TABLE III. Systematic error budget for a single-sodium measurement. The potassium and rubidium systematic error budgets are similar.

Source	Value (unc.)	Error in α (%)
First grating (1G)-detector distance z_{det}	2372.4(5.1) mm	0.43
Velocity (beam-shape model)	3023(4) m/s	0.25
Detector displacement x_1	135.00(3) μm	0.05
Detector translation ‖	50 mrad	0.30
Velocity distribution σ_v	149(14) m/s	0.20
δ_v/v of interfering atoms	0.20(5)%	0.10
Spacer thickness a	1.998(2) mm	0.20
Electrode diameter $2R$	12.663(25) mm	0.10
Electrode voltage V	10670(16) V	0.30
Electrode orientation (x,y,z)	(20,0.1,20) mrad	0.05
1G-int. region distance z_{int}	802.6(2.0) mm	0.25
Grating period d_g	100.0(1) nm	0.10
Molecule fraction	0(1)%	0.10
Grating tilt and g	0.0(1) mrad	0.01
Beam thickness (phase avg.)	80(20) μm	0.02
Total Systematic Error		0.80

most significant parameter in the error budget is the distance from the first grating to the detector, z_{det}, due to its effect on our measurement of v_0. The details of the beam shape modify the best-fit flow velocity as well. We measure the displacement of our detector translation stage using a Heidenhain MT-2571 length gauge with a linear encoder and fractional uncertainty of 0.02%. If the detector translation along the x axis is not perpendicular to the beam path along the z axis, then we would also report an incorrect velocity. We previously discussed how the velocity-selective detection of interfering atoms modifies v_0 and adds uncertainty in the polarizability. The effect of the velocity distribution on the measured phase becomes larger as the phase shift increases and the contrast decreases. Therefore, to minimize the uncertainty due to the velocity distribution, we ignore phase data points for which the relative contrast is less than 75%. This procedure yields an uncertainty of 0.20% in the polarizability for a 10% uncertainty in σ_v. Uncertainty in the distance from the first grating to the interaction region, z_{int}, causes uncertainty in the diffracted path separation s in the interaction region. Uncertainty in the electrode spacing a, radius R, and applied voltage V causes uncertainty in the strength of the electric field. Uncertainty in the electrode orientation about the x, y, and z axes yields a small uncertainty in the polarizability, as well.

The possibility of a small fraction of molecules in the beam contributes an additional source of error. The diffraction scans for the conditions under which we run the interferometer do not have sufficient resolution to determine the molecule fraction of the beam. By reducing the velocity of the beam and thus increasing the diffraction angle, we found that molecules contribute less than 1% of the flux. To calculate the corresponding uncertainty in our polarizability measurements we include a sum over two additional molecule interferometers in Eq. (11). We use the molecular polarizabilities measured by Tarnovsky *et al.* [14] in our calculations to find that the uncertainty in atomic polarizabilities due to the presence of molecules is less than 0.10%.

An additional source of error comes from the possible tilt of the entire interferometer board with respect to gravity. If the interferometer is tilted with respect to gravity by an angle θ, a dispersive phase shift of

$$\phi_{grav}(v) = \frac{2\pi L_g^2}{d_g v^2} g \sin\theta \qquad (18)$$

will result. This phase shift must be added to the total phase shift and the reference phase in the same way as the Sagnac phase. We estimate that $\theta < 0.1$ mrad and that the corresponding uncertainty in the polarizability is less than 0.01%.

V. CONCLUSIONS AND OUTLOOK

We measured both the absolute and relative polarizabilities of sodium, potassium, and rubidium using an atom interferometer with an electric-field gradient. Furthermore, we used our ratio measurements and the more-precise Ekstrom *et al.* measurement of sodium polarizability [5] to report higher-precision measurements of potassium and rubidium polarizability. These measurements provide benchmark tests of atomic theory calculations. Our ground-state polarizability measurements may be combined with transition Stark-shift measurements [34–37] to yield improved knowledge of excited-state polarizabilities and additional dipole matrix elements [33,38].

We are upgrading our apparatus to produce and detect beams of alkaline-earth-metal atoms. We are investigating new interaction region geometries and new ways to measure the flow velocity and velocity distribution of the atoms detected in the interferometer. We are also using diffraction from a nanograting to study ratios of van der Waals potentials for sodium, potassium, and rubidium [39].

[1] H. Gould and T. M. Miller, Adv. At., Mol., Opt. Phys. **51**, 343 (2005).

[2] A. Derevianko, W. R. Johnson, M. S. Safronova, and J. F. Babb, Phys. Rev. Lett. **82**, 3589 (1999).

[3] R. W. Molof, H. L. Schwartz, T. M. Miller, and B. Bederson, Phys. Rev. A **10**, 1131 (1974).

[4] A. Miffre, M. Jacquey, M. Büchner, G. Trénec, and J. Vigué, Phys. Rev. A **73**, 011603(R) (2006).

[5] C. R. Ekstrom, J. Schmiedmayer, M. S. Chapman, T. D. Hammond, and D. E. Pritchard, Phys. Rev. A **51**, 3883 (1995).

[6] M. Berninger, A. Stefanov, S. Deachapunya, and M. Arndt, Phys. Rev. A **76**, 013607 (2007).