We present new theoretical tools for accurate and efficient modeling of non-equilibrium fluctuation-induced phenomena—including non-equilibrium Casimir forces, thermal self-propulsion and self-rotation, and near-field radiative heat transfer—involving bodies of arbitrarily complex shapes and material properties. Our numerical tools are based on discretized integral equations, including both surface integral equations—valuable for efficient simulation of one or more homogeneous isotropic dielectric bodies—and volume integral equations, which allow modeling of complex material configurations, including anisotropic materials and bodies of continuously spatially varying dielectric permittivity. Using our new tools, we obtain new predictions of non-equilibrium fluctuation phenomena in novel geometries that would be unwieldy or impossible to treat using any other theoretical method; examples include photon torpedoes (asymmetric nanoparticles that accelerate in a characteristic direction when heated or cooled) and QED pinwheels (chiral nanoparticles that spontaneously begin to rotate when heated or cooled). In both of these cases, the motion of the nanoparticle is a recoil effect arising to balance a surplus or deficit of linear or angular momentum carried away by thermal radiation. Our new tools are available online as free, open-source software; documentation and tutorials may be found at http://GitHub.com/HomerReid.

Figure 1: Self-propulsion force vs. temperature on photon torpedoes—nanoparticles of diameter ~ 2 μm formed by juxtaposing various pairs of materials—embedded in a cold (0 K) environment.
Figure 2: Angular acceleration due to self-rotation torque vs. temperature on QED pinwheels - (chiral gold nanoparticles of thickness ~ 250 nm and diameter ~ 2 μm) embedded in a cold (0 K) environment.