New Application for kHz Laser Ranging: Time Transfer via AJISAI

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Ajisai for time transfer

Proposal: Kunimori et al. (Annapolis Workshop, 1992)

Between common-view stations

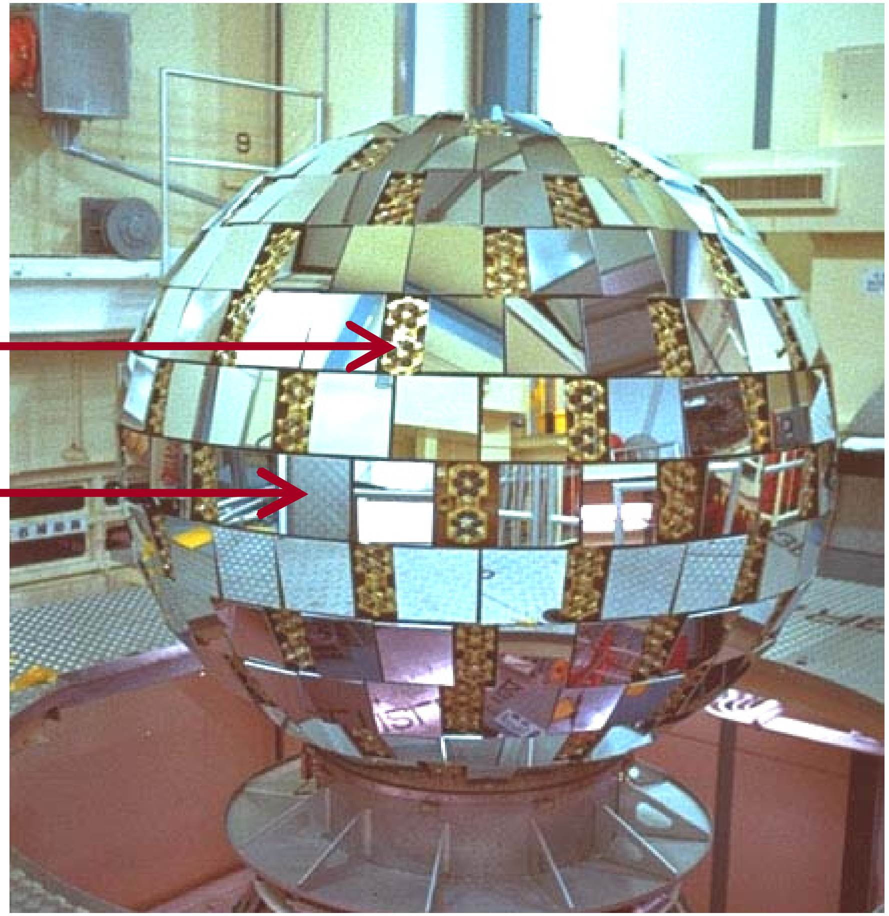
Reflection from mirrors

Unlimited lifetime

Purely geometric

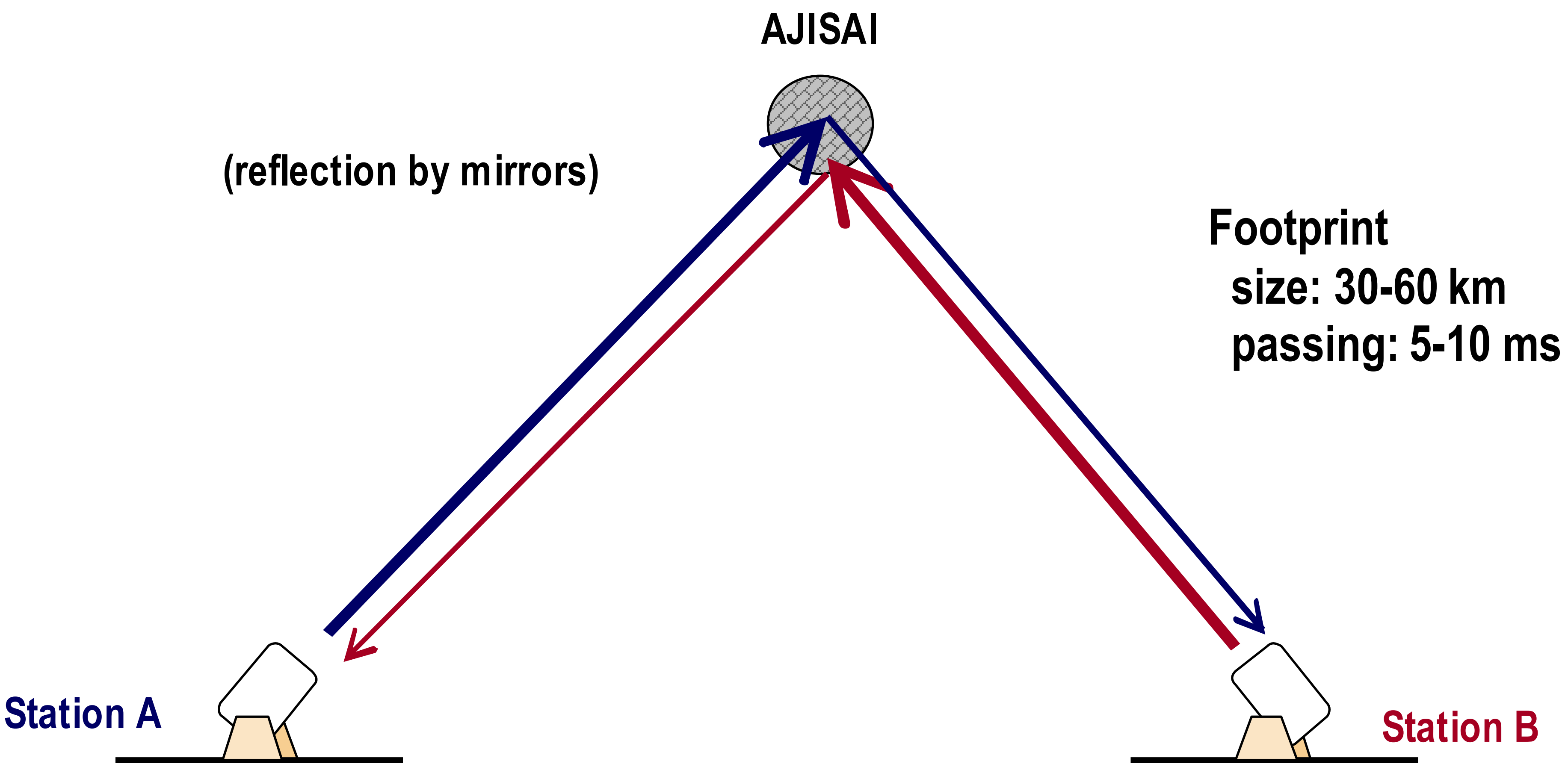
Retroreflectors

Curved mirrors
R = 8.5-9 m



Experiment Plan

Two-way time transfer: Kunimori et al. (1992)



Formulation

t_0

D_{A1}^* R_{A1}^*

ΔT_A **Difference of 2 two-way range observations.** ΔT_A

D_{A1}^* R_{A1}^*

D_{A1} R_{A1} A→A R_{A2} D_{A2}

L_A

$$\rho_{A\to B} - \rho_{B\to A}$$

$$= t_R(A\to B) - t_T(A) - t_R(B\to A) + t_T(B)$$

$$= 2\Delta T_{B-A} + [(R_{B2} - R_{B1}) - (R_{A2} - R_{A1})]$$

$$+ D_{B2} - D_{B1} - D_{A2} + D_{A1}$$

~ zero, or precisely modelled

$t_T(A) = t_0 - \Delta T_A - R_{A1}^* - D_{A1}^* + L_A$

$= [t_0 - R_{A1}^* - D_{A1}^* + L_A]_{for\ A}$

$t_R(A\to A)$

$= t_0 - \Delta T_A + R_{A2} + (R_{A1} - R_{A1}^*)$

$+ D_{A2} + (D_{A1} - D_{A1}^*) + L_A$

$= [t_0 + R_{A2} + (R_{A1} - R_{A1}^*)$

$+ D_{A2} + (D_{A1} - D_{A1}^*) + L_A]_{for\ A}$

D_{A1} R_{A1} A→B R_{B2} D_{B2}

Inward-delay minus Outward-delay

$t_R(A\to A)$

$= t_0 - \Delta T_A + R_{B2} + (R_{A1} - R_{A1}^*)$

$+ D_{B2} + (D_{A1} - D_{A1}^*) + L_A$

$= [t_0 - \Delta T_{(B-A)} + R_{B2} + (R_{A1} - R_{A1}^*)$

$+ D_{B2} + (D_{A1} - D_{A1}^*) + L_A]_{for\ B}$

It has been difficult, but

Timing

Signal-transfer geometry is satisfied just for **5 to 10 ms**.

(compare: **100 to 200 ms** time interval of 5-10 Hz rep. lasers)

This happens 3 times per Ajisai's spin period (currently ~ 2 s).

kHz laser won't miss any!

System

Need to detect a pulse coming from a remote station

→ Synchronise the timing of laser hitting the satellite.

→ Or, Set multiple range gates by exchanging firing info.

Event timer helps a lot.

Link

1 to 10 photons for a 100 mJ/pulse laser.

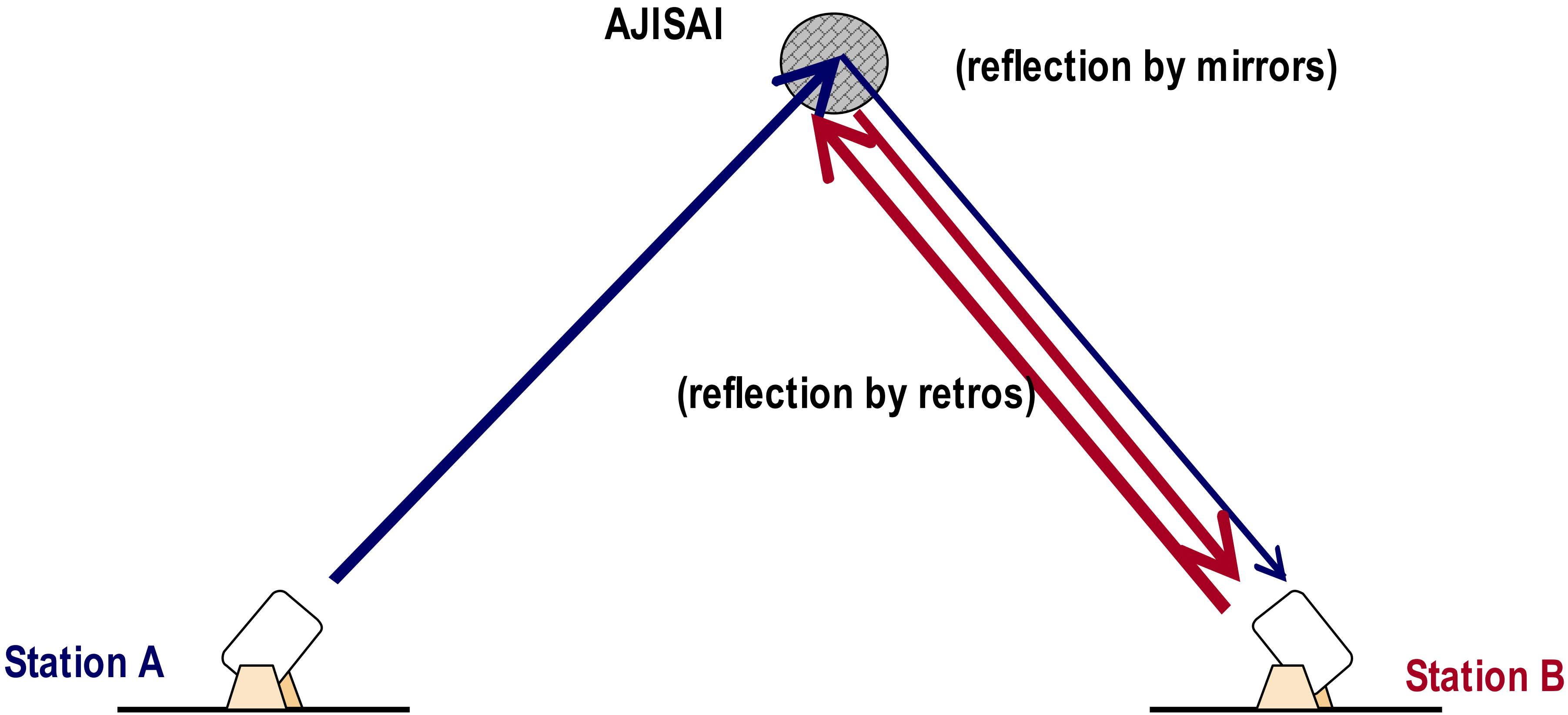
Dual (A→B and B→A) two-way range obs required.

0.005 ~ 0.05 photons/pulse with kHz laser

Single + SLR will do.

Experiment Plan

One-way + SLR time transfer: this study (2006)



New idea (2006): Formulation

A two-way range minus an SLR observation.
(no need for dual two-way ranges)

$$\rho_{A\to B} - \rho_{B\to B}$$

$$= t_R(A \to B) - t_T(A) - t_R(B \to B) + t_T(B)$$

$$\vdots$$

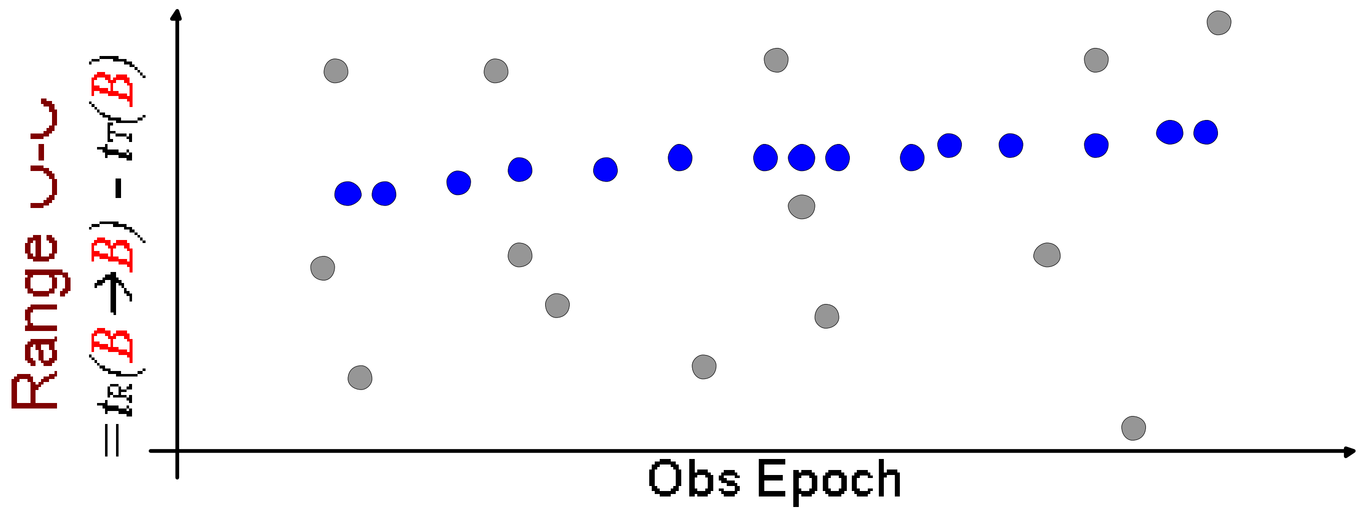
$$= \Delta T_{B-A} + \underline{[D_{A1} - D_{B1}]} + \underline{[R_{A1} - R_{B1}]}$$

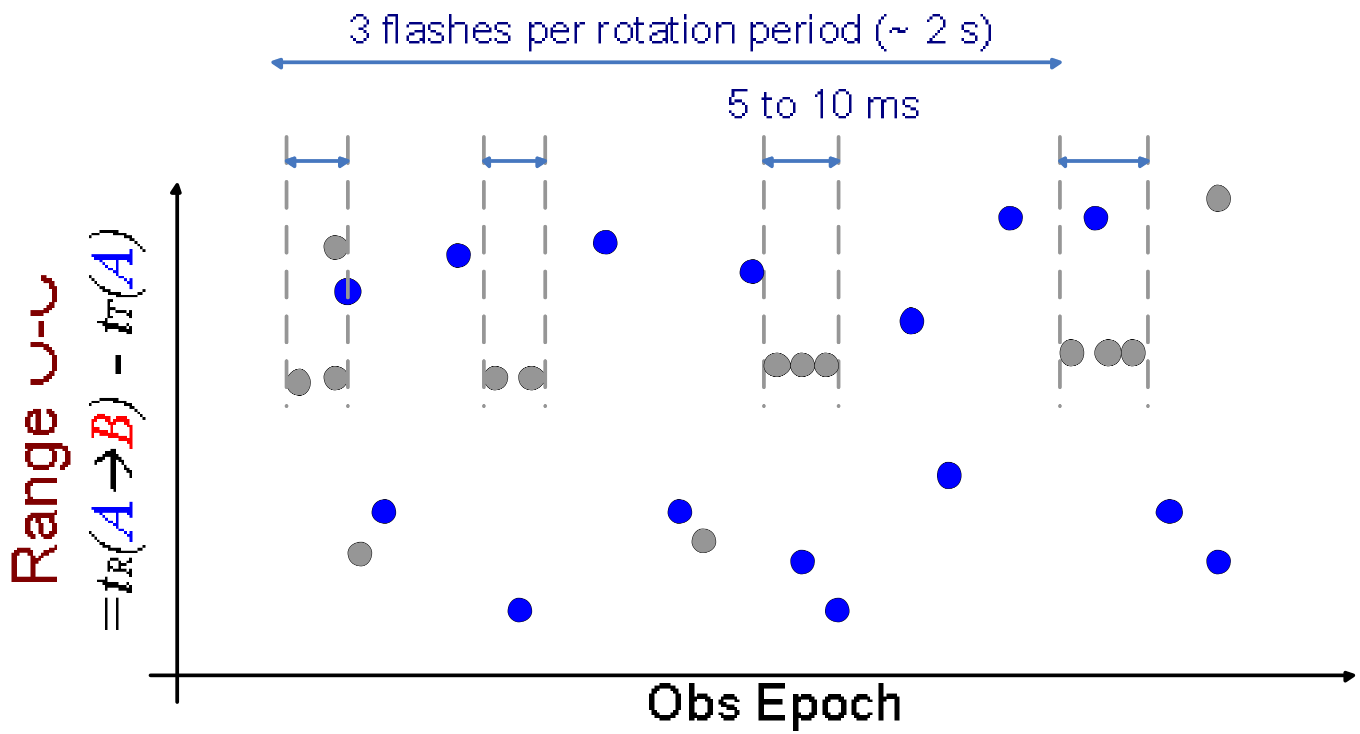
~ 3 to 5 cm (radial) accuracy from POD

Difference (A-B) of outward delay

How to find the "signal"

Assume synchronous laser.

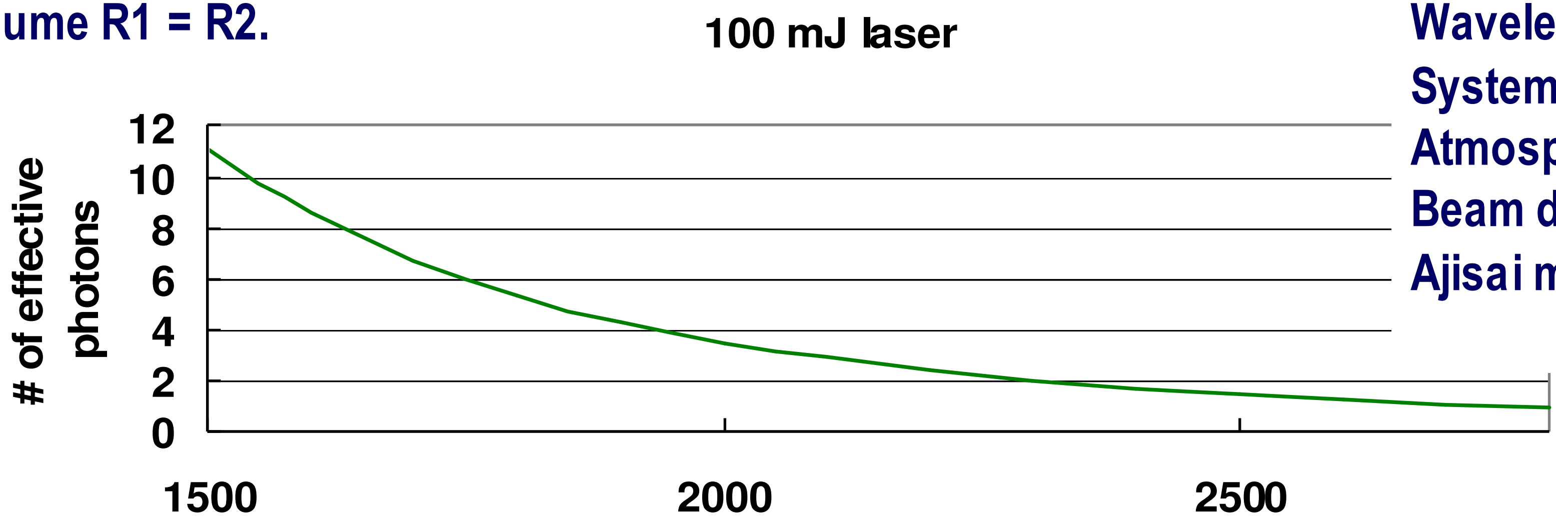


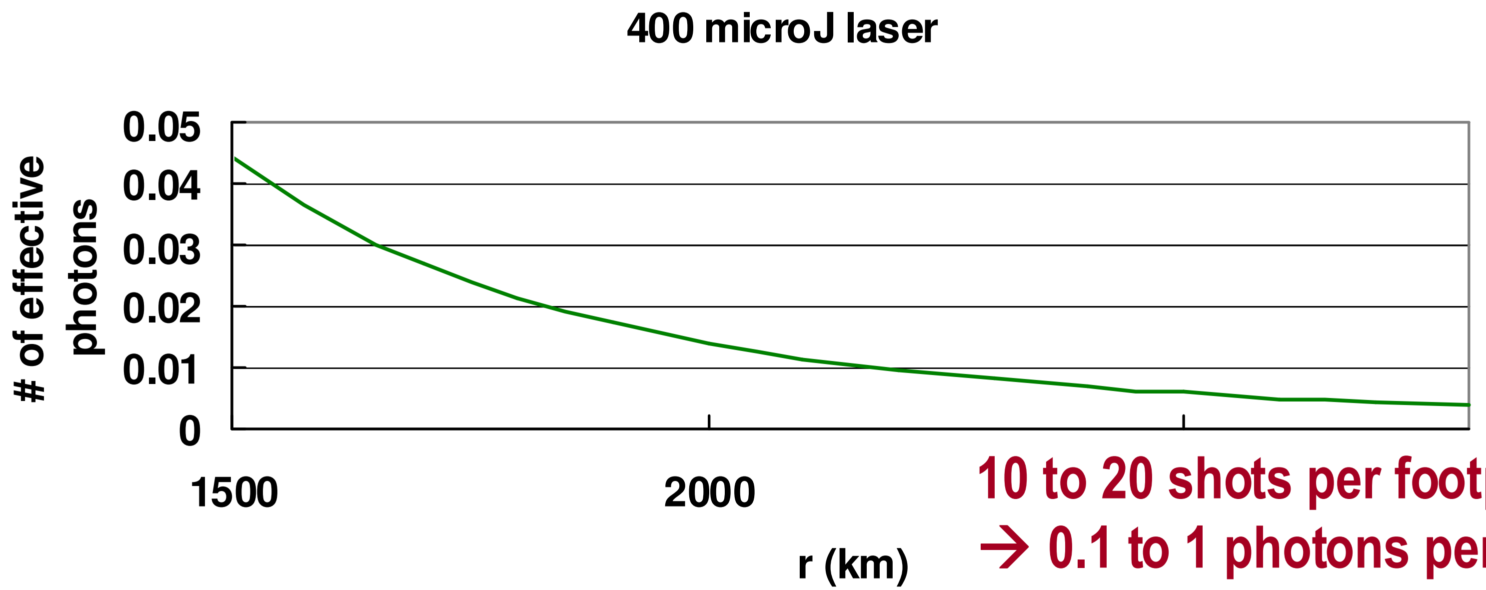


Link budget

Assume R1 = R2.

Wavelength 0.532 nm
System efficiency 0.7 x 0.1
Atmosphere 0.7 x 0.7
Beam div (radius) 5 arcsec
Ajisai mirror A = 0.38 m^2
R = 9 m





10 to 20 shots per footprint passing
→ 0.1 to 1 photons per footprint passing

Conclusions

Ajisai Time Transfer is getting more feasible now!

kHz laser: 10 to 20 shots per footprint passing

Event timer: Multiple stops

New algorithm: no need to get dual (A→B & B→A) range

But more to do, if you are interested

Time source: GPS? Linked to the national standard?

Synchronous ranging? Or, multiple range gate?

More photons: Strong laser? Higher rep rate? Any other way?

One-way system internal delay (Station A minus Station B)

Obs & studies on Ajisai's spin motion

Then, "< 100 ps accuracy" will be within sight!

Experiment Plan

Ordinary laser ranging