# Journal of Special Topics

## P3_10 The Extinction Criteria

Michael McNally, Allen Phong, Robert Pierce, Thomas Searle

*Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH.*

March 2, 2011

**Abstract**
This paper examines the possible early warning available before a "rogue" meteorite impact likely to cause the extinction of humanity. Deriving an "extinction criteria" from the Rayleigh Criteria and examining reflected light from an asteroid, it is established that a warning period of one week to two months would be available from detection of a "rogue" asteroid to impact.

**Introduction**

It is widely accepted that a meteorite approximately 10km in diameter was responsible for the mass extinction of the dinosaurs at the Cretaceous/Tertiary boundary[1]. Around $10^{12}$kg of rock were almost instantaneously vaporised and choked the atmosphere, blocking photosynthesis and generally making the environment hostile to life[1]. A similar event would have devastating effects on human society. Programs exist to detect and characterise near earth asteroids[2]. This paper examines the possible early warning available, if a previously unobserved asteroid on a collision course with Earth was detected by such a program.

**Telescope Resolution**

Telescopes are the only effective method to image objects at great distances, and are limited in resolution by the diffraction of electromagnetic radiation. The angular radius (θ) to the first diffraction minima of a feature resolved by a telescope is given by the formula[3]

$$\sin\theta = 1.22\,\frac{\lambda}{D}\ (1)$$

where λ is the wavelength of the radiation and D is the diameter of the collecting aperture. The Rayleigh Criteria (hence the title of this paper) is the observation that if two features are separated by an angle larger than θ then they can be considered resolved. This allows a reasonable estimate of the range at which a 10km asteroid could be detected.

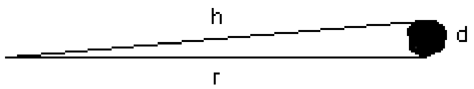


*Figure 1. Asteroid of diameter* d *at distance* r from the observer

From the diagram above, it can be deduced that

$$\sin\theta = \frac{d}{h}\ (2)$$

it can also be safely assumed that h ≈ r in this case. Taking this into account and equating the right hand sides of (1) and (2) gives

$$\frac{d}{r} = 1.22\,\frac{\lambda}{D}$$

which can be rearranged as

$$r = \frac{dD}{1.22\lambda}\ (3)$$

giving the range at which an asteroid of a given size can be resolved by a telescope of given diameter at a particular wavelength. As shorter wavelengths are absorbed strongly by the atmosphere, an asteroid can be most practically detected with visible light; a telescope of 1m diameter could detect an extinction level (d = 10km) asteroid at ranges between 10-100 million km. Optical telescopes of this size are relatively mobile and easy to automate to allow scanning of wide areas of the sky in a short time, an important factor in near earth asteroid detection[5].

**Reflected Light**

As well as the diffraction limit to resolution, there is also a limit imposed by the amount of light reflected by an asteroid. Optical telescopes of a scale described above are limited to an apparent magnitude of 20[6]. This can be expressed as a fraction of the solar flux at earth using

$$F_{Asteroid} = 100^{\frac{(m_{sol} - m_{20})}{5}} F_E (4)[7]$$

Substituting for the magnitude of the sun as observed at the earth (-26.7)[7] gives a ratio between observed solar and reflected flux of $2\times10^{-19}$ in order to be imaged. Examining the simplest case, where the asteroid is around 100 million km from the earth away from the sun, on the ecliptic. Flux at the earth can be expressed as

$$F_E = \frac{F_{sol}}{4\pi R^2} (5)$$

and the flux at the asteroid as

$$F_A = \frac{F_{sol}}{4\pi (R+r)^2} (6)$$

The flux observed from the asteroid on earth is given by

$$F_R = \frac{A\alpha F_A}{4\pi r^2} (7)$$

where A is the cross sectional area of the asteroid, α is the geometric albedo (combining reflection and scattering from the irregular surface,) R is one A.U. ($\approx 1.5\times10^{11}$m) and r is $1\times10^{11}$m. Combining equations 5,6 and 7 gives the expression

$$\frac{F_R}{F_E} = \frac{A\alpha R^2}{4\pi r^2 (R+r)^2} (8)$$

The lowest geometric albedo for asteroids is around 0.03[8]. Substituting in the appropriate values gives a ratio between observed solar and reflected flux of 2.3x10-17, two orders of magnitude larger than necessary to be imaged.

**Discussion**

A reasonable estimate for the speed of an asteroid arriving at the atmosphere is around 20kms$^{-1}$[9], assuming that this represents the approach velocity for times well under one orbital period (which will be one year, as typical orbital perihelion is around 1 A.U.[10]) and from the estimated range above this gives a warning time between one week and two months. This is clearly inadequate for any mitigating action to be taken. This is also not an unreasonable assumption, NASA's Near Earth Asteroid Tracking program uses a 1.2m diameter telescope[2]. Improvements could be made to this using larger diameter telescopes, however the linear scaling with telescope diameter would mean a large increase would be necessary.

**Conclusion**

With present technology, a rogue asteroid large enough to cause the extinction of the human race can be detected with a warning time of one week to two months, multiplied by the diameter of the telescope in metres. Improving the warning time further than around two years would require a significant investment, as this would require ground based telescopes larger than the largest (10-15m) currently available. Given the low historic frequency of major impacts it seems that the present warning system will suffice.

**References**

[1] Meteorite impact and the mass extinction of species at the Cretaceous/Tertiary boundary, K.O. Pope, S.L. D'Hondt, C.R. Marshall, PNAS vol. 95 no. 19 **(1998)**

[2] Near Earth Object Program, NASA, http://neo.jpl.nasa.gov/index.html

[3] Physics for Scientists and Engineers, p. 1103-1104, P.A Tipler, Freeman, 2004, 1.03.11

[4] *Ibid*, p. 340

[5] The Near-Earth Asteroid Tracking (NEAT) Program: An Automated System for Telescope Control, Wide-Field Imaging, and Object Detection, Steven H. Pravdo et al. The Astronomical Journal **117** 1616, **(1999)**

[6] Near-Earth asteroid search programs, G. H. Stokes, J. B. Evans, S. M. Larson, Asteroids III, University of Arizona Press, 2003

[7] Cornell University, ask an astronomer: what is apparent magnitude? http://curious.astro.cornell.edu/question.php?number=569, 22.03.2011

[8] The Asteroid Distribution in the Ecliptic, E.L. Ryan et al. The Astronomical Journal, APS, 137:5134–5145, **(2009)**

[9] The Variation in the Frequency of Meteorite Impact with Geographic Latitude, I. Halliday, Meteoritics, vol. 2 no. 3 p. 271, http://articles.adsabs.harvard.edu//full/1964Metic...2..271H/0000273.000.html, 1.03.11

[10] Physical Properties of Near-Earth Objects, R.P. Binzel et al. Asteroids III, University of Arizona Press, 2003