Simulation of Two-Way Laser Transponder Links: The Wettzell Experience

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Transponder: The Wettzell Experience

Applying for a satellite mission is one illustration of the chicken and egg problem

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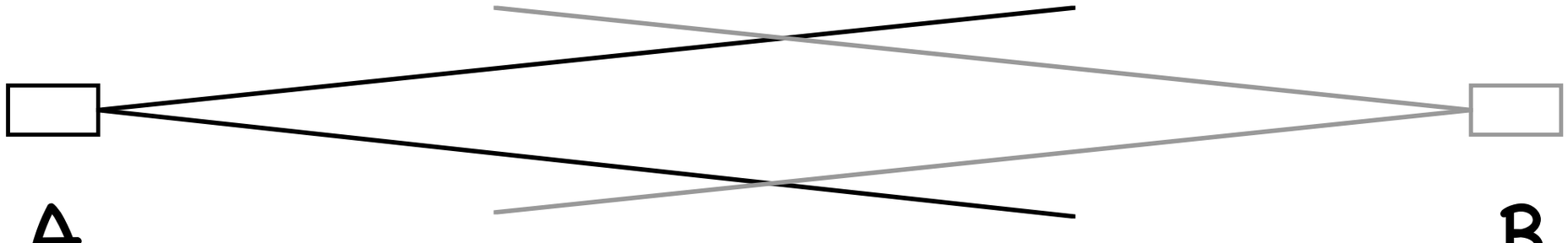
In order to get a mission approved, you must have shown, that you have done it already

Transponder improve the link budget: $\frac{1}{r^4} \rightarrow \frac{1}{r^2}$



… but they require an active space segment

Yoshino, Schreiber et al.:

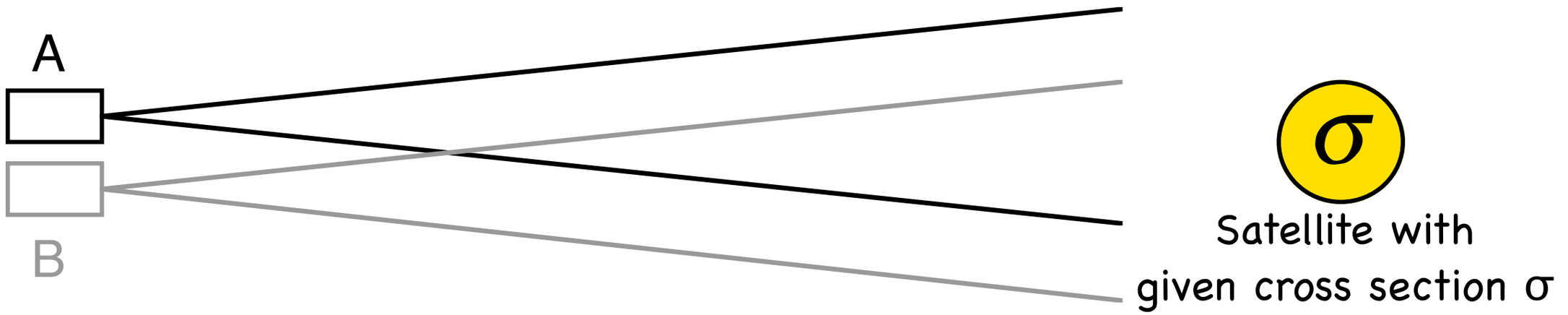
Lunar laser ranging by optical transponder collocated with VLBI radio sources on the moon

Proc. SPIE, Vol. 3865, 20 (1999); doi:10.1117/12.373027

NASA opportunity: Oberst, Schreiber, Müller, Nothnagel,… 2007?

How to demonstrate a mission goal, when there is no mission?

Transponder Simulation Experiment

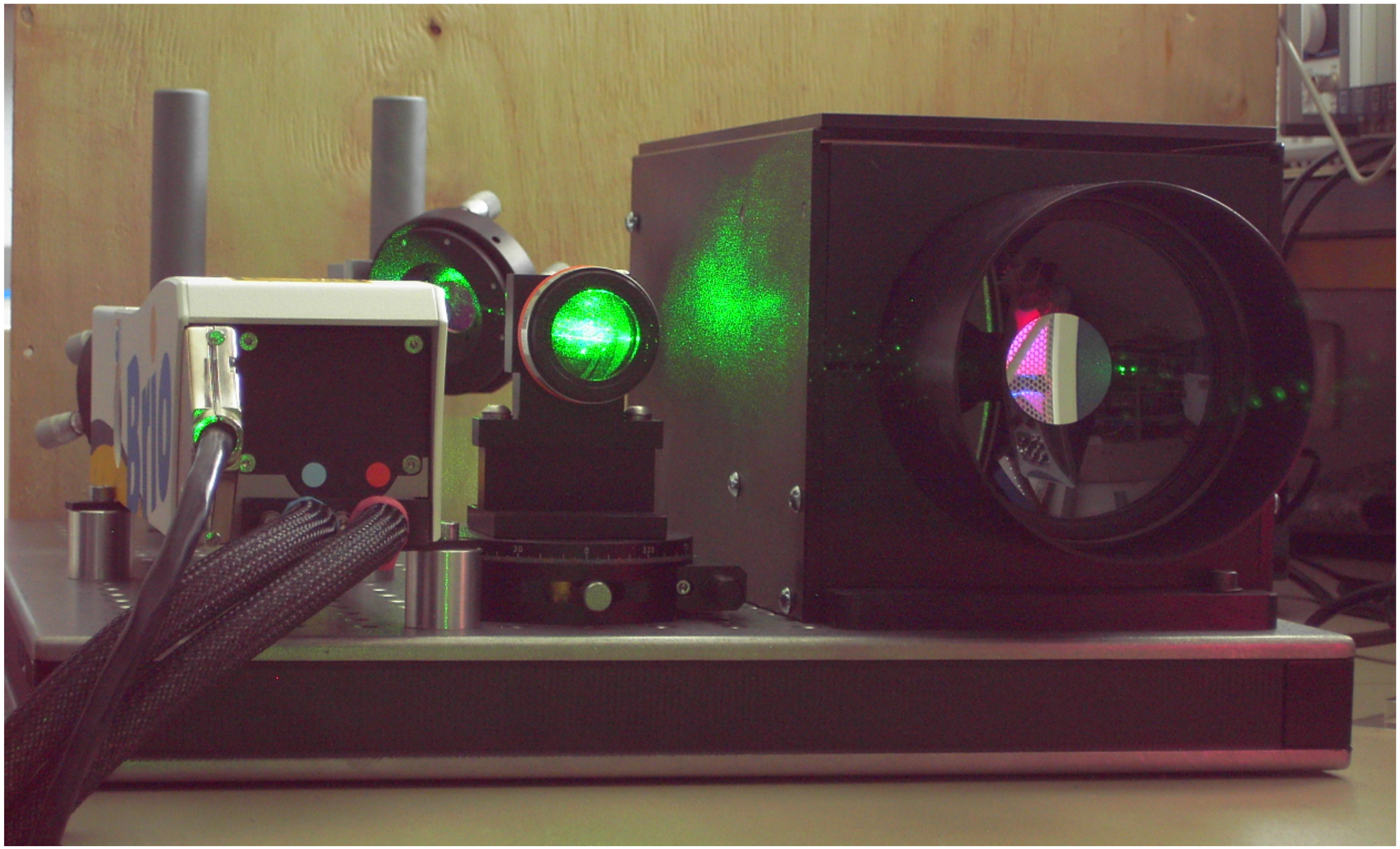


Concept: Folding beam path back and use satellite as mirror

$$r_t = r_s^2 \sqrt{\frac{4\pi}{\sigma} \frac{1}{T^{\sec\theta}}}$$

[Degnan 2006]

AltimeterDemonstrator



Alignment:

a) Laser beam pointed at target ≈ 200 m away

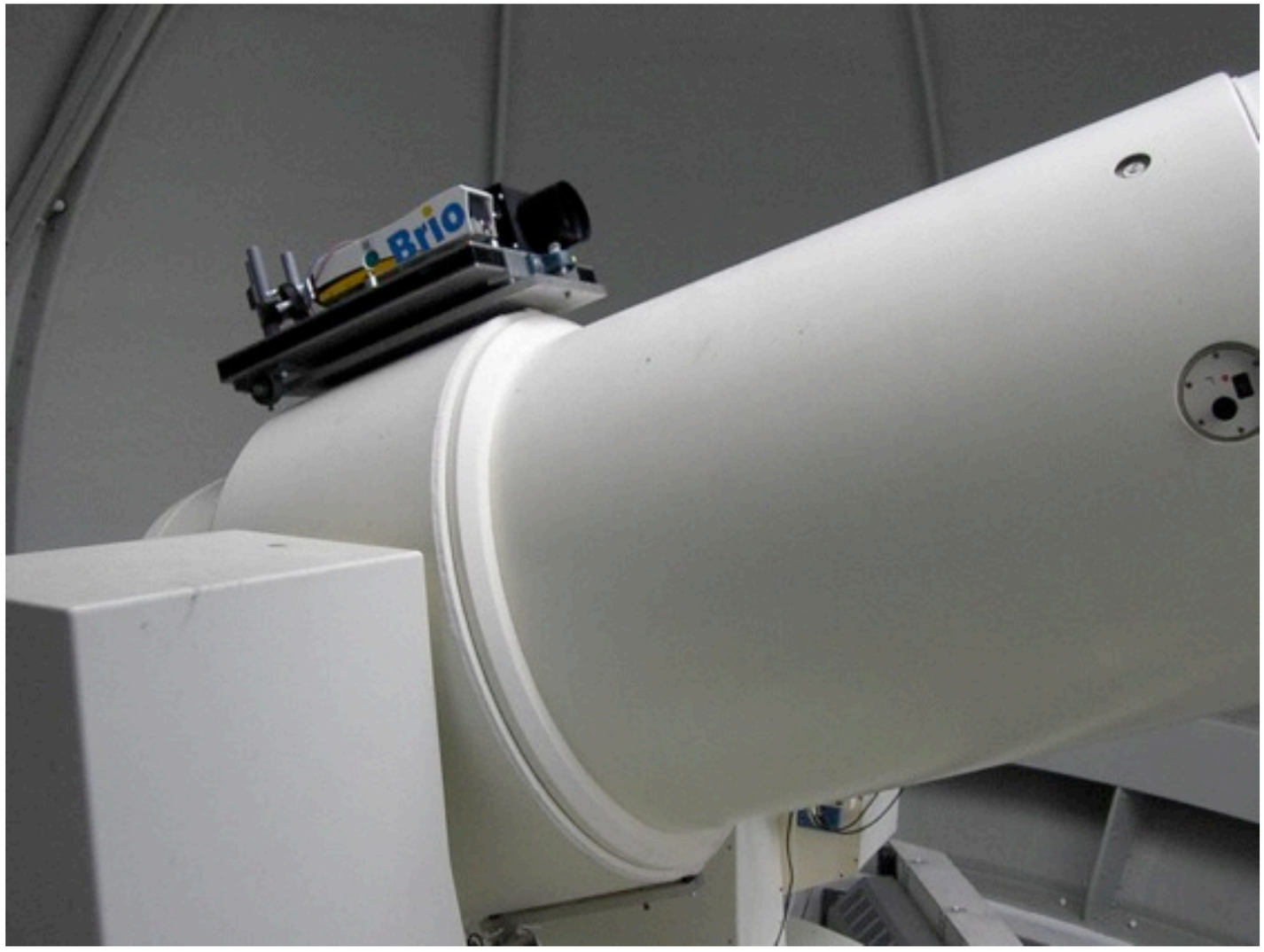
b) Receiver centered on laser beam spot (parallaxes)

c) WLRS pointed to landmark ≈6 km away

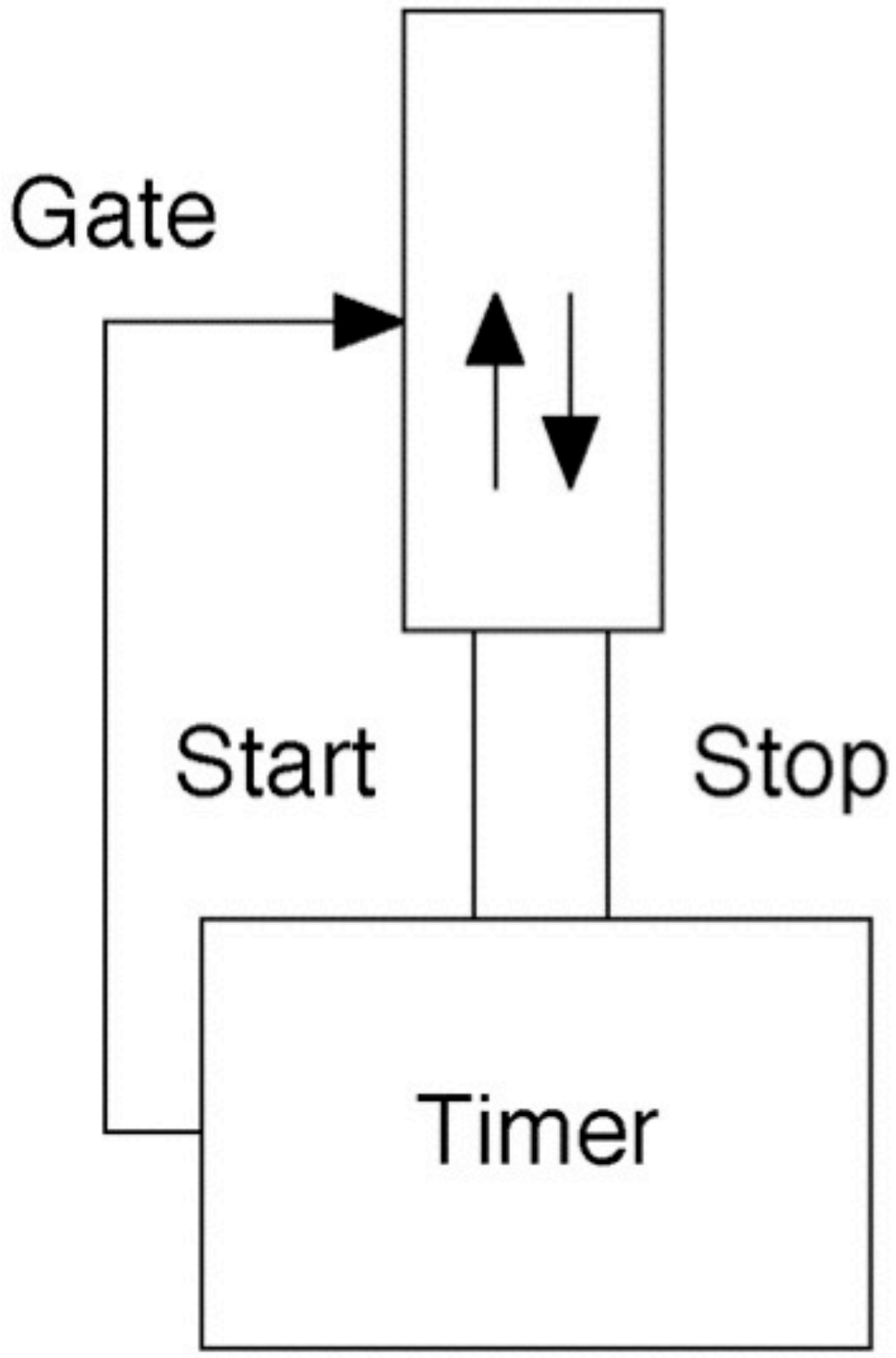
d) AltiDemon platform aligned to be centered on landmark

Laser beam offset ≈ 25″

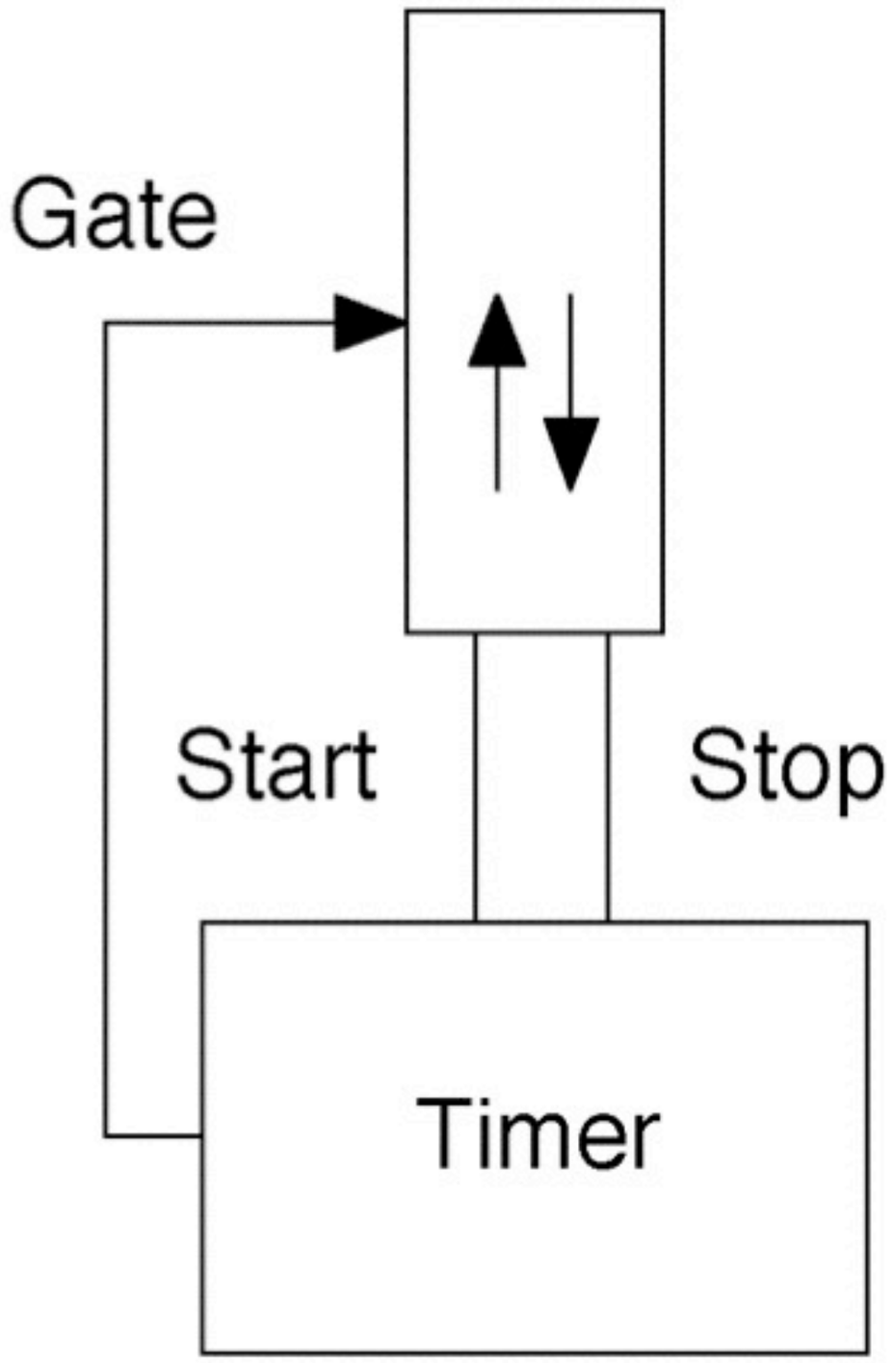
AltiDemon located on top of 8834

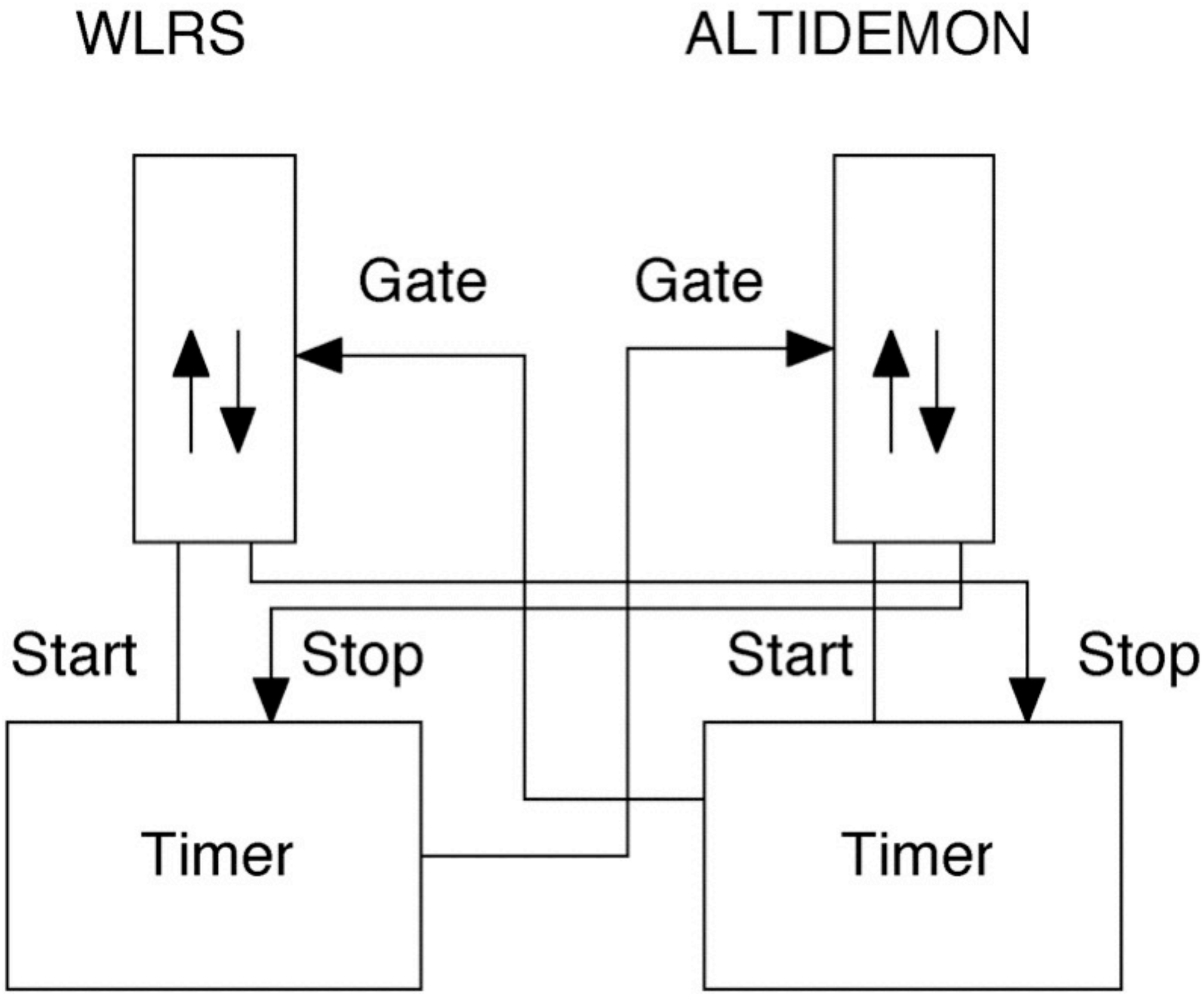


WLRS



ALTIDEMON




WLRS
ALTIDEMON
Gate
Gate
Start
Stop
Start
Stop
Timer
Timer

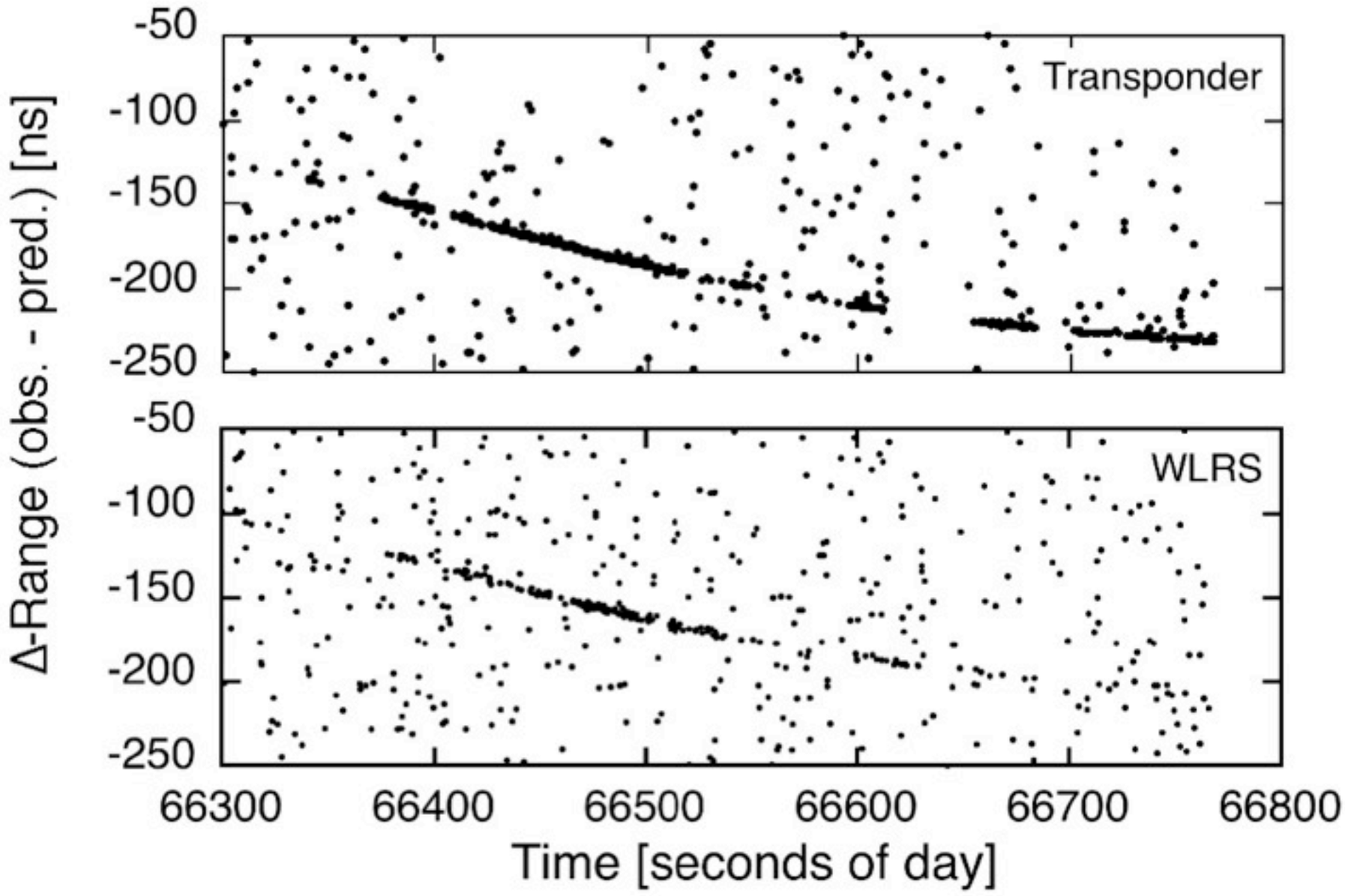
Theoretical Link-Budget

Config.	n_{ph} Ajisai	n_{ph} ERS	n_{ph} Lageos
W - A	4.5k	1.5k	10
A - W	36.8k	12.3k	85
W - W	830k	275k	1.9k
A - A	816	272	1.9

WLRS detector is APD; AltiDemon detector is SPAD [Degnan 2006]

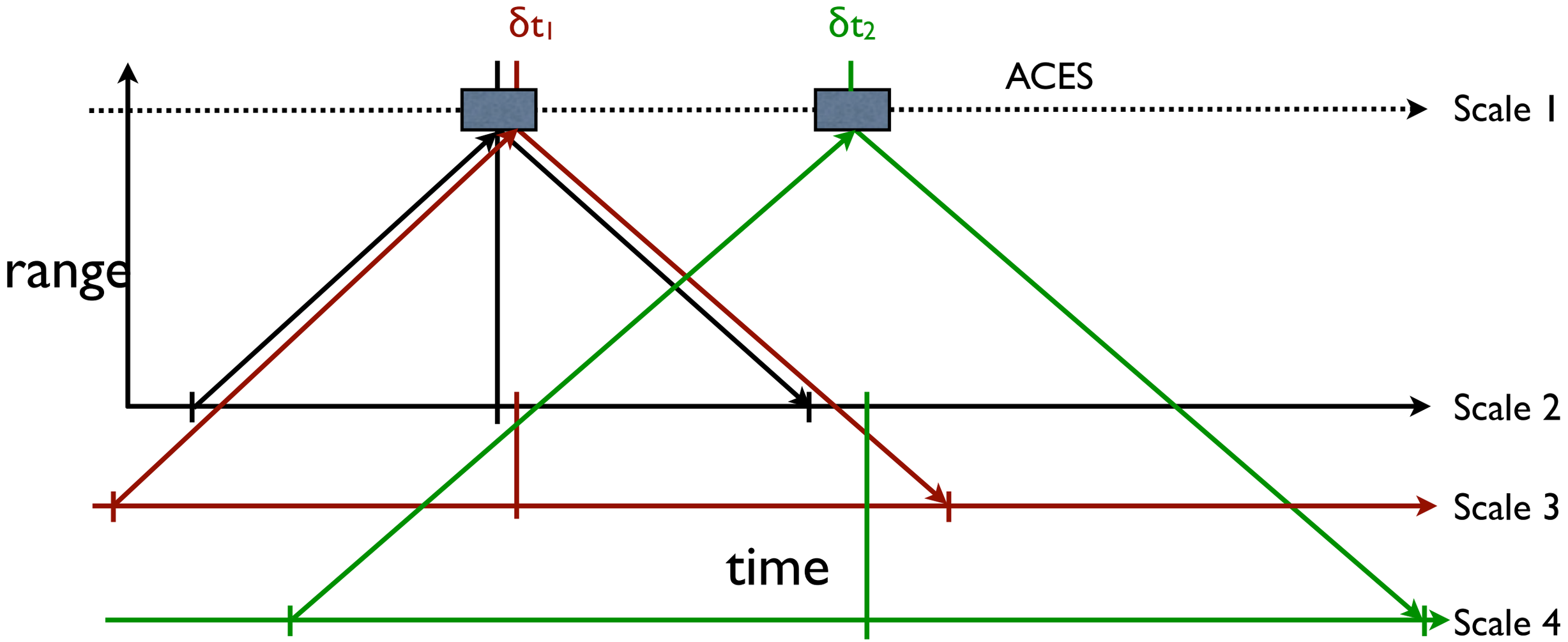
Zenith-Distance: 30° Atmosph.Transmission: 0.7

Transponder Operations



Schreiber et al.; Planetary and Space Science, **57**, 1485 - 1490, (2009)

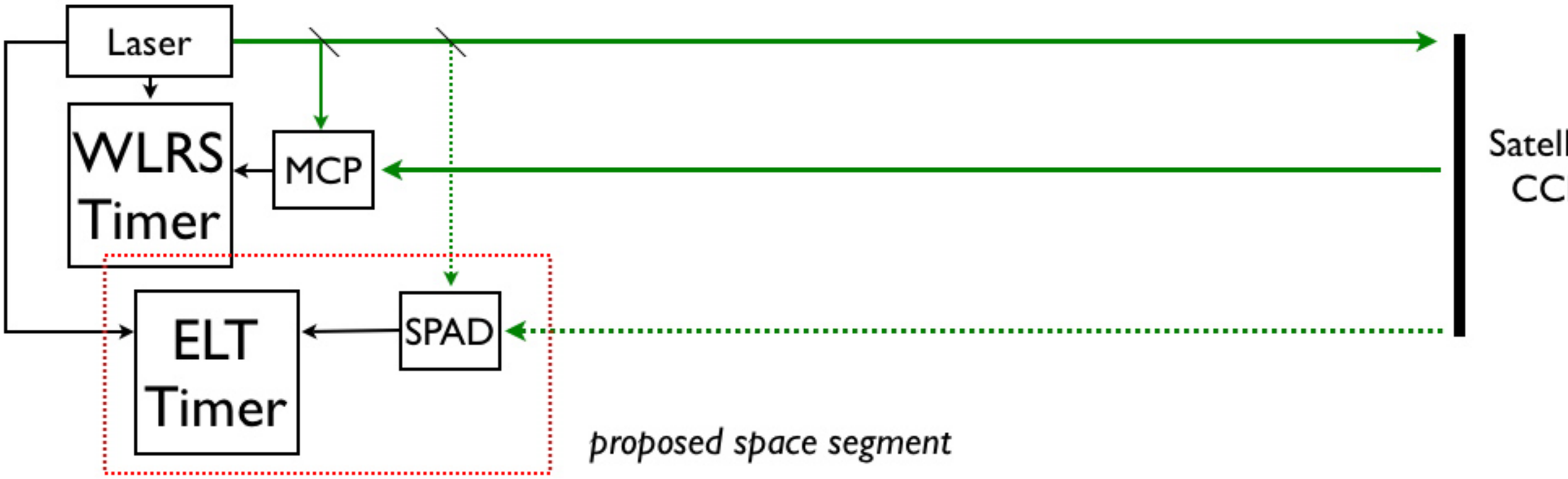
Time Transfer Concept

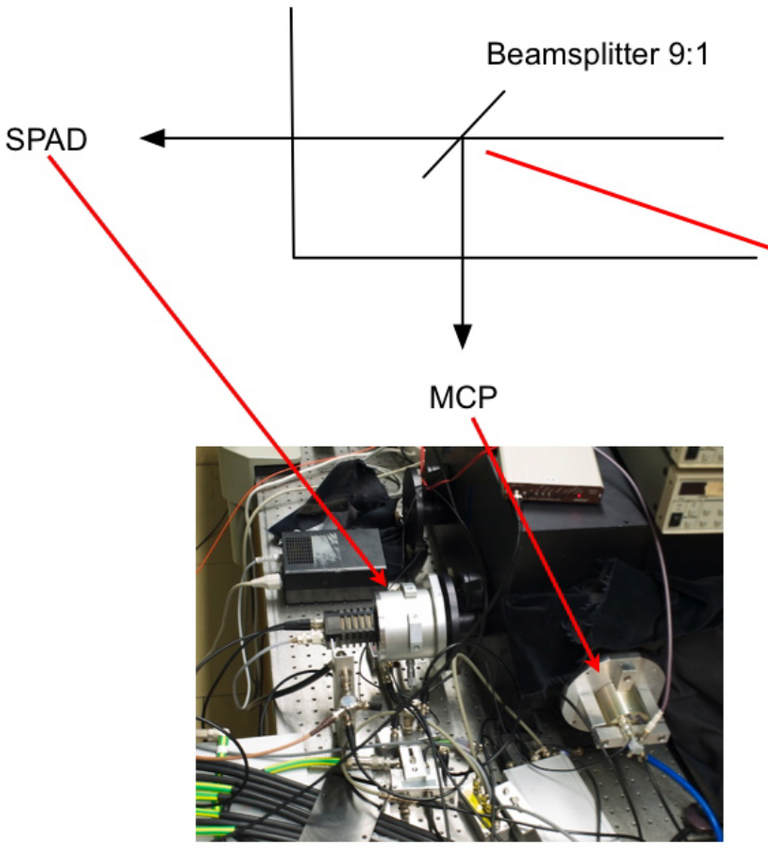


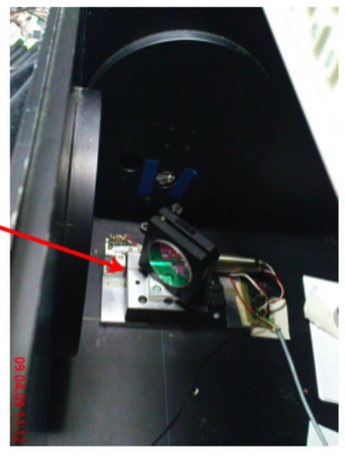
1. SLR establishes the time of arrival at the ACES payload (timescale 1) relative to timescale 2

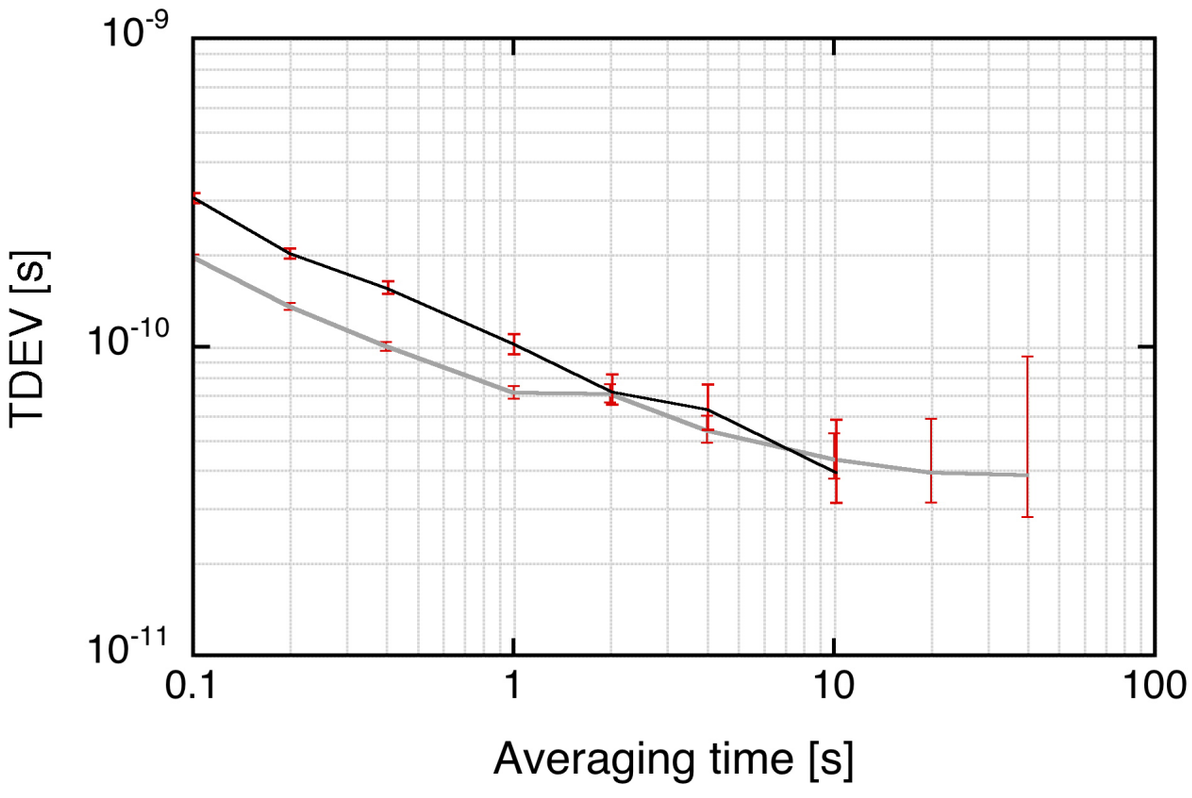
2. Common view observations between two ground stations establish the offsets between timescale 2 and 3 relative to timescale 1

3. Laser Ranging from yet another observatory at a later time (non common view) establish the offset between timescale 4 and timescale 1. Because of the stable ACES clocks this also provides the offsets between timescale 4 and timescale 2 and 3.


Laser
WLRS Timer
MCP
Satellite CCR
ELT Timer
SPAD
proposed space segment

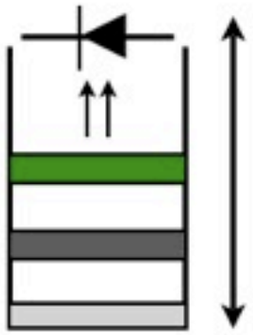

Beamsplitter 9:1
SPAD
MCP

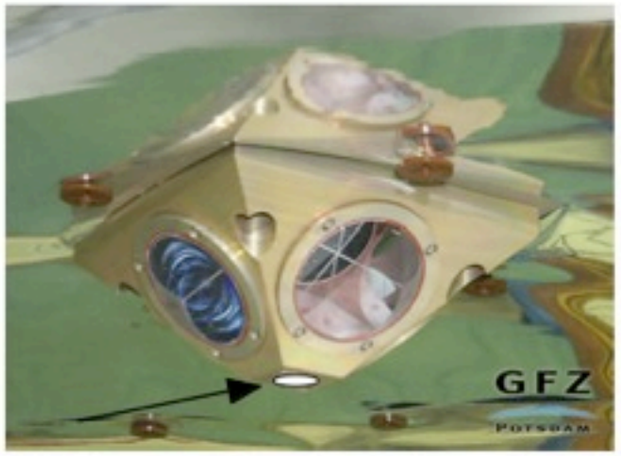



TDEV [s]
10-9
10-10
10-11
0.1
1
10
100
Averaging time [s]

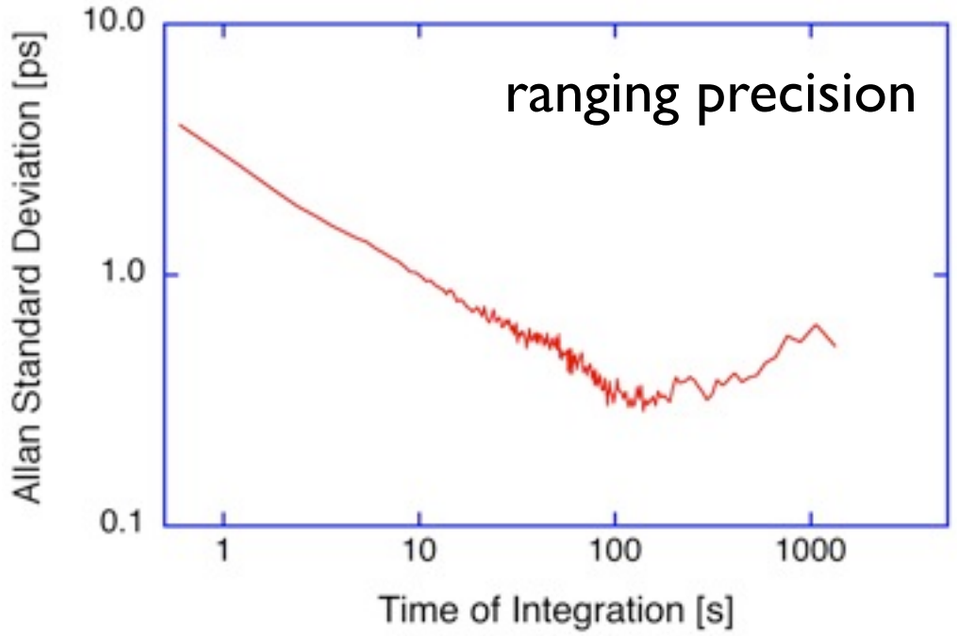
11. Detection Scheme and Properties

a)





b)

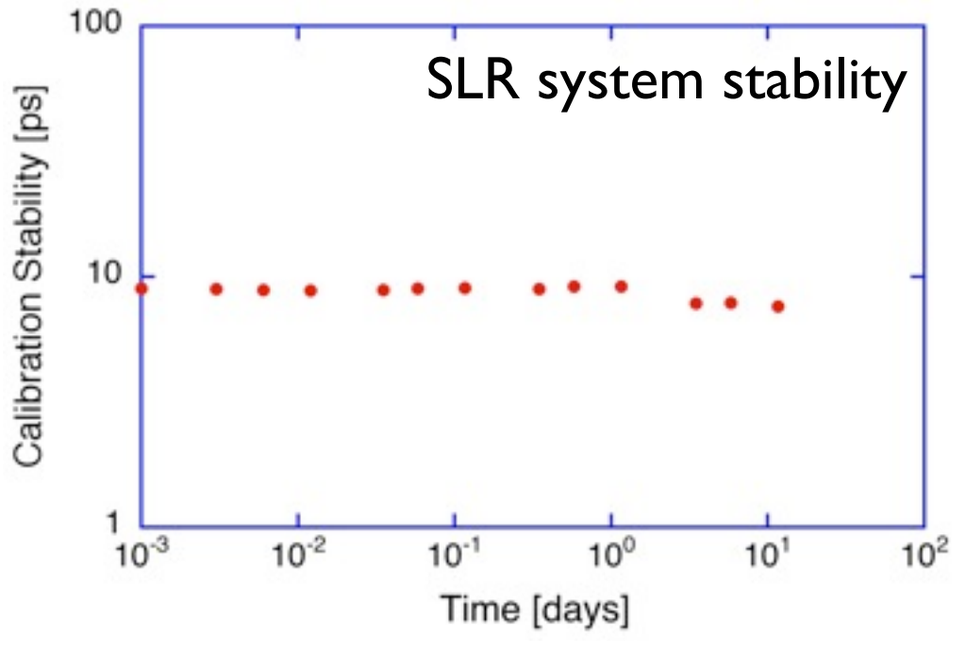


The onboard optical subsystem consists of a corner cube reflector and a photo-detector. Incoming laser pulses are both reflected back to the ground station and also timed on the satellite clock.

The application of an avalanche photo-diode (SPAD) operated at single photon light levels provides the highest precision, because biases from amplitude fluctuations are avoided.

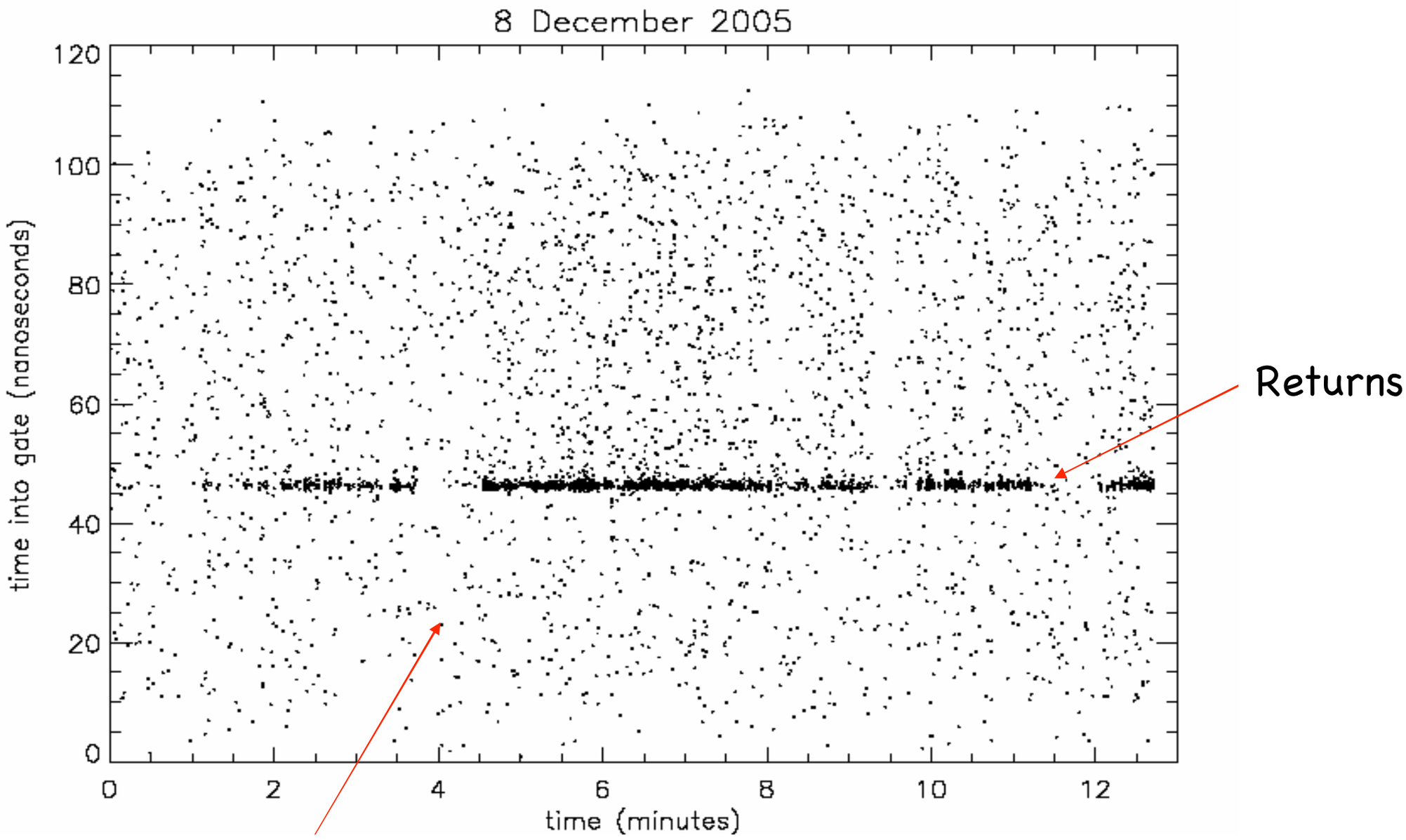
A neutral density filter and a diffusor plate in addition to a narrowband spectral filter attenuate the light level at the SPAD into the single photon regime (a). The detector is mounted in the center of the corner cube array (b). Ranging performance as obtained at the Geodetic Observatory Wettzell is indicated on the right (c).

c)

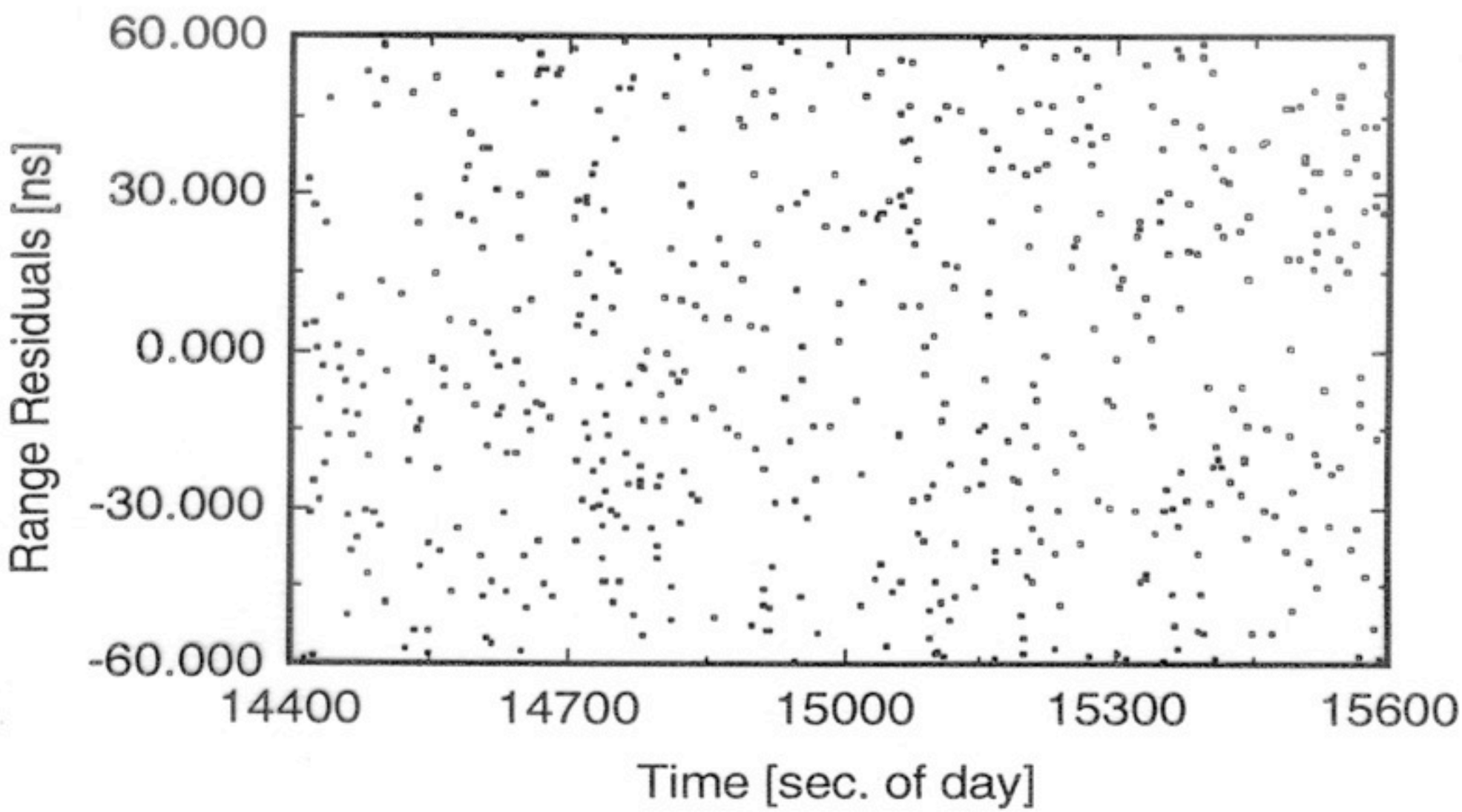


LLR: The Wettzell Experience

LLR @ APOLLO


8 December 2005
time into gate (nanoseconds)
120
100
80
60
40
20
0
0
2
4
6
8
10
12
time (minutes)
Returns
Noise

"LLR = Ranging @ weak SNR"

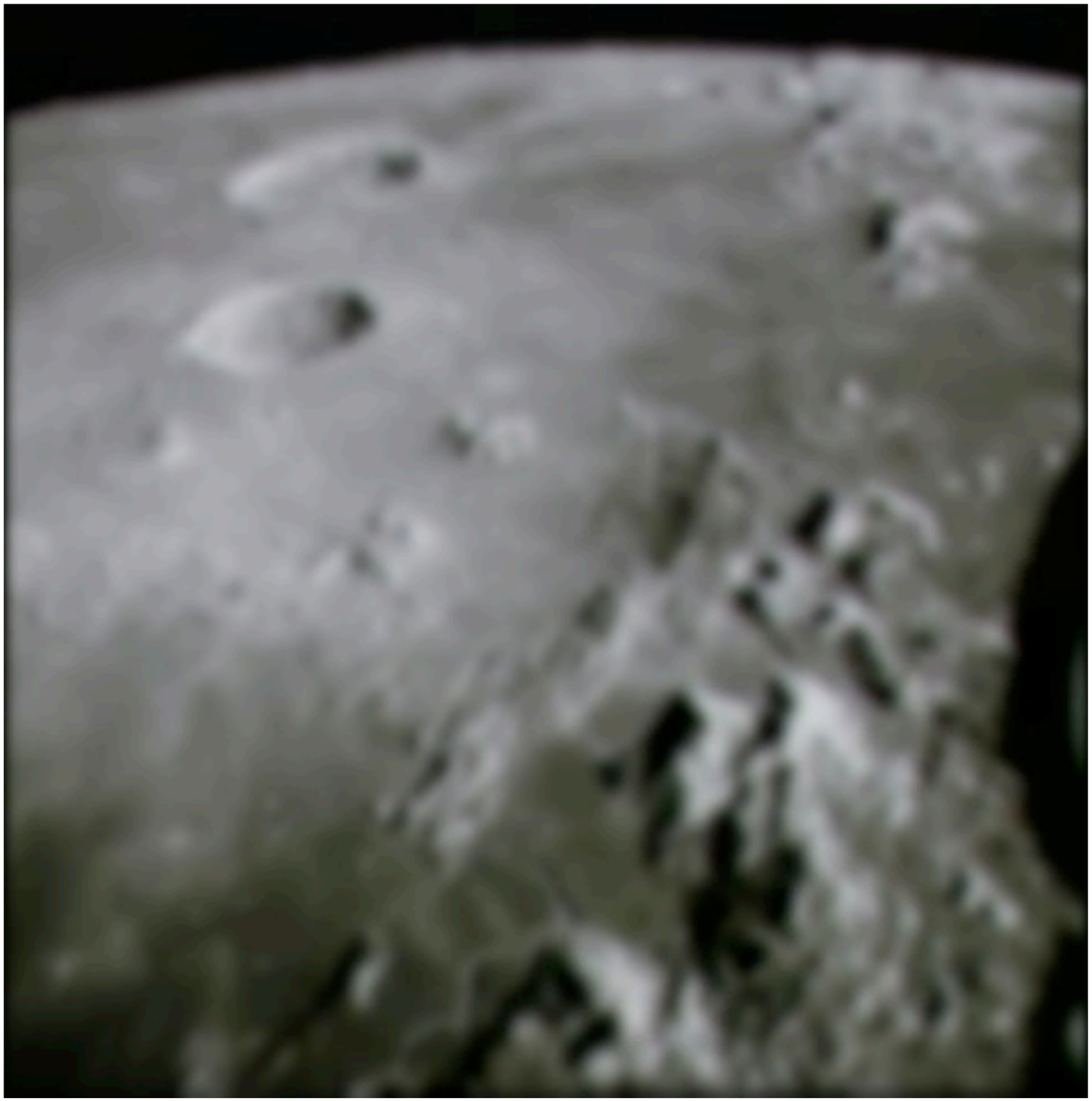


There is no joy on the residual screen...

Apollo 15 landing site

large CCR Array

lots of topographie



In Wettzell:

substantial blur
from Seeing > 5”

high latitude: 49.1°

lots of atmosphere: 659m

but: “fundamental station”

... and lots of humidity

Laser Link Equation

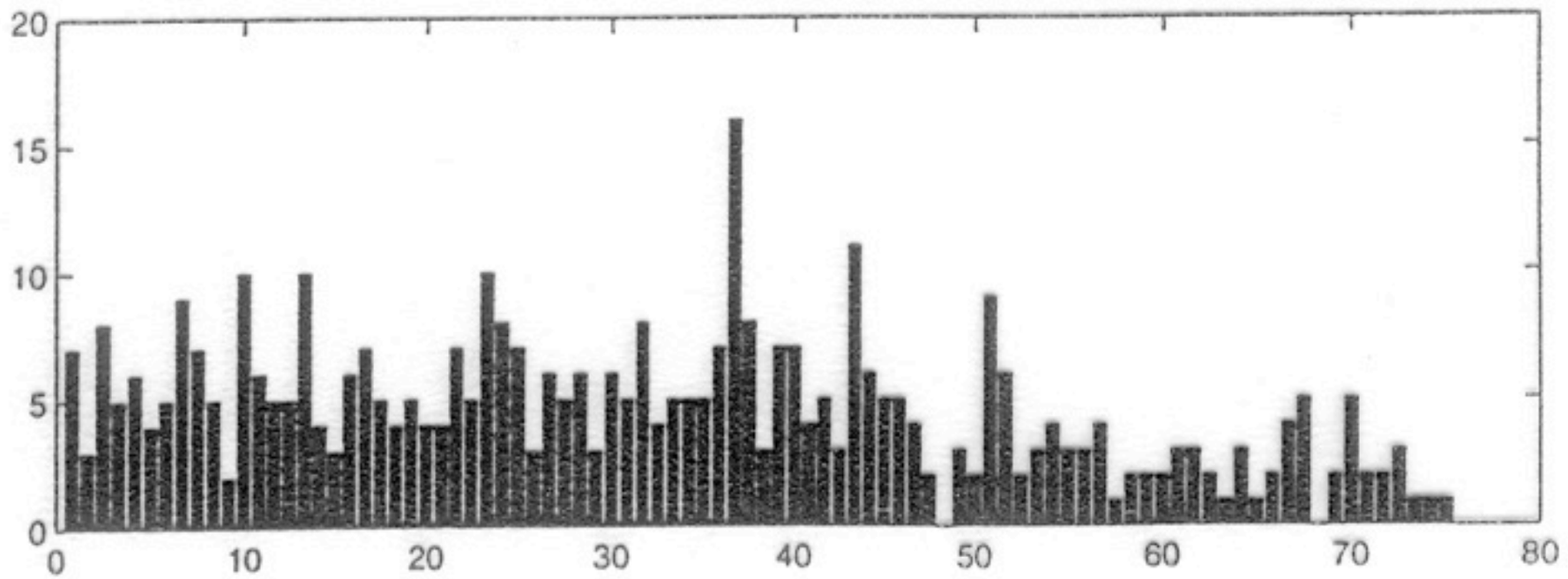
$$n_{pe} = \eta_q \left(E_T \frac{\lambda}{hc} \right) \eta_t G_t \sigma \left(\frac{1}{4\pi R^2} \right)^2 A_r \eta_r T_a^2 T_c^2$$

Comparison of LLR Systems

Parameter	WLRS	MLRS	OCA	Apache Point
η_q	0.7	0.2	0.4	0.3
E_T [mJ]	150	100	80	115
η_t	0.62	0.7	0.65	0.4
G_t	9×10^9*	5.1×10^{10}	5.1×10^{10}	5.1×10^{10}
A_r	0.44	0.44	1.76	9.6
η_r	0.35	0.45	0.4	0.25
n_{pe}	0.5	0.8	4.3	9.2

Apollo 15: r = 385000 km; Ta = 0.7, Tc = 0.9

* WLRS assumed seeing: 5″ all others 2″



Semipulse-train returns

End of a 400 ns Rangegate