Acta Astronautica 149 (2018) 25–34

Contents lists available at ScienceDirect

Acta Astronautica

journal homepage: www.elsevier.com/locate/actaastro

MASCOT2 – A small body lander to investigate the interior of 65803 Didymos′ moon in the frame of the AIDA/AIM mission

Caroline Lange[a,*], Jens Biele[b], Stephan Ulamec[b], Christian Krause[b], Barbara Cozzoni[b], Oliver Küchemann[b], Simon Tardivel[c], Tra-Mi Ho[a], Christian Grimm[a], Jan Thimo Grundmann[a], Elisabet Wejmo[a], Silvio Schröder[a], Michael Lange[d], Josef Reill[e], Alain Hérique[f], Yves Rogez[f], Dirk Plettemeier[g], Ian Carnelli[h], Andrés Galvez[h], Christian Philippe[i], Michael Küppers[j], Björn Grieger[j], Jesus Gil Fernandez[j], Jerzy Grygorczuk[k], Marta Tokarz[k], Christian Ziach[a]

[a] *DLR German Aerospace Center, Institute of Space Systems, Bremen, Germany*
[b] *DLR German Aerospace Center, Microgravity User Support Center, Cologne, Germany*
[c] *University of Colorado Boulder, 80309 Boulder, United States*
[d] *DLR German Aerospace Center, Institute of Composite Structures and Adaptive Systems, Braunschweig, Germany*
[e] *DLR German Aerospace Center, Institute of Robotics and Mechatronics, Wessling, Germany*
[f] *Univ. Grenoble Alpes, IPAG, F-38000 Grenoble, France*
[g] *Technical University Dresden, 01187 Dresden, Germany*
[h] *ESA European Space Agency, HQ, Paris, France*
[i] *ESA European Space Agency, ESTEC, Noordwijk, the Netherlands*
[j] *ESA European Space Agency, ESAC, Madrid, Spain*
[k] *ASTRONIKA Sp. z o.o., 00-716 Warsaw, Poland*

A R T I C L E I N F O

Keywords:
AIM
AIDA
Lander
Near-earth asteroids
MASCOT

A B S T R A C T

In the frame of Near-Earth-Object exploration and planetary defence, the two-part AIDA mission is currently studied by NASA and ESA. Being composed of a kinetic impactor, DART (NASA), and by an observing spacecraft, AIM (ESA), AIDA has been designed to deliver vital data to determine the momentum transfer efficiency of a kinetic impact onto a small body and the key physical properties of the target asteroid. This will enable derivation of the impact response of the object as a function of its physical properties, a crucial quantitative point besides the qualitative proof of the deflection. In the course of the AIM mission definition, a lander has been studied as an essential element of the overall mission architecture. It was meant to be deployed on Didymoon, the secondary body of the binary NEA system 65803 Didymos and it was supposed to significantly enhance the analysis of the body's dynamical state, mass, geophysical properties, surface and subsurface structure. The mission profile and the design of the 13 kg (current best estimate) nano-lander have been derived from the MASCOT lander flying aboard Hayabusa2. Differing from its predecessor by having an increased lifetime of more than three months, a surface mobility capability including directed movement, a sensor system for localization and attitude determination on the surface and a redesigned mechanical interface to the mother spacecraft. The MASCOT2 instrument suite consists of a bi-static, low frequency radar as main instrument, supported by an accelerometer, a camera, a radiometer and a magnetometer; the latter three already flying on MASCOT. Besides the radar measurements, the camera is meant to provide high-resolution images of the landing area, and accelerometers to record the bouncing dynamics by which the top surface mechanical properties can be determined. During the DART impact, MASCOT2 was expected to be able to detect the seismic shock, providing valuable information on the internal structure of the body. MASCOT2 was supposed also to serve as a technology demonstrator for very small asteroid landing and extended operations powered by a solar generator. In this paper, we describe the science concept, mission analysis of the separation, descent and landing phase, the operational timeline, and the latest status of the lander's design. Despite the fact that AIM funding has not been fully confirmed during the ESA Ministerial conference in 2016, MASCOT2 is an instrument package of high

* Corresponding author.
E-mail address: caroline.lange@dlr.de (C. Lange).

https://doi.org/10.1016/j.actaastro.2018.05.013
Received 22 November 2017; Received in revised form 14 March 2018; Accepted 6 May 2018

maturity and major interest for planetary defence and NEO science. With appropriate tailoring and optimization, it can be considered and studied for future missions.

1. Introduction

This paper describes the MASCOT2 lander and its mission to the moon of the near-Earth binary asteroid 65803 Didymos (see Table 1 for system details), which was studied in the frame of the Asteroid Impact and Deflection Assessment (AIDA) mission [1]. AIDA is an international cooperation between ESA and NASA, which has developed a double spacecraft (S/C) approach consisting of Double Asteroid Redirect Test (DART), a mission under study by the Johns Hopkins Applied Physics Laboratory with support from NASA Goddard Space Flight Center, NASA Johnson Space Center, and the Jet Propulsion Laboratory [2] and AIM, the European Space Agency's Asteroid Impact Mission. Under the umbrella of planetary defence, the two components play their share in order to investigate the effectiveness of a kinetic impactor in deflecting the trajectory of an asteroid. While DART will be sent on its way to produce the actual impact, the AIM mission has been envisaged to observe this impact and survey the Didymos system before and after with respect to the critical properties of such a system which are relevant in order to understand the impact process.

The detailed scientific objectives of the AIM mission are described by Michel et al. [4], but the overall concept aims at investigating properties of Didymoon such as mass, size, morphology density, internal structure, dynamical properties and thermophysical characteristics. In order to do so, the AIM baseline payload provides visual and thermal infrared imaging as well as radar (low and high frequency) instrumentation. AIM will also be equipped with a technology demonstrator for asteroid landing and extended operations: the MASCOT2 lander. The mission concept and the lander system design for the MASCOT2 surface science package will be reported in this paper. MASCOT2 stems from its predecessor MASCOT currently onboard Hayabusa2 en route to the asteroid (162173) Ryugu (formerly 1999 JU_3), where it will arrive and land in the second half of 2018 [5].

2. Science objectives and mission description

2.1. Overall science and operational concept

The MASCOT2 lander is not only a technology experiment, but also contributes to the main scientific objectives (SO) of the AIM mission such as:

(1) Characterizing the structural homogeneity of Didymoon and Didymain
(2) Estimate the average complex dielectric permittivity of Didymoon
(3) Determine the secondary's 3D structure including layering, spatial variability of density and block size distribution before and after the impact of DART
(4) Perform the mass determination and orbit characterization of the binary asteroid
(5) Determine the geophysical surface properties, topology and shallow subsurface
(6) Determine the chemical and mineral composition of Didymoon and Didymain

The chosen payload for the MASCOT2 mission reflects these objectives and provides respective measurement possibilities, which are listed in Table 2. The main instrument is the Low Frequency Radar (LFR), which will sound the interior structure of Didymoon on several occasions before and after the impact of DART [6–8]. This instrument is a bistatic radar measuring the radar wave propagation from the MASCOT2 lander to the orbiter throughout Didymoon. Like CONSERT on board ROSETTA and PHILAE, it consists of an antenna and an electronic box on both MASCOT2 and the AIM spacecraft. With several measurements for different lander/moon/orbiter geometries this radar operating at 60 MHz will provide the tomography in transmission of the body interior. Given the right observation geometrical configuration, the radar can probe Didymoon's interior before and after DART impact (main objective). The radar will not probe the entire interior of Didymain, but it will characterize the surface of this body (surface permittivity and roughness). During the visibility period LFR will also provide direct measurement of the orbiter/lander distance during the descent and after landing. This will support the determination of the gravitational field, of the dynamical state of the body and of any modifications due to the impactor (secondary objectives).

A camera (rebuilt from MasCam [9]) will perform imaging of the landing site and provide insight into the topography and mineralogical properties of the Regolith, while a radiometer (rebuilt from MARA [10]) will determine the thermal inertia at the landing site. During the landing and bouncing phase as well as possibly during the DART impact, an accelerometer (DACC) will be operated which has the potential to detect the seismic waves generated by the event, thus providing another source of information on the internal structure of the body.

A magnetometer derived or rebuilt from the MasMag instrument aboard MASCOT [11] is considered as an additional instrument given the resources were available. It could investigate the interaction of the major bodies and possible dust or other emanations of the Didymos system with the interplanetary medium. Following the experience of the PHILAE landing [12] it is expected to also support navigation during the descent and landing phase as well as during relocation on Didymoon towards the optimal operating location of LFR.

The MASCOT2 mission timeline is very much dominated by the overall AIM mission timeline. On the one hand, the AIM spacecraft has to deliver the lander at a point in time, which performs best in trades of mission analysis constraints such as fuel vs. mission risk and also provides the optimized timing in terms of lifetime of the lander versus timeframe of the DART impact. On the other hand, the LFR instrument requires synchronously choreographed operation between lander and orbiter beyond the usual data-relay functionality. The AIM timeline is shown in Fig. 1 and presents six main phases corresponding with different observation geometries for LFR, with the lander deployment in the second third of the AIM mission timeframe. Its primary mission is envisaged for three months, interrupted by a phase around the DART impact where contact with AIM is limited, which is in retreat to a safe distance of 100 km at that time (Fig. 2).

Table 1
Relevant parameters of asteroid (65803) Didymos.

Parameter	Value
Orbital Type	Amor
Taxonomic Type	S[a]
d_{main}	0.78 ± 0.08 km
r_{peri}	1.013 au
r_{apo}	2.276 au
Period	2.11 yrs
$T_{rot,1}$	2.26 h (primary)
$P_{orb} \approx T_{rot,2}$	11.91 h (secondary)
ρ_{bulk}	2.1 ± 0.6 g/cm^3
d_m/d_s	~1:5
ε/α	0.94/0.96
Thermal Inertia (TI)	50 …. 1000 $Jm^{-2}K^{-1}s^{-1/2}$

[a] Didymos, firstly classified as Xk-type asteroid, is now considered as an S-type based on its spectrum [3].