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# Mission design for Apophis Asteroid

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**Abstract**

The Apophis asteroid trajectory is going to work close to Earth and the Moon. Even if a mission is already planned to observe it, it can be completed by the mega-constellation and the potential of satellites on orbit and the others should do the same observation with sensors. It could produce a complete scan of the asteroïde. Then, the Earth System defence should be tested from the moment of the detection point through the trajectory follow-up until out of the trust zone. The design would be the on-line operations with the capacity to switch to a satellite to another through the slot management from a planning which can be anticipated with the known trajectory. The on-line operation system architecture shall take account the signal management with several functions observation, communication, surveillance thanks to Space ecosystem existing plus the RAMSES mission. The first step was to identified the Apophis asteroid as a dangerous asset. Then, the planification of mission through RAMSES mission built by a specific function. The last test-bed is to consider the trajectory between Moon and Earth with no more means to be sent in Space by a design of multi-function available.

**Keywords: detection, asteroid, computation, security architecture**

**Acronyms/Abbreviations : RAMSES, PDC, LLM, NEO**

## 1. Introduction

The organization to make the detection gathers the state of art with the following means the early detection as using telescopes and radar to spot potentially dangerous objects [1]. The Planetary Defence Bureau (PDC) is an international organisation that focuses on detecting, monitoring and preventing the impacts of near-Earth objects, such as asteroids and comets, that could pose a threat to Earth. The PDC works with space agencies and observatories around the world to share data and develop strategies to protect the planet.
The missions include the Goldstone Deep Space Communications Complex, the Arecibo Observatory, the Green Bank Telescope, the Haystack Radar, the Cassini. The telescopes used are the Pan-STARRS, the Catalina Sky Survey, the NEOWISE, the ATLAS, the Vera C. Rubin Observatory.
The tracking and the trajectory to compute the near-Earth objects are represented by the Minor Planet Center. Located at Harvard Observatory, it is responsible for collecting and distributing data on asteroids and comets. The NASA Computing Center uses data from telescopes and radars to track and predict the trajectories of near-Earth objects. The European Space Applications Centre contributes to the detection and monitoring of NEOs through various programmes and missions.
The Institute for Research on the Fundamental Laws of the Universe participates in research and analysis of NEO trajectories. The European Southern Observatory uses its advanced telescopes to observe and track asteroids and other near-Earth objects. The Defence planning developps strategies to deflect or destroy threatening objects if necessary. Other means are used to be to complete the processing by the programs as Space guard and the laser infrastructure like the OLA telescope. At last, the planetary security protocol also provides for the activation of the International Asteroid Warning Network (IAWN) and the Space Mission Planning Advisory Group (SMPAG) are tasked with monitoring the situation and developing strategies to mitigate any potential impact as rapid response. It takes the recommendations to the United Nations and evaluates different options for a spacecraft response to the potential risk. The IAWN coordinates global observations, shares real-time information with all the world's space agencies and develops strategies to mitigate potential impact. Even more, the strategies introduce the assets from Space like RAMSES mission planned for Apophis and the telescope in Space GAIA available by the intermediate

catalogues. The detection is built from the data gathered by these means through different pictures to underline the potential moves of the objects from a source given an input.

**2. Material and methods**

The methodology consists to provide a mission design to test and to improve the detection capacity for the asteroid with the test bed of Apophis in 2029. The point to be made is also linked with the detection for the assets lower than 10 meters which can represent a danger for the ground. The first step is to describe the Apophis asset and to note the missions able to use to manage its trajectory. Then, the second step is to be able to test the system defence by using the means available to follow the asset in its trajectory with the purpose to improve and to reinforce the detection capacity through an online operation for lower asset. This operation is relied on the security architecture with the data processing from the bifurcation points which shall be used to underline the trajectory of the assets. The purpose of the approach is to consider the means to be reinforced to improve the detection capacities by the combination of sensors and the algorithms based on the small quantity of data in the worse use case or by data known like the asteroid 2024 YR4 for which the risk has been re-evaluated for a size of 40 and 90 meters. The Apophis path becomes a test-bed to improve the detection methodology and anticipate the measures to mitigate the danger following the DART mission requirements or by other means to act on the asteroid for small deviation. Then, it considers to take account the asteroid detection which measures less than 15 metres able to make the destruction on the populated area. The detection is focused on the trajectory once the asteroids are identified and qualified. The condition of the identification and the qualification takes account the support of the algorithm to assist the computation of the data on the ground to detect in the images the detectable objets from small details.

**3. Theory and calculation**

The potential source of detection gathers the infrared (0,75 µm - 1000 µm), radio (> 10 km - 1 mm), the X-ray (0,01 nm - 10 nm), the gamma X-ray (< 0,01 nm ), the lensing gravitationnal (using all the wavelenghts), the radio frequency range from the geo-magnetic networks in which the magnetic field of Earth acts like a field of detection for any objects disturbing it on the external border and the one face to the Sun. This potential of detection is added with the GNSS signal in Space from the Lunar GNSS Receiver Experiment by using it to the Moon.
This purpose linked with the potential of detection looks for the use of the reflectivity and occultation of the asteroid via its observation context. The reflectivity of an asteroid's surface or albedo, varies according to its composition and texture. In general, asteroids have relatively low albedos compared with other celestial bodies [2].
The examples of typical albedos for different types of asteroid : C-type asteroids are rich in carbon and have low albedos, around 0.03 to 0.09, S-type asteroids are rich in silicates and have slightly higher albedos, around 0.10 to 0.22. M-type asteroids are metal-rich and have higher albedos, around 0.10 to 0.18.
These parameters shall be useful for the preliminary design of the mission. The wavelengh used are associated with the relative light intensity following the radio science parameters planned in Space from the RAMSES Mission, the means on orbits, the support on the ground like the radars, the GNSS stations ( figure 1).

| **Spectre** | **Wavelength (nm)** | **Relative light intensity (%)** |
|---|---|---|
| **Infrared** | 1000 | 15 |
| **Infrared** | 1500 | 30 |
| **Infrared** | 2000 | 45 |
| **Radio** | 1E6 (1 mm) | 10 |
| **Radio** | 1E7 (1 cm) | 25 |
| **Radio** | 1E8 (10 cm) | 40 |
| **Optic** | 400 | 60 |
| **Optic** | 500 | 80 |
| **Optic** | 600 | 75 |

Figure 1 : the light intensity/Wavelength

**4. Results and Discussion**

Apophis is the test-bed to apply the full potential of detection capacity. The point is the Apophis is already detected and its trajectory known [3]. The path could be integrated in the chain of detection through the all parameters mentioned in the theory and the computation to be able to use. After the definition of the Misson Design through the double goals that provide the path of Apophis asteroid, the requirements for the parameters for the detection shall follow each methods depending on the trajectory [4][5].

The support of the detection shall be used by the RAMSES mission. As the mission aims to study asteroid 99942 Apophis, which will pass close to Earth on 13 April 2029, one of the objectives of RAMSES would gather data through the detection methodologies and the observation techniques from the telescopes. The missions is planned to be launch on 2028 with the requirements in the design which should integrate the study of the detection capacity from Earth for the futur asteroid.

The instruments of RAMSES provide the support to measure the detection path. The camera gives the inputs for the Yarkovsky effect. This effect is a non-gravitational phenomenon in which the absorption and re-emission of heat from the Sun by an asteroid causes a continuous force on the asteroid. This force can change its trajectory over time. It depends on the asteroid's rotation, size, composition and surface temperature as mentionned on the classification (C-S-M). The angle and its value of the effect can be analysed to understand the potential link with the direct trajectory to Earth for an asteroid.

Considering an Yarkovky effect on the asteroid on its trajectory to Earth, the angle of the light from the Sun on the asteroid would determine a thrust with a modified trajectory as **the speed variation (Δv) : Δv=Δv(cos(θ)i+sin(θ)j) for :**

**-** Δv : Magnitude of thrust,

- θ : Angle of thrust compared with the initial directio, i et j :

- the unit components in radial and tangential directions, **as a new speed** vf=vi+Δv for {vi} : initial speed, the{vf} as final speed.

$$r(\theta) = \frac{p}{1 + e\cos(\theta)}$$

The derived trajectory takes account the parameter : r for the distance from the mass, p for the orbital parameter, e for the excentricity, θ for the angle with the Sun as reference.

The spectrometers given the chemical and mineralogical composition of the asteroid's surface would provide the albedos computation through the baseline signature for others asteroid. The laser altimeter measures variations in the asteroid's topography and detect surface movements. The magnetometer measures the asteroid's magnetic field and study its magnetic properties. The capacity to send a mission to an asteroid closing fast is also the way to let on the surface a small radio asset working like a beacon and able to be connected with Earth. This parameter with the interaction with the terrestrial magnetic field can detect the disturbance useful to mark the path for a potential asset crossing the magnetic field.

The Apophis albedos value turns around 0,23 with 23% of the sun light striking the asteroid is reflected. The rest is absorbed. The detection gives the path to Earth closing fast until 2027 with the diameter of 370 metres. The rest of the data gives the perihelion (closest point to the Sun) is evaluated approximately 0.746 AU (astronomical units), the aphelion (furthest point from the Sun) displays approximately 1.099 AU, the Orbital period is the 323 Earth days, the orbital inclination is the 3.331°. The orbital eccentricity is the 0.191. It means the albedos is reachable by the optic telescope. The question is the way to notice it in the image through the contrast and the brightness.

Then, its approach can be tested through the terrestrial magnetic field variation when the asset cross it and the Lunar GNSS Receiver Experiment (LuGRE) by using the signal from the constellation from Earth to improve the detection with the signal feed back. The receiver will track L1 C/A and L5 GPS signals, as well as Galileo E1 and E5a signals, and return pseudo-orange, carrier phase and Doppler measurements. With the trajectory known the means to test the detection process by the different wavelenghts with the light intensity, the GNSS constellation provides the alert capacity to mark the potential point of impact. The United States has proved the capacity to launch a rocket into 48 hours in case of emergency. As the asset will around 32 000 km, the last steps would be to send a probe as the model of DART mission to be able to change the trajectory without doing the impact procedure. The mission design should underline the functional architecture including these parameters from the figure 2.

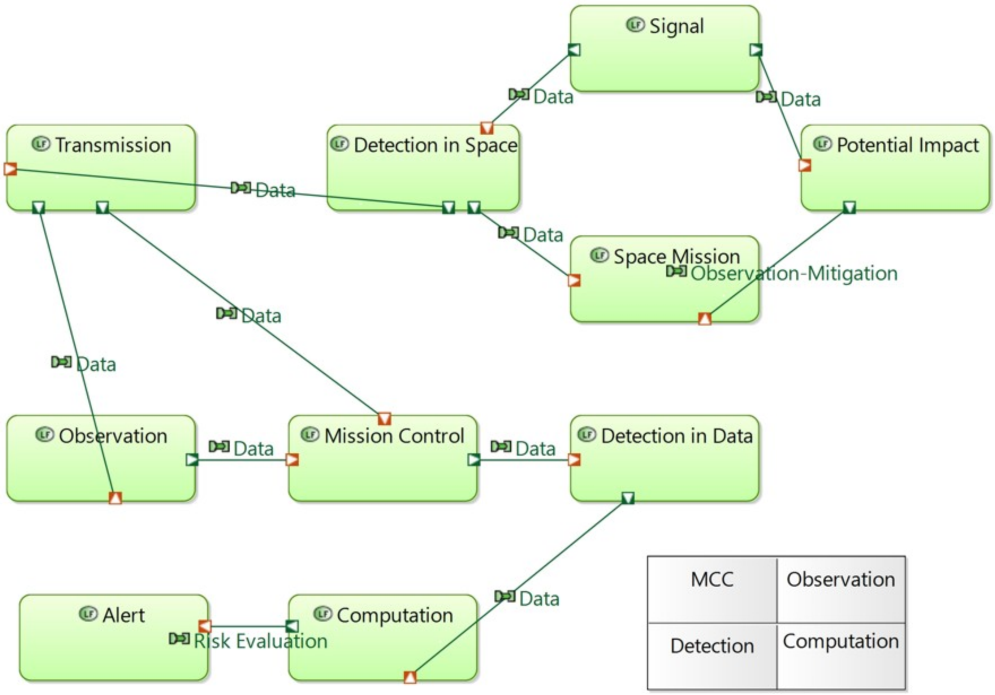


Figure 2 : Functional Architecture

The risk evaluation is linked with the capacity of the detection in data. The Turin scale provides the methodology to mark the levels from the scenarios and the probability of impact. The alert is given on terms of megatons of TNT. The description of design message includes the items with the colour codes. The level of scale are 0 with no chance of collision or the object is too small to pass through the Earth's atmosphere intact.
The level 1 to 4 considers a normal risk with no action required, the level 2 to 4 notices that the object to follow, the level 5 to 7 considers the dangerous object with significant risk of impact with regional consequences. The level 8 to 10 insists on the collision with the devastating consequences both local destruction to global climate catastrophe.
The colour codes considers the risk levels: White for No risk (level 0), Green for Normal risk (level 1), Yellow for Object to be monitored (levels 2 to 4), Orange for Dangerous object (levels 5 to 7), Red for Certain collision (levels 8 to 10). The point is to provide an alert quickly enough to warn the ground including for the assets superior at 10 metres through the radar infrastructures which are going to be built to detect the debris on the orbits. The signal could be extended further to detect the assets lower than 15 metres.
Considering the detection path and the data available on Earth, the processing can use the model of learning to improve the cycle by optimizing. Once the datas available by the sensors of the functional architecture, it seems to exploit them to provide the alert. In the mission design of Apophis, the simulation and the exercice should be done by Space forces and the alert chain on the ground like the scenario of the shutdown of the 2008 DC3 asteroid in Egypt. It would be to identify a trajectory event by the effect Yarkovsky, to simulate the impact point or to send a mission in Space to modify the trajectory by demonstrating the capacity to launch a mission in short times.
The process in the design considers the capacity to understand the data on the ground by the learning processing following several methods.
The art of statement shows that the capacity to capture data faster by the tools supporting the observation through the telescopes. The HelioLinc3D programme has been designed to assist the Vera C. Rubin Observatory, currently under construction in northern Chile, in its next decadal survey of the night sky. The aim of this artificial intelligence programme is to detect space objects in the vicinity of the Earth. For example, ATLAS observed 2022 SF289 three times on four separate nights, and HelioLinc3D was able to combine these fragments of data to put the pieces of the jigsaw together. This performance is given that the Vera-C.-Rubin observatory will only require two captures per night to detect potentially dangerous asteroids, instead of the four currently needed.
With this new rate of observation, a new type of discovery algorithm was needed to reliably spot HAPs. This is precisely what HelioLinc3D provides by being able to find data on asteroids spread over several days of observation.

The test will be done in the design of Apophis Observation to follow the processing of detection path till Earth via the RAMSES mission on support acting like a beacon by using the Doppler effect to mark the speed and by using the radial velocity.
It should be completed by other methods of data quantity. In the scenario, the test can be realised on the Apophis trajectory with the several scenarios from the datasets available. The scenario is to use only the light intensity of the images throught its magnitude, the spectral intensity from Planck, Lambert law for the angles, the Stefan-Boltzmann law for the surface radiation. This one is limited by the human capacity which can detect the level 6 of magnitude whereas an agent can detect the magnitude inferior to 6.
The formula which should be considered is E=I/d2 with E for lux (lx), I for the light intensity of the source (cd), d the distance of the source. The test can be realised on the open source data like the Sloan Digital Sky Survey.
The method uses the datasets with labels in the framework of detection model like Yolo, HelioLinc3D, Faster R-CNN, ATLAS. Once trained, the data are used on the other environment of Space data resulting from the observation [6].
The light intensity shall be associated with the vector function. Indeed, the snapshot of the images at different times would show the differences thanks to the vector function able to mark in the picture an asset moving in Space. The magnitude factors and the vector improve the algorithm which could display E=(I/d2)*v(t) with v for the vector marking the direction and t the time stamps.
The last parameters is introduced by the bifurcation of Turing to consider the Yarkovky effect on the asteroid. The Yarkovsky effect describes a non-gravitational force acting on an asteroid due to the absorption and re-emission of solar heat. The effect is caused by the anisotropic emission of thermal photons, which creates a small thrust on the asteroid.
The thrust modify the value of the vector which add a parameter for the light intensity formula E=(I/d2)*v(t) with $\vec{u} = \vec{AA'}$ where A is a position in Space and A' the futur position. It should provide E=(I/d2)*$\vec{u}$(t). The A' can record different position depending of the times noticed the images. The angle differences means the Yarkovky effect on the asteroid trajectory.
The light intensity should be understood as the anomalies in the cyber framework to mark the precision of the observation. It includes the GNSS coordinates from a receiver connected with the telescopes and the ephemeris datas. Other factors to be explored should be the way of RAMSES mission to exploit the interior belt and the exterior belt of Van Allen which would include the use of high energy particules in the case of the trajectory could cross the magnetic field. At last, the micro-lensing gravitationnal effect from the sensors and the data available on the ground could be also studied thanks the artificial intelligence techniques.
The point of the design mission is the way to test the methodology and the detection functions without and with the RAMSES Mission. From the artificial intelligence techniques to optimize the observation and the study of the data, the tools have proved to catch datas. The parameters integrable can pass through the HelioLinc3D [7].
The original data for the HelioLinc3D binding algorithm includes the source of detection linked with the magnitude, the photometric band and the site.
The purpose is to improve the algorithm through these parameters from the methodology described. The algorithm shall be noticed the following parameters with the preliminary parameter [7]:

- The magnitude shall include more detection sources at different moments from the sensors from the methodology (figure 1),
- The photometric band shall include more wavelength at different moments from the sensors and the techniques useful to detect the assets (figure 1),
- The code observation shall include the radar sites, the GNSS stations, the signal beacon of the Space mission like RAMSES. All these inputs are built in the minor planet center data format [8].

Due to the multiple sources and the labels of data, the model available which should be considered to complete the binding algorithm from HelioLinC2 could be :

- The Convolutif Neural Networks (CNN) [9] used for the detection and classification of objects in images depending on the light intensity and by the radial speed plus the Doppler effect the potential size of the object.
- The Semantic Segmentation Models such as U-Net and Mask R-CNN used to segment images into different classes, making it possible to precisely locate and classify objects in an image. It could provide the need of precision to improve the detection through the sensors. The Transformer-based models, such as DALL-E and Stable Diffusion, can be used to understand the relationships between objects in an image and classify them with high precision. This purpose should be provide by the Yolov4 algorithm by its capacity to analyse the images. This approach shall complete the process of the detection to the alert on the ground through the artificial engine to compute the

relationships. Within the new parameters in the HelioLinC2 algorithm, these parameters could improve the search [6].

## 6. Conclusions

The detection is linked with the asteroid threat for Earth and the populated town. With the exploration of the Moon, the trends suggests that the detection capacity could be improved by other means. Monitored from Earth to observe the ground-to-Space, the detection capacity would be also useful to manage the Earth orbits for the debris and the potential collision. The mission design for Apophis provides the baseline elements to be re-code for the detection processing on Earth with the security complete architecture in an operational exercice.

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