Volume Title
ASP Conference Series, Vol. **Volume Number**
Author

A Complete and Comprehensive Sky Background Model

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Abstract. In the current era of precision astronomy, a complete sky background model is crucial, especially as the telescopes become even larger in the next decade. Such a model is needed for planning observations as well as understanding and correcting the data for the sky background. We have developed a sky model for this purpose, and it is the most complete and universal sky model that we know of to date. It covers a wide range of wavelengths from 0.3 to 30 micron up to a resolution of 1,000,000 and is instrument independent. Currently it is optimized for the telescopes at Cerro Paranal and the future site Cerro Armazones in Chile. Our sky model includes several components necessary to describe the sky background flux, such as scattered moonlight and starlight, zodiacal light, airglow emission and continuum, thermal emission from the telescope and lower atmosphere, and scattering and absorption within the Earth's atmosphere. Each component was designed with the latest knowledge and results in the field and was thoroughly checked with archival ESO data. Our sky background model will be a valuable asset for astronomical observatories and the community.

1. Introduction

The complete and comprehensive sky background model[1] was originally developed as part of the Austrian Ascension to the European Southern Observatory (ESO) to improve the Exposure Time Calculator (ETC). The ETC allows a potential observer to estimate how long of an exposure is needed to observe a given object with a certain signal to noise ratio, which allows for better scheduling of telescope time. For this purpose, a reliable model is needed to be able to predict the amount of sky background that will also be observed, and we have developed such a model.

Since the sky background model is for the ESO ETC, it must be computationally quick. Components that are too slow are dealt with in Module 1, and the rest is calculated in Module 2. Together, they provide a sky background spectrum for the given observing conditions and instrument mode.

The sky background model could be used in a variety of ways, other than for the ESO ETC for Cerro Paranal. With some modifications it could be used in other locations where the atmospheric properties can be determined. It can also be applied

[1]`http://www.eso.org/observing/etc/skycalc/skycalc.htm`

to data reduction. Two software applications, `molecfit` and `skycorr`, using the sky model are presented at this conference as well (Noll et al. 2013; Kausch et al. 2013a,b).

2. Module 1

Calculating a synthetic spectrum is too time consuming for the ETC application, so we have calculated a synthetic sky spectra library. It consists of both radiance and transmission spectra. We use a merged atmospheric profile. Using MIPAS[2] (Michelson Interferometer for Passive Atmospheric Sounding), an instrument on-board the ENVISAT satellite, related profiles we have information on the different molecules in the atmosphere as well as temperature and pressure information up to 120 km at the equator. We combine this with profiles from GDAS (Global Data Assimilation System)[3] which provides $1^\circ \times 1^\circ$ spatial grid every 3 hours for the temperature, pressure and humidity up to 26 km. The third part comes for the local information at Cerro Paranal from the ESO meteo monitor[4], which gives the temperature, pressure and humidity every 20 min from a 30 m high platform. This combined atmospheric profile is then averaged into 2 month bins. The next step is to use the HITRAN (HIgh-resolution TRANsmission molecular absorption) database (Rothman et al. 2009), which contains physical properties of molecular line transitions. These data can be used to compute emission and absorption lines for the 30 molecular species present. This is then ran through LBLRTM (Line-By-Line Radiative Transfer Model) (Clough et al. 2005) to produce a set of radiance and transmission spectra. A separate library is also calculated with various humidity levels. Both libraries are done for a grid of different airmasses. From this library, the appropriate spectrum is chosen when the model is run. It can also be interpolated and extrapolated to better fit the observing conditions which are not covered by the library.

3. Module 2

Module 2 contains all the sky background components that are computationally quick to calculate. The transmission spectrum contains the information about the scattering and absorption that occurs in the Earth's atmosphere and the emission spectrum has the scattered moonlight, scattered starlight, zodiacal light, airglow continuum and emission lines, lower atmosphere thermal emission and the telescope background (Fig. 1).

For the transmission curve, scattering is considered by molecules and aerosols where we use the Rayleigh and Mie approximations, respectively. Rayleigh scattering is calculated using the well-established formula given by Liou (2002). Mie scattering is determined from Patat et al. (2011) empirical parametrization in the optical. The absorption is taken from Module 1.

The radiance spectrum has several components. For the scattered moonlight, we combine the lunar albedo fit from Kieffer & Stone (2005) with a 3-D scattering code (Noll et al. 2012) and realistic Mie scattering phase functions (Bohren & Huffman 1983; Warneck & Williams 2012). See Jones et al. (2013) for more details. The integrated

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[2] `http://www.atm.ox.ac.uk/RFM/atm/`

[3] `http://ready.arl.noaa.gov/gdas1.php`

[4] `http://archive.eso.org/asm/ambient-server?site=paranal`

starlight is determined from the Pioneer 10 data (Toller 1981; Toller et al. 1987; Leinert et al. 1998), with a mean spectrum from Mattila (1980). For the direct zodiacal light we follow the model by Leinert et al. (1998). Both the starlight and zodiacal light are also scattered and absorbed as extended sources, using our 3-D scattering code (Noll et al. 2012). Airglow, nonthermal emission from the upper atmosphere, is a highly variable component. We divide the different airglow emission lines into five variability classes where the lines should vary in the same way. With this, we fit the different airglow emission lines, and determine correction factors for each class depending on how they vary on average with season, time of night, and solar activity, using a dataset from Patat (2008). This is done for the continuum as well, taken at 0.543 μm. See Noll et al. (2012) for a detailed discussion. The emission lines from the lower atmosphere come from Module 1, and the telescope thermal emission is assumed to be a gray body, which depends on temperature.

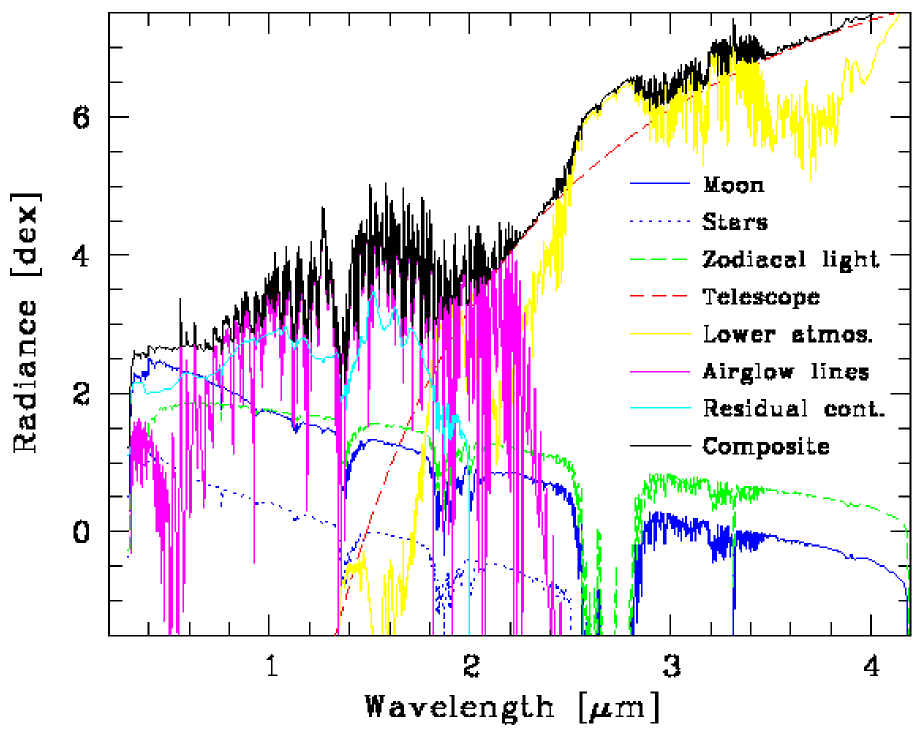

Figure 1. An example of the radiance spectrum for the sky background model showing the various components.

4. Performance

The overall performance of the sky background model is good with an error around 20% in the optical range. We have currently fully investigated the optical range using Patat (2008) (Fig. 2) and are in the process of evaluating the infrared regime using archival X-Shooter data.

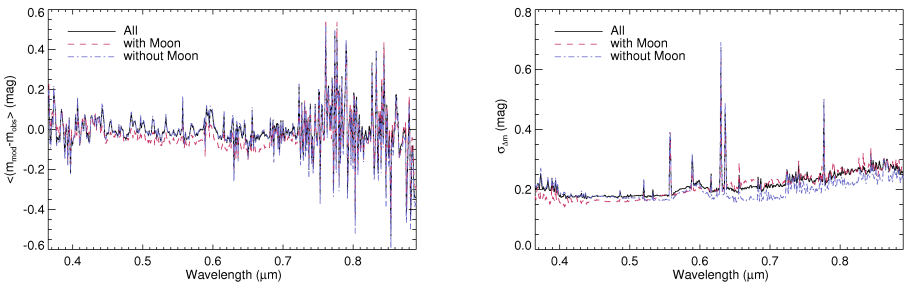

Figure 2. The mean (left) and sigma (right) of the difference between the sky background model and the observed data (Patat 2008) in magnitudes for all the data and those with and without moonlight present.

Acknowledgments. This study is carried out in the framework of the Austrian ESO In-Kind project funded by the Austrian Ministry for Research (BM:wf) under contracts BMWF-10.490/0009-II/10/2009 and BMWF-10.490/0008-II/3/2011. This publication is also supported by the Austrian Science Fund (FWF): P26130.

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