

## Lecture 4: Milankovitch Astronomical Theory GES-441

### Why do we have ice ages?

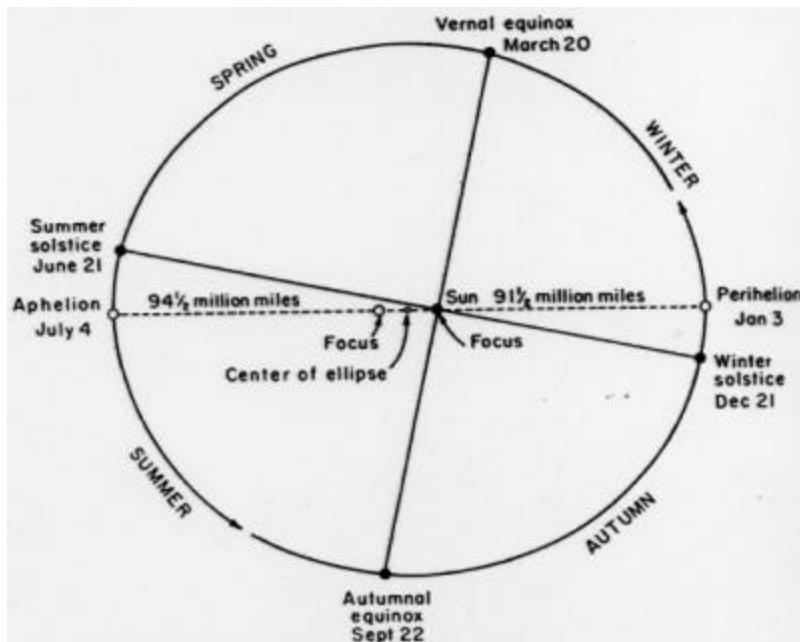
No consensus prior to 1976 – various theories, including volcanic activity, changes in carbon dioxide, solar activity

### Rebirth of Astronomical Theory

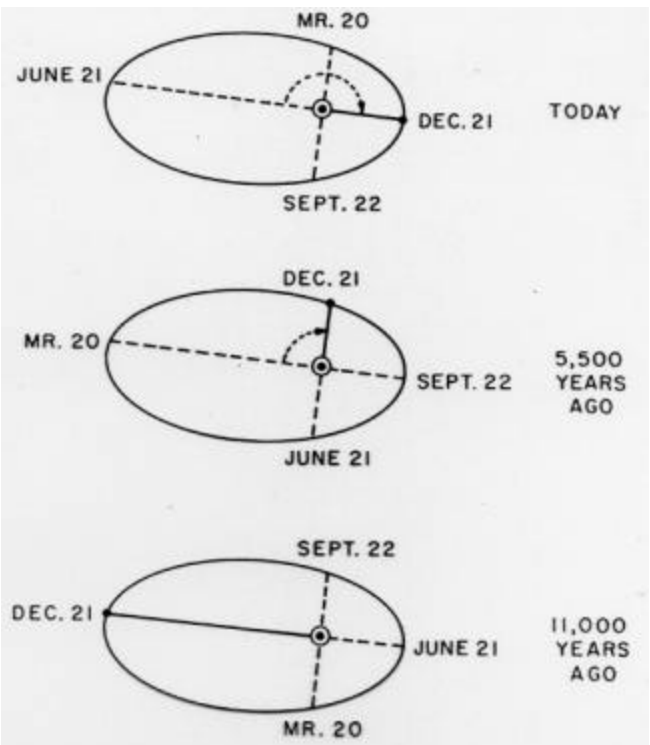
Eccentricity - ~100,000 year periodicity; changes severity of seasons

Tilt - 41,000 year periodicity, now 23.5 degrees, varies a couple degrees, poles colder when low tilt

Precession - 19,000-23,000 years, wobble of earth on its axis, changes when seasons fall on the orbit



*Figure 14.* Dates of equinox and solstice. At the equinoxes, the earth's axis is pointed at right angles to the sun, and the day and night are of equal length all over the globe. At the summer solstice, the North Pole is tipped in the direction of the sun and the northern hemisphere has the longest day of the year. At the winter solstice, the North Pole is tipped away from the sun, and the northern hemisphere has the shortest day of the year.



• EARTH ON DEC. 21

⊙ SUN

Figure 16. Precession of the equinoxes. Owing to axial precession and to other astronomical movements, the positions of equinox (March 20 and September 22) and solstice (June 21 and December 21) shift slowly around the earth's elliptical orbit, and complete one full cycle about every 22,000 years. Eleven thousand years ago, the winter solstice occurred near one end of the orbit. Today, the winter solstice occurs near the opposite end of the orbit. As a result, the earth-sun distance, measured on December 21, changes.

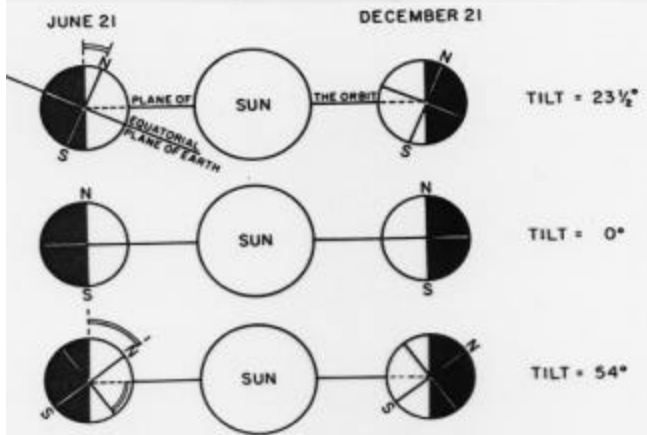


Figure 25. The effect of axial tilt on the distribution of sunlight. When the tilt is decreased from its present value of  $23\frac{1}{2}^\circ$ , the polar regions receive less sunlight than they do today. When the tilt is increased, polar regions receive more sunlight. The possible limits of these effects (never actually achieved) would be a tilt of  $0^\circ$ , when the poles would receive no sunlight; and  $54^\circ$ , when all points on the earth would receive the same amount of sunlight annually.

Figures from Imbrie and Imbrie, Ice Ages, Solving the Mystery.

An astronomical cause for ice ages first proposed by Joseph Adhemar, 1842

Precession responsible for ice ages; predicted ice age every 11,000 years (half-precession) with the two hemispheres being out of phase.

James Croll proposed that eccentricity was important and that when combined with precession, it could cause an ice age. He decided that winter in the Northern Hemisphere was the important season. His idea was that when eccentricity was high and precession caused winter in the NH to fall on the farthest point of the orbit, there were very cold winters and an ice age began in the NH. Also noted that tilt could be important. His predictions were not supported by the limited data available.

Milutin Milankovitch - worked on problem from 1910-1940. Decided that Croll had it wrong and that summer was the important season, because it's the persistence of snow that matters. Incorporated all three astronomical factors into his calculations and predicted warm periods at 125 ka, 105 ka, and 82 ka. Popular at first, but discarded when initial age data didn't agree. Also, did not take into account other factors, such as oceanic heat transport. Largely abandoned by 1960.

Meanwhile, there were developments in paleoclimate records. Marine terraces at Barbados indicating higher sea levels (warmer temperatures) were dated at 125 ka, 105 ka, 82 ka - the same times that Milankovitch predicted. But was it just a coincidence? We needed a longer record. About this time the oxygen-isotope method came into use as a way in which to determine ice volume on land. Oxygen isotopes of shells (foraminifera) in deep-sea cores show the record of changing ice volume over time.

$$*^{18}\text{O} = \{[(^{18}\text{O}/^{16}\text{O})_{\text{sample}} - (^{18}\text{O}/^{16}\text{O})_{\text{standard}}] / (^{18}\text{O}/^{16}\text{O})_{\text{standard}}\} * 1000$$

Evaporation of water favors removal of light  $^{16}\text{O}$ . Normally, this would work its way back to the ocean through rainfall. But during an ice age, it is locked up in ice on land, causing the ocean to become increasingly enriched in  $^{18}\text{O}$ .

In 1976, Hays, Imbrie, and Shackleton published the oxygen isotope results from a long deep-sea core. A spectral analysis of the core showed that major changes in ice volume occurred at the frequencies predicted by Milankovitch. This was considered proof that astronomical forcing drives the ice ages.

Today - there are some problems with Milankovitch theory

- 1) the 100,000 yr cycle is dominant in the record, yet it has the weakest astronomical effect; moreover, in the record, it doesn't always occur at 100,000 years - ranges from 80,000 to 125,000
- 2) does not explain asymmetry of ice-age signal
- 3) doesn't explain how whole earth can cool from northern hemisphere forcing
- 4) can't explain rapid climate change at all

Conclusion - Astronomical forcing probably paces the ice ages, but there is a lot more involved that we don't yet understand.