Human HET: *Challenge 4 Stay Focused*

By Brad Armosky and Mary Kay Hemenway

Introduction

Not only must a telescope gather and focus starlight, a telescope must track the star as Earth turns. This enables the telescope to gather light for a longer period of time and allows it to detect faint objects. Typically, a pair of perpendicular axes points the telescope anywhere in the sky visible from the observatory. These telescopes are sometimes referred to as "fully steerable." One of the axes, the right ascension axis, points in a direction parallel to Earth's rotation axis. As Earth turns eastward, the telescope turns westward around the right ascension axis at half the speed of the hour hand on a 12-hour clock. The other axis, the declination axis, is parallel to Earth's rotation pole. Moving along this axis allows north or south motion. But for telescopes with large mirrors, this type of two-axis telescope mount is only viable with extreme and costly engineering measures, owing to the weight and stress on the primary mirror. The advantage of this system is that the telescope can be pointed in any direction above the horizon.

HET is designed not to be fully steerable, in order to reduce complex and costly engineering problems associated with fully steerable telescopes. The primary mirror array rests permanently at an angle of 55 degrees above the horizon. HET may rotate on its concrete ring base between observations. A track straddled across the telescope aperture holds the tracker and PFIP (prime focus instrument package). The tracker positions PFIP at prime focus to collect light reflected from the primary mirror array below. As Earth rotates, a star transits HET's field of view; the tracker and PFIP slowly crawl along the track to follow the star's image at prime focus.

The students will use the basic law of reflection to draw rays reflected from a spherical mirror. Where they intersect is the region of prime focus. Since stars and other celestial objects are so distant, their light rays are nearly parallel to each other as they strike the primary mirror. As Earth rotates, the celestial object crosses the view of the telescope, resulting in a change of the incident ray angle. As this angle changes, so does the position of prime focus.

Goal

Discover that the focal region of the telescope moves as a star transits HET's field of view.

Materials

1. Activity sheets (three sheets showing five scenarios of light hitting the mirror from different directions). All three sheets are needed for each student.
2. Paper, pencil, and protractor for each student.

Texas Essential Knowledge and Skills

Science TEKS Process Skills

- plan and implement investigative procedures (6.2, 7.2, 8.2, IPC, Physics, Astronomy)
- relationships between science and technology (8.5)

Science TEKS Concepts

- Systems (6.5, 7.5)

Math TEKS

- Geometry and spatial reasoning (6.7, 7.8)
- Measurement (6.8)
- Underlying processes and mathematical tools (6.11, 6.13, 7.13, 7.15, 8.14)

Preparation

Distribute the activity sheets and materials to the students. Begin by engaging the students: Set them in the role of an astronomer on a quest for a large, cost-effective telescope. Review the odyssey of HET-related challenges and solutions that lead to this challenge so that students see how the challenges and solutions are all related to one another. Review the nature of the HET, and then lead to the problem facing them with this challenge. The activity sheet will help the students discover that the focal point moves as the star crosses the primary mirror array's field of view. Following that discovery, they may brainstorm about ways to capture light at that moving focal point. Each student should work on his or her own activity sheets, then discuss the solution in small groups

Problem

The challenge is to learn to track a star across HET's field of view without moving the telescope.

Solution

Explain that the lines striking the spherically curved cross section of the HET mirror array represents light rays from a distant star. Students are to draw the reflected ray for each incident ray on the basis of the law of reflection.

Each of the five sets features a different incident angle. The heavy line connecting the center of curvature and the mirror is a reference ray that indicates the incident angle.

Drawing the reflected ray

The radius of the arc representing HET's primary mirror is 3 inches. A 6-inch-diameter protractor (radius = 3 inches) is ideal for this activity.

1. Place the protractor eye at the point where the incident ray and mirror meet. Mark the point.
2. Pivot the protractor around the eye until the 90-degree mark meets the point marking the center of curvature.
3. Note the incident ray angle on the protractor, then mark the reflected ray angle point on the opposite side of the 90-degree mark along the outside of the protractor.
4. Draw the reflected ray through the points.

Or,

1. Lightly draw a reference line between the center of curvature and the point where the incident ray and mirror meet. This establishes a visible perpendicular reference.
2. Lay the protractor eye over the intersection point on the mirror.
3. Pivot the protractor so that the eye's baseline covers the reference line.
4. Measure the angle between the incident ray and mirror.

5. Pivot the protractor 180 degrees around the eye to realign the eye's baseline over the reference line.
6. Mark the reflected ray angle.
7. Draw the reflected ray by connecting the points.

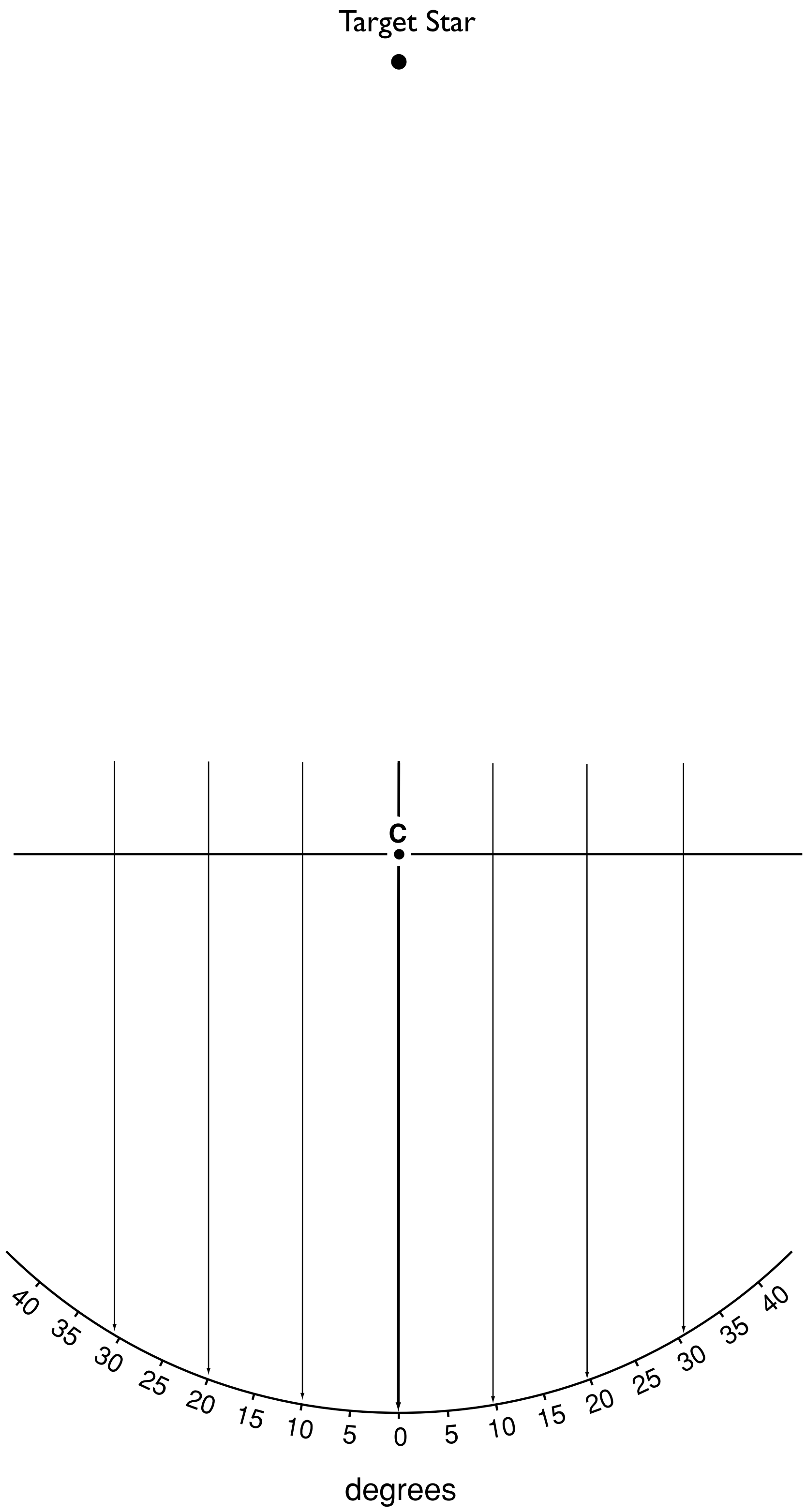
When the diagrams are completed, cut them out and align them while holding them up to a light. When examining the stack of all five, the focal points are aligned along a curve about halfway between the center of curvature and the mirror.

Once students have discovered that the focal point moves when the starlight enters from different directions, they are free to tackle the challenge of figuring out a way to keep the PFIP inside the focal region as a target star passes over HET's field of view.

The solution that astronomers and engineers settled on was to build a track across the top of the telescope. The tracker and PFIP ride upside-down on the track, so that PFIP faces the mirror. As the celestial object crosses HET's field of view, PFIP follows the star's image and gathers the light for HET's instruments.

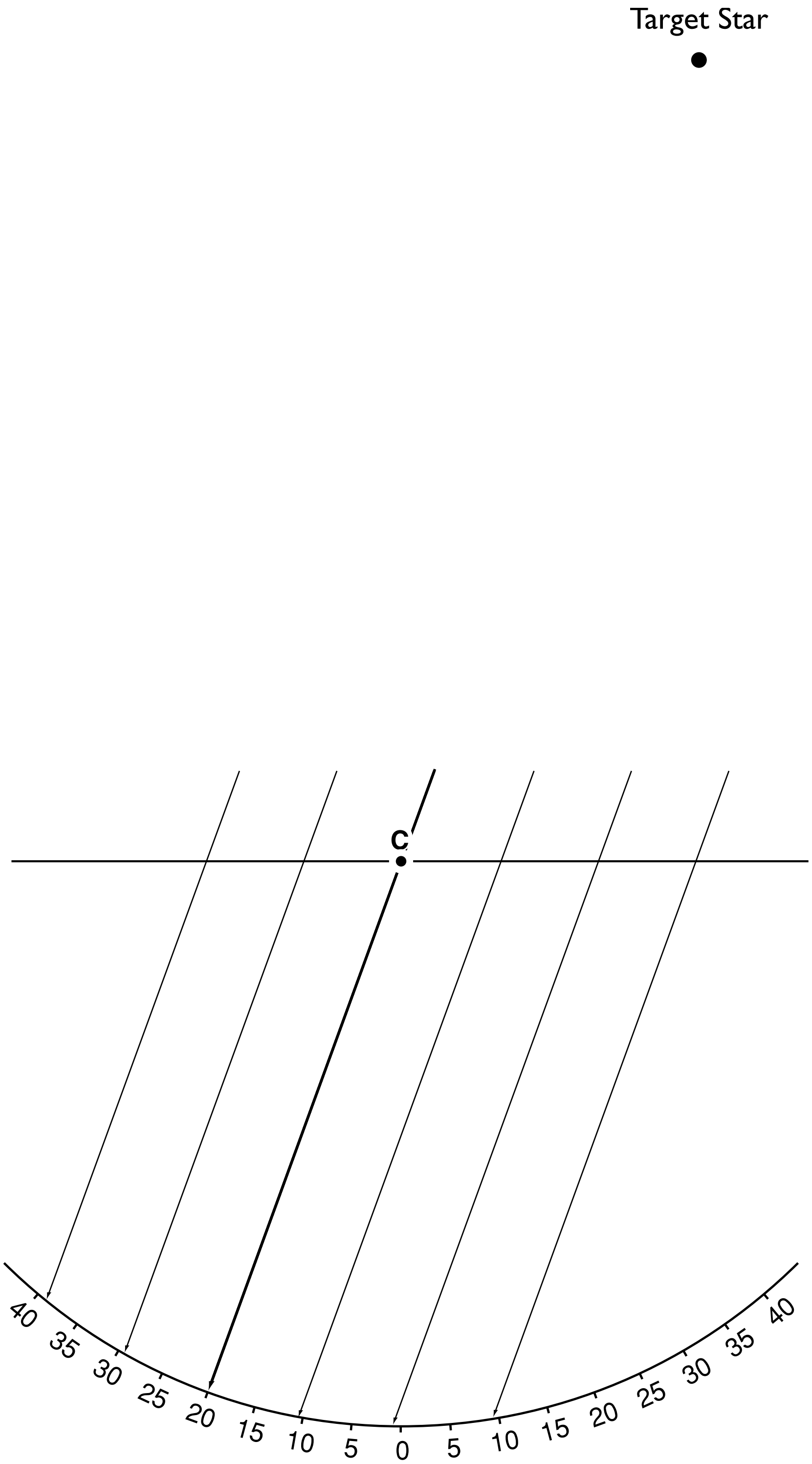
Warning: Some groups may suggest that instead of moving the tracker and PFIP, they should move the mirrors. This would work, but would actually be far more complicated and costly to implement than moving the tracker and PFIP. One reason is that observations halt while the mirrors are being aligned ; thus, it would be difficult to both collect starlight and align mirrors simultaneously.

Human HET: *CHALLENGE 4*
STAY FOCUSED ACTIVITY SHEET A



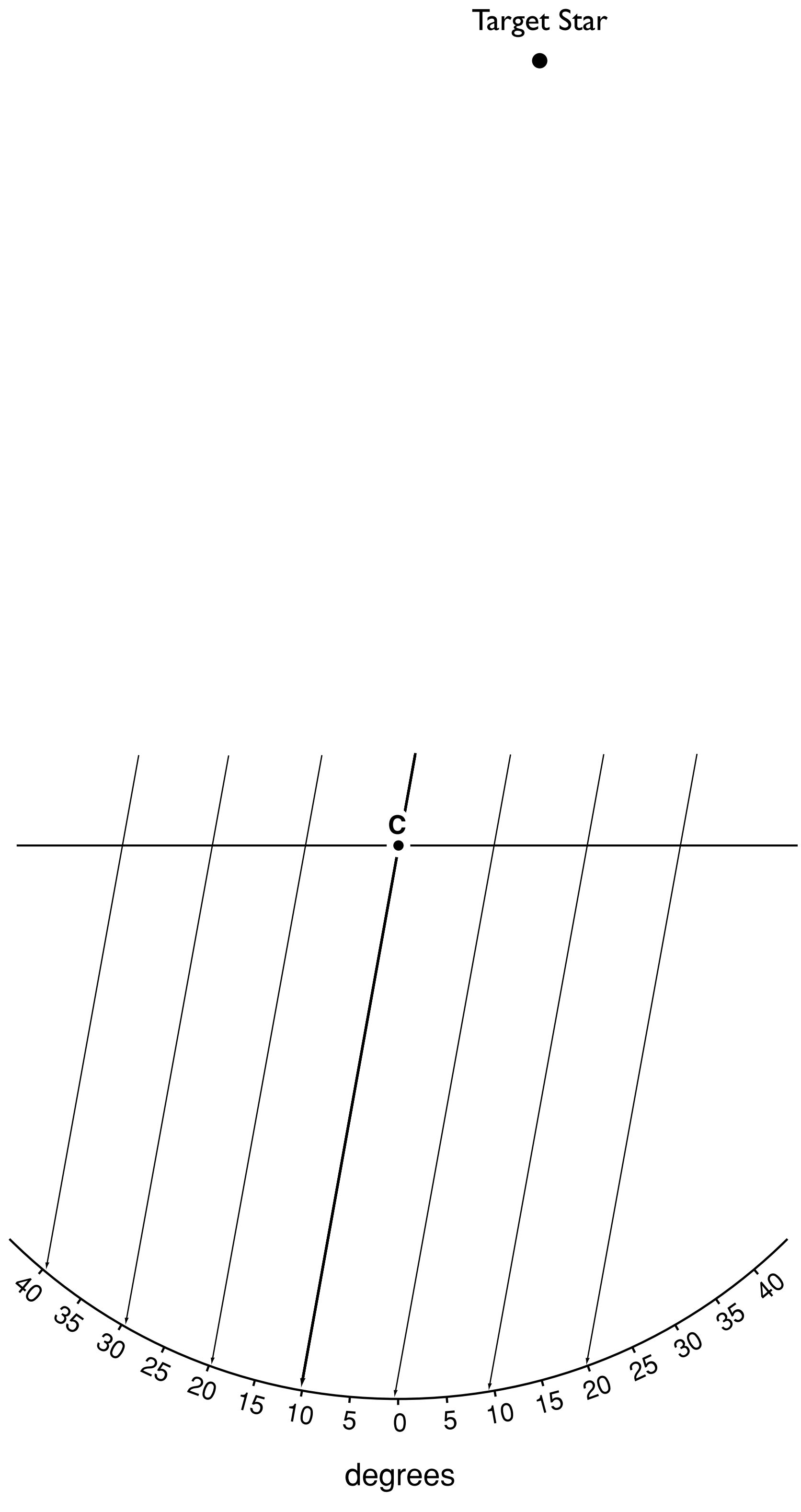
C - center of curvature

Human HET: *Challenge 4*
Stay Focused Activity Sheet B



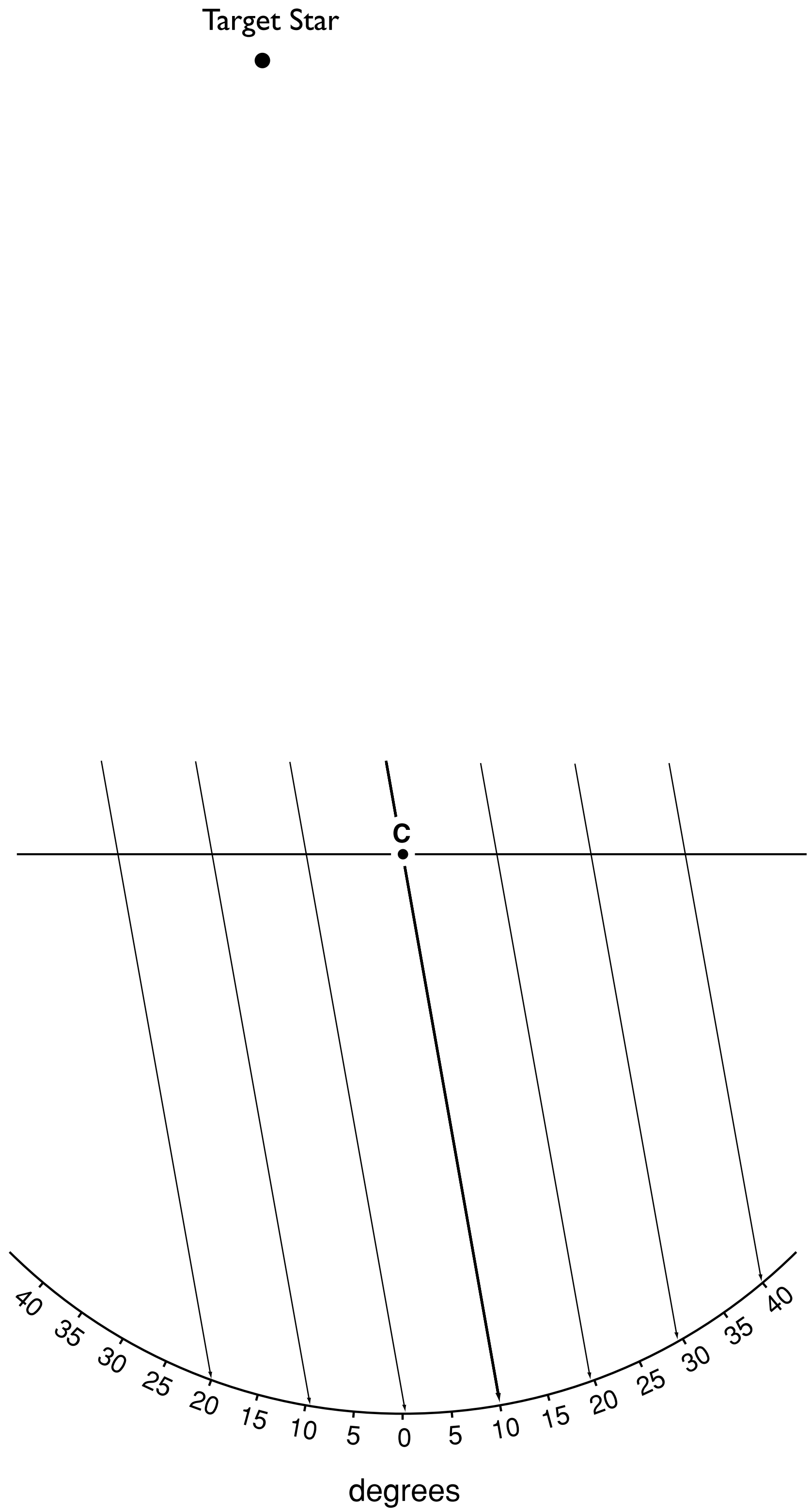
C - center of curvature

Human HET: *Challenge 4*
Stay Focused Activity Sheet C



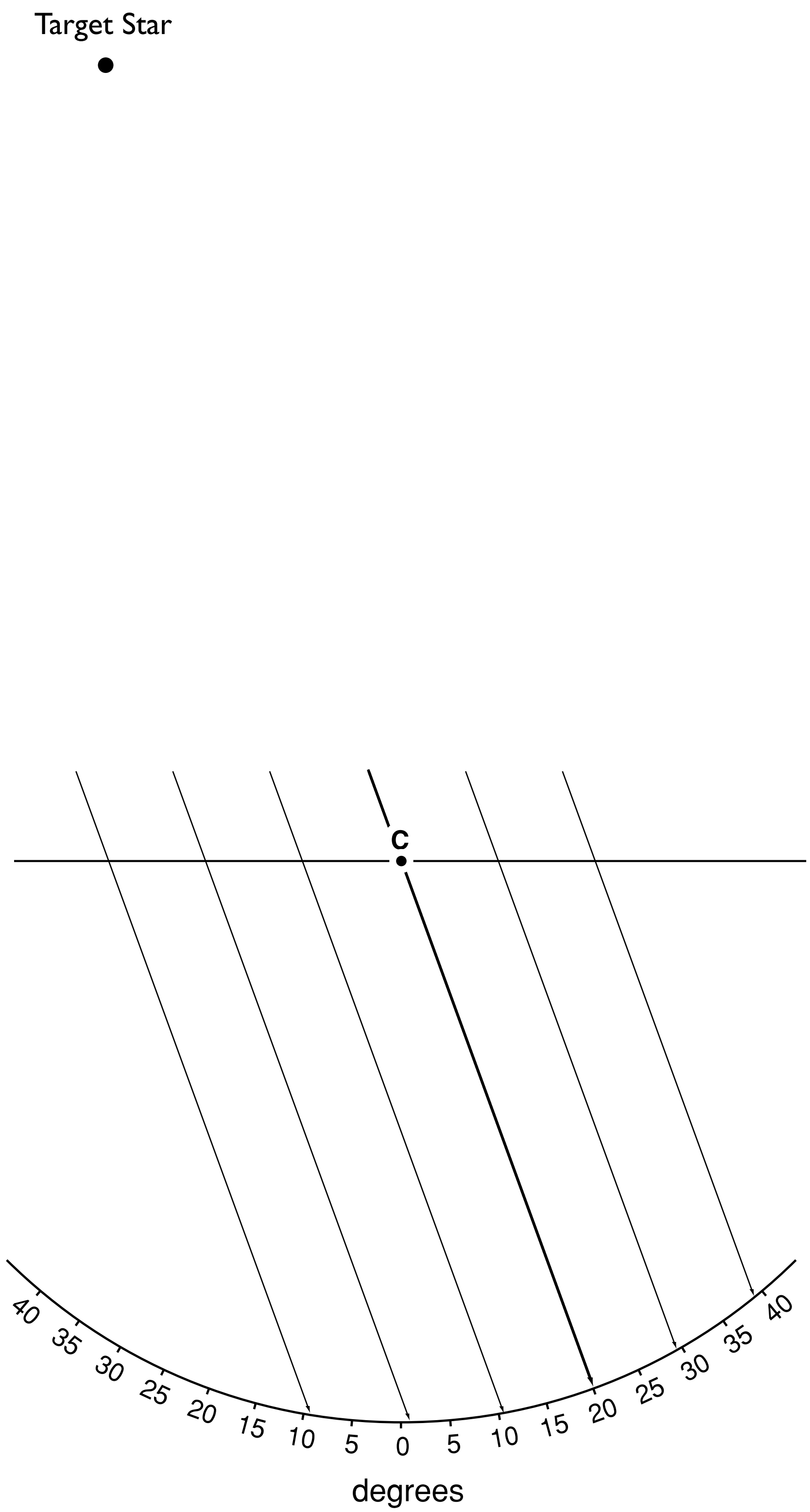
C - center of curvature

Human HET: *CHALLENGE 4*
STAY FOCUSED ACTIVITY SHEET D



C - center of curvature

Human HET: *Challenge 4*
Stay Focused Activity Sheet E



C - center of curvature