GPS Subsystem for the Primary Atomic Reference Clock in Space (PARCS) Experiment

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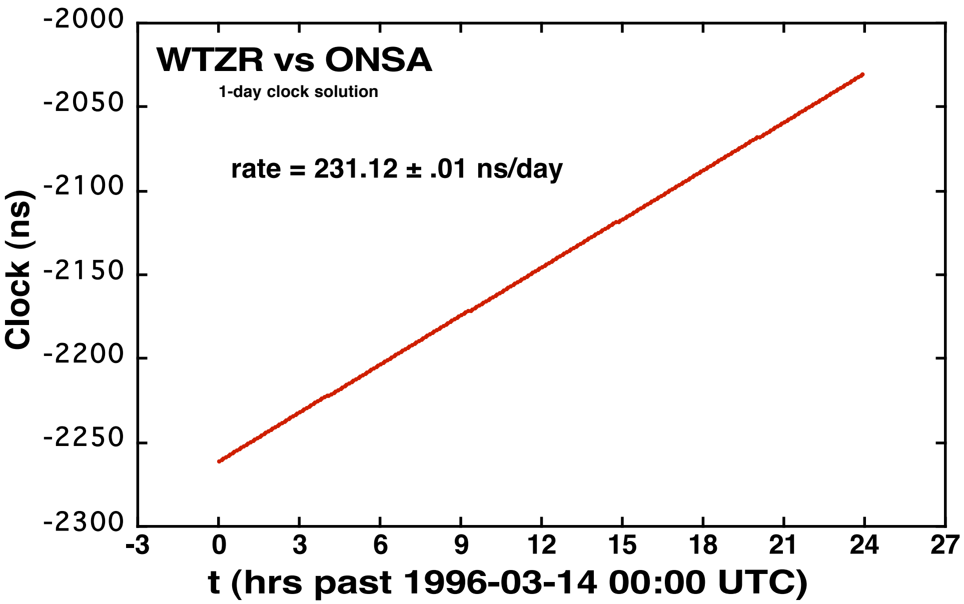
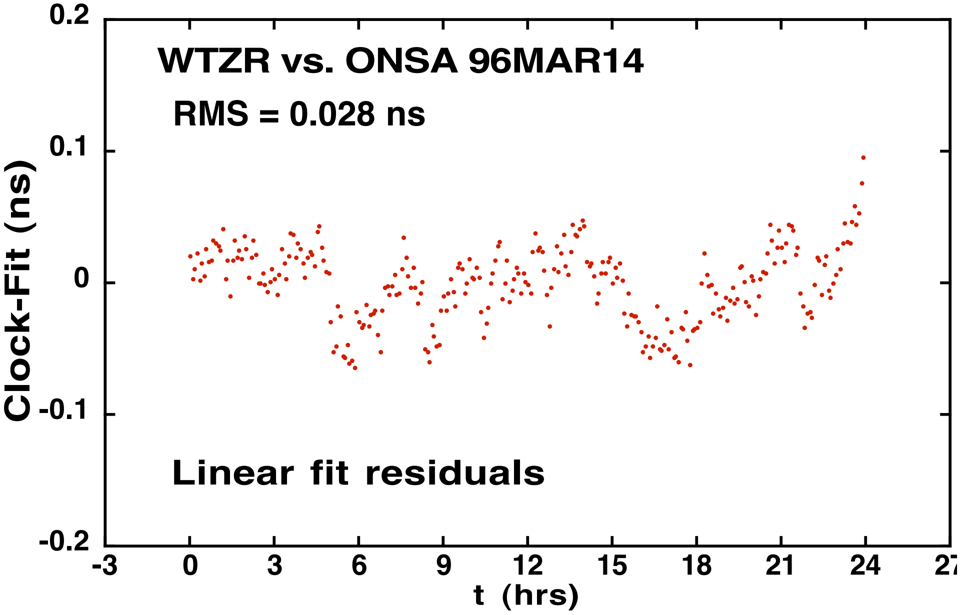
GPS-Based Time Transfer Between Ground Sites

GPS-based frequency transfer between a pairs of masers





BlackJack Space GPS Receiver

Present configurations

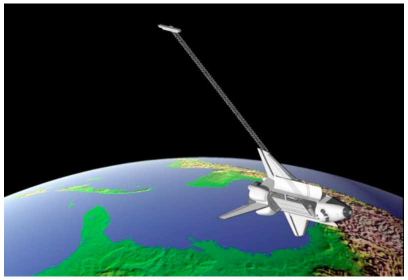
- Dual GPS frequencies (L1: 1575.42 MHz, and L2: 1227.60 MHz)
  - L2C capability recently demonstrated in space (on SAC-C)
- *1-4 GPS antennas*
- *non-GPS signal tracking (eg GRACE K-band ranging) ,*
- *External frequency input; timing pulse output,*
- *Redundant hardware*
- *Software reprogrammable*
- *Real Time GIPSY (RTG) for precision onboard orbit determination/timing*
- GPS occultation capability with open and closed loop models

In development

- TDRSS Augmentation Service for Satellites (based on the NASA GDGPS System)
  - Enhanced real-time orbit determination/timing
  - Extends GPS integrity to space
- *GPS L5, Galileo signals, Glonass signals tracking capability*
- *Ocean reflection signal acquisition*

JPL BlackJack GPS Receivers: > 37 Flight Years of Successful Operations in Space

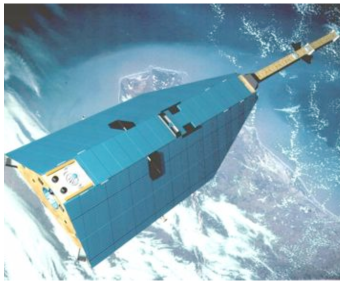
The most precise GPS receivers flown in space -- enabling new science and navigation capabilities



45-cm accuracy

SRTM

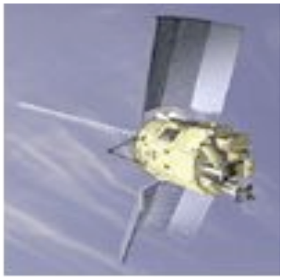
Feb 2000



4-cm accuracy

CHAMP

Jul 2000



4-cm accuracy

Sub-meter real-time demo

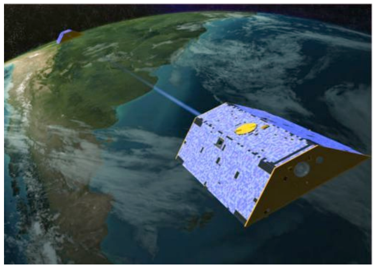
SAC-C

Nov 2000

1-cm accuracy

JASON-1

Dec 2001



2-cm accuracy

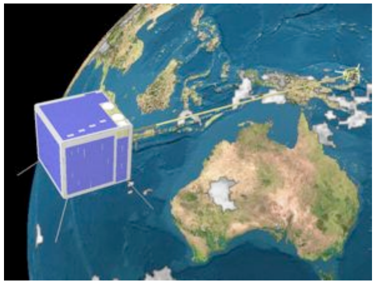
0.1 cm relative

GRACE

Mar 2002

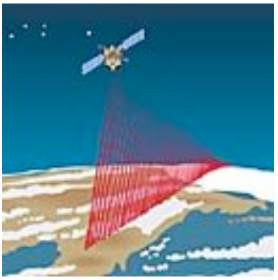
Dec 2002

FedSat



Dec 2002

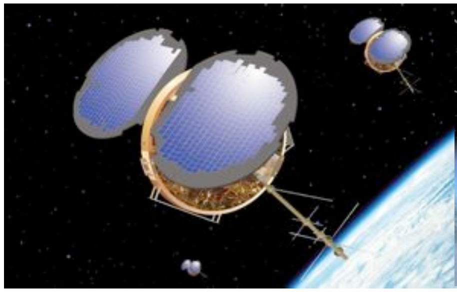
ICEsat



5-cm accuracy

April 2006

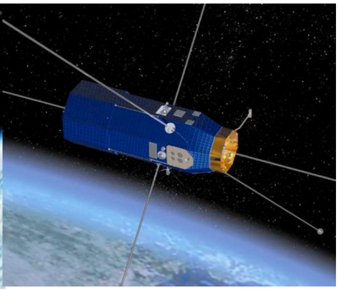
COSMIC



Missions In Development

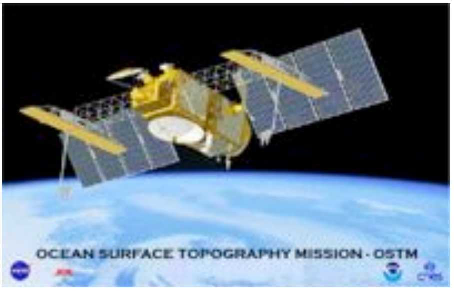
2007

C/NOFS



2008

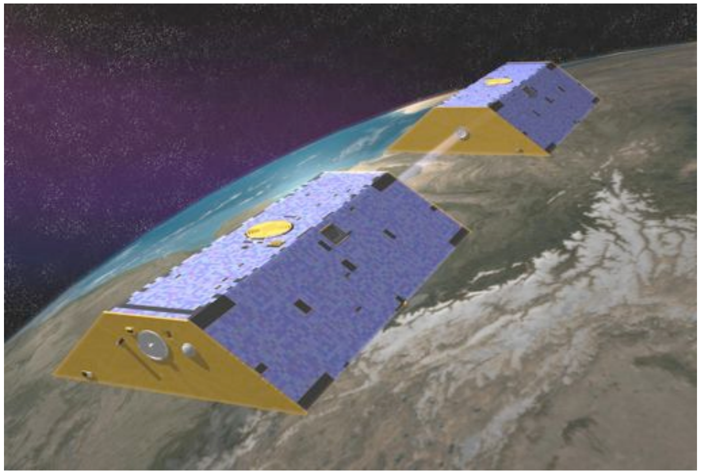
OSTM



BlackJack on GRACE

Functions

- GPS observations to enable precise orbit determination and time of measurements
- Measures the variation of inter-satellite range at the micron level, from which information on the variation of the gravity field can be derived
- Distributes timing signals, to synchronize other elements of the spacecrafts' Instrument Systems
- Software provides interpretation of star camera images, for spacecraft attitude control



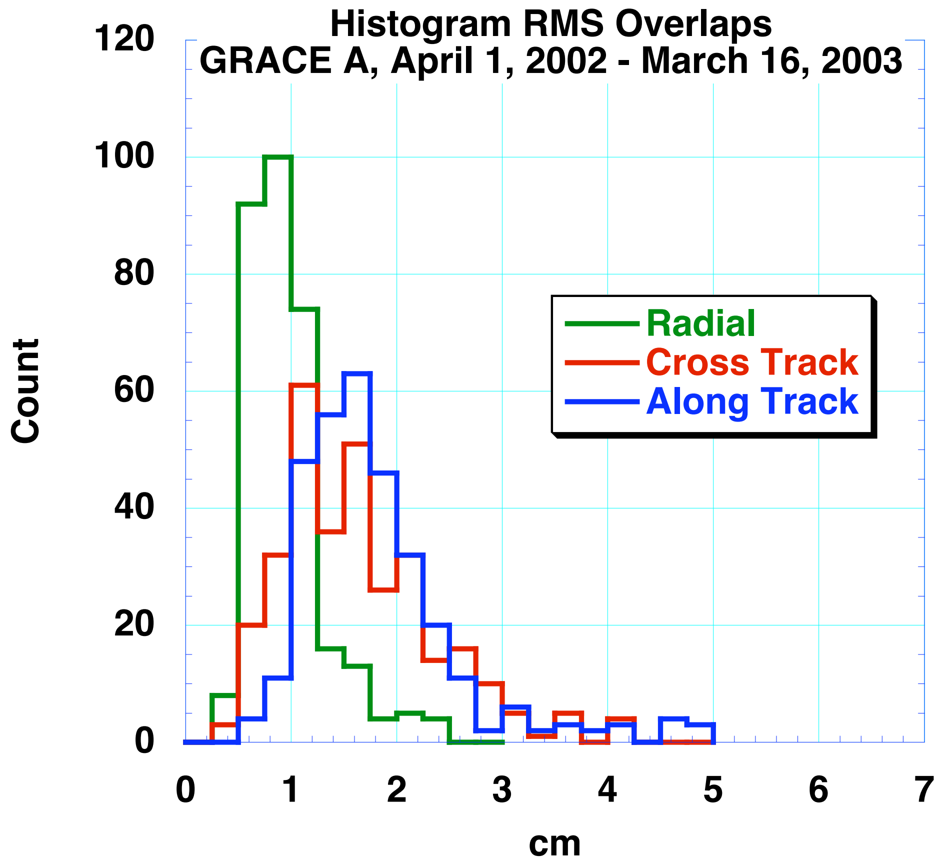
Note on Implementation

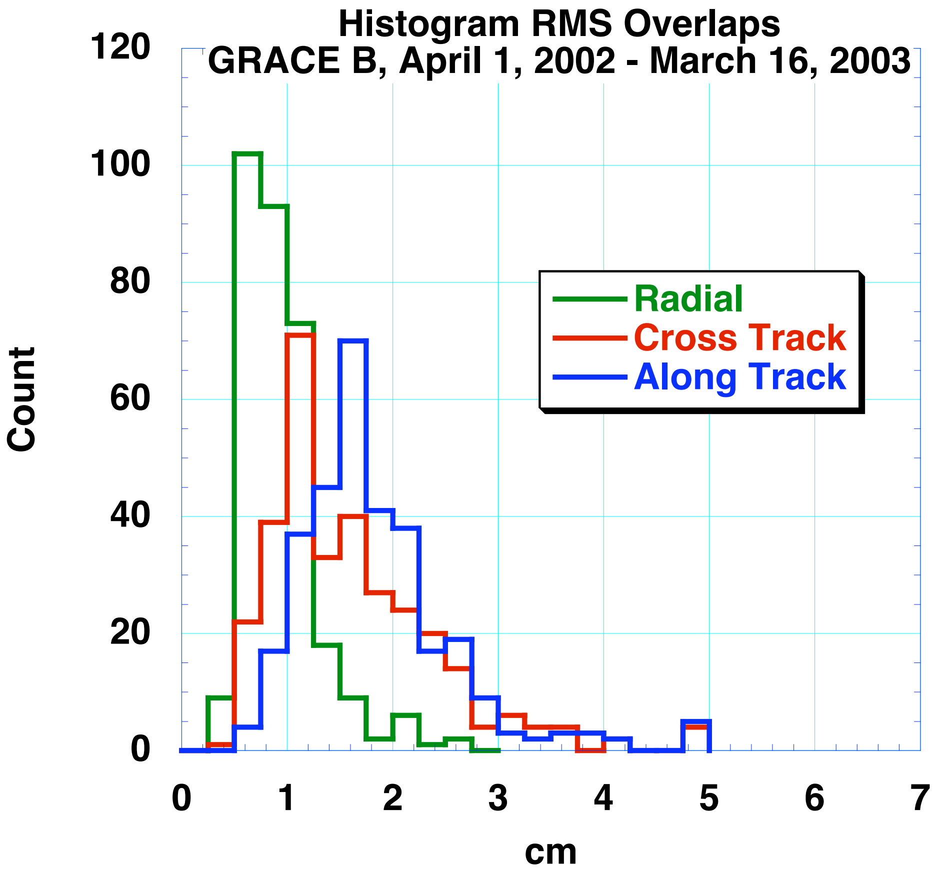
- The BlackJack GPS receiver and its additional GRACE-specific functions and redundant assemblies are divided into two enclosures:
  - *Instrument Processing Unit (IPU): digital electronics*
  - *Signal Processing Unit (SPU): RF/ analog front end*

BlackJack POD Performance on GRACE

graphs by Willy Bertiger

6 hr Overlap Statistics (using central 4 hrs.) of 30 hr. processing arcs:





GRACE A medians: 0.9 1.5 1.6 cm

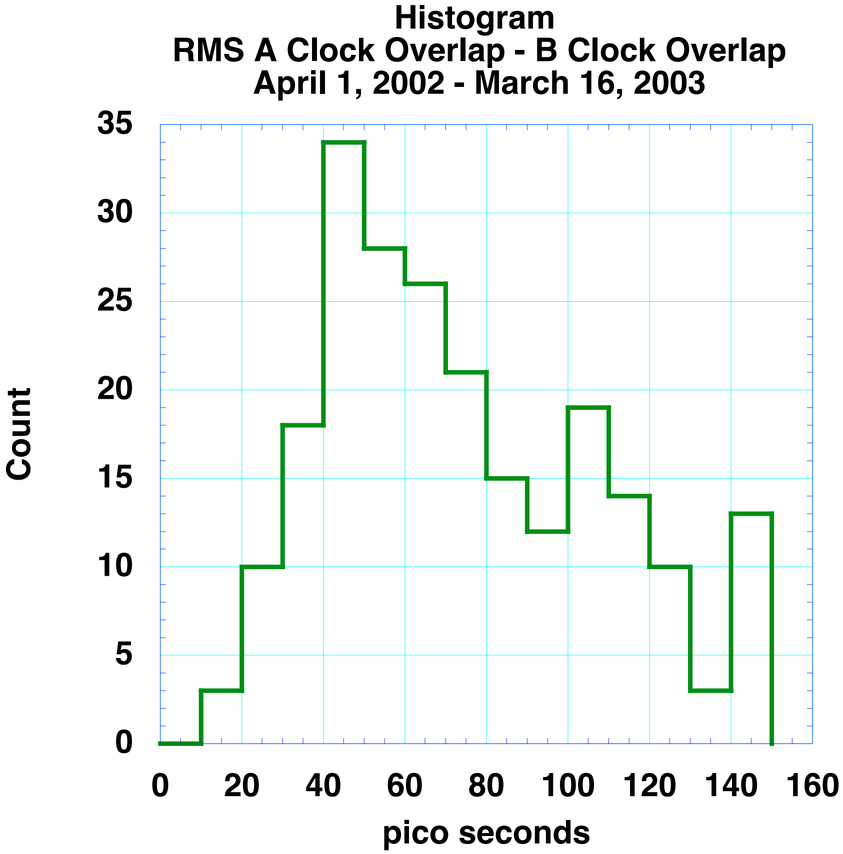
GRACE B medians: 0.8 1.4 1.6 cm

BlackJack Time Transfer Performance on GRACE

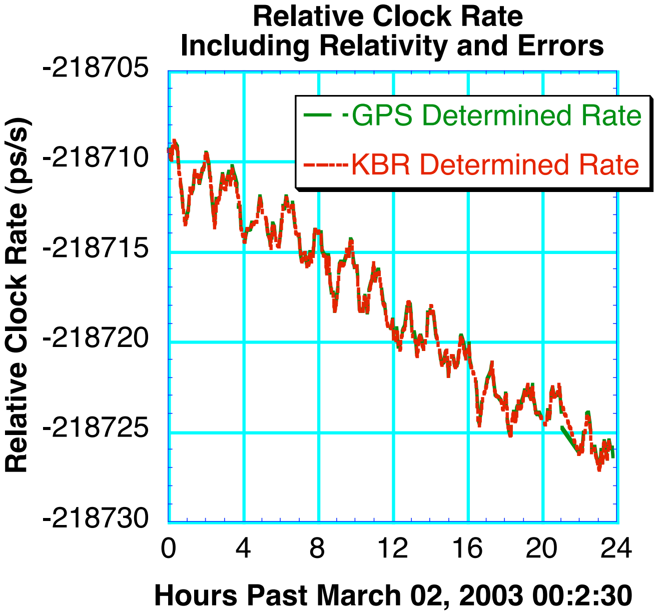
graphs by Willy Bertiger

6 hr Overlap Statistics (using central 4 hrs.) of 30 hr. processing arcs:

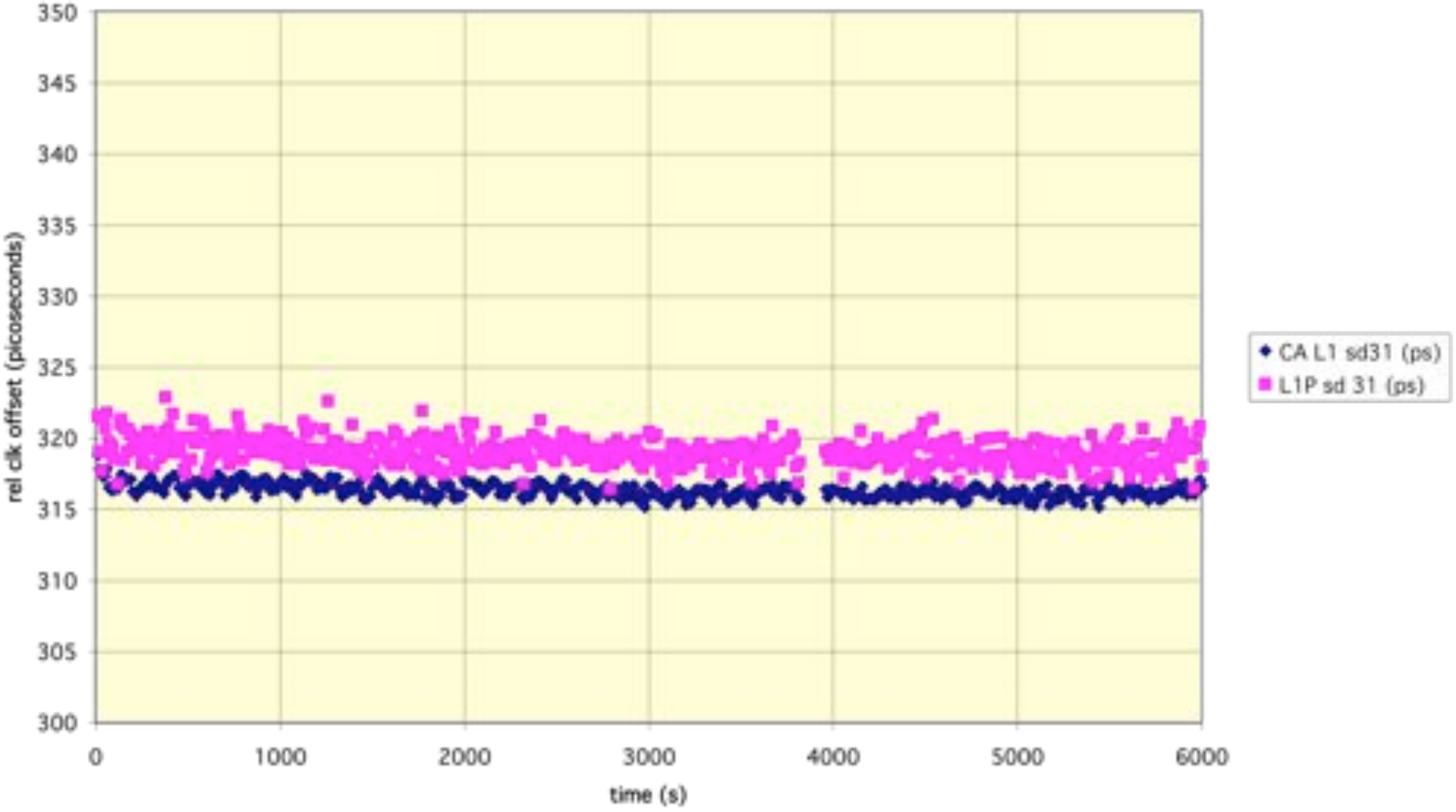
- This is a measure of the timing difference between the two orbiting clocks (rcvrs.)
- There are known and unknown error features in the relative clock rate
  - *Periodic errors of 0.070 ps/s, consistent with expected GPS errors*
  - *Bias of 0.065 ps/s that has not been explained*



Median: 68 ps

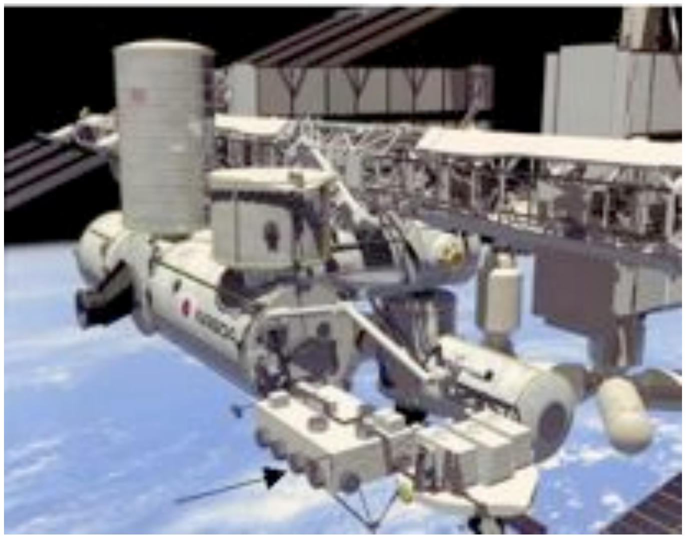


Carrier relative time transfer across power cycle
PRN31 single difference, zero baseline, common clock
data gap at 3900 seconds from power cycle on second receiver



PARCS Quick Look

The primary Reference Atomic Clock in Space (PARCS) ~~is~~ was an atomic clock / fundamental physics payload for the International Space Station (ISS).



- Study laser-cooled atoms in microgravity
- Produce a very accurate frequency standard
- Investigate Special and General relativity:
  - *Local Lorentz Invariance (LLI)*
  - *Local Position Invariance (LPI), with SUMO (maser) on LTMPE*

The role of GPS on PARCS

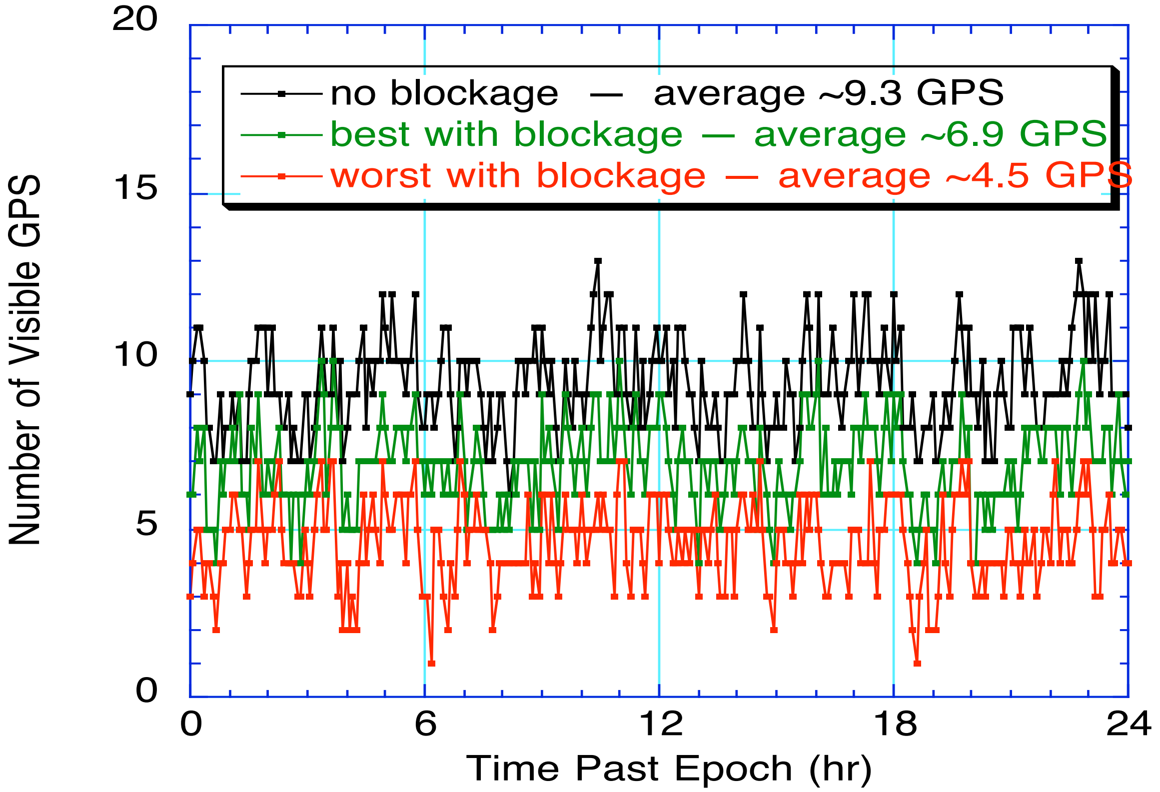
- Realization of the Second
  - Transfer of the frequency reference ("clock") to the ground using the GPS carrier phase technique.
  - On the ground a similar receiver is linked to the NIST-F2 cesium fountain clock.
- Precision Orbit Determination
  - High-accuracy knowledge of GPS antenna state provides information on frequency differences between PARCS and ground clocks
  - Position: provides information for gravitational redshift correction
  - Velocity: provides information for second-order Doppler shift correction

Challenges for GPS-Based Time/Freq Transfer on the Space Station

GPS visibility could be severely hampered

Complicated multipath environment

Complicated spacecraft dynamics necessitates kinematic positioning/timing

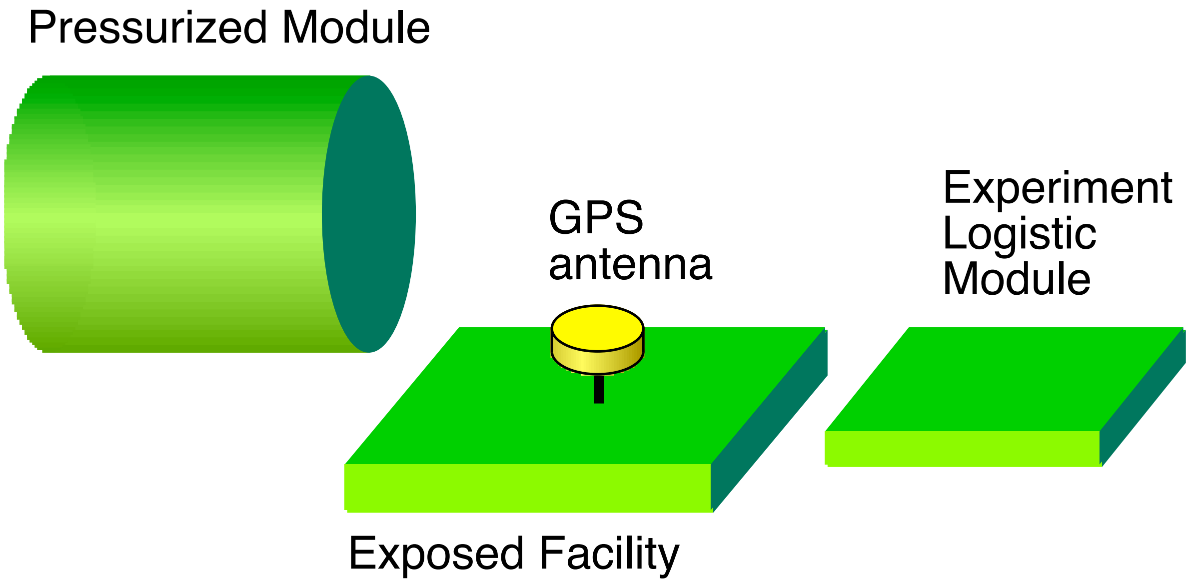


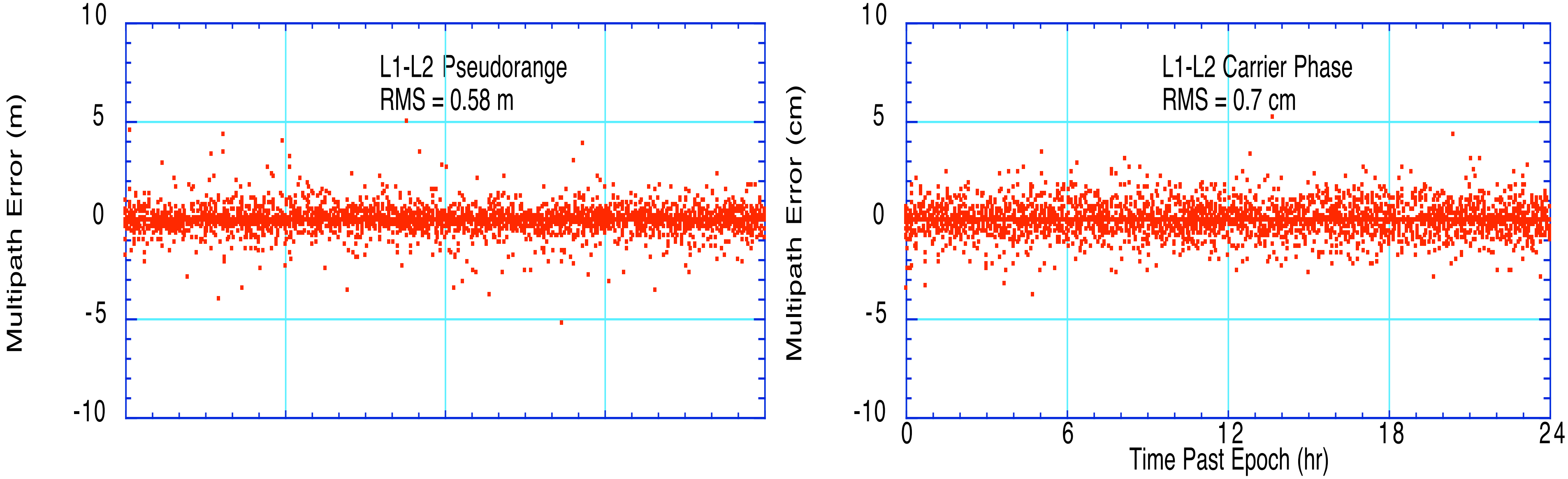
Simulation of Multipath Effects — a Simplified Model

Model reflection and edge diffraction

Include only stationary objects close to GPS antenna

- **3 simplified major bodies**





Frequency Transfer in Space - Covariance Analysis

Consider data noise only: 0.5 m for Pseudorange, 0.05 m for Carrier Phase

Scheme 1: Estimate clock rate with single long batch of data

constant clock rate: 1 cm/s **randomwalk clock: $5 \times 10^{-13} / \tau^{1/2}$**

Scheme 2: Derive rate from two 4-hr batches of clock bias estimates at ends of arc

randomwalk clock: $1 \times 10^{-8} / \tau^{1/2}$

Scheme 3: Derive rate by fitting through multiple 4-hr batches of clock bias estimates

randomwalk clock: $1 \times 10^{-8} / \tau^{1/2}$