Geophysical Research Abstracts
Vol. 17, EGU2015-2554, 2015
EGU General Assembly 2015

On the influence of non-LTE effects on OH rotational temperatures

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OH airglow is an important tracer of the state of the mesopause and its variability at about 87 km, since it is the dominating emission from the upper atmosphere in the optical to near-infrared wavelength regime. A great deal of the world-wide mesopause temperature records are based on OH. Lines of single OH bands are used to derive rotational temperatures, which are expected to be close to the ambient temperature if only lines from the lowest rotational levels are considered. However, establishing a rotational–translational equilibrium requires a sufficient frequency of suitable collisions, since the nascent level population distribution of OH by the hydrogen–ozone reaction is dominated by high rotational levels and radiative transitions can change the level by one quantum at most. At least for the upper parts of the OH emission layer, it is not clear whether this criterion is fulfilled, since the concentration of the crucial quencher O_2 is relatively low.

In order to evaluate the contribution of possible non-LTE effects, we have investigated the rotational temperatures from different OH bands and line sets. For this purpose, we used 343 high-quality spectra of the medium-resolution echelle spectrograph X-shooter mounted at the Very Large Telescope at Cerro Paranal in Chile. The data were taken between October 2009 and March 2013. They allowed us to measure P-branch based temperatures for 25 simultaneously observed OH bands from OH(8-2) to OH(9-7). For a comparison, we also derived rotational temperatures for the O_2b(0-1) band, where the emission peaks at about 94 km.

Our analysis revealed differences in the rotational temperatures depending on the line selection. The fourth rotational level is already significantly overpopulated compared to the lower levels and there are population differences of several per cent for the two spin-related electronic substates. After a correction of the temperatures from the different OH bands for these effects, we found that the OH rotational temperatures depend on the upper vibrational level v' of the band. They tend to increase with v'. This trend is distinctly stronger for even v', which results in a temperature maximum for $v' = 8$. The high-v' temperatures are much higher than the corresponding value for O_2b(0-1). The pattern can only be explained by a significant contribution of non-LTE effects. By an analysis of the temporal correlations for the O_2b(0-1) and different OH bands, we found an increase of the emission altitude with v'. Moreover, the spread of the v'-dependent rotational temperatures tends to become larger in the course of the night, which indicates temporal variations of the OH non-LTE effects. Therefore, any OH rotational temperature measurement has to be taken with care.