# Proposal for participation in the ACES mission with a fixed MWL ground terminal at KRISS


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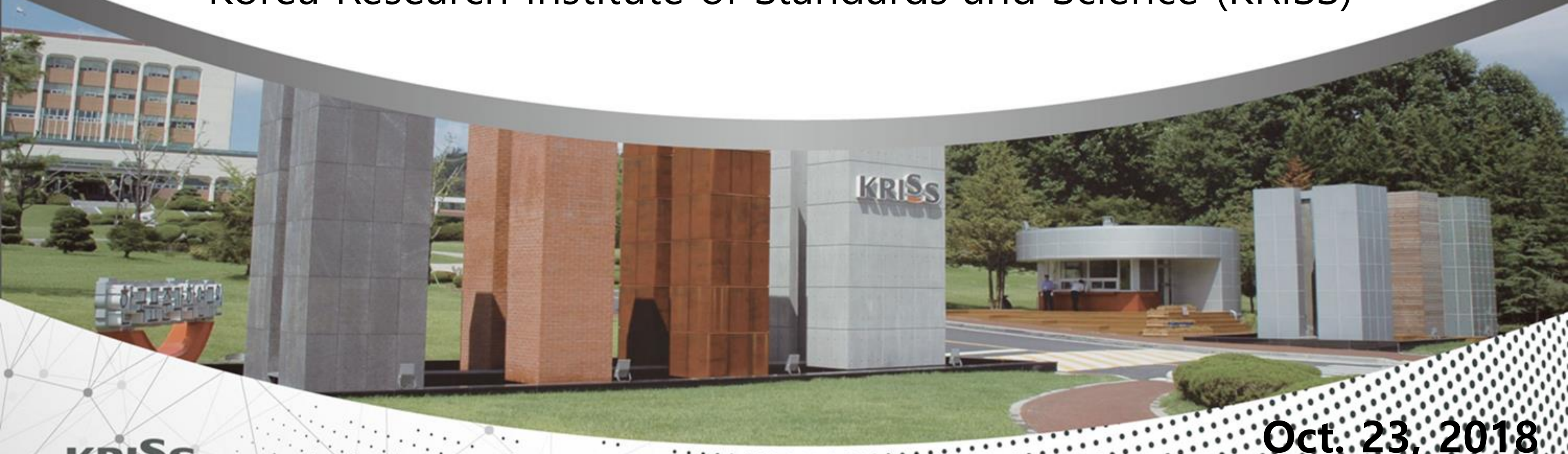
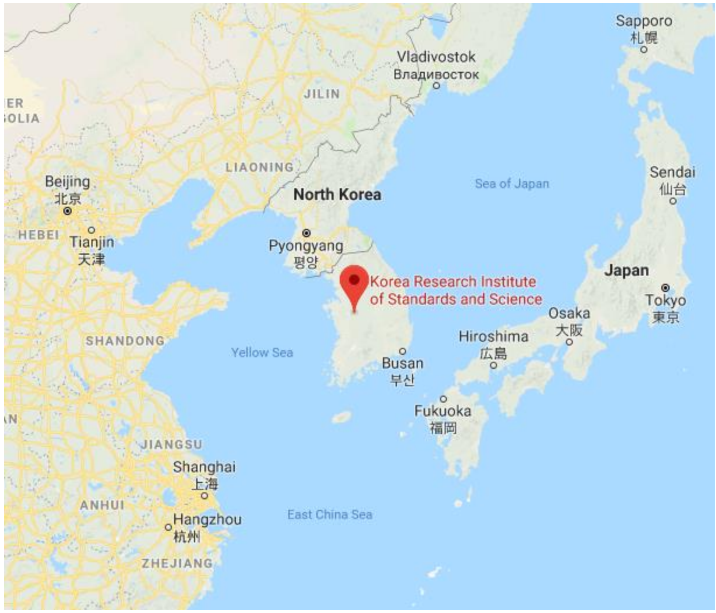


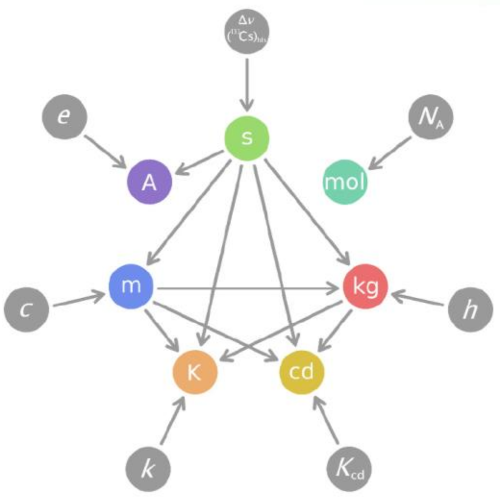

**Oct. 23, 2018**

**ACES Workshop 2018, - München**

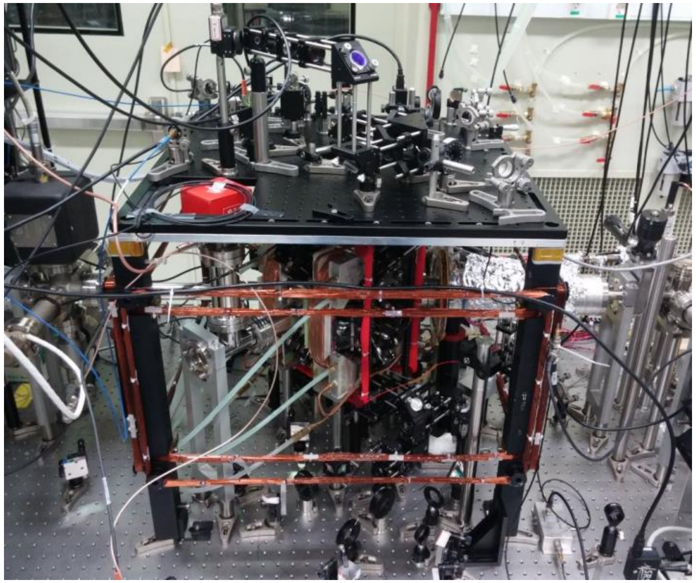
# Introduction to KRISS

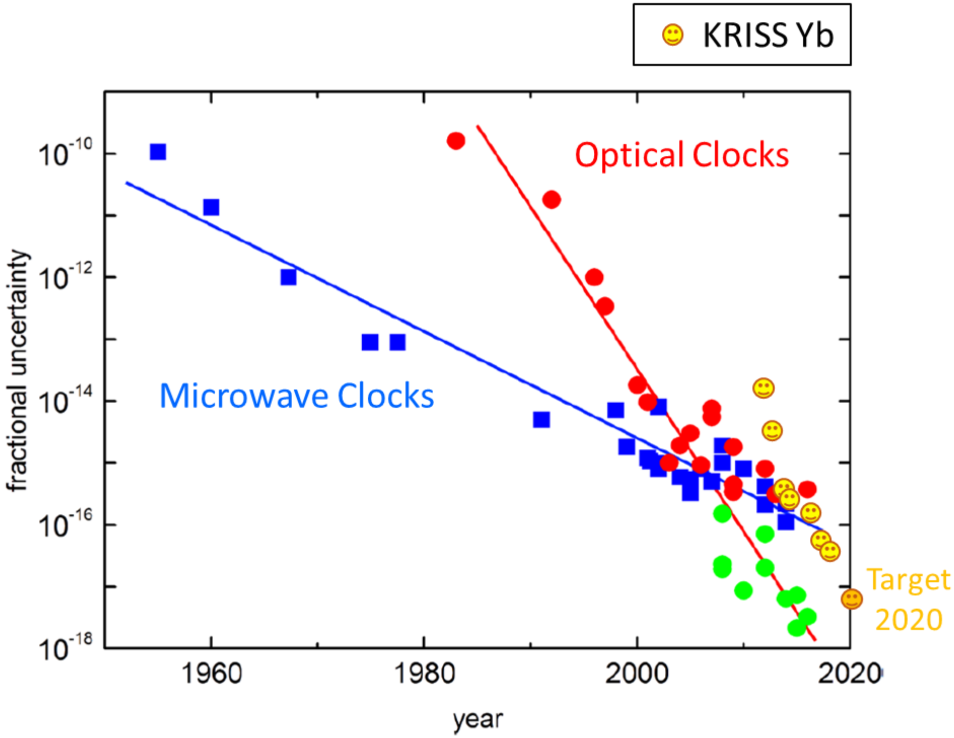



- Korea Research Institute of Standards and Science
- Located in Daejeon.
- National Metrology Institute representing the Republic of Korea.
- KRISS provides internationally recognized national measurement standards to its customers in various industries.



# KRISS Yb optical lattice clocks






Ref. Metrologia 55, 188 (2018)

- Redefinition of the SI second is expected in 2026 or 2030.
- KRISS is developing two Yb optical lattice clocks (Yb1, Yb2).
- The current total systematic uncertainty of Yb1 is $5.6\times10^{-17}$.
- Yb2 is under development with an aimed systematic uncertainty of $8\times10^{-18}$ in 2020 by tackling the blackbody radiation frequency shift.

# History of KRISS Yb optical lattice clocks

2003; Start of Yb project, Blue MOT.
2007~8; Green MOT.
2008~9; Trapping in an optical lattice
2011; first uncertainty evaluation
and absolute frequency measurement
2016; improved uncertainty evaluation.
2017; Yb(KRISS)/Sr(NICT) TWCP comparison.

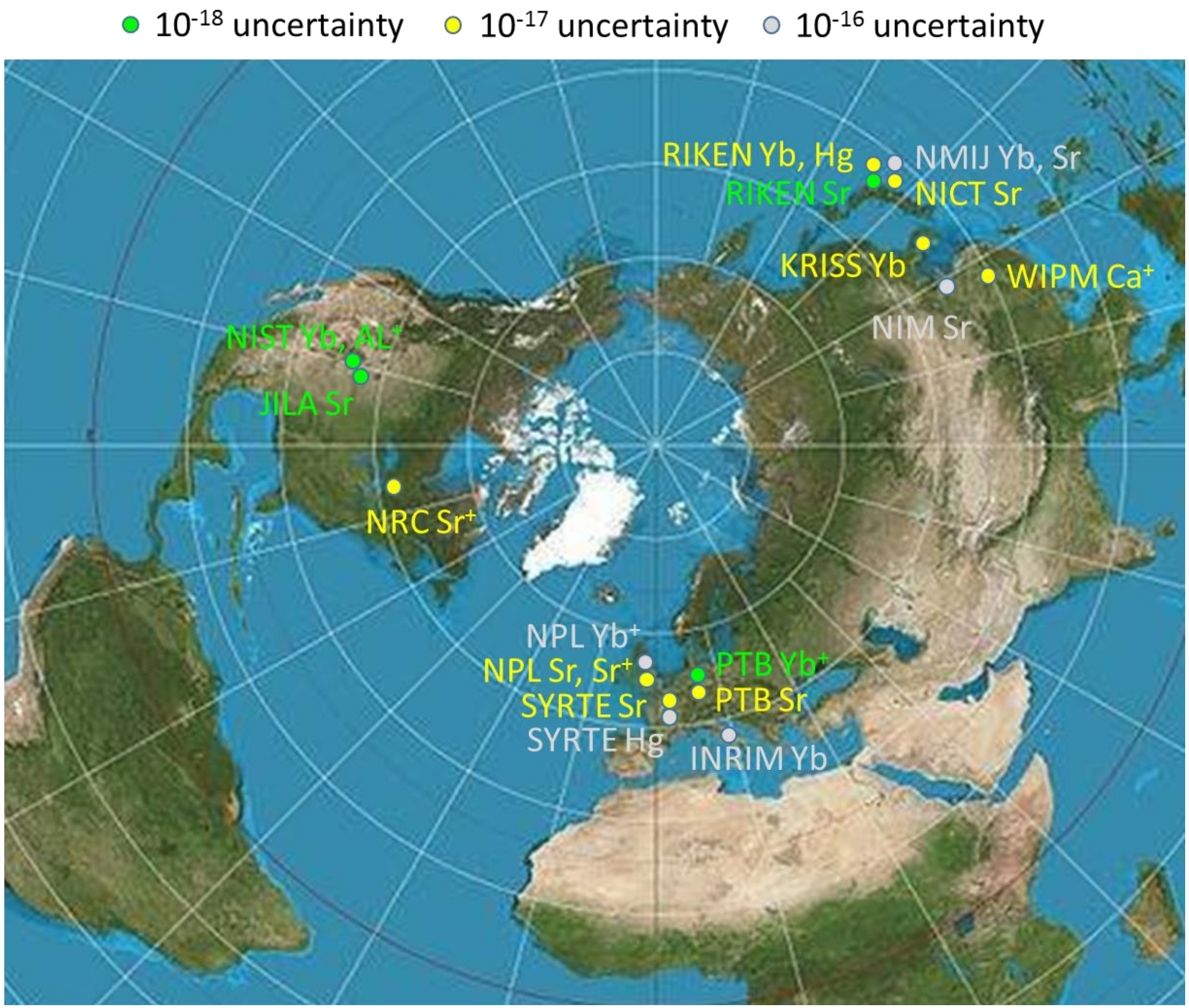
<Selected references>
[1] C. Y. Park et al., Metrologia, 50, 119 (2013).
[2] S. Lee et al., New J. Phys. 18, 033030 (2016).
[3] D.-H. Yu et al., J. Kor. Phys. Soc. 63, 883 (2013).
[4] H. Kim et al., Jpn. J. Appl. Phys. 56, 050302 (2017).
[5] M. Fujieda et al., IEEE Trans. Ultrason. Ferroelectr. Freq. Control., 65 ,973 (2018)

Coefficients by KRISS | Coefficients by other groups

$\times 10^{-16}$

| Effect | 2011 | 2012 | 2013 | 2014 | 2015 | 2016.12 | 2017.12 | 2018. 10. |
|---|---|---|---|---|---|---|---|---|
| Lattice light (scalar) | 141 | 2 | 2 | 2.0 | | 0.40 | 0.38 | 0.38 |
| Nonlinear lattice shift or hyperpolarizability | 0.8 | 0.8 | 0.8 | 0.2 | | 0.36 | 0.36 | 0.36 |
| Density shift | 52 | 52 | 3.9 | 0.29 | | 0.41 | 0.41 | 0.09 |
| Blackbody radiation | 4 | 6 | 0.7 | 0.7 | | 0.56 | 0.48 | 0.18 |
| Second-order Zeeman | 4 | 4 | 0.2 | 0.2 | | 1.46 | 0.02 | 0.02 |
| Probe light | | | 0.6 | 0.1 | | 0.04 | 0.04 | 0.04 |
| AOM phase chirp | | | | | | 0.03 | 0.03 | 0.03 |
| Servo error | | | 0.5 | 0.5 | | 0.67 | 0.08 | 0.08 |
| Static Stark shift | | | | | | 0.10 | 0.10 | 0.10 |
| Yb total | 150 | 53 | 4.9 | 2.9 | | 1.83 | 0.83 | 0.56 |

# Worldwide Distribution of Optical Clocks




Methods for Frequency comparison of optical clocks

1. Optical fiber $<10^{-18}$ (only In Europe)
2. Transportable $7\times10^{-17}$ (not fully developed)
3. Frequency ratio btw different clocks
4. Conventional satellite $>10^{-16}$ (insufficient)

KRISS

# Comparisons of Ground Clocks by ACES

- common view and non-common view comparisons of ground clocks with $10^{-17}$ frequency resolution after few days of integration time.



- Error < 0.3 ps over 300 s

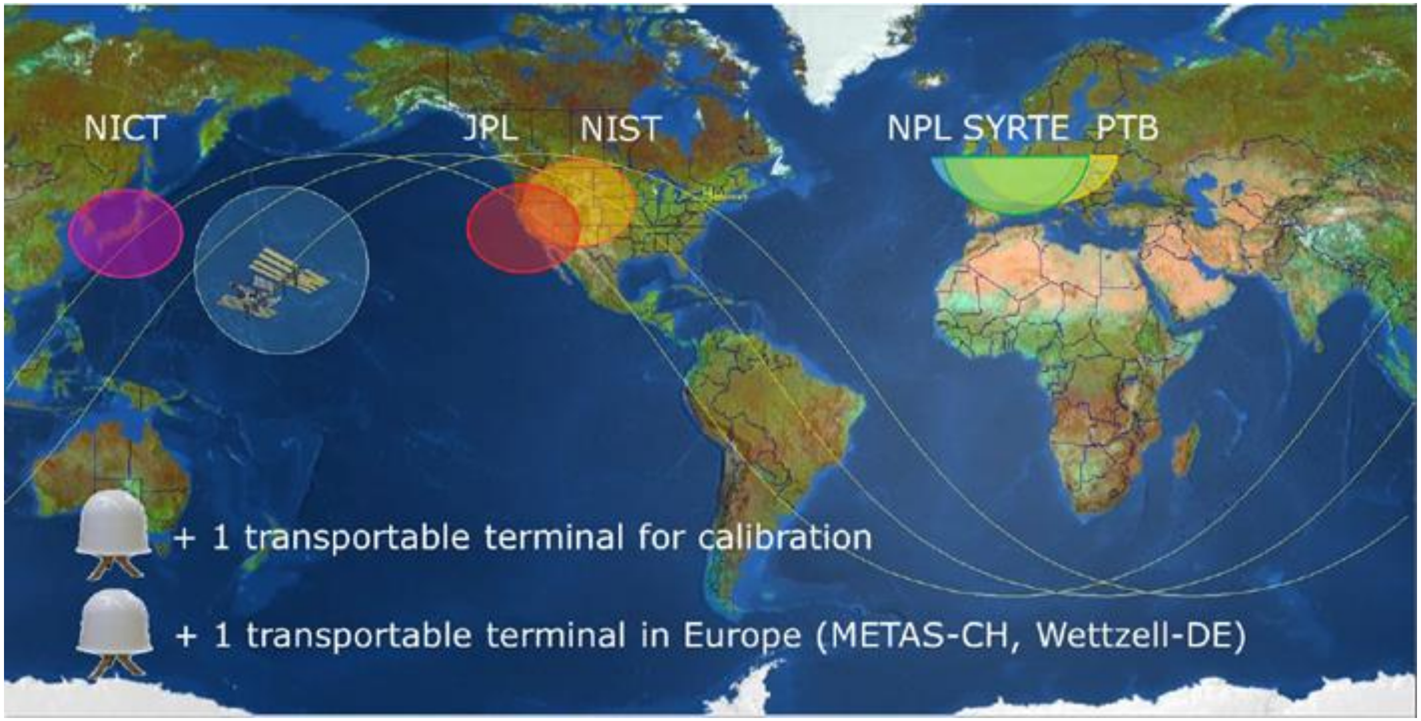
- Intercontinental comparison
- Error < 3 ps over 3000 s
- $10^{-17}$ Frequency comparison over 4~5 days

Ref. C. Salomon, ACES Workshop 2017

# MWL Ground Terminals


- 60 cm offset reflector antenna with a dual-band feed system automatically pointed in azimuth and elevation by a steering mechanism
- Protective radome cover (temperature stabilized by by an air conditioning system)
- Remotely controlled by the ACES MCC - steering unit based on ISS orbit prediction files, collects telemetry and science data both from the local clock and the MWL GT electronics

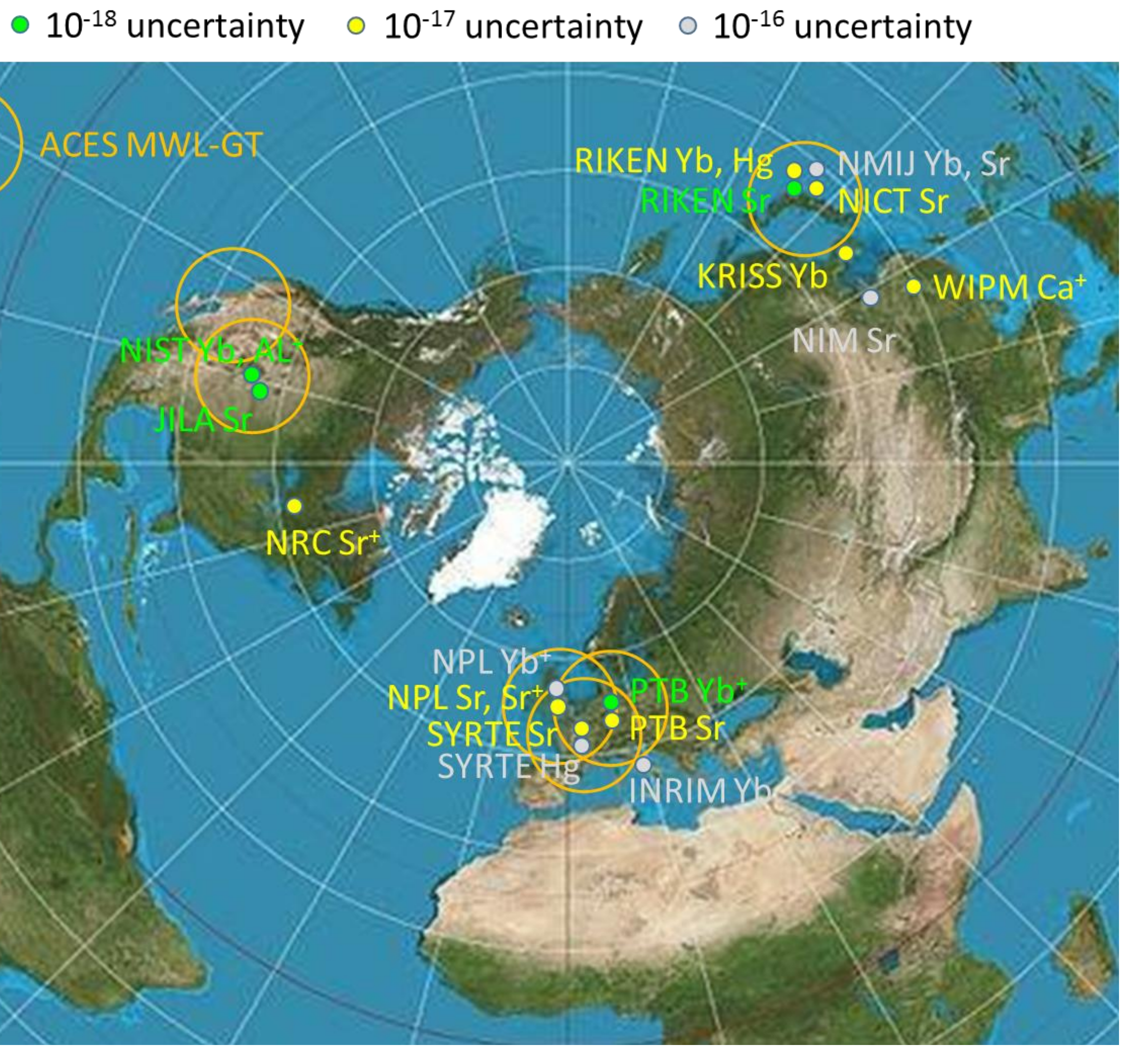
# Institutes Currently Hosting WML-GT




- Six fixed units; two in the US (JPL, NIST), three in Europe (SYRTE(FR), PTB(DE), NPL(UK)), and one in Asia (NICT(Japan)).
- One transportable MWL station in Europe; shared by other institutes, including the Wettzell geodetic observatory (Wettzell, DE), METAS (Bern, CH), and INRIM (Torino, IT).
- A second transportable station; dedicated to the calibration of MWL fixed terminals for time transfer experiments and for comparisons with the laser link ELT.


Ref. L. Cacciapuoti, ACES Workshop 2017

# Comparisons of Ground Clocks by ACES

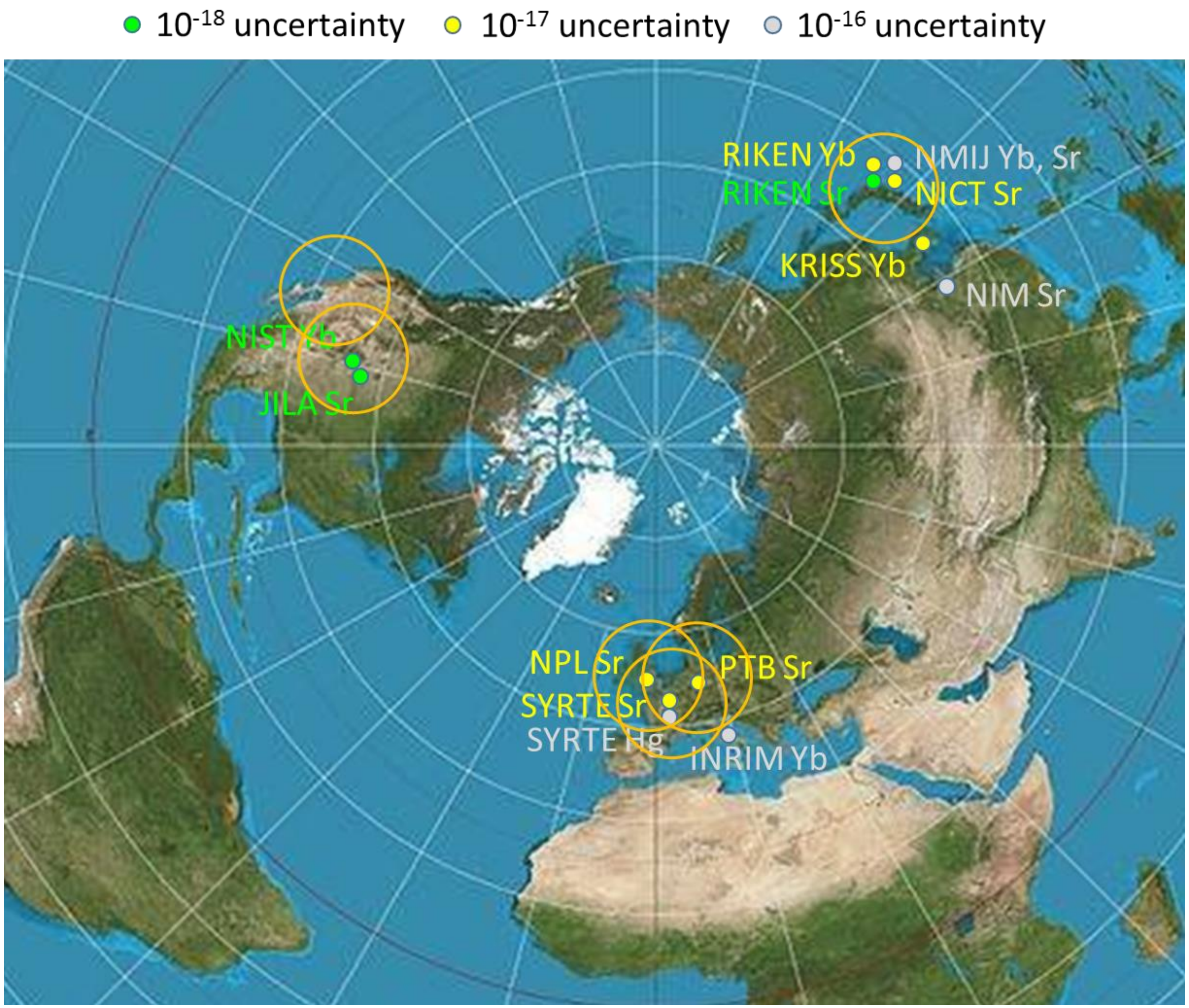



Methods for Frequency comparison of optical clocks

1. Optical fiber <$10^{-18}$ (only In Europe)
2. Transportable $7 \times 10^{-17}$ (not fully developed)
3. Local Frequency ratio btw different clocks
4. Conventional satellite >$10^{-16}$ (insufficient)
5. Frequency comparison by ACES; $10^{-17}$

KRISS

# Worldwide Distribution of Optical Lattice Clocks



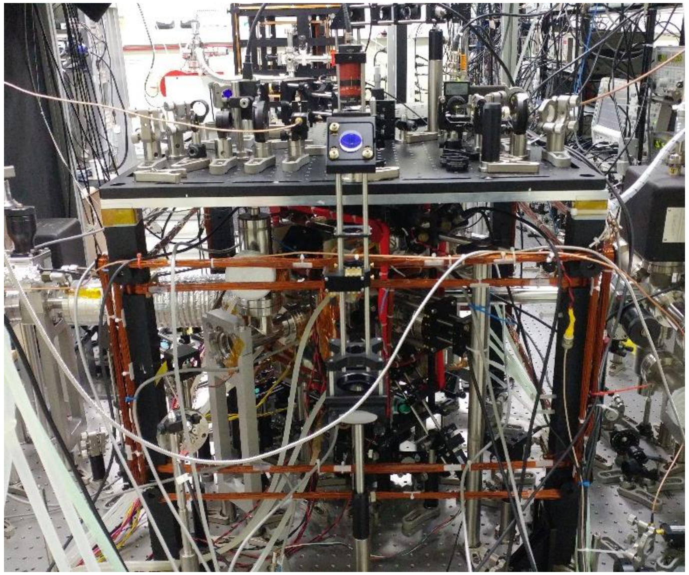

Optical lattice clocks have advantages, such as

1. Better stability
2. Popularity

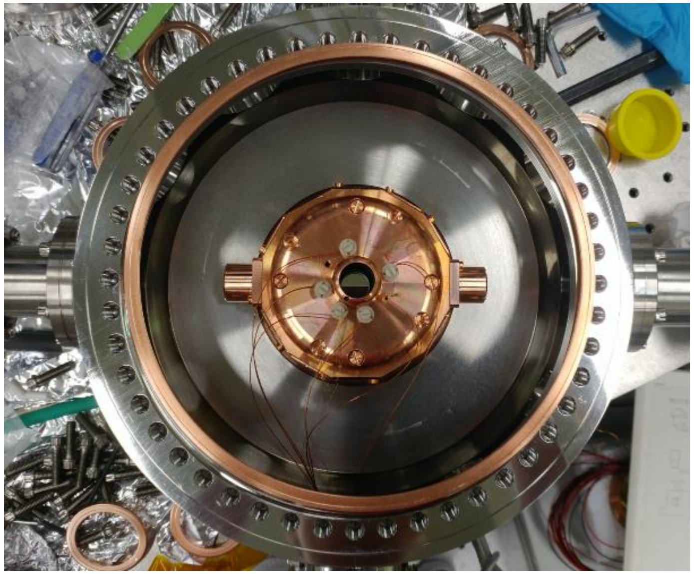
KRISS Yb OLC can be a good candidate for a better clock comparison.

# KRISS Yb optical lattice clock

## Yb1

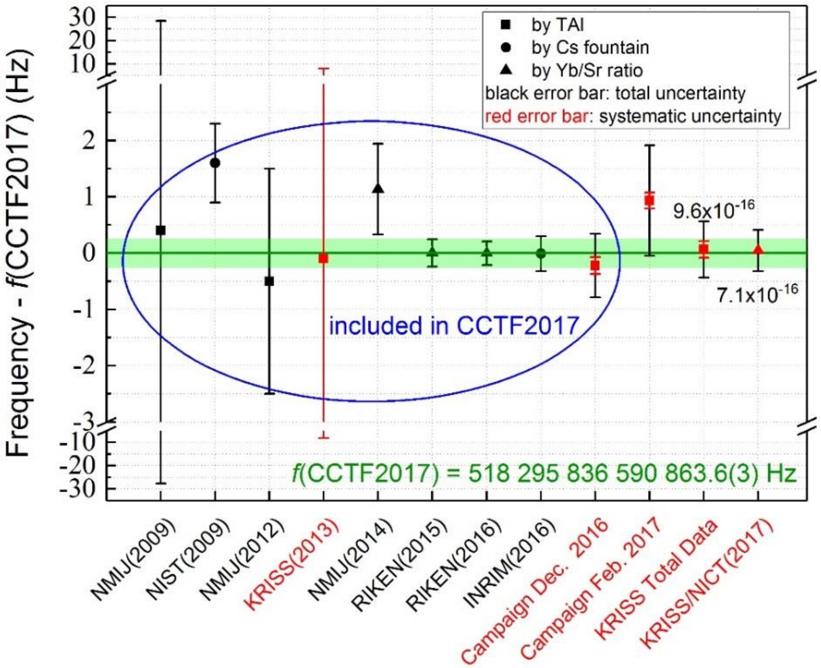


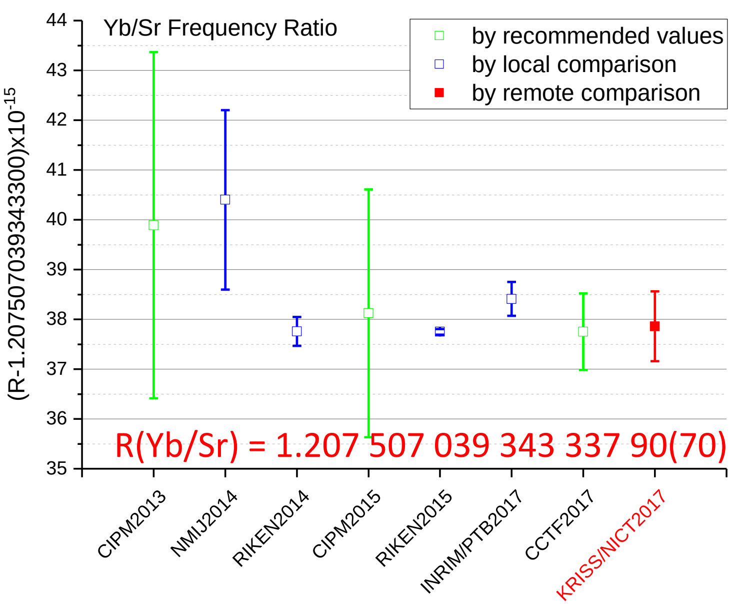
## Yb2



- Current KRISS Yb OLC uncertainty; $5.6 \times 10^{-17}$ (third-best for Yb after NIST and RIKEN). More than 1-day-long continuous clock operation is expected. (good availability for comparison)
- Expected KRISS Yb OLC uncertainty in 2020; $8 \times 10^{-18}$ (excellent for ACES)
- Expected absolute frequency measurement; $2.4 \times 10^{-16}$ (world best for Yb)

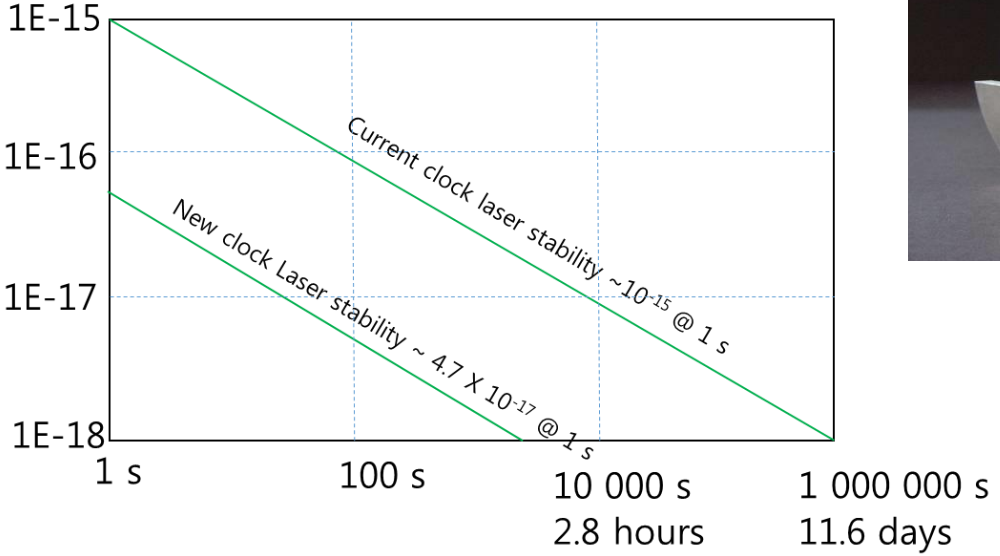
# Absolute frequency and ratio measurement

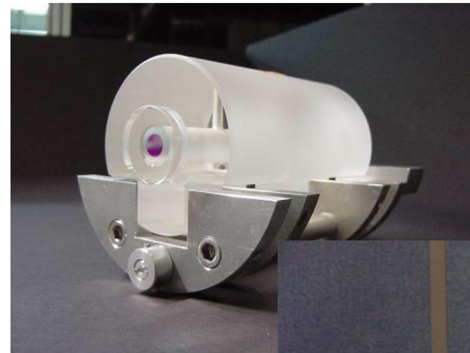


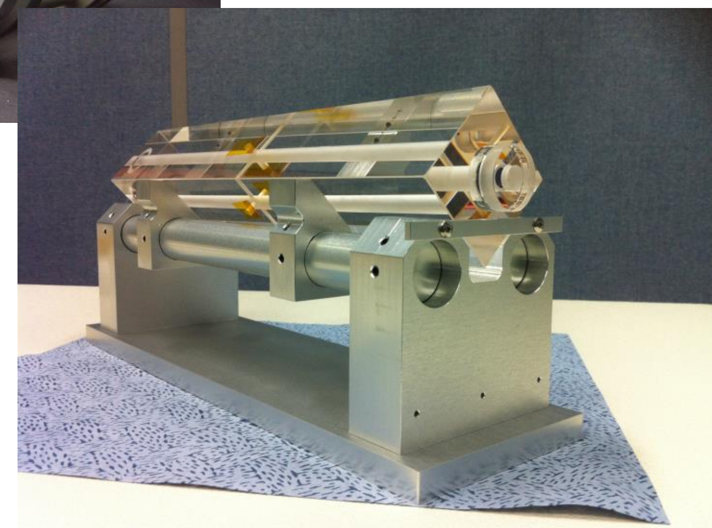




- Absolute frequency measurement using TAI with an uncertainty of $9.6 \times 10^{-16}$ ; contributed to the new CCTF recommendation of Yb frequency (CCTF2017).
- Absolute frequency measurement using KRISS Cs fountain clock is scheduled with an expected uncertainty of $2.4 \times 10^{-16}$.
- Yb(KRISS)/Sr(NICT) frequency ratio has been measured using a satellite (TWCP method) with an uncertainty of $5.8 \times 10^{-16}$.

# New clock laser system at KRISS





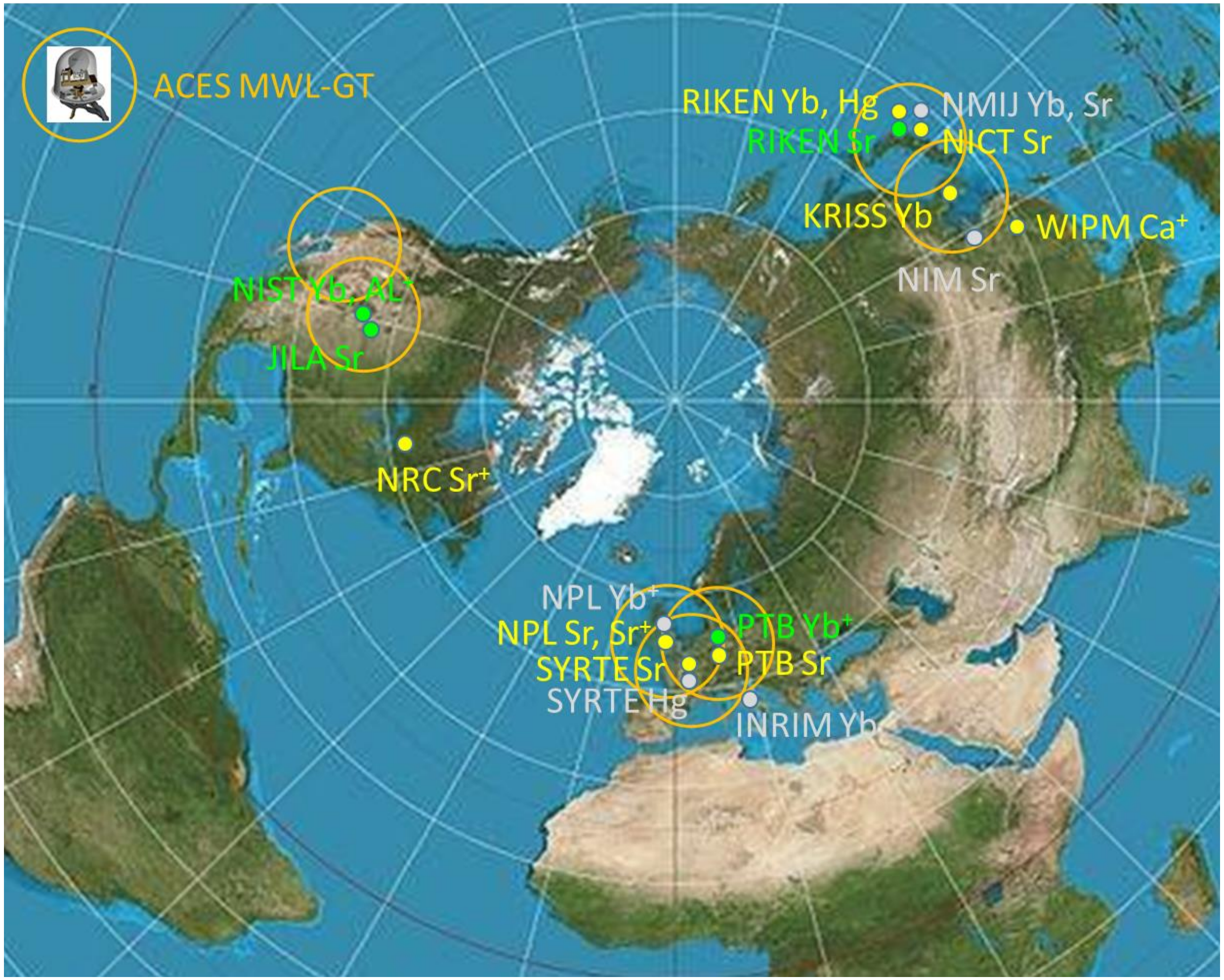
- 300-mm-long ULE cavity.
- Fused silica substrates with ULE compensation rings.
- 1156.8 nm crystalline mirror coatings.
- Overall thermal limit is expected to be $4.3\times10^{-17}$ ($3.5\times10^{-17}$ from the spacer, $8.5\times10^{-18}$ from the substrates, and $2.3\times10^{-17}$ from the mirror coatings).
- Systematic uncertainty evaluation at $10^{-18}$ level will be possible within 10,000 s.

# Development of KRISS Cs Fountain Clock

- During the past five years, 11 primary Cs fountain clocks from 8 different metrology institutes in Europe, the U.S. and Asia contributed to TAI.
- Absolute frequency measurement for optical clock by Cs fountain clock is important for continuity problem in the SI second redefinition.
- Uncertainty evaluation of KRISS Cs fountain clock will be finished in 2019. Expected absolute frequency measurement; $2.4 \times 10^{-16}$ (world best for Yb).

# KRISS Proposal for WML-GT

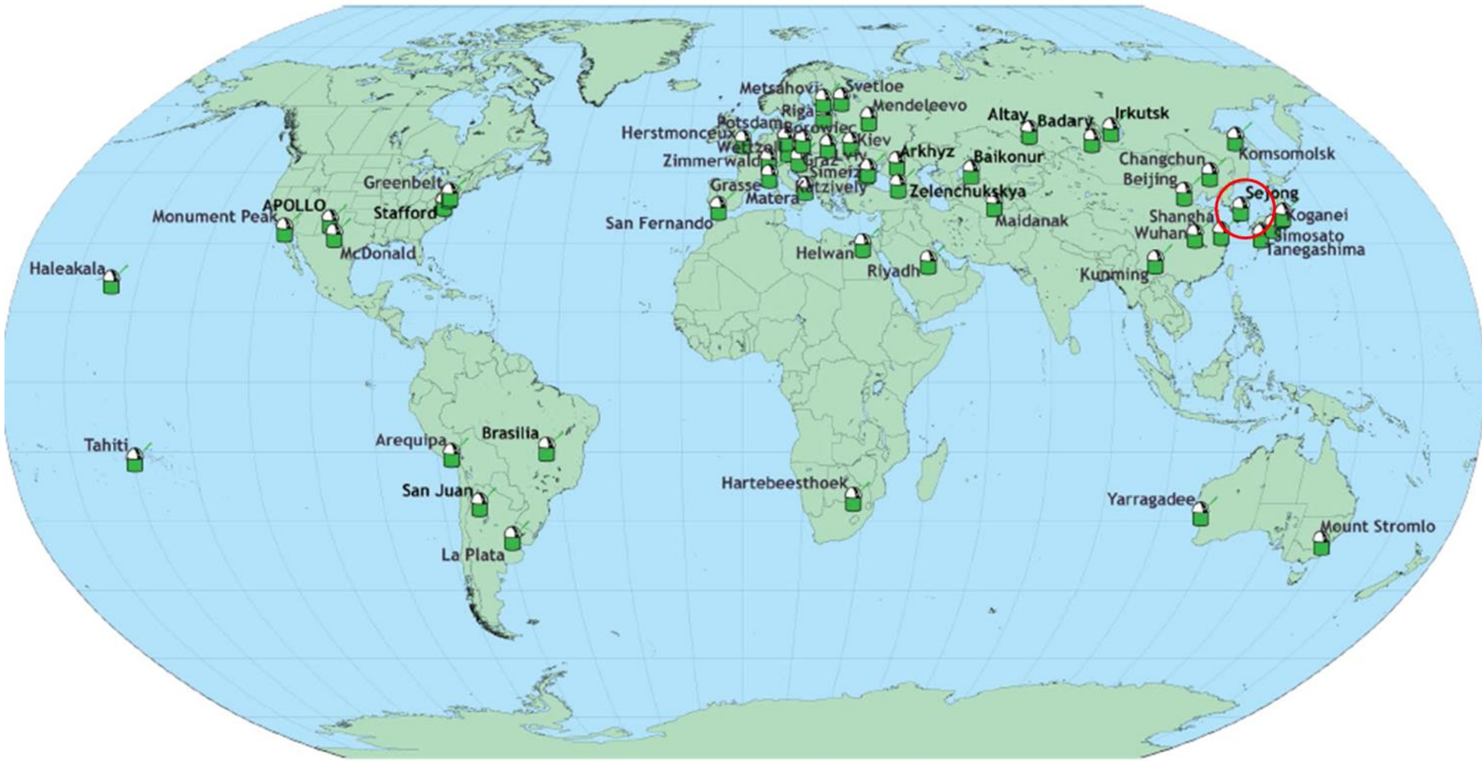
● $10^{-18}$ uncertainty ● $10^{-17}$ uncertainty ● $10^{-16}$ uncertainty



# Benefits of KRISS Participation

- Frequency comparisons between Yb optical lattice clocks - three continents all over the world (North America – NIST, Europe – INRIM, Asia – KRISS ,(and RIKEN)). Frequency ratio between KRISS Yb clock and various optical clocks worldwide.
- Common View (CV) optical clock comparison with NICT - Demonstration of the ultimate capability of the frequency comparison by ACES. Comparison between ACES MWL and TWCP.
- Improved accuracies of the ACES experiments (drift of fine structure constant, contribution to TAI, gravitational redshift, anisotropy of light, search for dark matter, gravitational wave detection, etc.).
- Potential contribution to ELT using an SLR at Sejong (about 30 km away from KRISS).

# ILRS Network of SLR Stations




- For intercontinental clock comparisons, at least two SLR stations with ELT, each with optical clock linked to it.
- SLR at Sejong has a possibility to be connected by optical fiber to KRISS Yb clocks. (about 30 km away from KRISS). – Cooperation with KASI required.

KRISS

Ref. L. Cacciapuoti, ACES Workshop 2017

# Process for ACES Participation

1. KRISS submit a research proposal to the ACES IWG highlighting their contribution to the mission: ground clocks (performance, availability, etc.) to be compared with ACES, additional T&F links available on site for the comparisons of ground clocks (TWSTFT, GPS, fiber links), SLR stations, possible interest to contribute to the ACES data analysis, etc.

   (done in Apr. 2018)

2. A representative of KRISS presents there proposal to ACES IWG.

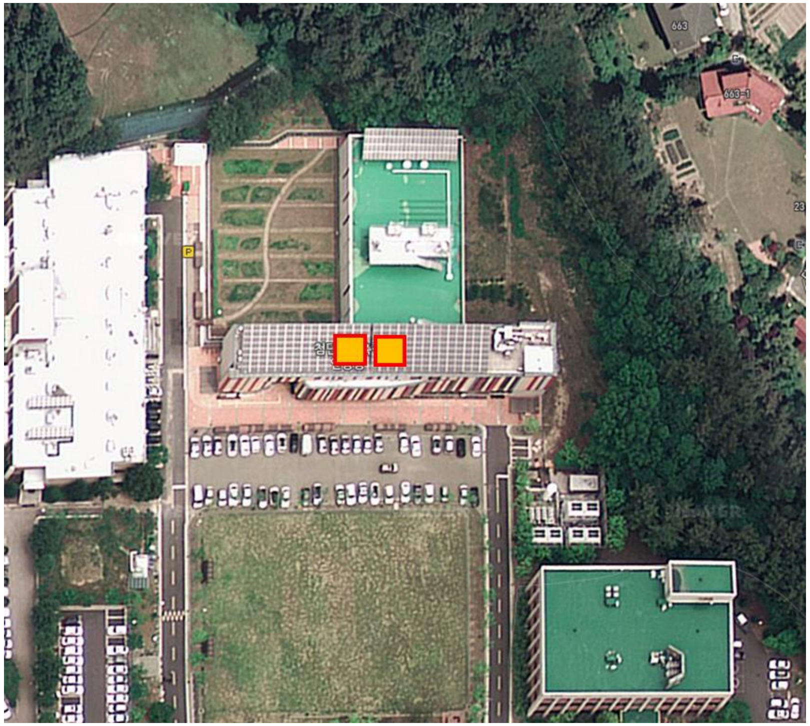
   (at ACES workshop 2018, Munich)

3. Evaluation by the ACES IWG, which will issue a recommendation to ESA for including KRISS in the ACES collaboration (expected in Nov. 2018)

4. ESA takes the final decision.

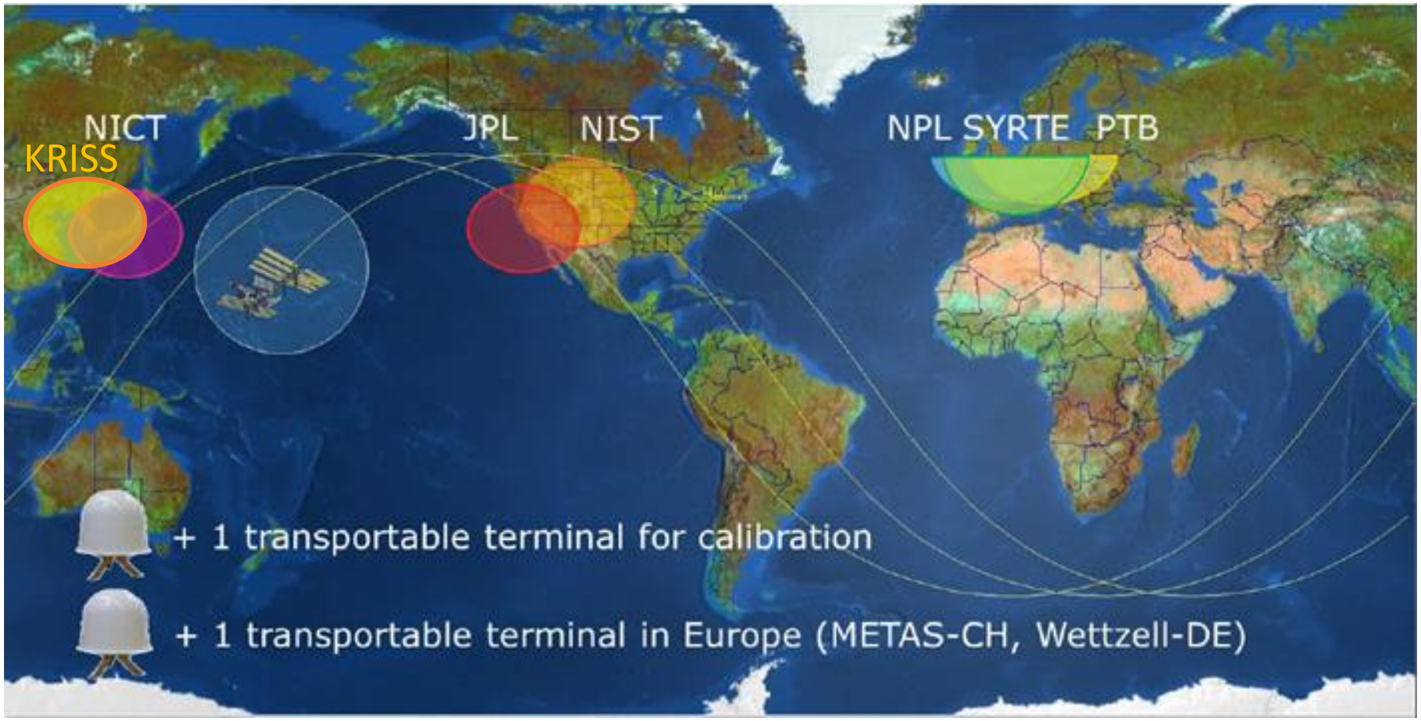
5. Procurement contract between ESA and KRISS. (hopefully, in early 2019)

# KRISS efforts for ACES participation



- Continuous improvement of Yb1, Yb2, and Cs-fountain clock.
- Preliminary investigation to prepare for MWL-GT installation at the rooftop of the building of KRISS Yb clock .
- KRISS management directors are highly positive about the KRISS participation in ACES by MWL-GT.
- Budget for the MWL-GT installation is expected to be available in 2019.

# KRISS Proposal for WML-GT




**Thank you for your attention !**