SDSU

College of Engineering
Aerospace Engineering

DESTINY

A Mission to Image an Exoplanet Using a Solar Gravitational Lens

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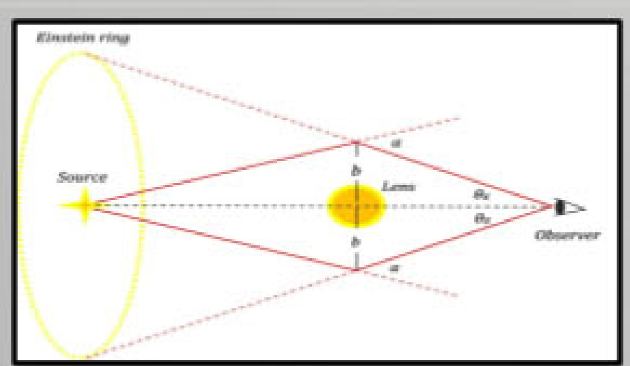
What is a Solar Gravitational Lens?

When light from a distant body passes near the sun, the gravity of the sun bends that light. If a spacecraft is positioned far enough and lined up with both the sun and the distant body, that light appears as a thin circle around the sun called an **Einstein Ring**. That ring contains highly magnified information from the planet. We can image that light and reconstruct it into an image.



Mission Purpose

With current telescopes, we can detect nearby exoplanets but not in enough detail to thoroughly study their surfaces, atmospheres, and potential for life. This mission uses the **SGL** to turn the sun into a telescope, giving us access to observe world such as **Proxima Centauri b** at a far higher resolution than conventional telescopes can achieve.

Mission Objective

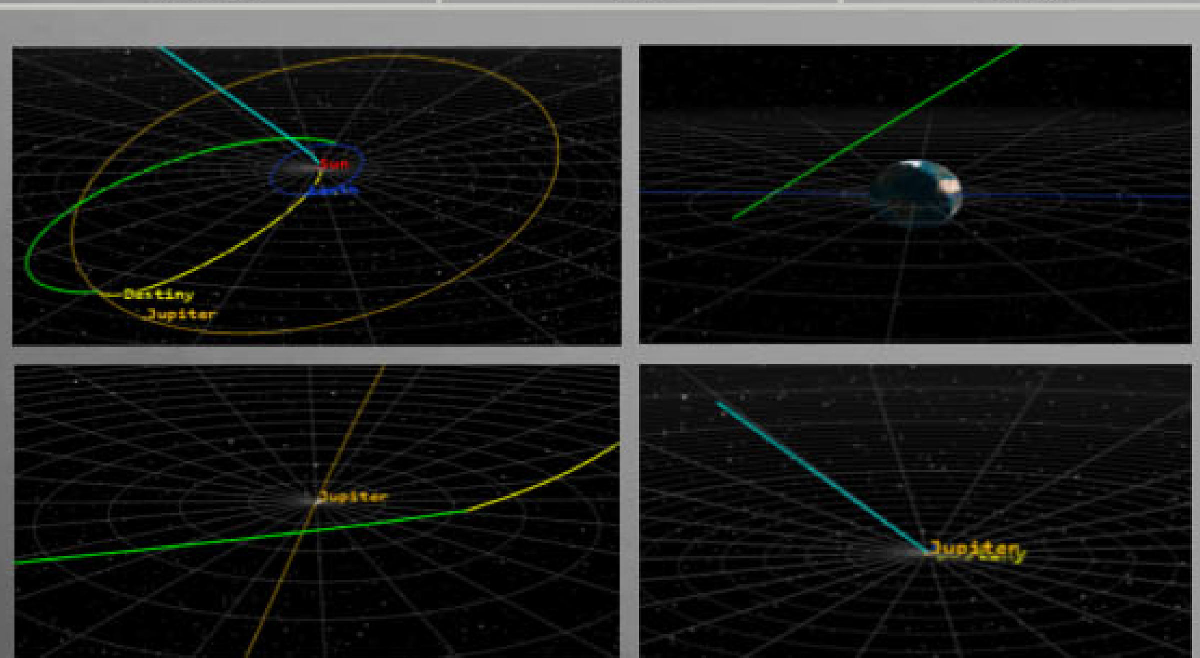
The objective of the mission is to send a spacecraft to observe the Einstein Ring of Proxima Centauri b, which can be seen between 650-950 AU from Earth. Once there, we can detect and measure the planet's Einstein Ring, suppress the interfering sunlight, and use the collected light to reconstruct the high-resolution image of the planet (about 10 km^2 per pixel!)

Mission Timeline

2049	Takeoff and Escape	**2058**	Pass 30 Au from Sun and Detach Sail
2054	Jupiter Oberth	**2058-2096**	Cruise towards anti-proxima Centauri b
2056	Solar Sail Deployment	**2096**	Begin imaging at 650 Au
2056	Solar Oberth	**2096+**	Spiral movement to maintain SGL

Flight Dynamics

ΔV Budget		
1 Jan 2038 00:00:00.000	GEO Escape	**12.5 km/s**
25 Dec 2042 10:54:16.841	Jupiter Oberth	**3.6 km/s**
8 Mar 2045 19:57:02.920	Solar Oberth	**41.6 km/s**
Mar 2085	Spiral	**4.8 km/s**



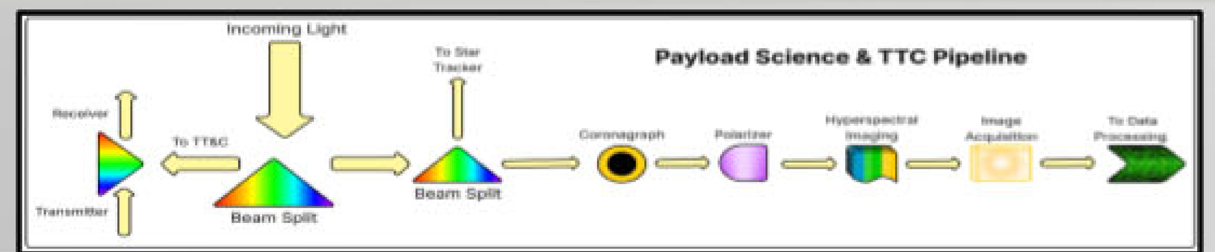
Payload

Functions similarly to modern space telescopes

- 1 m telescope focusing light into primary path (JWST-like)
- Light splits between Payload, TT&C, and ADCS
- 1.2 m focal length, 10 m effective focal length at chronograph
- 1 m aperture Internal Lyot Chronograph, 1e-7 light suppression
- Added Polarizer for increased solar light suppression
- Charged-Couple Device (CCD) Detector
  - Allows for high SNR light acquisition

Risks and Margins

- Mirror survivability
  - Covershield before science phase
- Detector degradation from radiation
  - Strong radiation shielding
- Maintain 20 kg mass limit



Thermal System

Thermal Environment

- Perihelion (~0.14 AU): extreme solar heating (~1000 K)
- Deep space (up to 900 AU): near-zero external heat (~2.7 K)

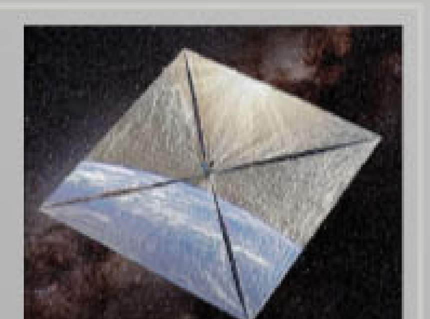
Design Approach

- Hybrid thermal control (passive dominant + active heating)
- Heat shield (perihelion), MLI (deep space), radiators (rejection)
- RTG provides internal heat source

Parameter	Value
Maximum Predicted Bulk Temperature	45 °C
Minimum Predicted Bulk Temperature	16 °C
Radiator area	$0.37A_{craft}$
Heater power (after 25 years)	12.4 W
Thermal margin	10%

Propulsion

Propulsion Mechanisms:
Spacecraft uses multiple mechanisms to minimize mass, including:



- 14 tons of **methalox** (Methane + LOX)
  - The methalox will be used to do high thrust burns far away from the Sun.
- 410m x 410m **solar sail**
  - The 1 micron thick solar sail, which uses the sun's light as propulsion, will be deployed when close to the Sun and give an incredible amount of kinetic energy to the craft.
- **Hydrazine**
  - The main thruster system used on Voyager, hydrazine will be used to do path corrections on the 40 year long cruise.
- **Electrospray propulsion**
  - A new technology, electrospray propulsion disperses fuel using electricity with little power and will spiral the craft in a radius equivalent to 4 Jupiters for 13+ years with only 53 pounds of propellant.

On-Board Computer

Image Processing:

- Uses staged image reconstruction
  - Generates a coarse global map first
  - Identifies high-information regions and analyzes deeper

Computer Requirements:

- Handle continuous measurement-based data acquisition
- Support staged reconstruction and data prioritization
- Operate autonomously due to multi-day up/downlink times
- Maintain reliable long-duration operation (~57 years)

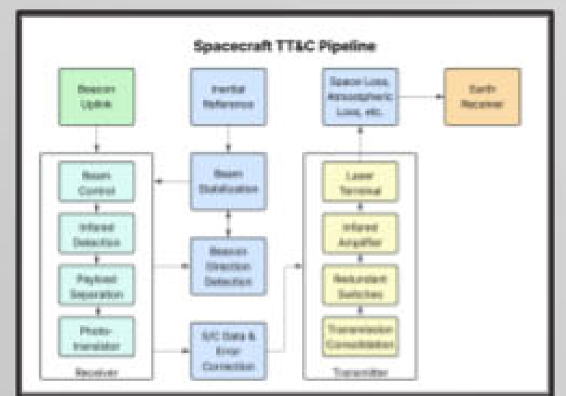
Telemetry, Tracking, & Commanding

Main TT&C Requirement
The spacecraft shall support a science data rate of 16 Gbits/year from 900 AU with a link margin > 3 dB.

Selected Architecture
NASA Deep Space Optical Communications (DSOC) Project.
nn 15 W laser | 1064 nm downlink | 1550 nm uplink

Ground Segment Design
Mission Ops Center (MOC) will be located at JPL and four 30-m class ground stations are selected for weather/line of sight.
Ortucchio, Italy | Mingenew-Nangetty, West Australia
Haleakala, Hawaii | Cerro Chajnantor, Chili

Commanding is Highly autonomous, with auto FDIR response



Downlink Link Budget Analysis at **950 AU**

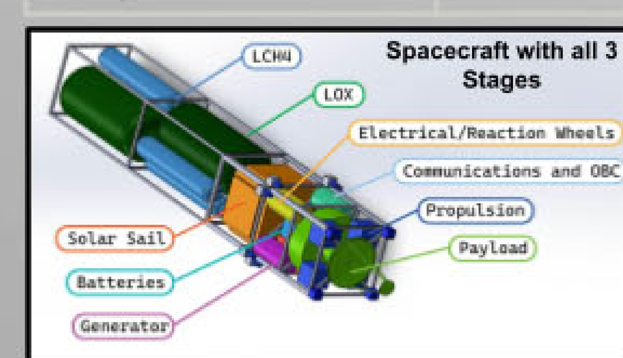
Term	Symbol	Value (dB)
Transmit Power	P_t	11.761
Tx Antenna Gain	G_t	127.85
EIRP	$P_t + G_t$	139.61
Free-space Path Loss	L_{FS}	424.49
Other losses (Pointing, Atmospheric, Optics)	L_{other}	5.3
Rx Antenna Gain	G_r	154.12
Received Carrier Power	P_r	-136.06
Noise Bandwidth	B	45000
System Temperature	T_s	500
G/T	$G_r - 10\log T_s$	127.13
Achieved Carrier to Noise Ratio	C/N	9.2779
Link Margin	M_{link}	3.0204

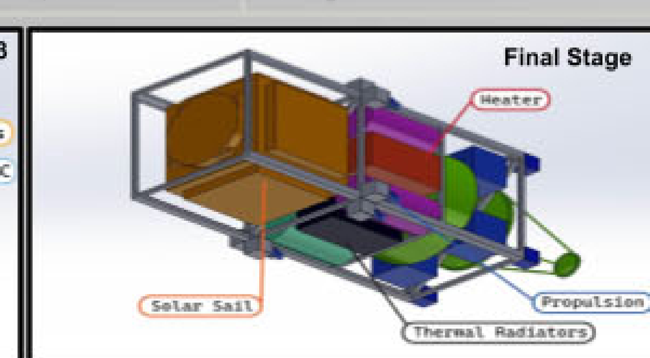
Structures

Primary structural design components

- Three Stages, post GEO, post Jupiter, post Sun
- Payload mirror system with retractable arms
- Solar Sail, Solar Shield, Titanium alloy (Ti-6Al-4V) Bus frame
- Factor of Safety of 1.4

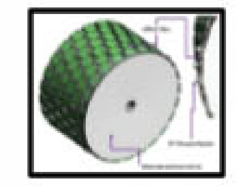
Mass Budget		
System	Dimensions	Weight
Total bus (all stages)	(1.5 m x 1.5 m x 11 m)	135 kg
Solar Sail	Deployed: (167772 m^2 SA) Housed: (2m^3)	167 kg
Tanks	(1.5 x 1.5 x 8 m)	1156 kg
Payload	Primary mirror (1 m D x 0.1 m H); Secondary mirror (.25m D x .025 m H); Analysis Equipment (1 m D x 1 m H)	22 kg
Sensors, electrical, OBC	Varied	27 kg
Thrusters	(80 mm D x 80 mm H)	8kg
Total Wet mass	(17.14 m^3)	13284kg
Total Dry mass	(1.5 m x 1.5 m x 11 m)	1288 kg

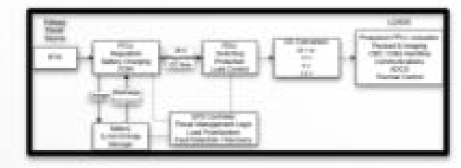




Electrical System

Main EPS Requirement
Must support a peak load of 90 W for entire mission
Selected Architecture
APPLE RTG: 233 W BoL → ~90 W EoL
Per tile: 200g -> 137 tiles @ 1.7 W -> 233 W
Battery: Nickel Hydrogen:
163 Wh, 5.2 kg, 23 cells in series
Bus voltage: 28 V DC





The Atomic Planar Power for Lightweight Exploration (APPLE) RTG chosen for modular design and ability to provide continuous DC power for the duration of the deep space mission.

Attitude Control & Dynamics

Devices	Model	Details	Use
Star Tracker (4)	Sodern Model SED16	12kg weight , 40W Power	Improve exposure, dynamic range in imaging and positions
Reaction Wheels (4)	Honeywell HR04	10.5kg weight, 25W Power	Stabilization control using ACSD and OBC

Simulation & Model Results

Design
Simulates Einstein ring intensity measurements at SGL focal region
Uses grid-based spatial sampling to approximate image plane coverage
Reconstructs 2D image via inverse mapping / deconvolution
Ring measurements → coarse image → refined image
Reconstructs Image in Stages
Initial low-resolution global map
Selective refinement of high-information regions
Results
Recoverable planetary structure from ring data
Improved image fidelity with increased sampling

Mission Summary

Mission Cost	Power	Dry Mass
$2.9 - $8.7 Billion	90 W until EoL	1288 kg
Total Mass	**Size**	**Mission Time**
14714.1 kg	1.5 m x 1.5 m x 3 m (Body) 410 m x 410 m (Solar sail)	57 Years

Acknowledgements

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