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As the curator of meteorites at the Vatican Observatory, Brother Guy has an extensive academic background and has written more than 100 scientific publications alongside numerous books.

Written from the control room of the Vatican Advanced Technology Telescope in Arizona, this feature delves deep into meteorites, addressing their creation, composition, location and importance. Tricks of the trade are put on the table as methods of analysing these pieces of cosmic debris are addressed. This all comes together for the grand aim of understanding how the Solar System and the objects within it were formed, four and a half billion years ago.

Magnificent Meteorites

I'm writing this from the control room of the Vatican Advanced Technology Telescope on Mt. Graham, Arizona. My work here is not so much different from observers around the world on any given night... except that this really isn't my work at all. I am a meteoriticist. My real work takes place in a laboratory 5000 miles away from this Arizona mountaintop, in the Pope's summer home of Castel Gandolfo, Italy, where the Vatican's meteorite collection is housed. In that lab I measure the physical properties of those rocks from the asteroid belt: density, porosity, magnetic properties. So why am I at a telescope?

I started out as a theorist. I wanted to use the physics and chemistry of small Solar System bodies to make computer models that could match what we actually see in the moons around the gas giant planets, or the asteroids that orbit between Jupiter and Mars. I had assumed that meteorites were good analogues for the material that made up those small bodies, but it was hard to find data for the physical properties of the meteorites. When I was assigned to the Vatican Observatory in 1993 and got to see the wonderful collection of meteorites, I worked out a rapid, non-destructive way to get the data I needed from these samples.



Melissa Brucker (University of Oklahoma grad student and Lowell Observatory pre-doc) and I at the controls of the Vatican Advanced Technology Telescope on Mt. Graham, Arizona, measuring Centaur light curves.
Image credit: Steve Tegler.

Blame it on Galileo!

In one sense, you can blame it on Galileo. Not only the man who invented the telescope (and whose problems with the Church eventually led it to found an astronomical observatory, in a sort of quiet apology for those problems). But it was the Galileo spacecraft that passed by asteroid Ida on its way to Jupiter in the early 1990s and discovered a moon orbiting that asteroid. By seeing how fast the moon moves around the asteroid, we could calculate how massive the asteroid pulling on it must be. Thus it became the first asteroid for which a mass and density could be measured. Since then, other techniques from radar echoes to adaptive optics on the largest telescopes have led to the discovery of dozens more moons around asteroids.



I took part in the 1996 field season of the Antarctic Search for Meteorites programme. Every year, hundreds of meteorites are recovered from the ice sheet of Antarctica, where they are well preserved by the cold. They're easy to spot against the white ice! Image credit: Sara Russell, Natural History Museum, London.

Tonight's work

Once you know the mass of an asteroid, you can divide that mass by the asteroid's volume to get its average density. And our meteorite densities turned out to be 20% to 50% larger than the densities of the asteroids from which they come; asteroid volumes are 20% to 50% empty space! The asteroids are not solid rocks but rather highly fractured and porous piles of rubble.

Meanwhile, during this same time a whole new collection of asteroid-like objects was discovered orbiting out beyond Neptune: the Kuiper belt. This apparently is the source for many of the comets we see. Are comets and Kuiper Belt bodies also made largely of empty space?

That's hard to tell. It's not only that they are so much farther away from us than the asteroids, but, unlike the asteroids, we don't have sample comets in our lab to measure. So how can we tell what they are made of? By comparing their detailed colours with the spectra of different materials in our lab. That's one reason I observed them with the telescope in Arizona, to measure their colours and guess their composition.



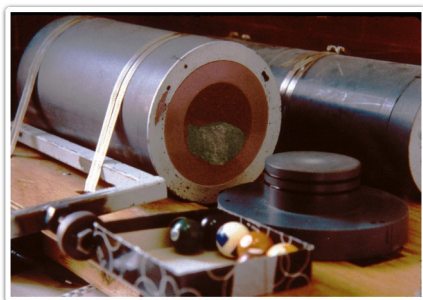
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In addition we have a hard time measuring the density of these distant objects. Finding their mass is hard as only a few have visible moons. Worse, they are so far from us that measuring their volumes is almost as difficult as measuring their masses.

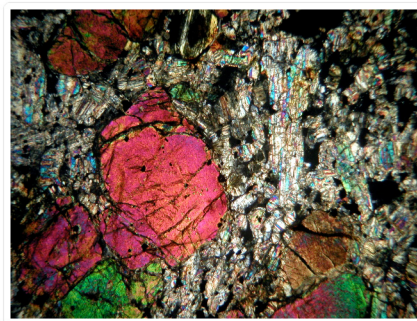
Tricks of the trade

There is a trick, however, that can let us make an intelligent guess at their average densities. If a body is not a single solid object but a very weak pile of rubble, then the faster it spins, the more its spin should pull it into an elongated shape. What holds such a body together against that spin is its gravity, which depends on its average density. So for a given spin rate, the more elongated it is, the lower its density must be.

If we can measure how fast a body spins, and how elongated it is, we should be able to estimate its density. By seeing how the brightness changes as it spins, we can compute not only how fast it is spinning but, from the difference between the brightest and the dimmest phases, how non-spherical it is. To get a complete fit requires observing this "lightcurve" at many different positions in the body's orbit around the Sun.



This helium pycnometer is used to determine the grain volume of meteorites. One tank is filled with helium at two atmospheres, the other (with the meteorite) at one atmosphere, and then the pressure between the two tanks is equalised; the larger the volume of the meteorite, the higher the final pressure. Image credit: Guy Consolmagno.



A slice of Dar al Gani 476, a shergottite meteorite, believed to come from Mars. Measuring the physical characteristics of meteorites allows us to understand better the planets and asteroids from which they come... both their current states, and their evolutionary history. Image credit: Guy Consolmagno.

And that's what we're working on tonight. We choose Centaurs, bodies perturbed out of the Kuiper belt, because as they approach the Sun we get to see them at many different aspects in their orbits. It would take hundreds of years to get the same range of aspects for the bodies out in the Kuiper belt itself. Even for Centaurs, however, we need lightcurve data taken over many decades. Tonight's data will be one more piece of evidence that may some day allow us to understand just how these distant objects are put together.

And then, ultimately, we can compare the structure of the asteroids from which my meteorites come, with the structure of the bodies from which comets come. Then, just maybe, out of that data we'll have new insights into how all those bodies, asteroids, meteorites and comets were formed back when the Solar System itself was formed, four and a half billion years ago.

This feature article was written as part of the Cosmic Diary Cornerstone project for the International Year of Astronomy 2009. To find out more, check out www.cosmicdiary.org and www.astronomy2009.org.