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# Measuring the Density of Ultracold Rydberg Atoms

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The energy exchange between ultracold, highly-excited, or Rydberg, atoms can be used to model quantum mechanical systems. When interpreting the results of these systems, it is important to know the density of the Rydberg atoms. In a recent experiment, we have studied several clusters of states that form a nearly harmonic ladder of clusters. The Rydberg atoms all start in one energy cluster, and the interactions between them allows energy to spread to all the other states. We have developed new analysis software along with a method in which a simple four-level system can calibrate the density for our experiment. This system has two- and three-body interactions which each depend differently on the density. We run many computer simulations with different densities of atoms in the initial state and store the time-dependence of the distribution of atoms among the four states. We compare our simulations to the experiment and pick the density that best fits the data. We present preliminary results of our analysis.

## Experiment

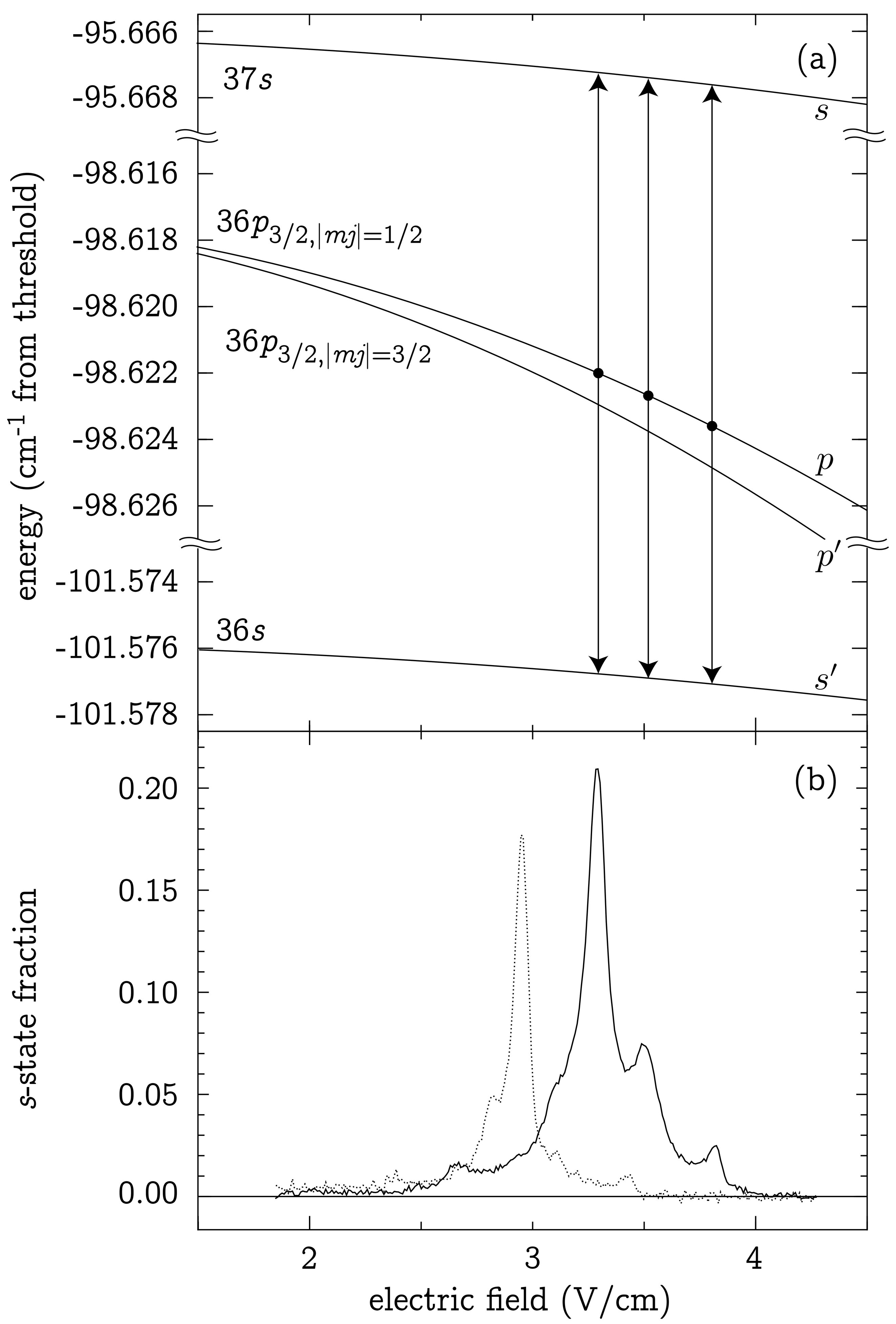
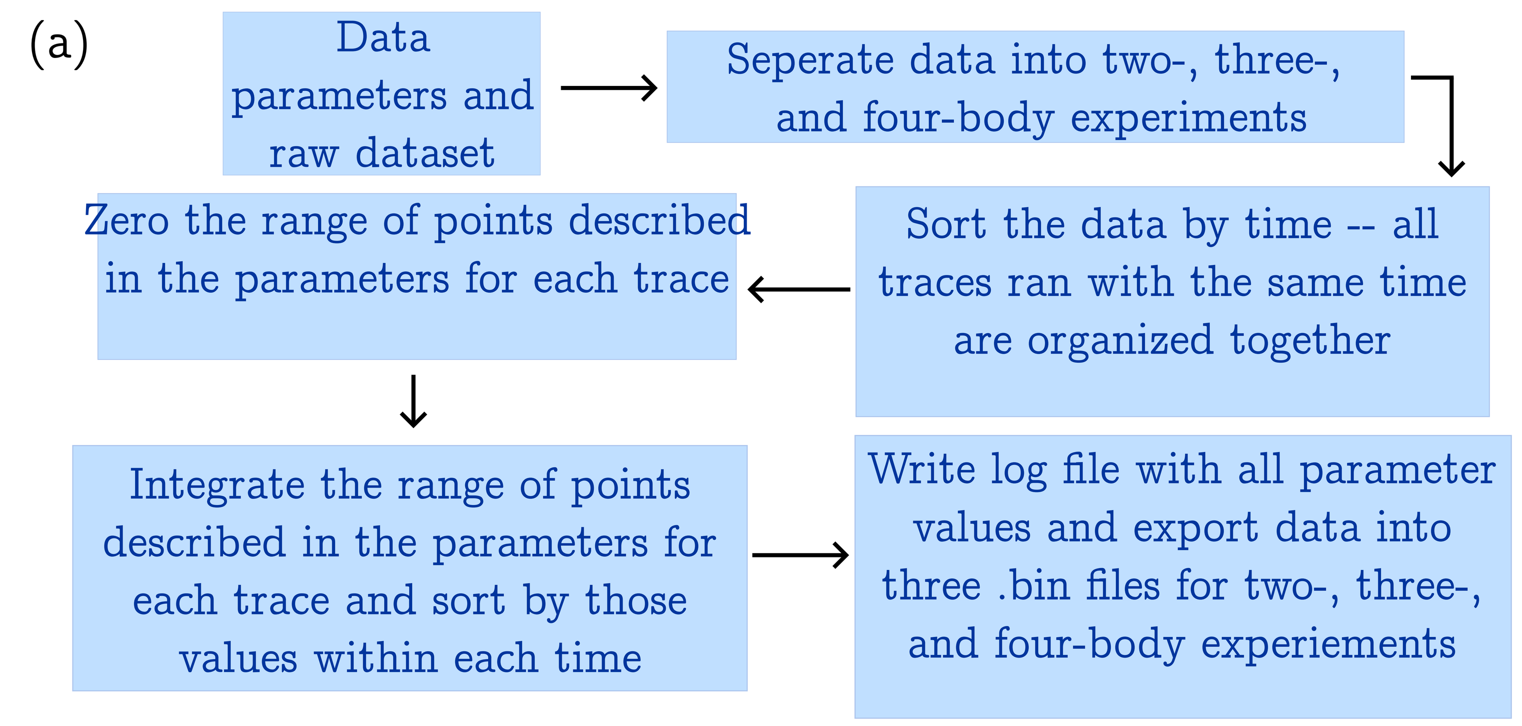



Figure 1. (a) Stark map showing the s, p, s', and p' energy levels as a function of electric field. Solid arrows indicate the locations of the three different electric fields at which the time dependence was studied in. All of the Rydberg atoms are initially excited to the p-state. As we allow the atoms to interact and move between the energy states, we measure the s-state fraction. We seperately tracked the s-state population when the atoms interacted on the two seperate fields where either two- or three- body interactions occur. (b) Experimental s-state fraction as a function of electric field for an initial state composed of p atoms (solid line).

## Data Processing



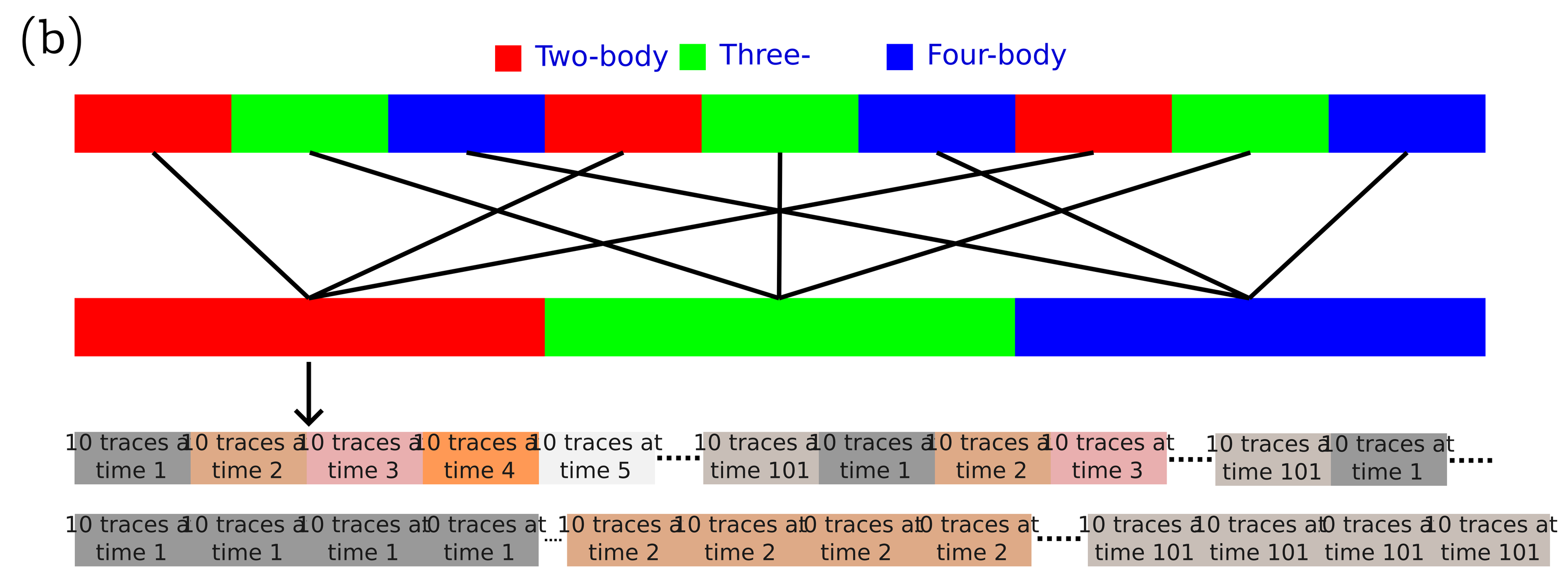




Figure 2. (a) Flowchart that describes the process that the preproccessing program follows. (b) Visual representation of the processes 2 and 3 in the flowchart. .

## Fitting the data

$$\chi_c^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

Figure 3. Chi-square statistic calculation. We interpolated the experimental data. The expected values were the true experimental data and the observed values were those in the simulation. In small increments of time, we calculated each chi-square component and summed them. We calculated the chi-square value for densities from 1 to 29 V/cm with scale factors from 1.0 to 400.0. (incrementing by 0.1).

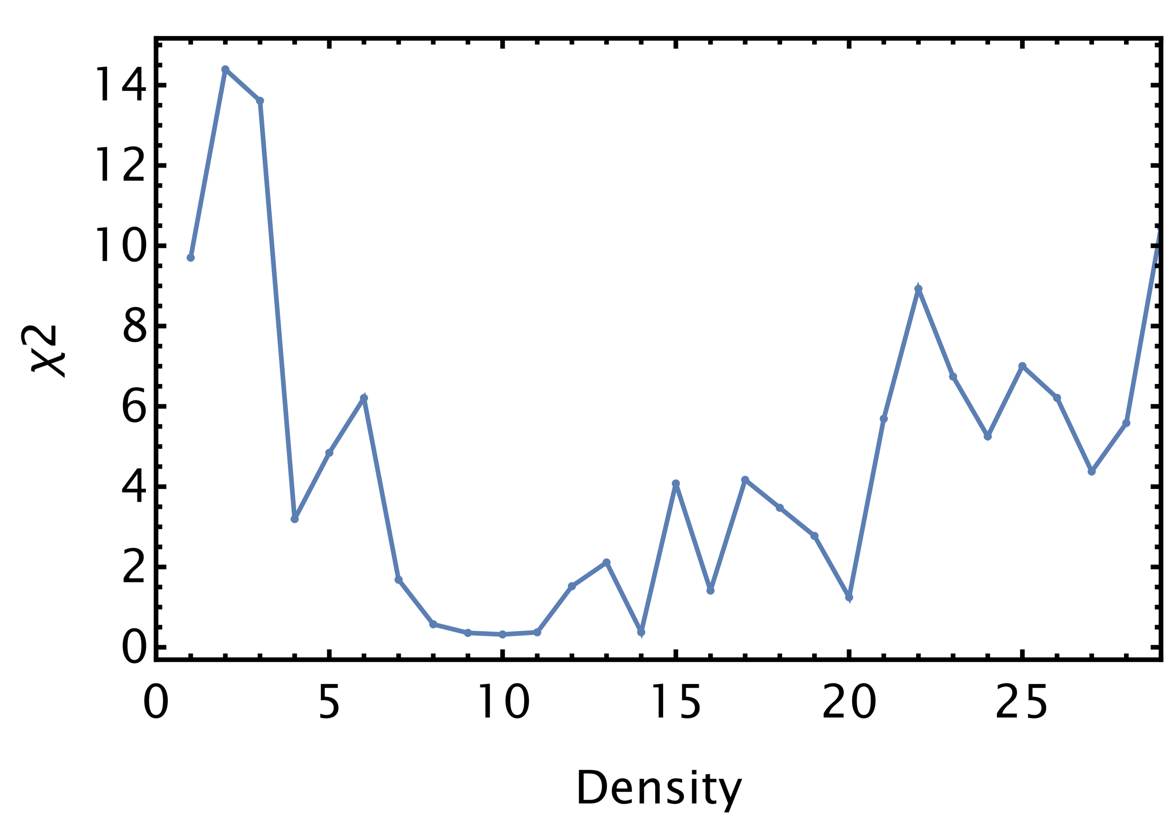



Figure 4. Plot of the results of calculating the lowest chi-square for all 29 denisities. At each density, the scale factor with the lowest chi-square value represents the optimal fit. The density value of the minima in this plot represents the density at which the simulation and the experiment had the least difference. Figure 7 plots the s-state fraction for the experimental data in this figure and the simulation at the optimal density.

## Results

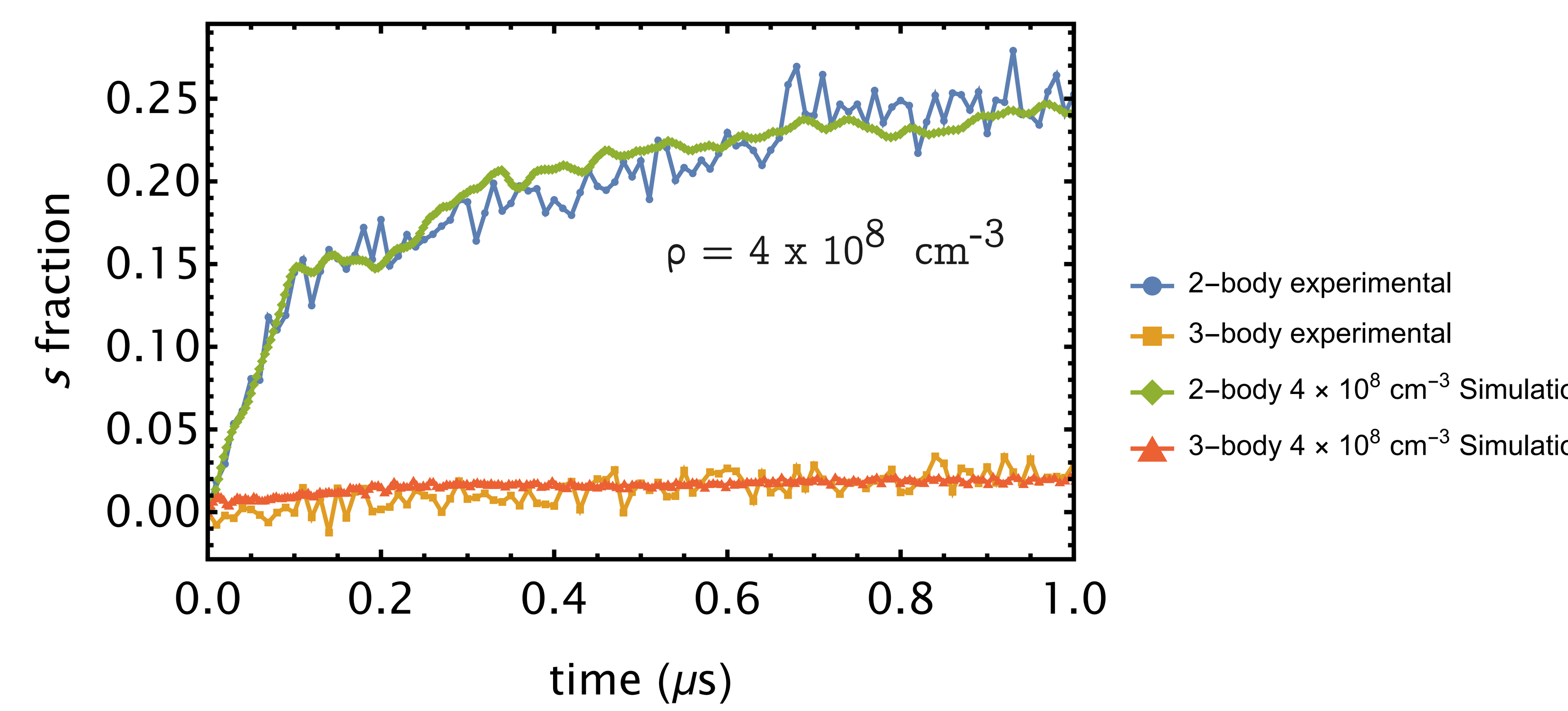



Figure 5. This experimental data was calculated to have the lowest chi-square value (1.40047) when fitted with a simulation ran at 4 x 10$^8$ cm$^{-3}$ with a scale factor of 149.5.

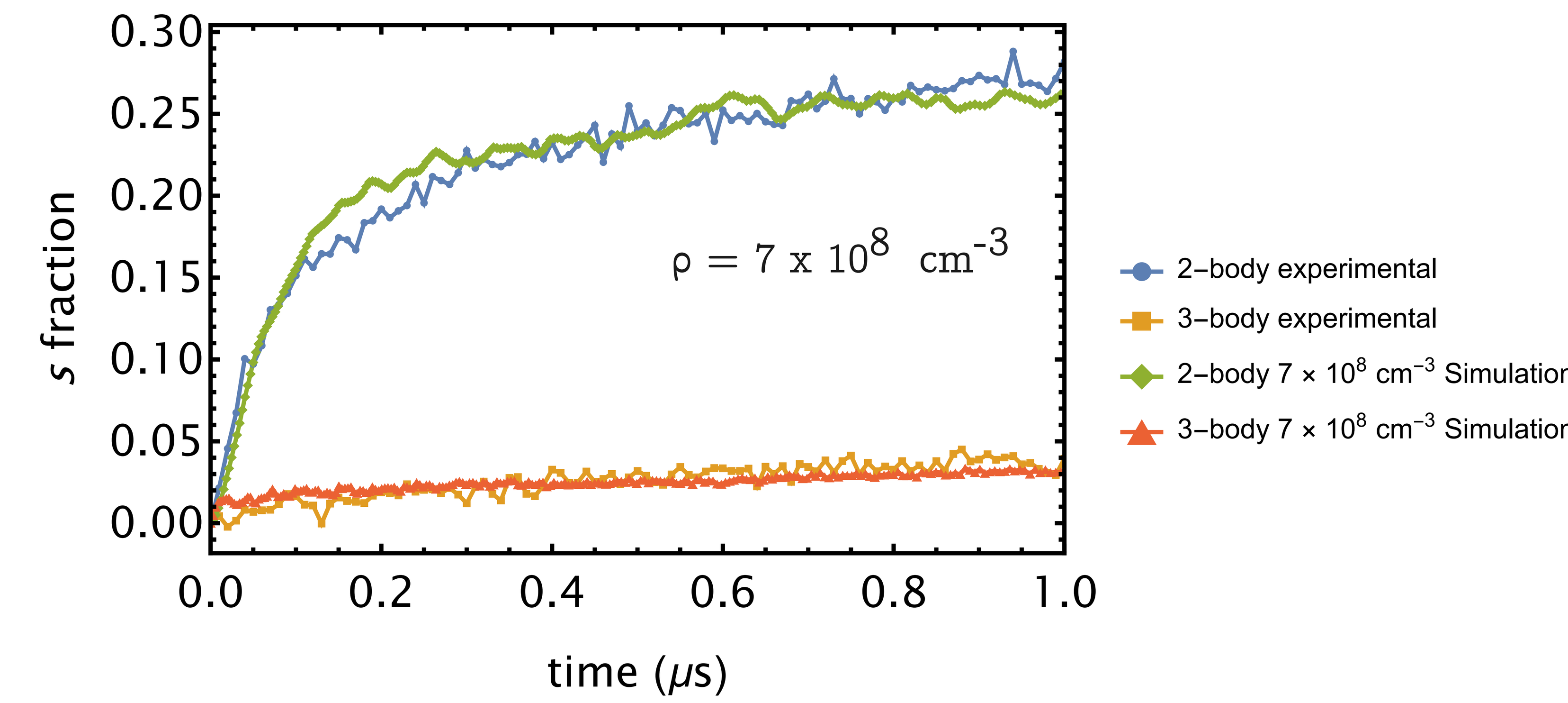



Figure 6. This experimental data was calculated to have the lowest chi-square value (0.722824) when fitted with a simulation ran at 7 x 10$^8$ cm$^{-3}$ with a scale factor of 96.7.

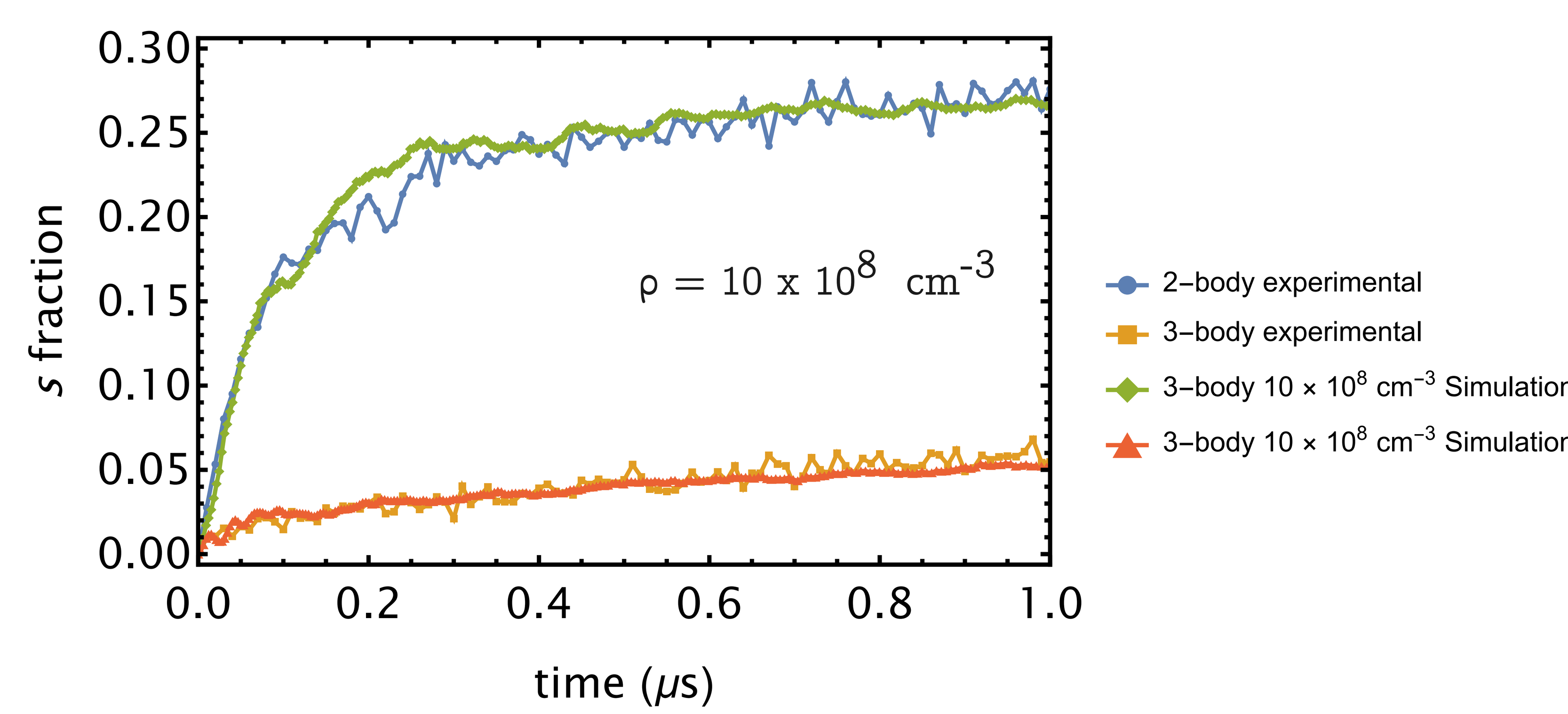



Figure 7. This experimental data was calculated to have the lowest chi-square value (0.31985) when fitted with a simulation ran at 10 x 10$^8$ cm$^{-3}$ with a scale factor of 24.4.

**Acknowledgments**

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