ROYAL OBSERVATORY OF BELGIUM

LIÈGE université

Comparison of the magnetic structures in full-disk solar Ca II K images and Sun-as-a-star S-Index

Grégory VANDEN BROECK

Royal Observatory of Belgium
Supervisors :

Frédéric CLETTE
Sabrina BECHET

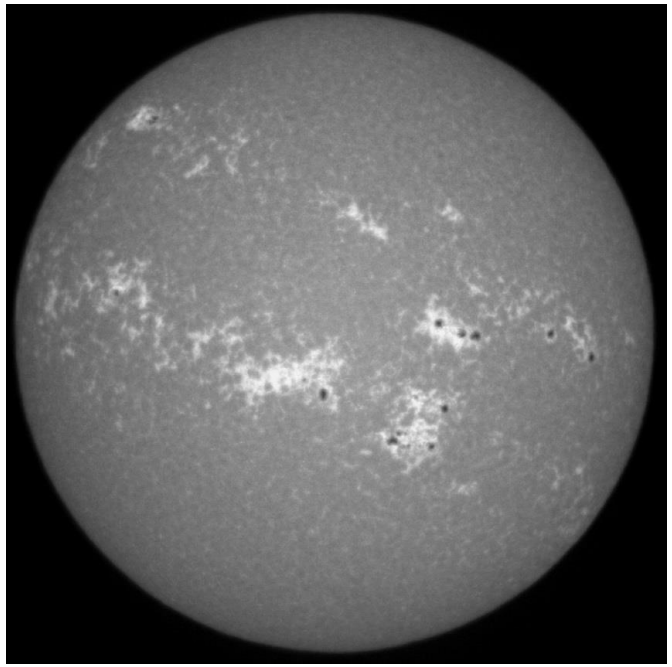
University of Liège
Supervisor :

Gregor RAUW

IUGG, Berlin
July 13, 2023

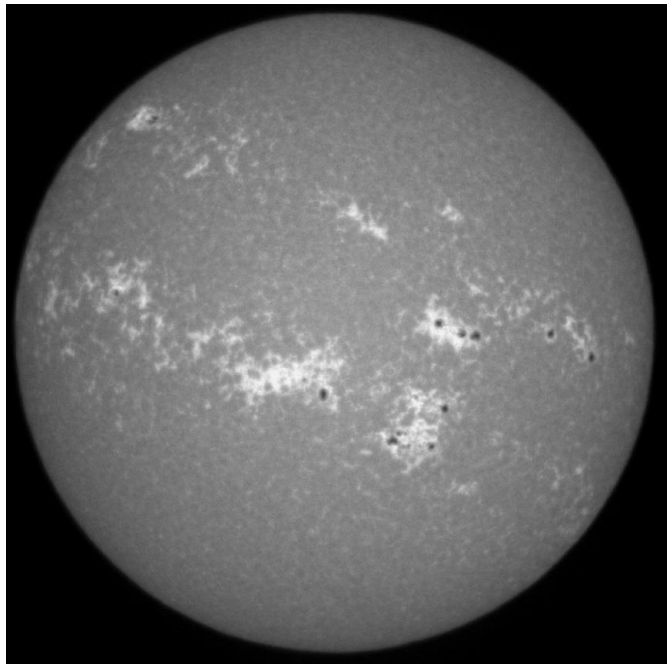
1. Introduction

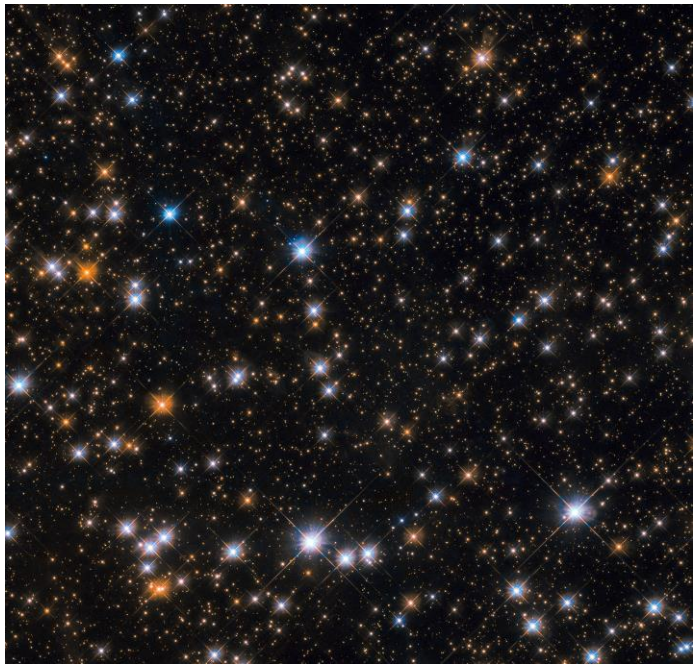
Aim : - Better understand the evolution of solar magnetic structures



1. Introduction

Aim : - Better understand the evolution of solar magnetic structures
- Compare solar magnetic activity with sun-like stars magnetic activity





https://www.nasa.gov/image-feature/goddard/2019/hubble-spots-flock-of-cosmic-ducks

Plages on the Sun

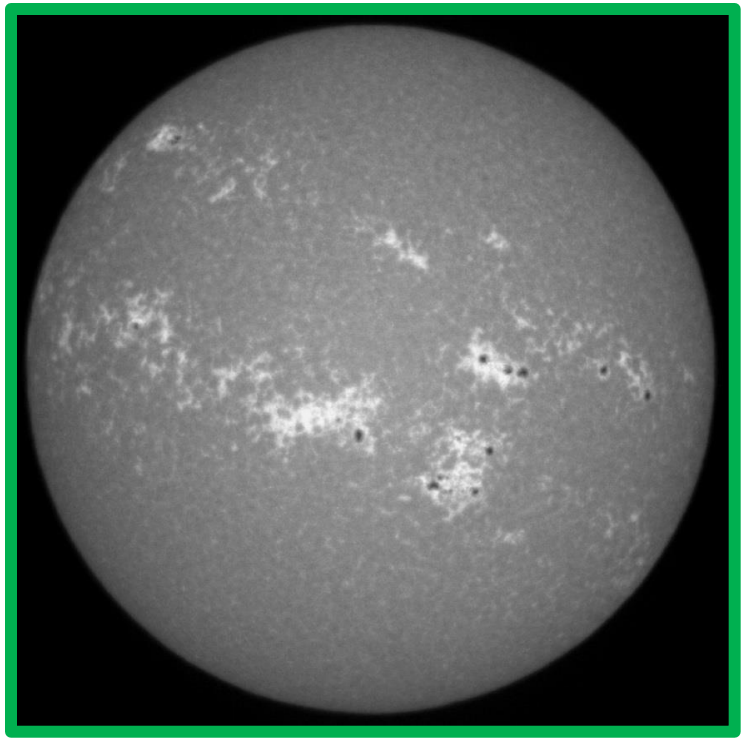
???

Whole disk spectrum of sun-like stars

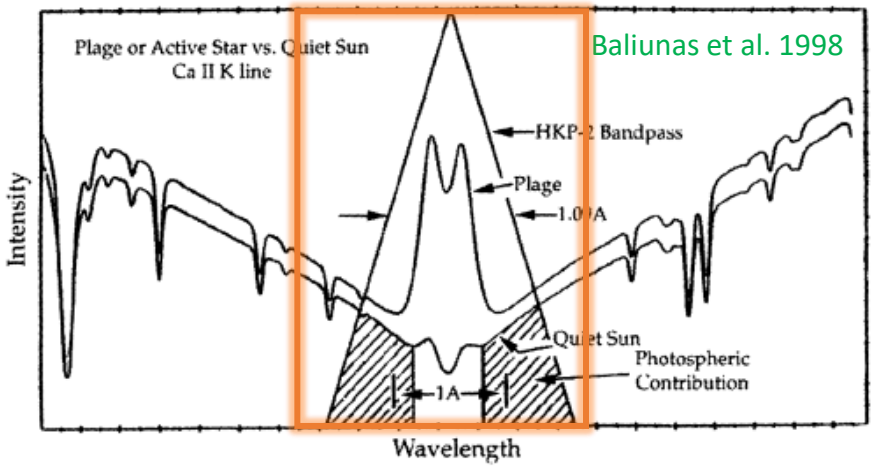
1. Introduction

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

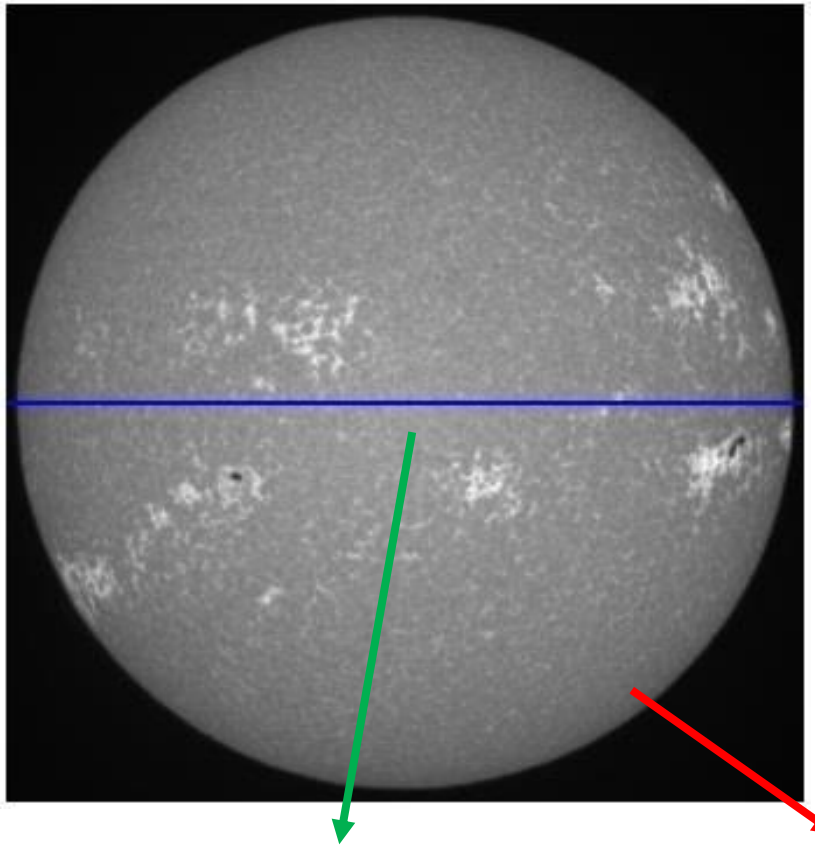
Filter bandpass : 2.7 Å

Dataset : ~ 21000 Ca II K images since July 2012

After data sorting → **2217 images**

2. Plage segmentation

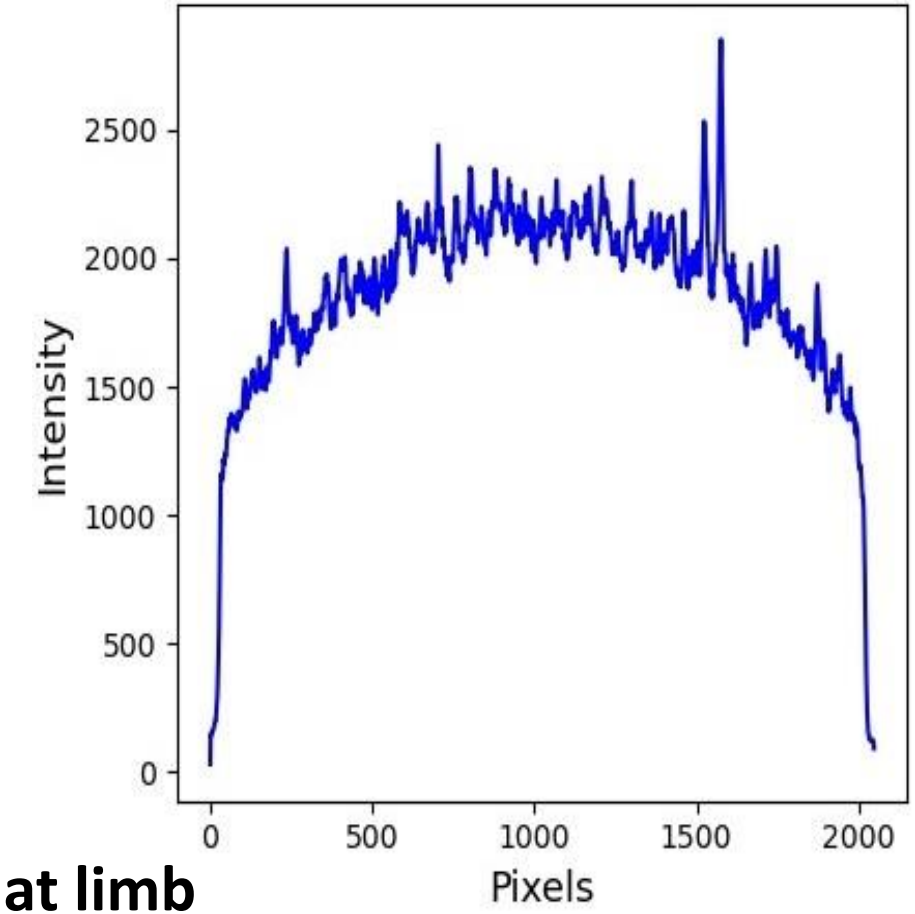
1) Limb darkening or CLV correction



Brighter at center

Darker at limb

Intensity profile along the blue line



Intensity decreases from center to limb

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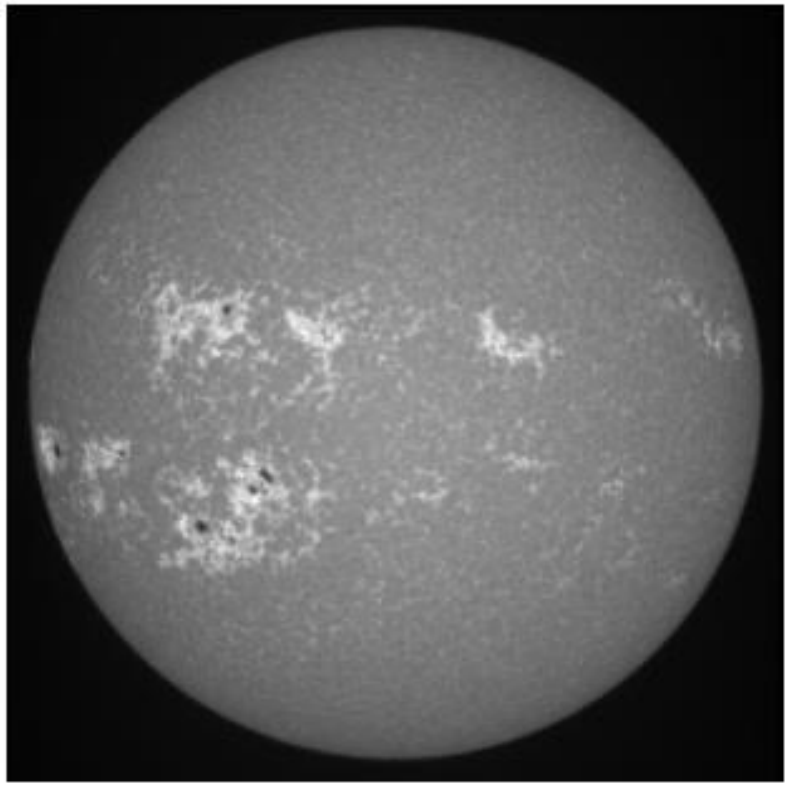
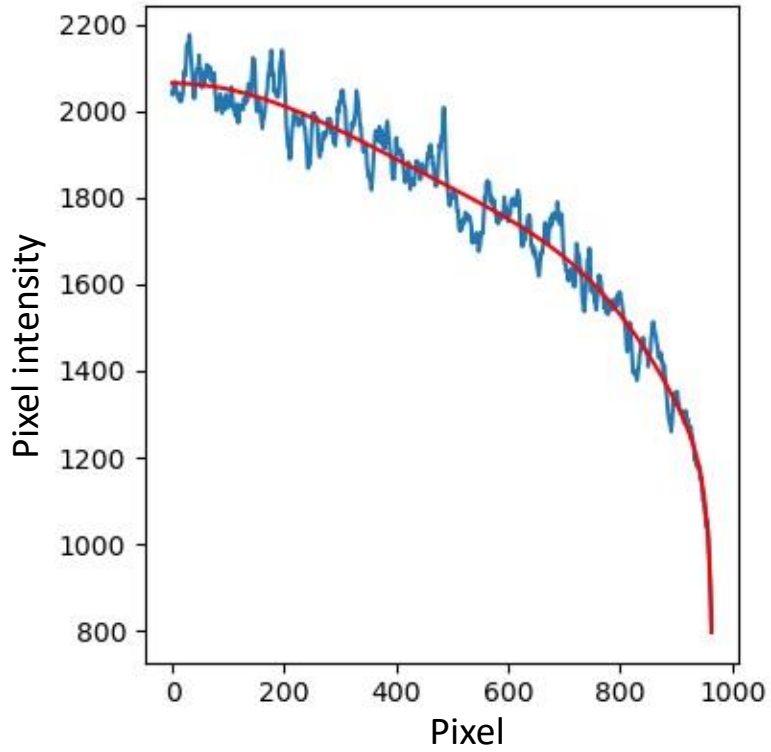


Method :

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.



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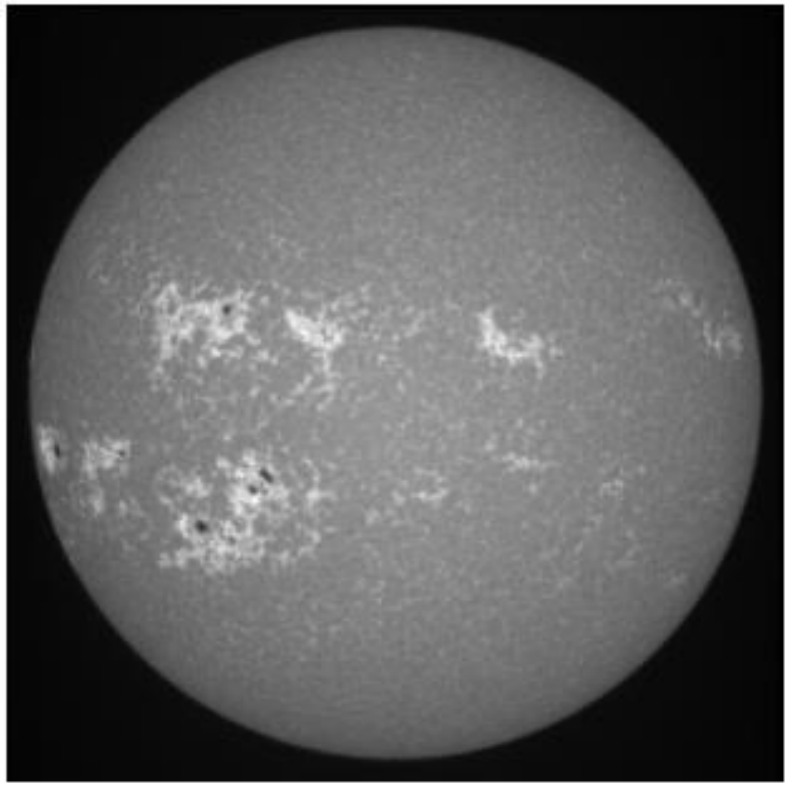

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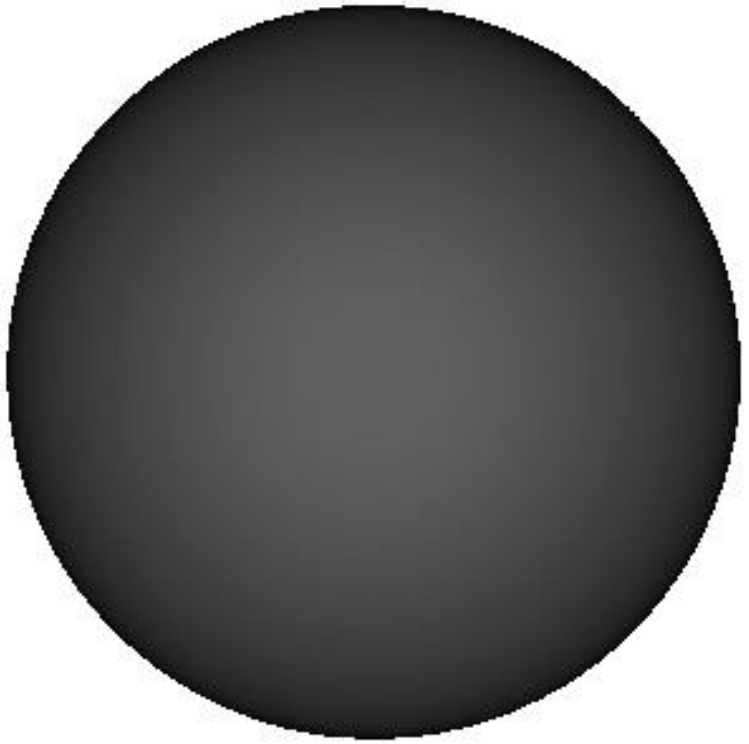

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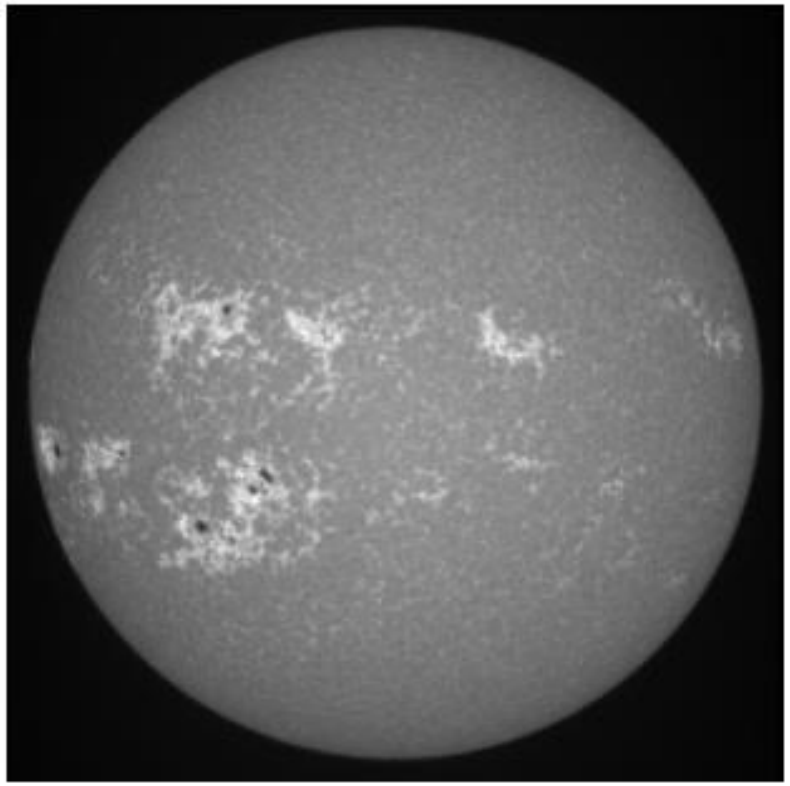

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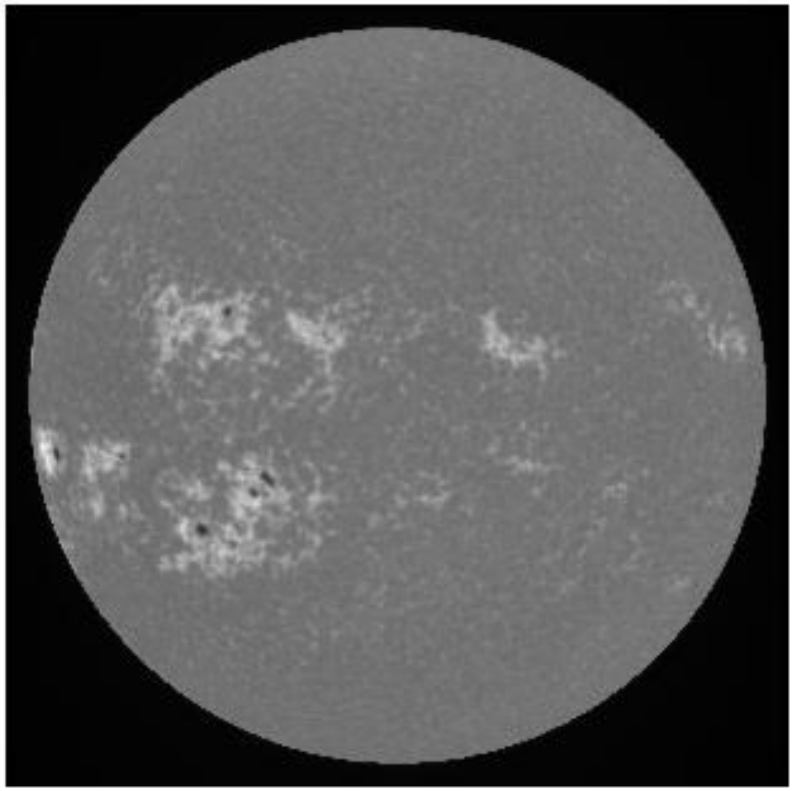

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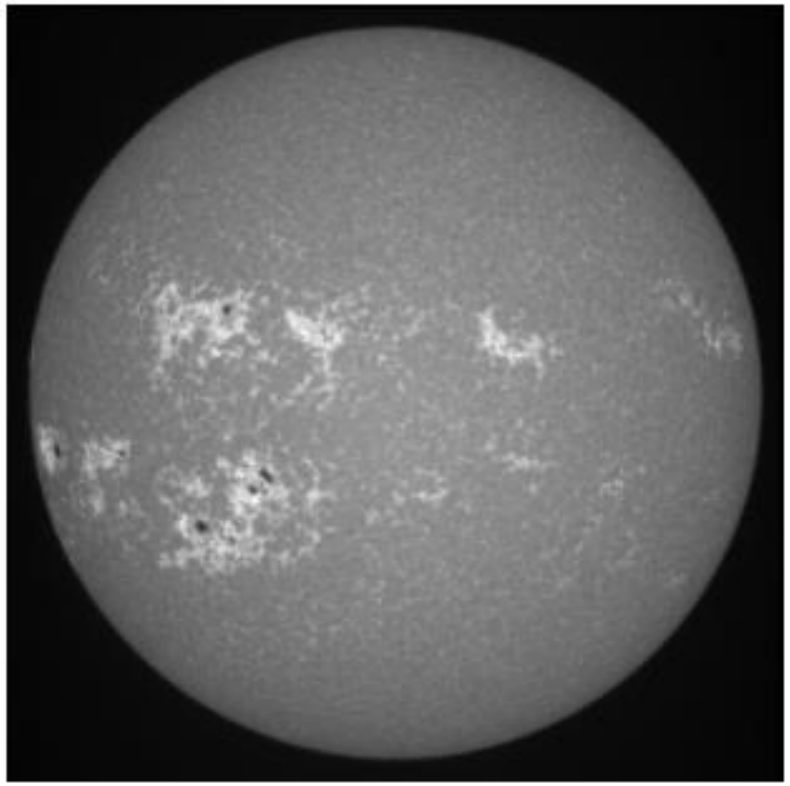

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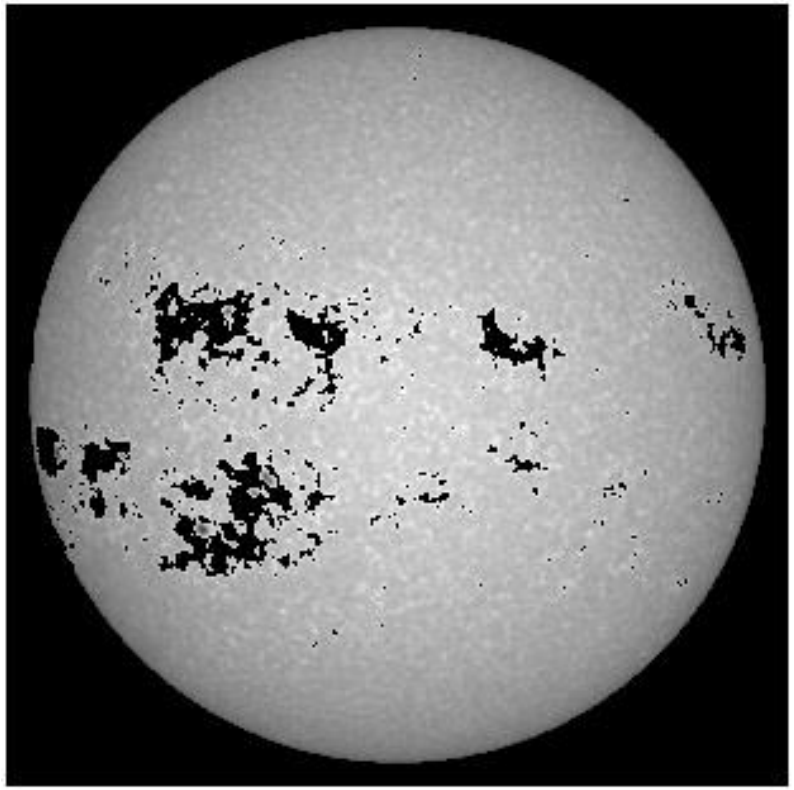

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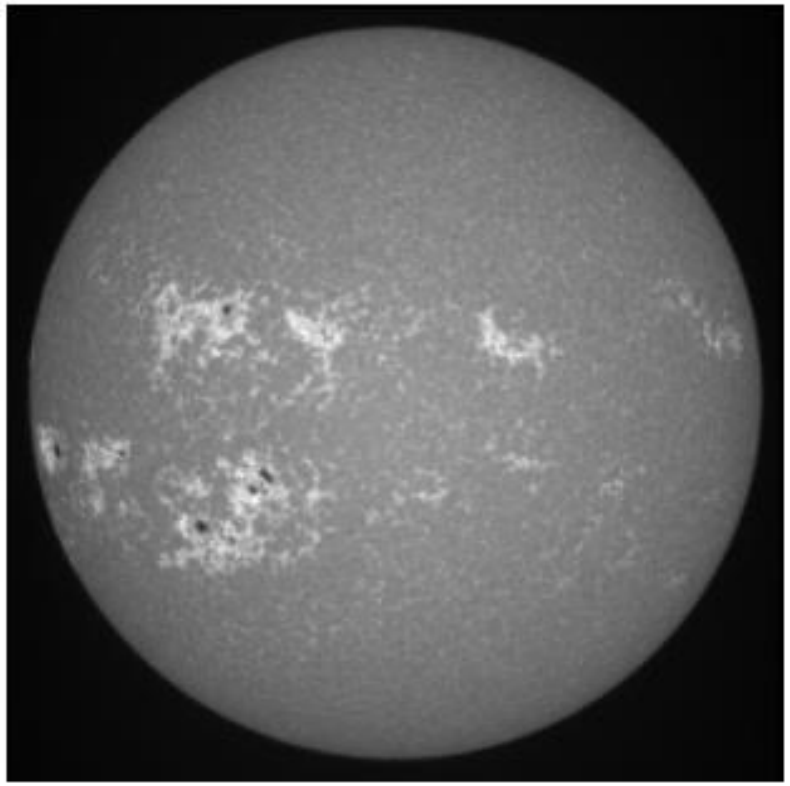

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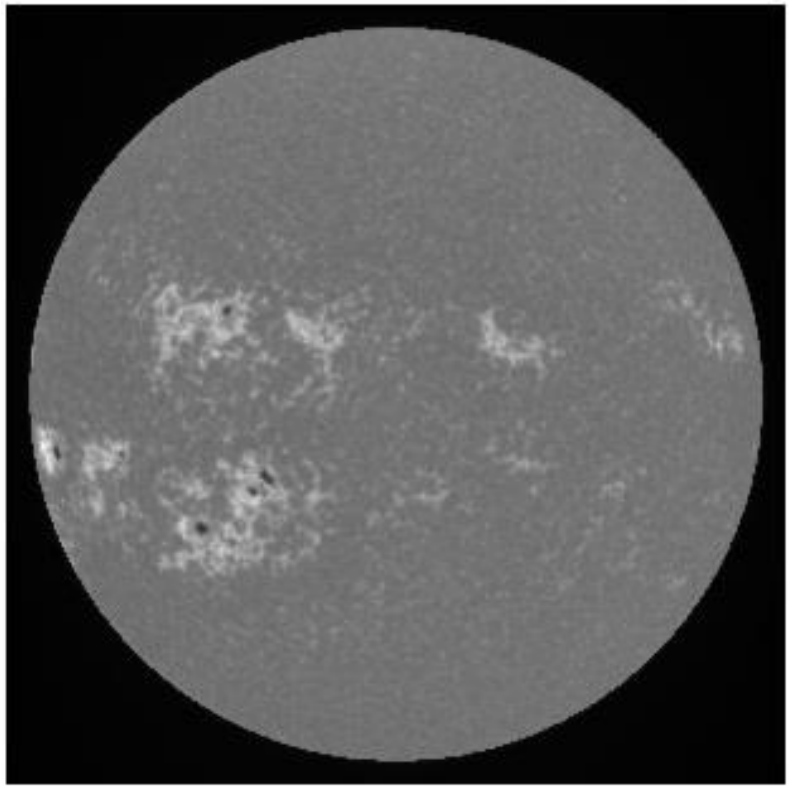

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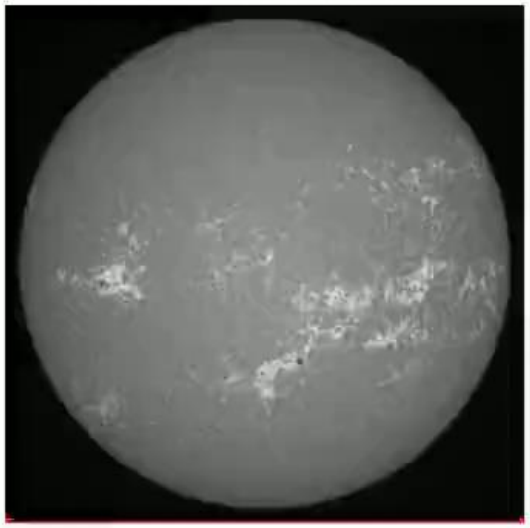
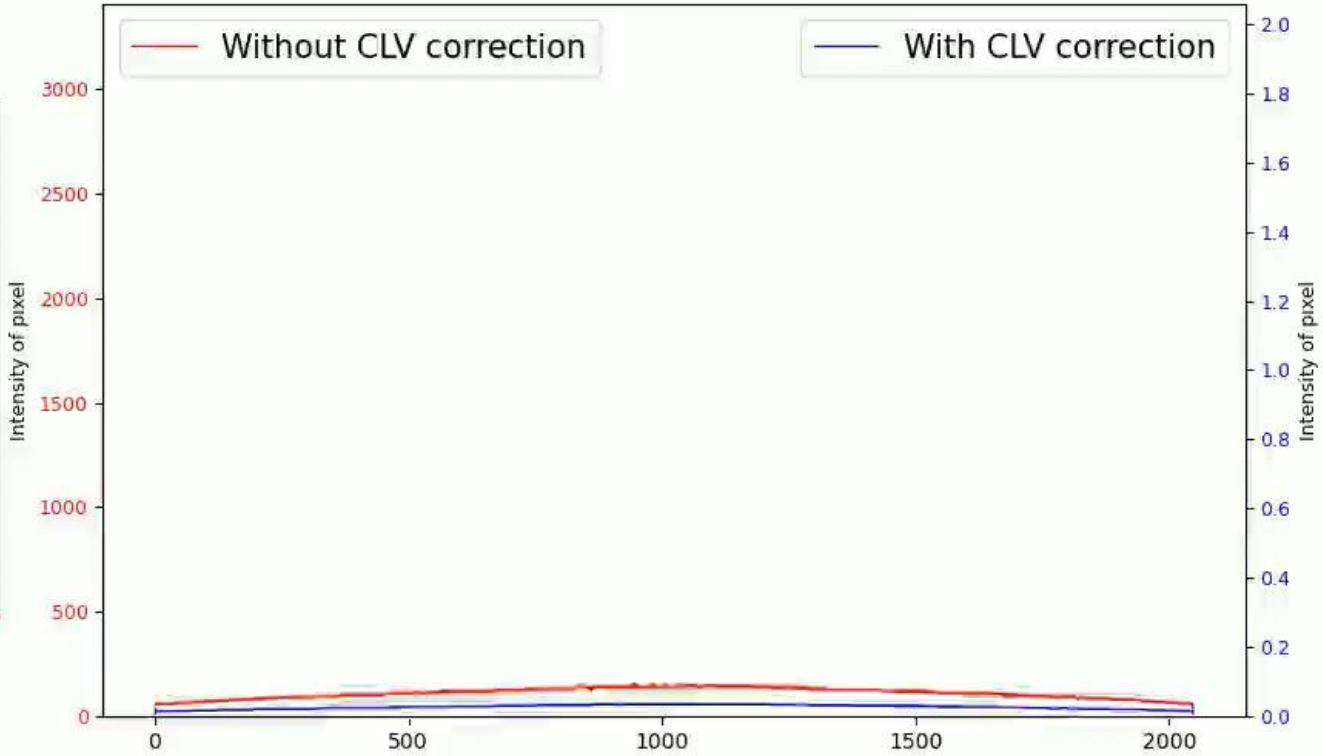
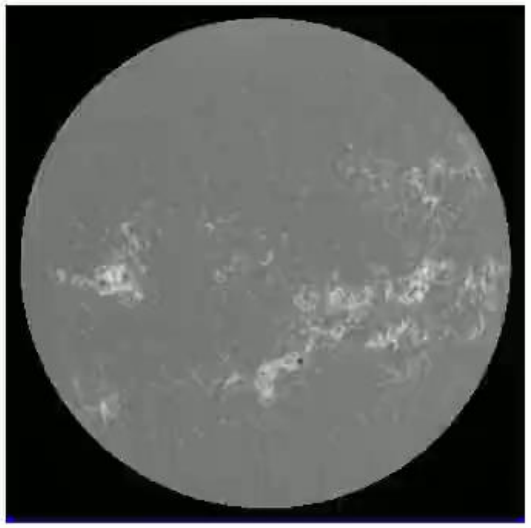
1) Limb darkening or CLV correction

Without CLV correction



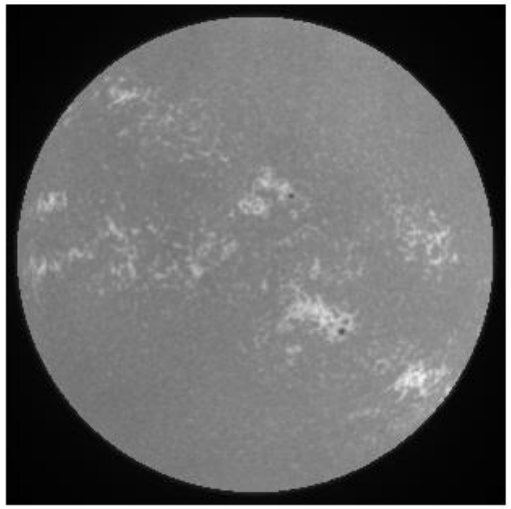


With CLV correction



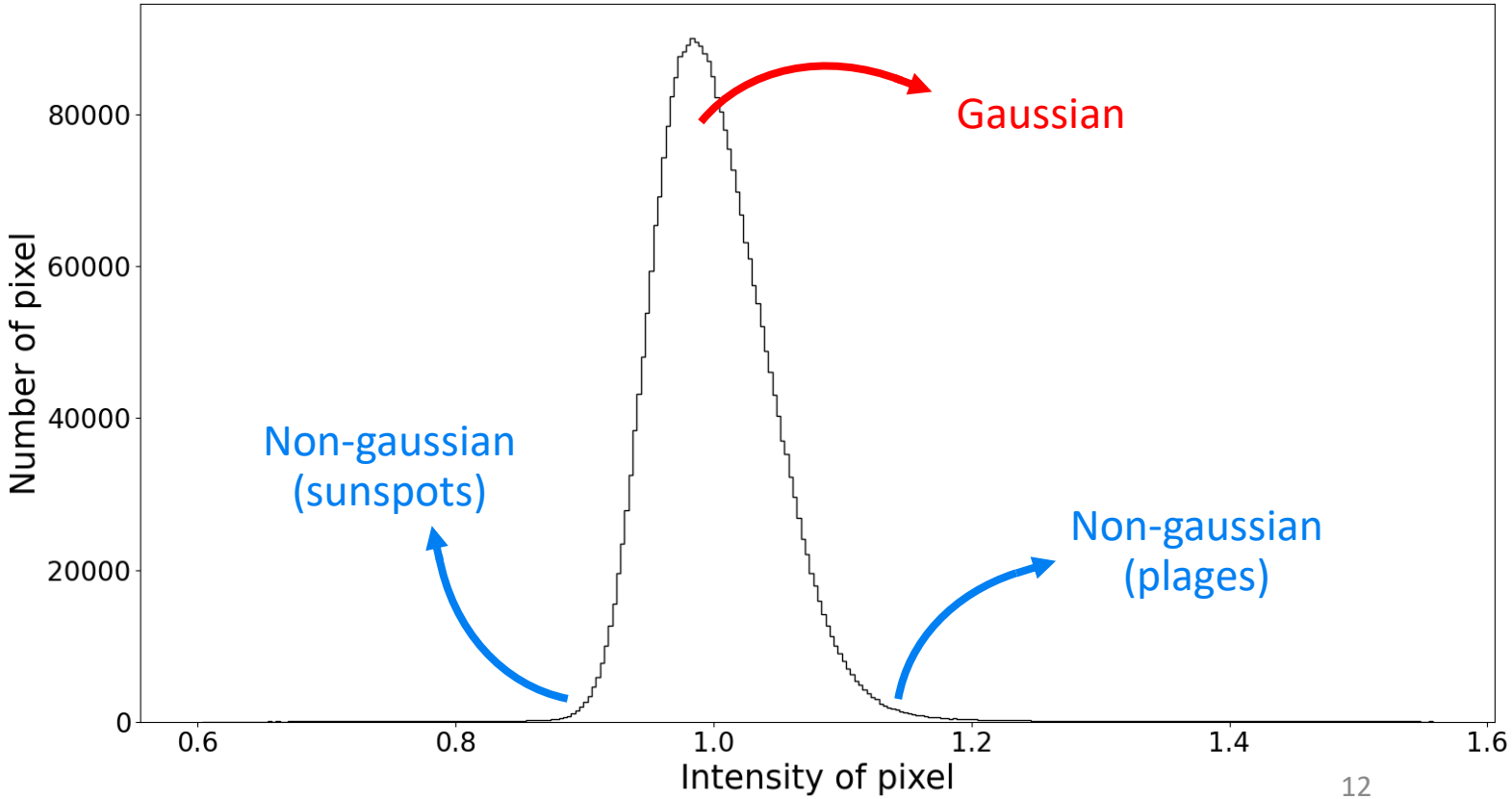
2. Plage segmentation

2) Segmentation method (Based on Chatzistergos et al. 2019)



Assumptions : • **Gaussian** background brightness distribution

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



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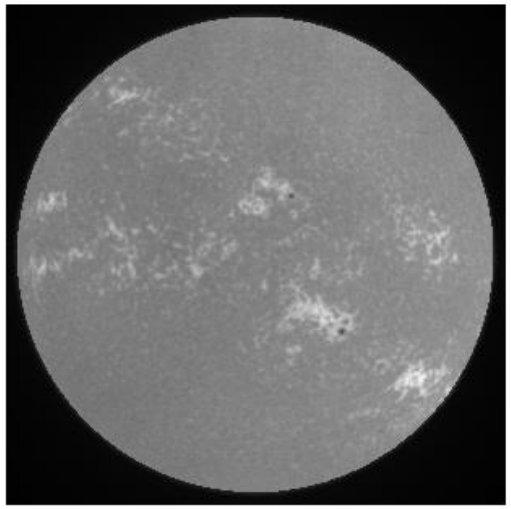

Quiet Sun doesn't vary in time ⇒ Threshold non affected by the solar activity

- Compute the **QS intensity** : I_{QS}

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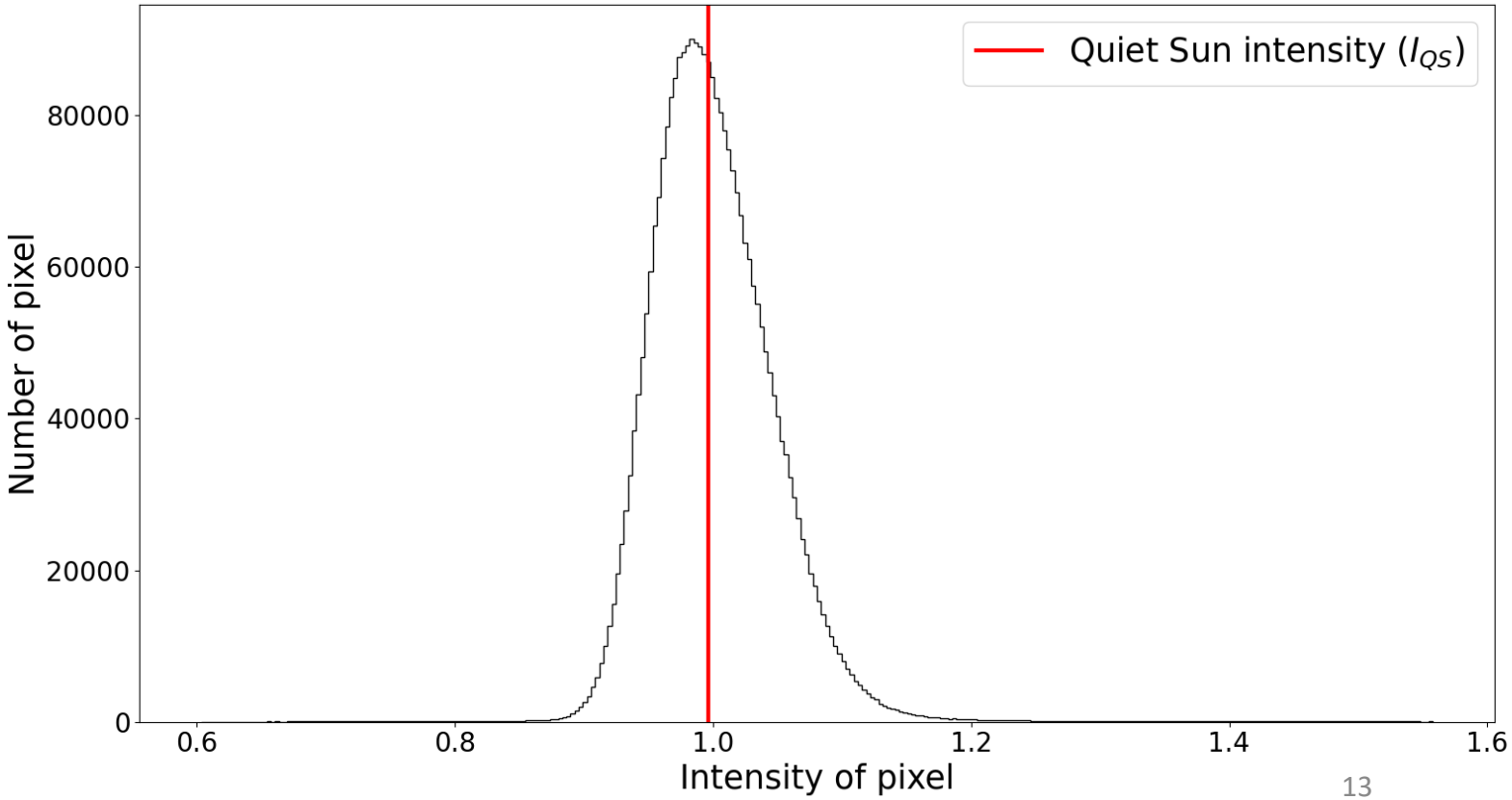

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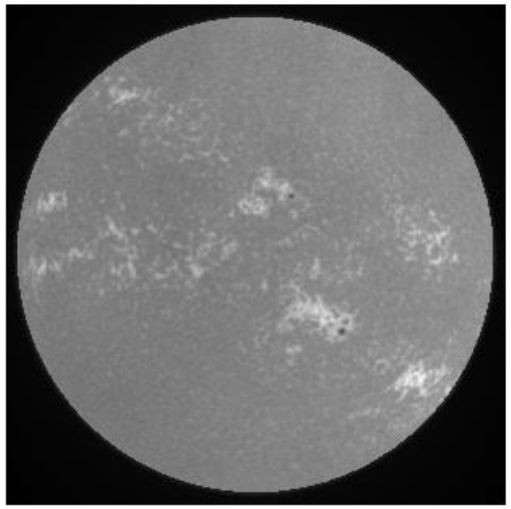

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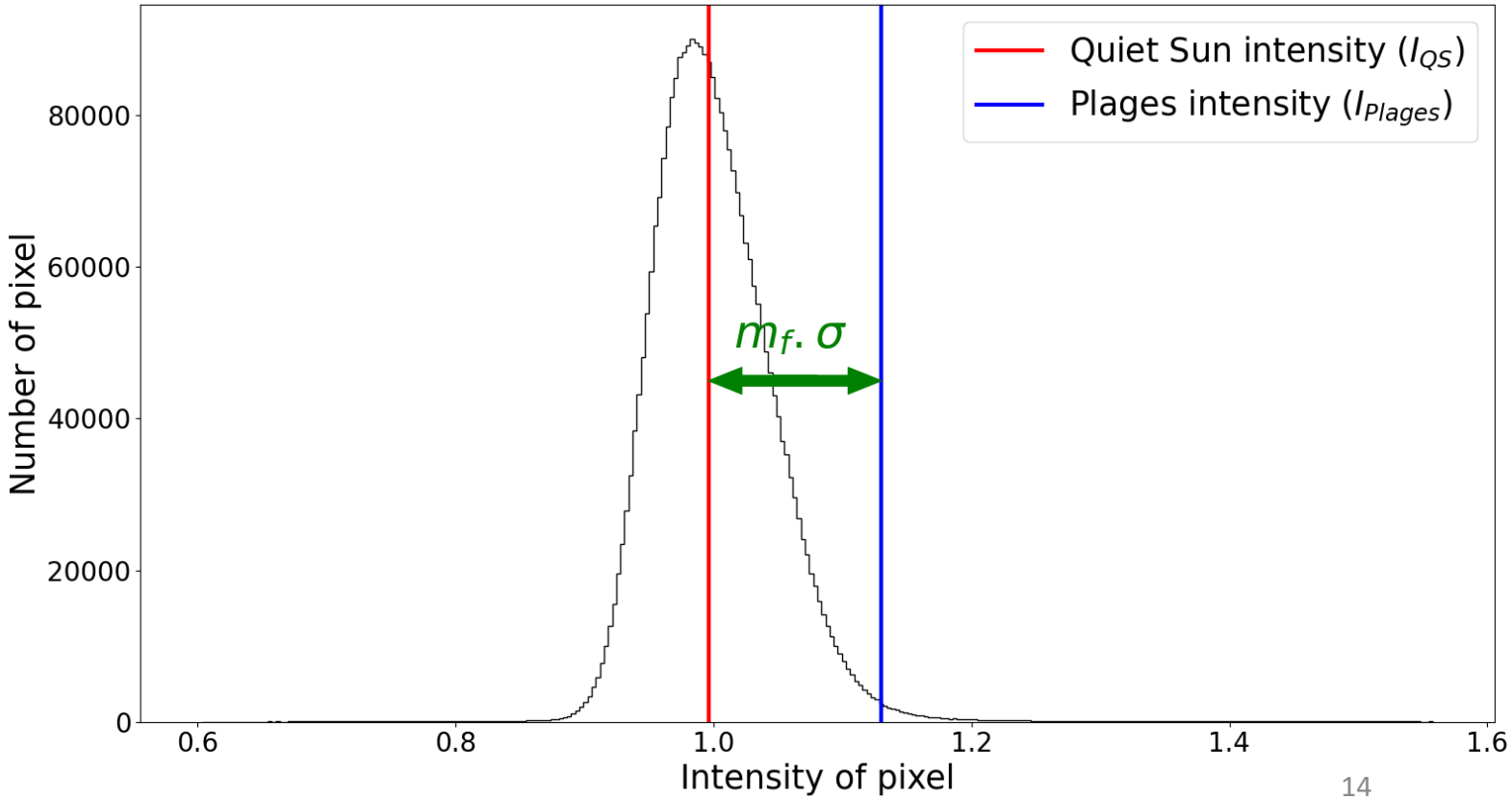

Quiet Sun doesn't vary in time ⇒ Threshold non affected by the solar activity

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

2. Plage segmentation

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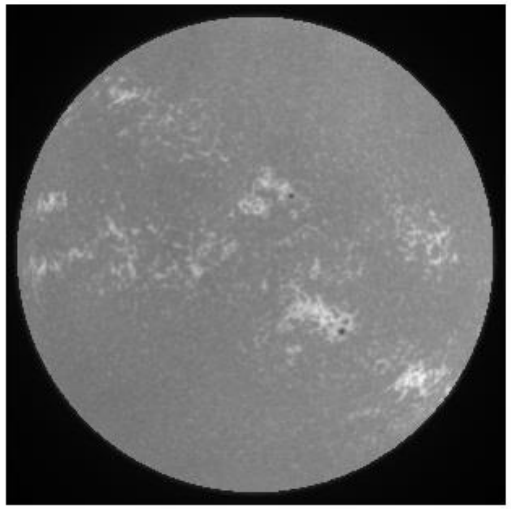

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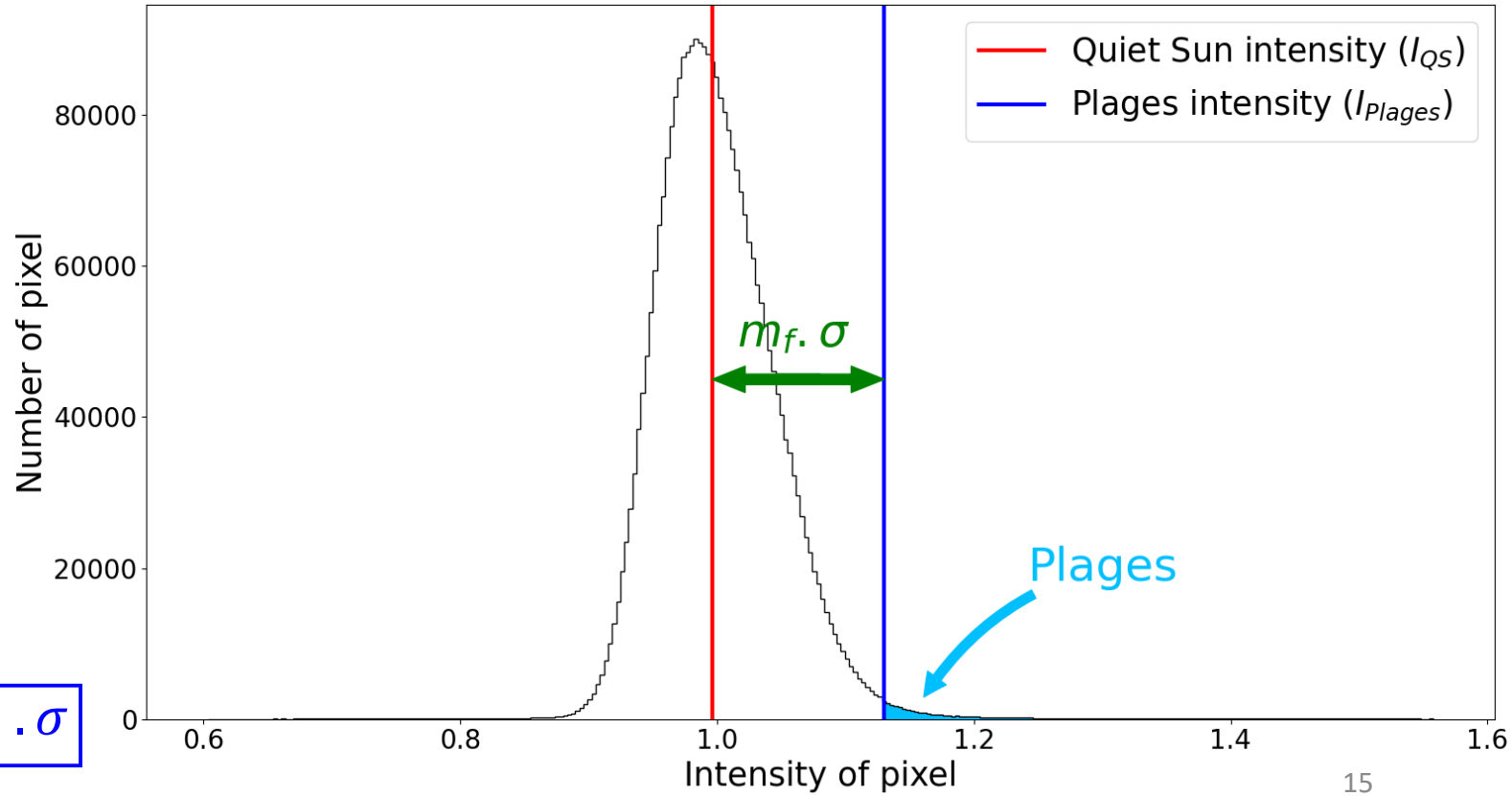
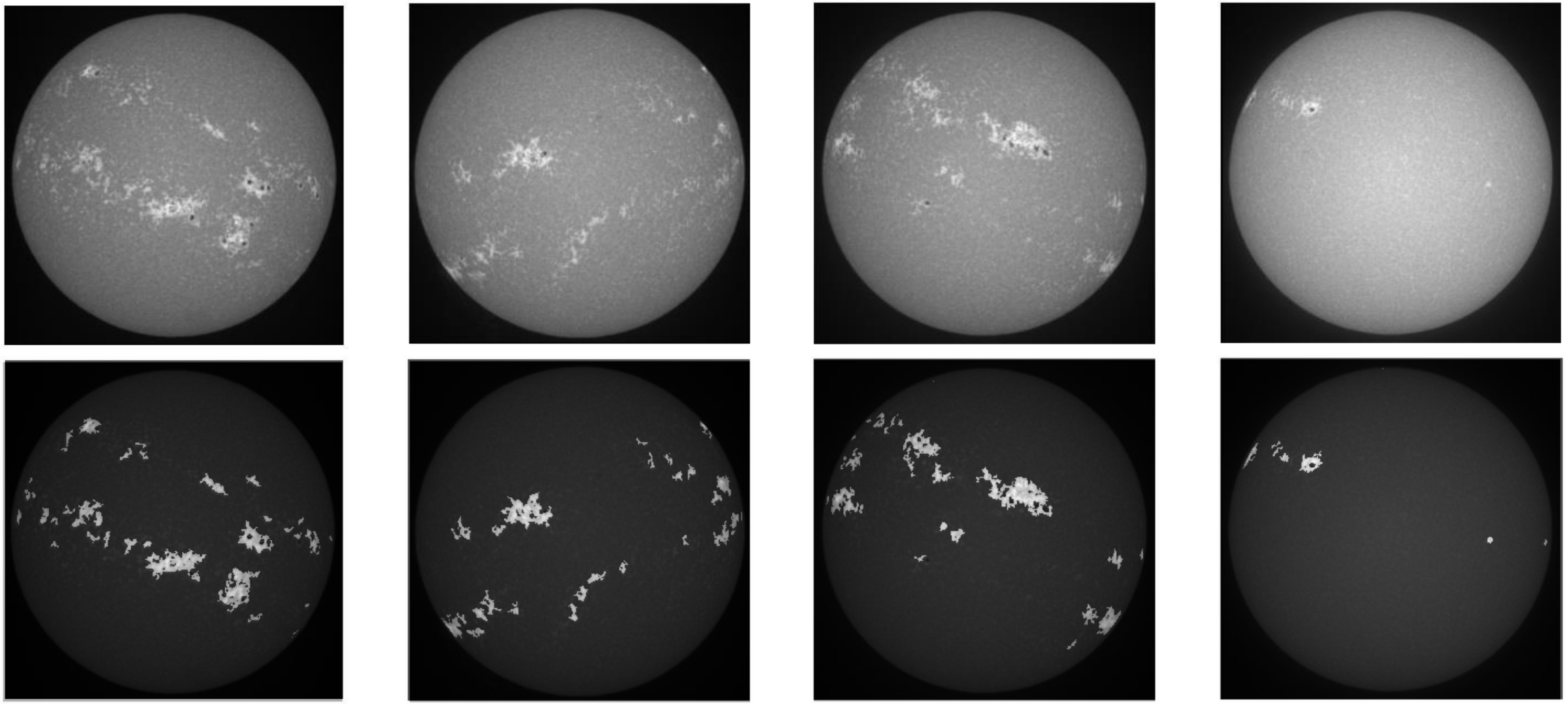


➡ **Plages intensity :** $I_{Plages} \geq I_{QS} + m_f \, . \sigma$

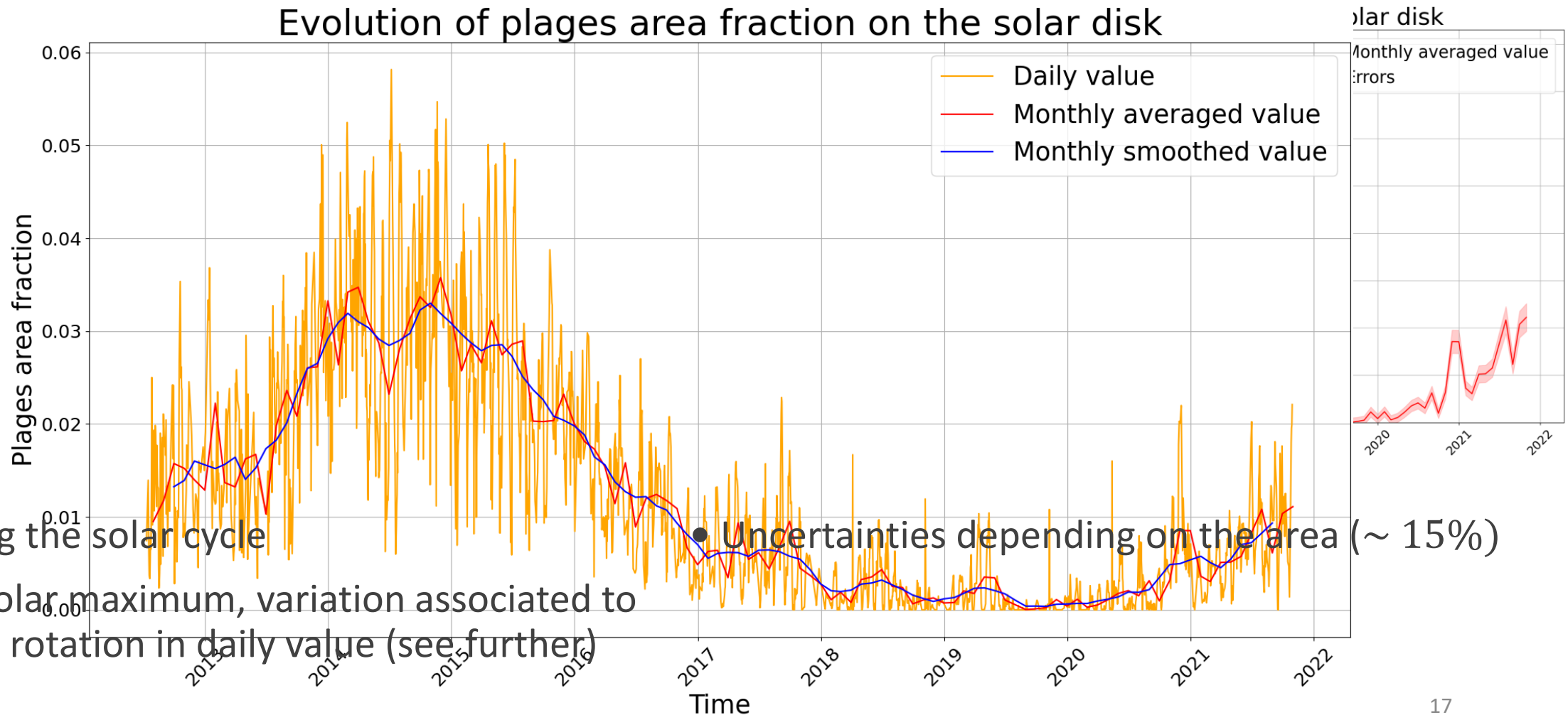
2. Plage segmentation

2) Segmentation method (Examples)



2. Plage segmentation

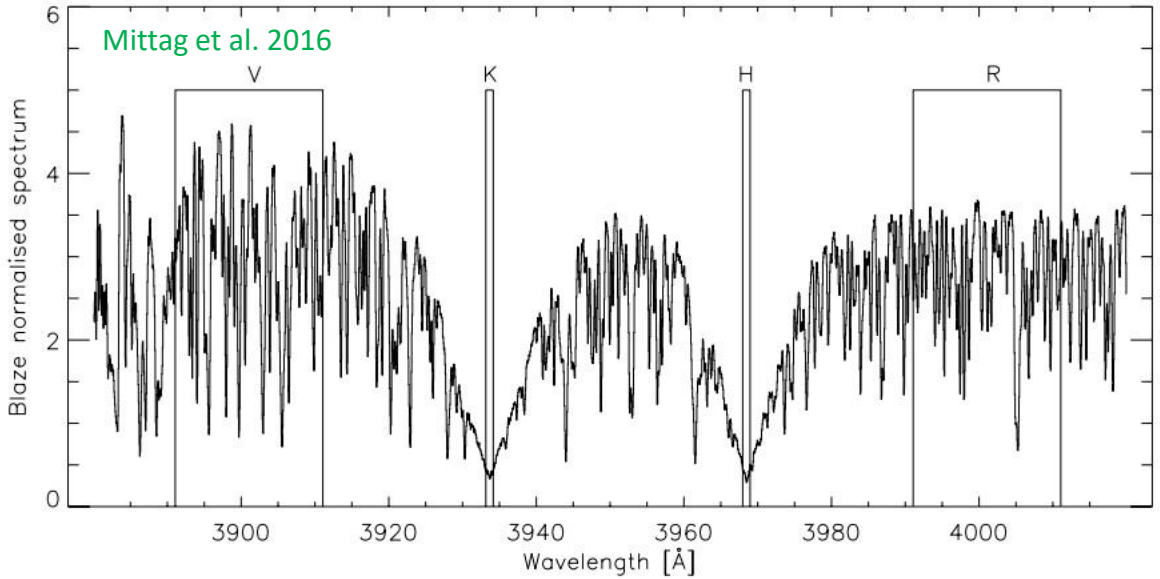
2) Segmentation method (Evolution of plages area)



- Following the solar cycle
- During solar maximum, variation associated to solar rotation in daily value (see further)
- Uncertainties depending on the area ($\sim 15\%$)

3. TIGRE S-Index

- **TIGRE** : Telescopio Internacional de Guanajuato Robótico Espectroscópico
- **Location** : Guanajuato, Mexico
- **Activities** : - Observing solar spectrum reflected by the Moon
  - Observing solar-type stars spectrum
- **TIGRE data** : *S-Index* → based on the flux in the Ca II H & K lines

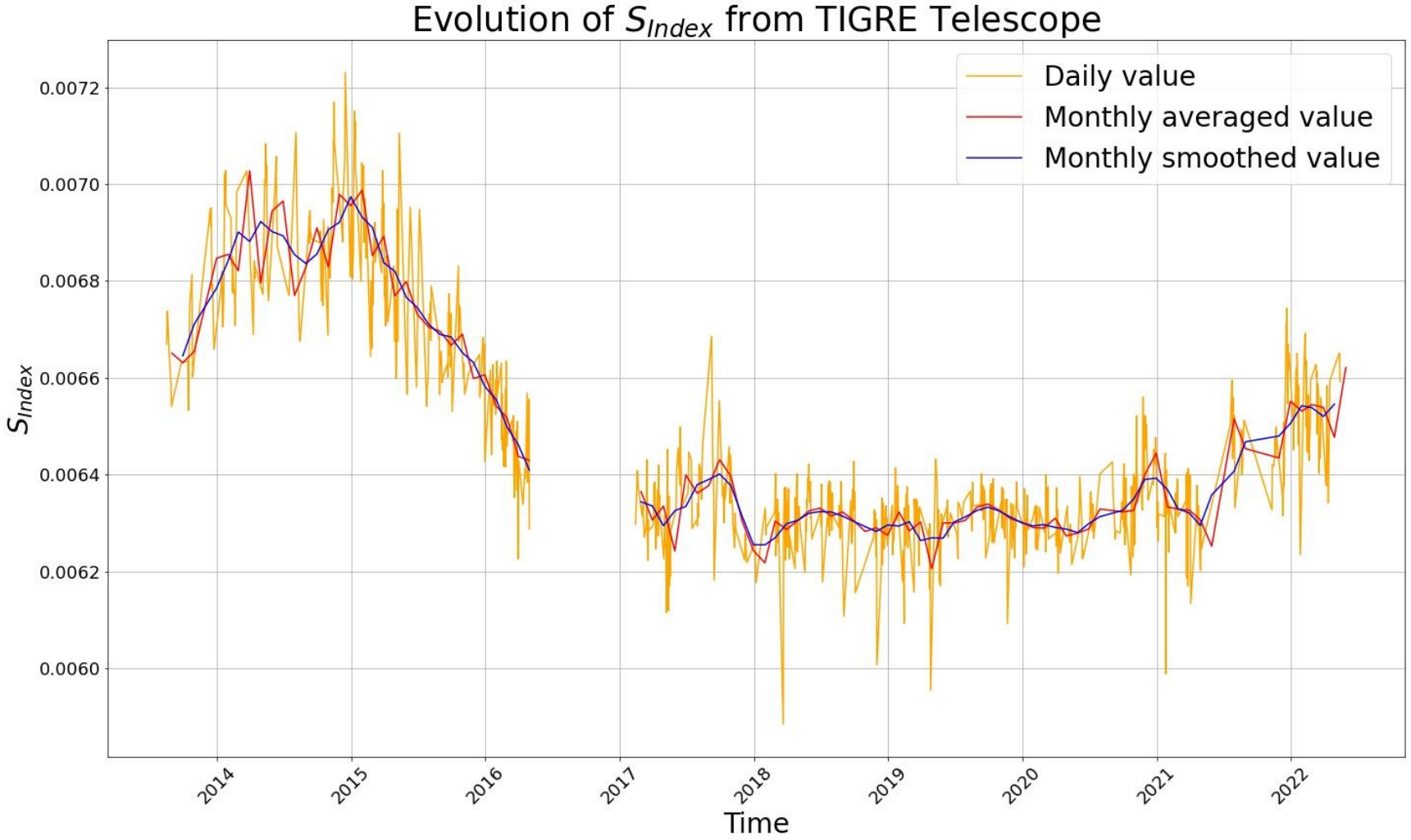


$$S = \alpha \left(\frac{N_H + N_K}{N_R + N_V} \right)$$

α is a calibration constant

3. TIGRE S-Index

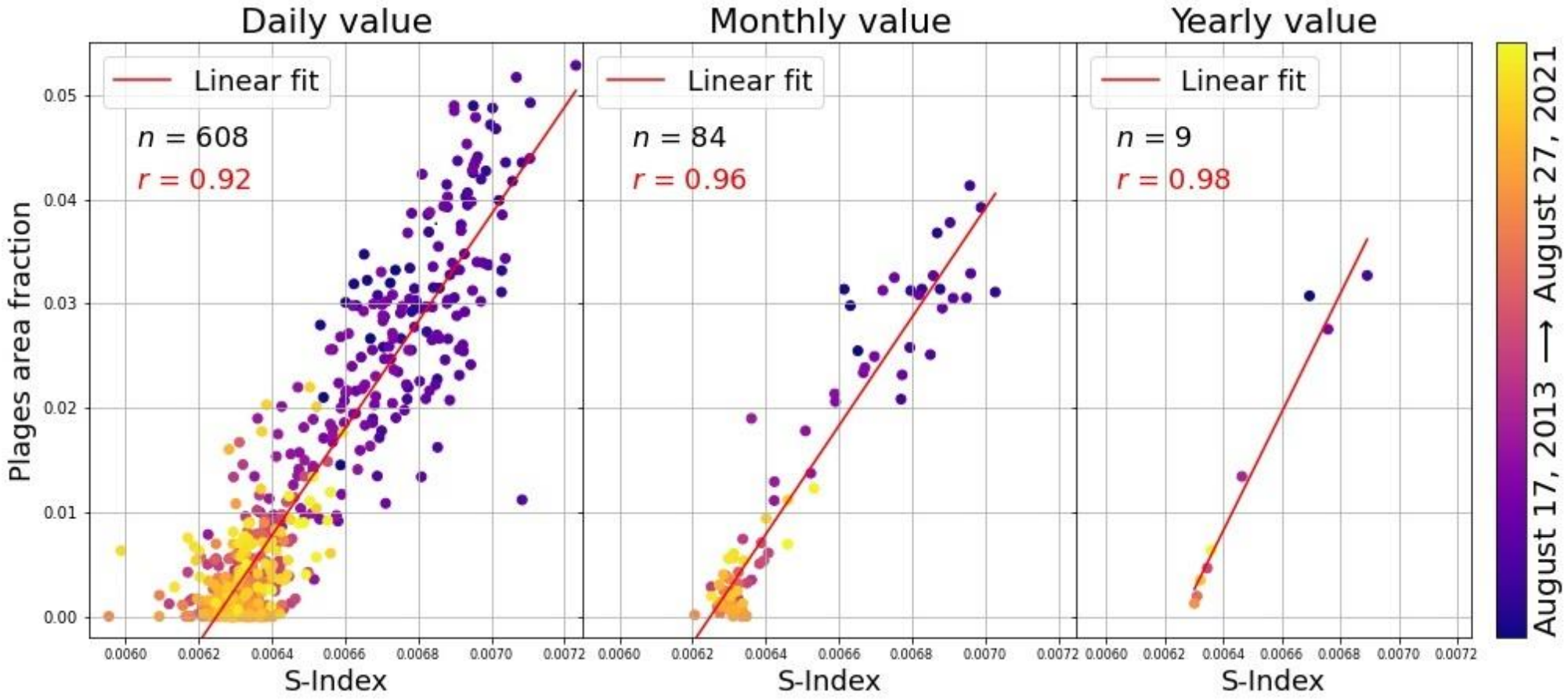
Solar S-Index



Schröder et al. 2017

- Following the solar cycle (maximum in 2014-2015 and minimum in 2019-2020)
- Gaps associated with technical issues (e.g. 2016-2017)
- Monthly interruptions due to the New Moon phases

4. USET vs TIGRE



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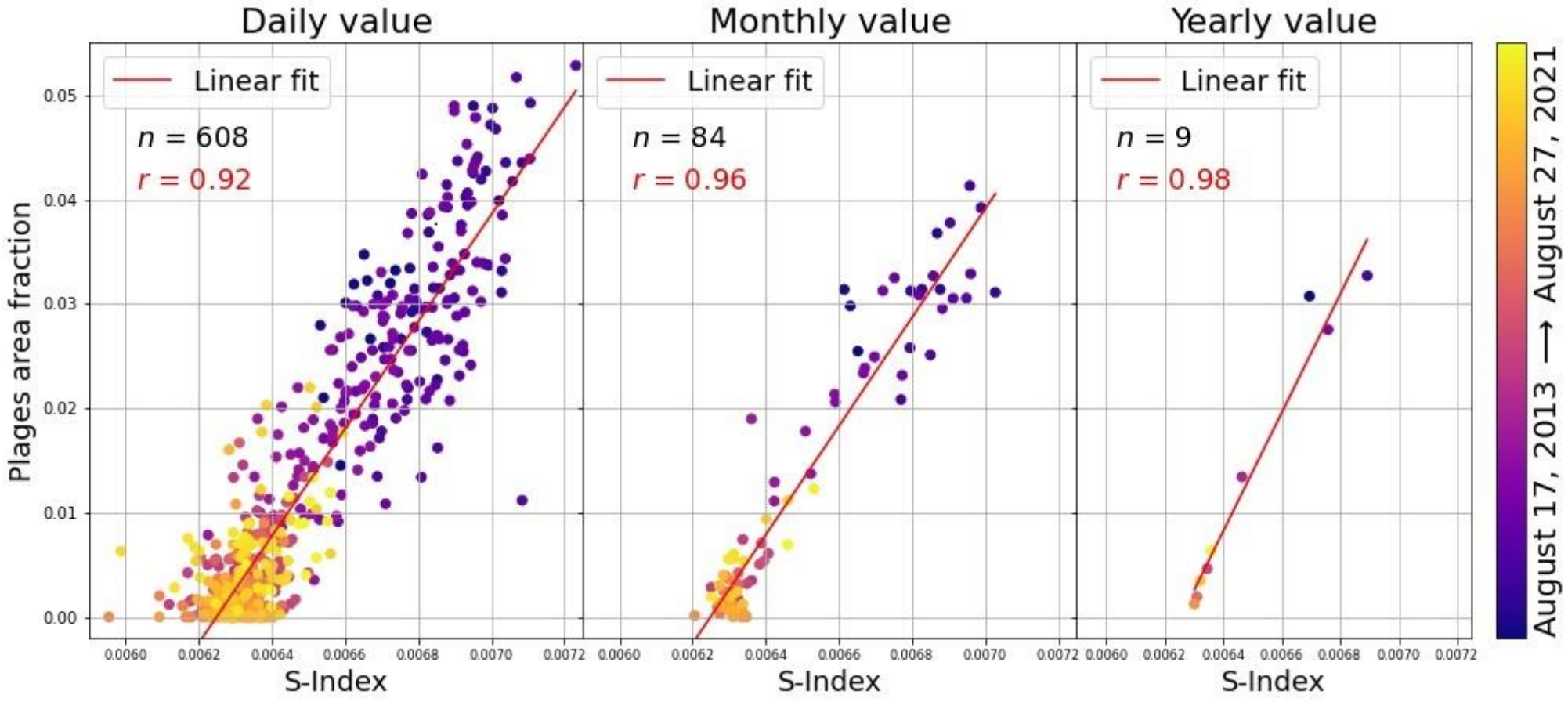
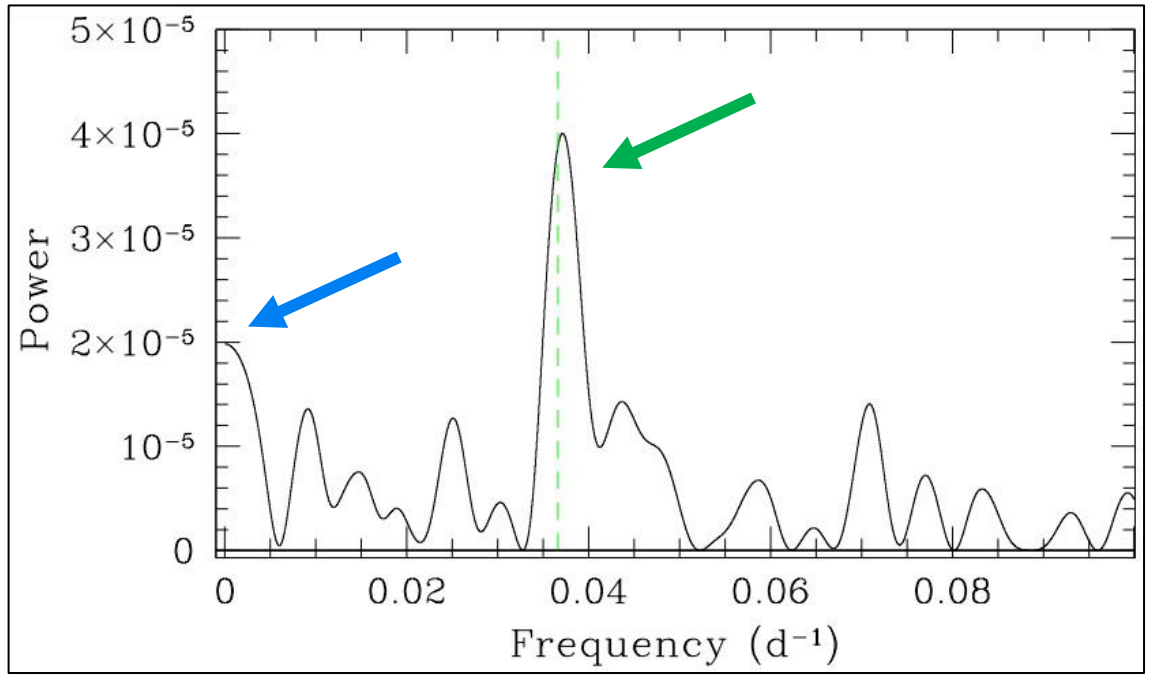


Correlation coefficient > 0.92 → **Strong linear relationship** between both variables

5. Periodic modulations

⇒ Search for presence of **rotation modulation** in the time series of plages



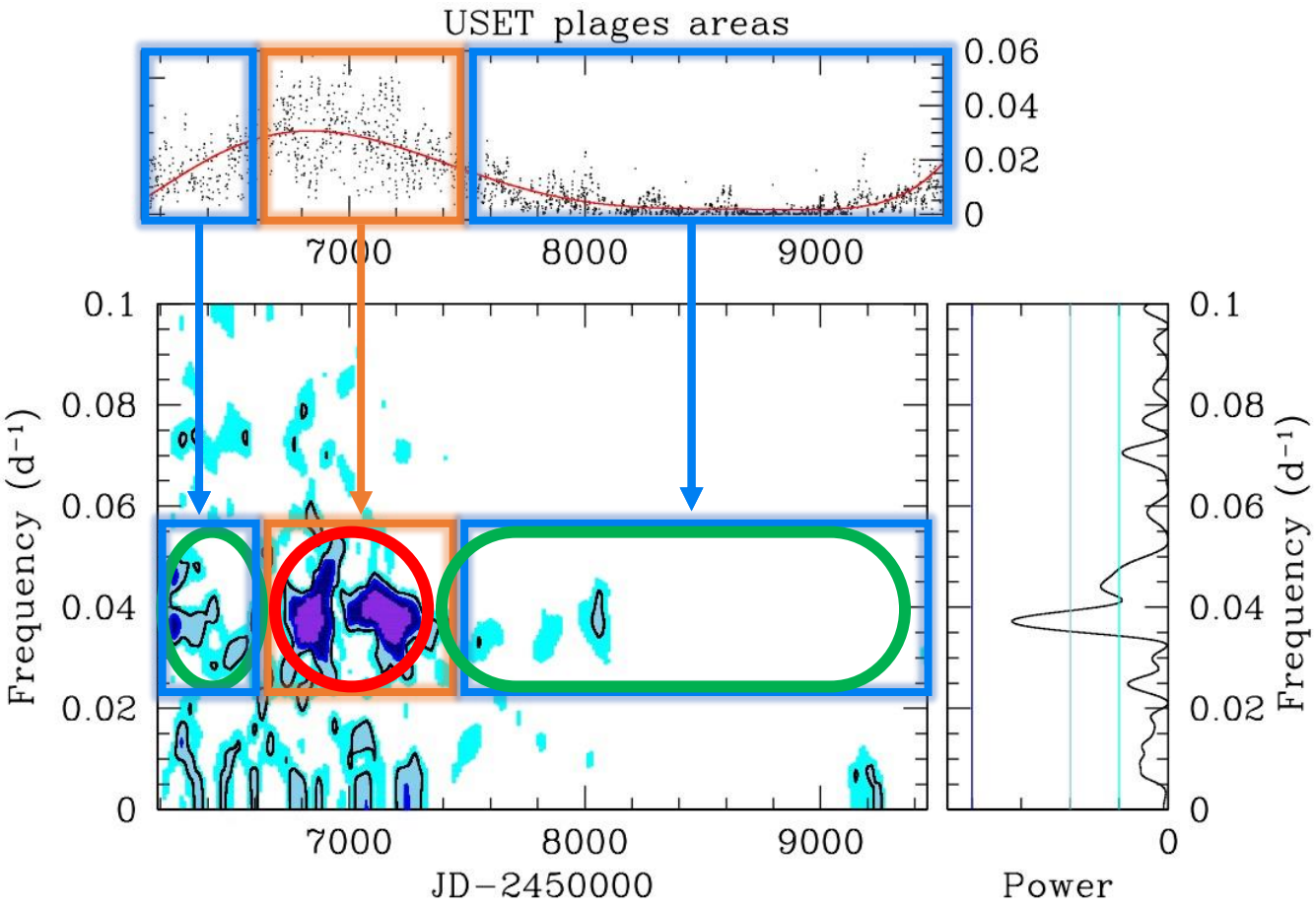
- ***Fourier method :*** Existence of a periodic signal
  ⇒ peak in the power spectrum
- Highest peak at $\sim 0.0367\ d^{-1}$ (green line) :
  ⇒ **Carrington rotation period** $(27.27\ d)$
- Weaker peak at **solar activity cycle** frequency because data covering less than $11\ y$

Conclusion : Solar rotation is present in plages time series

Question : Always present ? Variation with the solar cycle ?

5. Periodic modulations

Time-frequency diagram



Rotational modulation

very prominent
at the solar maximum
and descending phase

absent
at the solar minimum
and ascending phase

Distribution of plages in longitude

non-uniform
at the 2 maxima during
solar maximum

nearly uniform
at other periods of
the activity cycle

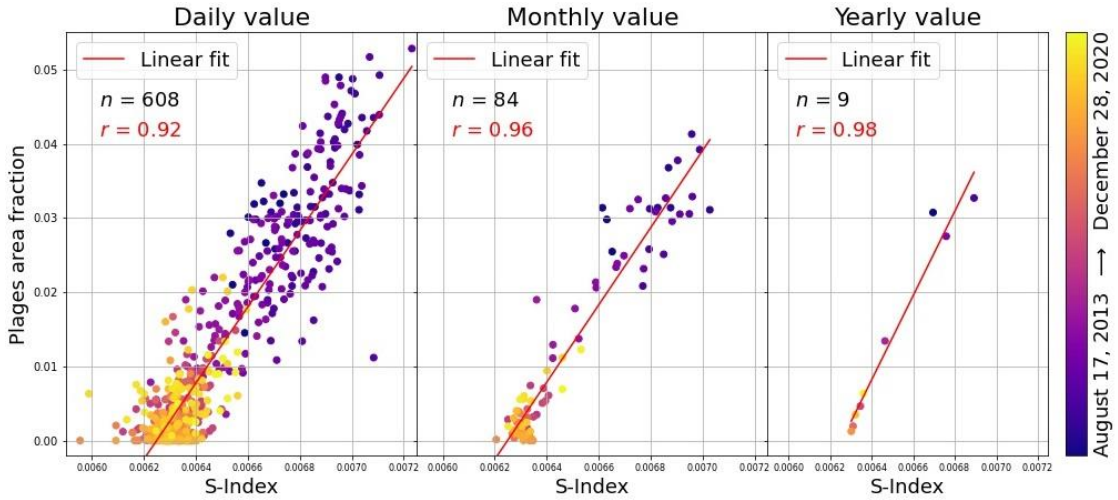
➡ Further verification on images

Conclusions

- **Strong linear relationship between USET Ca II K plages area and TIGRE S-Index**

- Solar rotation present in the plages time series near the maximum but not during other period

- Longitudal modulation in plages during solar activity cycle



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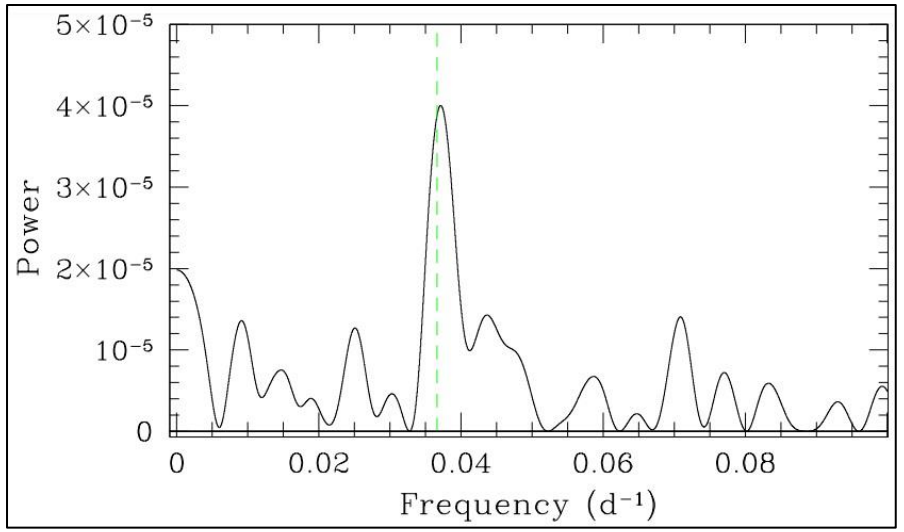

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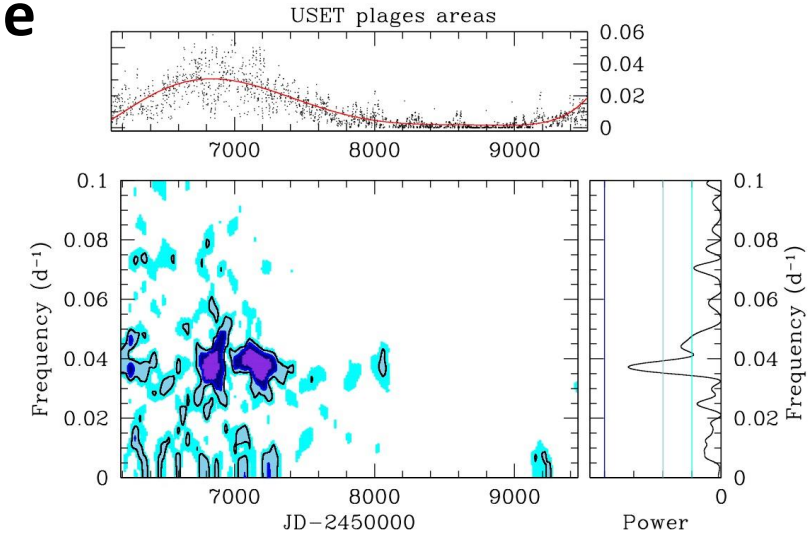
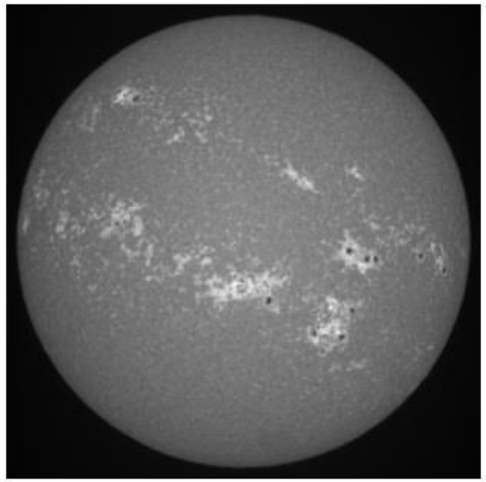
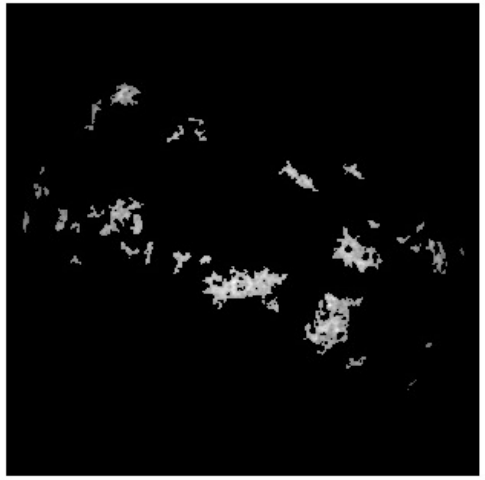


Thank you for your attention !

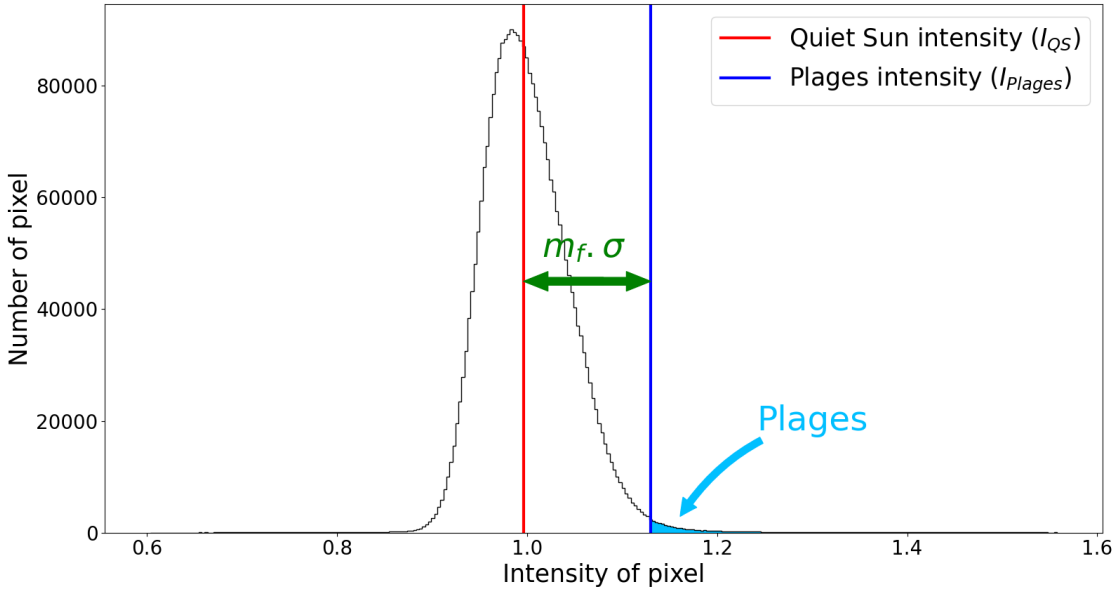
Plage segmentation

Segmentation method





1. Compute the mean intensity $\bar{I}$ and the standard deviation σ_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)



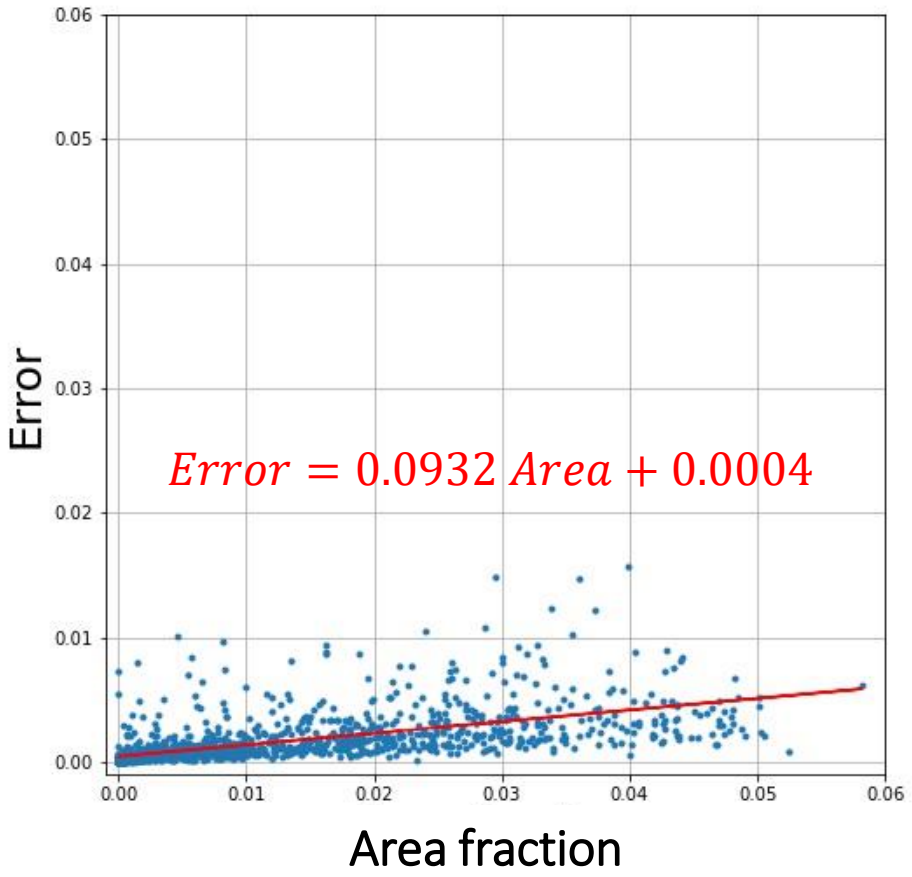
Plage segmentation

Uncertainty calculations

How ? Using the full dataset of ~ 21.000 images in the USET database

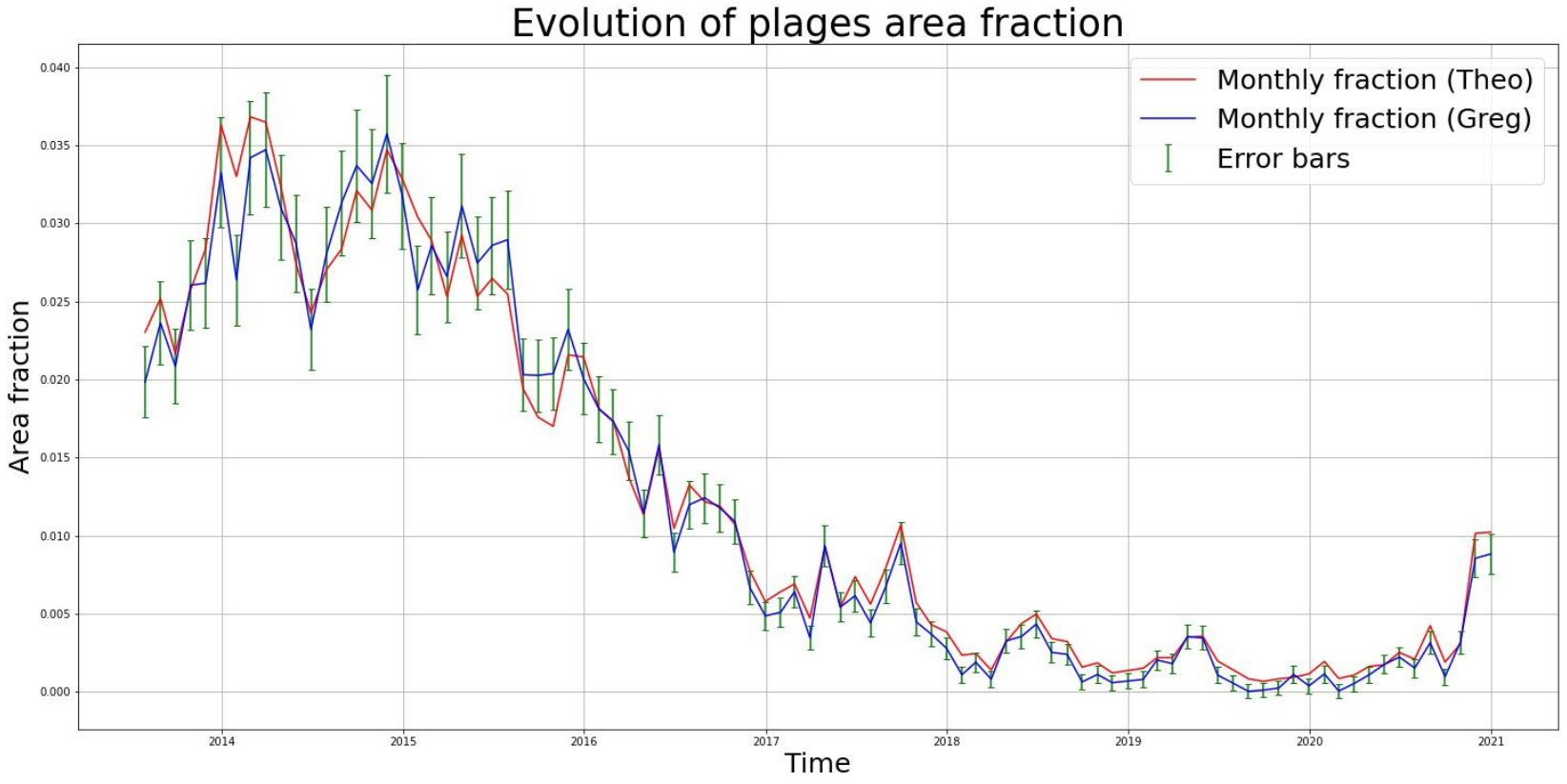
- Compute the area fraction for each image
- Compute the standard deviation for each day
- Remove the outliers
- Assume a 1D relationship between plages area and standard deviation
- Fit the data and get the equation

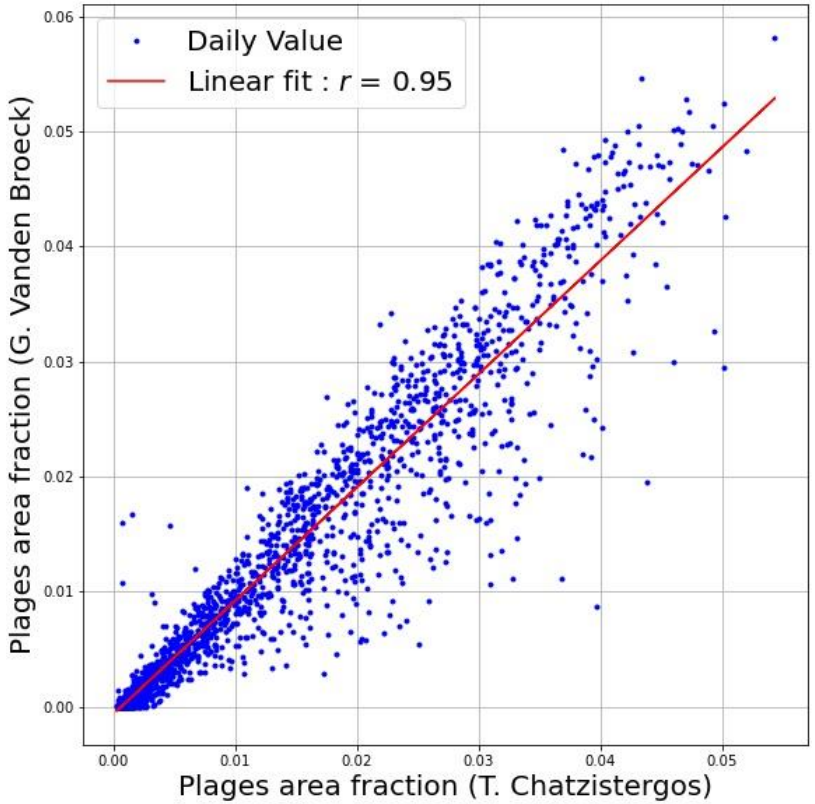
⇒ **Error proportional to the area**



Data serie validation

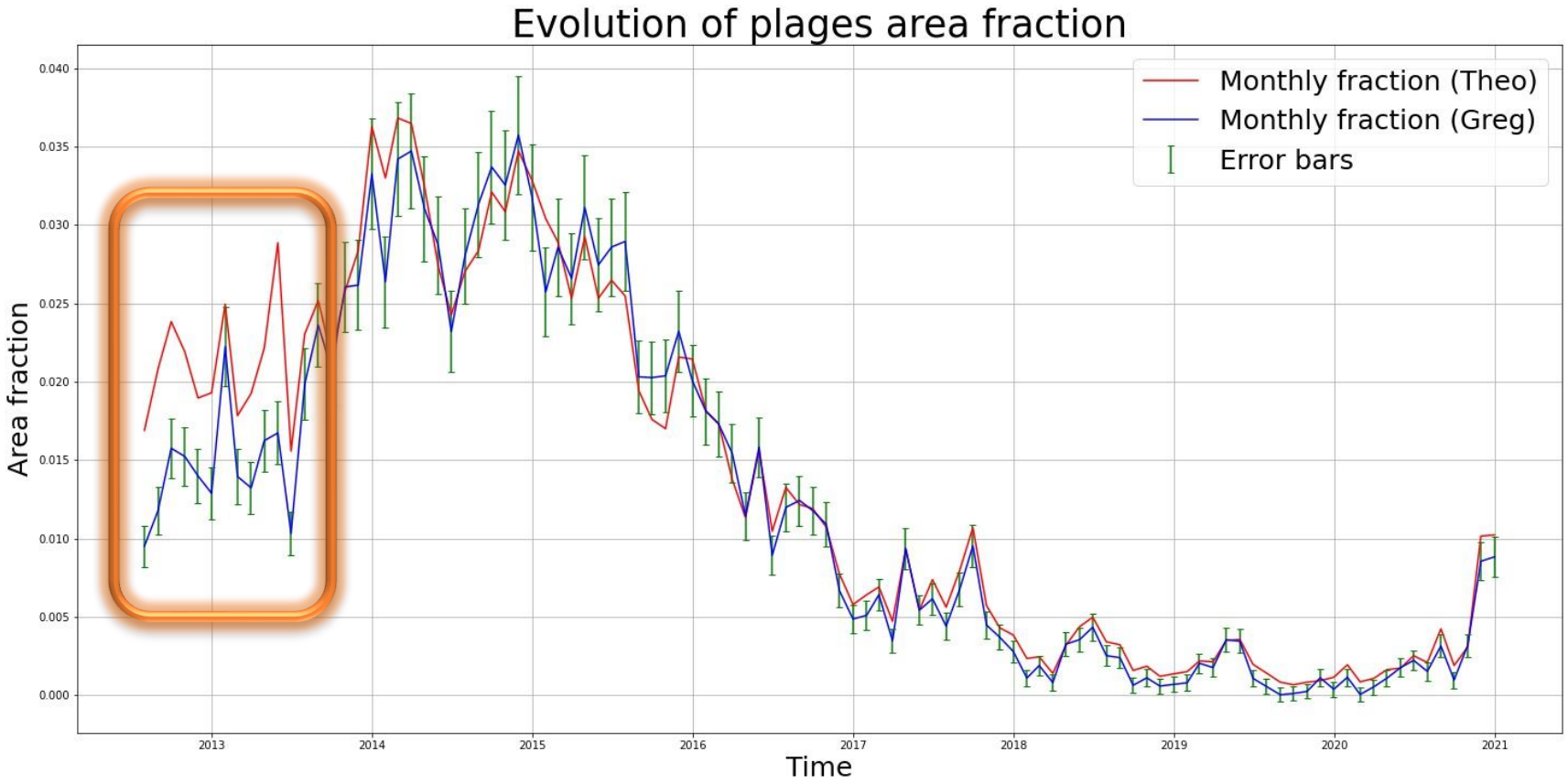
How ? Comparison with Theodosios Chatzistergos results on USET dataset (Chatzistergos et al. 2020)





Data set problem

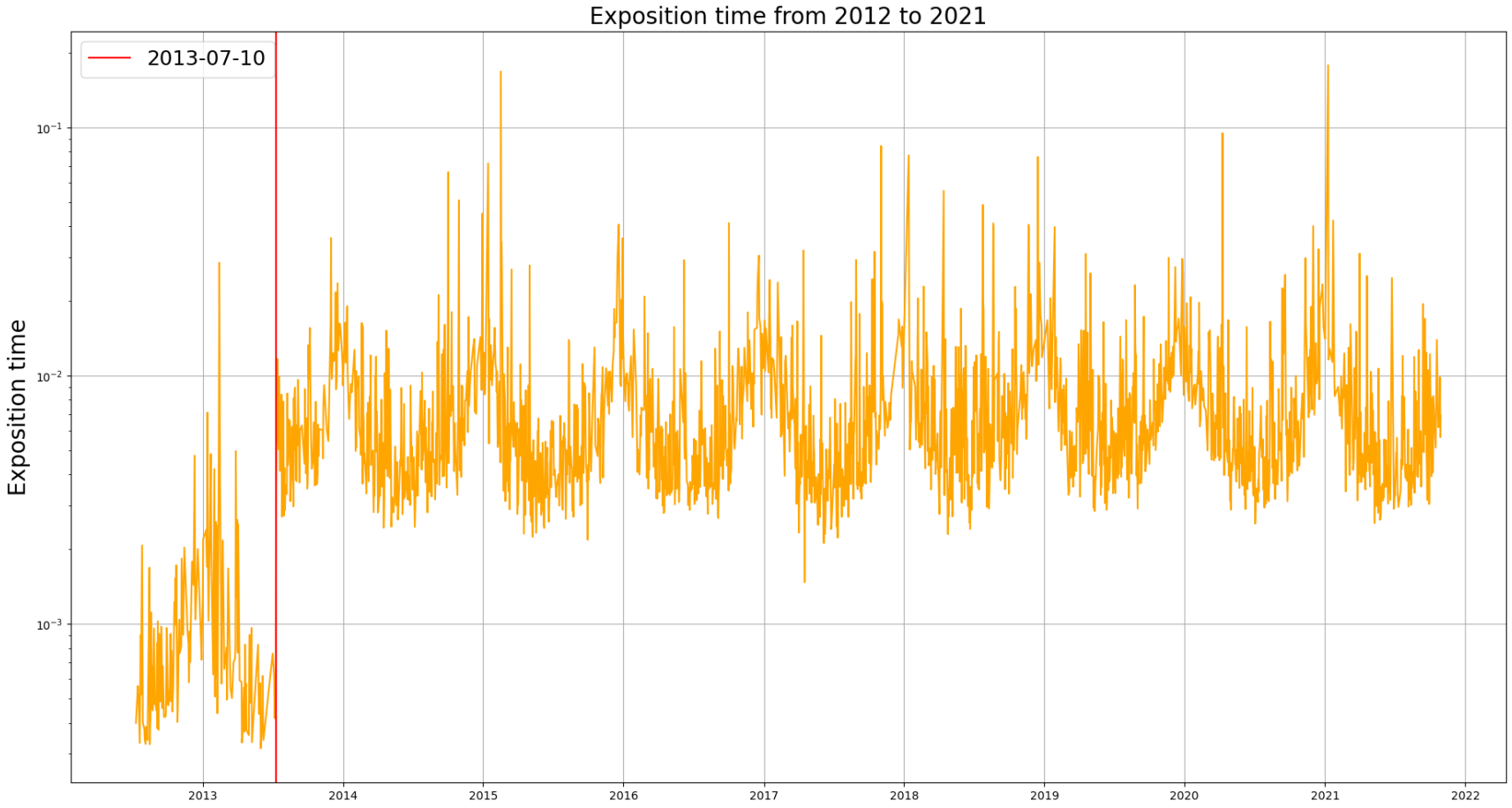
Comparison with T. Chatzistergos results on USET dataset (Chatzistergos et al. 2020)



Problem :

On July 10, 2013 : Installation of a neutral density filter on the Ca II K telescope

Data set problem

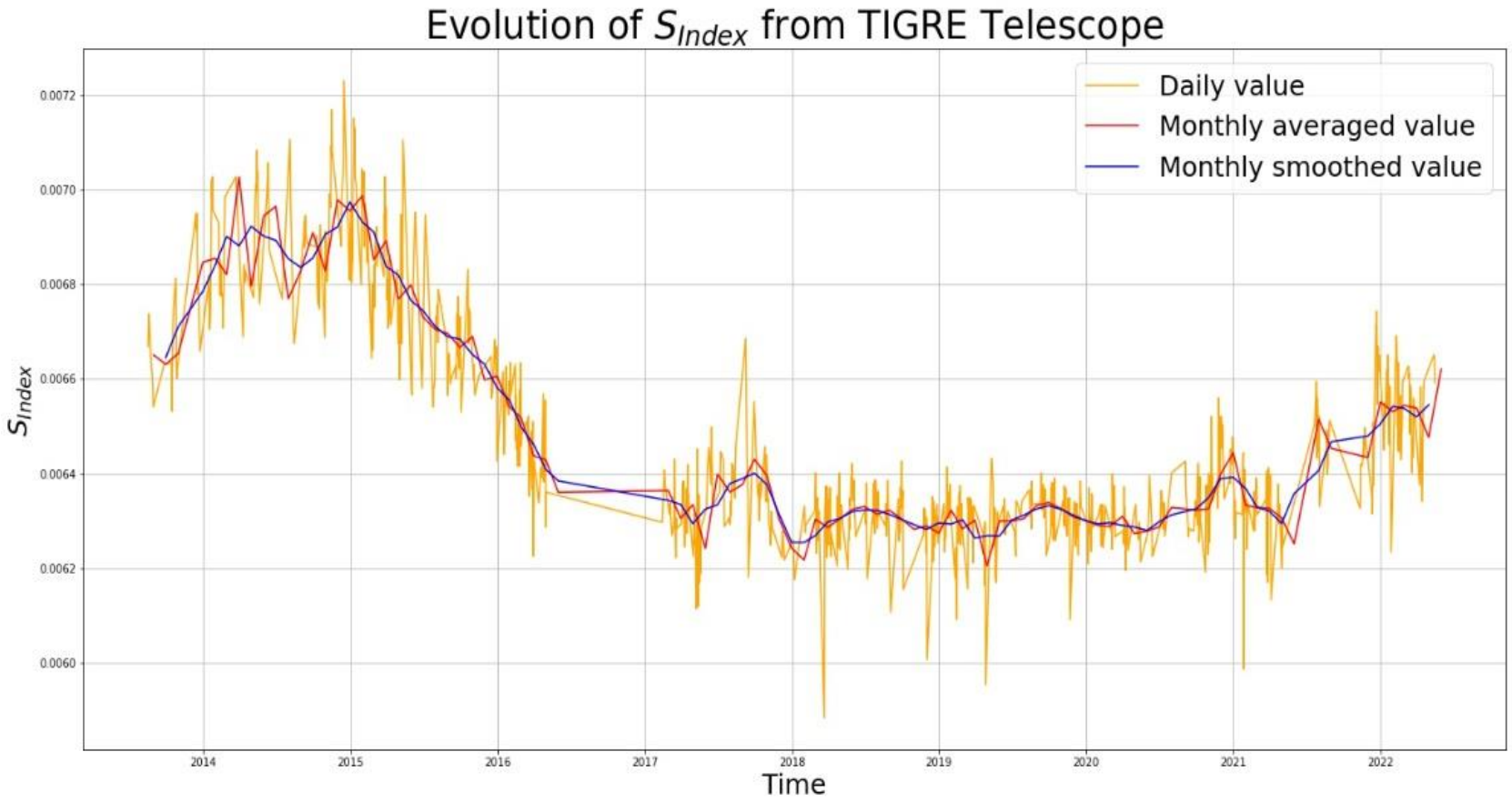


Problem :

On July 10, 2013 : Installation of a neutral density filter on the Ca II K telescope

Exposure time increased by a factor of 10

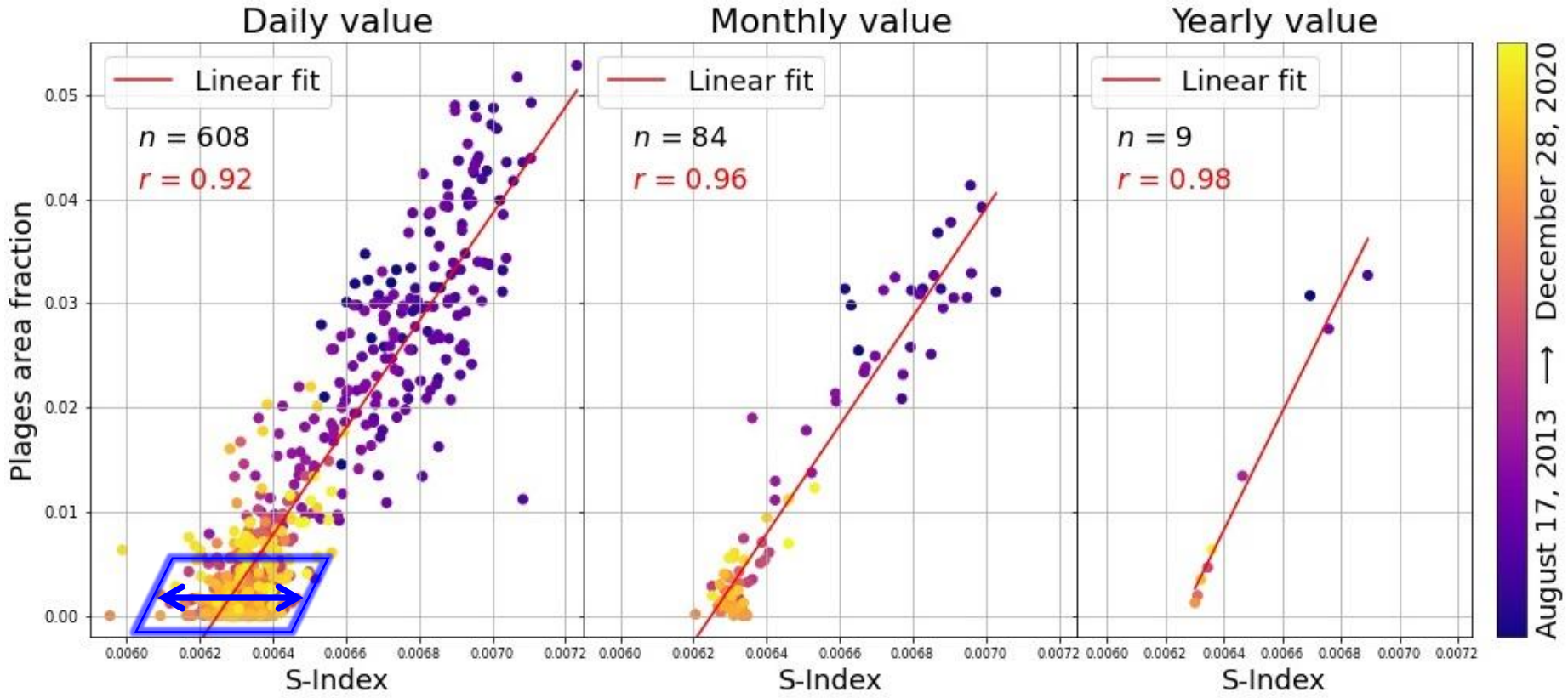
TIGRE technical issues



- Issues with time losses from **hours to days** : internet cuts and power failures

- Issues with time losses from **days to months** : hardware failures, power supply

USET vs TIGRE



Why does S-Index vary when no plage observed ?

→ Chromospheric network

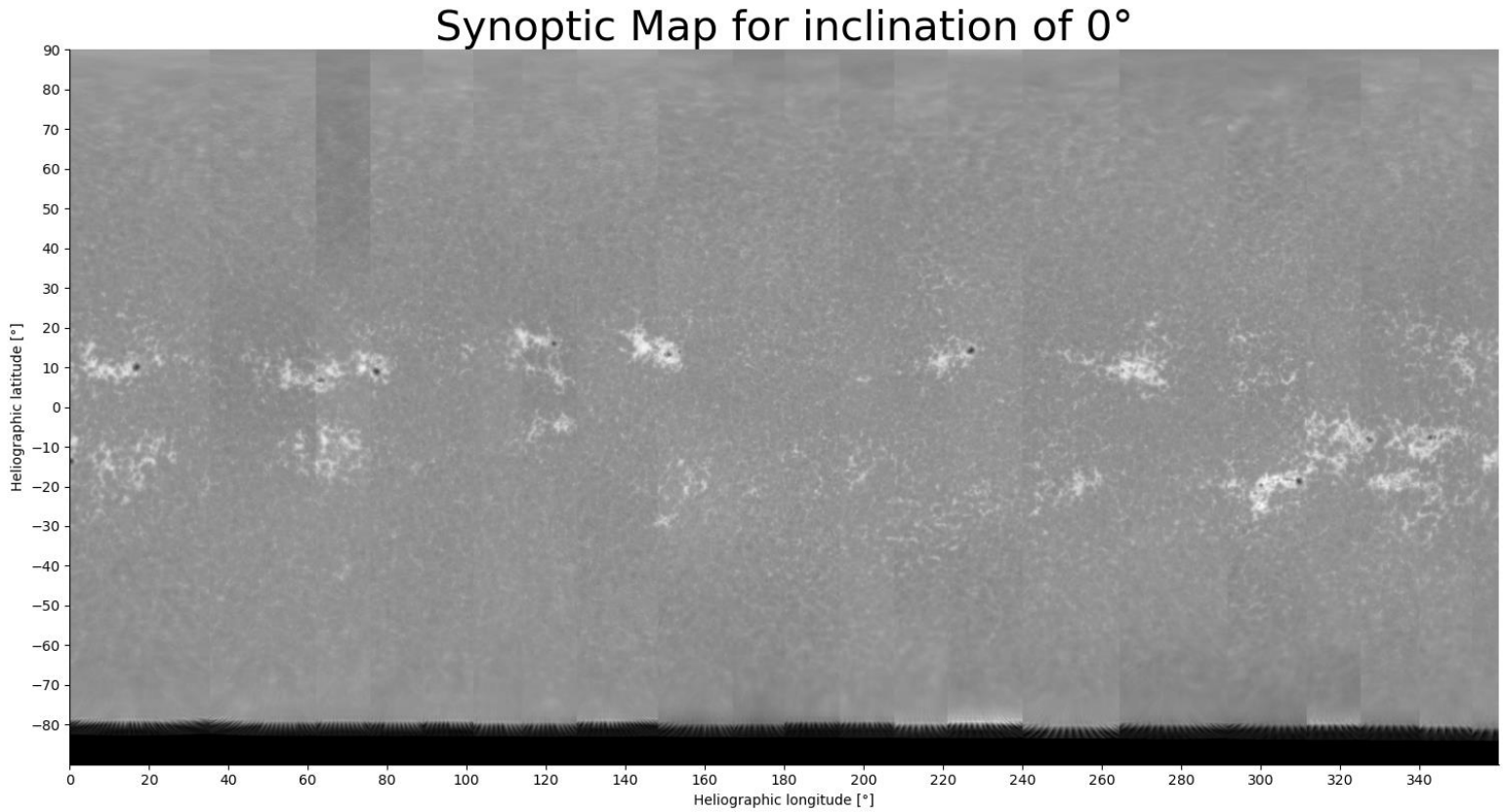
→ Time laps between Mexico and Brussel

→ Difference between photospheric measurements and area of pixels

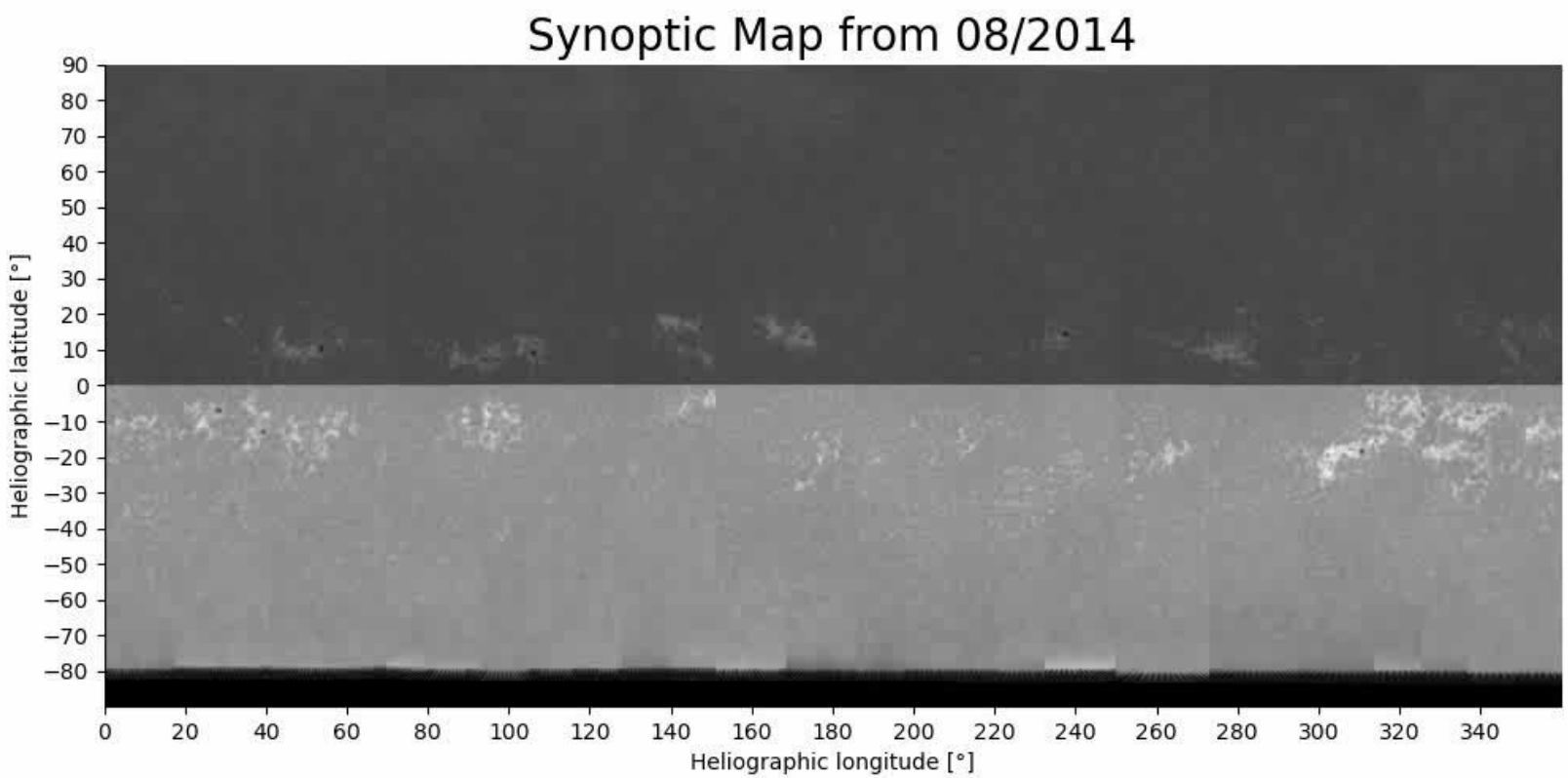
Synoptic map

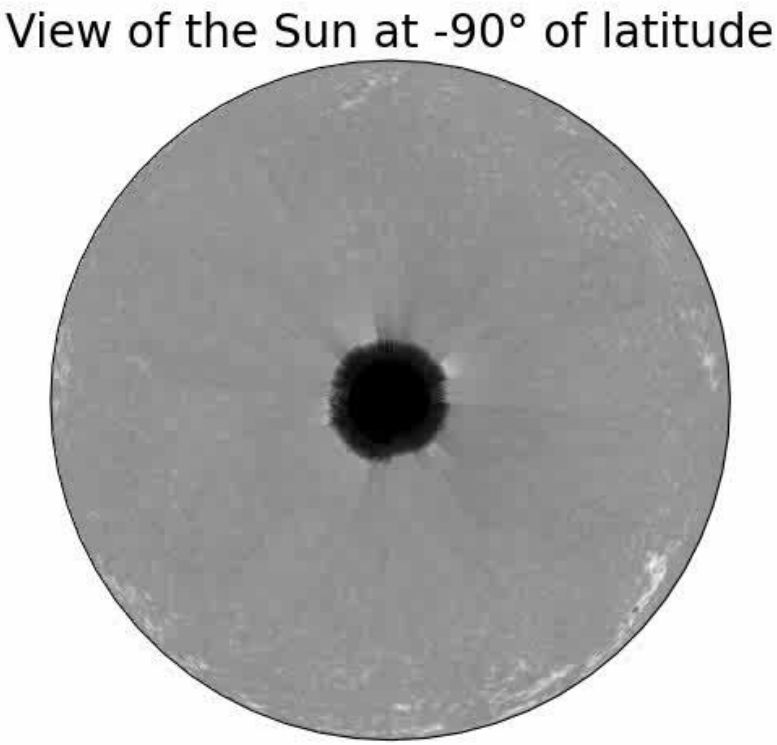
Aim : - Observing the distribution of the magnetic structures

- Reconstructing solar images for different angles of view



Synoptic map

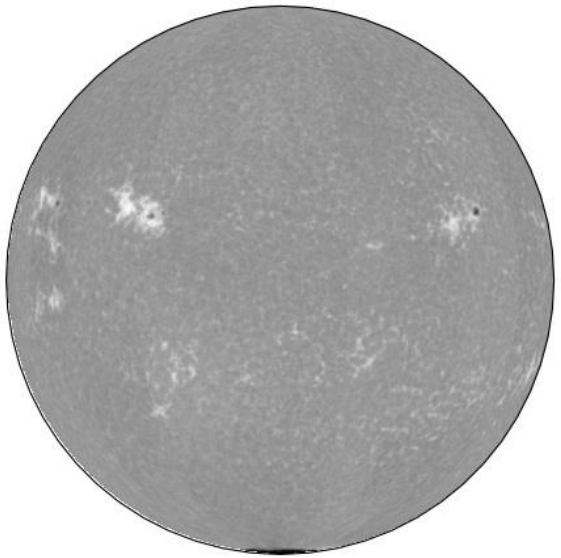




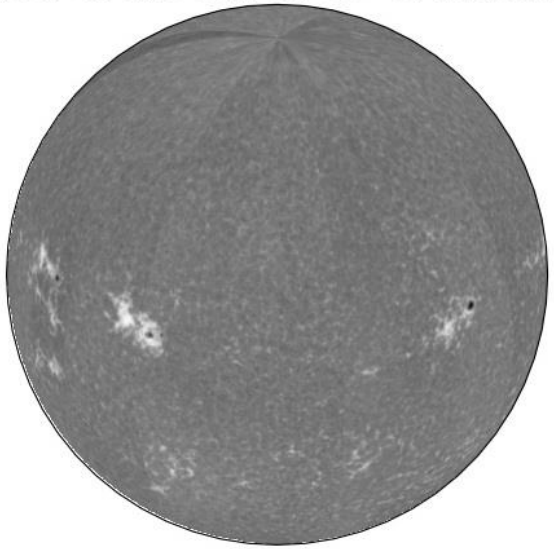
Next steps

- Computing Ca II K plages area for different inclinations
- Getting S-Index for multiple solar-type stars
- Comparing Ca II K plages with stellar S-Index to study the inclination angle of other stars
- Study the possible other cycles during the solar cycle

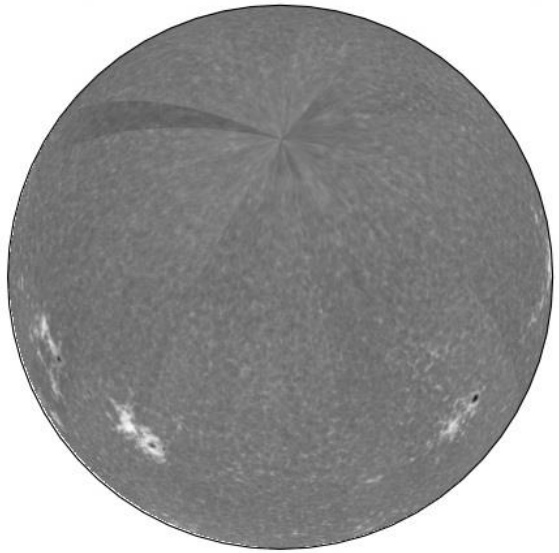
View of the Sun at 0° of latitude



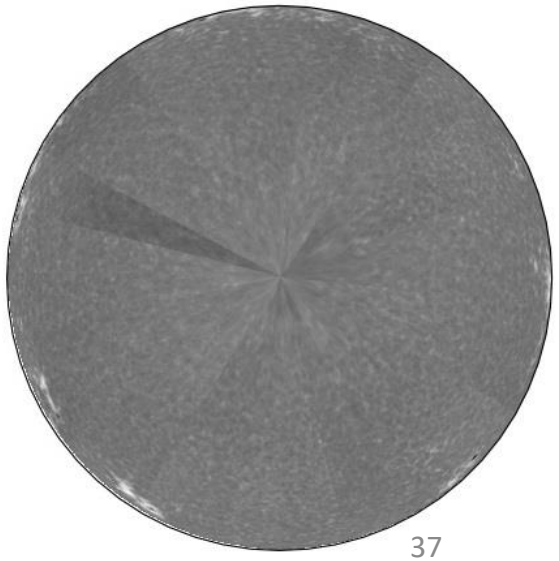
View of the Sun at 30° of latitude



View of the Sun at 60° of latitude

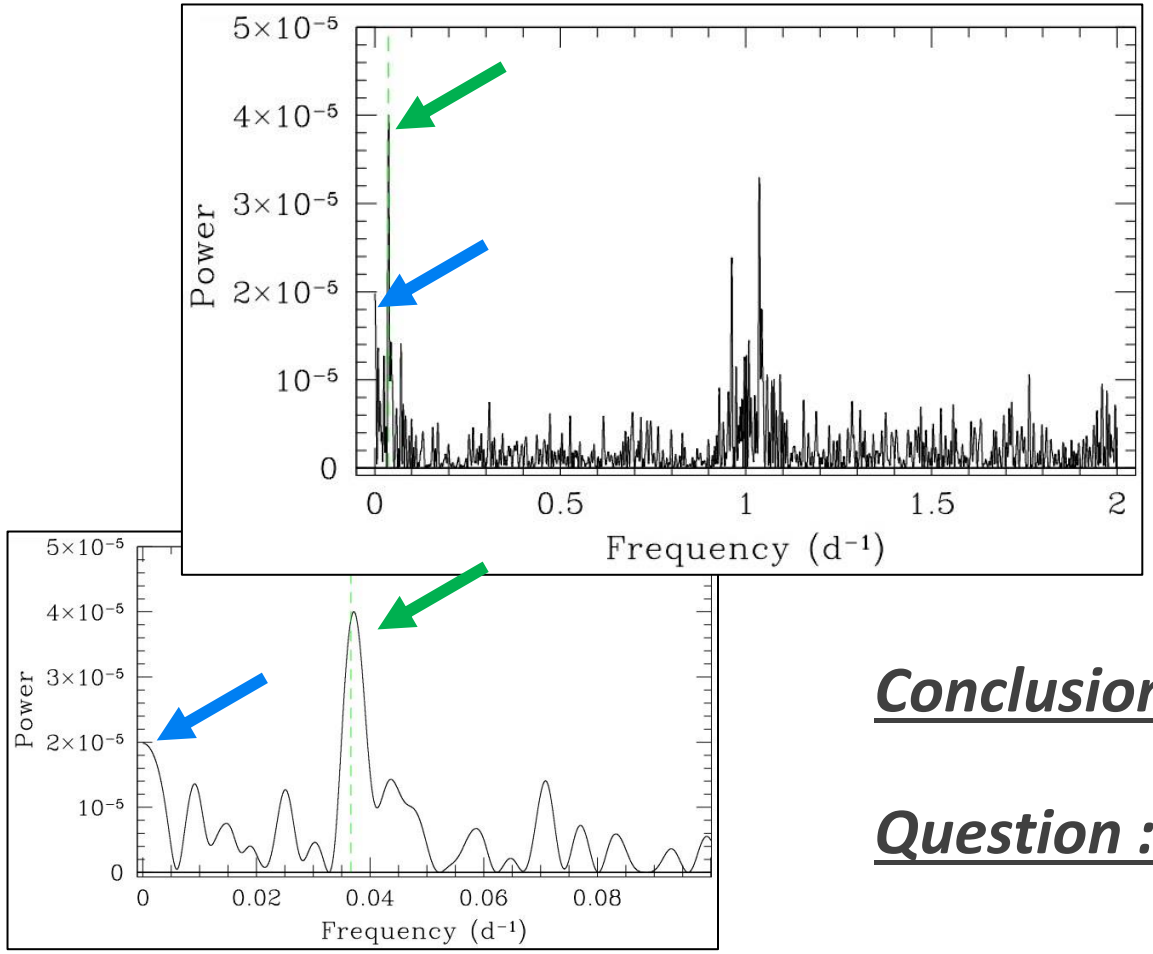


View of the Sun at 90° of latitude



5. Periodic modulations

⇒ Search for presence of **rotation modulation** in the time series of plages.



- ***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** $(27.27\ d)$
- Weaker peak at very low frequency :
  ⇒ **Solar activity cycle** $(11\ y)$

Conclusion : Solar rotation is present in plages time series

Question : Always present ? Variation with the solar cycle ?

5. Periodic modulations

Rotational modulation

Verification of **non-uniform distribution of plages in longitude** around the 2 maxima

Around 2014-05-22

Around 2015-06-26