “Onset”
 - ▶ The onset of what? What does [blank] onset mean?
 - ▶ What is “substorm onset” ?
- What is a substorm?
 - ▶ Turn it around: Why is it so difficult to define a substorm?
- Are substorms distinctly different from other modes of transport?
 - ▶ Can we learn anything from meteorology?
- Retaining institutional knowledge

The uses and abuses of “Onset”

on•set - The beginning of something, esp. something unpleasant : The *onset of* winter

What is an onset?

What is substorm onset?

Moving beyond timing.

What is an onset?

- An onset is a sharp change in intensity or character of your measurement.
 - ▶ Auroral brightening
 - ▶ Auroral breakup
 - ▶ Pi2 onset
 - ▶ Mid latitude positive bay
 - ▶ Near-Earth particle injection
 - ▶ Dipolarization
 - ▶ AL decrease

What is a *substorm* onset?

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 - ▶ Auroral brightening
 - ▶ Auroral breakup
 - ▶ Pi2 onset
 - ▶ Mid latitude positive bay
 - ▶ Near-Earth particle injection
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 - ▶ AL decrease
- And you believe your event is a substorm.

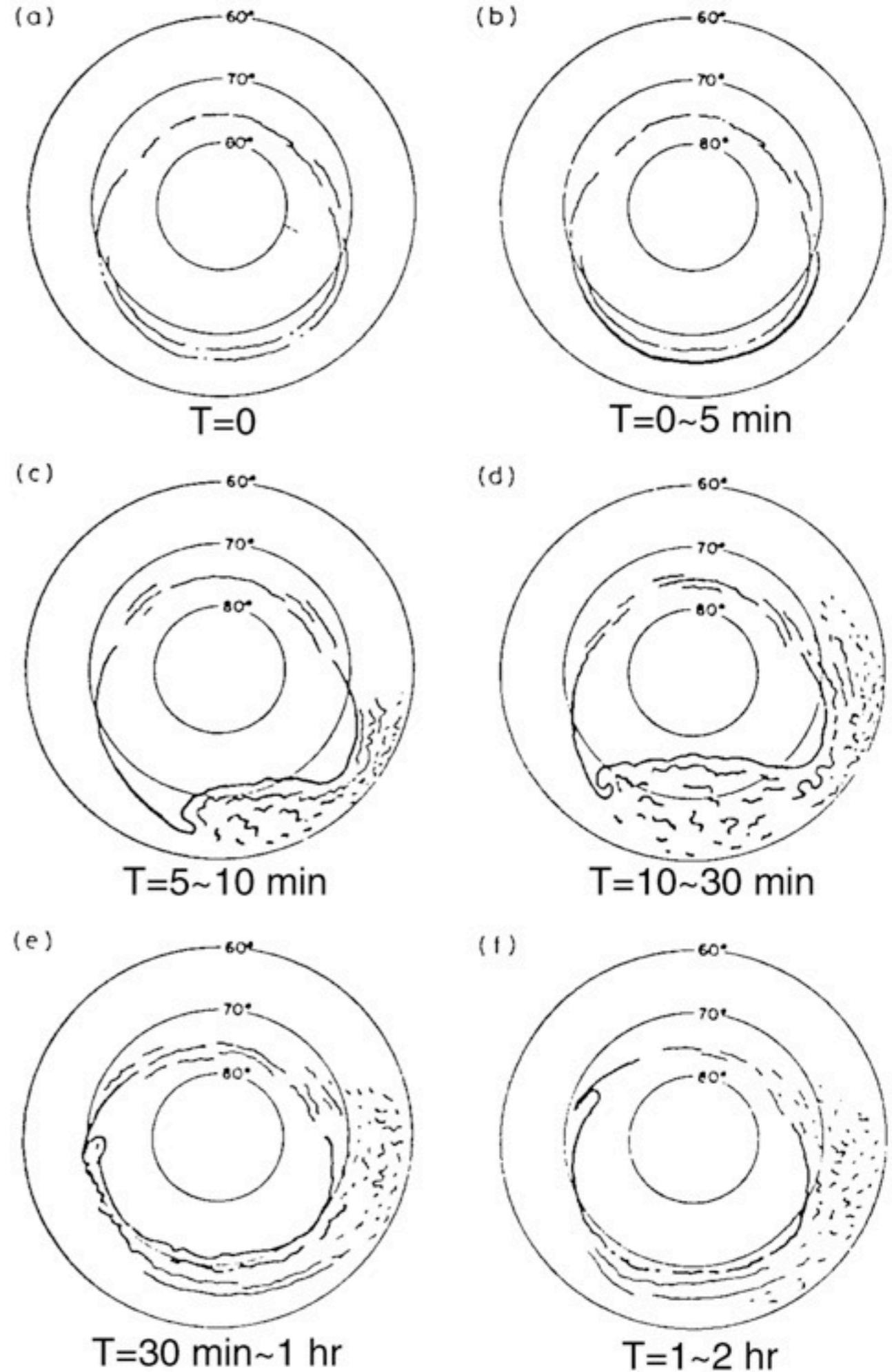
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We often use “onset” and “substorm onset” interchangeably. This is not correct.

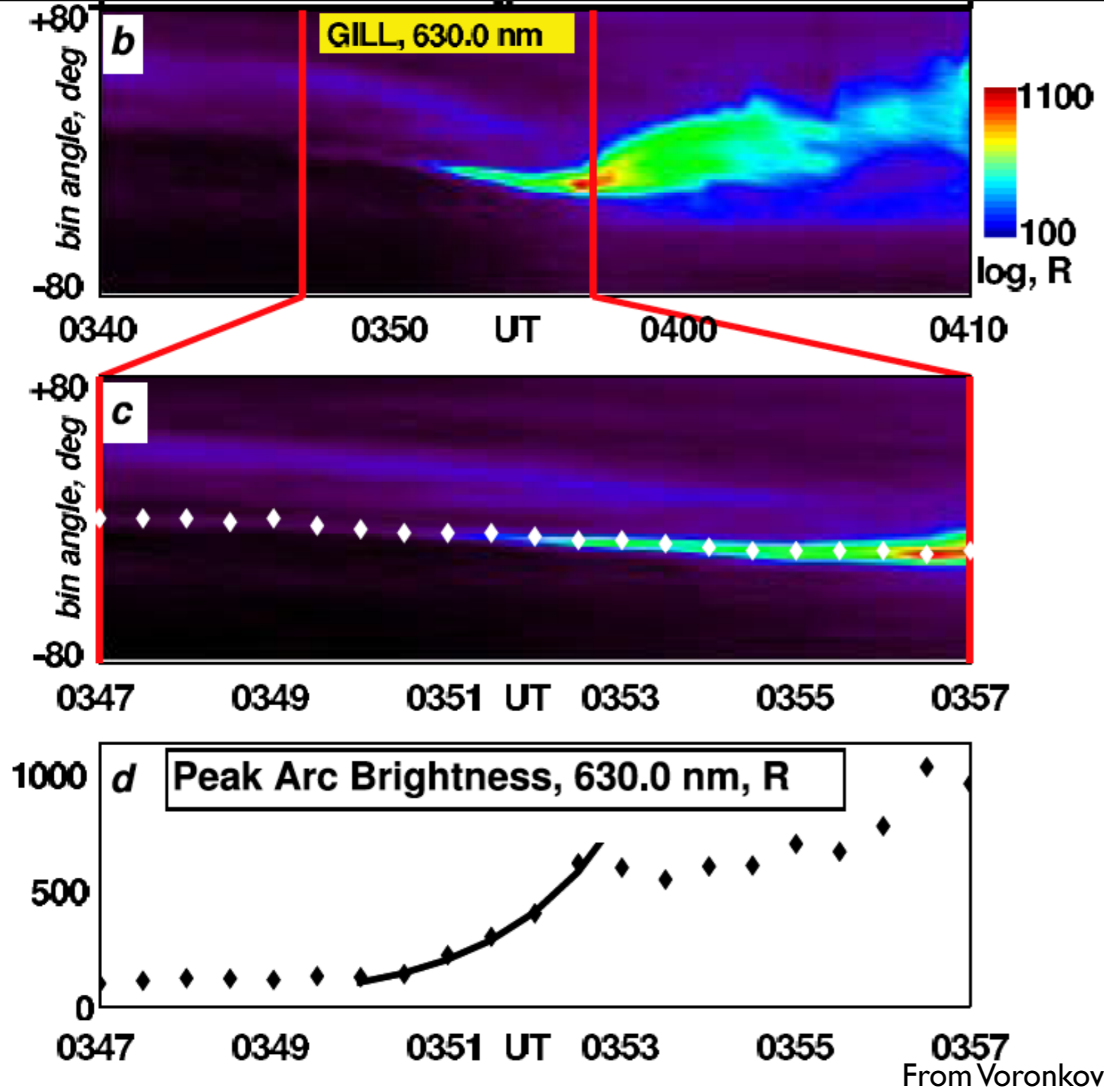
Auroral Onset

- Lead to definition of expansion phase “onset” as first brightening of aurora
- Problem: A substorm has its origins somewhere in the tail. Ionospheric effect is delayed.



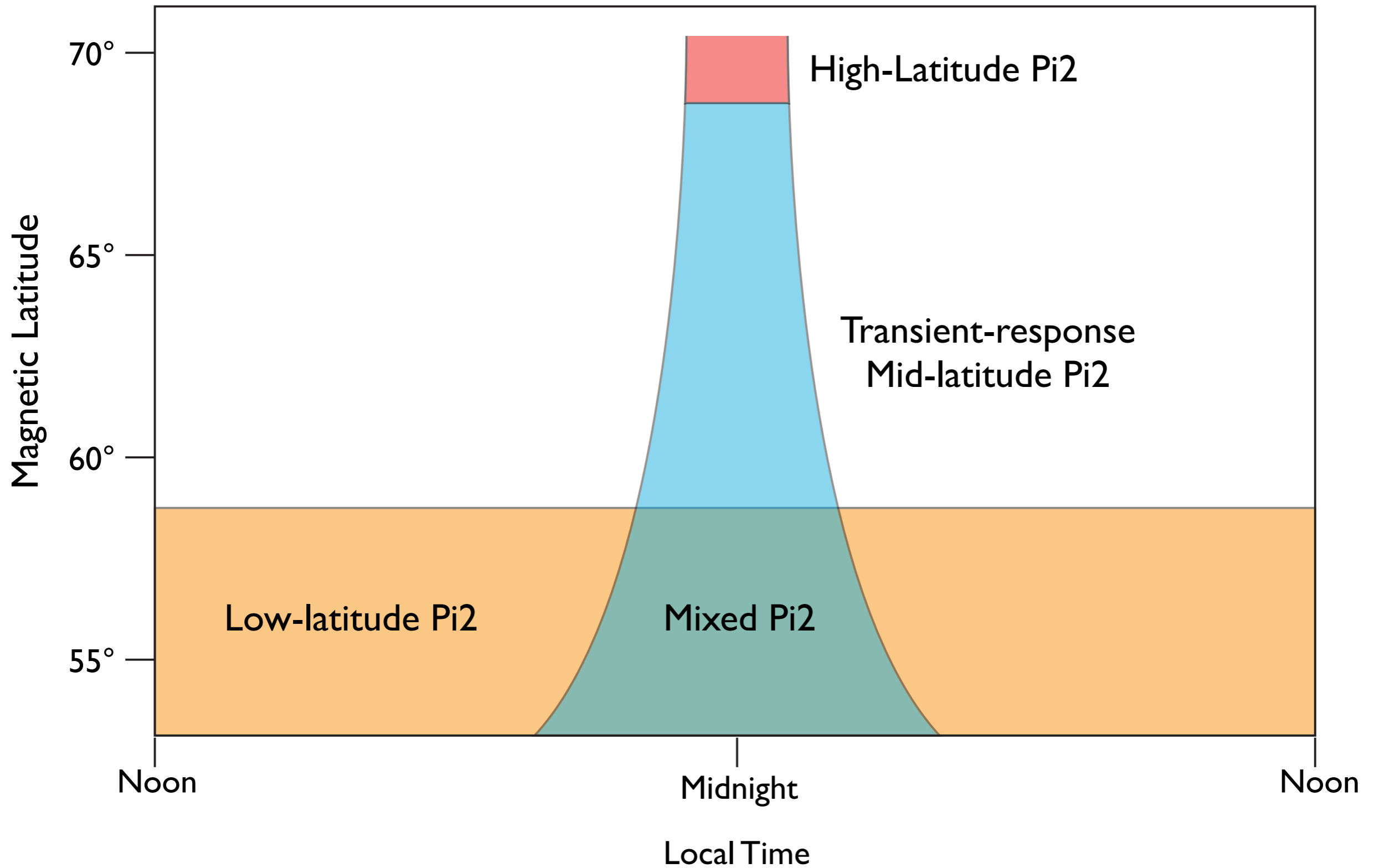
High-resolution Measurements

- Onset arc grows slowly out of the background.
- What is the onset?
- At least 2:
 - Initial brightening (change in intensification)
 - Breakup (change in structure; beading)

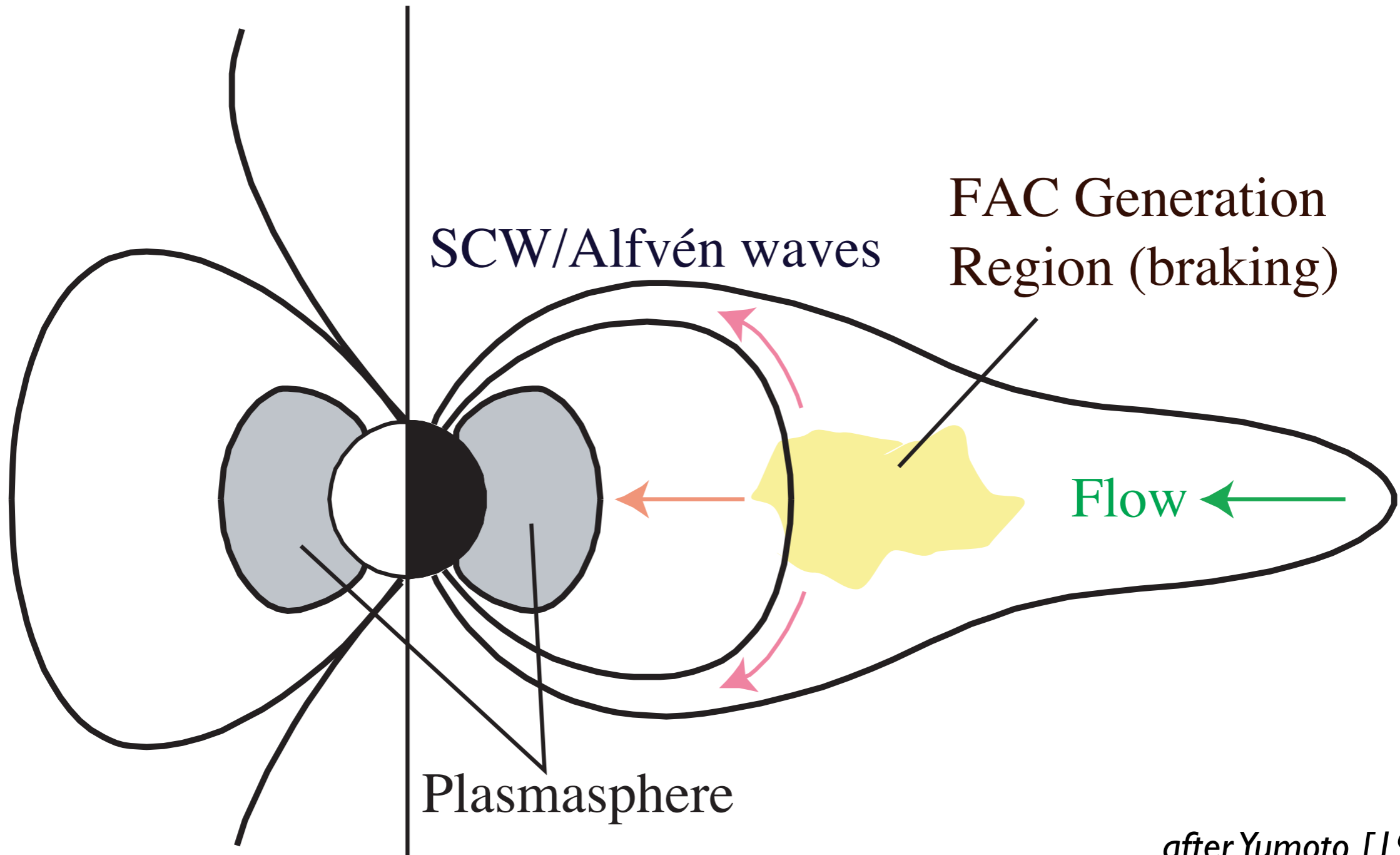


THEMIS observations are timing aurora and flows with high precision (Wednesday FG)
Also, Eric Donovan will discuss on Thursday

Pi2 Pulsations



Pi2 Pulsations

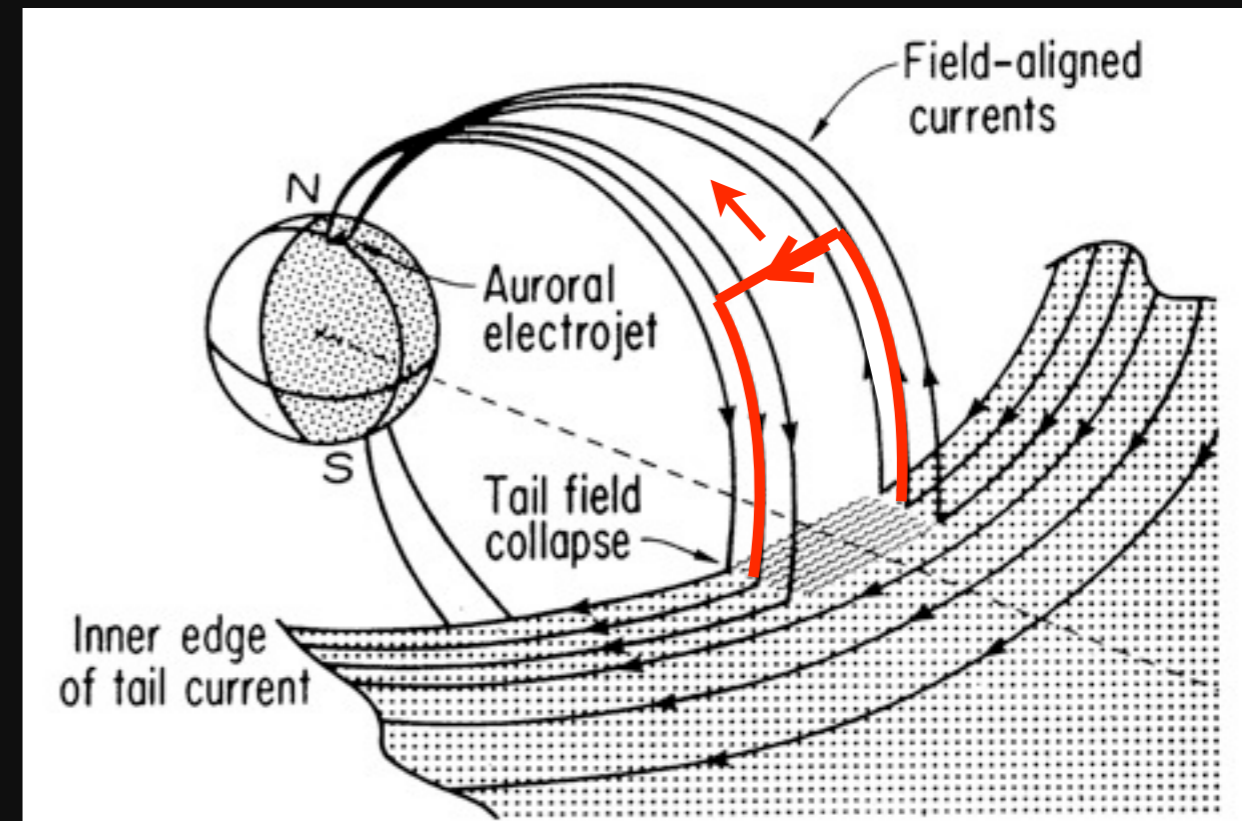
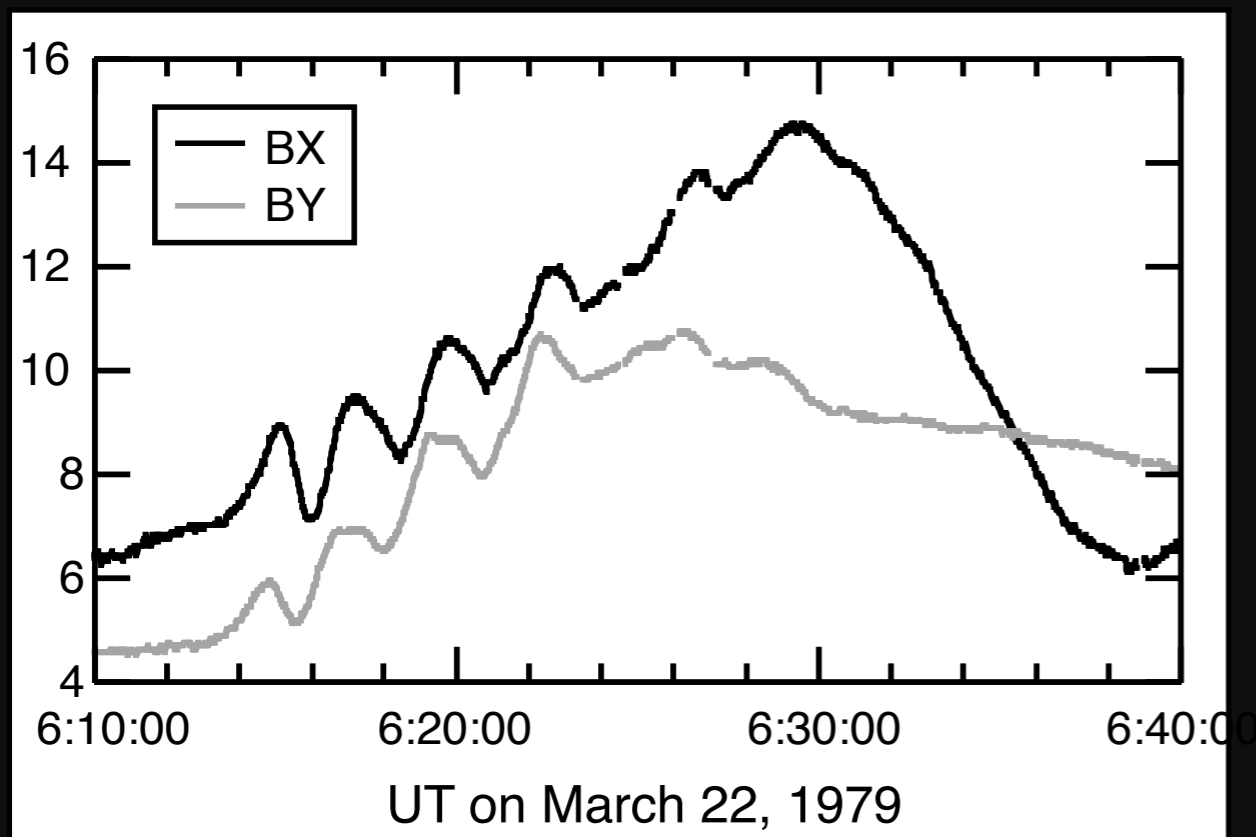


after Yumoto [1986]

Transient Response Pi2

- Transient response, aka “mid latitude Pi2”
 - ▶ Represent reflection of the leading edge of the substorm current wedge

$$E_r = \frac{2E_0}{1 + \Sigma_P/\Sigma_A} - E_0$$



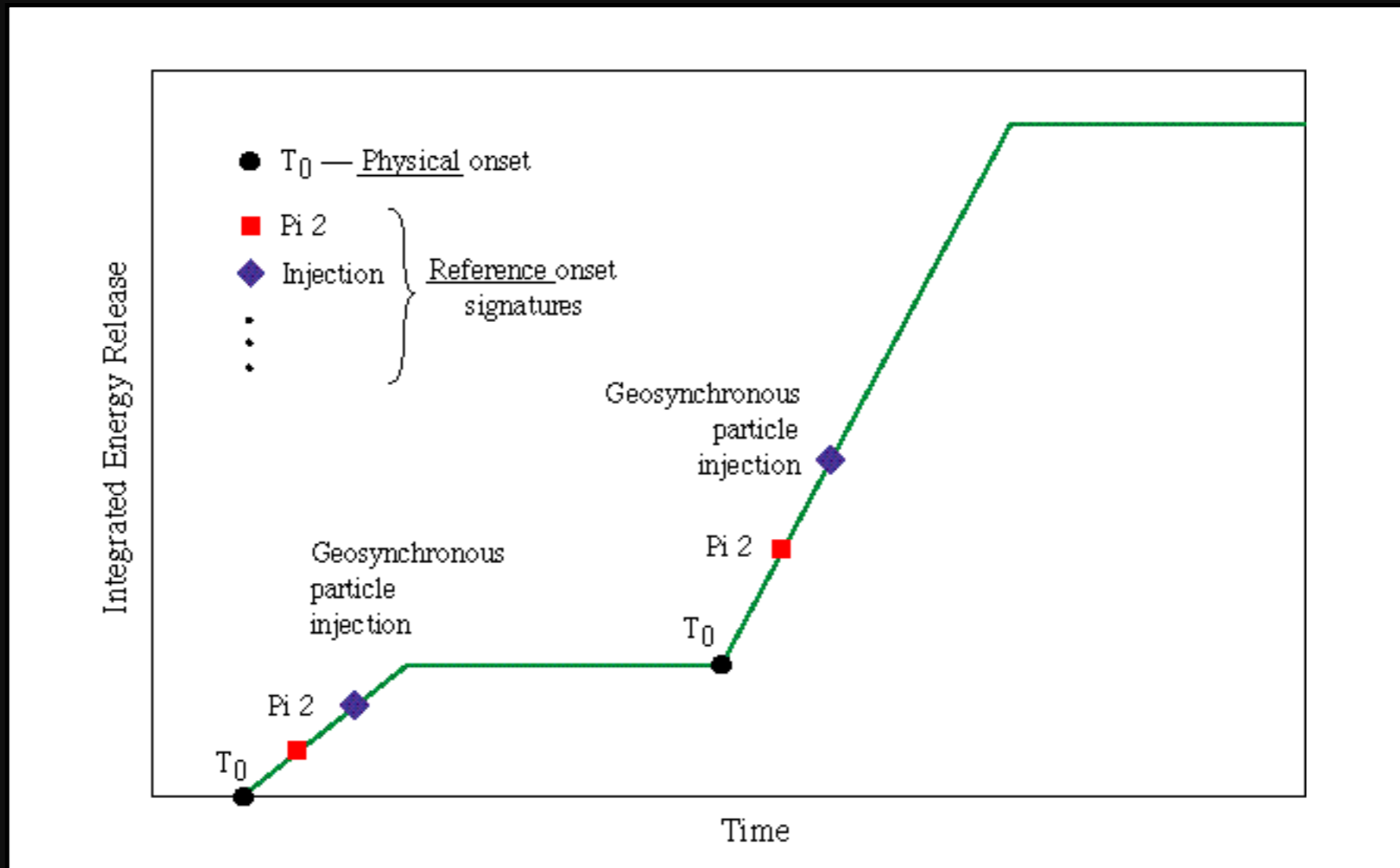
- Mid-latitude Pi2 are associated with the SCW, and can aid in timing near-Earth current diversion.
 - ▶ Need for a physical understanding of the relationship between Pi2 and auroral arc brightening
- Low-latitude / flank Pi2 are indicators that an impulsive/compressional energy released on the nightside. (i.e., flow braking, dipolarization, etc.)

Pi2 have physical significance beyond simple timing markers

- Understanding the linkage (physics) between the phenomena that occur around onset are the focus of the “first 10 minute” focus group.

What is Substorm Onset?

- Substorm onset is the moment that the magnetosphere transitions from storage to release of energy
- We don't see this transition; We see the effects:
 - ▶ Aurora, Pi2, flows, etc.



What is a substorm?

dog•ma - A principle or set of principles laid down by an authority as incontrovertibly true

Is this really a valid question?

Why is there no substorm metric?

How do substorms relate to other geomagnetic activity?

What is a substorm?

- Growth phase
 - ▶ Storage of energy in the lobes due to unbalanced flux transfer from dayside to nightside (~20 min)
- Expansion phase
 - ▶ Initial (explosive) release of stored energy (~10 min)
- Recovery phase
 - ▶ Refilling of the plasmashet (~30 min)

For each phase, we know the signatures in various magnetospheric regions (aurora, auroral indices, geo, midtail, etc.).

We know intuitively what a substorm is.

Growth phase

- Equatorward motion of arcs
- Increase in lobe magnetic field
- Plasmasheet thinning
- Earthward motion of inner edge of plasmasheet
- Stretching of field at geosynchronous
- Slight decrease in AL, increase in westward electrojet

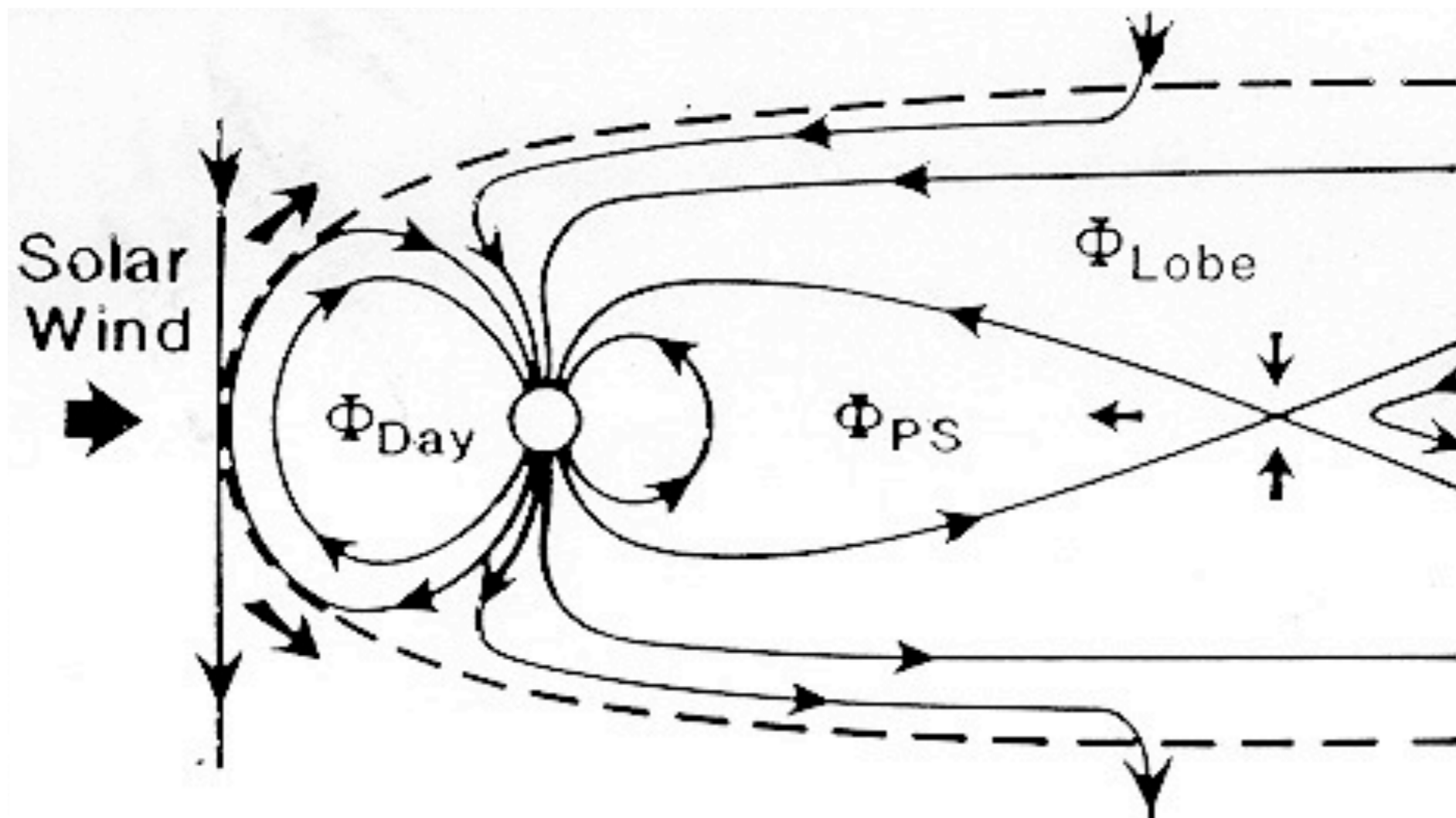
Expansion Phase

- Brightening and poleward motion of auroral arcs
- Westward traveling surge
- Decrease in lobe flux
- Near-Earth dipolarization
- Particle injections
- Pi2

Recovery Phase

- Thickening of plasmashheet
- Retreat of near-Earth neutral line
- Decrease in auroral activity
- AL decreases

A substorm is a global process by which the magnetosphere unloads stored energy, arising from imbalanced convection.



We know intuitively what a
substorm is.

So what's the problem?

What is a substorm?

The problem is that we are unable to quantify a substorm. As scientists, we need to be able to define the object we are studying.

Why is it so difficult to develop an objective, quantifiable definition of a substorm?





Which is the cat and which is the dog?



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How did you know?

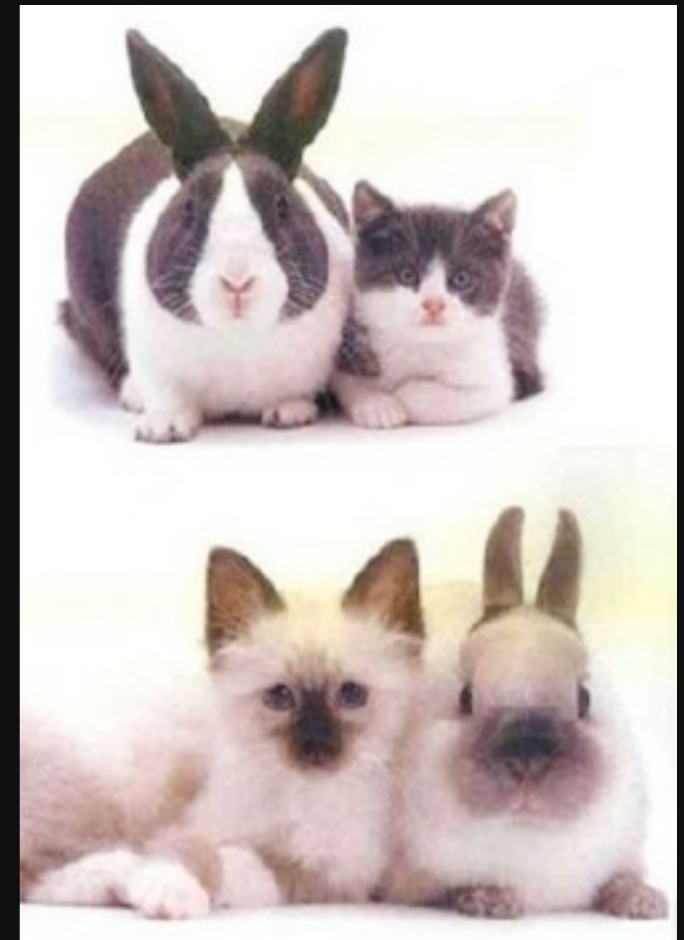


Which is the cat and which is the dog?

How did you know?

Answer: You intuitively know the difference

- Can you develop a quantitative, objective, easily measured metric to determine the difference?
- Given the array of shapes, sizes and colors, it's difficult.



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We face the same problem in defining a substorm



Quantifying Substorms

- Hurricanes and tropical storms use the Saffir-Simpson Scale
 - ▶ Which is based on **potential damage**, not dynamics
 - ▶ Requires recognition that the object is a tropical structure

Category	Wind speed (mph)	Damage
5	>155	Widespread damage
4	131-155	Roof failure
3	111-130	Wood homes
2	96-110	Roofing damage
1	74-95	Mobile homes
Tropical Storm	39-73	
Tropical Depression	0-38	

Quantifying Substorms

- Defining a hurricane in this fashion tells you nothing about the underlying dynamics. It's a way to count and inform the public.

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Quantifying Substorms

- We could develop substorm classification scale
 - ▶ Just as for hurricanes, must start with a basic premise

Category	$\Delta AL $	Auroral Extent
5	>1000	>51
4	501-1000	41-50
3	251-500	31-40
2	101-250	21-30
1	51-100	11-20
pseudo-breakup	0-50	0-10

Quantifying Substorms

- In the question of what is or is not a substorm, there is (often) an underlying disagreement:

Are flow bursts, pseudo-breakups and substorms manifestations of the same underlying physical process(es), and differ only in scale (region) or magnitude/intensity?

Or:

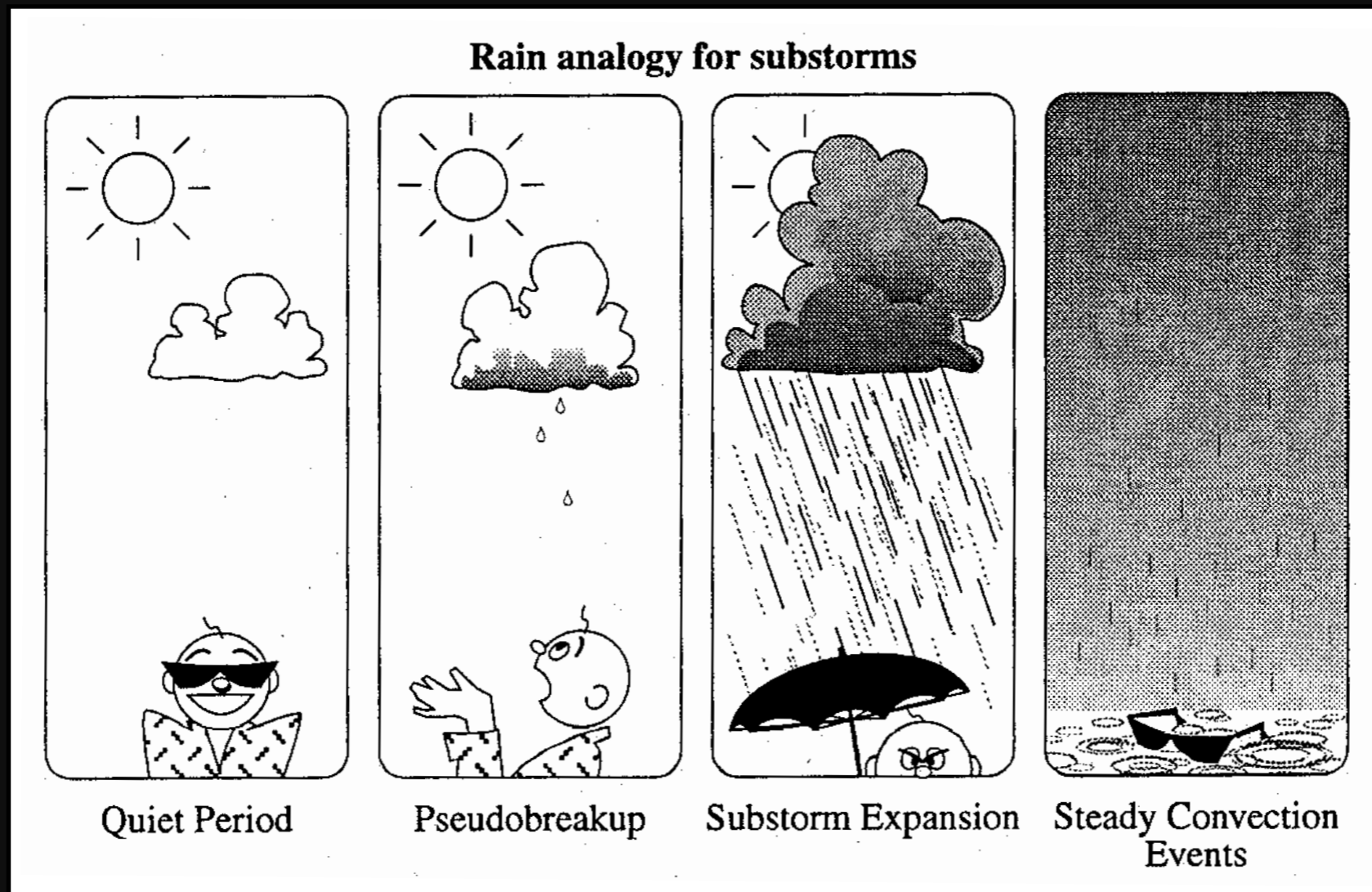
Do flow bursts, pseudo-breakups and substorms represent fundamentally different modes of magnetospheric transport?

Modes of transport

jam•ble -An untidy collection or pile of things

Continuum or discrete modes?

What (if anything) can we learn from meteorology?



- Possible that magnetospheric activity related to $B_z < 0$ is a continuum
 - ▶ Pseudo-breakups, substorms and SMCs are driven by same underlying dynamics.
 - ▶ Differ only in intensity, scale, and/or duration

- Possible that pseudo breakups, quiet time activations, substorms and steady convection events are driven by different underlying physical processes (or at least different triggers)
- Or different activity represents fundamentally different modes of magnetospheric transport.
 - ▶ e.g., thunderstorms, hurricanes, cold fronts, etc.

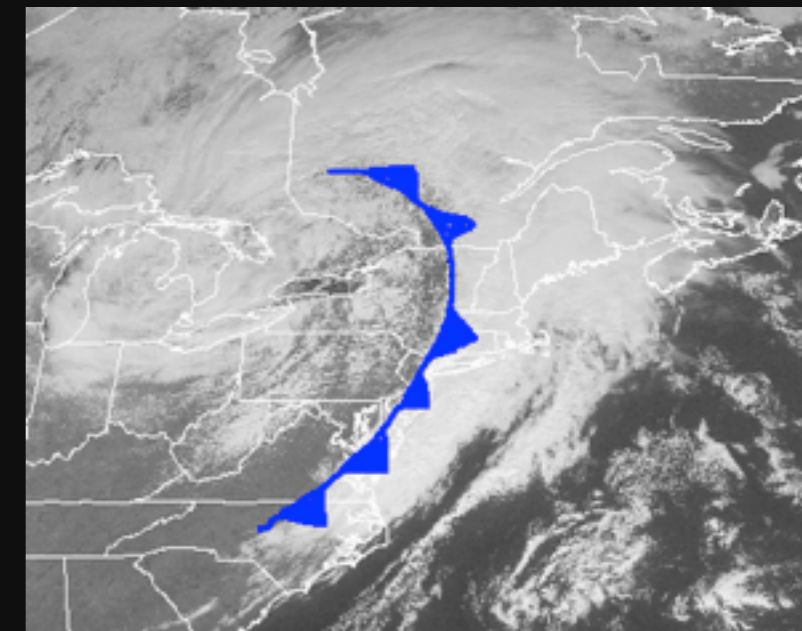
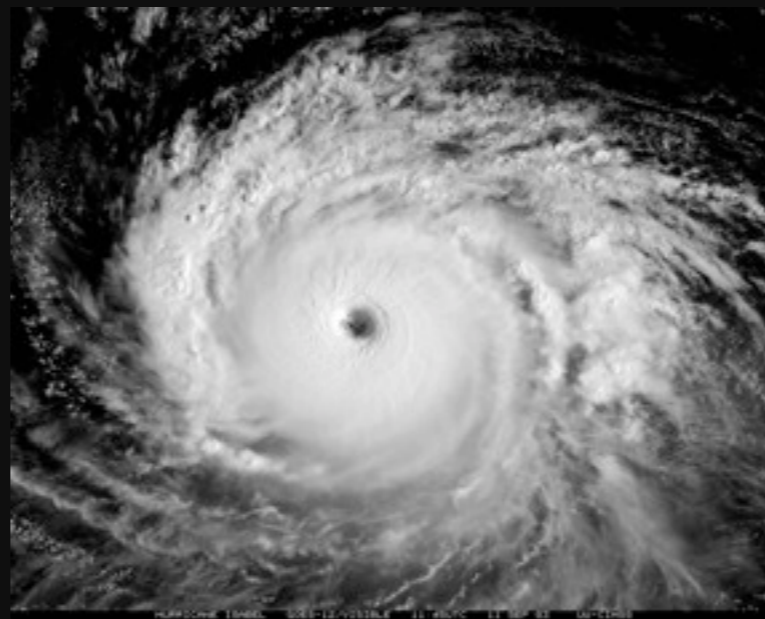
Small ... Large



Small ... Large



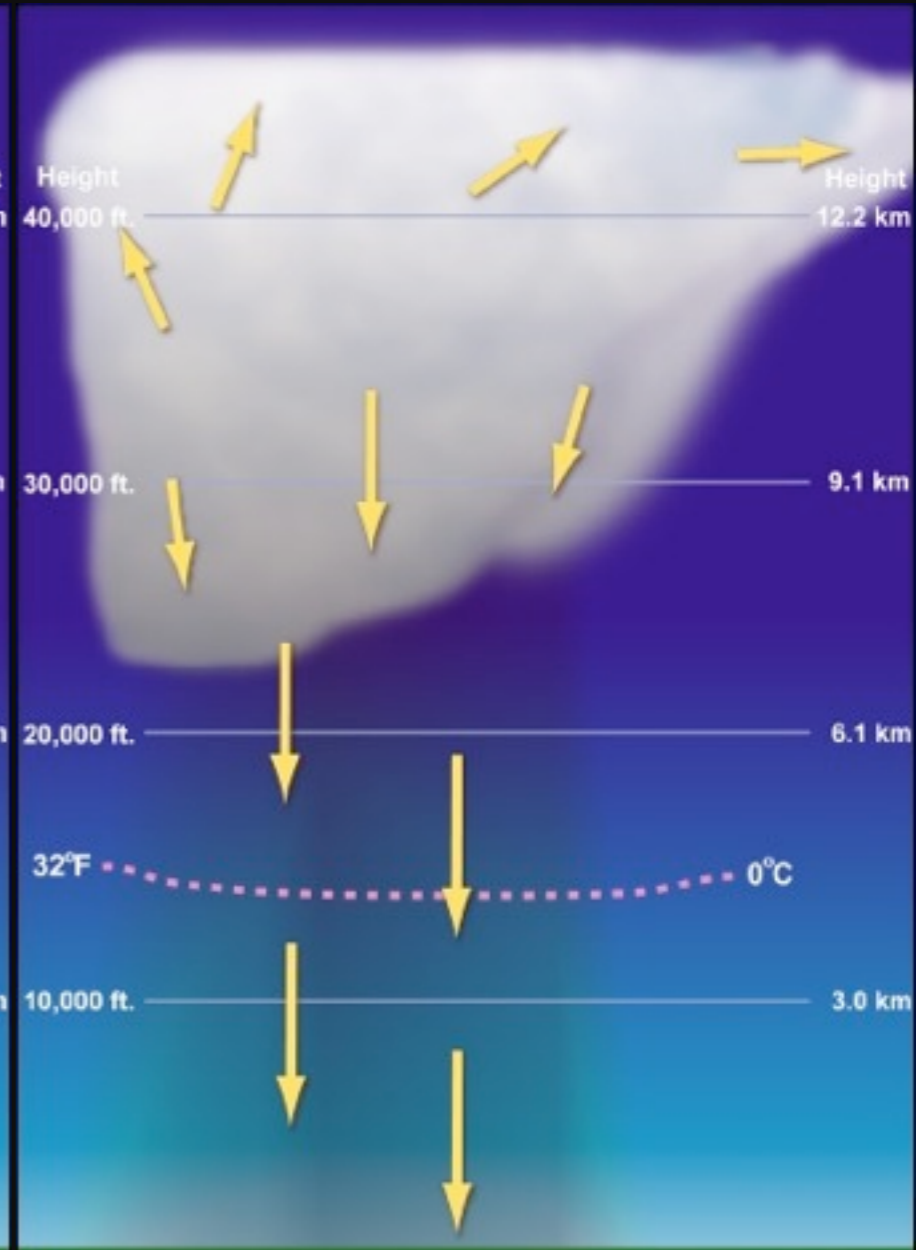
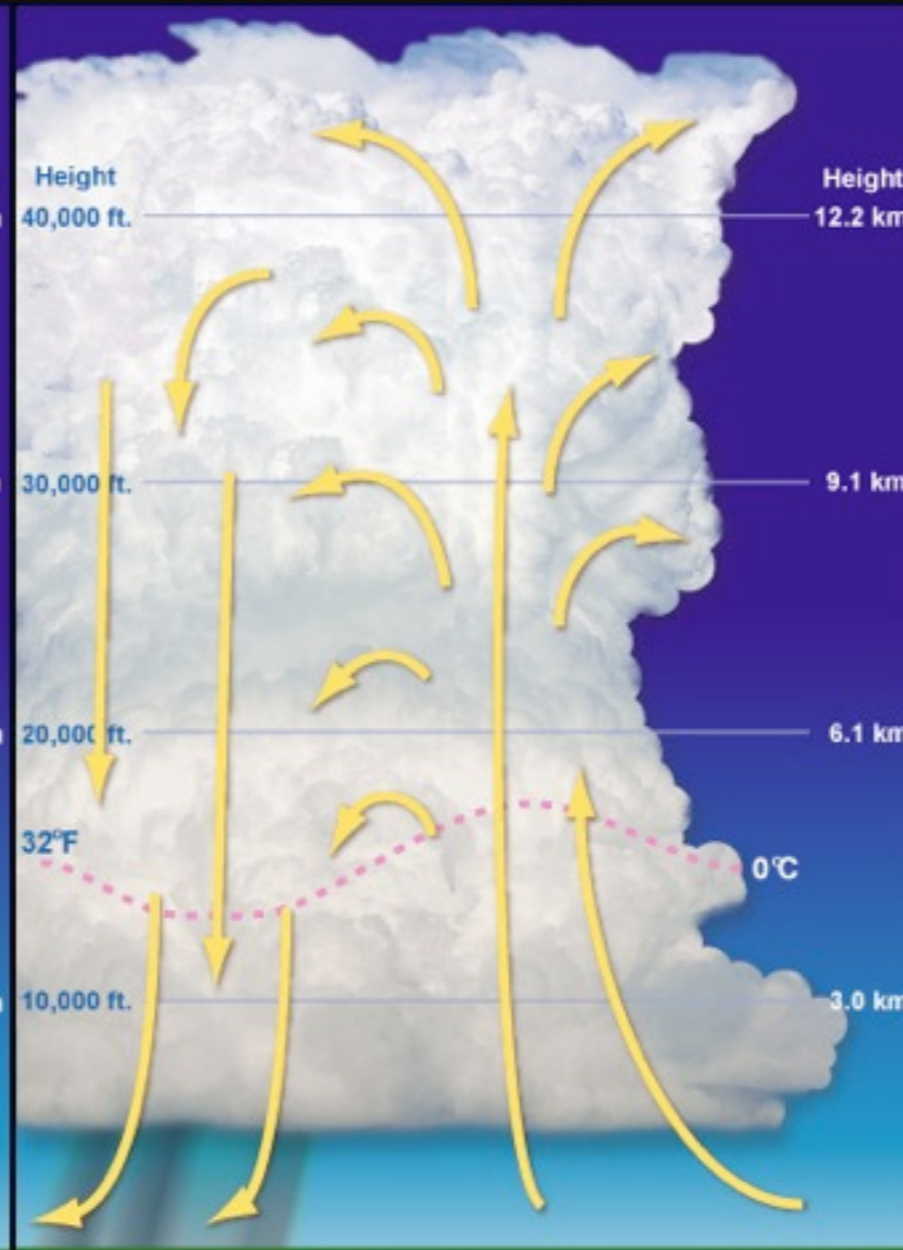
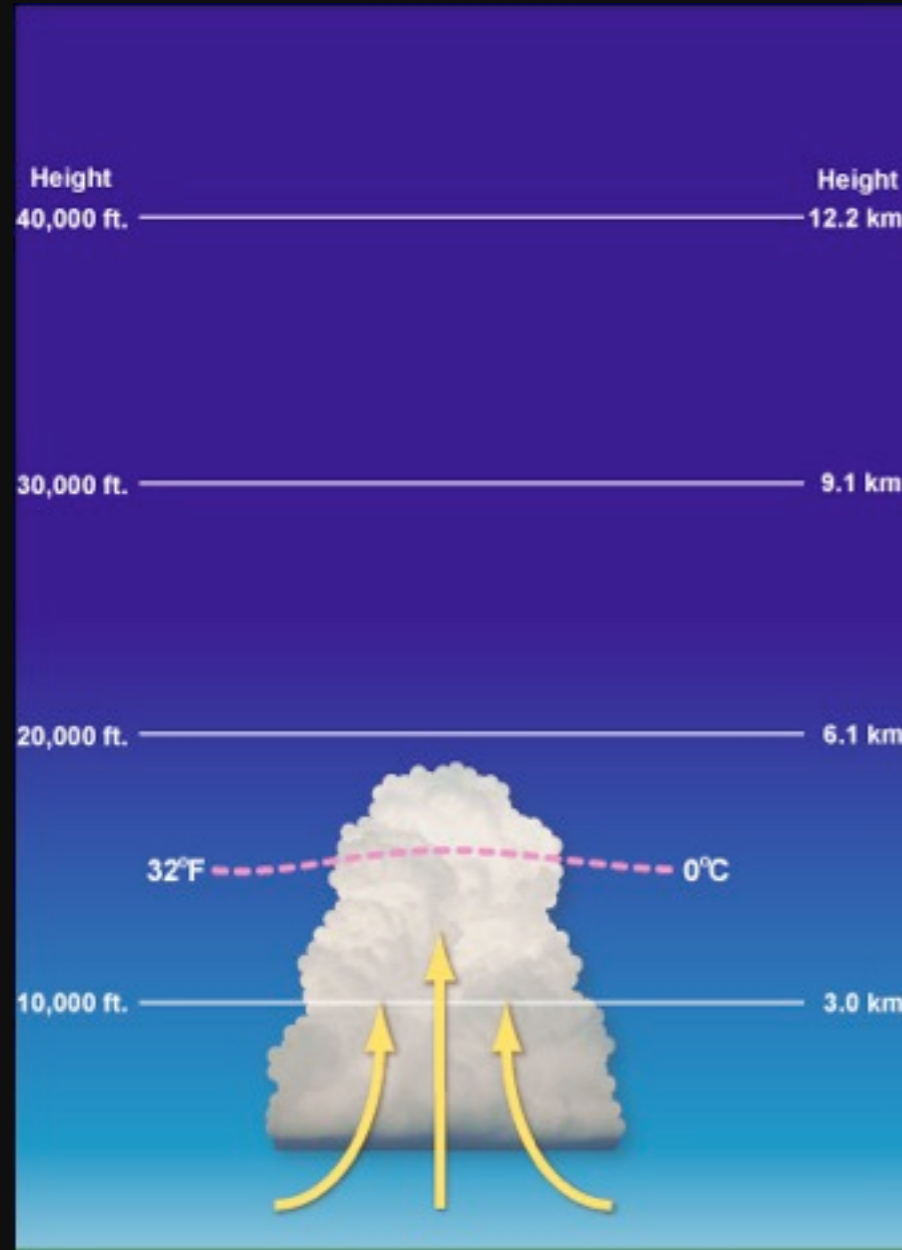
Small ... Large



No Rain

Heavy Rain

Light Rain



Towering Cumulus Stage

Mature Stage

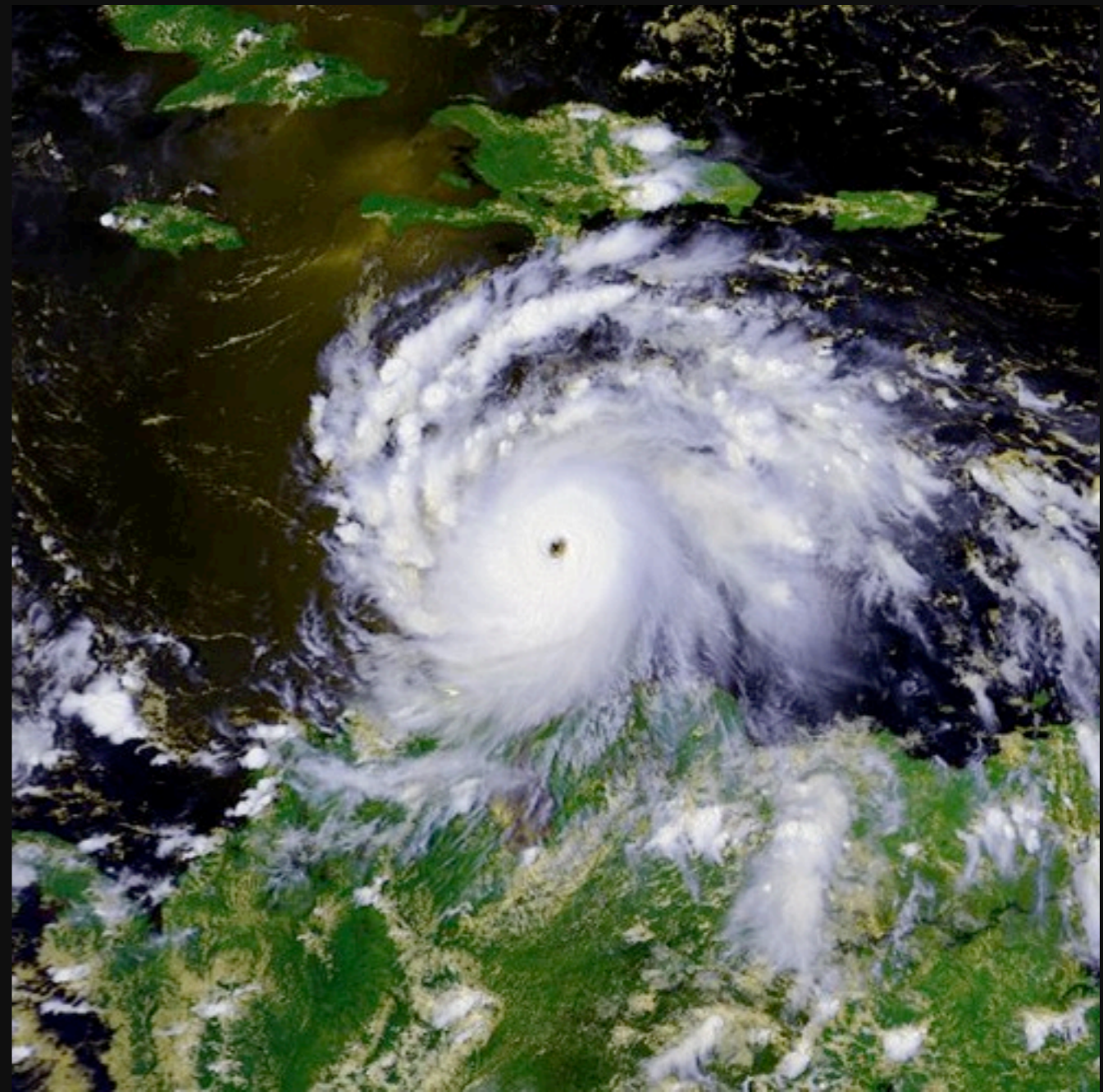
Dissipating Stage

Growth
Phase

Expansion
Phase

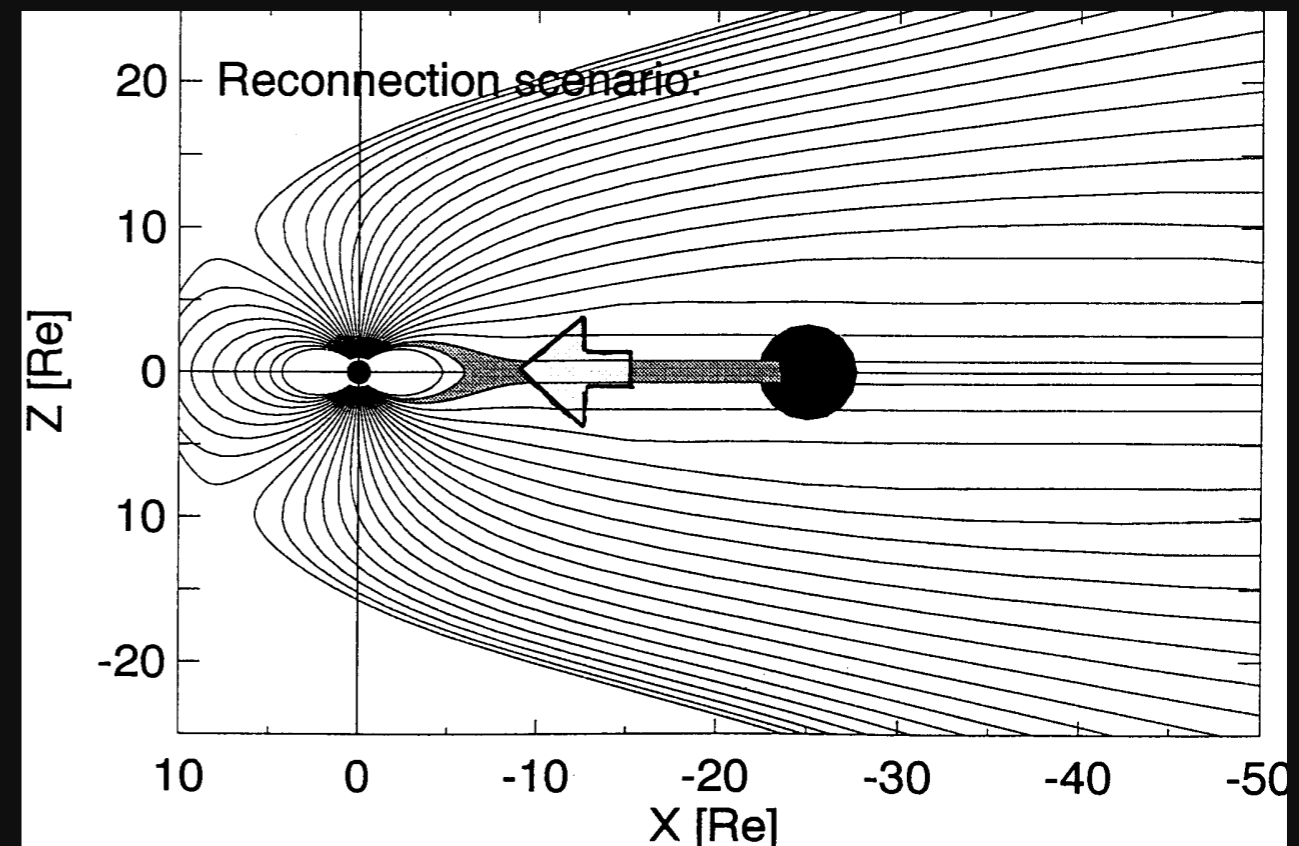
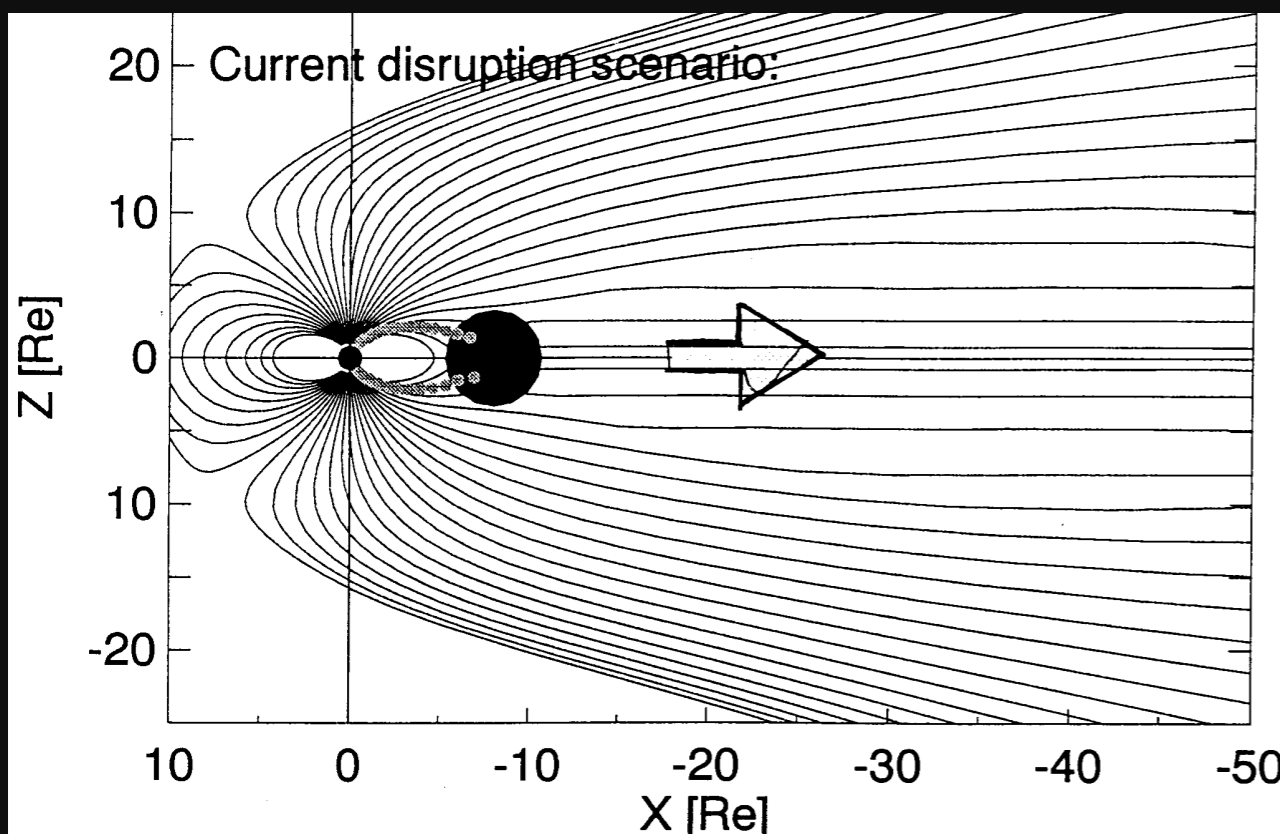
Recovery
Phase

- Thunderstorms occur in:
 - Hurricanes
 - Cold fronts
 - Randomly in humid air
- No one argues that the thunderstorms are different just because they occur in a different convective structure.



BBFs (more generically, flow bursts) are considered by some different if they occur during quiet time, pseudo breakups or during substorms

- Distilling the substorm problem to an inside-out/ outside-in controversy ignores the question of what is happening all the time
 - ▶ How do NGO models account for non-substorm activations, that appear to have similar temporal sequence as substorm onsets?
- Does the magnetosphere generate events with same characteristics (aurora, Pi2, flows) etc., in 2 different manners?



Retaining Institutional Knowledge

an•tiq•ui•ty - The ancient past, especially the period before
the middle ages

Competing with 'the google' and wikipedia
Consolidating knowledge

Starting Out

- Imagine you're a student just starting out on substorms.
 - ▶ Where to begin?
- We face a problem of volume
 - ▶ Tremendous amount of papers have been published on aurora, substorm current wedge, currents, etc.
 - ▶ Often difficult to know where to start
- Take the substorm current wedge
 - ▶ Recent papers have attempted to reinterpret the SCW

Furthermore...

- The ISTP era was quite successful in moving the field forward
 - ▶ But this knowledge has not been consolidated
- Current generation of scientists faces the challenge of retaining the institutional knowledge that will soon leave us.
 - ▶ I email Bob McPherron; he probably doesn't want everyone to do that
 - ▶ Don't want new missions to rediscover old science

Solution?

- Make old papers available electronically.
 - ▶ JGR goes back to 1949; other journals haven't caught up.
 - ▶ Still doesn't solve the problem of informing which papers are the ones we should be reading. Collections?
 - ▶ Unless we adapt to the digital era, we're likely to lose out to wikipedia and google.
- Encourage our senior scientists to write review papers before they retire.
 - ▶ Might also pair old with young (e.g., McPherron & Kepko on the SCW).
 - ▶ GEM challenge

Conclusions I

- “Substorm onset” vs. “onset”
 - ▶ We should phase out the use of the phrase “substorm onset”, especially since we don’t know what a substorm is.
 - ▶ Use “auroral breakup”, “auroral arc brightening”, “[region] Pi2 onset”, etc.
- How to define an onset?
 - ▶ Becoming increasingly clear that substorm signatures grow out of the background.
 - ▶ Important to know the physics underlying the onset phenomena, and how they relate to each other (Onset FG)

Conclusions II

- Why can we not develop criteria for defining a substorm?
 - ▶ We can. But disagreement over whether a continuum of activity exists or if substorms are special in some way.
- Magnetosphere does exhibit multiple modes of organized transport
 - ▶ Substorms, Steady magnetospheric convection, sawtooth.
 - ▶ Modes of transport FG (today)
- Need to summarize and retain institutional knowledge.