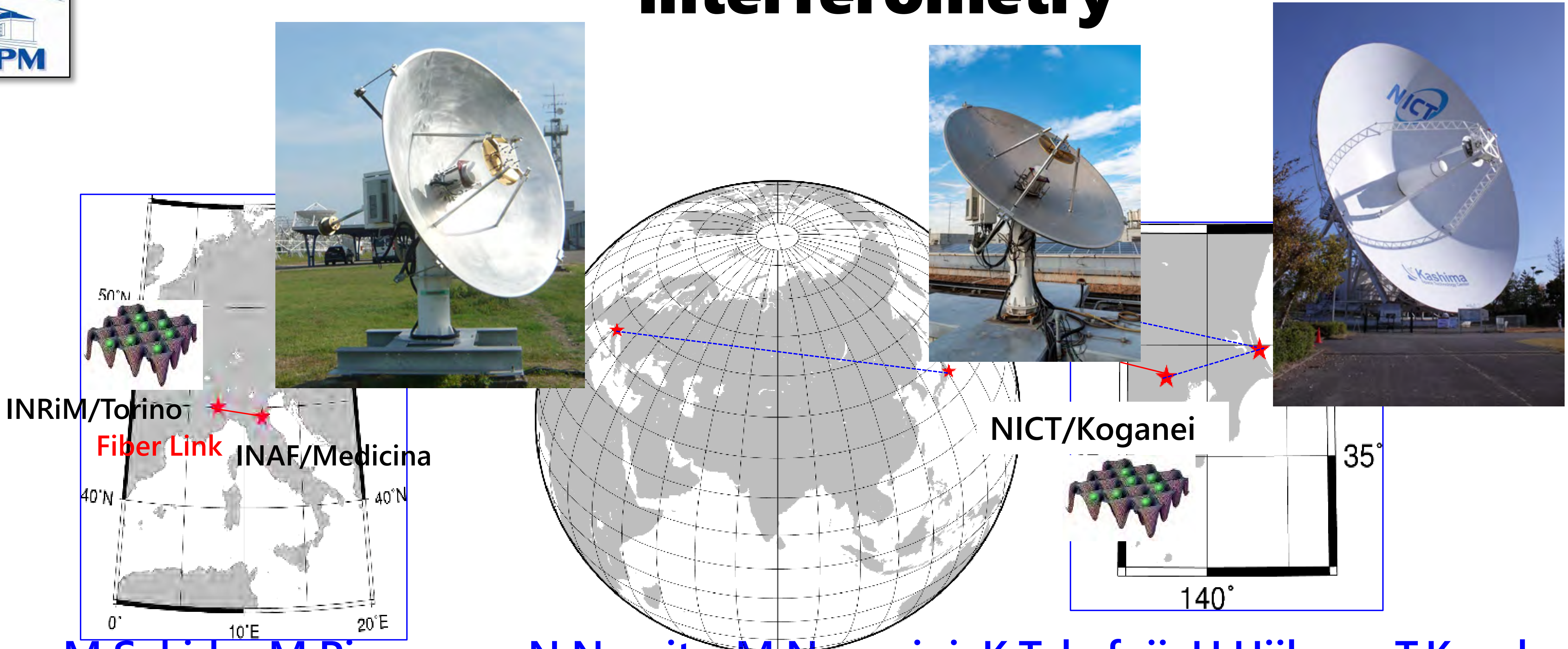
ATF 11 Nov. 2021

Intercontinental frequency link via broadband very long baseline interferometry



M.Sekido, M.Pizzocaro, N.Nemitz, M.Negusini, K.Takefuji, H.Ujihara, T.Kondo, C.Clivati, F.Perini, H.Hidekazu, J.Leute, G.Petit, Davide Calonico, Tetsuya Ido

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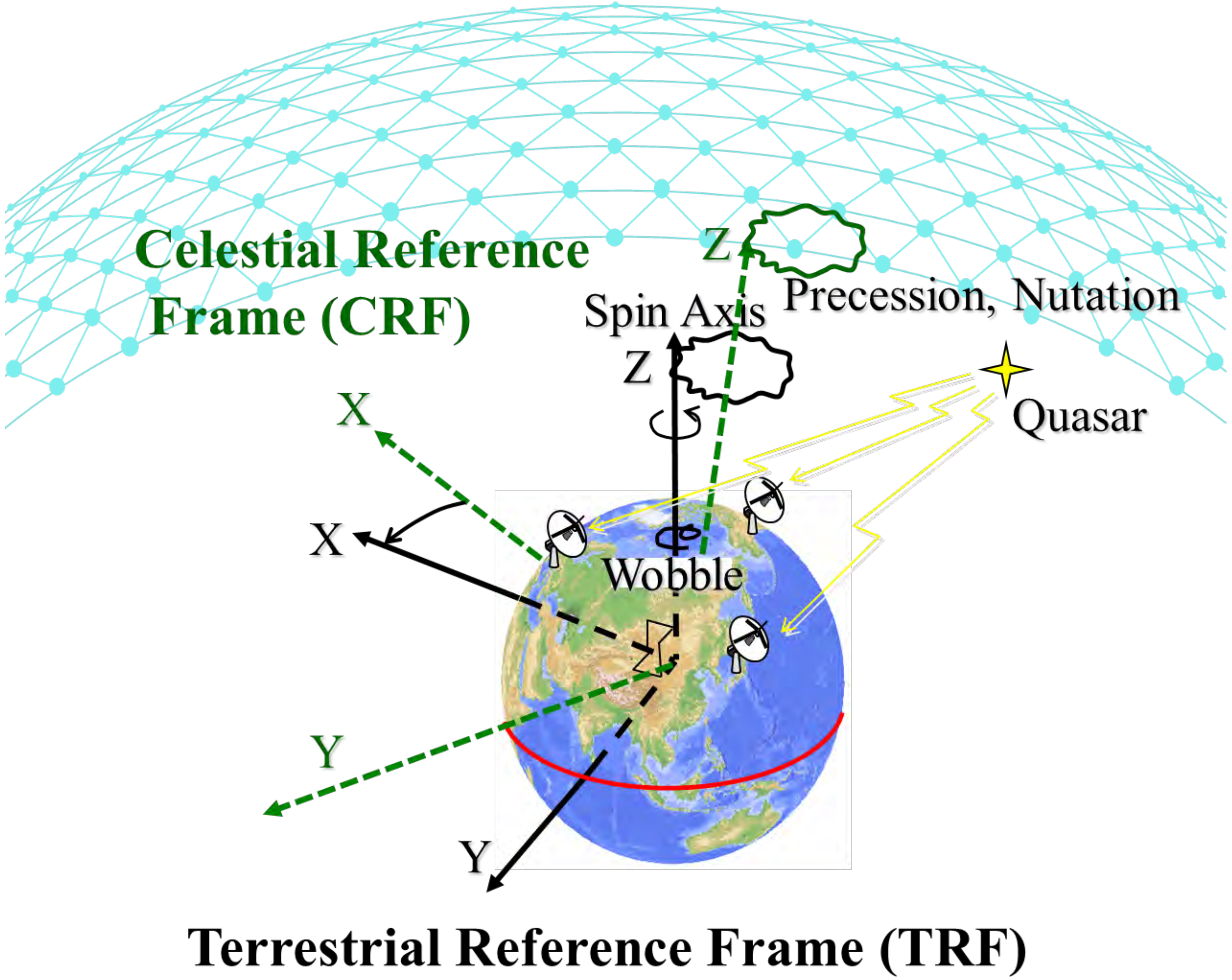
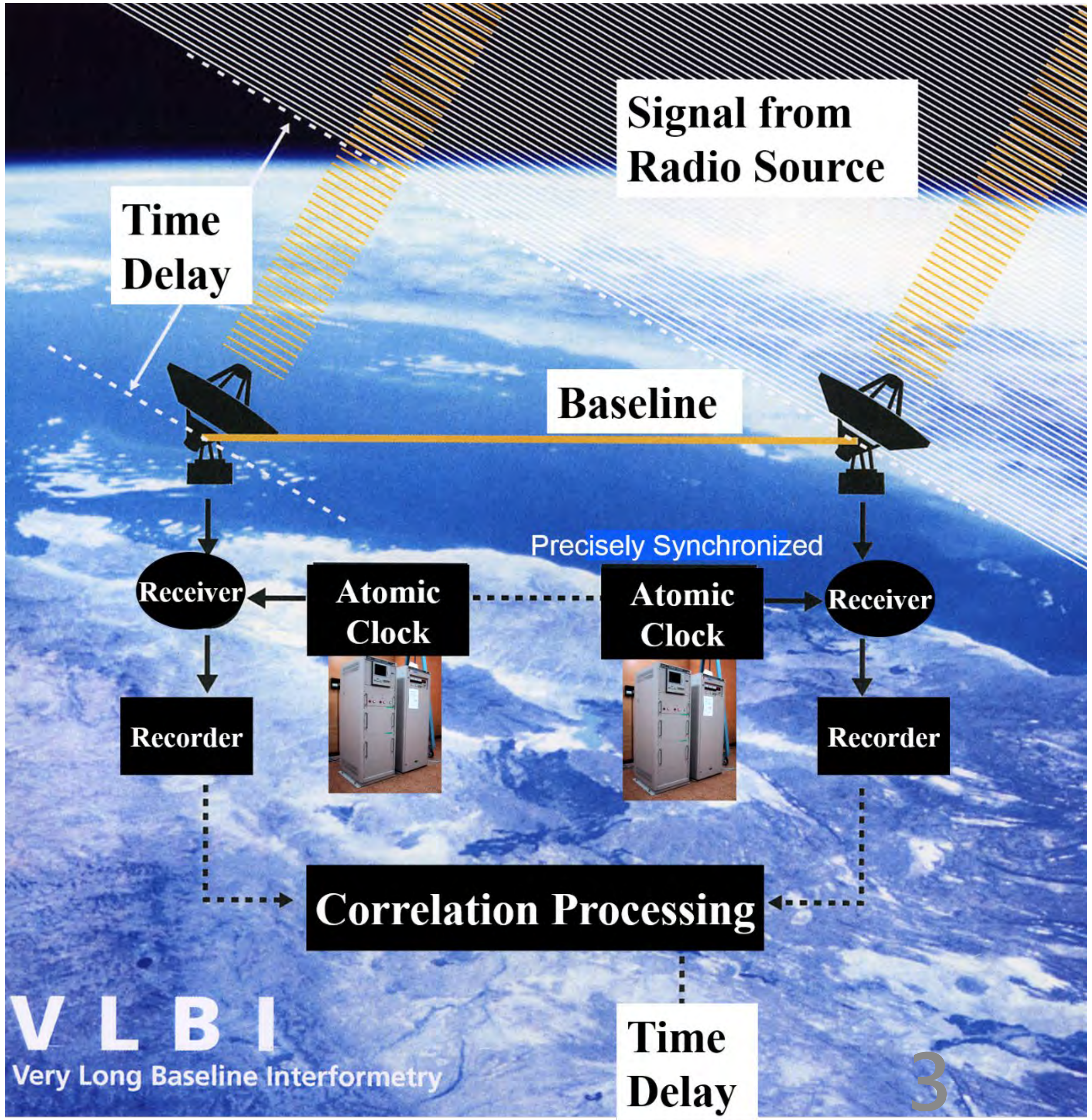
What is VLBI(Very Long Baseline Interferometry)

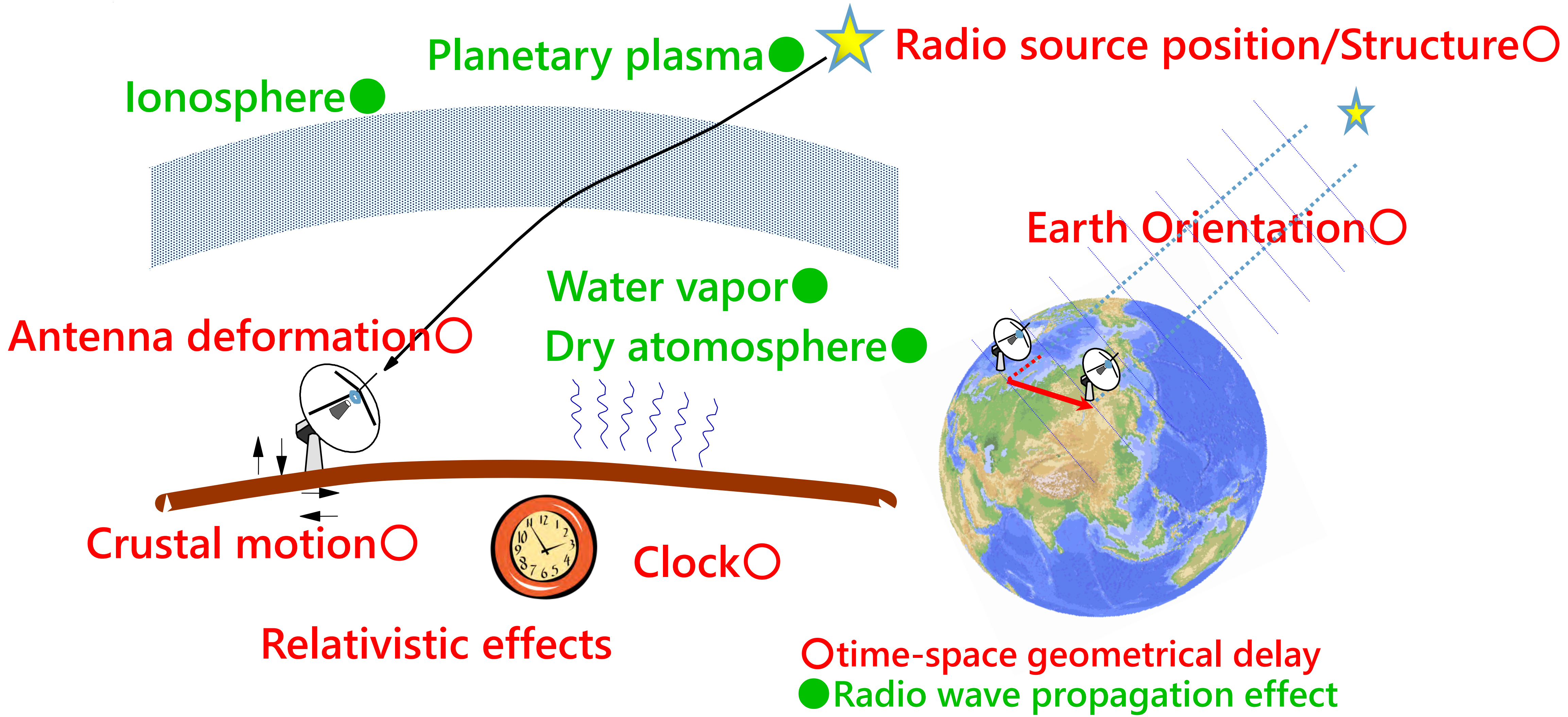




Coordinate system is stable
Radio source positions are fixed.
→ Advantages in long term stability

Various physical effects contributing to VLBI delay observable

$$\tau_{obs} = \tau_{geo} + \tau_{atm} + \tau_{ion} + \tau_{clock} + \tau_{inst}$$

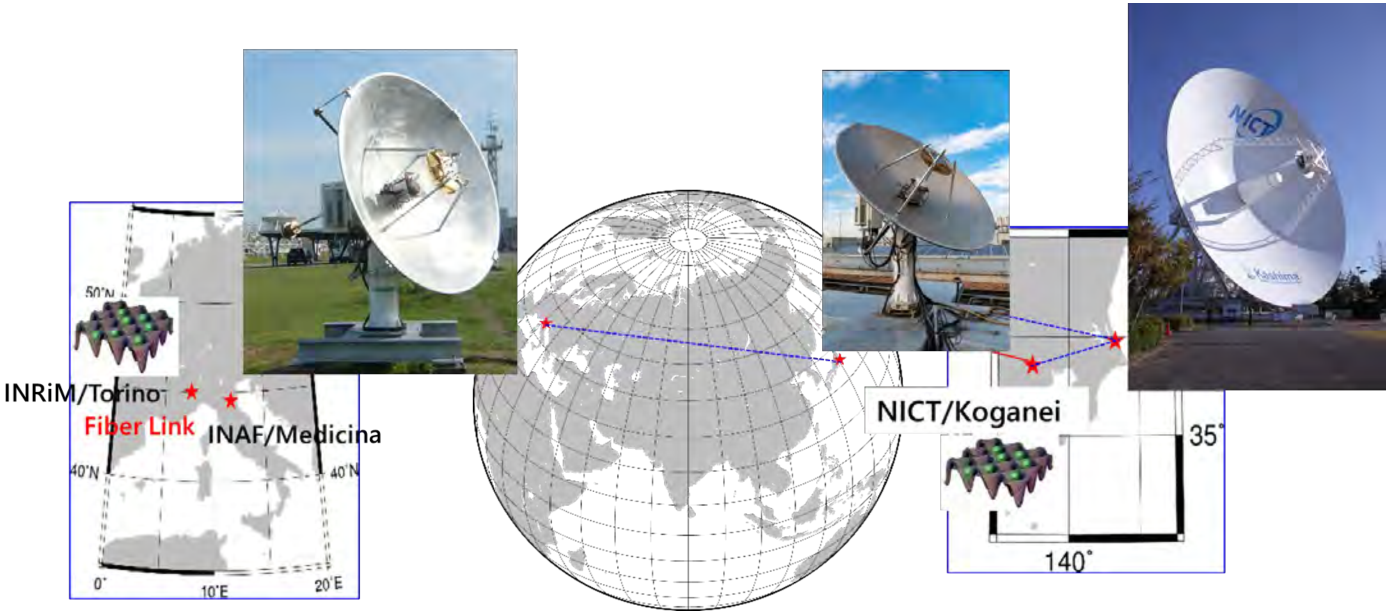


Frequency Link by VLBI Observation

$$\tau_{obs} = \tau_{geo} + \tau_{atm} + \tau_{ion} + \tau_{clock} + \tau_{inst}$$

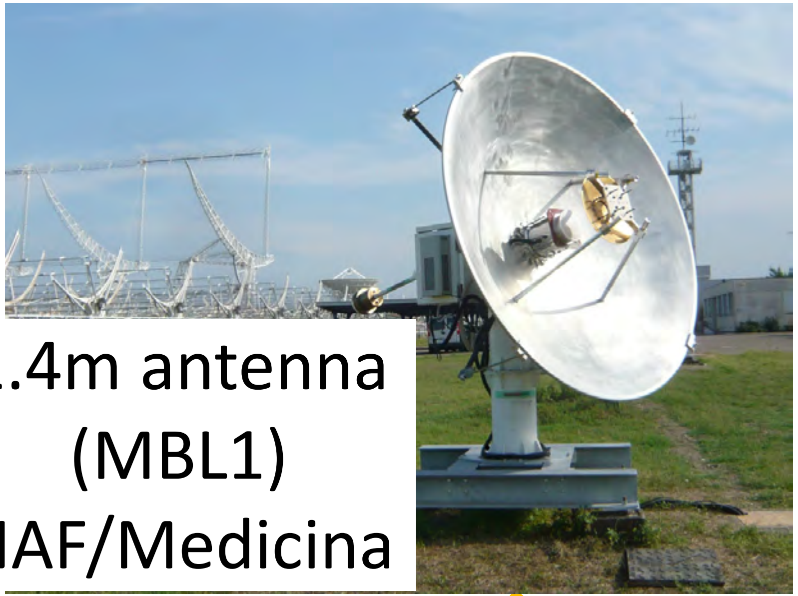
- Single delay data is derived from single scan. A scan is observation of a radio source for a short time (10 sec. – a few min.).
- Observing radio sources is switched from scan to scan.
- Switching radio sources between scan to scan is preferred as quick as possible. That is for estimate τ_{atm} by using Elevation dependency.
- Single VLBI session last for 24 - 40 hours.
- Single VLBI session contains 300-1500 scans, and are analyzed to estimate target parameters by least-square analysis.
- Parameters: station coordinaets(X,Y,Z), τ_{clock}, τ_{atm}, … are estimated.

These VLBI observation procedure is common for geodesy and frequency transfer.

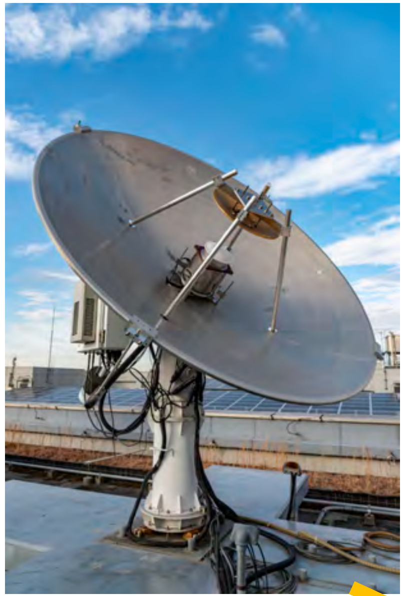


2. Intercontinental Frequency : INRiM(IT)–NICT(JP)

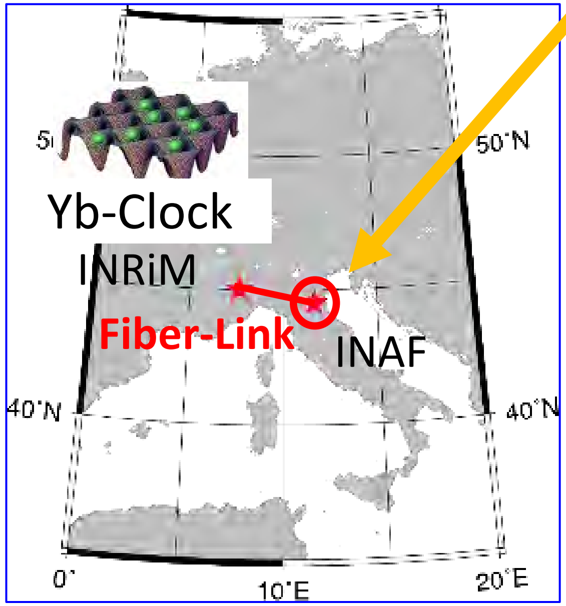
Three Broadband VLBI Stations



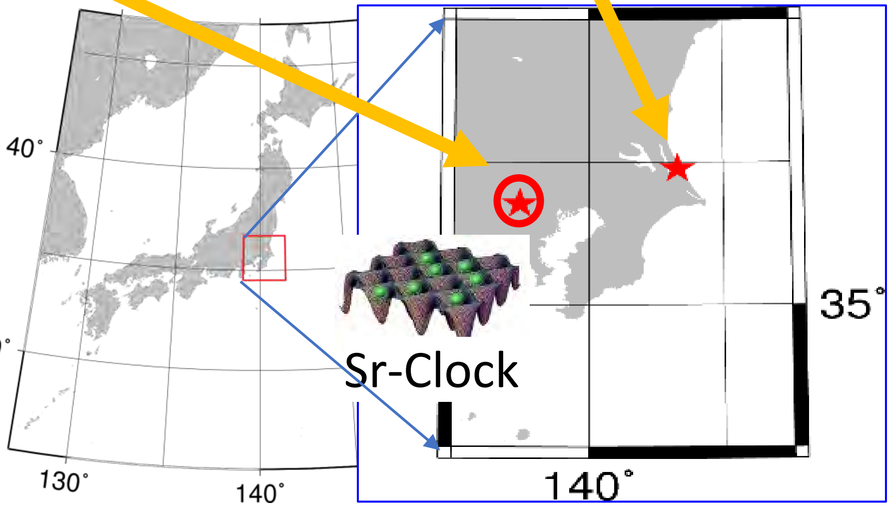
2.4m antenna
(MBL1)
INAF/Medicina



34m Diameter
(Kashima34)
NICT/Kashima

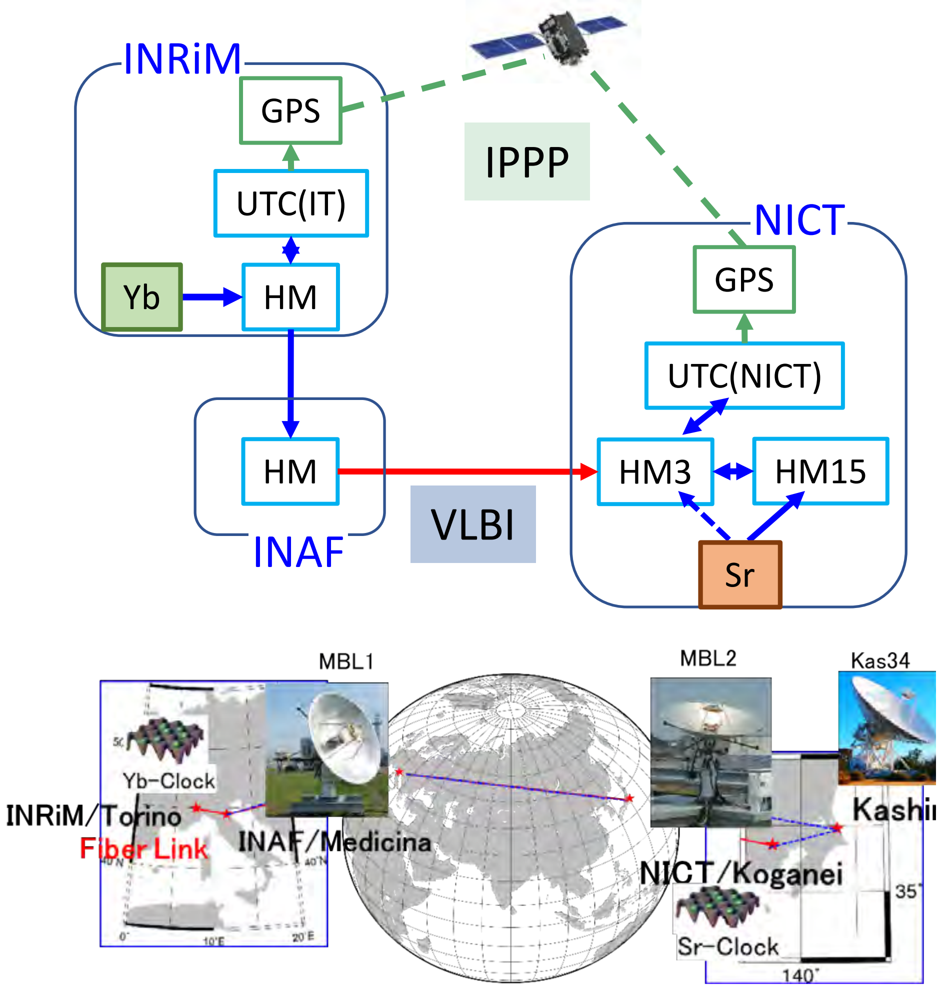


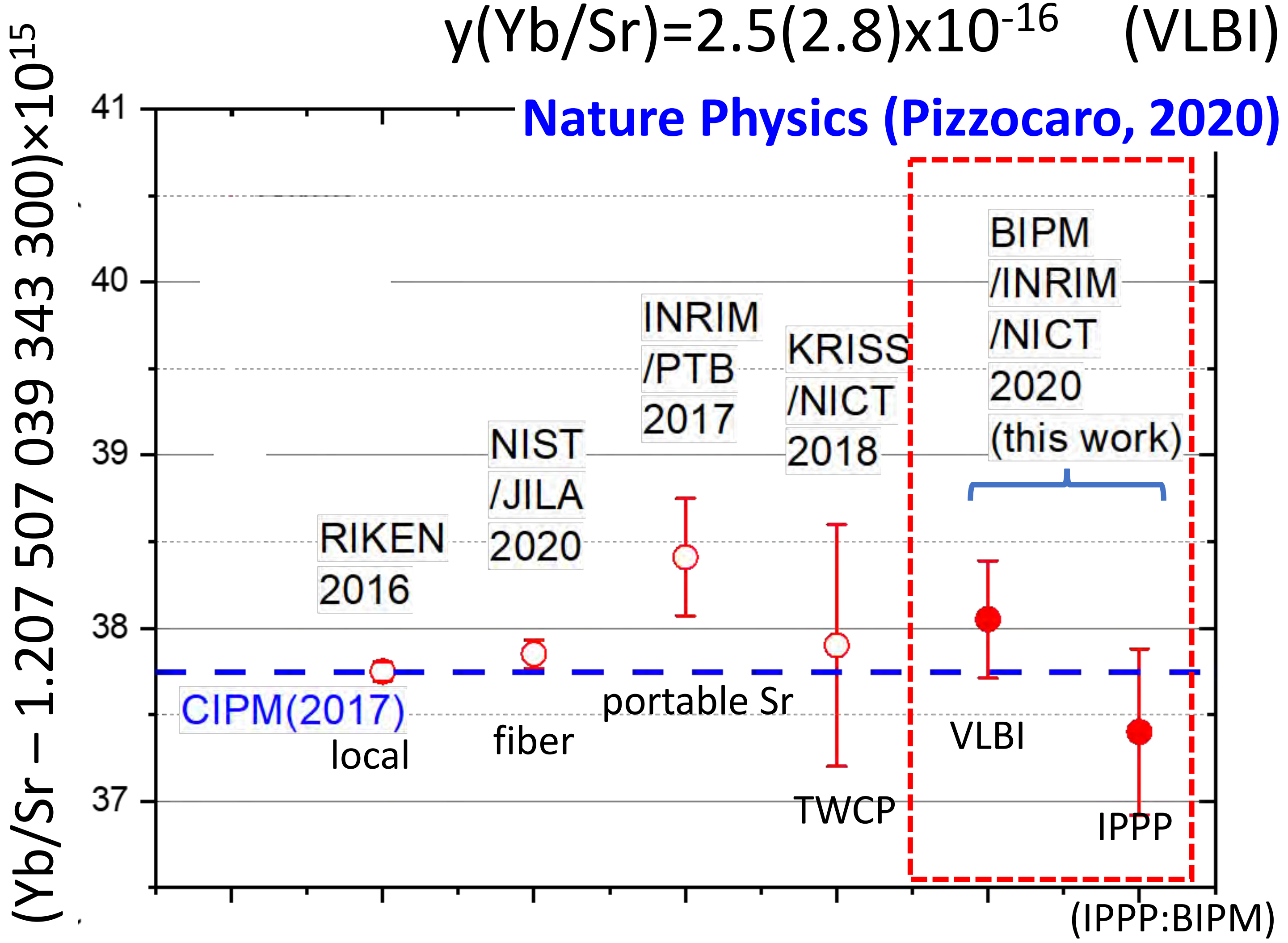
2.4m antenna
(MBL2)
NICT/Koganei



Yb/Sr Freq. Link: Comparison

Best precision for 9000 km distance





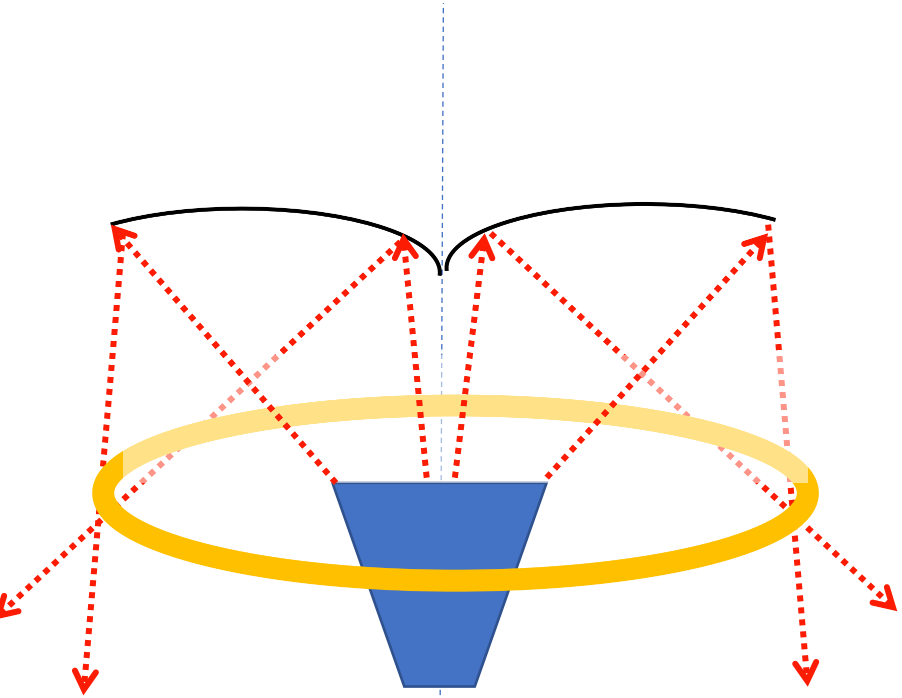
3. What's new in our VLBI

-Difference from conventional VLBI-

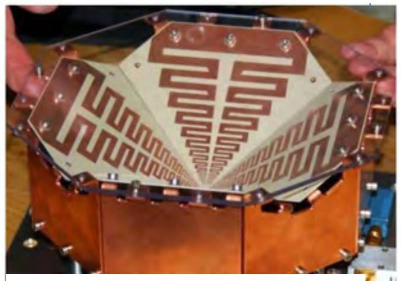
• Transportable small VLBI station	:	Portability, cost
• Broadband VLBI	:	Sensitivity improvement
	:	Improving delay precision
• Direct Sampling/Digital Filter	:	Improved stability
• Node-Hub style VLBI	:	Reduced uncertainty.

Reason why NICT Developed own Broadband Feeds

Requirement of **Broadband Frequency** and **Narrow beam width**

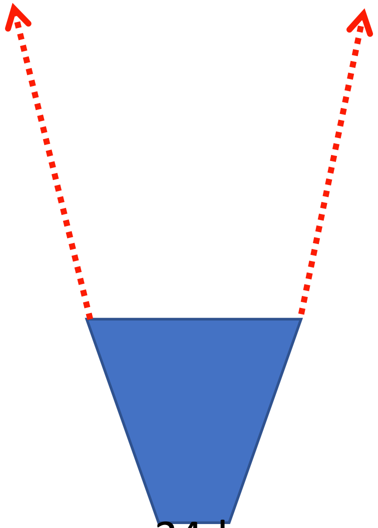


～120deg.

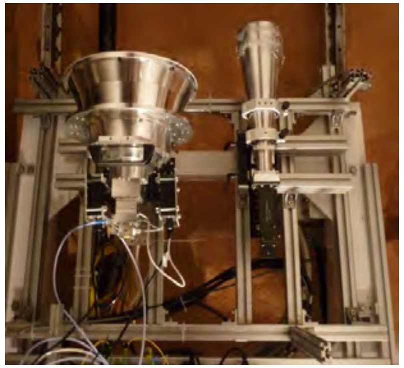


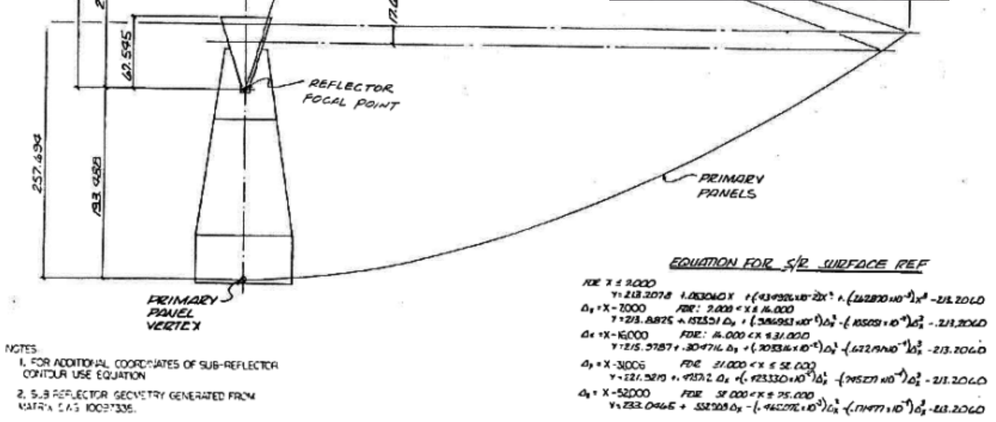
Eleven Feed

QRFH



～34deg.



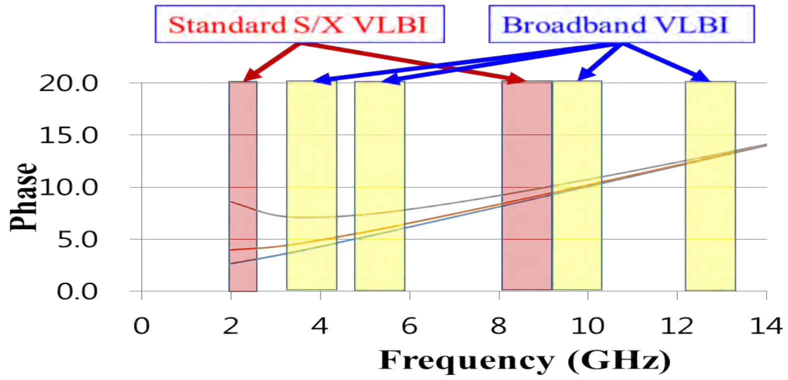


Broadband Feed and RF-Direct Sampling

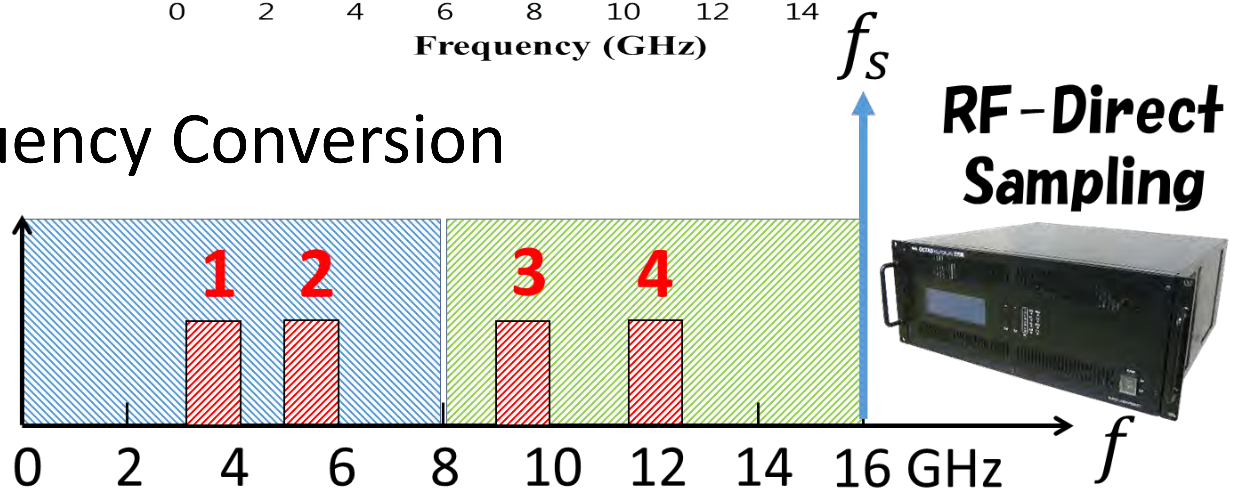
- Broadband VLBI, 3-14 GHz range

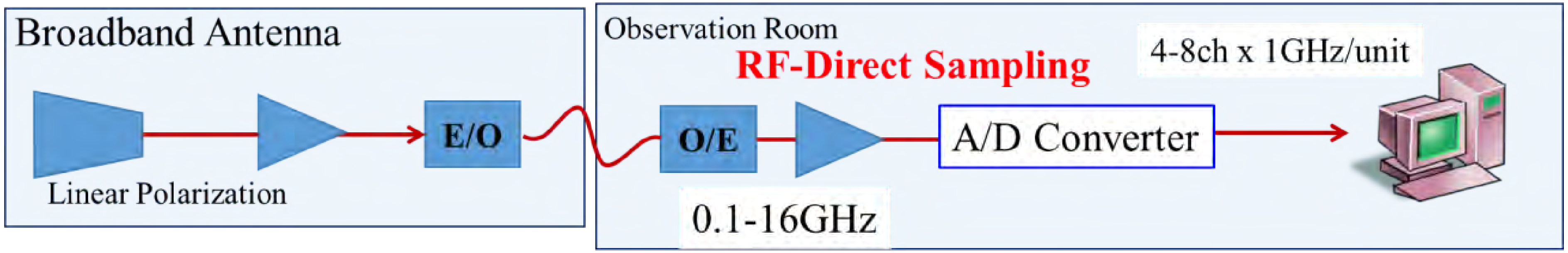
  One order large bandwidth

  → one order fine delay precision.



- **RF Direct Sampling**
  - Digitized without analog Frequency Conversion
  - Advantage at Phase stability

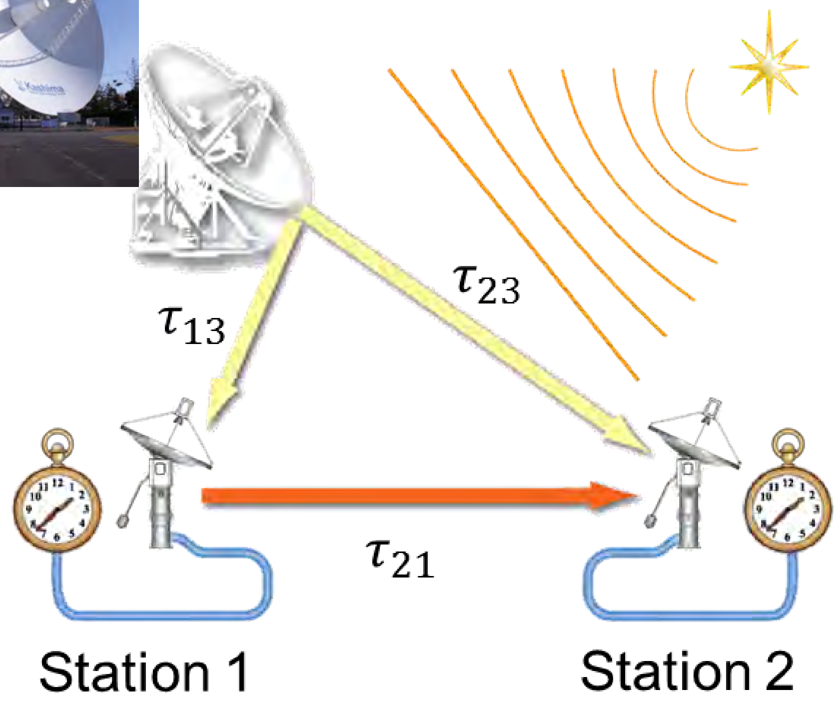




Node-Hub Style VLBI (using closure delay)

■**Boosting SNR:**

Poor SNR between small antenna pair is recovered by joint observation with high gain antenna.



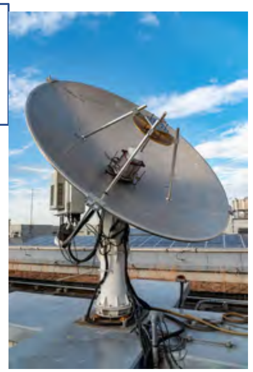
$$\mathrm{SNR} \propto S\, D_1 D_2 \sqrt{\frac{\eta_1}{T_{sys1}} \cdot \frac{\eta_2}{T_{sys2}} \cdot S_r}$$

D_n : Diameter
S : Radio Flux
η_n : Efficiency
T_{sys}: System noise.
S_r : Sampling rate

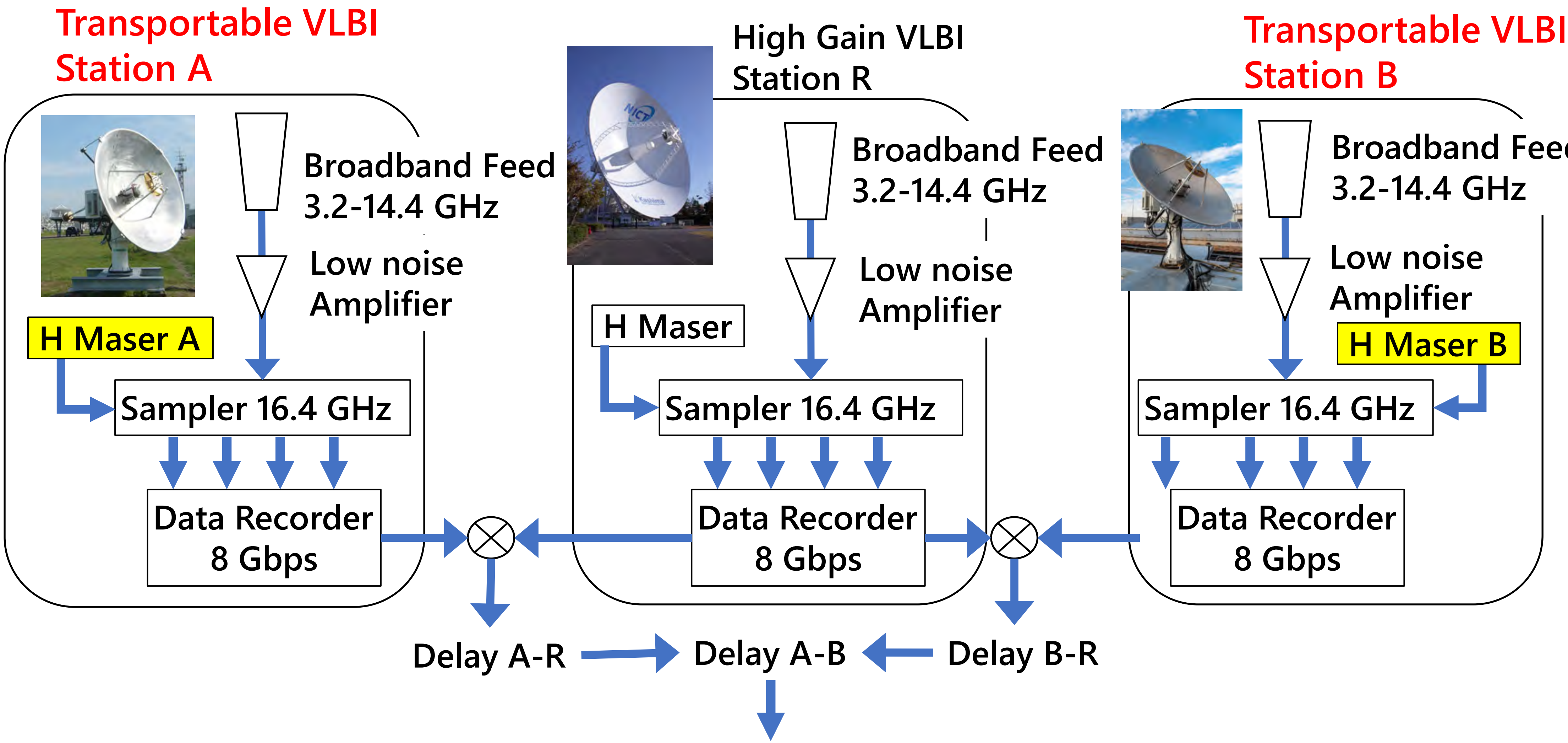
■**Cancel effect:** Large station(Gravitational Deformation, Cable delay)

■**Easy deployment**(Small antenna):
low-cost, transportable

$$\boldsymbol{\tau_{21} = \tau_{13} - \tau_{23}}$$



Node-Hub Style VLBI: Similarity with DMTD (Dual mixer time difference)



Clock difference between H maser A and B

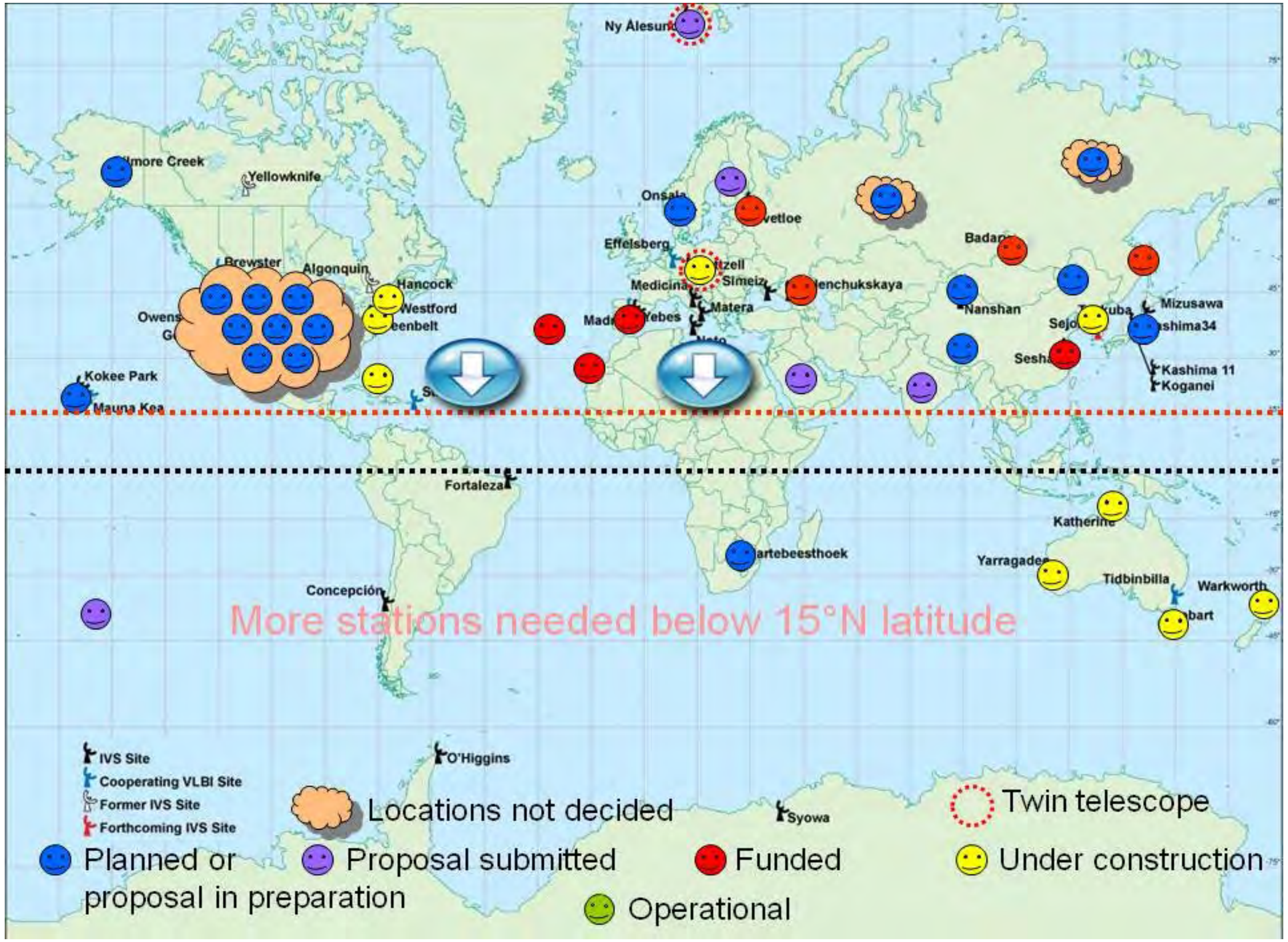
4. Prospect for future

VGOS(VLBI Global Observing System) of the IVS

International VLBI Service for geodesy and astrometry (IVS) is promoting new VGOS network for 1mm precision in geodesy.

- 13m diameter antenna
- broadband observation (2-14 GHz)

Ishioka 13m diameter antenna (GSI Japan)



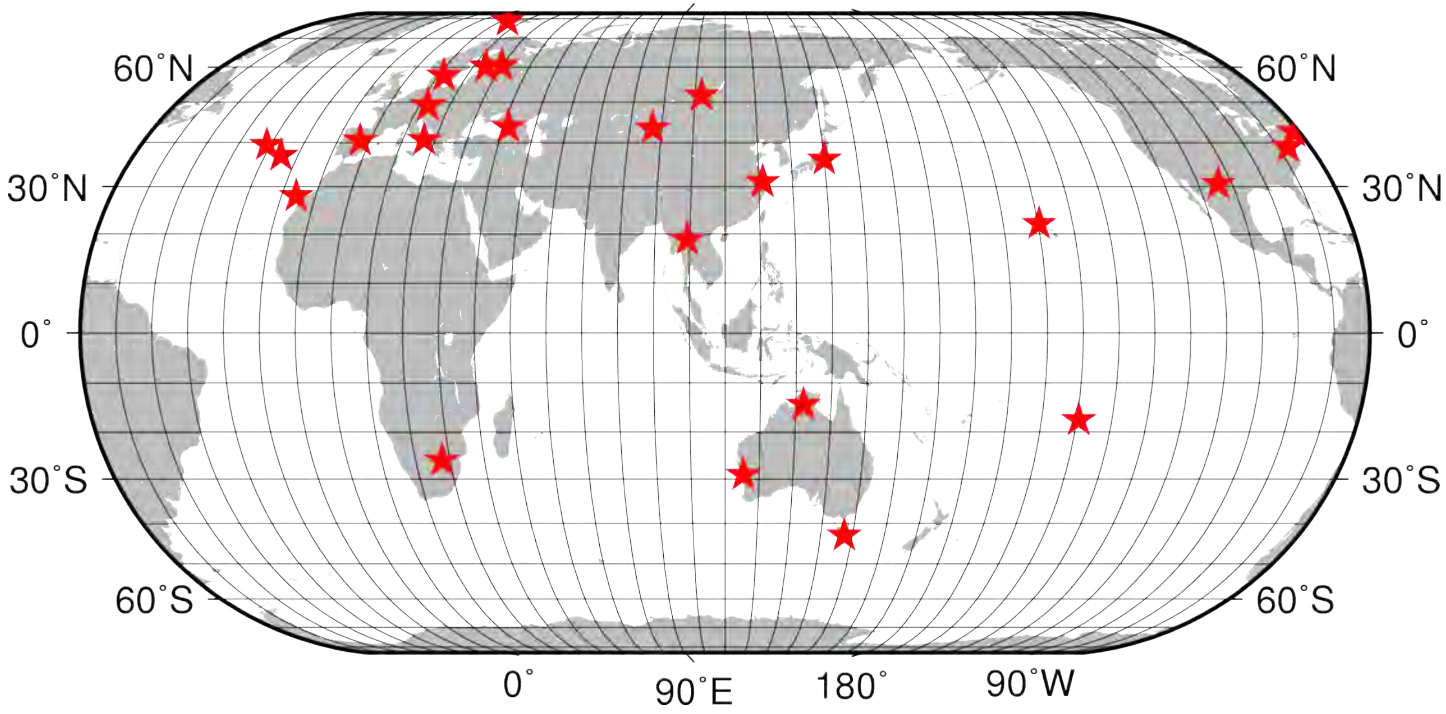
IVS/VGOS stations in Asia-Oseania Region

- There are multiple broadband VLBI stations in the Asia-Oseania region including in state under development.
- High speed network will be necessary for quick data transfer for correlation processing.
- Collaboration between IVS and between metrology community will be a key to enable global frequency link by using VLBI.

Kokee park in Hawaii

Shanghai (China)

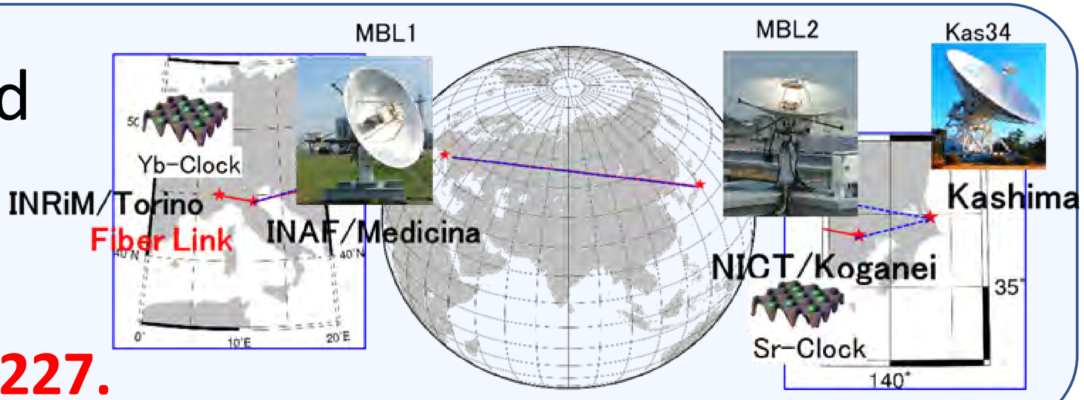
Ishioka (Japan)



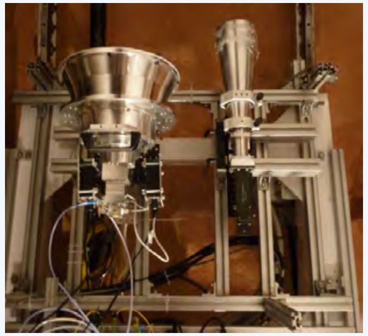
Summary

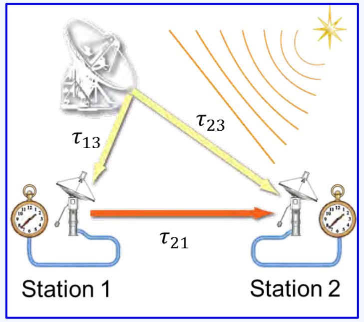
Freq. ratio Yb/Sr optical clocks was measured as $+2.5(2.8)\times10^{-16}$ on 9000 km distance.

For detail of VLBI frequency link:
Pizzocaro M. et al., (2021) Nature physics, 17(2):223-227.



Development: Broadband VLBI system(Feed, RF Direct-Sampling) and transportable VLBI with Node-Hub Style scheme.





For technical details:
Sekido, M., et al., (2021) Journal of Geodesy, 95 (41).

Thank you for your Attention

Acknowledgements

- A.Tampellini of INRiM, Y.Miyauchi, S.Hasegwa, H.Ishijima of NICT, T.Suzuyama, K.Watabe of NMIJ, Y.Fukuzaki, T.Wakasugi, S.Kurihara, Y.Umei, H.Ueshiba, S.Matsumoto of GSI for contribution to this work.
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- VLBI observation is supported by analysis software **Calc/Solve**, antenna control software **Field System9**, and scheduling software **Sked**, all developed by NASA/GSFC.