

SoHO: 20 ans d'observations solaires et heliosphériques



F. Baudin, IAS

Merci à: F. Auchère, K. Bocchialini, E. Buchlin, I. Gonzalez, M. Janvier, L.M.R. Lock, D. Müller, ...

Le contexte des missions spatiales solaires

📌 1973 : Skylab

📌 1980–1989 : SMM

📌 1992–2001 : Yohkoh

📌 1995– : SoHO

📌 1998–2010 : TRACE

📌 2002– : RHESSI

📌 2006– : STEREO

📌 2006– : HINODE

📌 2009– : SDO

📌 2018– : SolO

Objectifs de SoHO

SOHO was designed to answer the following three fundamental scientific questions about the Sun:

- What is the structure and dynamics of the solar interior?
 - Why does the solar corona exist and how is it heated to the extremely high temperature of about 1 000 000°C?
- Where is the solar wind produced and how is it accelerated?

Comment les atteindre ?

12 instruments

Spectroscopie

Imagerie

CDS
SUMER
UVCS

EIT
LASCO
SWAN

CELIAS
COSTEP
ERNE

GOLF
MDI
VIRGO

Magnétographie

Particules

Sismologie

A savoir

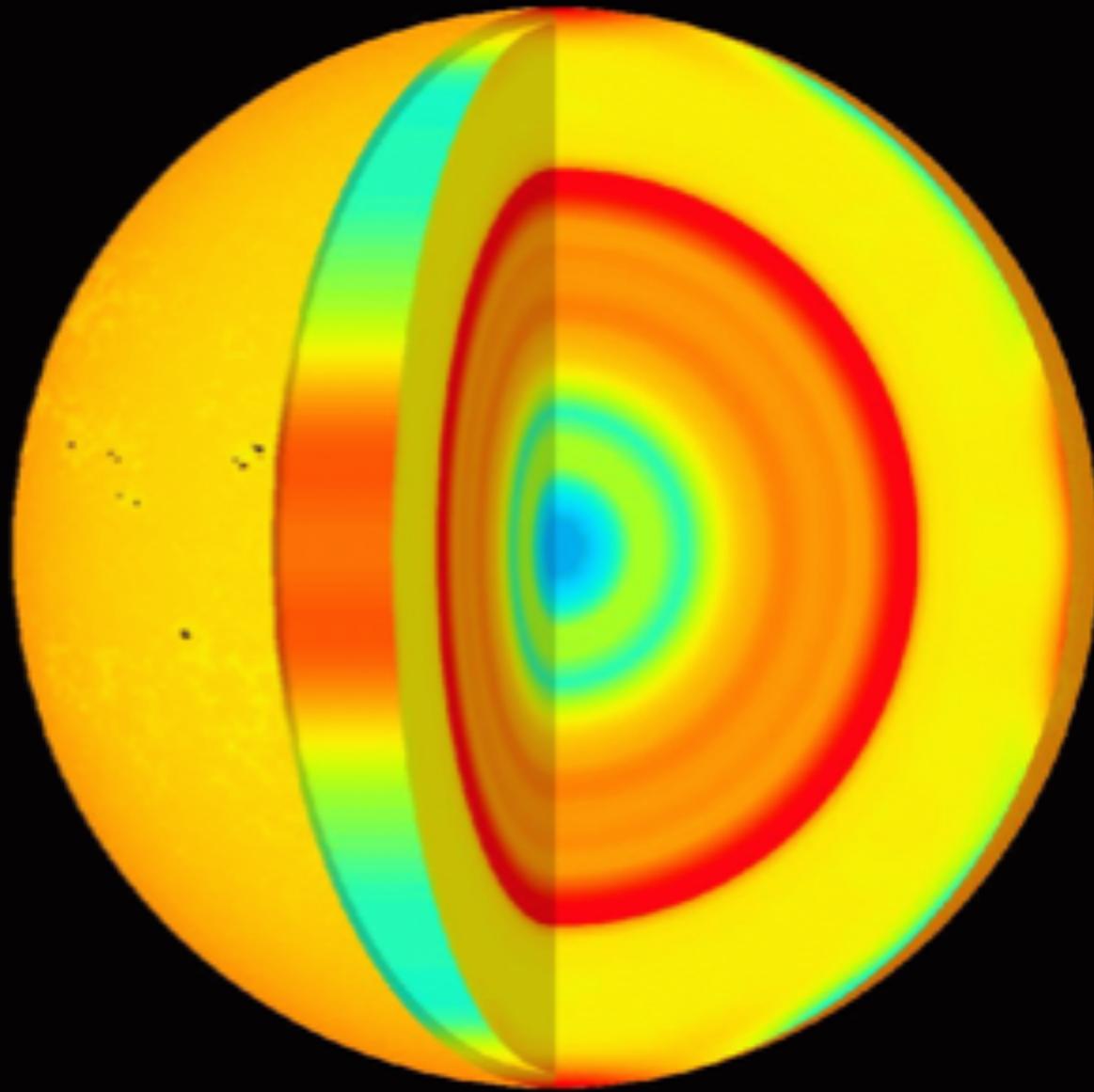
- Mission conjointe ESA/NASA + agences nationales
- Construit en Europe, lancé et opéré par la NASA
- Lancement en Décembre 1995
- Arrivée sur orbite en L1 en Février 1996
- Période nominale de 2 ans + 7 extensions (fin 2018... pour l'instant)

Objectifs de SoHO

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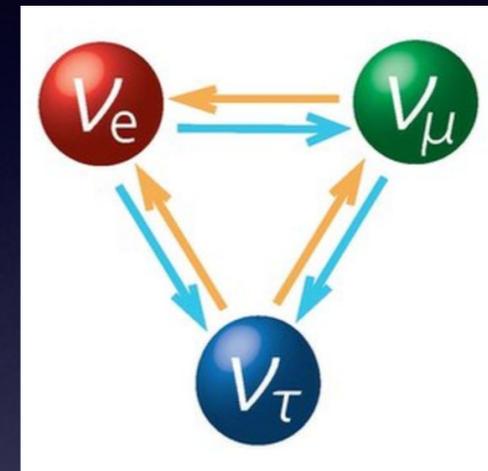
- What is the structure and dynamics of the solar interior?
- Why does the solar corona exist and how is it heated to the extremely high temperature of about 1 000 000°C?
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What is the structure and dynamics of the solar interior?



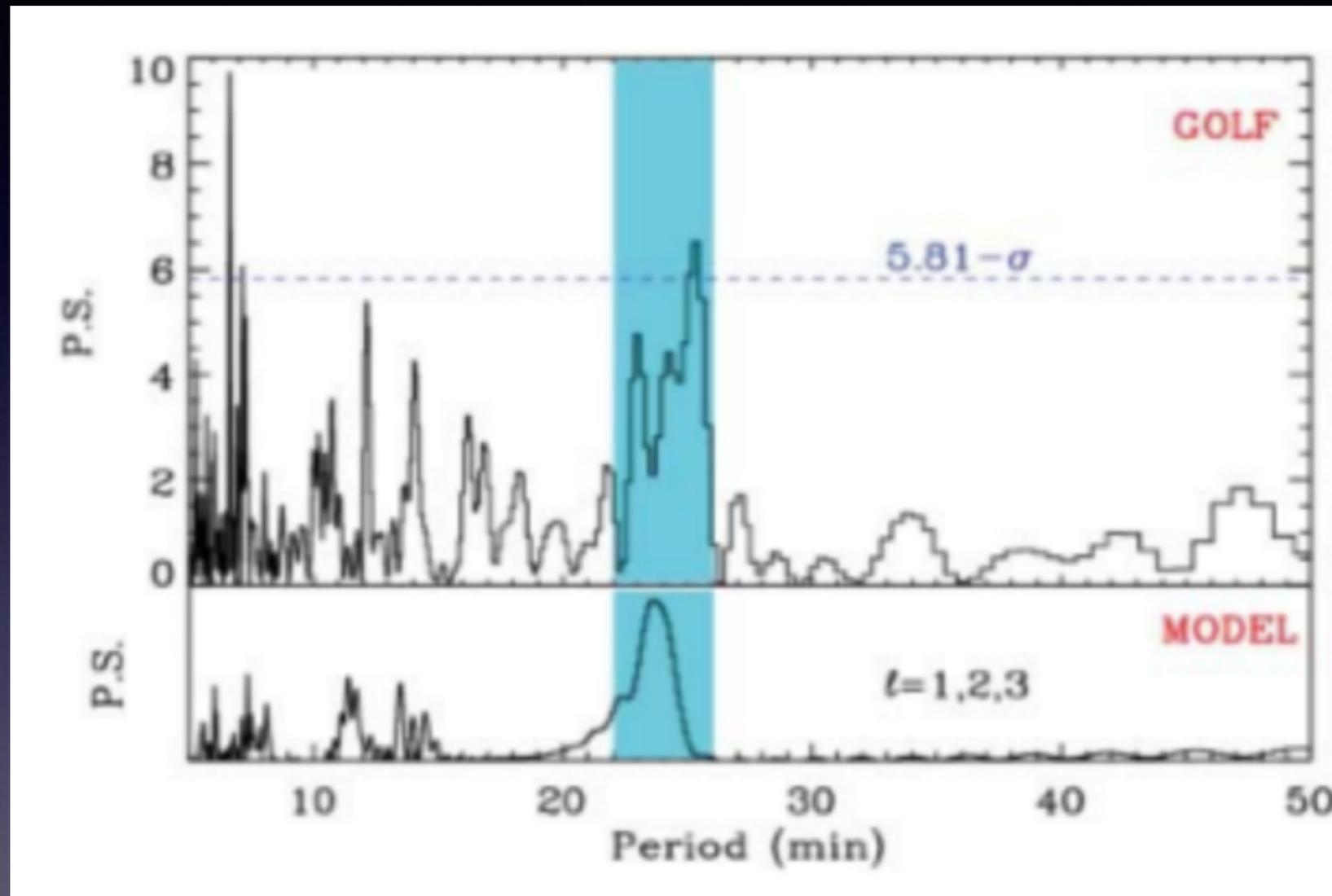
Ecart entre vitesse du son mesurée et
vitesse calculée d'après le modèle
standard

=> discontinuité sous la zone convective



Problème des
neutrinos
pas un problème
du modèle
standard solaire

What is the structure and dynamics of the solar interior?



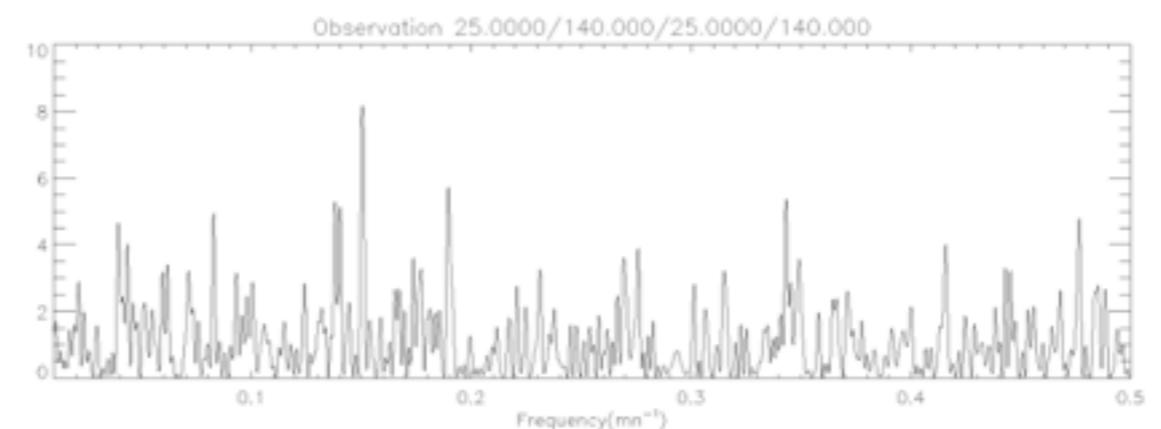
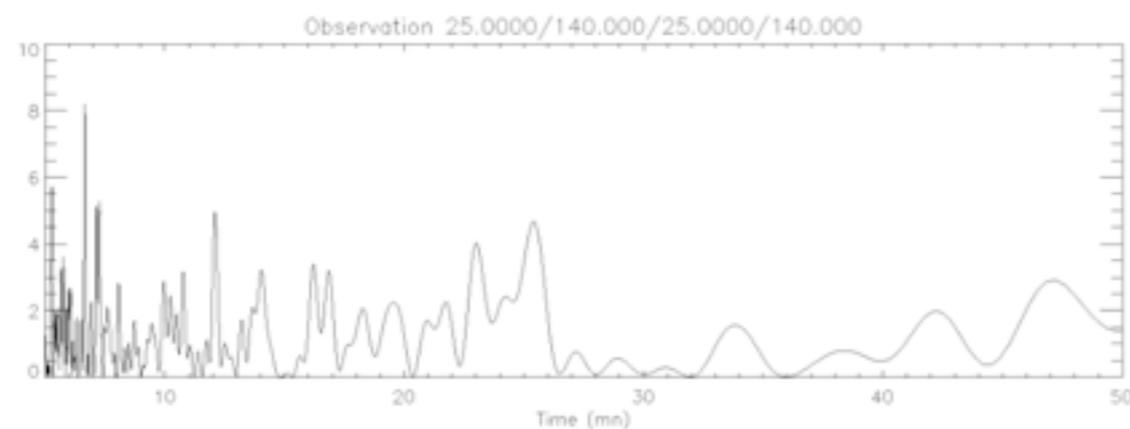
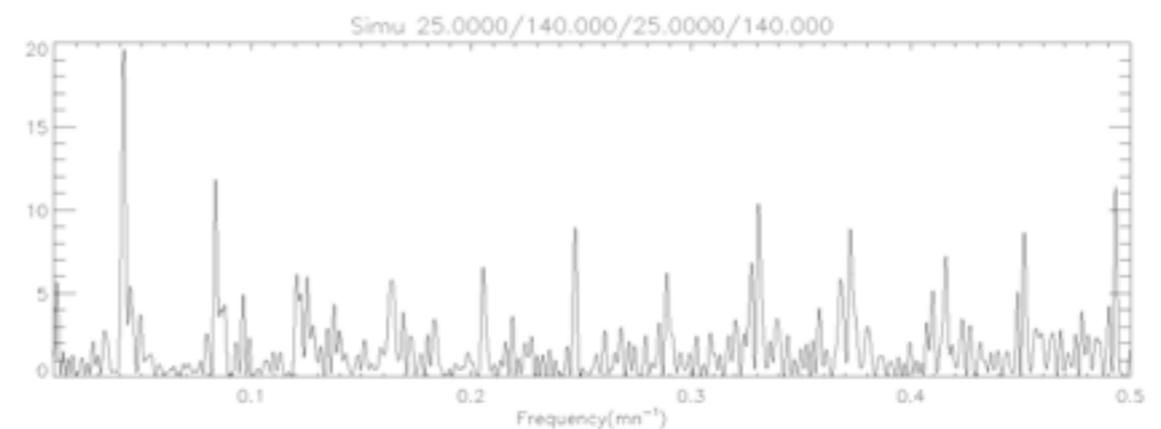
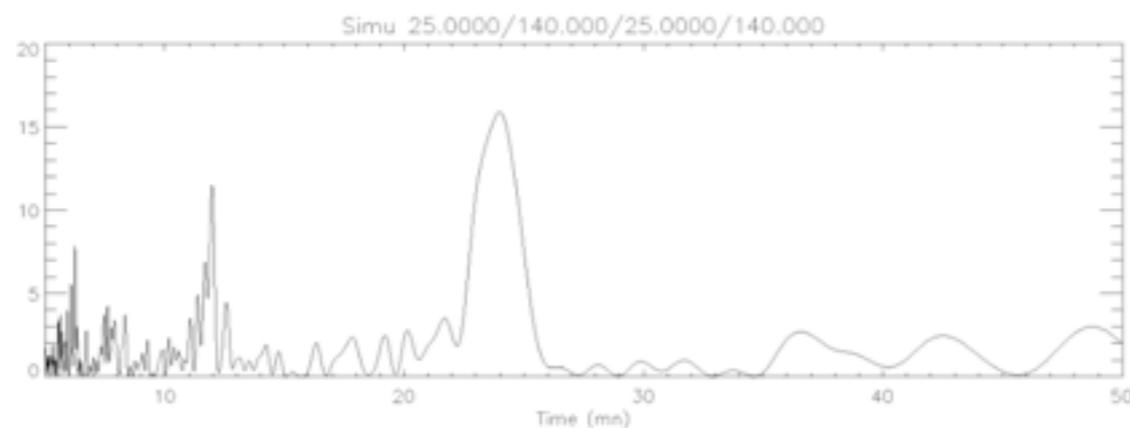
Les modes
graal...

Garcia et al. 2007

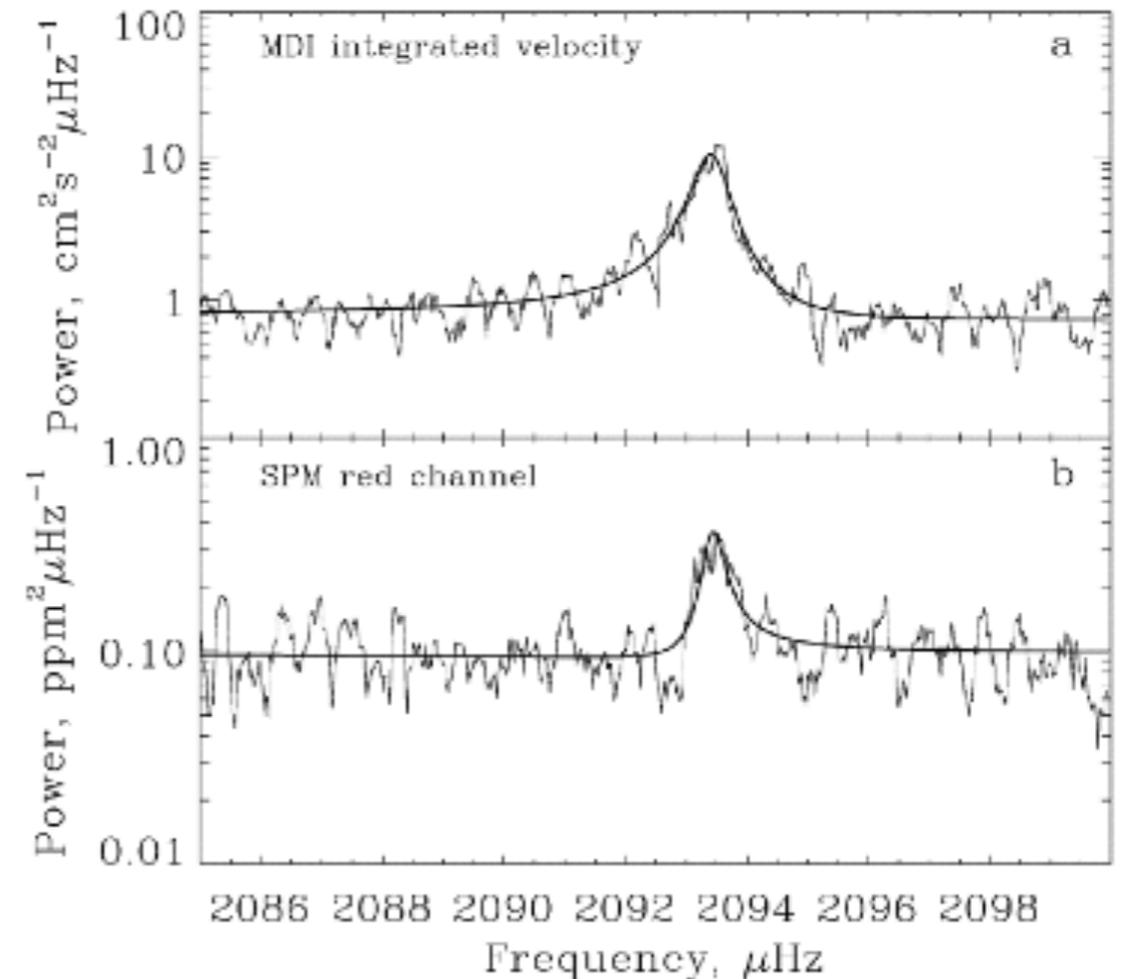
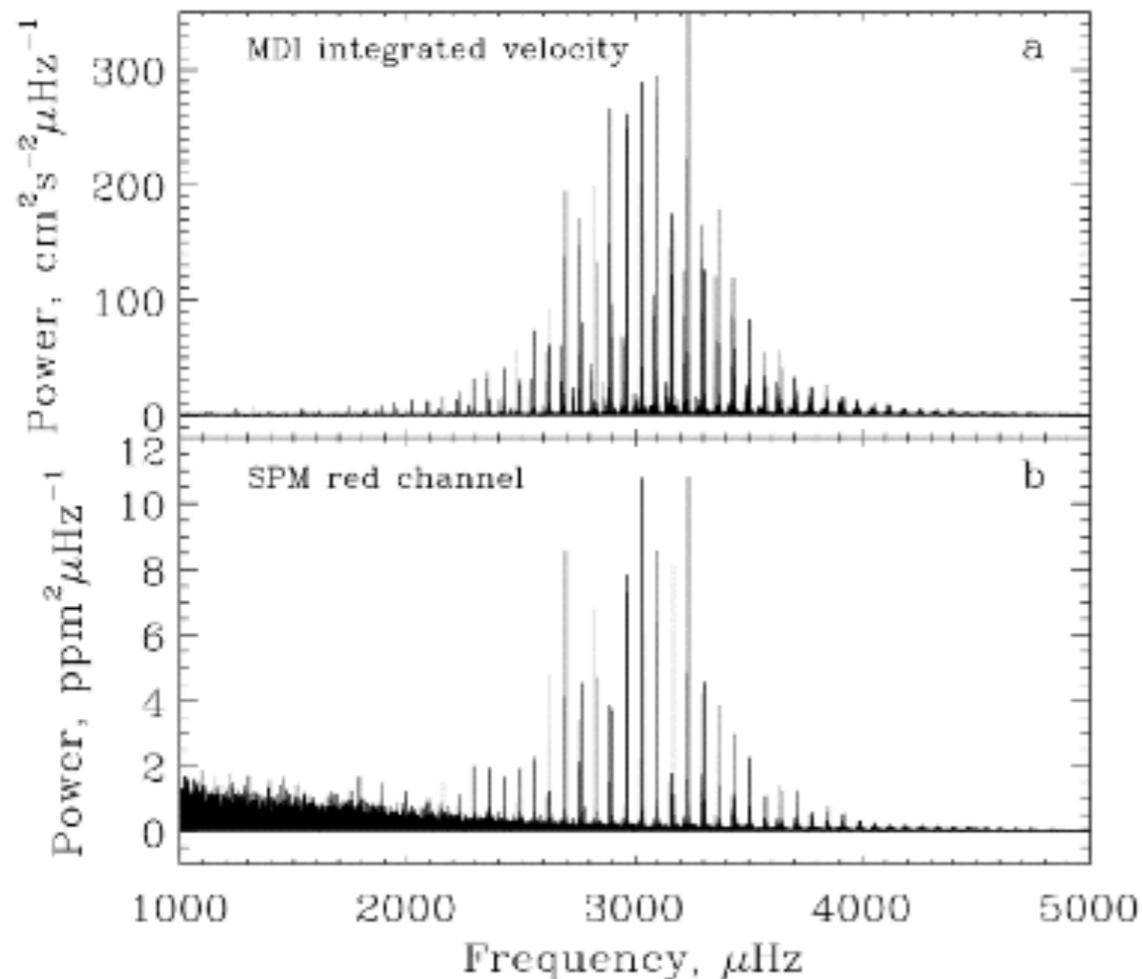
$$P_{n,l} \sim \overline{P}_{n,l} = \frac{P_0}{L} \left(n + l/2 - \frac{1}{4} + \vartheta \right)$$

What is the structure and dynamics of the solar interior?

Les modes
graal...



What is the structure and dynamics of the solar interior?

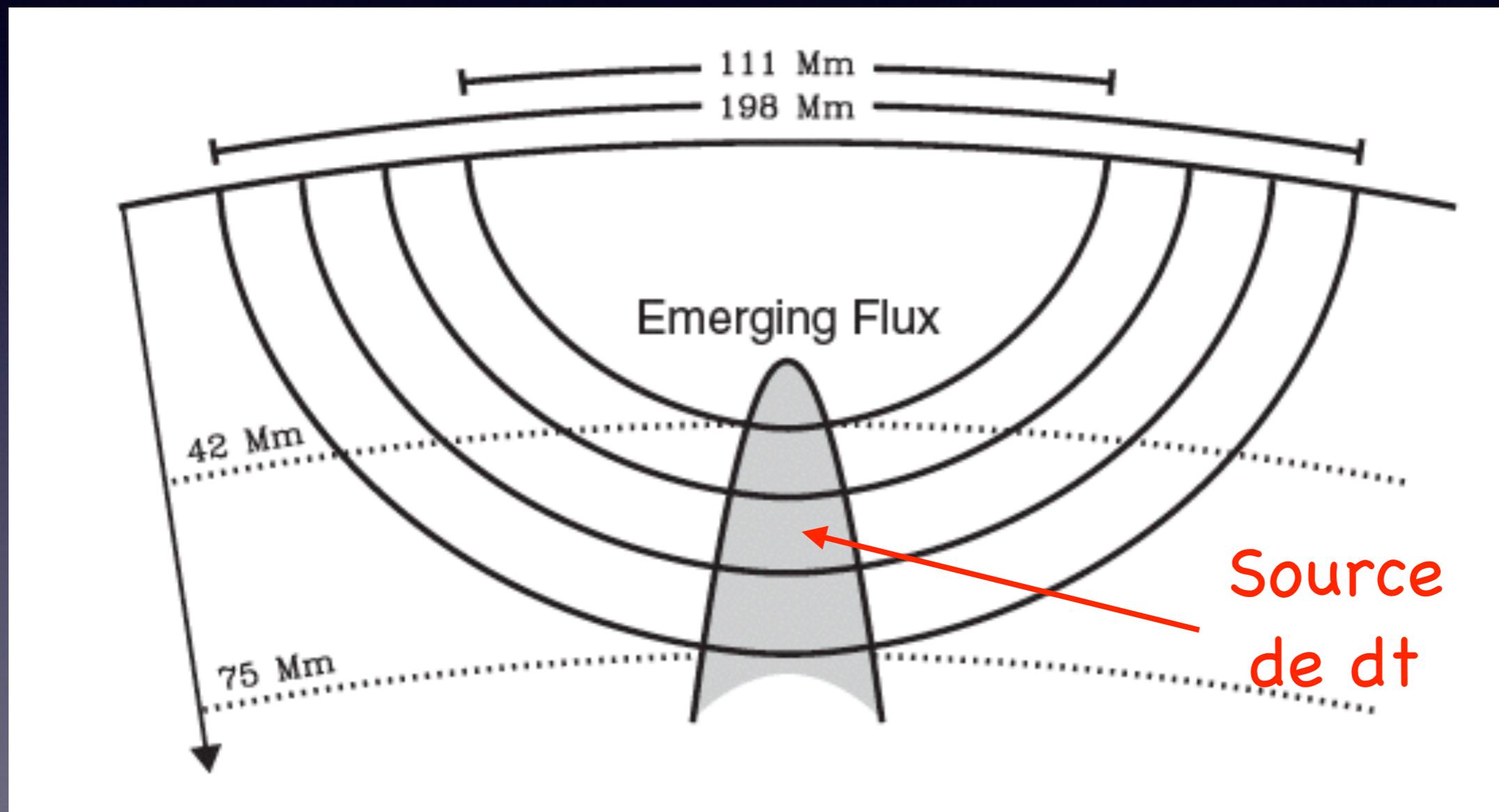


Toutain et al. 1998

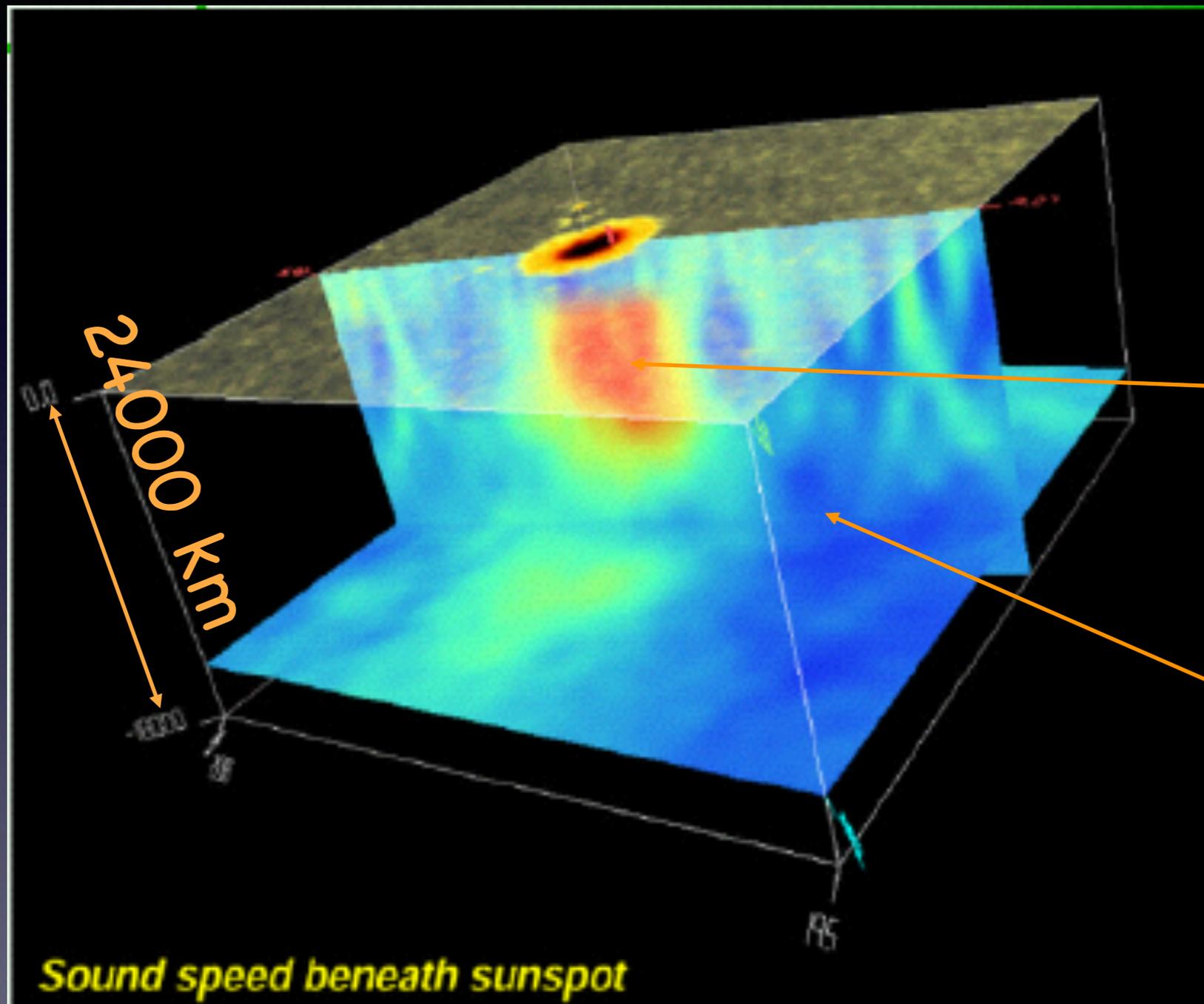
Mesures en intensité, en vitesse, un S/B exceptionnel
=> assymétrie des modes
=> excitation à qqes 100km sous la photosphère

What is the structure and dynamics of the solar interior?

Sismologie locale => détails subphotosphériques



What is the structure and dynamics of the solar interior?



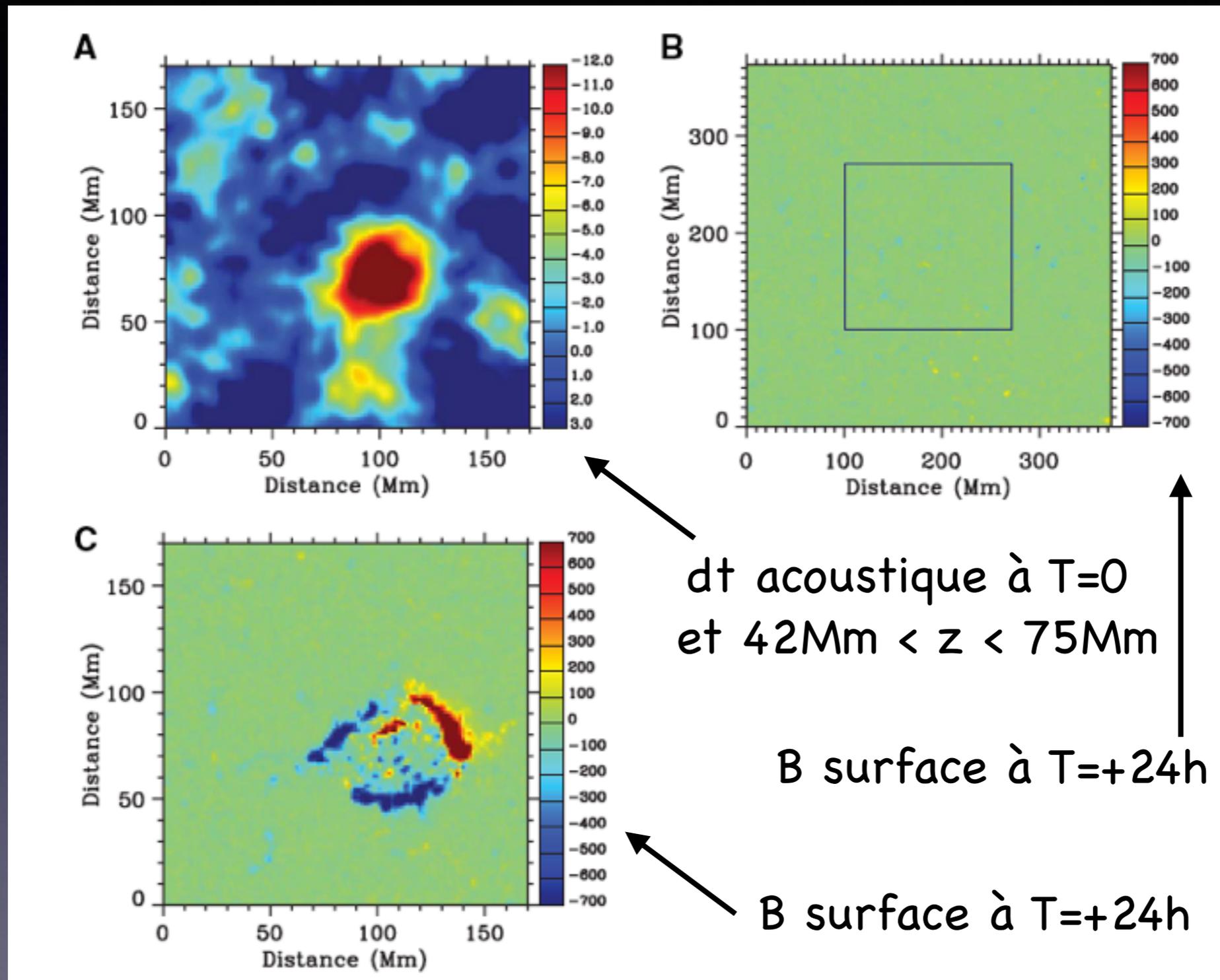
(Kosovichev et al., 2000)

Vitesse du son plus élevée (rouge)

Vitesse du son plus basse (bleue)

Structure 3D des taches (MDI)

What is the structure and dynamics of the solar interior?

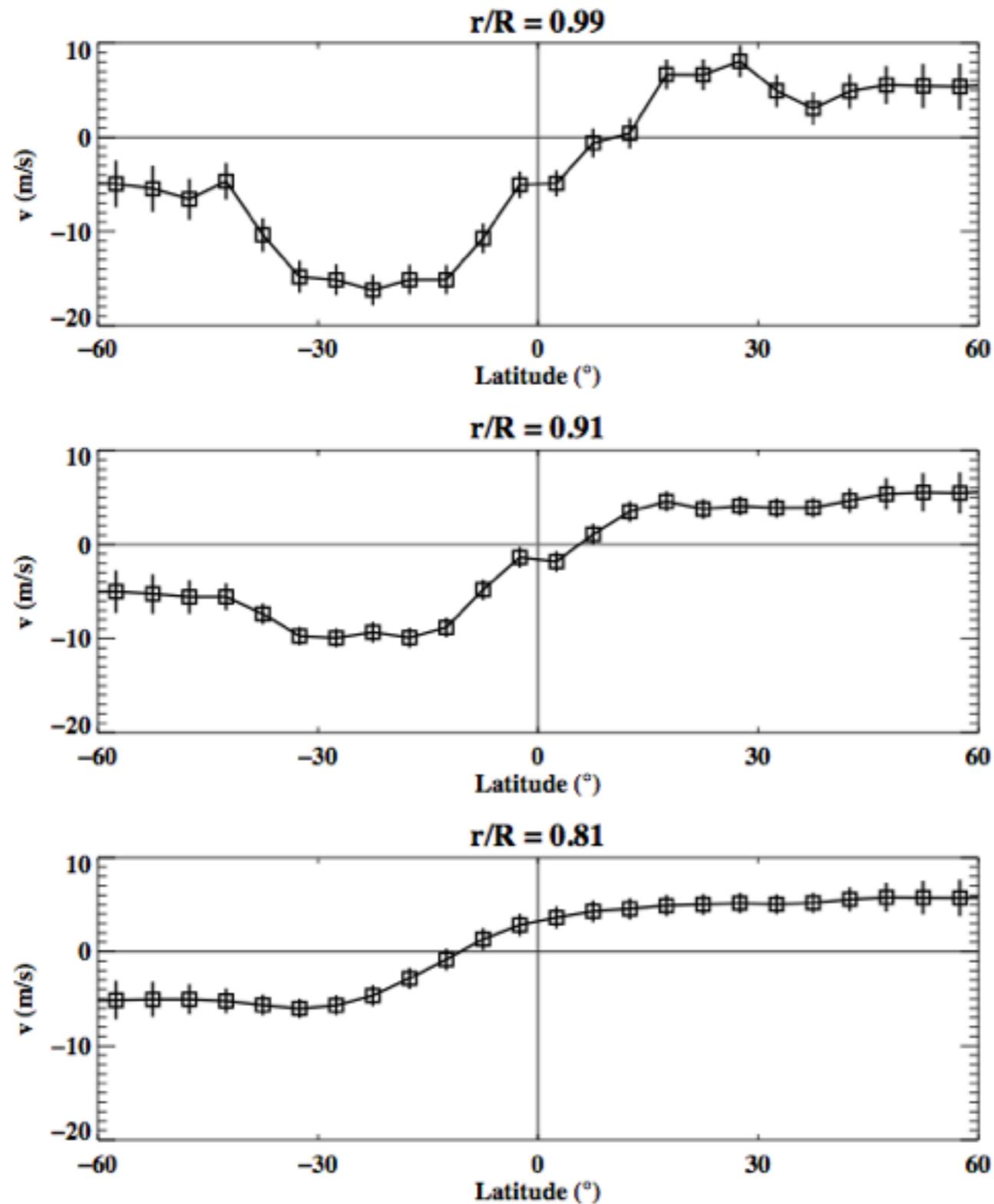


Ilonidis et al. 2011

Emergence d'une région active... mais résultat controversé

Sismologie locale

Meridional Flow Inversion Results

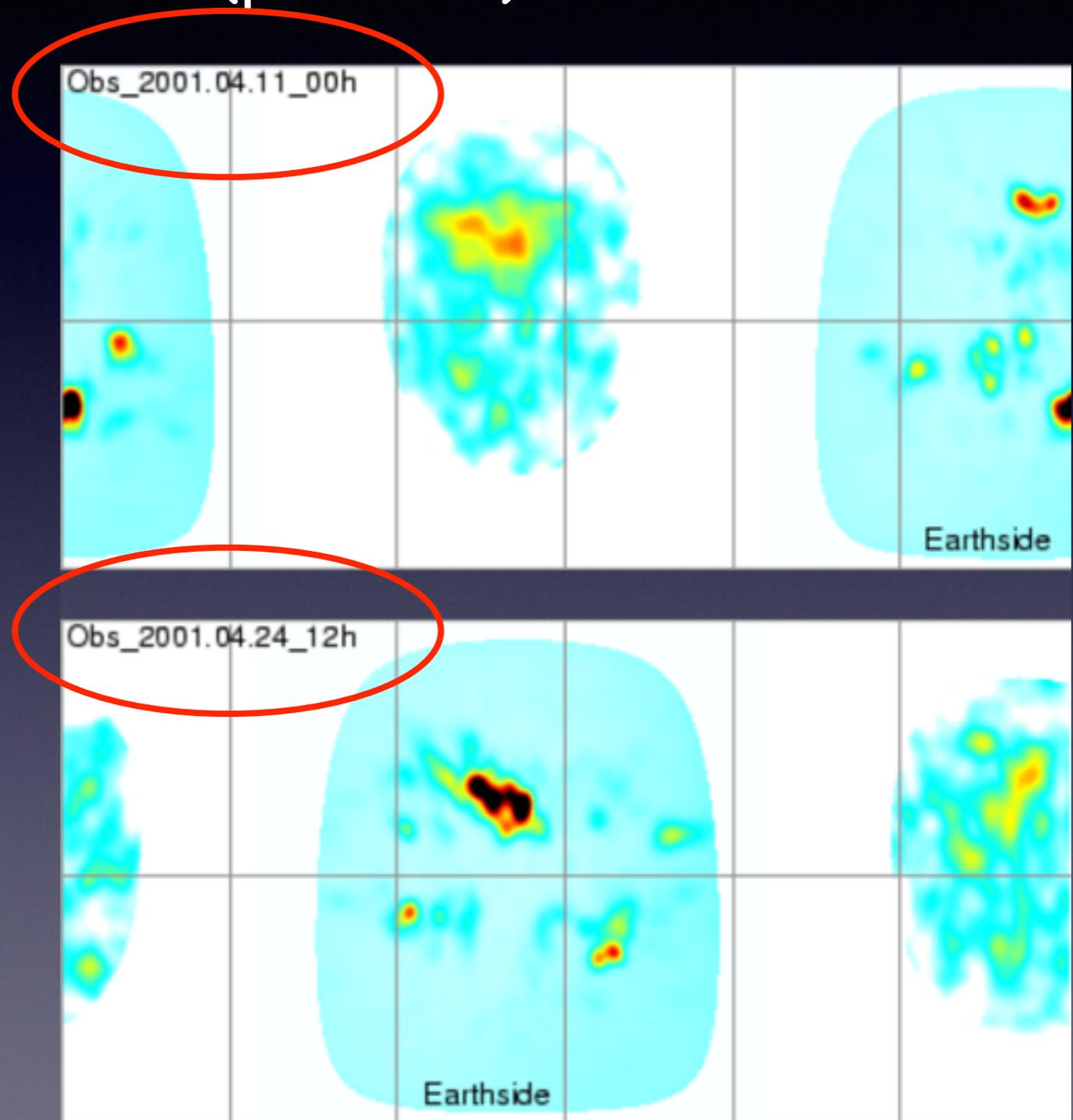
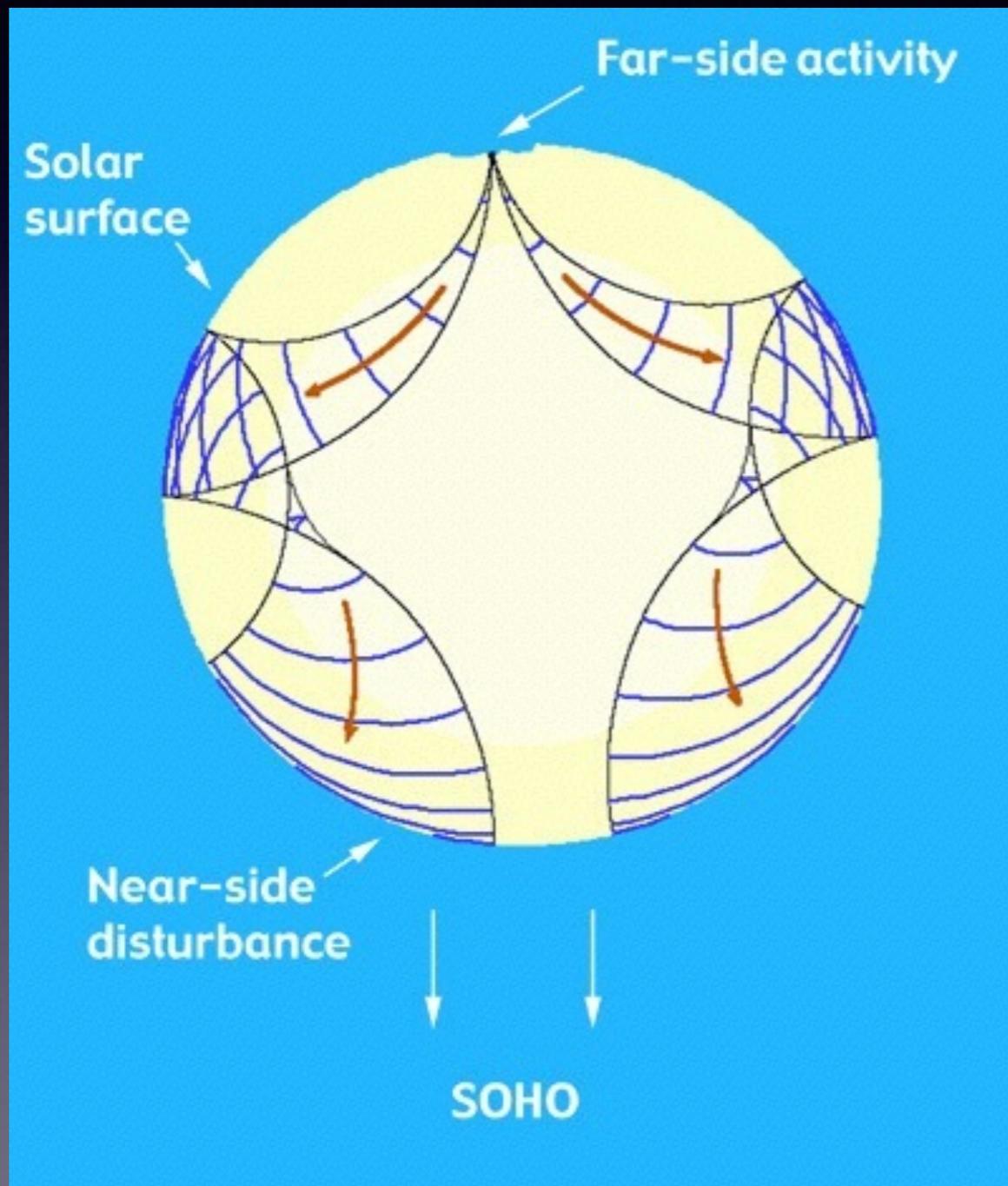


Flux
méridional

Giles et al. 1997

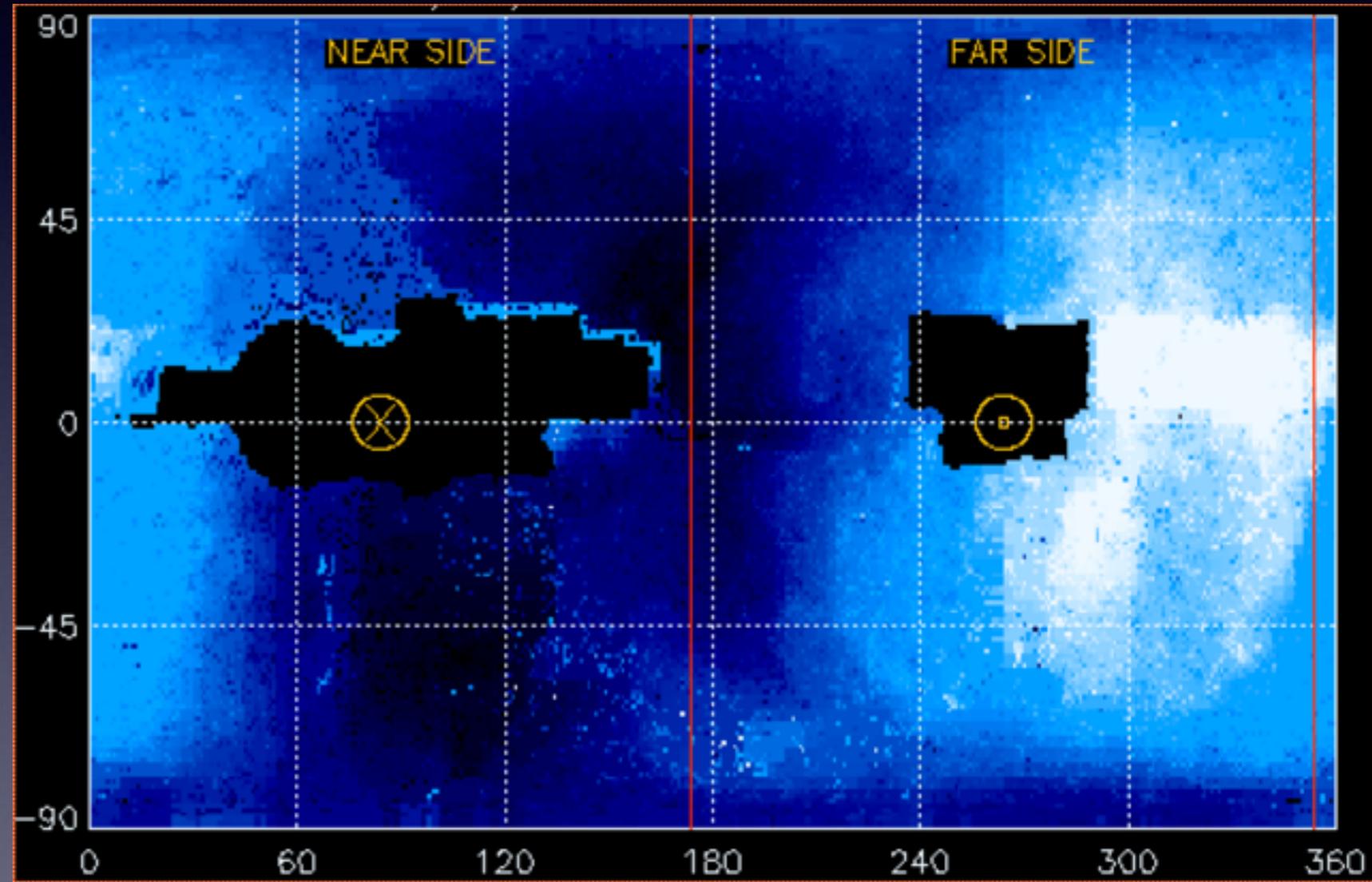
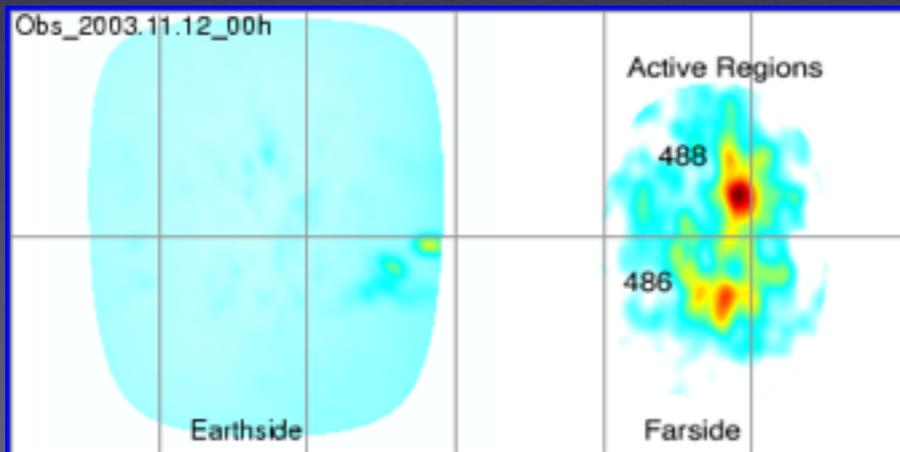
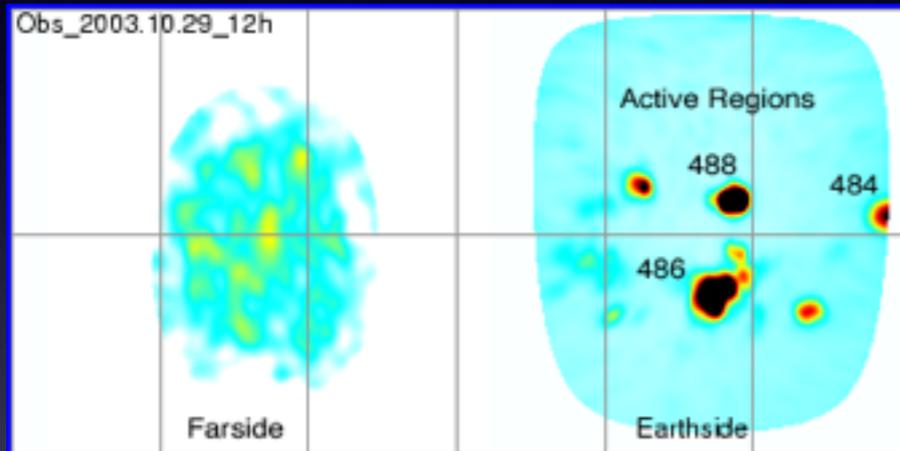
What is the structure and dynamics of the solar interior?

« The far side » (par MDI)



What is the structure and dynamics of the solar interior?

Un autre « far side » (par SWAN)

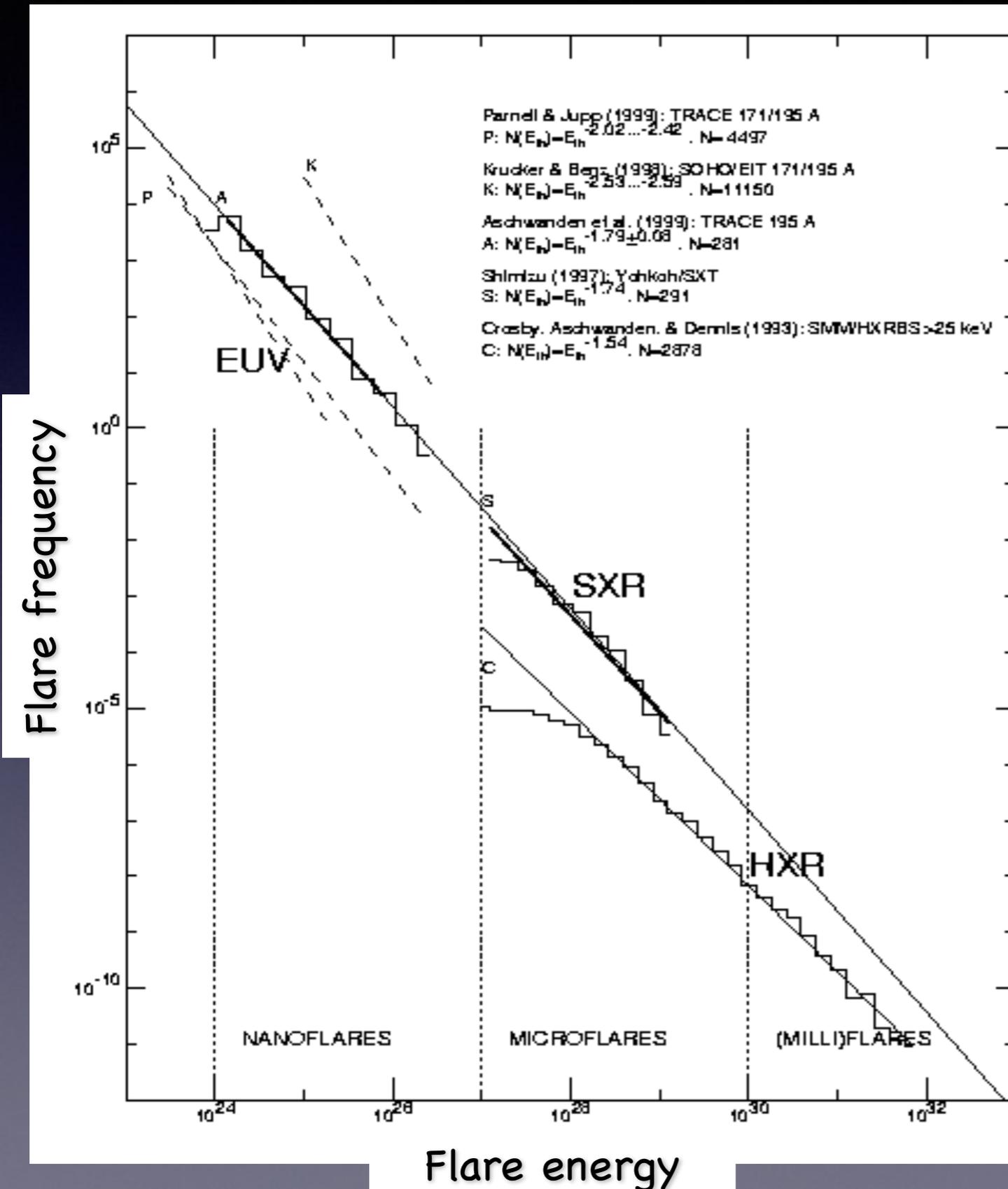


Objectifs de SoHO

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Why does the solar corona exist and how is it heated to the extremely high temperature of about 1 000 000°C?



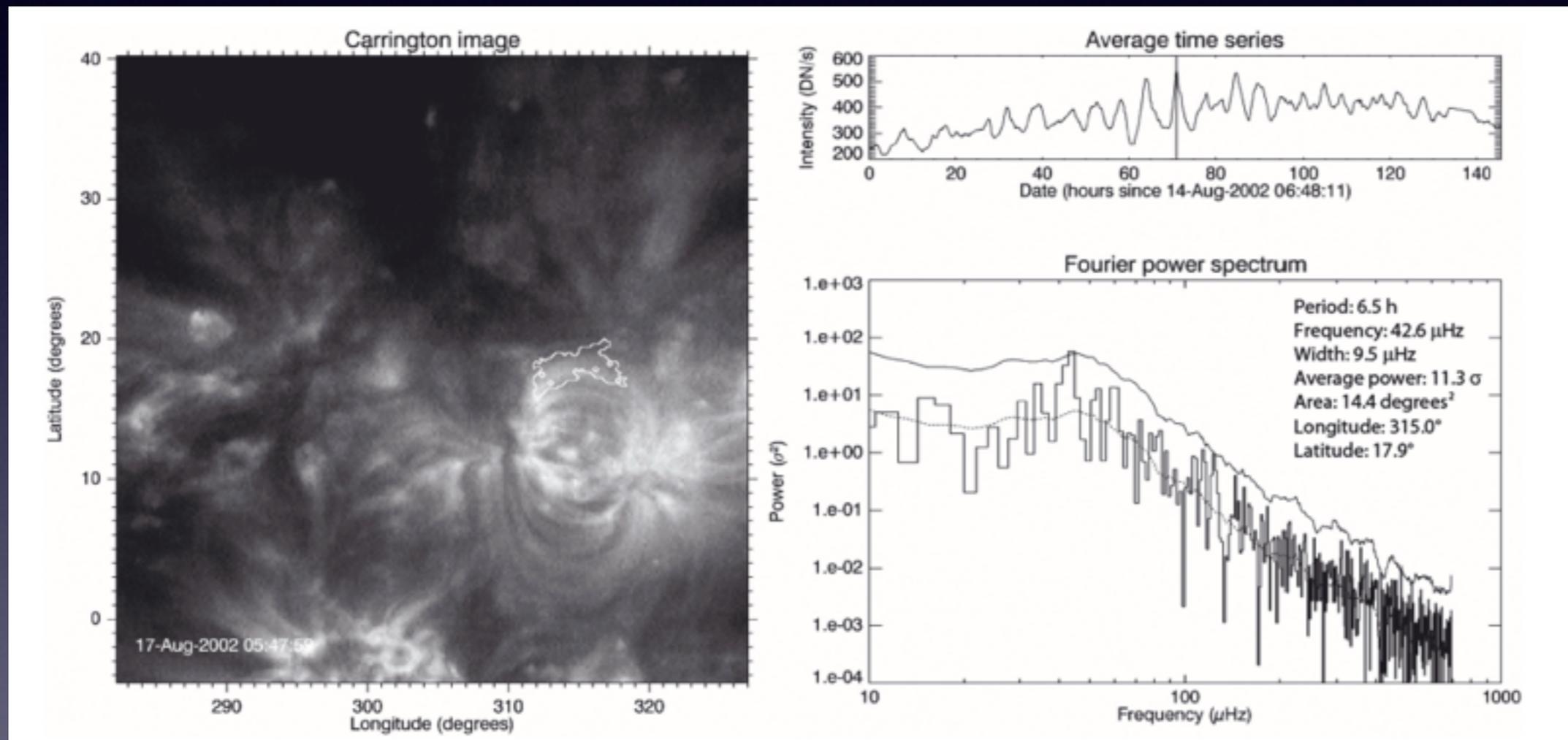
Distribution d'énergie des événements coronaux

=> difficulté: mesurer correctement l'énergie de ces événements

Aschwanden et al., 2000;
 Krucker & Benz, 1998;
 Berghmans et al., 1998;
 Aletti et al., 2000

Why does the solar corona exist and how is it heated to the extremely high temperature of about 1 000 000°C?

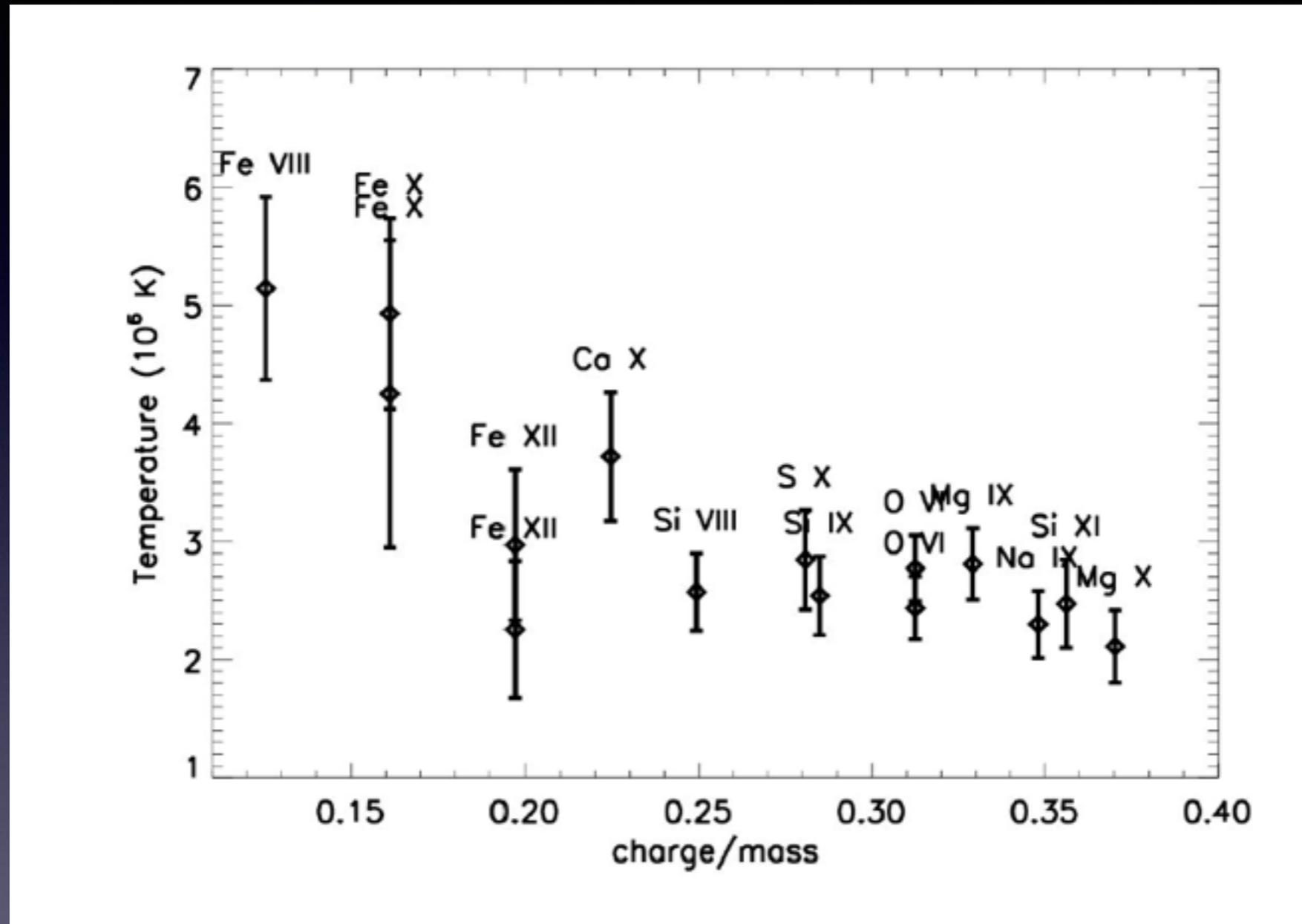
Détection de pulsations d'intensité avec des longues périodes (quelques heures) avec EIT
Balayage de l'archive EIT : statistiques pour tout le cycle solaire 23
Très répandue (environ 1/2 des régions actives), notamment dans les boucles



Auchère et al, 1999

Maintenant analyse thermique de ces boucles pulsantes avec SDO/AIA (Froment et al. 2015)
=> Signature observationnelle d'un chauffage quasi-continu, localisé à basse altitude
(voir posters 5.1, 5.5 et 5.14)

Why does the solar corona exist and how is it heated to the extremely high temperature of about 1 000 000°C?



Dolla & Solomon, 2009

Ions lourds beaucoup plus chauds que protons et électrons.
Apparemment dû à la résonance ion-cyclotron +
amortissement d'ondes d'Alfven

Why does the solar corona exist and how is it heated to the extremely high temperature of about 1 000 000°C?

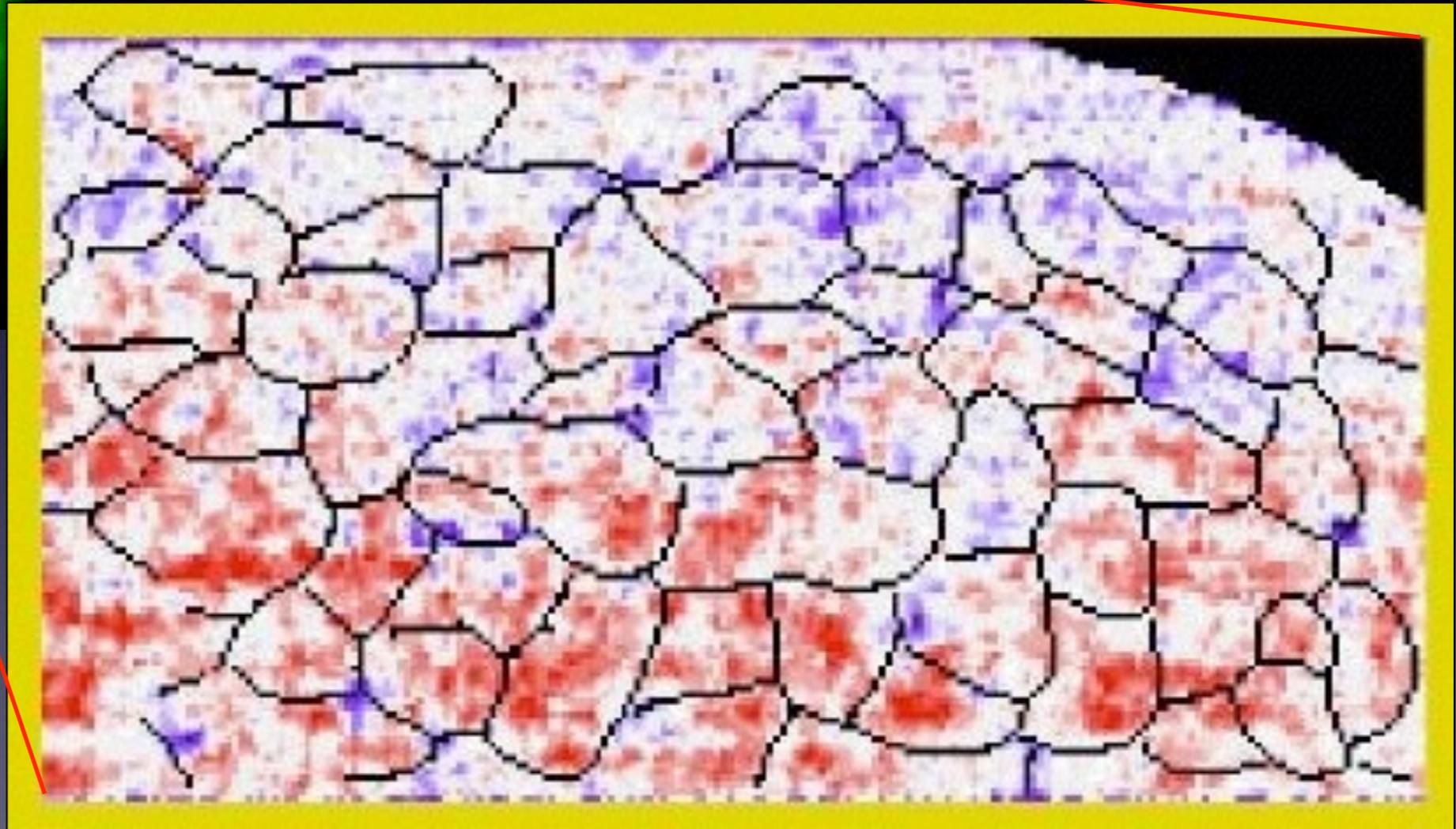
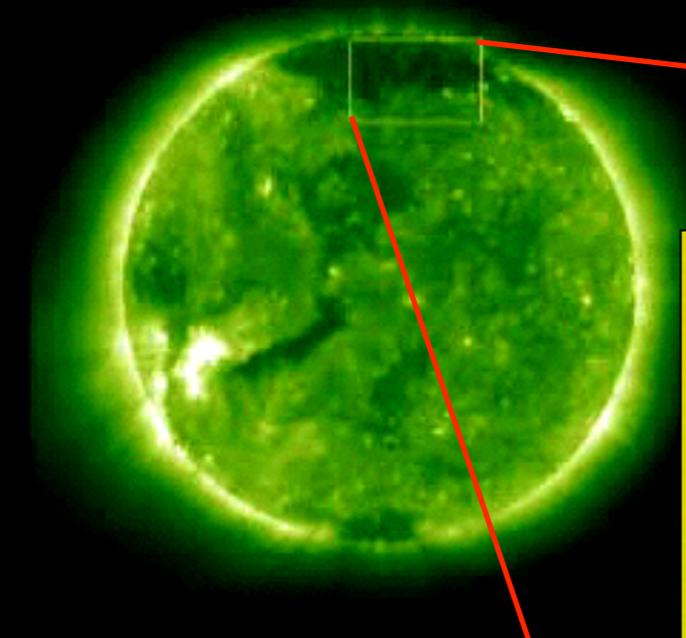
- Source d'énergie: l'énergie mécanique de la convection interne.
- Pas forcément le même mécanisme selon la région
- Système turbulent forcé, dont l'échelle de dissipation est inférieure à la résolution spatiale des instruments.
- Reconnexion => onde d'Alfven => amortissement résonance ion-cyclotron
- Problème concernant le chauffage par résonance ion cyclotron : fréquences prévues devraient être de l'ordre de 10^2 à 10^4 Hz, trop élevé pour les ondes d'Alfven de la couronne ($P \sim$ minute-heure)

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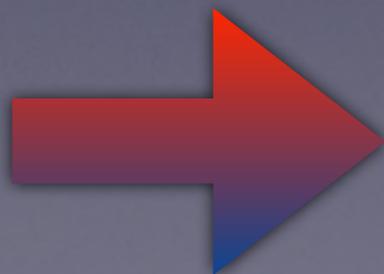
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Where is the solar wind produced and how is it accelerated?



Vitesse Doppler
/
Structures
magnétiques
chromosphériques

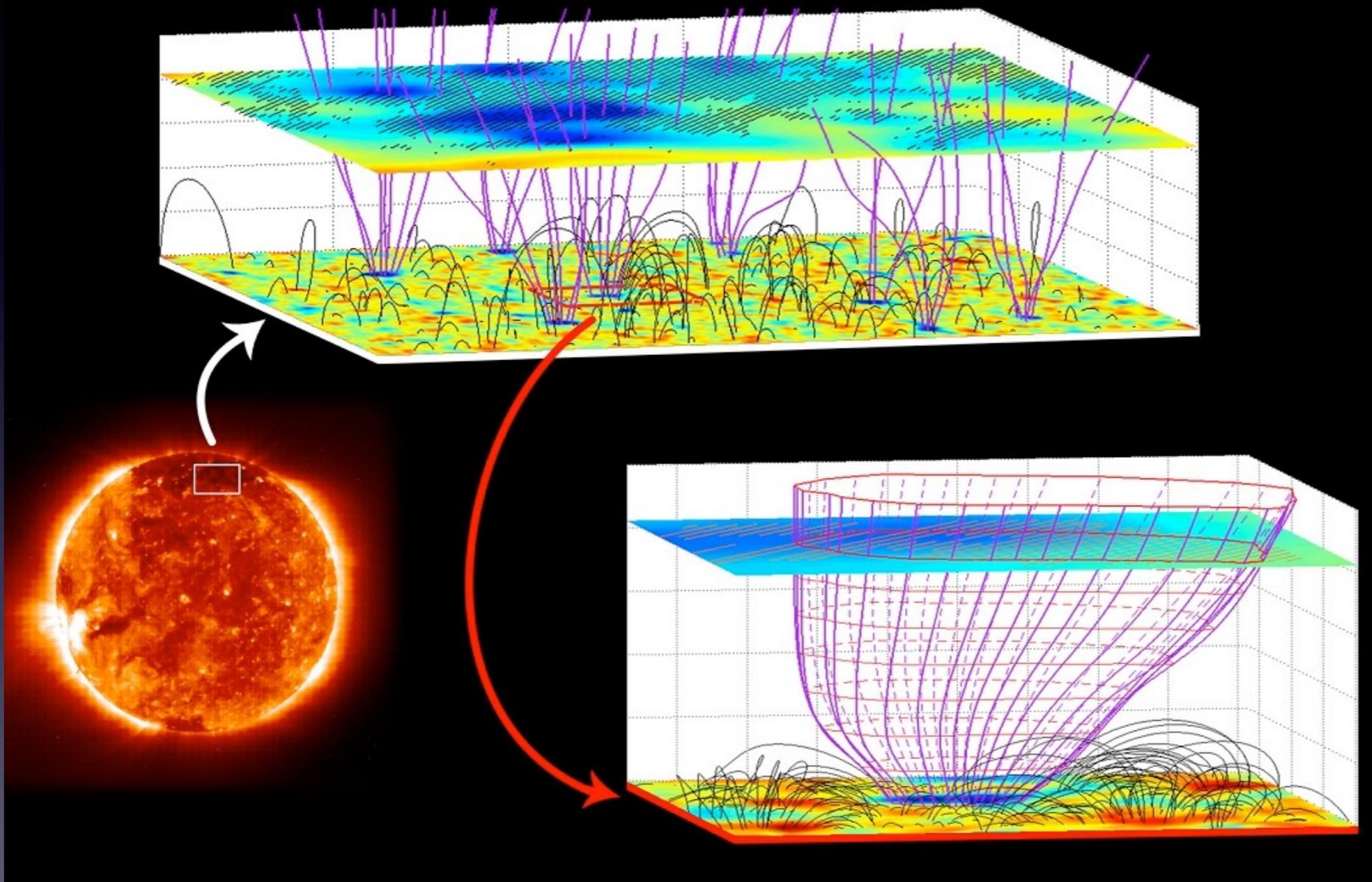
Hassler et al, 1999



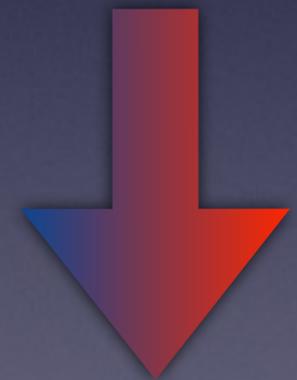
Vent initié très bas aux frontières du réseau de supergranulation

Where is the solar wind produced and how is it accelerated?

Tu et al, 2005

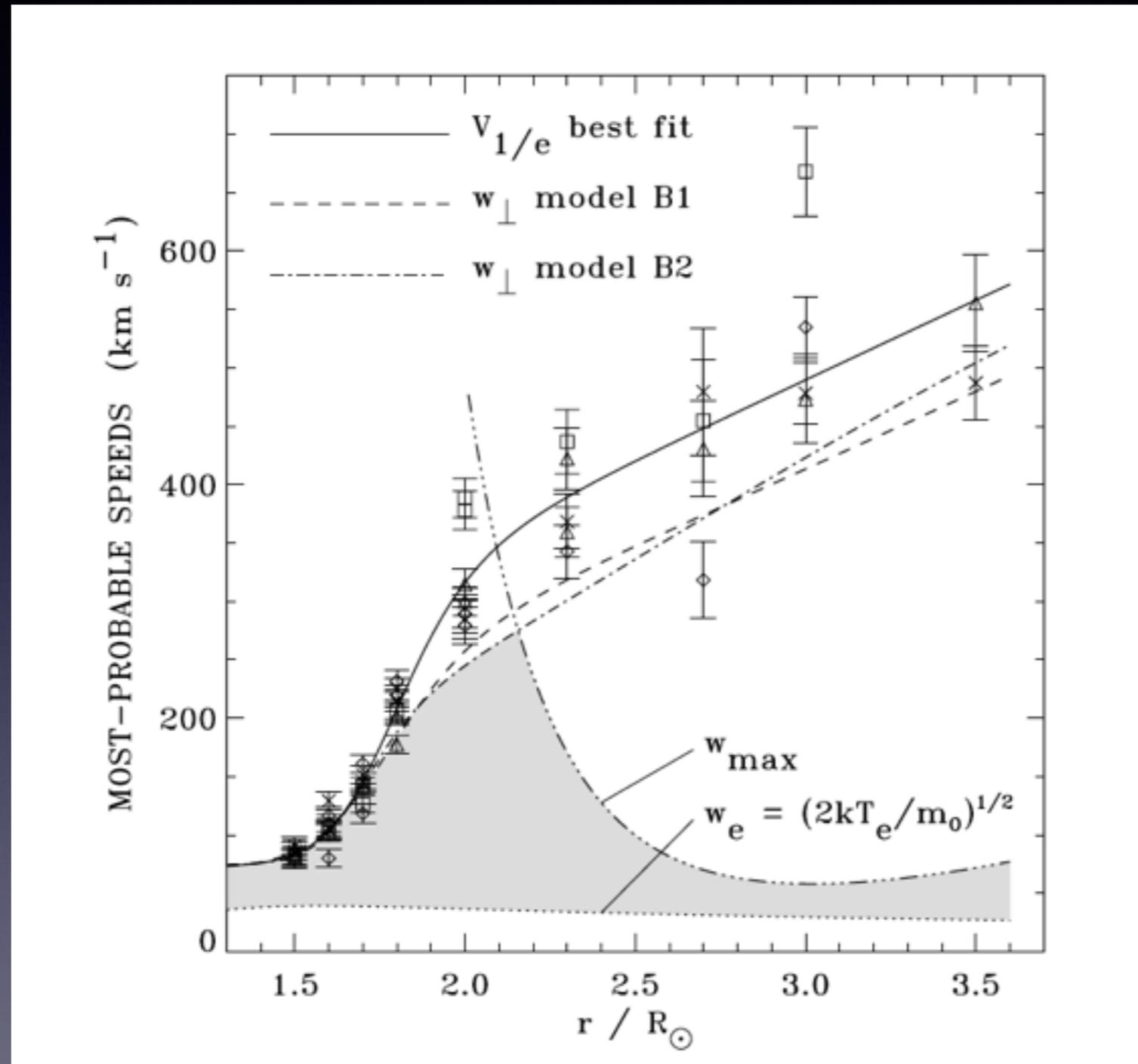


MDI magnetograms
Si II ($2 \cdot 10^4$ K)
C IV (10^5 K)
Ne VIII ($6 \cdot 10^5$ K)



Source du vent 5000–20000 km au dessus
de la photosphère dans des structures
magnétiques ouvertes

Where is the solar wind produced and how is it accelerated?



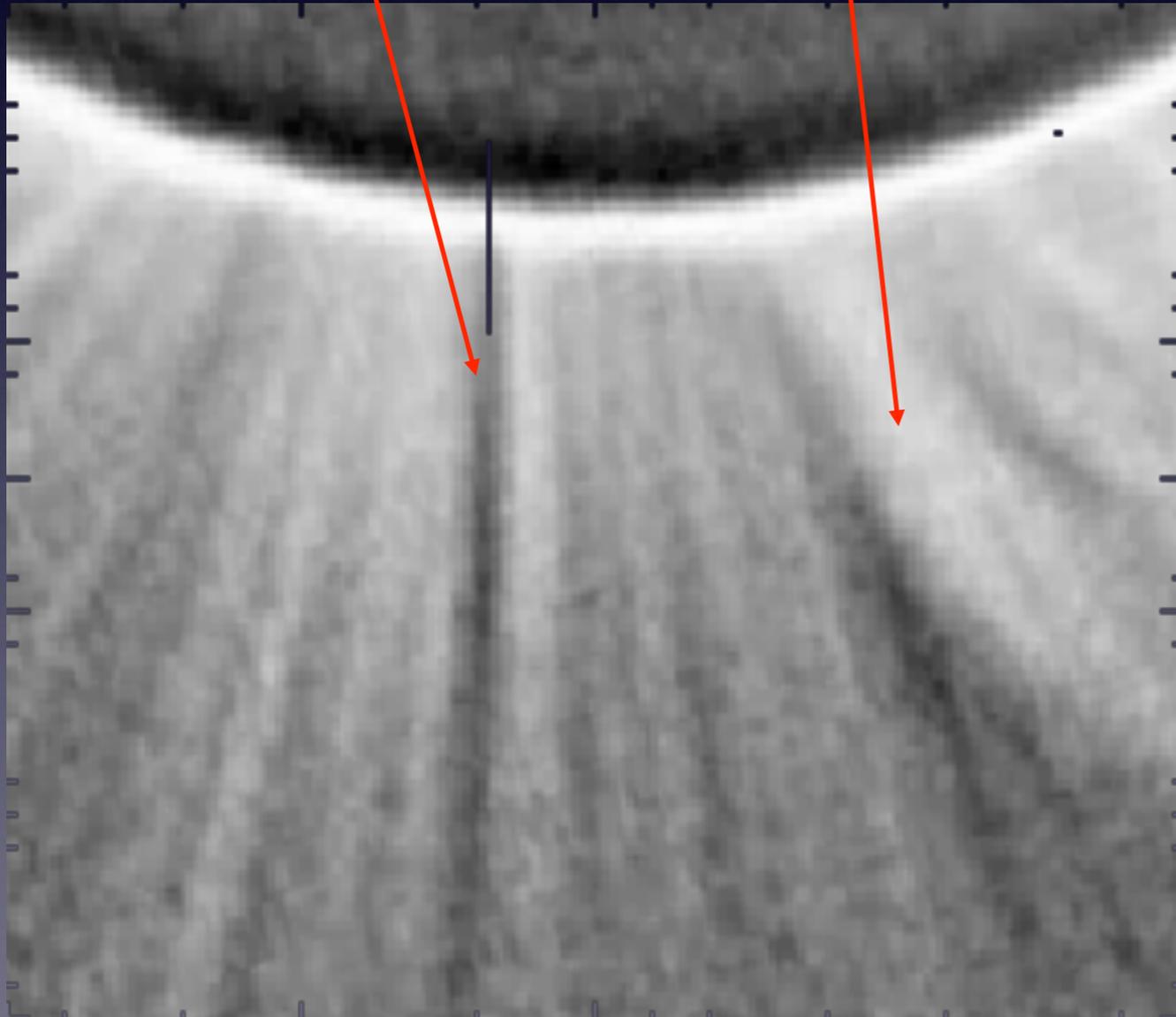
Cranmer et al, 1999

Mesures UVCS dans le cas d'un trou coronal

Where is the solar wind produced and how is it accelerated?

Interplume

Plume



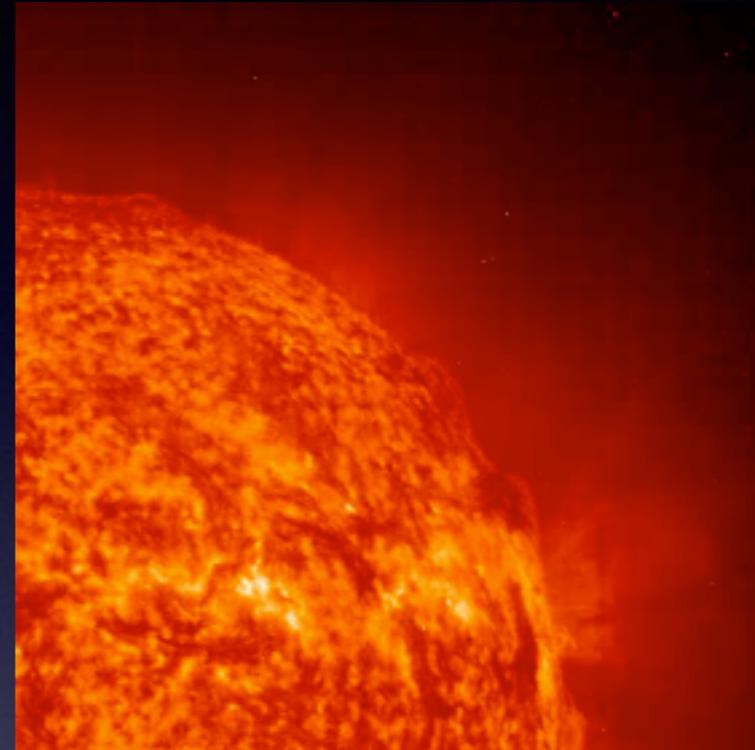
Contribution des Interplumes pour
Patsourakos & Vial, 2000; Teriaca
et al. 2003; ...

Contribution à 50 % pour les
plumes et à 50% pour les
Interplumes : Gabriel et al. 2003

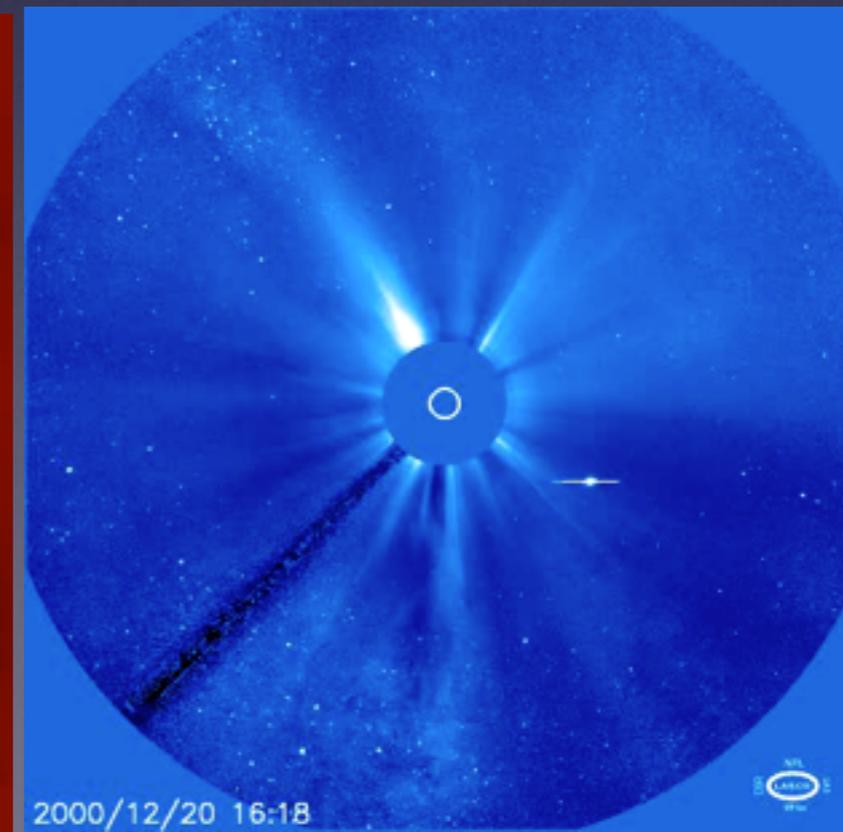
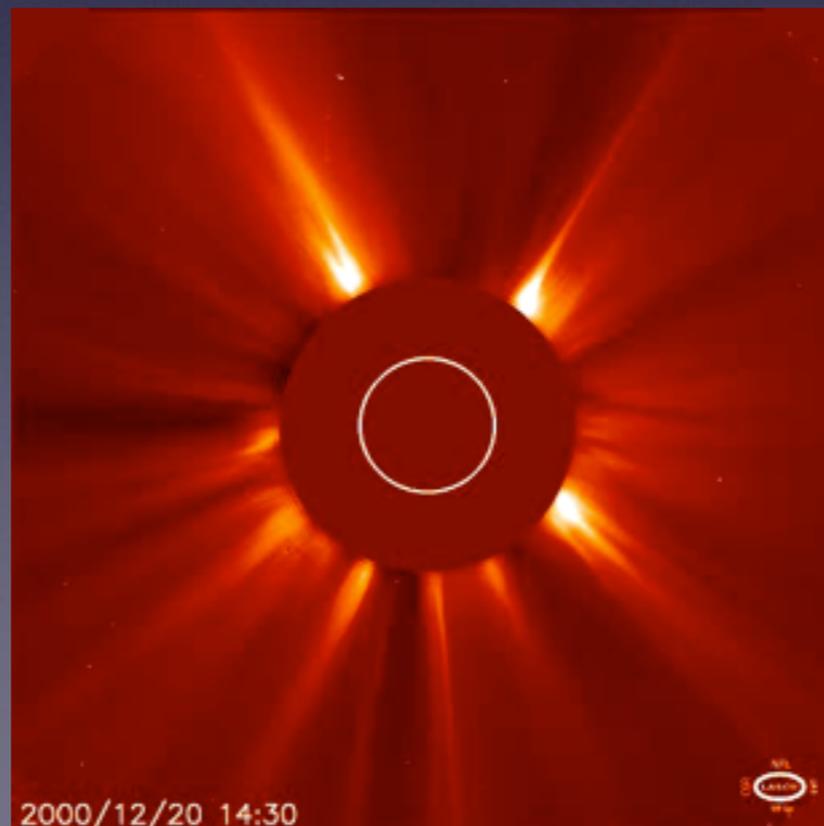
Dynamique de la couronne

Les CME vues par SOHO

« An order of magnitude more CMEs have been observed than the combined set of all CMEs observed in the pre-SOHO era »

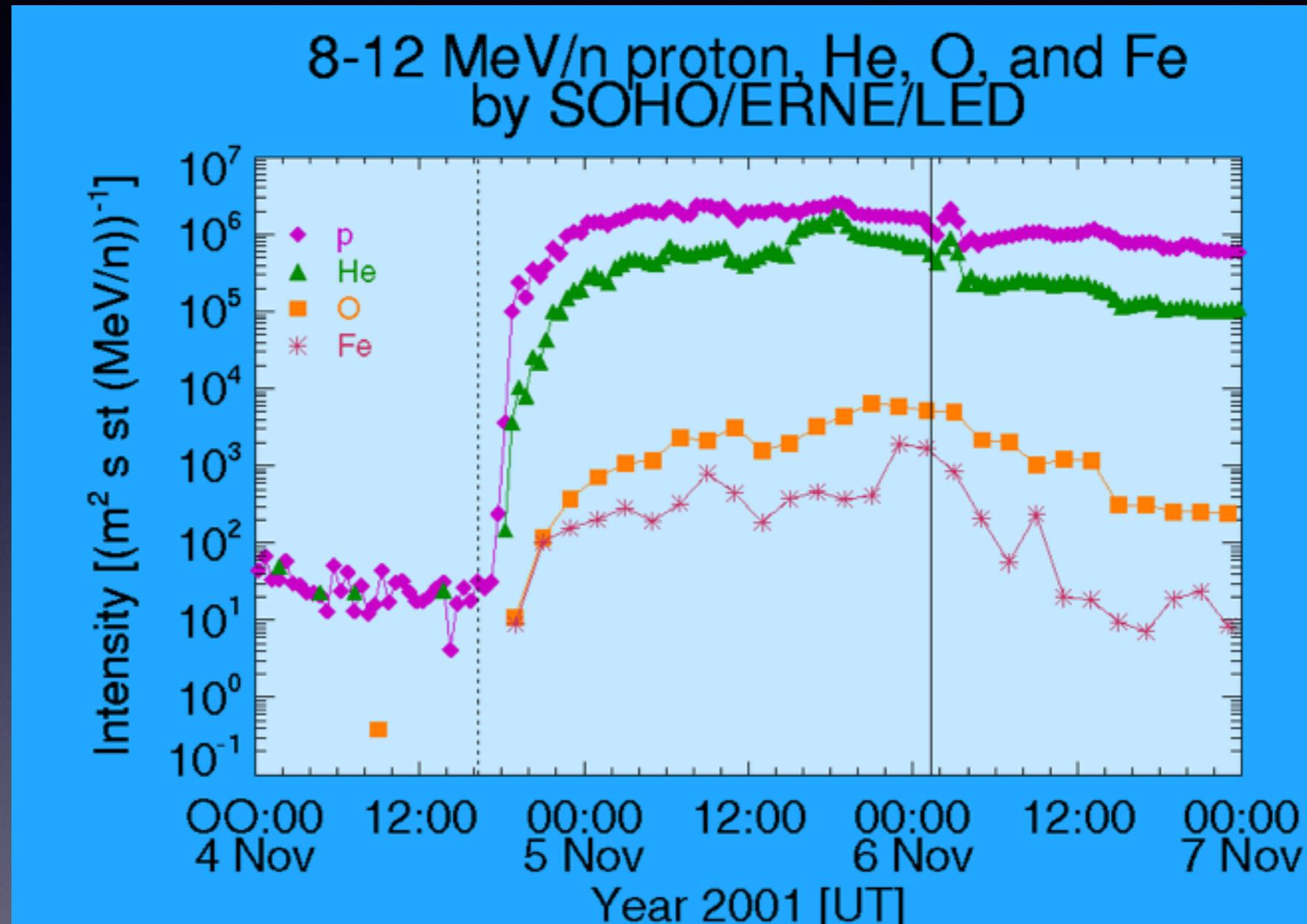


« Thousands of papers have been published using SOHO data »
(Gopalswamy 2012)



Dynamique de la couronne

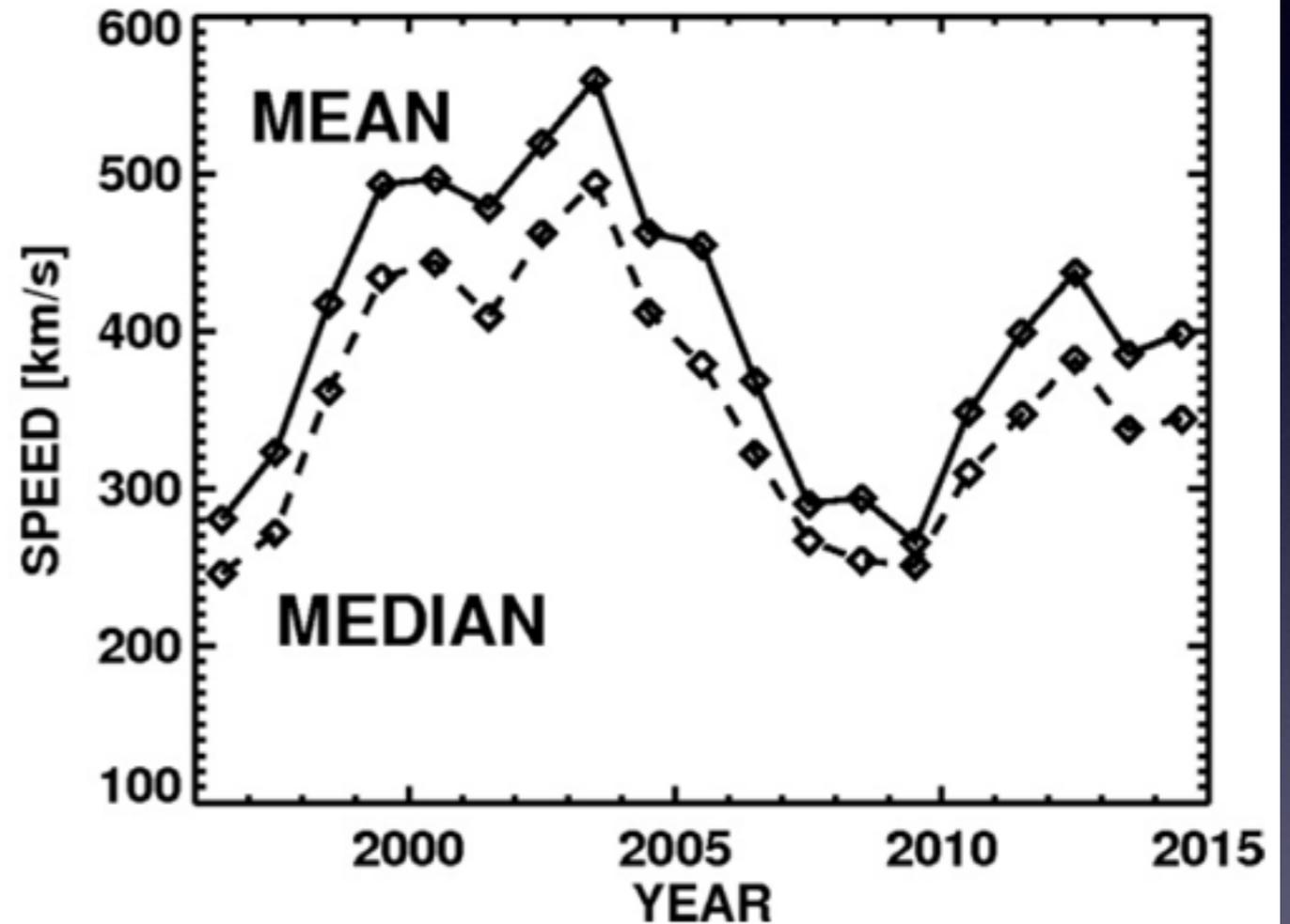
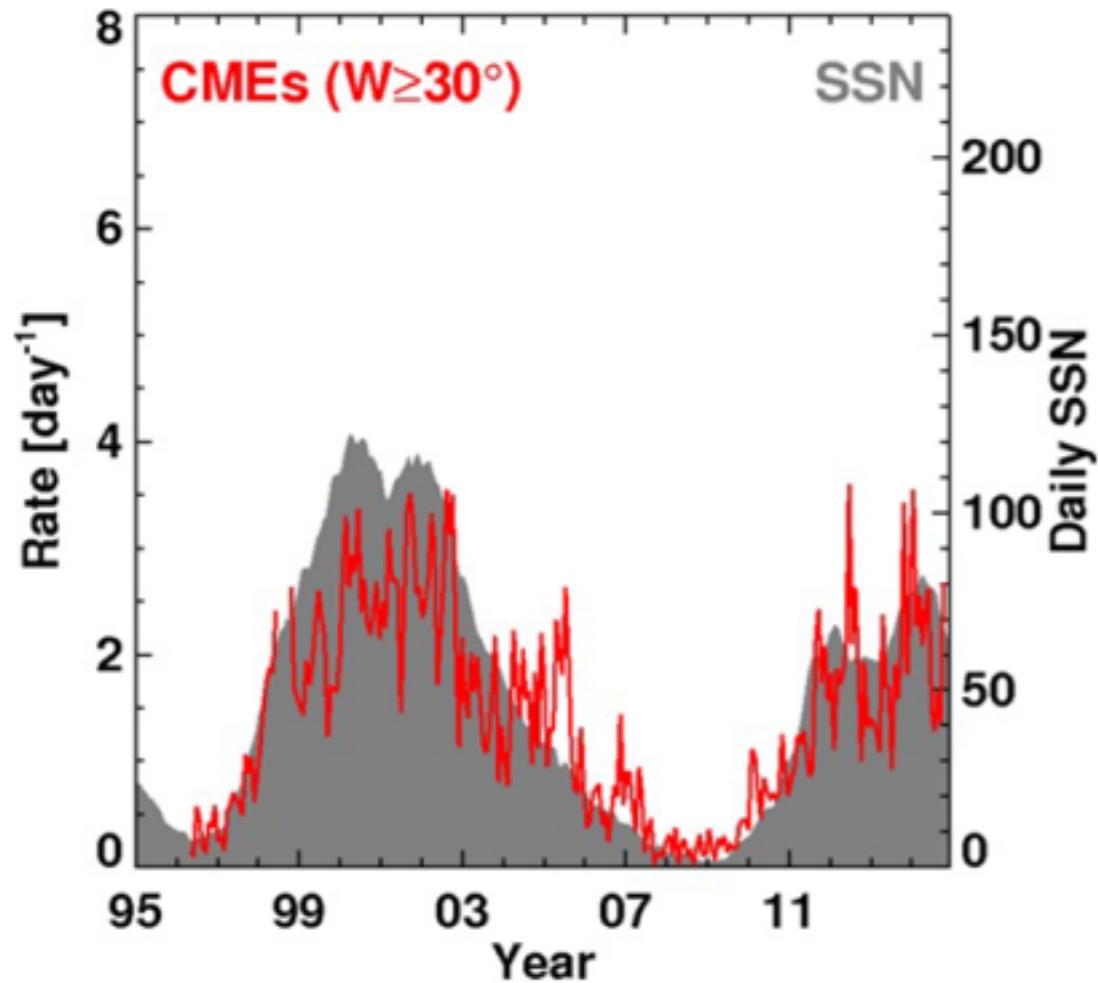
Les CME vues par SOHO



Flux de particules à L1

Dynamique de la couronne

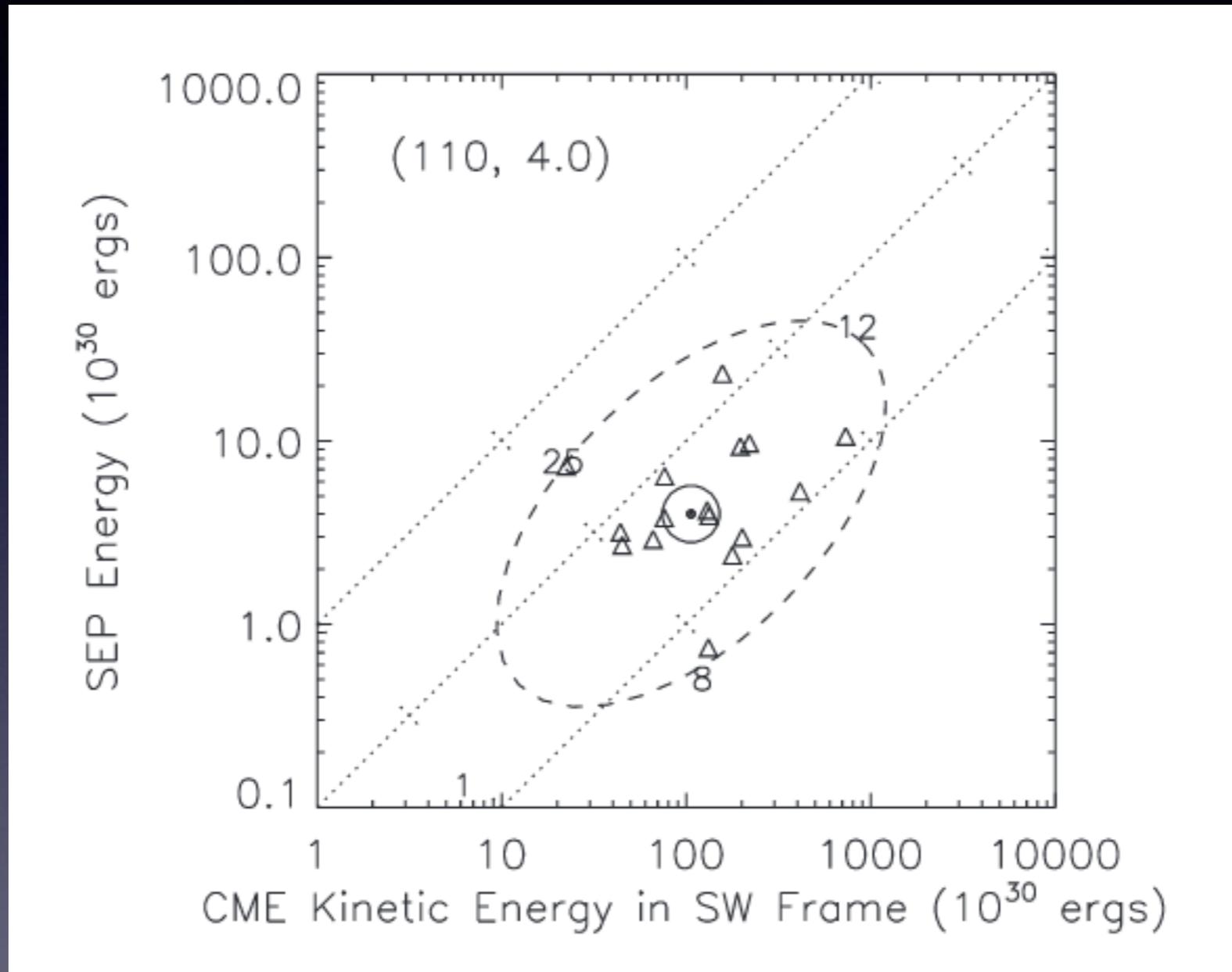
Les CME vues par SOHO



Correlation nb CME / SSN et vitesse / cycle

Dynamique de la couronne

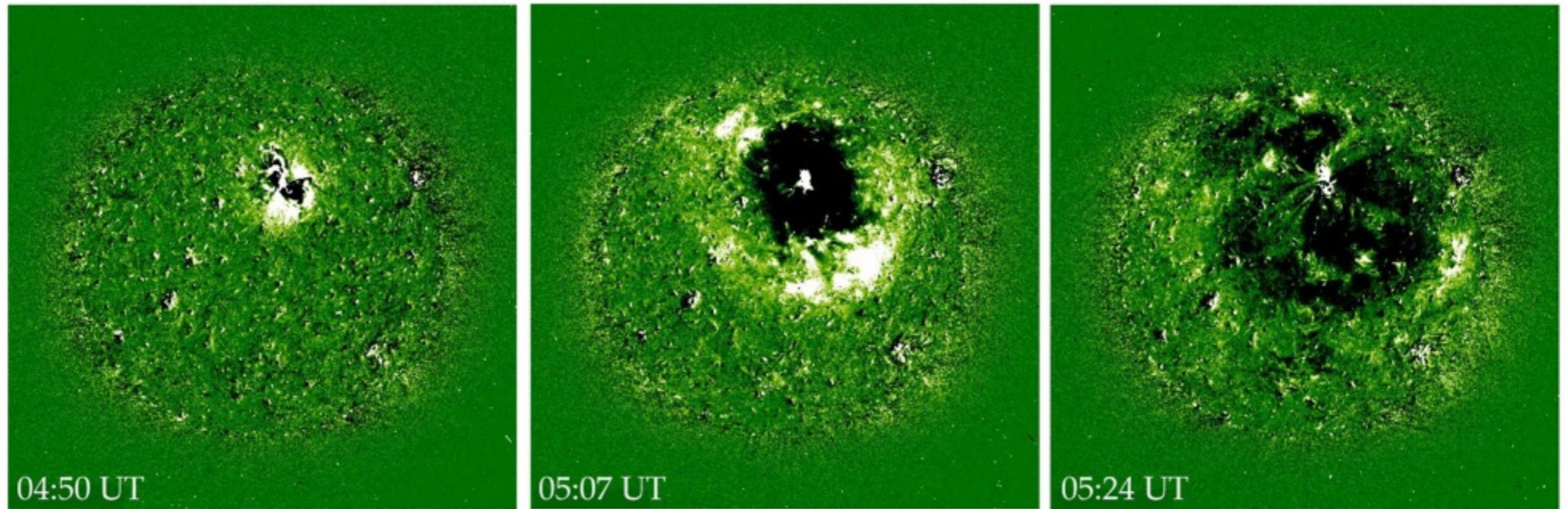
Les CME vues par SOHO



Emslie et al, 2012

Association fréquente CME/flare et majeure partie de l'énergie sous forme cinétique dans la CME

Dynamique de la couronne



SOHO-Extreme ultraviolet Imaging Telescope (EIT)

“Onde EIT” en expansion depuis le site d’initiation d’une éjection coronale de matière (CME)

Observation du 12 mai 1997

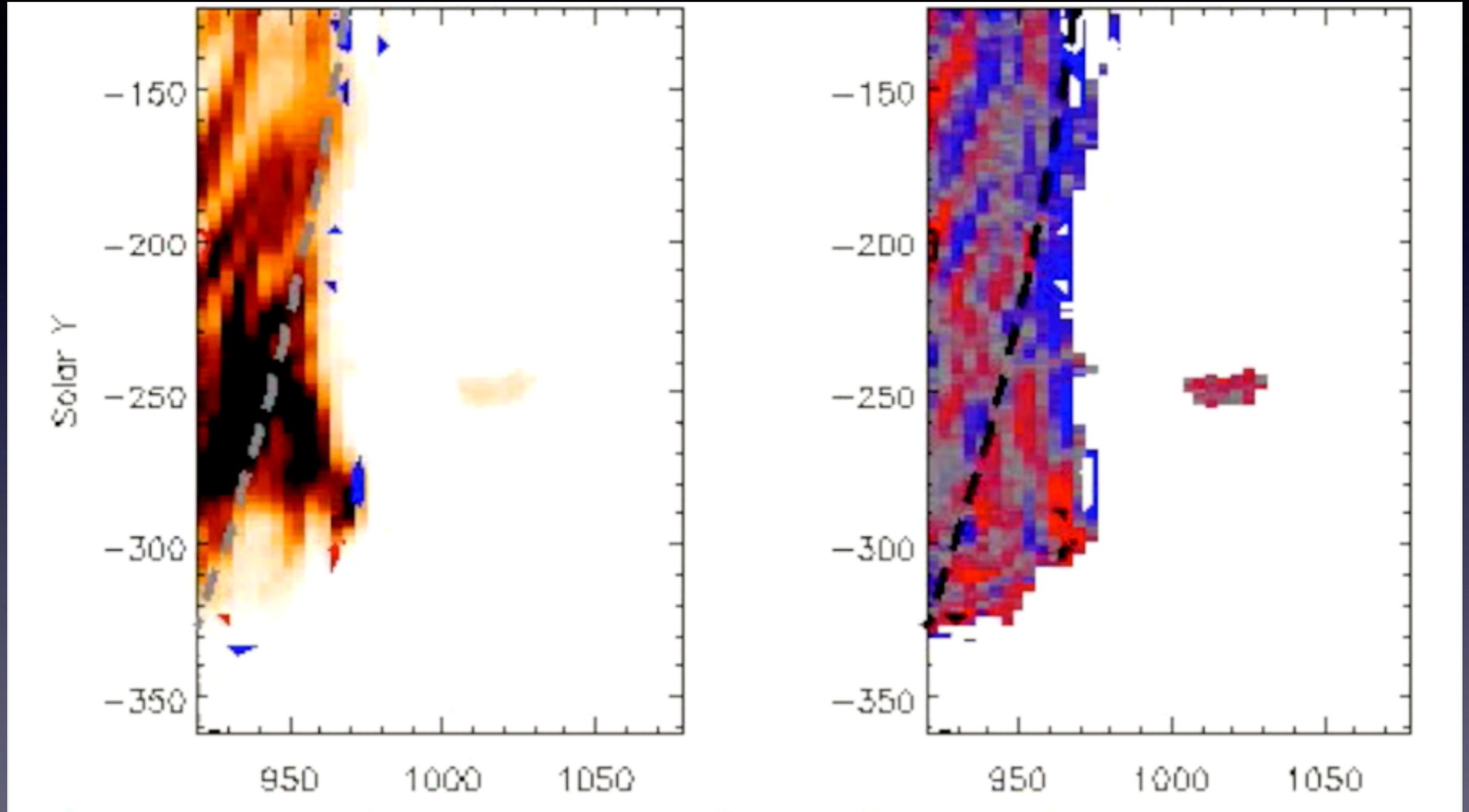
Différences d’images prises dans la raie du FeXII à 195 Å (1.5 MK)

Différence d’images dans la raie du Fe XII à 19.5 nm

Thompson et al., 1999

Détection de l’initiation d’une CME : ondes EIT
(onde magnéto-acoustique excitée par
le départ de la CME)

Diagnostic du plasma



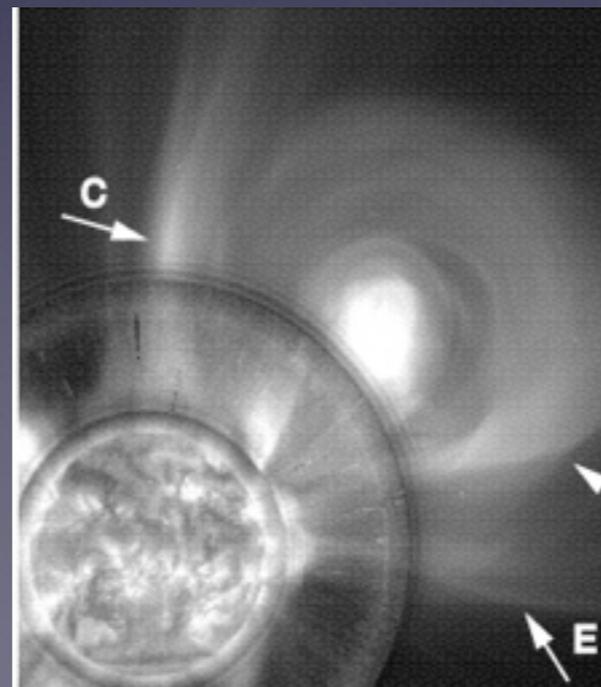
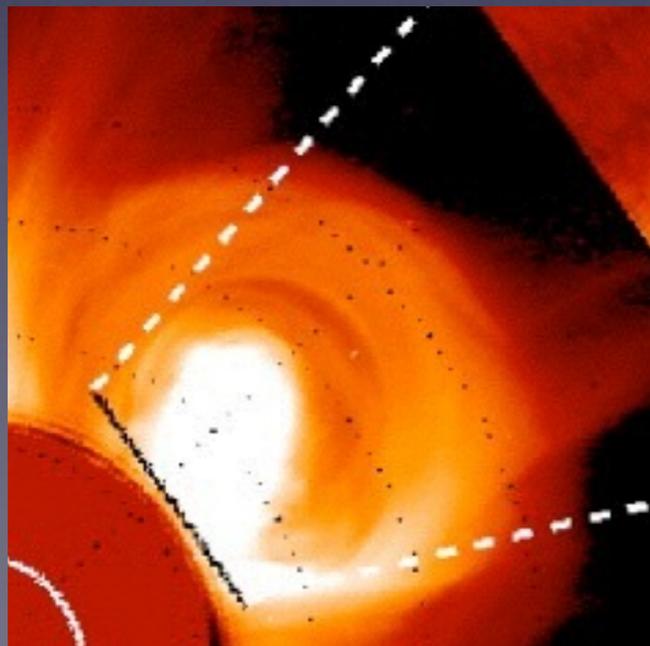
Observations intensité + Doppler

Diagnostic du plasma

Paramètres physiques d'une CME, observés à 2.3 rayons solaires

Objet	Densité (10^{10})	T (10^6)	T (10^6)
Streamer	2 - 3.1	1.4 - 1.8	1.5
Front	6	1.4 - 1.8	≤ 1.5
Protu (sommet)	5.4	1.6	≤ 1.6
Protu (pieds)	2	> 0.1	≤ 0.5

UVCS



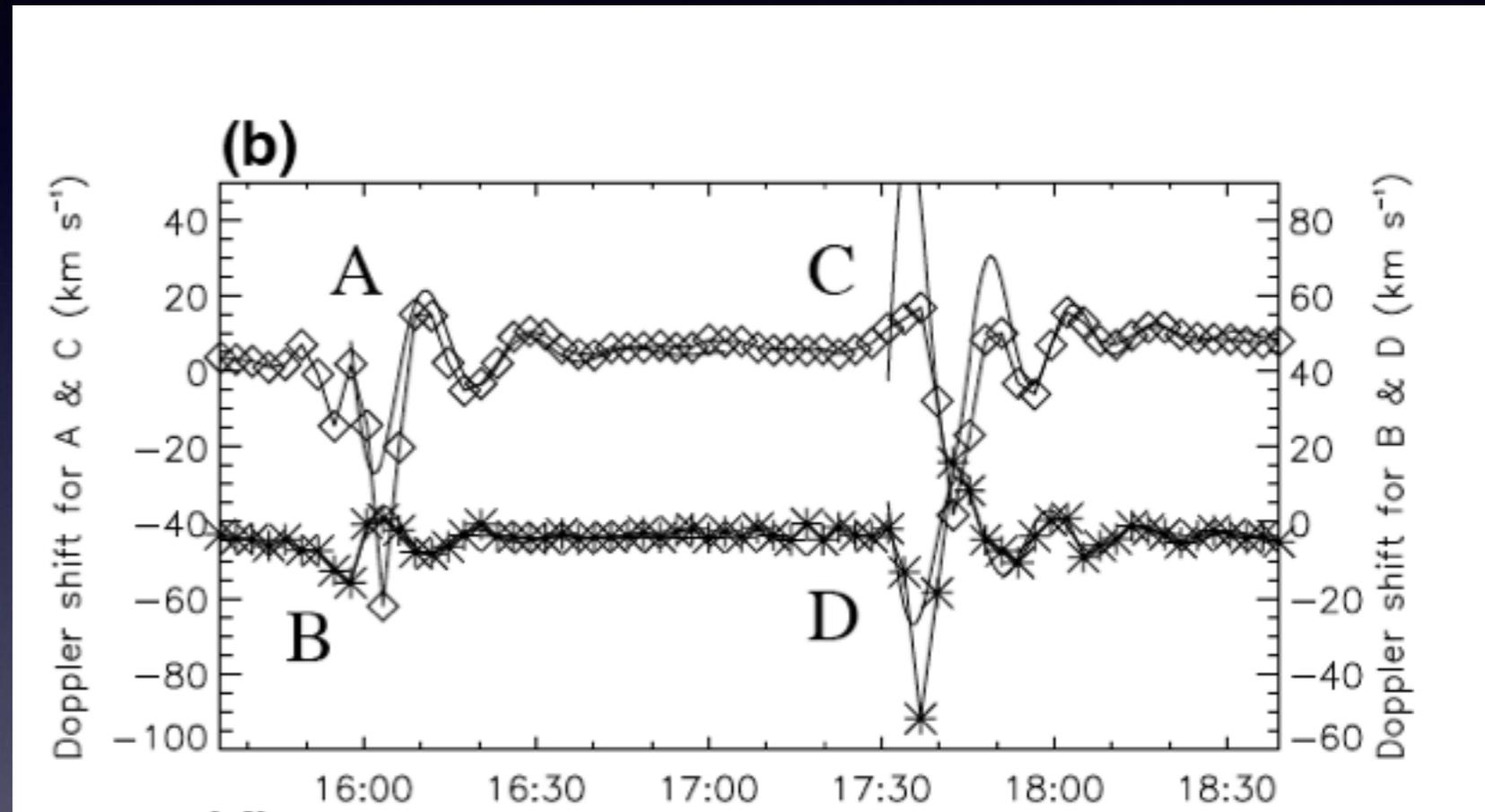
EIT+LASCO

Ciaravella et al. 2003

Dynamique de la couronne

Ondes & oscillations

Observation
d'oscillations en
intensité et vitesse
par SUMER dans
les raies Fe XIX et
Fe XXI (Kliem et al.
2002; Wang et al.
2002, 2003)



$7\text{mn} < \text{Périodes} < 31\text{mn}$; $v \leq 200 \text{ km/s}$
Temps d'amortissement de 5 à 35mn

Dynamique de la couronne

Ondes & oscillations

Oscillations interprétées comme ondes magnéto-acoustiques lentes observées en de multiples occasions:

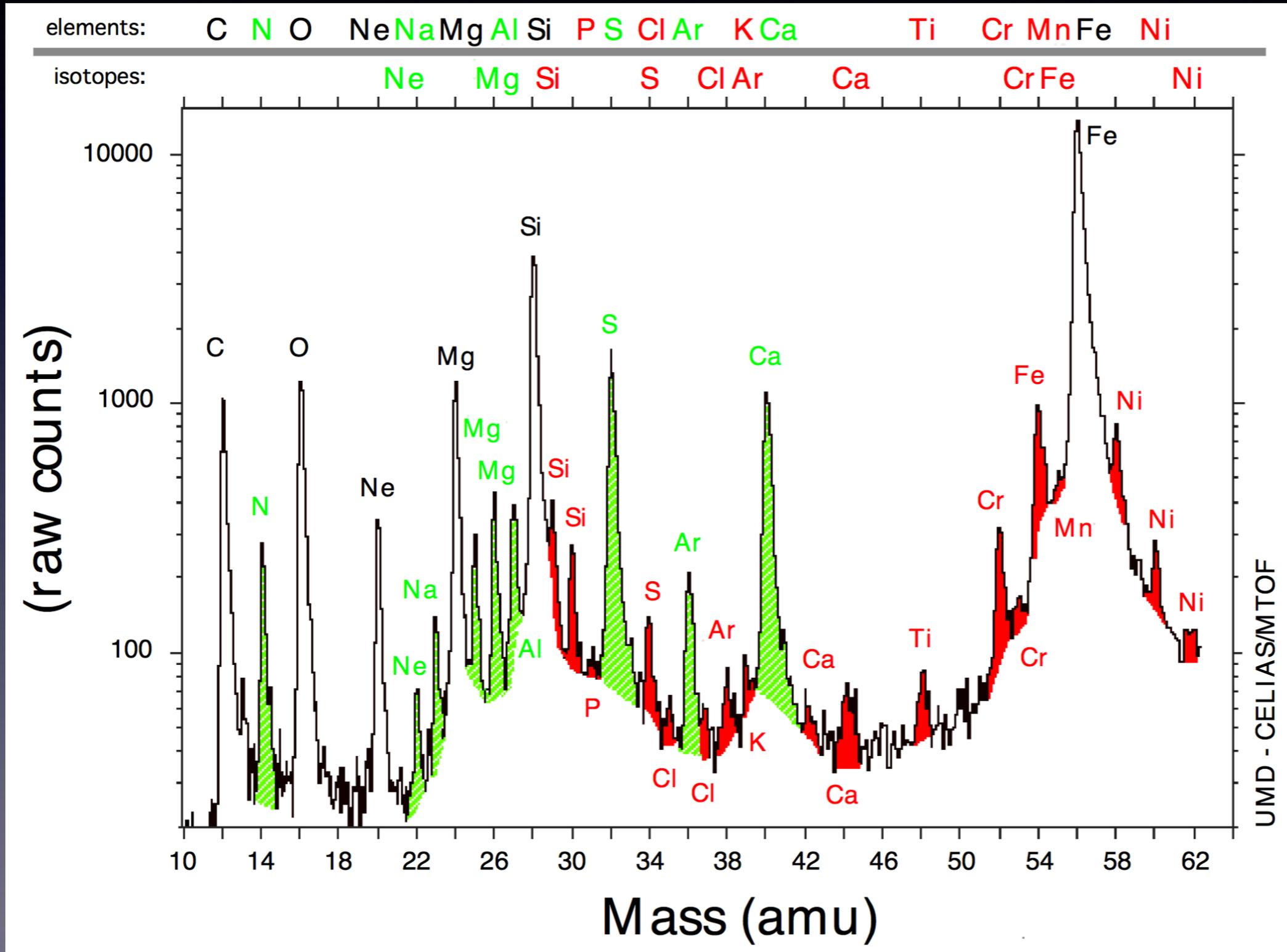
- à $1.9 R_{\odot}$ dans un trou coronal, $P \sim 9 \text{ mn}$, avec UVCS (Ofman et al, 1997, 1998)
- entre 1.01 et $1.2 R_{\odot}$ par EIT à 17.1 nm (DeForest & Gurman, 1998)
- aussi aux pieds de boucles (Berghmans & Clette, 1999)
- ...

=> sismologie coronale

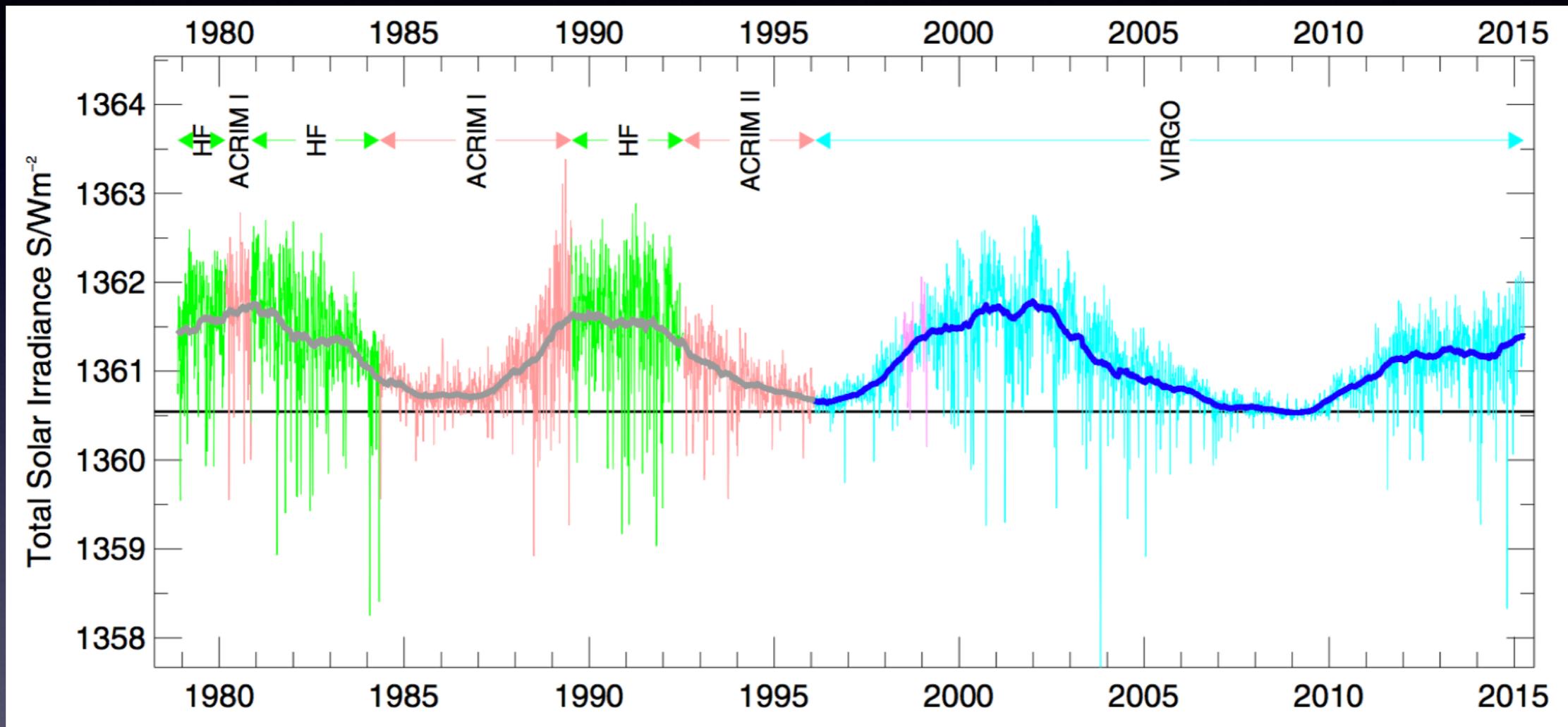
Composition du vent solaire

Elements and isotopes for which CELIAS/MTOF provided the first in situ solar wind observations

Elements not routinely observed by solar wind experiments

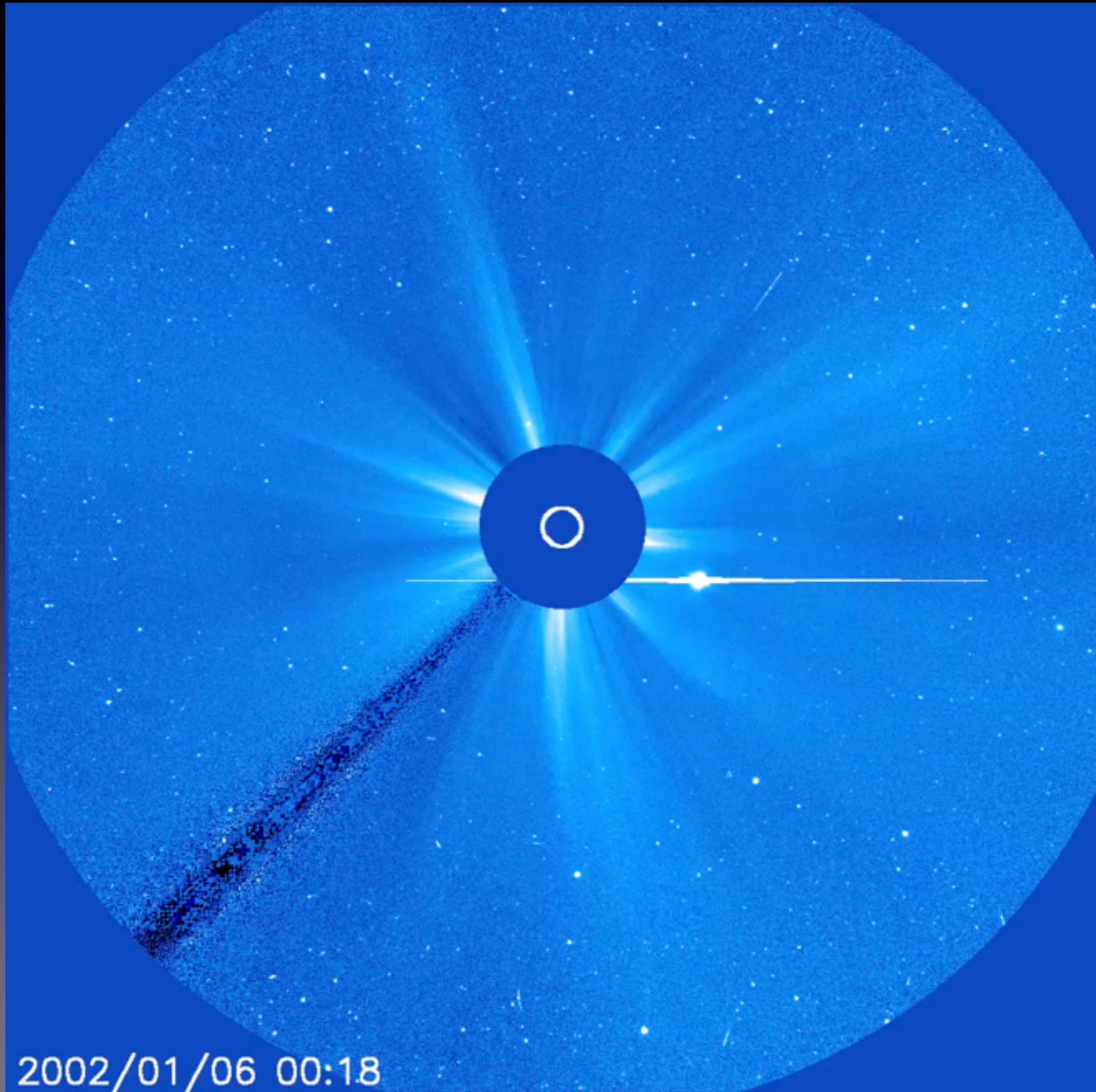


Total Solar Irradiance



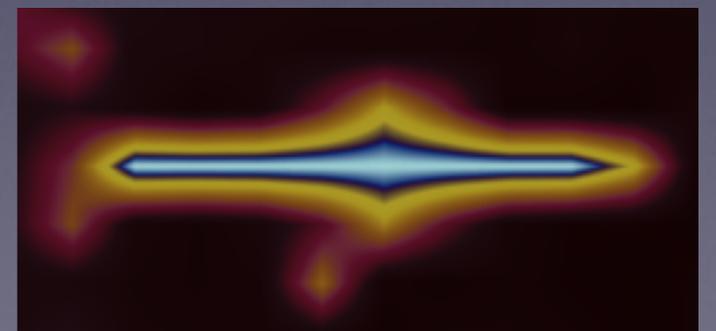
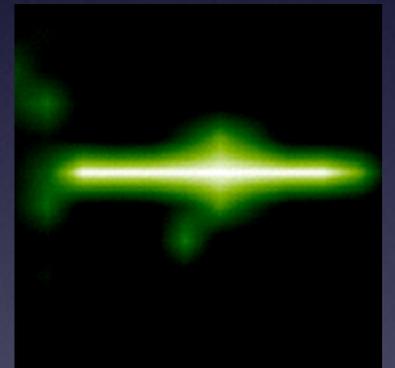
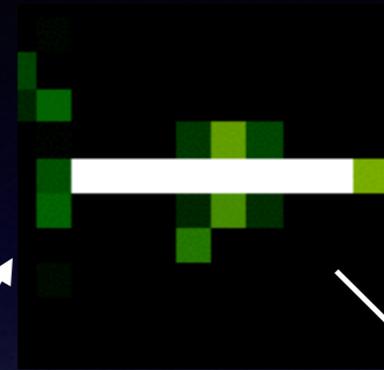
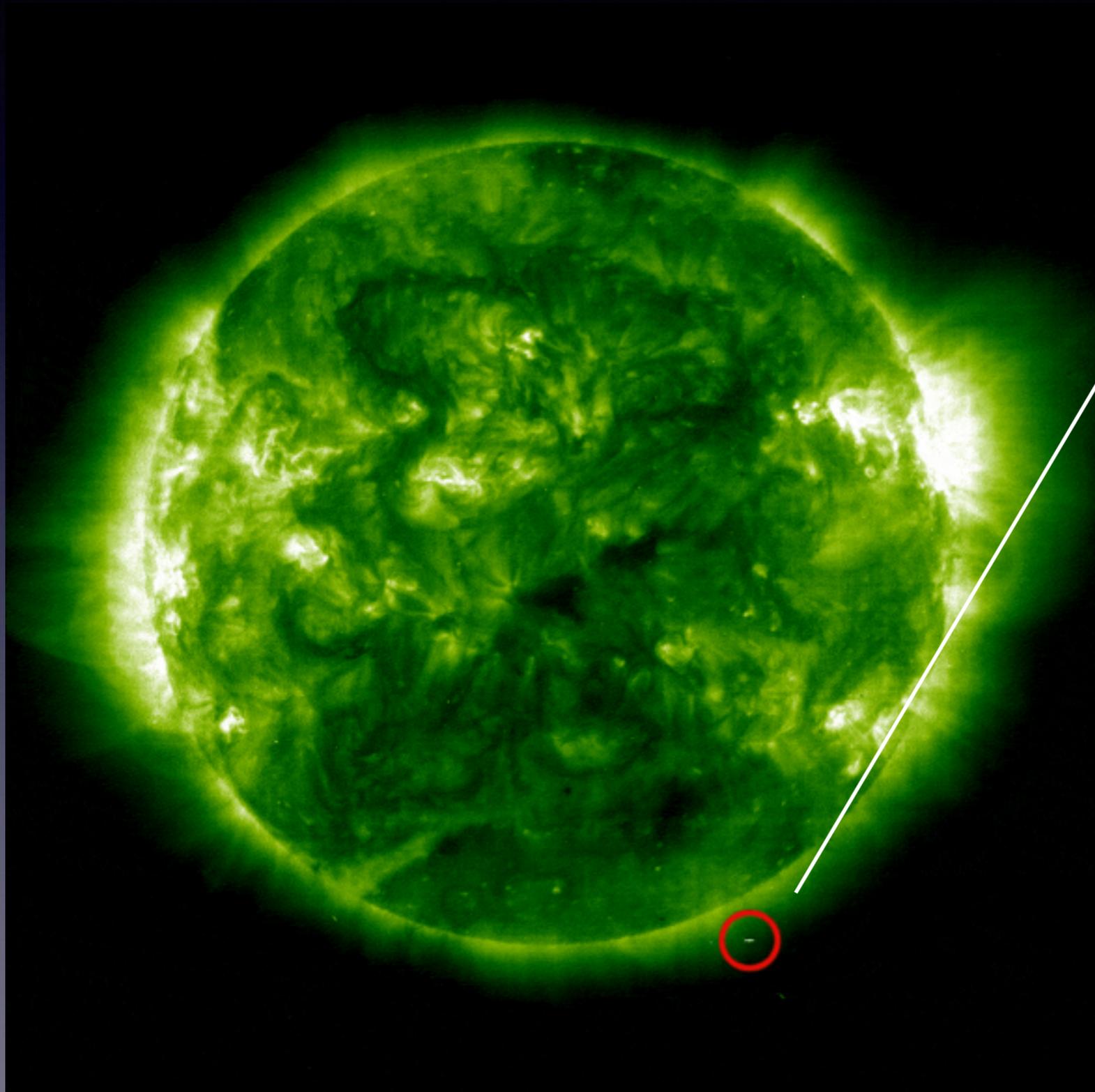
Mesures sur presque 4 cycles, dont 50%
par SOHO (VIRGO)

Comètes



Plus de 3000
comètes
découvertes par
SoHO
(pas mal déjà
disparues...)

Comment fabriquer un OVNI avec SOHO/EIT



Comment fabriquer un OVNI avec SOHO/EIT

'UFO' on NASA camera

By TIM UPTON

WASHINGTON: The object is certainly unidentified and appears to be flying.

Whether this enlarged image really shows a UFO piloted by aliens remains to be seen. But according to the people who released it this photo and hundreds like it are the best evidence yet of the existence of spacecraft from other worlds.

UFO investigators say the image was captured by the Solar and Heliospheric Observatory (SOHO), a NASA satellite that was launched in 1996 to

observe the sun. Since then, it is said, SOHO has captured hundreds of images of UFOs moving along a kind of alien superhighway.

SOHO is more than 1.5 million kilometres from Earth, with its camera trained towards the sun. Experts say the photographed objects are likely to be only hundreds of kilometres from its lenses.

Graham Birdsall, editor of *UFO* magazine, said: "The images are irrefutable in that they are from official satellites owned by NASA. They resemble the kind of spacecraft we used to see in sci-fi films like *Star Trek*."



UTTERLY ALIEN: The image investigators say shows a UFO.



Log In



Last News

- 29/09/2015: New page for Radiative transfer codes

[More news](#)

DATA

Data from:

- SOHO, TRACE, SPIRIT/CORONAS, SECCHI/STEREO
- PICARD
- AIA/SDO

Derived data products:

- Synoptic EUV solar maps
- Differential Emission Measure maps
- Library of EIT movies
- Library of STEREO and SOHO movies

Data from numerical simulations:

- 1D solar wind hydrodynamical code (VP)
- Magnetic field 3D simulations (soon available)

TOOLS

Software:

- Radiative transfer codes

Home / MEDOC

MEDOC

MEDOC (Multi Experiment Data & Operation Center) is a National Center for Space Solar Physics Data, approved by CNES, in the frame of an agreement between CNRS/INSU, Université Paris-Sud and CNES. MEDOC is located at Institut d'Astrophysique Spatiale in Orsay.

It was initially created (in 1995) and developed as a european data and operation center for the SOHO mission. Later, it got enriched with new data from other space based solar observations from TRACE (NASA), Spirit/CORONAS (Russian Federal Space Agency), STEREO (NASA). It became a national data center in 2012 and in parallel continued to enrich its data contents with AIA/SDO, Picard (CNES) and a close future should see data from Solar Orbiter included in MEDOC (a summary of the instruments –and their main characteristics– which data are available at MEDOC can be found [here](#)). MEDOC is more than a repository for data. First, it also operates some instruments observing the Sun (such as SOHO observation campaigns). Second, the scientists from the Institut d'Astrophysique Spatiale, which hosts MEDOC, have a good expertise about most of the instruments which data are available at MEDOC and can provide some valuable information about the use and interpretation of these data (use the contact link below). Finally, some products with added values and other services are also available at MEDOC, such as visualization tools, interpretation tools (plasma parameter diagnostic for example) or software and models to help analyzing and interpreting the data.

MEDOC is also open on the whole scientific community and has for natural partners the Centre de Données de Physique des Plasmas and BASS2000. So that we can report the publications using MEDOC to our funding agencies, please tell us about such publications, and please include the following text in the acknowledgements:

"This work used data provided by the MEDOC data and operations centre (CNES / CNRS / Univ. Paris-Sud), <http://medoc.ias.u-psud.fr/>"

[Most recent images of the Sun](#)

[List of instruments](#)

[Access to Data](#)

[Access to analysis tools and catalogs](#)

[Publications using MEDOC data](#)

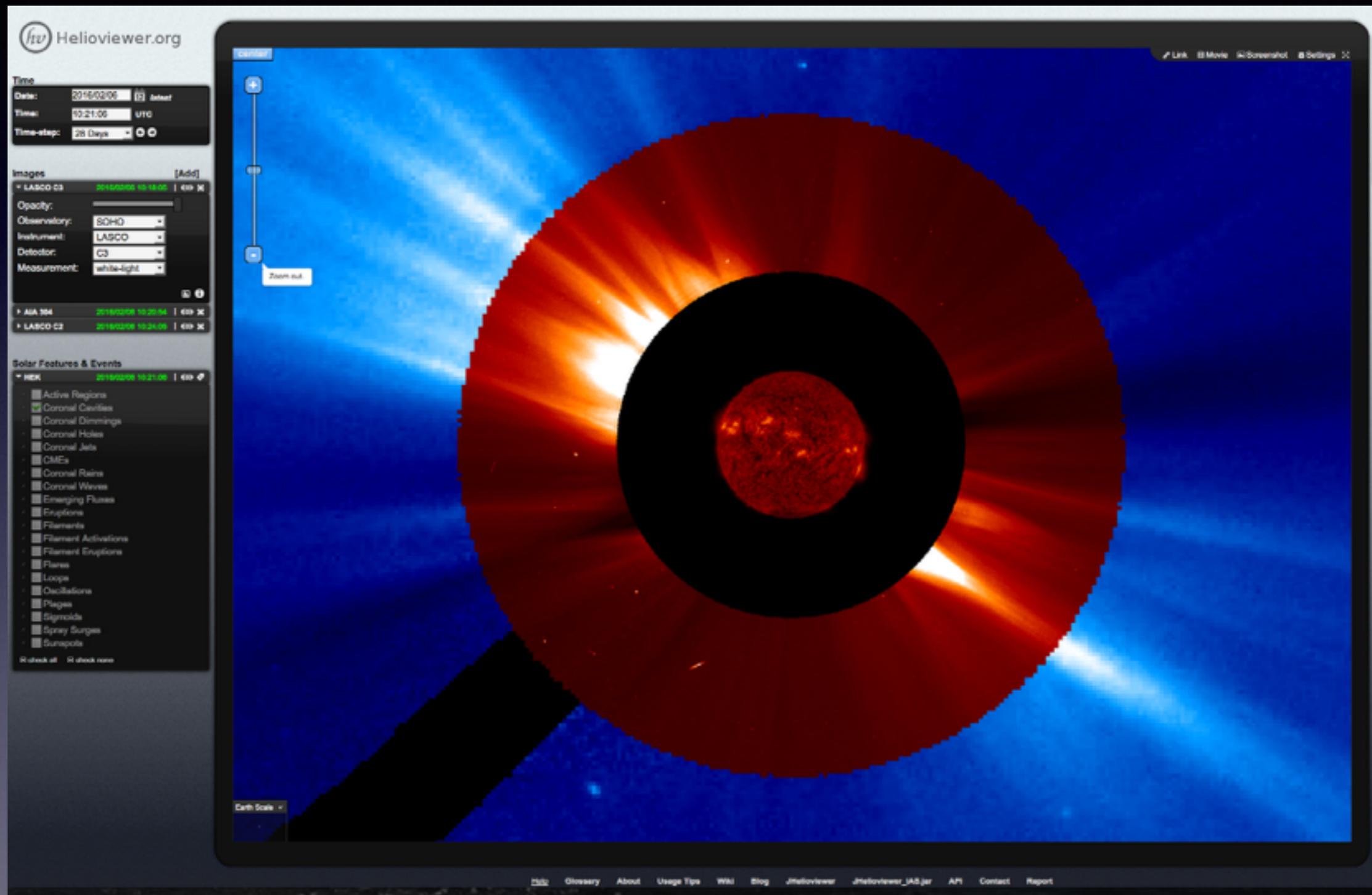
[News](#)

Toutes les données
SoHO et plus
encore (autres
manipes, outils...)



<http://idoc.ias.u-psud.fr/MEDOC>

Pour visualiser, combiner, toutes ces données :
Heliviewer@IAS



<http://heliviewer.ias.u-psud.fr/>

En conclusion

- Le Soleil observé de différentes manières: imagerie, spectroscopie, magnétographie, sismologie, particules => vue globale
- Le Soleil observé à de multiples longueurs d'onde => diagnostic physique
- Le Soleil observé en continu => vue dynamique... pendant presque 2 cycles d'activité!!!