

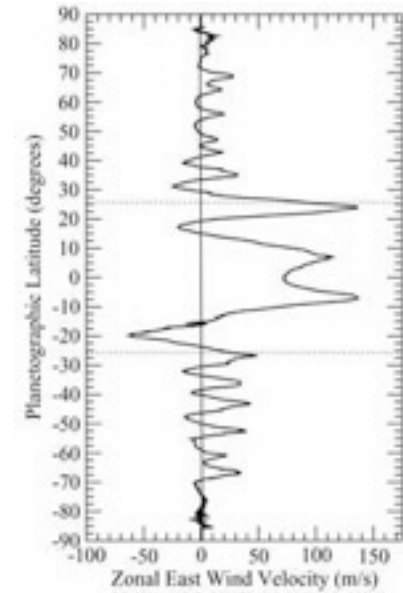
L'énigme de la période radio variable de Saturne

Philippe Zarka

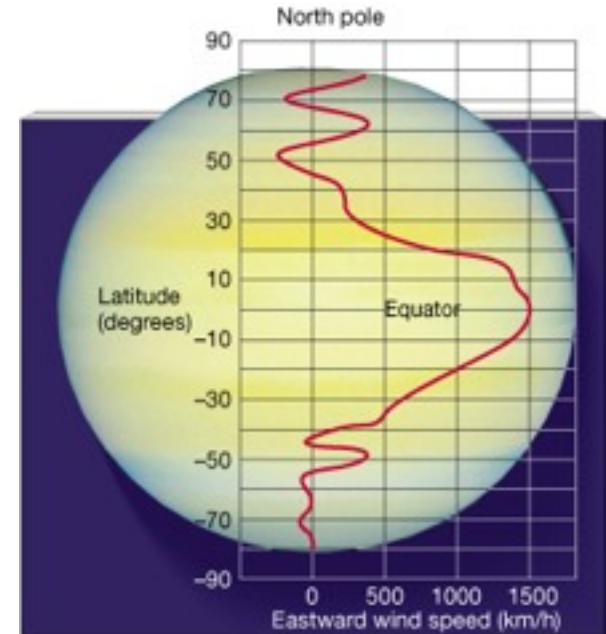
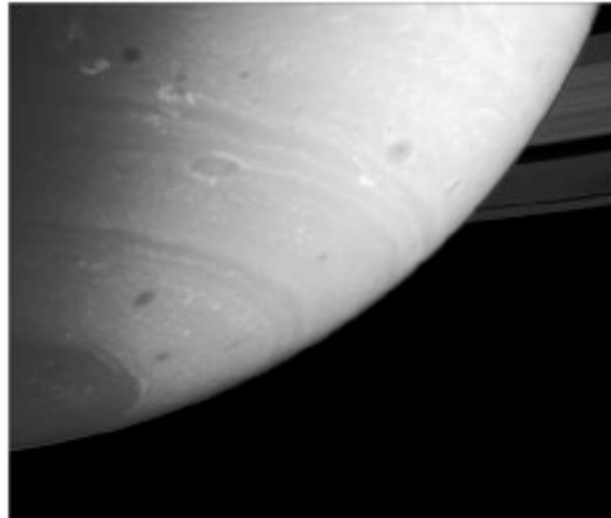
LESIA, CNRS - Observatoire de Paris, Meudon, France
philippe.zarka@obspm.fr

Rotation planétaire « visible » → imprécise

Jupiter



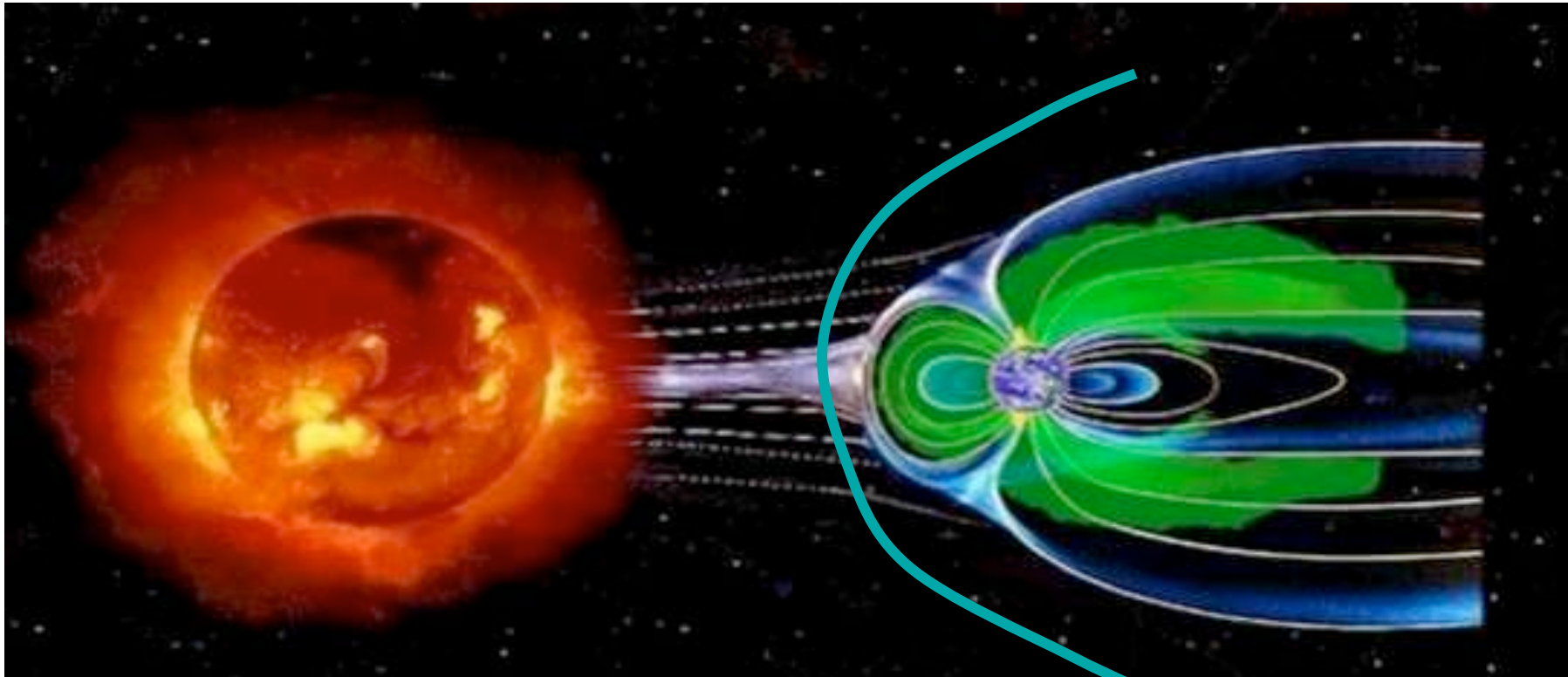
Saturne



Enjeux de la rotation planétaire (interne)

- Vitesse des vents
- Structure interne (répartition radiale et azimuthale des masses, interprétation des données gravitationnelles)
 - Transition H_2 moléculaire/métallique
 - Modèles de formation
- Forme de la planète (données d'occultation)
- Système de référence de longitudes
 - Fusion de données Pioneer, Voyager, Cassini...
 - Modèle de champ magnétique

Magnétosphères planétaires



MERCURY

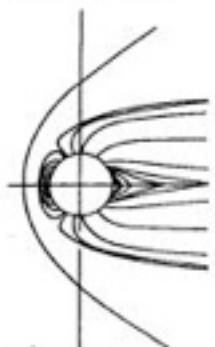
EARTH

JUPITER

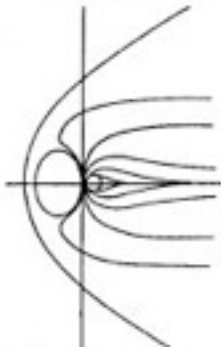
SATURN

URANUS

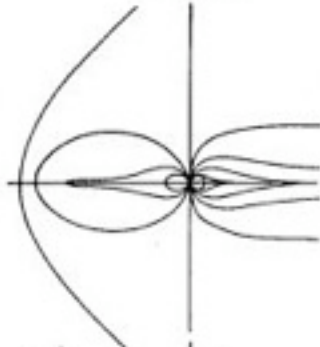
NEPTUNE



3.5×10^3 km



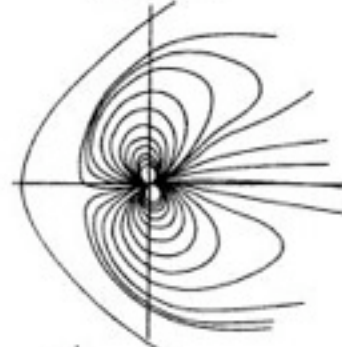
6.5×10^4 km



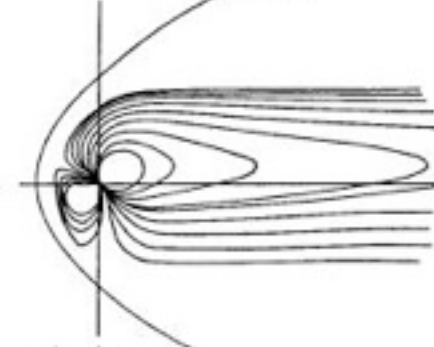
4.3×10^6 km



1.2×10^6 km

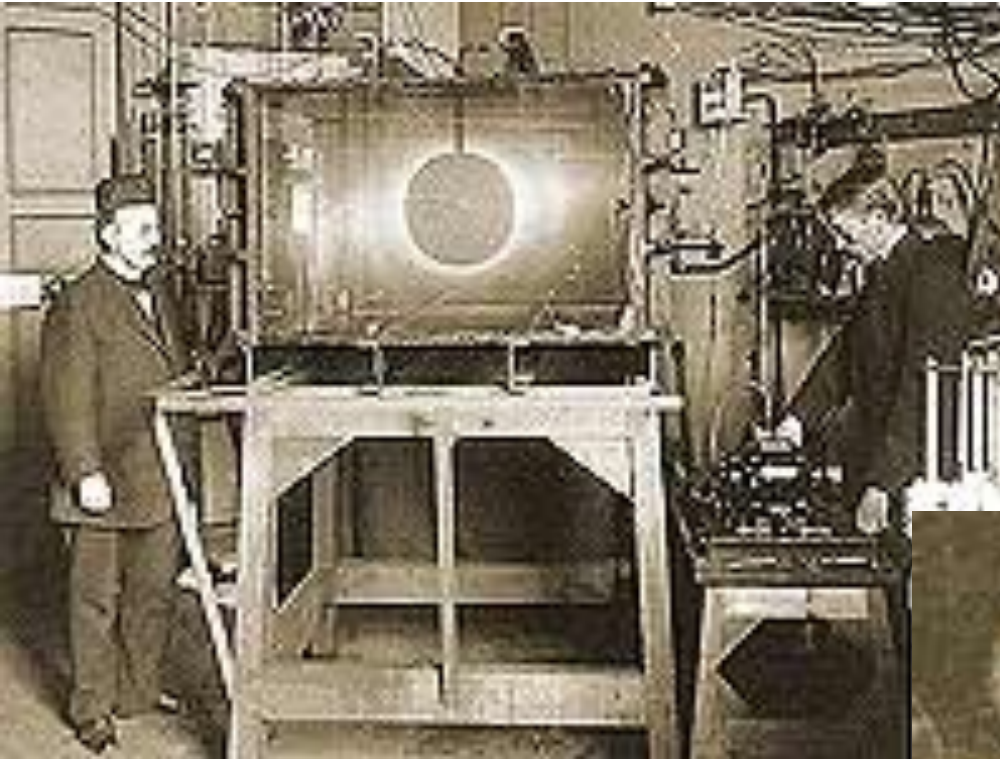


4.3×10^5 km



5.9×10^5 km

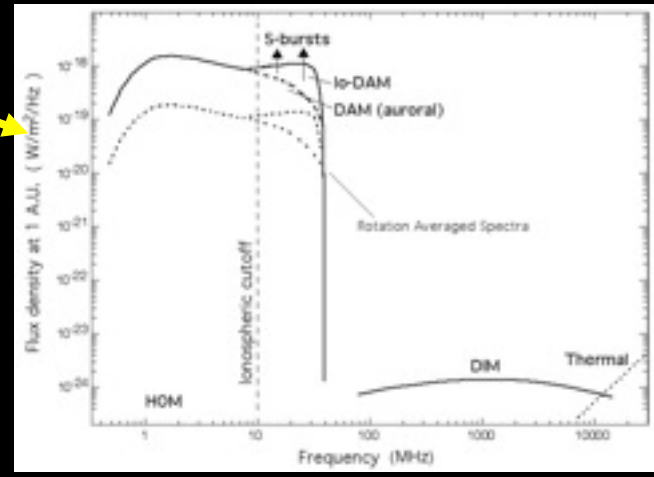
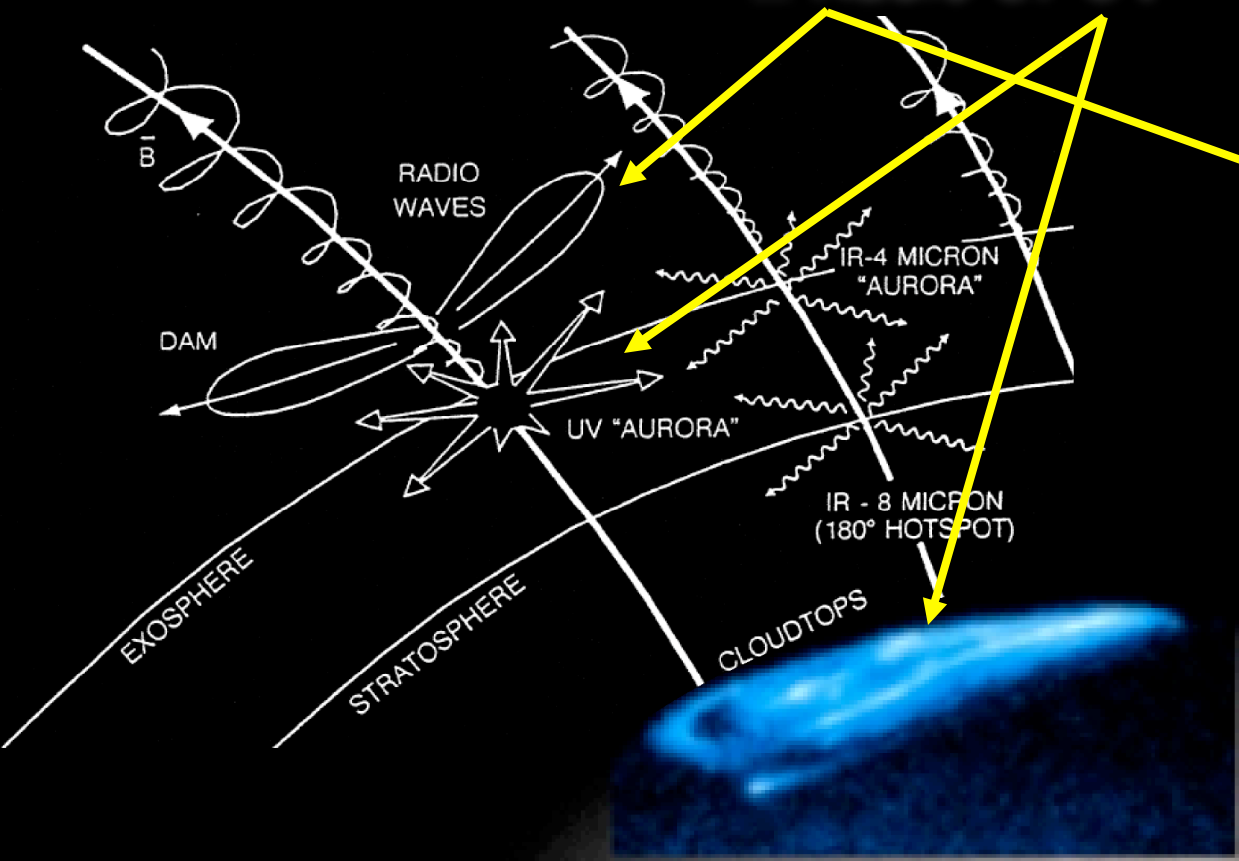
Électrons accélérés → émissions aurorales ...



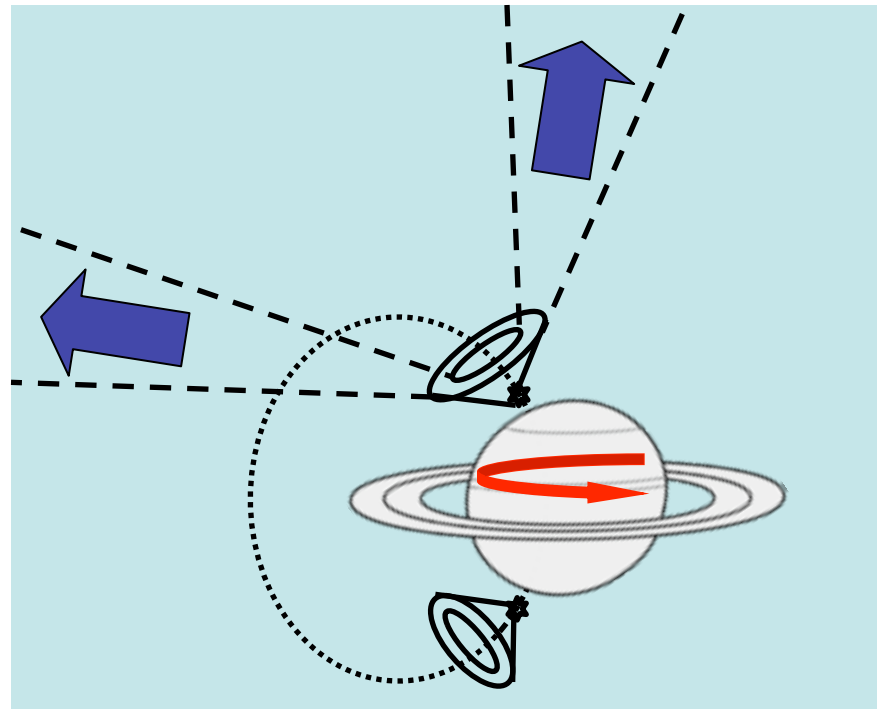
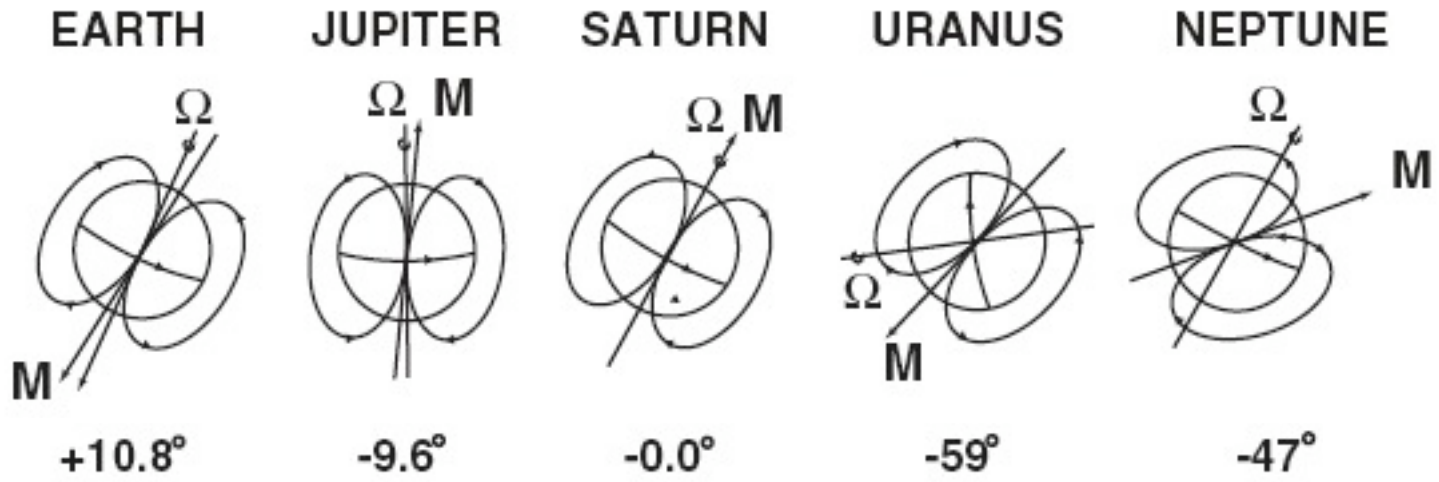
[Birkeland, 1910]



... Radio et UV

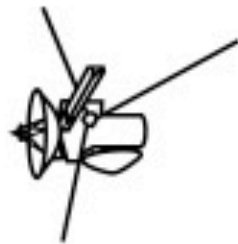
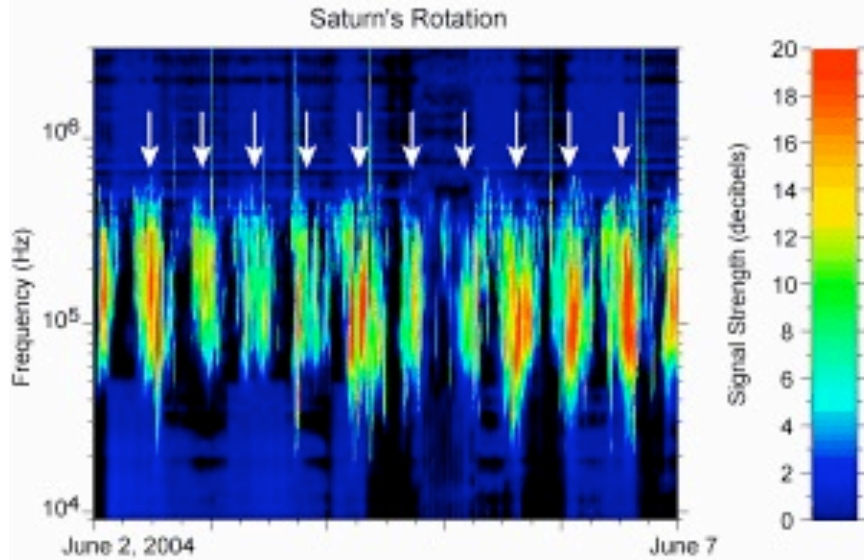


Rotation + B incliné + émissions radio anisotropes →

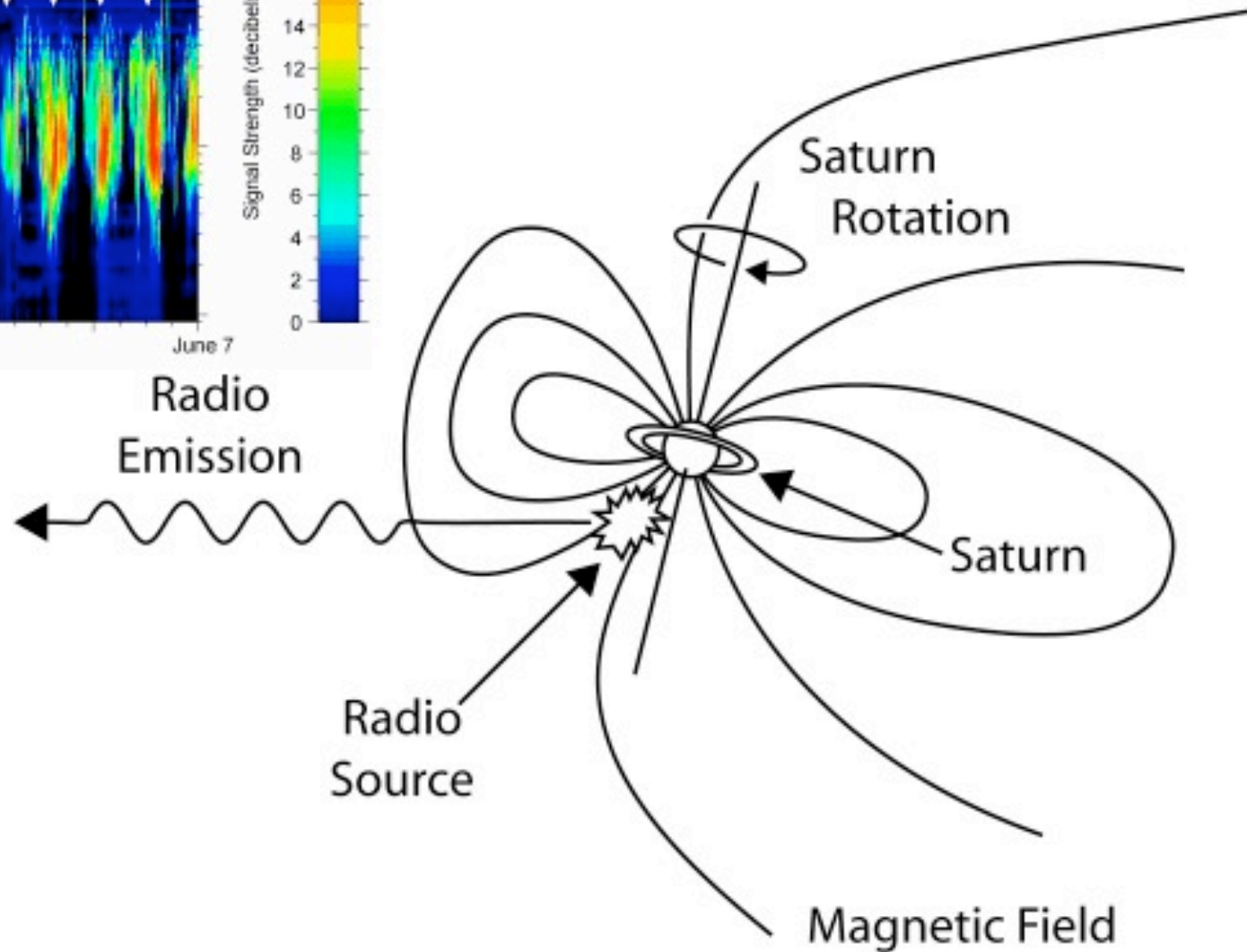


Forte modulation rotationnelle des émissions radio

A-D04-208-2

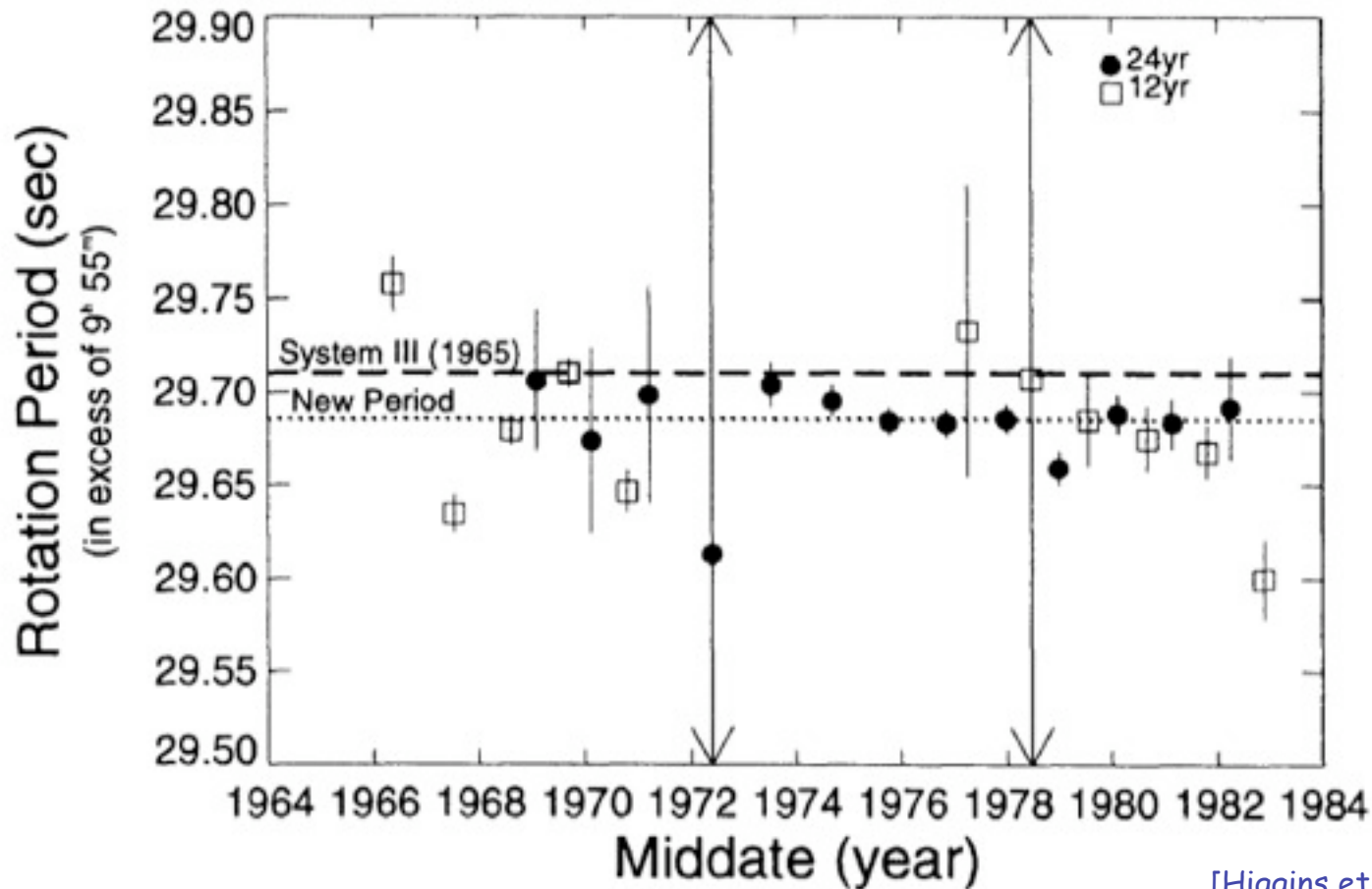


Cassini



Rotation de Jupiter

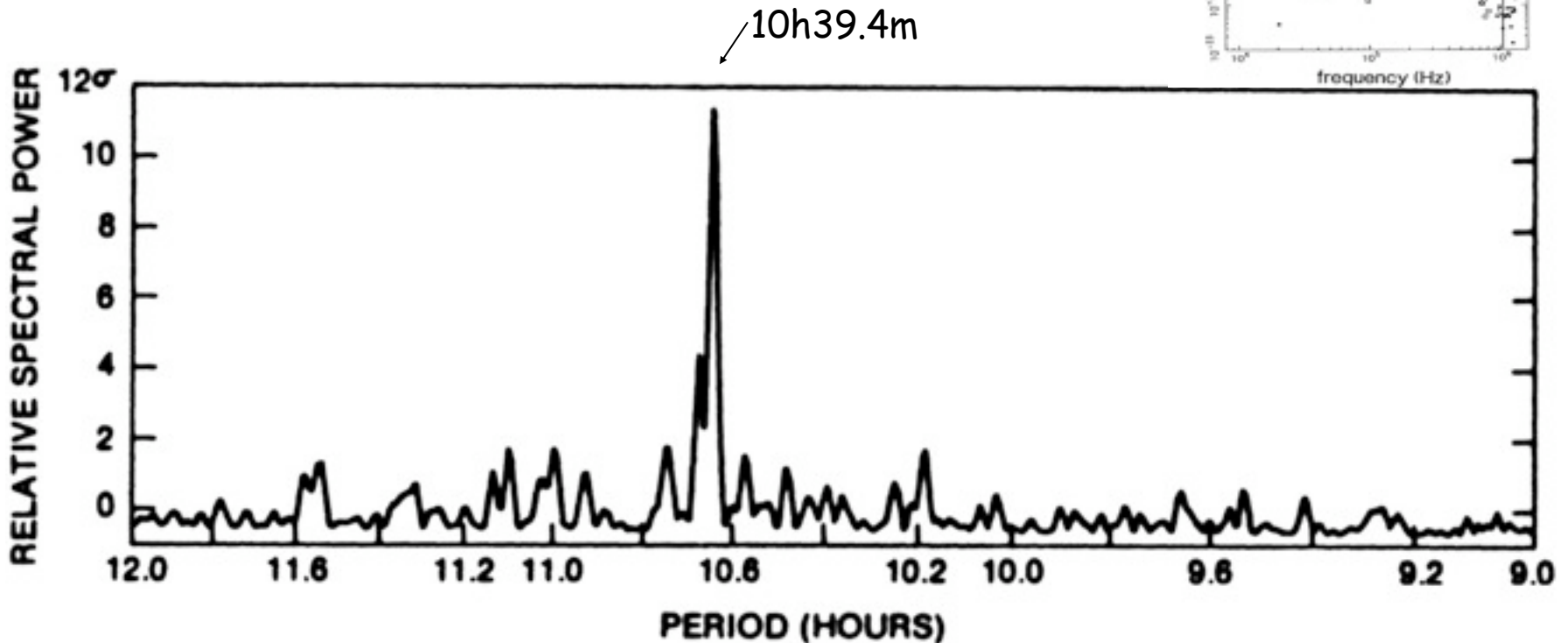
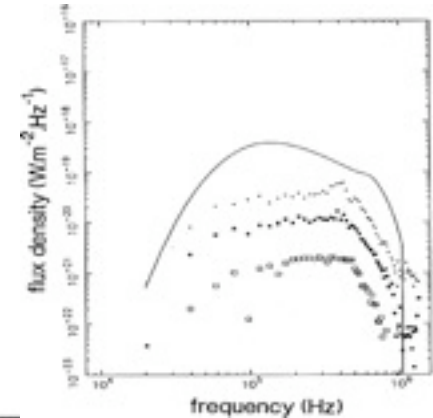
- Analyse de 24 ans d'observations radio décimétriques « sol »
⇒ $P_{\text{DAM}} = 9\text{h } 55\text{m } 29.685\text{s} \pm 0.04\text{s}$



[Higgins et al., 1997]

Rotation de Saturne

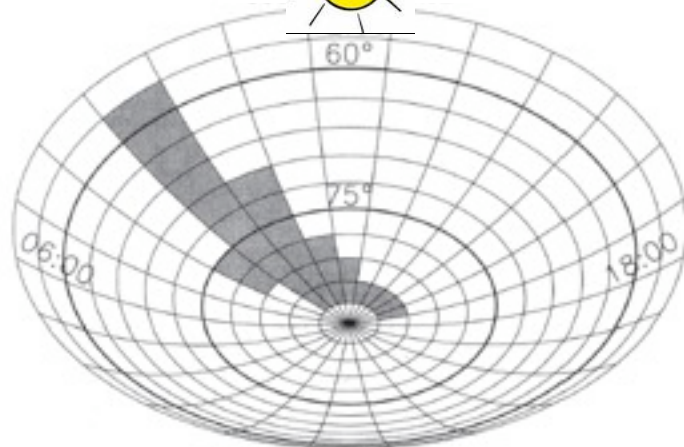
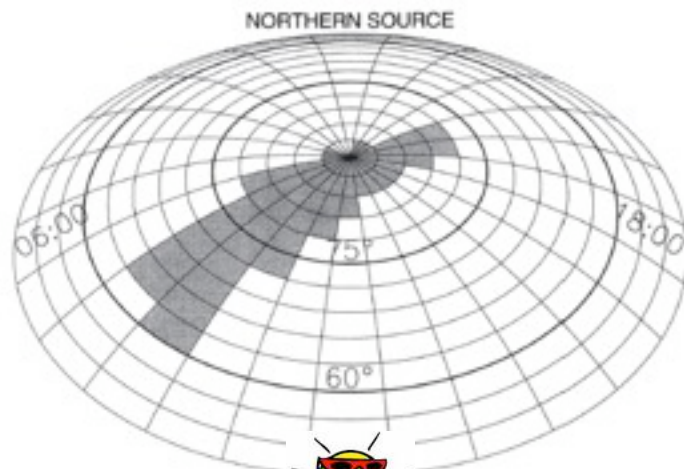
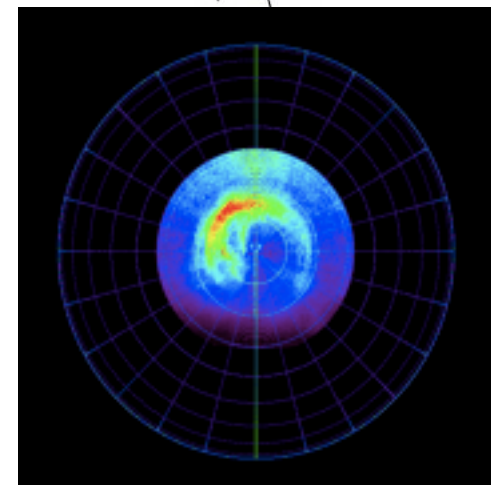
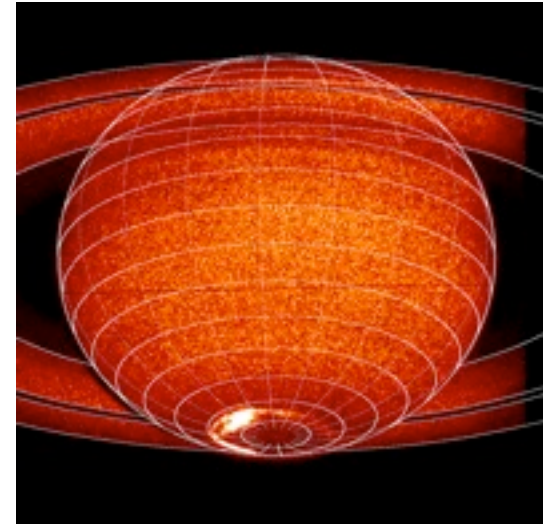
- Analyse de 267 jours d'observations par Voyager 1
 $\Rightarrow P_{SKR} = 10\text{h } 39\text{m } 24\text{s} \pm 7\text{s} \quad (\sim 2 \times 10^{-4})$



Émissions aurorales Radio (et UV) de Saturne

- Sources fixes dans l'espace

[Prangé et al., 2004]

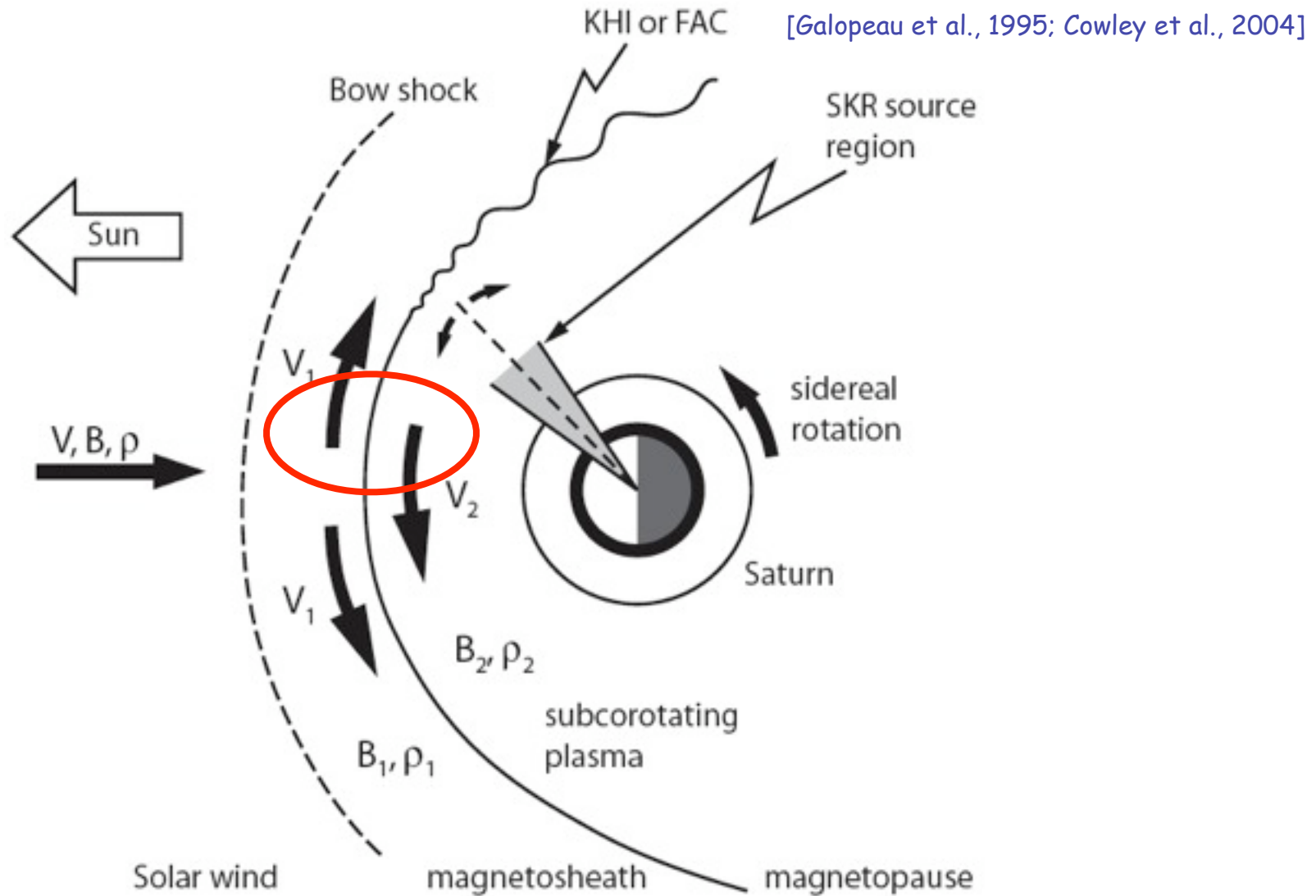


SOUTHERN SOURCE

[Galopeau, Zarka, LeQuéau, 1995]

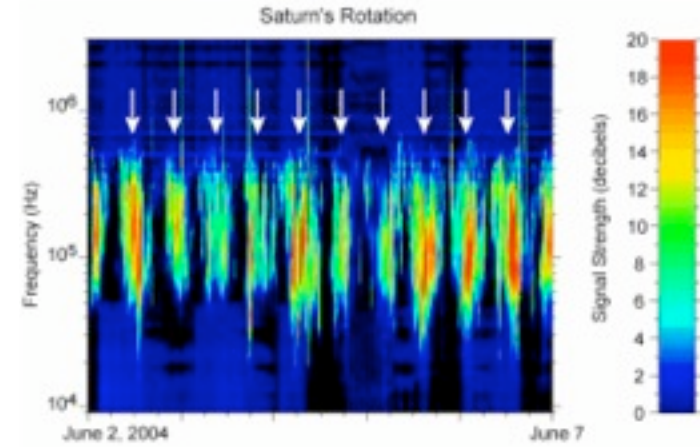
Émission radio de Saturne

- Origine des émissions ?

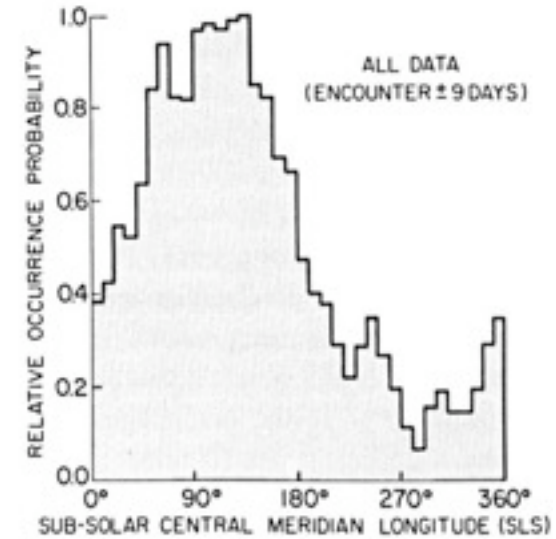
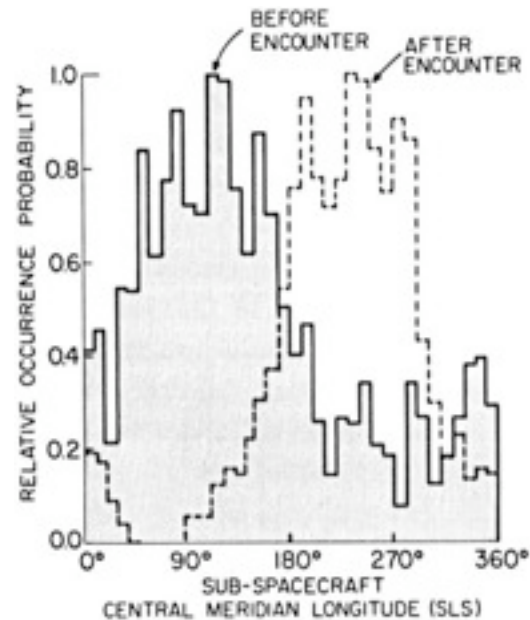


Émission radio de Saturne

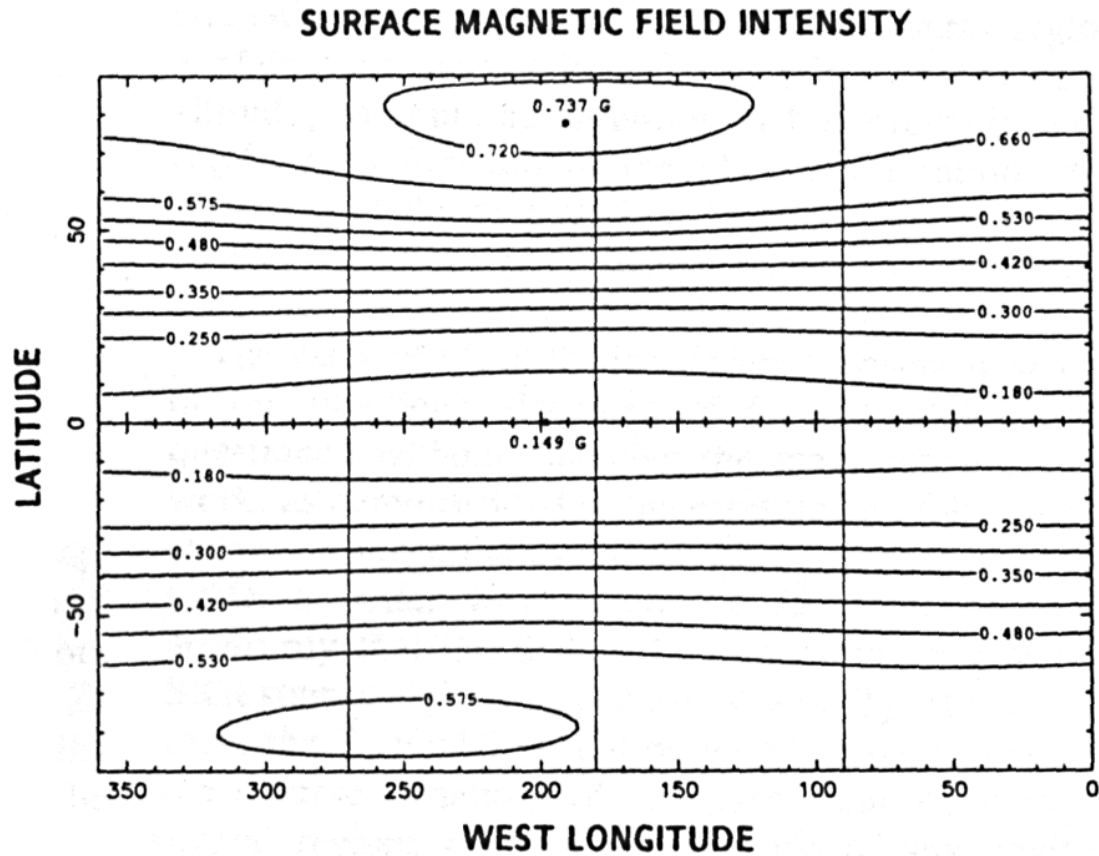
- Modulation « stroboscopique »



Voyager 1

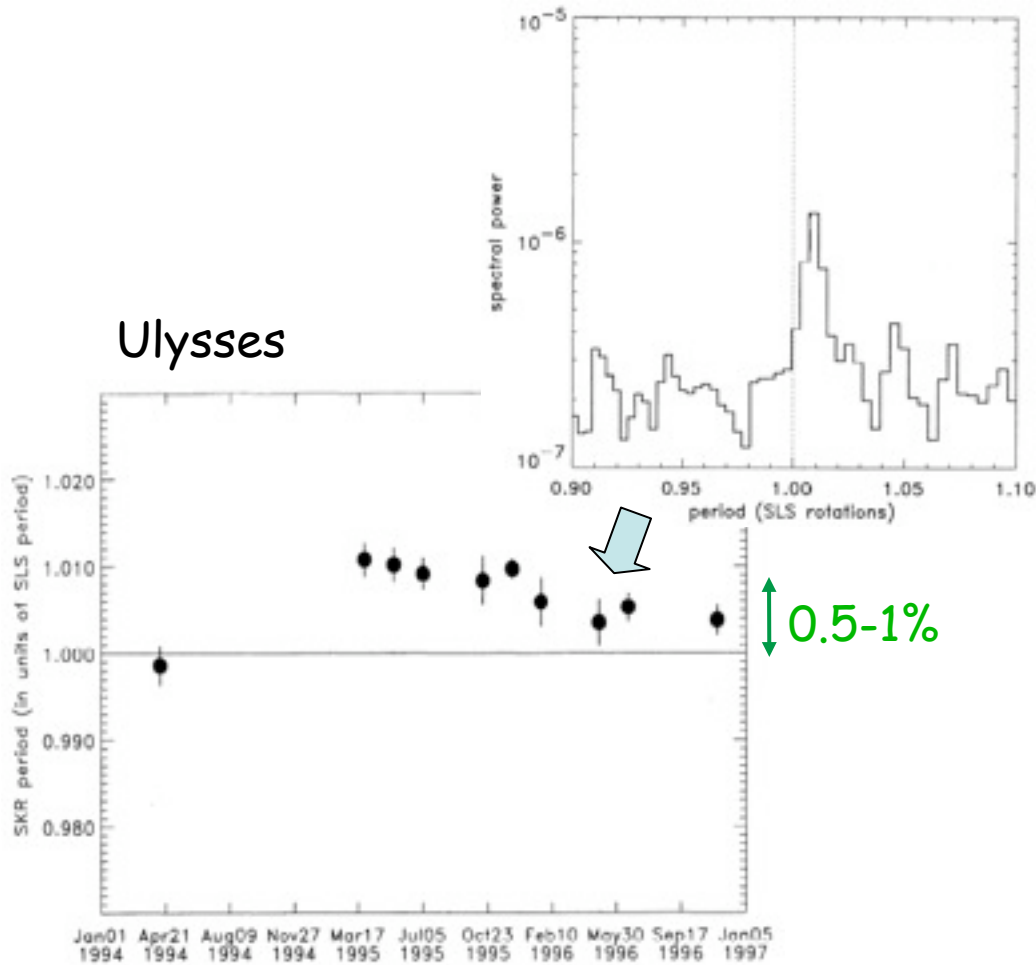


→ Anomalie magnétique en rotation ?

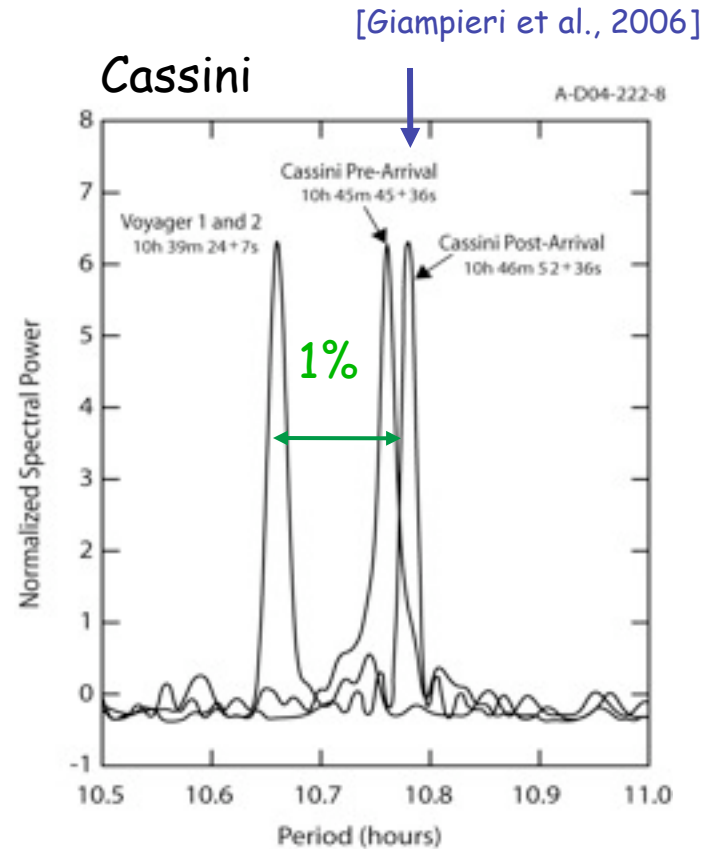


[Galopeau & Zarka, 1992]

Période radio variable de Saturne

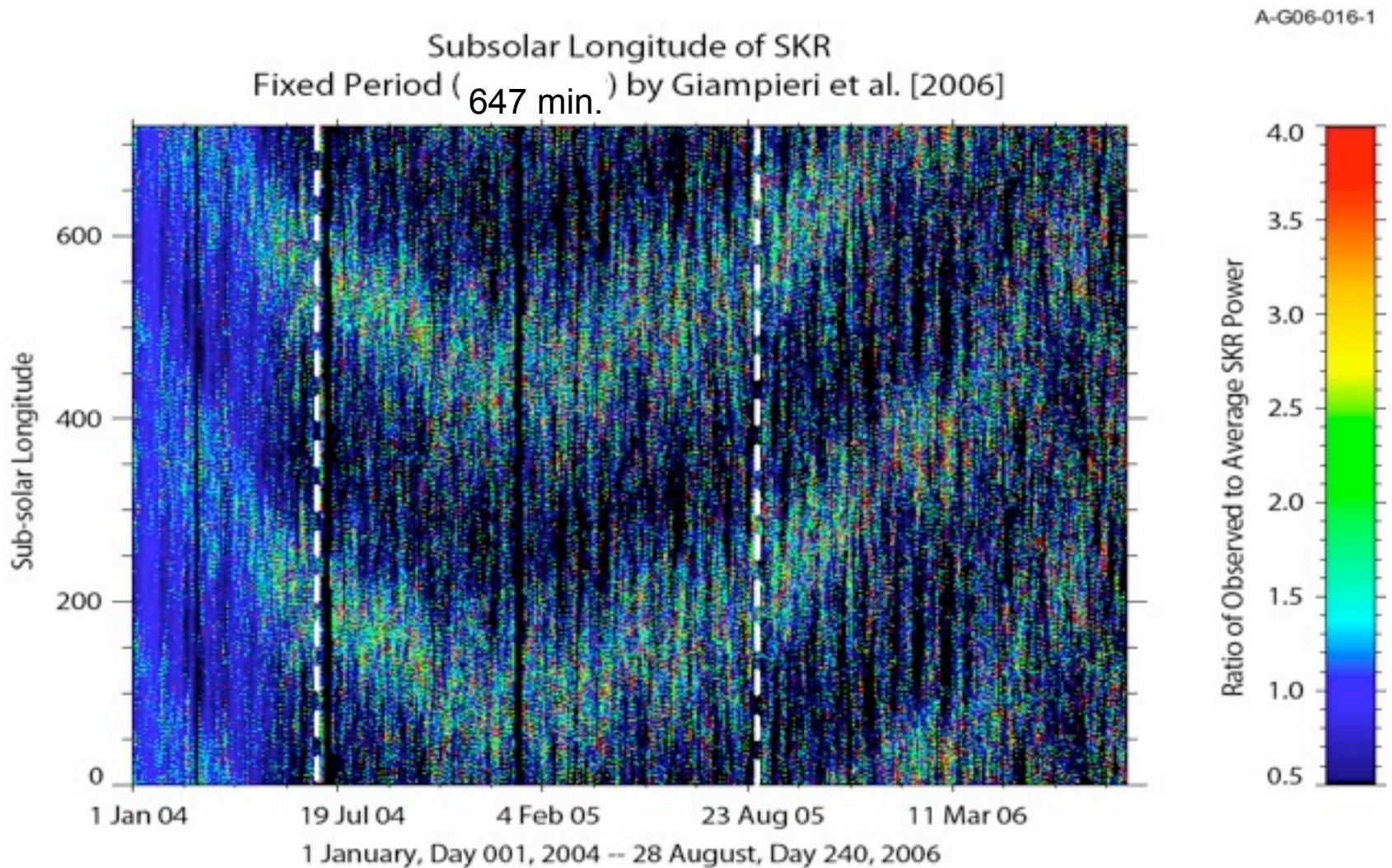


[Galopeau & Lecacheux, 2000]



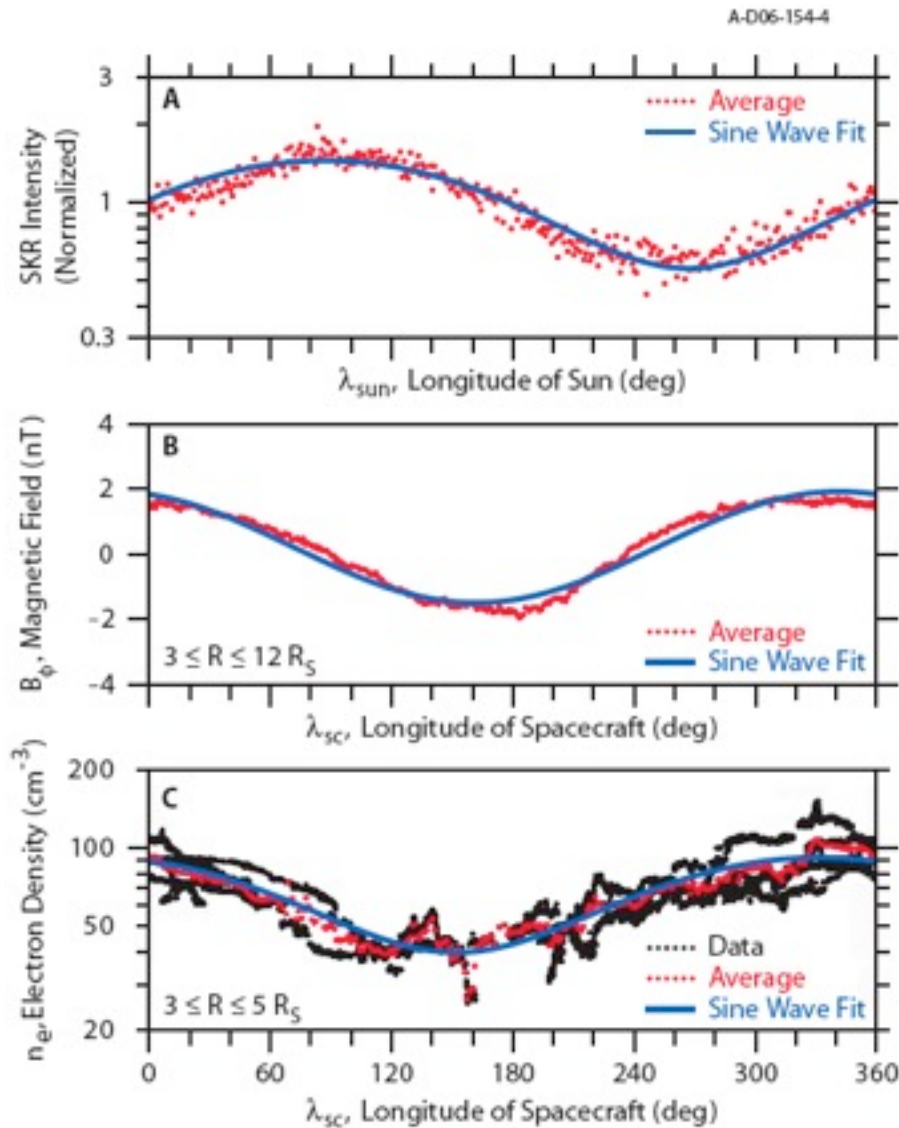
[Gurnett et al., 2005]

Période radio variable de Saturne



[Kurth et al., 2007]

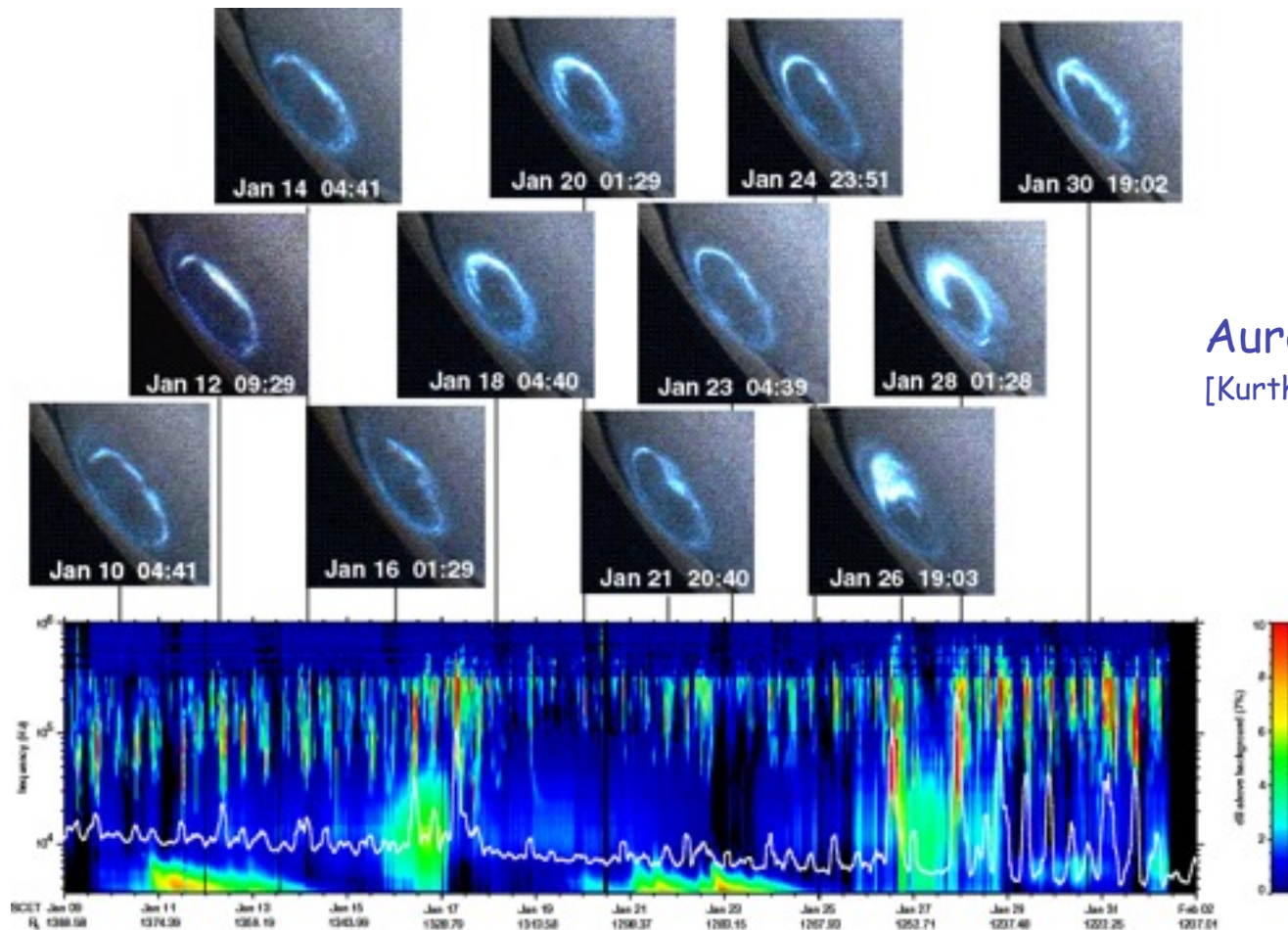
Variations similaires ?



Champ
magnétique B_{ϕ}

Densité de
plasma

Variations similaires ?



Aurores UV ?
[Kurth et al., 2005]

+ Position de la magnétopause ? [Clarke et al., 2006]

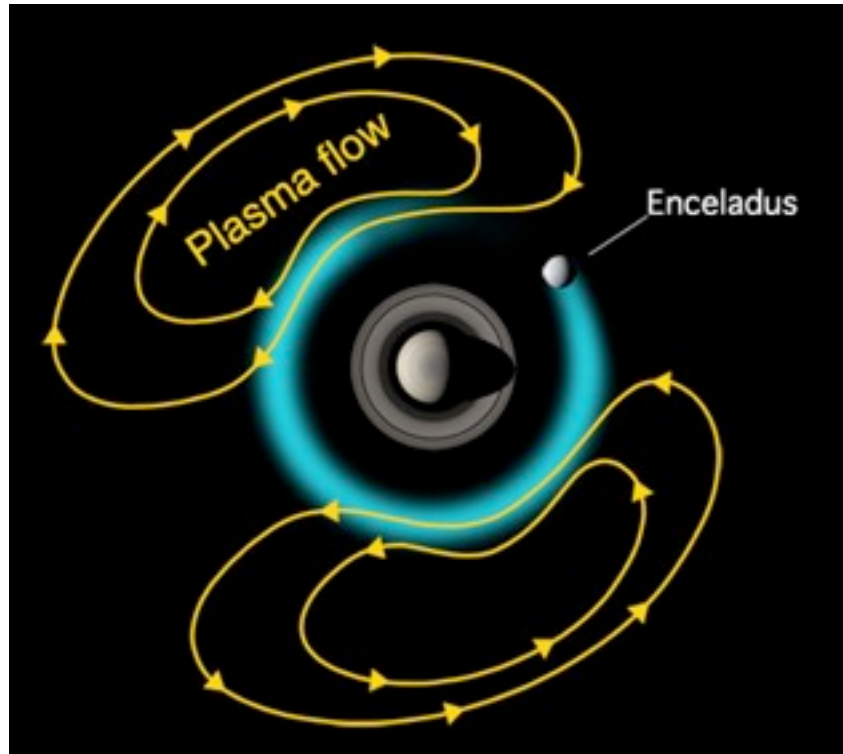
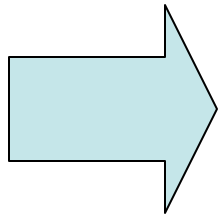
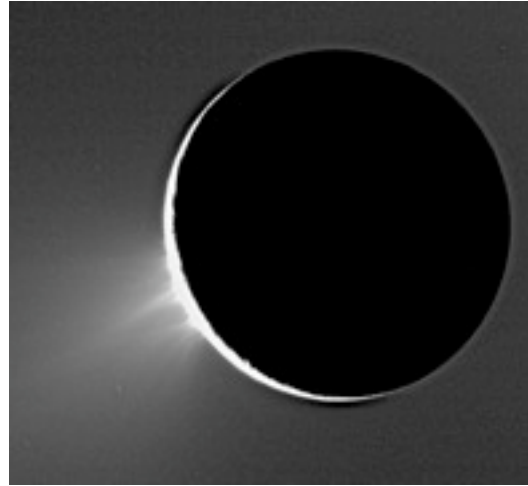
Variation de période énorme → énigme !

- Origine ?

→ pas de changement de la rotation vraie

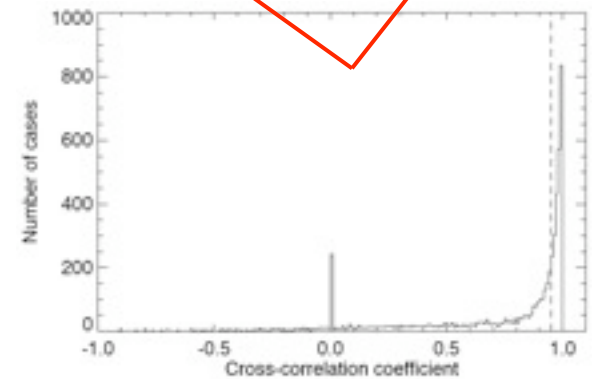
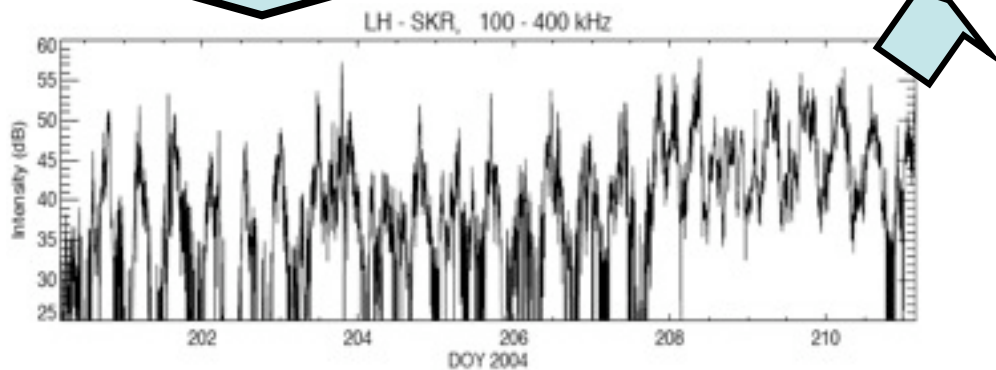
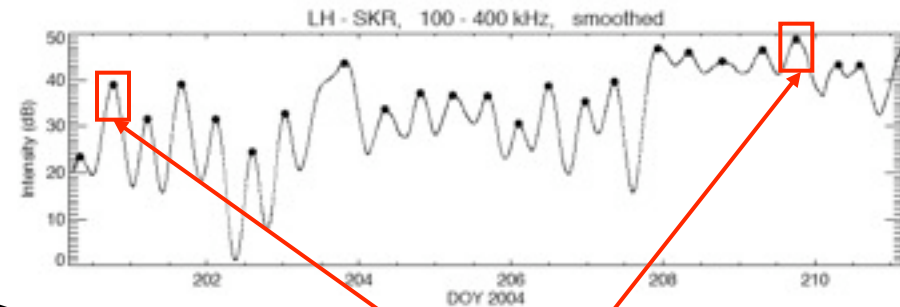
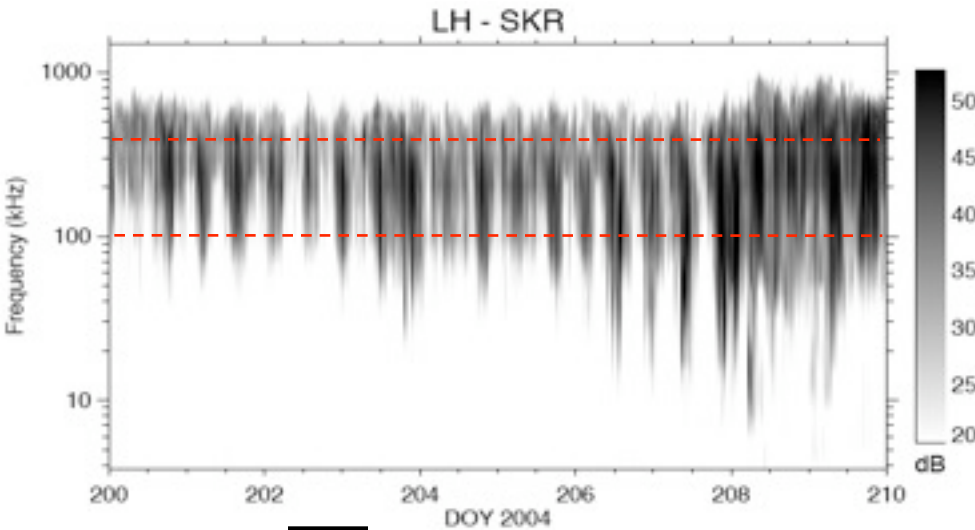
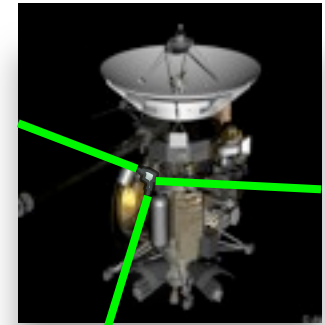
- Période interne vraie ?
- Différences Voyager - Cassini ?

Origine interne ? Encelade ?

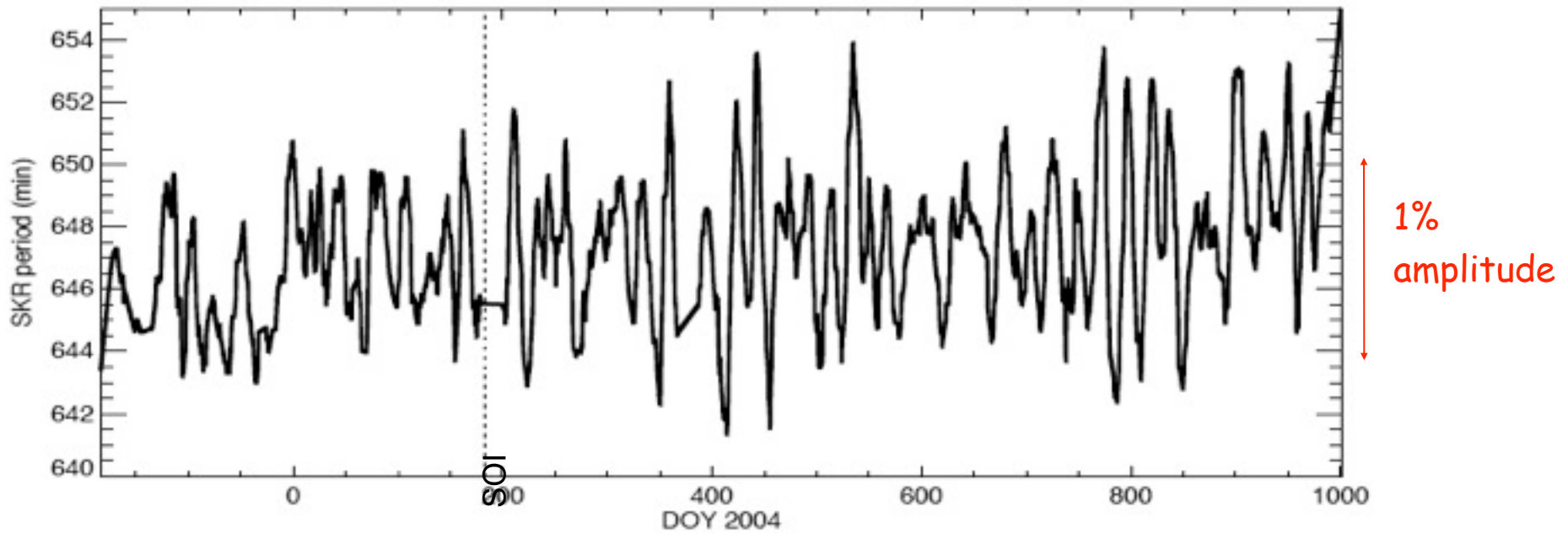


Analyse de >3 ans de données radio de Cassini

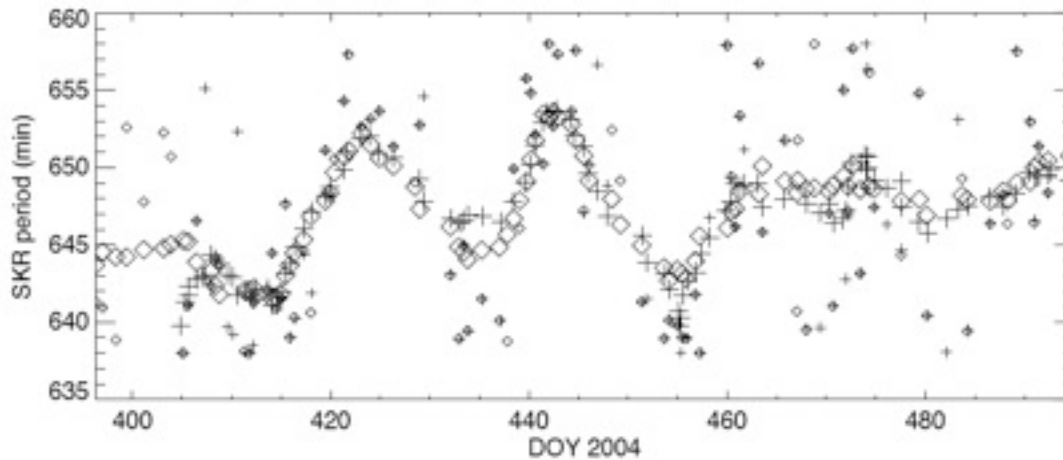
- Variations « rapides » de la période ?



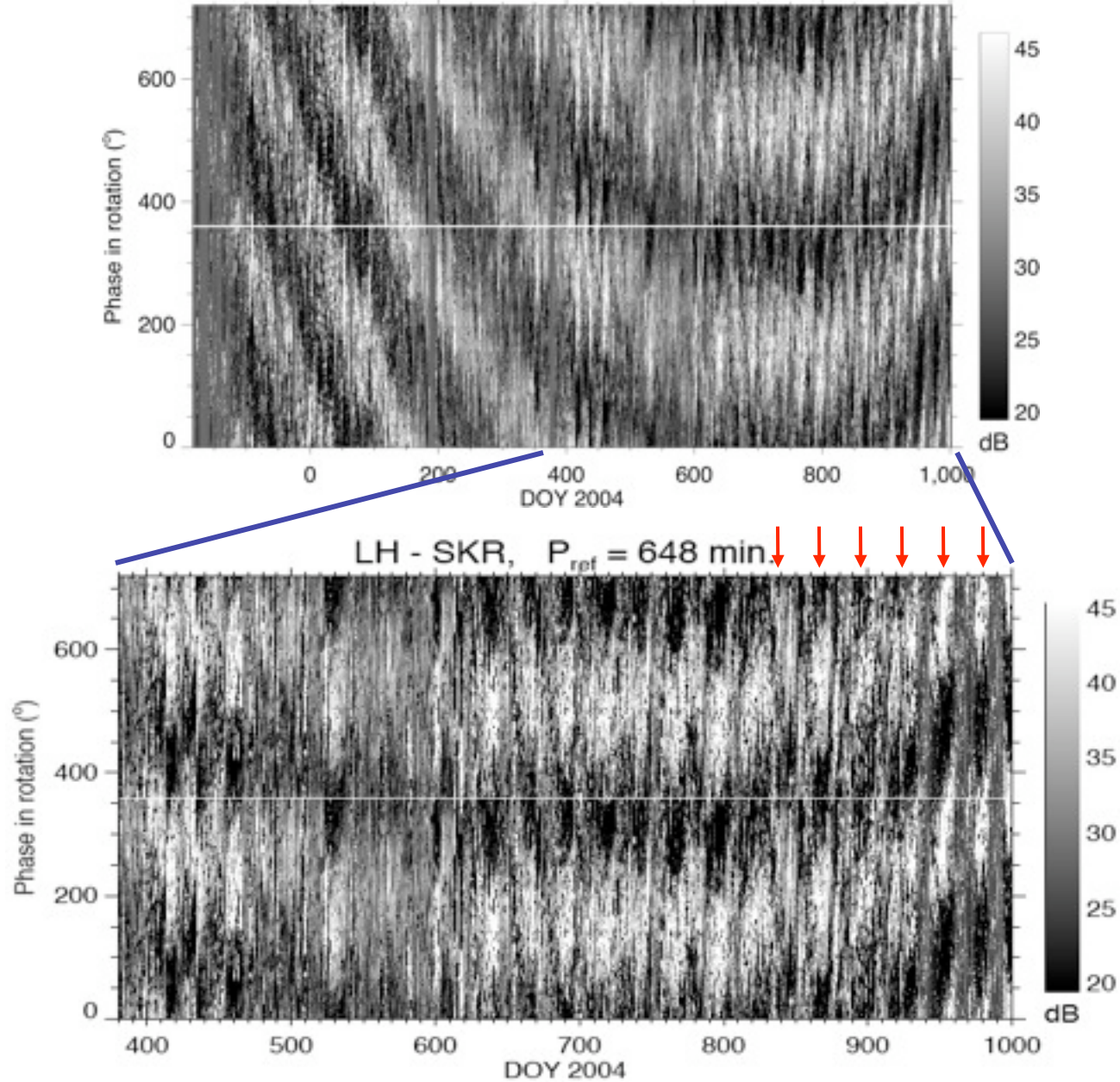
Oscillations de la période radio à 20-30 jours



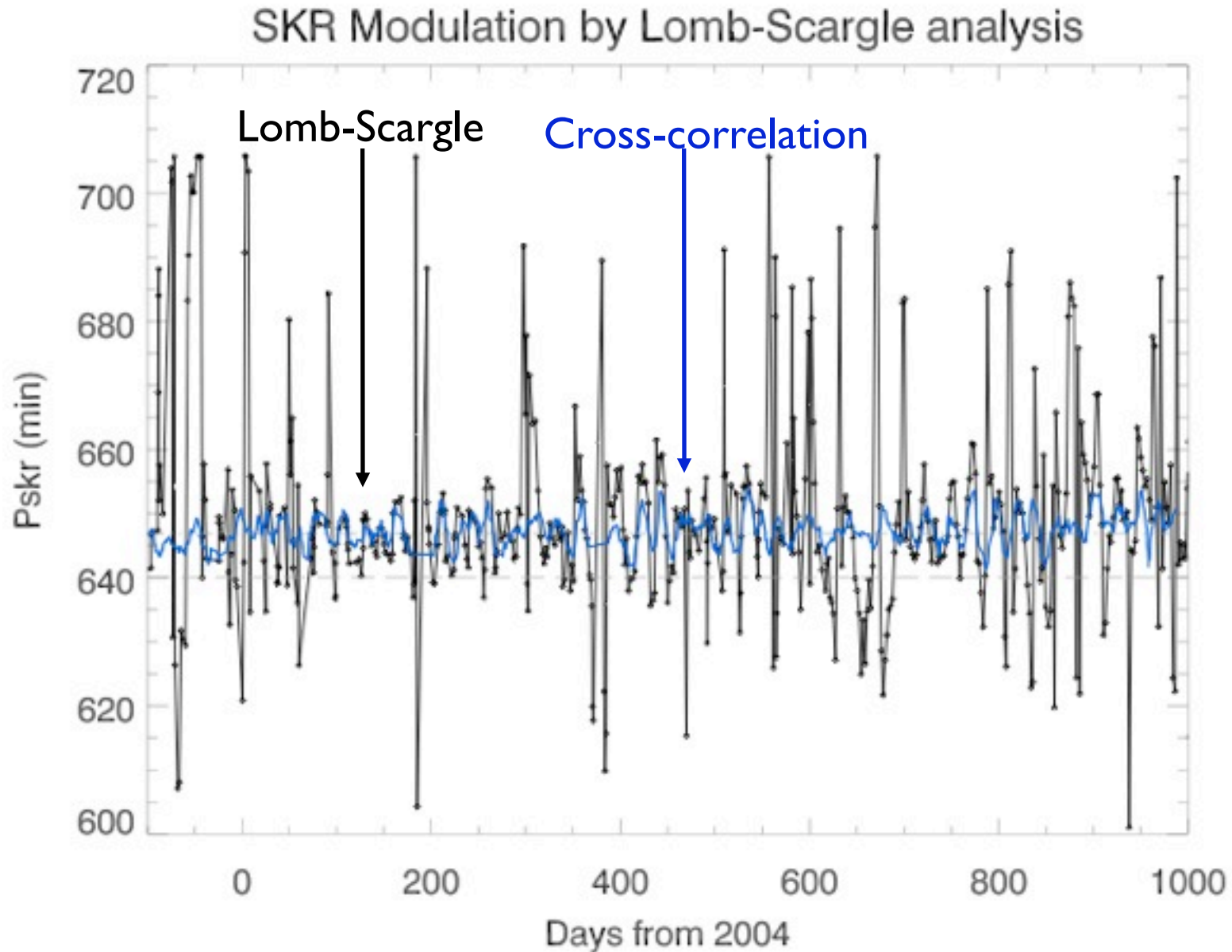
S/N ~5



Oscillations de la période radio à 20-30 jours

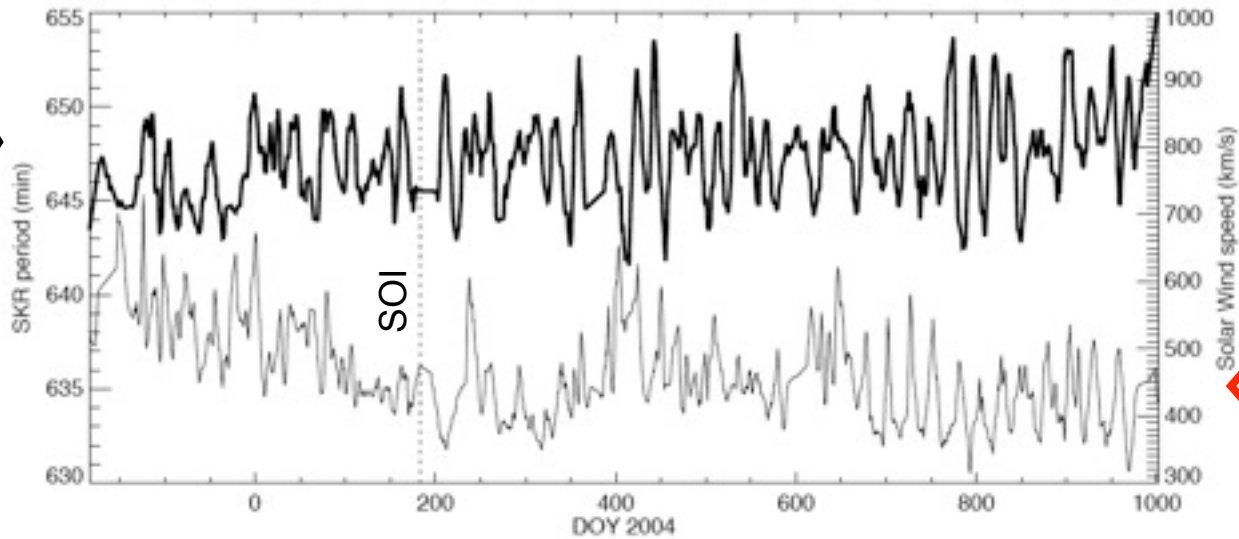


Oscillations de la période radio à 20-30 jours

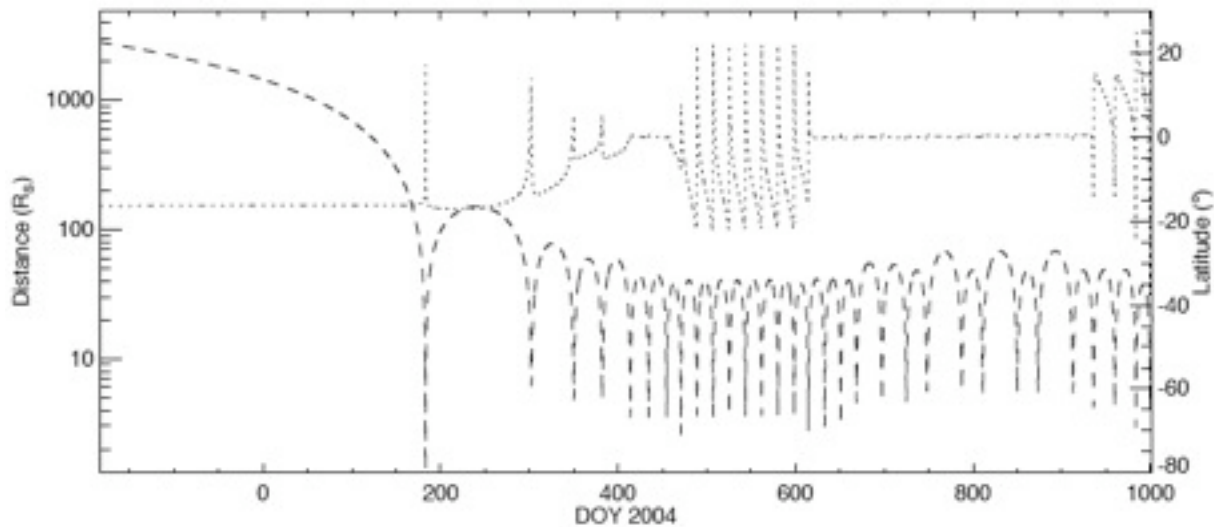


Origine de ces oscillations ?

P_{SKR} →



← V_{SW}
(proj. ballistique
depuis Wind)

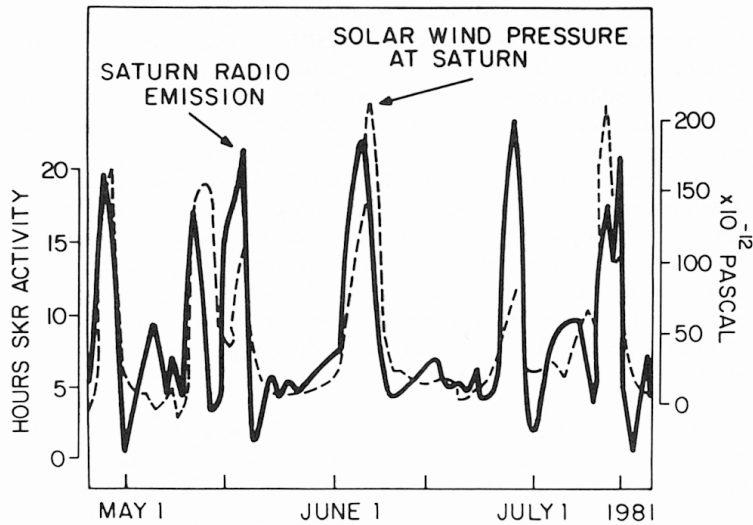


← Latitude

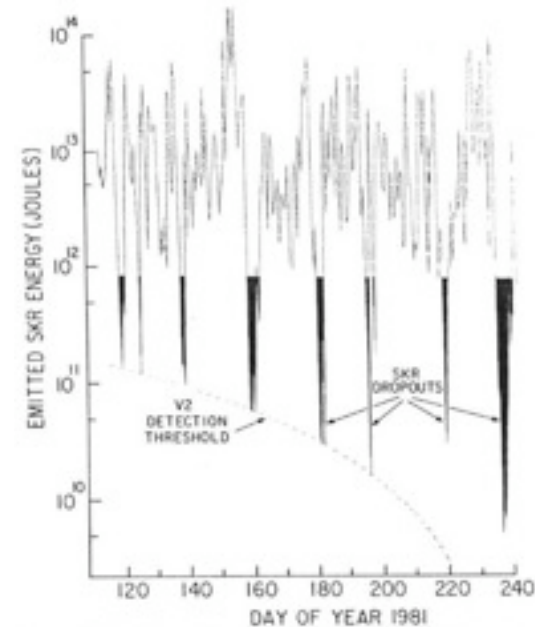
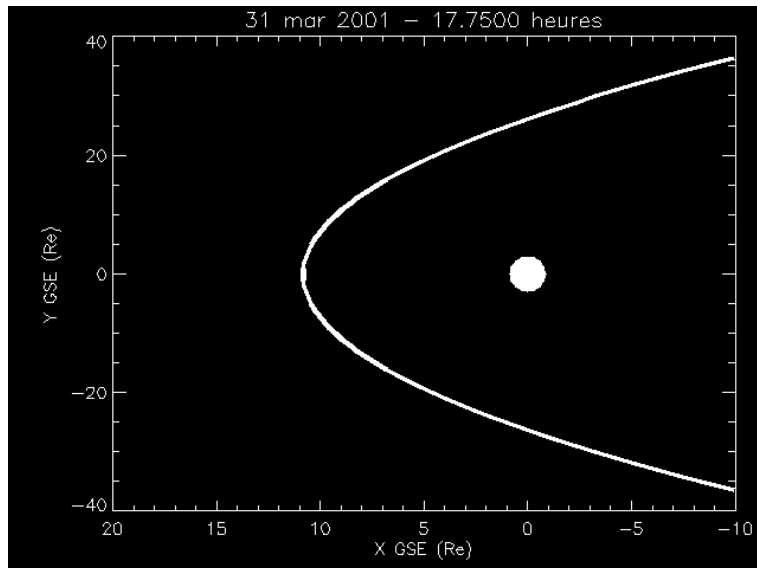
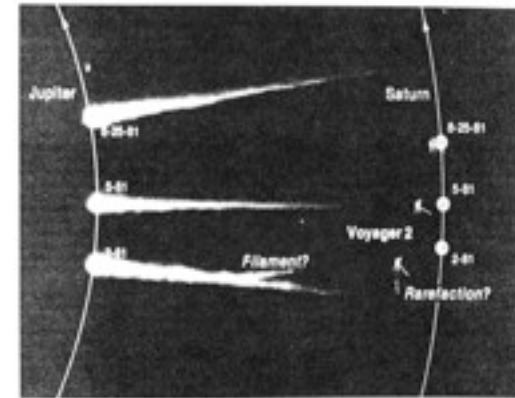
&

← Distance
de Cassini

Influence connue du Vent Solaire sur l'intensité radio

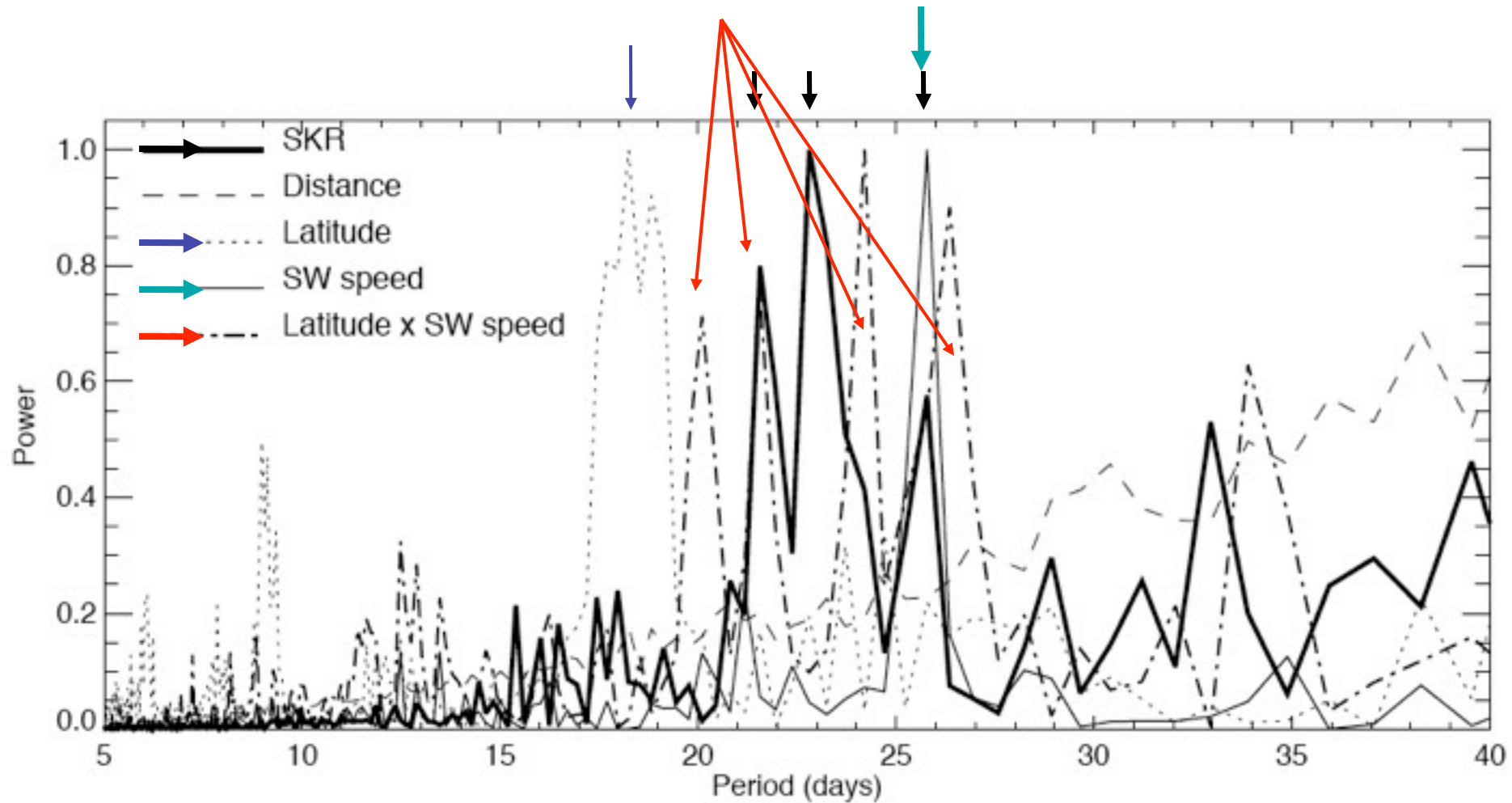


[Desch, 1982 ; Desch & Rucker, 1983]

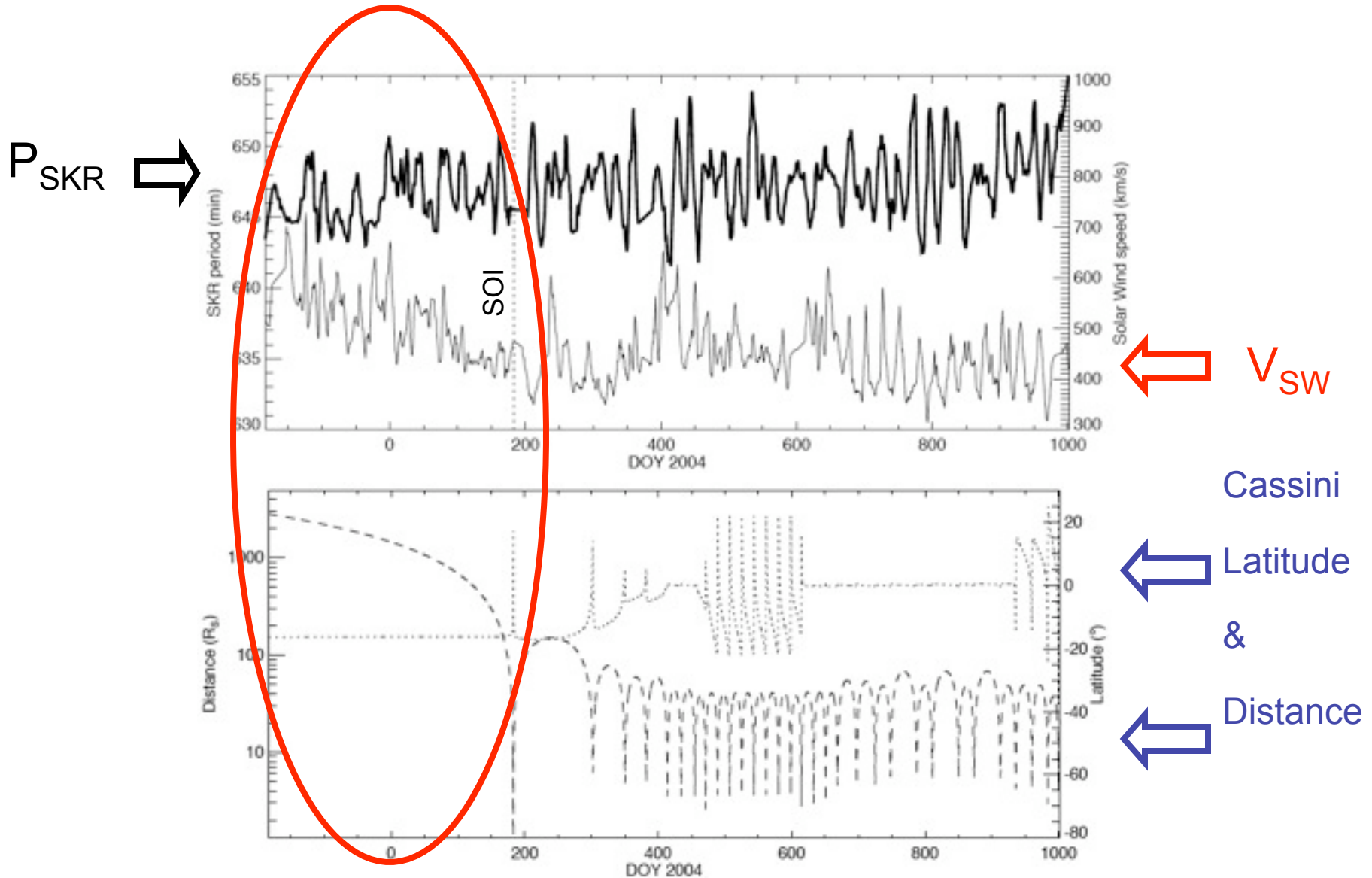


[Desch, 1983]

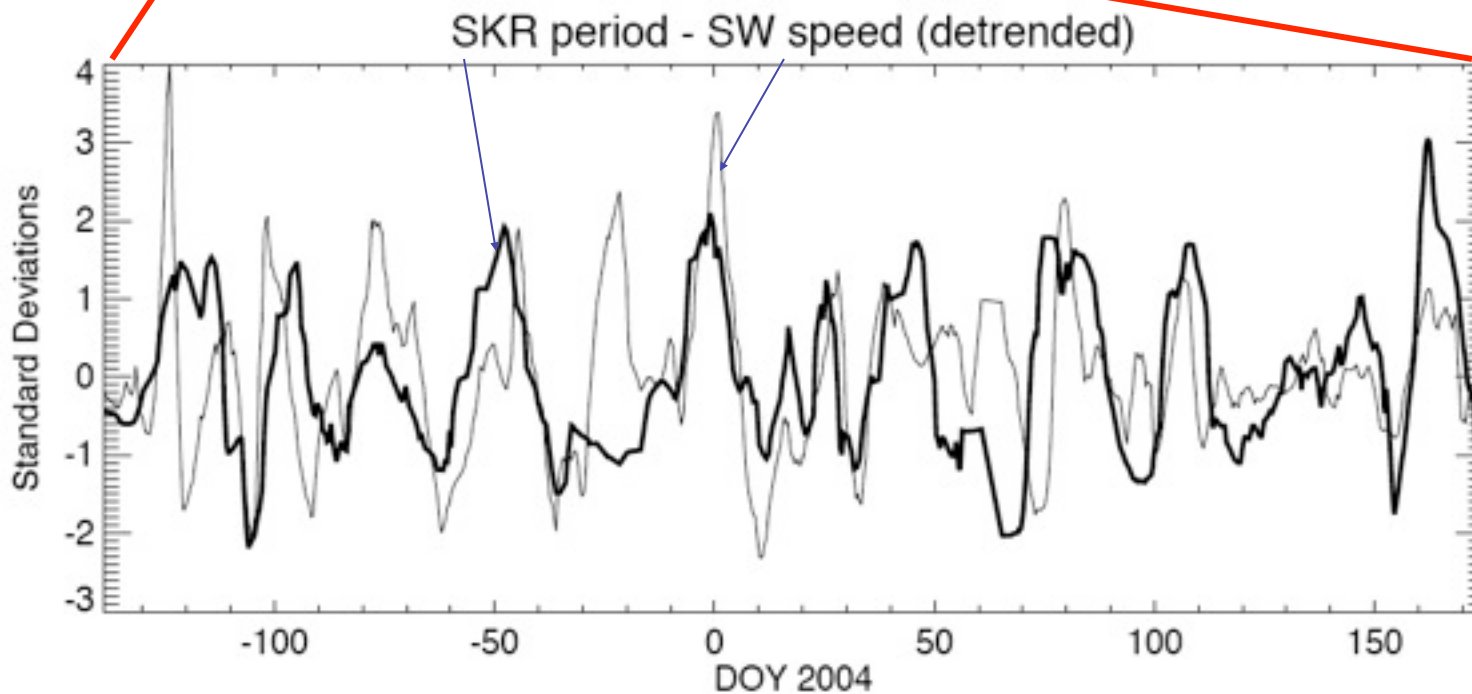
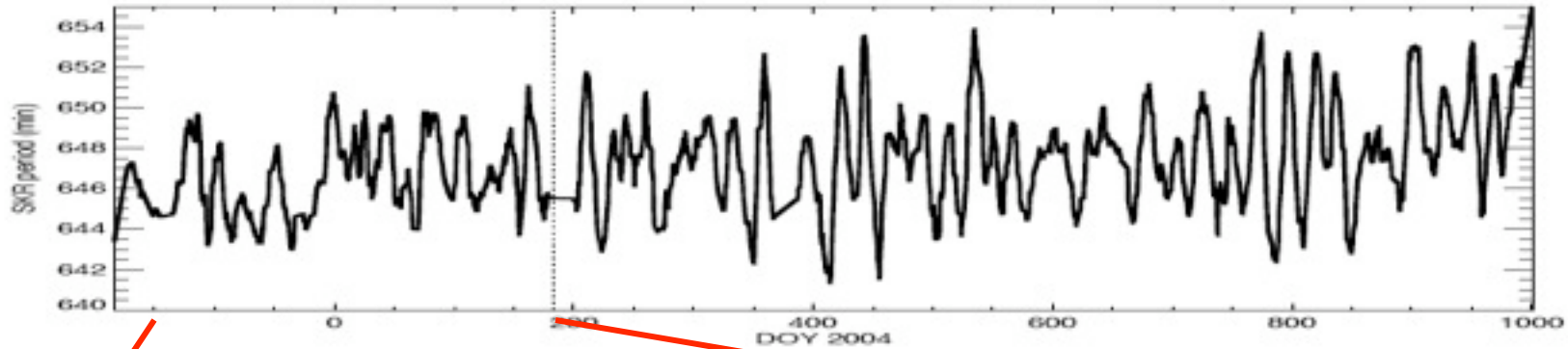
Période radio variable : Vent Solaire & Visibilité ?



Confirmation : trajectoire d'approche de Cassini



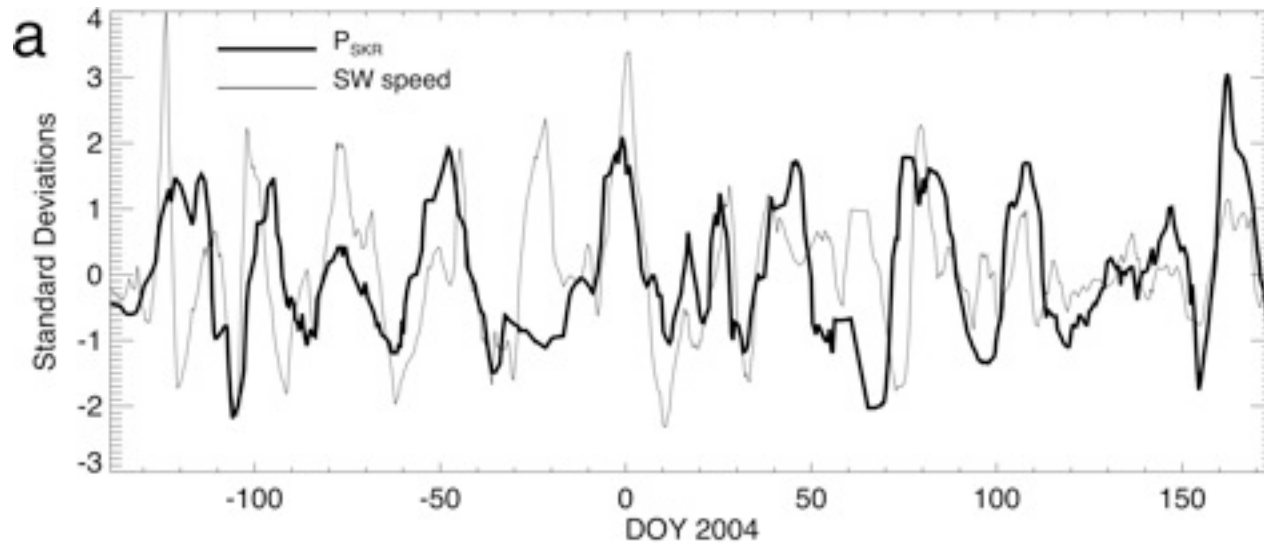
→ Corrélation Période radio - Vitesse vent solaire



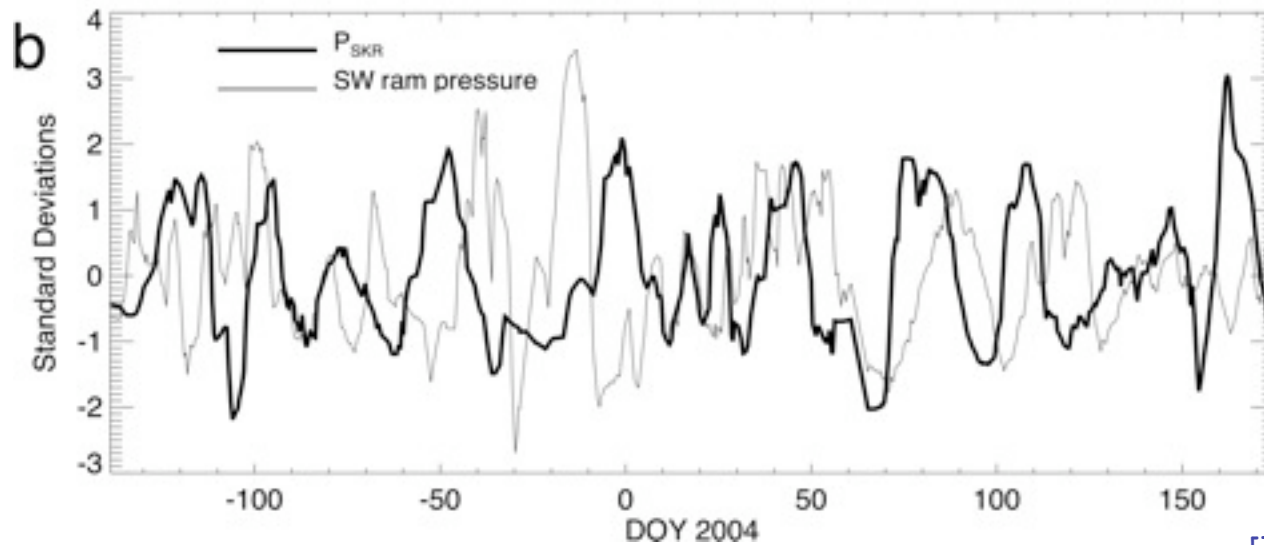
$C > +0.4$
confiance=100%

→ Origine externe !

→ Rôle particulier de la vitesse



$C > +0.4$

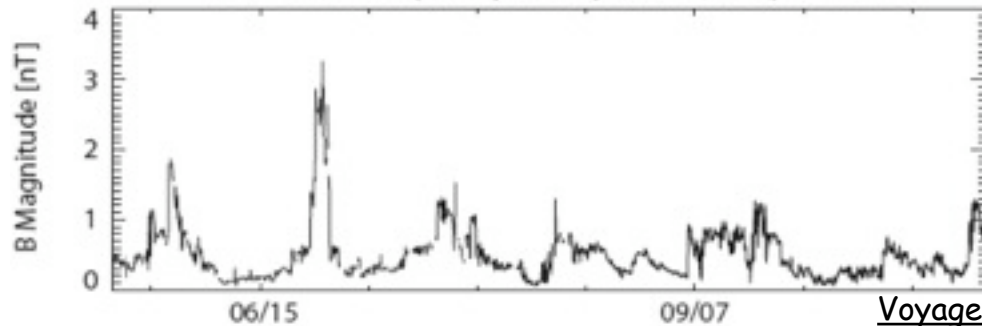


$C \sim -0.1$

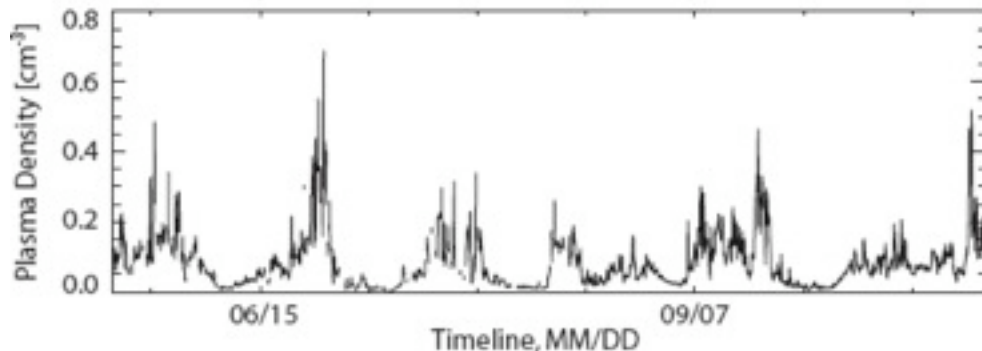
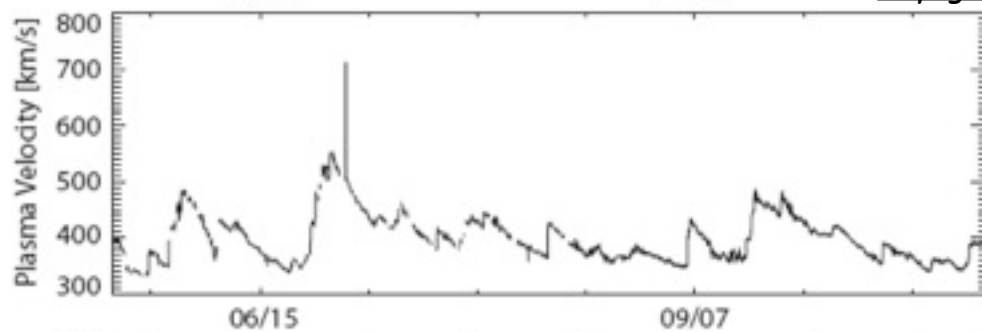
Explication (possible) de la période radio variable de Saturne

de Saturne

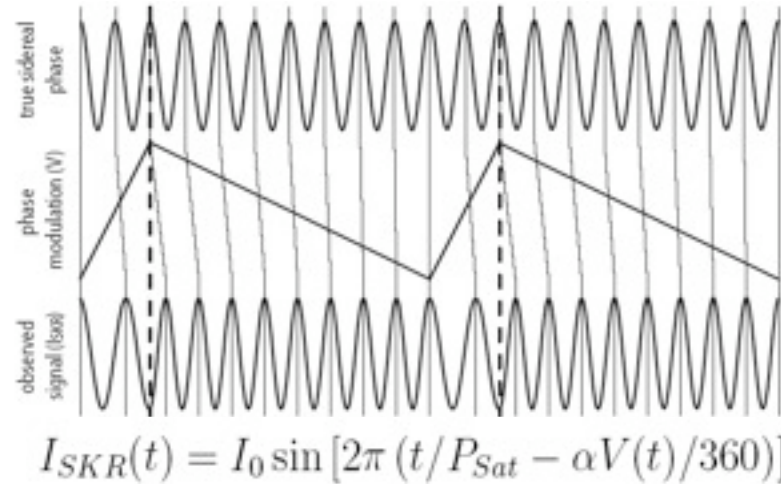
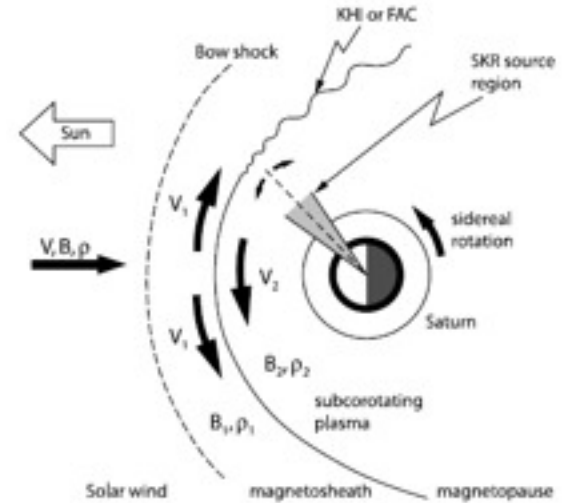
VOYAGER-1 Hourly Interplanetary Parameters by COHOWeb



Voyager 1 - CA

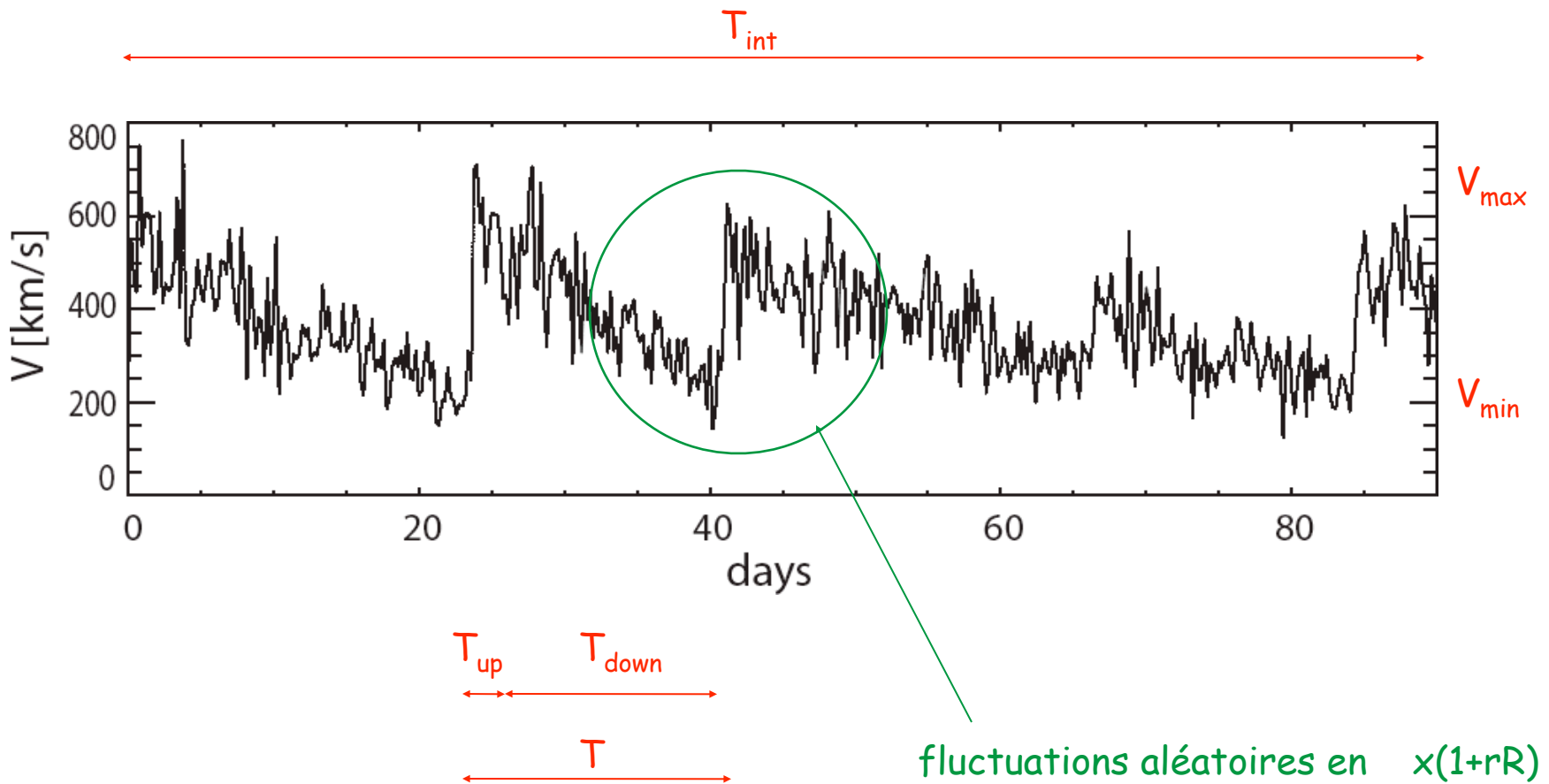


Timeline, MM/DD
1980/06/01-00:00 - 1980/11/01-23:00



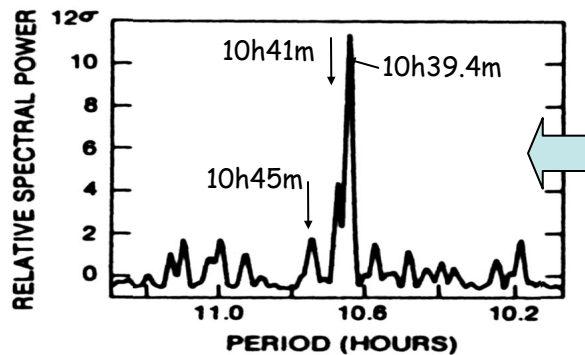
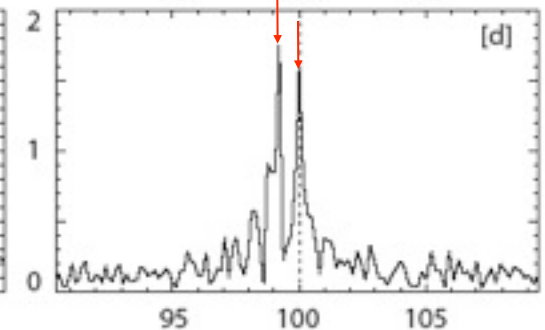
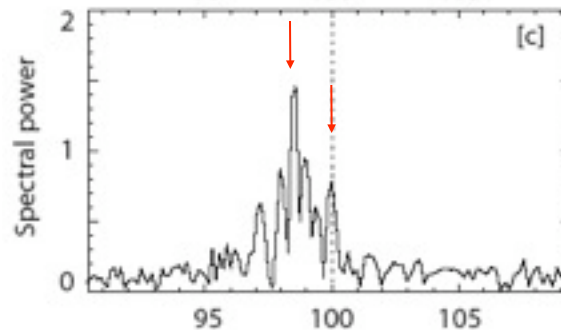
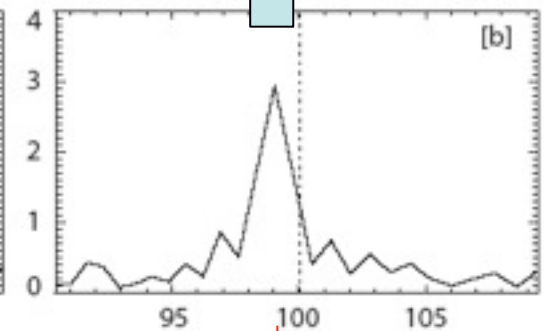
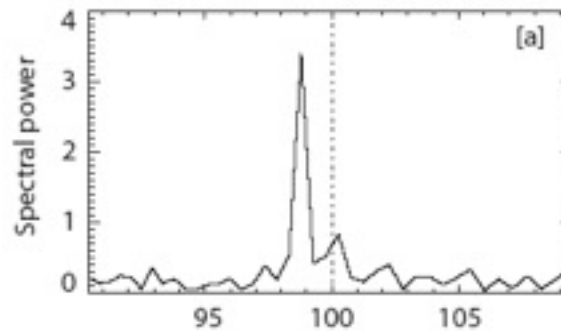
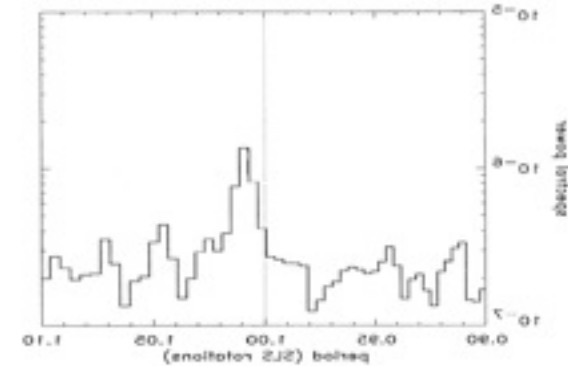
$$I_{SKR}(t) = I_0 \sin [2\pi (t/P_{Sat} - \alpha V(t)/360)]$$

Modélisation de la Vitesse du Vent Solaire ...

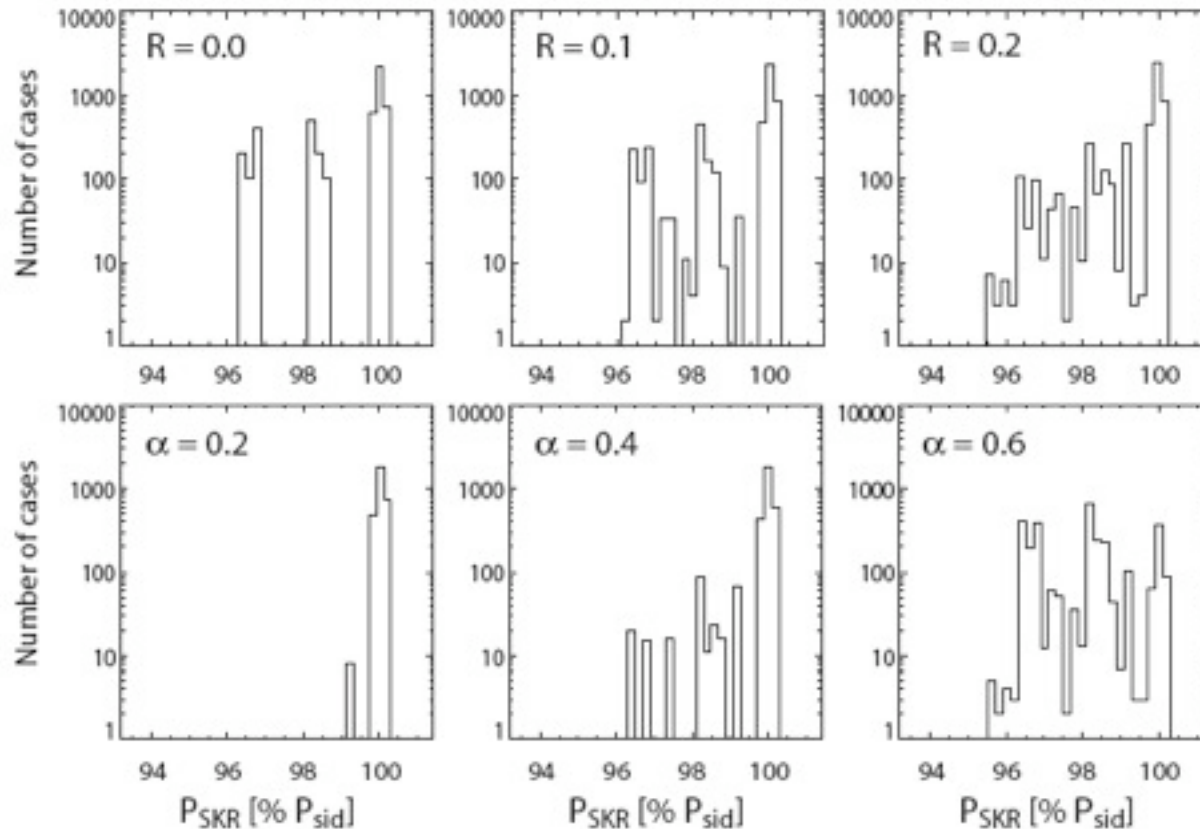


... et de la période variable résultante

	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

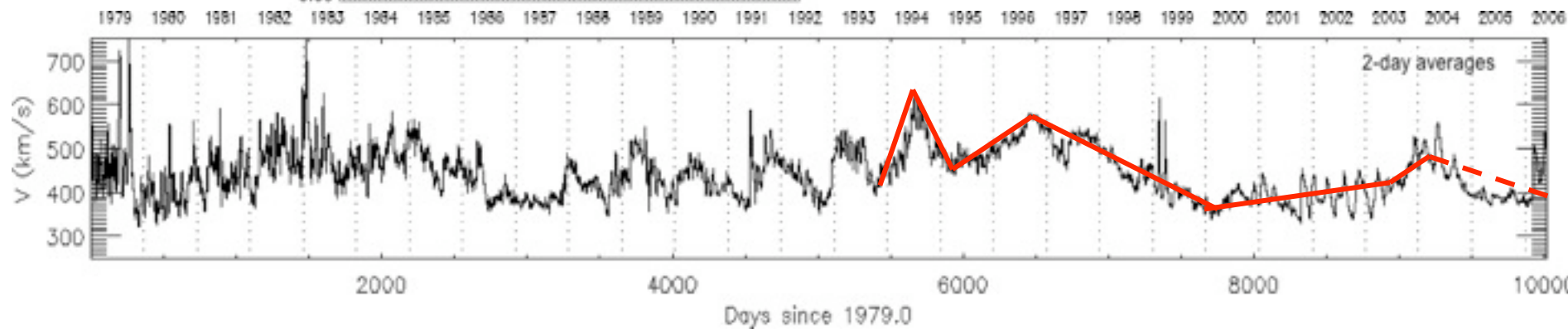
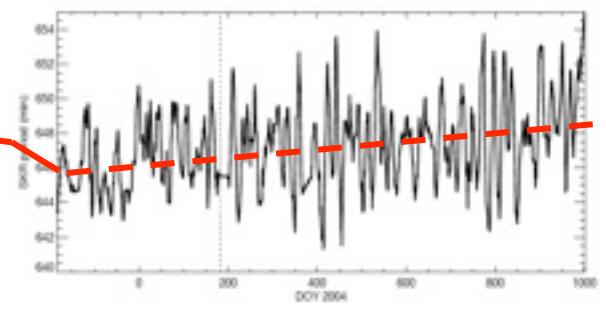
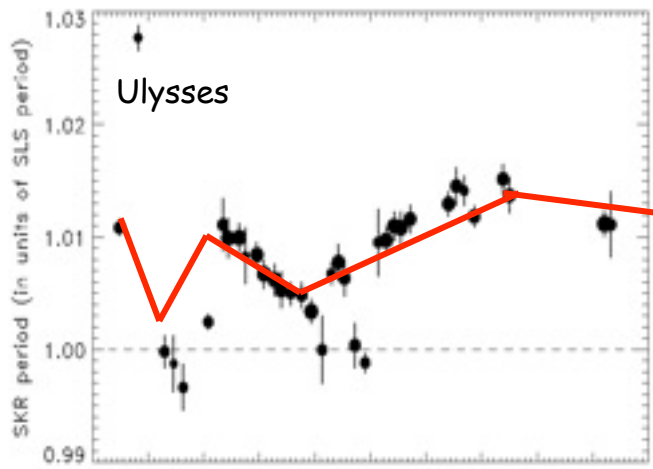
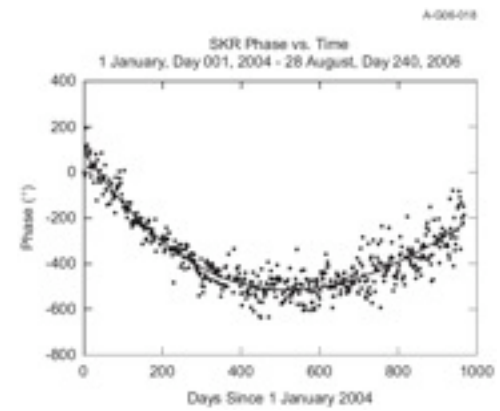
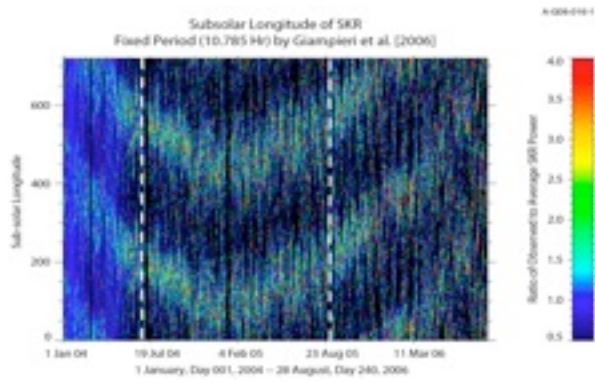


... et de la période variable résultante



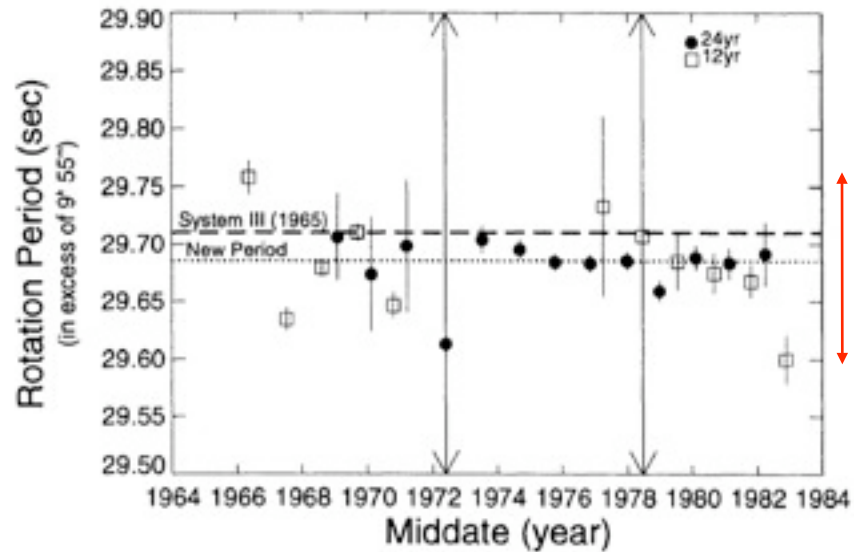
- $P_{\text{radio}} \in [0.96-1.] \times P_{\text{Saturne}}$
pour $R \geq 0.1$ $\alpha \geq 0.2$ °/(km/s) $T_{\text{int}} = <45 \text{ à } >270$ jours
- $P_{\text{radio}} \leq P_{\text{Saturne}}$ pour $\alpha > 0$

Variations à long terme ?



Rotation de Jupiter

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



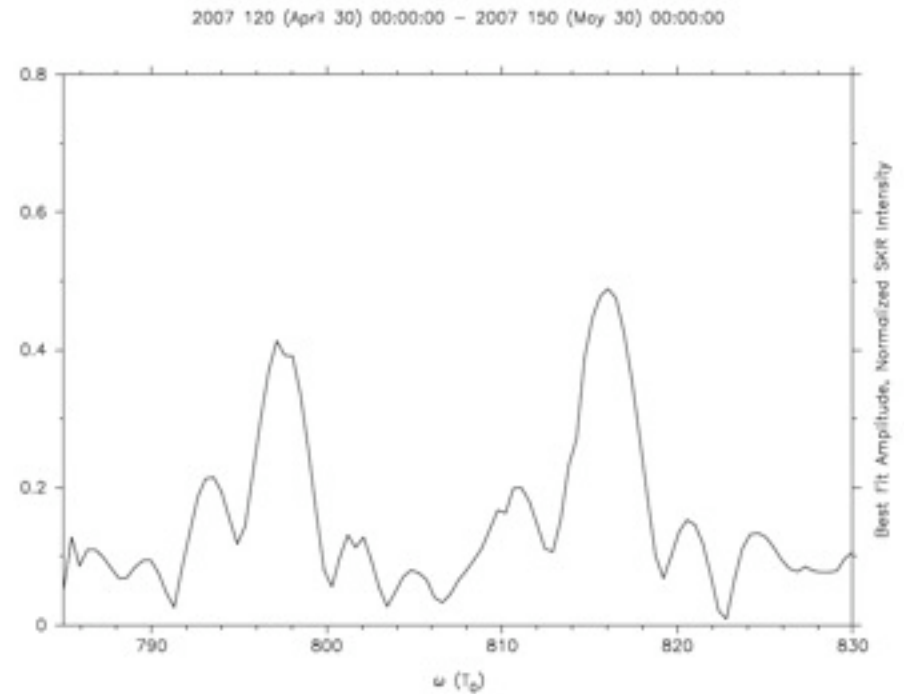
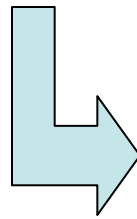
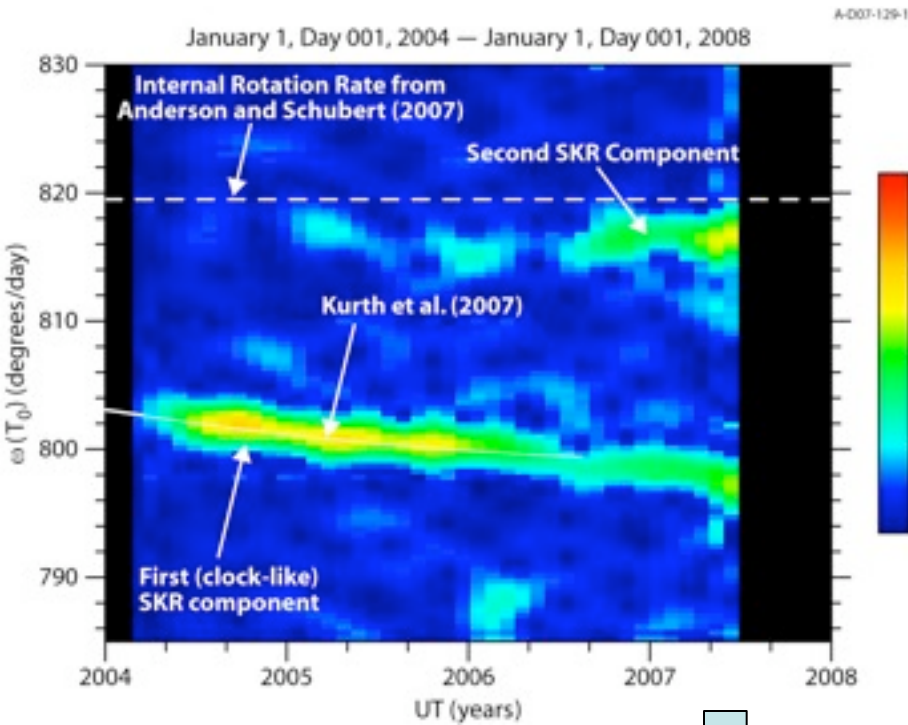
$$\pm 0.08\text{s} \sim 10^{-6}$$

Variation de la densité du tore de plasma de Io $\sim \times 2$ entre Voyager (1979) et Galileo (1995-97)

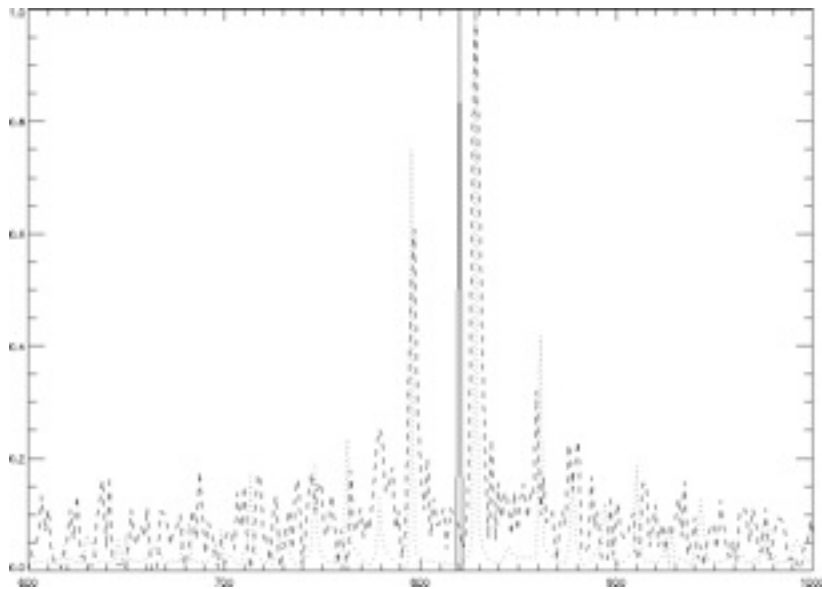
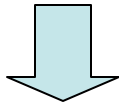
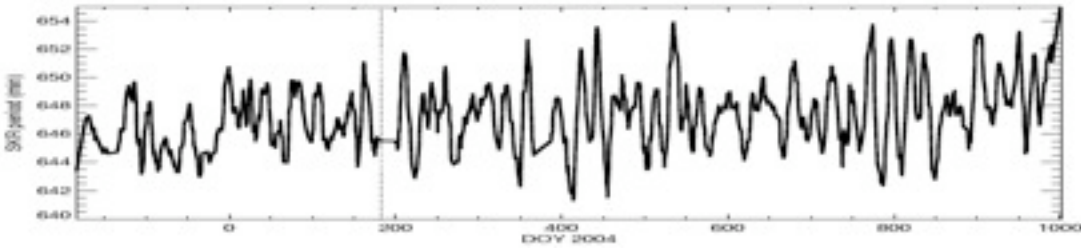
\Rightarrow longitude de la source radio varie de $\theta_A = 2\pi t_A / P_{\text{Jupiter}} \sim 10^\circ - 20^\circ$

\Rightarrow erreur sur $P_{\text{Jupiter}} = (\theta_A / 360^\circ) \times (P_{\text{Jup}} / 24 \text{ years}) \sim 10^{-6}$ comme observé !

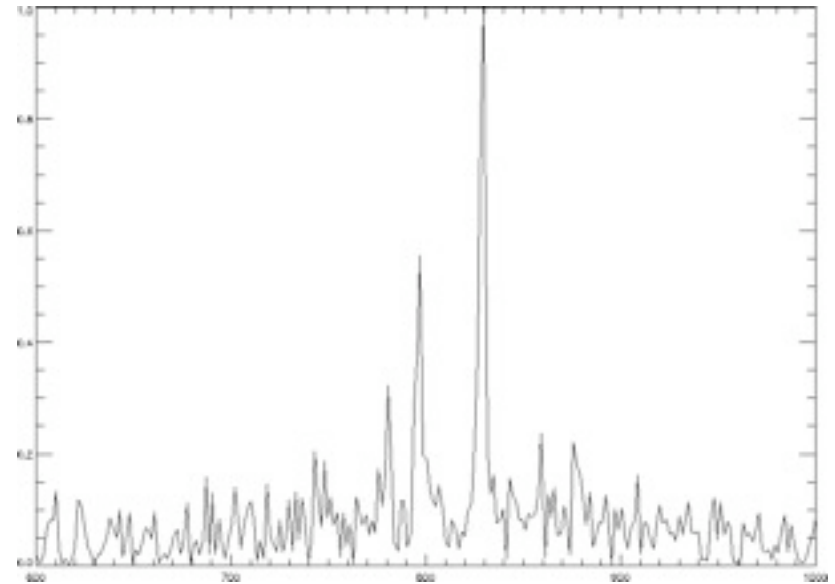
Dernier résultat de Cassini : 2 périodes radio ?



Peut-être dues à une période oscillante !

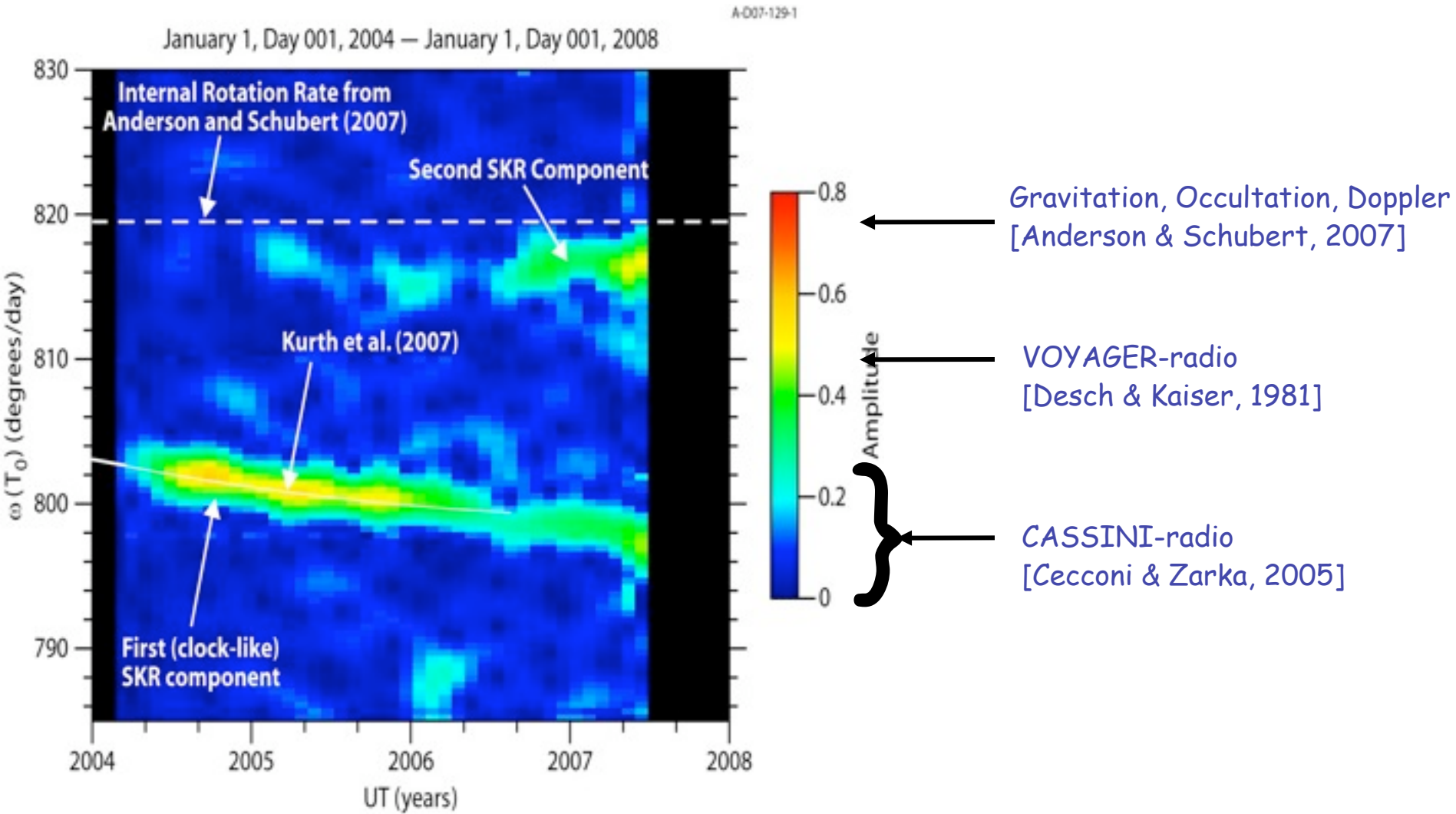


P_{Saturne}



P_{Radio}

Période de rotation interne de Saturne ? ...

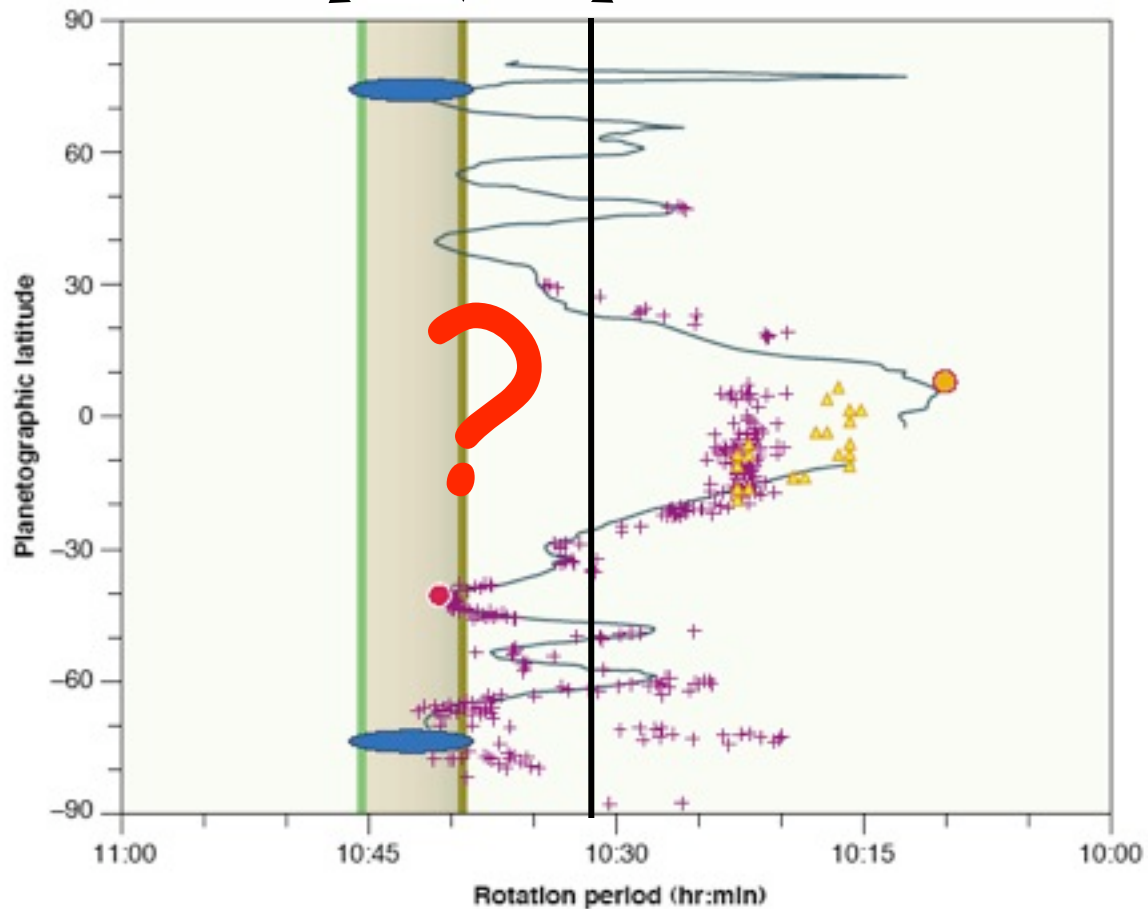


... et vitesse des vents atmosphériques

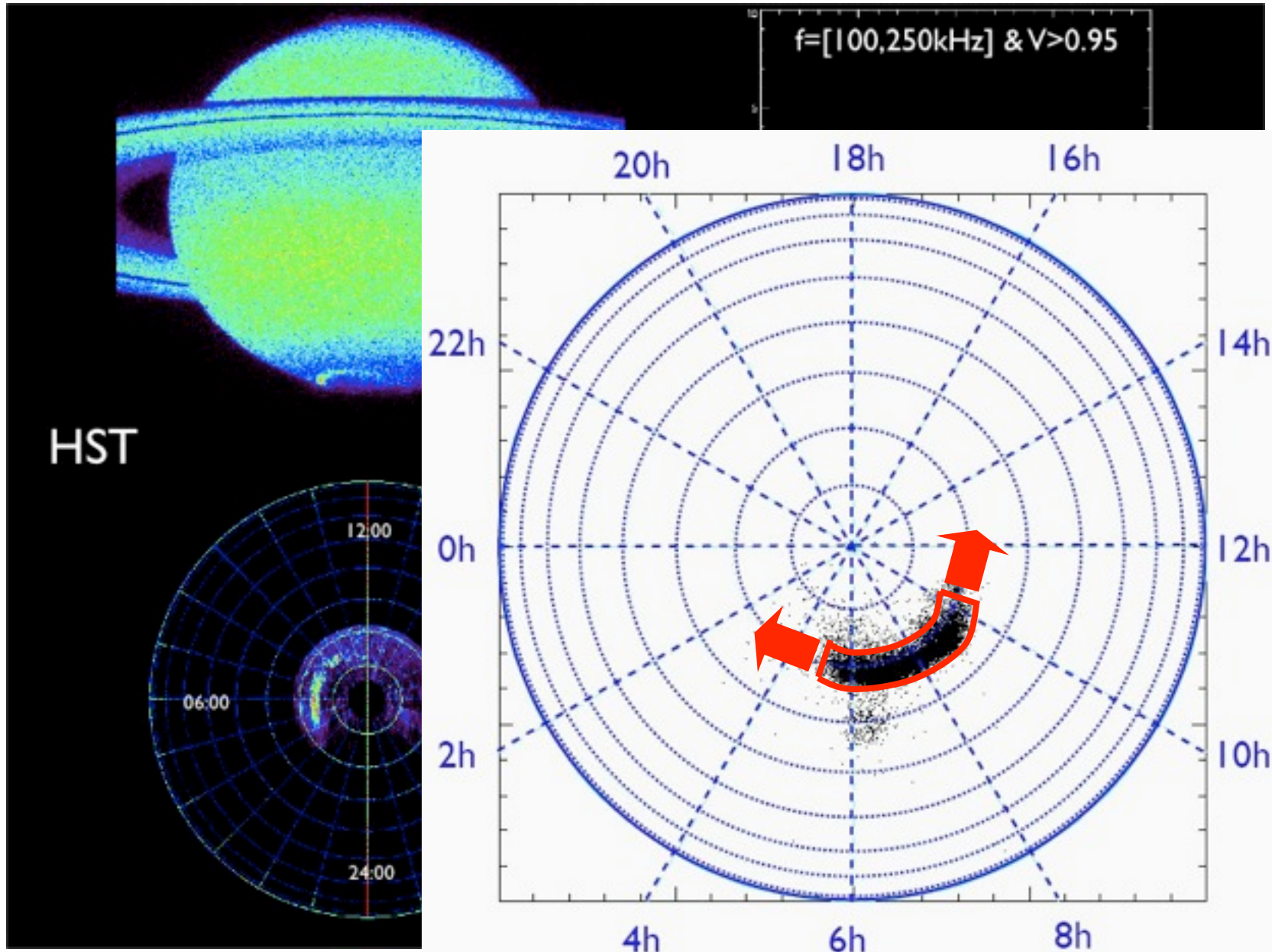
CASSINI-radio
[Cecconi & Zarka, 2005]

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

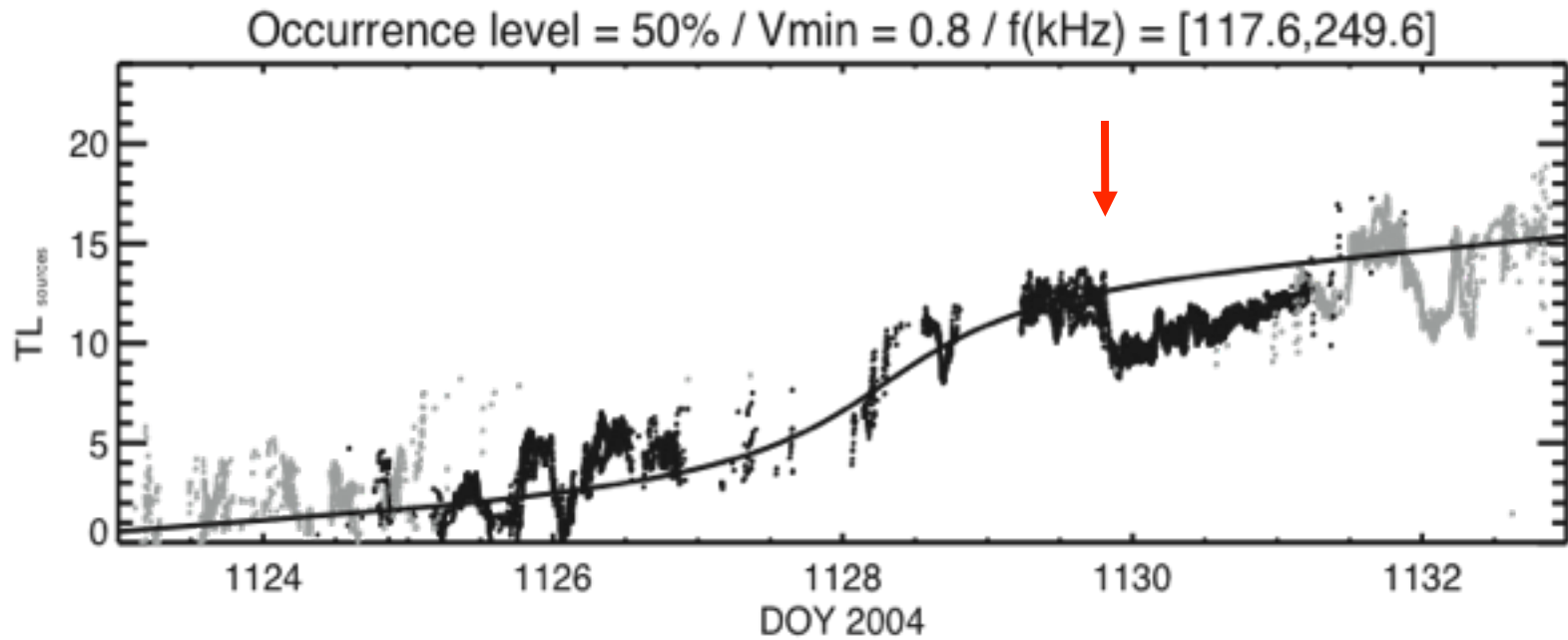
VOYAGER-radio
[Desch & Kaiser, 1981]



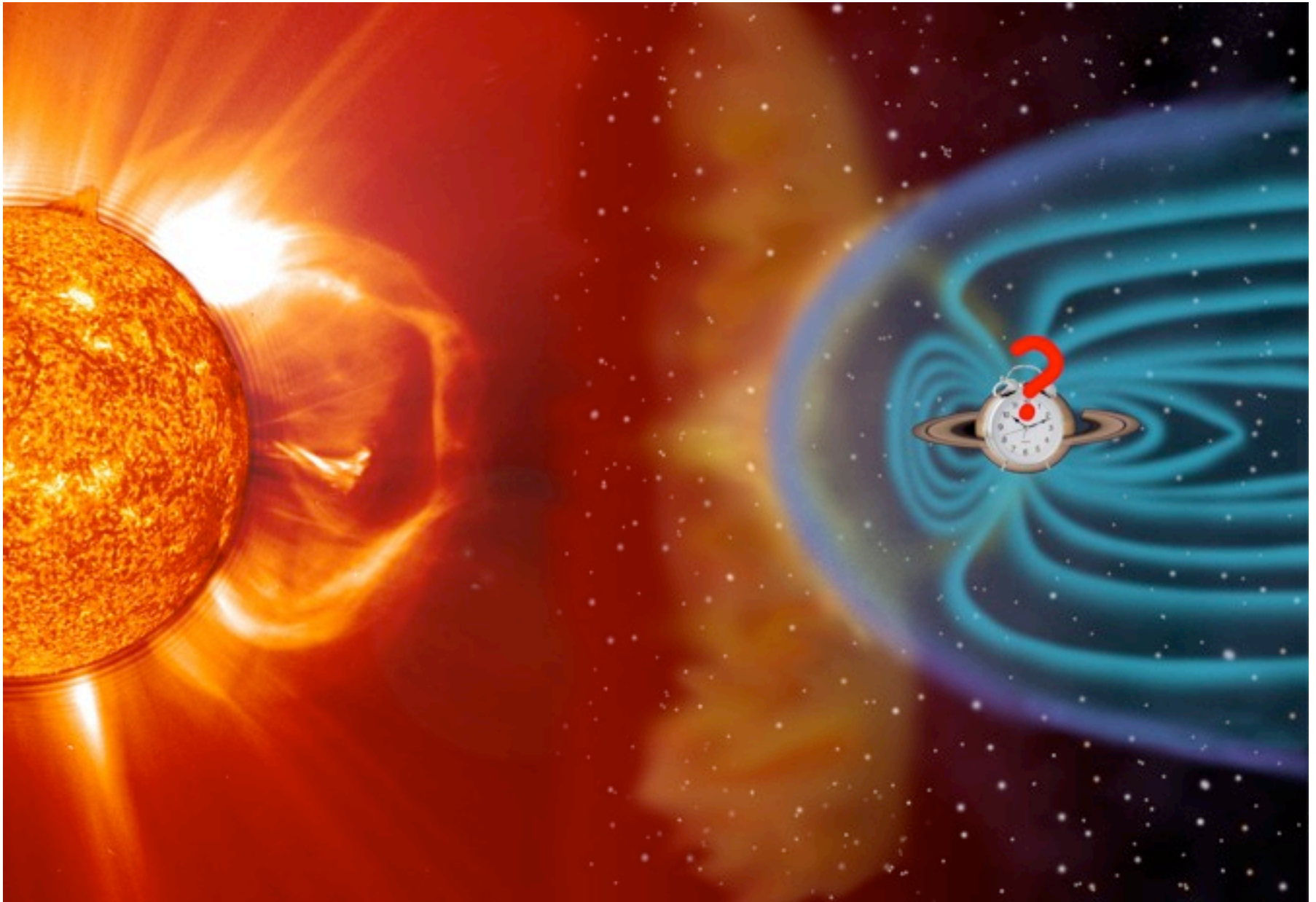
Une réponse à l'étude ...



Une réponse à l'étude ...



A suivre ...



Références :

- P. Zarka, L. Lamy, B. Cecconi, R. Prangé & H. O. Rucker, Solar Wind modulation of Saturn's radio clock, *Nature*, in press, 2007.
- B. Cecconi & P. Zarka, Model of a variable radio period for Saturn, *J. Geophys. Res.* 110, A12203, 2005.