

# Space Propulsion Systems

Shawn Sobel

# Overview:

Chemical rockets

Ion thrusters

Solar sail

Photonic

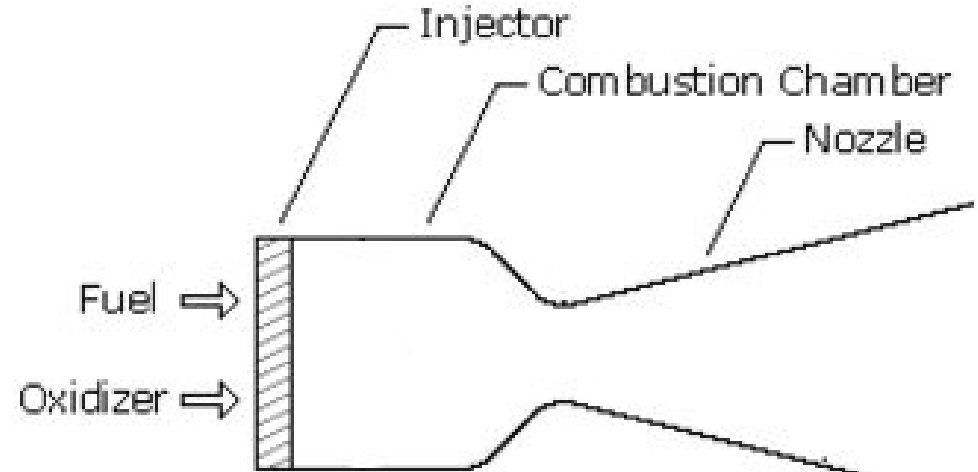
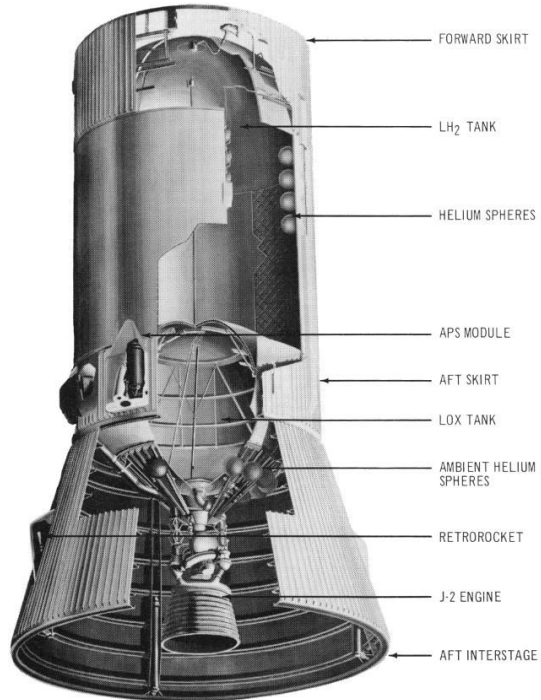
EM drive

# Overview:

- a) How it works
- b) History
- c) Feasibility for Mars travel
- d) Time until operational

# Chemical rockets

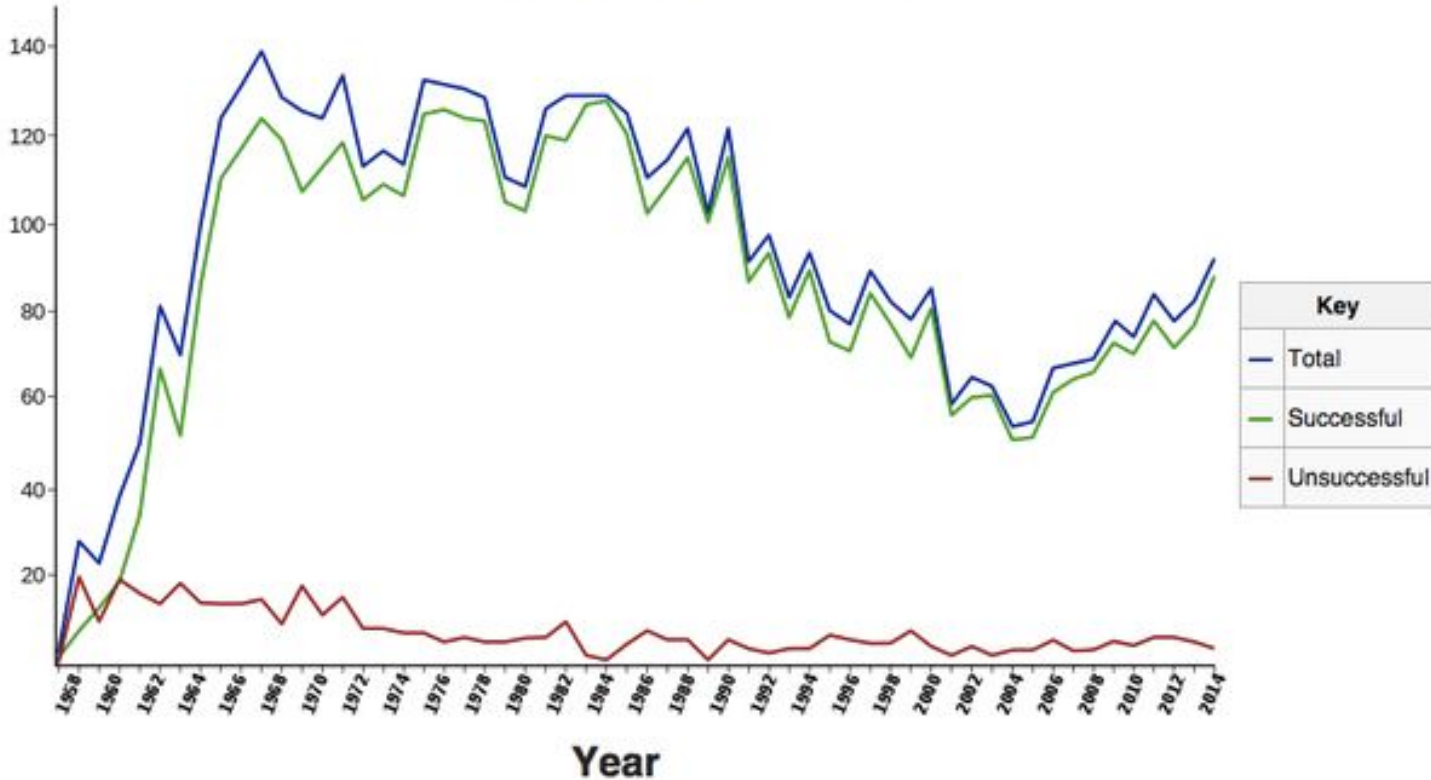
## How it works



# Chemical rockets

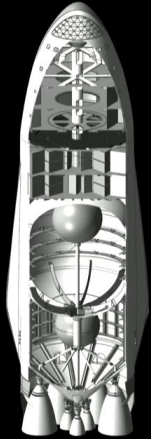
## History

Orbital launches by year



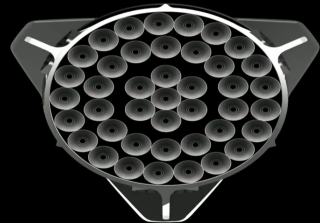
# Chemical rockets

## Feasibility for Mars travel



Length	49.5 m
Max Diameter	17 m
Raptor Engines	3 Sea-Level - 361s Isp 6 Vacuum - 382s Isp
Vacuum Thrust	31 MN
Propellant Mass	Ship: 1,950 t Tanker: 2,500 t
Dry Mass	Ship: 150 t Tanker: 90 t
Cargo/Prop to LEO	Ship: 300 t Tanker: 380 t
Cargo to Mars	450 t (with transfer on orbit)

Long term goal of 100+ passengers/ship

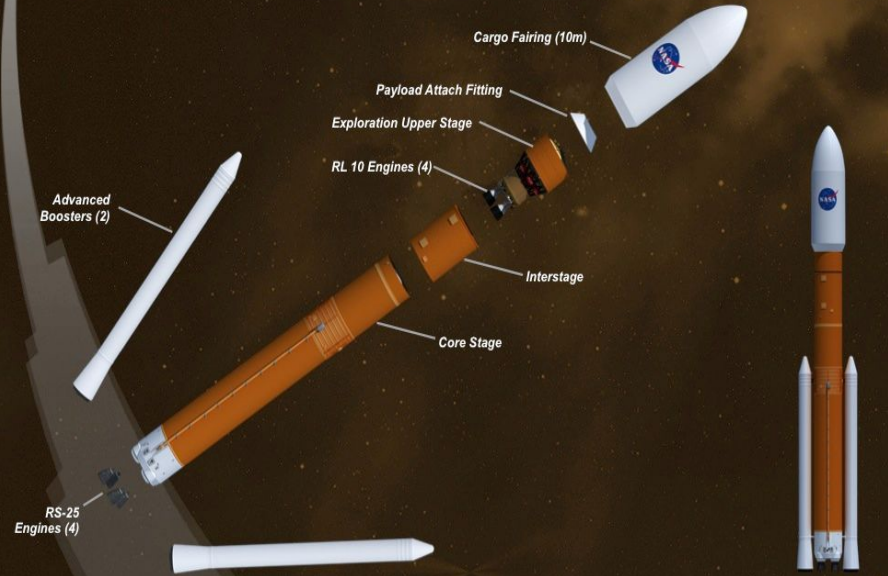


### Engine configuration

Outer ring: 21  
Inner ring: 14  
Center cluster: 7

Outer engines fixed in place  
Only center cluster gimbals

## SLS Block 2 (130-Metric-Ton) Cargo Expanded View



SLS Block 2 Cargo

# Chemical rockets

Time until operational

SpaceX:

Raptor is currently being tested



SLS:

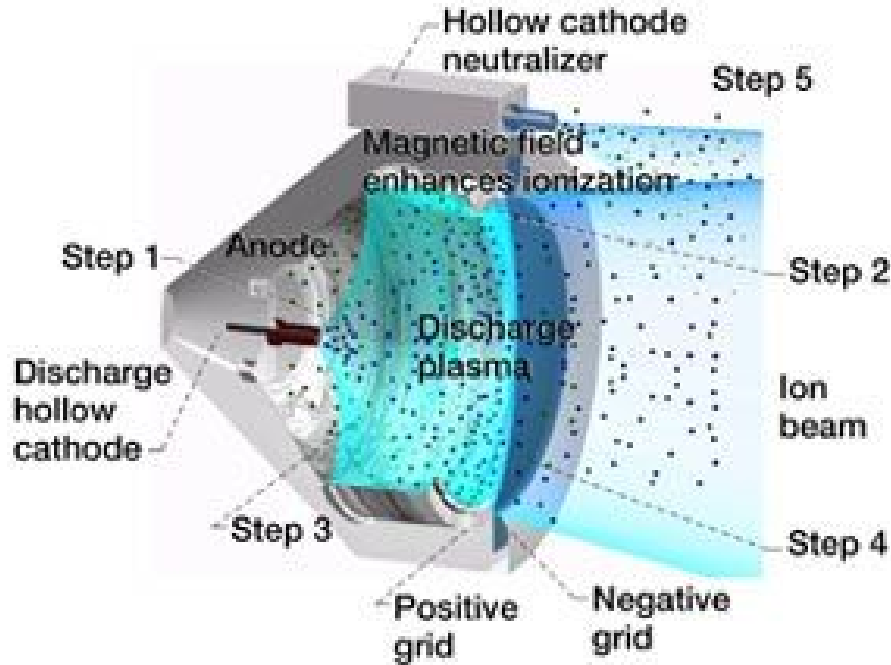
Engines are recycled OMS

Solid state boosters

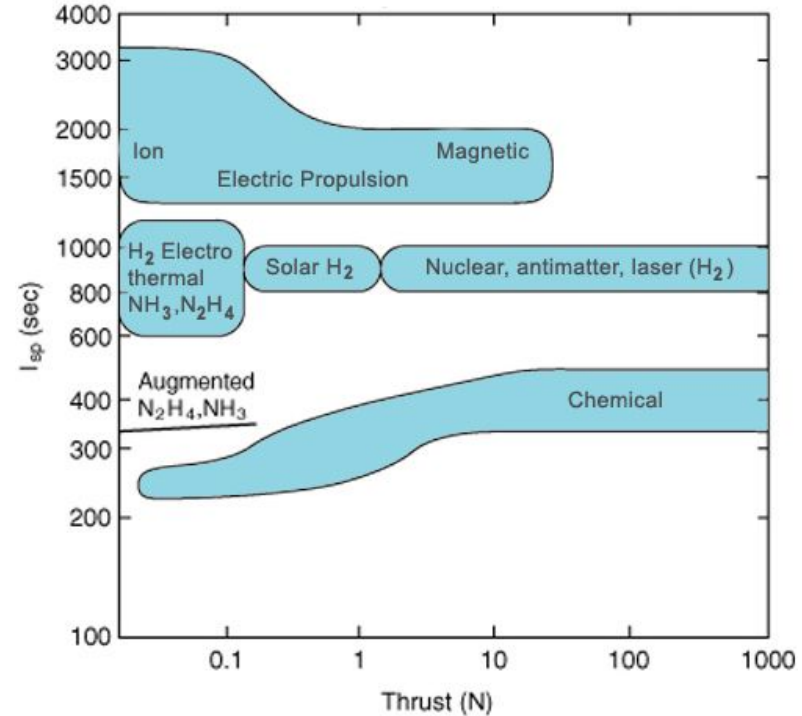


# Ion Thrusters

How it works



Range of Thrust and  $I_{sp}$  for Different Propulsion Systems





# Ion Thrusters

## History

100 geosynchronous Earth orbit communication satellites



Dawn Spacecraft



Deep Space 1 - more than 16,000 hours over 2 years.



# Ion Thrusters

Feasibility for Mars travel

Maximum thrust = 91 millinewtons



A 10- to 20-megawatt class VASIMR engine could propel human missions to Mars in as little as 39 days

**But** - 200 kilowatt now

# Ion Thrusters

Time until operational

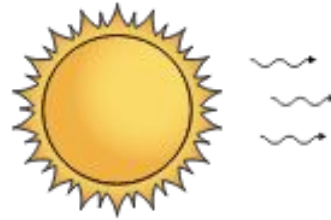
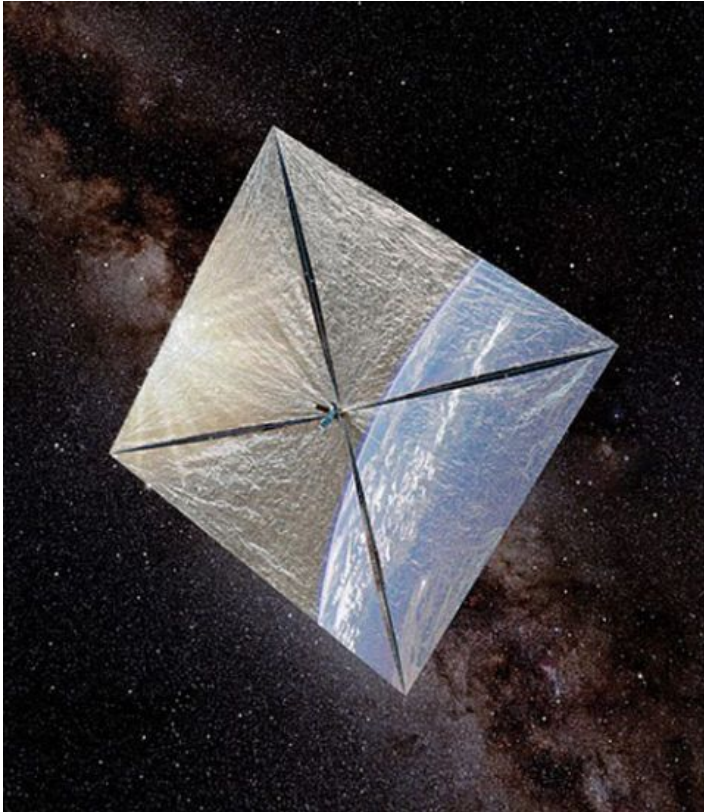
Regular - Operational

VASIMR - Unknown

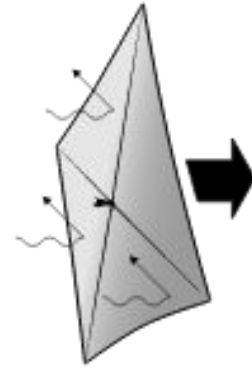


# Solar Sail

How it works



Photons have energy and momentum



The photons reflect off the sail, transferring momentum

# Solar Sail

## History

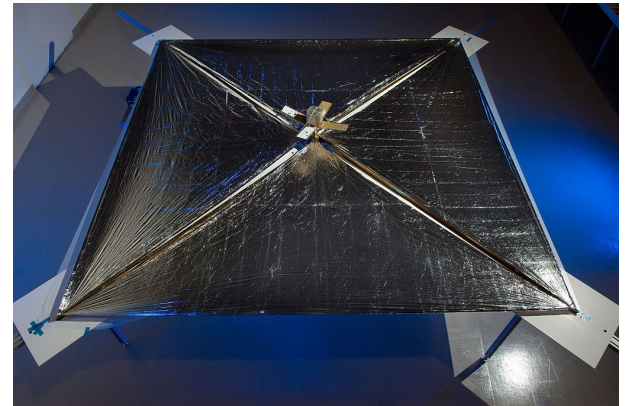
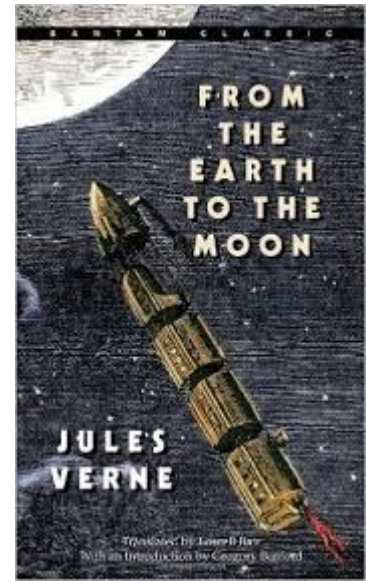
Jules Verne - 1865 book "From the Earth to the Moon"

Numerous ground deployments 1993- 2010s

First successful demonstration - 2010

Japan's Ikaros probe deployed its 46-foot-wide sail

NASA launched NanoSail-D in 2011 for 240 day mission



# Solar Sail

## Feasibility of Mars travel

Minimum: 1.5 years each way to Mars

800m x 800m produces 5N @ earth

Better idea: going closer to the sun (L1)

Sail Size m	Mercury Rendezvous		Venus Rendezvous		Mars Rendezvous		Mars Aerobrake	
	days	tons	days	tons	days	tons	days	tons
800 $\sigma = 5 \text{ g/m}^2$ w/o cargo	600	9	200	1	400	2	131	2
	900	19	270	5	500	5	200	5
	1200	28			700	9	338	10
2000 $\sigma = 3 \text{ g/m}^2$ w/o cargo	600	66	200	17	400	23	131	20
	900	124	270	36	500	40	200	40
	1200	184			700	66	338	70

# Solar Sail

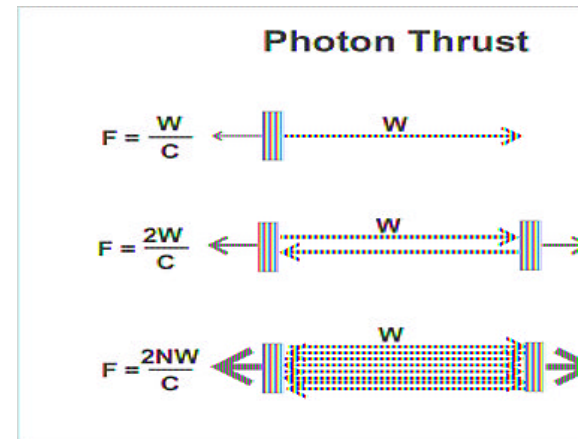
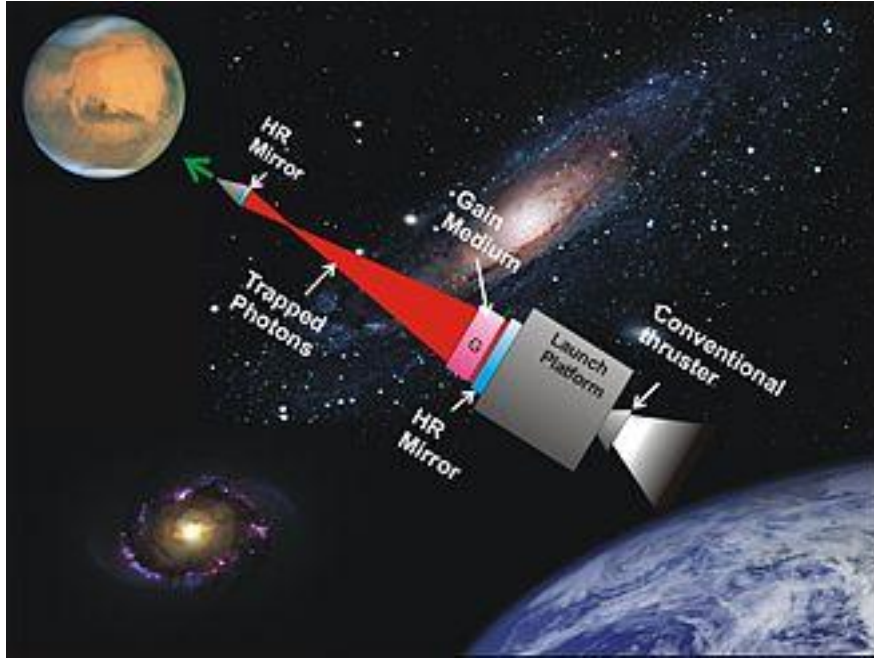
Time until operational

They are, but deployment is unreliable

No plans for use in Mars travel

# Photonic

How it works





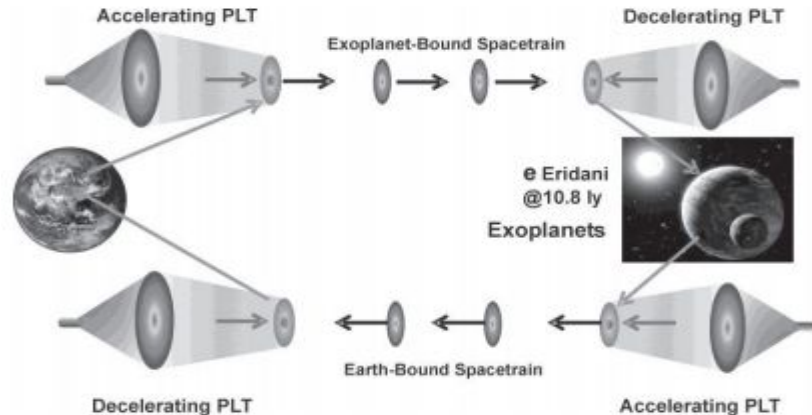
# Photonic

## History

December 2006 - photon thrust of 35 micronewtons by putting the laser-energizing medium between two mirrors as in typical lasers.

In August 2015 - photon thrust of 3.5 millinewtons. In addition, a small 1U CubeSat satellite was propelled and stopped in simulated zero-gravity.

## Proposed - The Photonic Railway



# Photonic

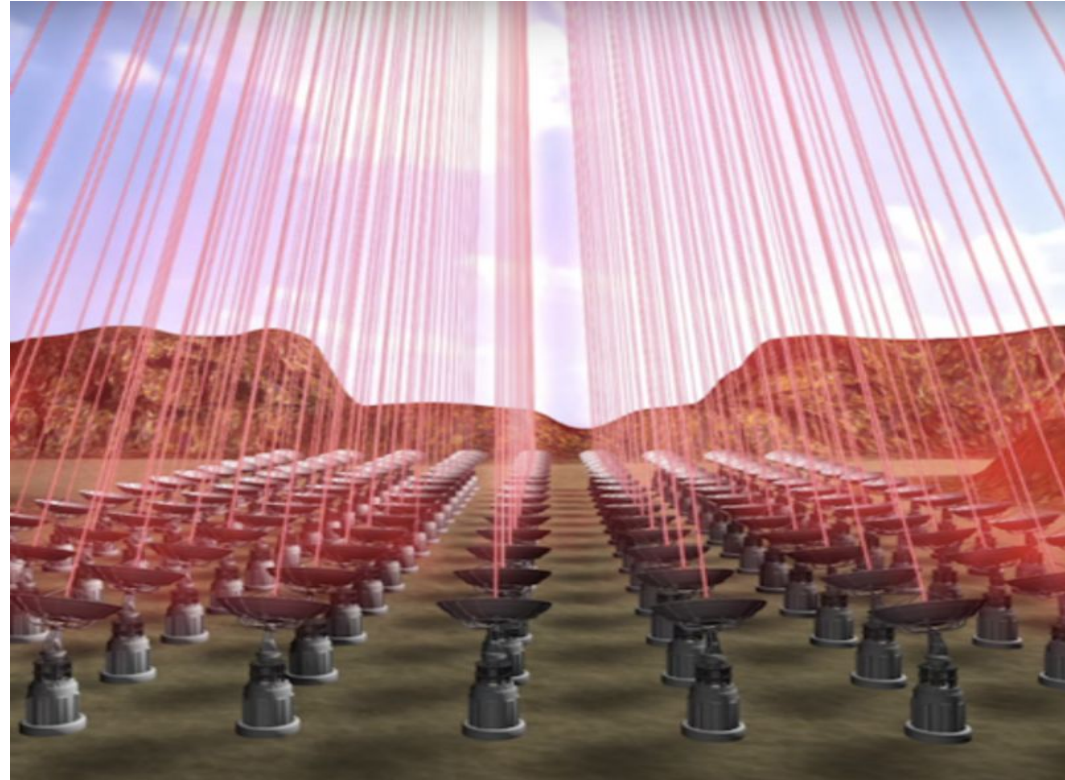
Feasibility for Mars travel

Very feasible:

**3 days for rover**

**30 days for humans**

Breakthrough Starshot project



# Photonic

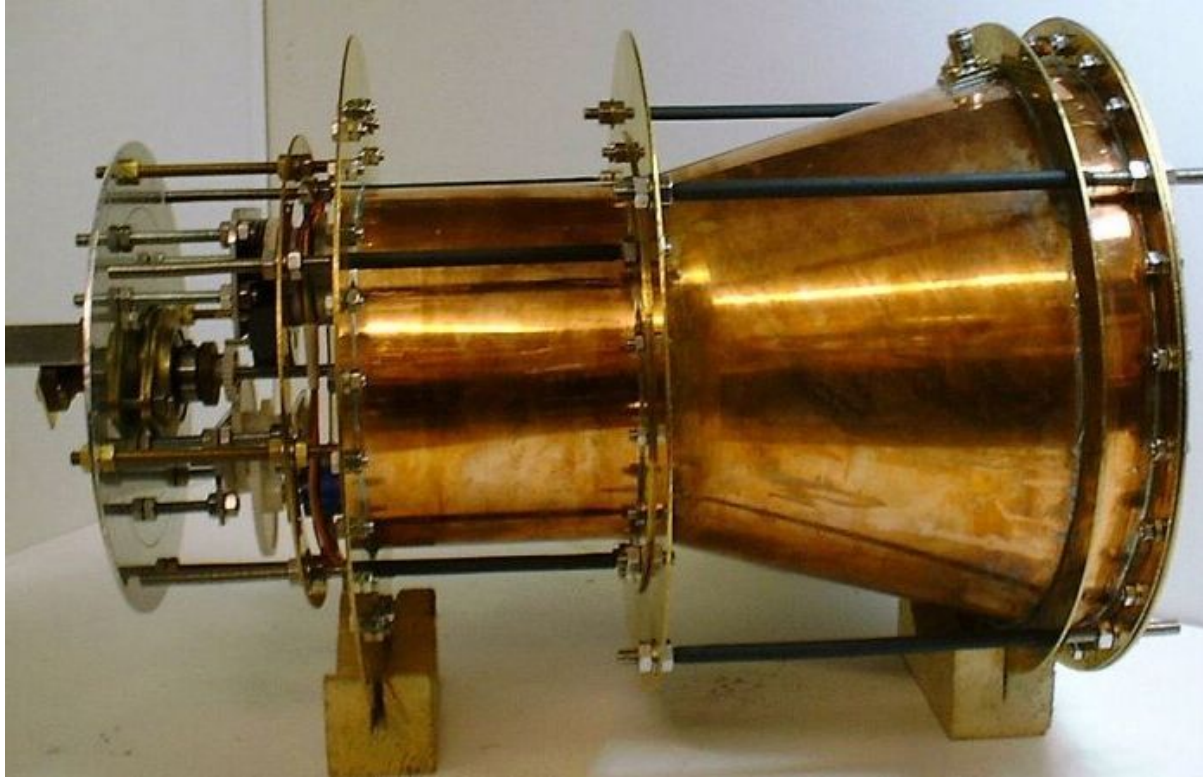
Time until operational

40 - 50 years for mars travel

50 - 100 years for “spacetrain”

# EM drive

How it works



Nonlocal hidden-variable theory, or pilot-wave theory

????????????????????????????????

Waves are both reflected and not reflected at the same? Thick and thin mirrors.

# EM drive

## History

2001 - Roger Shawyer presents idea

2007 - UK grants SPR an export licence to Boeing in the US

2008 - Juan Yang at Xi'an's Northwestern Polytechnical University (NWPU) initially reports significant thrust

2016 - Juan retracts her claims in 2016 after a measurement error was identified and improved setup measured no significant thrust.

2017 - EaglesWorks finishes experiment and publishes in peer reviewed journal

# EM drive

Feasibility for Mars travel



Probably not

# EM drive

Time until operational



# Overview:

Chemical rockets ★

Ion thrusters ★

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