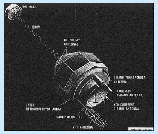
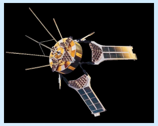
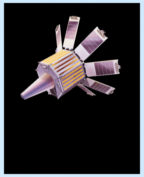
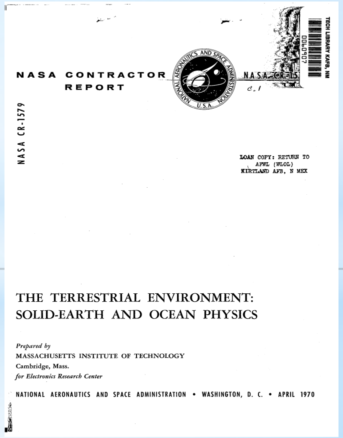
Early Satellite Laser Ranging and the Path Forward

- Early SLR satellites (Beacon B/C, GEOS ½, Diademe C/D were primarily satellites of opportunity
  - Co-located with Navy Doppler, C-band, S-band, GRARR, flashing lights (for Cameras)
  - Begin path toward more accurate geodetic products (networks, gravity field, polar motion, etc.)
- Around the time of the Williamstown Conference in 1969 (Kaula, The Terrestrial Environment: Solid-Earth and Ocean Physics, April 1970) the "SLR Space Geodesy Community" recognized that it could **move from static geodesy to dynamics** if we could:
  - Improve SLR ranging (cm accuracy)
  - Deploy a Global Network
  - Launch the right kind of target in space
- Improvement in LLR technology (LURE team/Apollo 11)
- Improvement in SLR by GSFC









NASA CONTRACTOR REPORT

NASA CR-1579

LOAN COPY: RETURN TO AFWL (WLOL) KIRTLAND AFB, N MEX

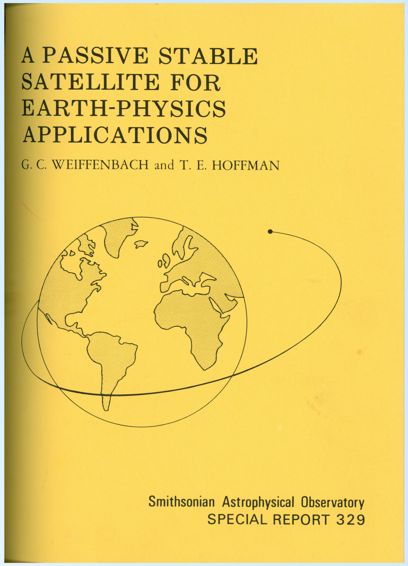
THE TERRESTRIAL ENVIRONMENT: SOLID-EARTH AND OCEAN PHYSICS

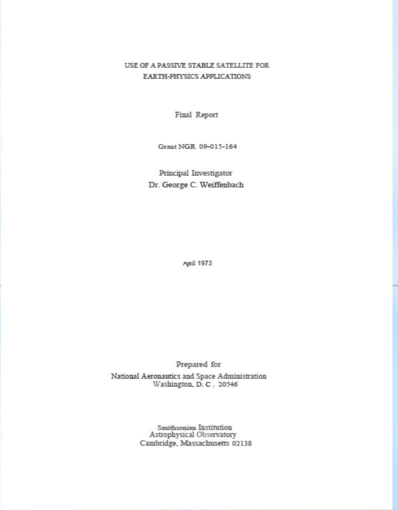
Prepared by MASSACHUSETTS INSTITUTE OF TECHNOLOGY Cambridge, Mass. *for Electronics Research Center*

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • APRIL 1970

Initial Concept for LAGEOS

- Proposed to NASA by SAO/George Weiffenbach (October 1970)
  - Original satellite called "Cannonball"
  - The Smithsonian Earth Physics Satellite (SEPS) Definition Study; NASA Technical Memorandum TM X-64632
  - Passive, high mass-to-area ratio ball uniformly covered with retroreflectors
  - Applications, mechanical and optical design, retro issues, signal link analysis, orbital acquisition, etc.
  - Lots of effort on the design and specification of the retro array
  - Orbital considerations
  - General design that could be scaled to different sizes
- Final Report to NASA by SAO/George Weiffenbach (April 1973)
  - "Use of a Passive Stable Satellite for Earth-Physics Application"s, NASA Grant NGR 09-015-164
  - Subcontract to ADL for Thermal – Optical Studies (based on design work they did on the Lunar Array)





USE OF A PASSIVE STABLE SATELLITE FOR EARTH-PHYSICS APPLICATIONS

Final Report

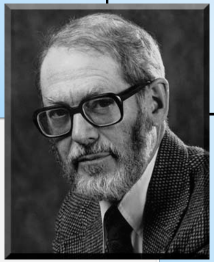
Grant NGR 09-015-164

Principal Investigator
Dr. George C. Weiffenbach

April 1973

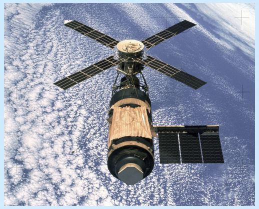
Prepared for
National Aeronautics and Space Administration
Washington, D. C. 20546

Smithsonian Institution
Astrophysical Observatory
Cambridge, Massachusetts 02138



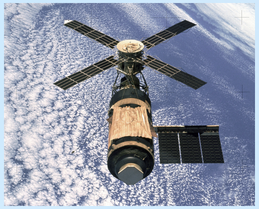
A Possible Opportunity

- The plan for the Saturn launched Skylab provided a possible opportunity for a space segment;
- Early safety concerns for the astronauts led to consideration of having a fueled rescue Saturn vehicle ready to go in case there was trouble – the problem was “what can we do with the vehicle if it isn’t needed?”
- A solution was a heavy payload that was cheap and relatively easy to load, and ready to go.
- George Weiffenbach and Tom Hoffman adapted the concept design to an 8000 lb “Cannonball Satellite” with a depleted Uranium core (very heavy);
- NASA subsequently decided that the rescue vehicle was not needed;
- BUT the idea was geminating;



LAGEOS, a Reality

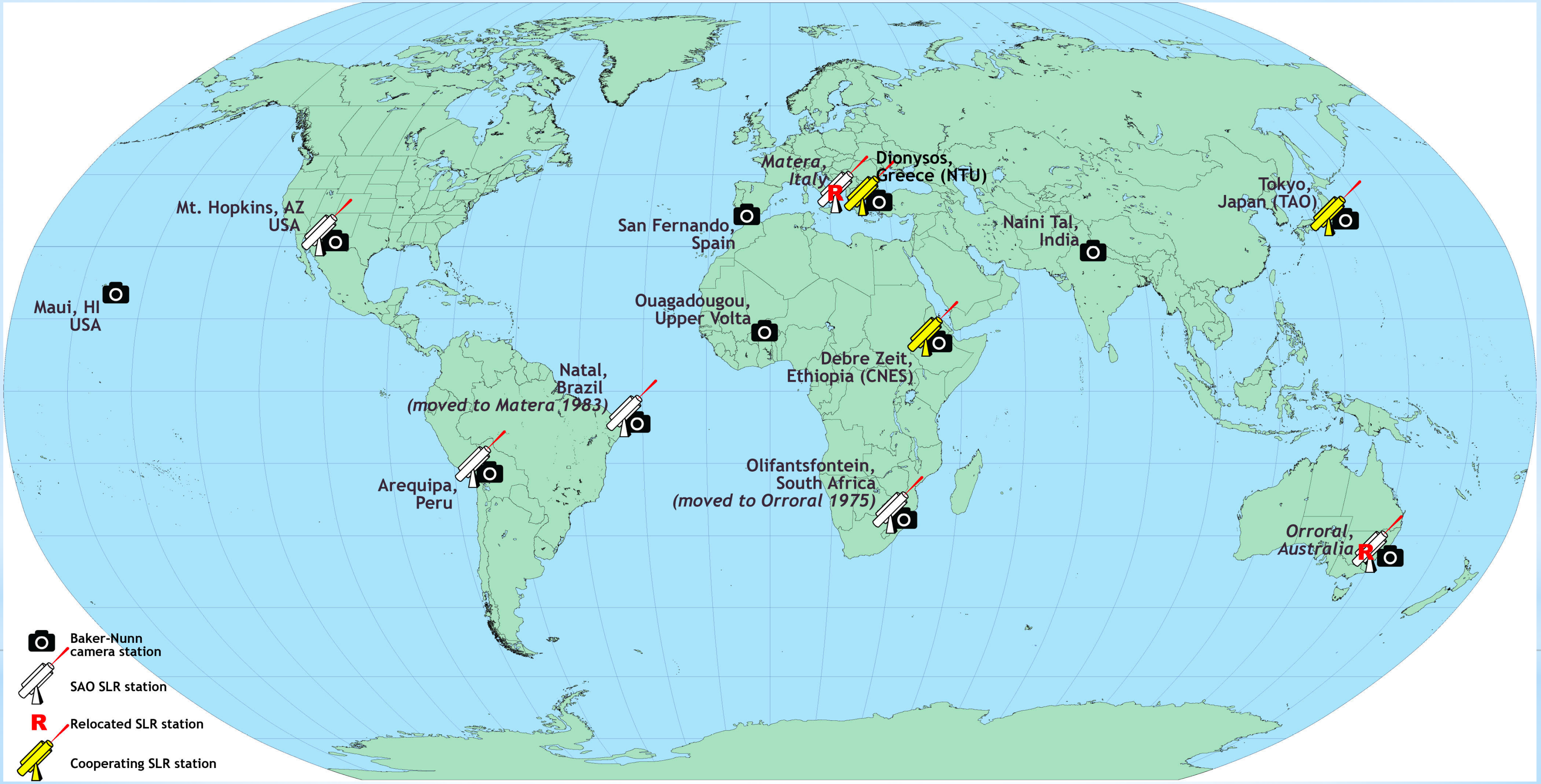
- LAGEOS Mission was accepted by NASA in 1973;
- Configuration was scaled to a Delta launch (no Uranium);
- Designed, built at Marshall Space Center; Bendix did the optical design work;
- Design included 4 Germanium Cubes for 10.6 micron studies at the request of Prof. Charles Towns
- Finally launched in May 1976
- LAGEOS was not the first passive, spherical satellite covered with retroreflecters; the French launched the Starlette satellite in early 1975.



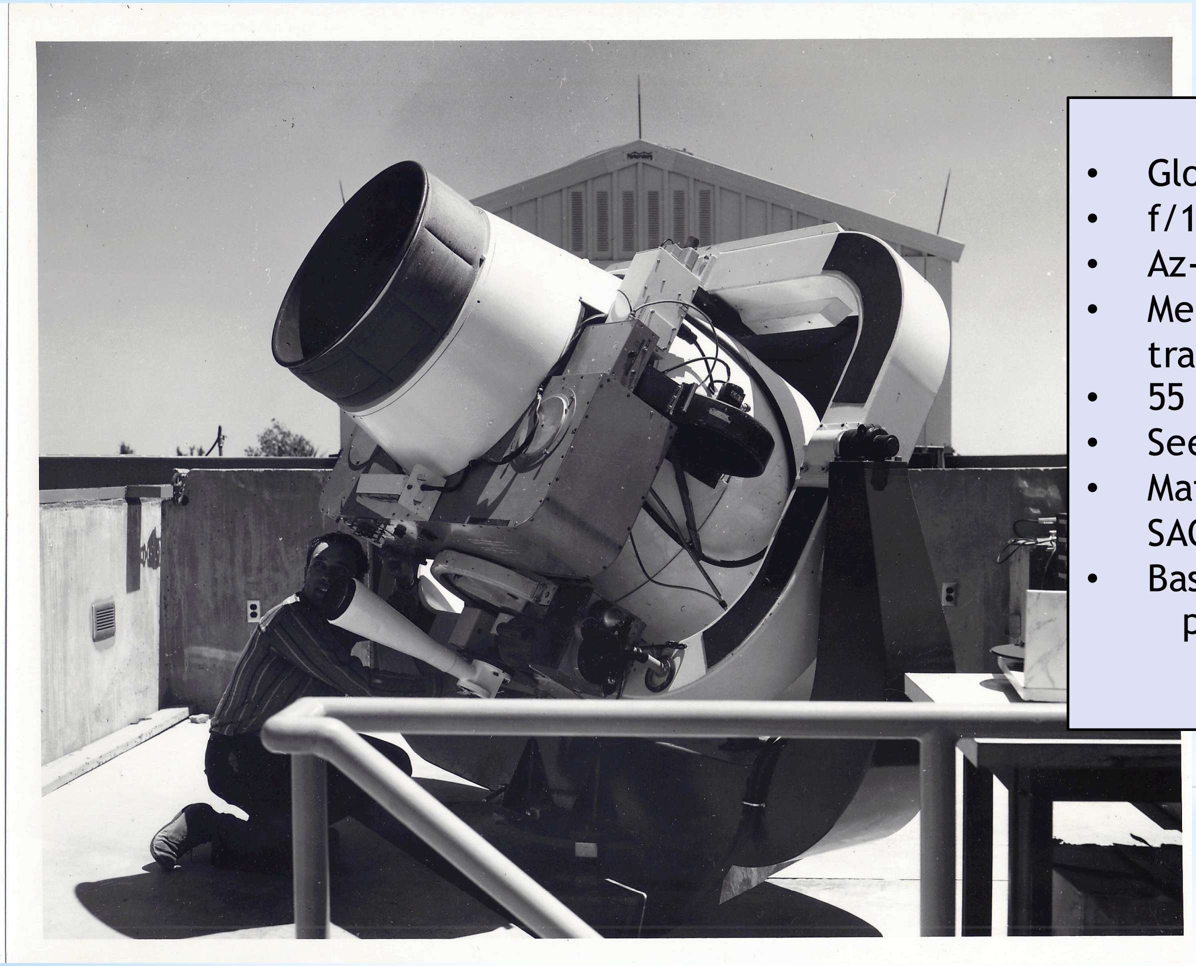
Orbital Acquisition Plan

- SAO developed the orbital acquisition plan for NASA
- The orbital acquisition Plan was based on:
  - Radio Beacon on the apogee kick motor that was to separate slowly from the LAGEOS; the battery operated beacon would last a few days;
  - The SAO Baker Nunn Camera network would photograph it;
  - Air Force radars would track;
- All of the sources of data would be merged at SAO and used to continuously update the SLR predictions;
- Near real-time communication

SAO and Partner Network



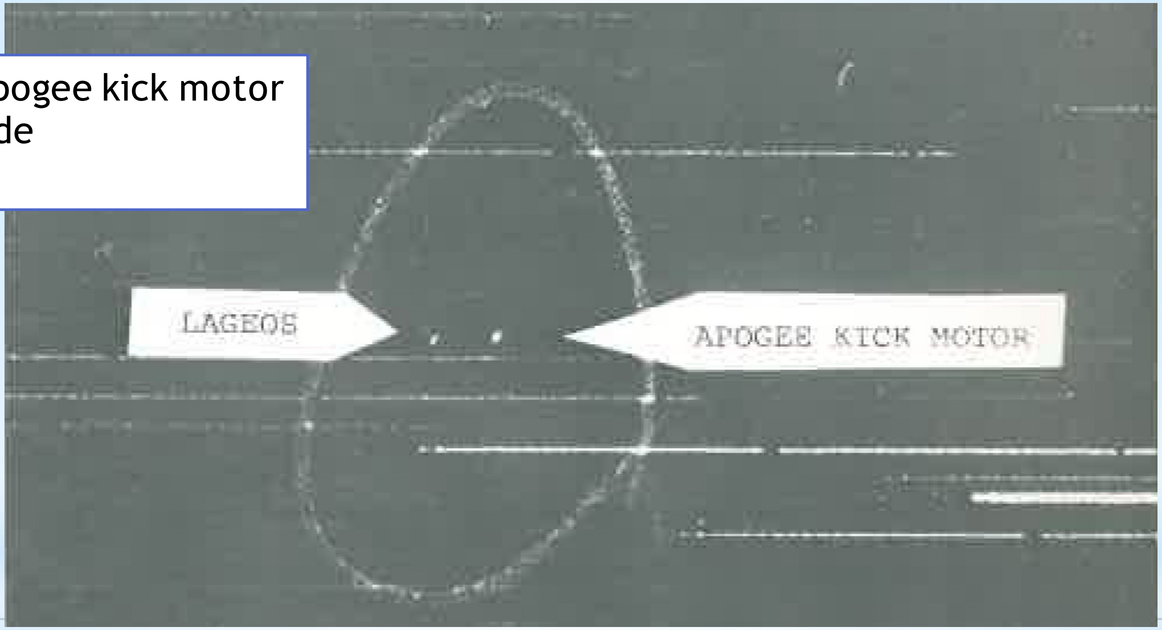
Baker Nunn Camera



- Global Network
- f/1 Schmidt Camera
- Az-Alt mount
- Mechanized film tracking transport
- 55 mm Film
- See down to 14 – 15 magnitude
- Main source of data for the early SAO Standard Earth Models
- Basis for satellite acquisition and predictions for SLR

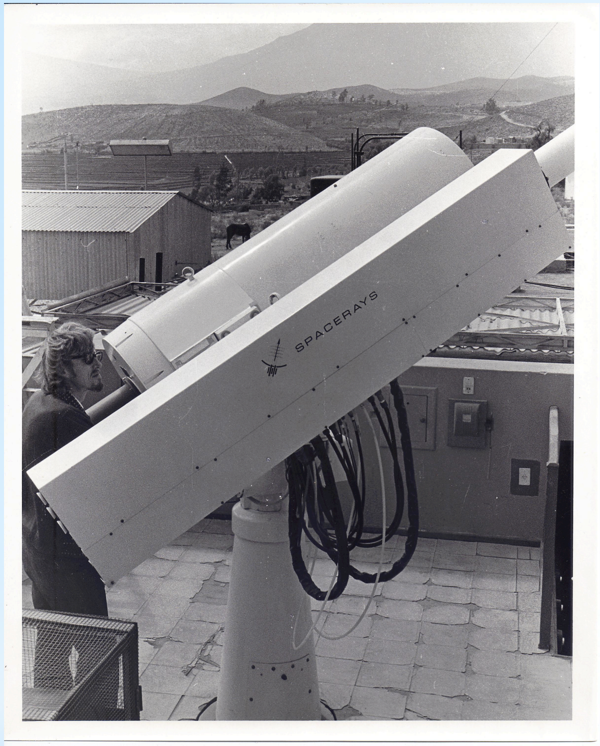
Lageos BN Photo after Launch taken from Maui Station

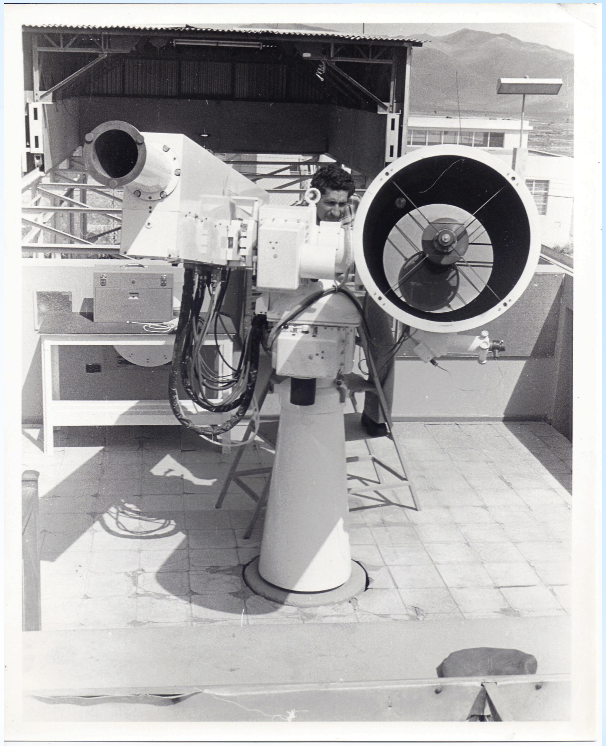
- With 4th stage apogee kick motor
- 12 – 13 magnitude
- May 4, 1976



LAGEOS AND AKM TAKEN 3 HOURS AFTER LAUNCH

SAO Laser Ranging System
Deployed 1970 -71





- Bi-Static, Az-Alt System
- Ruby oscillator/amplifier
- Day and Night Time Tracking
- 4 – 30 ppm
- 20 – 5 nsec pulse width
- Sites at Mt Hopkins, Arequipa, Natal, and Olifontsfontein/Orroral Valley

SAO Station at Mt. Hopkins (Arizona)

Camera and laser provide on site co-location

First LAGEOS SLR Data

* First Passes:
* Mt Hopkins May 7, 1976 23 hours 43 - 51 minutes (UT)
* Sat. YR DOY Time FOM 2 way range (ms)
* 7603901 76 128 23:43 .698243209921 46.922046251 76602770
* 7603901 76 128 23:48 .198178209921 46.272428308 76602770
* 7603901 76 128 23:51 .938126009921 45.750378150 76602770
*

* Data from Launch through July 10, 1976 (2 months)

Site	Sta.	Start	End	No. Passes	No. FR Obs.
Arequipa	9907	19760508	19760630	45	2464
Bermuda	7067	19760625	19760630	4	308
Greenbelt	7063	19760510	19760628	20	25252
Mount Hopkins	9921	19760507	19760703	87	8509
Natal	9929	19760512	19760703	42	3829

Mt Hopkins Team

The Mt. Hopkins camera-laser crew (plus two Cambridge visitors) pose in Amado after receiving awards for participation in the LAGEOS program; from left, Joe Delgado, John Gregory, Chad Poland, Jake Wohn, Don Patterson, Jim Peters, Al Almazan, and Station Manager Steve Criswell.

SLR Pass from GGAO

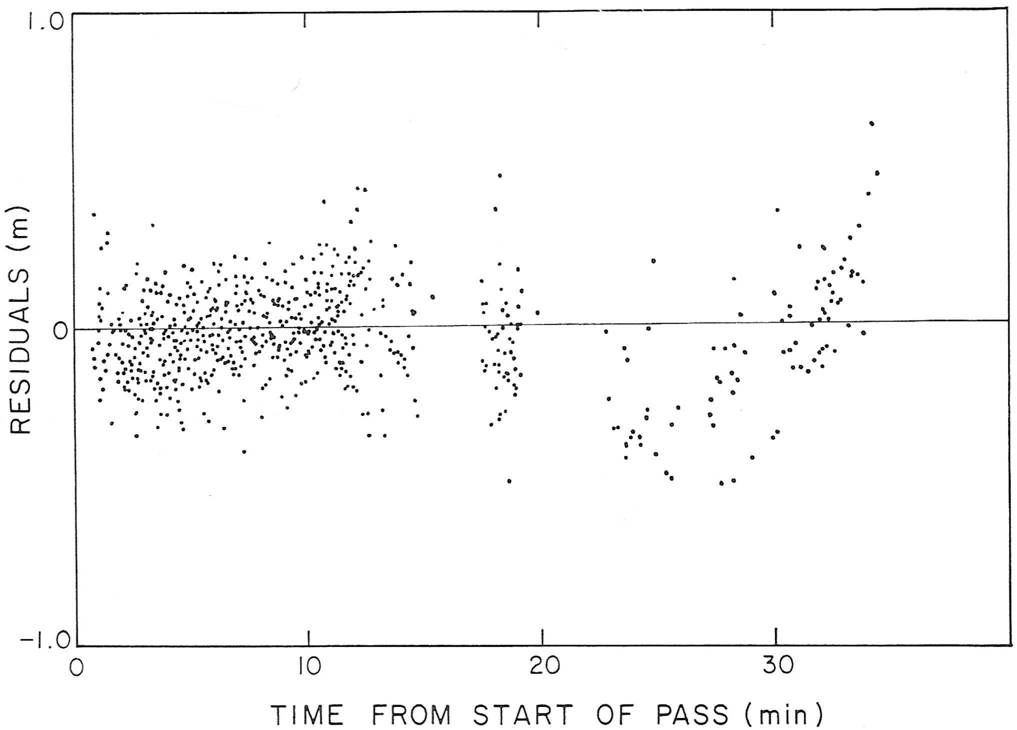
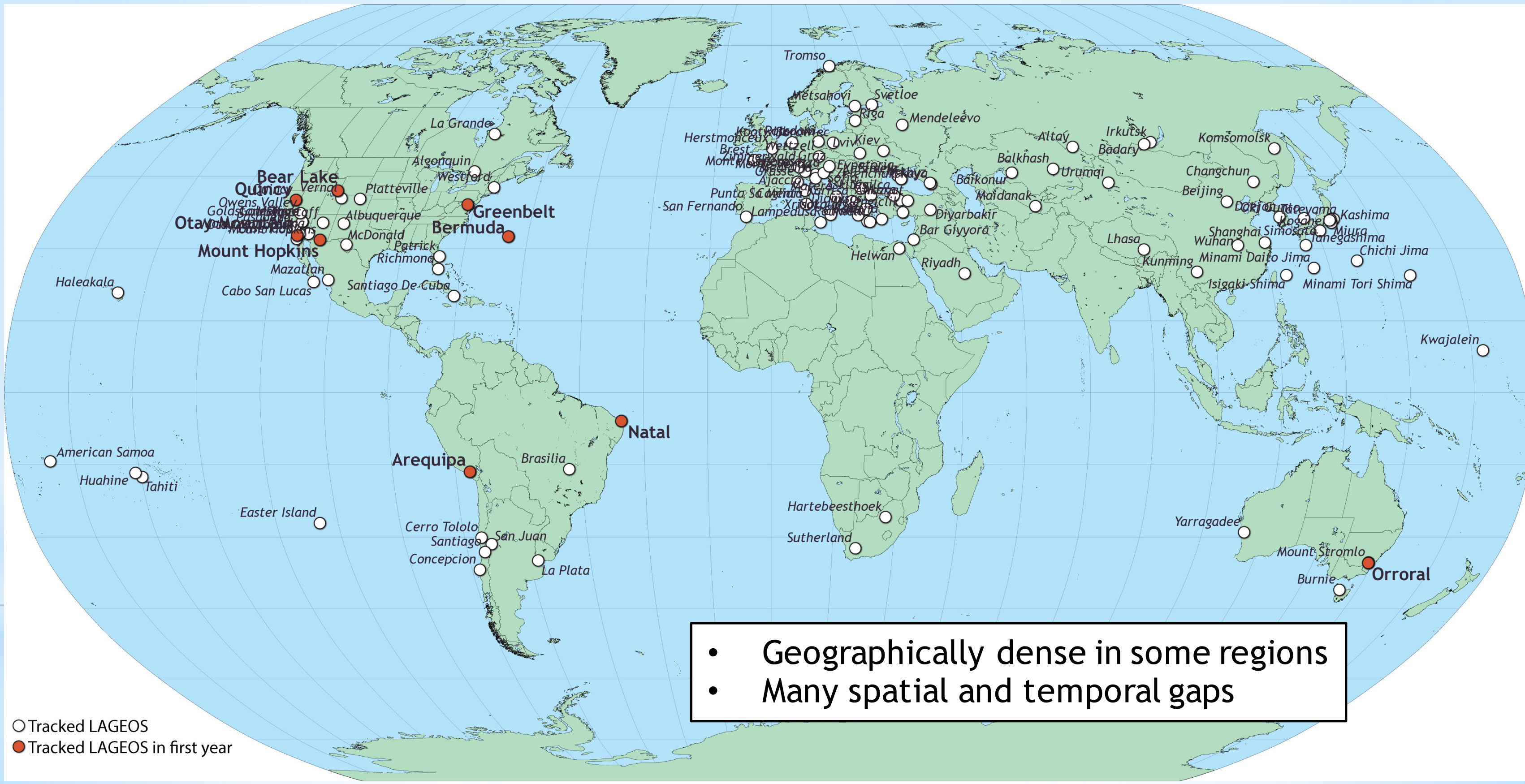


Fig. 3. Plot of range residuals versus time for 741 Lageos observations taken with the GSFC laser on 23 May 1976.

First Year Data Yield

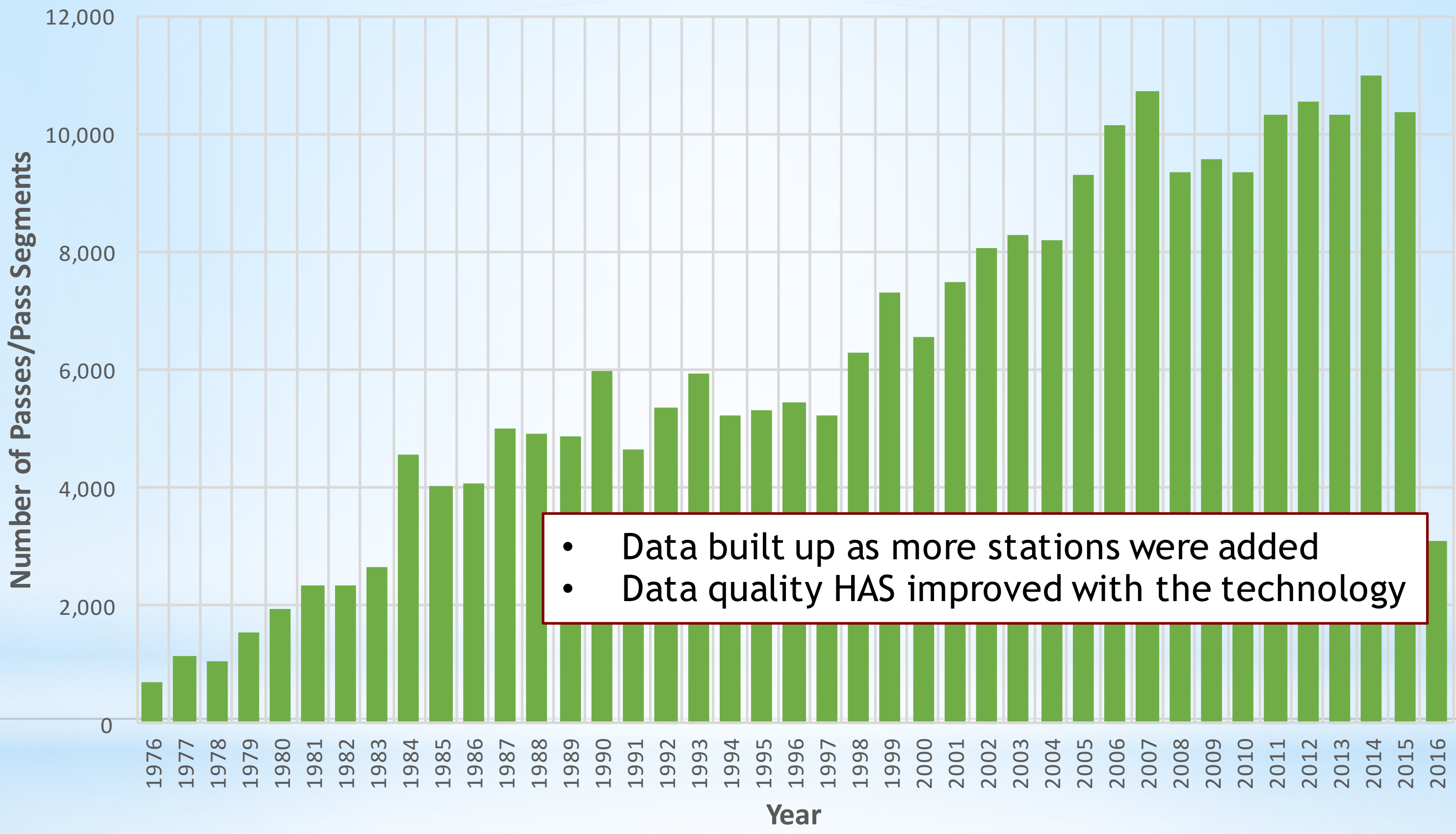
Site	Start	End	No. Passes
Arequipa	760508	770515	220
Bear Lake	760928	761125	45
Bermuda	760625	760630	4
Greenbelt	760510	770430	38
Mount Hopkins	760507	770529	329
Natal	760512	770526	144
Otay Mountain	760831	770422	152
Quincy	760827	761129	24
Orroral	760925	770528	199

SLR Stations that have tracked LAGEOS (entire history)



- Geographically dense in some regions
- Many spatial and temporal gaps

Lageos Data by Year



- Data built up as more stations were added
- Data quality HAS improved with the technology

LAGEOS and LAGEOS -2

- SLR (ILRS) Standard
- Now added LARES
- Still room for more LAGEOS Satellites