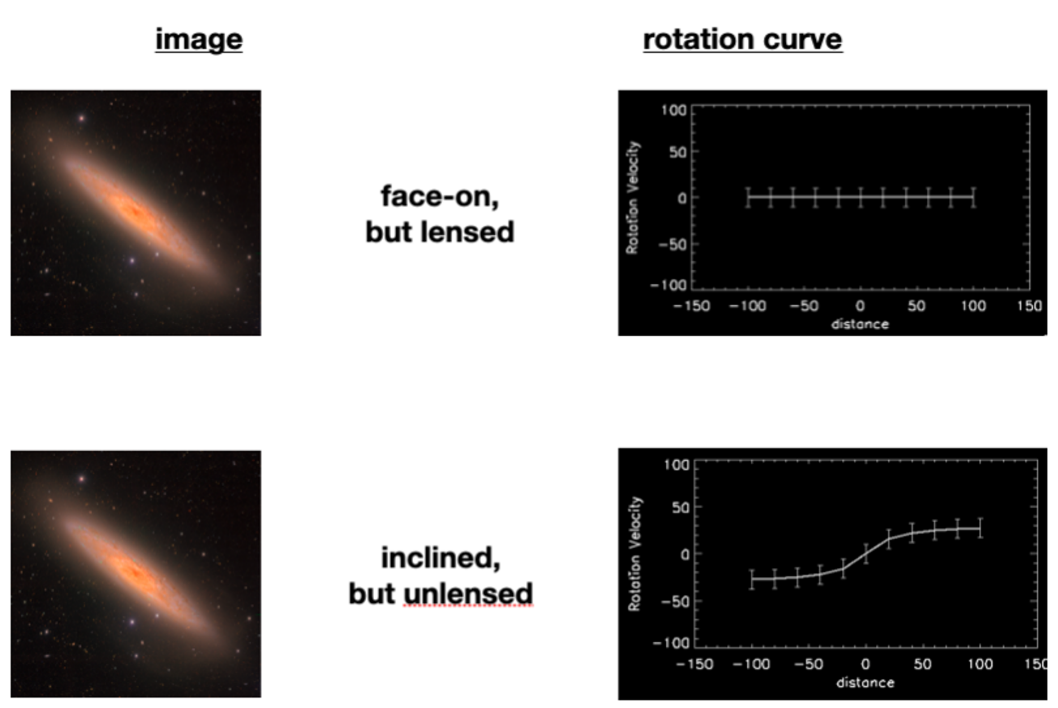
Eppur Si Muove: defining the next generation of cosmological missions

Principal Investigator: Eric Huff (326); Co-Investigators: Elisabeth Krause (University of Arizona), Tim Eifler (University of Arizona), Pranjal Rajendra Singh (University of Arizona), Hung-Jinh Huang (University of Arizona)

Program: FY21 SURP **Strategic Focus Area: Origin, evolution, and structure of the universe**

Objectives

This project will demonstrate that **measurements of galaxy kinematics**, made with **archival Keck Telescope slit spectroscopy**, can **reduce the noise** in our best cosmological probe **by an order of magnitude**.



Left: Cartoon showing how kinematic measurements – here, a rotation curve measured from slit spectroscopy -- can break the degeneracy between lensing **shear** and a galaxy's intrinsic **shape**.

The top panels show an image and spectrum from a face-on galaxy whose ellipticity is purely due to lensing; the bottom panels illustrate the case where the ellipticity is purely due to its line-of-sight inclination. The images are identical, but with spectroscopy these effects can be distinguished.

This is important because the random scatter in intrinsic galaxy shapes is the dominant source of noise in our lensing measurements.

Background

Maps of large-scale cosmic structure are sensitive probes of the nature of dark energy, which drives the accelerated expansion of the Universe. Most of the structure is dark matter, and can only be indirectly observed with gravitational lensing.
Lensing measurements are thus crucial for modern cosmology. They're also intrinsically very challenging, with a noise floor set by the intrinsic scatter in real galaxy properties.

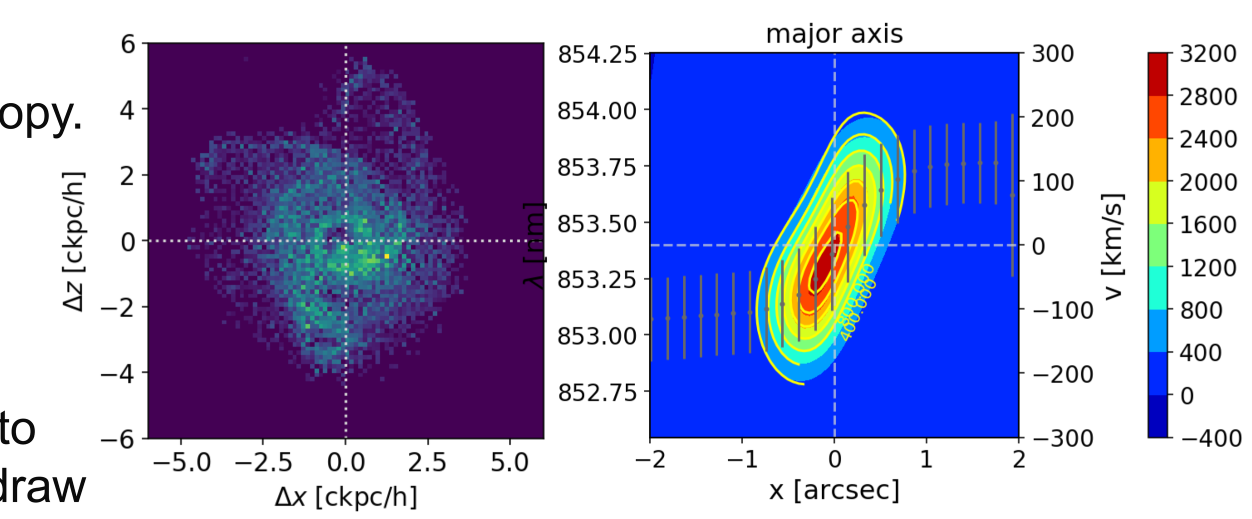
When a galaxy is lensed by foreground structures, its image and velocity field appear inconsistent. Those inconsistencies can be exploited to infer the magnitude and direction of the lensing signal. Using velocity information in this way controls for the intrinsic orientation of the galaxy; simulations indicate that this reduces the noise in the measurement by an approximately an order of magnitude.

If this works, it represents a major breakthrough, and could allow cosmic structures to be mapped with lensing at much higher precision than was previously possible. The benefits for science prioritized by JPL and NASA would be considerable…

…but first we have to show that that it works in real data.

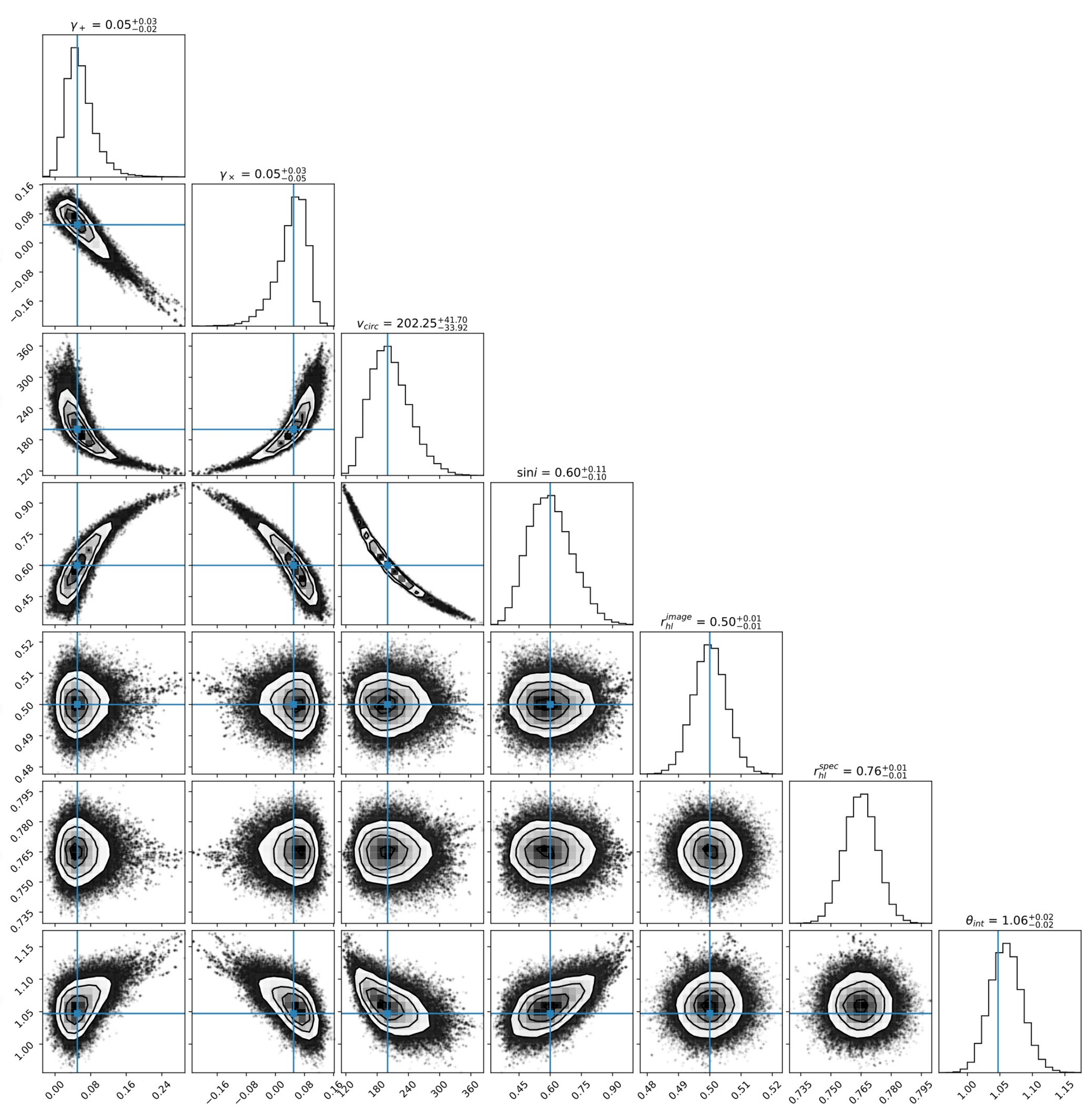
Approach and Results

We aim to generate a first kinematic lensing measurement using archival Keck slit spectroscopy. To do this, we have to build and test a retrieval pipeline that accurately recovers lensing shears from galaxy kinematics.



Left: Gas emission from simulated IllustrisTNG galaxy. **Right**: Plotted vertical error bars and colored contours show realistic synthetic Keck-DEIMOS spectrum of this galaxy; the overlaid contours show the best fit recovered by our retrieval pipeline.

Simulation: We use a realistic simulation suite to develop and validate our retrieval pipeline. We draw realistic galaxies from the IllustrisTNG cosmological simulation suite, synthesize simulated images, and add realistic observation effects and noise.



Above: Posterior probability distribution of parameters recovered from our simulated imaging+Keck spectra. The first two columns show the probably values of the two lensing shear parameters, given the data. The errors on the recovered values are +/- 0.025, **representing an order of magnitude improvement over current techniques.**

Retrieval: We have developed two independent forward-modeling pipelines that fit our combined imaging and spectroscopic data vector. These fit a 10-parameter model to each galaxy, describing the shear, morphology, kinematics, and several observational systematics effects.

Results: Both retrieval pipelines can demonstrate accurate weak lensing retrieval with a typical error of 0.03 or less. This represents a factor of 8-10 improvement relative to the state of the art. With systematic errors now under control, we will be able to use these retrieval methods for new kinematic lensing measurements on our target Keck-DEIMOS data.

Significance for NASA and JPL

Demonstrating kinematic lensing with slit spectroscopy would open up a great deal of new science with archival data, and dramatically improve the sensitivity to dark energy of the spectroscopic surveys that will be collected by the NASA flagship Roman Space Telescope and the ESA's Euclid space missions.

Publications

Two in prep.

National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

www.nasa.gov

PI/Task Mgr Contact
Email: Eric.M.Huff@jpl.nasa.gov

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