

MODULE 4 LESSON 1

LIGHT DETECTION AND RANGING

Module 4 | LIDAR Sensing

In this module...

- Operating principles of LIDAR sensors
- Basic LIDAR sensor models
- Working with LIDAR point clouds
- Localization via point cloud registration

Light Detection and Ranging Sensors

By the end of this lesson, you will be able to...

- Describe the operating principles of LIDAR sensors
- Use basic LIDAR sensor models in 2D and 3D
- Describe the major sources of measurement error for LIDAR sensors

LIDAR: Light Detection and Ranging



Velodyne



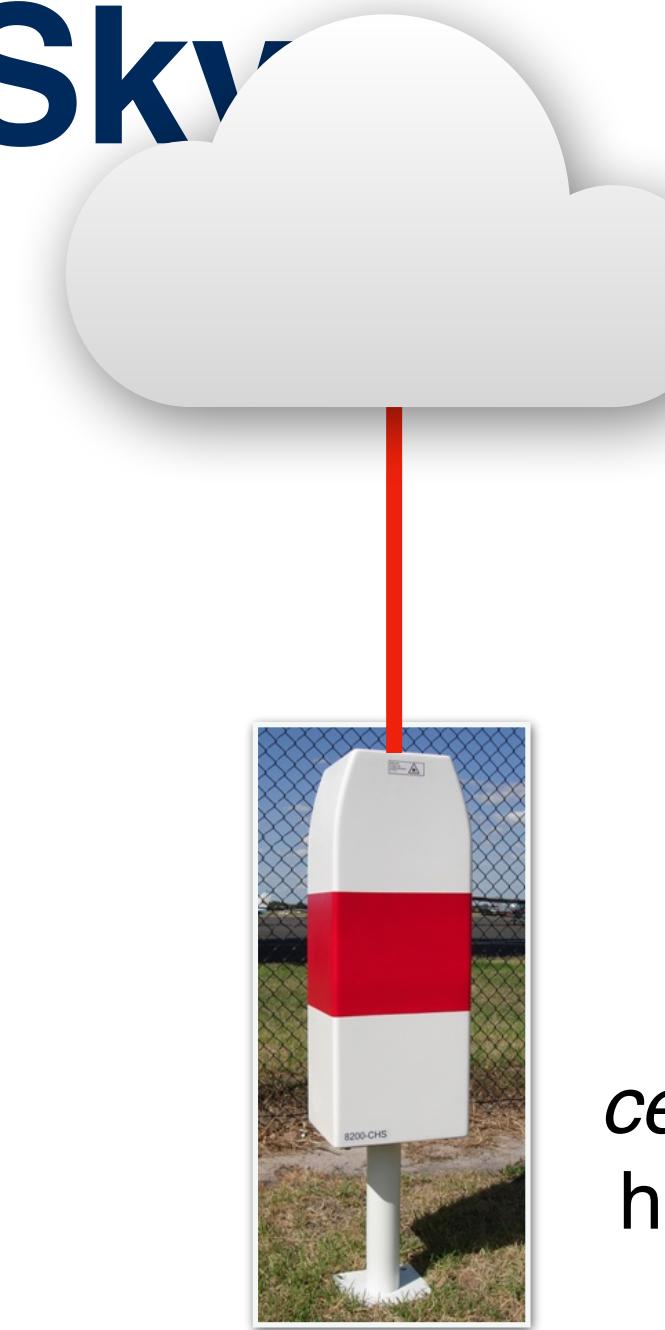
Hokuyo



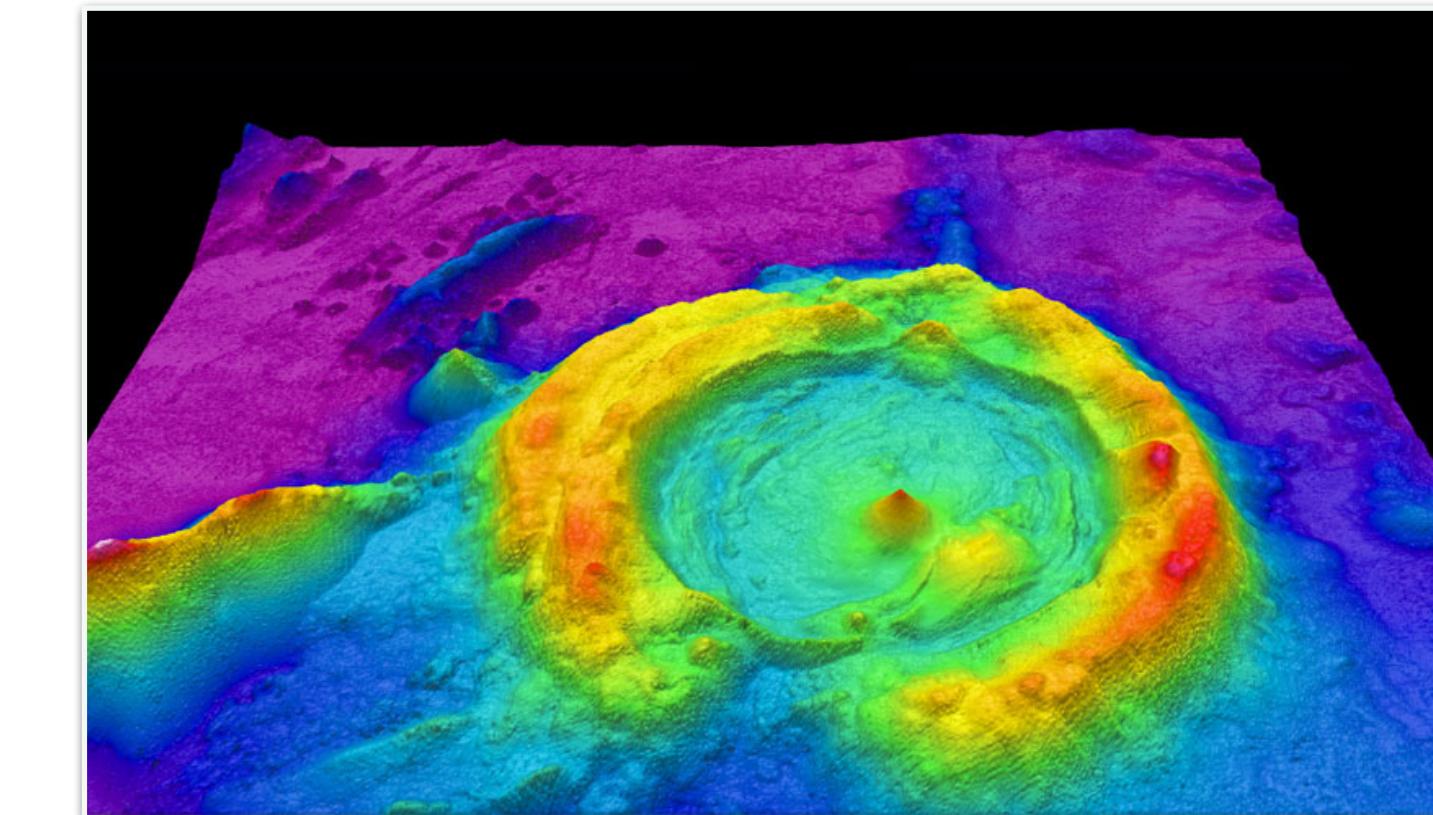
SICK

Measuring Earth, Sea and Sky

- LIDAR originated in the 1960s shortly after the invention of the laser
- First used by meteorologists to measure clouds
- Now commonly used for surveying and mapping

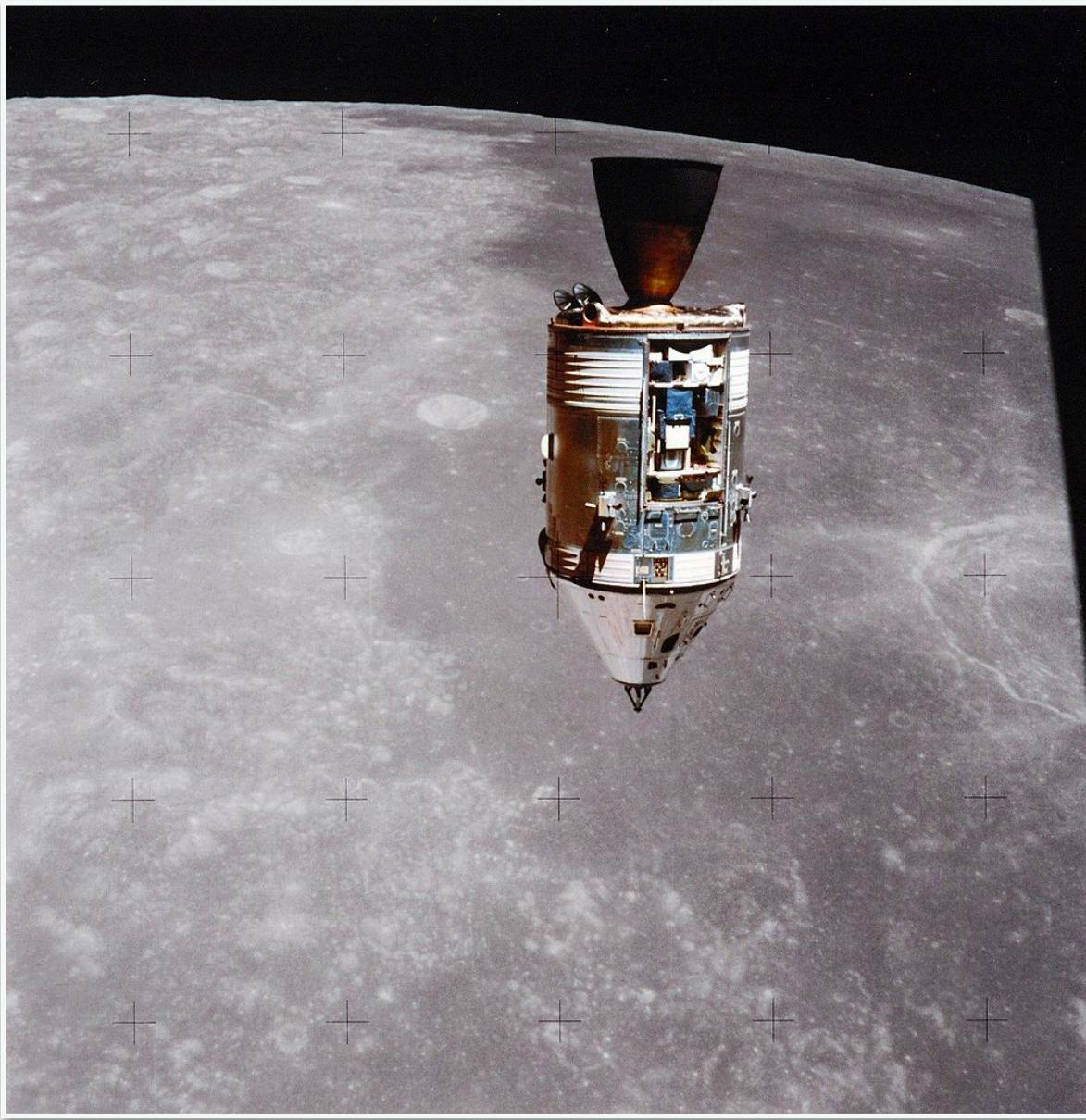


A ground-based
ceilometer measures the
height of a cloud ceiling

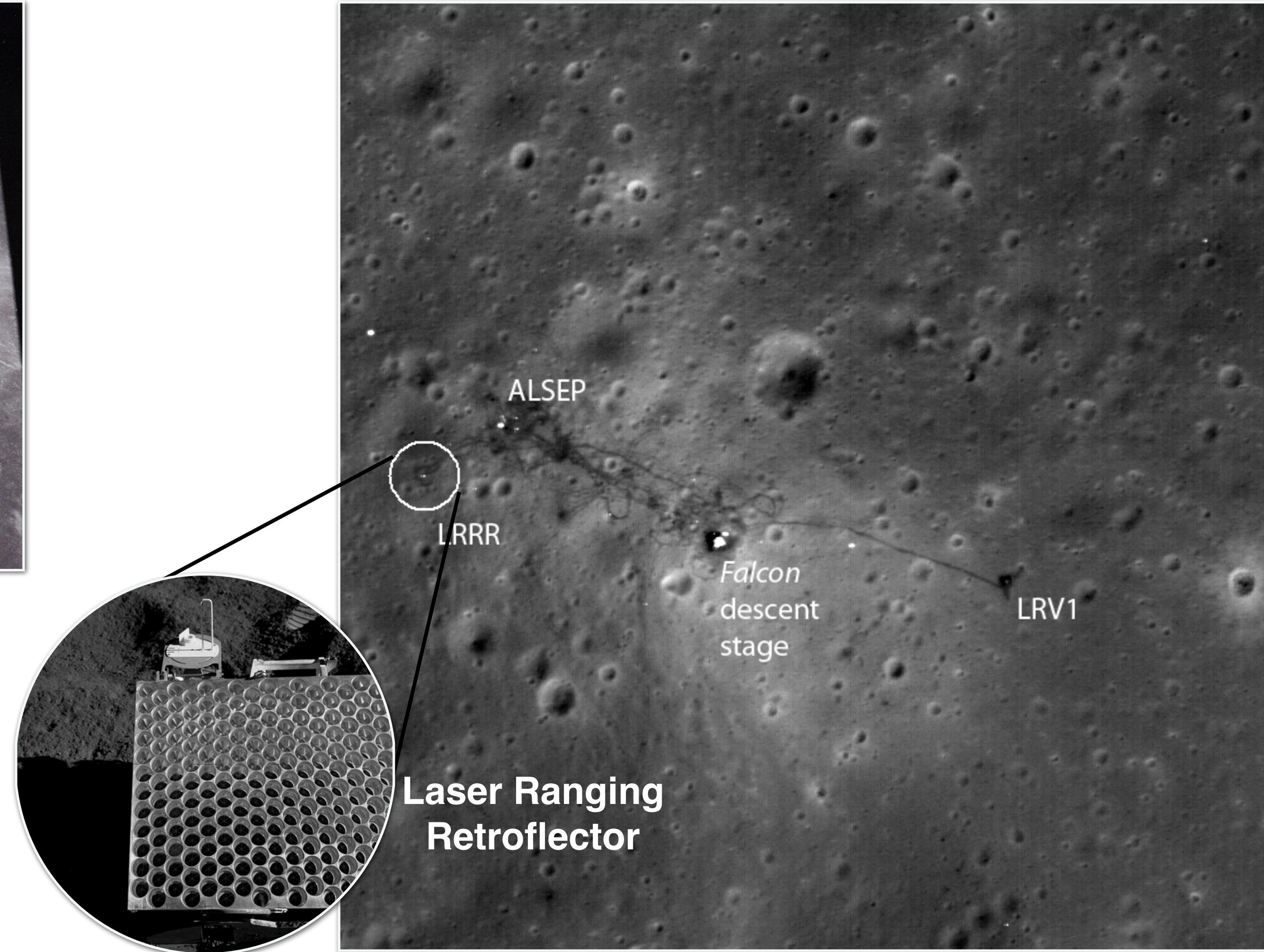


An airborne LIDAR measures the
geometry of the seafloor

Apollo 15



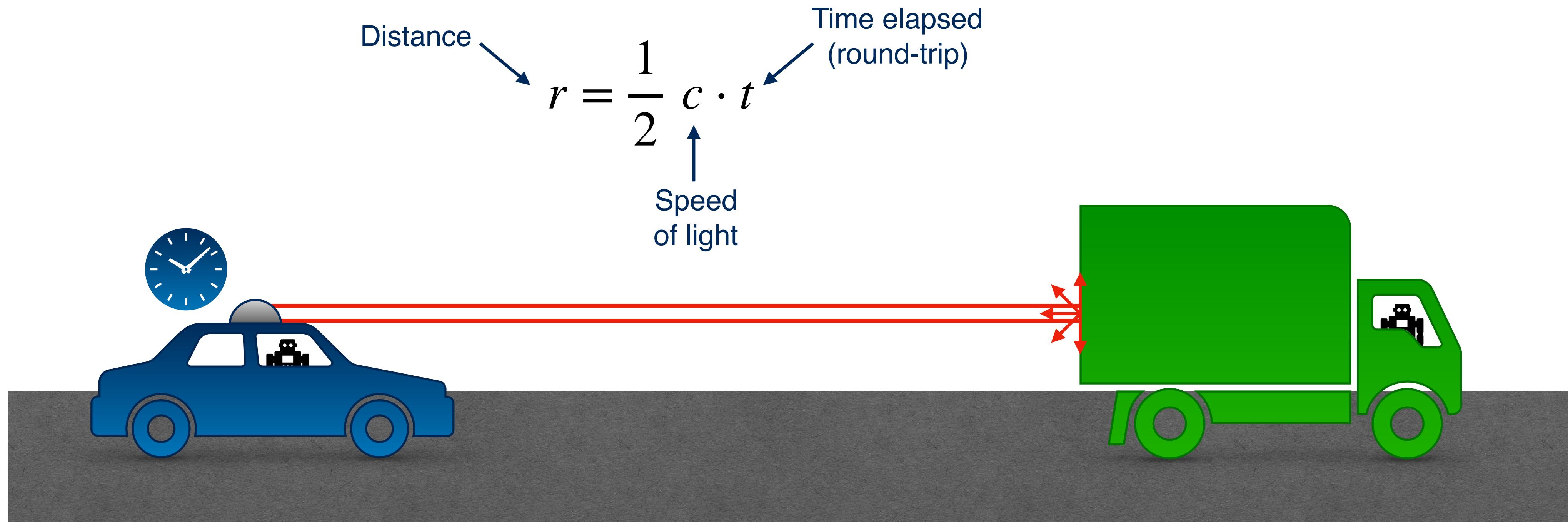
Apollo 15 Command Module



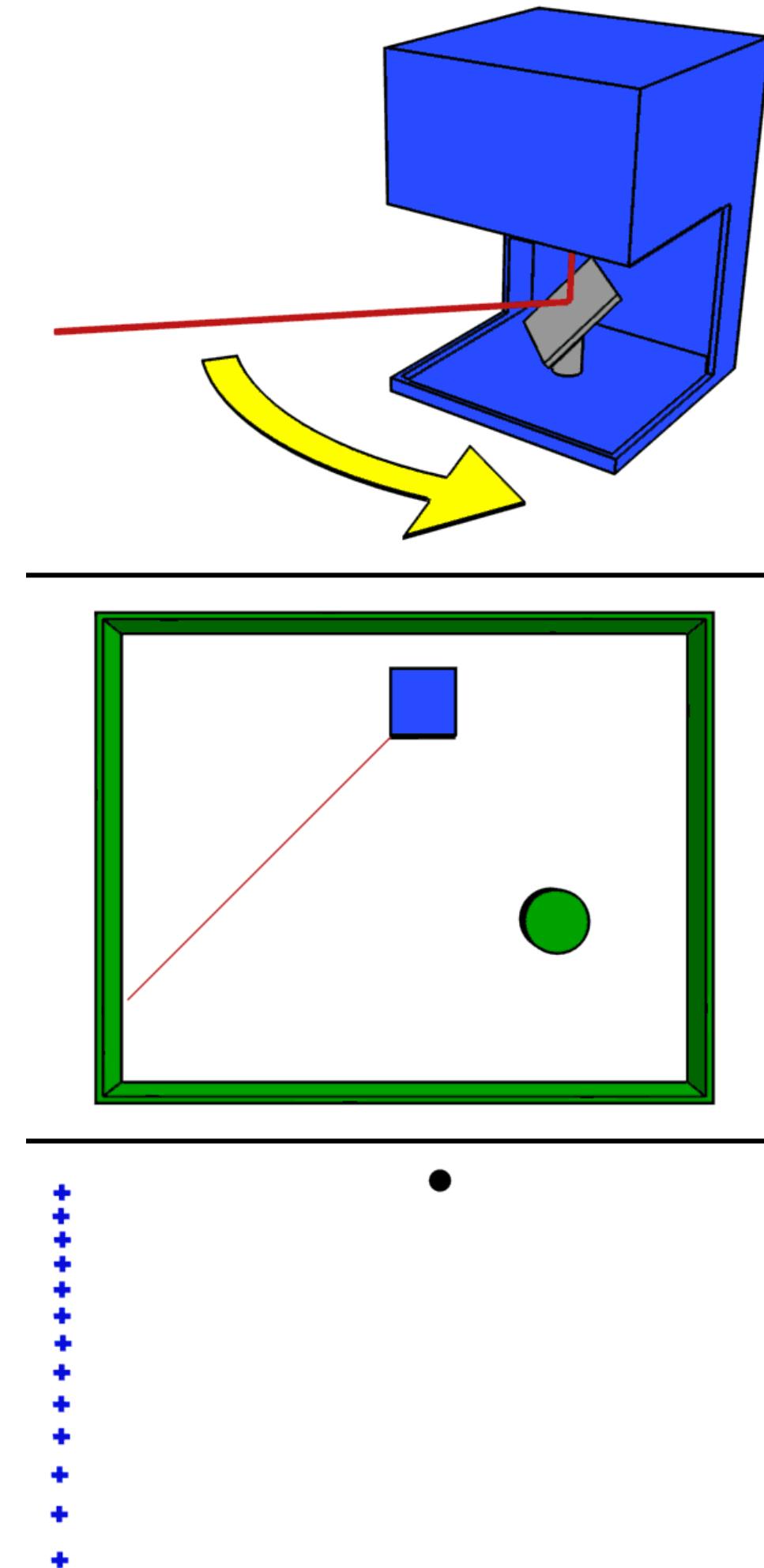
Apollo 15 Landing Site

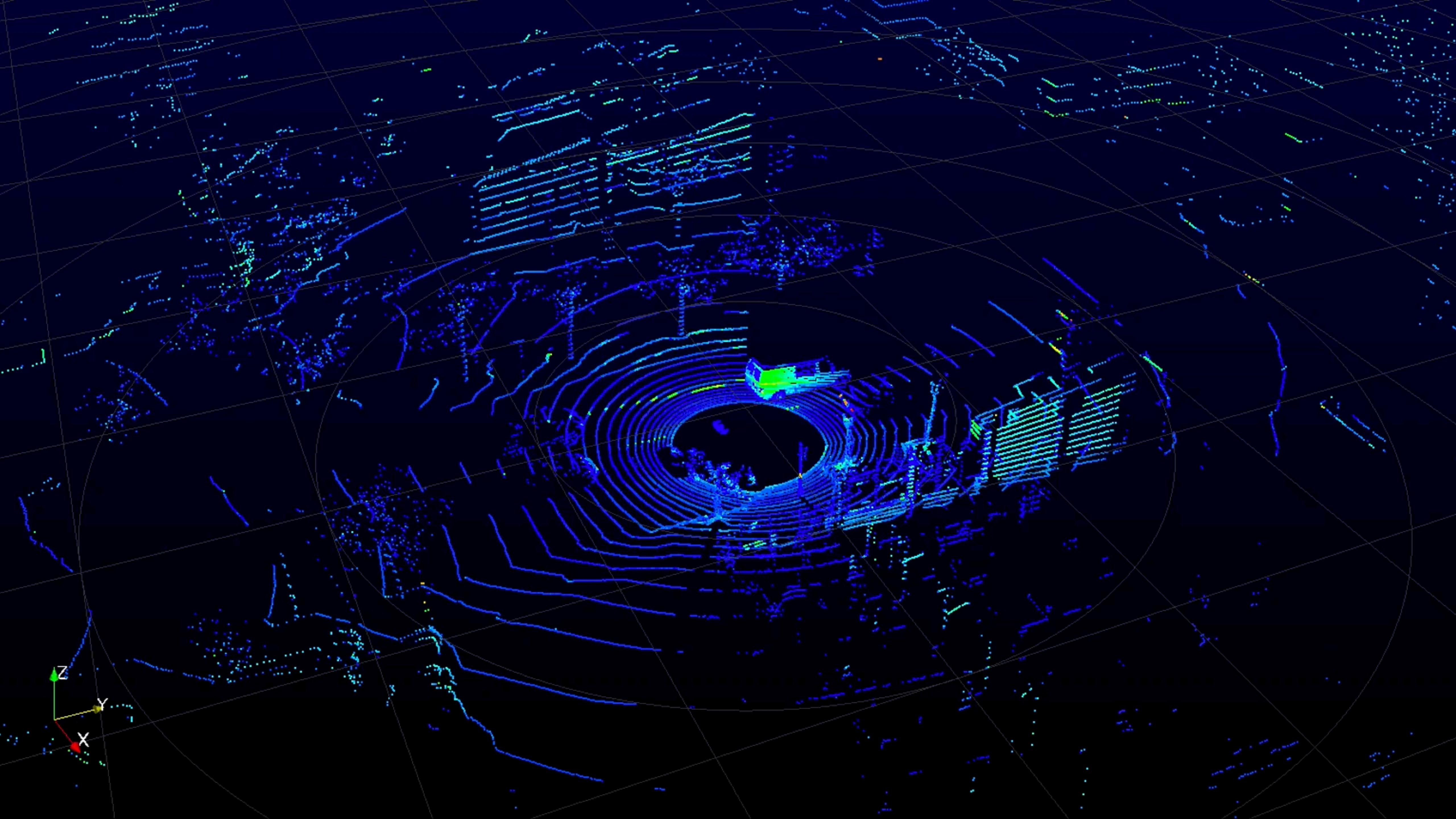
**Laser Ranging
Retroreflector**

Measuring Distance with Time-of-Flight



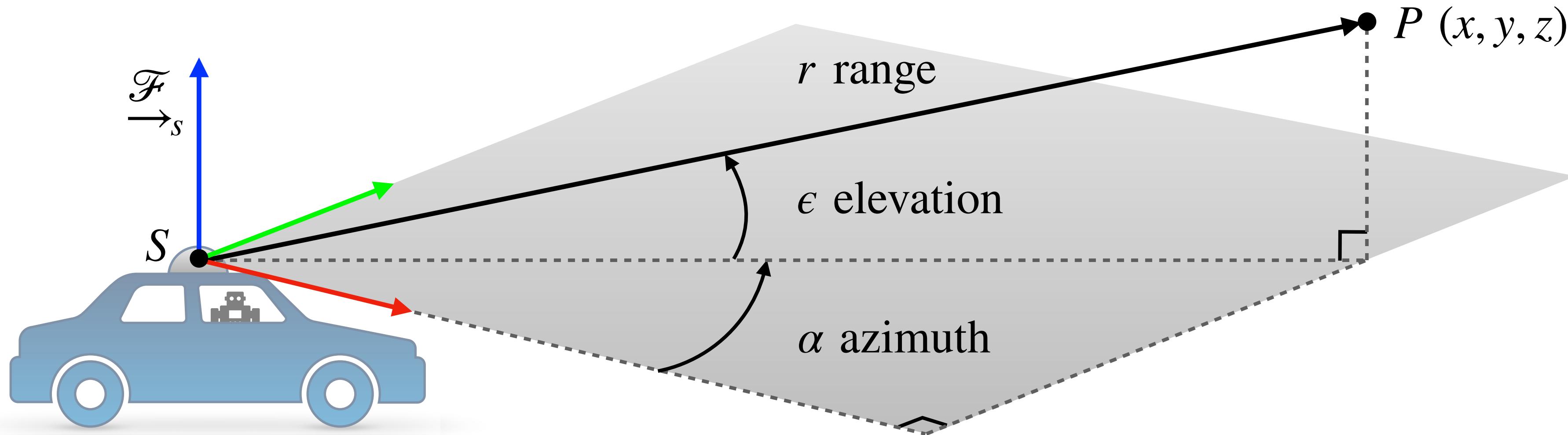
Measuring distance with time-of-flight



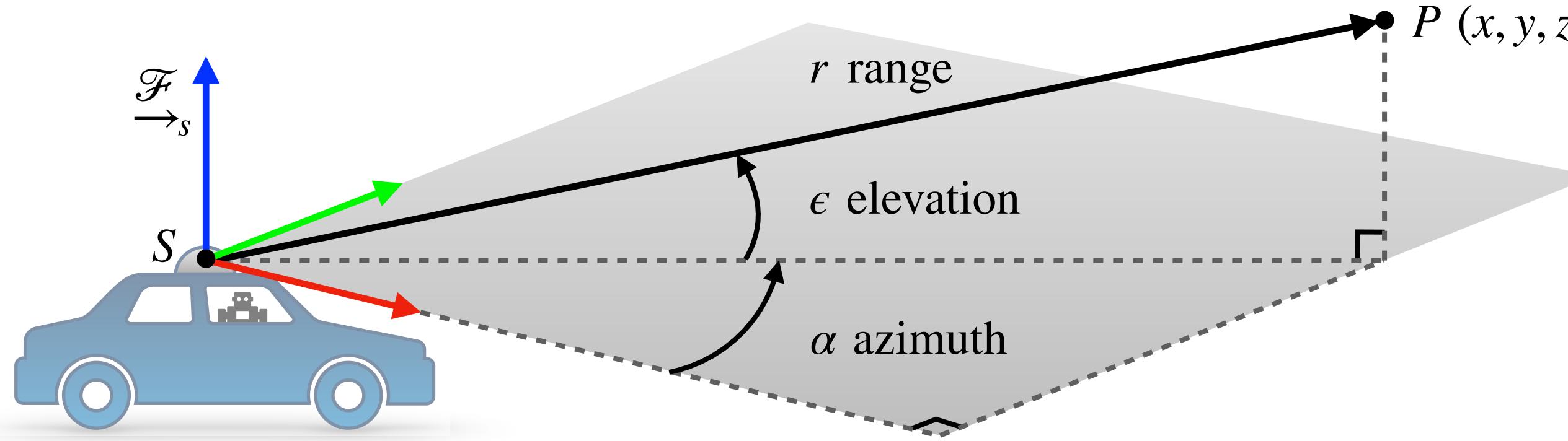


Measurement Models for 3D LIDAR Sensors

3D LIDAR sensors report *range*, *azimuth angle* and *elevation angle* (+ return intensity)



Measurement models for 3D LIDAR sensors



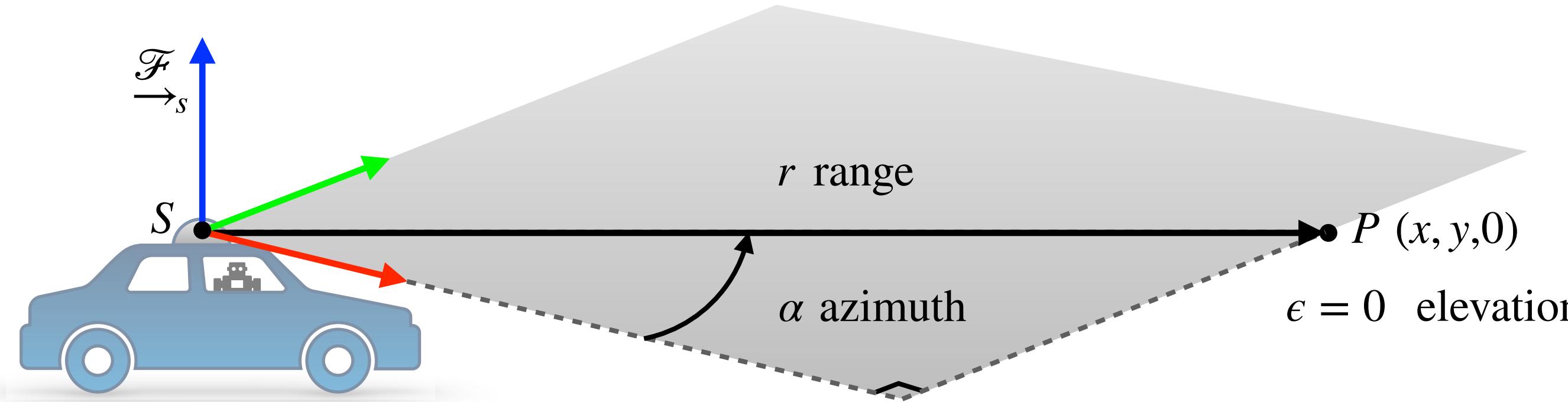
Inverse Sensor Model

$$\begin{bmatrix} x \\ y \\ z \end{bmatrix} = \mathbf{h}^{-1}(r, \alpha, \epsilon) = \begin{bmatrix} r \cos \alpha \cos \epsilon \\ r \sin \alpha \cos \epsilon \\ r \sin \epsilon \end{bmatrix}$$

Forwards Sensor Model

$$\begin{bmatrix} r \\ \alpha \\ \epsilon \end{bmatrix} = \mathbf{h}(x, y, z) = \begin{bmatrix} \sqrt{x^2 + y^2 + z^2} \\ \tan^{-1}\left(\frac{y}{x}\right) \\ \sin^{-1}\left(\frac{z}{\sqrt{x^2 + y^2 + z^2}}\right) \end{bmatrix}$$

Measurement models for 2D LIDAR sensors



Inverse Sensor Model

$$\begin{bmatrix} x \\ y \\ 0 \end{bmatrix} = \mathbf{h}^{-1}(r, \alpha, 0) = \begin{bmatrix} r \cos \alpha \\ r \sin \alpha \\ 0 \end{bmatrix}$$

Forwards Sensor Model

$$\begin{bmatrix} r \\ \alpha \\ 0 \end{bmatrix} = \mathbf{h}(x, y, 0) = \begin{bmatrix} \sqrt{x^2 + y^2} \\ \tan^{-1}\left(\frac{y}{x}\right) \\ 0 \end{bmatrix}$$

Sources of Measurement Noise

- Uncertainty in determining the exact time of arrival of the reflected signal
- Uncertainty in measuring the exact orientation of the mirror
- Interaction with the target (surface absorption, specular reflection, etc.)
- Variation of propagation speed (e.g., through materials)

Forwards Sensor Model (with Noise)

$$\begin{bmatrix} r \\ \alpha \\ \epsilon \end{bmatrix} = \mathbf{h}(x, y, z, \mathbf{v}) = \begin{bmatrix} \sqrt{x^2 + y^2 + z^2} \\ \tan^{-1}\left(\frac{y}{x}\right) \\ \sin^{-1}\left(\frac{z}{\sqrt{x^2 + y^2 + z^2}}\right) \end{bmatrix} + \mathbf{v}$$

$$\mathbf{v} \sim \mathcal{N}(\mathbf{0}, \mathbf{R})$$

Motion Distortion

- Typical scan rate for a 3D LIDAR is 5-20 Hz
- For a moving vehicle, each point in a scan is taken from a slightly different place
- Need to account for this if the vehicle is moving quickly, otherwise motion distortion becomes a problem

Summary I Light Detection and Ranging Sensors

- LIDAR sensors use laser pulses and time-of-flight to measure distances to objects along a specific direction
- 2D and 3D LIDARs work by sweeping the laser pulses in many directions across the whole environment
- In the next video we'll discuss point clouds and how to use them for state estimation