ROYAL OBSERVATORY OF BELGIUM

LIÈGE université

# Effect of the inclination angle of solar rotation axis on Ca II K structures using direct solar observations

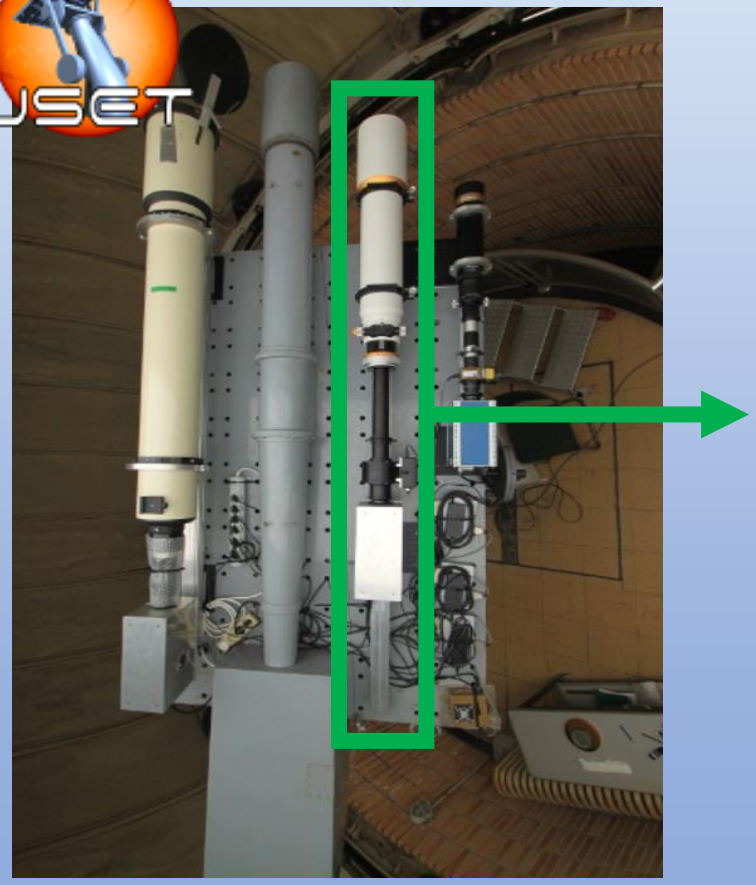
***Grégory VANDEN BROECK***

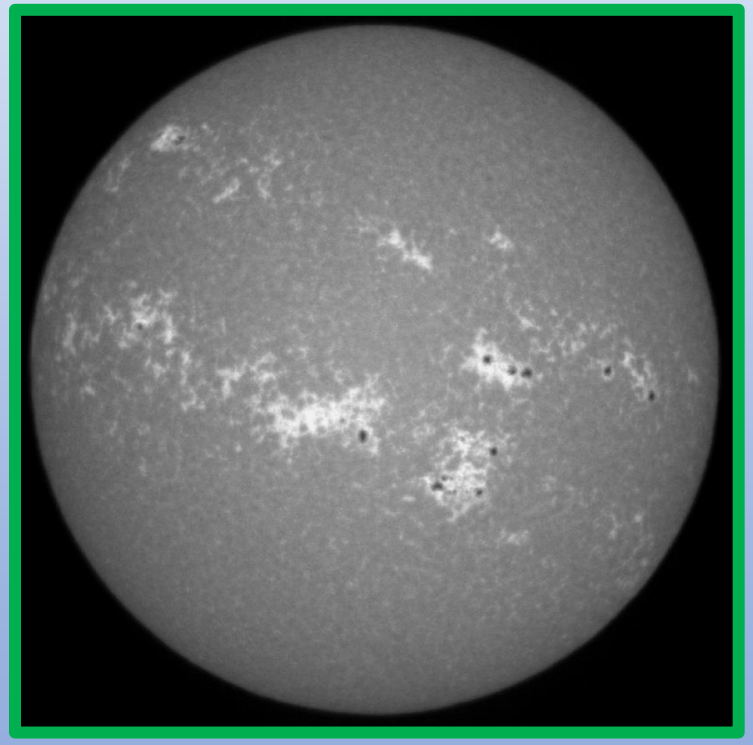
*TESS, Dallas*
*April 9, 2024*

# 1. USET index

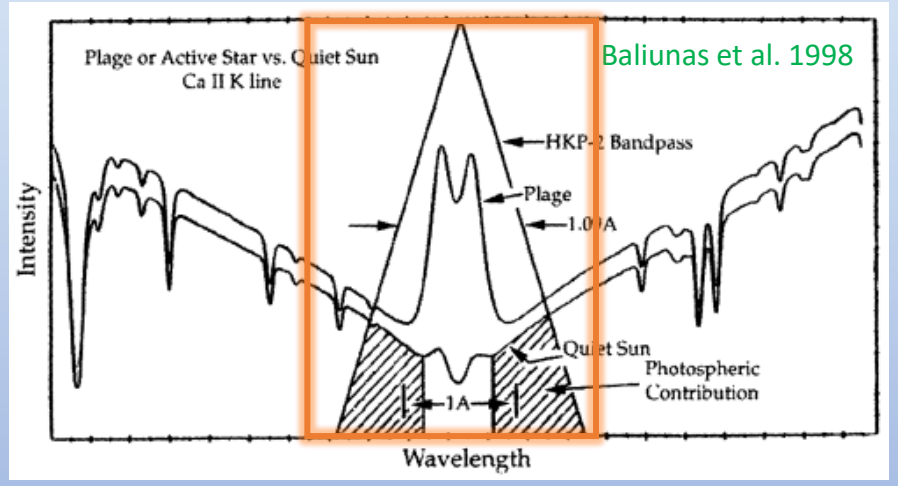
## *1.1. Dataset*

Exploitation of Ca II K images taken with USET (« Uccle Solar Equatorial Table »)



**Chromosphere (Ca II K)**




Ca II K line centered at : 3933.7 Å

Filter bandpass : **2.7 Å**

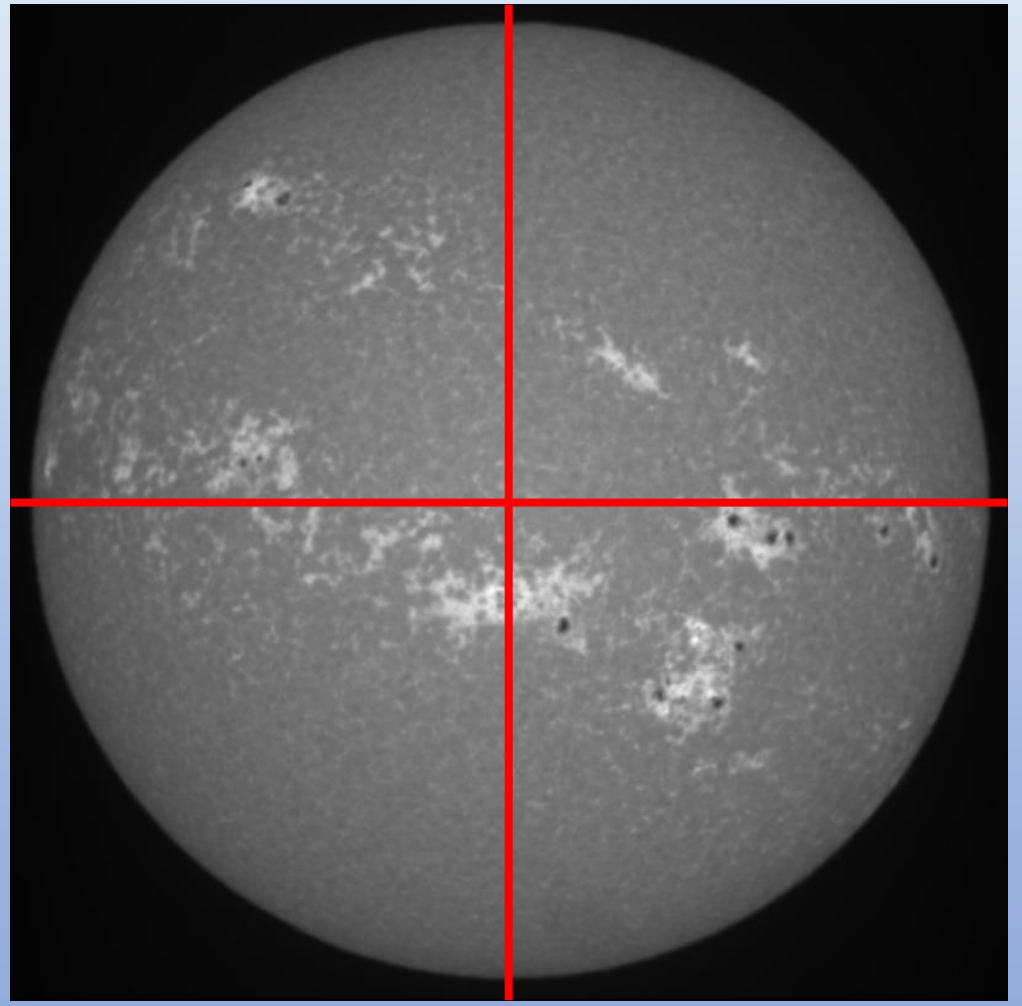
Dataset : ~ 23.000 Ca II K images since July 2012

After sorting → **2725 images**

# 1. USET index

## *1.2. Image processing*

- **Image recentering**



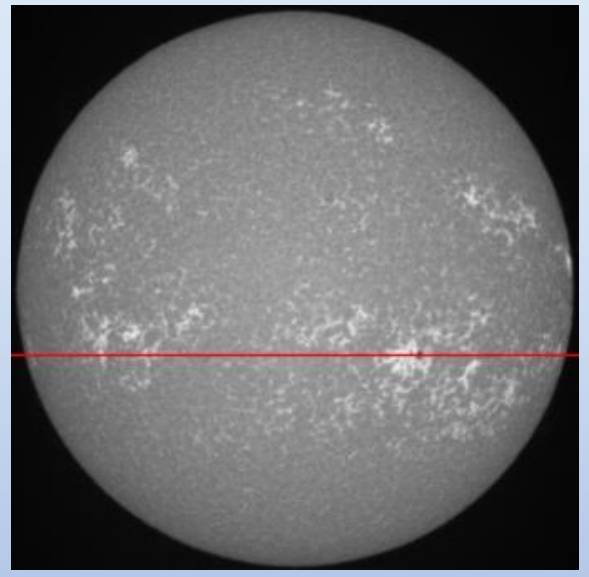
# 1. USET index

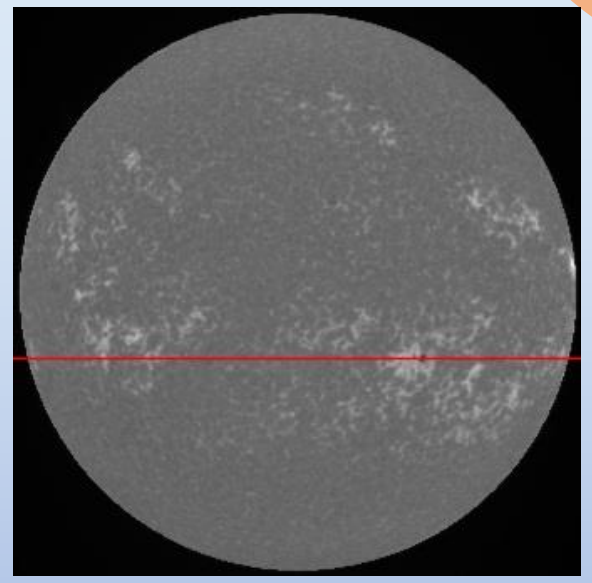
## *1.2. Image processing*

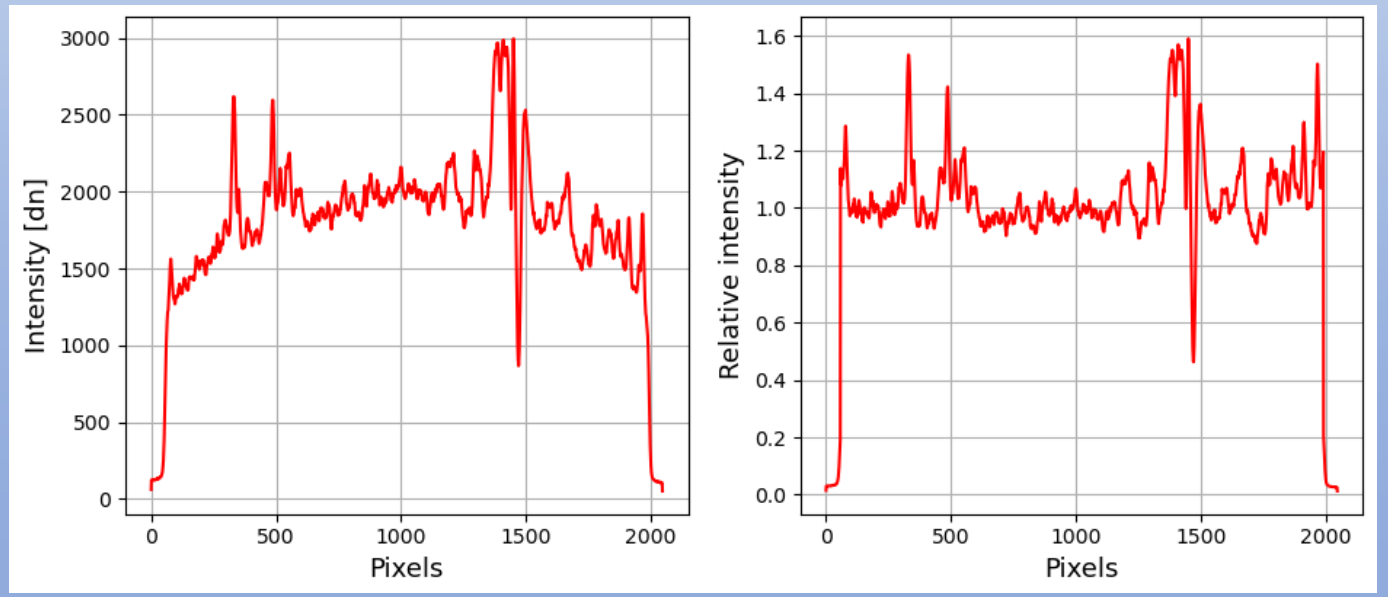
- Image recentering

- **Limb darkening correction**

→ Brighter at the center
→ Darker at the limb







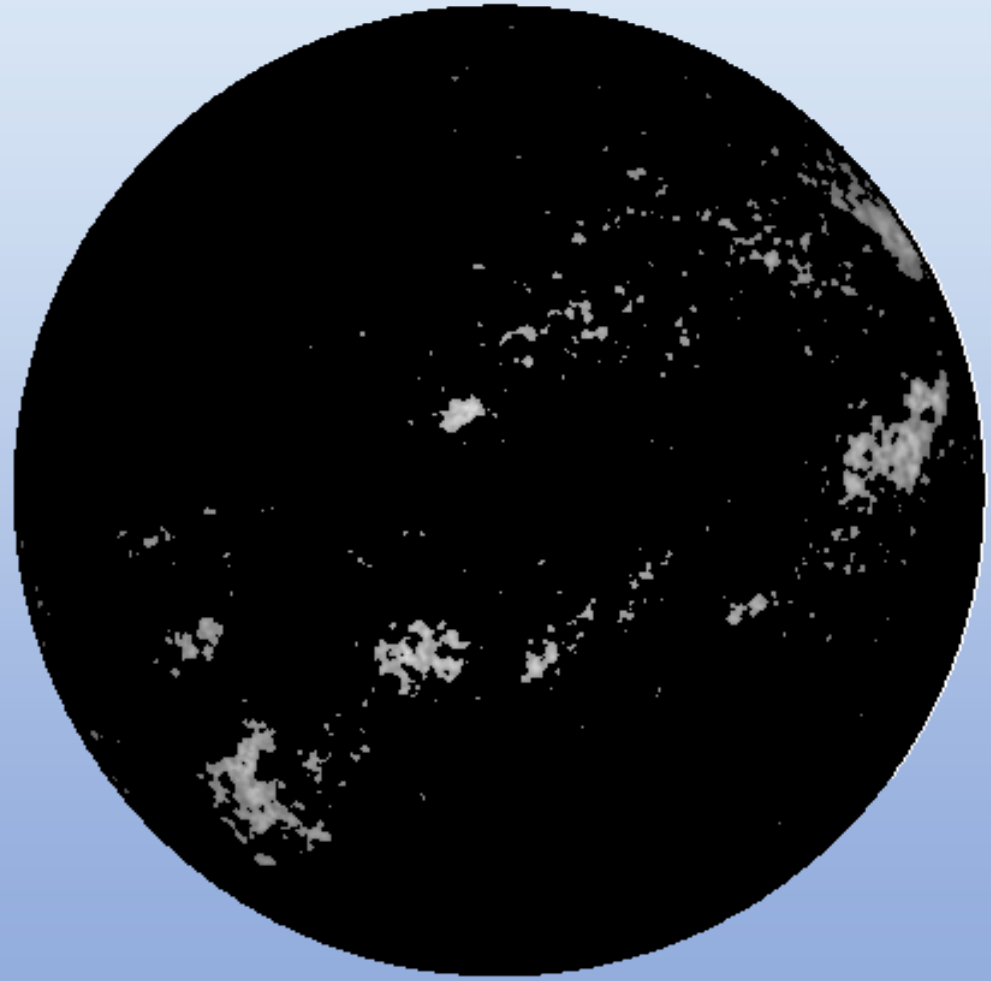
# 1. USET index

## *1.2. Image processing*

- Image recentering
- Limb darkening correction
- **Chromospheric structures segmentation**

→ Algorithm based on an intensity threshold

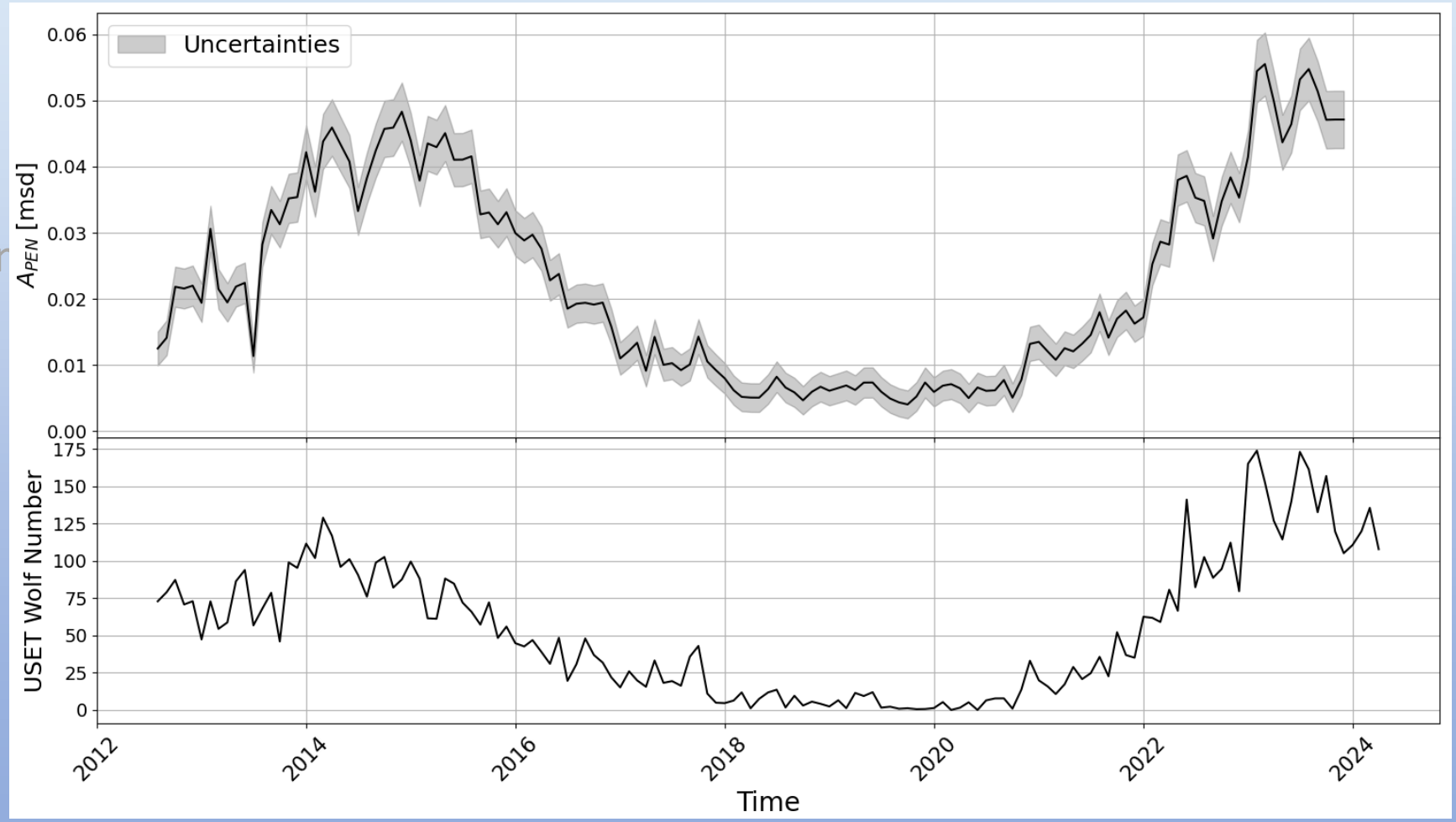
→ Structures segmented :
- Plages (bright extended structures)
- Enhanced network (small regions of decaying plages)



# 1. USET index

## *1.2. Image processing*

- Image recentering
- Limb darkening correction
- Chromospheric structures segr
- **Temporal evolution**
  - Following the solar cycle
  - Uncertainties depending linearly on the area
  - Short-term variations associated to solar rotation (see further)




Vanden Broeck et al. 2024 (submitted)

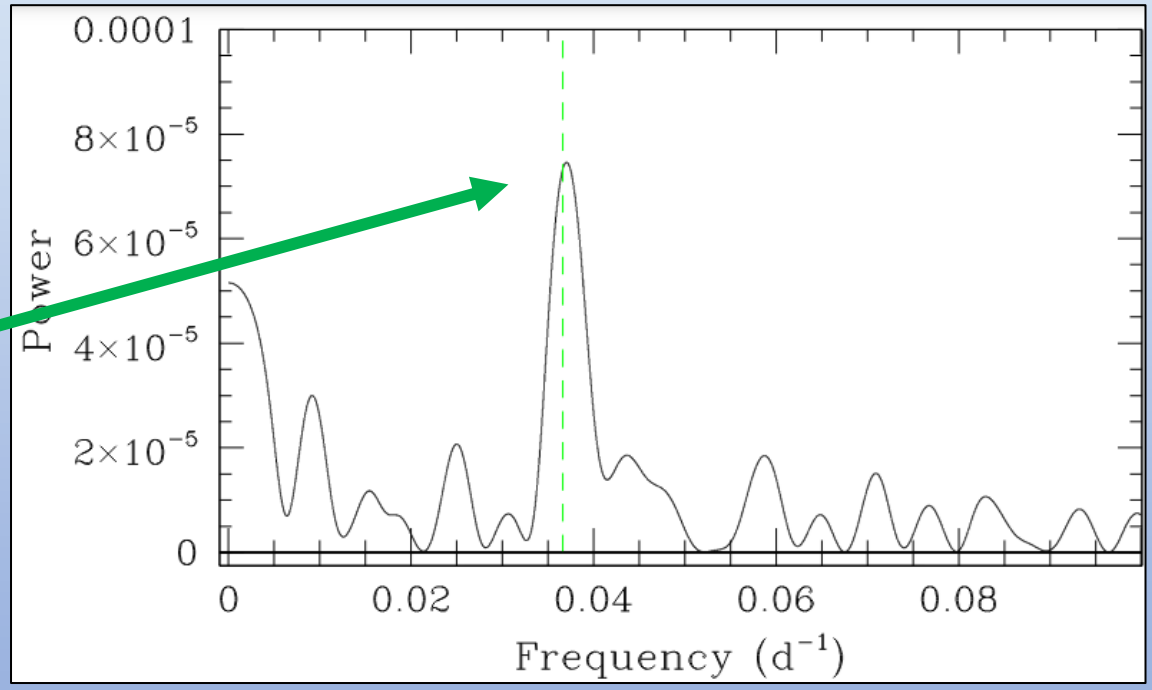
# 2. Periodic modulation

*Fourier analysis*

→ Search for presence of **rotation modulation** in the area fraction time series

- ***Fourier method :*** Existence of a periodic signal
  ⇒ peak in the power spectrum

- Highest peak at $\sim 0.0367\ d^{-1}$ (green line) :
  ⇒ **Carrington rotation period** $(27.27\ d)$



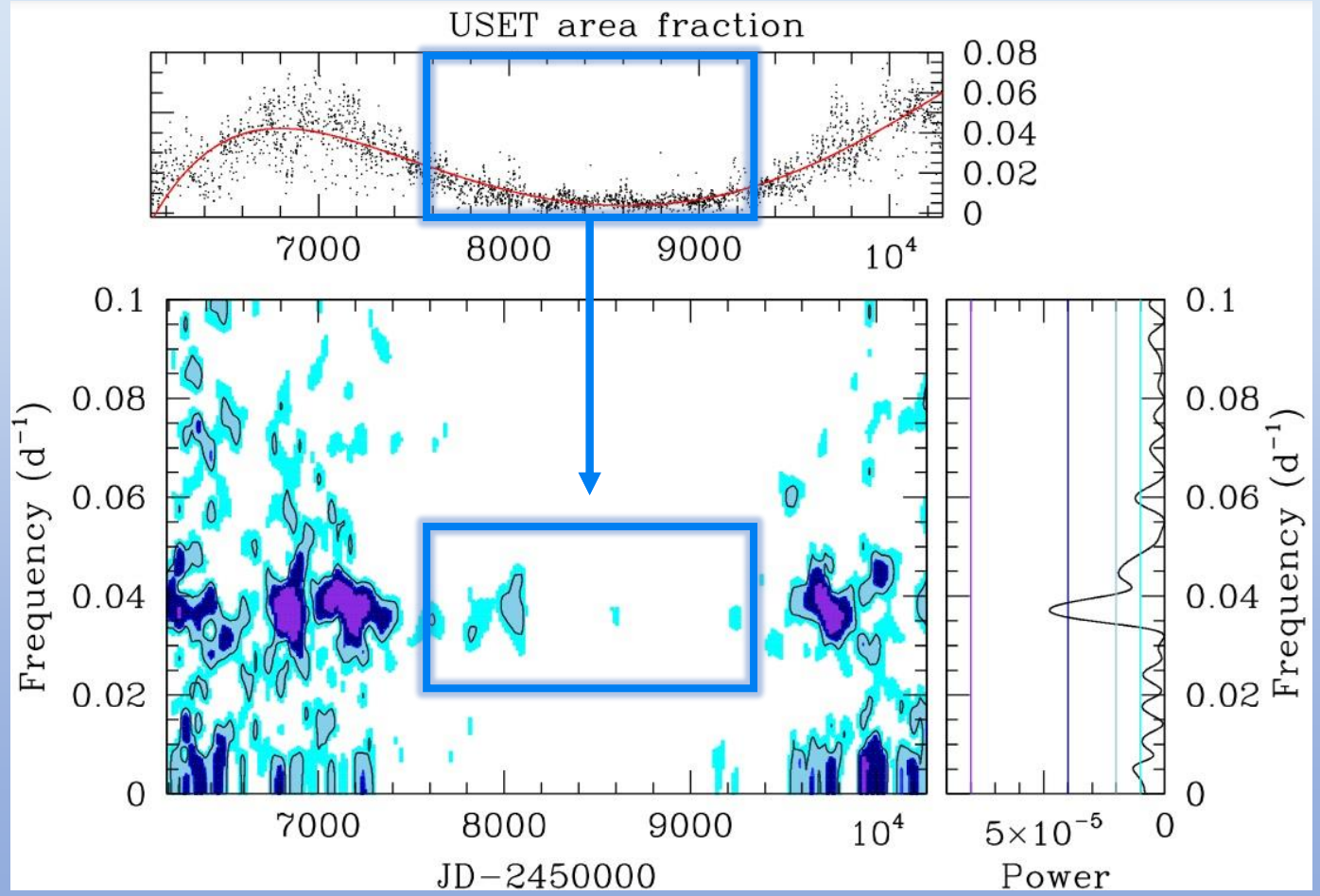

Vanden Broeck et al. 2024 (submitted)

***Conclusion :*** Solar rotation is present in area fraction time series

***Question :*** Variation with the solar cycle ?
Link with magnetic structures distribution ?

# 2. Periodic modulation

## *Time-frequency diagram*




Vanden Broeck et al. 2024 (submitted)

**Rotational modulation**

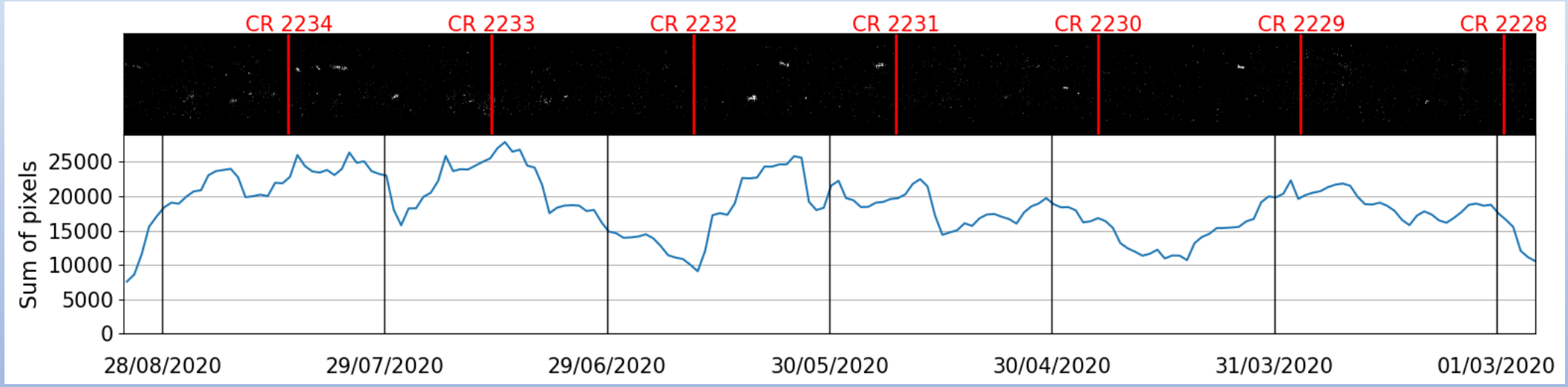
**Absent**

during the solar minimum

# 2. Periodic modulation

No modulation because :

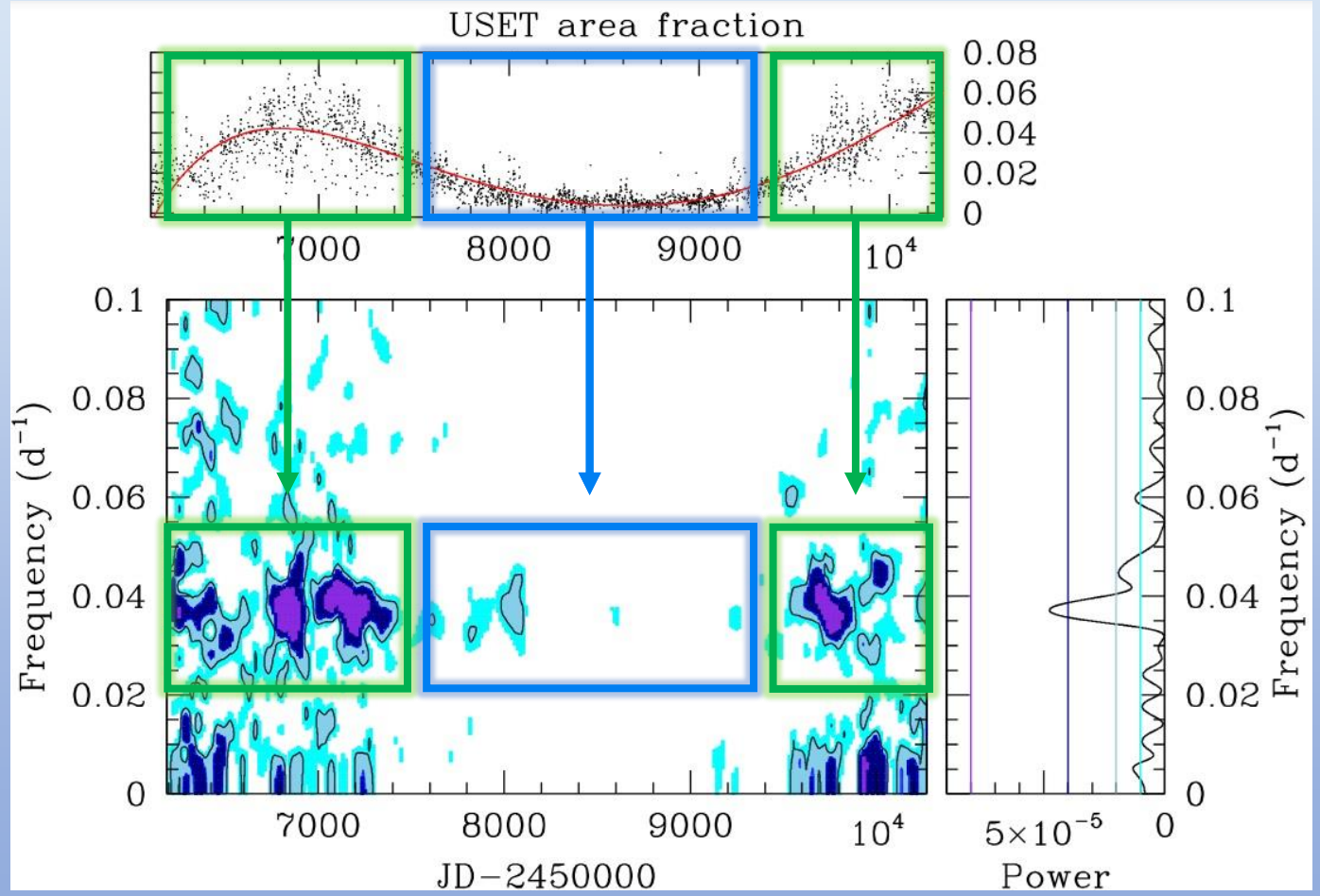
- Plage absent
- If plage present ⇒ it lasts for less than a rotation




Vanden Broeck et al. 2024 (submitted)

# 2. Periodic modulation

## *Time-frequency diagram*




Vanden Broeck et al. 2024 (submitted)

**Rotational modulation**

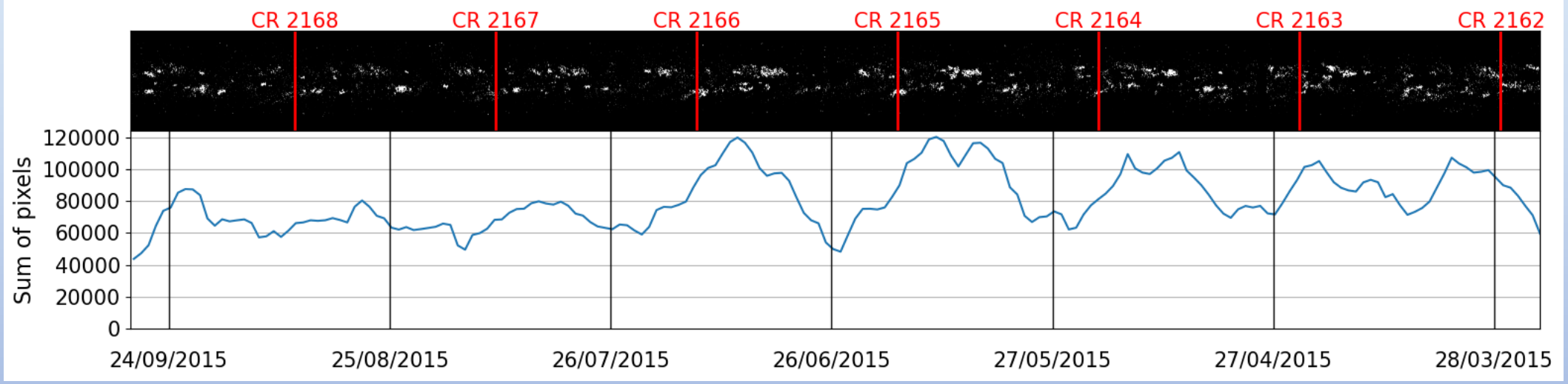
**Absent**
during the solar minimum

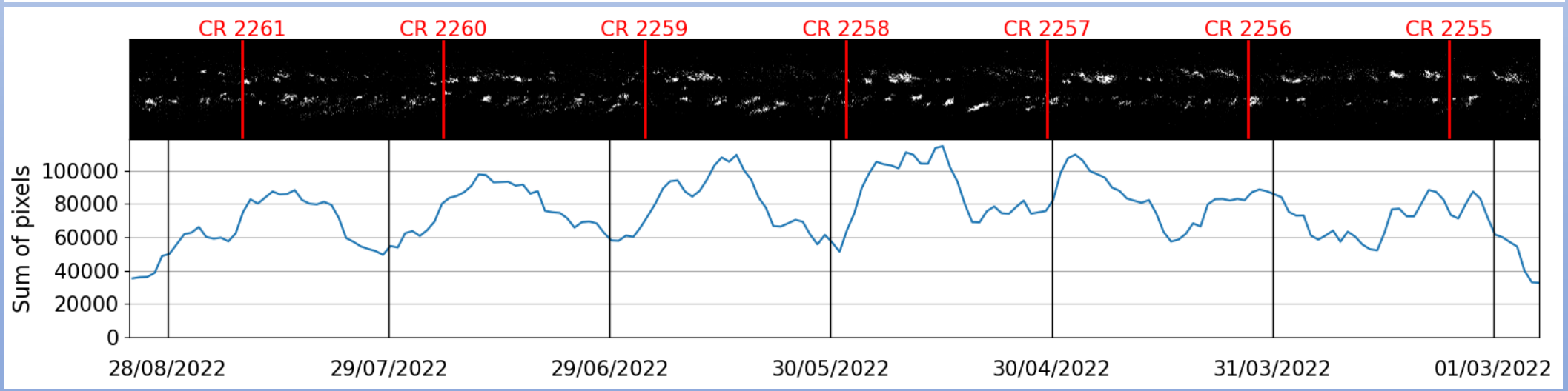
**Very prominent**
near the solar maxima

# 2. Periodic modulation

Succession of episodes with compact groups of plages and episodes with less activity.

→ Possible reason : some longitudes seem more favourable for emergence of magnetic flux, called “active longitudes”

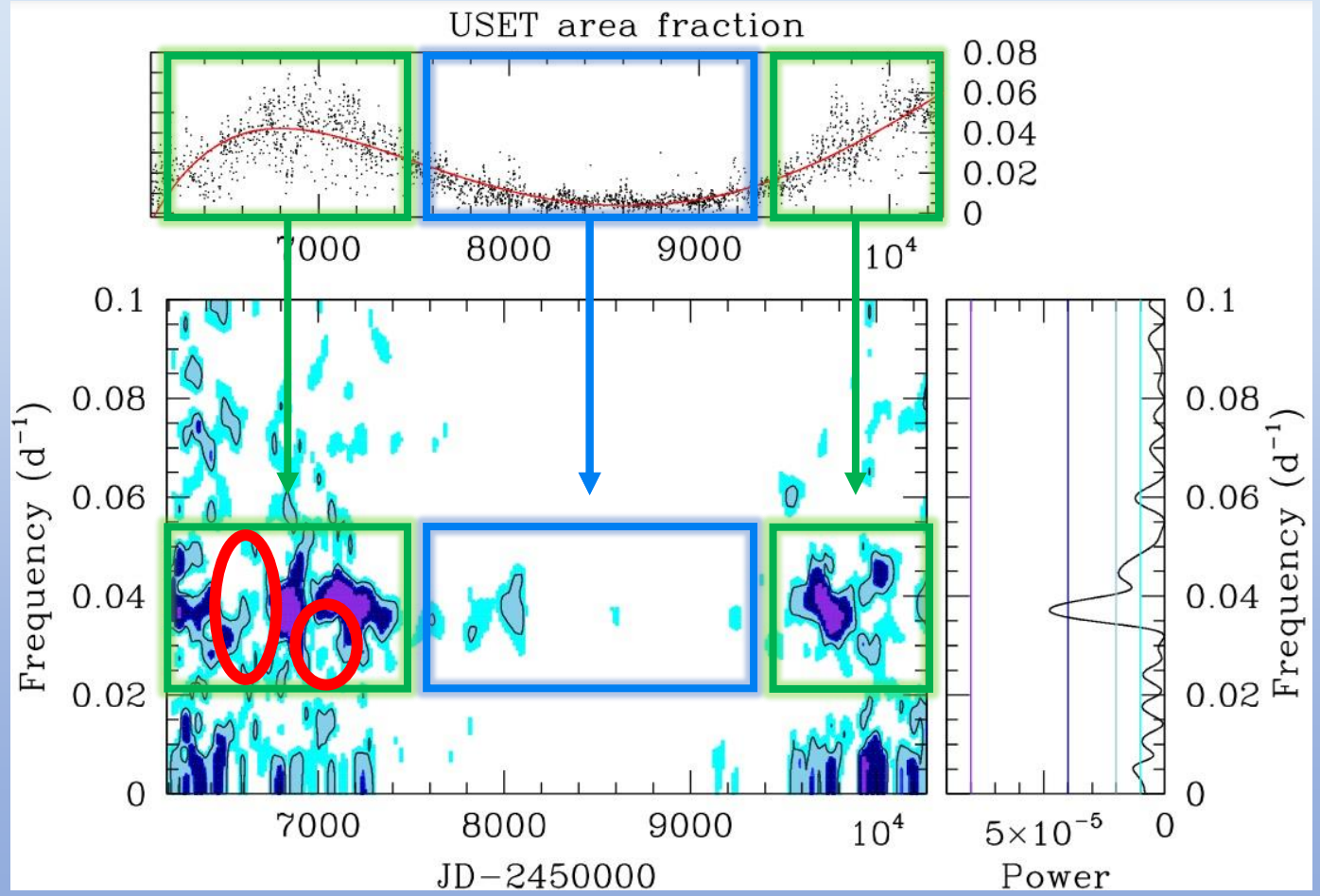



Vanden Broeck et al. 2024 (submitted)

# 2. Periodic modulation

## *Time-frequency diagram*




Vanden Broeck et al. 2024 (submitted)

**Rotational modulation**

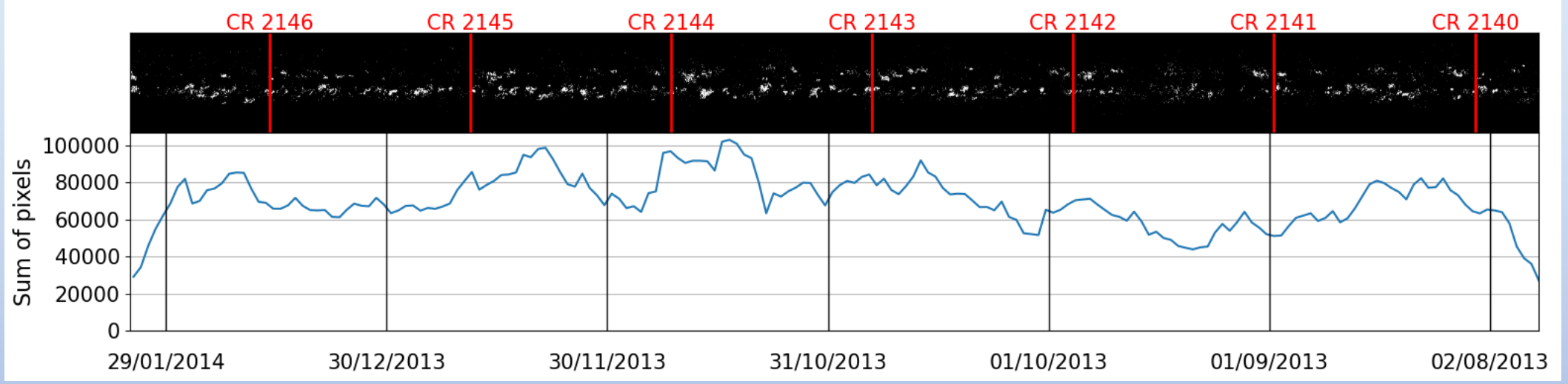
**Absent**
during the solar minimum

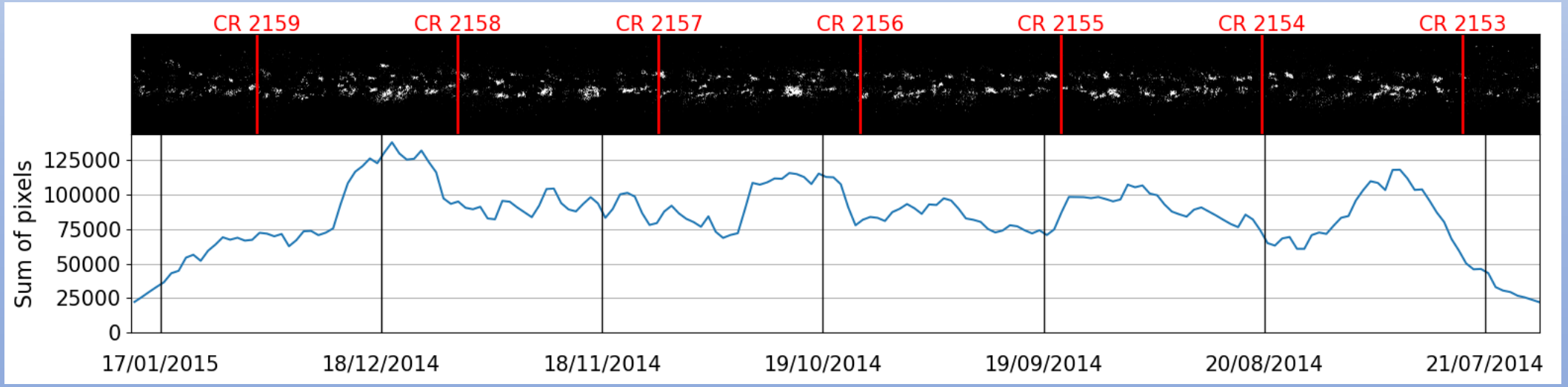
**Very prominent**
near the solar maxima

**Not clearly detected**
even near the solar maxima

# 2. Periodic modulation

No clear detection because distribution nearly uniform in longitude

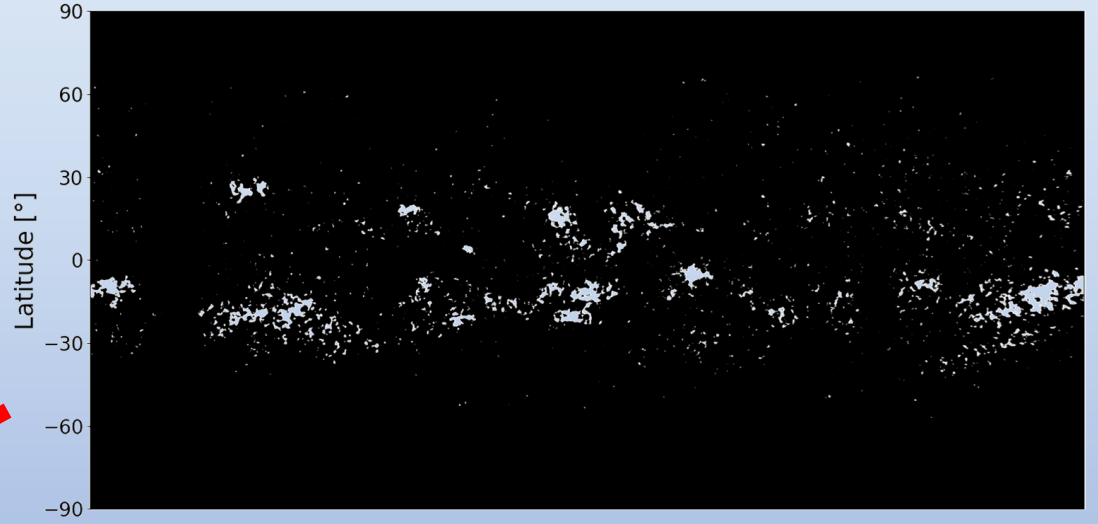


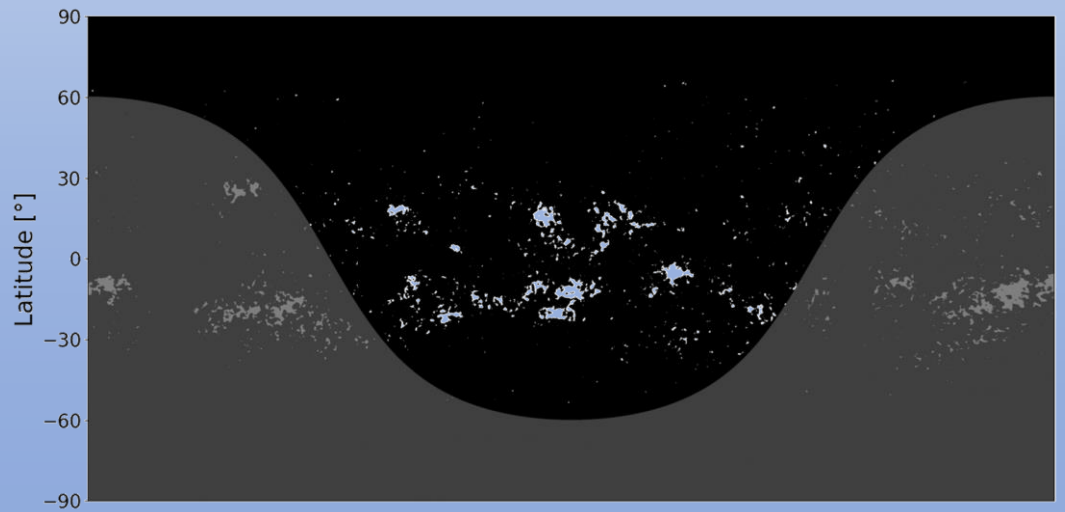



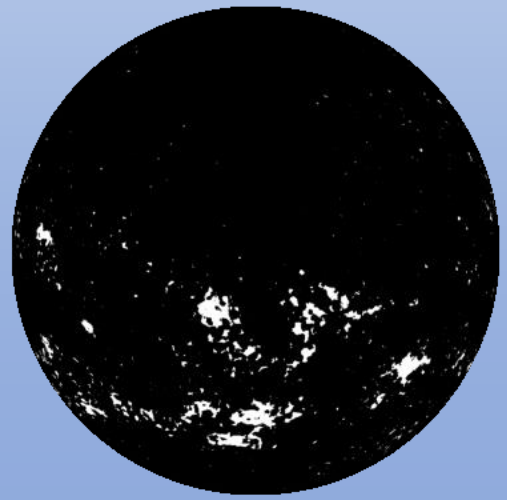

Vanden Broeck et al. 2024 (submitted)

# 3. Sun from different inclinations

## *3.1. Construction of inclinated solar images*

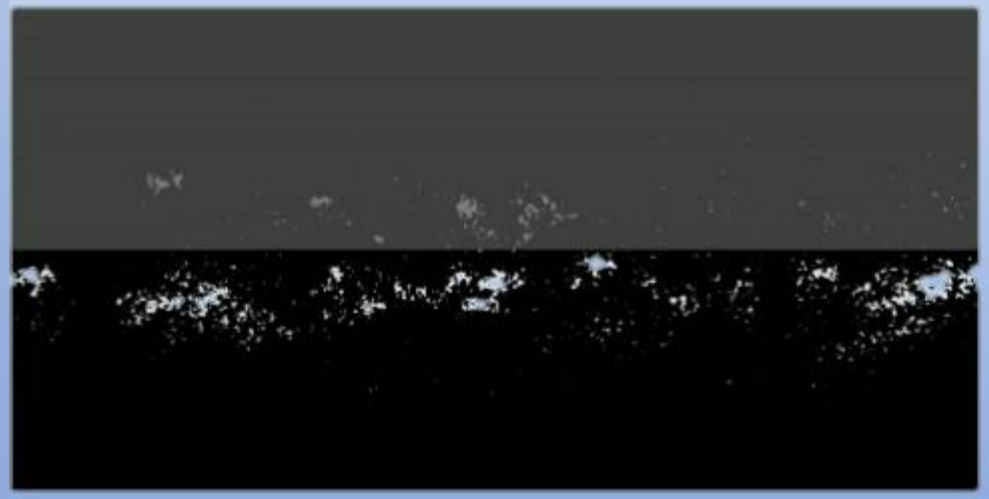


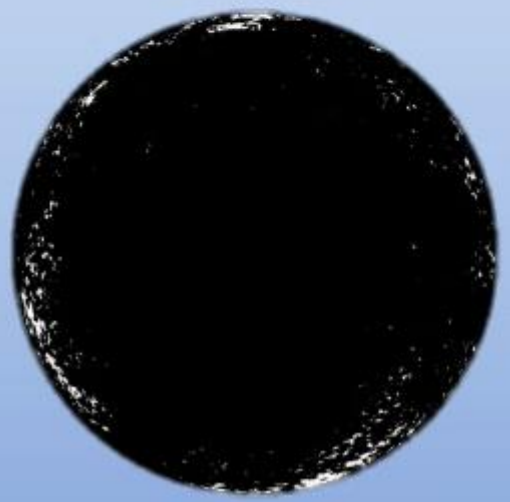



# 3. Sun from different inclinations

## *3.1. Construction of inclinated solar images*

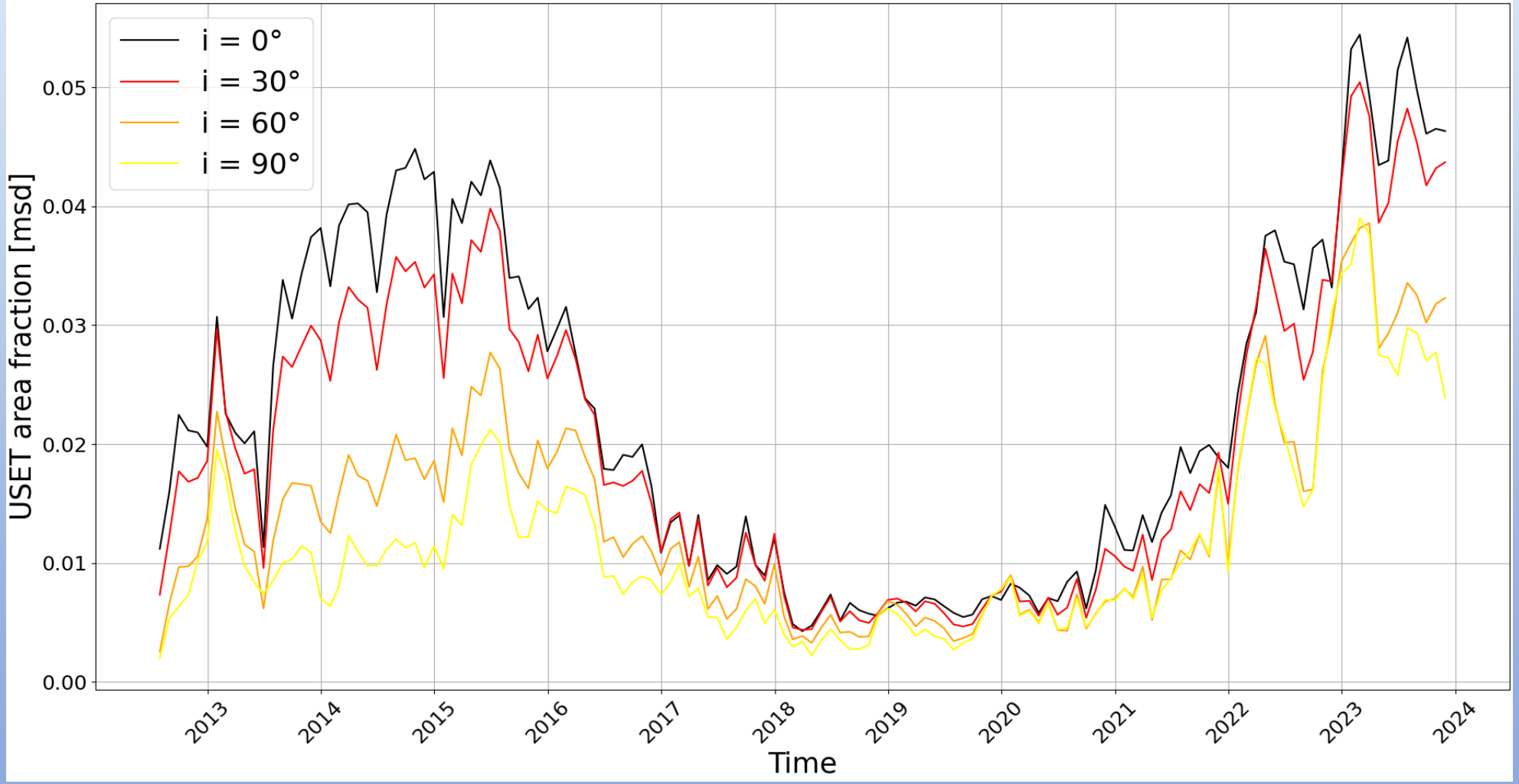





# 3. Sun from different inclinations

## *3.2. Effect of inclination on area fraction*

Temporal evolution of area fraction for solar Equator's view (0°) to North Pole view (90°)



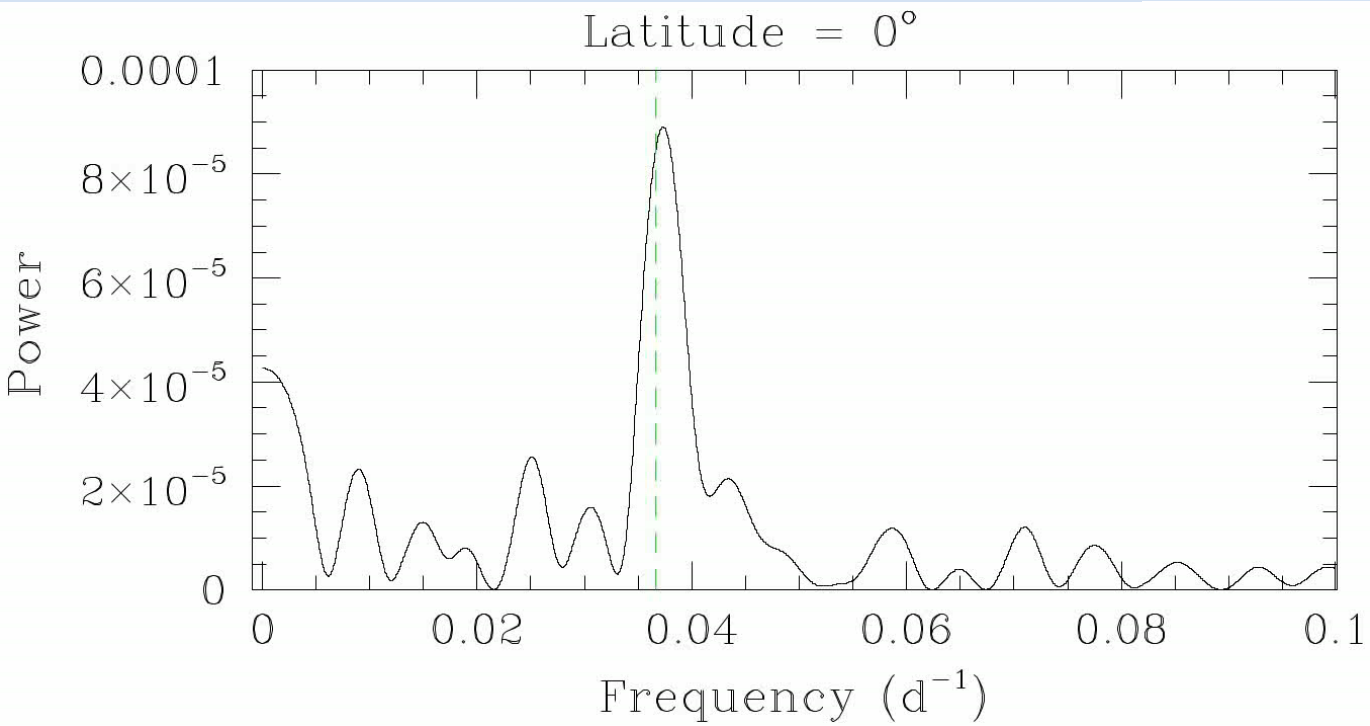

The more we observe from the Poles

The more the area fraction decreases

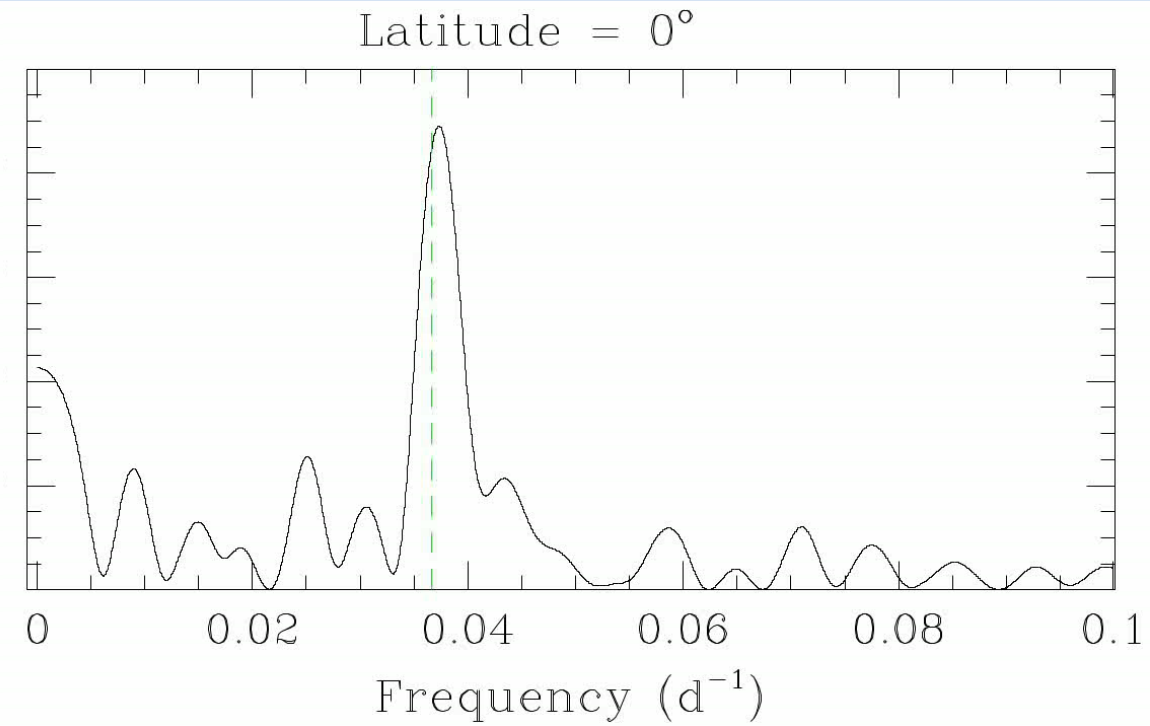
# 3. Sun from different inclinations

## *3.3. Effect of inclination on solar modulation*

**North hemisphere**



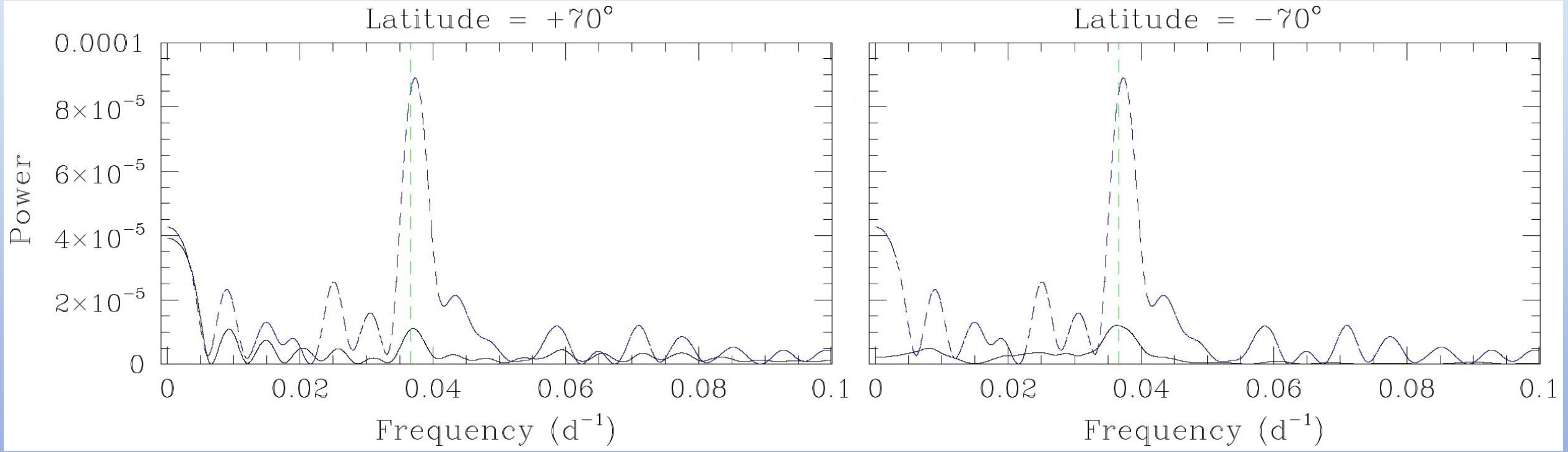

**South hemisphere**



# 3. Sun from different inclinations

## *3.3. Effect of inclination on solar modulation*

**North hemisphere** **South hemisphere**




⇒ Rotational modulation detected until an **inclination of 70°**

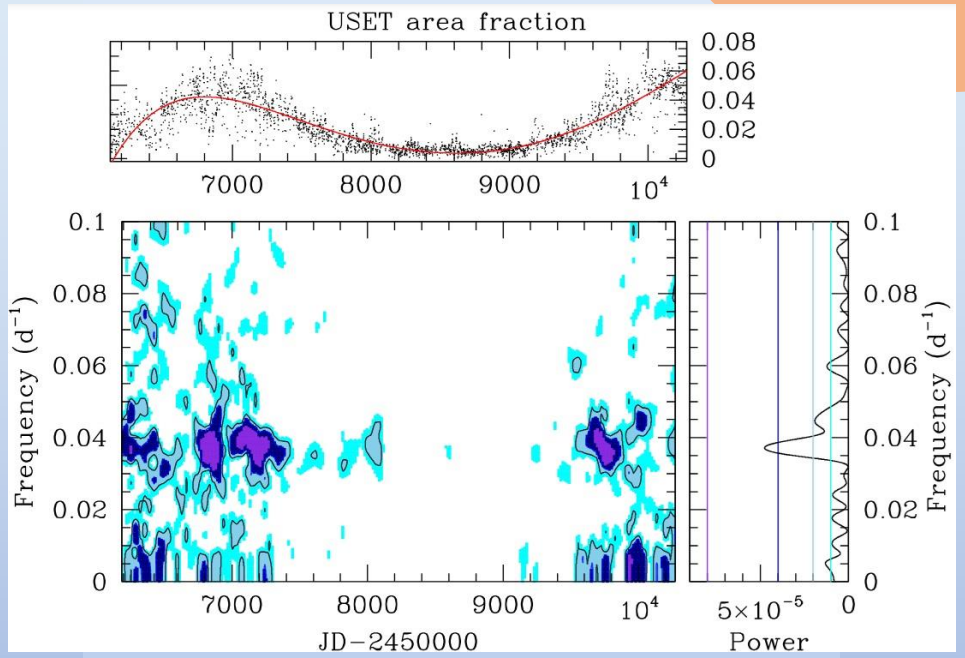
⇒ Assomption : Solar-type stars with rotation axis inclinated by > 70° → rotation period not visible

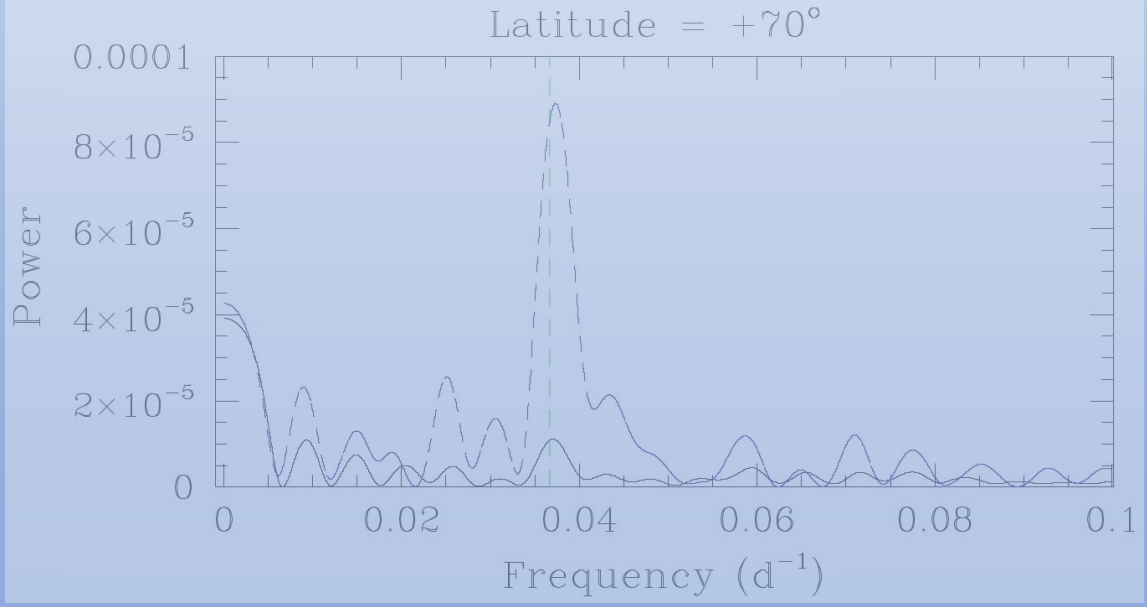
# 4. Summary

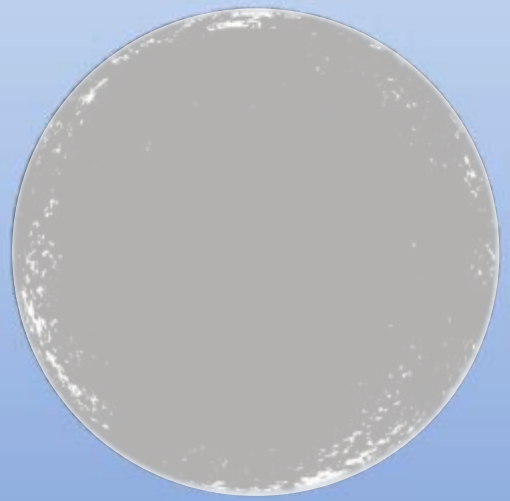
- **Detection of rotation period related to asymmetry in longitudinal distribution of bright structures**

- Solar images reconstructed from every angles of view

- Solar rotation period detected until 70° of inclination
  → application for solar-type stars



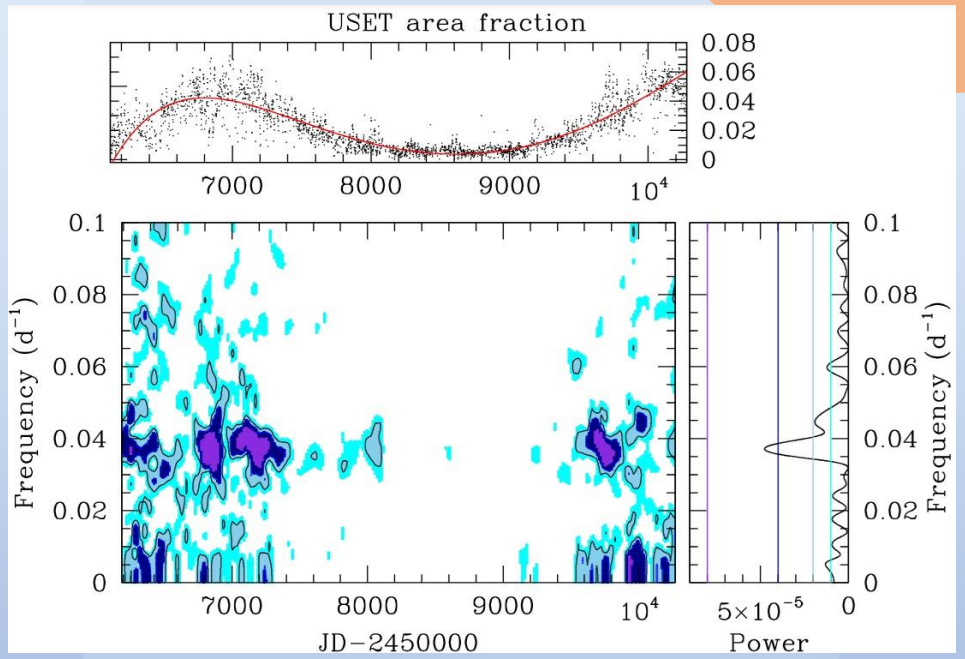



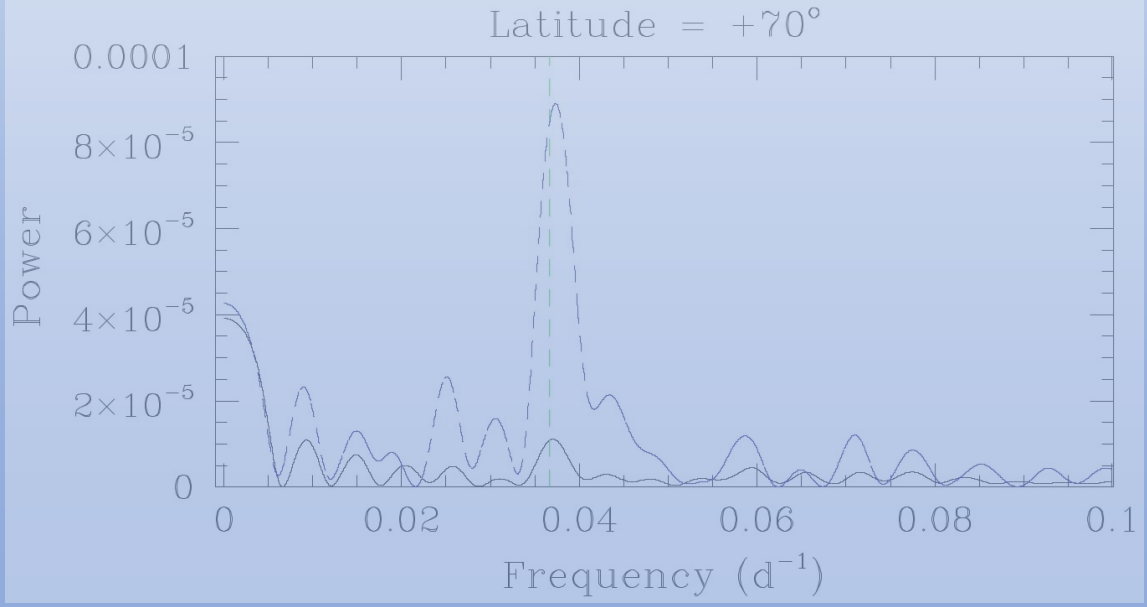
# 4. Summary

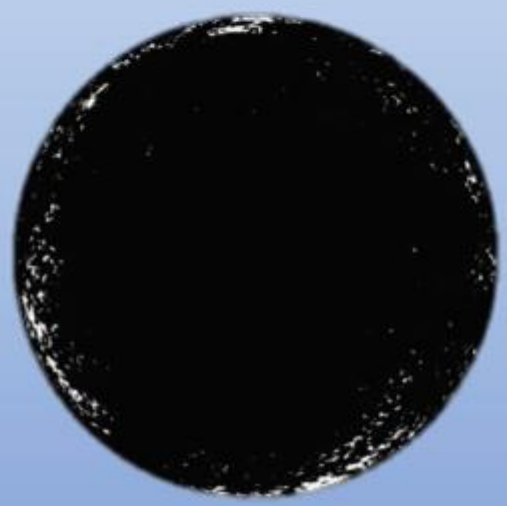
- **Detection of rotation period related to asymmetry in longitudinal distribution of bright structures**

- **Solar images reconstructed from every angle of view**

- Solar rotation period detected until 70° of inclination
  → application for solar-type stars



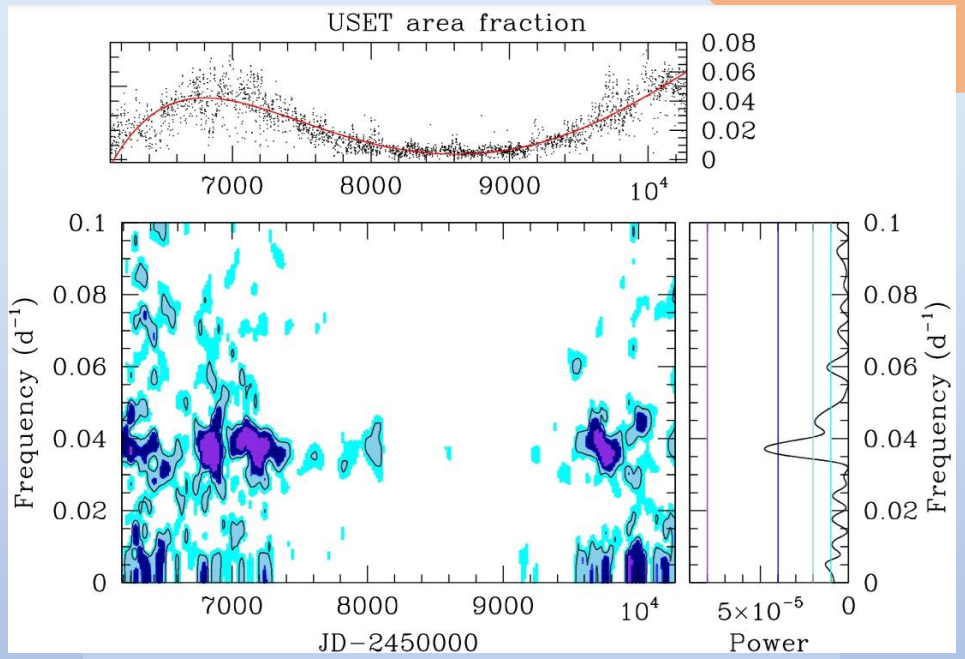



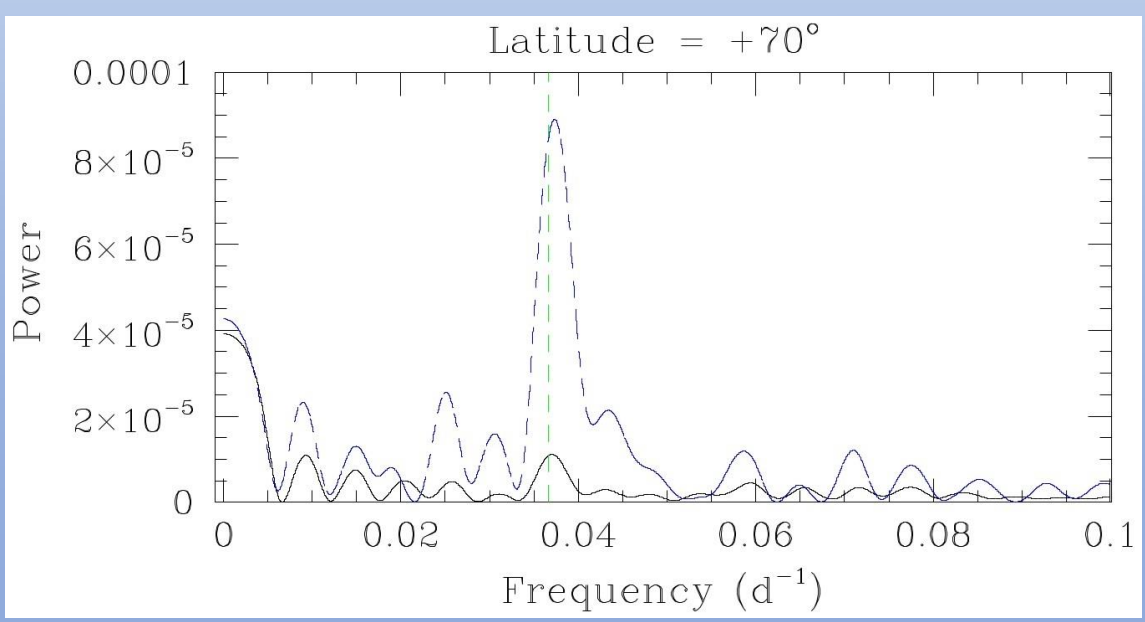
# 4. Summary

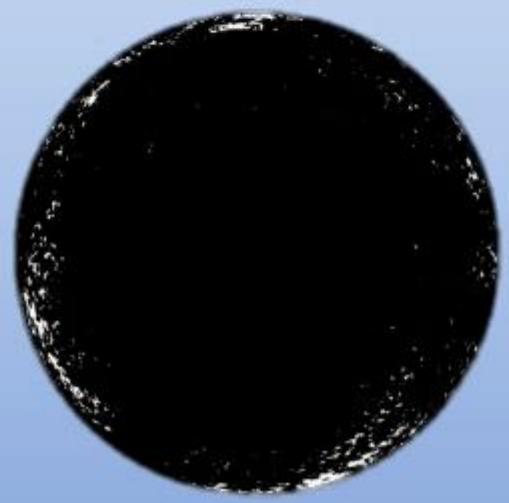
- **Detection of rotation period related to asymmetry in longitudinal distribution of bright structures**

- **Solar images reconstructed from every angles of view**

- **Solar rotation period detected until 70° of inclination**
  **→ application for solar-type stars**



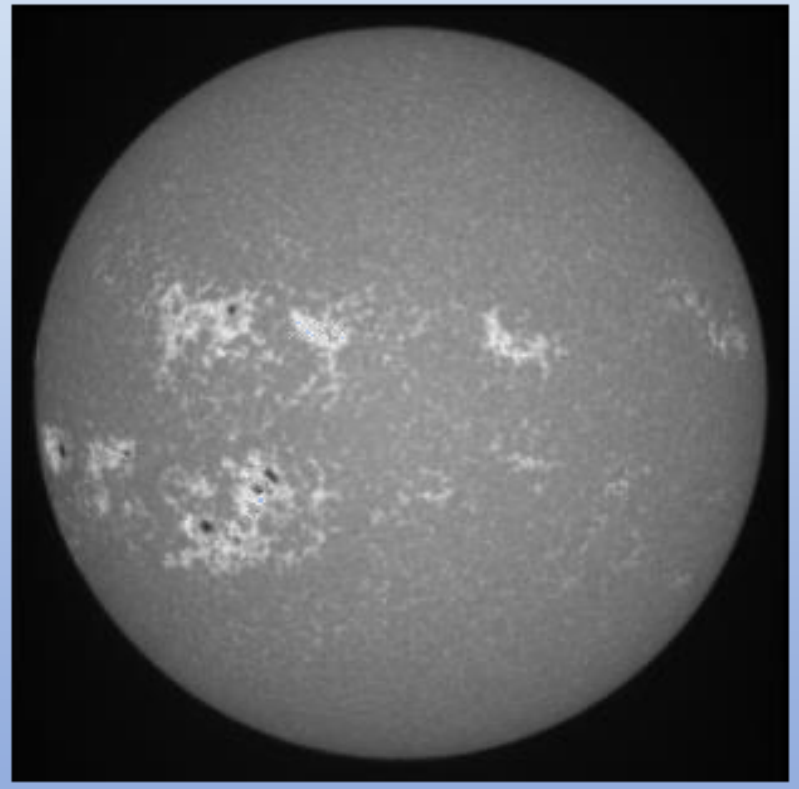



# *Thank you for your attention !*

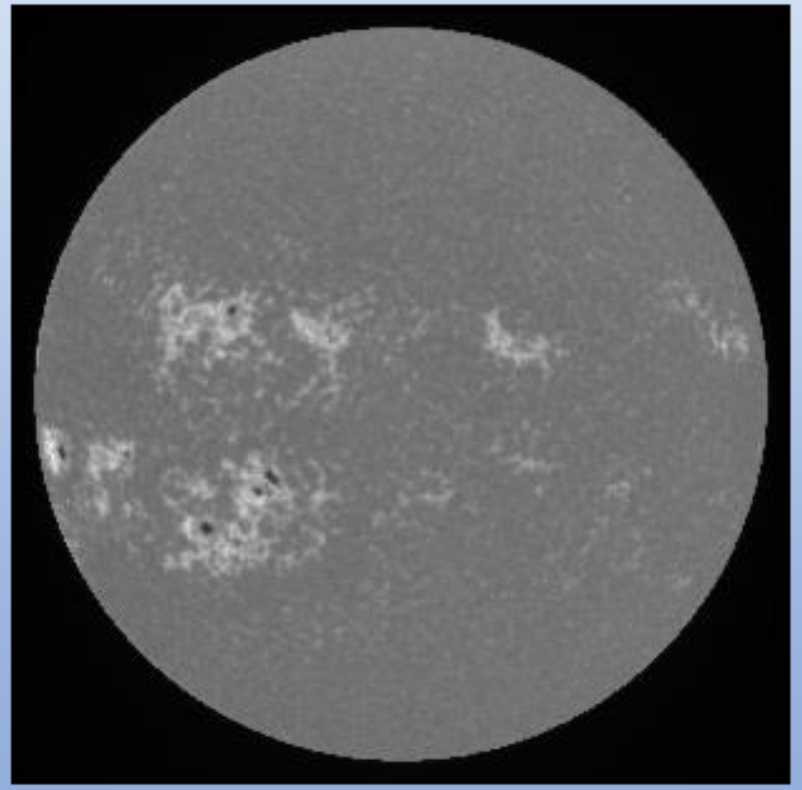
# Structures segmentation

*Limb darkening correction*



***Method :***

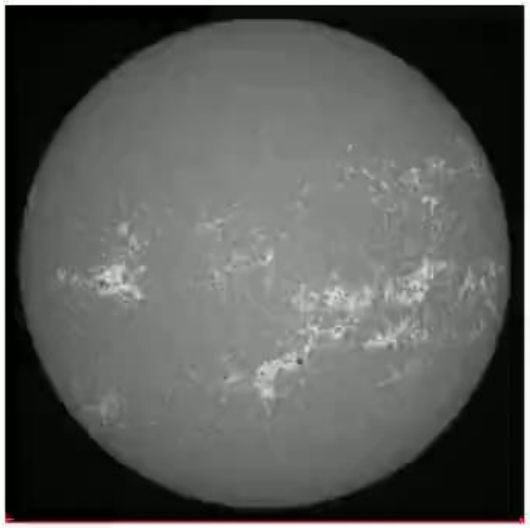
1. Fit the intensity profile
2. Create a mask based on the fit
3. Divide the matrix by the mask
4. Remove the bright plages
5. Repeat the steps 1. 2. & 3.

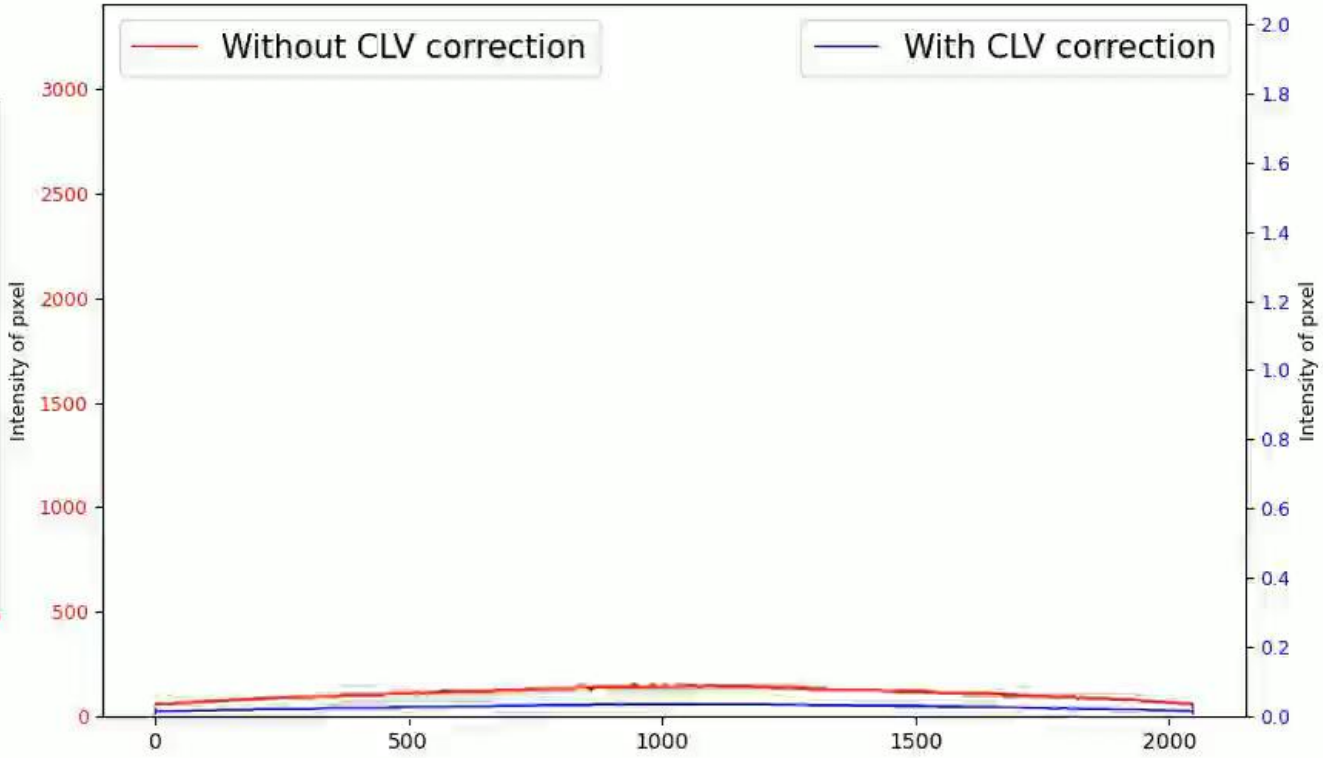


# Structures segmentation

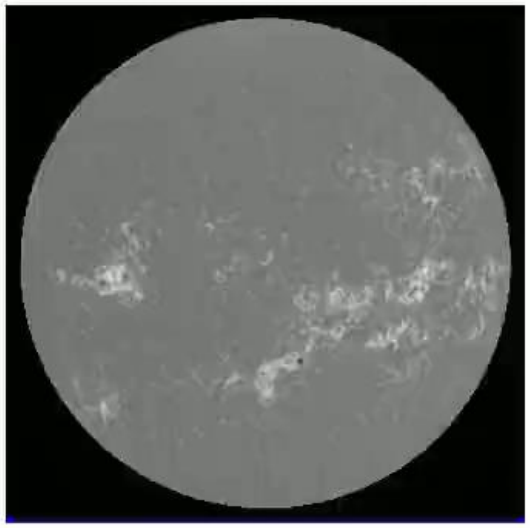
## *Limb darkening correction*

Without CLV correction



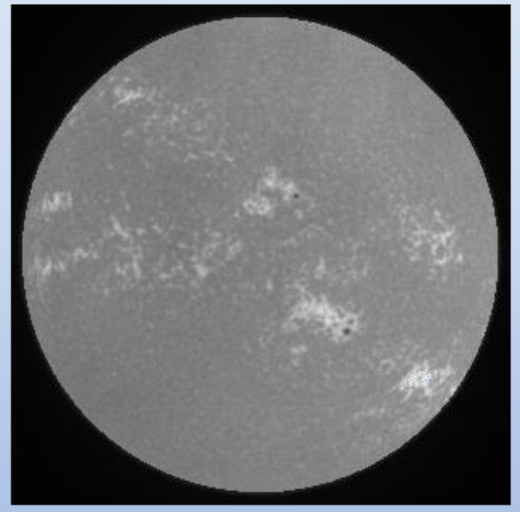



With CLV correction



# Structures segmentation

## *Segmentation method*



***Assumptions :*** • Gaussian background brightness distribution

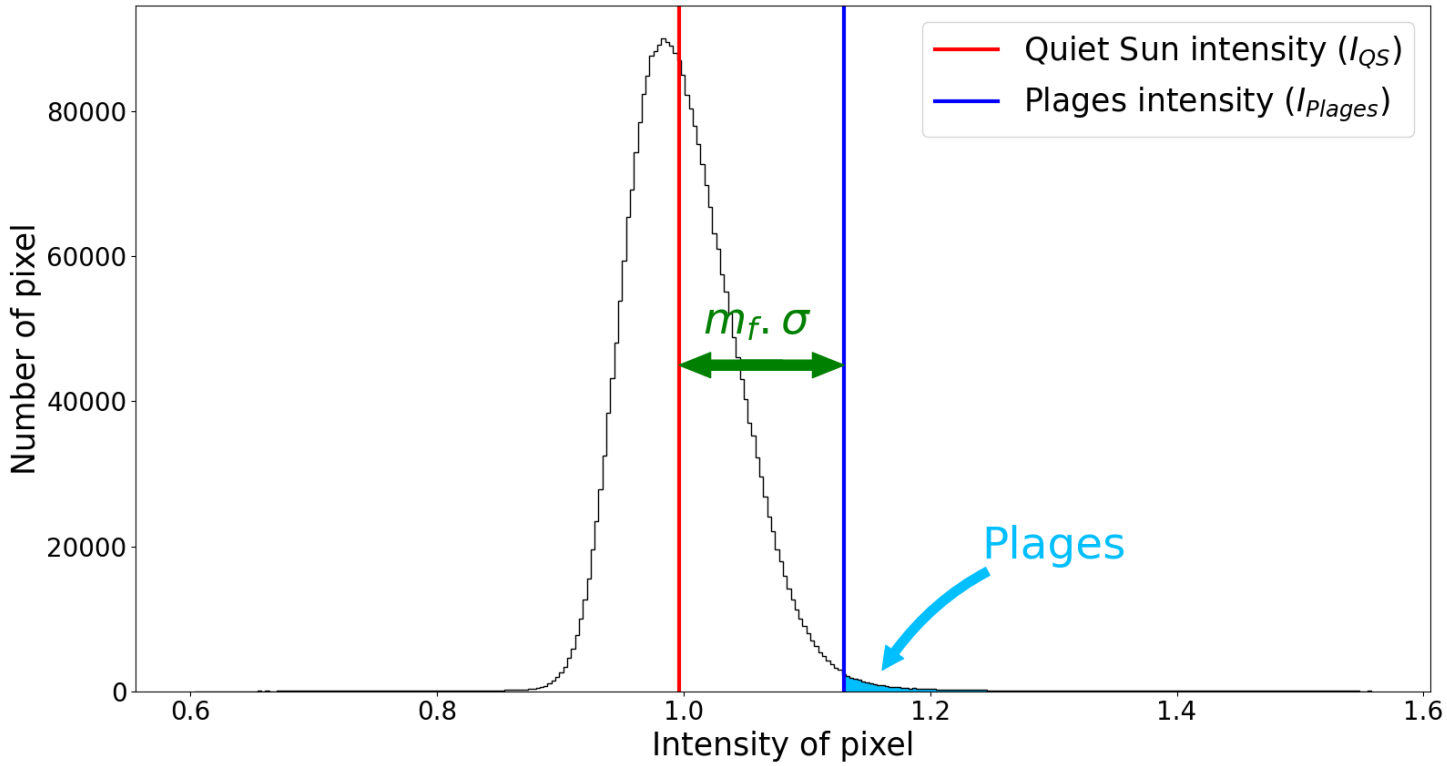
• Non-gaussian contribution to the wings (sunspots and plages)

Quiet Sun doesn't vary in time ⇒ Threshold non affected by the solar activity

- Compute the **QS intensity** : $I_{QS}$
- Compute the **standard deviation** $\sigma$ with an empirical **multiplicative factor** $m_f$

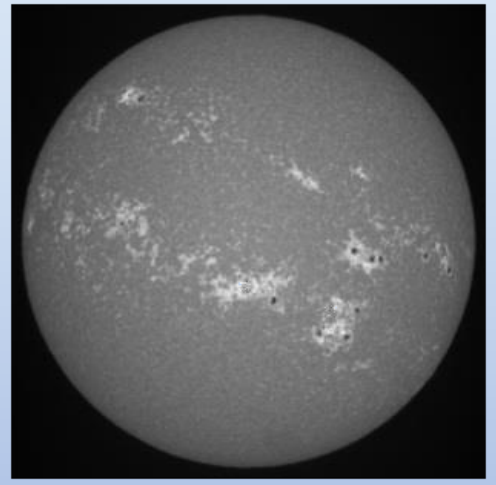
**Plages intensity :**

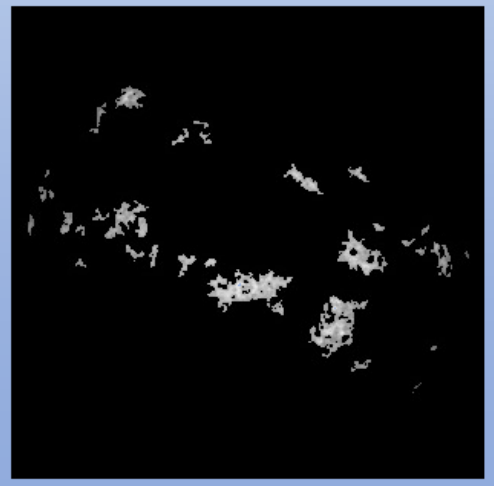
$$I_{Plages} \geq I_{QS} + m_f \, . \sigma$$



# Structures segmentation

## *Segmentation method*





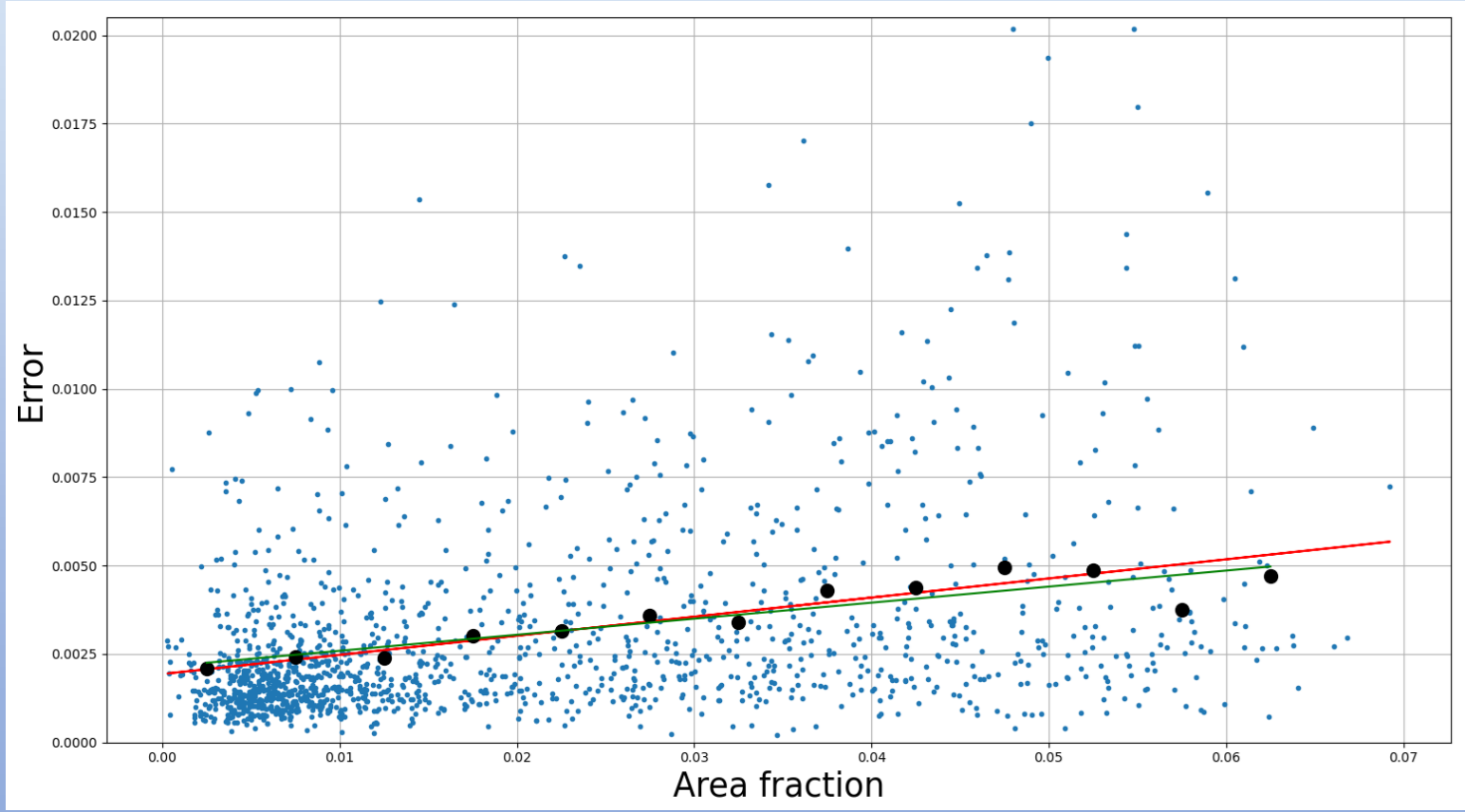
1. Compute the mean intensity $\bar{I}$ and the standard deviation $\sigma_I$ over the disk
2. Identify pixels with intensity within $\bar{I} \pm k\sigma_I$ (for $k$ in the range $0.5 - 3.0$)
3. Recalculate mean intensity and standard deviation for those intervals
4. The minimum of the calculated mean intensity $\bar{I}_{min}$ best represents the QS regions, $I_{QS}$
5. Intensity threshold to identify the plages is : $\boxed{I_{plages} \geq I_{QS} + m_f \, . \sigma_{min}}$ ($m_f$ is an empirical multiplicative factor)

# Structures segmentation

*Uncertainty calculations*

**How ?** Using the full dataset of ~ 23.000 images in the USET database

- Compute the area fraction for each image
- Compute the standard deviation for each day
- Remove the outliers
- Fit the data (red curve)
- Bin data by step of 0.25 (black dots)
- Fit the data (green curve)




⇒ **Error proportional to the area**