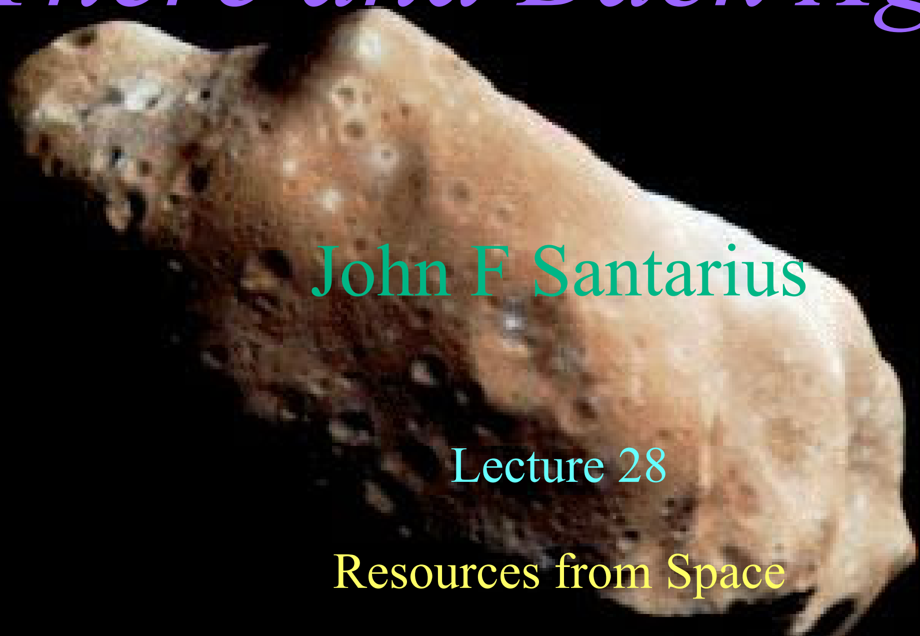
Travel to Asteroids and Moons

There and Back Again!



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Lecture 28

Resources from Space

NEEP 533/ Geology 533 / Astronomy 533 / EMA 601

University of Wisconsin

November 7, 2001

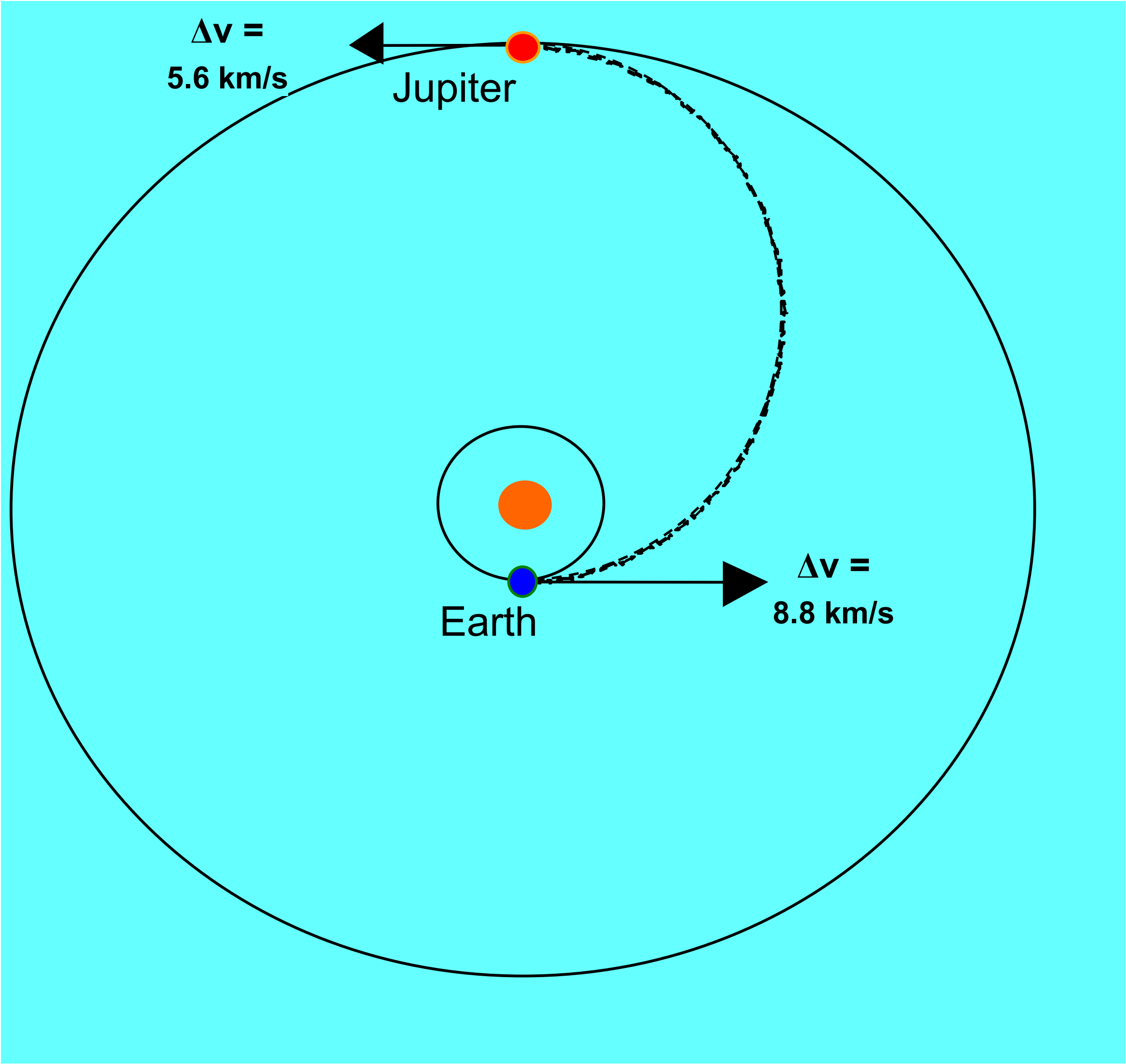
Launching from Moons Is Relatively Easy, but Planetary Gravitational Fields Can Be Large

Moon	***Surface escape Δv (km/s)***	***Planet escape Δv (km/s)***
Moon (Earth)	2.37	1.44
Io (Jupiter)	2.56	24.5
Europa (Jupiter)	2.02	19.4
Ganymede (Jupiter)	2.74	15.4
Callisto (Jupiter)	2.44	11.6
Titan (Saturn)	2.54	7.88

Escape from Planetary "Surfaces" Can Be Difficult

Planet	*Surface escape Δv (km/s)*	*Sun escape Δv (km/s)*
Mercury	4.25	67.7
Venus	10.4	49.6
Earth	11.2	42.1
Mars	5.03	34.1
Jupiter	59.6	18.5
Saturn	35.5	13.7
Uranus	21.4	9.62
Neptune	23.8	7.69
Pluto	0.97	6.71

Hohmann (Minimum-Energy) Two-Impulse Transfer



Characteristics of Hohmann Transfers from Earth into the Solar System

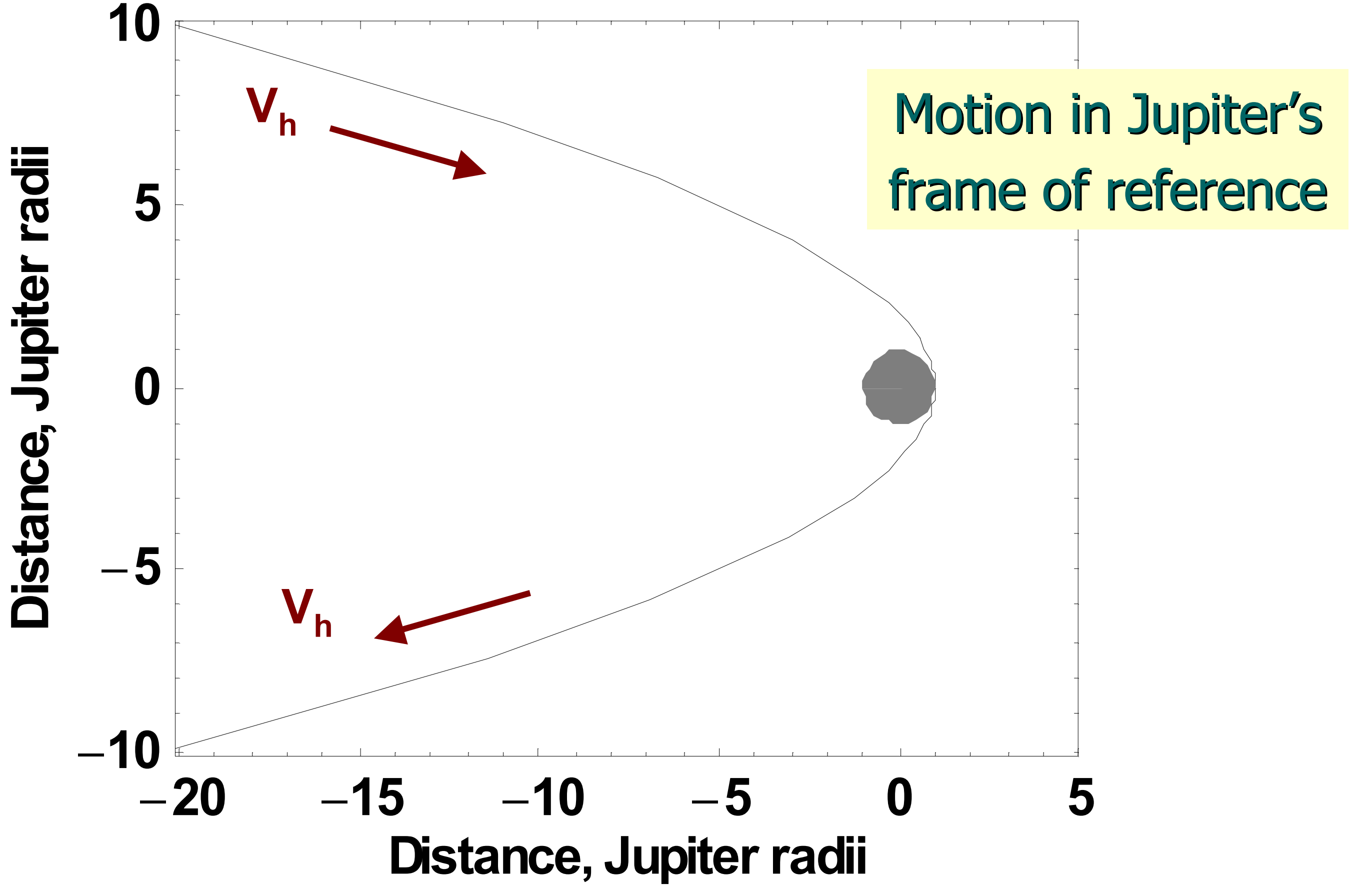
Planet	***Total Δv (km/s)***	***Travel time (year)***
Mercury	-17.2	0.29
Venus	-5.27	0.40
Mars	5.56	0.71
Asteroid belt	11.7	1.4
Jupiter	14.4	2.7
Saturn	15.7	6.0
Uranus	15.9	16
Neptune	15.7	30
Pluto	15.5	45

Hohmann Transfer Δv Values Drop Slightly for Outermost Planets

Planet	***First Δv (km/s)***	***Second Δv (km/s)***	***Total Δv (km/s)***
Saturn	10.30	5.44	15.7
Uranus	11.30	4.66	15.9
Neptune	11.60	4.05	15.7
Pluto	11.80	3.69	15.5

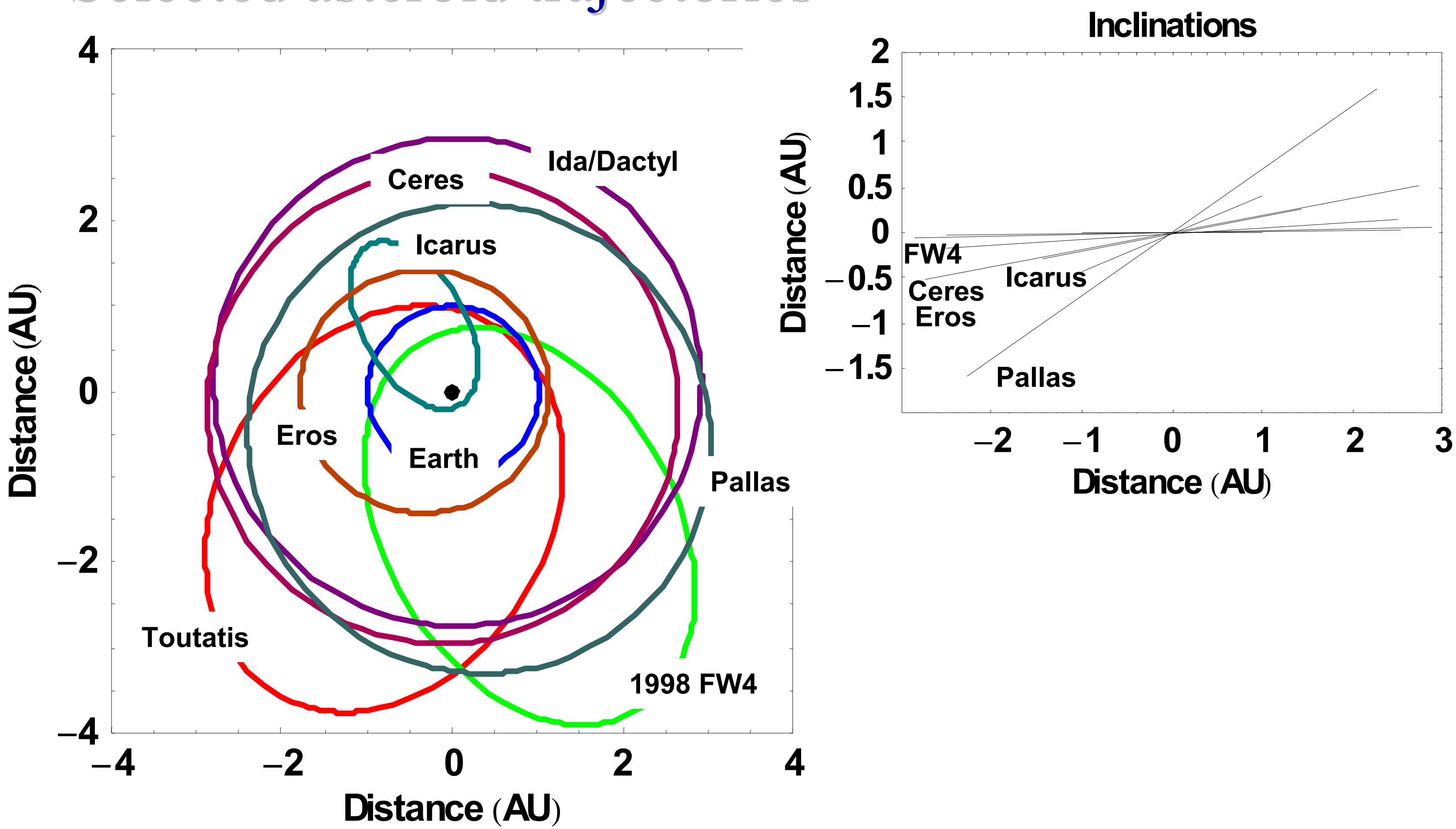
How Can Main-Belt Asteroids Best Be Moved to Earth? Aim at Jupiter and Get a Gravity Assist!

- In the spacecraft's frame of reference, the net result of the trade-off of momentum between it and Jupiter is a small change in the planet's velocity and a very large delta-v (~10 km/s) for the spacecraft.



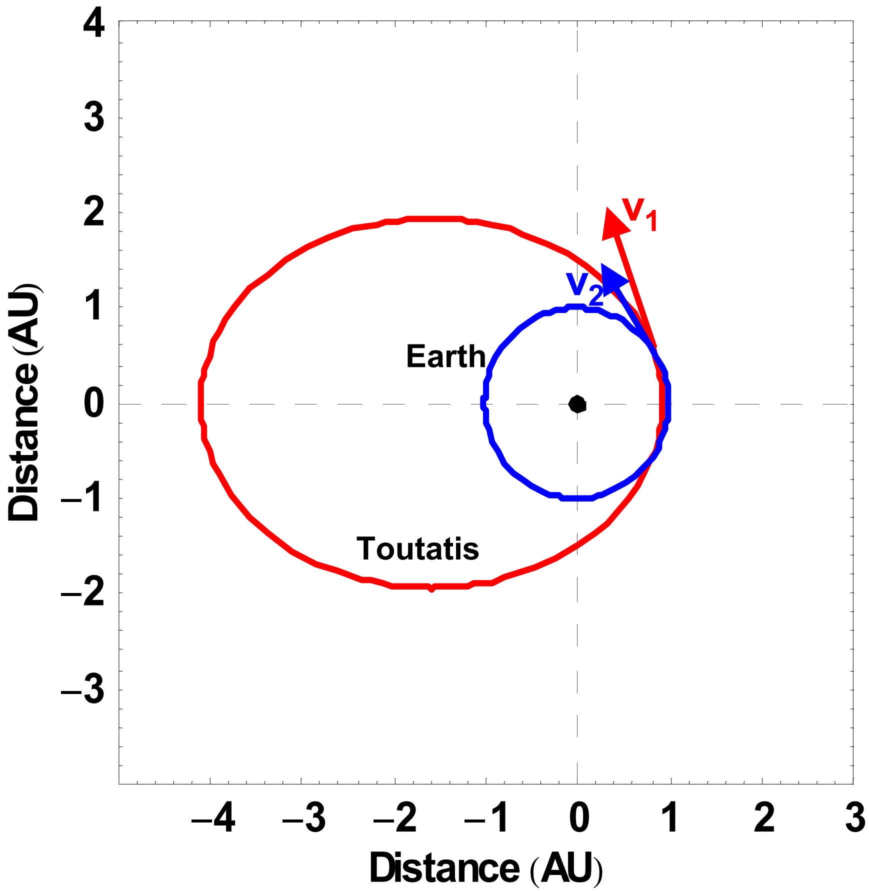
Many Asteroids Exist Outside of the Main Belt

- Selected asteroid trajectories



Large Eccentricities Lead to Large Δv's for Single-Impulse Deflection of Asteroid Orbits

- Toutatis: a=2.51 AU, e=0.63, i=0.5°



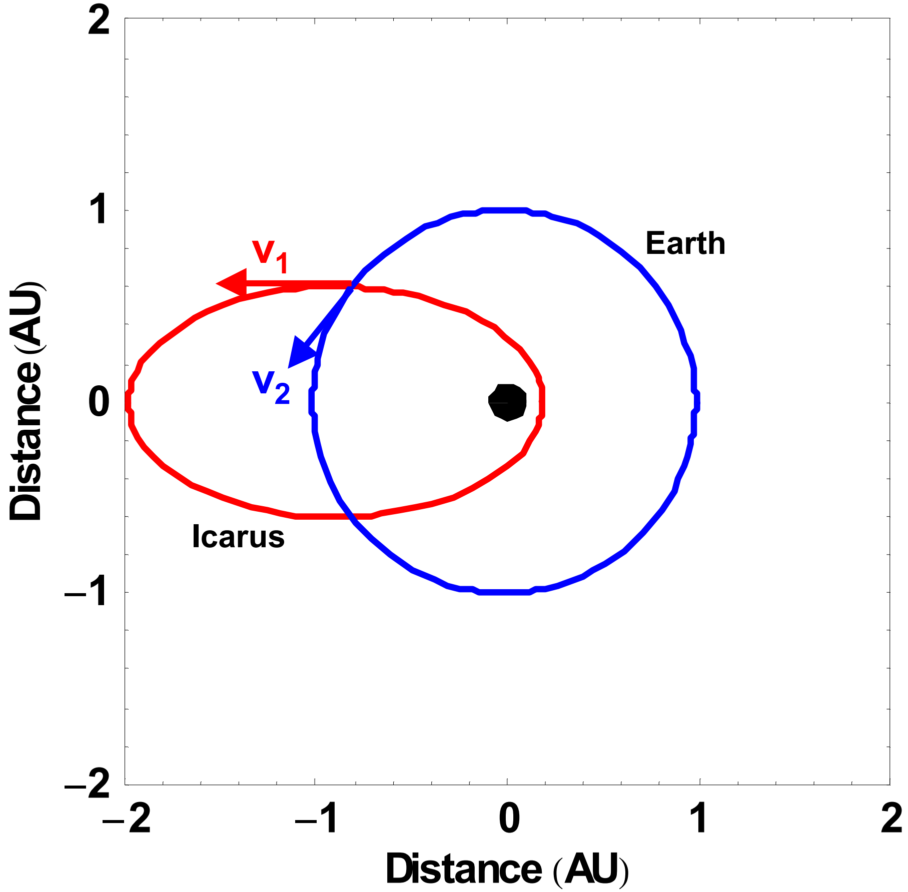
- Velocity on an elliptic orbit is

$$v = \left[GM \left(\frac{2}{r} - \frac{1}{a} \right) \right]^{1/2}$$

- Velocity of Toutatis as it crosses Earth's orbit is v_1 = 37.7 km/s.
- Earth's velocity is v_2=29.4 km/s (e=0.017 included).
- Angle between velocity vectors is 38°.
- Adding vectors gives Δv=10.8 km/s.

Large Inclinations Substantially Increase Δv's for Single-Impulse Deflection of Asteroid Orbits

- Icarus: a=1.08 AU, e=0.83, i=22.9°



- Velocity of Icarus as it crosses Earth's orbit is v_1 = 30.5 km/s.
- Earth's velocity is v_2=29.4 km/s (e=0.017 included).
- Angle between velocity vectors is 60°.
- Adding vectors *in plane* gives Δv=27.9 km/s.
- Inclination of orbits adds another 23.2 km/s
- Total Δv=51 km/s.

Hohmann Trajectories Can Give Low Δv's for Some Asteroids

- For asteroids with nearly circular orbits of low eccentricity and inclination, Δv's can be < 2 km/s.
  - For example, 1999 FA (~330 m diameter) has a=1.078, e=0.133, i=12.
    - The corresponding Hohmann trajectory to Earth has Δv=1.8 km/s.
  - Some asteroid resource literature quotes Δv's of 100's of m/s, but I have not personally verified these values.
- Note: the Moon can gravity assist with ~1 km/s.