Performance of KVN / KaVA
Phase Referencing Observations

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and on behalf of
KaVA Science sub-WG

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Errors coming from the **ATMOSPHERE** are still remain the most serious difficulty which significantly degrade the sensitivity and imaging capability of mm and sub-mm VLBI observation.

**Coherence**

\[ C(T) = \frac{1}{T} \int_0^T e^{i\phi t} dt, \]

**VLBI Sensitivity**

\[ S_v = (SNR) \frac{8k}{\pi \eta_c \sqrt{\eta_A \eta_A D_1 D_2 \sqrt{2B\tau}}}, \]

**Source**: BL Lac  
**Frequency**: 86 GHz

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>2</th>
<th>8</th>
<th>15</th>
<th>22</th>
<th>43</th>
<th>86</th>
<th>129</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coherence Time (sec)*</td>
<td>800</td>
<td>200</td>
<td>100</td>
<td>73</td>
<td>37</td>
<td>19</td>
<td>12</td>
</tr>
</tbody>
</table>

*Typical value of atmospheric phase stability ~ 10^{-13}
VLBI Phase Referencing

Increase coherence time by removing atmospheric fluctuations → weak source detection with high SNR

Atmospheric phase errors are calibrated by near by calibrators

lower frequency phase solutions

VERA dual-beam

KVN multi-freq. receiving system

(source: Asaki)
### KVN Multi-Freq. Simultaneous Observation

#### Fringe Phase

<table>
<thead>
<tr>
<th>Frequency</th>
<th>$C_{eff}$</th>
<th>22GHz</th>
<th>43GHz</th>
<th>86GHz</th>
<th>129GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>22 GHz</td>
<td>-</td>
<td>0.97</td>
<td>0.91</td>
<td>0.88</td>
<td></td>
</tr>
<tr>
<td>43 GHz</td>
<td>0.97</td>
<td>-</td>
<td>0.97</td>
<td>0.96</td>
<td></td>
</tr>
<tr>
<td>86 GHz</td>
<td>0.91</td>
<td>0.97</td>
<td>-</td>
<td>0.99</td>
<td></td>
</tr>
<tr>
<td>129 GHz</td>
<td>0.88</td>
<td>0.96</td>
<td>0.99</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

**Equation**

$$\phi_{high} \propto \frac{v_h}{v_l} \phi_{low}$$

**Description**

- **22 GHz:**
  - Non-dispersive characteristic of troposphere

- **43 GHz:**
  - Non-dispersive characteristic of troposphere

- **86 GHz:**
  - Non-dispersive characteristic of troposphere

- **129 GHz:**
  - Non-dispersive characteristic of troposphere

**Graphical Representation**

- **Time:** 0.005 to 0.030
- **Phase (deg):** -200 to 1200

**Legend:**
- Blue: 22 GHz
- Green: 43 GHz
- Red: 86 GHz
- Cyan: 129 GHz
43GHz Visibility Phase calibrated by FPT at 22GHz

Raw visibility phase at 43GHz

MFPR applied with K-band solint 0.3

43GHz
KVN Phase Referencing Test

- Observing Frequency: 22/43/86/129 GHz
- Bandwidth: 64MHz per each frequency
- Observation configuration:
  - conventional phase referencing (fast antenna switching btw. target & calibrator) with multi-frequency simultaneous observation
  - switching cycle: ~1 minutes
  - on source time per scan: 18~25 sec for each
- Source Pairs (separation angle, * calibrator)
  1. M87* - M84 (1.5 deg)
  2. J1222+0413* – NGC4261 (1.8 deg)
  3. 3C273* – 3C279* (10.4 deg)
Three Phase Referencing Methods in KVN

Calibrator  Target
M87  M84
1.5 deg

FAS  conventional PR

Fast Antenna Switching  3 deg/sec

22 GHz

KVN
SNR: M87-M84

SNR of M87 ~ 50

SNR of M87 ~ 40

SNR of M87 ~ 25

M87 – no detection at all freq.

M84 – no detection at all freq.
Fast Antenna Switching Phase Referencing
M87-M84 Test at 22GHz
Fast Antenna Switching Phase Referencing
M87-M84 Test at 43GHz

PLOT FILE VERSION 0  CREATED 29-OCT-2014 22:40:35
PHASE VS TIME FOR K13092a-Q. UVCOP.1 VECT AVER. CL = 8
IF 1 - 4  CHAN 1 - 256  STK LL

Calibrator  Target

M87
1.5 deg

Fast Antenna Switching
3 degrees

KVN
Fast Antenna Switching Phase Referencing
M87-M84 Test at 86GHz
Fast Antenna Switching Phase Referencing
M87-M84 Test at 129Ghz
Three Phase Referencing Methods in KVN

FPT + FAS
1. phase scaling of calibrator
2. apply conventional PR

FAS conventional PR
Example: FAS vs (FPT+FAS): M84 calibrated by M87

**FPT + FAS**

1. Phase scaling of calibrator
2. Apply conventional PR

![Graph showing phase vs time for different quadrants and channels, with markers for FPT(F from 22 to 43GHz) + FAS (43GHz)]

- **x**: 43GHz FAS phase
- **o**: FPT (from 22 to 43GHz) + FAS (43GHz)
Example: FAS vs (FPT+FAS) : M84 calibrated by M87

**FPT + FAS**
1. phase scaling of calibrator
2. apply conventional PR

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**Graph Description**

- **x**: 43GHz FAS phase
- **o**: FPT (from 22 to 43GHz) + FAS (43GHz)

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**Legend**

- due to un-calibrated (residual) delays...
  - e.g. (dispersive) instrumental (22/43), source structure, ionosphere ... etc
Three Phase Referencing Methods in KVN

**FAS** conventional PR

1. phase scaling of calibrator
2. apply conventional PR

**FPT + FAS**

- 1. phase scaling of calibrator
- 2. apply conventional PR

**FPT**

Frequency Phase Transfer
Comparison: Raw Visibility Phase & FPT Phase for M87

- **43GHz** Raw & FPT (22GHz phase x 2)
- **86GHz** Raw & FPT (22GHz phase x 4)
- **129GHz** Raw & FPT (22GHz phase x 6)
GPS Installation - close collaboration with KASI GPS group

1. KVN antenna position
   - displacement of KVN antenna position
   - In-Variant Point (IVP) measurement
     ➔ To monitor accurate KVN antenna positions

2. Atmospheric model calculation
   - Wet delay & TEC estimation
     ➔ To improve a phase referencing capability & astrometric accuracy

KVN 8Gbps Operations with FILA10G & Mark6

- current
  Mark5B : 1Gbps (BW = 256MHz)
  Mark5B+ : 2Gbps (BW = 512MHz)

- with FILA 10G + Mark6
  Mark6 : 8Gbps (BW = 4 x 512MHz) : 264 Mbit per each 22/43/86/129 GHz

Developments of Phase Tone Calibration System

- 1st approach: Quasi-optics Injection Method
  - Reference signal frequency : 200 MHz
  - Comb generator : commercial NTL(2.4mm connector, spec: <50 GHz)
  - Quasi-optics injection using DRWH, ellipsoidal mirror & Mylar sheet
  - Custom designed comb needed for 129 GHz-band power generation
  - Equalization problem have to be solved

KVN IVP from KaVA K-band Geodesy (10 epochs)

XYZ RMS variation
10 epochs: Yonsei - 1.39 cm, Ulsan - 1.39 cm, Tamna - 1.03 cm X-axis MJD / Y-axis Position (m)
KaVA Phase Referencing Test

- Observing Date: 2015 Feb 3
- Observing Frequency: 22 GHz
- KaVA 7 station (KVN+VERA)
- Bandwidth: 256MHz
- Observation configuration:
  - conventional phase referencing
    (fast antenna switching btw. target & calibrator)
  - switching cycle: ~ 1 minutes
  - on source time per scan: 18~25 sec
# Example of Source Pairs

<table>
<thead>
<tr>
<th>Cal/Tar SRC</th>
<th>S.A.</th>
<th>Self-detection (30 sec integration)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4C39.25</td>
<td>-</td>
<td>All detected (SNR~ several hundreds)</td>
</tr>
<tr>
<td>0928+390</td>
<td>0.77</td>
<td>few marginal detection at KYS &amp; KUS only</td>
</tr>
<tr>
<td>0922+364</td>
<td>2.84</td>
<td>few marginal detection at KYS &amp; KUS only</td>
</tr>
<tr>
<td>0932+367</td>
<td>3.00</td>
<td>No detection</td>
</tr>
<tr>
<td>0922+407</td>
<td>1.47</td>
<td>No detection</td>
</tr>
<tr>
<td>0927+352</td>
<td>4.05</td>
<td>No detection</td>
</tr>
<tr>
<td>0936+419</td>
<td>3.60</td>
<td>No detection</td>
</tr>
</tbody>
</table>

※ Yellow (Calibrator), Others (Targets), S.A. : Separation Angle (degree)
KaVA Phase Referencing Result (calibrated by 4C39.25)
Accurate Delay Errors Calibration

1. Large-scale systematic delay errors
   \[ \approx \text{correlation model (apriori) errors} \]
   \[ \text{clock} / \text{instrumental errors} \]

   Typically, \( \Delta \tau_a > 5 \text{ cm} \)
   \[ \rightarrow \text{this should be reduced} \sim 1 \text{ cm level} \]
   \[ \rightarrow \text{method: GPS/JAM application (ion/troposphere)} \]
   EOP correction
   Geodetic block or Multiple calibrators
   Pcal & special observing design

2. (Relatively) small-scale (random) delay errors
   \[ \approx \text{mostly weather related errors} \]

   Typically, \( 0.05 \text{ cm} (~15^\circ) < \Delta \tau_r < 0.5 \text{ cm} (~150^\circ) \) at 22GHz
   \[ \rightarrow \text{nearby calibrators} \]
Delay Errors – GSP/JAM ZTD Inputs

Intensive collaborations for the performance evaluation of KaVA PR is on-going on behalf of KaVA science WG
Thank you!