



Louis Friedman
05/17/2018

Magnifying Light by a 100 Billion Times with the Solar Gravity Lens to Image an Exoplanet

Slava Turyshev, Louis Friedman 16 May 2018

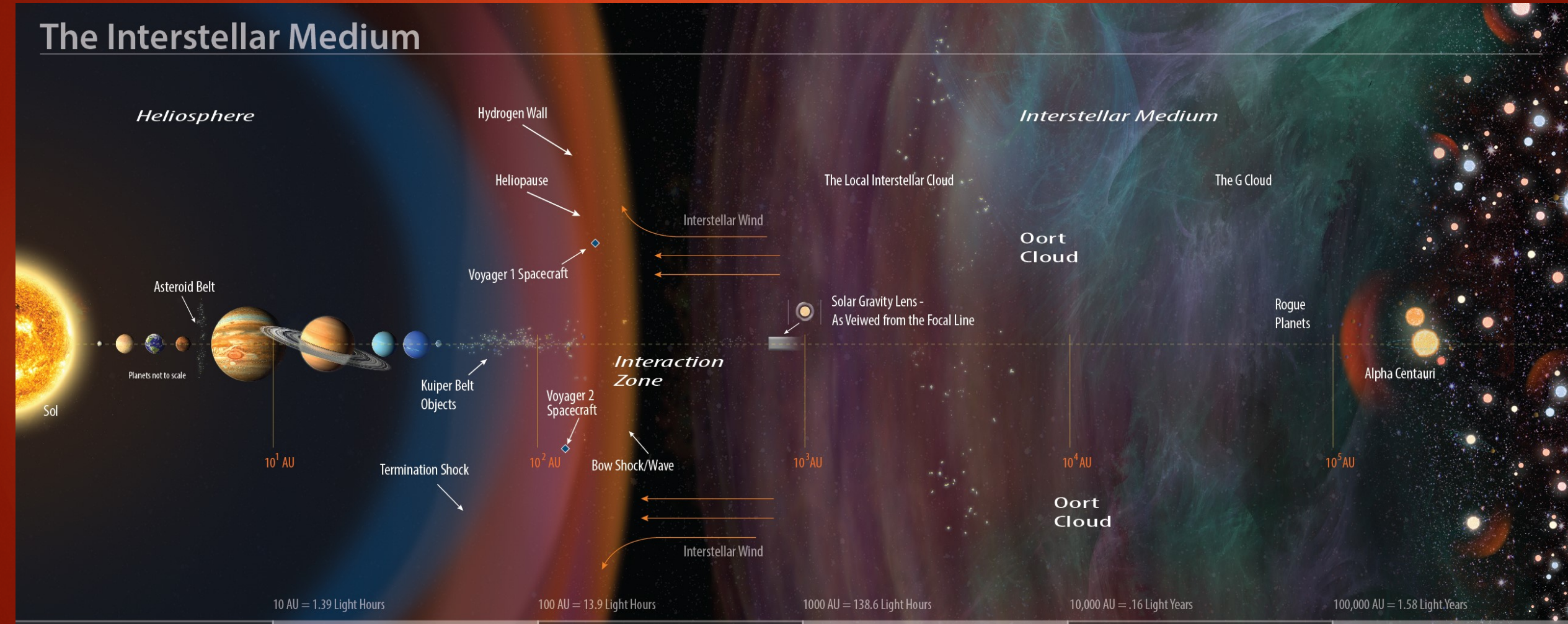
KECK INSTITUTE FOR SPACE STUDIES WORKSHOP ON THE TECHNOLOGY REQUIREMENTS TO OPERATE AT AND UTILE THE SOLAR GRAVITY LENS FOR EXOPLANET IMAGING – 15-18 MAY 2018

Motivation

- Space is big
- The Stars are Far
- The Planets are Small

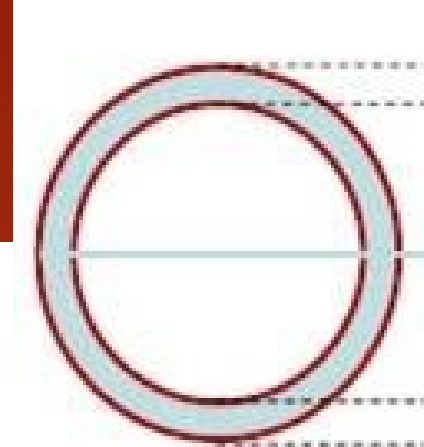


The Interstellar Medium



The Solar Gravity Lens

Image formed in Einstein Ring



←--Star

Sun

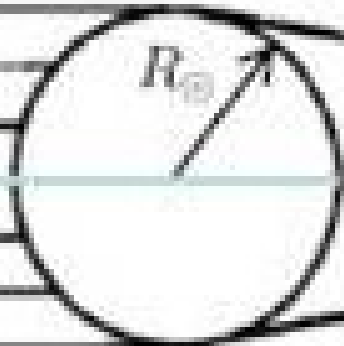
←-----547 +++ AU----->

telescope

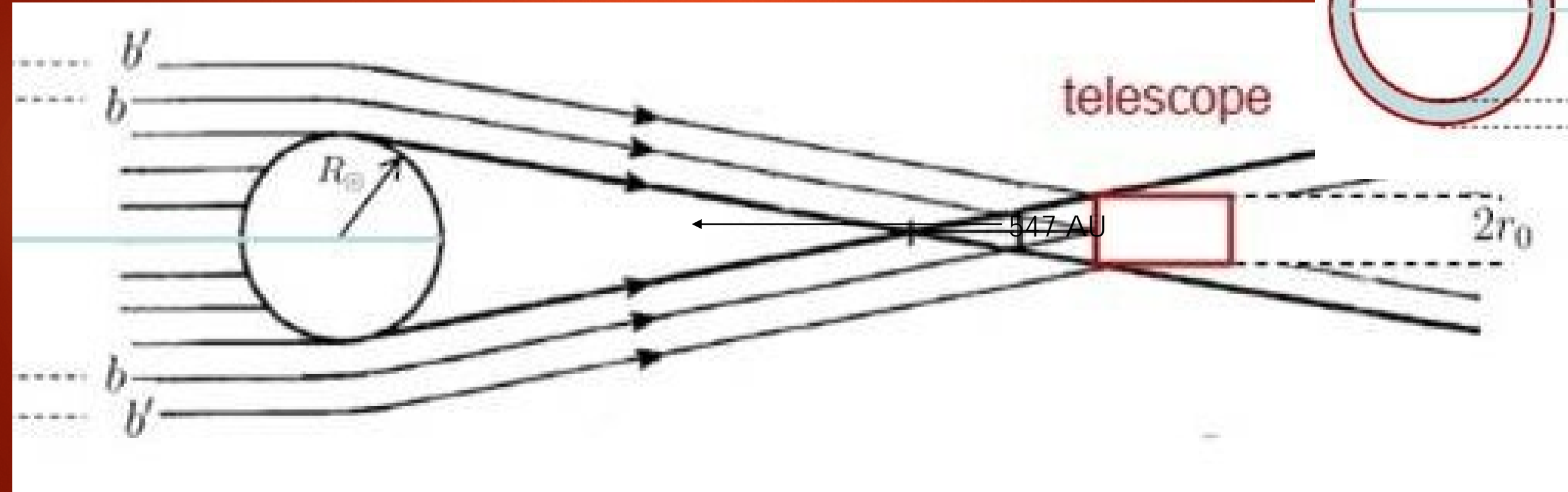
547 AU

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550-1000 AU: How to get there?

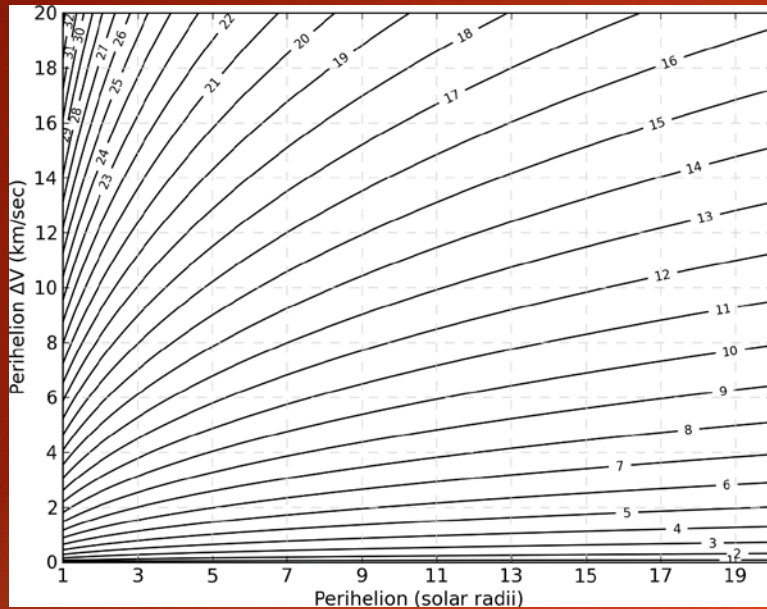
- ▶ Chemical propulsion fly very close to the Sun
- ▶ Solar Sail with large Area to Mass Ratio
- ▶ Solar Thermal
- ▶ Nuclear Electric

- ▶ Electric Sail
- ▶ Beamed Laser Electric Drive

SGLF Mission Architecture - Options

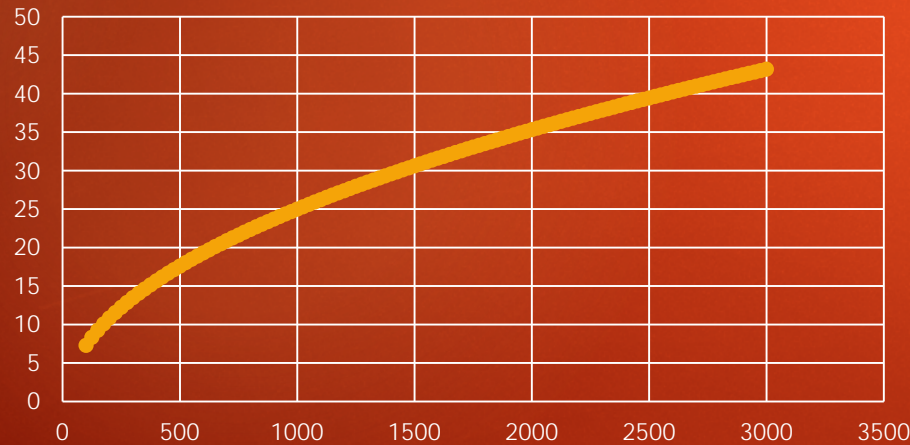
System	Technology	tradeoffs
Propulsion	Chemical	Big solid rocket motor burn very close to the Sun. Velocity limit ~18 AU/year
	Solar Sail	Lightest weight option; 200x200 m sail with 40 kg sc can achieve velocity ~25 AU/year
	Solar Thermal	Larger sc, new technology; cost? Also requires operation very close to Sun
SC Mass	<100 kg	Requires new technology, but smallsats are progressing fast
	<500 kg	Conventional, capability more certain; likely higher cost and longer trip times
Con Ops	Individual SC	Minimizes complexity; suitable for multiple targetting
	String of Pearls	Robust design, flexible operations
Comm	Radio	Probably only if sail can be antenna
	Optical	Lower power consumption and mass likely

Getting the Δv

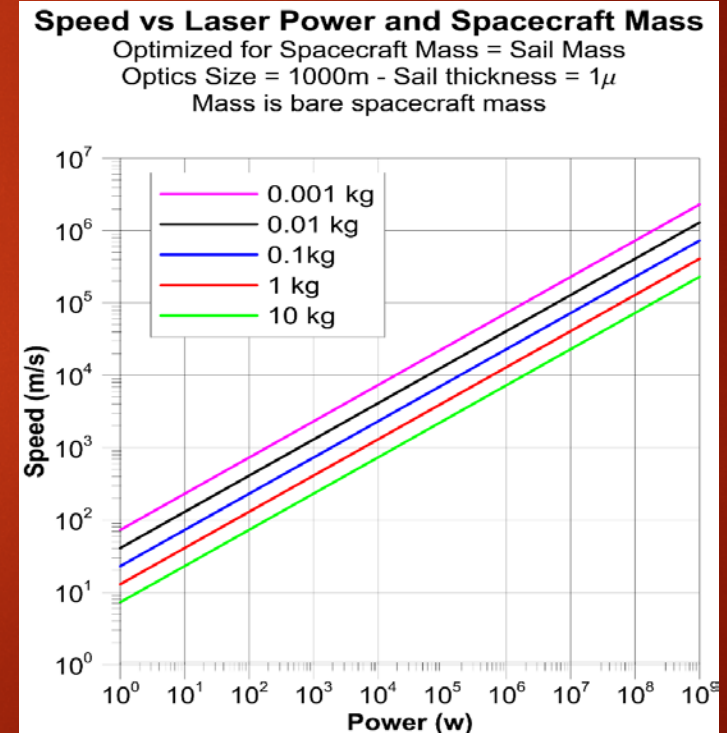


N. Arora,
JPL

Exit Velocity (AU/y) vs. Sail area/SC mass (m^2/kg)
with perihelion = 0.1 AU



D. Garber,
NXTRAC



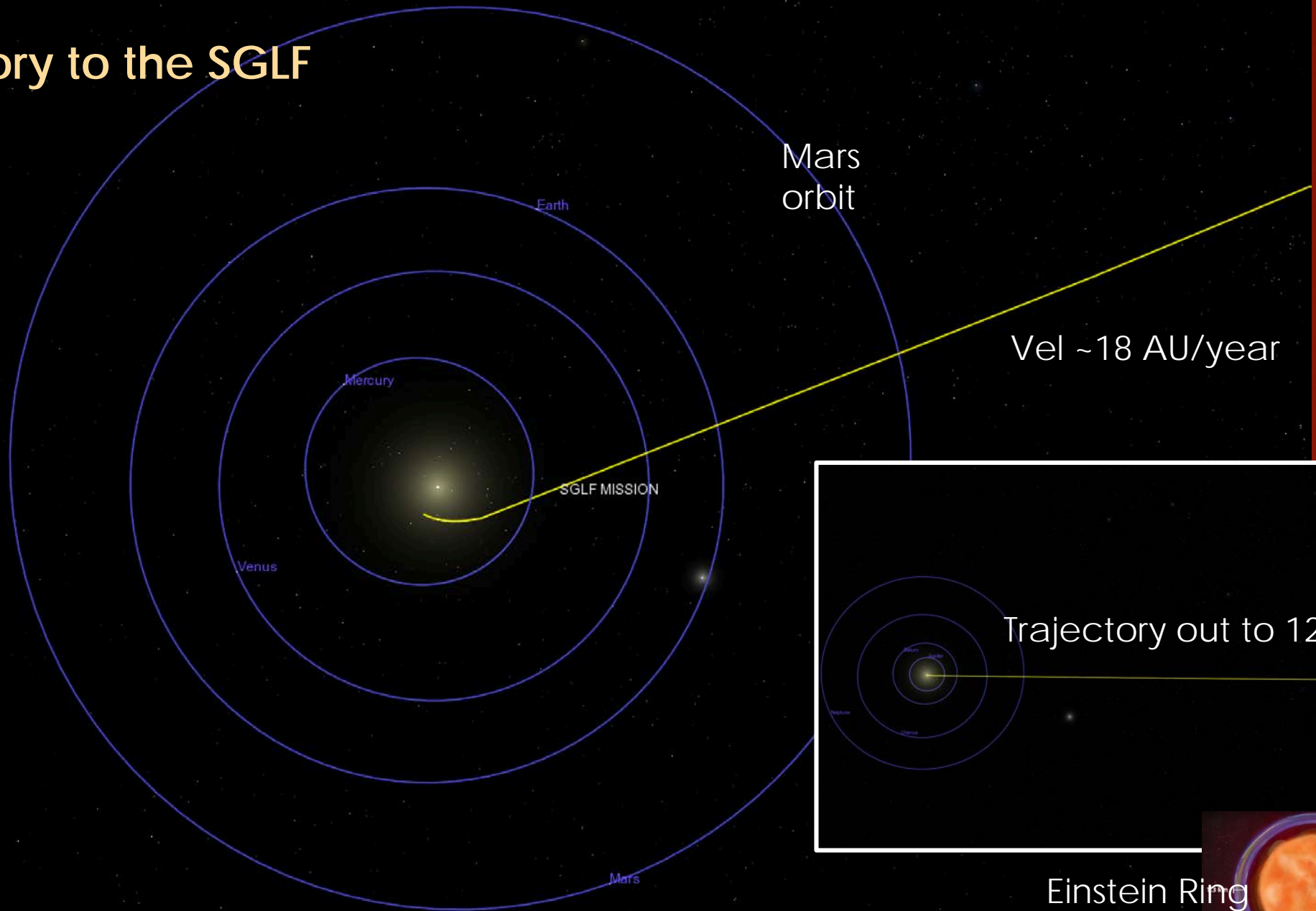
P. Lubin,
UCSB

Solar Sail Mission Example

- ▶ Sail area 200x200 meters; less than 2 kg
 - ▶ Density 0.04 g/cm² e.g. 0.25 micron polyimide or with carbon nanotubes.
- ▶ 30 kg spacecraft bus
- ▶ 15 kg for REP with 100 watts electric power
- ▶ Perihelion = 0.1 AU
- ▶ $A/m = 400000/50 = 800 \text{ m}^2/\text{kg} \Rightarrow \text{velocity} = 23 \text{ AU/year}$

Solar Sail Trajectory to the SGLF

$A/m=500 \text{ m}^2/\text{kg};$
 $r_p=0.1 \text{ !U}$



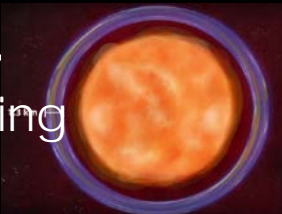
Mars orbit

Vel ~18 AU/year

SGLF MISSION

Trajectory out to 125 AU

Einstein Ring
@650 AU

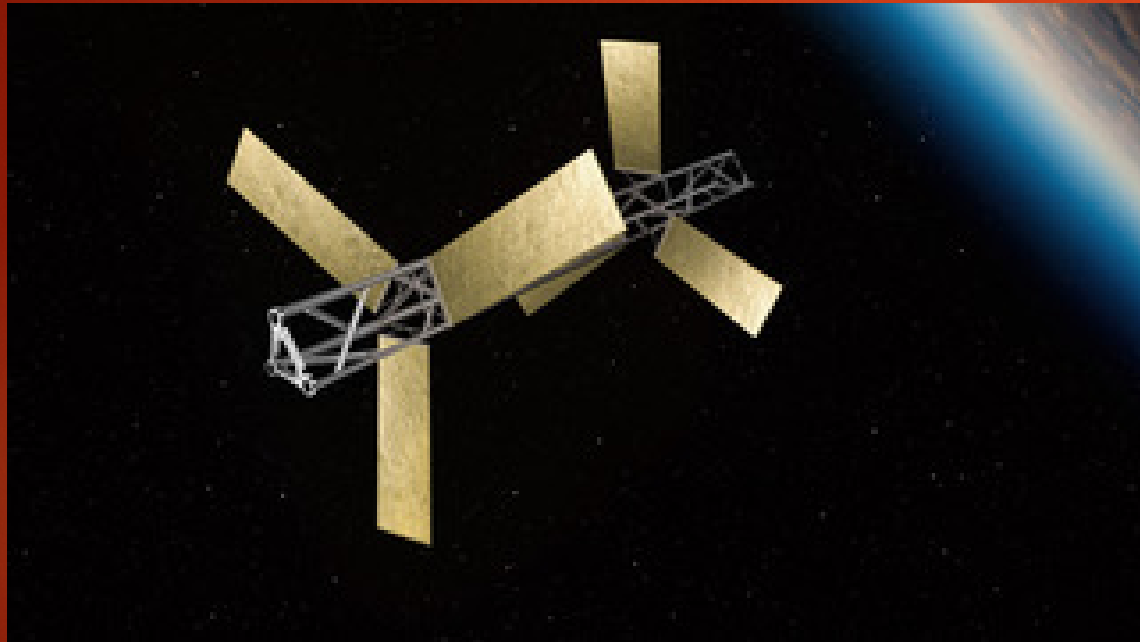


Other Mission Examples

- ▶ Chemical mission with Oberth Maneuver
 - ▶ Perihelion = 3 solar radii; velocity = 20AU/year
 - ▶ Solid Rocket Motor for large $\Delta v=12.5$ km/s
 - ▶ Large heat shield
- ▶ Solar Thermal Propulsion
 - ▶ JPL/MSFC study, sc mass=560kg => 20 AU/year
 - ▶ Perihelion = 3 solar radii, large heat shield
- ▶ Nuclear electric (ref. J. Brophy)
 - ▶ 2-stage 30kW SEP/20 kW NEP reaches 20 AU/year but with 40 year trip time
- ▶ E-sail (Ref. P. Januhen),
 - ▶ 20 tethers, each 10 km length => 23 AU/year
- ▶ Laser (ref. P. Lubin)
 - ▶ 100 GW laser, 1 Km telescope, 10 kg sc =>20 AU/year
- ▶ Laser electric (Ref. J. Brophy)
 - ▶ 100 MW space-laser, => 40 AU/year

The Spacecraft Challenge – Getting and Operating There

2 Examples: Solar Sail, Solar Thermal

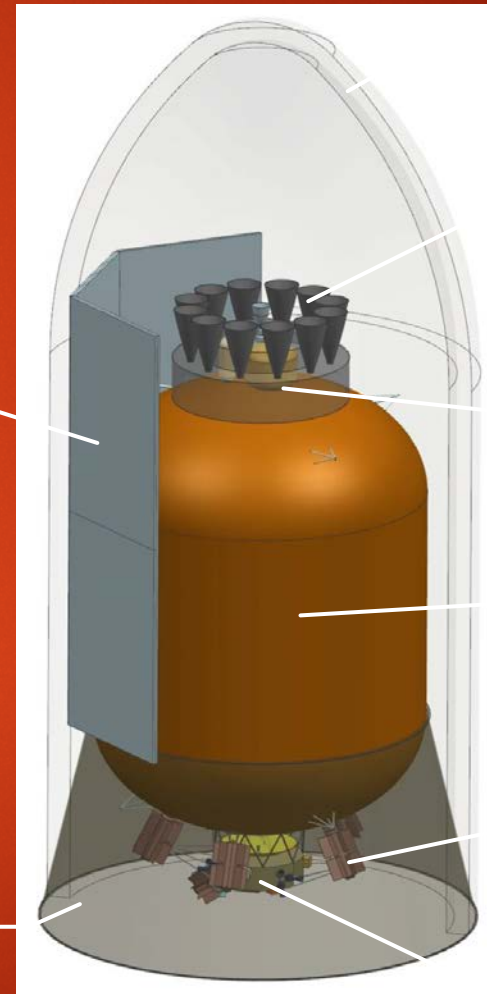


N.Barnes/D.Garber

JPL/MSFC

Sun Shield (double-folded for launch, middle panel is heat exchanger for STP, heating H₂ to 3400K)

Launch Vehicle Adapter
Jettisoned before perihelion maneuver



Launch Vehicle Fairing (SLS Block 2 - 8.5m)

Solar Thermal Propulsion (STP) Rockets (12x, to limit burn time to < 1.5 hrs.)

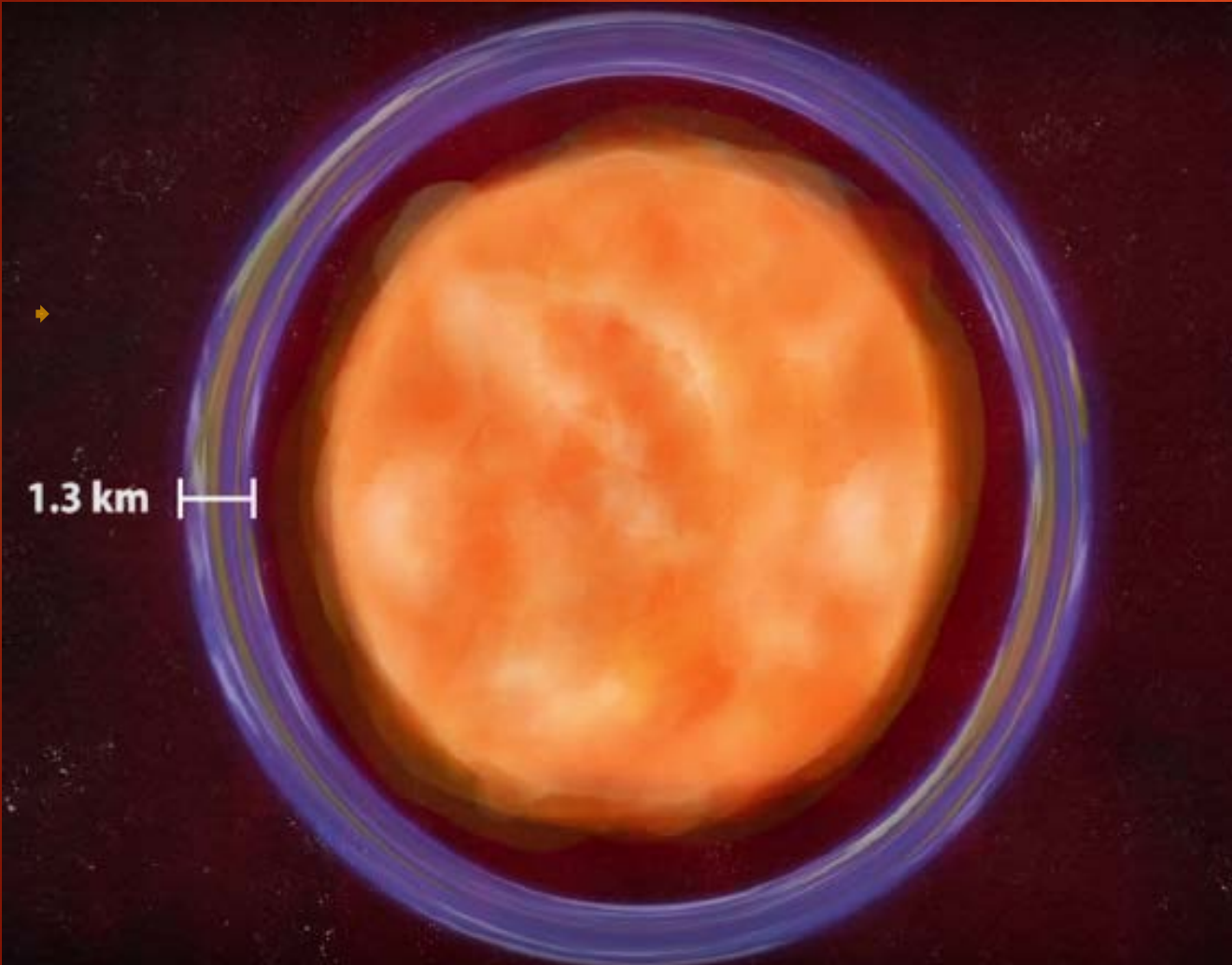
Bipropellant System (for TCMs before perihelion)

Liquid Hydrogen (LH₂) tank (cryocooled) carrying ~15.7 tons of propellant

Extra SMRTGs (providing > 1.2 kW for cryocooler)
Jettisoned before perihelion maneuver

ISM Probe (single SMRTG, ~560 kg wet)

Challenge: To Capture the Image in the Einstein Ring





Which propulsion will get us there first?



Time Scale for Propulsion Options

