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P1_4 Could Bruce Willis Predict the End of the World?

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Abstract

This article is a follow-up to the paper "Could Bruce Willis Save the World?" where the feasibility of splitting an asteroid with a nuclear weapon is studied. In this article the possibility of spotting the asteroid with the Hubble Space Telescope upon a "lucky image" was researched. It was found the asteroid could have been spotted as far as away as $1.32 \times 10^{14} m$.

Another Chance

In Back et al [1], it was shown that the action taken by the character played by Bruce Willis in the film "Armageddon" (1998) would not have been enough to have stopped an asteroid from impacting the Earth and causing an extinction-level event. As a follow-up, we now look into the ability of the telescopes of the time to detect such an asteroid at the distance found from the film.

The search for asteroids on potential collision courses with Earth is of considerable importance, as there is plenty of historical and archaeological evidence to show that extinction-level and other, much smaller (though still extremely damaging) impacts have occurred. Indeed, it is widely considered that it is a matter of when, not if, another large impact will occur, though it may not occur for millions of years. Whether we have any way of avoiding such an event becomes irrelevant if we are unable to detect such asteroids before the event occurs.

There are a number of sky searches that locate and track as many asteroids as is possible, such as the Near-Earth Asteroid Tracking project (NEAT) which uses large scale CCD images of the sky taken over a period of time and tracking any objects that move across the field of view in a way not dictated by the movement of the Earth. These objects are then studied further to find out whether they are asteroids, as many are, and to find their expected course.

Small field of view telescopes, such as the Hubble Space Telescope (HST) are not generally used for such searches as they are not designed for imaging large portions of the sky. However, for this article we will concentrate on the ability of the HST, most likely the most powerful and best placed telescope during the 1990's (the time when the film is set) to detect these asteroids based on a chance image of the region from which the asteroid is approaching.

This article will focus on one of the main reasons why the telescope might not detect the asteroid, namely the target not being bright enough to be seen.

A Dim Target

The HST has been able to detect objects up to the 31st magnitude [2] relative to the standard star Vega. Thus to find the limit of Hubble's range for seeing the asteroid of the film, we must calculate the distance at which the asteroid has an apparent magnitude of 31. This is based on the flux from the asteroid which in turn is based on the flux from the Sun. The formula for the flux of a point object (which both the asteroid and Sun can be approximated to be) is, as evaluated for the Sun:-

$$F = \frac{L}{4\pi d^2}, \tag{1}$$

where, F is the flux from the Sun, L is the luminosity of the Sun and d is the distance from the Sun. This equation is evaluated for the flux at the asteroid from the Sun.

The flux from the Sun is reflected by the asteroid based on a coefficient known as the albedo, which is the ratio of incident radiation to reflected radiation. The product of the flux, F, the asteroid's lit surface area, A, (assumed to be fully face-on, ie. $4\pi r^2$ where r is the radius of the asteroid) and the albedo, a, becomes the luminosity for another use of Equation (1). This time the equation is evaluated for the asteroid, to find the flux received at the Earth. As such, this received flux F_R is calculated using the equation:-

$$F_R = \frac{FAa}{4\pi {d_2}^2} = \frac{L\times 4\pi r^2 a}{4\pi\times 4\pi {d_2}^2 d^2} = \frac{Lar^2}{4\pi d^2 {d_2}^2}, \quad (2)$$

where d_2 is the distance from the asteroid to the HST. An approximation is used here, based on the assumption that the distance that the asteroid can be detected at is considerably greater than the 0 to 1AU difference between the asteroid-Sun distance and the asteroid-HST distance, depending on the relative positions of the Earth and Sun. This means $d \sim d_2$ and so the equation can be rewritten with a d^4 term.

This received flux is then compared with the flux from Vega, the standard star for the magnitude scale, to find the maximum distance the asteroid could be detected at using Equation (3) [3]:-

$$m_{max} - m_{Vega} = -2.5\log\left(\frac{F_R}{F_{Vega}}\right). \quad (3)$$

The flux from the star Vega was calculated using Equation (1) from standard data [4] as $2.51\times 10^{-8}\,Wm^{-2}$ and m_{Vega}, the apparent magnitude of Vega from Earth, is 0 by definition. m_{max} is simply the largest magnitude object the Hubble telescope can detect, so a simple rearrangement for d using the earlier definition of F_R from Equation (2) with the d^4 term discussed earlier gives the maximum distance the asteroid can be detected at:-

$$d = \sqrt[4]{\frac{Lr^2 a}{4\pi F_{Vega} 10^{\left(\frac{-m_{max}}{2.5}\right)}}} \quad (4)$$

The albedo of an asteroid may vary depending on its composition, however we shall use a value of 0.1, approximately true for an almost pure nickel-iron asteroid [5], similar to the one suggested in the previous paper [1]. The luminosity of the Sun is well documented as $3.8\times 10^{26}\,Wm^{-2}$ [6] and we use the value for the radius assumed in Back et al [1], $1000km$, and the value for m_{max} stated earlier, 31. The result is that the maximum distance the asteroid could be viewed at is $1.32\times 10^{14}m$.

Too Little, Too Late

In the film it was stated that the asteroid had been detected 18 days before impact [7], and it was assumed in Back et al [1] that the asteroid was travelling at a constant rate of $22{,}000\,mph$ ($10kms^{-1}$). Thus it is detected at a distance of $1.56\times 10^{10}m$, well within our calculated maximum distance. However it is also noted that, from the findings of Back et al [1], this is far too small a distance. According to the calculations, the distance to have any chance of splitting it early enough must be at least $1.3\times 10^{13}m$. The Hubble Space Telescope would therefore have been able to detect the asteroid at the point at which the asteroid would have had to have been split, though of course it would have had to have been detected much earlier to stand any chance of intercepting it first.

It is worth noting that the field of view of the telescope is 52 arcseconds by 52 arcseconds [8]. This translates as less than 0.02% of the sky, so the chance of the asteroid being in one of Hubble's images is extremely small.

References

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