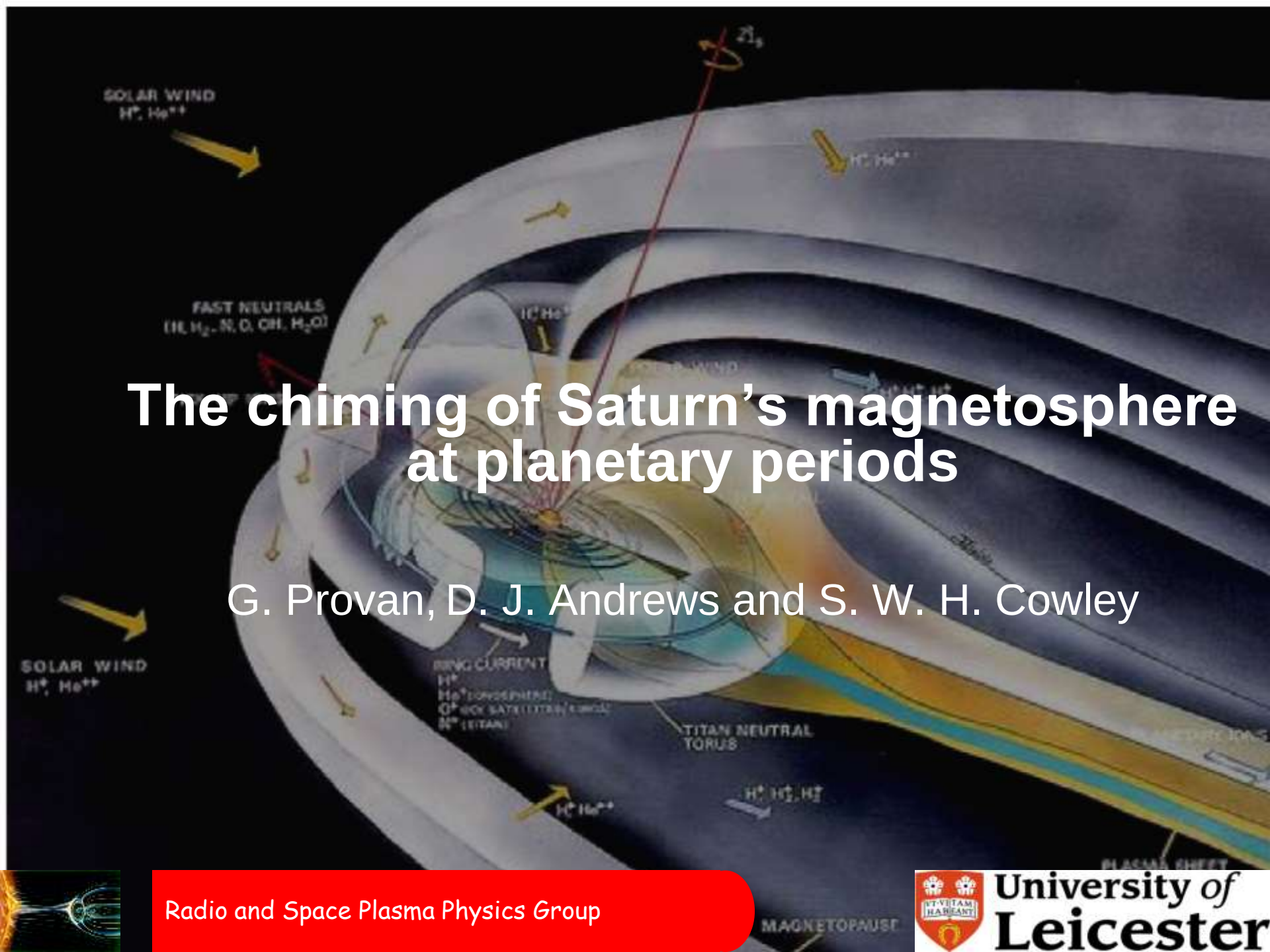


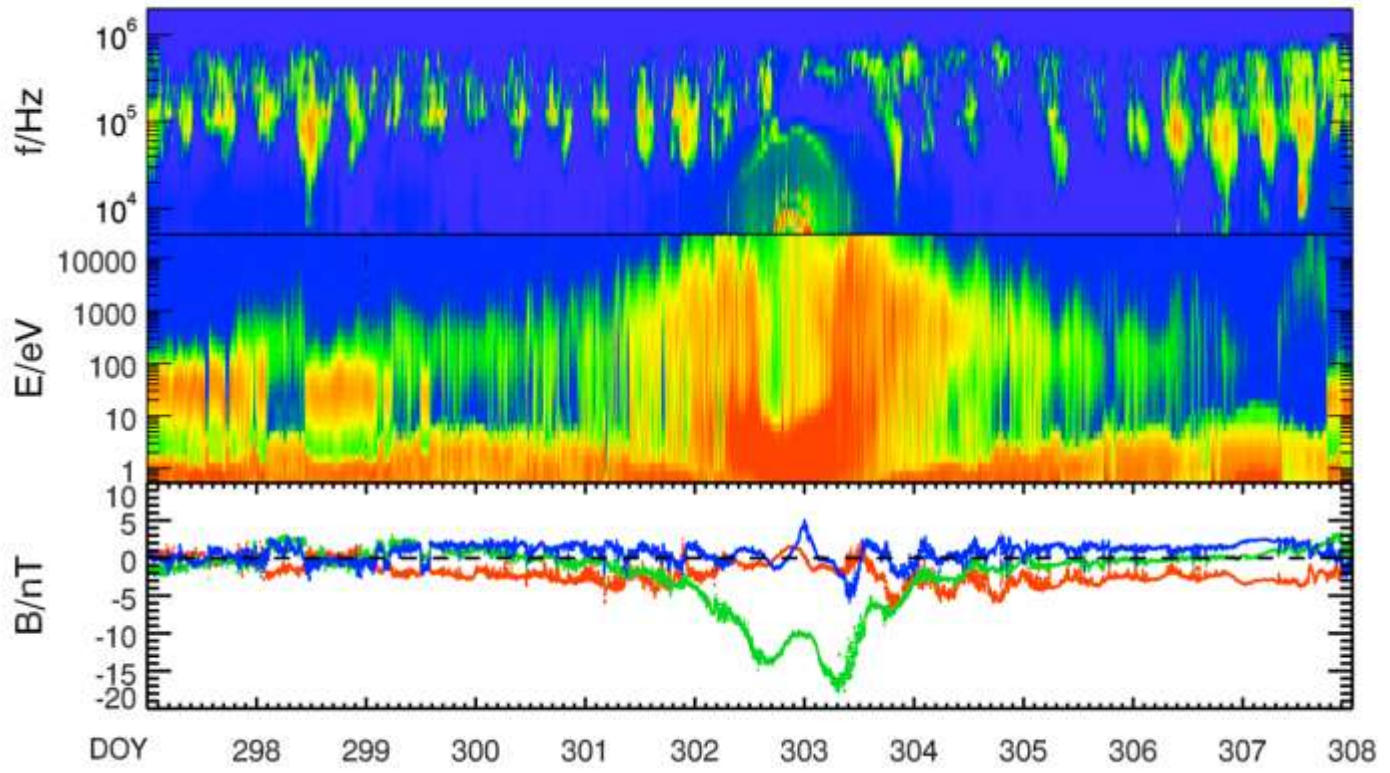
The chiming of Saturn's magnetosphere at planetary periods

G. Provan, D. J. Andrews and S. W. H. Cowley

Radio and Space Plasma Physics Group

University of Leicester

Saturn's planetary oscillations



Rev17

RPWS - pulsing of Saturn kilometric radiation (SKR)

CAPS/ELS - magnetopause oscillations

MAG/FGM -field oscillations

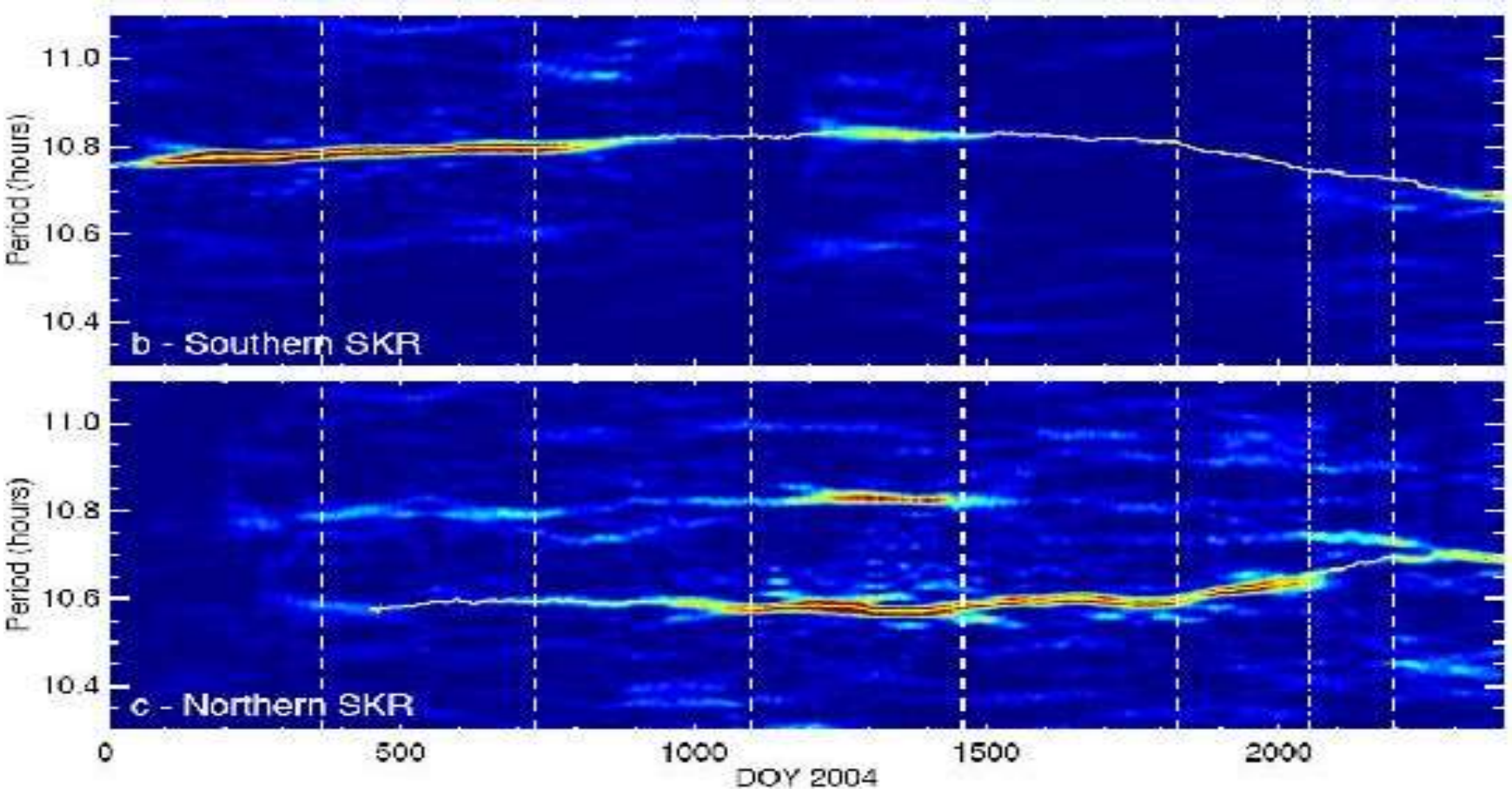
After Gérard et al., 2006

Near planetary period oscillations are observed throughout Saturn's magnetosphere.

- *Saturn kilometric radiation (SKR)*
- *magnetic field*
- *hot & cold plasma populations*
- *narrowband radio emissions*
- *auroral oval position, emitted power*
- *magnetopause & bow shock location*

Their source is by no means obvious as Saturn's internally generated field is close to axisymmetric (Burton et al., 2010)

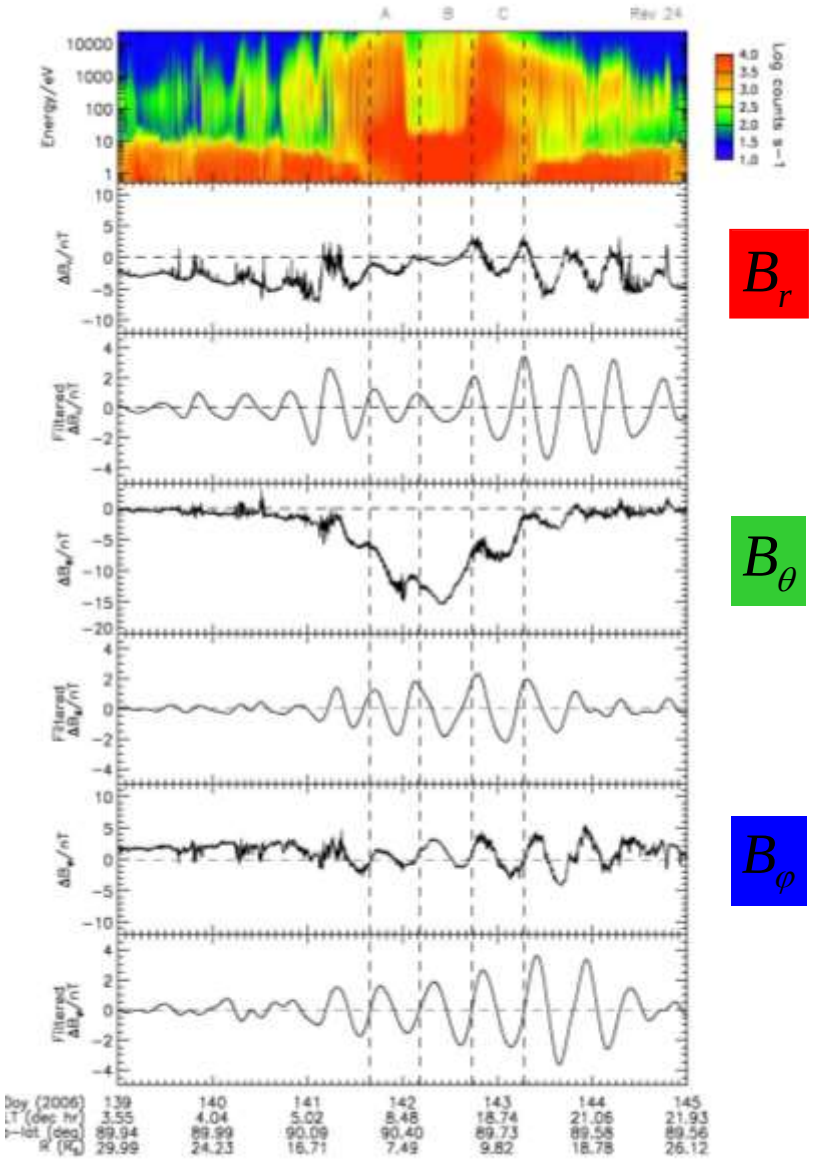
Planetary period oscillations first discovered in Saturn kilometric radiation observed by Voyager.
Periods different in two hemisphere and changes slowly over time.



Periodogram of Saturn's kilometric radiation, Lamy, 2011.

Core region, southern hemisphere summer when the Southern period dominated ($L<12\ R_s$)

1. The B_r and B_θ components are in phase, while the B_ϕ component is in lagging quadrature

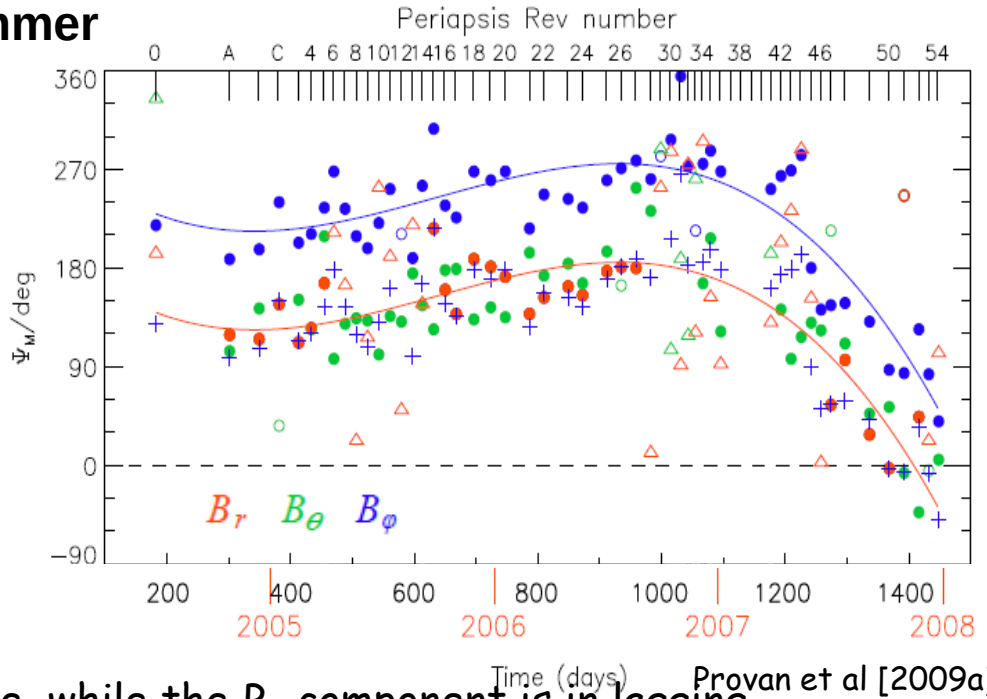


Core region, southern hemisphere summer (L<12 R_s)

$$B_{i,S}(\varphi, t) = B_{i,0S} \cos\left(\Psi_{i,MS}(\varphi, t)\right)$$

$$\Psi_{i,MS}(\varphi, t) = \Phi_{SKRS}(t) - \varphi - \psi_{i,MS}$$

Ψ_{MS} - phase of the magnetic perturbations
Φ_{SKRS} -phase of the southern hemisphere SKR oscillations as defined by Kurth et al., 2008.
φ - azimuthal position of the spacecraft
ψ_{MS} - phase of the magnetic oscillations relative southern hemisphere SKR oscillations.



Provan et al [2009a]

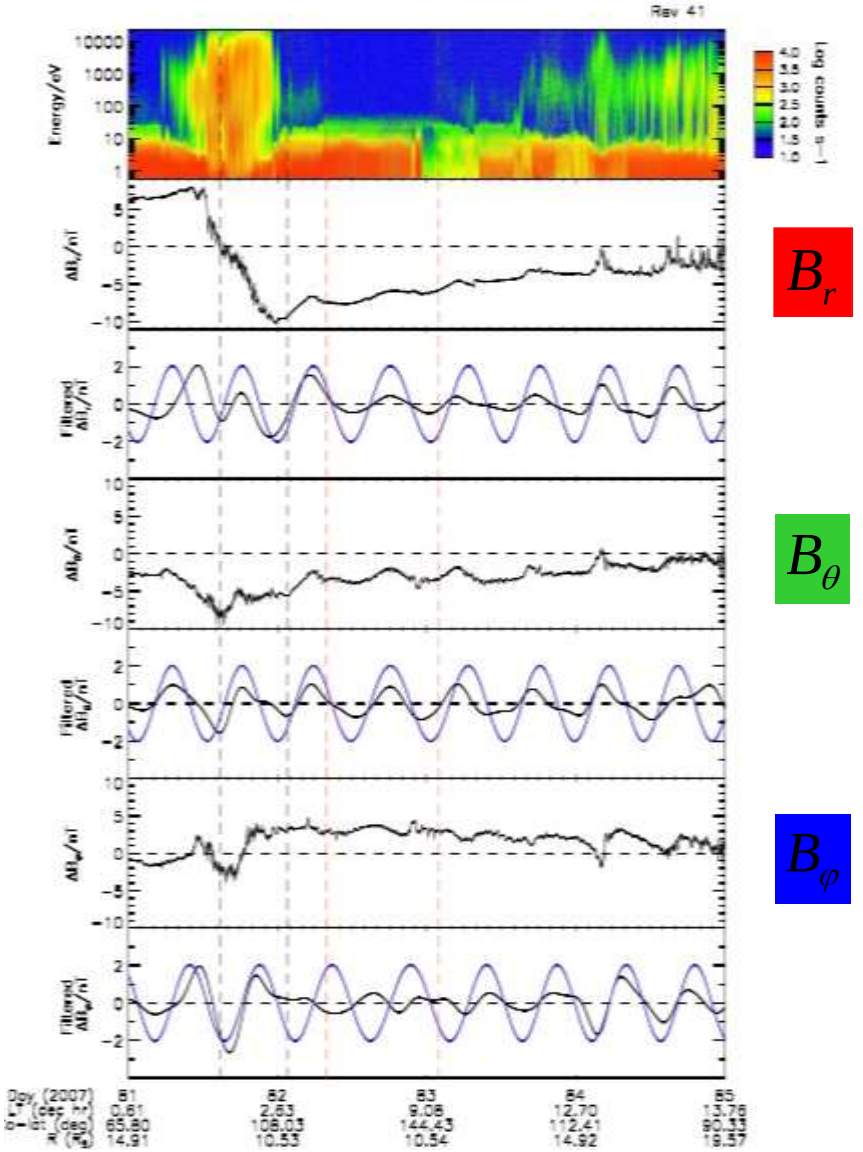
1. The B_r and B_Θ components are in phase, while the B_ϕ component is in lagging quadrature– means that 'core' field is quasi-uniform and rotates in sense of planetary rotation - originally suggested from Voyager and Pioneer data by Espinosa et al [2003].

2. Relative phase ψ_{Mr} remains approx fixed at ~150° over the interval constrained by SKR data - means that the transverse field points outwards at ~2 LT at SKR maxima

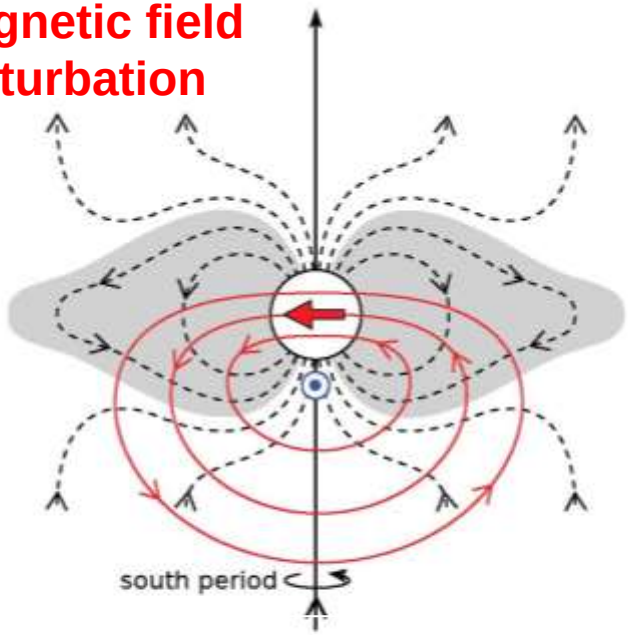
Questions
Phase drift of magnetic oscillations with respect to the southern hemisphere SKR?
Organized phase 'jitter' in all three components about the best fit line?

Southern polar region

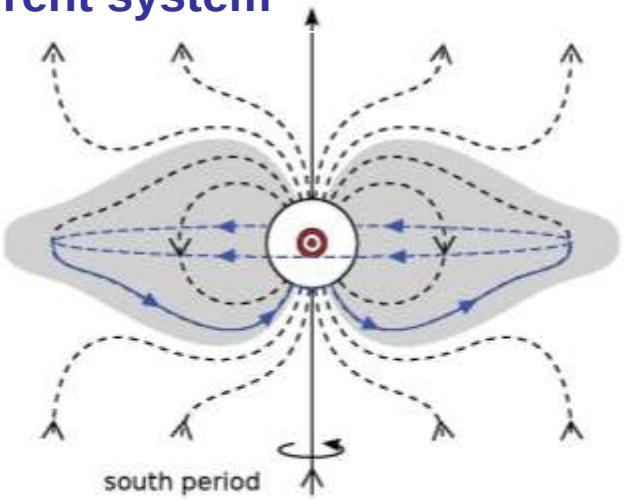
The B_r and B_θ components are in phase, while the Bφ component is in leading quadrature – this is the polarization of a rotating transverse dipole



Magnetic field perturbation

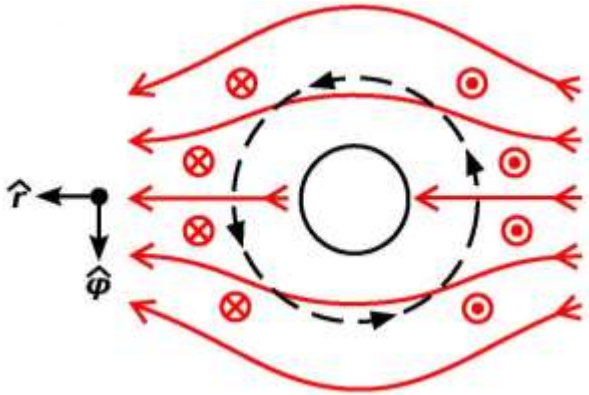


Current system



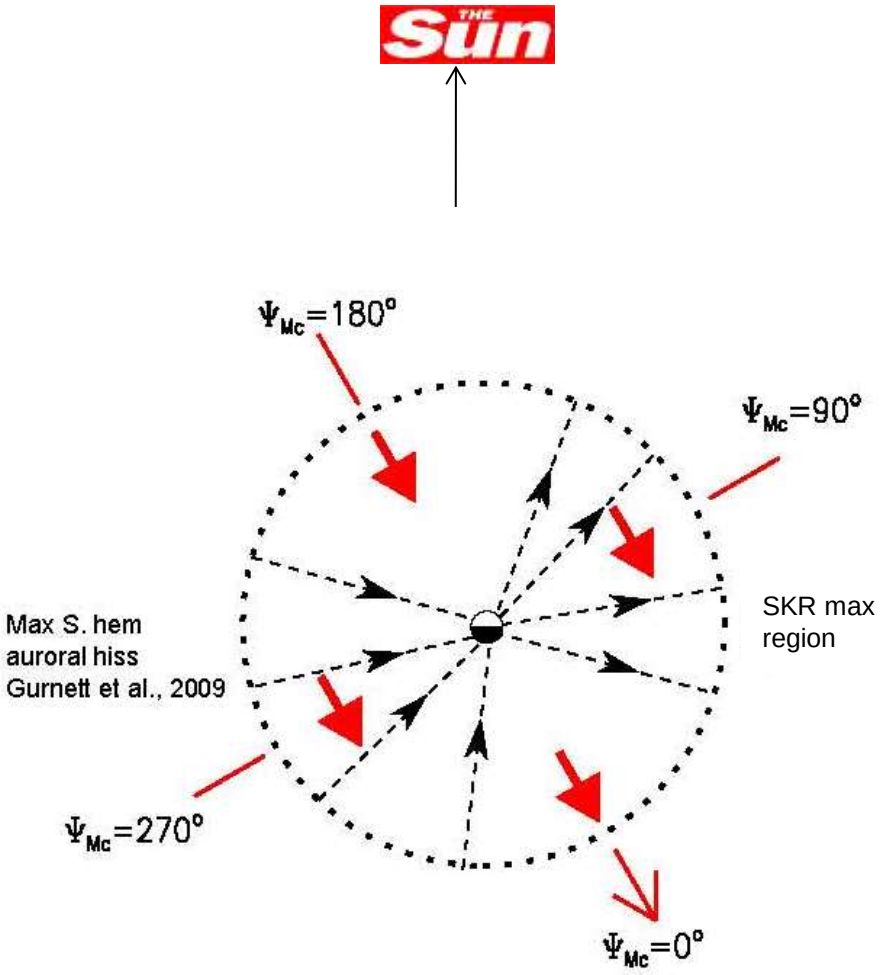
18 06

Andrews et al., 2010a



- Rotating current system producing magnetic perturbation field
  - *Produces observed rotating 'quasiuniform' equatorial field*
  - *'Quasi-dipolar' field at high-latitudes*
  - *Andrews et al. [2008,2010], Provan et al. [2009a]*

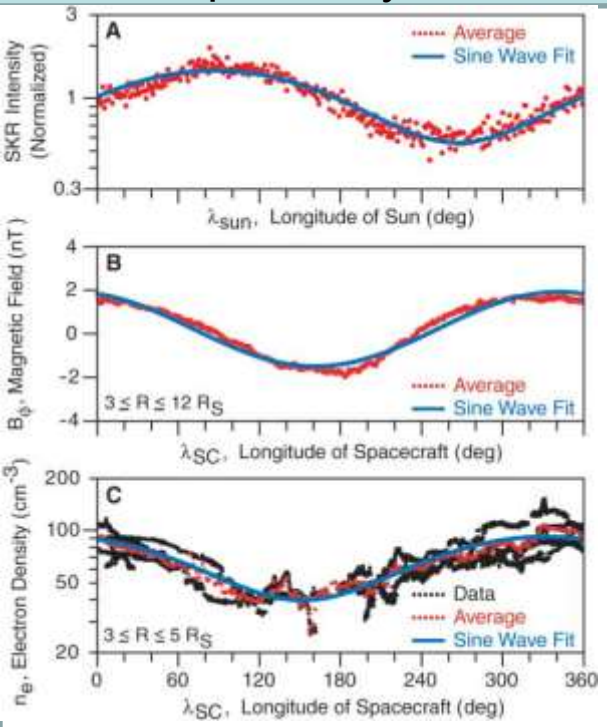
Saturn's planetary oscillations



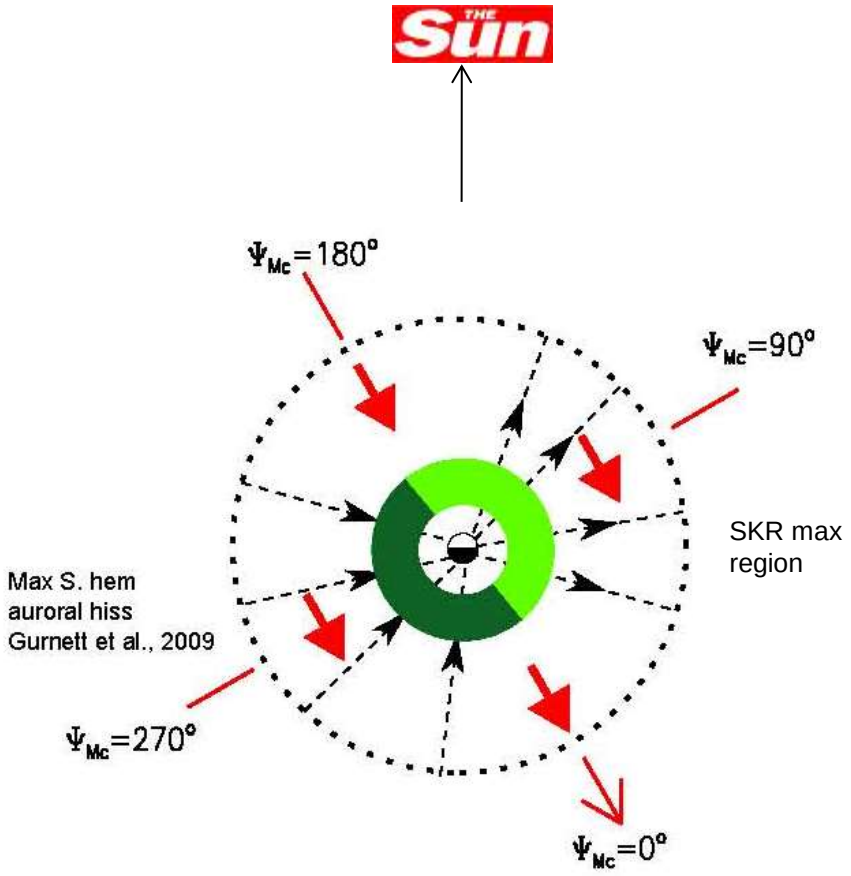
Red arrow show the direction of the phase front of the southern 'core' phase at SKR maxima. The phase fronts are pointed post-midnight and rotate around the planet at the Southern period

Black dashed lines show the direction of the field aligned currents.

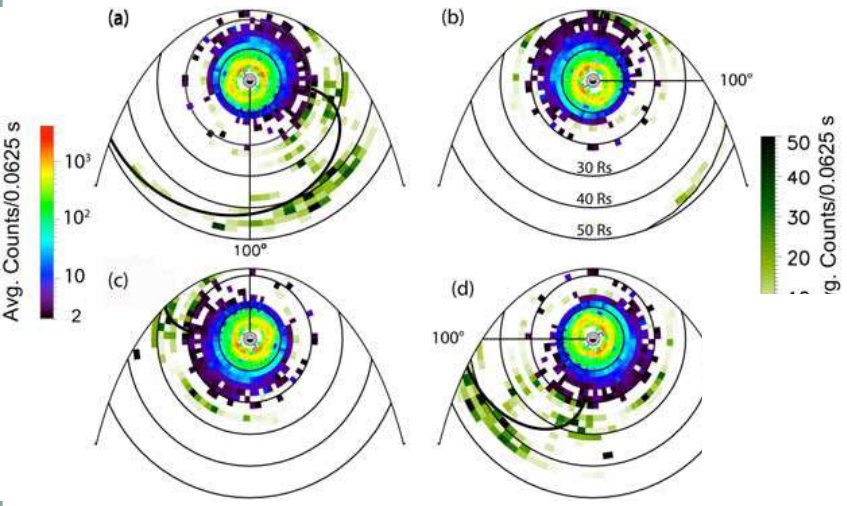
Saturn's planetary oscillations



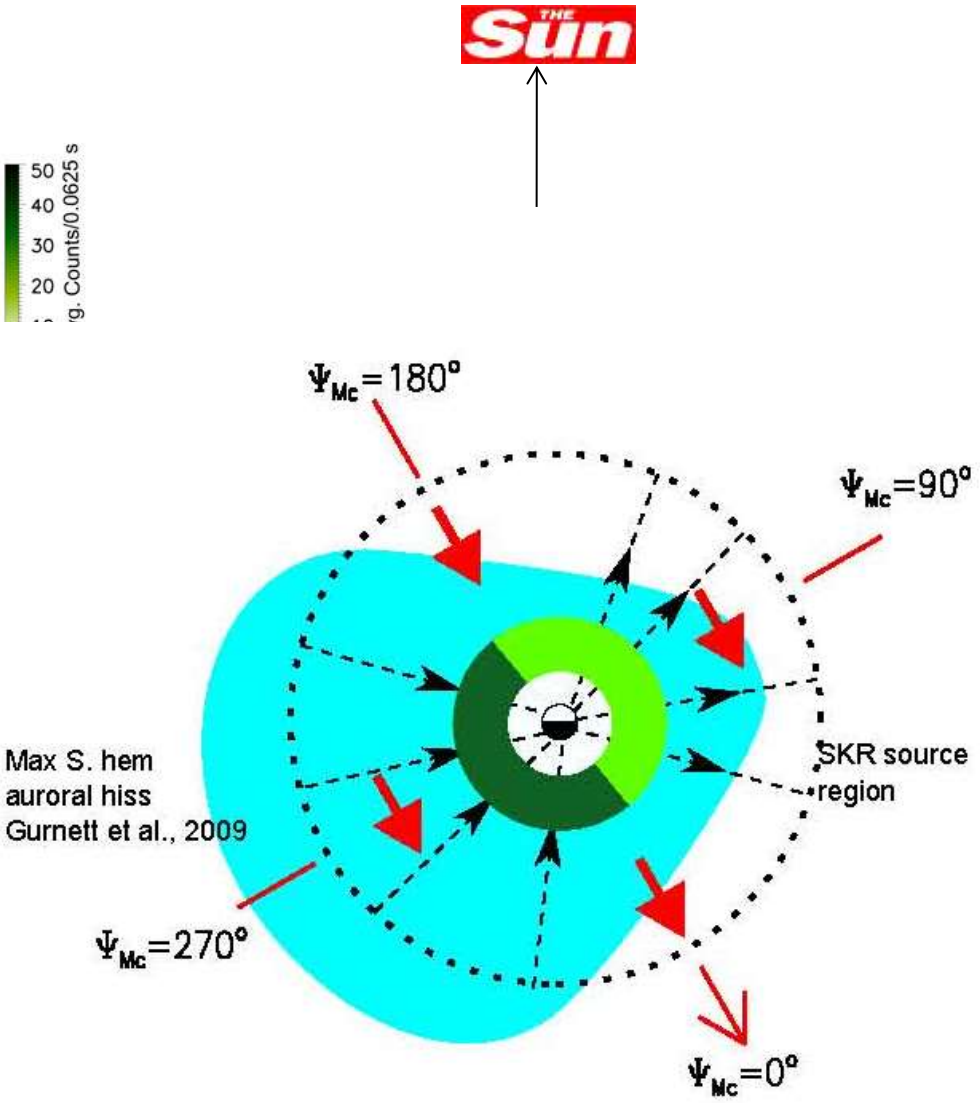
Gurnett et al., 2007



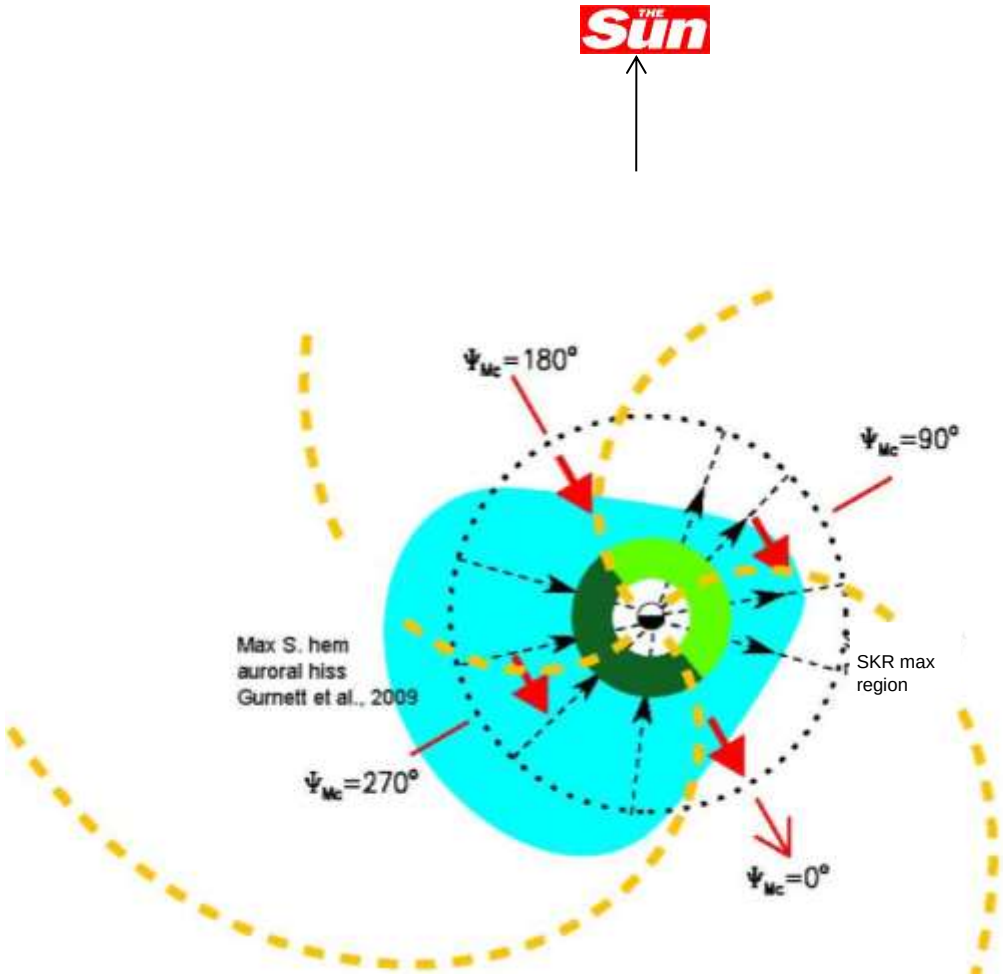
Dark green shows the high density region of Enceladus plasma torus.
Within the inner region of Saturn's plasma disk (within 3 to 5 Rs) the plasma and magnetic field rotate at the SKR period .
Peak in electron density and in the φ magnetic field are both in the dusk/pre-midnight region at SKR maxima (Gurnett et al. 2007).



Burch et al. (2009)

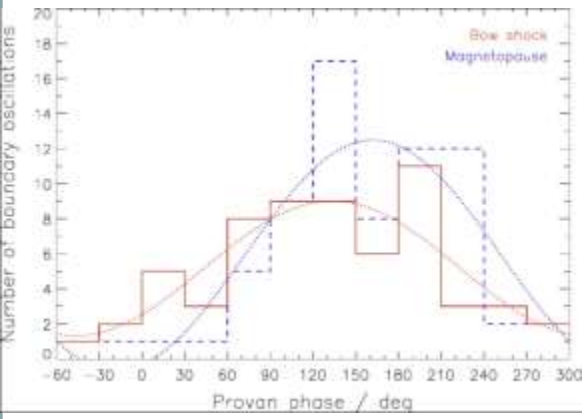


Burch et al. (2009) used CAPS ion data to observe a plasma cam stretching beyond 20 Rs. Cam peaks in the post-dusk sector, similarly to the inner density enhancement

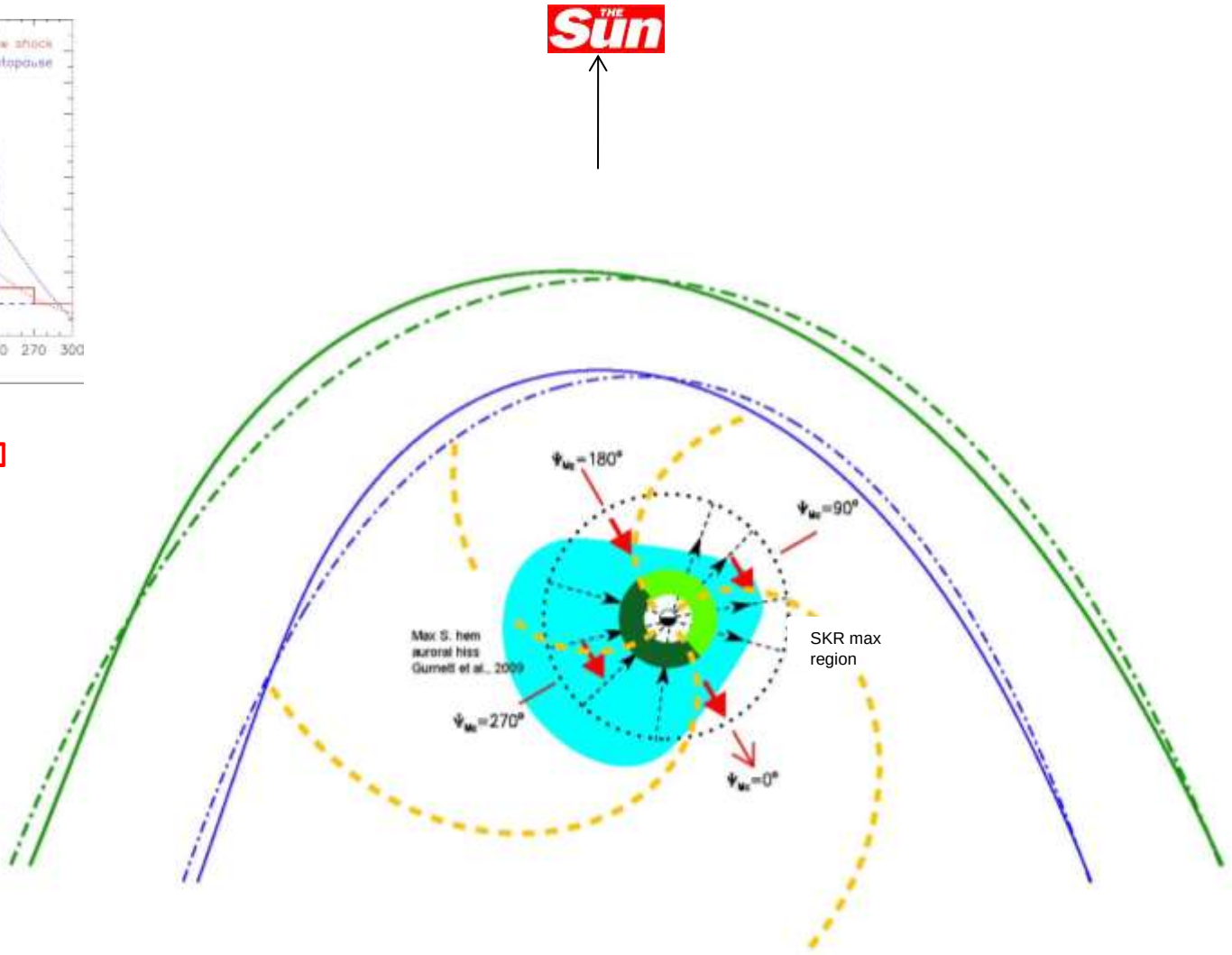


Andrews et al., 2010b and Clarke et al., 2010a, described the outward radial phase propagation of the magnetic oscillations.
The orange dashed spirals present the disturbance phase fronts (lines of constant B_Θ phase), connecting the Enceladus plasma torus to the dayside plasma bulge

Saturn's planetary oscillations

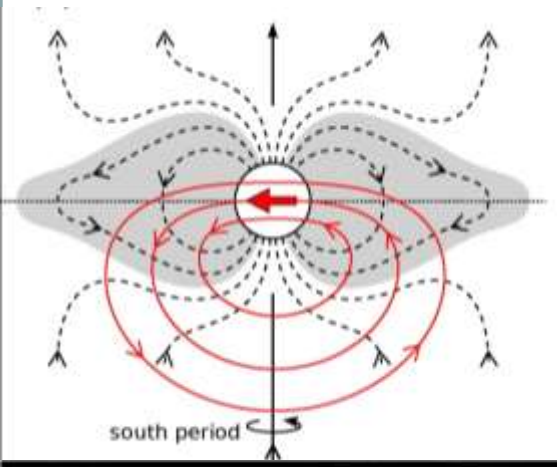


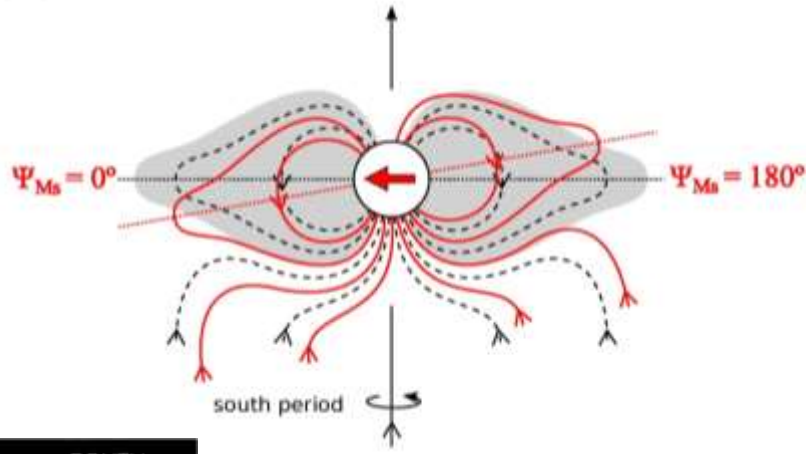
Clarke et al [2010a, 2010b]

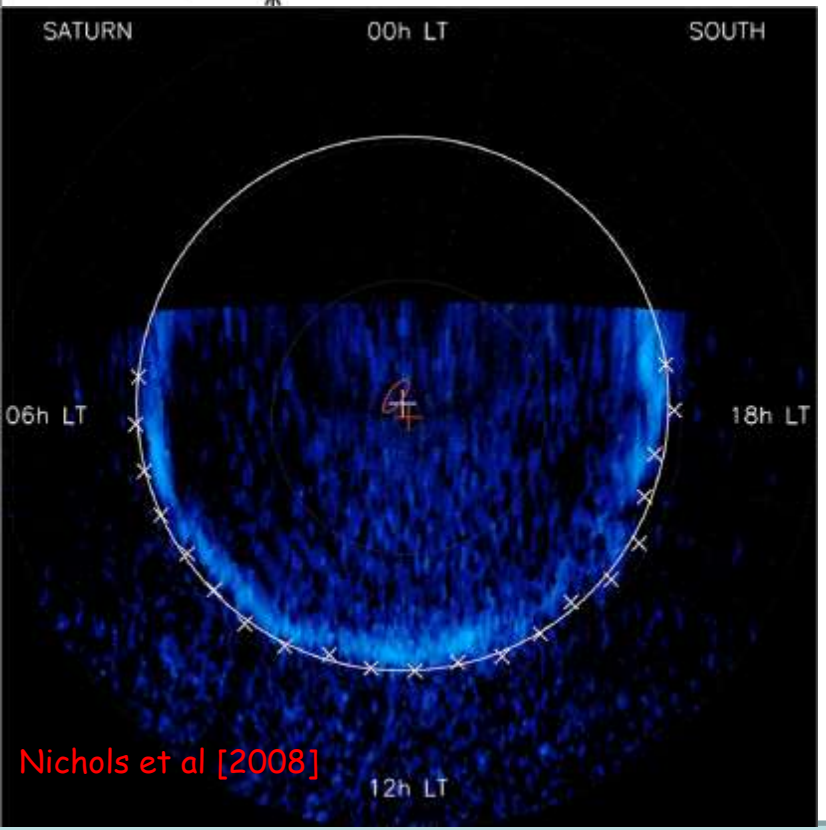


The orange dashed spirals present the disturbance phase fronts (lines of constant B_θ phase), connecting the Enceladus plasma torus to the dayside plasma bulge .....and the outwardly displaced magnetopause and bowshock boundaries

Saturn's planetary oscillations



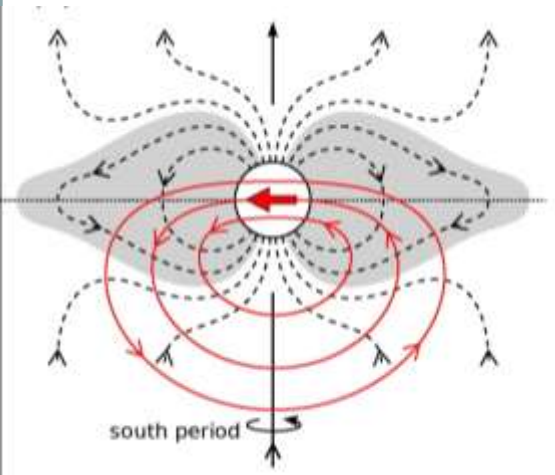


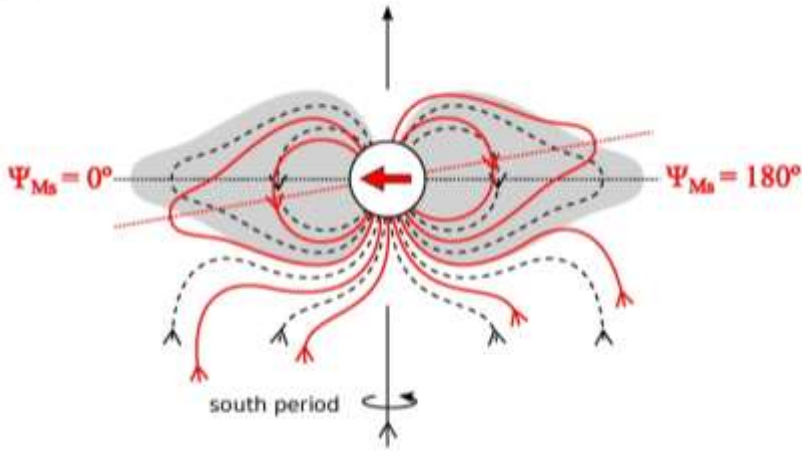


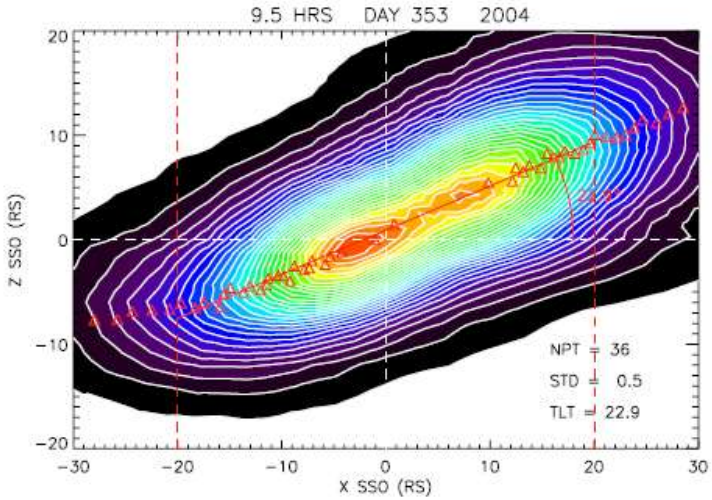
Tilting of the auroral oval found in SH HST images from 2007 and 2008 by Nichols et al [2008]

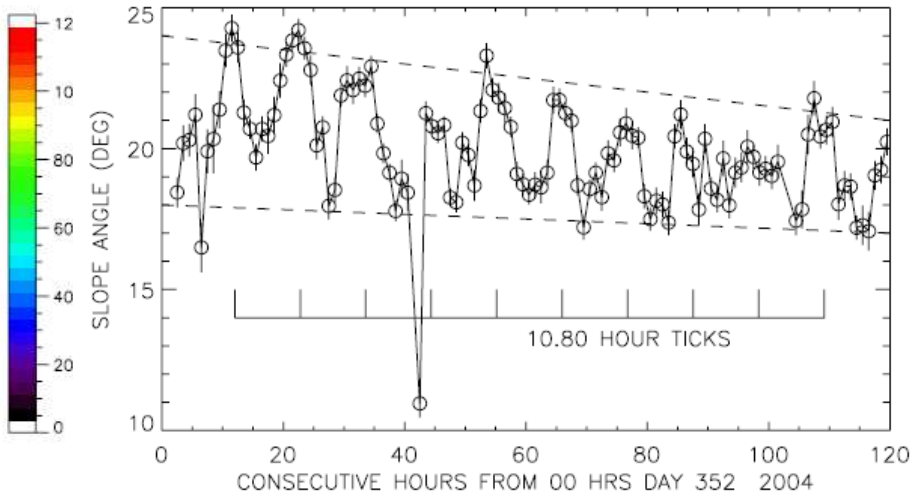
Phase has been established by Provan et al [2009b], displaced opposite to the direction of the radial core field as expected

Saturn's planetary oscillations



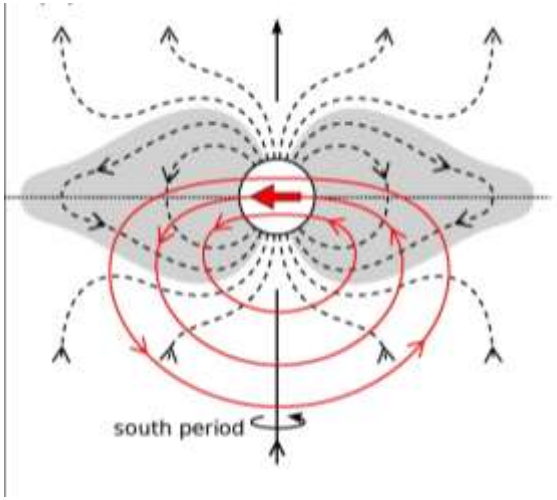


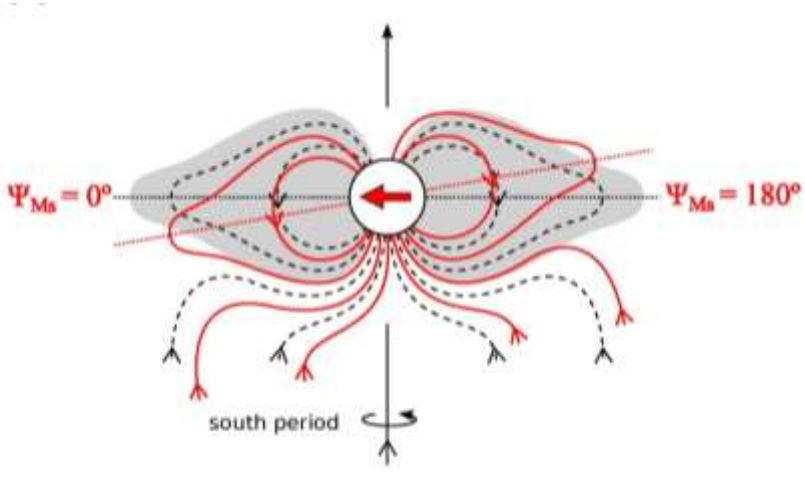


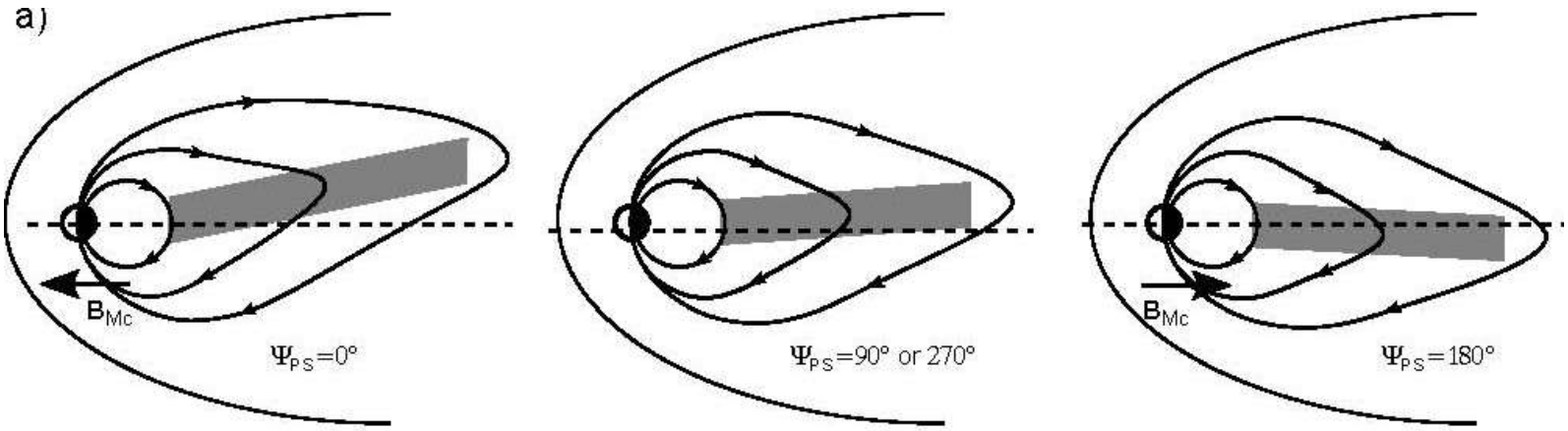


Carbary et al [2008]

Saturn's planetary oscillations

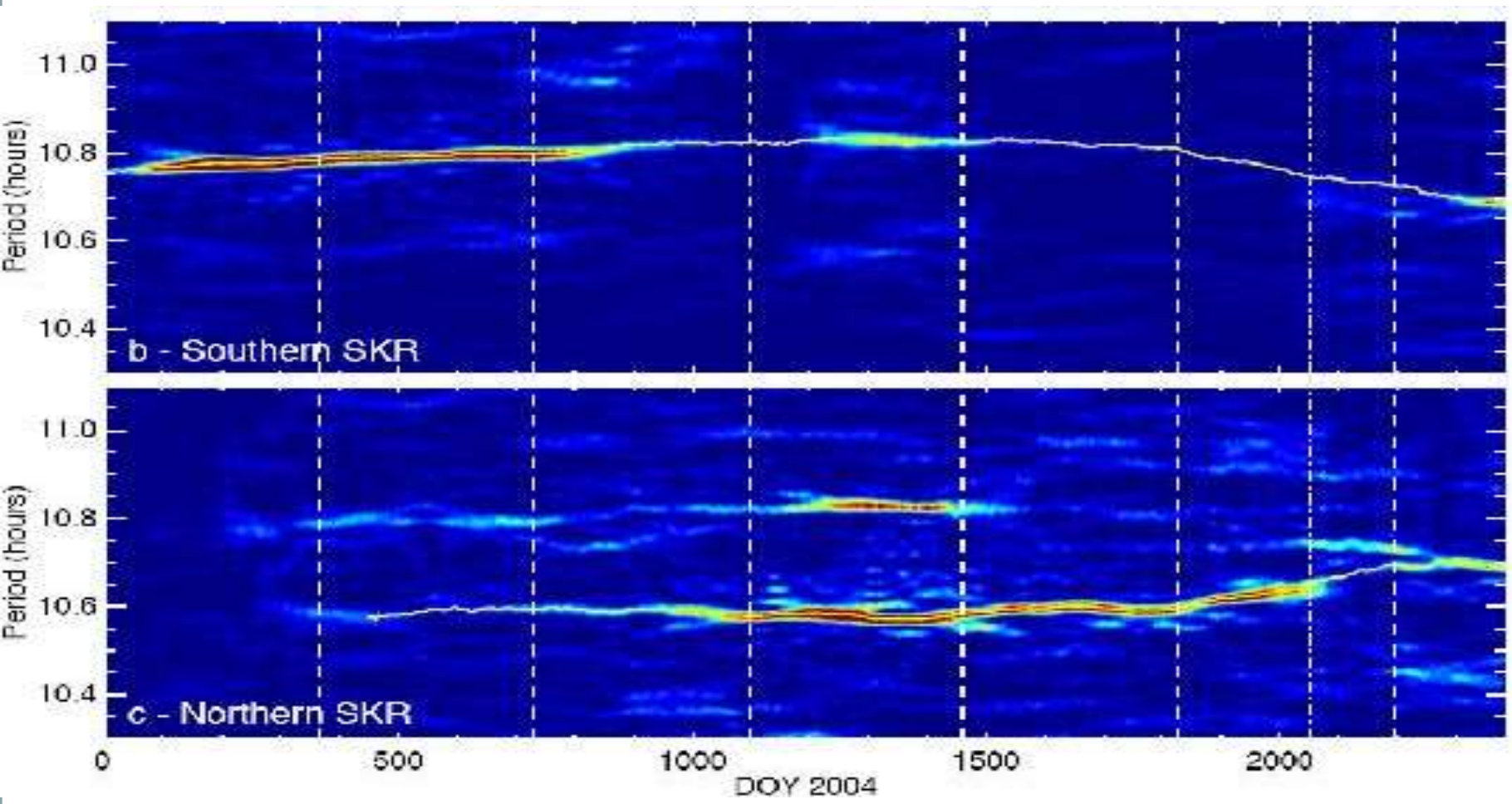




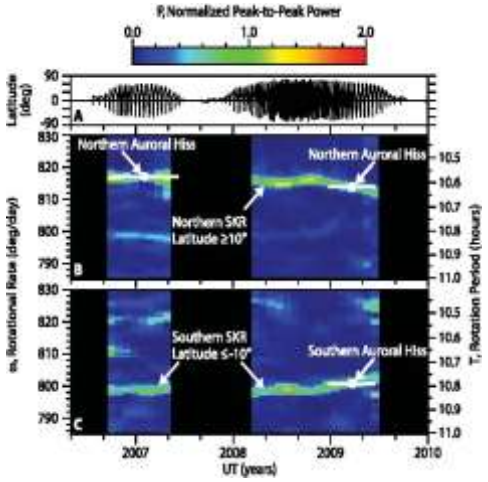


Arridge et al., 2011

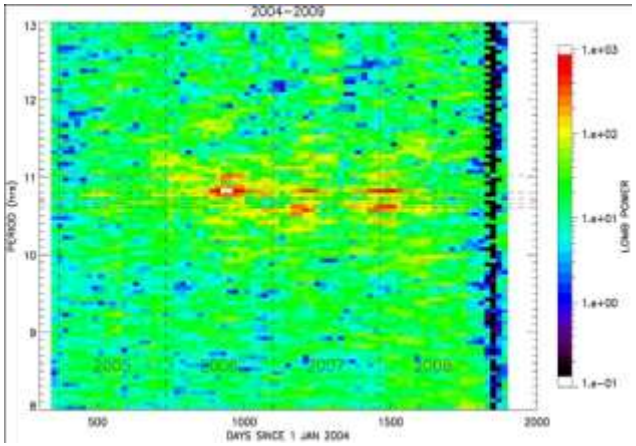
Dual periodicities



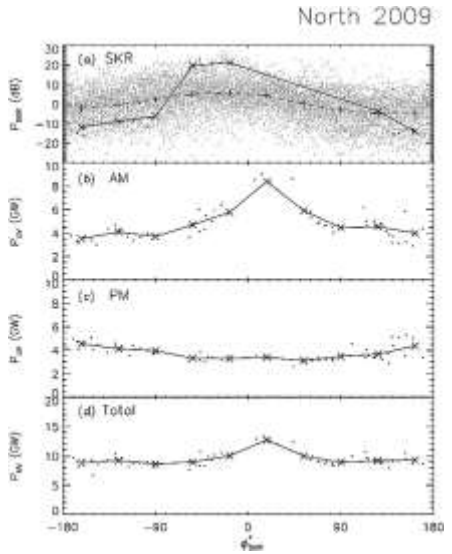
Dual periodicities



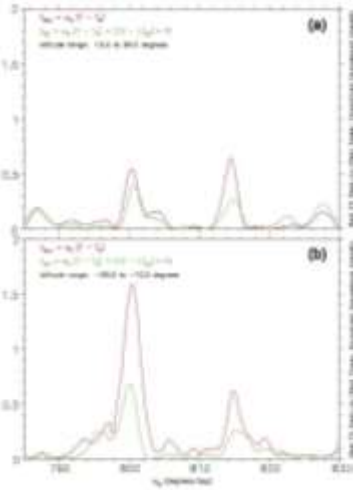
Dual periodicities observed in auroral hiss, Gurnett et al., 2009



In energetic electrons, Carbary et al., 2009

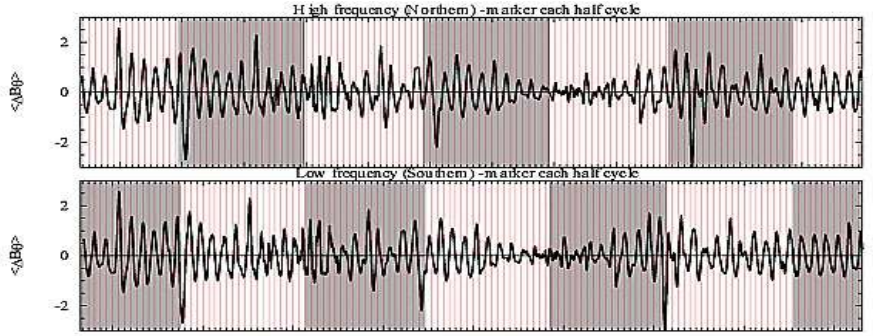


In the UV auroral oval Nichols et al, 2009



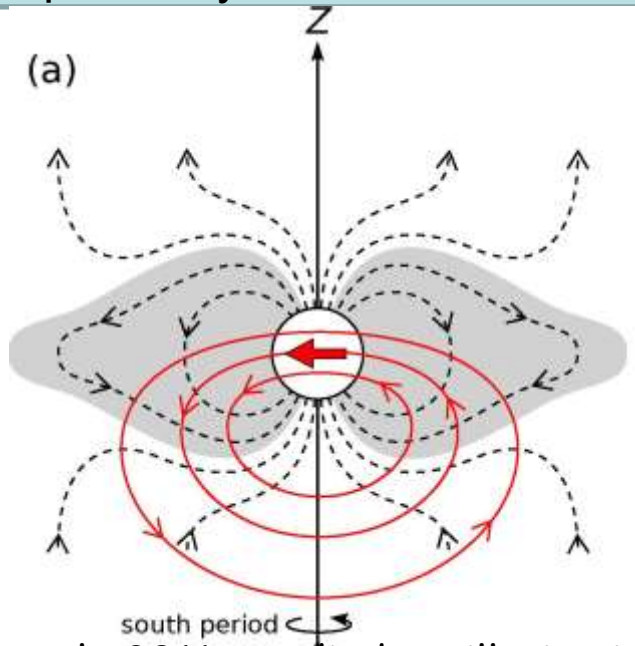
In narrowband radio emission, Ye et al., 2009

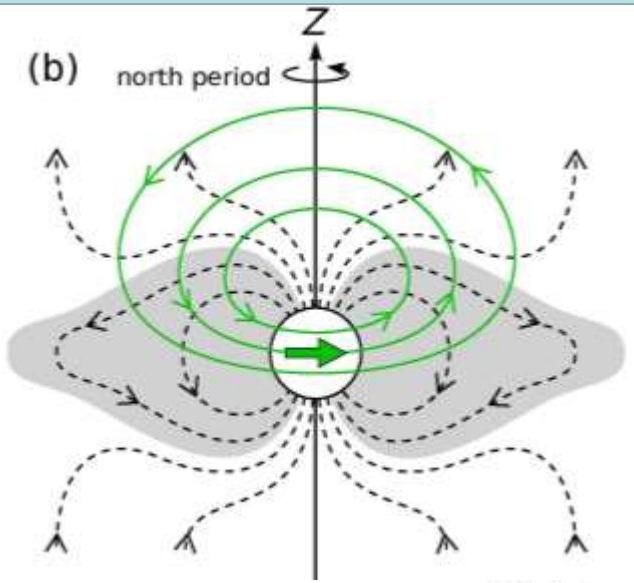
In the magnetic field oscillations as reported by Andrews et al., 2010 and Southwood,2011



	Jan-02 02:16	Jan-05 17:25	Jan-09 06:20	Jan-12 16:52	Jan-16 10:08	Jan-19 20:07	Jan-23 09:47	Jan-27 00:16	Jan-30 09:58
R	17.1	11.1	19.7	13.8	15.2	19.5	9.9	17.9	17.9
Lshell	27.0	45.6	20.1	65.2	50.3	20.0	18.1	26.0	23.4
Invl_at	78.9	81.5	77.1	82.9	81.9	77.1	76.4	78.7	78.1
mlat	37.3	-60.4	-7.9	62.6	-56.7	9.6	42.5	-33.9	29.0
LT	11.4	1.2	10.1	13.6	8.2	10.5	21.0	9.3	11.0

Saturn's planetary oscillations





Provan et al., 2011, studied oscillation in the 'core' region from 2004-2006, so during southern hemisphere summer

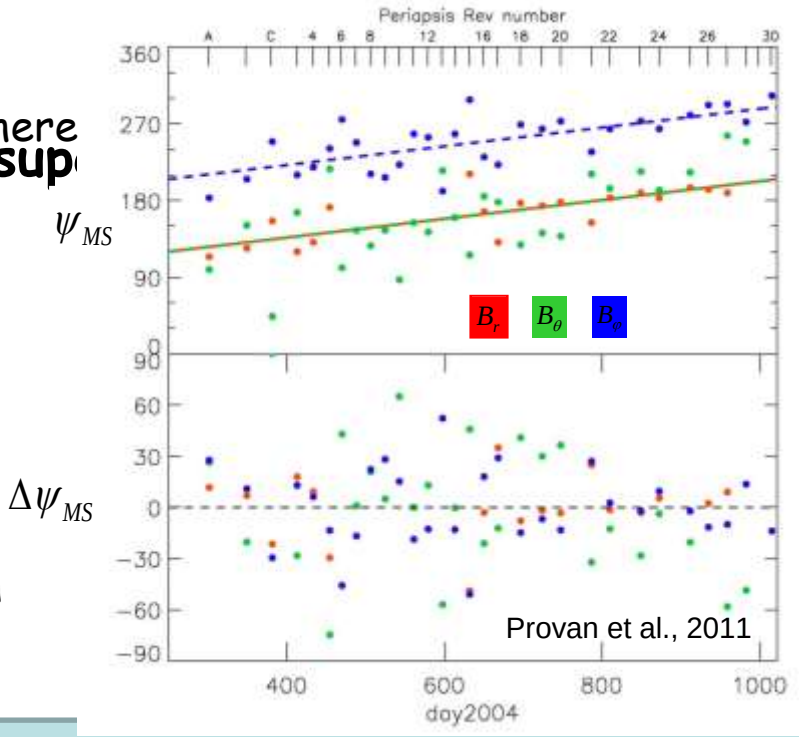
The northern and southern oscillations sup

ıe

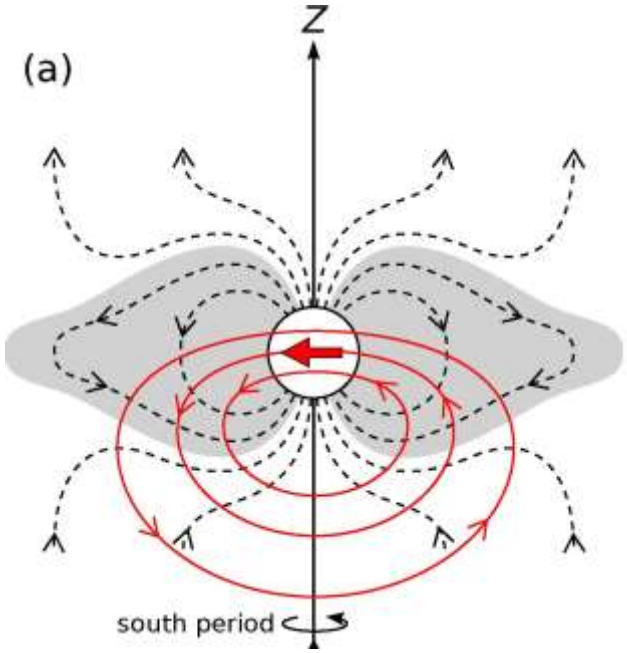
The superposition of these waves result in 'phase' jitter in the equatorial oscillation of ~±25 deg.

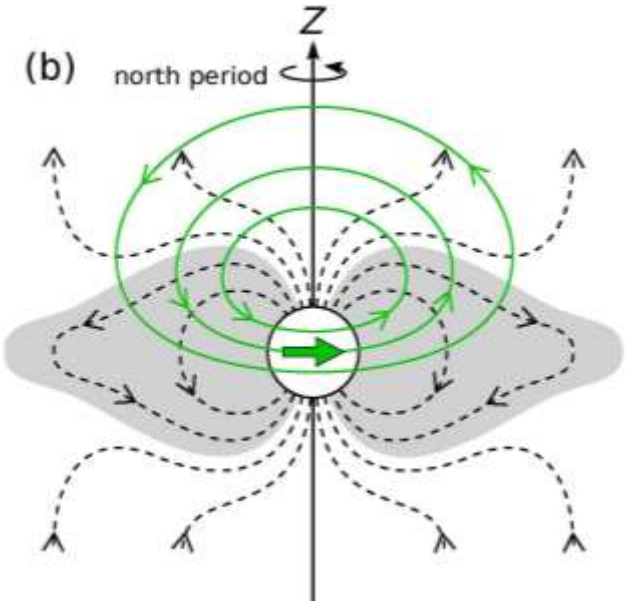
The 'jitter' has a period of ~23 days, this is the **beat period** of a ~10.6h and a 10.8 oscillation.

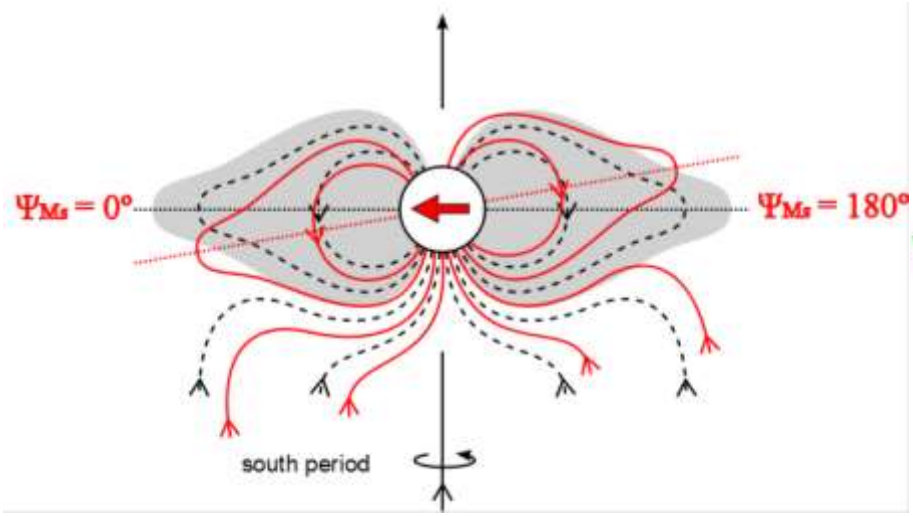
The amplitude of the northern-period oscillations in the equatorial region is ~30-40% of the southern-period oscillations.

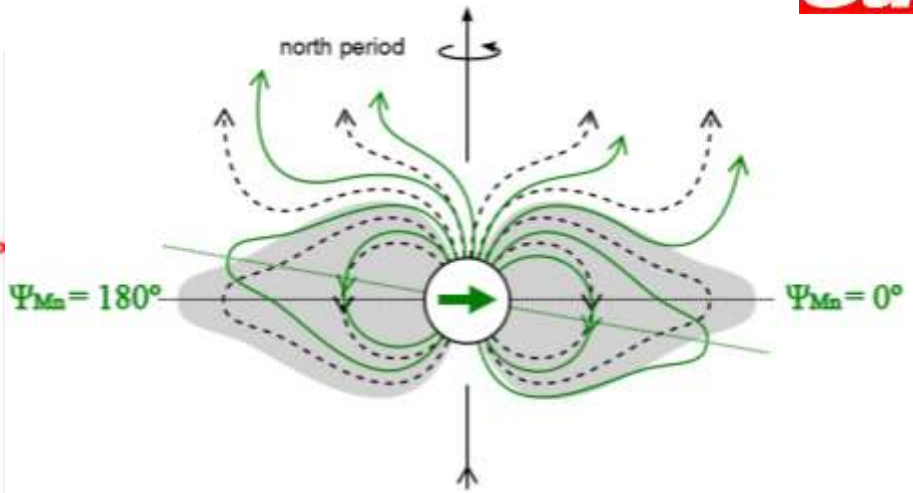


Saturn's planetary oscillations







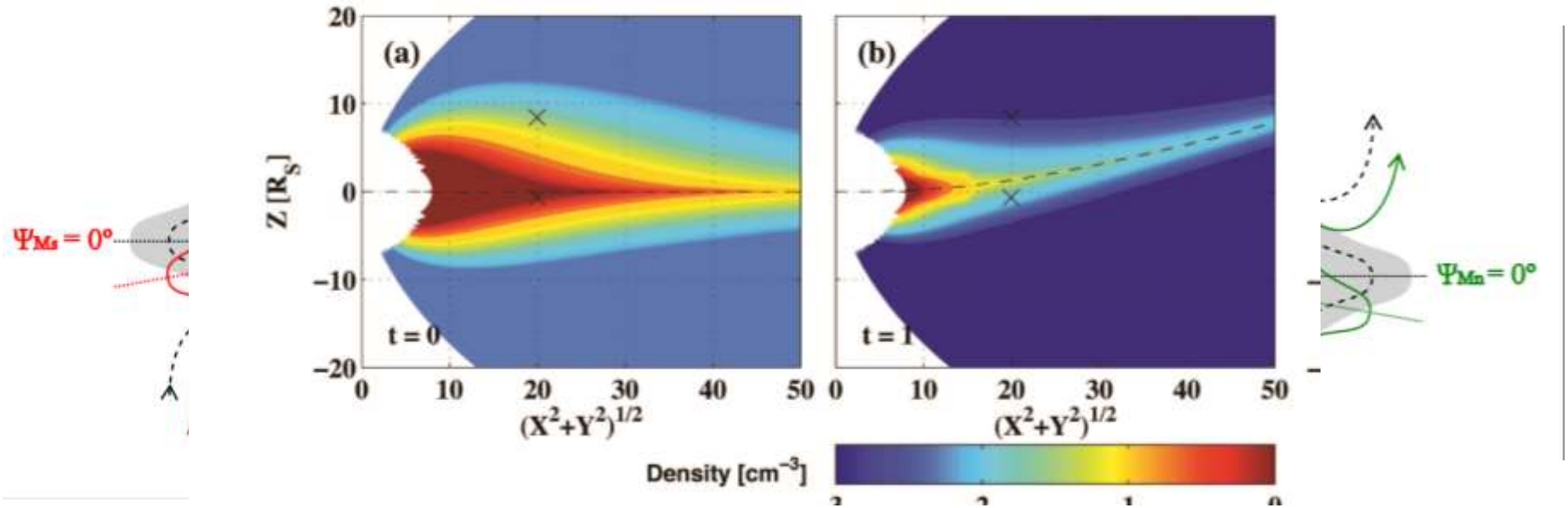


Provan et al., 2011

We should observe

Dual oscillations in the plasma sheet

- when the two oscillations are in phase the current sheet should 'flap' north and south
- when the two oscillations are in anti-phase the thickness of the current sheet should also be modulated – thickning and thinning of the plasma sheet previously suggested by Morooka et al., 2009.



Dual planetary period oscillations in the plasmasheet – see my poster

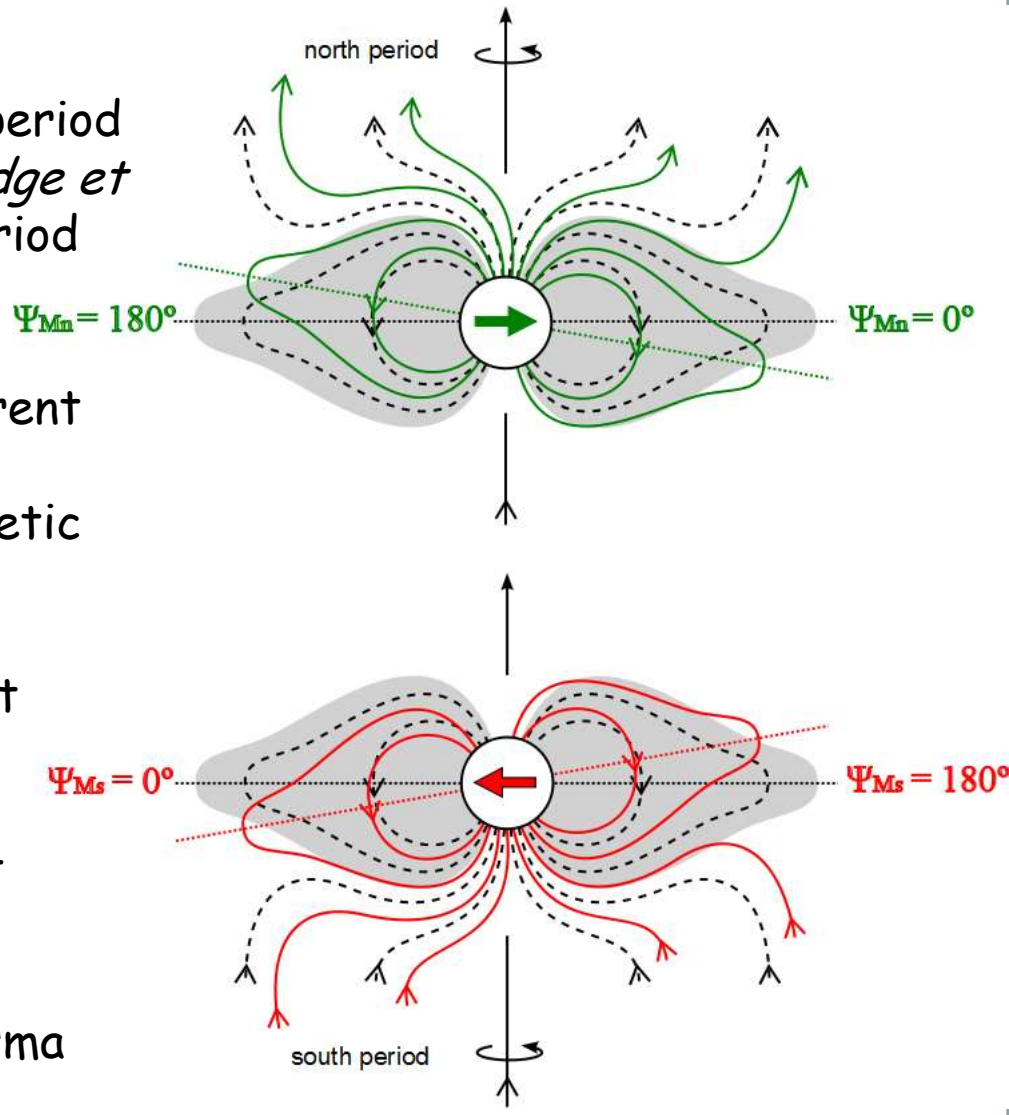
Oscillations are at the northern SKR period at 3 R_s above the current sheet [*Arridge et al.*, 2008] and at the southern SKR period below this.

Maximum upwards flapping of the current sheet occurs when the phase of the southern or northern oscillatory magnetic oscillation is ~180°.

At joint SKR maxima the plasma sheet thickness is at a maximum.

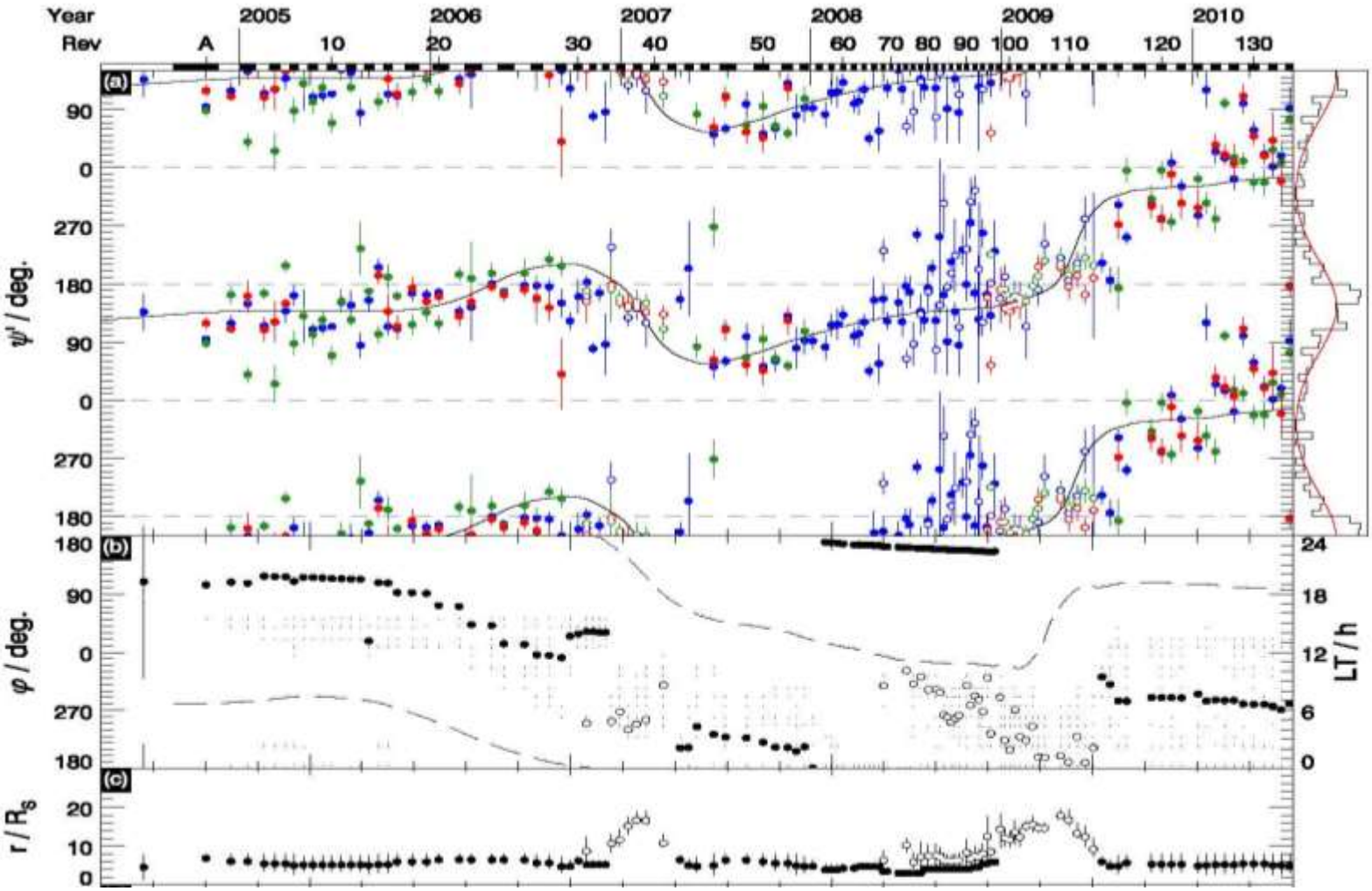
At joint SKR minima the plasma sheet thickness is at a minimum.

So the behaviour of the nightside plasma sheet depends on the 'beat' period

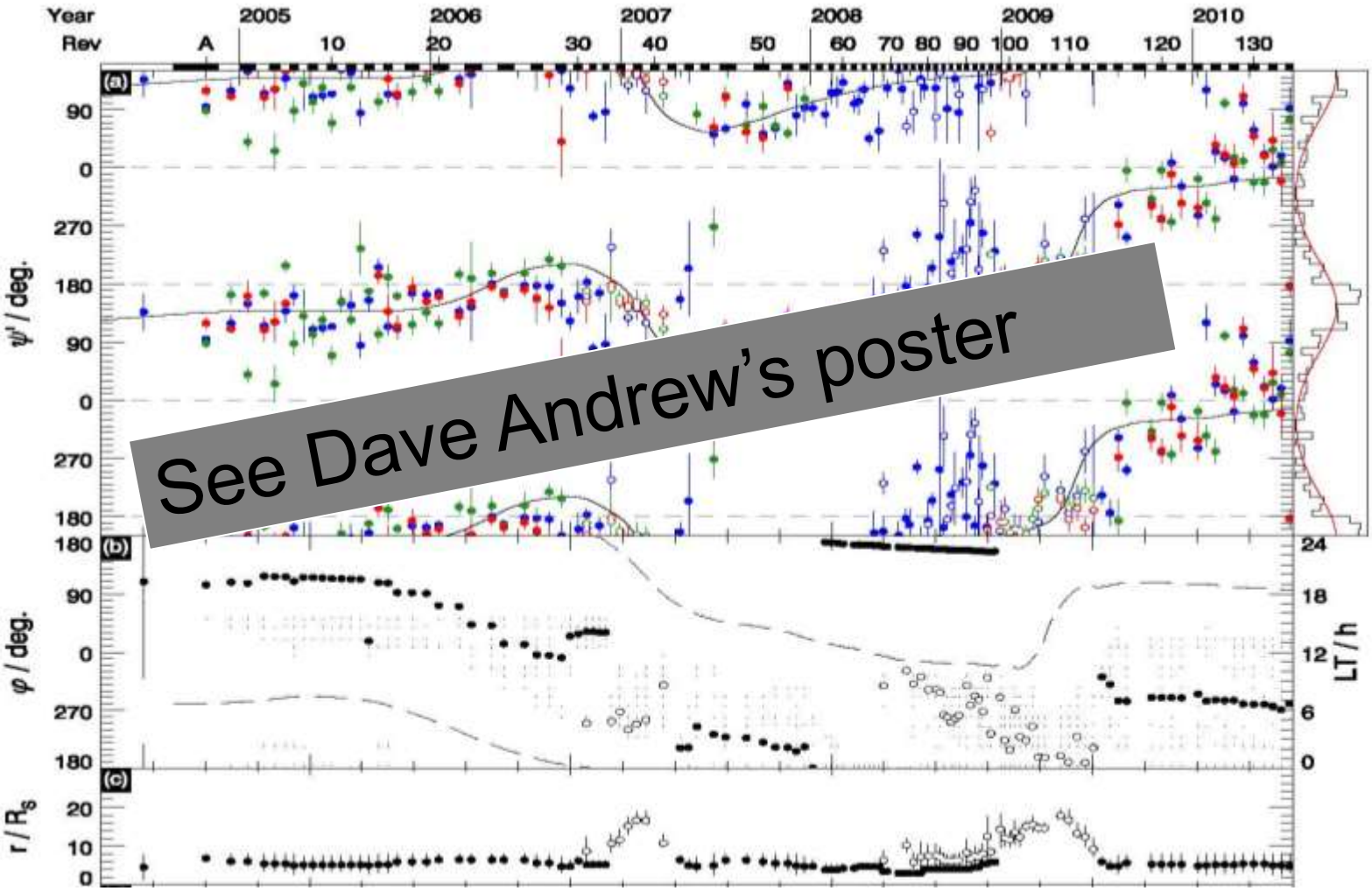


Quick summary of latest results from the Leicester group.....

Q. Is the period of the magnetic oscillations different from the SKR?



A. No – not if we assume a rotating source rather a 'strobe' , Andrews et al., 2011b

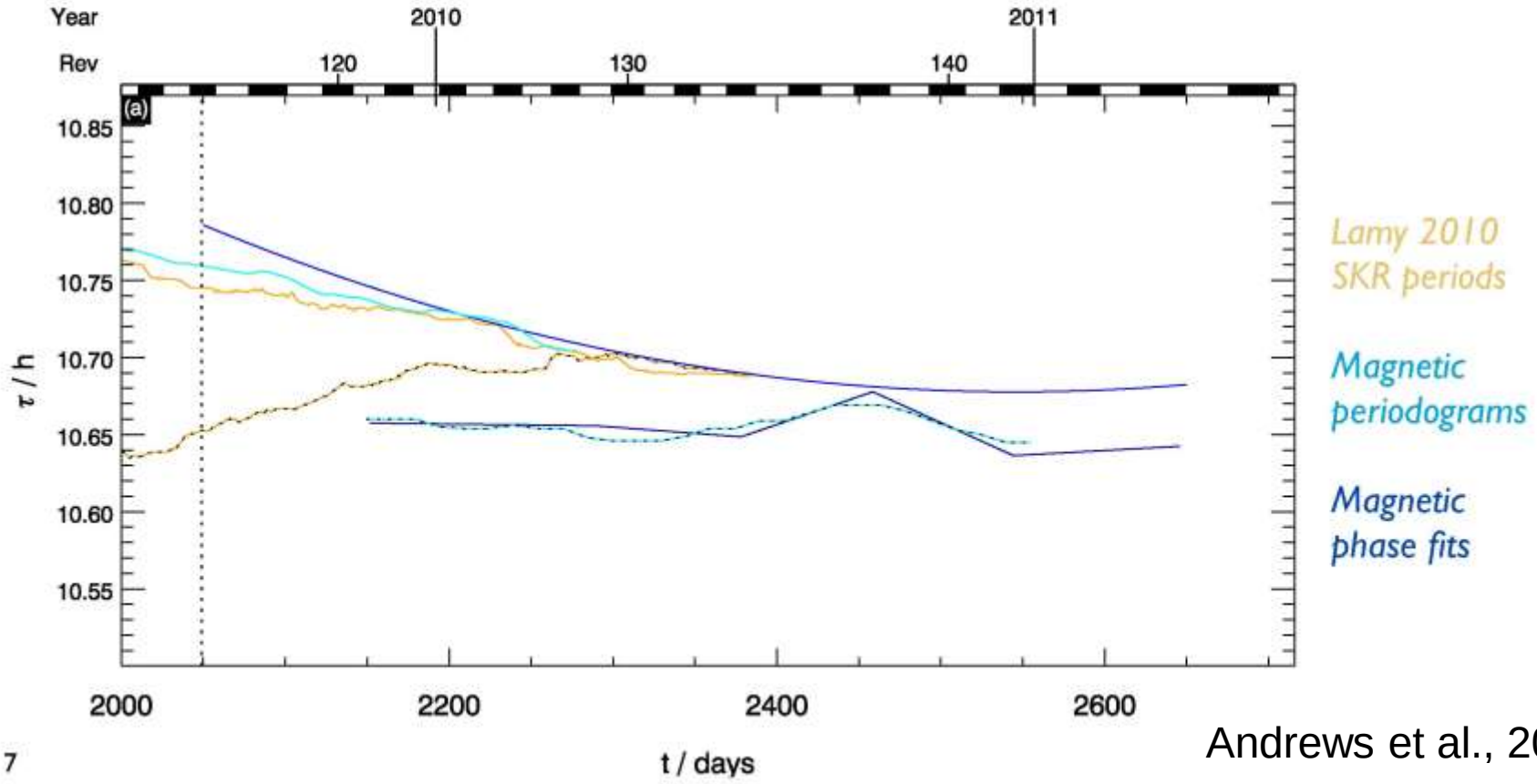


See Dave Andrew's poster

Comparison of magnetic and SKR periods

Andrews et al., 2011

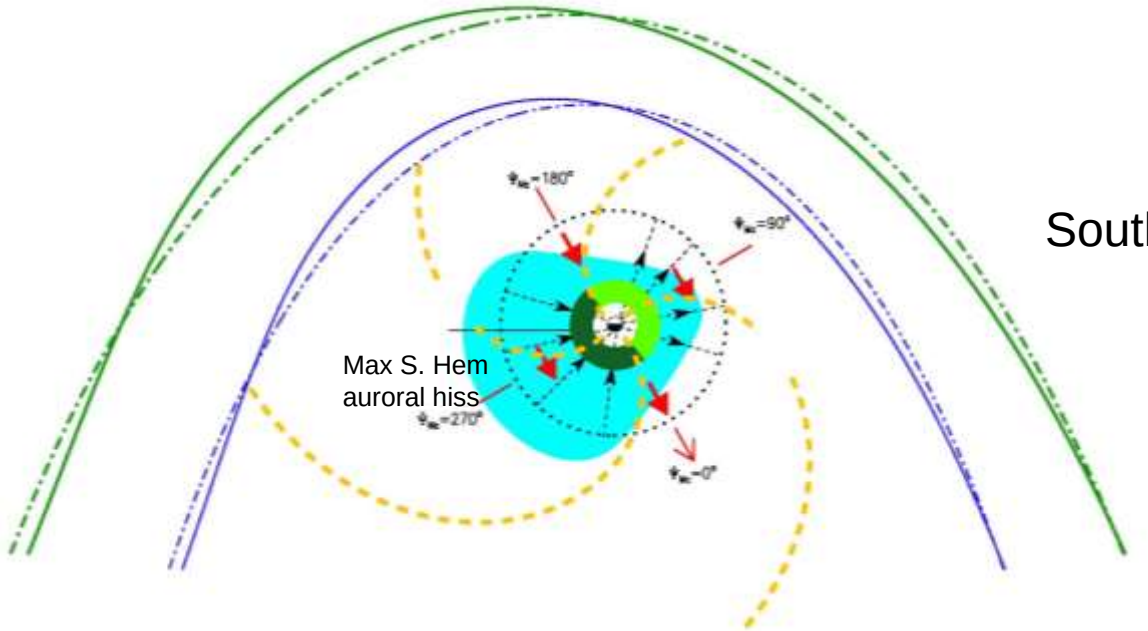
- Southern magnetic period(s) in agreement with southern SKR periods
- Not so with the northern magnetic periods
  - *Consistently shorter than the southern (no "crossing")*
  - *Suggestion of brief convergence ~200 days later than in the SKR (September 2010)*



Andrews et al., 2011b

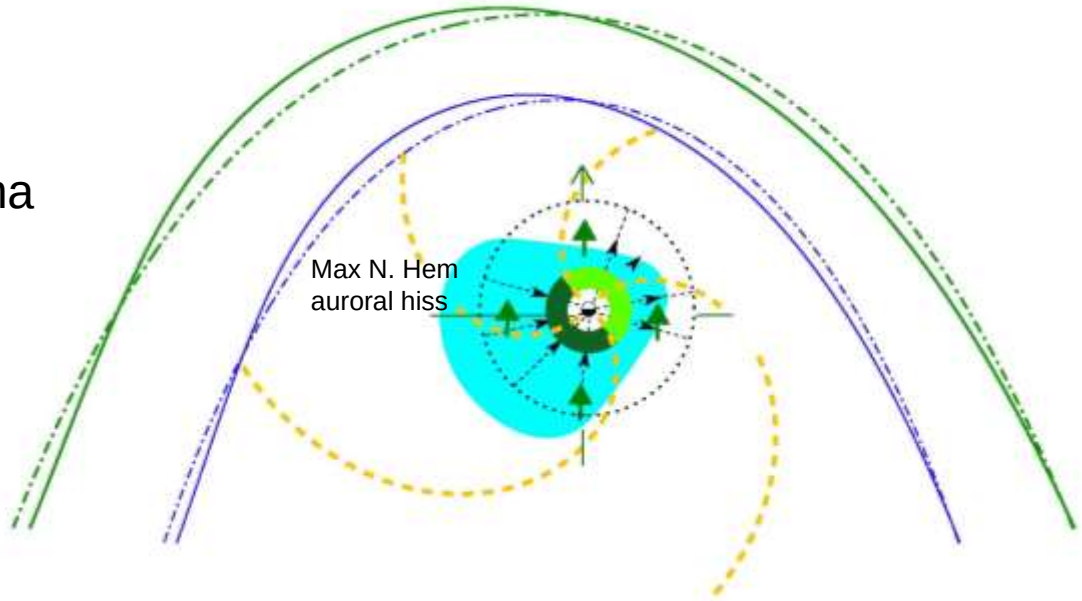
SUMMARY

- Planetary period oscillations are present throughout Saturn's magnetosphere.
- The magnetic field, currents and plasma effects appear to 'fit together'.
- The magnetic perturbations form 'loops' consistent with two transverse dipoles, one rotating at the Northern period and one at the Southern period.
- The joint magnetic moment of the background field and the perturbation field results in the tilting of the auroral oval, magnetic equator and plasma sheet.
- The two oscillatory systems suggest thickning and thinning of the plasmasheet.
- The SKR appears to rotate around Saturn.
- Magnetic field observation suggests the Northern and Southern periods have not 'crossed' – they do now have equal amplitude in the equatorial plane.

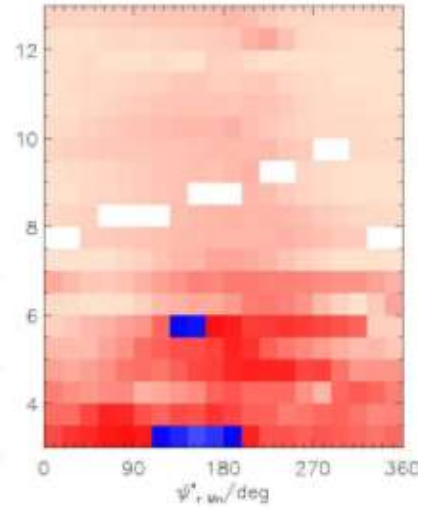


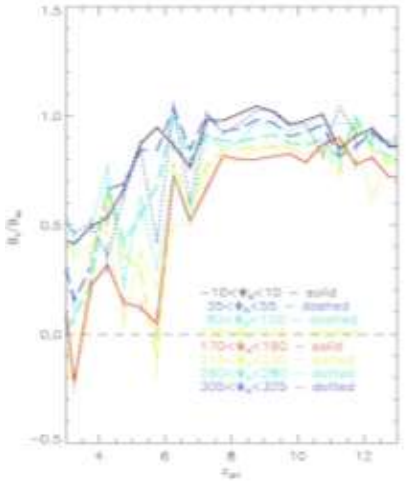
Southern SKR maxima

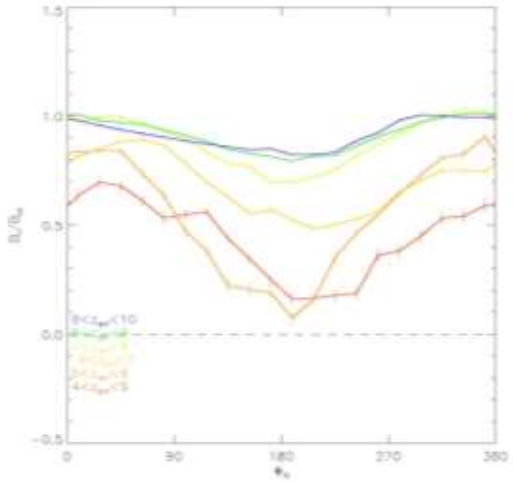
Northern SKR maxima

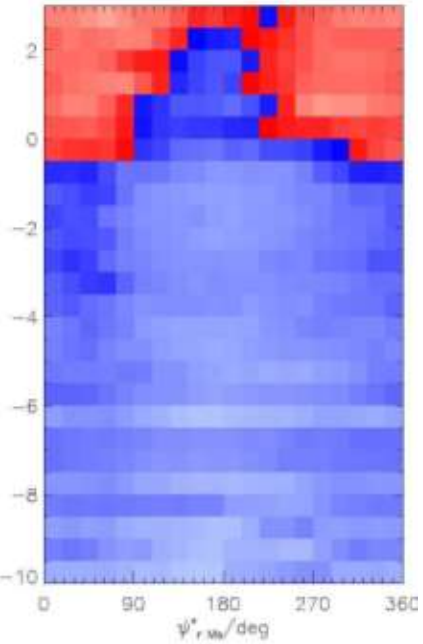


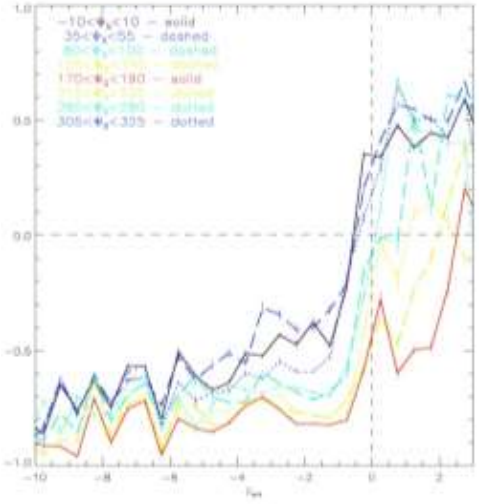
Saturn's planetary oscillations

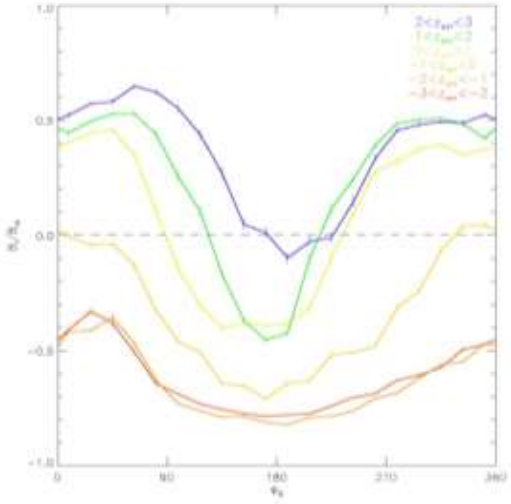


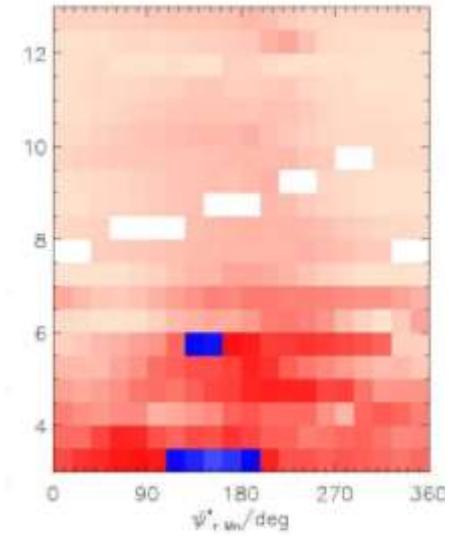


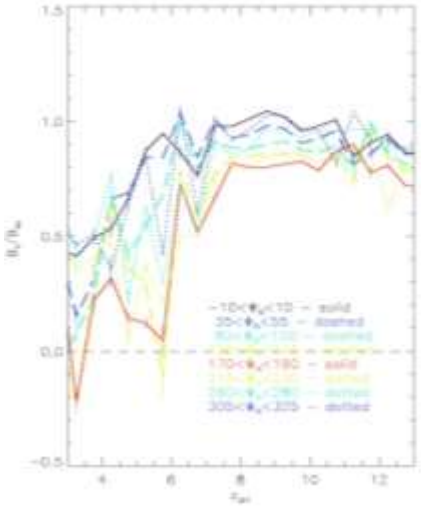


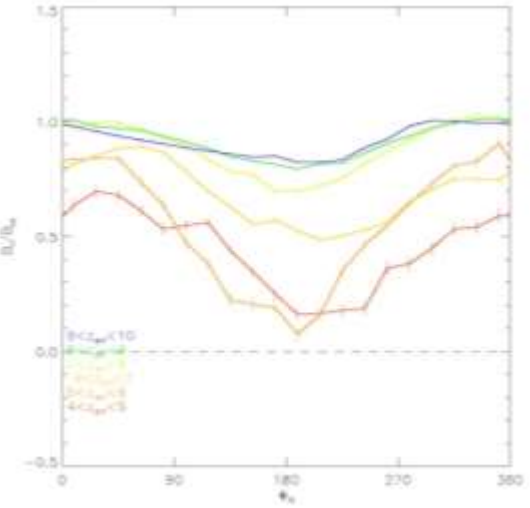







12
10
8
6
4
0
90
180
270
360


1.5
1.0
0.5
0.0
-0.5
4
6
8
10
12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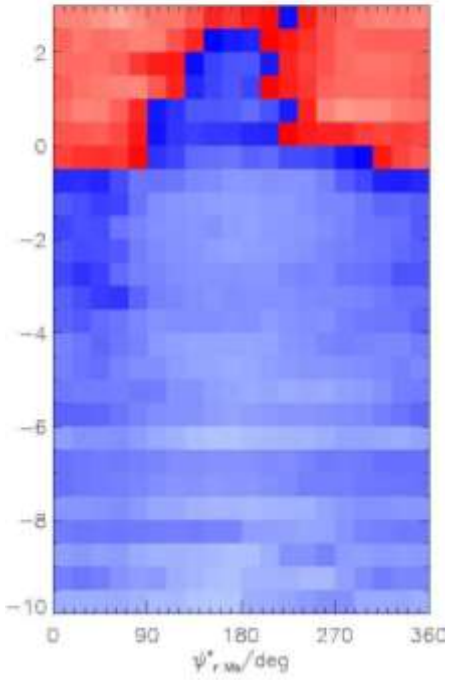
1.0
0.5
0.0
-0.5
0
90
180
270
360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-2
-4
-6
-8
-10
0
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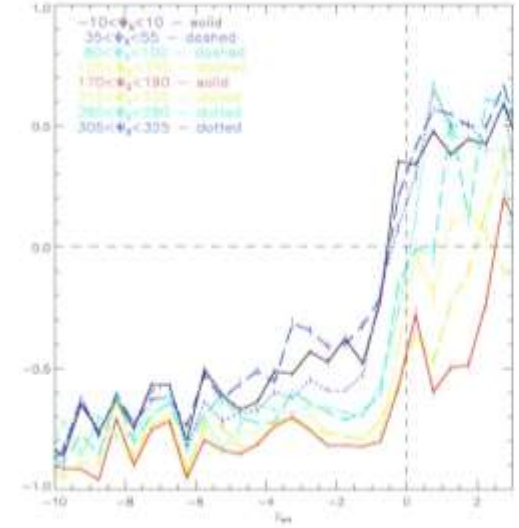
180
270
360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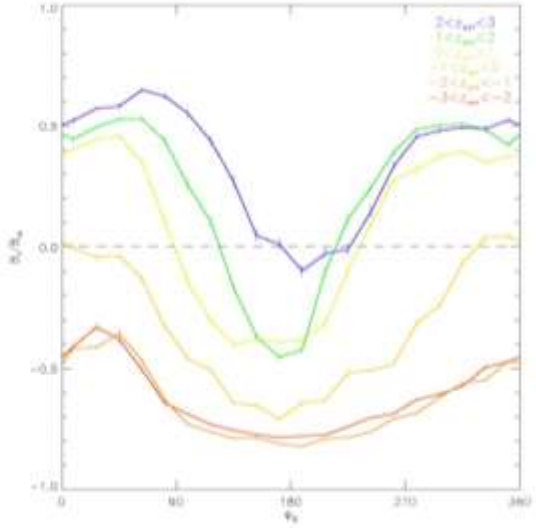
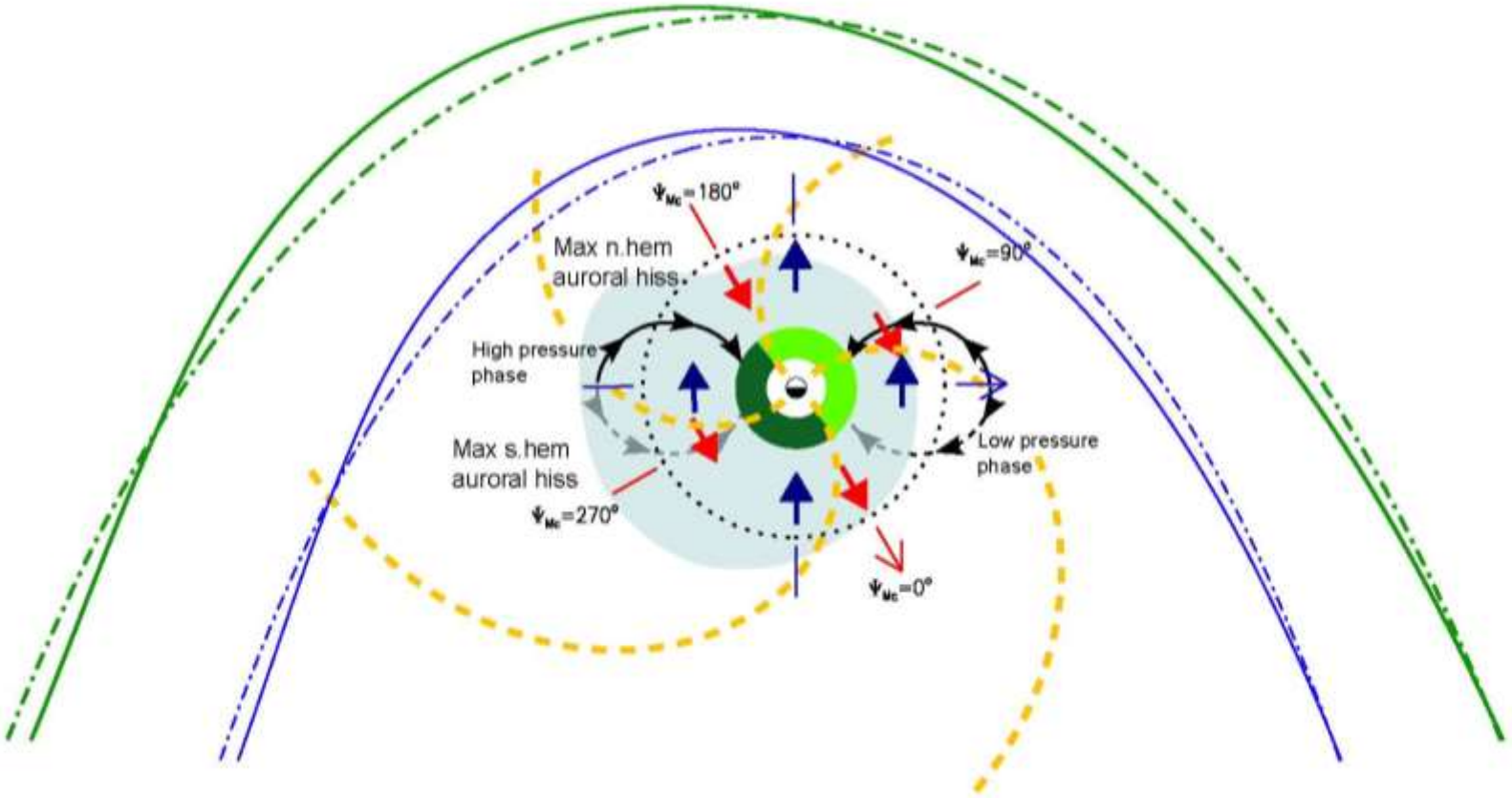
0.0
-0.5
-1.0
-10
-8
-6
-4
-2
0
2


1.0
0.5
0.0
-0.5
-1.0
0
90
180
270
360

Saturn's planetary oscillations



Provan et al., 2011

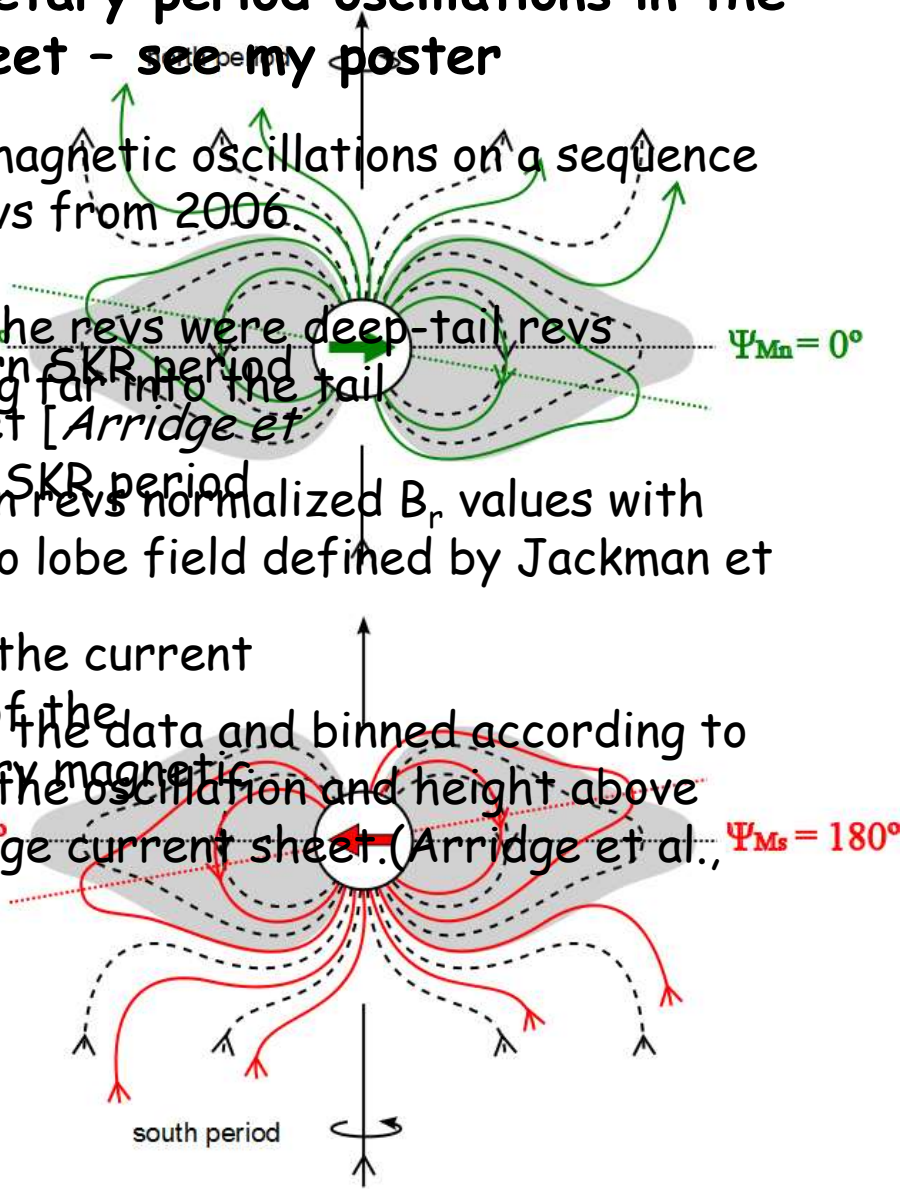
Dual planetary period oscillations in the Plasmasheet – see my poster

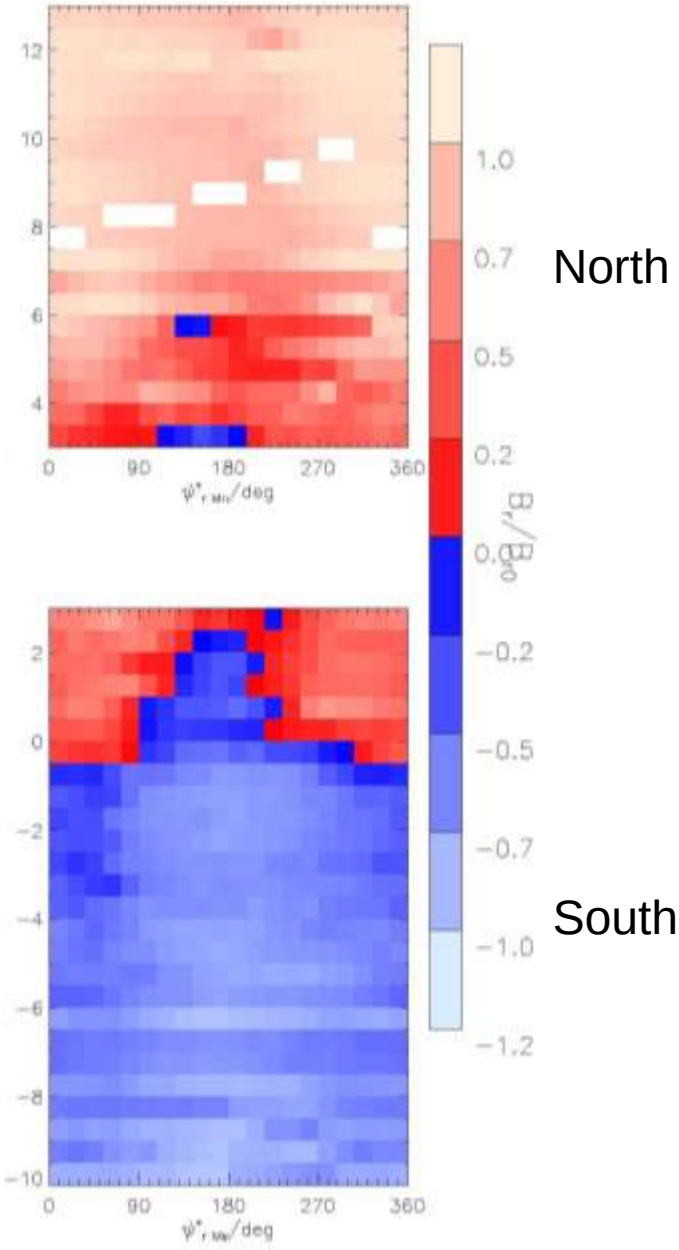
Studied magnetic oscillations on a sequence of ten revs from 2006.

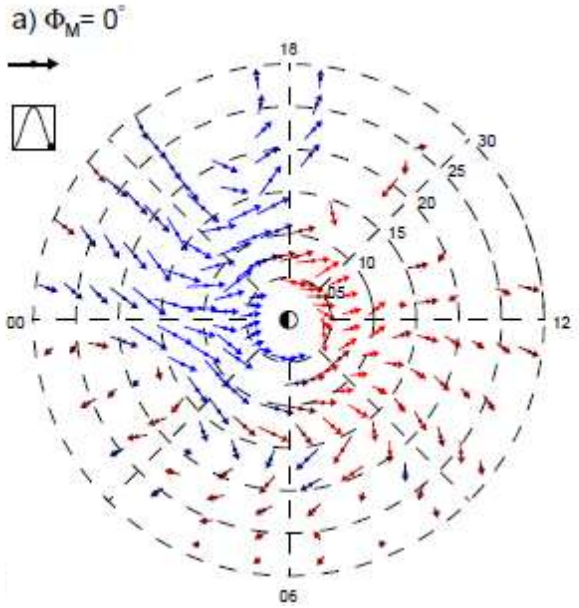
Most of the revs were deep-tail revs stretching far into the tail.

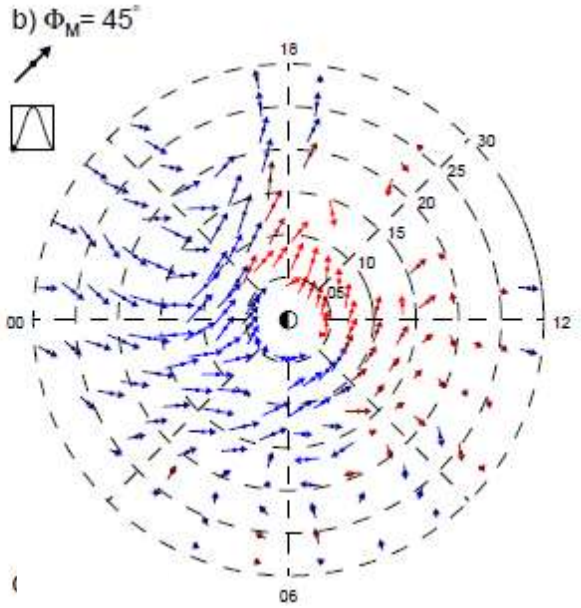
For all ten revs normalized B_r values with respect to lobe field defined by Jackman et al, 2011.

Averaged the data and binned according to phase of the oscillation and height above the Arridge current sheet (Arridge et al., 2008)

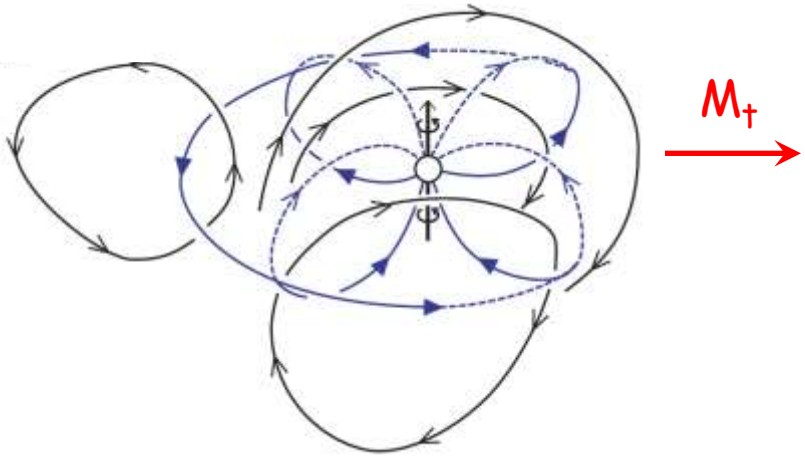




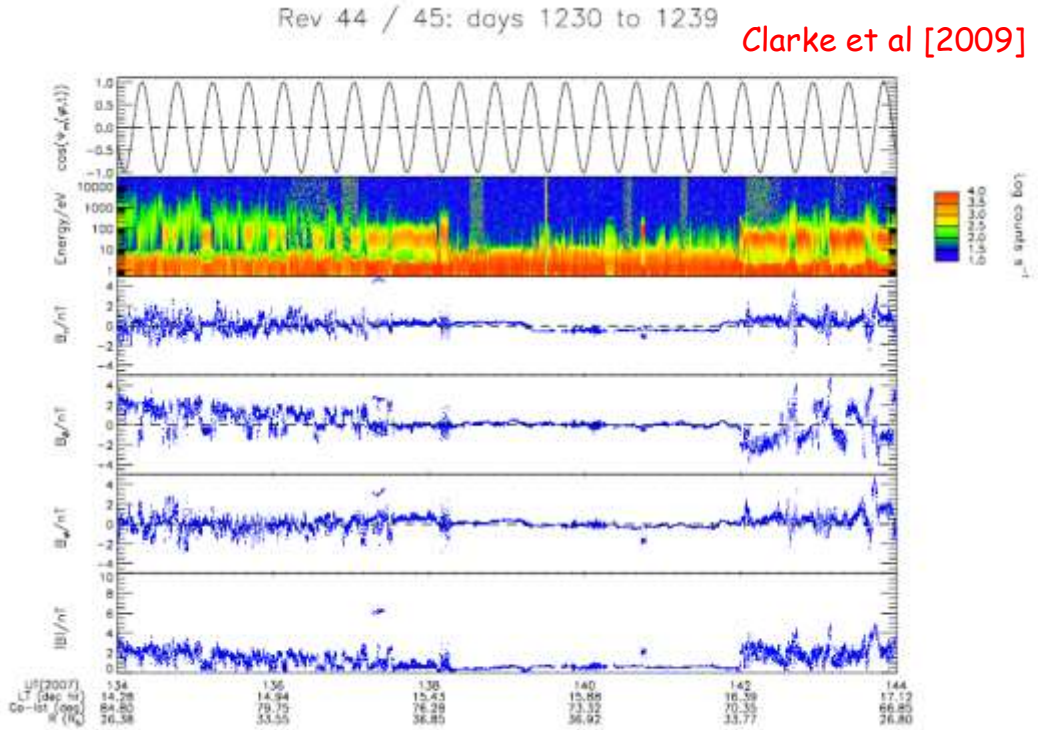




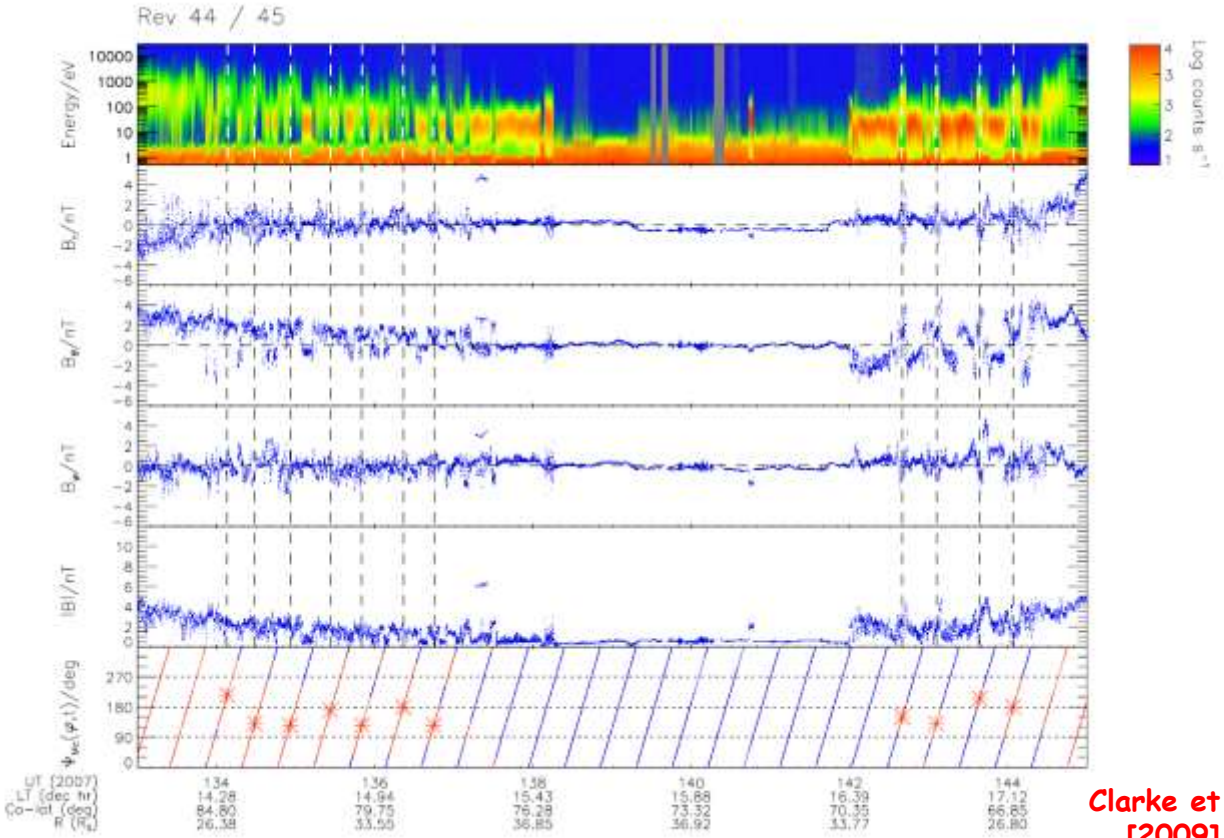
Andrews et al [2009]



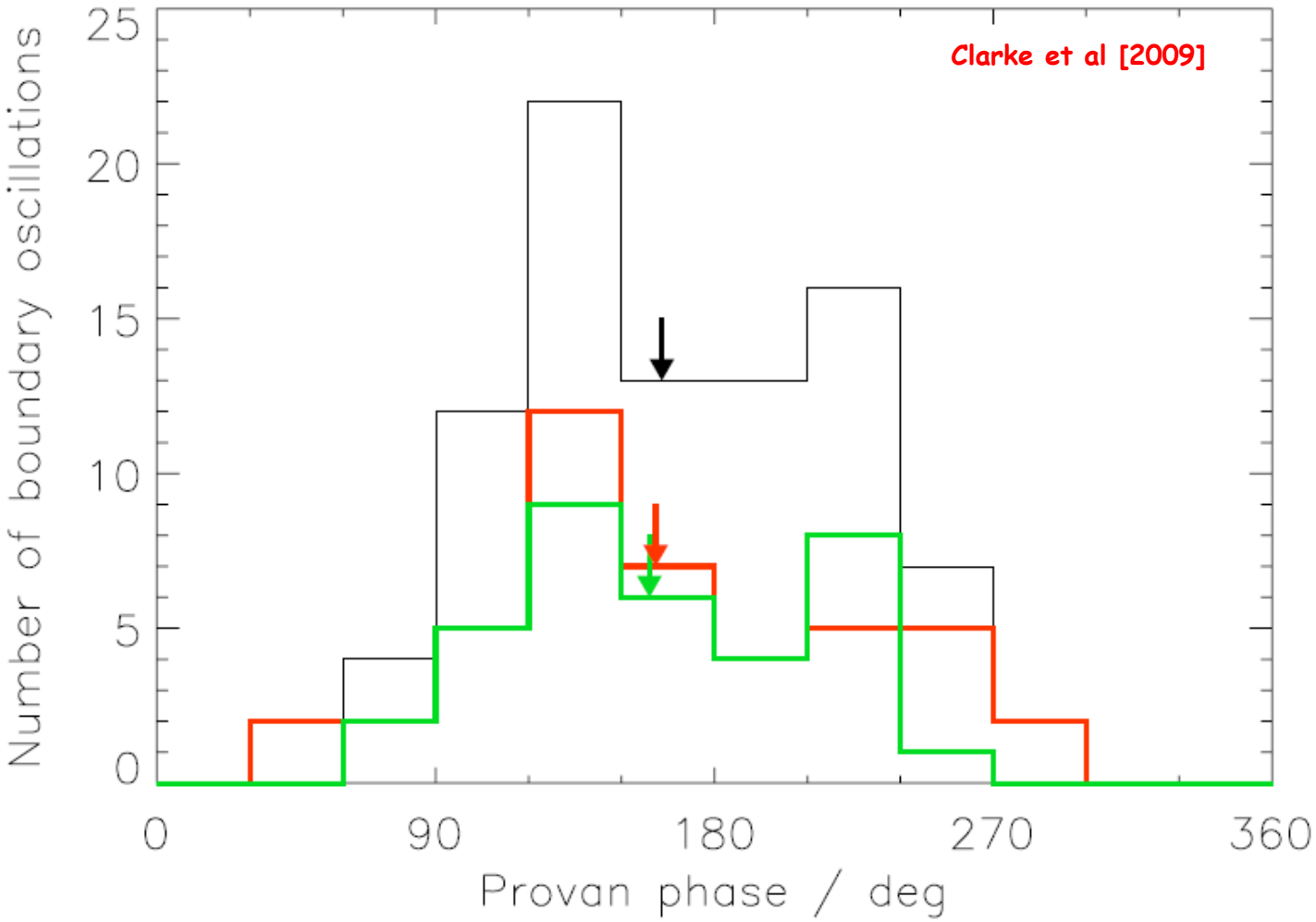
Provan et al [2009a]



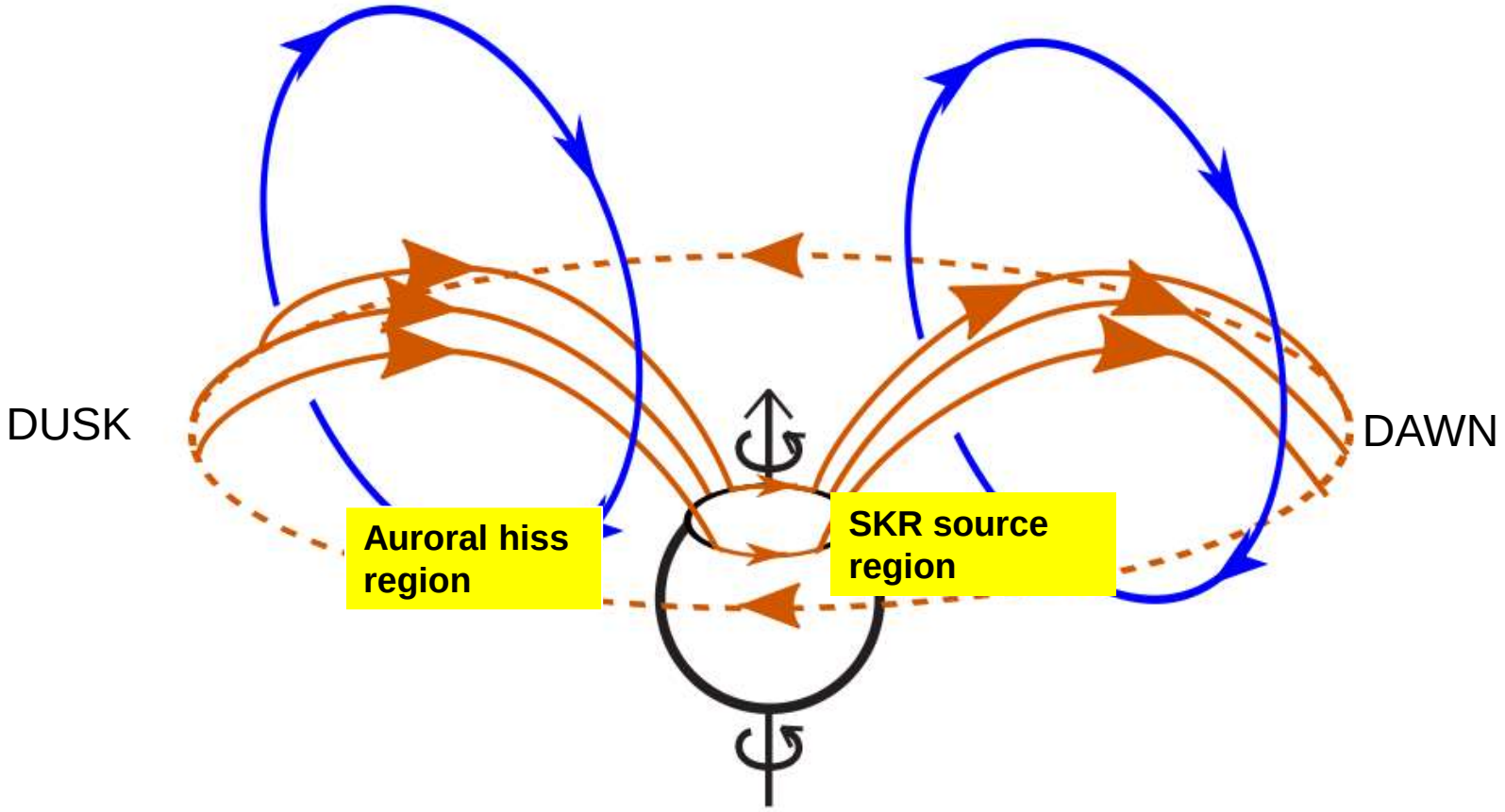
Clarke et al [2009]



Clarke et al [2009]

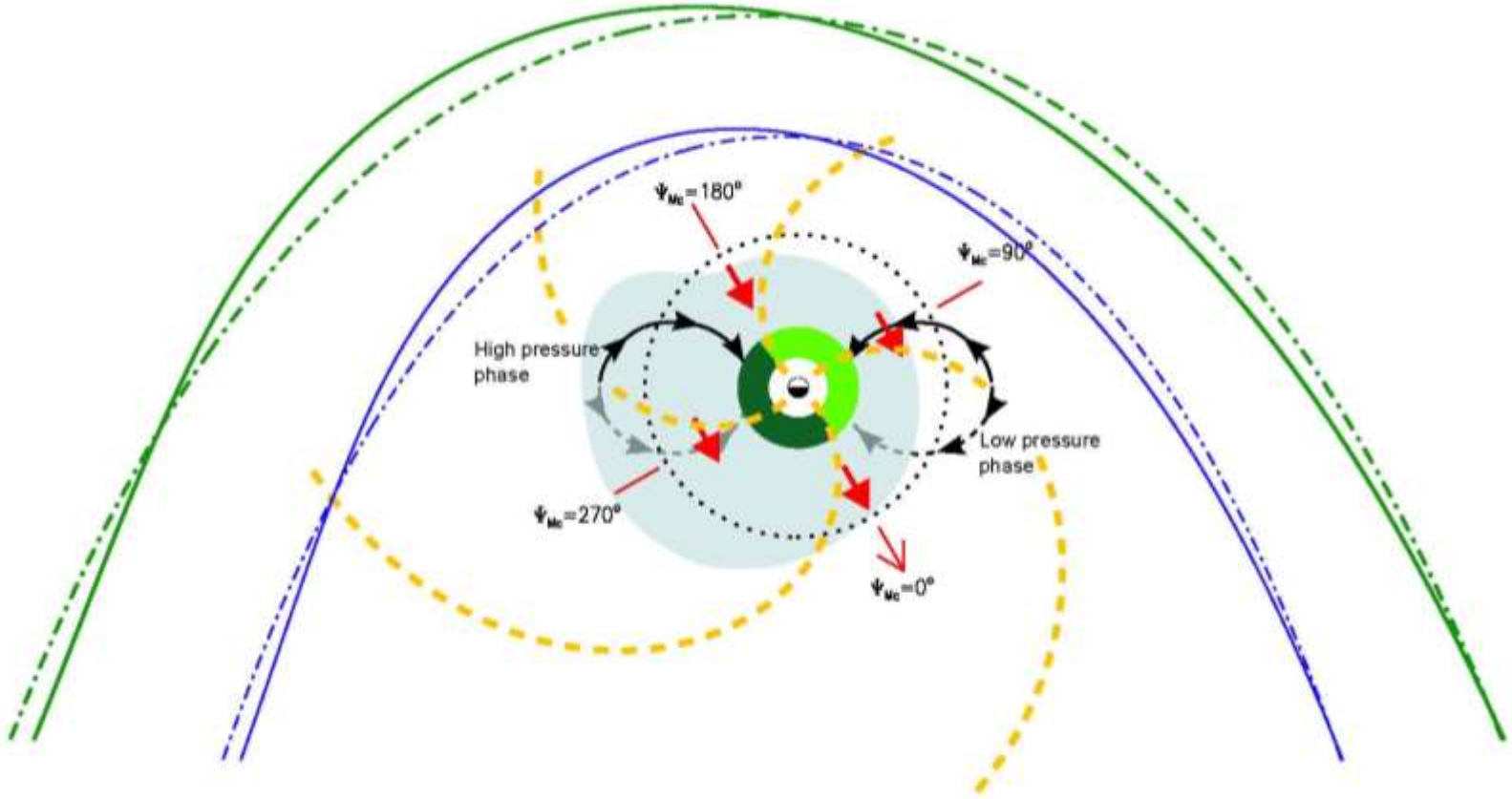

Clarke et al [2009]
Number of boundary oscillations
25
20
15
10
5
0
0
90
180
270
360
Provan phase / deg

Northern hemisphere at Northern SKR maxima



At Northern hemisphere SKR maximum downward FAC is the dusk sector,
– opposite to the principal source of the SKR.
Gurnett et al., 2009, that at Northern hemisphere SKR maximum peak auroral hiss is observd in the dusk sector

Saturn's planetary oscillations



Shows oscillatory phenomena at one particular instant of oscillation phase – actually SKR maximum

Clarke et al [2010b]

Equatorial 'cam' field points down-tail and towards dawn

Enceladus plasma torus density max is just past dusk, also the Burch et al [2009] 'plasma cam'

MP and bow shock bulges out on the afternoon side and is depressed inward at dawn

Oscillation phase spiral connects the MP and BS bulge, the plasma cam, and the torus density maximum