Asteroid Tracking using Optical Beacons

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Golden, CO

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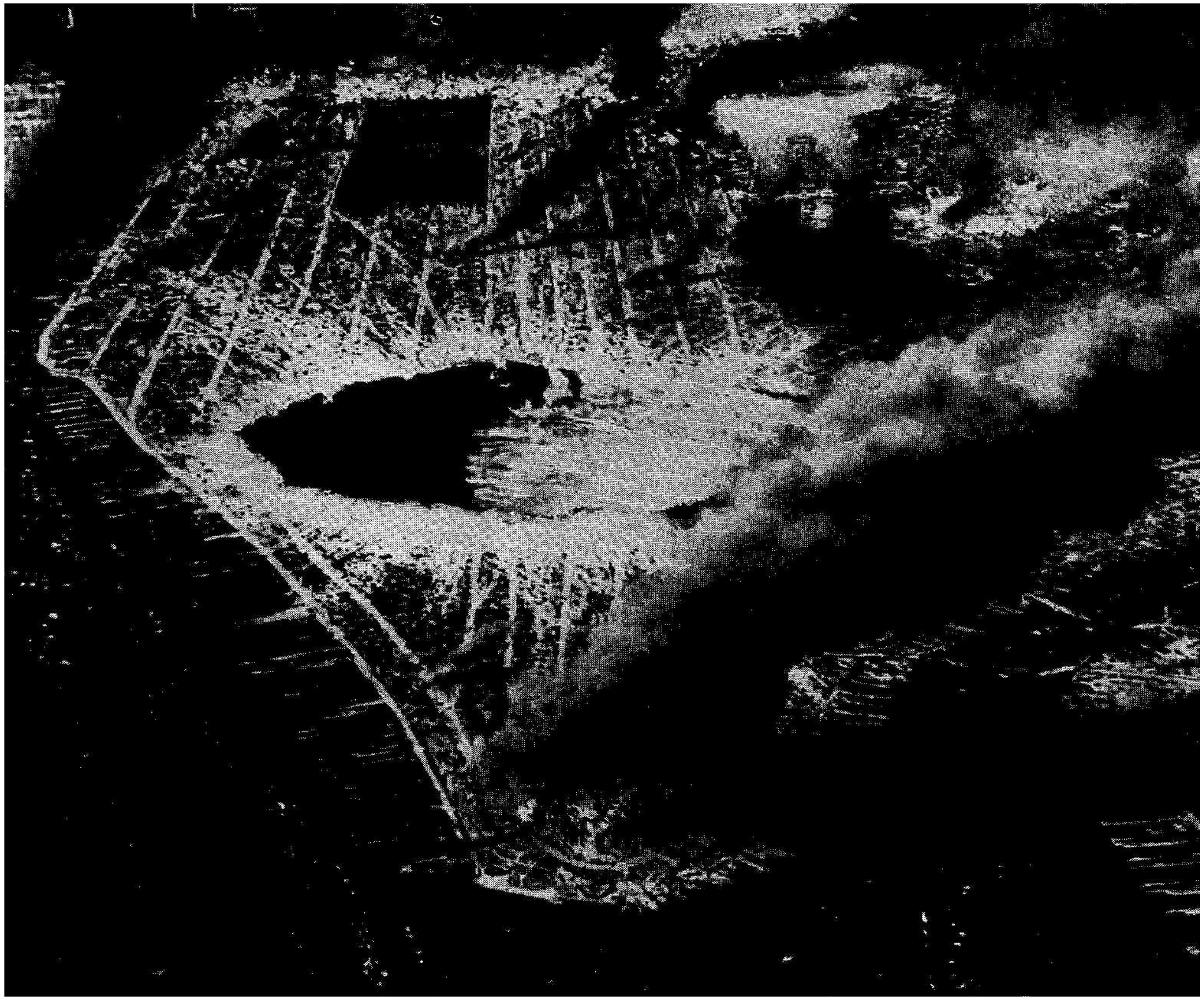
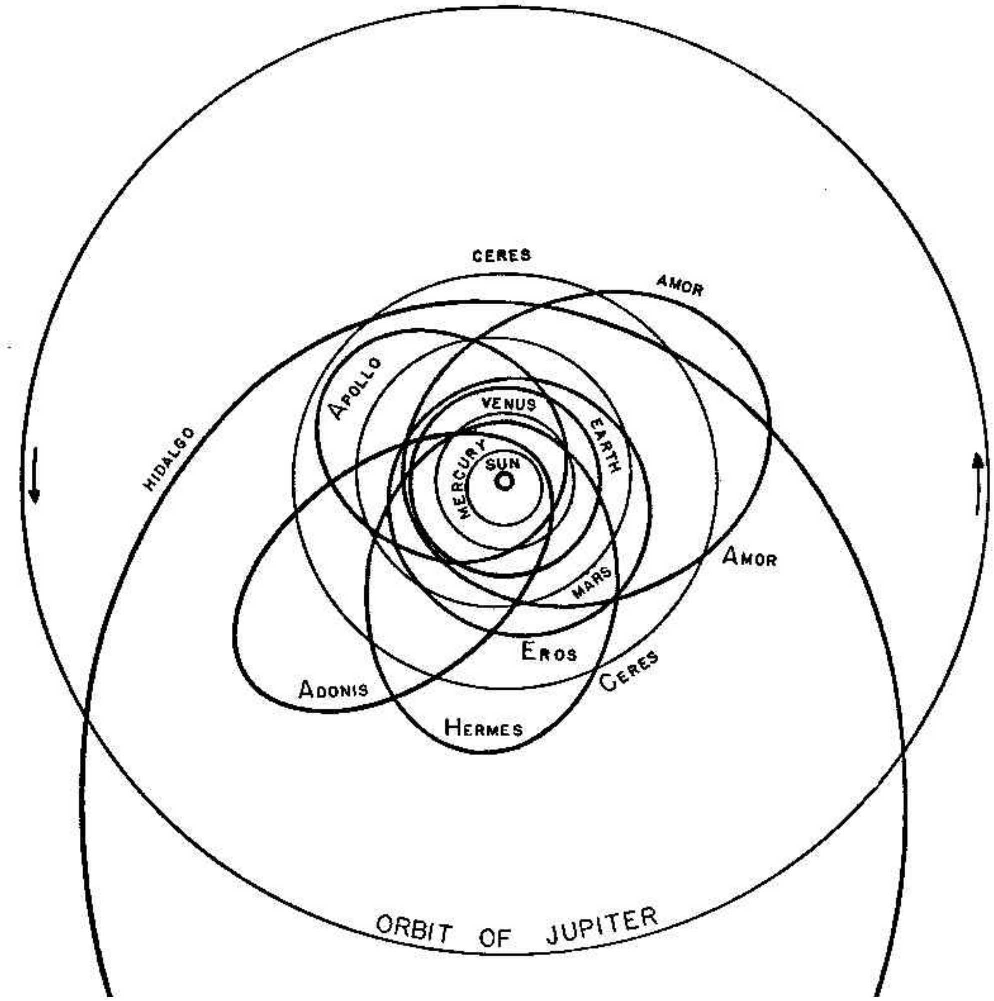
Why Track Asteroids?



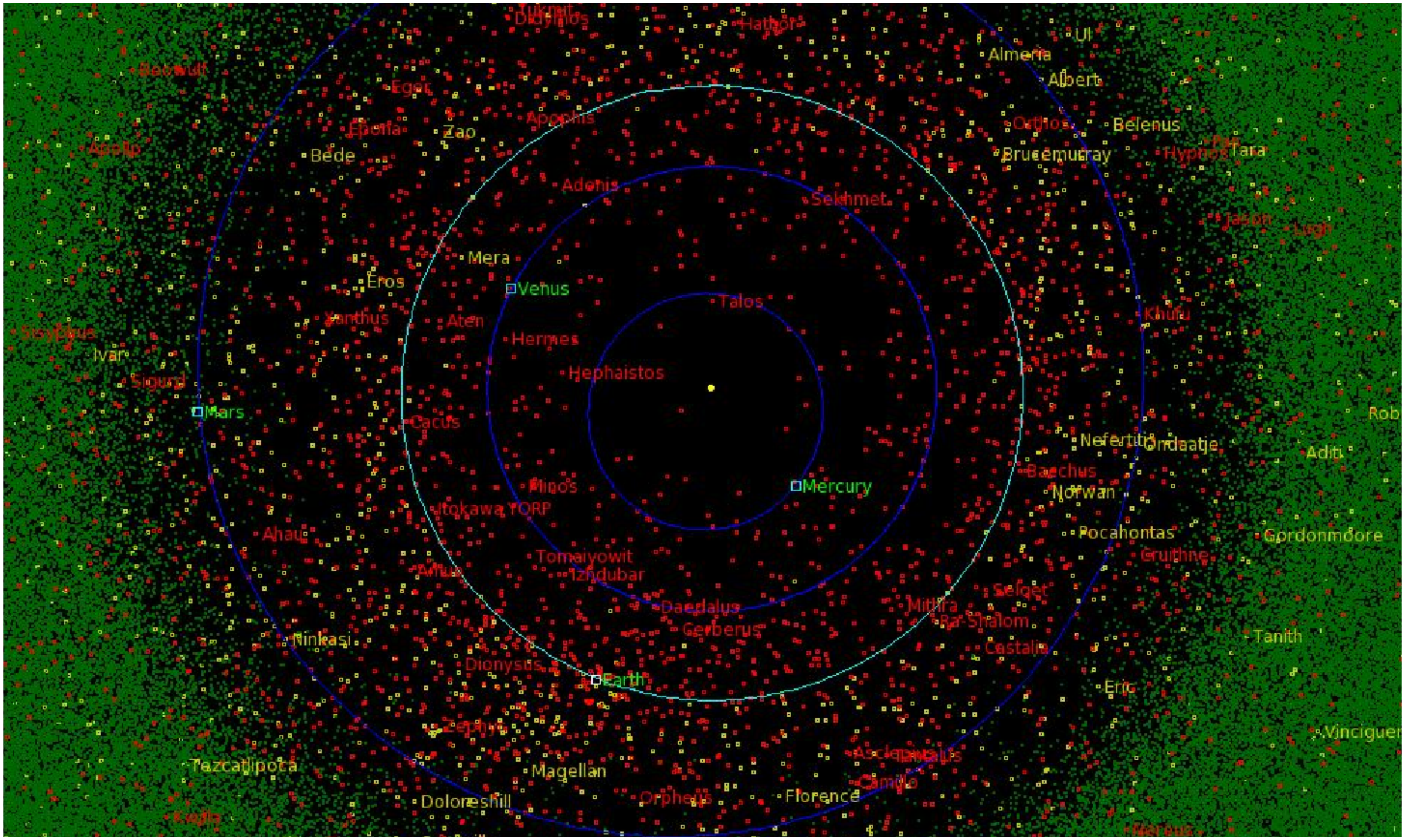
Artists Impression of what would happen if an Asteroid about 50 meters in diameter hit Manhattan Island

Bonestell, 1950

What We Used To Know About Asteroids

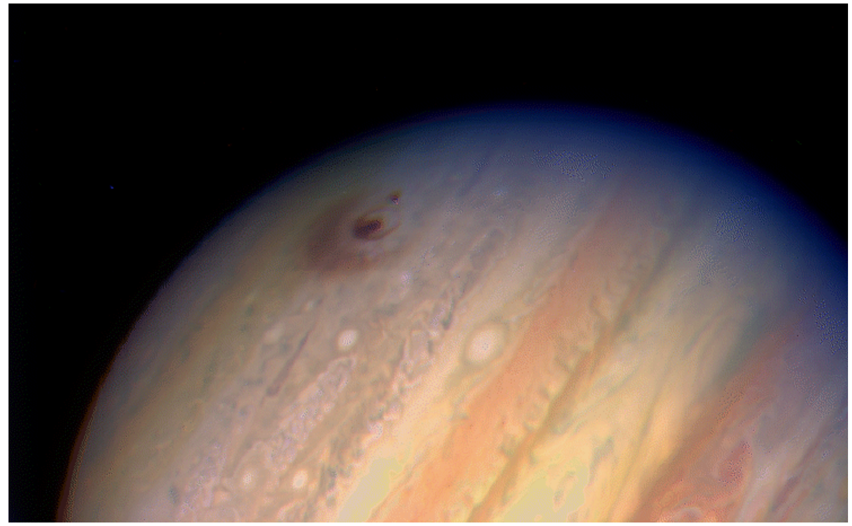


What We Now Know About Asteroids



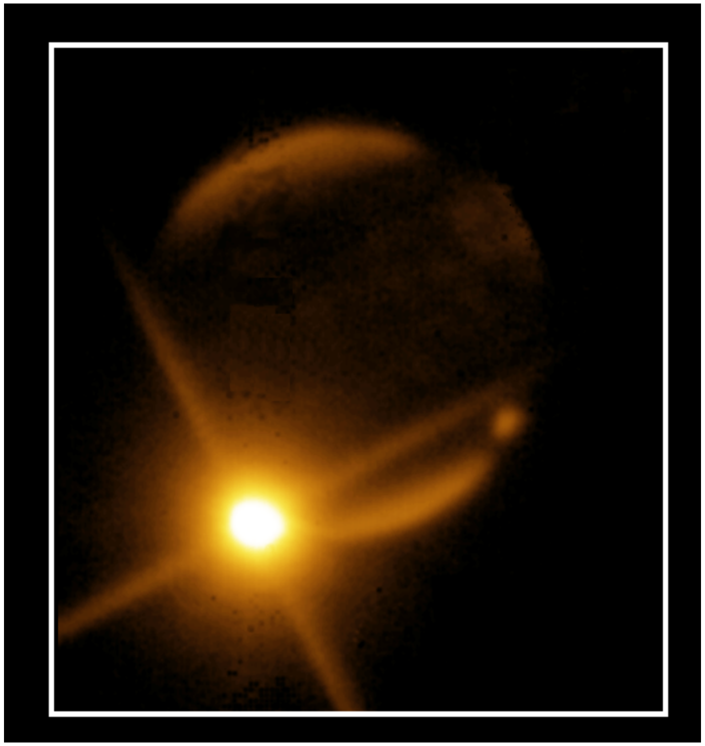
Green: Asteroid Belt **Yellow:** Amors **Red:** Apollo and Aten

Armagh Observatory, 2008



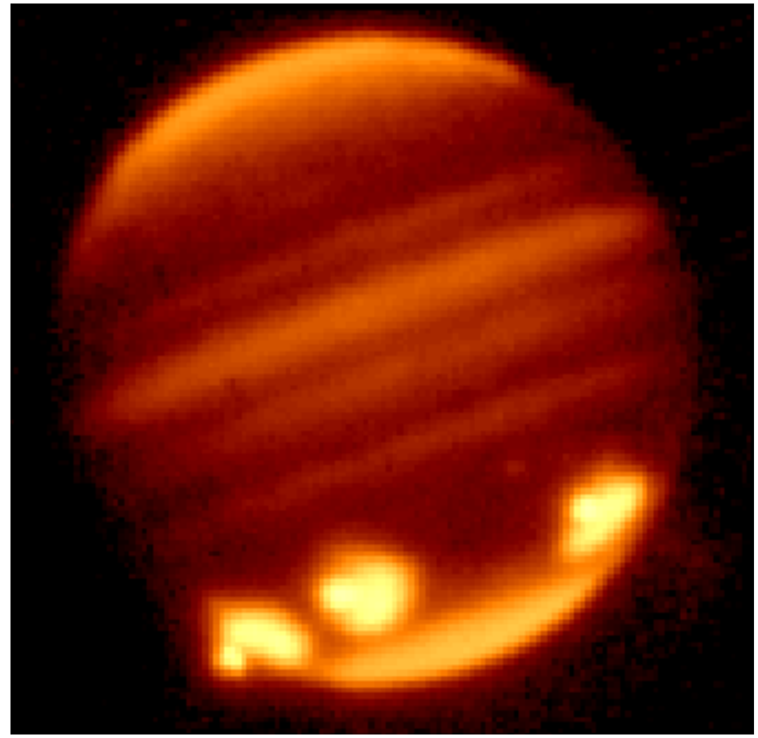
Shoemaker-Levy 9 Event, July 1994

NASA/HST 1994



Fragment G at 2.34 microns

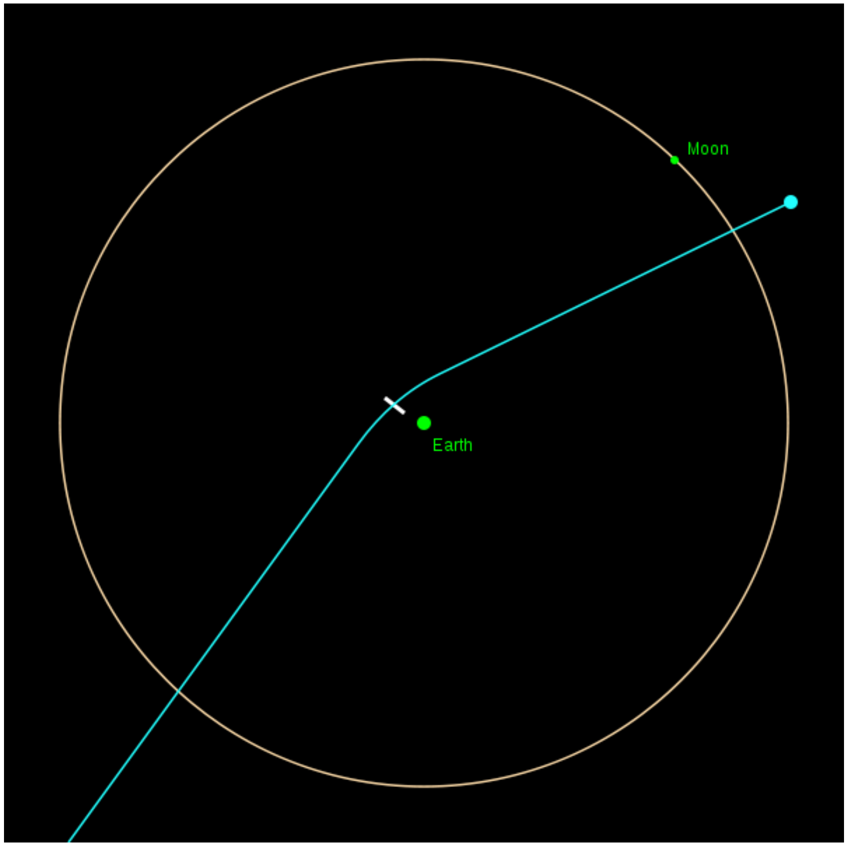
McGregor, 1994



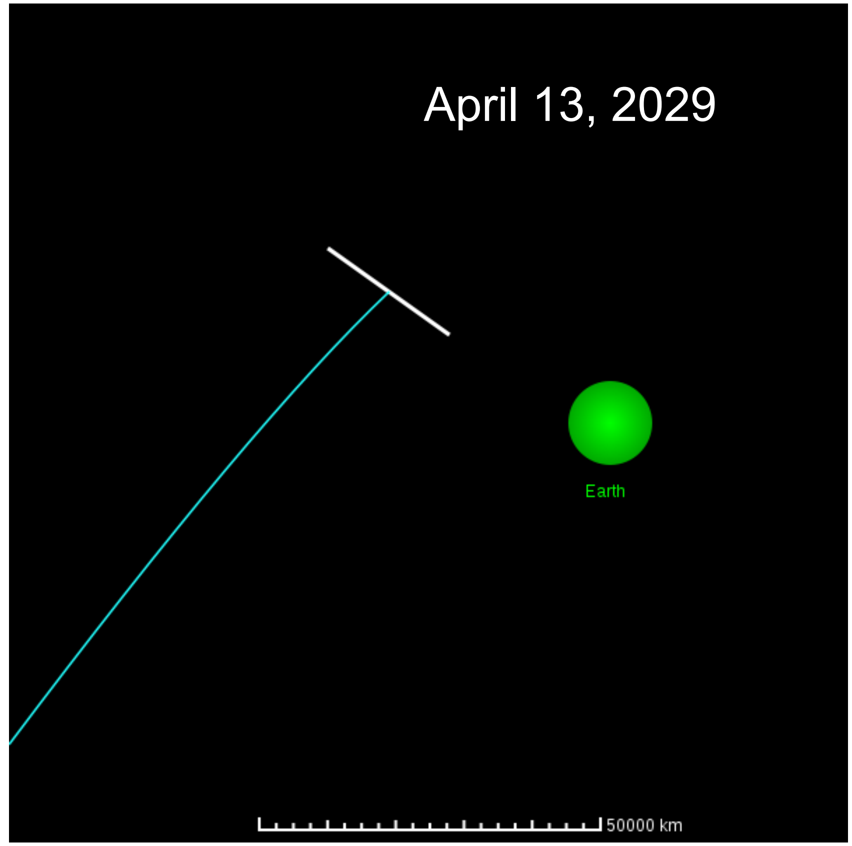
Multiple Fragments at 9 microns

NASA, 1994

Shoemaker-Levy 9 Event, July 1994

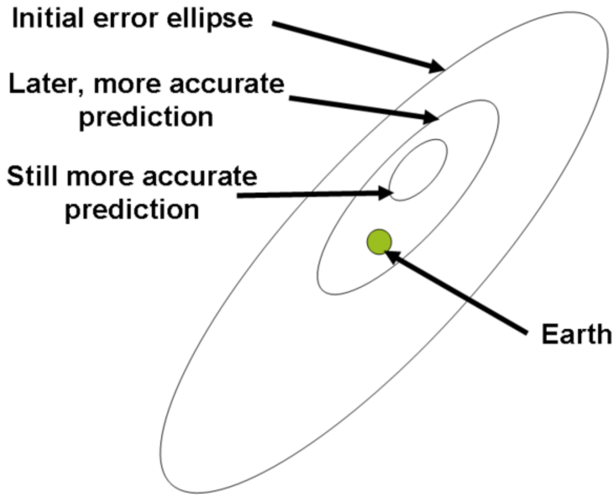


Polo, 2004



Polo, 2004

Asteroid 99942 Apophis



Scheffer, 2008

Possible Impact Sites in 2036 after “keyhole” interaction

Mariordo, 2008

Asteroid 99942 Apophis

A Tracking Beacon
In Orbit / on the Surface
of 99942 Apophis
would permit prediction
of possible keyhole interaction

Types of Asteroids

Composition

(Reflectance Spectra)

Shape

(Light Curve)

Asteroid Composition Classification

(early 1970’s)

C – Carbonaceous Chondritic ~75%

S – Stony Iron ~15%

M – Metallic

U - Unclassified

Asteroid Composition Classification -continued

(early 1990’s)

C,S,M,D,F,P,G,E,B,T,A,V,Q,R

← Increasing Abundance

Asteroid Shape (Light Curve)

Variations usually small

0.2 – 0.4 magnitude

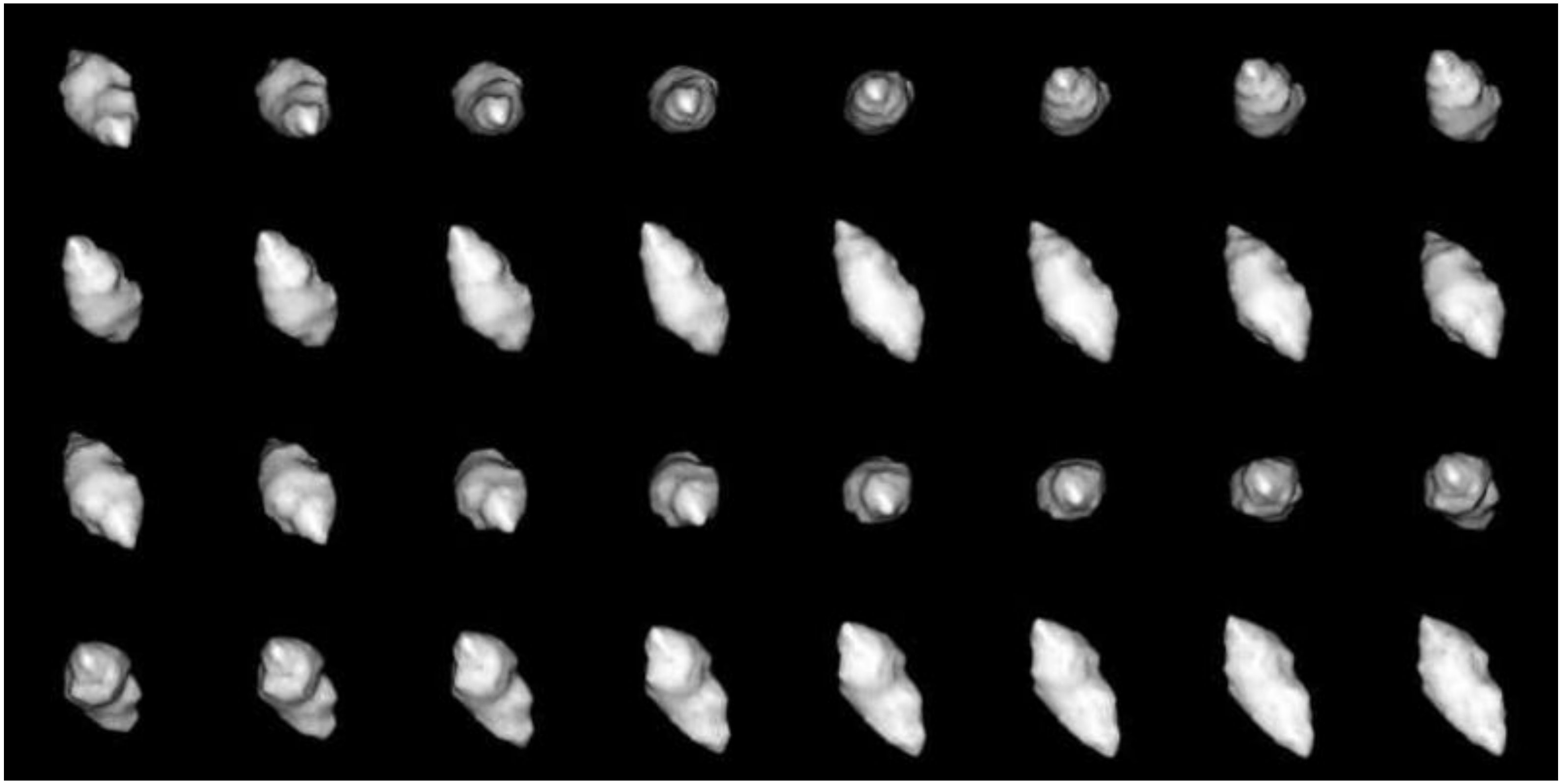
Largest 1620 Geographos 2.03 magnitudes

Most Rotation Periods between 6 and 13 hours

Fastest 1998 KY26 – 10.7 minutes

Slowest 288 Glauke – 47 days

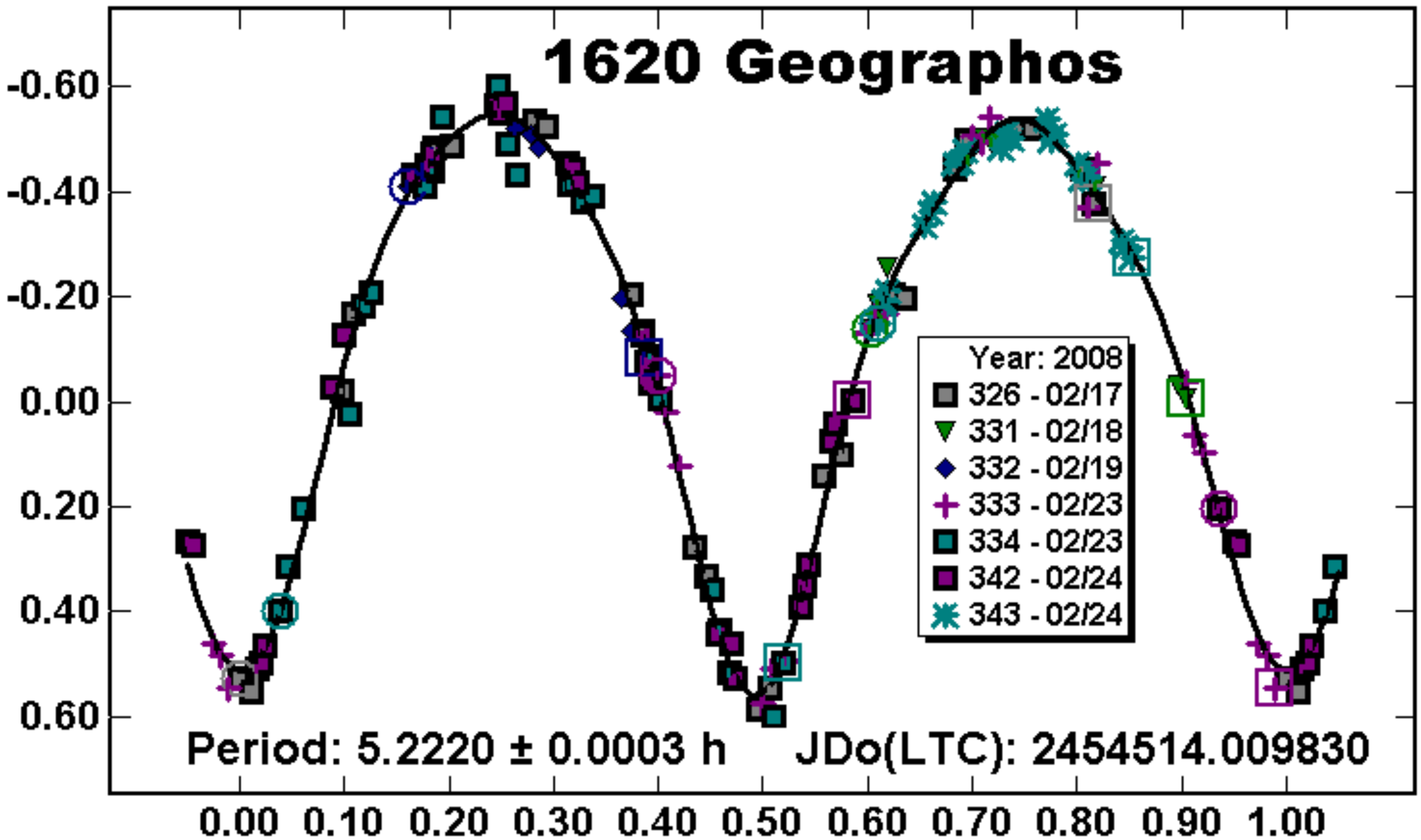
Asteroid Shape (Light Curve)



Asteroid 1620 Geographos

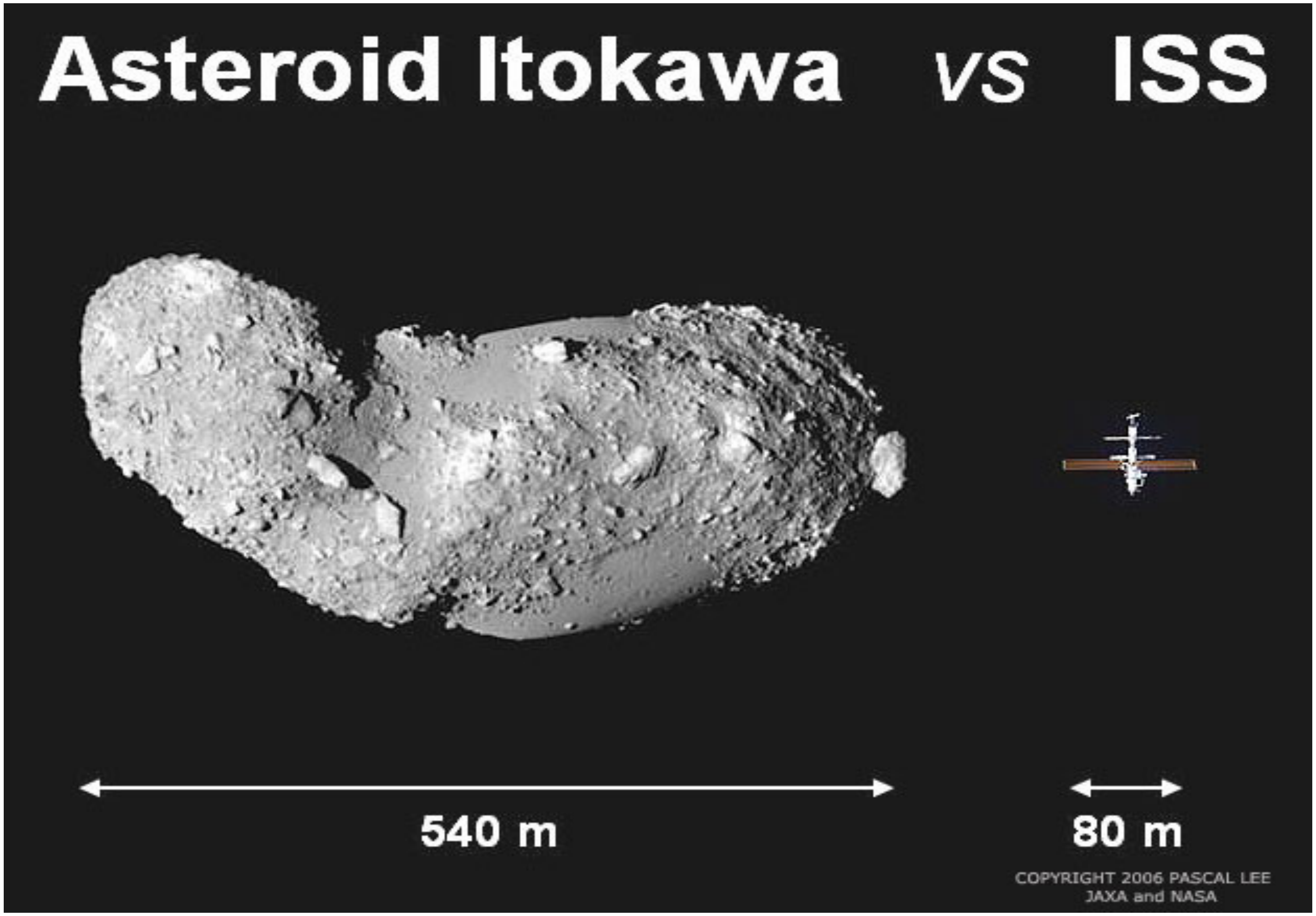
Hudson, 2004

Light Curve of 1620 Geographos

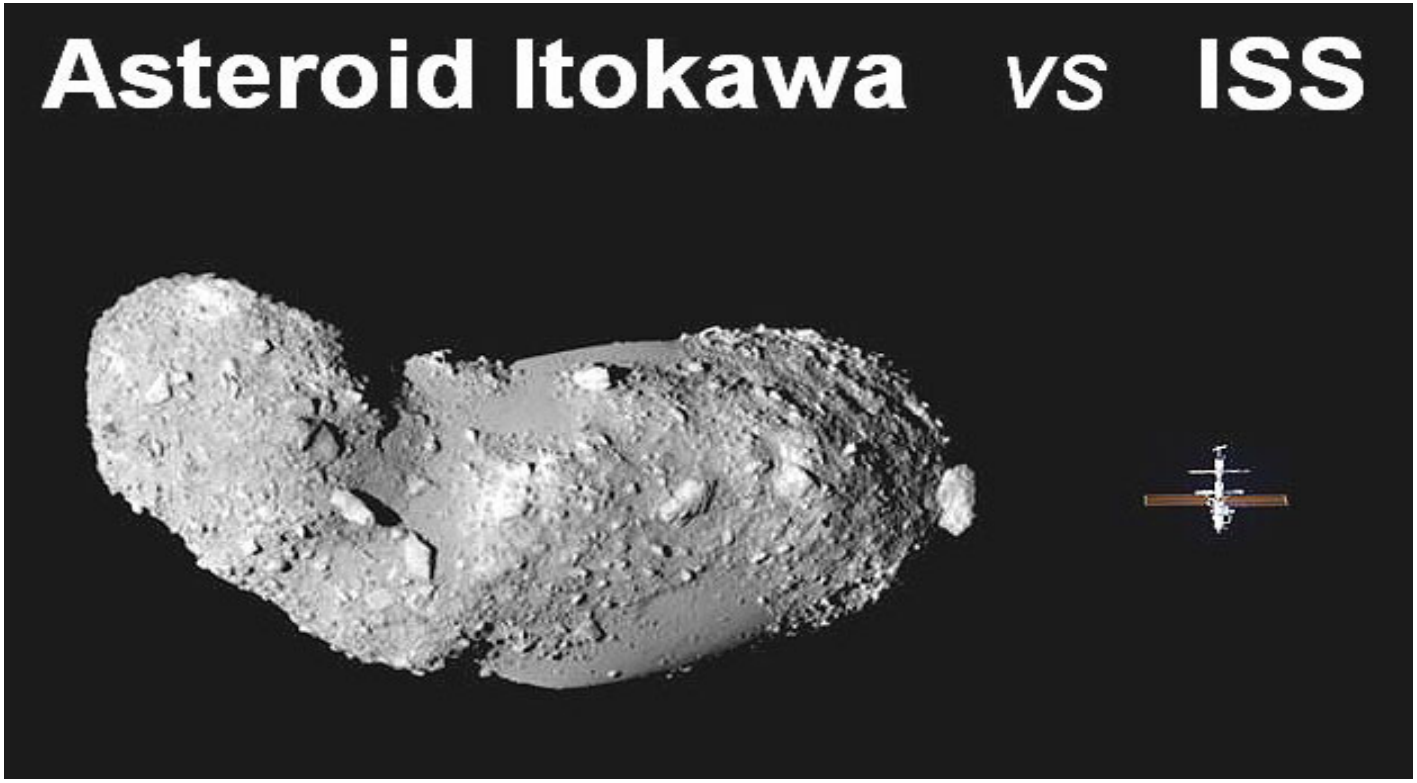


Bembrick, 2008

Asteroid 25143 Itokawa

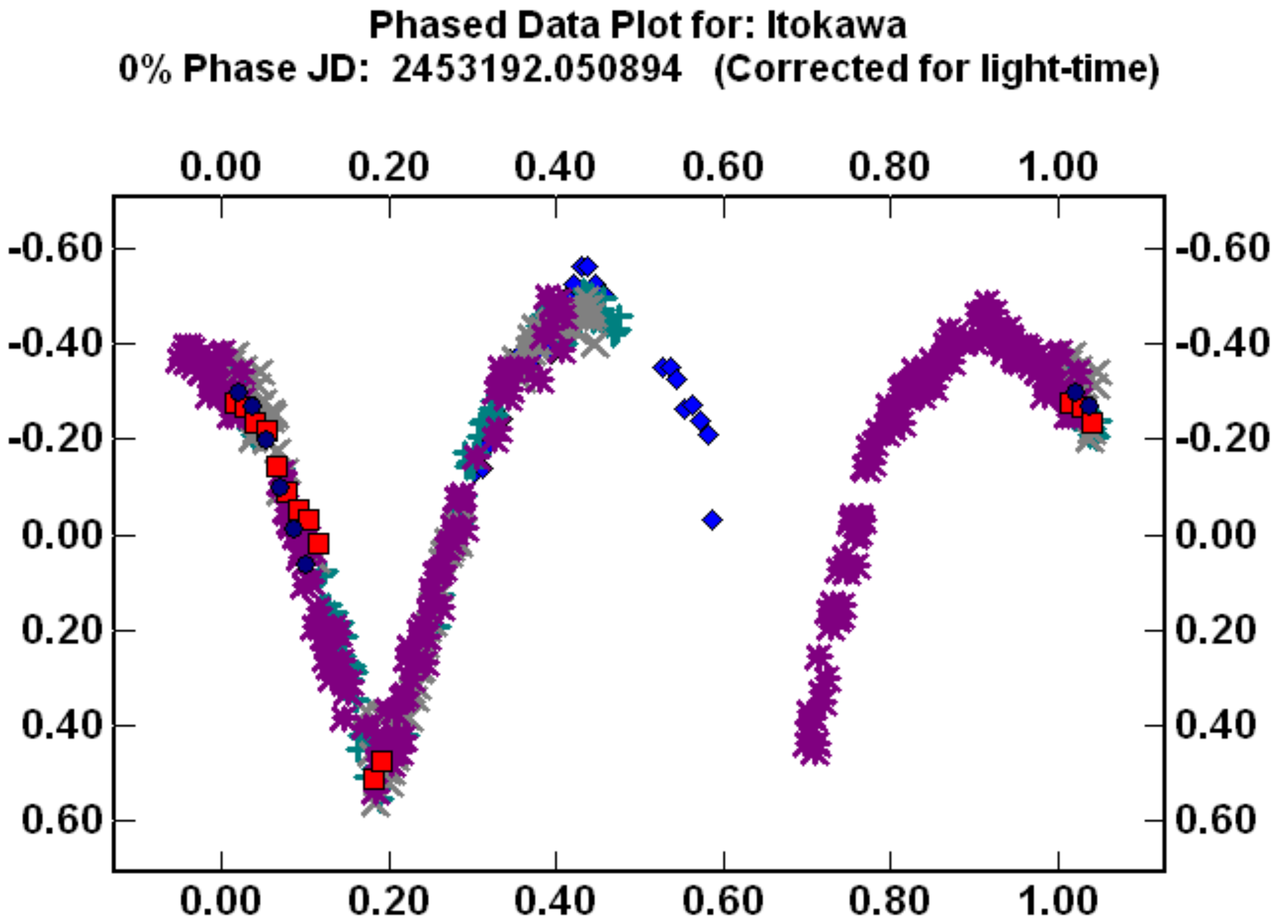


Asteroid 25143 Itokawa



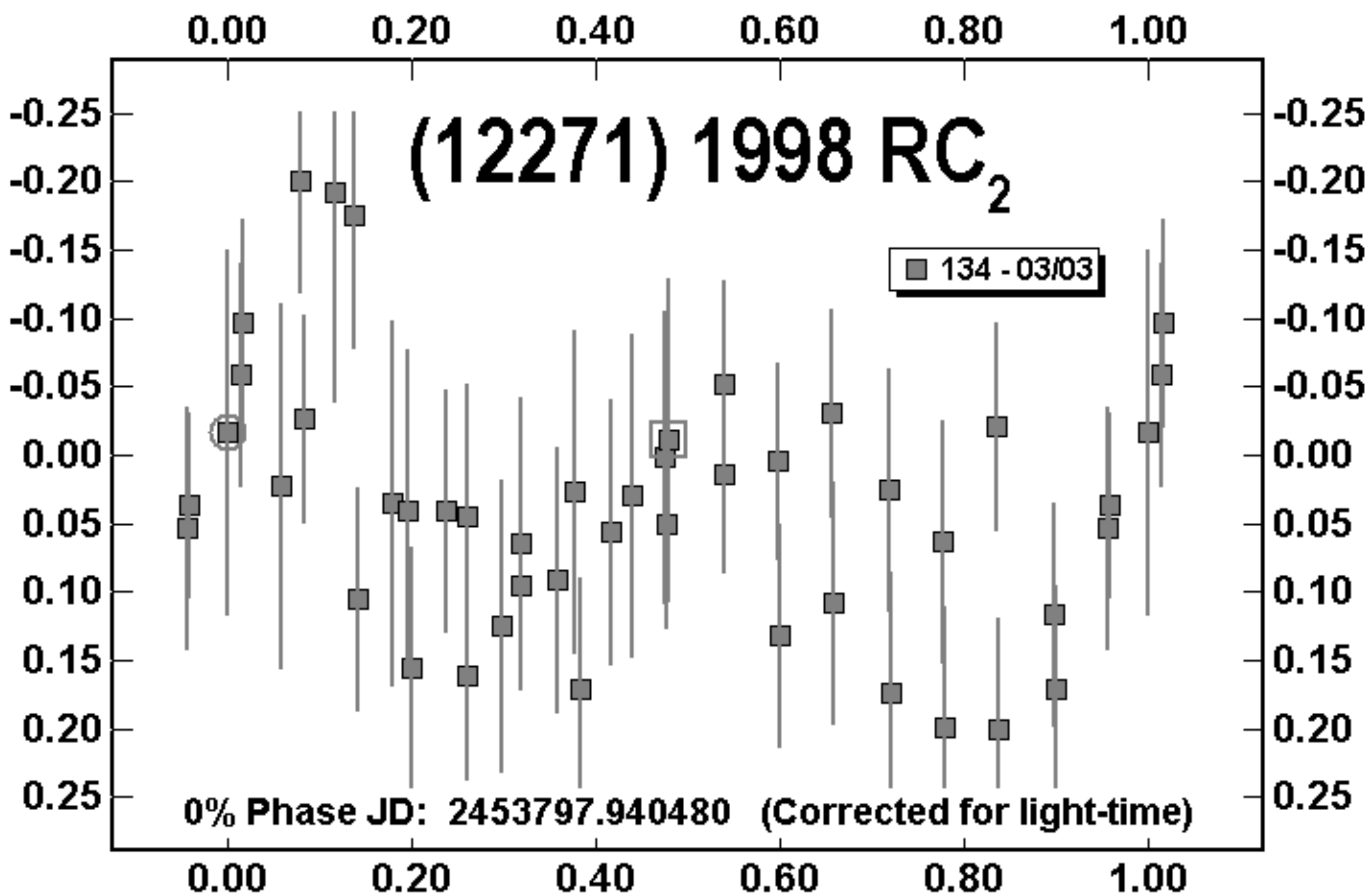
You can't park that here!

Light Curve of 25143 Itokawa



Bembrick, 2004

Example of a Complex Light Curve



Bembrick, 2006

Some Near Earth Fly-bys or Closest Approach for the month of May 2010

May 5 – Asteroid 2010 GGU21 ($1.86X10^6$ mi.)

May 5 – Asteroid 2010 FA81 ($4.19X10^6$ mi.)

May 5 – Asteroid 2010 HS20 ($7.25X10^6$ mi.)

May 7 – Asteroid 2009 BD ($2.14X10^6$ mi.)

May 9 – Asteroid 2010 GA24 ($4.46X10^6$ mi.)

May 11 – Asteroid 2005 JR5 ($5.67X10^6$ mi.)

Some Near Earth Fly-bys or Closest Approach for the month of May 2010 - continued

May 19 – Asteroid 2003 QC10 ($8.28X10^6$ mi.)

May 20 – Asteroid 2010 JM33 ($2.79X10^6$ mi.)

May 20 – Asteroid 11055 Honduras ($91.6X10^6$ mi.)

May 21 – Asteroid 2010 GA34 ($3.07X10^6$ mi.)

May 21 – Asteroid 1865 Cerberus ($31.1X10^6$ mi.)

May 23 – Asteroid 9969 Braille ($39.7X10^6$ mi.)

Previous / Present Missions to Asteroids

Near Earth Asteroid Rendezvous - Shoemaker

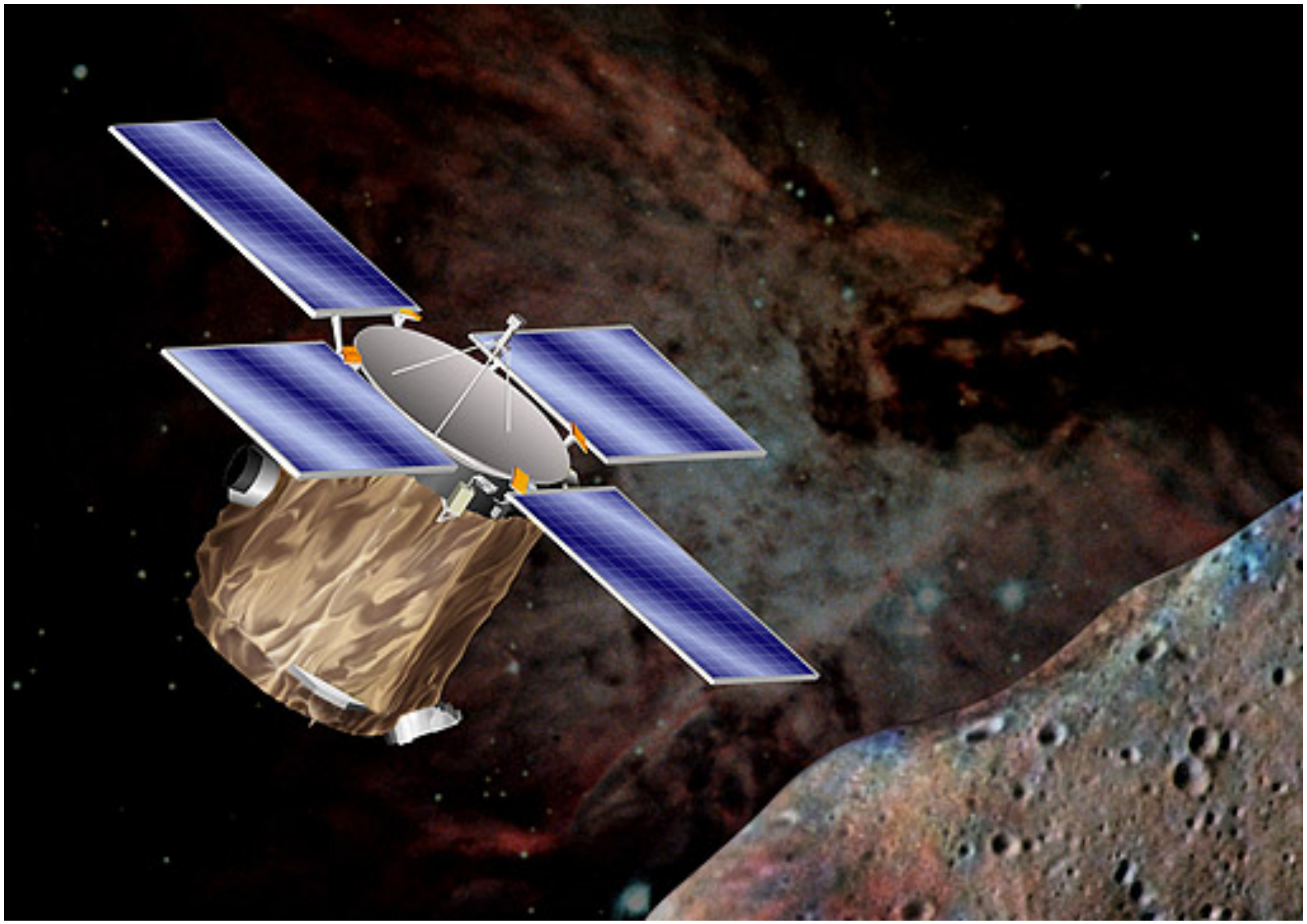
Launched Feb. 27, 1996

Fly By Asteroid Mathilde, June 27, 1997

Landed on Asteroid Eros, Feb. 28, 2001

Contact Lost

Near Earth Asteroid Rendezvous - Shoemaker



NASA/GSFC 1996

Previous / Present Missions to Asteroids

Hayabusa

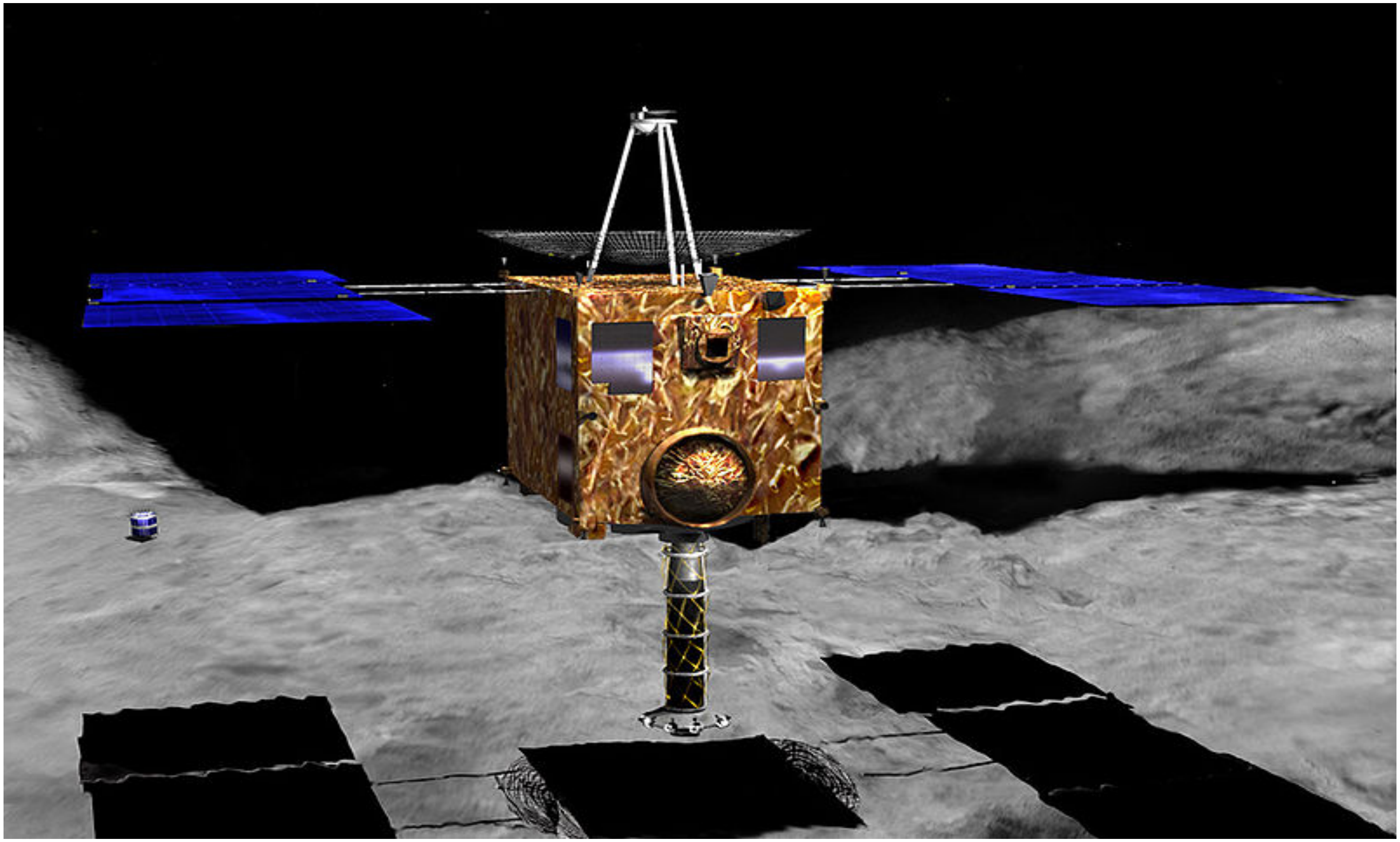
Launched May 9, 2003

Visited Asteroid Itokawa

Sample Acquired?

En Route back to Earth

Hayabusa



Garry, 2000

Previous / Present Missions to Asteroids

Rosetta

Launched March 2, 2004

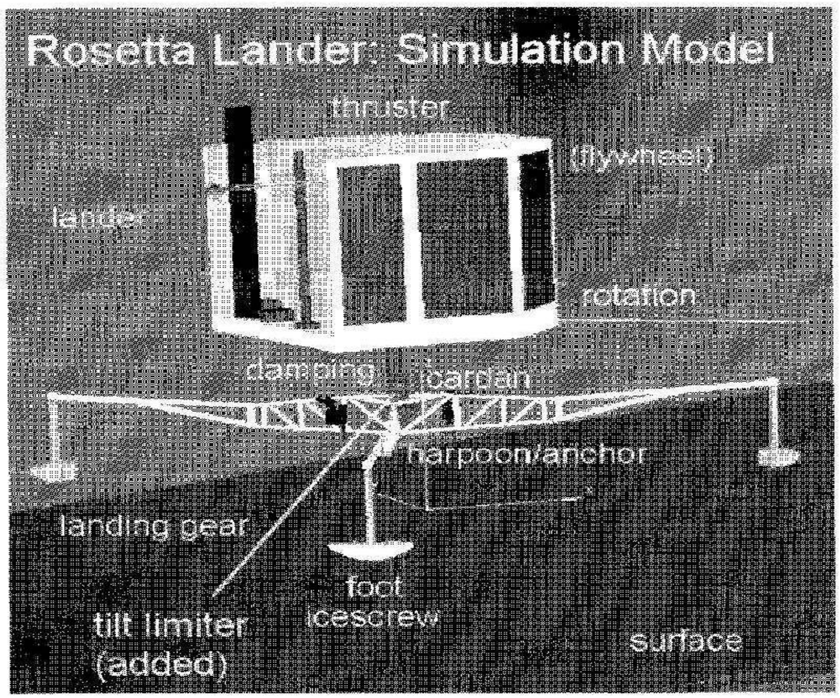
En Route to Fly-Bys of:

Asteroid 21 Lutetia

Asteroid 2867 Steins

Landing on Comet 67P/Churyumov-Gerasimenko

Rosetta



Colangeli, et al., 2004

Asteroid Tracking Beacon Design considerations

Communications Link

RF / Optical

Lander / Orbiter

Solar Powered

(Inner Solar System)

RF / Optical Comparisons

Narrow Beamwidth

$$\theta = 2.24\, \lambda / D$$

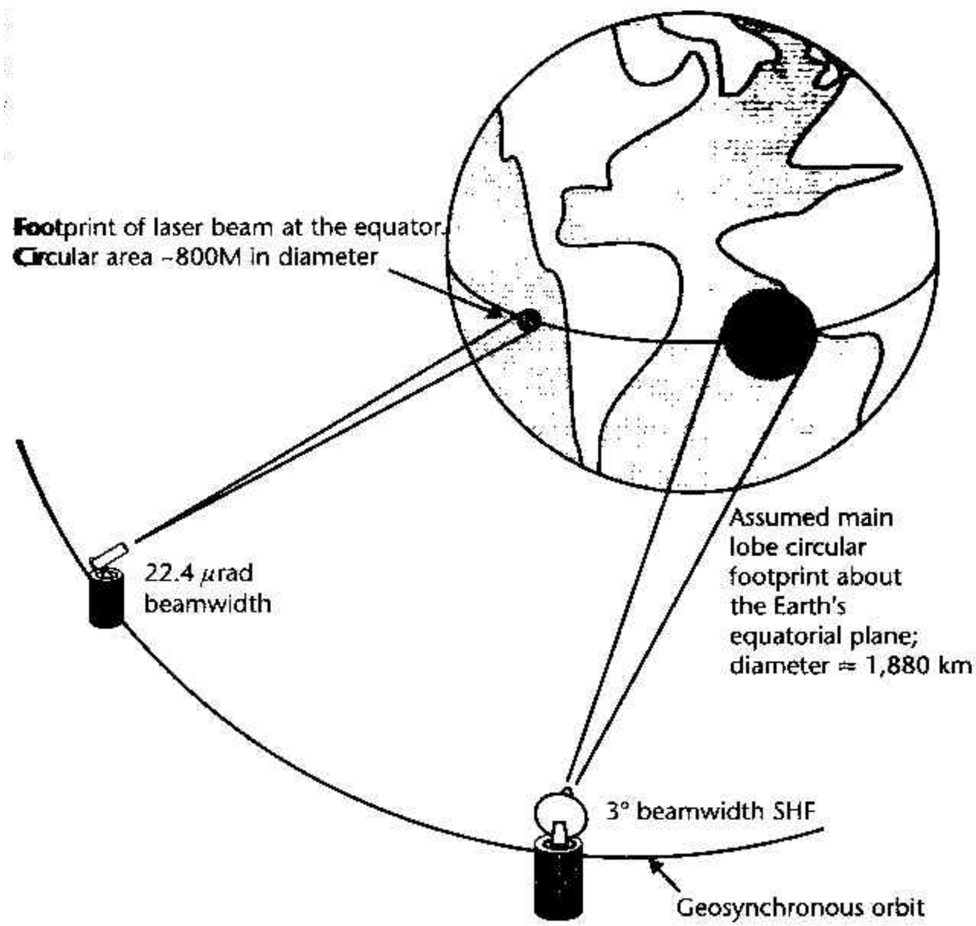
Aperture Gain

$$G = 10 \log_{10} (\pi D / \lambda)^2$$

where: λ is Wavelength

D is Aperture Diameter

RF / Optical Comparisons - Beamwidth



Optical:

λ = 1.0 um

D = 10 cm

R/F:

λ = 3 cm

(10 GHz)

D = 1.0 m

Aviv, 2006

RF / Optical Comparisons - Gain

RF:

λ = 3 cm, (10 GHz), D = 1.0 m

Aperture Gain = 40.4 dBi

Optical:

λ = 1.0 um, D = 10 cm

Aperture Gain = 109.94 dBi

RF / Optical Comparisons

Relevant Design Example:

Mars to Earth Optical Data Link

30 cm Mars Transceiver Aperture
10 m Earth Ground Station
1064 nm wavelength
5 Watt Transmitter Power
2.7 AU Range (251.1 X 10^6 mi)

Consequences of a More Compact Design

Reduced Payload Size and Mass

Smaller, Less Expensive Launch Vehicle

Multiple-Payload Bus Option

Additional Potential Capabilities

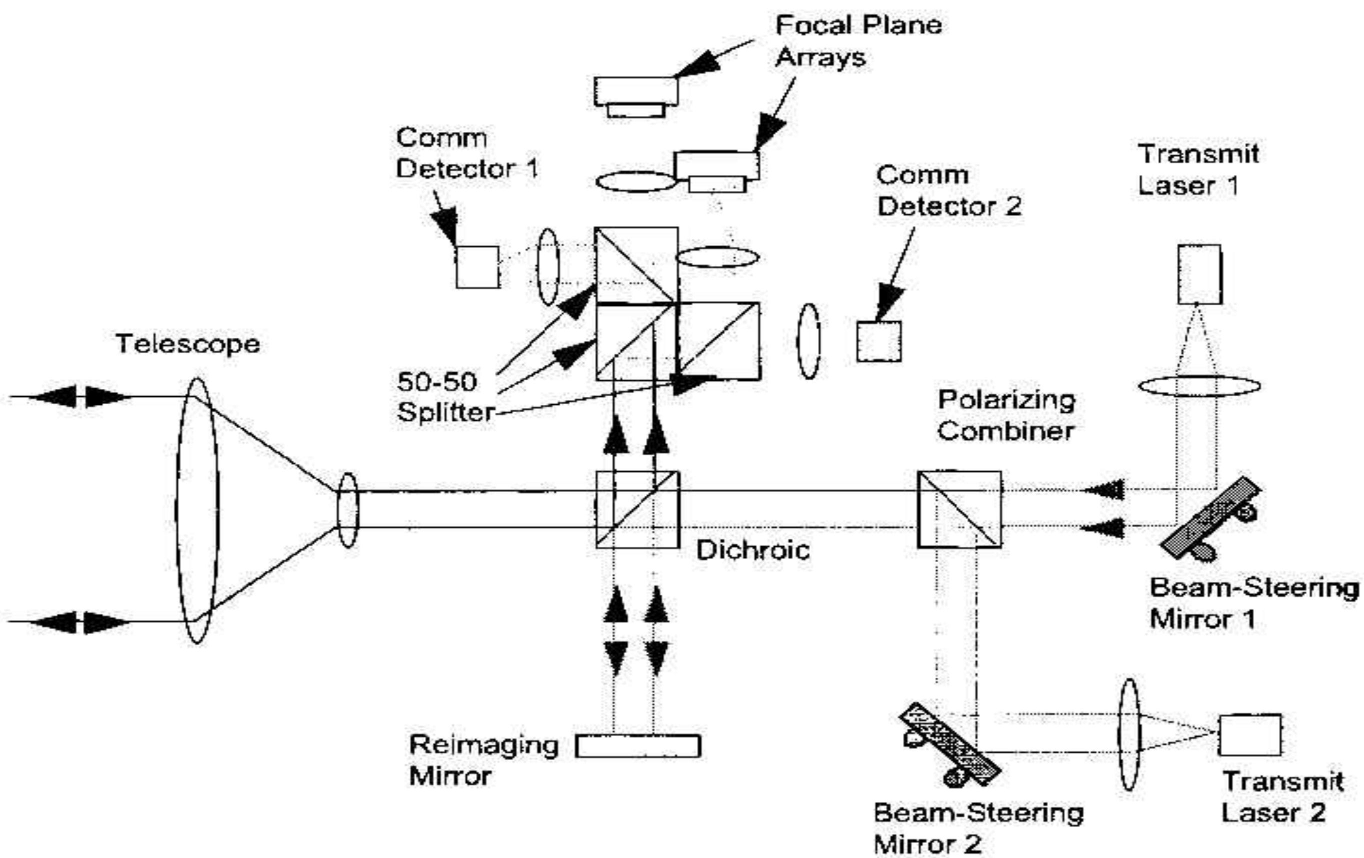
Beacon

Imaging / Hyperspectral

Other Sensing (Neutron Backscatter)

Space Weather Outpost

Examples of Flight Hardware



Hemmati, 2006

Examples of Flight Hardware

10 cm Aperture

1064 nm Xmit

532 nm Rcv

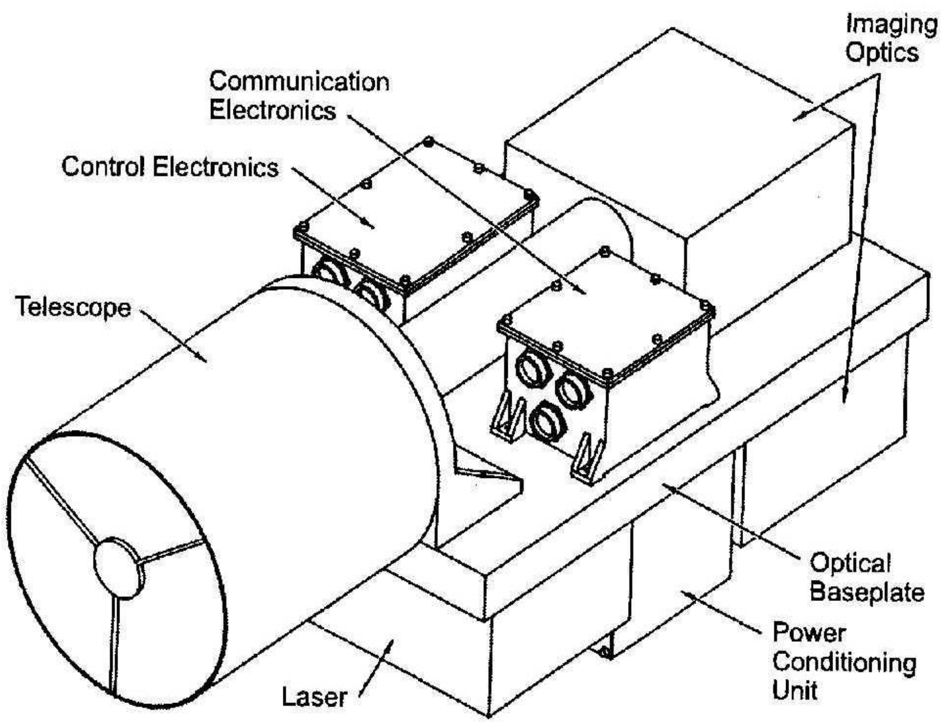
70 Watt Laser

~470 Watts
overall

JPL Optical Communication Demonstrator

Hemmati, 2006

Examples of Flight Hardware



28 cm Aperture

532 nm Xmit

1064 nm Rcv

400 mW Laser

52 kg

57 Watts

Optical Transceiver Package (OPTRANSPAC)

United States Air Force 1984

Hemmati, 2006

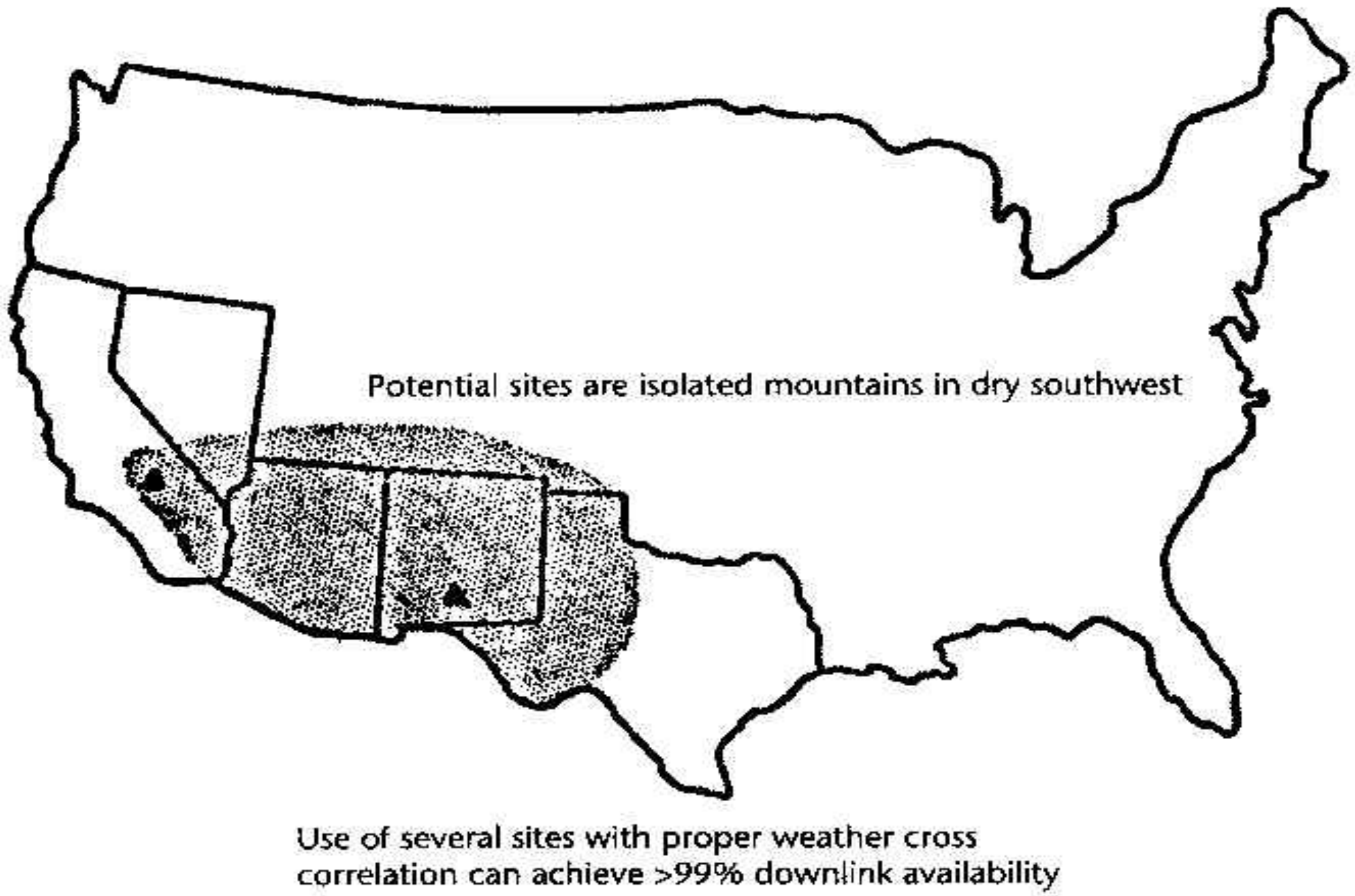
Ground Stations

1. Apache Mountain, NM
2. Apache Peak, AZ
3. Atascosa Peak, AZ
4. Baldy Peak, AZ
5. Big Hatchet Peak, NM
6. Black Top Mountain, NM
7. Capitan Mountains, NM
8. Capitol Peak, NM
9. Chiracahua Peak, AZ
10. Emory Peak, TX
11. Guadalupe Mt. Range, NM
12. Kingston Peak, CA
13. Luera Peak, NM
14. Millers Peak, AZ
15. Mt. Wrightson, AZ
16. Nogal Peak, NM
17. Oscura Peak, NM
18. Panamint Range, CA
19. Rose Peak, AZ
20. Sacramento Mountains, NM
21. Salinas Peak, NM
22. San Andreas Peak, NM
23. Sierra Blanca, NM

Selection Based on Dry Weather and Transportation Accessibility

Aviv, 2006

Ground Stations

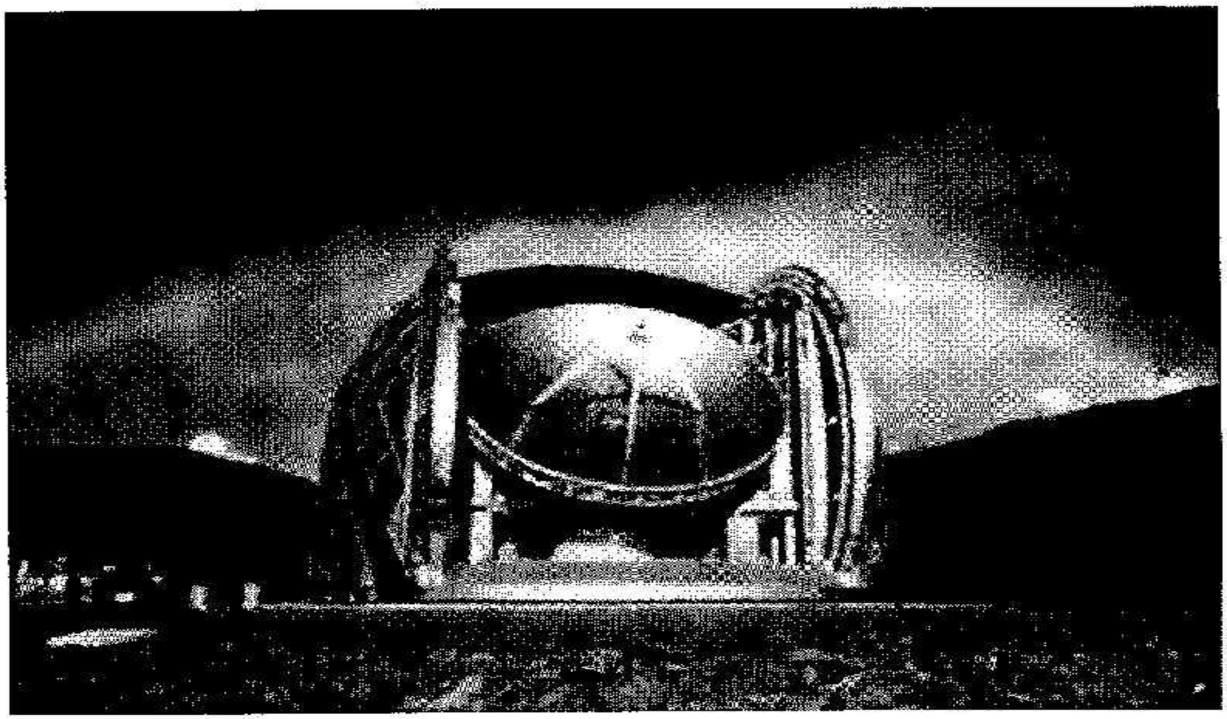


Aviv, 2006

Ground Stations

Aviv, 2006

Ground Stations

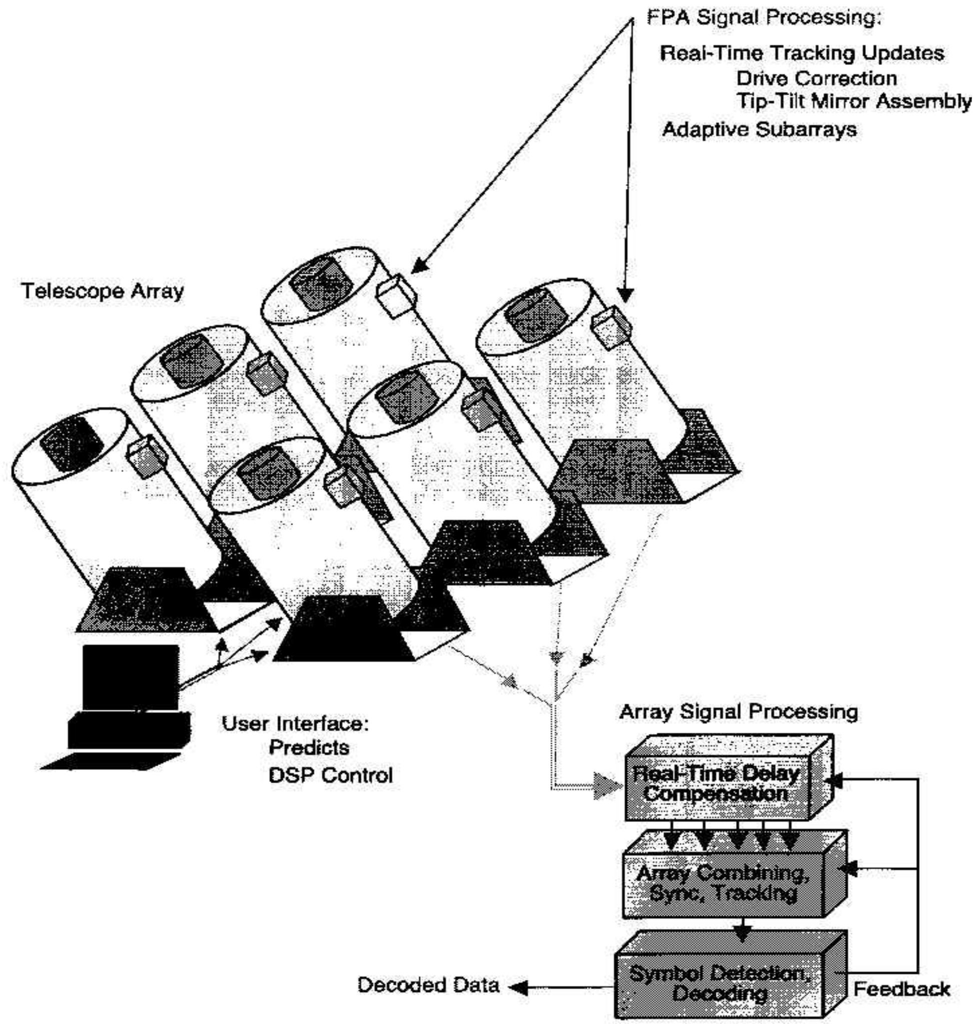


10.4 m Leighton Dish, Mauna Kea, Hawaii

Operated by Caltech

Hemmati, 2006

Ground Stations



Hemmati, 2006

Potential Response to Threatening Asteroids

Nature of Response Depends

Time Available to

Take Action

Potential Response to Threatening Asteroids

If Time is Very Short

Potential Response to Threatening Asteroids

If Time is Very Short

Run Away

Potential Response to Threatening Asteroids

If Time is Very Short - *Run Away*

If Time is Short

Potential Response to Threatening Asteroids

If Time is Very Short – *Run Away*

If Time is Short – *Blow it Up*

Potential Response to Threatening Asteroids

If Time is Very Short – *Run Away*

If Time is Short – *Blow it Up*

If Time is Moderate

Potential Response to Threatening Asteroids

If Time is Very Short – *Run Away*

If Time is Short – *Blow it Up*

If Time is Moderate – *Push it Aside*

Potential Response to Threatening Asteroids

If Time is Very Short – *Run Away*

If Time is Short – *Blow it Up*

If Time is Moderate – *Push it Aside*

If Time is Long

Potential Response to Threatening Asteroids

If Time is Very Short – *Run Away*

If Time is Short – *Blow it Up*

If Time is Moderate – *Push it Aside*

If Time is Long – *Eat it*

Asteroids as a Resource

Convenient Orbits (NEO)

Very Low Gravity Well

Abundant Solar Power

Asteroids as a Resource

Don’t Blow Up

The Hardware Store

Conclusions

Tracking Beacon Orbiter/Lander provides the ability to improve the precision of an Asteroid's trajectory

An Optical Beacon focuses more Transmitter Energy in a tighter Beam with a smaller Aperture than a RF approach

Conclusions

Reduction in Payload Size and Mass permits the use of smaller, less expensive Launch Vehicle

Opportunity for Multi-Mission Bus design

Don't Let This Happen to *Your* Planet

Ggsphere, 2009