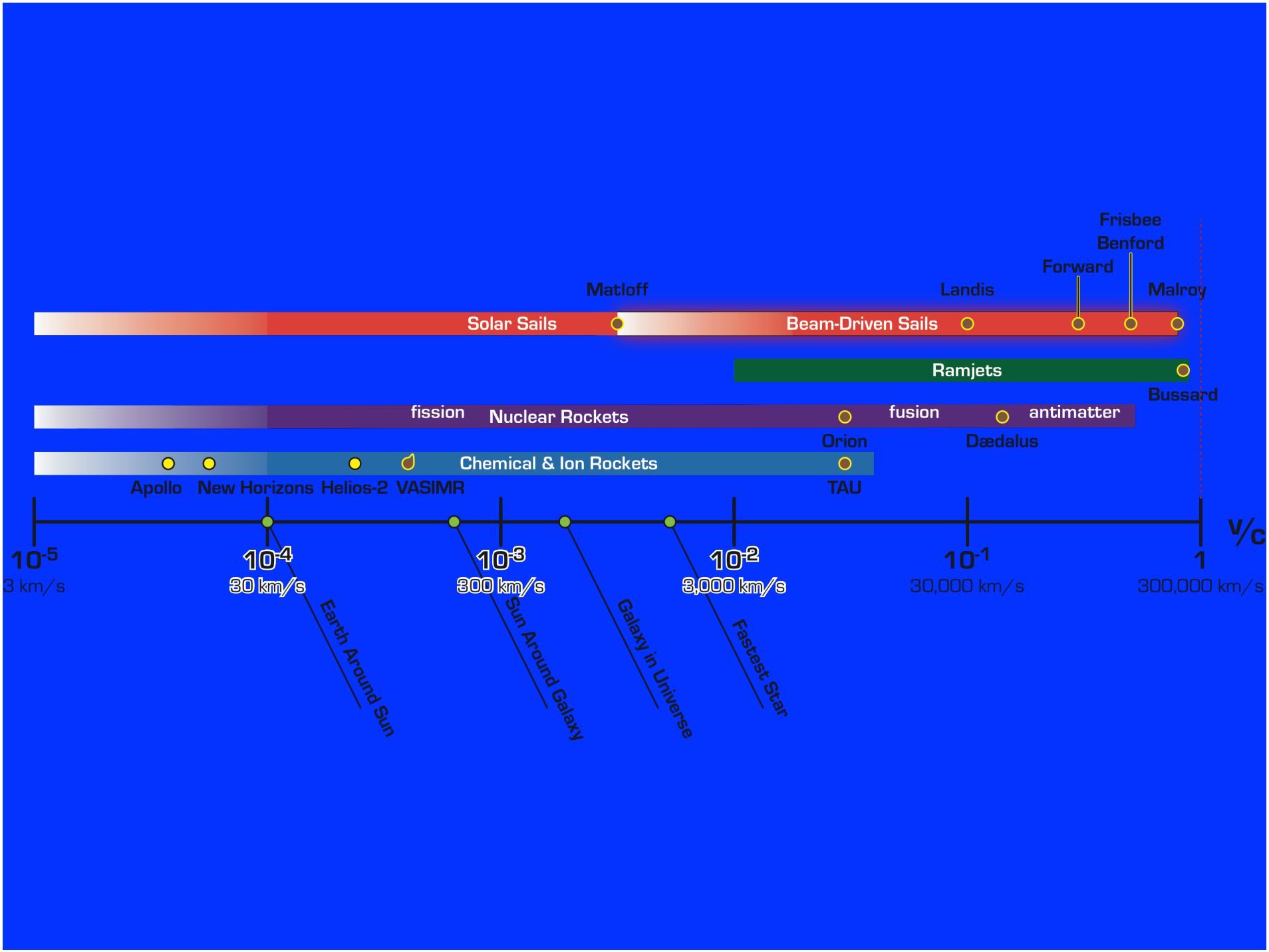
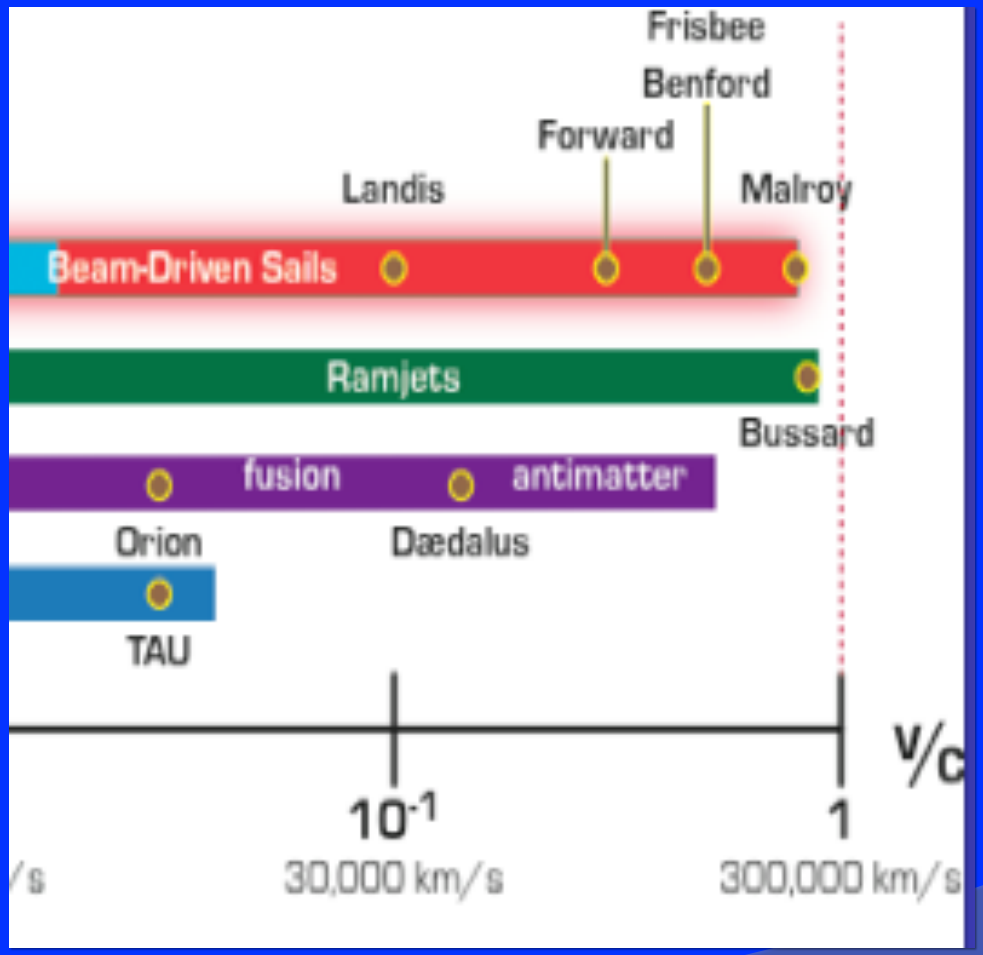

Frisbee
Benford
Forward
Matloff
Landis
Malroy
Solar Sails
Beam-Driven Sails
Ramjets
Bussard
fission
Nuclear Rockets
fusion
antimatter
Orion
Dædalus
Chemical & Ion Rockets
Apollo
New Horizons
Helios-2
VASIMR
TAU
v/c
10-5
3 km/s
10-4
30 km/s
10-3
300 km/s
10-2
3,000 km/s
10-1
30,000 km/s
1
300,000 km/s
Earth Around Sun
Sun Around Galaxy
Galaxy in Universe
Fastest Star

Starship Technologies >0.1c



Power Beaming is a Highly Visible Technosignature

- The most conspicuous observable feature of an advanced ET civilization may well be *leakage* from large-scale beaming of electromagnetic power over planetary, interplanetary and interstellar scales.

- Beaming is likely to be the brightest Technosignature of alien civilization, if they use that technology.

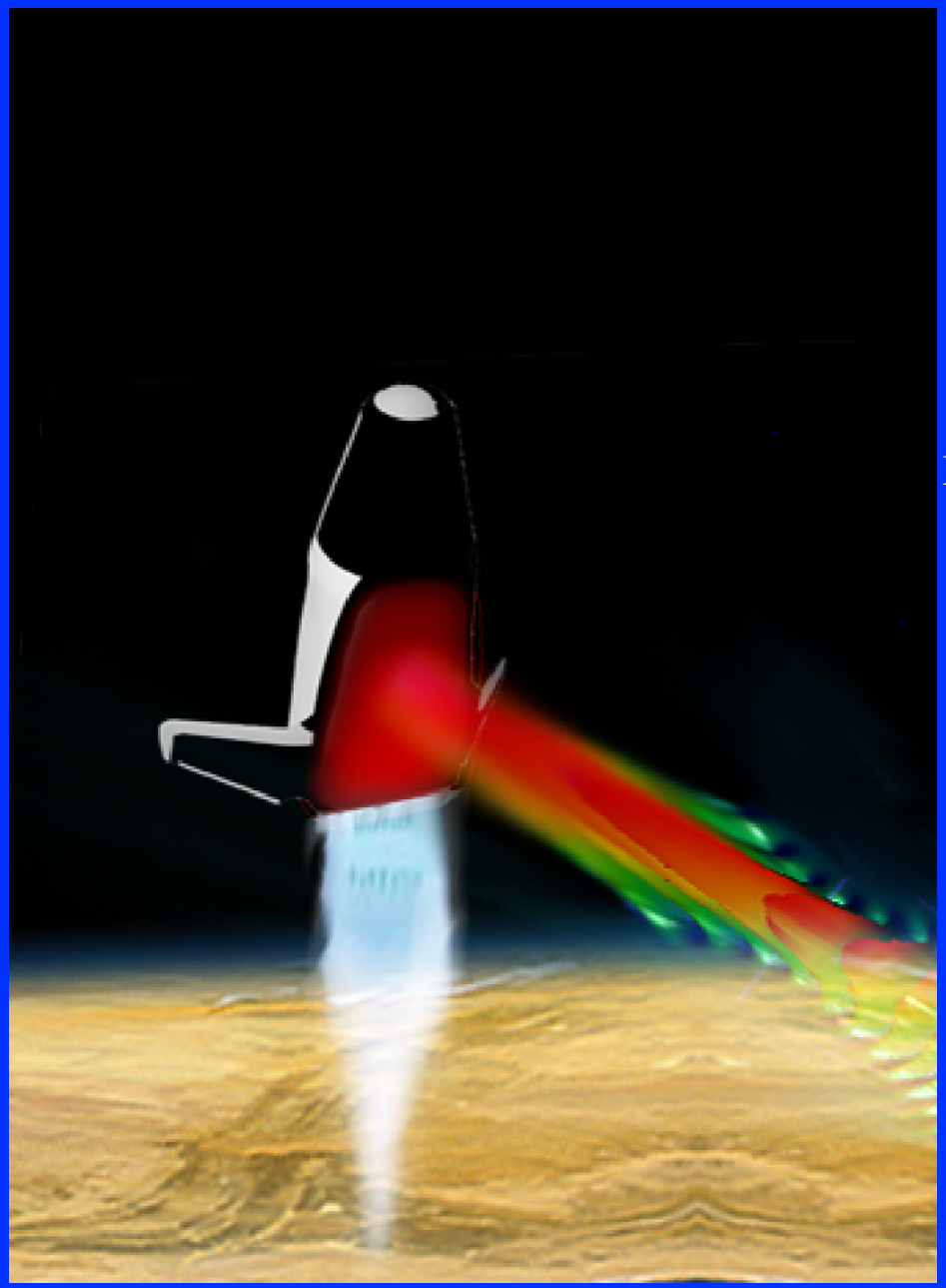
- Starshot EIRP is 10^30, vs. Arecibo EIRP 10^13.

Consequences:

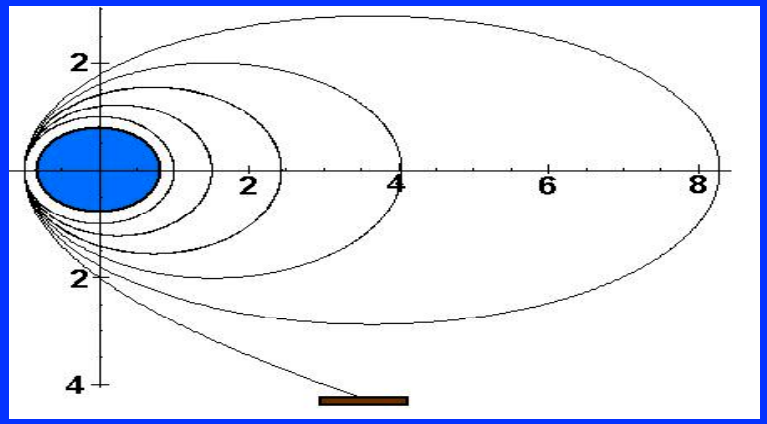
- We can put messages on Starshot.
- Messages may be found on ET power beaming leakage.

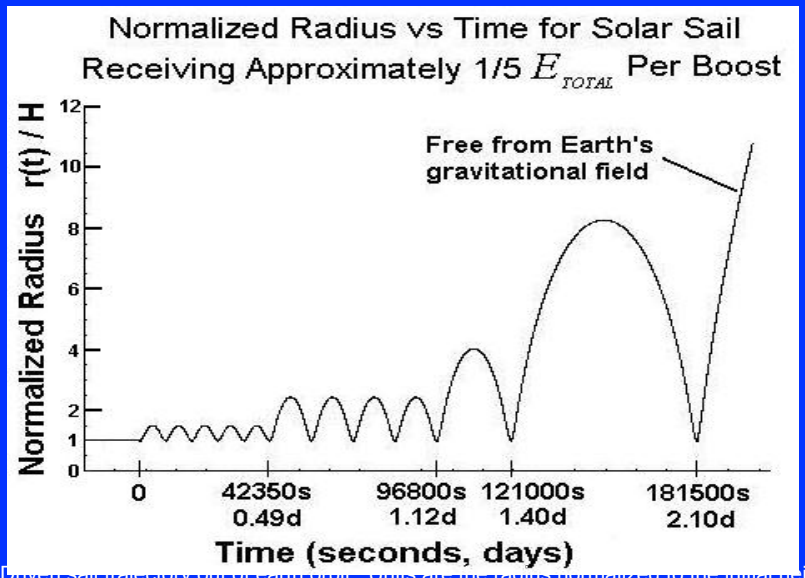
Beam-Driven Space Propulsion Applications

- Launch to Orbit
- Orbit-Raising
- Interplanetary Commerce ~100 km/sec
- Interstellar Precursors, ~100-1000 km/sec
- Starships, >1000 km/sec

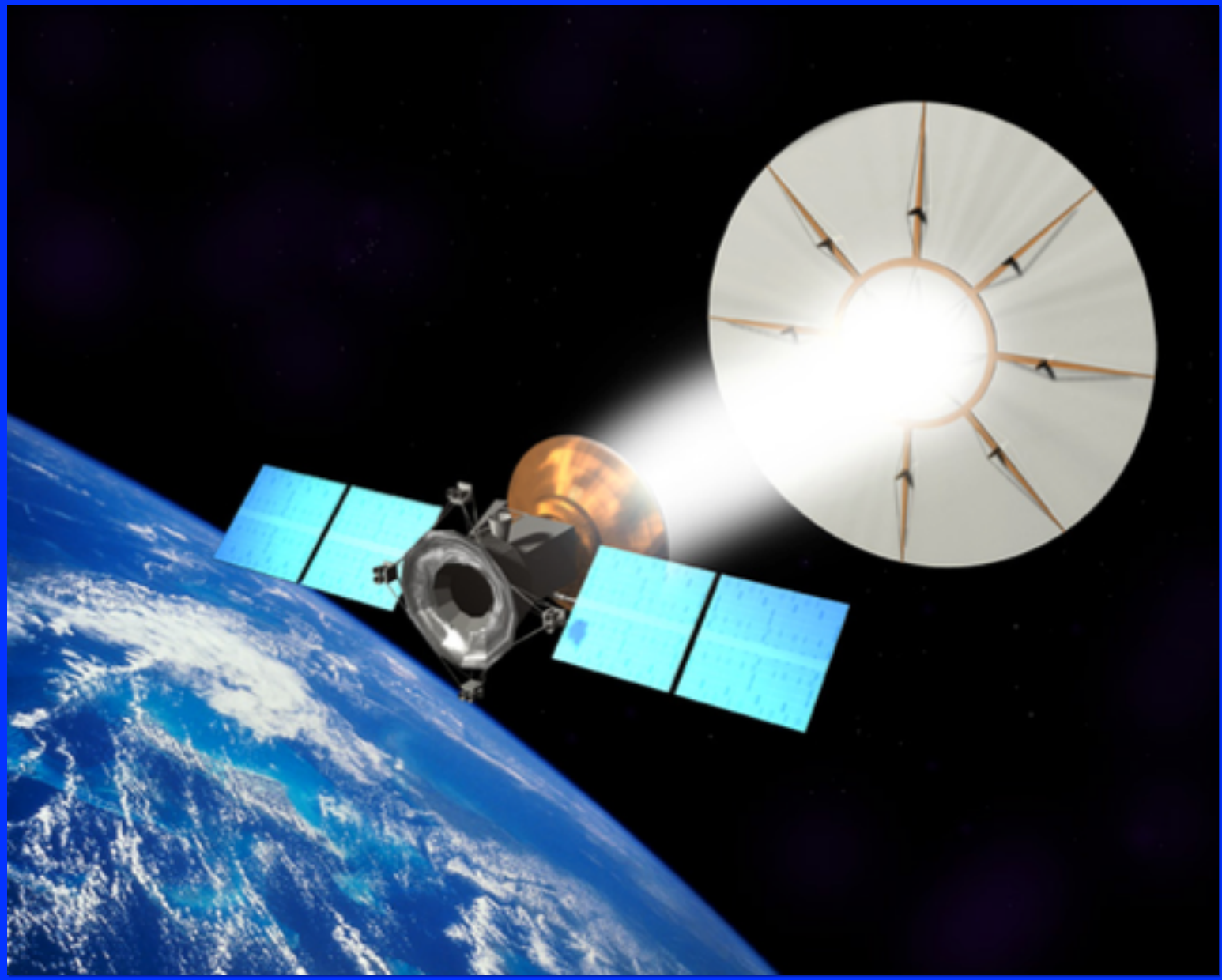


Microwave Thermal Rocket
in Flight

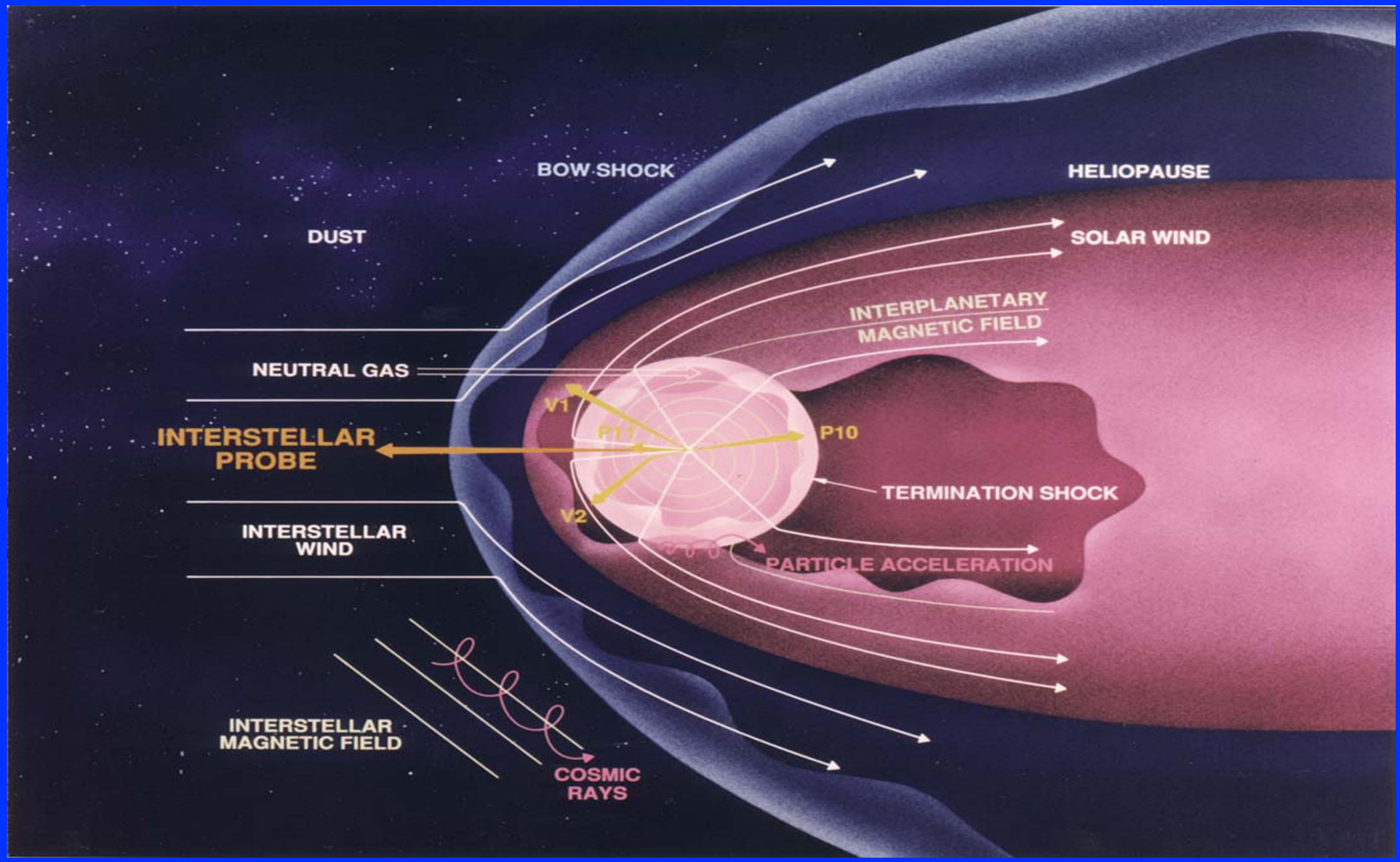




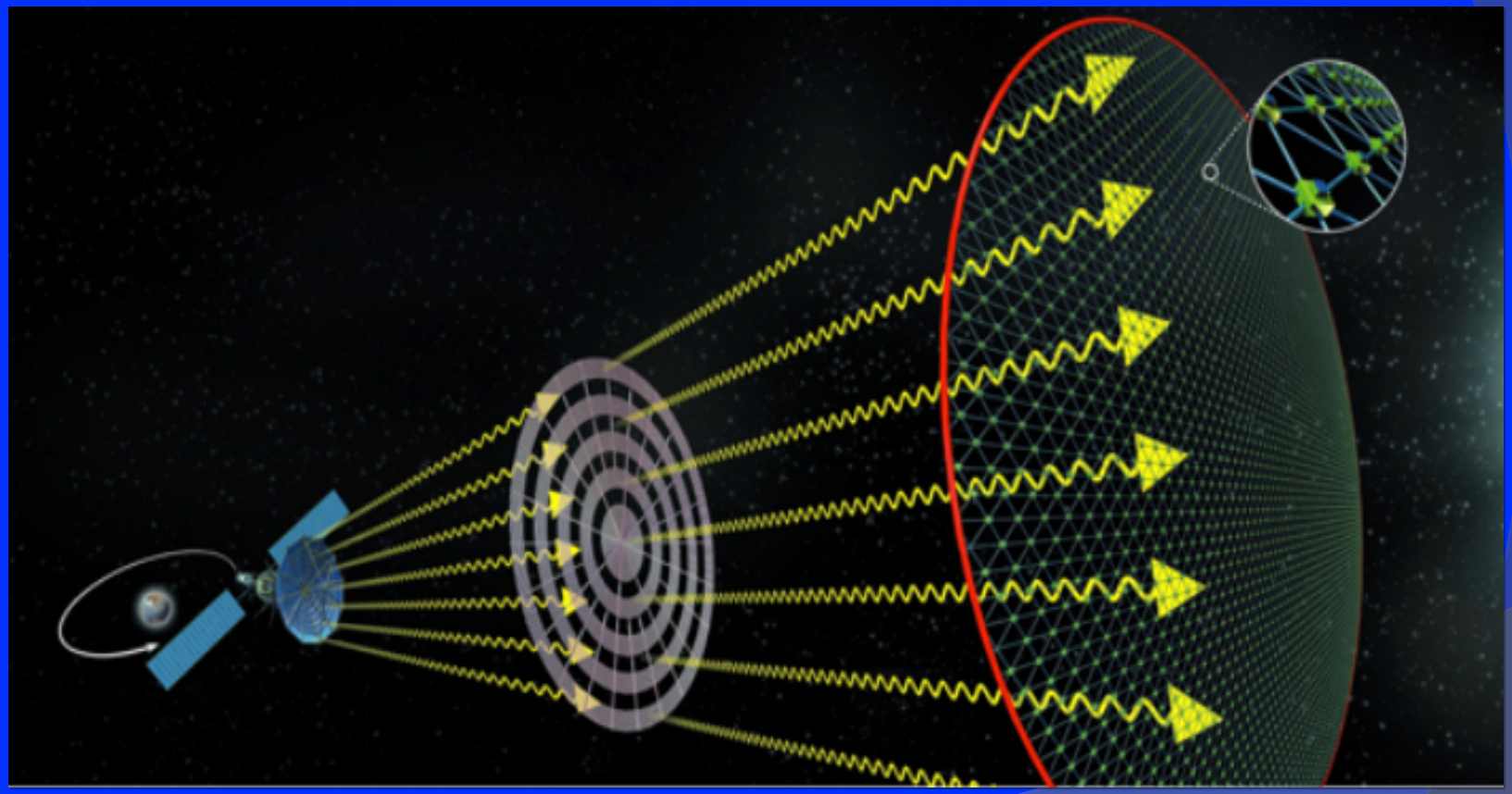
Beam-Driven sail trajectory out of earth orbit. Units are the radius normalized to the initial height H. Solar sail is not drawn to scale. b) Radius normalized to H vs. time for solar sail.



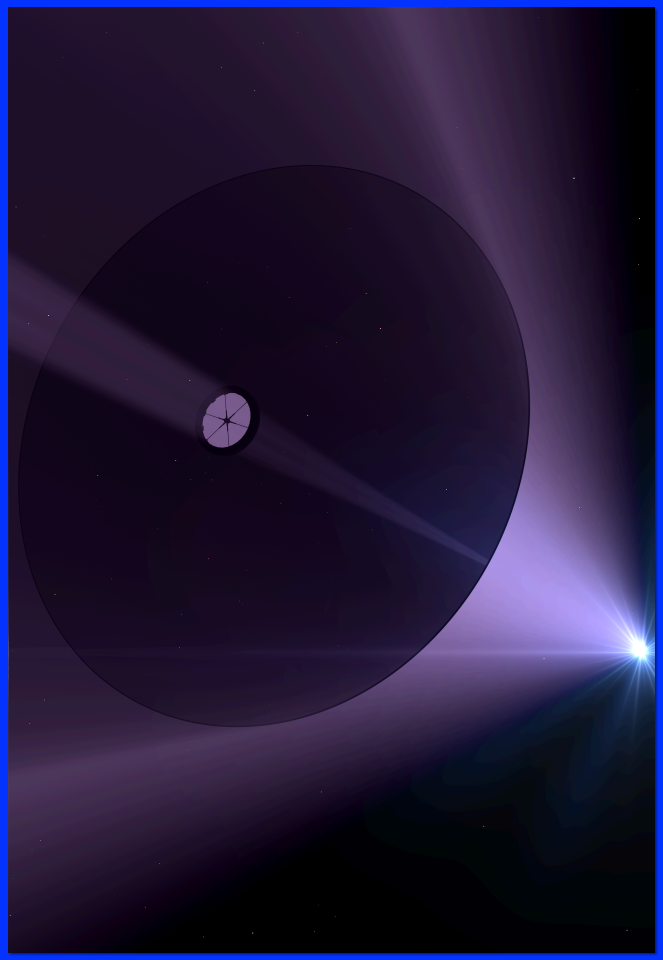
INTERSTELLAR FLIGHT MEANS >>100 KM/SEC

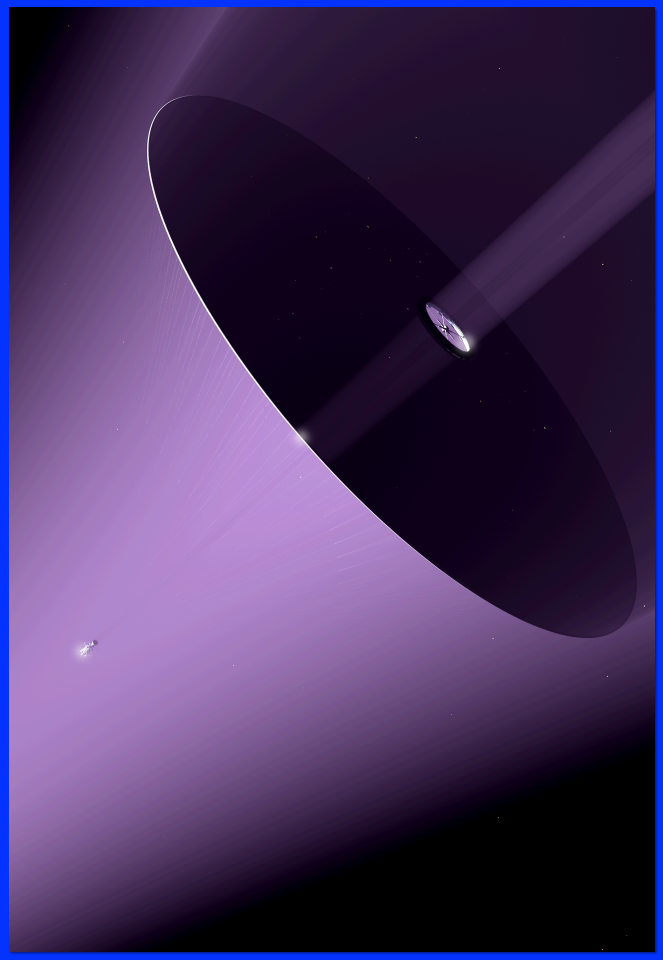


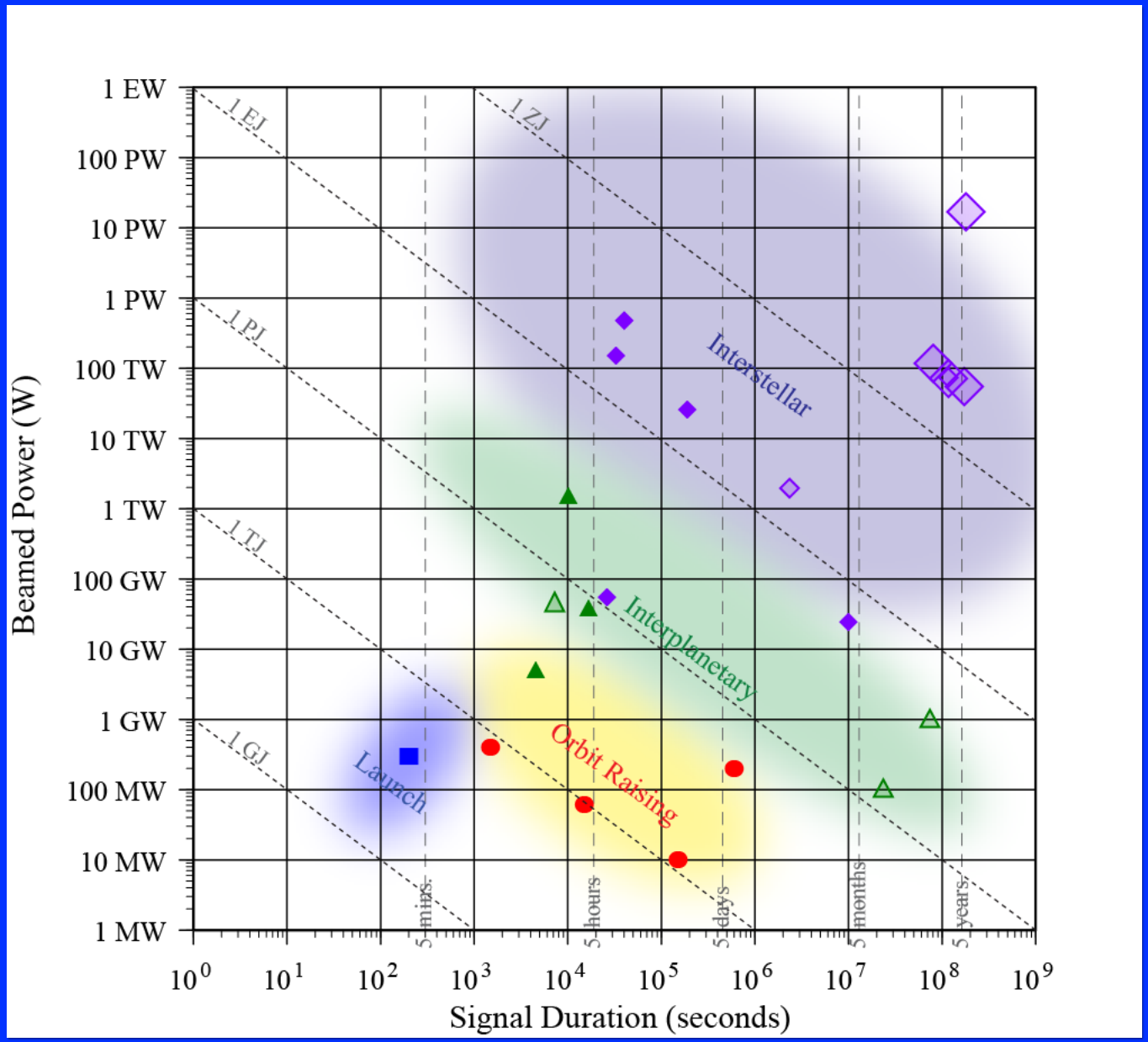
Bob Forward's *Starwisp*



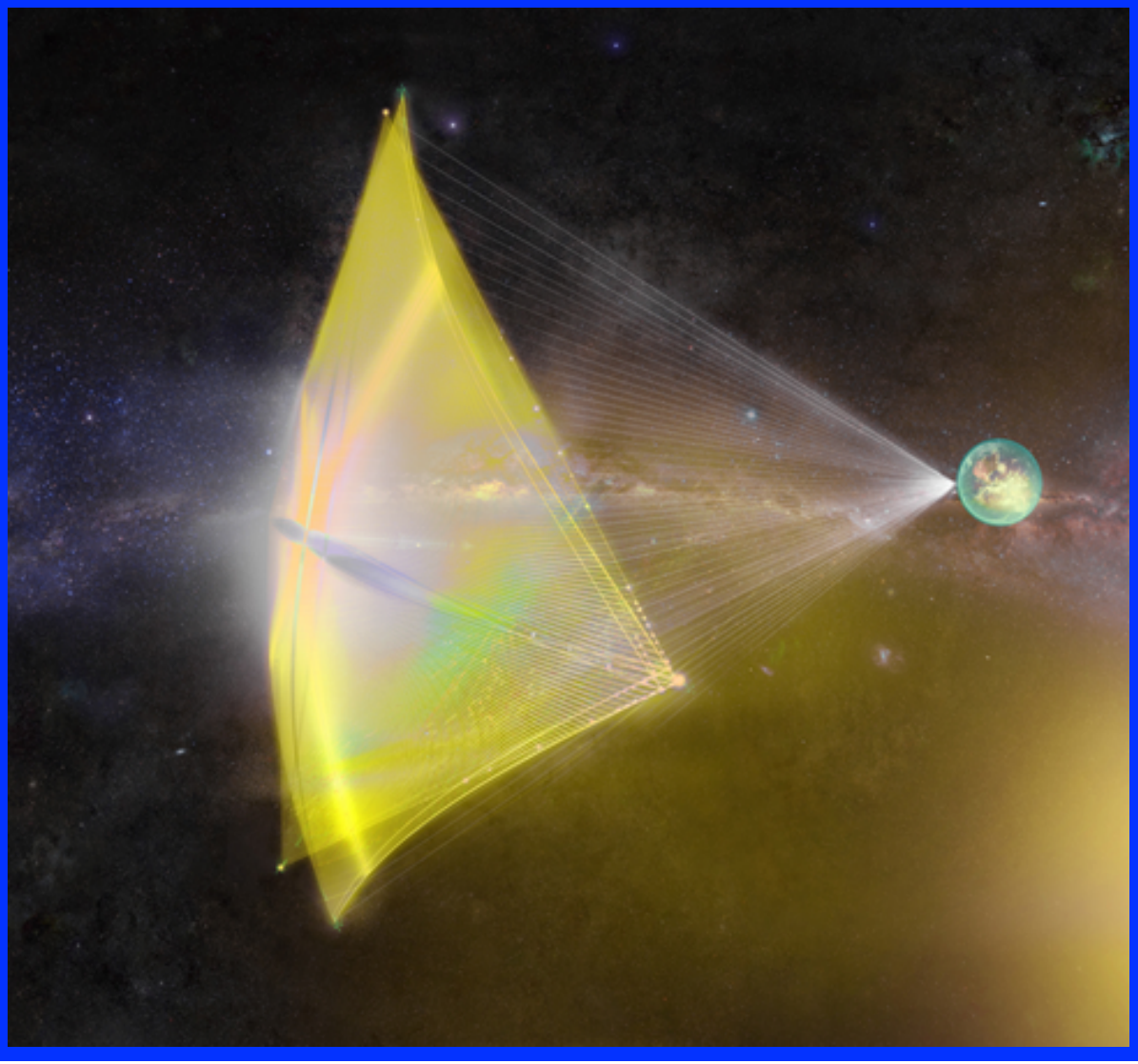
Sailships for Interstellar

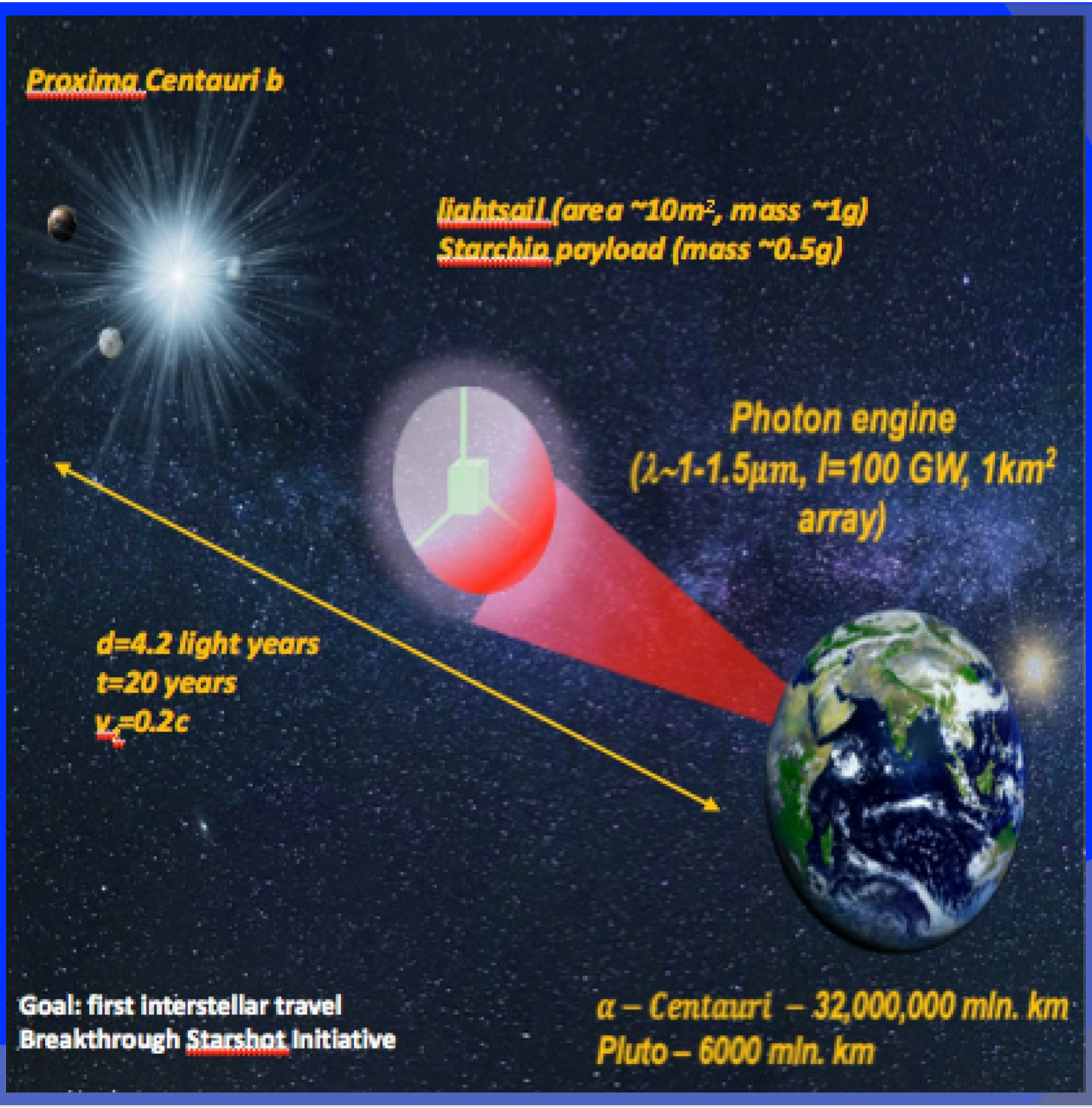


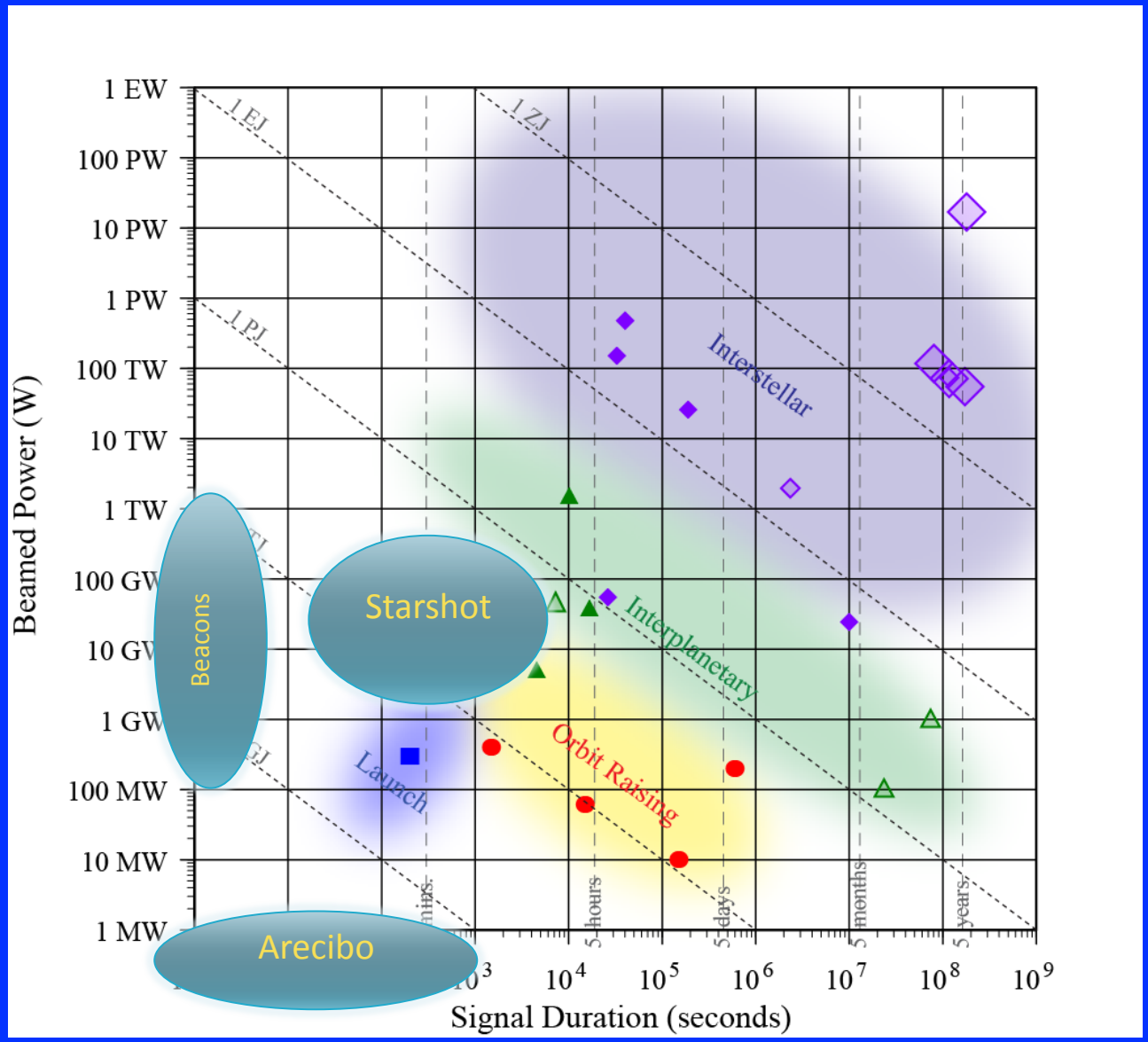



Beamed Power (W)
1 EW
100 PW
10 PW
1 PW
100 TW
10 TW
1 TW
100 GW
10 GW
1 GW
100 MW
10 MW
1 MW
1 EJ
1 ZJ
1 PJ
1 TJ
1 GJ
Interstellar
Interplanetary
Orbit Raising
Launch
5 mins.
5 hours
5 days
5 months
5 years
10^0 10^1 10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9
Signal Duration (seconds)

21st Century Starship Program: Starshot



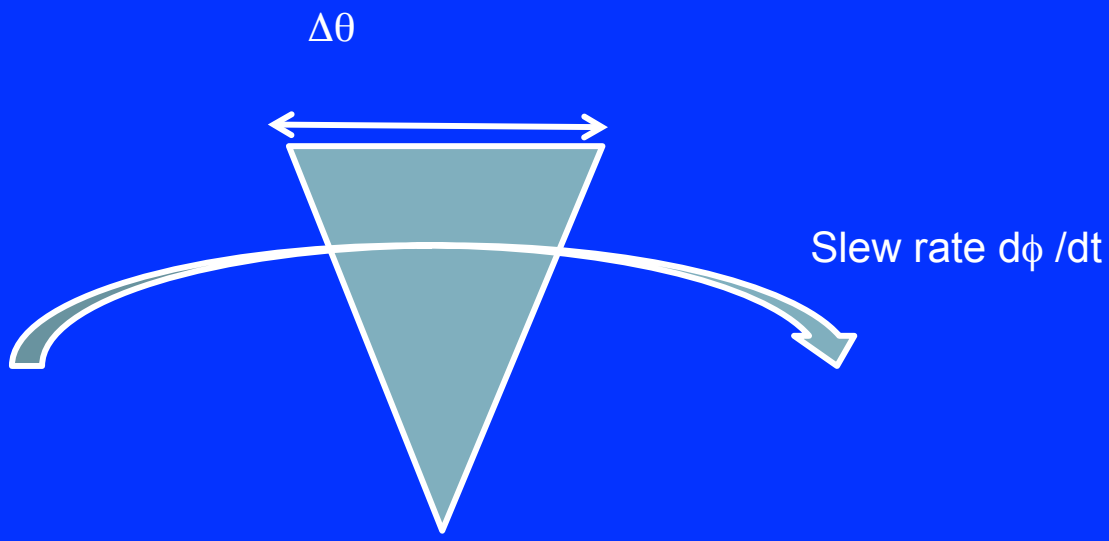

Proxima Centauri b
lightsail (area ~10m², mass ~1g)
Starchip payload (mass ~0.5g)
Photon engine
(λ~1-1.5μm, I=100 GW, 1km² array)
d=4.2 light years
t=20 years
v=0.2c
Goal: first interstellar travel
Breakthrough Starshot Initiative
α – Centauri – 32,000,000 mln. km
Pluto – 6000 mln. km


1 EW
100 PW
10 PW
1 PW
100 TW
10 TW
1 TW
100 GW
10 GW
1 GW
100 MW
10 MW
1 MW
Beamed Power (W)
1 EJ
1 ZJ
1 PJ
Interstellar
Starshot
Beacons
Interplanetary
Orbit Raising
Launch
Arecibo
5 hours
5 days
5 months
5 years
10^3
10^4
10^5
10^6
10^7
10^8
10^9
Signal Duration (seconds)

Representative Parameters for Applications of Power Beaming

Application	Frequency f [GHz]	Power P	Duration T	Repeat Time [sec]	Beamwidth $\Delta\theta$=2.44λ/D [radians (arcsec)]
Launch to Orbit	94	300 MW	minutes	Immediate	2×10^{-5} (4.1″)
Orbit Raising	94	300 MW	hour	hour	2×10^{-4} (41″)
Interplanetary	68	0.3 TW	hours	Immediate	4×10^{-6} (0.8″)
0.1 c Starship	100	1 TW	10 hours	days	2×10^{-8} (0.004″)
0.5 c Starship	3×10^{14} Hz (1 μm)	100 TW	years	years	2×10^{-11} (4.1μas)

Beam width and slewing



Representative Observable Parameters for Applications of Power Beaming

Application	Slew Rate $d\phi/dt$ [rad/sec]	EIRP $W = 4\pi P/\Delta\theta$ [W]	Time $\Delta\theta/(d\phi/dt)$ [sec]
Launch to Orbit	5×10^{-3}	10^{19}	0.04
Orbit Raising	10^{-4} - 10^{-5}	10^{16}	3
Interplanetary	7×10^{-8}	10^{25}	0.04 – 0.4
0.1 c Starship	0	10^{32}	long
0.5 c Starship	0	10^{38}	long

Comparing Observations to Power Beaming EIRP

- The 1 Hz channels could see *all* the applications, but they are *not seen*.
- • Launch from a planetary surface into orbits is *marginally detectable*, but not seen, at the threshold of the Allen Array for the 100 kHz observations, although unlikely at the frequencies observed. Orbit raising, which requires lower power, is *not detectable*.
- Interplanetary transfers by beam-driven sails should be detectable in their observations, but are *not seen*. This is for both the 1 Hz and for the 100 kHz observations.
- Starships launched by power beams, to other solar systems not our own, with beamwidths that we happen to fall within, would be detectable, but are *not seen*.

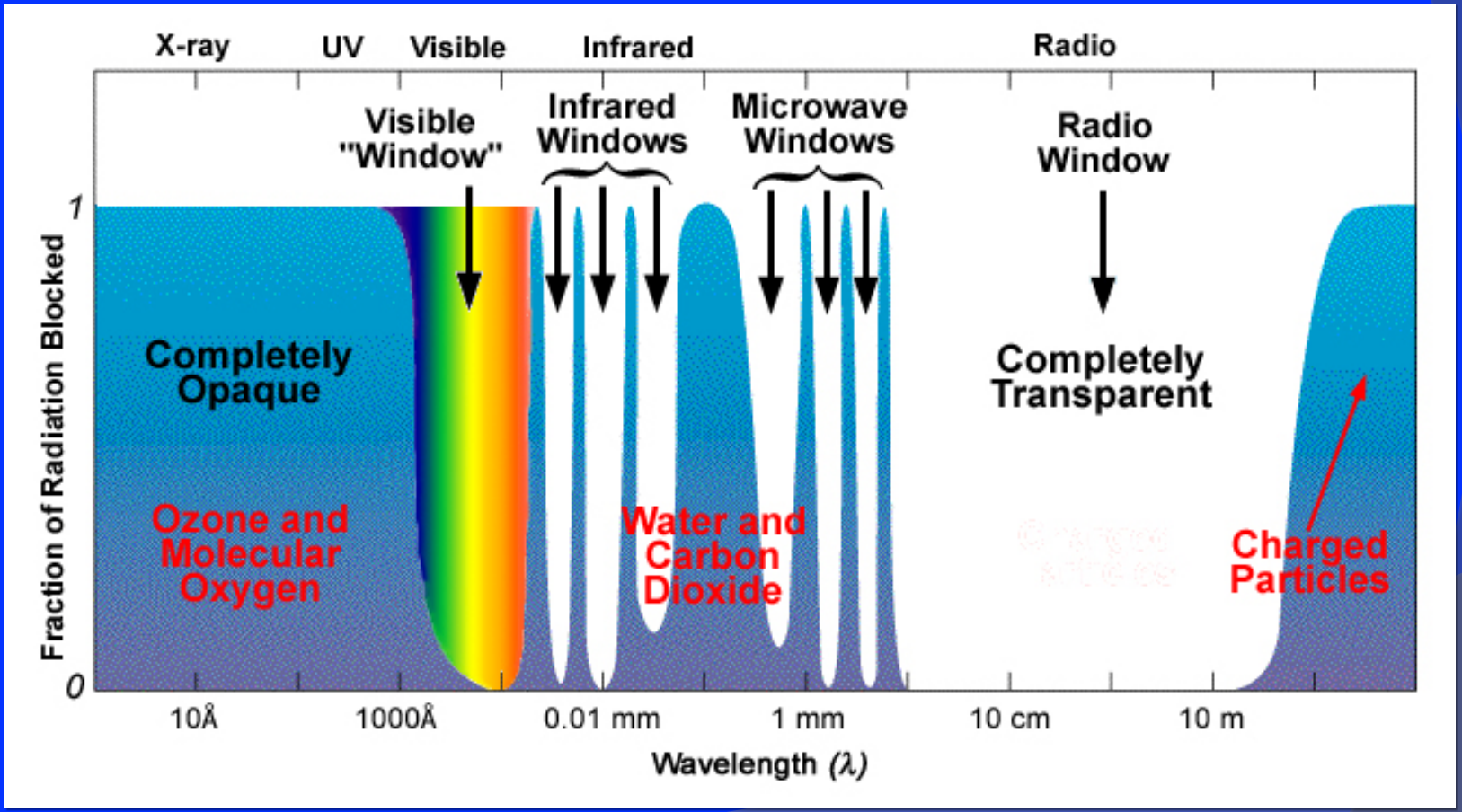
Caveats

- Power beaming is not an isotropic endeavor, and so the geometry of the transmitter and the intended recipient will produce a conjunction from our point of view only episodically.
- Observations were conducted for only a limited time and further observations would provide a more stringent constraint.
- The optimal frequencies we would presently use for power beaming are mostly in the millimeter band, so are outside the microwave range the Allen Telescope Array observed. So are laser frequencies.

Looking Forward-1

- The power beaming levels are high and transient and could easily dwarf any ETI civilizations routine leakage to space.
- More extensive observations should be made in more systematic studies of power beaming leakage.
- *Higher frequencies* should be observed: 35GHz, 70 − 115GHz, 130 − 170GHz and 200 − 320GHz.
- Such transient sources require longer observing times. A promising avenue is to revisit past observations of transient events, of which there are many.

Earth's Atmospheric Windows



Looking Forward-2

- Extraterrestrial intelligence would know their power beams could be observed.
- *They could put a message on the power beam* and broadcast it for our receipt at little additional energy or cost.
- By observing leakage from power beams *we may find a message* embedded on the beam.
- When we in future build large power beaming systems *we may put messages on them*.
- We should address the METI issue (messaging to ETI)—mankind should discuss and agree on what we wish to say.

Paper in *ApJ*, 825, 101 (2016)

POWER BEAMING LEAKAGE RADIATION AS A SETI OBSERVABLE

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ABSTRACT

The most observable leakage radiation from an advanced civilization may well be from the use of power beaming to transfer energy and accelerate spacecraft. Applications suggested for power beaming involve Earth-to-space applications such as launching spacecraft to orbit, raising satellites to a higher orbit, and interplanetary concepts involving space-to-space transfers of cargo or passengers. We also quantify beam-driven launch to the outer solar system, interstellar precursors and ultimately starships. We estimate the principal observable parameters of power beaming leakage. Extraterrestrial civilizations would know their power beams could be observed, and so could put a message on the power beam and broadcast it for our receipt at little additional energy or cost. By observing leakage from power beams we may find a message embedded on the beam. Recent observations of the anomalous star KIC 8462852 by the Allen Telescope Array (ATA) set some limits on extraterrestrial power beaming in that system. We show that most power beaming applications commensurate with those suggested for our solar system would be detectable if using the frequency range monitored by the ATA, and so the lack of detection is a meaningful, if modest, constraint on extraterrestrial power beaming in that system. Until more extensive observations are made, the limited observation time and frequency coverage are not sufficiently broad in frequency and duration to produce firm conclusions.

Keywords: space vehicles, extraterrestrial intelligence, stars:individual — KIC 8462852

1. OBSERVABLE POWER BEAMING

The most observable leakage from an advanced civilization may well be from the use of power beaming to transfer energy and accelerate spacecraft, both within and beyond the star system where the civilization is located. In future, such applications may make the Earth's radiation in the microwave, millimeter and visible/near-IR parts of the electromagnetic spectrum be very intense. Beaming of power for a variety

However, the driving of spacecraft by intense beams of radiation is far more focused than communication signals, and of course far more powerful. Therefore they could be far more easily detected.

It has previously been noted that such leakage from other civilizations could be observable (Benford 2008). Guillochon & Loeb (2015) have quantified leakage from beaming for interplanetary space propulsion, its observables, and implications for SETI Extraterrestrial Intelligence (ETI) having

Space Solar Power not easily Observed