Highlights of Astronomy, Vol. 13
International Astronomical Union, 2003
O. Engvold, ed.

The ISHTAR Mission: Probing the Internal Structure of NEOs

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Abstract. ISHTAR (Internal Structure High-resolution Tomography by Asteroid Rendezvous) is a mission developed through ESA General Studies programme. The study, led by Astrium in cooperation with several scientific institutes throughout Europe, has produced a spacecraft design capable of performing multiple asteroid rendezvous and to characterize them with a focussed set of instruments. The ISHTAR concept is centred around a Radar Tomography paylod able to probe the internal structure of a small asteroid to depths of few hundred meters, combined with a small camera for investigation of the surface properties and a radio science experiment for gravity field measurement. This combination will allow the first detailed characterization of a NEO and will give valuable insights into the origin and evolution processes that govern the NEO population. In particular, ISHTAR will be able to visit at least 2 NEOs belong-

https://doi.org/10.1017/S1539299600016981 Published online by Cambridge University Press

ing to two different spectral classes, thereby allowing us to probe the diversity of the NEO population.

1. Introduction

ISHTAR (Internal Structure High-resolution Tomography by Asteroid Rendezvous) is a mission proposed in response to ESA's recent call of ideas for NEO exploration and discovery. In particular, the focus of NEO space exploration is to collect the information necessary to develop strategies to protect our planet from future impacts (Morrison et al. 2003). The internal structure of NEOs is a key parameter in this respect, as it affects the likelihood of fragmentation when a force is applied to the asteroid.

ISHTAR will address key issues related to the threat NEOs pose to Earth: it will help assess the impact hazard, by providing the first data on the internal strength of NEOs, it will provide the basis for devising mitigation techniques, by helping to discriminate between destructive and deflective strategies and it will greatly advance our understanding of how NEOs form and collide with other planets.

2. Mission Objectives

The principal objective of the ISHTAR mission is to characterize all the physical parameters of an asteroid and in particular to investigate its internal structure. This is important to assess the 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 both for scientific aim and 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.

A high priority for the mission is to visit more than one asteroid, due to the high compositional diversity of the near-Earth asteroid population (Binzel et al. 2001). 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 supposed to be similar to carbonaceous and one similar to stony material.

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 will contribute to the study of the evolution of the solar system.

3. Payload

The Payload to assess all the key parameters mentioned earlier can be composed of a small complement of instruments, centred around a radar tomographer, essential to probe the interior of the asteroid.

The full set of instruments on board ISHTAR are:

- 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 several 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 determination). The camera will also be able to measure the asteroid rotation and to search for surface regolith. The ISHTAR camera will

https://doi.org/10.1017/S1539299600016981 Published online by Cambridge University Press

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 2.5 μm, which can be used to determine the mineralogical composition of the asteroid surface.

4. Mission and Spacecraft 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. Many other possibilities are available.

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.

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 maneuver 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 up 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.

5. 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. The combination of instrument and multiple rendezvous will allow the first detailed physical characterization of the NEO population. The whole mission is possible within the constraint of a small spacecraft (408kg) and the financial envelope of an ESA 'flexi' mission (150 MEuros).

Within a relatively inexpensive package and a short implementation phase, ISHTAR will finally be able 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, of protecting ourselves from this NEO threat.

ISHTAR is one of the several studies (Simone, Don Quijote, Earthguard 1, Euneos, Remote Observing) financed by ESA, aimed to improve the knowledge of NEOs as potential hazardous asteroids. A mission to NEOs can be optimized merging some of these different concepts. These studies show that the scientific community is ready to endorse a mission to NEOs as soon as ESA or a national space agencies will consider it.

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https://doi.org/10.1017/S1539299600016981 Published online by Cambridge University Press