PROJECT SUMMARY

Intellectual merit. The recent Decadal Survey of Astronomy and Astrophysics called for a vigorous technology development and ground-based effort to study the polarization of the Cosmic Microwave Background (CMB), with the goal of discovering the signature of inflation and preparing for a dedicated space mission in the next decade. This proposal will advance the technologies needed for CMB polarization studies using coherent detectors. The technology will also be applicable to other ground-based millimeter-wave radio telescopes and has the potential to increase the power of these telescopes by orders of magnitude.

Three areas will be addressed: (i) development of improved polarimeter array modules with the specific goal of meeting all of the science goals of the Q/U Imaging ExperimenT (QUIET); (ii) advancing the state-of-the-art of millimeter-wave amplifiers with an aggressive performance metric of 15 K noise from 85–115 GHz; and (iii) producing resulting low-noise amplifier chips in sufficient quantity to supply QUIET Phase II as well as the radioastronomy community at large.

QUIET is a ground-based experiment that uses coherent detection to measure polarized CMB signals. QUIET Phase I, now observing in Chile, has successfully demonstrated the technology using front-end amplifier modules with an an average receiver noise of ~ 70 K and shown a remarkable resiliency against systematic errors. With the detectors used for Phase I, multiple telescopes would be needed to detect a tensor-to-scalar perturbation ratio $r < 0.01$ in a three-year observation window. The work proposed will address known deficiencies with the existing design and improve the module performance by at least a factor of two, thereby reducing the number of telescopes required to one and leading to substantial cost savings. Furthermore, better amplifiers will be designed and constructed to improve the noise performance of the modules. The proposed amplifiers will be short-gate (< 50 nm) devices with InGaAs channels produced on either InP or GaAs substrates. Model data suggest that these devices are capable of reaching 15 K noise temperature, only three times the fundamental quantum limit. To achieve this ambitious goal the investigators will probe beyond state-of-the-art performance by working in collaboration with the Fraunhofer Institute for Applied Solid State Physics (IAF), a research foundry that has already achieved performance parity with short-gate InP devices and seeks to design devices specifically for cryogenic performance.

Broader impacts: Research and knowledge transfer. The program will develop and demonstrate the technology needed for the next generation of coherent receivers for radioastronomy and cosmology. The primary goal is to enable the QUIET Phase II experiment, which has the potential for major discoveries in cosmology and astrophysics. A specific product of the work will be more than 2000 very low-noise MMIC amplifiers covering 85–115 GHz, enough to supply all of the devices required for QUIET Phase II and make hundreds of others available to the community at large for projects such as ALMA, CARMA, and GBT. They will make possible focal-plane array receivers that will enormously increase the power of these radio telescopes and leverage the large investment that they represent. The technical developments will be disseminated by publication in engineering and astronomy journals and conference presentations.

Broader impacts: Education and Training. Three postdoctoral students and at least one graduate student will receive training in state-of-the-art radio instrumentation in this program, and undergraduate students will explore the excitement of the field via lab work and summer fellowships. The international collaboration and the exchange of students and postdocs between Caltech, JPL, University of Chicago, Fermilab, KEK, and IAF will help train the next generation of scientists and engineers needed to carry out the ambitious observational goals in millimeter and sub-millimeter radioastronomy for the next decade.