NLTE Analysis on high-Resolution H-band Spectra of Neutral and singly-Ionized Calcium

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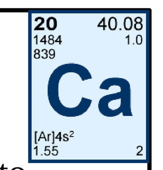
Introduction



Calcium belongs to the α–element group and is a key element to study chemical evolution history of the Galaxy. It can be measured over a wide metallicity range and is adequate for spectroscopic analysis.

Most previous investigations focused on optical high-resolution Ca but are limited in the Galactic Bulge due to the extinction. APOGEE is one of the SDSS projects that aims to explore red giants across the Galaxy and has obtained IR spectra for more than 300,000 stars and provided abundances up to 20 elements. Surveys found discrepancies between abundances determined from optical and APOGEE IR data for several elements and suggested that the systematic errors might be caused by departures from LTE.

This work investigated whether our Ca model atom is valid to study Ca line formations in H-band spectra, and to what extent these Ca lines departure from LTE.

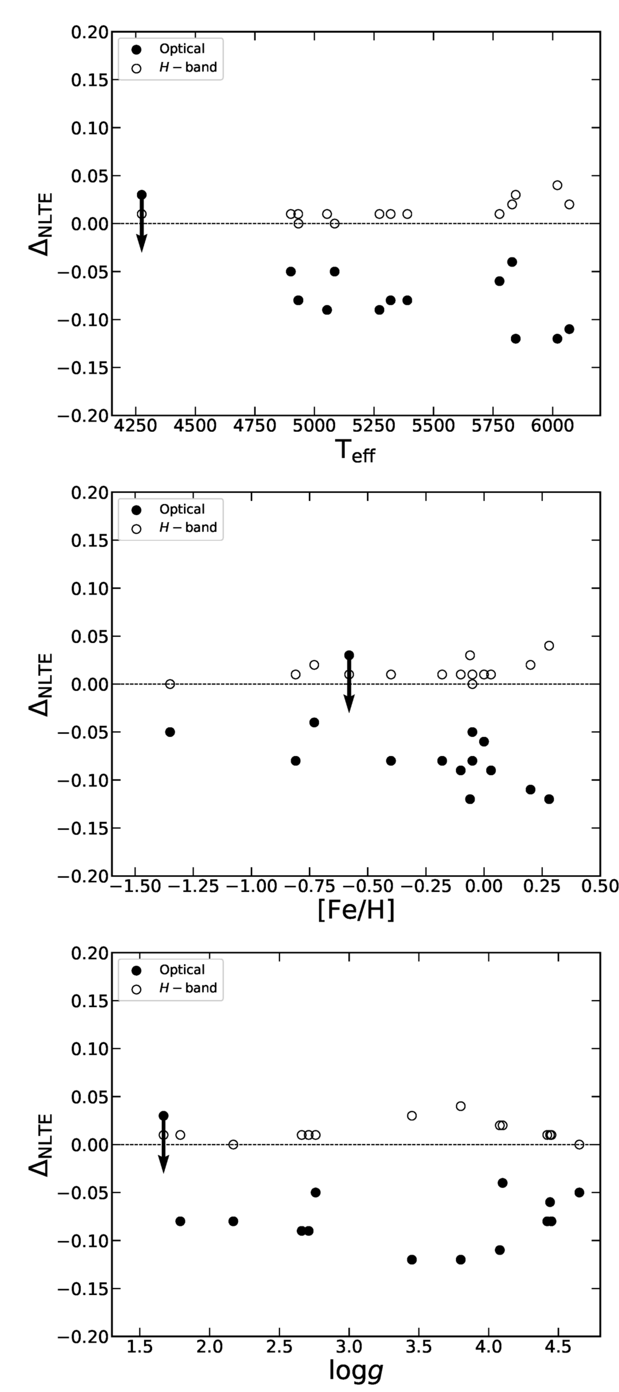
Methods

Ca abundances were derived under both LTE and NLTE for optical and H-band spectra using SIU software after the following five facets are designated:

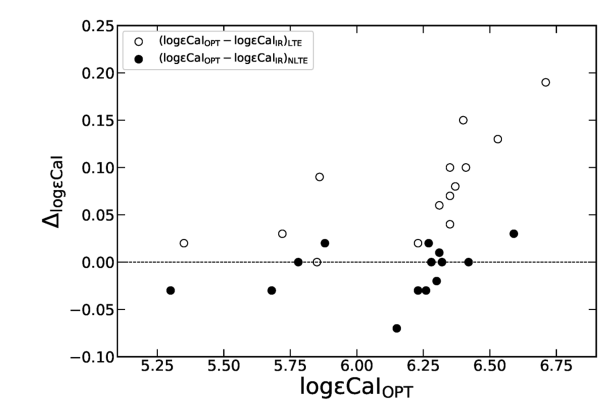
1. stellar parameters for sample stars
2. complete model atom constructed with data of inelastic collisions with hydrogen atoms from quantum-mechanical calculations
3. MARCS-OS model atmospheres selected for abundances determination
4. required scale-factor S_H in departure coefficients calculations for the reason that quantum-mechanical collisional data are currently not available for all sub-levels
5. selected lines with their line data and with molecular features removed near them

Results

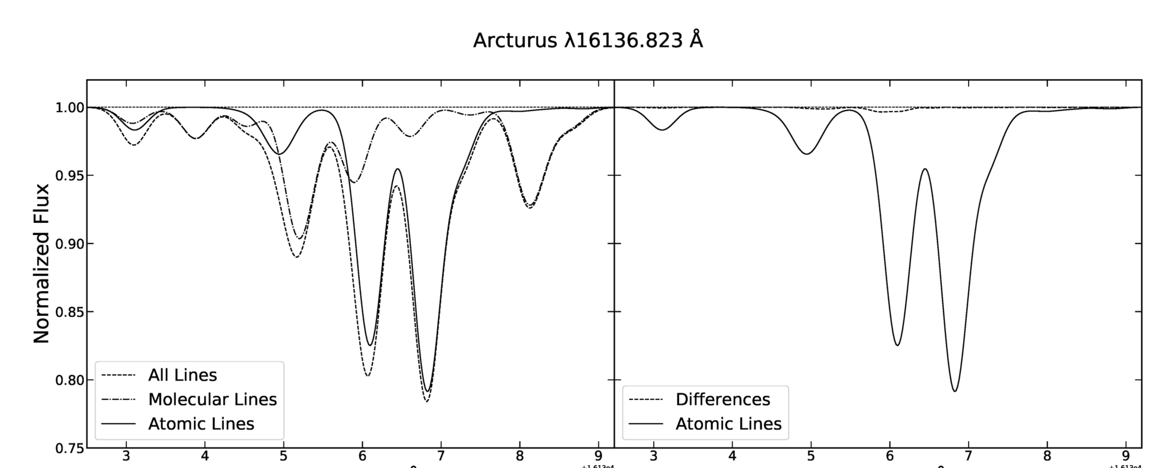
1. We got Ca abundances 6.31 and 5.88 for Sun and Arcturus under NLTE condition, respectively.
2. The mean difference between Ca I and Ca II is -0.026±0.061.
3. The mean difference between optical and H-band Ca I is -0.009 ±0.026.
4. NLTE corrections on Ca I lines in APOGEE data range from 0.00 to 0.03 dex.



Mean NLTE corrections of sample stars vs. stellar parameters. Δ_{NLTE} = log εCa$_{NLTE}$ log εCa$_{LTE}$.



NLTE Ca abundances derived from optical lines are consistent with those from APOGEE spectra, whereas a clear trend exists for LTE abundance dierences.



Removing molecular features: the left panel plots computed synthetic spectra of Arcturus around the Ca I line at λ16136 with all lines, with only atomic lines, and with only molecular features, respectively; the right panel shows the calculated atomic spectrum and the dierence between the calculated atomic line spectrum and the 'recovered' atomic line spectrum.

Conclusions

1. Our model is valid for H-band spectra analysis:
   a. Abundances of Sun and Arcturus match their 'known' values.
   b. Ca ionization balance between Ca I and Ca I meets.
   c. Optical and H-band lines can give consistent Ca abundances.
2. Inelastic collisions with hydrogen atoms should be taken into account in NLTE Ca abundance analyses. A careful investigation suggests that the classical Drawinian rate scaled by S_H = 0.1 is a good approximation when no quantum-mechanical rates are available.
3. In the stellar parameter space that our sample stars cover, the NLTE mechanism is the ultraviolet over-ionization. The NLTE effect enhances absorption in the cores but depletes absorption in line wings. The sign and value of the net NLTE correction on a moderate line depend on relative contributions of the line core and wings; NLTE corrections are usually negative on strong lines, and typically positive on weak lines.
4. NLTE corrections on H-band spectra are quite small in the stellar parameter space of our sample. But we do recommend to carry out investigations on H-band Ca under NLTE condition.
5. One may expect that NLTE effect becomes stronger as surface gravity decreases, but our figure doesn't show a clear trend. Please note that three data points with log g between 3.4 and 4.1 have the highest effective temperatures in our sample stars, we think that their big negative NLTE corrections are mainly due to their high temperatures. Because stars with lower surface gravities usually have lower effective temperatures, the trend with log g is somewhat covered by the temperature effect in our data set.

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Acknowledgments

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