Exploring non-LTE Effects in Exoplanet Atmospheres

By Sam Wright

Atmospheric Effects

The work done to date on the retrieval of exoplanet atmospheres has assumed that the species present are in local thermodynamic equilibrium (LTE). However it is known, for instance on Earth, that non-LTE effects are present in planetary atmospheres and give rise to spectra that vary from the LTE case. The physical features present in some exoplanet atmospheres will drive molecules to non-LTE states, such as:

- In high altitude shock regions at the boundaries of very fast jet streams: here molecules will lose energy in the rotational mode preferentially to the vibrational mode, giving rise to non-LTE effects.
- In parts of the atmosphere exposed to heavy solar radiation: here stellar pumping will provide energy only to the molecule's vibrational mode, driving it to a state of non-LTE.

These non-LTE molecular states produce emission and transmission spectra that differ considerably from their LTE equivalents: these differences are then detectable under the right circumstances.

Generating non-LTE absorption cross sections

The cross sections are generated using the ExoCross package with ExoMol line lists. ExoCross treats non-LTE by taking separate vibrational and rotational temperatures and approximating the total energy as the sum:

$$\tilde{E}_{\nu,J,k} = \tilde{E}^{\mathrm{vib}}_{\nu} + \tilde{E}^{\nu,\mathrm{rot}}_{J,k}$$

The population is then taken as:

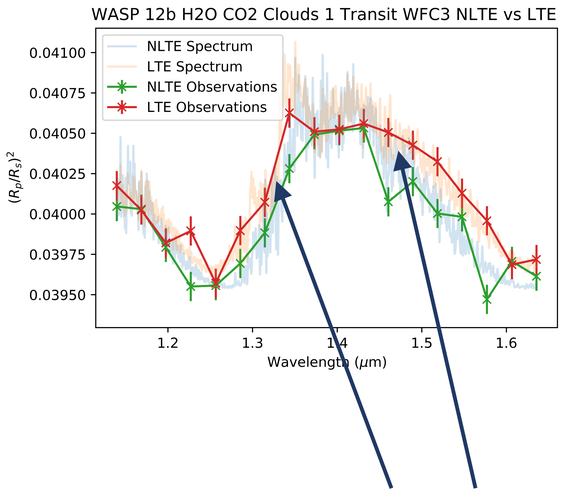
$$n = \frac{e^{-\frac{E_{\mathrm{vib}}}{kT_{\mathrm{v}}}} e^{-\frac{E_{\mathrm{rot}}}{kT_{\mathrm{r}}}}}{Q_{\mathrm{v}} Q_{\mathrm{r}}}$$

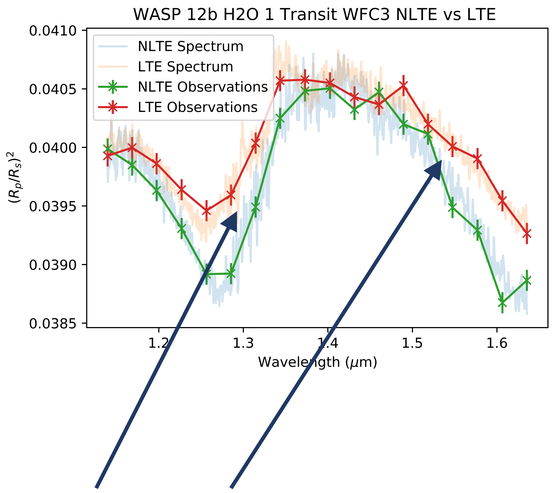
ExoCross: a general program for generating spectra from molecular line lists. Yurchenko et al. (2018)

Detectable non-LTE effects

Modelled transmission spectra of WASP-12b's atmosphere

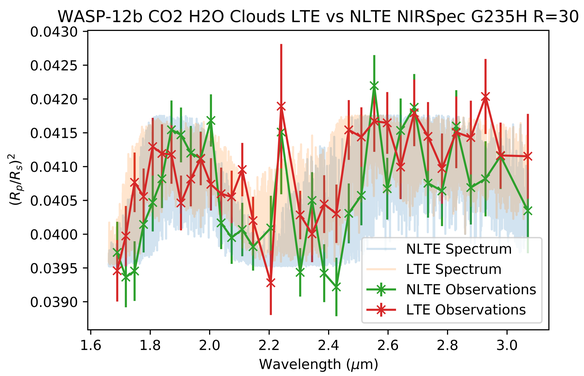
HST

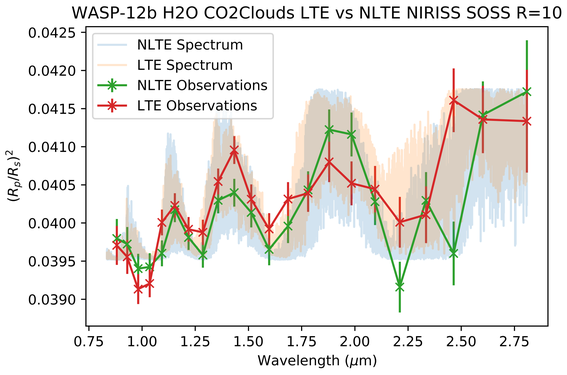


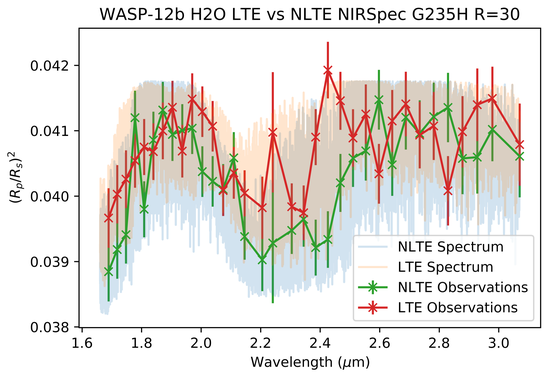


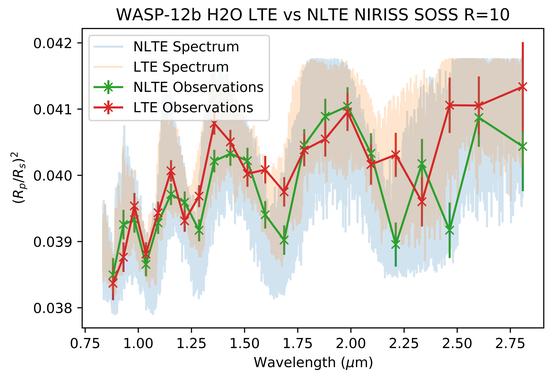
Clear absence of "shoulders" in the non-LTE case

JWST









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