Killer Asteroids, NASA & LSST

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Outline

• Background: the Congressional NEO mandates

• Expected LSST performance for finding NEOs

• Connection with NASA and the impact on LSST
What is LSST:
an optical/near-IR survey of half the sky in multiple bands (ugrizy) to $r = 27.5$ based on about 1000 visits over a ten-year period:
a catalog of $\sim 10$ billion stars and $\sim 10$ billion galaxies with exquisite photometry, astrometry and image quality

The Main LSST Science Themes

- **Dark Energy and Dark Matter** (four billion galaxies with excellent photometry and shape measurements, a million SNe, clusters of galaxies, millions of quasars)
- **The Solar System Map** (140m killer asteroids, several $10^6$ main-belt, $\sim 100,000$ trans-Neptunian, Sedna-like to beyond 200 AU)
- **The Transient Universe** (a variety of time scales ranging from $\sim 10$ sec, to the whole sky every 3 nights, 1000 visits)
- **The Milky Way Map** (main sequence to 100 kpc, RR Lyrae to 400 kpc, geometric parallaxes for all stars within 300 pc)
“Killer” Asteroids: They do exist and may strike!
FIGURE 2.1 Meteor Crater (also known as Barringer Crater) in Arizona, with the Great Pyramids of Giza and the Sphinx inserted for size comparison. This crater is one of the most familiar impact features on the planet. This crater is about 1,200 meters in diameter and 170 meters deep; the interior of the crater contains about 220 meters of rubble overlying bedrock. The crater was formed about 50,000 years ago through the impact of a ~40-meter iron-nickel meteorite moving at ~13 km/s. SOURCE: Crater image courtesy of U.S. Geological Survey, composite created by Tim Warchocki.
Lifetime Risk of Death for the USA

A shortened version of the list compiled by Alan Harris.

- All accidents: 1 in 36
- Motor vehicle accident: 1 in 90
- Suicide: 1 in 120
- Homicide: 1 in 185
- Airplane crash: 1 in 30,000
- Lightning strike: 1 in 43,000
- Legal execution: 1 in 60,000
- Asteroids (no known, all sizes): 1 in 70,000
- Terrorism (incl. Sep 11): 1 in 80,000
- Amusement park rides: 1 in 1,100,000
- Shark attack: 1 in 8,000,000

With current NEO survey completion: 1 in 720,000
For the whole world expect about 100 fatalities per year.
The Congressional NEO mandates to NASA:

1. The first, in 1998 and now referred to as the Spaceguard Survey, called for the agency to discover **90 percent of NEOs with a diameter of 1 kilometer or greater within 10 years.** An object of this limiting size is considered by many experts to be the minimum that could produce global devastation if it struck Earth.

2. The second mandate, established in 2005, called for NASA to detect **90 percent of NEOs with diameters of 140 meters or greater by 2020.** An object of this limiting size is considered by many experts to be the minimum that could produce large tsunamies if it struck Earth.
The New Congressional NEO mandate to NASA:

The objectives of the George E. Brown, Jr. NEO Survey Act (Public Law No. 109-155) are to detect, track, catalog, and characterize the physical characteristics of NEOs equal to or larger than 140 meters in diameter with a perihelion distance of less than 1.3 AU (Astronomical Units) from the Sun, achieving 90 percent completion of the survey within 15 years after enactment of the NASA Authorization Act of 2005.

The Act was signed into law by President Bush on December 30, 2005:

NASA should find 90% of 140m or larger NEOs by 2020.
Why 90% and 140m, by 2020?

1. Risk reduction by a factor of 10.
2. Below 140m, the impact of tsunamis decreases.
3. 2020: to make the mandate current and relevant.

FIGURE 2.5 Model of fatalities per event for impacts of various size NEOs. The solid curve represents the total fatalities associated with both ocean and land impacts, including those with global effects. The sharp increase in the solid (red) curve reflects the assumption of a large increase in fatalities for an impact that crosses the global-effect threshold. SOURCE: Courtesy of Alan W. Harris, Space Science Institute.
Why 90% and 140m, by 2020?

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**Impact rate for 140m:**

1 in 10,000 years

$6 \times 10^{-9}$ chance to hit before the end of this presentation!

**FIGURE 1.1** Current estimates of the average interval in years between collisions with Earth of near Earth objects of various sizes, from ca 3 meters to 9 kilometers in diameter. The uncertainty varies from point to point, but in each case is of the order of a factor of 2, there is also a strong correlation of the values from point to point. **SOURCE:** Courtesy of Alan W. Harris, Space Science Institute.
Can LSST do it?

How bright are 140m NEOs?

Need simulations:

- Median Values: $\bar{R} \sim 2$ AU and $\bar{D} \sim 2.1$ AU, implies $V \sim 25$
- Full Analysis: $R$, $D$, phase effects, etc.
- **Top Left:** the distribution of the Johnson V band apparent magnitudes for 140m NEOs observed during night time, median $\bar{V} = 25.5$
- **Bottom Left:** the cumulative distribution of the brightest $V$ magnitude over 10 years: **10% of 140m NEOs are NEVER brighter than $V = 23.8$**
- **Conclusion:** It is impossible to fulfill the NASA goal unless $V > 24$. Need to reach the equivalent of $V \sim 25$ in each observation.
Direct implications of the Congressional NEO mandate:

- **Telescope Aperture:** 140m object size implies $V \sim 25$ imaging, to reach $V \sim 25$ in 15 sec **need a 10m-class telescope**

- **Field of view:** in order to cover the sky frequently enough, **need a $\sim 5-10 \text{ deg}^2$ large field of view**, therefore $A\Omega$ product (etendue) needs to be at least several hundred m$^2\text{deg}^2$ (also, a large FOV implies a gigapixel-class camera)

- **Data Rate:** frequent coverage of the whole sky at subarcsec resolution implies **enormous data rates** (e.g. for LSST $\sim 30$ TB/night, 60 PB over 10 years)

- **Conclusion:** A system with an etendue of several hundred m$^2\text{deg}^2$, with a gigapixel-class camera and a sophisticated and robust data system, is required to fulfill the Congressional mandate: **this is LSST!**
**LSST Science Drivers: the Solar System Inventory**

Studies of the distribution of orbital elements as a function of color and size; studies of object shapes and structure using colors and light curves.

- **Near-Earth Objects**: about 100,000
- **Main-Belt Asteroids**: about 10,000,000
- **Centaurs, Jovian and non-Jovian Trojans, trans-Neptunian objects**: about 200,000
- **Jupiter-family and Oort-cloud comets**: about 3,000–10,000, with hundreds of observations per object
- **Extremely distant solar system**: the search for objects with perihelia at several hundred AU (e.g. Sedna will be observable to 130 AU).

**LSST is interested in Solar System objects irrespective of the NASA’s NEOs mandate.**
LSST NEO capabilities:

- **Baseline Cadence:** two visits closely separated in time (15-60 min), each visit reaching $V \sim 24.8$, revisiting every few days
- **Simulations:** real historical weather and seeing data, exquisite modeling of observational effects
- **Results:** The LSST baseline design cadence can achieve, over 10 years, a completeness of 90% for objects larger than $\sim 250$ m diameter, and 80% completeness for $>140$ m.
- **NEO optimization:** short-dashed: baseline cadence (10 yrs; 5% of time specialized for NEOs); solid: 15%; long-dashed: 15% of time specialized for NEOs: reaches 90% completeness ($>140$ m) in 12 yrs.
Can LSST fulfill the NEO Mandate?

Simulations: LSST system can reach the 90% completeness level for 140m and larger objects in about 12 years, with about 15% of the observing time optimized for NEO survey.

1. The time of first light will be driven by funding. The earliest plausible date, 2015, implies that the 90% completeness level for 140m NEOs could be reached around 2027.

2. The "effective" cost of an optimized NEO survey would be about $120M. This funding would be most useful during operations, with a small fraction spent during construction phase.
Can LSST fulfill the NEO Mandate?

LSST has already communicated these findings to NASA/NRC and the international community:


4. **Publications** (e.g., astro-ph/0701506)
Defending Planet Earth: Near-Earth Object Surveys and Hazard Mitigation Strategies

New report:
http://www.nap.edu/openbook.php?record_id=12842

The selected approach to completing the George E. Brown, Jr. Near-Earth Object Survey will depend on nonscientific factors:
(paraphrased by Ž.I.):

1. If 2020 important: a space mission (best-case scenario: complete by 2022)
2. If cost conservation important: a large ground-based telescope

The report also said:
Of the ground-based options mentioned in the statement of task and the additional ones submitted to the committee in its public request for suggestions, the most capable appears to be the Large Synoptic Survey Telescope.
Space mission vs. Ground-based survey

This figure, produced by the space mission proponents, has two important errors:

1. In reality, the median heliocentric distance for NEOs is 2 AU, and not 1 AU!
2. The boundary for the LSST sensitivity volume is the orbit of Venus: LSST can detect NEOs in the red region!
The Congressional NEO mandate to NASA:
NASA should find 90% of 140m or larger NEOs by 2020.

Implications for LSST:

1. LSST is the only ground-based survey that can reach the 90% completeness limit.
2. The NEO optimization would have a non-negligible impact on the rest of the survey: equivalent to about $120M.
3. Most of the impact on the system deployment. During the construction phase, only a limited impact on some software development.
4. The final decision about the NEO mandate will be based on “non-scientific factors”.
5. Opportunities for efficient synergy between NSF, NASA and DOE.