WISE Observations of Near Earth Asteroids

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ABSTRACT:
The Wide-field Infrared Survey Explorer will survey the entire sky in the thermal infrared with a 40 cm cryogen-cooled telescope, imaging in 4 bands from 3.3 microns to 23 microns. WISE will survey close to the circle perpendicular to the Earth-Sun line and cover the whole sky in six months. A given patch of sky will be imaged 10 or more times, with 3 hours being the typical time between visits. This survey pattern easily separates asteroids from celestially fixed objects. The 12 micron band of WISE is very sensitive to thermal emission from NEOs. Known NEOs that cross the 90 degree elongation circle during the WISE mission will be measured at 12 microns, and the SNR will be good enough to determine radiometric diameters and albedos for objects down to 150 meter diameter at 0.7 AU distance. For new discoveries the WISE survey will provide a sample of asteroids that is not biased toward high albedo objects. By surveying at 90 degree elongation, WISE will be more likely to find objects with orbital periods near one year than the typical search done at opposition. The WISE survey pattern will provide discovery orbits good enough to direct ground-based recovery undertaken within 2-3 weeks. WISE will launch with cryogen sufficient for a mission lasting up to one year. In that time WISE can detect one-fifth of all NEO's larger than 0.7 km diameter. WISE will enable a prototype test of thermal infrared search techniques for asteroids at minimal cost as a natural by-product of its all-sky survey.

INTRODUCTION

Mission Status

The Wide-Field Infrared Survey Explorer (WISE) is a medium-class Explorer (MidEx) currently in an extended phase B study. The mission confirmation review for WISE was held in November 2005 and WISE was judged to be “confirmable” but confirmation to enter phase C/D has not yet occurred. Nonetheless WISE is now purchasing long-lead time items such as the solid hydrogen cryostat tanks and the flight mirrors. With appropriate funding in FY 2007 and beyond, WISE could be launched in late 2009.

Mission Design

WISE will be launched into a Sun synchronous nearly polar 500 km orbit over the terminator. This allows WISE to always point away from the Earth and perpendicular to the Earth-Sun line. After a one month in-orbit checkout, WISE will survey the entire sky in six months by laying down strips of 47 arc-min frames running from pole to pole in ecliptic coordinates with longitudes approximately $\pm 90^o$ from the longitude of the Sun. The frames within each strip will be taken 11 seconds of time apart, and the 3.8 arc-min/sec orbital rate will space the frames about 43 arc-min apart, giving about 10% overlap between frames. The next strip will be advanced in longitude by about +34 arc-minutes followed by a third strip -26 arc-minutes in longitude from the first. The net effect of this toggle is to “widen” the patrolled area to about 80 arc-minutes and to keep the scan pattern approximately perpendicular to the Earth-Sun line.

Each frame from WISE will cover the 47 arc-minute FOV in four bands with 1024x1024 arrays. The central wavelengths of the four WISE bands are 3.3, 4.7, 12 and 23 microns. The required sensitivity level in these bands are 0.12, 0.16, 0.65 and 2.6 mJy for a 5 standard deviation detection of a point source with 8 usable frames. WISE expects to get 8 usable frames over more than 99% of the sky. But for single-frame detections of asteroids it is more appropriate to take a 7 standard deviation limit of 2.6 mJy at 12 microns, which is the WISE band most sensitive to near-Earth objects (NEOs).

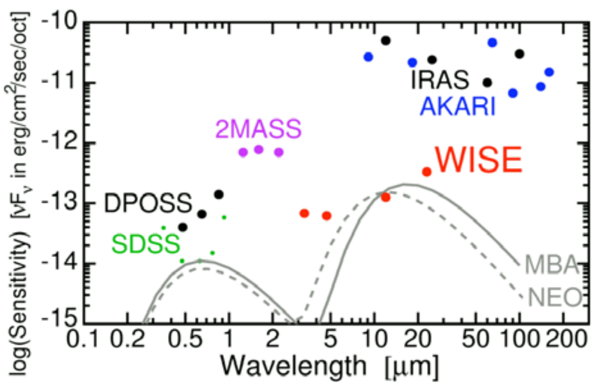

Figure 1: The 5 sigma point source detection limits for several large area surveys are shown with the dot size indicating the sky coverage. The MBA curve shows a 1 km diameter body with 5% albedo 2.8 AU from the Sun, while the NEO curve show a 0.2 km body 1 AU from the Earth and 1.4 AU from the Sun.

The pixel size for WISE is 2.75 arc-seconds. The angular resolution at 12 microns and shorter wavelengths will be 6 arc-seconds FWHM. The expected astrometric accuracy will be about 0.5 arc-seconds for sources with high SNR.

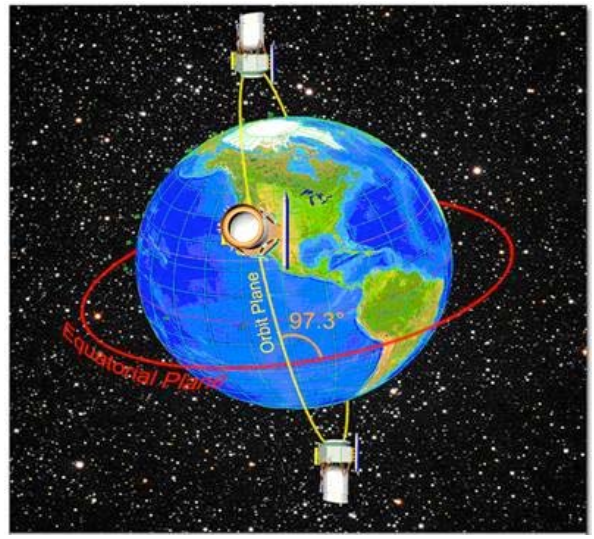

Figure 2: The WISE orbit has 97^o inclination and crosses the equator at 6 AM and 6 PM.

ASTEROID OBSERVATIONS

A typical main belt asteroid (MBA) moves about 0.2 degrees/day in the same direction as the scan pattern, which is moving at 0.985 degrees/day. The relative motion of 0.8 degrees/day means that a typical MBA is within the effective width of the scan strip for 1.7 days. Observations are typically separated by 1.6 or 3.2 hours, so a typical MBA is observed 14 times over a 1.7 day arc.

The time span of WISE observations allows for good coverage of the typical rotation period of an asteroid. Small bodies are often quite aspherical and show large amplitude rotational light-curves. WISE data will provide both an initial estimate of the rotation period and rotationally averaged infrared flux for radiometric size determinations.

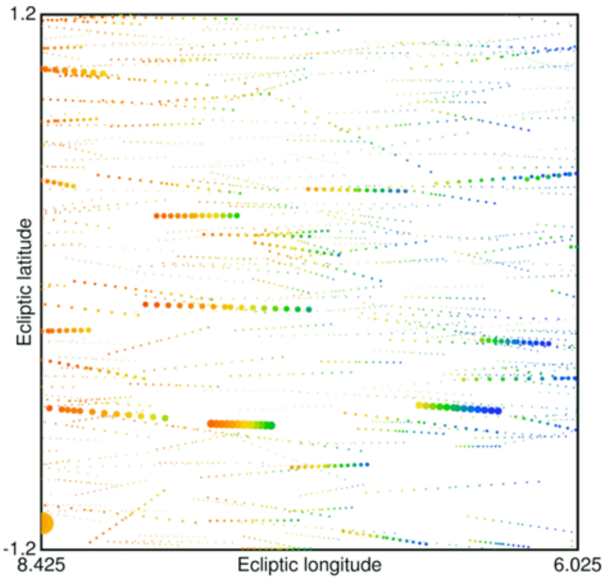

Figure 3: Simulated WISE observations of asteroids in Bowell's list over a few days in December 2004, for 1/7200th of the sky. Dot area is proportional to the SNR, and even the smallest dots are easy single-frame detections. Dot color shows the date of observation from early (blue) to red (late).

NEOs have much higher angular rates and there is a very wide range of rates.

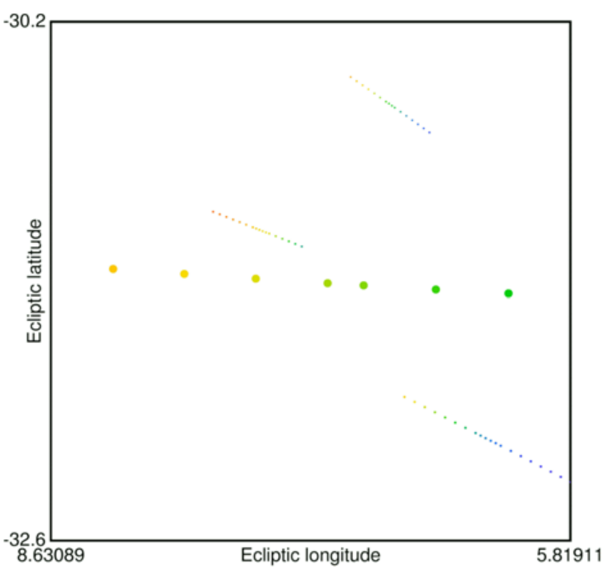

Figure 4: Simulated WISE observations centered on the Dec 2004 close pass of 99942 Apophis (2004 MN4). This NEO is moving about 2.3°/day.

Earlier Missions

The earliest thermal infrared surveys (Price and Walker 1976) did not provide a large number of repeat visits to every source. As a result many follow-up attempts came up empty because of either: cosmic ray hits masquerading as a true source, or an asteroid being a true source but one that had moved on by the time the follow-up data were taken. To avoid these difficulties the InfraRed Astronomical Satellite (IRAS), launched in 1983, provided two levels of redundant coverage: seconds confirmation provided by multiple strips of detectors in the focal plane, and hours confirmation (HCON) provided by overlapping the survey strips from successive orbits. Cosmic rays would fail seconds confirmation and asteroids would fail hours confirmation and not become part of the IRAS catalog of celestial sources. Of course the IRAS observations of asteroids also provide a very valuable database for asteroid diameters using the radiometric techniques.

The 2 Micron All Sky survey (2MASS) was conducted in the near infrared where asteroids are not very prominent, and chose to use only seconds confirmation. The positions of numbered asteroids at the time of 2MASS observations were computed and the known asteroids were flagged in the catalog of celestial objects.

Advantages of Infrared Observations

WISE will be detecting asteroids by their thermal emission at 12 microns. For a given asteroid diameter, the total infrared emission is proportional to 1 minus the albedo, while the optical reflected light signal scales like the albedo. The range of albedos for NEOs seen by Stuart & Binzel (2004) is from 0.023 to 0.63, a range of 27:1. The corresponding range of 1 minus the albedo is only 2.6:1. So infrared observations alone give a much more secure diameter than optical data alone. A combination of IR data and optical data gives both diameter and albedo information.

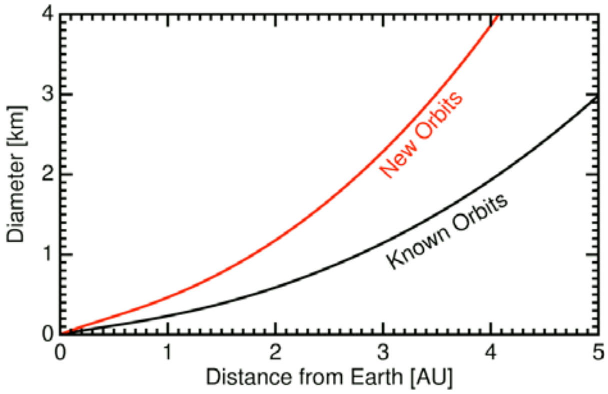

Figure 5a: Minimum detectable diameter for asteroids as function of distance for new orbits in red, showing the single frame detection limit, and for known orbits in black, where 8 frames can be stacked.

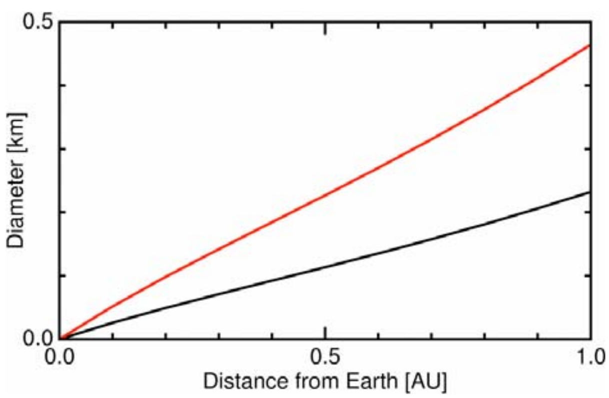

Figure 5b: Blowup of Figure 3a for the NEO region, showing that 140 meter diameter objects can be discovered up to 0.3 AU from the Earth.

Since asteroids typically have low albedos, the total power in the infrared peak of the asteroid SED is many times larger than the power in the optical peak. The detectability of the signal given perfect detectors will depend on the number of photons in the peaks, which is nearly 100 times larger for the infrared peak. But the number of background photons will also be larger in the thermal infrared. For observations in space the background is primarily due to the zodiacal light which has a spectrum that is very similar to the spectrum of an NEO, since both the interplanetary dust and NEOs are rocks in space at thermal equilibrium 1 AU from the Sun. For this case the detectability in a given pixel size varies like the square root of the photons per logarithmic frequency interval, and IR observations are favored by a factor of 10 over optical observations.

A further reason why thermal infrared surveys are very effective at finding asteroids is the relative dimness of both stellar photospheres and interstellar dust at 12 microns. This means that asteroids are fairly prominent in thermal infrared images. Figure 6 shows that the number of celestial sources brighter than a small NEO goes down by a factor of 100 when going from the optical to the thermal infrared.

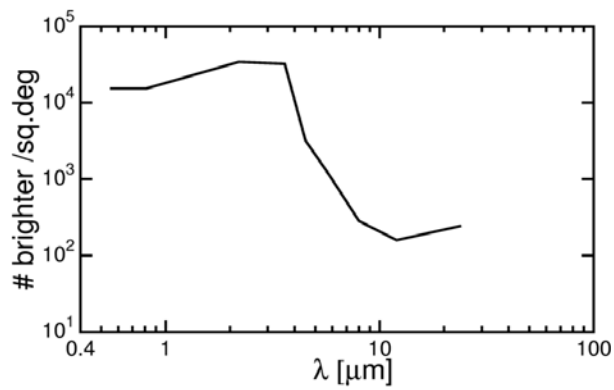

Figure 6: Number of celestial sources per square degree brighter than a 150 meter diameter asteroid 0.5 AU from the Earth at 60^o elongation as a function of wavelength.

Searching at Small Elongations

In order to survey the entire sky, WISE has to observe 90^o away from the Sun to cover the ecliptic poles. WISE will in fact do the entire survey at elongation very close to 90^o: from

88-97°. According to Chesley and Spahr (2003), the asteroids most likely to impact the Earth are usually found between 60° and 90° elongation. Thus WISE will be better at finding potential impactors than a survey centered at opposition, with elongations near 180°.

WISE Survey Completeness Modeling

The probability that WISE will observe a given asteroid depends on the distribution of orbital elements which will determine whether the asteroid crosses the WISE scan path during the mission, and then the object distance during that crossing will determine the minimum detectable diameter. We have taken small samples from the large statistical asteroid model prepared by the Pan-STARRS project (Jedicke 2006) following the description in Bottke *et al.* (2002). When an object crossed the scan path, the third most favorable frame was used to compute the minimum detectable diameter, so at least 3 observations were required for a detection. For typical MBAs moving at 0.2 degrees per day it will take about 7.5 months before the scan circle crosses all objects. Once that has occurred, all object down to some fairly uniform diameter will have been detected since to zeroth order all MBAs are seen at the same distance. Figure 7 shows that in a 12 month mission WISE will be able to discover almost all MBAs bigger than 3 km.

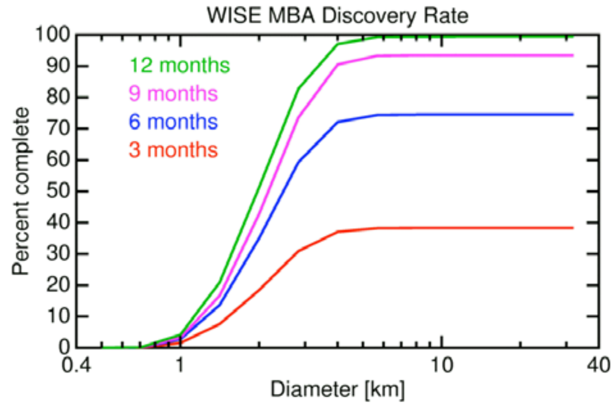

Figure 7: WISE completeness for discovering main belt asteroids.

A similar calculation for a sample of NEOs gives a much different picture. NEOs have orbital periods close to 1 year and as a result their synodic periods can be quite long. WISE will be able to detect very small asteroids that happen to make a close pass during its mission, but will get only distant views, if any, of other objects. In order to make a fairly complete survey of NEOs one needs a longer mission duration. Figure 8 shows the resulting discovery rate.

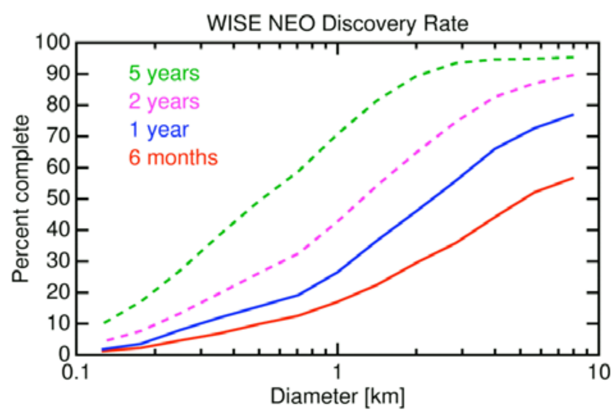

Figure 8: WISE completeness for NEOs. The dashed lines show mission durations that will not be possible with WISE, but they are included to show the capabilities of WISE-like surveys.

Thus in an extended 12 month mission WISE will be able to discover about one-fifth of all NEOs bigger than 0.7 km. If there are 1000 NEOs bigger than 1 km, and the N(>D) law goes like D^{-3}, then WISE will see several hundred new NEOs.

Value of the WISE Archive

It is important to remember that WISE can go much deeper for objects with known orbits where the multiple frames on a given source can be stacked. This means that the WISE archive will provide infrared data that can be used to find radiometric diameters for MBAs down to 1 km diameter, and for 20% of NEOs down to 0.25 km diameter. Once an orbit is known well enough to compute a good angular rate and approximate position during the WISE survey, the archived individual frames can be stacked using shifts computed from the angular rate. In this kind of analysis, asteroids can be seen to flux levels a bit below the sensitivity limit for celestial sources since they typically move in the direction of the scan pattern and thus get more observations, and since the confusion noise due to crowding of celestial sources is greatly reduced. For a typical albedo the useful flux limit for the WISE archive corresponds to a V magnitude of 23.

Thus the WISE archive will be able to provide both radiometric diameter information and another astrometric epoch for objects discovered after the WISE mission.

WISE Extended Mission

The baseline all-sky celestial survey will be completed 7 months after launch. But WISE is designed with a cryogen lifetime that covers 13 months of operation, for a 1 month IOC plus a 12 month survey that will cover the whole sky twice, giving increased reliability and a sqrt(2) improvement in SNR. But the extension has a more dramatic effect on NEO observations, since it nearly doubles the number of objects that will be seen. This 6 month extension of the mission was included in the Phase F portion of the WISE proposal.

A second part of the WISE Phase F proposal was to fund a rapid turnaround of asteroid observations to allow ground-based followup and recovery of WISE discovered objects. NEOs in WISE data will show distinctive angular rates and also rather warm 12/23 micron colors. This will allow the followup effort to be concentrated on the most interesting objects. Funding to support ground-based followup was included in the WISE Phase F proposal. Since the original proposal was submitted, the WISE baseline plan for data transmission from the TDRSS ground station in White Sands to IPAC has changed from FedEx to a high speed leased line. Thus the data latency will be small. But some extra data analysis funding will be needed up front to make sure that the moving object detection software is working right from the start of the mission.

Conclusion

WISE is a thermal infrared all sky survey mission, funded by NASA's Astrophysics Division with primary science goals including very distant ultra-luminous infrared galaxies and very nearby ultra-low luminosity stars. It is designed in a way that allows asteroids to be easily distinguished from fixed celestial objects and will thus provide very valuable data about asteroids in general and near-Earth objects in particular. The greatest contribution from WISE will be the IR data needed for radiometric diameter determinations of a very large number of asteroids. This will provide information about the distributions of albedos for asteroids of different sizes and orbital characteristics.

References

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Cost Summary

The WISE Phase F proposal listed costs of 5.6 M$ in FY 2002 dollars for funding both the extended mission operations and the rapid ground-based recovery and followup of interesting NEOs.