BREAKTHROUGH
INITIATIVES

Breakthrough Starshot – Photon Engine Overview for Sail Industry Day

May, 2018

Overview

- Functions and conceptual layout
- Concept of operations
- Beam characteristics

Generic Functional Block Diagram

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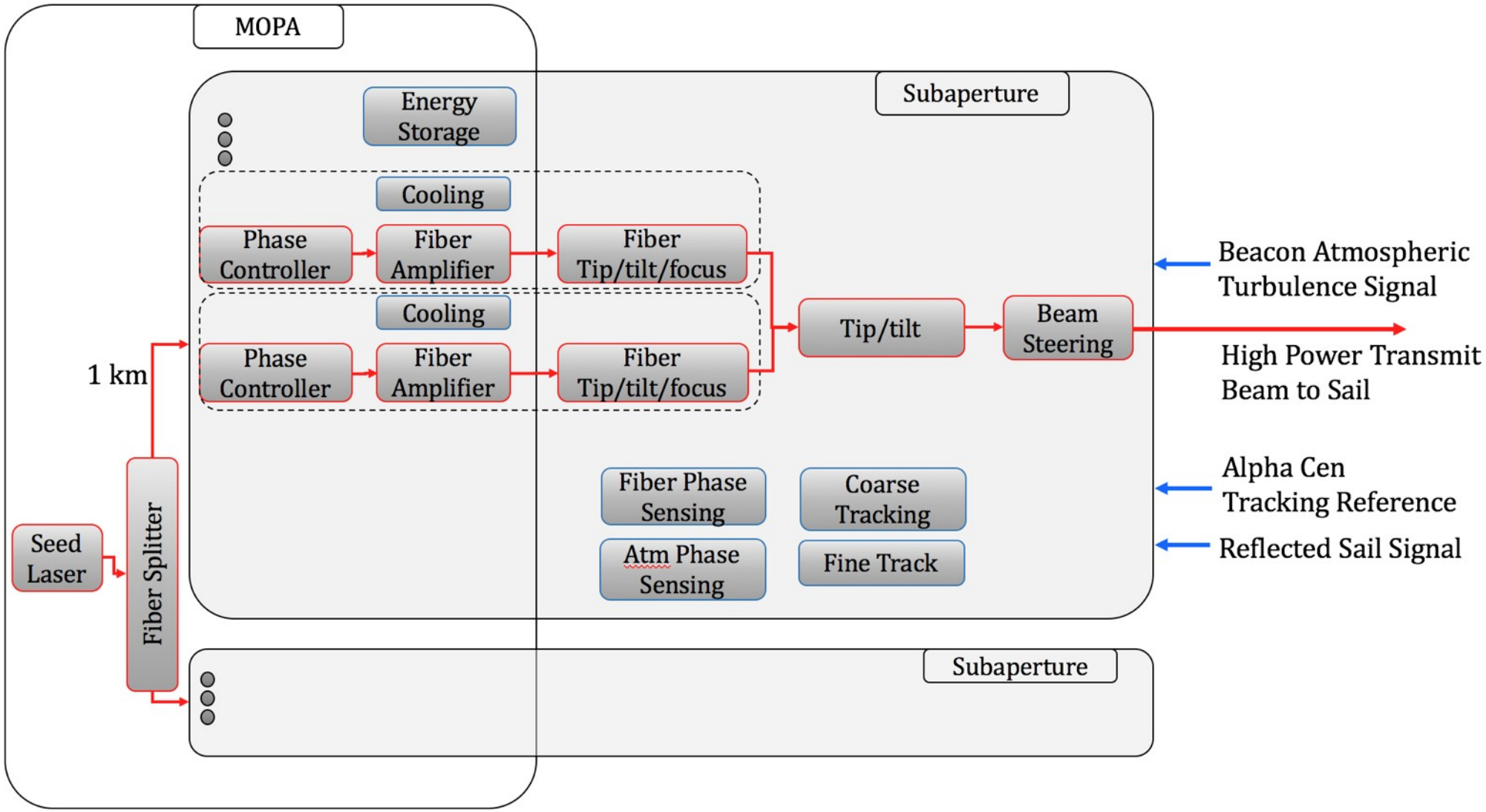
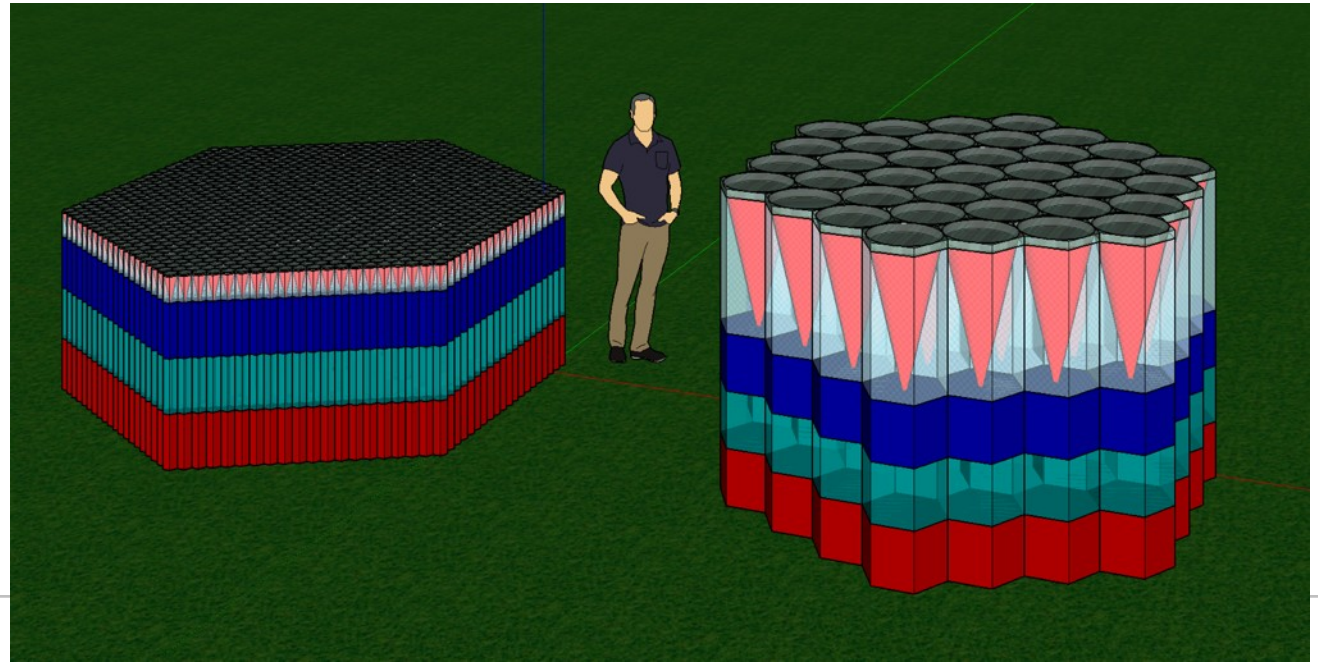


Physical layout

- Chip scale – mm subapertures,W-level emitters. Billions of subapertures.
- Centimeter scale – kW-level emitter approximately sized to atmospheric coherence diameter,r_0. Millions of subapertures.
- Meter scale – many emitters combined to MW levels per subaperture. Thousands of subapertures.
- Undetermined which path is best. The atmospheric coherence diameter and phasing solution will eliminate some options. Cost will drive the remaining solution space.



CONOPS

1. Sail deploys from mothership at ~ 60 Mm from earth
2. Mothership beacon and starlight is used to locate the sail, determine proper trajectory, and measure the atmosphere. Absolute pointing is 3.5 μrad (1 AU at 4 ly).
3. Launch initiates. Beam must be within the 'capture window' of the sail. Startup transients exist due to fiber heating and limitations of the power and cooling systems. Beam is at less than full power and is smaller than the sail. Beam is stable to ~λ/D (.3 nrad) unless intentionally broadened.
4. Launch progresses. Beam overfills the sail and rises to full power.
5. Obstacle avoidance. Beam propagates near a satellite or plane and dims sufficiently to avoid damage and stay within regulatory limits. Sail coasts during this interruption.
6. Launch resumes at full power. Some recapture and beam transients may exist.
7. Beam termination at ~10 min. Beam has moved ~2° in beamer coordinates. Measure final velocity and trajectory.

Realistic beam profile

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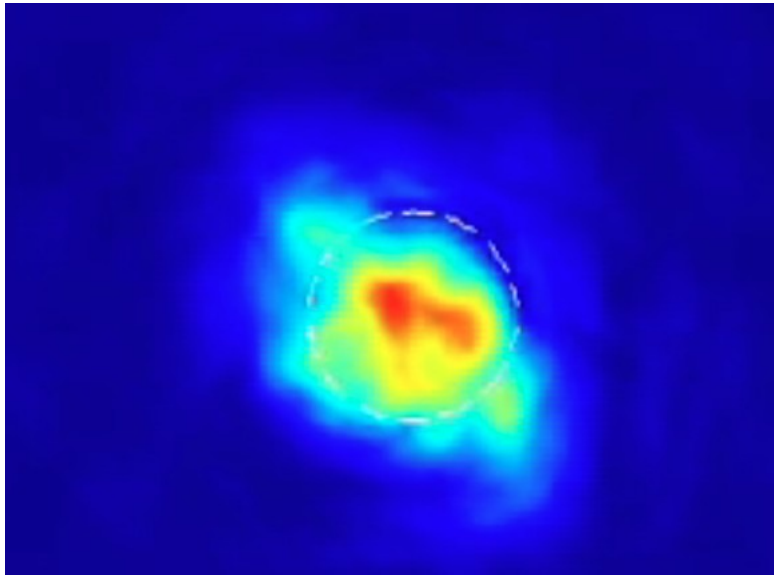
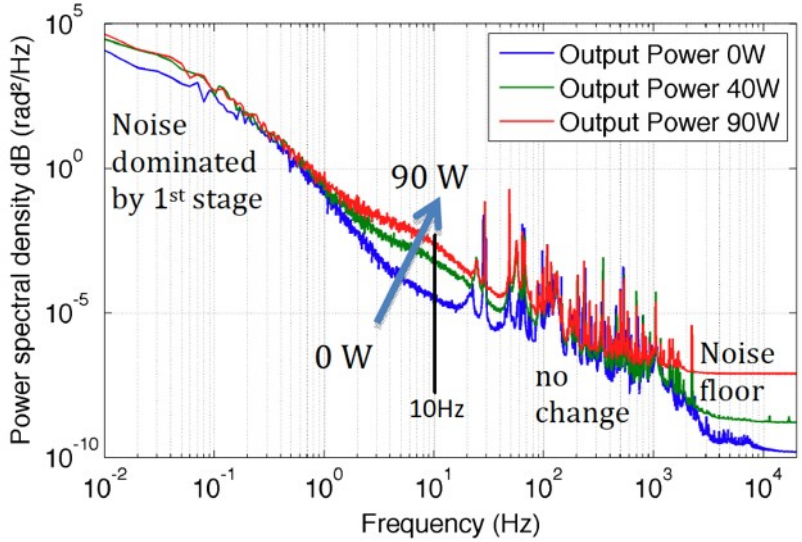
- Fiber phase noise disturbance frequency on the order of kHz.
- Atmospheric disturbance frequency on the order of a few hundred Hz
- While the time-averaged, compensated beam will produce smooth steady beams, the instantaneous irradiance profile can change dramatically.



- The beam cannot compensate for the sail state.
  - Time of flight delays preclude the use of feedback control
  - The sail must accommodate and ride the beam
- Startup transients and predictive avoidance transients
  - Power and thermal considerations tend to produce more unstable beam in the first ¼ - ½ second. Reduced beam quality and increased LOS jitter may result.



Deliverable from TimeLike

- Wave-optic simulation effort will produce the time-evolution of irradiance at the sail. Primary purpose of this effort is to deliver to the sail team a realistic estimate of the beam so evaluations of sail concepts, stability and damage potential can begin without assuming an ideal beam.
  - Includes all known disturbances based on measured or predicted values.
  - Includes compensation/control based on current state of the art in adaptive optics and phased array components
- Initial profiles will include Gaussian beam (baseline) and OAM.

- This initial effort attempts to decouple the modeling/beamer/sail efforts and hand over a useful dataset/model. Future efforts will likely require integrated multi-disciplinary modeling.
- Effort expected to start early June

Beam Shaping

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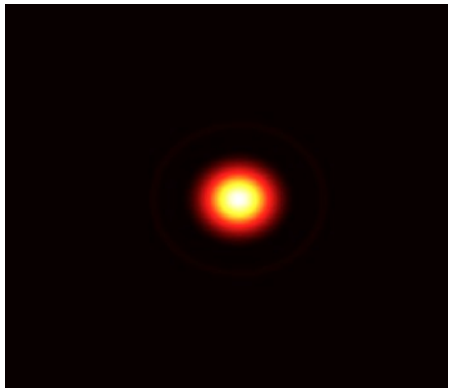
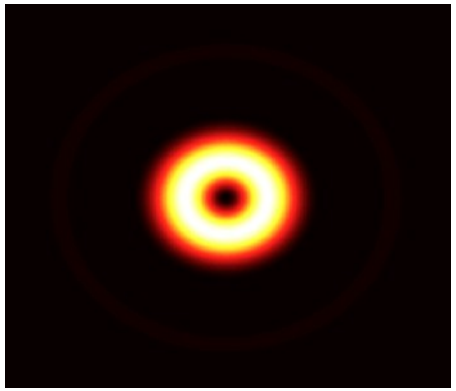
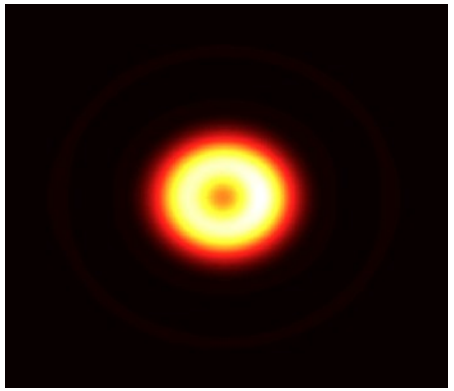


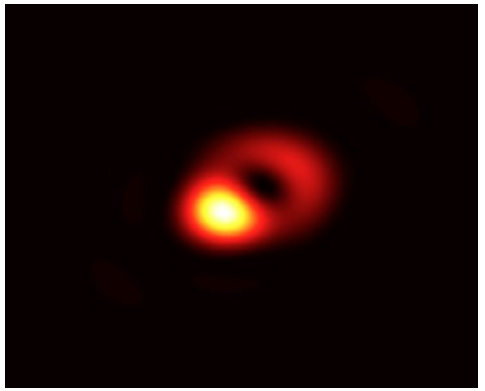
Baseline Gaussian



Orbital Angular Momentum m=1

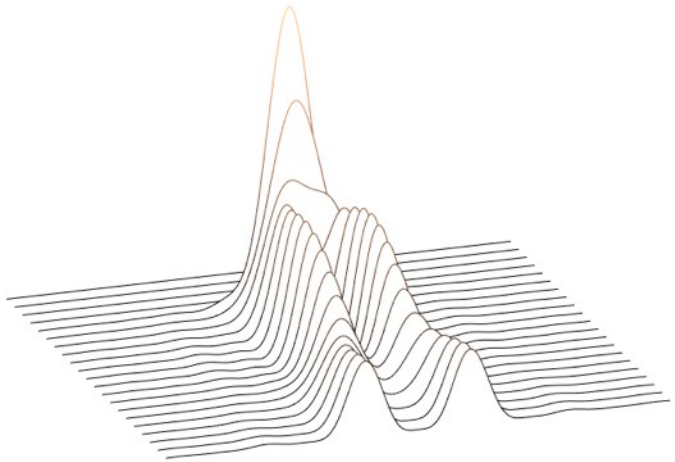


Time-averaged



Asymmetric

- Baseline should be assumed until proven incompatible with stability. This minimizes capex
- Other shapes possible through amplitude and phase control
- Time-averaging allows additional shapes by beam steering or amplitude/phase control. Individual changes can occur at MHz.
- Polarization state may be adjustable



Final remarks

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- The sail-beamer interface is critical to a successful launch
- We look forward to working with sail contract winners!

Wesley A. Green
Director Starshot Photon Engine
wesleygreenoptics@gmail.com
520-647-4219