The enigma of Saturn's variable radio period

Philippe Zarka

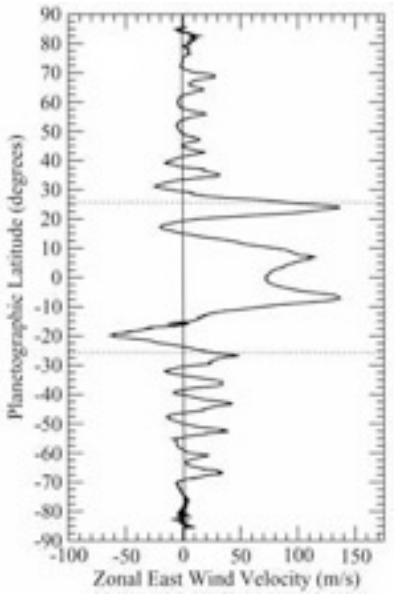
LESIA, CNRS - Observatoire de Paris, Meudon, France
philippe.zarka@obspm.fr

- Planetary rotation
- Planetary radio emissions
- Radio measurements of Saturn's rotation period
- Saturn's variable radio period
- Why does it vary ?
- What may cause the variation ?
- What is Saturn's internal rotation period ?
- Next …

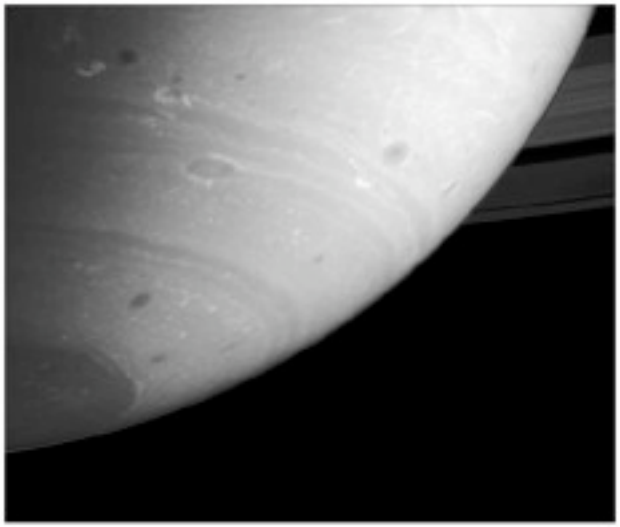
- Planetary rotation
- Planetary radio emissions
- Radio measurements of Saturn's rotation period
- Saturn's variable radio period
- Why does it vary ?
- What may cause the variation ?
- What is Saturn's internal rotation period ?
- Next …

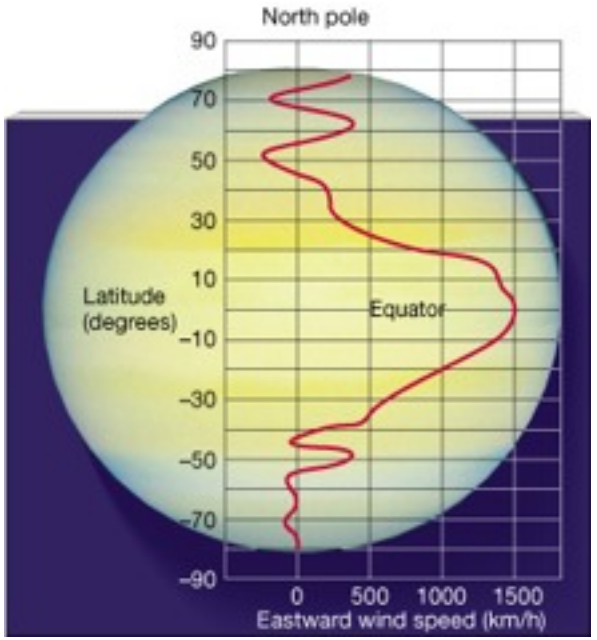
Planetary rotation measured in the Visible is not accurate

Jupiter



Saturn



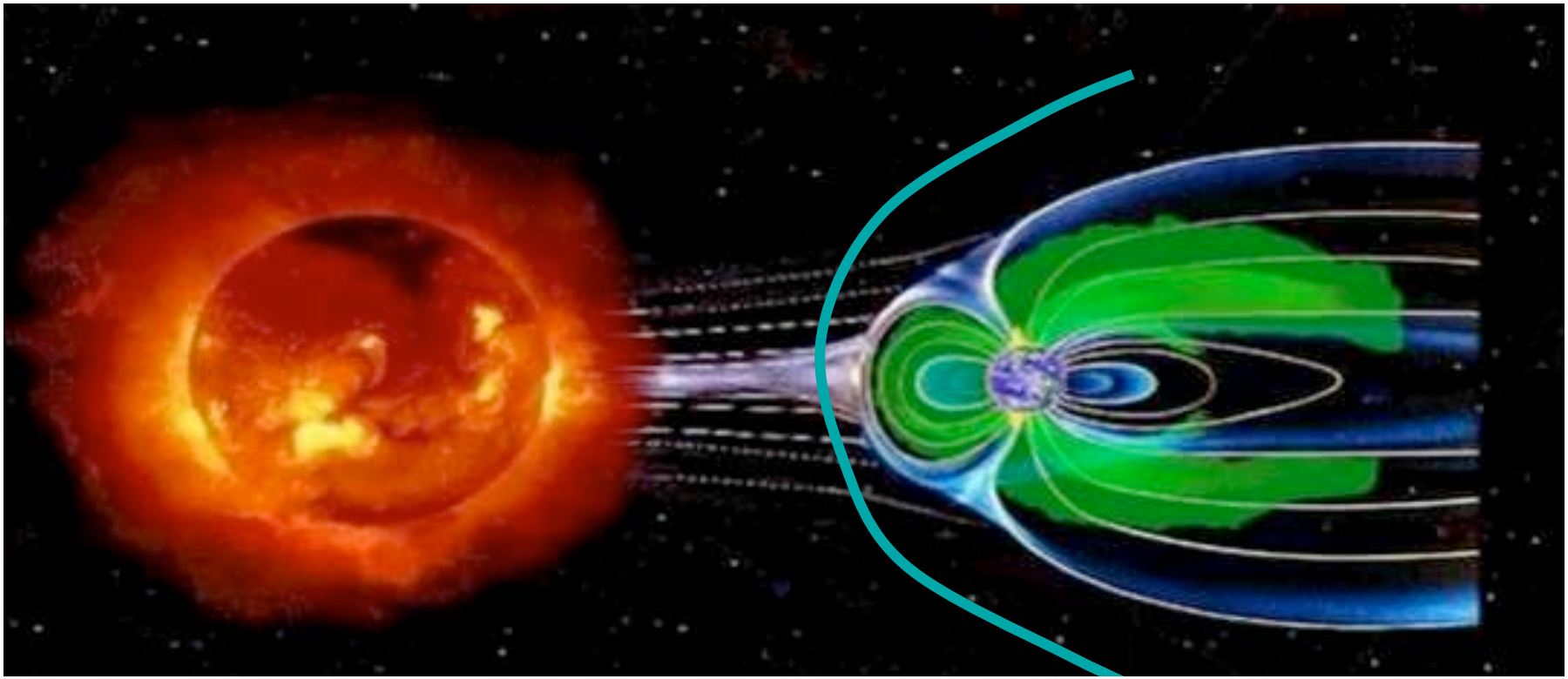


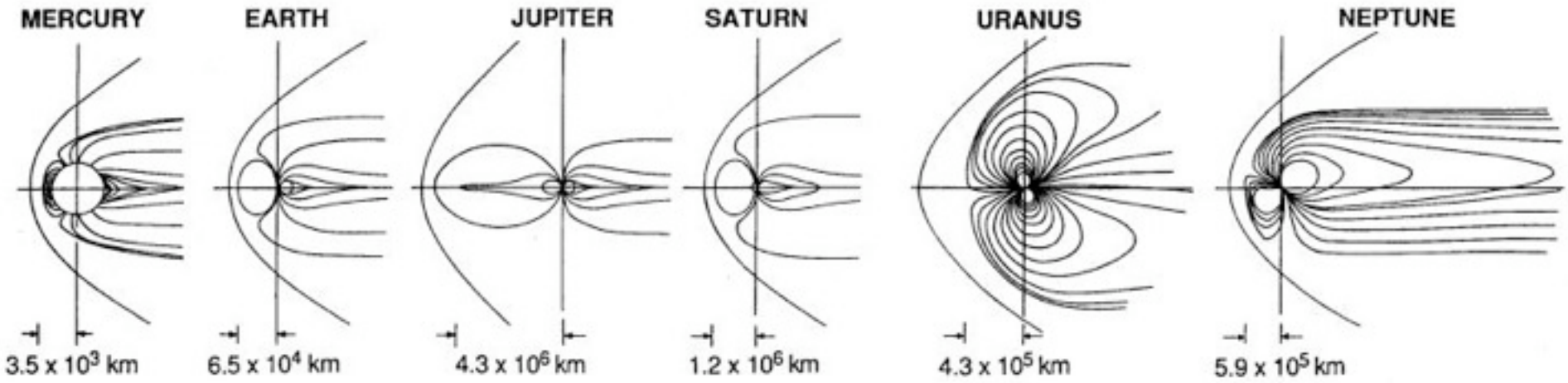
Outcomes of (internal) planetary rotation measurement

- Atmospheric winds speed
- Internal structure ($m(r,\theta,\varphi)$, interpretation of gravitation data)
  - Transition molecular/metallic H_2
  - Formation models
- Planetary shape (//occultation data)
- Reference Longitude System
  - Merging of Pioneer, Voyager, Cassini… data
  - Magnetic field model

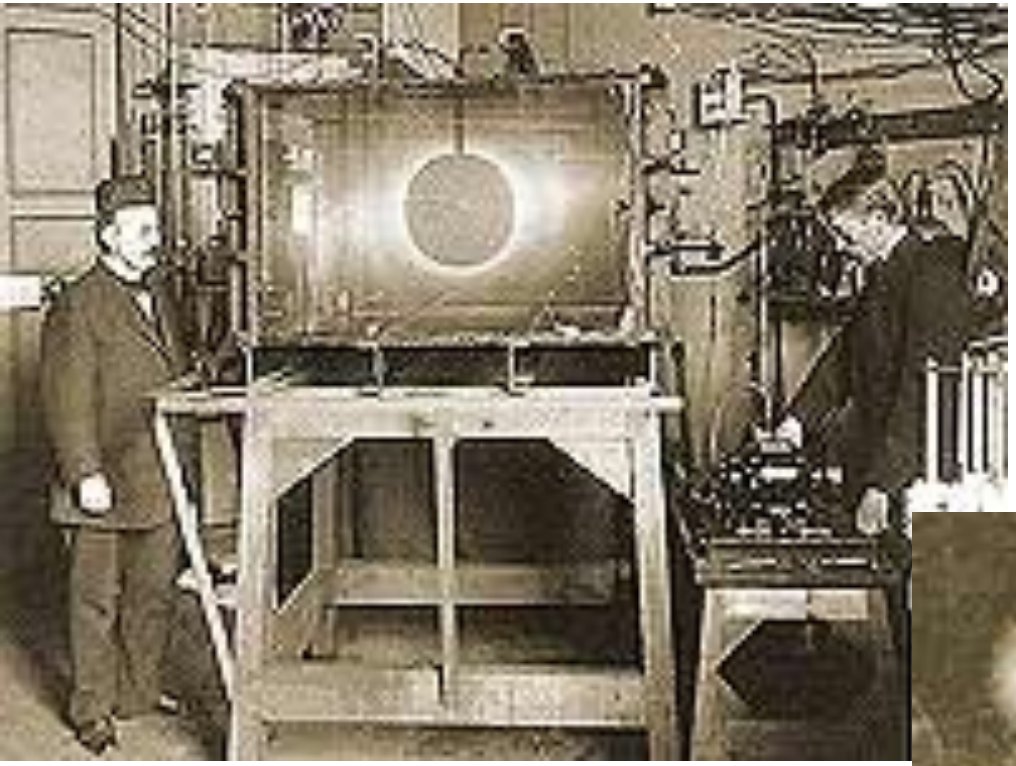
- Planetary rotation
- Planetary radio emissions
- Radio measurements of Saturn's rotation period
- Saturn's variable radio period
- Why does it vary ?
- What may cause the variation ?
- What is Saturn's internal rotation period ?
- Next …

Planetary magnetospheres



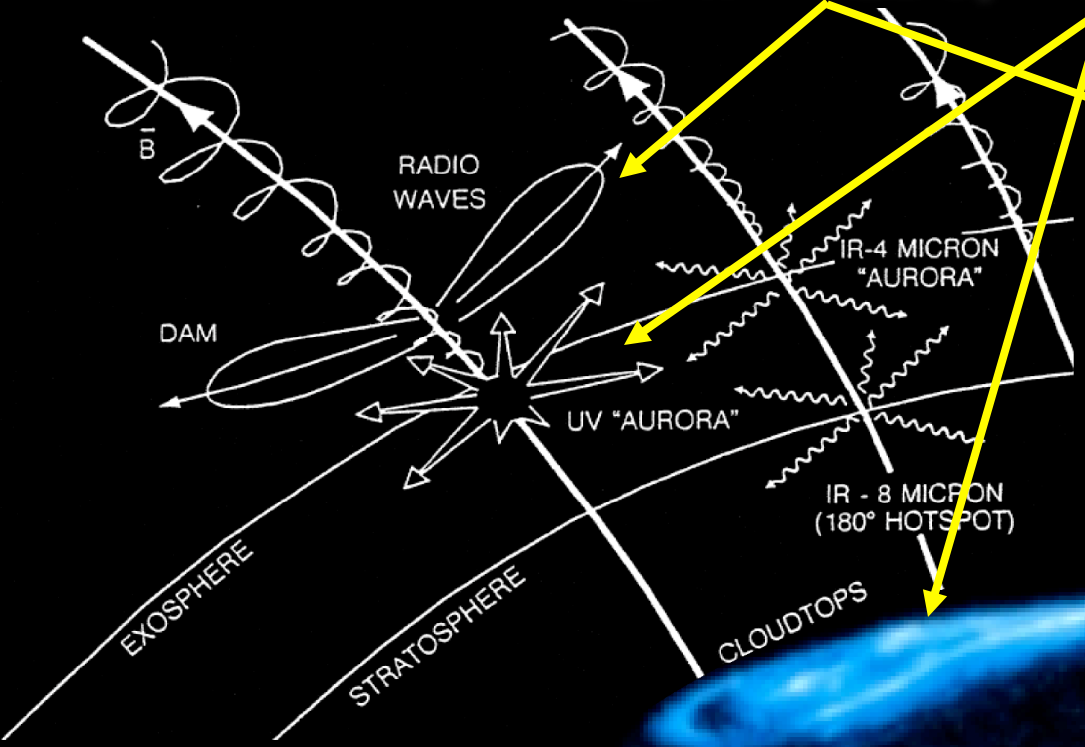


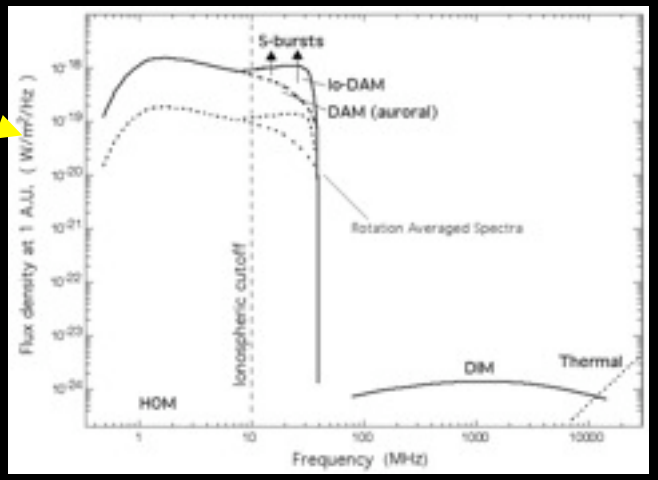
Accelerated electrons → auroral emissions …



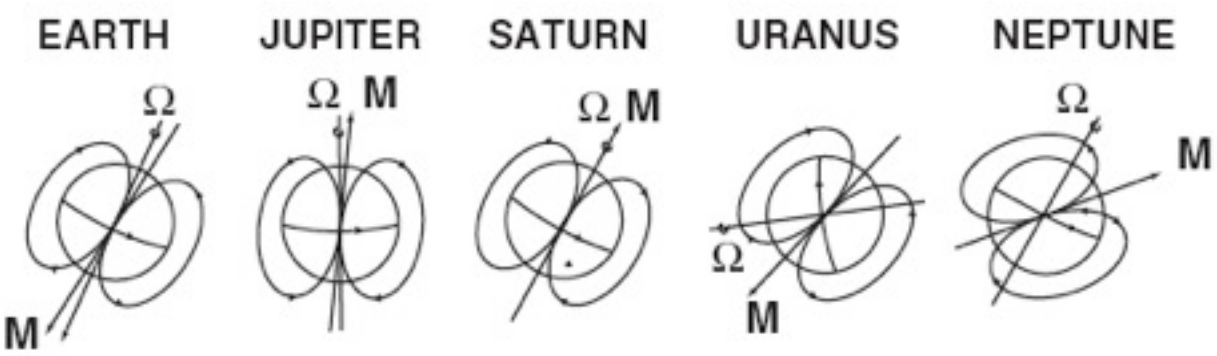
Birkeland's « Terella » [1910]

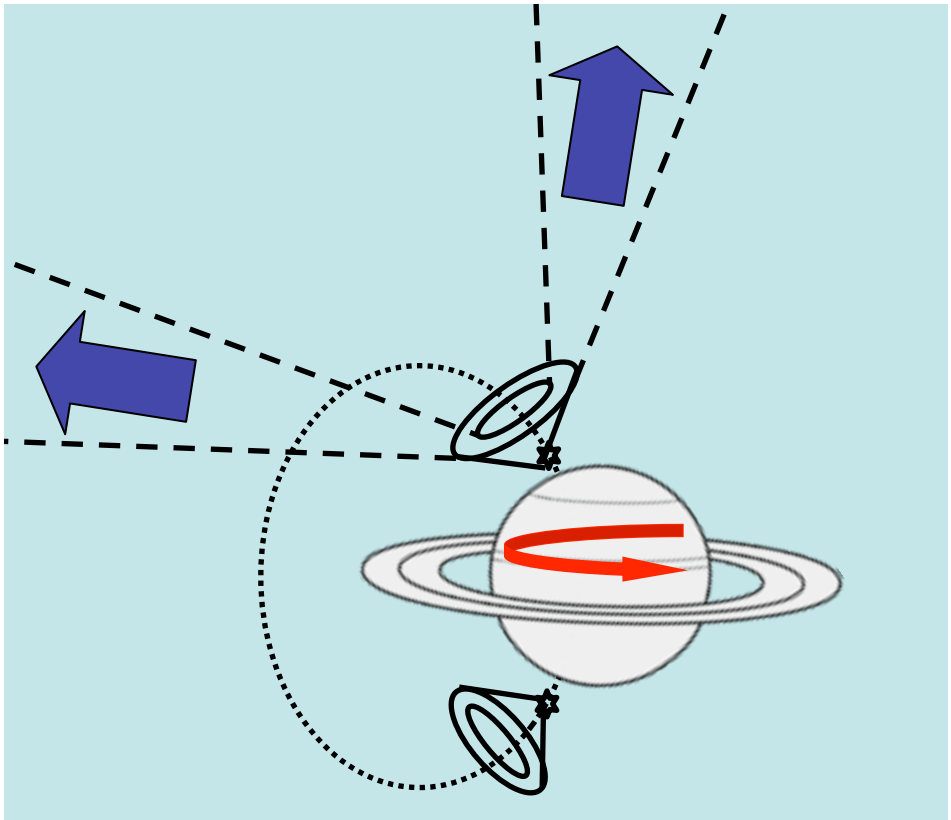
… in Radio, UV, IR



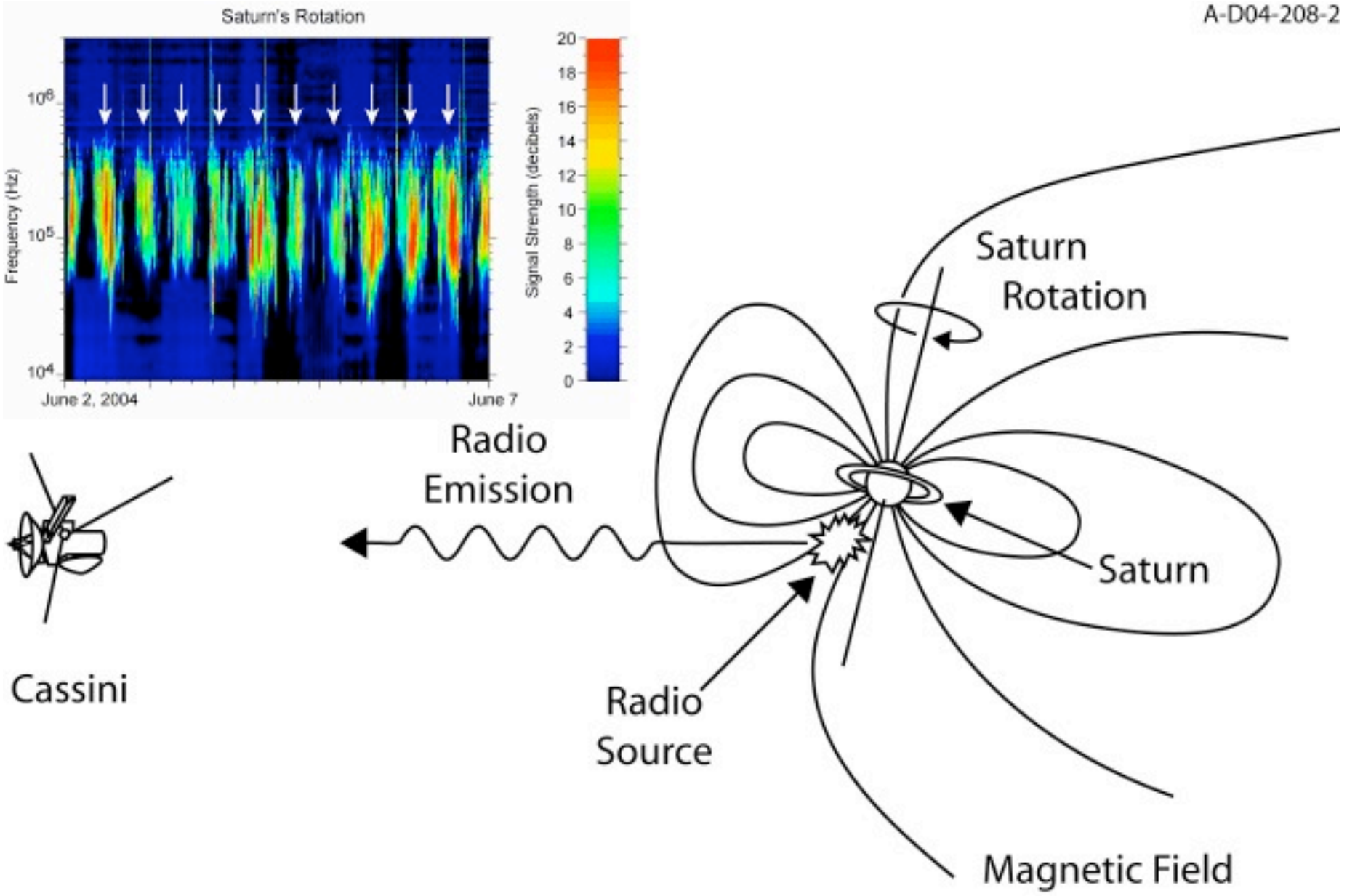


Rotation of radio beam(s) →





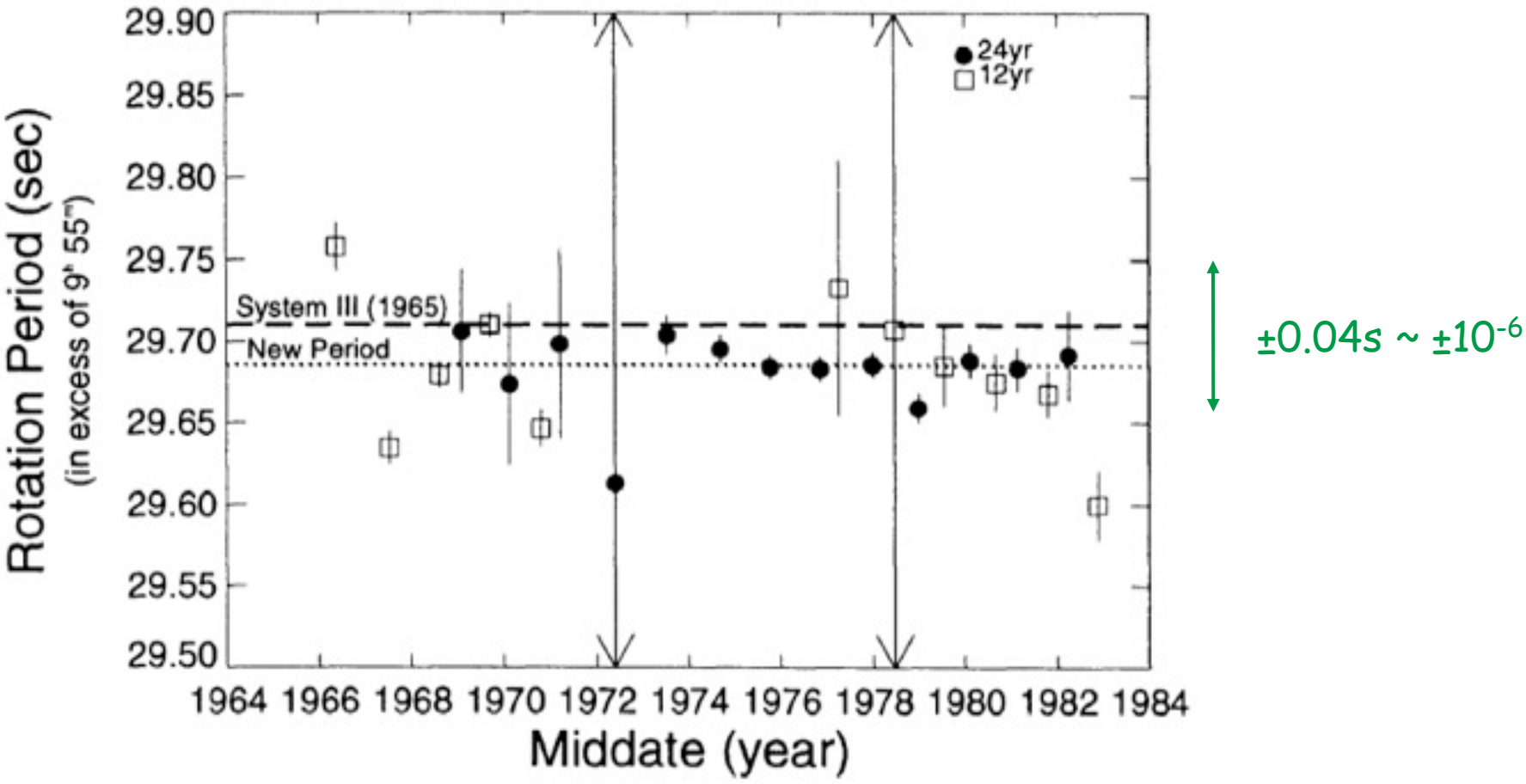
→ Periodic variation of radio emissions



Rotation of Jupiter

- Analysis of 24 years of ground-based radio decameter observations

  $\Rightarrow P_{DAM}$ = 9h 55m 29.685s ± 0.04s



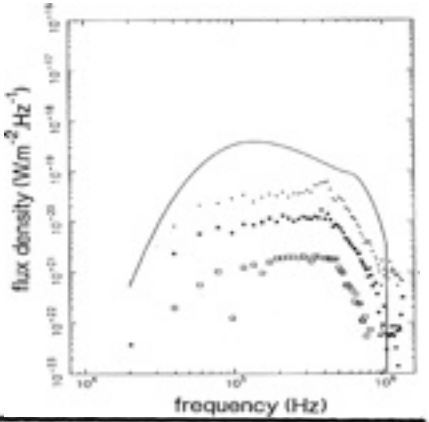
[Higgins et al., 1997]

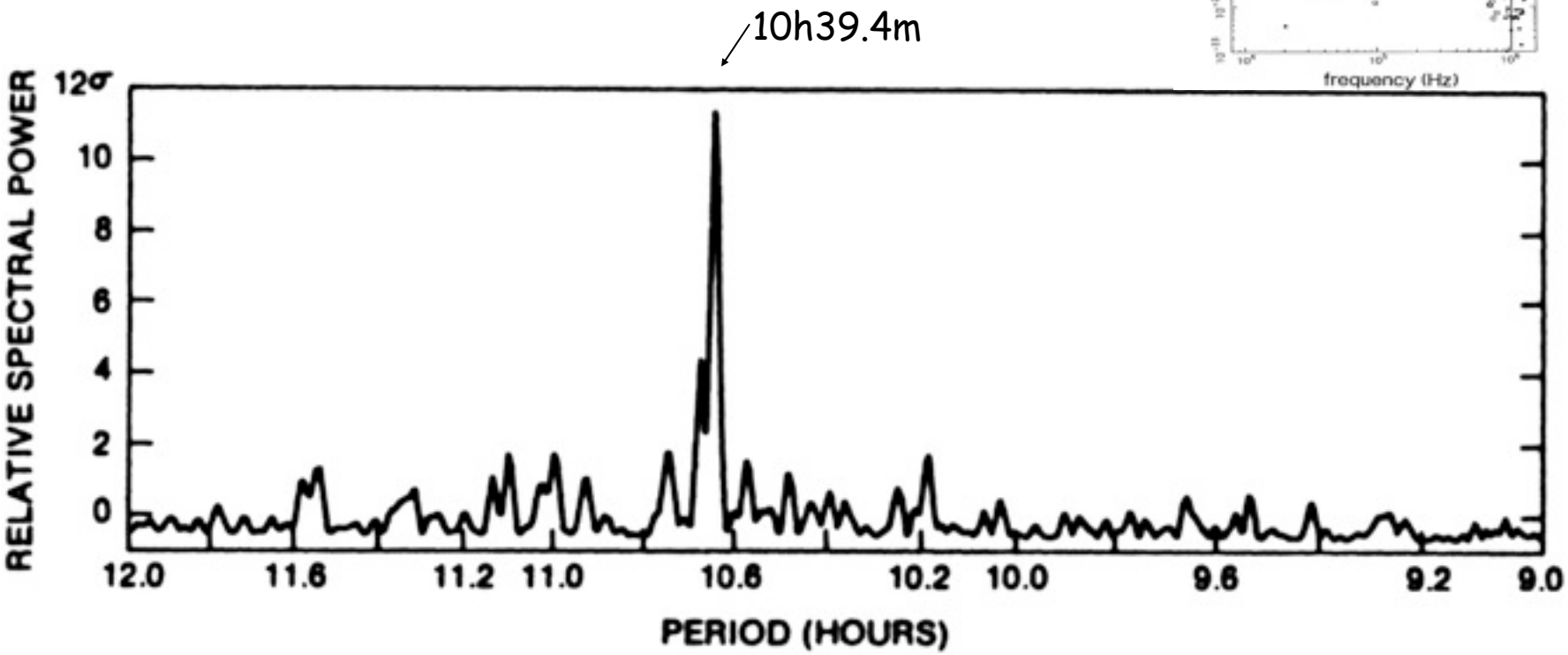
- Planetary rotation
- Planetary radio emissions
- Radio measurements of Saturn's rotation period
- Saturn's variable radio period
- Why does it vary ?
- What may cause the variation ?
- What is Saturn's internal rotation period ?
- Next …

Rotation of Saturne

- Analysis of 267 days of Voyager 1 observations

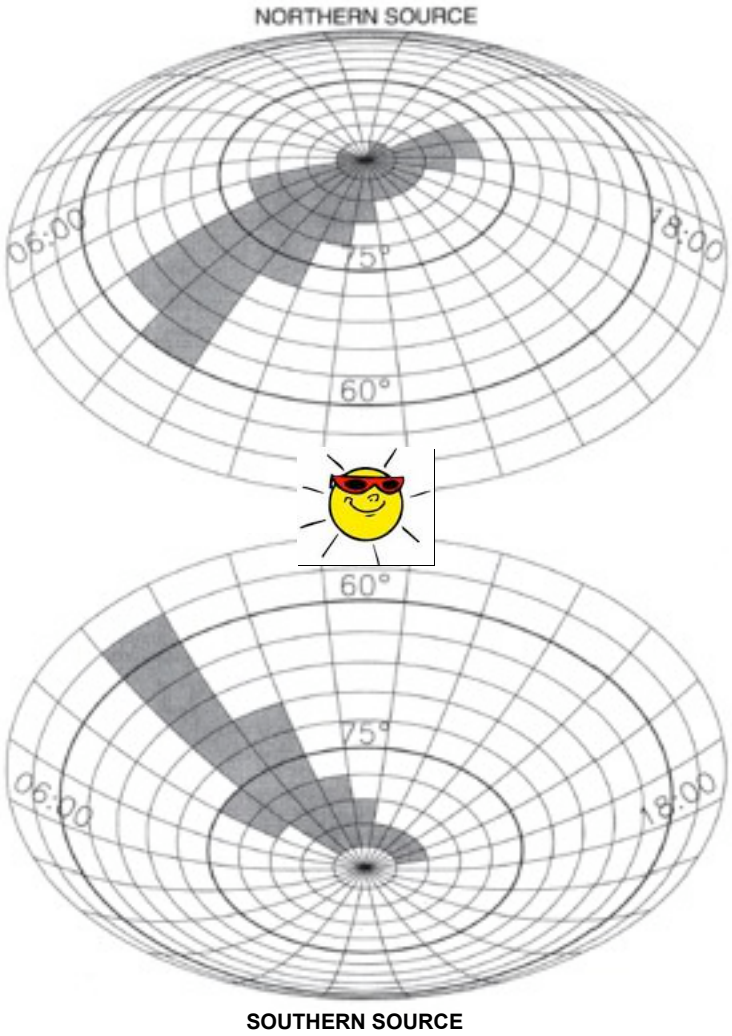
  $\Rightarrow P_{SKR}$ = 10h 39m 24s ± 7s (~2×10^{-4})





[Desch & Kaiser, 1981]

Saturn's Radio (and UV) auroral sources are fixed in space



dawn

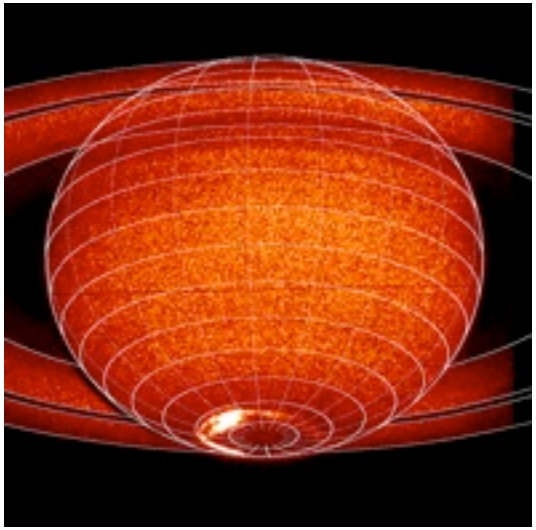
dusk

dawn

dusk

[Galopeau, Zarka, LeQuéau, 1995]

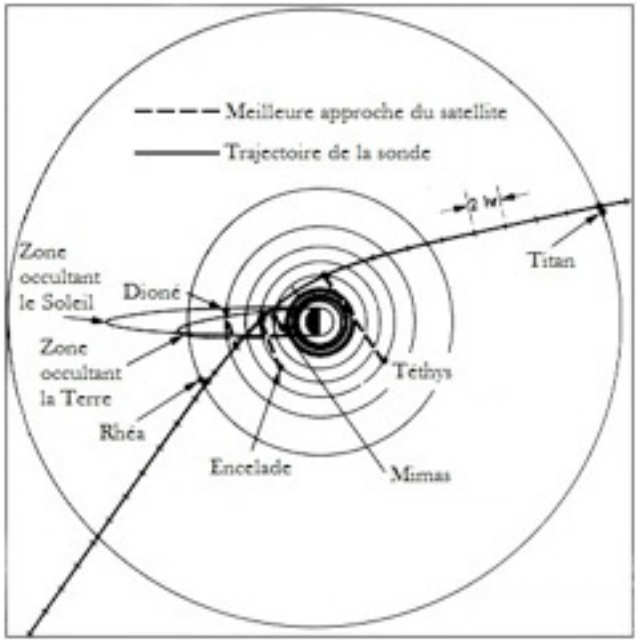
matin

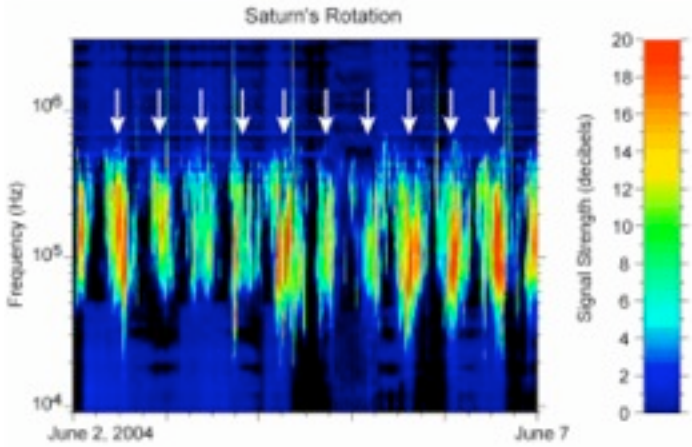


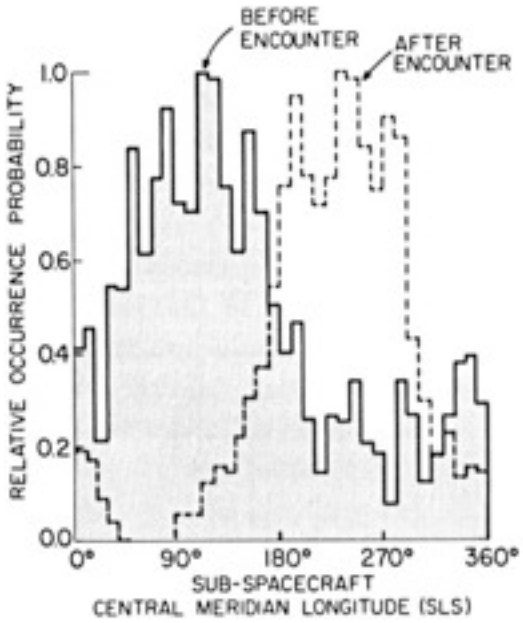
[Prangé et al., 2004]

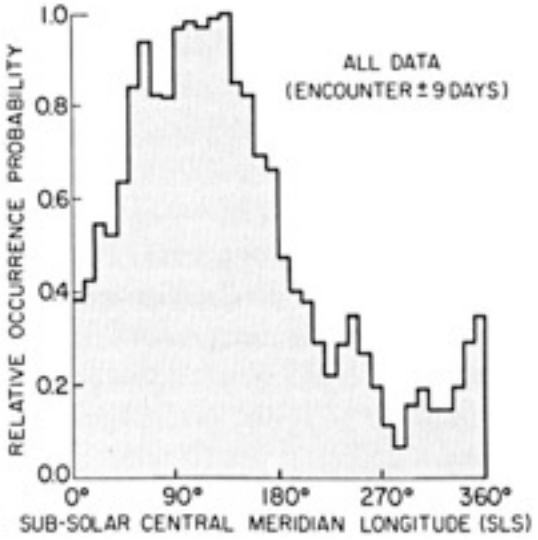
→ Radio emissions modulation is « stroboscopic »

Voyager 1



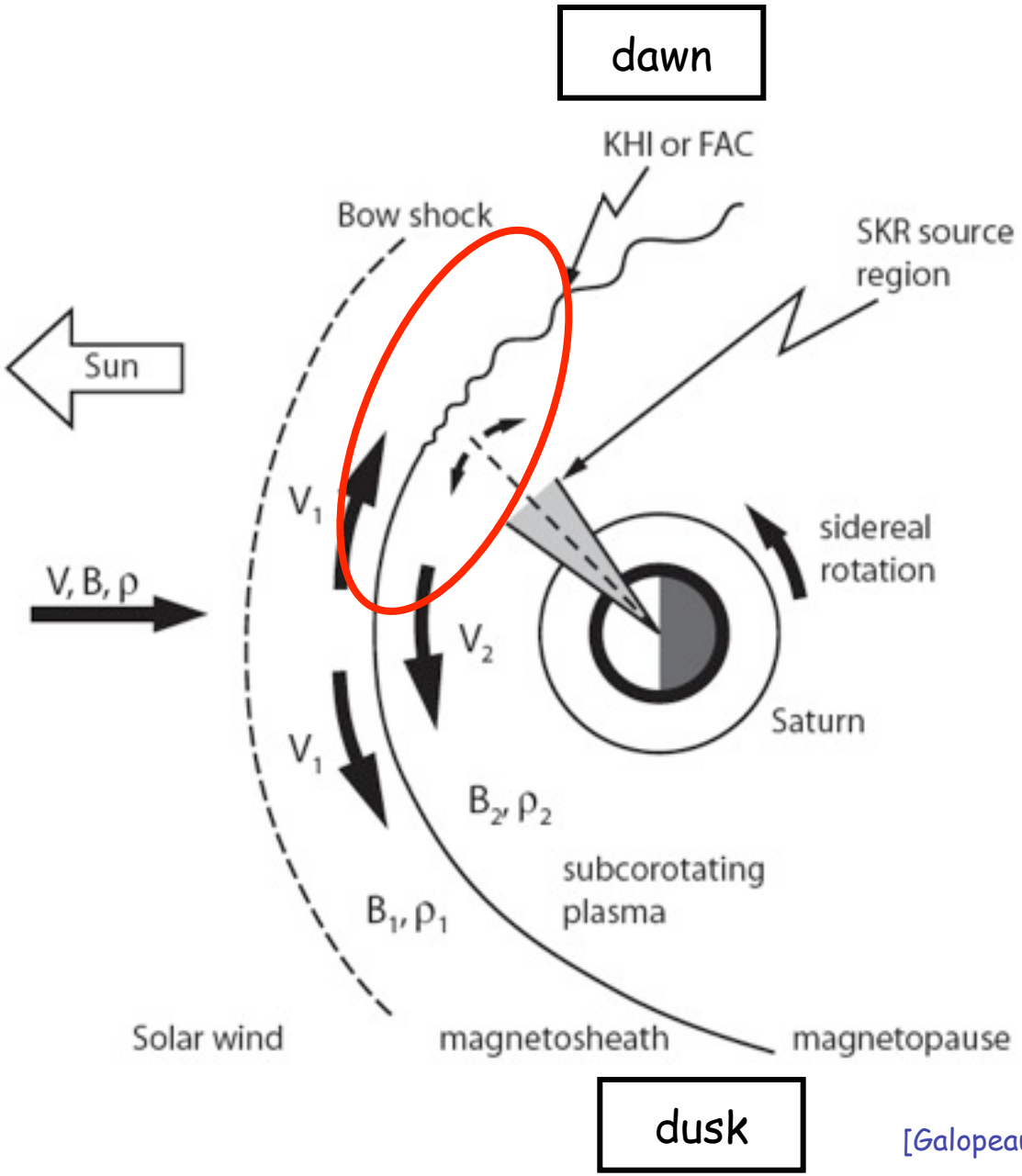






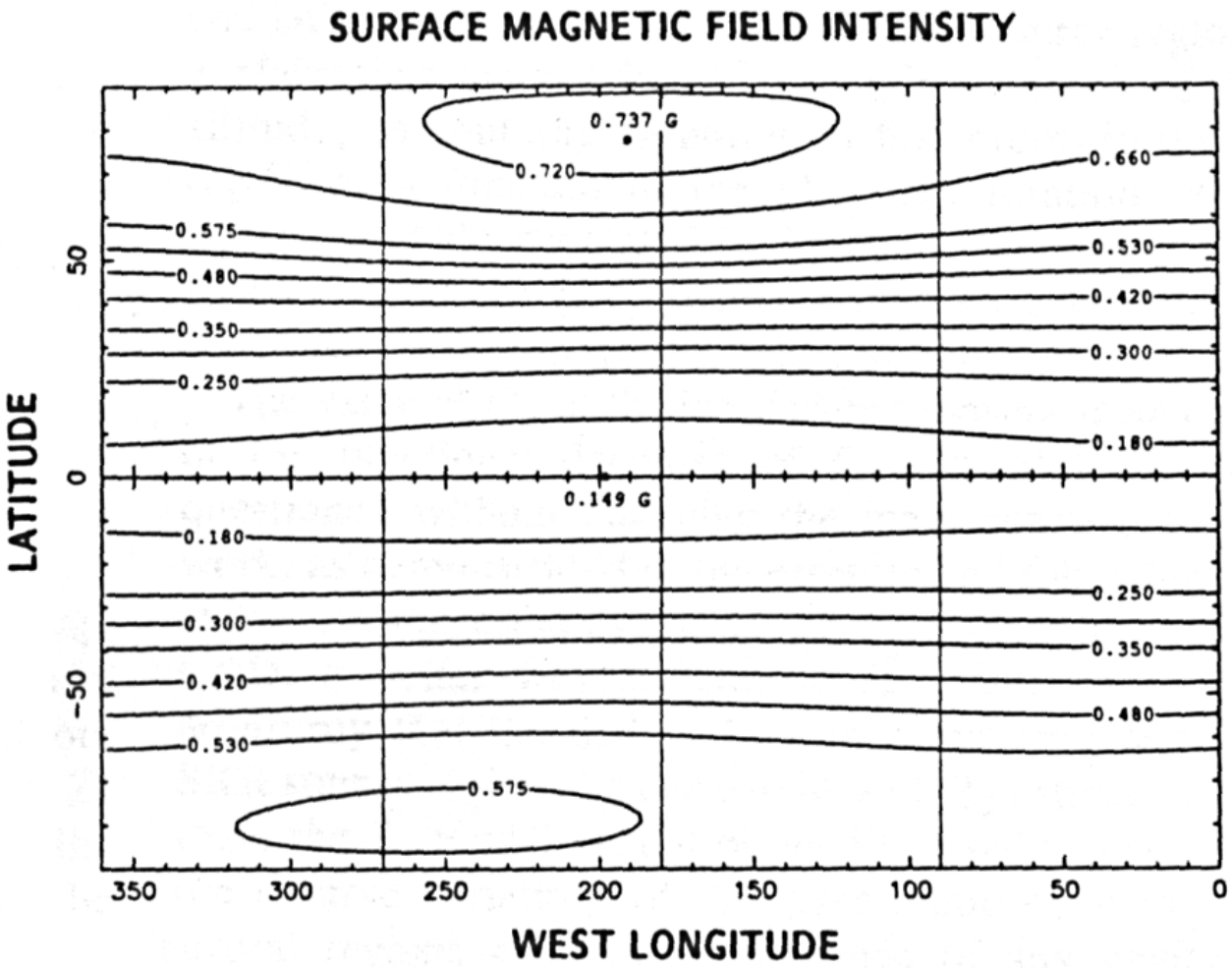
[Warwick et al., 1981]

Radio sources are on the « morning » side



[Galopeau et al., 1995; Cowley et al., 2004]

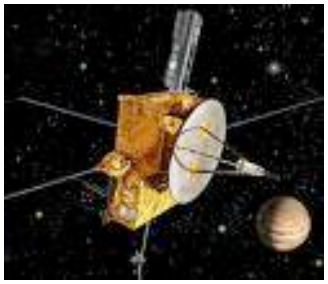
+ Magnetic « anomaly » in rotation



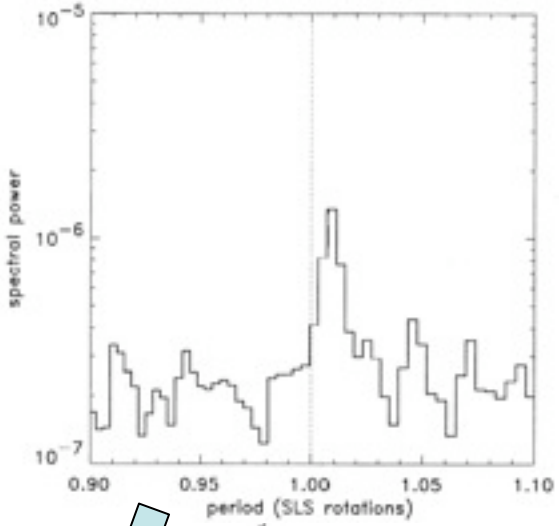
[Galopeau & Zarka, 1992]

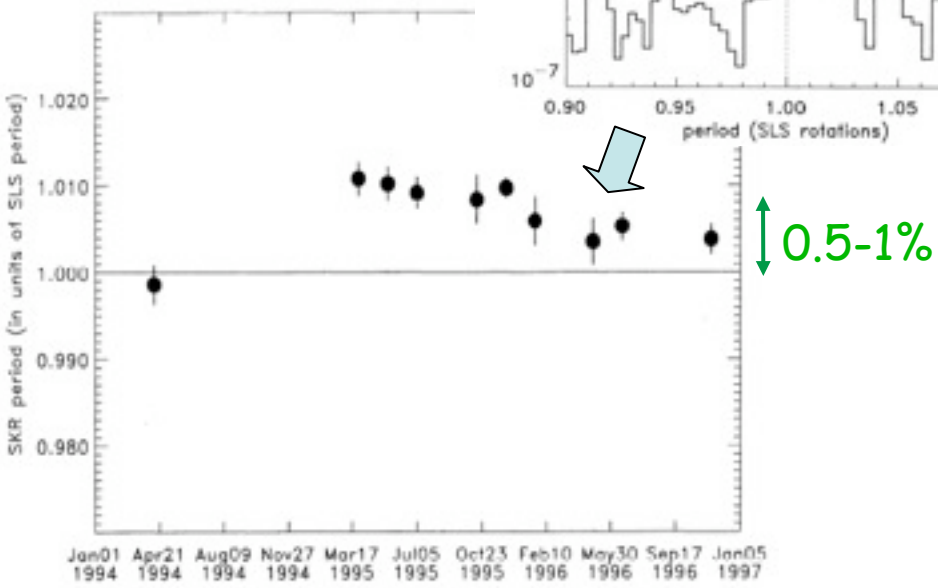
- Planetary rotation
- Planetary radio emissions
- Radio measurements of Saturn's rotation period
- Saturn's variable radio period
- Why does it vary ?
- What may cause the variation ?
- What is Saturn's internal rotation period ?
- Next …

Saturn's variable radio period

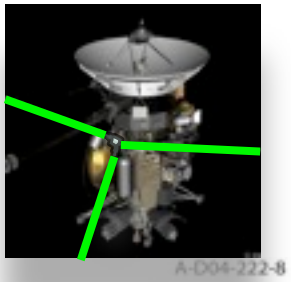


Ulysses

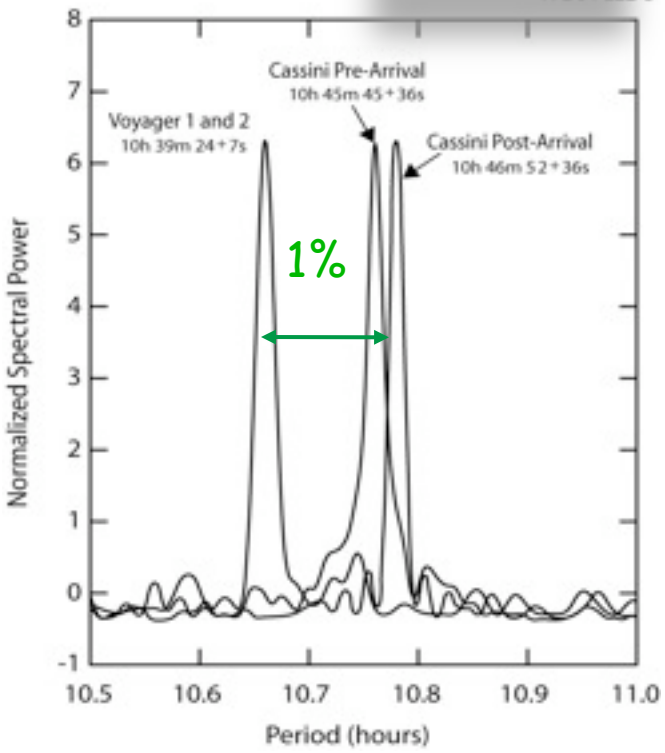




[Galopeau & Lecacheux, 2000]

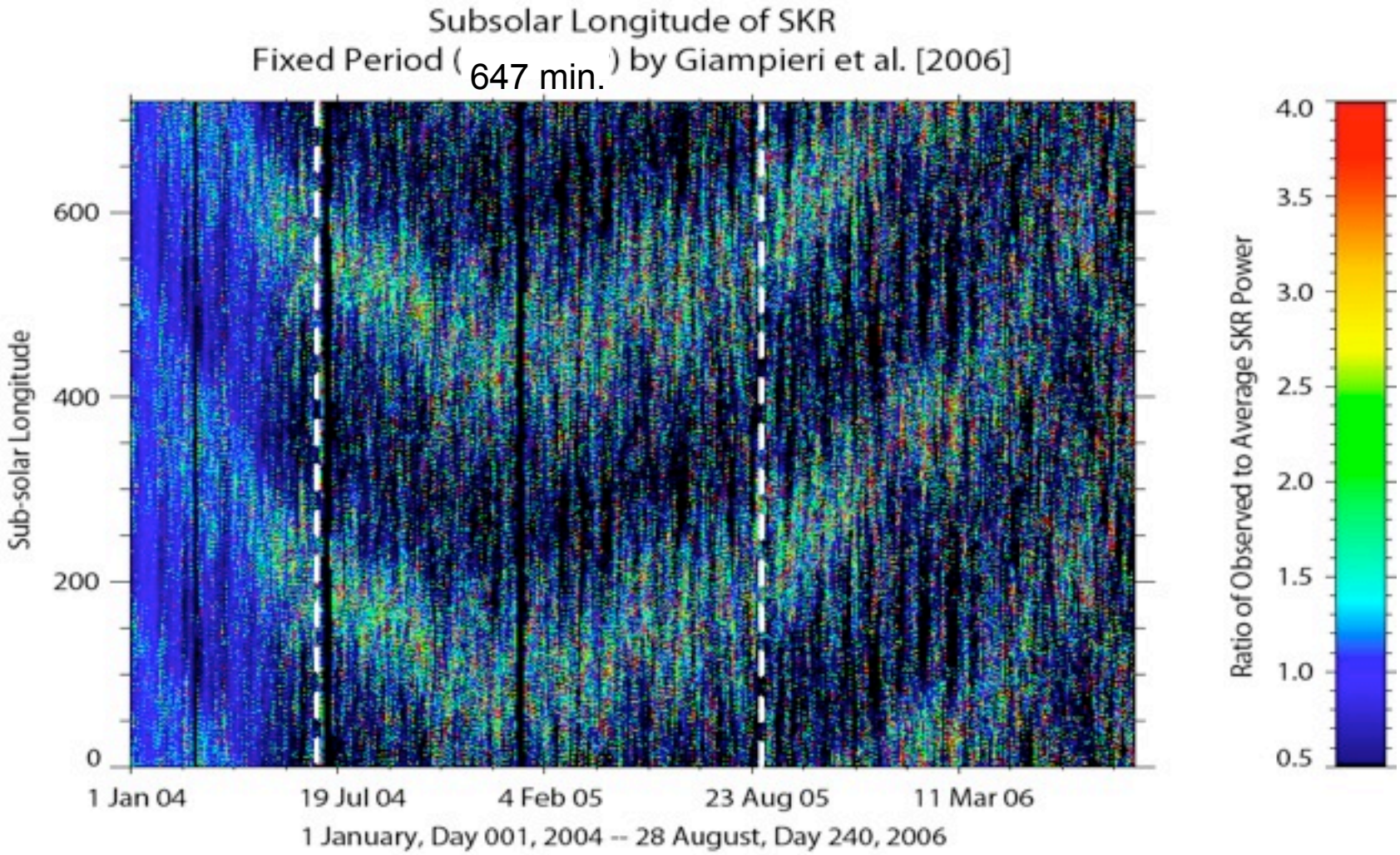


Cassini



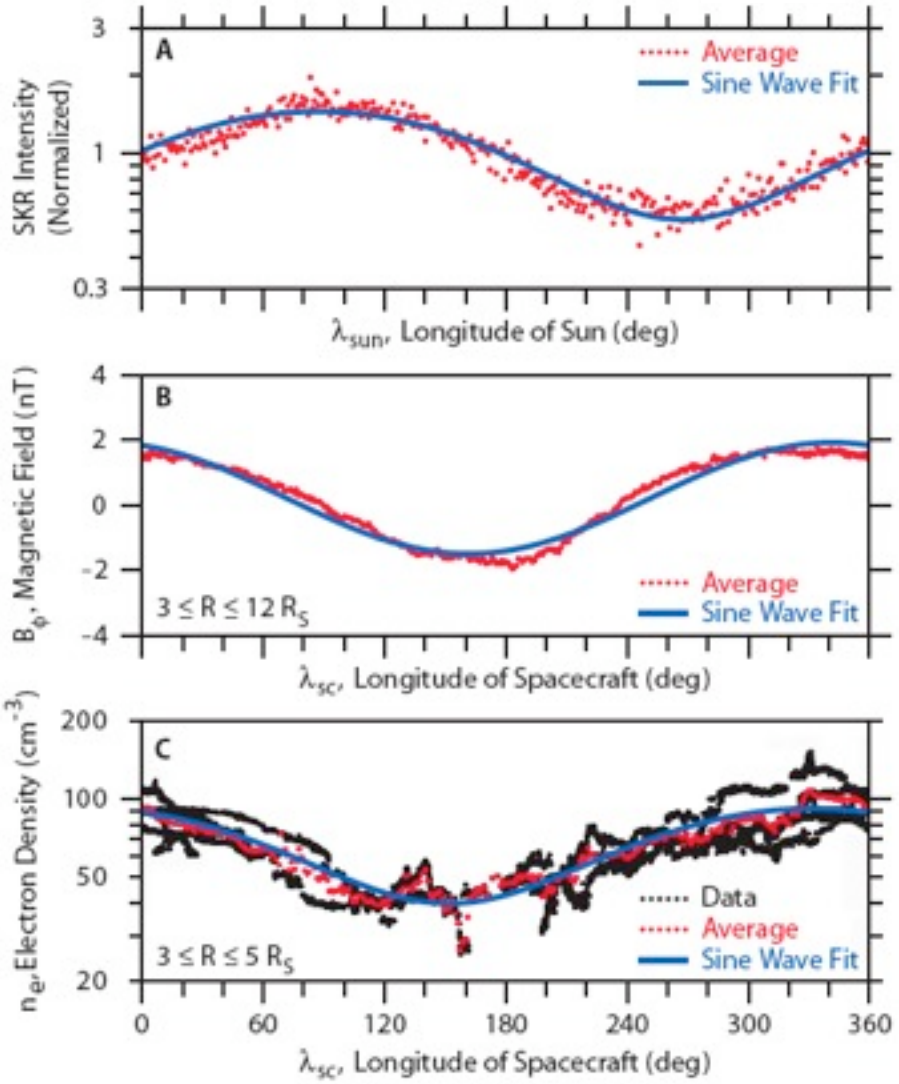
[Gurnett et al., 2005]

Saturn's variable radio period



[Kurth et al., 2007]

Similar variations measured for …



[Gurnett et al., 2007]

Radio emissions

Azimuthal magnetic field B_φ

Plasma density in inner MS ?

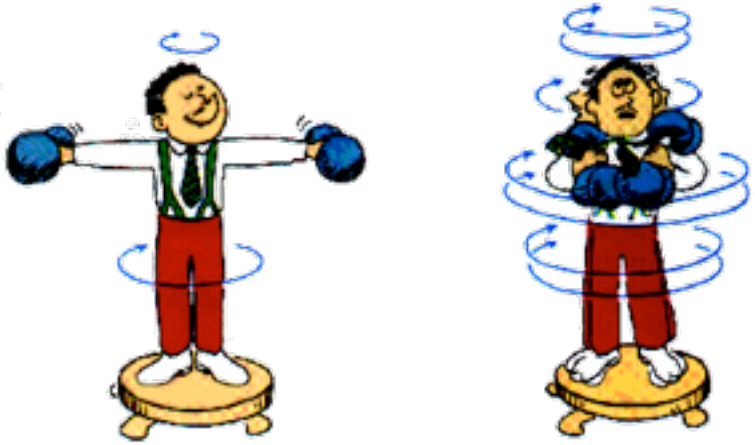
+ UV aurora ?

+ Position of Magnetopause ?

1% period variation is huge (~15 min. @ Earth !)

- Origin ?

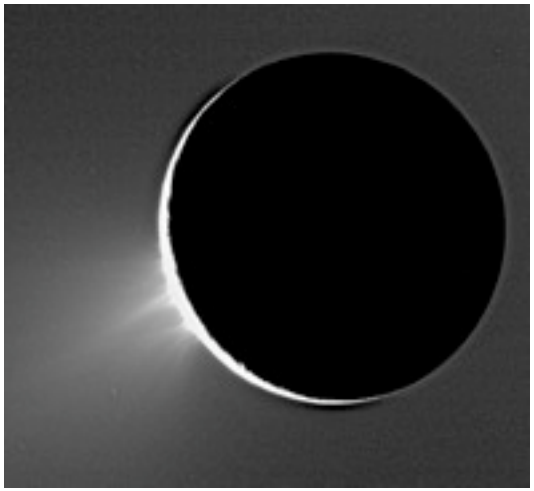
  → no change in Saturn's true rotation !

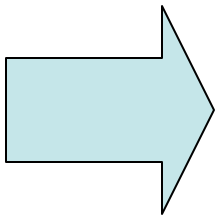


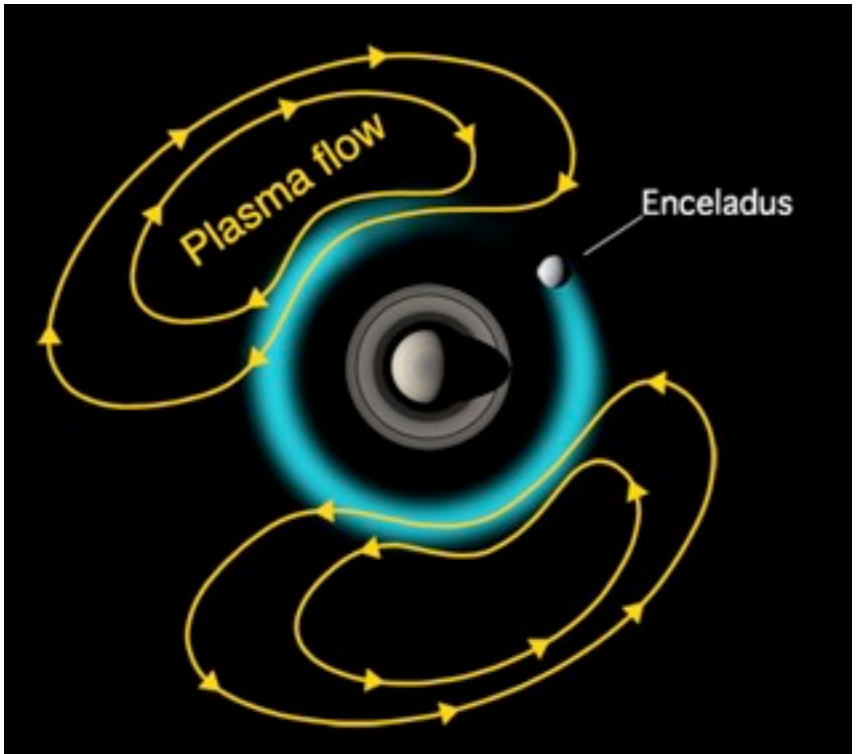
- True internal period ?
- Differences Voyager - Cassini ?

- Planetary rotation
- Planetary radio emissions
- Radio measurements of Saturn's rotation period
- Saturn's variable radio period
- Why does it vary ?
- What may cause the variation ?
- What is Saturn's internal rotation period ?
- Next …

Internal origin ? Enceladus ?



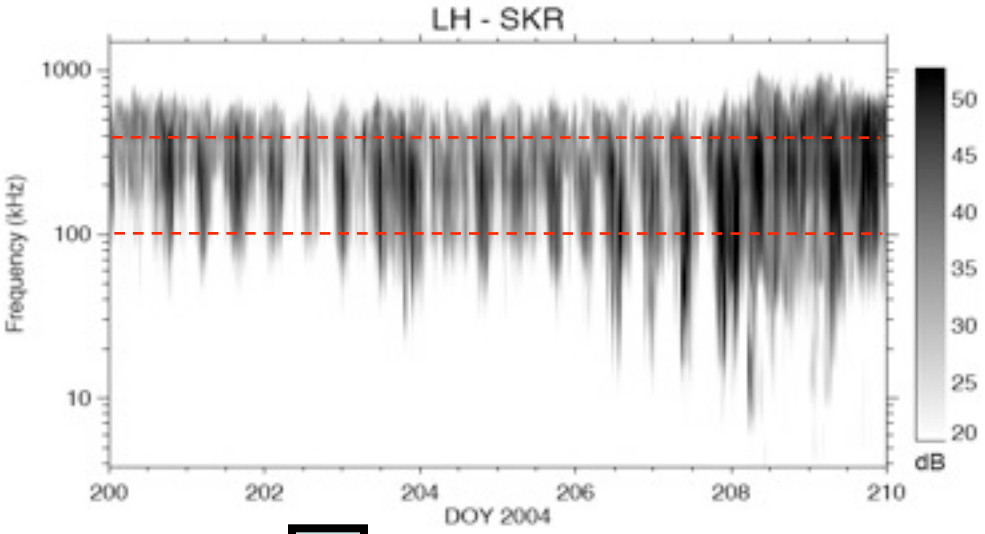


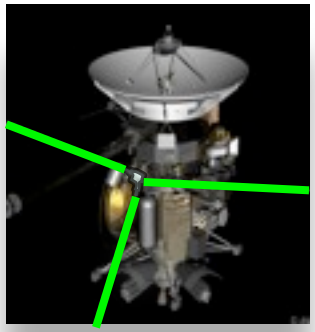


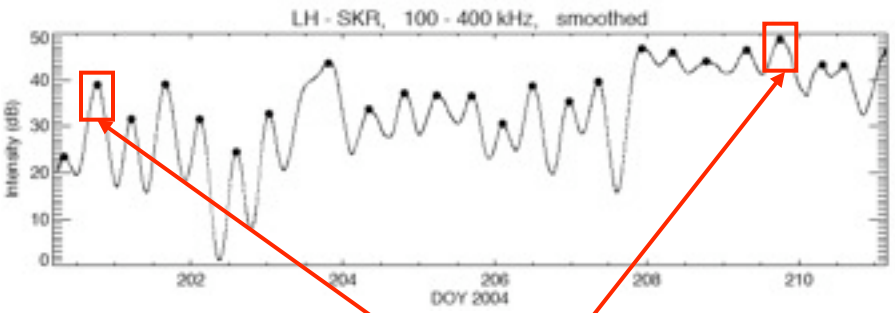
[Gurnett et al., 2007]

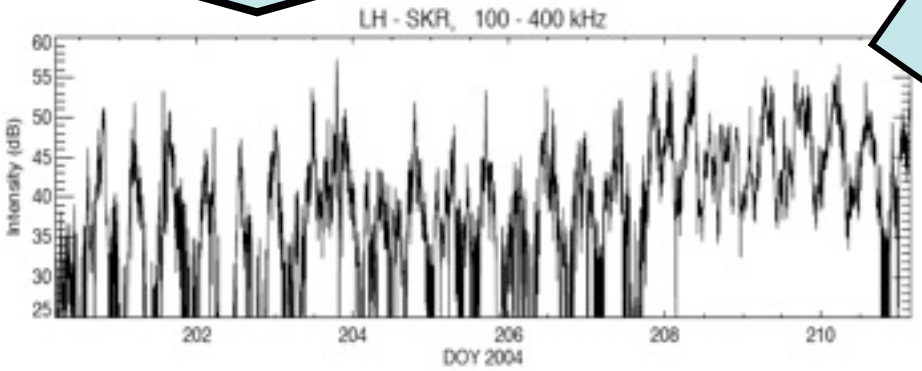
Analysis of >3 years of Cassini radio data

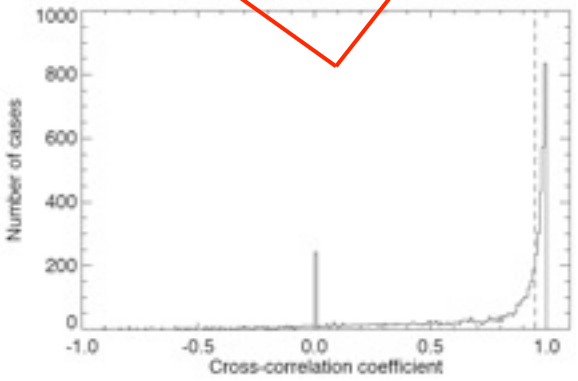
- « Short-term » period variations ?





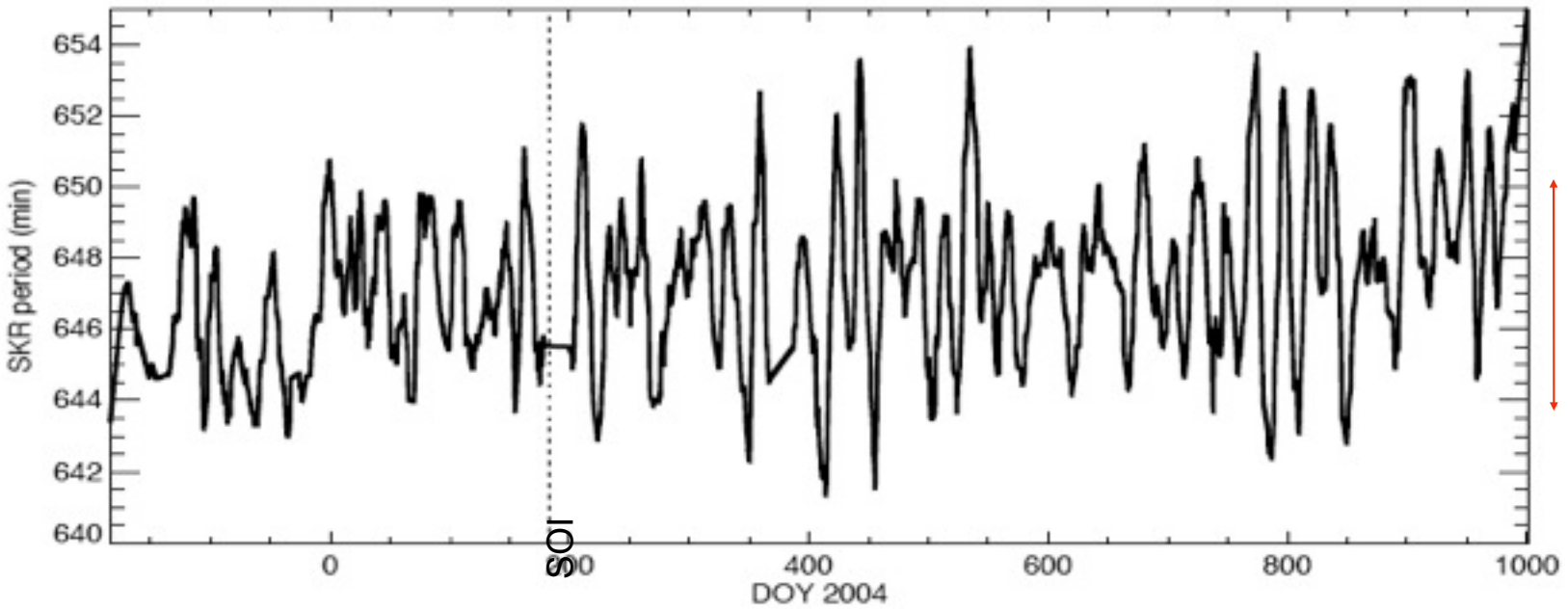




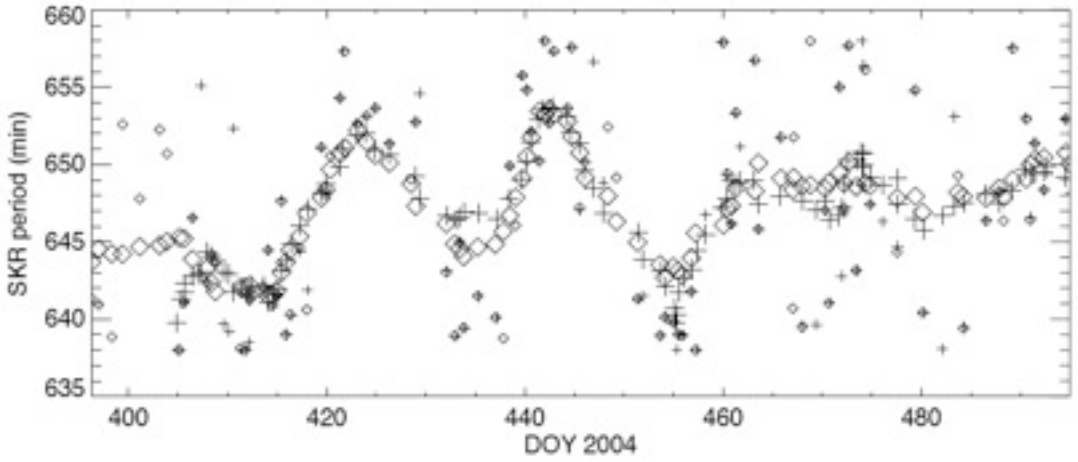


[Zarka et al., 2007]

Oscillations of radio period discovered at 20-30 days

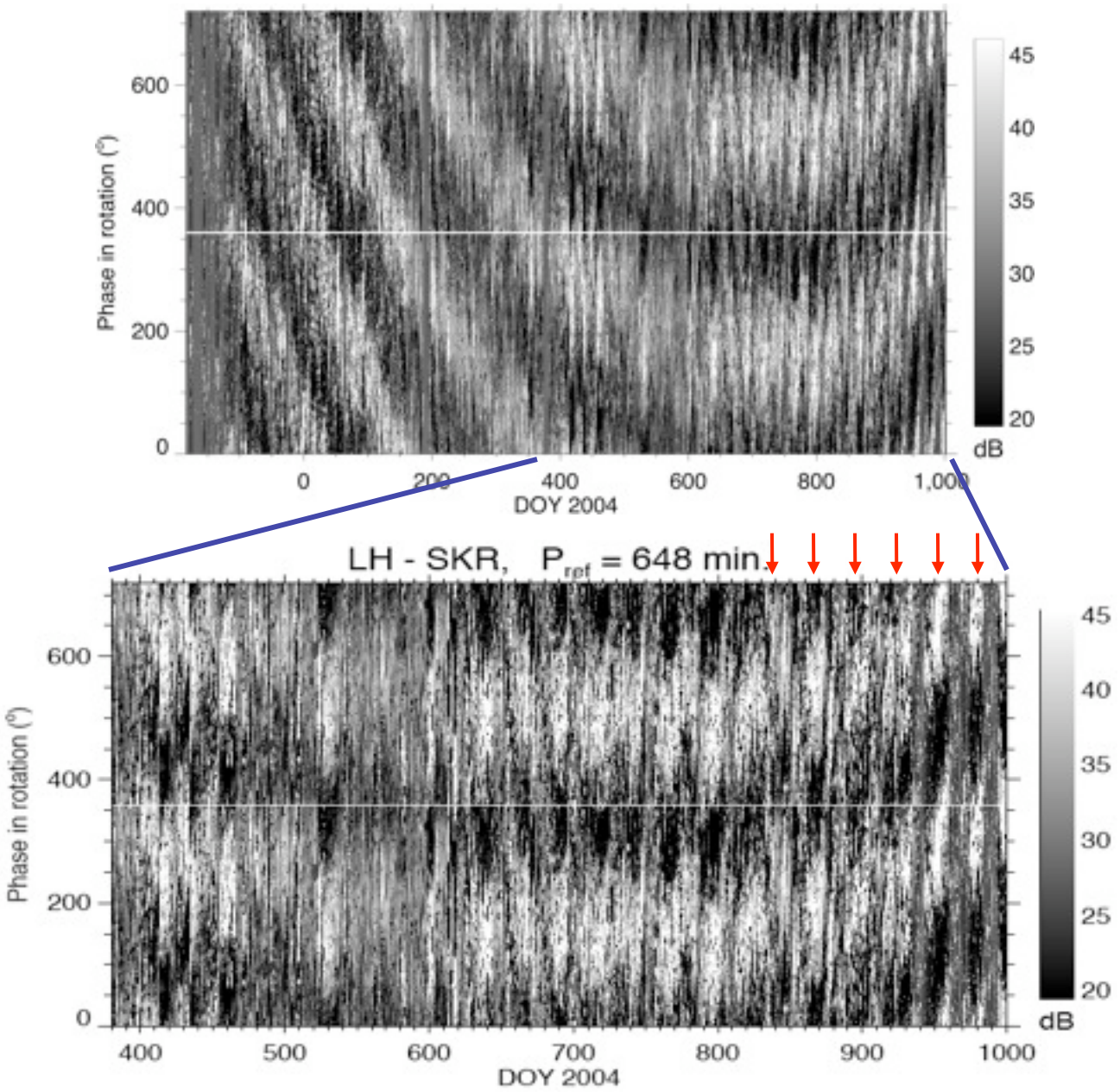


S/N ~5



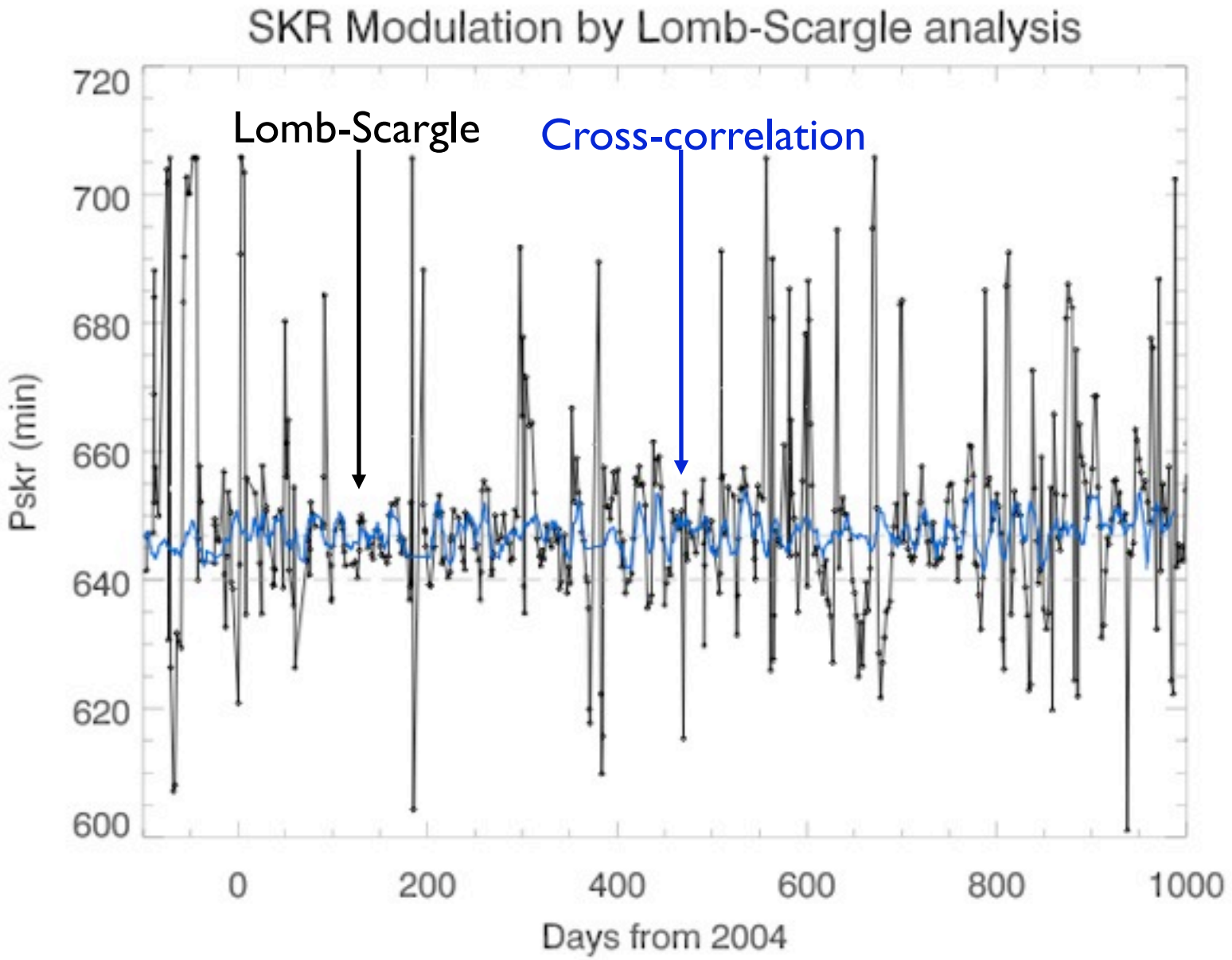
[Zarka et al., 2007]

Oscillations of radio period discovered at 20-30 days



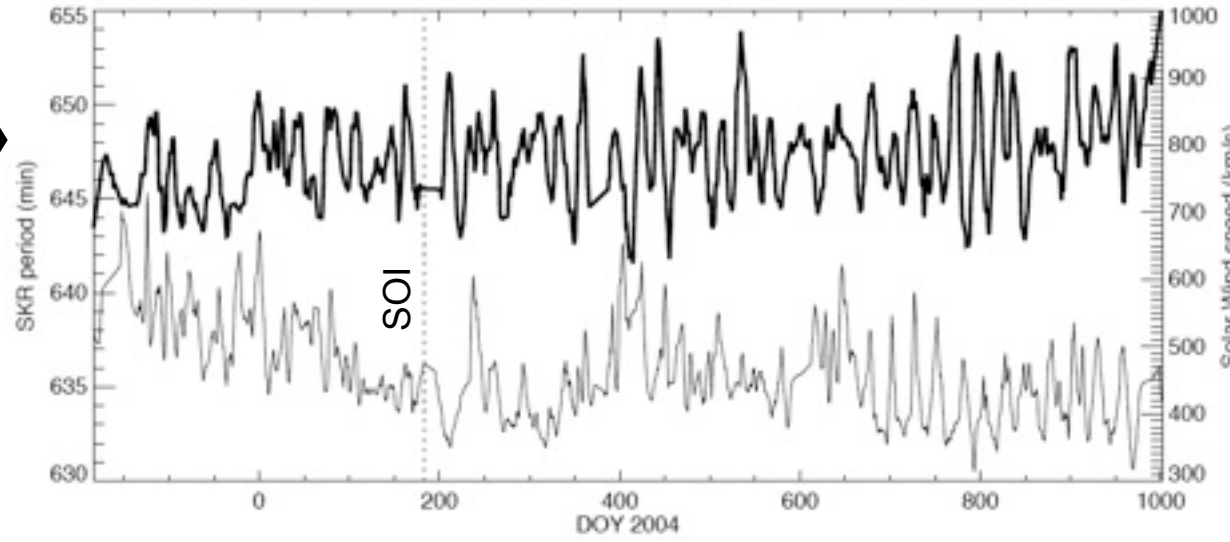
[Zarka et al., 2007]

Oscillations of radio period discovered at 20-30 days



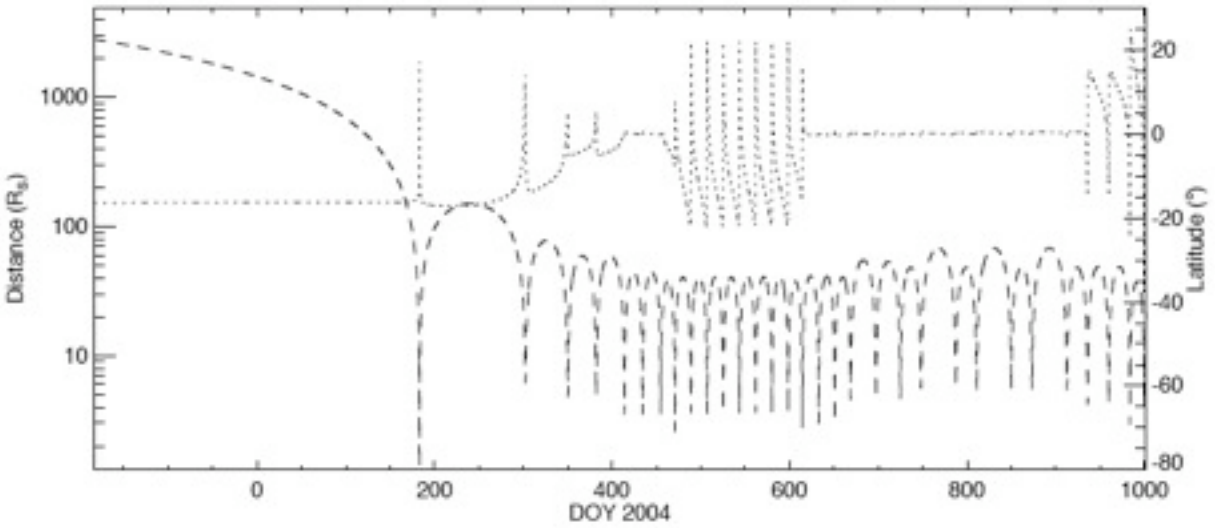
Origin of these oscillations ?

P_{SKR} ⇨



⇦ V_{SW}

(ballistic projection from Wind)



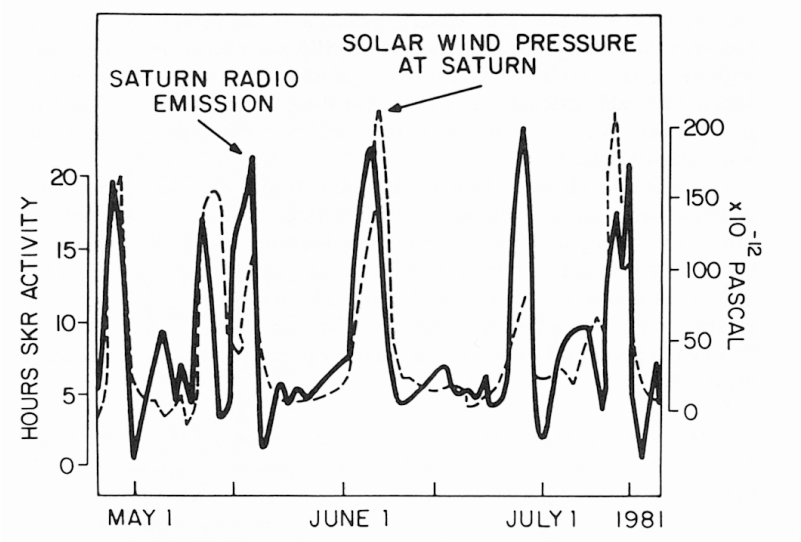
⇦ Latitude

&

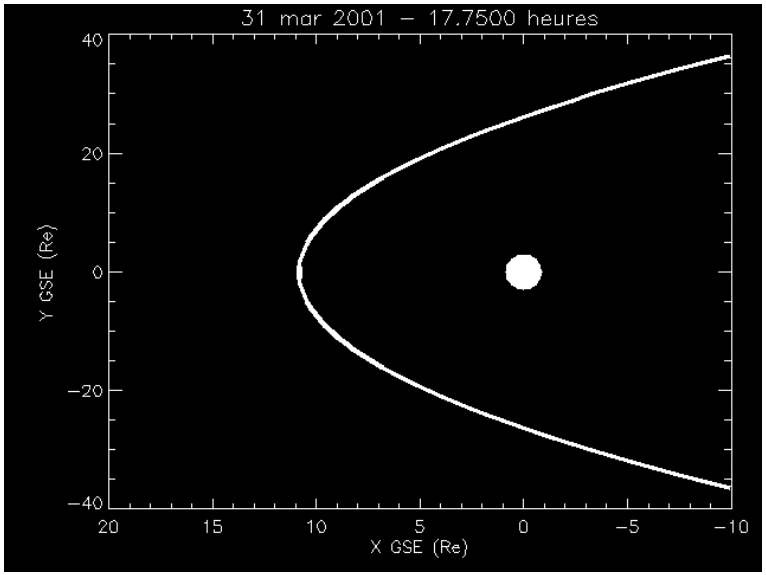
⇦ Distance of Cassini

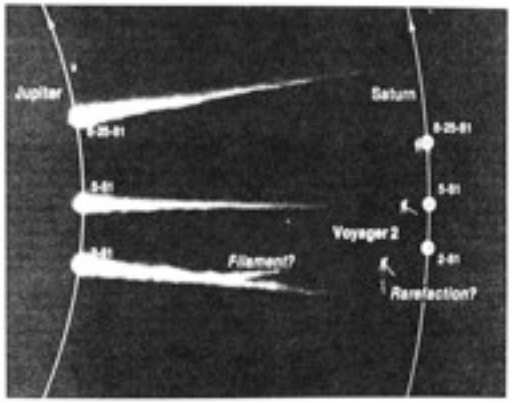
[Zarka et al., 2007]

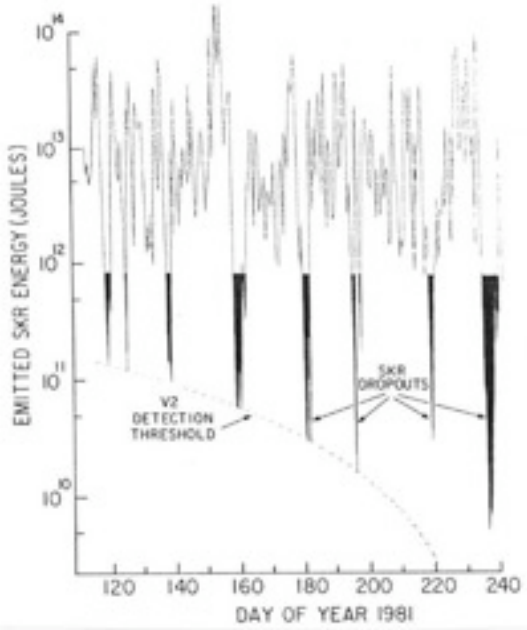
Well-known influence of Solar Wind on radio intensity



[Desch, 1982 ; Desch & Rucker, 1983]

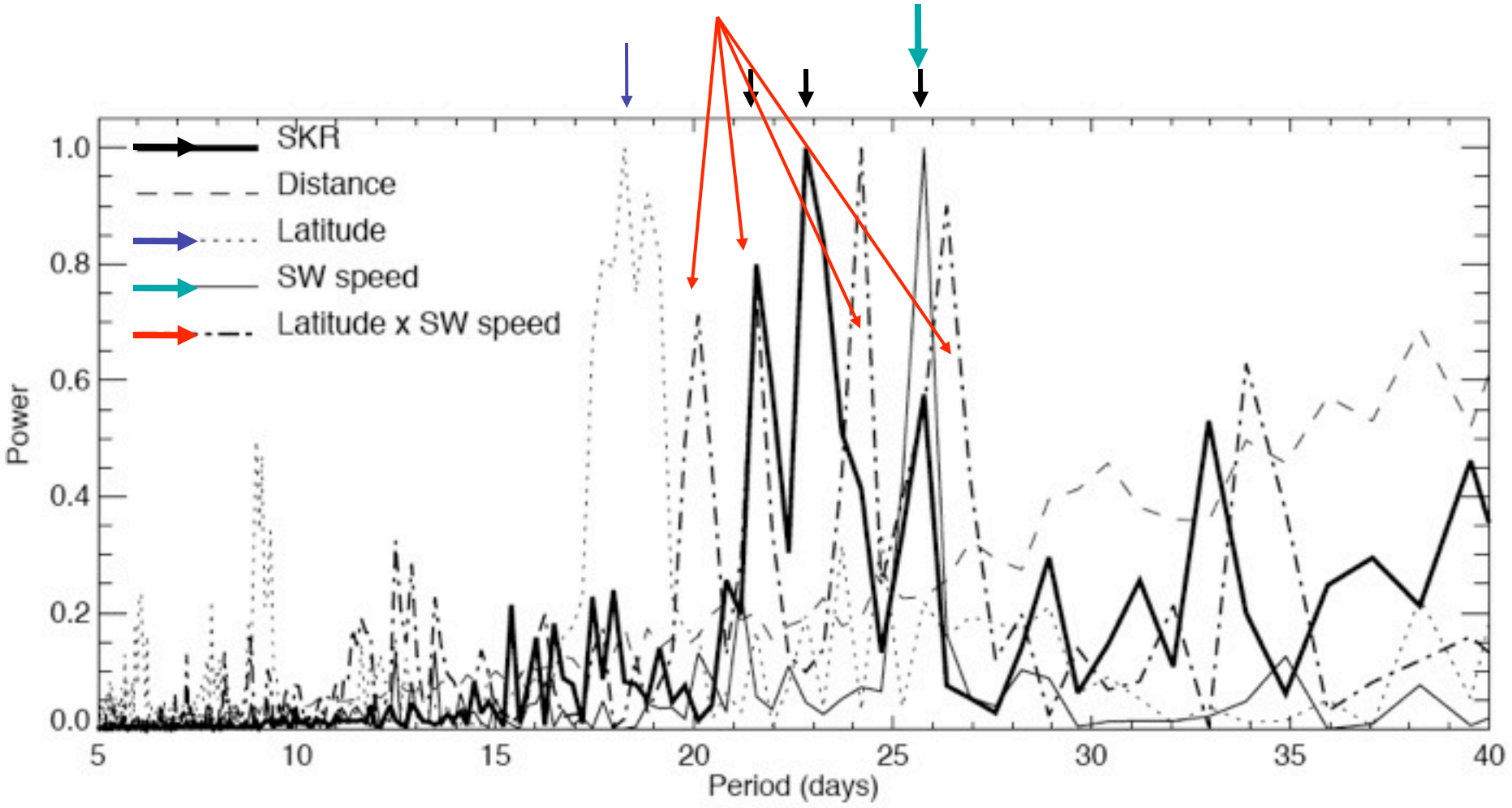






[Desch, 1983]

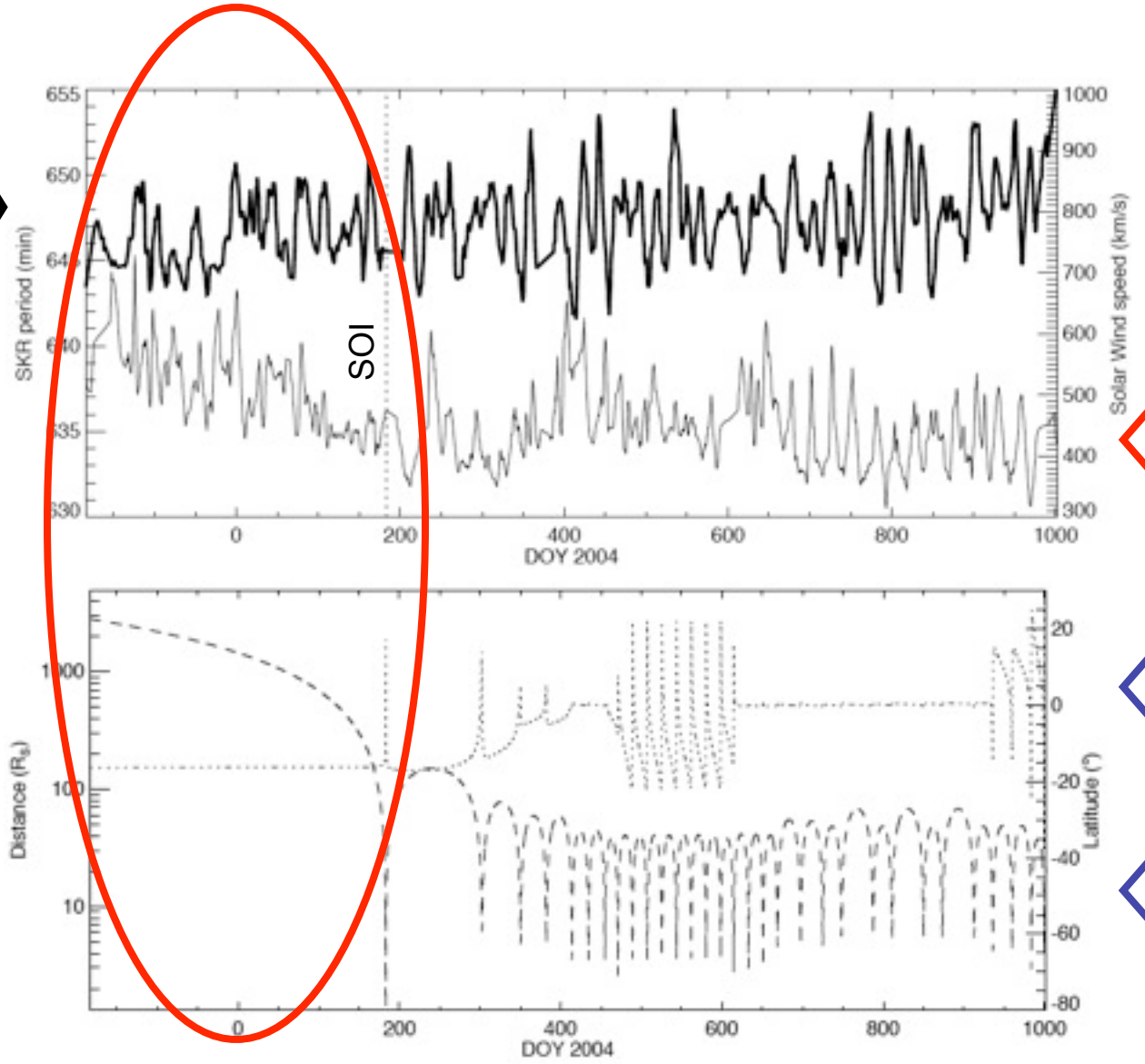
Variable radio period : Solar Wind & Visibility ?



[Zarka et al., 2007]

Confirmation : Cassini's approach trajectory

P_{SKR}



V_{SW}

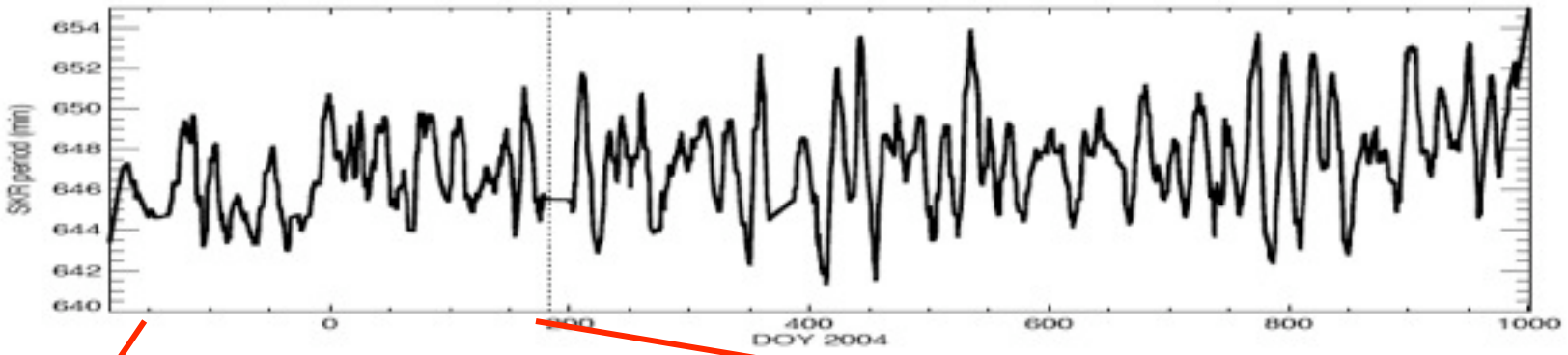
Cassini

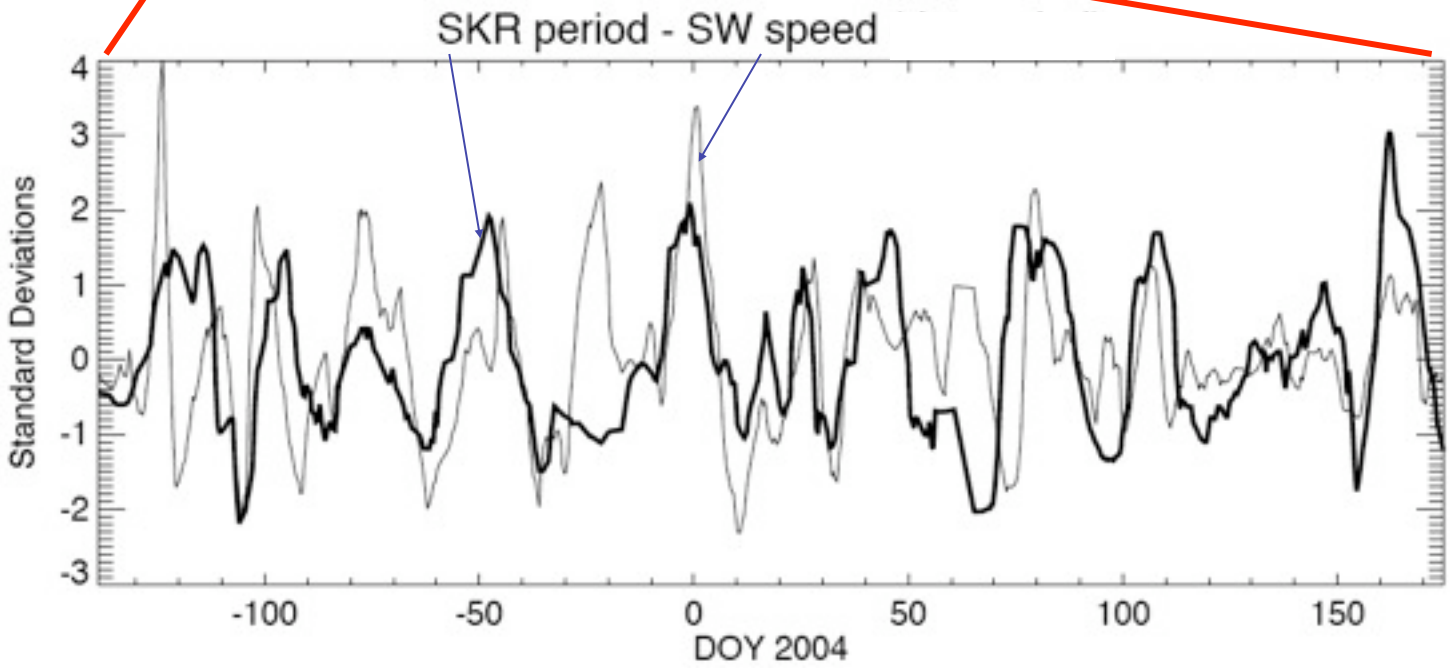
Latitude

&

Distance

→ Relation between Radio period and Solar Wind speed





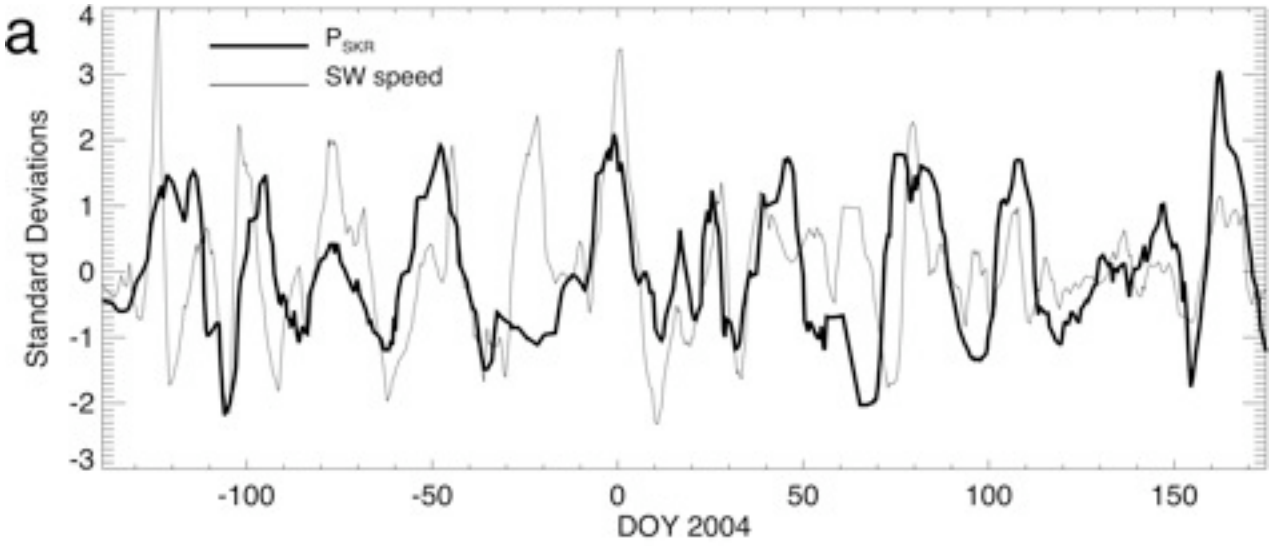
correlation > 40%

confidence = 100%

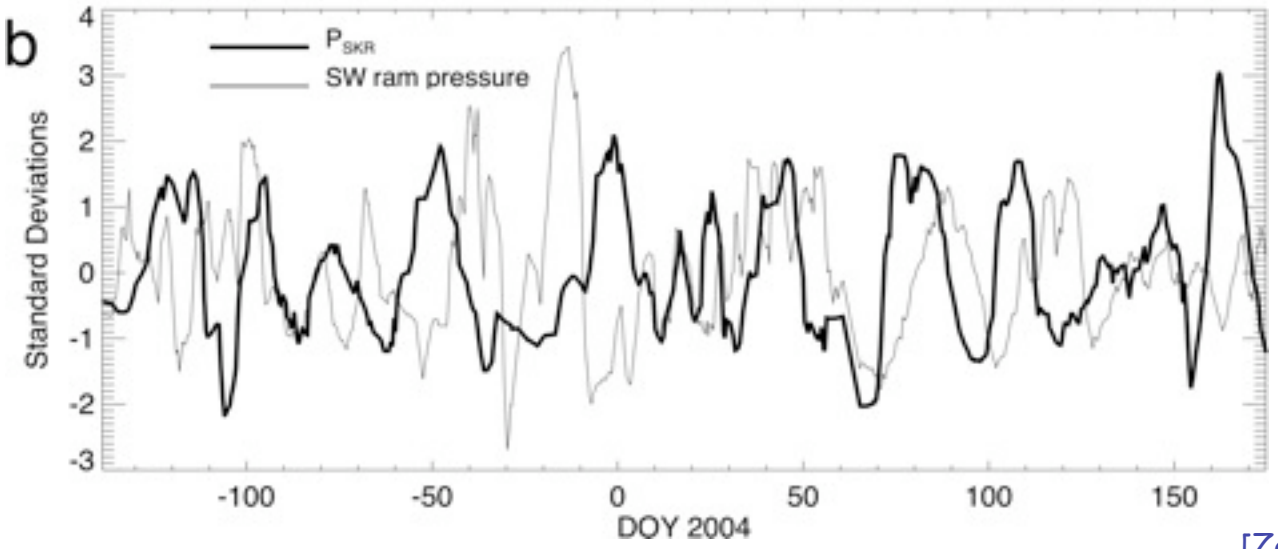
[Zarka et al., 2007]

→ External origin !

→ Special role of Solar wind speed



C > 40%

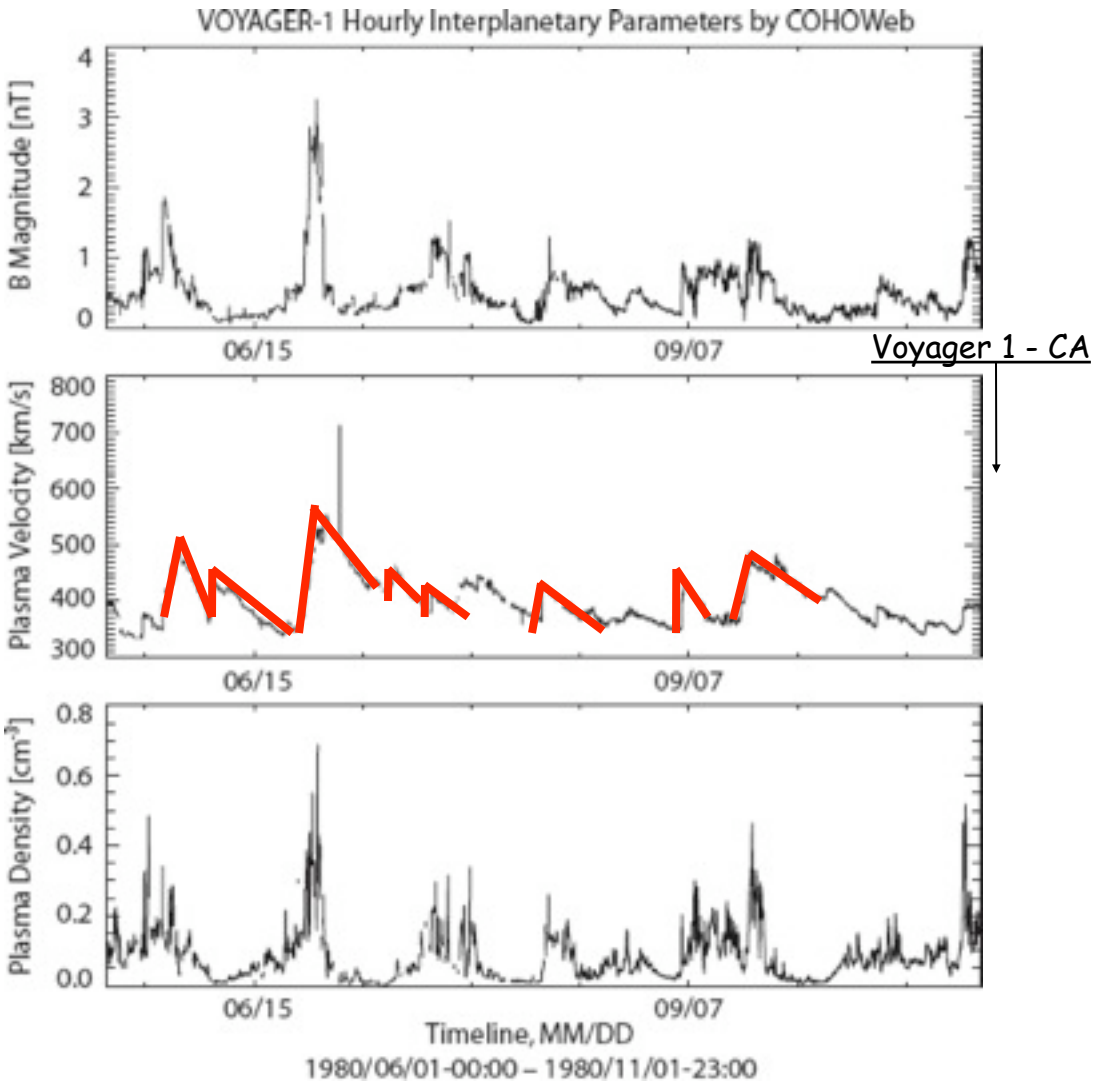


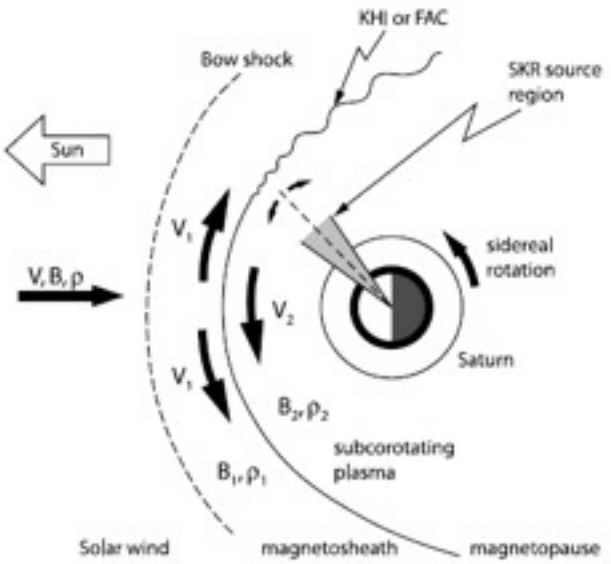
C ~ -10%

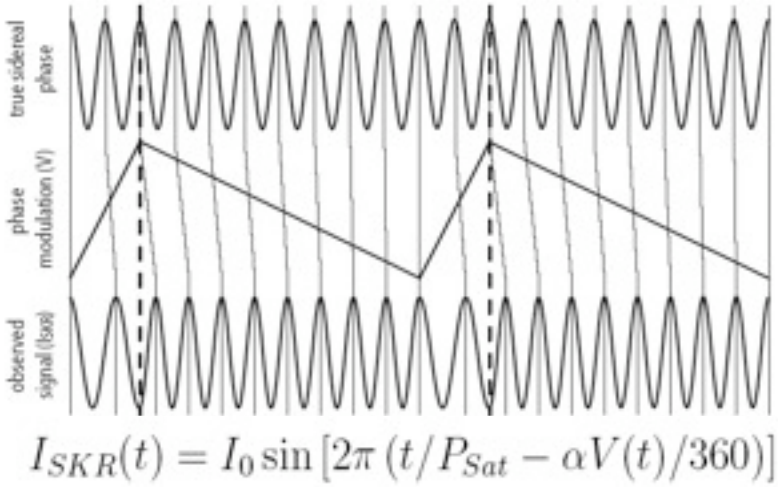
[Zarka et al., 2007]

- Planetary rotation
- Planetary radio emissions
- Radio measurements of Saturn's rotation period
- Saturn's variable radio period
- Why does it vary ?
- What may cause the variation ?
- What is Saturn's internal rotation period ?
- Next …

One (possible) explanation for Saturn's variable radio period



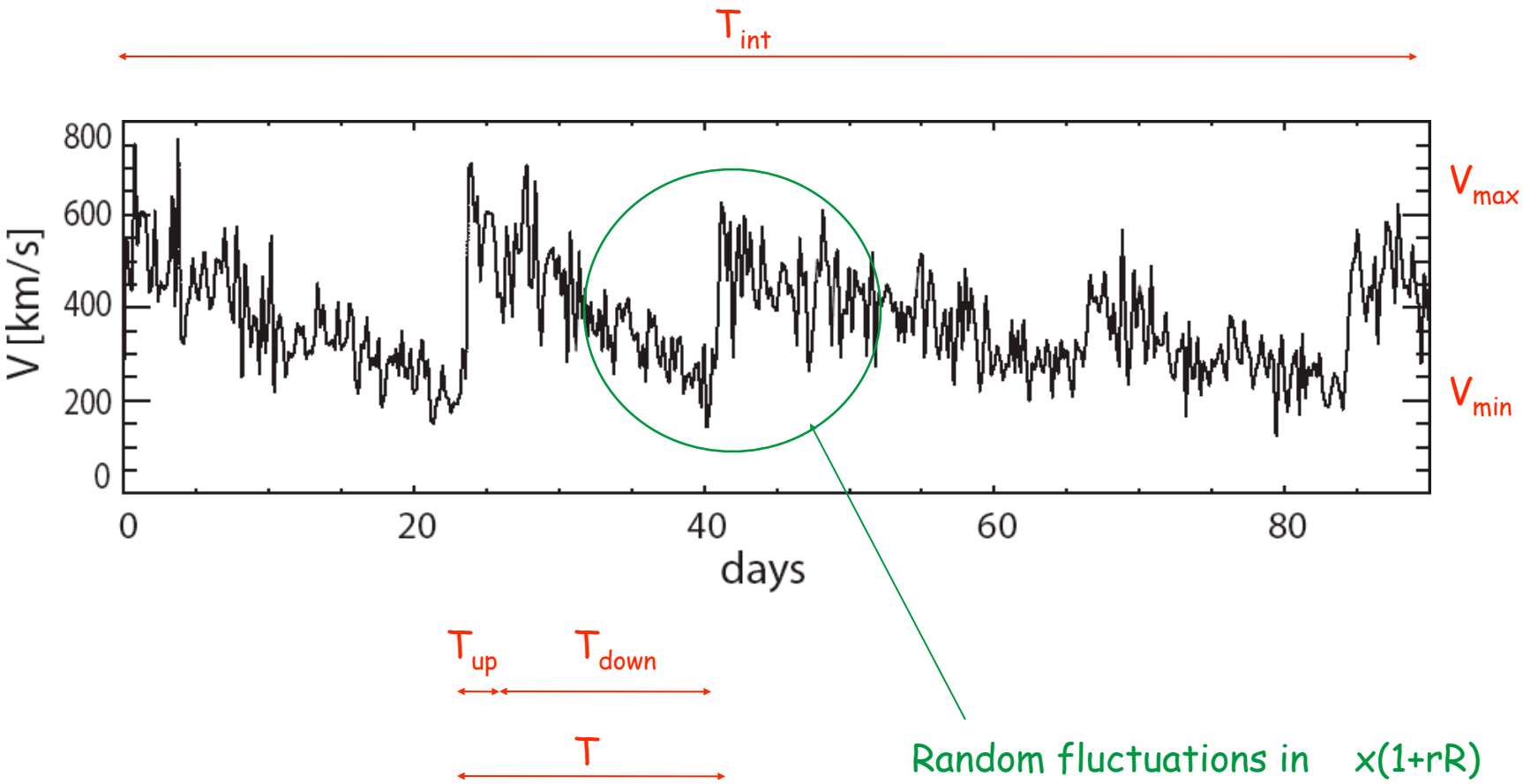




$$I_{SKR}(t) = I_0 \sin\left[2\pi\left(t/P_{Sat} - \alpha V(t)/360\right)\right]$$

[Cecconi & Zarka, 2005]

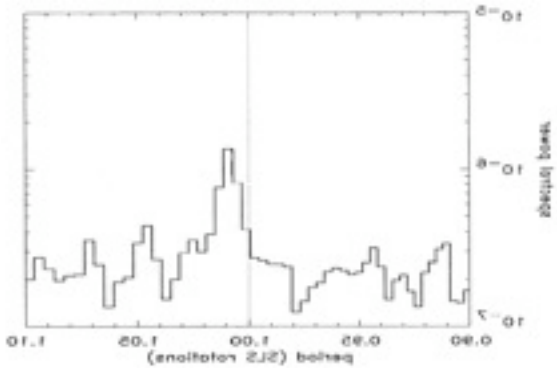
Solar Wind speed modelling …

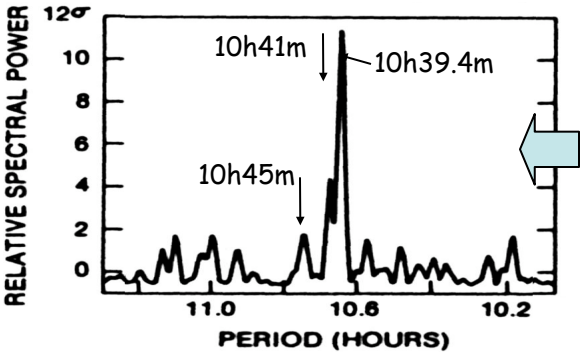


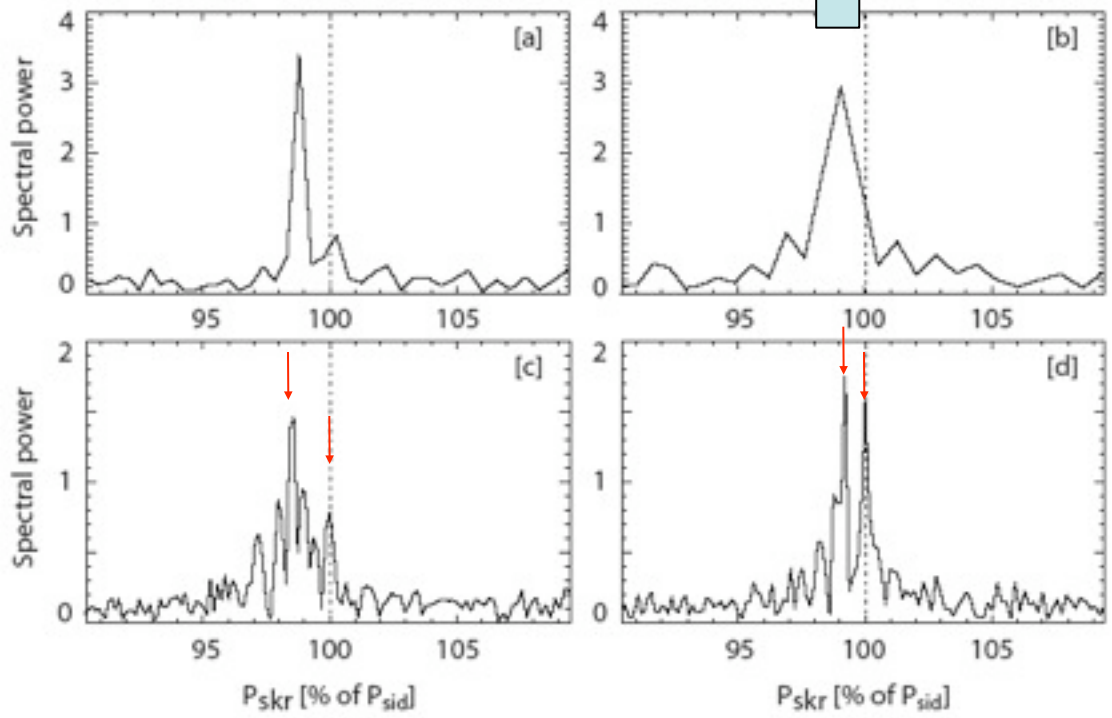
[Cecconi & Zarka, 2005]

… and resulting variable period

	T_{int}	T	α	R	P_{SKR}/P_{Sat}
[a]	90	26	0.5	0.2	0.987
[b]	60	26	0.4	0.2	0.993
[c]	270	26	0.6	0.2	0.985
[d]	270	26	0.6	0.2	0.991

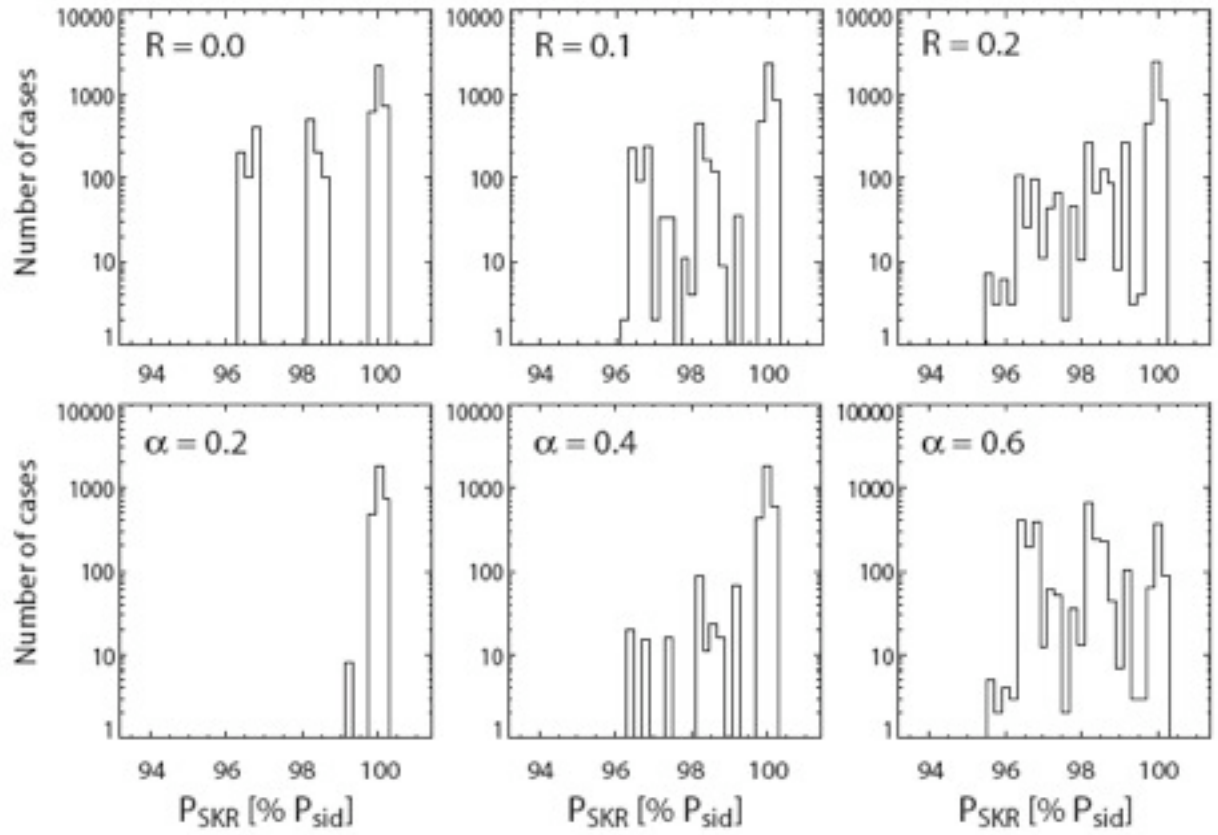






[Cecconi & Zarka, 2005]

… and resulting variable period



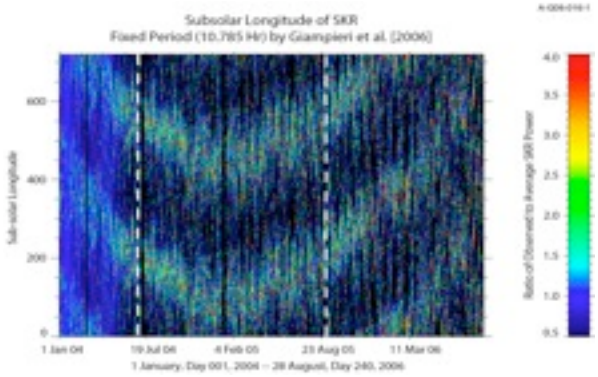
- $P_{radio} \in [0.96\text{-}1.] \times P_{Saturn}$

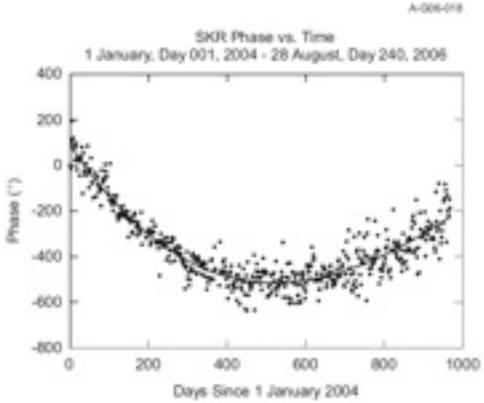
  for $R \geq 0.1$ $\alpha \geq 0.2$ °/(km/s) T_{int} = <45 à >270 days

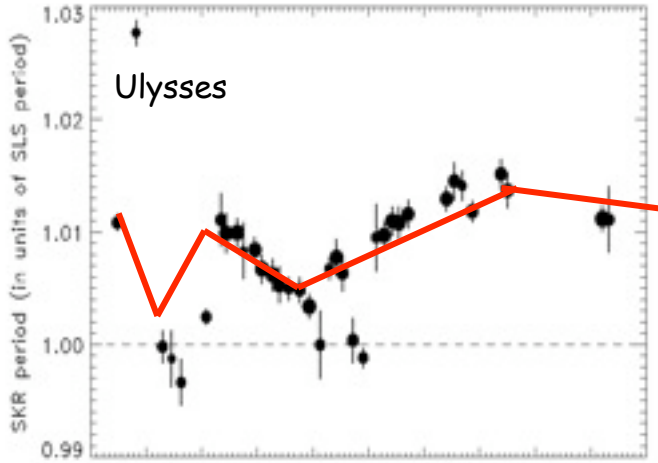
- $P_{radio} \leq P_{Saturn}$ for $\alpha > 0$

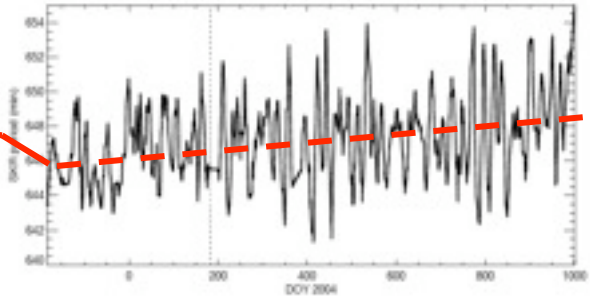
[Cecconi & Zarka, 2005]

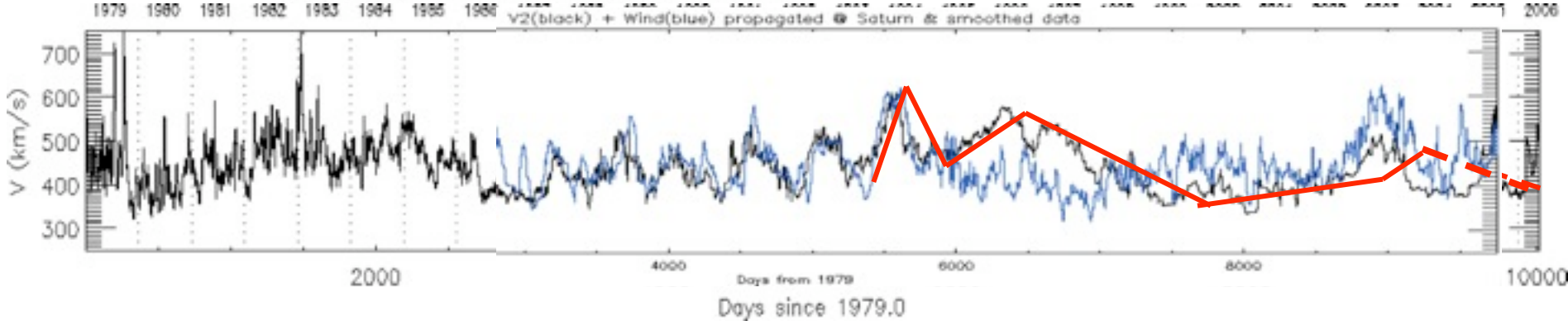
Long-term variations ?





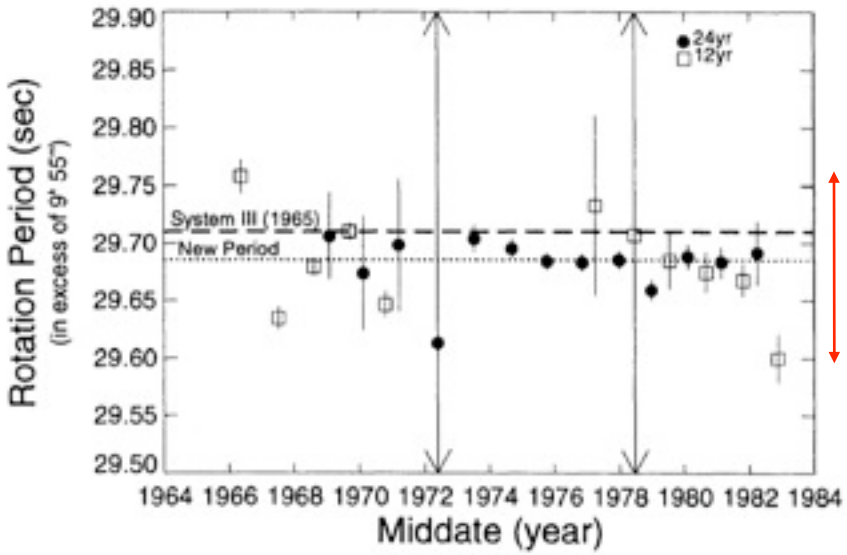






Rotation of Jupiter

$P_{Jupiter}$ = 9h 55m 29.685s



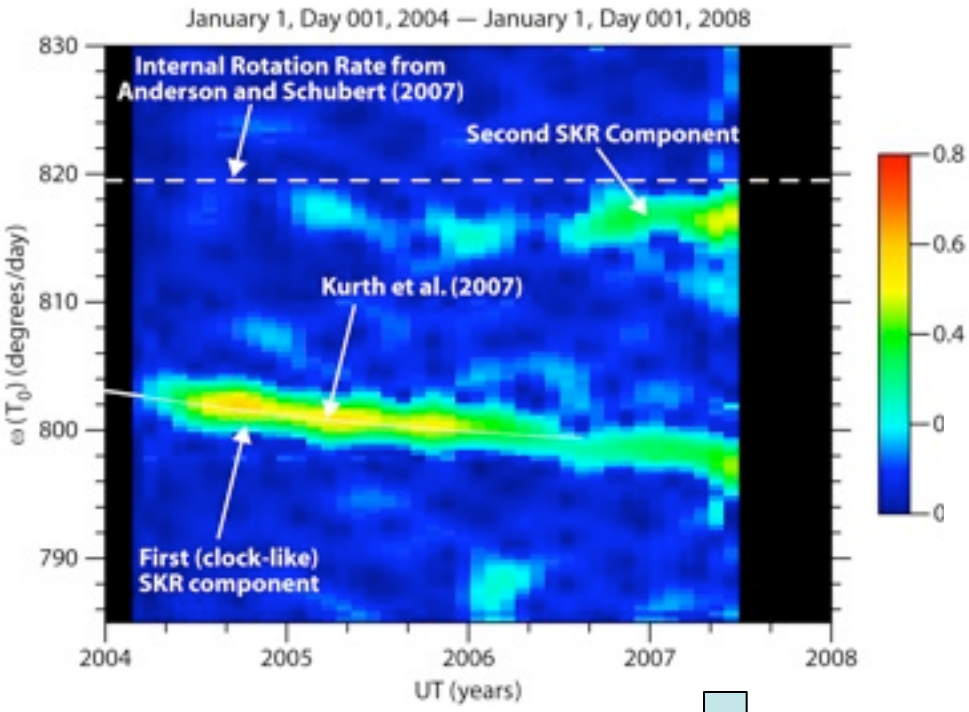
±0.08s ~10^{-6}

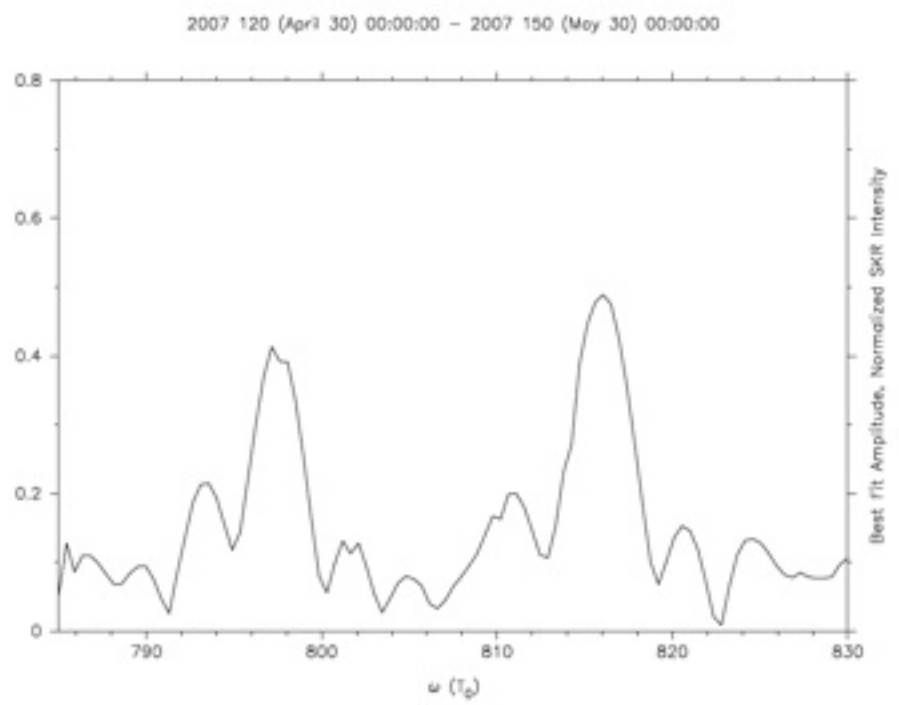
Density variation of Io plasma torus ~ x2 between Voyager (1979) and Galileo (1995-97)

⇒ radio source longitude varies by $\theta_A = 2\pi\, t_A / P_{Jupiter}$ ~ 10°-20°

⇒ error on $P_{Jupiter}$ = (θ_A/360°) x (P_{Jup}/24 years) ~ 10^{-6} as observed !

Latest Cassini result : 2 radio periods ?

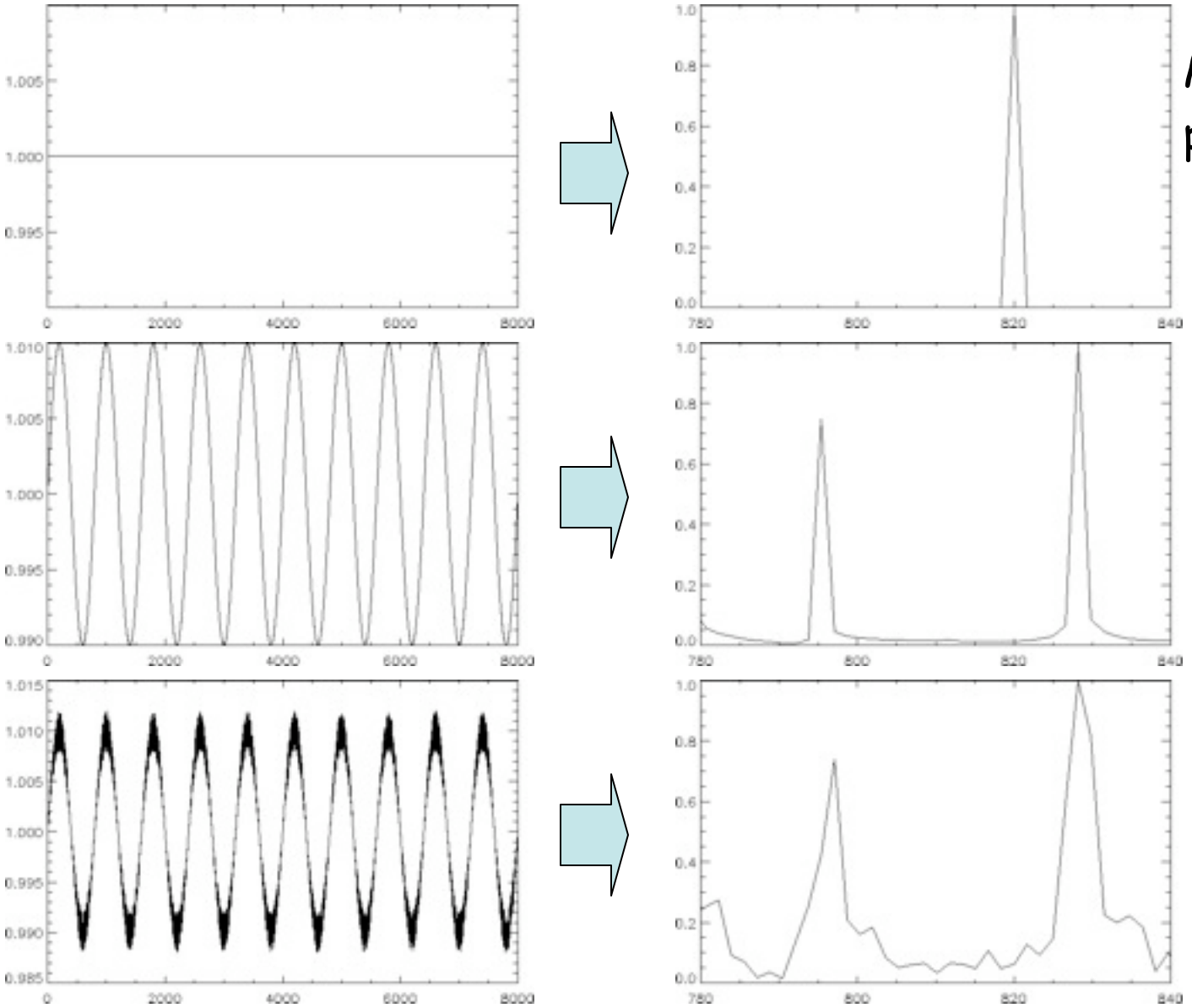




[Gurnett et al., 2007]

May be due to the oscillating period !

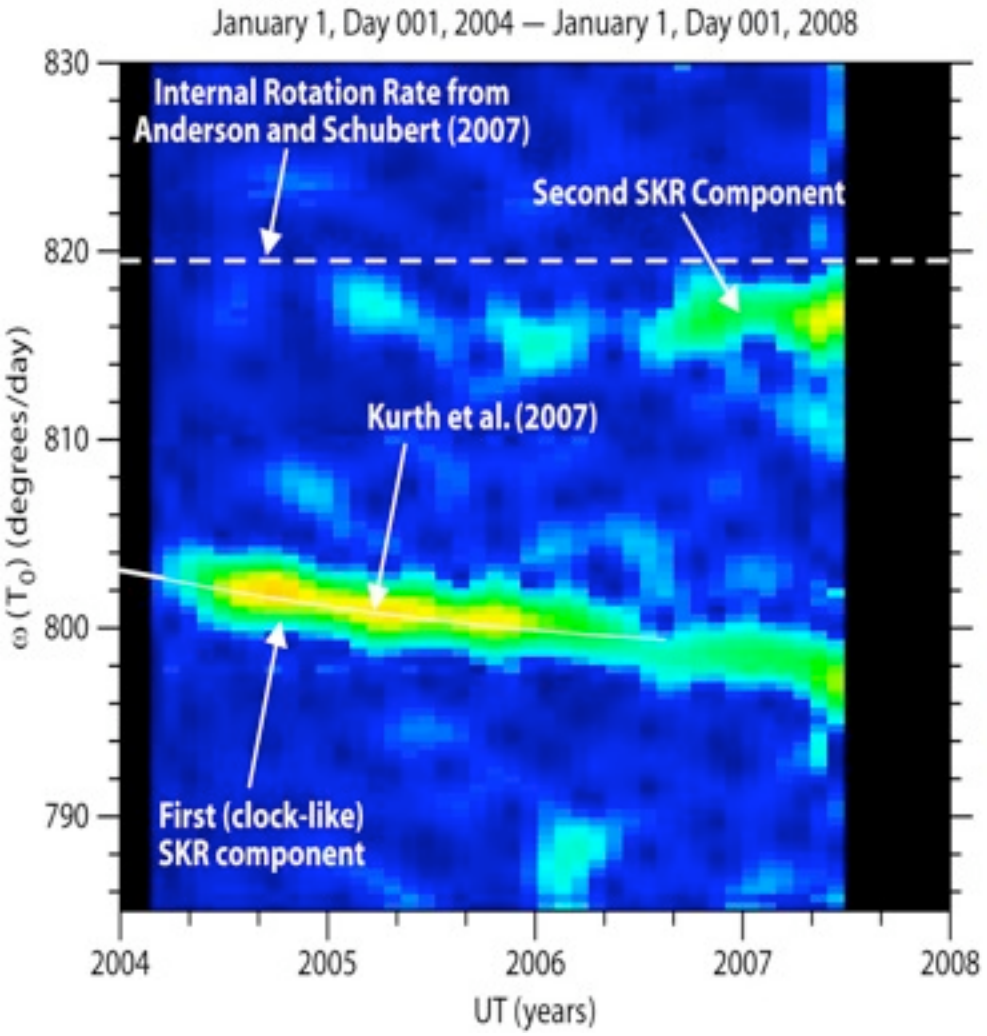
Actual period



Measured period

- Planetary rotation
- Planetary radio emissions
- Radio measurements of Saturn's rotation period
- Saturn's variable radio period
- Why does it vary ?
- What may cause the variation ?
- What is Saturn's internal rotation period ?
- Next …

Saturn's internal rotation period ? ...



Gravitation, Occultation, Doppler
[Anderson & Schubert, 2007]

VOYAGER-radio
[Desch & Kaiser, 1981]

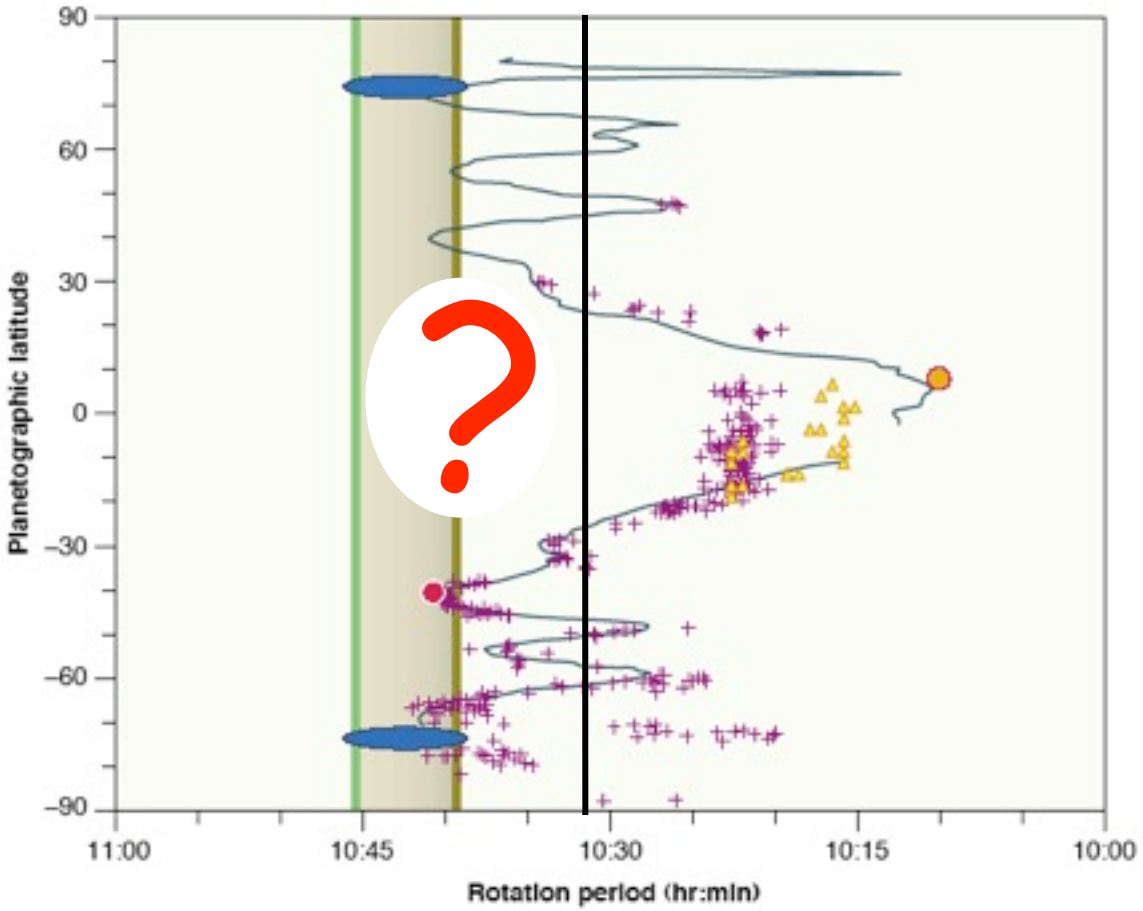
CASSINI-radio
[Cecconi & Zarka, 2005]

… and atmospheric winds speed

CASSINI-radio
[Cecconi & Zarka, 2005]

VOYAGER-radio
[Desch & Kaiser, 1981]

Gravitation, Occultation, Doppler
[Anderson & Schubert, 2007]



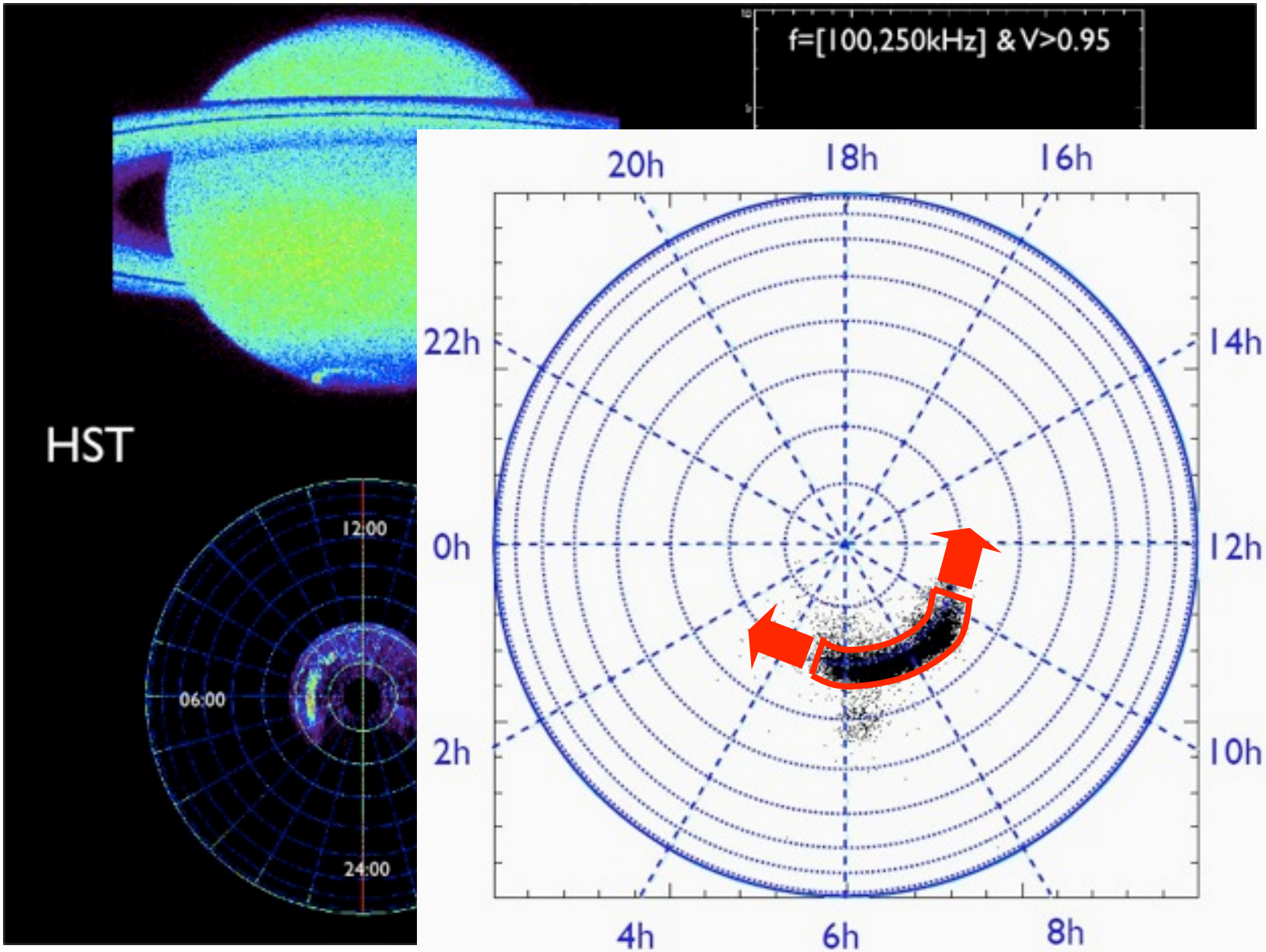
Is there ONE internal rotation period at Saturn ?

- Differential rotation versus latitude ?

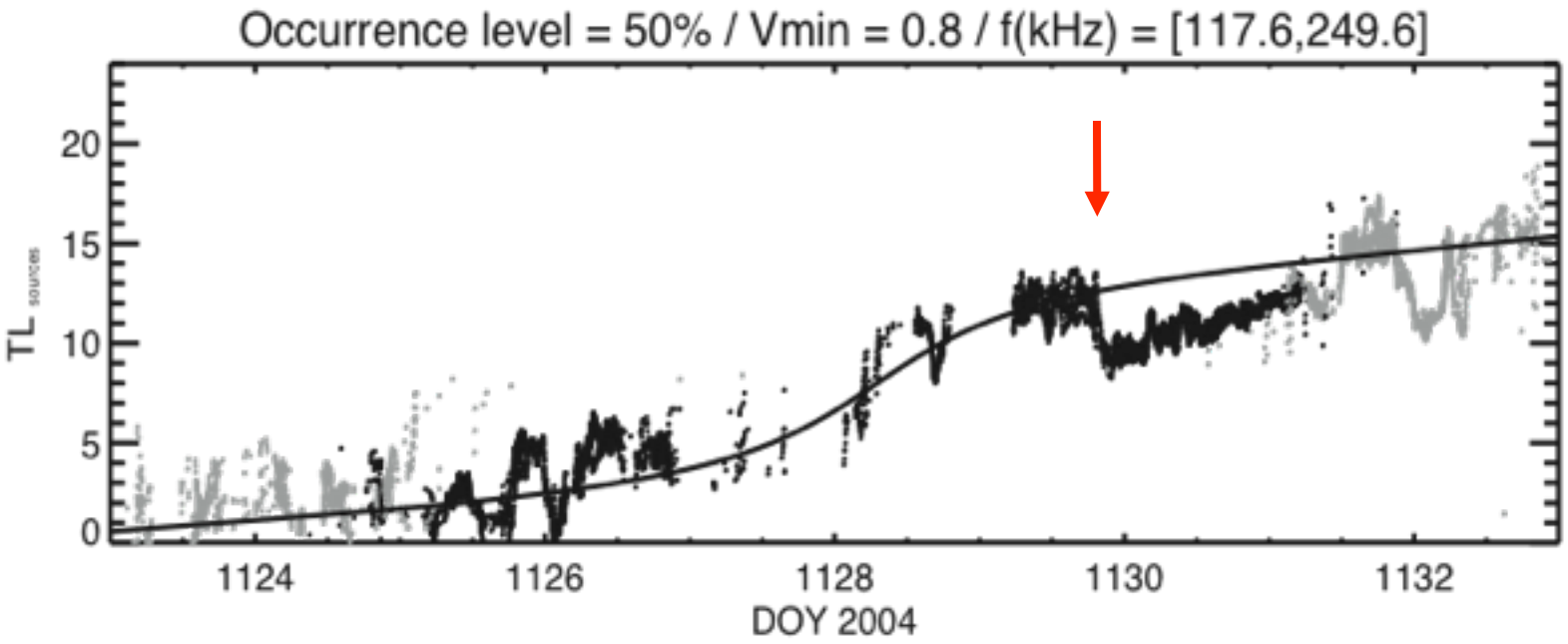
- Differential rotation versus depth ?

- Planetary rotation
- Planetary radio emissions
- Radio measurements of Saturn's rotation period
- Saturn's variable radio period
- Why does it vary ?
- What may cause the variation ?
- What is Saturn's internal rotation period ?
- Next …

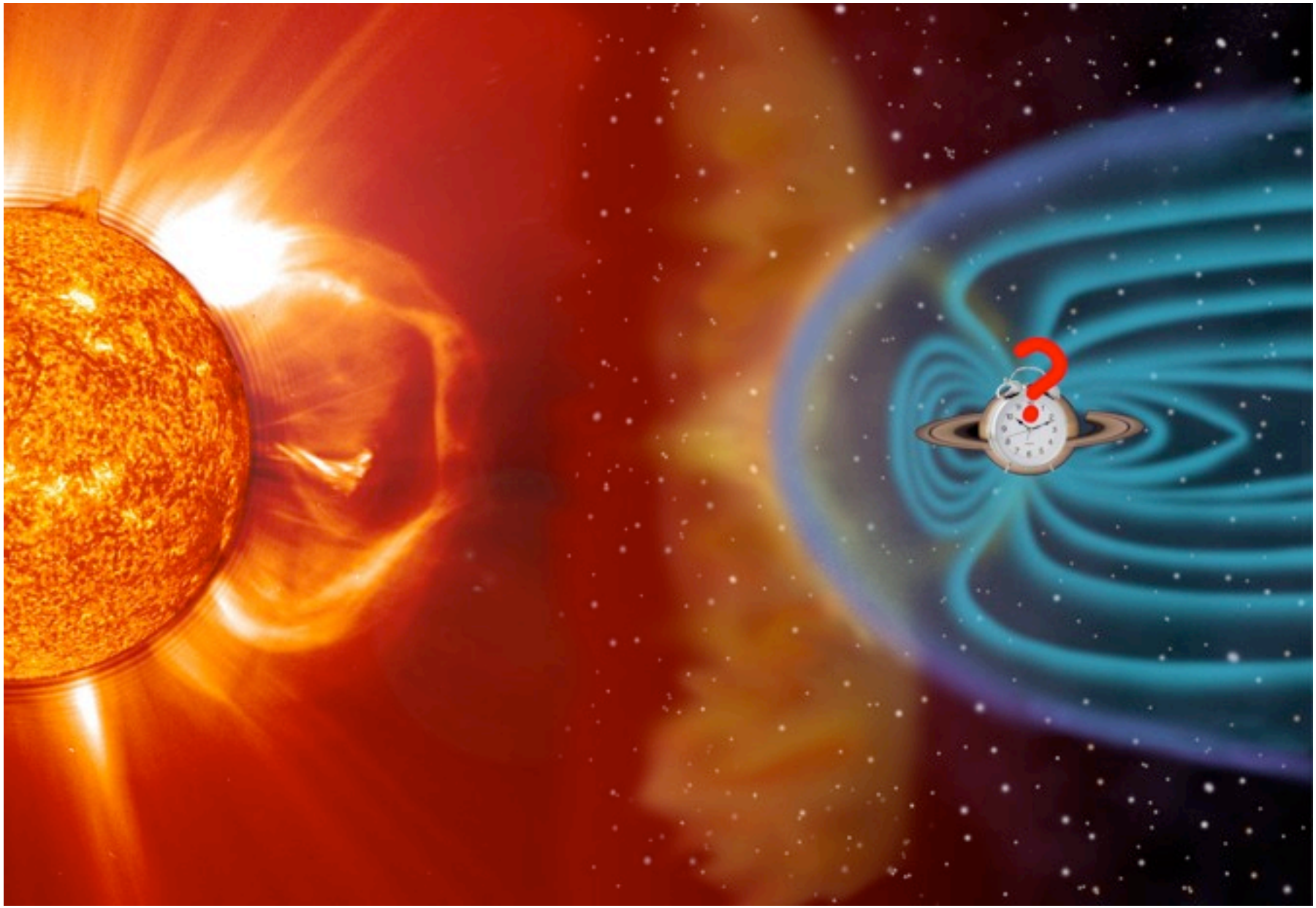
A possible answer under study …

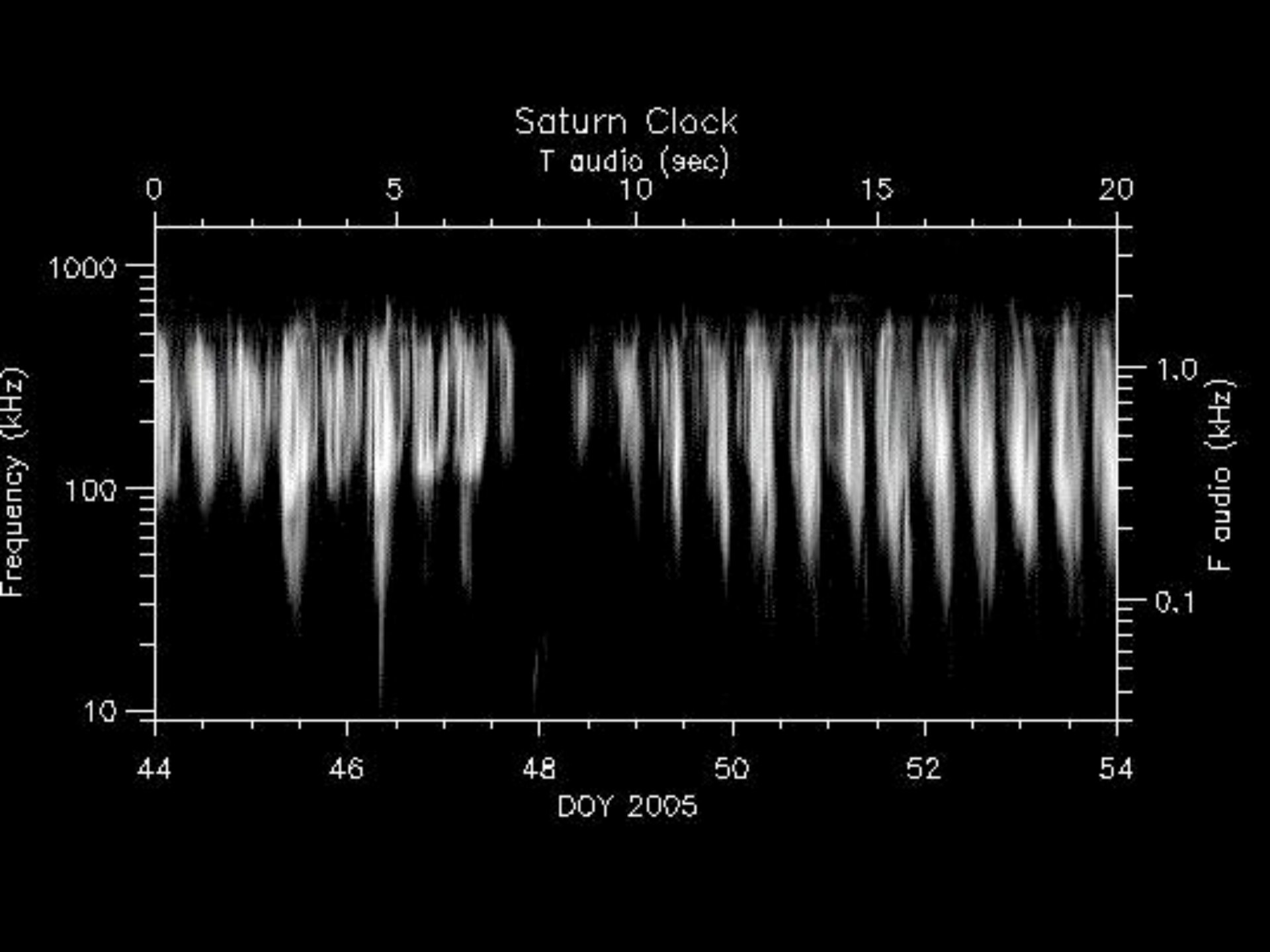


A possible answer under study …



To be continued …




Saturn Clock
T audio (sec)
0
5
10
15
20
1000
100
10
Frequency (kHz)
1.0
0.1
F audio (kHz)
44
46
48
50
52
54
DOY 2005

References :

- P. Zarka, L. Lamy, B. Cecconi, R. Prangé & H. O. Rucker, Modulation of Saturn's radio clock by solar wind speed, Nature, 8 Nov. 2007.

- B. Cecconi & P. Zarka,
  Model of a variable radio period for Saturn,
  J. Geophys. Res. 110, A12203, 2005.