APOPHIS 2029

A UNIQUE MISSION OPPORTUNITY

Jean-Yves Prado

CNES Toulouse - France
■ APOPHIS reminder

■ The April 2029 flyby

■ Mission objectives

■ Sequence of events
  ♦ Launch
  ♦ Orbit transfer
  ♦ Relative navigation
  ♦ Flight operations

■ Scientific payload

■ Conclusion
Discovery

Discovered by: Roy A. Tucker, David J. Tholen, Fabrizio Bernardi

Discovery date: June 19, 2004

Orbital characteristics

Aphelion distance: 1.099 AU
Perihelion distance: 0.746 AU
Orbital period: 323.6 d (0.89 year)
Inclination: 3.331°

Physical characteristics

Dimensions: ~250 m (estimated)
Mass: $2 \times 10^{10}$ kg (estimated)
Rotation period ~30h

Mass of APOPHIS ~ 200 x
APOPHIS Flyby of the Earth on April 13, 2029

New Period 419 +/- 2 Days

Arrival Period 323 days

Earth Motion
Possible Resonant Orbits

Resonance Condition: \( T_{ap} = \frac{m}{n} T_{Earth} \)
Pass Geometry

The orbit of APOPHIS relative to the Earth is retrograde ($i=140^\circ$)
Mission Overview

Launch on 30° inclination orbit
Classical azimuth from Kourou
250x600,000 km
Vapogee~30 m/s
Sequence of Events

- T0=Launch
- T0+20 d
- Distance to APOPHIS (km)
- Perigee boost provided by launcher
- Relative navigation
- MIRZA velocity / APOPHIS 100 m/s
- ~7 hours thrust
- Engine separation
- SISMOD Separation
- SISMOD Unfolding
- MIRZA Re-ignition
- Descent imaging
- Laser Ranging
- Data Downlink
- Data recording
- SISMOD Landing
- Tperigee~Tlaunch+22 days

Sous Comité scientifique et Technique - COPUOS
APOPHIS 2029
Vienne
8-19 février 2010
Landing Sequence

On SISMOD: seismometers/accelerometers

On MIRZA: radio sounder
laser reflector
descent imaging
relay of SISMOD data
Principle of Seismology on a NEO

From C.BLITZ Thesis, 2009

EROS~100xAPOPHIS
- 1Hz-50Hz seismometers
- < milli-g sensible accelerometers
- natural waves from
  - thermal response to sun heat
  - gravitational tides at perigee
- waves induced by MIRZA impact
Radio Sounding

- Radio sounder inherited from CONERT/ROSETTA
- Role of the orbiter performed from ground
- Frequency in the [50-100MHz] range
- Needs to be adapted to the rotation characteristics of APOPHIS
- Presently Period ~30 hrs, orientation unknown
- Receiving Earth station to be defined through international cooperation
Laser Ranging

Still used after more than 30 years

< Meter level accuracy

No power needed on the reflector

Can be used only during the approach of APOPHIS
## Preliminary Mass Budget

<table>
<thead>
<tr>
<th>Item</th>
<th>Mass (kg)</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Launch capacity</td>
<td>6500</td>
<td>ARIANE 5 ECA /Kourou</td>
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<tr>
<td>Launched mass</td>
<td>5000</td>
<td></td>
</tr>
<tr>
<td>Transfer Module</td>
<td>4800</td>
<td></td>
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<tr>
<td>Dry mass</td>
<td>550</td>
<td></td>
</tr>
<tr>
<td>Fuel</td>
<td>4250</td>
<td>Isp 325 s</td>
</tr>
<tr>
<td>MIRZA</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Dry mass</td>
<td>90</td>
<td></td>
</tr>
<tr>
<td>Fuel</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>SISMOD</td>
<td>70</td>
<td>Including 50kg P/L</td>
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<tr>
<td>Launch Margin</td>
<td>1500</td>
<td></td>
</tr>
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### Further Studies

<table>
<thead>
<tr>
<th>Phase</th>
<th>Main actions</th>
<th>Constraints</th>
<th>Outcomes</th>
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</table>
| 1 - In orbit delivery | Westward launch | - Safety  
- First stage and boosters dropping zone | Delivery of the TM+MIRZA on a 250x~1,000,000km, i=30° |
| 2 – Elliptic to hyperbolic orbit transfer | ~6 km/s thrust by Transfer Module (TM) | - Thrust duration  
- Thrust accuracy  
- APOPHIS ephemeris accuracy | Delivery of the MIRZA module on an orbit close to APOPHIS’s, ahead of it |
| 3- Relative navigation and touch down | Optical navigation | - Final precision ~10 meters / APOPHIS  
- APOPHIS geometry  
- Soil characteristics | - delivery of the science package on APOPHIS surface  
- impact by MIRZA bus a few minutes later |
| 4 – Science operations | Data transmission, Radio sounding Laser echo | - Data management  
- Visibility from ground stations  
- Tracking from ground telescopes (weather,...) | - seismology data  
- radio sounding  
- laser reflector orientation validation |
Conclusion

• Such a mission has to be fully International

  • Needs of observation campaigns in 2012-2013 and 2020-2021
  • Needs of data exchange prior to and during the APOPHIS flyby
  • Avoid any risk of conflict from different initiatives
  • The threat from APOPHIS is a global issue
  • It will be covered by the media worldwide

• A space mission to APOPHIS in 2029 would be an excellent rehearsal for an international response to the NEOs threat under the UN auspices
Apophis in the Egyptian Mythology

A snake that tried to kill the Sun (Ra) every morning