Enhanced light-assisted-collision rate via excitation to the long-lived $5S_{1/2}$-$5D_{5/2}$ molecular potential in an ^{85}Rb magneto-optical trap

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We report measurements of a significant increase in the two-body loss rate in an ^{85}Rb magneto-optic trap (MOT) caused by the addition of light resonant with the $5P_{3/2}$-to-$5D_{5/2}$ transition (776 nm) in Rb. Exposure to the additional light resulted in up to a factor of 5 decrease in the steady-state number of atoms in the MOT. This loss is attributed to more than an order of magnitude increase in the light-assisted collision rate brought about by the 776-nm light. By measuring the intensity dependence of the loss rate, the loss channel was identified to be the relatively long-lived $5S_{1/2}$-$5D_{5/2}$ molecular potential.

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I. INTRODUCTION

Since early in the development of laser cooling and trapping [1], it has been observed that light has a large influence on ultracold atomic collisions in magneto-optical traps (MOTs) [2]. Atom pairs that are excited resonantly onto molecular potential curves accelerate along those curves and can spontaneously emit a redshifted photon or approach to close internuclear distances where state changes can occur. In both cases, excess energy is converted to kinetic energy of the atom pair, and can lead to trap loss. These collisions have been extensively studied in one- and two-color experiments where the applied laser light is nearly resonant between a single pair of principal quantum states (e.g., the ground S state and the first excited P state in alkali metal atoms) [3–10].

These light-assisted collisions are not limited to just a single pair of states. Collision channels involving more highly excited states are also associated with molecular potentials that can lead to loss in a light-assisted collision. Owing to larger energy splittings and smaller matrix elements, the molecular potential at long range for states that do not couple by an electric dipole tend to be "flat" (i.e., constant) as compared to states that do couple by an electric dipole. The corresponding atom acceleration is then much smaller for these relatively "flat" states. In this work, we study light-assisted collisions that involve an excitation to one such "flat" molecular potential. This is done by applying $5S_{1/2}$-$5P_{3/2}$ and $5P_{3/2}$-$5D_{5/2}$ resonant light simultaneously to atoms in a ^{85}Rb MOT [11]. We find that the light-assisted collision loss rate is increased by over an order of magnitude from the addition of the $5P_{3/2}$-$5D_{5/2}$ resonant light, even though the molecular potential is flat and the overall light intensity is only increased by a factor of 2. By characterizing the behavior of these light-induced losses, we identify the likely loss mechanism as owing to a combination of the long lifetime of the $5D_{5/2}$ and a radiative cascade decay through steeper intermolecular potentials at closer internuclear separations.

Investigations of multi-excited-state photoassociative ionizing collisions (as opposed to light-assisted trap loss collisions in this work) have been reported in Rb for both quasicontinuous wave [12] and ultrashort pulsed configurations [13] when both $5S_{1/2}$-$5P_{3/2}$ and $5P_{3/2}$-$4D_{5/2}$ light was present. We find that the collision channel producing our observed trap loss is different that the collision channel responsible for ion production in Refs. [12] and [13].

The ability to use multiple excited states in a light-assisted collision is potentially useful for deliberate control of ultracold collisions [14] and ion formation during the ultracold collisions [12,13], as long-lived molecular excited states also allow for the transport of atom pairs to close internuclear separations along an excited state. Conversely, light-assisted collisions are often problematic in experiments where they are not the main focus of study. For instance, they limit the density in MOTs and optical traps [7]. Light-assisted collisions involving multiple transitions to various excited states could be a limitation in experiments with ultracold gases where excited-state atoms and molecules are created, such as Rydberg atom formation [15–17]. It could also impose limitations on extensions of laser cooling involving higher-energy excited states than the first excited state [18–20], if the excitation pathway involves similar states. Given the convenience of obtaining diode lasers resonant with the $5P_{3/2}$-$5D_{5/2}$ transition in Rb at 776 nm, the $5D_{5/2}$ state would appear to be an excellent candidate for these studies. However, the presence of large light-assisted collision losses presents a potentially serious complication.

This article details our measurements of the increased light-assisted collision losses in an ^{85}Rb MOT due to the addition of light resonant with the $5P_{3/2}$-$5D_{5/2}$ transition at 776 nm. To characterize the loss rate, we measured the loss coefficient in steady state. Under different density and light intensity conditions we were able to determine that the loss was two body in nature, and we determined the probable loss channel for the atoms in the MOT.

II. EXPERIMENTAL APPARATUS

The MOT was created using standard techniques [21]. It consisted of three orthogonal beams from the primary trapping laser (which we will refer to as L1, at 780 nm) which were retroreflected to create a six-beam configuration with a total intensity between 23 and 42.5 mW/cm^2 for different experimental conditions. The MOT was loaded from a background vapor of Rb, which was provided by a set of Rb getters in our vacuum chamber. The beams from L1 were detuned between 6 and 18 MHz to the red of the $5S_{1/2}$ ($F = 3$) to $5P_{3/2}$ ($F = 4$) cycling transition in ^{85}Rb as desired. In

addition to L1, we used light from a hyperfine repump laser (at 795 nm tuned to the $F = 2$ ground state to $F = 3$ excited state D_1 transition). The number of atoms trapped in the MOT was determined through a calibrated fluorescence measurement. The fluorescence of the MOT was captured in a lens and focused down onto a photodiode, which provided the primary signal for these measurements. To calibrate the fluorescence signal, a standard probe absorption measurement was made. The optical depth of the atom cloud was measured by a resonant laser probe image at a specific detuning for L1, and the atom number extracted from this absorption measurement was related to the reading measured by the photodiode. We related the calibration measurement to other detunings of L1 that we used by using the fact that the fraction of atoms in the MOT in the $5P_{3/2}$ excited state was taken to be [22]

$$f = \frac{I/2I_{\text{sat}}}{[1 + I/I_{\text{sat}} + 4(\delta/\Gamma)^2]}, \tag{1}$$

where δ is the detuning of the laser and Γ is the natural linewidth of the transition ($2\pi 6$ MHz) [23].

To this standard MOT configuration, we added additional light from a second laser (which we will call L2, at 776 nm) to provide a second excitation up to the $5D_{5/2}$ level. Initially, we aligned a single beam from L2 with the atoms in order to provide excitation. In this configuration, we noticed that excitation from L2 resulted in a strong force on the MOT, which deformed the shape of the MOT and pushed atoms out of the trap. In order to suppress these effects, we aligned L2 along the same three-beam path as L1 to create a balance of forces (Fig. 1). When in this configuration, there was no noticeable net force on the MOT. Along this path, L2 was also expanded to a diameter ~1.5 cm, giving a total six-beam intensity of 25 mW/cm^2 at the location of the atoms. At this intensity, the loss due to direct photoionizing transitions ($5D_{5/2}$ to the continuum via either L1 or L2) was negligible in our subsequent measurements.

The frequency of L2 was controlled by monitoring a fluorescence signal in a Rb vapor cell. A pickoff beam from L2 was counterpropagated through a cell with a beam on

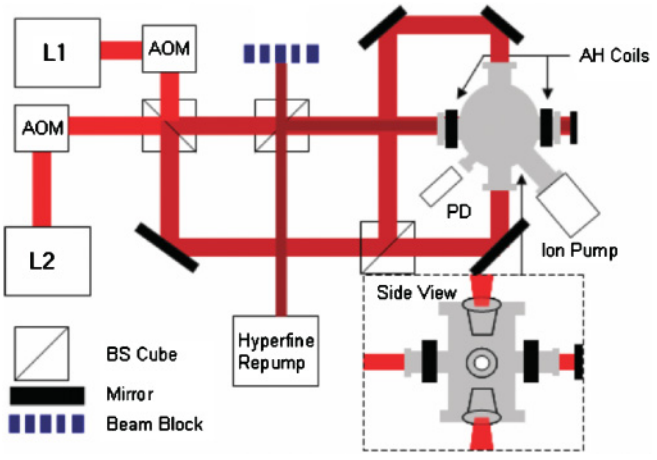

FIG. 1. (Color online) Our experimental setup. Note here that that L1 (780 nm) and L2 (776 nm) are aligned along the same path through the vacuum chamber. (AOM: acousto-optic modulator; AH: anti-Helmholtz coils; PD: photodiode; BS: beam splitting.)

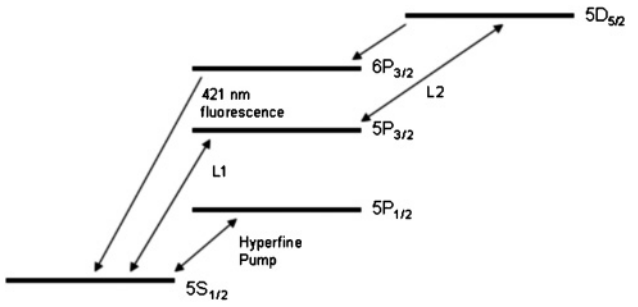

FIG. 2. Relevant energy levels for our experiment. (Not to scale.)

resonance with the $5S_{1/2}$ to $5P_{3/2}$ transition (called L1a). When L2 was resonant with the $5P_{3/2}$-to-$5D_{5/2}$ transition, a fraction of the atoms decayed to the ground state through the $6P_{3/2}$ state, fluorescing at 421 nm (Fig. 2). This 421-nm fluorescence could be observed by eye in the cell. This was accompanied by a slight but measurable reduction in the amount of infrared fluorescence observed in the cell. By measuring the infrared fluorescence, we monitored the detuning of L2 with respect to the $5P_{3/2}$-to-$5D_{5/2}$ transition during the course of our measurements. The frequency of L2 was calibrated by altering the frequency of L1a by a known amount and measuring the change in piezoelectric transducer (PZT) voltage of L2 at the minimum of infrared fluorescence. For control of the frequency of L2 during measurements, the PZT voltage was adjusted in order to achieve the maximum loss (i.e., the minimum fluorescence) from the MOT.

The number of atoms in the MOT as a function of time is governed by the rate equation

$$\dot{N} = R - \frac{N}{\tau} - \beta\bar{n}N - kN, \tag{2}$$

where N is the number of atoms in the trap, R is the load rate, τ is the load lifetime, β is the two-body loss coefficient, k is an additional one-body loss coefficient due to the presence of L2, and $\bar{n}$ is the average density. R and τ are found by loading from an empty trap without L2 light present, so that $\beta = k = 0$. The load curve $N(t)$ fits very well to an exponential curve, which implies a negligible amount of background two-body losses in the absence of L2 for our conditions. When the MOT filled completely, we determined R by solving the rate equation in steady state: $R = N_{\text{max}}/\tau$. With L2 light present, a large reduction of the number of atoms in the MOT was observed (approximately a factor of 5 reduction in the steady-state MOT number, seen in Fig. 3). When the 776-nm light is applied, the equilibration time of the MOT is shortened significantly. This implies that the loss was not from a simple reduction in the load rate (R) into the MOT, and suggests a need for additional loss terms (k,β) in the load rate equation. This conclusion was also supported by a measurement of the initial slope of the fill from an empty MOT, where R dominates the load process. The observed initial slope did not change with the addition of the 776-nm light on the 10% level. This small (<10%) dependence is not unreasonable. In Ref. [11], only a small effect was observed for ^{85}Rb, albeit for very different conditions. For the majority of our experimental conditions, the L1 and L2 light is resonant with only a very narrow velocity class of atoms, resulting in a muted impact for the total

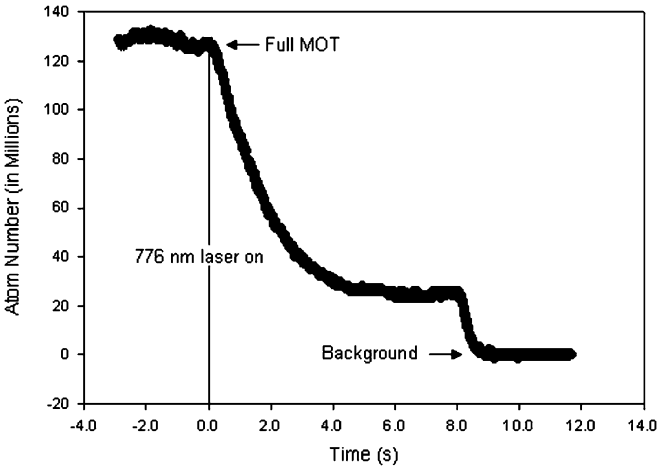

FIG. 3. This is a typical fluorescence signal from the MOT before and during the application of the 776-nm light. The MOT is filled to equilibrium without the 776-nm light present. At $t = 0$, the 776 nm light is applied, and the MOT fluorescence can be observed to decrease on a time scale much faster than the ∼20 s MOT fill time, indicating the presence of additional losses.

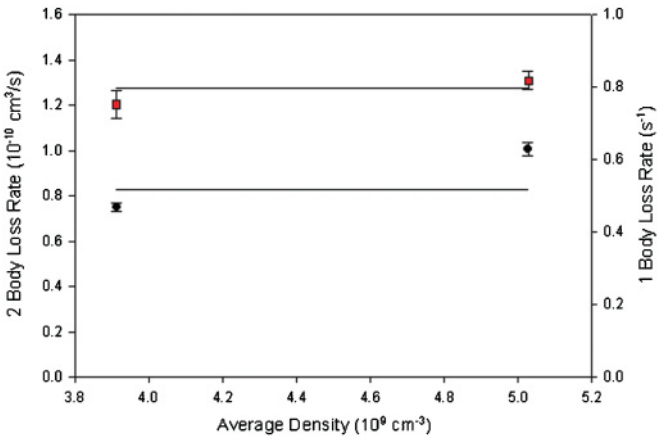

FIG. 4. (Color online) Density dependence of the one- and two-body loss calculations. The one-body loss calculation is represented by black circles. The two-body loss calculation is represented by red squares. The one-body loss calculations show a significant statistical difference at different densities whereas the two-body loss calculations are consistent within statistical uncertainty. A simultaneous one- and two-body calculation produced a value for the one-body loss coefficient consistent with zero.

Doppler cooling. Also, the addition of the blue-detuned L2 light produces antidamping from direct two-photon transitions, but damping through alterations in the $5S_{1/2}$-$5P_{3/2}$ scattering rate.

One possible way to determine the value of the additional loss coefficients would be to fit Eq. (1) to the type of data presented in Fig. 3. However, we did not use this technique and decided to measure the loss coefficient in steady state for the following reasons. When the 776-nm light is applied (at $t = 0$ in Fig. 3), the volume changes significantly. The time-dependent nature of this would have significantly complicated both the data collection and analysis. With the L2 frequency technique we used, drifts during data collection would have negatively affected the data in a time-dependent measurement.

In order to solve for the two loss coefficients (k and β), we first determined whether a one- or a two-body loss mechanism was dominant over the other. When loading the MOT, the number and density of the atoms trapped drifts slowly over time and successive measurements because the background Rb vapor is slowly pumped out of the system after getter flashes. For measurements at both low and high density, we solved Eq. (2) for the loss coefficients individually, assuming that the other coefficient is zero (Fig. 4). This measurement showed that our observations were more consistent with a dominant two-body loss process.

We can solve for the two-body loss coefficient β in steady state as

$$\beta = \frac{V}{N\tau}\left(\frac{N_{\max}}{N} - k\tau - 1\right), \tag{3}$$

where V is the volume of the MOT, and $N_{\max}$ is the full MOT number without L2 light. To determine the volume, an image of the fluorescing MOT in steady state is recorded through an optical access port. The image is fit to a two-dimensional Gaussian distribution in order to determine the rms widths of the MOT. In the image, the features of the vacuum chamber of known dimensions are visible, allowing a calibration of the distance scale in the image. The volume is extrapolated from this two-dimensional profile by observing that the third dimension, as seen through a different view port, is approximately the size of the others.

III. MEASUREMENTS AND DATA

For our standard conditions, we observed a loss coefficient of $\beta = [2.05 \pm 0.06(\text{statistical}) \pm 1.0(\text{systematic})] \times 10^{-10}$ cm^3/s, which is more than an order of magnitude larger than the two-body loss coefficient for L1 light alone at the detunings used in our experiment ($\sim 10^{-11}$ cm^3/s for our intensities) [8]. This increase occurs with less than a factor of 2 change in overall light intensity.

To identify the loss channel involved in this process, we investigated how changes in the intensity of L1 and L2 changed the value of the loss coefficient β. From a maximum intensity of 42.5 mW/cm^2 for L1 and 25 mW/cm^2 for L2, we reduced the intensity of one of the lasers while keeping the other laser intensity constant. The scaling of β with intensity indicates the number of photons involved in the loss process, and thus gives insight into the collision channels to which the atom pairs are excited. In the absence of saturation, the intensity scales directly with the number of photons involved in the collision channel. Saturation can complicate the picture, and may lead to a reduction in the intensity scaling.

To perform these intensity variation measurements, L1 was detuned to several chosen frequencies between 6 and 18 MHz to the red of the $5S_{1/2}$-$5P_{3/2}$ transition, and L2 was then set to the frequency that produced the maximum reduction of the MOT number for a given frequency of L1. For $\delta = -12$ MHz for L1, this was 20 MHz to the blue of the $5P_{3/2}$-$5D_{5/2}$ transition for L2. For a $-\Delta$ change in detuning of L1, the frequency of maximum loss in L2 had a corresponding shift of approximately Δ. There was no measurable change in

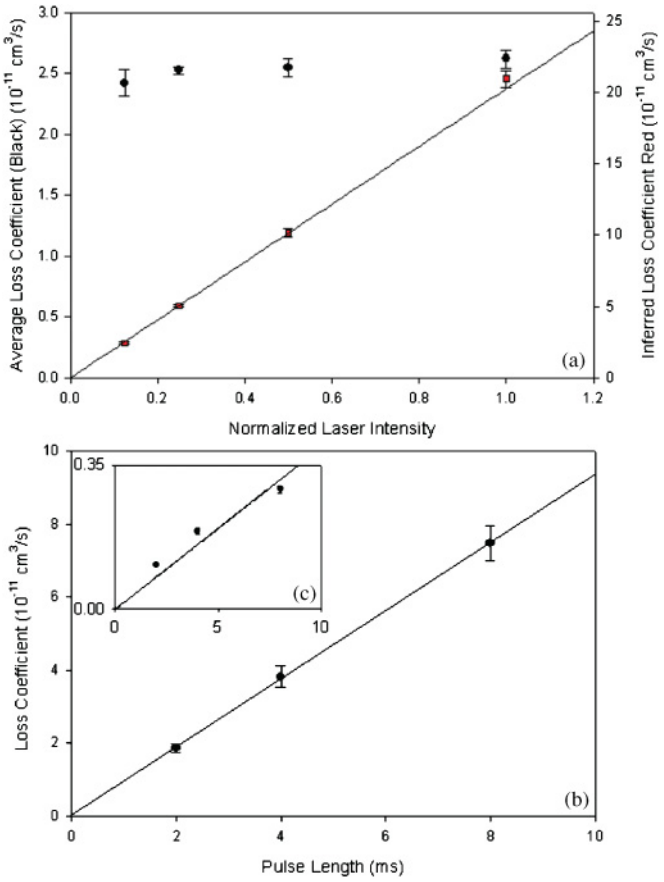

FIG. 5. (Color online) Loss rates under various conditions for L2 (776 nm). (a) shows the loss rate with constant average power (shorter pulses at higher intensity for L2) for different L2 intensities (black circles). The red squares show the inferred loss rates (as if L2 was not pulsing, and on for the full duty cycle) for the different intensities. (b) shows the loss rate as a function of pulse length for a constant intensity (12 mW/cm^2). (c) shows a one-body fit to the data from (b). The vertical axis is the one-body loss rate in units of s^{-1}, and the horizontal axis is pulse length in ms. It can be seen here that a two-body analysis fits much better to the data.

the frequency of L2 at maximum loss for different intensities of L2.

To measure the loss rate variation with L2, the intensity of L2 was varied with constant L1 intensity in a pulsed configuration in two ways. The pulse sequences were performed by using an AOM for the L2 light. Both sequences had a 10-ms duty cycle. The first way kept the average power of the laser constant, meaning that as the pulse length was shortened, the intensity of the laser was increased to compensate. This was done with intensities at their full (25 mW/cm^2), half, quarter, and one-eighth levels. In this configuration, the overall loss rates under each of the different conditions yielded values that were equal to within statistical uncertainty [Fig. 5(a)]. This measurement implies a linear scaling of β with the intensity of L2, with no indication of saturation. Additional measurements at even lower intensities of L2 gave no indication of saturation of a multiphoton process due to L2. The second configuration kept the intensity of the beam constant (at 12 mW/cm^2) while altering the length of the pulse. In this configuration, the scaling of the loss rate was linear with pulse length [Fig. 5(b)].

The data in Figs. 5(b) and 5(c) strongly confirm the two-body nature of the loss because the atom density varies substantially in this data when the intensity and detuning of L2 are held constant. A one-body loss fits the data poorly. In addition, assuming that the number variation is owing solely to a variation in the load rate, R, fits the data even more poorly. This is because a change in R is effectively "zero-body" loss that implies a particular scaling of the steady-state number with pulse length that is not the same as what we observed. Taking this further, data such as that in Figs. 5(b) and 5(c) can be used to constrain the range of possible variation of R by allowing such a variation as a fit parameter in a addition to the two-body loss coefficient. In doing so, we find that these data constrain R to vary by less than 10% given the statistical uncertainty of the measurements. In this analysis we assumed that any change in R would be proportional to the pulse length of the L2 light.

To find the dependence on the intensity of L1, we varied both L1 and L2 in a pulsed configuration (2-ms pulse out of a 10-ms duty cycle), but with the pulses for the two lasers in phase and 180° out of phase. L1 was pulsed for 2 ms at reduced intensity and was at full intensity for the rest of the duty cycle, whereas L2 was on for 2 ms and off for the rest of the duty cycle. The experiment was done in this configuration so as to not change the loading parameters for the MOT significantly while varying the intensity of L1 as L2 was applied. For one such measurement, we measured the loss rate with an L1 intensity of 30 and 22.5 mW/cm^2, a ratio of 0.75. We calculated the ratio of the loss coefficient β measured under the two different intensity conditions and found a ratio of 0.75 ± 0.01 for $\delta = -12$ MHz for L1. This measurement would suggest linear dependence of β on L1. Additional measurements at larger detunings also showed linear behavior.

IV. MODELS OF ATOM MOTION

Given the observed two-body nature of the loss rate, and the intensity dependences of L1 and L2 on the loss coefficient, we can attempt to identify the loss channel of the collision. The collision dynamics will be determined by molecular potential curves formed by long-range dipole-dipole interactions between an atom pair. In order to get an insight into these dynamics, we used a simplified model of the molecular potentials in which we modeled the atom motion classically along the potential curves. For the range of internuclear separations relevant to this work, these molecular potentials can be calculated with sufficient precision using perturbation theory [24]. We did not take into account the hyperfine structure in this simple model. Interactions between atoms with even total electron angular momentum (e.g., $5S$-$5S$, $5S$-$5D$) will have relatively flat potentials at long range due to a lack of a resonant dipole-dipole interaction. When L1 is detuned to 12 MHz to the red of the $5S_{1/2}$-$5P_{3/2}$ cycling transition, the light drives transitions resonantly from the ground state to the $5S_{1/2}$-$5P_{3/2}$ molecular potential at ~90 nm internuclear separation. We modeled the $5S$-$5P$ potential curve with a-C_3/r^3 potential ($C_3 = 18.4$, in atomic units) and the $5S$-$5D$ potential with a-$(C_5/r^5 + C_6/r^6)$

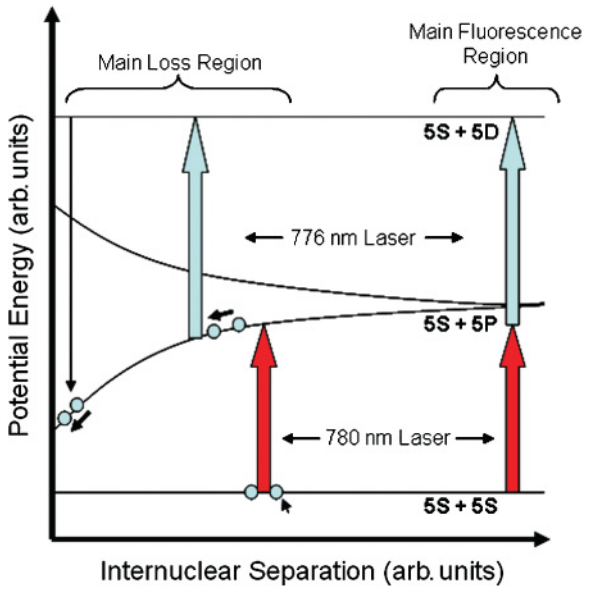

FIG. 6. (Color online) A diagram of the loss channel we identify in the main text. Atom pairs excited to the 5*S*-5*P* molecular potential by L1 accelerate until they are excited by L2 up to the 5*S*-5*D* state. The long lifetime of the 5*S*-5*D* state allows the atom pair to travel into a region where they can be lost from the trap upon their decay to the 5*S*-5*P* state, due to increased acceleration along the slope of the 5*S*-5*P* potential curve.

potential ($C_5 = 0.5079$ and $C_6 = 11.32 \times 10^4$, in atomic units) [24] (Fig. 6). The 5*S*-5*D* potential is approximately flat for the internuclear separations of interest for this discussion. The maximum loss in the MOT was seen when L2 was detuned by 20 MHz to the blue of the natural transition, which is 8 MHz blue detuned of a coherent transition from the 5*S* to the 5*D* state. This implies that when an atom pair is excited up to the 5*S*-5*P* state, it accelerates along the potential curve for some amount of time before it is in resonance with L2. When excited up to the 5*S*-5*D* molecular potential, the relatively long lifetime of the 5*D* state (∼200 ns [25]) allows the atom pair to travel along this curve to a much closer internuclear separation. If the atom pair decays back down to the 5*S*-5*P* molecular potential within ∼40 nm internuclear separation, the atoms will begin to have a significant probability of accelerating along the curve to the escape velocity of the trap (∼10 m/s). This radiative escape probability increases sharply as the atoms approach to even closer separations along the 5*S*-5*P* potential. Also, state changing collisions can occur if the atom pair reaches close internuclear separations. While the atom pair can reach the 5*S*-5*P* potential at a close separation through off resonant transitions from the ground state, the probability for this is very low, meaning decay from an upper state is the more likely mechanism. We believe that this mechanism is responsible for the increased loss in the trap observed through the application of L2 light.

In our initial examination of the possible collision channels, there appeared to be a puzzle. At particular internuclear separations, both L1 and L2 are resonant with particular transitions. The polarization averaged incoherent single-atom saturation intensities for the $5S_{1/2}$-$5P_{3/2}$ transition and the $5P_{3/2}$-$5D_{5/2}$ are 4.97 and 14.7 mW/cm^2, respectively. Despite the fact that the L1 and L2 intensities exceed these values, we observed no evidence of saturation in the loss rate coefficients on either transition. Initial estimates using our simple model indicated that strong saturation should be observed for our conditions, particularly for L1.

However, by incorporating additional effects in our model, the amount of expected saturation is significantly decreased. One change was incorporating the fact that in general there are two broad classes of 5*S*-5*P* excited states, strongly radiating (with the pair of atoms in a symmetric superposition of the ground and excited state [26]) and weakly radiating (the pair of atoms in an antisymmetric superposition). The strongly radiating states (whose lifetime is ∼13 ns) require excitation close to the $5P_{3/2}$-$5D_{5/2}$ resonant internuclear separation or they will decay back to the ground state. Because at this internuclear separation the $5S_{1/2}$-$5P_{3/2}$ light is detuned by approximately a natural linewidth for the conditions measured, the degree of saturation is reduced. The weakly radiating states are by their nature only weakly coupled to the ground state as only retardation effects make the excitation probability to these states nonzero.

To further evaluate the reduction in saturation for the weakly coupled states, we constructed a model consisting of Landau-Zener avoided crossings [27,28] at the internuclear separations where L1 and L2 coupled different states to one another. The goal was to see how the fraction of atoms delivered into a region of 40–50 nm internuclear separation depended on L1 and L2 intensity for the parameters relevant to our measurements. Note that these weakly radiating states are only weakly radiating on the 5*S*-5*P* to 5*S*-5*S* molecular transition and decay normally from the 5*S*-5*D* state. In these calculations, the atoms' motion was modeled semiclassically along dressed state potential curves. For typical collision velocities in our gas, we observed that a factor of 2 reduction in L1 intensity reduced the net probability to be on the 5*S*-5*D* asymptote at close internuclear separation to ∼60%–65% of its initial value. For L2, a factor of 2 reduction reduced the probability to ∼55% of its initial value. Similar degrees of reduction were observed due to the off-resonant transitions of the strongly-radiating states.

While this degree of saturation is large enough that had it been present we would have detected it in our data, it is significantly less than what we naively expected. More quantitative calculations are complicated by the fact that there are ∼500 long-range molecular states associated with different combinations of spin and electronic states for the colliding pair. Also, many of these states have a complicated (i.e., not solely attractive) structure [29] and the two-photon nature and variable polarization of the light fields in space add more complications. We note that our data cannot rule out combinations where saturation is balanced by other loss effects (e.g., intensity-dependent collisional flux enhancement [30]), but such balancing would have to be just right to produce the linear scaling that we observe.

As an additional characterization, we also measured the nature of the 421-nm fluorescence from the MOT that is due to the $5D_{5/2}$ cascade decay to the ground state via the $6P_{3/2}$ state. This was done to give us a better insight into the single-atom transitions taking place inside the MOT. In this measurement, we ramped the frequency of L2 over

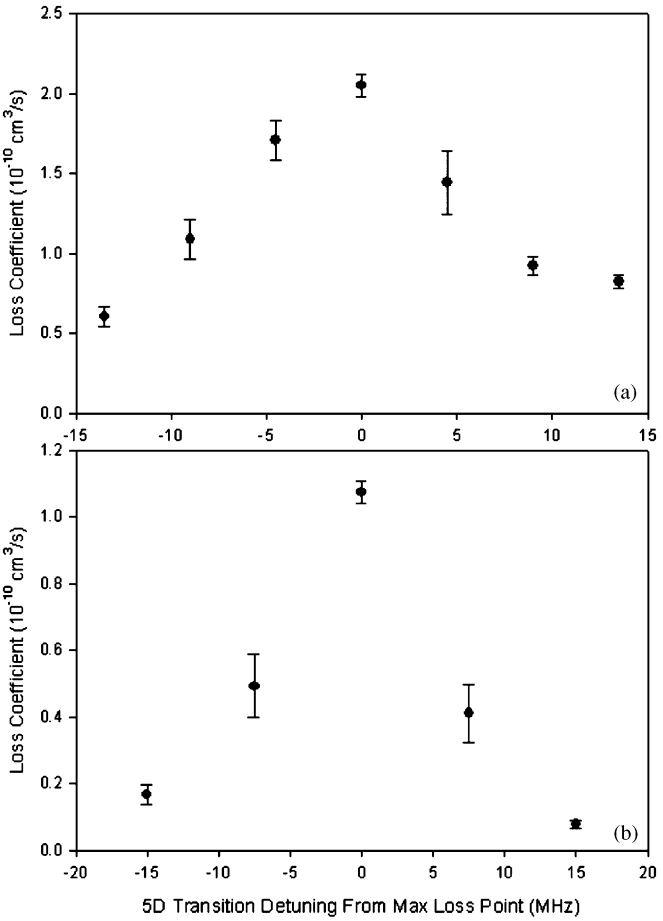

FIG. 7. Two-body loss rate as function of L2 detuning from the point of maximum loss. (a) shows the loss rate with a 12-MHz red detuning for L1. (b) shows the loss rate for 18-MHz detuning for L1. The width of these curves is ∼15–20 MHz, which is much wider than that of the 421-nm fluorescence.

the transition to the $5D_{5/2}$ state at our maximum intensity (25 mW/cm^2) and at half intensity and measured the fluorescence at 421 nm by using a filter to block out any infrared light. When the intensity of L2 was reduced by a factor of 2, the peak fluorescence was only reduced by ∼25%, suggesting that this particular single-atom transition is saturated. This observation is consistent with an Autler-Townes model of a four-level atom consisting of the 5*S*, 5*P*, 5*D*, and 6*P* states with averaged Clebsch-Gordan coefficients for the transitions. The full width at half maximum of the fluorescence peak was measured to be ∼3 MHz, which implies that the transition is coherent on the time scale of several tens of nanoseconds even though the transition is driven from two sources, L1 and L2. This width is much less than the width of the loss coefficient with detuning (see Fig. 7). It was also observed that the peak of the fluorescence was not at the same detuning for L2 as the point where we observed the maximum loss from the MOT. The maximum loss is ∼10 MHz to the blue of the point of the maximum 421-nm fluorescence for $\delta = -12$ MHz on L1. This indicates that the point of maximum 421-nm fluorescence corresponded to a coherent two-photon transition from the ground state to the 5*D* excited state, and the point of maximum loss in the MOT corresponds to some acceleration along the 5*S*-5*P* molecular potential in order to carry atom pairs into closer separation along the 5*S*-5*D* potential. [31]

The simplified models we have used do not take into account the hyperfine structure of the various states, particularly the $5D_{5/2}$ state. The $5D_{5/2}$ state in ^{85}Rb has an inverted hyperfine structure, meaning that the highest angular momentum value of F lies at the lowest energy. When observing the maximum fluorescence in the MOT, the most probable excitation from the $5P_{3/2}$ ($F = 4$) level is to the $5D_{5/2}$ ($F = 5$) level. From the $5D_{5/2}$ ($F = 5$) level, it is highly likely (more than 80%) that the atom will experience a spontaneous decay route that ultimately results in the atom returning to the $5S_{1/2}$ ($F = 3$) ground state. In contrast, when we observed the maximum loss in the MOT, we were tuned nearly on resonance with the $5D_{5/2}$ ($F = 4$) state, whose spontaneous decay channels have reasonable probability to put atoms out of resonance with both L1 and L2, leaving the atom in a "dark" state until repumped from the $F = 2$ ground state by the hyperfine repump laser. In principle, this process could lead to losses from the trap due to loss of cooling efficiency, which would change the steady-state number in the MOT. We observe no such effect, which in any case would be a one-body loss instead of a two-body loss. This can be explained by the fact that we have a strong repump laser to pump atoms back to the $F = 3$ ground state from the $F = 2$ ground state quickly. In addition, the Clebsch-Gordan coefficients for the $5P_{3/2}$ $F = 4$ to the $5D_{5/2}$ $F = 4$ are 1/2 of those of the $F = 5$ transition, which would reduce the transition rates by a factor of 4 (the Clebsch-Gordan coefficients for the transition to the $5D_{5/2}$ $F = 3$ state are lower by a factor of 17). So the transition to the $5D_{5/2}$ $F = 5$ state will be the dominant transition.

V. CONCLUSION

In summary, we have investigated the increased two-body loss rate produced by the addition of laser light that excites atoms in a MOT up to the 5*S*-5*D* molecular potential curve. We confirmed that the dominant loss was two-body in nature. Our measurements showed that the two-body loss rate was increased by over an order of magnitude with only a factor of 2 change in the overall light intensity. Using intensity variation measurements, we have been able to conclude that the loss channel likely involves a single photon transition from our main trapping laser and a single photon transition from a second laser tuned to excite to the $5D_{5/2}$ level. Finally we measured the width of the loss coefficient as a function of L2 frequency for two frequencies of L1. While this work was performed with the excitation to a particular long-lived excited state, we expect that this class of losses induced are not unique to the ^{85}Rb $5S_{1/2}$-$5D_{5/2}$ state and could possibly be observed in other experiments involving excitations to similarly long-lived states.

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