CENTRE NATIONAL D'ÉTUDES SPATIALES

APOPHIS 2029

A UNIQUE MISSION OPPORTUNITY

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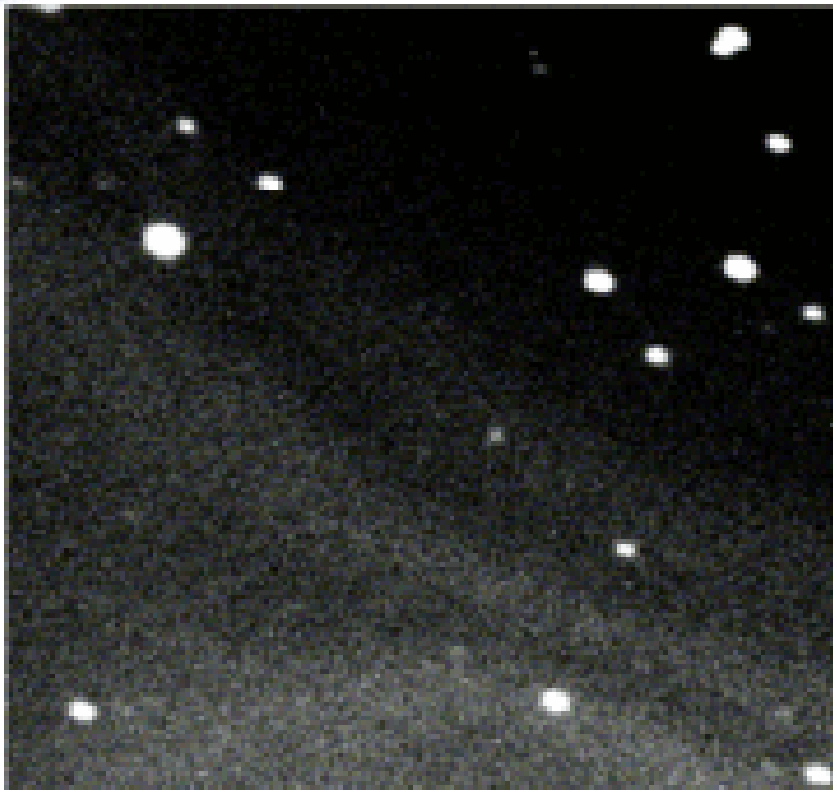
Presentation Outline

- APOPHIS reminder
- The April 2029 flyby
- Mission objectives
- Sequence of events
  - Launch
  - Orbit transfer
  - Relative navigation
  - Flight operations
- Scientific payload
- Conclusion

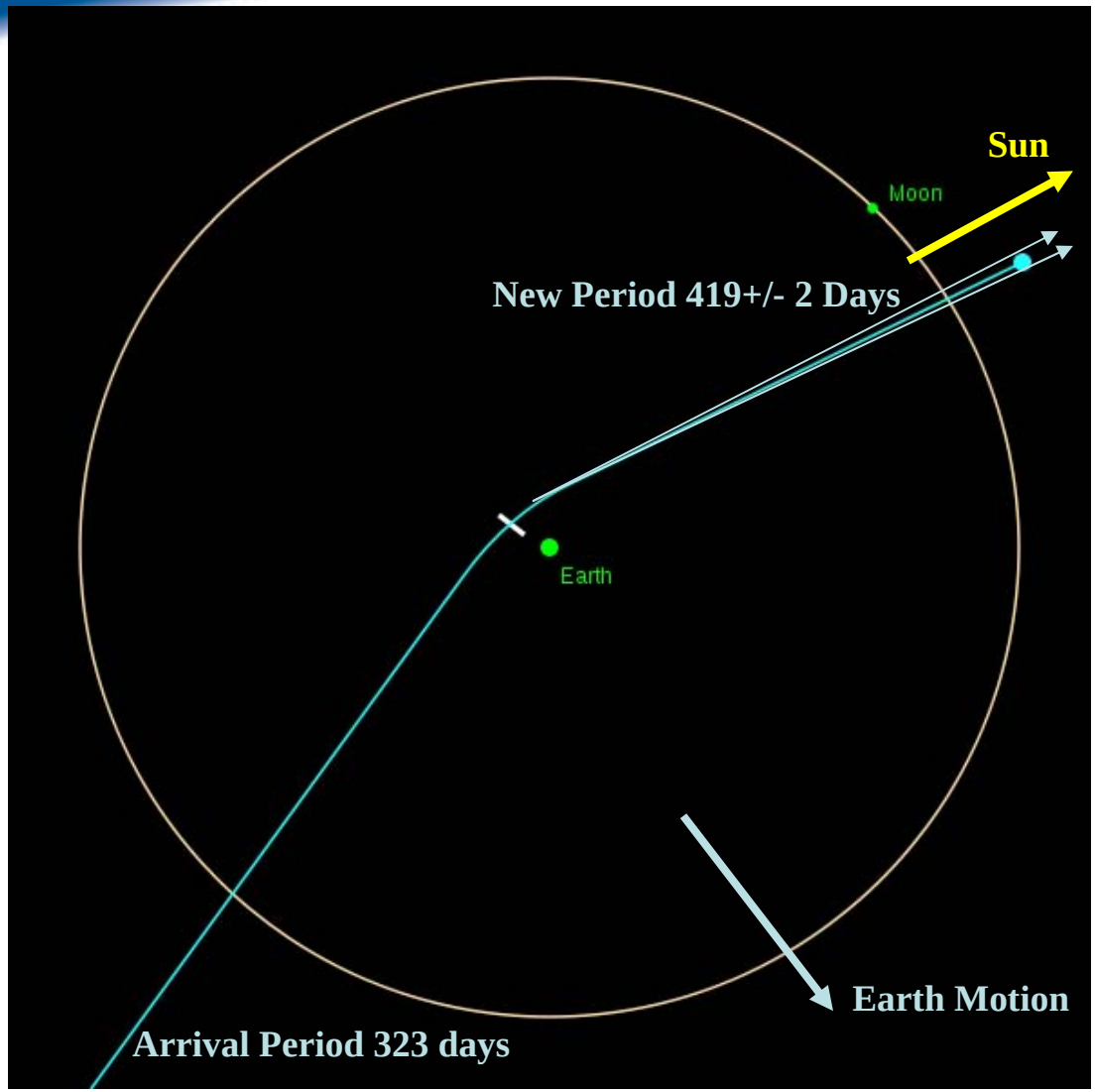
APOPHIS



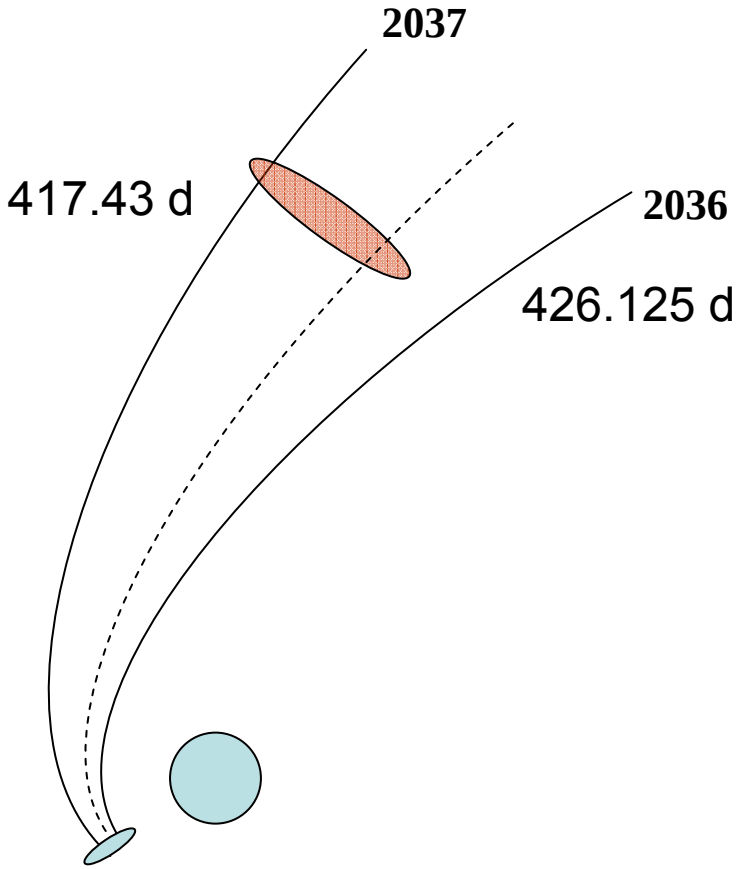
Discovery	
Discovered by:	Roy A. Tucker, David J. Tholen, Fabrizio Bernardi
Discovery date:	June 19, 2004
Orbital characteristics	
Aphelion distance:	1.099 AU
Perihelion distance:	0.746 AU
Orbital period:	323.6 d (0.89 year)
Inclination:	3.331°
Physical characteristics	
Dimensions:	~250 m (estimated)
Mass:	2×10^{10} kg (estimated)
Rotation period ~30h	

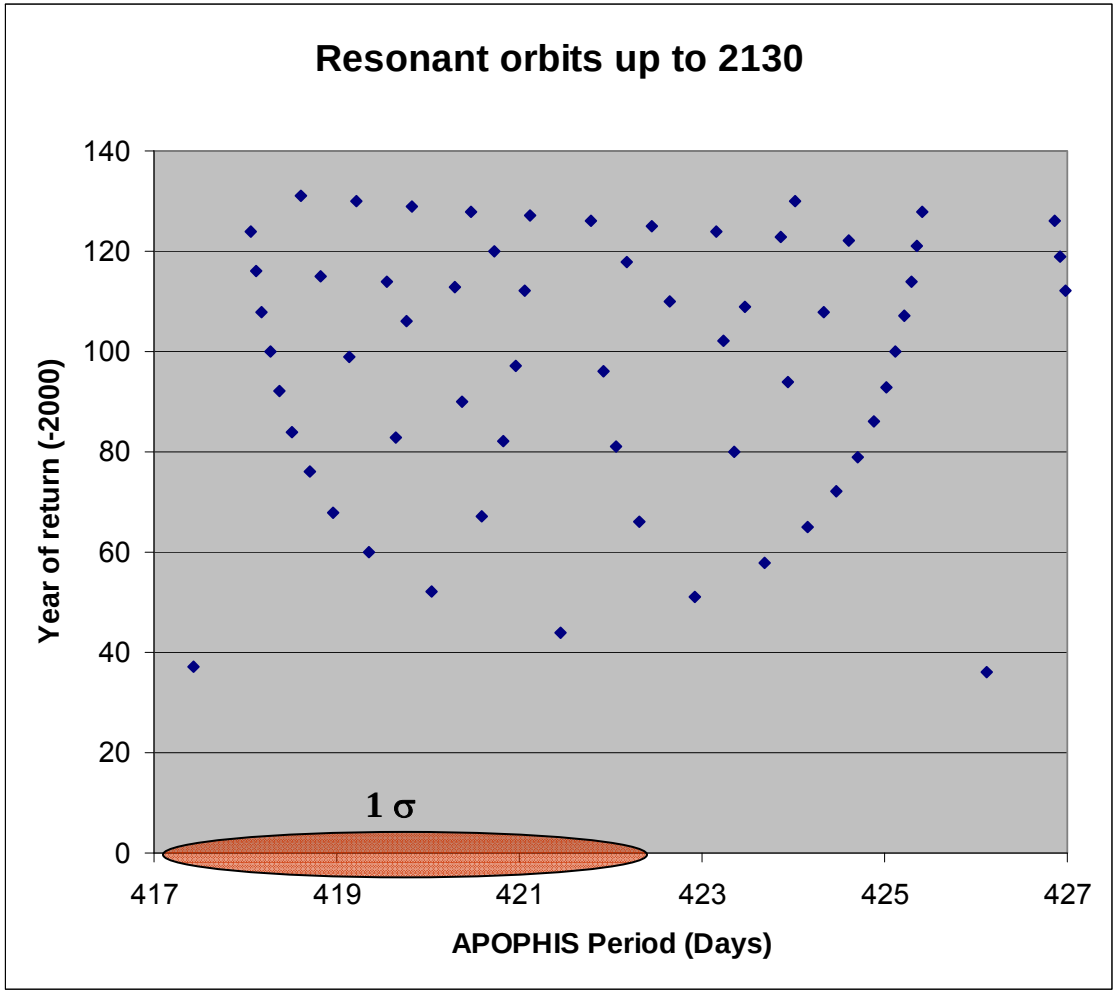
Mass of APOPHIS ~ 200 x

APOPHIS Flyby of the Earth on April 13, 2029



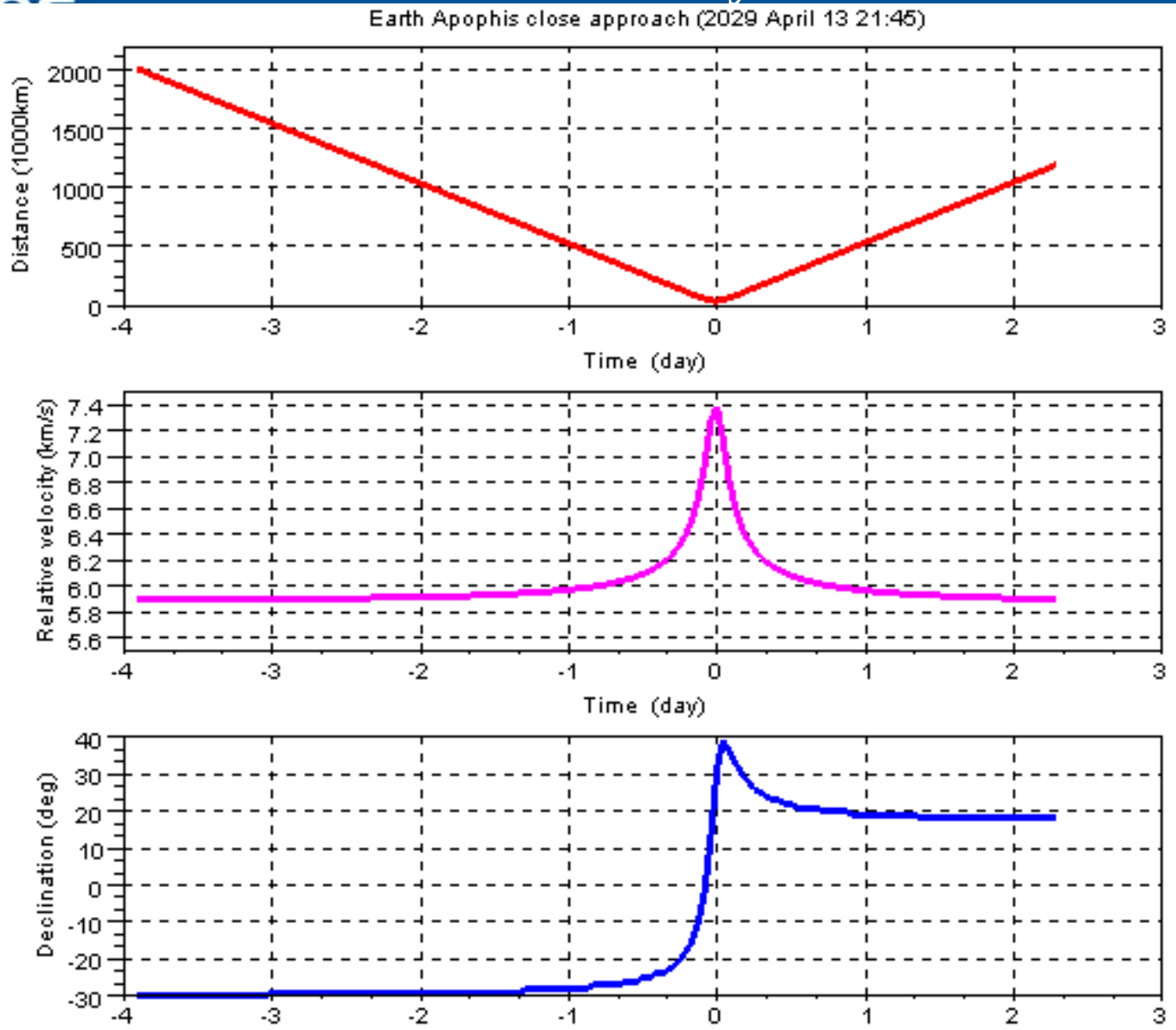
Possible Resonant Orbits





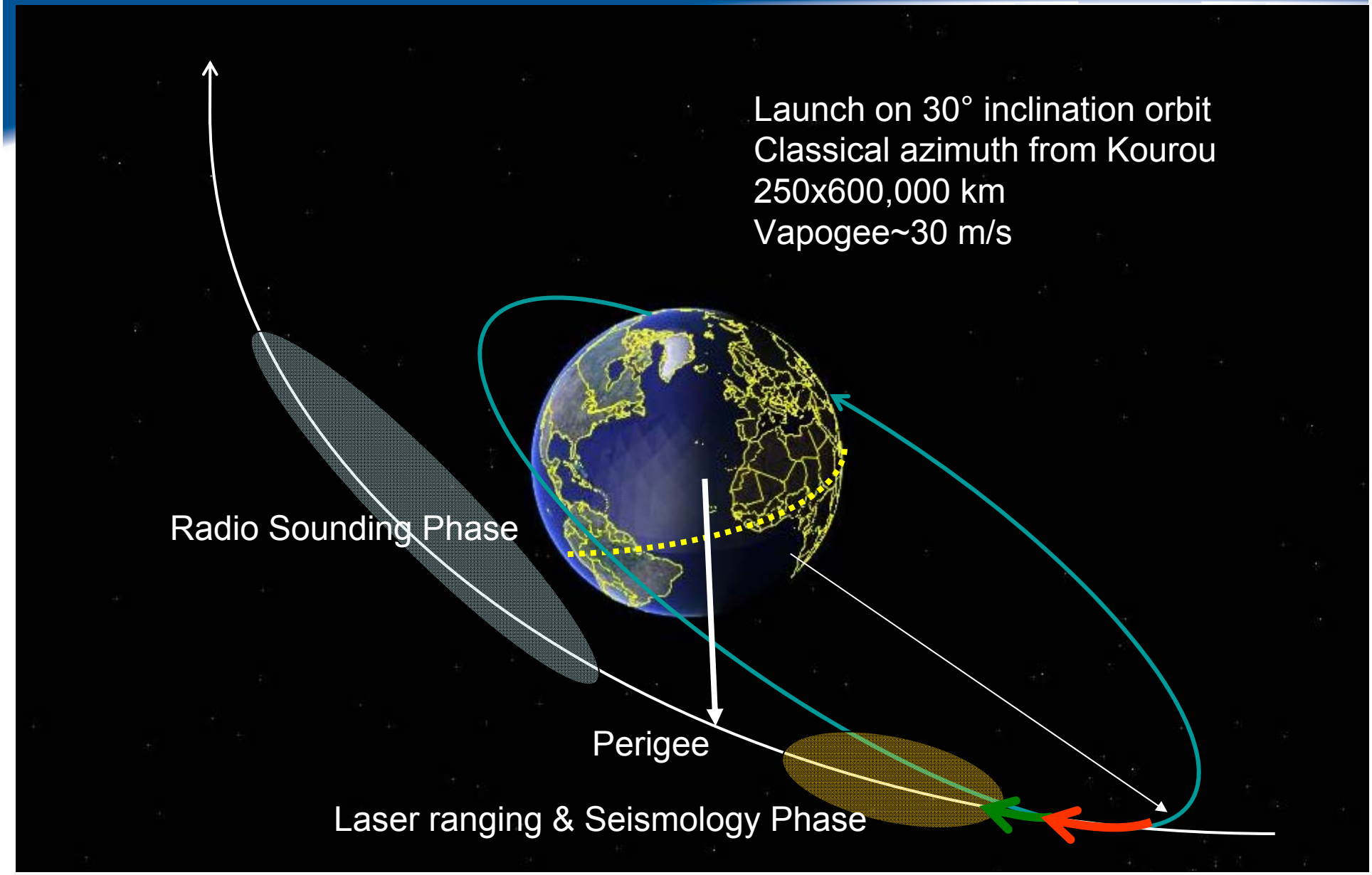
Resonance Condition: $T_{ap}=m/n\ T_{Earth}$

Pass Geometry

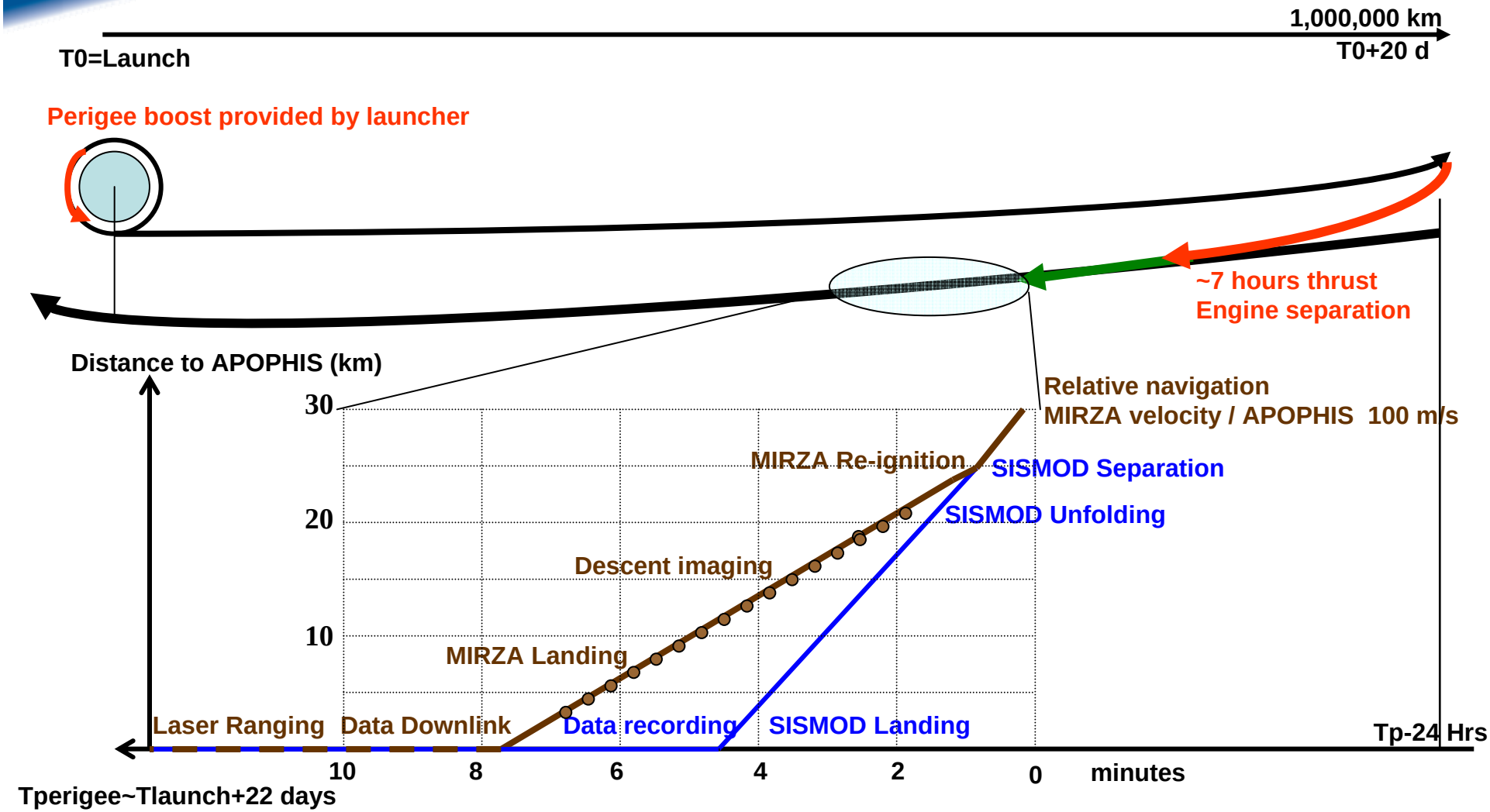


The orbit of APOPHIS relative to the Earth is retrograde (i=140°)

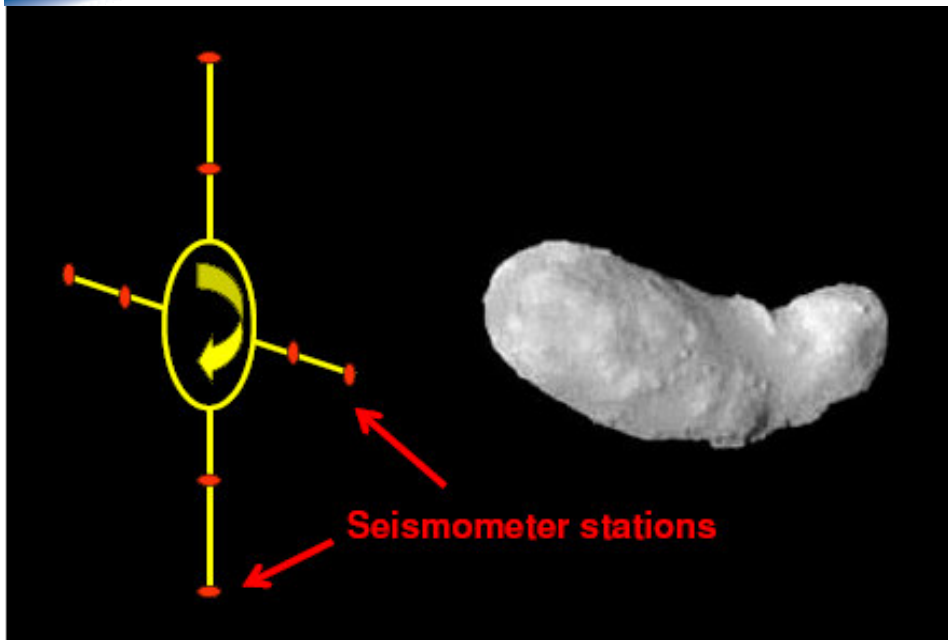
Mission Overview

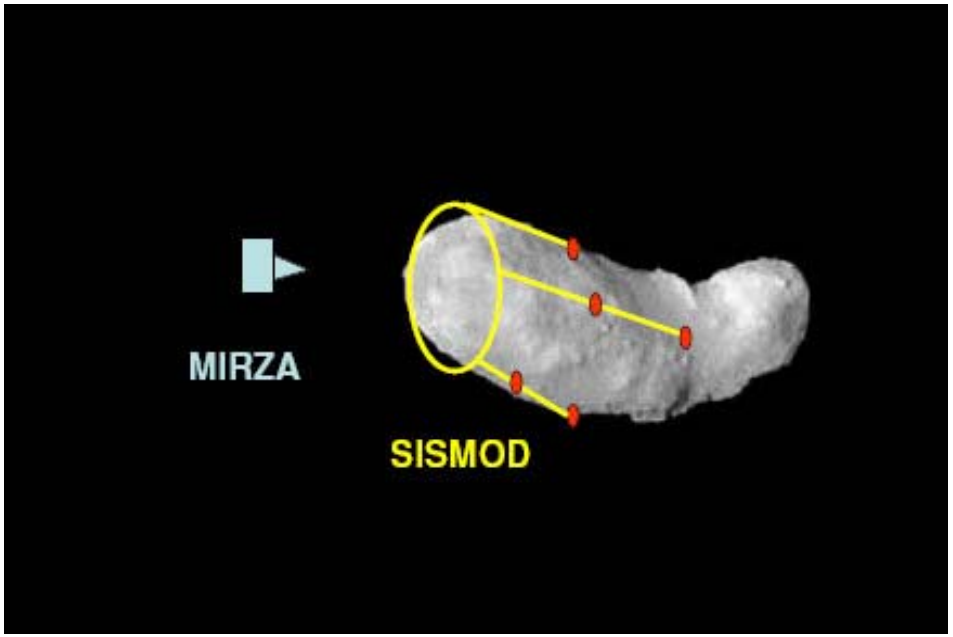


Sequence of Events



Landing Sequence

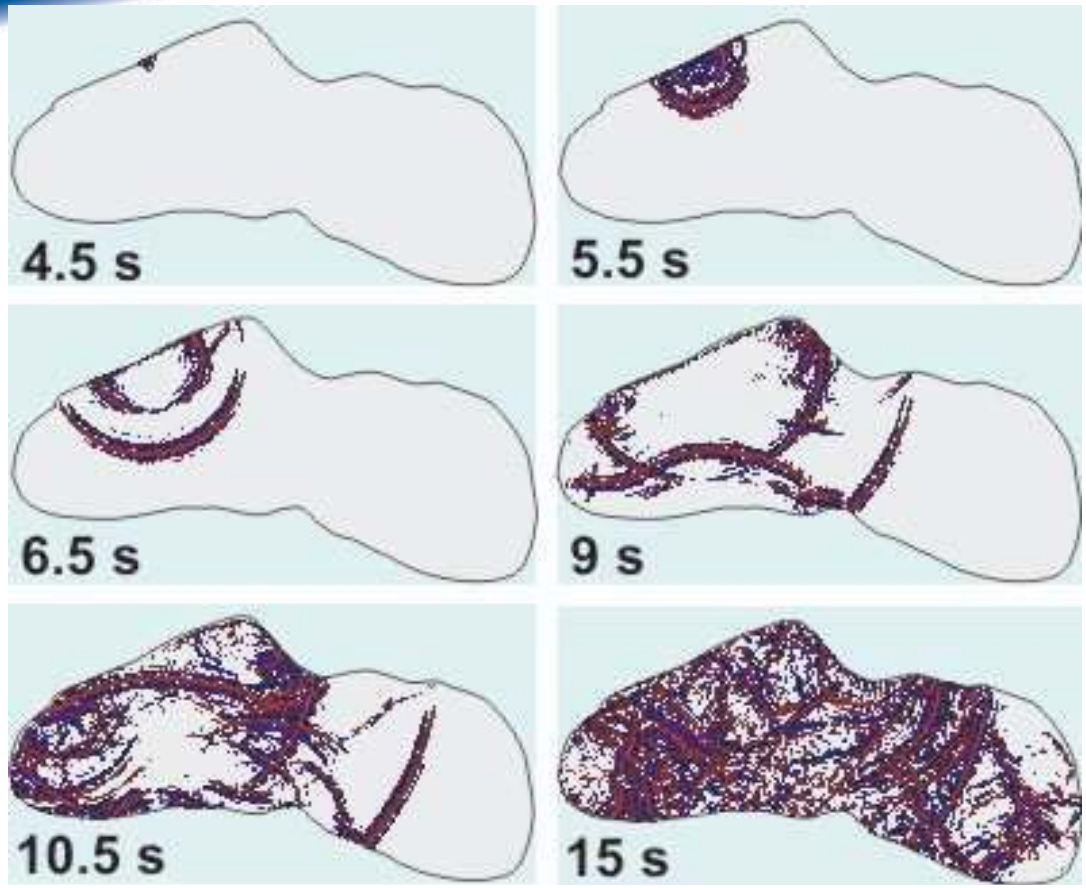




On SISMOD : seismometers/accelerometers

On MIRZA: radio sounder
laser reflector
descent imaging
relay of SISMOD data

Principle of Seismology on a NEO

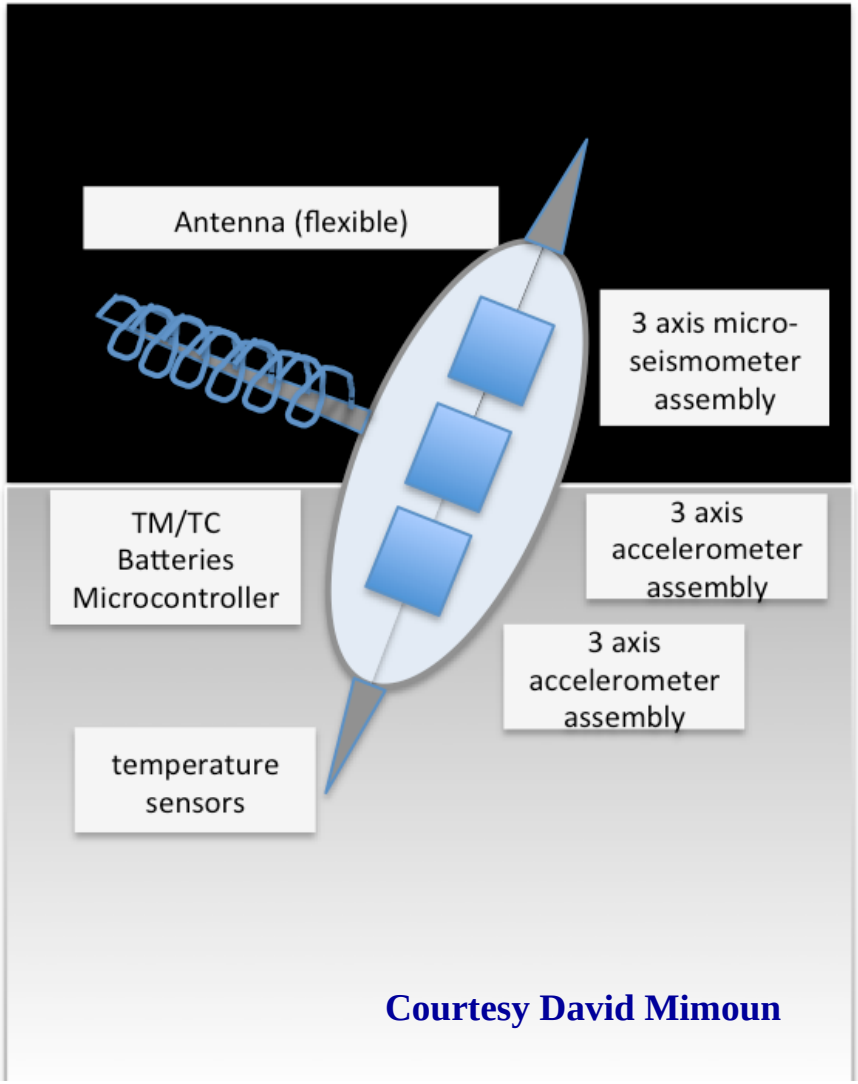


EROS~100xAPOPHIS

From C.BLITZ Thesis, 2009

Seismometers / Accelerometers

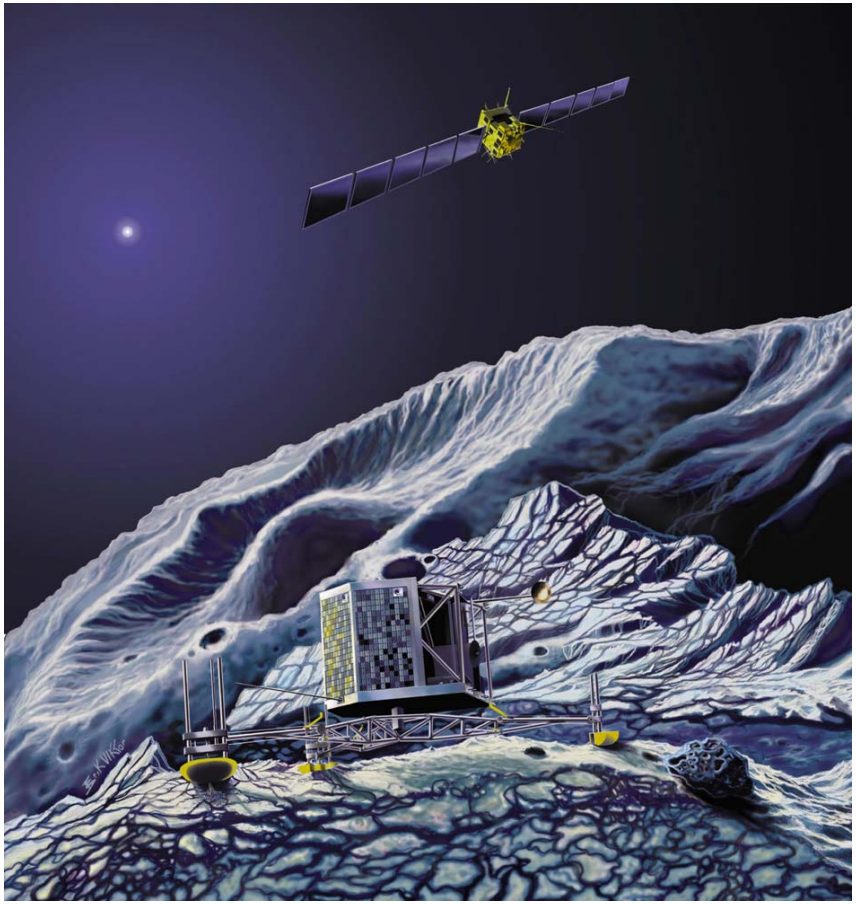
- 1Hz-50Hz seismometers
- < milli-g sensible accelerometers
- natural waves from
  - thermal response to sun heat
  - gravitational tides at perigee
- waves induced by MIRZA impact



Courtesy David Mimoun

Radio Sounding

- Radio sounder inherited from CONSERT/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

L17

Still used after more than 30 years

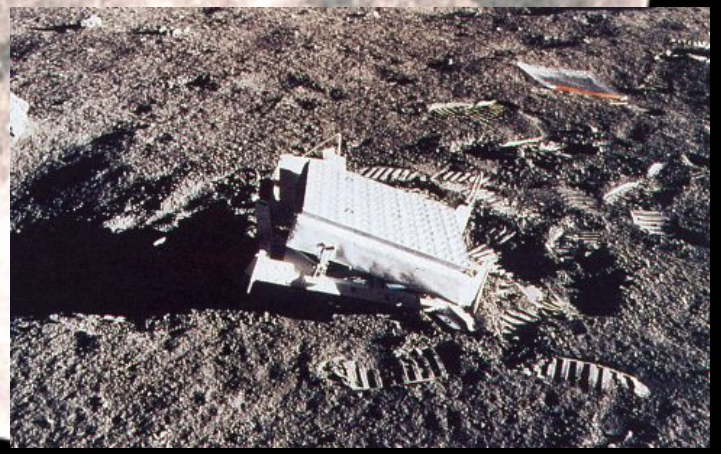
< Meter level accuracy

No power needed on the reflector

Can be used only during the approach of APOPHIS

A14

A11



Preliminary Mass Budget

	Item	Mass (kg)	Remark
Launch capacity		**6500**	**ARIANE 5 ECA /Kourou**
Launched mass		**5000**	
	Transfer Module	**4800**	
	Dry mass	**550**	
	Fuel	**4250**	**Isp 325 s**
	MIRZA	**200**	
	Dry mass	**90**	
	Fuel	**40**	
	SISMOD	**70**	**Including 50kg P/L**
Launch Margin		**1500**	

Further Studies

Phase	Main actions	Constraints	Outcomes
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 iniatives**
  - **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