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: FY21 R&TD Strategic Initiative **Strategic Focus Area: Astrophysics Data Analysis**

Motivation:

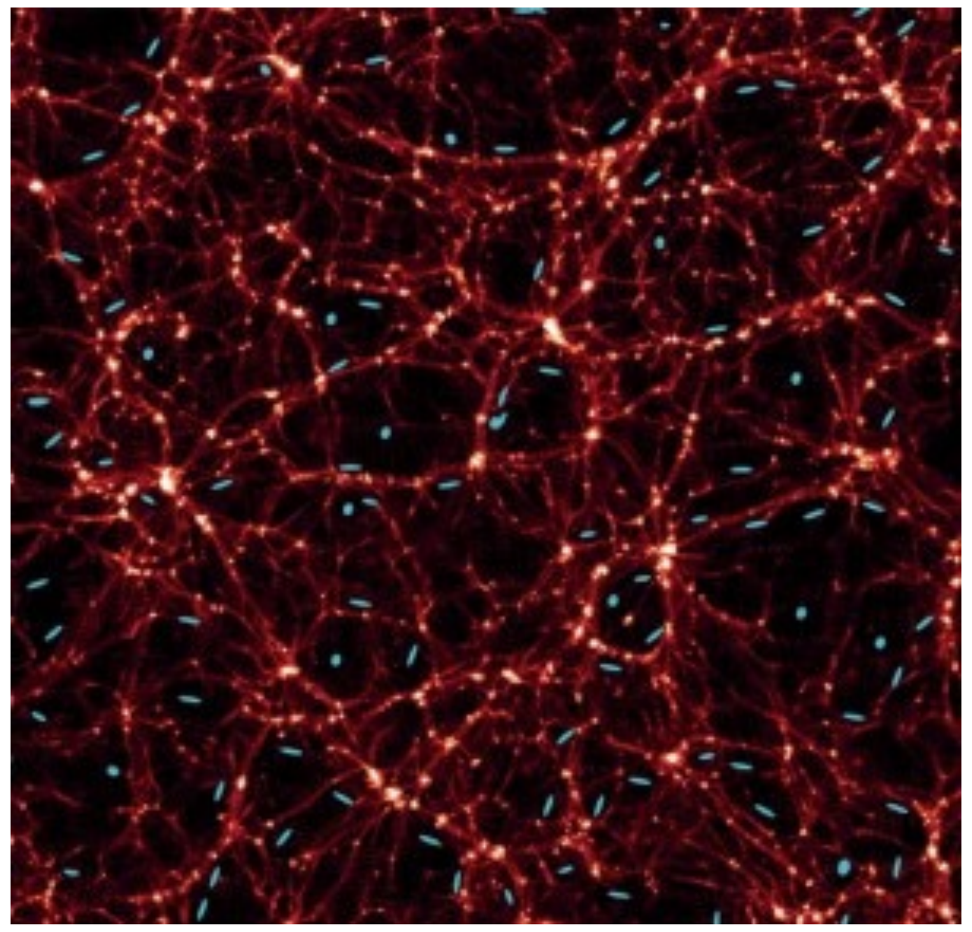
Dark energy remains one of the most important unsolved mysteries in modern physics, and is a major science driver for the Roman Space Telescope, the ESA's Euclid mission, and several other major investigations.
The data analyses for these programs are especially challenging, and statistical inconsistencies currently exist between the best current constraint which may indicate unanticipated systematic errors in current methods, or may be the signatures of new physics.
By contributing to current ground-based cosmological data analyses, we remain at the leading edge of current science, and advance the state of the art to prepare for the next generation of cosmological probes.

Background:

Our current understanding of the history of the Universe holds that it starts out from a singularity, undergoes an early phase of rapid expansion (inflation), after which expansion continued, decelerating during the so-called matter dominated phase. Then, five billion years ago, the expansion of the universe started *accelerating*. This acceleration continues, and the energy density associated with it is now the dominant component of the universe today.

A representative simulation of the large-scale structure of the Universe is shown at **right, in red**. Observable galaxies trace this structure, but imperfectly. This structure also distorts the images of distant background galaxies, with a direction illustrated by the blue elllipses. This **weak lensing** effect is an unbiased probe of structure, but measurements of it are intrinsically noisy

Current and future planned surveys combine these measurements to constrain dark energy. Current, ground-based surveys are developing methods and know-how which will be critical for forthcoming NASA missions.



Publications (selected from 49 in FY 21)

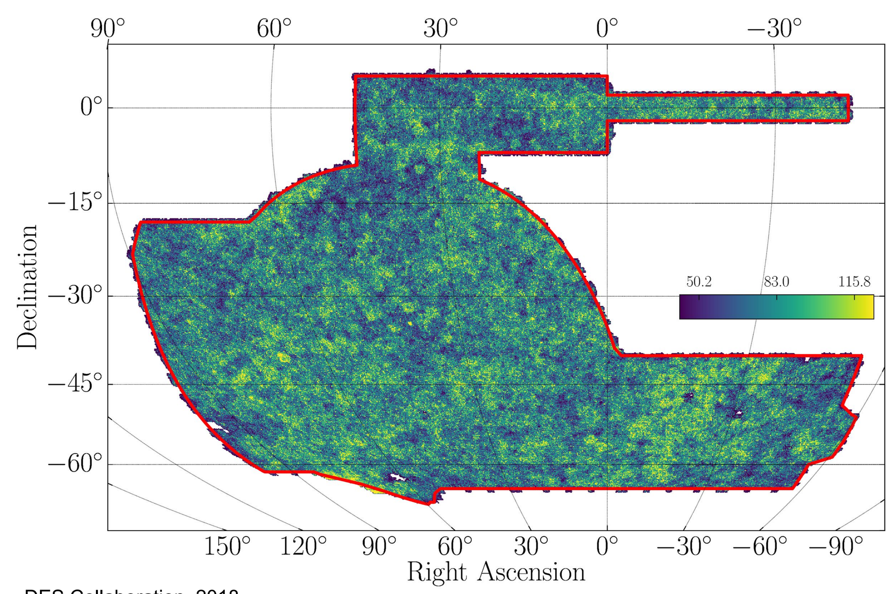
Abbott, T.M.C. and **137 colleagues** 2021. The Dark Energy Survey Data Release 2. The Astrophysical Journal Supplement Series 255. doi:10.3847/1538-4365/ac00b3
Vazsonyi, L., **Taylor, P.L.**, Valogiannis, G., Ramachandra, N.S., Ferte, A., Rhodes, J. 2021. Constraining f(R) Gravity with a k-cut Cosmic Shear Analysis of the Hyper Suprime-Cam First-Year Data. arXiv e-prints.
Taylor, P. L., Markovic, K., Pourtsidou, A., **Huff, E**. 2021. The RSD Sorting Hat: Unmixing Radial Scales in Projection. arXiv e-prints
DES Collaboration and 169 colleagues 2021. Dark Energy Survey Year 3 Results: Cosmological Constraints from Galaxy Clustering and Weak Lensing. arXiv e-prints
Lee, S., **Huff, E**, and 103 colleagues 2021. Probing gravity with the DES-CMASS sample and BOSS spectroscopy. arXiv e-prints.
Taylor, P. L., Bernardeau, F., **Huff, E**. 2021. x -cut Cosmic shear: Optimally removing sensitivity to baryonic and nonlinear physics with an application to the Dark Energy Survey year 1 shear data. Physical Review D 103.
Shirasaki, M., **Huff, E.M.**, **Markovic, K.,** Rhodes, J.D. 2021. A Semianalytic Model of the Pairwise Velocity Distribution between Dark Matter Halos.\The Astrophysical Journal 907. doi:10.3847/1538-4357/abcc68
Everett, S. and **99 colleagues** 2020. Dark Energy Survey Year 3 Results: Measuring the Survey Transfer Function with Balrog. arXiv e-prints.

Benefits to NASA and JPL

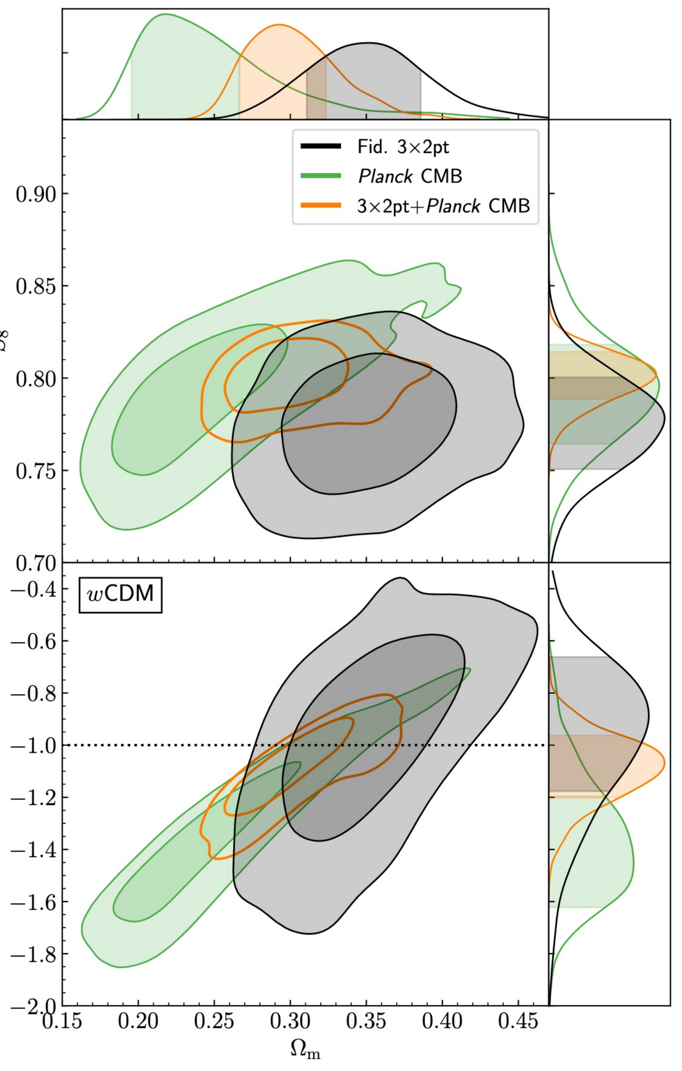
JPL is involved in the Roman Space Telescope, the ESA's Euclid mission, and ground-based peer programs like the Vera Rubin Telescope, all with the aim of better understanding the nature of dark energy. These future programs will benefit from tools, algorithms, and know-how generated by analyses on the best current ground-based data. This work is essential to keep the lab's leading role in answering cosmological science questions that remain major NASA priorities.

Approach and Results, continued

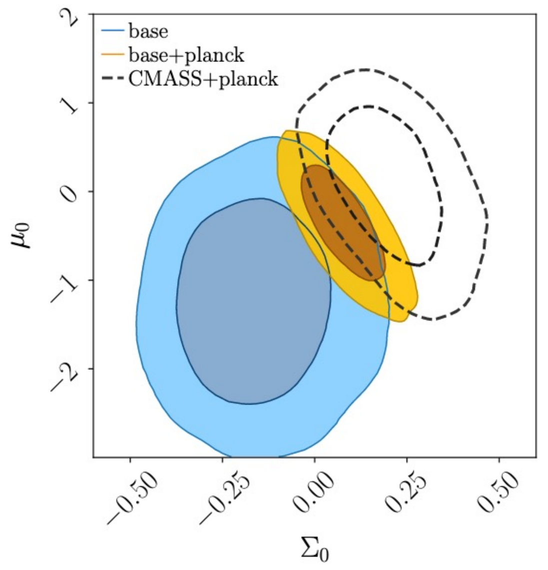
Dark Energy Survey Year 3 Analyses



DES Collaboration, 2018

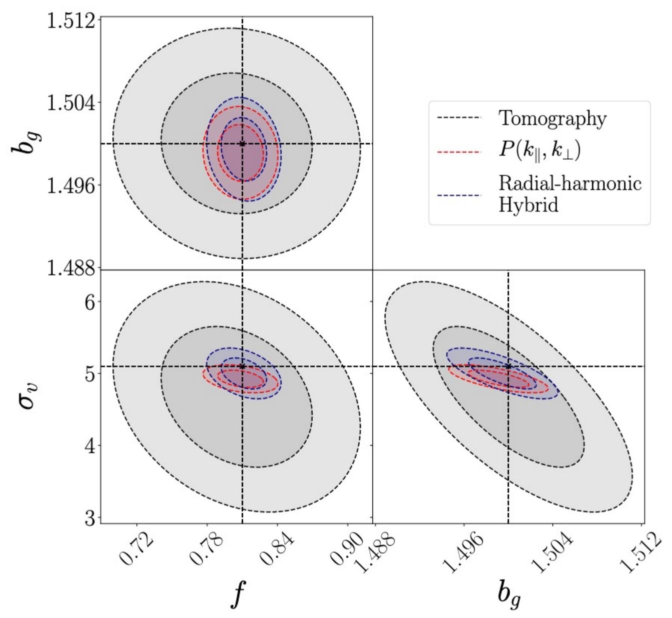


DES is an ongoing ground-based survey that covers 5000 square degrees of the southern sky in five photometric bands (coverage map **above, center**) using a purpose-built wide-field camera. Analysis of the first three of its five years of data have provided the strongest constraints on the dark energy to date (**final results above, right**).



Team members have developed analysis techniques that made critical contributions to the final DES results.
Huff developed the shear calibration methods used to obtain reliable weak lensing measurements, which will be used in future surveys.
Ferté leads the group determining consistency of these data with General Relativity and alternative theories of gravity.
Huff made major contributions to Lee *et al* analysis, which established a new method for resolving cosmological tensions by combining data from DES with other ground-based surveys (results at left).

New Analysis Techniques



As part of this effort, team members have developed new methods to combine data from multiple cosmological probes.
Taylor, **Markovic**, and **Huff** have developed a new method for mitigating the effects of modeling uncertainties associated with galaxy formation on cosmological models. Plot at left, from recent paper, compares forecast constraints on cosmological parameters done with perfect certainty (red contours) to current methods for removing galaxy formation uncertainties (grey lines). New method effectively recovers information normally lost to mitigation of these uncertainties, making future cosmological analyses substantially more sensitive.

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