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QSOnic: fast quasar continuum fitting

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Summary

Distant quasars shows absorption features at wavelengths shorter than the Lyα emission line in their spectrum due to intervening neutral hydrogen gas. The Lyα forest technique uses these absorption lines to map out the matter distribution in vast volumes when the universe was 1.5–3 billion years old ($2 \lesssim z \lesssim 5$). This map of the cosmos successfully constrained cosmological models using the Baryon Acoustic Oscillations feature in the 3D correlation function (du Mas des Bourboux et al., 2020), various dark matter models (Iršič et al., 2017) and the sum of the neutrino masses (Palanque-Delabrouille et al., 2015) using the 1D Lyα forest power spectrum (Karaçaylı et al., 2022, 2024).

The density of the intervening gas is infered from the transmitted flux fraction which is the absorption depth relative to the unabsorbed quasar continum. The field has devised a simple continuum model to homogenize the analysis across quasars so that the errors in estimated continuum are contained to well-known modes. This model assumes each quasar continuum C_q is a scaling of a mean quasar continuum shape $\bar{C}$ by a polynomial of $\ln \lambda$. For example, an order 1 polynomial introduces amplitude a_q and slope b_q terms for each quasar such that $C_q = (a_q + b_q \ln \lambda)\bar{C}$. The quasar continuum fitting algorithm is then an iterative solution that minimizes χ^2 for each quasar and updates the mean quasar continuum using the stack of all quasar continua after every iteration (du Mas des Bourboux et al., 2020; Karaçaylı et al., 2024). This methods requires efficient parallelization due to computational time and memory needed.

Statement of need

`QSOnic` is an MPI-parallelized, highly optimized Python package specifically built for the Dark Energy Spectroscopic Instrument (DESI), which will collect approximately almost a million Lyα quasar spectra in the near future (DESI Collaboration et al., 2016). `QSOnic` is designed to overcome the numerical challenge posed by this large quantity of spectra by MPI parallization that can distribute the memory and workload across multiple compute nodes, and to provide an efficient API to read and manupulate DESI quasar spectra to allow implemetation of other algorithms within the Lyα forest framework. It provides detailed intermediate data products including best-fit parameters for each quasar and a delete-one Jackknife estimate for the covariance matrix used in pipeline noise calibration correction calculation. These intermediate products are crucial to ascertain the precision of the fitted continua and the pipeline noise corrections.

`QSOnic` will be used in the future scientific publications of the 1D Lyα forest power spectrum and the 3D correlation function measurements from DESI data.

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