広帯域VLBIシステムの開発状況と EVGA meeting 報告

関戸　衛、鹿島VLBIグループ（NICT)

2017年　第16回TDCシンポジウム

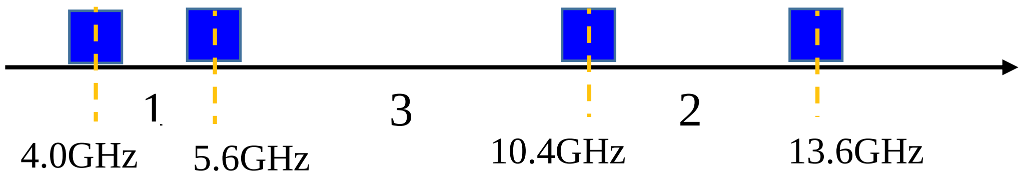
GALA-V Project Overview

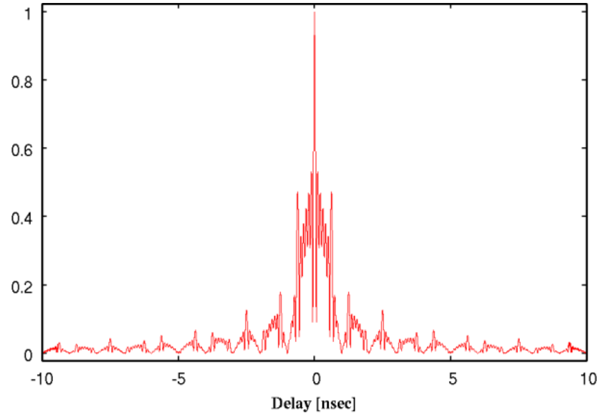
Frequency comparison by using Transportable Broadband telescopes

- VLBI Sensitivity :VLBI Sensitivity=$\propto D_1 D_2 \sqrt{BT}$

  B: 32MHz → 1024MHz (32 times)

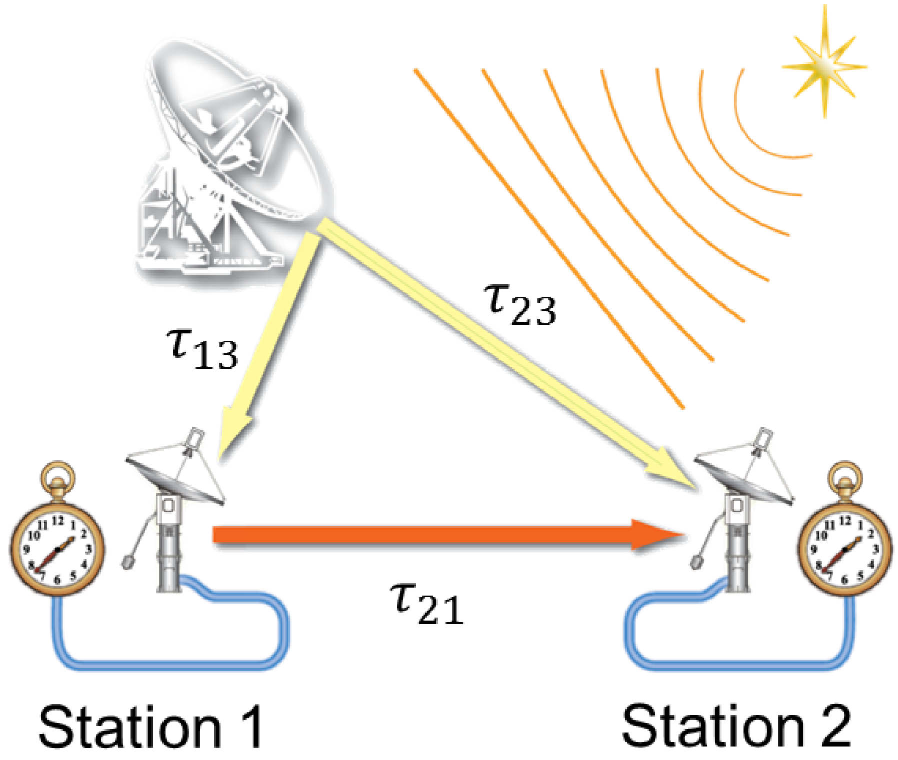
- Radio Frequency： 3-14 GHz
- Data Acquisition： 4 band (1024 MHz width)
  - Nominal Freq. Array: Fc=4.0GHz, 5.6GHz, 10.4GHz, 13.6GHz
  - Effective Bandwidth：3.8GHz (10 times more than Conventional)





Delay Resolution Function

10 time higher resolution will be gained by broader bandwidth

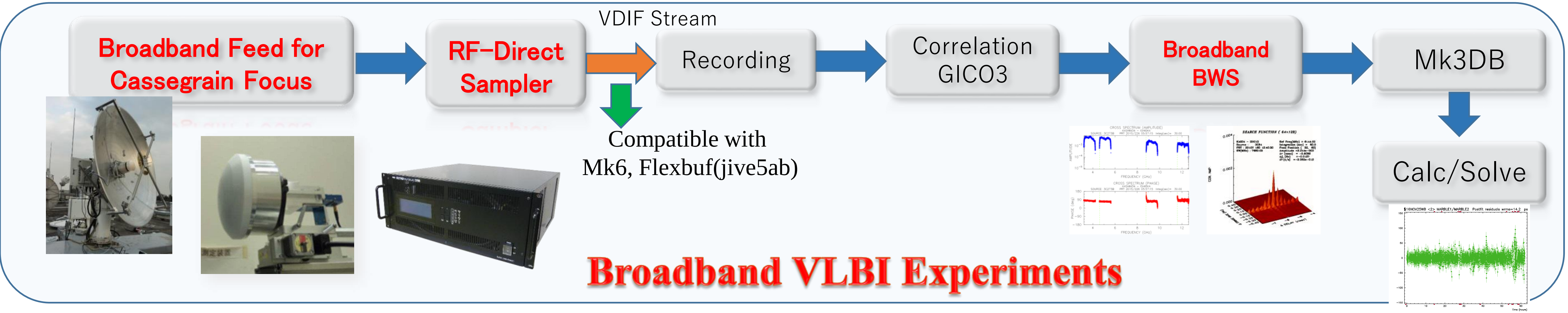


$$\tau_{21} = \tau_{13} - \tau_{23}$$

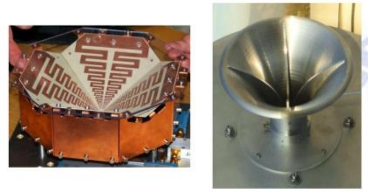
By using closure delay relation.

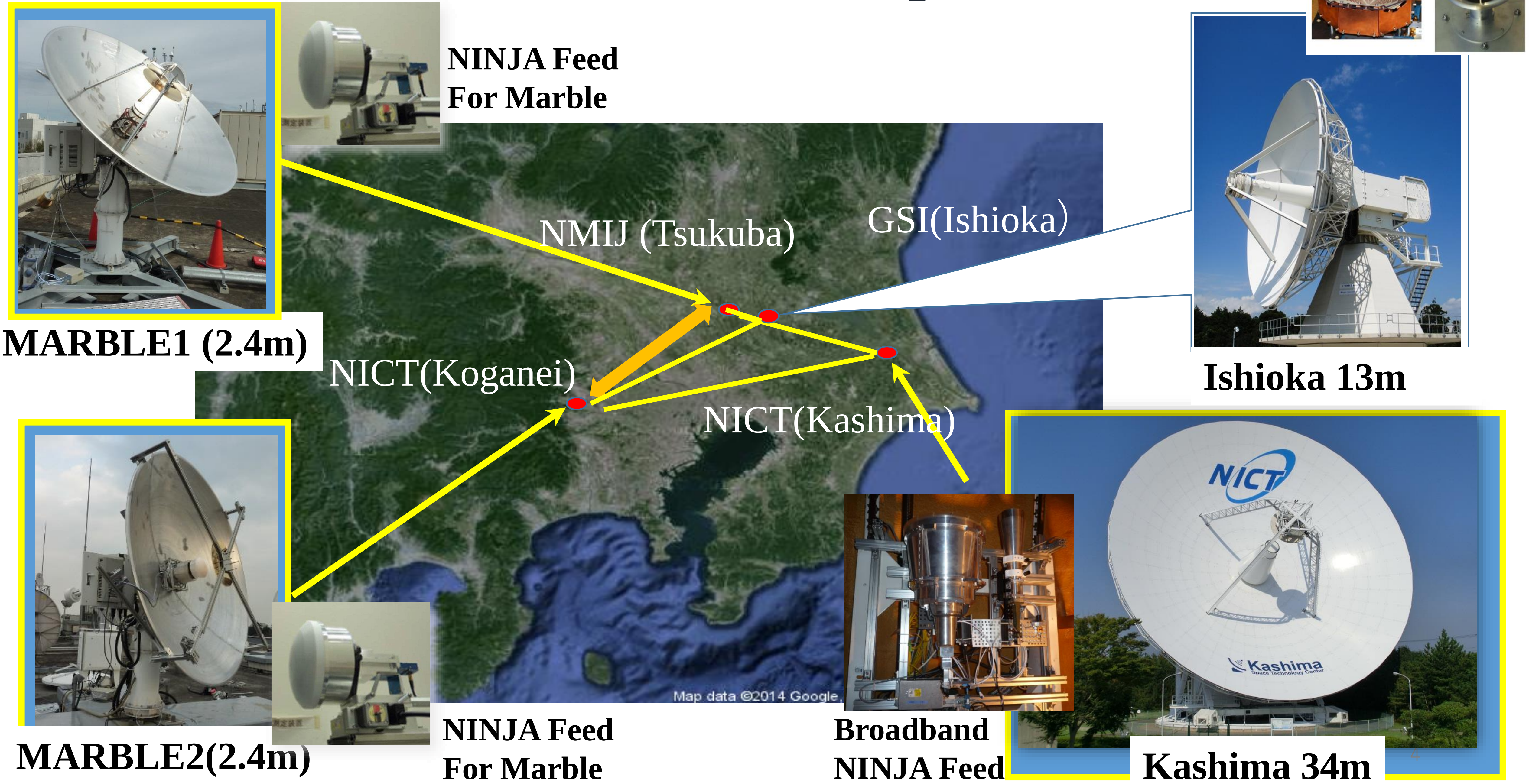
受信機開発・データ取得・処理・解析まで

- **Components of the GALA-V System**
  - 広帯域フィード　ー氏原
  - RF–Direct SamplingとGICO3ソフトウェア相関器　ー岳藤
  - 広帯域バンド幅合成　ー近藤



Broadband VLBI Stations in Japan

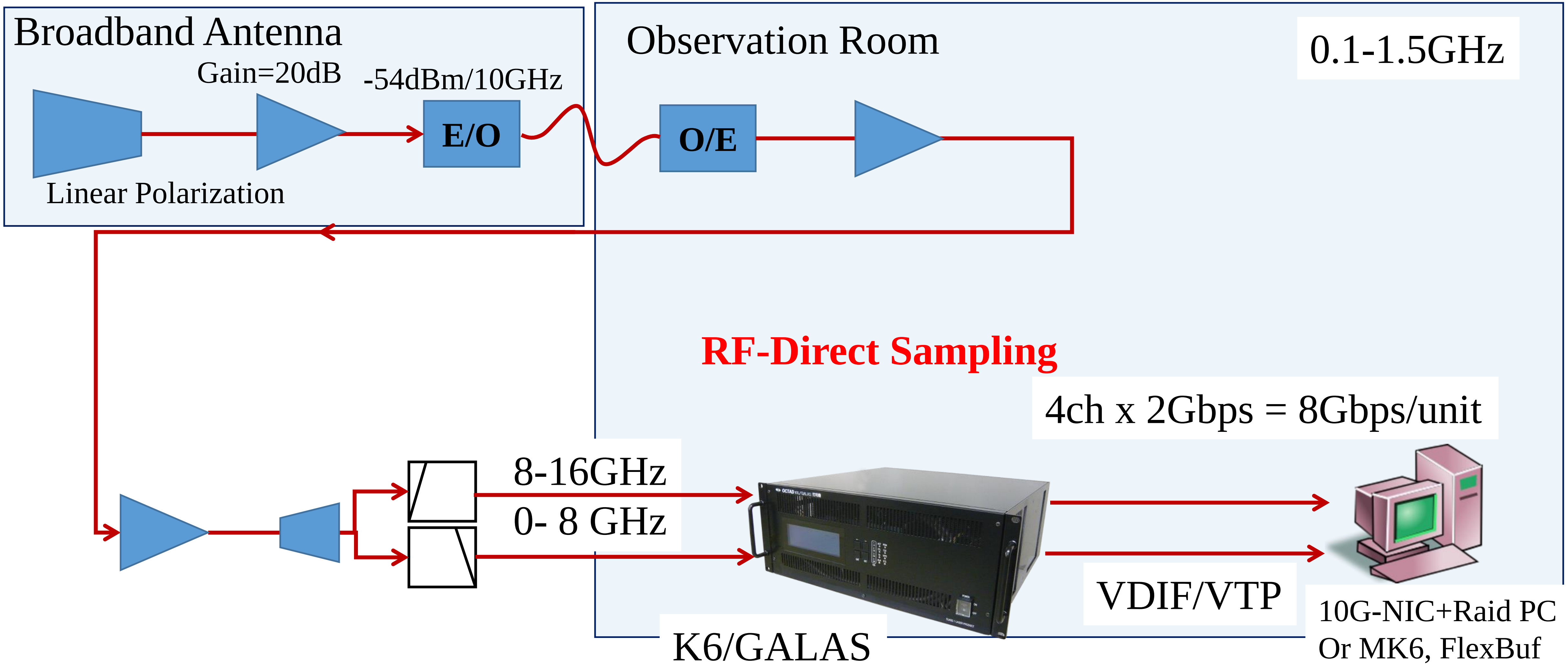




Data Acquisition System

300k=-174 dBm/Hz
-74dBm/10GHz

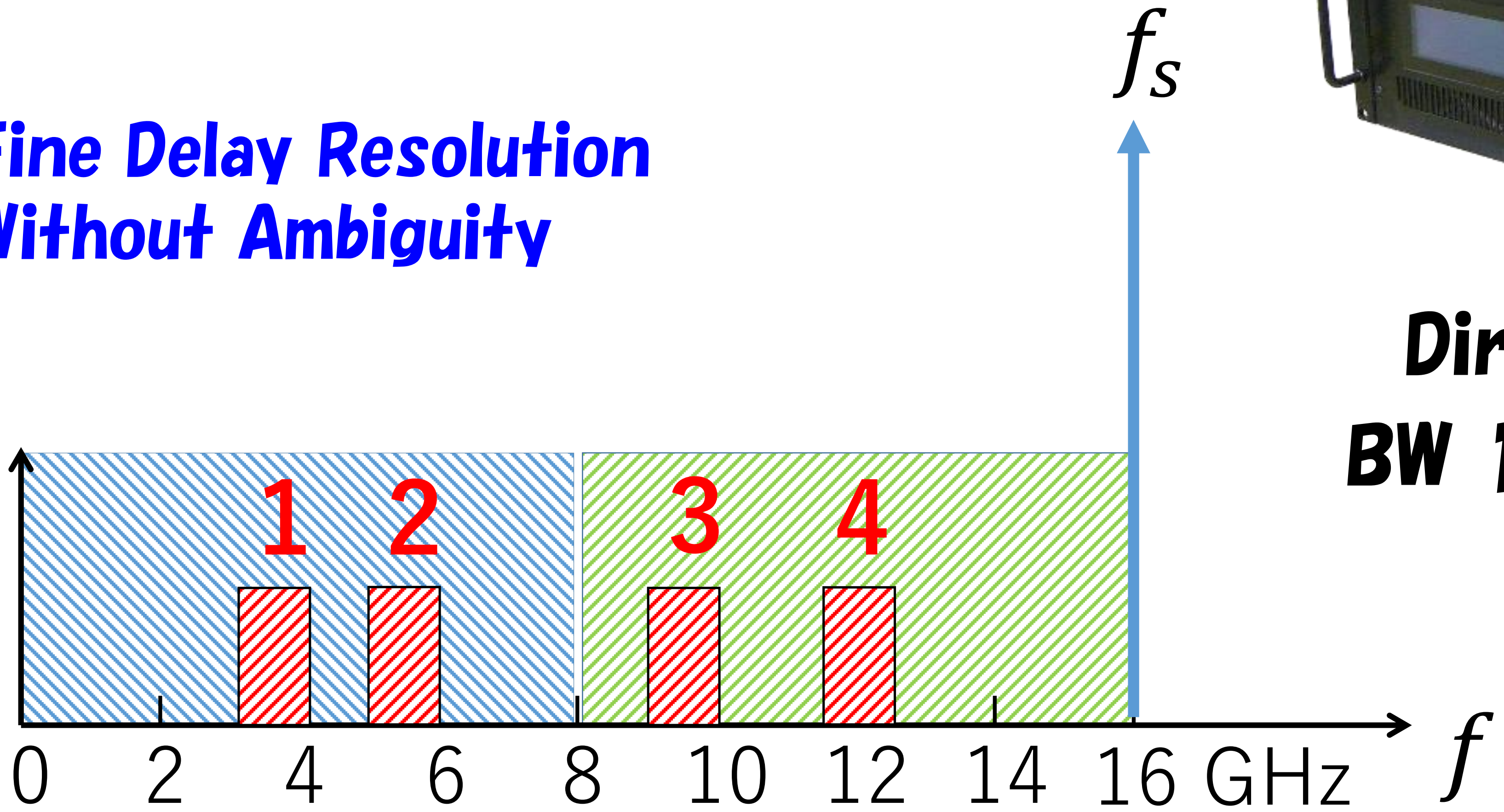
We have to be careful to compromise (1)avoiding saturation of system and (2) increase of noise figure, as discussed by Chris(2012) .



As close as Zero Redundancy

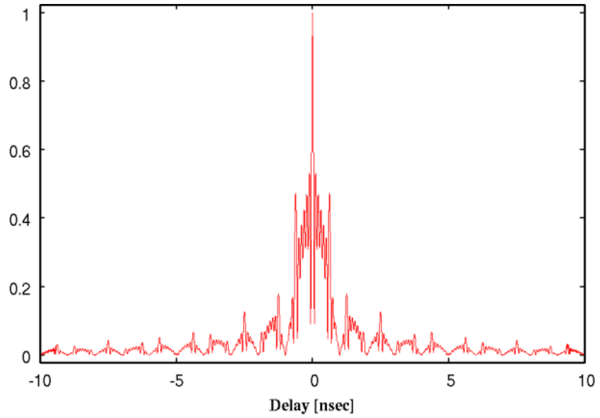
Frequency allocation

Fine Delay Resolution
Without Ambiguity

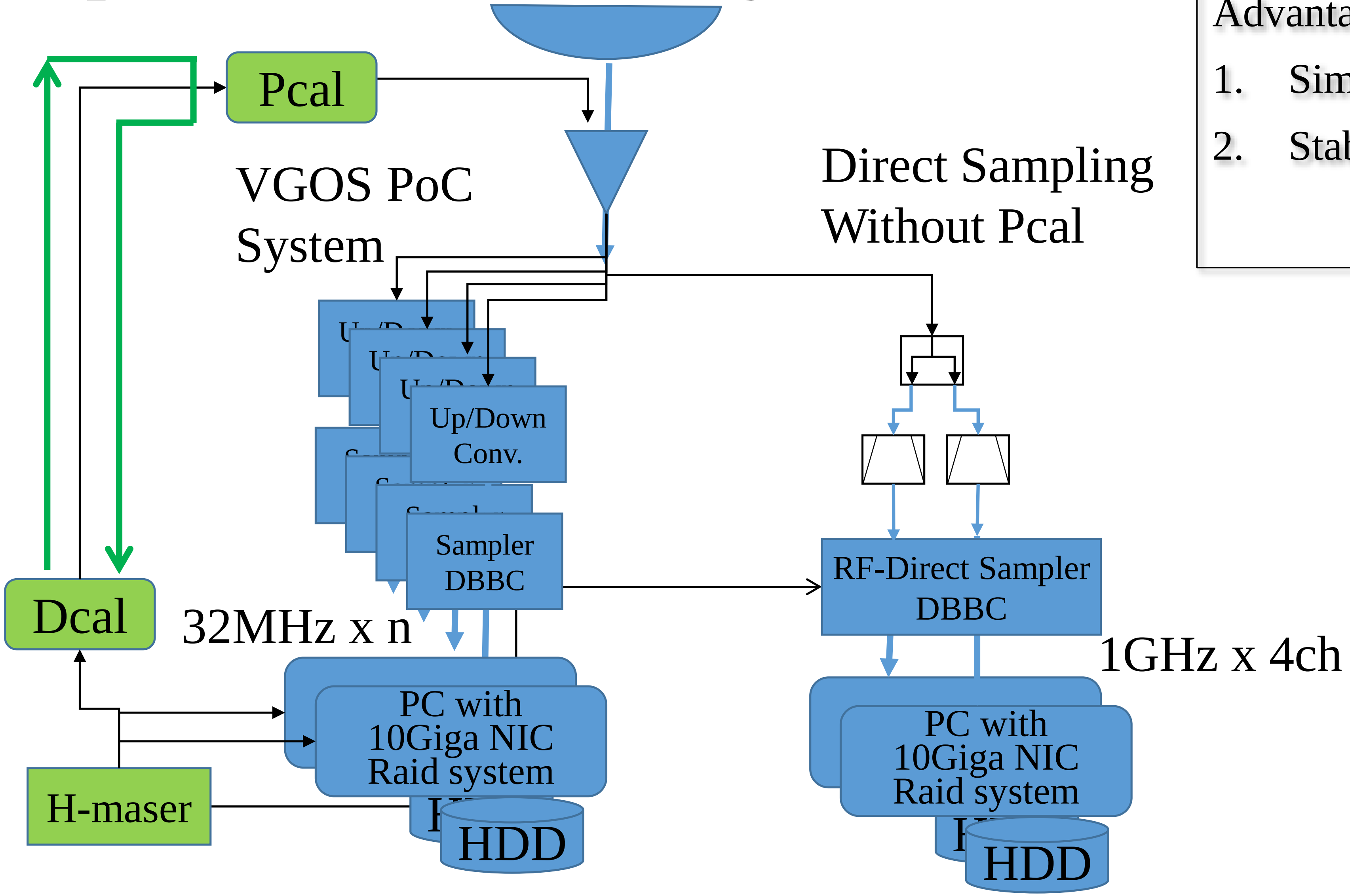


Direct Sampling
BW 1024MHz each

Lower Edge= 3.2, 4.8, 8.8, 11.6GHz



Advantages of RF-Direct Sampling Technique possible Pcal-free system



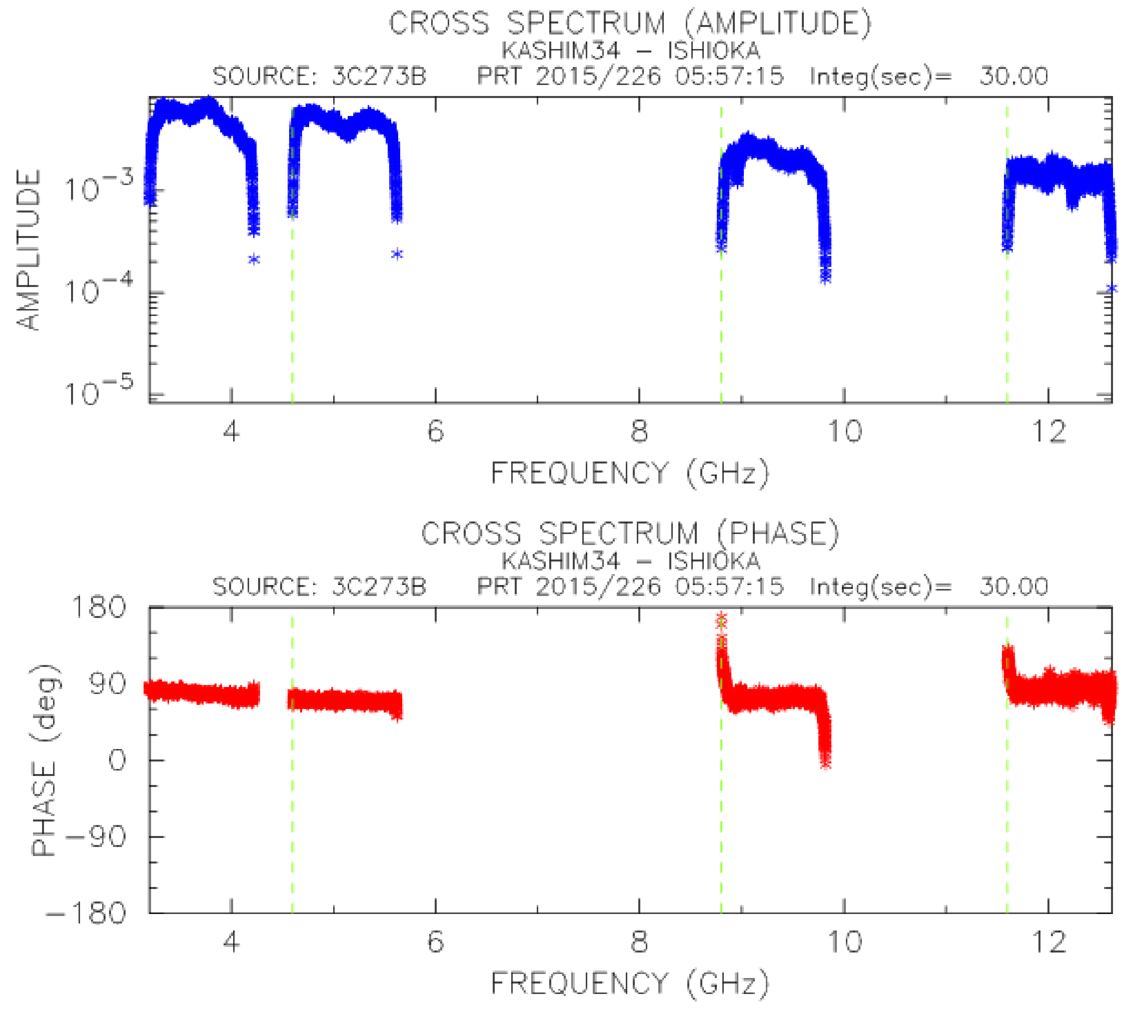
Advantages of Direct sampling

1. Simple and less system components.
2. Stable inter-band phase relation

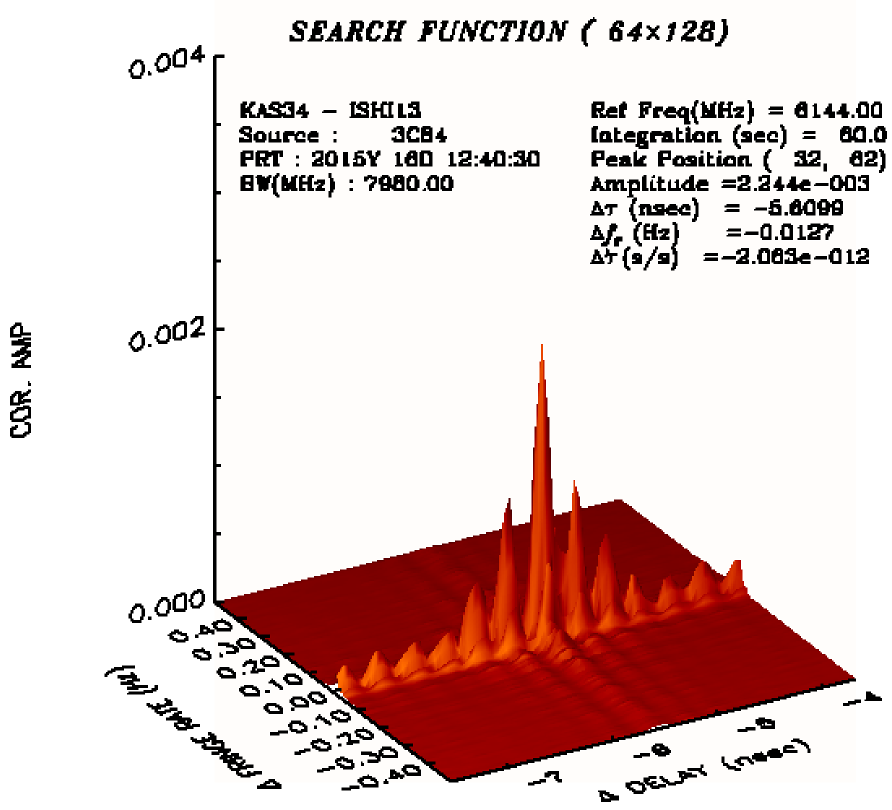
   => (Pcal,Dcal free)

Full Bandwidth Synthesis #1-#(6-14GHz)

Cross Spectrum

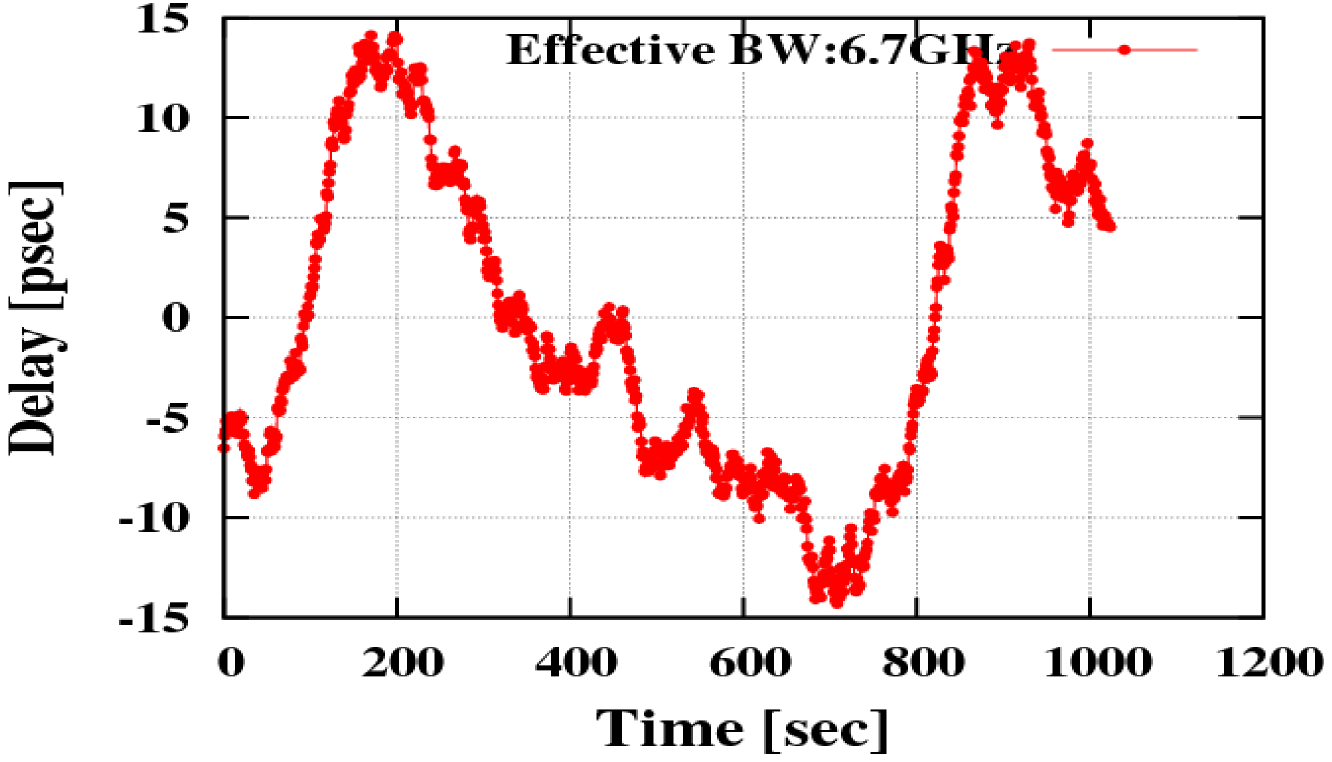


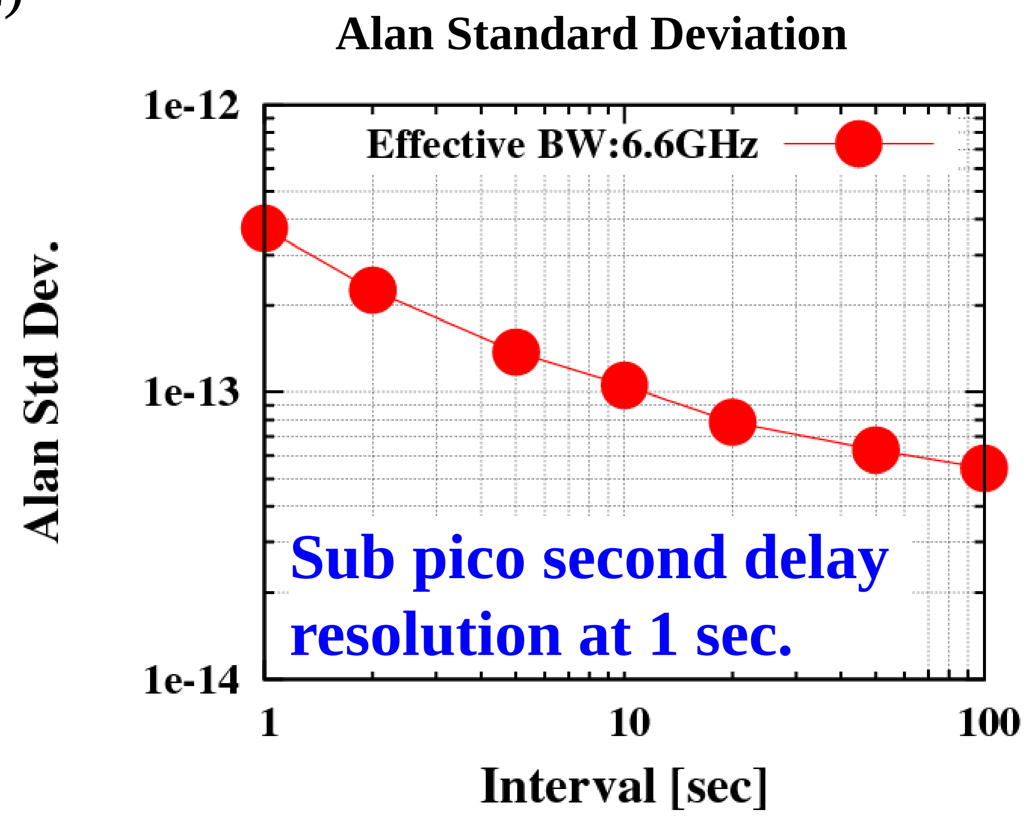
Delay Resolution Function



Delay Behavior Broadband Group Delay (3.2-12.6GHz) Kashima34 – Ishioka 13m

Exp. on 14 Aug.2015,
Freq. array=(Lower Edge=3.2, 4.8, 8.8, 11.6GHz)



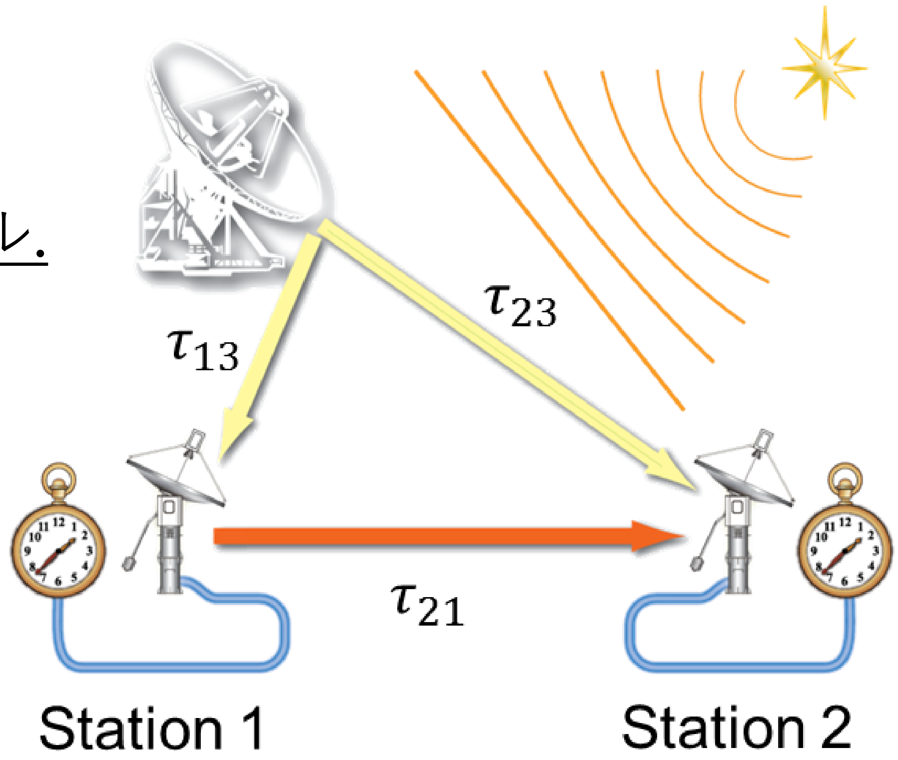


‘Small – Small’ Baseline

- Closure delay(閉合遅延) relation used for ‘small-small’ baseline.

$$\tau_{21}(t_1) = \tau_{23}(t_1)\text{-}\tau_{13}(t_1) - \tau_{13}(t_1)\dot{\tau}_{12}$$

- Advantage:
  - 速い駆動速度・変形が小さい
  - 大型アンテナの重力・熱変形の影響キャンセル.
  - Lower Cost
- Disadvantage:
  - Limited Sensitivity,
  - 閉合遅延への天体構造の影響.



Delay Precision

Broadband(small-small)

v.s.

Conventional 8180-8680MHz

S/X **500MHz(T2 session)**

2.4m Diameter

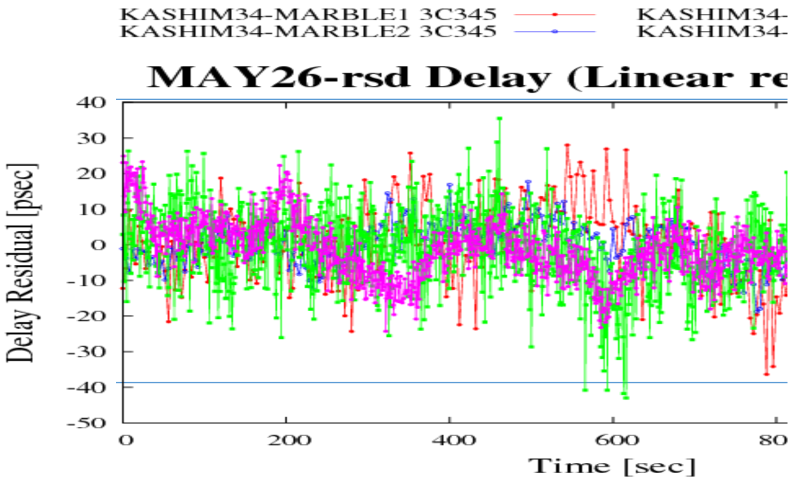
1.6m Diameter

3C273B

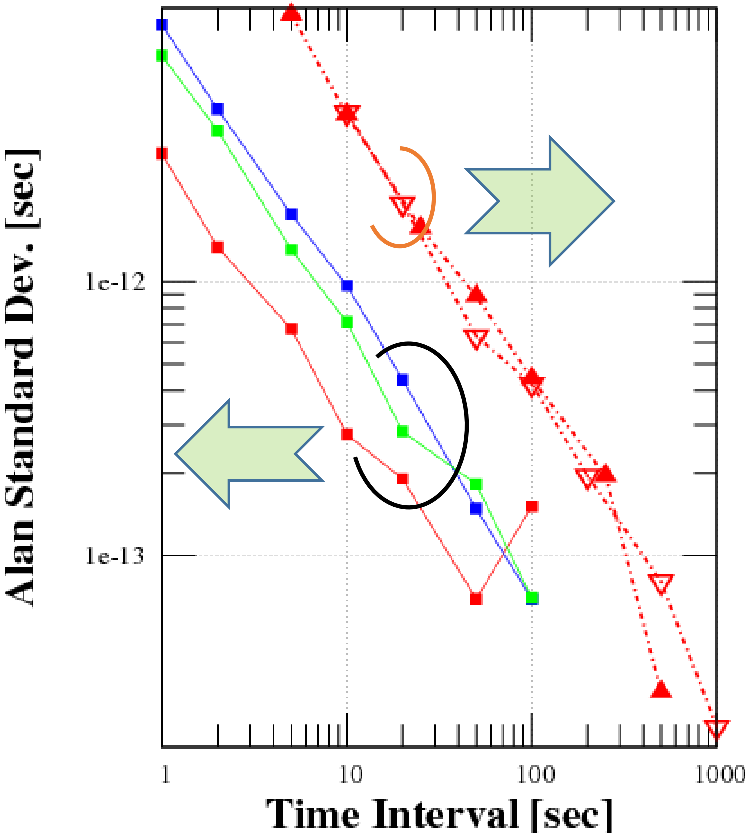
4C39.25

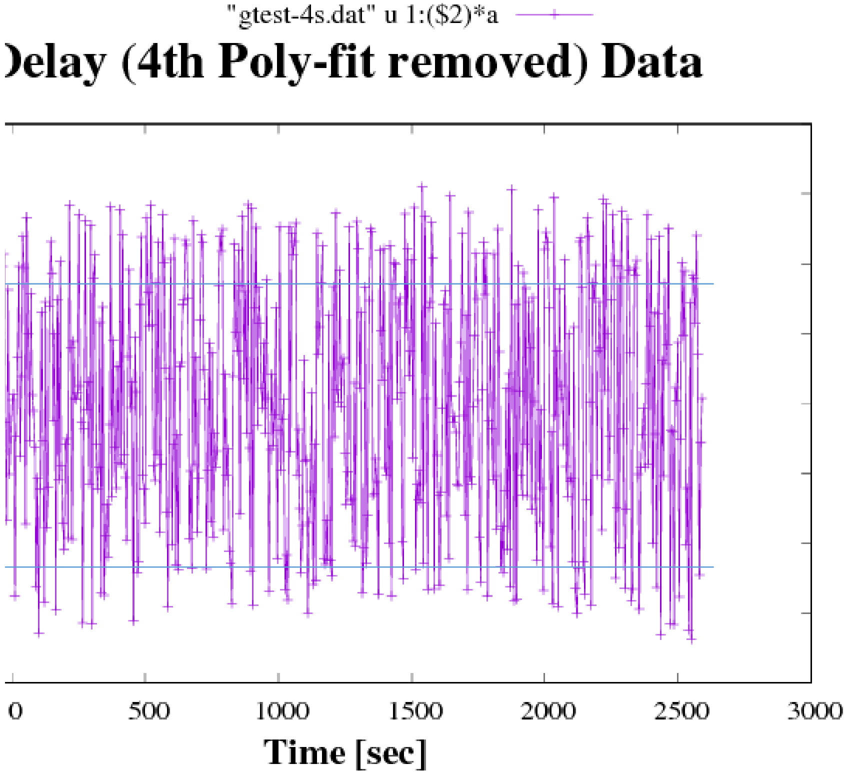
Broadband

'small-small' ba
by closure delay



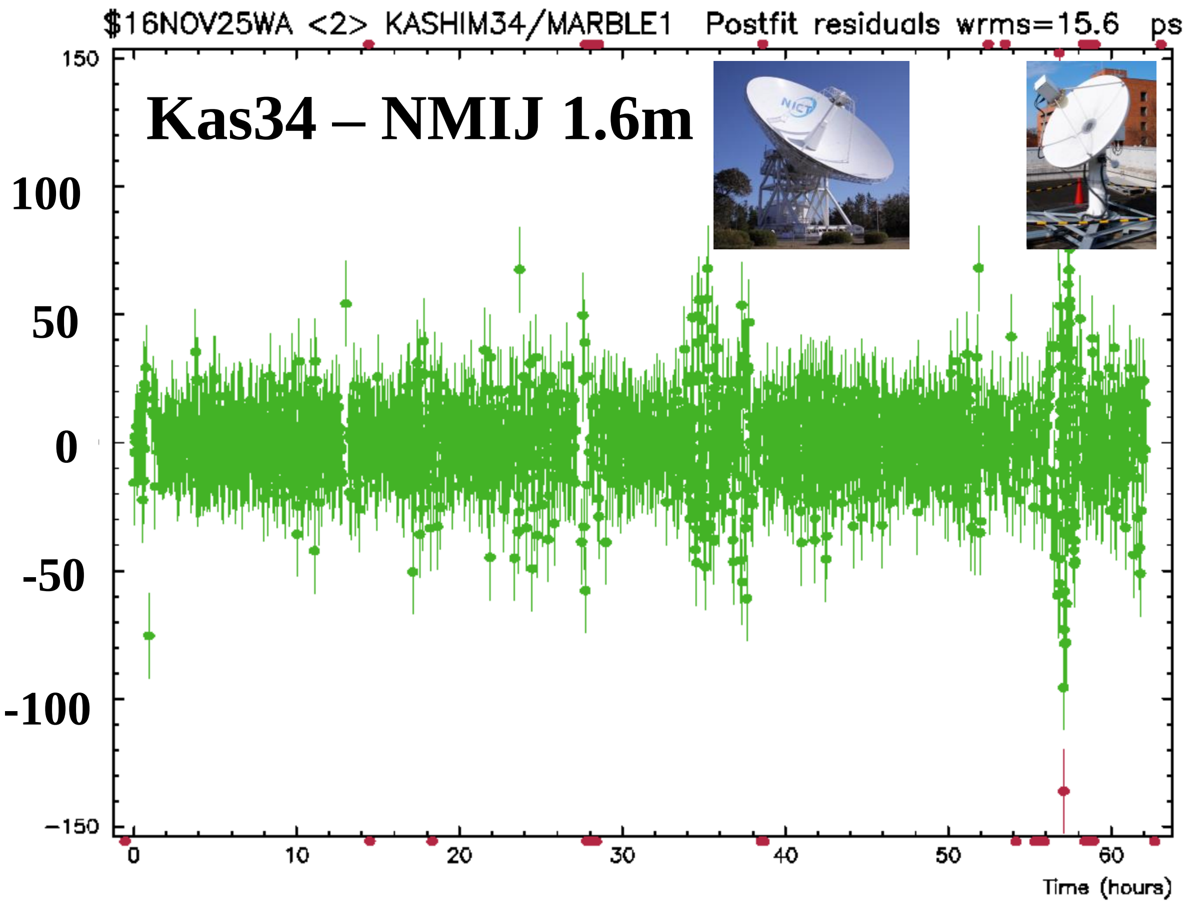
2016MBL1-MBL2Dec-cmp

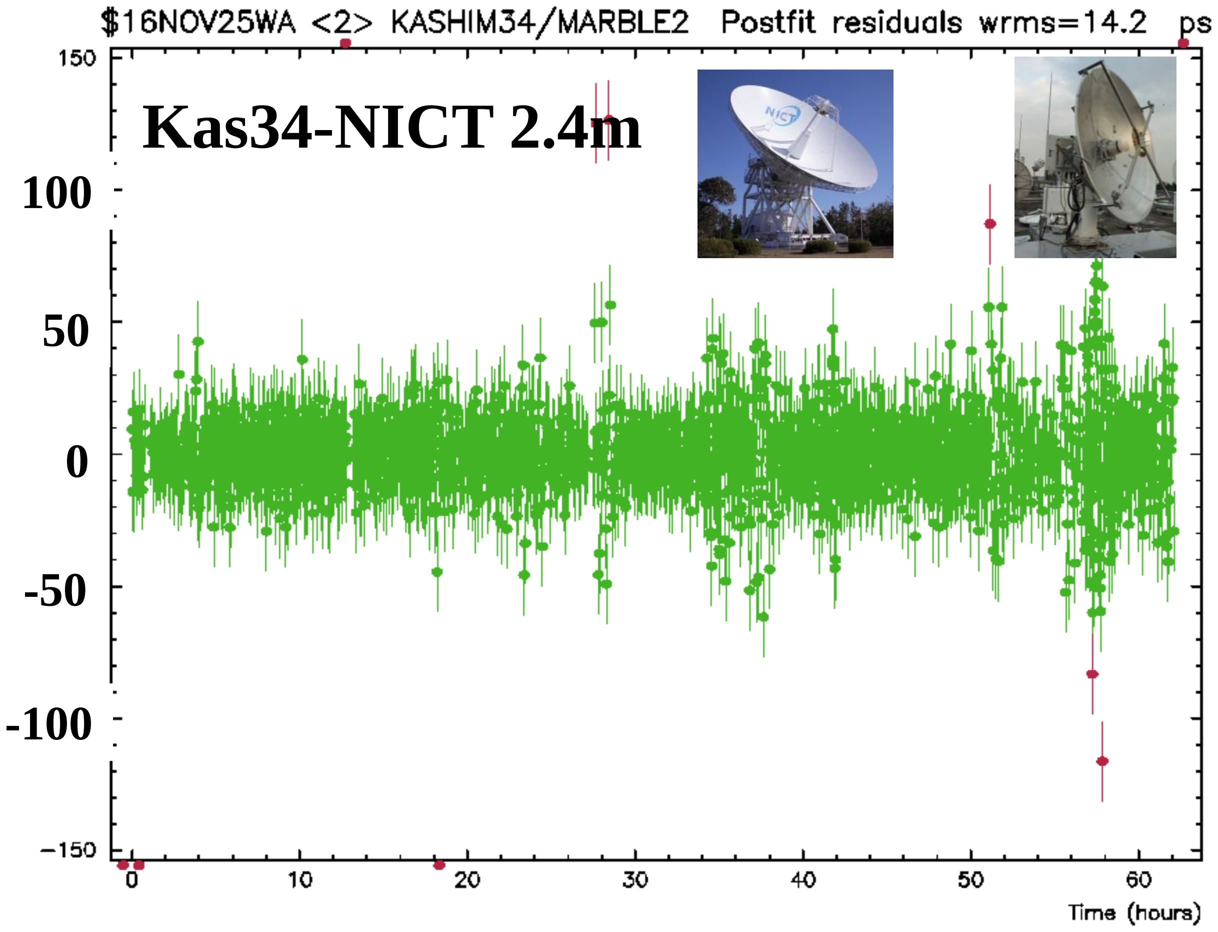




CALC/SOLVE Residual

WRMS Delay Residual ~ 16ps

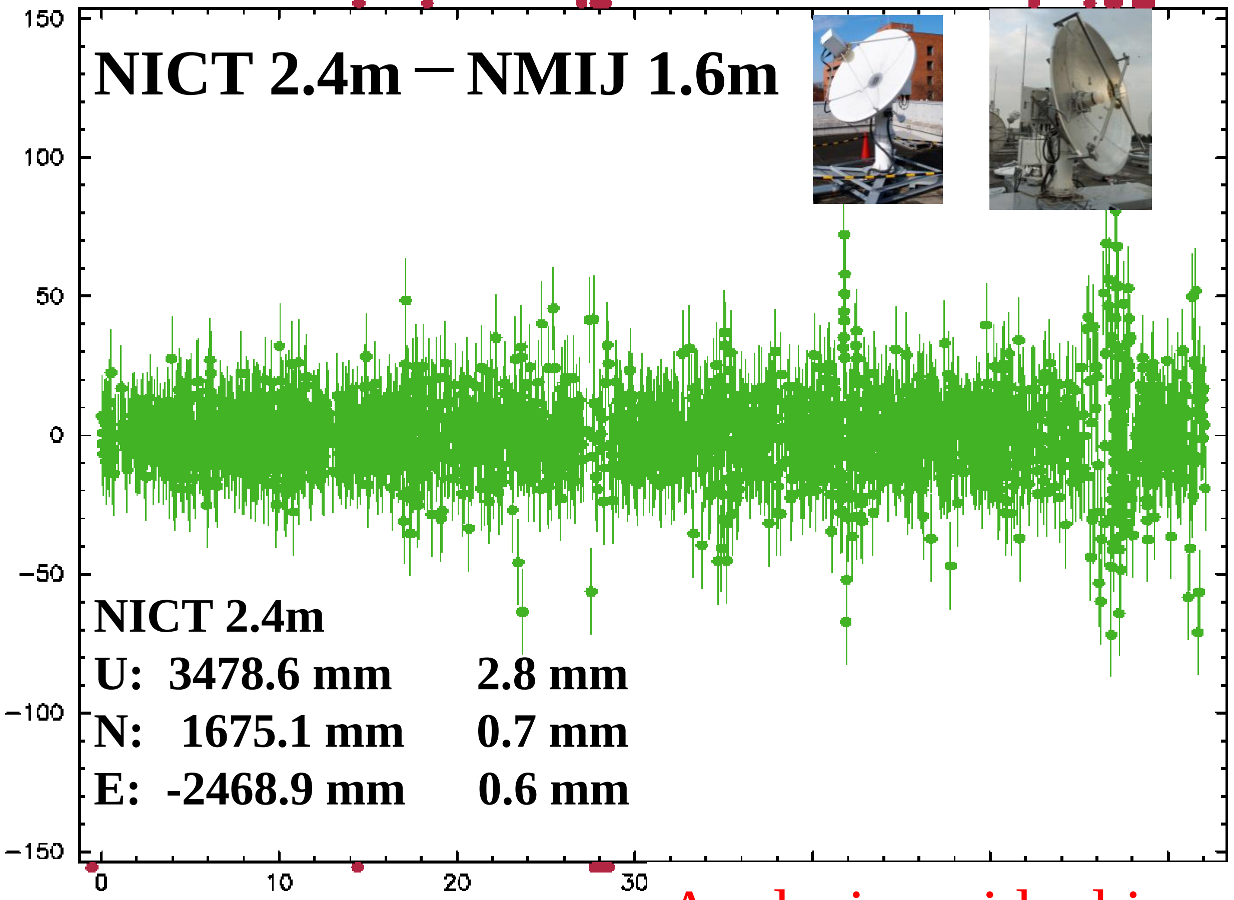




CALC/SOLVE Residual

$$\tau_{21}(t_1) = \tau_{23}(t_1) - \tau_{21}(t_1) - \tau_{21}(t_1)\dot{\tau}_{23}$$

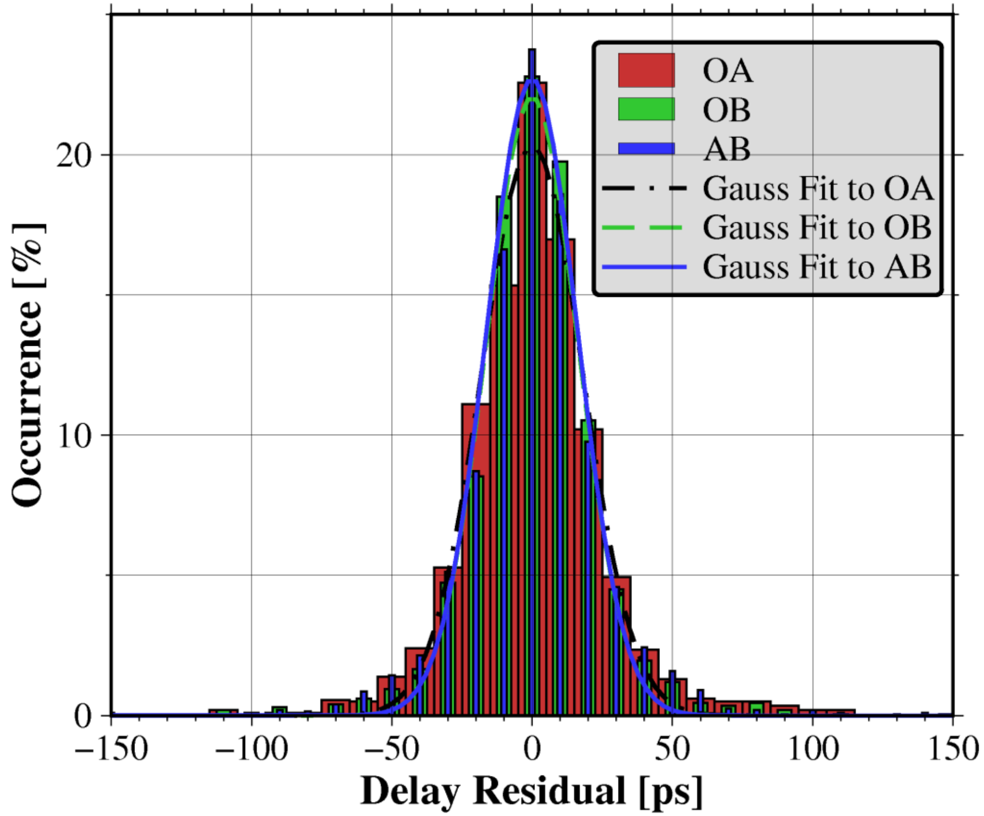
WRMS Delay Residual ~ 15 psec



O:Kashim34

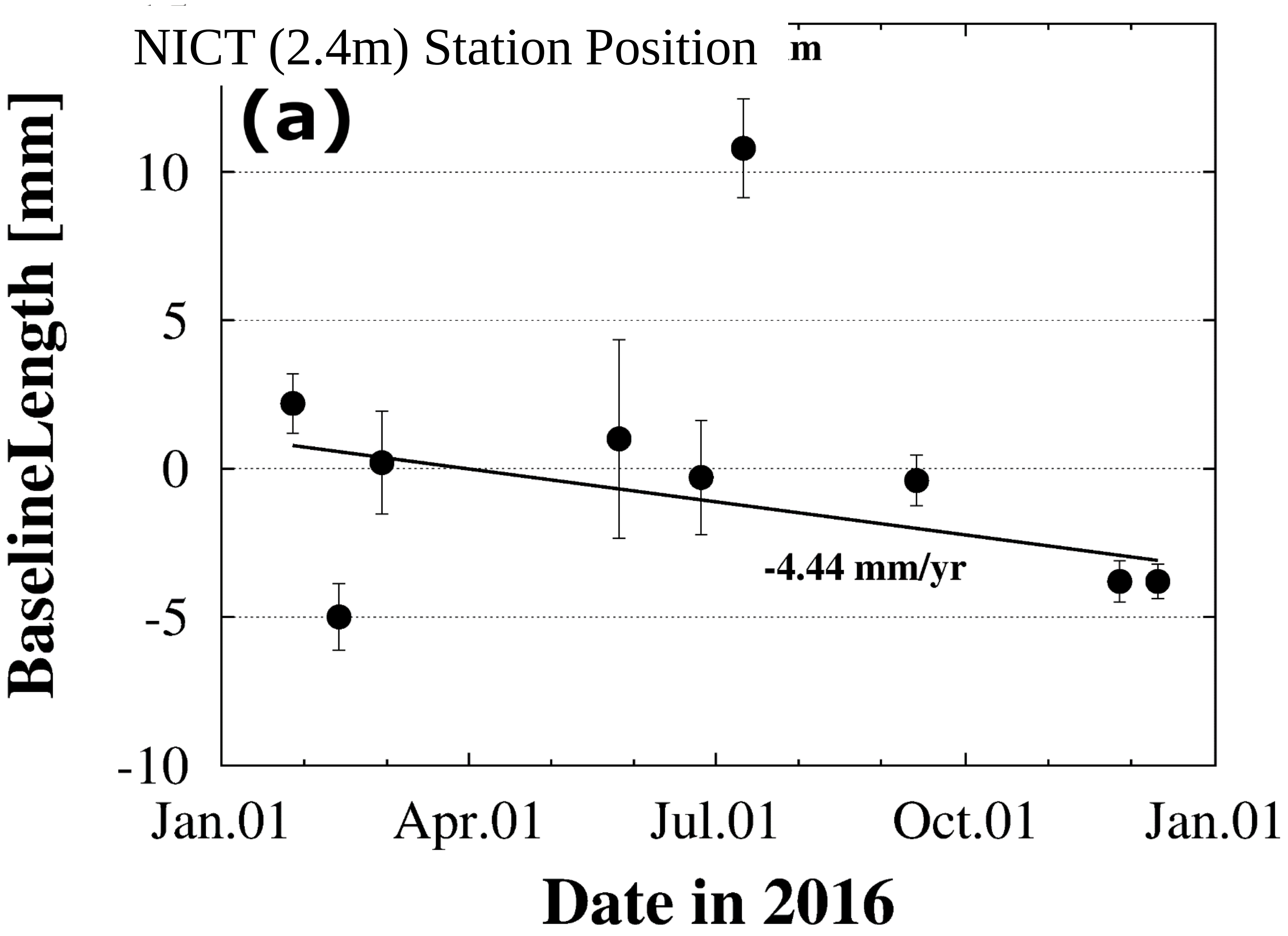
A:MARBLE1 NMIJ 1.6m

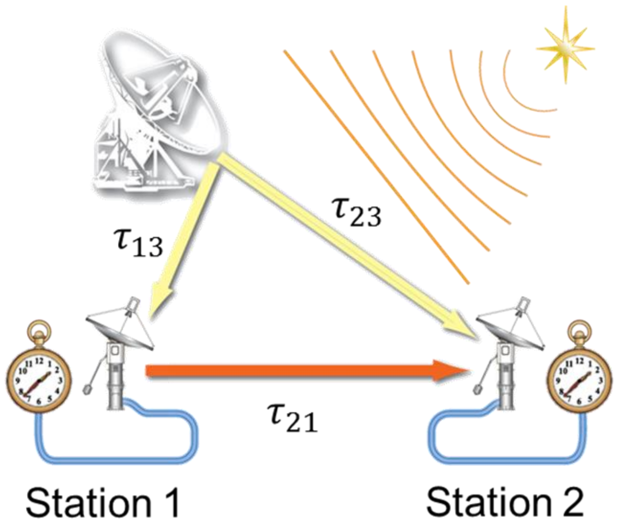
B:MARBLE2 NICT 2.4m



Analysis residual is no more dominated by measurement precision, but unknown excess delay, it may be troposphere.

Position Solution of MBL1-MBL2

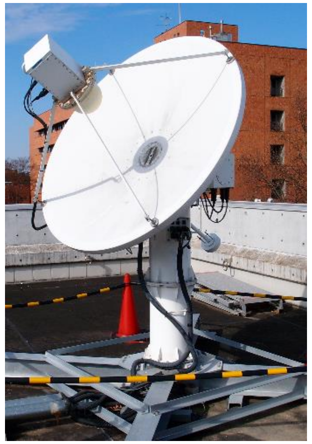




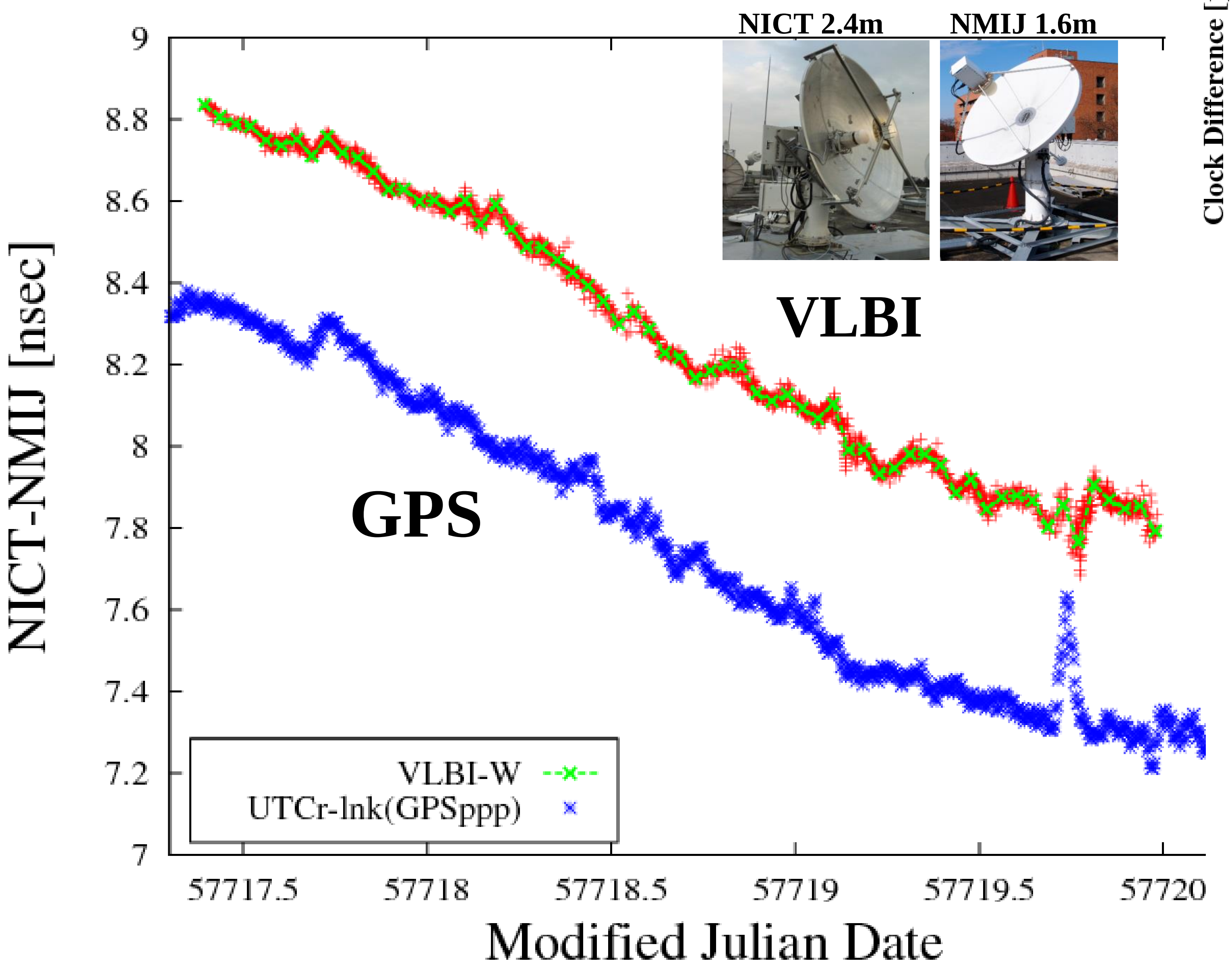
$$\tau_{21} = \tau_{13} - \tau_{23}$$

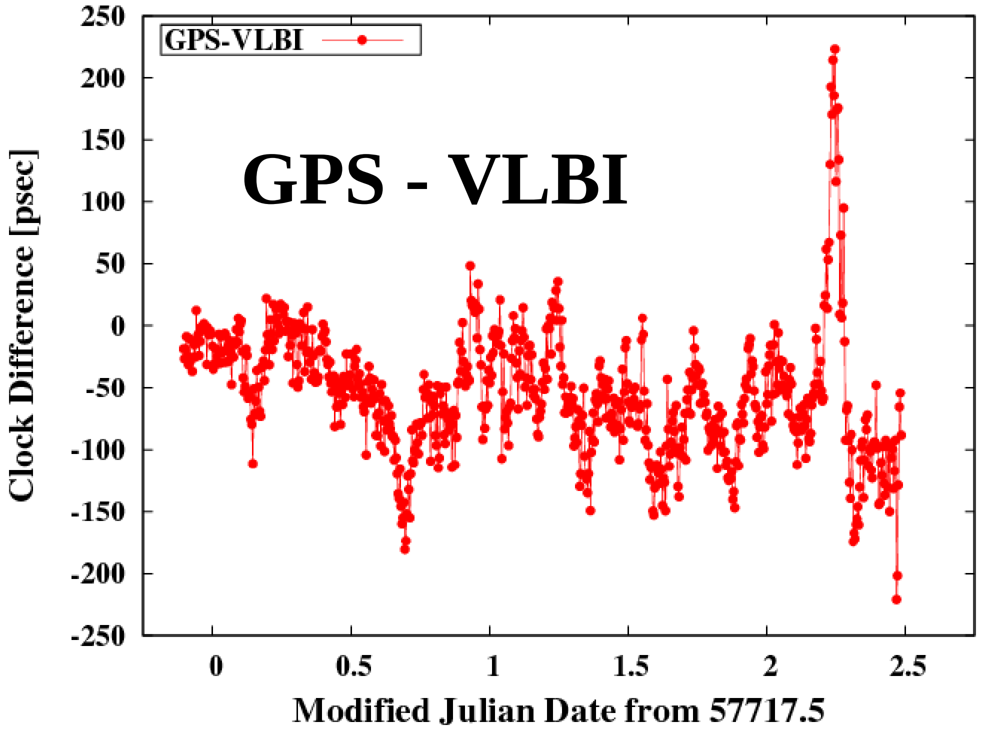
NICT 2.4m

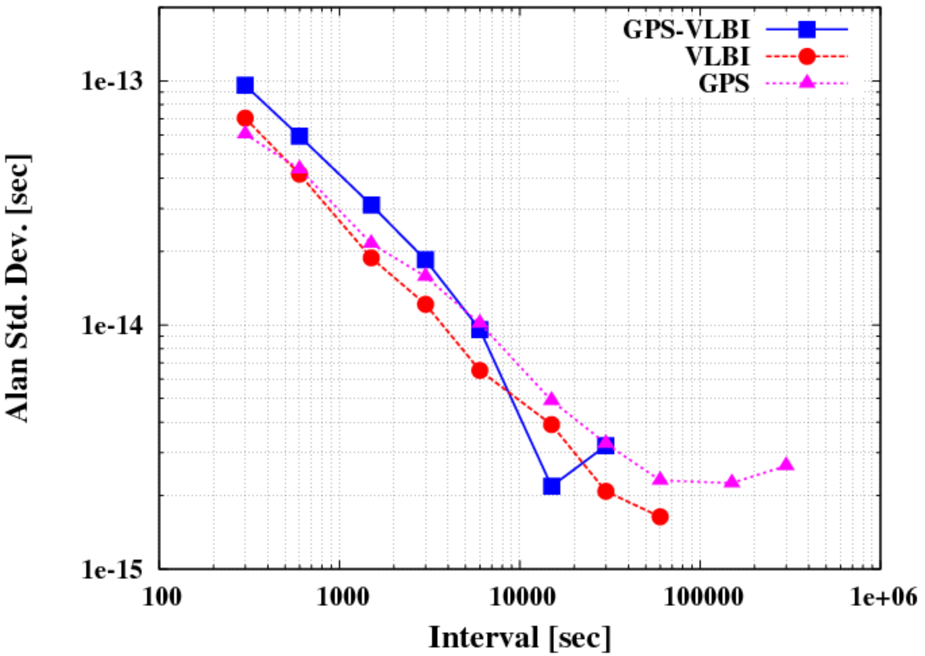
NMIJ 1.6m



Clock Comparison via VLBI and GPS-ppp
2016Nov25 UTC(NICT) – UTC(NMIJ)







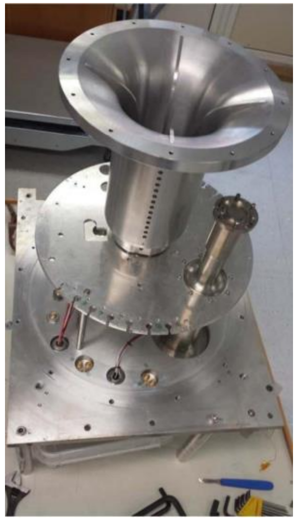
EVGA meeting(5/15-18) 報告

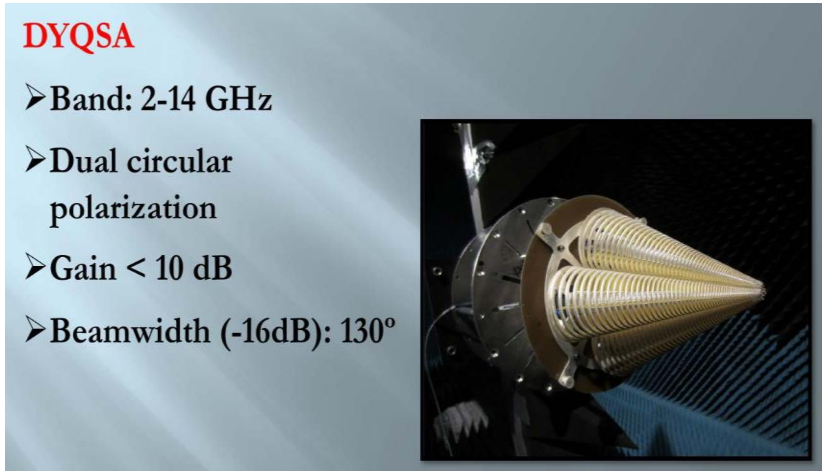
- ENVの広帯域VLBI：BRAND Project
- 電波源構造の効果

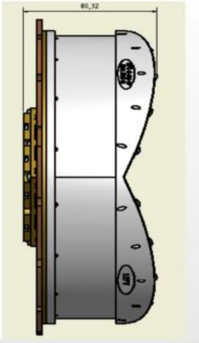
EVGA meeting 報告: BRAND Project

- 欧州の広帯域化プロジェクトBRAND(BRoadbAND) EVN
  - Leader：Gino Tuccari(イタリアINAF)、Walter Alef(ドイツMaxplank)
  - **Freq.： 1.5 GHz – 15GHz**
  - Motivation：Fast freq. switch@EVN, スペクトルインデックス, Faraday Rotation, Pulsar
  - Technique: 高速サンプリング、デジタルフィルタ

Onsala 20m
4.0–12.5GHz受信機
の計画







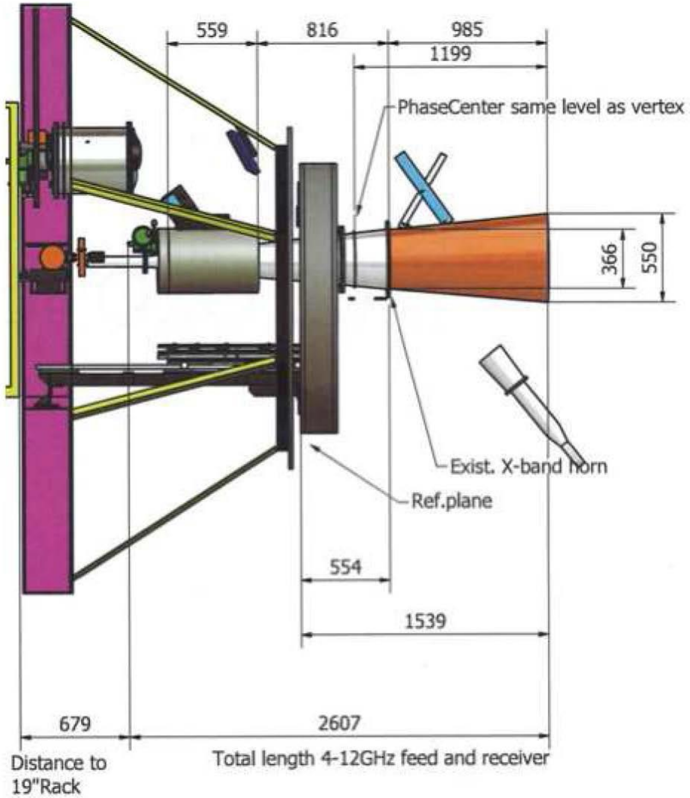
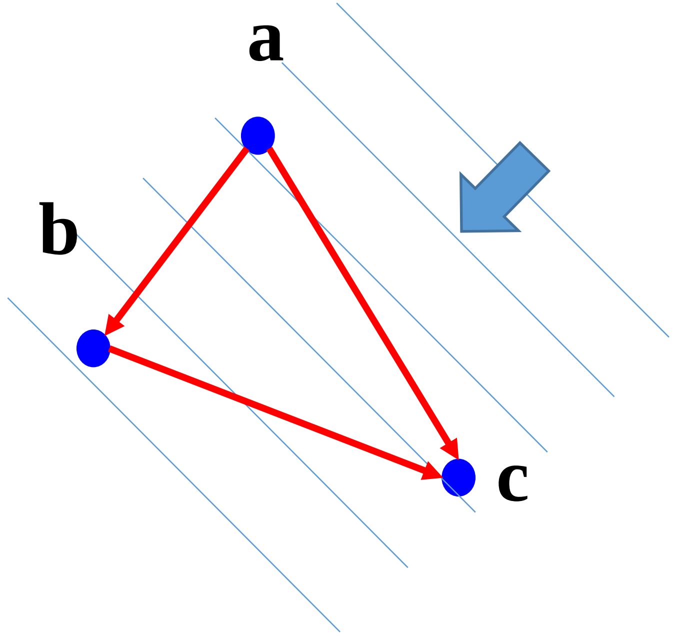


Fig. 4 The proposed mechanical arrangement of the 4.00–12.25 GHz horn for the 20-m telescope.

EVGA meeting 報告: 電波源構造の影響

- Xu H Ming(SHAO), Anderson M. James(GFZ):
    - Ming H Xu, et al.(2016) AJ, 152, (5), id. 151, p.11
    -
- CONT14の結果を使って　閉合遅延、閉合位相、閉合振幅　の情報から電波源の構造の影響を調べている。



遅延観測量

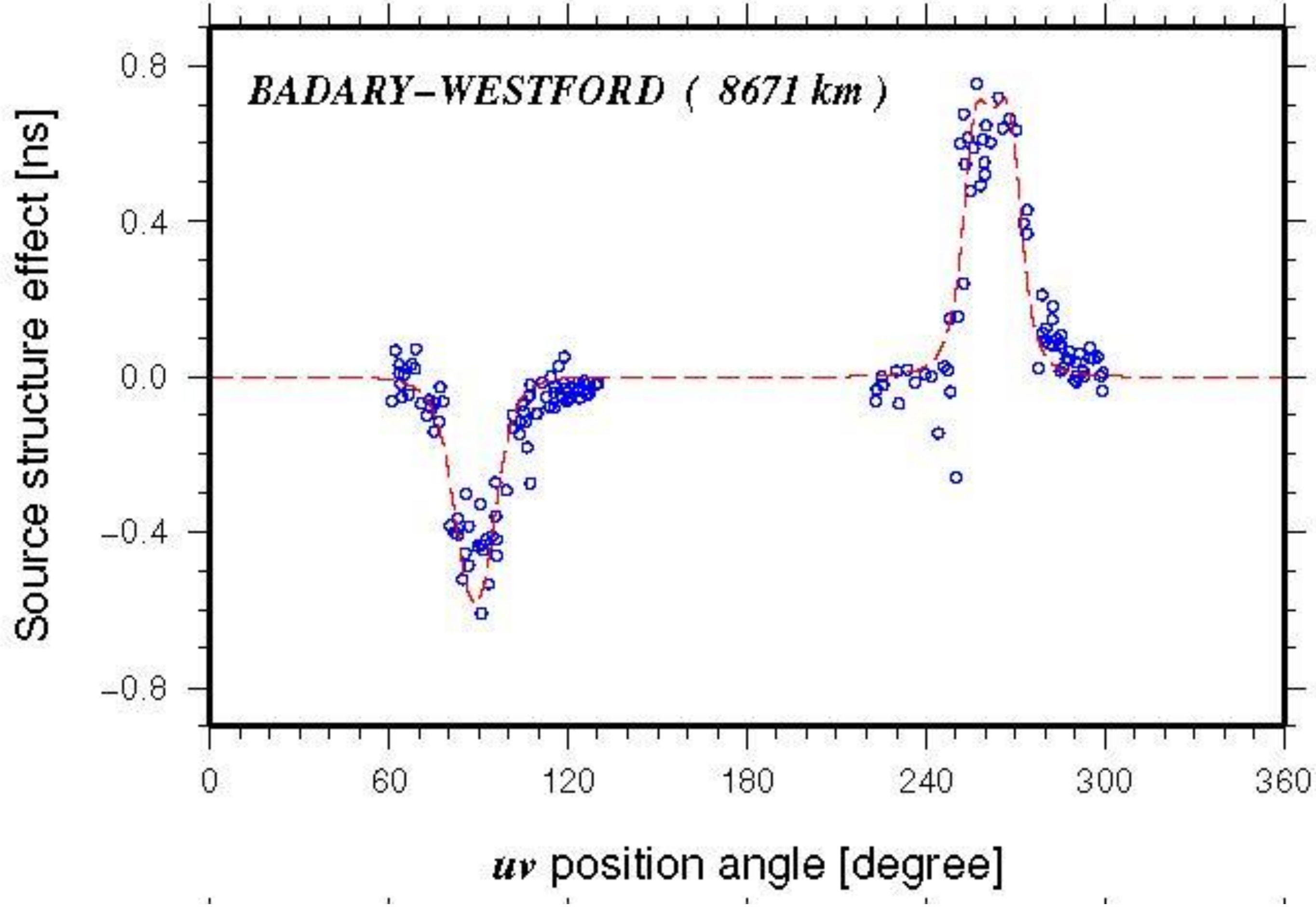
$$\tau_{ab}^{obs} = \tau_{ab}^{geo} + \tau_{ab}^{atm} + \tau_{ab}^{ins} + \tau_{ab}^{str}$$

閉合遅延

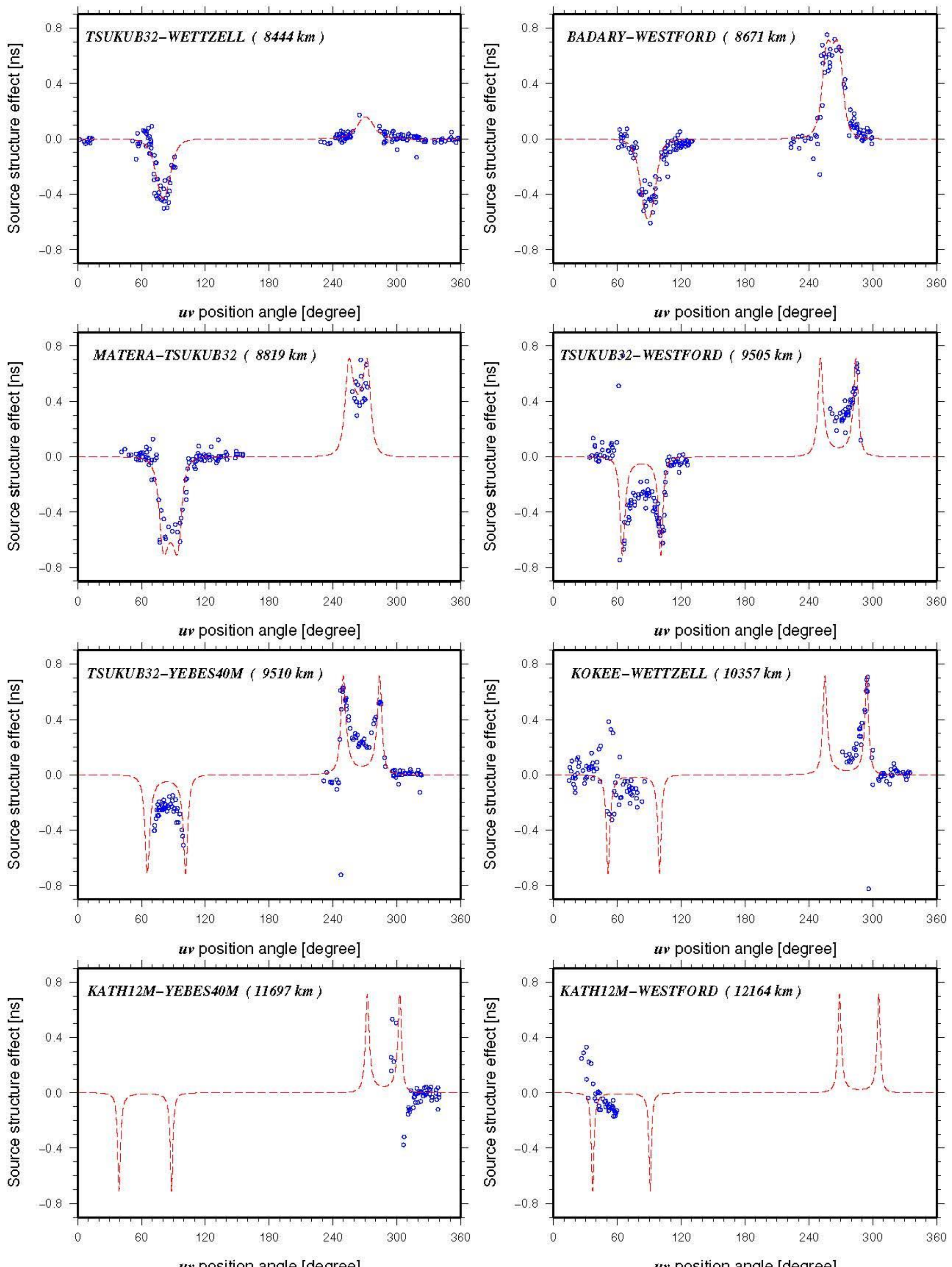
$$\tau_{ab}^{obs} + \tau_{bc}^{obs} + \tau_{ca}^{obs} = \tau_{ab}^{str} + \tau_{bc}^{str} + \tau_{ca}^{str}$$

0642+449のCONT14観測データに「２点源モデル」でFitして電波源構造の影響を計算した結果

0642+449のCONT14観測データに「２点源モデル」をパラメータ推定して電波源構造の影響を計算した結果



THE SOURCE STRUCTURE OF 0642+449



EVGA meeting 報告: 電波源構造の影響

- WRT

$$\vec{k}_P = \vec{k}_{P0} + \overrightarrow{\delta\theta}$$

$$V(B,\lambda) = \int_\Omega I(\vec{P},\lambda) exp\left\{-\frac{2\pi}{\lambda} i\vec{B}\cdot\vec{k}_P\right\} d\Omega$$

$$= exp\left\{-\frac{2\pi}{\lambda} i\vec{B}\cdot\vec{k}_{P0}\right\} \int_\Omega I(\vec{P},\lambda) exp\left\{-\frac{2\pi}{\lambda} i\vec{B}\cdot\overrightarrow{\delta\theta}\right\} d\Omega$$

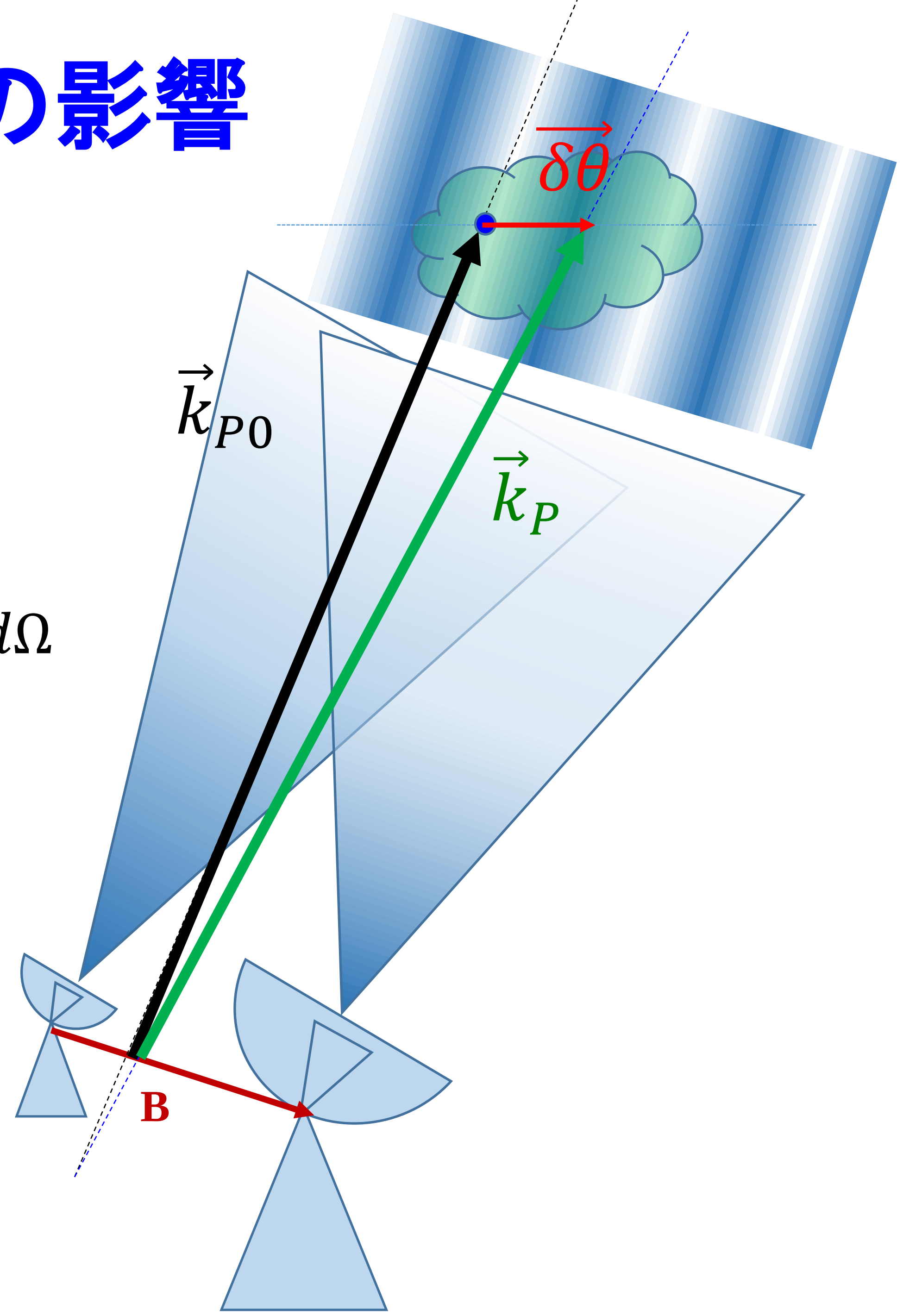
$$= Aexp\{i(\phi_g + \phi_s)\}$$

相関位相は

$$\phi_s = arg\left[\int_\Omega I(\vec{P},\lambda) exp\left\{-\frac{2\pi}{\lambda} i\vec{B}\cdot\overrightarrow{\delta\theta}\right\} d\Omega\right]$$

群遅延は

$$\tau_g = \frac{d\phi}{d\omega}$$



2点電波源の場合

- P.Charlot(1990) AJ 99(4)pp.1309-1326

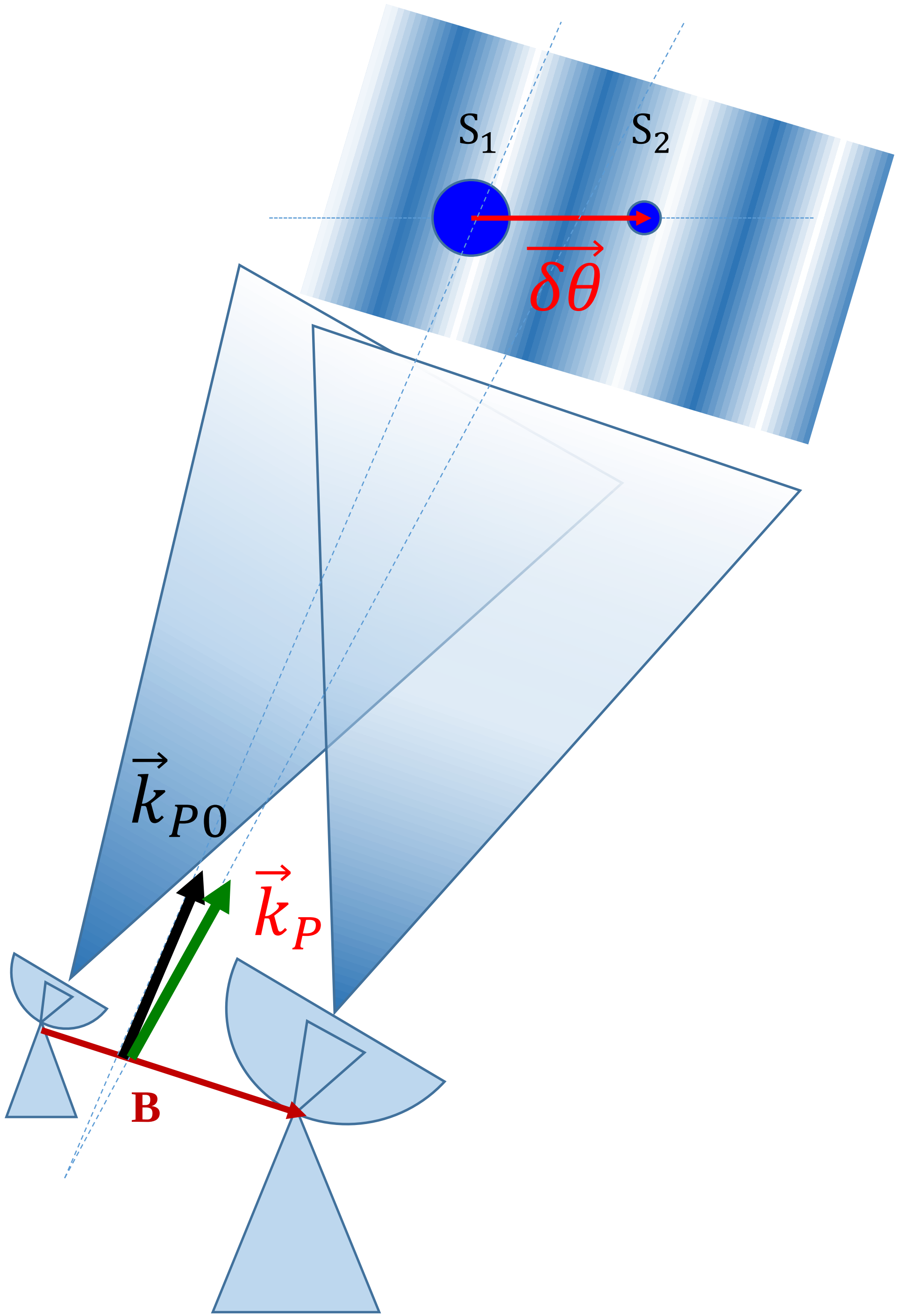
$$\phi_s = \frac{2\pi K}{1+K} R + tan^{-1}\left\{\frac{-K sin(2\pi R)}{1+K cos(2\pi R)}\right\}$$

2点のフラックス比 $K = \frac{S_2}{S_1}$

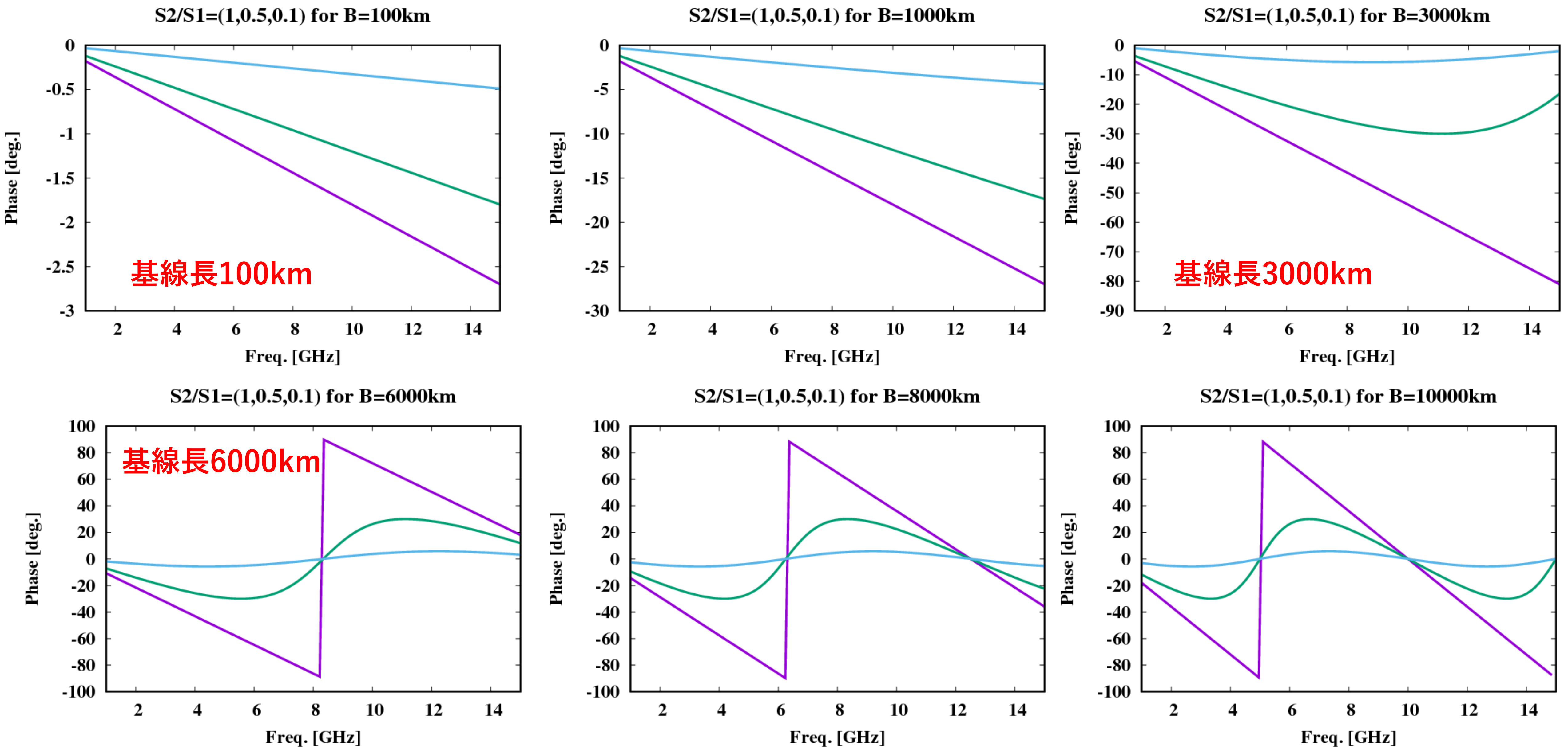
2点のベクトルと基線ベクトルの角度

$$\mathrm{R} = \frac{\vec{\mathrm{B}} \cdot \overrightarrow{\delta\theta}}{\lambda} = \frac{\delta\theta}{\lambda / B_p} = \frac{B_p}{c} \cdot \delta\theta \cdot f$$

$$= 0.0133 \left(\frac{B_p}{1000km}\right)\left(\frac{\delta\theta}{1mas}\right)\left(\frac{f}{1GHz}\right)$$



相関位相



S2/S1=(1,0.5,0.1) for B=100km
Phase [deg.]
Freq. [GHz]
基線長100km
S2/S1=(1,0.5,0.1) for B=1000km
Phase [deg.]
Freq. [GHz]
S2/S1=(1,0.5,0.1) for B=3000km
Phase [deg.]
Freq. [GHz]
基線長3000km
S2/S1=(1,0.5,0.1) for B=6000km
Phase [deg.]
Freq. [GHz]
基線長6000km
S2/S1=(1,0.5,0.1) for B=8000km
Phase [deg.]
Freq. [GHz]
S2/S1=(1,0.5,0.1) for B=10000km
Phase [deg.]
Freq. [GHz]

Thank you for Attention

まとめ

- 3-14GHzの広帯域観測が可能になり、サブピコ秒精度の遅延計測が可能となった。
- 長基線では、電波源の影響が無視できない程度寄与すると予想される。