The OH-Airglow as a Tool to Characterize Extra-Solar Planets?

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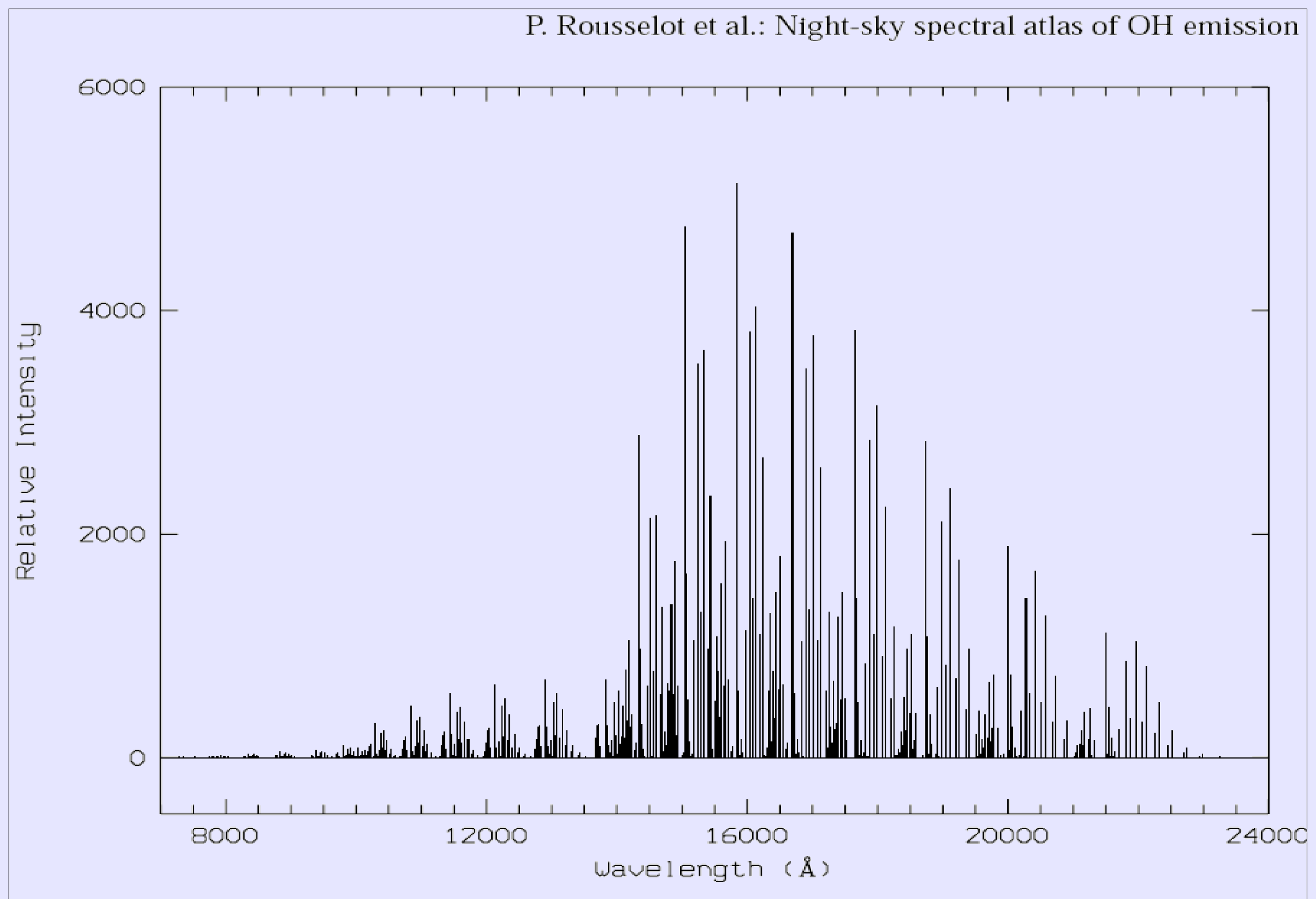
Introduction

At present various projects to find planets or entire planetary systems around main sequence stars in the solar neighborhood are under way. A multitude of next generation programs for planet searches are ongoing. In the era of ELTs, that is when ELTs will be operational, there will be literally 1000s of confirmed planetary systems. There even may exist spectro-photometric detections of Earth like planets in the habitable zones of their respective host stars. At this point it becomes inevitable to consider the next logical step: the spectroscopic analysis of the atmospheres of these Earth like planets and the search for water and oxygen.



Telluric OH-Emission Spectrum: Plot from atlas of OH-lines over the VLT (Rousselot et al. 2000, A&A). Precise frequencies available from fully resolved FTS-lab spectra exist (Abrams et al. 1994).

Any cross dispersed Echelle spectrograph which can observe the H-band in one exposure would detect 10-20 bright lines of the OH-Meinel bands.

High-resolution spectroscopy, i.e. resolving v·sin(i) of these planets, in the wavelength regime of 950-1750nm is presented as a powerful and promising tool. In view of the obvious contrast problems in detecting such planets, non-LTE features are specifically targeted. Sensitivity estimates for the detection of the non-thermal OH glow in oxygen-bearing atmospheres are given. With 8m-class telescopes such as the VLT such a search is impossible, but an NIR Echelle spectrograph at the projected ESO 40m telescope could detect Earth-like planets at a distance of ~10 parsec. The technical requirements for the best detectability will be sketched. Preparatory work with CRIRES, ESO's Cryogenic will be described. CRIRES is ESO's adaptive optics assisted Cryogenic Infrared Echelle Spectrograph with a nominal resolution of 3km/s operating from 950 to 5500nm (55.000-315.000GHz).

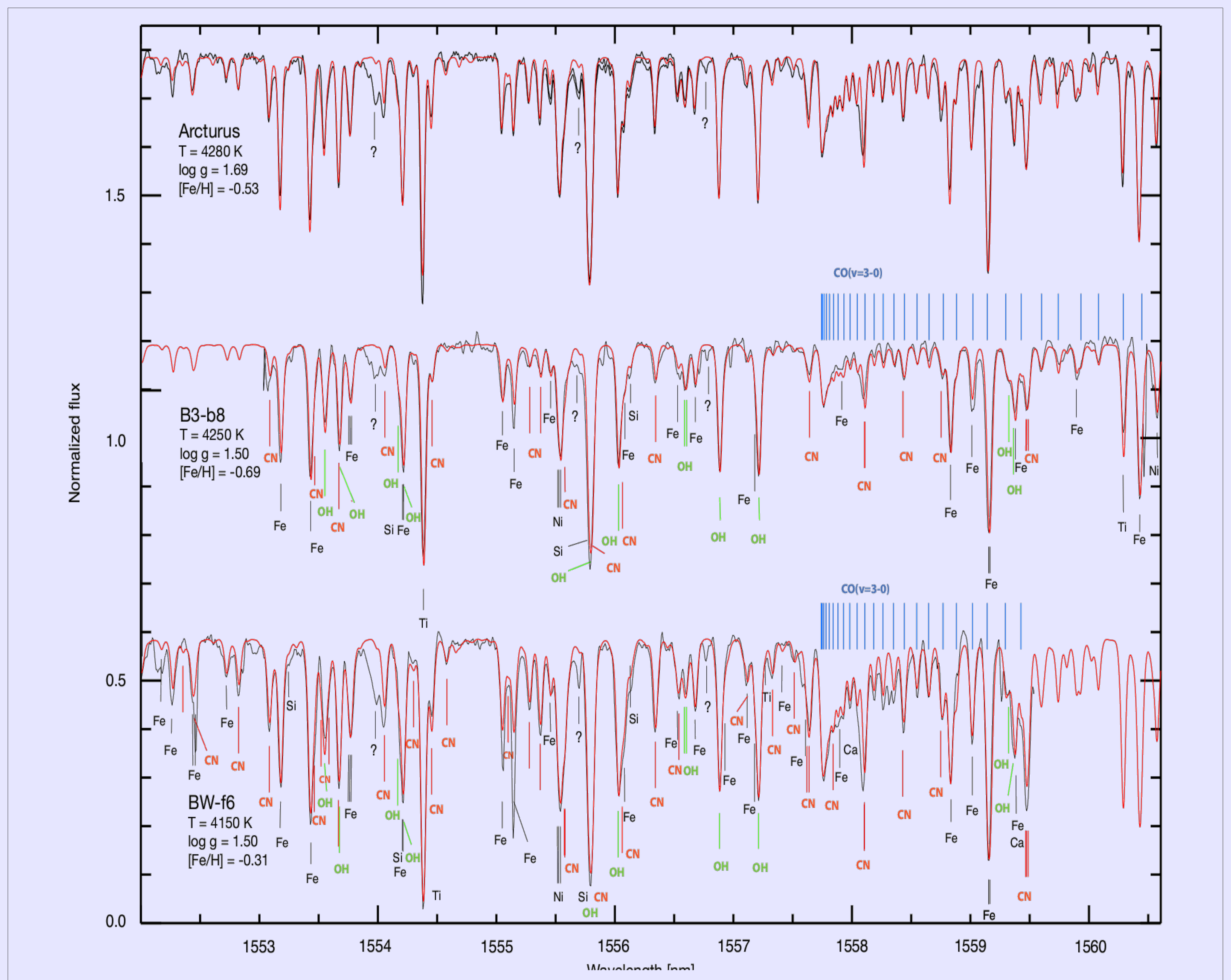
Why OH?

Using our own Solar system and here the cases of Mars and Earth as reference, one has an example of atmospheric spectra with large intervals dominated by optically thin narrow molecular absorption lines.

The OH-airglow is a non-thermal emission feature releasing chemical energy stored in the ozone molecule via the reaction:

$$O_3 + H \rightarrow OH^* + O_2$$

The Hydrogen atoms result from destruction of water by UV photons outside of the ozone layer. Compared to other non-LTE effects and fluorescence lines these lines are quite bright, hence unique.



Examples of typical stellar spectra in the H-band – here obtained for abundance studies (from Ryde et al., arXiv: 0910.0448, A&A accepted)

As can be seen, the stellar spectra against which the planet would need to be detected can very well be modeled and hence do not pose a major obstacle in retrieving the OH signal

Last not least, the OH-airglow peaks at 1700nm and the photospheres will be fainter while all straylight effects, scaling with $\lambda^{-1.3}$ to λ^{-4} are substantially reduced as compared to e.g. the R-band.

Why an Echelle Spectrograph?

Again using our own Solar system and here the cases of Mars and Earth, then we find that atmospheric spectral lines have intrinsic widths corresponding to the speed of sound. Observing a planet the resulting line profile will be broadened by the rotation of the planet. Telluric planets rotate slowly, hence v·sin(i) is of order of 1km/s.
To achieve maximum suppression of the light of the central star, or best contrast, the resolution of the Echelle spectrograph should just match the spectral line profiles, i.e. R ~ 100 – 150 000, or 1 to 1.5km/s per pixel, assuming Nyquist sampling.

An Educated Guess on Signal Strength

Running the new ESO atmospheric model[1] to determine the night sky OH-airglow one gets typical radiances of 170ph/(s m^2 $arcsec^2$) for some 10-15 strong lines each. When observing our Earth, the night side only, at a distance of 10pc, then at the focus of a 1000m^2-telescope, one would expect 10^{-5} photons per second and line. However, assuming that the dayside of such a super-Earth is 10^3-times brighter and the planet 10 times bigger in diameter, then one could expect 1ph/s/line, i.e. quite a substantial signal.

How to Improve the Radiometry?

By observing the Earth-shine from Paranal using CRIRES the disk-integrated OH-airglow can be observed. The geometry is almost identical to quadrature, the geometry one would use when characterizing exo-Earths. This would be done twice, once with the waxing and once with the waning Moon. Comparing the dark side (telluric OH plus Earth-scattered sunlight) with the bright side of the Moon will allow to constrain the approximate Albedo of the local Lunar surface to arrive at absolute spectro-photometry.

Outlook and Future Work

The CRIRES instrument will be used to constrain, starting from the telluric OH-airglow, the radiance that can be expected from a super-Earth during quadrature.

At this point there are good reasons to assume, that a cross-dispersed high-resolution near-IR Echelle spectrograph – similar to the SIMPLE project study – could detect oxygen-bearing atmospheres of super Earths in the Solar neighborhood.

1 http://www.eso.org/observing/etc/bin/webapps/skymodel_calculator/script/skymodel_calculator

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