Development and On-orbit Performance of Moderate-cost Spherical Retroreflector Arrays for the Starshine Program

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Outline

- Starshine program, physical/orbit properties, and SLR opportunity
- Random phase approximation design of SLR arrays
- Spherical SLR array design and Monte Carlo Simulations
- Observational results and verification
- Conclusions

Starshine Program Charactistics

- Basic mission is educational outreach (http://azinet.com/starshine/)
- Low-altitude and risk-tolerant allows for testing spherical arrays built from inexpensive BK7 retroreflectors (stock and unspoiled)
- Test results used by ANDE

- Starshine 2: 18.7 inches outer diameter, 87 pounds
- Starshine 3: 36 inches outer diameter, 200 pounds

Starshine Orbits

- Starshine 2 released at 380 km on December 16, 2001 and re-entered on April 26, 2002 -- NASA Space Shuttle (STS 108) as Hitchhiker payload
- Starshine 3 released at 470 km on September 29, 2001 and current re-entry estimate March 9, 2003 -- Athena Launch Vehicle from Kodiak, Alaska
- SLR observations for Starshine 3 only
- 74 SLR observations from November 2001 through August 2002

Random Phase Appoximation for Array LRCS

Degnan's expression for laser radar link:

$$N_{\mathrm{pe}} = \eta_D E_0 \left(\frac{\lambda}{hc}\right) \eta_T G_T \underbrace{\sigma_{\mathrm{LRCS}} \left(\frac{1}{4\pi R^2}\right)^2} A_R \eta_R T_a^2 T_c^2 \ ,$$

where two bracketed factors involve orbit/array design and

$$\sigma_{\mathrm{LRCS}}(k_x, k_y) = \rho \frac{4\pi}{\lambda^2} \left|\tilde{a}(k_x, k_y)\right|^2$$

For an array:

$$\begin{aligned} \sigma_{\mathrm{LRCS}} &= \rho \frac{4\pi}{\lambda^2} \left| \left(\sum_{m=1}^{L} \tilde{a}_m e^{i\alpha_m} \right) \left(\sum_{n=1}^{L} \tilde{a}_n^* e^{-i\alpha_n} \right) \right| \ , \\ &= \rho \frac{4\pi}{\lambda^2} \left| \sum_{m=1}^{L} \sum_{n=1}^{L} \tilde{a}_m \tilde{a}_n^* e^{i(\alpha_m - \alpha_n)} \right| \ . \end{aligned}$$

Random Phase Appoximation for Array LRCS (continued)

For brief interval τ, α_m and α_n phase relations appear in averaged LRCS as

$$\overline{\sigma_{\mathrm{LRCS}}} = \rho \frac{4\pi}{\lambda^2} \left| \sum_{m=1}^{L} \sum_{n=1}^{L} \frac{\tilde{a}_m \tilde{a}_n^*}{\tau} \int_0^{\tau} e^{i[\alpha(t)_m - \alpha(t)_n]} dt \right| ,$$

$$= \rho \frac{4\pi}{\lambda^2} \sum_{m=1}^{L} \left| \tilde{a}_m \right|^2 .$$

Approximation based on small correlation between α_m and α_n

Spherical Direction Distributions with Minimum Electostatic Energy

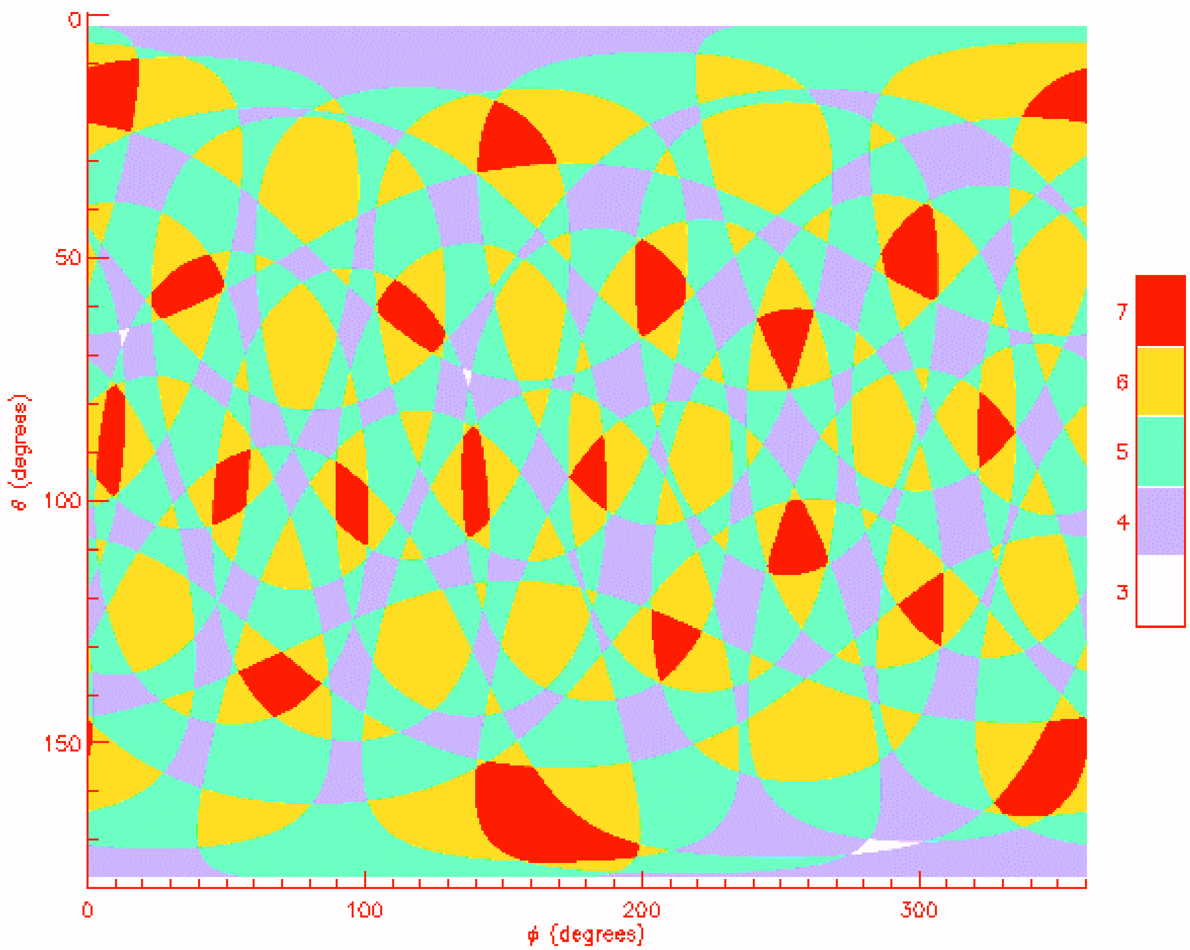
- Uniform direction distribution in 3-dimensions only has solutions for n = 4 (tetrahedron), 6 (cube), 8 (octahedron), 12 (dodecahedron), and 20 (icosahedron)
- Neil J. A. Sloane (AT&T Shannon Lab) lists solutions for closely related minimum electostatic energy problem for n = 4 -> 132, 192, 212, 272, and 282 -- Many thanks Neil! (http://www.research.att.com/~njas/electrons/dim3/)
- Combining random phase approximation LRCS estimate and Sloane's direction library allowed parametric study of performance

Monte Carlo Parametric Study

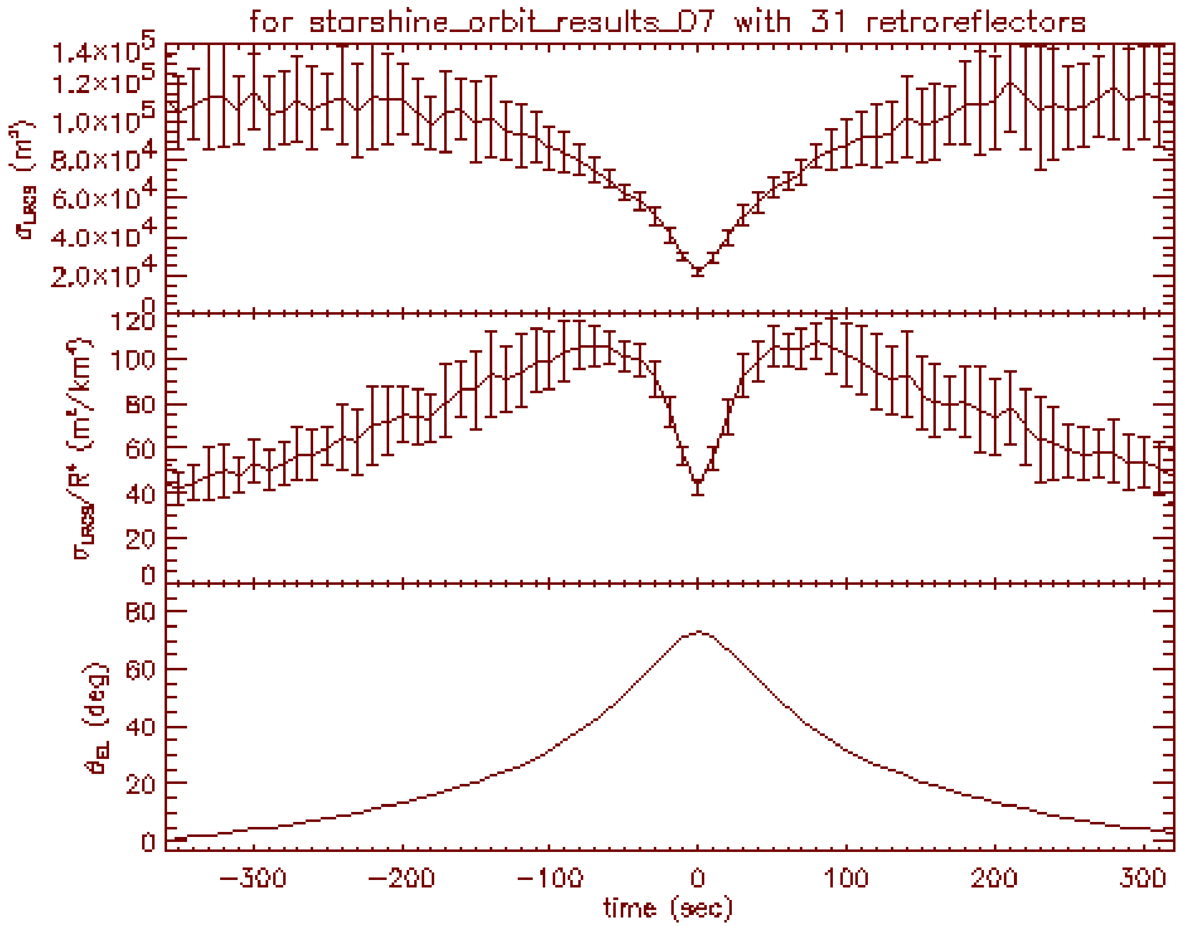
- Generated a set of circular orbital pass geometries for NRL's SLR station near D.C.
- At each point on each pass computed LRCS for 25 random orientations -- estimated mean and standard deviation
- Varied number of retroreflectors -- Noticable suppression of LRCS/R^4 variability slowed at 31 retroreflectors
- For 31 retroreflectors, local angular neighborhood has 5 other retroreflectors within field of view limit -- 3 closer, 2 slightly further

- Then determined best fit to Starshine's restricted direction set and reran monte carlo

31 Element Field of View Coverage Plot (at 532 nm)



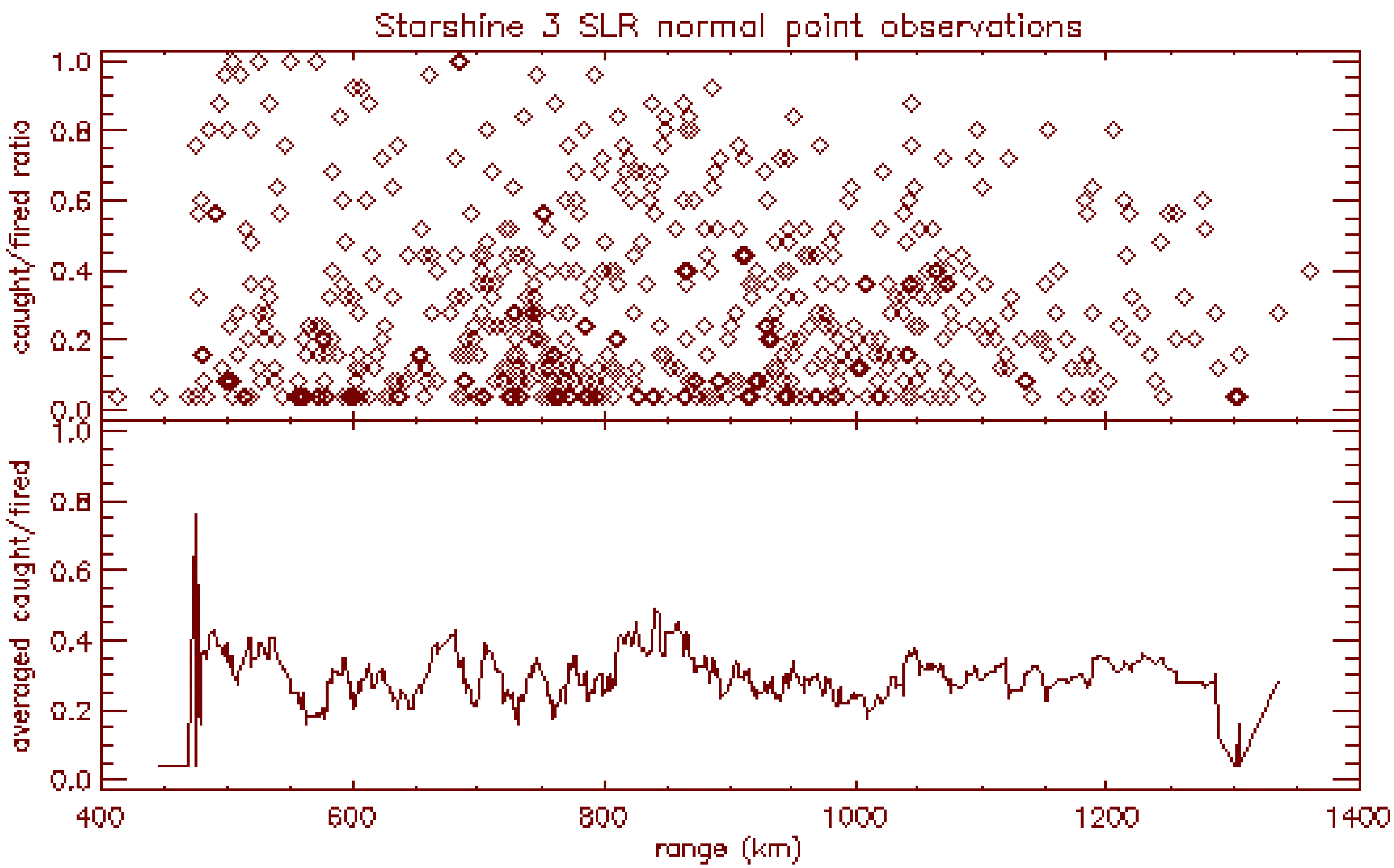
Typical Monte Carlo Result



SLR Observations of Starshine

- Starshine 3 has been acquired and ranged by multiple SLR stations
- Sufficient return for tracking once acquired -- normal point return ratio distribution as function of range qualitatively similar other LEO targets
- Acquisition does require an accurate orbit due to low altitude

Starshine Normal Point Ranging Fraction



Conclusions

- Monte Carlo based on random phase approximation verified
- BK7 retroreflectors work for LEO arrays with year+ lifetimes
- SLR tracking of ANDE should be straightforward given the similarity of retroreflector array to Starshine

- Many thanks to ILRS for SLR observations to date and host school kids at sites
- Many thank to ILRS for any future SLR observations