Exoplanet Study

Interstellar Laser Communications

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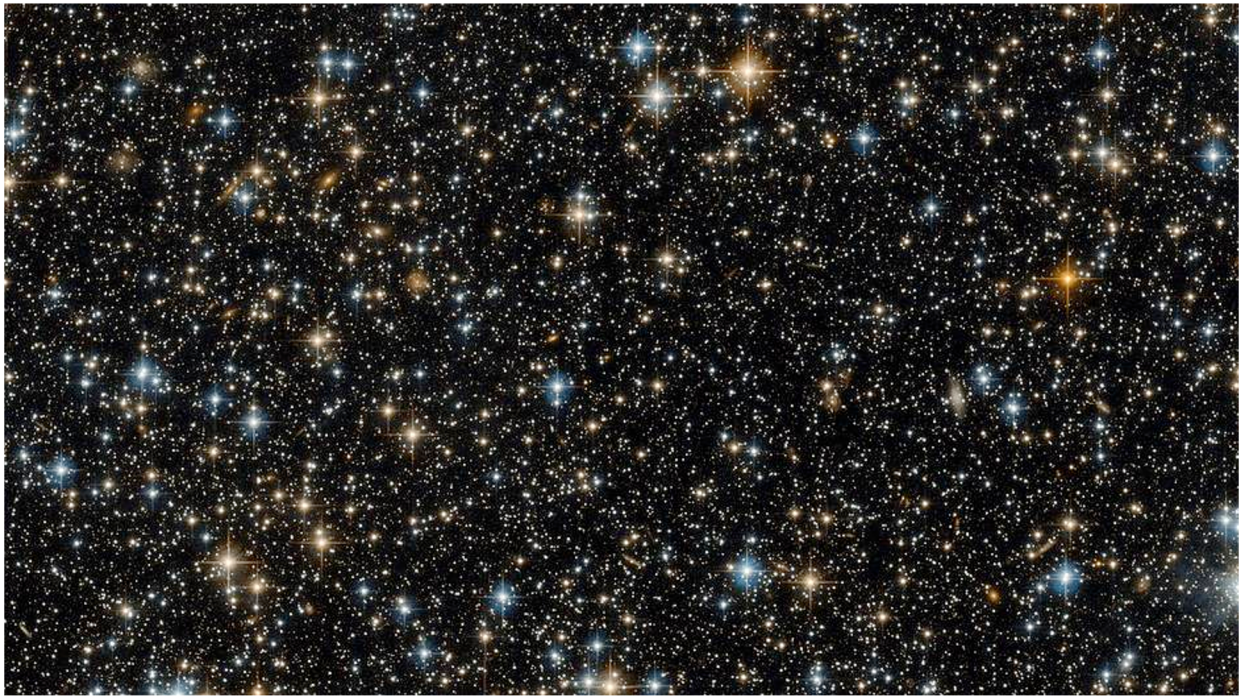
Problem: How to communicate from 5-15 Ly

1. **Direct-to-Earth (DTE) link from inter-stellar spacecraft**
2. **Gravity lensing ?**
3. **Other ???**



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Interstellar DTE

- **Assume a 30-40 m diameter photon bucket at Earth as a ground collecting aperture**

Cumulative Space and Receiver Loss/Gain - 4.37 Ly

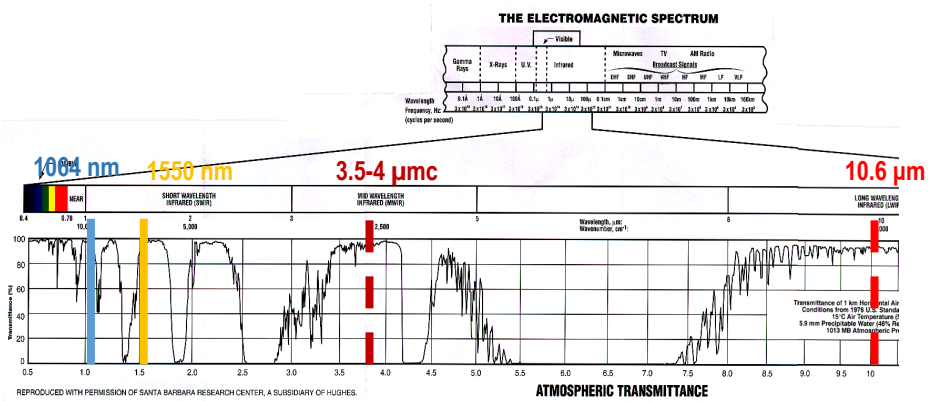
Range					2.76E+05	AU	2.76E+05	AU
Space Loss	-470.47	dB	-470.47	dB				
Ground Net Gain	154.12	dB	151.62	dB	40	m	30	m
Impl. Losses	-8.01	dB	-8.01	dB				
	-324.36	dB	-326.86	dB				

Cumulative Space and Receiver Loss/Gain - 15 Ly

Range					9.49E+05	AU	9.49E+05	AU
Space Loss	-481.18	dB	-481.18	dB				
Ground Net Gain	154.12	dB	151.62	dB	40	m	30	m
Impl. Losses	-8.01	dB	-8.01	dB				
	-335.08	dB	-337.57	dB				

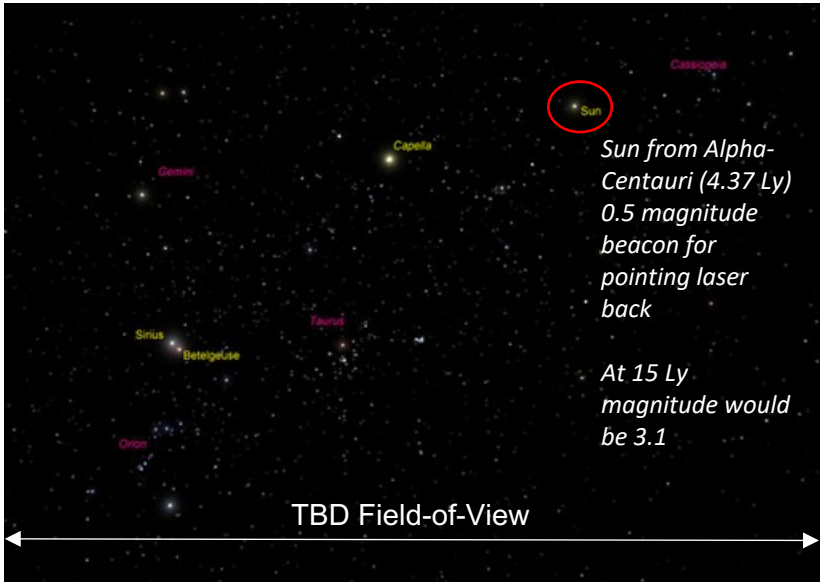
- **Estimate emitted isotropic radiated power (EIRP) in dB-W to receive a given number of photon-counts**
  - Assuming 100 photoelectrons/second (pe/s) from 15 Ly
  - EIRP required is 166-169 dB-W @ 1550 nm

- **Why 1550 nm?**
  - Assume collecting aperture is on the ground
  - Laser availability/atmospheric transmission
  - Expect substantial Doppler shift ~ 95 nm (initial estimate, TBC)
  - Shifted 1550 nm has transmission window 1064 nm may be blocked
  - Re-visit wavelength selection in future
    - 1550 nm not most energy efficient etc.



http://www.coseti.org/atmosphe.htm

Operational strategy use sun as beacon



Sun from Alpha-Centauri (4.37 Ly) 0.5 magnitude beacon for pointing laser back

At 15 Ly magnitude would be 3.1

http://www.learnastronomyhq.com/articles/how-would-our-sun-look-from-alpha-centauri.html

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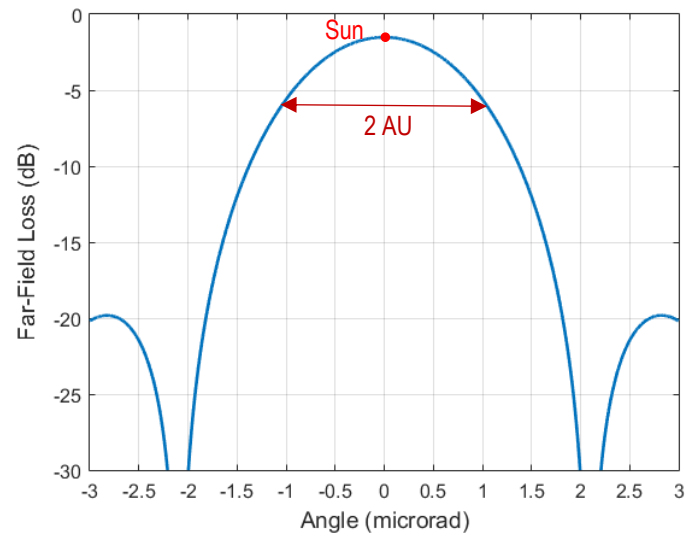
Interstellar DTE (cont.)

- **Robust concept will be to make laser footprint at Earth to be > 2 AU**
  - As long as flight transceiver at interstellar range can track Sun and point beam back Earth will be illuminated
    - LOS relative angular motion in 5-15 years and point-ahead requirements need study
  - Approximate optimal far-field gain and pointing loss from 15 Ly (Max pointing loss of -6.08 dB)
  - 100 cm diameter telescope with 20% obscuration provides net gain of 118.5 dB
  - Allow -3 dB transmit efficiency

Ground Ap. Dia. (m)	40	30
Laser power (dB-W)	50.7	53.2
Approx. Laser Avg. Pwr (Kilowatts)	130	250

Average required power For 6.08 dB pointing loss



- Received photo-electron (phe) flux is 100-470 phe/s

- Average laser powers are consistent with Air Force sponsored 100 kW laser development programs
  - DoD is scaling High energy Lasers to support 100 kW in rugged fieldable packages that might be relevant
- Pulsed lasers can achieve PW peak powers in femtosecond pulses ~ 10-30 J per pulse
- Need to develop lasers that combine these schemes into a single laser
- Laser lifetime of > 50 years (assumed time to reach destination) needs development and study

Estimated data-rates of 100-200 bps for worst pointing & 400-800 bps for when Earth is in front of Sun (TBC)

Assumes advanced adaptive optics so no background penalty

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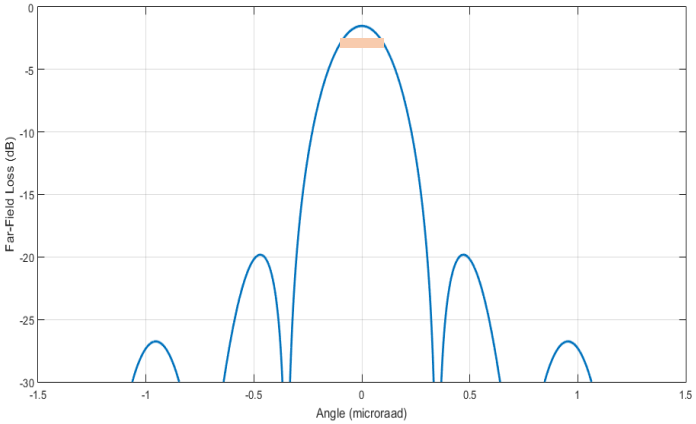
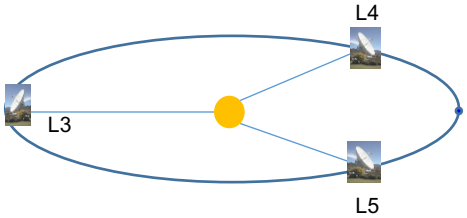
Interstellar DTE (cont.)

- **An alternate DTE concept is to track on Sun but point to Earth**
  - Need s/c to compute Earth position relative to sun ?
    - Beam footprint in this case is 0.1 AU
    - Performing step-stare to cover a 2 AU region could find Earth and communicate for dwell time ?
  - This allows narrowing the laser beam
  - For example, if we assume a JWST class transmitter with 6m dia. and < 20 mas (97 nrad) pointing jitter
  - Increases detected phe/s to 8500-9000 pe/s
  - Data-rates of 2-5 kb/s, notionally
  - Lower laser power (data-rates) for lower risk/cost



- **Additive background noise from sky brightness**
  - Not addressed so far though
  - Estimated background additive noise with signal strength
  - Photon-counting links degrade due to noise unless mitigated
    - Deploy Receivers in space
      - Need to worry about stray light only
      - Can be largely mitigated by architecture and design
      - Can use coherent receiver (new light science opportunities !)
    - Implement adaptive optics system
      - Need multi-beam laser guide stars
      - Systems like this coming online at ESO but not for daytime



Notional receiver architecture for interstellar laser comm.
~ 30-40 m telscopes deployed at Earth Sun Lagrange points

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Gravity Lensing

- **Use Sun as a gravity lens to focus laser signal received**
- **Place receiver at gravity lens focus**

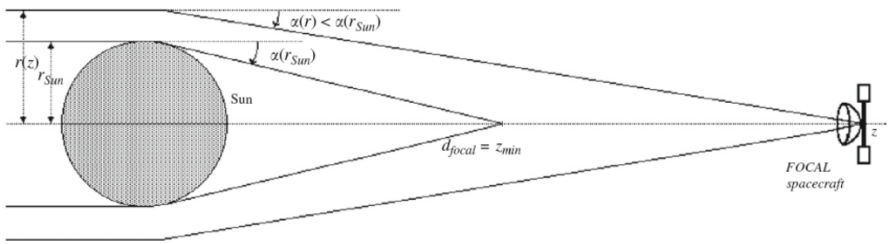
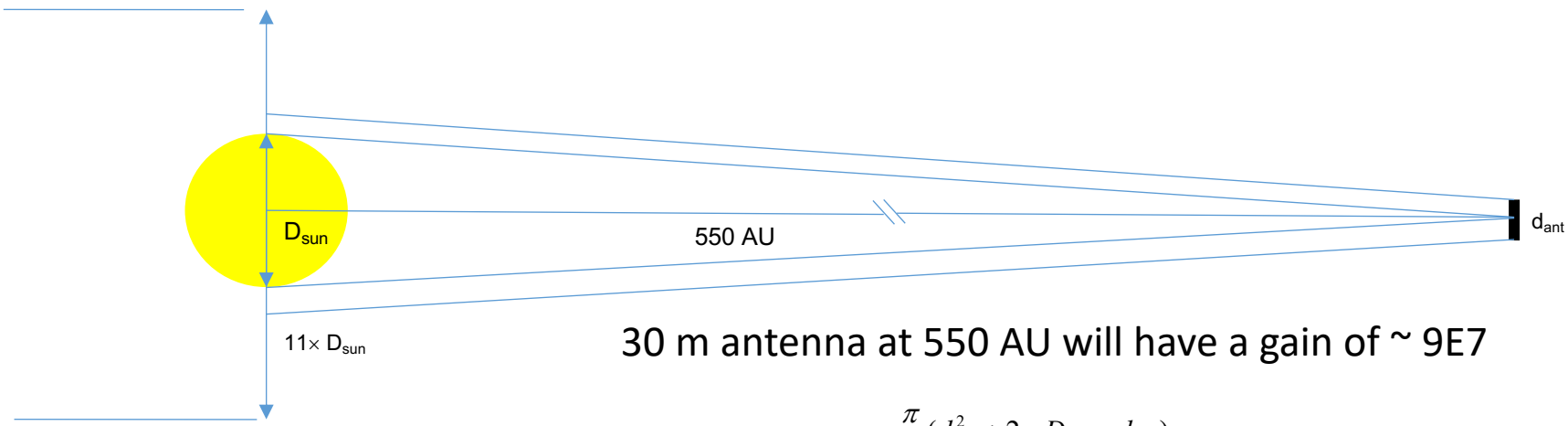


Figure 1 Basic geometry of the gravitational lens of the Sun (Maccone[2])

- **Need better understanding of light collection using gravity lens**
  - Appears as if a "ring" of laser signal will be focused depending on receiver location
  - Moving receiver farther than 550 AU will result in larger ring sizes



30 m antenna at 550 AU will have a gain of ~ 9E7

$$Gain = \frac{\frac{\pi}{4}(d_{ant}^2 + 2 \times D_{Sun} \times d_{ant})}{\frac{\pi}{4}\left(d_{ant}^2\right)} \approx 2\frac{D_{sun}}{d_{ant}}$$

FOCAL: Deep Space Science and Telecommunications Using the Sun's Gravitational Lens

Principal Investigator: Les Johnson, NASA Marshall Space Flight Center[i]
Co-Investigators: Dr. Claudio Maccone,[ii] Dr. Eric Davis,[iii] and Dr. Michael LaPointe[iv]

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Other

- **Daisy chain spacecraft and relay information back to Earth**
  - Staggered launch so that com link between spacecraft
    - 960 AU in 50 years 20 s/c per year (link distance ~ 1000 AU)
  - Reliable, redundant, eases comm, prohibitively expensive?

Summary

- Completed 0th order sanity check on feasibility of laser communication from 15 Ly
- Need to explore more wavelengths
- View laser lifetime as the highest risk
- Ground receiving infrastructure with large astronomical telescopes also needs study
  - Can we live with only nighttime operations
  - Assume detectors and receivers will be available
- Implications of 15 year light time not fully explored
- Gravity lensing need to be better understood

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