

# ***Delta-VLBI Test Observation at HAYABUSA's approach to ITOKAWA***

関戸衛, 市川隆一 (NICT),  
吉川真, 望月奈々子, 村田泰宏,  
加藤隆二, 市川勉, 竹内央, (ISAS/JAXA)  
大西隆史 (富士通)

# Outline

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- $\Delta$  VLBI 測定の精度
  - Signal バンド幅  $\Rightarrow$  群遅延精度
  - 基線長
- $\Delta$  VLBI observation of HAYABUSA
  - Epoch: 2005年 11月 4日, 12日, 19日, 25日
  - 参照天体離角: 2~8度
- $\Delta$  VLBIでどの程度の精度(確度)で遅延量が得られるか? 大気遅延・クロックの校正ができるか?

# Spacecraft Navigation R&RR + VLBI

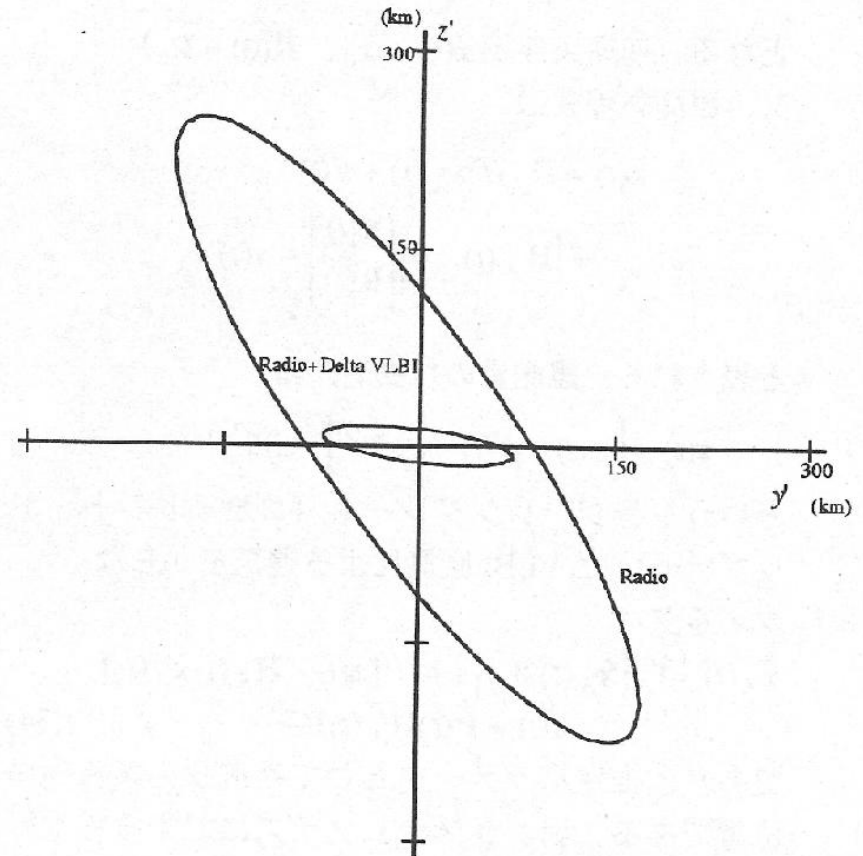
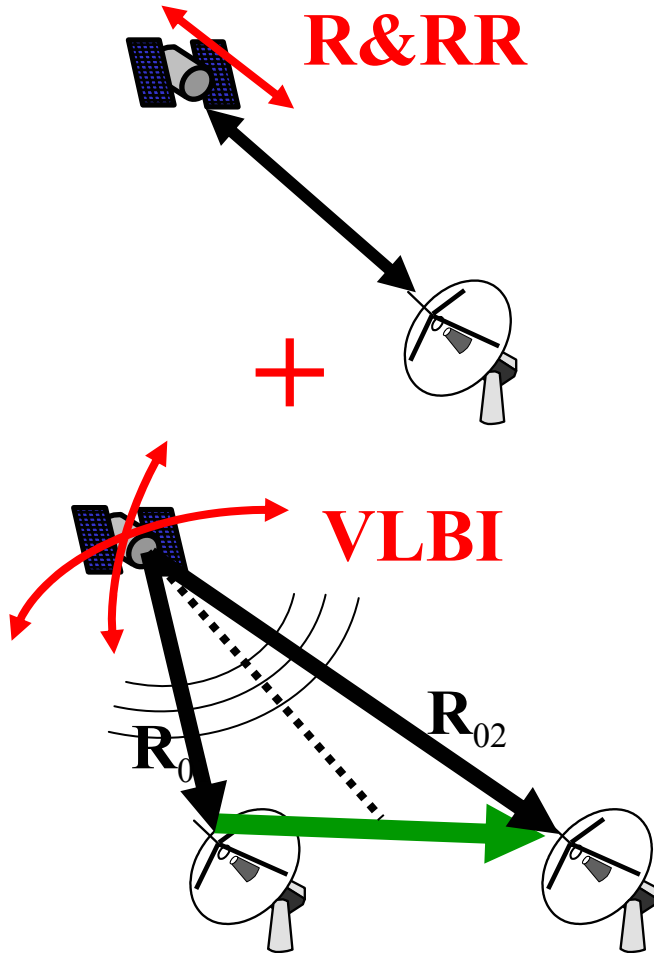


Fig. 7 誤差橢圓

# △ VLBI 計測精度

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角度分解能を決める  
遅延計測精度、基線長

# Relation between Angular Resolution and Delay Resolution

$$\Delta L = c \Delta \tau$$

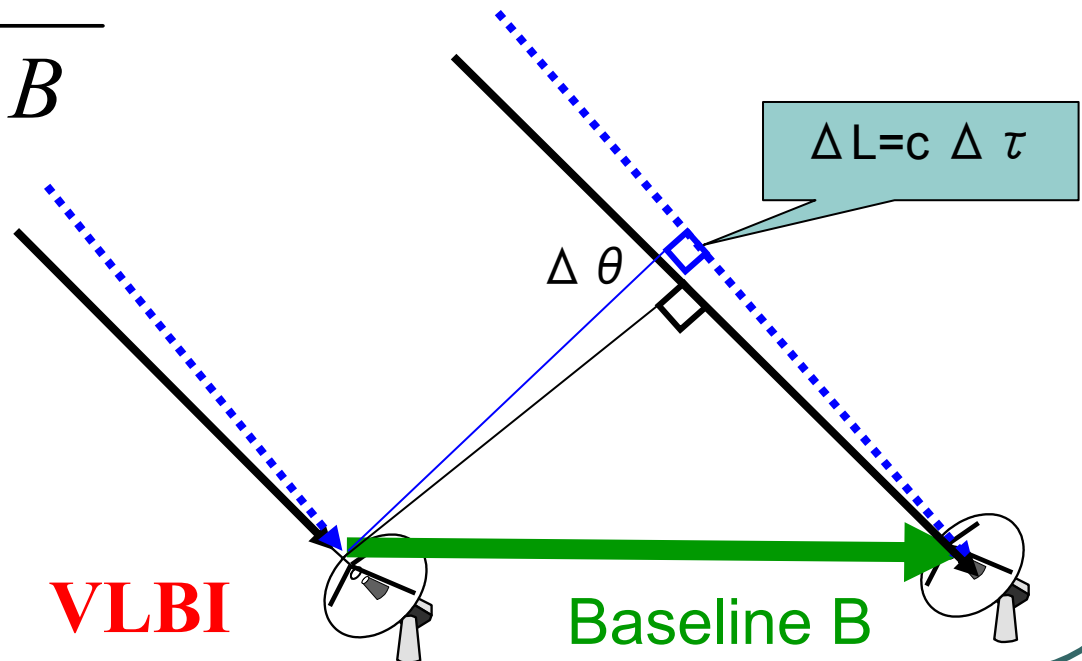
$$\Delta \theta = \frac{\Delta L}{B} = c \frac{\Delta \tau}{B}$$

遲延精度:  $\Delta \tau$

基線長:  $B$

確度分解能:  $\Delta \theta$

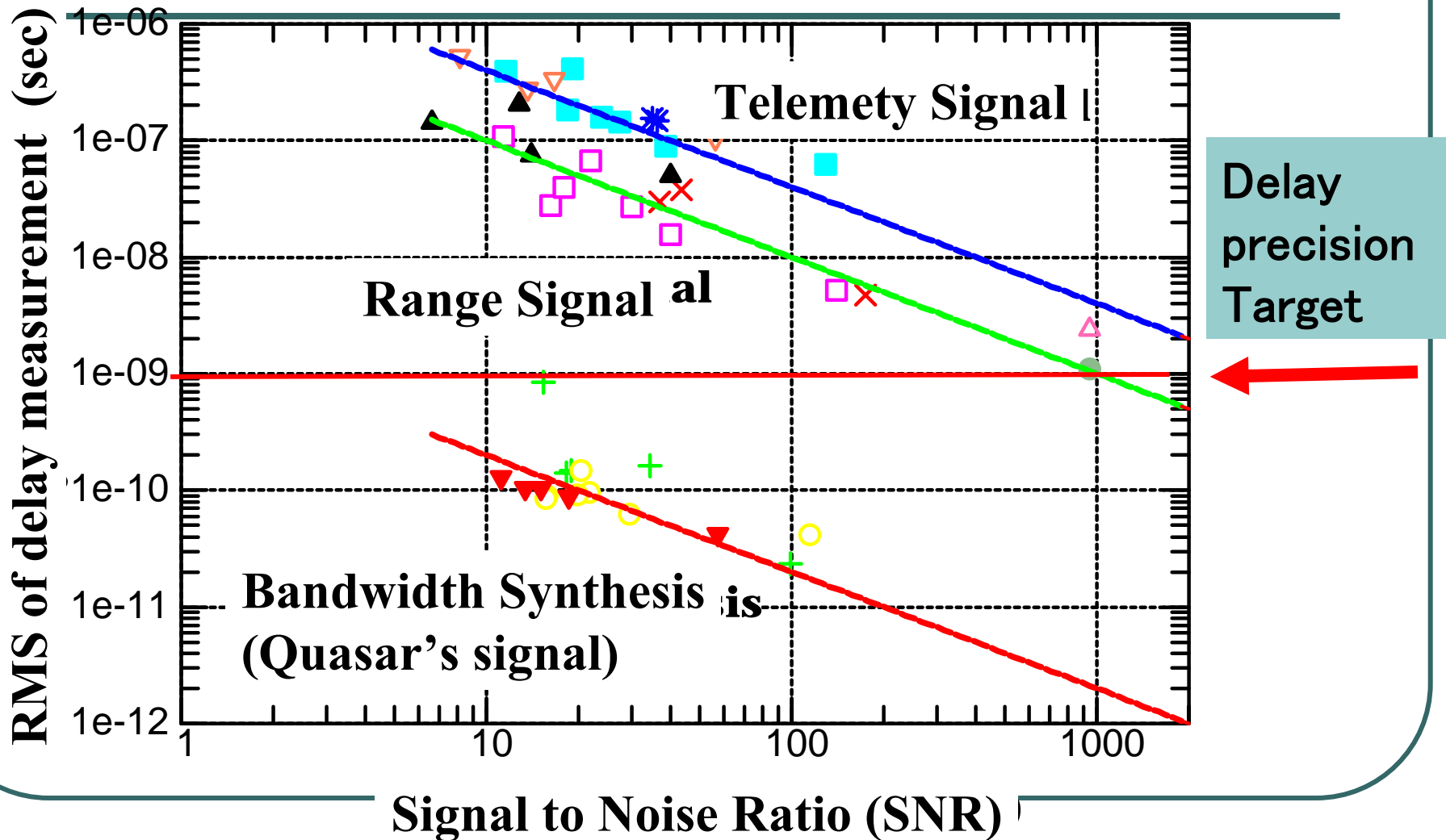
光速:  $c$



# 群遅延計測精度

Hayabusa Observations  
In May /30 ~ July 4 2005

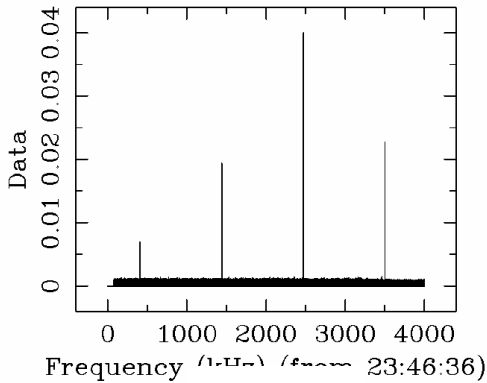
$$\sigma_{\tau} = \frac{A}{(SNR \times EffectiveBandwidth)}$$



# VLBI 観測量: 群遅延

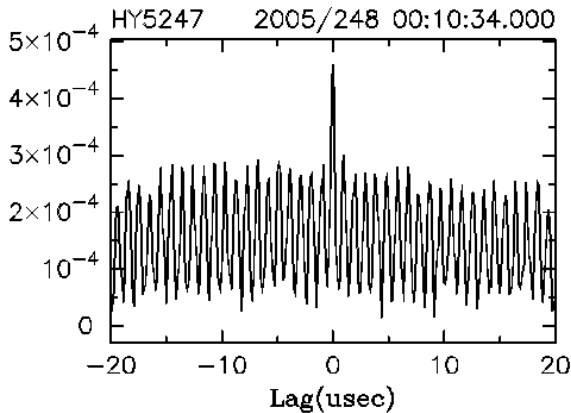
## DDOR signal

0.000 - 1.000 sec.  
8e+03 kHz-1bit Auto Cor Spectrum



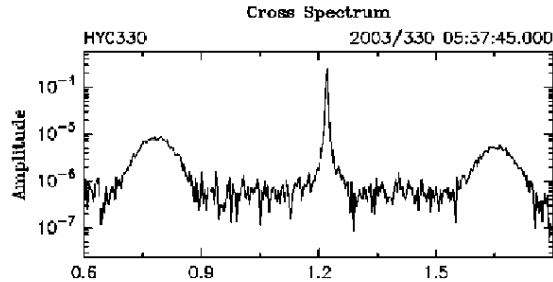
← 4MHz →

### Fringe



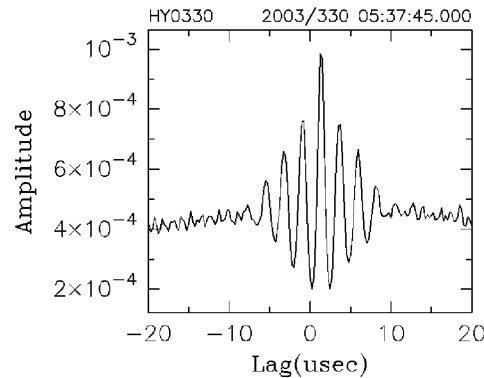
Effective Bandwidth  
450kHz

## Range signal



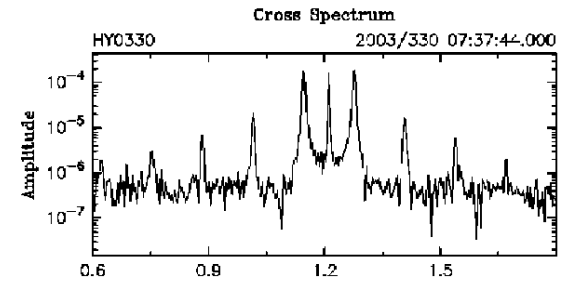
← 1MHz →

### Fringe



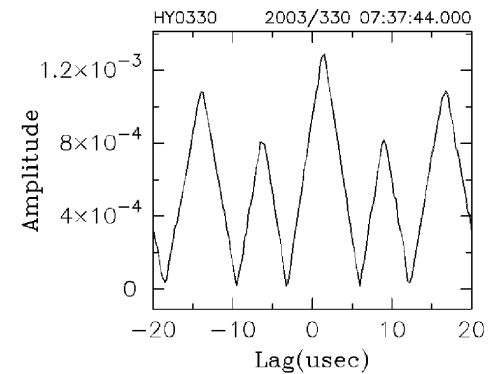
Effective Bandwidth  
100kHz

## Telemetry Signal



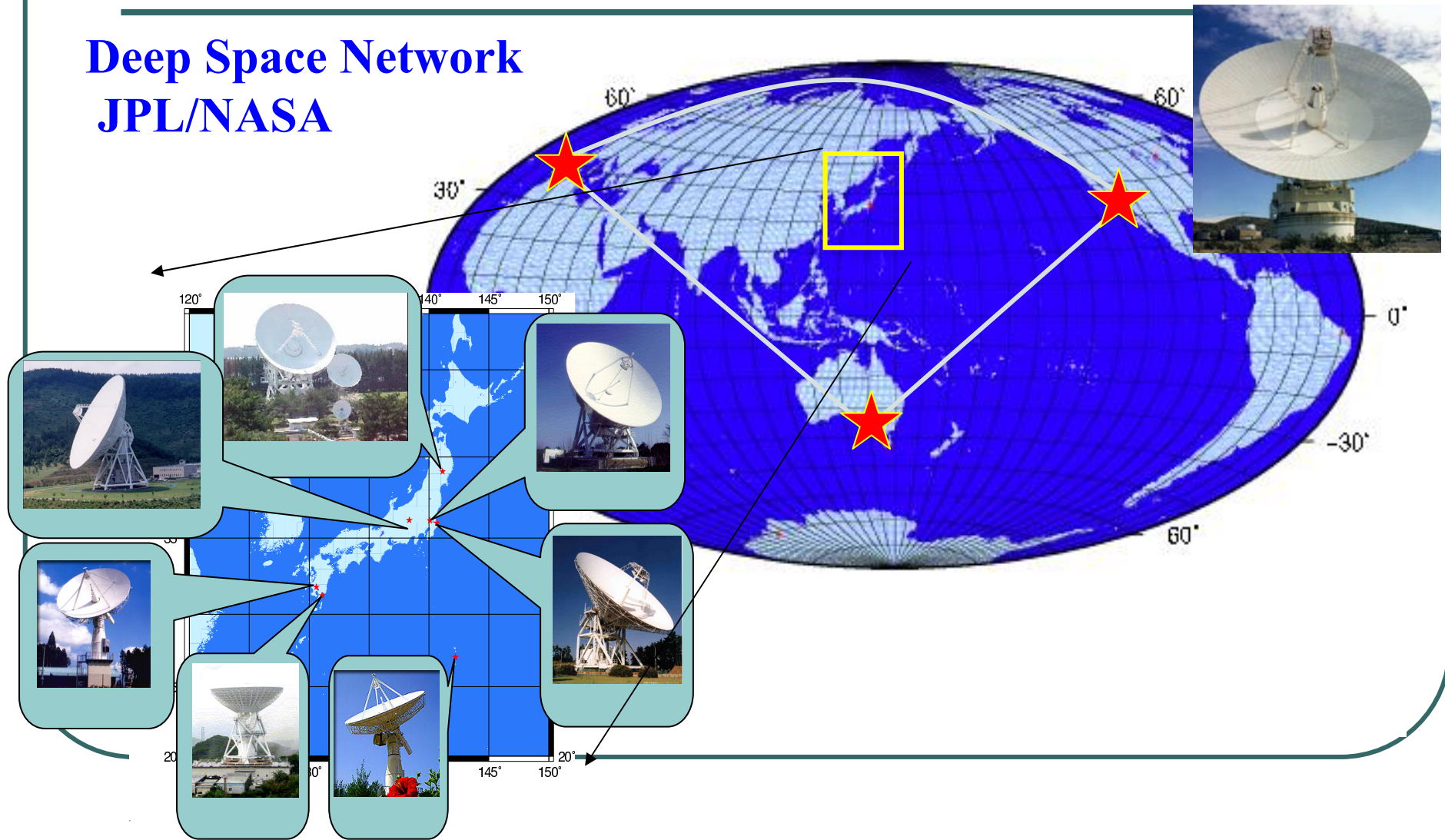
← 1MHz →

### Fringe



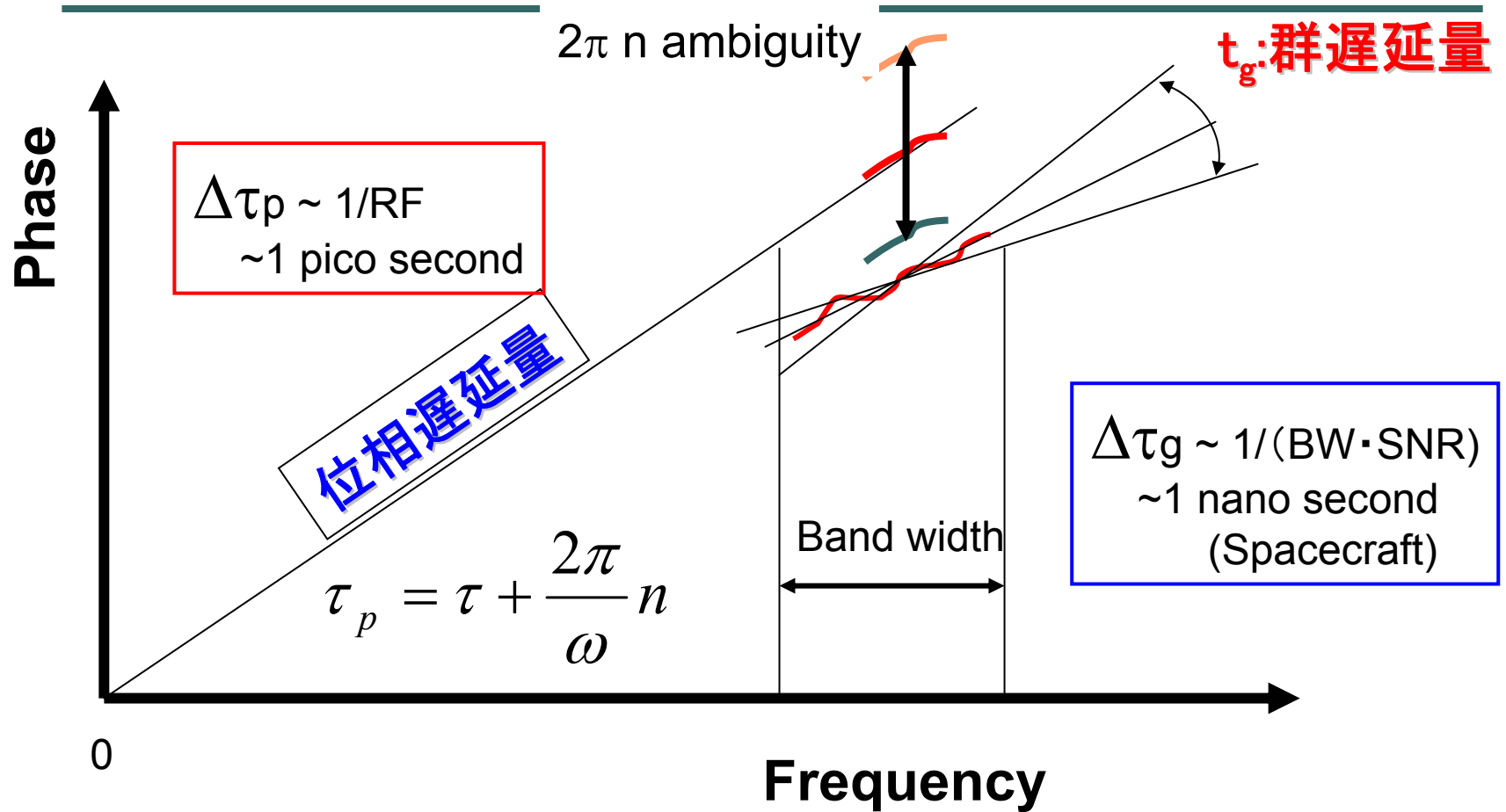
# Deep Space Network and Japanese Domestic VLBI stations

Deep Space Network  
JPL/NASA

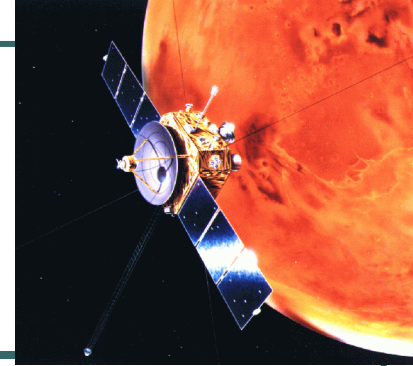




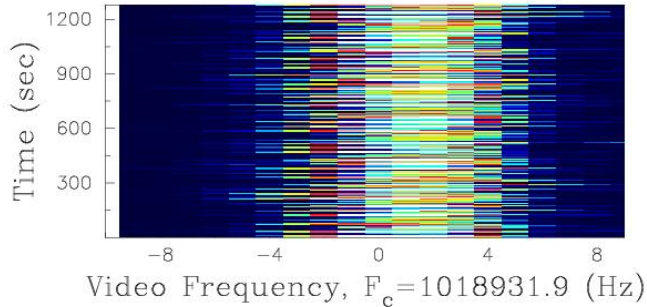
# VLBI 観測量: 群遅延 & 位相遅延



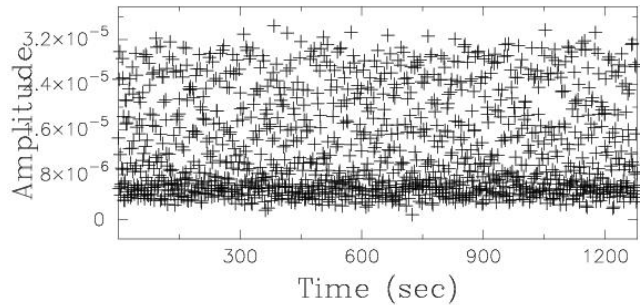
# Alternative Choice: 位相遅延量



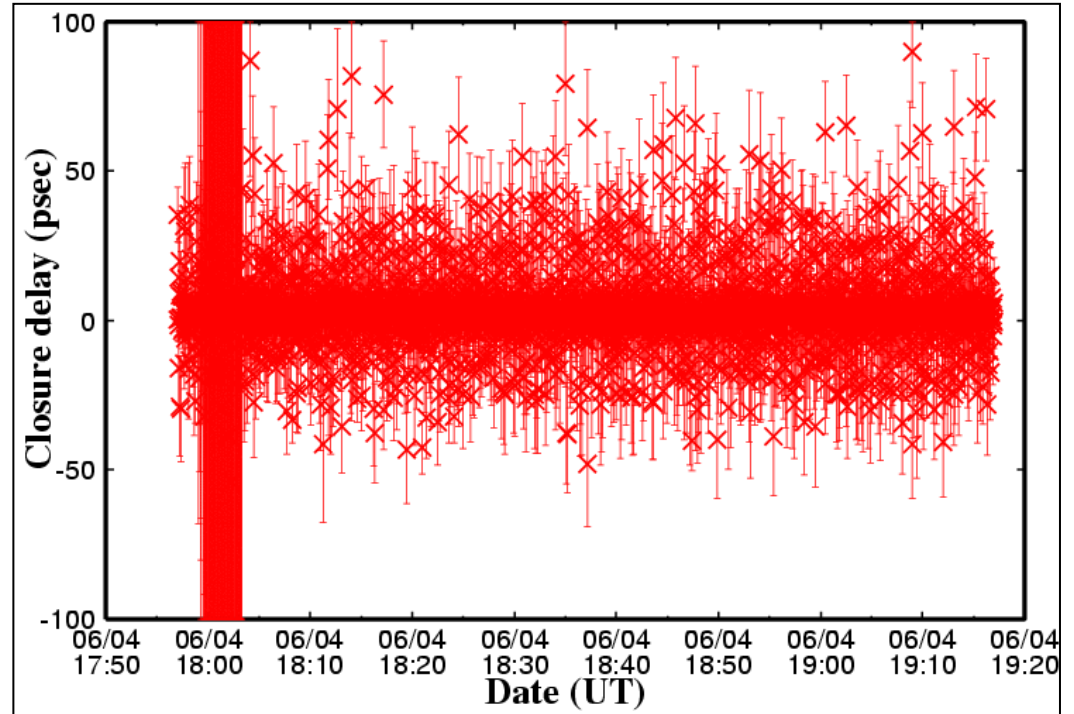
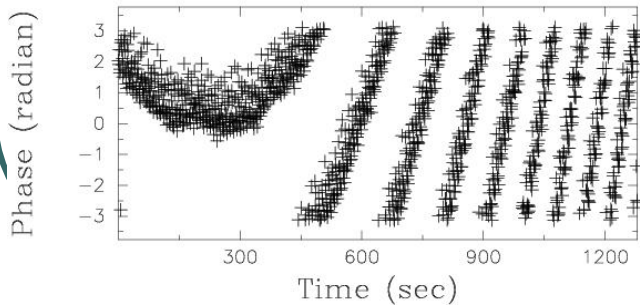
Dynamic Cross Spectrum: Rate Corrected ch=1



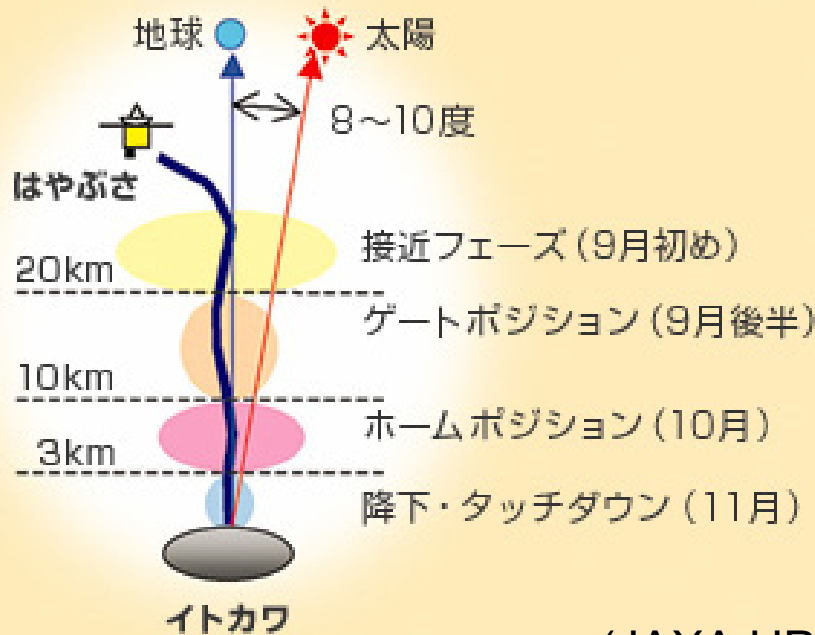
Dynamic Cross Spectrum: Rate Corrected ch=1



Dynamic Cross Spectrum: Rate Corrected ch=1



# Hayabusa's Touchdown Approach to ITOKAWA in Nov. 2005

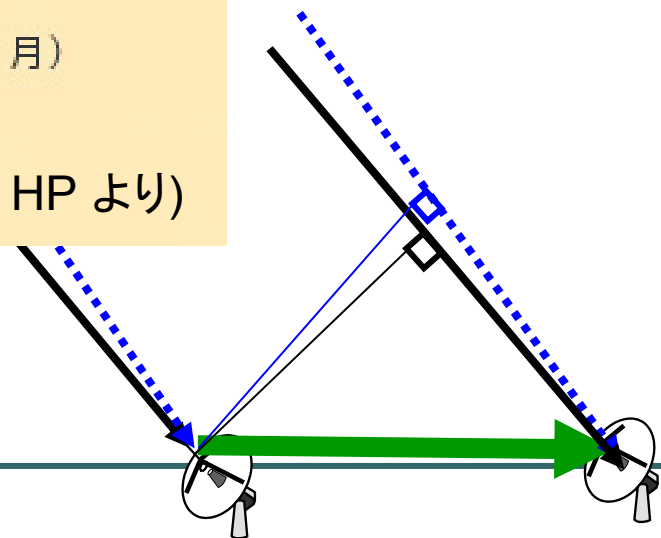


- △ VLBI Observation
- Nov. 4<sup>th</sup>
  - Nov. 12<sup>th</sup>
  - Nov. 19<sup>th</sup>
  - Nov. 25<sup>th</sup>

(JAXA HP より)

Fringe spacing:  $\frac{\lambda}{B} \times n$

B=50km :	190km
B=300km :	33km



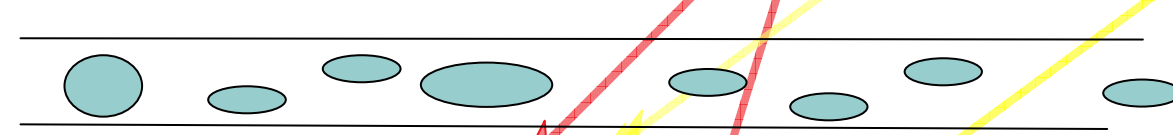
# Delta-VLBI is for Calibration of Atmosphere, Clock offset

$$\tau = \tau_{geo} + \tau_{clock} + \tau_{atm} + \tau_{inst} + \dots$$

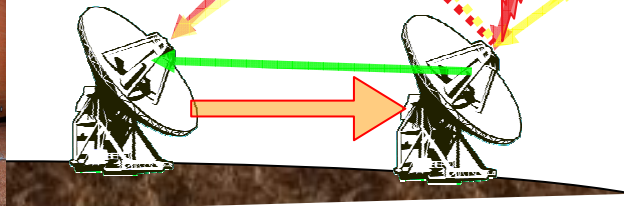


Ionosphere

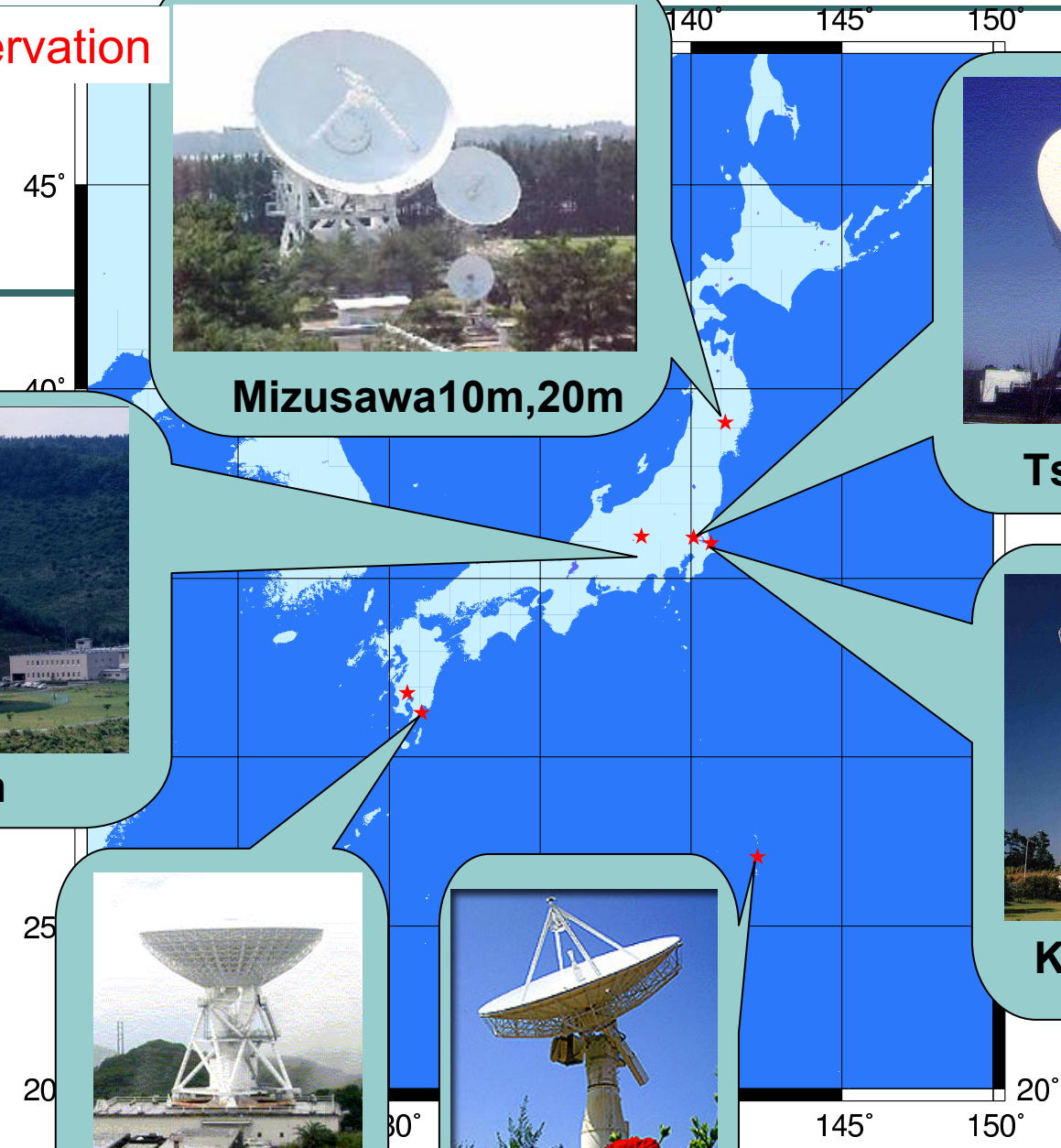
Atmosphere



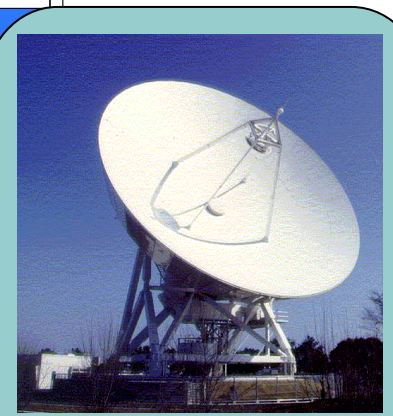
Atomic  
Clock  
(H-Maser)



**HYBS VLBI observation**



**Mizusawa 10m, 20m**



**Tsukuba 32m**



**Usuda 64m**



**Kashima 34m**



**Uchinoura 34m**



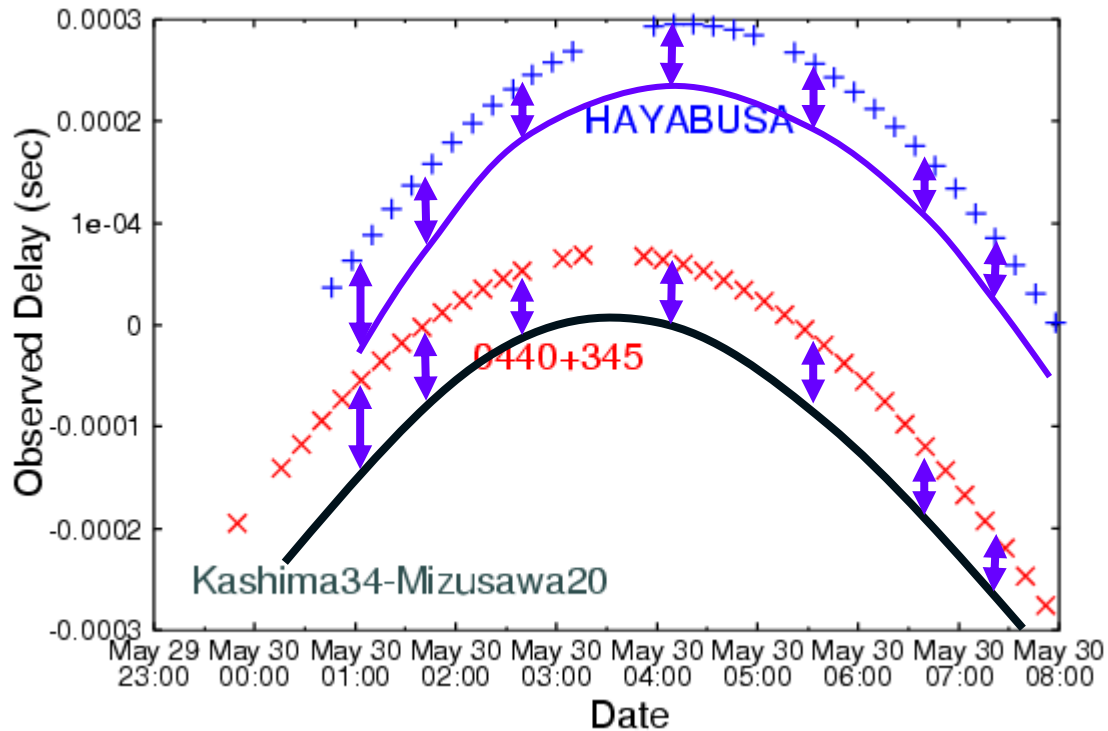
**Chichi 10m**

## **△ VLBI of HAYABYSA in Nov. 2005**

Epoch	Reference Source (Angular Distance)	Switching Cycle	Observation Stations
4 <sup>th</sup> Nov.	1352-104(3.3deg)	6 min.	O,T,C
12 <sup>th</sup> Nov.	1430-178(3.3deg.) 1443-162(2.4deg.)	6 min. Alternatively	O,T
19 <sup>th</sup> Nov.	1443-162(5.5deg.) 1430-178(8.5deg.)	6 min. Alternatively	O,T,M
25 <sup>th</sup> Nov.	1514-241(6.8deg.) 1504-166(7.1deg.)	6 min. Alternatively	O,T

O:Kashima34, T:Tsukuba32m, C: Chichijima10m, M: Mizusawa 20m

# Delta-VLBI: データ処理の手順



June 28 - July 4 2005  
Spacecraft: HAYABUSA  
0440+345: 6 deg. Away  
Switching cycle: 8 min.

# △ VLBIによる遅延量の補正

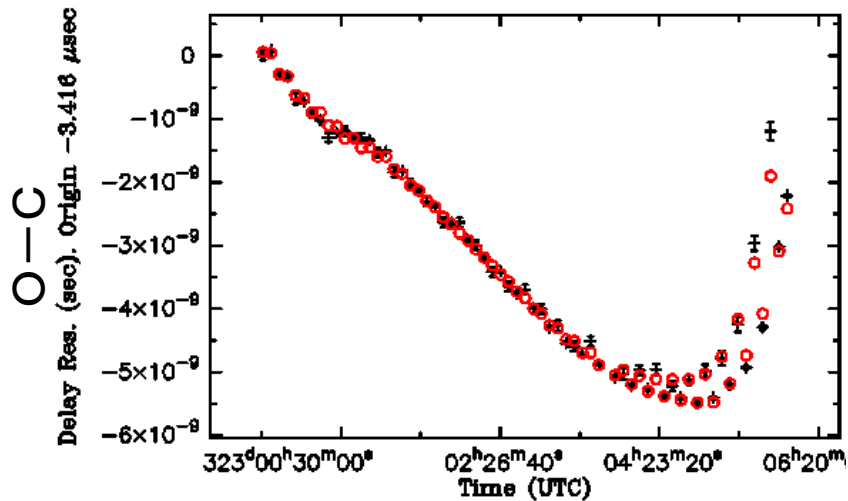
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△ VLBIによりどの程度の精度(確度)で遅延量が計測できるか？

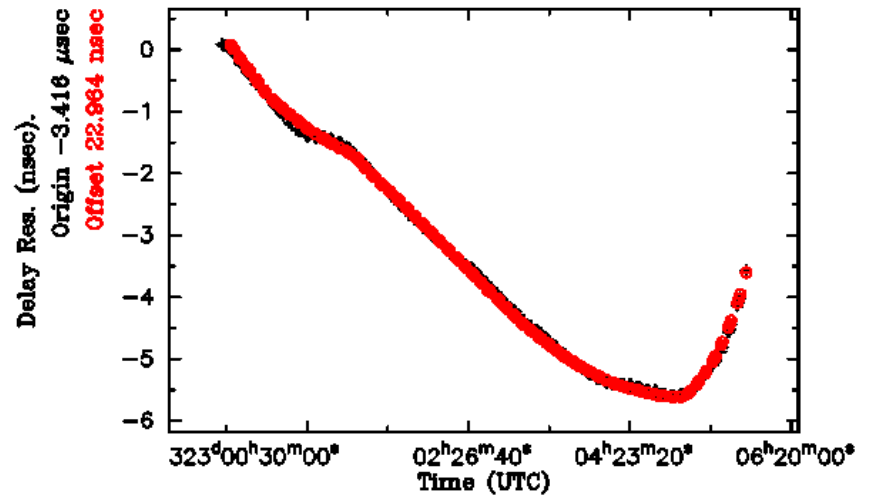


# 2005/11/19 鹿島34-水沢20基線

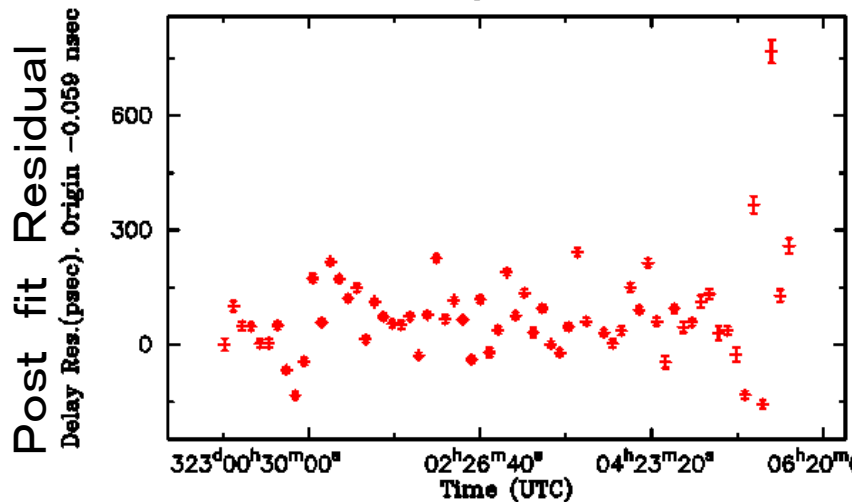
## 基準電波源へのモデルフィット



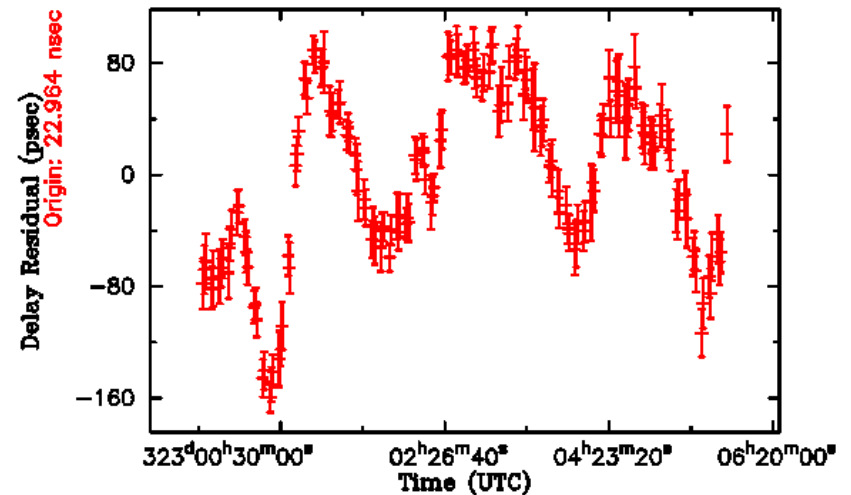
## HYBSへのモデル適用 (nsec)



## Reference Delay Post-Fit-Residual



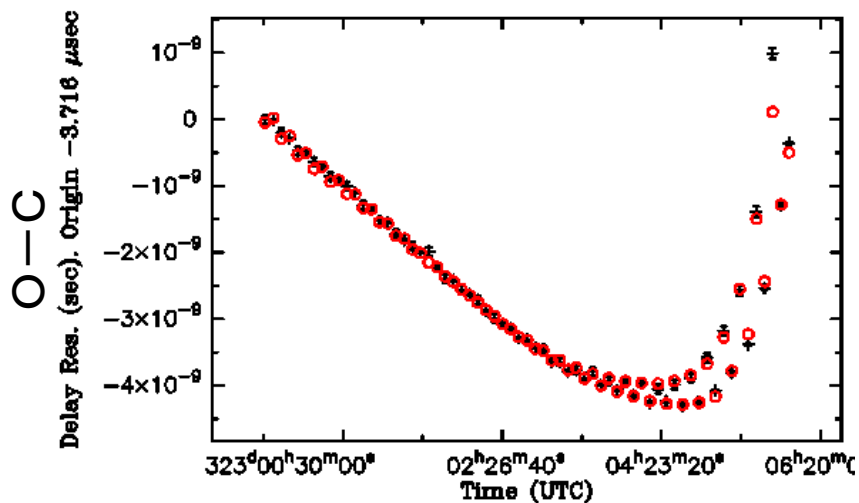
## Target Delay Post-Correction-Residual



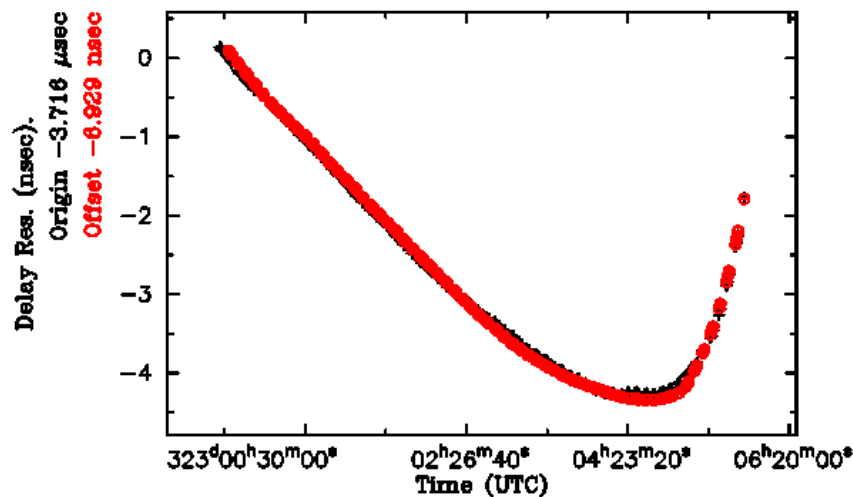
$$\tau = \tau_0 + \dot{\tau}(t - t_0) - \tau_{atm,x} fm(El_x) + \tau_{atm,y} fm(El_y)$$

# 2005/11/19 つくば32-水沢20基線

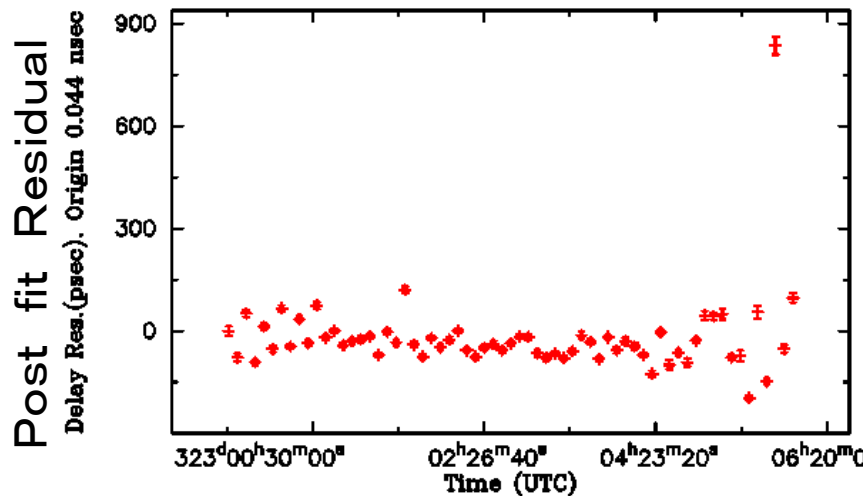
## 基準電波源へのモデルフィット



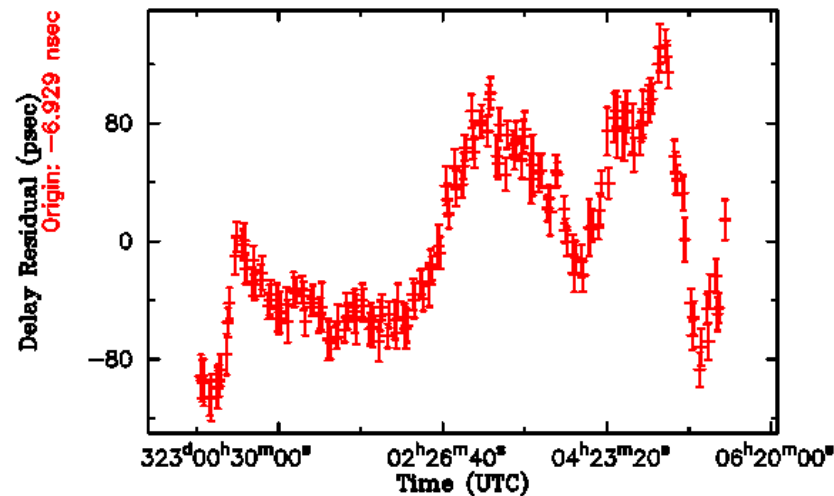
## HYBSへのモデル適用 (nsec)



### Reference Delay Post-Fit-Residual



### Target Delay Post-Correction-Residual



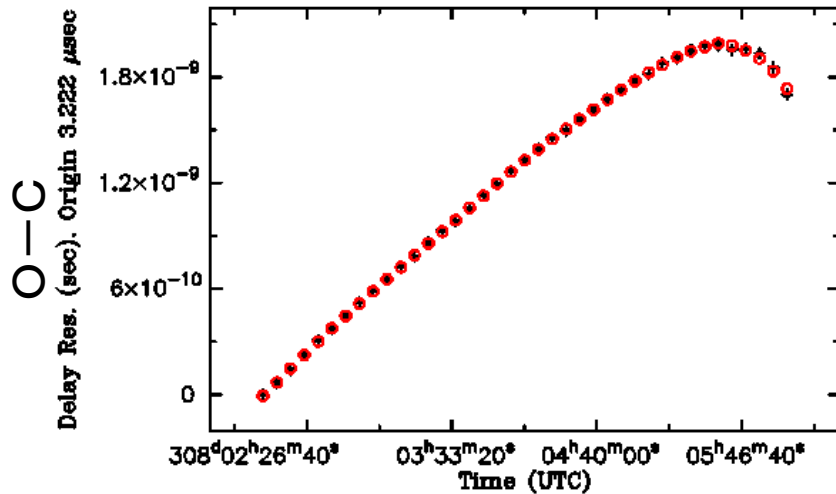
$$\tau = \tau_0 + \dot{\tau}(t - t_0) - \tau_{atm,x} fm(El_x) + \tau_{atm,y} fm(El_y)$$

マルチエポック折れ線

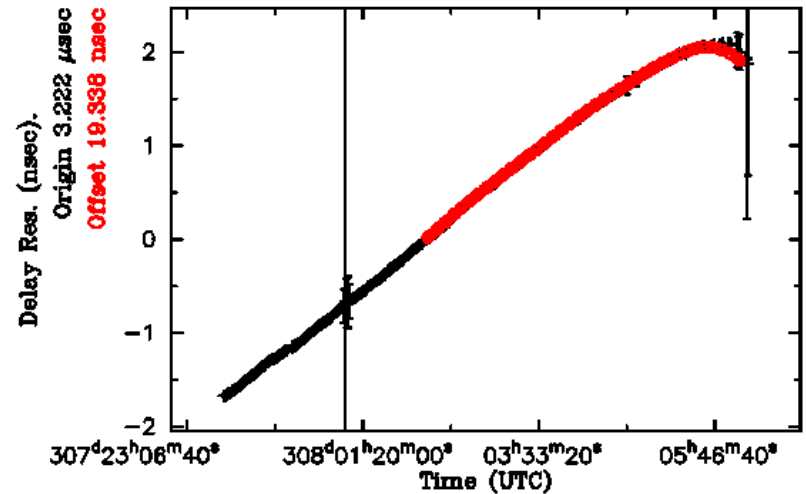
# 2005/11/4 鹿島34-つくば32基線

大気補正に  
地上THP使用

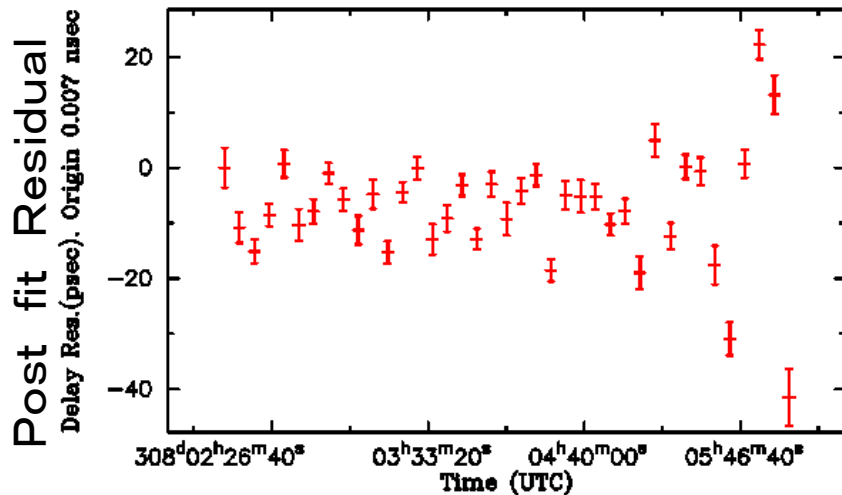
## 基準電波源へのモデルフィット



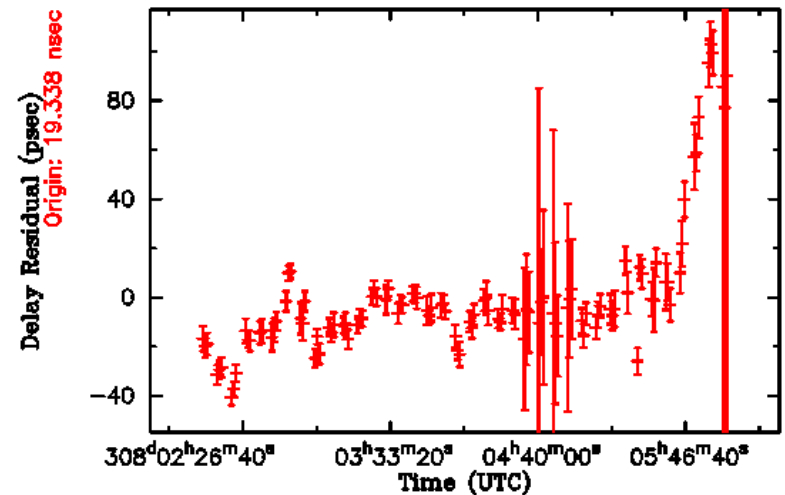
## HYBSへのモデル適用 (nsec)



### Reference Delay Post-Fit-Residual



### Target Delay Post-Correction-Residual

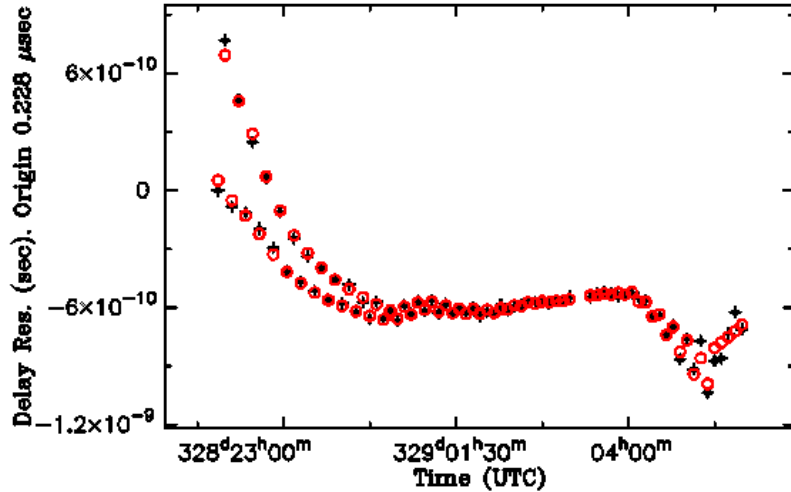


$$\tau = \tau_0 + \dot{\tau}(t - t_0) - \tau_{atm,x} fm(El_x) + \tau_{atm,y} fm(El_y)$$

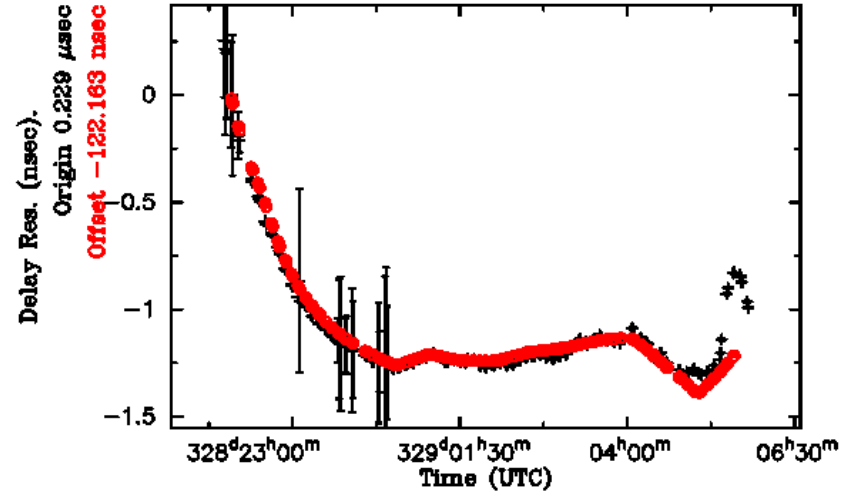
マルチエポック折れ線

# 2005/11/25 鹿島34-つくば32基線

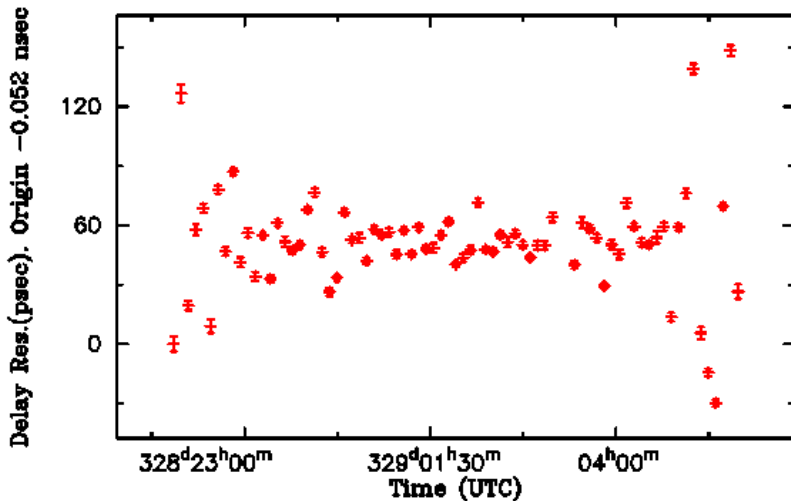
## 基準電波源へのモデルフィット



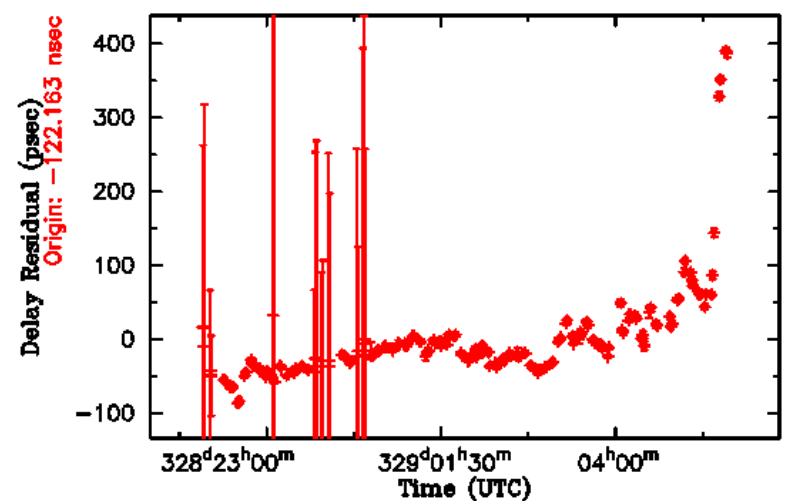
## HYBSへのモデル適用 (nsec)



## Reference Delay Post-Fit-Residual



## Target Delay Post-Correction-Residual



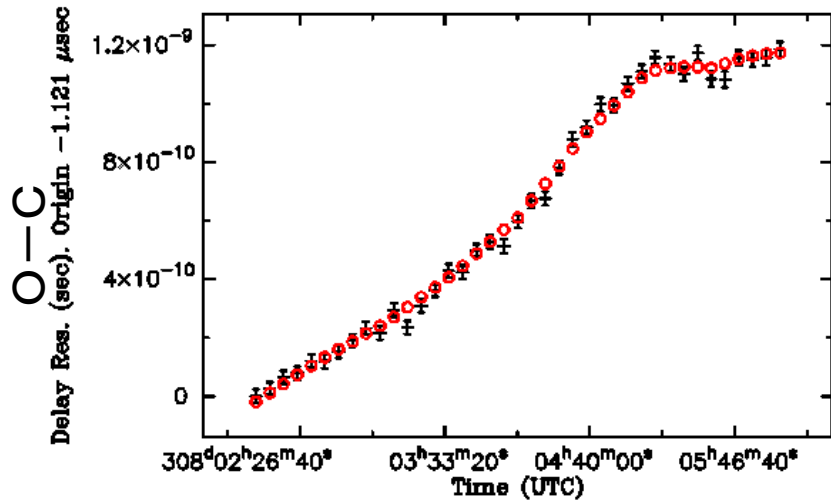
$$\tau = \tau_0 + \dot{\tau}(t - t_0) - \tau_{atm,x} fm(El_x) + \tau_{atm,y} fm(El_y)$$

マルチエポック折れ線

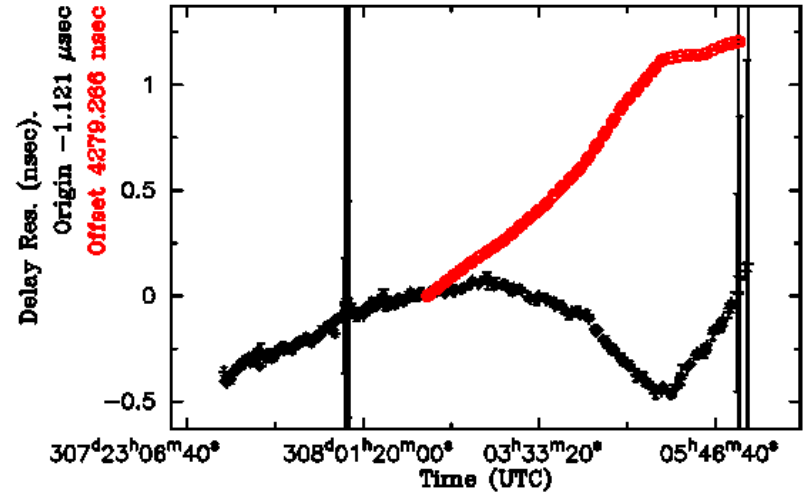
# 2005/11/4 つくば32-父島11基線

大気補正に  
地上THP使用

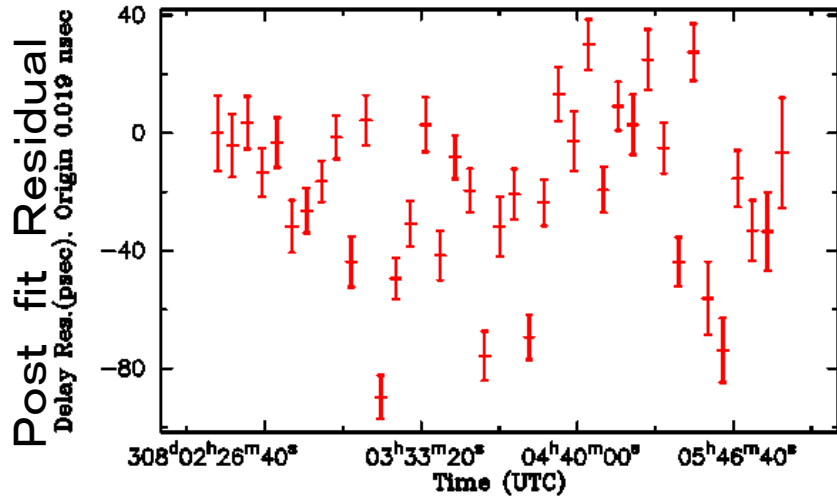
## 基準電波源へのモデルフィット



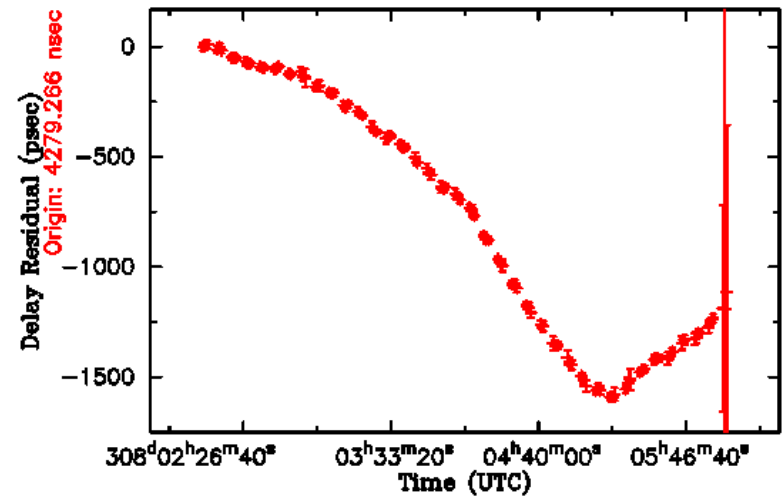
## HYBSへのモデル適用 (nsec)



## Reference Delay Post-Fit-Residual



## Target Delay Post-Correction-Residual



$$\tau = \tau_0 + \dot{\tau}(t - t_0) - \tau_{atm,x} fm(El_x) + \tau_{atm,y} fm(El_y)$$

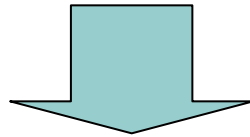
マルチエポック折れ線

## Delta-VLBI: データ処理の手順

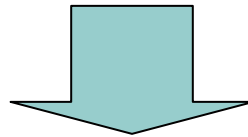
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$$\tau_{HYBS} = \tau_{geo} + \tau_{clock} + \tau_{atm} - \tau_{ION} + \dots$$

$$\tau_{QSO} = \tau_{geo} + \tau_{clock} + \tau_{atm} + \tau_{ION} + \dots$$



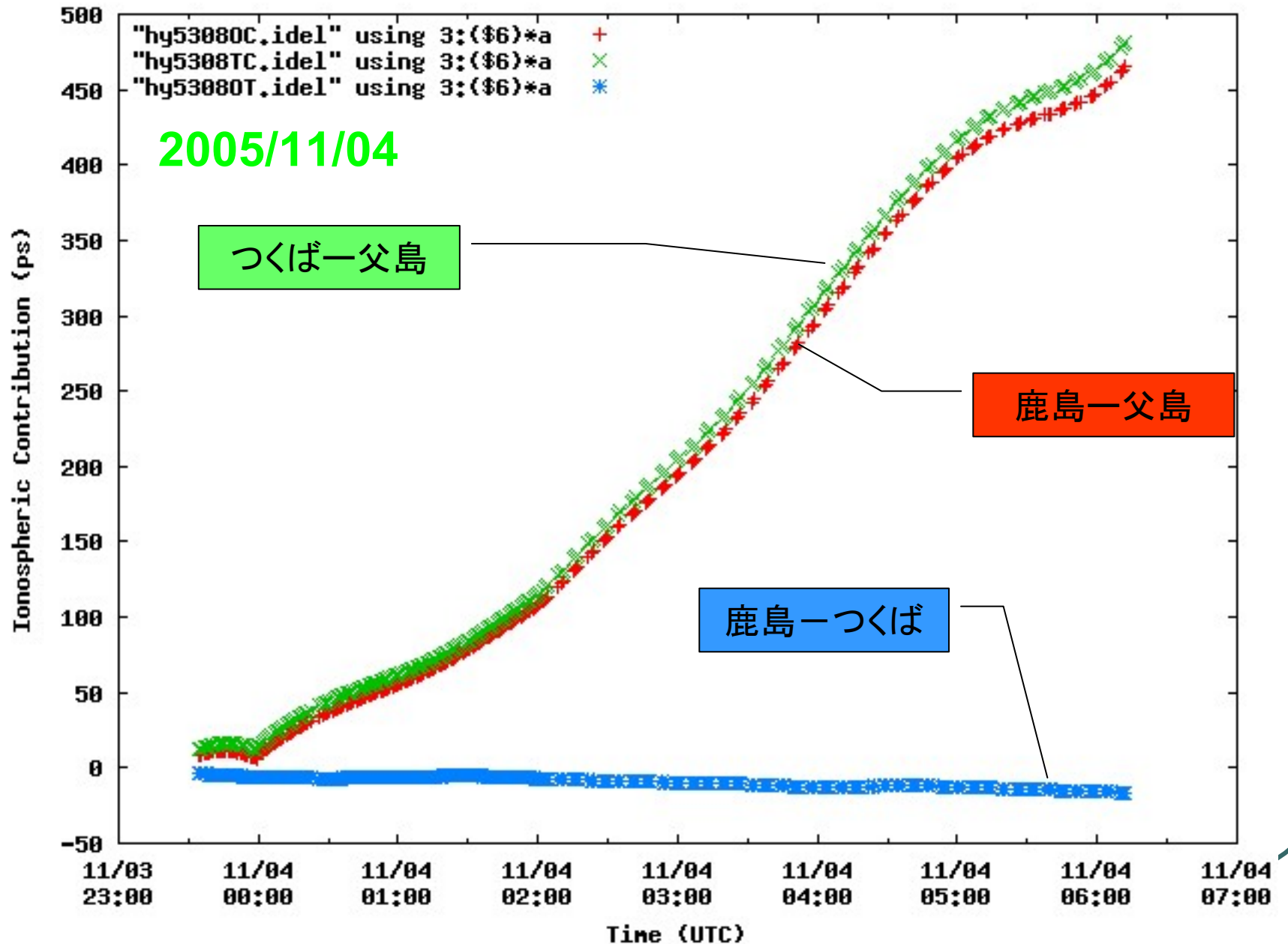
$$\tau_{QSO}^O - \tau_{QSO}^C = \tau_{clock} + \tau_{atm} + \tau_{ION} + \dots$$



$$(\tau_{HYBS}^O - \tau_{HYBS}^C) - (\tau_{QSO}^O - \tau_{QSO}^C) = \Delta\tau^{Rsd}_{HYBS} - 2\tau_{ION} + \alpha$$



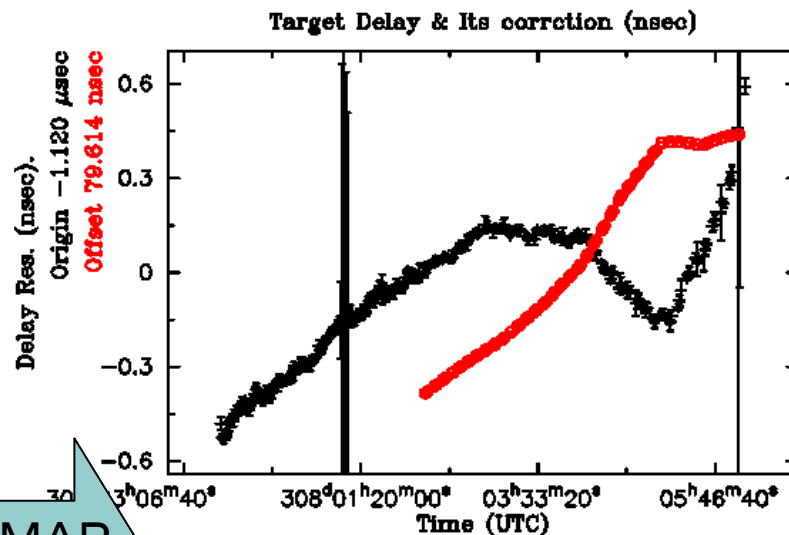
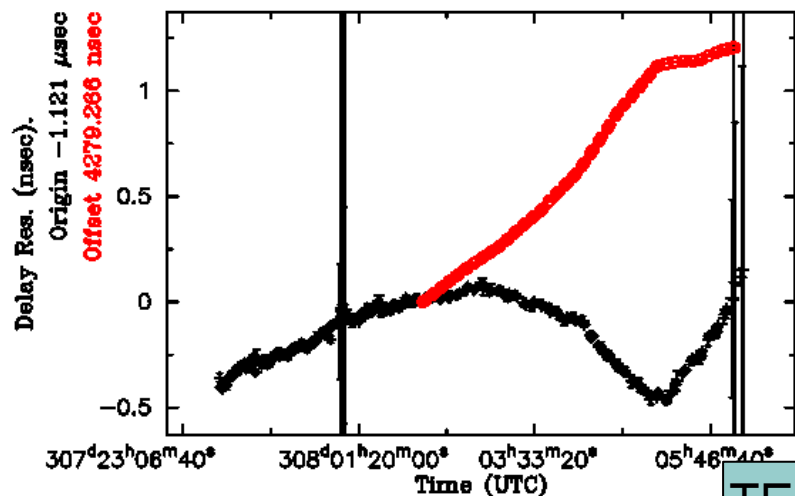
# GIM/CODEを使って計算された電離層遅延量 (HAYABUSA)



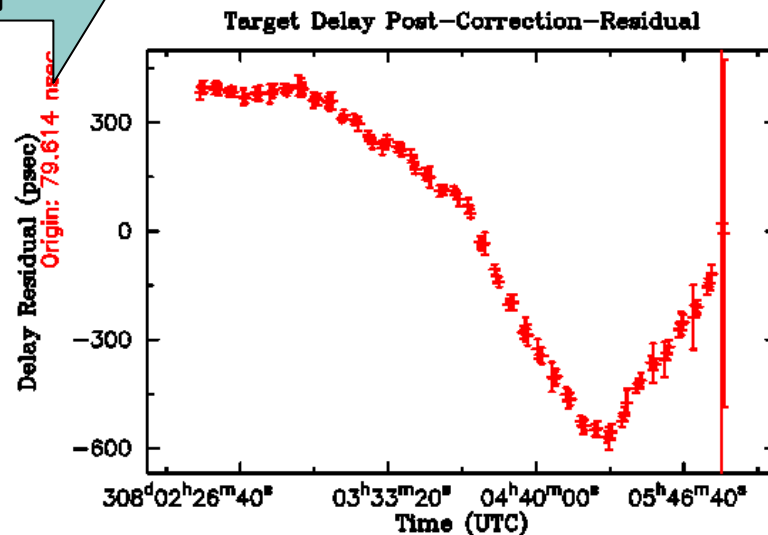
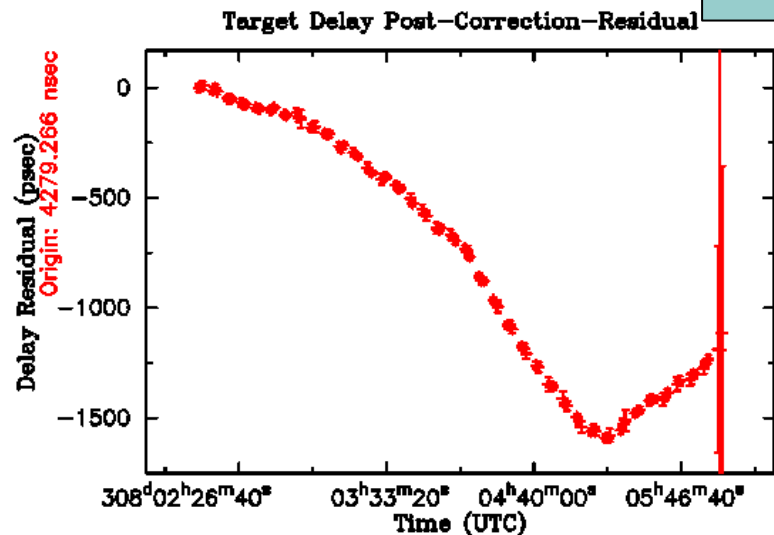


# 2005/11/4 つくば32-父島11基線

## HYBSへのモデル適用 (nsec)



TEC-MAP  
適用



$$\tau = \tau_0 + \dot{\tau}(t - t_0) - \tau_{atm,x} fm(El_x) + \tau_{atm,y} fm(El_y)$$

マルチエポック折れ線

# Summary

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## ● 2005年11月のHAYABUSA観測

- 高い遅延分解能を得るため位相遅延量を使用。
- 高い軌道予報値により位相の不定性を0と仮定。
- HAYABUSAの位相遅延量をクエーサの群遅延量により補正

## ● 結果

- $\Delta$ VLBIによる、幾何学的遅延量の計測精度を数百psec程度達成。 JPLのDDORと同程度

## ● 課題

- 信号の帯域幅  $\Rightarrow$  群遅延
- $\Delta$ VLBIの補正方法について要検討: 位相遅延一位相遅延