VLBI Application for Spacecraft Navigation

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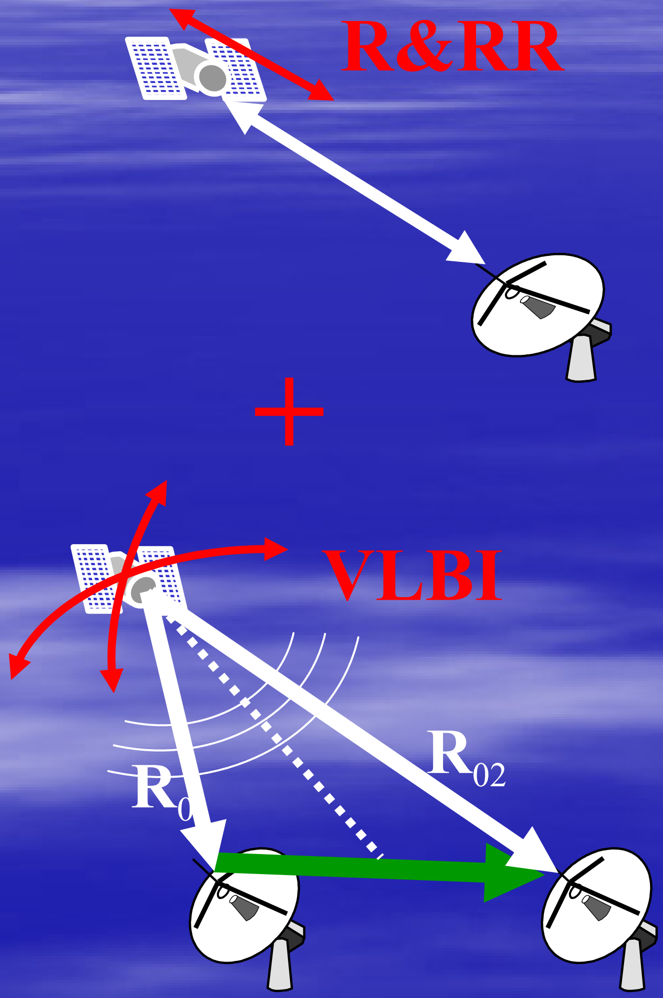
Spacecraft Navigation R&RR + VLBI



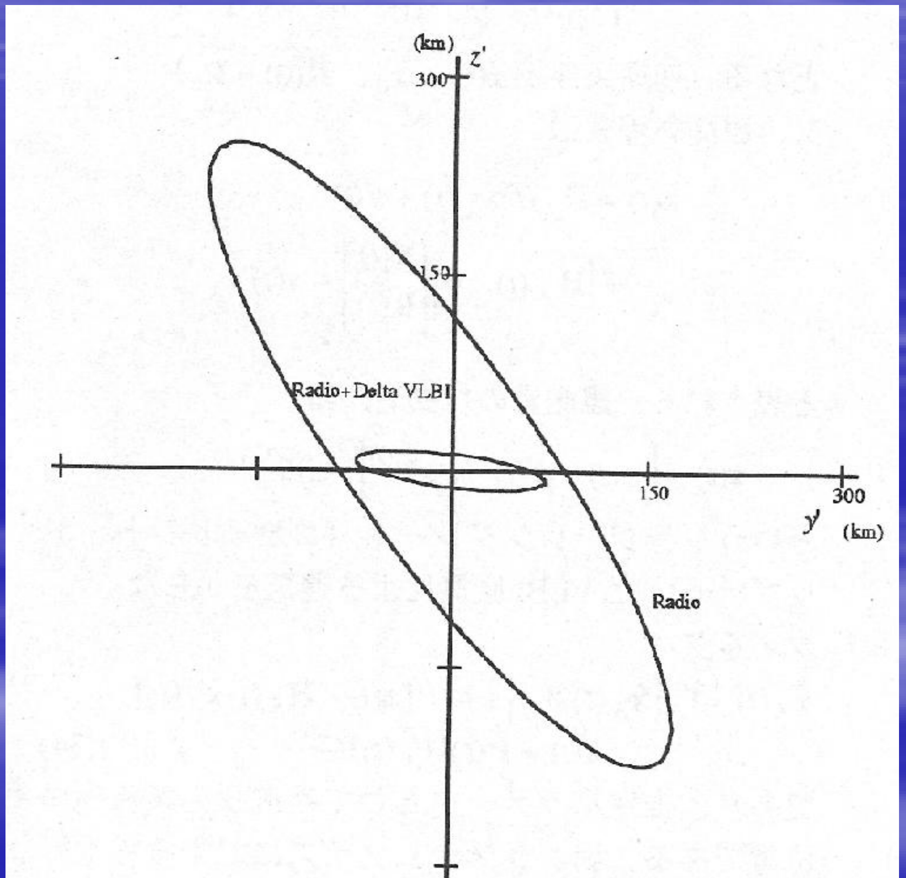
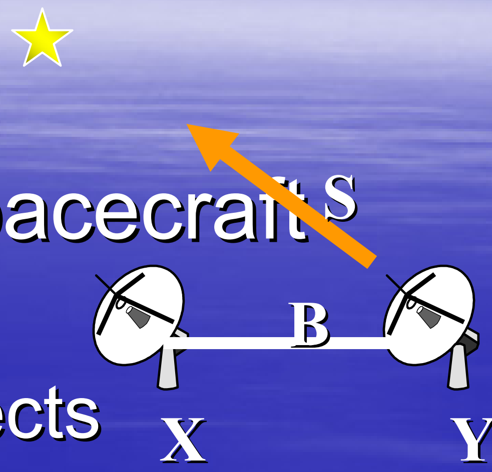
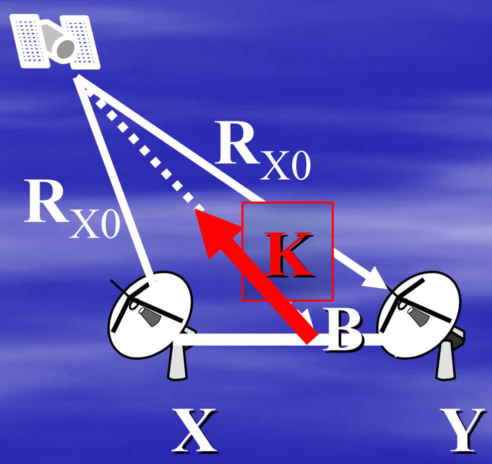


Fig. 7 誤差楕円

Outline



- What is difference? VLBI for Spacecraft
  - – Observation Equation
  - – Curved wave front = Parallax effects
- Data Acquisition Terminal
  - – K5/VSSP: Disk-Based system
    + Software Correlator
- Observables & Delta VLBI
  - – Group Delay
  - – Phase Delay

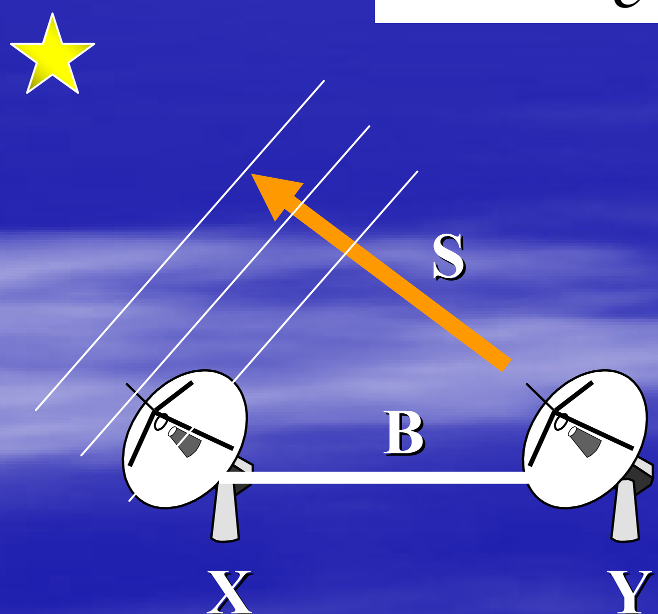


VLBI delay model for finite distance radio source

Standard VLBI

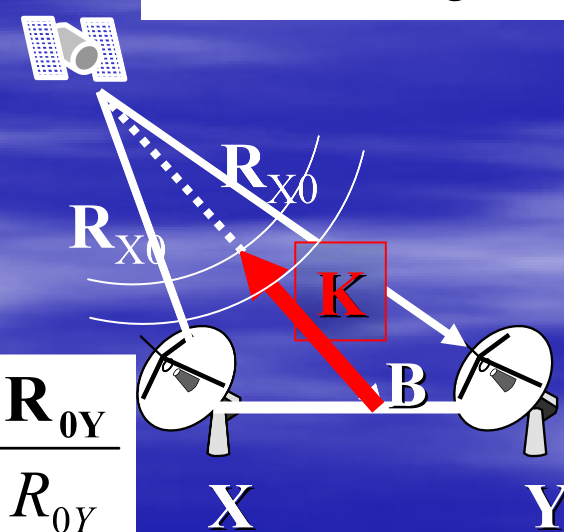
$$\mathbf{B} = \mathbf{X} - \mathbf{Y}$$

$$\tau = -\frac{\mathbf{B} \bullet \mathbf{S}}{c}$$



VLBI for finite distance radio source

$$\tau = -\frac{\mathbf{B} \bullet \mathbf{K}}{c}$$



$$\mathbf{K} = \frac{\mathbf{R}_{0X} + \mathbf{R}_{0Y}}{R_{0X} + R_{0Y}}$$

(Fukuhisma 1993 A&A)

Relativistic VLBI delay model for finite distance radio source

CONSENSUS MODEL (M.Eubanks 1991)

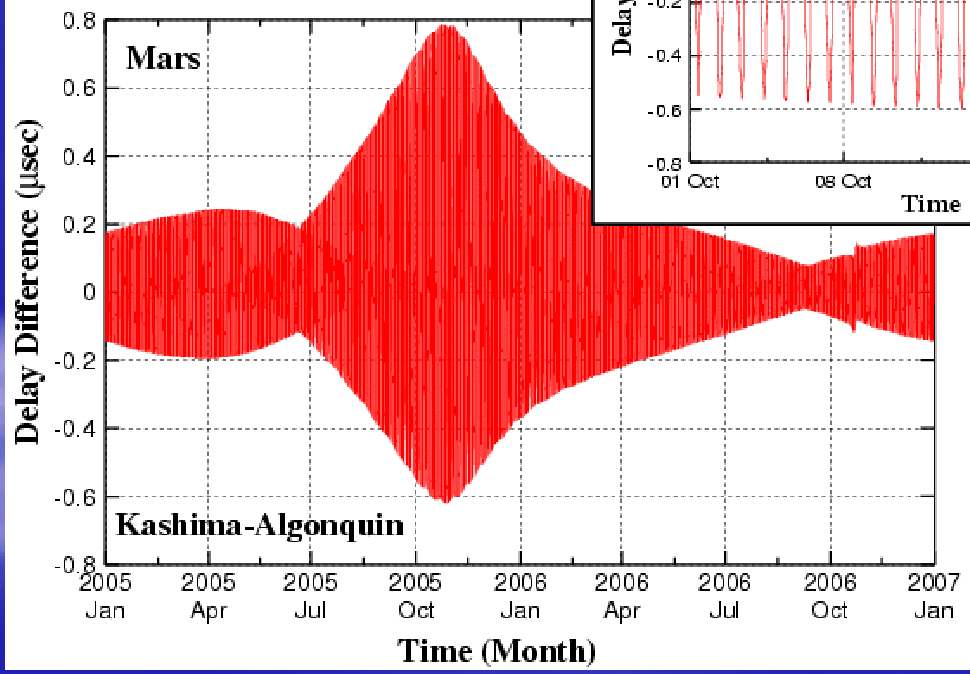
$$\tau_2 - \tau_1 = \frac{\Delta t_g - \frac{\vec{\mathbf{S}} \bullet \vec{\mathbf{b}}}{c}\left[1-(1+\gamma)U - \frac{V_e^2 + 2\vec{\mathbf{V}}_e \bullet \vec{\mathbf{w}}_2}{2c^2}\right] - \frac{\vec{\mathbf{V}}_e \bullet \vec{\mathbf{b}}}{c^2}\left(1 + \frac{\vec{\mathbf{S}} \bullet \vec{\mathbf{V}}_e}{2c}\right)}{1 + \frac{\vec{\mathbf{S}} \bullet (\vec{\mathbf{V}}_e + \vec{\mathbf{w}}_2)}{c}}$$

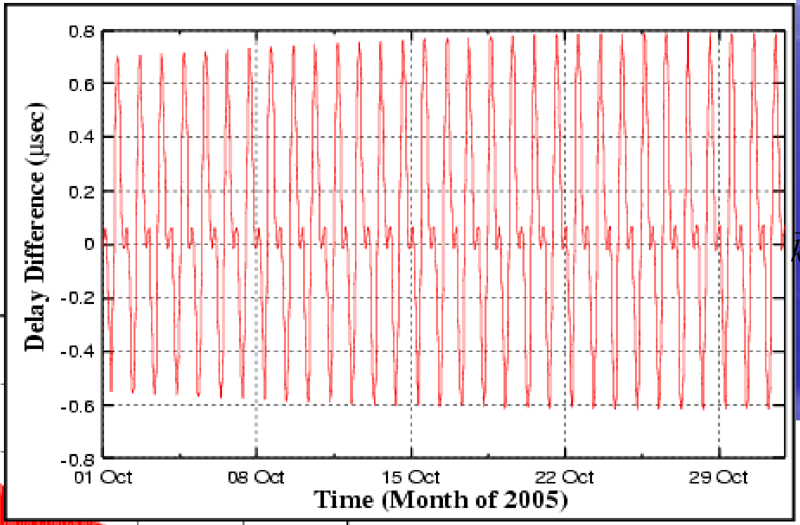
Finite Distance VLBI MODEL (Sekido & Fukushima 2005)

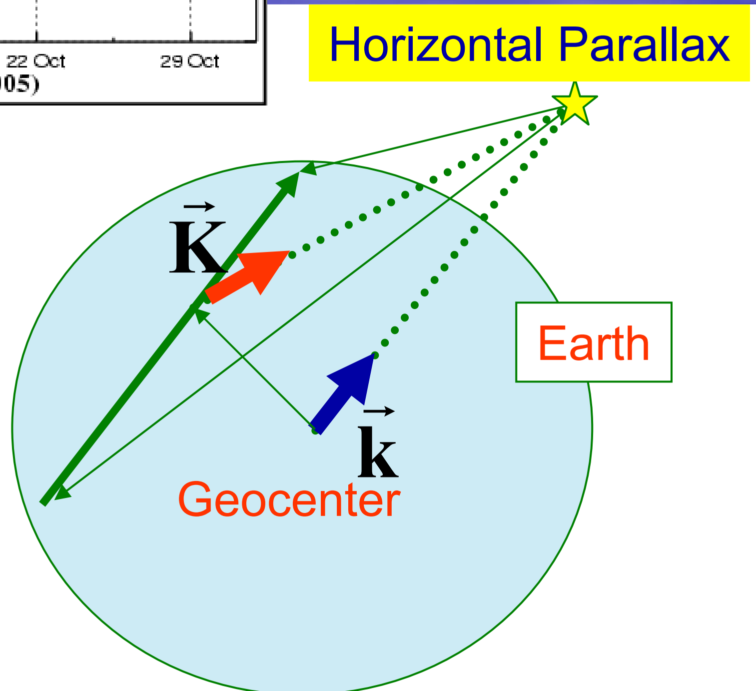
$$\tau_2 - \tau_1 = \frac{\Delta t_g - \frac{\vec{\mathbf{K}} \bullet \vec{\mathbf{b}}}{c}\left[1-(1+\gamma)U - \frac{V_e^2 + 2\vec{\mathbf{V}}_e \bullet \vec{\mathbf{w}}_2}{2c^2}\right] - \frac{\vec{\mathbf{V}}_e \bullet \vec{\mathbf{b}}}{c^2}\left(1 + \vec{\mathbf{R}}_{02} \bullet \frac{\vec{\mathbf{V}}_2}{c} - \frac{\vec{\mathbf{K}} \bullet \left(\vec{\mathbf{V}}_e + 2\vec{\mathbf{w}}_2\right)}{2c}\right)}{\left(1 + \vec{\mathbf{R}}_{02} \bullet \frac{\vec{\mathbf{V}}_2}{c}\right)\left[1 + \frac{\vec{\mathbf{K}} \bullet \vec{\mathbf{B}}(\beta_2^2 - \beta_{02}^2)}{2R_{02}(1+\beta_{02})^2}\right]}$$

FVLBI – Consensus model

Mars: Kashima-Algonquin(9000km)

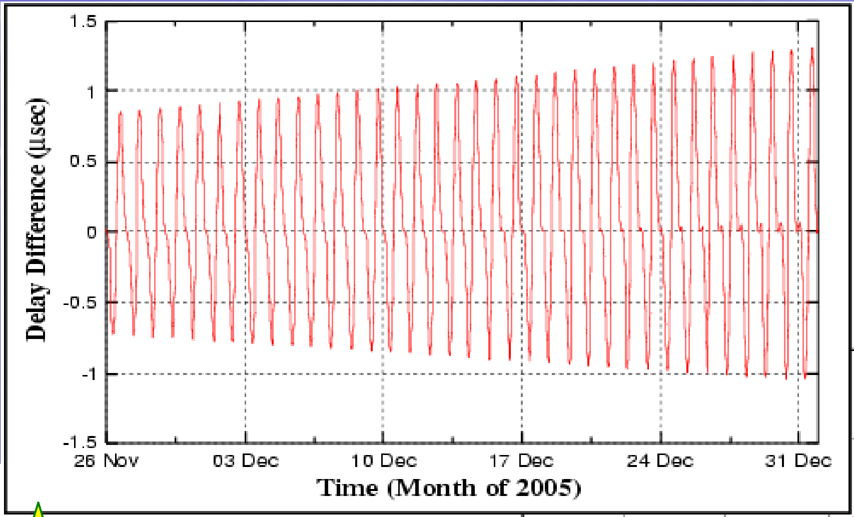




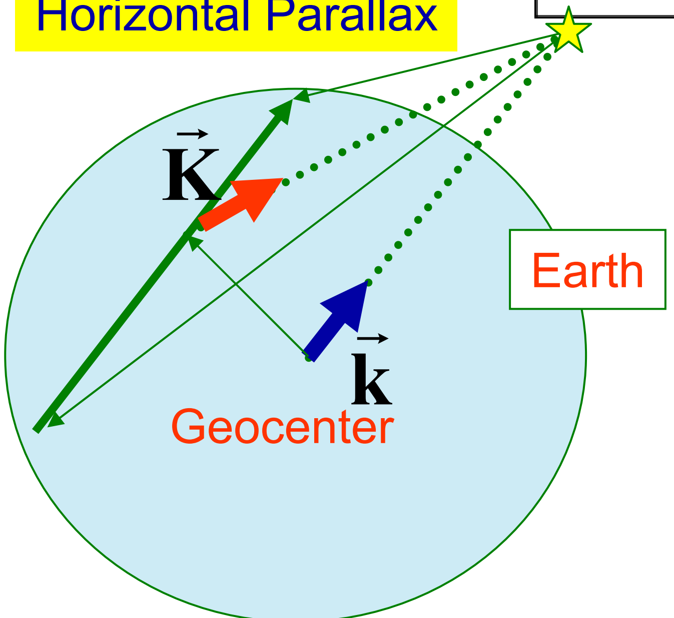


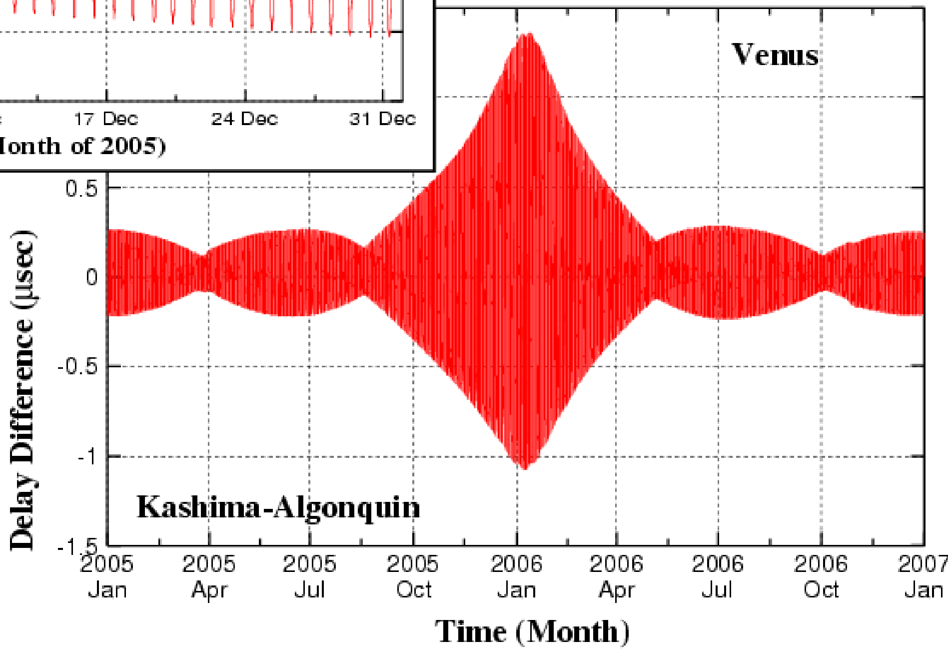
FVLBI – Consensus model

Venus: Kashima-Algonquin(9000km)

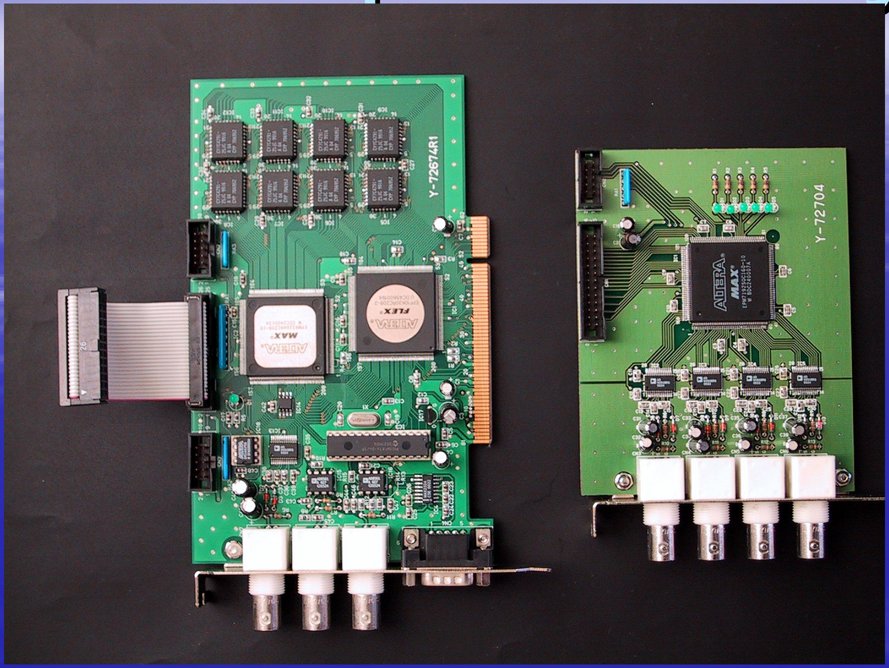


Horizontal Parallax





Data Acquisition System：K5/VSSP

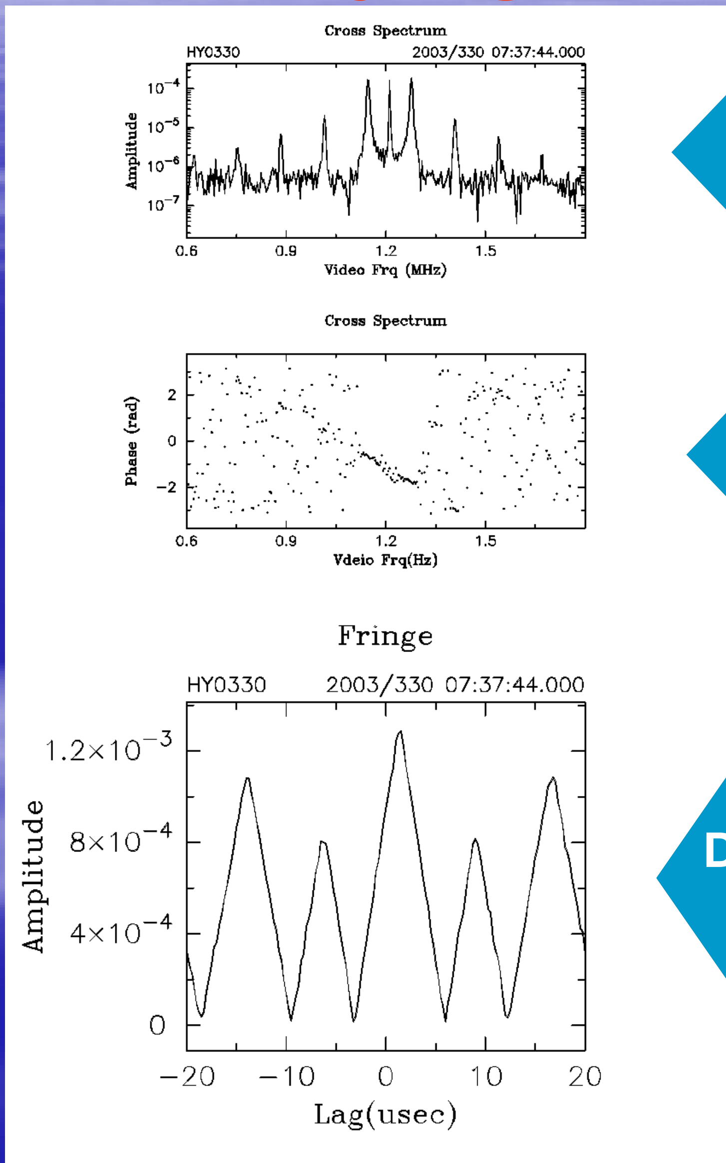


K5 VLBI System

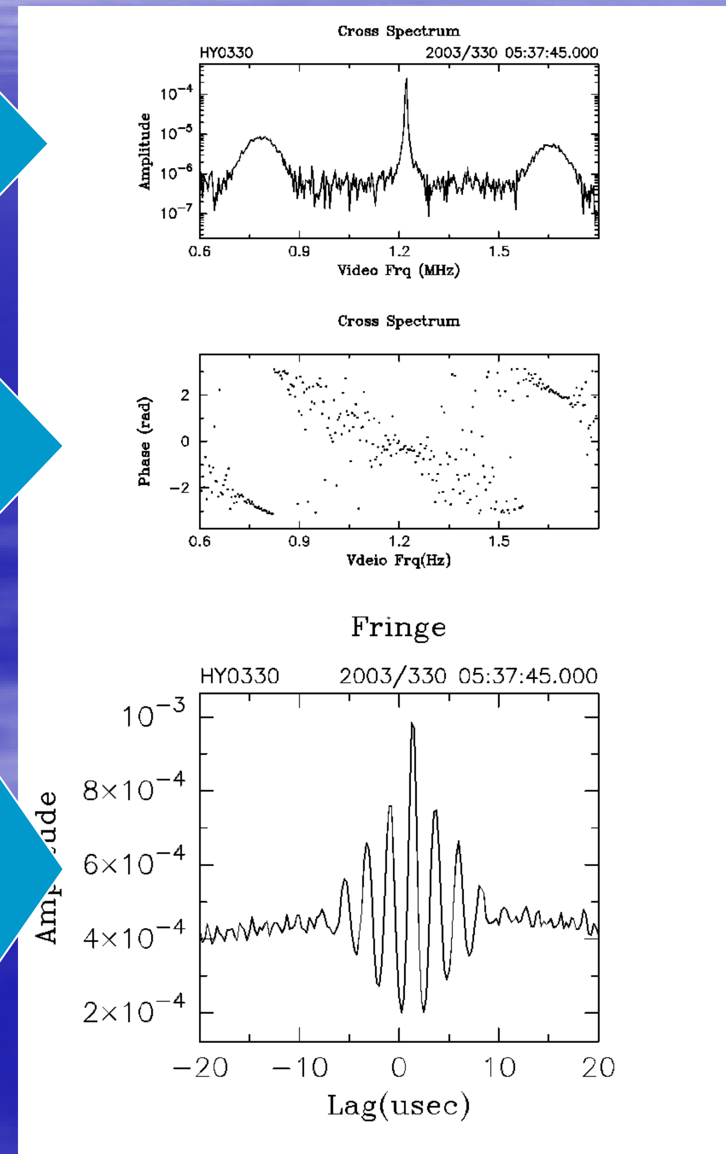
- Sampling rate:40k-16MHz
- Quantization bit: 1-8bit
- 4ch/board
- 10MHz,1PPS inputs
- Max rate: 64Mbps/board

Observable: Group Delay

Telemetry Signal



Range signal



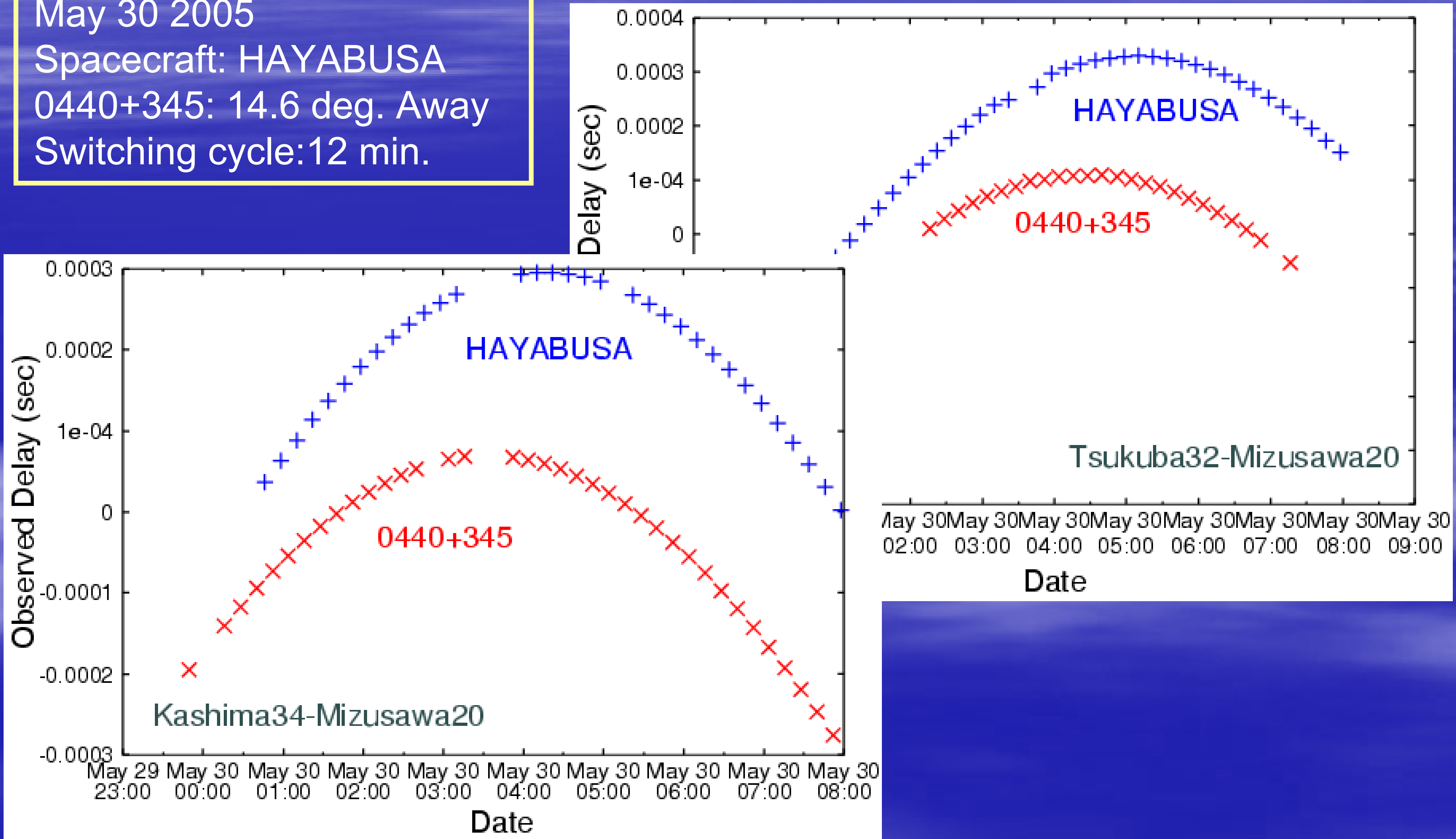
Spectrum

Fringe Phase

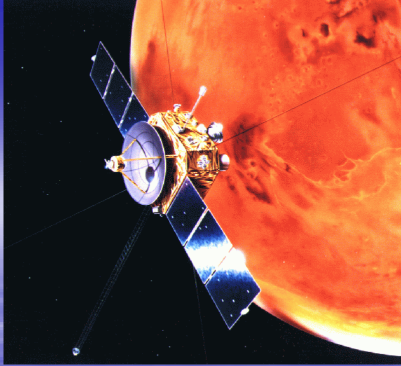
Delay Resolution Function

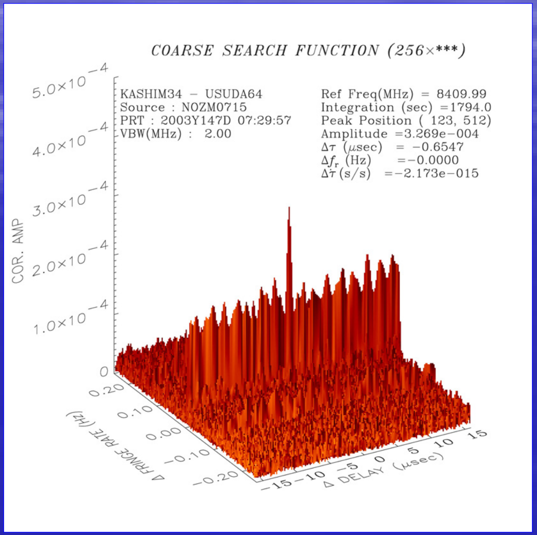
Group Delay: Delta-VLBI

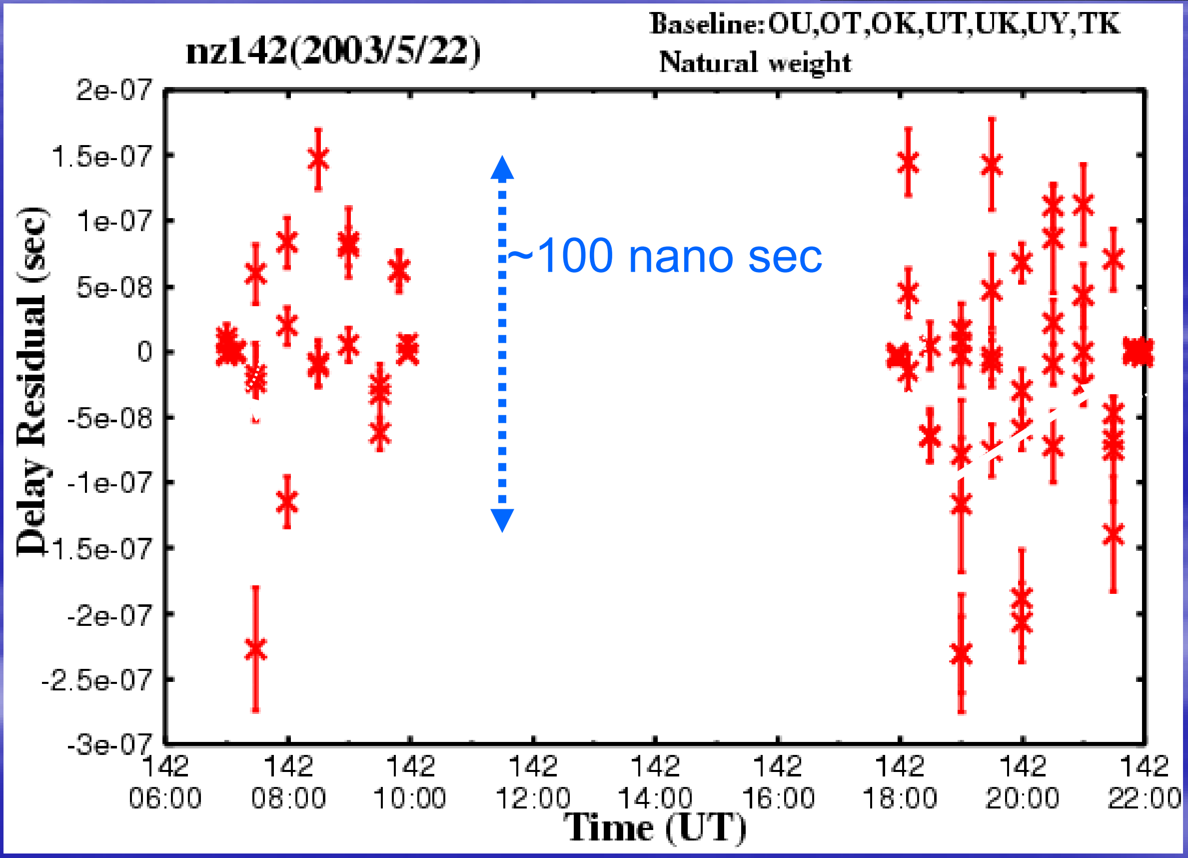
May 30 2005
Spacecraft: HAYABUSA
0440+345: 14.6 deg. Away
Switching cycle:12 min.



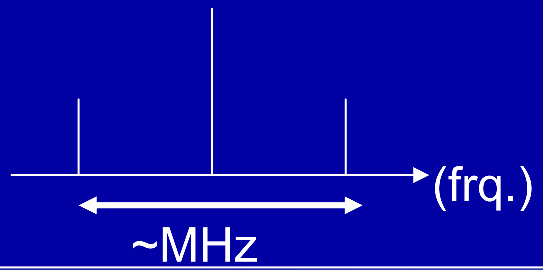
Group Delay (Post-fit Residual)
Astrometric Analysis



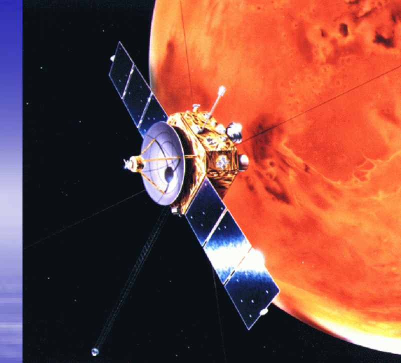


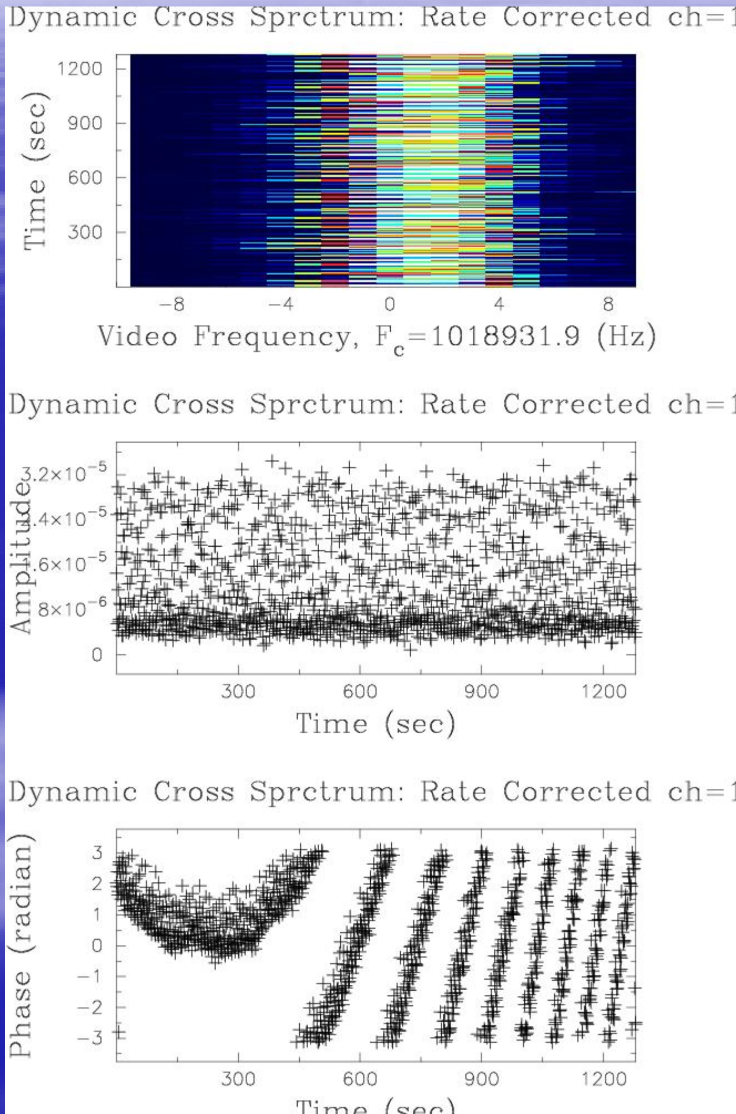


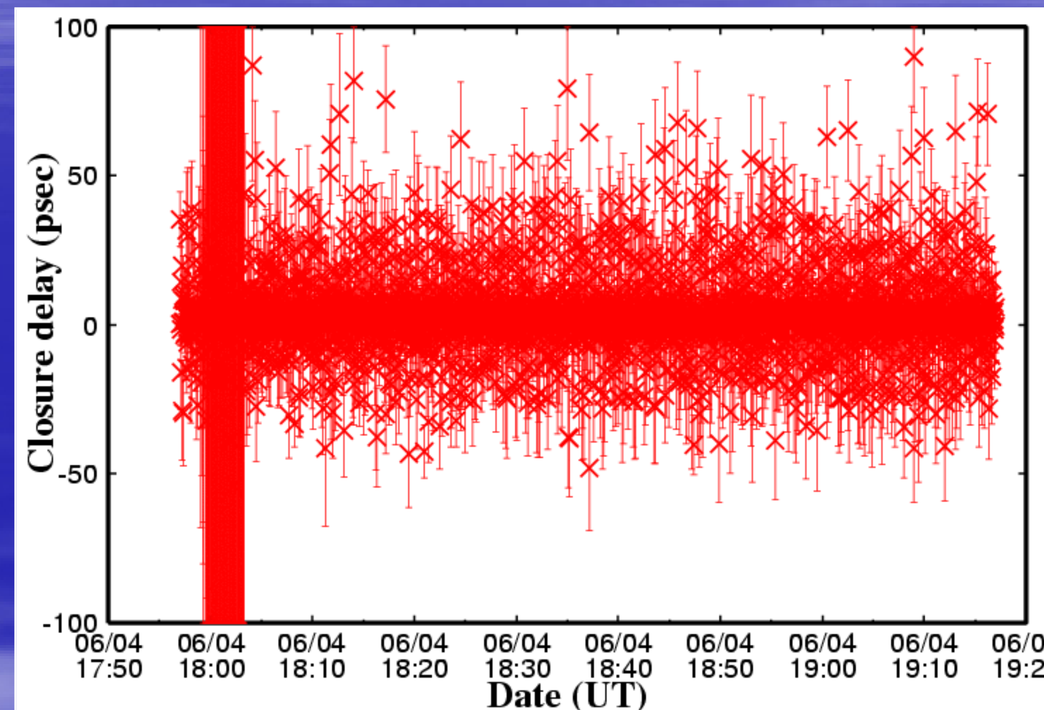
Signal type from Spacecraft



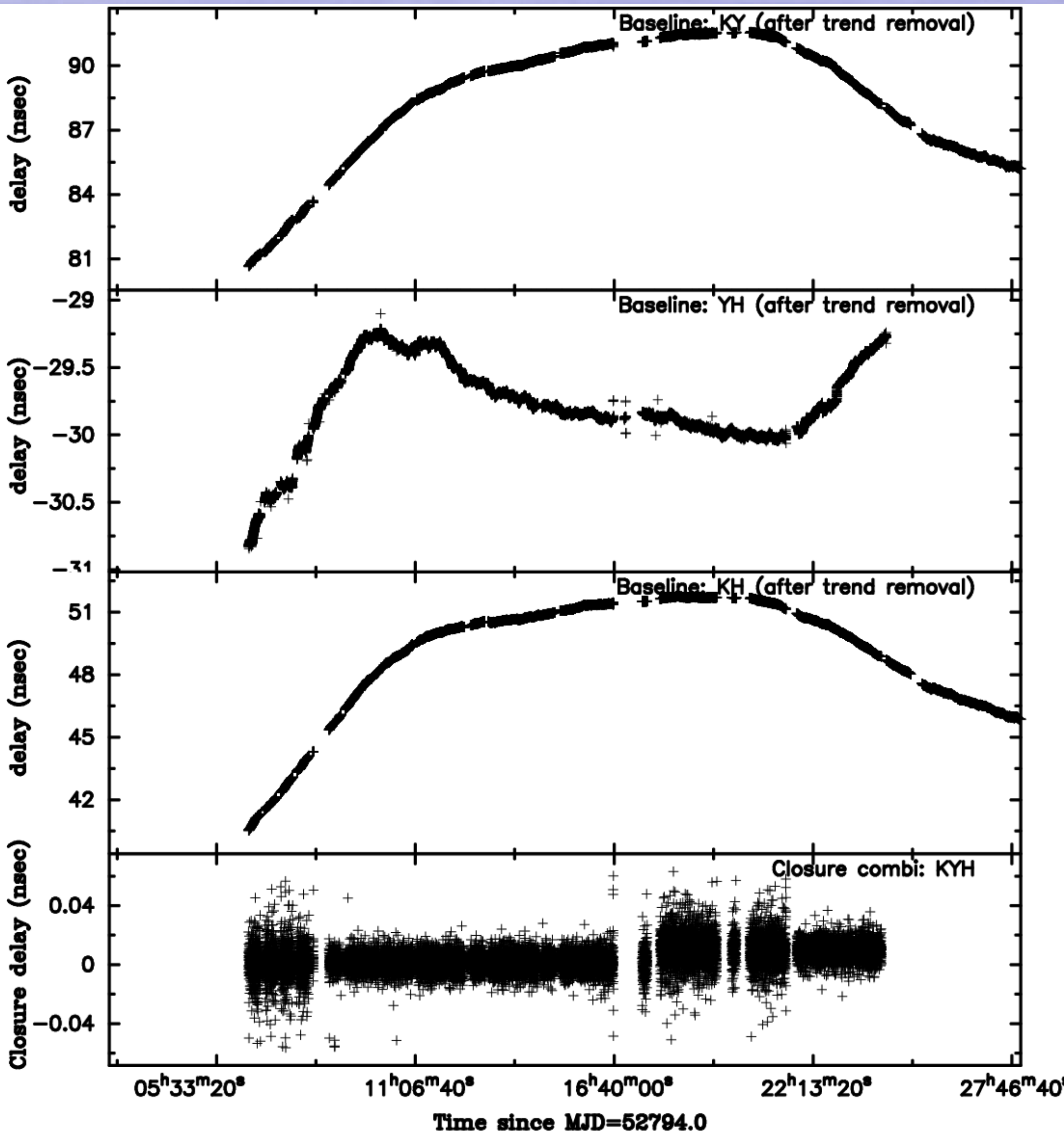
Observable:Phase delay

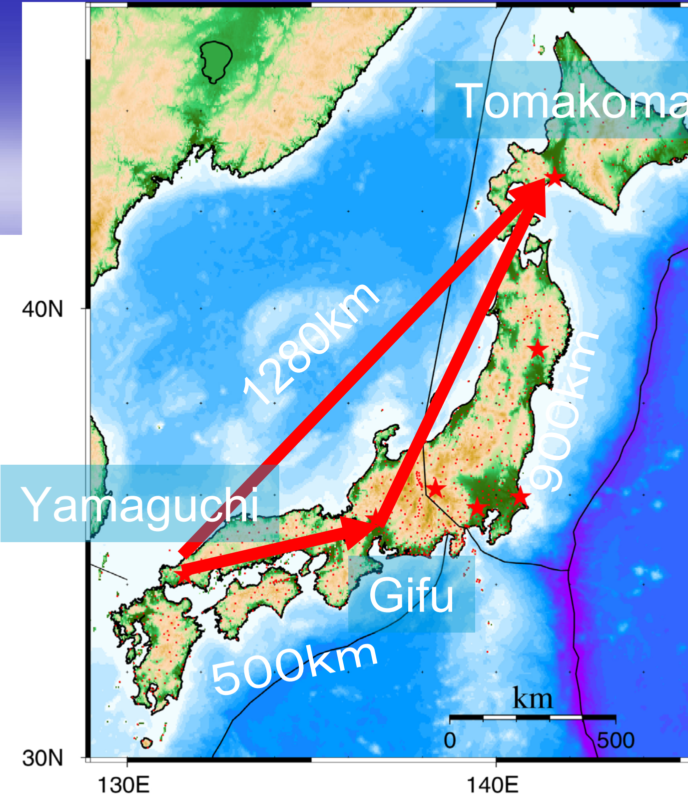






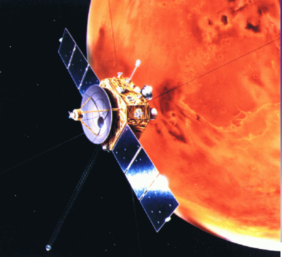
Closure phase delay





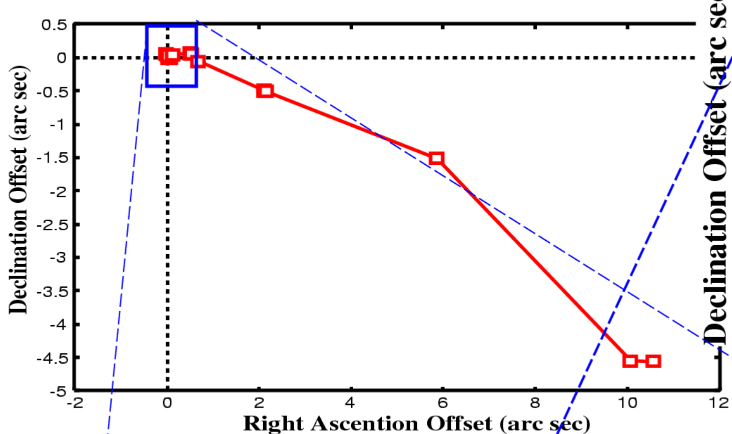
As result of phase connection, Very precise delay observable was obtained over 24 hours.

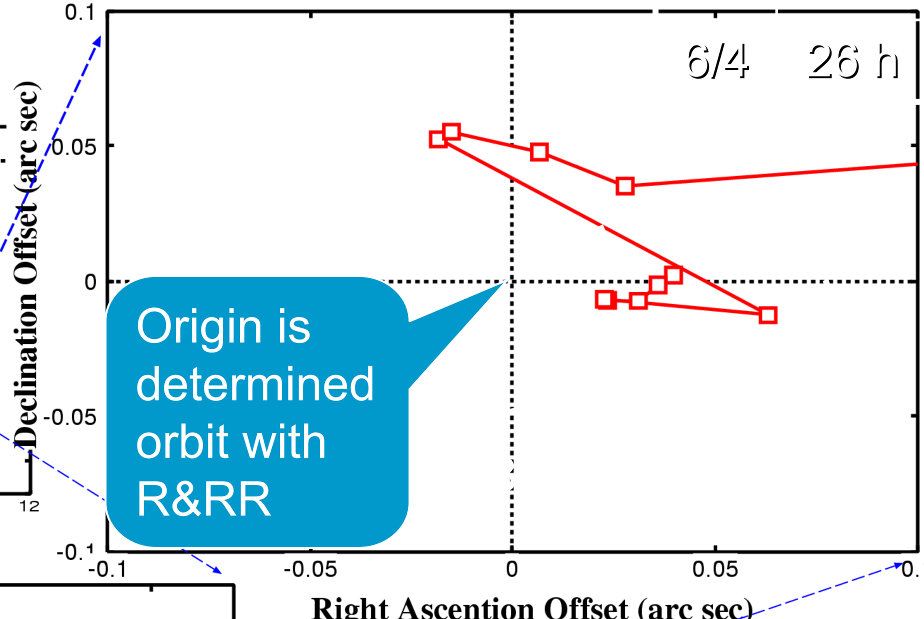
(June 4th experiments)

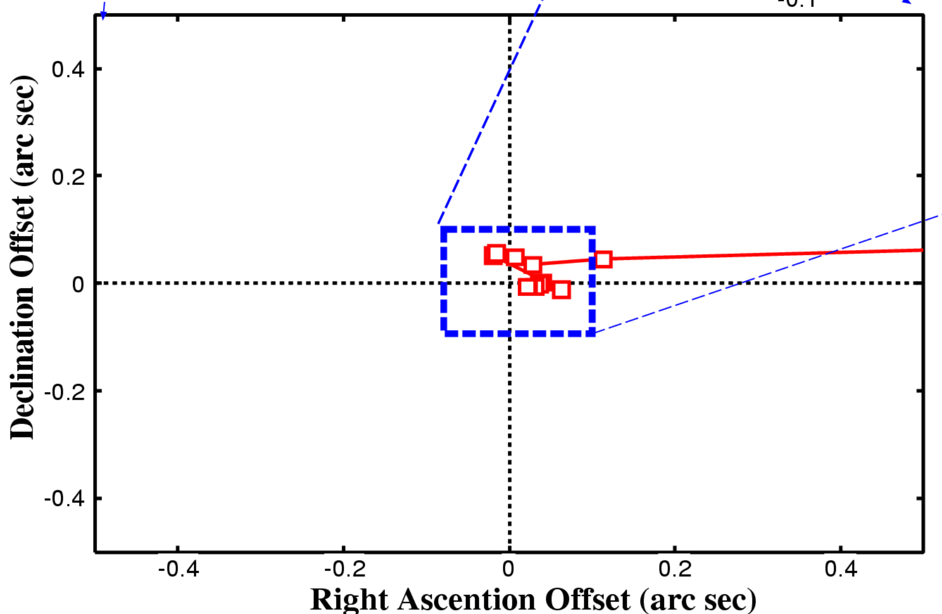


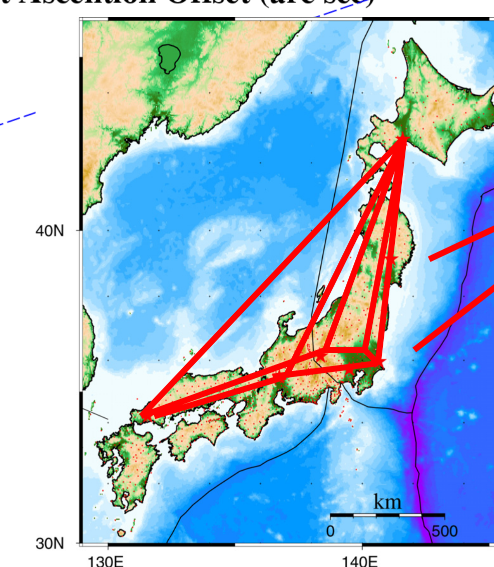
Radio source coordinates

	Tobs	Nstn	Nbase
6/4	26 h	7	21





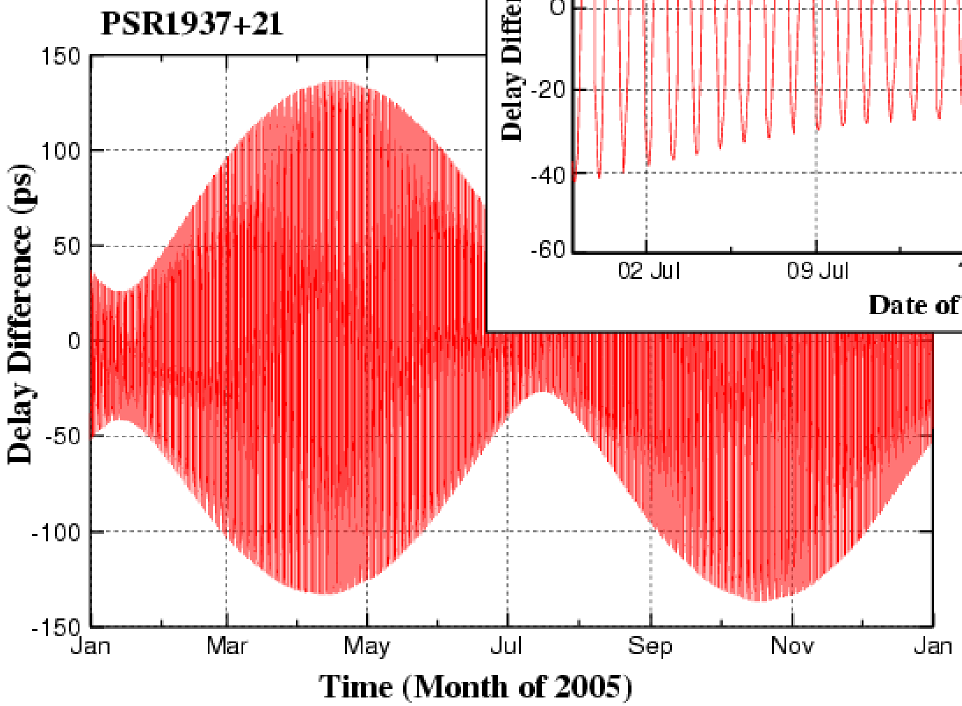


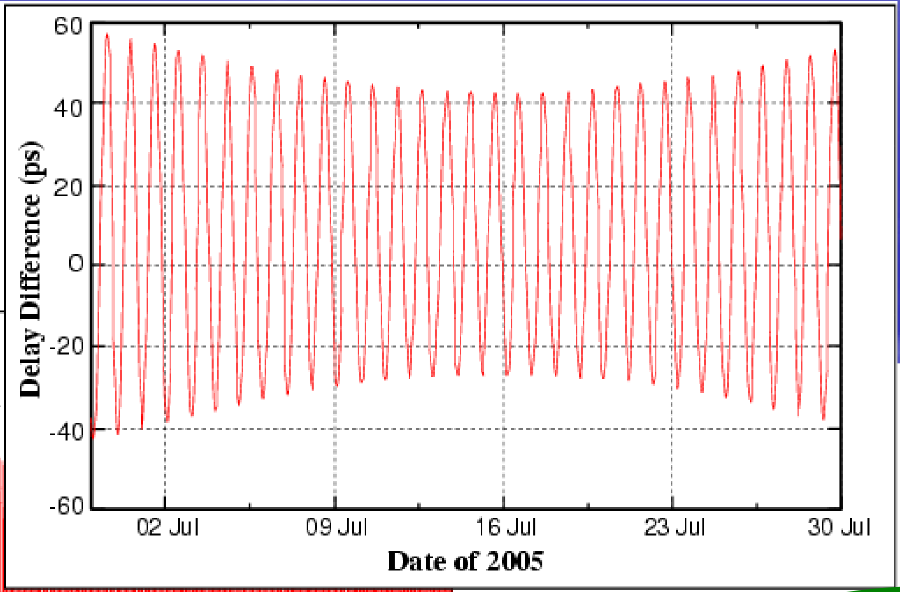


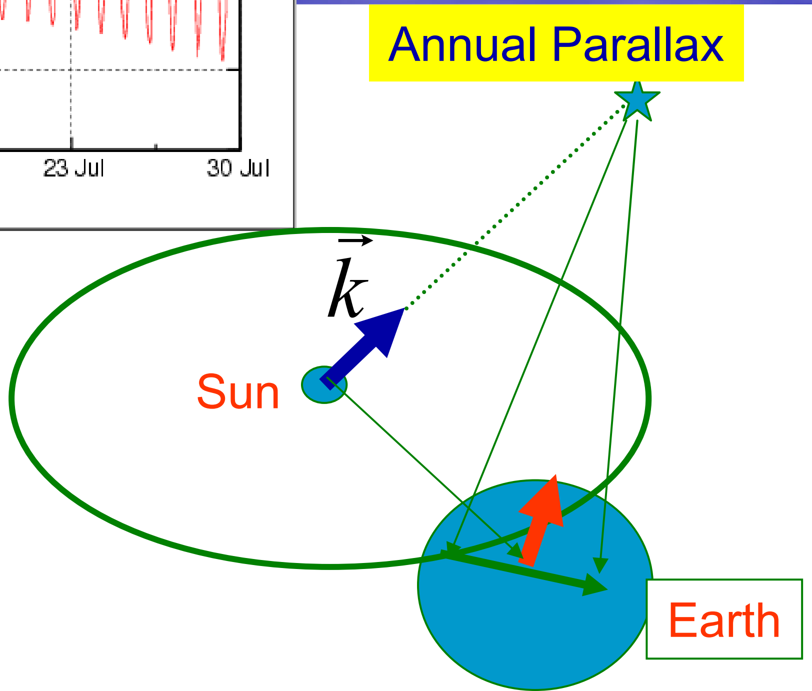
Summary

- VLBI delay model for Finite distance Radio Source:
  - Curved wave front = parallax
- Disk-Based Data Recording System + Software Correlator:
  - Network + Flexible Data processing
- Observable:
  - Currently: Delta-VLBI with Group Delay
  - Future: Delta-VLBI with Phase delay

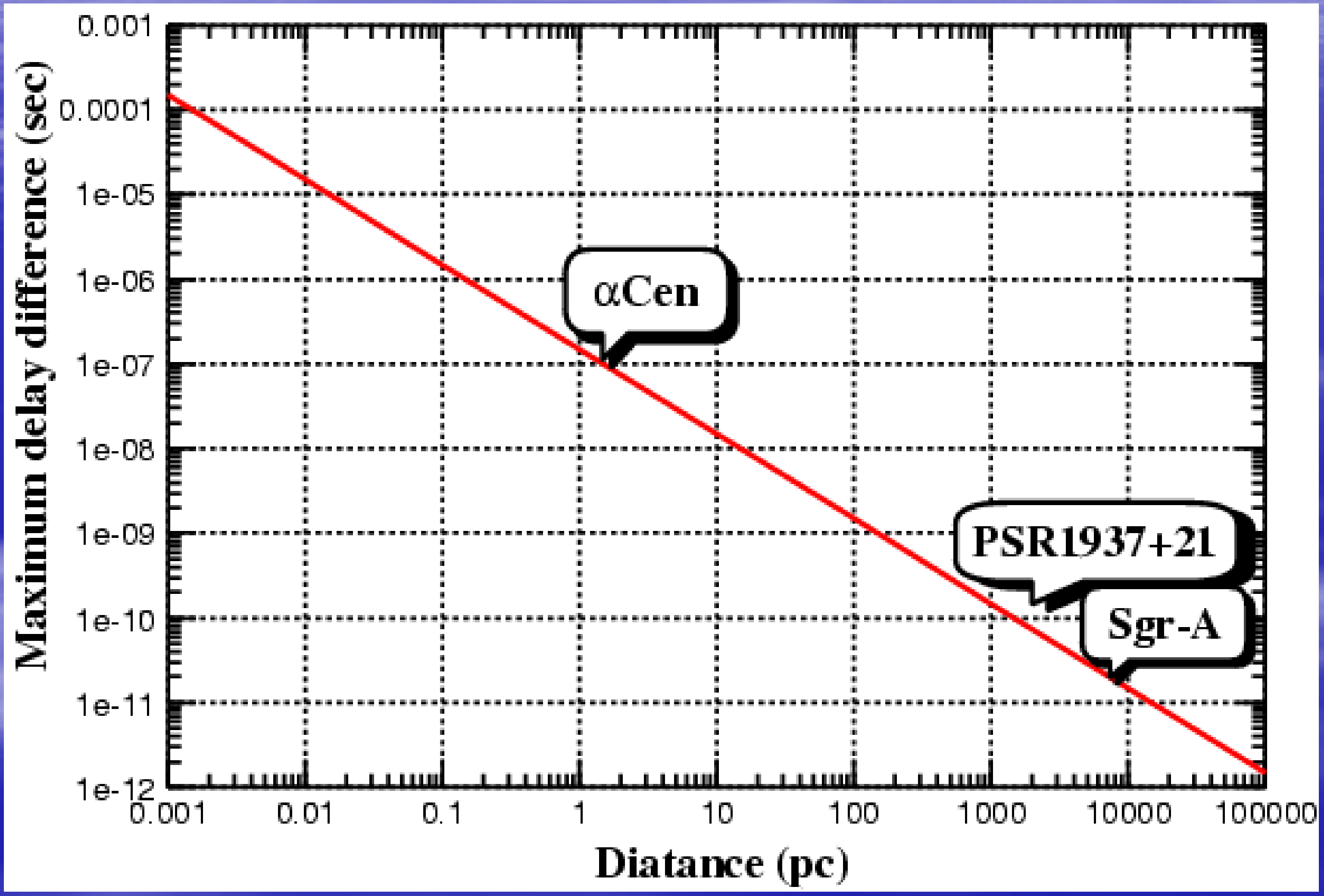
FVLBI – Consensus model PSR1937+21: Kashima-Algonquin(9000km)





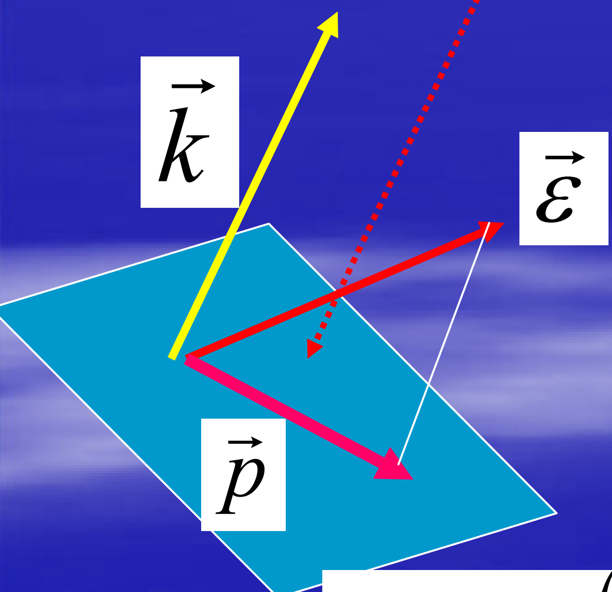


Delay effect by Annual parallax

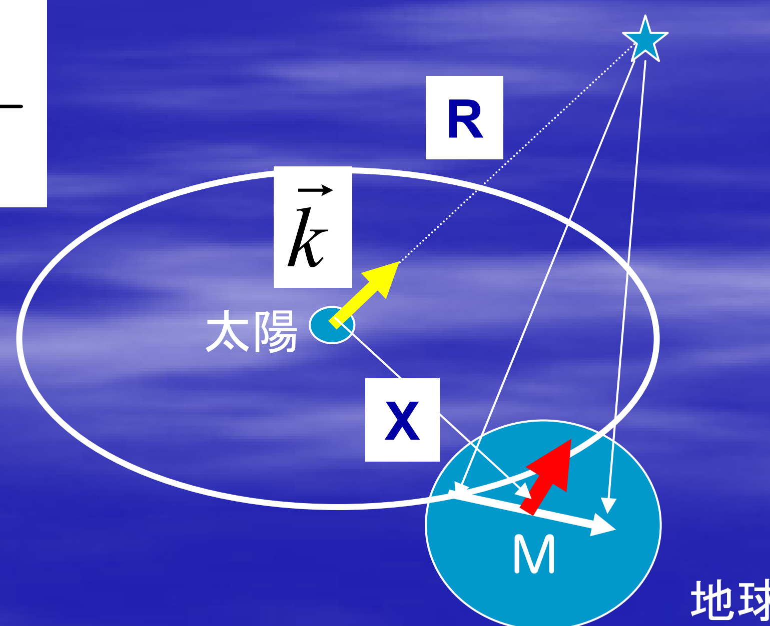


有限距離モデル—Consensus
距離　≧10pc

$$\Delta\tau = \frac{\vec{\mathbf{b}}}{c}\bullet\vec{p} + \frac{\vec{\mathbf{b}}\bullet\vec{k}}{c}\left\{-\left[\vec{p}+\vec{k}\right]\bullet\frac{\vec{V}_2}{c} + \frac{\left|\vec{V}_2\times\vec{k}\right|^2}{2c^2R_{02}}\left(\vec{\mathbf{b}}\bullet\vec{k}\right)\right\}$$



$$\vec{\varepsilon} = \frac{\vec{X}}{R}$$



視差ベクトル

$$\vec{p} \equiv \vec{\varepsilon} - \left(\vec{\varepsilon}\bullet\vec{k}\right)\vec{k}$$