Atmosphere models of solar magnetic regions derived from high-resolution spectro-polarimetric observations

Alice Cristaldi, Ilaria Ermolli
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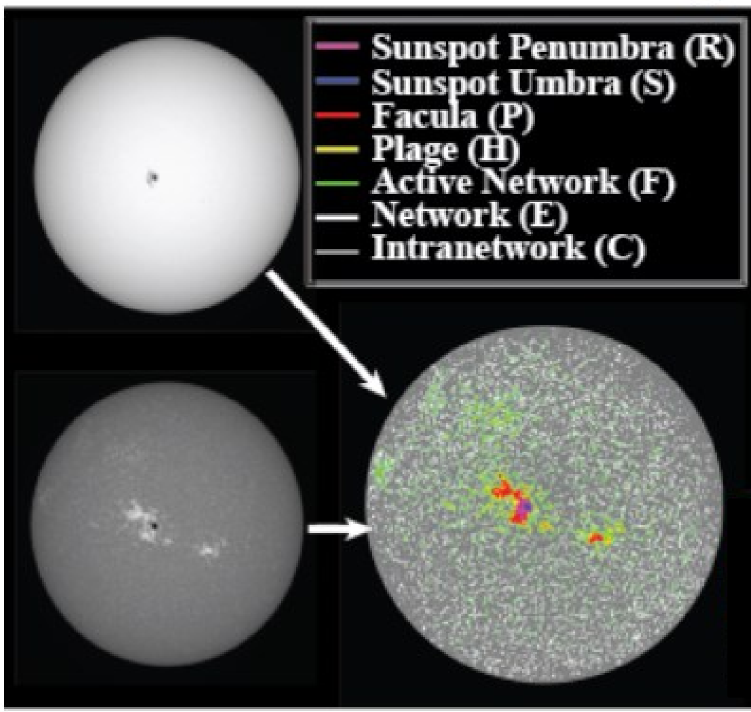
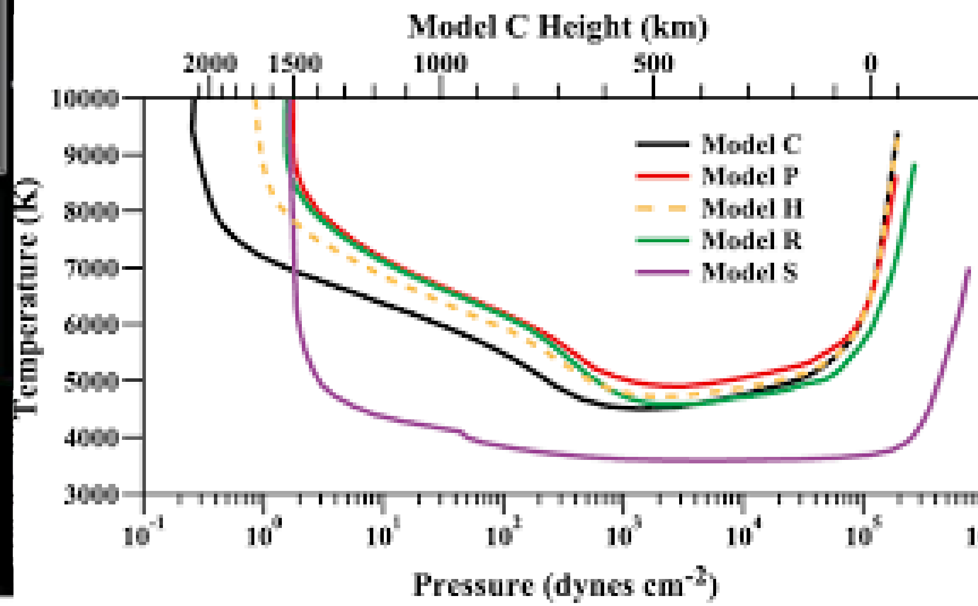
Modelling Solar Irradiance

• **Semi-empirical** : aimed at reconstructing the solar spectrum from intensity spectra of surface features, weighted by surface coverage.



Courtesy of Fontenla

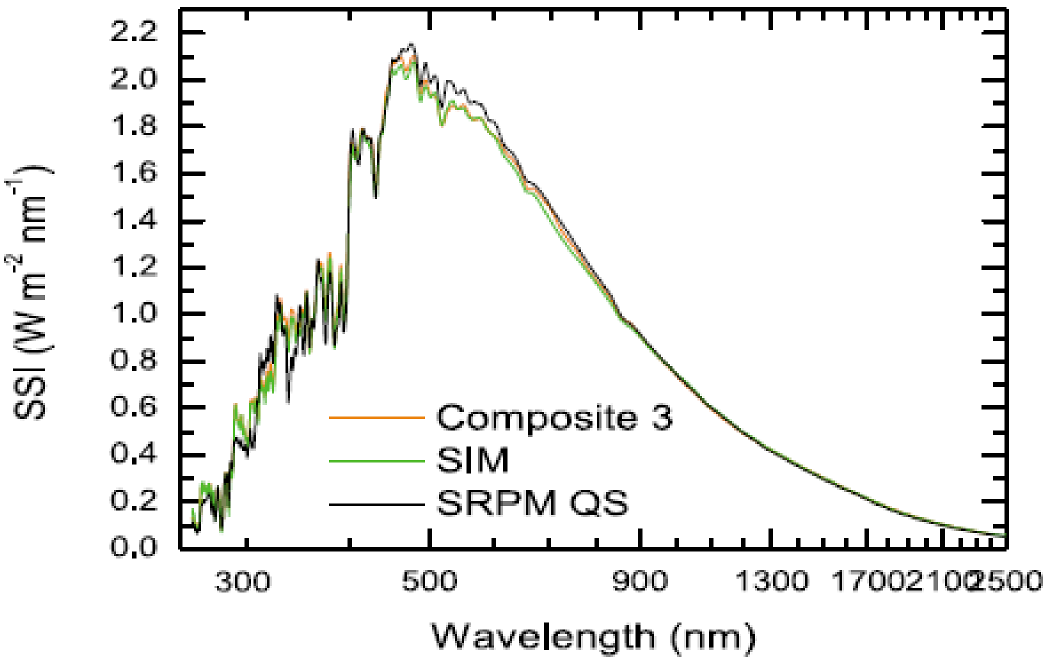
Solar atmosphere models by Fontenla et al., 2006



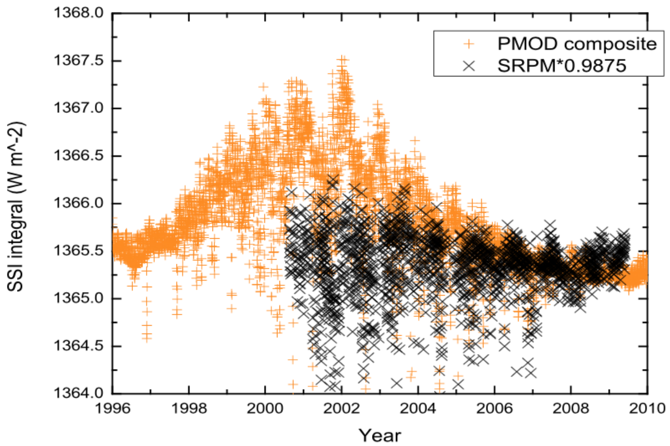
e.g. , so far: **SATIRE** (Yeo et al. 2014 and ref therein), **SRPM** (Fontenla et al. 2011), **COSI** (Haberreiter et al. 2008; Shapiro et al. 2010) and **SolMod3D** (Haberreiter 2011)

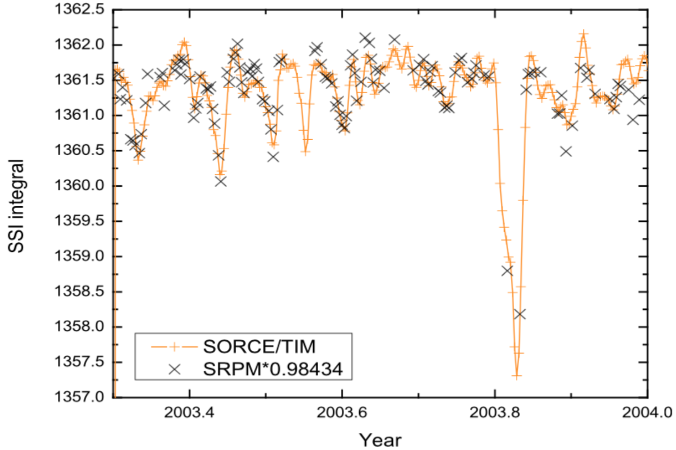
Modelling Solar Irradiance

LIMITS: **1-D** solar atmosphere models derived by low resolution observations. Are they accurate enough? (Uitenbroek & Criscuoli, 2011)



[Fontenla et al. 2011]





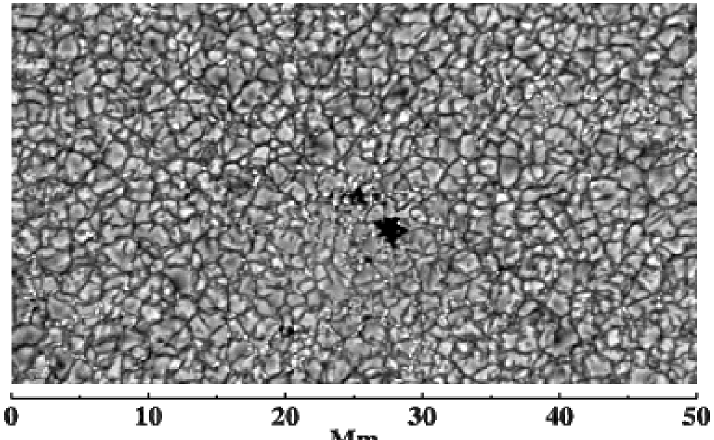
Our study

Current models need improvements (**small-scale** details, **3-D**)

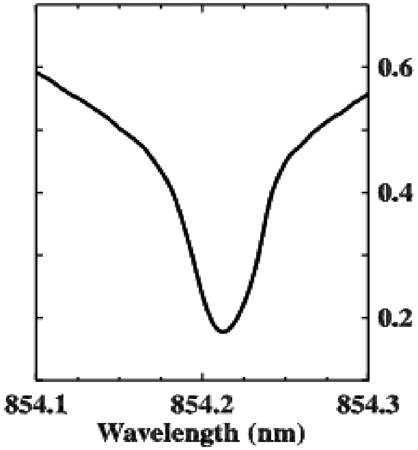
Aim: to derive atm models **from** high **spatial** and **spectral** resolution full-Stokes **observations** for improved irradiance estimates

Spatial scales resolved down to ~ 100 km

Spectral resolving power > 200000



Cauzzi et al. 2008

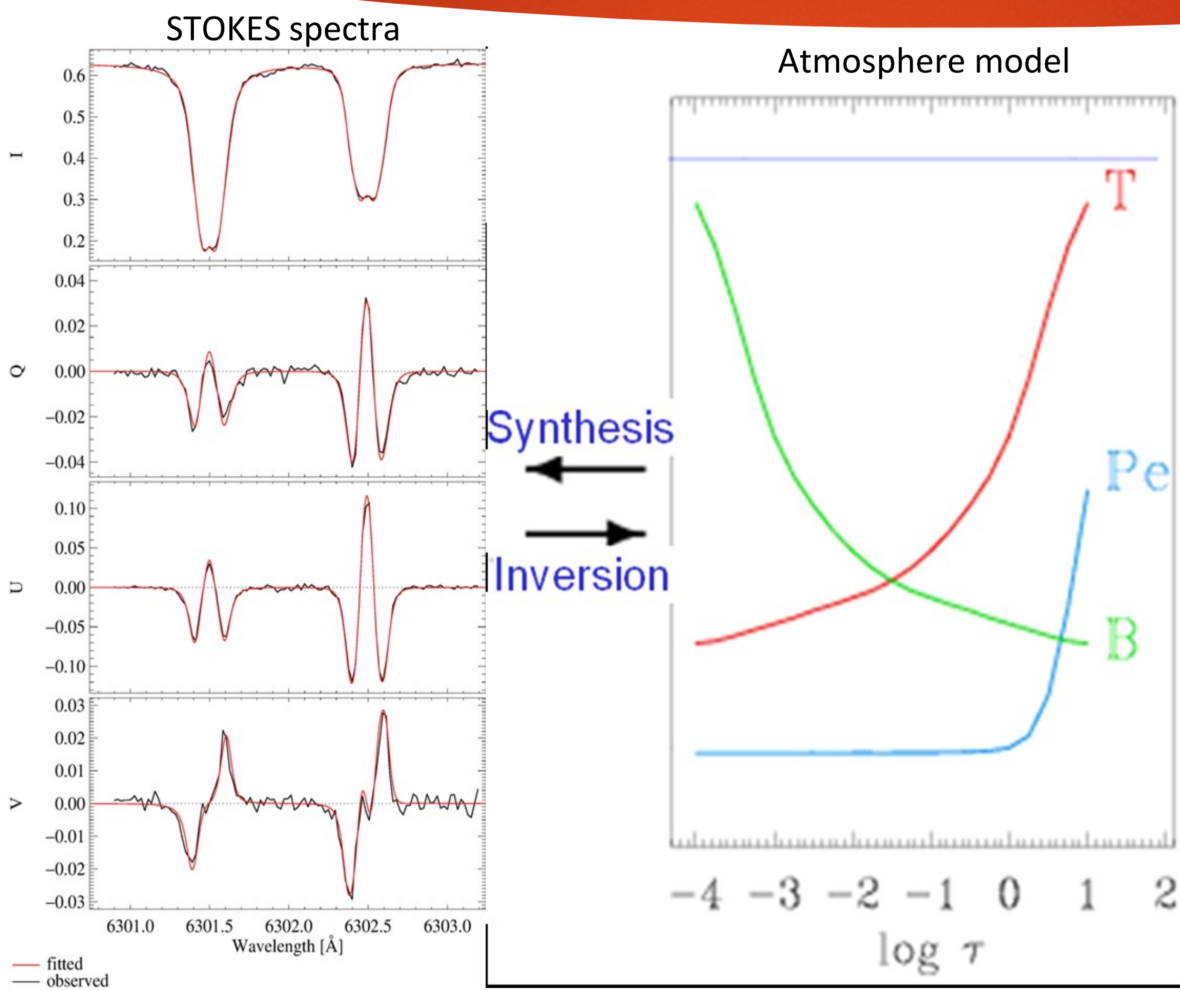


Ground-based available data

• SST/**CRISP** (Swedish 1-m Solar Telescope/ CRisp Imaging SpectroPolarimeter) August 6, 2011 - **Fe I 630 nm (photospheric lines)**

• DST/**IBIS** (Dunn Solar Telescope/Interferometric BIdimensional Spectrometer)
April 10, 2015 - **Fe I 617.3 nm (photospheric) and Ca II 854.2 nm (chromospheric)**

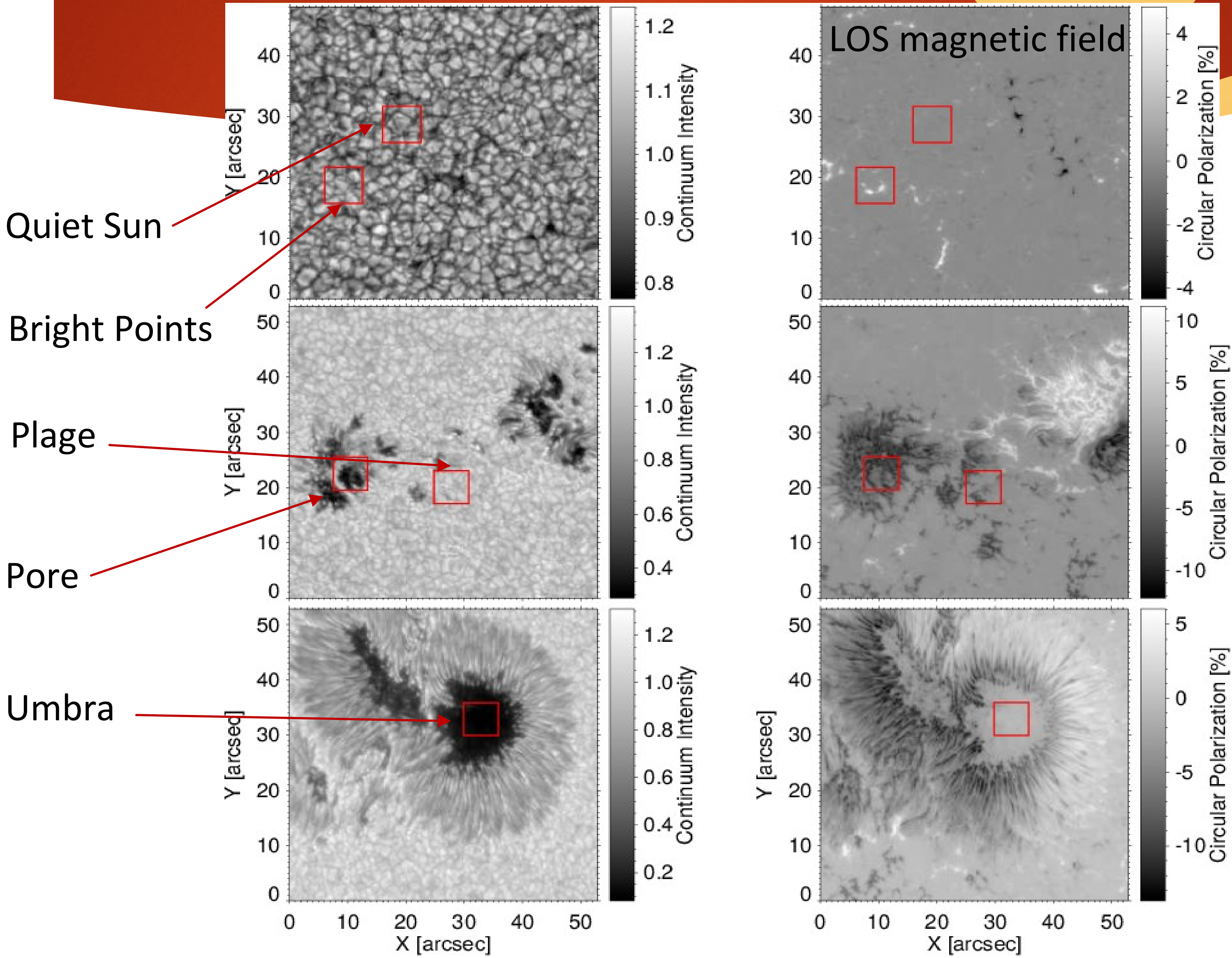
Inversion codes employed



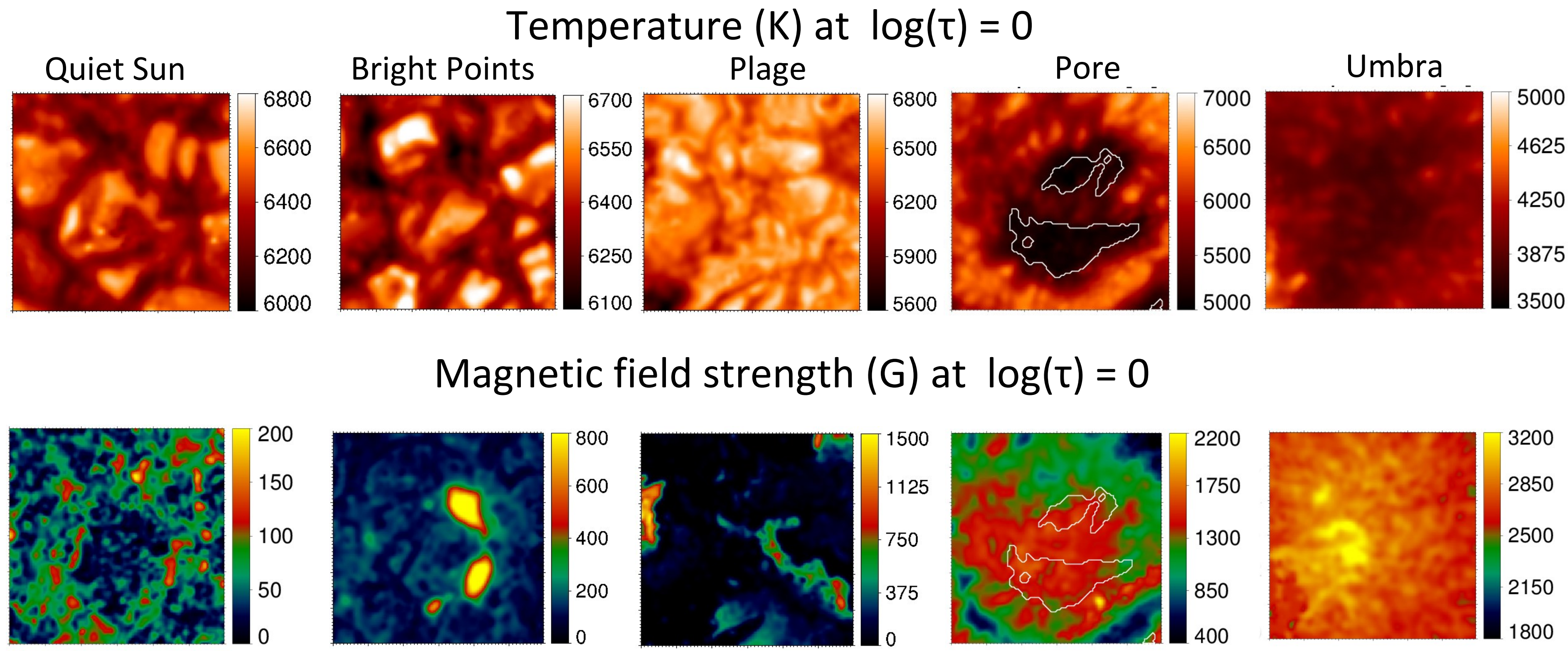
- **SIR** (Stokes Inversion based on Response functions, Ruiz Cobo & Del Toro Iniesta, 1992, ApJ, 398, 375)
  - works under the LTE (Local Thermodynamic Equilibrium) hypothesis.
  - **CRISP** data: **Fe I doublet at 630 nm**

- **NICOLE** (H. Socas-Navarro et al., 2015 A&A, 577, A25)
  - works under the Non-LTE hypothesis.
  - Inversion of chromospheric lines
  - **IBIS** data: **Fe I line at 617.3 nm and Ca II line at 854.2 nm**

SST/**CRISP** analysed features



RESULTS from SIR inversion of SST/CRISP data



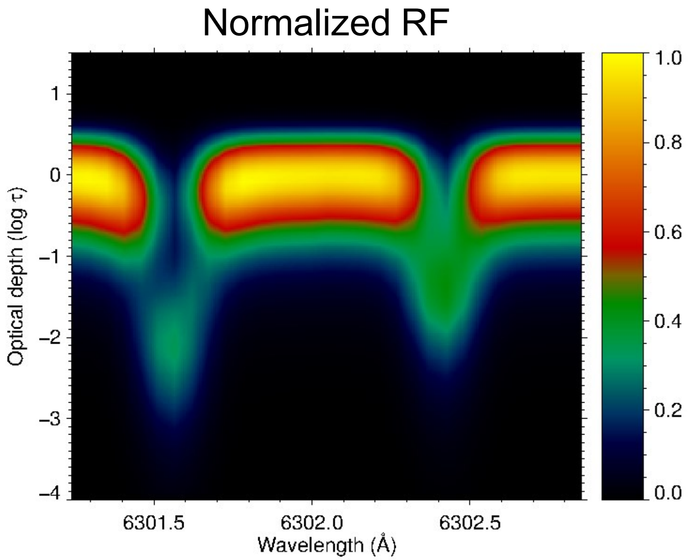
Cristaldi et al., in prep.

Temperature average profiles
Quiet Sun

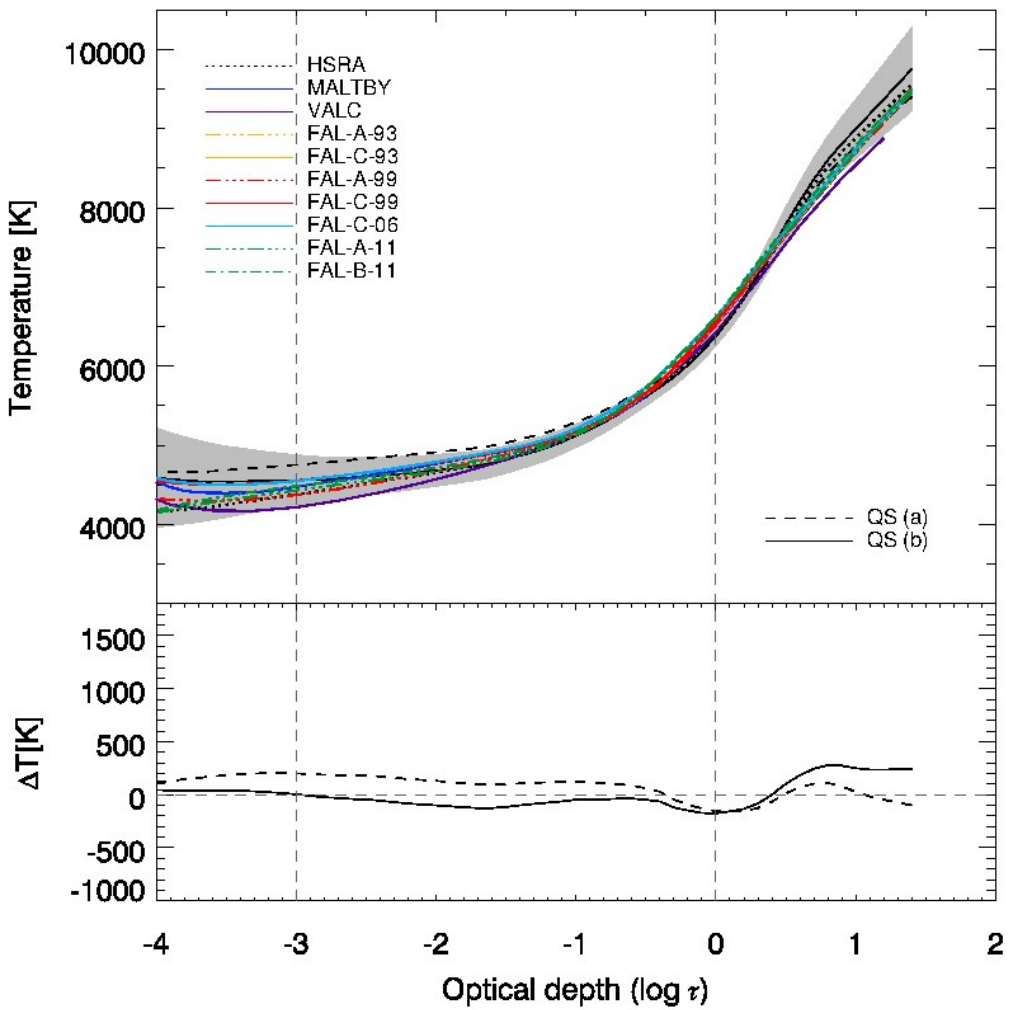
Response function

(Caccin et al, 1977; Landi & Landi, 1977)

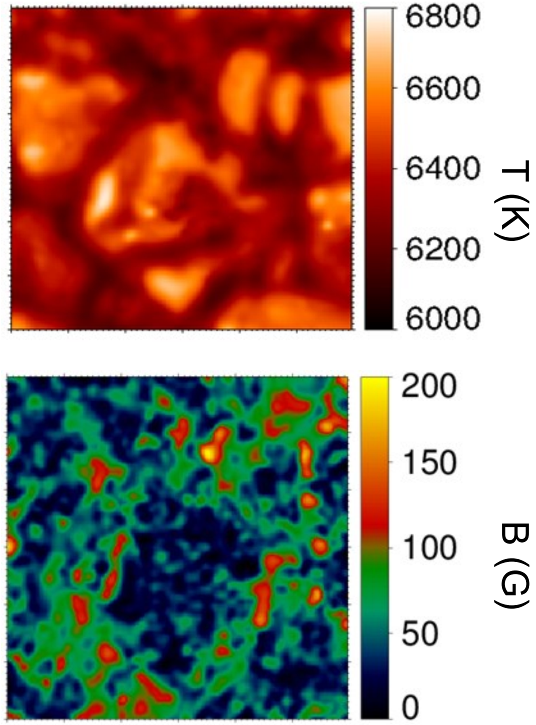
$$R(\lambda, \tau) = \frac{\Delta I\ (\lambda)}{\Delta T(\tau)}$$

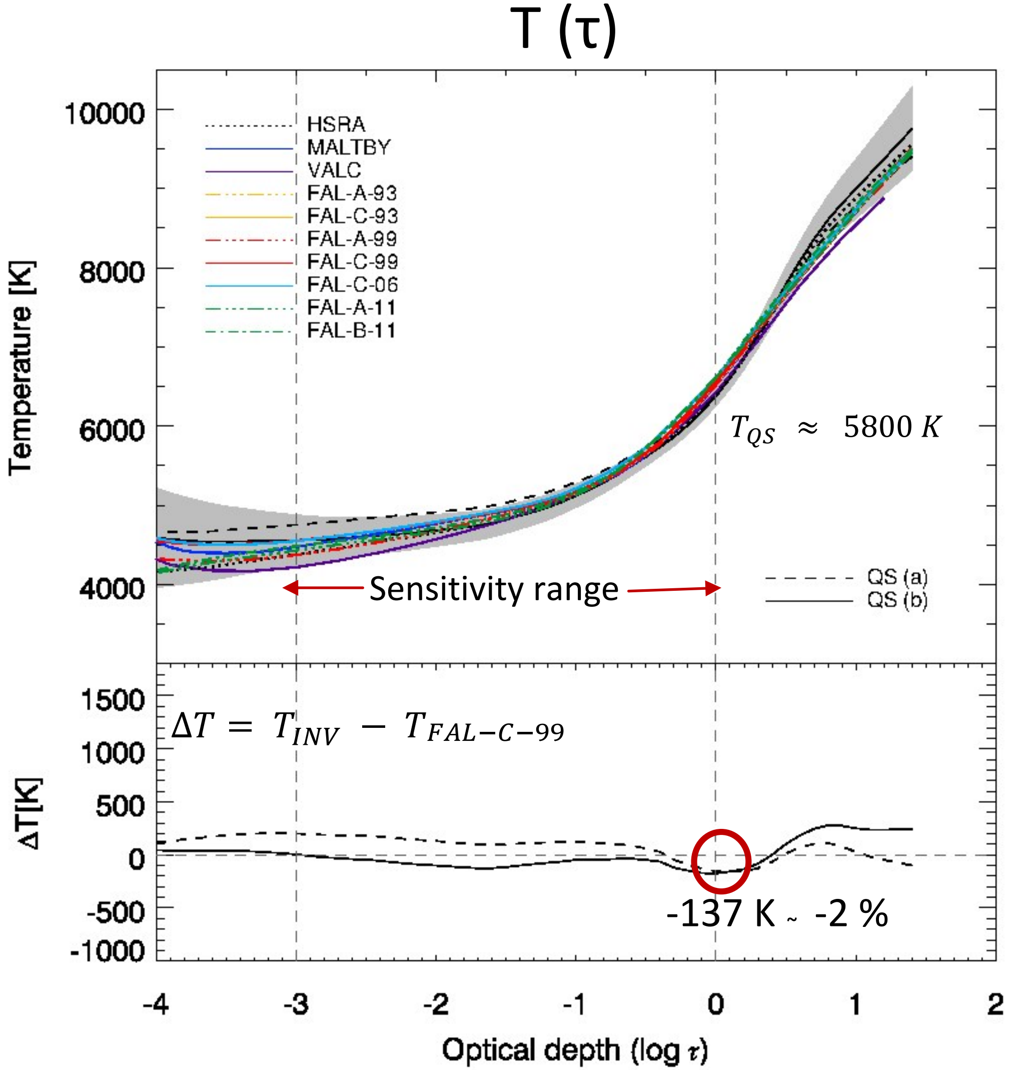


T (τ)

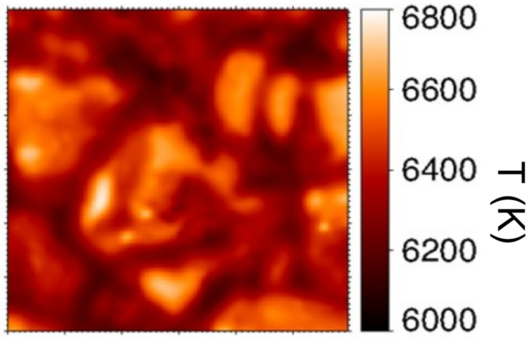


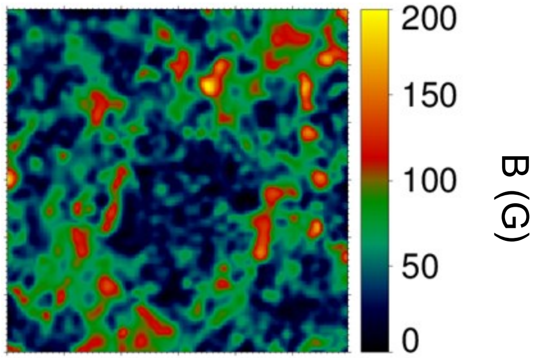
Temperature average profiles
Quiet Sun



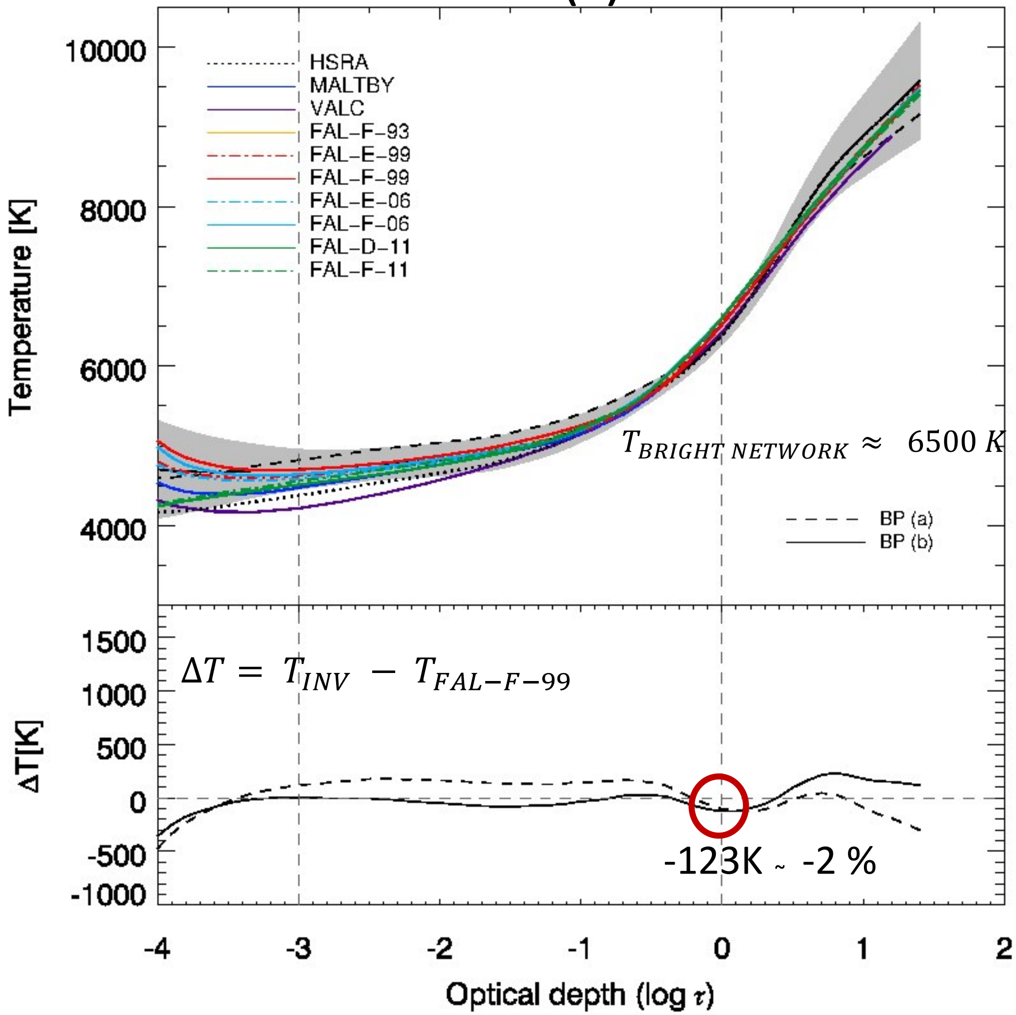


Temperature average profiles
Bright Points

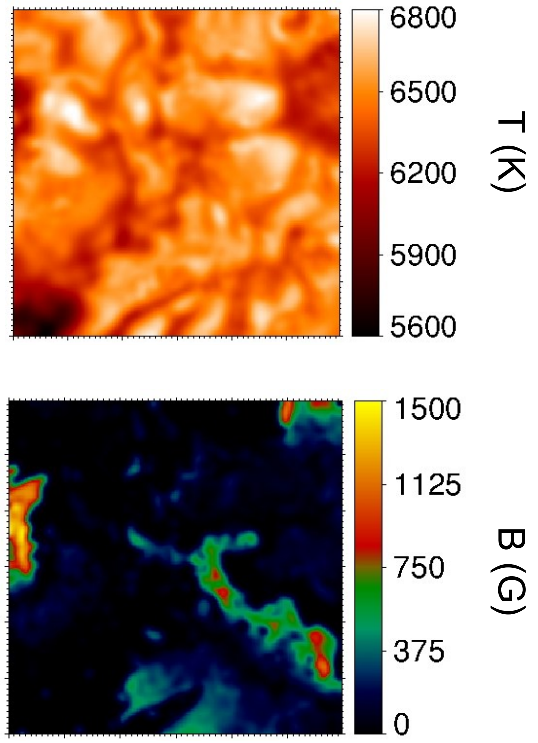


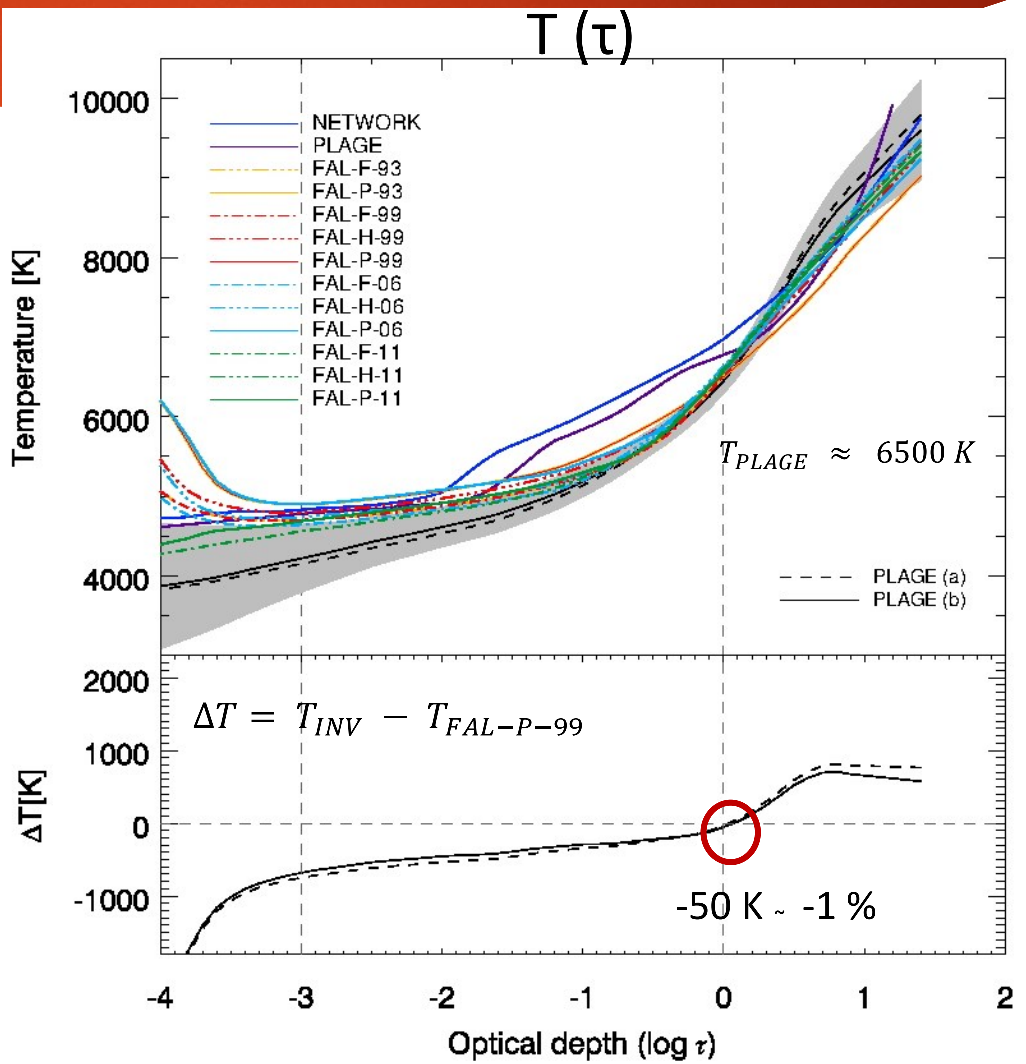


T (τ)



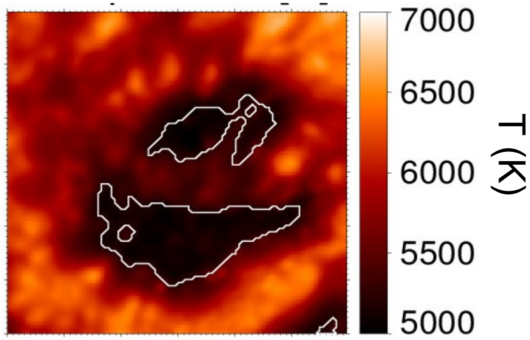
Temperature average profiles
Plage

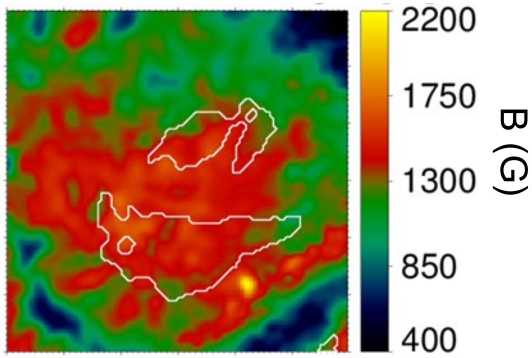


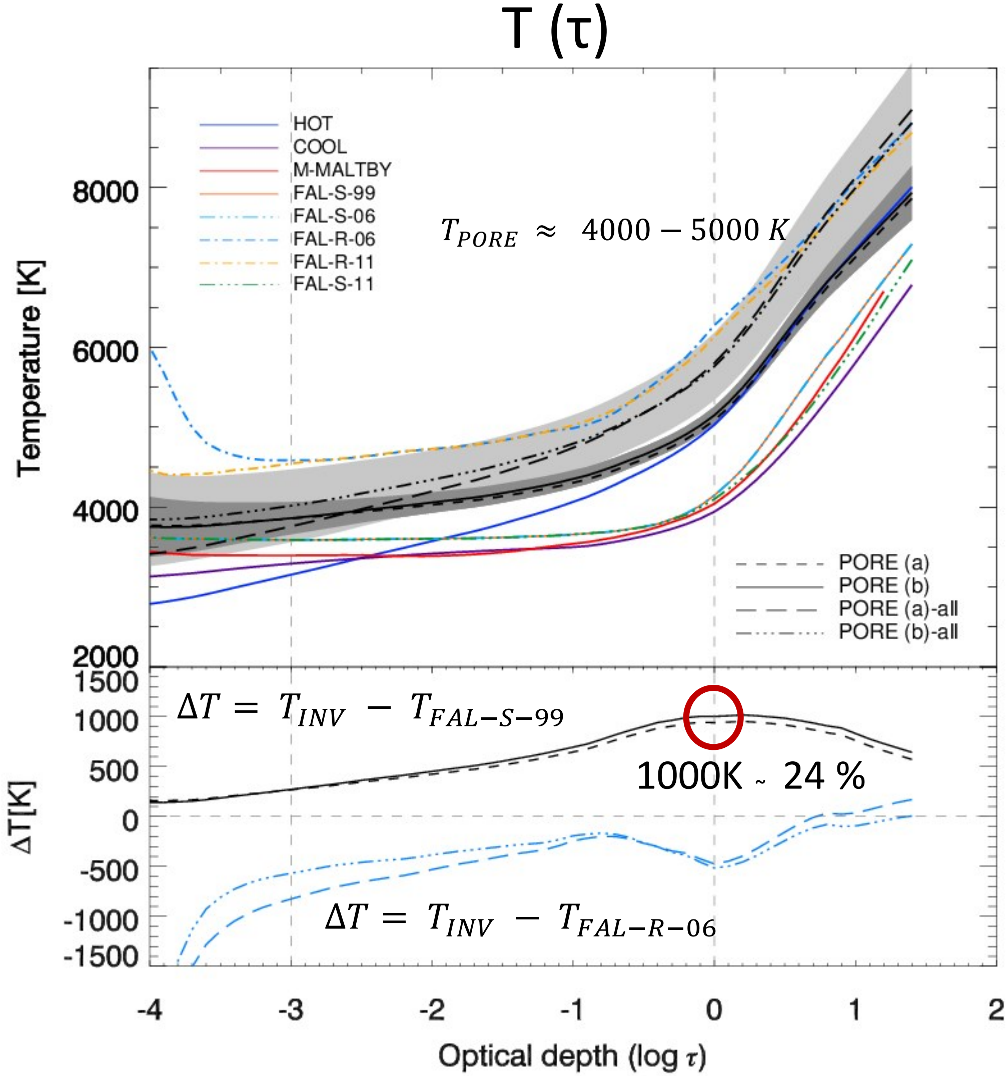


Temperature average profiles

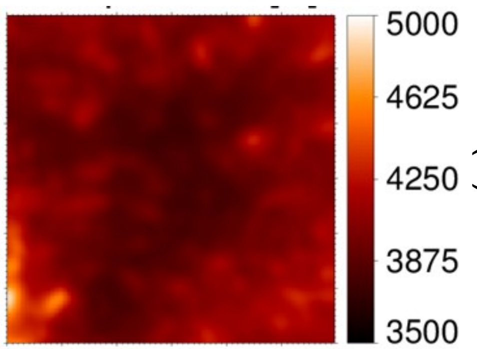
Pore

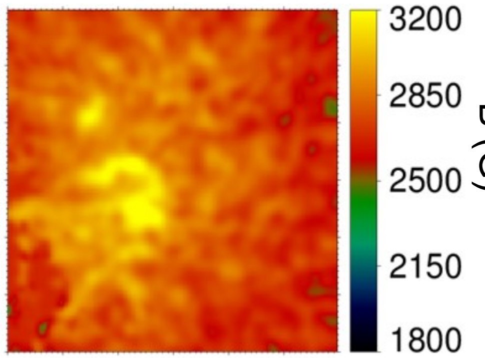




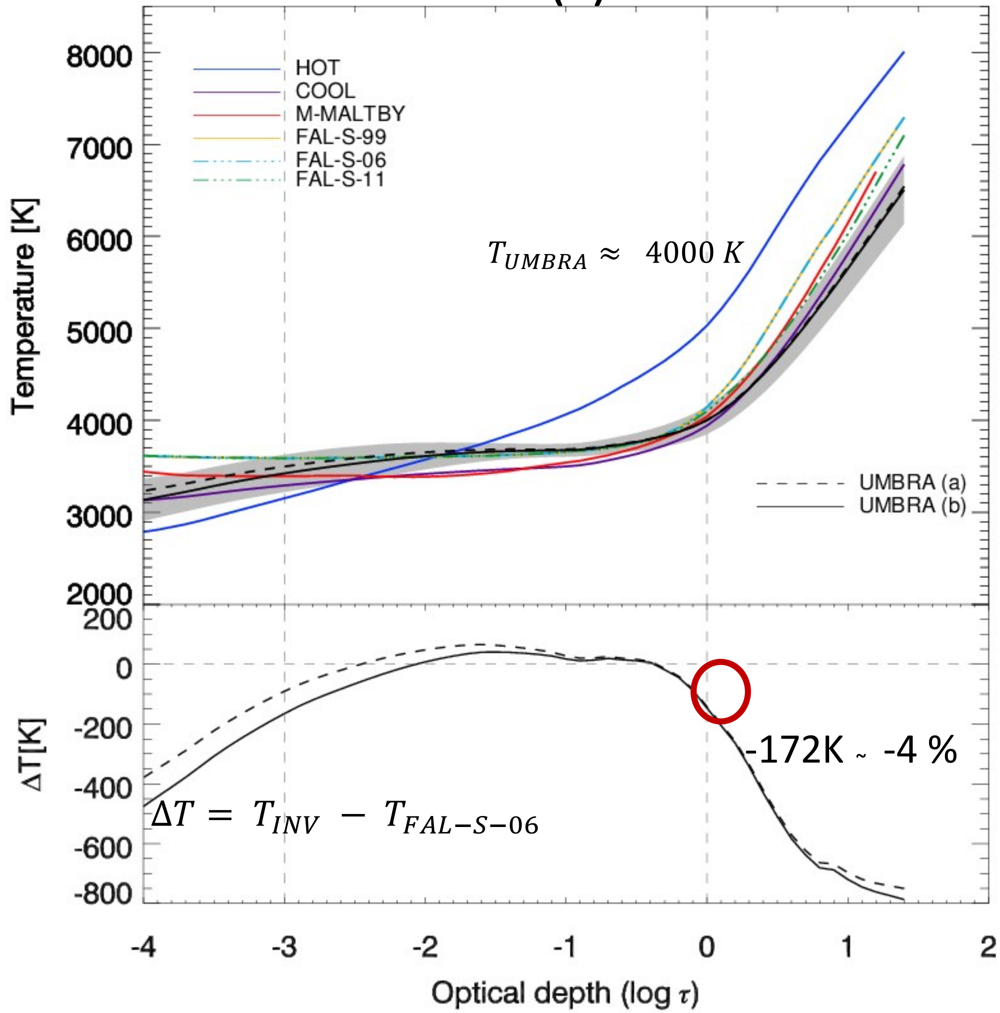


Temperature average profiles
Umbra

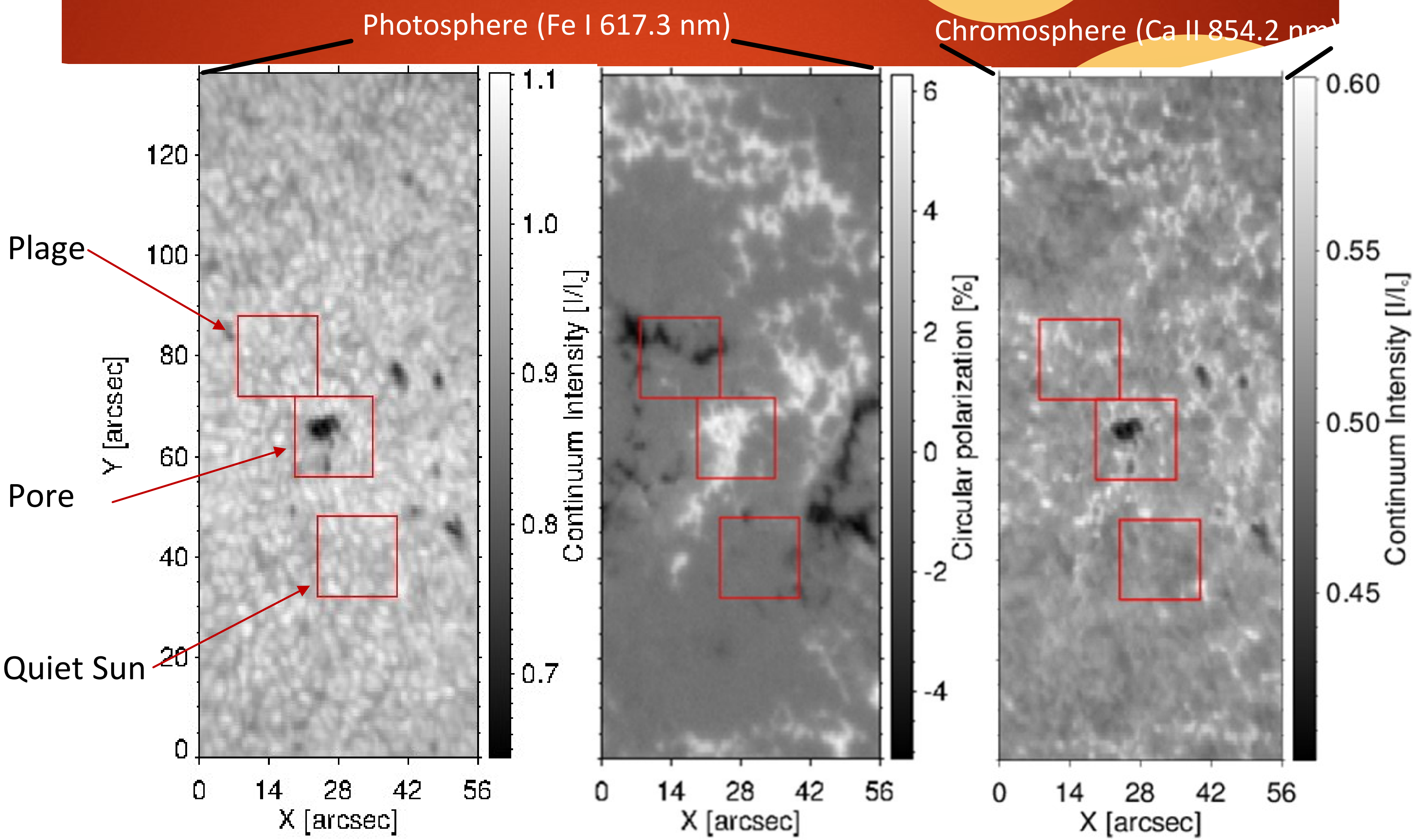




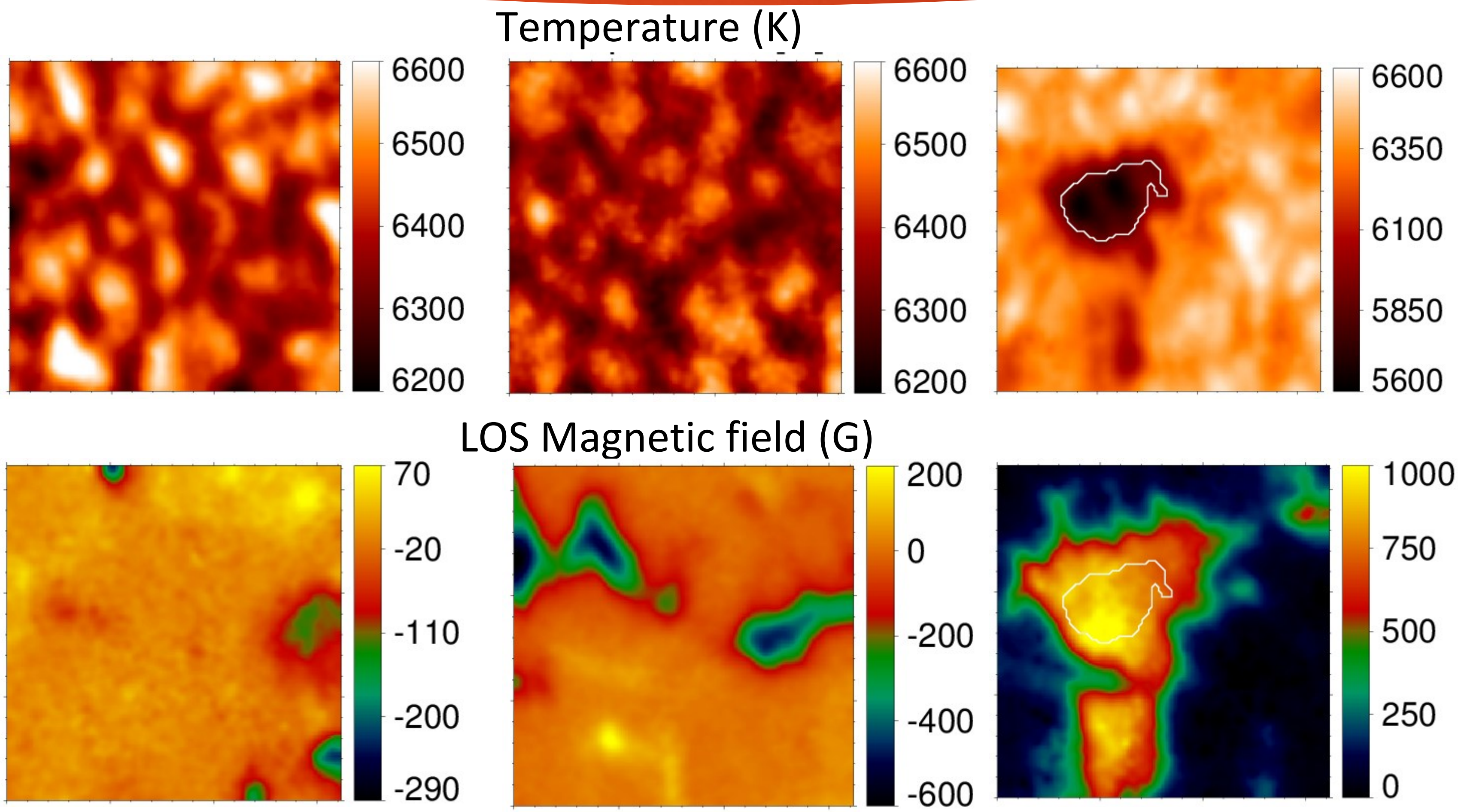
T (τ)



DST/**IBIS** analysed features



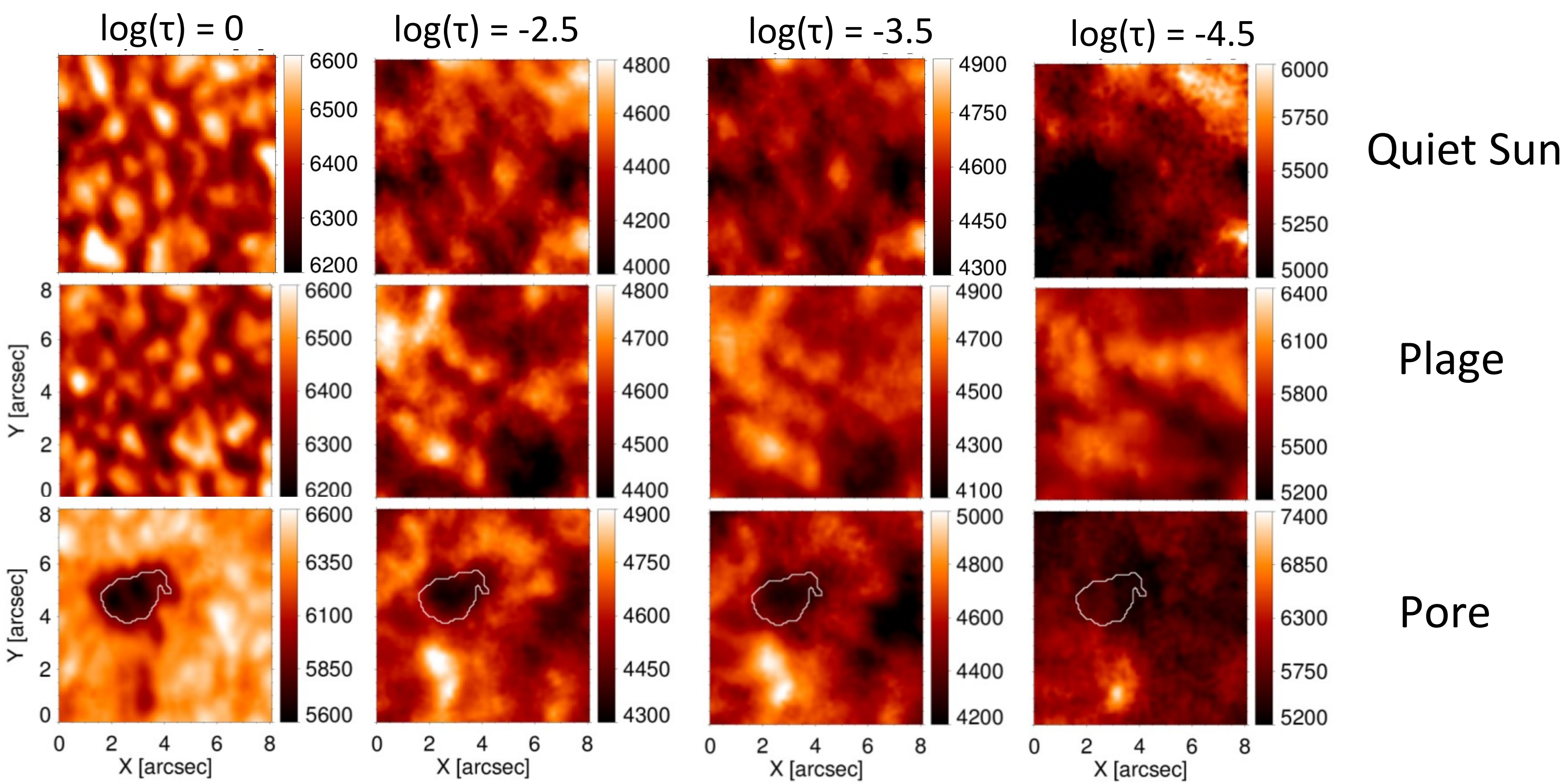
RESULTS from NICOLE inversion of DST/IBIS data



Cristaldi et al., in prep.

RESULTS from NICOLE inversion of DST/IBIS data

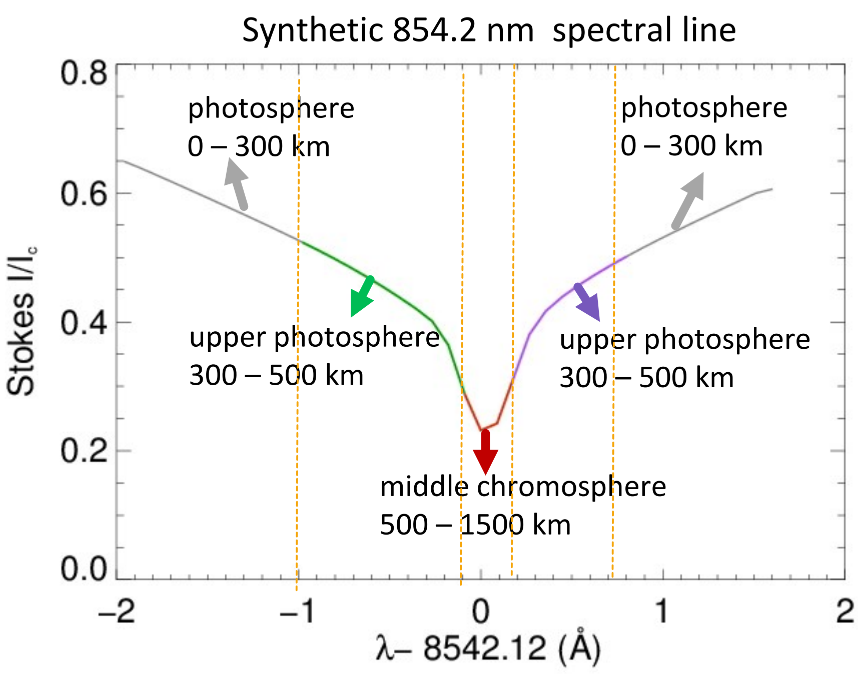
Temperature (K)

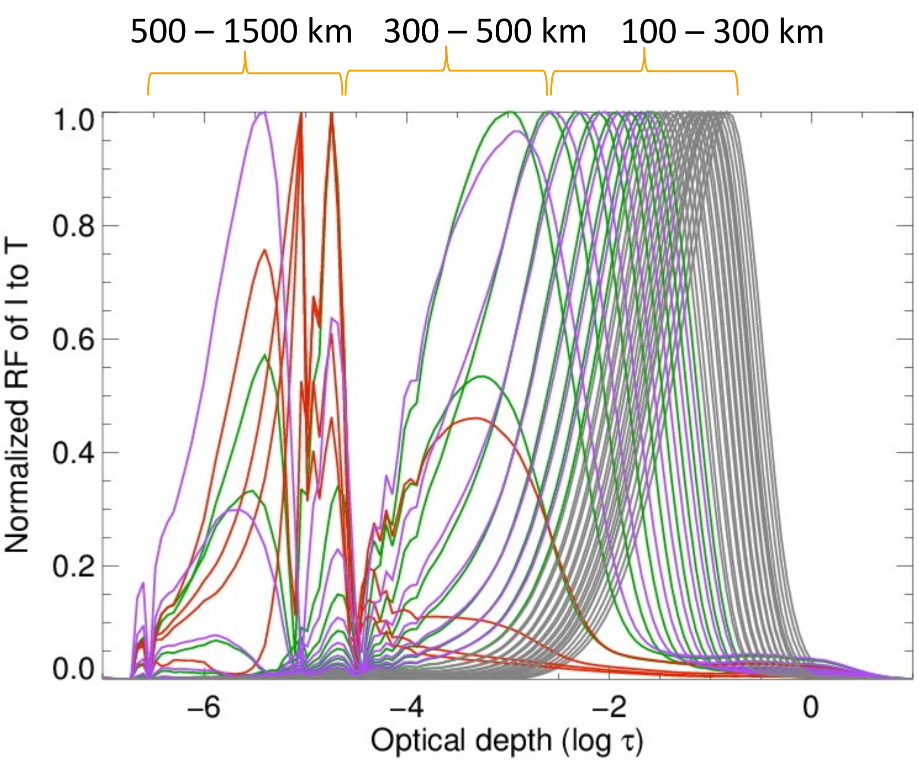


RF of the Ca II 854.2 nm

Response Function (RF): $R(\lambda, \tau) = \frac{\Delta I(\lambda)}{\Delta T(\tau)}$

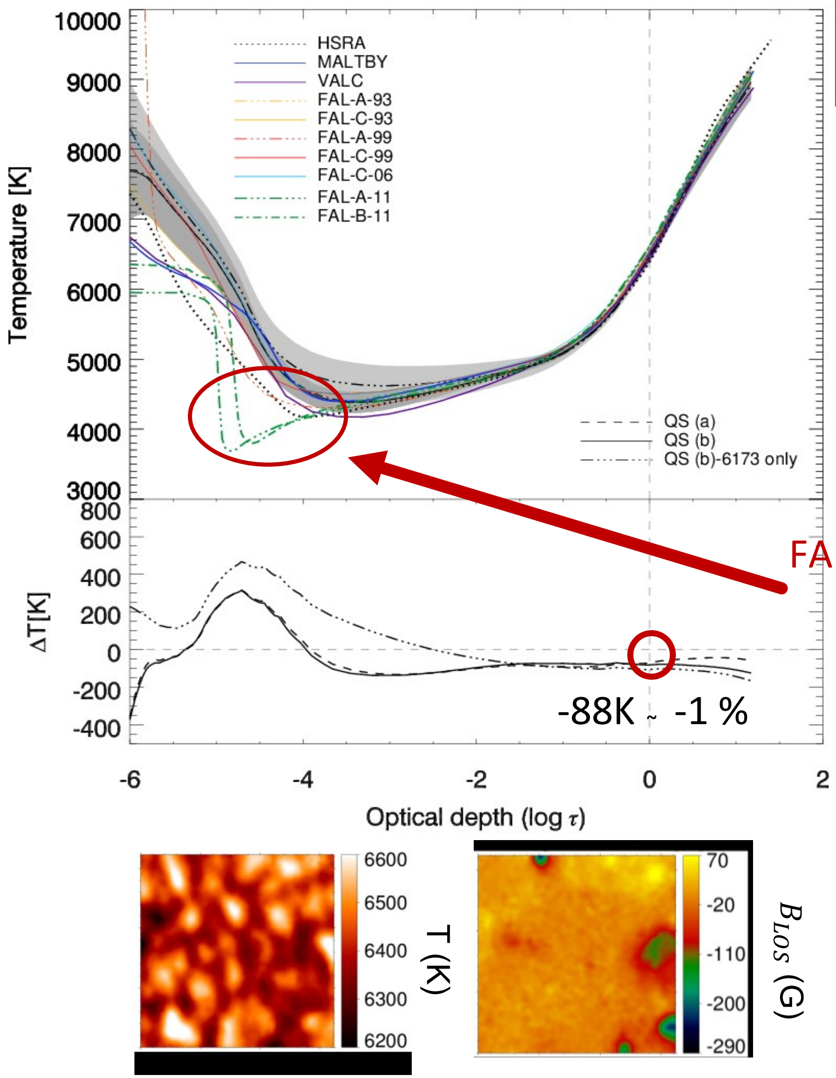
(Caccin et al, 1977; Landi & Landi, 1977)



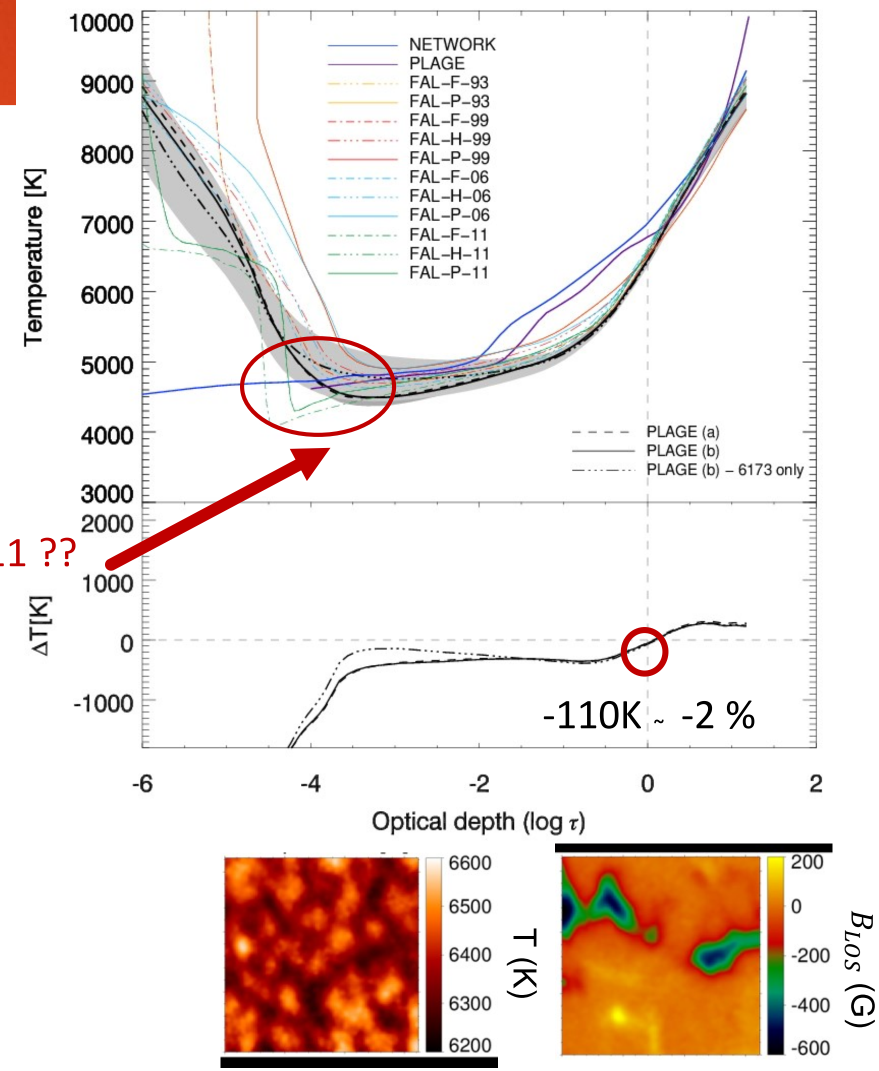


Temperature average profiles

Quiet Sun and **Plage**

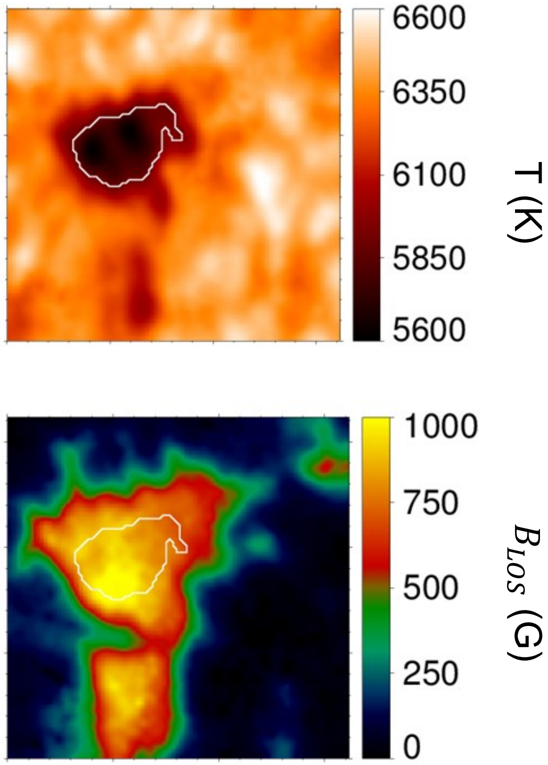


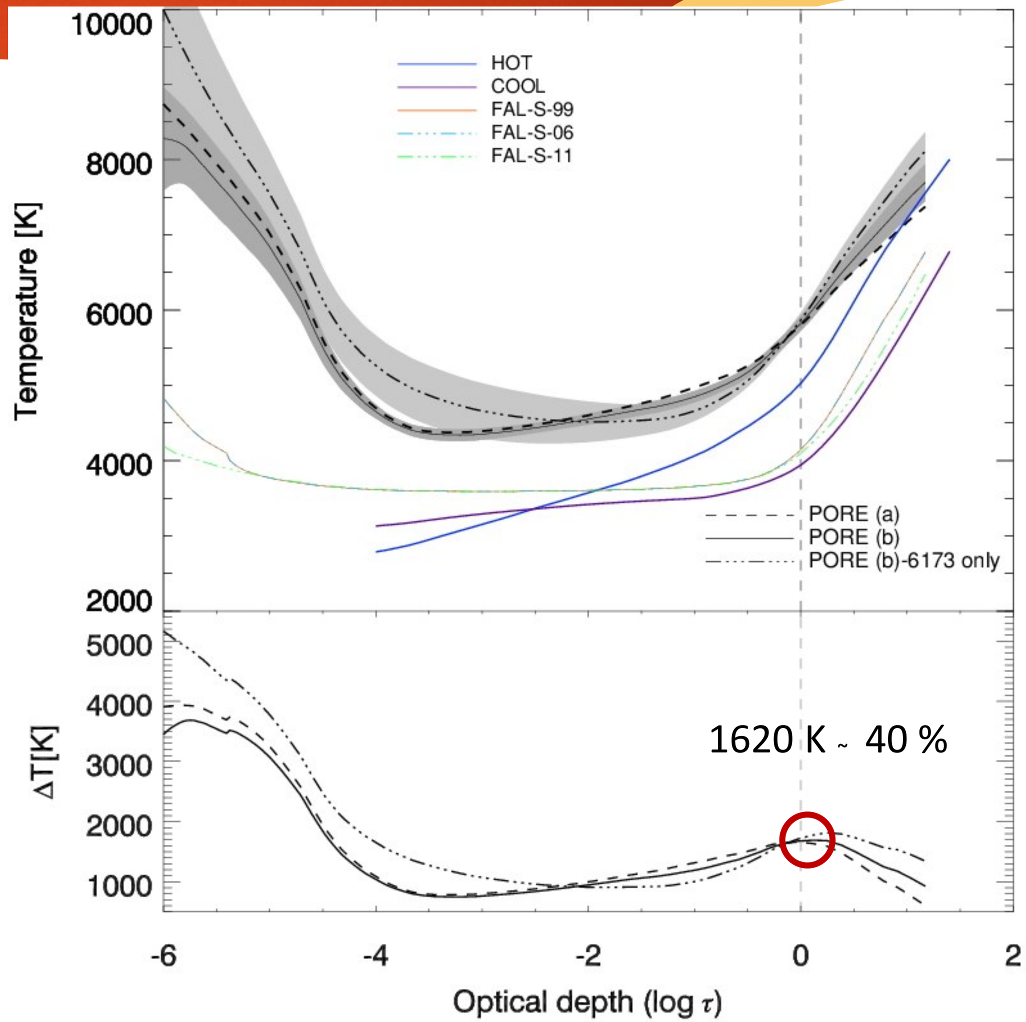
FAL 2011 ??



Temperature average profiles
Pore

log(τ) = 0





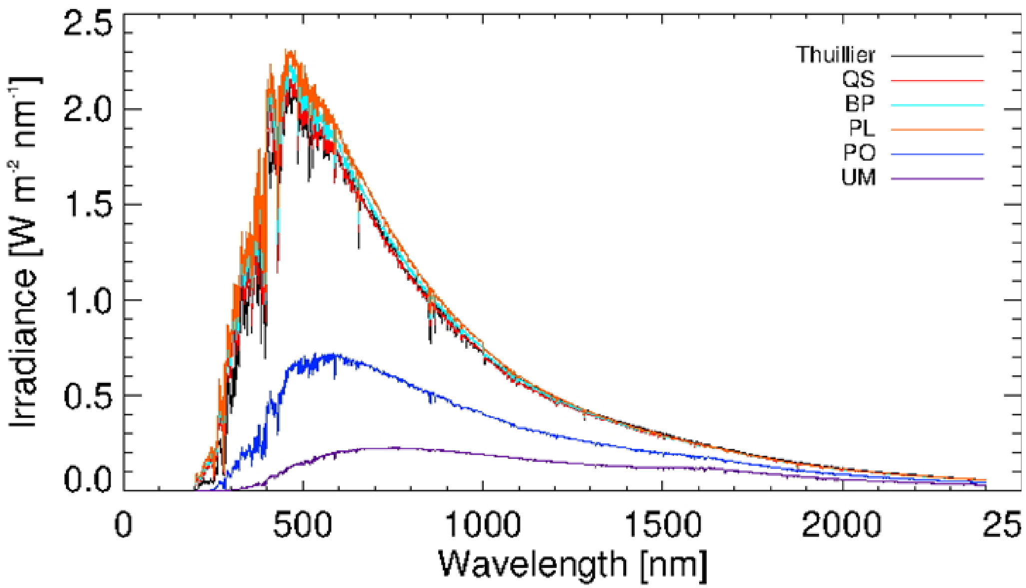
Effects on Irradiance reconstructions: Synthesis with the RH code (CRISP data)

Numerical radiative transfer code based on the formalism of Rybicki & Hummer

(Rybicky&Hummer 1991,1992; Uitenbroek 2001)

- CRD/PRD
- Polarized transfer
- 1D, 2D, 3D Cartesian grids
- Spherical geometry

Effects on Irradiance reconstructions: Synthesis with the RH code in the range 200-2400 nm

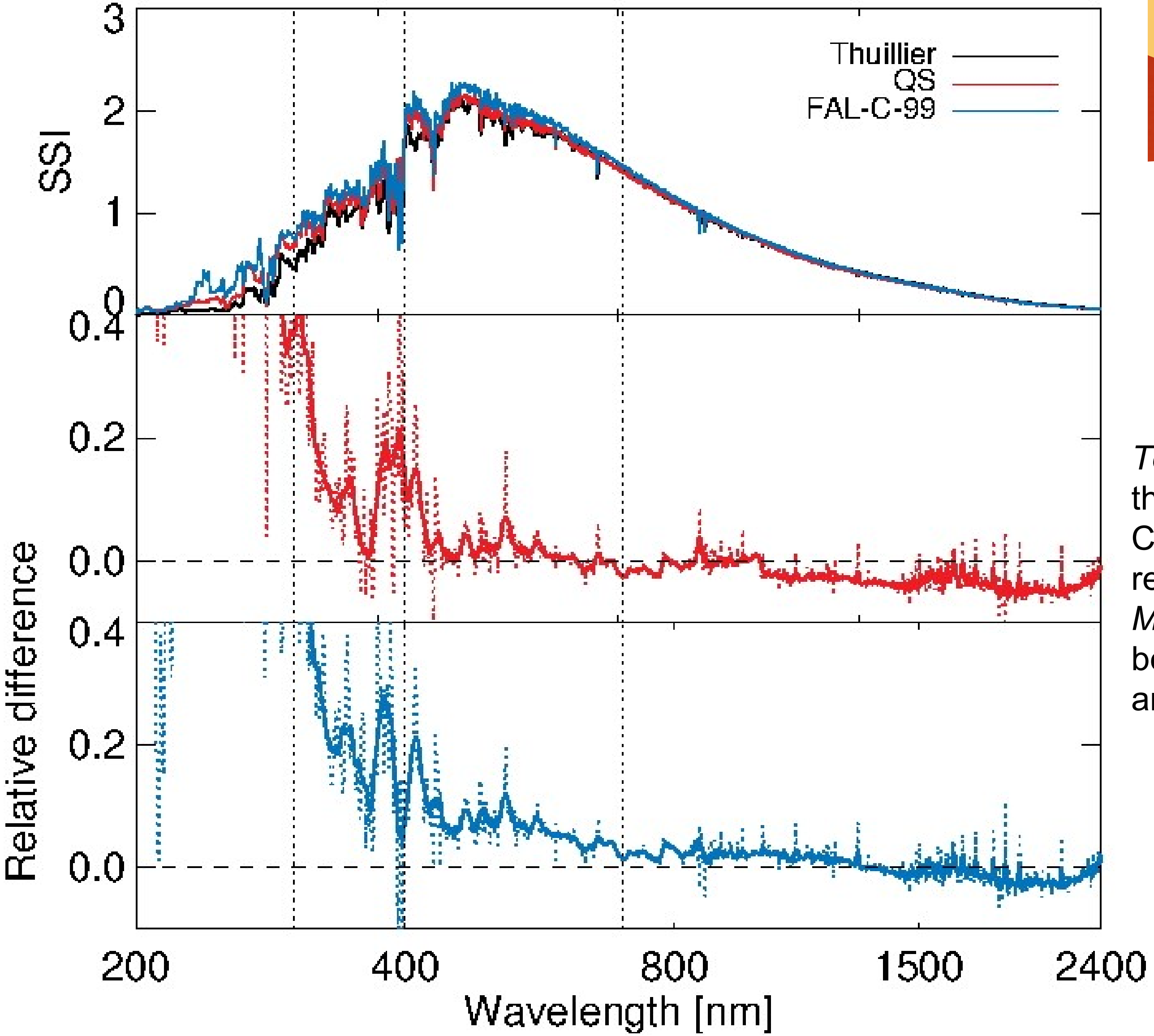


Obs region	SSI obs $[W/m^2]$	Model label	SSI FAL $[W/m^2]$	Rel. diff. [%]
QS	1354.60	C	1416.85	4.6
BP	1404.10	E	1426.06	1.6
PL	1453.55	F	1446.77	-0.5
PL	1453.55	H	1510.46	3.9
PO	624.24	R	1205.53	93
PO	624.24	S	303.36	-51
UM	273.57	S	303.36	11

SI from 200 to 2400 nm computed from the obs-based QS, BP, PL, PO, and UM models derived from inversion of CRISP data, and measured reference data by Thuillier et al. (2004). All spectra from obs-based models were convolved with a 1 nm Gaussian kernel to account for the spectral resolution of available measurements in the VIS range.

Spectrally integrated flux from 200 to 2400 nm computed from the obs-based atmospheres and the FAL-(C-E-F-H-S, 1999) and FAL-R (2006) models, with respective relative differences.

Effects on Irradiance reconstructions:



Top panel: SI spectra derived from the synthesis on the QS and FAL-C(1999) models compared to the ref. data by Thuillier et al.(2004). *Middle and bottom panels*: rel. diff. between the synthesized spectra and the ref. data.

Conclusions

- **First coherent study** of atmospheric models from spectropolarimetric observations in the framework of SI reconstruction (a few other works by e.g. Socas-Navarro 2011, Buehler et al. 2015 limited to analysis of a single FOV and few existing semi-empirical models).
- We found significantly **lower agreement** between our synthesis results and reference data in the **NUV** and **UV** bands, than in the visible and NIR bands.

What's next?

- Need to improve current models of both **bright** and **dark** magnetic features employed for SI reconstructions (IBIS data).
- Check accuracy of synthesis results for the different spectral bands, expecially in the **NUV** and **UV**.
- Further study required to account for, e.g., center-to-limb dependence of the intensity emerging from features observed at different positions, and for the different brightness of each magnetic feature depending on their filling factor.