A theory of magnetosphere-ionosphere-atmosphere coupling at Saturn

David Southwood
Imperial College
London

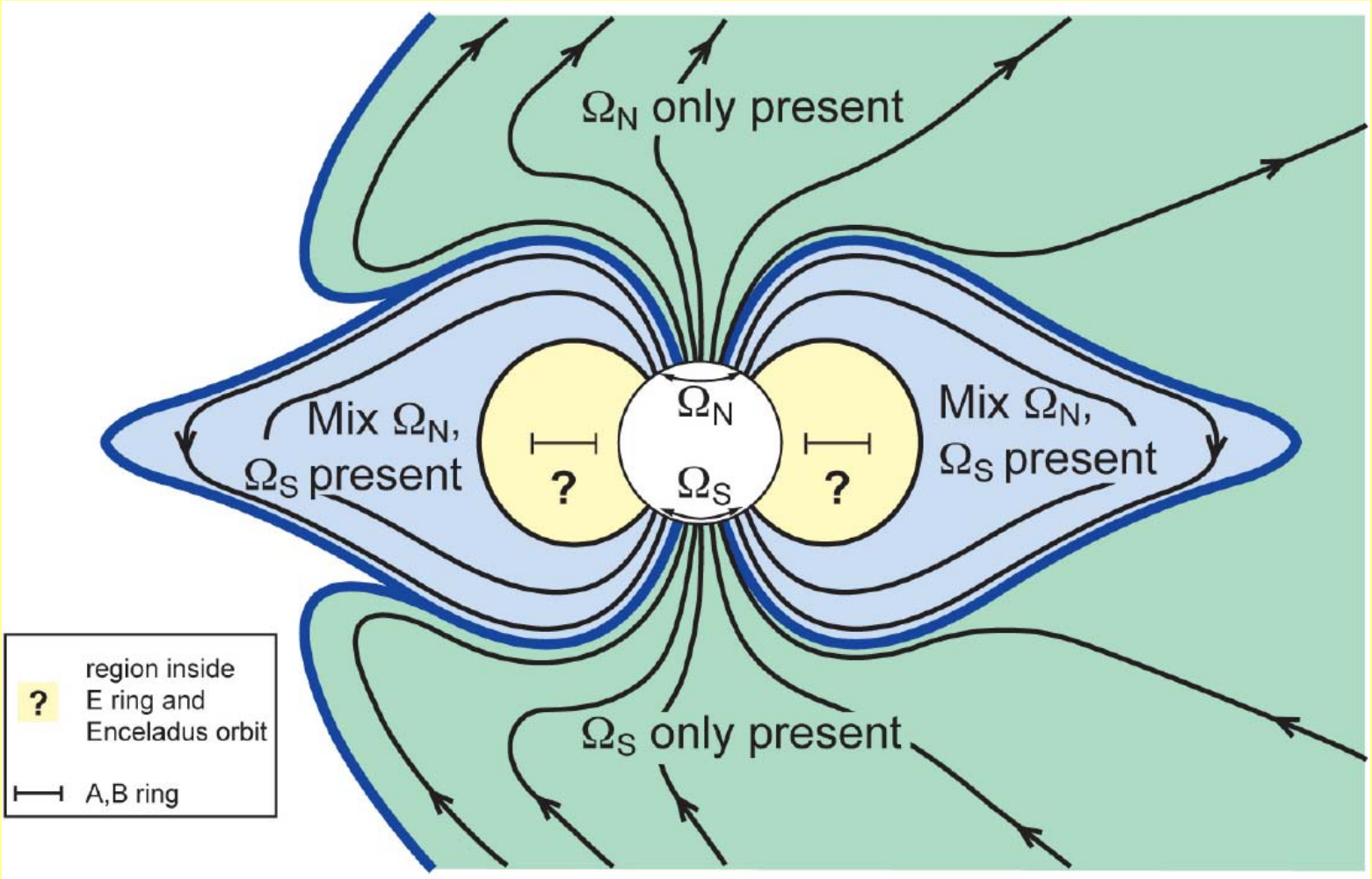
National Astronomy Meeting
Manchester UK
March 27th 2012

Key, but not sole, data inspiration

New data analysis:

Planetary period oscillations in Saturn's magnetosphere: Evolution of magnetic oscillation properties from southern summer to post-equinox

D. J. Andrews, S. W. H. Cowley, M. K. Dougherty, L. Lamy, G. Provan and D.J. Southwood (2012)
JGR in press



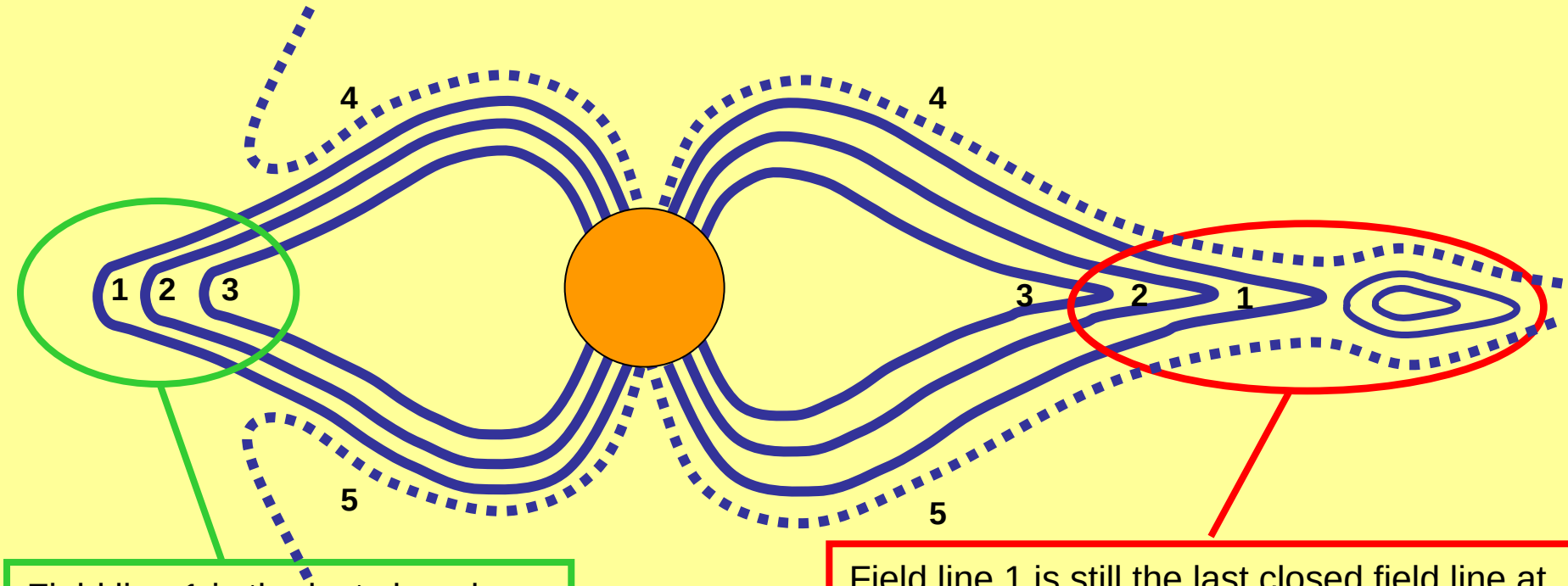
Saturn – rotationally dominated magnetosphere controlled by polar cap ionospheres

1. **Planetary rotation is fast enough that little or no flux is exchanged with solar wind in one rotation (10.7 hr) (negligible Dungey cycle).**
2. **Material is lost down-tail from magnetosphere at least once per 10.7 hr rotation but *m* = 1 distribution of input plasma (from dipole regions implies probably only over ~ ½ of cycle (as "loaded" sector passes through tail).**
3. **Loss occurs through the plasma being accelerated towards the field line equator by centrifugal acceleration from northern and southern polar ionospheres to speed larger than local Alfven speed.**
4. **The centrifugal acceleration originates from the ionosphere at the boundary of the polar cap – and the stress is transmitted (through FAC) up the field into the magnetosphere.**
5. **By the time of ejection, (breaking of the field) the northern and southern parts of the flux tube *cannot communicate (parallel speed in excess of local Alfven speed)*. Material north of the equator is ejected by north polar cap; material south of equator by south.**

Open-closed field line boundary in a rotationally dominated magnetosphere

Polar cap (open) field

Last closed field lines



Field line 1 is the last closed field line in the noon sector
Field line 3 is “true last closed field line” – i.e will complete circuit around Earth

Field line 1 is still the last closed field line at midnight but field lines 1, 2 “break” in the night sector and lose material into a plasmoid – which moves downtail
3 is the last closed field line in this sector that *does not lose material. It thus moves into morning more stressed than flux tubes polewards.*

Polar cap field lines 4 and 5 are permanently open and rigidly rotate with ionosphere

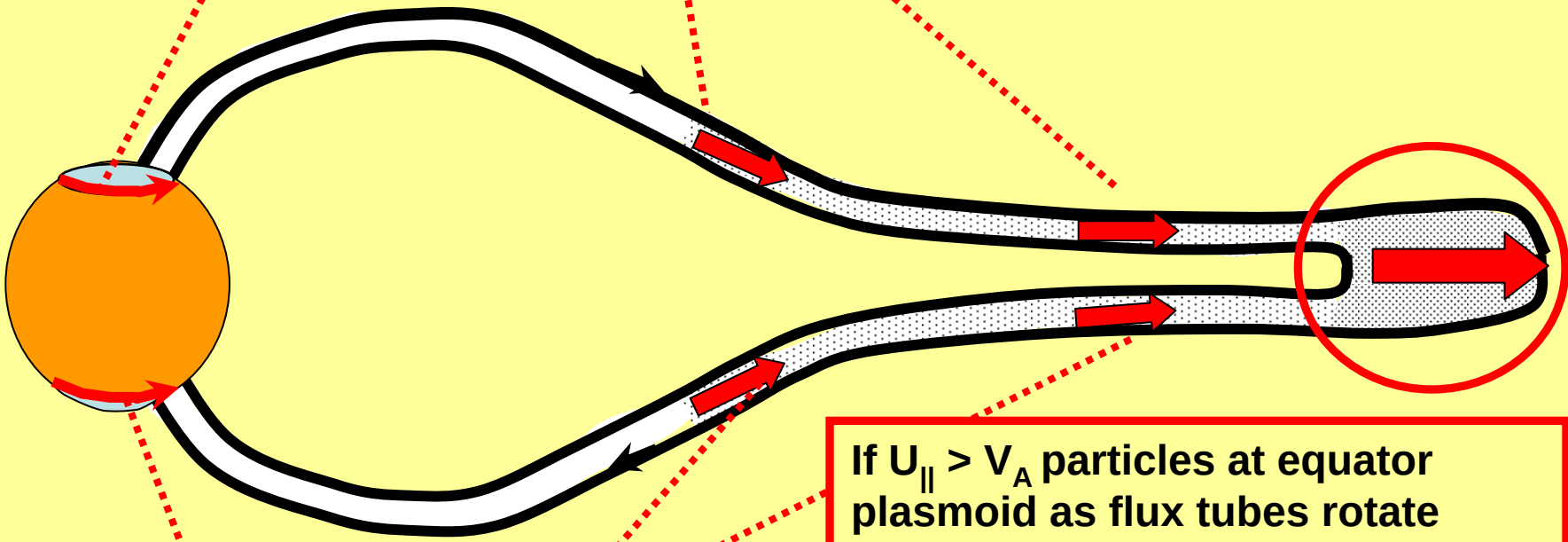
Saturn – rotationally dominated magnetosphere controlled by polar cap ionospheres

1. **Planetary rotation is fast enough that little or no flux is exchanged with solar wind in one rotation (10.7 hr) (negligible Dungey cycle).**
2. **Material is lost down-tail from magnetosphere at least once per 10.7 hr rotation but *m* = 1 distribution of input plasma (from dipole regions implies probably only over ~ ½ of cycle (as "loaded" sector passes through tail).**
3. **The centrifugal acceleration originates from the ionosphere at the boundary of the polar cap – and the stress is transmitted (through FAC) up the field into the magnetosphere.**
4. **Loss occurs through the plasma being accelerated towards the field line equator by centrifugal acceleration from northern and southern polar ionospheres to speed larger than local Alfven speed.**
5. **By the time of ejection, (breaking of the field) the northern and southern parts of the flux tube *cannot communicate (parallel speed in excess of local Alfven speed)*. Material north of the equator is ejected by north polar cap; material south of equator by south.**

Acceleration in afternoon/evening on last closed field lines

Acceleration is provided for northern part of flux tubes

by the *torque* from northern polar cap ionosphere



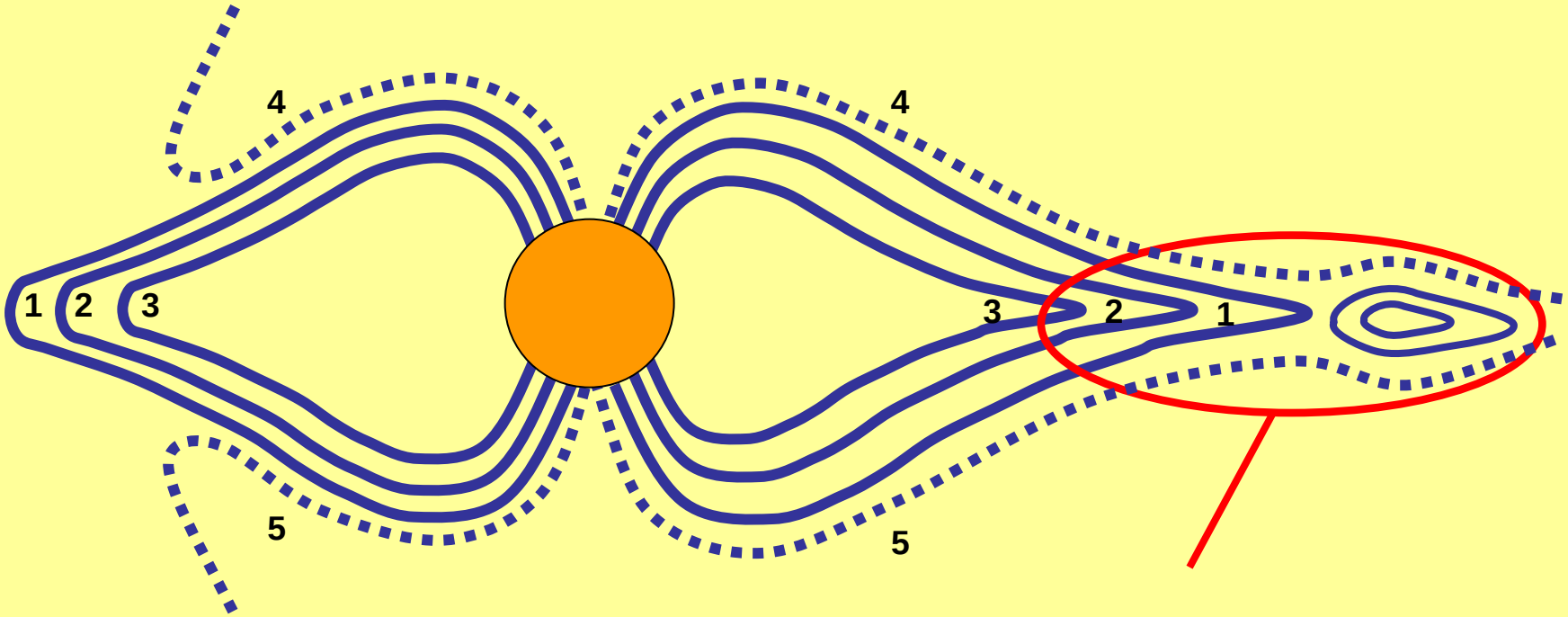
If $U_{||} > V_A$ particles at equator plasmoid as flux tubes rotate across tail and plasma is lost

Acceleration is provided for southern part of flux tubes

by the *torque* from southern polar cap ionosphere

Saturn – rotationally dominated magnetosphere controlled by polar cap ionospheres

1. **Planetary rotation is fast enough that little or no flux is exchanged with solar wind in one rotation (10.7 hr) (negligible Dungey cycle).**
2. **Material is lost down-tail from magnetosphere at least once per 10.7 hr rotation but *m* = 1 distribution of input plasma (from dipole regions implies probably only over ~ ½ of cycle (as "loaded" sector passes through tail).**
3. **The centrifugal acceleration originates from the ionosphere at the boundary of the polar cap – and the stress is transmitted (through FAC) up the field into the magnetosphere.**
4. **Loss occurs through the plasma being accelerated towards the field line equator by centrifugal acceleration from northern and southern polar ionospheres to speed larger than local Alfven speed.**
5. **By the time of ejection, (breaking of the field) the northern and southern parts of the flux tube *cannot communicate (parallel speed in excess of local Alfven speed)*. Material north of the equator is ejected by north polar cap; material south of equator by south.**

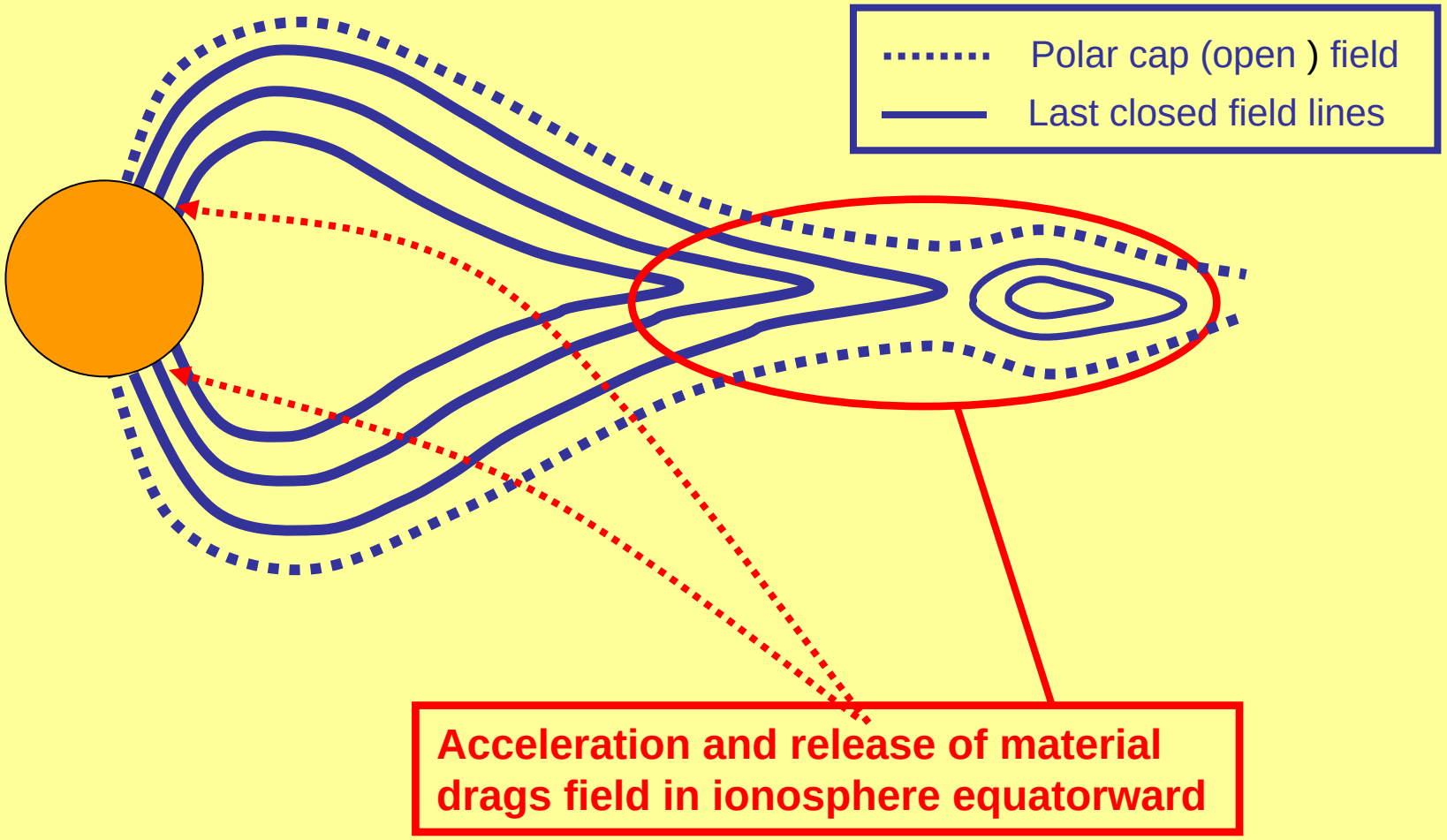


5. By the time of ejection, (breaking of the field) the northern and southern parts of the flux tube *cannot communicate (parallel speed in excess of local Alfven speed)*. Material north of the equator is ejected by north polar cap; material south of equator by south.

Loss is controlled *separately* by northern and southern polar cap ionosphere rotation rates!

5. **The *m* = 1 symmetry of inner magnetospheric transport leads to a general *m* = 1 symmetry including the asymmetric release of material.**
6. **The larger centrifugal force exerted by the loaded sector and its release makes a net field displacement *in the ionosphere towards the equator*. This creates a rocking of the auroral zones causes the an auroral oval rotational distortion.**

7. **The rocking is also experienced open field in the polar cap ionosphere. Overall rotating *m* = 1 vortical motions *in the ionospheric plasma* are induced, (at N and S rotation rates respectively), centred on the open closed boundary in both hemispheres.**
8. **The two polar caps act as "tuning forks" through controlling the loss from system and because polar caps are "empty" and so field is fairly rigid**
9. **Mixed signal with Ω_N and Ω_S is also then pumped into closed field area (where reflection allows equilibration of Alfvén signal – not possible in polar caps or indeed on outermost closed field lines – which are going to break)**



5. The *m* = 1 symmetry of inner magnetospheric transport leads to a general *m* = 1 symmetry including the asymmetric release of material.
6. The larger centrifugal force exerted by the loaded sector and its release makes a net field displacement *in the ionosphere towards the equator*. This creates a rocking of the auroral zones causes the an auroral oval rotational distortion.

5. **The *m* = 1 symmetry of inner magnetospheric transport leads to a general *m* = 1 symmetry including the asymmetric release of material.**
6. **The larger centrifugal force exerted by the loaded sector and its release makes a net field displacement *in the ionosphere towards the equator*. This creates a rocking of the auroral zones causes the an auroral oval rotational distortion.**

7. **The rocking is also experienced open field in the polar cap ionosphere. Overall rotating *m* = 1 vortical motions *in the ionospheric plasma* are induced, (at N and S rotation rates respectively), centred on the open closed boundary in both hemispheres.**
8. **The two polar caps act as "tuning forks" through controlling the loss from system and because polar caps are "empty" and so field is fairly rigid**
9. **Mixed signal with Ω_N and Ω_S is also then pumped into closed field area (where reflection allows equilibration of Alfvén signal – not possible in polar caps or indeed on outermost closed field lines – which are going to break)**