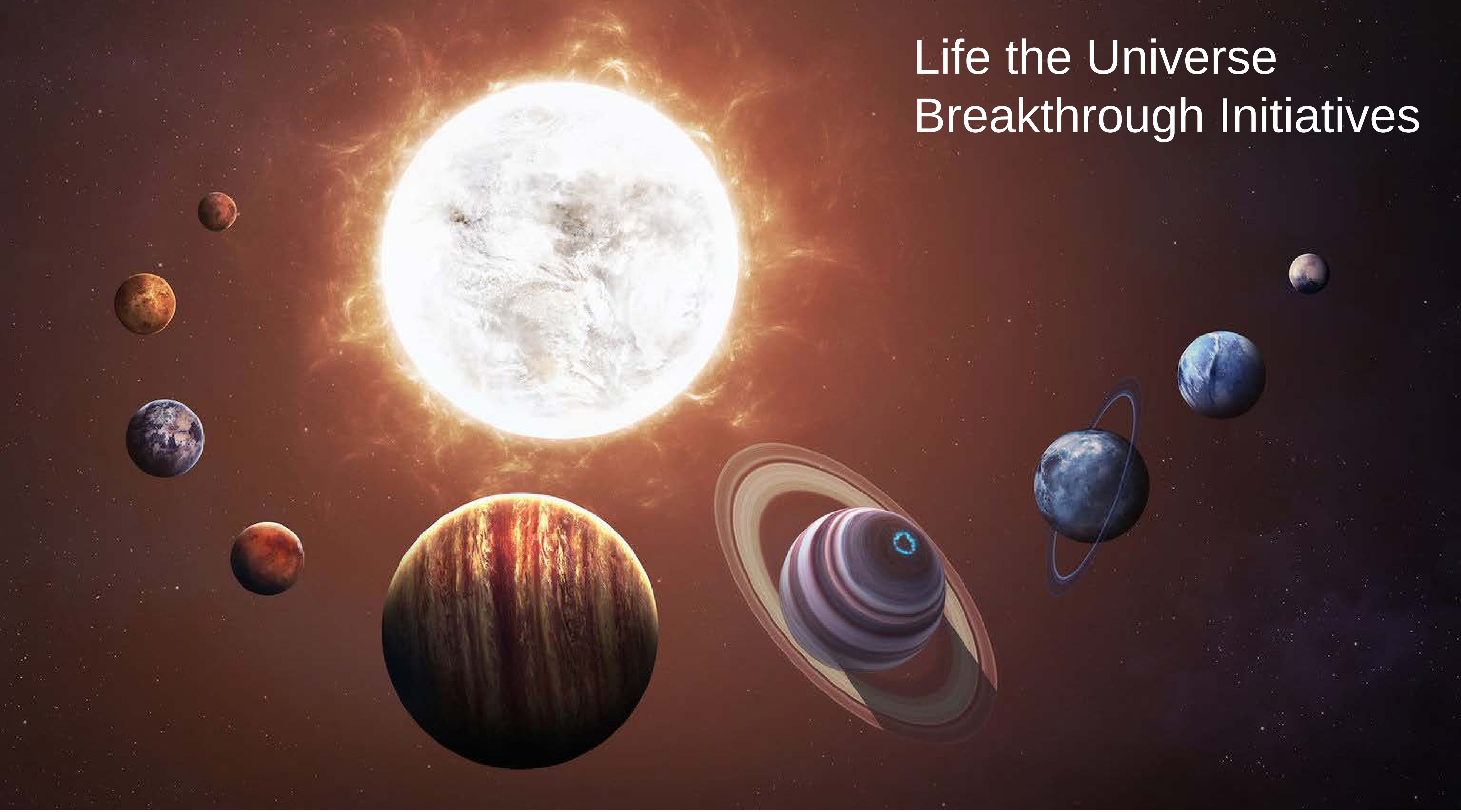
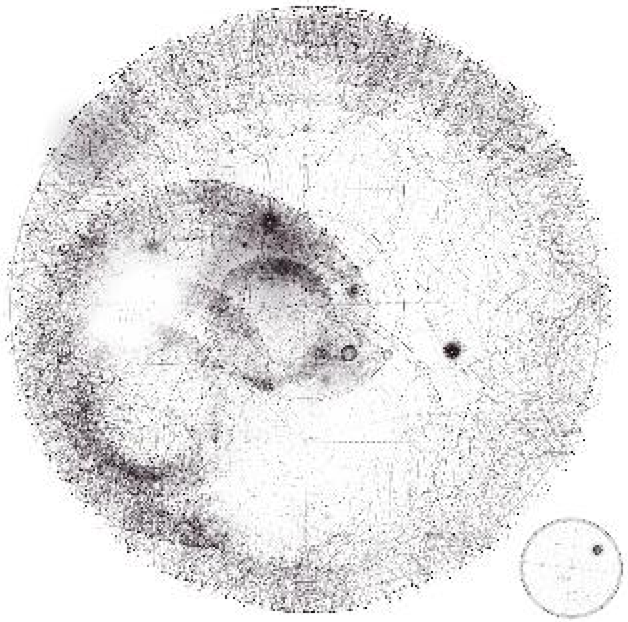
Life the Universe
Breakthrough Initiatives

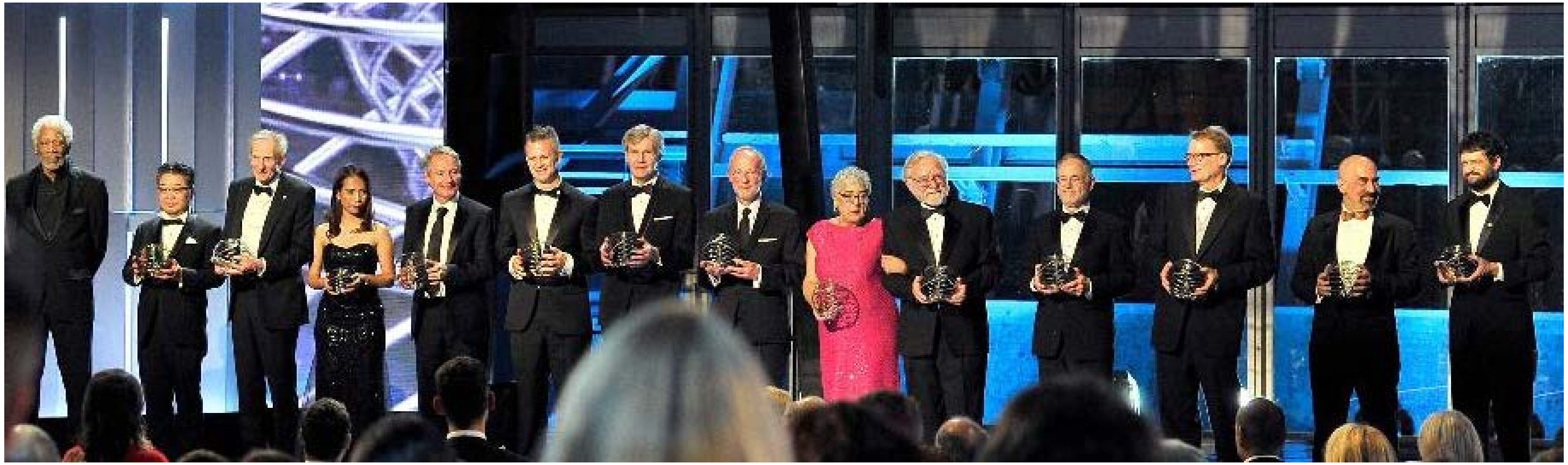




Introduction

BREAKTHROUGH
INITIATIVES

2018 Breakthrough Prize Winners



2018 Breakthrough Prizes in Life Sciences Awarded:
Joanne Chory, Don W. Cleveland, Kazutoshi Mori, Kim Nasmyth, and Peter Walter.

2018 Breakthrough Prize in Physics Awarded;
Charles L. Bennett, Gary Hinshaw, Norman Jarosik, Lyman Page Jr., David N. Spergel, and the WMAP Science Team

2018 Breakthrough Prize in Mathematics Awarded;
Christopher Hacon and James McKernan. (13)

New Horizons in Physics Prizes Awarded;
Christopher Hirata, Douglas Stanford, and Andrea Young. ($100,000) each

New Horizons in Mathematics Prizes Awarded;
Aaron Naber, Maryna Viazovska, Zhiwei Yun, and Wei Zhang. (7) ($300,000) each

Breakthrough Junior Challenge

BREAKTHROUGH
INITIATIVES

2017 Hillary Diane Andales.

Submit application and video no later than
July 1, 2018 at 11:59 PM Pacific Daylight Time
Ages 13 to 18

$250K Scholarship
$100K Lab
$50K Teacher

2015 Ryan Chester Ohio

BREAKTHROUGH LISTEN

Berkeley
UNIVERSITY OF CALIFORNIA

GREEN BANK
OBSERVATORY

CSIRO

UNIVERSITY OF CALIFORNIA
OBSERVATORIES

SETI HOME

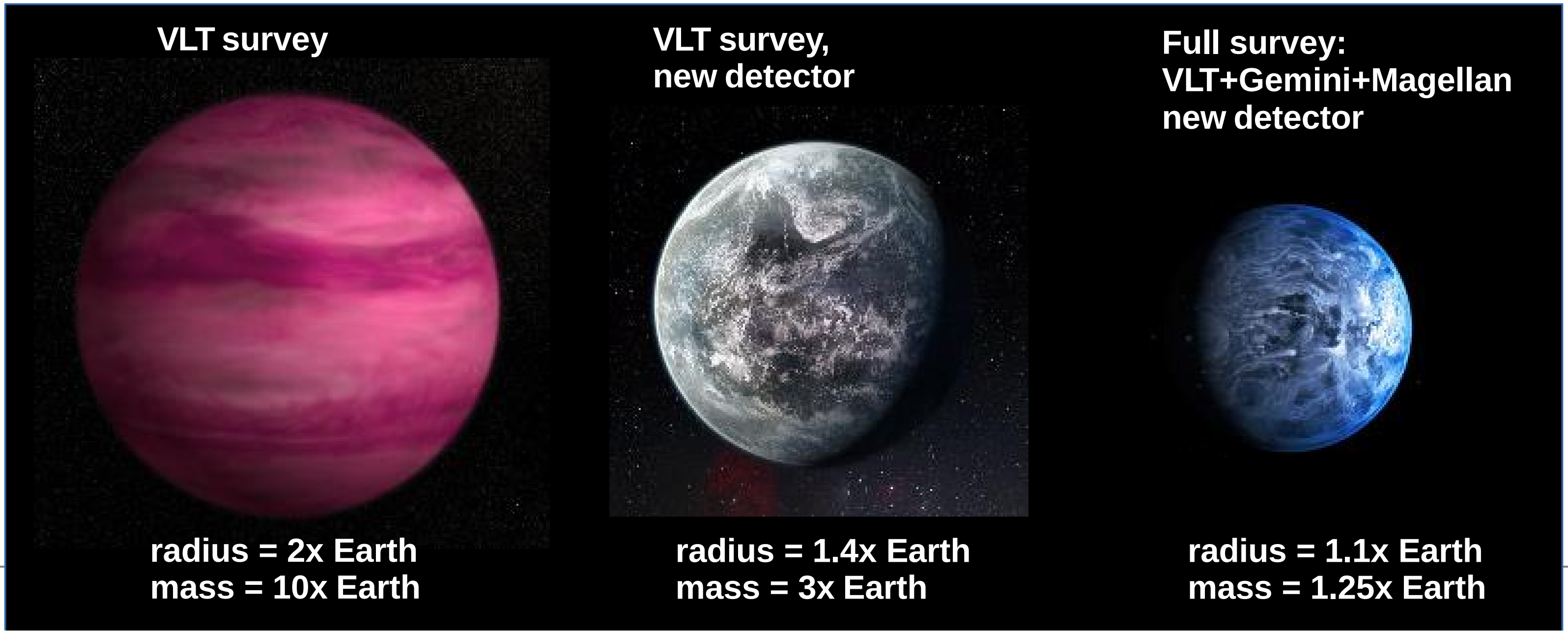
BTW 10um : current and future capabilities

VLT only survey, current camera:
Can detect ~2 Earth radius rocky planets = ~10 Earth mass in Alpha Cen A&B system

Full survey (VLT, Gemini, Magellan), new detector:

-detector alone brings 4x gain in efficiency (same observation requires ¼ of the time).
At equal exposure time, 2x gain in sensitivity:
from 2 Earth radius / 10 Earth mass to 1.4 Earth radius / 3 Earth mass

-Gemini and Magellan increases equivalent exposure time by x3 → additional 1.7x gain in sensitivity from 1.4 Earth radius / 3 Earth mass to 1.1 Earth radius / 1.25 Earth mass



Earth

Visiting planets of the nearest stars within our lifetime

BREAKTHROUGH INITIATIVES

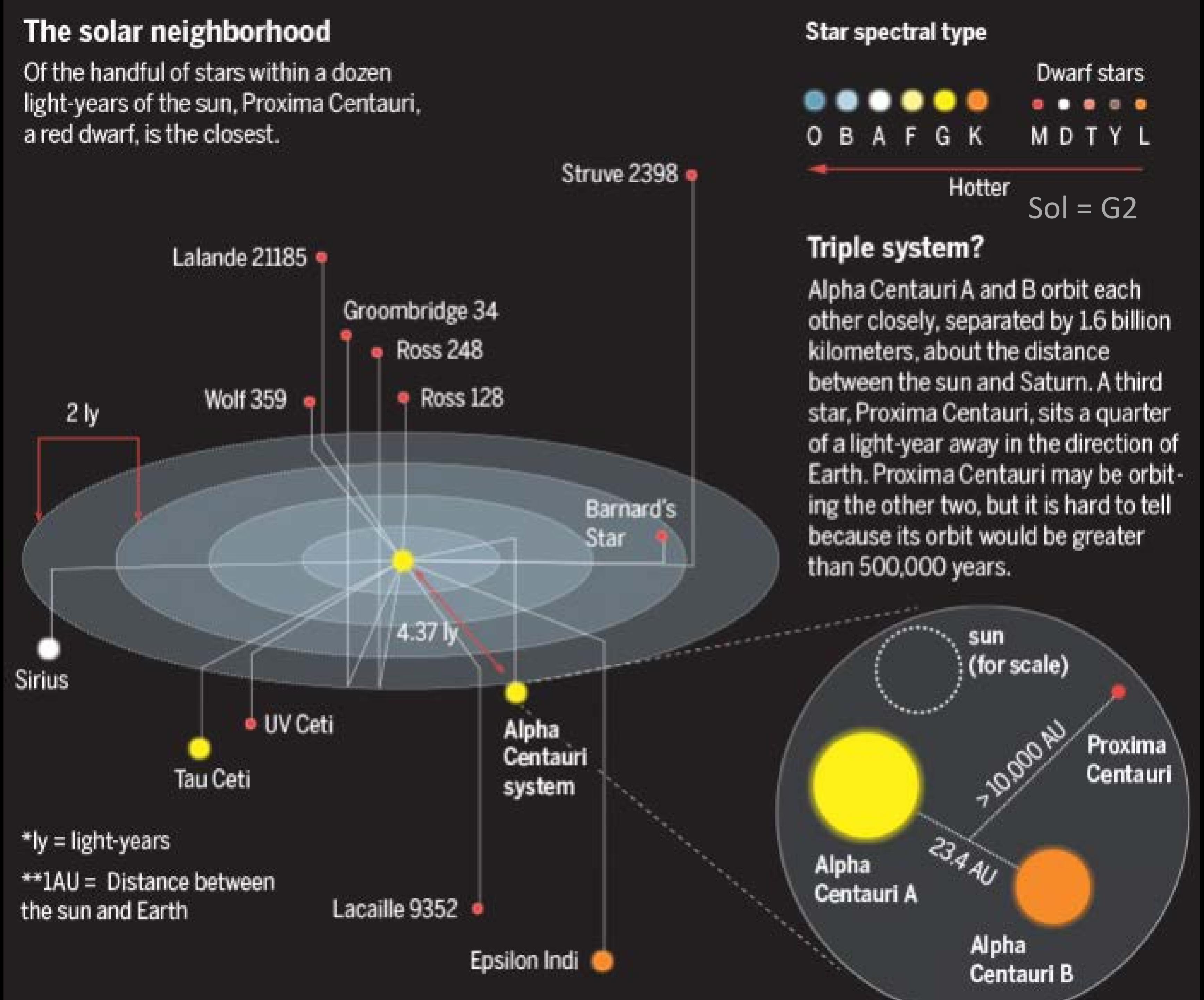
- Basic question for humankind:

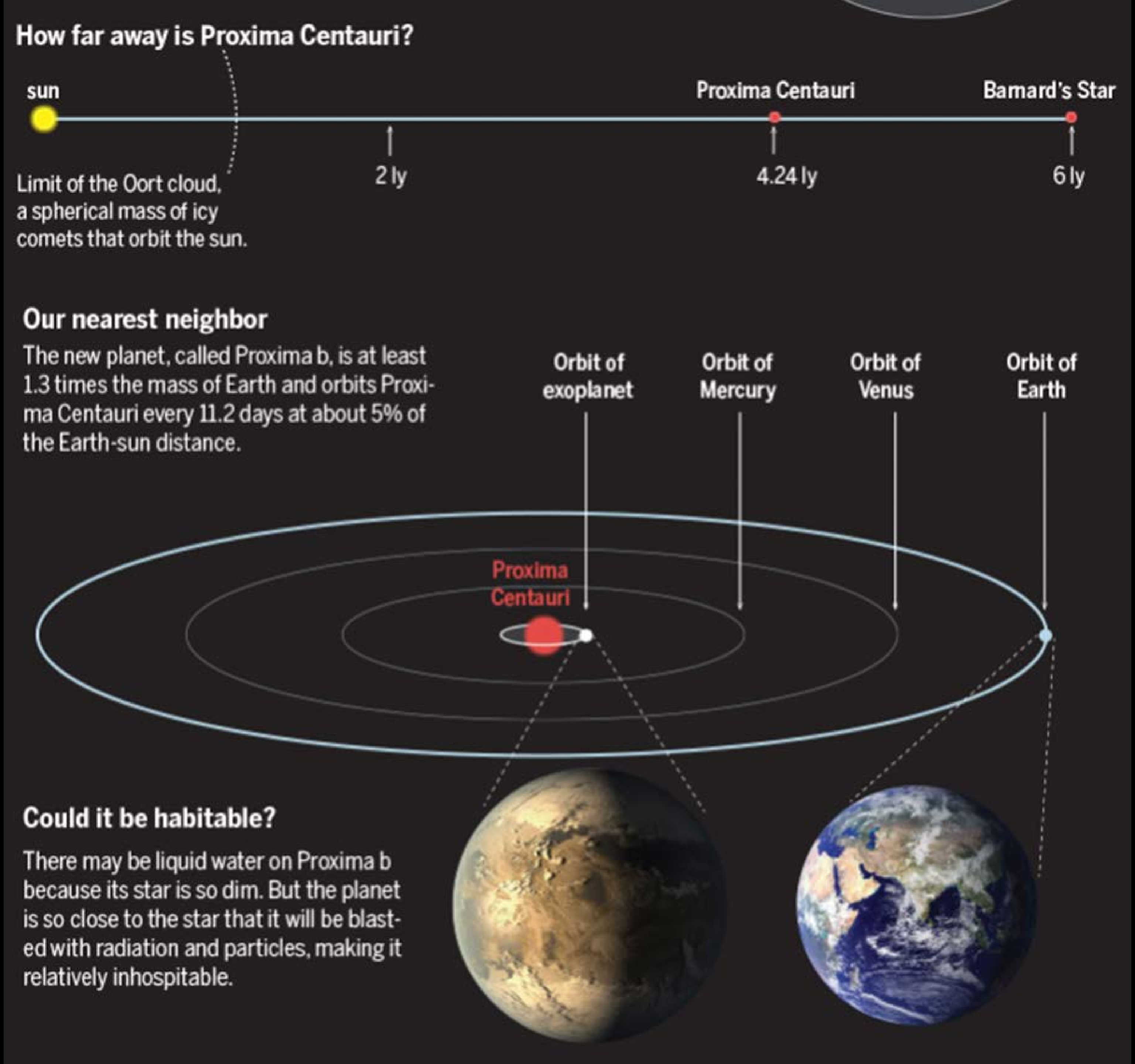
  “Are we alone?”

- NASA space telescope: ~1/4 of all stars host a ‘habitable zone’ planet
- Nearest stars: < 10 light years
- Nearest star with habitable zone planet: Promixa b

Promixa b is in the ‘habitable zone’ of Promixa Centauri, where liquid water could exist on it surface

(Image courtesy Science magazine 2016)


The solar neighborhood
Of the handful of stars within a dozen light-years of the sun, Proxima Centauri, a red dwarf, is the closest.
Star spectral type
Dwarf stars
O B A F G K
M D T Y L
Hotter
Sol = G2
Triple system?
Alpha Centauri A and B orbit each other closely, separated by 1.6 billion kilometers, about the distance between the sun and Saturn. A third star, Proxima Centauri, sits a quarter of a light-year away in the direction of Earth. Proxima Centauri may be orbiting the other two, but it is hard to tell because its orbit would be greater than 500,000 years.
Struve 2398
Lalande 21185
Groombridge 34
Ross 248
Wolf 359
Ross 128
2 ly
Barnard's Star
4.37 ly
Sirius
UV Ceti
Tau Ceti
Alpha Centauri system
Lacaille 9352
Epsilon Indi
sun (for scale)
>10,000 AU
Proxima Centauri
23.4 AU
Alpha Centauri A
Alpha Centauri B
*ly = light-years
**1AU = Distance between the sun and Earth


How far away is Proxima Centauri?
sun
Proxima Centauri
Barnard's Star
2 ly
4.24 ly
6 ly
Limit of the Oort cloud, a spherical mass of icy comets that orbit the sun.
Our nearest neighbor
The new planet, called Proxima b, is at least 1.3 times the mass of Earth and orbits Proxima Centauri every 11.2 days at about 5% of the Earth-sun distance.
Orbit of exoplanet
Orbit of Mercury
Orbit of Venus
Orbit of Earth
Proxima Centauri
Could it be habitable?
There may be liquid water on Proxima b because its star is so dim. But the planet is so close to the star that it will be blasted with radiation and particles, making it relatively inhospitable.

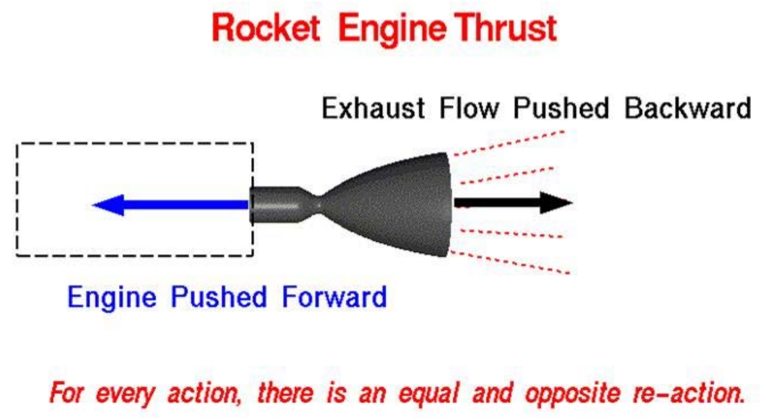
How to get there?

BREAKTHROUGH INITIATIVES

- Chemical rockets?
- Ion engines?

- Rocket equation:
- $V_{rocket} = V_{exhaust} \ln (m_{initial}/m_{final})$

- Fastest spacecraft:
  - New Horizons
  - $v = 16100$ m/s
  - $t_{Proxima\ Centauri} = 79{,}000$ years

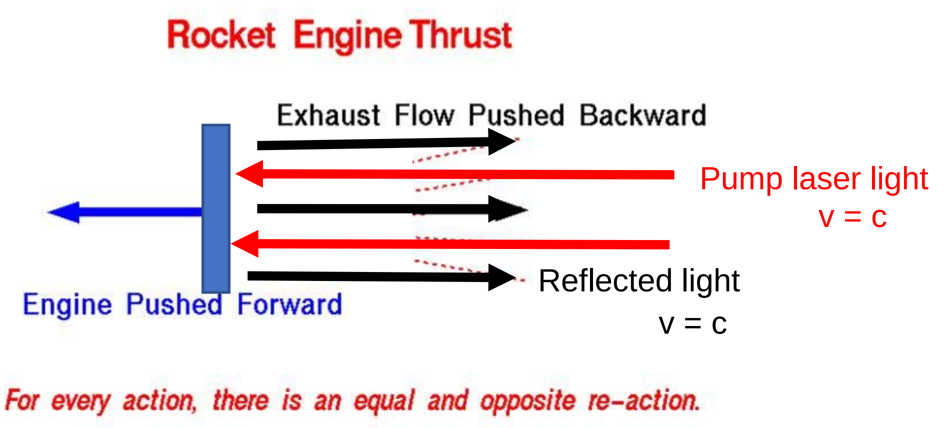


Engine	Effective exhaust velocity (m/s)	Specific impulse (s)
Turbofan jet engine (actual V is ~300 m/s)	29,000	3,000
Space Shuttle Solid Rocket Booster	2,500	250
Liquid oxygen-liquid hydrogen	4,400	450
Ion thruster	29,000	3,000

How to get there?

BREAKTHROUGH INITIATIVES

- Need to travel at v ~ c
- Radiation pressure:
- $\Delta p = 2E/c$
- Starshot:
    - v= 0.2c
    - **$t_{\text{Proxima Centauri}}$ = 21 years**



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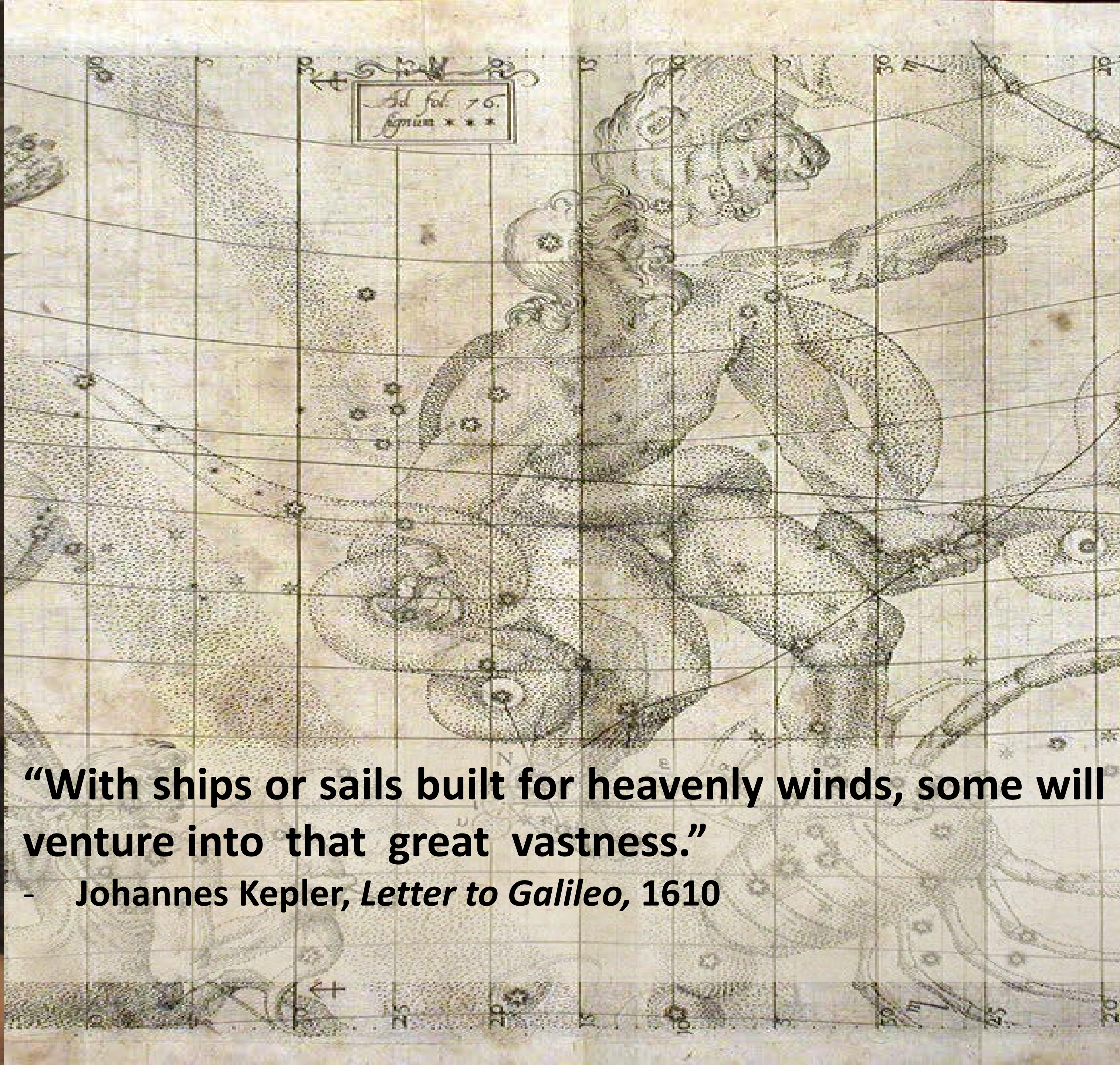
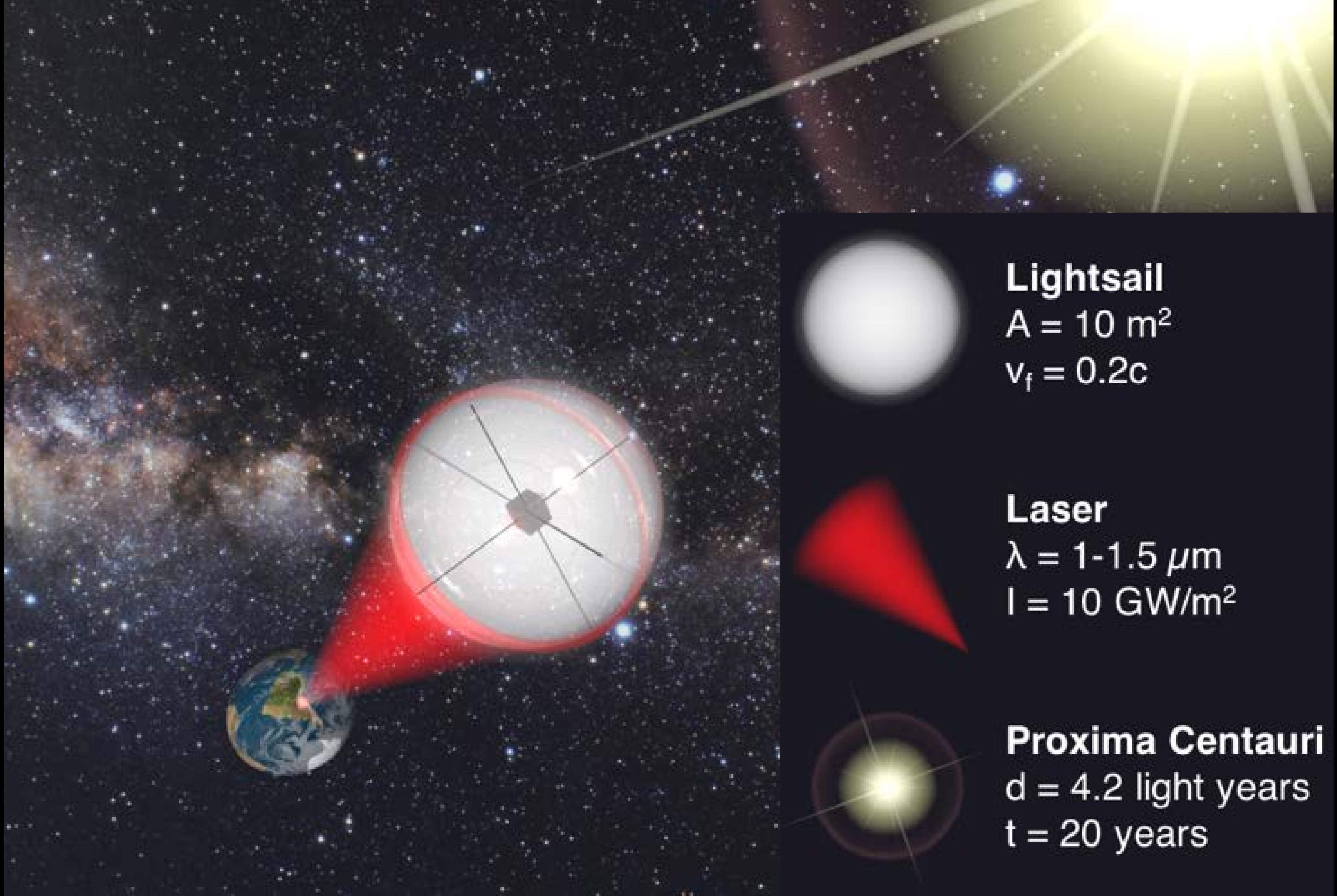
Radiation pressure	**3×10^8**	**~Intensity**



"With ships or sails built for heavenly winds, some will venture into that great vastness."

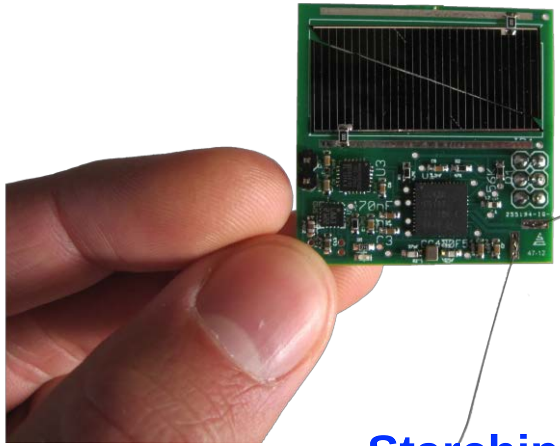
- Johannes Kepler, *Letter to Galileo,* 1610

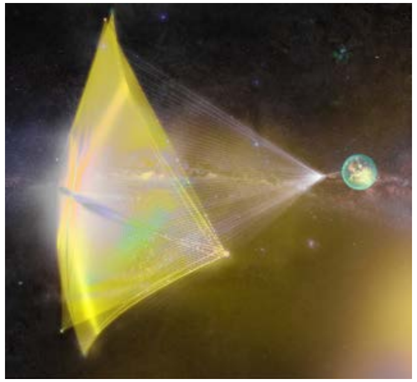
Laser-Driven Lightsail for Interstellar Travel

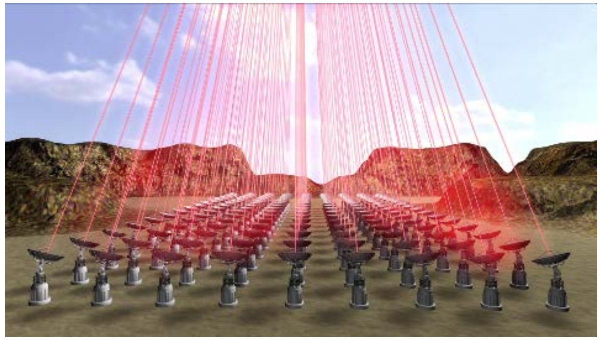


3 Enabling Technologies for Laser-Driven Sails

BREAKTHROUGH INITIATIVES







Starchip:

Moore's Law for

Electronics Scaling

Lightsail:

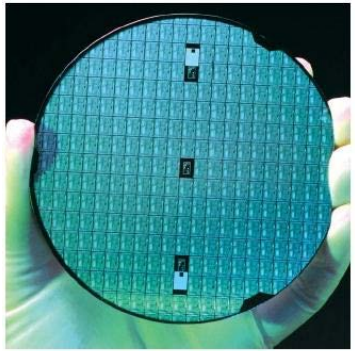
Nanomaterials and

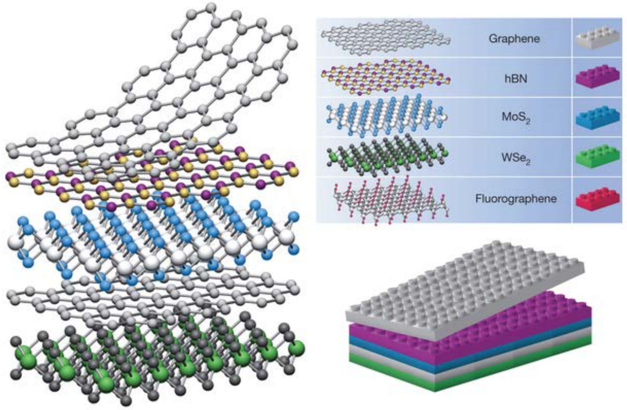
nanophotonic design

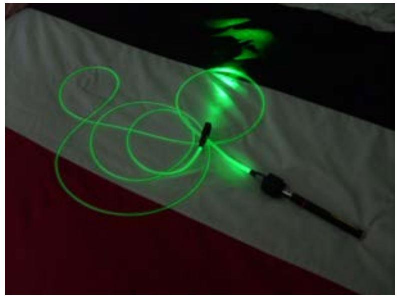
Photon engine:

Solid-state lasers &

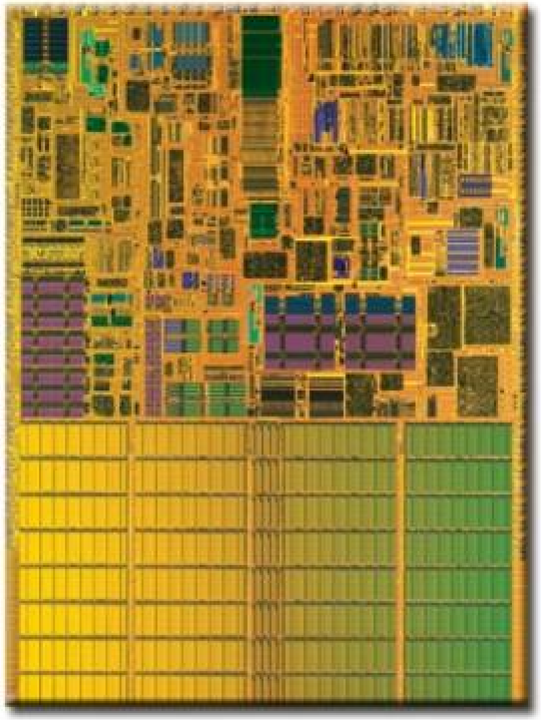
fiber optics







StarChip size



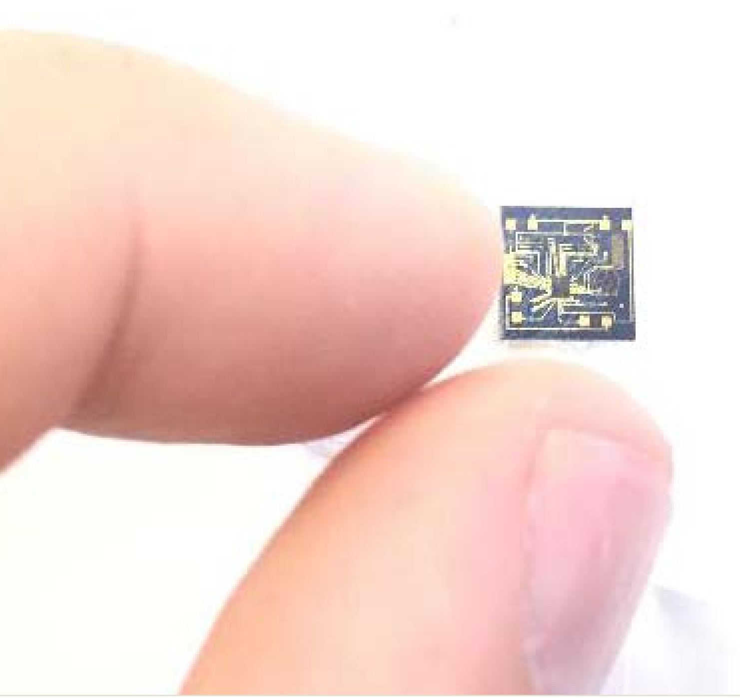
15mm

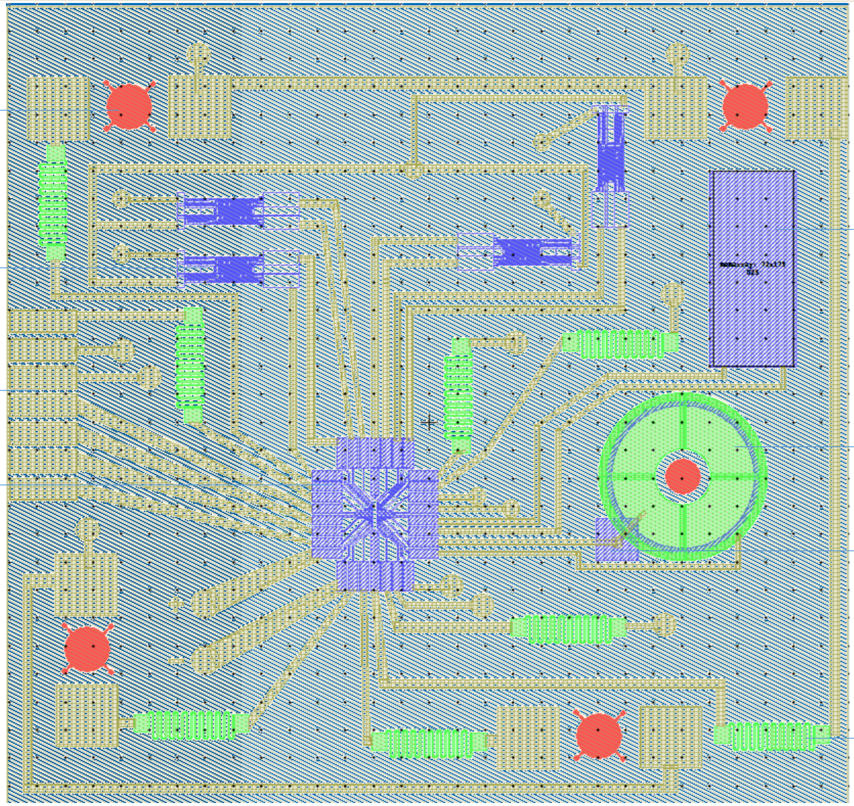
StarChip

25mm

Apple Watch chip

BREAKTHROUGH STARSHOT





Star Shot

- Near Term Goals 2018 to 2022
  - Series of demonstrations reduce risk and demonstration
  - Develop systems models to predict systems performance
  - Concentrate on LASER (~55%), Sail(~30%), Comms (10%) and Systems (5%)
- Long Term 2022 to 2030
  - Design and Demonstrate end to end system
- Far Term Goals 2040 to 2060
  - Send a probe to a nearby (< 5pc) earth like planet in the habitable zone
  - Probe to achieve 20% light speed
  - Return meaningful scientific data to earth within 5 years of encounter

DRAFT Sail RFP Released Next week

Breakthrough Starshot

INPUTS

0.2 c target speed
1.06 micron wavelength
60,000 km initial sail displacement from laser source

Sailcraft
1 g payload
0.2 g/m^2 areal density
0.001% absorptance
70% reflectance
970 K maximum temperature
1.7 effective emissivity (2-sided)

Beamer
$0.01/Watt laser cost
$500/m^2 optics cost
$50/kWh storage cost
50% wallplug to laser efficiency
70% of beam power emerges from top of atmosphere

MARCH 2018 CENTAURI SYSTEM MISSION POINT DESIGN

$8.4B CAPEX comprised of:
- $2.0B lasers (200 GW transmitted power)
- $3.0B optics (2.8 km array effective diameter)
- $3.4B energy storage (68 GWh stored pulse energy)

$7M energy cost per Starshot (68 GWh @$0.1/kWh)

4.2 m sail diameter
3.8 g sail mass

9 min (521 s) beam duration
10 min (594 s) sail acceleration time

40 Pa temperature-limited photon pressure
562 N temperature-limited force
15,000 g's temperature-limited acceleration
2,300 g's final acceleration (at 0.15 au, 73 ls from source)

34 kW/m^2 beamer maximum radiant exitance
14.4 GW/m^2 sailcraft theoretical maximum irradiance
8.5 GW/m^2 sailcraft temperature-limited irradiance

Photon Engine Challenges

- **Atmospherics**
  - Atmospheric compensation of >1km apertures
  - Generating/maintaining the irradiance profile on the sail
- **Phasing**
  - Phasing up to 50M devices
  - Pointing the beamer array and stabilizing the beam
  - High fill factor array
- **Production**
  - Manufacturing the beamers
  - Cost predictability and control
  - Producing the power and storing the energy

Sail Challenges

Material properties, which influence the choice of materials and how the sail with the sail is to be made, are its reflectivity, absorptivity and transmissivity, tensile strength in its areal density.

Sail thickness: 50 nm, Sail Density: 0.7 g/cm^3, Sail reflectivity: 0.99995, Sail Absorptance : 0.00001, Sail emissivity: 0.5, Acceleration withstand 60,000 gs

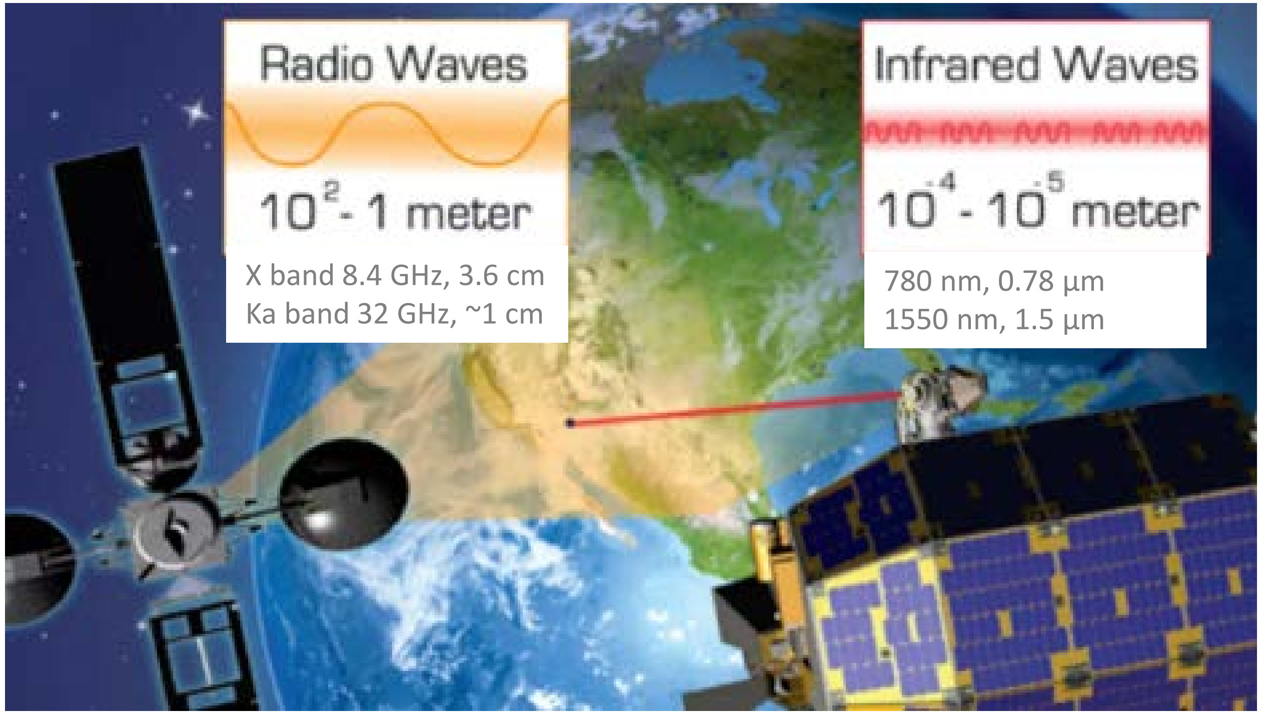
Total optical power: 50 GW

Stability, is influenced by sail shape, beam shape and the distribution of mass, such as payload, on the sail.

Laser system interactions, with the sail through its power density distribution on the sail, causing acceleration, the duration of the beam, the width of the beam, the pointing error of the beam as well as its pointing jitter.

Communication

- Return 100 images from ~4 Light Years
  - 4 mega pixel images, 16 bit per image, 64 Mbits per image (144K/sec)
- RTG - ~ 0.3g Pu-238 400 mWthermal /g *.3 g* 7% conversion eff ~ 10 mW
- Pointing Attitude Determination and Control Finding Earth
- Error correction



lunar-laser-communication-1.PNG

$$\frac{P_{Rx,Opt.}}{P_{Rx,RF}} \propto \left(\frac{\lambda_{RF}}{\lambda_{opt.}}\right)^2$$

Challenges

BREAKTHROUGH INITIATIVES

StarChip
- Components at gram scale

Sail
- Structure/materials
- Integrity under thrust
- Stability on the beam

Laser array
- Cost
- Power generation & storage
- Cooling
- Combining beams
- Atmospheric effects

Policy issues

Launch
- Precision pointing at sail
- Aiming trajectory at exoplanet
- Launch safety & space debris

Cruise
- Collisions
- Functioning over decades in space

Flyby
- Pointing camera at planet

Communication
- Pointing transmitter at Earth
- Sending images using laser
- Receiving images with laser arrayg

Solar System Assumptions