Lessons from Scheduling Lunar Laser Ranging Observations

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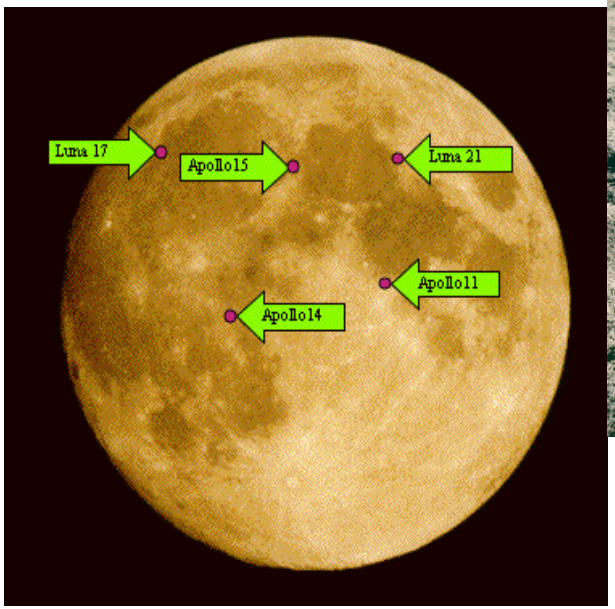
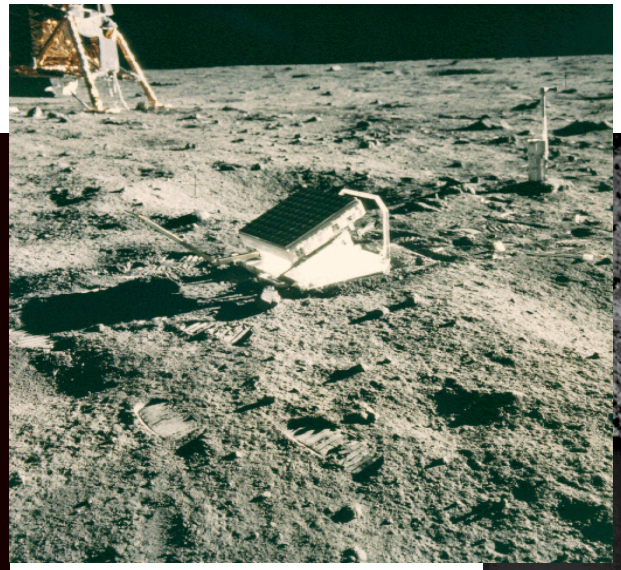
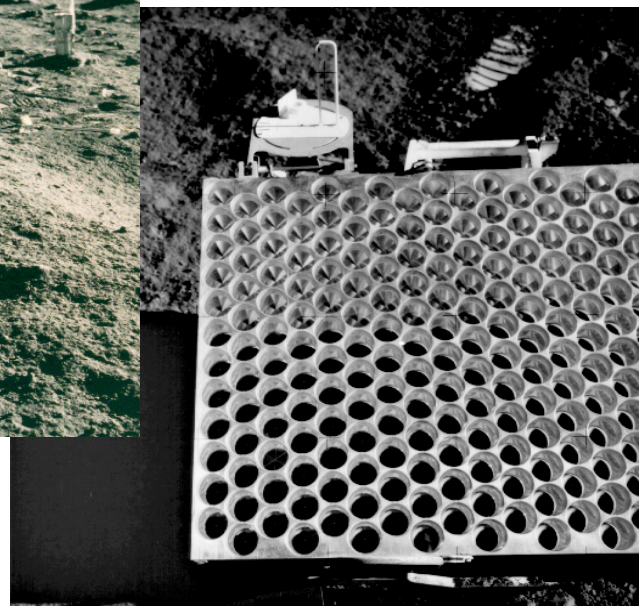
Introduction to LLR

- 2-way laser ranging to retro reflectors left on the moon by
  - Apollo 11, 14, and 15
  - Luna (17 and) 21







LLR Scheduling Challenge

- One 12 hour "pass" every day
- Too long to observe in one stretch
  - Need to observe other targets as well
  - Do not have 24/7/365 observer coverage
  - Weather – clouds, rain, snow, dust, wind
  - Cannot observe at new moon
- Limited number of ranging stations: 1-3
  - $1/R^4$

What Science Requires - I

- Lunar structure (probing the lunar core and mantle)
- Round-robin, multi-reflector sub-cm normal points in a 1 hour span
- Data should be obtained at least several times (3-5) per month
- Spacecraft navigation and Solar System ephemeris generation (where is the Earth?)
- Several (5-10) sub-cm normal points distributed throughout a month
- Data should be obtained every month

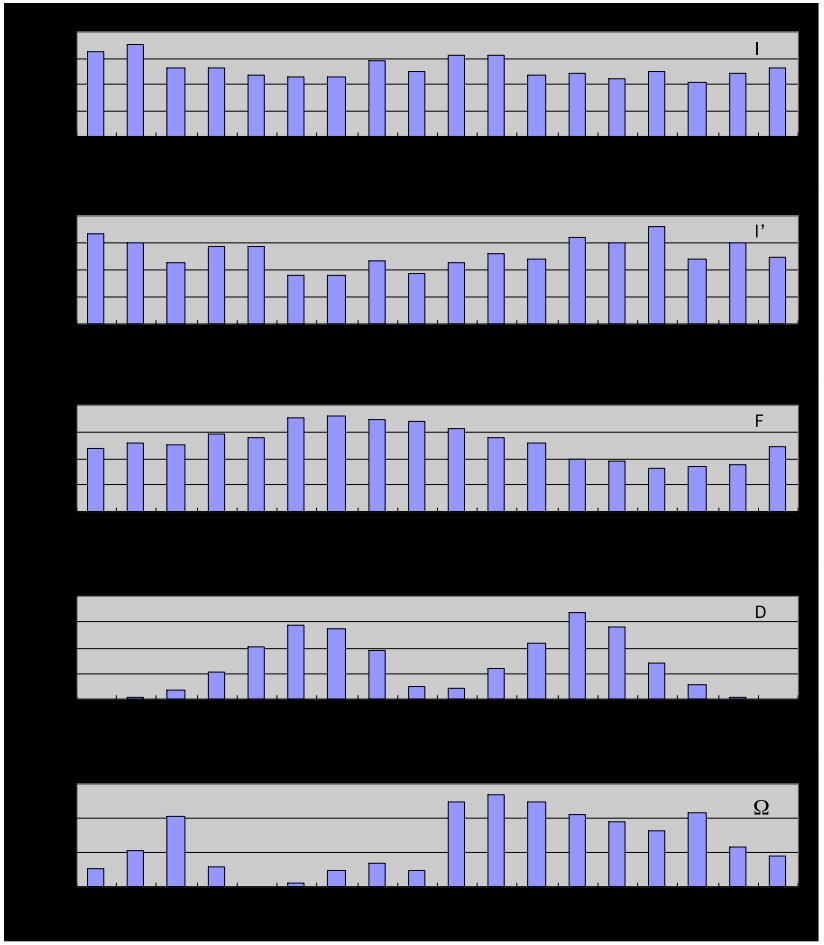
What Science Requires - II

- General relativity & gravitation (Nordtvedt effect, geodetic precession, G-dot)
- Sub-cm data covering all lunar phases
- Data should be obtained every lunation
- Earth Orientation (looking for sub-daily signals)
- Several sub-cm normal points (5 or more) within a 2 hour span
- Data should be obtained as many days as possible during a month
- Obsolete

Sample Schedule

- 45 minute observing time slot
  - Observe Hadley reflector (largest) until have sufficient data for a sub-cm normal point (everything)
  - Observe as many of other reflectors as possible in remaining hour schedule (lunar structure)
- Repeat above at -3 hour, meridian, +3 hours (dUTC)
- Repeat above everyday except new moon +/- 2 days, every month (everything)

LLR Data Distribution



- Inclination - OK
- Solar mean anomaly - OK
- Lunar mean arg of latitude - OK
- Lunar mean elongation - “Achille's heel”
- Longitude of the node – 18.6 year cycle - OK

Conclusion

- Scheduling cannot be done in a vacuum!
- Must look at science requirements
- Must be flexible
- Will not get all the data desired
- *What is really important?*