



# **Inversions du champ magnétique solaire: observations**

*Jean-Marie Malherbe*

**Observatoire de Paris**

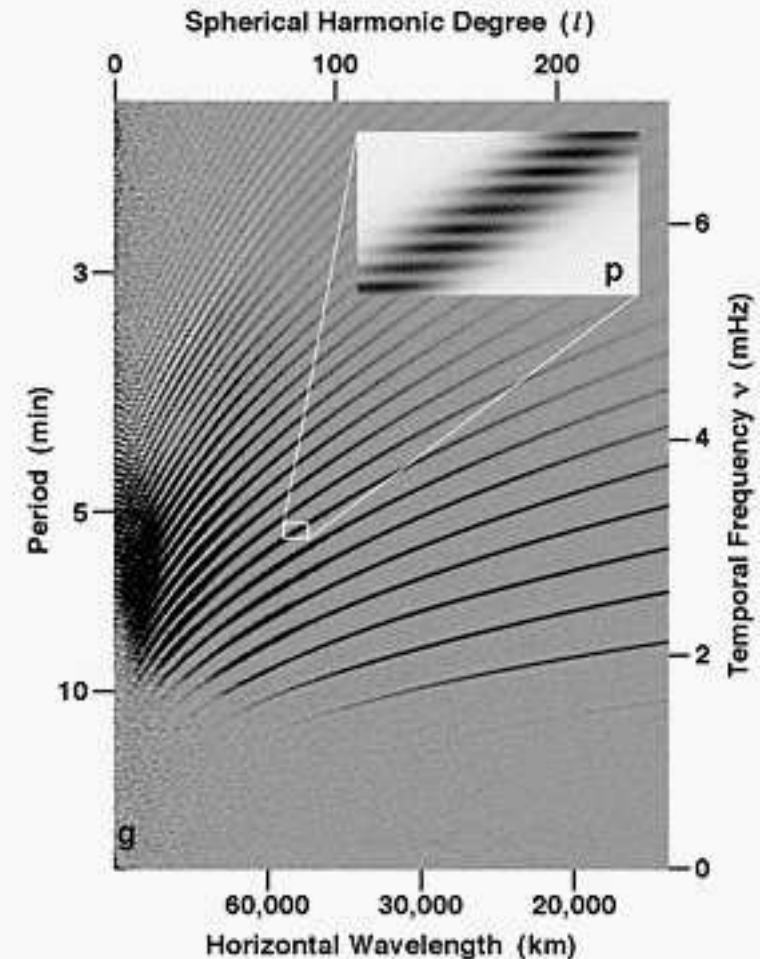
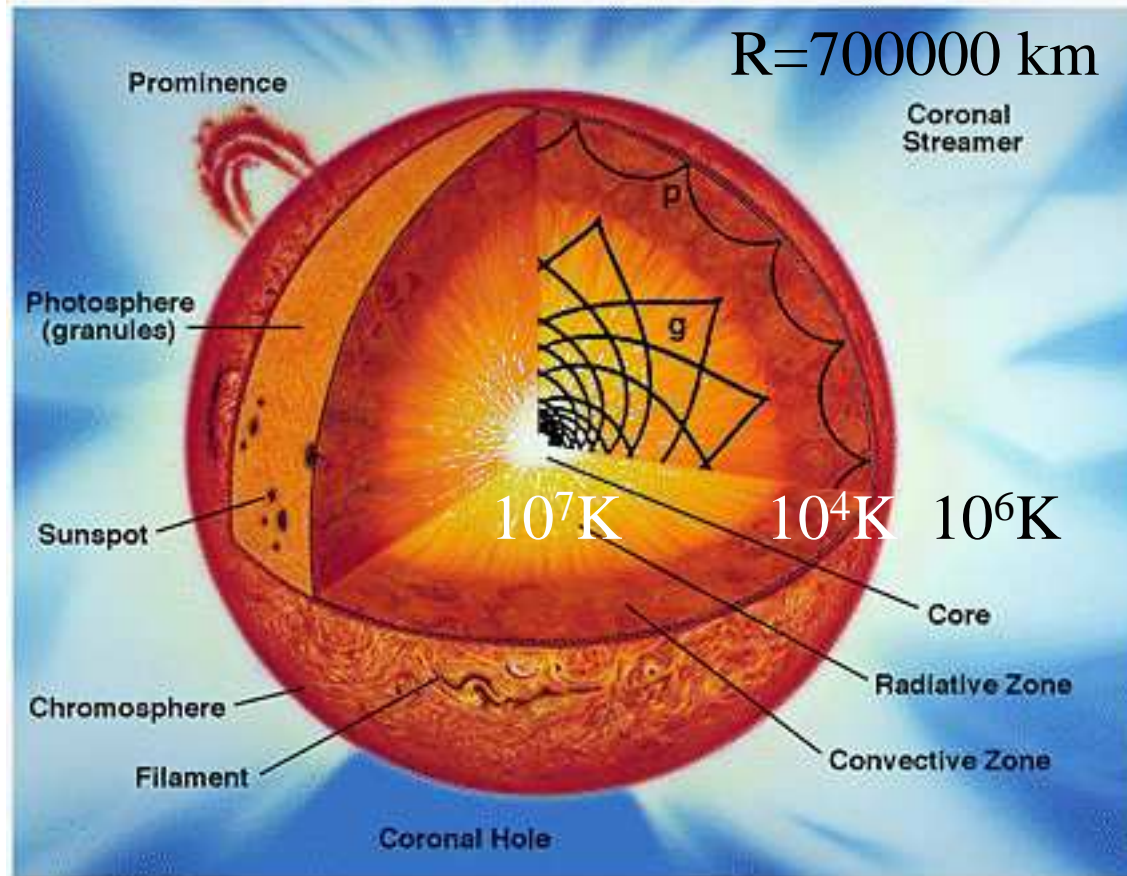
**I – L'étoile Soleil**

**II – Variabilité/cyclicité multi-longueur d'onde**

**III – Inversions magnétiques**

**IV – Des anomalies dans la cyclicité**

Cœur, zone radiative, zone convective: inaccessibles au télescope  
Photosphère, chromosphère, couronne: observables à distance



Héliosismologie : étude des modes propres de vibration de la surface, permettant un sondage indirect de la structure interne

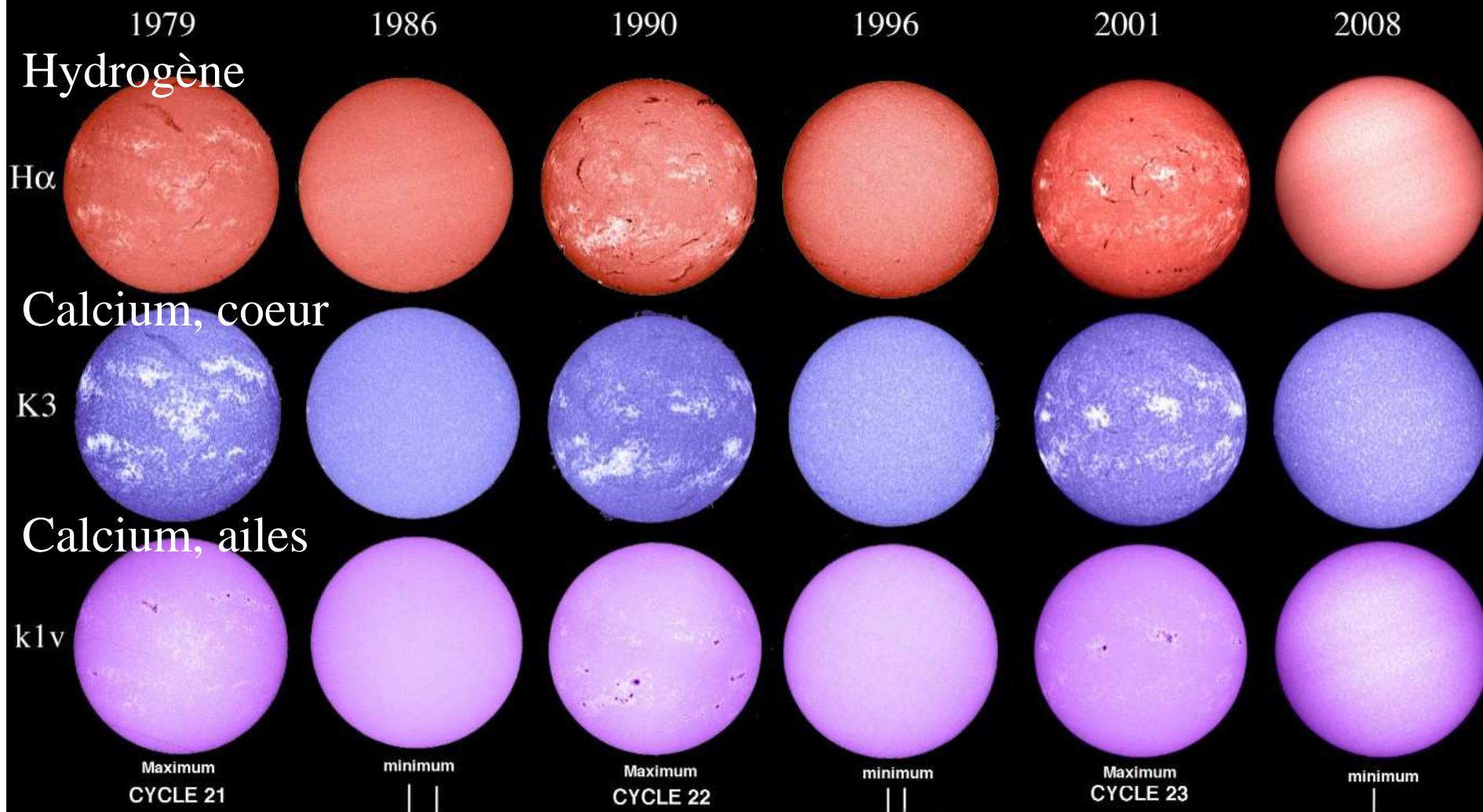


# **Inversions du champ magnétique solaire: Observations**

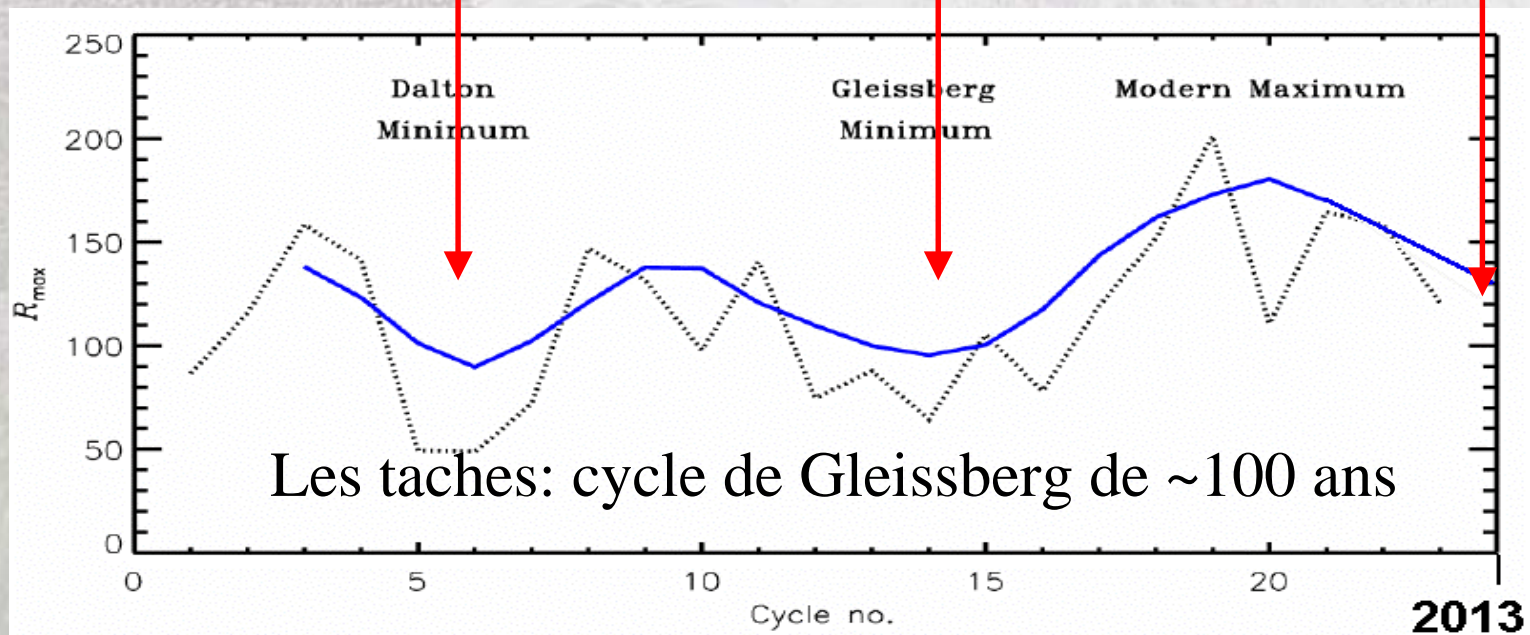
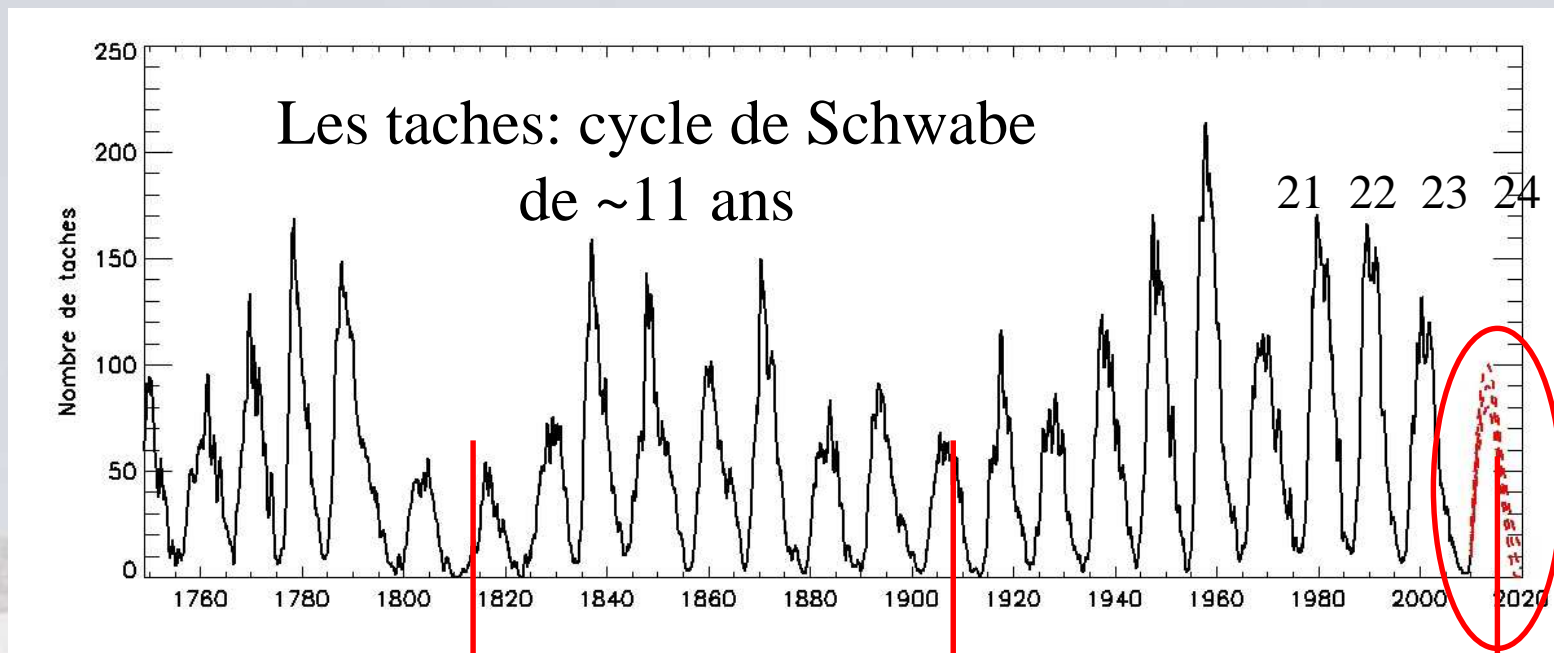
## **II – Variabilité multi-longueur d'onde**

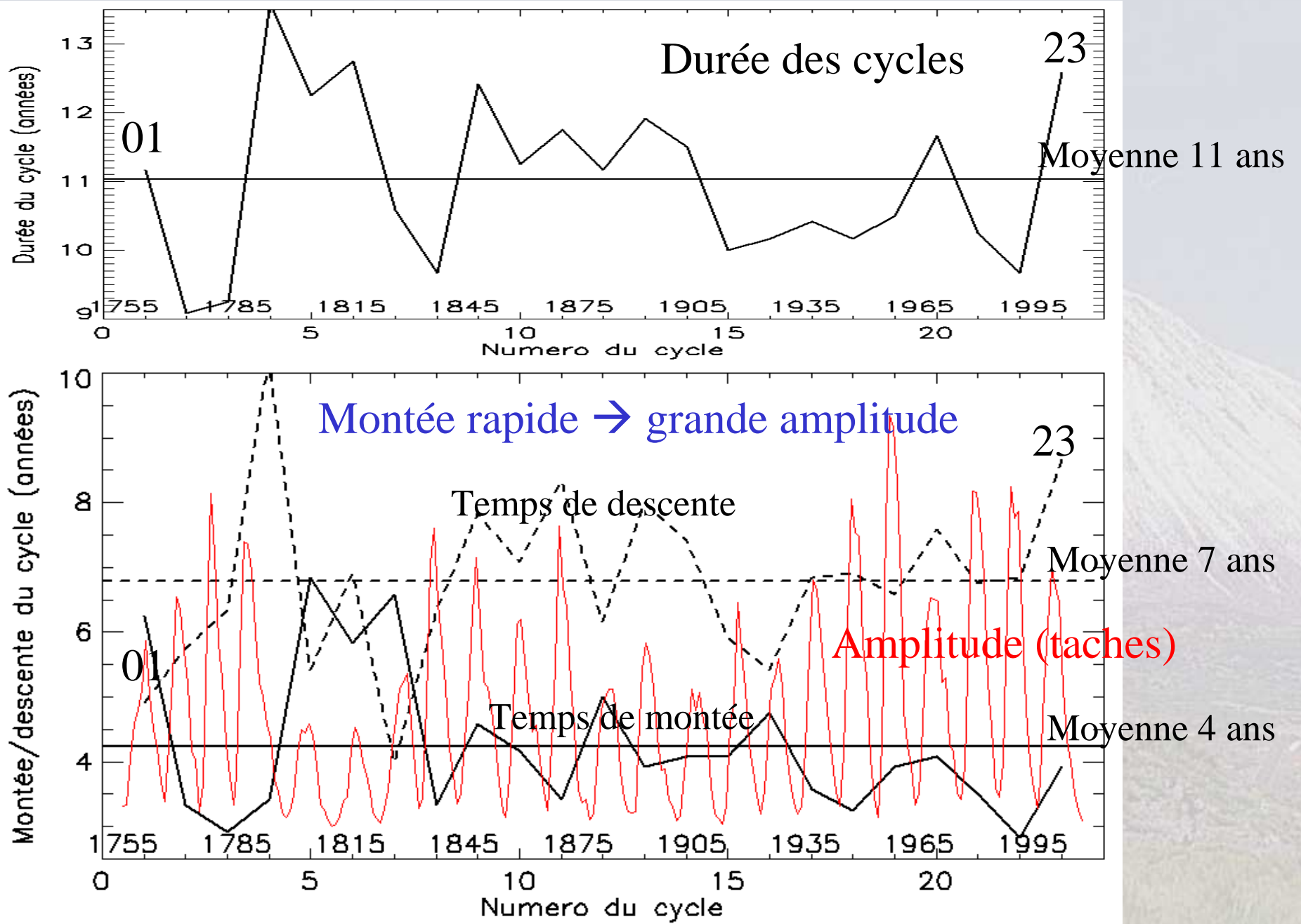
**Optique, rayons cosmiques, irradiance, UV, rayons X**

# CYCLES DE 11 ANS

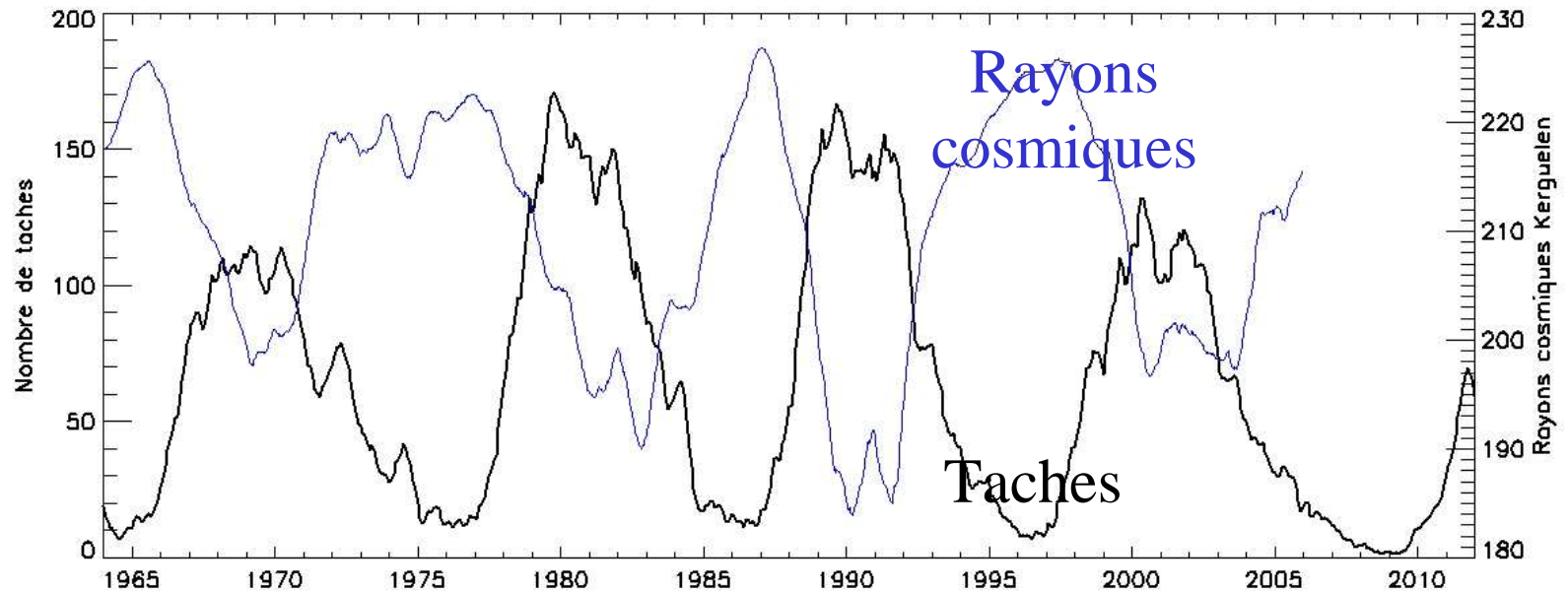


Observatoire de Paris – site de Meudon

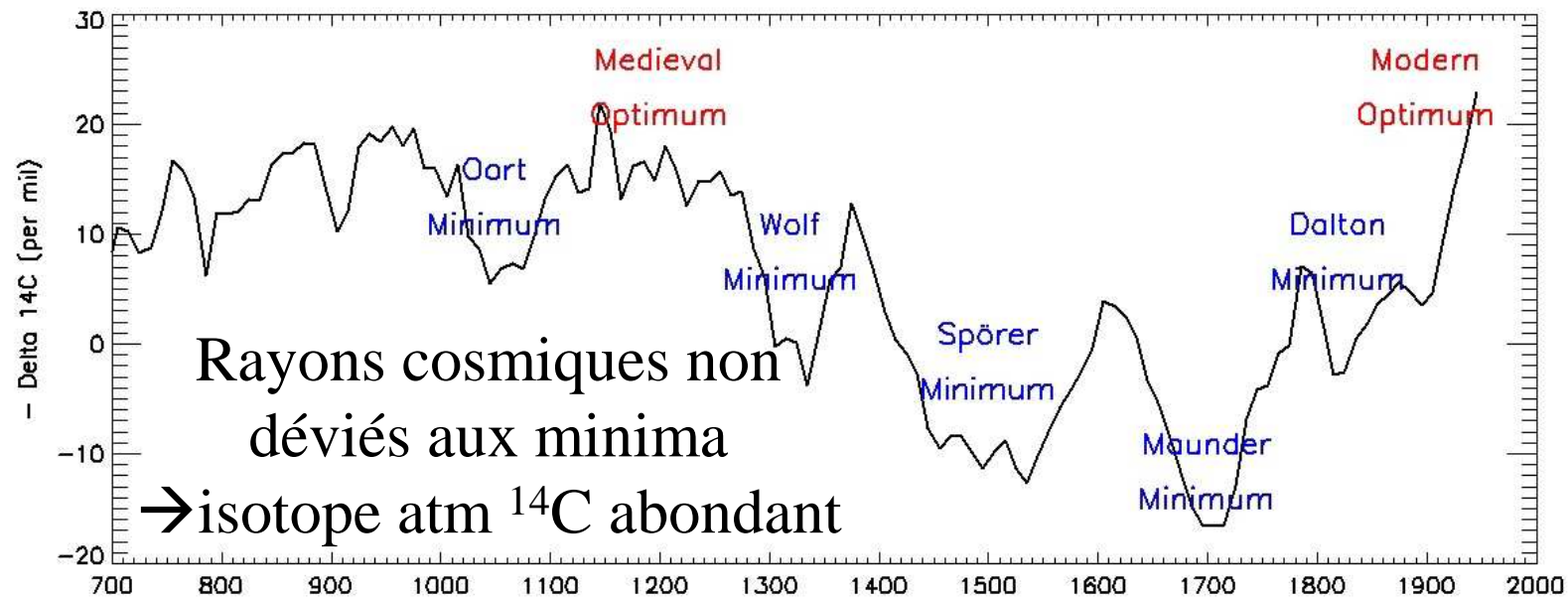


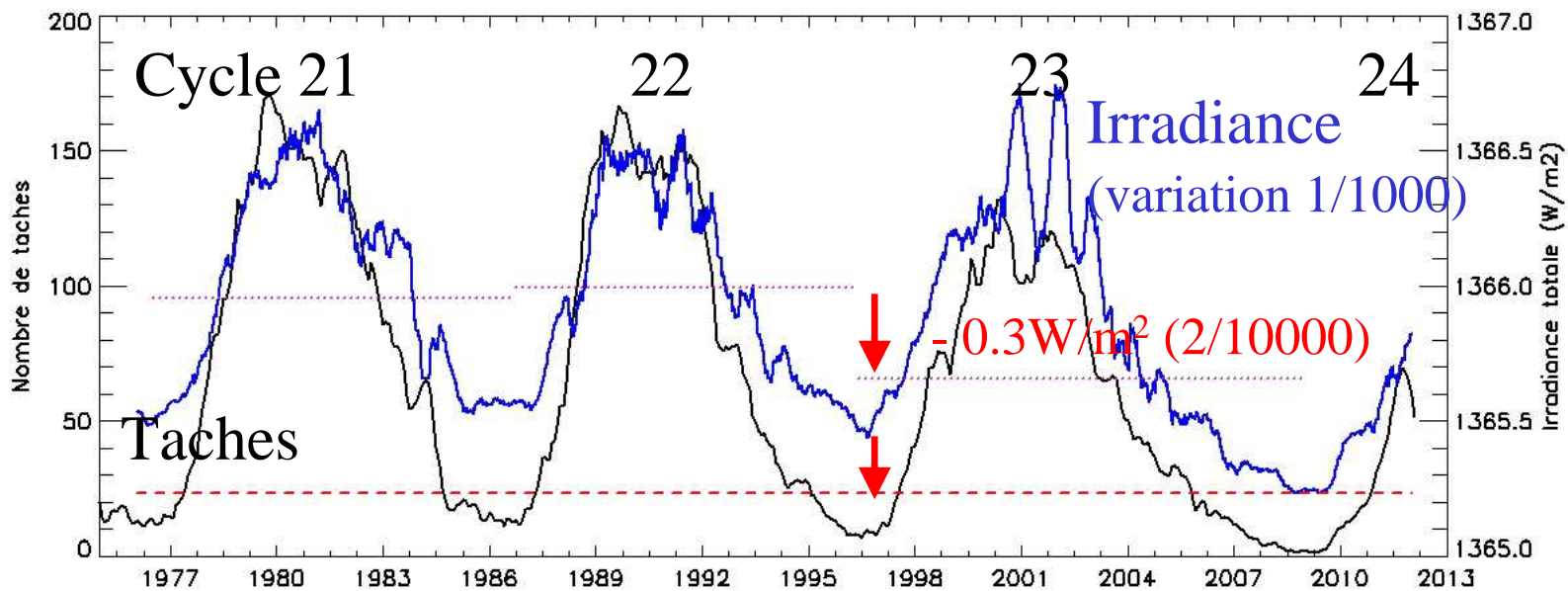


*Rayons cosmiques en anti corrélation avec les taches*

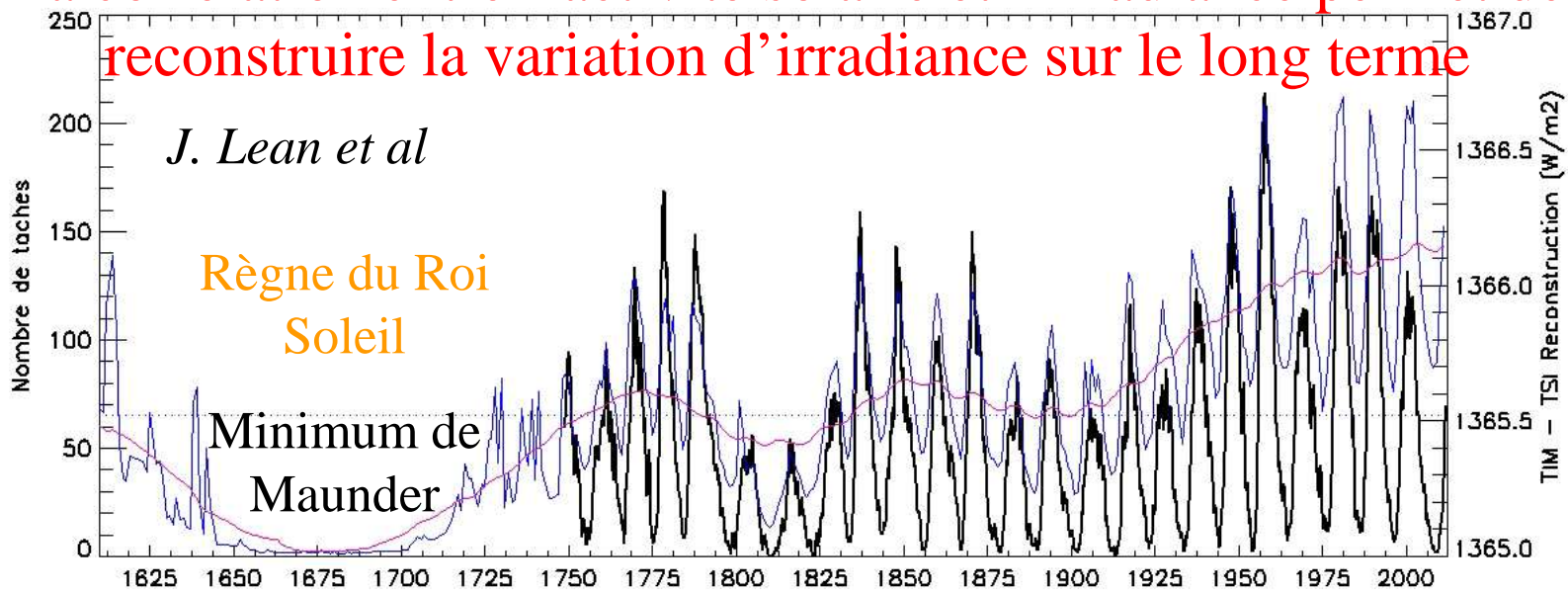


## Isotope cosmogénique $^{14}\text{C}$ et reconstruction de la variabilité solaire

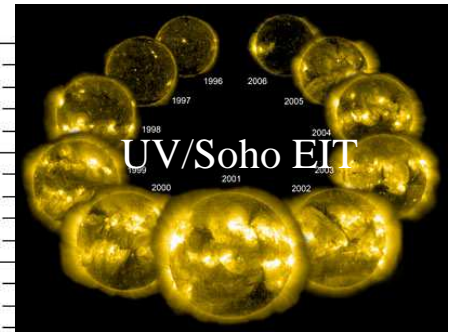
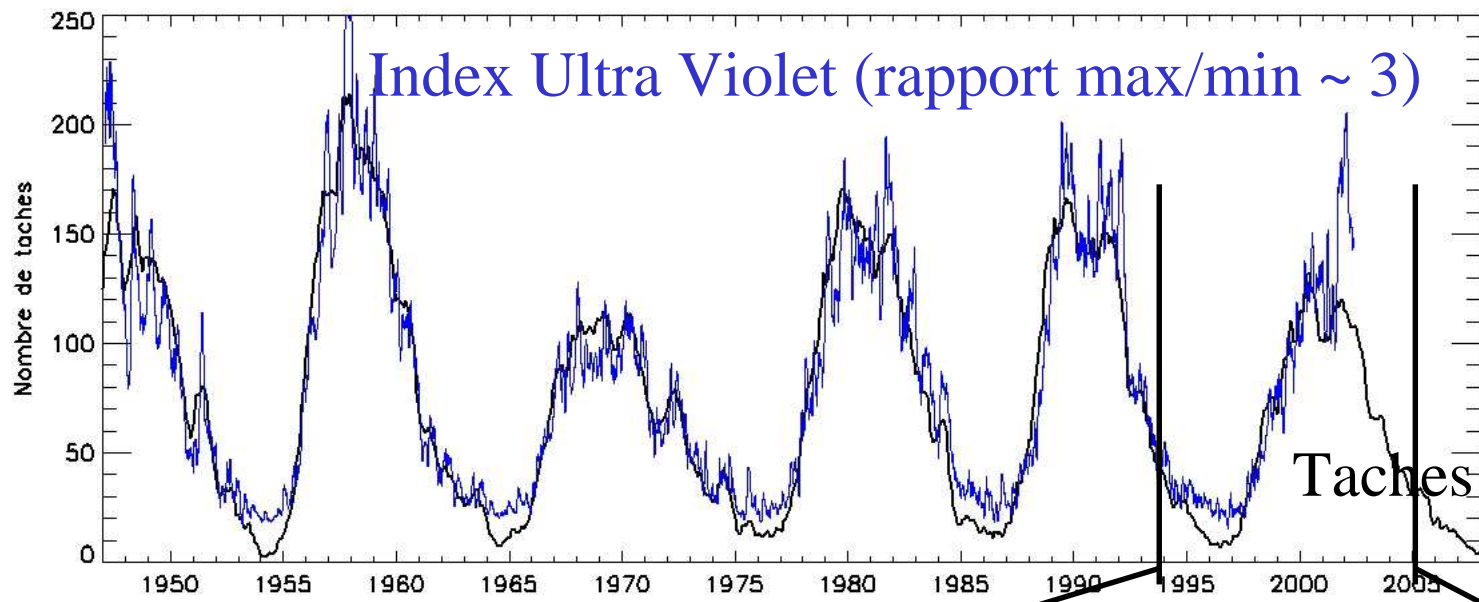




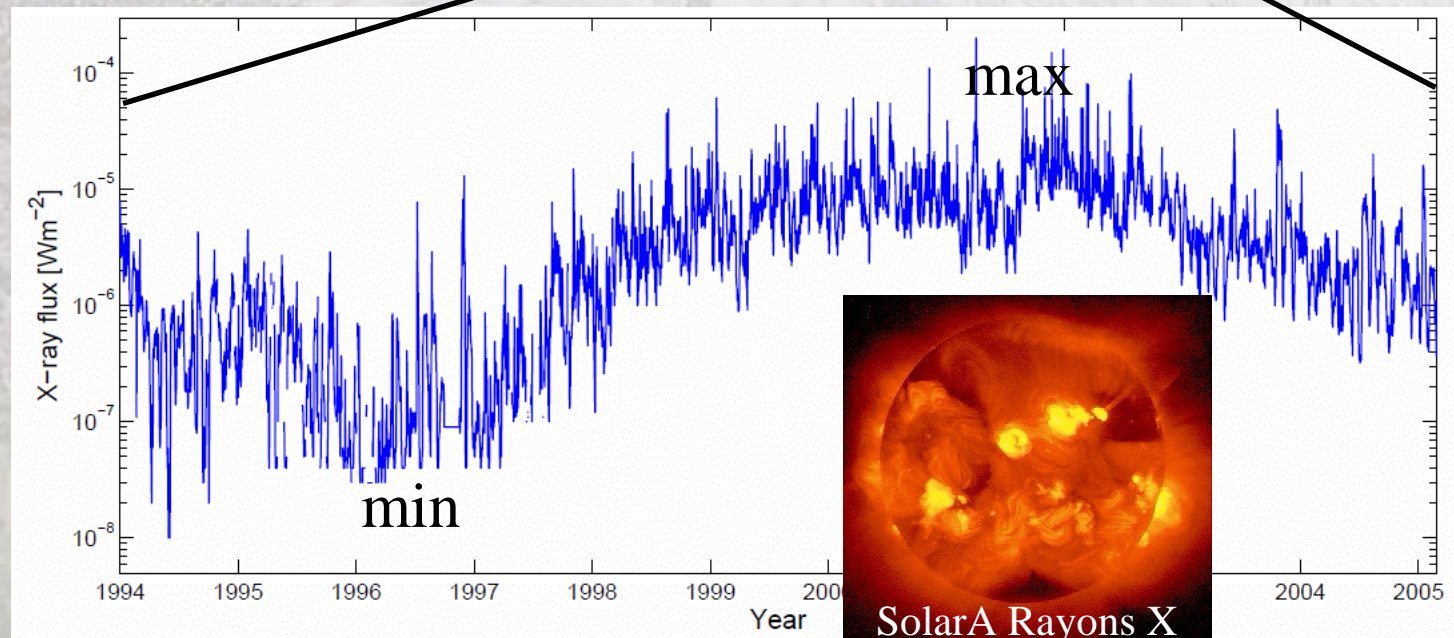
La corrélation entre l'activité solaire et l'irradiance permet de reconstruire la variation d'irradiance sur le long terme







Rayons X  
 échelle log  
 (rapport  
 max/min >  
 100)

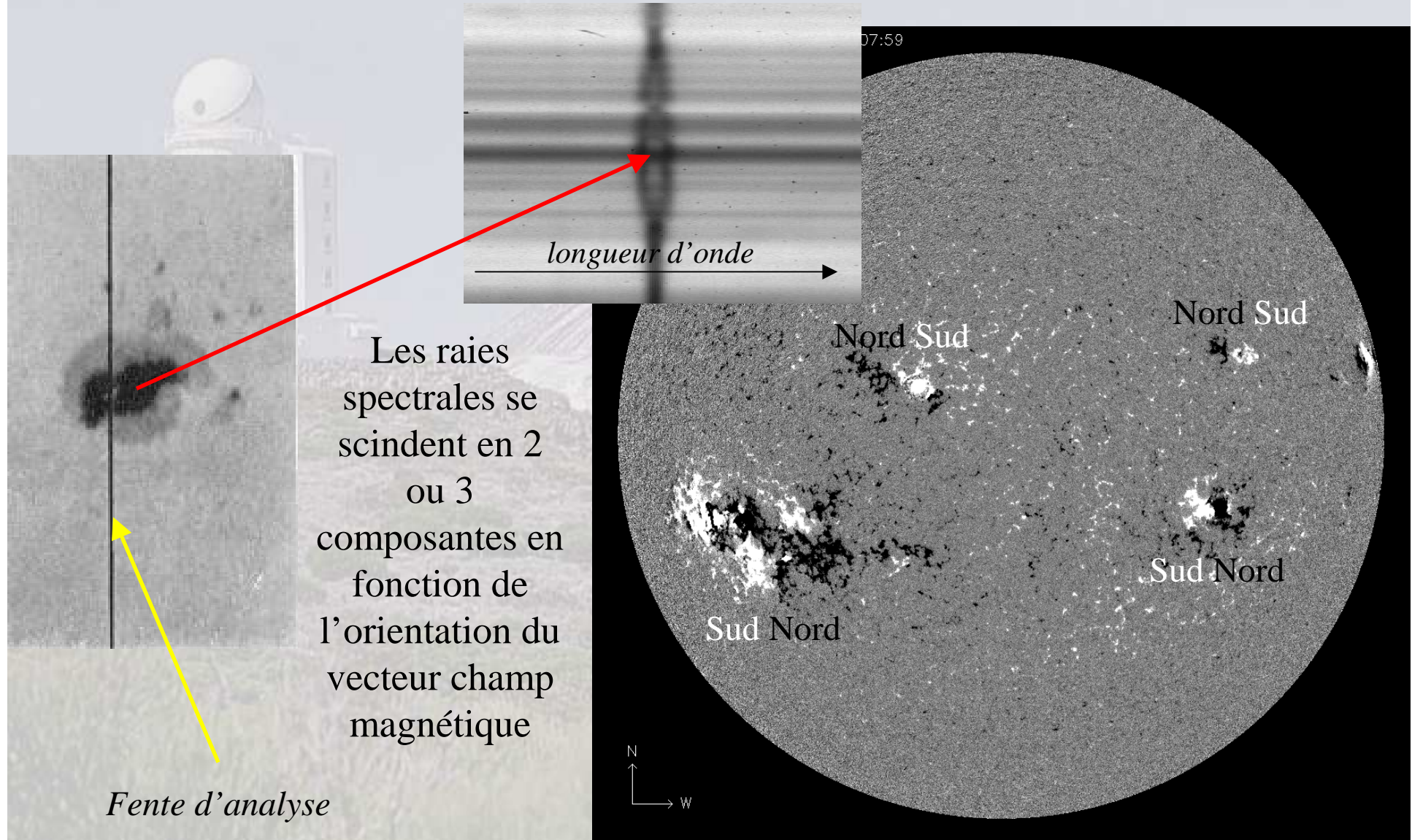




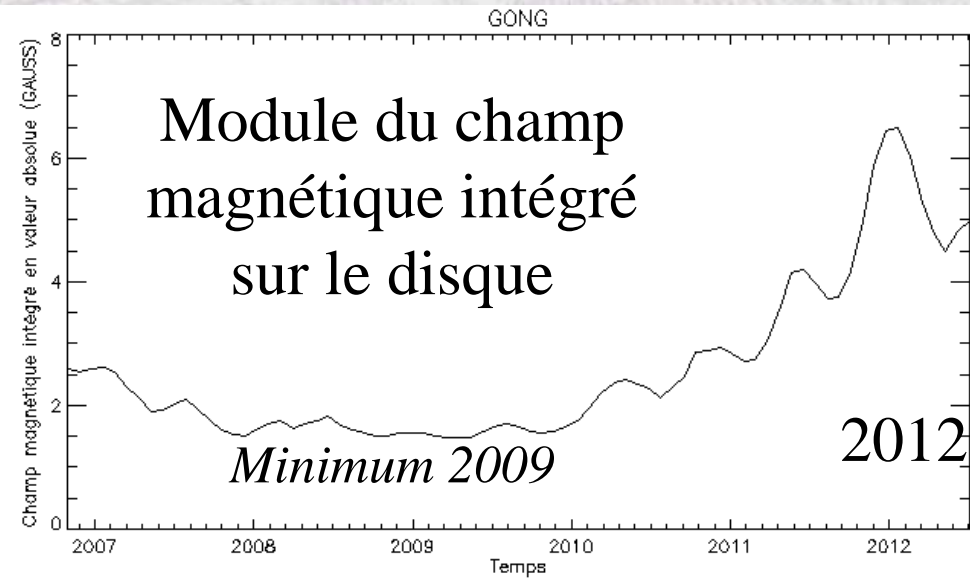
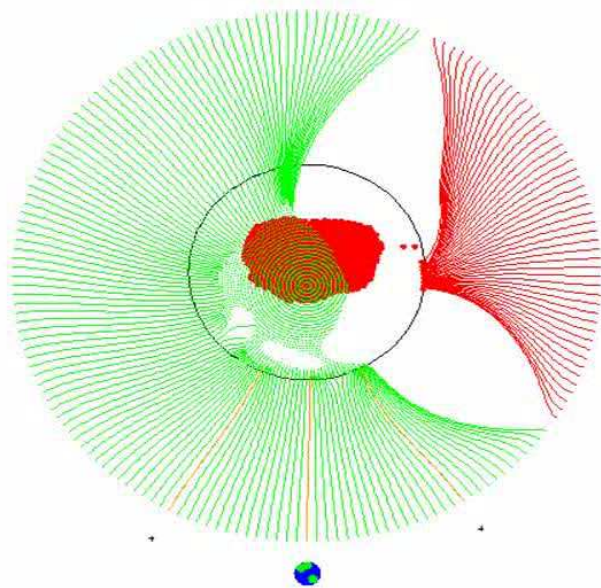
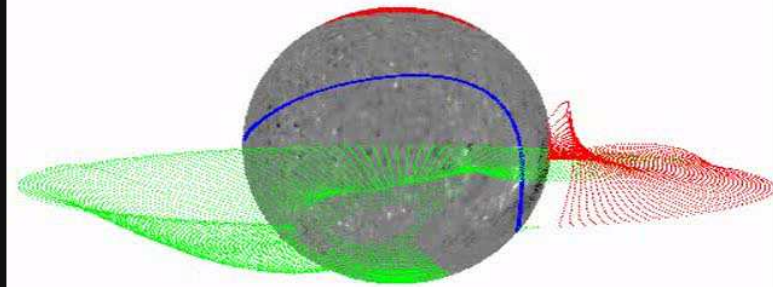
# Inversions du champ magnétique solaire: observations

## III – Inversions magnétiques

*George Hale (1868-1938) découvre la nature magnétique des taches (1908) et le cycle de 22 ans (1919) en y observant l'effet Zeeman*

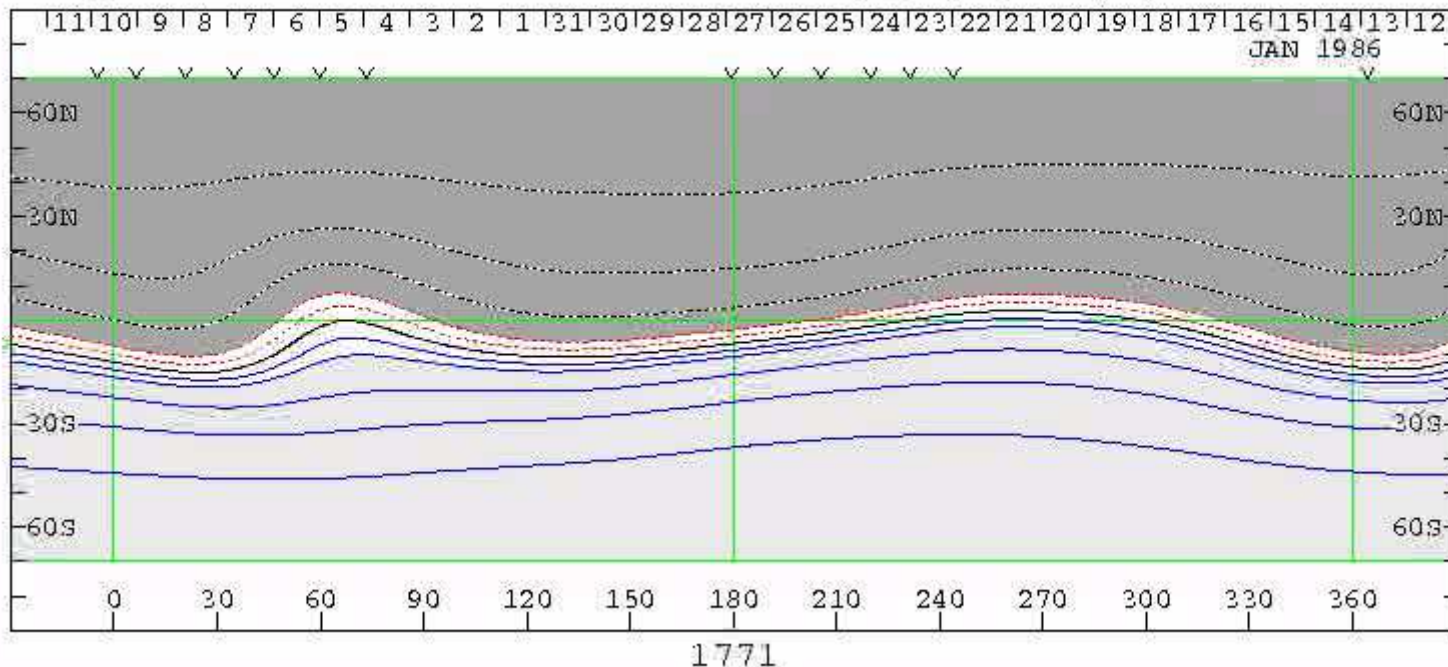


Réseau sol GONG (6 stations réparties en longitude), champs, ligne neutre et secteurs magnétiques extrapolés de 2007 à 2012 vus de la Terre →  
et dans le plan de l'écliptique



ss250\_R field

0, +0.5, 1, 2.5, 5, 10 MicroTesla

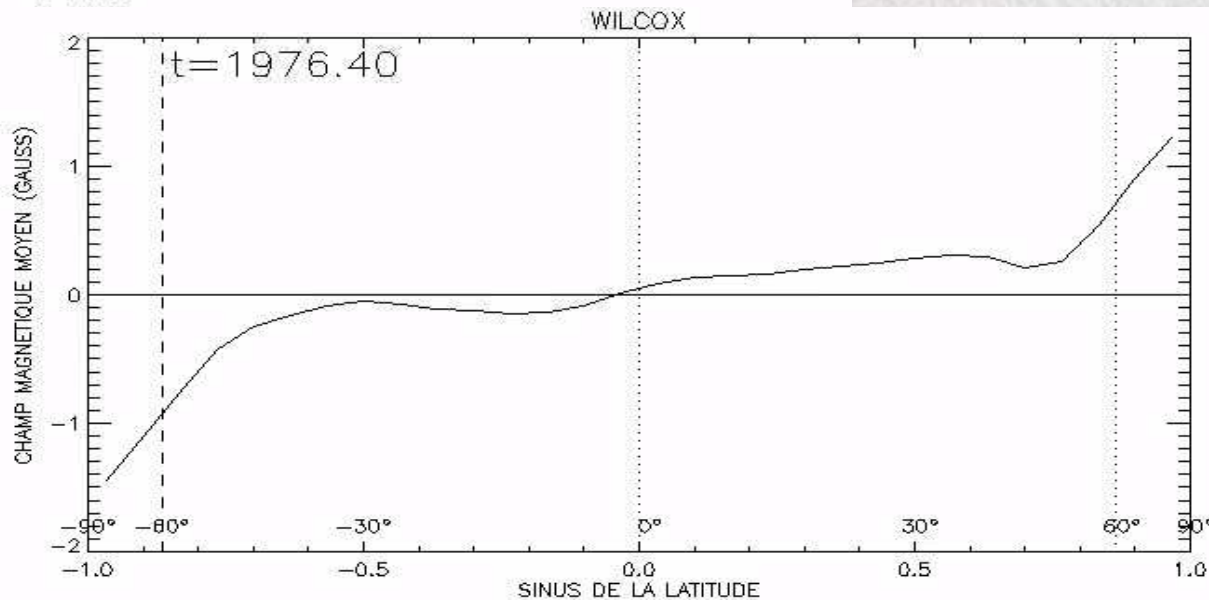


← WILCOX  
cartes  
magnétiques  
synoptiques  
par rotation  
Cycle 22 de  
1986 à 1997

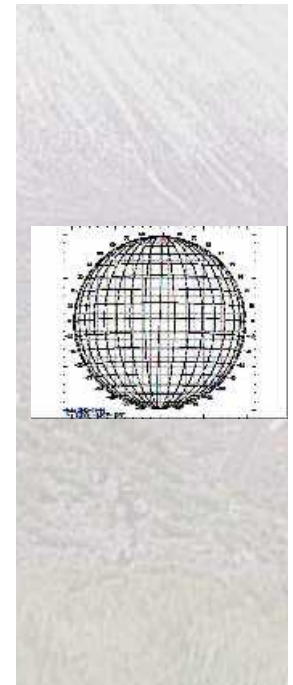
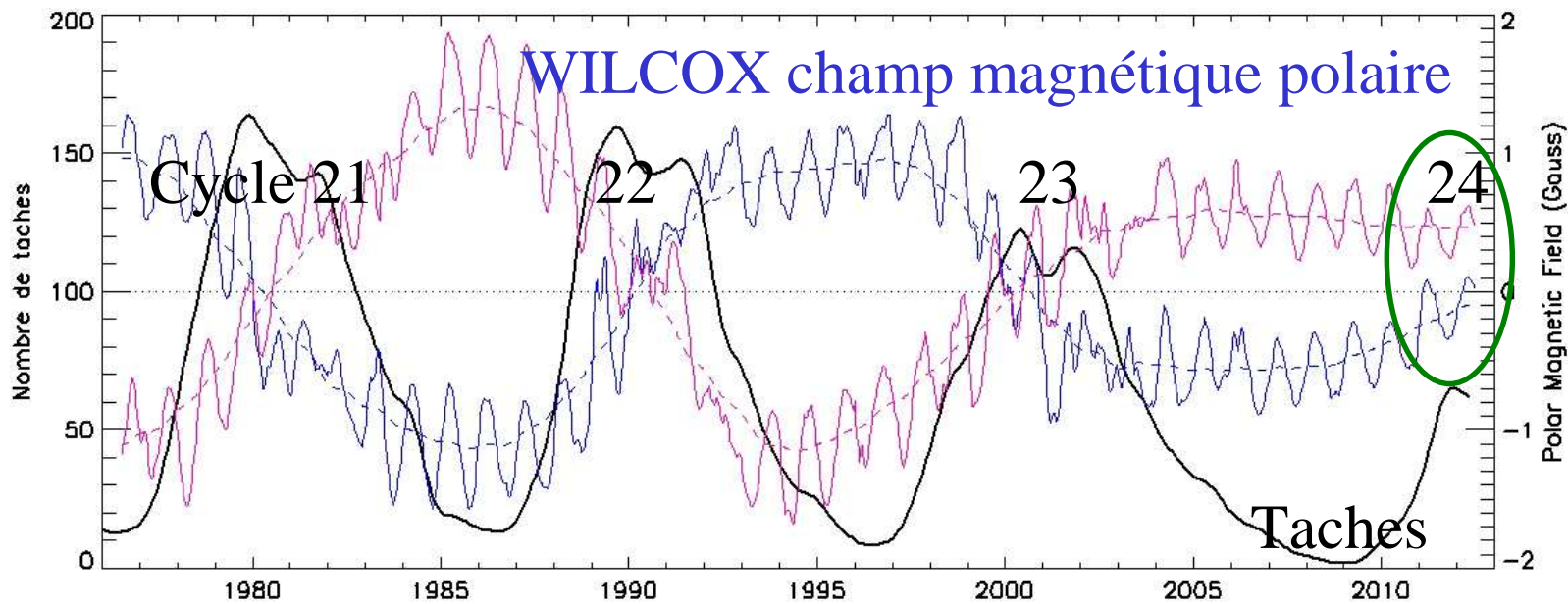
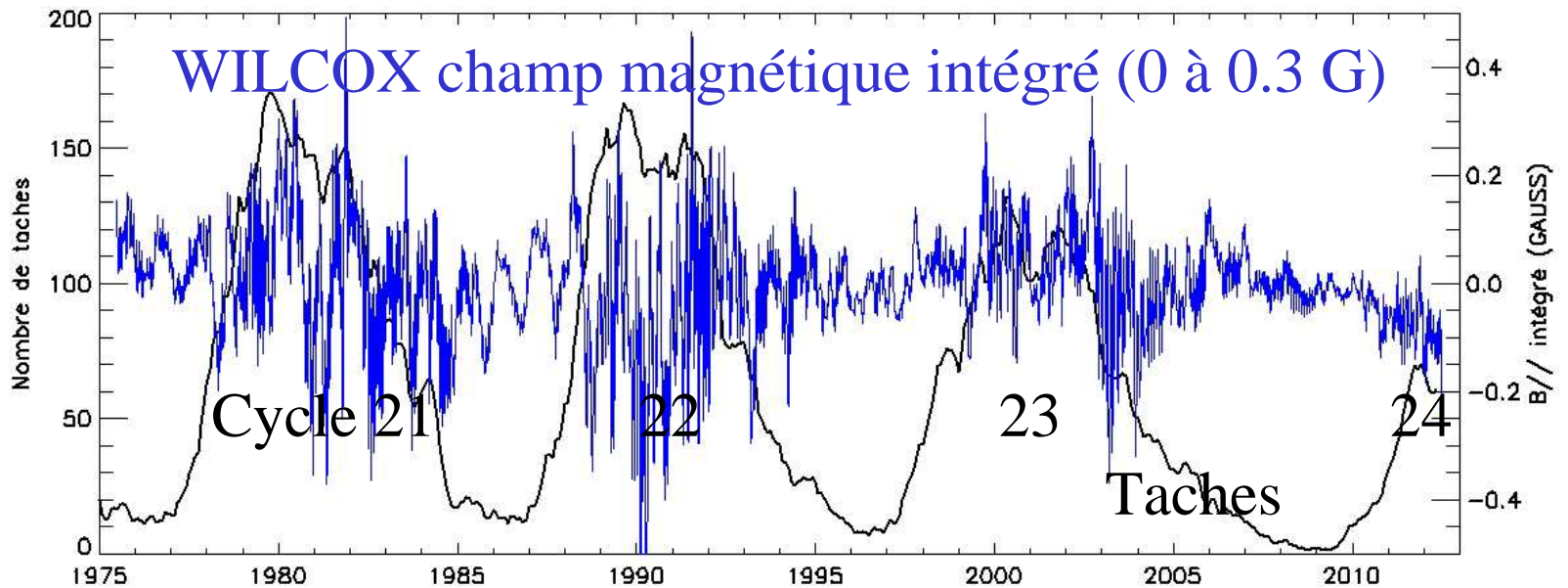
## WILCOX (USA)

Champ magnétique  
moyen en fonction de  
la latitude

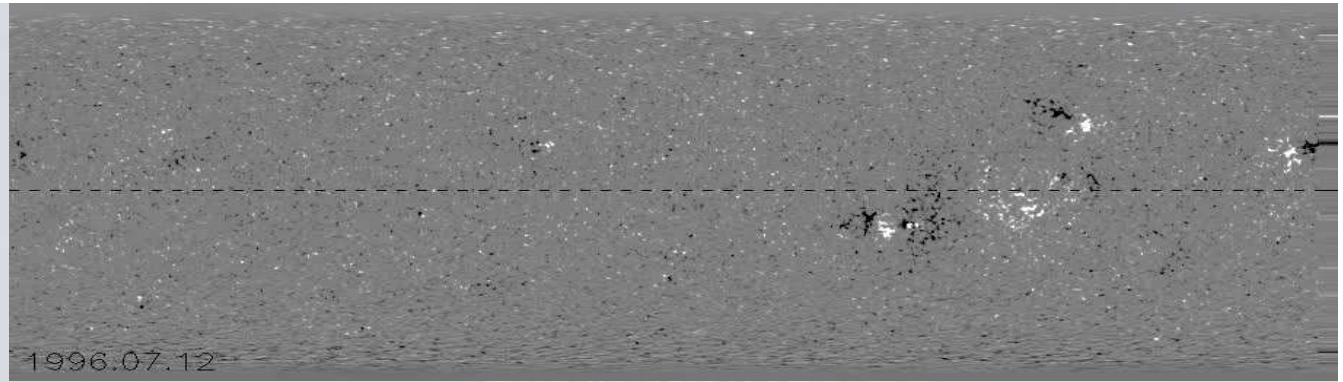
De 1976 à 2011 →



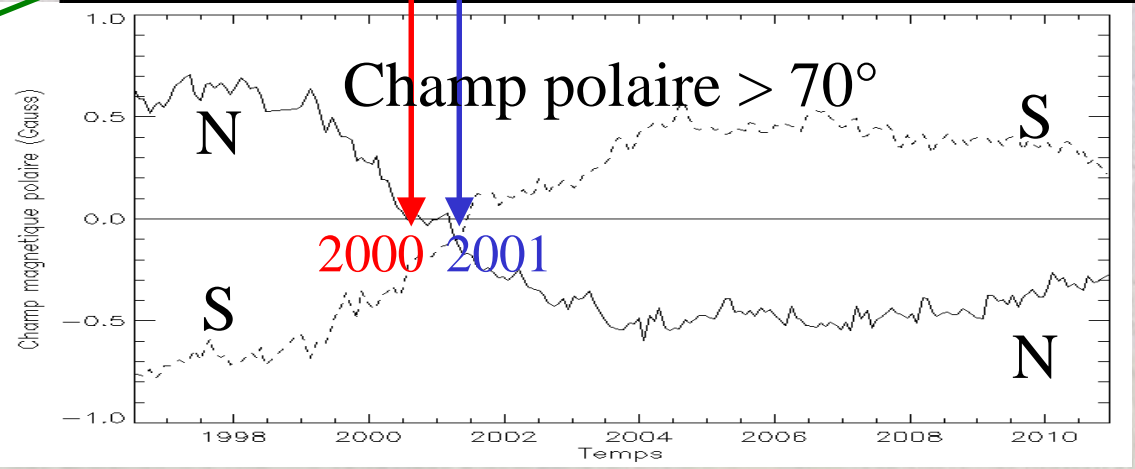
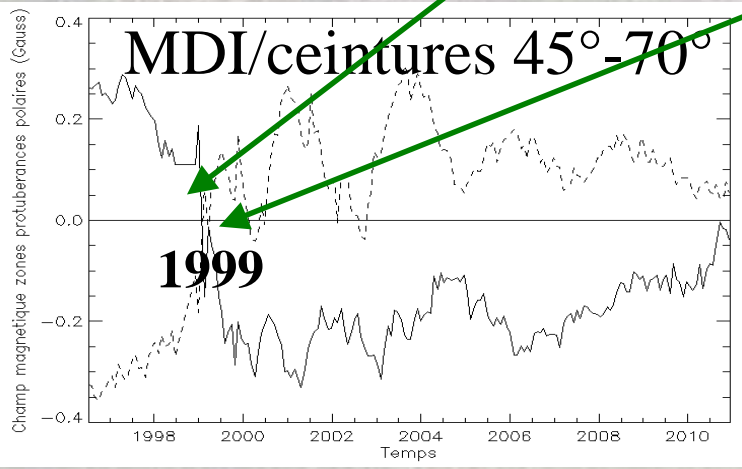
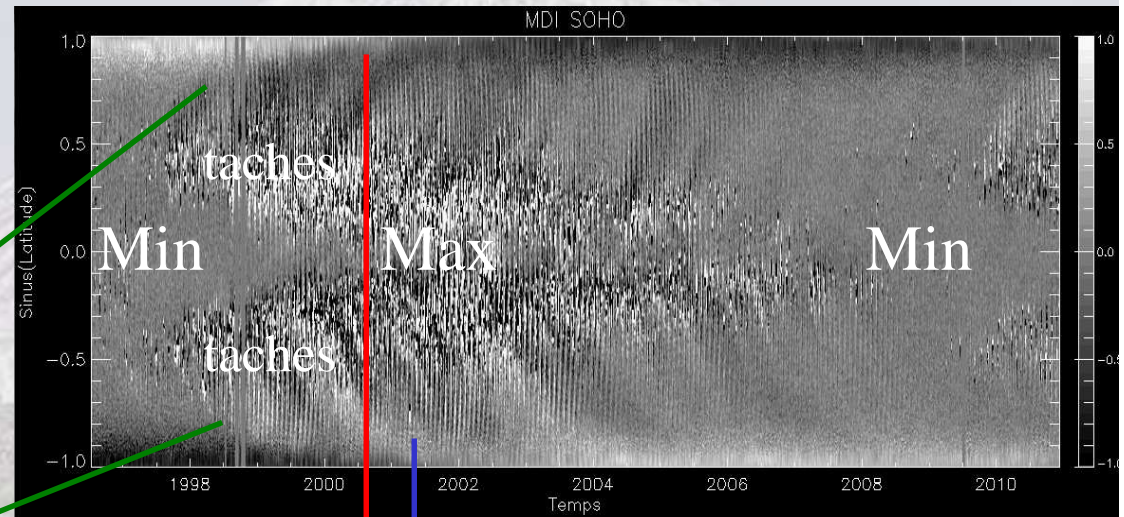
Inversions  
du champ  
au  
maximum  
  
*Champ  
fort au  
minimum*

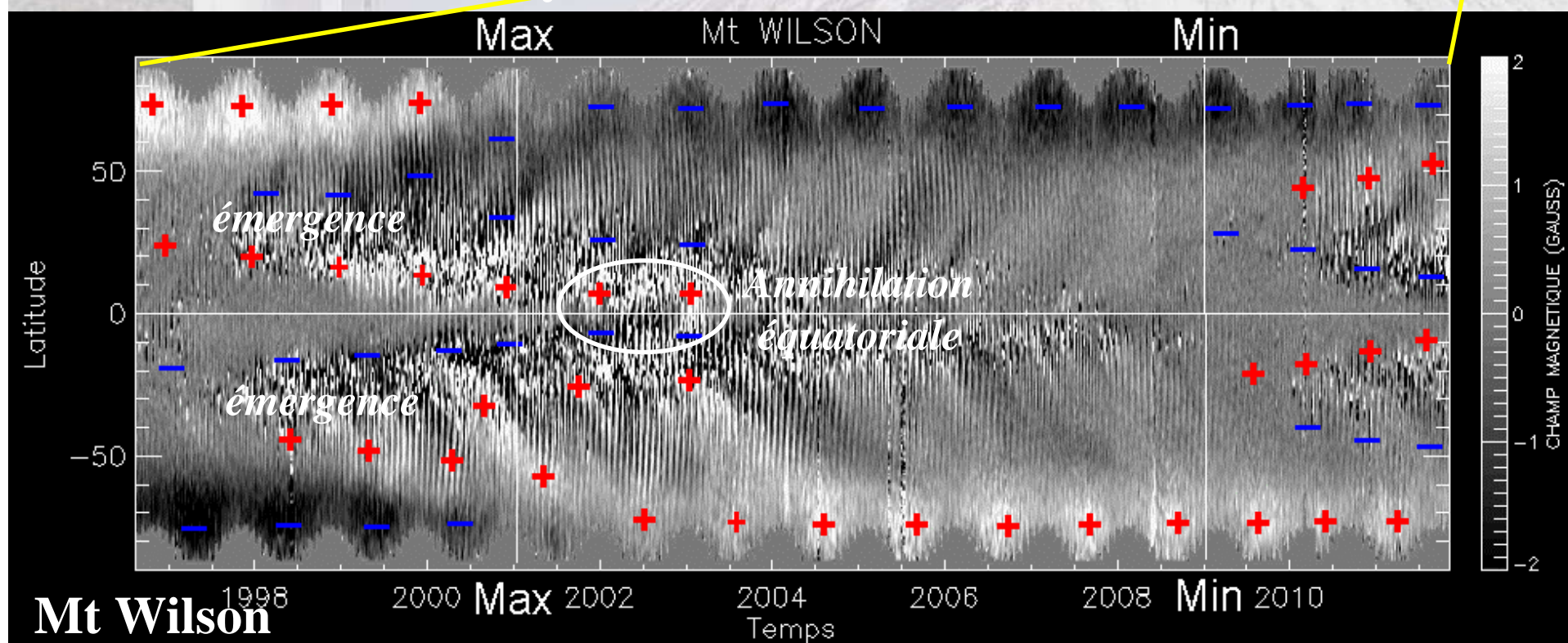
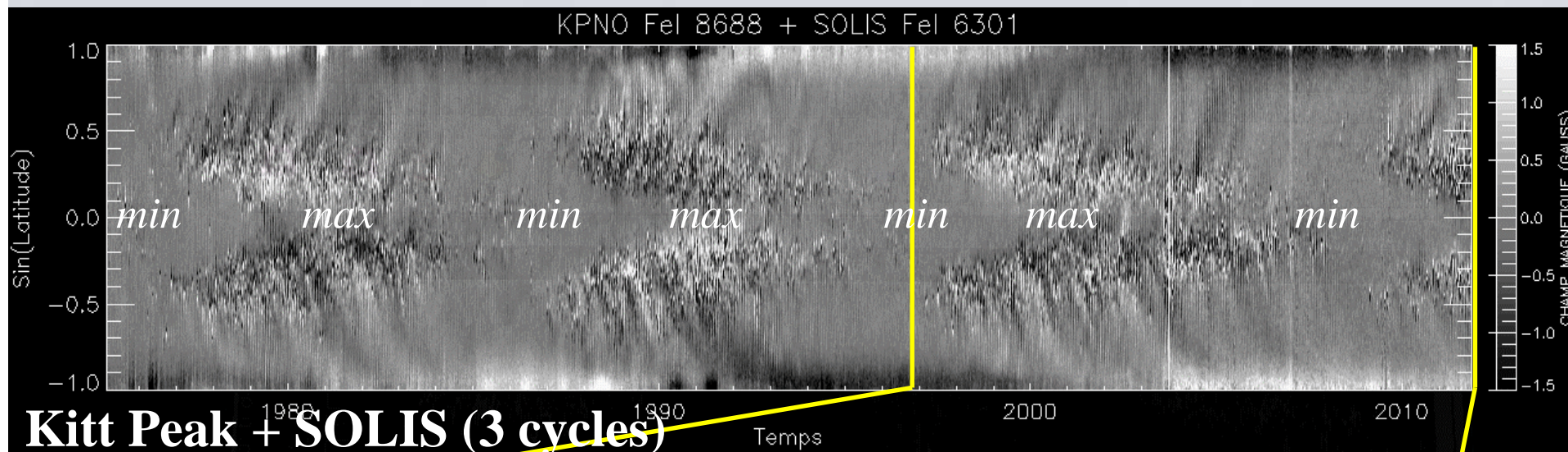


Satellite  
SOHO/MDI cartes  
synoptiques (x,y)  
par rotation

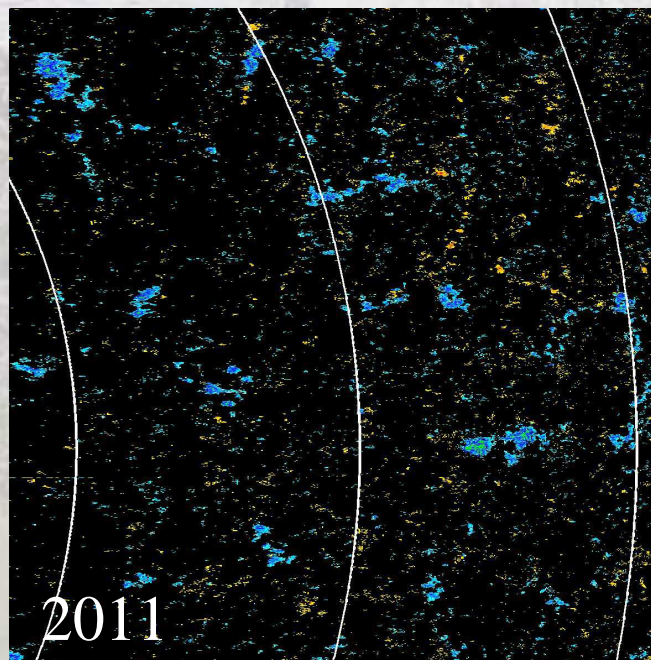
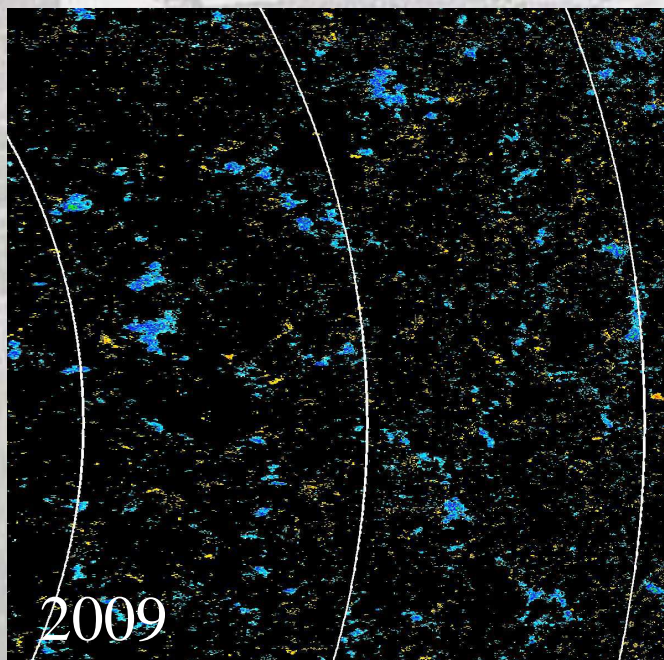
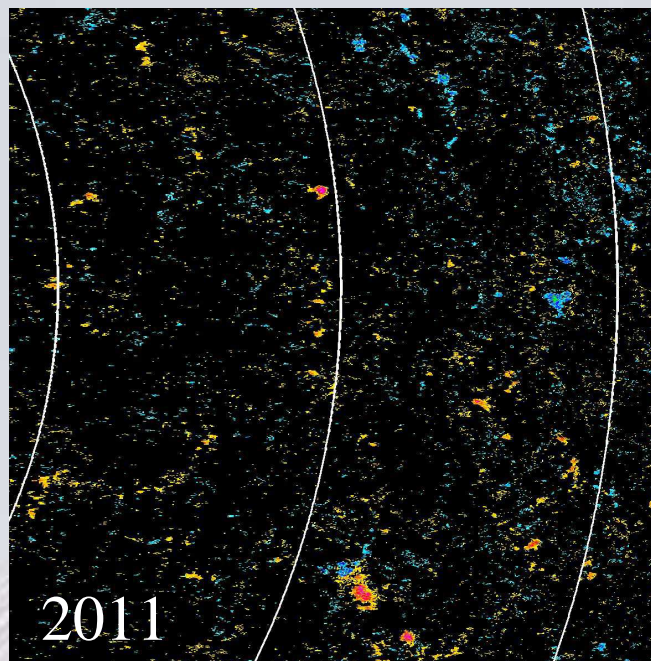
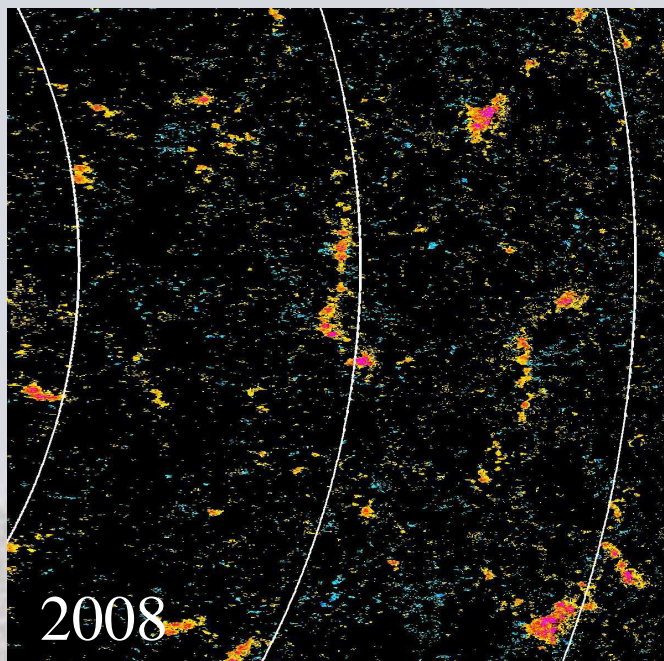


↓  
Champs  
magnétiques de  
1996 à 2011  
(temps, latitude)









Satellite  
Hinode, pôle  
NORD 70°-85°

Inversion  
N/S mi 2012  
en avance  
d'un an sur  
l'inversion  
S/N prévue  
mi 2013

Satellite  
Hinode, pôle  
SUD 70°-85°

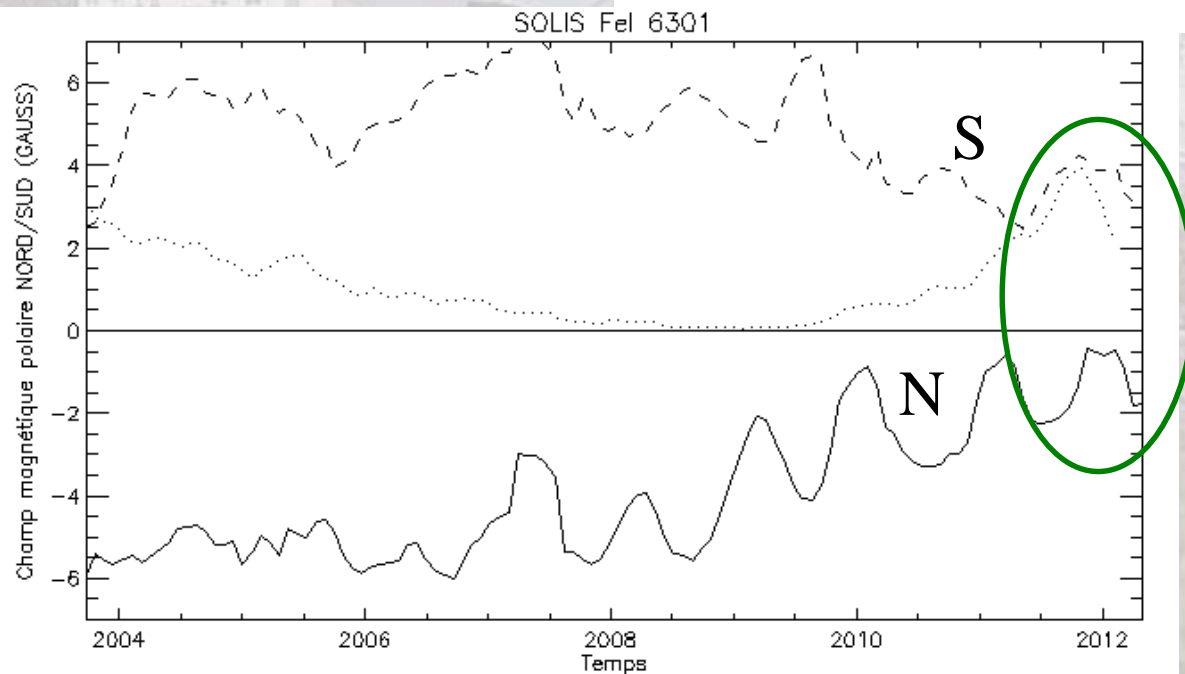
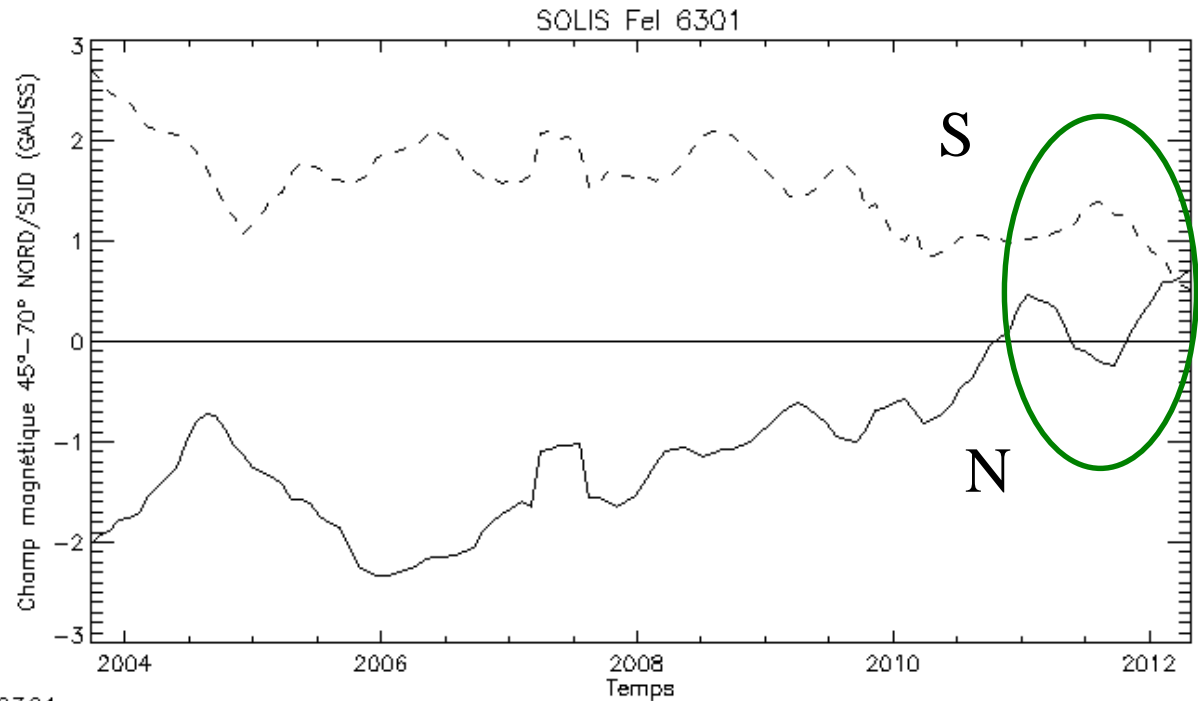
# SOLIS KITT PEAK

Inversion ceinture

45°-70°

Nord mi 2011

Sud mi 2012 ?

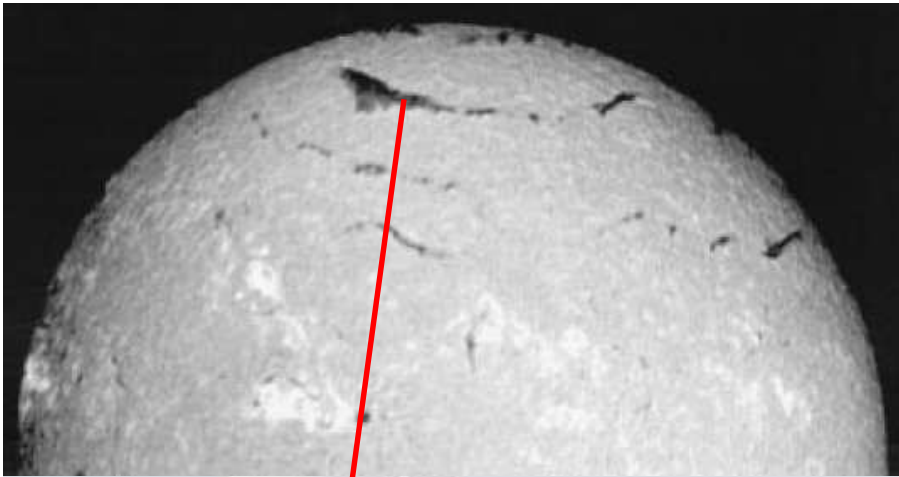


# SOLIS KITT PEAK

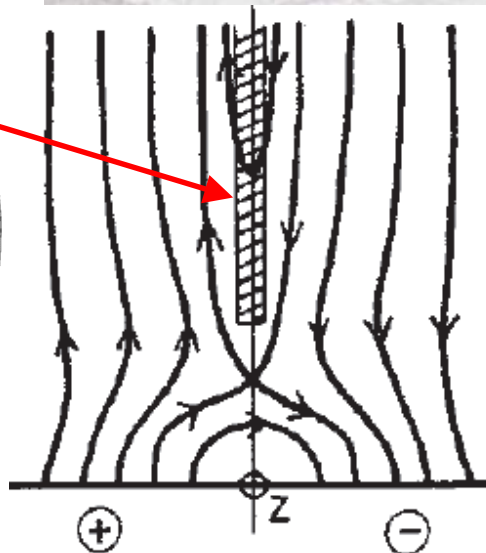
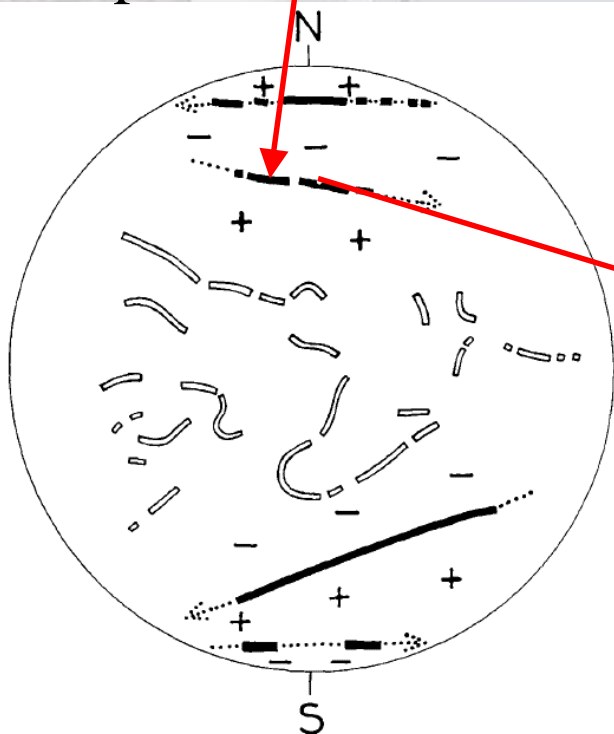
Inversion polaire

Nord mi 2012

Sud mi 2013 ?

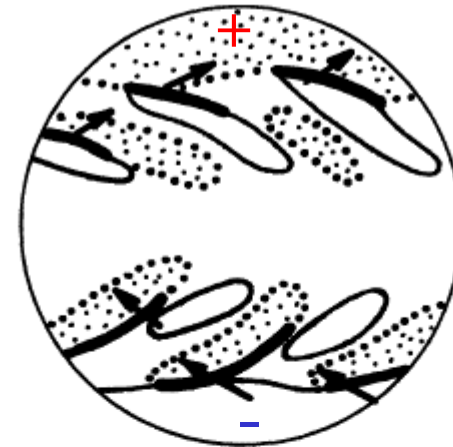


Inversions du champ magnétique axial  
des protubérances des ceintures polaires



filaments des ceintures polaires

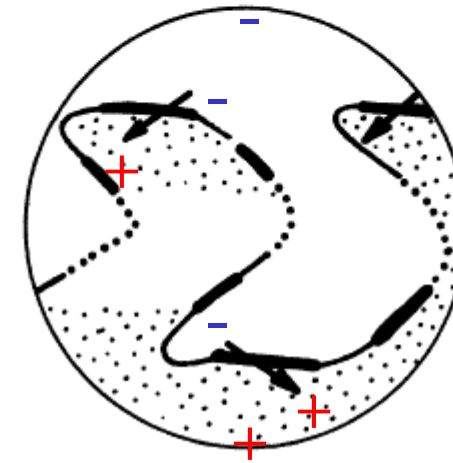
(a)



Minimun cycles 19/20

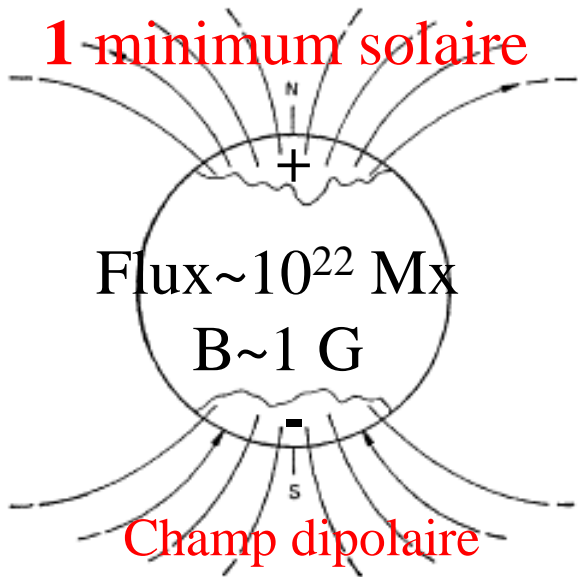
filaments des ceintures polaires

(b)



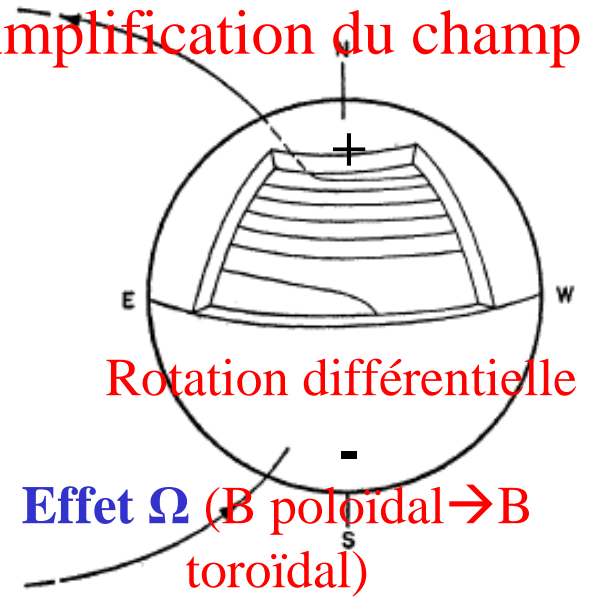
Minimun cycles 20/21

# 1 minimum solaire



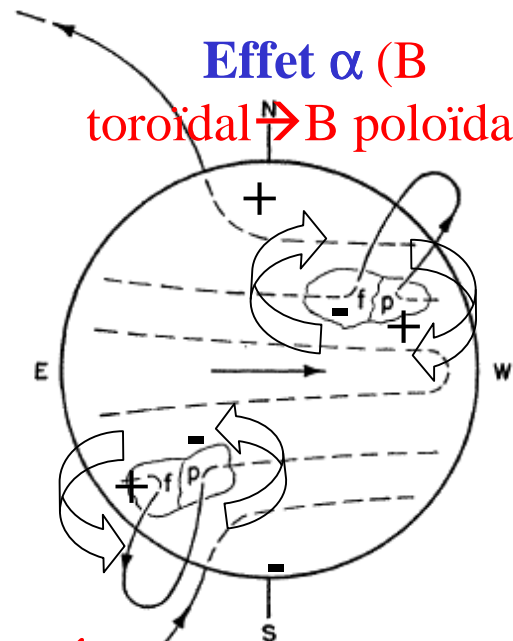
## Modèle dynamo de Babcock Leighton

# 2 Amplification du champ



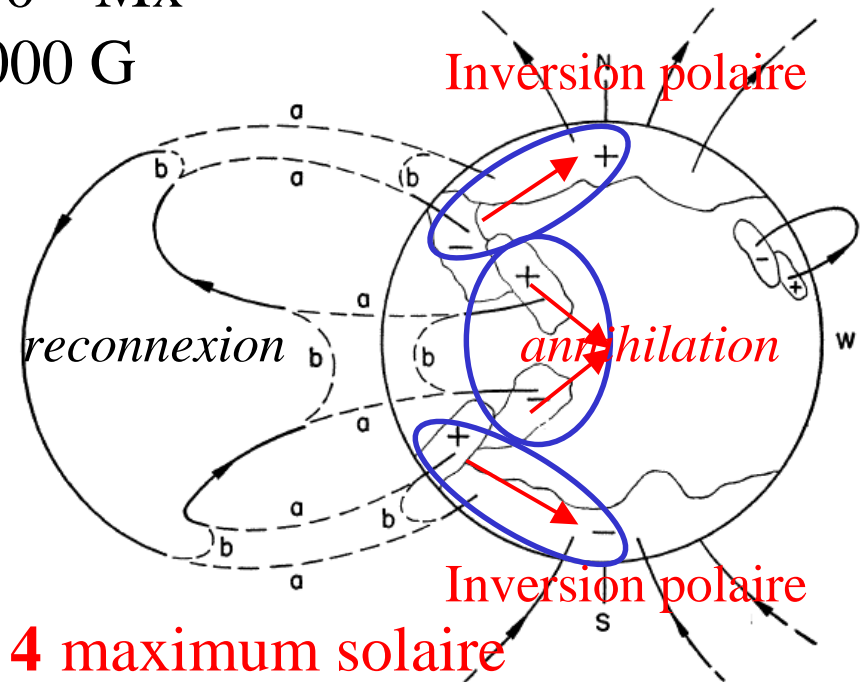
Au maximum  
 Flux  $\sim 10^{25}$  Mx  
 B  $\sim 1000$  G

Effet  $\alpha$  (B toroidal  $\rightarrow$  B poloidal)



$\leftarrow$  Émergence des taches et mouvements anticycloniques (horaire au N, antihoraire au S) liés à la force de Coriolis

Inversion polaire



# 4 maximum solaire

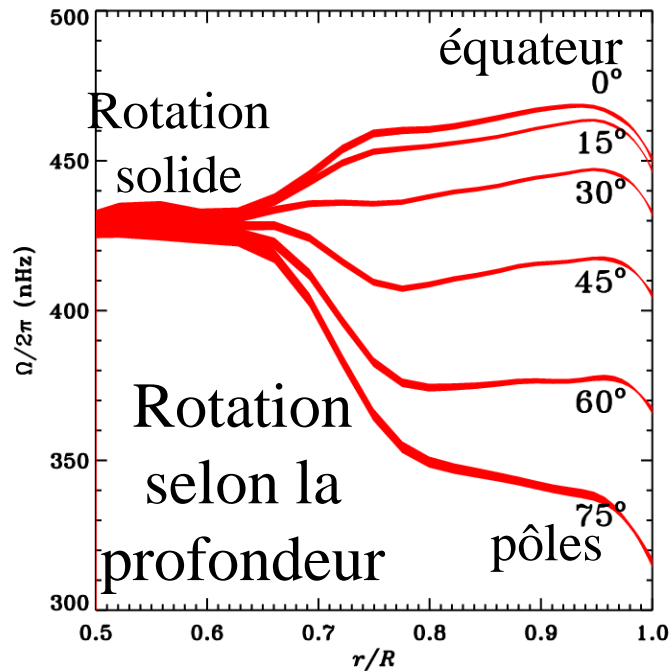
# 3 Émergence du champ



# **Inversions du champ magnétique solaire: observations**

**IV – Des anomalies dans la cyclicité  
Cycle 23 et Grand Minimum de Maunder**

# Rotation différentielle



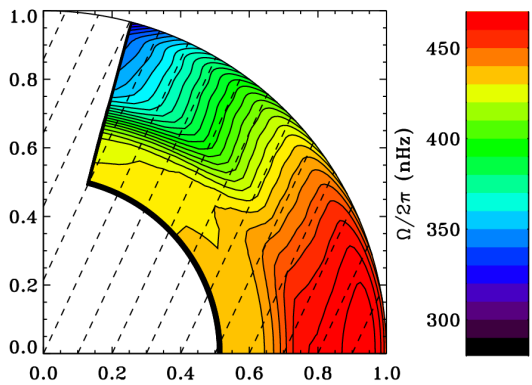
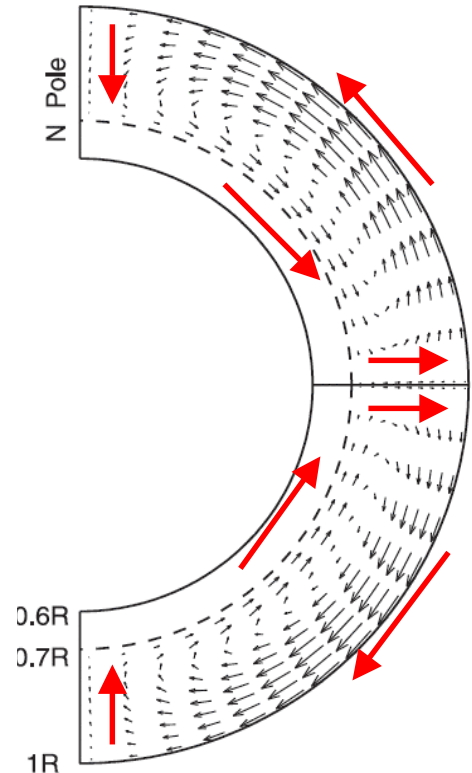
# Circulation méridienne

(dépend de la latitude, de la profondeur et du temps)

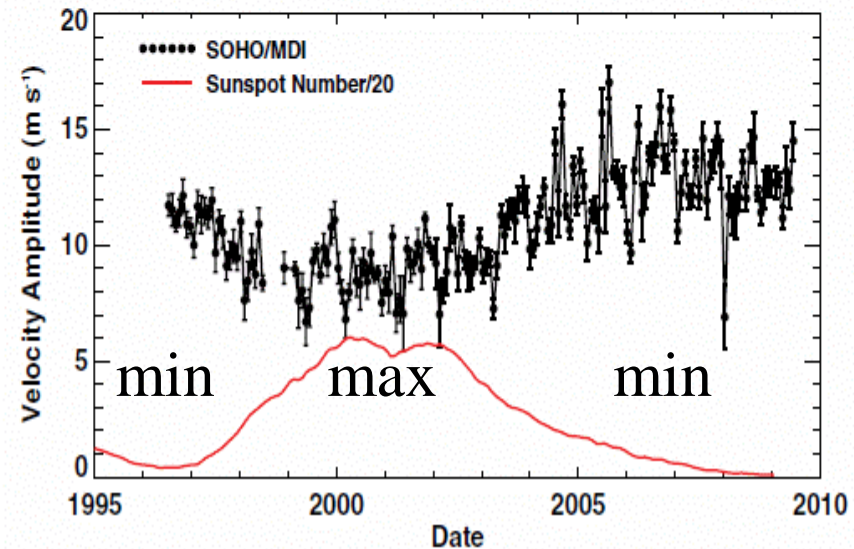
$$v \sim 10 \text{ m/s}$$

→ Durée du cycle

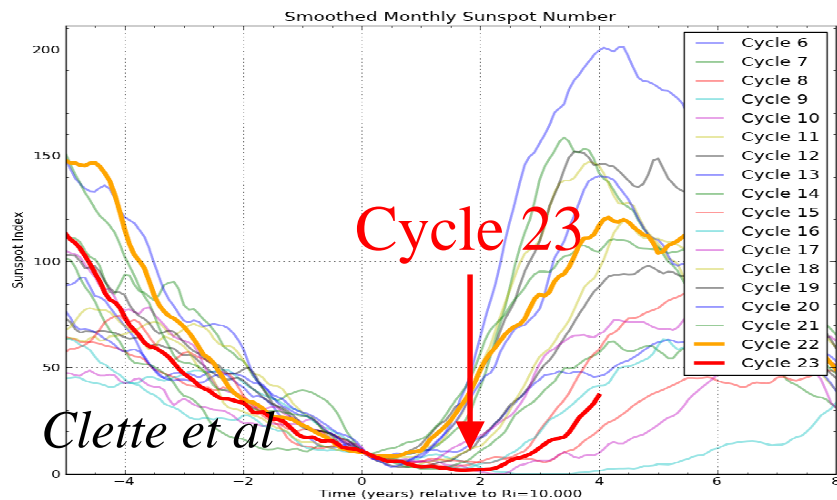
$$T \sim \pi R/v \sim 10 \text{ ans}$$



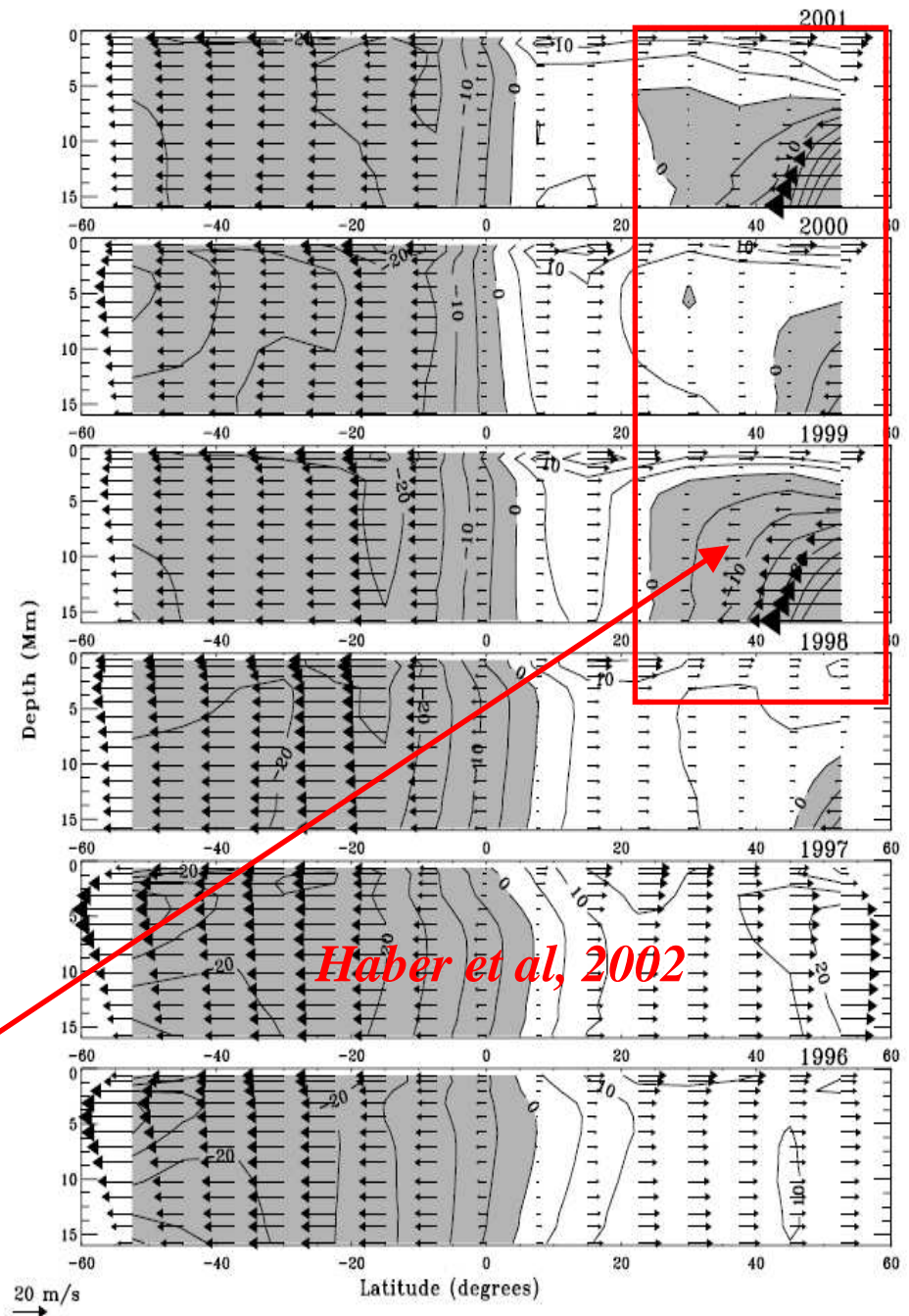
# Résultats SOHO/MDI

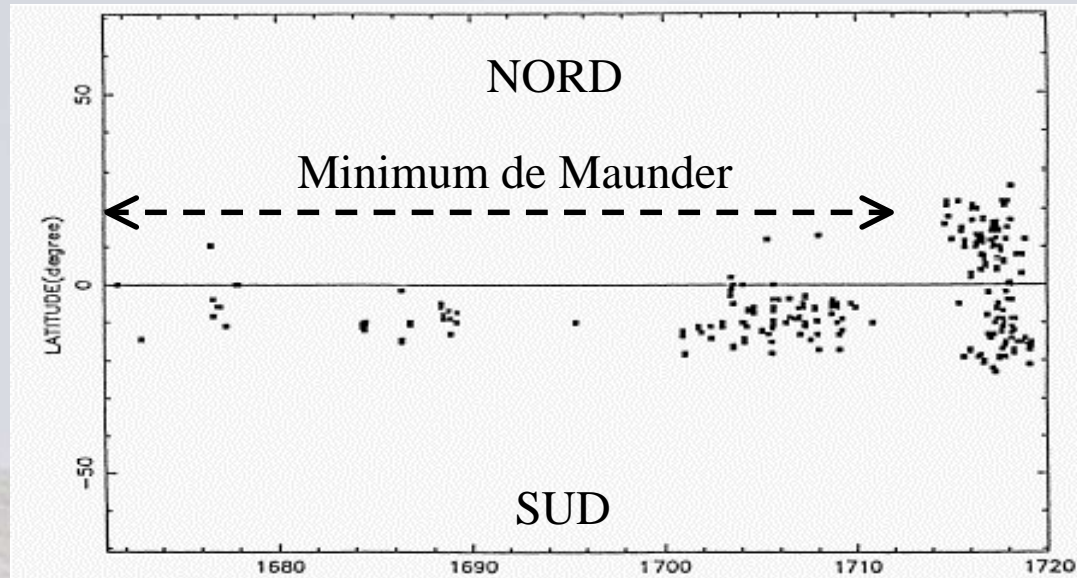


Cycle 23: long (12.7 ans),  
 minimum prolongé, champ  
 magnétique polaire faible,  
 nombre de jours sans taches le  
 plus petit depuis 100 ans



cellule profonde au Nord avant  
 le maximum du cycle 23  
 (résultat SOHO/MDI)

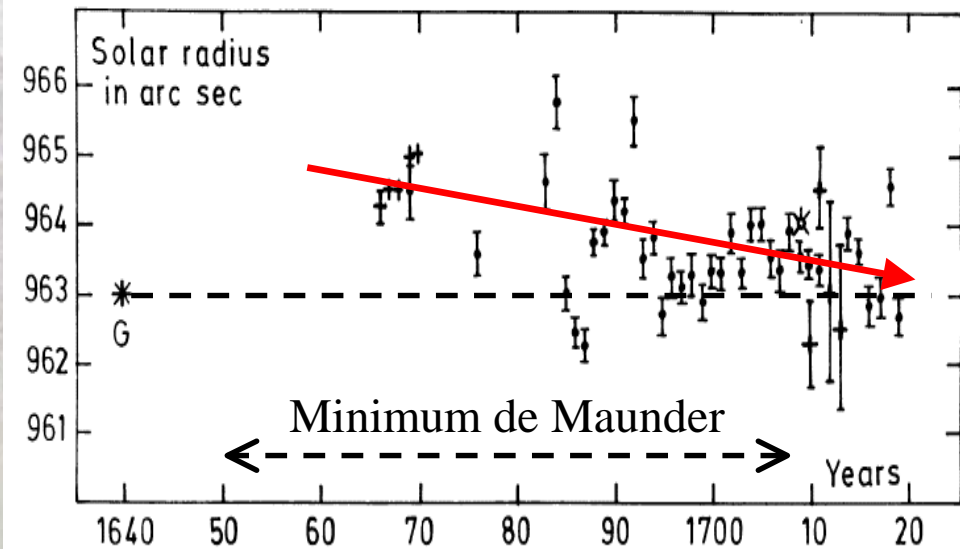
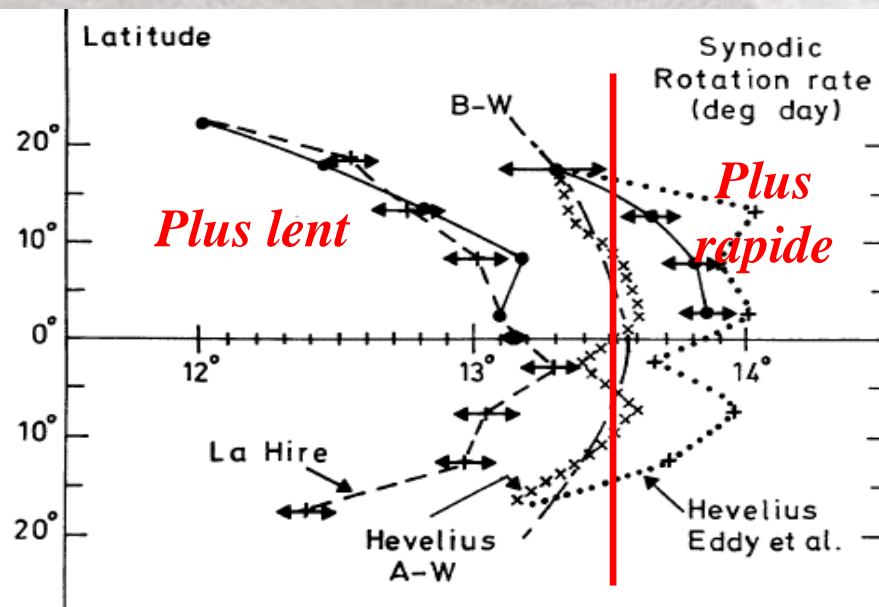




## Minimum de Maunder 1645-1705

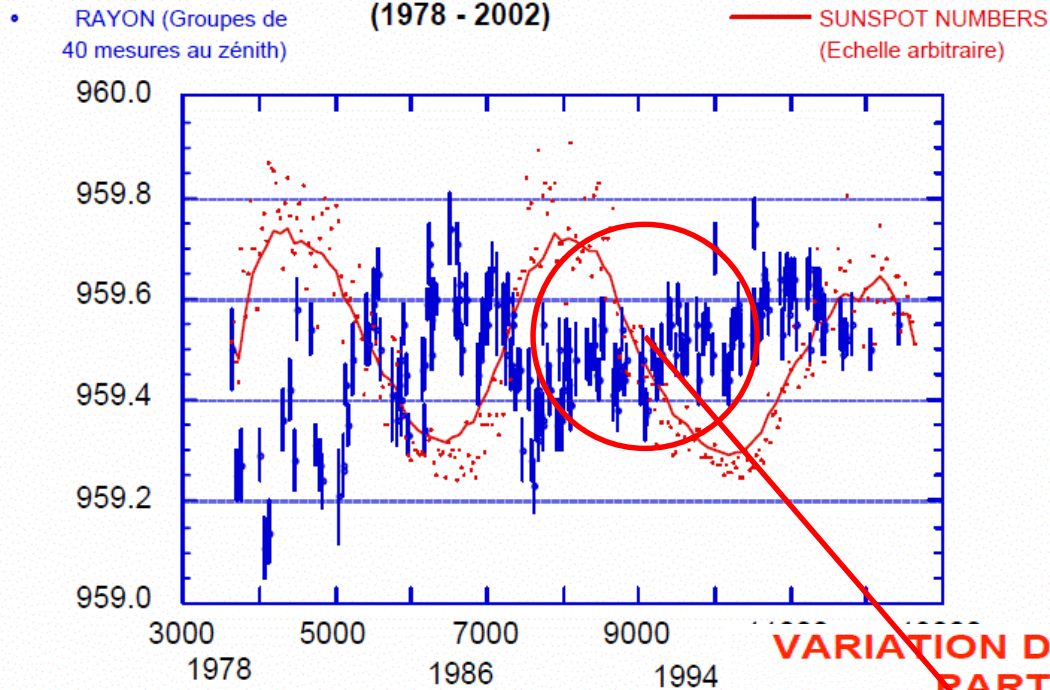
Asymétrie marquée  
Nord Sud des taches ?  
Rotation plus rapide ?  
Soleil plus gros ?

*Minimum de Maunder, à l'époque du « Roi Soleil »*





## DEMI-DIAMETRE A CALERN

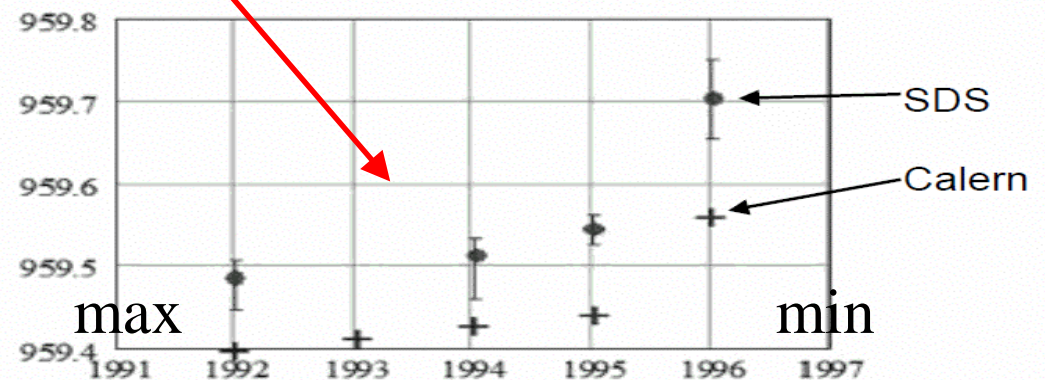


← Comment le rayon solaire varie t-il au cours du cycle ? Anticorrélation ?

← F. Laclare (astrolabe de CALERN/OCA)

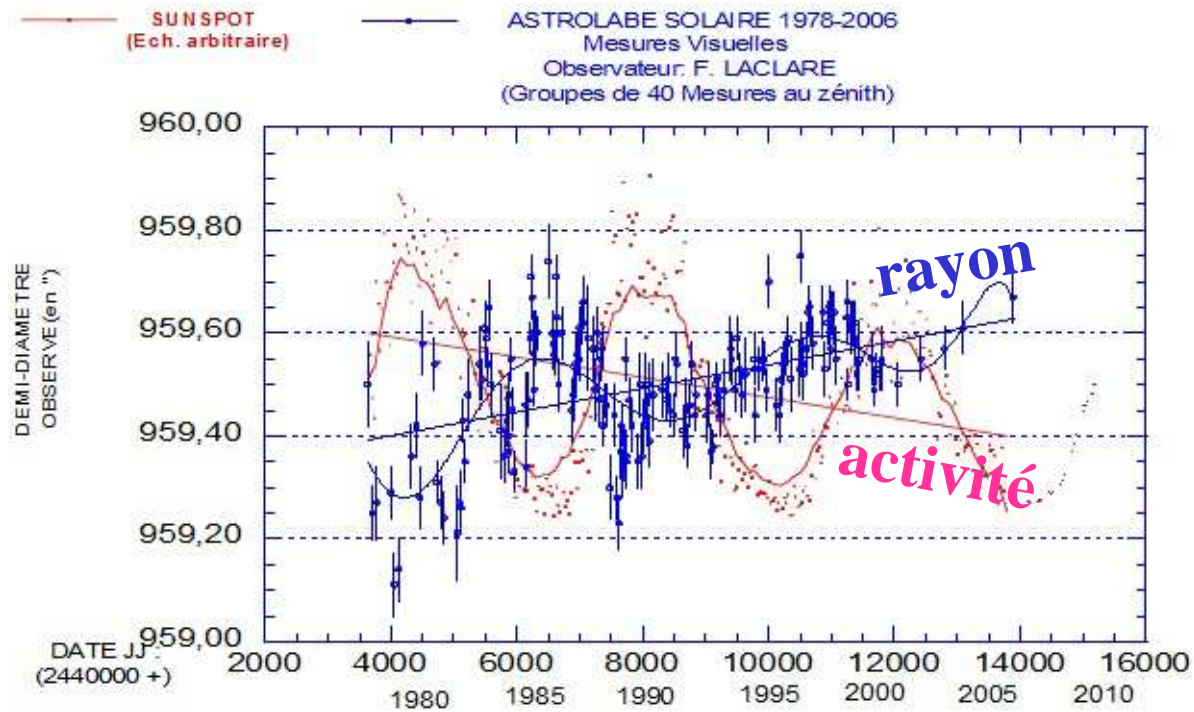
### VARIATION DU DIAMETRE SOLAIRE OBSERVEE A PARTIR DE MESURES EN BALLON

Sofia et al. (1994) ont construit l'instrument Solar Disk Sextant (SDS) comportant une **référence angulaire**. Quatre vols sous ballons stratosphériques ont été effectués.



Une augmentation de 0.2" a été mesurée tandis que l'activité solaire diminuait (Egidi et al., 2006).

Mesures ponctuelles du rayon solaire en ballon à 40 km: un Soleil plus gros de 0.2'' au minimum solaire (S. Sofia, Yale University) ? →



← L'activité solaire décroît depuis 3 cycles.  
 Le rayon solaire semble augmenter de 0.2'' (CALERN); est ce un effet solaire ?  
 L'atmosphère joue t-elle un rôle ?

Réponse possible : satellite  
 PICARD/CNES (2010-2013) +  
 instrument identique au sol →



PICARD (1620-1682)

