Investigation of the FeO pseudo-continuum using astronomical facilities

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Introduction

The metal layers in the Mesosphere and Lower Thermosphere [MLT], created by ablation from meteorites, are probed from space via limb sounding and from ground by the means of rockets, LIDAR systems and optical facilities. A world-leading optical facility is the Very Large Telescope (VLT) operated by the European Southern Observatory (ESO) located in the Chilean Atacama desert (24° 37′ 33″ S, 70° 24′ 11″ W). While the data are optimized for astronomical purpose, atmospheric properties can also be derived from astronomical spectra. The X-shooter echelle spectrograph at the VLT is a well suited instrument for studies of the MLT. It operates in a wavelength regime from 0.3 to 2.5 µm at medium-to-high resolution. Line emissions, such as Na, OH, O_2 or O, are clearly detectable and are used for studies on the MLT [1]. [2] and [3] showed that also pseudo-continuum emission, like FeO, can be detected in the night-sky spectrum. Here we use a sample of ~1400 spectra, taken by X-shooter between October 2009 and March 2013, to study the FeO pseudo-continuum.
We are comparing it to the theoretically derived spectrum by [4]. Furthermore, the large sample allows us to investigate the seasonal variation of its intensity.

Spectral variation

Up to now the largest sample of FeO spectra was collected by [3] and consisted of five nights in March 2000 and four nights in October 2000. Furthermore, [4] derived a theoretical spectrum of the FeO emission based on [2]. Here we used a sample of 1403 spectra, taken between October 2009 to March 2013, to create five median spectra. The individual spectra were sorted according to their emission strength in the main peak (see Fig. 1a), and divided into five intensity bins with the dark blue colored spectrum consisting of the weakest 20% of our sample, and the red one consisting of the strongest 20% (Fig. 1a). The grey regions indicate the parts in the spectrum which are strongly influenced by absorption or other airglow emission.
Fig. 1b shows the the median spectra scaled to the theoretical spectrum derived by [4]. To scale the spectra we calculated the flux of the FeO emission between 0.58 and 0.68 without the grey shaded regions.
We find no deviations within the median spectra with respect to the emission strength. To investigate the deviation of the observed spectra and the theoretical spectrum we calculated the difference of the median spectra in 1b to [4], shown in Fig. 1c. Our data shows an excess between 0.587 to 0.592 µm, a deficiency in flux between 0.6 to 0.615 µm and an excess in flux between 0.615 to 0.62 µm. The latter one could be caused by the X-shooter instrument or NiO, whereas the excess between 0.587 and 0.59 could be caused by NiO or other metal oxides (see [5] and [6]). Furthermore, the main peak is more structured in the model, while we observe no structure in that spectral range. The resolution of the instrument is not an issue since the resolving power of X-shooter is good enough to resolve possible features.

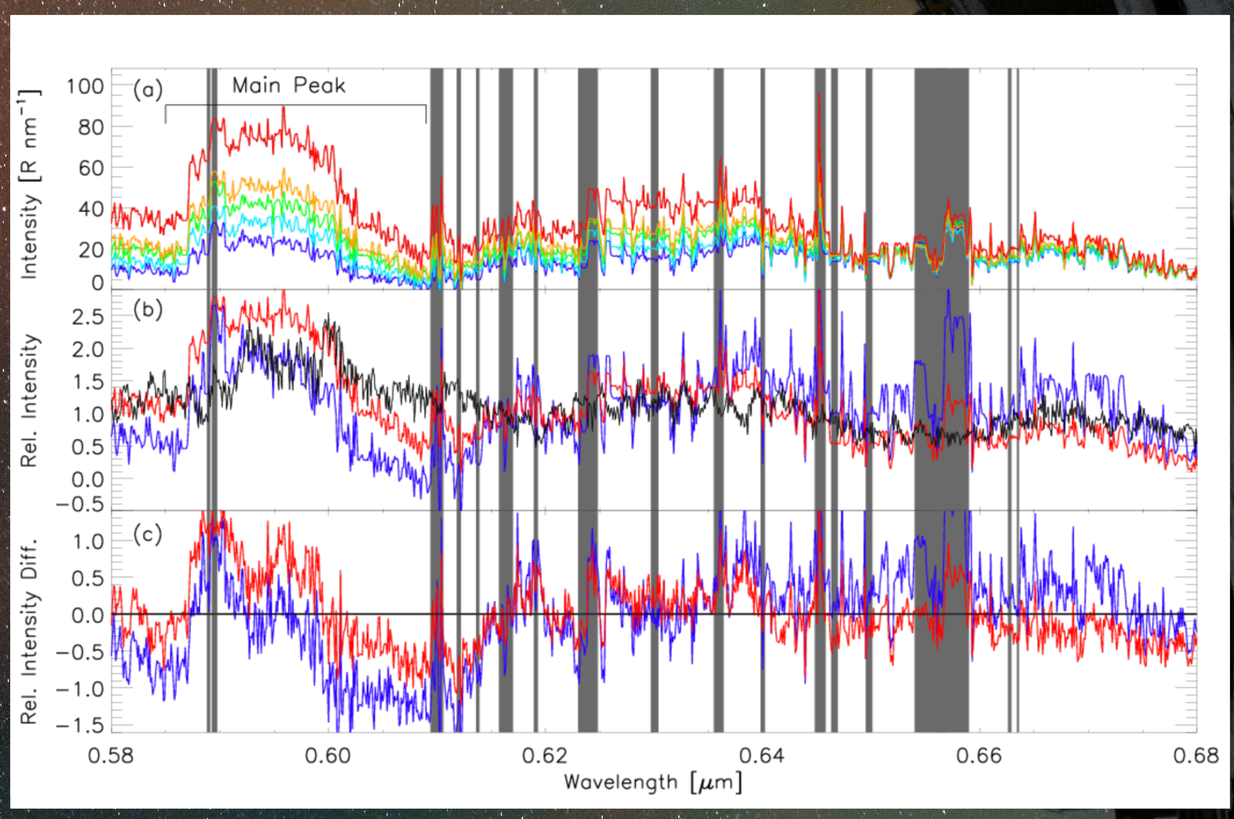

Fig. 1: Comparing FeO spectra:
(a) FeO median spectra from five main peak intensity bins. The median spectrum consisting of the lowest intensity spectra is plotted in dark blue, while the median of the highest intensity spectra is shown in red.
(b) The highest and the lowest intensity median spectra were scaled to the theoretical spectrum (black). This was achieved by scaling the intensities between 0.58 and 0.68 µm without the grey shaded regions.
(c) The median spectra, derived for Fig. 1b are used to show the difference between the median spectra and the theoretical one. We subtracted the theoretical spectrum from our median spectra and plotted the difference of the relative intensities. The spectra in 1b and 1c have the same scaling.

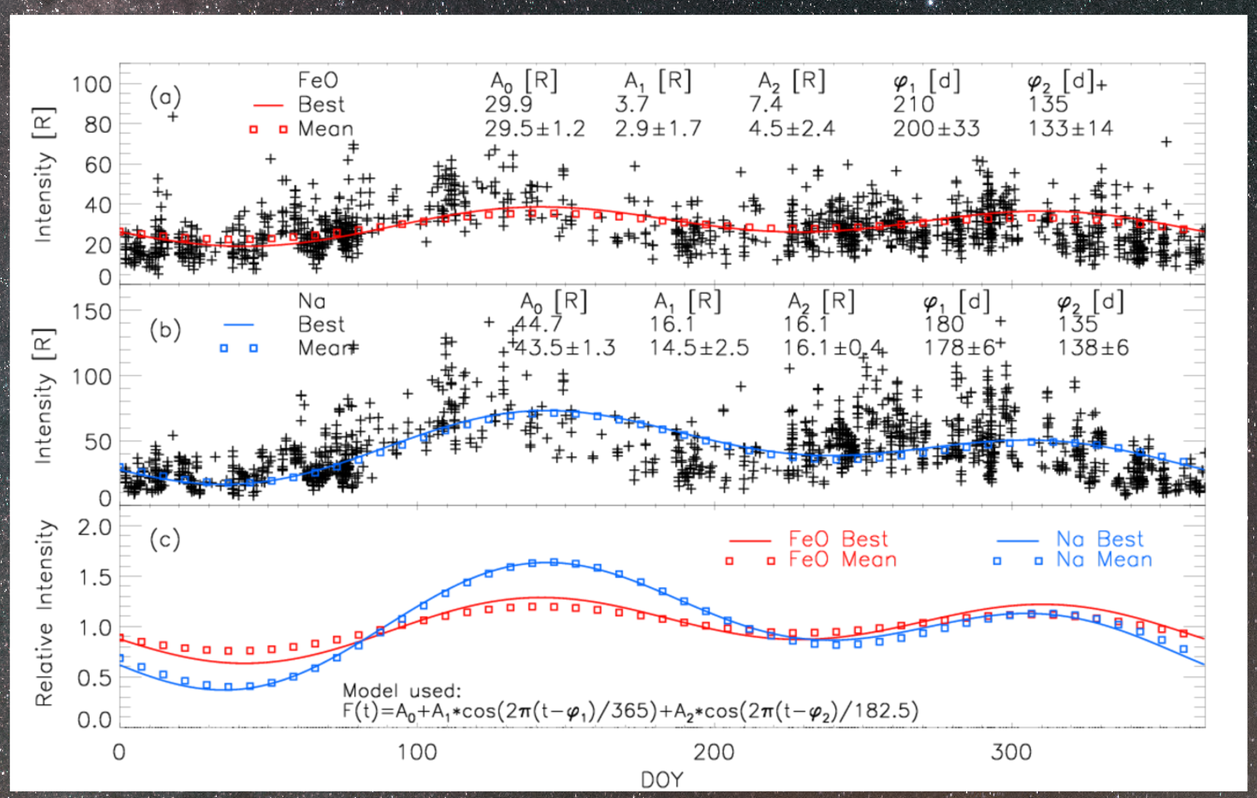

Fig. 2 Seasonal Variation:
(a) FeO intensity measurements (black crosses) with the solutions for the model overplotted in red. The solid line shows the result obtained by a best-fit approach, the squares illustrate the solution of the Bayesian approach.
(b) Na intensity measurements (black crosses) with the solutions for the model overplotted in red. The solid line shows the result obtained by a best-fit approach, the squares illustrate the solution of the Bayesian approach.
(c) Comparison of the seasonal variation of FeO (red) and Na (blue). The solid lines are the results of a best-fit approach, while the squares indicate the solution of the Bayesian approach.

Seasonal Variation

Emitters like OH and Na show seasonal variations at all latitudes. The relation of the annual (AO) and semi-annual oscillation (SAO) varies with latitude [7]: The lower the latitude the more dominant is the SAO. Here we compare the seasonal variation of Na and FeO (see Fig. 2) by using a harmonic analysis approach. The intensity for the FeO pseudo-continuum was measured within the main peak (see Fig. 1a).
To derive the amplitudes and phases for the harmonic oscillation we performed a minimum χ^2 fit (labeled as best in Fig. 2) and Bayesian statistics (labeled as mean in Fig. 2). A_0 denotes the annual mean while A_1 and A_2 correspond to the amplitude of the AO and SAO respectively with φ_1 and φ_2 being the corresponding phases. We expect the seasonal variation of Na and FeO to be closely related since the emission originates at approximately the same height, and both emitters have the common source of meteorites and ozone as reactant.
Looking at the emitters separately, the deviations between best and mean are well within the derived errors of the Bayesian approach and the step size used for the parameter grid in the χ^2 approach. In general, the two derived models for FeO and Na agree well with each other. FeO and Na show in the analysis of the mean a prominent SAO signature of 15% and 37% with respect to their annual means. Comparing the phases of Na and FeO we find the SAO to be in phase with each other while the AO is off by ~1 month, which is still well within the errors derived of the Bayesian approach.

Conclusion

We used data from ESO VLT to investigate the airglow pseudo-continuum of FeO. The sample consisting of ~1400 spectra, taken between October 2009 and March 2013, is the largest available sample to study FeO emission so far. The spectra were used for a comparison of the spectral shape with a theoretical spectrum as well as for dynamical studies. We found significant deviations from the theoretical spectrum. The dynamics of Na and FeO are closely linked in phase and both emitters show a prominent SAO.

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