Performance of KVN / KaVA Phase Referencing Observations

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Korea Astronomy & Space Science Institute
and on behalf of
KaVA Science sub-WG

2015 East Asian VLBI Workshop @ Hokkaido Univ. **2015 JUL 8**

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

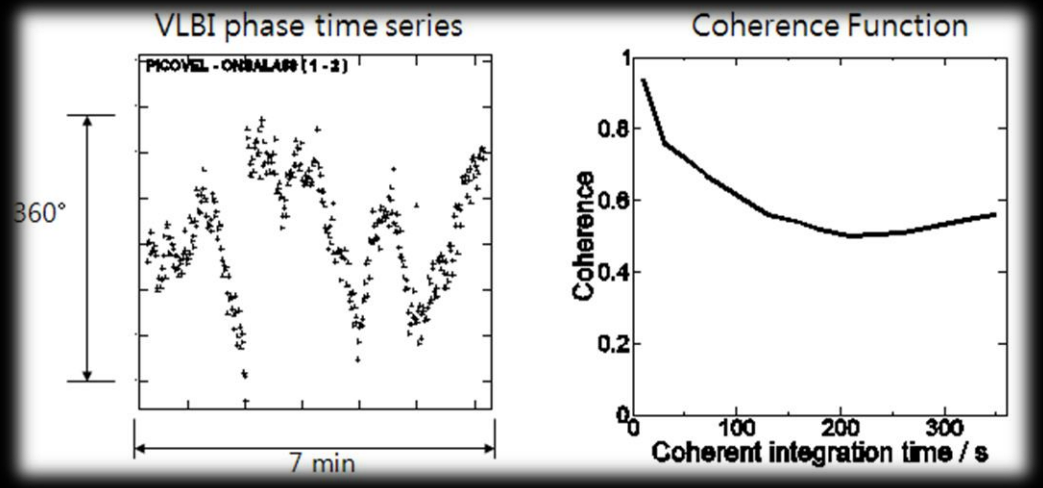
Coherence

Coherence Function

$$C(T) = \left| \frac{1}{T} \int_0^T e^{i\phi t} dt \right|,$$

VLBI Sensitivity

$$S_\nu = (SNR) \frac{8k}{\pi \eta_c} \frac{\sqrt{T_{S_1} T_{S_2}}}{\sqrt{\eta_{A_1} \eta_{A_1}} D_1 D_2 \sqrt{2B\tau_a}}$$



Pico Veleta – Onsala baseline (A. Roy)
Source : BL Lac
Frequency : 86 GHz

Coherence Time

Frequency (GHz)	2	8	15	22	43	86	129
Coherence Time (sec)*	800	200	100	73	37	19	12

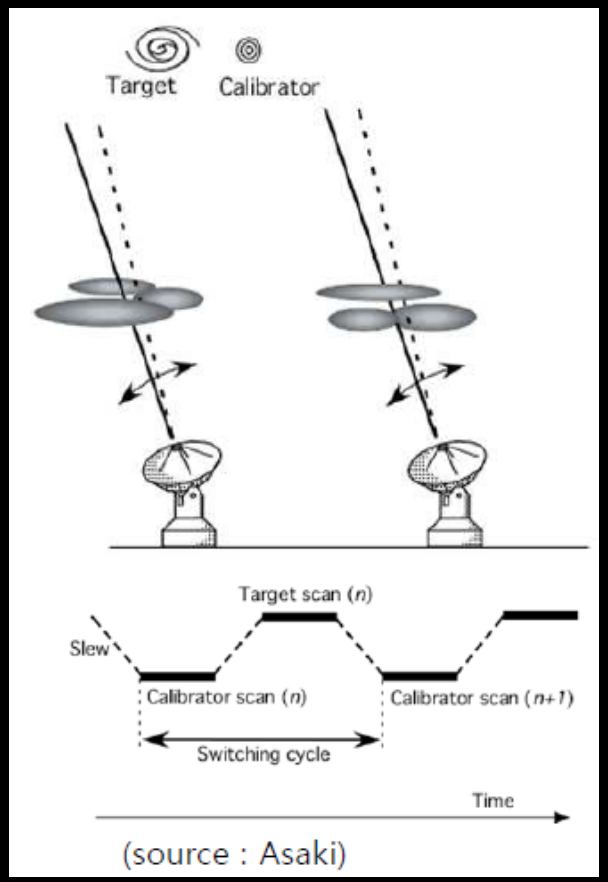
*Typical value of atmospheric phase stability ~ 10^{-13}

VLBI Phase Referencing

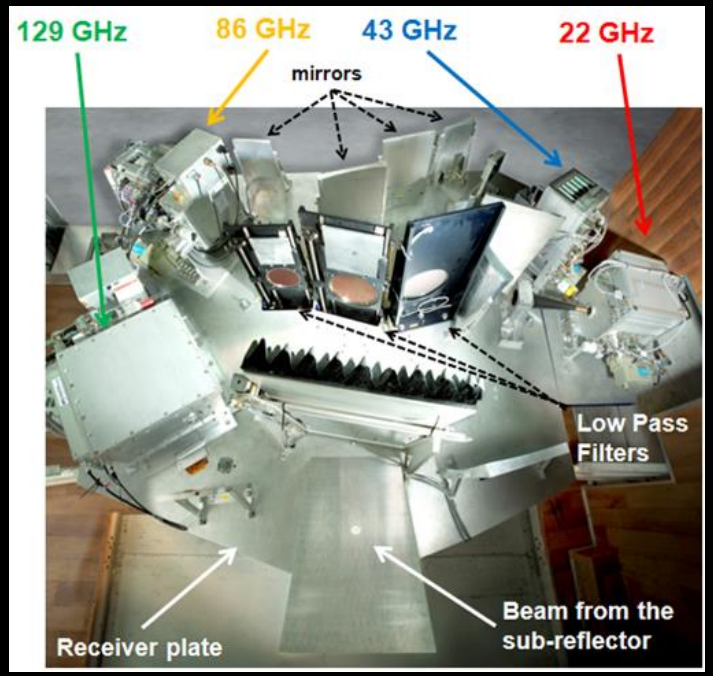
Increase coherence time by removing atmospheric fluctuations
→ weak source detection with high SNR

Atmospheric phase errors are calibrated by

near by calibrators **lower frequency phase solutions**

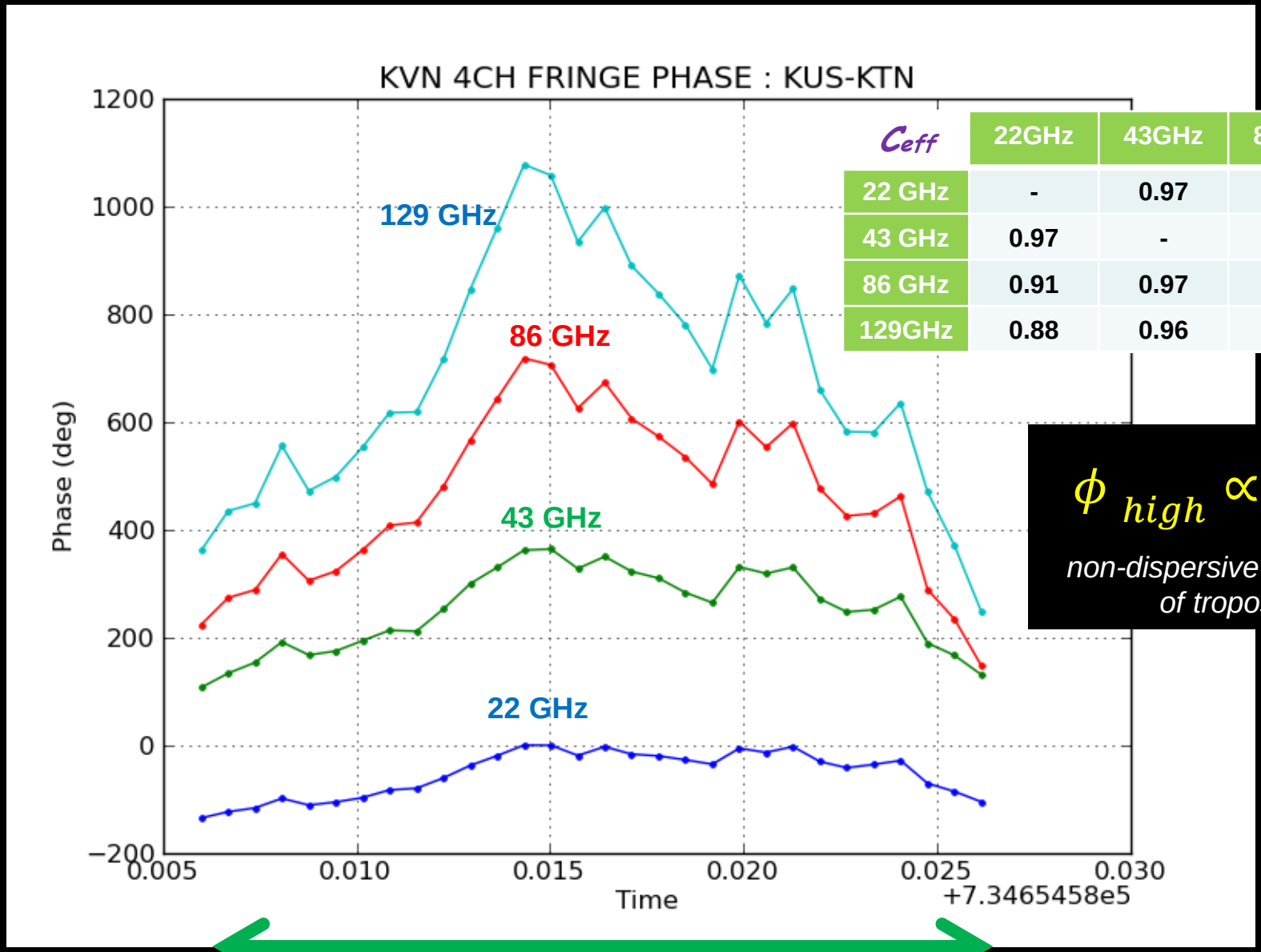


VERA dual-beam



KVN multi-freq. receiving system

KVN Multi-Freq. Simultaneous Observation



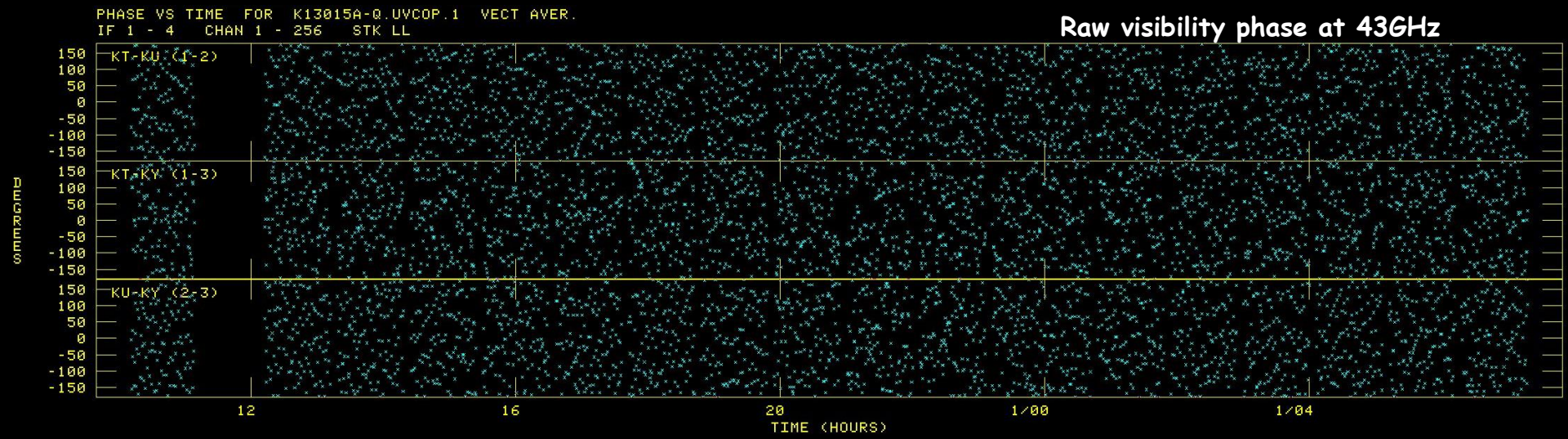
Ceff	22GHz	43GHz	86GHz	129GHz
22 GHz	-	0.97	0.91	0.88
43 GHz	0.97	-	0.97	0.96
86 GHz	0.91	0.97	-	0.99
129GHz	0.88	0.96	0.99	-

$$\phi_{high} \propto \frac{\nu_h}{\nu_l}\phi_{low}$$

non-dispersive characteristic of troposphere

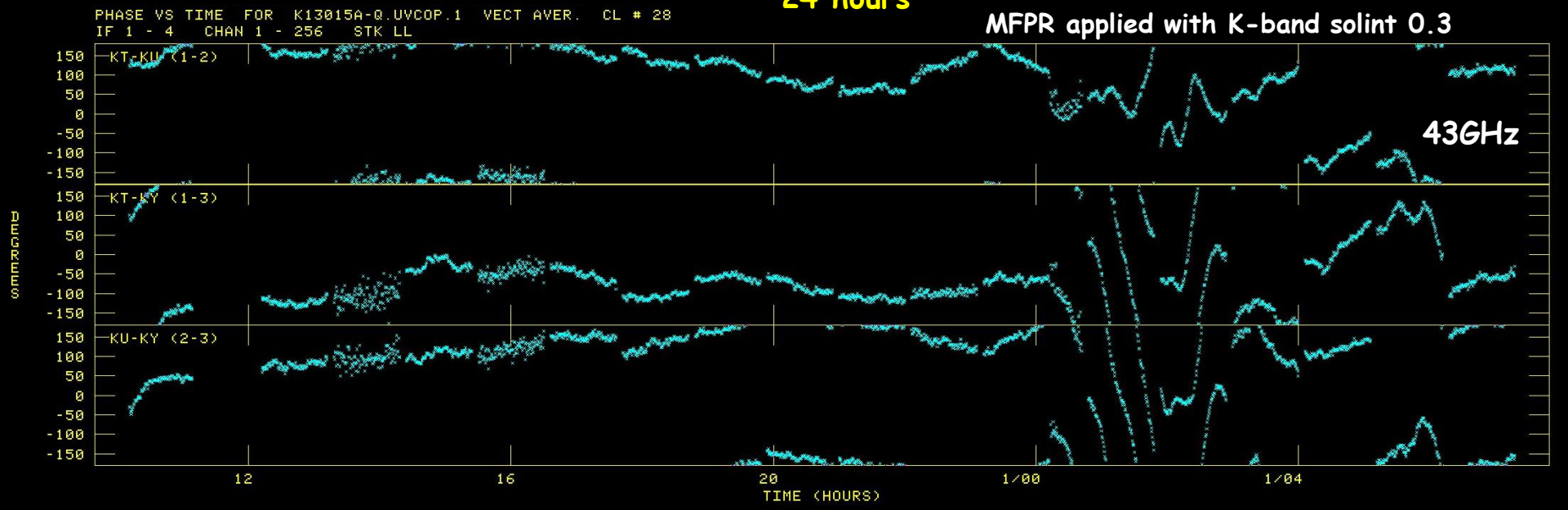
30min

43GHz Visibility Phase calibrated by FPT at 22GHz

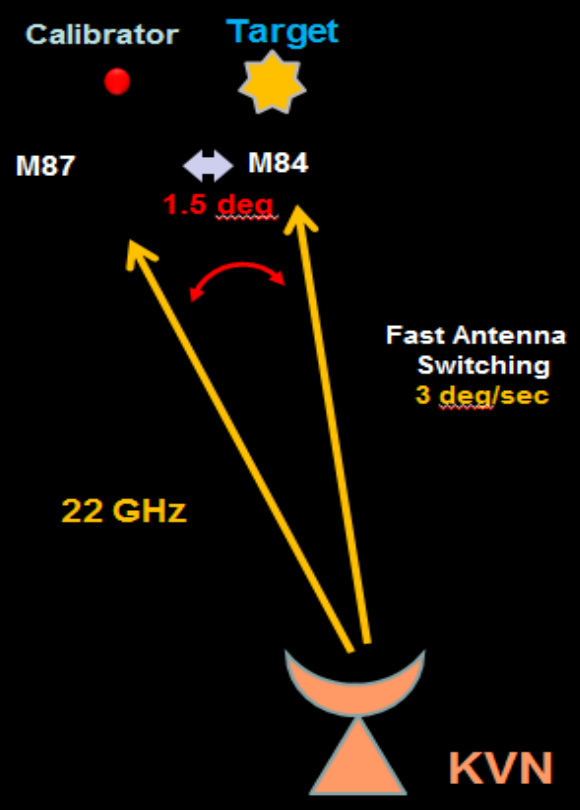


NRAO150 0133+476 3C84 1308+326 3C279 3C345 NRAO530 SGR-A 3C454.3 2255-282
0202+149 1023+131 3C273 1633+382 NRAO512 FAS 1921-293 BLLAC NRAO150

24 hours



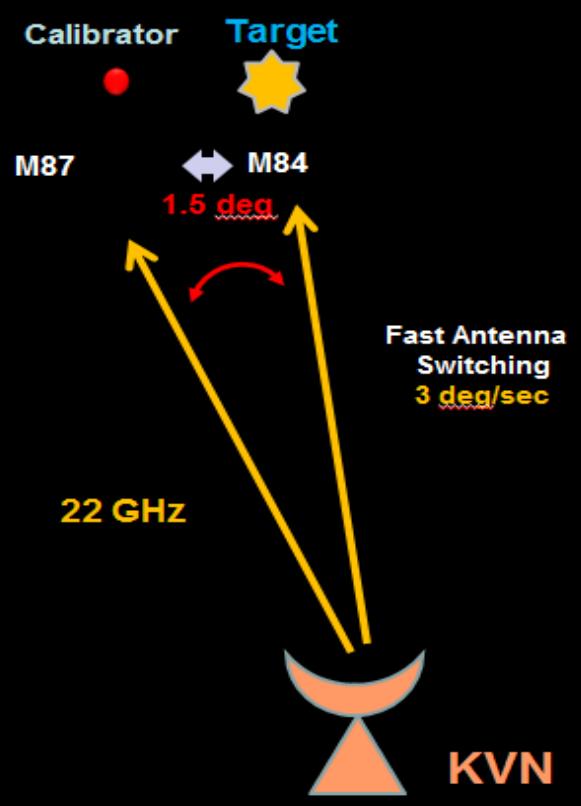
KVN Phase Referencing Test



- 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)

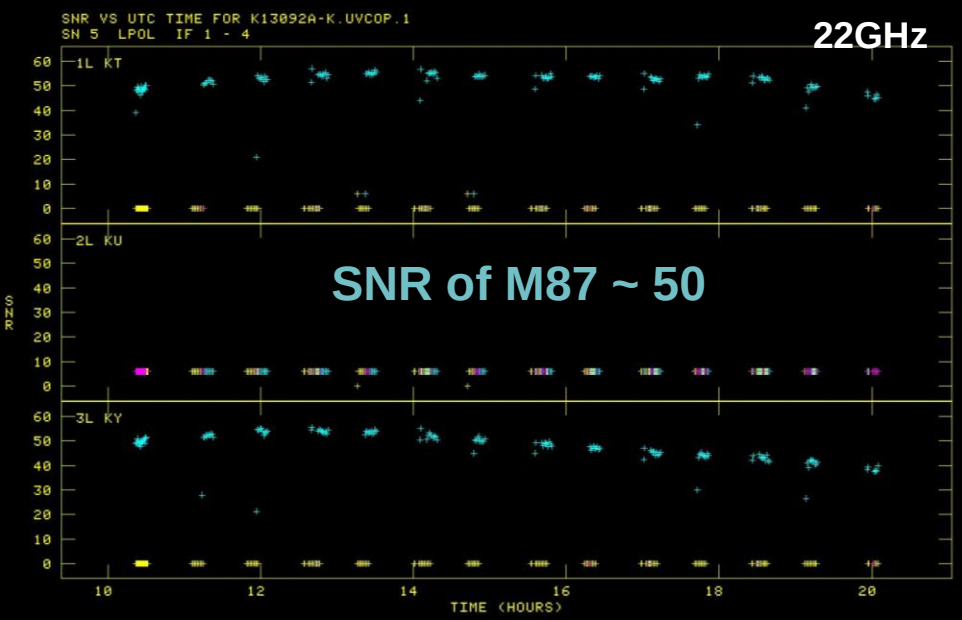
Three Phase Referencing Methods in KVN

FAS conventional PR

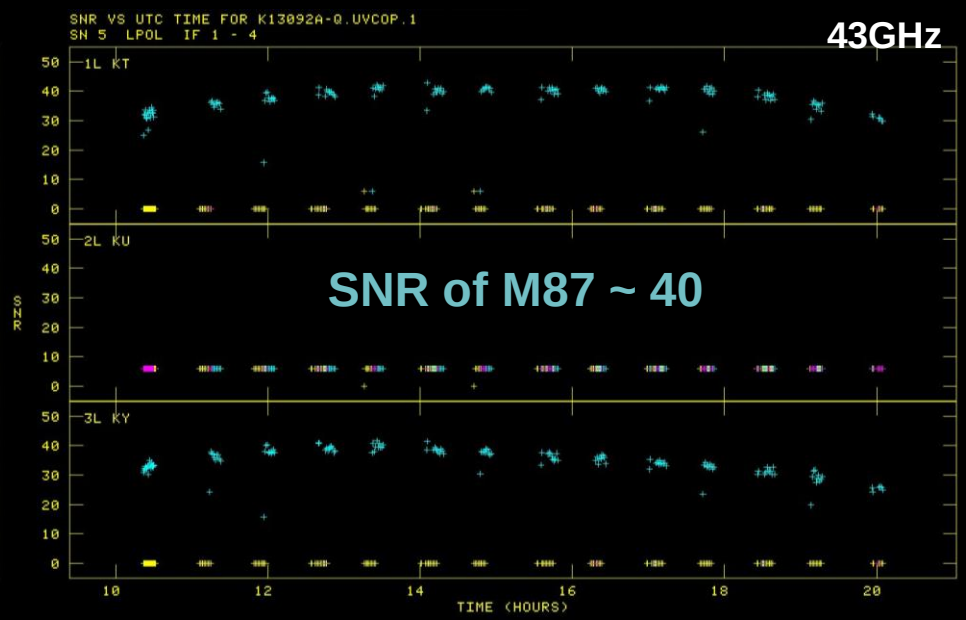


SNR: M87-M84

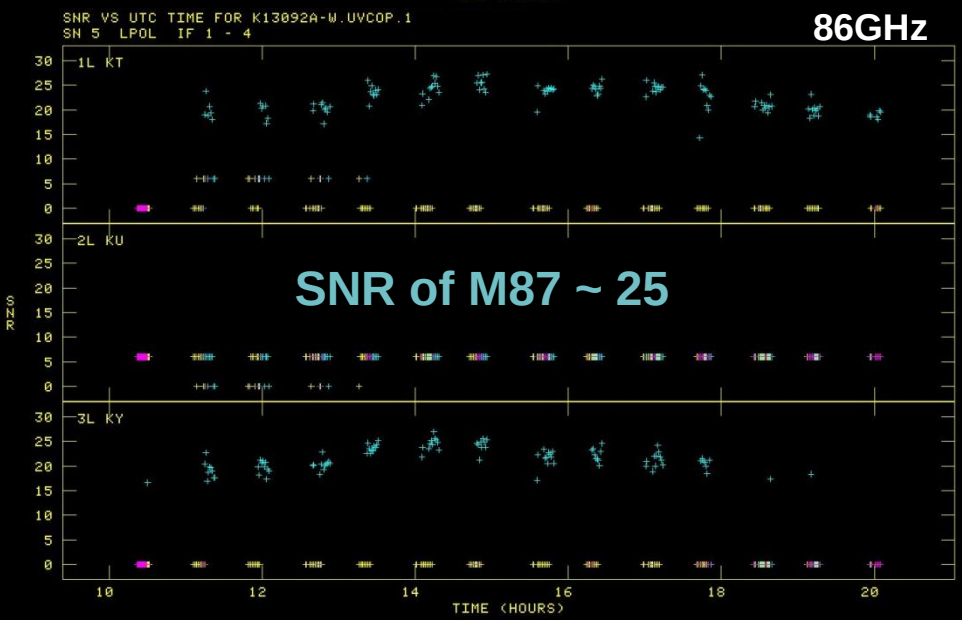
M84 – no detection at all freq.



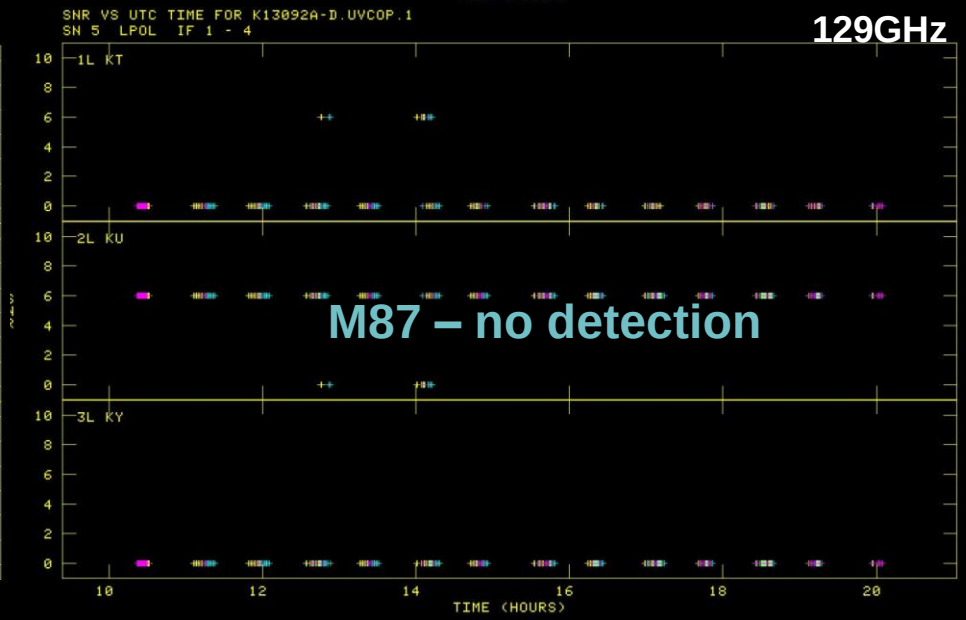
SNR of M87 ~ 50



SNR of M87 ~ 40

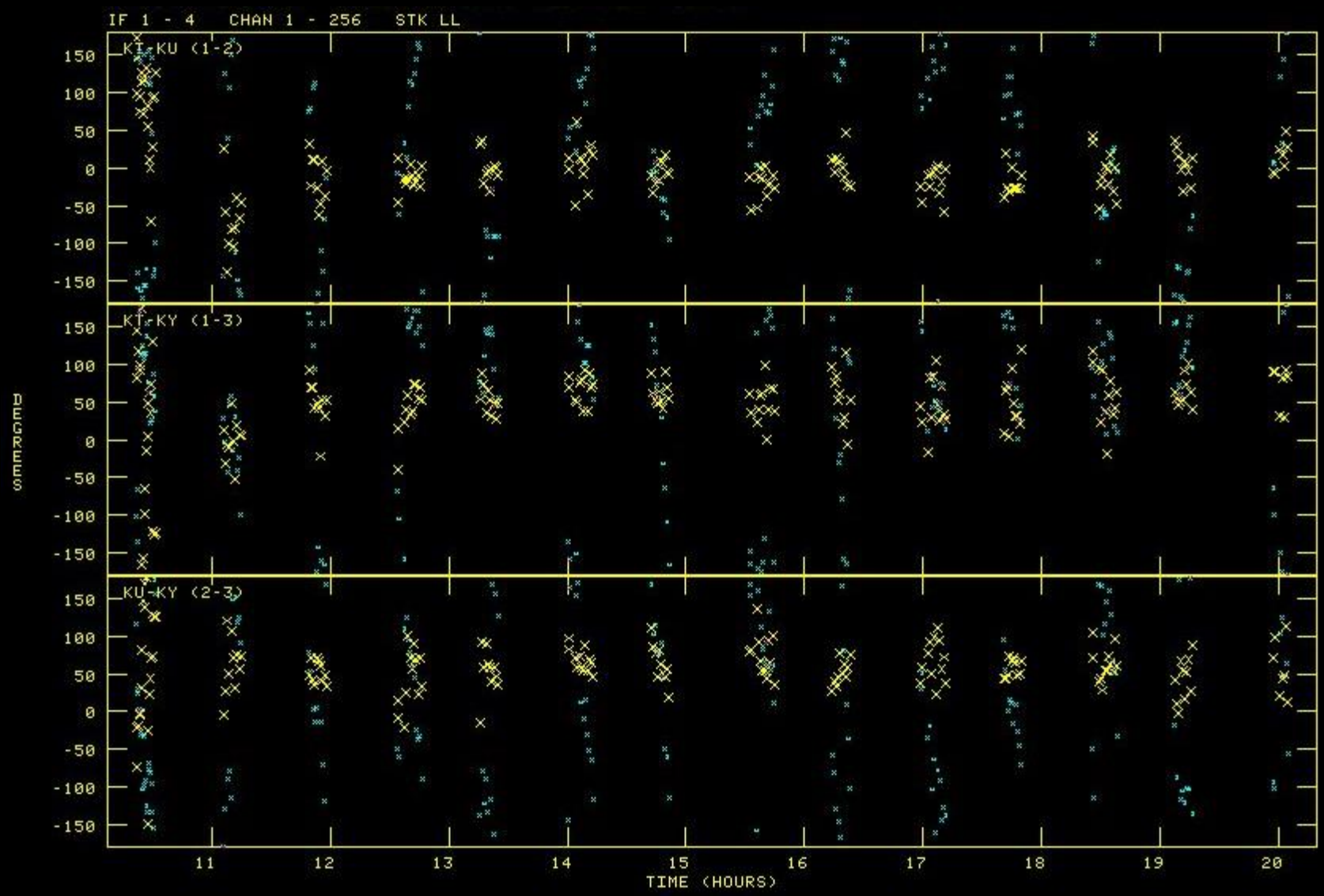


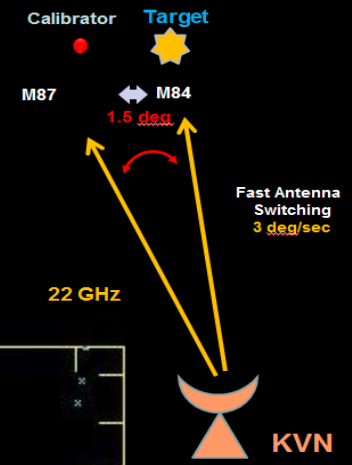
SNR of M87 ~ 25



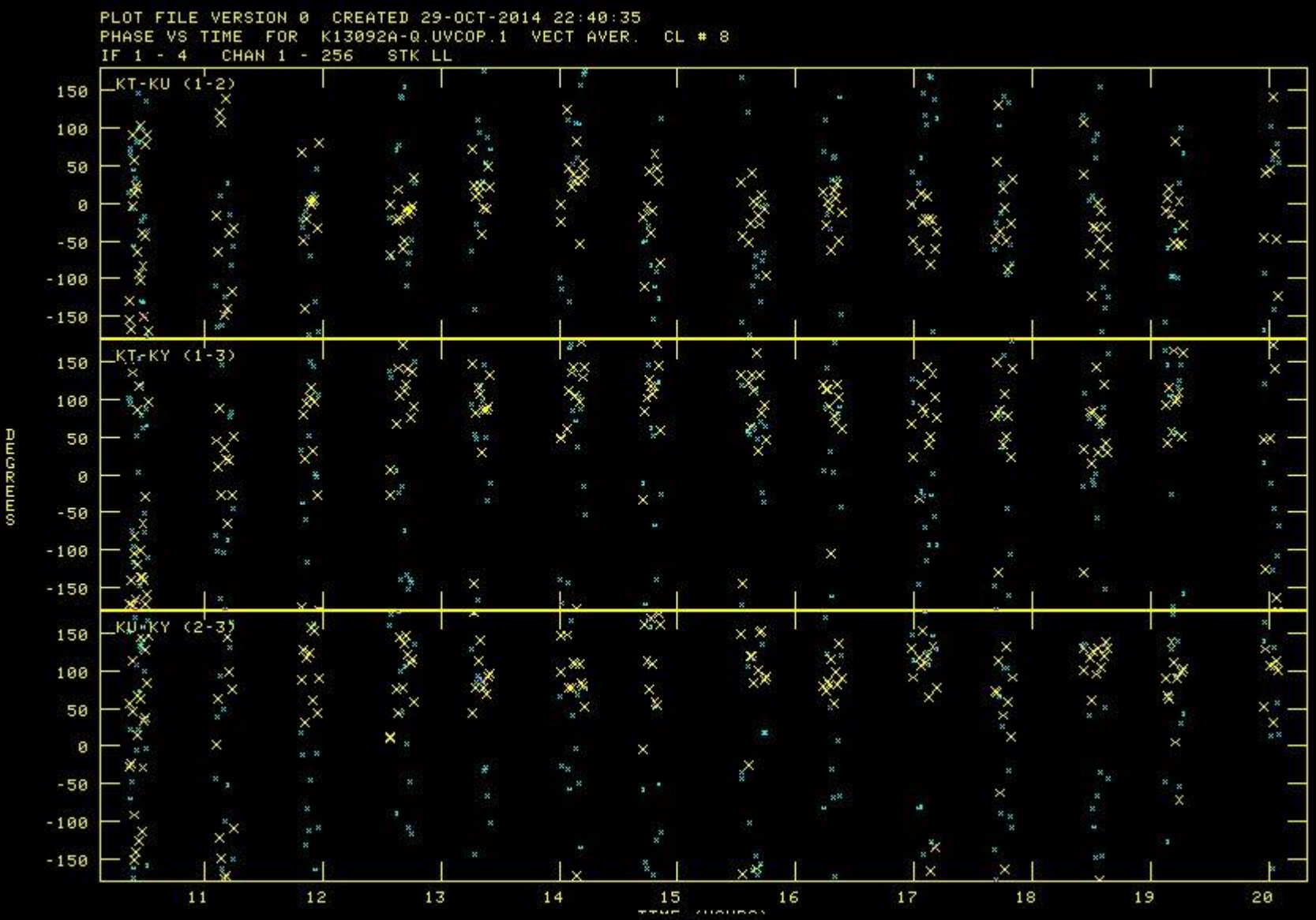
M87 – no detection

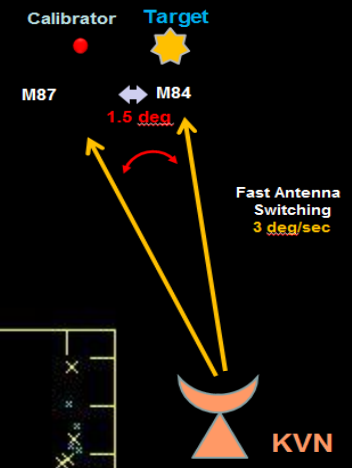
Fast Antenna Switching Phase Referencing
M87-M84 Test at 22GHz



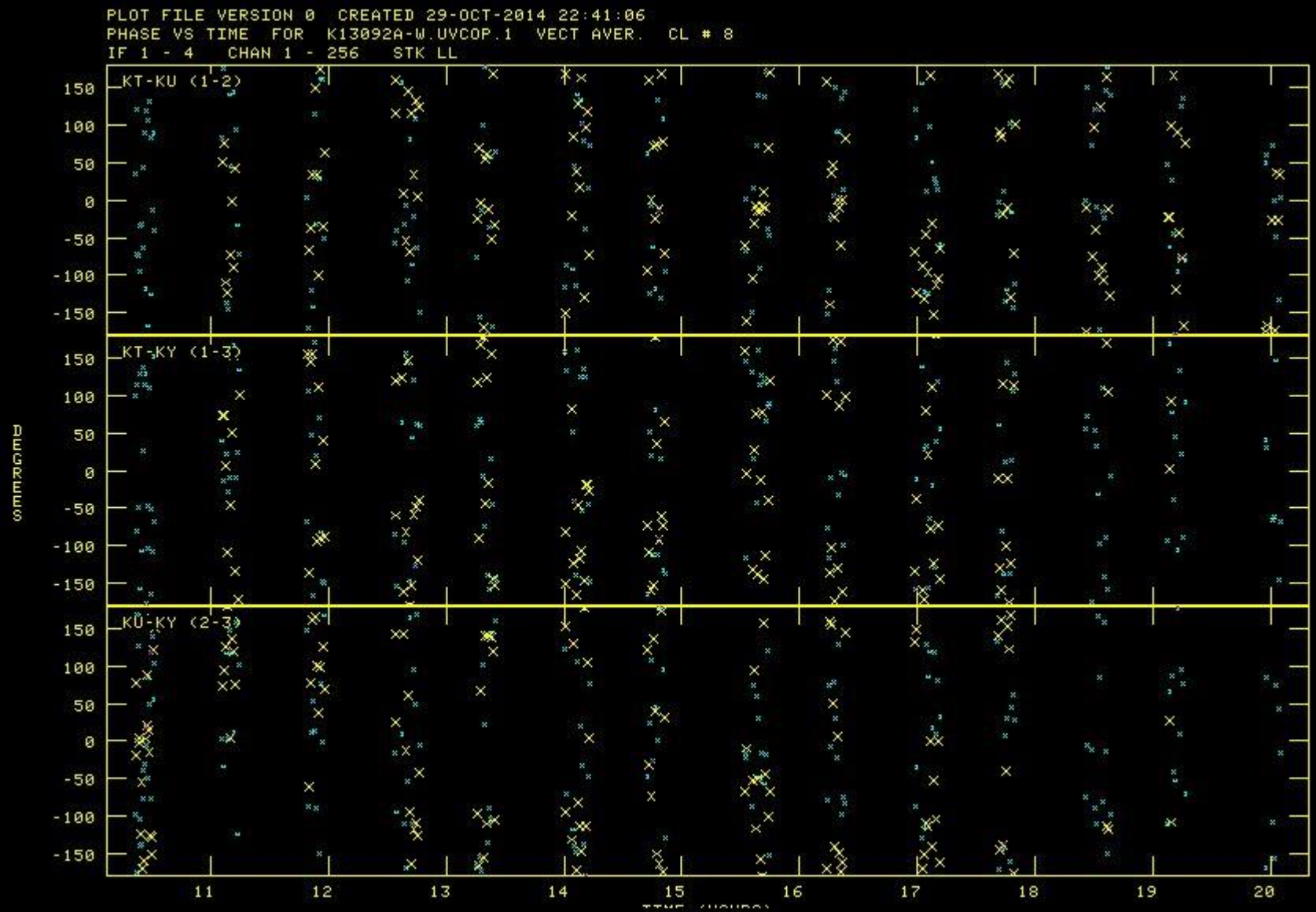


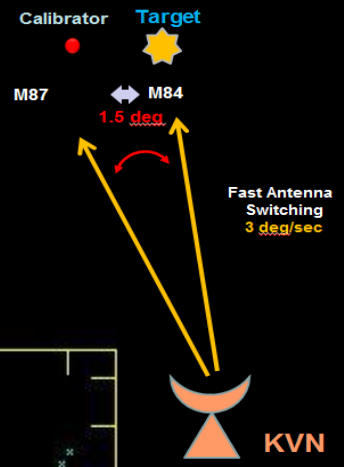
Fast Antenna Switching Phase Referencing
M87-M84 Test at 43GHz



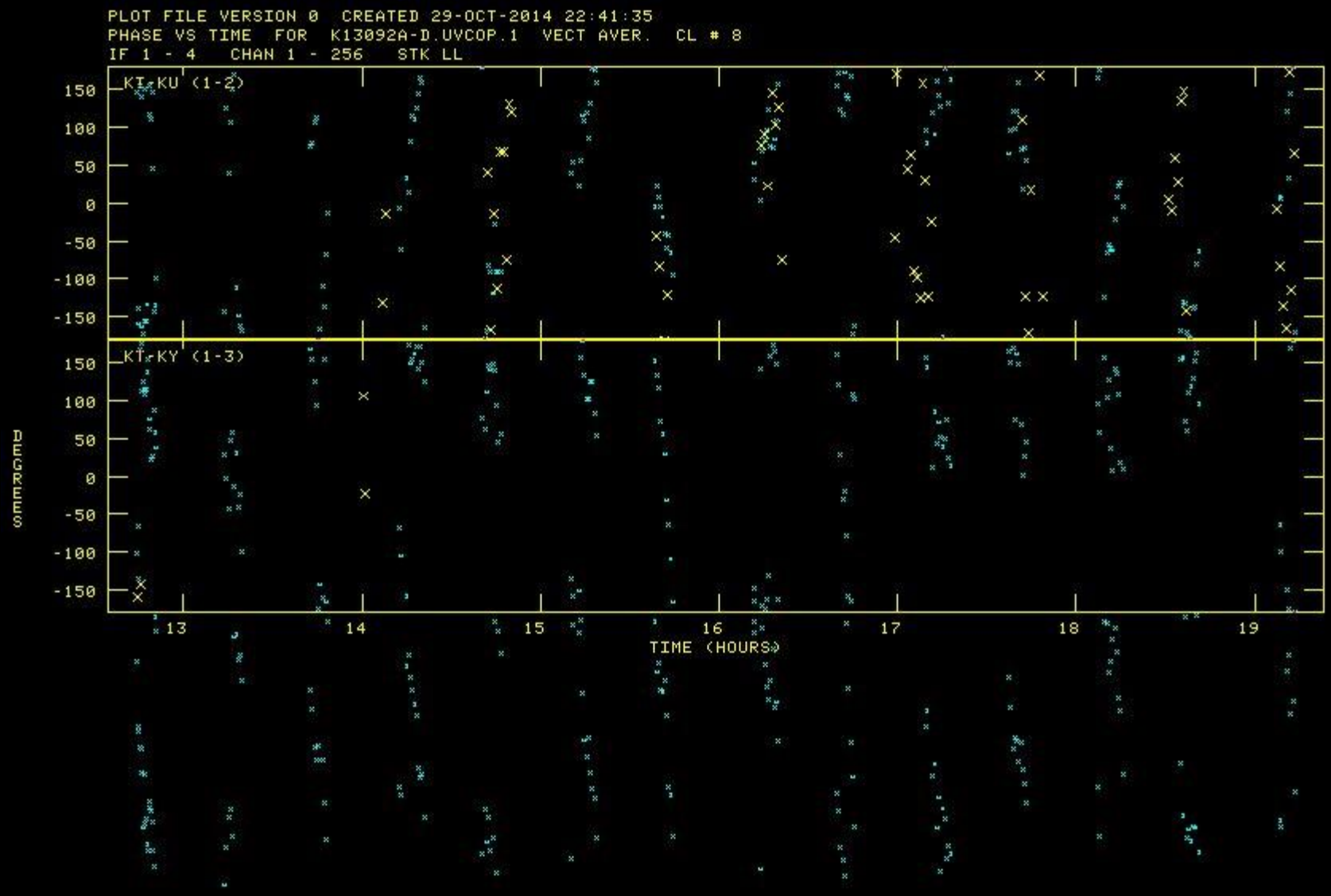


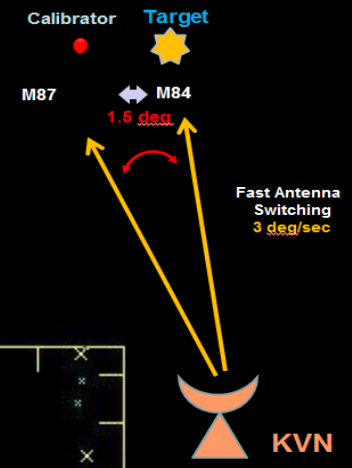
Fast Antenna Switching Phase Referencing
M87-M84 Test at 86GHz





Fast Antenna Switching Phase Referencing
M87-M84 Test at 129Ghz

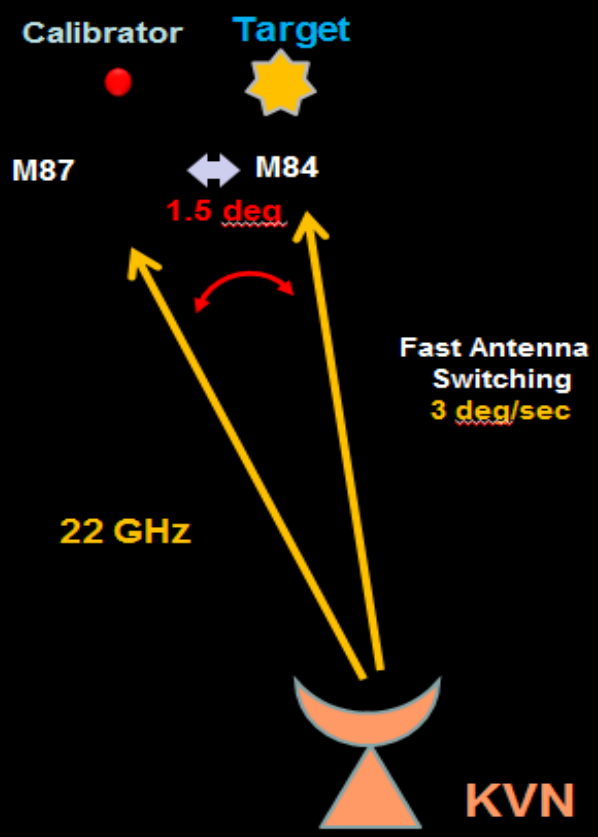


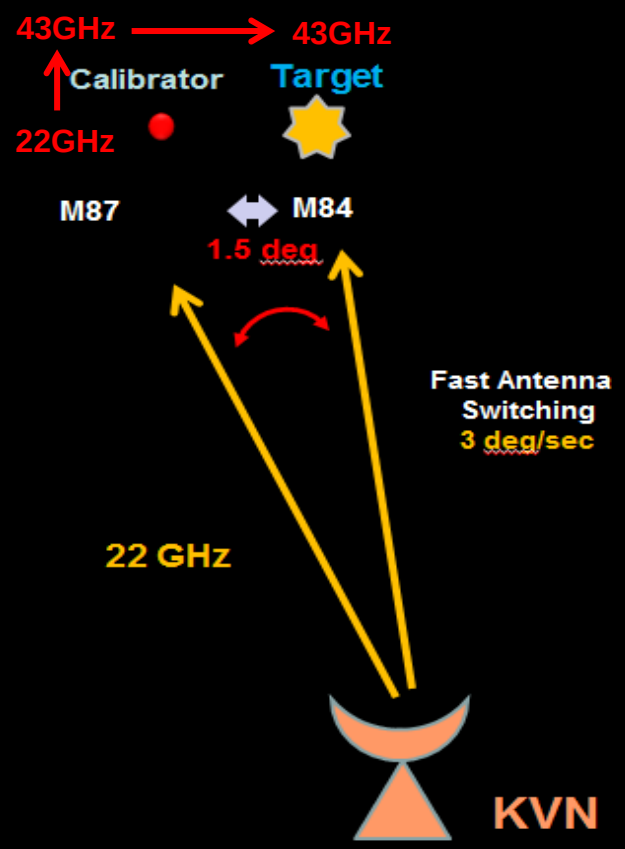


Three Phase Referencing Methods in KVN

FAS conventional PR

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



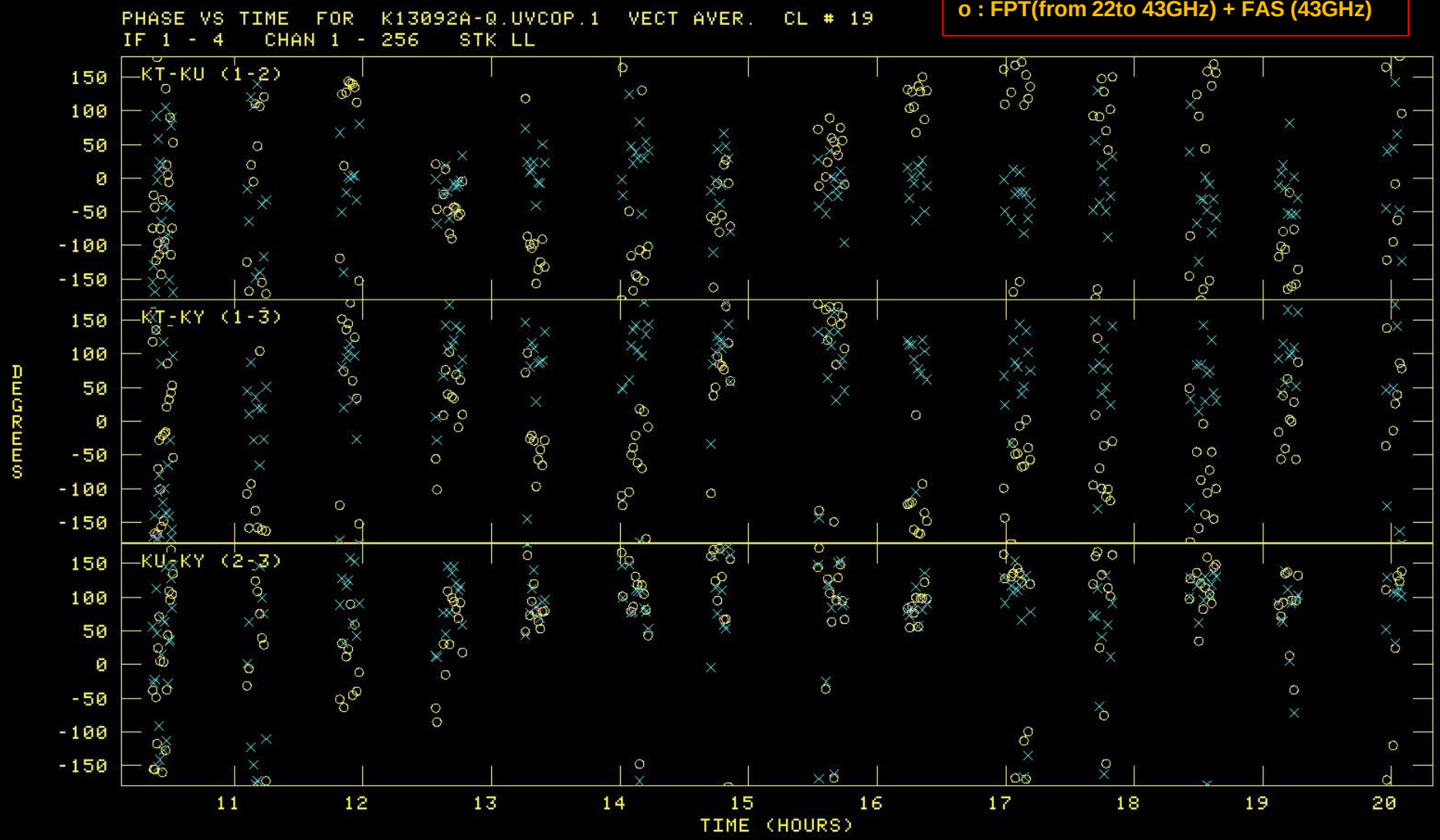


Example : FAS vs (FPT+FAS) : M84 calibrated by M87

FPT + FAS

1. phase scaling of calibrator
2. apply conventional PR

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



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

FPT + FAS

1. phase scaling of calibrator
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x : 43GHz FAS phase
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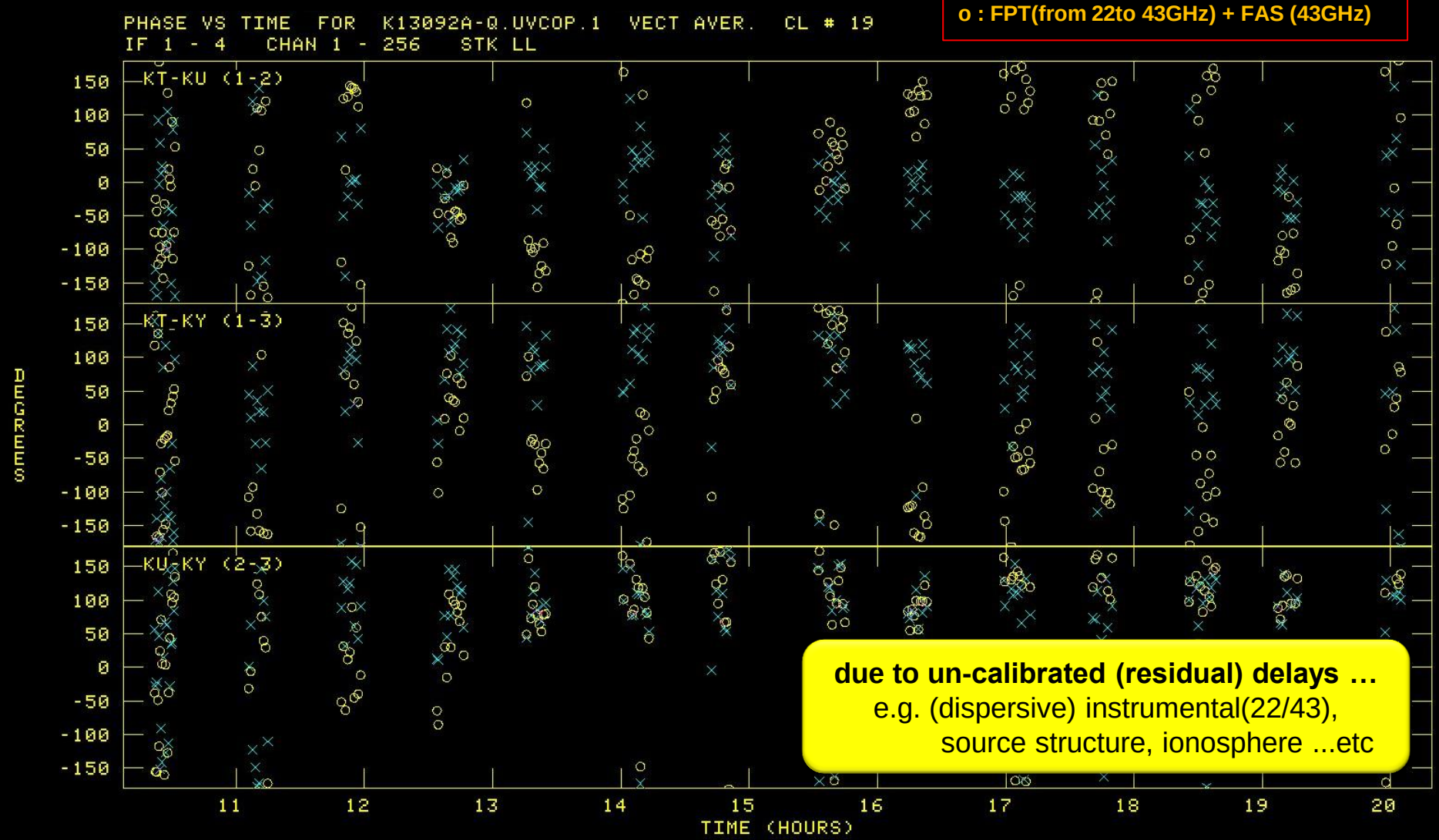


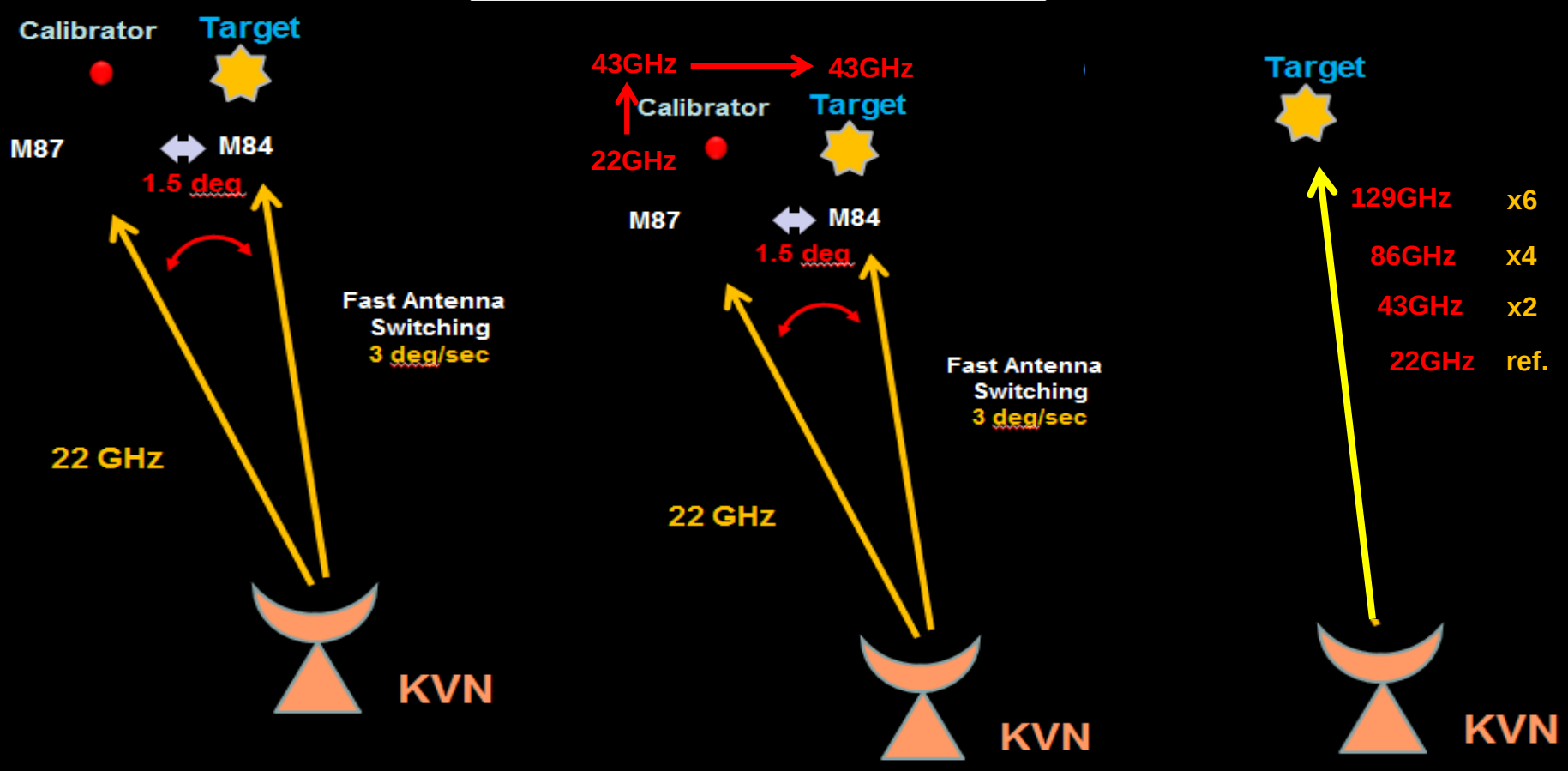
due to un-calibrated (residual) delays …
e.g. (dispersive) instrumental(22/43),
source structure, ionosphere ...etc

Three Phase Referencing Methods in KVN

FAS conventional PR

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

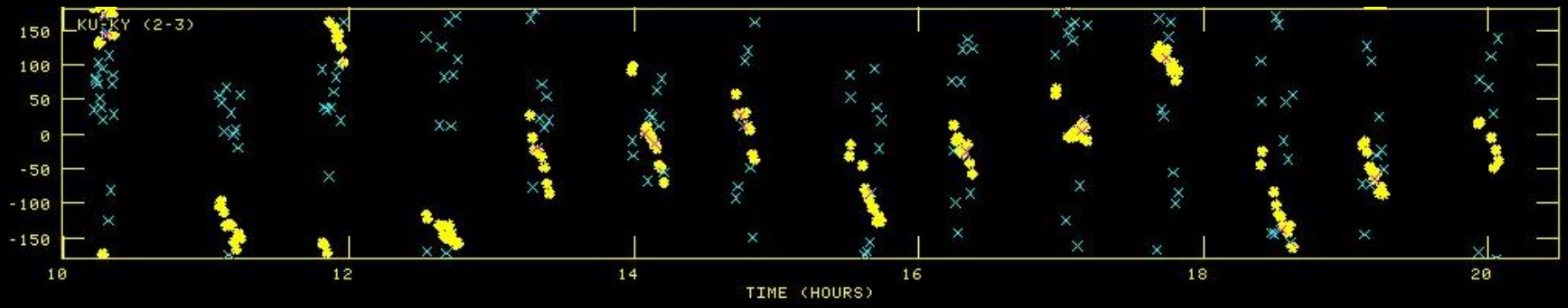
FPT
Frequency Phase Transfer



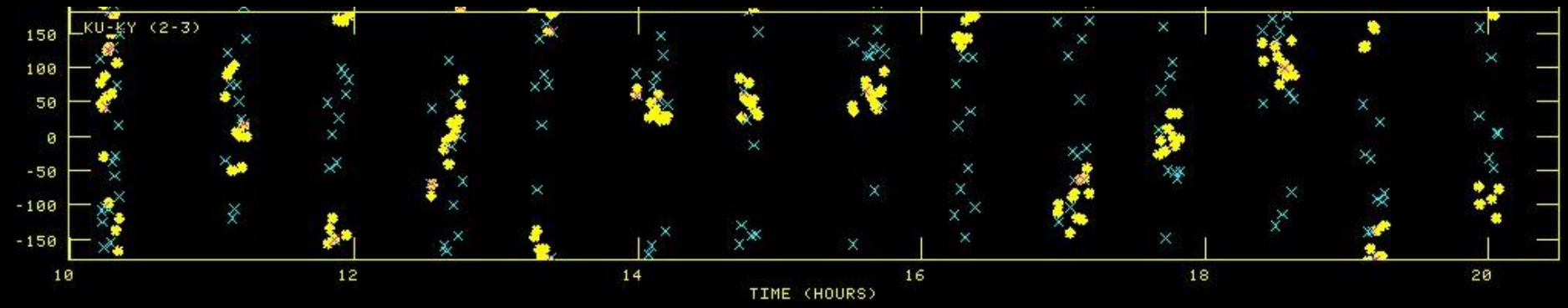
Comparison: Raw Visibility Phase & FPT Phase for M87

43GHz Raw & FPT (22GHz phase x 2)

86GHz Raw & FPT (22GHz phase x 4)



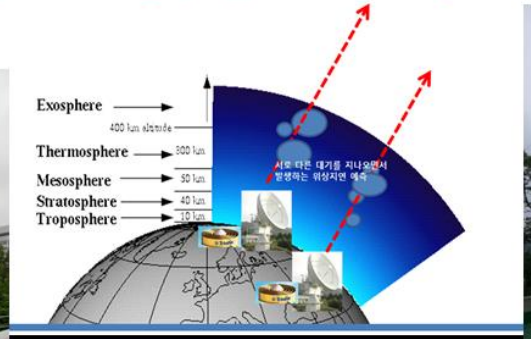
129GHz Raw & FPT (22GHz phase x 6)



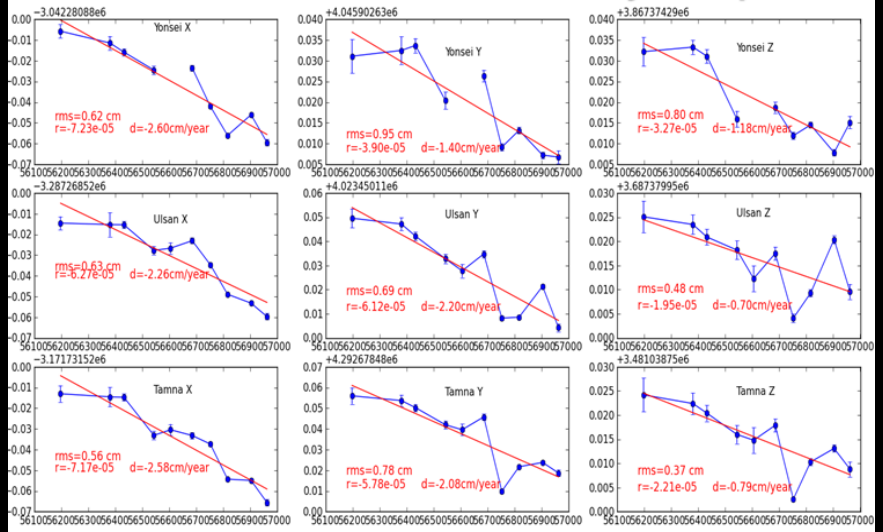
GPS Installation - close collaboration with KASI GPS group

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

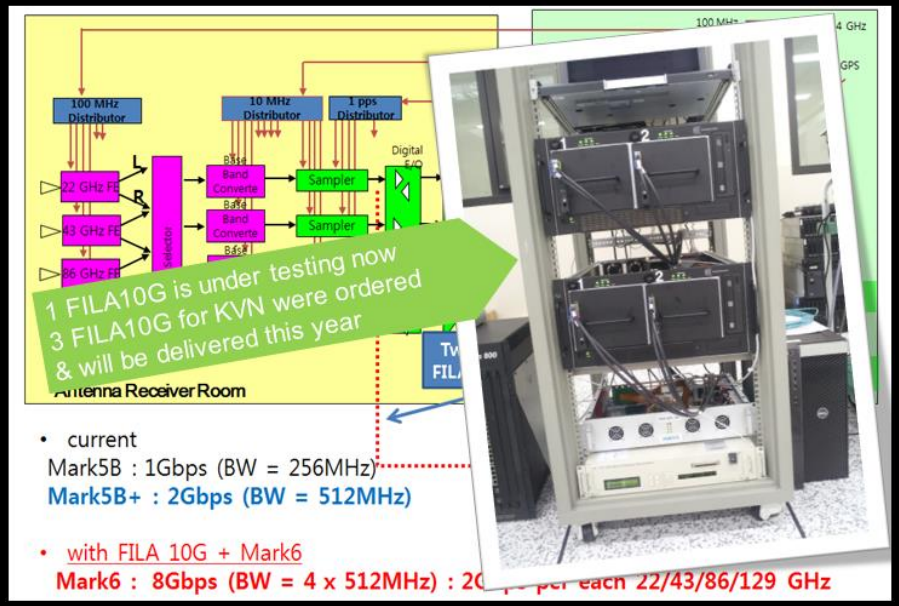


KVN IVP from KaVA K-band Geodesy (10 epochs)



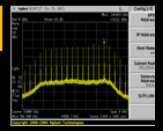
XYZ RMS variation
10 epochs: Yonsei ~ 1.39 cm, Ulsan ~ 1.39 cm, Tamna ~ 1.03 cm X-axis: MJD Y-axis: Position (m)

KVN 8Gbps Operations with FILA10G & Mark6

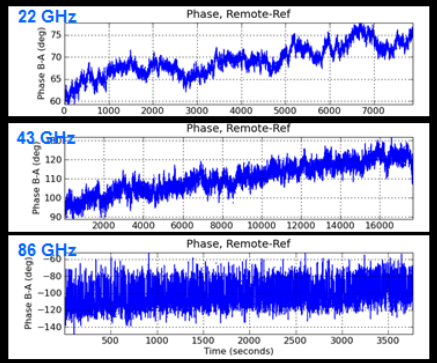


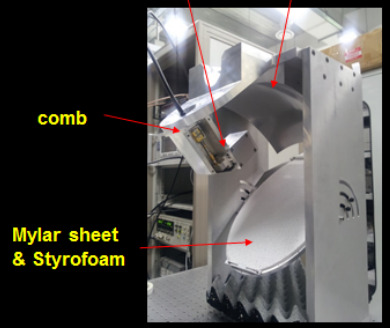
- current
  Mark5B : 1Gbps (BW = 256MHz)
  Mark5B+ : 2Gbps (BW = 512MHz)
- with FILA 10G + Mark6
  Mark6 : 8Gbps (BW = 4 x 512MHz) : 2C per each 22/43/86/129 GHz

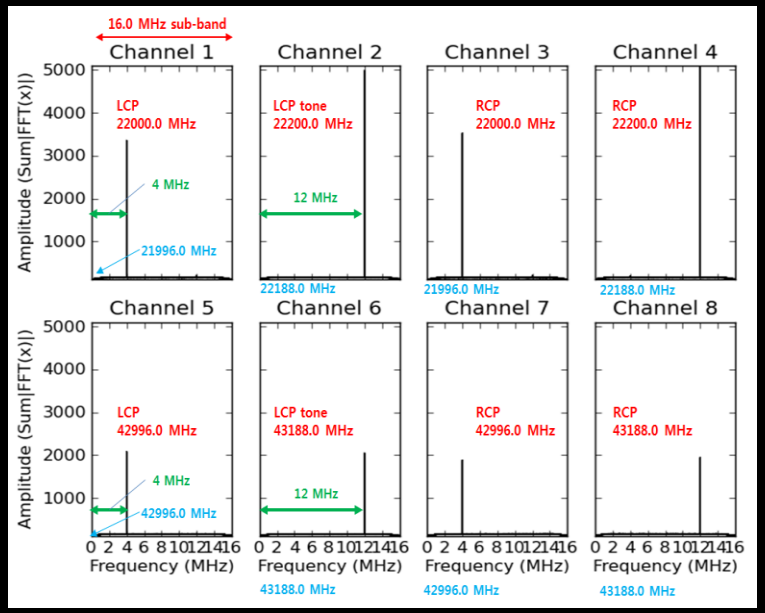
Developments of Phase Tone Calibration System

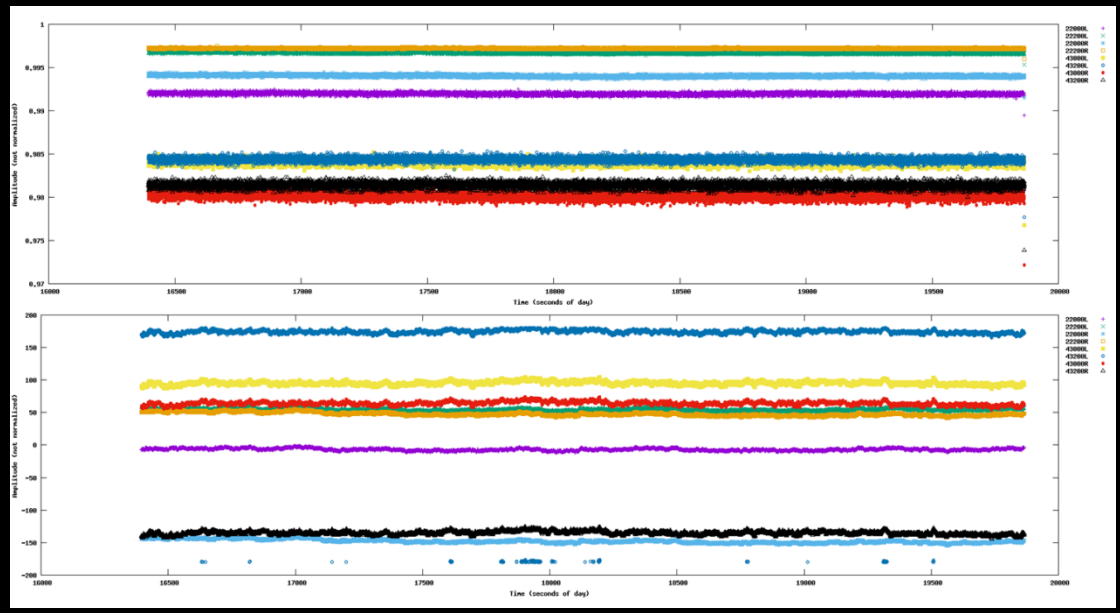


- **1st approach: Quasi-optics Injection Method**
  - Reference signal frequency : 200 MHz
  - Comb generator : commercial NLTL(2.4mm connector, spec: <50 GHz)
  - Quasi-optics injection using DRWH, ellipsoidal mirror & Mylar sheet
  - Custom designed comb needed for 129 GHz-band power generation
  -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

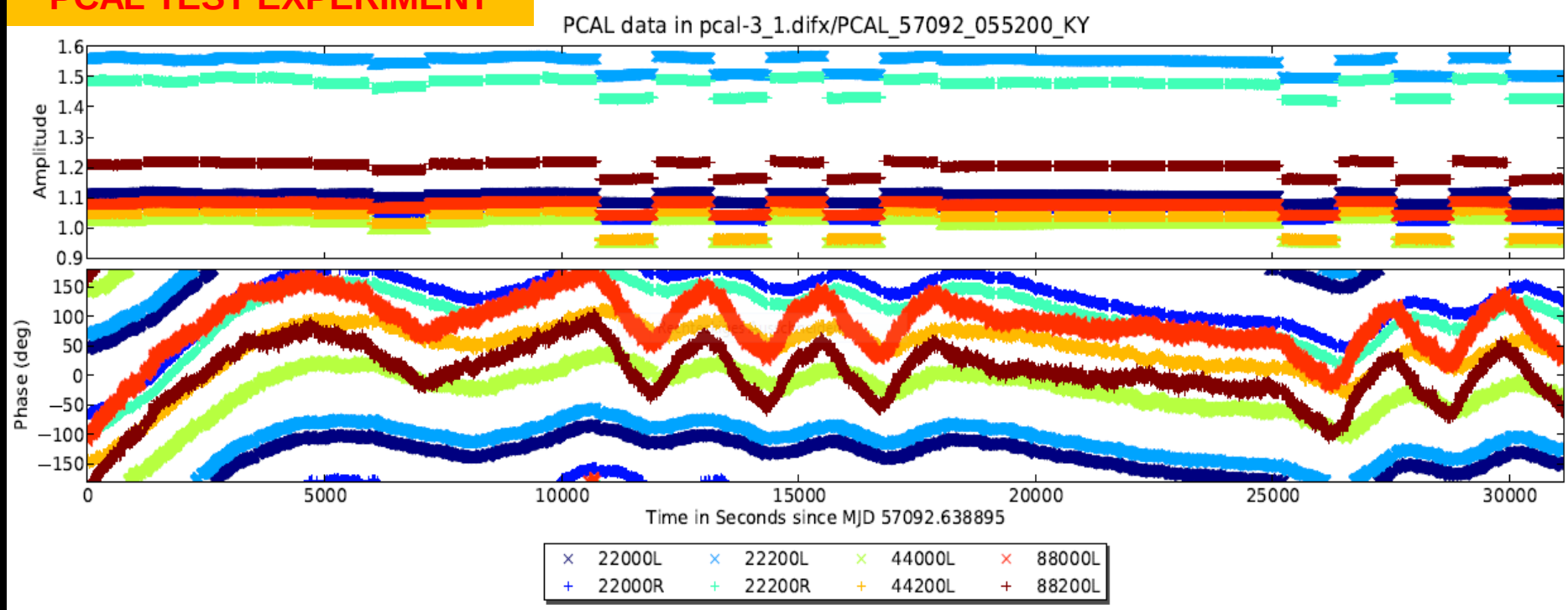






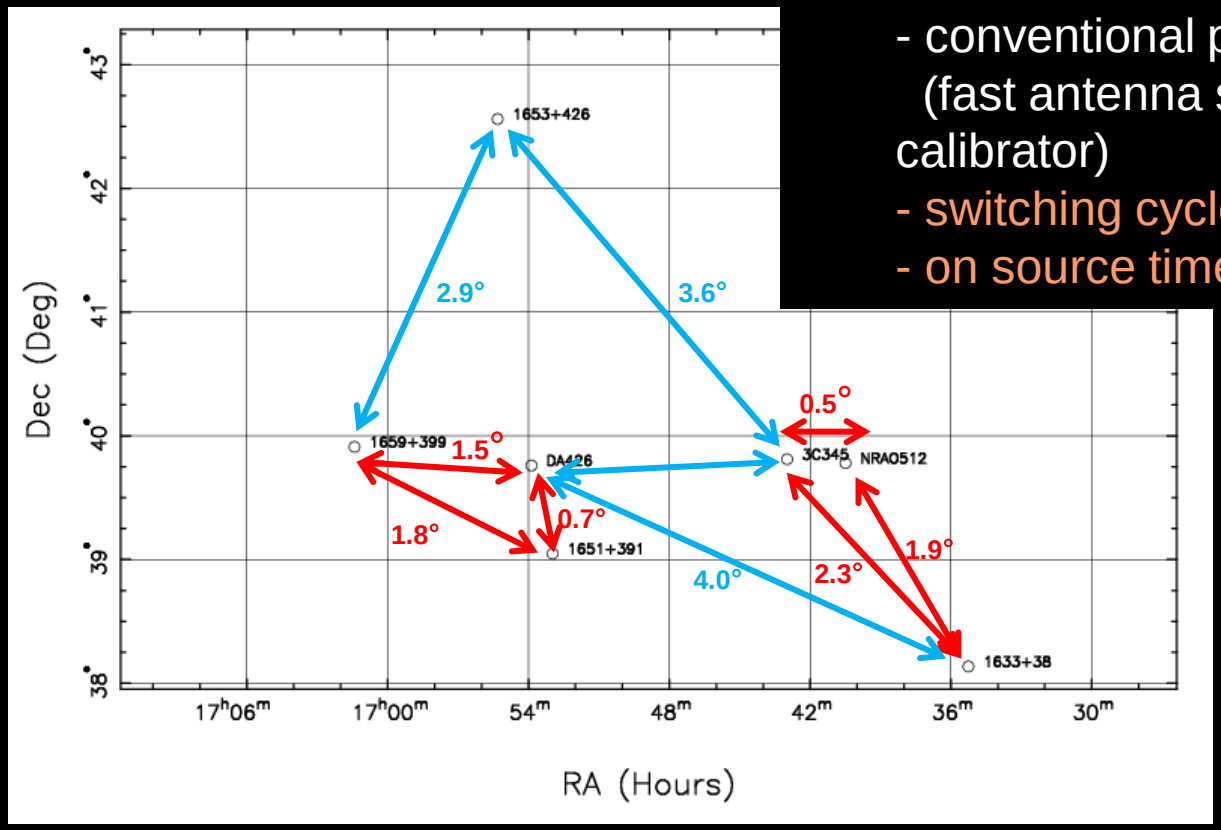


PCAL TEST EXPERIMENT



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

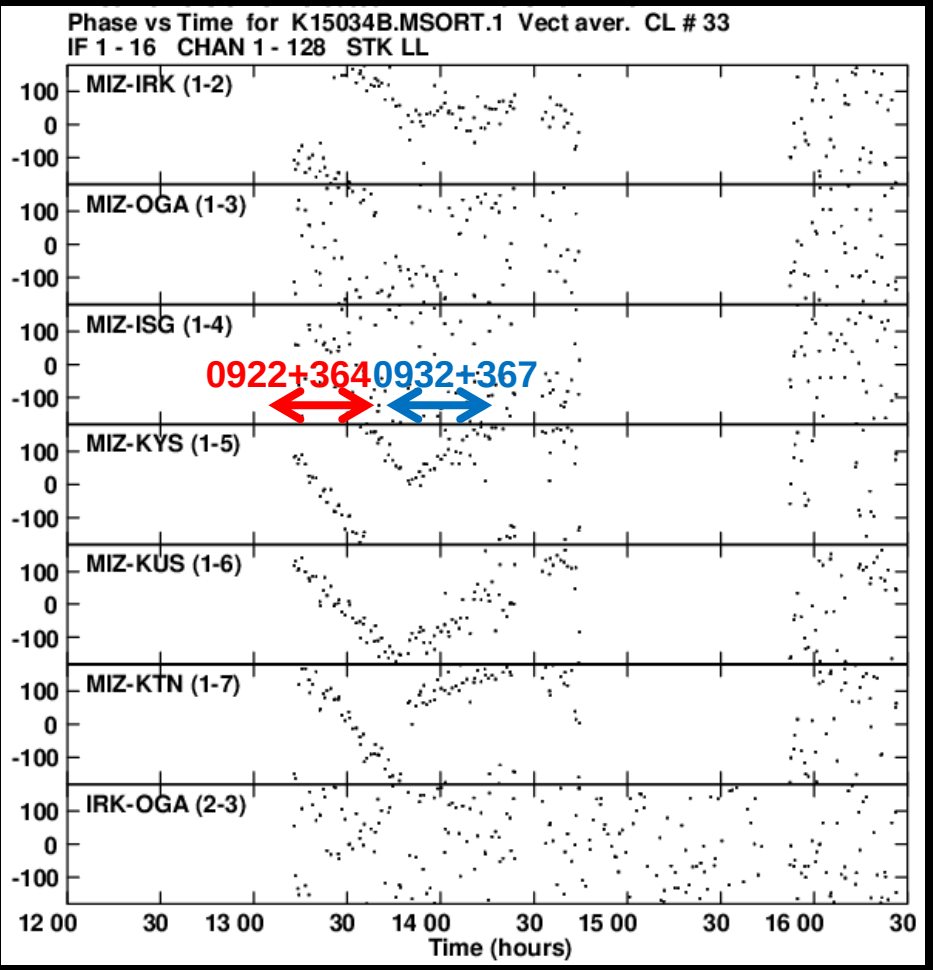


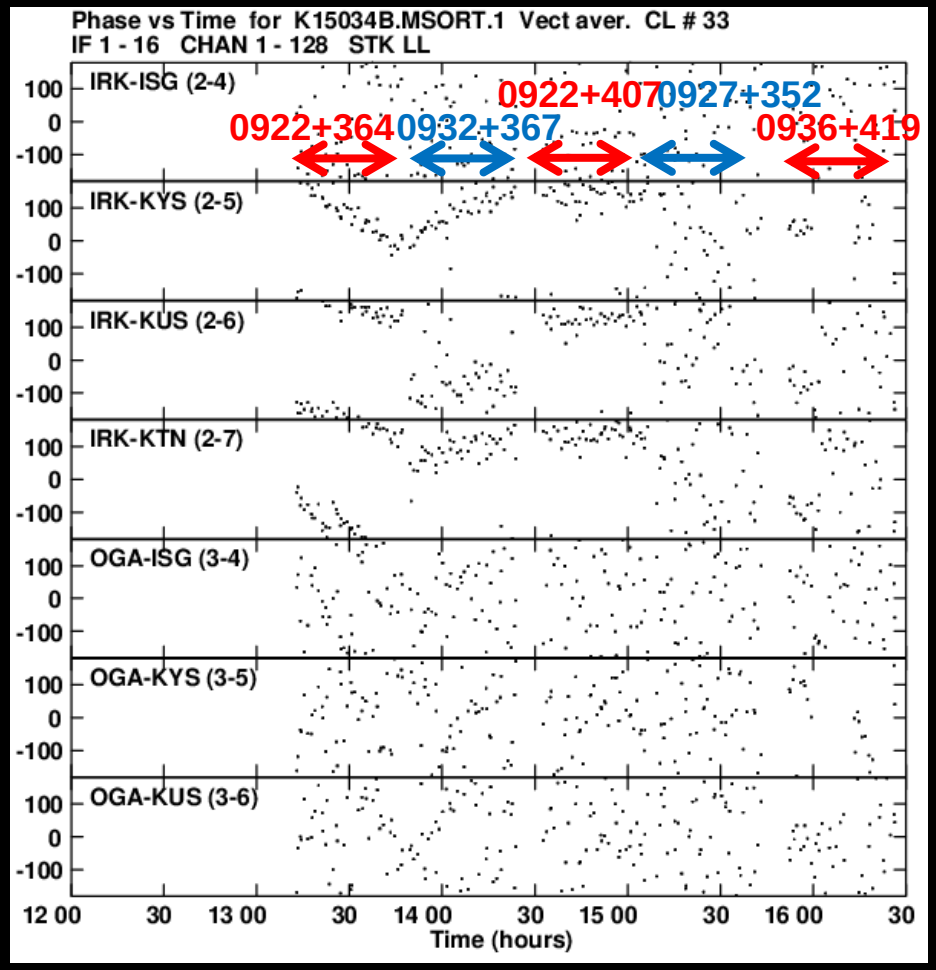
Example of Source Pairs

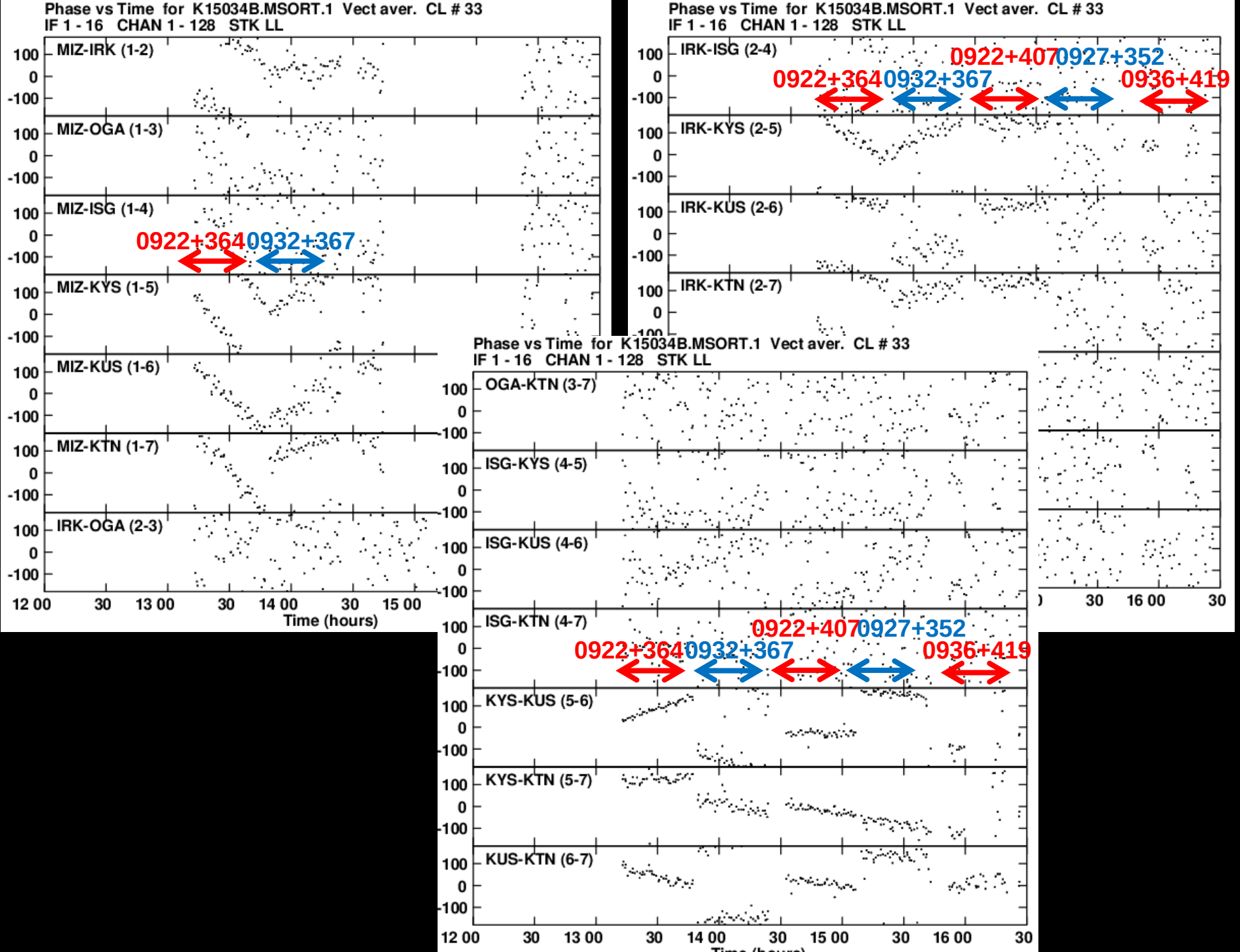
Cal/Tar SRC	S.A.	Self-detection (30 sec integration)
4C39.25	-	All detected (SNR~ several hundreds)
0928+390	0.77	few marginal detection at KYS & KUS only
0922+364	2.84	few marginal detection at KYS & KUS only
0932+367	3.00	No detection
0922+407	1.47	No detection
0927+352	4.05	No detection
0936+419	3.60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

※ Yellow (Calibrator), Others (Targets), S.A. : Separation Angle (degree)

KaVA Phase Referencing Result (calibrated by 4C39.25)






Phase vs Time for K15034B.MSORT.1 Vect aver. CL # 33
IF 1 - 16 CHAN 1 - 128 STK LL
MIZ-IRK (1-2)
MIZ-OGA (1-3)
MIZ-ISG (1-4)
0922+364
0932+367
MIZ-KYS (1-5)
MIZ-KUS (1-6)
MIZ-KTN (1-7)
IRK-OGA (2-3)
12 00
30
13 00
30
14 00
30
15 00
Time (hours)
IRK-ISG (2-4)
0922+407
0927+352
0922+364
0932+367
0936+419
IRK-KYS (2-5)
IRK-KUS (2-6)
IRK-KTN (2-7)
30
16 00
30
OGA-KTN (3-7)
ISG-KYS (4-5)
ISG-KUS (4-6)
ISG-KTN (4-7)
0922+407
0927+352
0922+364
0932+367
0936+419
KYS-KUS (5-6)
KYS-KTN (5-7)
KUS-KTN (6-7)
100
0
-100

Accurate Delay Errors Calibration

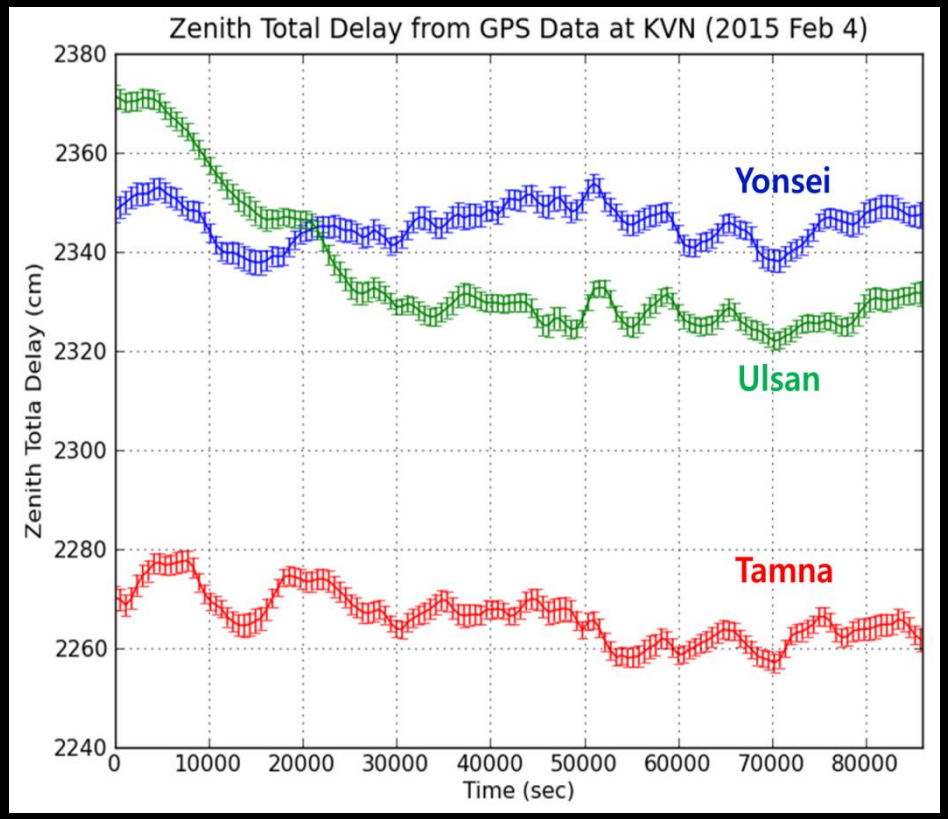
1. **Large-scale systematic delay errors**
   ≈ correlation model (apriori) errors
   clock / instrumental errors

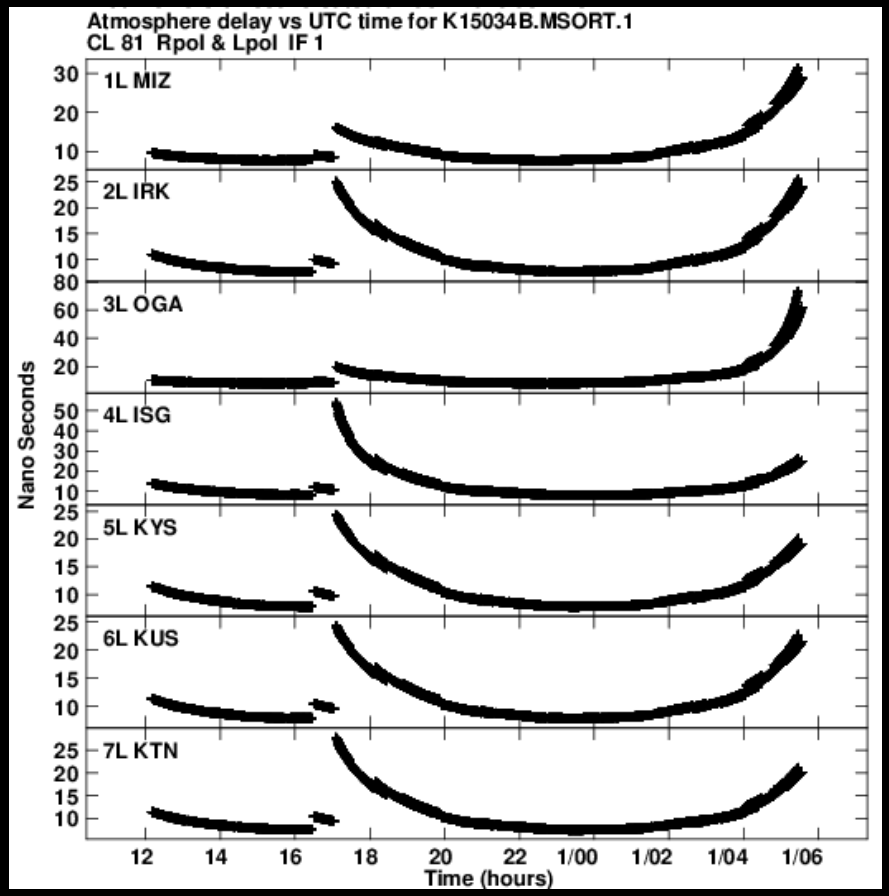
   typically, $\Delta\tau_a > 5$ cm
   → this should be reduced ~ 1 cm level
   → method : GPS/JAM application (ion / troposhere)
   EOP correction
   Geodetic block or Multiple calibrators
   Pcal & special observing design

2. **(Relatively) small-scale (random) delay errors**
   ≈ mostly weather related errors

   typically, 0.05 cm (~15°) < $\Delta\tau_r$ < 0.5 cm (~150°) at 22GHz
   → nearby calibrators

Delay Errors – GSP/JAM ZTD Inputs





ZTD (raw) from GPS
for KaVA 22GHz PR Test Observation

ZTD in AIPS from JAM
for KaVA 22GHz PR Test Observation

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


Thank you!
Nanshan 26 m
Miyun 50 m
Yonsei 21 m
Ulsan 21 m
Gifu 11 m
Usuda 64 m
Tomakomai 11 m
Mizusawa 20 m
Tamna 21 m
Takahagi 32 m
Tianma 65 m
Sheshan 25 m
Yamaguchi 32 m
Hitachi 32 m
Kunming 40 m
Ishigakijima 20 m
Iriki 20 m
Kashima 34 m
Tsukuba 32 m
Ogasawara 20 m
The East Asia VLBI Network
(Image Credit: Reto Stöckli, NASA Earth Observatory)
6.7 GHz
8 GHz
22 GHz
43 GHz
Wajima-san