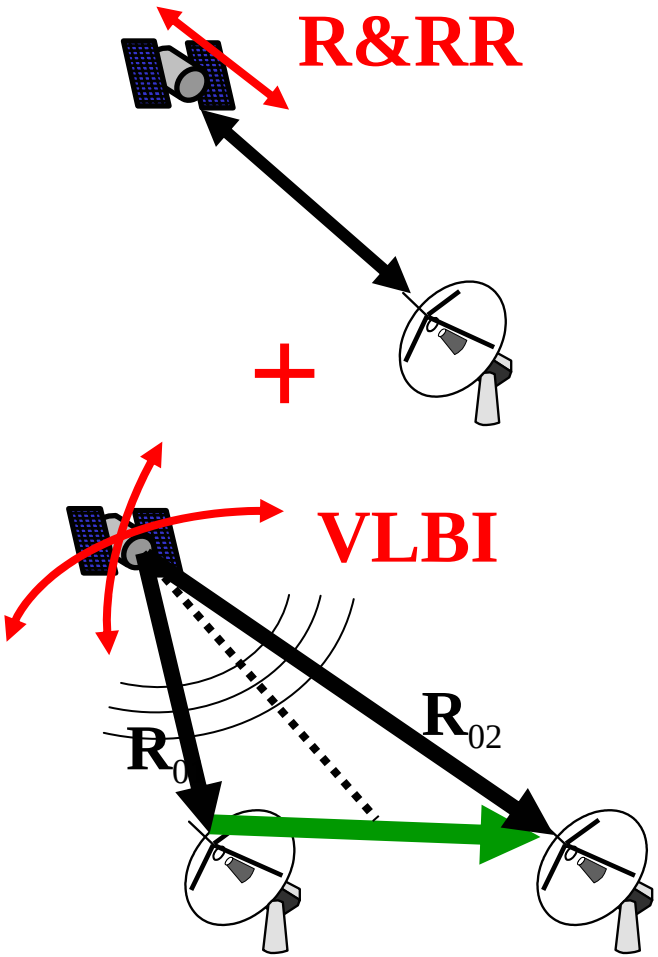
宇宙飛翔体の相対VLBI観測における遅延計測精度評価

関戸衛労、市川隆一(NICT)

吉川真、竹内央、加藤隆二、市川勉
(JAXA)

Spacecraft Navigation
R&RR + VLBI



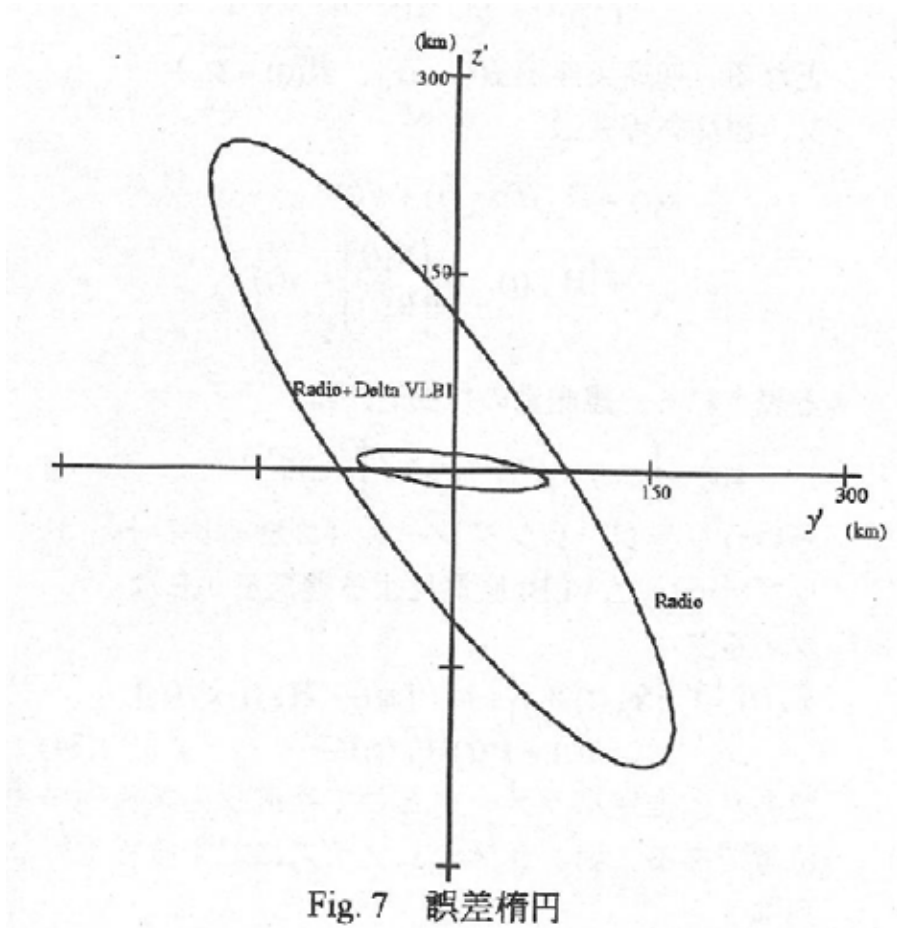


Fig. 7 誤差楕円

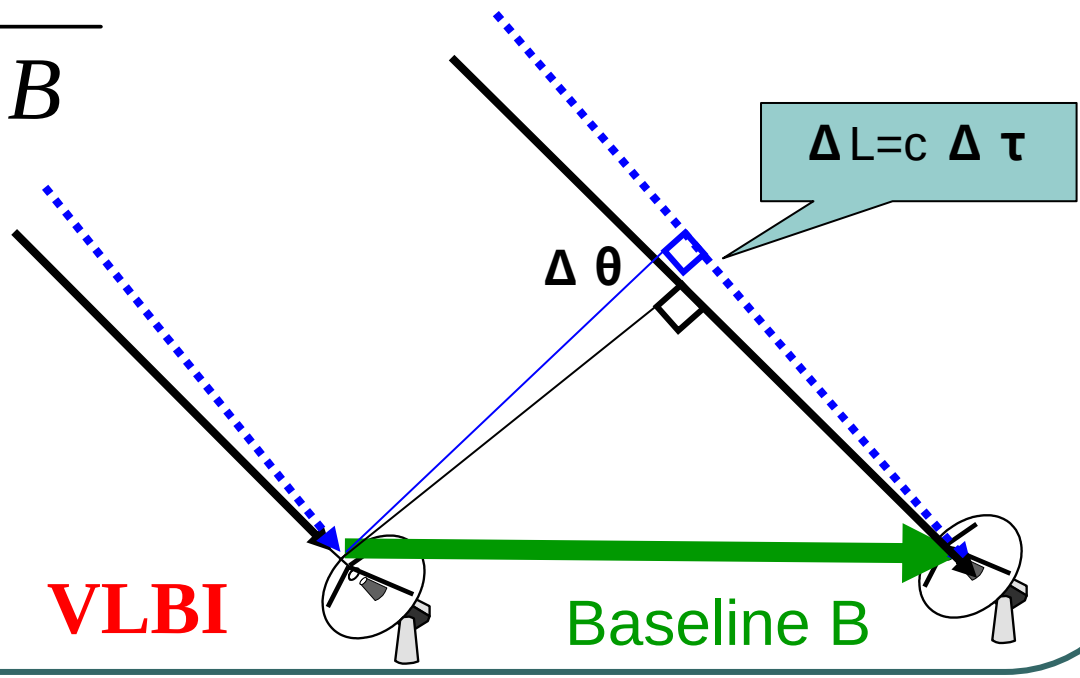
相対VLBI 精度

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

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

遅延計測精度: **Δ τ**
基線長: B
角度分解能: **Δ θ**
光速度: c

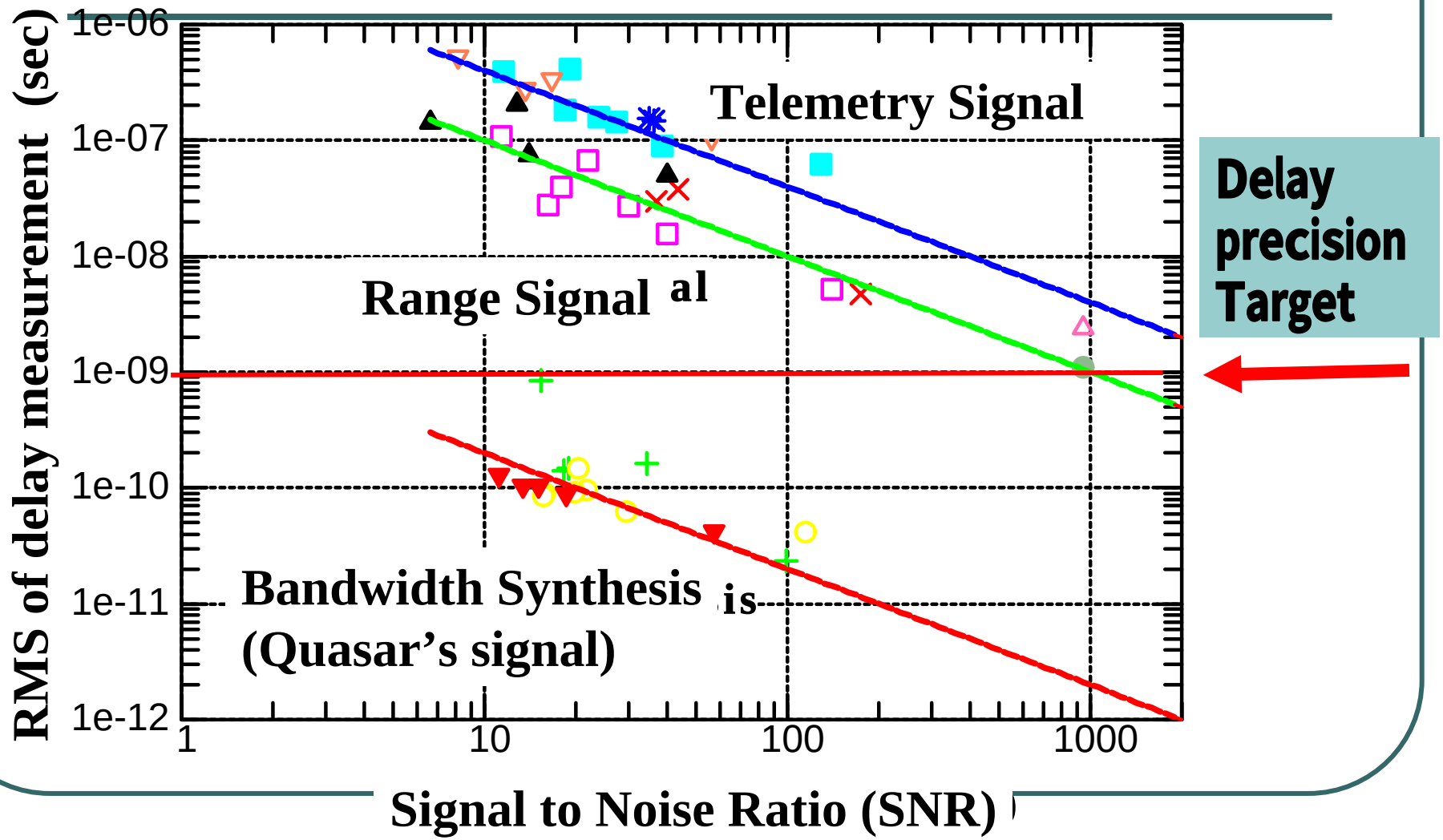
1 ns/1000km ➔ 0.3 μ radian
(60mas)
45km@1AU
1ns/8000km ➔ 40 n radian
(8mas)
6km@1AU



Precisoin of Groud Delay

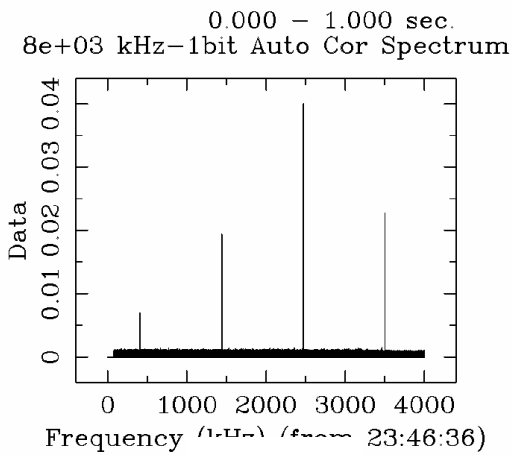
$$\sigma_\tau = A / (SNR \times Bandwidth)$$

Hayabusa Observations
In May /30～July 4 2005

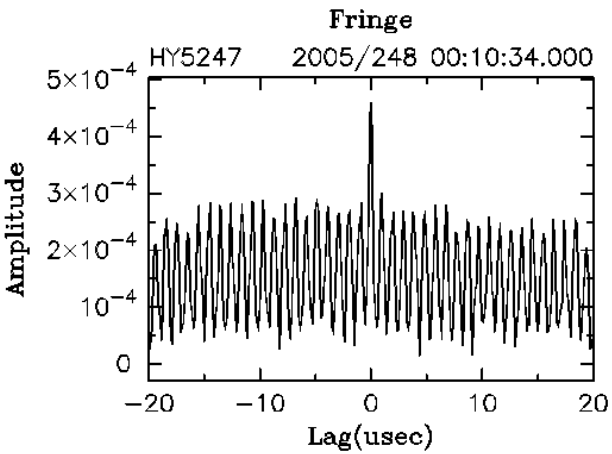


VLBI Observable: Group Delay

DDOR signal

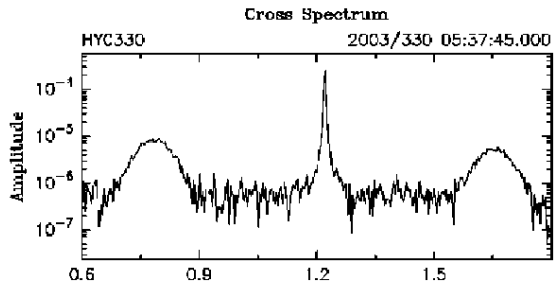


← 4MHz →

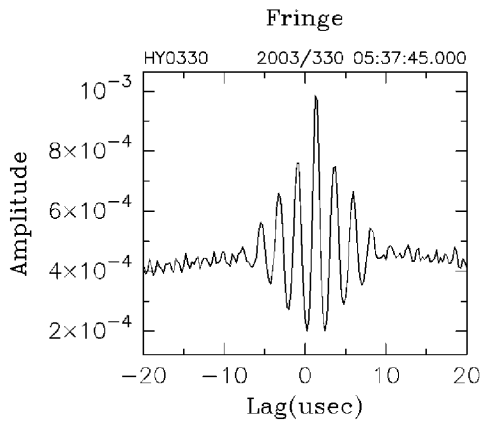


Effective Bandwidth 450kHz

Range signal

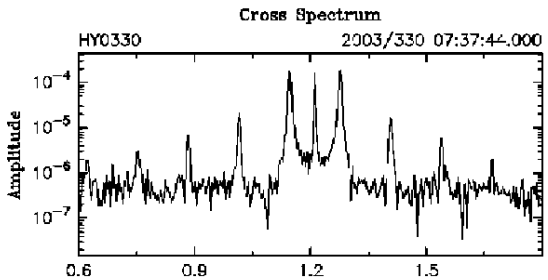


← 1MHz →

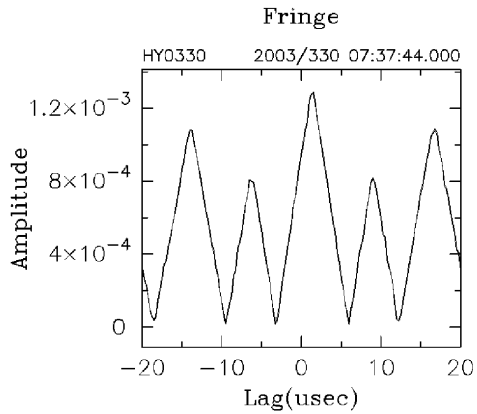


Effective Bandwidth 100kHz

Telemetry Signal

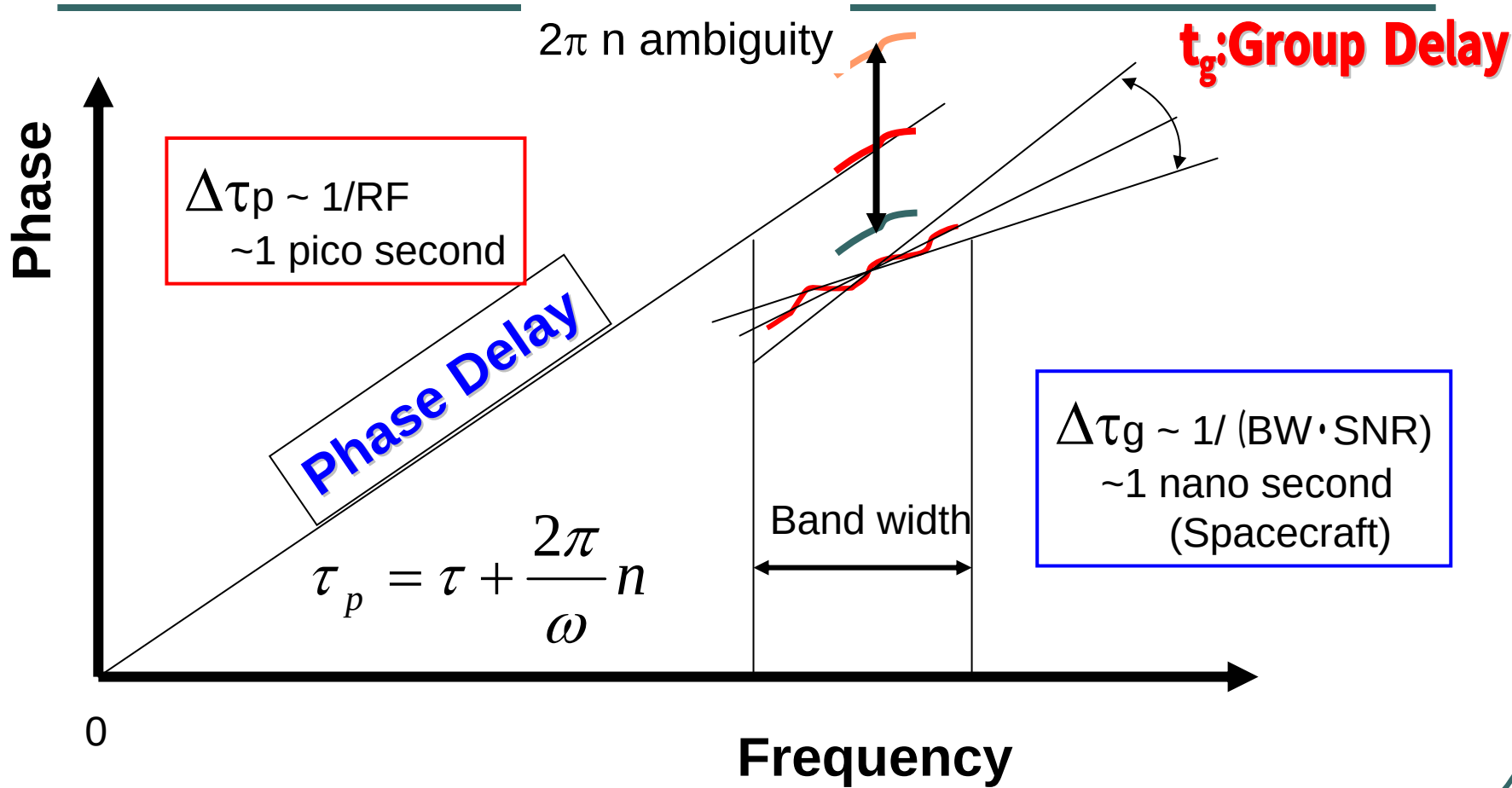


← 1MHz →

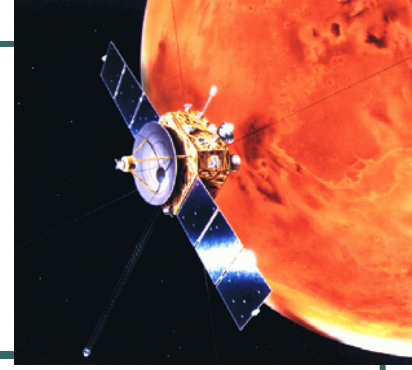


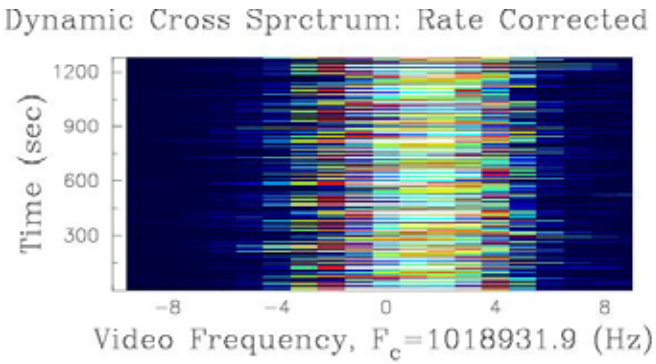
VLBI Delay Observable:

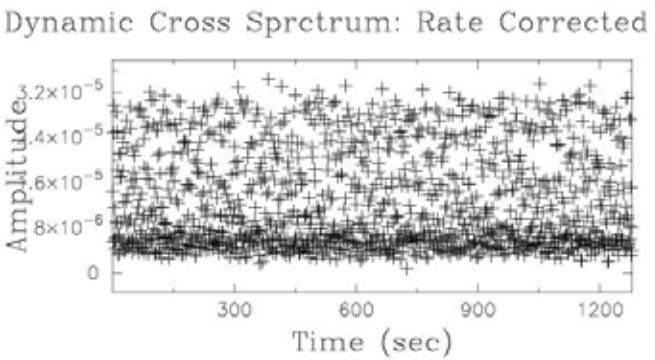
Group & Phase

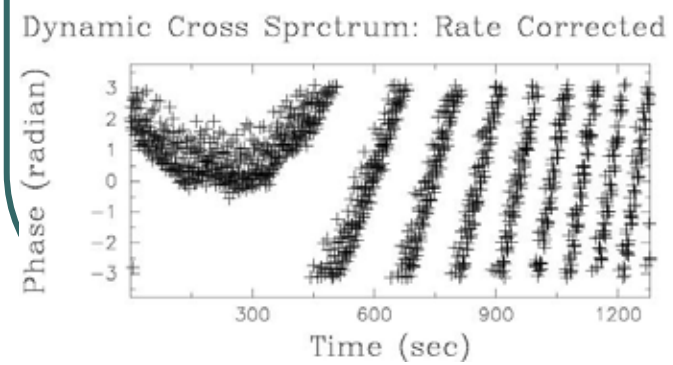


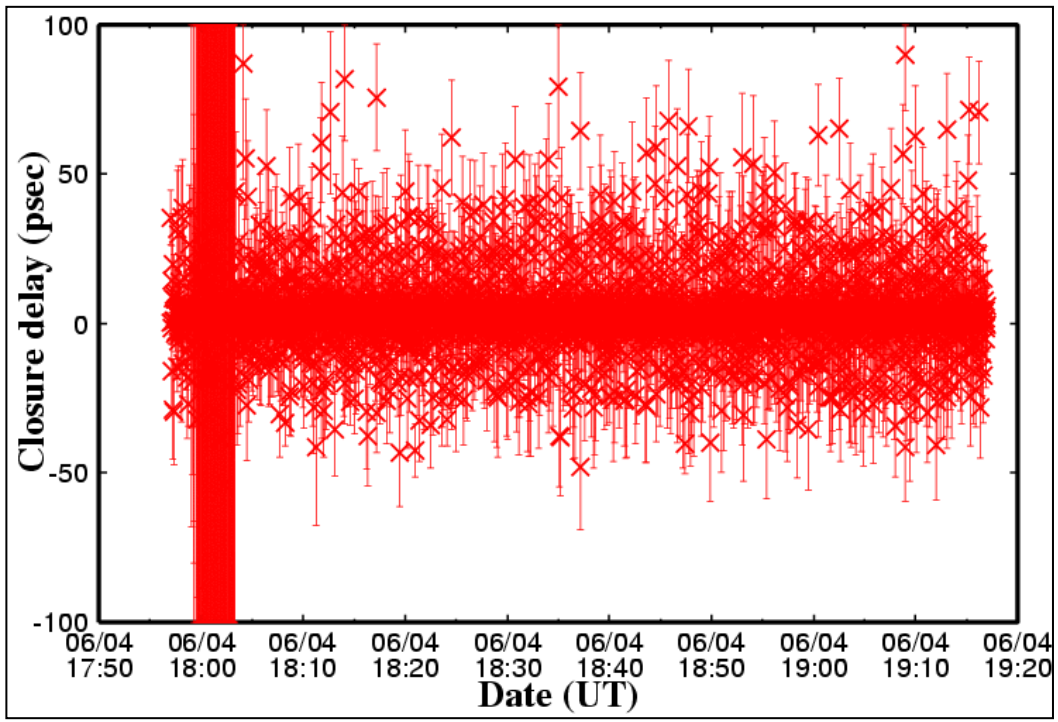
Alternative Choice:位相遅延量



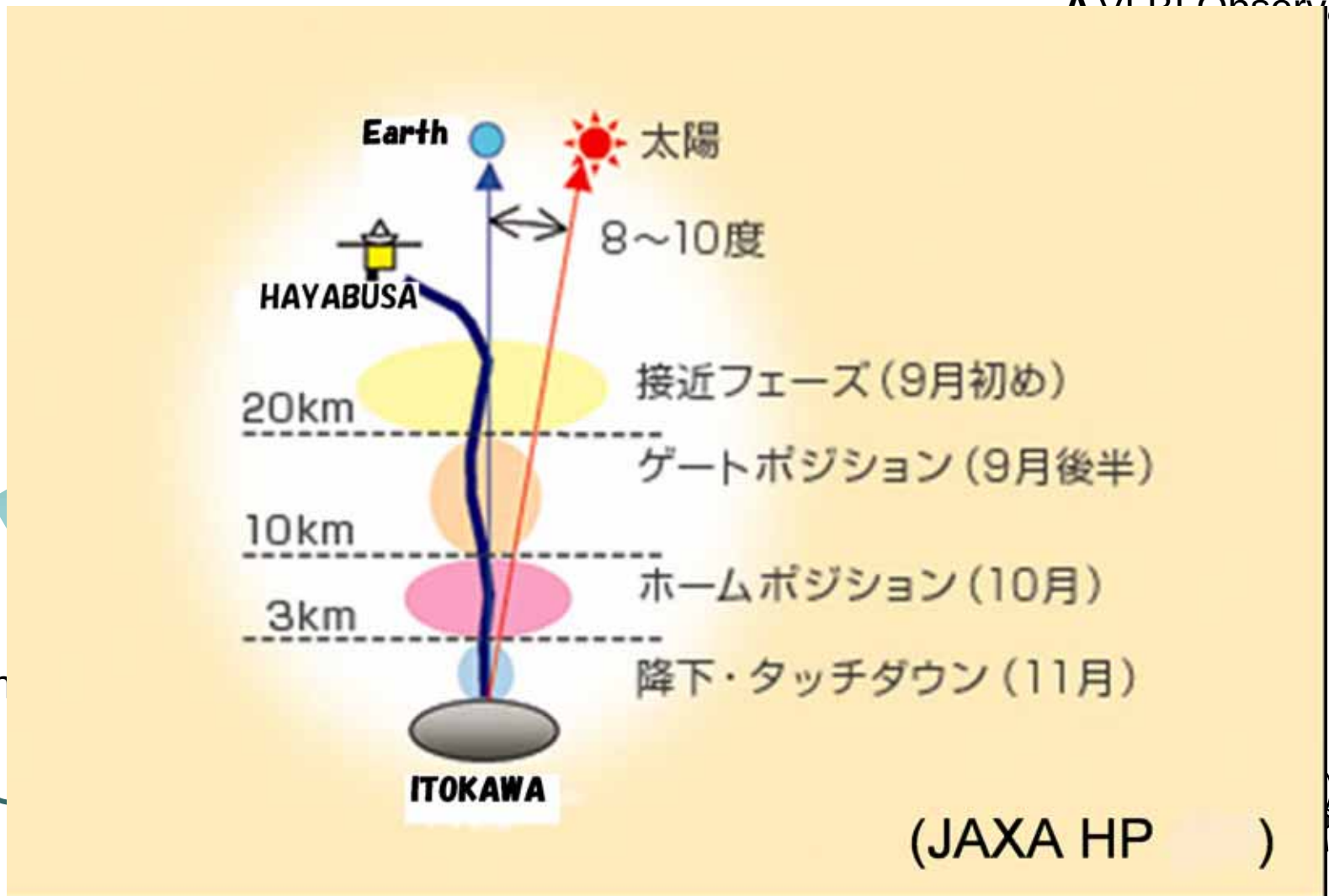








Hayabusa's Touchdown Approach to ITOKAWA in Nov. 2005



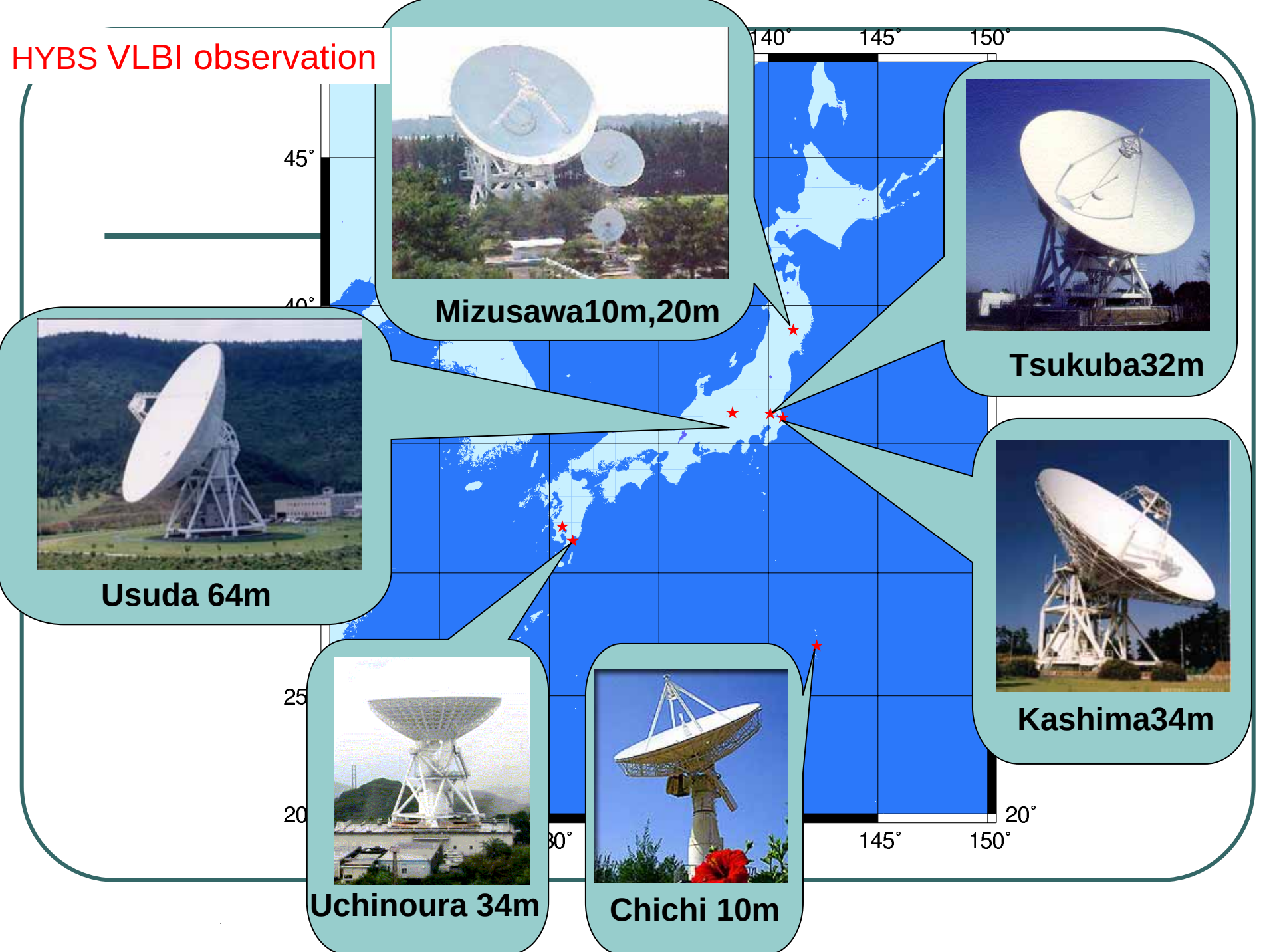
ΔVLBI of HAYABYSA in Nov. 2005

観測周波数：8.4GHz

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

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

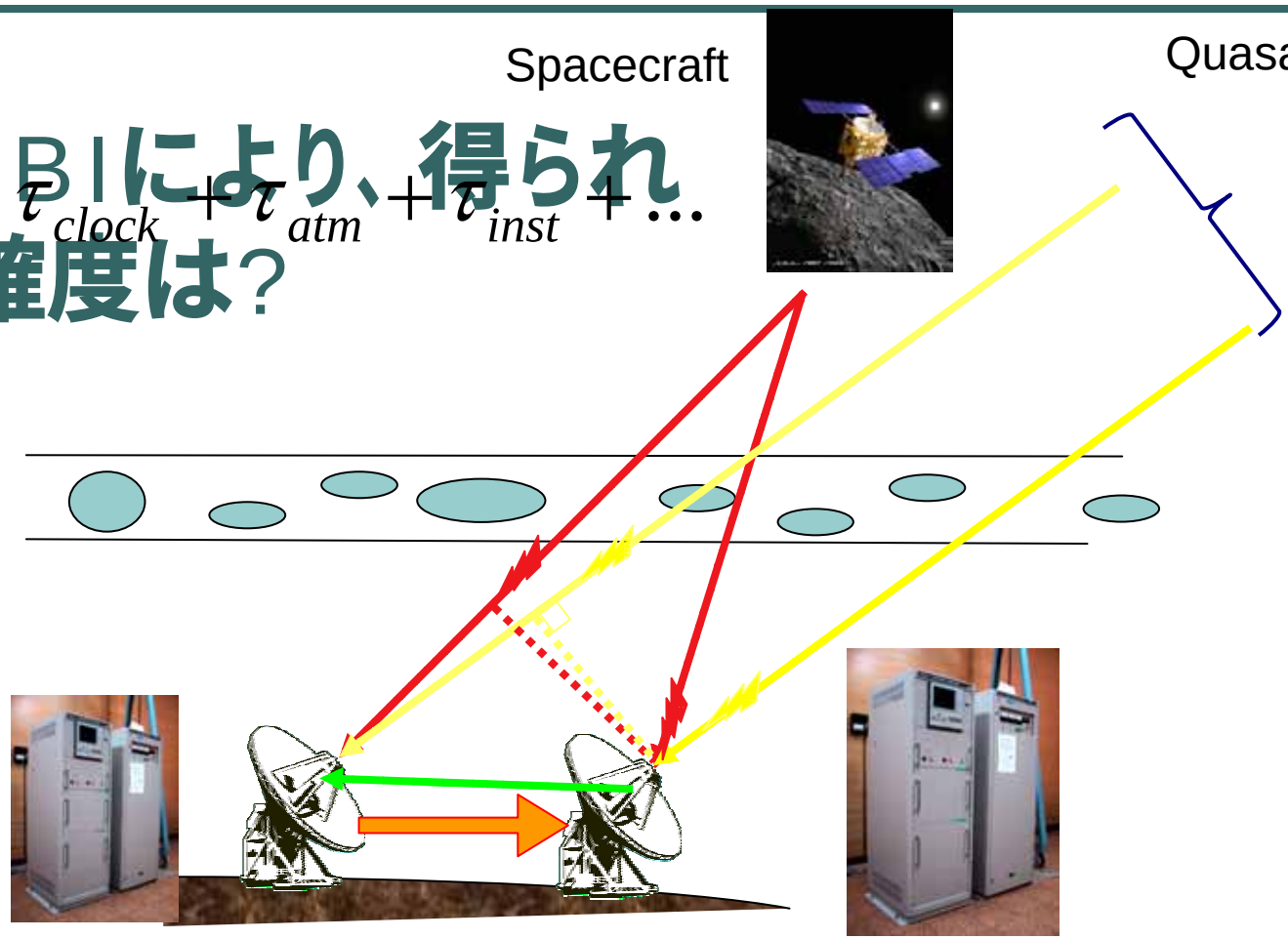
HYBS VLBI observation



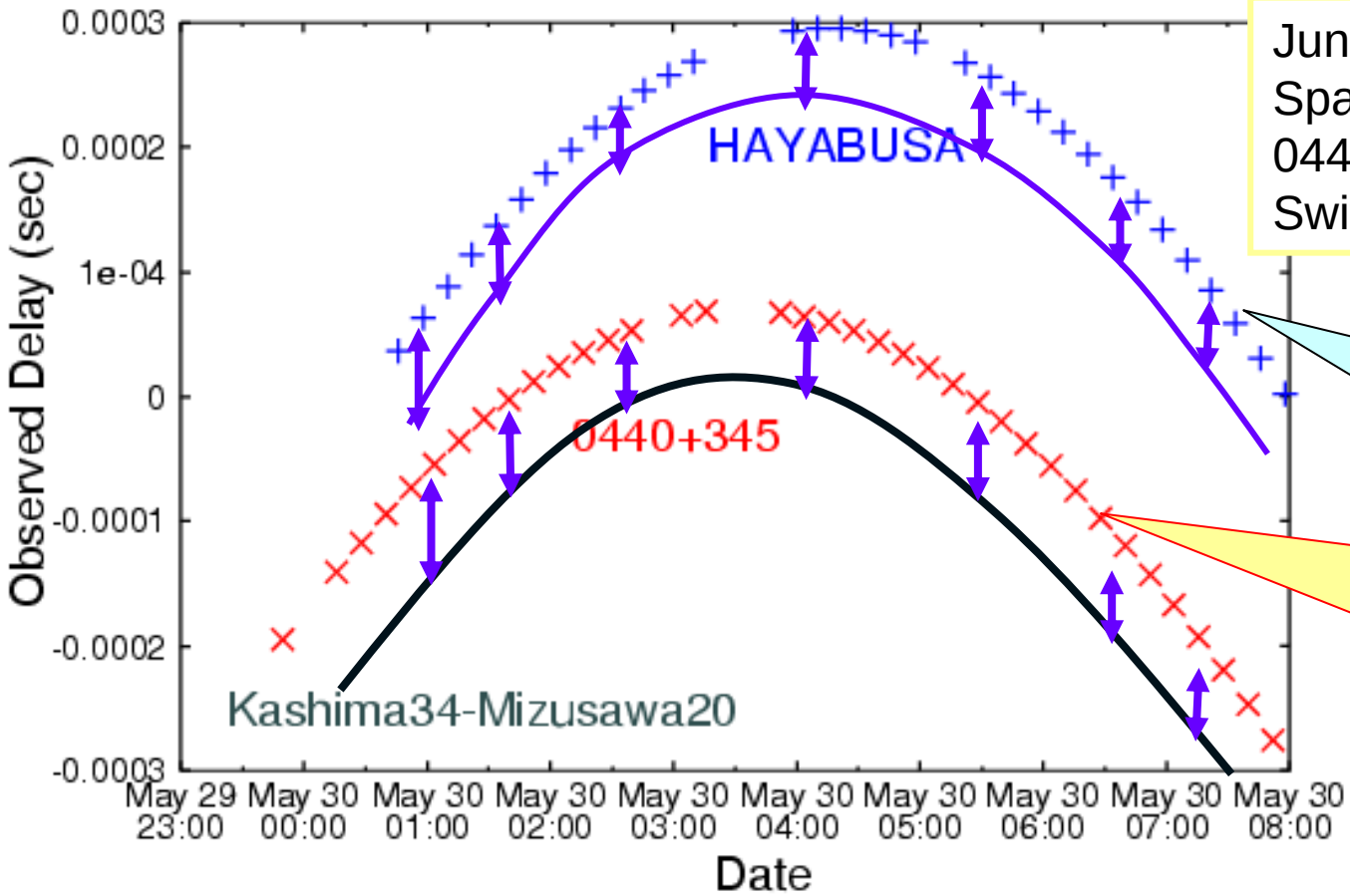
相対ＶＬＢＩによる遅延校正

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

相対ＶＬＢＩにより、得られる遅延確度は？



Delta-VLBI: Data Processing Scheme



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

位相遅延量
(キャリア信号)

群遅延
と
位相遅延量
(連続スペクトル)

大気(Elx,Ely,t)クロックモデルによる内挿

参照電波源 (Quasar)の群遅延量

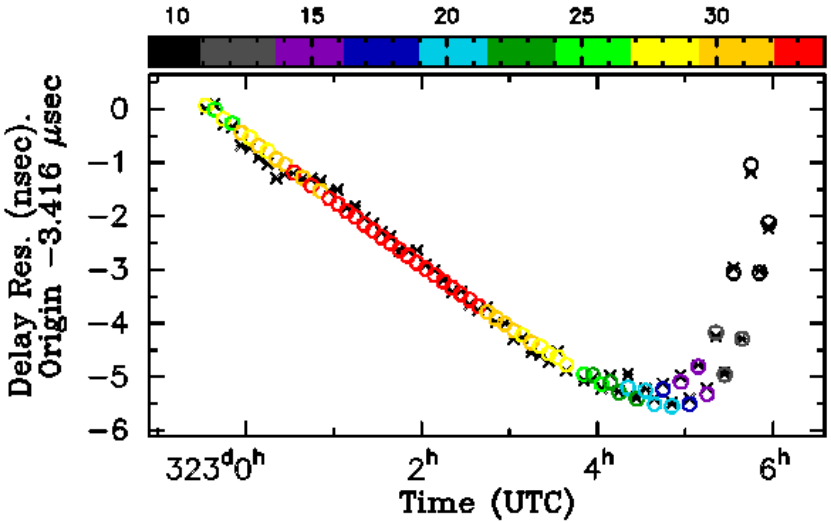
$$\tau = \tau_{geo} + (\tau^{0}_{clock} + \tau^{1}_{clock} t)$$
$$+ (\tau^{0}_{atm,y} + \tau^{1}_{atm,y} t)\, fm(El_y) - (\tau^{0}_{atm,x} + \tau^{1}_{atm,x} t)\, fm(El_x)$$

HAYABUSAの位相遅延量

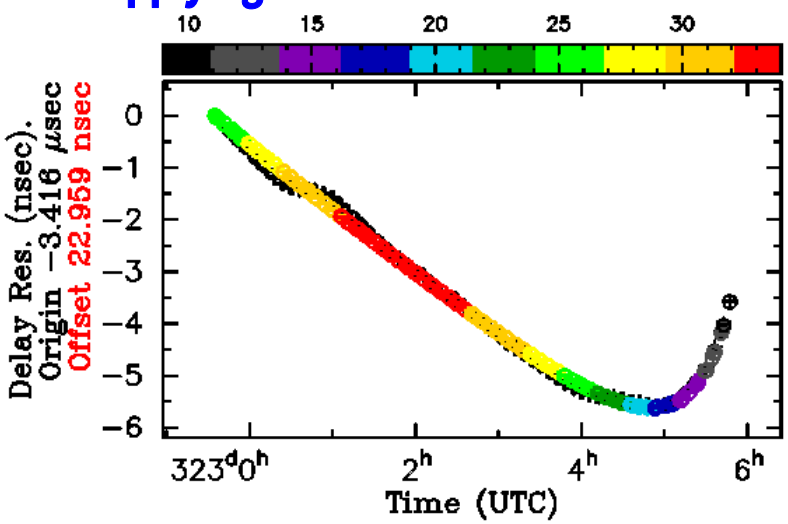
2005/11/19 Kashima34-Mizusawa20 (300km)

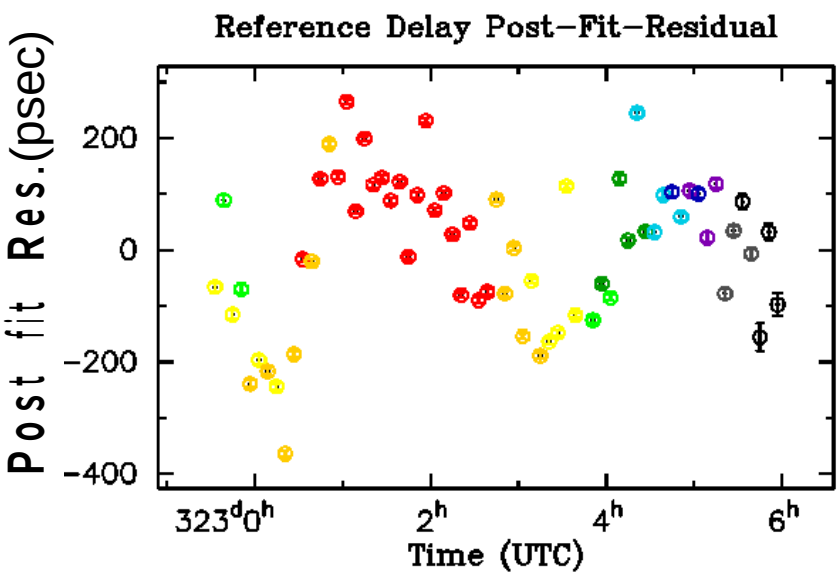
Calib:Geometry

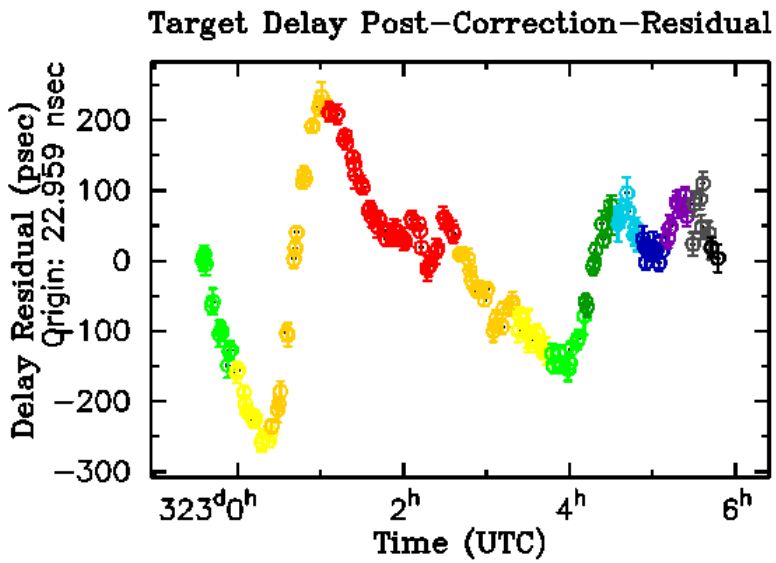
Model Fitting to Reference source



Applying to HYBS







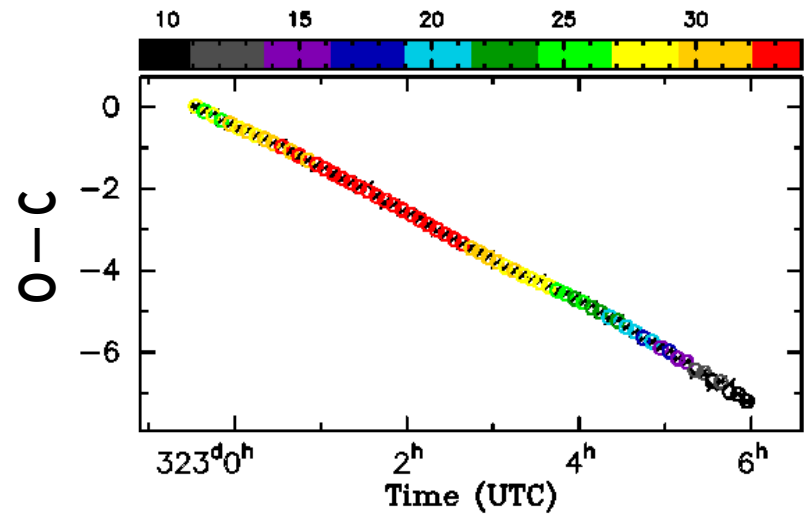
$$\tau = \tau_0 + \dot{\tau}(t - t_0) - \tau_{atm,x}\, fm(El_x) + \tau_{atm,y}\, fm(El_y)$$

Piece-wise linear

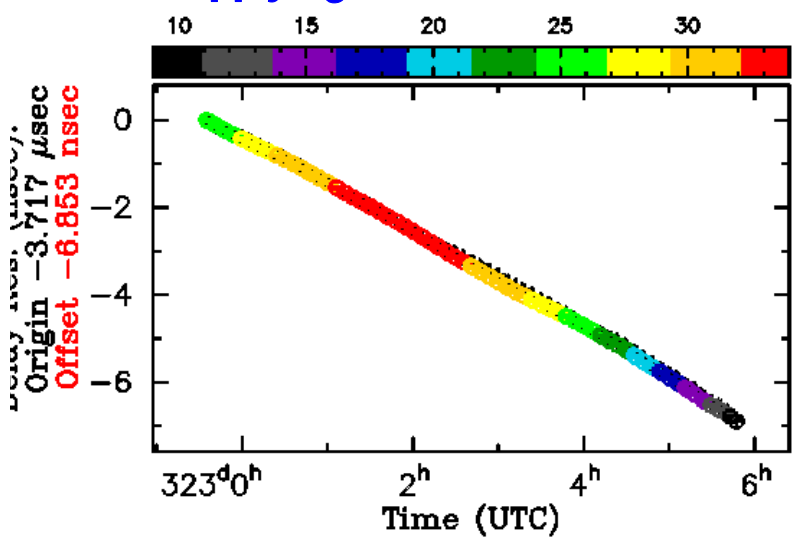
2005/11/19 Kashima34-Mizusawa20 (300km)

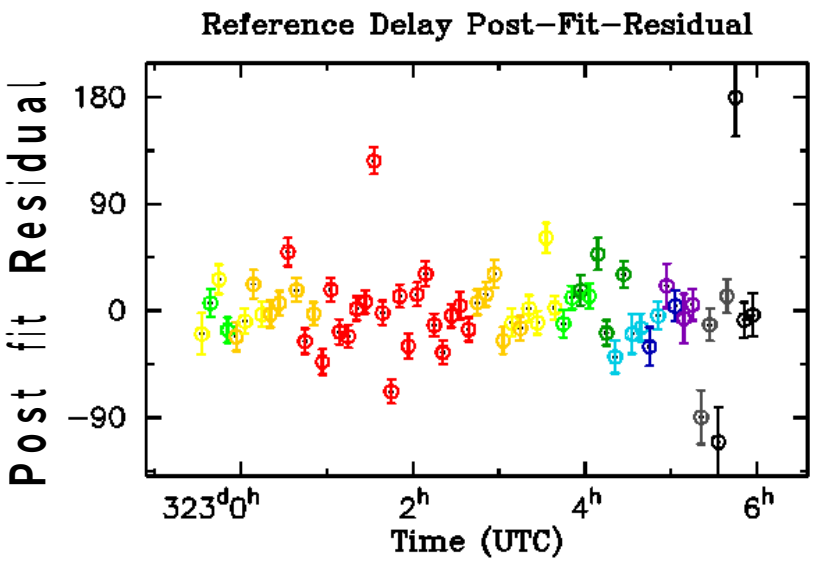
Calib: Geo.+Atm.

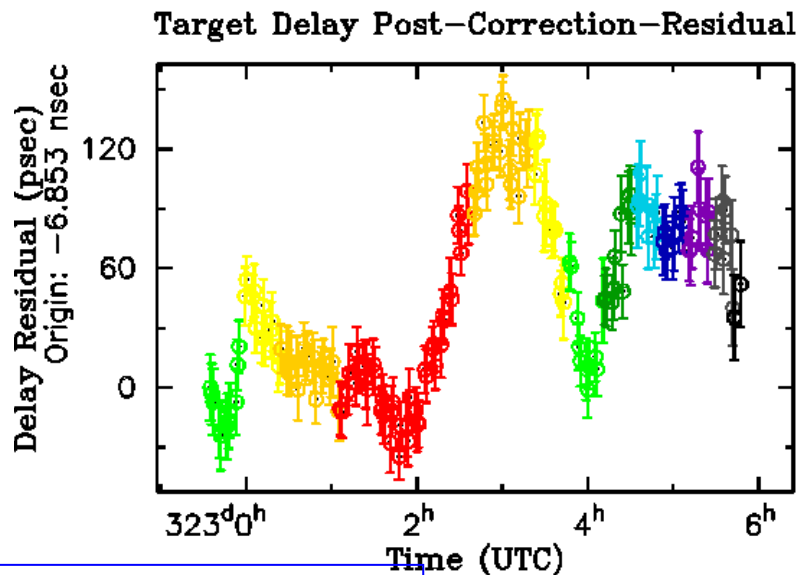
Model Fitting to Reference source



Applying to HYBS







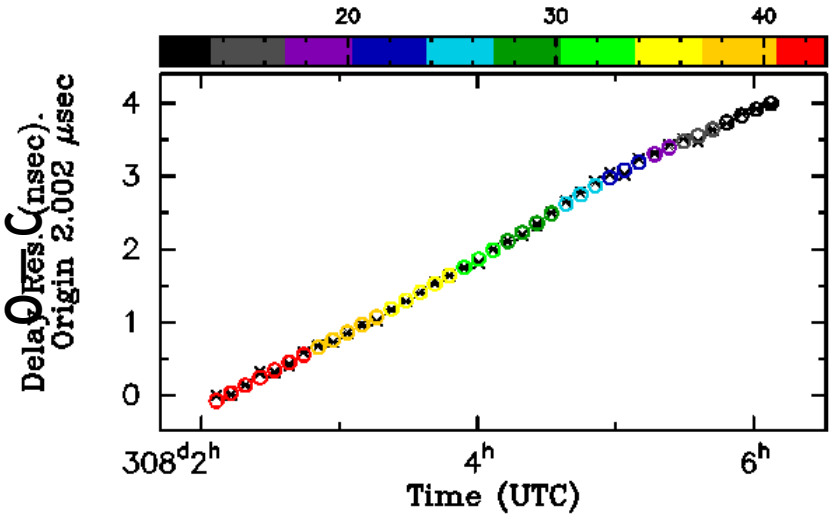
$$\tau = \tau_0 + \dot{\tau}(t - t_0) - \tau_{atm,x}\, fm(El_x) + \tau_{atm,y}\, fm(El_y)$$

Piece-wise linear

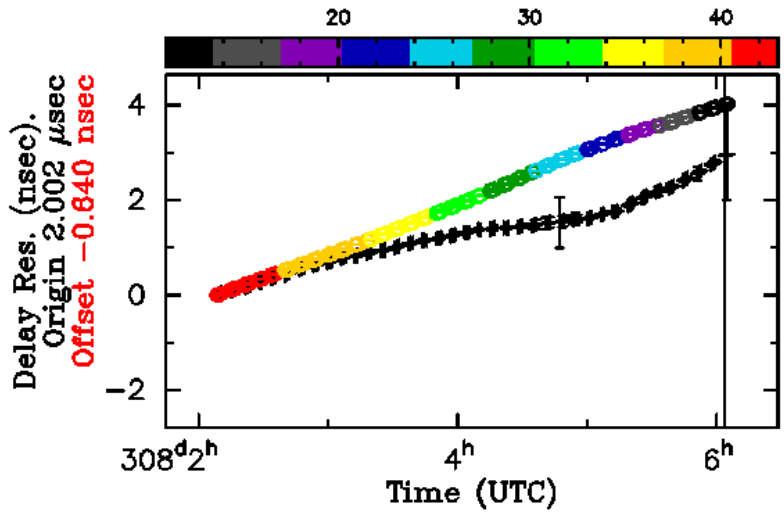
2005/11/4 · Kashima34-Chichijima10 (1000km)

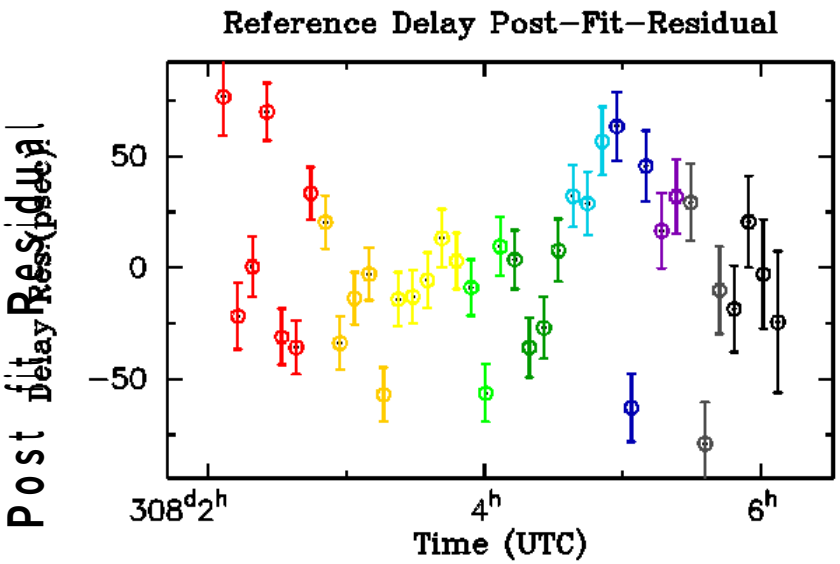
Calib: Geo.+Atm.

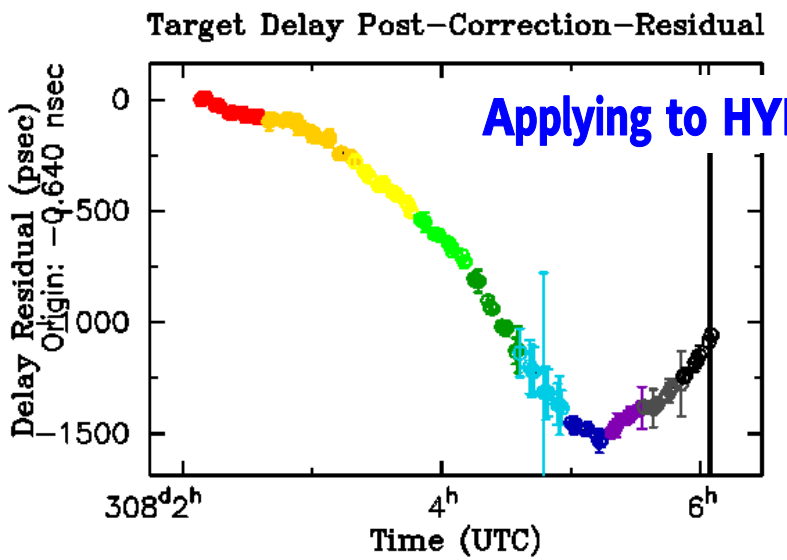
Model Fitting to Reference source



Applying to HYBS







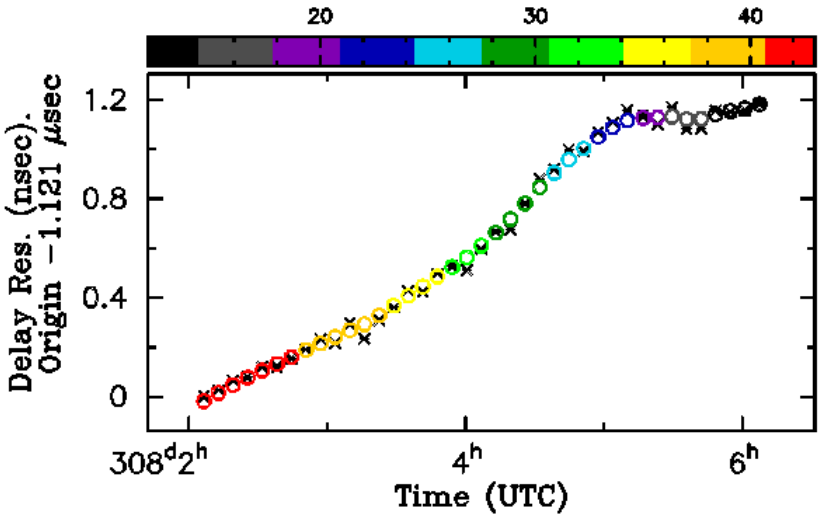
$$\tau = \tau_0 + \dot{\tau}(t - t_0) - \tau_{atm,x}\, fm(El_x) + \tau_{atm,y}\, fm(El_y)$$

Piece-wise linear

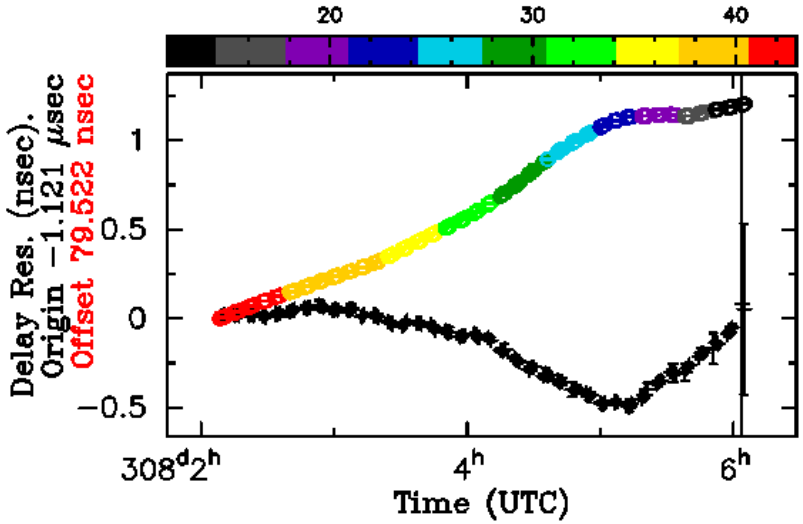
2005/11/4 · Tsukuba32-Chichijima10

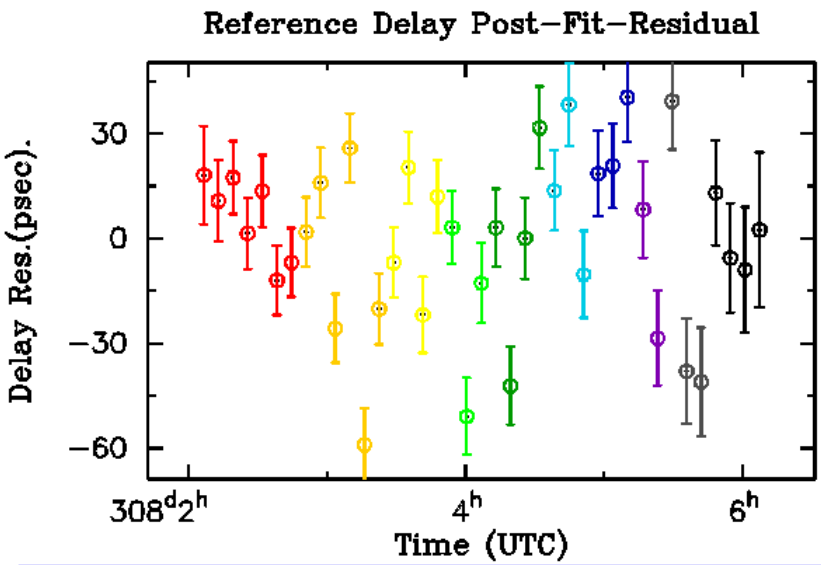
Calib: Geo.+Atm.

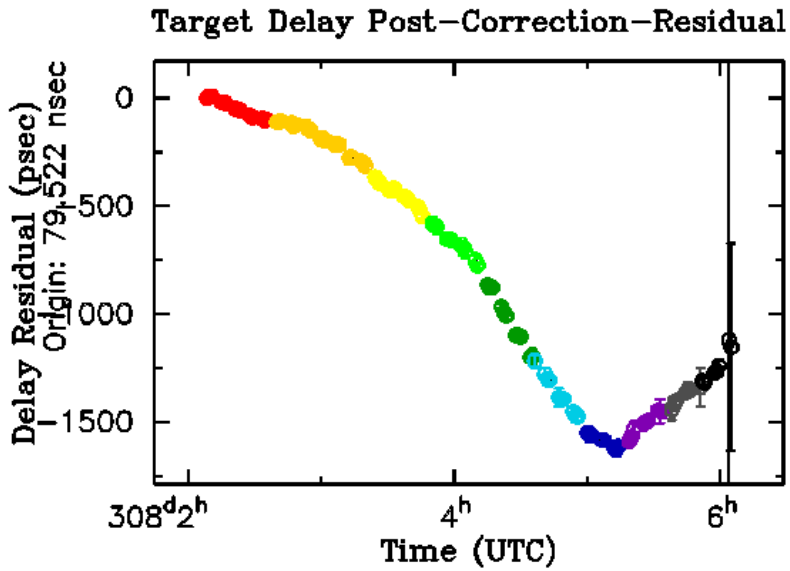
Model Fitting to Reference source



Applying to HYBS







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

Piece-wise linear

Delta-VLBI: 位相遅延と群遅延

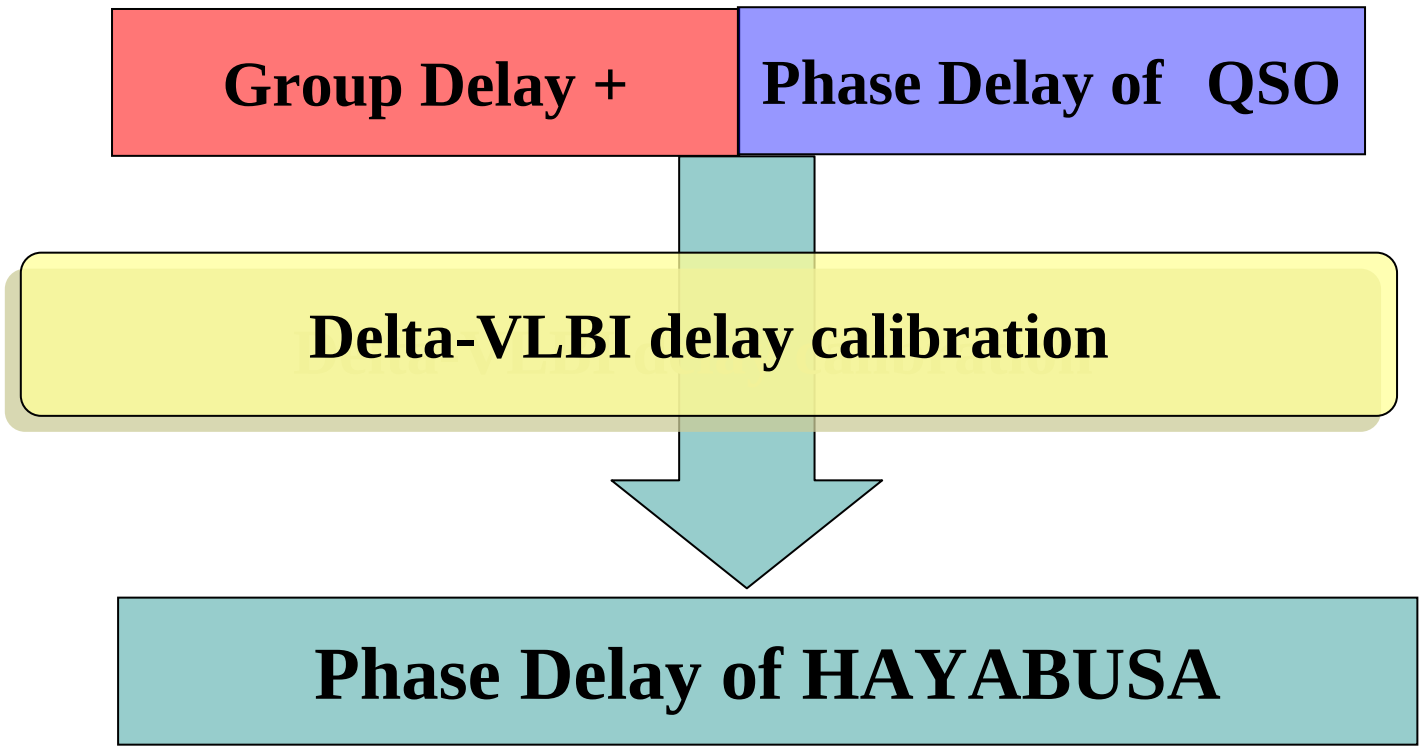
$$\tau_{HYBS} = \tau_{geo} + \tau_{clock} + \tau_{atm} - \tau_{ION} + \ldots$$

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

$$\tau^{O}_{QSO} - \tau^{C}_{QSO} = \tau_{clock} + \tau_{atm} + \tau_{ION} + \ldots$$

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

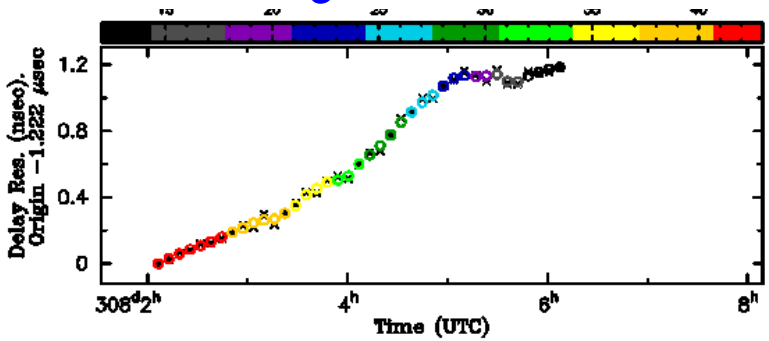
クエーサの位相遅延量を併用した相対ＶＬＢＩ遅延校正

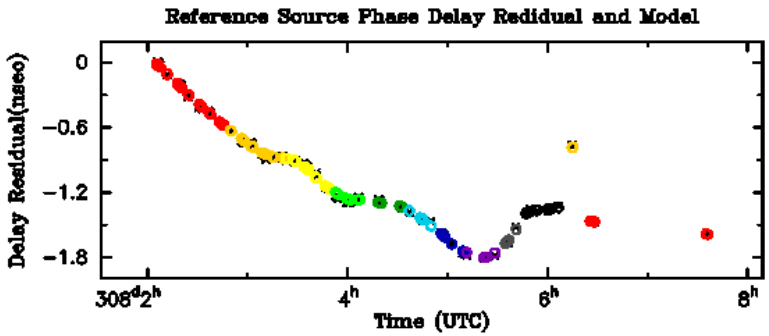


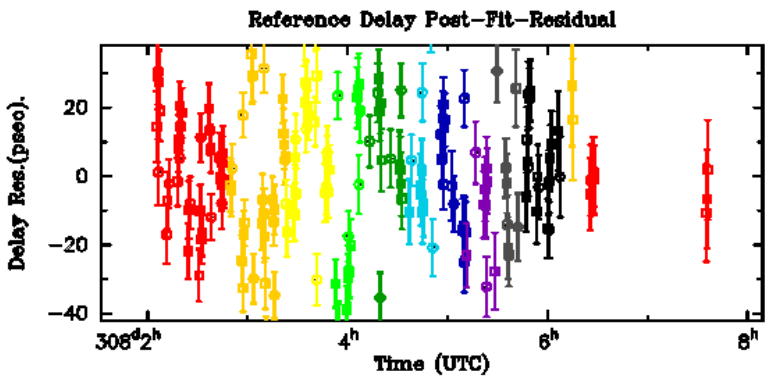
2005/11/4 Tsukuba32-Chichijima10

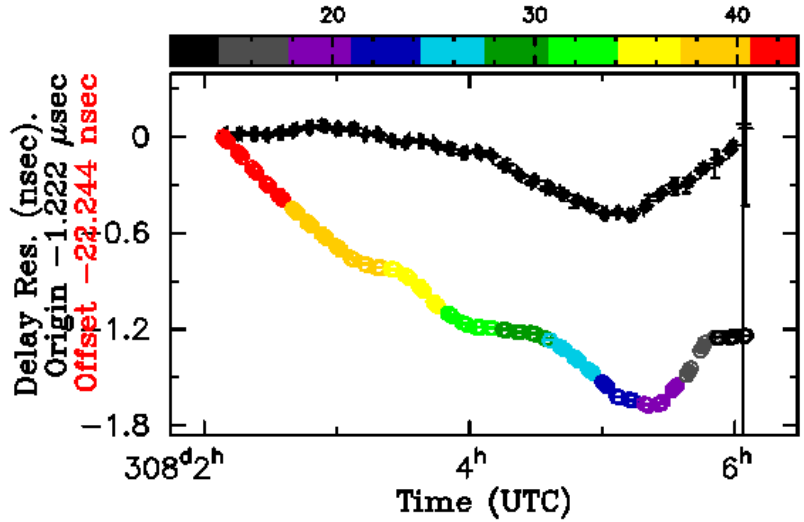
Applying to HYBS

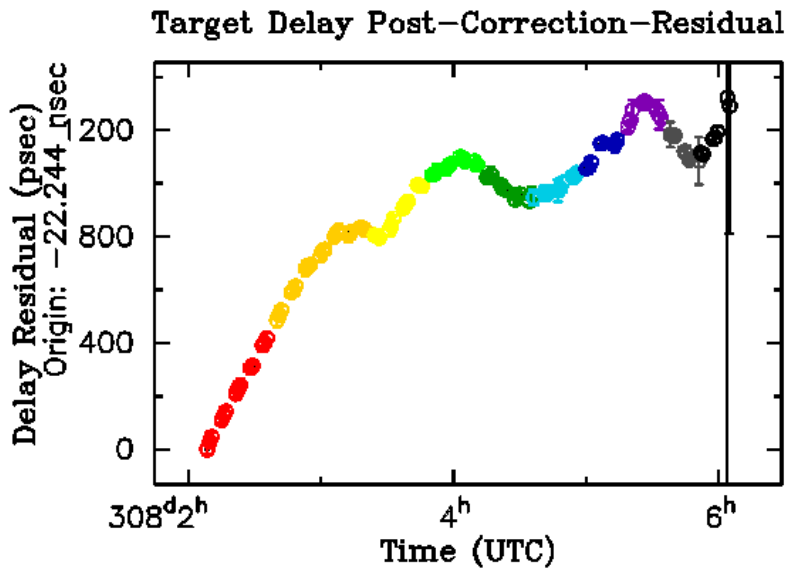
Model Fitting to Reference source







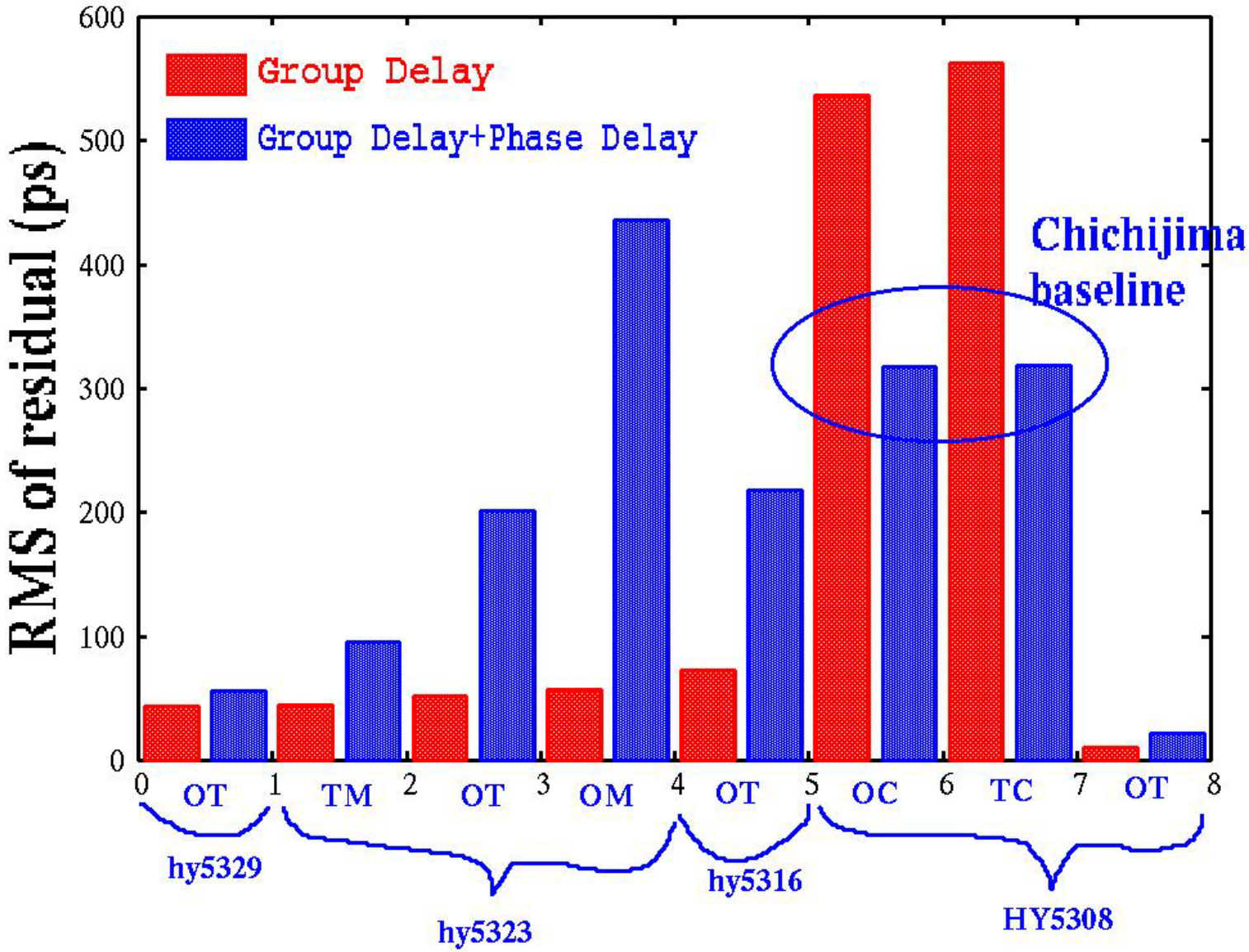




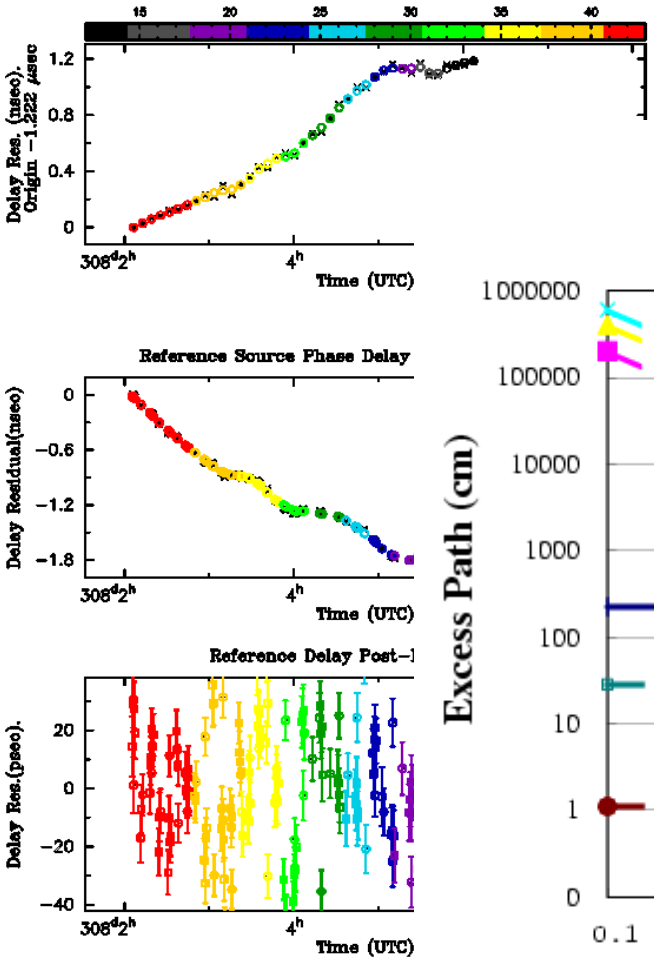
$$\tau = \tau_0 + \dot{\tau}(t - t_0) - \tau_{atm,x}\, fm(El_x) + \tau_{atm,y}\, fm(El_y)$$

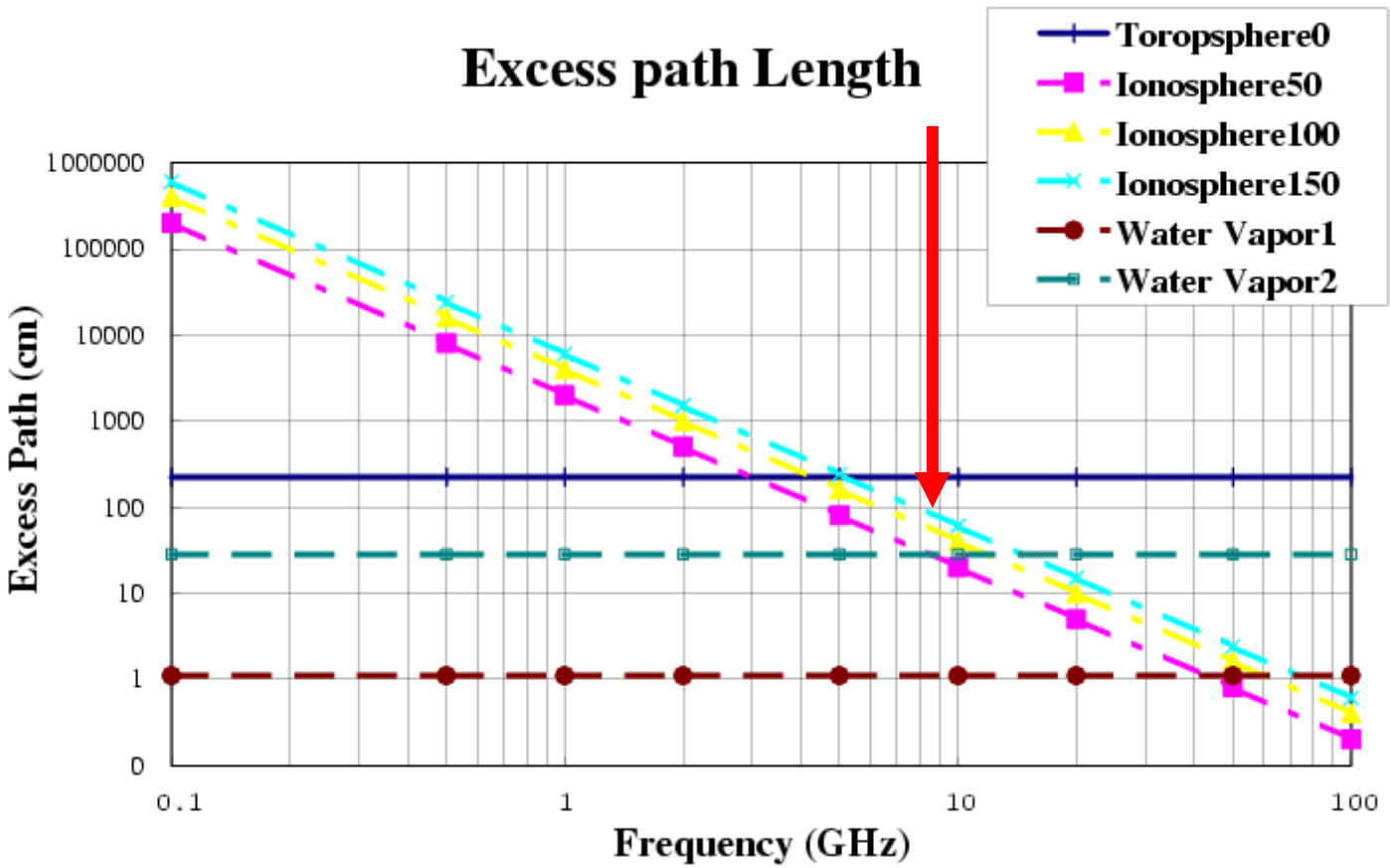
Piece-wise linear

Statistical Comparison on Cal. With Group and Group/Phase

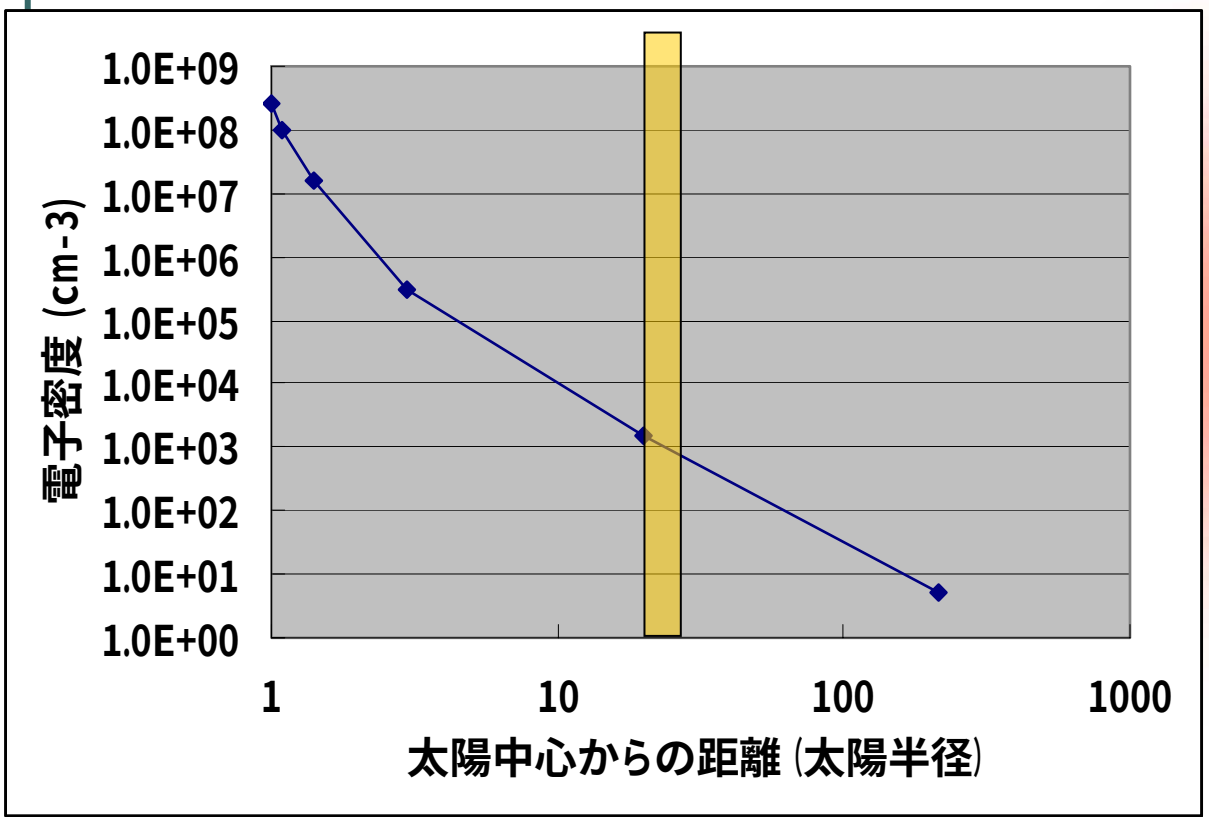


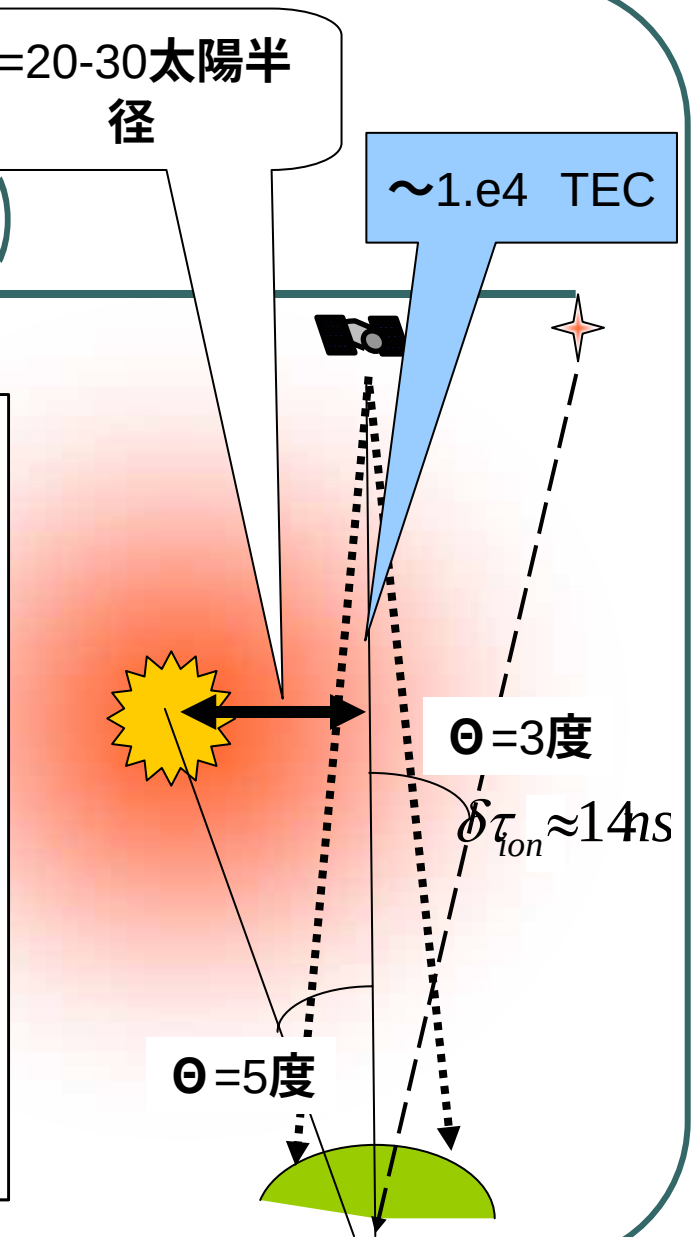
電離媒質の遅延の寄与


Delay Res. (nsec).
Origin −1.222 μsec
Time (UTC)
Reference Source Phase Delay
Delay Residual(nsec)
Time (UTC)
Reference Delay Post−
Delay Res.(psec).
Time (UTC)

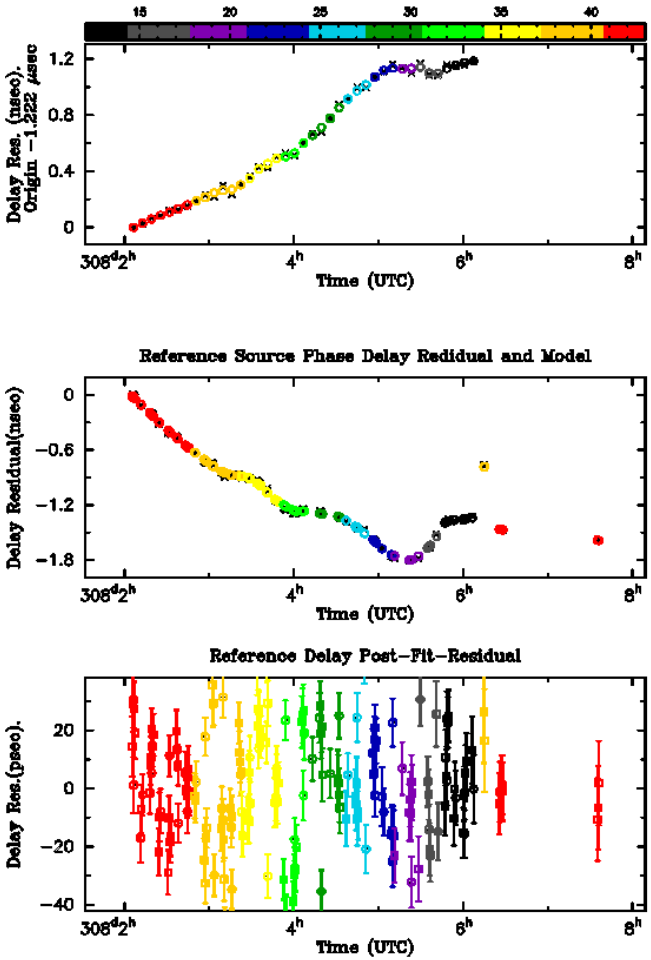

Excess path Length
Toropsphere0
Ionosphere50
Ionosphere100
Ionosphere150
Water Vapor1
Water Vapor2
Excess Path (cm)
Frequency (GHz)

太陽近傍のプラズマ(コロナ)





太陽プラズマの寄与



- **群遅延と位相遅延がほぼ逆センス**
  - Exess-delay**ほとんどが電離媒質による遅延**
    - **電離遅延**=1.5ns(=>１００TECU)
    - **中性遅延**=0.3ns
- **太陽コロナNeから見積もり**
  - **経路中の電子柱密度**～1**万**TECU
  - 1deg**の角度差**=>3.7**太陽半径**
    =>65ns**相当**
- **電離層＜＜太陽コロナの影響**

まとめ

- **結果**
  - 群遅延量･位相遅延量を抽出し相対VLBI の遅延補正精度について評価した.
  - 太陽離角の小さなHAYABUSA観測において、電離媒質（太陽コロナ）による影響が大きい
- **課題**
  - 太陽近傍を通る電波観測の場合、飛翔体も2周波観測が必要であろう。＝＞将来の水星、金星探査ミッション.
  - 群遅延計測の精度向上～レプリカ信号を使った相関処理