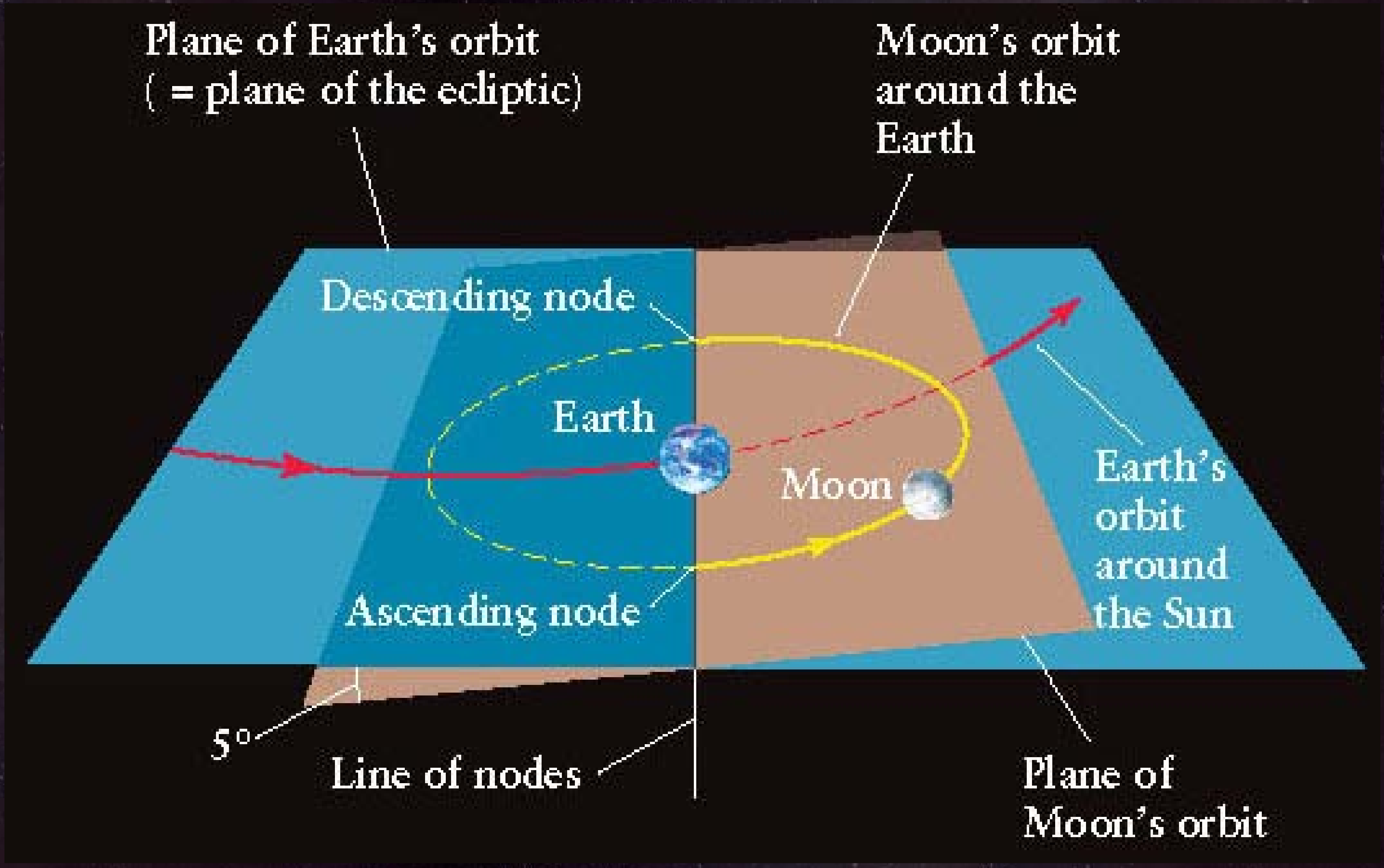
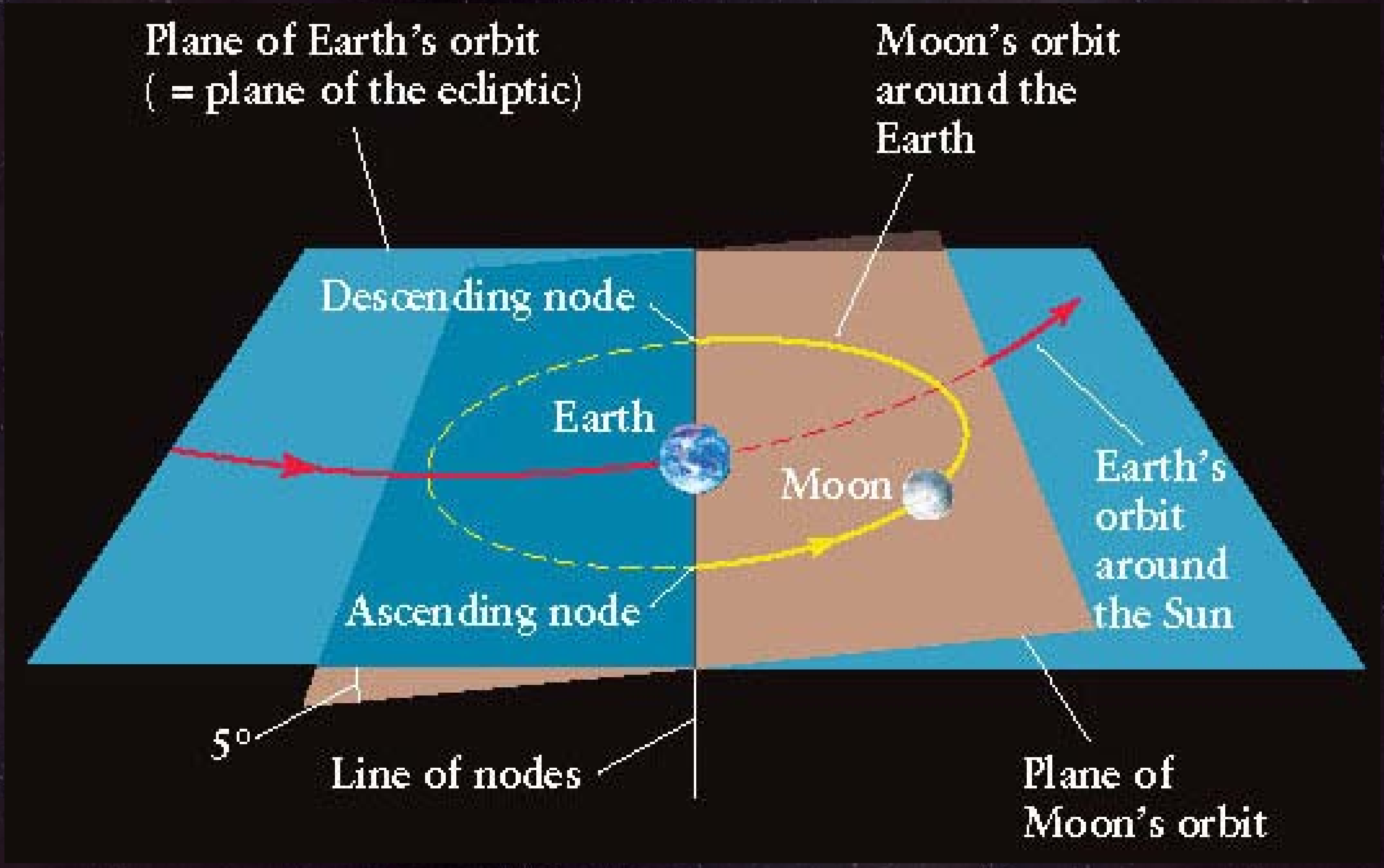
Predicting eclipses

The plane of the Moon's orbit around the Earth is inclined by about 5 degrees relative to the plane of the Earth's orbit around the Sun.



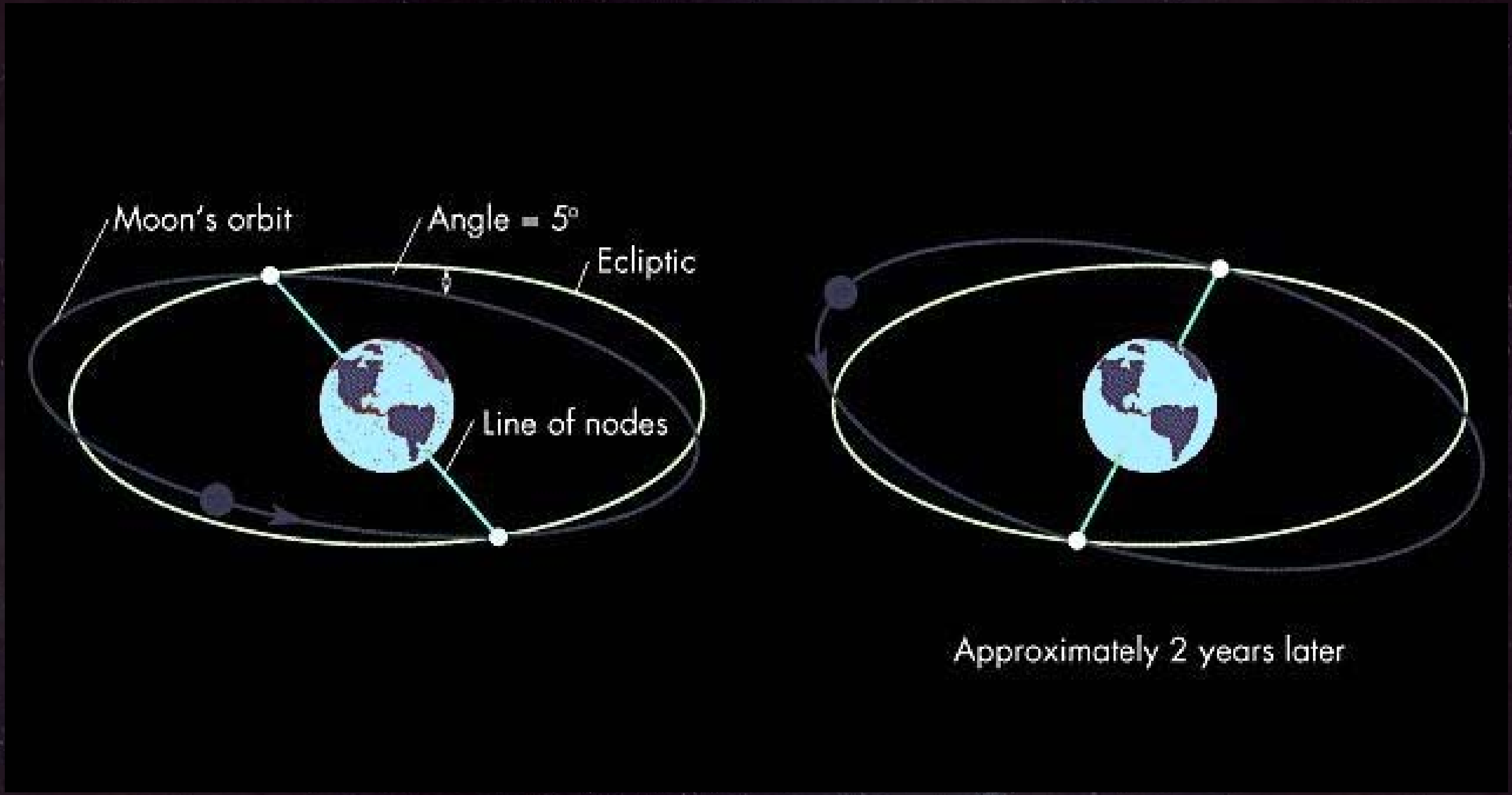
Predicting eclipses

The line on which the two orbital planes cross is called the *line of nodes*.



Predicting eclipses

The gravitational pull of the Earth's equatorial bulge causes the line of nodes to precess. The direction in which the line of nodes points rotates completely once every 18.6 years.



Predicting eclipses

Because of the precession of the nodes, the line of nodes points towards the Sun slightly more frequently than once a year – it happens every 346.6 days – a period of time known as an *eclipse year*.

$$19 \text{ eclipse years} \approx 223 \text{ lunar months} \approx 6585.3 \text{ days}$$

This means that if a new moon occurs when the Earth, Moon and Sun all lie on the line of nodes (that is, a total solar eclipse occurs), then 6585.3 days later, the same alignment will occur, and another solar eclipse will be observed.

This period of 6585.3 days, or just over 18 years, is called a *Saros cycle*.

Predicting eclipses

Because a Saros is not a whole number of days, successive eclipses in a Saros cycle will occur on different parts of the Earth.

Three Saros cycles contain an almost whole number of days, so after three Saros cycles, an eclipse will occur not far from where one had occurred 54 years previously.

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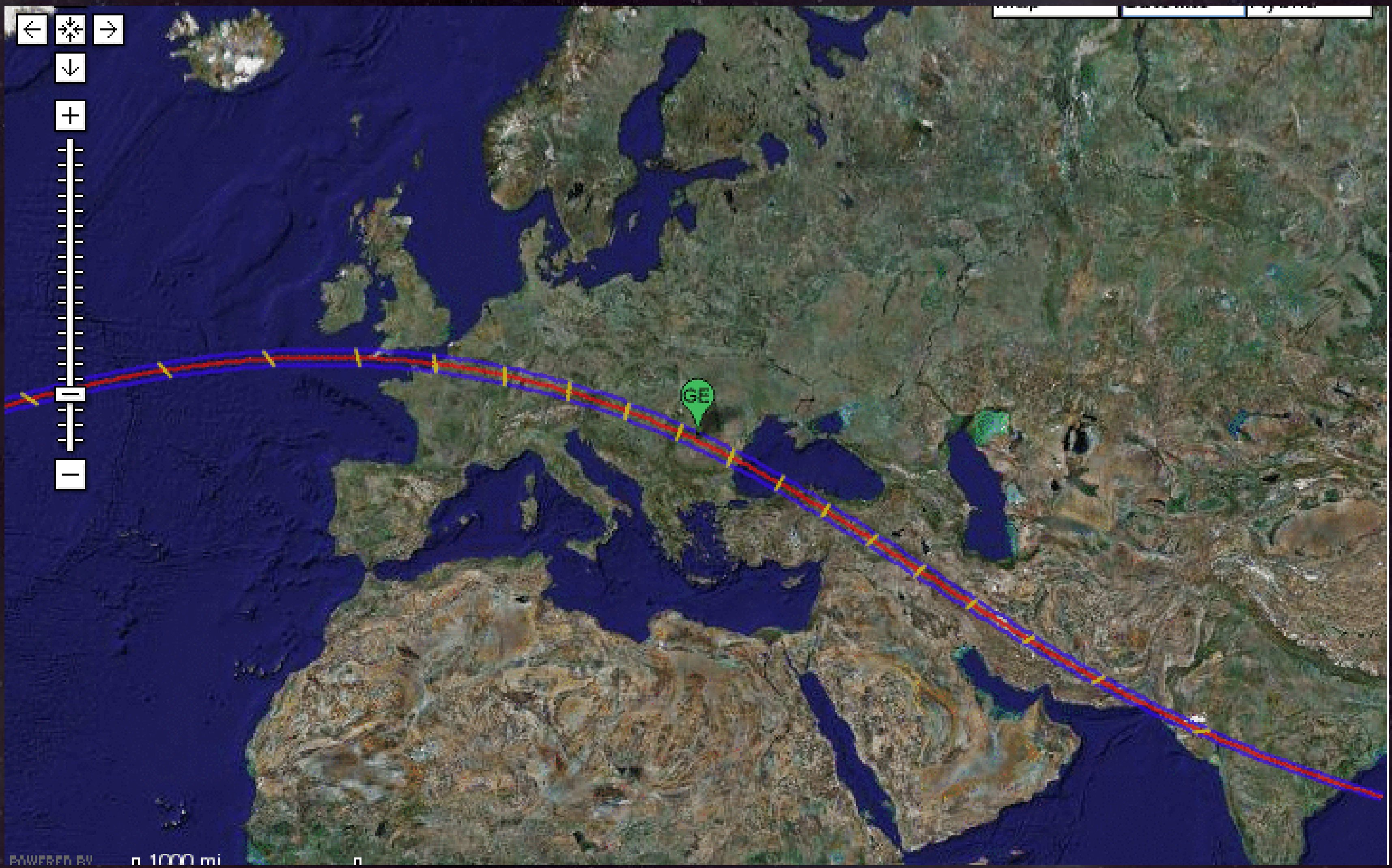
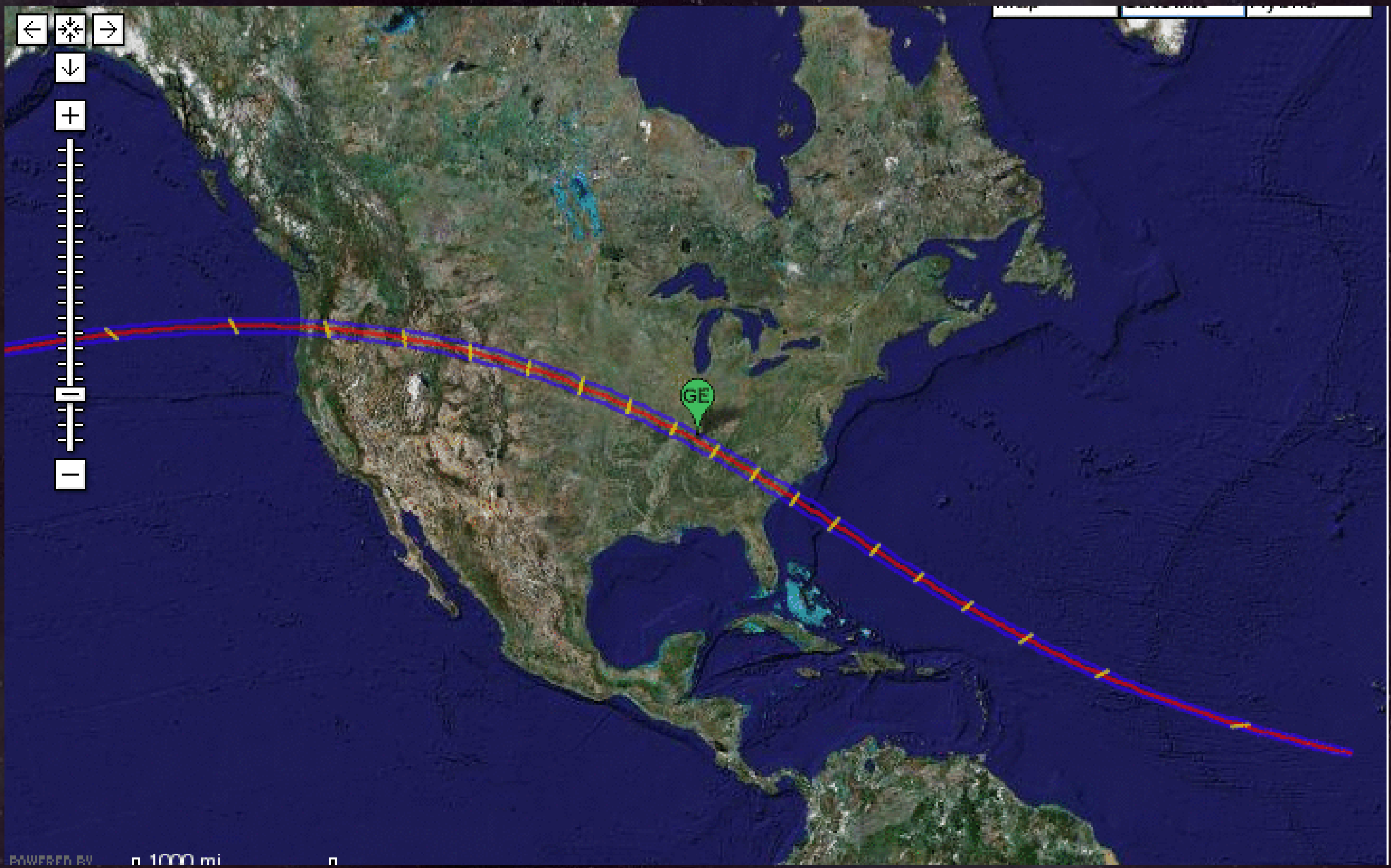
Predicting eclipses



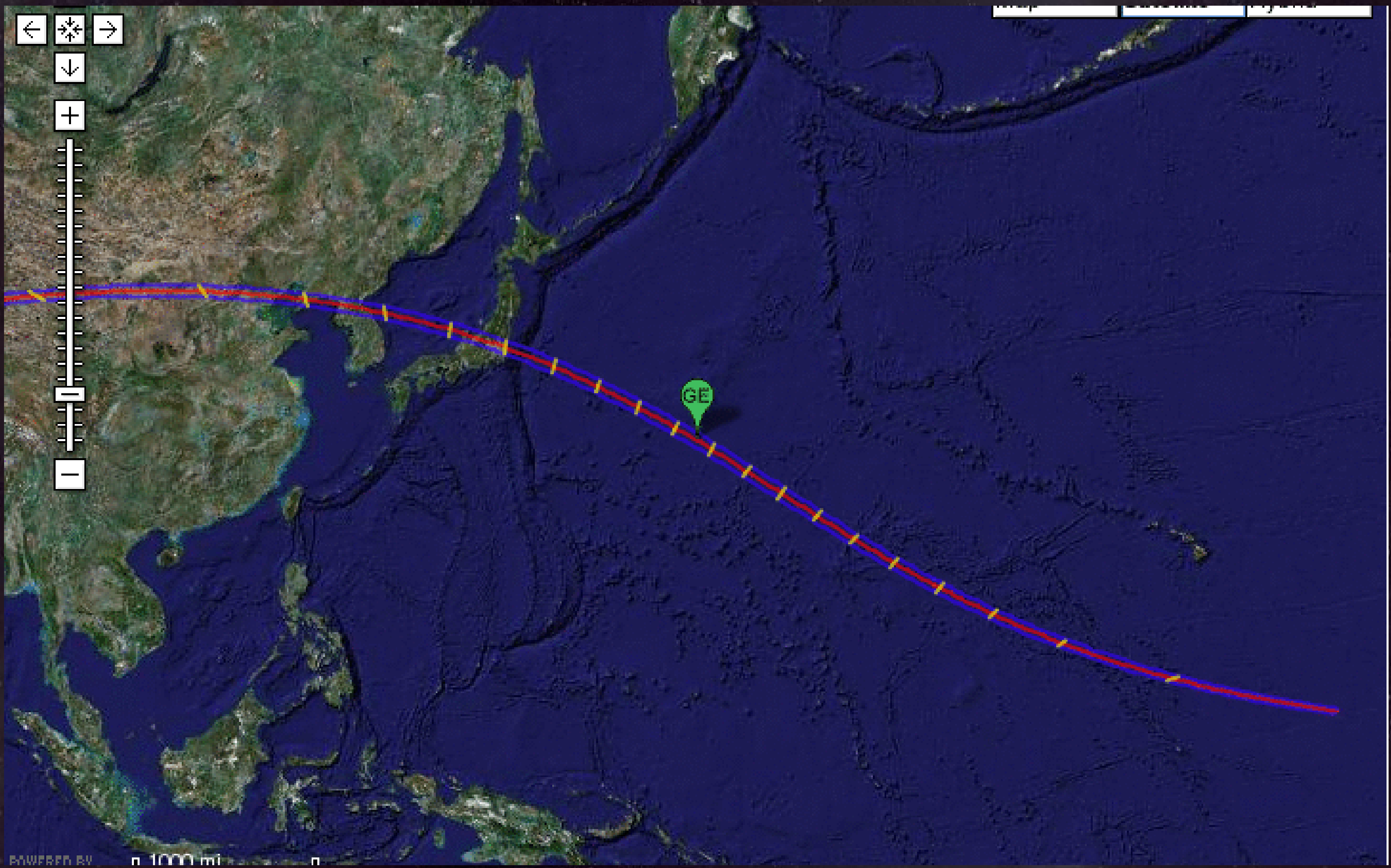
11 August 1999

Predicting eclipses



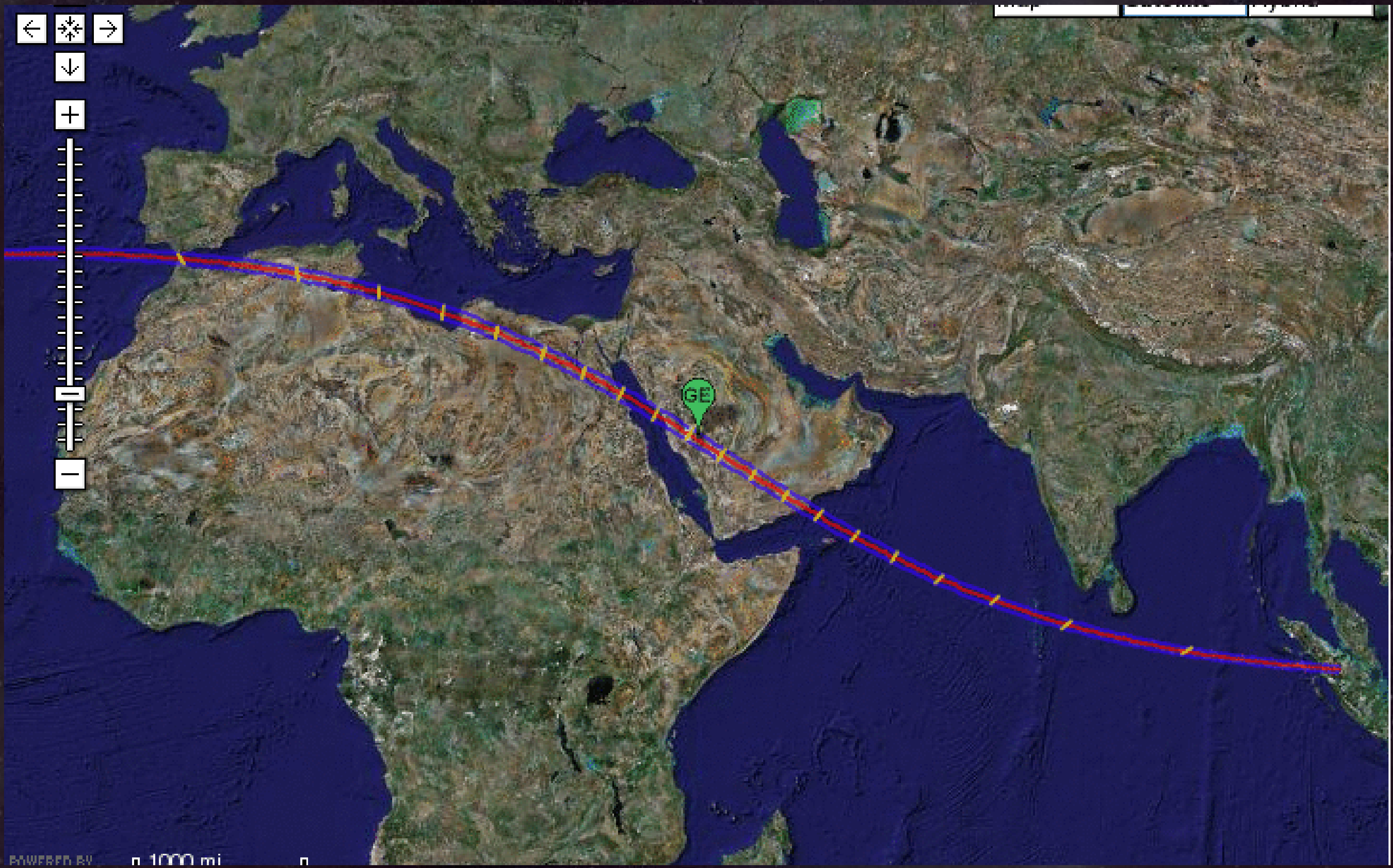
21 August 2017

Predicting eclipses



2 September 2035

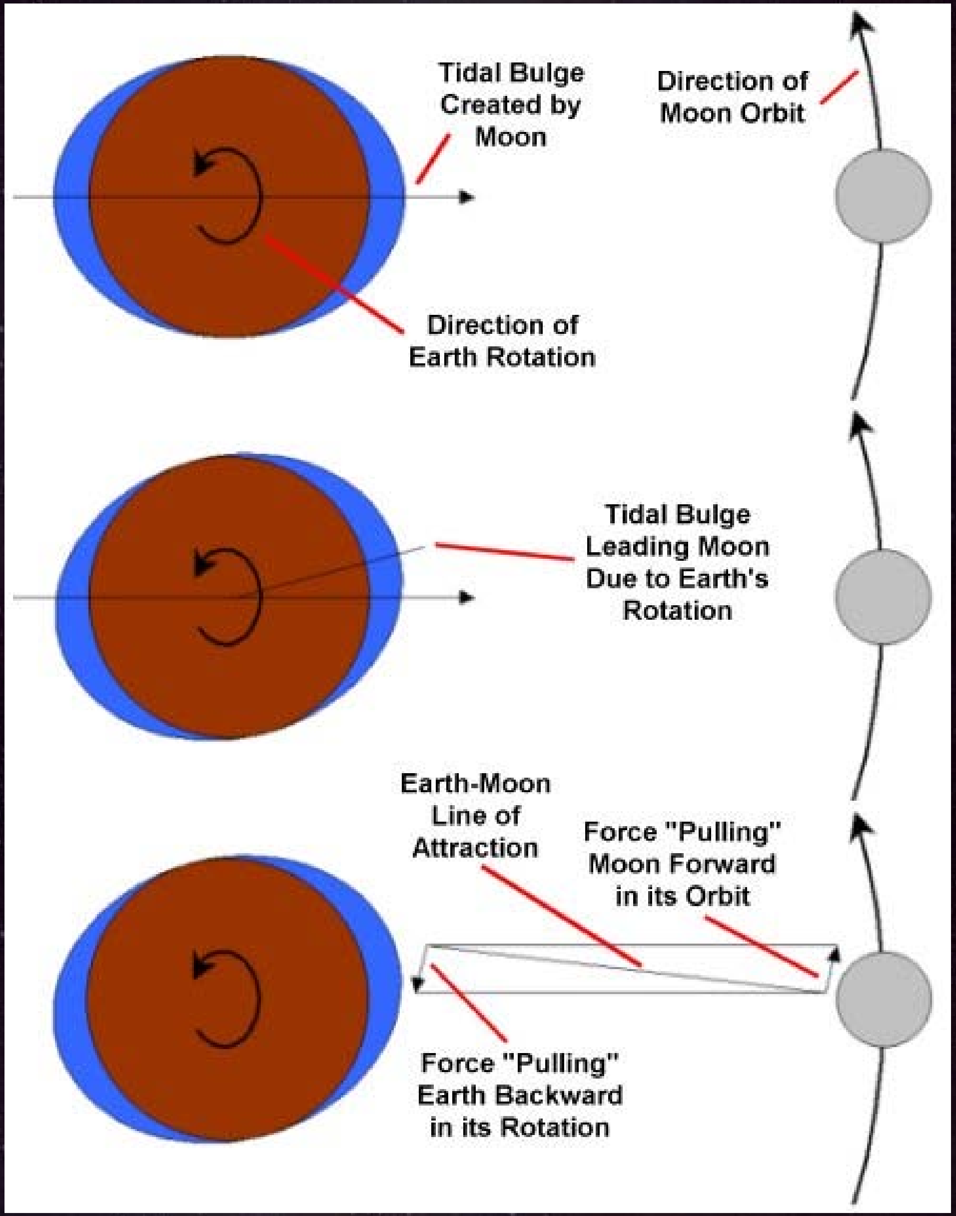
Predicting eclipses



12 September 2053

Solar eclipses – a temporary phenomenon

Because of tides, the Moon is moving away from the Earth at about 3.8cm per year on average. So, eventually, it will be too small to completely obscure the Sun.



Solar eclipses – a temporary phenomenon

At the same time, the Sun is very slowly getting larger as it evolves. These two effects mean that in about 600 million years, there will be no more total solar eclipses – only annular ones.

How we discovered the Earth was not flat

The Earth has been known to be (approximately) spherical since Classical times.

Columbus did not think he might sail off the edge of the world. His geography was hazy, but not *that* hazy. The idea that mediaeval people were Flat Earthers came about only in the 19th century.

(The idea that Columbus discovered America is another historical error!)

How we discovered the Earth was not flat

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How we discovered the Earth was not flat

The Greeks noted that during the partial phases of lunar eclipses, the shadow edge is always circular.

They observed that lunar eclipses only happen at full moon, and correctly surmised that they are caused by the shadow of the Earth.

If the shadow of the Earth is round, then the Earth must be spherical.

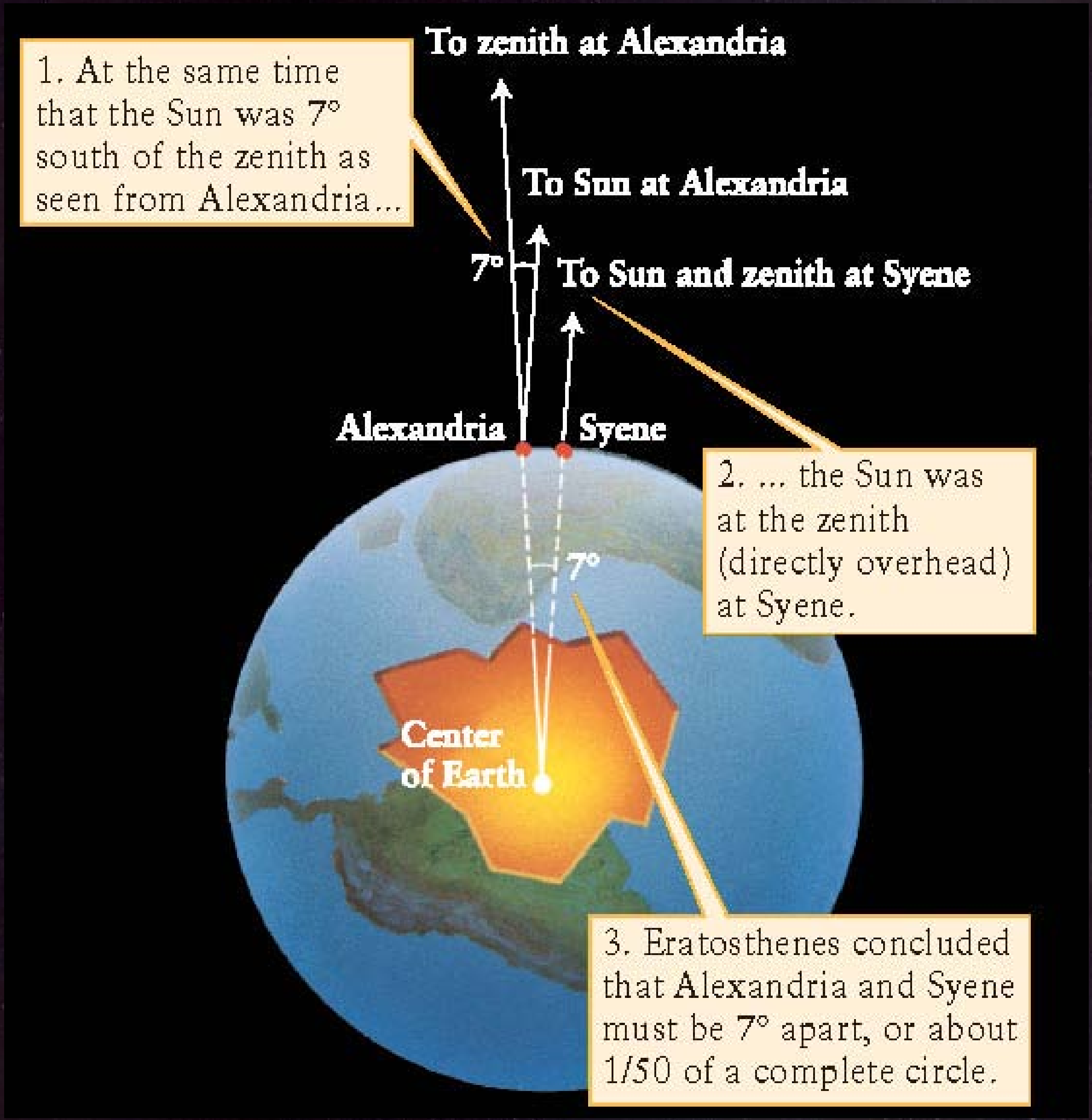
Early measurements of the Earth's circumference

Eratosthenes (276BC - 194BC) was the chief librarian of the Great Library of Alexandria

He observed that from Syene (modern day Aswan), the Sun was directly overhead at the Summer Solstice, while from Alexandria, it was 7 degrees away from the zenith.

7 degrees is ~1/50 of a complete circle. Eratosthenes deduced that the distance from Syene to Aswan was therefore 1/50 of the Earth's circumference.

Early measurements of the Earth's circumference



Early measurements of the Earth's circumference

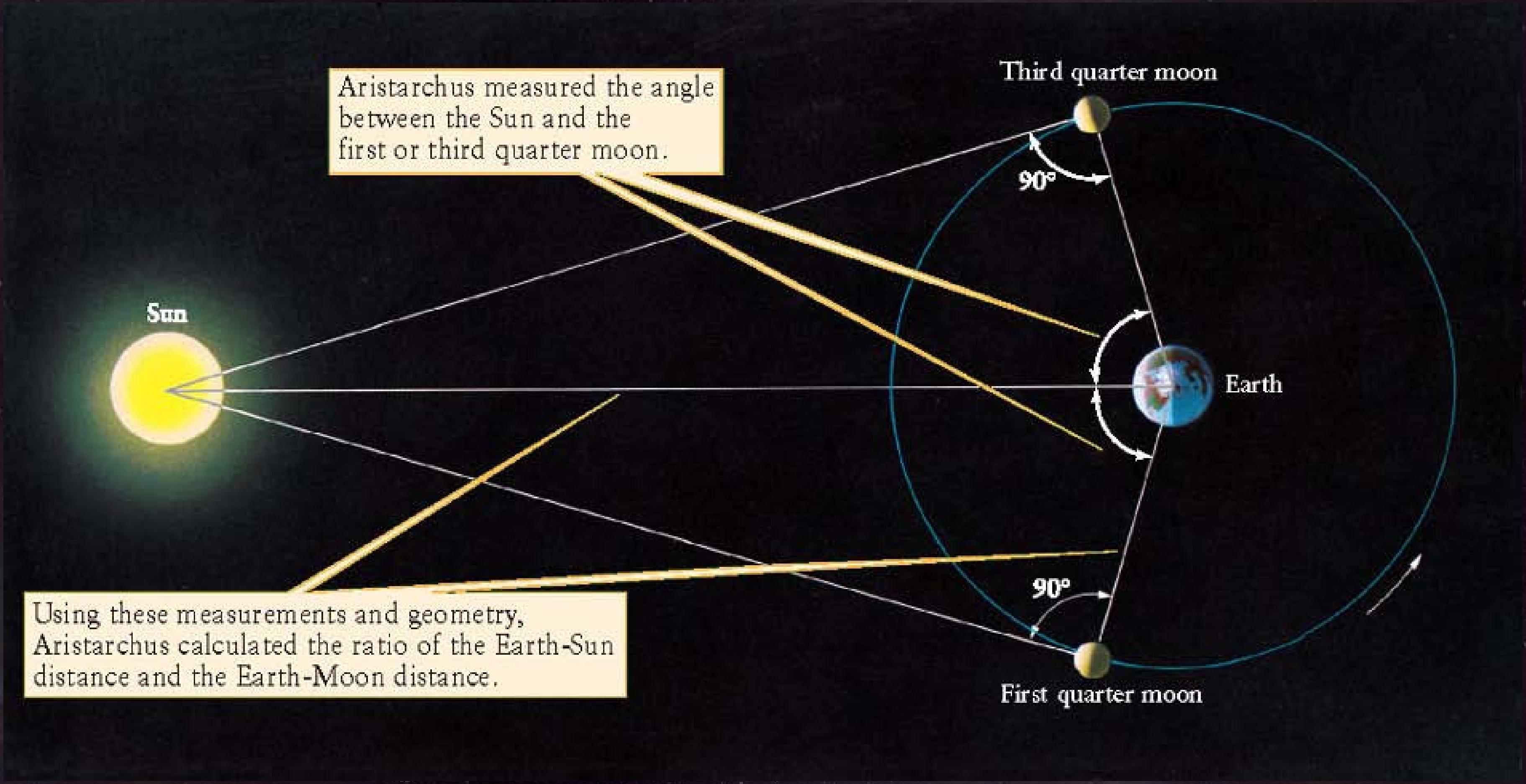
The distance from Syene to Alexandria was 5000 stades, and so Eratosthenes gave the circumference of the Earth as 250,000 stades.

But what was a stade? Different definitions are given in different classical texts. It could have been between 160 and 200m, and so Eratosthenes' circumference was between 40,000 and 50,000km.

The circumference of the Earth is ~40,000km, so Eratosthenes' measurement was pretty good.

More Greek measurements

Aristarchus (310BC – 230BC) estimated that the angle between a half-moon, the Earth and the Sun was 87 degrees:



More Greek measurements

He used trigonometry to estimate that the Sun was 20 times more distant than the Moon.

But his angles were wrong – the angle is actually about 89.85 degrees, and the Sun is 390 times further away than the Moon.

Aristarchus pointed out that the Moon and the Sun appear the same size, and so he also stated that the Sun was 20 times bigger than the Sun.

His answer was wrong but his working was correct. So, he would have got some marks in an exam.

Chapter 4 – gravitation and the planets

In this chapter we will learn about:

- How ancient astronomers understood the Universe – as a geocentric system
- How Copernicus revolutionised our understanding, with the heliocentric model
- How Tycho and Kepler laid the foundations for understanding the motions of the planets
- Galileo's spectacular advances with telescopes
- How Newton brought all this understanding into the theory of gravitation

Geocentricity

We have heard about early efforts to measure the circumference of the Earth, and the scale of the Solar System.

In classical times, the fundamental understanding of the Moon, Sun, and other bodies in the Solar System was that they orbited the Earth – the so-called *geocentric model*.

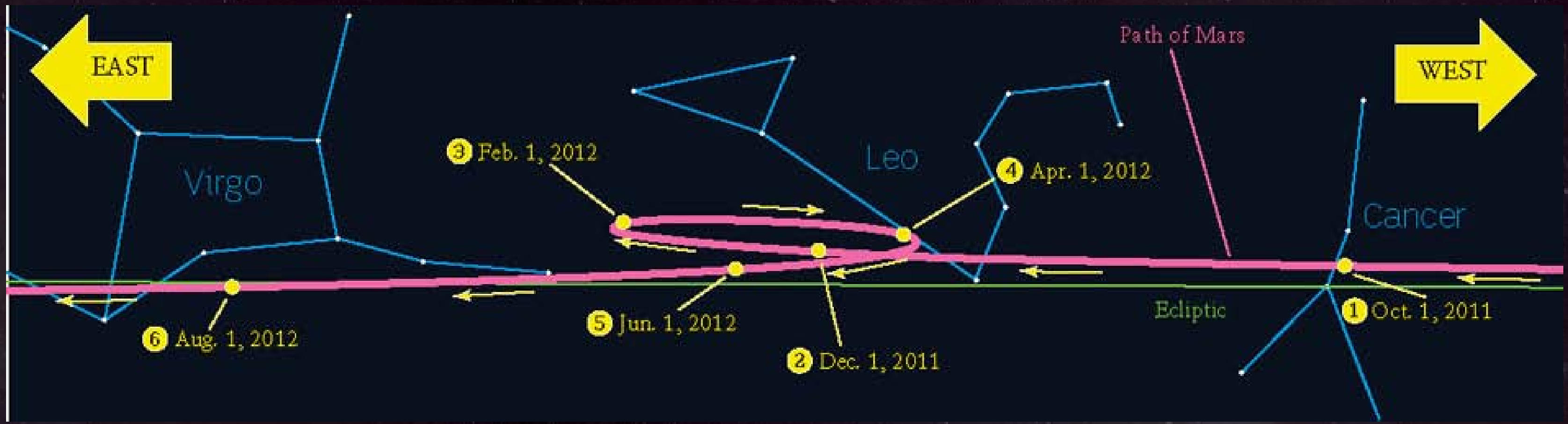
It was thought that the Moon, Sun, Mercury, Venus, Mars, Jupiter and Saturn orbited on concentric spheres, centred on the Earth.

The stars lay on a much more distant sphere.

Geocentricity

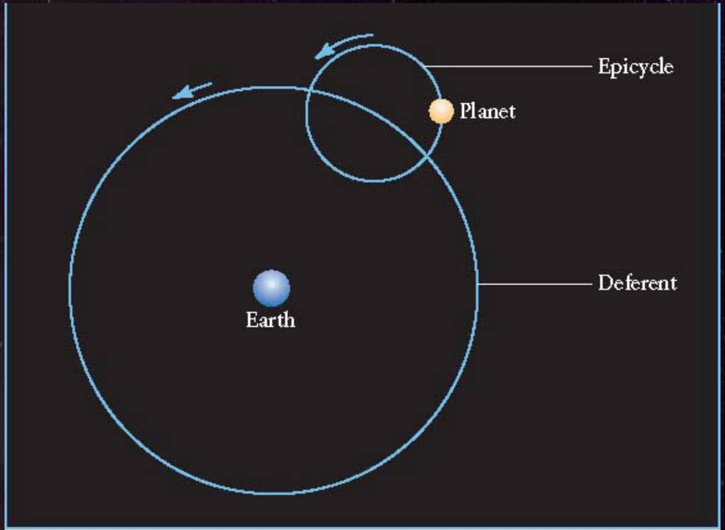
One difficulty with the simplest geocentric models is that planets do not proceed always in one direction across the sky, but sometimes appear to stop and move in the other direction, with respect to the stars.

This is called *retrograde motion*.

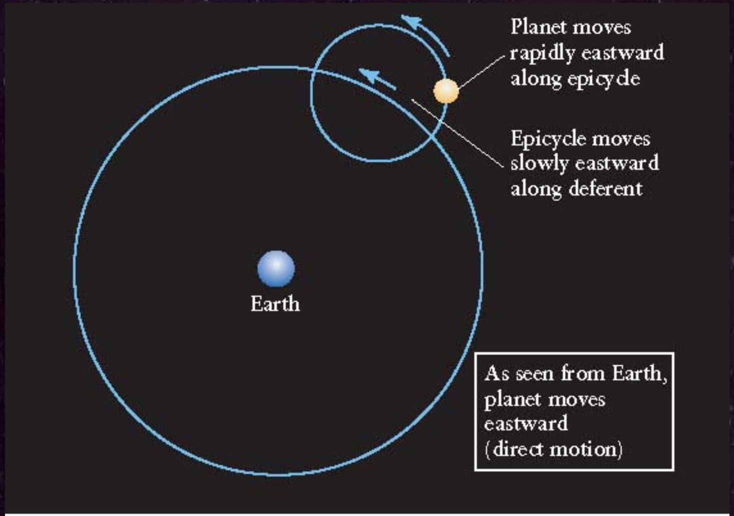


Epicycles

Classical astronomers explained this phenomenon with the use of *epicycles* – the idea that the heavenly bodies orbited around points which themselves orbited the Earth.



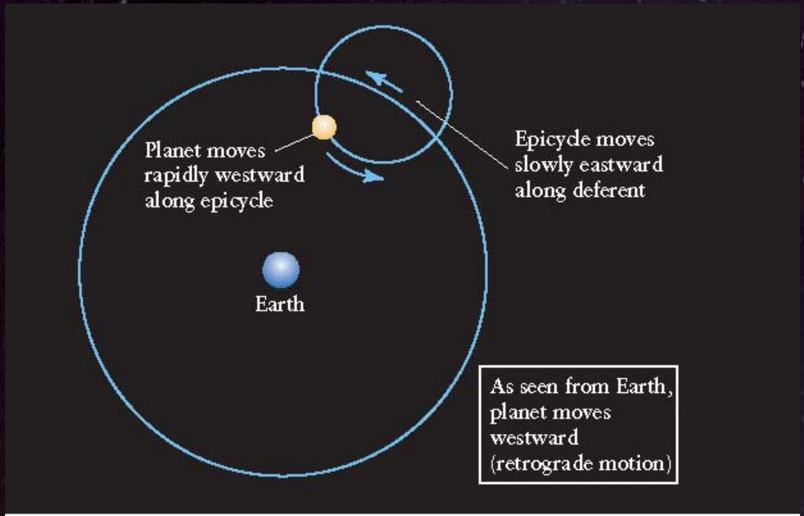
(a) Planetary motion modeled as a combination of circular motions



(b) Modeling direct motion

Epicycles

Classical astronomers, led by Hipparchus and Ptolemy, explained this phenomenon with the use of *epicycles* – the idea that the heavenly bodies orbited around points which themselves orbited the Earth.



(c) Modeling retrograde motion

Epicycles

The geocentric system with epicycles is known as the *Ptolemaic system*. Ptolemy produced the *Almagest*, one of the great works of classical knowledge, in which he used his system to predict the motions of the planets, with unprecedented accuracy.

The Ptolemaic system endured for many centuries.

But scientists in the Middle Ages began to question it: Each planet's epicycles behaved differently, and there appeared to be no underlying logic relating them.

Also, more precise measurements eventually required the addition of more and more epicycles.

Occam's Razor

Occam's Razor holds that generally, a simple explanation is to be preferred to a more complex one. The universe is more likely to be governed by laws with underlying simplicity.

The ever increasing number of epicycles contradicted this, and astronomers sought a more fundamentally simple model of the universe.

A major breakthrough came with the work of Copernicus, in the 16th Century.