Investigating metals in the MLT using astronomical facilities

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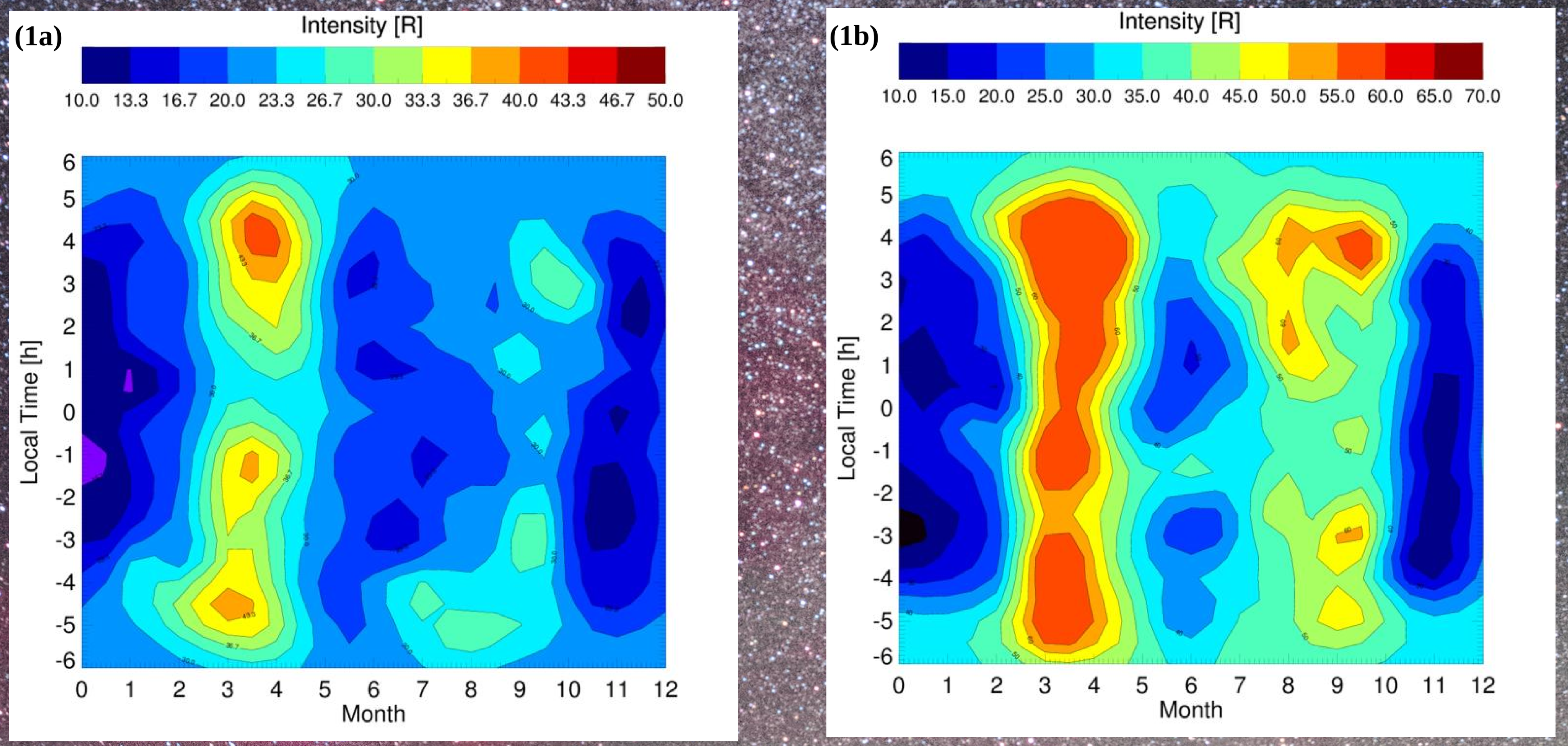
Introduction

Metals in the mesospheric region, such as Na, Fe or Ni, originate from meteoric ablation in the upper atmosphere. Through reactions with ozone they emit airglow. In the case of Fe and Ni the airglow originates from their oxidised form which unlike the atomic line emission from Na results in pseudo-continuum emission. This pseudo-continuum is difficult to observe since it is a broad but weak spectral feature compared to the line emissions arising from sodium.

For this study on metals in the mesospheric region we used data taken with the astronomical X-shooter spectrograph mounted at the Very Large Telescope (VLT, 24°S, 70° W) of the European Southern Observatory (ESO) in Chile. The 3662 spectra used in this study cover a 3.5 year period from October 2009 to March 2013. With this data set, seasonal and diurnal variations are studied. Furthermore, the measurements are compared to the Whole Atmosphere Community Climate Model (WACCM) to derive the quantum yields for $Fe+O_3$ and $Na+O_3$.

In future this study can be expanded by the MaNGA survey (Mapping Nearby Galaxies at APO) at the Apache Point Observatory (APO) in New Mexico/USA (32° N, 105° W). These data allow us to study the contribution of NiO to the FeO pseudo-continuum emission in detail.



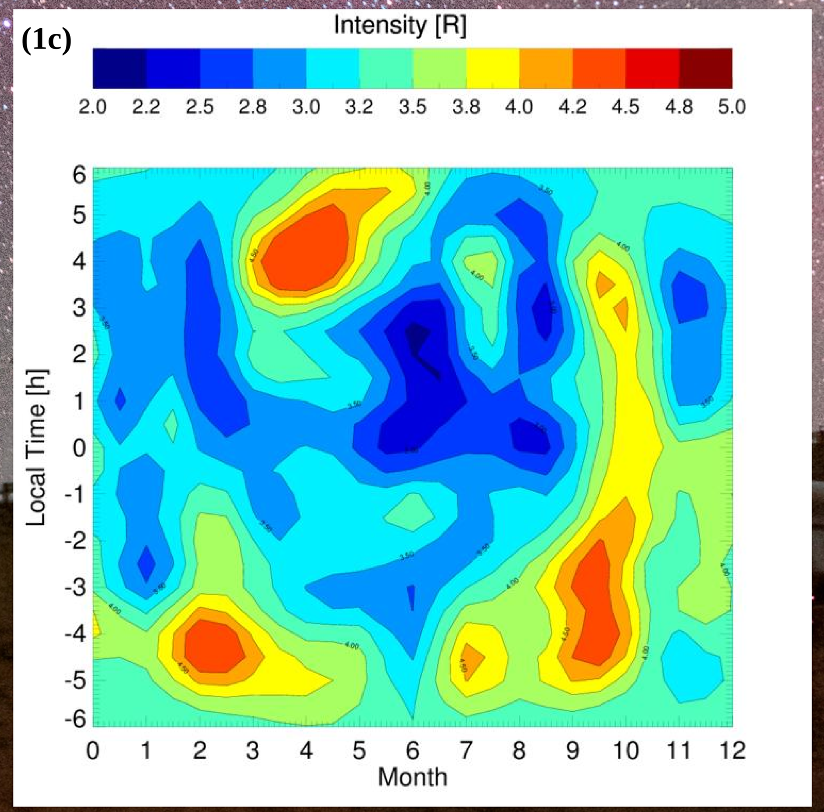


Fig. 1: Climatologies
Panels (a), (b) and (c) show a two-dimensional representation of the FeO, Na and OH(9-4) intensity. The ordinate describes the local time in hours, with 0 denoting midnight. The abscissa comprises the year and is subdivided in months, with the labels denoting the end of each month.

1. Variations

X-shooter allows detailed studies on the diurnal and seasonal behavior of FeO and Na. We found a semi-annual oscillation of 27% and 30% with respect to the annual mean for FeO and Na, respectively. This compares to 17% and 25% in the amplitude of the annual oscillation for FeO and Na, respectively.

These emissions have been compared to the emission of OH(v'=9) which is located at a similar height and also needs O_3 as reactant. The seasonal behaviour also shows the presence of a semi-annual oscillation at the beginning of the night. This pattern is not observed in the middle and at the end of the night.

The emission heights of the three emitters are overlapping. This fact excludes dynamics as a major cause for the difference in the patterns of the three climatologies. The change in concentrations of Fe, Na and H, their sources and sinks are other possible explanations.

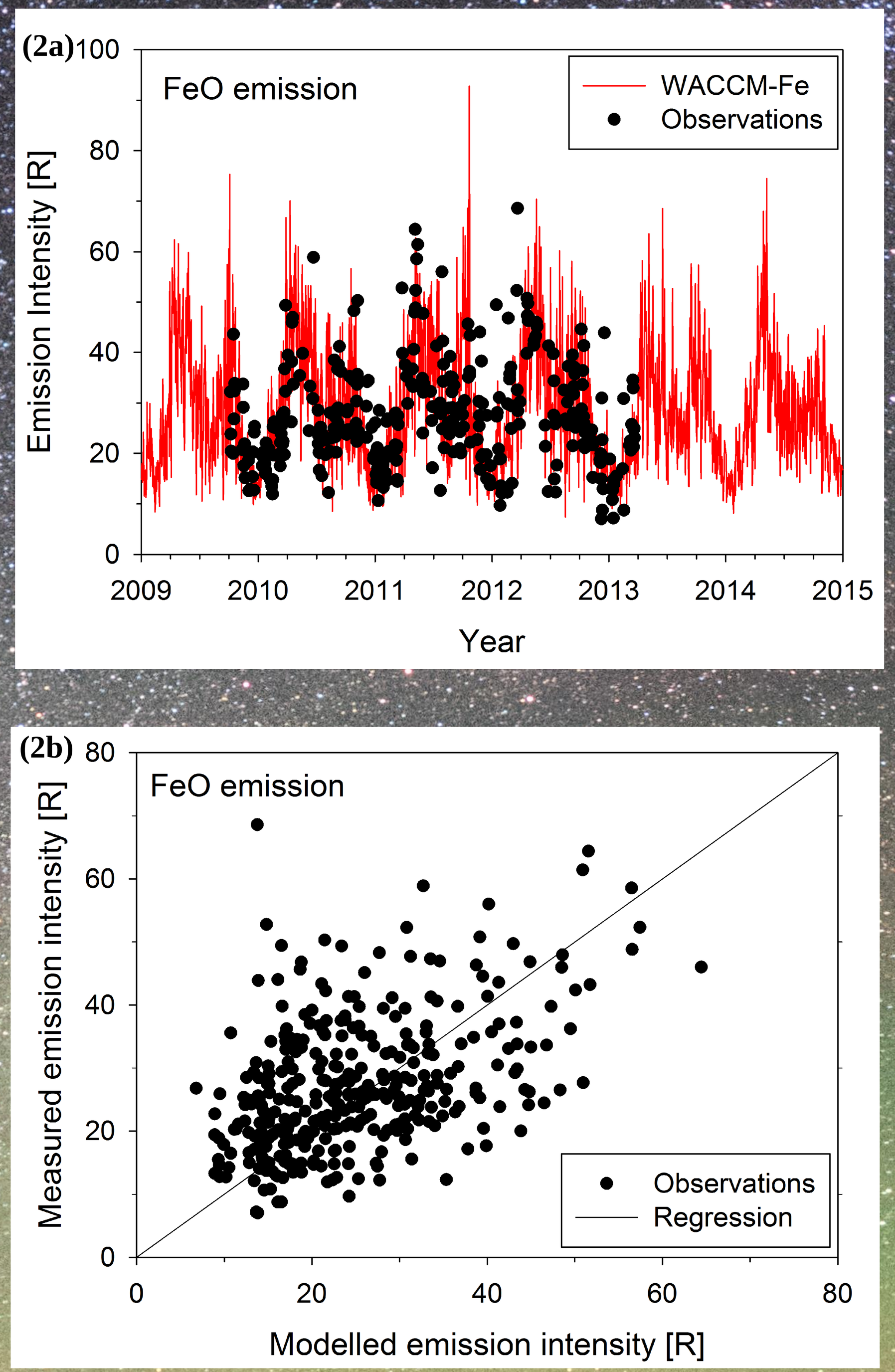


Fig. 2: Comparison of the measured and modelled FeO emission intensity.
In panel (a) the absolute intensities over the period 2009-2015 are illustrated. Panel (b): correlation between the measured and modelled intensities. Note that the modelled intensities are scaled to produce a 1:1 regression line through the origin.

2. Quantum Yields

The WACCM, considers the whole atmosphere from the ground up to an altitude of 140 km ($6.0x10^{-6}$ hPa) and couples chemistry and climate models leading to an interactive chemistry and dynamics from the surface to the lower thermosphere.

To obtain the airglow intensities from the model the integrated FeO and Na volume emission rates between 80 and 100 km were calculated. To gain this information the modelled concentrations of Fe, Na and O_3 were used and for the reactions of $Fe+O_3$ and $Na+O_3$ the modelled temperatures were applied. Nightly averaged values were produced from January, 1 2009 to December, 31 2015, and then compared to the nightly average of the observational data.

It has to be noted that there are uncertainties in the O_3 concentration between 86 to 89km. [1] showed that the downward transportation of atomic O from the thermosphere is insufficient. For a better handling of this effect a comparison of O_3 from WACCM and measured O_3 profiles from SABER at 24° was done. We found that the O_3 concentration from WACCM is on average 45 to 56% lower than the measured concentration from SABER.

The quantum yield for $Fe+O_3$ was calculated as 7.5 to 13±3%, based on the modelled FeO spectrum [2], depending on whether SABER or WACCM data are used to determine the O_3 concentration.

In other studies like [3] and [4] the quantum yield for $Fe+O_3$ was determined as 2 to 6% and 100% respectively.

The quantum yield for the Na reaction was calculated to be 6.5 to 11±2% depending on the O_3 data being taken from SABER or WACCM. These values are in good agreement with the results obtained by [5] and [6].

A more detailed discussion can be found in [7].

3. Outlook

The X-shooter sample already allowed for new studies on the metals in the MLT. However, so far we are unable to disentangle the different continuum contributions of FeO, NiO and NO+O.

The MaNGA survey, carried out at the APO in New Mexico would not only enable us to disentangle the various continuum contribution but would also provide us with comparison data on the northern hemisphere.

The APO is not located at as remotely as the VLT. It is surrounded by a military airport in the west and cities in the south and north-west. These settlements cause an artificial sky-background consisting of LED, Na and Hg lamps. In Fig. 3 a median spectrum from the MaNGA survey is compared to the spectra of LED, Na and Hg lamps. For a sufficient lamp-background subtraction either low altitude observations at different azimuth angles or dedicated observations of the scattered artificial sky-background from clouds would be needed before one can try to disentangle the pseudo-continuum emissions from FeO, NiO and NO+O.

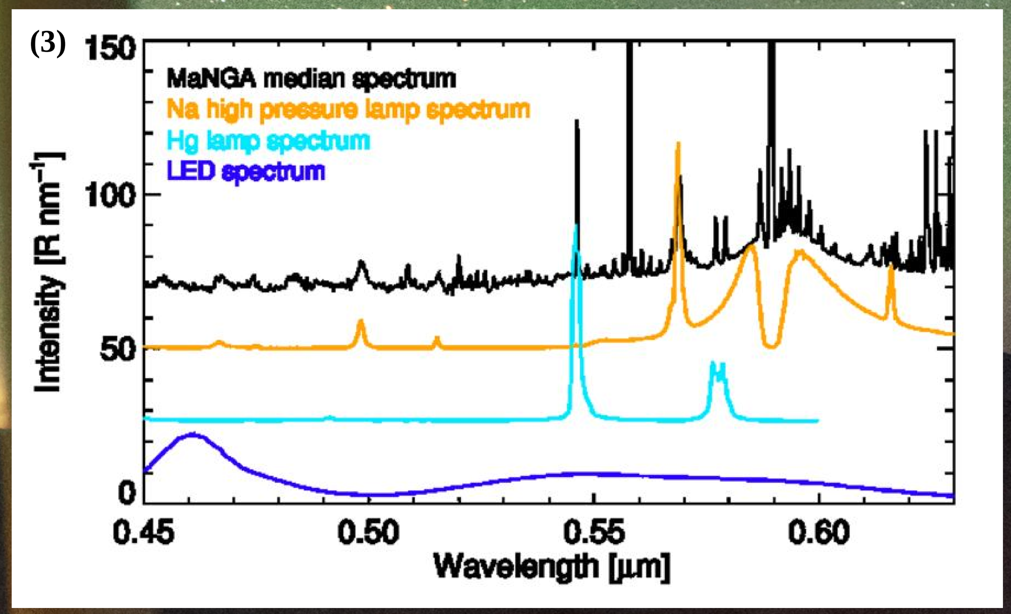


Fig. 3: MaNGA median spectrum and light pollution
The median spectrum of 2788 MaNGA exposures is illustrated with the intensity given on the ordinate in R nm^{-1}. In orange, light blue and dark blue a sodium high pressure lamp spectrum, a mercury lamp spectrum and a LED spectrum are plotted, respectively. The intensities of the lamp spectra are given in arbitrary units and are vertically shifted for a better recognition of the individual features. The abscissa describes the wavelength in µm.

Conclusions

The seasonal behaviour of the FeO and Na emission was studied using the X-shooter spectrograph. A semi-annual amplitude of 27% and 30% with respect to the annual mean for FeO and Na was found, while the amplitude of the annual oscillation was found to be 17% and 25% for FeO and Na, respectively. Furthermore, simulations with WACCM lead to a quantum yield of 7.5 to 13% for $Fe+O_3$ and 5.5 to 11% for $Na+O_3$, which is in agreement with the studies of [4] and [5].

In the future the MaNGA survey will be a valuable asset to our study of the FeO pseudo-continuum. After the artificial sky-background subtraction it allows for observations covering the NiO and FeO pseudo-continuum with one spectral arm and thus reducing possible error sources for the estimate of the NiO contribution.

References:

[1] Smith et al., Journal of Advances in Modeling Earth Systems, Vol. 6, 883. 2015
[2] Gattinger et al., Canadian Journal of Physics Vol. 89, 239-238, 2011
[3] West & Broida, Journal of Chemical Physics, Vol. 62, 189, 1975
[4] Saran et al., Journal of Geophysical Research, Vol. 116, D12303, 2011
[5] Clemesha et al., Journal of Geophysical Research, Vol. 100, 18, 1995
[6] von Savginy et al., Geophysical Research Letters, Vol. 43, 12651, 2016
[7] Unterguggenberger et al., Atmospheric Chemistry and Physics, Vol. 17, 4177, 2017

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