The Ring Current of Saturn

Nick Sergis

Office of Space Research, Academy of Athens

Cassini/MIMI, MAG and CAPS colleagues

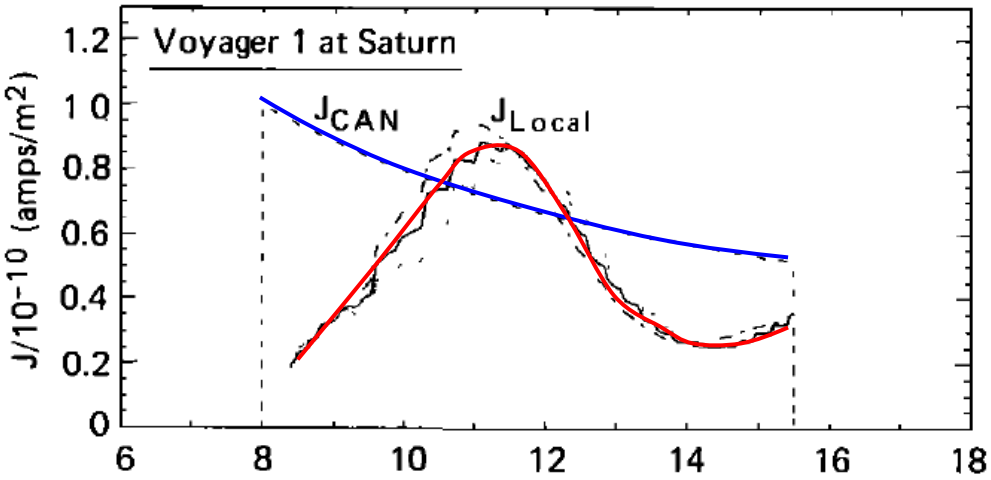
with special acknowledgements to C.M. Jackman, D.G. Mitchell, D.C. Hamilton, N. Krupp, S.M. Krimigis, and M.K. Dougherty.

2011 MOP meeting, Boston, MA, USA, July 11-15, 2011

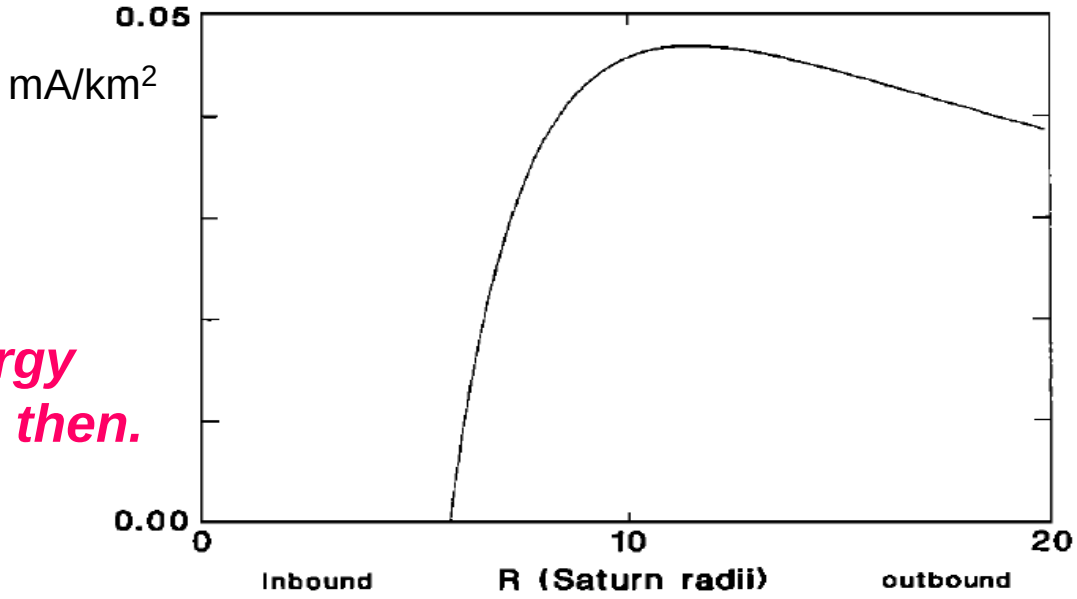
Since the early 1980ies, several studies have attempted to derive the radial profile of the current density in the Saturnian magnetosphere:

Connerney et al., 1983
magnetic field data
(Voyager I and II)

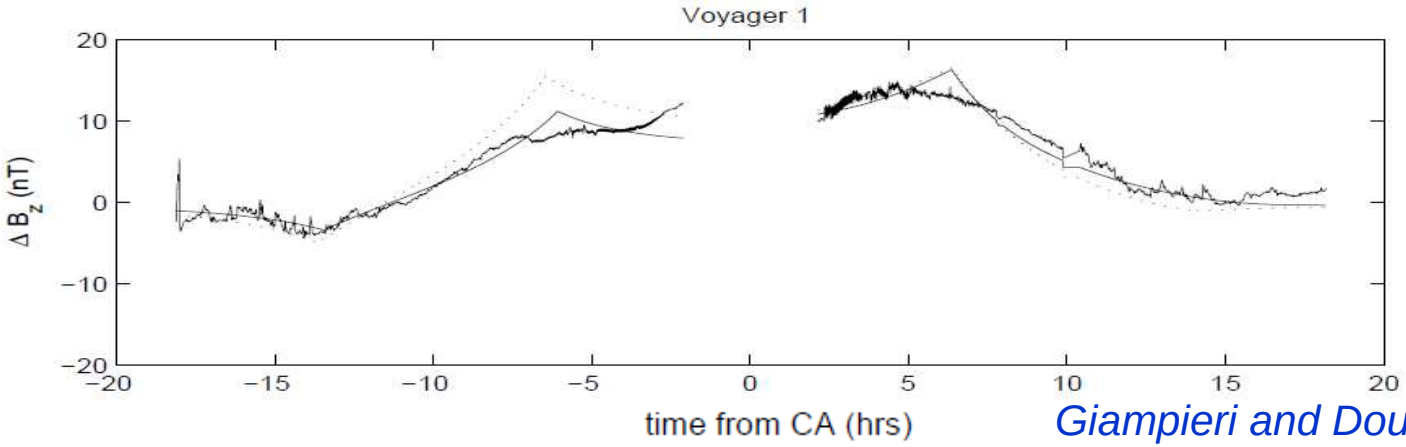
Mauk et al., 1985
magnetic field and
energetic particle data
(Voyager I and II)



Beard and Gast, 1987
magnetic field data
(Pioneer 11, Voyager I and II)



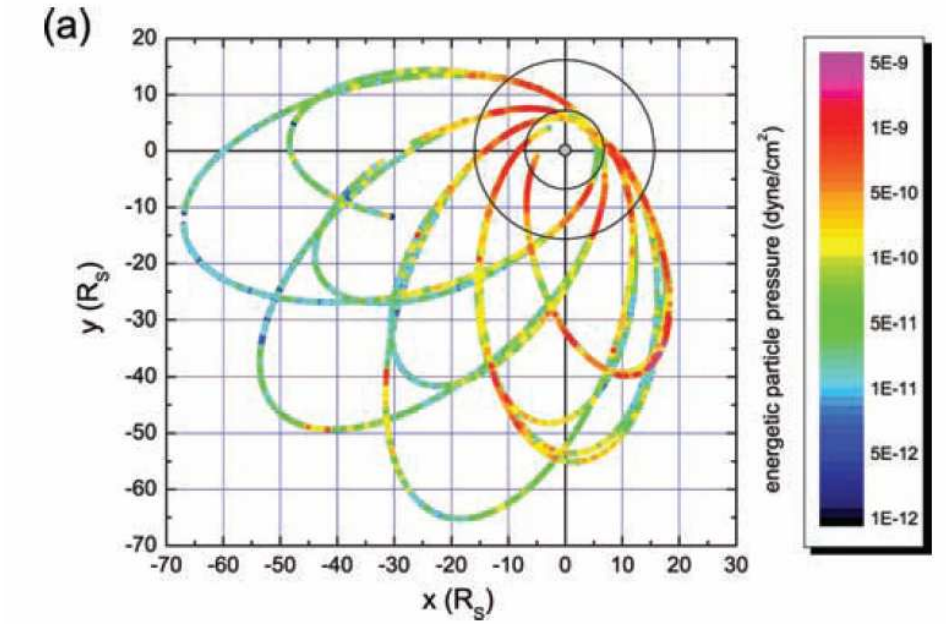
However, the full particle energy distribution was not available then.



Giampieri and Dougherty, AnGeo, 2004

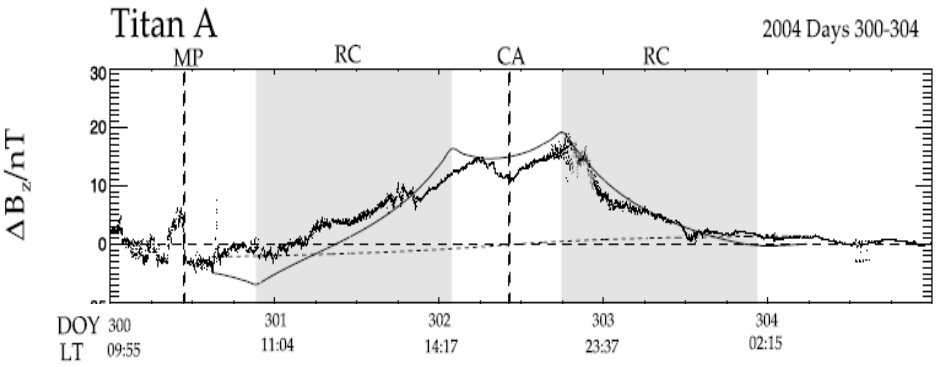
Giampieri and Dougherty used a Connerney-like model to fit Pioneer 11 and Voyager 1 and 2 magnetic field data. An axisymmetric current sheet model is inadequate for describing the Saturnian ring current (local time and temporal variation not compatible with the assumption of an axisymmetric disk). **Then Cassini got there…**

2004-2006 Cassini equatorial coverage



Notice that the noon-to-dusk sector is missing…

Sergis et al., 2009

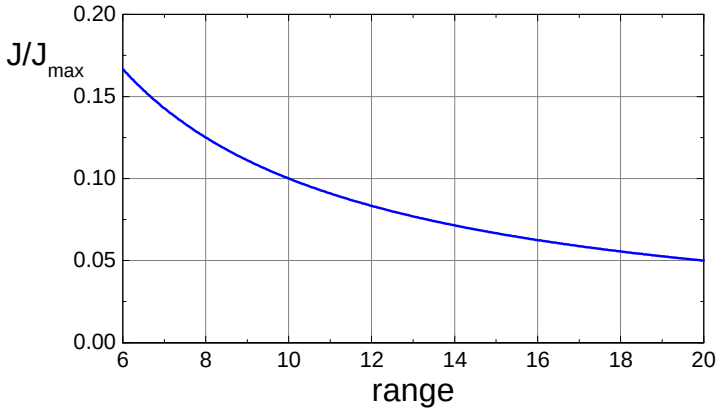


Inner radius (6.5 R_S)

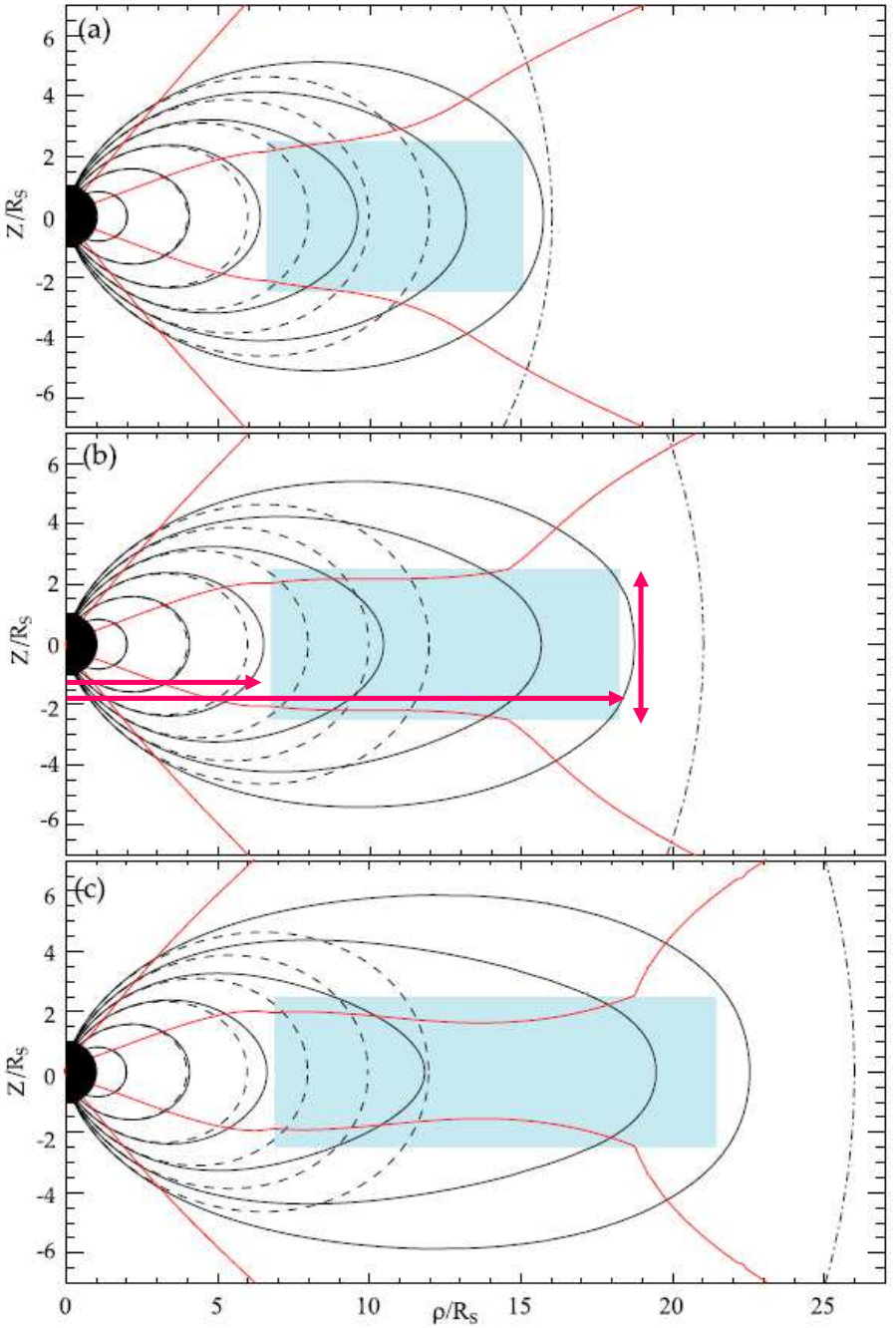
Outer radius (15 R_S to 21 R_S)

Thickness (5 R_S)

J_{phi}~1/ρ



As was later shown, when particle data were also included in the analysis, this assumption proved incorrect. J_{phi} drops with radial distance faster than 1/r.



Bunce et al., JGR, 2008

Average ring current density

Sergis et al., GRL, 2010

The radial, steady-state, force balance equation can be solved for the azimuthal current density:

$$J_\phi \approx \frac{1}{B_z}\left(\rho\frac{V_\phi^2}{r} - \frac{\partial P}{\partial r} - \frac{P_\perp}{R_C}\left(\frac{A-1}{A}\right)\right) \qquad \left(A = \frac{P_\perp}{P_{//}}\right)$$

inertial contribution

pressure gradient

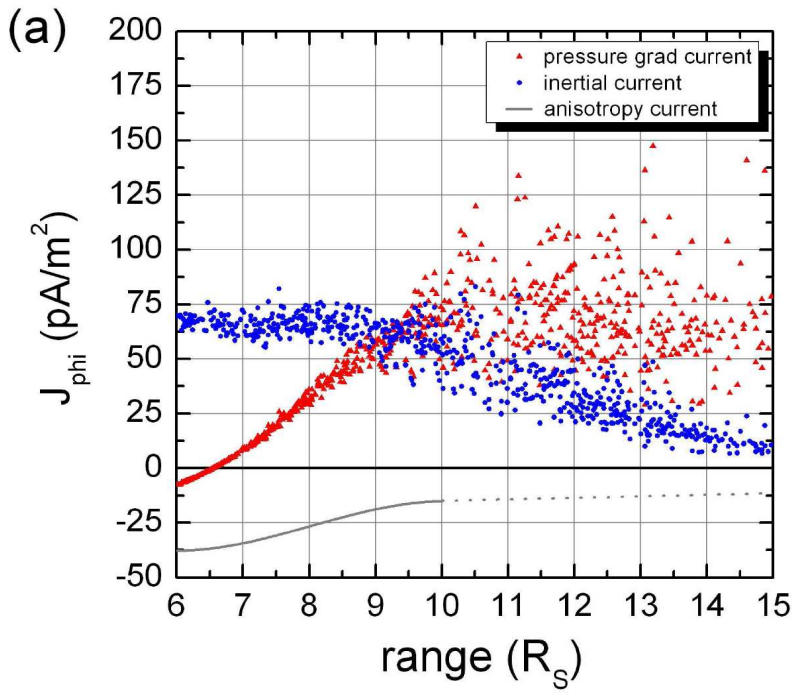
anisotropy

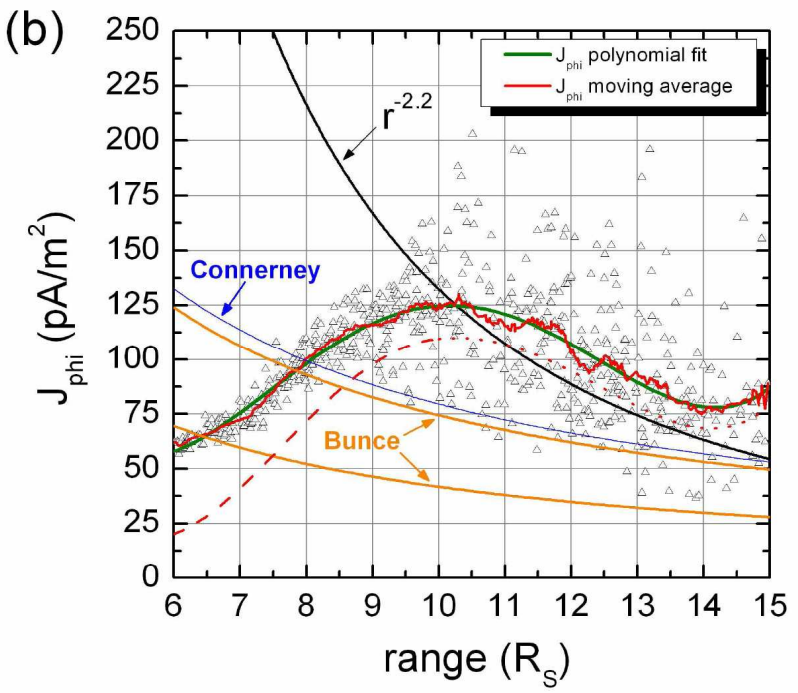
inertial inside 9 R_S

pressure gradient driven beyond 10 R_S

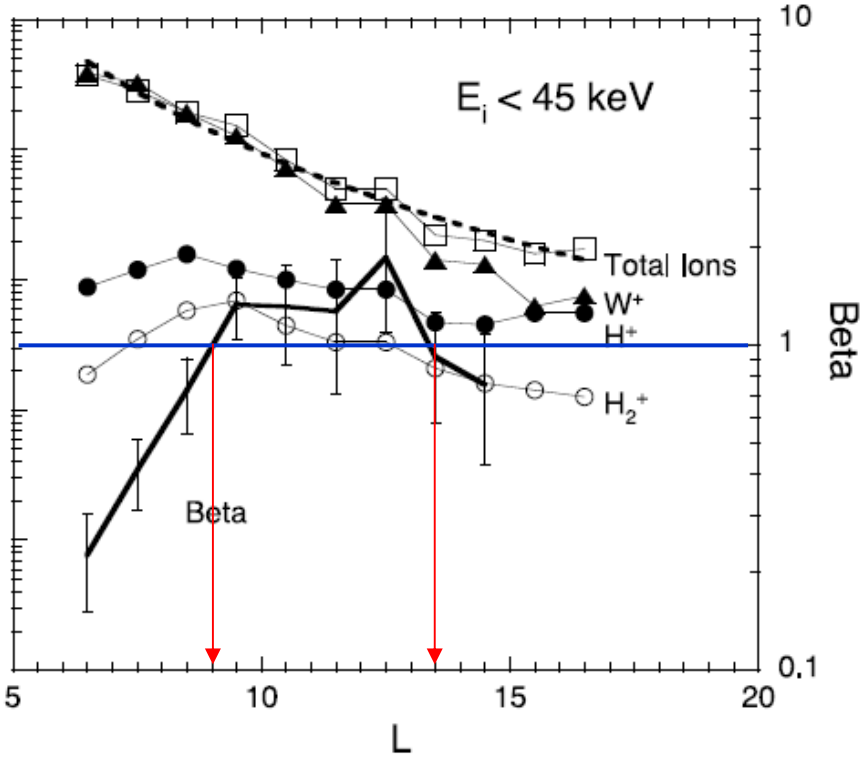
Jφ has a maximum

and drops outwards faster than 1/r

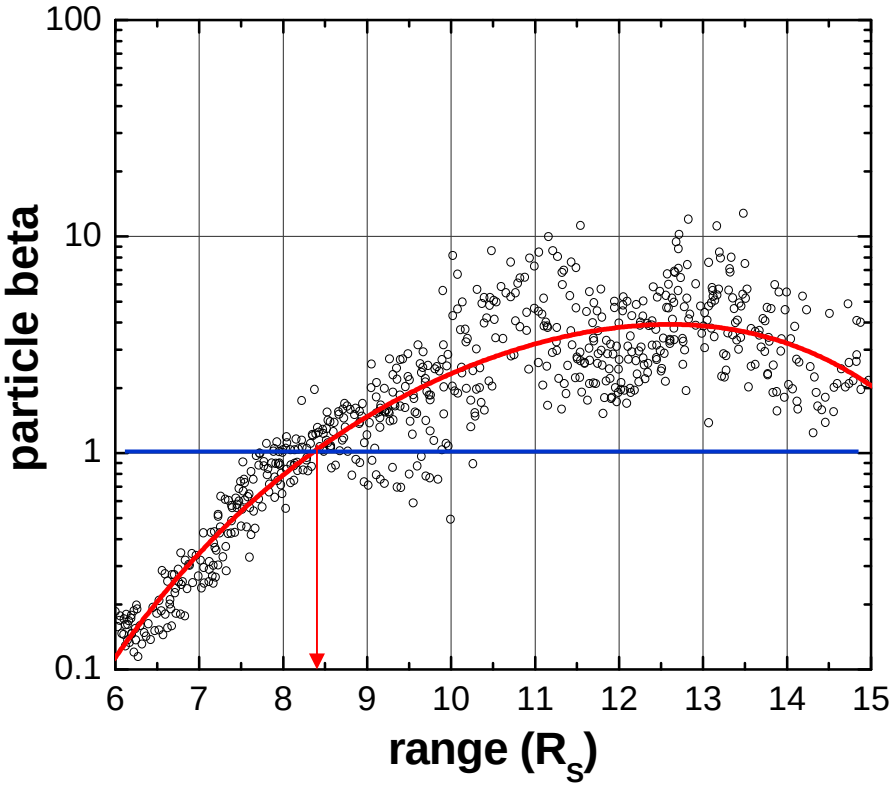




Plasma β in the Saturnian magnetosphere



Thomsen et al., JGR, 2010.
E<45 keV particle pressure.

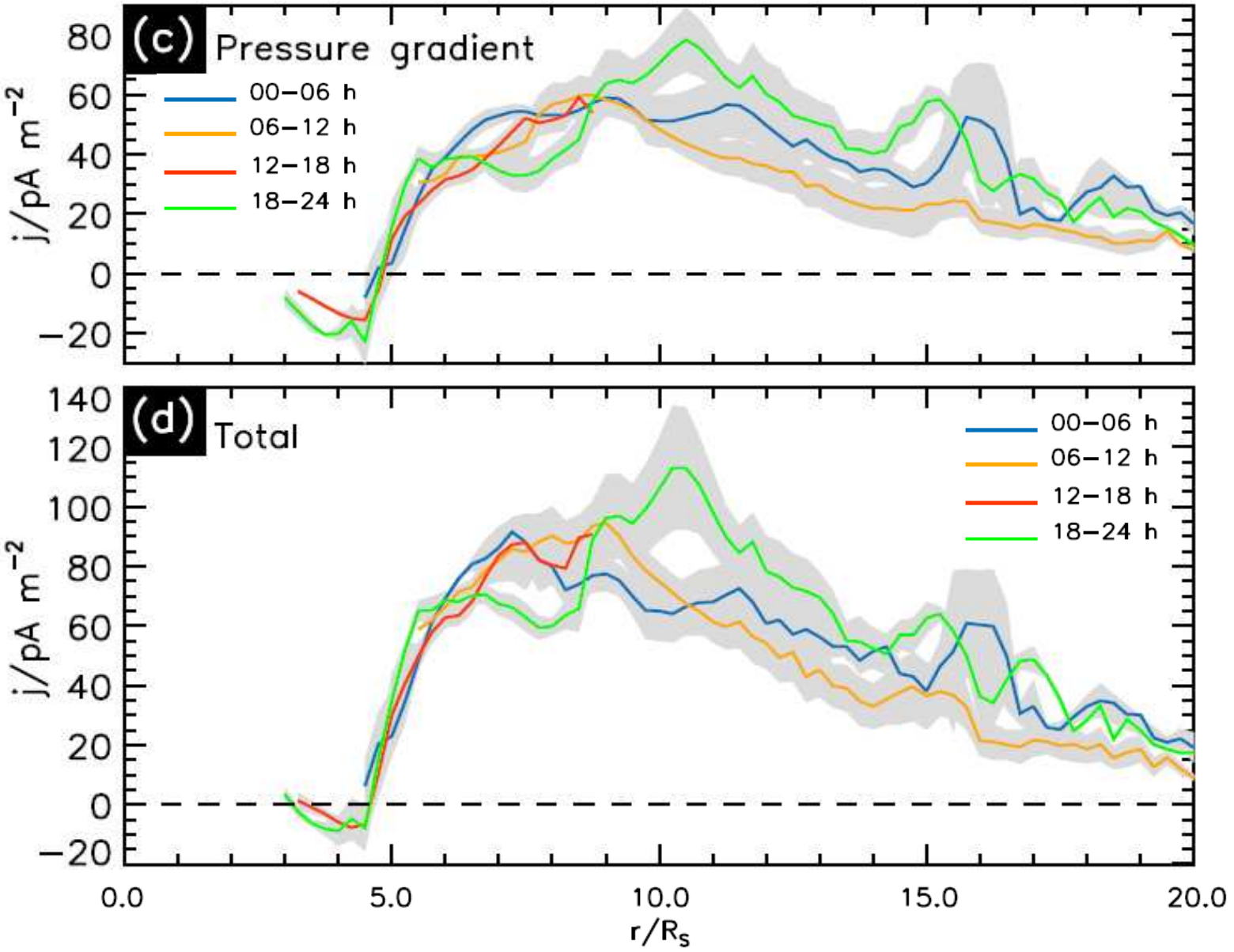


Equatorial orbits 2004-2006,
total (CAPS+MIMI) particle pressure.

Saturn possesses a high-β magnetosphere with β>1 outside 8 R_S, reaching an (average) maximum of 2-10 near 11 to 14 R_S.

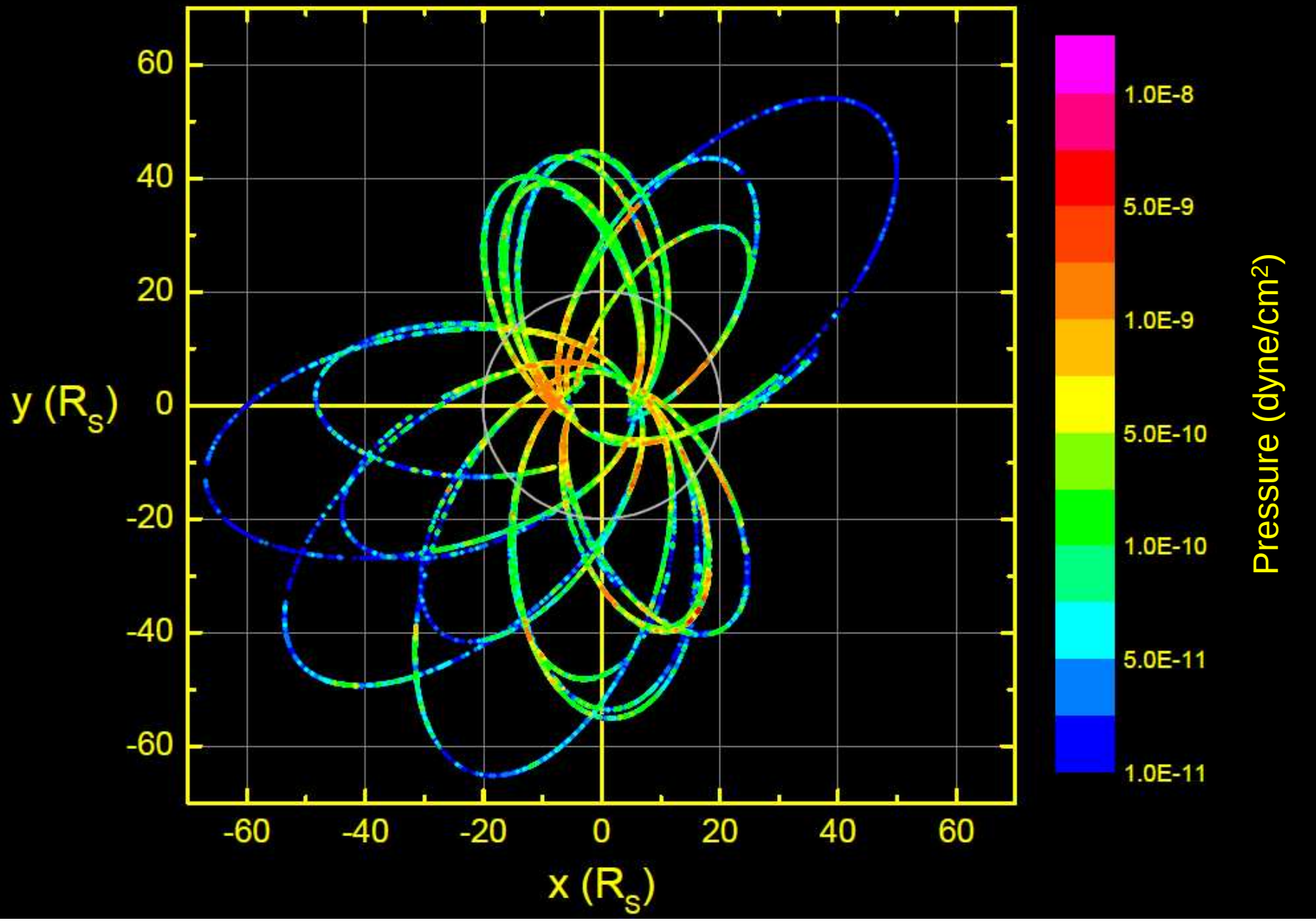
High-β values (~ 1) are maintained up to the dayside magnetopause

***Kellett at al.*, 2011** analyzed the magnetic field and plasma data (2004-2006) per Local Time sector and found higher (x2) current densities in the nightside.
Still, noon-to-dust is missing…



2004-2011 Cassini equatorial coverage and suprathermal pressure map.

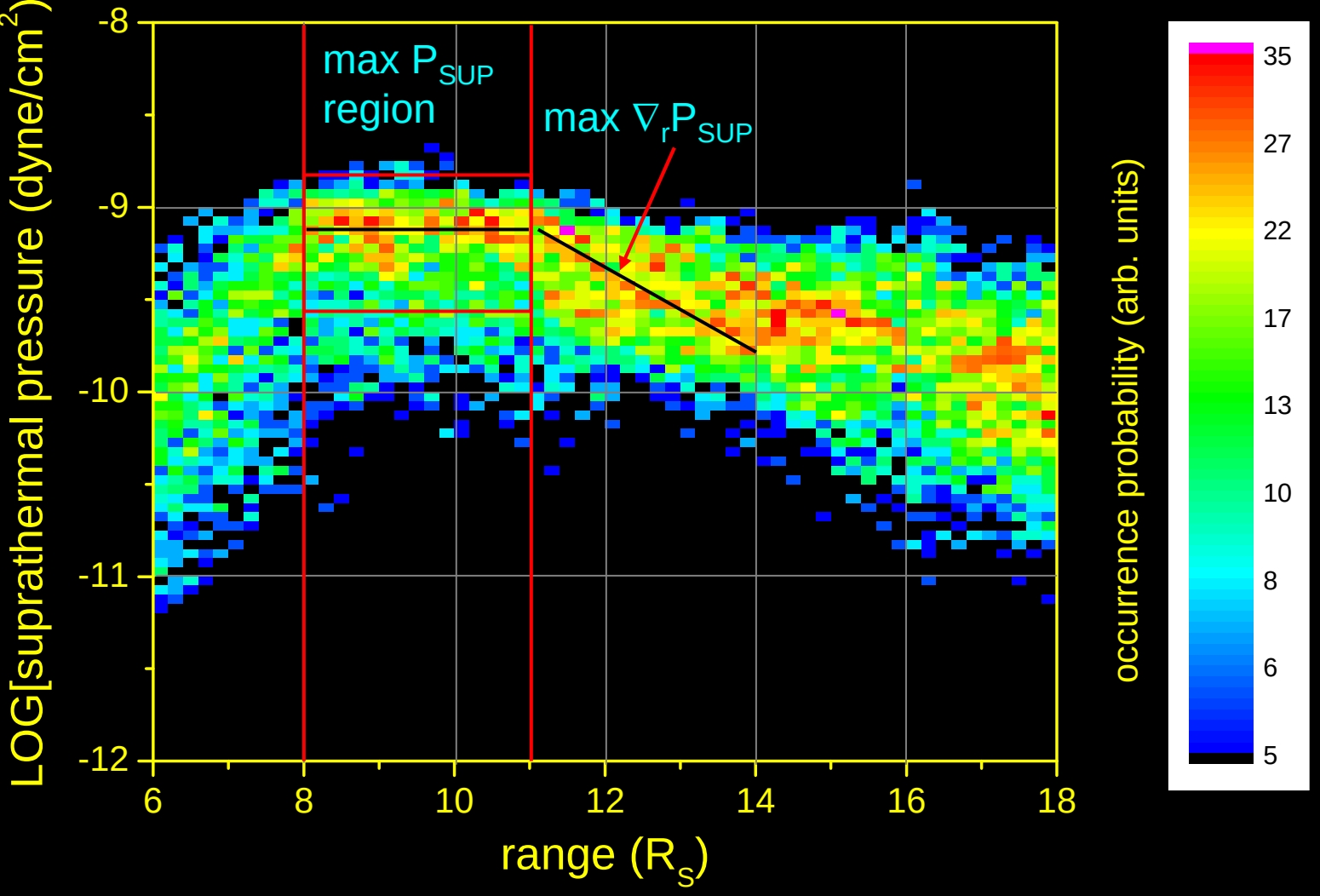
All local times are now covered (but with a 7-year span…)



2004-2011, full MIMI data set (E>3 keV)

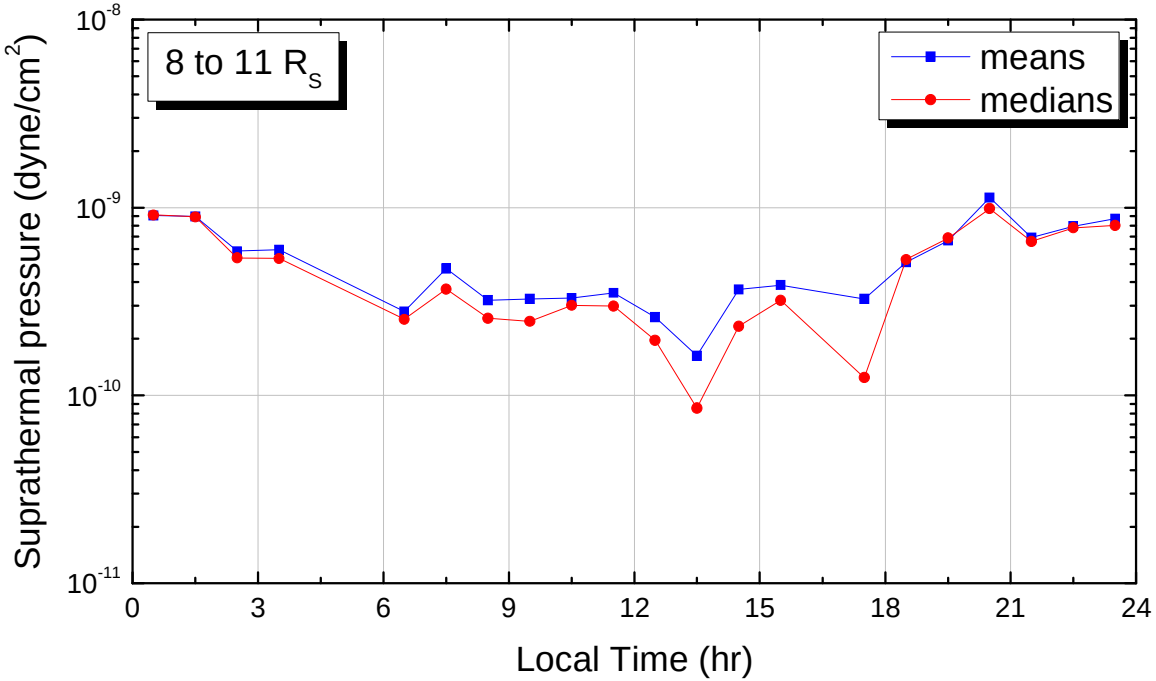
NEW RESULTS!

Occurrence probability map for the equatorial suprathermal plasma pressure in the Saturnian magnetosphere from Cassini/MIMI, all local times, July 2004-April 2011.

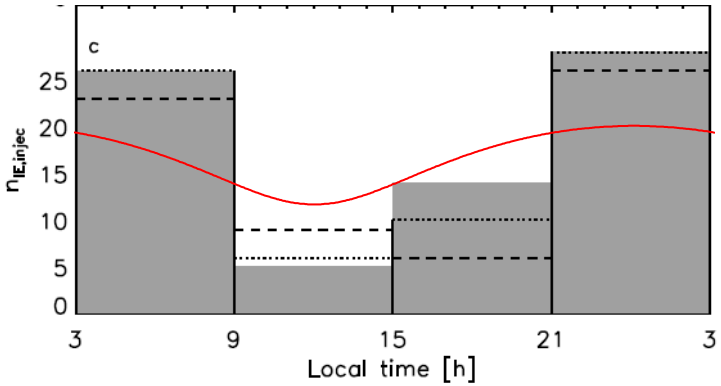


We now look at the local time variation of the maximum suprathermal pressure (plateau between 8 and 11 R_S)

Clear local time variation, perfectly noon-to-midnight symmetric, with nightside (max) pressure being higher by a factor of ~4.

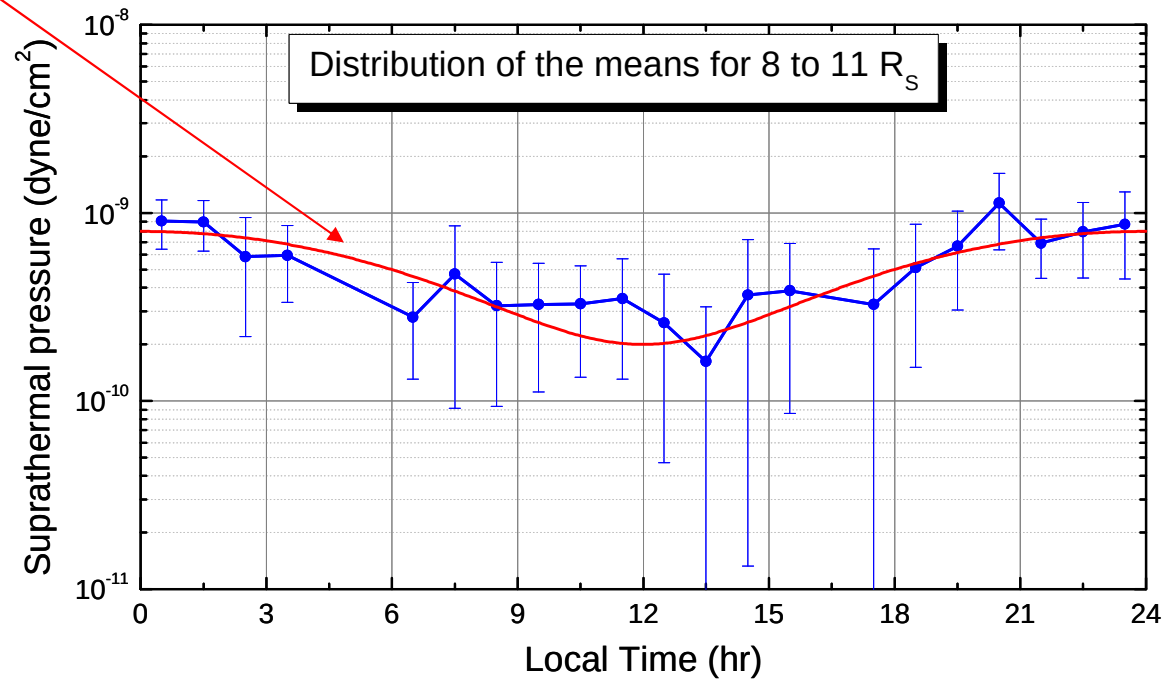


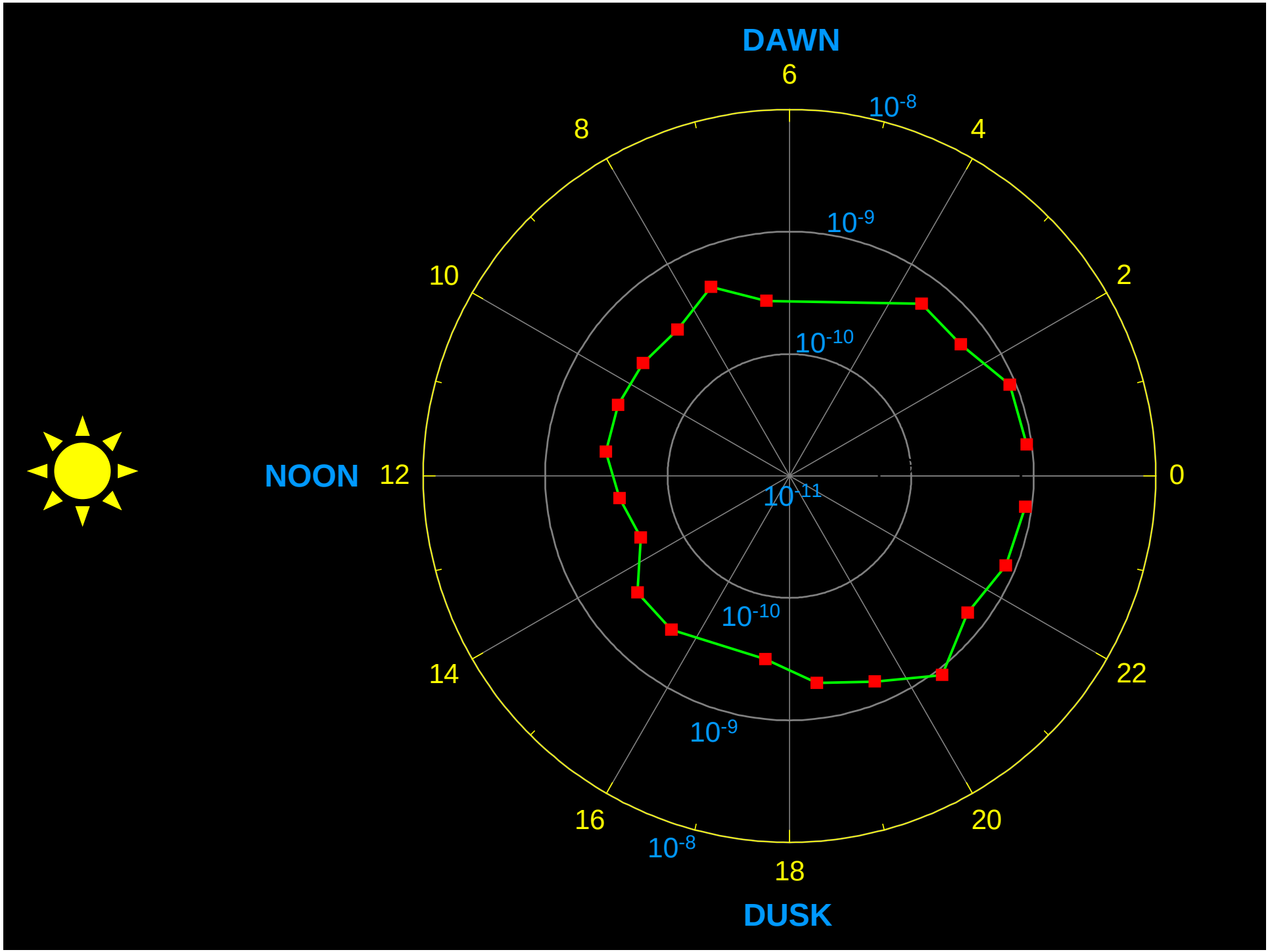
$5\times10^{-10} + 3\times10^{-10}\cos(0.262\times LT)$



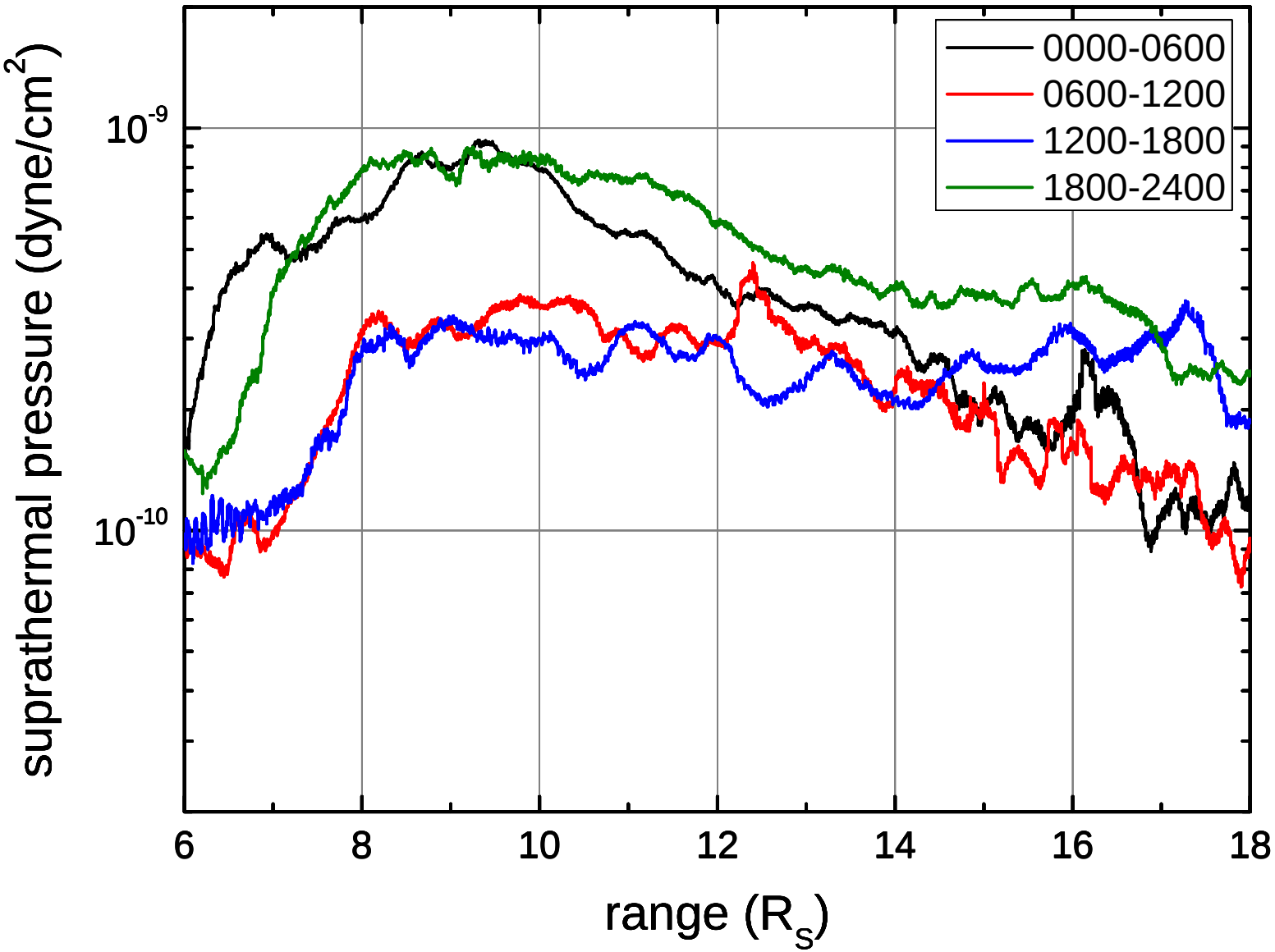
Weighted distribution of the energetic particle injections in local time.

Mueller et al., JGR, 2010

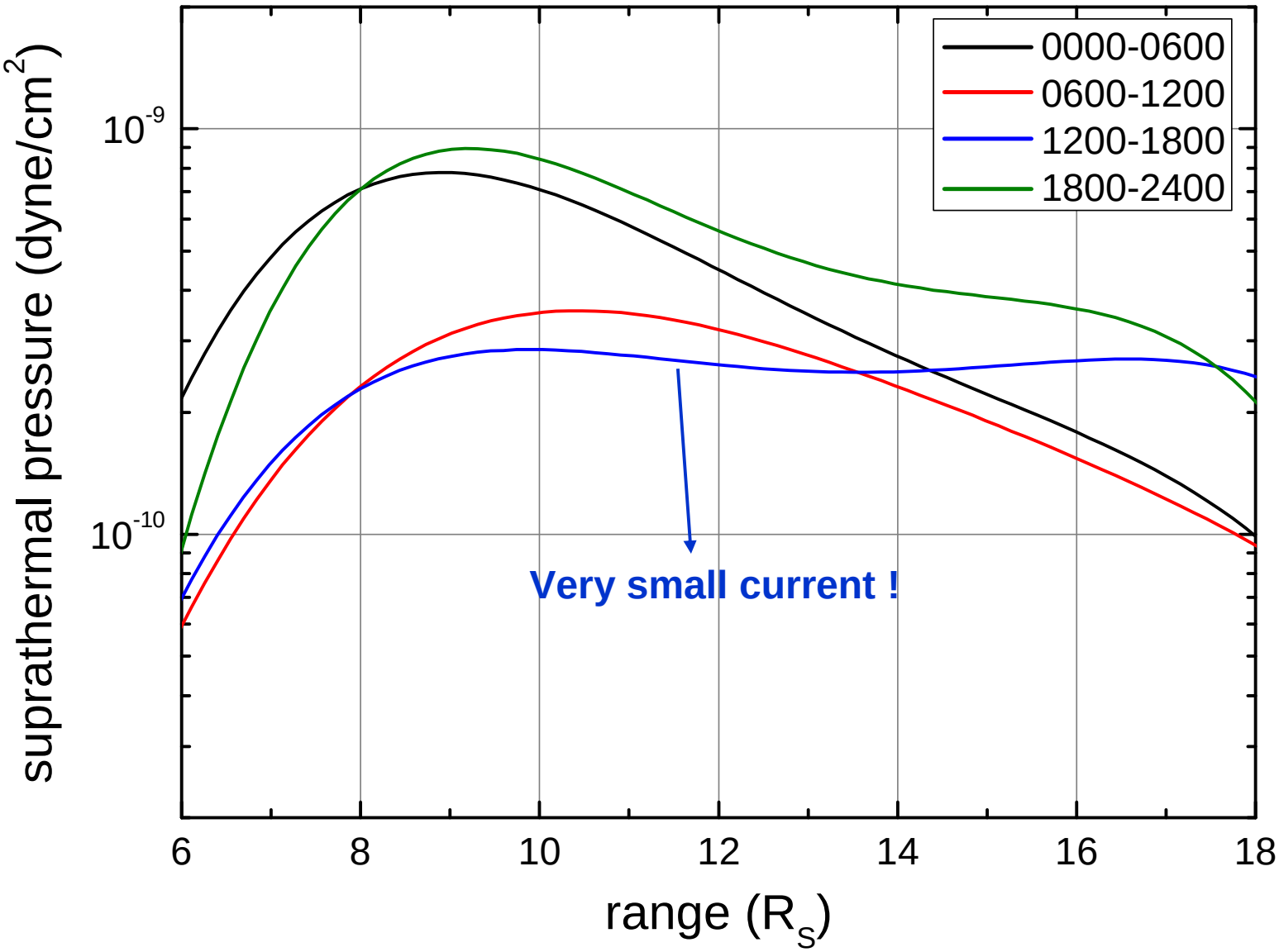



DAWN
6
8
4
10
2
12
0
14
22
16
20
18
DUSK
NOON
10-8
10-9
10-10
10-11
10-10
10-9
10-8

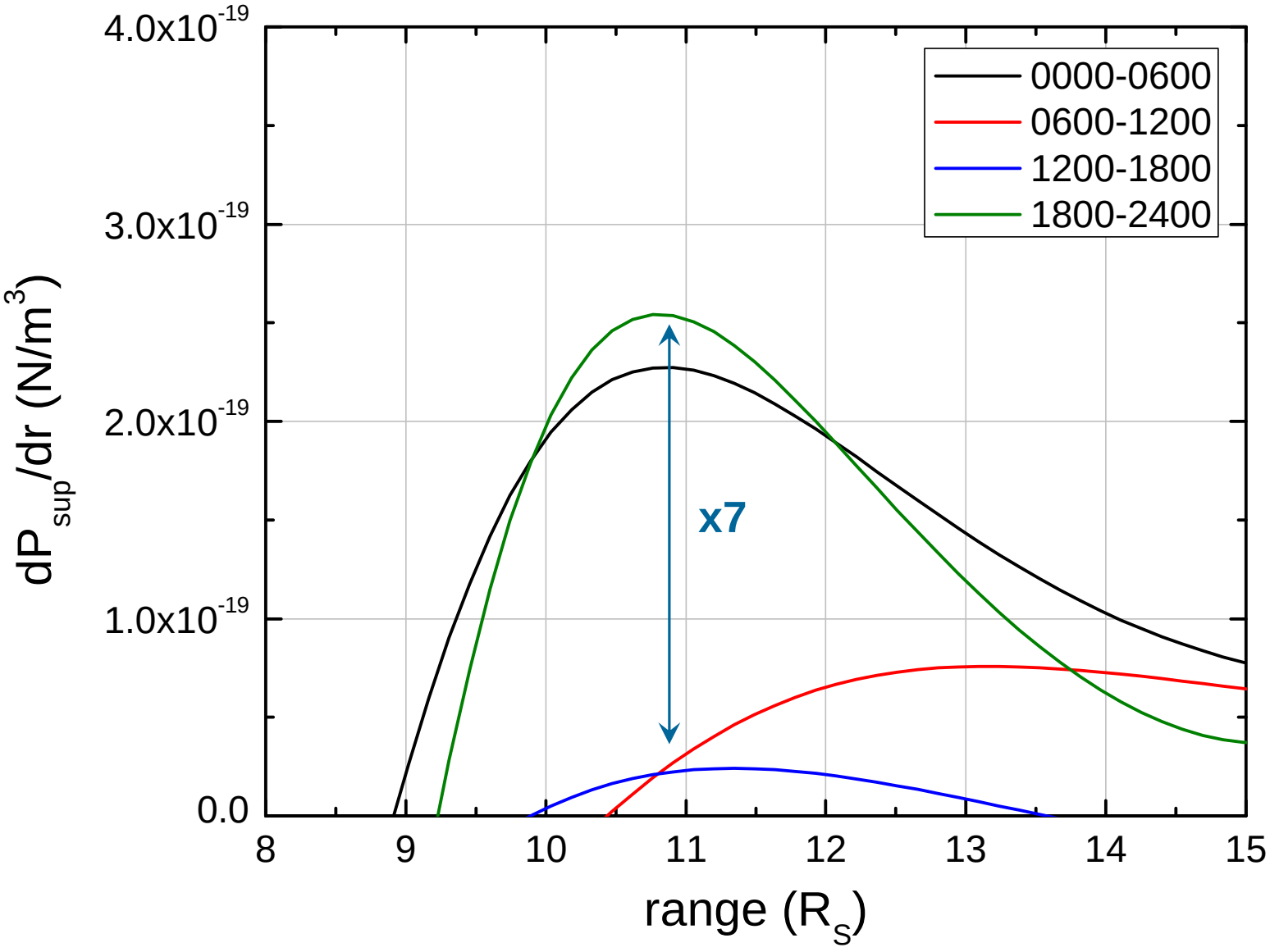
Suprathermal pressure radial profile per Local Time sector



Fitting with 4th order polynomials



Suprathermal pressure gradient ($\nabla_r P_{sup}$) along the radial direction per Local Time sector

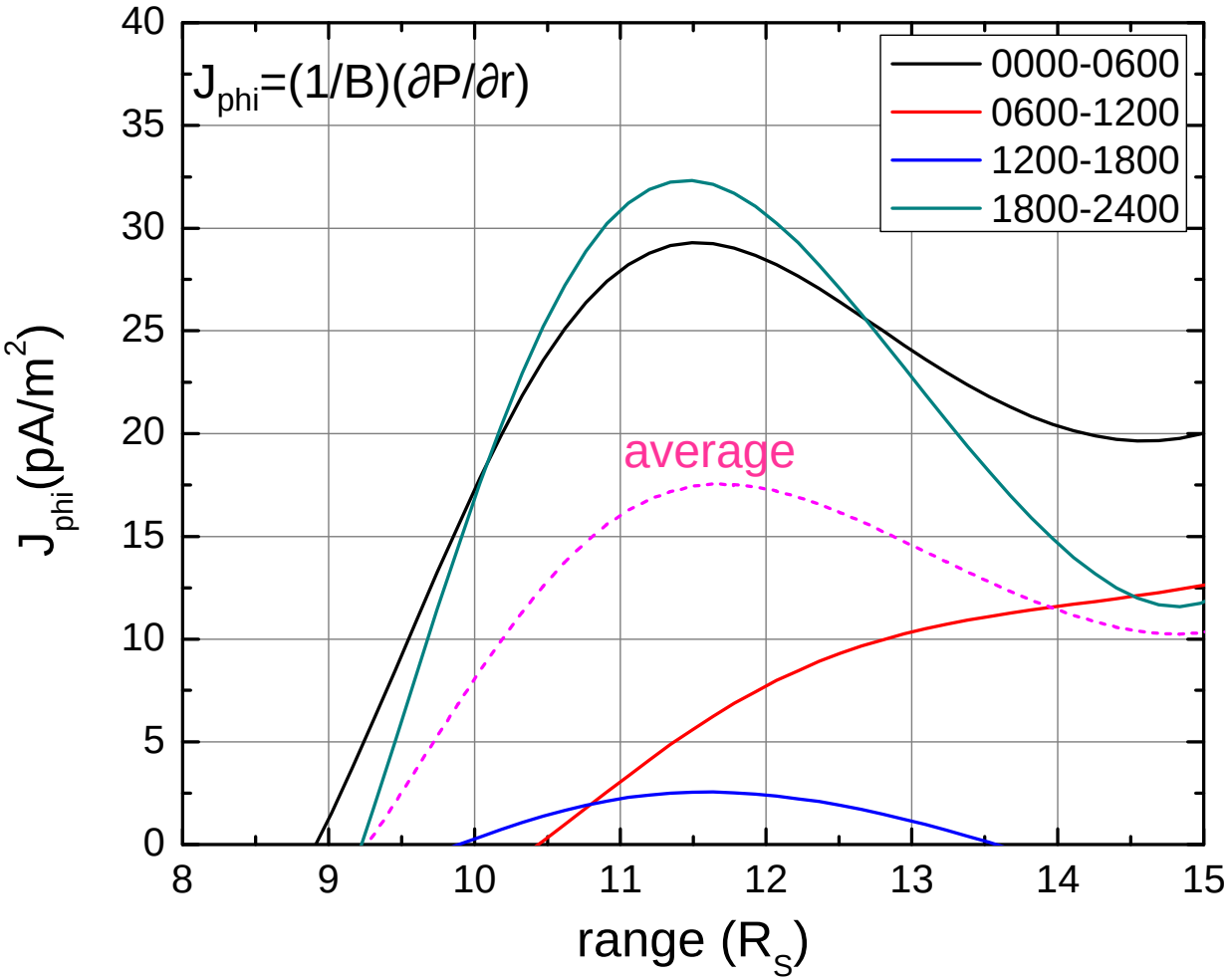


By including the magnetic field measurements (courtesy of M. Dougherty and C. Jackman of the Cassini/MAG team), we can derive directly the average suprathermal contribution to the pressure grad-driven component of the Saturnian ring current, per local time sector.

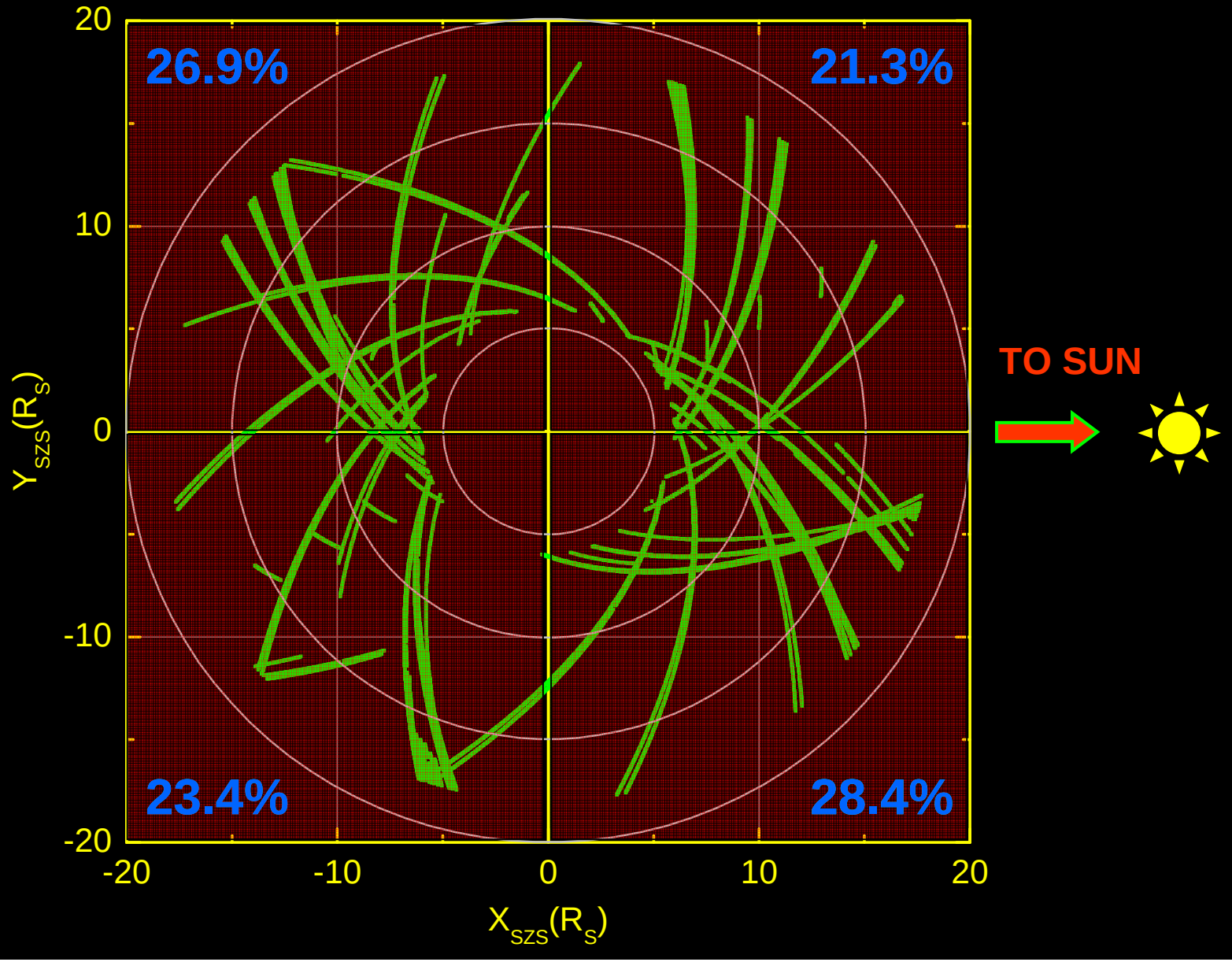
$$J_\phi \approx \frac{1}{B_z}\left(\rho\frac{V_\phi^2}{r} - \frac{\partial P}{\partial r} - \frac{P_\perp}{R_C}\left(\frac{A-1}{A}\right)\right)$$

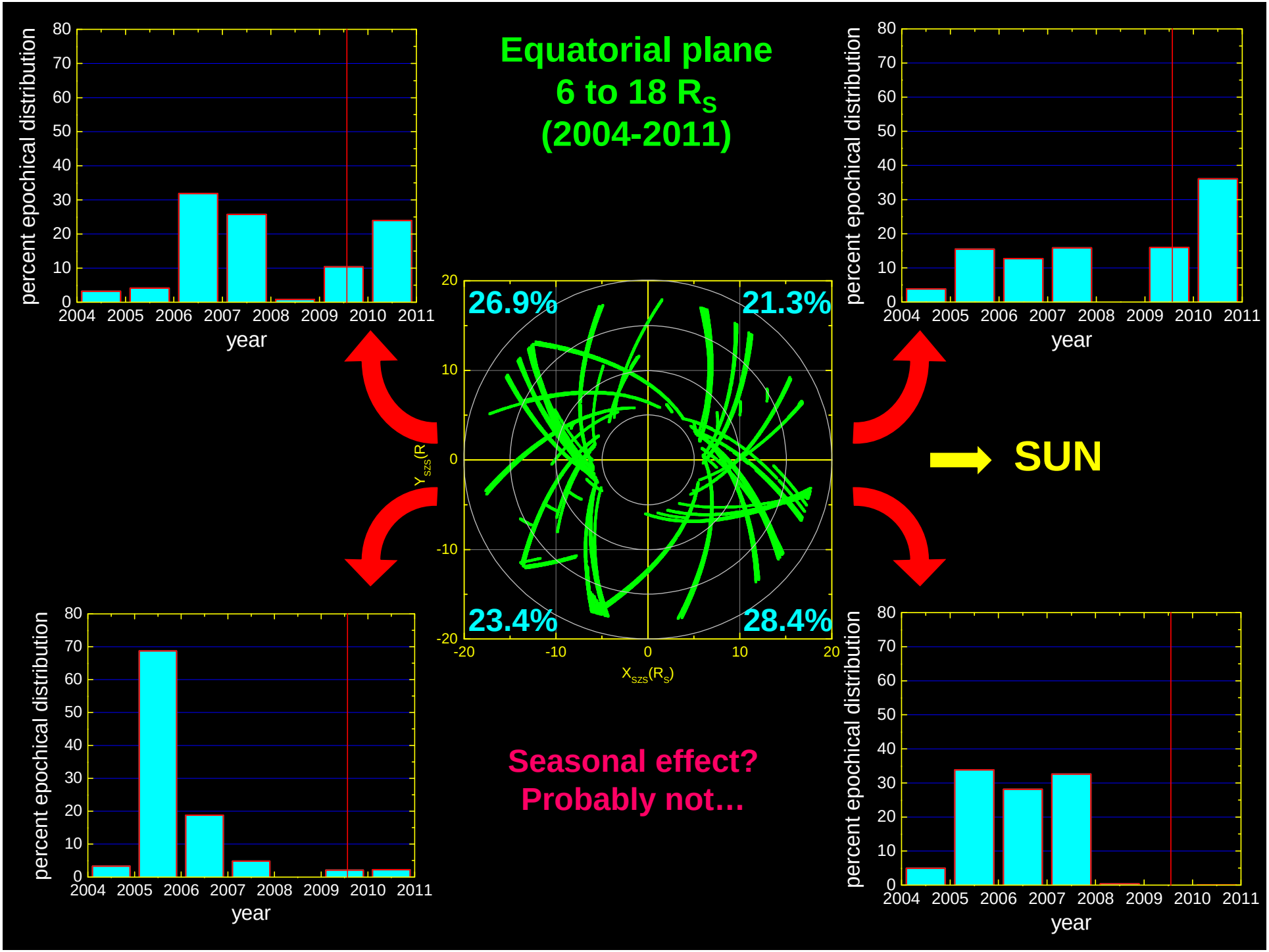
Significant local time asymmetry.

This ring current component almost vanishes in the noon-to-dusk sector!



Let us take a look at the coverage statistics: equatorial plane 6 to 18 R_S (2004-2011)




Equatorial plane
6 to 18 R_S
(2004-2011)
26.9%
21.3%
23.4%
28.4%
SUN
Seasonal effect?
Probably not…
percent epochical distribution
year
$X_{SZS}(R_S)$
$Y_{SZS}(R$

Conclusions

Analysis of plasma, energetic particle and magnetic field data acquired by Cassini from the beginning of the mission to this day (2004-2011) show that:

1. The equatorial plane of the Saturnian magnetosphere is being progressively covered in ***all local time sectors for a wide range of radial distances*** (6-18 RS), making possible the ***mapping of the particle pressure*** and the ***study of the overall structure of the planetary ring current.***

2. The radial profile of the suprathermal pressure and the corresponding pressure gradient ($-\partial P/\partial r$) present ***significant dependence on local time*** being higher by a factor of 2 to 8 in the nightside, resulting a ***local time dependent ring current.*** The average ring current density appears as recently reported (*Sergis et al*., 2010 *Kellett et al*., 2011).

3. As Cassini continues its equatorial plane orbits, more data will be analyzed and better coverage will be obtained. By early 2012 (perhaps EGU 2012) we will be able to have a complete picture of the ring current structure. Also, **conditions symmetric to equinox** (e.g. 2007-2011) will be available for direct comparison (seasonal change?)

Thank you!