Measuring Altitude

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Techniques for measuring altitude

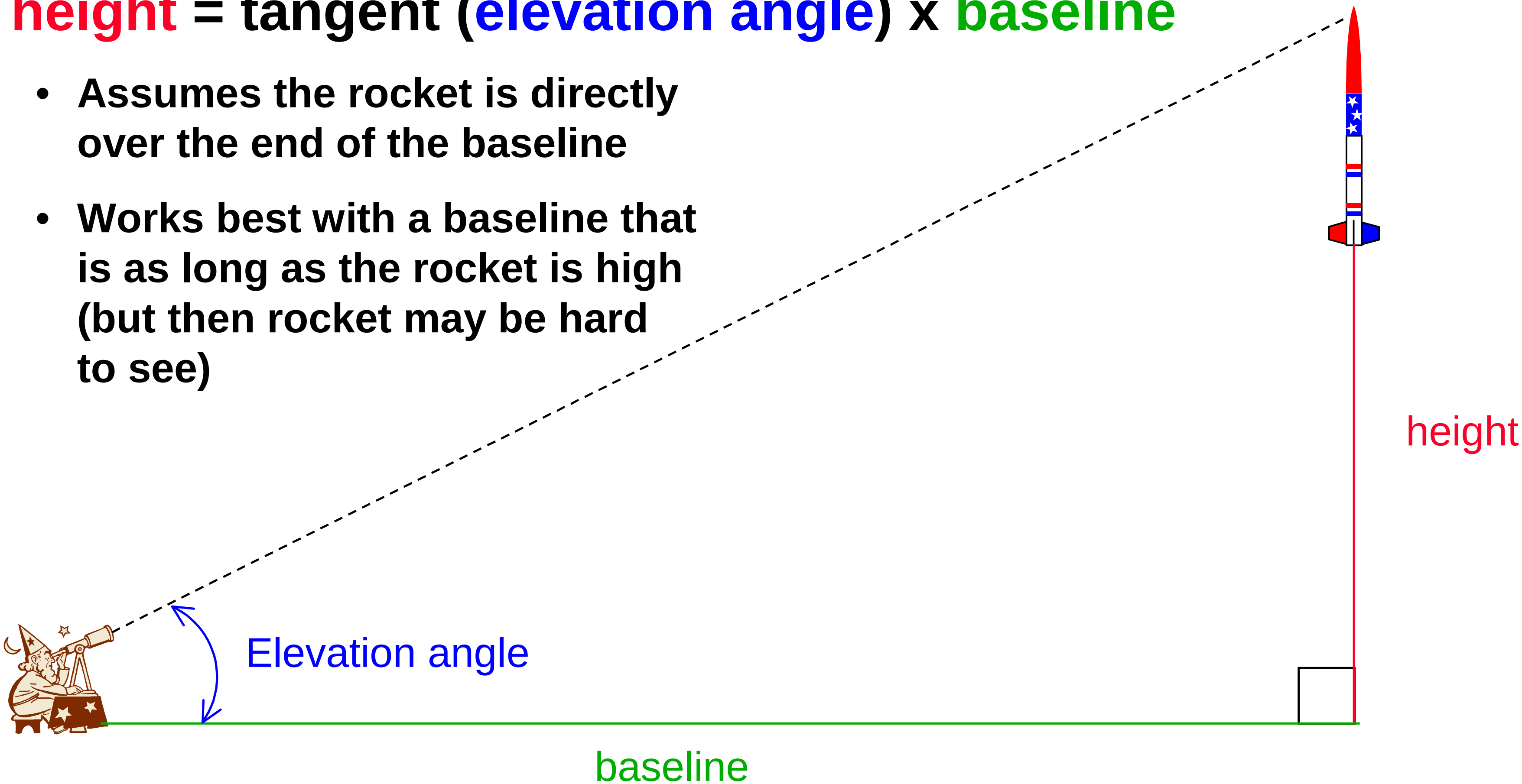
- Dropping standard objects at apogee
  - Ping pong balls
  - Standard weight and streamer combination
  - Can be accurate but hard to see
- Altimeters
  - Accelerometer
  - Barometric
  - Add weight and expense
- Theodolites
  - Single station
  - Multiple station
  - No change to the rocket
  - Still the gold standard for NAR

Single station measurement

Simple trigonometry:

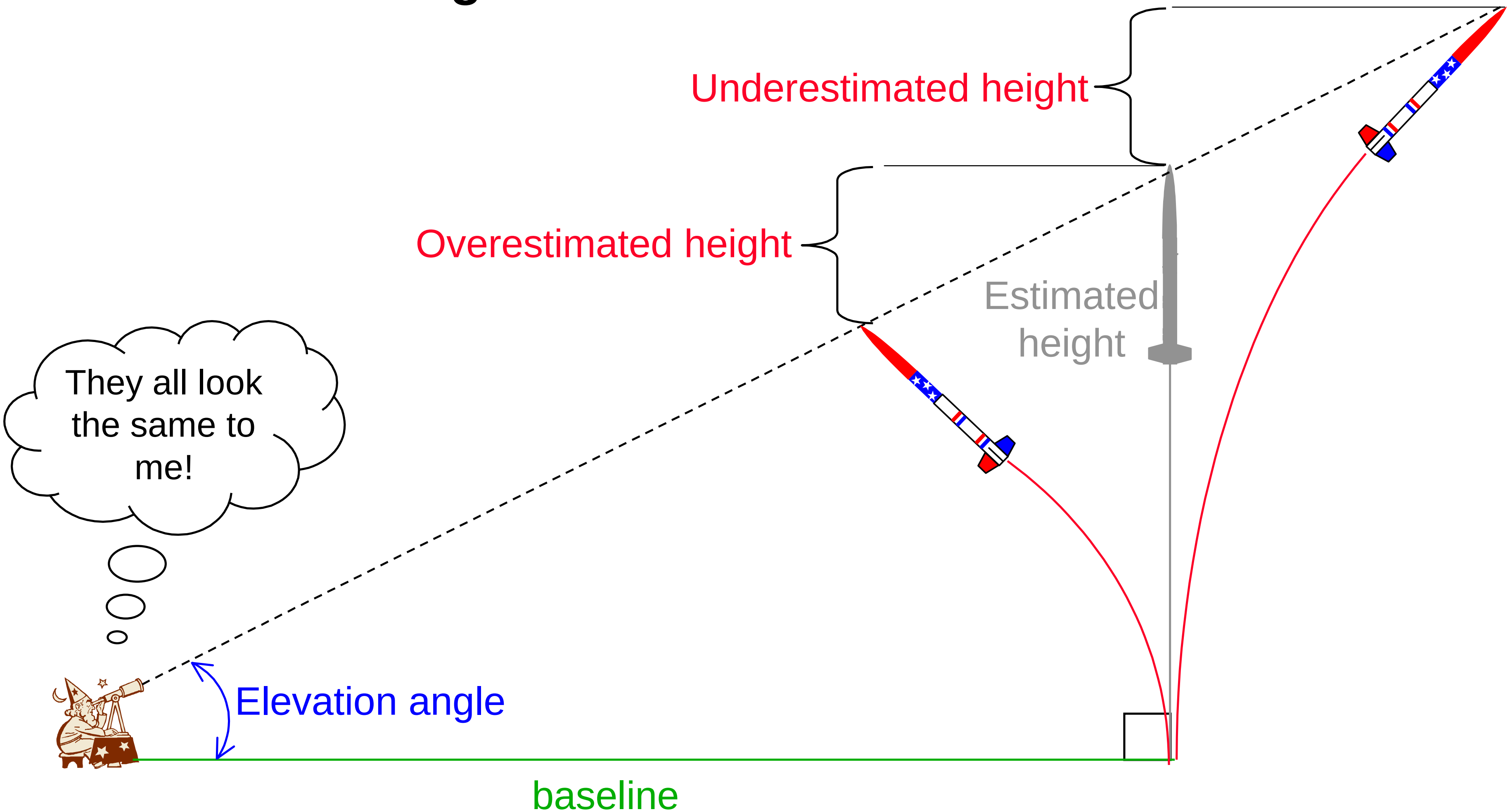
height = tangent (elevation angle) x baseline

- **Assumes the rocket is directly over the end of the baseline**
- **Works best with a baseline that is as long as the rocket is high (but then rocket may be hard to see)**



Single station measurement error

Weather cocking leads to errors!



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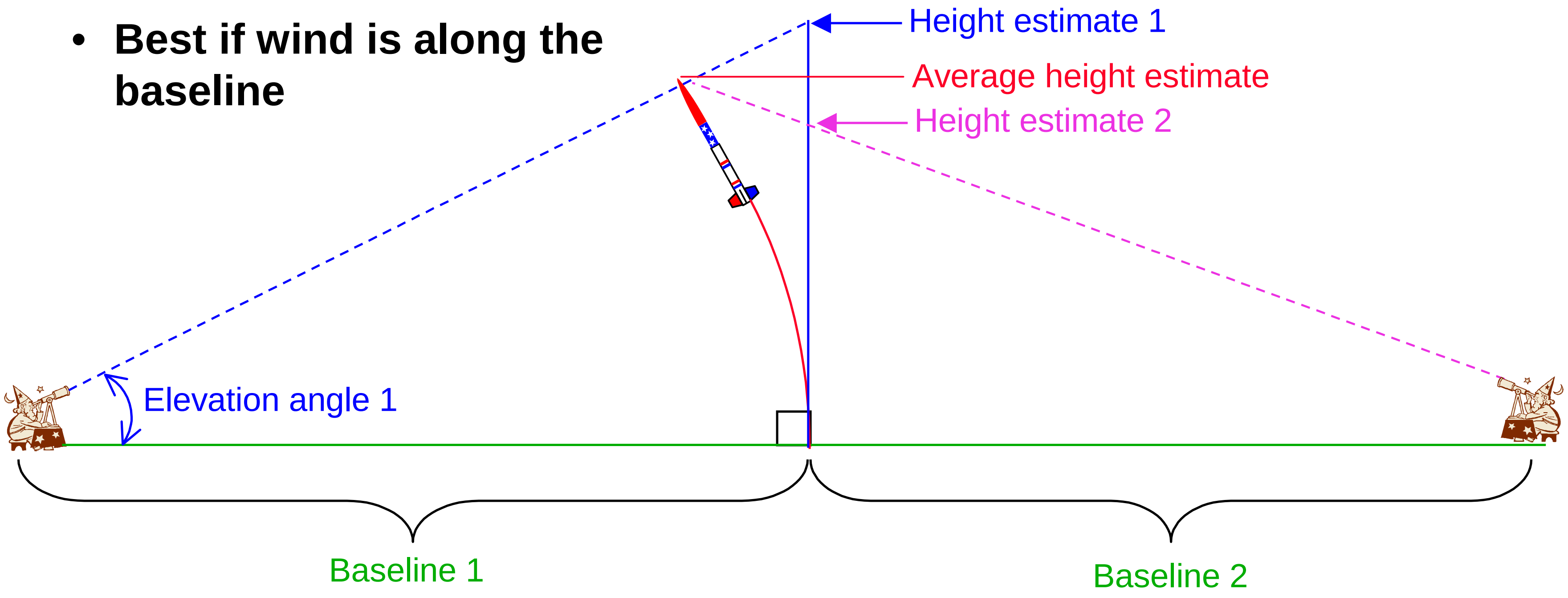
Single station error correction

Additional stations can help, but increase the variability of the estimate

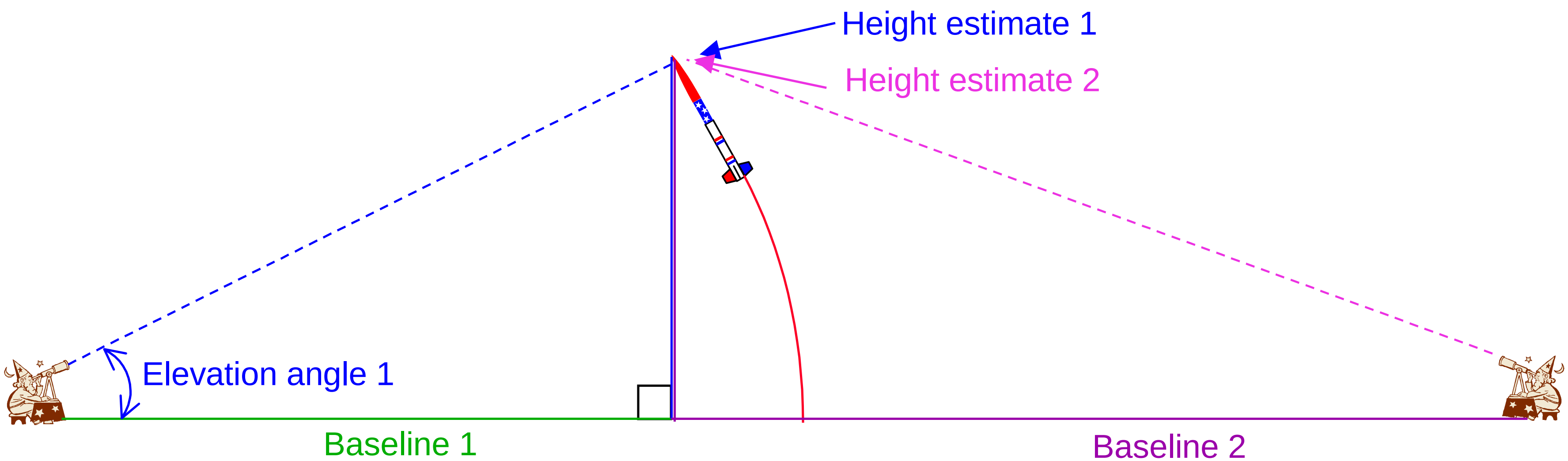
- **Best if baselines are orthogonal**
- **Best if wind is along the baseline**



Need for multiple station measurement

What if we knew the *real* baseline?

- **Estimates would be very accurate!**



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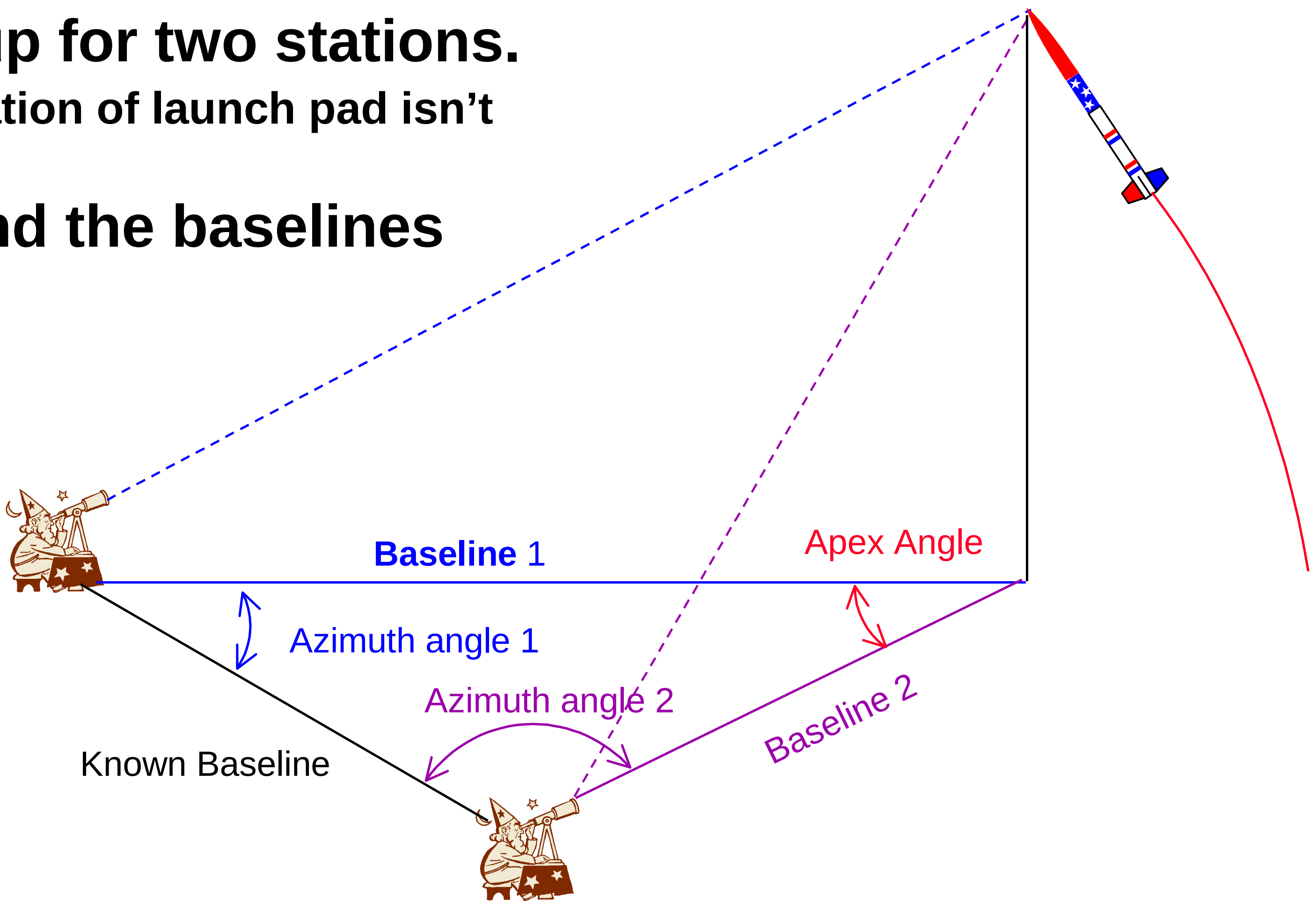
Two station measurement
(One method)

Basic set up for two stations.

(Note that location of launch pad isn't very relevant!)

Step 1: Find the baselines



Apex Angle = 180 - azimuth angle 1 - azimuth angle 2

Baseline 1 = known baseline * sin(azimuth angle 2) / sin(apex angle)

Baseline 2 = known baseline * sin(azimuth angle 1) / sin(apex angle)

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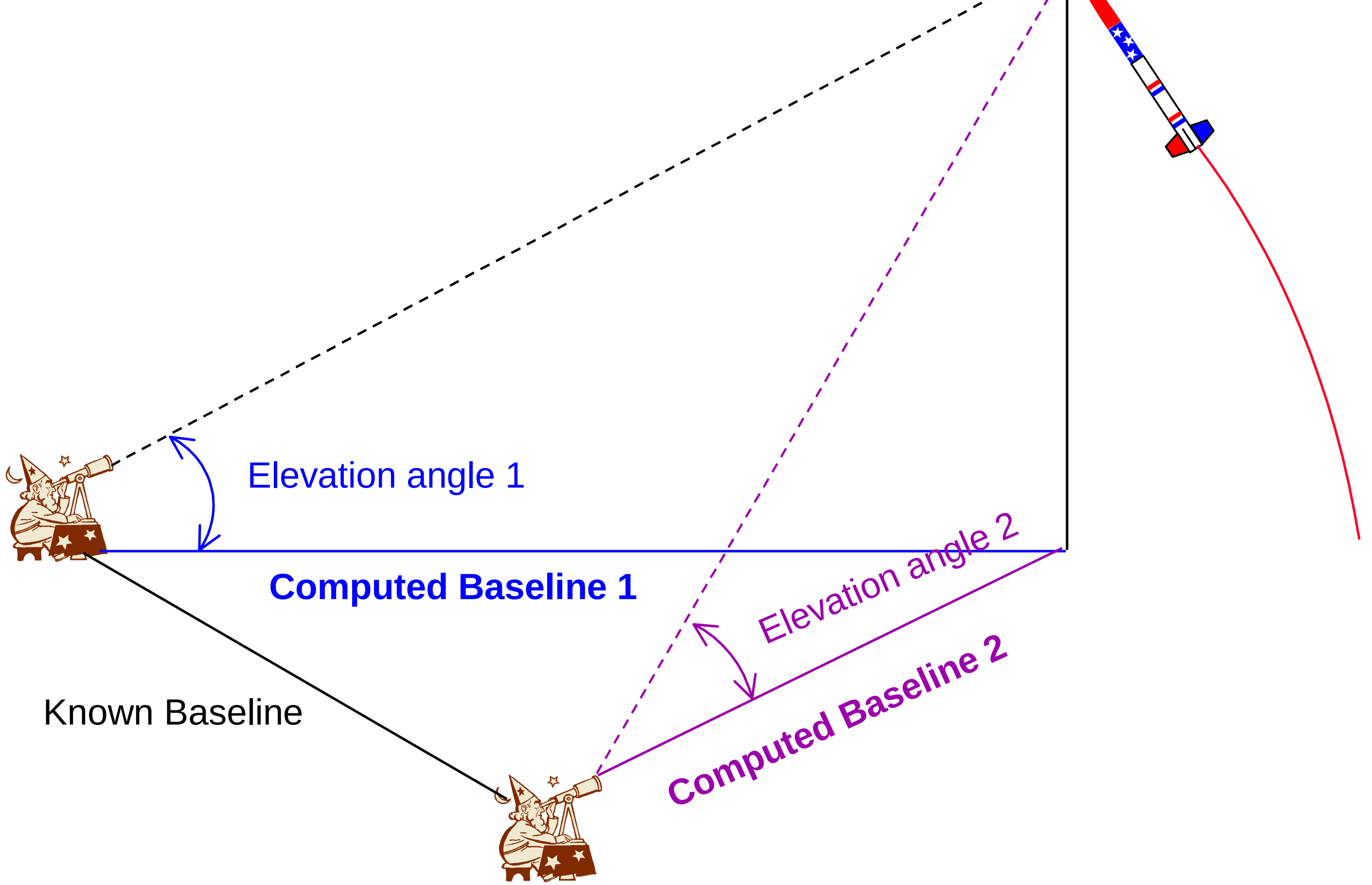
Two station measurement

Step 2: Determine two estimates of altitude, one from each baseline

Estimate 1 = Baseline 1 * tan(Elevation angle 1)

Estimate 2 = Baseline 2 * tan(Elevation angle 2)



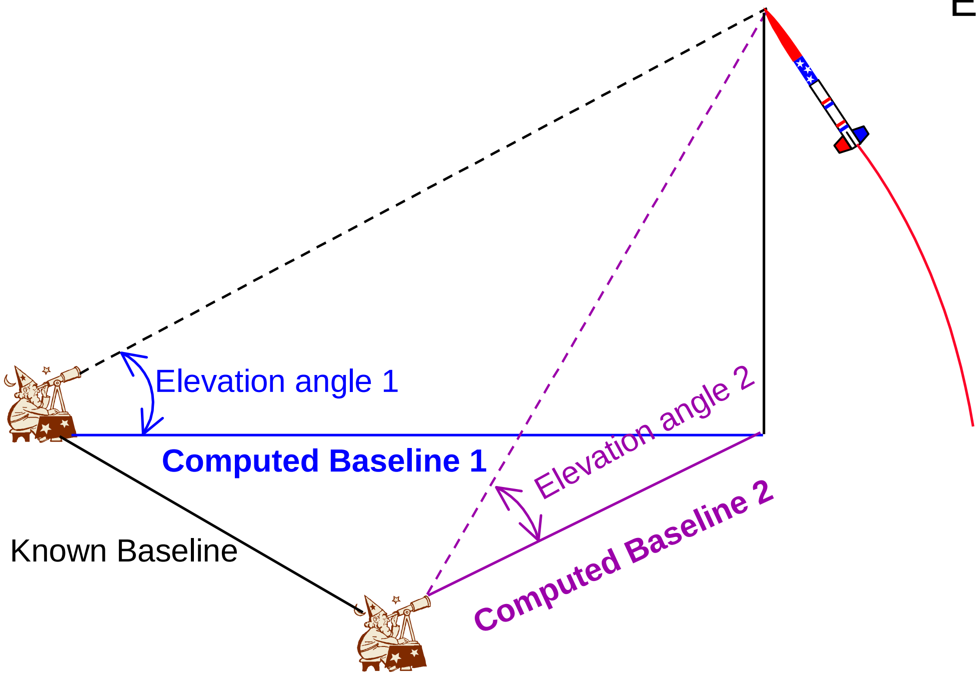
Two station measurement

Step 3: Compare two estimates

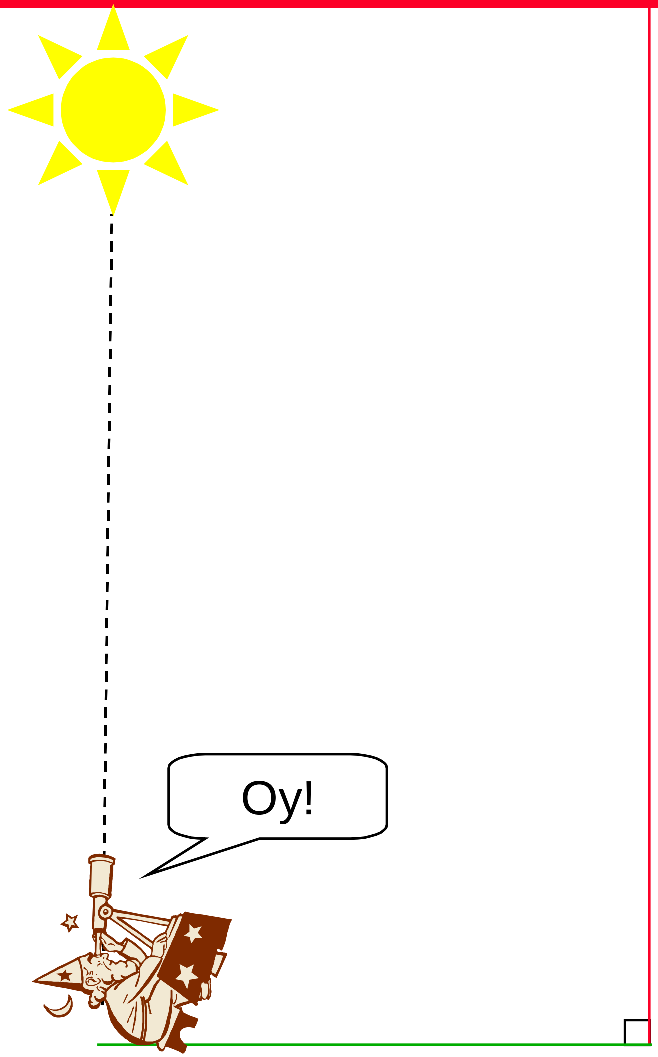
- **If difference is less than 10% ("closed track"), use average**
- **If difference is greater than 10% ("open track"), don't count**

$$\text{Error} = 100 * \frac{(\text{Estimate 1} - \text{Estimate 2})}{(\text{Estimate 1} + \text{Estimate 2})}$$

$$\text{Altitude} = (\text{Estimate 1} + \text{Estimate 2}) / 2$$



Implementation details



- Minimum error when measured angles are near 45 degrees. The sine function doesn’t change much near 90 degrees, and the tangent of 90 degrees is infinity!
- To avoid looking into the sun, it is best to have the baseline run East-West, and to be offset to the south of the pads