Collisional-radiative models for the next generation solar spectroscopy

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Rationale

Spectroscopic methods employed to analyse spectra of hot, optically thin plasmas (as e.g. in the outer atmosphere of the Sun) very often employ the so called "coronal approximation" or "coronal model", which assumes that all atomic/ionic levels are excited by electron collisions from the ground state, followed by spontaneous radiative emission. However, with the availability of increasingly accurate atomic data and of high quality observations, the need is becoming evident of taking into account all the relevant processes determining level populations of atomic and ionic states, including the presence of metastable levels and of radiative (photoexcitation/ionization) processes.

Objectives

To overcome the limitations of the Coronal Model, more realistic Collisional-Radiative Models (CRM) have been worked out for various elements (e.g.: Dufresne et al. 2021a, Dufresne et al. 2021b). In particular, radiative processes have been shown to be important even in the corona far from the solar surface, as in the case of transitions between excited states of helium (Del Zanna et al. 2020) and of other elements (as done by Del Zanna et al. 2018).

The goal of this project is to carry out such studies, following on the previous Del Zanna et al. 2020 study on the CRM model applied to helium in the solar corona, to compute the expected line radiances in the range observable with the infrared spectro-polarimeter CryoNIRSP - installed at the 4-meter class Daniel K. Inouye Solar Telescope (DKIST) - in various coronal features. These results will then be extended to cases involving optically thick (e.g. chromospheric) plasmas.

Deliverables

1) An updated CRM (Collisional-Radiative Model) of He, Fe, Si, and other elements whose lines are in the range observable by CryoNIRSP, using a modified version of the CHIANTI software and atomic database (Del Zanna et al. 2021).
2) An extension of those CRM models to chromospheric and transition region, and lower corona plasmas, using state-of-the art radiative-transfer codes such as RH (Uitenbroek, ApJ 2001).

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DKIST/CryoNIRSP Observations

A proposal submitted for the DKIST Operation Commissioning Phase Cycle 2 was approved (August 2022 call); The science review found the proposal to be in the top 25% of ranked proposals.

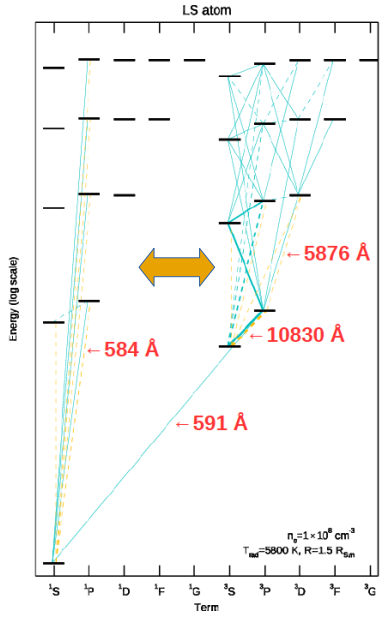
Observations were run in June and July 2023 at the CryoNIRSP spectropolarimeter in coronal mode.

Exchange visits with the University of Cambridge

In June-July 2023, an exchange visit at the University of Cambridge, Department for Applied Mathematics and Theoretical Physics, was carried out to collaborate with G. Del Zanna on improving the CRM model for helium, with the additional goal of applying this revised model in the analysis of the then scheduled DKIST/CryoNIRSP observations.

The main topic of the visit was an update of the singlet-triplet collisional rates from excited levels (typically, models and databases include only rates for the 1s2p ^{3}P – 1s^2 ^{1}S and 1s2s 3S – 1s^2 ^{1}S transitions) and an analysis of their effect on the observed spectra.

A second visit, by G. Del Zanna to OAC is being planned for Spring 2024.



Schematic Grotrian diagram for neutral helium
The double arrow indicates the group of collisional transitions added to the CRM model.

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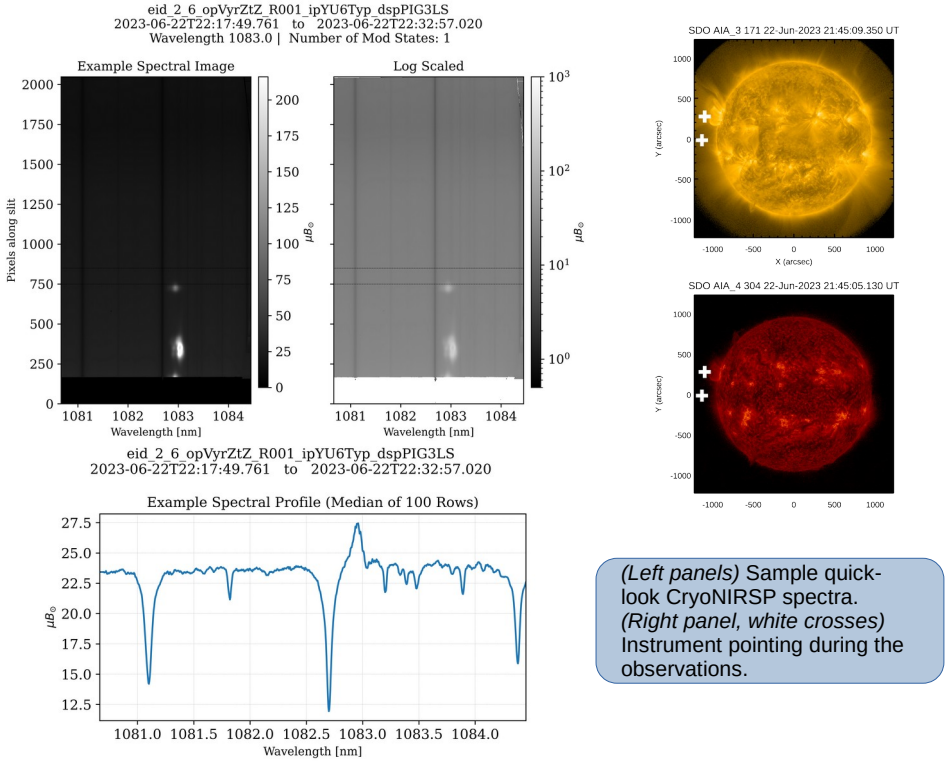
Analysis of DKIST/CryoNIRSP spectra

Quick look spectra from the June-July runs were made available by the DKIST Ops Team last month.

A first report on these observations was presented at the Fourth Meeting of the Italian Solar and Heliospheric Community (SoHE 2023: Arcetri, 25-27 October 2023).

Issues

- The significant delay in the availability of the funds caused a mismatch with the schedule of the main collaborator, G. Del Zanna, and consequently a further delay in the joint work. Given the current status of the project, the second deliverable, i.e. an application to optically thick plasmas, may not be completed by summer 2024 as originally planned.
- The CryoNIRSP data pipeline is still in testing, thus some ad hoc analysis of the raw data is required at this stage, thus reducing margins in the project timeline.



(Left panels) Sample quick-look CryoNIRSP spectra. *(Right panel, white crosses)* Instrument pointing during the observations.