Observed UV contrast of magnetic features and implications on solar irradiance models

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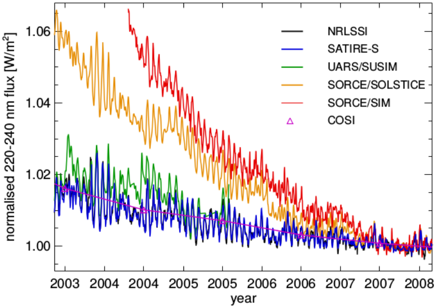
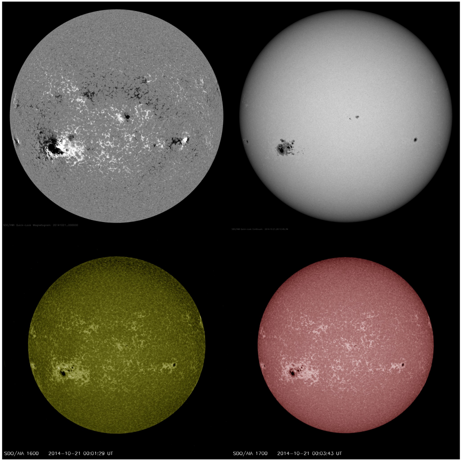
Goal of our work

- Solar irradiance is the main contribution to the earth climate energy.
- TSI variations are well known.
- However variations of the solar irradiance in UV are strongly discussed. There are important differences between the variations predicted by the different models and with the observations.
- In our work, we aim at better characterizing of the contrast in the UV domain, for constraining models and observations.



Data

- Data used :
    - HMI 45s magnetograms
    - HMI 45s continuum images at 617.3*nm*
    - AIA images at 160*nm*
    - AIA images at 170*nm*
- Data are taken between August 7, 2010 and December 31, 2016 with a 5 days step between each data point

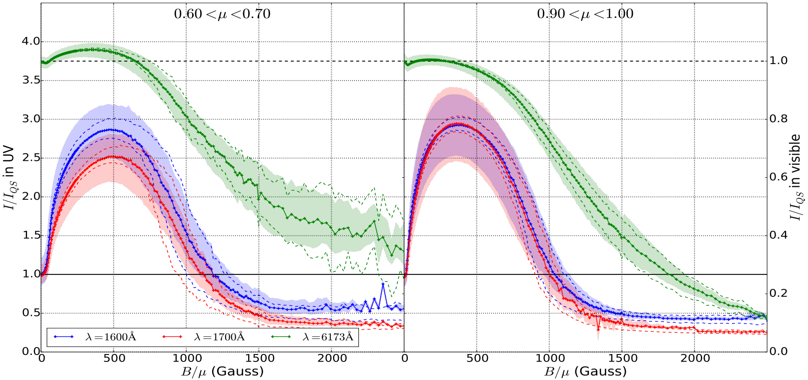


Data processing

- Images co-alignement
- Active regions are identified as regions where $B > B_{thresh}$ where B_{thresh} is defined as $3\sigma_B$, where σ_B is determined with the same method than in Yeo *et al.* (2013)
- CLV and flat field are treated at once and determined from quiet Sun pixel only.
- We divide each AIA image by the CLV_{QS} and we obtain contrast images. The contrast is defined like :

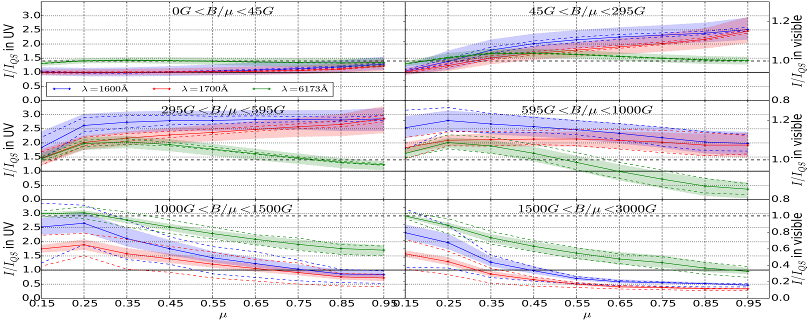
$$C_{pixel}(\lambda, B/\mu, \mu) = \frac{I_{pixel}(\lambda, B/\mu, \mu)}{I_{QuietSun}(\lambda, B/\mu, \mu)}$$

Contrast in function of magnetic field



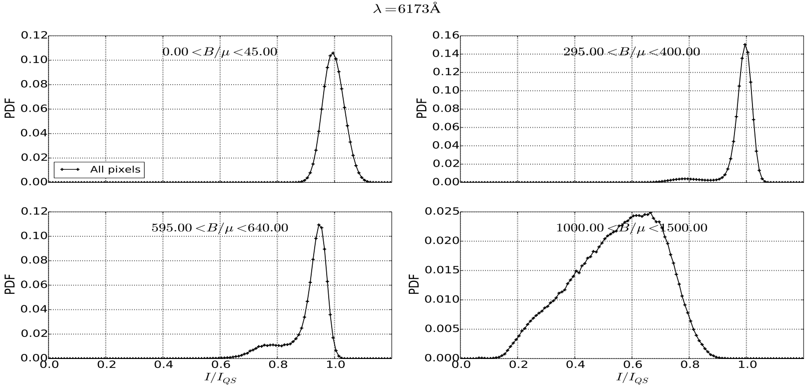
- Contrast in the visible and at 170*nm* agree with those found by Yeo (Yeo *et al.* (2013) and Yeo *et al.* (2017, in prep))
- Contrasts in UV are, as expected, much stronger than in visible
- Except at the center of the solar disk, contrasts at 160*nm* are always stronger than those at 170*nm*. Probably caused by the C IV line included in the 160nm passband

Contrast vs heliocentric angle



- For $1.0kG < B/\mu < 1.5kG$, contrast of the sunspots become bright at $\mu \sim 0.3$ in the visible and at $\mu \sim 0.7$ in UV
- Unlike in visible and as expected, the faculae are observable whatever μ
- CLV at 160*nm* decreases more slowly than at 170*nm* for the medium magnetic field. It may be due to a fainter absorption.
- For high magnetic field, CLV at 160*nm* increases strongly than at 170*nm*. It may be due to heating of the chromosphere and a weaker absorption.

Probability density function (PDF) of the contrast of pixels **in visible at disk center**

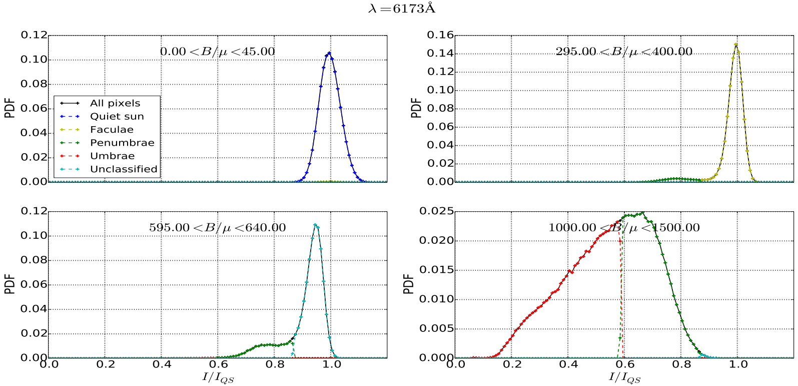


- These distributions are relatively broad. It thus seems difficult to associate a single contrast with a given value of B/μ and μ
- Distribution of the pixel's contrast shows a bimodality for the medium magnetic field
  $\Rightarrow$ The magnetograms alone are not sufficient to define the solar structures.
- Same at UV wavelengths but discussed later

Structure identification with continuum images and magnetogramms

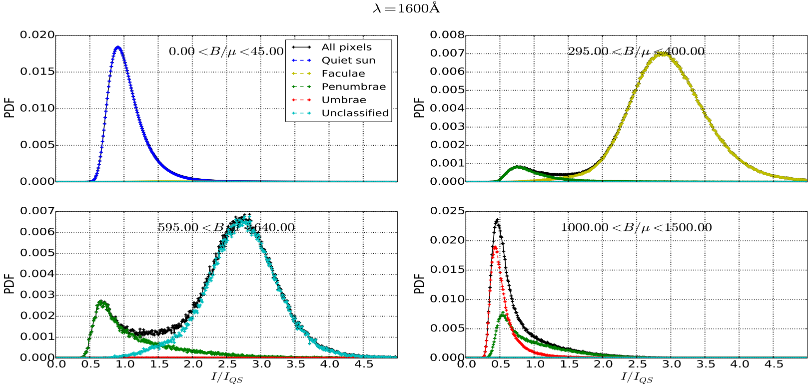
- We rely on the SATIRE criteria as defined in Yeo et al 2014 :
  - All pixels with $|B| > 45G$ are defined as active regions
  - If the value of the contrast at $617.3nm$ of an active pixel is below than 0.59 $\Rightarrow$ sunspot umbrae
  - If the value of the contrast at $617.3nm$ of an active pixel is between 0.59 and 0.87 $\Rightarrow$ sunspot penumbrae
  - All active pixels which are not an umbrae or penumbrae pixels and which have a magnetic field below $B_{cut} = 600G$ are regarded as faculae
  - All pixels which are not an umbrae or penumbrae pixels and which have a magnetic field above $B_{cut} = 600G$ are flagged as unclassified pixels
- To validate our segmentation, we computed the ratio between the sunspot umbrae area and the total sunspot area. We obtain a ratio of 0.18 ± 0.04, therefore very close to the expected ratio of 0.2.
- We also found an excellent correlation with the daily sunspot area (DSA) from the Royal Greenwich Observatory

PDF of the contrast of solar structures at **disk center at** 617.3*nm*



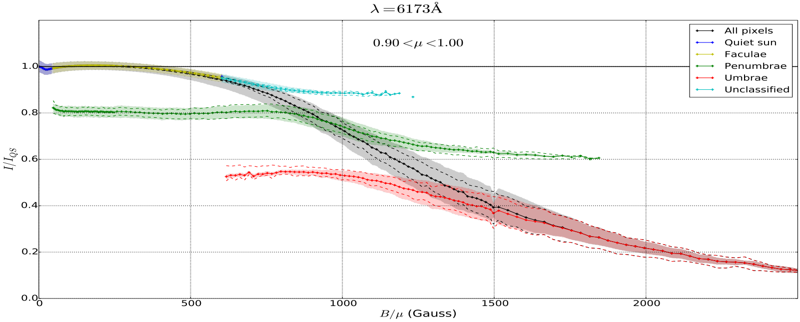
- Segmentation criteria appear correct. Each mode of the distribution corresponds to a pre-defined structure
- Penumbrae and umbrae seem to belong to the same contrast distribution
- Contrast of unclassified pixels similar to those of the quiet Sun

PDF of the contrast of solar structures **at disk center at** 160*nm*



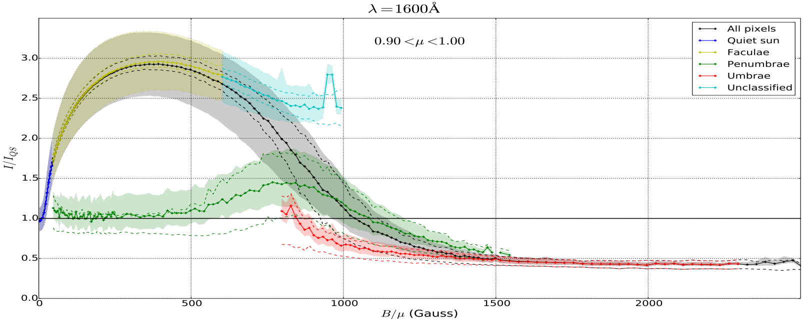
- The bimodality is more pronounced in UV and, as in visible, each mode corresponds to a pre-defined structure
- Contrast of unclassified pixels is similar to those of the faculae

How do structures contrast vary with B/μ?



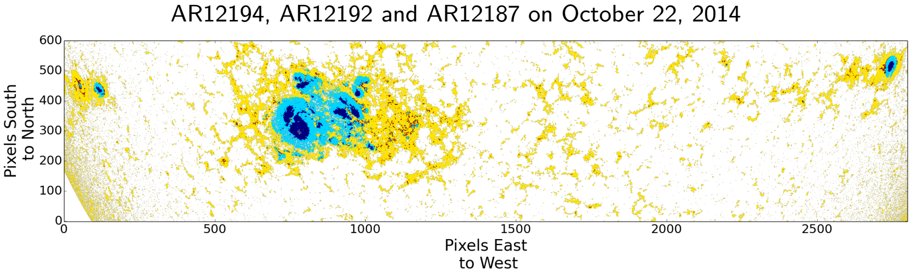
- For each value of B/μ, several structures are present
- Variations of the contrast at the center of the disk :
  - Faculae contrast increases until $\sim 250G$, and decreases until $\sim 600G$. Contrast varies by $\sim 5\%$
  - Penumbrae contrast varies by $\sim 25\%$
  - Umbrae contrast decreases by $\sim 75\%$
- Contrast of unclassified pixels is between quiet Sun and penumbrae contrast, and decreases when B/μ increase.

How do structures contrast vary with B/μ ?



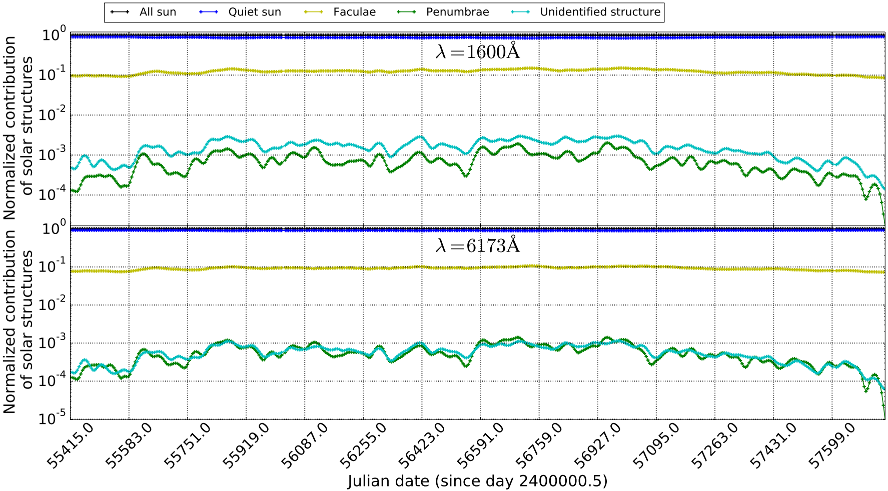
- For each value of B/μ, several structures are present
- Variations of the contrast at the center of the disk :
  - Faculae contrast increases until $\sim 250G$, and decreases until $\sim 600G$. Contrast varies by $\sim$ 70%
  - Penumbrae contrast varies by $\sim$ 60%
  - Umbrae contrast decreases by $\sim$ 60%
- In UV, contrast of unclassified pixels is close to the one of faculae, and decreases when B/μ increase.

Position of the unclassified pixels



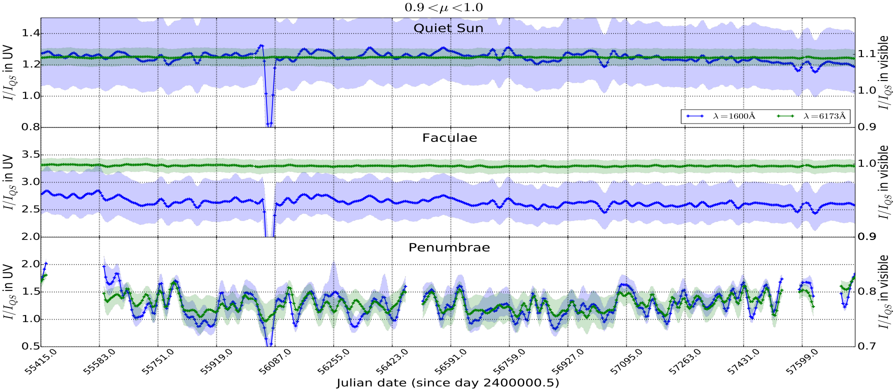
- Unclassified pixels (red pixels in the images) are mostly concentrated near the sunspots. But some unclassified pixels are found in the active regions without sunspot.
- We are currently trying to define more precisely the spatial distribution of the unclassified pixels, and in particular their distance from the sunspots

Contributions of the solar structures to the irradiance



- The largest contribution to irradiance comes from the quiet Sun.
- Contribution from unclassified pixels is always similar, or even greater, than that of the penumbrae.

Time evolution of the contrast of solar structures



- We see high frequency variations of the contrast, and we suppose that is a statistical effect.
- No structures show correlated variations with the solar cycle. This seems true for the three wavelengths we studied.
- Variation of the irradiance during the solar cycle seems to be due only to the change of the coverage of the structures, within the experimental uncertainties.

Conclusion and work in progress

- Contrasts are stronger in UV than in the visible
- Contrast at 160nm behaves similarly to 170nm. CLV at 160nm decreases more slowly toward the limb than 170nm for the faculae. We suppose that is due to the presence of the C IV line in the passband and less absorption.
- Unclassified pixels look like faculae in UV and their contribution to the solar irradiance seems, in absolute value, as important as that of penumbrae
- Contrasts of structure do not seem to vary during the solar cycle