Pushing the Limits of Dark Energy Experiments

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Background

Understanding the accelerated expansion of the Universe is one the biggest unsolved problems in fundamental physics. This was recognized by the 2011 Physics Nobel Prize to the three astronomers who lead the research teams that found observational evidence for this phenomenon (Riess et al., 1998; Perlmutter et al., 1999). The main reason for its protagonism in fundamental physics is that a complete understanding of the accelerated expansion lies either in a new kind of negative pressure energy component (dubbed under the generic name of Dark Energy) or in the modification of Einstein's General Relativity.

The Dark Energy Spectroscopic Instrument (DESI) is a world-class experiment that is designed to bring the most significant experimental advance on this front. DESI will take the spectra of 35 million galaxies to make the most accurate measurement of the expansion history of the Universe on the timescale 2019-2024 using the Baryon Acoustic Oscillation (BAO) technique (D. J. Eisenstein et al., 2005; Cole et al., 2005). DESI will be the leading experiment in observational cosmology during that period.

One of the significant milestones to prepare DESI is a full simulation of its expected five years of operations. This simulation will test all the software components that will be used on the real data. It will also help to test strategies to maximize DESI's scientific return. The results of this simulation exercise will also be useful to the broad scientific community expecting to use DESI data products.

The work to simulate DESI builds upon the accumulated experience of its precursors (Dawson et al., 2013), it also integrates the knowledge of different groups of experts (Nord et al., 2016). From the engineers designing the instrument, to the astronomers processing the data, including the expert simulators of universes and galaxies. In this project we will work with data from this simulation effort to help DESI in getting closer to answer fundamental questions about the nature of our Universe.

Objectives

The main objective is to analyze the data resulting from a simulation of five years of DESI operations. This will allow us to reach three goals:

- Forecast DESI's accuracy to constraint the expansion history of the Universe.
- Quantify the degree to which different instrumental systematic errors can degrade DESI's performance.
- Test strategies to mitigate systematic effects and maximize DESI's scientific return.

Methodology

This project aims at quantifying the expected performance of the DESI experiment. This requires an end-to-end simulation of the DESI survey including: mock catalogs for the galaxy populations to be observed (Schlegel et al., 2015), simulating the 5 years of telescope operations including weather and observational cadence, assigning optical fibers to the galaxy targets (Cahn et al., 2015), generating simulations of the raw spectrograph data (Edelstein & DESI Collaboration, 2015) and processing those simulated data with the full spectroscopic pipeline, resulting in a redshift catalog. Every link n this chain contributes its share of inefficiencies to the final measurement of the BAO signal (D. Eisenstein & DESI Collaboration, 2015).

The simulation process allows the DESI project to test dataflows, check software scaling and generate realistic datasets for science preparation before the survey starts. The current project proposal takes a starting point the realistic simulated datasets for science preparation. Using this data we will use and develop software to

- Estimate in detail the accuracy at which DESI can measure the BAO signal at different cosmic epochs.
- Quantify the impact on the BAO measurement inefficiencies from major parts/steps in the survey.
- Implement strategies to reduce the above mentioned inefficiencies.

The main methodology thus consists in **using software to make a simulation-based quantitative assessments about DESI's performance in measuring the BAO signal**.

Significance

First and foremost, the significance of this project lies in its potential to expand our knowledge about the physical Universe. DESI is a world-class experiment in the area of observational cosmology and will be second to none in this research field during its operational time.

This collaboration will also enrich the Colombian scientific community. Colombia participates in very few world class experiments in the physical sciences. Being able to contribute to DESI will have a long lasting impact in the new generation of young scientist involved in the project as students.

This will also naturally impact my career. Participation in DESI allows me to contribute my research skills at the service of a large collaboration, increasing the chances to tackle projects of ever increasing complexity and relevance to the scientific community.

I also work as a regional coordinator for the *Astronomy for Development* (AfD) initiative [1], whose motto is to use astronomy to create a better world. The AfD initiative deploys projects that use the cultural, technical and scientific aspects of astronomy to engage with local communities and impact their development status. My time at the Lawrence Berkeley National Laboratory (the host institution) will allow me to create new partnerships and gather novel ideas to achieve the AfD goals.

Evaluation and Dissemination

DESI has a formal project management structure. Under this framework there are well defined milestones and deadlines for the different tasks defined in the current proposal. The internal evaluation process by the managers in the collaboration provides a natural strategy to asses the project's success.
I also foresee three main strategies to disseminate the results of this work.

1. The software contributions written during the project's development will all be publicly available through the public DESI repository [2].
2. The analysis of the data challenge results are of interest to the scientific community. As such we will publish our conclusions in astronomical journals of wide international circulation.
3. The project results will also be presented in scientific meetings both international and local (Colombian/Latinamerican) to enhance the impact on the development of the Colombian astronomical community,

Justification

DESI is coordinated by the Lawrence Berkeley National Laboratory. The collaboration includes close to 300 scientists in 40 institutions around the world. Most of the simulation work is done in different locations (including Bogota) and it is coordinated via virtual meetings. However, to consolidate progress (i.e. by releasing software or data to the collaboration) it is crucial to spend a minimal amount of time in face-to-face meetings.

Since 2014 I have used funding from my University and the DESI collaboration to spend at least one week per semester at Berkeley Lab writing and integrating software for the data simulation pipeline. As DESI gets closer to starting operations in January 2019, the experiment has reached a point where the end-to-end simulation effort has matured and gained relevance to the operational aspects of the project.

[1] `http://andean.astro4dev.org/`
[2] `https://github.com/desihub/`

A significant and timely contribution to DESI needs the focused effort on site at Berkeley Lab that a Fulbright fellowship can best provide.

Duration

I expect to spend a total of 16 weeks working on site at Berkeley Lab starting mid August 2017 through December 2017.

Currently we are working on the preparation of the full simulation (August-December 2016) and the associated analysis tools. We will perform the simulation next year (January-July 2017) and complete the analysis in the period August-December 2017.

The analysis stage will be the focus of my visit to Berkeley Lab. We foresee four stages, each one fitting into a 4-week period.

1. Measure the accuracy at which the simulated data constrains the expansion history of the Universe.

2. Quantify different instrumental systematic errors can degrade the experiment's performance. The focus will be on the effect of fiber assignment and success of the spectroscopic pipeline.

3. Run simplified simulations to test strategies that mitigate systematic effects and maximize DESI's scientific return.

4. Consolidate a detailed report on the results from the end-to-end simulation challenge. The full report is aimed at the DESI collaboration. A condensed version will be published for the broader scientific community interested in understanding the kind of data that the DESI collaboration will produce.

These tasks depend on software that we are constrained to develop in the period August 2016 - July 2017. As the simulation progresses we will analyze small chunks of data to fine tune the required tools.

The experience we gain in this one-year preparation period ensures that being able to do focused work during 16 weeks on site at LBL, using mostly existing tools, is the only critical step to succeed in the global analysis task.

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