Project Summary

A New Frontier in Dark Matter Substructure Studies

Intellectual Merit. The Cold Dark Matter paradigm for the universe predicts that galaxy dark matter halos should contain thousands of bound subhalos left over from the hierarchical galaxy formation process. Strong gravitational lensing provides the only direct test of this prediction in galaxies outside the Local Group. Gravitational lens flux ratios have been used to place the first constraints on dark matter substructure in galaxies out to redshift $z \sim 1$. Now the PI proposes to open a new frontier in substructure studies with gravitational lens time delays. Time delays offer a number of advantages. The theory of time delays and substructure is rich and tractable, providing a rigorous foundation and revealing how to observe and analyze lenses to best probe substructure. Time delays provide access not only to the total amount of substructure, but also to the distribution of subhalo masses. Good data are attainable now that will yield constraints on the mean properties of substructure in (lens) galaxies at redshifts $0.2 \lesssim z \lesssim 1$. Future large samples will allow us to measure substructure as a function of galaxy mass, redshift, and environment. This will revolutionize the study of dark matter substructure, provide unique access to the astrophysics of galaxy formation on small scales, and even yield astrophysical constraints on the fundamental nature of dark matter.

Broader Impact. Physics undergraduate education naturally involves formal training in physical concepts and mathematical analysis. If we want students to understand science as a dynamic process of discovery and analysis, though, we need to teach them other skills as well: reading and writing, evaluating evidence, and analyzing arguments. These critical thinking skills are usually taught informally, through mentorship, and primarily to graduate students. The PI proposes to integrate scientific critical thinking into undergraduate education by creating a vibrant astrophysics learning community comprising four elements. First, he will create a special topics seminar to introduce freshmen to research in astrophysics. Second, he will create a new course for sophomores to learn how to read, critique, and compose scientific arguments in different styles of scientific communication. Third, he will create a student-led astrophysics reading group for students to continue honing their critical thinking skills. The reading group will create "science reader's guides" for dissemination, and will host a visiting research lecture each semester aimed at undergraduates. Fourth, the PI will use these activities to guide students into research projects, including his own research group. Though the focus is astrophysics, all elements except the research project will appeal to students from all areas of science and engineering. The community will be vertically integrated so that beginning students may interact with and learn from more experienced students, and then later take their turn as peer mentors. The PI will use established assessment tools to evaluate and adjust his pedagogical methods in these various interactive learning environments. He will also disseminate his new pedagogical methods for use by other instructors.