# Asteroid Collisions

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## Abstract

The asteroid belt is not a quiet place. Collisions occur on a yearly basis, very occasionally shattering large asteroids into many small asteroids. Understanding this process is key to learning the history of the asteroid belt. With this summer's work, we created a program to compute the probability of collisions between any two asteroids over large time scales, as well as the velocity distribution over all collision scenarios. Combining these probabilities with observations of the size distribution, we computed the timescale for disruptive collisions as a function of asteroid size. We plan to use these calculations to address a number of astronomical questions next summer.

## Why Collisions?

The asteroid belt, sort of like rings in a tree, stores a record of the solar system's history. The primary players in this history are collisions, the Yarkovsky effect, and gravitational resonances. Many current asteroids were formed when collisions broke apart old asteroids, making collisions very fundamental to understanding the belt's historical record.

## Computing Collision Probabilities

These computations are complex and nuanced enough to have caused confusion in the published literature. Each orbit lies in a separate plane. The line where two asteroids' planes intersect is where they can collide. The planets' gravitational tugs (especially Jupiter's) change the angle between planes over time, as well as two orbits' relative orientation. Only when the orientations are right will two asteroids collide, and we must consider every collision-producing orientation at every inclination. We created a program to rigorously compute these probabilities. We verified its results by comparison with the latest published work.

Two asteroids aren't very exciting, though. To be able to run the program over many thousands of asteroids and millions of pairings—whole swaths of the asteroid belt—we optimized heavily and eliminated over 95% of the program's run time.

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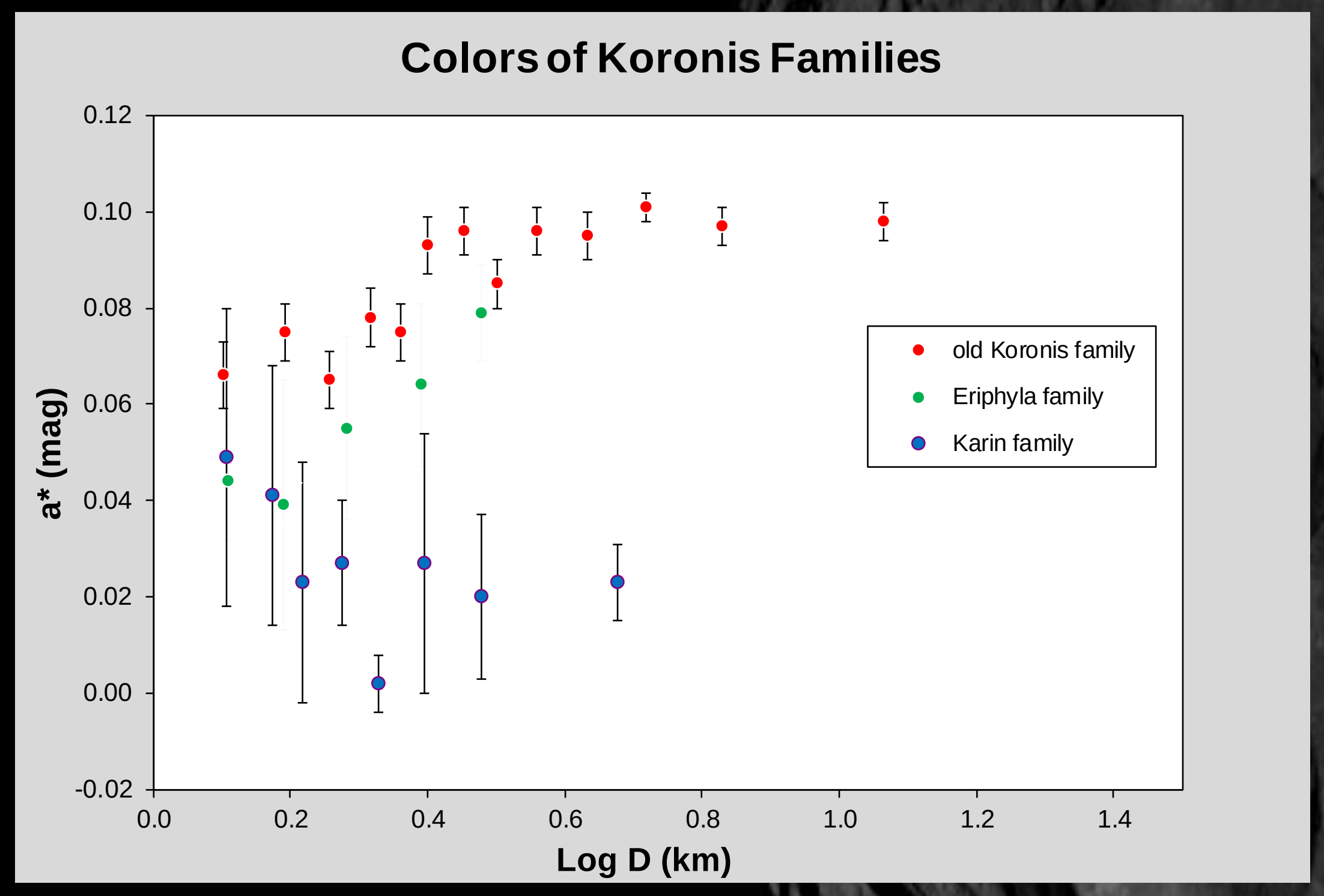
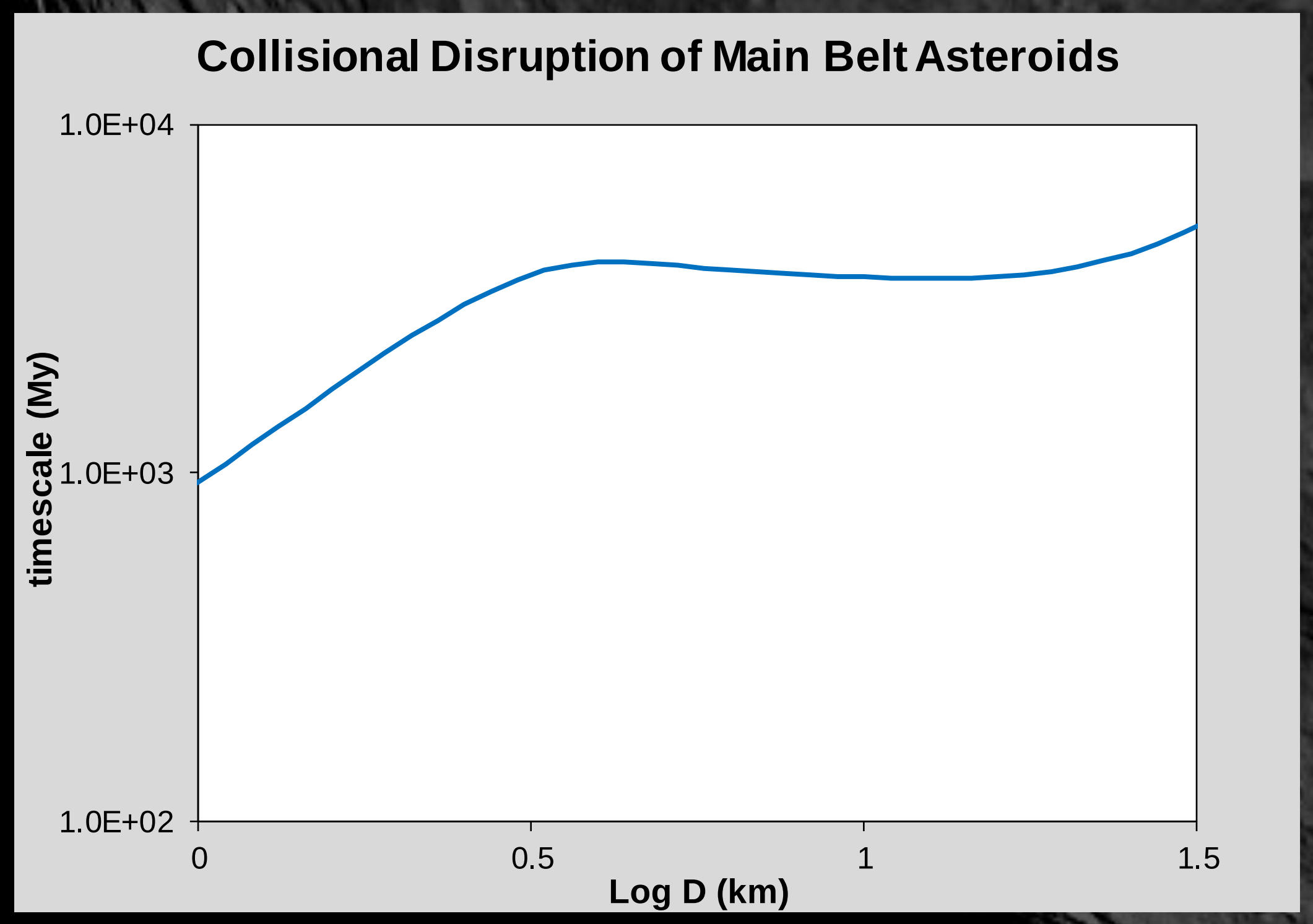
## Application

The Koronis zone is an isolated, undisturbed area of the asteroid belt. In this niche, the Koronis collisional family has the unique property of containing four subfamilies formed in subsequent collisions. All asteroids in a given subfamily formed at the same time, but each subfamily has a different age. This makes the zone ideal for studying a phenomenon called *space weathering*, in which the Sun's radiation changes asteroids from slightly-red to slightly-blue over time. We see among the Koronis families that older asteroids are more red, as we would expect.

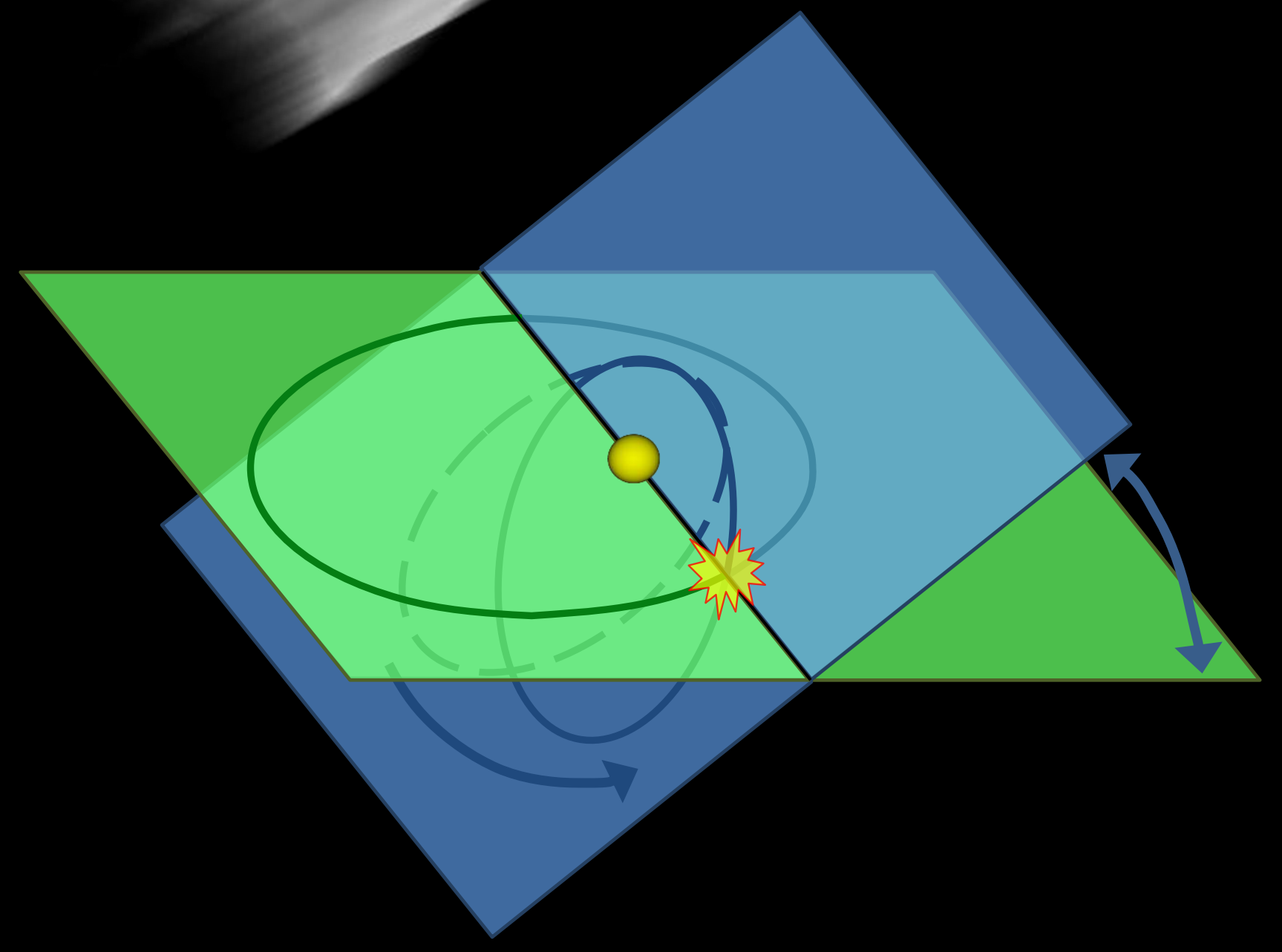


Average color (a*), where higher numbers are more red, as a function of asteroid diameter (D) for three of the Koronis families (Koronis, Eriphyla, and Karin, with ages 2000 My, 220 My, and 5.7 My, respectively).

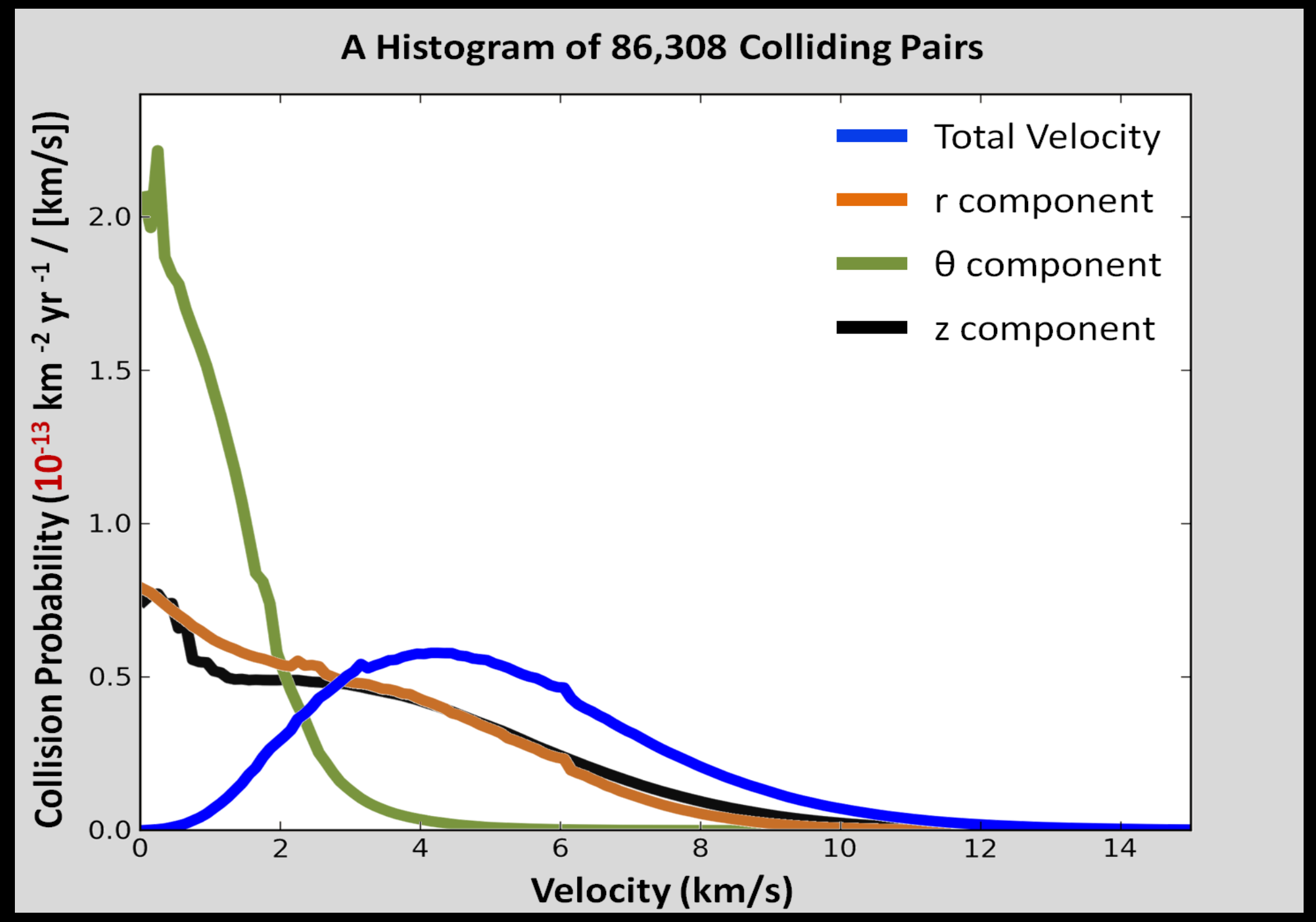
However, we also see that larger asteroids tend to be redder than smaller asteroids of the same age. We suspect collisions may cause this trend, but further analysis is required to model this behavior in detail.



Timescale for collisional disruption of a main belt asteroid as a function of the asteroid diameter.



Two asteroid orbits in their separate planes.



Sample program output from 449 asteroids (100,576 total pairs, of which 14,268 could never possibly collide) showing probability of collision against velocity of collision. Shown are relative collisional speed as well as its three components: **r** (speed towards or away from the sun), **θ** (speed around the sun in the orbital plane) and **z** (speed perpendicular to the orbital plane).

## Work Remaining

There are a number of problems for which our program would be useful. Some possibilities include:

**Reorientation timescales:** Re-radiation of sunlight interacting with an asteroid's spin will, over time, cause it to drift towards or away from the sun. (This is called the Yarkovsky effect.) Collisions that change an asteroid's spin direction will change the direction it is drifting. Frequent collisions cause back-and-forth movement that slows an asteroid's drift rate. Understanding this drift rate is important in dating large collisions by looking at the rubble. If the rubble has drifted apart a lot, the collision happened long ago, but if frequent collisions lower the drift rate, every collision is much older than we thought.

**Inner Zone of the Asteroid Belt:** In past summers, another student looked at the spin direction for one specific group of asteroids (the Flora family) and found ten out of ten asteroids spinning in the same direction. Given the age of these asteroids, we can put a limit on how frequently collisions can change an asteroid's spin direction.

**Koronis History:** We plan to further model the color characteristics of the Koronis subfamilies, as well as the frequency and character of other families in the Koronis zone. Many generic asteroid collisional models have been published. The unique properties of the Koronis zone should allow stringent tests of these models, perhaps lending support to one over the others.

## Acknowledgments

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