Early Concepts of Timekeeping: Time Without Gears

Price Russ

Chapter 107

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Background

- Two main divisions are length of year and time of day.
  - Time of day would be secondary in a primitive society
- Seasons and length of year are important for planning.
  - Farming, hunting, shelter, war, magic, and so forth
- Timekeeping evolved independently in many places.
  - I will stick to concepts and methods from Egypt, Babylonia, and Greece because our system evolved from practices of these societies
- Until very recently all timekeeping systems were based on the movement of objects in the sky.

As much as possible, I will avoid technical terms and math.

What changes can be seen in the sky?

Day

Seasonal variation in length of daylight

Changes in the path of the sun

Night

Stars stay in fixed positions relative to each other (except planets)

Stars move around a fixed point in the sky

Moon- changes shape, time of rising, and N/S position

Seasonal variation in the time when stars rise and set

It helps to live where you can see the horizon, but some jungle civilizations have developed elaborate timekeeping systems; e.g., the Maya.

What changes can be seen on the ground?

Day

- Shadows moving as day progresses
- Seasons – weather, animals, vegetation

Night

- Seasons
- Not much else

Length of the year

Positions of sun and stars correlate with seasons.

- Also the moon, but we will ignore lunar calendars for this discussion

Ways to mark seasons – count days between

- Maximum or minimum length of noon shadow
- No noon shadow or sun penetrates deep well (only in tropics)
- Positions of selected stars at twilight (morning or evening)

Length of the year

- Egyptians used heliacal rising of Sirius as beginning of year
  - Day when a star is first visible above the horizon in the morning
  - How sensitive is that?
  - Progression is ~1º per day or 4 modern minutes of time
  - Moon's angular diameter is ~½º, so stars move about 2x moon diameter per day => could accurately observe the heliacal rising.
- Length of year set by Aristarchus of Samos in 280 BCE by measurements of the equinox.
- Hipparchus determined the year to be 365.2465 days in 35 BCE.
  - Compared his measurements to predictions based on Aristarchus.
  - Modern value is 365.2422. Fractional difference is 10 parts in a million.

How did we get 24 hours per day?

The Egyptians did it.

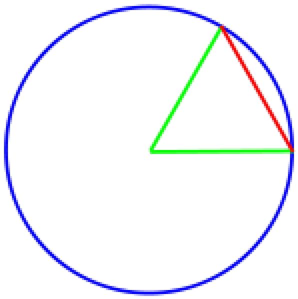
- Calendar divided year into 36½ periods of 10 days each, called decades
- By 2100 BCE they were associating the heliacal rising of a star with each decade. The stars were called decans.

  Because of seasonal effects the decans were not equally spaced
- On any given night one could observe the rising of ~12 decans.
- This resulted in the night being divided into 12 time units.
- By analogy they divided the period of sunlight into another 12 time units.
- Bingo! 24 principal time units per day.

How did the circle come to have 360º?

The Babylonians did it.

- The exact origin is unclear (at least to me).
- Need to know that Babylonian math was quite advanced and used base 60. (We use base 10.)
  - Base 60 is handy because it has lots of factors
- Theory 1:
  - Based on days per year but an error of 5 is pretty big.
  - Persians used a 360 day year.
- Theory 2:
  - On a circle, layout a chord whose length = radius
  - 6 such chords go exactly around the circle
  - Divide the chord of a circle into 60 parts.
  - This results in unequally spaced degrees. (Can not trisect an angle.)
  - Might be the origin because use of 360 predates Greek geometry



How did the circle come to have 360º?

Theory 3:

Movement of the sun among the stars was divided in 12 stages (danna) associated with the stars of the zodiac.

Each danna was composed of 30 lengths (us).

30 x 12 = 360

Conclusion: Who knows? Not me.

How did we get 60 minutes per hour and degree?

The Babylonians did it.

Comes naturally from their use of base 60 numbering system

Incidentally: “Second” comes from second-minute.

1/60th of a second is called what?

(A third.)

The daily grind

In addition to tracking the year, there is a need to follow the progress of the day.

Mentioned the Egyptians dividing the day into 24 units and how they measured them at night.

Need techniques to use when sunlight dominates.

Who knows what time it is?

The Shadow knows!

Any shadow can be used to tell time, but some are more practical and precise than others.

The vertical stick

A stick is handy because its shadow is narrow and well defined.

Both orientation and length of shadow contain information.

One of earliest time tracking devices with Egyptian obelisks being extreme examples.

Can not simplistically divide day into either equal or temporal hours.

Temporal hour is 1/12th of the time the sun is “up”

Temporal hours are also called uneven hours.

With some math can make a useful instrument for time-keeping or mapping the position of stars (sun included).

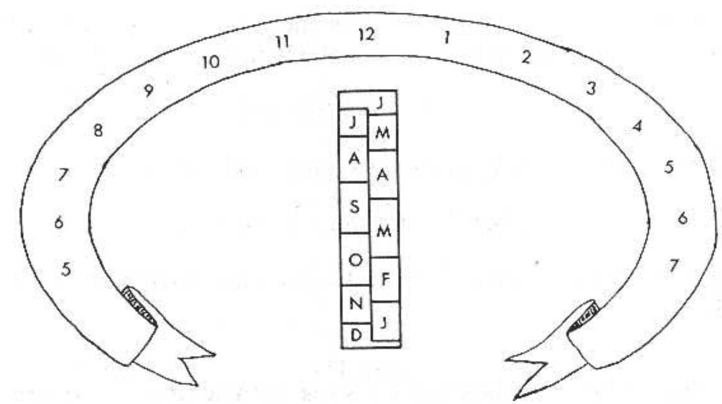
For astronomy low angles are a problem because “baselines” get very long.

The equal hour vertical stick sundial

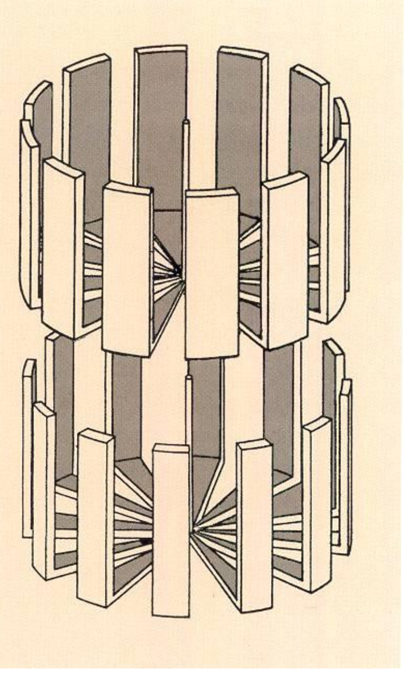
For equal hour timekeeping with a vertical stick, the dial is elliptical and the stick (gnomon) must be moved along the north south axis as indicated in the diagram where the abbreviations stand for the months. The major axis of the ellipse must be oriented east-west and the ratio of the axes depends on the latitude.

Such a dial is called analemmatic.

This is related to but not the same as the term analemma applied to the figure 8 variation of the position of the sun in the sky at mean noon.



The Rama Yantra (India, early 18th century)



Another extreme example.

For astronomy in horizontal system describe positions of bodies by angle above the horizon and angle in horizontal plane.

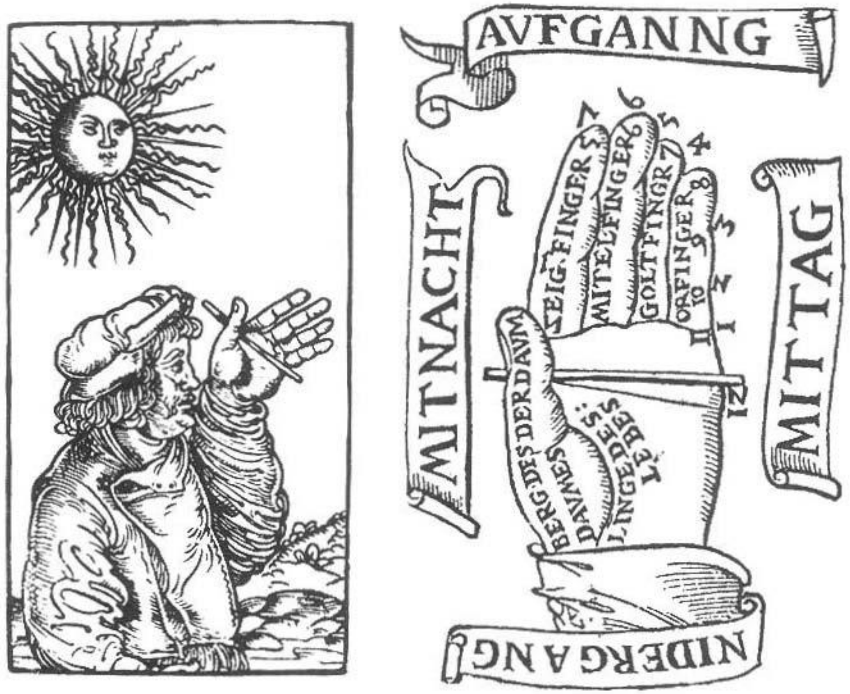
With pole in ground hard to make measurements because have to put your eye on the ground.

In Rama Yantra floor raised and instrument split into two parts to allow observations. Low angle problem solved by making measure-ments of angles less than 45º on vertical walls.

Overall not a practical instrument.

The Hand Dial (a stick trick)

If one knows approximate east-west line, can use a handheld stick to tell time.



Egyptian Shadow Clocks

Version 1 (~1450 BCE):

Wooden board with block at end

Marked for 5 time units (sixth would be at infinity)

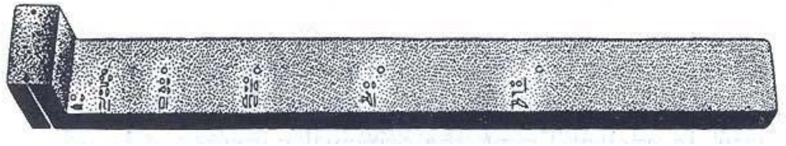
Marks are at 1, 3, 6, 10, and 15 block heights from the block

Used by placing board horizontal (level) and turning such that the shadow of the block falls on the board.

Time units are based on progressive spacing.

Time units are neither equal or temporal.

Even at noon, shadow would not go to 0 length.



Similar device still used in Egypt.

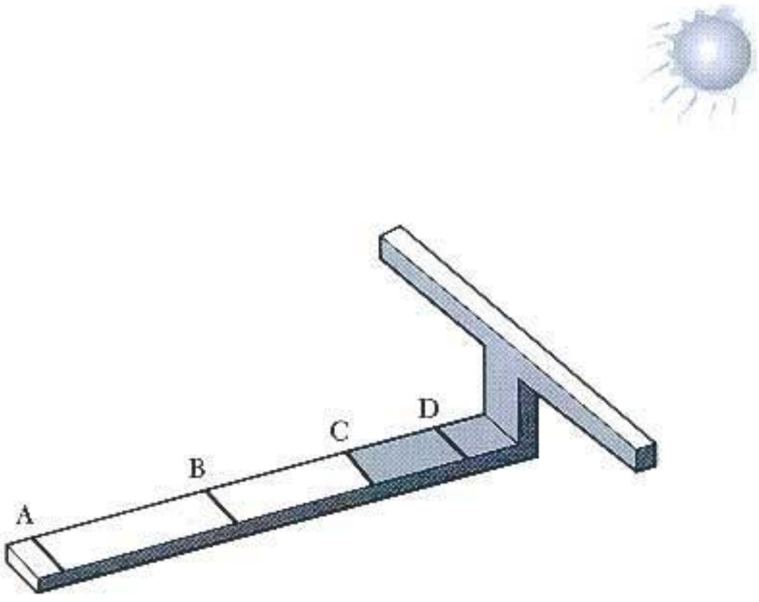
Egyptian Shadow Clocks

Version 2:

Block of version 1 replaced by a tee shaped bar.

Bar aligned along north-south (meridian) line.

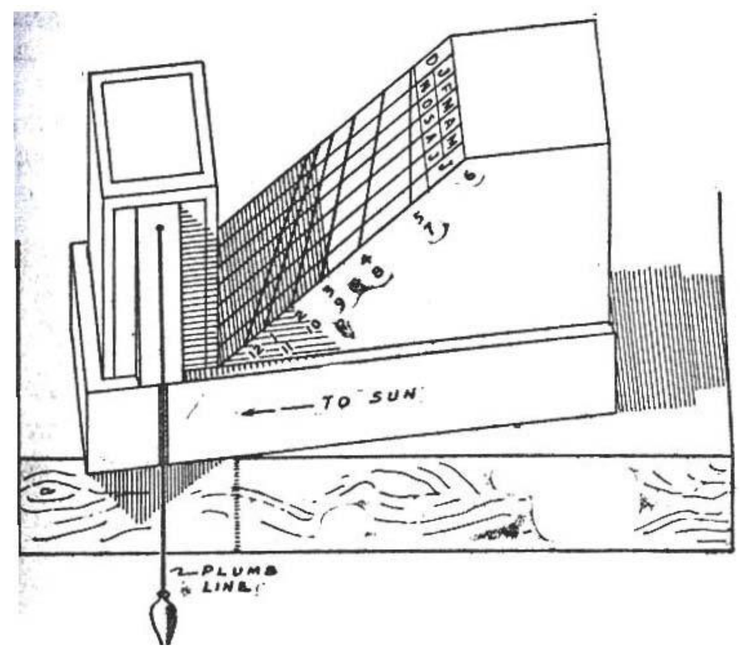
Had to reverse position after noon, but will always show noon.



Egyptian Shadow Clocks

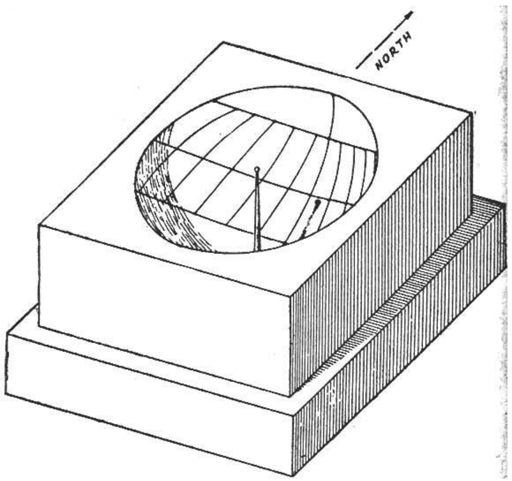
Version 3 (~330 BCE):

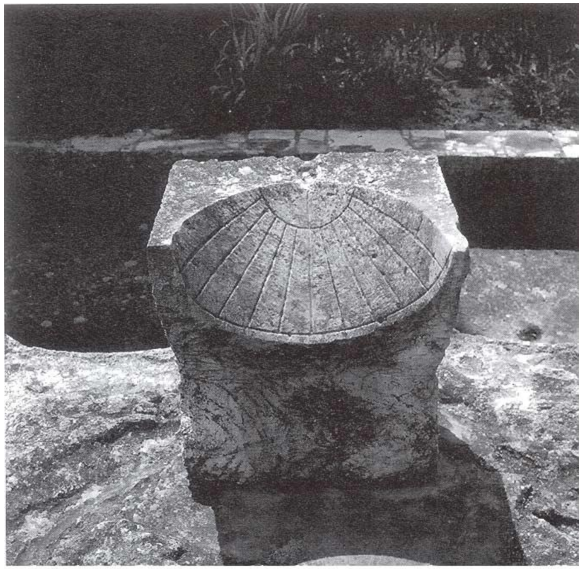
- Aligned like version 1 – block to sun
- Shadow of a block falls on a tilted plane.
- Overcomes problem of long shadows early and late in day.
- Can read noon.
- Scales added that allow for seasonal changes.



Babylonian sundial - hemicycle

- Can be thought of as an inverted view of the sky
- Developed ~300 BCE by Berossos and used for 1000 years
- Measured temporal hours.
- Many versions with different amounts cut away from full hemisphere





A more advanced hemicycle

The hemisphere can be marked with any set of coordinates.

The Jai Prakash Jantra in Jaipur is an example.

- Marked with both horizontal and equatorial coordinates.
  - Equatorial system measures equal hour time.
- Also marked with other information.

Why is north (or south) important?

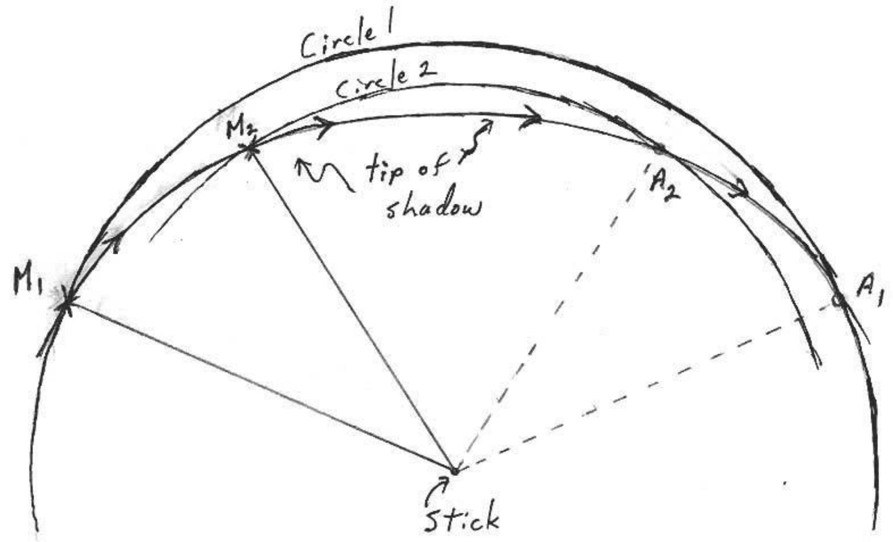
- Establishes plane between observer and axis of Earth.
- We perceive objects in the sky as rotating around Earth’s axis.
- When an object is in this meridian plane, it is at its highest point in the sky.
  - More precisely observable than events such as rising and setting
- Noon is Sun’s passage across the meridian plane.
  - Useful reference point for time related activities

Why is celestial pole important?

- Establishes points (north and south) in the sky to which Earth’s axis points.
- Because the radius of Earth is miniscule compared to stellar distances, a rod on Earth’s surface pointing to the celestial poles has the same relationship to heavenly bodies as the actual axis.

Finding north

- Using a vertical stick or plumb line, mark the length of the shadow at some time in the morning, M_1. Can repeat at other times; eg, M_2.
- Draw circles through M_1, M_2, and so forth using the stick as the center.
- Take a nap.
- When tip of shadow crosses the circles, mark the points.
- Bisect the angle formed by M_1, the stick and A_1.
  As a check repeat for M_2, A_2
- The bisecting line is the meridian.



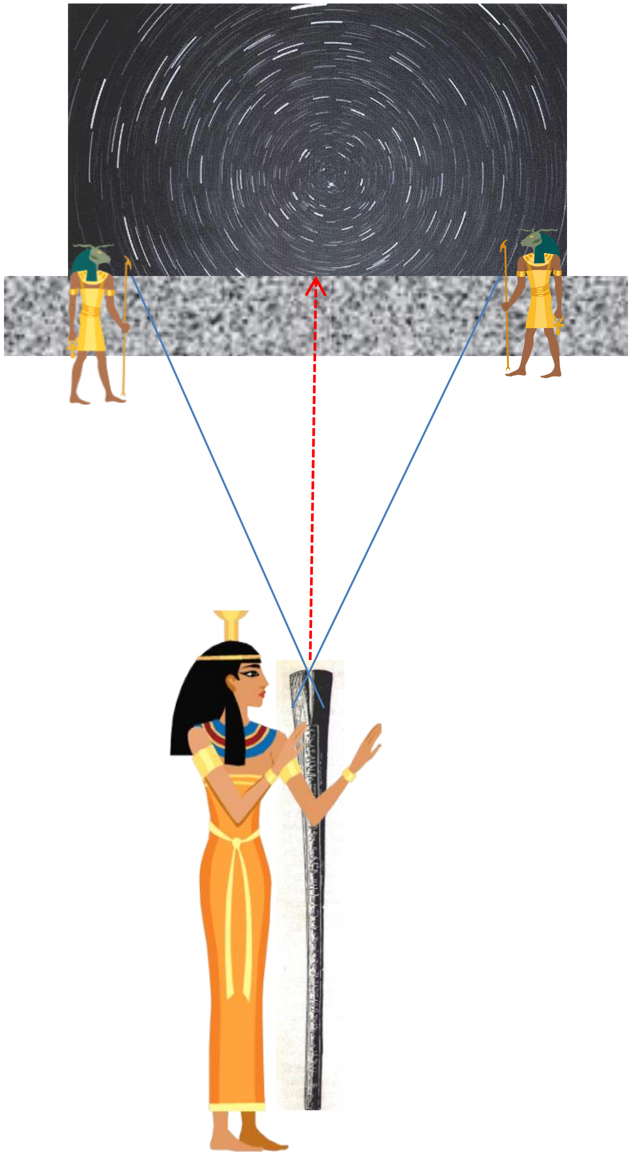
Finding north a better way (Follow the Egyptians)

- Set a vertical pole in the ground with a slit in the top at a convenient high for looking through the slit (Egyptian merkhet).
- Some distance away establish a lengthy artificial horizon running roughly east-west. Water can be used to establish level.
- While observing the artificial horizon through the slit, have an assistant (slaves work well) mark the spots at which several stars rise.
- Relax until the stars are about to set below your horizon.
- Observe the stars through the slit and have the assistant mark the spot on the horizon where they set.
- Bisect the angle between the rising point, stick, and setting point.
- How accurate is the method?

  Say star is 2º from north when observed, horizon is 100 yards away and error in position is 1 foot. Error is 0.2º.

    Should be able to do much better.

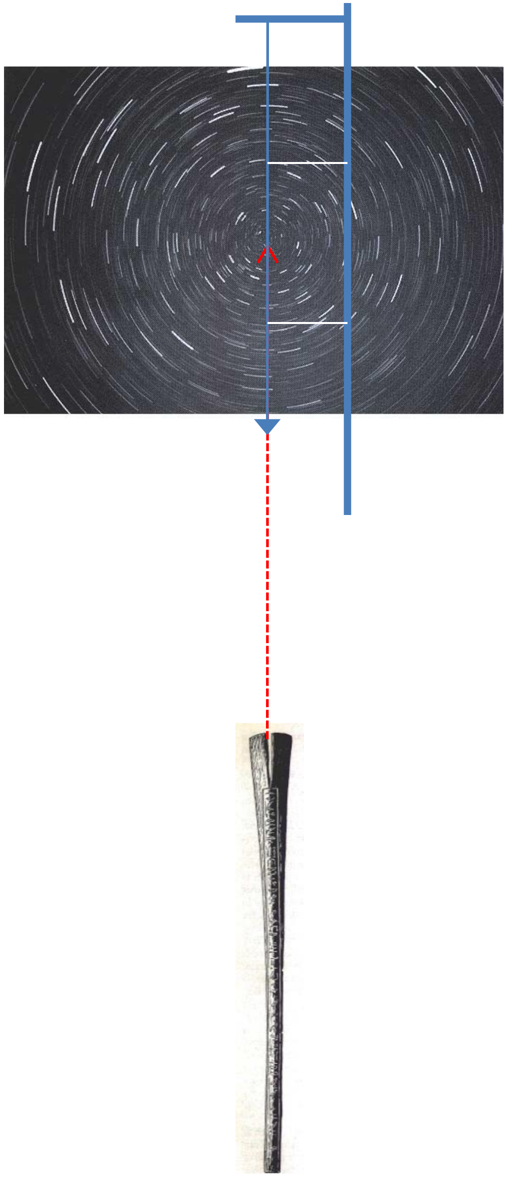
Finding north a better way (Follow the Egyptians)



Finding the celestial pole

- Set up a plumb line along the meridian and a merkhet south of it.
- Observe a star as it crosses the plumb line.
- Have an assistant mark the point of crossing.

  Do not disturb the line. Mark the point on a stick next to the line.
- Wait 12 hours and observe it again as it passes the plumb line again.
- Bisect the angle formed by the observations and the merkhet.



The equatorial sundial

Around 1st century CE, someone figured out that a dial with the gnomon pointing to the celestial pole would keep equal hour time.

In simplest form the dial is perpendicular to the gnomon and therefore parallel to the equator.

Dials based on gnomon pointing to celestial pole are called equatorial.

If a solid dial is used, shadows of the gnomon fall on the north side of the dial from the spring to the fall equinox and on the south side from fall to spring.

The equatorial sundial

Can take many forms

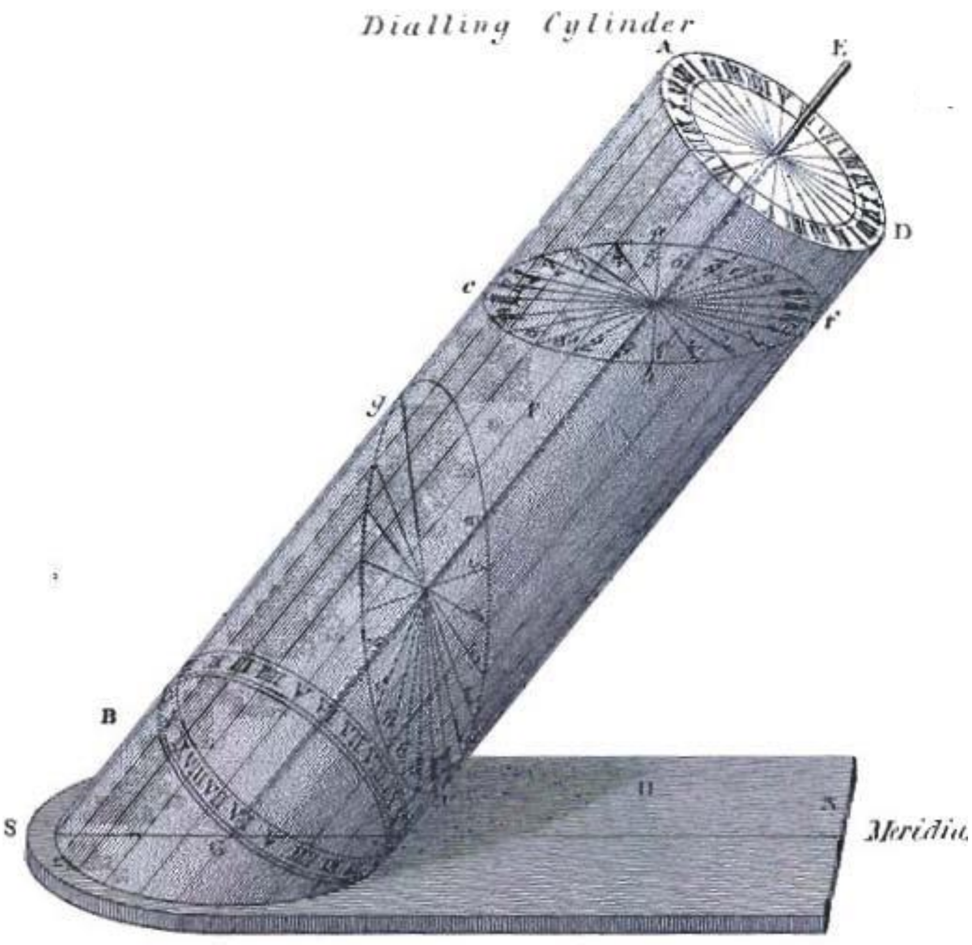
Samrat Yantra (Jaipur) 27 m high

Biggest but not best.

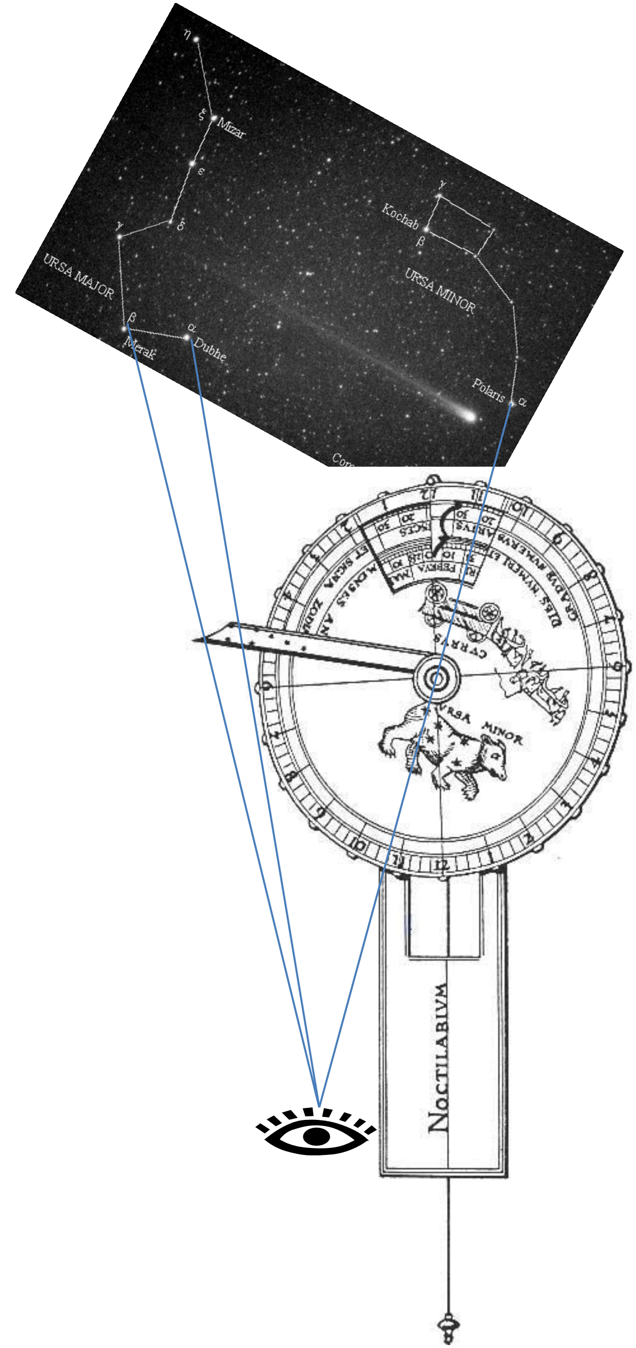
Penumbra limits ability to read edge of shadow

The equatorial sundial

All equatorial sundials can be thought of a slices through the “dialing cylinder”.



Keeping time at night



The nocturnal

Not developed until 15th century

To use

- Adjust dial for day of year
- View Polaris through center hole
- Align arm with Pointer stars in Big Dipper
- Read time from dial