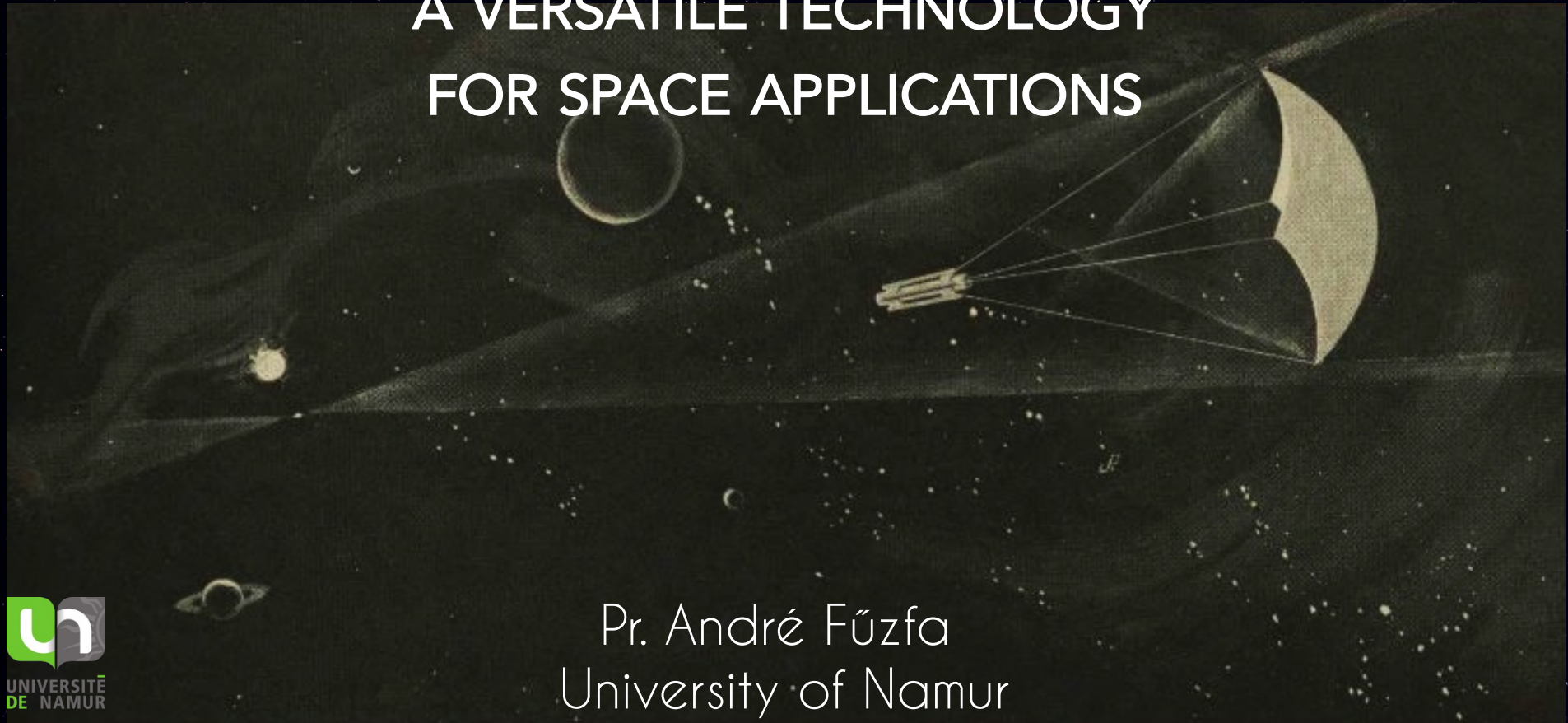
DIRECTED-ENERGY: A VERSATILE TECHNOLOGY FOR SPACE APPLICATIONS



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What means « directed-energy »?

★Beams to remotely deliver energy over large distances

★Electromagnetic coherent radiation

→ Maser (1953) : microwaves

→ Laser (1960) : optical/infrared

→ Phased arrays

★Particles (charged/neutral), plasma, acoustic waves, etc.

★Combination of high-power and « long » duration

★Versatile technology:

→ defense

→ space debris mitigation ; asteroid redirection

→ space-based solar power through wireless power transmission

→ propulsion

Directed-energy: an actual technology

★ Operational/experimental weapons
- → Fastest possible (speed of light)
- → Invisible (infrared) and silent
- → Precision and aiming (flat trajectory, gravity almost insensitive)
- → No ammunition but power supply
- → Tracking for energy delivery
- → Lower cost per target
- → Space warefare (satellite-blinding, etc.)
- → Blooming by target evaporation, beam diffraction, atmospheric scattering and absorption


Legend: Archimedes mirrors by G. Parigi

★ Developed at least by
- → China, France, Germany, India, Iran, Pakistan, UK, USA, Russia, Turkey.


Laser Weapon System on USS Ponce

Directed-energy for space defense

★Satellite-blinding

★Space debris removal/deorbiting

→ vaporization and thrust

★Asteroids

→ Remote composition analysis

→ Orbital parameters refinment

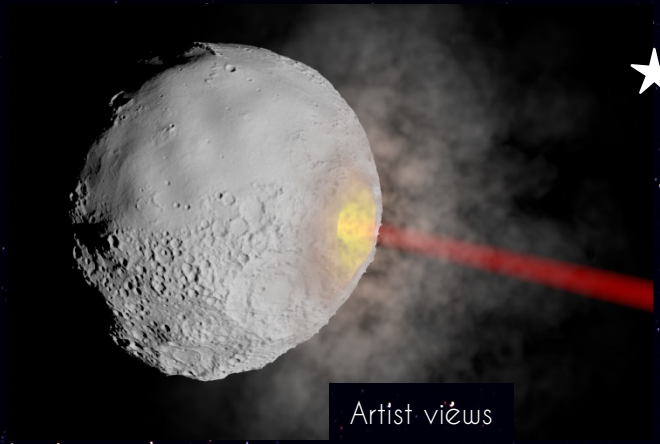
→ redirection and deviation

→ orbital capture

★ United Nations Outer Space Treaty

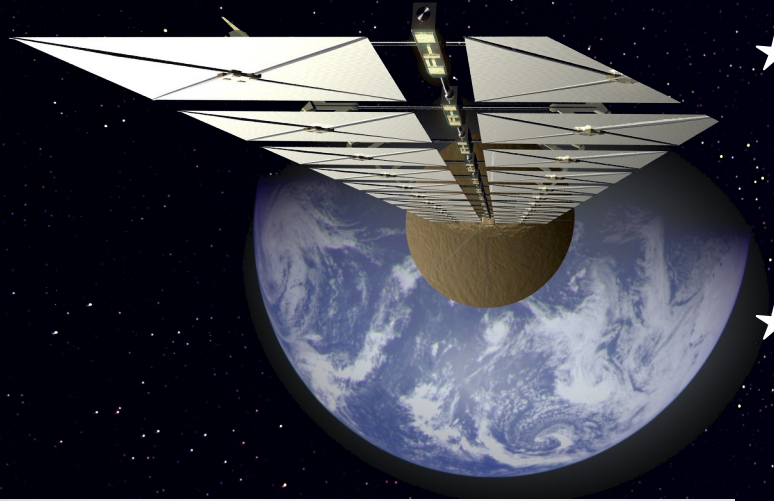
→ Resolution 2222 (1966) Article 4:

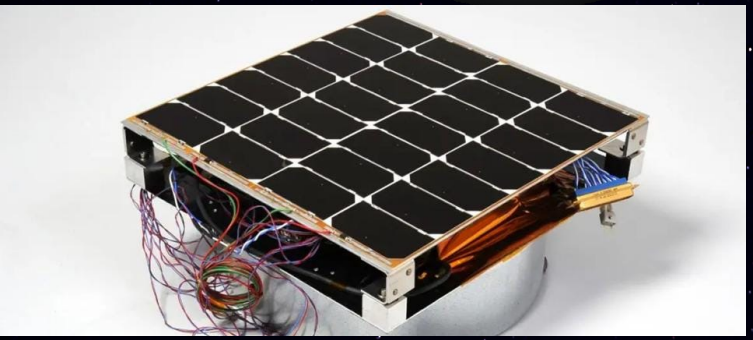
« States shall not place nuclear weapons or other weapons of mass destruction in orbit or on celestial bodies or station them in outer space in any other manner »



Artist views

Directed energy for powering earth and space (1/2)





Photovoltaic Direct Current to Radio Frequency Antenna Module (PRAM)
On flight in May 2020.

★Space-based solar power
- → collectors in space
- → wireless power transmission
- → receiving power via antenna

★Advantages
- → possible almost continuous illumination
- → constant optimal orientation
- → no atmospheric disturbances

★ Difficulties:
- → space launch costs
- → maintenance and hostile conditions
- → heat management

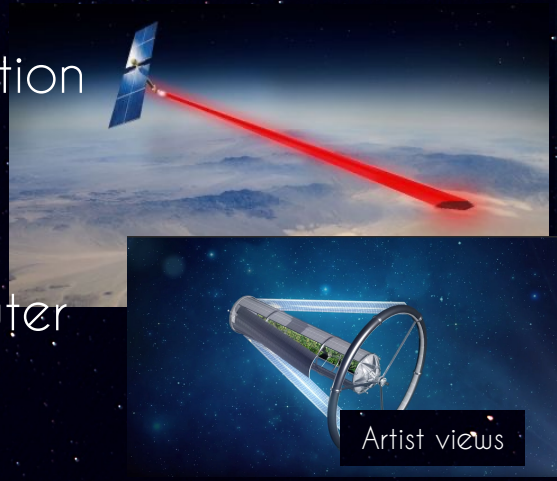
★Actively pursued by
- → China, India, Japan, UK, USA, Russia

Directed energy for powering earth and space (2/2)

★Wireless power transmission
- → laser or microwave
- → development of solar-pumped laser
- → Difficulties :
  - beam spreading and focusing
  - large receiving ground station
  - Efficiency loss in power conversion and transmission

Nikola Tesla's Wardenclyffe wireless station (1904)

★Solar energy for powering space toward industrialization
- → alternative to nuclear generators
- → remote power to distant space stations or planets
- → propelling lightsails
- → external power supply of electric propulsion for outer solar system and interplanetary exploration

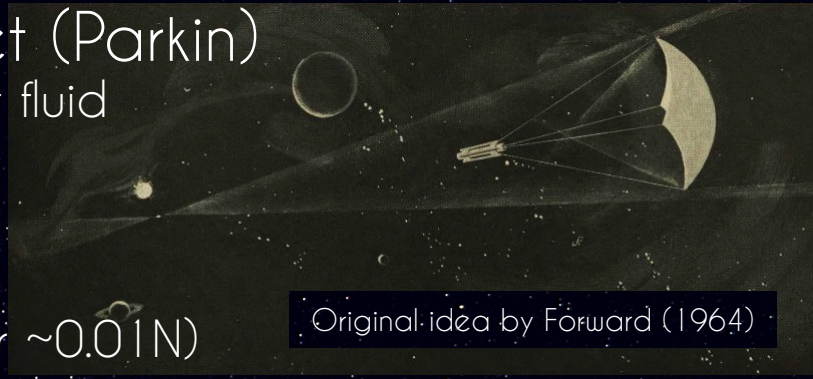


Artist views

Directed energy for space propulsion (1/2)

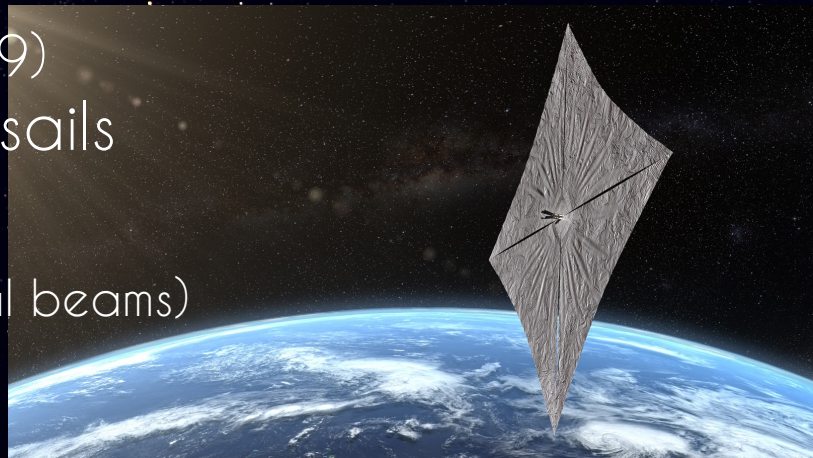
★ Microwave and laser thermal rocket (Parkin)
→ remote heating of on-board inert propellant fluid

★ Propellantless propulsion : lightsails
→ radiation pressure **Thrust = Power / c**
(1Newton for 300 MW)
→ Around Earth : 10^{-6} N thrust/m^2 (ionic thruster ~0.01N)
→solar sailing: decaying thrust with distance

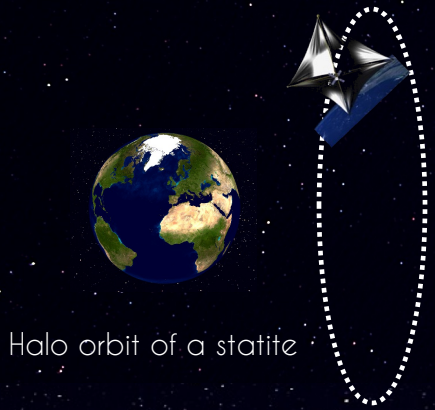

Original idea by Forward (1964)

★Solar sails space missions spatiales
IKAROS, NanoSail-D, Lightsail (2010-2019)

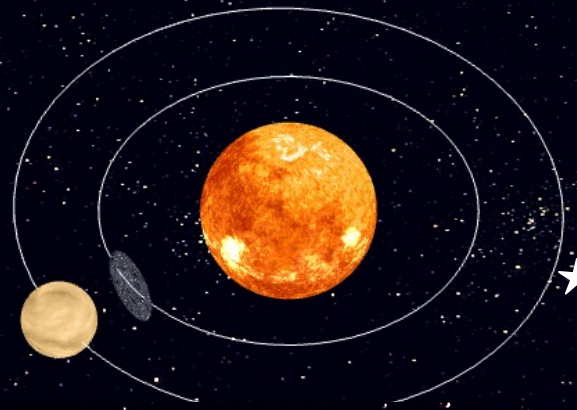
★ Improvement: beam-propelled lightsails
→ overcoming the solar flux decay
→ access to higher velocities
→ external attitude and course control (several beams)
→ propulsion + powering



Directed energy for space propulsion (2/2)



Halo orbit of a statite



Statite in syncrhonous orbit with Venus

★Statite = static + satellite : continuously operated lightsail
- → Non-keplerian orbits and halo orbits
- → Modified Lagrange points

★ Applications
- →Solar storm alerts (Space weather)
- →Micro-sail constellations
- → Freight transportation with laser-aided solar sails
- → Hybrid propulsion (electric/plasma+sail) interplanetary spaceflight
- → Interstellar exploration up to relativistic velocities

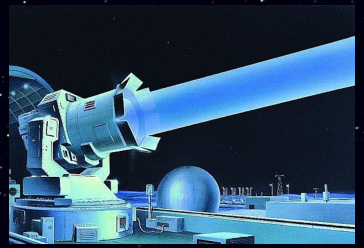
★Challenges for material sciences
- → high reflectivity
- → low surface mass density
- → high mechanical and temperature resistance

Breakthrough Starshot (2016)

★ Board: Y. Milner, M. Zuckerberg, S. Hawking, etc.

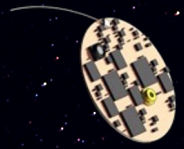
★ Network of ground-based propelling beams (IR laser 10-100 GW)

★ Solar powered (10-100km^2 collecting surface)



Military project: 1MW

★ Flyby of Proxima Centauri
with robotic nanocrafts ~1-10grams

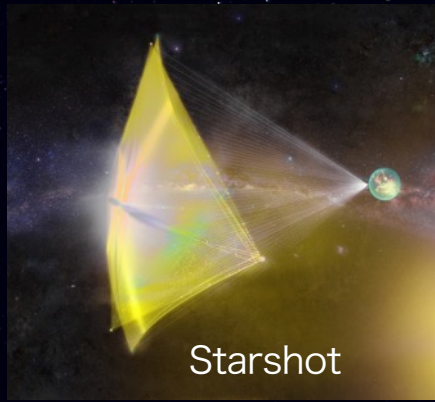


★ V~0.2 c ; 20 years-long trip

★ Development : 30 years

★ Estimated cost: 10 billion USD

★ Relativistic astrodynamics (UNamur)



K. Parkin, Acta Astronautica 152, p. 370-384 (2018)

A. Füzfa, Physical Review D 99, 104081 (2019)
A. Füzfa, W. Dhelonga, O. Welcomme, Physical Review Research 2, 043186 (2020)

DIRECTED-ENERGY, A KEY TECHNOLOGY FOR SPACE EXPLORATION

★ Currently : military prototypes and early deployment

★Peaceful applications in Space:

→ space-debris analysis and remote removal

→ Asteroid protection and exploitation

→ Key to space-based solar power for Solar System industrialization

→ Propellantless propulsion and continuously operated lightsails (space stations and observatories, freight transportation)

→ Hybrid propulsion for manned interplanetary flights (electric/plasma + sail)

★The future of the Solar System?

An educative SCI-FI novel based on established science