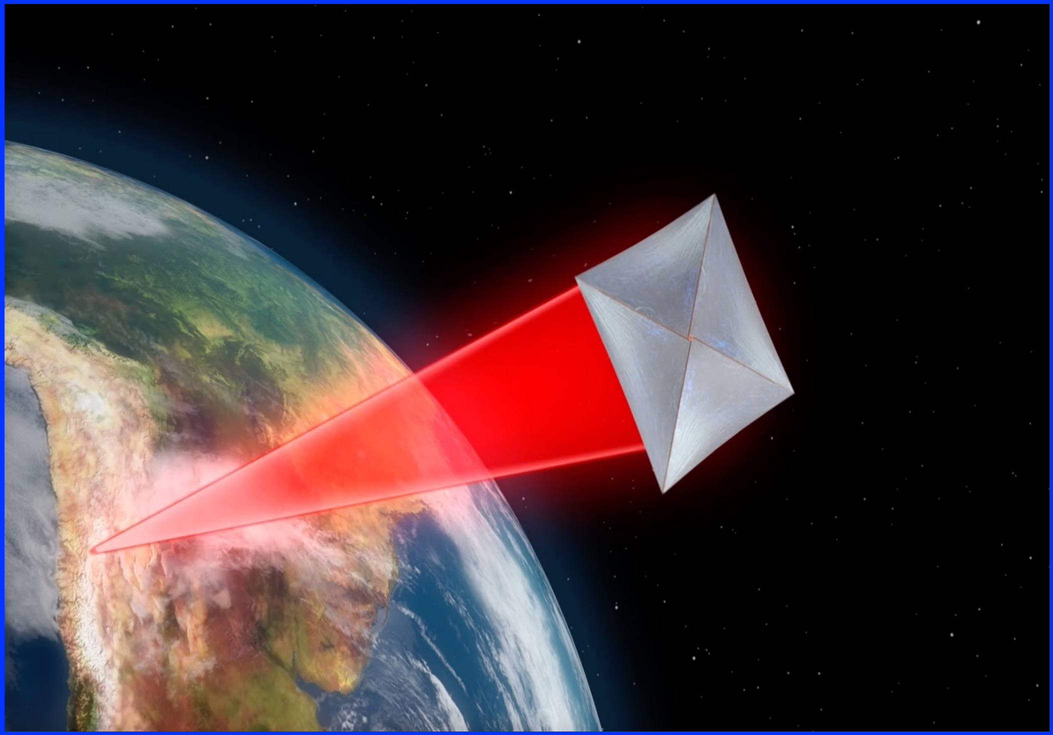
Starshot Project Status



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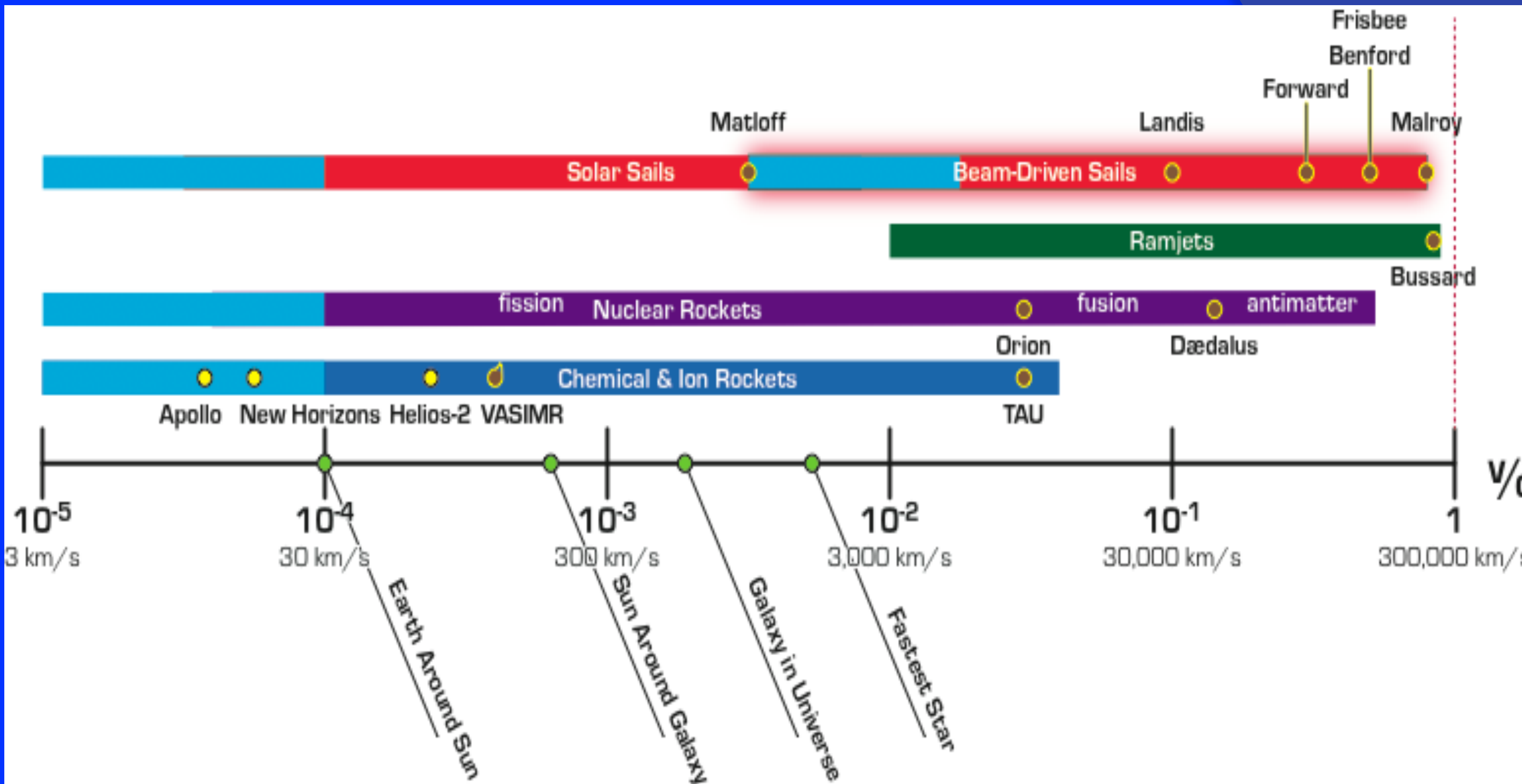
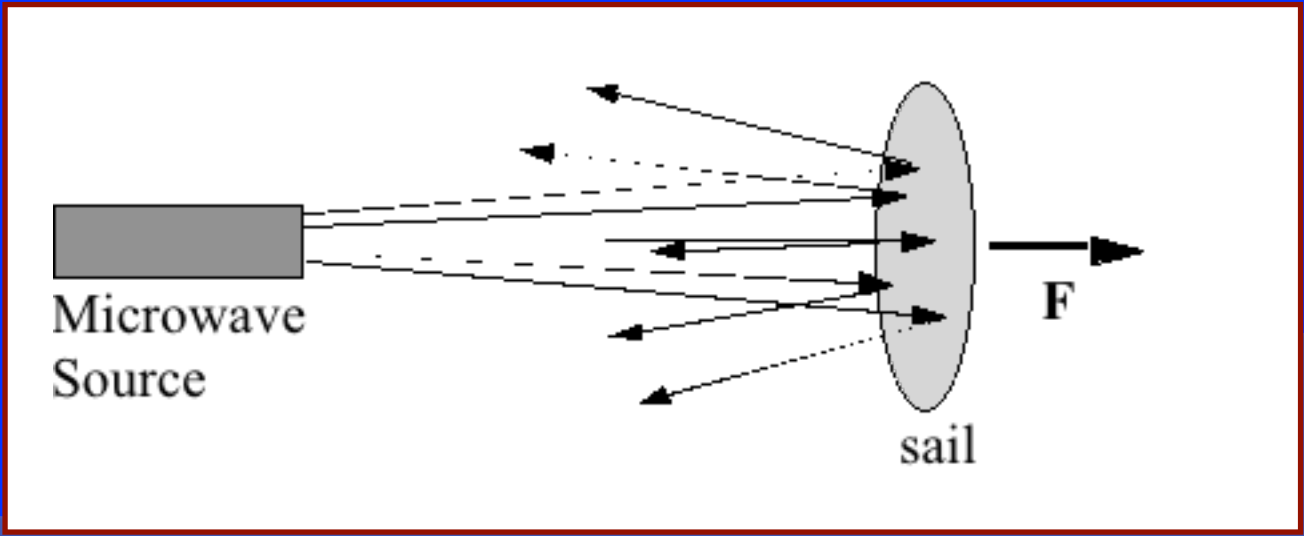


Frisbee
Benford
Forward
Matloff
Landis
Malroy
Solar Sails
Beam-Driven Sails
Ramjets
Bussard
fission
Nuclear Rockets
fusion
antimatter
Orion
Dædalus
Chemical & Ion Rockets
Apollo
New Horizons
Helios-2
VASIMR
TAU
v/c
10^{-5}
3 km/s
10^{-4}
30 km/s
10^{-3}
300 km/s
10^{-2}
3,000 km/s
10^{-1}
30,000 km/s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

Beam-Driven Sails

- Electromagnetic waves have momentum, both axial and angular.
- Therefore, a reflected beam of light exerts force proportional to its power: **F = 2P/c**

In practical units: F=6.7 newtons/gigawatt

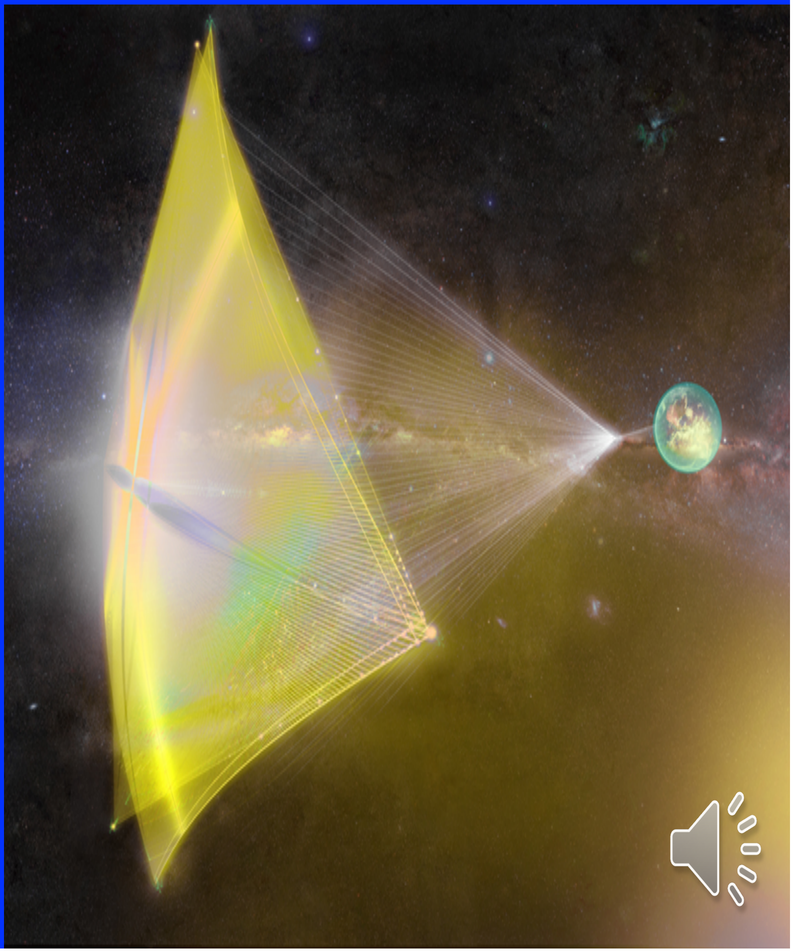


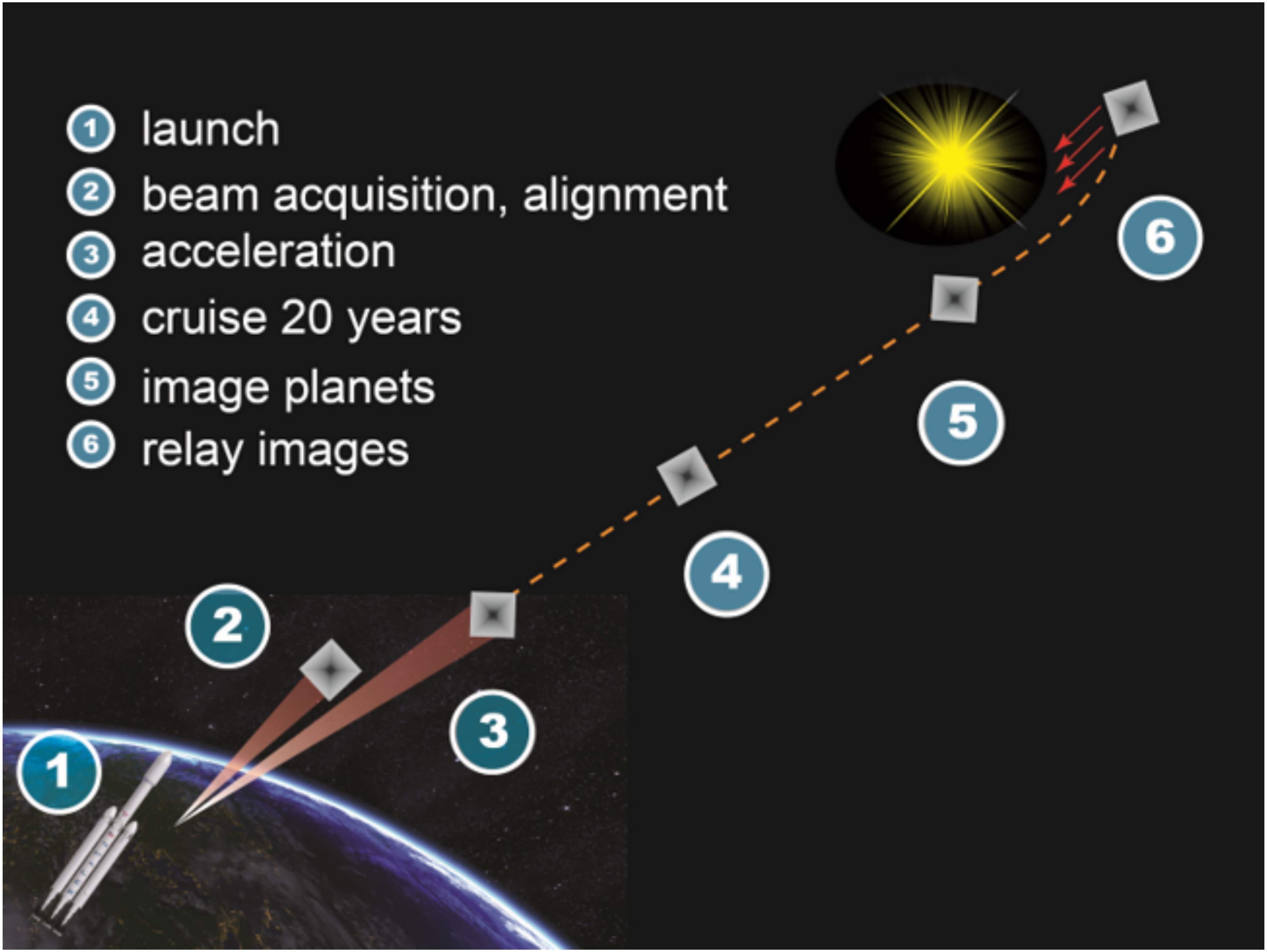
Video frames of First Sail Flight, 2000

30 msec
framing
interval

BREAKTHROUGH STARSHOT

- Send 1-10 gram of scientific instrumentation to the Alpha Centauri system to study it.
- Image its planets, look for life and transmit the results to Earth.
- Do so by using a beam emitted from the Earth to accelerate a sail carrying the instrumentation to 0.2c.
- The capital cost of the equipment shall be less than $10B.



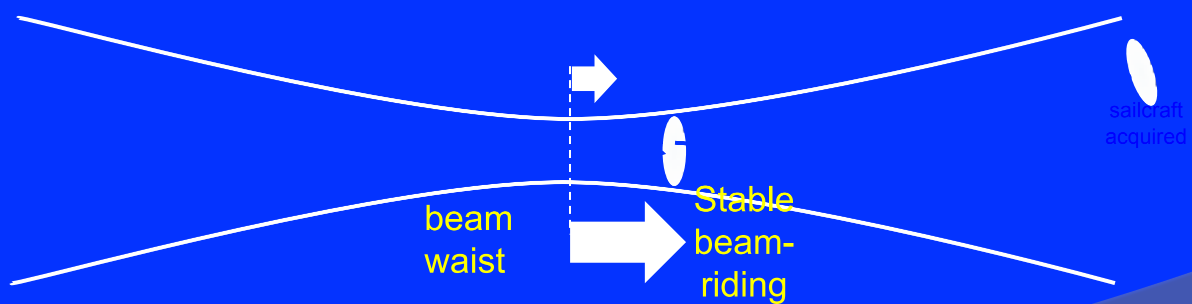


1 launch
2 beam acquisition, alignment
3 acceleration
4 cruise 20 years
5 image planets
6 relay images
1
2
3
4
5
6

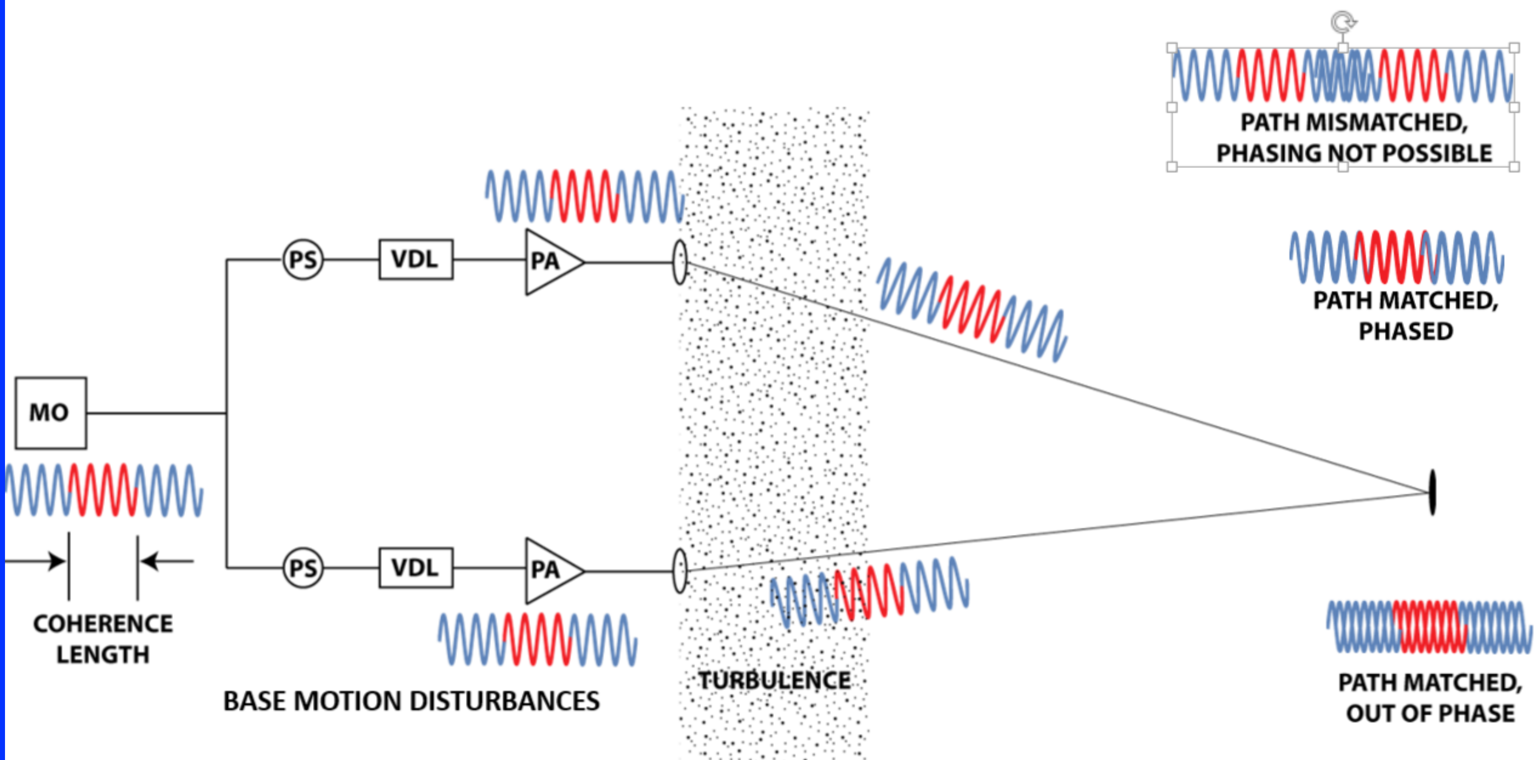
Top 3 Risks for Beamer

- LASER Array Phase Control
- Atmospheric Phase Coherence/ Adaptive Optics
- Keeping Array pointed for a few minutes on 4 m sail
  - Half-power beam width (HPBW) is 30 μas
  - Hubble space telescope pointing stability is 2-5 mas
  - Mitigation: Sail rides the beam (passively or actively)

P



Phasing Challenge



THE OPTICAL PATH LENGTH $\int n(z)dz$ FOR ALL LASERS MUST BE WELL WITHIN THE COHERENCE LENGTH AND THE PHASING BETTER THAN $\lambda/10$ BETWEEN ALL BEAMS. WE MUST ALSO MATCH AMPLITUDE AND POLARIZATION OF ALL BEAMS AND MINIMIZE POINTING JITTER.

Top 3 Risk Areas for Sailcraft

- **Sail integrity** under thrust/ reflectivity, absorptivity, uniformity etc.
  - Multitude of material requirements
  - Stress concentration
  - Beam uniformity requirements

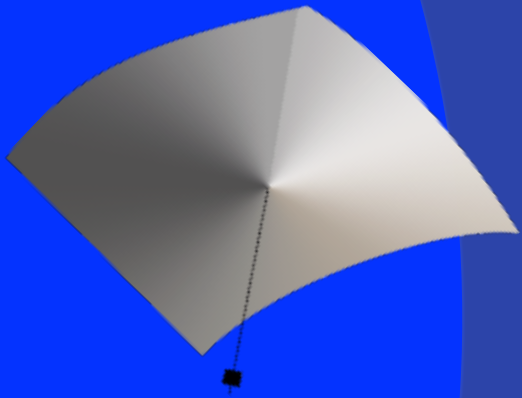
- **Sail stability** on the beam (for a few minutes)
  - Being addressed by Sailcraft committee
    - Near future RFP for program of experiments and simulations
  - Also interested in ideas that passively beam-ride using tailored angular reflectance, for example, instead of Sailcraft shape or a hollow beam

- **Sending Data (images) back** from Alpha C with one watt laser and 4 m antenna
  - Link budget being addressed by cross-cutting team

No consensus has been reached on the "most suitable" geometry for sail stability

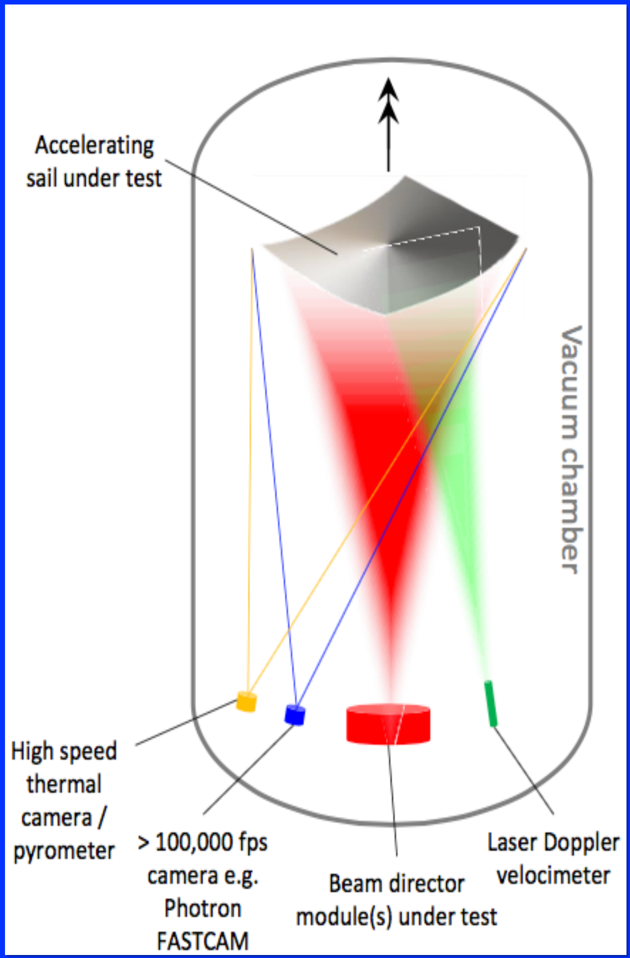
Circular membrane with integrated payload

Gas-filled sphere



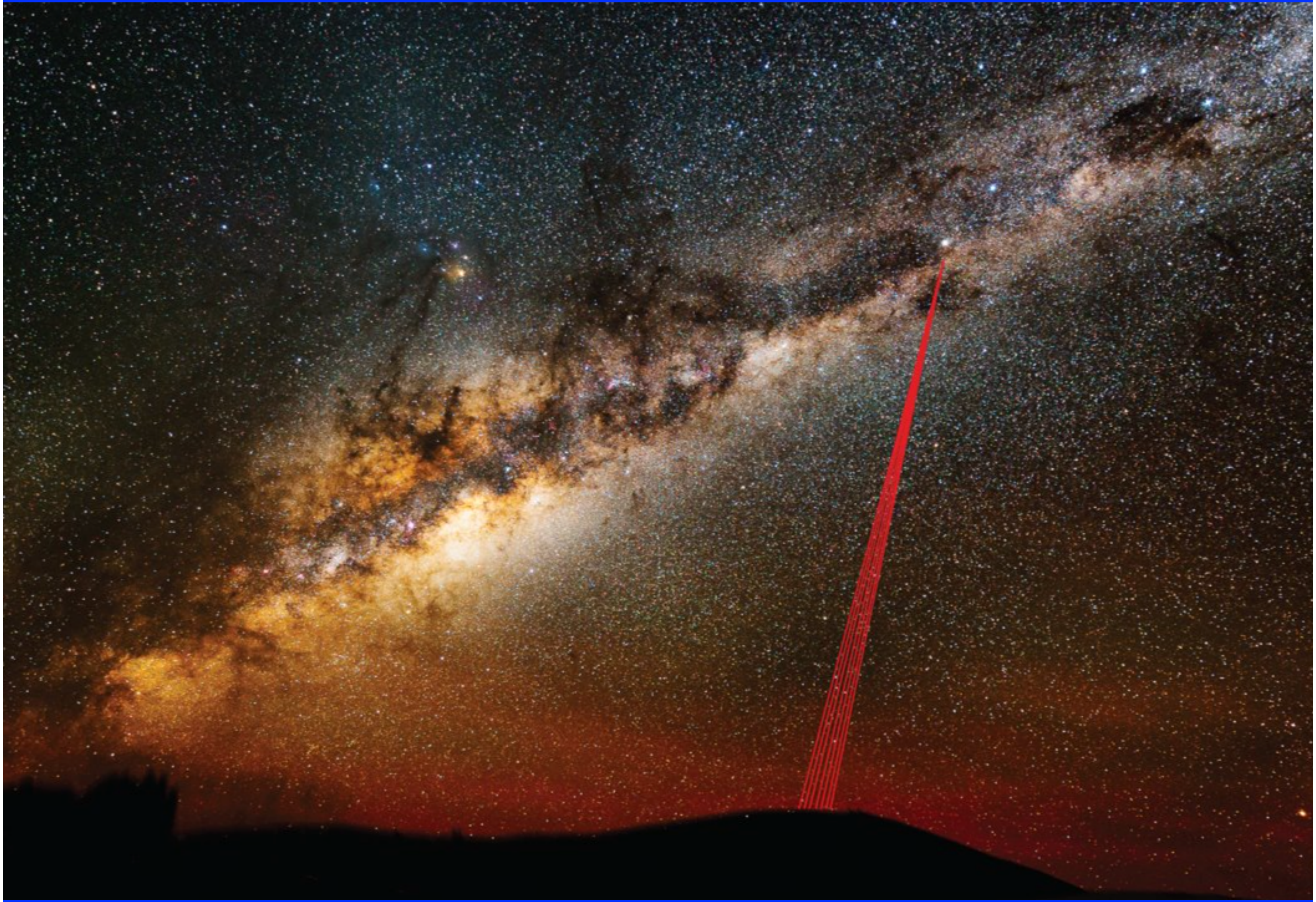
Square membrane with lumped separate payload

Sail Flight Chamber (Acceleration & Stability)

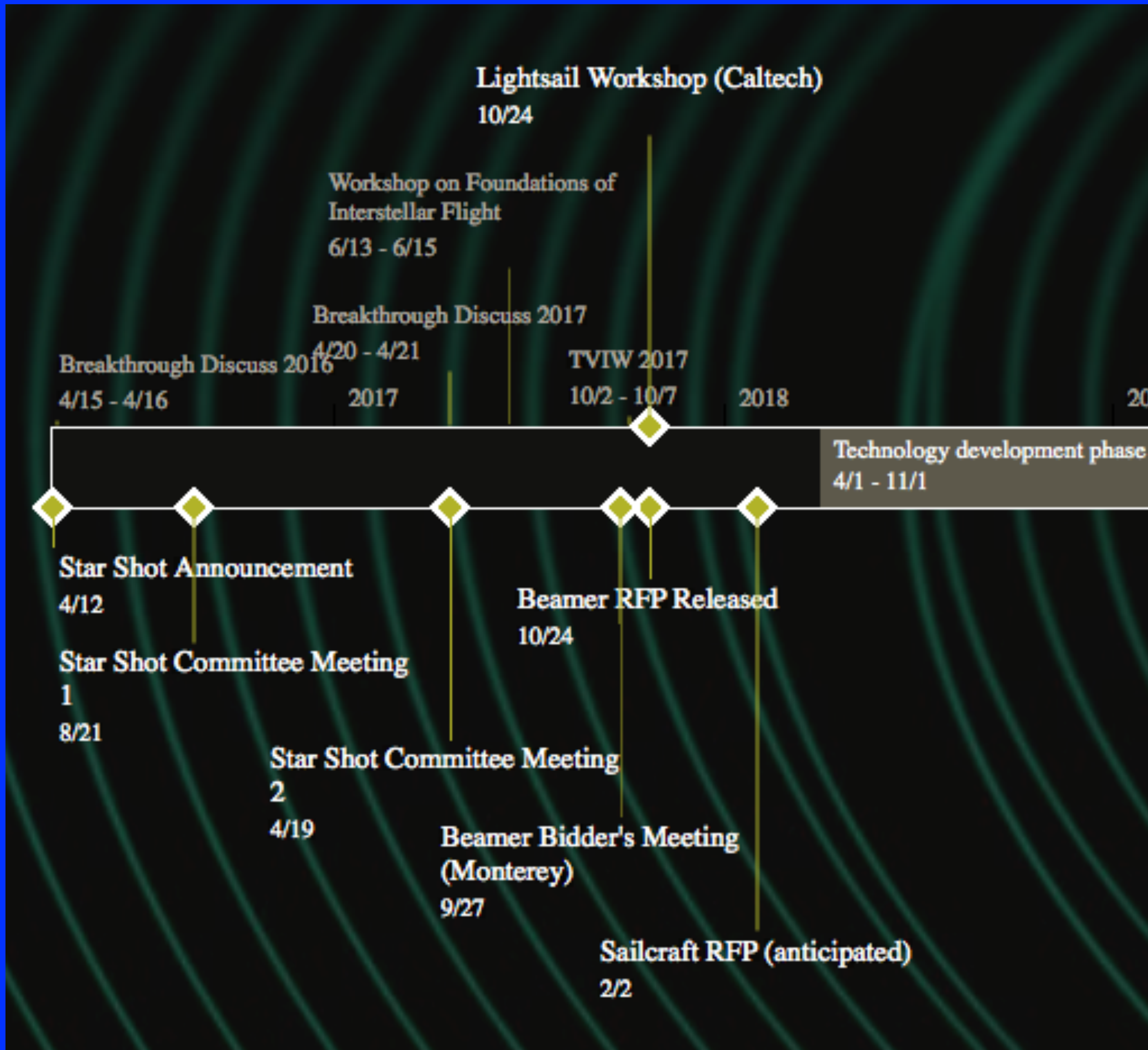


A free-flying sail experiment at high vacuum

Diagnostics will include measures of position, velocity and velocity vector components, acceleration, orientation, imagery and temperatures. Induced instabilities can be tracked in real time.



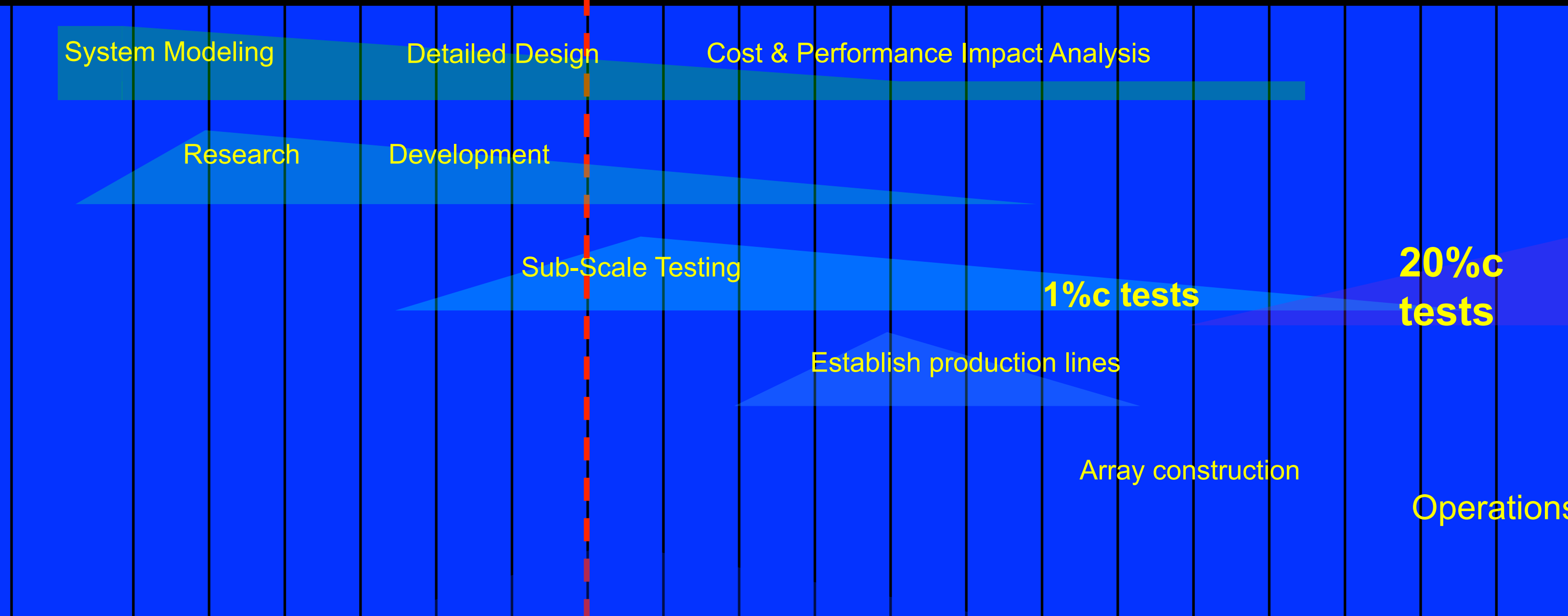
Backup Slides



Lightsail Workshop (Caltech)
10/24
Workshop on Foundations of Interstellar Flight
6/13 - 6/15
Breakthrough Discuss 2017
4/20 - 4/21
Breakthrough Discuss 2016
4/15 - 4/16
2017
TVIW 2017
10/2 - 10/7
2018
Technology development phase
4/1 - 11/1
Star Shot Announcement
4/12
Star Shot Committee Meeting 1
8/21
Beamer RFP Released
10/24
Star Shot Committee Meeting 2
4/19
Beamer Bidder's Meeting (Monterey)
9/27
Sailcraft RFP (anticipated)
2/2

Roadmap

	2016	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Power:		10 kW		100 kW		1 MW		10 MW		100 MW			1 GW			10 GW			100 GW	
Diameter:		1 m		5 m		10 m		50 m		100 m			500 m			1 km			5 km	
Cost:	50 $/W	10 $/W		3 $/W		1 $/W		0.2 $/W		0.05 $/W		0.01 $/W								
Phase:	A	B	C					D								E				



1/23/18

Starshot Beam-Driven Sail Test Facility(s)

- Experimental capabilities to test a variety of sails under vacuum, with the focus being on assessing stability of the sail riding on the beam. This apparatus will have a *vertically* pointing beam. Diagnostics will include measures of
- position,
- velocity and velocity vector components, acceleration,
- orientation,
- imagery,
- background gas composition (due to any outgassing of the sail) and
- temperatures.

Other Test Facility Requirements

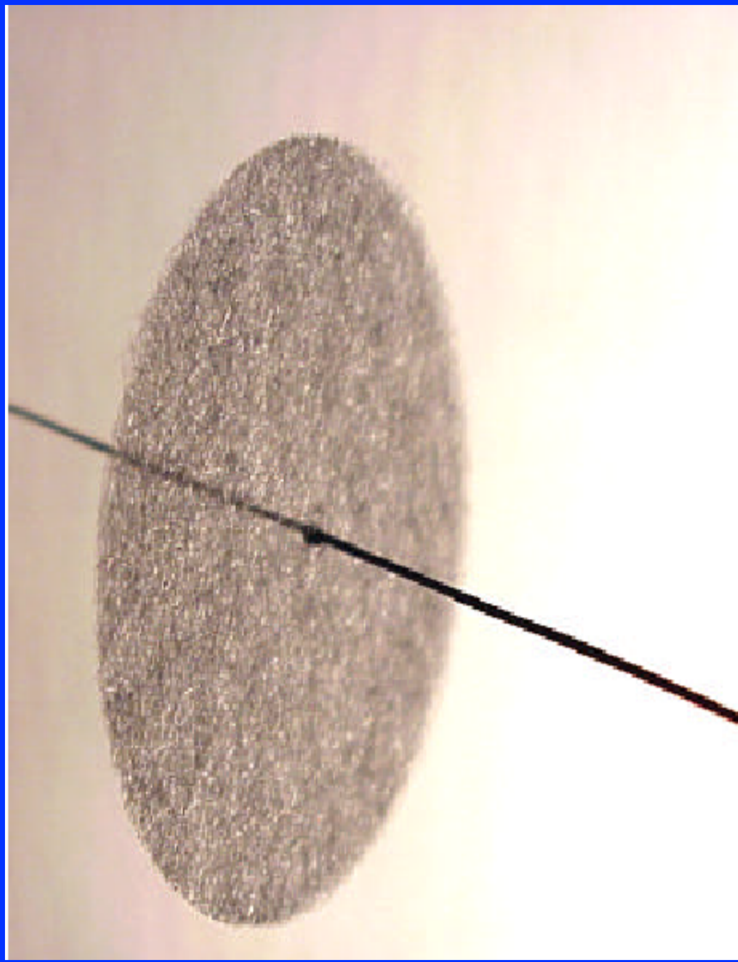
- Data Acquisition & Analysis,
- Diagnostic Calibration Lab,
- Vacuum equipment support,
- Specialized tools,
- Machine shop,
- Conference room
- etc.

Sail Materials Development

- Starshot must optimize beam-driven sail performance (tensile strength, arial mass density (g/m^2), reflectivity, operational temperature, emissivity and absorbtivity):

- Survey results on many candidate sail materials.
- Narrow to ~2 materials for lab tests
- Construct a mini-wafer prototype of size ~1-10 cm^2
- Test in Facility for stability & acceleration

Carbon Fiber Microwave Sail



Material: Carbon Fiber Mat

Diameter: 3 cm

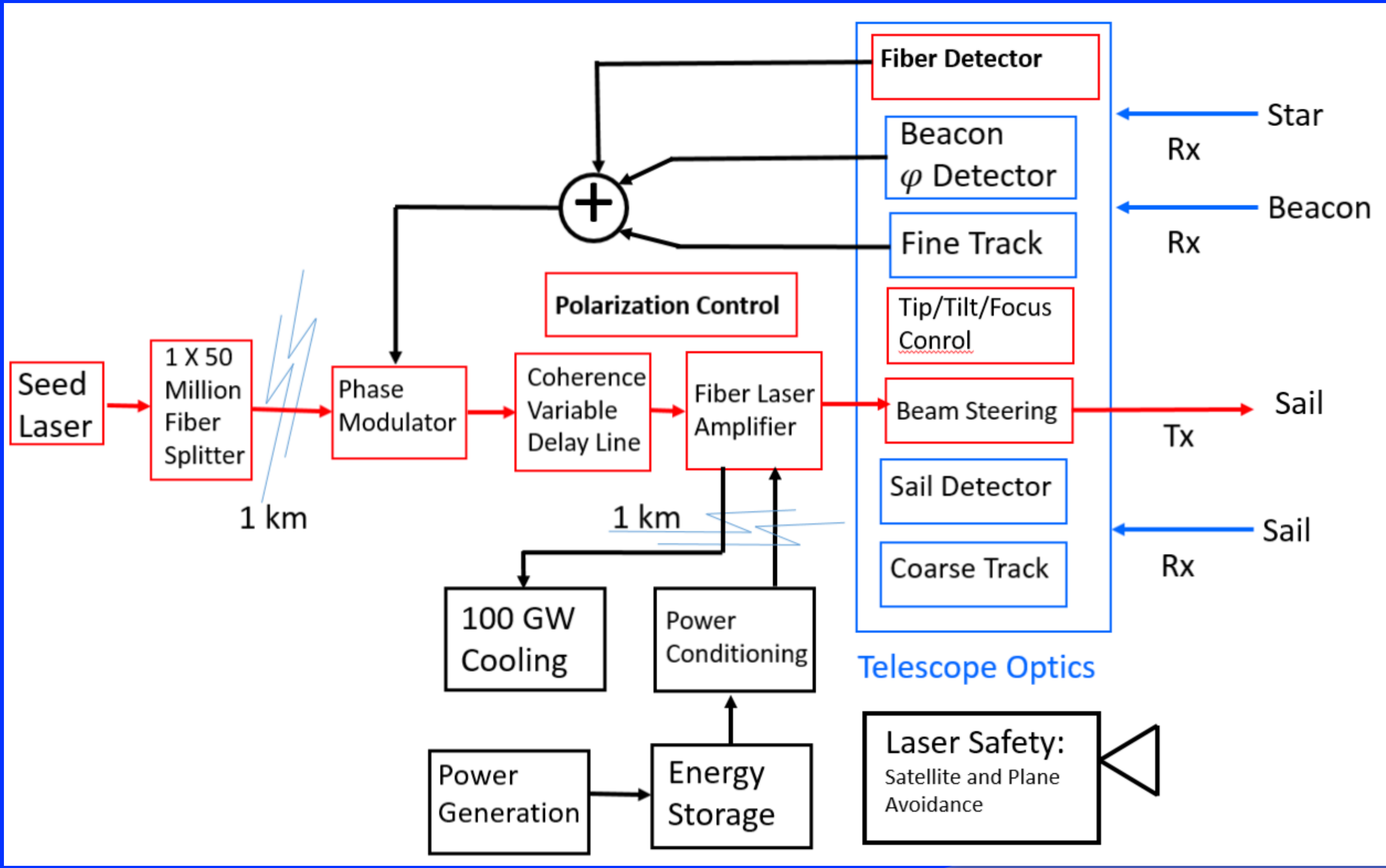
Thickness: ~ 1 mm

Mass: ~ 6 mg

Areal Density: ~ 8.5 g/m^2

Microwave Reflectivity: ~ 90%!

Beamer Functional Diagram



Summary

◆ No consensus has been reached on the "most suitable" geometry for stable sail flight.

◆ Sail Material choices abound, but requirements are daunting.

◆ We must develop
- Sail Simulation Codes
- Beam-Driven Sail Test Facilities

We are hopeful!