The Pyramids of Gizeh

The most magnificent of the Seven Wonders of the World, and the only one to survive, is the Great Pyramid of Khufu and its neighbors on the Gizeh Plateau just outside Cairo, Egypt.

Built by the Pharaoh Khufu in 2560 BC, it took great teems of dedicated laborers over 20 years to haul 6 millions of tons of limestone into the classic shape. The Pharaohs Khafre and Menkau-Re that followed Khufu attempted to duplicate this feat, but on lesser scales.

The pyramids remain to this day a spectacular, and awe-inspiring example of ancient craftsmanship, but also a source of mystery; Little wonder considering that it was a monument designed as a tomb for a god! One of the most common discussions of this monument is the way that it is oriented on the Gizeh Plateau. Careful surveys of its shape, dimensions, and various angular measures have resulted in many 'findings' by both professional archeologists, and amateur historians.

The Great Pyramid is not a rough-hewn or fabricated monument, as was often common for builders living 4500 years ago, but is instead a very precisely-built geometric object. The most basic geometric feature that has been agreed upon thanks to accurate surveying is that its base is exactly square to a fraction of a degree. That means that the corner angles are almost exactly 90 degrees. The next geometric feature is that two of the opposite base edges are aligned exactly along a north-south axis to 1/30 of a degree. In Egyptian mythology, the direction of the rising (east) and setting (west) sun was an important event, so with very high precision, the opposite faces of the Great Pyramid face exactly due-east and due-west.

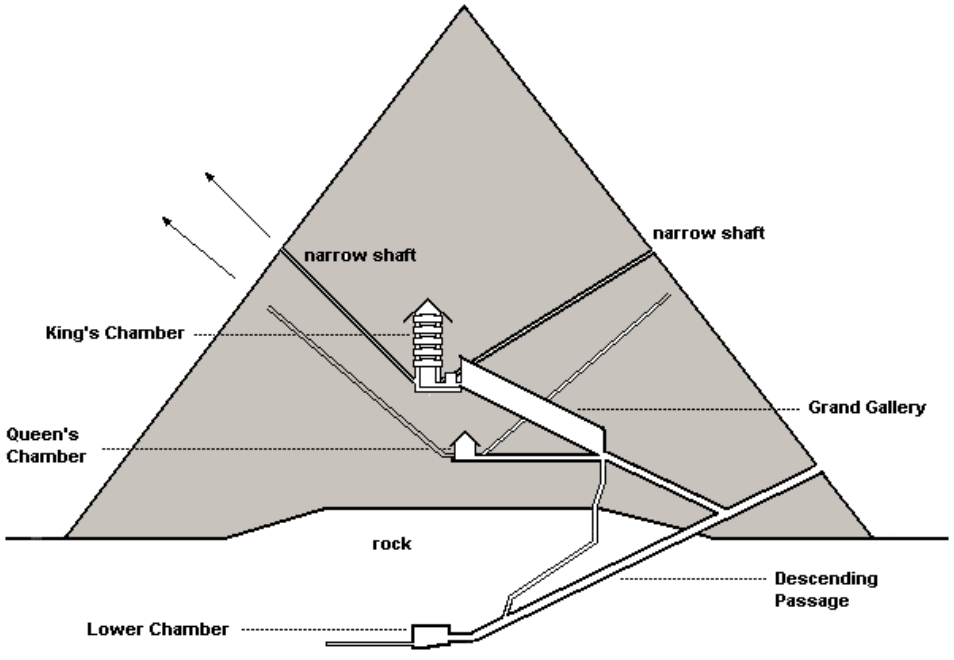
Although there are no obvious geometric elements of the Great Pyramid that serve as pointers to sunrises and sunsets related to the solstices or equinoxes, events, there are internal features that seem to match other astronomical directions of interest: the directions of certain stars of significance to ancient Egyptian mythology.

To take advantage of these astronomical alignments, you have to think in 3-dimensions, not just along the horizontal plane defined by sunsets and sunrises! The most interesting of these stellar alignments may be with the bright star Sirius, also associated with the goddess Isis; the wife of Osiris who was resurrected after death.

Great Pyramid of Khufu (upper right).

The Pyramid of Khafre (lower right) on the Gizeh Plateau. Horizontal black bar in the upper right corner equals a physical length of 100 meters.

The Sphynx statue is located near the lower right just above the GOOGLE text.



Inside the Pyramid of Khufu are a number of chambers and shafts that were built into the pyramid as the pyramid was being assembled. This sketch is a cross-section of the pyramid along the North-South axis through the apex of the pyramid. North is to the right. The two arrows show the pointing directions of the 'Sirius' shaft (lower) and the 'Orion' shaft (upper). The Orion shaft opens to the outside, however, the Sirius shaft is blocked by 16 meters of limestone blocks and cannot be used to see stars in the sky.

Education Standards Satisfied by This Activity

(See Benchmarks for Science Literacy, Project 2061, AAAS)

1c – The Scientific Enterprise

G6-8 "Important contributions to the advancement of science, mathematics and technology have been made by different kinds of people, in different cultures, at different times.

G9-12 "The early Egyptian, Greek, Chinese, Hindu and Arabic cultures are responsible for many scientific and mathematical ideas and technological innovations.

2a – Patterns and Relationships

G9-12 "Although mathematics began long ago in practical problems, it soon focused on abstractions from the material world, and then on even more abstract relationships among these abstractions.

3A - Technology and Science:

G6-8 "Engineers, architects and others who engage in design and technology use scientific knowledge to solve practical problems. But they usually have to take human values and limitations into account as well.

4B – The Earth

G6-8 "Because the Earth turns daily on an axis that is tilted relative to the plane of earth's yearly orbit around the sun, sunlight falls more intensely on different parts of the Earth during the year. The difference in heating produces the planet's seasons and weather patterns.

11B – Models

G3-5 "Geometric figures, diagrams, and maps can be used to represent objects, events and processes in the real world although such representations can never be exact in every detail.

Problem 1 - The Sirius shaft points exactly due-south, and is tilted at an angle of exactly 39^{o} 30' 00" to the horizontal (horizon). The table below gives the years when the star Sirius reaches the indicated elevation angle looking due-south. Plot this data, and create a linear equation y = mx + b, that matches the slope, m, and y-intercept, b, for the tabular data.

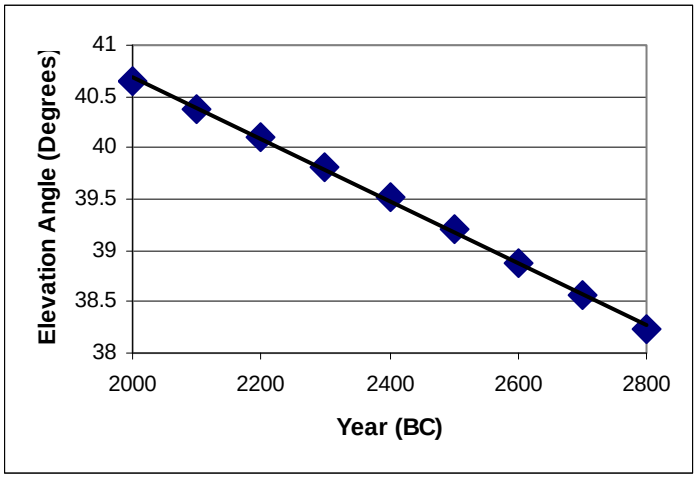
Year (BC)	Elevation (^{o} ' ")
2000	40 39 12
2100	40 22 45
2200	40 06 08
2300	39 48 29
2400	39 30 41
2500	39 12 20
2600	38 53 10
2700	38 33 58
2800	38 13 53

Problem 2 - From this data, and assuming that the Sirius shaft was designed to point exactly at Sirius at the time the pyramid was constructed, about what year was the pyramid built by this assumption?

Problem 3 - Through independent archeological studies, the Great Pyramid of Khufu was built between 2540 BC and 2560 BC. What would have been the elevation angle of Sirius during this time period?

Problem 4 - If the Sirius shaft had been continued to the outside face of the pyramid so that the sky could be seen from the bottom of the 65-meter shaft, the angular size of the 20 centimeter square opening would have been 00^{o} 11' wide. What can you conclude about your answer to Problem 2, and the assumption of the Sirius alignment?

Problem 1 - The Sirius shaft points exactly due-south, and is tilted at an angle of exactly 39^{o} 30' 00" to the horizontal (horizon). The table below gives the years when the star Sirius reaches the indicated elevation angle looking due-south. Plot this data, and create a linear equation y = mT + b, that matches the slope, m, and y-intercept, b, for the tabular data in years, T.
Answer: The equation is **Y = -0.003 T + 46.4747**



Problem 2 - From this data, and assuming that the Sirius shaft was designed to point exactly at Sirius at the time the pyramid was constructed, about what year was the pyramid built by this assumption? Answer: Y = 39.50 so solving for T we get 39.50 = -0.003T + 46.4747 and so **T = 2325 BC**.

Problem 3 - Through independent archeological studies, the Great Pyramid of Khufu was built between 2540 BC and 2560 BC. What would have been the elevation angle of Sirius during this time period?
Answer: Taking the middle-year of T = 2550 BC we get an angle of Y = -0.003 (2550) + 46.4747 so **Y = 38.82^{o}**

Problem 4 - If the Sirius shaft had been continued to the outside face of the pyramid so that the sky could be seen from the bottom of the 65-meter shaft, the angular size of the 20 centimeter square opening would have been 00^{o} 11' wide. What can you conclude about your answer to Problem 2, and the assumption of the Sirius alignment?

Answer: The width of the window is only 0.18 degrees. This means that it could only have seen Sirius when it was at elevation angles between 39.5 + 0.18/2 = 39.59^{o} and 39.5 - 0.18/2 = 39.41^{o}. This spans a time range from T = 2295 BC to 2355 BC. This is much earlier than the actual construction period between 2540 and 2560 BC. **This means that, even if the shaft had extended all the way to the pyramid's surface, you would not have been able to see Sirius in this window until 200 years later, making the alignment theory seem unreasonable.**