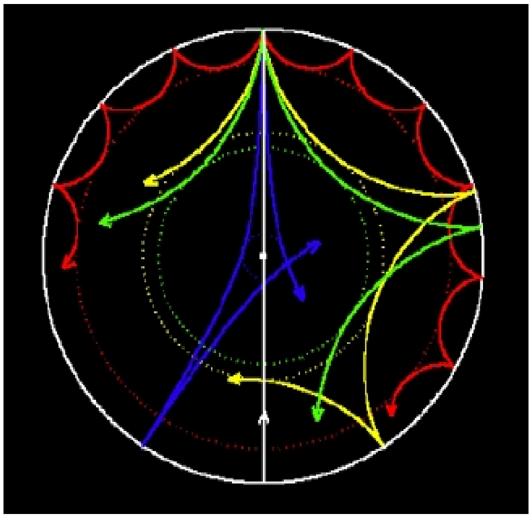
Sound waves from turbulent activity on the star's Surface are reflected through the interior along a variety of paths. The surface layer, producing the light we see, moves up and down in complex ways that cause brightness changes over many different time scales from seconds to minutes.

One of the hallmarks of a truly successful space mission is that, not only does it meet all of its planned scientific goals for which it was designed, but that it contributes to advancements in science well-beyond the perimeter of its own specialized research areas.

Recently, the Kepler satellite, which was designed to detect Earth-sized planets orbiting other stars, has made a series of discoveries that have revolutionized the subject of stellar structure and evolution.

Using the minute brightness changes that indicate sound waves traveling in the interiors of giant stars, Kepler data has now confirmed a fundamental hypothesis of stellar evolution proposed by physicist George Gamow nearly 75 years ago!

As stars no longer have enough hydrogen fuel in their cores to sustain them, they switch to fusing hydrogen into helium in a thin shell just outside the core. This shell-burning phase is the prelude to the star becoming a red giant or red supergiant star, depending on its mass. By measuring the brightness changes in many of these red giant stars, Kepler data has been used to probe the interior structure of these stars, revealing just such a shell-burning zone! The sound waves that bounce from the surface to the inner shell are reflected back to the surface where that cause minute brightness changes over time. These 'seismic waves' can be modeled to reveal the location, thickness and depth of the shell-burning zones.

Problem 1 - Draw a circle to represent a star's surface. Draw a series of semi-circles of different radii similar to the ones in the diagram above, but where the sequence of circles along the circumference have the same ending point as its starting point. This represents a 'standing wave' on the surface. The point on the surface where the arc meets the surface is called the 'node'. How many nodes do you count for circles of the different radii that you create?

Problem 2 - If the location of the shell-burning zone outer edge is half-way to the center of the star, for the arc that just touches the shell-zone, how far apart will the nodes be on the surface of the star, if the radius of the star is 5 million kilometers?

Problem 3 - If the speed of the wave is 1,000 km/sec, how many seconds elapse in the travel between the nodes, and what would you see in the light from this star?

Problem 1 - Draw a circle to represent a star's surface. Draw a series of semi-circles of different radii similar to the ones in the diagram above, but where the sequence of circles along the circumference have the same ending point as its starting point. This represents a 'standing wave' on the surface. The point on the surface where the arc meets the surface is called the 'node'. How many nodes do you count for circles of the different radii that you create?

Answer: For example, divide the circle into four equal quadrants. Place the compass in the upper right quadrant at a position on the circumference that is half-way between the two points where the horizontal and vertical lines intersect the circumference. Set your compass radius so that it touches one of these points, then draw the interior arc. Repeat this for the other three quadrants. Divide the circle into five equal parts and repeat this construction process. The number of nodes for each compass radius length are shown in the table below. The arc radius is given in terms of the length of the radius of the circle taken as R=1.0.

Nodes	Number of arcs	Radius of arc
2	**2**	**1.414**
3	**3**	**1.000**
4	**4**	**0.765**
5	**5**	**0.618**
6	**6**	**0.518**
7	**7**	**0.445**
8	**8**	**0.390**

Students may prove that, if the radius of the circle is defined as R, and the number of nodes on the circumference is N, the general formula for the arc radius is just

$$d = R\sqrt{2 - 2\cos\left(\frac{\pi}{N}\right)}$$

Problem 2 - If the location of the shell-burning zone outer edge is half-way to the center of the star, for the arc that just touches the shell-zone, how far apart will the nodes be on the surface of the star, if the radius of the star is 5 million kilometers?

Answer: If the shells outer edge is half way to the center of the star, its radial location is 0.500 in units of the star's radius. The closest wave arc that come close to this is for the Node=6 arc with R = 0.518. The full circumference of the star's circle is 2π, so the nodes are located along the circumference a distance of $2\pi/N = 2\pi/6$ or $\pi/3$ apart in multiples of the radius of the star. Since the star's radius is 5 million km, the nodes are located (3.141) x (0.333) x (5million km) = **5.22 million km apart**.

Problem 3 - If the speed of the wave is 1,000 km/sec, how many seconds elapse in the travel between the nodes, and what would you see in the light from this star? Answer: The wave travels along the arc between the node points, whose radius is 5.2 million km, and length is 3.141 x (5.22 million km) = 16.4 million km.
T = 16.4 million km/(1000 km/s) = 16,400 seconds or about 4.6 hours.
The light from the star may 'flicker' slightly in brightness with a period of 4.6 hours.