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Sunrise-3: Science targets and mission capabilities for understanding the solar atmosphere

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Introduction

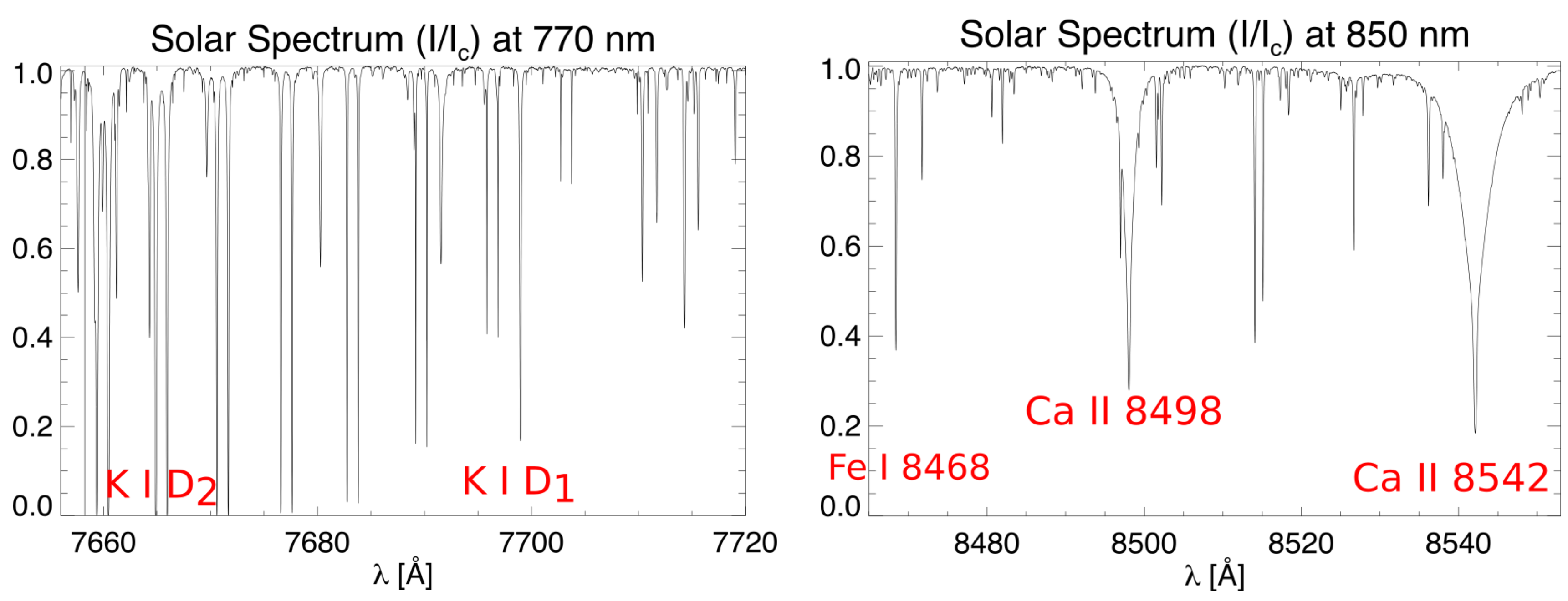
Sunrise Chromospheric Infrared spectro-Polarimeter (SCIP) is an instrument under development for the third flight of the Sunrise balloon, scheduled for 2021.

Description:

- 1 metre optical solar telescope
- Launch from the ESRANGE space center in Kiruna, Sweden.
- Stratospheric balloon with an average flying altitude of **35 km**.
- **Seeing-free**, high spatial resolution polarimetric observations at **UV-Visible-IR**.
- **International collaboration** between Japan, Germany, Spain and USA.

Spectral lines observed by SCIP

The instrument will observe multiple spectral lines simultaneously at two infrared spectral regions, 770 and 850 nm, where we can find Zeeman sensitive photospheric and chromospheric lines (see, for instance, red labels).



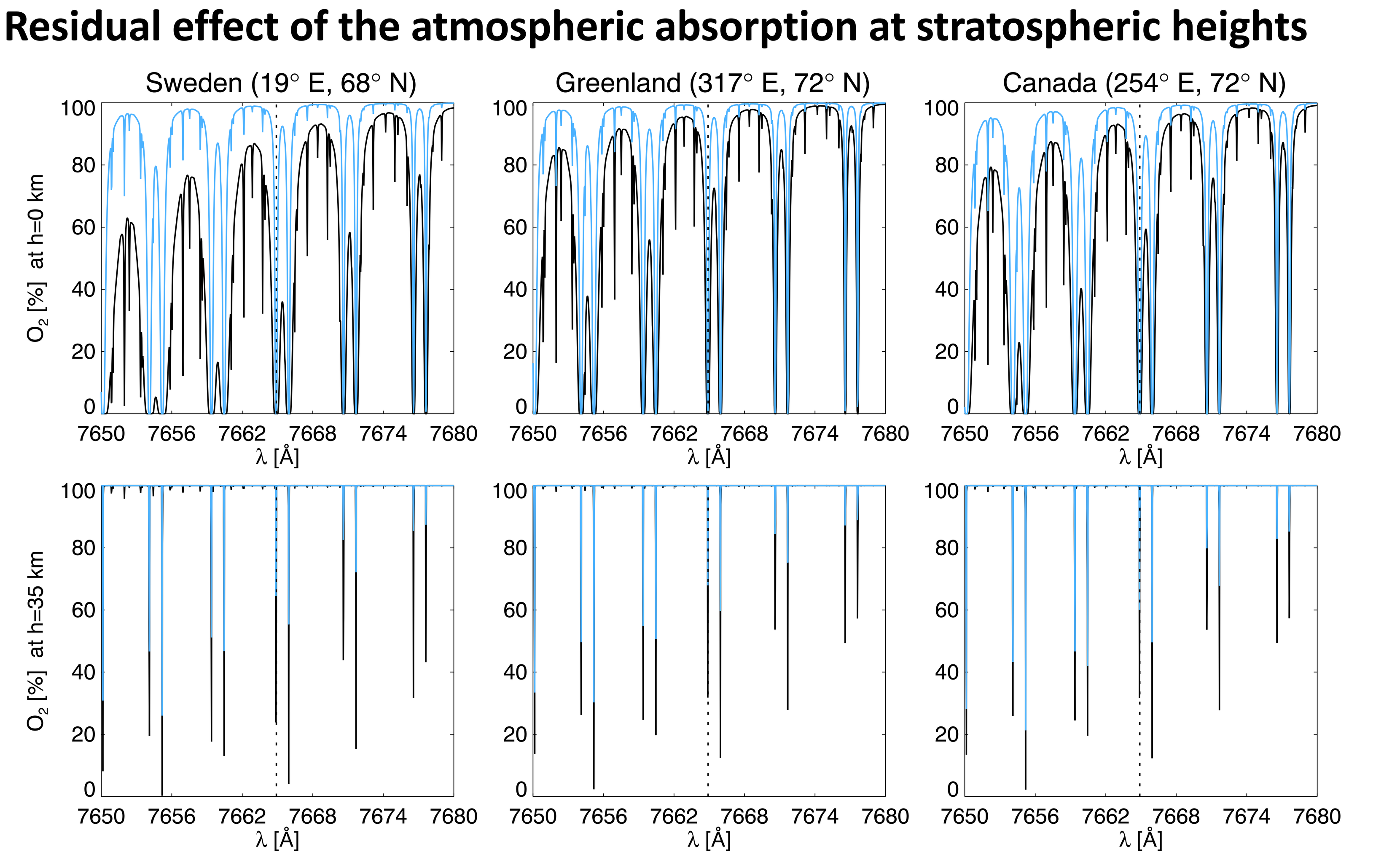
These spectral windows contain two of the most capable lines to understand the dynamics of the upper photosphere (K I D_1) and the magnetism of the solar chromosphere (Ca II 8542 Å). In addition, thanks to the balloon conditions, we can have access for the first time to K I D_2, a spectral line blocked by telluric O_2 absorption.

Some of these lines have never been observed before with polarimetry. Thus, we need to characterize them with theoretical studies before the launch of Sunrise using, e.g. **3D RMHD simulations** and numerical codes that solve the **radiative transfer equation**.

See the works of Quintero Noda et al. (2016, 2017a,b,c, 2018a,b) for more details.

Results

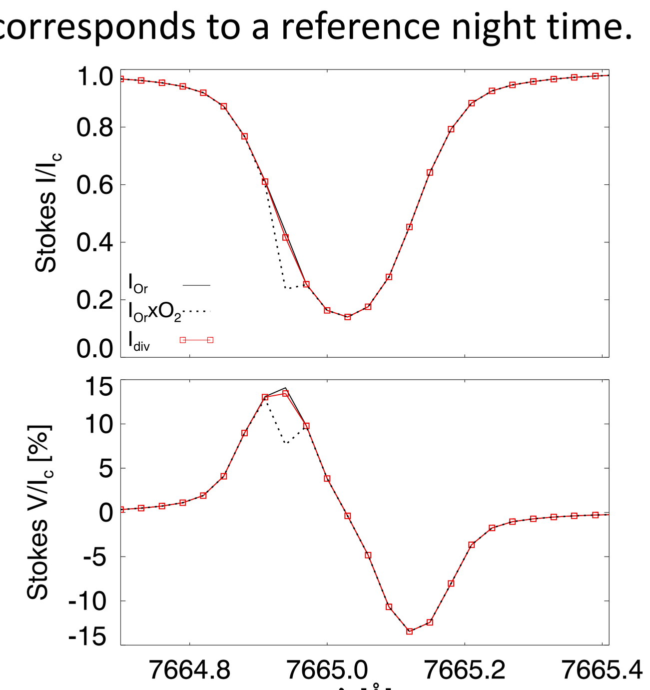
1. Residual effect of the atmospheric absorption at stratospheric heights



Oxygen molecule transmittance in the Earth's northern hemisphere. The top row shows the transmittance at ground level while the bottom row corresponds to the results for an observatory at **35 km** above the sea level. Blue designates daytime while black corresponds to a reference night time.

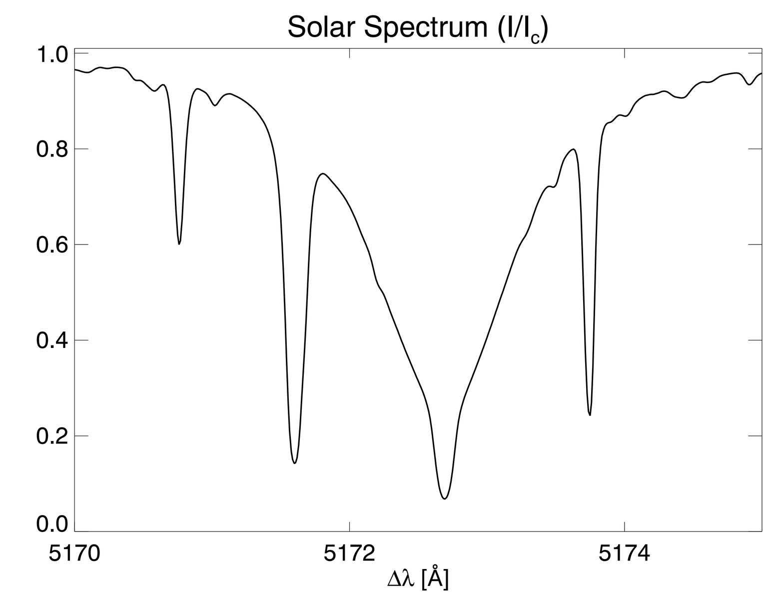
We studied the effect the residual O_2 absorption has on K I D_2, and we found that it is important when the line is **Doppler shifted** due to plasma motions on the Sun.

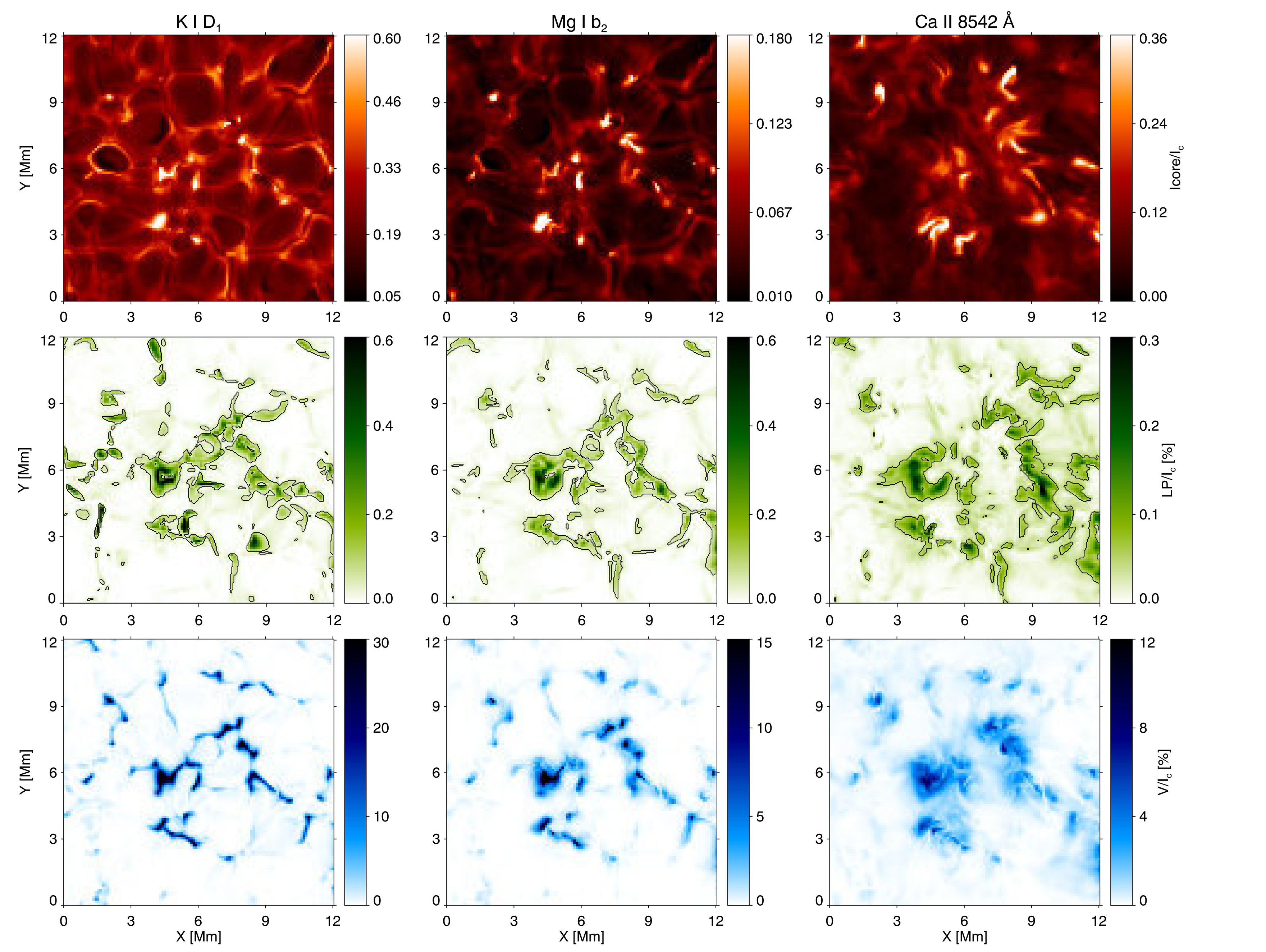
However, we investigated if we can remove that residual contribution. We aim to obtain the telluric contribution from the ratio of two solar observations at different airmass (pointing to the Sun at different elevations) and then to divide the observations by that contribution. The results indicate that we can **correct it very well**, see red profiles versus black ones.



2. Synergy between different instruments

We performed theoretical studies of the spectral lines observed by additional instruments on Sunrise. In particular, the Imaging Magnetograph eXperiment (IMaX, Martinez Pillet et al. 2010). This instrument will have access in this flight to the Mg I b_2 line (right figure). A spectral range that has been barely observed in the past and that we have studied theoretically to understand its possibilities as well as their **complementarity** with SCIP spectral lines.





Spatial distribution of line core intensity (top), total linear (middle), and circular polarisation (bottom) using the RHMD simulation presented in Carlsson et al. (2016).

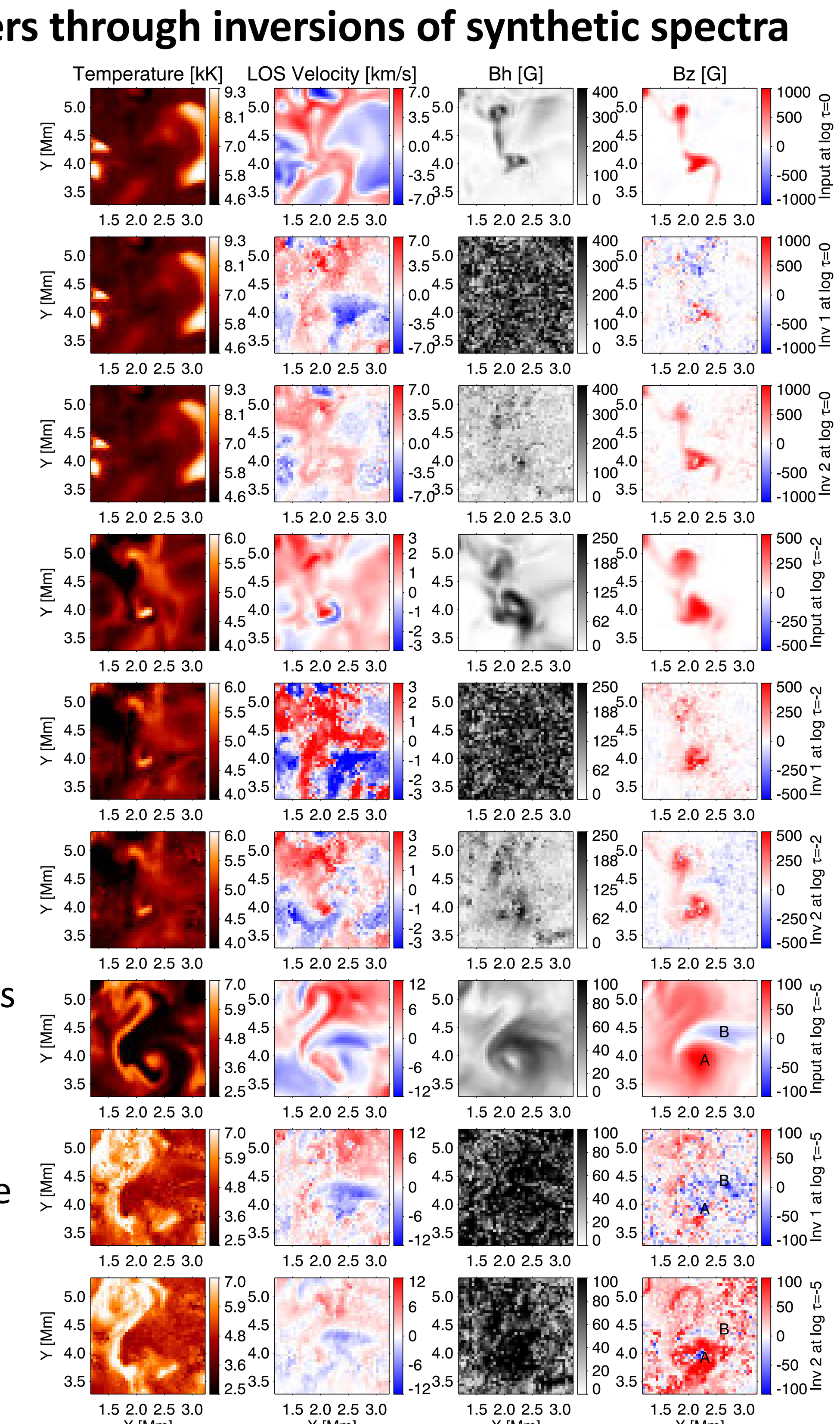
When comparing with SCIP main lines, we can see that the spectral line observed by IMaX is sensitive to the atmospheric parameters at heights that **fall in between** those covered by SCIP lines. This further strengthens the complementarity between Sunrise instruments.

3. Inferring the atmospheric parameters through inversions of synthetic spectra

We employed the realistic simulation presented in Iijima & Yokoyama (2017) to study the benefits of observing one single line versus the **full spectral window at 850 nm** (see the right figure in the introduction) for inferring the physical parameters at different atmospheric heights.

We present a preliminary comparison in the right plot. Each column corresponds to an atmospheric parameter while rows designate the input values (rows 1, 4, and 7), the results from the inversion of a single spectral line (rows 2, 5, and 8), and the results of inverting the SCIP spectral region at 850 nm (rows 3, 6, and 9).

For this test, we used a default configuration, **not optimised yet**, and the same for both cases to check the advantages of observing more lines. In this regard, we can see that there are significant **improvements** in the LOS velocity, and magnetic field while temperature results are very similar. Thus, although we need to improve our inversion configuration further, it is evident that our decision of observing more spectral lines is the **optimum one**.



Summary

Sunrise/SCIP will observe multiple spectral lines simultaneously, and it will achieve **unprecedented polarimetric accuracy and atmospheric height coverage**. Thus, it will be able, for the first time, to unveil the magnetic and thermodynamic properties of different solar phenomena, helping us to answer long-standing questions as, e.g. the coronal heating.