Optical Transponders for Space Missions

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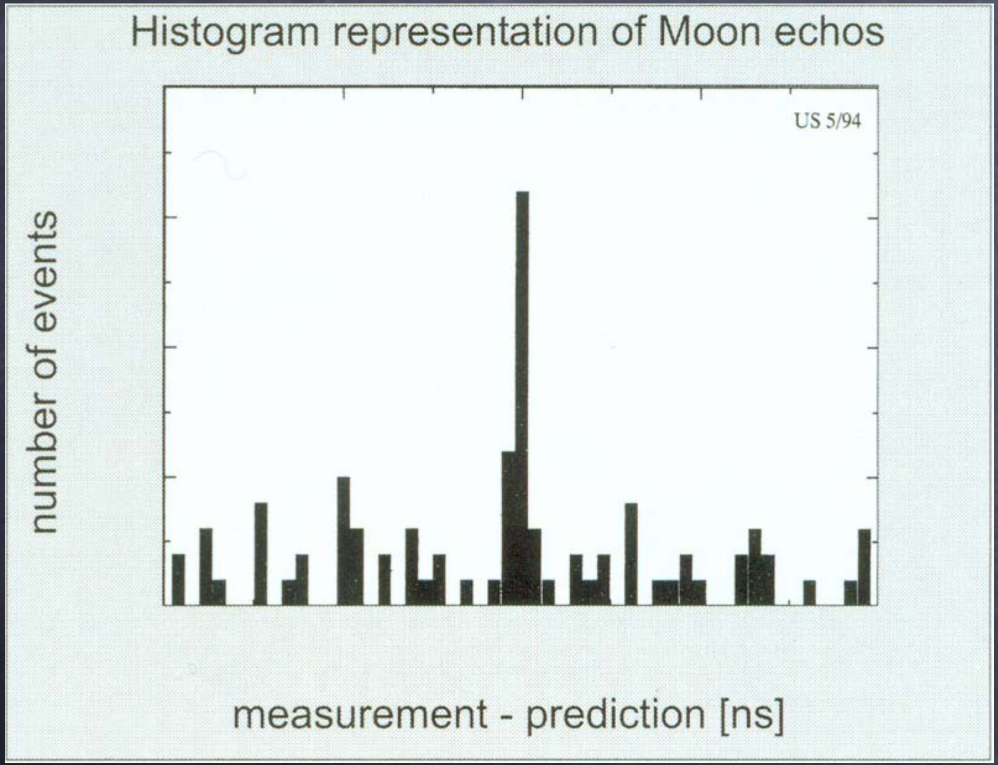
Transponder Consideration

- SLR is routine for 300 km < r < 360 000 km
- no interplanetary links (navigation, POD)
- optical communications now in space
- higher complexity in space now possible

Example LLR



- 1 cm in optical Range comes to 30 ps
- 1 Single-Photon event per 5 minutes is the lower limit
- SNR

For all practical purposes there will be no 2-way laser ranging beyond the moon distance.

There are about 32 SLR targets in the sky - so every concept has to be based on good SNR

Laser Link Equation

$$n_{pe} = \eta_q \left(E_T \frac{\lambda}{h\,c} \right) \eta_t G_t \sigma \left(\frac{1}{4\pi R^2} \right)^2 A_r \eta_r T_a^2 T_c^2$$

Transponder Link Equation

$$n_{pe} = \frac{\eta_q \eta_r T_A T_B}{h\,\nu\,\Omega_t} E_A A_B \frac{1}{r^2}$$

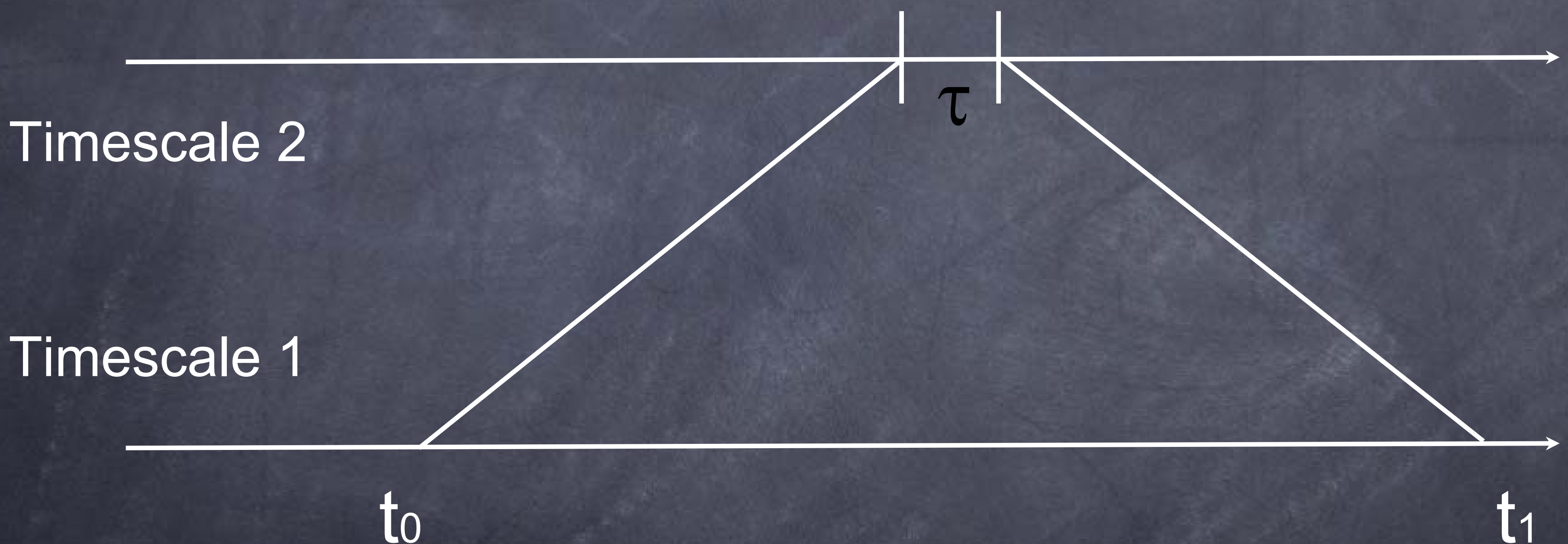
$$\frac{1}{r^2} \approx \sigma \left(\frac{1}{4\pi R^2} \right)^2$$

- Transponders can take Optical Ranging a lot further

- Balanced Systems

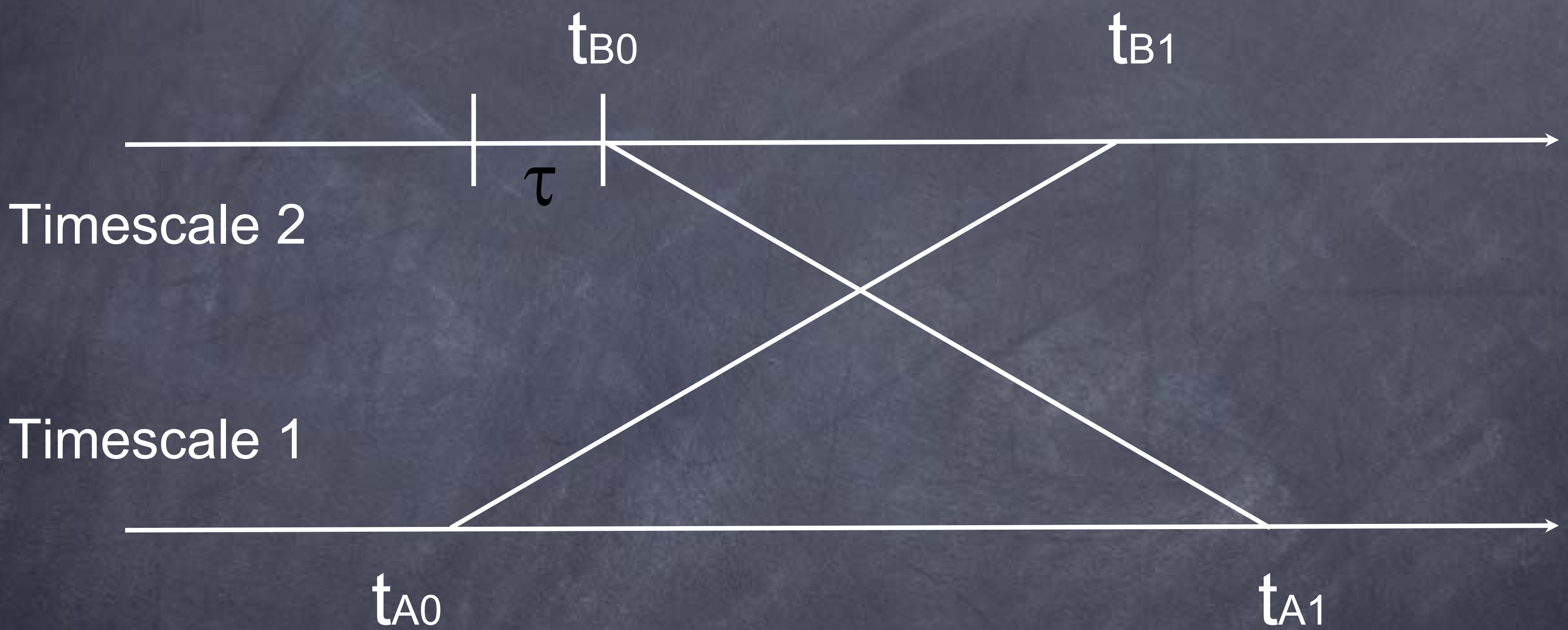
- Satellites with CCR make good simulation targets

Echo-Response Transponder



$$r = \frac{c\,(t_1 - t_0 - \tau)}{2}$$

Asynchronous Transponder

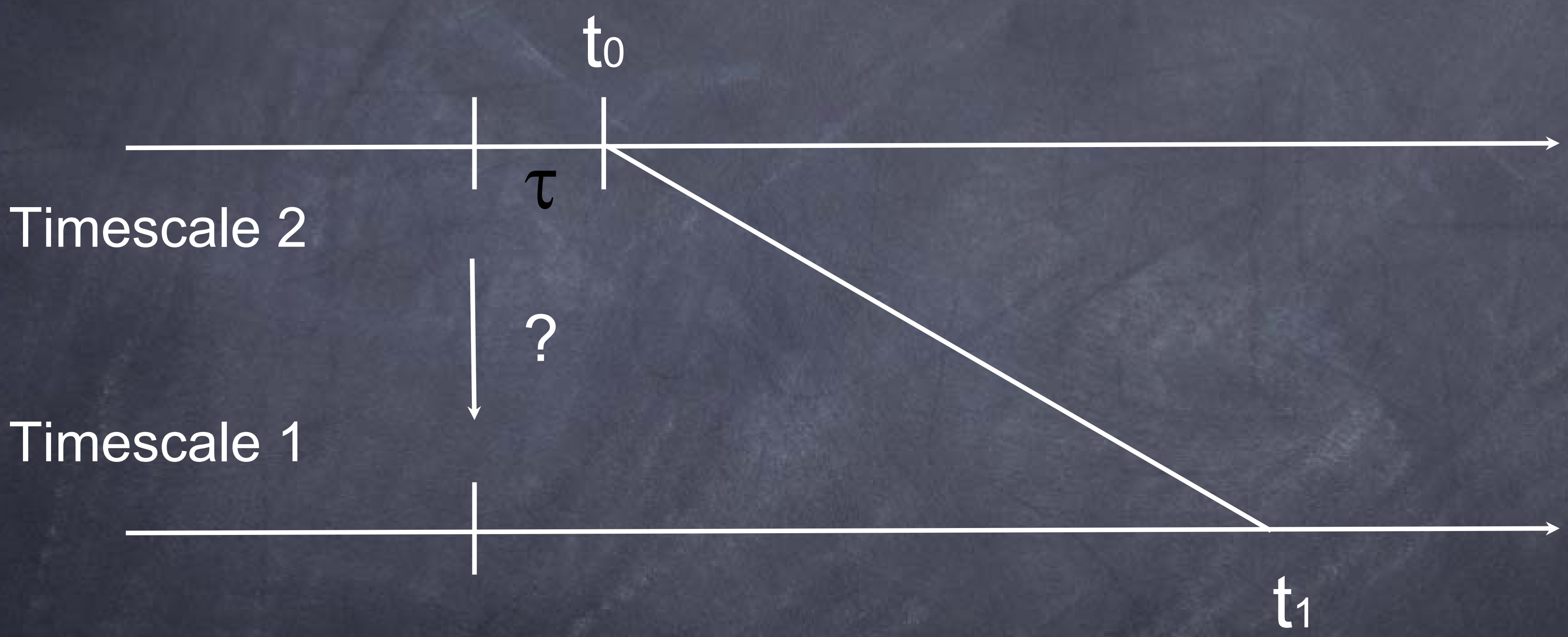


$$R = \frac{c}{2}(t_{BA} + t_{AB}) = \frac{c}{2}[(t_{A2} - t_{A1}) + (t_{B2} - t_{B1})]$$

$$\tau = \frac{[(t_{A2} - t_{A1}) - (t_{B2} - t_{B1})]}{2\,(1 + \frac{\dot{R}}{c})}$$

J.J. Degnan: Journal of Geodynamcis

1-Way Ranging

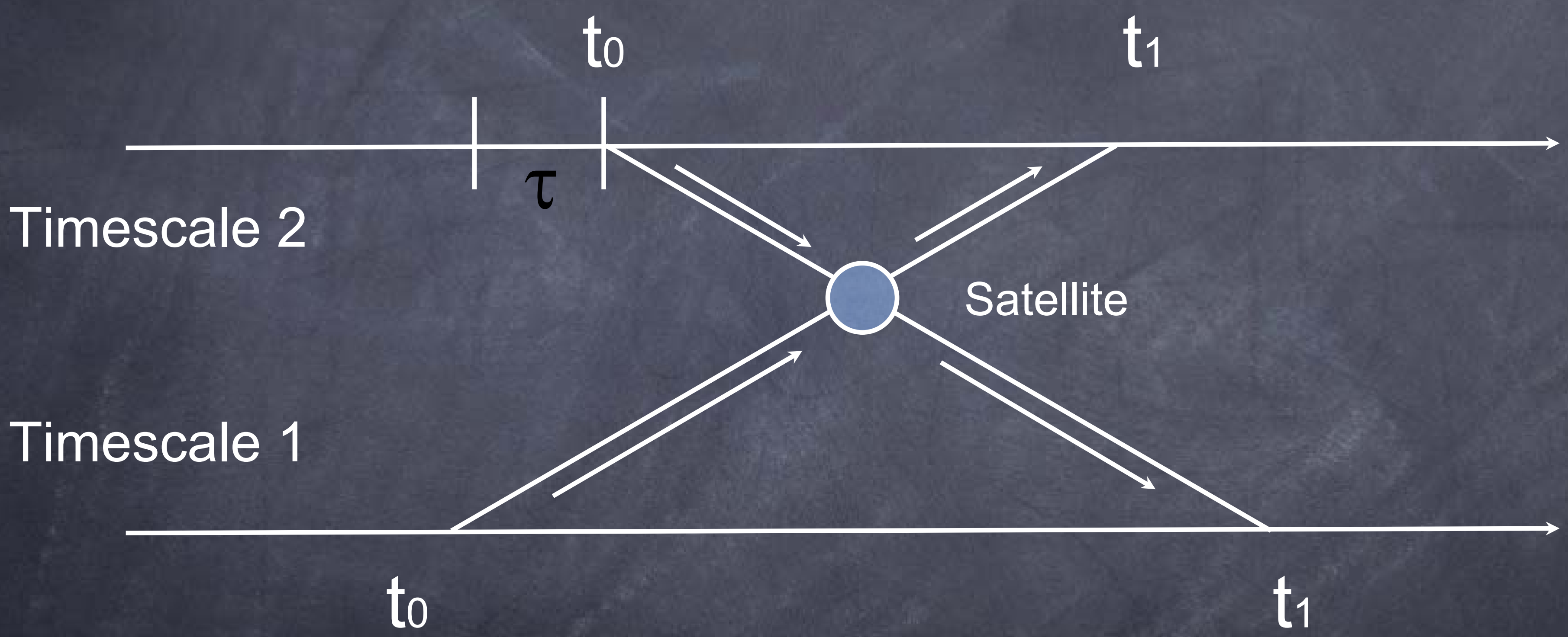


Synchronisation Problem!

One-Way Ranging?

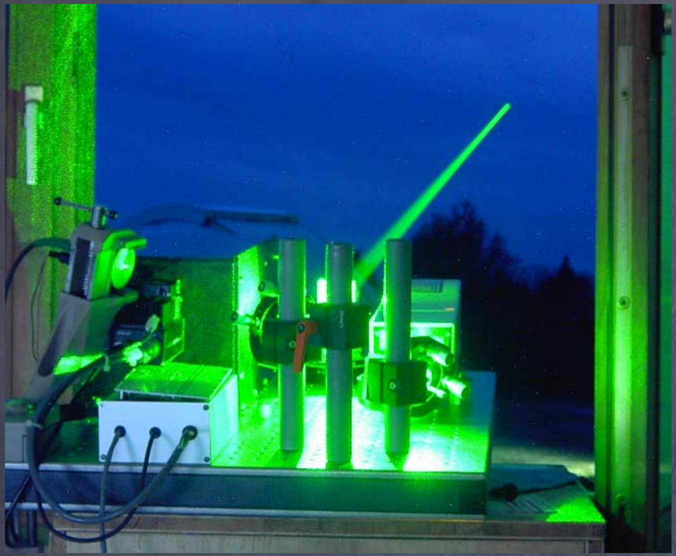
- Laser Beacon (on GPS or Galileo)
- Inverted Laser Beacon (on GPS or Galileo)
- Timescale Synchronisation (Issue not on GNSS)
- Clock Issues (Unbiased Clock Interrogation at the ps level)

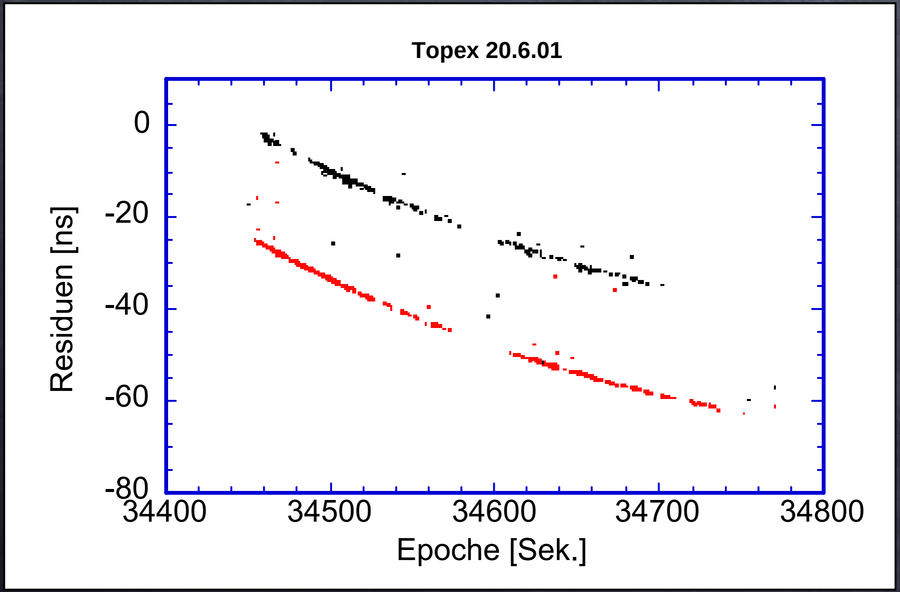
Transponder Testbed



Exploring Timescales ≈ put the 2 systems side by side

Testbed Operations





Transponder Experiments within ILRS

MOLA: 80 000 000 km (1-way)
MLA: 24 000 000 km (2-way)

LOLA on LRO: (1-way -> POD)