What causes auroral arcs…
and why we should care?

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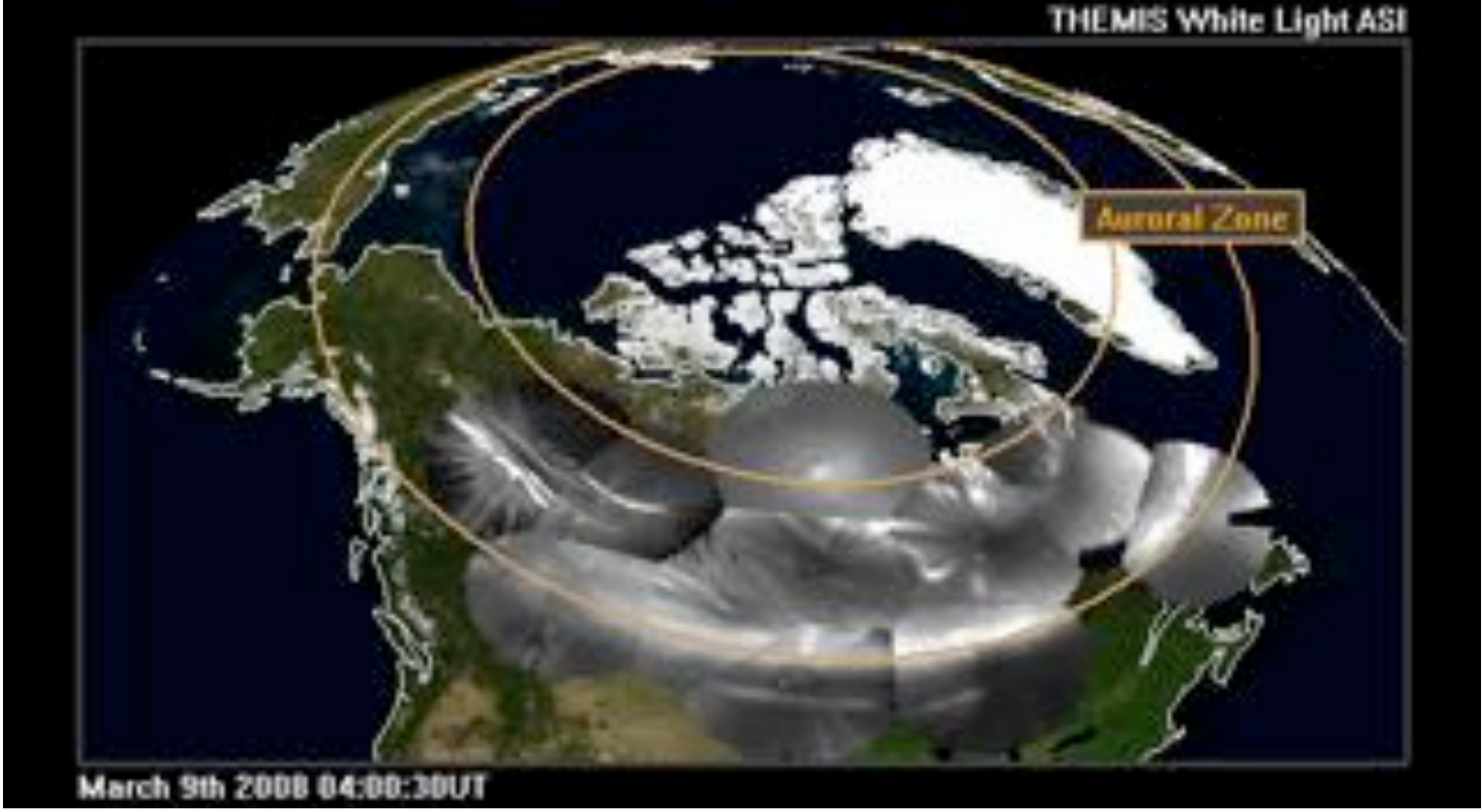
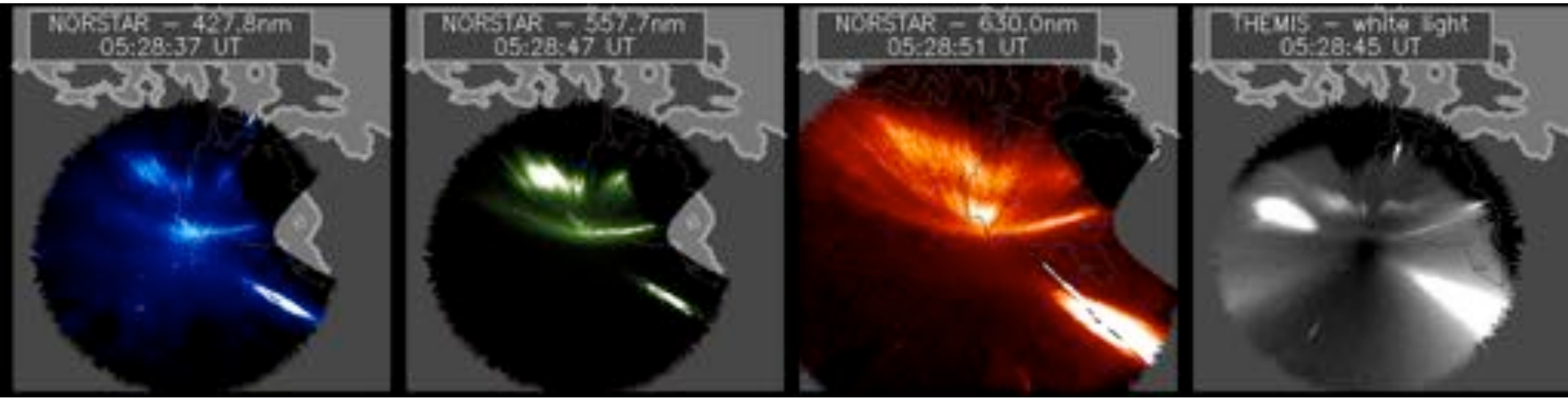
NASA Goddard Space Flight Center



Aurora are the most visible manifestation of space weather.

Yet despite decades of research, the magnetospheric source for the aurora remains largely unknown.

Multispectral data complicate things.



4278 Å
Responds to medium energy electrons (keV and up)

5577 Å
Responds to both protons and electrons (>1 keV)

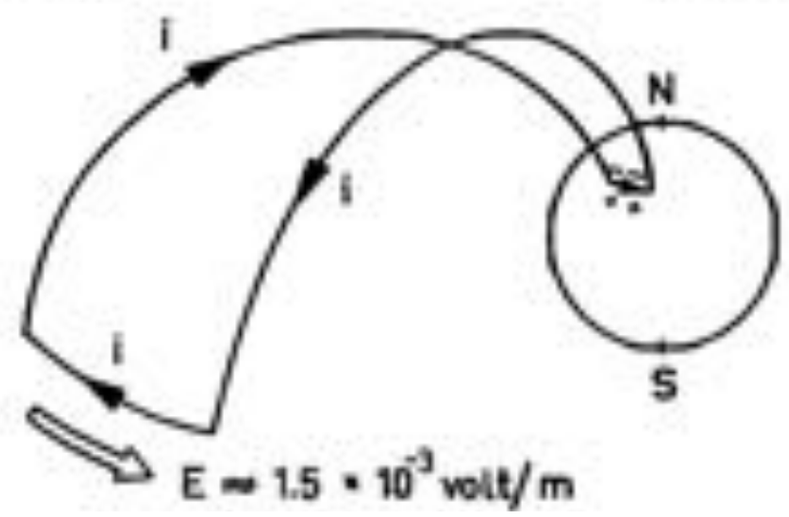
6300 Å
Responds to low energy electrons (eV - 1 keV)

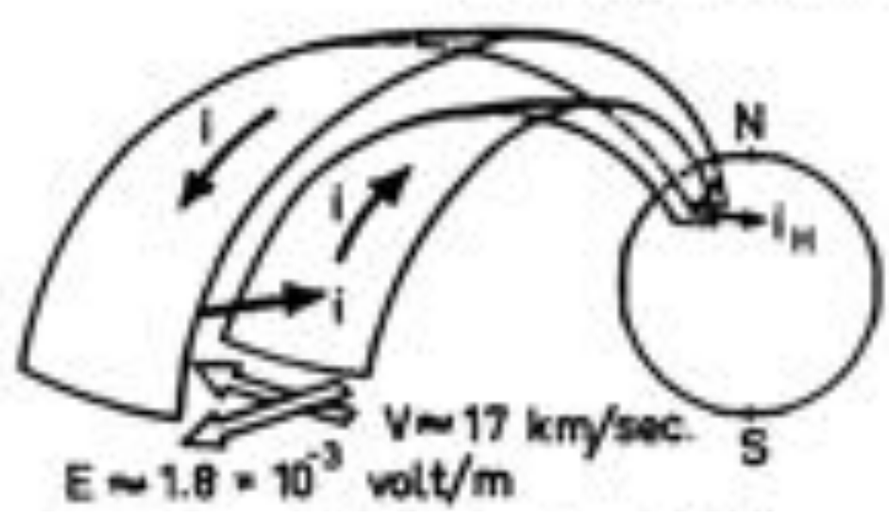
White Light
Similar response as 5577

"Energetic"

Kepko et al. 2008 GRL

Arcs are regions of active MI coupling
Closure details reveals information about magnetospheric generator





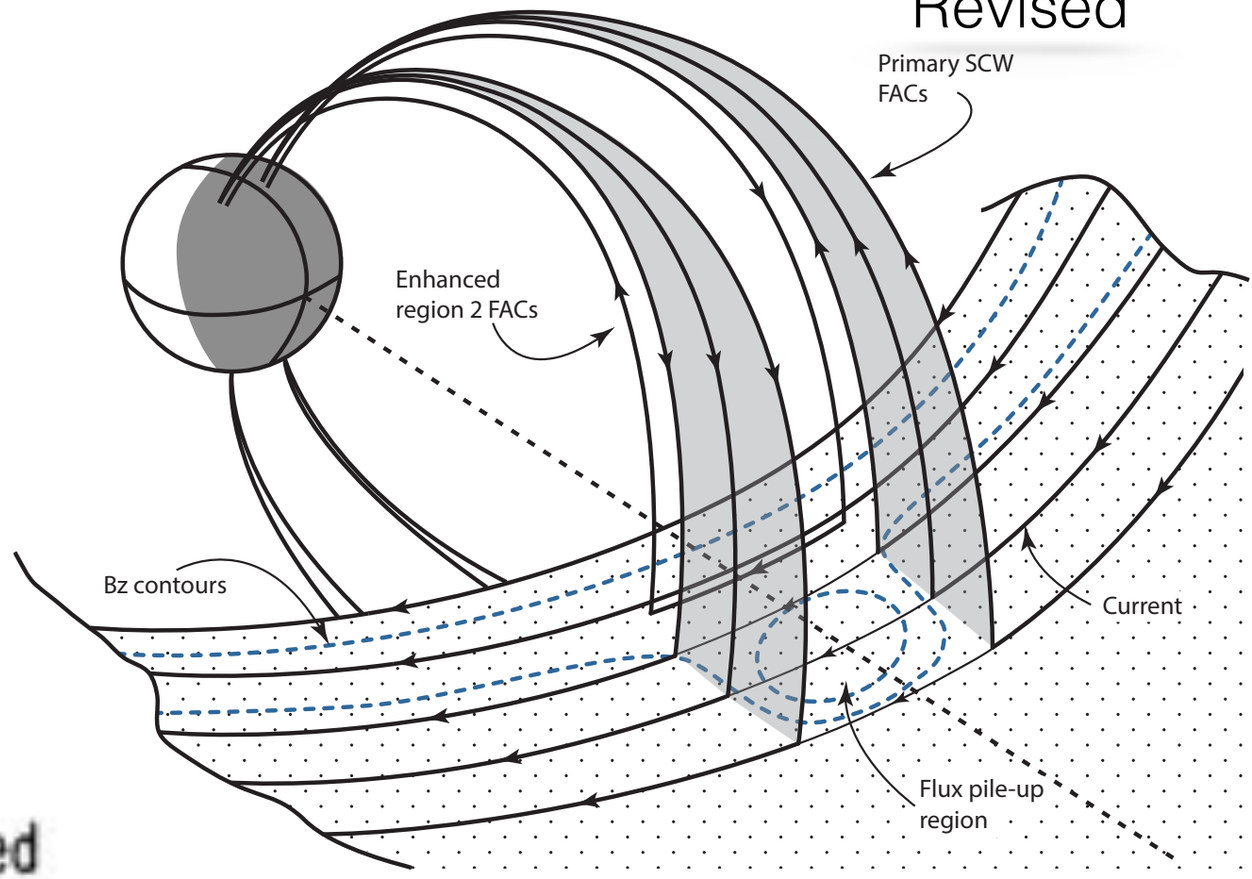
Two issues:

1. Auroral zone often used as 2-d screen of magnetospheric motions. When is this valid?

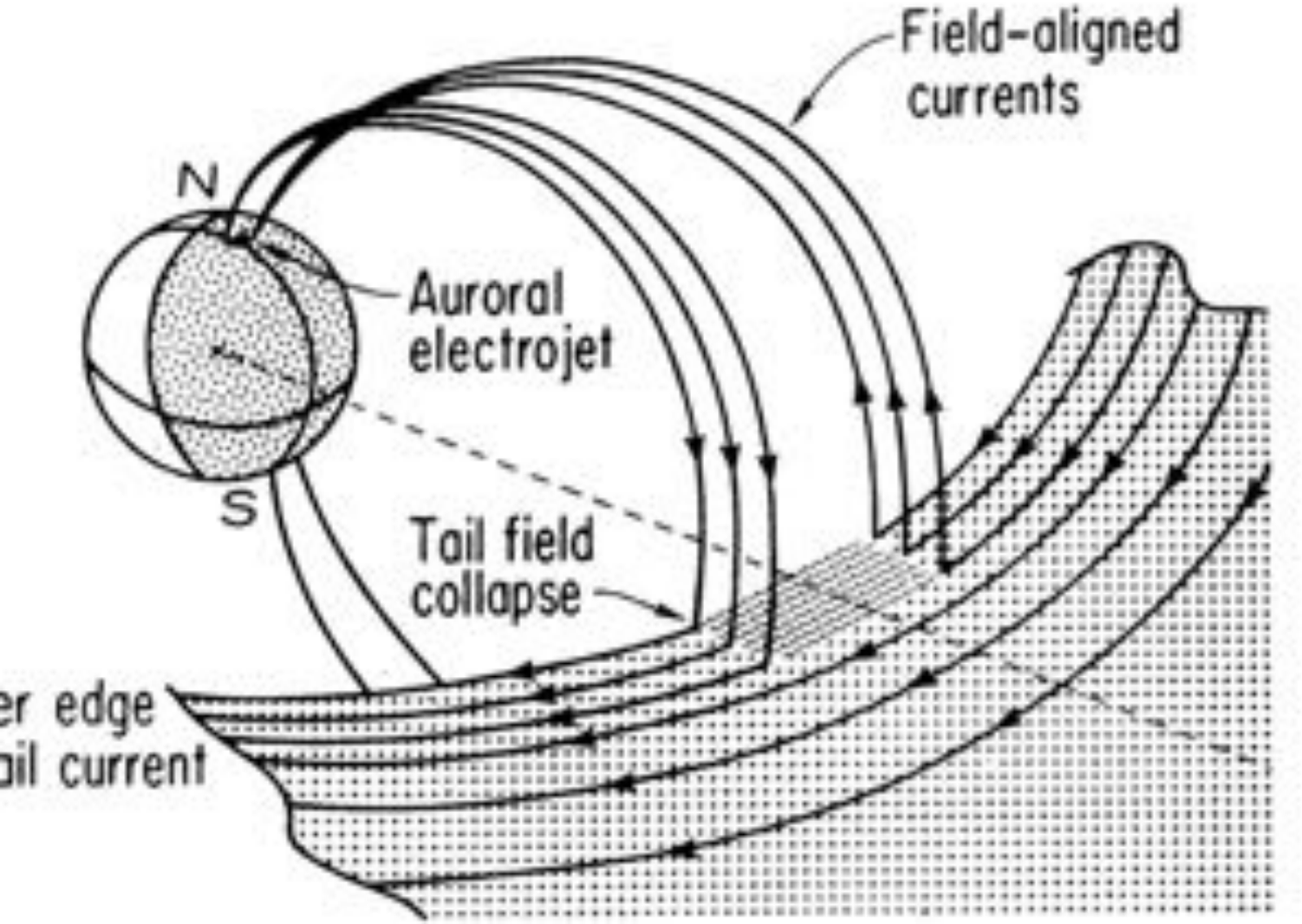
2. Important to have physics-based understanding of magnetospheric dynamics

Magnetospheric observations and simulations indicate inner loop with R2 sense

Revised



Traditional

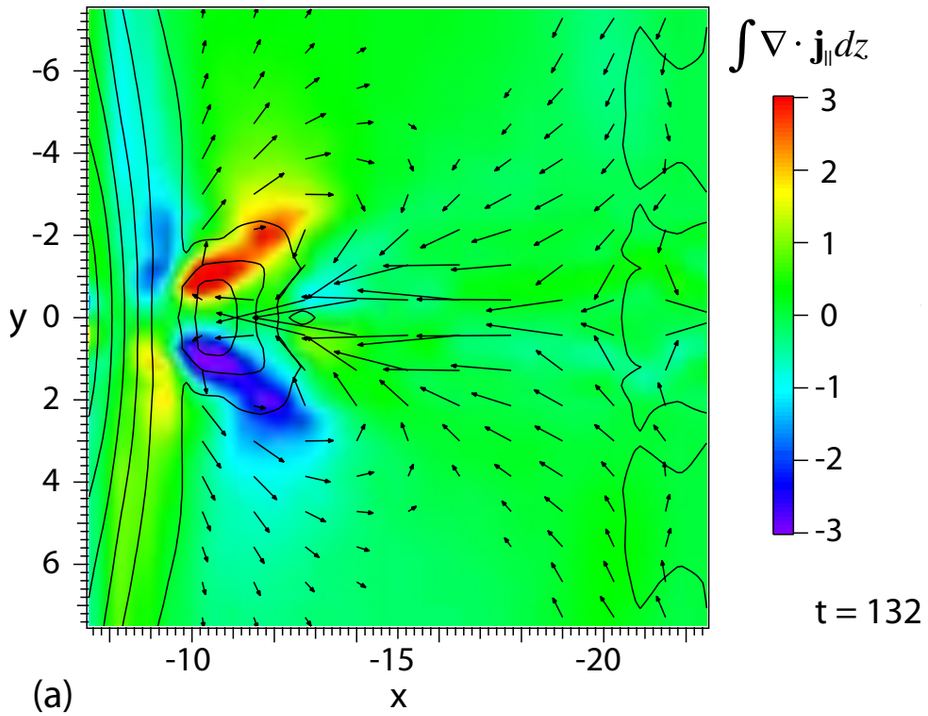


More physical to think of currents driven by pressure gradients, not diverted

Kepko et al. [2014] in SSR

Simulations provide insight into magnetospheric drivers

Total current

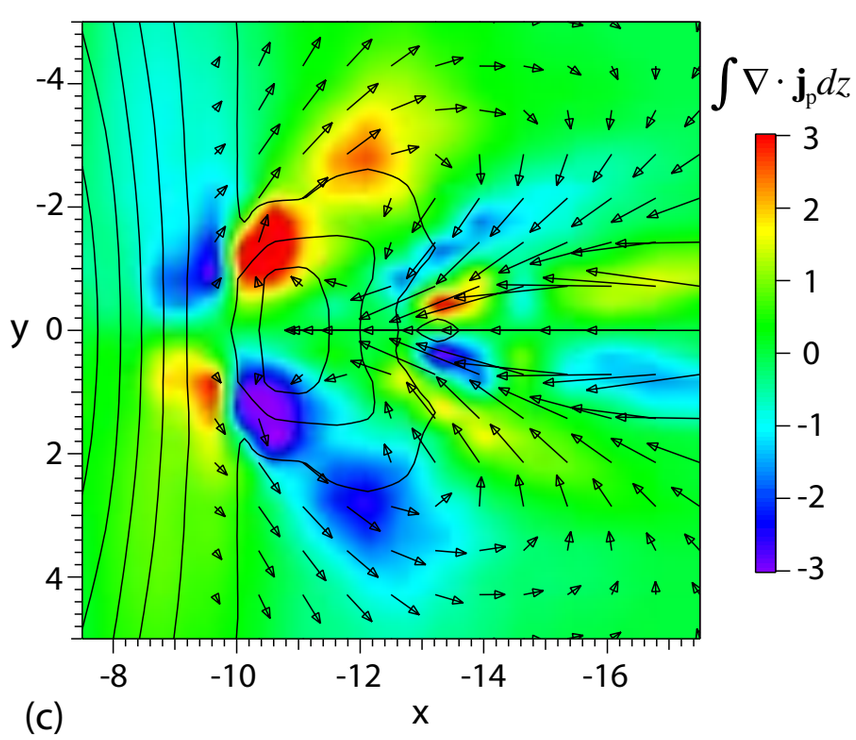


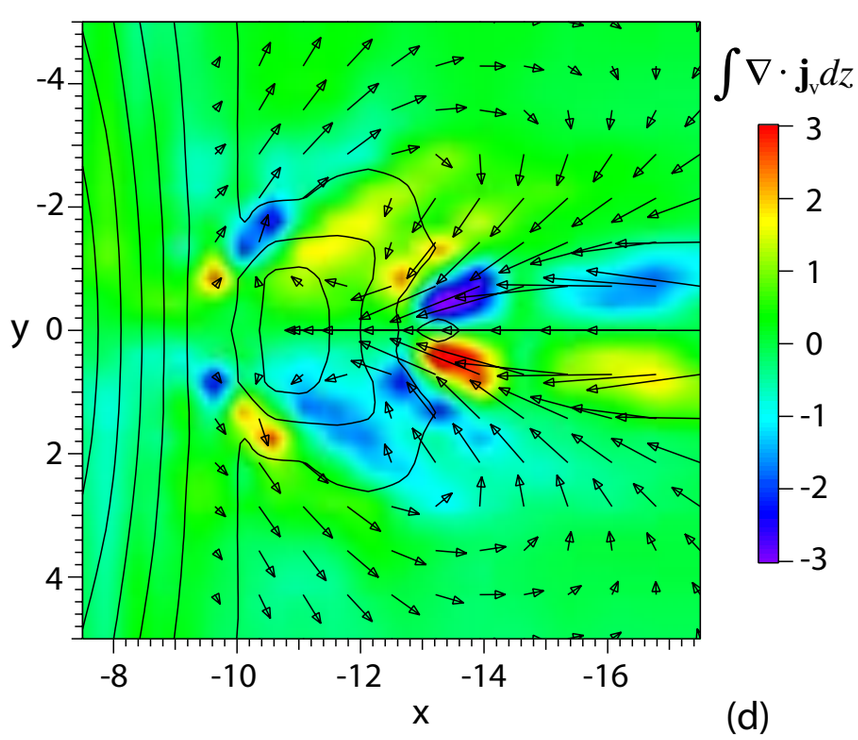
vorticity

$$\frac{j_{\parallel}}{B} = -\int_0^s \nabla \cdot \left(\frac{\mathbf{B}}{B^2} \times \rho \frac{d\mathbf{u}}{dt} + \frac{\mathbf{B}}{B^2} \times \nabla P \right) \frac{ds}{B}$$

pressure gradients

Pressure-gradient driven



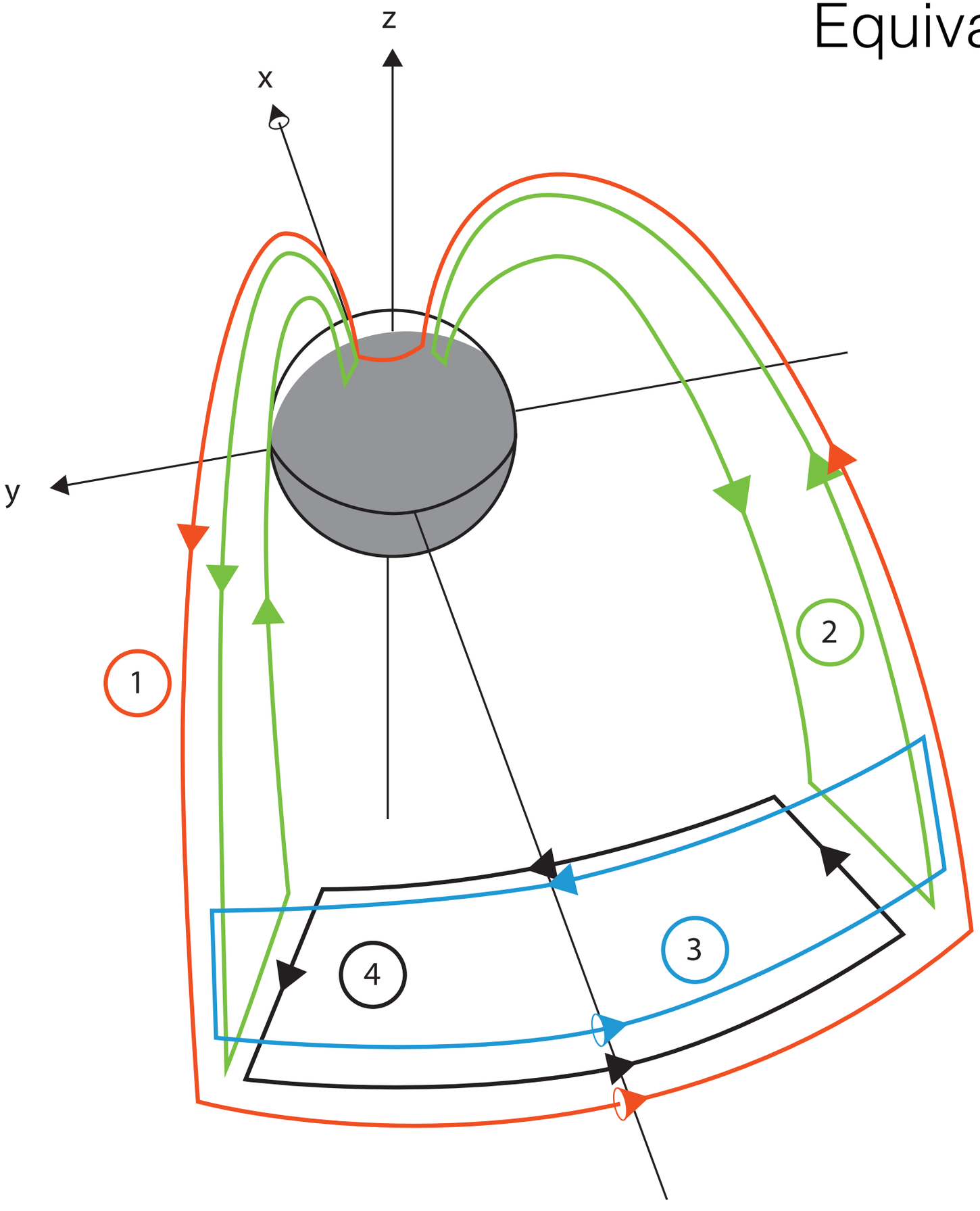


Inertial term

Flow builds up pressure gradient, which survives after flow stops

Kepko et al. [2014] in SSR

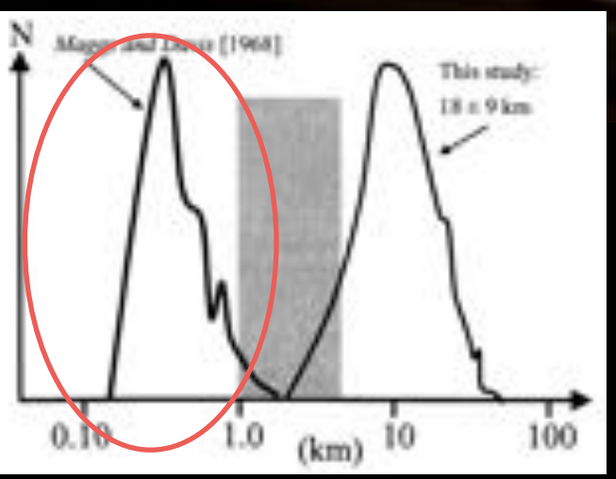
Equivalent magnetospheric currents

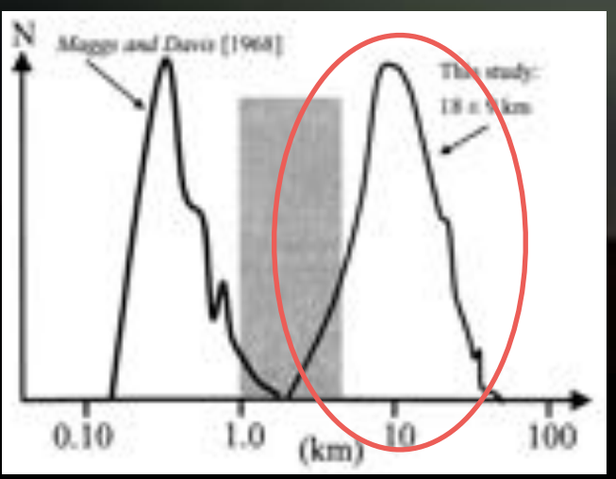


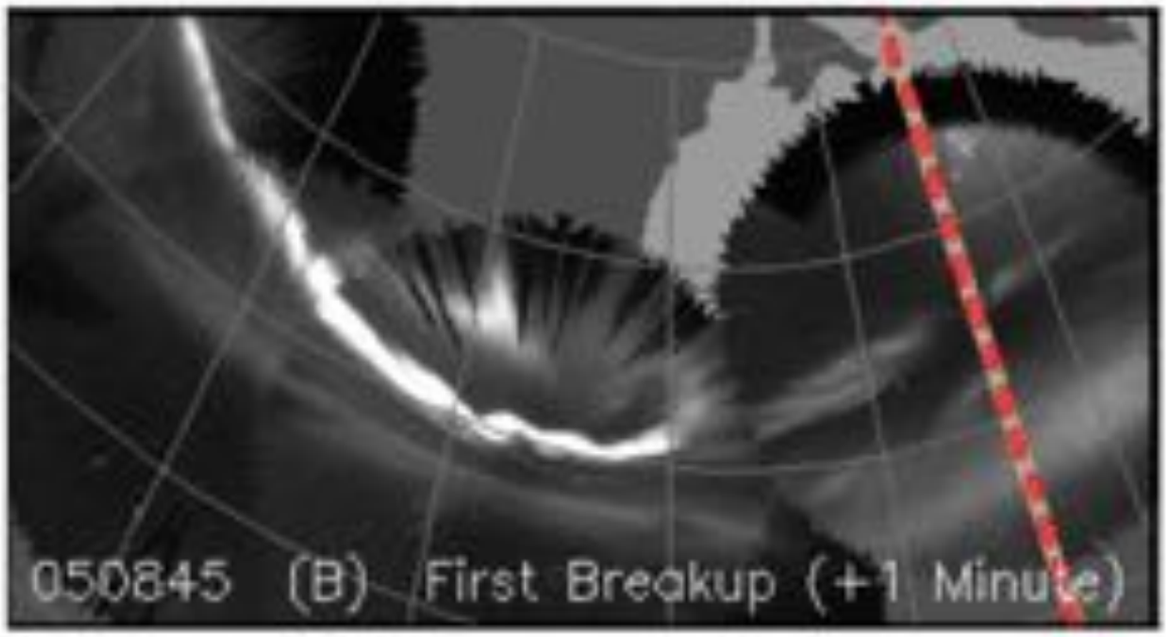
1. Ionospheric kickback
2. Azimuthal containment
3. Transient kink
4. Expansion

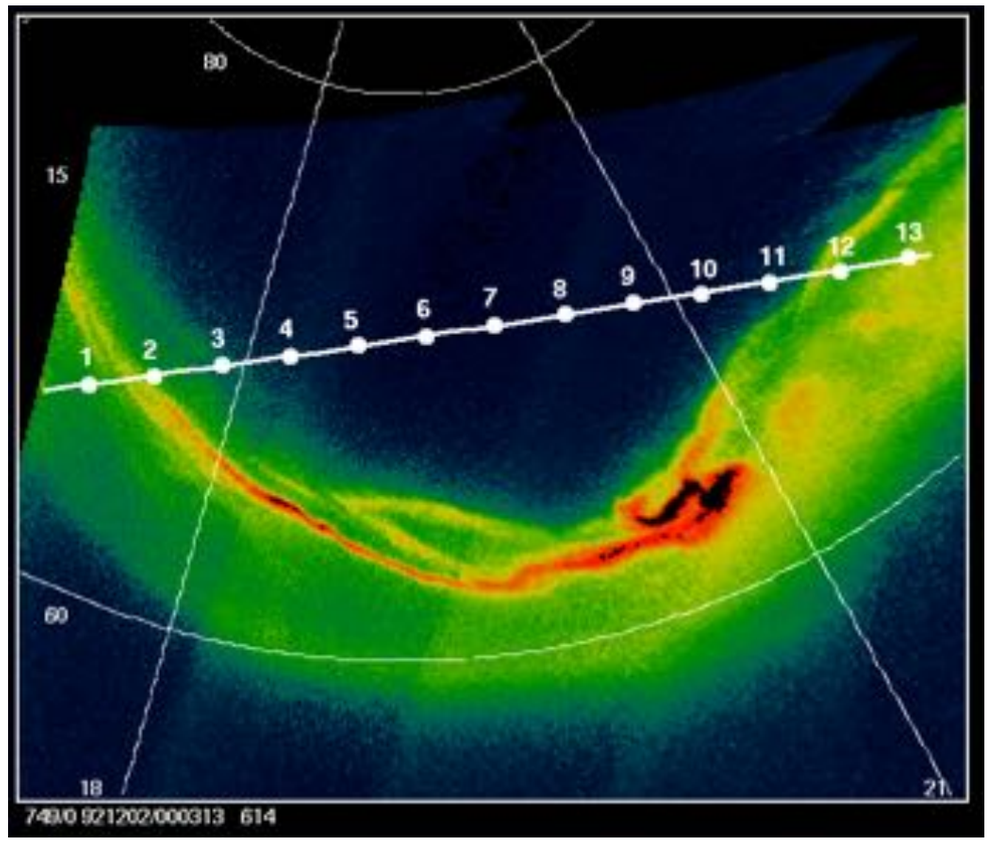
Details depend on time history of flows

Kepko et al. [2014] in SSR

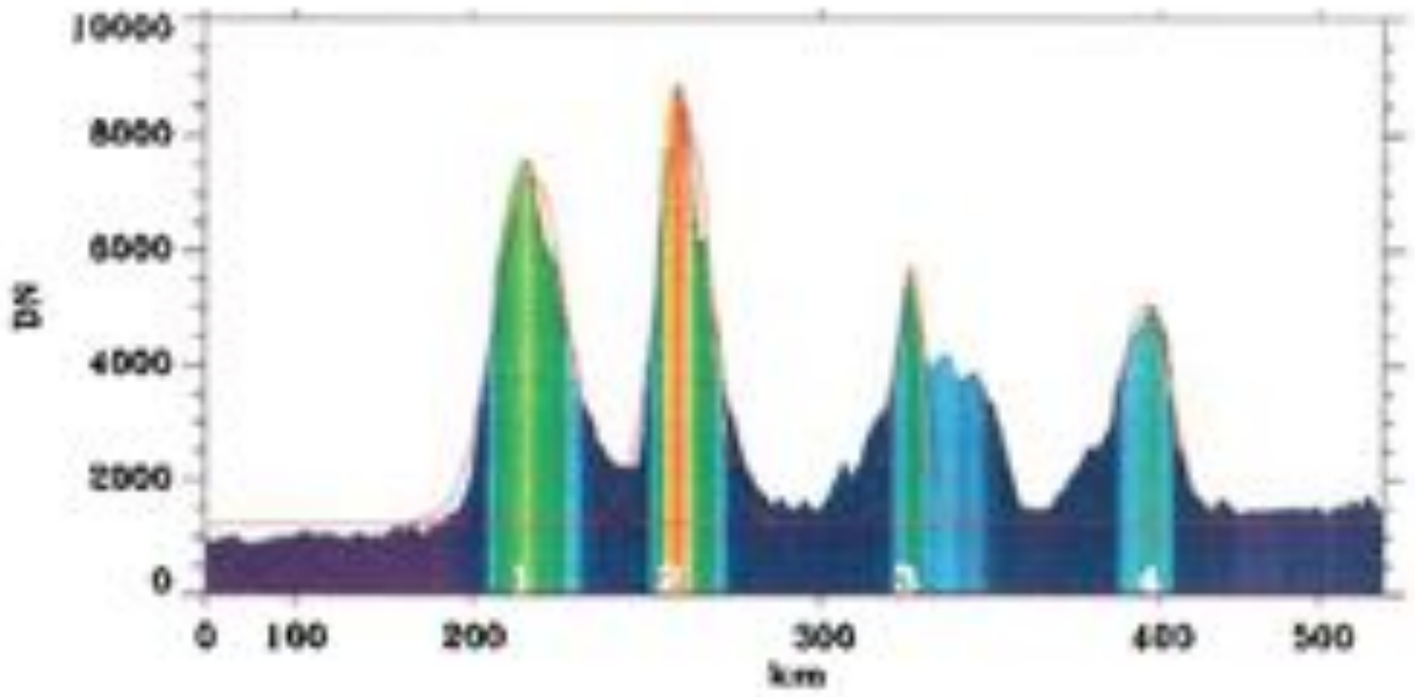

N
This study:
18 x 9 km
0.10
1.0
(km)
10
100

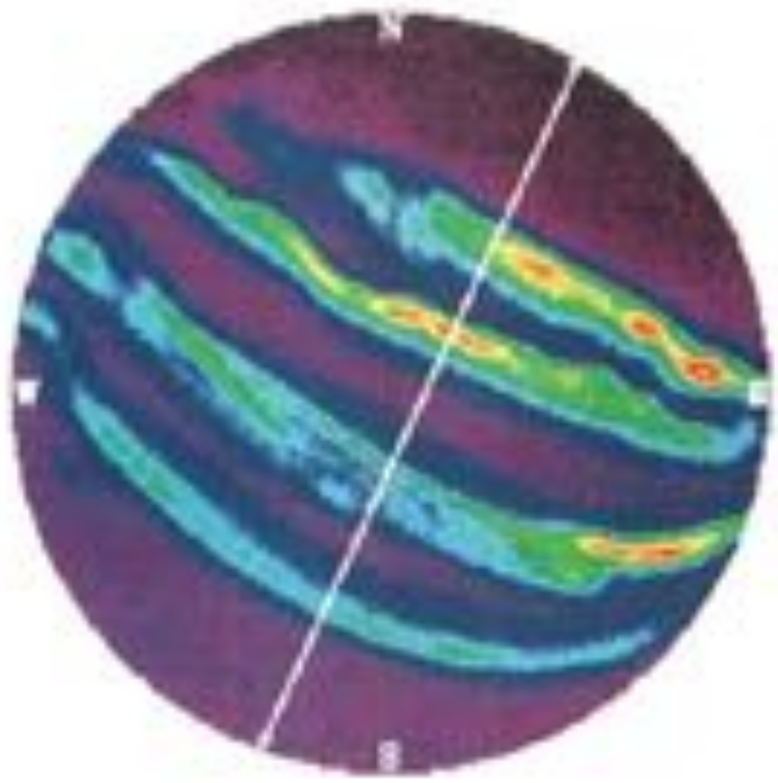

N
Maggs and Davis [1968]
This study:
0.10
1.0
10
100
(km)



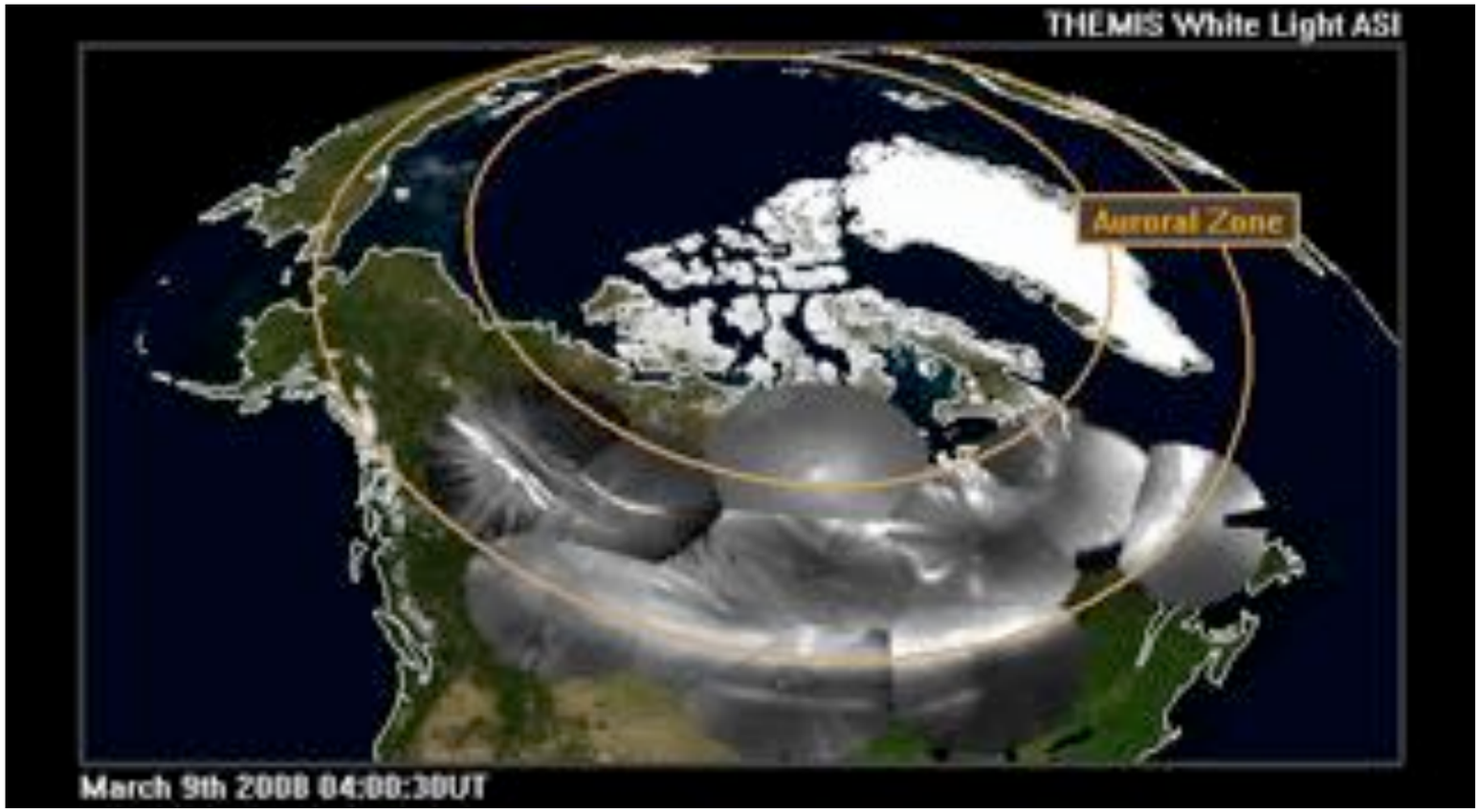


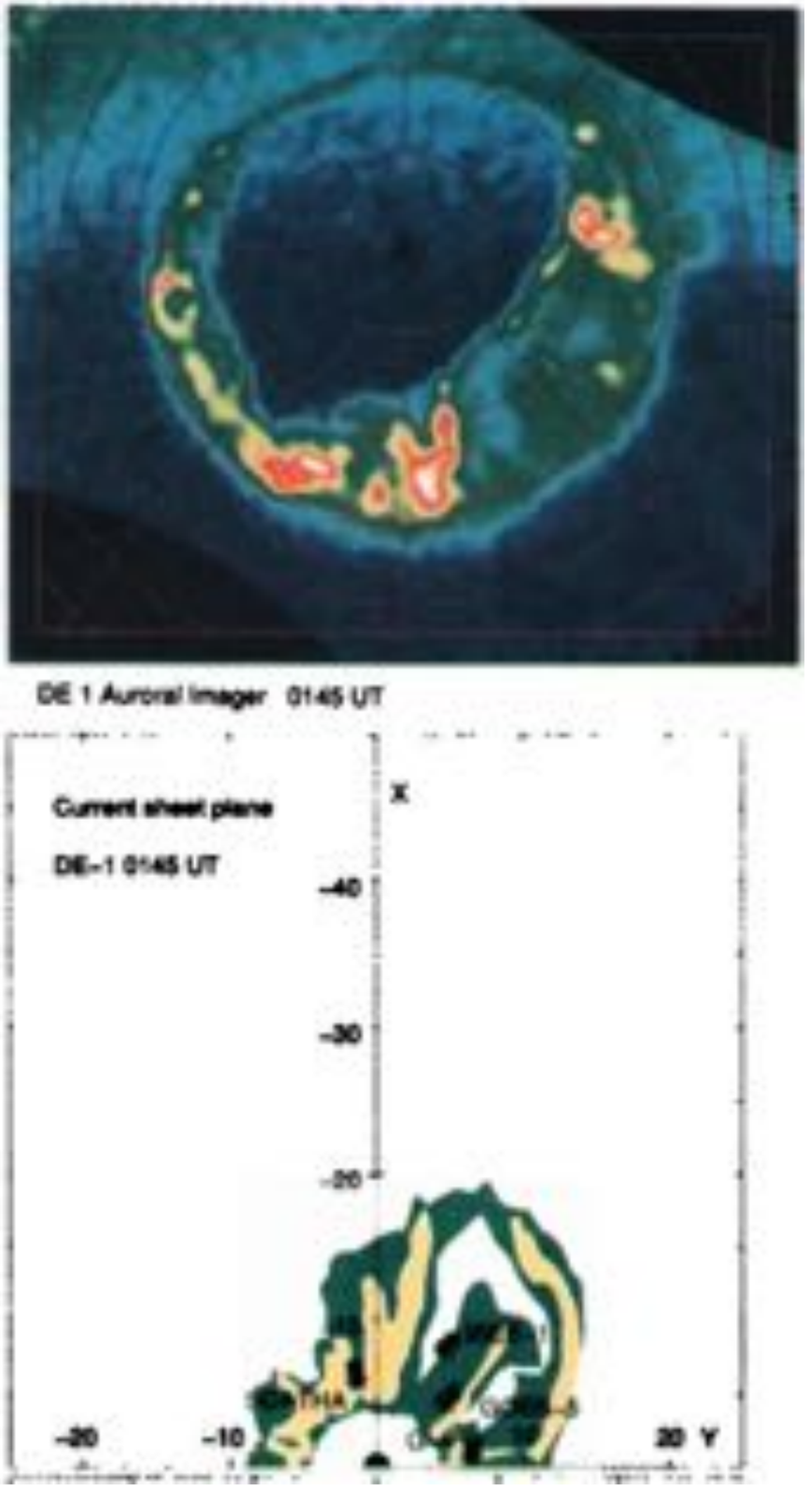
Many types of mesoscale arcs.
1 theory to fit them all?





Would like to be able to use aurora as proxy for magnetospheric dynamics





Pulkkinen, 1995

Primary questions of auroral arcs:

- What creates/sustains the growth phase arc?
- What causes the growth phase arc to brighten? And what does it mean?
- What creates the (new?) onset arc?
- Are beads at onset of magnetospheric origin?
- How do streamers relate to flow bursts?
- What are multiple, parallel arcs?
- What sustains long arcs located away from transition region?
- Polar cap arcs?

And

To what extent is ionosphere modifying this 2-d picture?

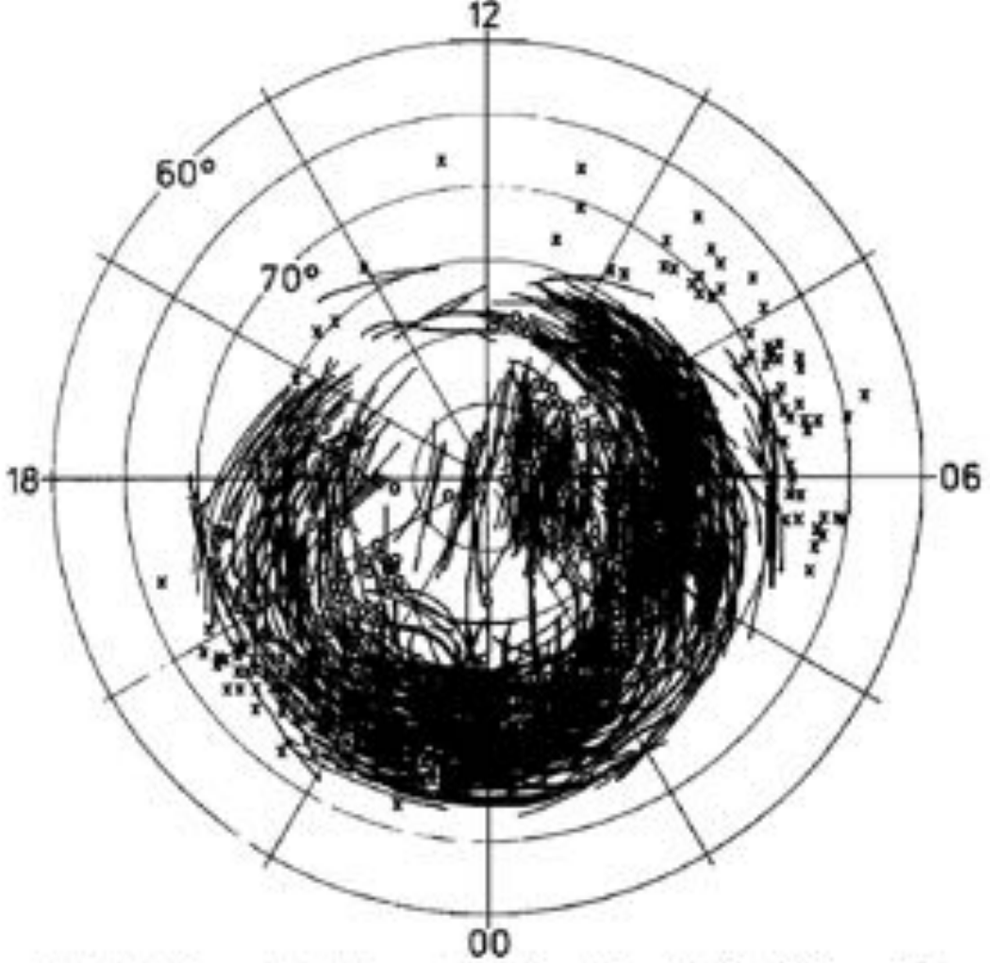
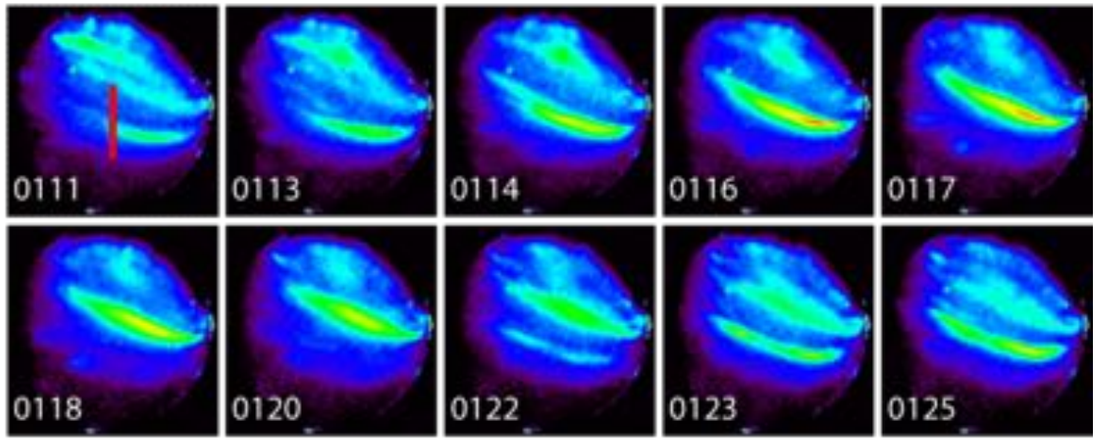
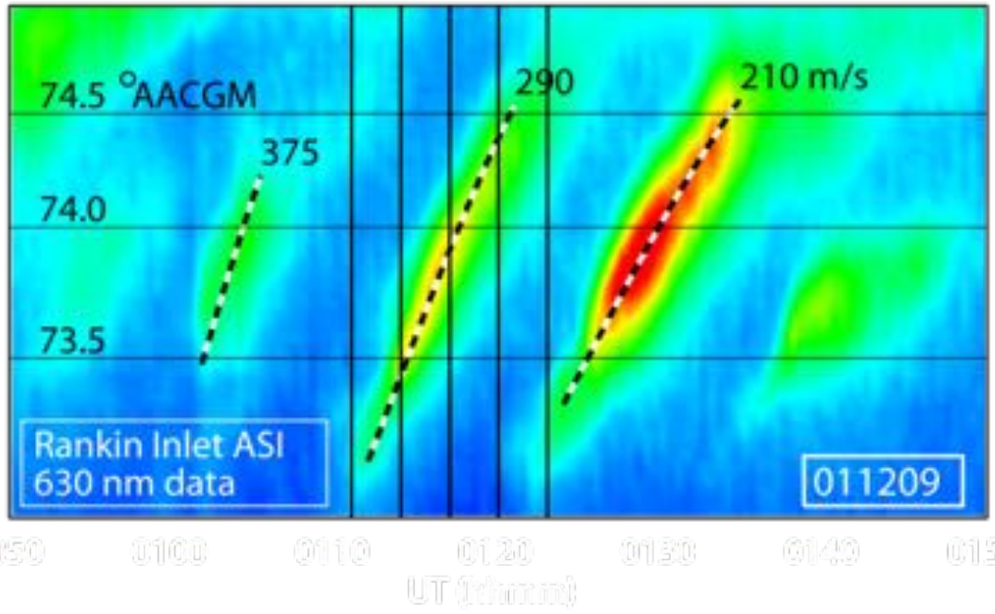


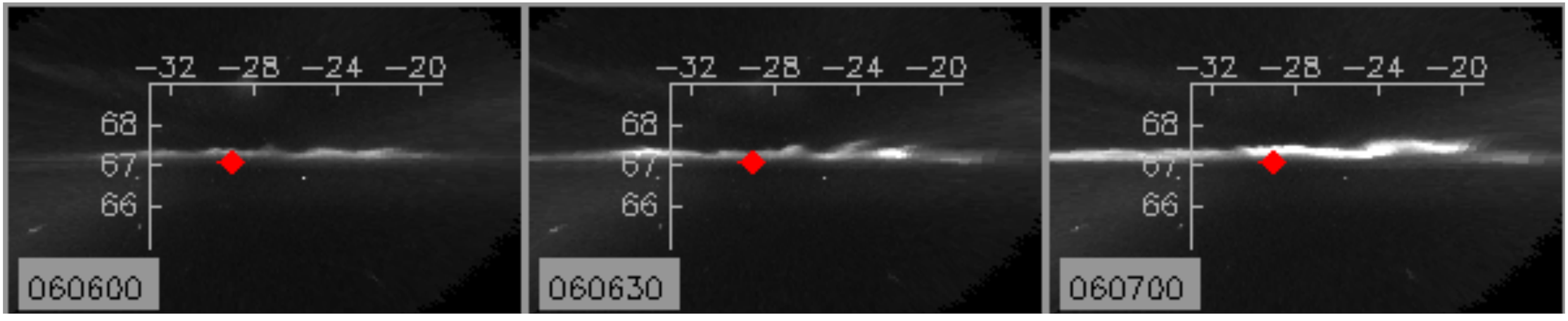
Fig. 7. Mass plot of discrete arcs for $AE = 41$–50 nT (from Figure 4) shown together with the equatorial (crosses) and poleward (circles) boundary points from Figures 6a and 6c.

Lassen & Danielsen, JGR, 1989



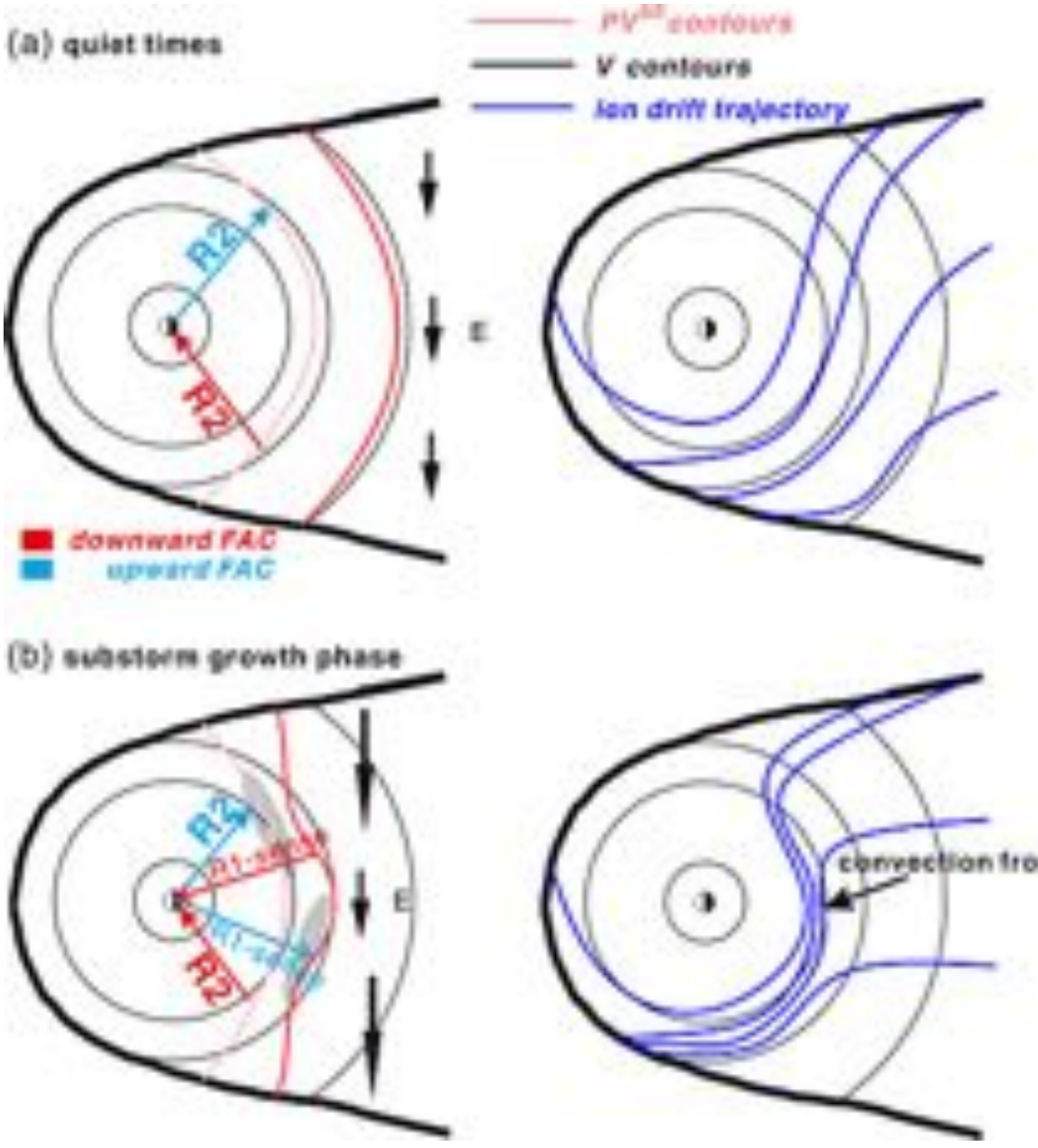
FLR arcs (infrequent)





In the late growth phase it is <u>often</u> the case that the onset arc is essentially ***exactly parallel to the constant geomagnetic latitude***

Growth phase arc



Several ideas that explain single arc.

Fail for multiple growth phase arcs

Yang, 2013

Substorm onset
(I promise this will not turn into a substorm talk)

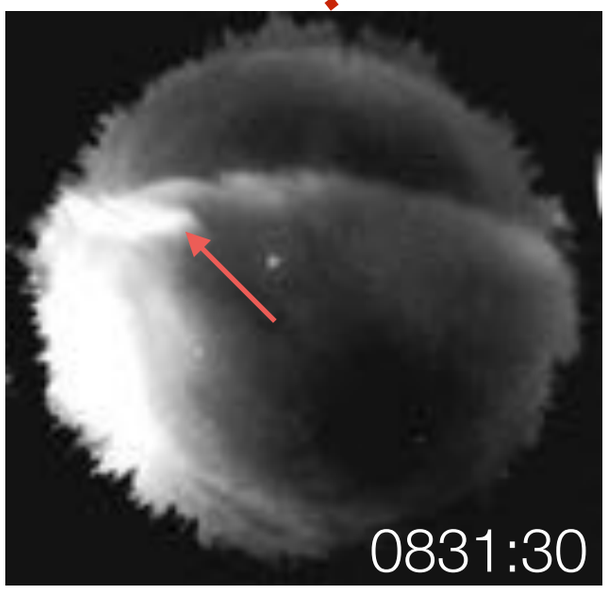
Onset timing is important, because the sequence of energy release is inferred from when the arc ‘brightens’ in relation to other indicators

Traditional onset
(Pi2, SCW, etc)

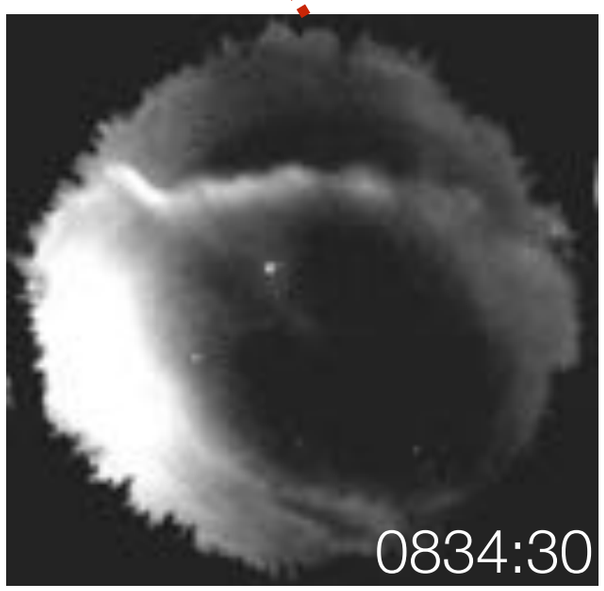
Lyons 2012
onset

0818 0824 0830 0836 0842 0848

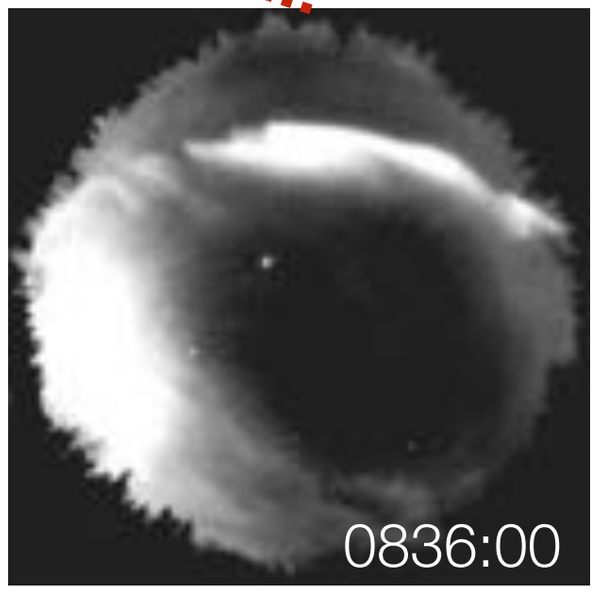
Jan 27, 2007
(*Lyons et al., 2012*)



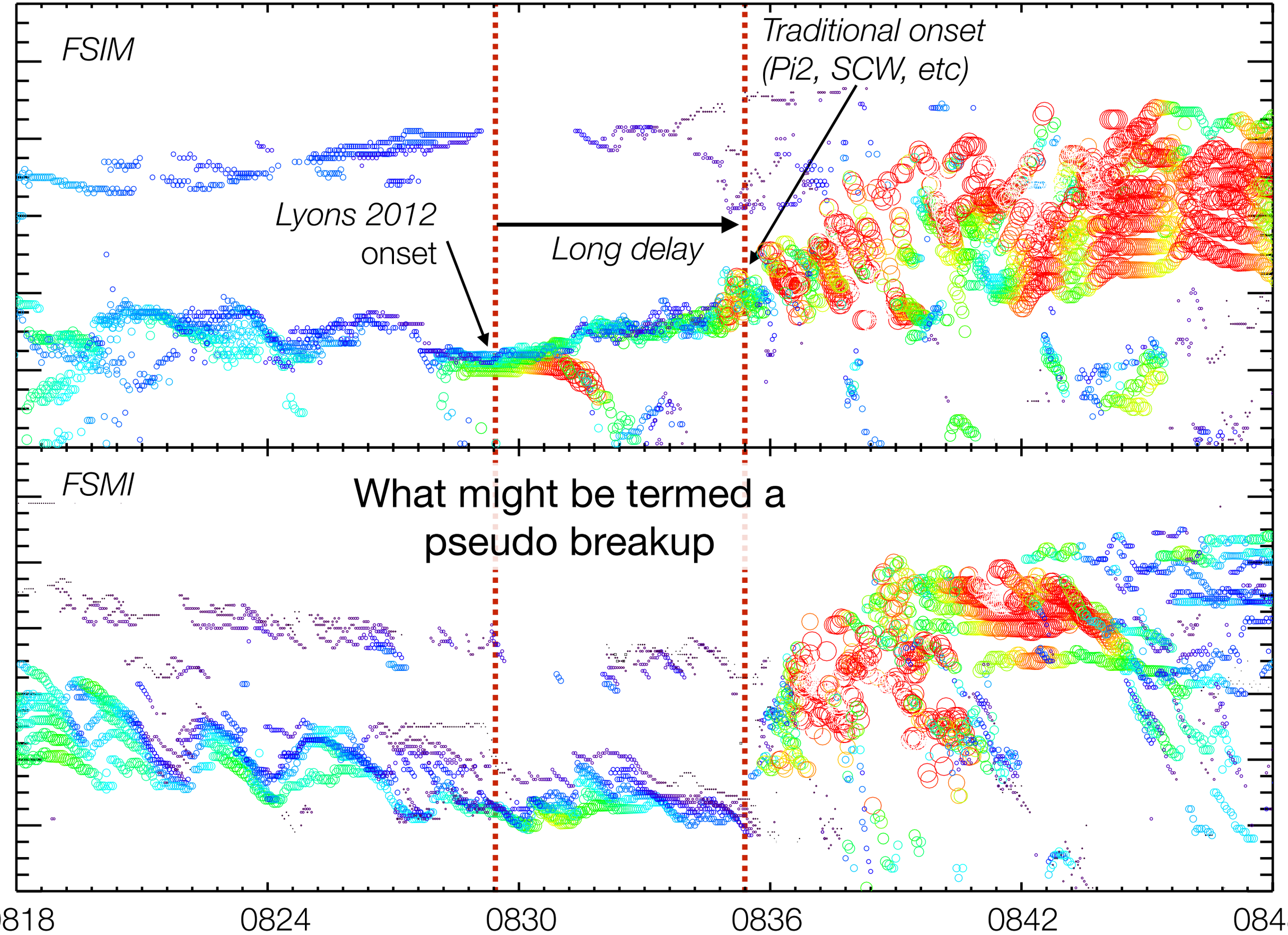
Growth phase arc brightening and ripple.



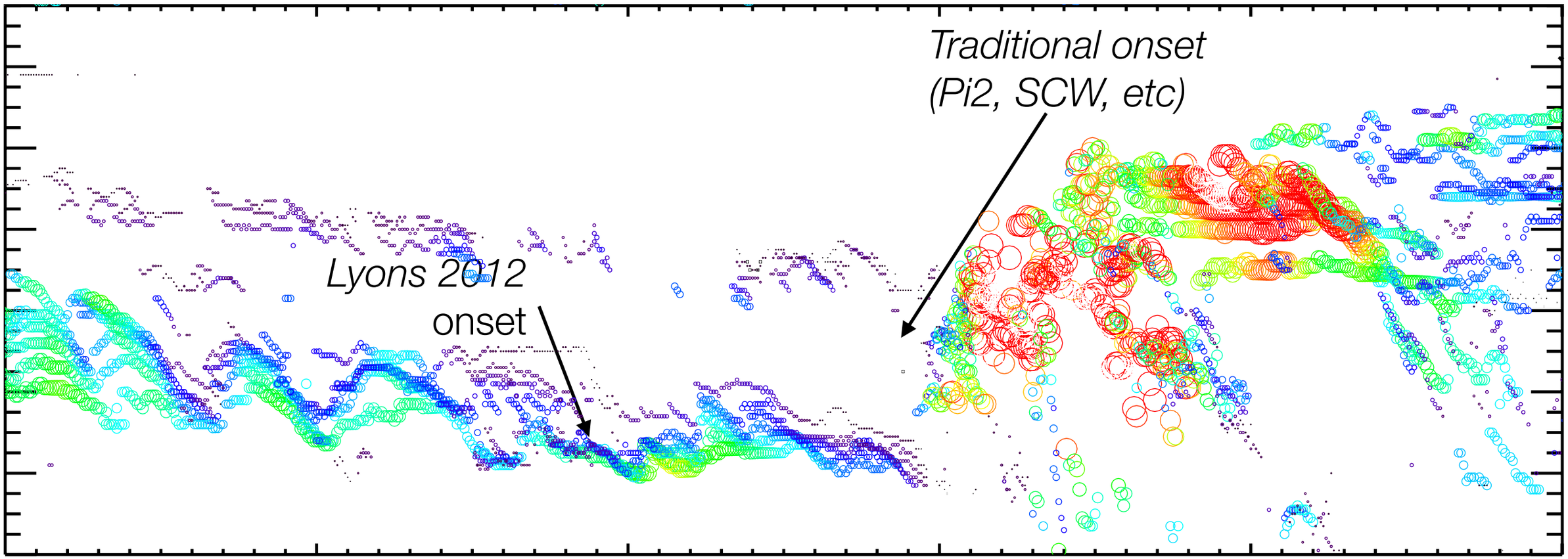
Little progress



Expansion, finally


FSIM
Traditional onset
(Pi2, SCW, etc)
Lyons 2012
onset
Long delay
FSMI
What might be termed a
pseudo breakup
0818
0824
0830
0836
0842
0848

Why it matters:



We ascribe significance to (even a little) arc brightening

But we do not know what sustains the growth phase arc.

When it brightens (or changes structure)*, is it because:

1. The underlying *growth phase arc* process intensified or changed?

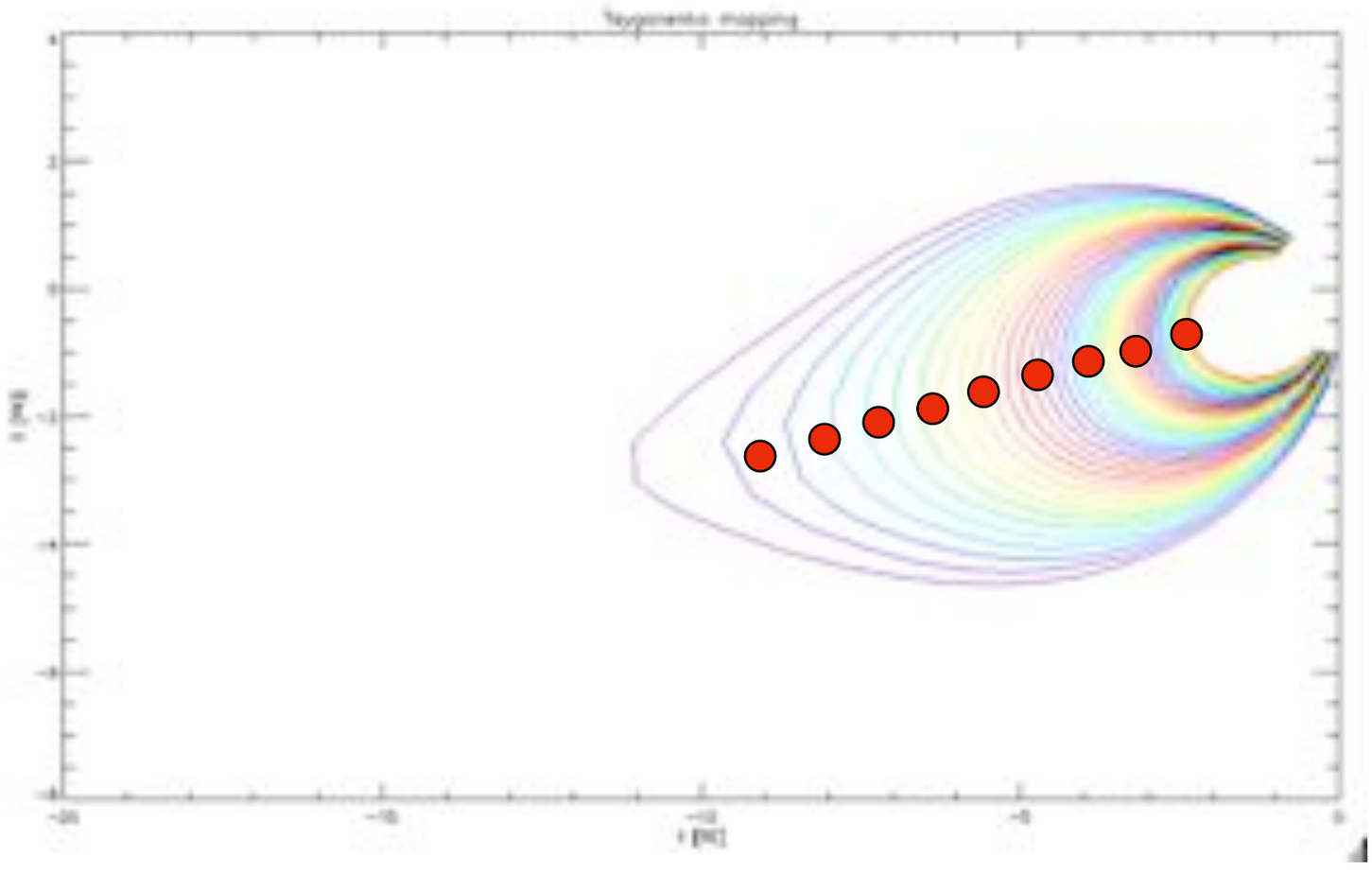
or

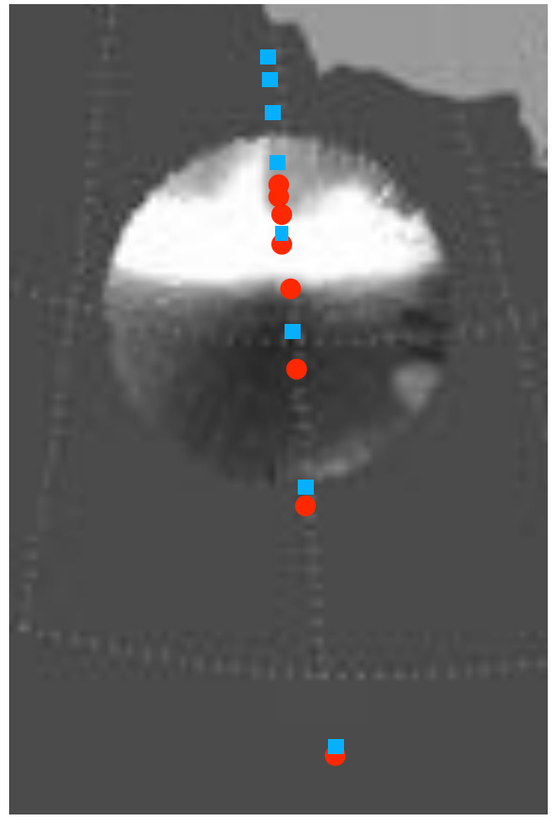
2. Unloading has begun and the magnetosphere is changing topology or energy state.

Those are very different things.

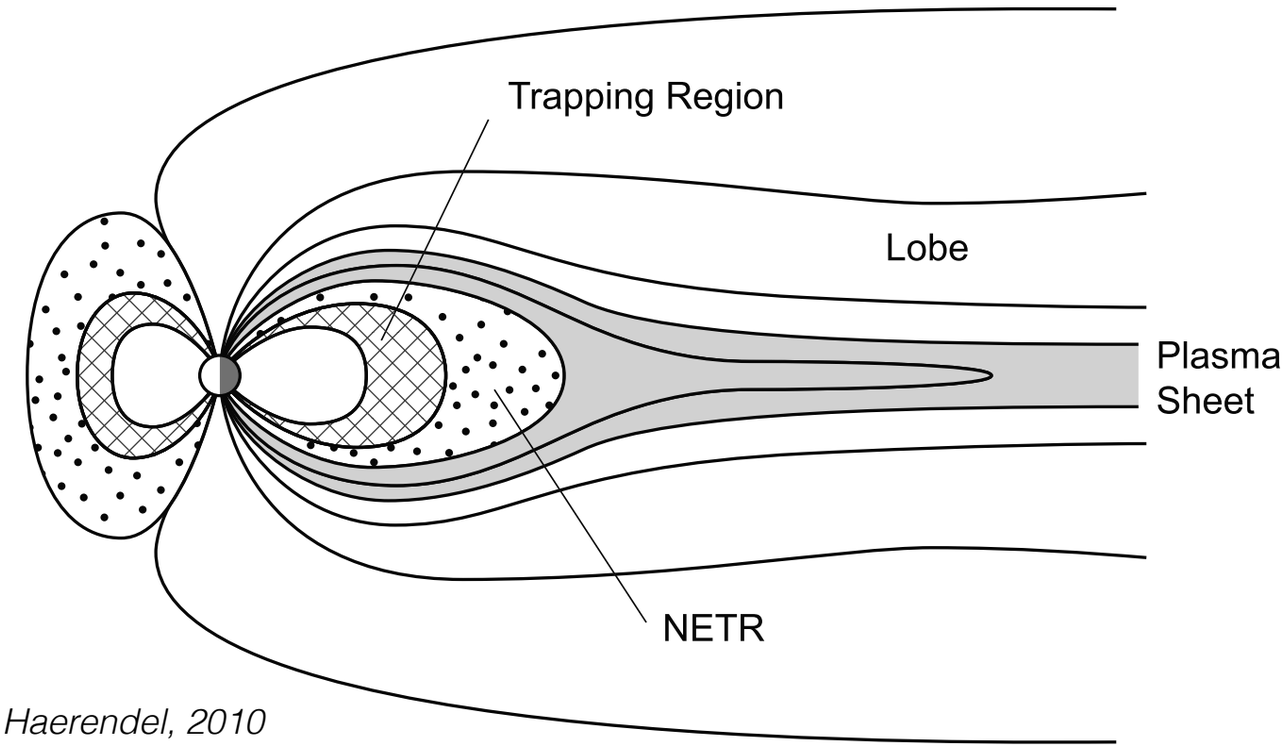
*With the caveat: It might be a new arc entirely

Arc problem is one of mapping
Solve the mapping, measurement is (likely) easy

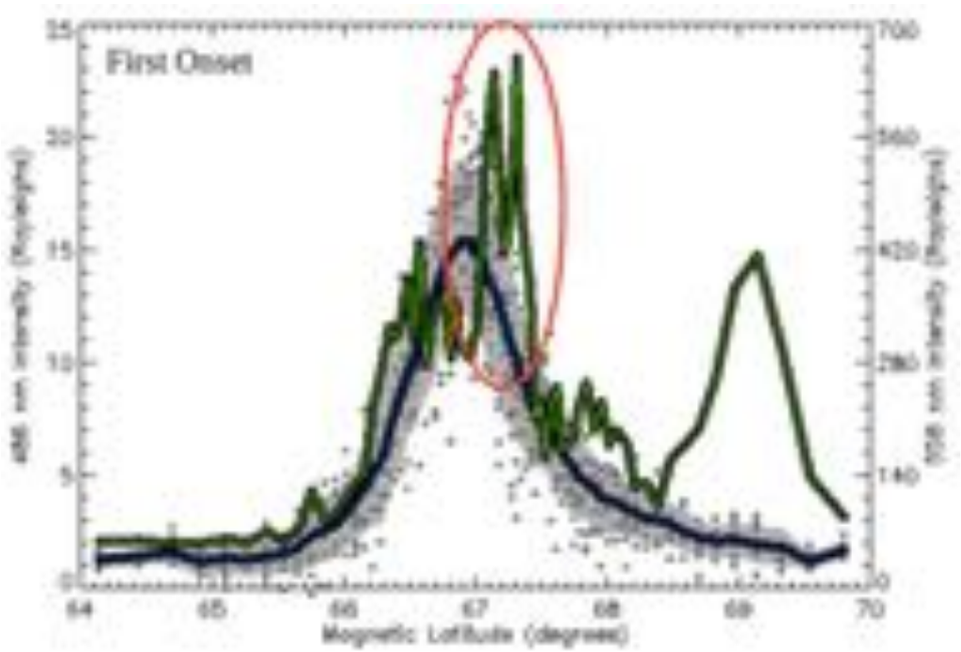




Solution 1: Phenomenological mapping
Electron aurora at poleward shoulder of proton aurora



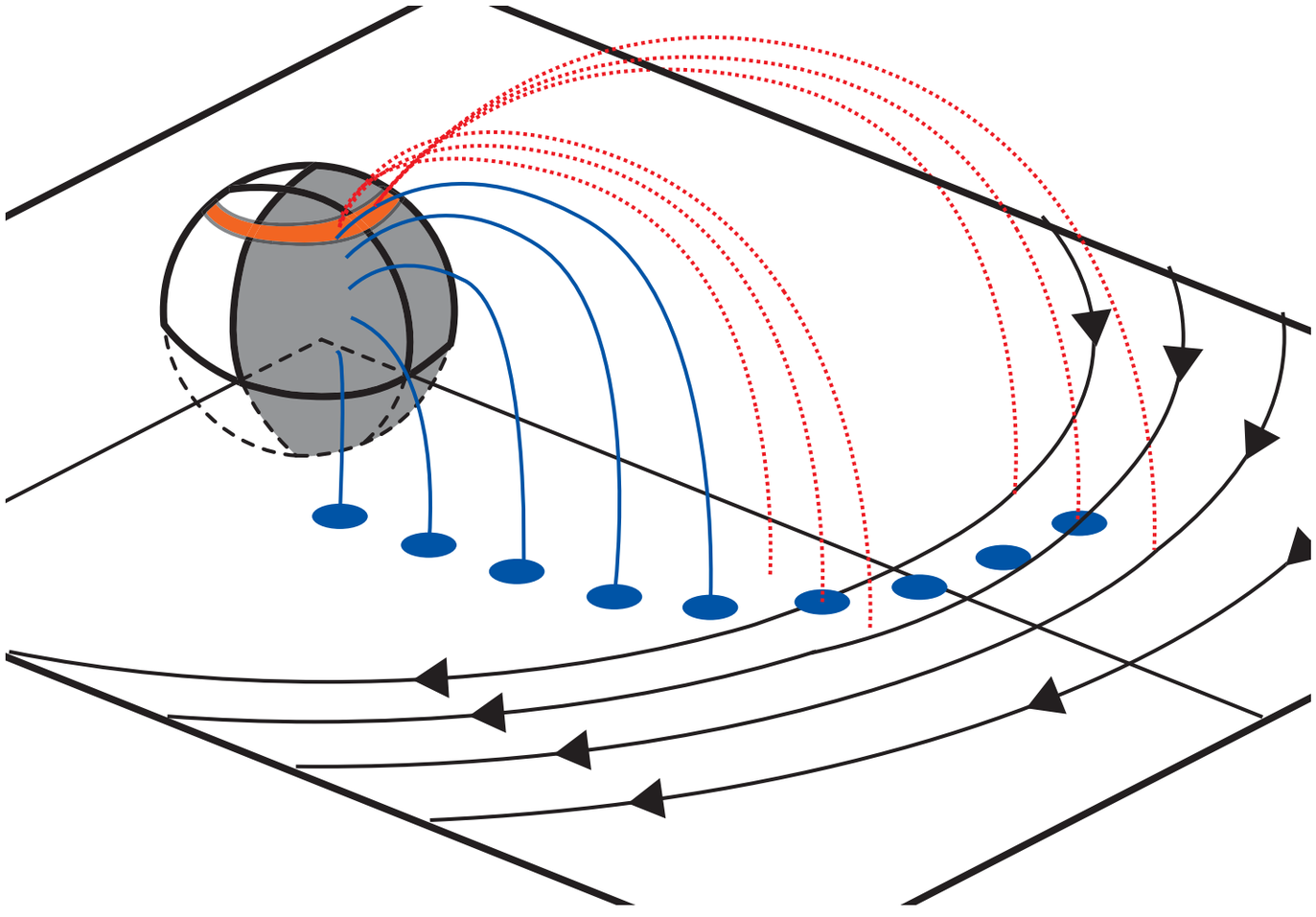
Haerendel, 2010



Caused by pitch-angle scattering; located at NETR

If we regularly knew where this boundary was in the magnetosphere, we could map the electron aurora

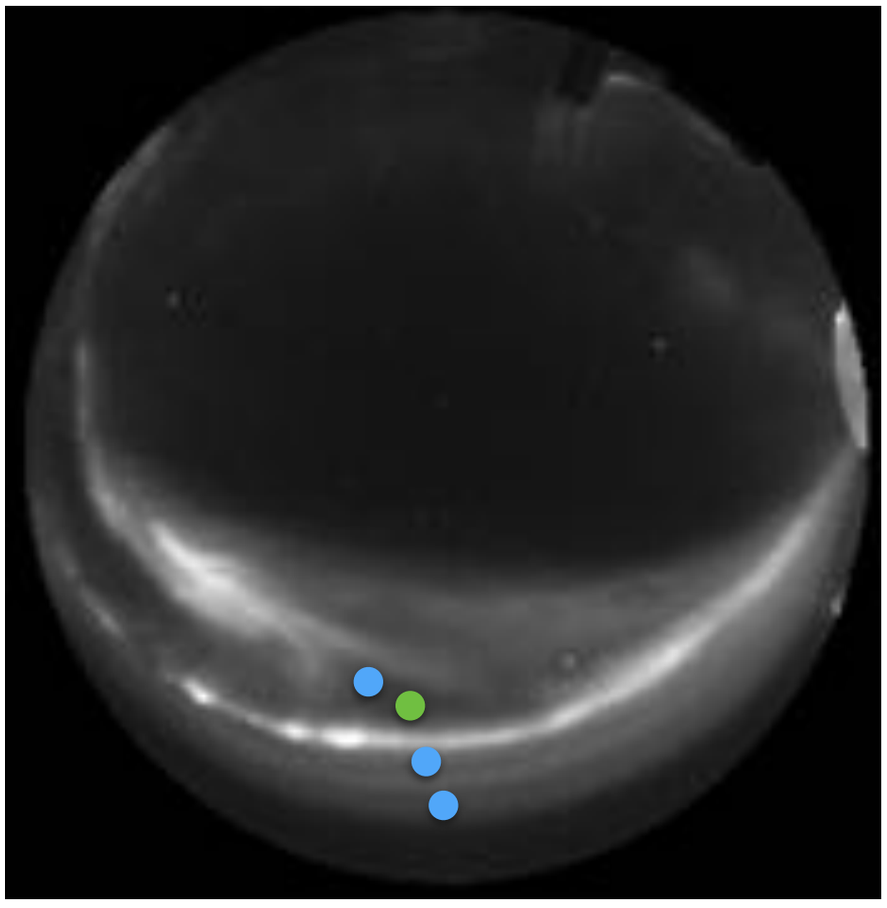
Solution 2: Bootstrapped mapping / adaptive modeling
Large swarm of small satellites (magcon)

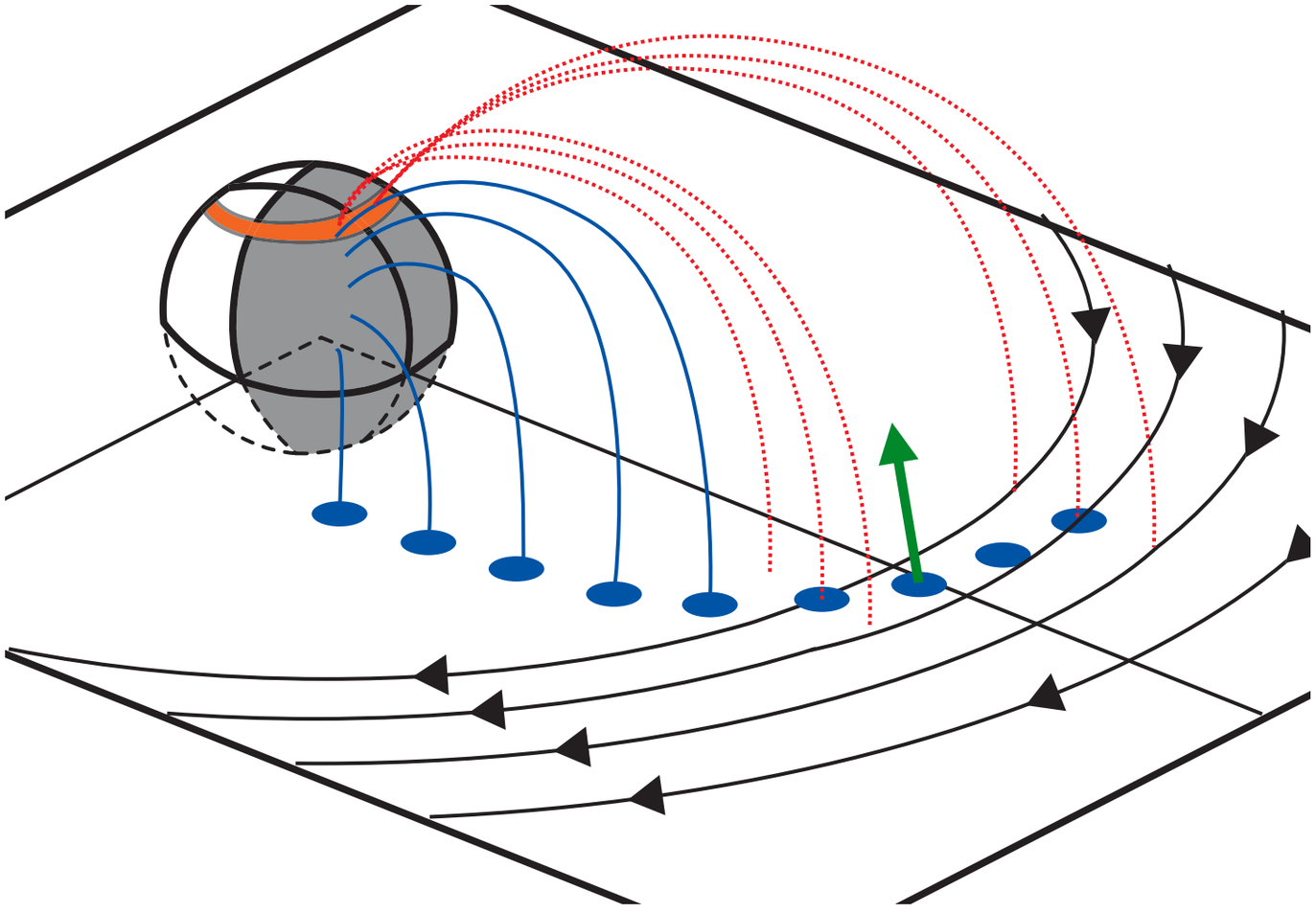


String of pearls of 9 probes determines magnetic configuration

Measurements of electron and ion distribution functions provides necessary measurements for identifying the generator mechanism(s): electron T steps; ion pressure gradient; magnetic shear; flow shear; ULF waves

Solution 3: Active mapping supplemented by small satellite swarm





Open questions & comments

- We need to discover the magnetospheric drivers (plural) of auroral arcs.
  - (Another phrasing: find the magnetospheric counterpart to arcs)
- Onset arc is probably separate from growth phase arc.
  - Driven by independent processes?
  - Possibly nearly co-located, difficult to separate
  - This makes interpreting auroral brightenings far more difficult
- A brightening of the growth phase arc could be unrelated to the mechanism generating the onset arc
  - We do not know what creates the growth phase arc.
  - We do not know what it means when it brightens.
- What powers the onset arc?
- We do not know what creates multiple (or even single!) equatorward drifting arcs.
- Are all streamers flow bursts?

And

To what extent is ionosphere modifying this 2-d picture?

Need to solve the mapping problem; need simultaneous, continuous, multi-scale/ wavelength observations (in situ + TREX)