Enabling Technologies for Photon-Counting Spectroscopy with the Origins Space Telescope (OST) in the Far/Mid-Infrared Region

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***Abstract*—** Photon-counting detectors are highly desirable for reaching the ~ 10^-20 W/ √ Hz sensitivity permitted by the Origins Space Telescope (OST). They address the most difficult technology challenge for the OST: to capture and detect every single photon. The OST, a mid- to far-infrared cryogenic observatory concept, is being developed for consideration as a major NASA mission for the next Decadal Survey. An objective this facility is to allow rapid spectroscopic surveys of the high redshift universe at 420 – 800 µm, using arrays of integrated spectrometers with moderate resolutions (R = λ/Δλ ~1000), to create a powerful new data set for exploring galaxy evolution and the growth of structure in the universe. A second objective is to perform higher resolution (R ~ 100,000) spectroscopic surveys at 20–300 µm, a uniquely powerful tool for exploring the evolution of protoplanetary disks. Finally, the OST aims to do sensitive mid-infrared (5–40 µm) spectroscopy of thermal emission from rocky planets in the habitable zone using the transit method. These OST science objectives are exciting, but they are impossible to reach without a significant leap forward in detector technology.

We are developing unique Kinetic Inductance Detectors (KIDs) that can count photons in the far/mid-IR. Combined with µ-Spec - our Goddard-based on-chip far-IR spectrometer - these detectors will enable the first OST science objective mentioned above. For OST's mid-IR science objectives, a different optical coupling design is needed for the KIDs, but the detector technology is readily transferable. Since KIDs are highly multiplexable in nature their scalability will be a major improvement over current technologies that are severely limited in observing speed due to small numbers of pixels.

To reach the required sensitivities we are developing superconducting resonators made from thin aluminum films on single-crystal silicon substrates. Under the right conditions, small-volume inductors made from these films can become ultra-sensitive to single photons >90 GHz. Understanding the physics of these superconductor-dielectric systems is critical to performance. At GSFC we have achieved a very high quality factor of 0.5 x 10^6 for a 10-nm aluminum resonator at n ~ 1 microwave photon drive power, by far the highest value for such thin films reported in the literature. We measured a residual dark electron density of < 5 /µm^3 and extremely long excitation lifetime of ~ 6.0 ms, both within requirements for photon-counting. Using a detailed model we simulated the detector when illuminated with randomly arriving photon events and show that photon counting with >95% efficiency at 0.5 - 1.0 THz is achievable. To realize an optically coupled device, the challenge is to integrate these resonators with the fabrication process of our on-chip spectrometer, µ-Spec.

I will report on the above developments and plans to continue this project through funding from a recently awarded ROSES-APRA grant and a Roman Technology Fellowship award. I will also put in context work on two related technologies: a) µ-Spec at GSFC and b) wide-bandwidth quantum-limited parametric amplifiers. Together, these three technologies will enable a wide spectrum of science investigations with the OST.