

# **VLBI analysis with c5++ - status quo and outlook**

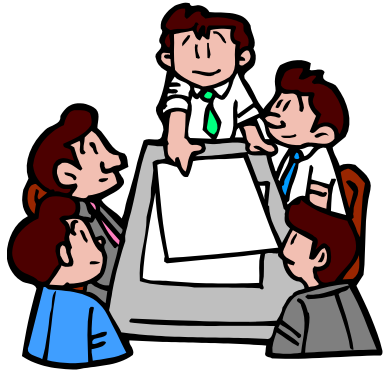
Hobiger T.<sup>1</sup>, Sekido M.<sup>1</sup>, Otsubo T.<sup>2</sup>, Gotoh T.<sup>1</sup>,  
Kubooka T.<sup>1</sup>, Takiguchi H.<sup>1</sup> and Takeuchi H.<sup>3</sup>

- (1) NICT, Japan
- (2) Hitotsubashi Univ., Japan
- (3) JAXA, Japan

# Content

- c5++ and VLBI
  - Multi-technique space geodetic analysis software
  - VLBI analysis and some features
    - Automated ambiguity resolution
    - Real-time UT1 estimation
    - Software validation
- Upcoming release
- Summary and outlook

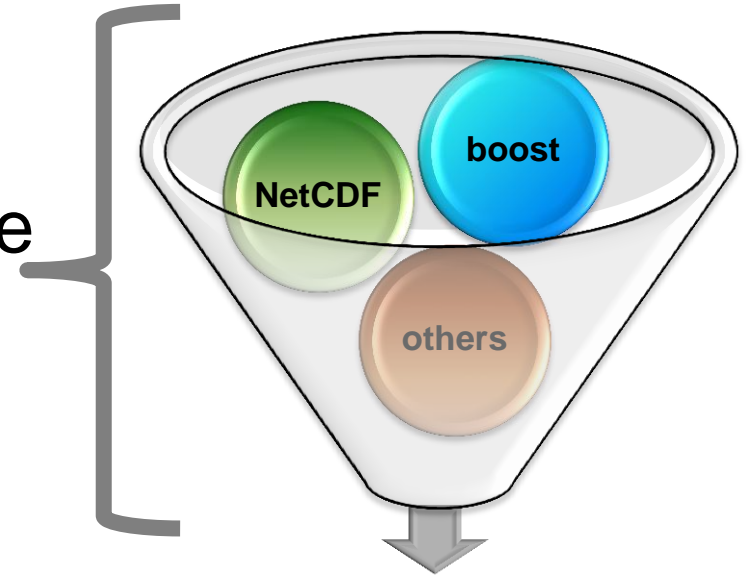
# c5++ a multi-technique space geodetic analysis software



Developer team



Open-source  
libraries



c5++ library

SLR

LLR

GNSS

GEO  
etc.

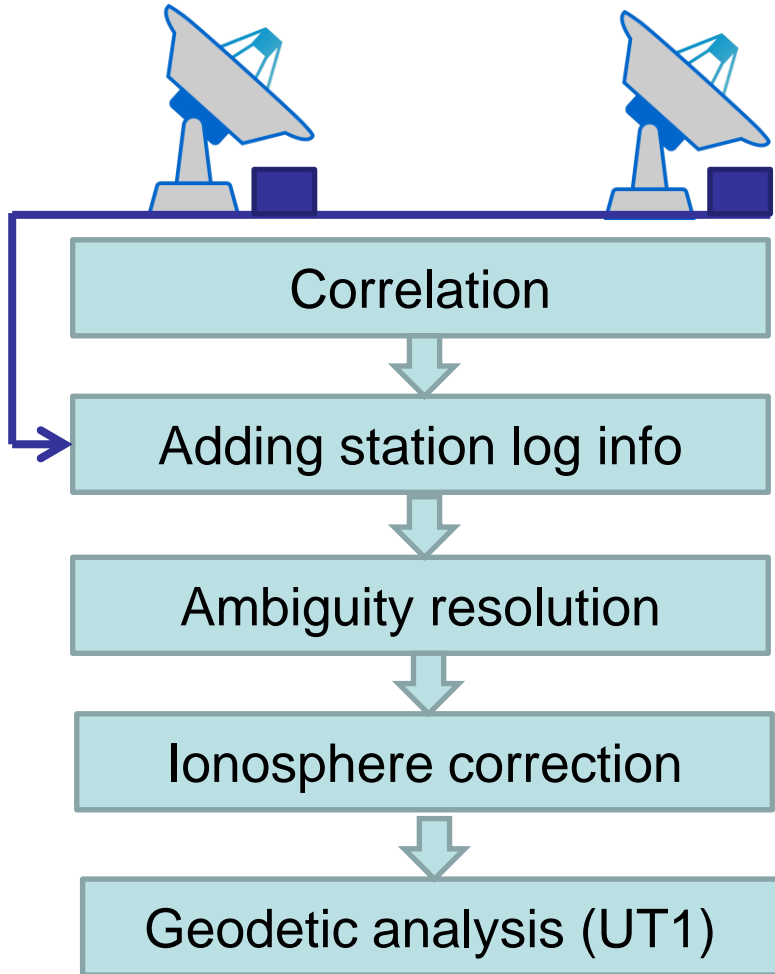
Deep  
space

**VLBI**

**this talk**

# Some features and results


# Automated processing of UT1 sessions



## Automation

Currently	with c5++
✓	✓
✓ (partly)	✓
X	✓
✓	✓
✓	✓

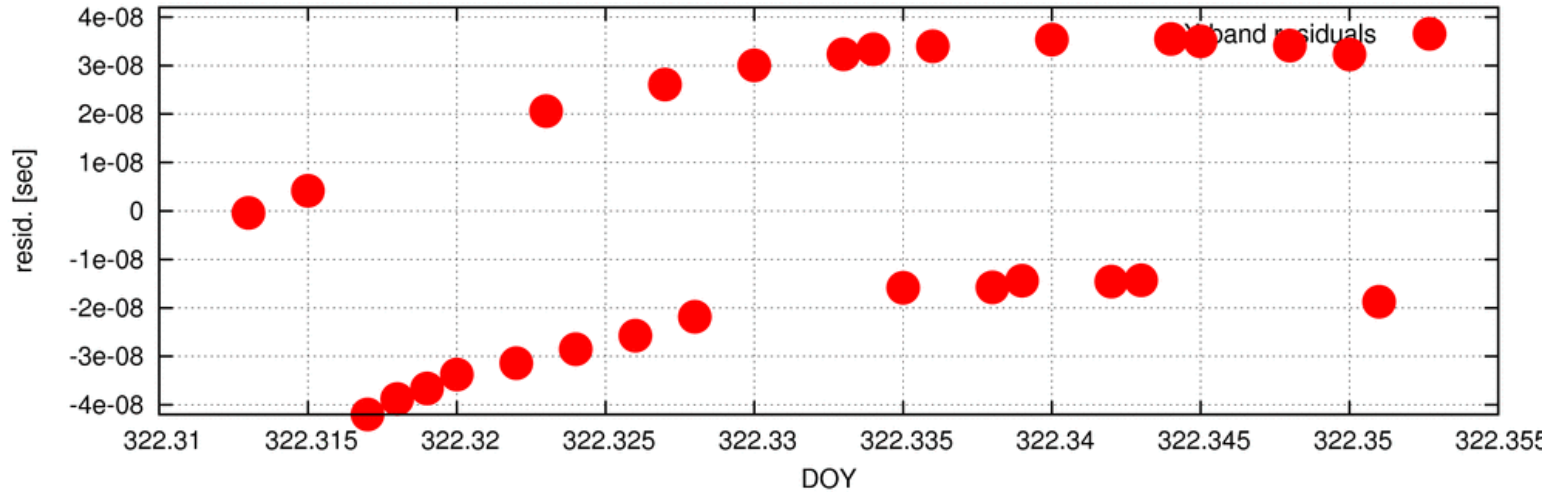
# Automated ambiguity resolution and UT1 estimation with c5++

- 
- ① Use X and S-band as independent observations which share a common clock + an offset between the bands
  - ② Estimate only clock
  - ③ Look at residuals and shift ambiguities according to X/S band spacing
  - ④ If none of the residuals exceed the corresponding ambiguity spacing stop iteration
  - ⑤ Compute ionosphere correction
  - ⑥ Compute UT1

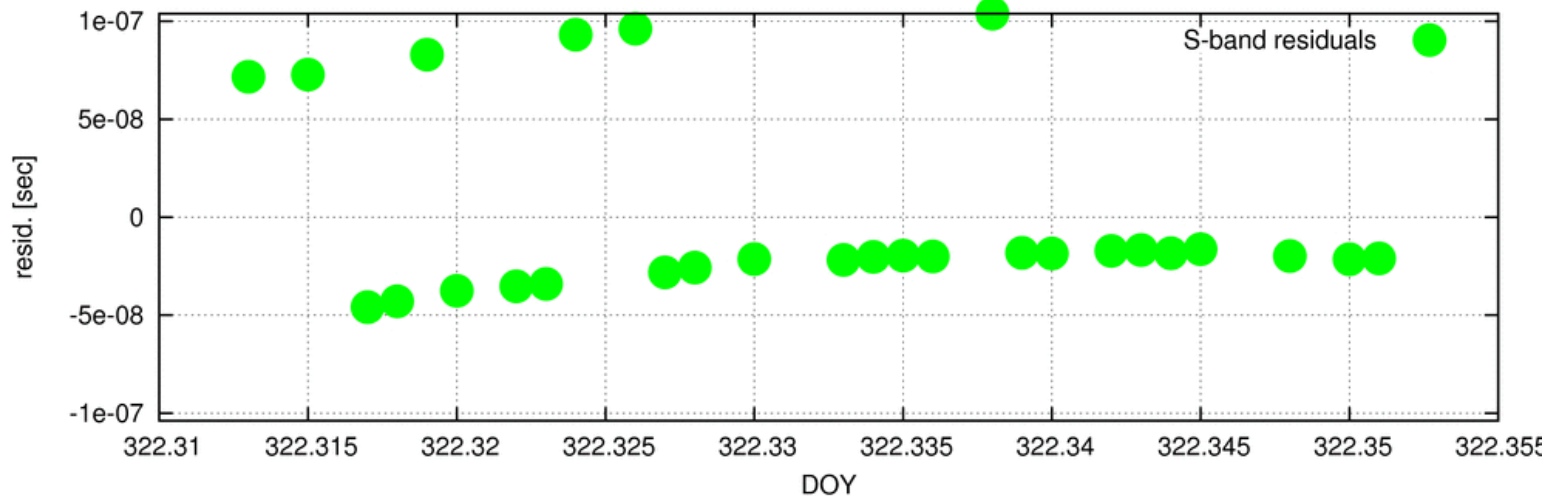
# Example : Wettzell-Tsukuba, 2006/11/18

Experiment K06322 - iteration.1

X-band residuals



S-band residuals



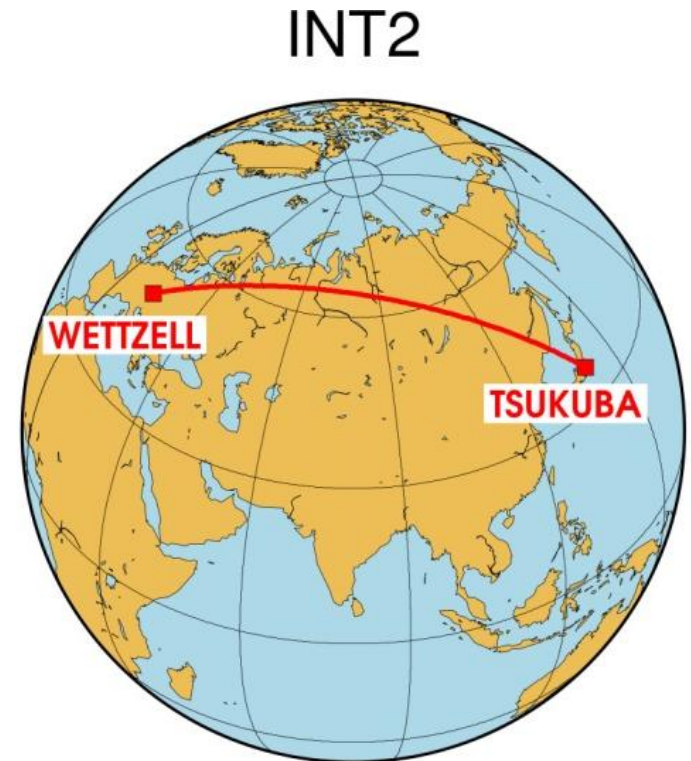
# Single Baseline UT1 estimation

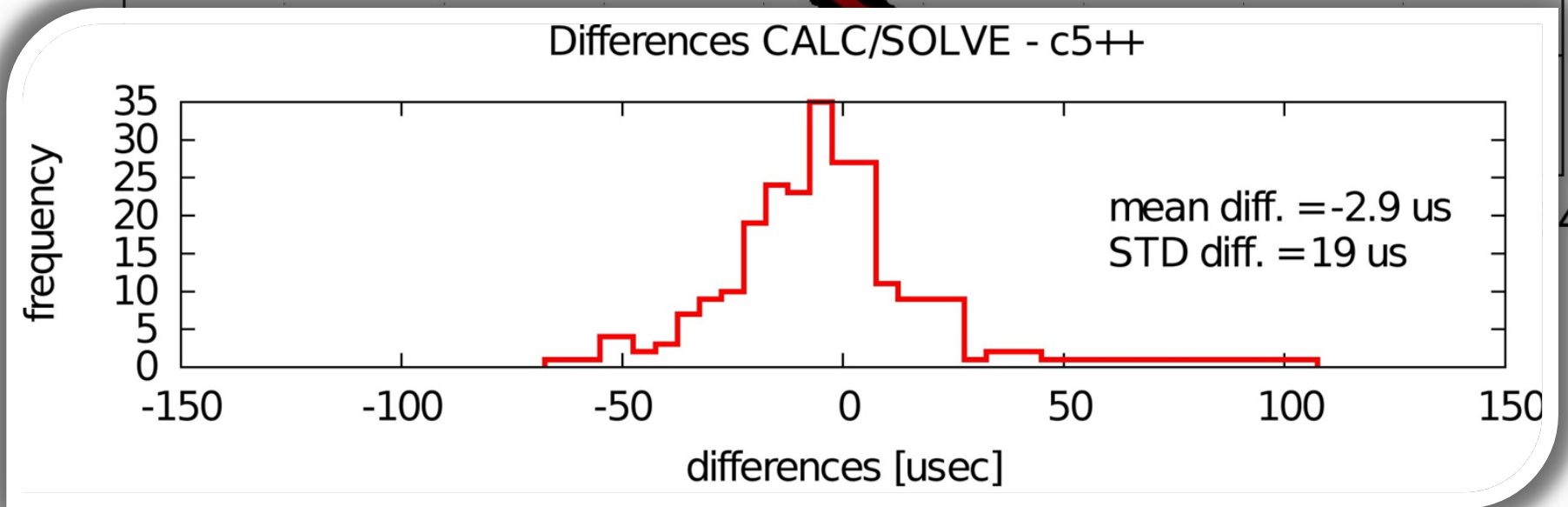
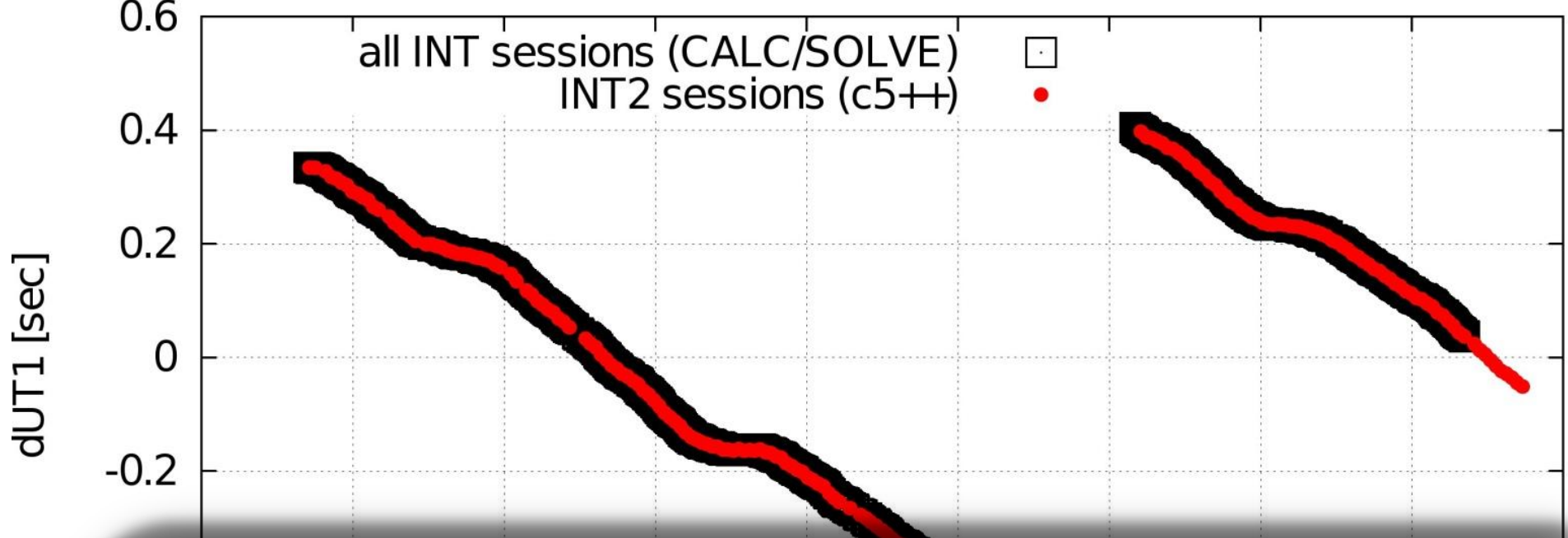
- In accordance to IERS 2003 conventions
- Optional SNR filter to reject observation with low SNR
- Estimated parameters :
  - Quadratic clock (3 unknown)
  - Troposphere ( 2 unknown)
  - UT1 offset (1 unknown)
- LSQ/Gauss-Markov Model
- $3\sigma$  outlier test and re-run possible
- Output results in IERS format



# Results from automated re-processing

- using correlator output
- using station logs
- Processing all INT2 sessions between Jan. 2006 and May 2010
- No human interaction
- Compare against CALC/SOLVE based results computed by GSI

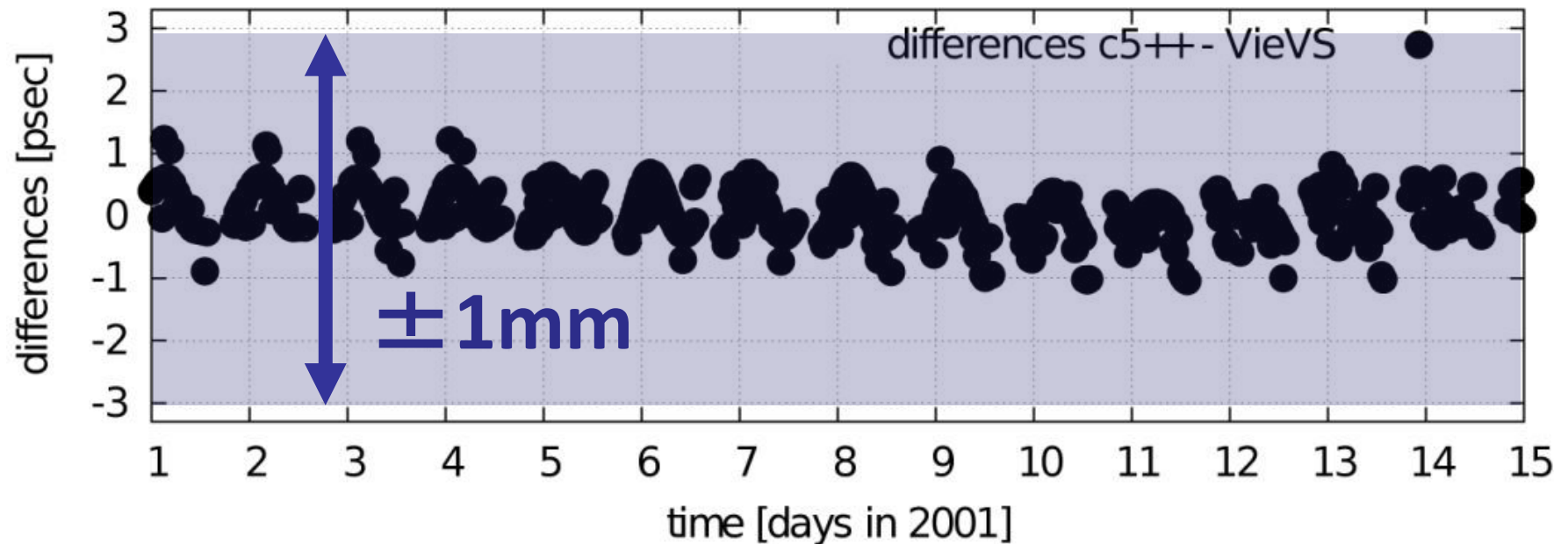




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# Software validation

- We joined the IVS “Comparison Campaign of VLBI Data Analysis Software”



Many thanks to L. Plank for feedback during this evaluation

# Next release and further development

- Implements IERS 2010 conventions
- Prepared for new VLBI data format
- Allows multi-baseline ambiguity resolution
- Input/output of SINEX files
- Implements a more sophisticated outlier detection algorithm
- Kalman filter for time-transfer by VLBI (i.e. NICT's main research target starting from April 2011)
- Combination of space geodetic techniques on the observation level
- Space craft navigation of deep-space missions (JAXA)

# Summary

- Benefit from large development team
- modules provided by experts in the corresponding fields
- Usable across different space geodetic technique  
→consistency
- Only a few additional VLBI-only modules required
- The VLBI module of c5++ has been applied to fully automated estimation of UT1 (being used by GSI, results submitted to the IERS for evaluation)
- Software validated within the IVS comparison campaign
- Automatically processed UT1 results agree well with manually analyzed CALC/SOLVE estimates

# Outlook

- Make use of parallel architectures to speed up computation intensive parts (mainly orbit module, less affecting VLBI)
- Following the goal of GGOS, we'd like to provide a flexible multi-technique space geodetic analysis software
- Support other applications as well
  - Time and frequency transfer by VLBI
  - Space craft tracking

# ***Thank you very much for your attention !***

## ***Acknowledgments:***

GSI, Japan (data, real-time tests, etc.)

Vienna Univ. of Techn. (software validation)

IVS (data)

IERS

## *Further reading:*

*Hobiger T., Otsubo T., Sekido M., Gotoh T., Kubooka T. Takiguchi H., Fully automated VLBI analysis with c5++ for ultra-rapid determination of UT1, submitted to Earth, Planets, Space, 2010.*