The Si I 1082.7 nm line is in emission in sunspot umbrae

David Orozco Suárez
Carlos Quintero Noda
et al.

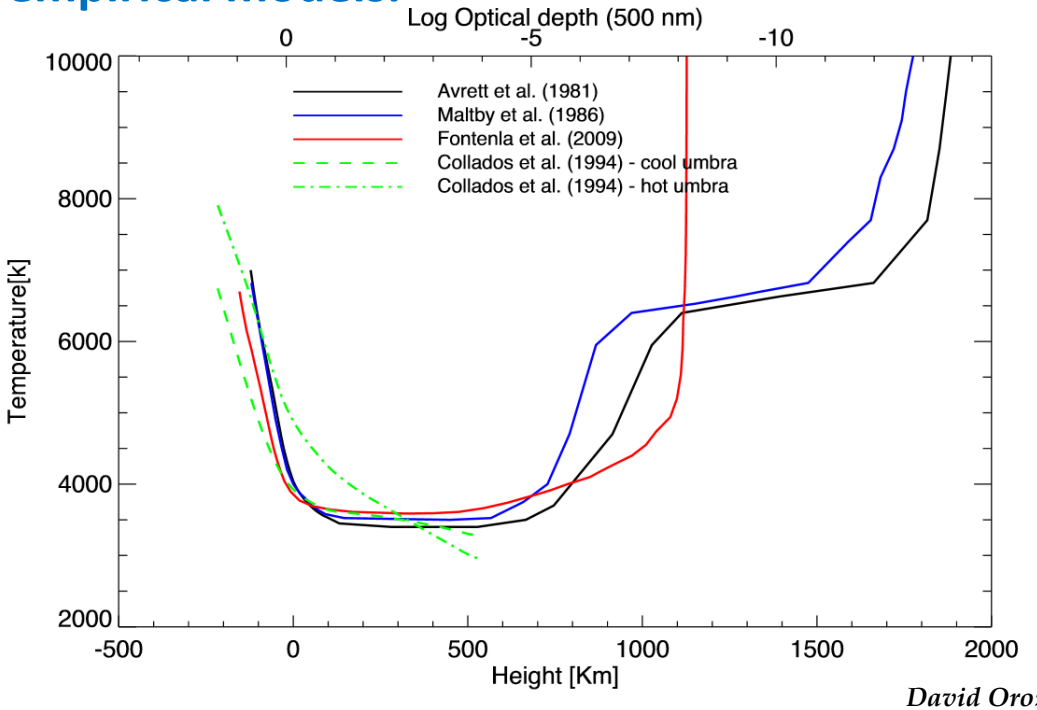
Instituto de Astrofísica de Andalucía (IAA-CSIC), Granada, Spain
et al.

SPG
Solar Physics Group

INSTITUTO de ASTROFISICA de ANDALUCIA
CSIC
I·A·A

Introduction

- ★ In the literature, there are several proposed empirical models specific to sunspot umbrae.
- ★ These models have difficulties to properly reproduce the solar chromosphere.
  - ★ Example: Iwai et al. (2016) report that observed sunspot umbral temperature brightness at 8.8 mm range is much less than predicted by current empirical models.



David Orozco Suárez

SPG
Solar Physics Group

Observations and data analysis

- Recent GREGOR observations of the Si I 1082 nm can help improve current atmospheric models
- In our case, we use GREGOR data taken on 27 June 2014 with GRIS.
- Data were subjected to standard preprocessing.
- The spectral stray-light (about 8%) was removed.
- Then, we de-convolved the data from the GREGOR PSF:
  - Assuming 40% stray-light calculated with the mercury transit.
  - Taken the GAOS information for constructing the core of the PSF.
- The deconvolution is done using the PCA method.

$$\mathrm{PSF}(r) = \alpha G_1(r, \sigma_1) + (1 - \alpha) G_2(r, \sigma_2)$$

David Orozco Suárez

Results

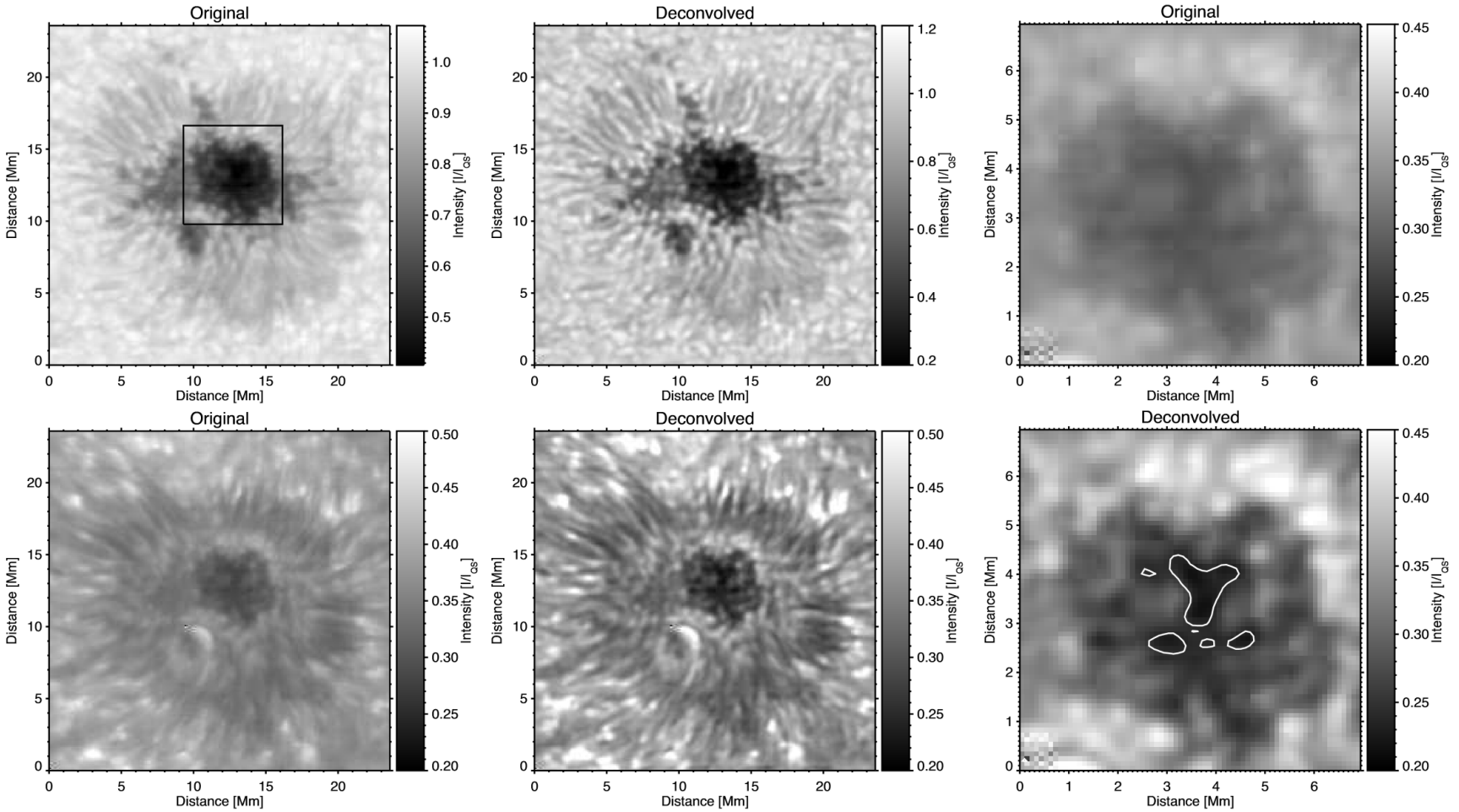


Fig. 2. Intensity maps of the observed NOAA 12096 sunspot corresponding to the continuum (left and center panels at the top of the figure) and to the Si I 1082.9 nm line core (left and center panels at the bottom). The left panels represent the original data and the center panels the reconstructed data. The right-most panels show a zoom over the original (top) and reconstructed (bottom) sunspot umbra in the continuum (see the square in the top-left panel). The contours outline the region where the Si I 1082.9 nm continuum is below 25% of the average quiet Sun.

Results

- ★ Most interesting part is in the observed Stokes profiles
  - ★ They are in emission at the sunspot umbra.
  - ★ Stokes V shows a reversal at the zero crossing point.

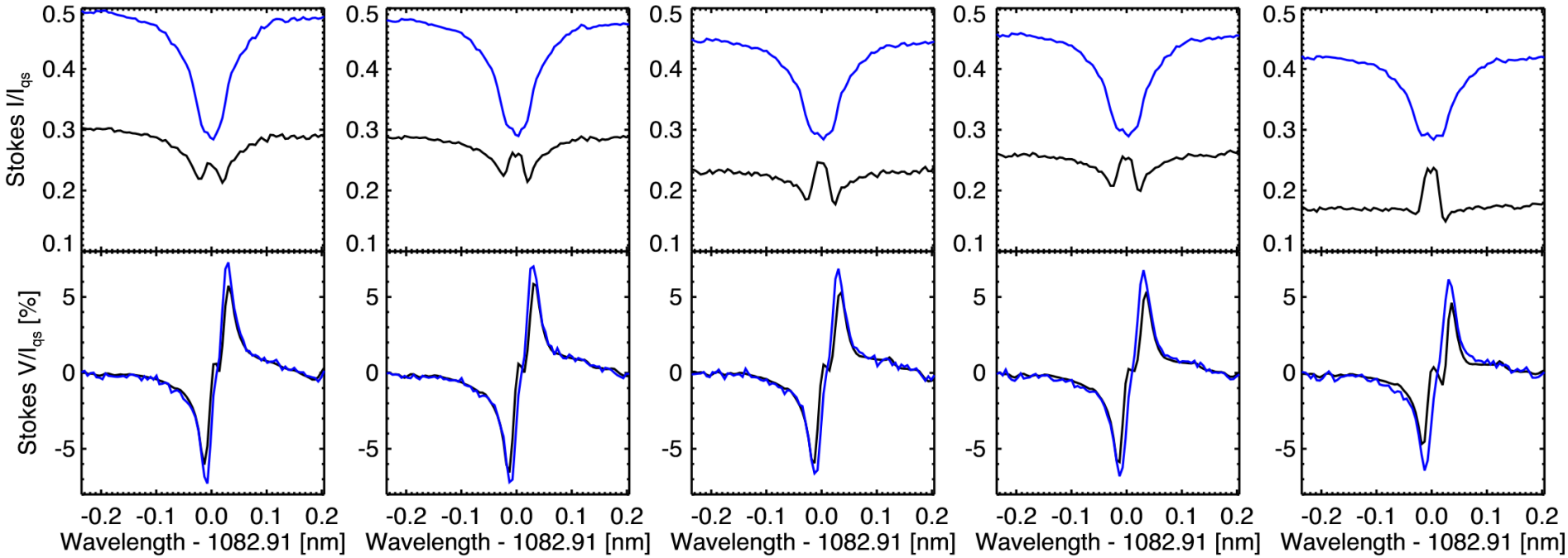


Fig. 3. Variation of the original (blue color) and reconstructed (black color) Stokes I/I_{QS} and V/I_{QS} profiles as we move from the inner penumbral boundary (first column) to the center of the umbra (last column).

Results

- ★ This results are more or less independent on the seeing conditions, i.e., the stray-light (scattered light) is about constant and it is the main contributor to the PSF.
- ★ This figure shows how the emission disappears when the stray light is above 20%
- ★ Continuum values of about 20% for the umbra are within current model predictions (e.g., Kiess, Christoph et al. 2014)

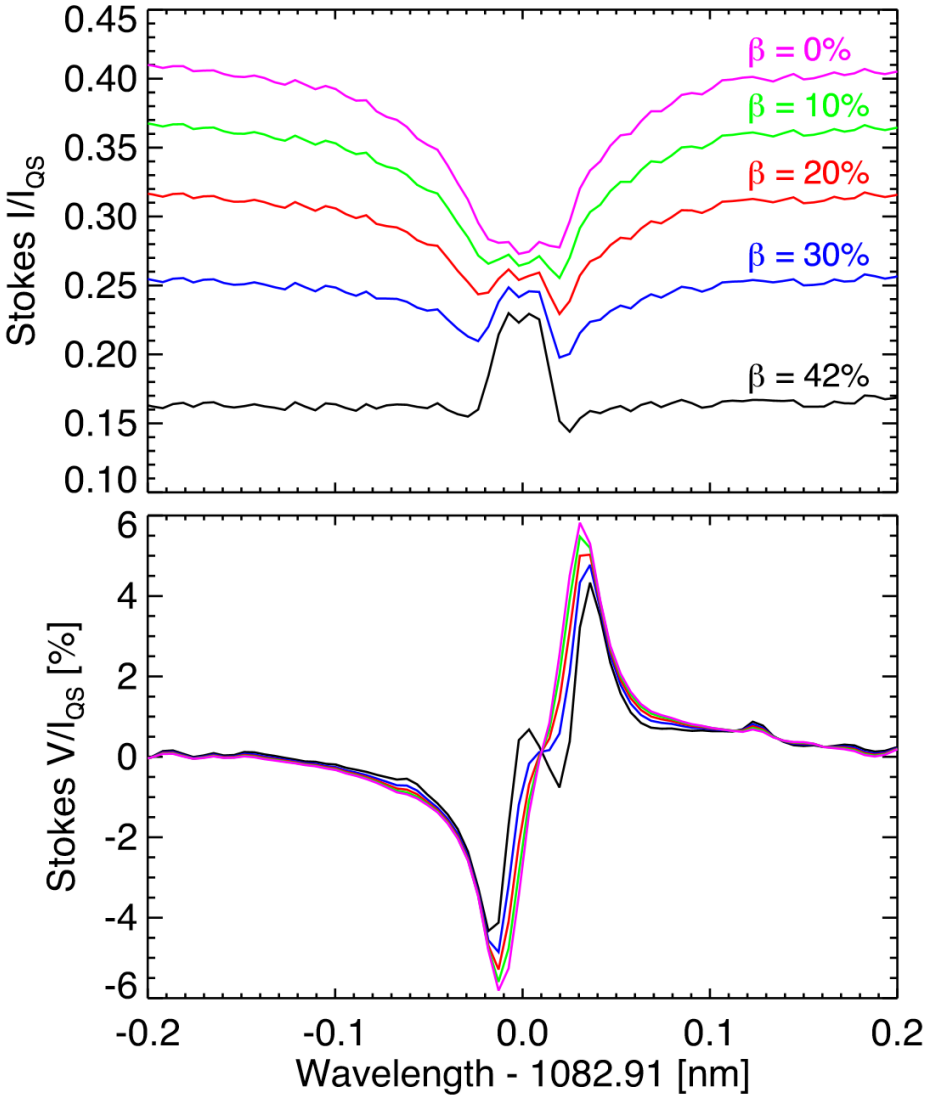


Fig. 4. Variation of Stokes I/I_{QS} and V/I_{QS} profiles with the amount of scattered light β from 0% to 42%.

Results

- We investigated whether it is an artifact of the deconvolution technique.
- But, different deconvolution methods provide the same results (e.g., maximum entropy method).
- Degraded observations to VTT with 10% of scattered light and same seeing conditions.
- It should have been seen before at the VTT but no one has reported this before.

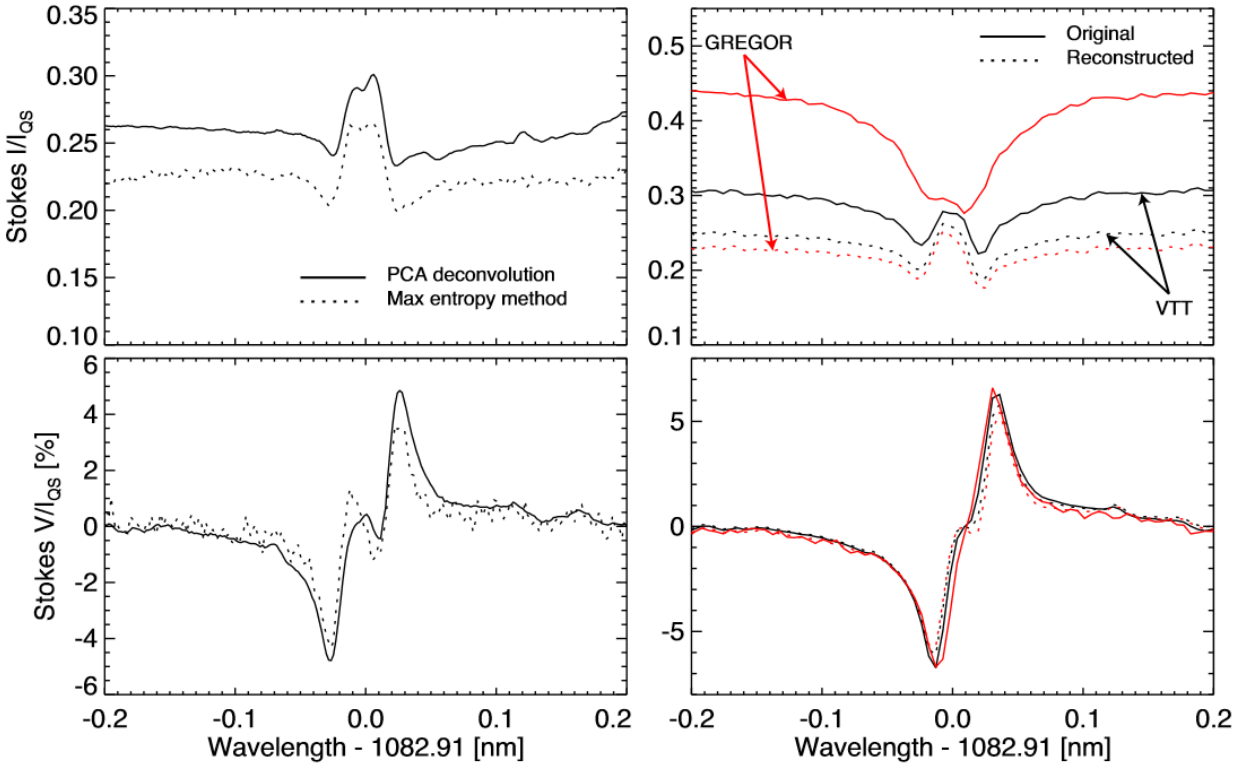
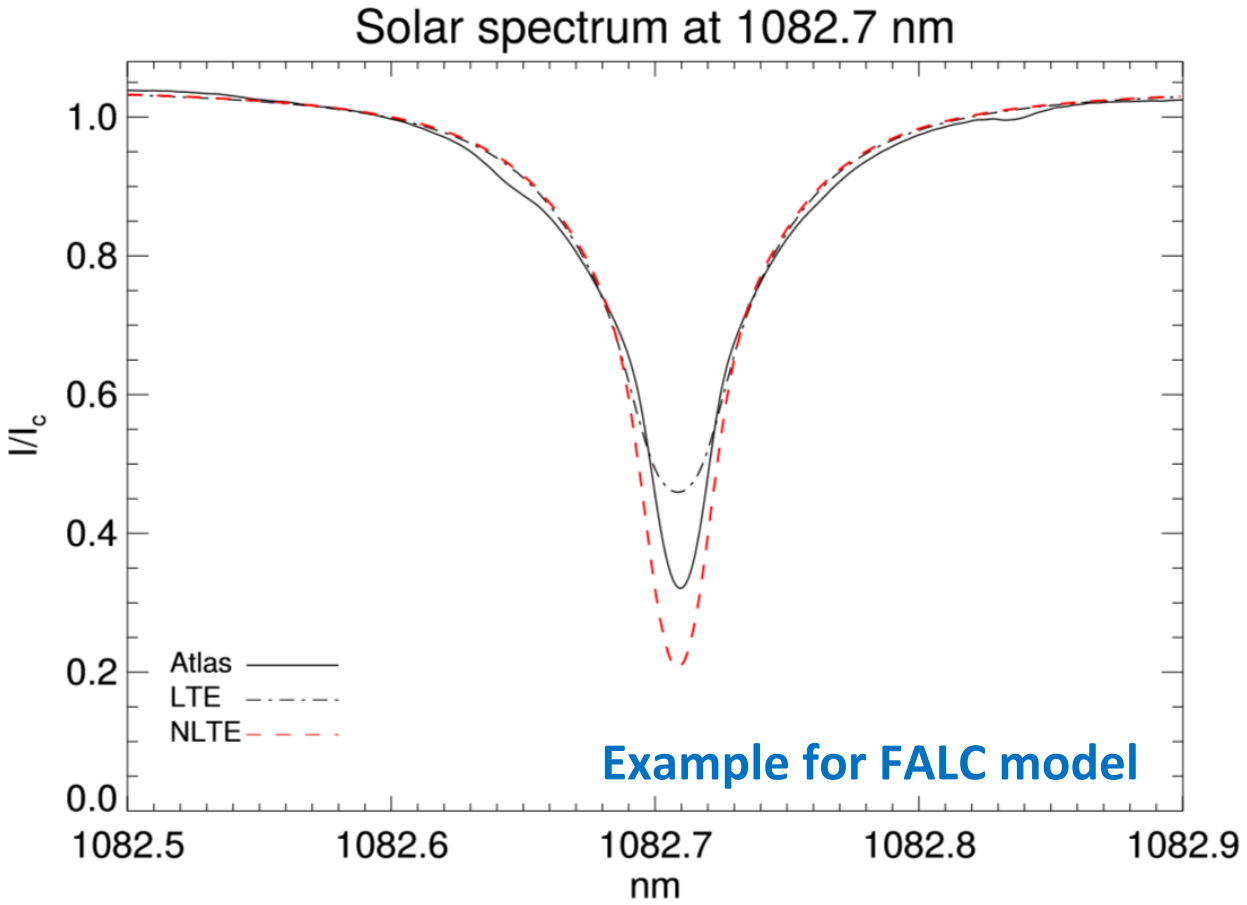


Fig. 5. Left panels represent an umbra Stokes I/I_{QS} and V/I_{QS} profiles reconstructed using the PCA deconvolution method and the maximum entropy method. The right panels show an umbra Stokes I/I_{QS} and V/I_{QS} profile as one would see them by GREGOR and the German VTT. The solid line represent the non-reconstructed data while the dotted stands for the reconstructed one. Black line corresponds to the German VTT and red to the GREGOR telescope.

Si 1082.7 nm in NLTE

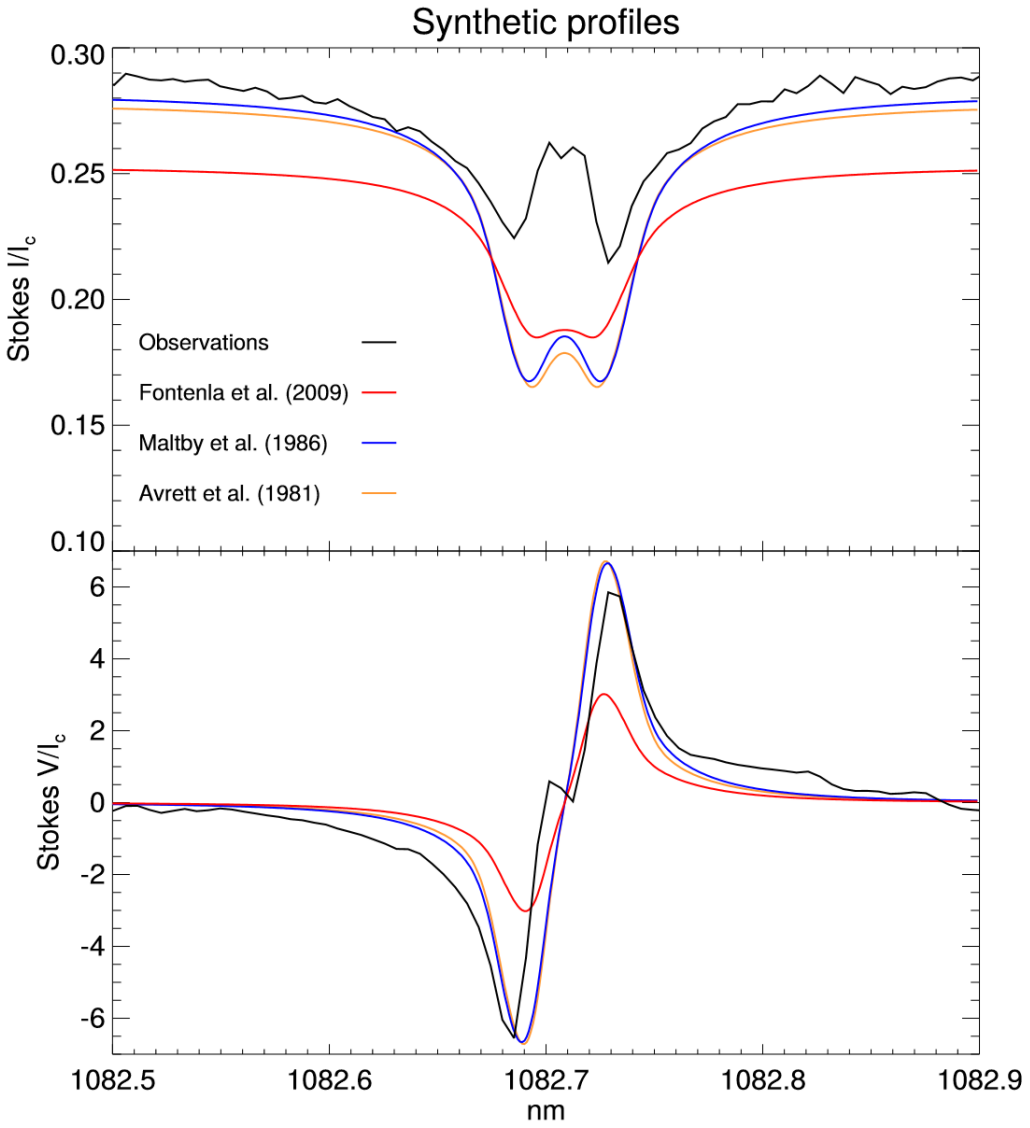
- ★ The Si I line is in non-local thermodynamic equilibrium
- ★ Use the model of Bard & Carlsson (2008) and NICOLE code (Socas-Navarro et al. 2015) to synthesize the line.



David Orozco Suárez

NLTE synthesis

- Take umbra models, synthesize the Si I line, and compare with the observations.
- Similar continuum values
- The line core of the synthetic profiles is NOT in emission
- They show the Zeeman splitting due to a strong vertical field.
- No Stokes V reversal at the zero-crossing point.
- Where does the emission come from?



David Orozco Suárez

NLTE inversions

- In this very moment we are performing inversions of the profiles with NICOLE.
- Results will come soon

SPG
Solar Physics Group

Conclusions

- ★ The silicon Line is in emission in sunspot umbrae
- ★ Only visible at high resolution and after removing scattered light from the data.
- ★ May contribute to a better modeling of current umbra models at chromospheric heights.
- ★ Still inversion results to come but first results show that the temperature minimum region is located at lower height in sunspot umbrae.
- ★ This may provide natural explanation for the observations in the mm range.