Development of
the multi frequency phase referencing method in Very Long Baseline Interferometry(VLBI)

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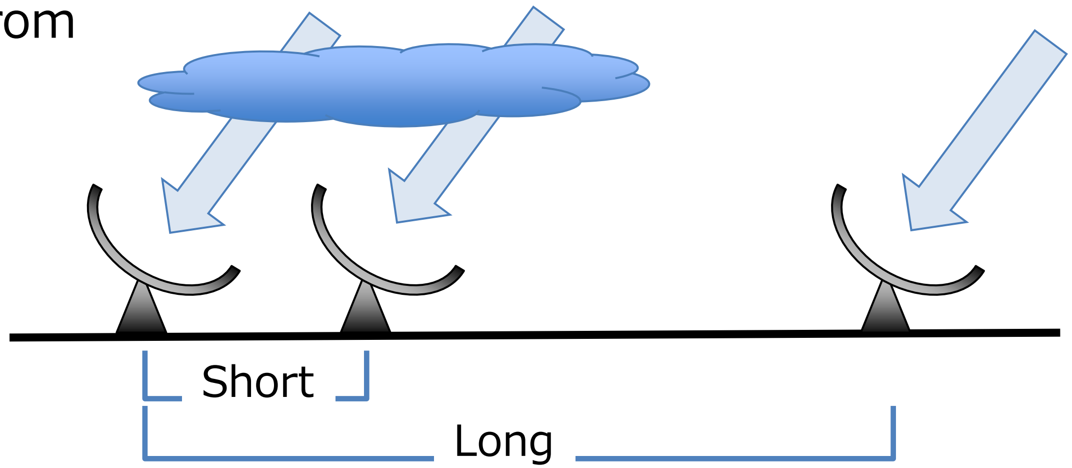
Motivation of this study

Water vapor in the lower atmosphere (troposphere) **is problematic** in VLBI observations in terms of phase stabilities.

More serious phase errors from
- longer baselines.
- higher frequencies.



It is important
to correct phase errors
due to the water vapor.

In analyzing the cosmic radio waves observed by VLBI,
we'll **correct phase errors due to the atmosphere**
in order to obtain accurate observables in VLBI.

Experiments

Goal

To show the feasibility of the multi frequency phase referencing.

To correct higher frequency phases using lower frequency ones.

VLBI observation

Sources	①BL Lac, J0244+6228 ②S Per
Array	KVN(Korean VLBI Network)
Date	March 30, 2012
Frequency	**22 GHz** (22.21501660 GHz) **43 GHz** (42.81401660 GHz) **86 GHz** (86.21001660 GHz)

$\Phi_{43/22} = \Phi_{22} \times (43\text{GHz}/22\text{GHz})$

The multi frequency phase referencing method

1. To generate the calibration data from phases multiplied by the frequency ratio.
2. To subtract the calibration data from the higher frequency phases.

① Results (BL Lac)

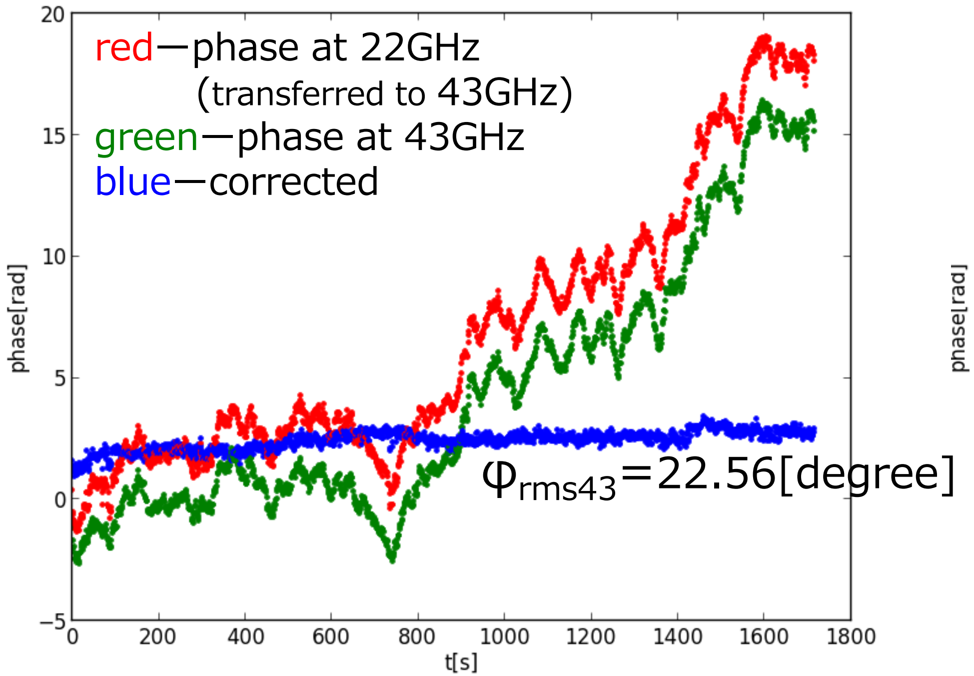


fig.1 Phase correction at 43GHz.

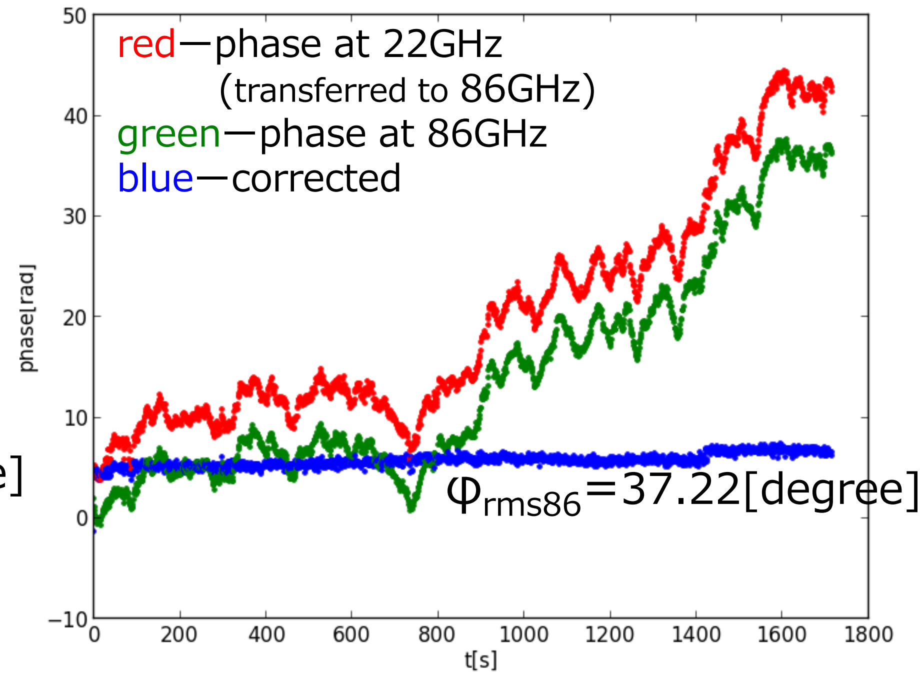


fig.2 Phase correction at 86GHz.

The time variation of the 22 GHz phases are very similar to the 43 and 86 GHz phases.
We can successfully reduce phase errors at 43 and 86 GHz less than 1 radian.

Using lower frequency phases, we can correct higher frequency ones.

① Results (J0244+6228)

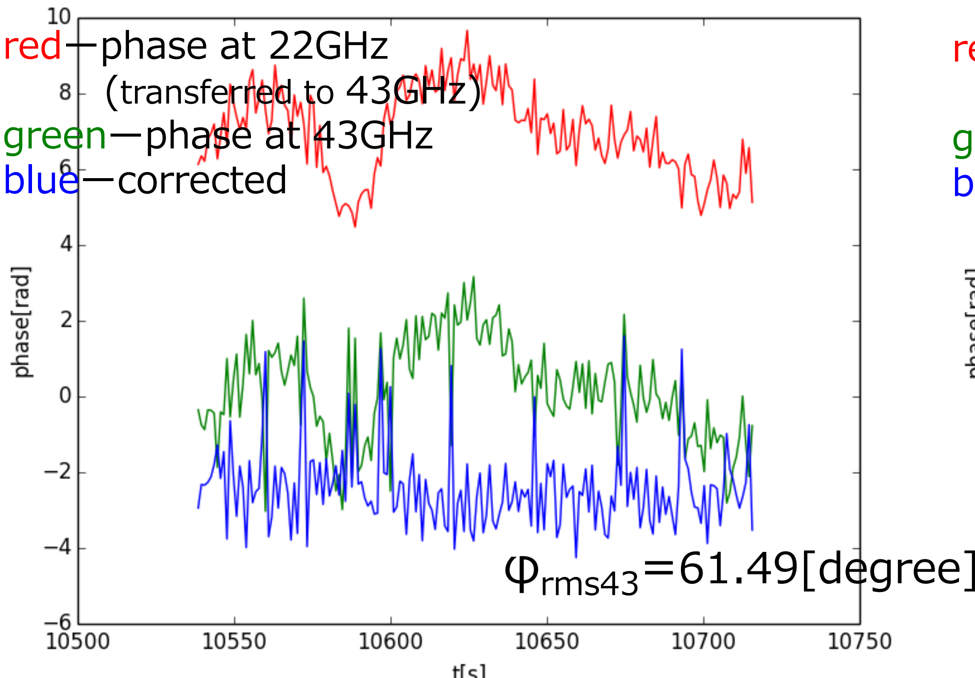


fig.3 Phase correction at 43GHz(segment6).

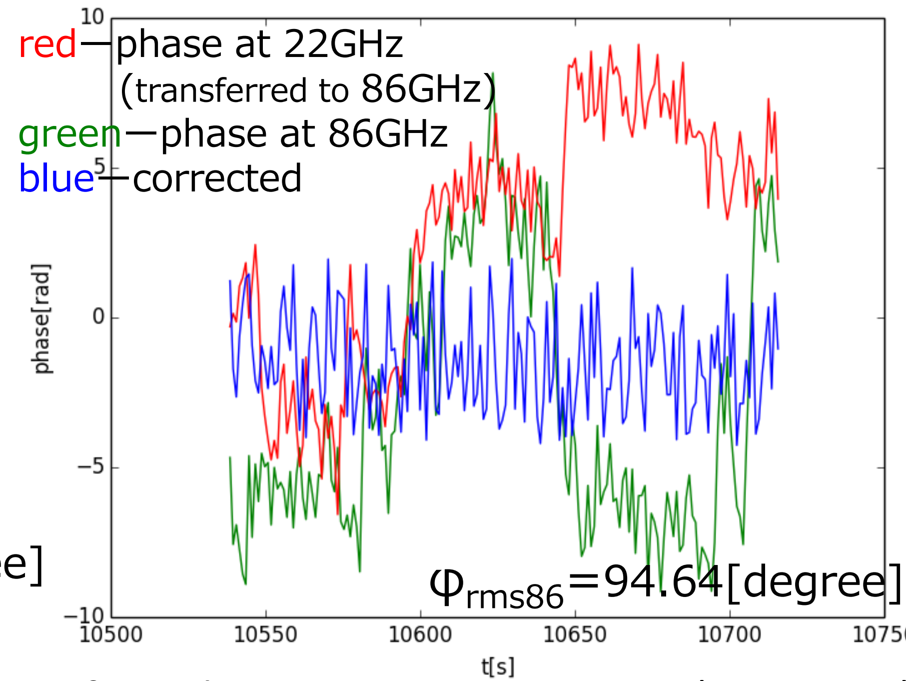


fig.4 Phase correction at 86GHz(segment6).

In the case of J0244+62, we separately processed each of the short-term scans (3 min).

Rms phase after the MFPR cannot be reduced to the same level achieved for BL Lac with the same algorithm.

1**The thermal noise** at the lower frequency of J0244+62 is larger than that of BL Lac
2The transferred noise disturbs to infer **2π ambiguities** properly

① Summary (BL Lac, J0244+6228)

We have been **developing the MFPR algorism with Python**.
For BL Lac, we can **successfully correct the VLBI phases at 43 and 86 GHz using 22 GHz phase**.
On the other hand, it is **difficult to achieve the same correction level** for J0244+62.
Because the signal-to-noise ratio of the source is lower than that of BL Lac, the automatic 2π ambiguity correction is not successful.

↓

1.
To develop an algorism which can properly treat **the 2π phase ambiguity** in the case of lower signal-to-noise ratio.

2.
To apply the modified program to other sources to **quantitatively verify the effectiveness of MPFR**.

② On-going work for S Per (1)

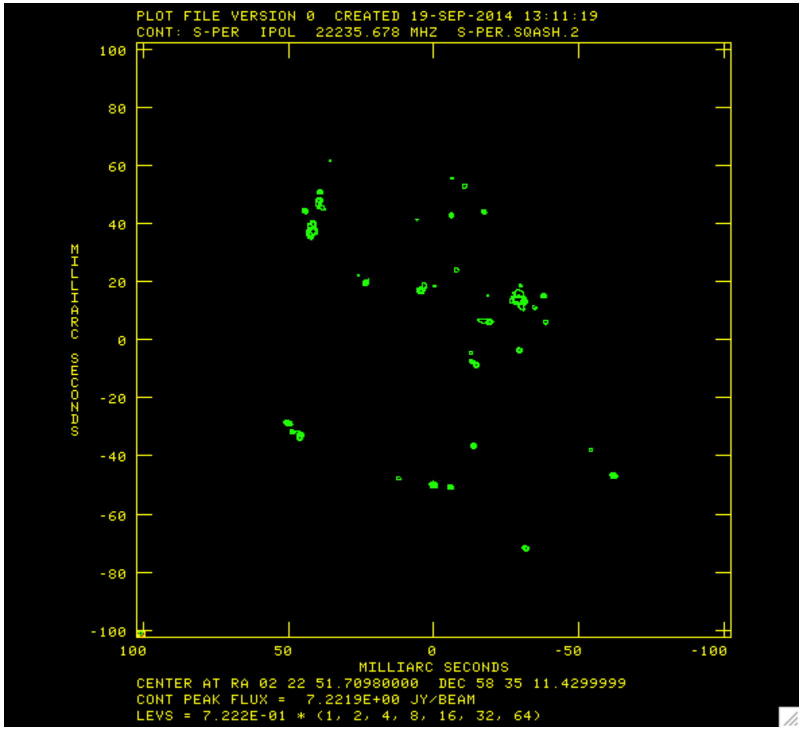


fig.5 H_2O maser distribution for the full velocity range

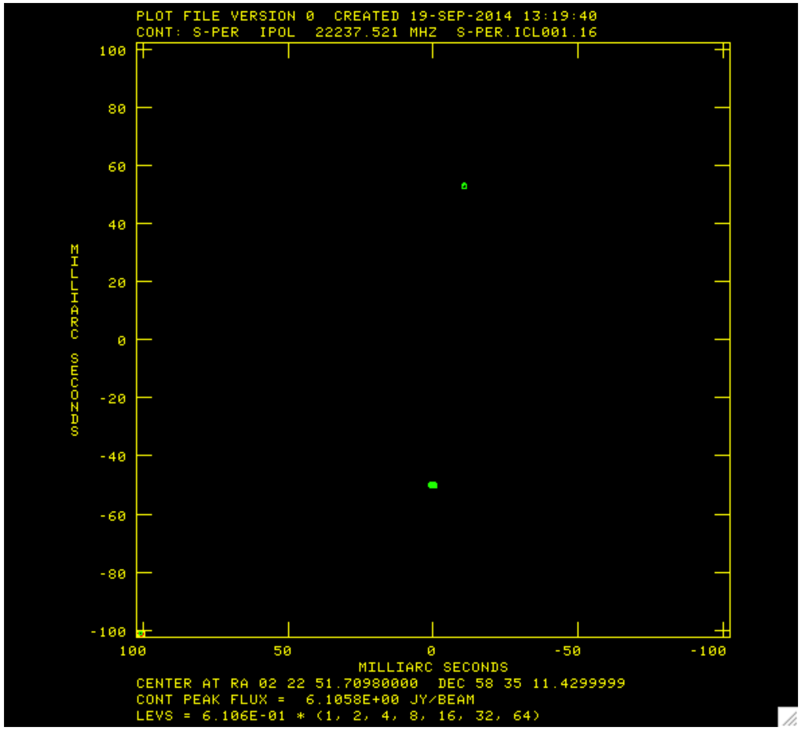


fig.6 H_2O maser distribution at V_{LSR} of 45.6 km s^{-1}

We have obtained the spatial H_2O maser distribution from the VERA+KVN observation at the same time.

LSR velocity range : -20.72 km s^{-1} ～ -62.44 km s^{-1}

② On-going work for S Per (2)

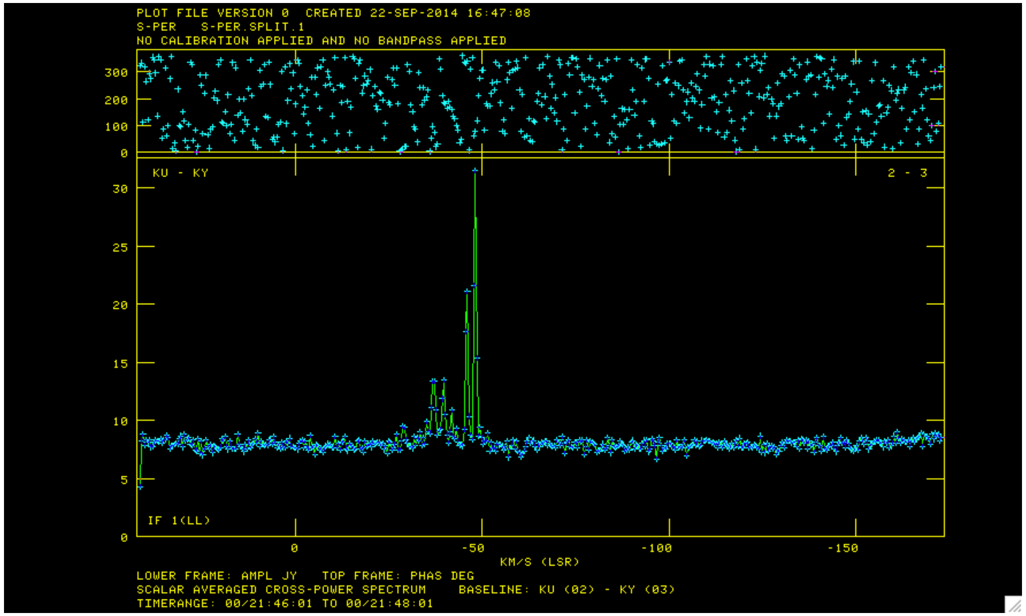


fig.7 H_2O maser spectle

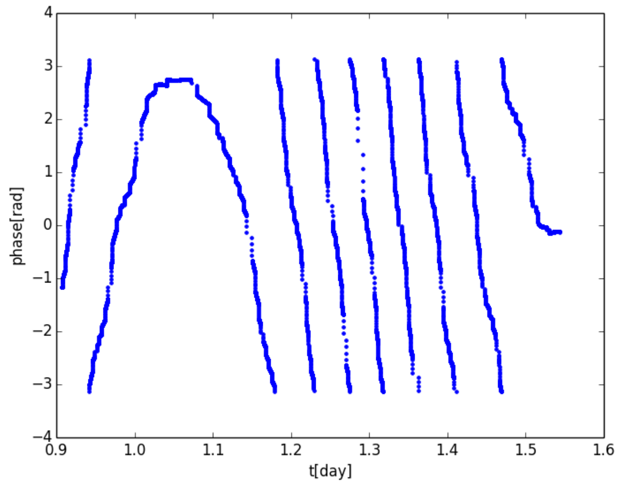


fig.8 Visibility phase at V_{LSR} of -45.6 km/s

Maser emission at V_{LSR} of -45.64km s^{-1} is stable in time.
This indicates that the this maser feature seems to have a point-like structure.

This velocity channel is used for making the calibration data.
The visibility phase was calculated to be subtracted from fringe phase in order not to transfer the source structure effect at 22 GHz.

② On-going work for S Per (3)

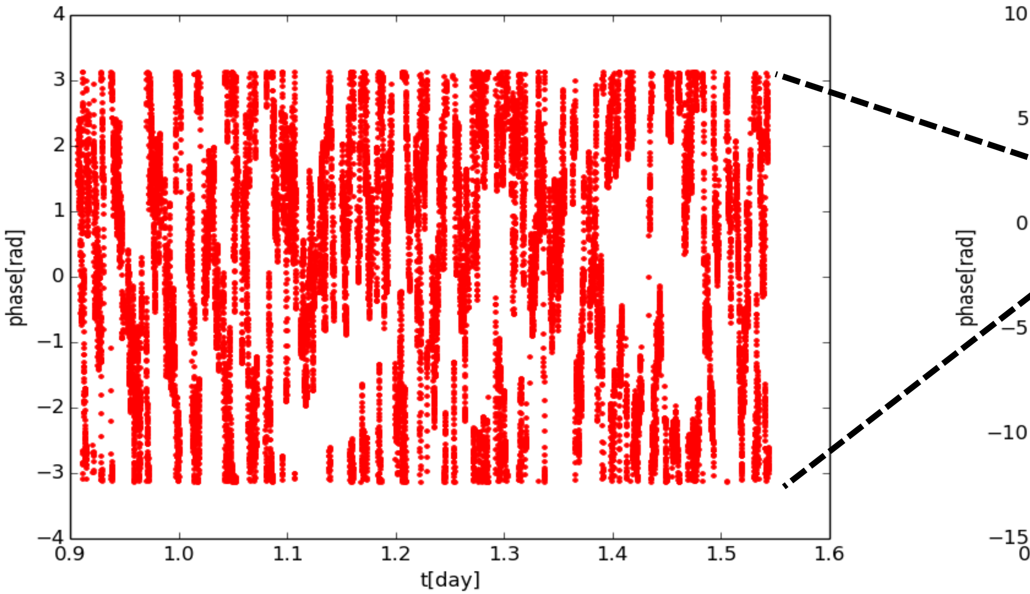


fig.9 Fringe phase after subtracting the H_2O maser visibility phase at 22GHz

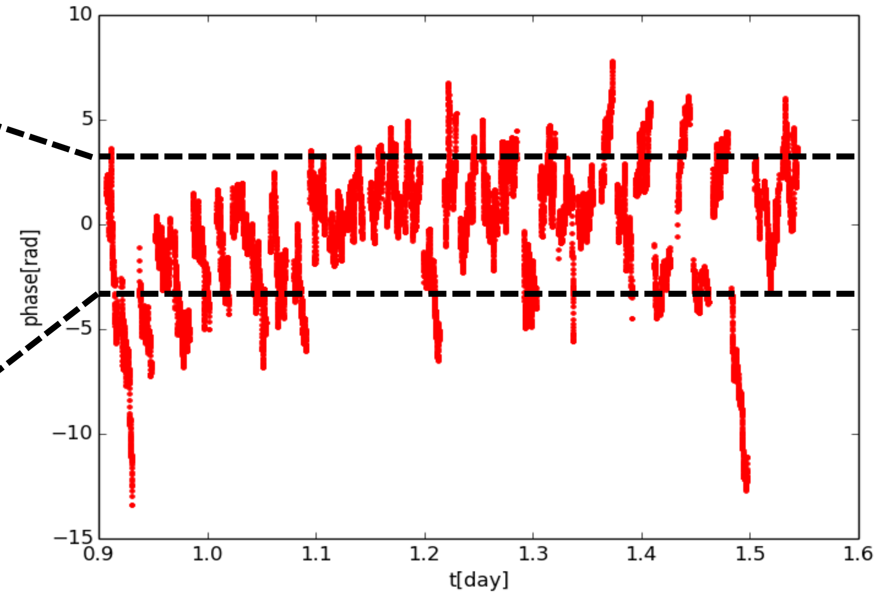


fig.10 The same of fig.9, but showing the phase connection result with consideration of the 2π ambiguity

In the case of S Per, we separately processed each of the short-term scans, and treated the 2π phase ambiguity.

② On-going work for S Per (4)

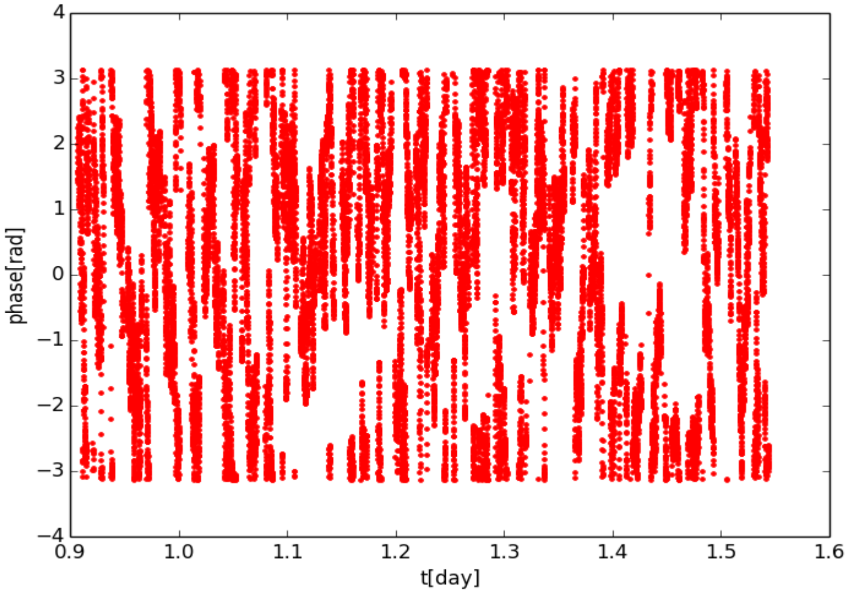


fig.9 Fringe phase after subtracting the H_2O maser visibility phase at 22GHz in Python

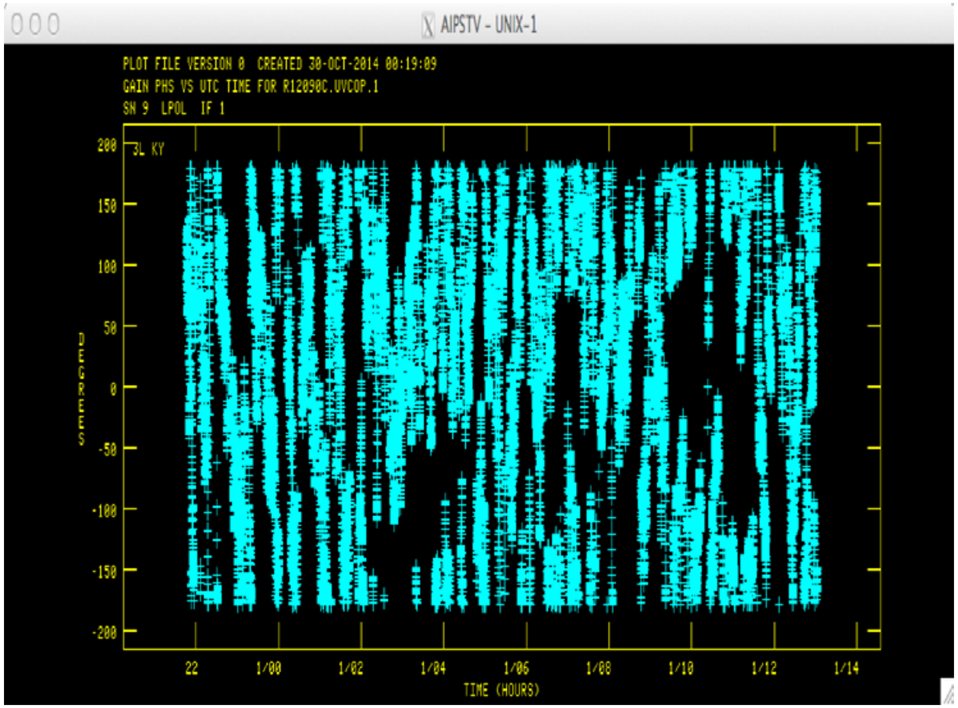


fig.11 Fringe phase after subtracting the H_2O maser visibility phase at 22GHz in AIPS

We have been developing a Python program to create the MPFR calibration data for the S Per SiO masers into an AIPS SN table.

Summary of the study

BL Lac, J0244+62

We have **applied the MFPR method for two sources**.
In the case of high signal-to-noise ratio, the develop program **work correctly**. For the weaker source, the **2π ambiguity correction is still a subject** to be solved.

S Per

We have **developed a Python program to create MPFR calibration data** using 22 GHz water maser emission to correct 43 GHz SiO maser phases. The calibration data will be formatted into the AIPS SN table to be applied in AIPS.

Future works

(1) To implement an algorithm to properly treat 2π ambiguity for lower signal-to-noise ratio cases.
(2) S Per SiO maser correction with the MPFR to **improve the coherence and the signal-to-noise ratio**.