Near-Field VLBI Delay Models

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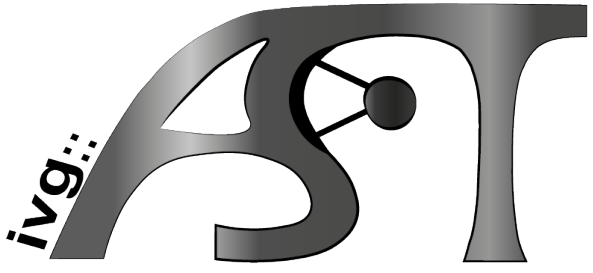

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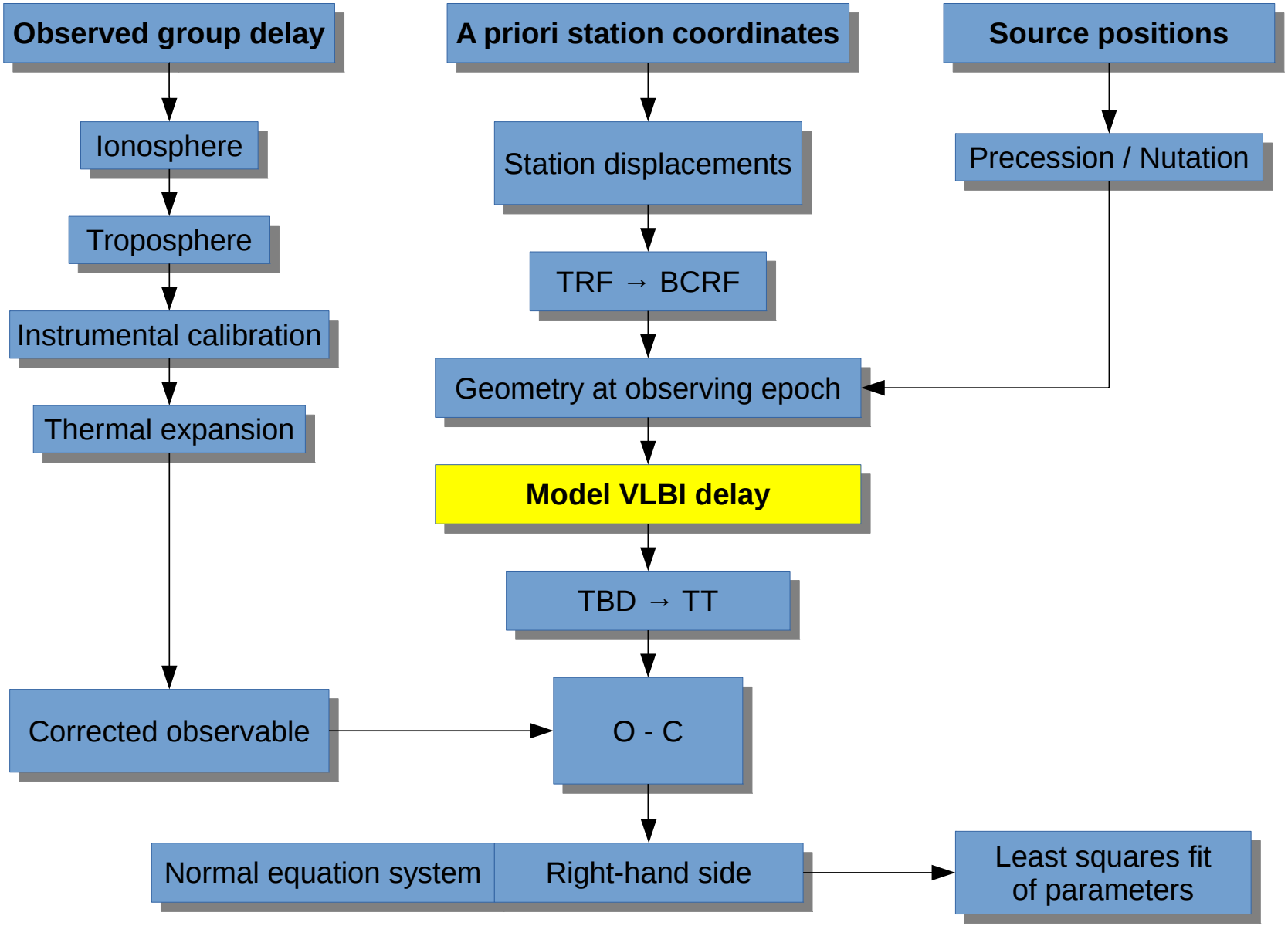
VLBI Post-correlation analysis steps



Infinite distance VLBI geometric delay

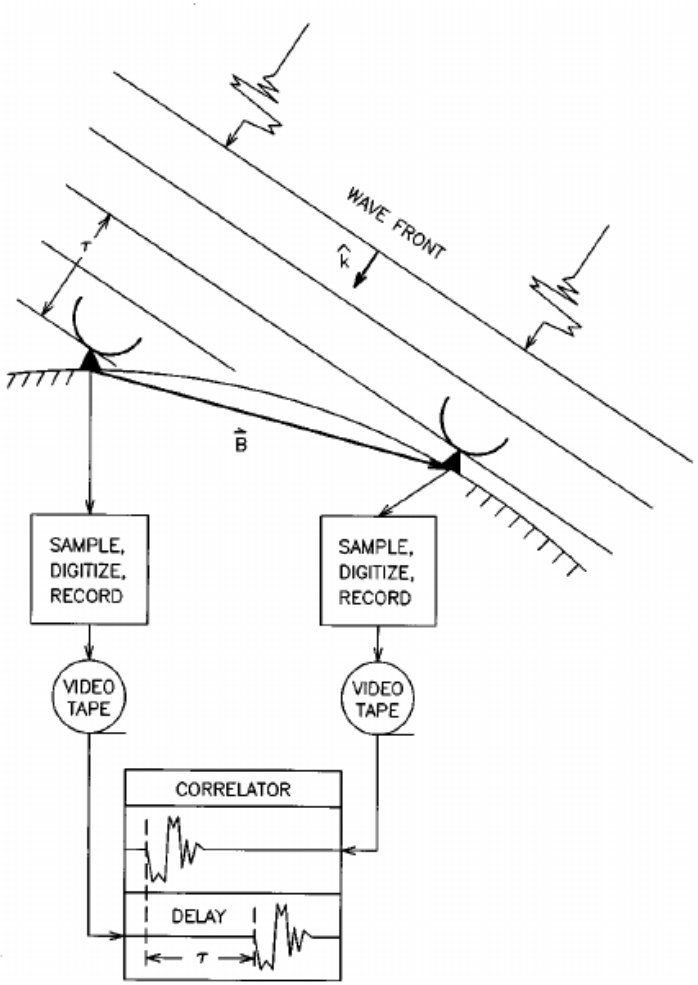


Figure : Schematic diagram of a VLBI experiement. Figure 1 in Sovers et al. (1998).

Geometric delay:

$$\tau \propto \vec{b} \cdot \hat{k}$$

plus corrections.

Assumption: Plane wavefronts.

$\Rightarrow$ **Not applicable for near-field sources.**

Near-field VLBI delay model I

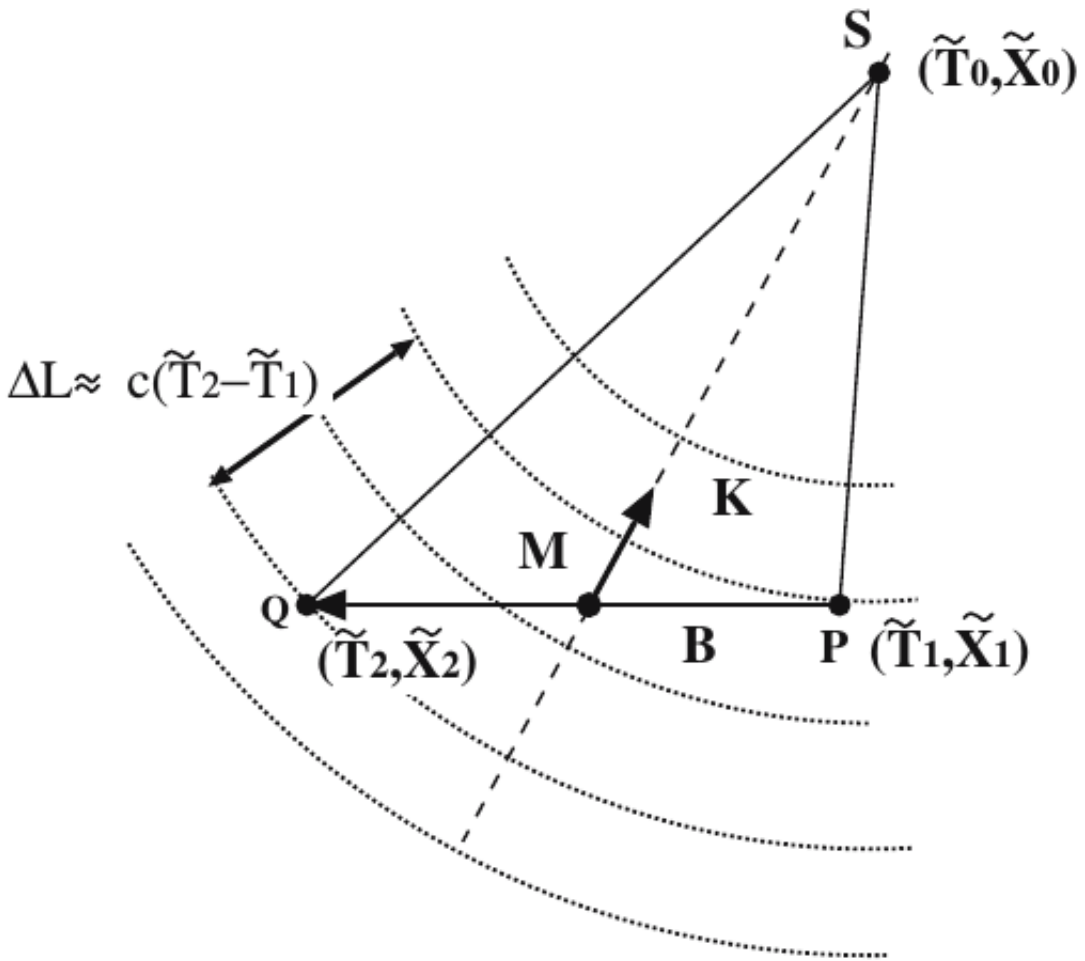


Figure : Configuration of a VLBI observation for a radio source at finite distance (Fig. 1 in Sekido & Fukushima 2006).

Near-field VLBI delay model I

Light-time equation:

$$\tilde{T}_0 = \tilde{T}_1 - \frac{\left|\tilde{\mathbf{X}}_0(\tilde{T}_0) - \tilde{\mathbf{X}}_\mathrm{E}(\tilde{T}_1) - \mathbf{R}_{1\mathrm{E}}(\tilde{T}_1)\right|}{c} - \Delta T_{\mathrm{g},\,01}$$

Pseudo source vector:

$$\mathbf{K} \stackrel{\mathrm{def}}{=} \frac{\mathbf{R}_1(\tilde{T}_1) + \mathbf{R}_2(\tilde{T}_1)}{R_1(\tilde{T}_1) + R_2(\tilde{T}_1)}$$

with

$$\begin{aligned} \mathbf{R}_i(\tilde{T}_1) &= \tilde{\mathbf{X}}_0(\tilde{T}_0) - \tilde{\mathbf{X}}_i(\tilde{T}_1) \\ &= \tilde{\mathbf{X}}_0(\tilde{T}_0) - \tilde{\mathbf{X}}_\mathrm{E}(\tilde{T}_1) - \mathbf{R}_{i\mathrm{E}}(\tilde{T}_1) \end{aligned}$$

Sekido & Fukushima (2006)

Near-field VLBI delay model I

VLBI delay for a radio source at finite distance in the TT frame:

$$\tau = \frac{-\frac{\mathbf{K}\cdot\mathbf{b}}{c}\left(1-\frac{2W_\mathrm{E}}{c^2}-\frac{V_\mathrm{E}^2+2\mathbf{V}_\mathrm{E}\cdot\mathbf{v}_2}{2c^2}\right)-\frac{\mathbf{V}_\mathrm{E}\cdot\mathbf{b}}{c^2}\left(1+\frac{\hat{\mathbf{R}}_2\cdot\mathbf{V}_2}{c}-\frac{(\mathbf{V}_\mathrm{E}+2\mathbf{v}_2)\cdot\mathbf{K}}{2c}\right)+\Delta T_\mathrm{grav}}{\left(1+\frac{\hat{\mathbf{R}}_2\cdot\mathbf{V}_2}{c}\right)(1+H)}$$

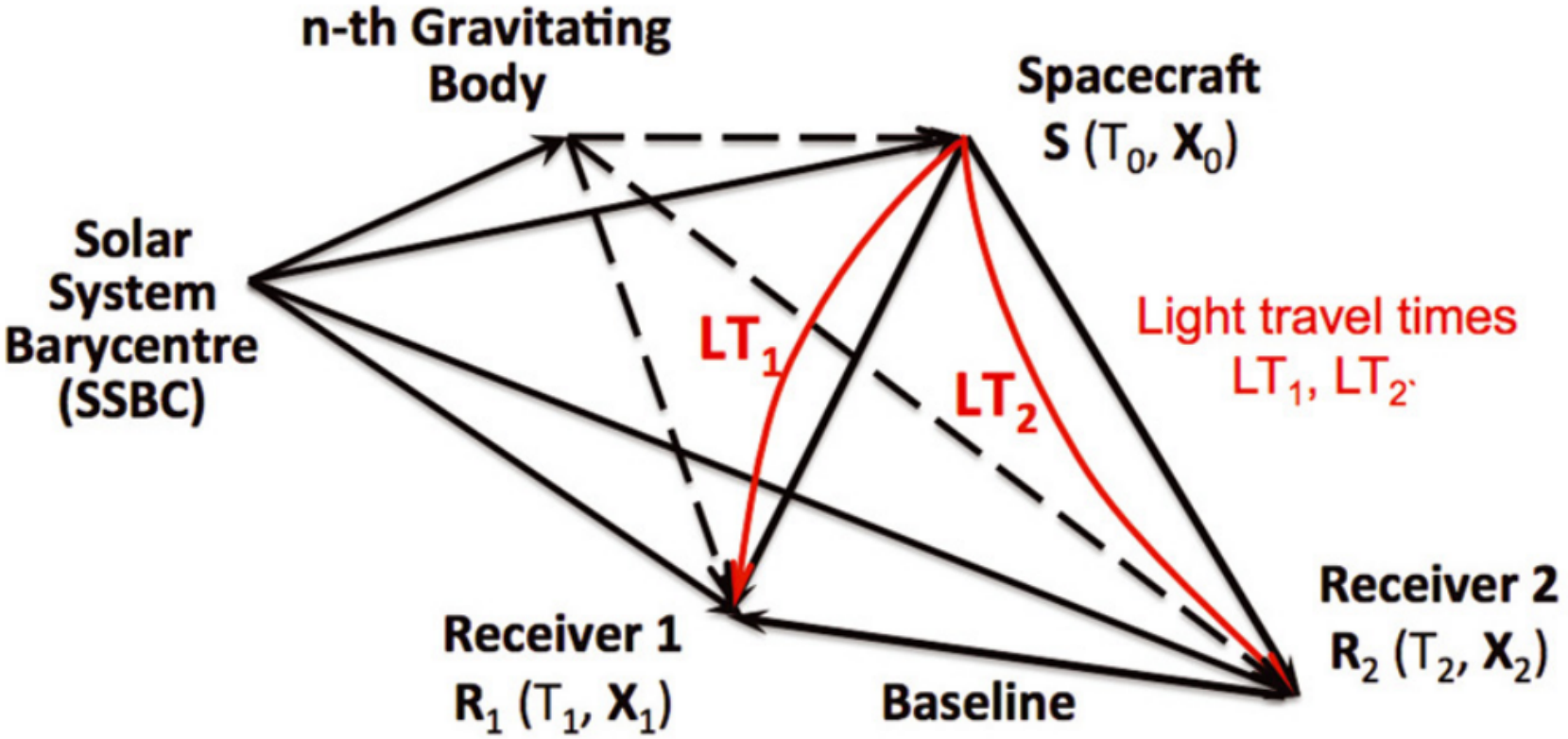
Eq. (20) in Sekido & Fukushima (2006)

Infinite distance delay:

$$\tau = \frac{-\frac{\hat{\mathbf{k}}\cdot\mathbf{b}}{c}\left(1-\frac{2W_\mathrm{E}}{c^2}-\frac{V_\mathrm{E}^2+2\mathbf{V}_\mathrm{E}\cdot\mathbf{v}_2}{2c^2}\right)-\frac{\mathbf{V}_\mathrm{E}\cdot\mathbf{b}}{c^2}\left(1+\frac{\hat{\mathbf{k}}\cdot\mathbf{V}_\mathrm{E}}{2c}\right)+\Delta T_\mathrm{grav}}{1+\frac{\hat{\mathbf{k}}\cdot(\mathbf{V}_\mathrm{E}+\mathbf{v}_2)}{c}}$$

IERS Conventions (2010, Chapt. 11)

Near-field VLBI delay model II



Transformation from TBD to TT:

$$\tau = \left(\frac{T2 - T1}{1 - L_C} \cdot \left[1 - \frac{1}{c^2} \left(\frac{V_{\mathrm{E}}^2}{2} + U_{\mathrm{E}} \right) \right] - \frac{\mathbf{V}_{\mathrm{E}} \cdot \mathbf{b}}{c^2} \right) \cdot \left(1 + \frac{\mathbf{V}_{\mathrm{E}} \cdot \dot{\mathbf{r}}_{2,\,\mathrm{gc}}}{c^2} \right)^{-1}$$

Duev *et al.* (2012)

VLBI Observations of GPS satellites

- August 24, 2015, 12:00 – 16:00 UTC
- Baseline Hobart – Ceduna ($\sim 1700\,\mathrm{km}$)
- Observed satellites: PRN02, 12, 24, 25
- SP3 final ephemerides

Plank *et al.* (in preparation)
Hellerschmied *et al.* IVS GM 2016

Results I

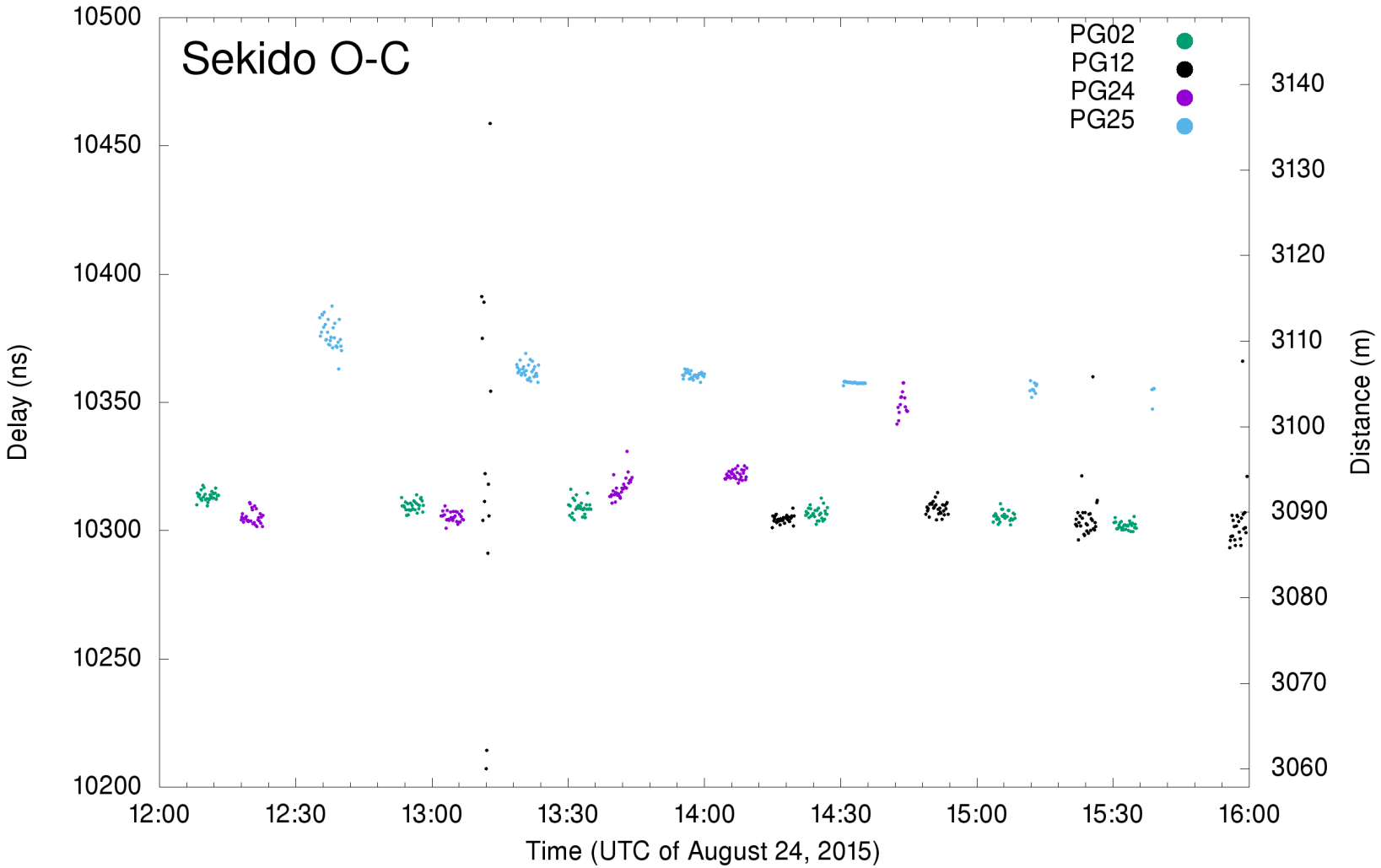


Figure : Observed delays minus computed with Sekido & Fukushima (2006).

Results II

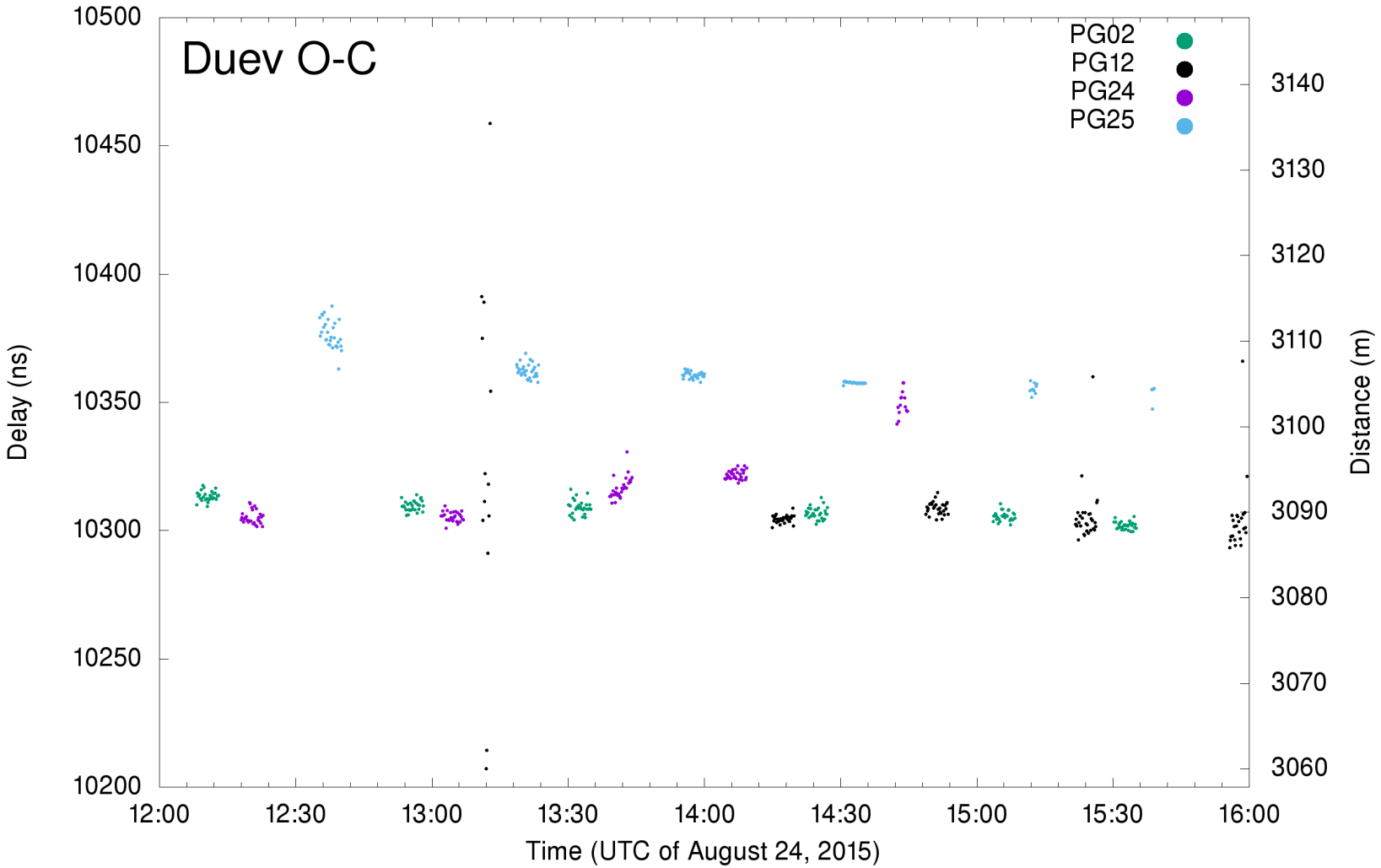


Figure : Observed delays minus computed with Duev *et al.* (2012).

Difference between models

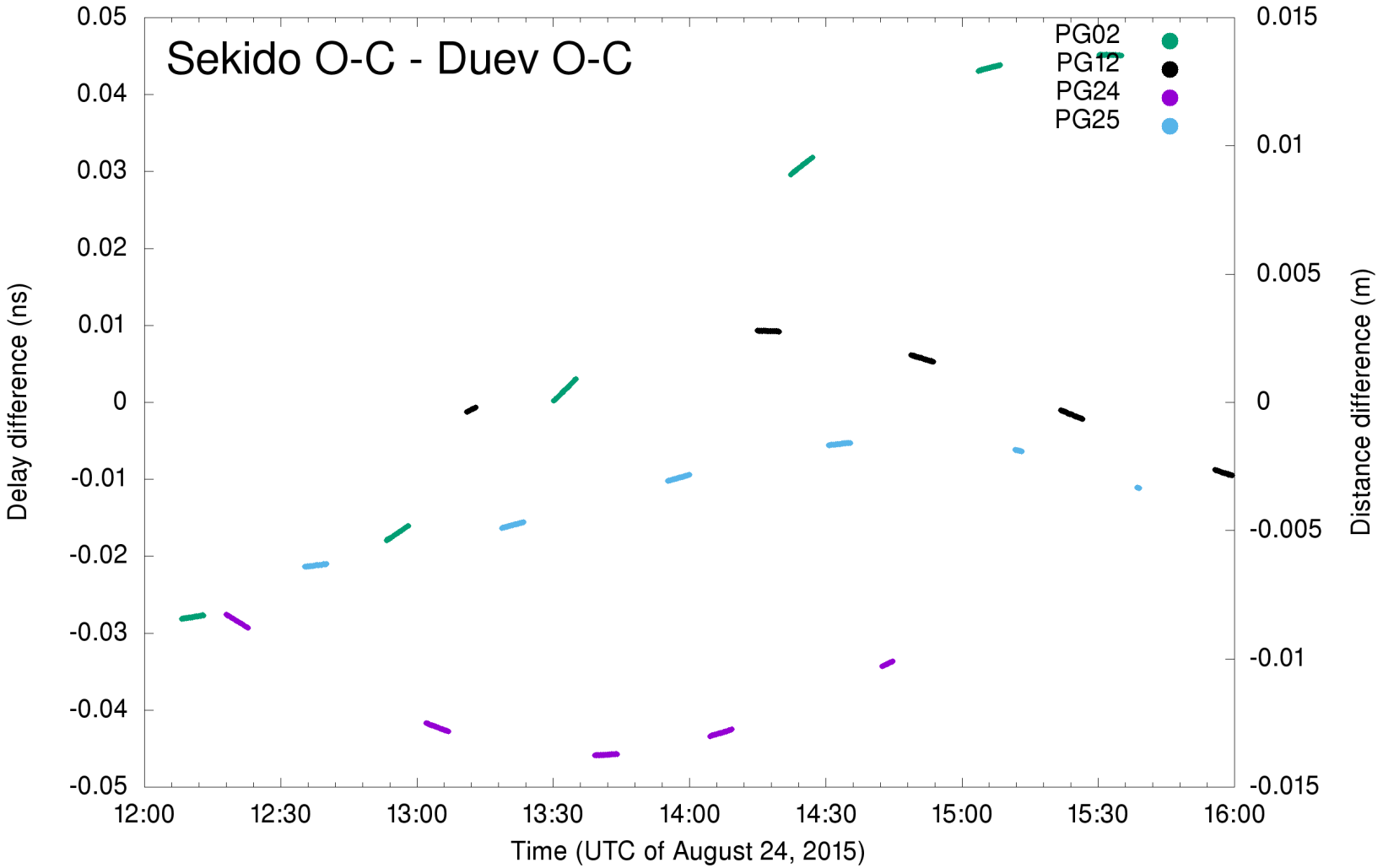


Figure : Difference between Sekido & Fukushima (2006) and Duev *et al.* (2012).

Summary

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Two near-field VLBI delay models

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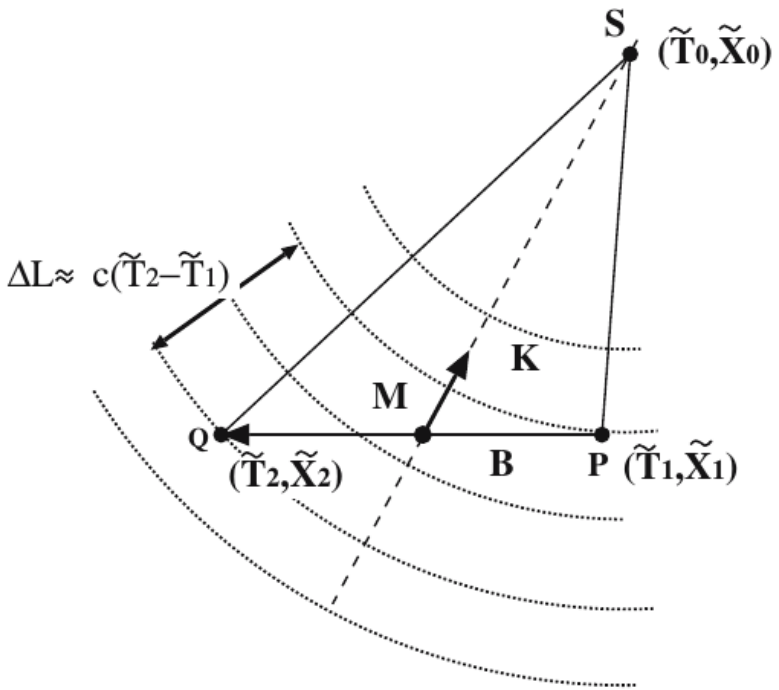

Sekido & Fukushima (2006)

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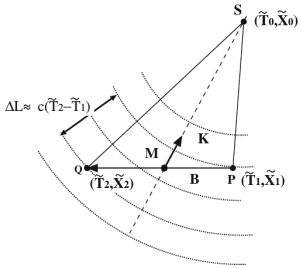

Sekido & Fukushima (2006) (pseudo source vector)

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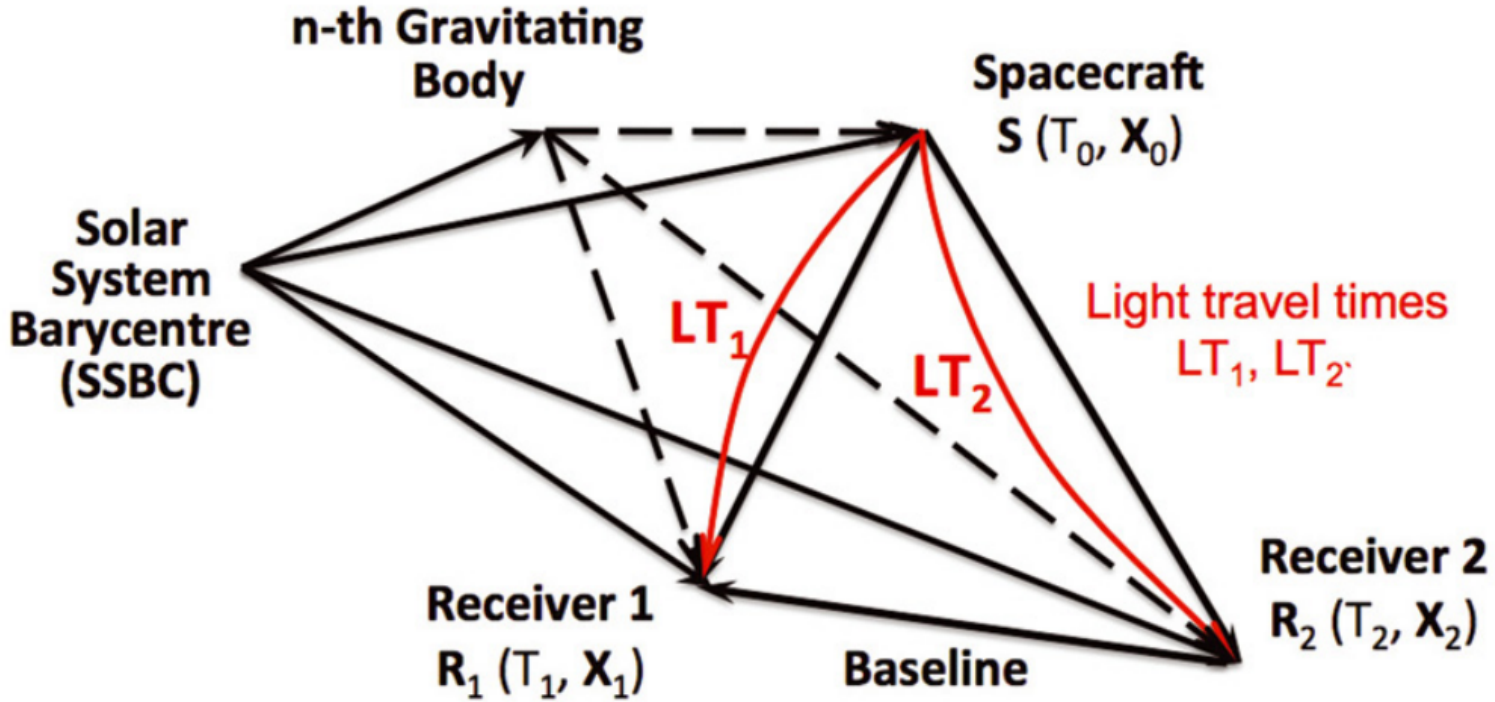

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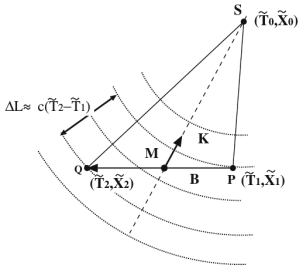

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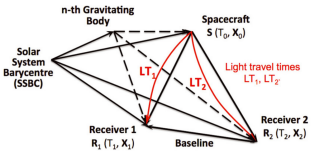

Duev *et al.* (2012) (solve light-time equation twice)

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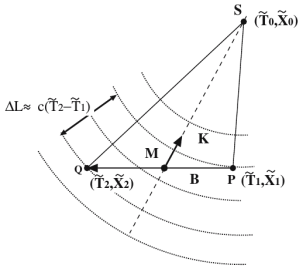

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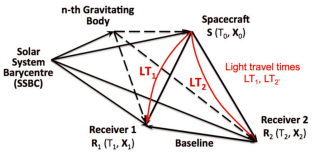

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Results with our implementation

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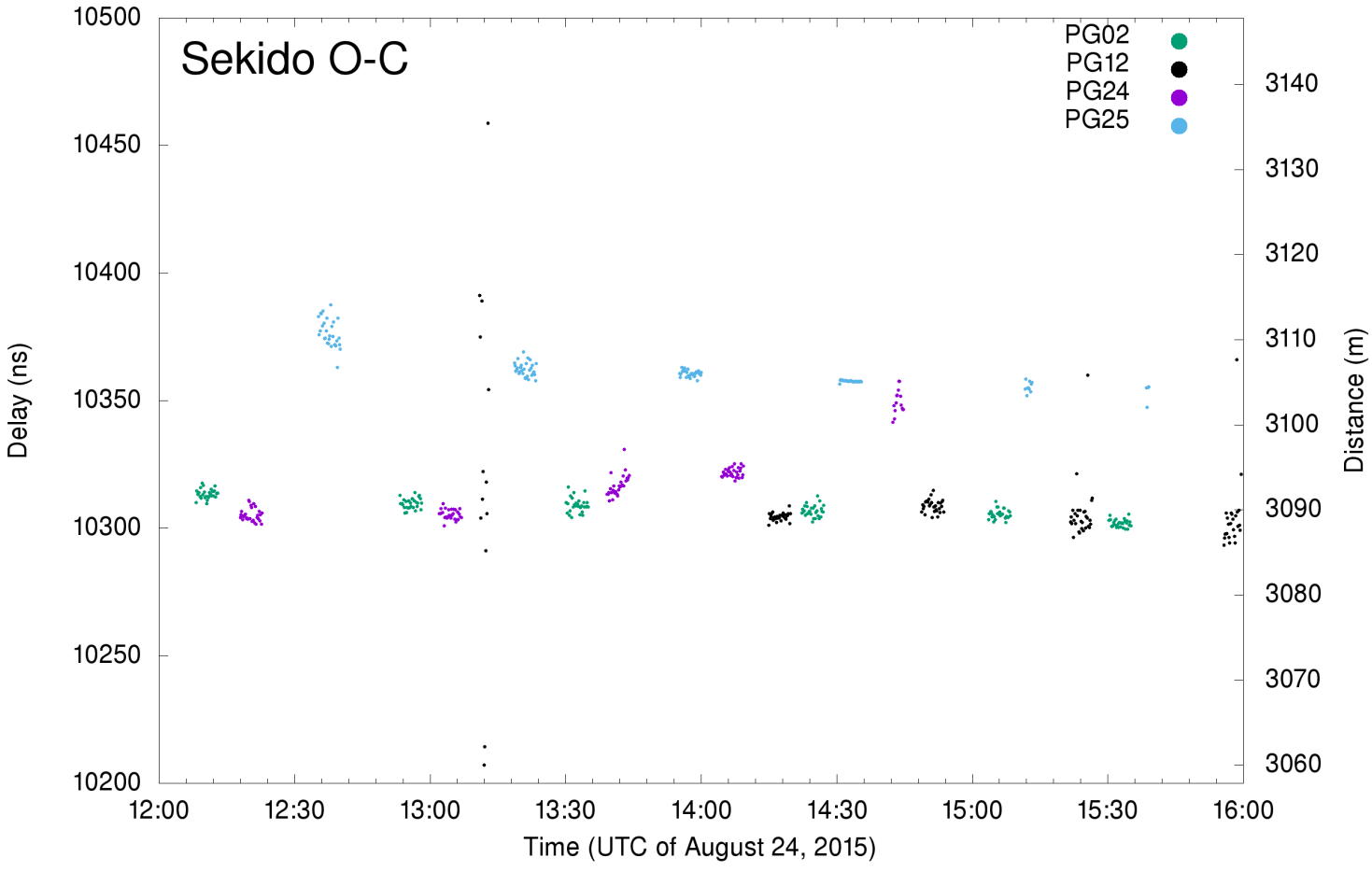

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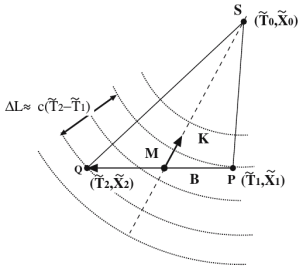

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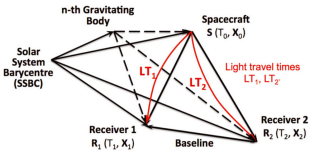

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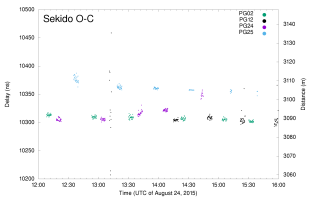

GPS satellites have individual systematics

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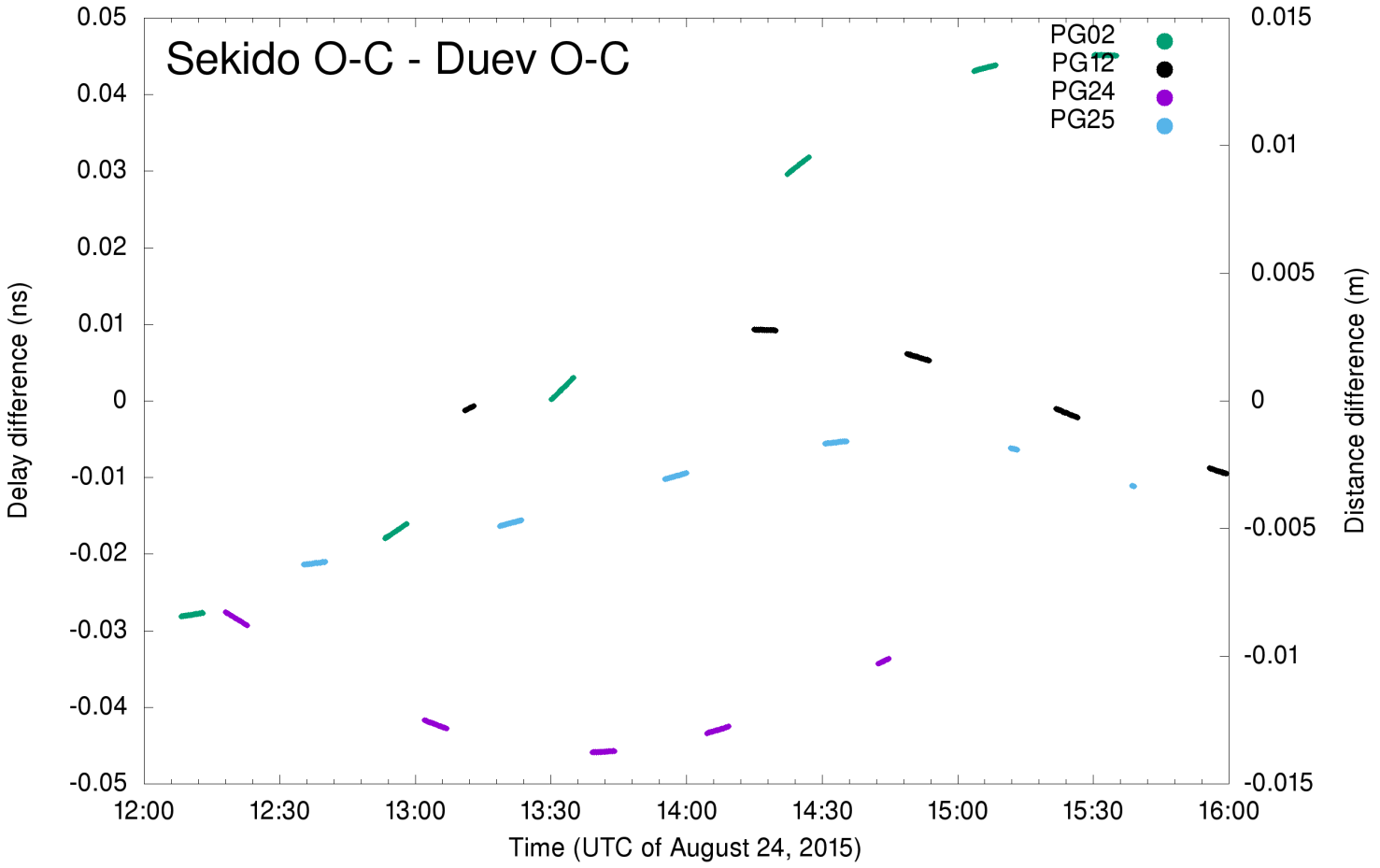

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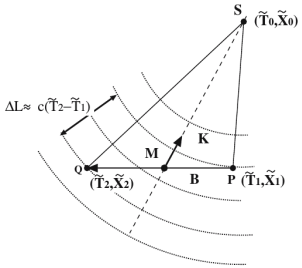

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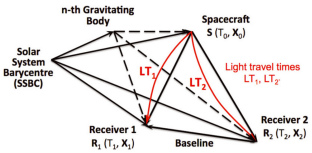

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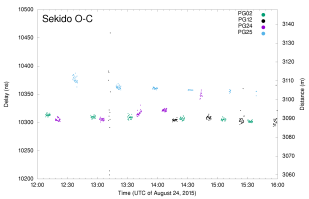
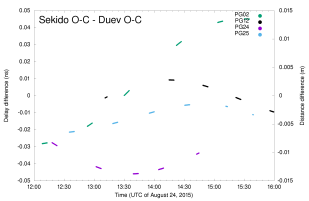


GPS satellites have individual systematics



Sekido $-$ Duev $\approx \pm 50$ ps

Appendix

Figure : Artist's impression of a GPS IIF satellite in orbit (Source: Wikipedia).