Geostationary Lidar

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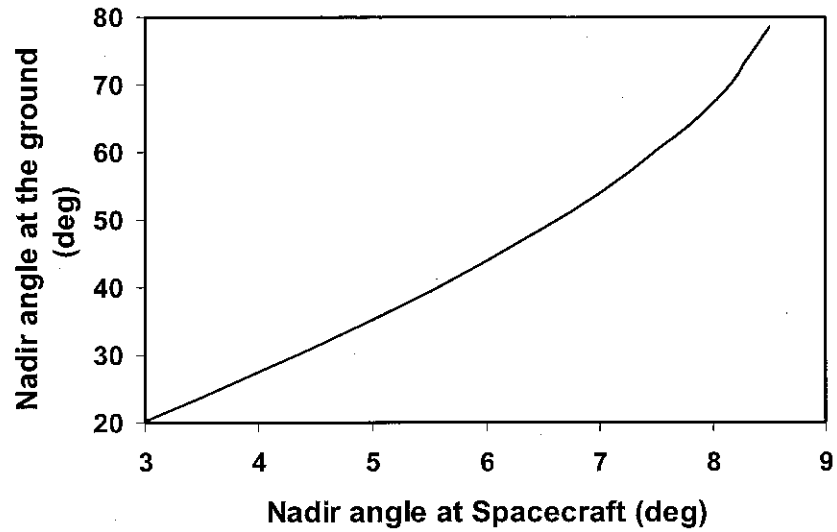
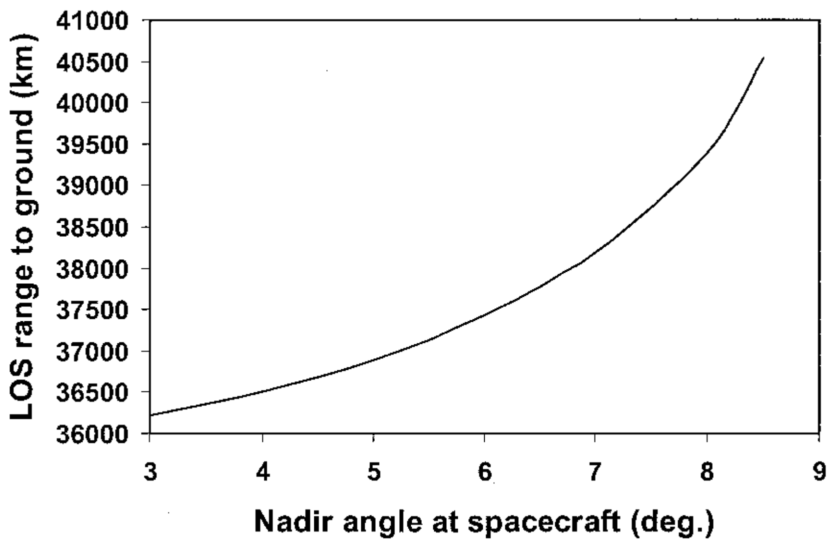
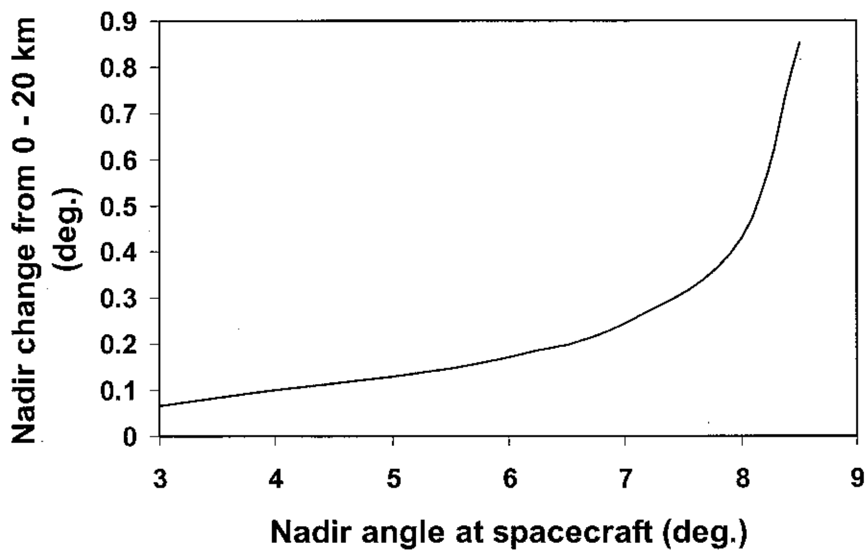
Vary the Nadir Angle?

As we vary the nadir angle at the spacecraft to provide coverage the nadir angle at the ground and the slant path through the atmosphere both increase.

Not only does the nadir angle at the surface change but the variation in nadir angle through the atmosphere also changes due to the increasing slant range.







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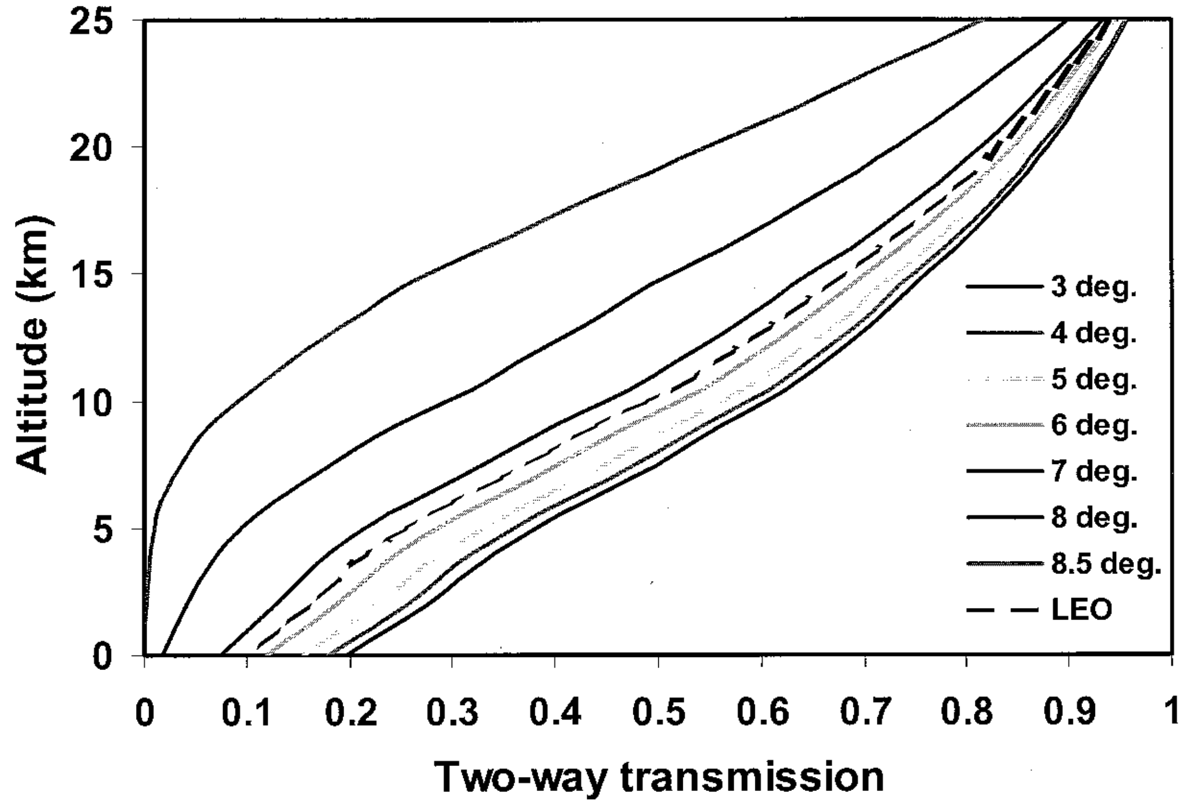
Atmospheric Attenuation

Varying the nadir angle leads to a nadir angle dependent atmospheric extinction. The two way atmospheric extinction shown here is compared to that for an instrument in a 400 km orbit altitude with a 45 degree nadir angle. The initially shallow nadir angle of the geostationary system leads to an improvement in atmospheric transmission over a LEO system, however the atmospheric loss increases rapidly for nadir angles above 6-7 deg due to the increased slant path through the atmosphere.



The sample plot is for a 355 nm wavelength using the NMP* reference atmospheres.

•Emmitt, Spinhirne, Menzies, Winker & Bowdle, "Target atmospheres for use in DWL Concept studies", http://www.swa.com/ALD/LidarProducts/targetAtm/

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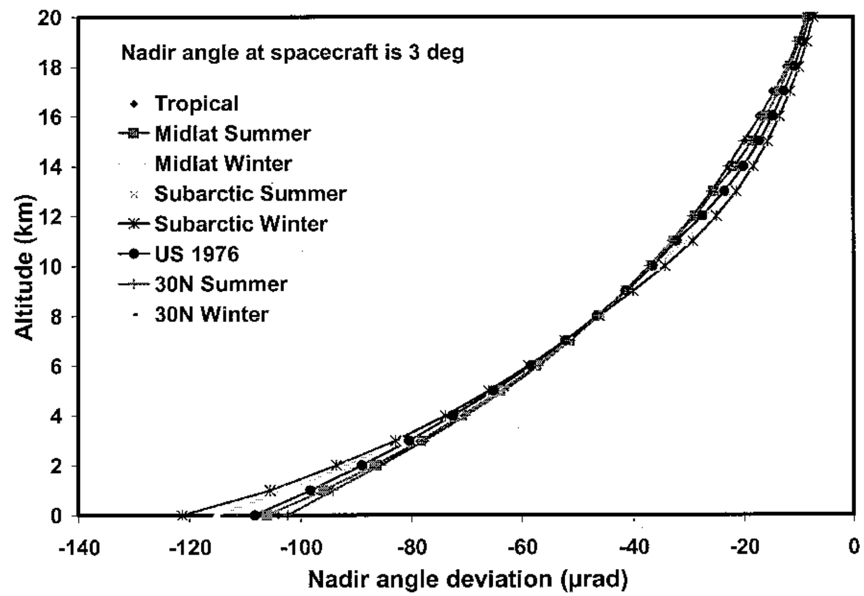
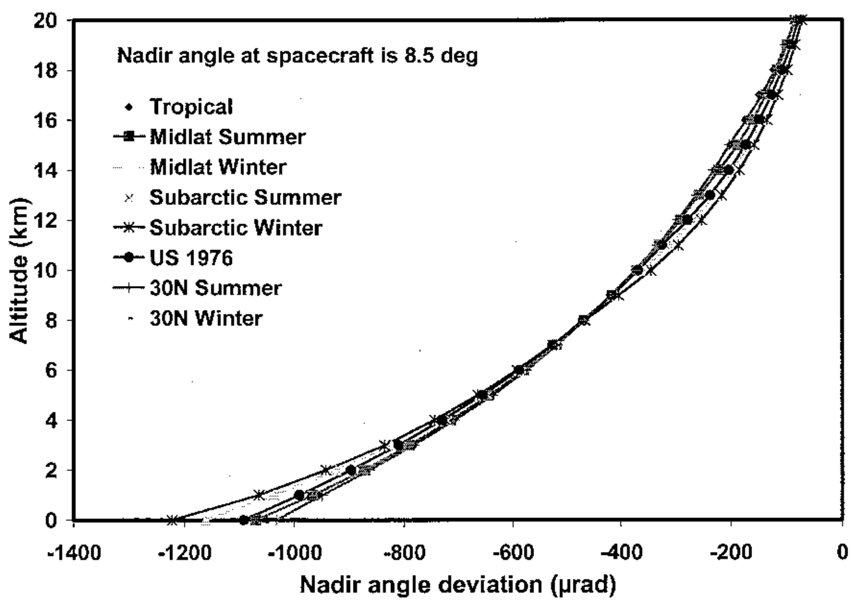
Atmospheric Refraction

As the nadir angle is varied the path through the atmosphere also varies and the amount of bending due to atmospheric refraction will also vary.
Atmospheric refraction also depends on the local pressure and temperature profile. This combination of variation with nadir angle and local condition leads to considerable variability in the amount of refractive bending likely to be experienced.





The uncertainty in the nadir angle results in an uncertainty in the knowledge of the position of the measurement (later slide).

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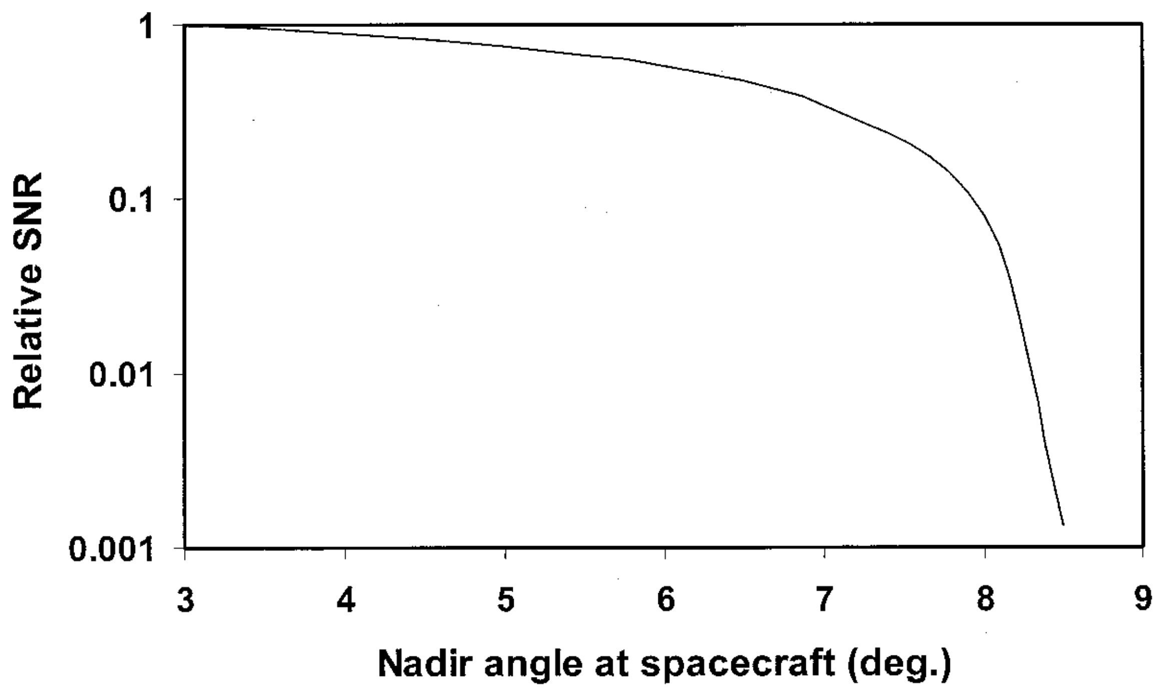
Signal to Noise Ratio

The signal to noise ratio (SNR) is a function of both the atmospheric extinction and the range to the target both of which vary with nadir angle.

We can combine these terms to show the SNR dependence on nadir angle.

The example shown is for a 355 nm system.



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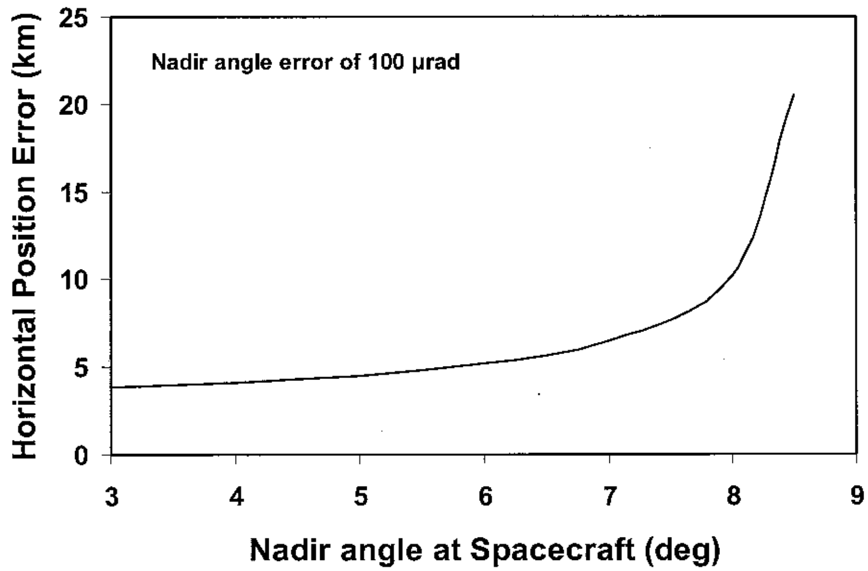
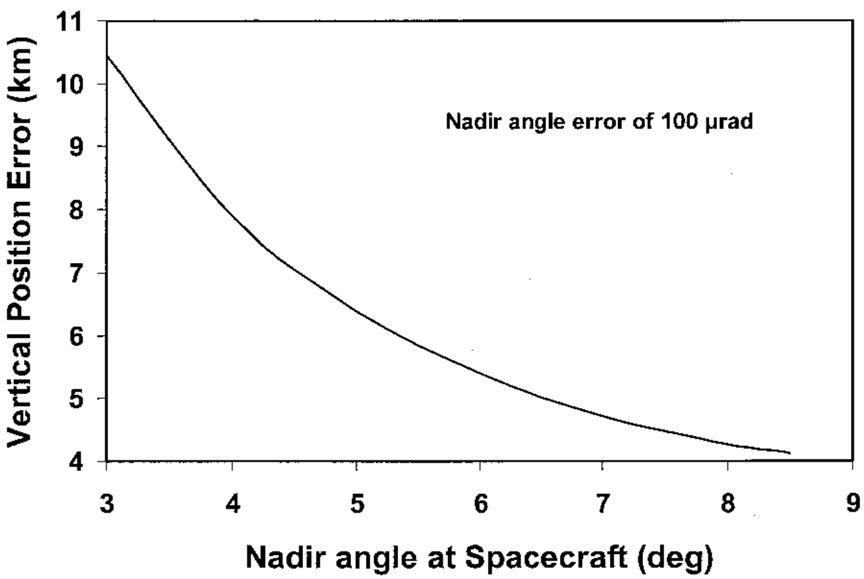
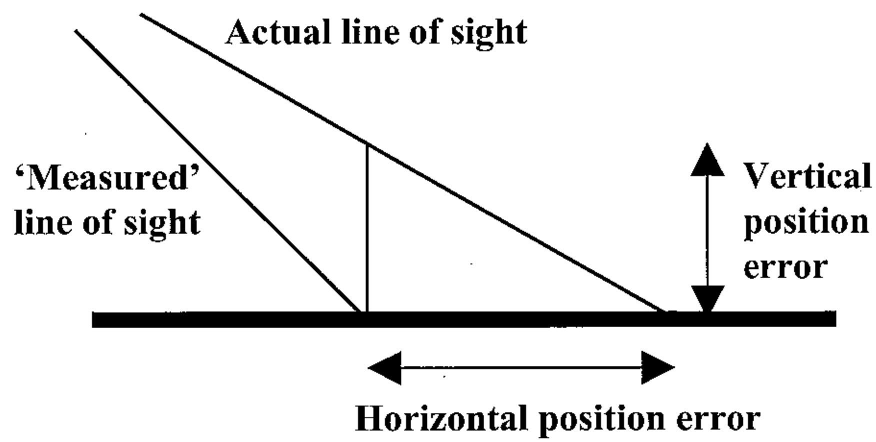
Position Knowledge

Errors in the pointing angle knowledge result in an incorrect position assignment.

If we wish to place the measurement to within 500m in the vertical we will require ~ 5 - 12 μrad pointing knowledge but atmospheric refraction (see previously) may prevent this level of position knowledge from being achieved even with perfect attitude knowledge systems.







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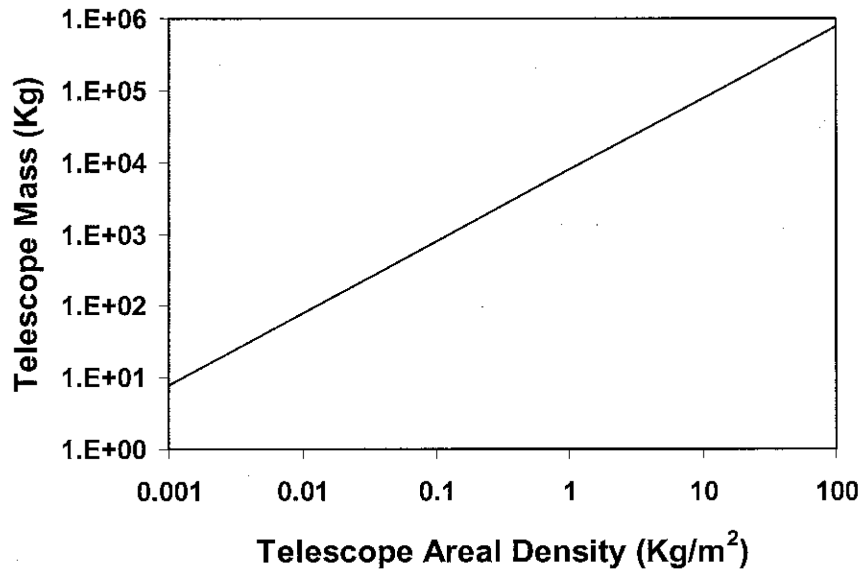
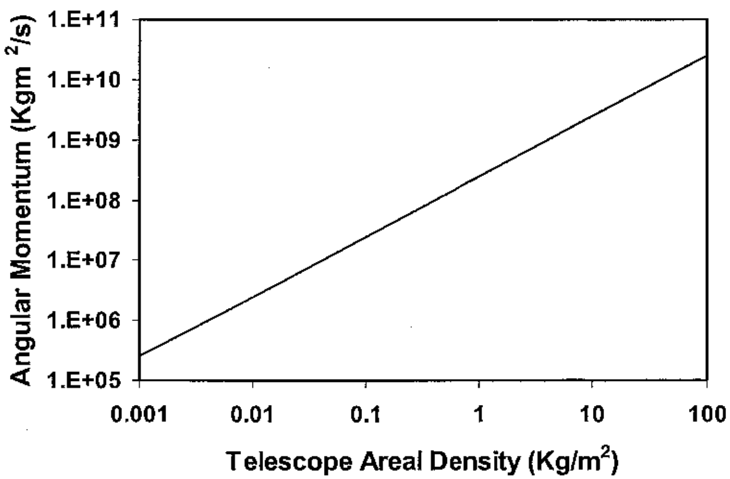
Pointing a 100 m Optic

Conventional lidar design concepts have relied on a scanner or rotating telescope. A ~100m diameter telescope of any design will have considerable mass and moment of inertia.

Current space telescope development is for the realisation of practical < 10 Kg/m^2 areal densities. To obtain a 'reasonable' mass for the geolidar telescope will require significant improvement on this. For the scan patterns discussed for the geostationary lidar, we are looking at scan rates up to ~800 μrad/sec. This is much smaller than the scan rate of a typical LEO lidar design (~0.3 rad/sec).





The large size of the telescope still leads to a large angular momentum making scanning of the entire telescope in the step/stare pattern required a difficult proposition. Alternate scan techniques would probably be required. (e.g. moving secondary c.f. Arecibo radio telescope & other more advanced concepts).

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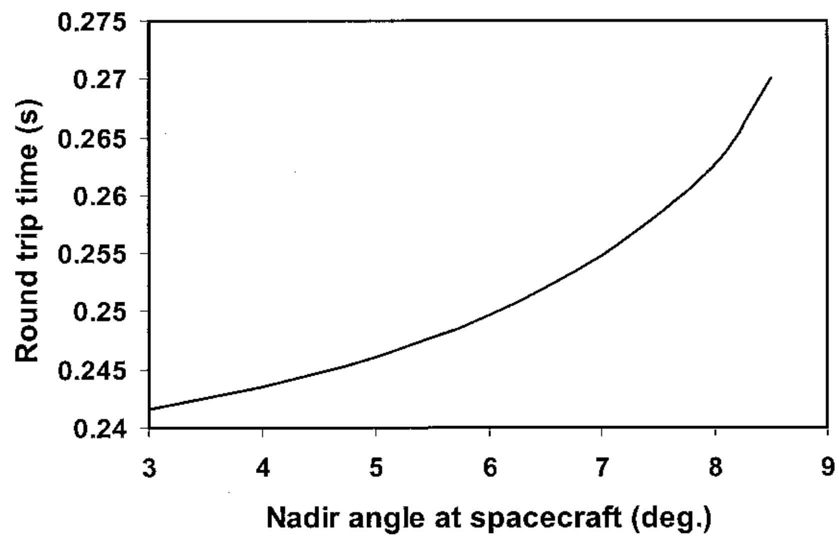
Pointing Stability

There are two pointing stability requirements.

The first is that during the round trip time of flight of ~0.25 seconds the alignment between the transmit and receive optical apertures must be maintained to prevent degradation in SNR. For a nominal target size of ~<20 km this requires maintaining alignment to better than 40 μrad over 0.25 seconds.

The second requirement is that during the 5s data collection time the position error for the measurement volume does not exceed the desired accuracy. For the nominal 500m height assignment discussed previously this leads to a 1 – 2 μrad/s rate requirement for the targeted mode.



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Pointing Knowledge and Control

Spacecraft	Pointing Control (deg)	(µrad)	Pointing Knowledge (deg)	(µrad)	Rate Error (deg/sec)	(µrad/sec)
Clementine	0.05	873	0.03	524		
Discovery/NEAR	0.1	1745	0.003	52		
Discovery/Mars Pathfinder	1	17453	N/a			
Explorer/SMEX-SWAS	0.0008	14	-			
Explorer/SMEX-TRACE	0.006	105	-			
Explorer/MIDEX-MAP	0.03	524	-			
New Millennium/Deep Space 1	0.2	3491	N/a			
New Millennium/Earth Observer 1	0.009	157	N/a			
SSTI/Lewis	-		0.004	70		
SSTI/Clark	2	34907	0.02	349		
Surveyor/ Mars Global Surveyor	0.57	9948	0.18	3142		
Surveyor/ Mars Surveyor '98 Orbiter	1.1	19199	N/a			
RADCAL	10	174533	5	87266		
STS Orbiter[2]	0.1	1745	0.1	1745	0.2 or larger	3491 or larger
NPOESS (0- 10 Hz) RMS/axis	0.01	175	0.002778	48	0.03	524
NPOESS (>10 Hz) RMS/axis			0.001389	24		

This chart shows the pointing control and knowledge capabilities of various spacecraft.

Sources:
"The Cosmos on a Shoestring: Small Spacecraft for Space and Earth Science", Liam Sarsfield, Critical Technologies Institute, RAND (1998).
"Hitchhiker Accommodations and Requirements Specifications (CARS)", HHG-730-1503-07, NASA GSFC, (December 1996).
"Interface Requirements Document (IRD) for NPOESS Spacecraft and Sensors", NPOESS Integrated Program Office, Version 3, (May 1999).

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Comments

The requirements for a geostationary lidar system are driven by the nadir angle at which it operates and there is a knee in the design curve in the 6-7 degree nadir angle region above which the requirements become considerably tighter. Limiting the nadir angle to slightly larger than 6 deg would require 4 spacecraft to completely cover the equator but would leave regions above (North) and below (South) ~ 45 deg latitude uncovered.

For a Doppler lidar instrument in a LEO orbit the instrument and spacecraft pointing requirements are driven by the line of sight velocity accuracy due to the large component of the relative velocity between the spacecraft and the target. For GEO orbit this relative velocity is removed and the pointing knowledge requirements are driven by the position knowledge requirements.

The requirements for a DIAL system operating from a GEO orbit will be more stringent than from LEO because of increased sensitivity of the differential absorption to errors in the nadir angle.

Although this study was to assume the availability of a 100 m class telescope a brief assessment of the optical properties required was carried out. In general the stressing requirement for such a large telescope will be maintaining its stability – the optical quality required will be fairly modest and both this author and a number of individuals with whom he spoke felt that the stability requirements are more challenging than the optical finish requirements.

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