Monitoring Greenhouse Gases with Astronomical Observations

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I. Introduction

Modern telescopes are usually equipped with high-precision spectrographs. In order to correct ground based observations from the influence of the Earth's atmosphere astronomers also observe the plain night sky close to the astronomical source of interest to estimate atmospheric radiation, and specific stars, so-called telluric standard stars (TS stars). TS stars are objects with either well known, or hardly any spectral features (e.g. white dwarfs). Therefore, changes in these spectra occur mainly due to the variability of the Earth's atmospheric transmission.

Since the atmospheric emission/transmission in the optical/thermal infrared and the absorption of stellar radiation reflect molecular abundances in the atmosphere, such plain night sky and TS spectra can be used to investigate the atmospheric composition, i.e. to obtain column densities of various greenhouse gases ([1], [2]).

II. The Method

The determination of molecular column densities is performed as follows (see Fig.1): Based on the observing date a merged model atmosphere is created by means of a static atmospheric standard profile[a], GDAS profiles[b] (providing P, T, and rel. humidity on a 3h basis for the observing site), and the on-site meteo monitor. This model atmosphere is fed to a radiative transfer code, e.g. LNFL/LBLRTM[c] ([5]), together with the line data base HITRAN2008[d] ([4]).

This approach ensures that the atmospheric conditions for the model coincide as closely as possible to those at the time of the observations. The specific molecular absorption and emission features are fit by varying the corresponding abundance profiles iteratively implementing a Levenberg-Marquardt χ^2 minimisation algorithm (mpfit package[e]). The resulting best-fit profile is then used to determine the column densities of the molecular content.

III. Results and Outlook

This method was originally developed to estimate the amount of precipitable water vapour above the observing site of the ESO Very Large Telescope, Cerro Paranal, Chile ([1]). Water vapour strongly hampers astronomical infrared observations, thus this knowledge is crucial for scheduling and conducting infrared observations at astronomical telescopes.

Fig. 2 shows an example of a transmission spectrum taken via a TS star with the instrument CRIRES, a high-resolution infrared spectrograph mounted at the ESO Very Large Telescope (VLT). The best-fit (red line) corresponds to a precipitable water vapour (PWV) value of about 0.9 mm.

In principle, this method is applicable to all molecules present in the Earth's atmosphere. We are currently in a testing phase to apply this fitting procedure to other greenhouse gases, e.g. CO_2, and methane, with additional ESO instruments.

Almost all large telescope sites worldwide (see Fig. 3) are equipped with spectrographs, which are appropriate for this purpose. As they all require the same calibration observations described above for every night such a spectrograph is in use, a frequent monitoring of greenhouse gases on a coarse world wide grid is in principle possible.

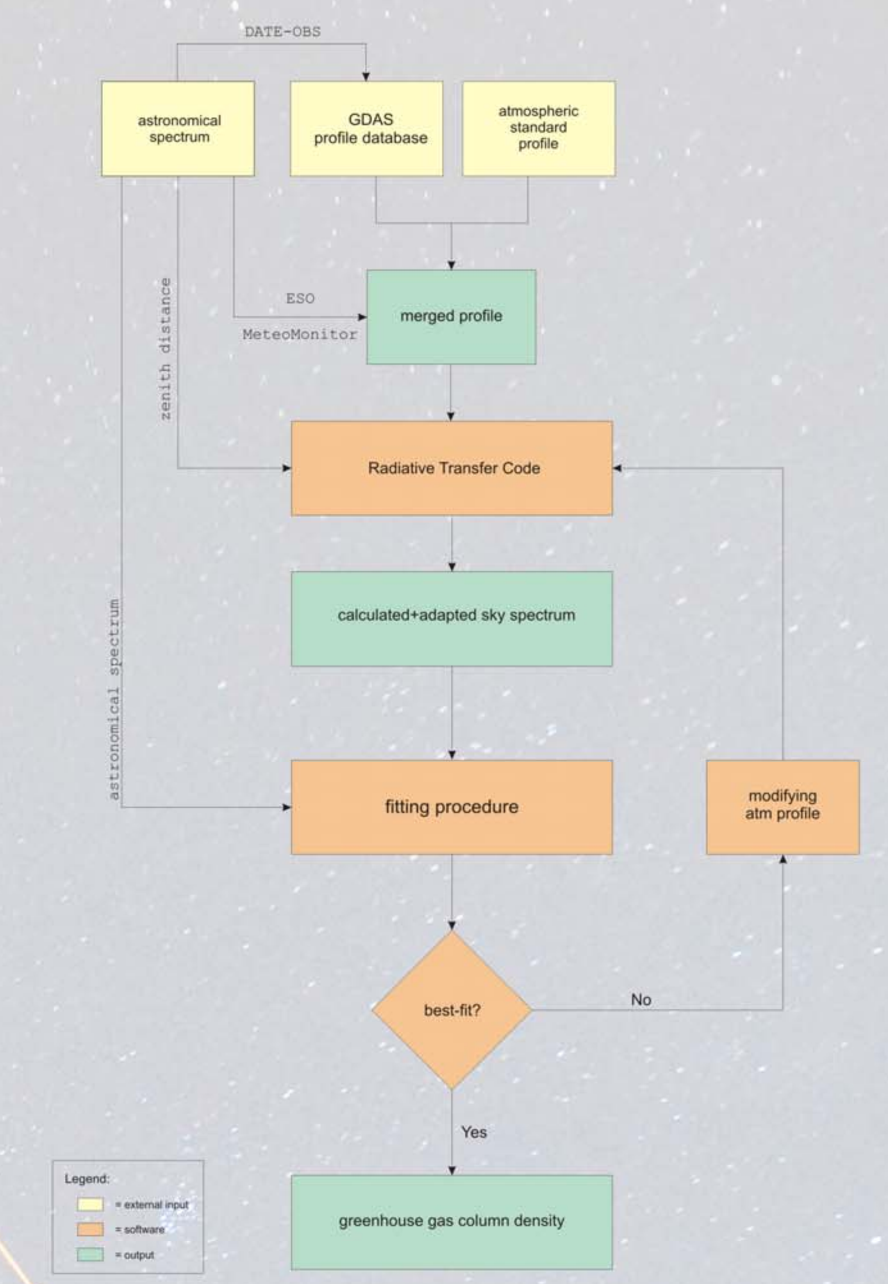

Figure 1: Principle workflow of the fitting procedure ([2]): Based on the observing date an apropriate atmospheric profile is created and used as input for a radiative transfer code to calculate and iteratively fit a sky spectrum. The best fit is finally used to determine molecular column densities.

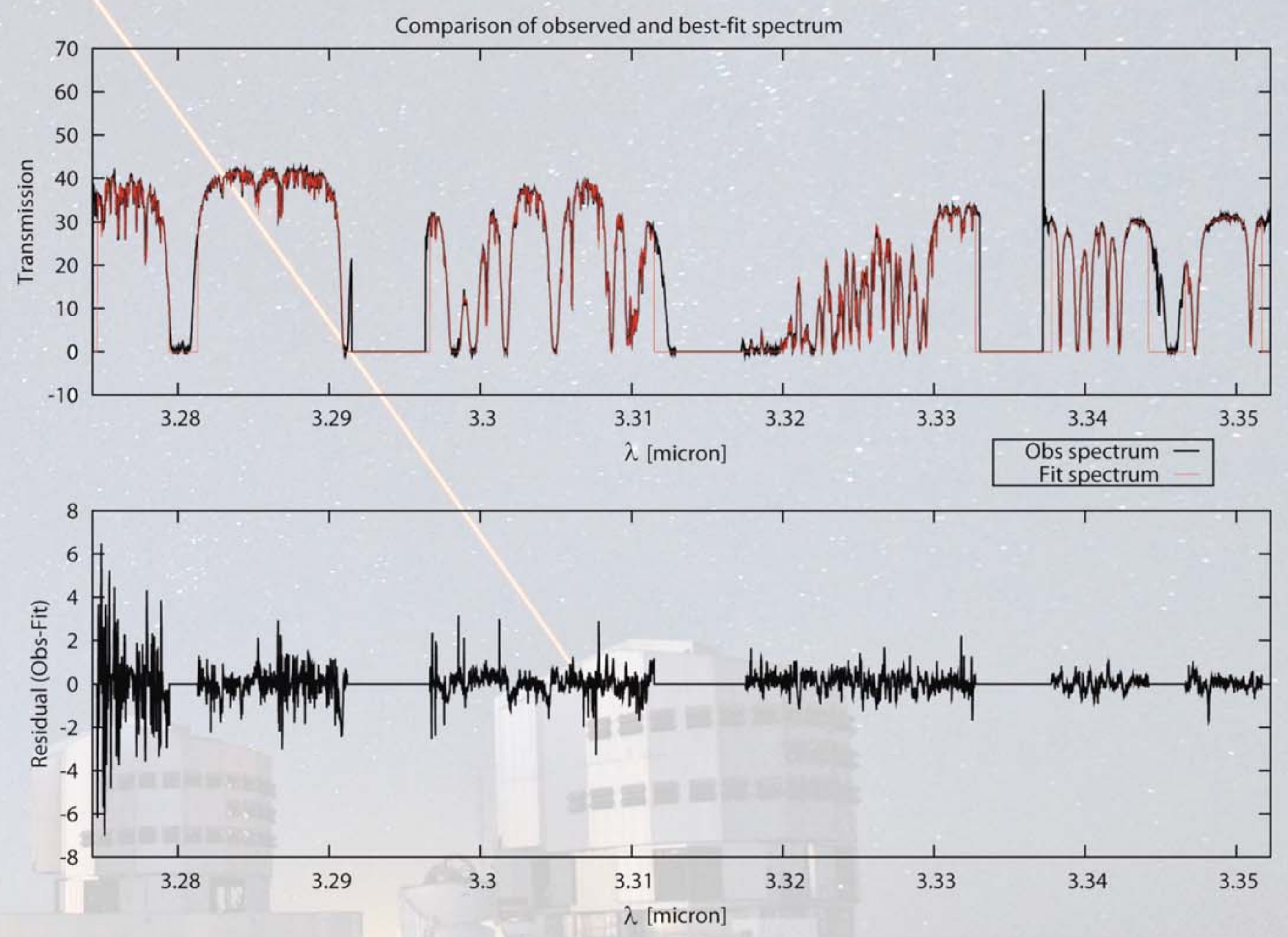

Figure 2: Upper panel: High resolution transmission spectrum obtained from a telluric standard star (black lines). The red line shows a best-fit spectrum calculated with a radiative transfer code on the basis of a modelled atmosphere. Lower panel: Residual between observed and modelled spectrum (see also [3]).

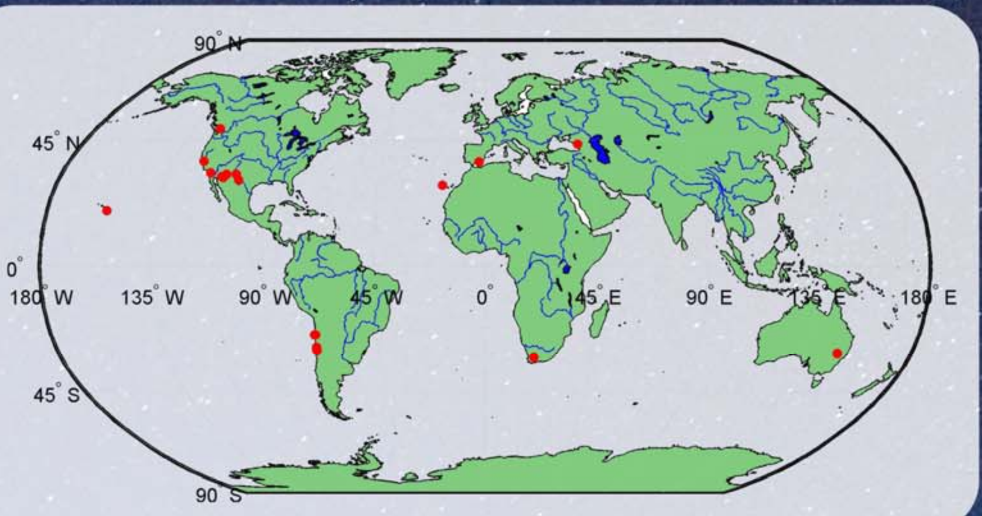

Figure 3: World map showing the observing sites of current state-of-the-art telescopes (red dots).

References:

[1] Smette et al., 2009, IAU XXVII General Assembly, ESO Chile
[2] DR06 Molecfit User Manual, VLT-MAN-ESO-19550-5286, and references therein
[3] Clough et al. 2005, JQSRT 91, 233
[4] Rothman et al. 2009, JQSRT 110, 533

Links:

[a] Reference Forward Model: `http://www.atm.ox.ac.uk/RFM/atm/`
[b] Global Data Assimilation System: `http://ready.arl.noaa.gov/gdas1.php`
[c] Line-By-Line Radiation Transfer Model: `http://rtweb.aer.com/lblrtm_frame.html`
[d] High-resolution transmission molecular absorption database: `http://www.cfa.harvard.edu/HITRAN/`
[e] MPFIT: `http://www.physics.wisc.edu/~craigm/idl/cmpfit.html`

Acknowledgements: **This study is carried out in the framework of the Austrian ESO In-Kind project funded by BM:wf under contracts BMWF-10.490/0009-II/10/2009 and BMWF-10.490/0008-II/3/2011.**

European Geosciences Union General Assembly 2012, April 22-27, Vienna, Austria, EGU2012-9239