Copernicus on Trial

The experiments he could not perform.

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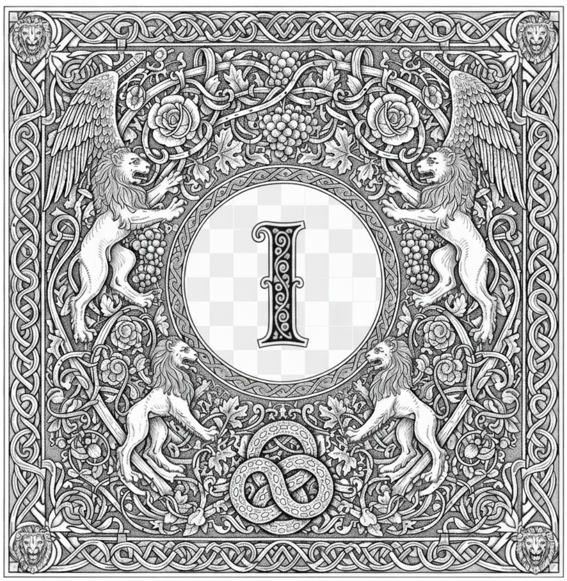
Tangent Press

Contents


I

Part I

INTRODUCTION

Chapter 1

Why This Book Exists

If you have not run into anyone who questions the shape of the Earth, consider yourself lucky. Speaking for myself, I think I was a lot happier as a kid watching NASA do its magic on TV. Throughout adolescence I wanted nothing else but to be an astronaut. As an adult, I've become jilted. I believe little (if anything) that NASA has "accomplished," and I can't honestly tell you whether we live on a spinning ball or a flat disc.

This book is an attempt to assemble claims, predictions, and experiments in one place so that the question can be approached with measurement rather than ridicule.

1.1 The state of the debate

The flat-Earth movement has grown dramatically since 2015. What was once a fringe curiosity is now a global phenomenon with millions of adherents, conferences, documentaries, and an active online presence.

The response from mainstream institutions has been largely dismissive. Scientists, educators, and media personalities tend to treat flat-Earth belief as a joke or a symptom of ignorance. The standard approach is ridicule: "Just look at a photo from space. Case closed."

This approach has failed. The movement continues to grow. And if you spend any time listening to flat-Earthers explain their position, you begin to understand why.

1.2 Why ridicule doesn't work

Flat-Earthers are not stupid. Many are intelligent, curious people who have simply lost trust in official sources of information. They have noticed inconsistencies in NASA footage. They have seen demonstrations that appear to show flat water over long distances. They have asked questions that their teachers could not answer.

When they raise these questions publicly, they are mocked. This confirms their suspicion that the establishment is hiding something. The ridicule becomes evidence of a cover-up.

Meanwhile, globe-Earthers rarely engage with the actual claims. They appeal to authority ("Scientists say..."), point to photos (which flat-Earthers believe are fabricated), or simply express disbelief that anyone could question something so "obvious."

Neither side convinces the other. The debate generates heat but no light.

1.3 What this book offers

This book takes a different approach. It does not mock. It does not appeal to authority. It does not ask you to trust NASA, the government, or any institution.

Instead, it offers experiments—things you can do yourself, with equipment you can buy, at locations you can visit—that produce different results depending on which model is correct.

If the Earth is a globe, certain experiments will produce certain results. If the Earth is flat, those same experiments will produce different results.

You do not need to trust anyone. You collect the data yourself. You interpret the results yourself. Whatever you find, you will know it firsthand rather than believing it secondhand.

1.4 Who this book is for

This book is for anyone who wants to settle the question through measurement rather than argument:

- **Flat-Earthers** who want a fair, scientific test of their model—not a debate rigged with appeals to authority.
- **Globe-Earthers** who want to move beyond "just trust the experts" and actually demonstrate the shape of the Earth.
- **Skeptics** who are tired of both sides talking past each other and want experiments that can actually resolve the dispute.

- **Educators** who want to teach critical thinking and the scientific method using a genuinely contested question.

1.5 What this book does not do

This book does not tell you what to believe. It does not argue for one model over another. It presents both models fairly, identifies testable predictions where they differ, and provides detailed instructions for conducting those tests.

If you perform the experiments and share your results, you contribute real data to a question that has been argued with rhetoric for too long.

The Earth is either curved or it is not. Let's find out.

Chapter 2

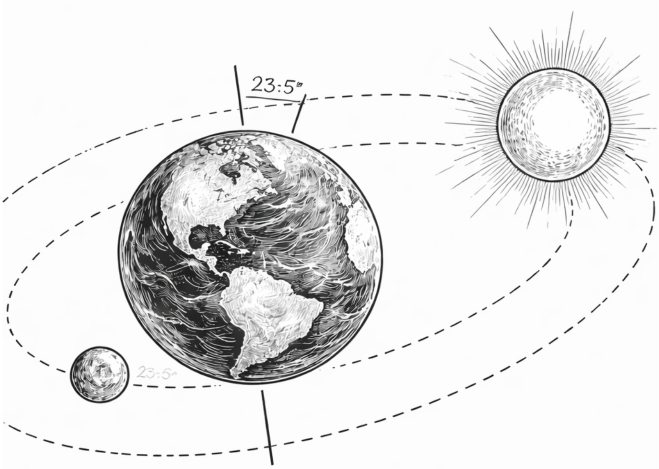
Heliocentric vs. Geocentric

Most of us were taught a heliocentric worldview: the Sun is the center of our solar system. Our Sun is a star—the closest star to Earth. When we look into the night sky, we see countless other stars. In the modern picture, each is associated with its own system of planets. Taken together, it can make a person feel insignificant: a speck on a speck among millions of specks.

The geocentric model claims that Earth is the center of our solar system and that the Sun, stars, and planets orbit the Earth. Today this is a rare view of cosmology. I mention it only because there are people who hold this view and the number seems to be growing; in modern internet discourse, it sometimes functions as a “baby step” toward flat-Earth cosmology.

Chapter 3

Globe Earth Cosmology

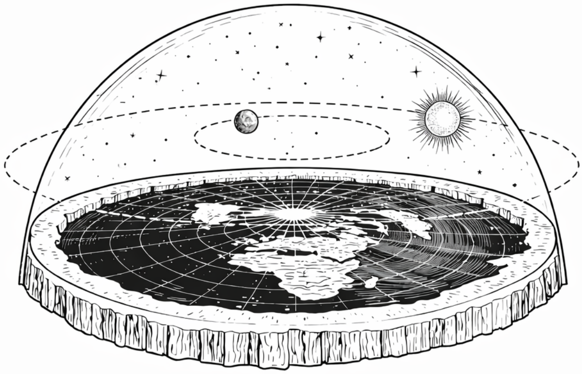


In the mainstream model:

- Earth is approximately an oblate spheroid with an equatorial radius of about 3,963 miles (6,378 km) and a polar radius of about 3,950 miles (6,357 km).
- The mean Earth–Sun distance is about 93.0 million miles (149.6 million km) (1 astronomical unit).
- The Sun's radius is about 432,300 miles (696,000 km); Earth's is about 3,959 miles (6,371 km) (mean).
- The Moon's mean distance is about 238,900 miles (384,400 km), and its radius is about 1,079 miles (1,737 km).
- Earth rotates once per sidereal day (about 23 hours 56 minutes), which corresponds to roughly 1,040 mph (465 m/s) at the equator.
- Earth orbits the Sun once per year at about 66,600 mph (29.8 km/s).
- The Sun orbits the center of the Milky Way, and the Milky Way is moving relative to other galaxies; on larger scales, the universe is expanding.

Chapter 4

Flat Earth Cosmology



Very few people take the time to understand even the basics of a flat-Earth cosmology. Before dismissing it as medieval nonsense, one should at least understand what is being claimed.

In the flat-Earth model, the Earth can be considered an upside down frisbee:

- The North Pole is at the center, with Polaris (the North Star) above it.
- Antarctica is not a continent at the bottom of a globe, but an "ice wall" around the perimeter.
- There is no South Pole in the usual sense; "south" is said to mean "toward the outer ring."
- The Earth is fixed, while the Sun and Moon are smaller, closer, and travel above the surface in paths (often described as circular or elliptical).

Additional claims in the flat-Earth model include:

- the Sun and Moon are much much closer than the Globe-Earth model suggests
- a ship travelling North goes toward the point in the middle of the frisbee
- a ship travelling South goes toward the rim of the frisbee
- "around the Earth" is interpreted in the same sense of "around the block"
- a ship travelling East or West goes in a circle around the pole
- the world is covered by an impenitrable dome called the firmament


II

Part II

OBSERVABLE PHENOMENA

Chapter 5

Introduction

This part catalogs observable phenomena that people argue about endlessly online. The pattern is always the same: someone presents an observation as "proof," the other side offers an alternative explanation, and the debate goes nowhere.

The purpose here is to show that **both models can account for these observations**. This does not mean both models are correct—it means these particular observations do not settle the question. If you want to prove which model is correct, you need a different kind of test (see Parts 3 and 4).

For each phenomenon below, we give:

- What is observed
- The globe-Earth explanation
- The flat-Earth explanation
- Why it does not settle the debate

Chapter 6

Sunrise and Sunset

Observed: The Sun appears in the east, arcs across the sky, and disappears in the west.

Globe explanation: Earth rotates on its axis. The Sun is fixed relative to Earth's daily motion. Sunrise and sunset are the moments when your location rotates into or out of the Sun's light.

Flat-Earth explanation: The Sun is smaller and closer than claimed, and travels in a circle above the flat plane. Sunset occurs when the Sun moves far enough away that perspective and atmospheric effects cause it to disappear from view.

Bottom line: Both models predict a Sun that appears to rise and set. Standing on the surface, you cannot distinguish between rotation into view and recession from view.

Chapter 7

Horizon from Aircraft

Observed: From commercial aircraft at 35,000–40,000 feet, the horizon appears flat. Passengers occasionally claim to see curvature, but pilots with flat cockpit windows generally do not.

Globe explanation: At 40,000 feet, the expected curvature is subtle (horizon dip of about 3.5°). Passenger windows are curved and can create optical distortion. The curvature is real but difficult to perceive.

Flat-Earth explanation: The horizon appears flat because it is flat.

Bottom line: Human perception of large-radius curvature is weak. Window distortion and atmospheric haze make this observation unreliable as proof for either side.

Chapter 8

Ships Disappearing Over the Horizon

Observed: Distant ships appear to sink below the horizon, hull first, then superstructure.

Globe explanation: The curved surface of the Earth blocks the lower portions of distant objects first. This is geometric occlusion.

Flat-Earth explanation: This effect is caused by perspective compression and atmospheric refraction. With sufficient optical zoom (telescope, camera), the entire ship can often be brought back into view, proving it was not actually "over" a curve.

Bottom line: The zoom-back phenomenon is documented and repeatable. Globe-Earthers attribute it to refraction; flat-Earthers say it disproves curvature. The argument continues.

Chapter 9

Ocean Tides

Observed: Ocean water levels rise and fall in predictable cycles correlated with the Moon's position.

Globe explanation: Gravitational pull from the Moon (and Sun) creates tidal bulges in the oceans. Earth's rotation causes locations to pass through these bulges twice daily.

Flat-Earth explanation: The Moon influences the oceans through electromagnetic or other effects. The exact mechanism varies among flat-Earth proponents, but the correlation with lunar position is acknowledged.

Bottom line: Both sides agree tides are real and Moon-correlated. The debate shifts to *why*—and mechanism debates are harder to settle than geometric ones.

Chapter 10

Star Trails

Observed: Long-exposure photographs show stars tracing circular arcs. In the Northern Hemisphere, they circle around Polaris (the North Star).

Globe explanation: Earth rotates on its axis. Stars are fixed; their apparent motion is caused by Earth's rotation. Polaris is nearly aligned with Earth's rotational axis.

Flat-Earth explanation: The stars (or the dome they are embedded in) rotate above the flat Earth. Polaris is above the North Pole (center of the disk), so stars appear to circle it.

Bottom line: Both models predict circular star trails centered on Polaris in the Northern Hemisphere. The observation alone does not distinguish between a rotating Earth and a rotating sky.

Chapter 11

Different Stars at Different Latitudes

Observed: Observers at different latitudes see different constellations. The Southern Cross is visible from Australia but not from New York.

Globe explanation: Earth is a sphere. Your latitude determines which portion of the celestial sphere you can see. Southern Hemisphere observers face "outward" in a different direction than Northern Hemisphere observers.

Flat-Earth explanation: Perspective and the dome geometry cause different stars to be visible from different positions on the flat plane. Stars near the "edge" of visibility simply cannot be seen from certain locations.

Bottom line: Both models can be adjusted to account for latitude-dependent star visibility. The debate becomes about the specific geometry of the dome or sphere.

Chapter 12

Seasons

Observed: Most locations experience seasonal temperature changes. Summer and winter occur at opposite times in the Northern and Southern Hemispheres.

Globe explanation: Earth's axis is tilted 23.5° relative to its orbital plane around the Sun. When the Northern Hemisphere tilts toward the Sun, it receives more direct sunlight (summer). Six months later, it tilts away (winter).

Flat-Earth explanation: The Sun's circular path above the flat Earth changes radius throughout the year. In northern summer, the Sun travels in a tighter circle closer to the center (North Pole). In northern winter, it travels in a wider circle closer to the rim.

Bottom line: Both models can produce opposite seasons in opposite hemispheres. The mechanisms differ, but the predicted observation is the same.

Chapter 13

Lunar Eclipses

Observed: During a lunar eclipse, the Moon darkens and often turns reddish. The shadow crossing the Moon has a curved edge.

Globe explanation: Earth passes between the Sun and Moon. Earth's shadow falls on the Moon. The shadow is curved because Earth is a sphere.

Flat-Earth explanation: Some other object (sometimes called the "shadow object" or "black sun") passes in front of the Moon. The curved shadow does not require a spherical Earth.

Bottom line: The curved shadow is consistent with a spherical Earth, but flat-Earth models introduce alternative explanations. Without independent verification of what is casting the shadow, the debate continues.

Chapter 14

Time Zones

Observed: When it is noon in New York, it is midnight in Beijing. The Sun is overhead at different times in different locations.

Globe explanation: Earth rotates, bringing different longitudes into sunlight at different times.

Flat-Earth explanation: The Sun is a localized light source that illuminates only a portion of the flat plane at any given time. As it circles, different areas receive daylight.

Bottom line: Both models predict time zones. The observation does not distinguish between a rotating sphere and a circling spotlight.

Chapter 15

Circumnavigation

Observed: Ships and aircraft can travel continuously east or west and eventually return to their starting point.

Globe explanation: Earth is a sphere. Traveling in one direction around a sphere returns you to the start.

Flat-Earth explanation: On the flat-Earth map (azimuthal equidistant projection), traveling east or west means traveling in a circle around the North Pole. You return to your starting point without ever crossing an edge.

Bottom line: Both models allow circumnavigation. East-west circumnavigation does not distinguish between them.

Chapter 16

Gravity and Falling Objects

Observed: Objects fall downward when released. A dropped ball accelerates toward the ground.

Globe explanation: Mass attracts mass (Newton's law of gravitation). Objects fall toward Earth's center because Earth is massive.

Flat-Earth explanation: "Down" is simply the direction things fall. Some flat-Earth models propose the flat plane accelerates upward at 9.8 m/s^2; others reject the Newtonian framework entirely and treat density/buoyancy as the explanation.

Bottom line: Both sides agree that objects fall. The debate is about *why*—a question of mechanism, not observation.

Chapter 17

Photos and Videos from Space

Observed: NASA and other space agencies publish photographs showing a spherical Earth from orbit.

Globe explanation: These are photographs of reality.

Flat-Earth explanation: These images are fabricated, composited, or captured with fisheye lenses that distort a flat surface into an apparent curve. Space agencies are not trustworthy sources.

Bottom line: This debate is about trust and institutional credibility, not direct observation. If you do not trust the source, the evidence is dismissed. If you do trust the source, the evidence is accepted. Neither side convinces the other.

Chapter 18

Flight Paths

Observed: Long-distance flights sometimes take routes that appear curved or indirect on standard maps (Mercator projection).

Globe explanation: The shortest path between two points on a sphere (a great circle) appears curved on flat map projections. Airlines follow great-circle routes to save fuel.

Flat-Earth explanation: On the flat-Earth map (azimuthal equidistant), these same routes appear straight or direct. The "curved" appearance is an artifact of the Mercator projection.

Bottom line: Flight paths can be made to look sensible on either map. The argument becomes about which projection is "correct"—a circular debate.

Chapter 19

Midnight Sun

Observed: During summer at polar latitudes (above 66.5°N or below 66.5°S), the sun remains visible for 24 hours. It circles the horizon, dipping toward it but never setting. Time-lapse videos show the sun tracing a complete circle in the sky.

Globe explanation: Earth's axis is tilted 23.5° relative to its orbital plane. During summer at polar latitudes, the pole is tilted toward the sun, keeping it above the horizon throughout the full 24-hour rotation.

Flat-Earth explanation: The sun travels in a circle above the flat plane. At the center (North Pole), the sun's circular path keeps it visible from all directions—it never moves "behind" anything to set. The sun is a localized light source that illuminates a limited area, and during northern summer, its path stays tight enough to remain visible from polar regions.

Bottom line: Both models can account for the midnight sun in the Arctic. The flat-Earth model requires a specific geometry of the sun's path and illumination pattern, but it is not contradicted by this observation alone.

Chapter 20

Antarctic 24-Hour Sun

Observed: During the Antarctic summer (December–January), locations south of the Antarctic Circle experience 24-hour daylight, with the sun circling the horizon just as it does in the Arctic summer.

Globe explanation: Same as the Arctic midnight sun—the Antarctic is tilted toward the sun during southern summer, keeping the sun above the horizon for 24 hours.

Flat-Earth explanation: This is more difficult to explain on the standard flat-Earth map. If Antarctica is the outer rim, the sun's circular path would have to become enormous during southern summer to remain visible from all points along the rim simultaneously. Some flat-Earth models propose that the sun's path expands and contracts seasonally, or that Antarctica is not configured as a simple rim.

Bottom line: The Antarctic midnight sun is harder to reconcile with simple flat-Earth geometry than the Arctic version. However, flat-Earth proponents argue that few independent observers have documented it firsthand, and that official claims come from institutions they do not trust. The debate shifts to questions of access and verification.

Chapter 21

Selenelion (Horizontal Eclipse)

Observed: During some lunar eclipses, both the sun and the fully eclipsed moon are visible simultaneously, both near opposite horizons. This is called a "selenelion" or "horizontal eclipse." Photographs and videos show the sun above one horizon while the eclipsed (red) moon sits above the opposite horizon.

Globe explanation: This is possible due to atmospheric refraction. The sun and moon are actually just below the horizon geometrically, but refraction bends their light upward, making both appear above the horizon at the same time. The eclipse geometry still holds—Earth's shadow is falling on the moon—but the observer sees both objects lifted by atmospheric effects.

Flat-Earth explanation: If the eclipsed moon and sun are both above the horizon simultaneously, something other than Earth must be casting the shadow on the moon. This supports the "shadow object" hypothesis—an unseen body that passes in front of the moon during eclipses. On a flat plane, there is no geometric contradiction in seeing both sun and moon above the horizon.

Bottom line: The selenelion is a real, documented phenomenon. Globe-Earthers attribute it to refraction; flat-Earthers cite it as evidence against the standard eclipse model. The debate hinges on whether atmospheric refraction is sufficient to explain observations, or whether an alternative shadow source is required.

Chapter 22

Polar Star Rotation

Observed: Time-lapse photography at the poles shows stars rotating in a complete circle around a central point—Polaris in the north, Sigma Octantis (dimmer) in the south. The stars never rise or set; they trace horizontal circles.

Globe explanation: At the poles, you are looking straight up along Earth's axis of rotation. All stars appear to circle the celestial pole as Earth rotates beneath them.

Flat-Earth explanation: The stars (or the dome they are embedded in) rotate above the flat plane. At the center (North Pole), stars circle directly overhead. The flat model predicts this same pattern.

Bottom line: Polar star trails are consistent with both models. The observation does not distinguish between a rotating Earth and a rotating sky/dome.

Chapter 23

Coriolis Effect

Observed: Large-scale phenomena like hurricanes rotate counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere. Long-range artillery and aircraft navigation must account for a deflection effect. Foucault pendulums slowly rotate their plane of swing over time.

Globe explanation: The Coriolis effect arises from Earth's rotation. Objects moving over the surface are deflected because the surface itself is rotating beneath them at different speeds at different latitudes.

Flat-Earth explanation: Some flat-Earth proponents deny that the Coriolis effect is real or significant. Others attribute observed rotations to local electromagnetic or atmospheric effects unrelated to Earth's shape. The debate often shifts to whether the effect has been measured reliably by independent observers.

Bottom line: The Coriolis effect is well-documented in meteorology and ballistics, but its interpretation depends on the underlying model. Globe-Earthers see it as evidence of rotation; flat-Earthers question the measurements or offer alternative mechanisms.

Chapter 24

High-Altitude Balloon Footage

Observed: Weather balloons and amateur high-altitude balloon projects send cameras to 100,000+ feet (30+ km). Footage shows the horizon as a curved line, with the curvature becoming more pronounced at higher altitudes.

Globe explanation: At high altitude, you can see far enough in all directions that the curvature of Earth's surface becomes visible. The higher you go, the more pronounced the curve.

Flat-Earth explanation: The apparent curvature is caused by lens distortion. Most cameras—especially action cameras like GoPros—use wide-angle or "fisheye" lenses that curve straight lines near the edges of the frame. When the horizon passes through the curved portion of the lens, it appears curved even if it is actually straight.

Evidence cited by flat-Earthers: In some balloon footage, the horizon appears to curve upward when the camera tilts one way and downward when it tilts the other way—an artifact of lens distortion, not real curvature.

Bottom line: The debate becomes about lens calibration. Globe-Earthers point to footage shot with rectilinear (non-fisheye) lenses that still shows curvature. Flat-Earthers argue that all such footage is either doctored or uses hidden wide-angle elements. Without agreed-upon lens standards and chain-of-custody for footage, the argument continues.

Chapter 25

Southern Hemisphere Flight Times

Observed: Commercial flights between southern cities (e.g., Santiago to Sydney, Johannesburg to Perth) take certain amounts of time. These flight times can be compared against the distances implied by different maps.

Globe explanation: On a globe, southern hemisphere cities are connected by great-circle routes that pass over the southern Pacific or Indian Oceans. Flight times match the great-circle distances reasonably well.

Flat-Earth explanation: On the standard flat-Earth map (azimuthal equidistant centered on North Pole), southern hemisphere locations are near the outer rim. Distances between points on opposite sides of the rim would be enormous—far greater than globe distances. Some flat-Earthers argue that:

- These flights do not actually exist or are much rarer than claimed.
- The flights make secret stops or take indirect routes.
- The flat-Earth map geometry is not accurately represented by the azimuthal equidistant projection.

Bottom line: Flight times are real and verifiable by passengers. However, the debate shifts to questions of actual routes flown, whether published distances are accurate, and whether commercial aviation data can be trusted. Flat-Earthers who have flown these routes sometimes report that the experience did not match their expectations, but interpretation varies.

Chapter 26

Weight Variation by Latitude

Observed: Precision measurements show that objects weigh slightly more at the poles than at the equator—approximately 0.5% difference. A 200-pound person would weigh about 1 pound more at the poles than at the equator.

Globe explanation: Two factors contribute:

- **Centrifugal effect:** Earth's rotation creates an outward pseudo-force that is strongest at the equator (where rotational velocity is highest) and zero at the poles. This reduces apparent weight at the equator.
- **Oblate shape:** Earth bulges at the equator, so the surface is farther from the center of mass there. Gravitational acceleration decreases with distance from the center.

Both effects reduce weight at the equator relative to the poles.

Flat-Earth explanation: Weight variation by latitude is not a standard prediction of flat-Earth models. Some flat-Earthers:

- Dispute the measurements as unreliable or fabricated.
- Attribute the variation to local density differences in the underlying structure.
- Propose alternative mechanisms unrelated to Earth's shape.

Bottom line: The 0.5% weight difference is small and requires precision equipment to measure reliably. It is well-documented in scientific literature, but flat-Earthers often distrust such sources. An independent experimenter would need a high-precision scale and the ability to travel between polar and equatorial regions—a significant undertaking to verify personally.

Chapter 27

Ball Toss in a Moving Vehicle

Observed: If you are riding in a car, train, or airplane moving at constant speed, you can toss a ball straight up and catch it straight down. The ball does not fly backward even though the vehicle is moving forward at high speed.

Globe explanation: This demonstrates the principle of inertial reference frames. When you toss the ball, it already shares the vehicle's forward velocity. In the absence of acceleration, everything inside the vehicle—including the air and the ball—moves together. There is no force to push the ball backward.

The same principle applies to Earth's rotation: we are moving with the Earth, the atmosphere is moving with the Earth, and objects we release continue moving with the Earth. We do not feel the motion because there is no acceleration (constant angular velocity).

Flat-Earth explanation: This observation is sometimes cited as evidence that Earth cannot be rotating. The argument goes: "If Earth were spinning at 1,000 mph at the equator, we would feel it. Helicopters could hover and let the ground move beneath them. Jumping would land you in a different spot."

The flat-Earth response to the inertial frame explanation is skepticism: if everything is moving together, how could you ever detect the motion? This leads to the question of what experiments *could* detect constant rotation.

Bottom line: The ball-in-car experiment demonstrates inertial frames but does not distinguish between models. Both sides agree on what happens; they disagree on whether the principle extends to a rotating Earth. The observation itself is neutral.

Chapter 28

Conclusion

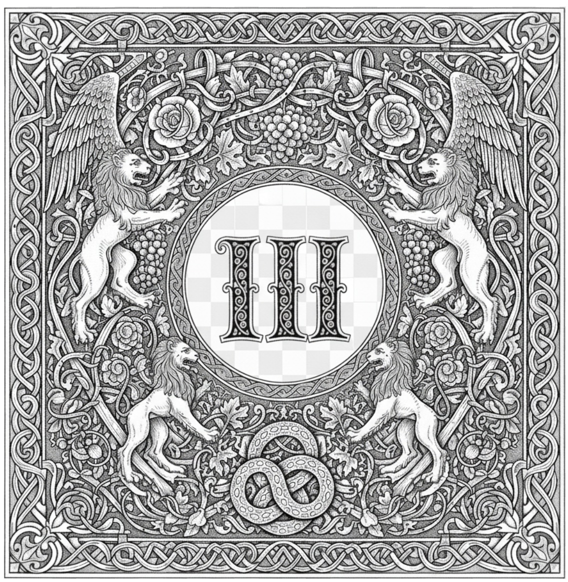
Every phenomenon in this part follows the same pattern:

1. Someone observes something real.
2. Globe-Earth offers an explanation.
3. Flat-Earth offers a different explanation.
4. The debate shifts to assumptions, mechanisms, and trust.

These arguments do not end because **the observations themselves do not force a unique conclusion**.

This does not mean both models are equally valid. It means that if you want to settle the question, you need a different kind of test—one where the two models make **different, measurable predictions**.

Parts 3 and 4 focus on exactly that.


III

Part III

CURVATURE PROOFS

Chapter 29

Introduction

This part presents experiments that test a specific geometric question: does the Earth's surface curve away from a straight line over distance, or does it remain flat?

The globe model predicts curvature. The flat model predicts no curvature. These are mutually exclusive predictions about a measurable quantity—not matters of opinion or interpretation.

Unlike the phenomena in Part 2 (which both models can explain), the experiments here are designed to produce **different outcomes** depending on which model is correct. That is what makes them decisive.

29.1 What these experiments measure

The experiments in this part focus on line-of-sight over long distances. If you set up a laser at point A aimed perfectly horizontally, where will it arrive at point B several miles away?

- **Globe prediction:** The surface curves away. The beam passes increasingly high above the surface as distance increases. At 9 miles, it should be approximately 50 feet above a target at the same starting height.

- **Flat prediction:** The surface does not curve. The beam remains at constant height above the surface and hits the target.

Globe Prediction: Beam passes over target

Flat Prediction: Beam hits

This is a geometric test, not a debate about mechanisms or authorities. You aim a beam, you see where it arrives (or doesn't), and you record the result.

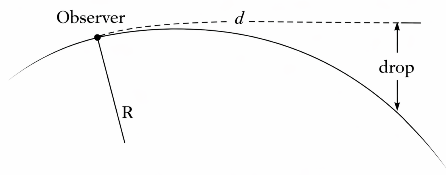
29.2 Why geometry, not mechanisms

Discussions about Earth's shape often drift into deep questions about gravity, density, buoyancy, and why large bodies of water take the shape they do. Those debates can continue indefinitely because they involve competing frameworks of explanation.

This part sidesteps those debates entirely. The experiments measure *geometry*—the physical shape of the surface—without requiring agreement on *why* it has that shape.

If you perform the experiment and get a result, the result stands regardless of your theory about gravity or your trust in institutions. That is the point.

29.3 Curvature mathematics (as a prediction tool)



Flat Prediction: Beam hits

If Earth is modeled as a sphere of radius R, a standard approximation for geometric "drop" (the amount by which the surface falls below a straight tangent line over distance d) is:

$$\text{drop} \approx \frac{d^2}{2R}.$$

Using $R \approx 3{,}959$ miles (6,371 km), a common rule-of-thumb approximation is:

$$\text{drop} \approx 8\,\text{inches per mile}^2.$$

29.3.1 Example calculations

- Distance: 6.2 miles (10 km). Expected drop: about 25.7 feet (7.85 m).
- Distance: 8.7 miles (14.0 km). Expected drop: about 50 feet (15.24 m).
- Distance: 12.4 miles (20 km). Expected drop: about 103 feet (31.4 m).
- Distance: 31 miles (50 km). Expected drop: about 643 feet (196 m).

These calculations are not proofs by themselves; they are a way to generate a prediction that a measurement can test. The same caution applies to atmospheric refraction: it can be significant and must be measured or bounded rather than assumed away.

If you want an experiment where the predicted effect is comfortably larger than small surveying errors, it can be useful to aim for a setup where the spherical-model prediction implies a drop on the order of 50 feet (about 15 m) or more.

Bodies of water are often chosen because, over modest distances and time scales, the surface is usually close to a local equipotential surface and is convenient to access. Flat, uniform terrain (such as salt flats or deserts) can also be suitable.

Chapter 30

Candidate sites and repeatability

The most valuable site is not the most dramatic one; it is the one that many readers can repeat. The goal here is to provide enough examples that a reader can choose a nearby location and run the same measurement protocol.

30.1 North America

The table below is intended to list sites suitable for line-of-sight laser/optical tests. For each site, the intended fields are:

- Point A: latitude/longitude and a short access note.
- Point B: latitude/longitude and a short access note.
- Distance: miles (km).
- Expected drop: feet (m), computed from the stated model and assumptions.

Point A	**Point B**	**Distance**	**Expected drop**
Chicago, IL (Navy Pier area) 41.891 N, 87.607 W	St. Joseph, MI (shore access) 42.109 N, 86.485 W	53 mi (85 km)	1,870 ft (570 m)
Metairie, LA (south shore) 30.000 N, 90.170 W	Mandeville, LA (north shore) 30.359 N, 90.066 W	24 mi (38 km)	384 ft (117 m)
Cape May, NJ 38.938 N, 74.907 W	Lewes, DE 38.782 N, 75.139 W	17 mi (27 km)	193 ft (59 m)
Port Angeles, WA 48.118 N, 123.430 W	Victoria, BC 48.428 N, 123.365 W	20 mi (32 km)	267 ft (81 m)
Santa Monica, CA (pier area) 34.010 N, 118.497 W	Catalina Island, CA (Avalon area) 33.342 N, 118.327 W	26 mi (42 km)	451 ft (137 m)
Great Salt Lake, UT (Antelope Island causeway) 41.060 N, 112.250 W	Great Salt Lake, UT (shore access) 41.230 N, 112.600 W	20 mi (32 km)	267 ft (81 m)
Chesapeake Bay Bridge-Tunnel (south terminus) 36.967 N, 76.113 W	Chesapeake Bay Bridge-Tunnel (north terminus) 37.100 N, 75.990 W	17.6 mi (28 km)	206 ft (63 m)
Erie, PA (Presque Isle) 42.153 N, 80.090 W	Long Point, ON 42.583 N, 80.450 W	32 mi (51 km)	683 ft (208 m)
Corpus Christi, TX 27.800 N, 97.396 W	Port Aransas, TX 27.834 N, 97.061 W	19 mi (31 km)	241 ft (73 m)
Key West, FL 24.555 N, 81.780 W	Marathon, FL 24.713 N, 81.090 W	48 mi (77 km)	1,536 ft (468 m)
Milwaukee, WI (lakefront) 43.039 N, 87.906 W	Muskegon, MI (shore access) 43.235 N, 86.248 W	80 mi (129 km)	4,267 ft (1,301 m)
Sheboygan, WI (lakefront) 43.750 N, 87.714 W	Ludington, MI (shore access) 43.956 N, 86.452 W	60 mi (97 km)	2,400 ft (732 m)
Green Bay, WI (Fox River mouth) 44.515 N, 88.016 W	Sturgeon Bay, WI (Door County) 44.834 N, 87.377 W	29 mi (47 km)	561 ft (171 m)
Boston, MA (downtown waterfront)	Provincetown, MA (Cape Cod)	50 mi (80 km)	1,667 ft (508 m)

Point A	**Point B**	**Distance**	**Expected drop**
Portland, ME (waterfront) 43.659 N, 70.256 W	Portsmouth, NH (harbor area) 43.071 N, 70.760 W	52 mi (84 km)	1,803 ft (550 m)
New London, CT 41.355 N, 72.099 W	Block Island, RI 41.172 N, 71.558 W	20 mi (32 km)	267 ft (81 m)
Gloucester, MA 42.615 N, 70.663 W	Portsmouth, NH 43.071 N, 70.760 W	36 mi (58 km)	864 ft (263 m)
Newport, RI 41.490 N, 71.312 W	Martha's Vineyard, MA 41.454 N, 70.603 W	35 mi (56 km)	817 ft (249 m)
Hyannis, MA 41.652 N, 70.283 W	Nantucket, MA 41.283 N, 70.099 W	26 mi (42 km)	451 ft (137 m)
New Bedford, MA 41.636 N, 70.934 W	Martha's Vineyard, MA 41.454 N, 70.603 W	22 mi (35 km)	323 ft (98 m)
Bridgeport, CT 41.186 N, 73.195 W	Port Jefferson, NY 40.946 N, 73.069 W	18 mi (29 km)	216 ft (66 m)
Woods Hole, MA 41.526 N, 70.671 W	Oak Bluffs, MA (Martha's Vineyard) 41.454 N, 70.559 W	9 mi (14 km)	54 ft (16 m)
San Francisco, CA (Ocean Beach) 37.759 N, 122.511 W	Farallon Islands, CA 37.700 N, 123.000 W	27 mi (43 km)	486 ft (148 m)
Ventura, CA 34.280 N, 119.294 W	Santa Cruz Island, CA (Channel Islands) 34.030 N, 119.740 W	20 mi (32 km)	267 ft (81 m)
San Diego, CA (Point Loma) 32.672 N, 117.242 W	Oceanside, CA (pier area) 33.195 N, 117.379 W	32 mi (51 km)	683 ft (208 m)
New York, NY (Lower Manhattan) 40.703 N, 74.017 W	Sandy Hook, NJ 40.467 N, 74.010 W	18 mi (29 km)	216 ft (66 m)
Philadelphia, PA 39.952 N, 75.164 W	Cape May, NJ 38.938 N, 74.907 W	47 mi (76 km)	1,473 ft (449 m)
Cleveland, OH (lakefront) 41.505 N, 81.690 W	Long Point, ON 42.583 N, 80.450 W	90 mi (145 km)	5,400 ft (1,646 m)

30.2 Central America

Point A	Point B	Distance	Expected drop
Panama City, PA (Amador Causeway) 8.952 N, 79.530 W	Colón, PA (shore access) 9.356 N, 79.901 W	36 mi (58 km)	864 ft (263 m)
San José, CR 9.933 N, 84.084 W	Puntarenas, CR 9.977 N, 84.833 W	47 mi (76 km)	1,473 ft (449 m)
Managua, NI 12.115 N, 86.236 W	Granada, NI 11.934 N, 85.956 W	22 mi (35 km)	323 ft (98 m)
León, NI 12.434 N, 86.879 W	Corinto, NI 12.482 N, 87.173 W	18 mi (29 km)	216 ft (66 m)
San Salvador, SV 13.692 N, 89.219 W	La Libertad, SV 13.488 N, 89.322 W	16 mi (26 km)	171 ft (52 m)
Tegucigalpa, HN 14.072 N, 87.193 W	Comayagua, HN 14.454 N, 87.638 W	41 mi (66 km)	1,121 ft (342 m)
Guatemala City, GT 14.634 N, 90.506 W	Puerto San José, GT 13.932 N, 90.821 W	62 mi (100 km)	2,563 ft (781 m)
Belize City, BZ 17.504 N, 88.196 W	San Pedro, BZ 17.915 N, 87.965 W	33 mi (53 km)	726 ft (221 m)
San Juan del Sur, NI 11.252 N, 85.870 W	Tamarindo, CR 10.300 N, 85.839 W	66 mi (106 km)	2,904 ft (885 m)
Roatán, HN 16.324 N, 86.535 W	La Ceiba, HN 15.770 N, 86.796 W	43 mi (69 km)	1,233 ft (376 m)

30.3 South America

Point A	**Point B**	**Distance**	**Expected drop**
Buenos Aires, AR 34.603 S, 58.382 W	Colonia del Sacramento, UY 34.471 S, 57.844 W	31 mi (50 km)	641 ft (195 m)
Montevideo, UY 34.901 S, 56.164 W	Punta del Este, UY 34.960 S, 54.950 W	72 mi (116 km)	3,456 ft (1,053 m)
Rio de Janeiro, BR 22.906 S, 43.172 W	Niterói, BR 22.885 S, 43.115 W	10 mi (16 km)	67 ft (20 m)
Santos, BR 23.960 S, 46.333 W	Guarujá, BR 23.993 S, 46.257 W	10 mi (16 km)	67 ft (20 m)
Salvador, BR 12.971 S, 38.501 W	Itaparica Island, BR 12.888 S, 38.679 W	12 mi (19 km)	96 ft (29 m)
Fortaleza, BR 3.732 S, 38.527 W	Aquiraz, BR 3.902 S, 38.392 W	14 mi (23 km)	131 ft (40 m)
Recife, BR 8.057 S, 34.882 W	Olinda, BR 7.996 S, 34.855 W	9 mi (14 km)	54 ft (16 m)
Lima, PE 12.046 S, 77.043 W	Callao, PE 12.056 S, 77.118 W	10 mi (16 km)	67 ft (20 m)
Guayaquil, EC 2.170 S, 79.922 W	Salinas, EC 2.214 S, 80.968 W	66 mi (106 km)	2,904 ft (885 m)
Quito, EC 0.180 S, 78.468 W	Santo Domingo, EC 0.250 S, 79.170 W	45 mi (72 km)	1,350 ft (411 m)
Cartagena, CO 10.391 N, 75.479 W	Barranquilla, CO 10.963 N, 74.796 W	60 mi (97 km)	2,400 ft (732 m)
Santa Marta, CO 11.241 N, 74.205 W	Barranquilla, CO 10.963 N, 74.796 W	45 mi (72 km)	1,350 ft (411 m)
Valparaíso, CL 33.047 S, 71.612 W	Viña del Mar, CL 33.024 S, 71.552 W	10 mi (16 km)	67 ft (20 m)
Concepción, CL 36.827 S, 73.050 W	Talcahuano, CL 36.716 S, 73.116 W	10 mi (16 km)	67 ft (20 m)
Punta Arenas, CL 53.164 S, 70.917 W	Porvenir, CL 53.299 S, 70.367 W	27 mi (43 km)	486 ft (148 m)
Rio Grande, AR 53.787 S, 67.699 W	Ushuaia, AR 54.801 S, 68.303 W	131 mi (211 km)	11,443 ft (3,488 m)
São Luís, BR 2.529 S, 44.302 W	Alcântara, BR 2.407 S, 44.415 W	10 mi (16 km)	67 ft (20 m)
Belém, BR 1.455 S, 48.503 W	Mosqueiro Island, BR 1.150 S, 48.450 W	21 mi (34 km)	294 ft (90 m)
[illegible]	[illegible]	[illegible]	[illegible]

30.4 Europe

Point A	**Point B**	**Distance**	**Expected drop**
London, UK 51.507 N, 0.128 W	Dover, UK 51.129 N, 1.313 E	76 mi (122 km)	3,851 ft (1,174 m)
Dover, UK 51.129 N, 1.313 E	Calais, FR 50.951 N, 1.858 E	26 mi (42 km)	451 ft (137 m)
Amsterdam, NL 52.368 N, 4.904 E	Rotterdam, NL 51.924 N, 4.479 E	36 mi (58 km)	864 ft (263 m)
Copenhagen, DK 55.676 N, 12.568 E	Malmö, SE 55.605 N, 13.003 E	17 mi (27 km)	193 ft (59 m)
Stockholm, SE 59.329 N, 18.069 E	Uppsala, SE 59.858 N, 17.638 E	44 mi (71 km)	1,291 ft (393 m)
Oslo, NO 59.913 N, 10.752 E	Moss, NO 59.434 N, 10.657 E	35 mi (56 km)	817 ft (249 m)
Helsinki, FI 60.170 N, 24.938 E	Tallinn, EE 59.437 N, 24.754 E	51 mi (82 km)	1,734 ft (529 m)
Lisbon, PT 38.722 N, 9.139 W	Setúbal, PT 38.524 N, 8.888 W	27 mi (43 km)	486 ft (148 m)
Porto, PT 41.157 N, 8.629 W	Aveiro, PT 40.640 N, 8.654 W	35 mi (56 km)	817 ft (249 m)
Barcelona, ES 41.385 N, 2.173 E	Tarragona, ES 41.118 N, 1.244 E	51 mi (82 km)	1,734 ft (529 m)
Valencia, ES 39.469 N, 0.376 W	Alicante, ES 38.345 N, 0.481 W	78 mi (126 km)	4,056 ft (1,236 m)
Madrid, ES 40.417 N, 3.704 W	Toledo, ES 39.863 N, 4.027 W	42 mi (68 km)	1,176 ft (359 m)
Paris, FR 48.857 N, 2.352 E	Rouen, FR 49.443 N, 1.099 E	70 mi (113 km)	3,267 ft (996 m)
Marseille, FR 43.296 N, 5.369 E	Toulon, FR 43.124 N, 5.928 E	30 mi (48 km)	600 ft (183 m)
Nice, FR 43.710 N, 7.262 E	Cannes, FR 43.552 N, 7.017 E	16 mi (26 km)	171 ft (52 m)

Point A	**Point B**	**Distance**	**Expected drop**
Rome, IT 41.903 N, 12.496 E	Naples, IT 40.852 N, 14.268 E	117 mi (188 km)	9,126 ft (2,781 m)
Naples, IT 40.852 N, 14.268 E	Salerno, IT 40.682 N, 14.768 E	30 mi (48 km)	600 ft (183 m)
Venice, IT 45.440 N, 12.316 E	Trieste, IT 45.650 N, 13.776 E	71 mi (114 km)	3,360 ft (1,024 m)
Milan, IT 45.465 N, 9.190 E	Turin, IT 45.070 N, 7.686 E	78 mi (126 km)	4,056 ft (1,236 m)
Vienna, AT 48.208 N, 16.373 E	Bratislava, SK 48.148 N, 17.107 E	34 mi (55 km)	771 ft (235 m)
Berlin, DE 52.520 N, 13.405 E	Potsdam, DE 52.390 N, 13.064 E	16 mi (26 km)	171 ft (52 m)
Hamburg, DE 53.551 N, 9.993 E	Lübeck, DE 53.866 N, 10.687 E	35 mi (56 km)	817 ft (249 m)
Zurich, CH 47.376 N, 8.542 E	Lucerne, CH 47.050 N, 8.305 E	24 mi (39 km)	384 ft (117 m)
Kraków, PL 50.065 N, 19.945 E	Katowice, PL 50.264 N, 19.023 E	41 mi (66 km)	1,121 ft (342 m)
Dublin, IE 53.350 N, 6.260 W	Liverpool, UK 53.408 N, 2.991 W	133 mi (214 km)	11,793 ft (3,594 m)

30.5 Middle East

Point A	**Point B**	**Distance**	**Expected drop**
Dubai, AE 25.204 N, 55.271 E	Abu Dhabi, AE 24.453 N, 54.377 E	87 mi (140 km)	5,046 ft (1,538 m)
Doha, QA 25.286 N, 51.531 E	Al Khor, QA 25.683 N, 51.505 E	31 mi (50 km)	641 ft (195 m)
Kuwait City, KW 29.375 N, 47.977 E	Al Jahra, KW 29.337 N, 47.659 E	21 mi (34 km)	294 ft (90 m)
Manama, BH 26.228 N, 50.587 E	Dammam, SA 26.420 N, 50.088 E	30 mi (48 km)	600 ft (183 m)
Muscat, OM 23.588 N, 58.383 E	Sohar, OM 24.365 N, 56.746 E	105 mi (169 km)	7,350 ft (2,240 m)
Jeddah, SA 21.485 N, 39.192 E	Rabigh, SA 22.798 N, 39.035 E	91 mi (146 km)	5,520 ft (1,683 m)
Tel Aviv, IL 32.085 N, 34.782 E	Haifa, IL 32.794 N, 34.989 E	55 mi (89 km)	2,017 ft (615 m)
Beirut, LB 33.894 N, 35.502 E	Tripoli, LB 34.436 N, 35.849 E	44 mi (71 km)	1,291 ft (393 m)
Amman, JO 31.954 N, 35.911 E	Aqaba, JO 29.532 N, 35.006 E	173 mi (278 km)	19,949 ft (6,080 m)
Cairo, EG 30.044 N, 31.236 E	Alexandria, EG 31.201 N, 29.918 E	112 mi (180 km)	8,363 ft (2,549 m)
Port Said, EG 31.266 N, 32.300 E	Damietta, EG 31.417 N, 31.814 E	31 mi (50 km)	641 ft (195 m)
Istanbul, TR 41.008 N, 28.978 E	Bursa, TR 40.195 N, 29.060 E	58 mi (93 km)	2,243 ft (684 m)
Izmir, TR 38.423 N, 27.142 E	Kusadasi, TR 37.862 N, 27.257 E	41 mi (66 km)	1,121 ft (342 m)
Ankara, TR 39.933 N, 32.859 E	Konya, TR 37.872 N, 32.492 E	145 mi (233 km)	14,017 ft (4,273 m)
Nicosia, CY 35.185 N, 33.382 E	Larnaca, CY 34.918 N, 33.623 E	21 mi (34 km)	294 ft (90 m)
Aqaba, JO 29.532 N, 35.006 E	Eilat, IL 29.557 N, 34.951 E	9 mi (14 km)	54 ft (16 m)
Tehran, IR 35.690 N, 51.389 E	Qom, IR 34.640 N, 50.876 E	77 mi (124 km)	3,957 ft (1,206 m)
Lattakia, SY 35.531 N, 35.791 E	Tartus, SY 34.889 N, 35.886 E	10 mi (16 km)	67 ft (20 m)
Limassol, CY 34.679 N, 33.044 E	Paphos, CY 34.776 N, 32.424 E	10 mi (16 km)	67 ft (20 m)
Hurghada, EG 27.258 N, 33.812 E	Safaga, EG 26.732 N, 33.936 E	11 mi (18 km)	81 ft (25 m)

30.6 India

Point A	**Point B**	**Distance**	**Expected drop**
Mumbai, IN 19.076 N, 72.878 E	Pune, IN 18.520 N, 73.857 E	74 mi (119 km)	3,651 ft (1,113 m)
Mumbai, IN 19.076 N, 72.878 E	Alibag, IN 18.641 N, 72.872 E	30 mi (48 km)	600 ft (183 m)
Chennai, IN 13.083 N, 80.270 E	Puducherry, IN 11.941 N, 79.808 E	92 mi (148 km)	5,643 ft (1,720 m)
Kolkata, IN 22.573 N, 88.364 E	Haldia, IN 22.026 N, 88.062 E	47 mi (76 km)	1,473 ft (449 m)
Hyderabad, IN 17.385 N, 78.487 E	Warangal, IN 17.968 N, 79.594 E	89 mi (143 km)	5,281 ft (1,609 m)
Bengaluru, IN 12.972 N, 77.594 E	Mysuru, IN 12.295 N, 76.639 E	79 mi (127 km)	4,161 ft (1,268 m)
Ahmedabad, IN 23.023 N, 72.572 E	Vadodara, IN 22.308 N, 73.181 E	62 mi (100 km)	2,563 ft (781 m)
Jaipur, IN 26.913 N, 75.787 E	Ajmer, IN 26.449 N, 74.639 E	79 mi (127 km)	4,161 ft (1,268 m)
Delhi, IN 28.614 N, 77.209 E	Agra, IN 27.176 N, 78.009 E	116 mi (187 km)	8,971 ft (2,734 m)
Kochi, IN 9.932 N, 76.267 E	Kozhikode, IN 11.258 N, 75.780 E	94 mi (151 km)	5,893 ft (1,796 m)

Point A	**Point B**	**Distance**	**Expected drop**
Thiruvananthapuram, IN 8.524 N, 76.936 E	Kanyakumari, IN 8.088 N, 77.538 E	46 mi (74 km)	1,411 ft (430 m)
Visakhapatnam, IN 17.686 N, 83.218 E	Kakinada, IN 16.989 N, 82.247 E	87 mi (140 km)	5,046 ft (1,538 m)
Surat, IN 21.170 N, 72.831 E	Daman, IN 20.397 N, 72.832 E	53 mi (85 km)	1,870 ft (570 m)
Goa (Panaji), IN 15.490 N, 73.827 E	Gokarna, IN 14.547 N, 74.319 E	71 mi (114 km)	3,360 ft (1,024 m)
Lucknow, IN 26.847 N, 80.947 E	Kanpur, IN 26.449 N, 80.331 E	49 mi (79 km)	1,600 ft (488 m)
Patna, IN 25.594 N, 85.137 E	Gaya, IN 24.796 N, 85.007 E	60 mi (97 km)	2,400 ft (732 m)
Bhubaneswar, IN 20.296 N, 85.824 E	Puri, IN 19.814 N, 85.831 E	33 mi (53 km)	726 ft (221 m)
Indore, IN 22.719 N, 75.857 E	Ujjain, IN 23.176 N, 75.788 E	35 mi (56 km)	817 ft (249 m)
Bhopal, IN 23.259 N, 77.413 E	Hoshangabad, IN 22.747 N, 77.719 E	44 mi (71 km)	1,291 ft (393 m)
Chandigarh, IN 30.733 N, 76.779 E	Shimla, IN 31.104 N, 77.173 E	35 mi (56 km)	817 ft (249 m)

30.7 Greece

Point A	Point B	Distance	Expected drop
Athens, GR 37.984 N, 23.728 E	Corinth, GR 37.940 N, 22.951 E	44 mi (71 km)	1,291 ft (393 m)
Thessaloniki, GR 40.640 N, 22.944 E	Katerini, GR 40.269 N, 22.503 E	44 mi (71 km)	1,291 ft (393 m)
Heraklion, GR 35.338 N, 25.144 E	Chania, GR 35.513 N, 24.018 E	64 mi (103 km)	2,731 ft (832 m)
Rhodes, GR 36.434 N, 28.217 E	Lindos, GR 36.092 N, 28.087 E	23 mi (37 km)	353 ft (108 m)
Patras, GR 38.246 N, 21.735 E	Nafpaktos, GR 38.392 N, 21.827 E	14 mi (23 km)	131 ft (40 m)
Volos, GR 39.365 N, 22.942 E	Larissa, GR 39.639 N, 22.419 E	29 mi (47 km)	561 ft (171 m)
Kavala, GR 40.939 N, 24.402 E	Alexandroupoli, GR 40.848 N, 25.873 E	77 mi (124 km)	3,957 ft (1,206 m)
Ioannina, GR 39.665 N, 20.853 E	Corfu, GR 39.624 N, 19.921 E	48 mi (77 km)	1,536 ft (468 m)
Chios, GR 38.370 N, 26.136 E	Mytilene, GR 39.104 N, 26.557 E	55 mi (89 km)	2,017 ft (615 m)
Kalamata, GR 37.042 N, 22.114 E	Sparta, GR 37.075 N, 22.429 E	20 mi (32 km)	267 ft (81 m)

30.8 China

Point A	**Point B**	**Distance**	**Expected drop**
Beijing, CN 39.904 N, 116.407 E	Tianjin, CN 39.084 N, 117.200 E	70 mi (113 km)	3,267 ft (996 m)
Shanghai, CN 31.230 N, 121.474 E	Suzhou, CN 31.299 N, 120.585 E	56 mi (90 km)	2,091 ft (637 m)
Shanghai, CN 31.230 N, 121.474 E	Hangzhou, CN 30.274 N, 120.155 E	105 mi (169 km)	7,350 ft (2,240 m)
Guangzhou, CN 23.129 N, 113.264 E	Shenzhen, CN 22.543 N, 114.057 E	65 mi (105 km)	2,817 ft (859 m)
Shenzhen, CN 22.543 N, 114.057 E	Hong Kong, HK 22.319 N, 114.169 E	18 mi (29 km)	216 ft (66 m)
Chengdu, CN 30.572 N, 104.066 E	Leshan, CN 29.552 N, 103.766 E	86 mi (138 km)	4,931 ft (1,503 m)
Chongqing, CN 29.563 N, 106.551 E	Wanzhou, CN 30.815 N, 108.404 E	145 mi (233 km)	14,017 ft (4,273 m)
Wuhan, CN 30.593 N, 114.305 E	Huangshi, CN 30.201 N, 115.038 E	60 mi (97 km)	2,400 ft (732 m)
Xi'an, CN 34.341 N, 108.939 E	Baoji, CN 34.363 N, 107.237 E	100 mi (161 km)	6,667 ft (2,032 m)
Nanjing, CN 32.060 N, 118.797 E	Wuxi, CN 31.491 N, 120.312 E	90 mi (145 km)	5,400 ft (1,646 m)

Point A	**Point B**	**Distance**	**Expected drop**
Qingdao, CN 36.067 N, 120.383 E	Yantai, CN 37.464 N, 121.447 E	107 mi (172 km)	7,633 ft (2,327 m)
Dalian, CN 38.914 N, 121.614 E	Lüshun, CN 38.812 N, 121.263 E	23 mi (37 km)	353 ft (108 m)
Shenyang, CN 41.805 N, 123.432 E	Anshan, CN 41.108 N, 122.995 E	58 mi (93 km)	2,243 ft (684 m)
Harbin, CN 45.803 N, 126.535 E	Daqing, CN 46.590 N, 125.103 E	92 mi (148 km)	5,643 ft (1,720 m)
Kunming, CN 25.038 N, 102.718 E	Dali, CN 25.693 N, 100.180 E	190 mi (306 km)	24,067 ft (7,335 m)
Xiamen, CN 24.479 N, 118.089 E	Quanzhou, CN 24.874 N, 118.675 E	44 mi (71 km)	1,291 ft (393 m)
Fuzhou, CN 26.074 N, 119.296 E	Ningde, CN 26.665 N, 119.523 E	45 mi (72 km)	1,350 ft (411 m)
Haikou, CN 20.045 N, 110.199 E	Sanya, CN 18.252 N, 109.512 E	140 mi (225 km)	13,067 ft (3,983 m)
Urumqi, CN 43.825 N, 87.617 E	Turpan, CN 42.951 N, 89.189 E	100 mi (161 km)	6,667 ft (2,032 m)
Changsha, CN 28.228 N, 112.939 E	Yueyang, CN 29.357 N, 113.128 E	78 mi (126 km)	4,056 ft (1,236 m)

30.9 Japan

Point A	Point B	Distance	Expected drop
Tokyo, JP 35.676 N, 139.650 E	Yokohama, JP 35.443 N, 139.638 E	18 mi (29 km)	216 ft (66 m)
Tokyo, JP 35.676 N, 139.650 E	Chiba, JP 35.607 N, 140.106 E	25 mi (40 km)	417 ft (127 m)
Osaka, JP 34.693 N, 135.502 E	Kobe, JP 34.690 N, 135.195 E	19 mi (31 km)	241 ft (73 m)
Osaka, JP 34.693 N, 135.502 E	Kyoto, JP 35.012 N, 135.768 E	27 mi (43 km)	486 ft (148 m)
Nagoya, JP 35.181 N, 136.907 E	Toyohashi, JP 34.770 N, 137.391 E	44 mi (71 km)	1,291 ft (393 m)
Hiroshima, JP 34.385 N, 132.455 E	Iwakuni, JP 34.165 N, 132.219 E	20 mi (32 km)	267 ft (81 m)
Fukuoka, JP 33.590 N, 130.402 E	Kitakyushu, JP 33.883 N, 130.875 E	44 mi (71 km)	1,291 ft (393 m)
Sapporo, JP 43.061 N, 141.354 E	Otaru, JP 43.197 N, 140.994 E	20 mi (32 km)	267 ft (81 m)
Sendai, JP 38.268 N, 140.869 E	Ishinomaki, JP 38.434 N, 141.302 E	30 mi (48 km)	600 ft (183 m)
Niigata, JP 37.916 N, 139.036 E	Nagaoka, JP 37.447 N, 138.851 E	40 mi (64 km)	1,067 ft (325 m)
Kanazawa, JP 36.562 N, 136.656 E	Toyama, JP 36.696 N, 137.213 E	35 mi (56 km)	817 ft (249 m)
Naha, JP 26.213 N, 127.680 E	Okinawa City, JP 26.335 N, 127.801 E	14 mi (23 km)	131 ft (40 m)
Kagoshima, JP 31.596 N, 130.558 E	Miyazaki, JP 31.907 N, 131.421 E	60 mi (97 km)	2,400 ft (732 m)
Nagasaki, JP 32.750 N, 129.877 E	Sasebo, JP 33.160 N, 129.722 E	33 mi (53 km)	726 ft (221 m)
Shizuoka, JP 34.975 N, 138.383 E	Hamamatsu, JP 34.710 N, 137.727 E	44 mi (71 km)	1,291 ft (393 m)

30.10 Australia

Point A	**Point B**	**Distance**	**Expected drop**
Sydney, AU 33.869 S, 151.209 E	Wollongong, AU 34.427 S, 150.893 E	43 mi (69 km)	1,233 ft (376 m)
Sydney, AU 33.869 S, 151.209 E	Newcastle, AU 32.928 S, 151.781 E	74 mi (119 km)	3,651 ft (1,113 m)
Melbourne, AU 37.814 S, 144.963 E	Geelong, AU 38.149 S, 144.361 E	47 mi (76 km)	1,473 ft (449 m)
Melbourne, AU 37.814 S, 144.963 E	Mornington, AU 38.217 S, 145.037 E	28 mi (45 km)	523 ft (159 m)
Brisbane, AU 27.469 S, 153.025 E	Gold Coast, AU 28.017 S, 153.400 E	47 mi (76 km)	1,473 ft (449 m)
Brisbane, AU 27.469 S, 153.025 E	Sunshine Coast, AU 26.650 S, 153.066 E	57 mi (92 km)	2,167 ft (660 m)
Perth, AU 31.952 S, 115.861 E	Fremantle, AU 32.056 S, 115.743 E	12 mi (19 km)	96 ft (29 m)
Perth, AU 31.952 S, 115.861 E	Mandurah, AU 32.535 S, 115.742 E	45 mi (72 km)	1,350 ft (411 m)

Point A	**Point B**	**Distance**	**Expected drop**
Adelaide, AU 34.928 S, 138.601 E	Victor Harbor, AU 35.551 S, 138.622 E	43 mi (69 km)	1,233 ft (376 m)
Hobart, AU 42.882 S, 147.327 E	Port Arthur, AU 43.152 S, 147.849 E	34 mi (55 km)	771 ft (235 m)
Darwin, AU 12.463 S, 130.845 E	Palmerston, AU 12.496 S, 130.985 E	14 mi (23 km)	131 ft (40 m)
Cairns, AU 16.918 S, 145.778 E	Port Douglas, AU 16.483 S, 145.466 E	34 mi (55 km)	771 ft (235 m)
Townsville, AU 19.258 S, 146.816 E	Ayr, AU 19.580 S, 147.406 E	37 mi (60 km)	913 ft (278 m)
Canberra, AU 35.280 S, 149.131 E	Goulburn, AU 34.751 S, 149.721 E	56 mi (90 km)	2,091 ft (637 m)
Rockingham, AU 32.292 S, 115.729 E	Mandurah, AU 32.535 S, 115.742 E	10 mi (16 km)	67 ft (20 m)
Newcastle, AU 32.928 S, 151.781 E	Port Macquarie, AU 31.431 S, 152.908 E	156 mi (251 km)	16,224 ft (4,945 m)
Wollongong, AU 34.427 S, 150.893 E	Nowra, AU 34.883 S, 150.600 E	33 mi (53 km)	726 ft (221 m)
Melbourne, AU 37.814 S, 144.963 E	Ballarat, AU 37.563 S, 143.855 E	69 mi (111 km)	3,174 ft (967 m)
Sydney, AU 33.869 S, 151.209 E	Canberra, AU 35.280 S, 149.131 E	154 mi (248 km)	15,813 ft (4,820 m)
Brisbane, AU 27.469 S, 153.025 E	Toowoomba, AU 27.560 S, 151.953 E	78 mi (126 km)	4,056 ft (1,236 m)

Chapter 31

Equipment

This section describes practical equipment requirements for long-range line-of-sight tests. Any use of lasers must prioritize safety and legal compliance.

31.1 Laser selection

31.1.1 Range requirements

For a 50 ft expected drop, the minimum one-way distance is approximately 9 mi. With a retroreflector at the far end, the laser beam travels the distance twice (out and back), requiring 18 mi round-trip capability. Manufacturer ratings are optimistic—expect 80% of rated range in practice. Therefore, **minimum laser rating: 22–25 mi** for the shortest experiments.

Candidate sites in this book range from 9–150 mi, with most in the 9–50 mi range (50–1,700 ft expected drop). Practical limits for amateur equipment:

- **9–12 mi:** 50–100 ft expected drop; minimum practical experiment; achievable with 5 W lasers.
- **12–50 mi:** 100–1,700 ft expected drop; achievable with 5–10 W lasers and quality retroreflectors.
- **50–100 mi:** Requires 10–20 W lasers, large retroreflector arrays, ideal atmospheric conditions.
- **100–150 mi:** At the edge of amateur capability; stretch goal requiring exceptional conditions.

Sites with expected distances over 100 mi should be considered stretch goals. The tables in this book focus on practical distances under 100 mi, with emphasis on the 50–100 ft drop range (9–12 mi) as the most accessible experiments.

31.1.2 Why NOT visible light

Visible lasers (green 532 nm, blue 450 nm) are **not recommended** for these experiments:

- **Eye hazard from reflections:** Any return signal strong enough to detect visually is strong enough to cause eye damage if it reflects unexpectedly.
- **Impractical detection method:** You cannot safely stare into the distance waiting for a reflection. The return beam could arrive at any moment.
- **Legal visibility:** Visible beams attract attention from law enforcement, aircraft pilots, and bystanders, creating unnecessary complications.

Solution: Use infrared (IR) lasers with electronic detection. IR is invisible to the human eye, eliminating the temptation to look for the beam visually. Detection requires a photodetector with audible feedback—you hear a beep when the return signal arrives, rather than risking eye exposure.

31.1.3 Recommended: Infrared lasers

Wavelength	Power	Effective Range	Notes
808 nm (near-IR)	5–10 W	30–60 mi	Most common high-power IR diode; cheap; good atmospheric transmission
980 nm (near-IR)	5–15 W	40–80 mi	Excellent atmospheric window; less eye hazard than 808 nm
1064 nm (Nd:YAG)	1–5 W	50–100 mi	Best atmospheric transmission; industrial/scientific grade; expensive
1550 nm (eye-safe IR)	1–10 W	30–70 mi	"Eye-safe" at lower powers (does not focus on retina); telecom wavelength; detectors readily available

Recommended choice: 808 nm or 980 nm diode laser, 5–10 W. These offer the best combination of power, cost, atmospheric transmission, and detector availability. Budget: $100–500 for the laser module; requires driver circuit and power supply.

31.1.4 Legal framework

High-power IR lasers are **Class 4** devices, same as visible lasers. However, IR lasers have some practical advantages:

- **Not visible to pilots or bystanders**, reducing risk of "laser strike" reports.
- **Federal law (18 U.S.C. § 39A)** still applies—do not aim at aircraft, even with IR.
- **State laws** typically regulate by power class, not wavelength; check local regulations.
- **No permit required** for personal/scientific use in most US jurisdictions.

Recommended precautions:

- File a NOTAM with the FAA if operating near flight paths (even for IR).
- Conduct experiments in remote areas away from airports.
- Keep the beam aimed horizontally over water or flat terrain.
- Document the scientific purpose of your experiment.

31.1.5 IR laser suppliers

- **Opt Lasers** (optlasers.com) — Industrial laser modules, 808 nm and 980 nm, 1W–15W, $100–800
- **LaserLands** (laserlands.net) — Diode modules with drivers, $50–300
- **DTR's Laser Shop** (dragonlasers.com) — Diodes and complete builds, $50–500
- **Thorlabs** (thorlabs.com) — Scientific-grade modules, 1W–10W, $500–5,000
- **eBay/AliExpress** — Bare diodes and cheap modules; quality varies; suitable for experienced builders

31.2 Detection system

31.2.1 Core requirement: Audible feedback

You cannot and should not visually detect the return beam. The detection system must:

- Detect IR light at the laser wavelength (e.g., 808 nm, 980 nm).
- Produce an **audible beep or tone** when a return signal is detected.
- Distinguish the laser signal from ambient IR (sunlight, thermal sources).

31.2.2 Detection approaches

Option 1: Photodiode + amplifier + audio circuit

- Silicon photodiode sensitive to your wavelength (e.g., BPW34 for 808 nm).

- Transimpedance amplifier to convert photocurrent to voltage.
- Comparator or threshold circuit to trigger on signal detection.
- Piezo buzzer or speaker for audible output.
- Narrowband optical filter to reject ambient light.
- **Cost:** $50–150 in parts; requires electronics skills.

Option 2: Commercial laser power meter with audio

- Ophir, Thorlabs, or Coherent power meters with analog output.
- Connect analog output to a simple threshold/buzzer circuit.
- **Cost:** $300–2,000 for meter; more reliable but expensive.

Option 3: Modified security sensor

- Active IR security beams (used for perimeter alarms) operate at 808 nm or 940 nm.
- The receiver unit already has detection circuitry and alarm output.
- Replace the matched emitter with your long-range laser.
- **Cost:** $50–200; search “active infrared beam sensor” or “photoelectric beam detector.”
- **Suppliers:** Amazon, security supply stores (e.g., EMX Industries, Seco-Larm).

Option 4: Arduino/Raspberry Pi based detector

- Photodiode connected to analog input.
- Software threshold detection with audible and visual feedback.
- Can log detections with timestamps for documentation.
- **Cost:** $30–100; requires programming.
- Search “Arduino photodiode detector” or “Raspberry Pi light sensor.”

31.2.3 Optical filtering

Ambient IR from the sun and warm objects will swamp your detector without filtering:

- **Narrowband filter:** 10 nm bandwidth centered on your laser wavelength. Thorlabs, Edmund Optics, or eBay. $30–150.
- **Collimating tube:** A long narrow tube in front of the detector rejects off-axis light.
- **Operate at night:** Dramatically reduces ambient IR; strongly recommended.

31.2.4 Recommended detection setup

For most experiments, the simplest reliable approach:

1. **Modified security beam receiver** (Seco-Larm E-931-S50RRQ or similar), $80–150.
2. **808 nm narrowband filter** in front of receiver lens, $30–50.
3. **Small telescope or binocular** to gather more light onto the receiver.
4. Connect alarm output to **piezo buzzer** for audible indication.
5. **Total cost:** $150–300 for detection system.

31.2.5 Required safety equipment

Even though IR is invisible, it is still dangerous:

- **IR laser safety glasses:** OD 5+ at your wavelength. Search "808nm OD5 laser safety glasses" or "980nm laser goggles." $50–150.
- **IR viewing card:** A phosphorescent card that glows visibly when IR light hits it. Hold it in front of the laser to confirm the beam is emitting, or place it at a target to verify the beam is hitting. Used at Point A during setup and field testing—not needed during the actual long-range experiment. Search "IR detector card 800-1100nm." $10–30.
- **Interlock key switch:** Prevents accidental activation.
- **Warning signs:** "Invisible laser radiation" signs at experiment site.

31.3 Retroreflectors vs. flat mirrors

31.3.1 Why retroreflectors are essential

A flat mirror requires near-perfect alignment: even a 0.01° tilt error deflects the return beam by 0.02°, which at 10 mi is approximately 1,800 ft off-target. You would never see the return.

Corner-cube retroreflectors solve this problem. They return incoming light back toward its source regardless of the angle of incidence (within their acceptance angle, typically ±15–30°). This is the same technology used on:

- Lunar retroreflectors left by Apollo missions (still used for Earth-Moon ranging)
- Road signs and bicycle reflectors
- Surveying prisms

31.3.2 Retroreflector types

Type	Size	Price	Range	Notes
Surveying prism	62 mm	$80–200	20–50 mi	Highest optical quality; single corner cube
Surveying prism array	3–7 prisms	$150–400	50–100 mi	Multiple prisms; recommended for max range
Sheet retroreflector (large)	2'×2'	$60–120	30–60 mi	Mount 4+ sheets on board; good budget option
Sheet retroreflector	12"×12"	$20–50	15–30 mi	Single sheet; moderate distances only
Bicycle/safety reflector	2–4"	$5–15	<5 mi	Testing/alignment only; not for experiments

31.3.3 Recommended products (Amazon)

Surveying prisms (best for long range):

- Search: "62mm surveying prism" or "total station prism"

- **AdirPro Prism Assembly** — Single 62 mm prism with target, \$80–120
- **SECO Surveying Prism** — Professional grade, \$150–200
- **360° Prism** — Accepts light from any horizontal direction, \$100–180

Prism arrays (maximum return signal):

- Search: "triple prism surveying" or "prism array"
- **AdirPro Triple Prism Assembly** — Three 62 mm prisms, \$200–300
- For 50+ mi experiments, consider mounting multiple single prisms in a cluster

Sheet retroreflectors (budget option):

- Search: "reflective sheeting 3M" or "retroreflective tape high intensity"
- **3M Diamond Grade Reflective Sheeting** — 12"×12" sheets, \$15–30
- **High Intensity Prismatic (HIP) reflective tape** — Rolls 2"×30', \$20–40
- Mount multiple sheets on a board to create a large reflective target

31.3.4 Mounting considerations

- **Stability:** Use a sturdy tripod; wind vibration will blur the return signal.
- **Height:** Mount at the same height as the laser source for horizontal beam path.
- **Aiming:** Surveying prisms have a target pattern for rough alignment; sheet reflectors work at any angle.
- **Size vs. distance:** For 50+ mi, use multiple prisms or large sheet arrays (2'×2' minimum).

31.3.5 Expected return signal

The return signal decreases with the fourth power of distance (inverse square out, inverse square back). At 50 mi with a single 62 mm prism and 5 W laser, expect a return signal approximately 1/10,000,000 of the transmitted power—detectable with a sensitive photodetector but not visible to the eye. Larger retroreflector arrays proportionally increase the return signal.

31.4 Putting it all together

31.4.1 Pre-experiment field testing

Before traveling to your experiment site, test all equipment in a large open field (a few hundred yards is sufficient):

1. **Set up the laser on a tripod** at one end of the field. Hold an IR viewing card a few inches in front of the laser aperture—you should see a glowing spot where the invisible beam hits the card. This confirms the laser is emitting.

2. **Set up the retroreflector** at the far end, mounted on a stable tripod at the same height as the laser.

3. **Set up your detector** next to the laser, aimed at the retroreflector.

4. **Aim the laser at the retroreflector.** Use the IR viewing card to verify the beam is hitting the target.

5. **Verify detection:** You should hear the audible beep indicating a return signal.

6. **Block the laser beam** with your hand or a card. The audible signal should stop immediately.

7. **Unblock the beam.** The signal should return.

8. **Misalign the laser** slightly. The signal should weaken or stop, confirming your detector is responding to the retroreflected beam, not stray light.

If the audible detection does not work reliably at 200–500 yards, troubleshoot before attempting a multi-mile experiment.

31.4.2 Equipment checklist

At Point A (laser station):

- IR laser with power supply/batteries
- Sturdy tripod with fine adjustment head
- IR detector with audible output
- Narrowband filter for detector
- IR viewing card
- IR safety glasses (OD 5+ at your wavelength)
- Smartphone for coordination and GPS
- Notebook for recording observations

At Point B (reflector station):

- Retroreflector (prism array for 50+ mi)
- Sturdy tripod with leveling capability
- Bubble level or smartphone level app
- Binoculars (to visually locate Point A)
- IR safety glasses
- Smartphone for coordination
- Flashlight or headlamp for night setup

31.5 Setting up your reflector

31.5.1 Location selection at Point B

- Position at the pre-calculated GPS coordinates.
- Ensure clear line of sight to Point A—no trees, buildings, or terrain obstructions.
- Set up on stable ground; avoid soft sand or mud that may shift.
- If over water, set up on a pier, dock, or stable platform at water's edge.

31.5.2 Leveling and height

- **Match the height** of the laser at Point A. If the laser is 4 feet above the ground/water, the reflector should be at 4 feet.
- **Level the tripod** using a bubble level. The reflector should be perpendicular to the expected beam path.
- For surveying prisms with a target pattern, orient the target face toward Point A.

31.5.3 Aiming the reflector

Corner-cube retroreflectors do not require precise aiming—they return light over a wide acceptance angle (±15–30°). However, for maximum return signal:

- **Point the reflector face toward Point A** as closely as practical.
- Use binoculars to identify landmarks at Point A (lights, structures) and orient the reflector toward them.
- For sheet retroreflectors, ensure the reflective surface is facing Point A, not angled away.

Once set up, the Point B team should move away from the reflector to avoid blocking the beam or creating safety hazards.

31.6 Operating the laser

31.6.1 Pulse vs. continuous beam

Continuous beam is recommended for initial detection:

- Easier to detect—the return signal is constant, making the audible beep steady and unmistakable.
- Simpler equipment—no pulse timing circuitry needed.
- Allows slow, careful aiming adjustments while listening for signal strength changes.

Pulsed operation is useful for:

- Confirming the signal is from your laser (pulse the beam on/off; does the detector follow?).

- Reducing thermal stress on the laser during extended operation.
- Distinguishing your signal from ambient IR noise.

Recommendation: Start with continuous beam for initial alignment and detection. Once you have a signal, switch to manual pulsing (turn the laser on/off every few seconds) to confirm the detector is responding to your beam.

31.6.2 Aiming procedure

1. Use GPS or maps to determine the compass bearing from Point A to Point B.
2. Aim the laser in that direction using a compass or smartphone.
3. Slowly sweep the beam in small increments (left/right, up/down) while listening for the audible detector.
4. When you hear a signal, stop and fine-tune for maximum signal strength.
5. Have the Point B team confirm via phone that you are aimed at the reflector (if they can see IR on a viewing card or camera).

31.6.3 If no signal is detected

Before giving up, systematically troubleshoot:

1. **Verify equipment function:** Return to short-range testing. Does the detector beep when you aim at a nearby reflector (10–50 feet)?
2. **Check alignment:** Are you aimed at the correct bearing? GPS coordinates correct?
3. **Check line of sight:** Is there fog, haze, or an obstruction you didn't notice?
4. **Check reflector setup:** Call the Point B team. Is the reflector still standing? Aimed correctly? At the right height?
5. **Widen your search:** Sweep the laser in a larger pattern—you may be off by more than expected.
6. **Increase detector sensitivity:** If your detector has adjustable gain, increase it.

7. **Wait for better conditions:** Atmospheric conditions matter. Try again on a clearer night with less humidity.
8. **Reduce distance:** If 50 miles isn't working, try a 20-mile site first to validate your equipment.

If after systematic troubleshooting you still cannot detect a return signal, the experiment is inconclusive—not a failure, but not a success either. Document your setup, conditions, and observations for future attempts.

31.7 Interpreting results

This is the purpose of the entire experiment: to test the predictions of two competing models.

31.7.1 The globe model prediction

If Earth is a sphere with radius $R \approx 3{,}959$ mi, the surface curves away from a straight line. Over distance d, the geometric drop is approximately:

$$\text{drop} \approx \frac{d^2}{2R} \approx \frac{d^2}{7{,}918} \text{ (in miles)}$$

At 9 mi, this gives a drop of approximately 50 ft.

Prediction: If both the laser and reflector are set at the same height above the water (e.g., 4 ft), a perfectly straight laser beam should pass approximately 50 ft **above** the reflector. The beam misses the reflector entirely. **No reflection. No beep.**

31.7.2 The flat plane prediction

If the surface is flat (no curvature), a laser beam aimed horizontally will remain at constant height above the surface.

Prediction: The beam hits the reflector. **Reflection. Beep.**

31.7.3 Atmospheric refraction

Light does not travel in a perfectly straight line through the atmosphere. Due to air density gradients (warmer air is less dense than cooler air), light bends slightly downward as it travels. This is called **atmospheric refraction**.

Standard atmospheric refraction reduces the *apparent* curvature by approximately 14% (refraction coefficient $k \approx 0.14$). This means:

- Geometric drop at 9 mi: 50 ft
- Apparent drop with standard refraction: $50 \times (1 - 0.14) \approx 43$ ft

Refraction varies with atmospheric conditions:

- **Standard conditions:** $k \approx 0.14$ (reduces apparent drop by 14%)
- **Temperature inversion (looming):** k can exceed 1.0, bending light so much that distant objects appear *above* their geometric position—this can cause "impossible" sightings
- **Hot surface (inferior mirage):** Light bends upward, increasing apparent drop

Important: Under standard atmospheric conditions, refraction bends light downward by approximately 14% of what the geometric curvature would predict. It does not eliminate the predicted effect—it reduces it. At 9 mi, even with aggressive refraction ($k = 0.3$), the globe model still predicts a drop of approximately 35 ft—far too much for a 4 ft-high laser to hit a 4 ft-high reflector.

On the flat model, refraction is irrelevant to this question—the surface is flat, so there is no geometric drop to reduce.

31.7.4 Interpreting your results

The experiment produces one of two outcomes.

Outcome A: No signal detected (no beep)

- The beam did not reach the reflector.
- This is consistent with the globe model prediction: the surface curved away and the beam passed overhead.
- Before concluding, verify equipment function with a short-range test.

Outcome B: Signal detected (beep)

- The beam reached the reflector and returned.
- This contradicts the globe model prediction: a 50 ft drop should have caused the beam to miss entirely.
- Atmospheric refraction cannot account for a 50 ft difference—even aggressive refraction only reduces apparent drop by 15 ft.

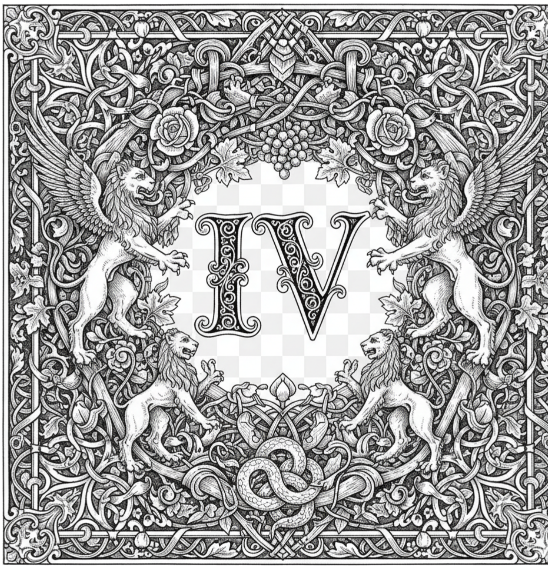
- The locations in this book were selected over water or flat desert with known GPS coordinates. The distances are not in question.

Replication:

- One successful detection is significant. Multiple detections at different locations are conclusive.
- Document everything: date, time, weather, equipment, coordinates, and results.
- Share your methods and data so others can replicate.

31.7.5 The value of this experiment

You are not relying on authority, textbooks, or training data. You are collecting your own measurements under controlled conditions. Whatever the outcome, you will have firsthand experience rather than inherited belief.


IV

Part IV

SOUTH POLE PROOFS

Chapter 32

Introduction

The curvature experiments in Part 3 test whether the surface curves *away* from a straight line over distance. This part tests a different prediction: whether longitude lines *converge* as you travel south.

32.1 The competing predictions

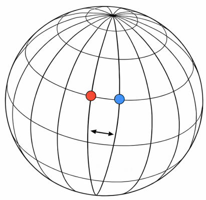
Globe-Earth model:

- Longitude lines (meridians) converge toward both poles.
- At the equator, 1° of longitude spans about 69 miles.
- At 60° latitude, 1° of longitude spans about 35 miles (half as much).
- At the poles, all meridians meet at a single point.
- Two objects traveling due south from different longitudes should get **closer together**.

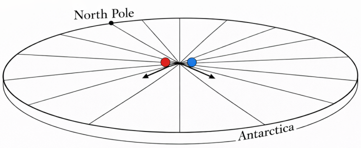
Flat-Earth model:

- The North Pole is at the center; Antarctica is the rim.
- Longitude lines radiate outward from the center like spokes on a wheel.
- As you travel south (toward the rim), the spokes get **farther apart**.
- Two objects traveling due south from different longitudes should get **farther apart**.

This is a decisive test. The two models make opposite predictions about a measurable quantity: the distance between two points at the same latitude as latitude changes.



Globe: Travelers converge



Flat: Travelers diverge

32.2 Why Antarctica matters

On a globe, the South Pole is the point where all southern meridians converge. On a flat Earth, there is no South Pole—only an ice wall at the rim.

The Antarctic Treaty (1959) restricts independent travel to Antarctica. Flat-Earthers argue this is to prevent people from discovering the truth. Globe-Earthers argue it is for environmental protection and safety.

This part does not require reaching Antarctica. The convergence (or divergence) of meridians is measurable at *any* latitude change in the Southern Hemisphere. We can test the prediction using accessible locations.

Chapter 33

The Experiment

33.1 Concept

1. Select two points at the same latitude but different longitudes (e.g., 20° apart).
2. Measure the east-west distance between them.
3. Travel south to a higher latitude (e.g., 20° further south).
4. Measure the east-west distance again at the new latitude.
5. Compare the two measurements.

Globe prediction: The second measurement is *smaller* than the first.
Flat prediction: The second measurement is *larger* than the first.

33.2 The mathematics

On a sphere of radius R, the east-west distance between two points at latitude ϕ separated by longitude difference $\Delta\lambda$ is:

$$d = R \cdot \cos(\phi) \cdot \Delta\lambda$$

where $\Delta\lambda$ is in radians.
Example: Two points 20° of longitude apart.

- At the equator ($\phi =$ 0ř): cos(0ř) = 1.0, so $d = R \cdot \Delta\lambda$ (maximum distance).
- At 35°S ($\phi =$ 35ř): cos(35ř) ≈ 0.82, so $d \approx 0.82 \cdot R \cdot \Delta\lambda$.

- At 55°S ($\phi = 55$ř): $\cos(55$ř$) \approx 0.57$, so $d \approx 0.57 \cdot R \cdot \Delta\lambda$.

The distance between those same two longitudes **decreases by 30%** going from 35°S to 55°S on a globe.

On a flat Earth with the North Pole at center, the distance between radial lines *increases* as you move outward (south).

33.3 Accessible test locations

You do not need to reach Antarctica. The following locations are accessible by commercial travel:

South America:

- 35°S: Buenos Aires, Argentina (longitude 58°W) to Valparaíso, Chile (longitude 72°W) — 14° apart.
- 55°S: Ushuaia, Argentina (longitude 68°W) — southernmost city in the world.

Australia / New Zealand:

- 35°S: Sydney, Australia (longitude 151°E) to Adelaide (longitude 139°E) — 12° apart.
- 45°S: Queenstown, New Zealand (longitude 168°E).

South Africa:

- 34°S: Cape Town (longitude 18°E).
- Limited southern options (ocean beyond).

South America offers the best test corridor: you can travel from 35°S to 55°S entirely by road.

Chapter 34

Measurement Methods

The key requirement is measuring east-west distance **without relying on GPS or government data**.

34.1 Method 1: Vehicle odometer

The simplest approach. Rent a car and drive.

Protocol:

1. At 35°S, drive east-west along a road that follows the latitude line as closely as possible.
2. Record odometer reading at start and end.
3. Calculate distance traveled.
4. Travel south to 55°S.
5. Repeat the east-west drive at the new latitude.
6. Compare distances.

Challenges:

- Roads do not follow perfect latitude lines.
- Terrain forces detours.
- Odometer accuracy varies (typically $\pm 3\%$).

Mitigation:

- Use a calibrated bicycle odometer or surveyor's wheel for higher accuracy.

- Choose road segments that run predominantly east-west.
- Correct for north-south deviations using compass bearings.

34.2 Method 2: Radio time-of-flight

For experimenters with amateur radio (ham) licenses.

Two stations with synchronized clocks can measure the propagation time of radio signals. Distance = (round-trip time × speed of light) / 2.

Equipment per station:

- HF transceiver (100W, covers 3–30 MHz) — $500–1,500
- Precision timing source (rubidium oscillator or cesium clock) — $1,000–5,000 used
- Antenna (dipole or vertical) — $50–200
- Logging equipment (computer with sound card for timing) — $500

Protocol:

1. Station A transmits a precisely timed pulse.
2. Station B receives, logs arrival time, and retransmits.
3. Station A receives the response and logs arrival time.
4. Round-trip time yields distance.

Precision: With rubidium clocks, timing precision of 1 microsecond gives distance precision of about 300 meters (speed of light = 300,000 km/s).

Challenges:

- Ionospheric skip can add path length (signal bounces off ionosphere).
- Ground-wave propagation is more reliable but limited to shorter distances.
- Requires amateur radio license in both countries.

Mitigation:

- Use frequencies that favor ground-wave propagation (lower HF, 3–5 MHz).
- Conduct measurements at night when ionosphere is more stable.
- Take multiple measurements and average.

34.3 Method 3: Triangulation with surveying equipment

Classical surveying uses theodolites and known baselines to measure distances through triangulation.

Equipment:

- Theodolite or total station — \$500–2,000 used
- Surveyor's chain or tape (100m) — \$50–100
- Tripods and targets — \$100–200

Protocol:

1. Establish a baseline of known length (measure with chain).
2. Sight to a distant target and measure angles from both ends of baseline.
3. Calculate distance to target using trigonometry.
4. Chain together multiple triangles to span large distances.

Challenge: This method requires many measurements to span hundreds of miles. It is labor-intensive but fully independent of electronic systems.

34.4 Method 4: Satellite messenger timing (partial independence)

Devices like Garmin inReach or SPOT use satellite networks to report position.

Limitation: These rely on satellite infrastructure. However, you can use them to *verify* that two devices are at the claimed positions, then measure distance between positions using an independent method.

This is a hybrid approach: use satellites for position confirmation, use physical measurement for distance.

Chapter 35

Detailed Protocol: South America Corridor

This is the most accessible version of the experiment.

35.1 Team composition

- **Team A:** Starts at Buenos Aires, Argentina (34.6°S, 58.4°W).
- **Team B:** Starts at Mendoza, Argentina (32.9°S, 68.8°W).
- Longitude difference: approximately 10.4°.

35.2 Phase 1: Northern baseline (35°S)

1. Both teams travel to latitude 35°S.
2. Team A positions at 35°S, 58°W (east of Buenos Aires, near the coast).
3. Team B positions at 35°S, 68°W (near Mendoza).
4. Measure the east-west distance between teams using Method 1 (odometer) or Method 2 (radio).
5. **Expected distance on globe:** Approximately 570 miles (920 km).

35.3 Phase 2: Travel south

Both teams travel due south:

- Route 3 runs along the Argentine coast.
- Route 40 runs along the Andes.
- Both routes reach Tierra del Fuego.

35.4 Phase 3: Southern baseline (55°S)

1. Both teams position at latitude 55°S.
2. Team A: 55°S, 58°W (near Río Grande, Tierra del Fuego).
3. Team B: 55°S, 68°W (near Ushuaia or Chilean territory).
4. Measure the east-west distance between teams using the same method as Phase 1.

35.5 Phase 4: Compare measurements

Globe prediction:

- Distance at 35°S: 570 miles.
- Distance at 55°S: $570 \times \frac{\cos(55ř)}{\cos(35ř)} = 570 \times \frac{0.574}{0.819} \approx 400$ miles.
- **Decrease of approximately 30%.**

Flat prediction:

- Distance at 55°S should be *greater* than at 35°S.
- The exact amount depends on the flat-Earth model geometry, but any increase contradicts the globe.

Chapter 36

Interpreting Results

36.1 If distance decreases going south

- Consistent with globe-Earth geometry.
- Longitude lines are converging toward a southern pole.
- The measured ratio should match $\cos(\phi_2)/\cos(\phi_1)$.

36.2 If distance increases going south

- Contradicts globe-Earth geometry.
- Consistent with a flat-Earth model where south is toward the rim.
- The rate of increase would reveal the geometry of the flat surface.

36.3 If distance stays the same

- Contradicts both standard models.
- Would suggest a cylindrical or other unusual geometry.
- Demands re-examination of measurement methods.

36.4 Error analysis

For the result to be meaningful, measurement error must be smaller than the predicted difference.

Globe prediction: 30% decrease over 20° of latitude.

Required precision: Better than ±10% to distinguish clearly.

Odometer accuracy: Typically ±3%, adequate for this test.

Radio ranging accuracy: With microsecond timing, ±0.1% over 500+ miles, more than adequate.

Chapter 37

Alternative: The Triangle Test

Instead of two teams, use three.

37.1 Concept

1. Position three teams in a triangle at latitude 35°S.
2. Measure all three sides of the triangle.
3. All three teams travel south to 55°S, maintaining their relative longitude positions.
4. Measure all three sides again.

Globe prediction: All three sides shrink proportionally.
Flat prediction: All three sides grow.
Advantage: Three measurements provide redundancy and cross-checking.

Chapter 38

Equipment Summary

38.1 Minimum viable equipment (odometer method)

- Rental car with working odometer — \$50–100/day
- Compass (for bearing corrections) — \$20–50
- Paper maps of region — \$20–40
- Notebook and camera for documentation — \$0–50

Total: \$500–1,500 for a two-week expedition (excluding flights and lodging).

38.2 Radio ranging equipment (per station)

- HF transceiver (Icom IC-7300 or similar) — \$1,000–1,500
- Rubidium frequency standard (used) — \$500–1,500
- Antenna and feedline — \$100–300
- Laptop with audio interface — \$500–1,000
- Power supply / batteries — \$100–200

Total per station: \$2,200–4,500. Two stations: \$4,400–9,000.

38.3 Surveying equipment

- Used theodolite — $300–1,000
- Surveyor's chain (100m) — $50–100
- Tripods and targets — $100–200

Total: $450–1,300.

Chapter 39

Practical Considerations

39.1 Permits and access

- Argentina and Chile allow tourist travel to Tierra del Fuego without special permits.
- Ham radio operation requires reciprocal licensing (obtain before travel).
- No Antarctic Treaty restrictions apply—you are not entering Antarctica.

39.2 Timing

- Southern Hemisphere summer (December–February) offers best weather and longest days.
- Roads in Patagonia can be rough; allow extra travel time.
- Plan 2–3 weeks for the full experiment.

39.3 Documentation

- Video-record all measurements.
- Photograph odometer readings, compass bearings, and landmarks.
- Publish raw data so others can verify and replicate.

Chapter 40

Summary of the Patagonia Experiment

This experiment tests a clear, measurable prediction:

Do longitude lines converge or diverge as you travel south?

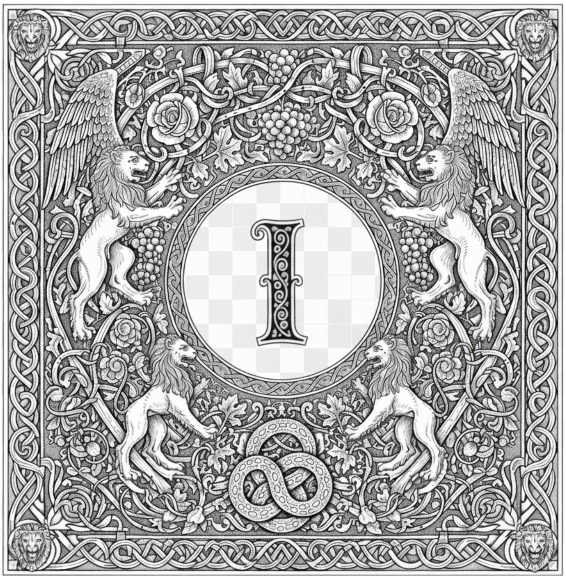
- **Globe:** Converge. Distance between fixed longitudes decreases.
- **Flat:** Diverge. Distance between fixed longitudes increases.

The experiment does not require:

- GPS or satellite data (you measure distance directly).
- Government permission (use public roads in Argentina/Chile).
- Trust in scientific institutions (you collect and publish your own data).

The equipment is commercially available. The locations are accessible. The prediction difference (30%+) is far larger than measurement error.

If you perform this experiment and publish your results—whatever they show—you contribute real data to a question that is usually argued with rhetoric.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Part V

CONCLUSION

Chapter 41

What Comes Next

This book has presented experiments—not arguments, not appeals to authority, not photographs you must trust. Experiments. Things you can do yourself, with equipment you can buy, at locations you can visit.

The question of Earth's shape is not settled by consensus or ridicule. It is settled by measurement. And measurement requires people willing to do the work.

41.1 The Invitation

If you have read this far, you are not a passive observer. You are someone who cares about evidence. Whether you believe the Earth is a globe, a flat plane, or something else entirely, you now have a roadmap for finding out.

- **Pick an experiment.** Start with something accessible. The laser-over-water test requires minimal equipment. The Patagonia longitude experiment requires travel but produces unambiguous results.
- **Document everything.** Video your setup. Photograph your equipment. Record raw data. Transparency is what separates science from assertion.
- **Share your results.** Whatever you find—even if it surprises you—publish it. Real data advances the conversation; hoarded data does not.

41.2 Join the Community

We have created a space for readers to share their work:

reddit.com/user/CopernicusOnTrial

Post your:

- Equipment setups and purchasing recommendations
- Methodology descriptions and lessons learned
- Raw data, photographs, and video documentation
- Results and analysis—whatever they show

This is not a debate forum. It is a place for experimenters to compare notes, troubleshoot setups, and build a public record of independent measurements.

41.3 A Final Word

For centuries, questions about Earth's shape were settled by authority: priests, professors, institutions. You were told what to believe, and belief was enough.

That era is ending. Equipment that once required university labs now fits in a backpack. Locations that once required expeditions now require only a plane ticket. The tools of verification are in your hands.

Use them.

The Earth is either curved or it is not. The stars either rotate or they do not. Longitude lines either converge or diverge. These are not matters of opinion. They are matters of measurement.

Go measure.