Nourishing Mind, Body and Spirit

<Group, Location>

The Physics of Space Travel

Presenter : <Name>

Stratford Astronomy Group

20yy Mmm dd Ddd hh:mm EDT/EST

1 Overview

2 Mass, Weight and Thrust

3 Getting to the Moon and Planets

4 Interstellar Travel

1 Overview

At present, due to technology and costs, mainly restricted to interplanetary travel.

There are five exceptions :
Voyagers 1 &2;
Pioneers 10 & 11;
New Horizons.

2 Mass, Weight and Thrust

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Thrust for Space Travel has to overcome 1 Earth Gravity, or that from where a Spacecraft is launched, eg from the surface of our Moon.

2 Mass, Weight and Thrust

Earth Orbit

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To get a Satellite or Crewed Spaceship into Earth Orbit requires Thrust to overcome the Mass of the launch vehicle & satellite/spaceship (the latter being the Payload).

2 Mass, Weight and Thrust

Escape Velocities

The Escape Velocity, ie non-orbital, of Earth is 11.2 km/s.

The Escape Velocity of the Moon is 2.4 km/s.

Escape Velocity general equation : $v_e = \sqrt{2GM/R}$

To clarify, the combined mass of the Payload and its Launch Vehicle must achieve a Thrust greater than its Mass from its Launch Point.

2 Mass, Weight and Thrust

Apollo 11 launch

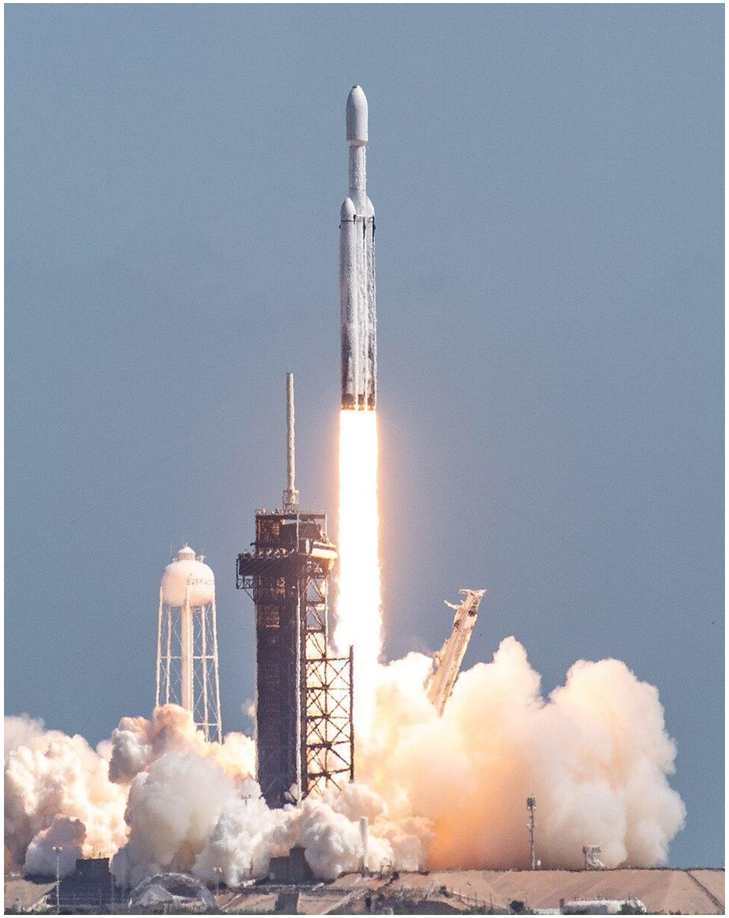
The total mass of the Apollo 11 Launch Vehicle, 3 Modules, Moon Lander & Ascent Vehicle & all fuel was 3 000 000 kg (3 000 tonnes).

The lift-off thrust of the Saturn C5 first stage was ~3 500 t.

3-Stage Launch Vehicle to reduce mass needed to get to the Moon.

Fuel accounted for 94.3% total mass of the above.

2 Mass, Weight and Thrust



Falcon 9 Heavy Lift

The lift-off thrust of the Saturn C5 first stage was ~3 500 t.

The Saturn C5 remains the most powerful launch vehicle.

The Falcon 9 “Heavy Lift” launch vehicle produces ~2 320 t thrust, including its strap-on boosters.

All launch vehicles to date are chemically propelled, eg mix of Liquid O_2, Liquid H_2, Kerosene, various solid propellants.

3 Getting to the Moon and Planets

Orbital velocity for Earth is 7.9 km/s.

The Escape Velocity, ie non-orbital, of Earth is 11.2 km/s.

To reach the Moon and Planets requires optimization to maximize Payload Mass and to minimize Fuel Mass (including the fuel tanks and engines).

Hence the need for Staged Launch Vehicles, and separate rocket engines to move a payload from Earth Orbit to the Moon or Planets (and their moons).

3 Getting to the Moon and Planets

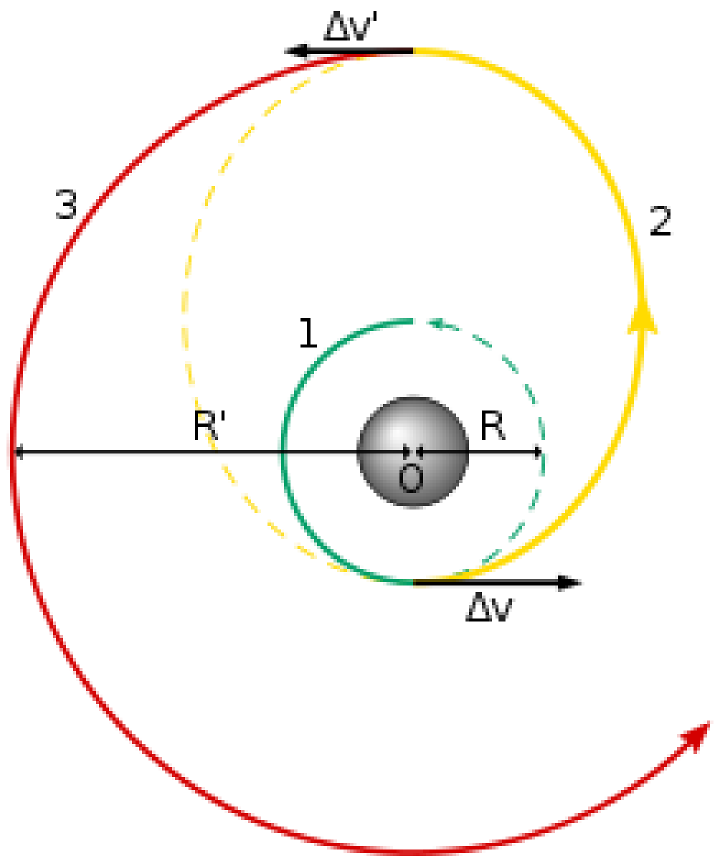
There are two basic methods :

1 Optimize Planetary Alignment, eg between Earth and Mars (single target/destination);

2 Gravitational Slingshot(s), for single or multiple targets/destinations.

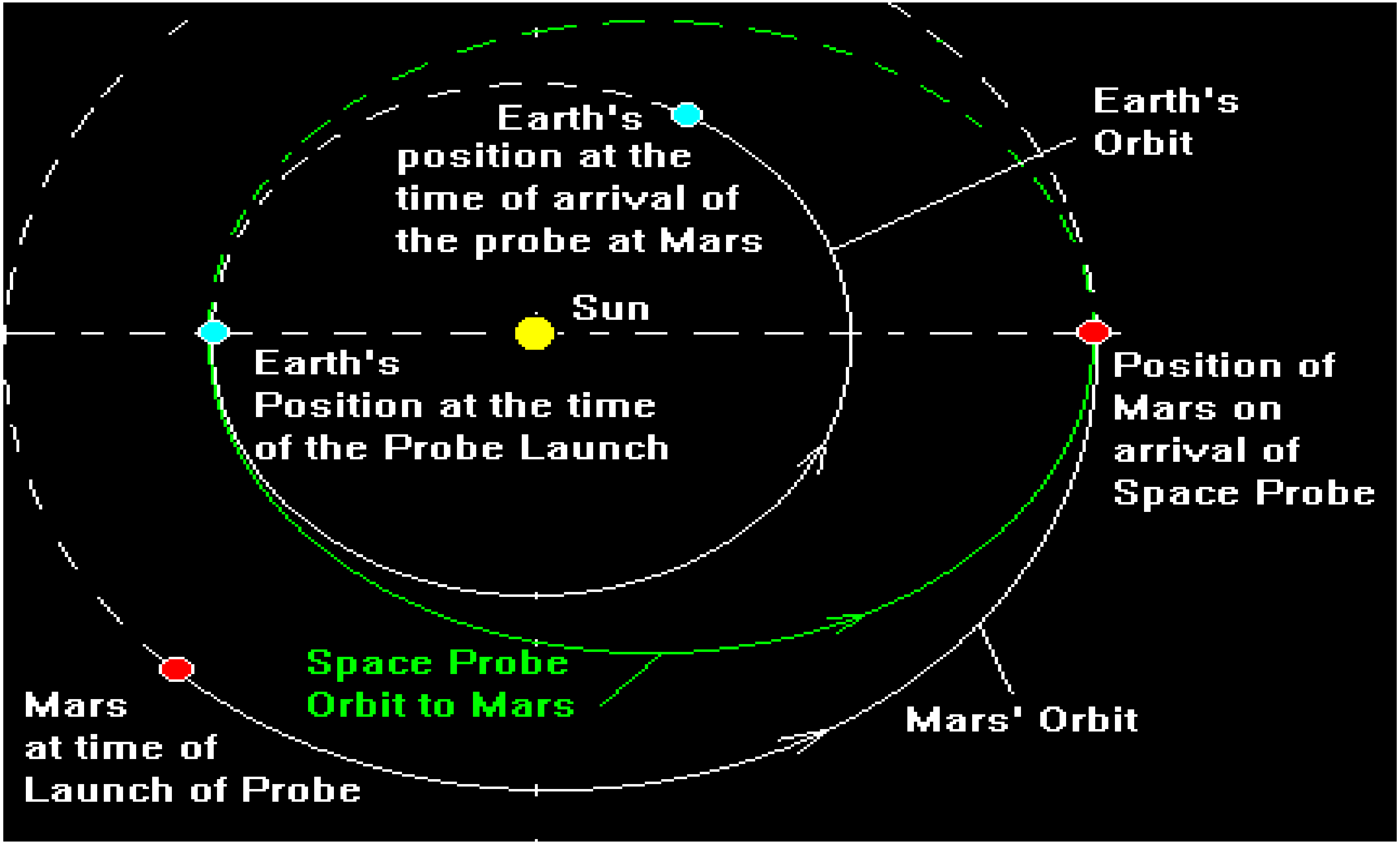
3 Getting to the Moon and Planets

Hohmann Transfer Curve



3 Getting to the Moon and Planets

Hohmann Transfer Curve



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3 Getting to the Moon and Planets

Gravitational Slingshot(s), for single or multiple targets/ destinations : the field of Astrodynamics.

3 Getting to the Moon and Planets

Gravitational Slingshot(s), for single or multiple targets/ destinations while minimizing time spent to get there : Astrodynamics.

A gravitational slingshot uses a massive body (eg planet) to use that body's motion around the Sun to accelerate a spacecraft (payload).

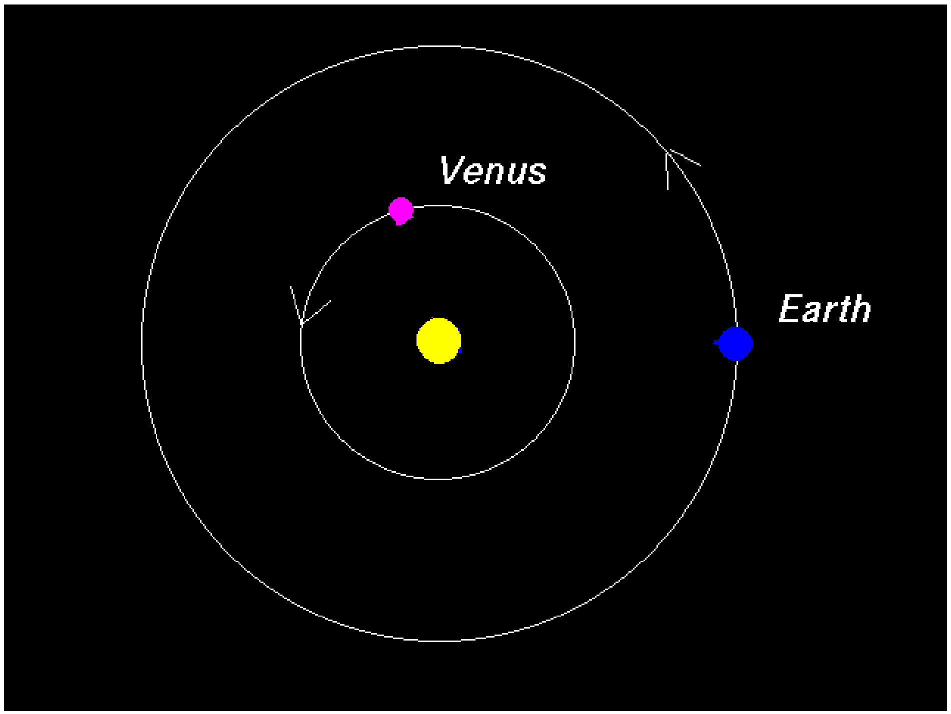
A gravitational slingshot is more complicated than just hurling a spacecraft around a planet.

3 Getting to the Moon and Planets

From high school maths, remembering vector addition and subtraction, when a spacecraft approaches a planet it will accelerate due to capture by the planet's gravity, however when it passes (hopefully) the planet, that planet's gravity will decelerate the spacecraft by the same amount, thus little loss of travel time will be gained.

The real trick is to use the planet's Orbital Velocity around the Sun, using "Orbital Velocity Gravitational Drag" from the planet to impart acceleration to the spacecraft.

3 Getting to the Moon and Planets

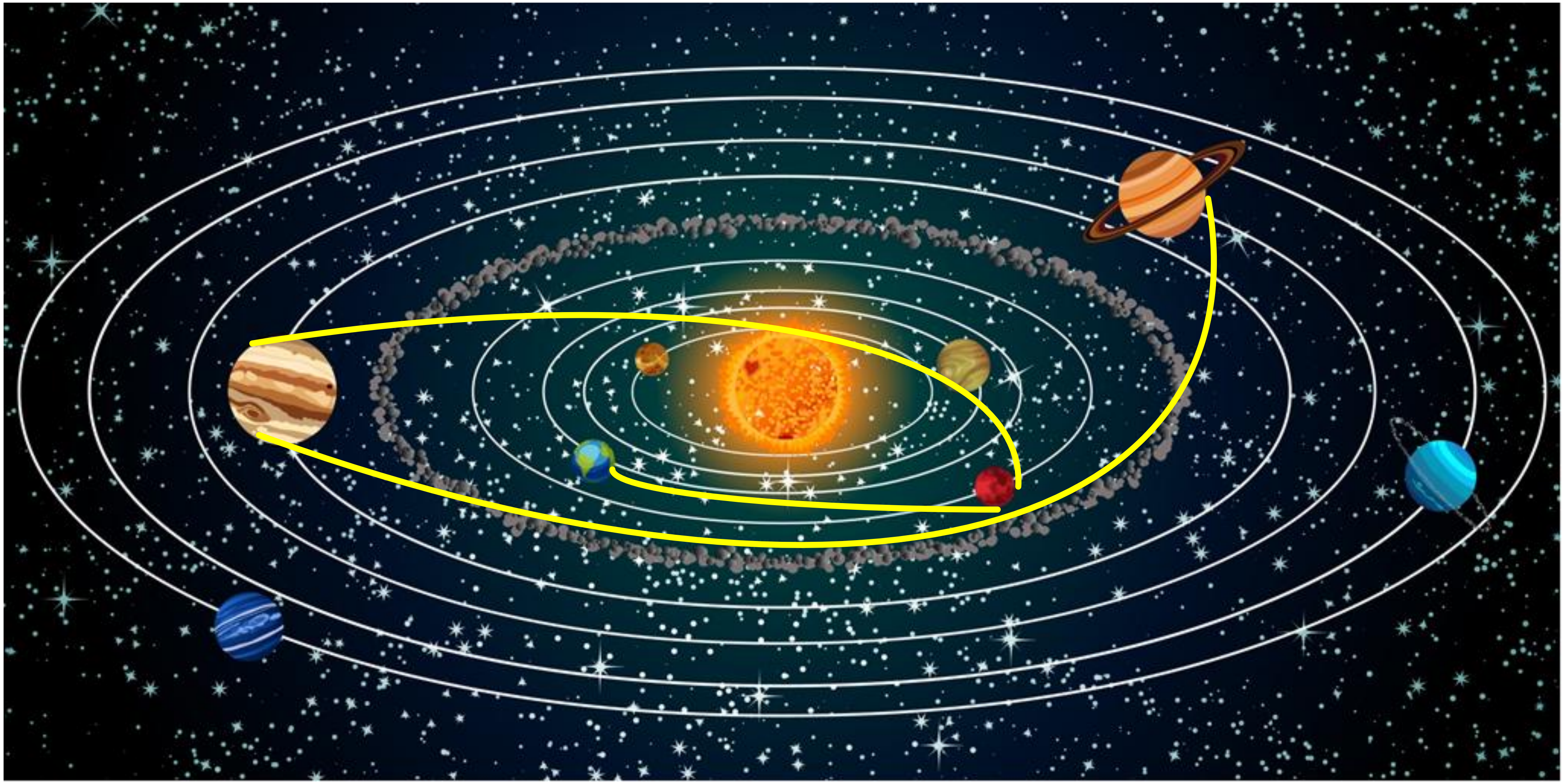


Venus orbits the Sun at ~35 km/s, thus approaching Venus, trailing its trajectory, in theory can add 35 km/s to a spacecraft's speed.

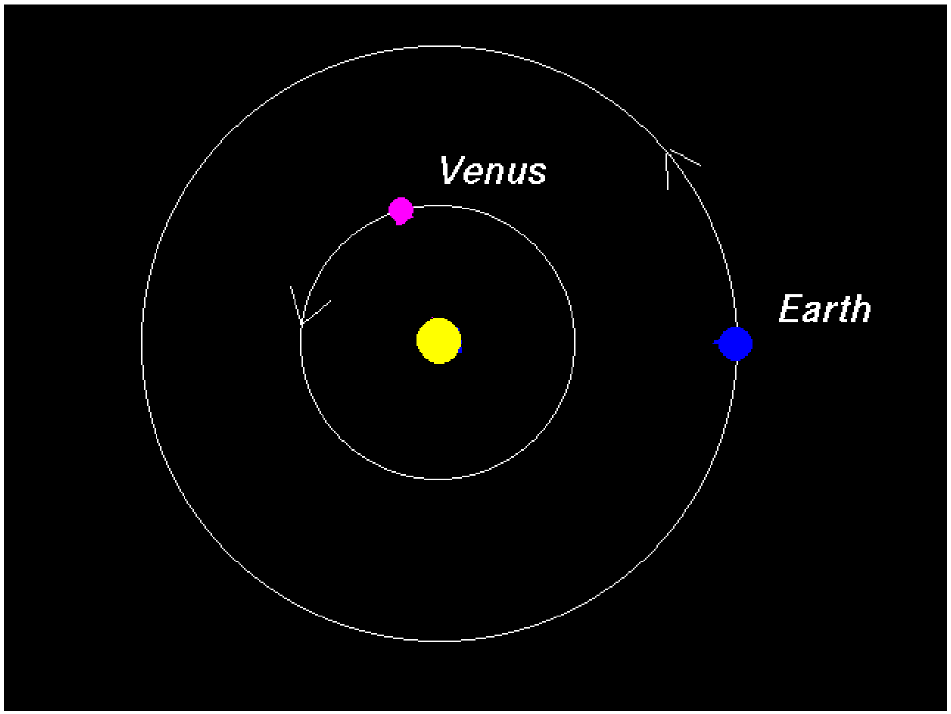
"In theory" assumes that the spacecraft can maximize the Gravitational Drag, and complicated maths, in a field called Astrodynamics, will optimize the acceleration **and** resultant direction.

3 Getting to the Moon and Planets

Fuel-Payload efficiency : multiple planetary visit : Astrodynamics



3 Getting to the Moon and Planets



Orbital Velocities

Mercury ~ 50km/s
Venus ~ 35km/s
Earth ~ 30 km/s
Mars ~ 24 km/s
Jupiter ~ 13 km/s
Saturn ~ 9.7 km/s
Uranus ~ 6.8 km/s
Neptune ~ 5.4 km/s

Physics of Space Travel

Radio / Maser / Laser Communication from Earth

Distance and Average Time from Earth				
Planet	**Nearest Approach**	**Nearest Approach**	**Farthest Retreat**	**Farthest Retreat**
	Mkm	**Time**	**Mkm**	**Time**
Mercury	92	5m 07s	392	21m 48s
Venus	42	2m 18s	342	19m 03s
Earth	0	0	0	0
Mars	150	8m 18s	450	25m 00s
Jupiter	628	34m 54s	928	51m 36s
Saturn	1,277	1h 11m	1,577	1h 28m
Uranus	2,721	2h 31m	3,021	2h 48m
Neptune	4,347	4h 02m	4,647	4h 18m
Pluto	5,763	5h 20m	6,063	5h 37m

4 Interstellar Travel

If we used a Saturn C5 launch vehicle and its second and third stages to send a 1 kg spacecraft to our nearest stellar neighbour, Proxima Centauri, ~4.24 light years distant, it would take just over 40 000 years for that spacecraft to coast there; presently it is impractical to carry more fuel on board thus reducing launch speed, with a realistic limit on Launch Mass v Launch Thrust.

A spacecraft could have a fully-fuelled rocket engine waiting for it in space orbit to which it could attach and gain extra speed, and use Gravitational Slingshots, however only reducing journey time by a tiny amount cf 40 000 years.

4 Interstellar Travel

Ion Engine

All is not lost, however with present technology it could still take nearly 39 000 years to reach Proxima Centauri, but will the human race remember that a spacecraft is out there, assuming humanity is still alive & well.

An Ion Engine uses a light mass, eg xenon gas, which is ionized then propelled by a high-voltage electric field as an exhaust (10-20 km/s), moving the spacecraft forward at low acceleration continuously for a long period of time.

Realistically, with current technology, interstellar travel is still impractical.

4 Interstellar Travel

Ion Engines : Present Usage

Dawn (NASA)

To asteroid belt bodies Ceres and Vesta.

Commercial Satellites

To adjust orbits.

Research

Several operating, and telemetry feedback used to amend theories and corresponding design.

4 Interstellar Travel

Bussard Engine (ramjet)

A theory developed in 1960 by physicist Robert Bussard which primarily would use a colossal magnetic field (web) many thousands of km at its outer diameter to funnel interstellar hydrogen into a compression module to allow fusion to occur and generate enormous energy to propel a spacecraft for an indefinite period of time.

Bussard's theory has been the subject of research over many years, however knowledge of the density of H and H_2 in the interstellar void, let alone that in our own solar system shows present technology is impractical.

4 Interstellar Travel

Warp Drive (*Star Trek* etc)

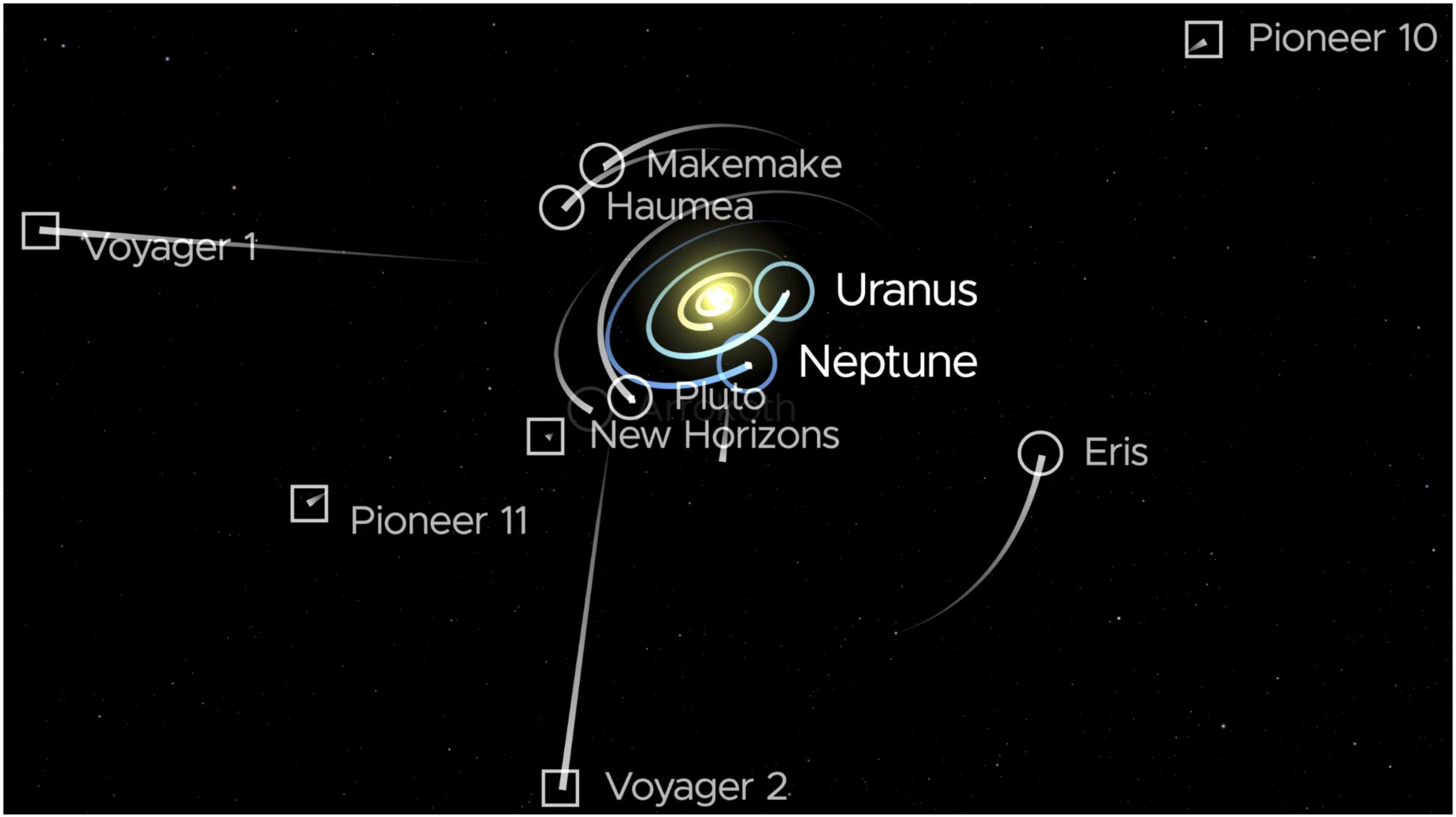
Wouldn’t that be nice !

4 Interstellar Travel

Earlier we mentioned we have are 5 interstellar Spacecraft.

The following depicts their relative positions as of 2025 Mar 30 :

4 Interstellar Travel



source : various universities

4 Interstellar Travel

Telescopes and Communication

Present optical, infra-red and radio telescopes are providing us with masses of data of the universe, outwith our solar system looking back in time.

Perhaps sometime we'll receive a message from an extra-terrestrial source, however responses will take time due to the light-year distances involved. Oh for Star Trek !

4 Interstellar Travel

Interstellar Visitors

There are three known objects :

1i / ’Oumuamua (2017)

2i / Borisov (2019)

3i / ATLAS (2025)

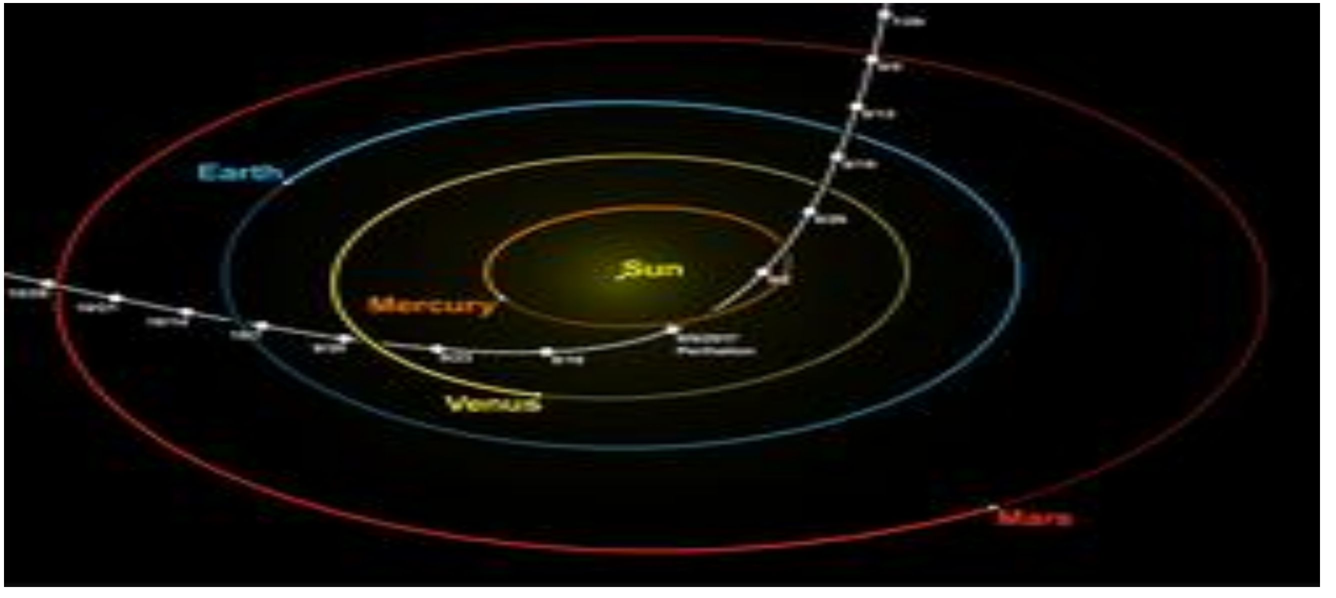
All exceeded the Escape Velocity of the Sun at their closest approach to the Sun

Escape Velocity general equation : $v_e = \sqrt{2GM/R}$

4 Interstellar Travel

Interstellar Visitors

1i / ’Oumuamua (2017)

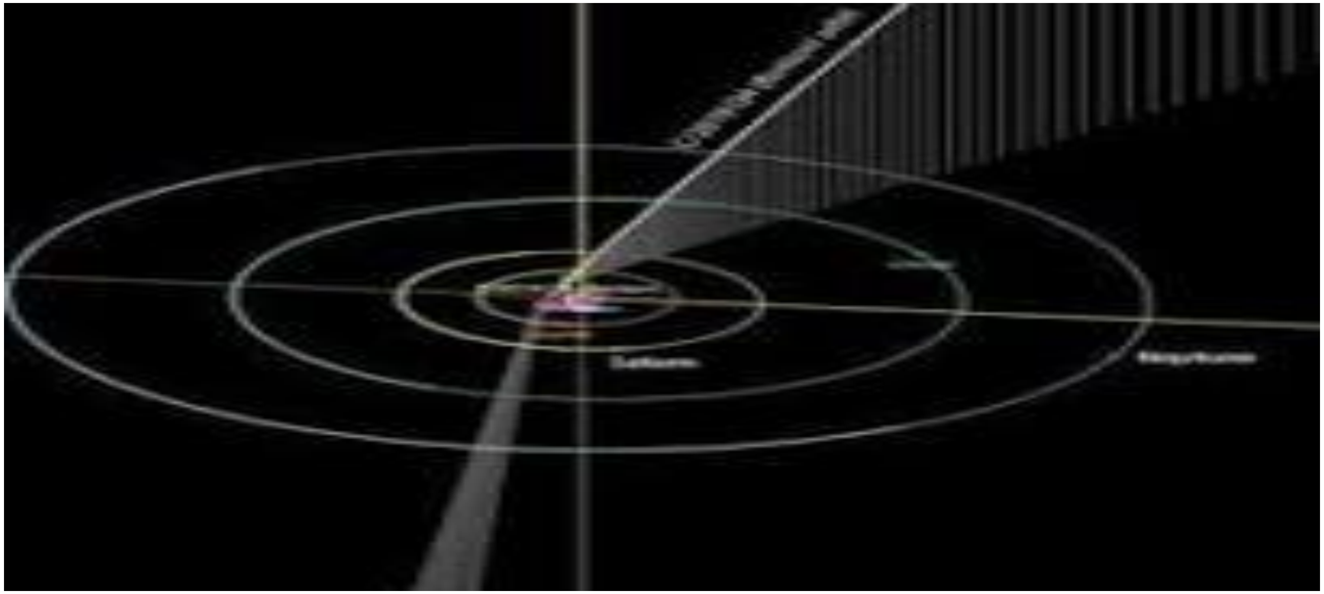


v ~26.3 km/s

4 Interstellar Travel

Interstellar Visitors

2i / Borisov (2019)

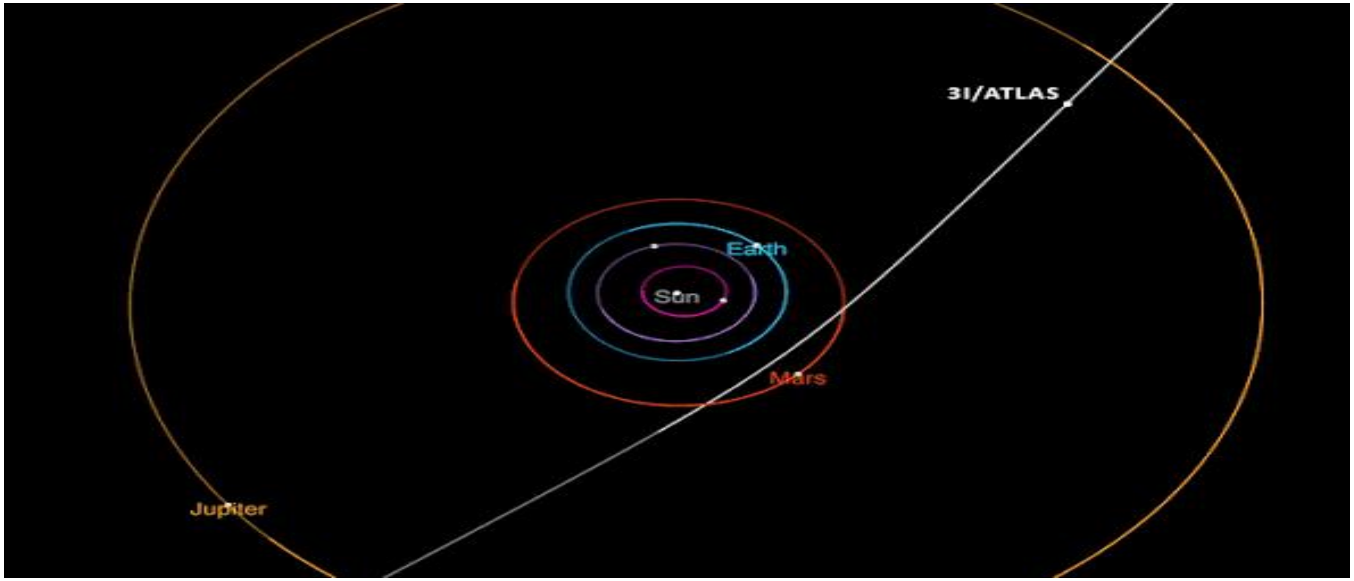


v ~43.9 km/s

4 Interstellar Travel

Interstellar Visitors

3i / ATLAS (2025)



v ~68.3 km/s

Thank You

Questions

(and hopefully answers !)