Starshot Photon Engine Architecture Study

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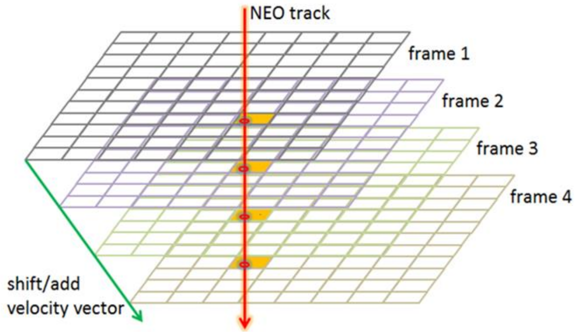
Current and Relevant Prior Research '

- Synthetic Tracking, search for NEOs (Near Earth Asteroids)
  - For CCD images of moving objects, there is a hard magnitude limit, long exposure time doesn't help when the object has moved more than 1 PSF
- Synthetic tracking uses multiple exposures and a shift/add algorithm to increase sensitivity.
  - For a fast NEO (0.25 arcsec/s) a ***30cm*** telescope with SynTrk (400s) has the same limiting mag as an ***8m telescope*** (CCD)(30s)
- In 2017 ~2000 NEOs were discovered, (equal to (~6) 30cm Telescopes)

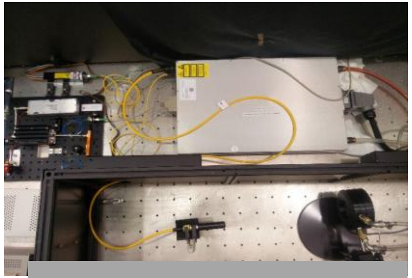


Since we don't know the velocity of the asteroid prior to detection, we try ~10,000 velocities in our search. Search performed with ~Teraflop GPUs.

The most striking advantage is cost. Each 28cm telescope+cmos sensor is ~$5,000.

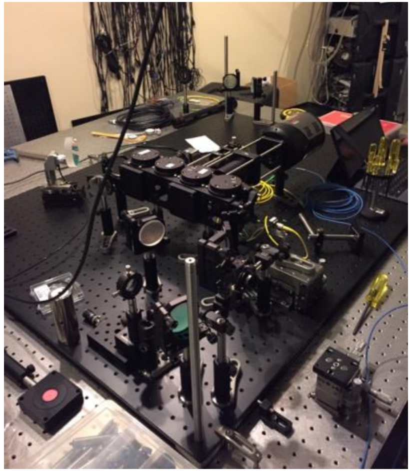
Current and Relevant Prior Research I

- High power LADAR facility
  - 1KW average, 3KW peak power
  - Low (50W) power coherent LADAR (~100 hz linewidth)
- In the past, we build a series of long baseline stellar interferometers.
- The largest being the Keck interferometer, coherent combination of the two 10m Keck Telescopes.



KW fiber amplifier

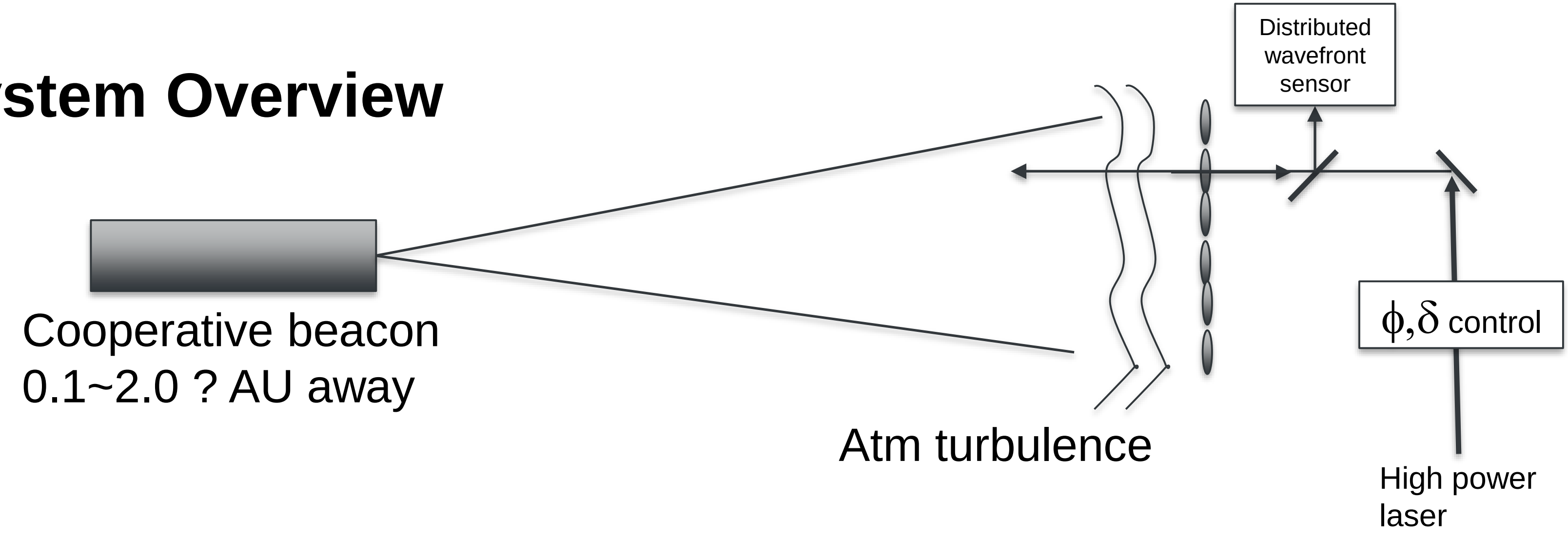
LADAR transceiver



Starshot Photon Engine Architecture Study

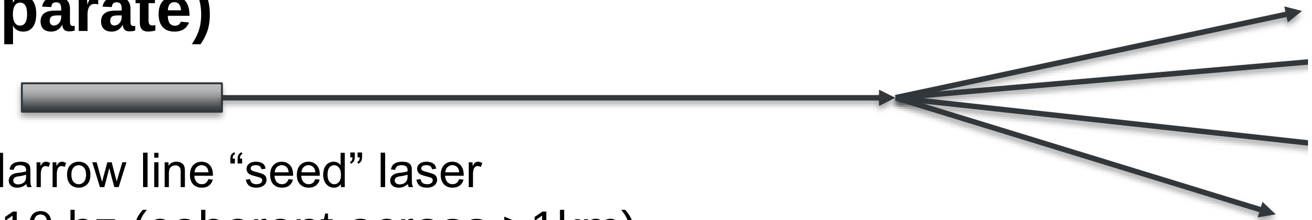
- Background (1)
  - High power lasers. In the past ~10 years there has been a lot of progress in high power fiber lasers. Fiber lasers because operate in a single mode fiber produce diffraction limited beams even when the fiber undergoes significant thermal heating.
  - However the power density is very high and non-linear effects (SBS) limit the maximum output power. Most of the increase in max power (>1KW) comes from spectrally broadening the laser light.
  - Phasing a single freq laser only requires control from 0~2pi. But it’s much more complicated to phase a broad band signal.

System Overview



- Traditional AO wavefront sensors (Hartman) work with contiguous apertures. Or (such as Keck) with segmented apertures that are "roughly phased" with overlapping edge sensors prior to the AO system.
- The system we proposed is a distributed wavefront sensor will measure both the *delay and phase* of the wavefront from the beacon.

Delay and phase control of High Power beam (sensing is separate)

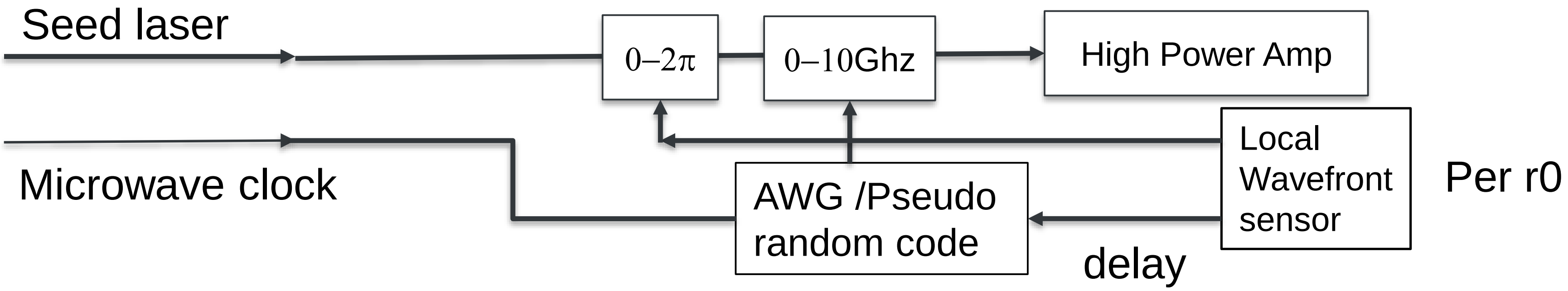


Distribute “seed” to 1000’s/millions of laser amplifiers

Narrow line “seed” laser
~10 hz (coherent across >1km)
Also distribute microwave clock with < 0.02nsec
(sync’d including fiber length variations to 1000’s/ millions of amplifiers)

- In the Keck interferometer, we “phased” the two 10m telescope using mechanical/optical delay lines. This works but is too expensive for use in the starshot photon engine. (delaylines more expensive than the individual laser) Current cost of a 1KW laser amplifier < $100K.
- Km long optical delaylines move 10cm/s with 10nm precision ~$1M/each want to bring phasing control cost down >100X.

Phase and delay control at each laser amplifier



- The broadband light >10Ghz to the amplifier is needed to avoid SBS.
- Normally one would use a thermal white noise source to generate the electrical broadband signal. But with multiple Laser amplifiers, we would want to the same noise source at all lasers. (for a “static” laser this could be distributed and delayed using fixed fiber lengths. But if the beam is to be steered across the sky it’s better for the delay to be electrically programmed.
- A 10Ghz AWG is ~$100K, the proposed effort is to find a ~$10K alternative and simulate its performance.

Wavefront Sensor Effort

- Traditionally wavefront sensors that bridge a non-contiguous distributed aperture needed some way to interfere the light between adjacent apertures.
- What we’re proposing is a wavefront sensor that only uses digital connections between the sub-apertures.
- The proposed effort is to define the WFS components in more detail and perform a simulation of how well this would work.
- The purpose is to provide the signals to drive the 0-2pi phase control and the AWG delay control.