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
  \[ R = 8.5-9 \text{ m} \]
Experiment Plan

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

Station A

AJISAI

(reflection by mirrors)

Footprint
size: 30-60 km
passing: 5-10 ms

Station B
Formulation

\[ t_{R}(A \rightarrow B) - t_{T}(A) - t_{R}(B \rightarrow A) + t_{T}(B) \]

\[ t_{T}(A) = t_{0} - \Delta T_{A} - R_{A1}^{*} - D_{A1}^{*} + L_{A} \]

\[ = t_{0} - \Delta T_{A} + R_{A2} + (R_{A1}^{*} - R_{A1}) + D_{A2} + (D_{A1} - D_{A1}^{*}) + L_{A} \]

~ zero, or precisely modelled

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

**Inward-delay minus Outward-delay**
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).

**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.

**Link**

1 to 10 photons for a 100 mJ/pulse laser.
Dual (A→B and B→A) two-way range obs required.

kHz laser won’t miss any!
Event timer helps a lot.
0.005 ~ 0.05 photons/pulse with kHz laser
Single + SLR will do.
Experiment Plan

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

Station A

AJISAI
(reflection by mirrors)

Station B

(reflection by retros)
New idea (2006): Formulation

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

\[ \rho_{A \rightarrow B} - \rho_{B \rightarrow B} \]

\[ = t_R (A \rightarrow B) - t_T (A) - t_R (B \rightarrow B) + t_T (B) \]

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

~ 3 to 5 cm (radial) accuracy from POD

Difference (A-B) of outward delay
How to find the “signal”

Assume synchronous laser.
Assume $R_1 = R_2$.

- **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  
\[ \Rightarrow \text{0.1 to 1 photons per footprint passing} \]
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

(reflection by retros)

Station A

AJISAI

Station B