The NAVSTAR 35 and 36 Laser Retro-Reflector Experiments

19th International Workshop on Laser Ranging
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Annapolis, Maryland

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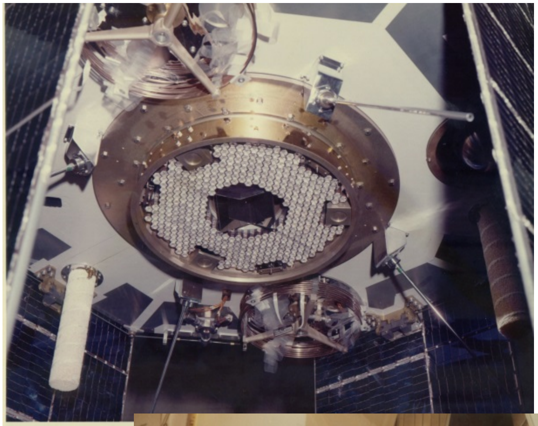
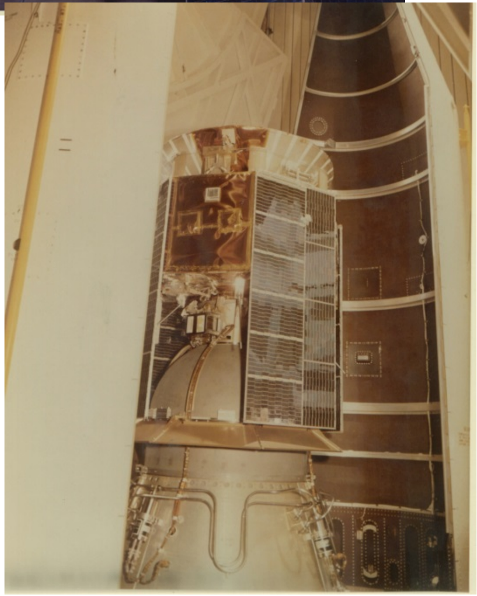
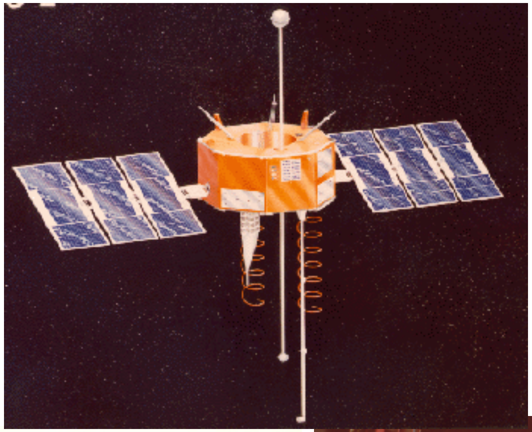
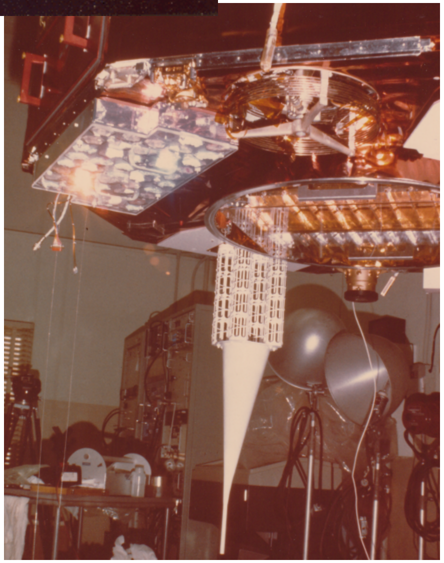
Early Attempts with Laser Retro-Reflector Arrays





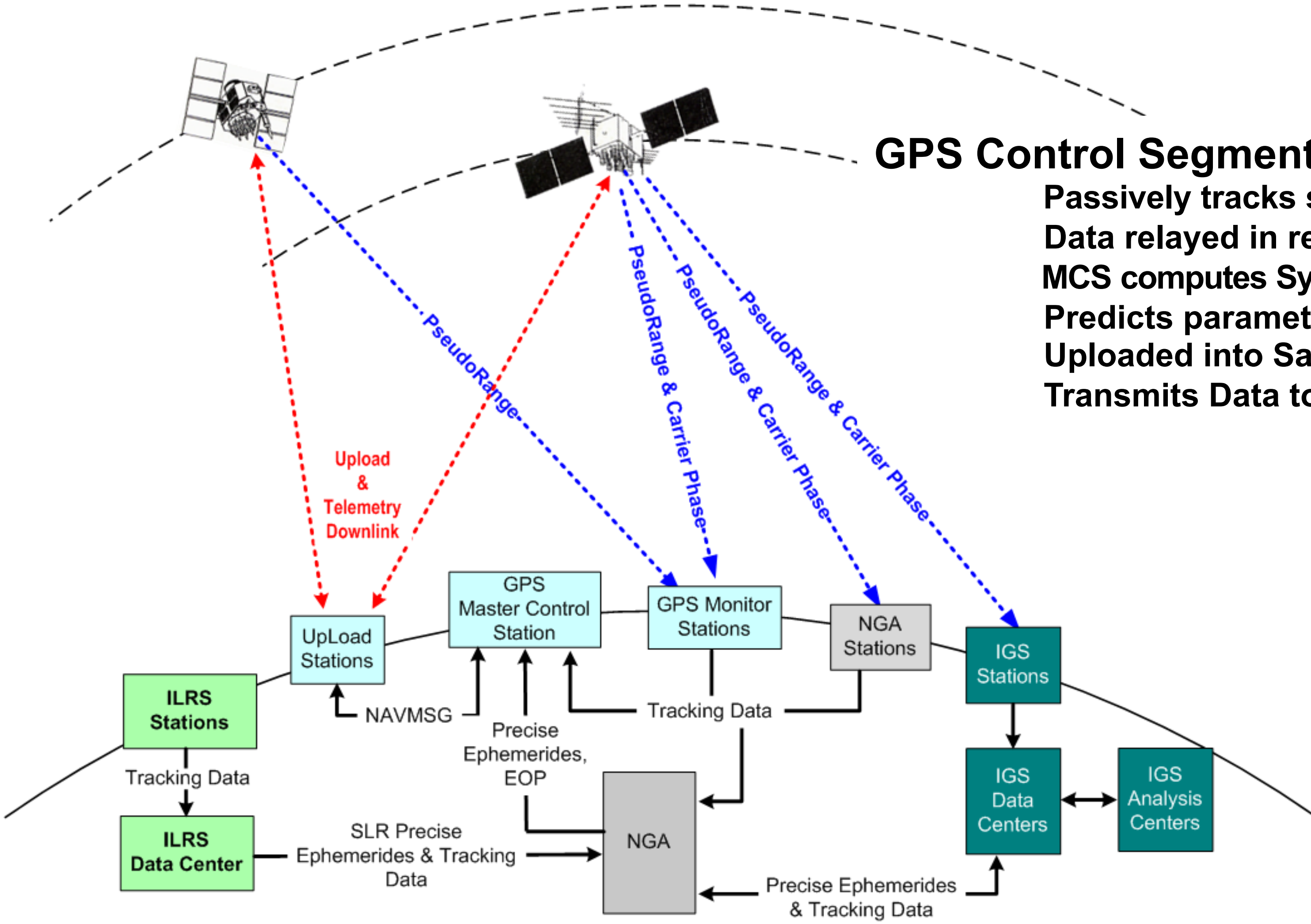
NTS-1: 1974
13897.5 km Circular Orbit





NTS-2: 1977
20188.4 km Circular Orbit

GPS OPERATIONS



GPS Control Segment

- Passively tracks satellites in view
- Data relayed in real time to MCS
- MCS computes System parameters
- Predicts parameters for a Day
- Uploaded into Satellite Memories
- Transmits Data to Users

GPS PASSIVE CONCEPT

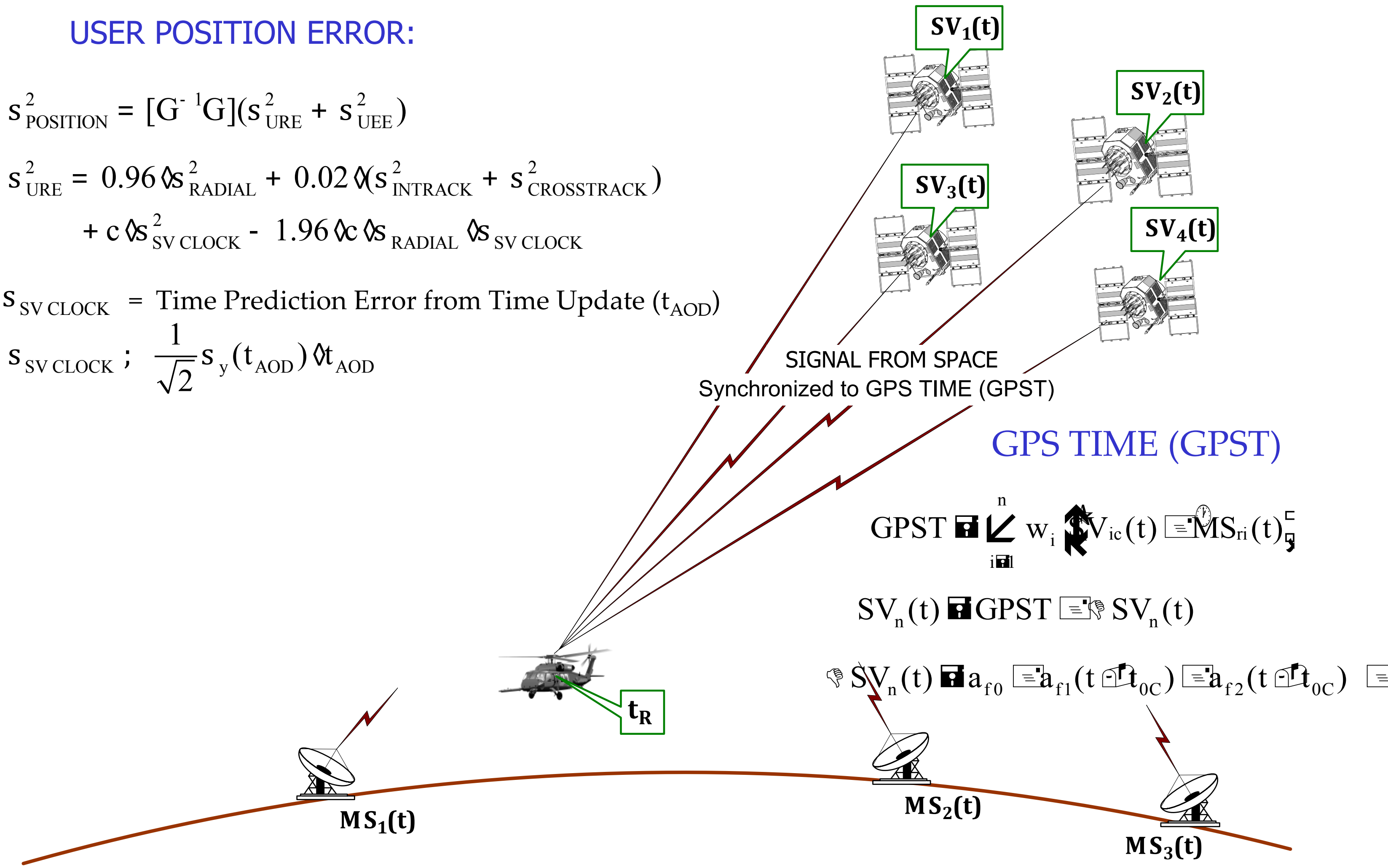
USER POSITION ERROR:

$$s^2_{POSITION} = [G^{-1}G](s^2_{URE} + s^2_{UEE})$$

$$s^2_{URE} = 0.96 \cdot s^2_{RADIAL} + 0.02 \cdot (s^2_{INTRACK} + s^2_{CROSSTRACK})$$
$$+ c \cdot s^2_{SV\ CLOCK} - 1.96 \cdot c \cdot s_{RADIAL} \cdot s_{SV\ CLOCK}$$

$s_{SV\ CLOCK}$ = Time Prediction Error from Time Update (t_{AOD})

$$s_{SV\ CLOCK} ; \frac{1}{\sqrt{2}} s_y(t_{AOD}) \cdot t_{AOD}$$

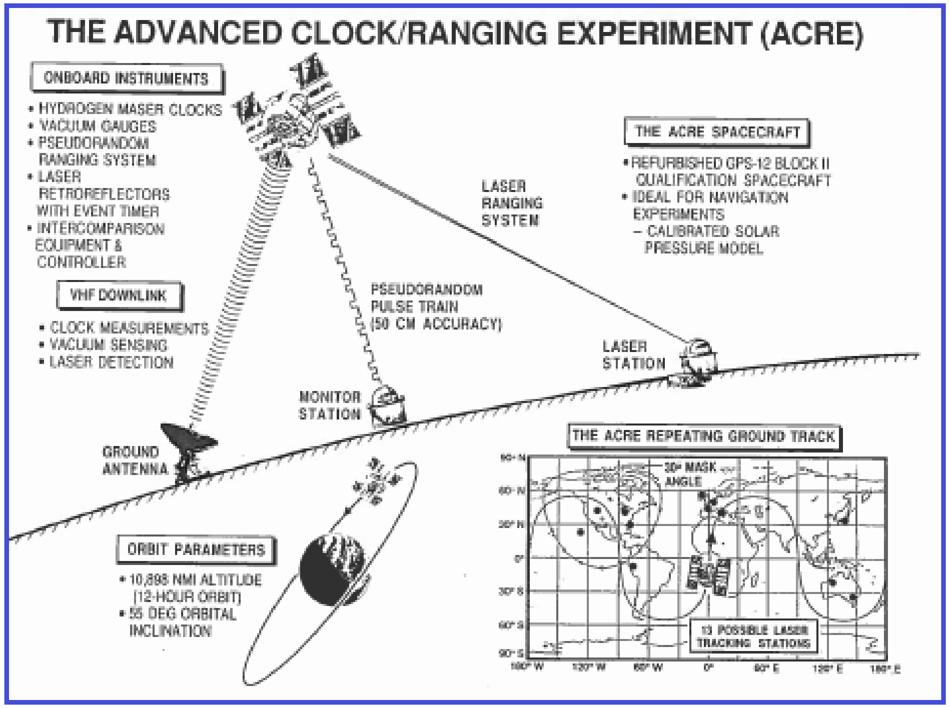


$$GPST = \sum_{i=1}^{n} w_i [SV_{ic}(t) - MS_{ri}(t)]$$

$$SV_n(t) = GPST - SV_n(t)$$

$$\Delta SV_n(t) = a_{f0} + a_{f1}(t - t_{0C}) + a_{f2}(t - t_{0C}) + \Delta t_r$$

Advanced Clock Ranging Experiment (ACRE)

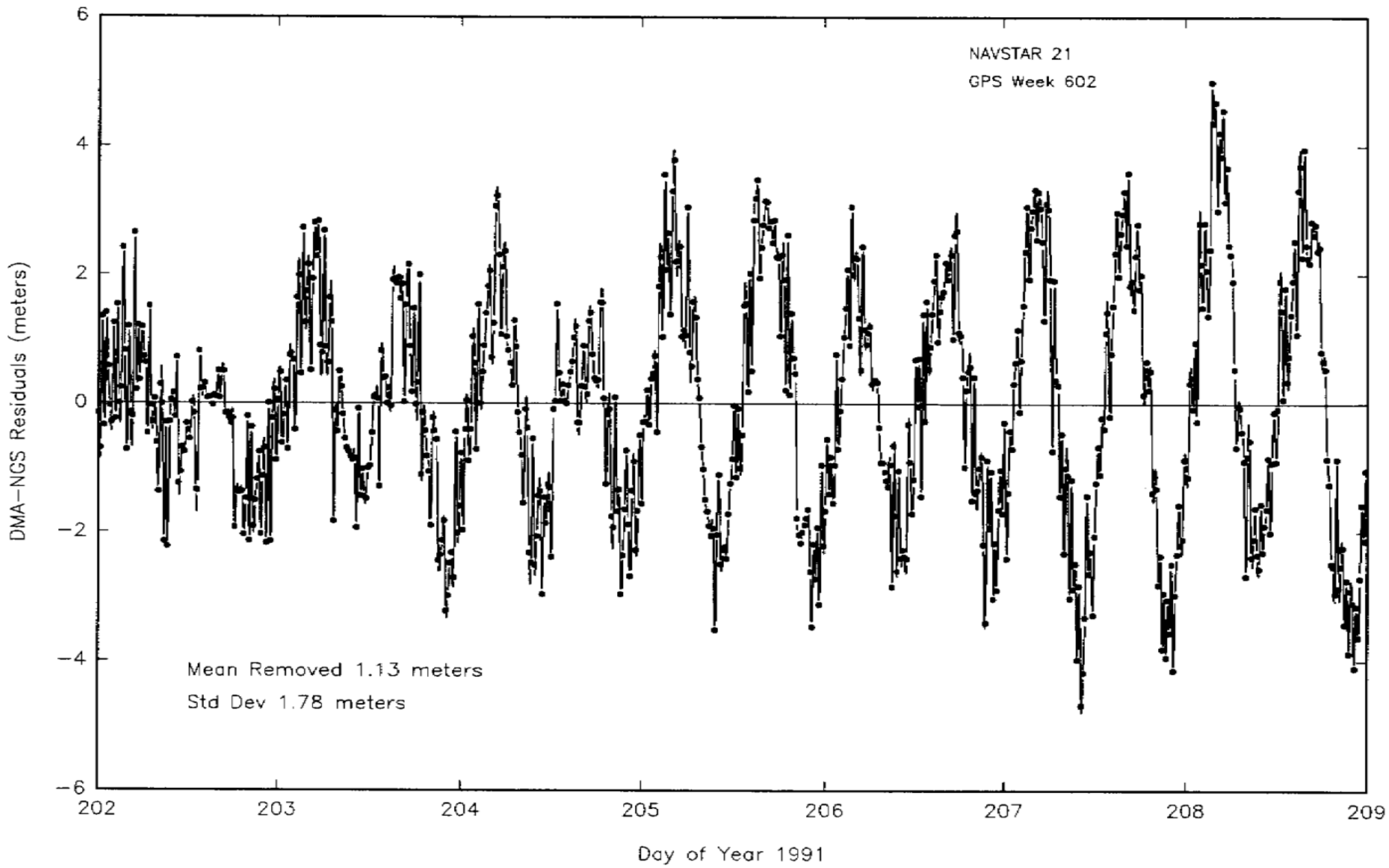


Original Concept:

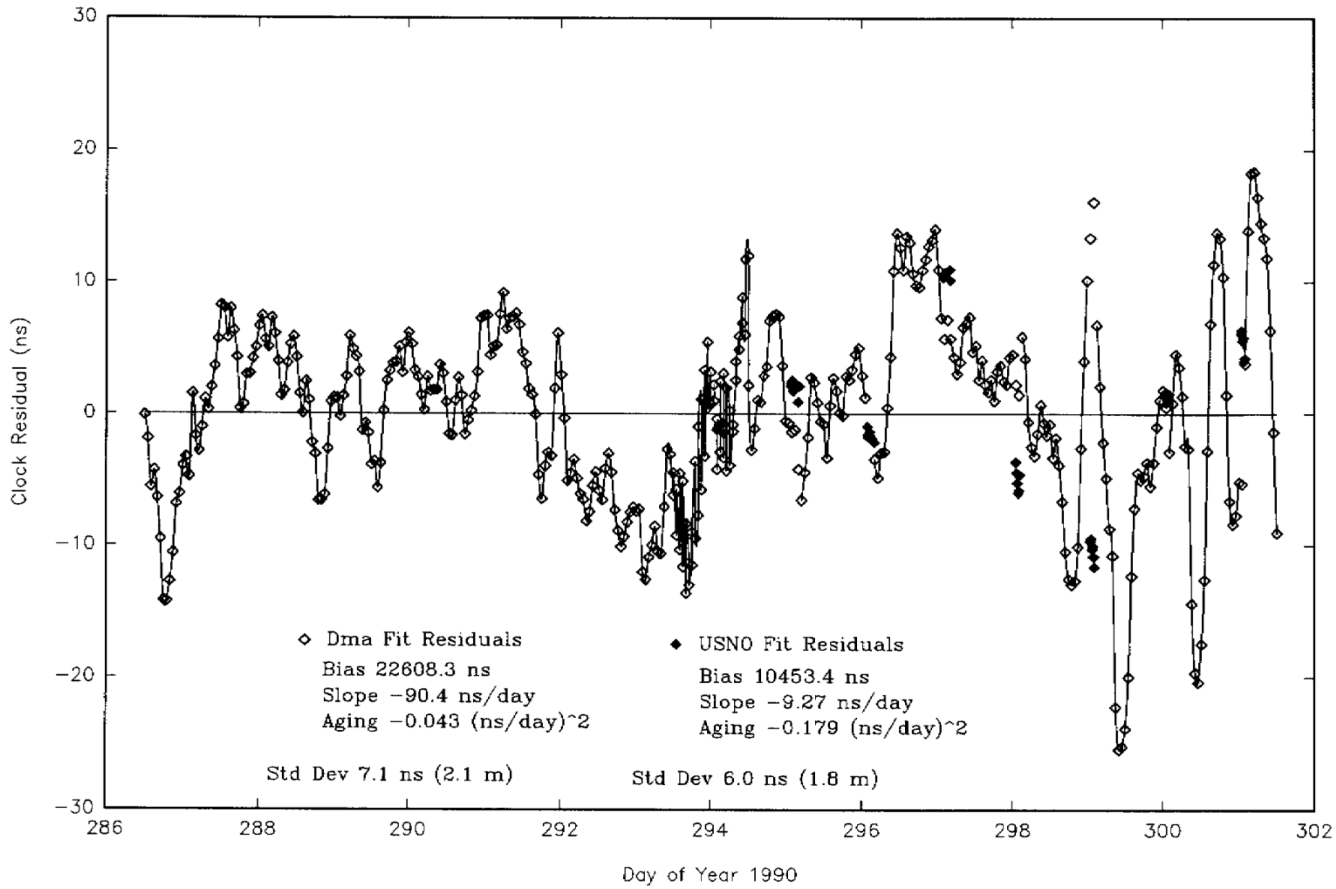
- Use NAVSTAR Qual Vehicle for technology satellite flight
- Transmit GPS experimental signal
- Incorporate multiple new clocks
- PRARE System for independent ranging system
- VLBI Transmitter
- Laser Retro-reflector Array
- GPS Orbit
- Space Test Program support for integration and Launch

NAVSTAR 21 ORBIT RESIDUALS

GPS Week 602



NAVSTAR 21 CLOCK ESTIMATE



Clock Residuals for NAVSTAR 21 comparing DMA post-fit Clock Performance with Data taken at the Naval Observatory.

EXPERIENT COORDINATON

AFSPACECOM SPADOC Laser Clearinghouse Waiver Response 27 Oct 1987 – blanket waiver for NASA lasers (MOBLAS 2-8, TLRS 1-4, SLR 2, Quantell YG 402 DP

NRL Ltr to GPS JPO 17 Nov 1992 Laser Tracking Experiment for GPS Satellite

GPS JPO Response Laser Tracking Experiment for GPS 12 Jan 1993

GPS JPO SMC 12 April 1993, forwarding Rockwell Int Special Study 60 Final Report, GPS Laser Tracking Experiment dtd 26 Jan 1993

AFSPACECOM to UM approving installation on Two Block IIA satellites 2 Mar 1993

IGS recognized by IAG in 1993, call for participation Feb 1991, test campaign 1992, began operations Jan 1994

LRE ESTABLISHED

Memo Of Agreement USAF-STP, GPS JPO, NRL for NCST-801 ACRE and STP Mission S93-2 and S9401 9 March 1994 (Sent out 26 Aug 1993)

UM Proposal to NRL 17 March 1993 – Three flight panels of 32 Retro's each plus a weight-size dummy panel. Two delivered in May 1993, preceded by dummy panel and followed by a third array in a few weeks. Cost $100K

Memo Of Agreement NRL GSFC support of LRE on GPS, NRL 9/20/93, GSFC 7/29/1993

NAVSTAR 35 Launched 30 August 1993

NRL Ltr to 2SOPS Laser Tracking Experiment for GPS Satellite 3 Nov 1993

NAVSTAR 36 Launched 10 March 1994

Laser Retro-reflector Design

- 32 Retroreflector cubes
- Total weight: 1.27kg
- Dimension: 8in x 10in
- <u>Optical cross section: 20x10^6 m^2</u>
- Return rate from MOBLAS-5 on the order of 2% at MEO
- GPS orbit at 22,000 km

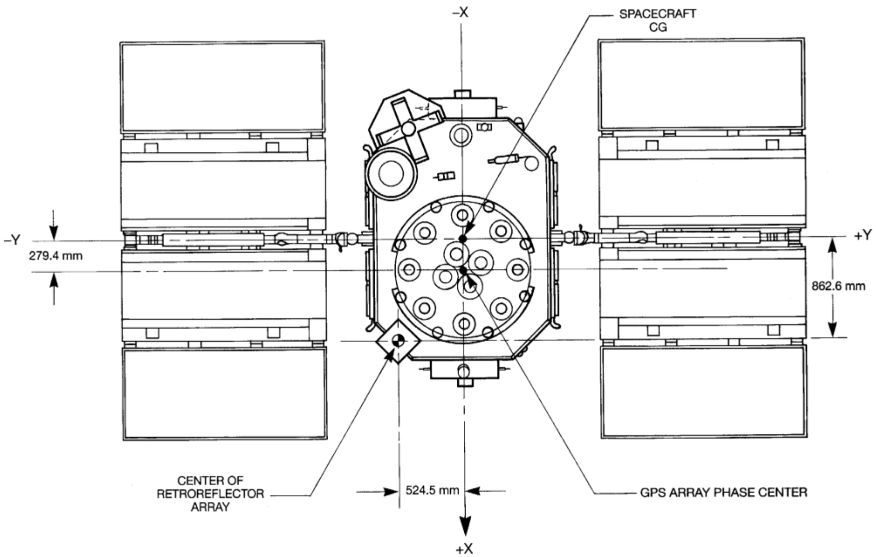
Provided by Grant to Univ Maryland

Built by Russian Institute for Space Device Engineering

- Three panels provided
- Dummy Mass model for Fit check
- Operators Manual
- Engineering Manual

Integration onto Vehicle by STP

NAVSTAR 35 & 36
Laser Retro-Reflector Experiment



2SOPS PAWG 1998 (O'Toole, NSWC)
SLR Residuals (cm)
(December 1997 – February 1998)

	OCS (ZAOD)		NIMA		IGS	
SVN	Mean	RMS	Mean	RMS	Mean	RMS
35	-23.1	51.2	-3.0	8.2	-3.0	6.7
36	-106.3	178.4	-3.3	7.5	-4.1	5.9
35&36	-71.9	140.6	-3.2	7.8	-3.7	6.2

Coordinated NRL experiment to investigate separation of orbital and clock errors

Non-interference with GPS Operational Control Segment

Tracking Coordinated by Air Force Laser Clearinghouse

Measurements provided by ILRS through MOA with NASA GSFC

Applications

Initial attempts for SLR-only orbits hampered by lack of daylight tracking

Comparisons with GPS systems RF observations for calibration/validation

Comparisons with Geodetic RF observations

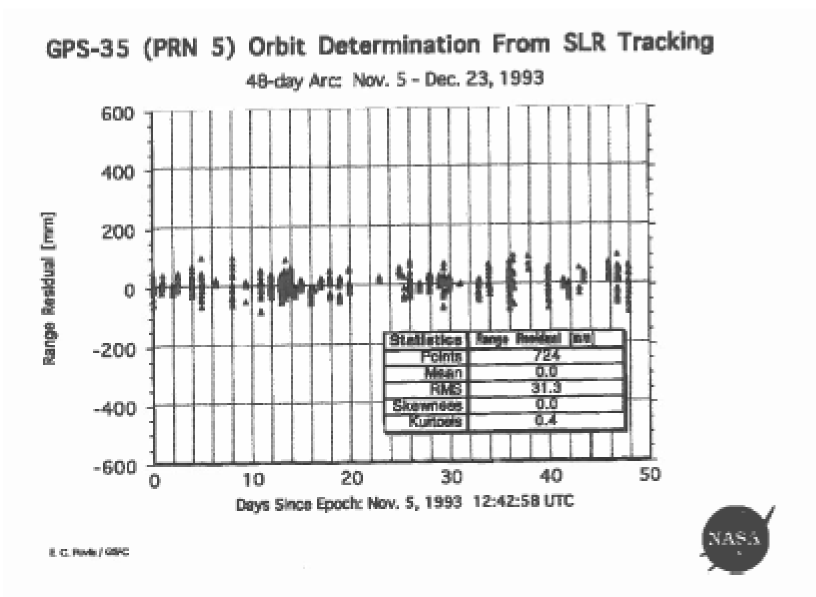
Inclusion in Geodetic orbit determinations

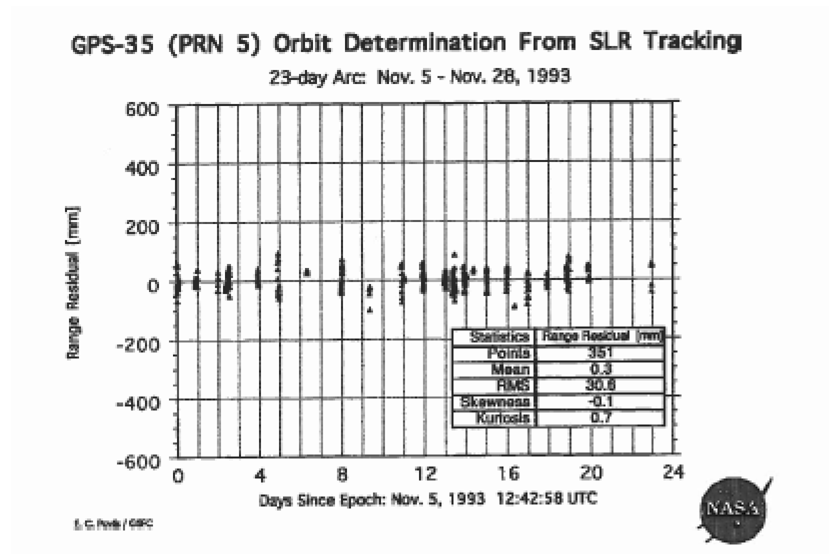
TRACKING and CAMPAIGNS

Many Campaigns have been conducted since the experiment began

Goal of SLR only orbit for clock evaluation has been elusive

LRE has contributed to validation of IGS and GPS orbit determination





E. C. Pavlis, “Comparison of GPS S/C Orbits determined from GPS and SLR Tracking Data”, Adv. Space Res. Vol. 16 No 12 pp (12)55-(12)58 1995, COSPAR

Comparisons

Table 4 SUMMARY Of SLR RESIDUAL STATISTICS (cm)
Statistics Include Data From Both Satellites With Satellite Center Of Mass (CM)
Bias Solutions Carried Out In The GPS Satellite's Local Reference Frame (X,Y,Z).
(3242 normal points, 273 in shadow, 2969 in sunlight)

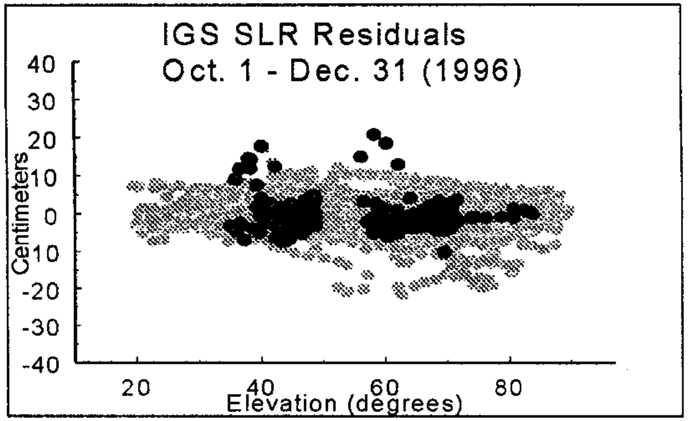
	GPS35 CM Adjustment			GPS36 CM Adjustment		
	X	**Y**	**Z**	**X**	**Y**	**Z**
NIMA	0.12	0.06	-1.98	-0.60	0.23	7.04
JPL	-0.41	-0.21	6.85	-0.43	0.17	5.06
IGS	-0.36	-0.19	6.10	-0.42	0.16	4.93

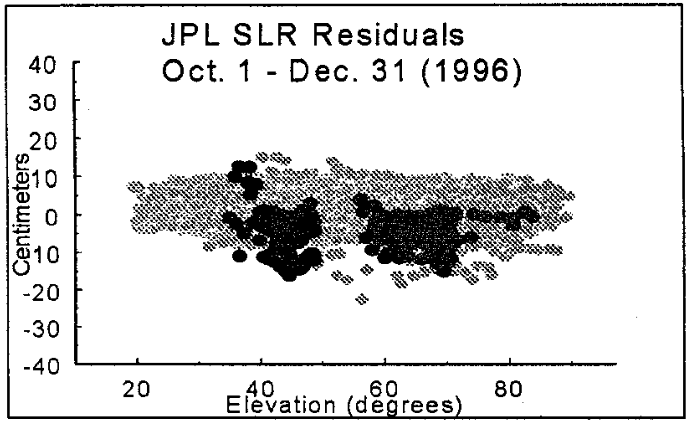
SLR Residuals Including CM Adjustments

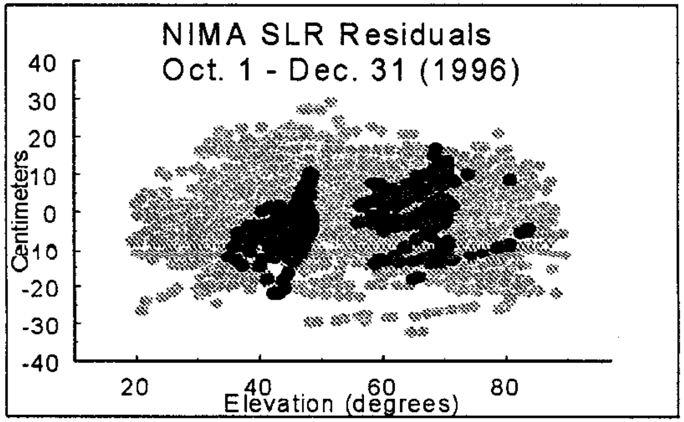
	Mean	**RMS**
NIMA Data	-0.00	9.49
Shadow	-2.46	8.13
Sunlight	0.22	9.61
JPL Data	-0.00	4.61
Shadow	-4.49	6.41
Sunlight	0.41	4.41
IGS Data	-0.00	3.93
Shadow	-0.63	4.01
Sunlight	0.06	3.92

J.W. O'Toole, "Evaluation of NIMA GPS Satellite Ephemerides using NASA Laser Ranging Data", in PLANS IEEE, 1998,pp 371-378

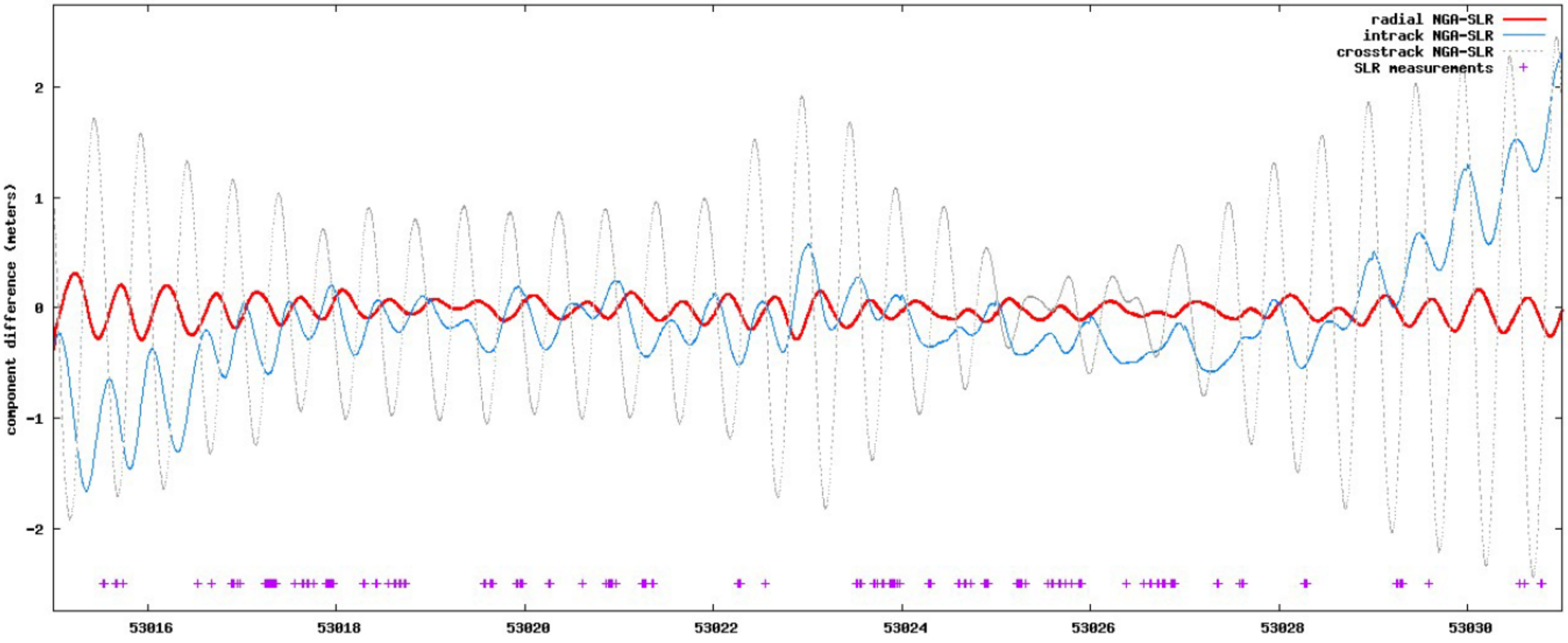
Independent Orbit Validation







NAVSTAR 35 Residuals

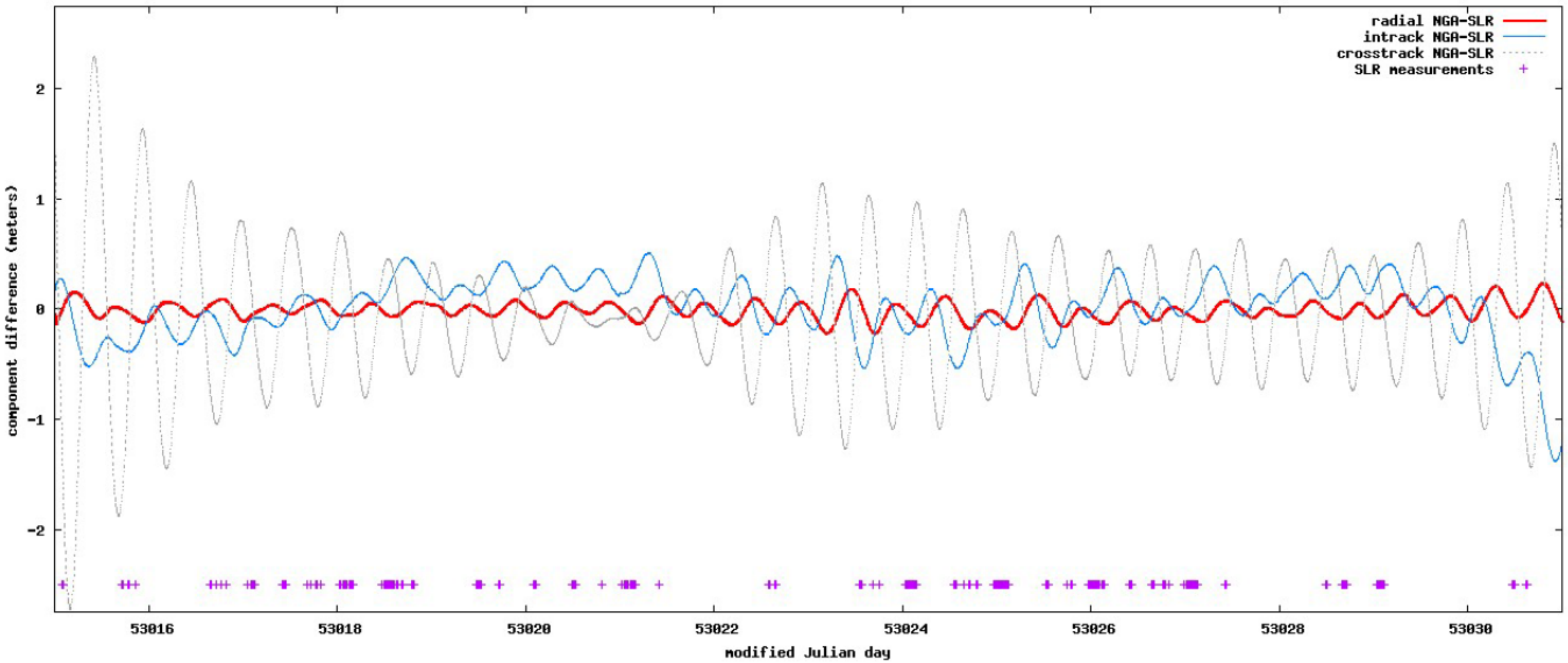


	SVN 35 Mean (m)	SVN 35 Stdev (m)	SVN 36 Mean (m)	SVN 36 Stdev (m)
NGA Final	-0.009	0.034	0.010	0.026
NGA Public	-0.028	0.051	-0.023	0.041
IGS Final	-0.010	0.026	0.009	0.024
JPL	-0.003	0.029	0.009	0.026
BROADCAST	0.832	0.477	0.094	1.308

13-26 Jan 2004

M. Davis, et al, NGA GPS Navigation Assessment using SLR Techniques, NRL, March,2005

NAVSTAR 36 Residuals



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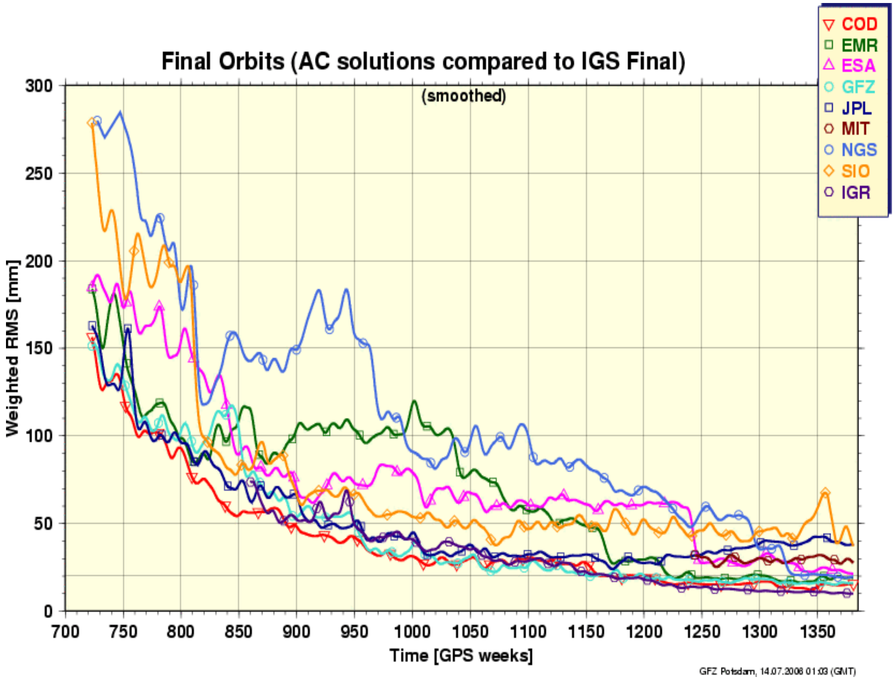
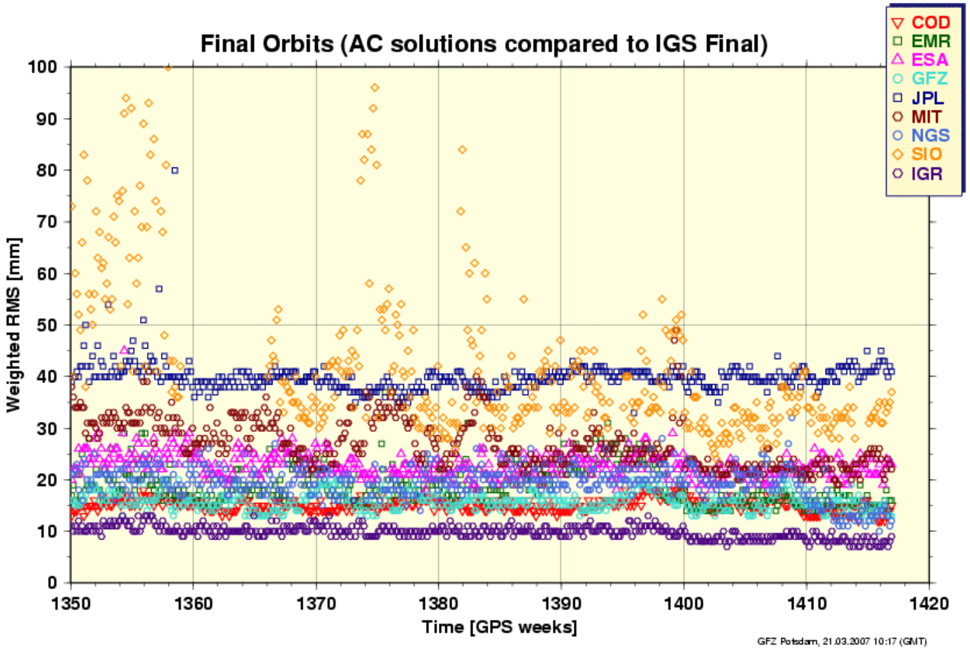
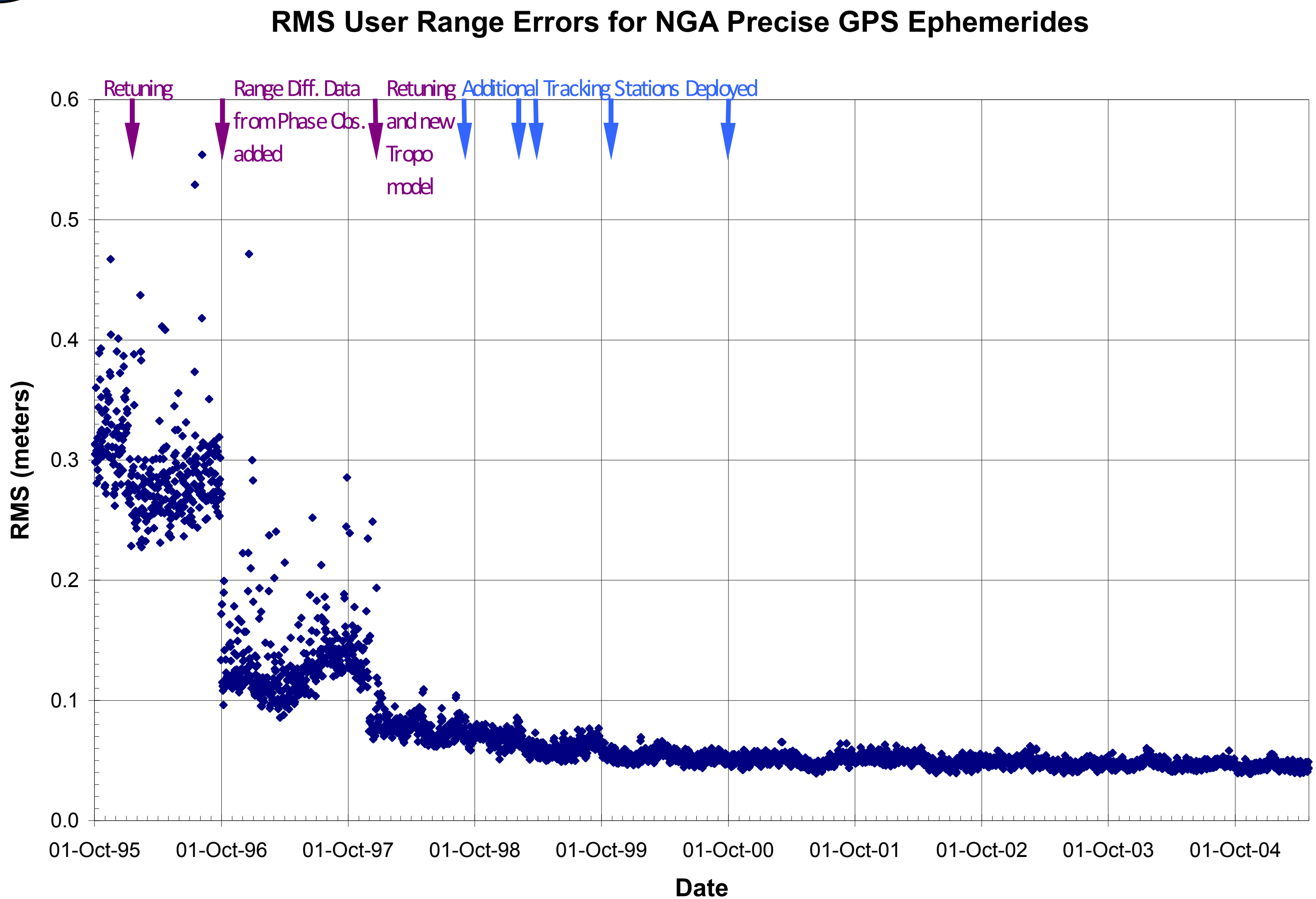
M. Davis, et al, NGA GPS Navigation Assessment using SLR Techniques, NRL, March,2005

IGS Final Orbits





GPS PRECISE EPHEMERIDES



ADVANCED SPACE PNT BRANCH
U.S. NAVAL RESEARCH LABORATORY

GPS and SLR Future Operations

Retro-reflector Arrays

GPS, GLONASS, and GIOVE will have arrays based on similar design

COMPASS has a newer design – initial ranging experience indicates considerably stronger return signal

Increased number of satellites with arrays

Network upgrades in process