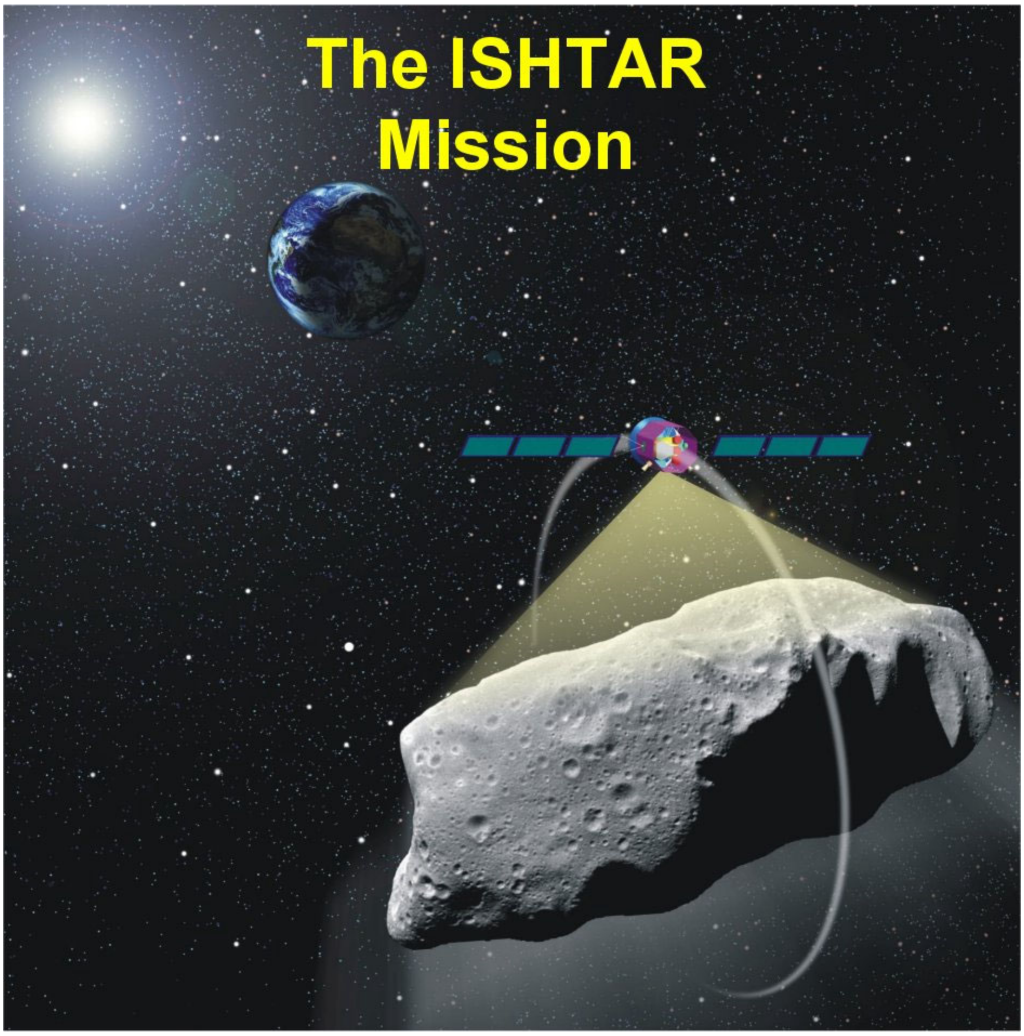

The ISHTAR Mission
Executive Summary for Publication on ESA Web Pages

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Mission Objectives

The principal objective of the ISHTAR mission (Internal Structure High-resolution Tomography by Asteroid Rendezvous) is to characterize all the physical parameters of an asteroid that are key to assess its impact hazard and to the development of effective mitigation strategies.

To determine how dangerous an asteroid is in case of impact, two parameters are crucial: the bulk mass, which determines the total energy of impact and the internal cohesion, which determines the likelihood of fragmentation in the atmosphere. To develop ways of deflecting or destroying an asteroid, again internal cohesion is a key parameter, because it determines the energy necessary to break it up into small fragments or the likelihood of fragmenting when trying to deflect it. Other important parameters for developing mitigation strategies are the asteroid surface properties, like depth of regolith, surface geology, spin, etc.

The main goal of ISHTAR is to determine those parameters that affect the internal cohesion of the asteroid. In particular, the radar tomographer will probe the internal structure, while the remaining payload will determine the mass, mass distribution, density and surface properties. This will provide us with all the key data necessary to develop ways of protecting the Earth from the asteroid threat.

Due to the high diversity of the near-Earth asteroid population, it is also considered a high priority for the mission to visit more than one asteroid within the same mission, so that our conclusions are not based simply on a sample of one. In particular, a large fraction of NEOs can be classified either as stony or carbonaceous, with significantly different density, composition and (presumably) internal structure. Therefore, the baseline ISHTAR mission is designed to visit 2 asteroids, one carbonaceous and one stony.

Finally, from a scientific perspective, knowledge of the surface mineralogy, when combined with the other key parameters listed above, would give invaluable insights into the origin and evolution of asteroids and of the solar system as a whole.

Near-Earth Objects present a real danger to life on Earth, yet very little is known about their nature, composition and internal structure.
Top: the Meteor crater in Arizona giver us an example of an NEO hitting the ground
Bottom: NEO 4179 Toutatis is a Potentially Hazardous Asteroid, with a small probability of impacting Earth

Payload

All the key parameters mentioned earlier can be measured with a small complement of instruments, centred around a radar tomographer, essential to probe the interior of the asteroid. This is the full set of instruments on board ISHTAR:

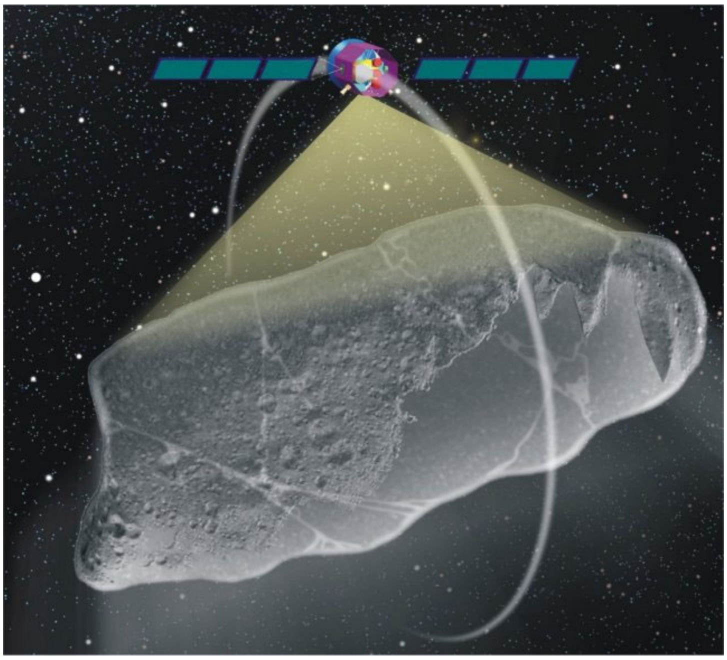
- A Radar Tomographer to measure the internal structure
- A Radio Science Experiment to measure the asteroid gravity field (mass & mass distribution)
- A Multispectral Imager to measure the surface properties
- An IR Spectrometer to measure the surface mineralogy

The Radar Tomographer uses low-frequency radio waves that can penetrate deep inside solid rock, down to depths of hundreds or even thousands of meters. The depth of penetration is determined by the radar frequency and by the composition of the asteroid. On ISHTAR, the radar tomographer is used in a synthetic-aperture reflection mode, where the signal reflected off the asteroid is measured from a 'virtual' grid of locations around the object, allowing reconstruction of a 3D image of the asteroid interior. The spatial resolution of this 'SAR' radar is determined by the number of points in the grid and the frequency used. The ISHTAR radar tomographer, operating at two frequencies of 10 and 30 MHz, will be able to penetrate to depths of over 300m below the surface with spatial resolution of up to 10m (in length, width and depth)

The Radio Science Experiment utilizes the spacecraft communication systems to transmit and receive radio beacons from/to Earth. This will allow location of the spacecraft with respect to Earth to within a few meters and thereby reconstruction of the asteroid gravity field through the deflections in the spacecraft trajectory. The measurement is based on a Doppler Ranging technique that provides both the distance and the radial velocity of the spacecraft relative the Ground Station on Earth. The radio science experiment utilizes a dual X-band and Ka-band transmitter for the downlink signal and an X-Band receiver for the uplink. In addition an on-board Ultrastable Oscillatior (USO) provides a frequency reference. This way, ISHTAR will be able to measure the mass of the asteroid to within 0.5% and also to detect an asymmetric mass distribution in the asteroid interior.

The Multispectral Imager is based on a miniature CCD camera operating at visible wavelengths and provided with 3 broadband spectral filters to obtain colour information. This microcamera will map the surface of the asteroid to study its topology, geology and to measure the asteroid volume (necessary for the density measurement). The camera will also be able to measure the asteroid rotation and to search for surface regolith. The ISHTAR camera will be able to resolve details of the order of 1.0 m and to determine density to within 2% accuracy.

The IR Spectrometer will provide an IR spectrum of the asteroid surface in the wavelength region between 1.0 μm and 2.5μm, which can be used to determine the mineralogical composition of the asteroid surface.



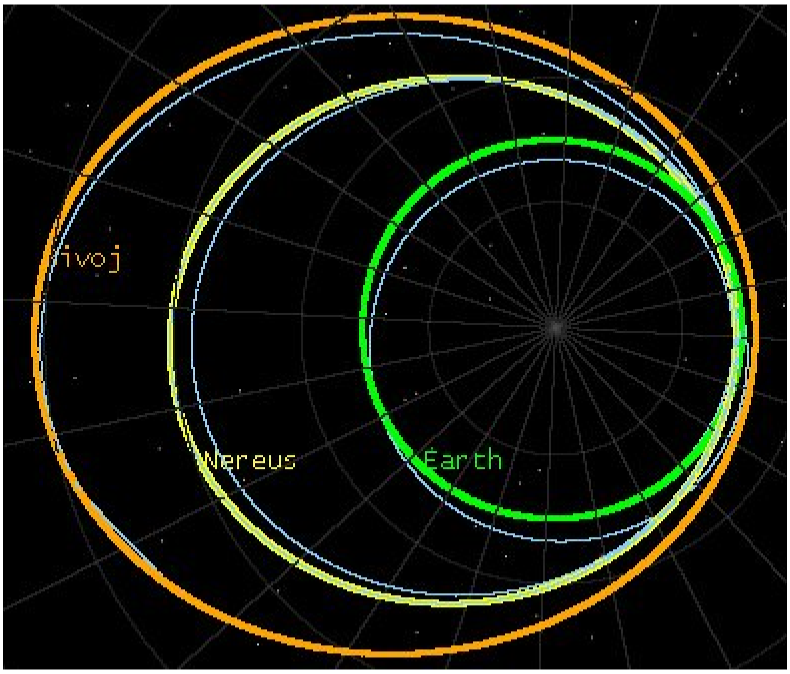
Radar Tomography will reveal structures deep below the surface of the asteroid

Mission Design

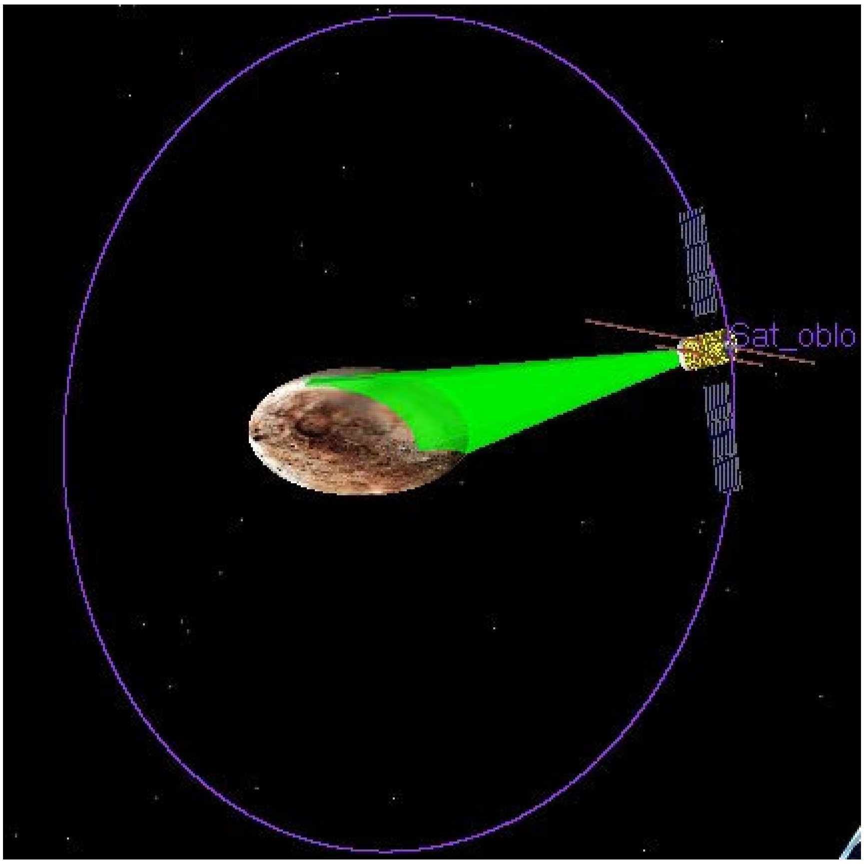
The ISHTAR mission was designed to be sufficiently flexible to be able to access a wide range of targets. A pair of asteroids was specially selected for their scientific interest and used to size the mission, but in its current design ISHTAR is actually capable of reaching over 30 different asteroid pairs, leaving great flexibility for both target selection and choice of launch date. A Solar Electric Propulsion (SEP) system was selected as the one providing the best performance for this type of mission.

In the baseline mission ISHTAR will launch in September 2011 with a Dnepr rocket to reach asteroid (4660) Nereus after 3 years of interplanetary cruise. After a stay at Nereus of nearly 15 months during which extensive science measurements can be performed, ISHTAR will then transfer to asteroid (5797) Bivoj, which it will reach after another 2 years. After reaching Bivoj ISHTAR will repeat the same type of science measurement during a period of at least 3 months. The total mission duration is approximately 7 years.

While the radio science and imaging measurement can be performed at relatively high altitudes from the asteroid surface (10-20 km or more), the radar tomographer requires smaller distances, the lower the altitude the better. To avoid excessive perturbation of the spacecraft orbit by the (potentially highly irregular) asteroid gravity field, ISHTAR will still limit orbital altitude to about 2-3 km, where stable orbits exist. In fact, we have shown that even for a highly elongated asteroid with a 2:1 aspect ratio, it is possible to find stable orbits at 3 km altitude that are also synchronous with the Sun, avoiding the spacecraft going into eclipse. The good ground coverage also required by the radar can be achieved by placing ISHTAR into a near-polar orbit.



Orbits of the target asteroids for ISHTAR: (4660) Nereus and (5797) Bivoj. The thin blue line represents the trajectory of the ISHTAR spacecraft.



During the Radar Phase, ISHTAR will operate in a near-polar dawn-dusk orbit at around 2-3 km altitude form the surface of the asteroid. It was possible to demonstrate that such orbits are stable, even for highly elongated objects.

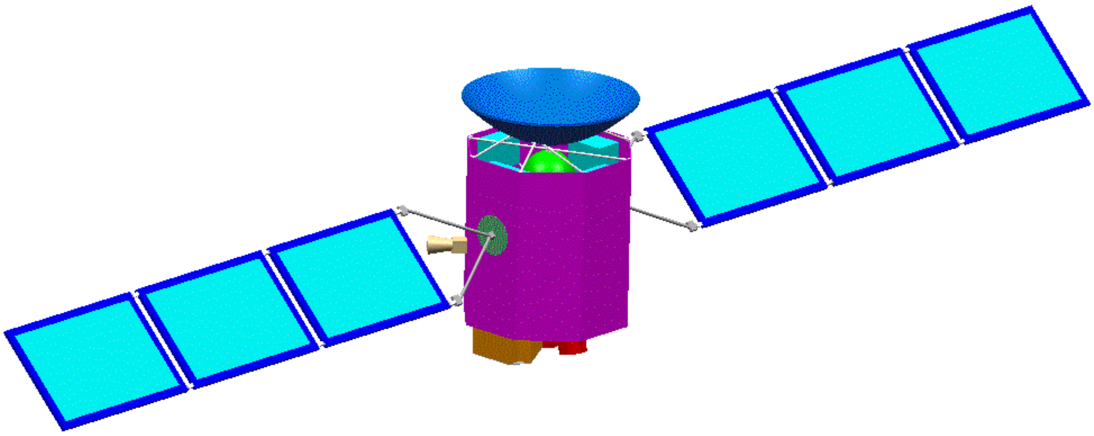
Spacecraft Design

The ISHTAR spacecraft was designed to achieve its mission goals as a low-cost mission. To achieve this, the approach has been to keep the spacecraft small, while minimizing the spacecraft complexity. Whenever possible the design has used existing, 'state of the art' system, for the payload as well as the other spacecraft subsystems. In fact, all ISHTAR components are based on existing technology, with perhaps the exception of the radar tomographer, which is however still made of space-qualified components and it is an evolution of ground-based instrumentation.

Consistent with this low-cost approach, ISHTAR is baselined for an inexpensive Dnepr launcher and a launch mass of 408 kg, including 20% system margin. Note that this is well below the limit capacity of the Dnepr launcher, which is capable of delivering up to 860 kg into Earth escape. The total spacecraft dry mass is only 300 kg, with 25 kg of payload. A further mass saving of 20-30 kg is possible by the use of an Earth Gravity Assist manoeuvre in the mission design, which leads to significant propellant savings.

The spacecraft structure is based on an octagonal, wound monocoque structure in CFRP developed by Astrium Ltd, and capable of delivering high levels of robustness and stability at very low cost. The propulsion system utilizes 3 ion engines (1 redundant) providing op to 18 mN of thrust each. These engines require relatively large solar arrays providing 1600W of power. This, however, has the indirect advantage that plenty of power is available for telecommunications and the science instruments once ISHTAR reaches its target asteroids.

The communication systems is based on a dual X and Ka band transmitter and an X-band receiver working through a 1.0m diameter parabolic High Gain Antenna. The spacecraft is also equipped with a toroidal Medium Gain Antenna and two Low Gain Antennae, all working in X-band. This system allows downloading of science data at rates of over 1000 bps from distances of around 2.0 AU from Earth.



A low-budget mission like ISHTAR utilizes a small, but highly specialized spacecraft to focus on the key objectives for a NEO exploration mission: namely, to measure those parameters that are essential to develop strategies to protect the Earth

Conclusion

The ISHTAR mission has the potential to revolutionize our understanding of Near-Earth Objects and to provide us with the information needed to develop strategies to protect the Earth. Within a relatively inexpensive package and a short implementation phase, ISHTAR will finally be ale to answer key questions about these mysterious objects that have a long history of interaction with our planet. In so doing, ISHTAR will help us to have the means, for the first time in the Earth's history, of protecting ourselves from this NEO threat.