National Aeronautics and Space Administration

Mass and Motion, Tension and Concordance: What are tensions in current data telling us about dark energy?

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Program: FY22 R&TD Strategic Initiative
Strategic Focus Area: Astrophysics Data Analysis - Strategic Initiative Leader: Charles Lawrence

Background:

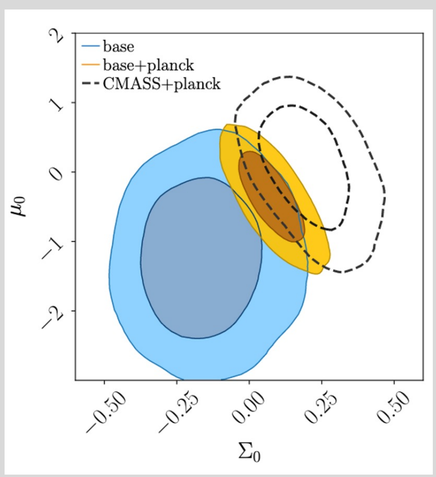
More than twenty years after its discovery, the nature of cosmic acceleration is still a major mystery. Current data are broadly consistent with a universe dominated by a cosmological constant and cold dark matter (the model termed LCDM), but there are emerging empirical tensions within the most recent data sets and deep theoretical problems with the cosmological constant as a physical model for dark energy. The community is now focused on searching for evidence of deviations from LCDM. There exists a variety of powerful cosmological data sets available from ground-based surveys, but it is not yet clear how best to optimally combine them.

Objective:

The existing ground-based surveys are the direct precursors to the forthcoming *Nancy Grace Roman* and *Euclid* space missions, both of which have significant JPL science leadership. New methods and techniques are needed in order to fulfill the full potential of these data sets. The purpose of this R&TD is to perform a joint analysis of the best existing cosmological survey data, learn as much as we can about the nature of dark energy, and in so doing develop the tools and methods needed to perform accurate, robust cosmological inference the forthcoming *Roman* era.

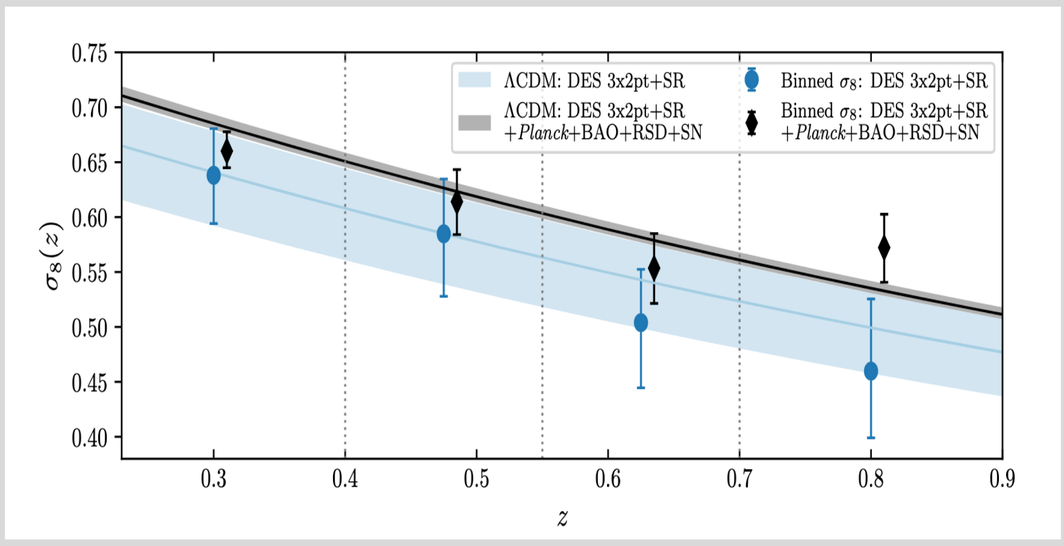
Approach and results

Constraining the Nature of Gravity with the Dark Energy Survey and the Sloan Digital Sky Survey:



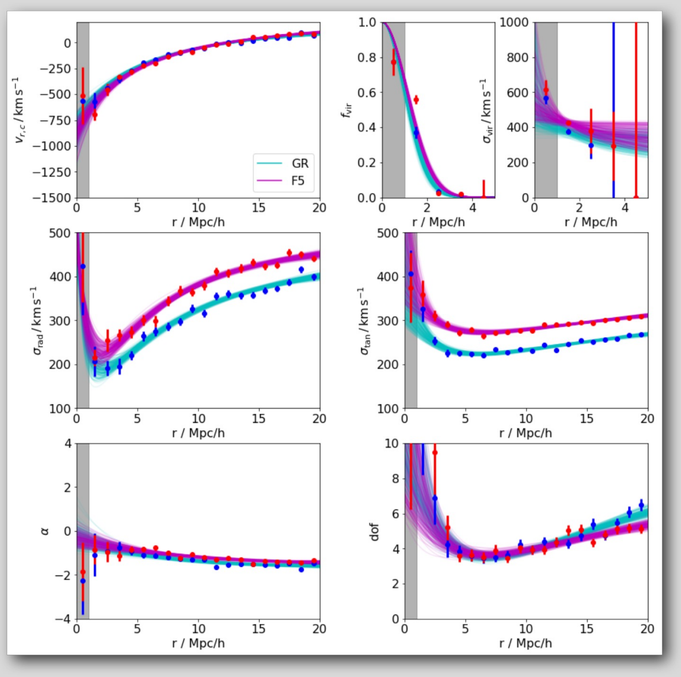
Combining data from spectroscopic and imaging surveys provides a new window into the nature of dark energy. The plot at left, from [2], shows posterior probability constraints on parameters describing deviations from General Relativity from two cosmological survey programs, and demonstrates a method for combining data from surveys that only partially overlap on the sky, which will be important for the next generation of cosmological surveys.

In particular, this work combines spectroscopic measurements of *Redshift-Space Distortions*, which are sensitive to the motions of galaxies, with weak lensing-based measurements of the distribution of matter, including dark matter.



A key probe of the nature of dark energy is the growth of cosmic structure over time. The plot above, from [1], shows the contraints obtained on this growth from the Dark Energy Survey's Year 3 analysis. This work was co-led at JPL by Dr. Agnes Ferté, a JPL postdoc until August 2022.

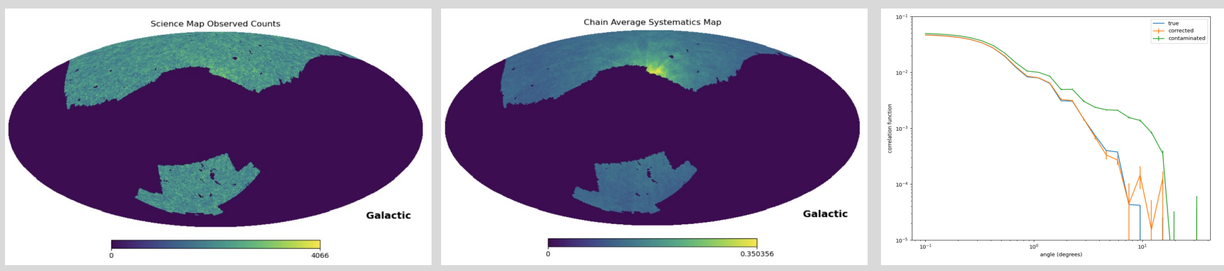
Improving Models that Link Mass and Motion



On scales below ~30 Mpc, theoretical models for galaxy formation do not accurately model the clustering of galaxies around clusters in redshift space. We have developed an analytic model for the distribution of positions and velocities of galaxies in the neighborhood of massive galaxy clusters. A comparison of model fits to the velocity distribution of galaxies around clusters in simulations is shown at left.

This model produces accurate predictions for the redshift-space distorted galaxy clustering measurements in simulations, and appears to be robust to changes in galaxy formation models. The ability to accurately model these small scales has the potential to as much as triple the parameter constraints from cosmological analyses.

Developing Methods for Blind Systematic Error Mapping



We have developed a method that permits a joint analysis of two overlapping cosmological surveys to detect and eliminate systematic errors in both, with no prior knowledge about those systematics. The top left shows a simulated survey map, with realistic systematics embedded. Our method uses Bayesian forward modeling to recover maps of systematic errors (center), and largely eliminate their effects on galaxy clustering measurements (top right).

Benefits to JPL and NASA:

Under this award, the team has taken advantage of access to the best current ground-based cosmological surveys to develop tools and methods for maximizing the science return from the next generation of JPL-involved NASA and ESA dark energy investigations.

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Clearance Number: CL#
Poster Number: R20022

Selected Publications (from 43 published or submitted in FY22):
[1] Dark Energy Survey Year 3 Results: Constraints on extensions to LambdaCDM with weak lensing and galaxy clustering — DES Collaboration and 161 colleagues 2022, submitted to PRD
[2] Probing gravity with the DES-CMASS sample and BOSS spectroscopy **— Lee, S.**; **Huff, E. M.**; Choi, A.; Elvin-Poole, J.; Hirata, C.; Honscheid, K.; MacCrann, N.; Ross, A. J.; Troxel, M. A.; Eifler, T. F. and 97 more 2022, MNRAS, 509, 4982
[3] Redshift space distortions: Unmixing radial scales in projection **— Taylor, P.L.**, **Markovic, K.**, Pourtsidou, A., **Huff, E**. 2022.

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