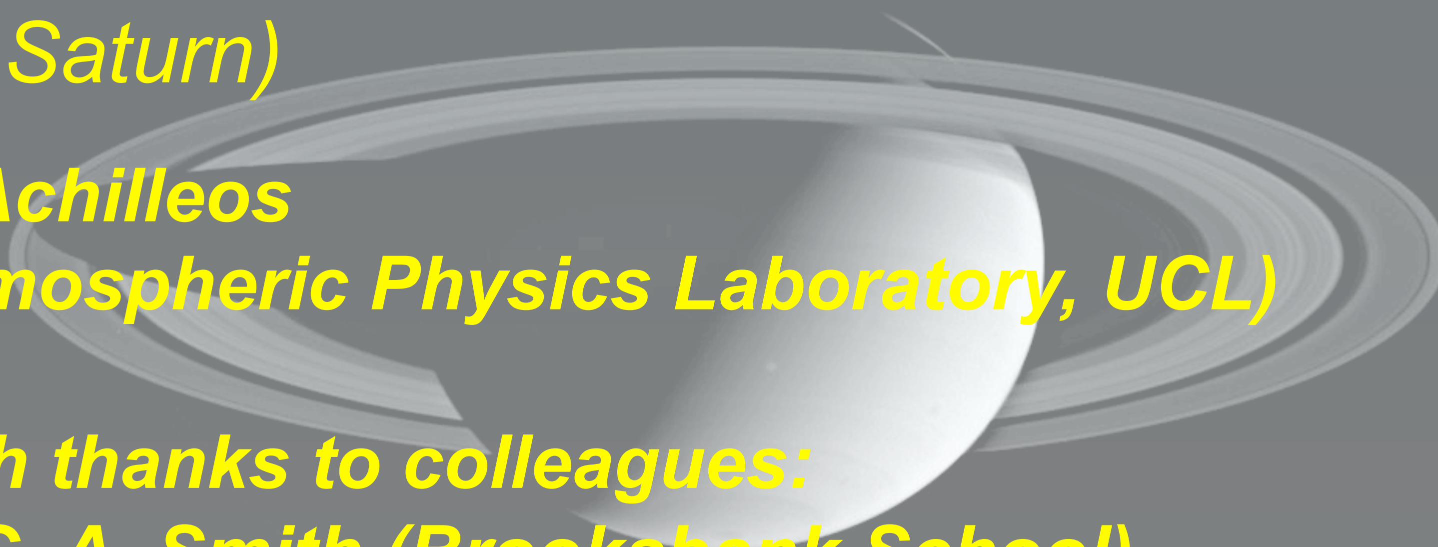
The Role of the Atmosphere in Magnetosphere-Ionosphere Coupling (at Saturn)



N. Achilleos
(Atmospheric Physics Laboratory, UCL)

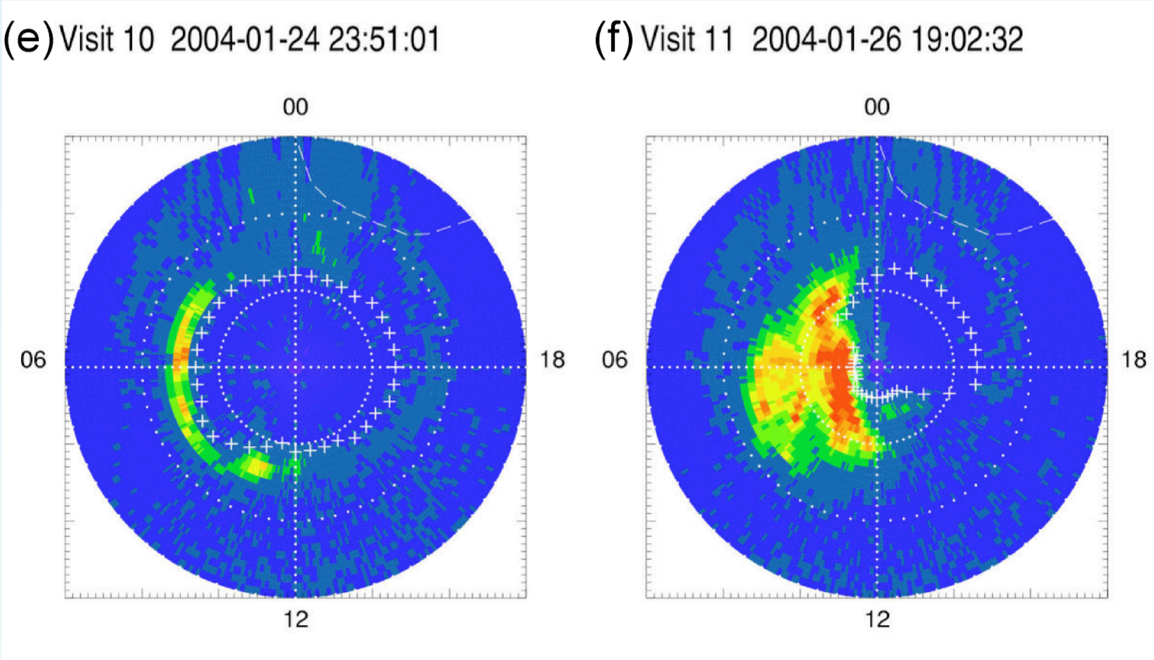
With thanks to colleagues:
C. G. A. Smith (Brooksbank School),
C. Tao, S. V. Badman (JAXA) and
A. D. Aylward (UCL)

An important remark

‘If you want to model a cow, you have to start with a sphere.’

C. T. Russell (MAG meeting at AGU, 2008)

Setting the Scene: Saturn's Dynamic Aurora



- HST images of Saturn's southern UV aurora presented by *Badman et al (JGR, 2005).*
- Concurrent observations by Cassini → planet's auroral response to the passage of a solar wind compression / shock.
- Compression → magnetic reconnection on the nightside, which closes of order 10 GWb of open magnetic flux.
- Polar cap boundary (main oval) strongly contracts to higher latitudes.

Time scales ?

- Timescale for '*dipolarization*' of a distended flux tube:
<~ 0.5-1 hr (observed by *Bunce et al, GRL, 2005; see also poster by Arridge et al., this meeting)*
- How does this compare to the timescale on which the magnetospheric plasma can be accelerated by currents linking to the ionosphere / thermosphere ?

$$t_{MI} = {}^{1}/_{2} \left(\sigma / \Sigma_P^{*} B_i B_z\right) \quad (\rho_e / \rho_i)^2$$

(Expression from *Cowley and Bunce PSS 2003)*

- Surface density of plasma sheet in outer magnetosphere:
  $\sigma \sim 30 / (2\pi\rho_e)$ tonnes R_S^{-2} *(Arridge et al, GRL, 2007)*
- Effective Pedersen conductance $\Sigma_P^{*} \sim$ 1-4 mho *(Bunce et al, Ann. Geo., 2003; Cowley et al, 2008)*
- Ionospheric field $B_i \sim 40000$ nT
- Magnetospheric field $B_z \sim 3$ nT
- MSP/ISP distance ratio $(\rho_e / \rho_i) \sim 100$ for $\rho_e \sim 40$ RS

Thus **$t_{MI} \sim$ 0.5 - 2 hours, $t_{MI} \sim t_{dip}$**

Approach to Modelling

- Start with the UCL axisymmetric thermosphere model of Saturn (*Smith and Aylward, Ann. Geo., 2008)*. Now uses the ***auroral profile*** by *Tao et al.* (*Icarus, 2011*).

- Modify the profile of ***plasma angular velocity*** $\boldsymbol{\Omega_M}$ in the UCL model by shifting the position of the 'polar cap boundary' where Ω_M changes value from ~0.8 Ω_S to ~0.3 Ω_S (*use the fit by Cowley et al. (JGR, 2004) to observations presented by Richardson, J. D. (JGR, 1995) and Stallard et al., Icarus, 2004).*

- *N.B. Since* $\mathbf{t_{MI} \sim t_{dip}}$ → *for future work - 'feedback' from thermosphere on* $\boldsymbol{\Omega_M}$ *evolution.*

- *In more detail:*

- Start with a ***'contracting' phase*** where the cap shrinks:

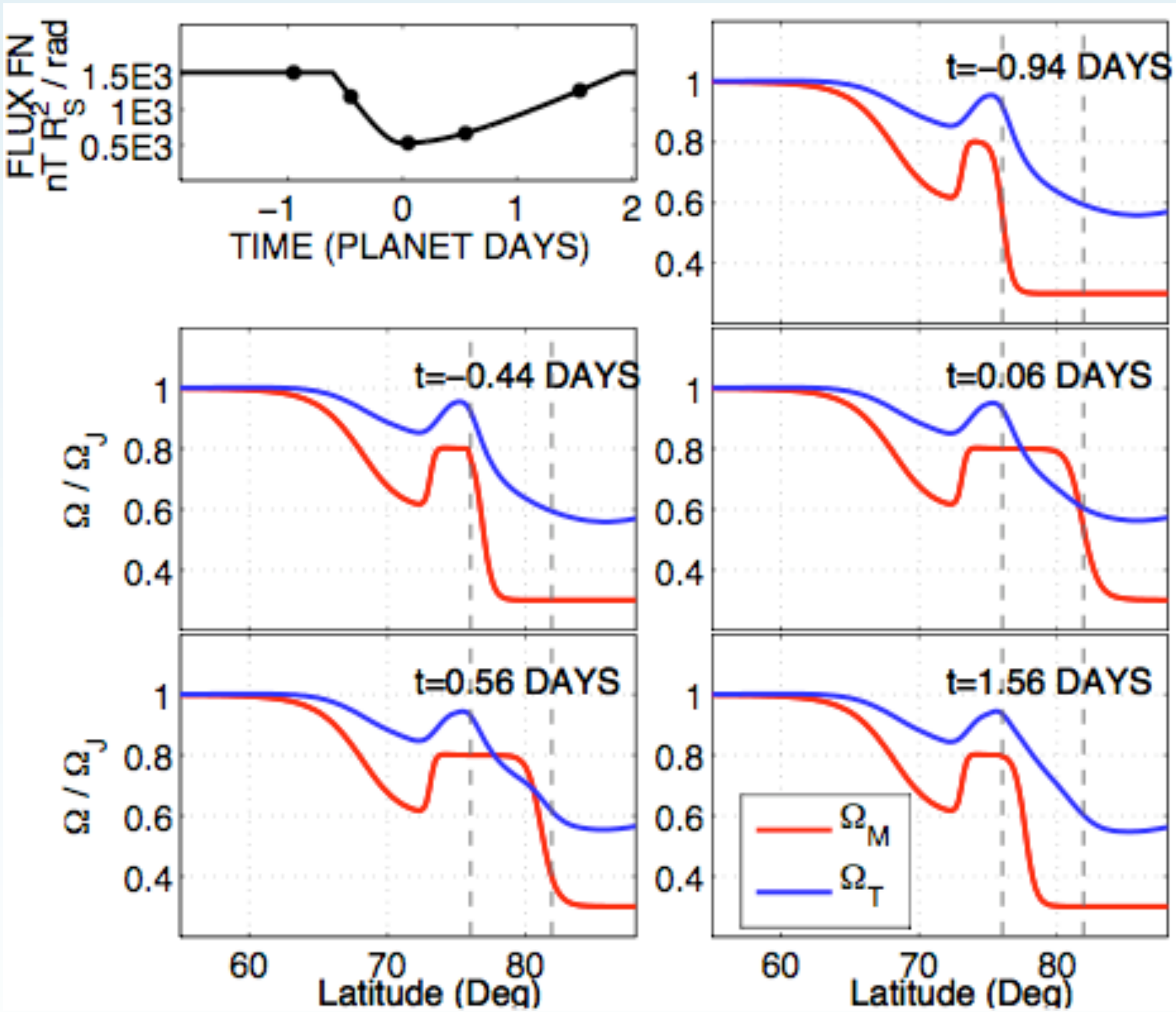
$D\Phi / Dt = -220\ kV / radian$ (e.g. *Badman and Cowley., Ann. Geo. 2007)*

- Follow with an ***'expansion phase'*** where the cap expands:

$D\Phi / Dt = 70\ kV / radian$

Angular velocity of magnetosphere and thermosphere

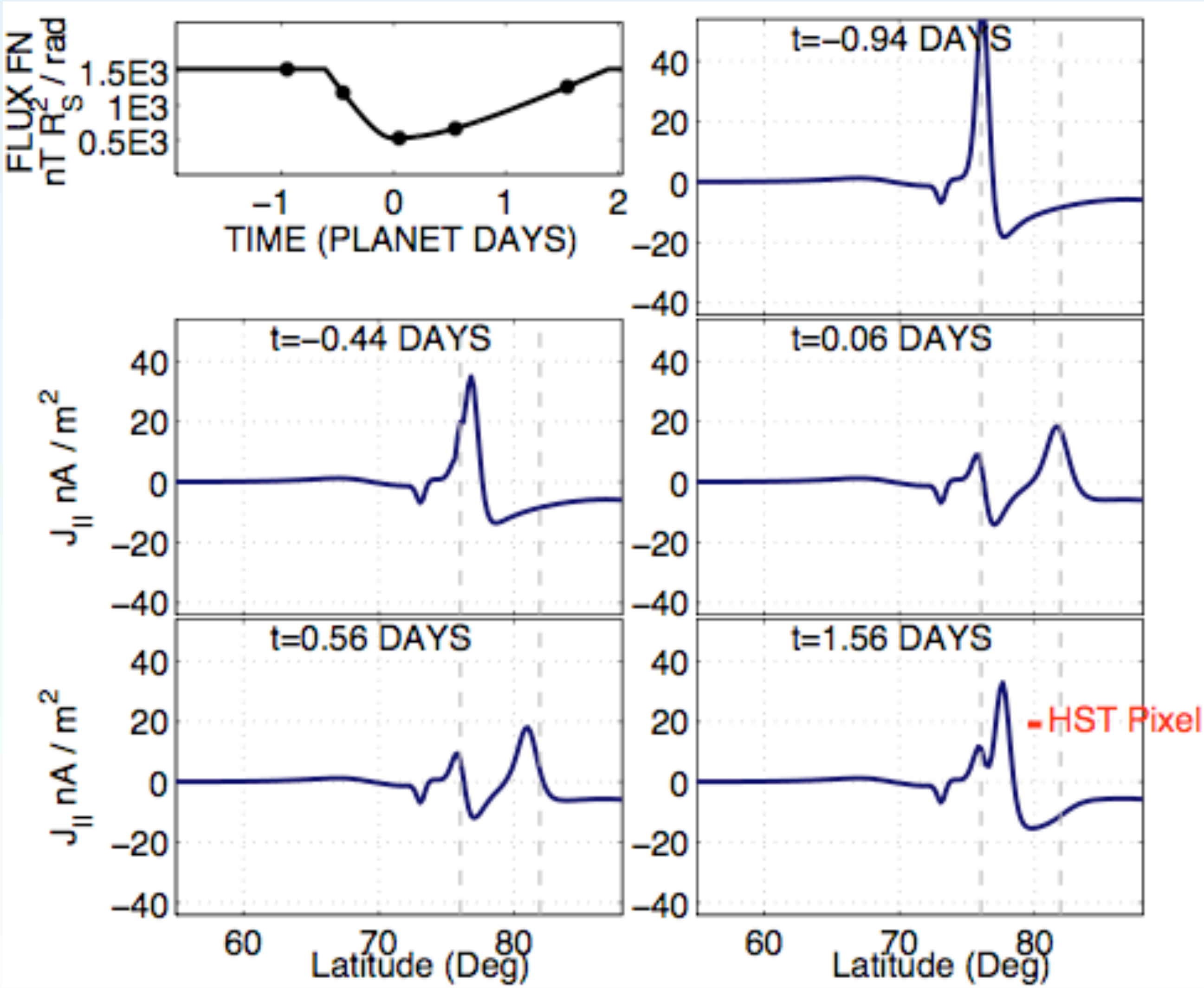
t=0 is most ‘contracted’ position of polar cap boundary.



- *Thermosphere is ‘slow’ to respond to change in Ω_M*
- *Ionospheric current ∝ (Ω_T - Ω_M)*
- *At certain phases, $\Omega_T < \Omega_M$ - this leads to interesting predictions for auroral current*

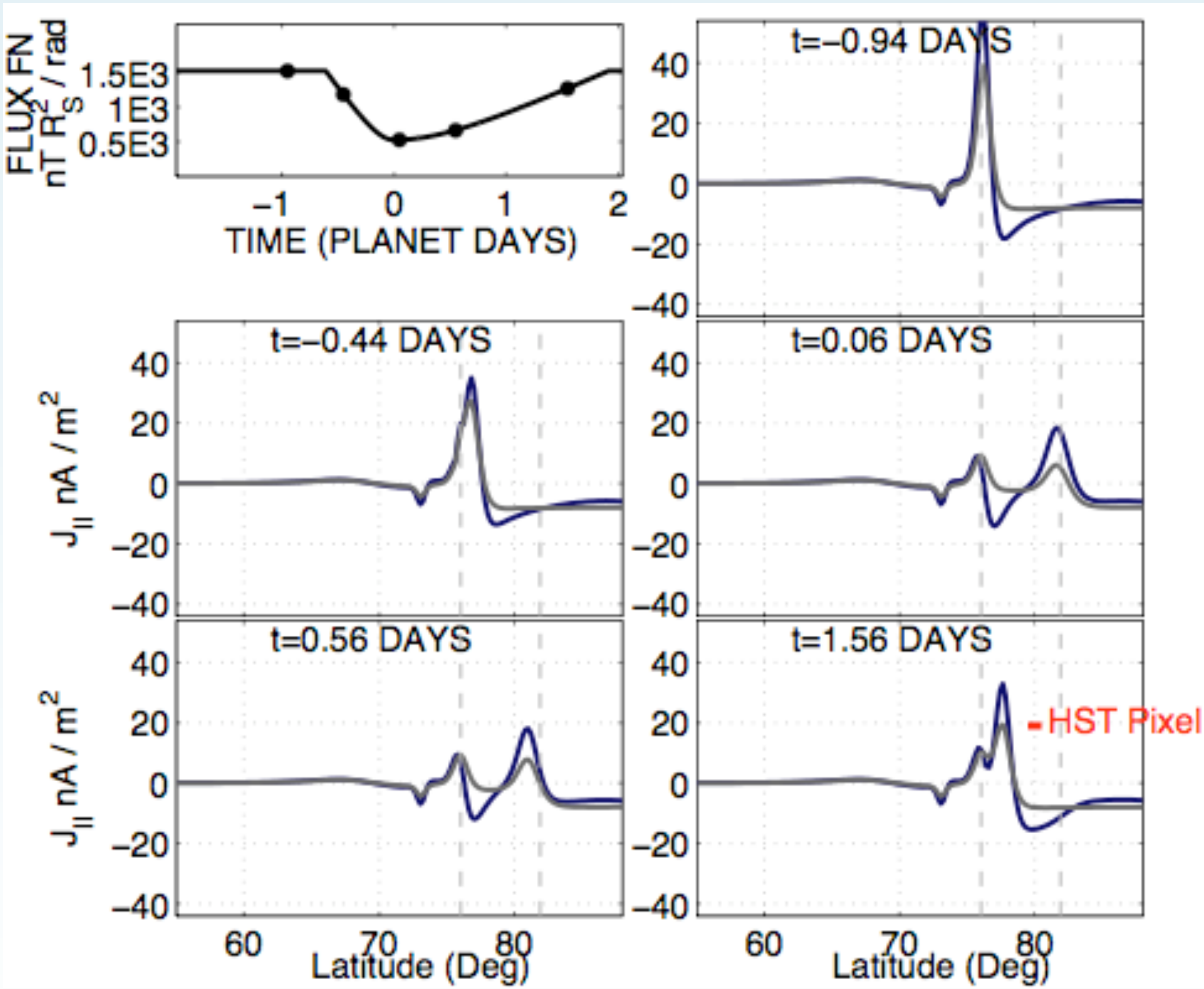
Field-Aligned Currents

t=0 is most 'contracted' position of polar cap boundary.



- *(Ω_T - Ω_M) flow pattern leads to appearance and movement of a broad, higher-latitude oval or 'ring'.*
- *The emission pattern may appear as a 'bifurcation'.*
- *Here we use Σ_P = 1 mho, higher values produce higher current density.*

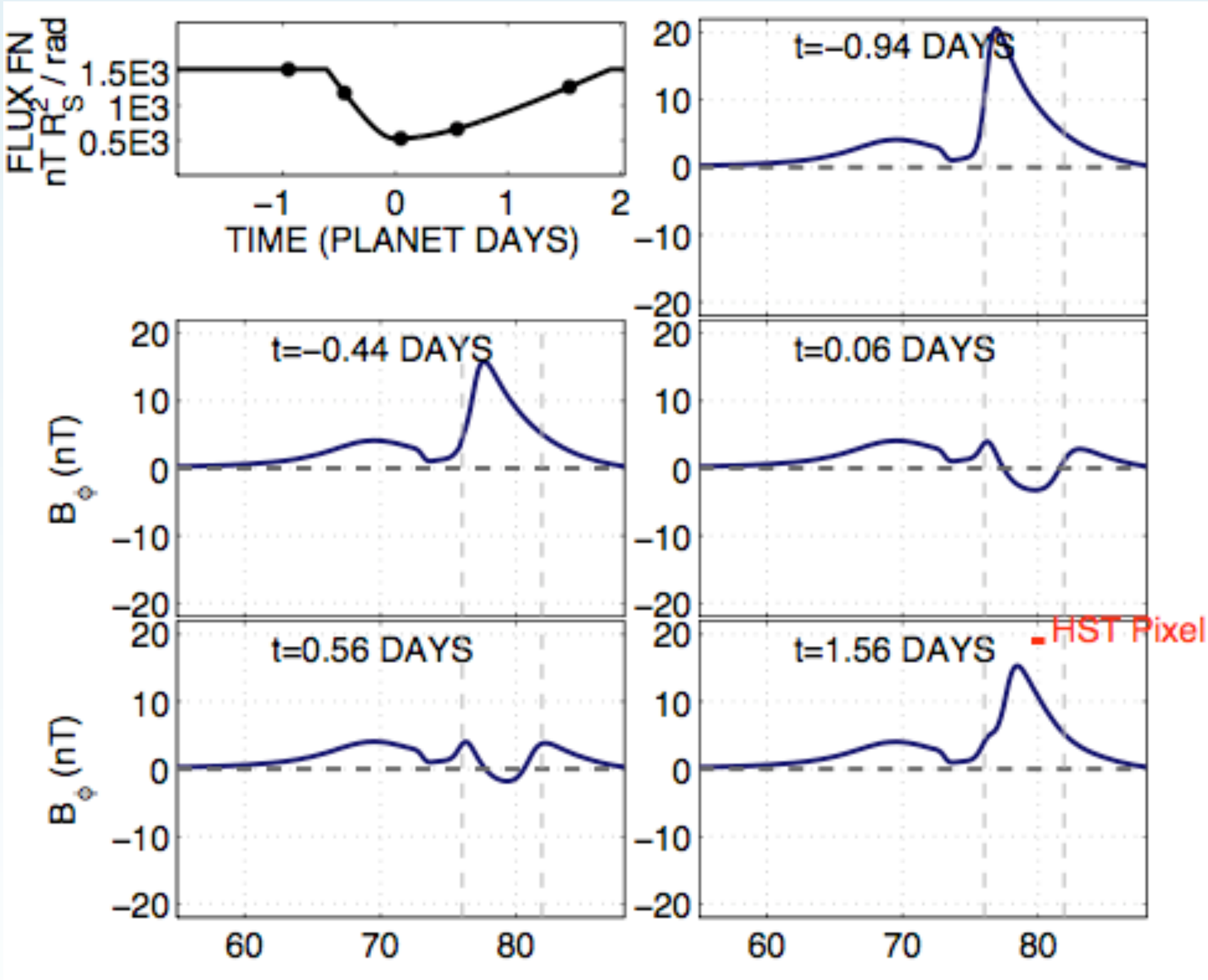
Field-Aligned Currents: Actual vs. 'Constant K=0.5'



- *The grey profiles assume ionospheric current calculated using:*
  $(1 - \Omega_T) = K(1 - \Omega_M)$

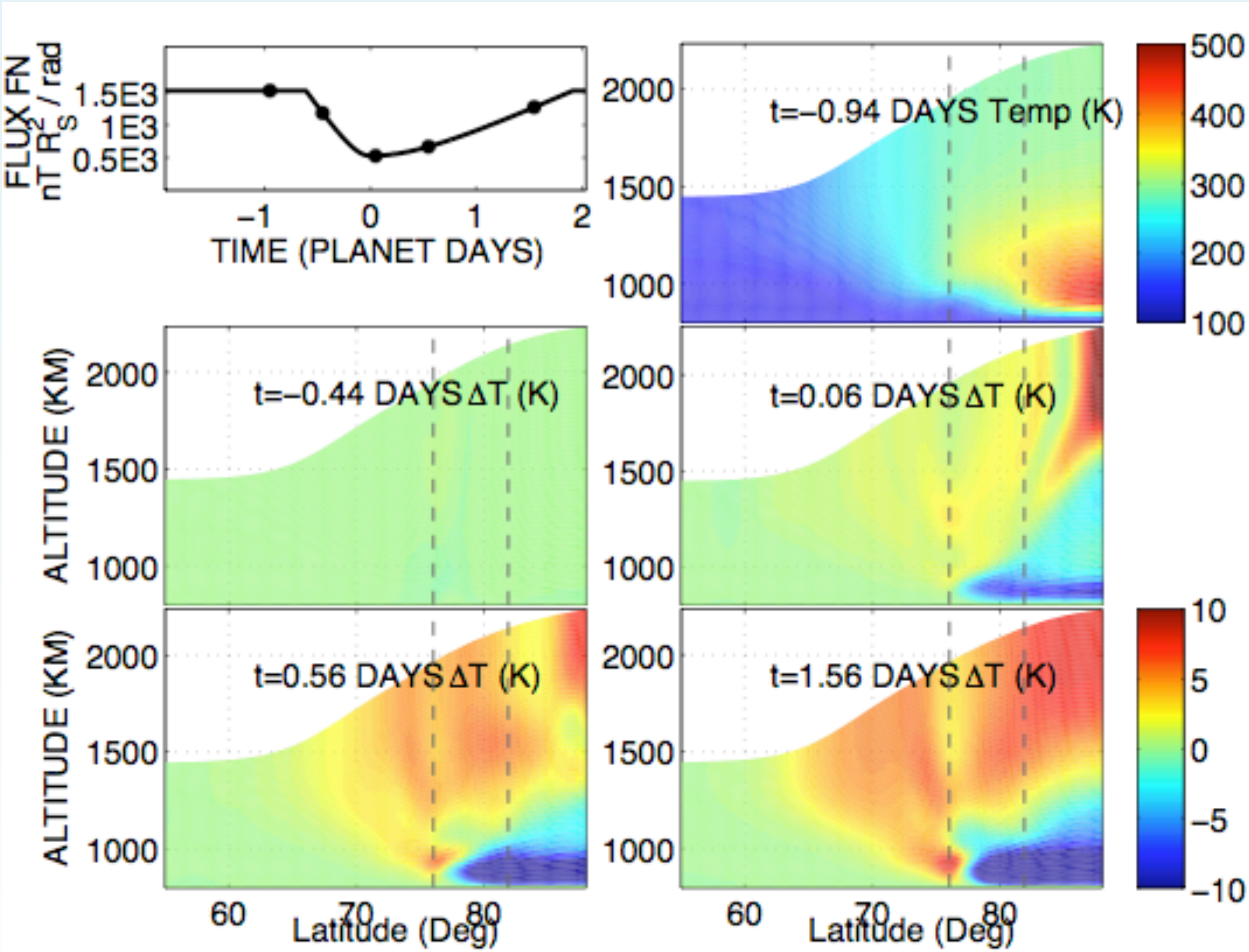
Azimuthal Field Bϕ above Ionosphere

- *Use axi-symmetric Ampere's Law to calculate* **Bϕ** following e.g. *Cowley et al (Ann. Geo. 2008)*



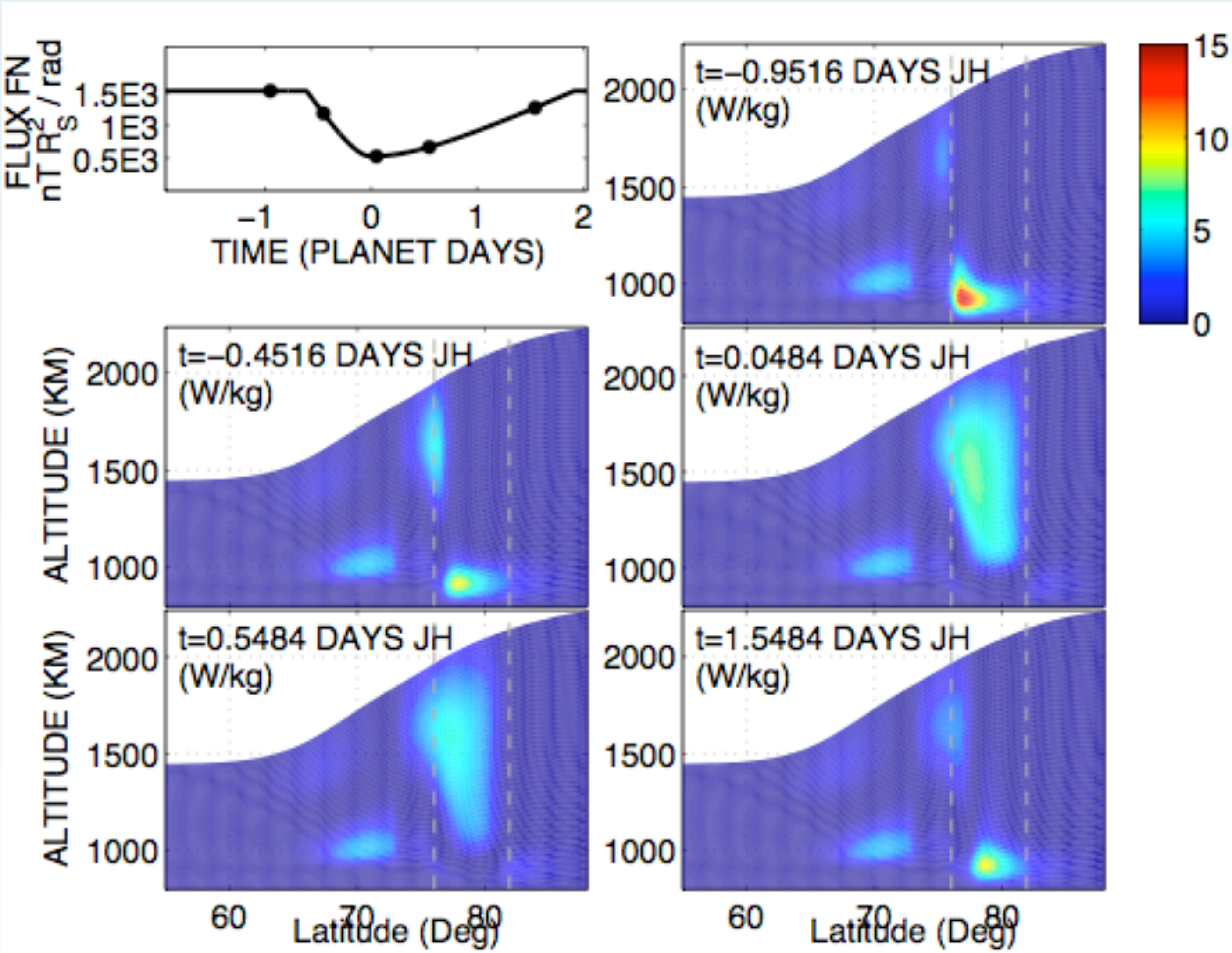
- In certain regions, obtain **negative Bϕ i.e. *'leading' field*** <u>*without* any super-corotation of plasma.</u>
- This happens when neutrals rotate slower than plasma $\Omega_T < \Omega_M$, but ***both subcorotate***.
- *Observations?*

Neutral Temperature



- *'Wave fronts' of temperature enhancement propagate outwards from sites of Joule heating.*
- *Observations?*

Joule Heating



- *Unusual patterns of Joule heating, around time of the 'reversal' in the ordering:*

$\Omega_T < \Omega_M$

- *Note that Ω_T is a 'weighted' average of flow velocities over all altitudes in the model.*

Summary

- *The thermosphere* *does* *respond to changes in the magnetosphere, but these changes are* ***not immediate****.*

- *This situation is* ***'intermediate'*** *between assumptions of a* ***perfectly corotating*** *thermosphere, and one which 'instantly' responds with a* ***'uniform' slippage****.*

- *The resulting patterns of auroral current are significantly* ***modulated*** *by atmospheric dynamics, and qualitatively similar to observed morphology.*

- *Resulting azimuthal field can be* ***leading, without the need*** *for super-corotating plasma.*

- *Need further investigation and help from auroral observers, as to implications for observations in UV and IR aurora.*