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# Integrating light-curve and atmospheric modelling of transiting exoplanets

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## Abstract

Spectral retrieval techniques are currently our best tool to interpret the observed exoplanet atmospheric data. Said techniques retrieve the optimal atmospheric components and parameters by identifying the best fit to an observed transmission/emission spectrum. Over the past decade, our understanding of remote worlds in our galaxy has flourished thanks to the use of increasingly sophisticated spectral retrieval techniques and the collective effort of the community working on exoplanet atmospheric models. A new generation of instruments in space and from the ground is expected to deliver higher quality data in the next decade, it is therefore paramount to upgrade current models and improve their reliability, completeness and numerical speed with which they can be run. In this paper, we address the issue of reliability of the results provided by retrieval models in the presence of systematics of unknown origin. More specifically, we demonstrate that if we fit directly individual light-curves at different wavelengths (L - retrieval), instead of fitting transit or eclipse depths, as it is currently done (S - retrieval), the results obtained are more robust against astrophysical and instrumental noise. This new approach is tested, in particular, when discrepant simulated observations from HST/WFC3 and Spitzer/IRAC are combined. We find that while S-retrievals converge to an incorrect solution without any warning, L - retrievals are able to identify potential discrepancies between the data-sets.

## 1. Introduction

Current atmospheric retrieval models have focused on inferring a planet's atmospheric composition and structure by fitting a theoretical spectrum to an observed transmission/emission/reflection spectrum (e.g.[6][5][7][1][4][3][2]) This approach does not account for the existing correlation between orbital parameters and atmospheric components, as only transit/eclipse depths are processed by current retrievals. In other words, the very fact that only transit depths are used creates an interruption in the error propagation pathway as transit depths are extracted from the light curves, without accounting for potential correlations between atmospheric and orbital parameters. The complete light curve fitting should be included in the likelihood of the atmospheric retrieval to accurately propagate uncertainties in parameters such as inclination, semi-major axis or limb-darkening coefficients.

In this paper, we focus on transiting planets and propose a novel, more comprehensive approach that takes the retrieval process one step closer to the raw data, by integrating the light-curve fitting process into the atmospheric retrieval process. The new approach can uncover systematic errors that were difficult to detect, while retrieving atmospheric information from transit/eclipse spectra.

## 2 The L - retrieval

Our proposed method takes the entire atmospheric retrieval process closer to the observed data: instead of fitting the final transit/eclipse spectrum, information from each raw light-curve is used to derive directly the atmospheric components. For clarity, the former approach will be called the spectral retrieval, or 'S - retrieval', hereafter and the latter one the light-curve retrieval, or 'L - retrieval'. See Figure 1 for a schematic comparison between the two approaches.

## 3. Conclusion

By fitting directly the light-curves, we can propagate the systematic uncertainties and parameter correlations from the light-curves to the estimate of the atmospheric parameters. We find the L - retrieval to be more robust to correlations in the parameter space and

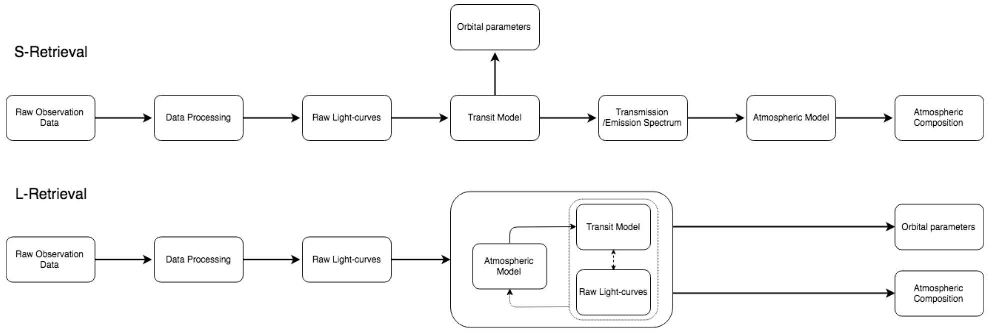


Figure 1: Comparison between the S - retrieval and our proposed approach, the L - retrieval. The major difference between the two is the merge of two separate fitting processes into one, bypassing the creation of a transmission/emission spectrum during the fitting process.

to generally yield tighter parameter constraints compared to the classical S - retrieval.

When combining data of multiple instruments or epochs, bias offsets are possible due to systematic errors in the instrument calibration, stellar noise, or poorly constraint orbital parameters. The S - retrieval is oblivious to the constraints in the orbital parameters, and will always strive to provide the best fit by biasing the atmospheric model parameters. On the other hand, we found the L - retrieval to be highly sensitive to such effects and provide a significantly better safeguard against such systematic offsets. As more suitable instruments become available in the future, the field will move rapidly towards multi-instrument atmospheric retrievals. The L - retrieval approach described here may offer an optimal solution to interpret multiple data-sets, taken at different times and/or with different instruments.

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