6. Getting Involved in the Search

Investigation

IASC Founder and Director: Patrick Miller

Asteroid Search Campaign

In Chapter 1, we saw how asteroids can be major threats to the well being of life on Earth. You can find out more about the NASA efforts concerning near Earth asteroids at the NASA Ames Research Center's *Asteroid and Comet Impact Hazards* page

http://impact.arc.nasa.gov/

You can join the Hands-On Universe Asteroid Search, which began as a research project started by high school teachers Hughes Pack and Tim Spuck in 1996. In October of 1998 students at Northfield Mount Hermon School in western Massachusetts, USA, discovered a faint and distant Kuiper Belt object, now known as 1998 FS144. The project has used images from large telescopes, observatory archives, and small telescopes for asteroid tracking, searching, and discovery. The web site currently has four main options.

Current status of the Hands-On Universe research projects can be found through the "Staying Up to Date" pages for *A Changing Cosmos* chapter 7

http://lhs.berkeley.edu/gss/uptodate/10acc

For example, the International Astronomical Search Collaboration (http://iasc.hsutx.edu/) is an educational outreach program for high schools and colleges, provided at no cost to the participating schools. IASC ("Isaac") a collaboration of

- Hardin-Simmons University (Abilene, TX),
- Hands-On Universe, (HOU - Lawrence Hall of Science, University of California, Berkeley),
- Astronomical Research Institute (http://ari.home.mchsi.com in Charleston, IL), and
- Astrometrica (H. Raab, Austria).

Most recently, HOU collaborates the NASA WISE mission (Wide-field Infrared Survey Explorer)

http://wise.ssl.berkeley.edu/mission.html

WISE will survey the whole sky in infrared light, producing an all-sky image atlas and catalogue of over 300 million infrared sources. In addition to asteroid research, WISE scientists will study the coldest and nearest stars, regions of new star and planet formation, the structure of the Milky Way Galaxy, Ultra-luminous infrared galaxies, and the large scale structure of the Universe.

> *The worlds come into being as follows: many bodies of all sorts and shapes move from the infinite into a great void; they come together there and produce a single whirl, in which, colliding with one another and revolving in all manner of ways, they begin to separate like to like.*
>
> —Greek philosopher (atomist),
> Leucippus (~480-420 B.C.)

Appendix A: Space Rock Vocabulary

Asteroid
Naturally formed solid bodies that orbit the sun, have no atmosphere and no signs of gas or dust coming from them. Most are found in orbit between the orbits of Mars and Jupiter.

Breccia
Rock made from pieces of rocks formed earlier.

Carbonaceous Chondrite
Stony meteorite containing chondrules and volatiles.

Chondrite
A stony meteorite containing chondrules.

Chondrule
Round, glassy part of meteorite made from silicates.

Coma
Roughly spherical area of vaporizing gases and dust around the nucleus of a comet.

Comet
Small bodies of rock, iron and frozen water and gases that orbit the sun in elliptical orbits. As they get close to the sun the gas vaporizes leaving a tail of dust and debris.

Comet Head
The nucleus and coma of a comet.

Dust Tail
Trail of gases, dust and debris left behind as a comet gets close to the sun.

Ejecta
Pulverized rock scattered by impacts on an object's surface.

Fireball
A very bright meteor.

Kuiper Belt
Small asteroids obiting the sun between the orbits of Uranus and Neptune thought to be the source of comets.

Light-year
The distance light travels in a year. About 10^{13} km or 6 trillion (thousand billion) miles.

Meteor
A bright streak of light that appears briefly in the sky. It is sometimes called a *shooting star* or *falling star*. It is actually caused by a meteoroid entering the earth's atmosphere, heating up so much that it glows and creates a trail of melted and vaporized meteoroid particles.

Meteorite
Any meteor striking the ground.

Meteoroid
A solid object moving in interplanetary space, of a size considerably smaller than an asteroid and considerably larger than an atom. It can be a piece of comet debris.

Meteor Shower
When the Earth enters a meteoroid stream left by a comet it produces a meteor shower.

Oort Cloud
A spherical region outside the orbit of Pluto thought to be the source for long-period comets with orbits of longer than 200 years.

Orbit
The path an object takes as it moves around another object.

Rotation
An object spinning about its center.

Volatiles
Carbon compounds, frozen gases and other materials that when heated vaporize.

Appendix B:

Determining Asteroid Characteristics from WISE Data

by Matt Fillingim

We've identified an asteroid in the WISE data. Will it hit Earth? If it were to impact Earth, how bad would it be: a puff of smoke in the atmosphere or the end of civilization as we know it?

The starting point will be a **sequence of images** from WISE. What can we learn from the data?

POSITION:

The first thing we (and the WISE software pipeline) can determine is the **position** of the object. The satellite measures the right ascension and declination of the object in space. From just three measurements at different times, the position and **orbit** of the asteroid can be estimated.

In 1801, Carl Friedrich Gauss developed a method to calculate the orbits of Ceres, the first asteroid discovered (now technically designated a dwarf planet), using three measurements of right ascension and declination. His method was first widely published in 1809. This method relies on Johannes Kepler's first two Laws of Planetary Motion published in 1609:

1. The orbit of every planet is an ellipse with the Sun at a focus.
2. A line joining a planet and the sun sweeps out equal areas during equal intervals of time.

We can estimate the object's position in space by making some assumptions that simplify the mathematics. Our three observation times will be called t1, t2, and t3. We can approximate the area swept out by the object between times t1 and t2 and between times t2 and t3 as triangles rather than sections of an ellipse so that the ratio of the times between observations is equal to the ratio of the areas of the triangles (approximately) swept out by the object. Using this simplification, we can estimate the Sun-object and Earth-object distances. We need these distances to calculate the temperature and size of the asteroid later on.

[*lSpreadsheet "example_ceres.xls" calculates these distances – it uses cross products and linear algebra which may be beyond most students. It is derived from the notes of Dr. J. B. Tatum at the University of Victoria (http://www.astro.uvic.ca/~tatum/celmechs.html). Minor Planet Ephemeris Service (http://www.cfa.harvard.edu/iau/MPEph/MPEph.html) at the Minor Planet Center will also give these numbers; "r" is the Sun-object distance and "Delta" is the Earth-object distance.*]

To completely describe the orbit of an object, we need six variables known as the **orbital elements**. These six orbital elements describe the size, shape, and orientation of the orbit. The complete process of calculating an orbit is a mathematically intensive process. One of the jobs of the Minor Planet Center (http://www.cfa.harvard.edu/iau/mpc.html) is to calculate the orbits of asteroids and other objects based on observations from professional and amateur astronomers alike. Many observations are necessary to make better estimates of the orbit and to refine the orbit. Also, gravitational interactions with planets and other asteroids can slightly change the orbit of asteroids over time. So even for well known objects, new observations are important to continue to refine their orbits.

The WISE software pipeline will **identify all of the known objects** in the images, which will be *most* of the objects in the images. The orbital elements for known objects can be found using the Minor Planet Ephemeris Service (http://www.cfa.harvard.edu/iau/MPEph/MPEph.html) at the Minor Planet Center (http://www.cfa.harvard.edu/iau/mpc.html). Just type in the name or number of the asteroid in the box and be sure to click the MPC 8-line button near the bottom of the page.

[*Note: I also have a black-box program that calculates the orbital elements that I got online and rewrote in IDL (Interactive Data Language). I don't think that the full calculation is spreadsheet-able.*]

So from observations we've computed the Sun-asteroid and Earth-asteroid distances. With the help of the Minor Planet Center, we know the orbit of the asteroid. How close will the asteroid get to Earth? To calculate this, we need two of the orbital elements: a, the semi-major axis of the ellipse, which measures how far away the asteroid is from the Sun *on average* (for a perfect circle, the semi-major axis is equal to the radius), and e, the eccentricity, which measures elliptical the orbit is (a perfect circle has an eccentricity of 0).

The closest the asteroid gets to the Sun (called perihelion) is calculated from the equation
$R_{perihelion} = a(1 – e)$
The farthest the asteroid get from the Sun (called aphelion) is calculate similarly
$R_{aphelion} = a(1 + e)$

How close will it come to Earth? The semi-major axis of Earth's orbit is 1 Astronomical Unit (AU), defined as the average Earth-Sun distance. If either the perihelion or aphelion is close to 1 AU, then the asteroid comes close to Earth orbit. If the perihelion is less than 1 AU and the aphelion is greater than 1 AU, then the asteroid actually crosses Earth's orbit. These are the asteroids to watch out for!

INTENSITY:

We can also learn a lot about the asteroid (rotation rate, temperature, size, etc) from its intensity – how bright it appears in the WISE images.

Rotation Rate:

The **light curve** can be created by plotting the intensity of an object as a function of time from a sequence of images. If the object is not spherical (for example, potato-shaped), the brightness of the object will changes as it rotates. If the object rotates quickly enough (a typical asteroid has an 8-hour rotation period, some have periods that are shorter and some have periods that are considerably longer), the **rotation rate** can be measured from the brightness variations of the light curve. The ratio of the maximum to minimum brightness is equal to the ratio of the maximum to minimum area facing the Earth as it rotates. This ratio is a measure of the "potato-ness" of the object.

From the rotation rate, we can also get an estimate of the **lower limit** of the asteroid's **density**. An object held together by its own gravity (a "pile of rubble" as opposed to a giant rock), will fly apart if spins too fast – that is, when its centrifugal acceleration is larger than its surface gravity:
$\omega^2 R > GM/R$
where ω is the rotation rate (2π/rotation period), R is the asteroid's radius, G is the universal gravitational constant, and M is the asteroid's mass. After a little algebra,
$\rho < (3.3/P)^2$
where ρ is density in g/cm^3 and P is the rotation period in hours. If the density is lower than this number, the asteroid will spin itself apart. In most cases, this will give a very low number (much less than 1 g/cm^3 which is the density of water). This is the lower limit of the density; it can certainly be, and usually is, much higher.

Temperature:

By equating the solar energy reaching the asteroid to the thermal energy emitted by the asteroid, the **temperature** of the asteroid can be calculated. As shown below, in general, the temperature of the asteroid only depends upon its distance from the Sun (with some simple assumptions).

The incident solar energy is
$P_{in} = \pi R_A^2 \times L_S / 4\pi r_{SA}^2$
where R_A is the radius of the asteroid and πR_A^2 is the cross-sectional area of the asteroid; L_S is the solar luminosity (the power output of the Sun) and is equal to 3.827×10^{26} Watts; r_{SA} is the Sun-asteroid distance (determined above), so $L_S/4\pi r_{SA}^2$ is the solar power per unit area at r_{SA}. The incident solar energy, then, is the solar power intercepted by the asteroid.

For a blackbody (an object that is a perfect absorber of radiation), the thermal power radiated is
$P_{out} = 4\pi R_A^2 \sigma_{SB} T_A^4$
where σ_{SB} is the Stefan-Boltzmann constant (5.6704×10^{-8} W/m²K⁴), and T_A is the temperature of the asteroid in Kelvins. This is known as the Stefan-Boltzmann Law.

Setting $P_{in} = P_{out}$ and solving for T_A gives
$T_A^4 = L_S / (16\pi\, \sigma_{SB}\, r_{SA}^2)$

However, in reality, asteroids are not blackbodies, they are graybodies (not quite perfect absorbers of radiation), so P_{in} and P_{out} must be slightly modified:
$P_{in} = \pi R_A^2 \times L_S \times (1 - A) / 4\pi r_{SA}^2$
where A is the asteroid albedo (the amount of sunlight reflected), so (1 – A) is the amount of sunlight absorbed by the asteroid.

$P_{out} = 4\pi R_A^2 \varepsilon \sigma_{SB} T_A^4$
where ε is the asteroid's emissivity, a measure of how well the asteroid radiates energy (a perfect blackbody has an emissivity of exactly 1).

The refined temperature estimate is
$T_A^4 = L_S\, (1 - A) / (16\pi\, \varepsilon \sigma_{SB}\, r_{SA}^2)$.

In general, the emissivity, ε, is often assumed to be 0.9. Measured asteroid albedos vary between 0.023 and 0.63. If the albedo is unknown, a common assumed value is 0.1, so (1 – A) is 0.9. In this case, the blackbody temperature and the greybody temperature are the same, and the only measured quantity is the Sun-asteroid distance, r_{SA}.

[*An alternate way to try to calculate the temperature is to use the intensities of the asteroid as observed by (up to) four wavelengths observed by WISE. The brightness as a function of wavelength of a blackbody follows* ***Planck's Law****:*

$$I(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{\frac{hc}{\lambda kT}} - 1}.$$

where λ is wavelength, h is the Planck constant ($6.62606896 \times 10^{-34}$ Joule-second), c is the speed of light (299,792,458 meters/second), and k is the Boltzmann constant ($1.3806504 \times 10^{-23}$ Joule/Kelvin). The temperature of a blackbody determines its intensity (I), or brightness, as a function of wavelength. The measured brightness at four different wavelengths can be used to determine the "best fit" temperature. This temperature can be compared to the one calculated using the distance only.

Size:

By using the infrared brightness from the WISE images with the Sun-asteroid and Earth-asteroid distances, the **size** of the asteroid can be calculated. How bright the asteroid looks to us as observers on Earth, depends on how big the asteroid is and how away it is from us. Since we already computed how far it is from us from its position, how bright the asteroid is depends on its size.

As stated above, the solar power incident on the asteroid is
$P_{in} = \pi R_A{}^2 L_S (1 – A)/4\pi r_{SA}{}^2$
If the object is in thermal equilibrium (which is probably reasonable if it is a relatively slow rotator), then the incident solar power is equal to the total thermal radiation emitted by the asteroid, the thermal luminosity, L_{th}.
$P_{in} = L_{th}$
Since the thermal radiation is emitted in all directions, the brightness WISE observes, B_{th}, is decreased by $1/4\ \pi r_{EA}{}^2$, where r_{EA} is the Earth-asteroid distance.
$B_{th} = L_{th}/4\ \pi r_{EA}{}^2 = P_{in}/4\ \pi r_{EA}{}^2 = \pi R_A{}^2 L_S (1 – A)/(4\pi r_{SA}{}^2\ 4\pi r_{EA}{}^2)$
$R_A{}^2 = 16\pi\ r_{SA}{}^2\ r_{EA}{}^2\ B_{th}/[L_S (1 – A)]$
$R_A = 4\ r_{SA}\ r_{EA} \{\pi B_{th}/[L_S (1 – A)]\}^{1/2}$

If there is a large variation in the light curve, that is, if the asteroid is potato shaped, an average radius can be calculated from the average brightness. Similarly, the maximum and minimum dimensions can be calculated from the maximum and minimum brightness of the light curve.

The WISE software pipeline should also automatically compute the size of the asteroid. This size can be compared to the size computed above.

From coordinated visible light observations, the **albedo** can be measured. The asteroid brightness in the visible is simply the reflected sunlight.
$L_v = \pi R_A{}^2 L_S/4\pi r_{SA}{}^2 A /4\pi r_{EA}{}^2$
The ratio of the visible to thermal infrared brightness is
$L_v/L_{th} = A/(1 – A)$
So the albedo is
$A = L_v/(L_{th} + L_v)$

Once the albedo is measured rather than assumed, the size calculation above can be refined.

The albedo can also give an indication of the **composition** of the asteroid. Asteroids with very low albedos ~ 0.03, that is, very dark asteroids, are called C-type and are typically rocky. Brighter asteroids with albedos between 0.1 and 0.2 are either S-type – metallic (nickel-iron) mixed with rock (silicate) – or M-type – purely metallic.

The composition also gives an indication of the **density** of the asteroid. The densities of C, S, and M class asteroids are 1.38, 2.71, and 5.32 g/cm^3, respectively. There is a wide range of asteroid densities, but if albedo or composition is unkown, a density of 2 kg/m^3 can be assumed.

[*If it is not feasible to calculate the albedo with visible measurements (which it is quite possible that it won't be), then an albedo and density or a range of albedos and densities can be assumed. Albedos range from 0.023 to 0.64 with a typical value being 0.1. Densities range from 1.38 to 5.32 g/cm^3 with a typical value of 2 g/cm^3 (or so says Wikipedia, at least).*]

Mass:

From size of the asteroid and its density, the **mass** of the asteroid can be calculated. The volume of the asteroid is
$V_A = 4/3\ \pi\ r_A{}^3$
The mass is simply the volume multiplied by the density from above.

Lastly, the kinetic energy of the asteroid can be computed. The **kinetic energy** is

KE = 1/2 x mass x $(\text{velocity})^2$

The **velocity** (at least the transverse velocity parallel to Earth's orbital motion – there is no measurement of the line of sight velocity away from or toward Earth) can be measured from the sequence of WISE images. The angular distance the asteroid moves between the first image and last image in a sequence can be measured from the WISE images. Using the measured right ascensions (RA) and declinations (DEC) the angular distance, theta, is

theta = $\cos^{-1}$[sin(DEC1) x sin(DEC2) + COS(DEC1) x COS(DEC2) x COS(RA1 – RA2)]

where all angles are in radians.

The actual distance the asteroid travels is

distance = r_{EA} x theta

The velocity is then this distance divided by the time between the first and last image in the sequence.

[*Alternately, with another black-box, the orbital elements can be converted into state vectors – instantaneous position and velocity vectors – then the magnitude of the velocity vector can be used.*]

In SI units, the kinetic energy is in Joules (the mass is in kilograms and the velocity is in meters per second). For comparison, a typical stick of dynamite contains about 2×10^6 Joules. The largest nuclear bomb ever detonated was about 2×10^{17} Joules.

Appendix C: Web Resources

Astronomical Research Institute
http://ari.home.mchsi.com/index.htm

Hands-On Universe website
http://www.handsonuniverse.org/

Image Processing Software
http://astro.uchicago.edu/yerkes/outreach/activities/ipsoftware.html

International Astronomical Search Campaign (IASC) website
http://iasc.hsutx.edu/

JPL Horizons Web Interface
http://ssd.jpl.nasa.gov/horizons.cgi

Minor Planet Center
http://www.cfa.harvard.edu/iau/mpc.html

WISE website
http://wise.ssl.berkeley.edu/
Materials for HOU-WISE workshops
http://www.handsonuniverse.org/hs/wise/index.html

Yerkes Education Website
http://astro.uchicago.edu/yerkes/outreach/activities.html/
Asteroid image sets from Yerkes 24 inch
http://astro.uchicago.edu/yerkes/outreach/activities/Explorations/images/Asteroids/