The Rhythm of Time

The evolution of the calendar

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The Origin of the Calendar

God made the days and nights but man made the calendar – Anon.

All calendars are based on:

- the succession of days and nights
- the waxing and waning of the moon
- the rhythm of the seasons (movement of the sun).

Learning to count (simple arithmetic) marks the beginning of observational astronomy (astrology!) and the idea of the calendar

The Need for a Calendar

- The beginnings of agriculture (seasons: when to sow, when to reap)
- trading between different communities and various centres of the ancient world
- the development of what we know today as civilisation

Many religious festivals are also associated with the cycle of the seasons and with the phases of the moon
$\Rightarrow$ need for defining a civil year

These mark the beginnings of keeping track of the passage of time and hence the development of the calendar.

Standardising the Civil Year

The civil year in terms of the seasons needed to be reconciled with the phases of the moon, various religious ceremonies that were associated with them and with the movement of the stars.

This non-trivial problem meant that the development of the ancient calendar went hand-in-hand with the development of ancient astronomy.

So, where's the problem...

Days, Months and Years

The problem with designing an accurate civil calendar $\Rightarrow$ the three natural units of time – the day, the month and the year – are based on different movements of the heavenly bodies. . .

- the earth's rotation about its axis,
- the moon's revolution around the earth
- and the earth's revolution around the sun – or its movement with respect to the stars.

No convenient way to relate these three concepts of time:
A solar year $\sim$ 365.25 days ; lunar month $\sim$ 29.53 days
Twelve lunar months $\sim$ 354 days (a little short of a year). Thirteen lunar months are 18 days too many. There are even two ways to define the year – in terms of the seasons and in terms of the stars!

Every single calendar that exists in the world today is an attempt to reconcile these various irreconciliable units!

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How many calendars?

Leaving aside the prehistoric calendars of which there are many,

- The Babylonian and Near East calendars
- The Egyptian calendar
- The calendars of China, East and Far East Asia
- The Indian calendars (many!)
- The Mayan and Aztec calendars
- The European calendars (at least four)
- The Roman and Julian calendars
- The Jewish, Islamic and Baha'i calendars
- The Gregorian calendar
- The French Republican calendar

In this talk, I will only discuss the Indian and Gregorian calendars

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Whiz-bang intro to Astronomy!

Understanding the motion of the sun, the stars, the moon, and the earth needs a basic understanding of astronomy and astronomical jargon.

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Pre-Copernican astronomy (Ptolemic)

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a geocentric view of the universe

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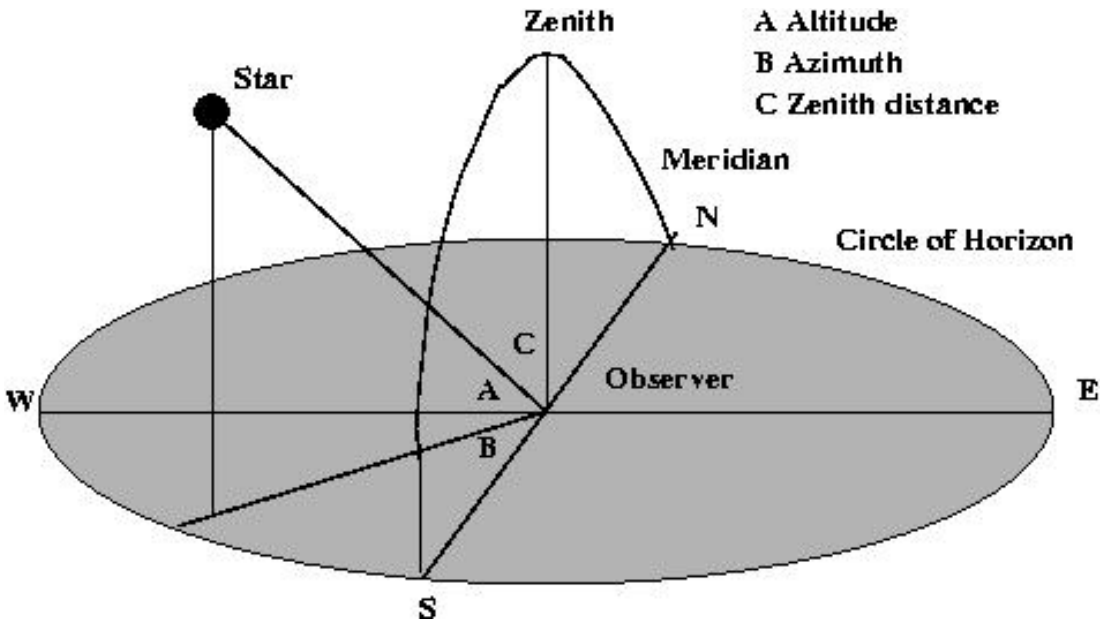
- Horizon – plane with observer at the centre
- Zenith – perpendicular to the horizon plane
- Meridian – vertical semicircular disk with observer at centre (N-S line)



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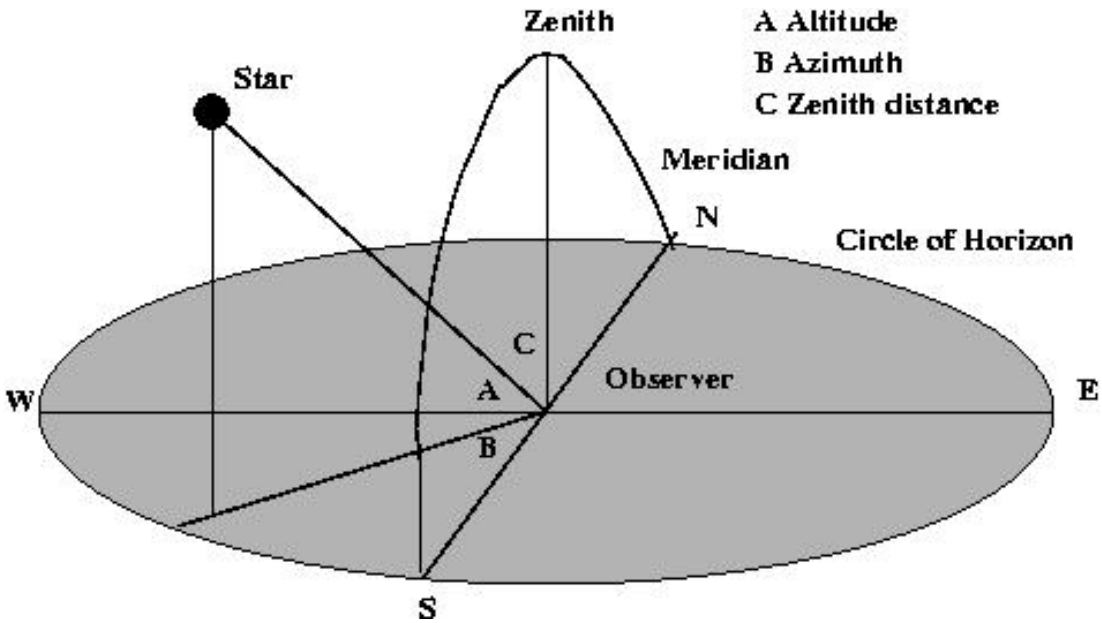

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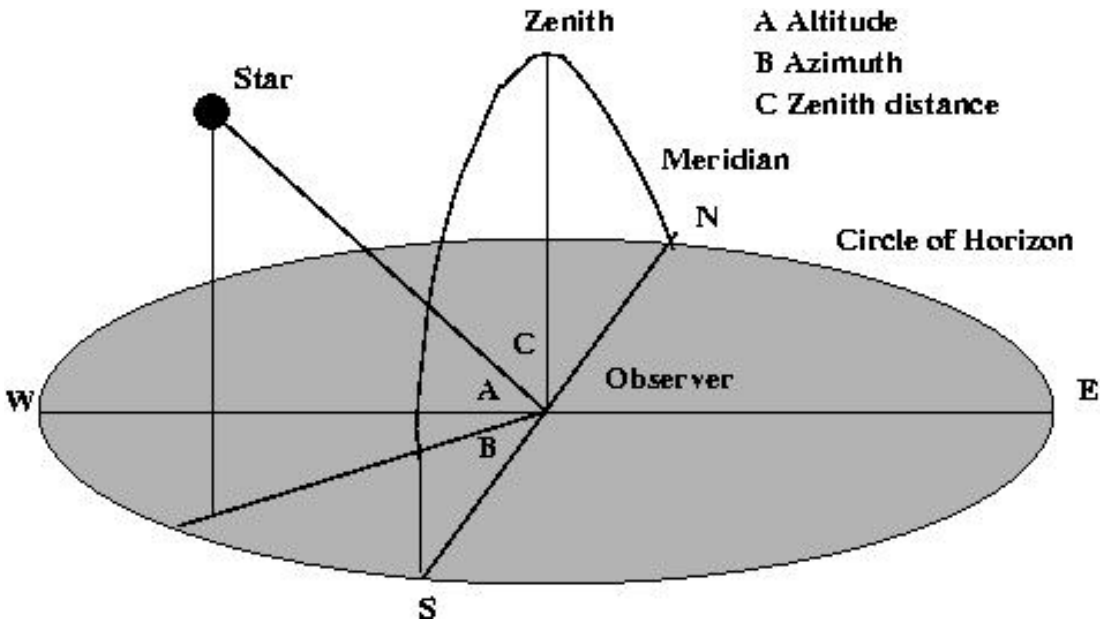

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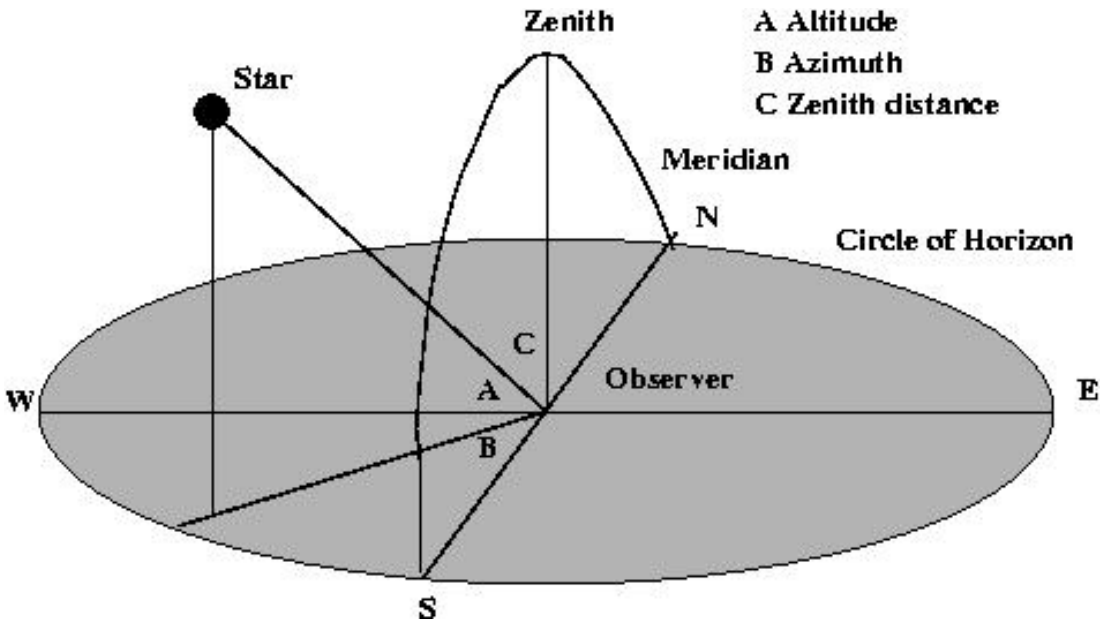

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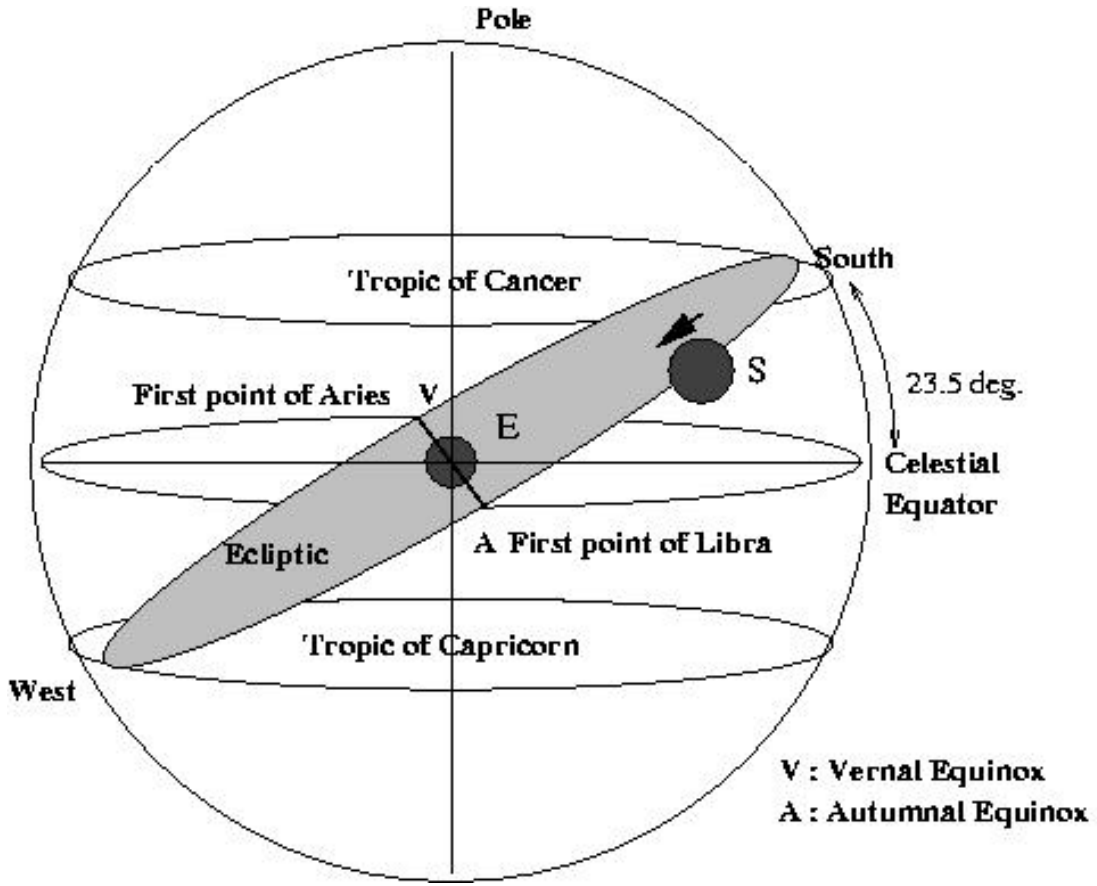
Astronomical coordinate systems – Celestial Sphere

The Celestial Sphere is the (apparent) sphere of the sky above and below us

- Ecliptic – (apparent) path of the sun - the plane of which is at 23.5° to the
- Celestial Equator – great circle perpendicular to the pole (the earth's equator lies in the same plane)
- Equinoxes V,A – intersection of these two planes



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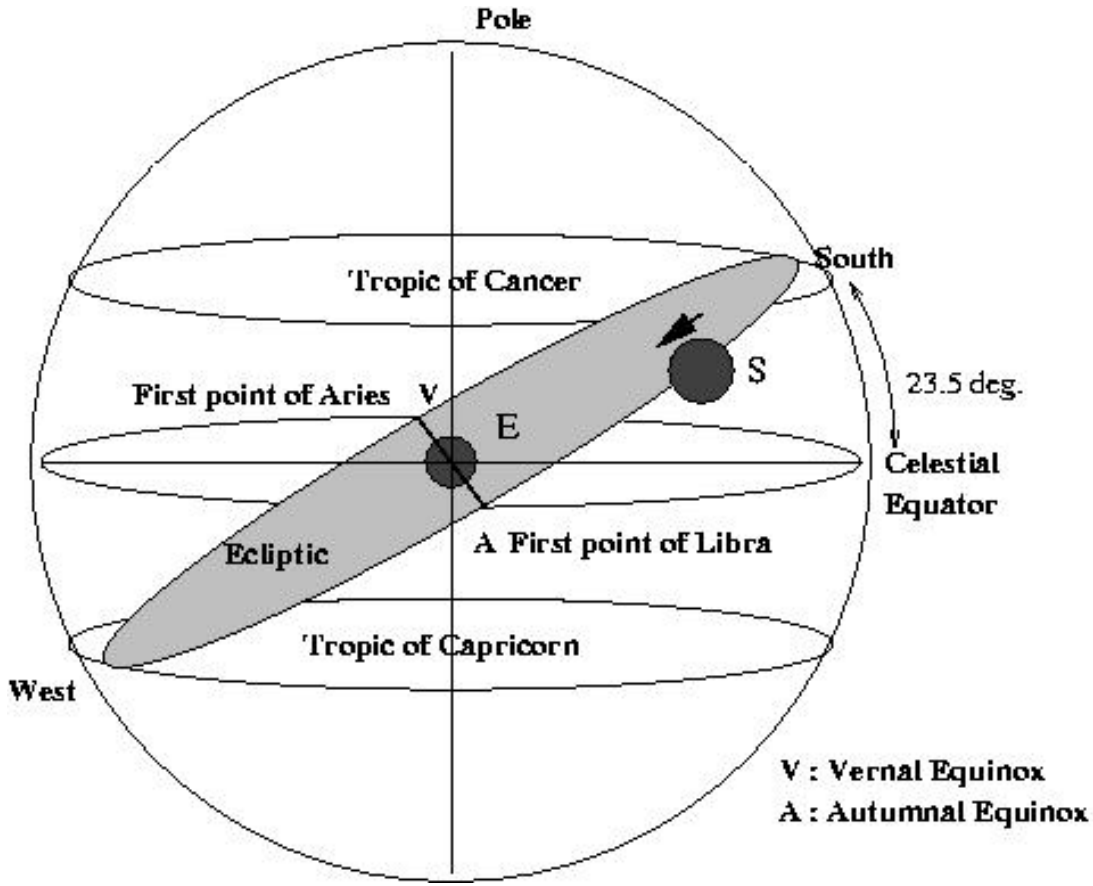

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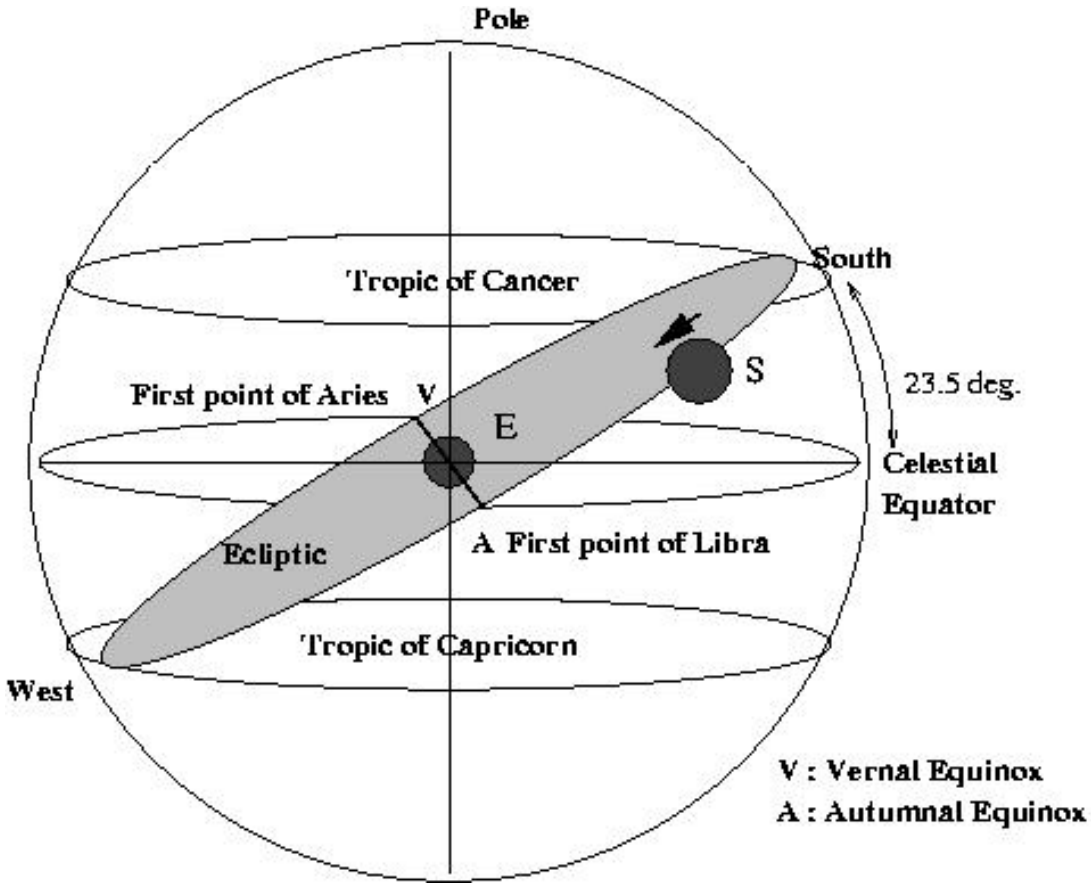
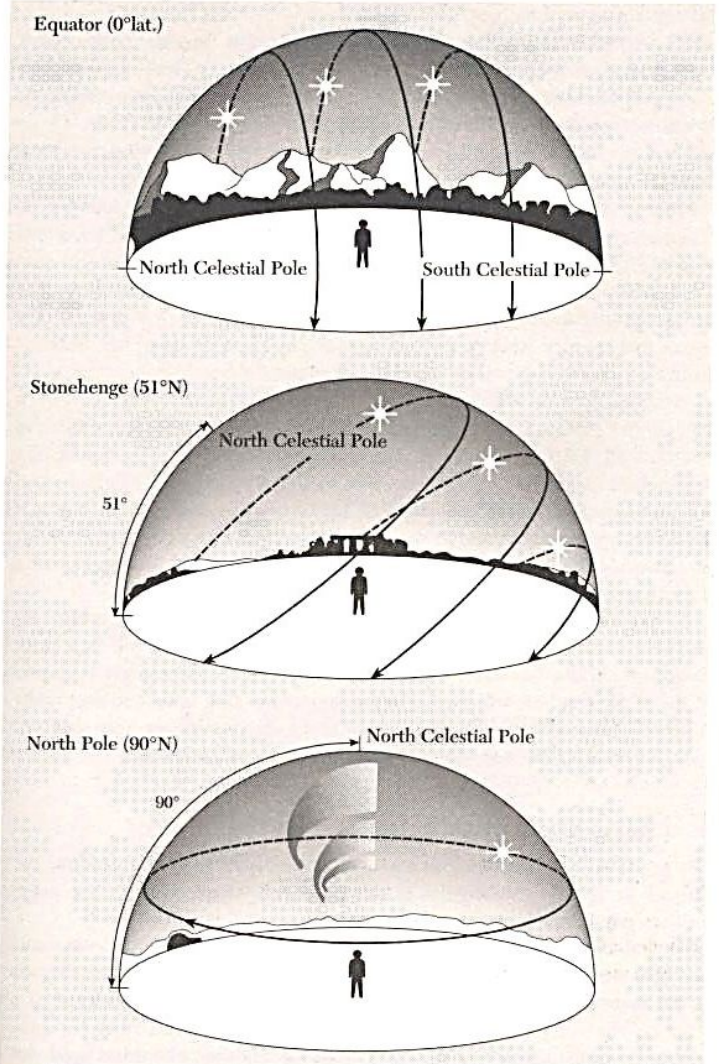


Movement of the stars in the Celestial Sphere

Stars rise in the east (Orient: to grow, be born, rise) and set in the west (Occident: to fall down, to die, set).

- At the equator no stars are circumpolar since the pole star is near the horizon
- In between, the pole star mounts higher and higher in the heavens as we move from equator to pole, and more and more stars become circumpolar
- At the north pole, all stars are circumpolar - they neither rise nor set since the pole star is directly overhead



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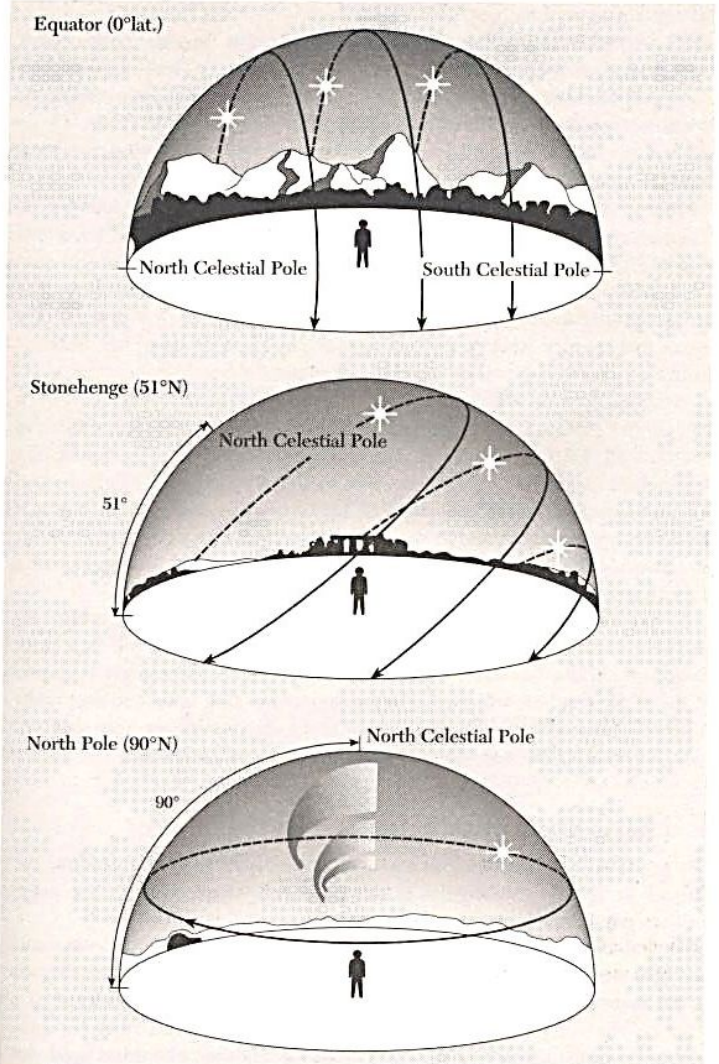

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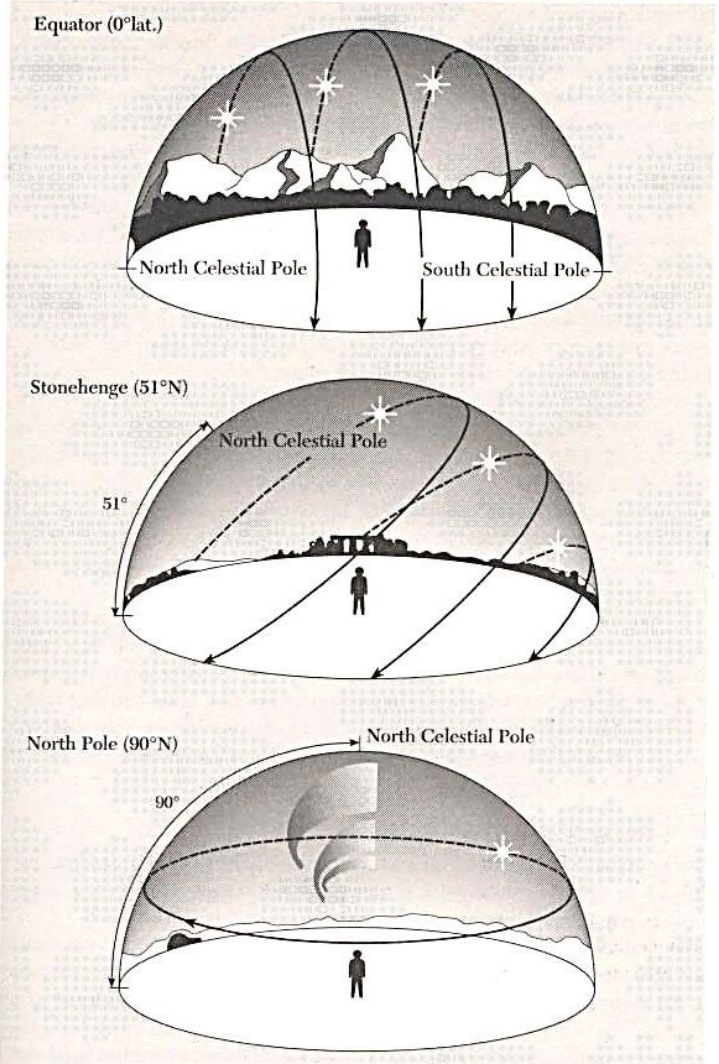
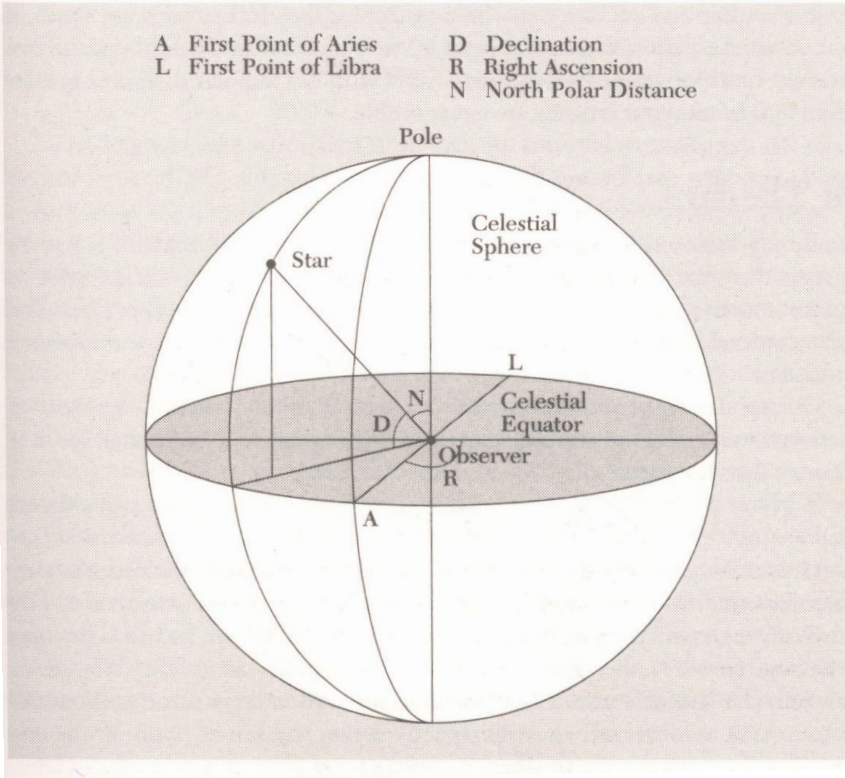


Position of a star in the Celestial Sphere

The altitude and azimuth of a star are its latitude and longitude on the celestial sphere as it appears to an observer – depends on observer's position and the time as the celestial sphere carrying the star rotates. Alternately



- Declination: fixed latitude in celestial sphere
- Right Ascension: fixed longtitude in celestial sphere measured from the first point of Aries
- North polar distance: complement of declination, angle between pole and the star

Declination and right ascension for fixed stars do not change (except for effects of precession. . .), those of the sun, moon and planets do as they move is the celestial sphere

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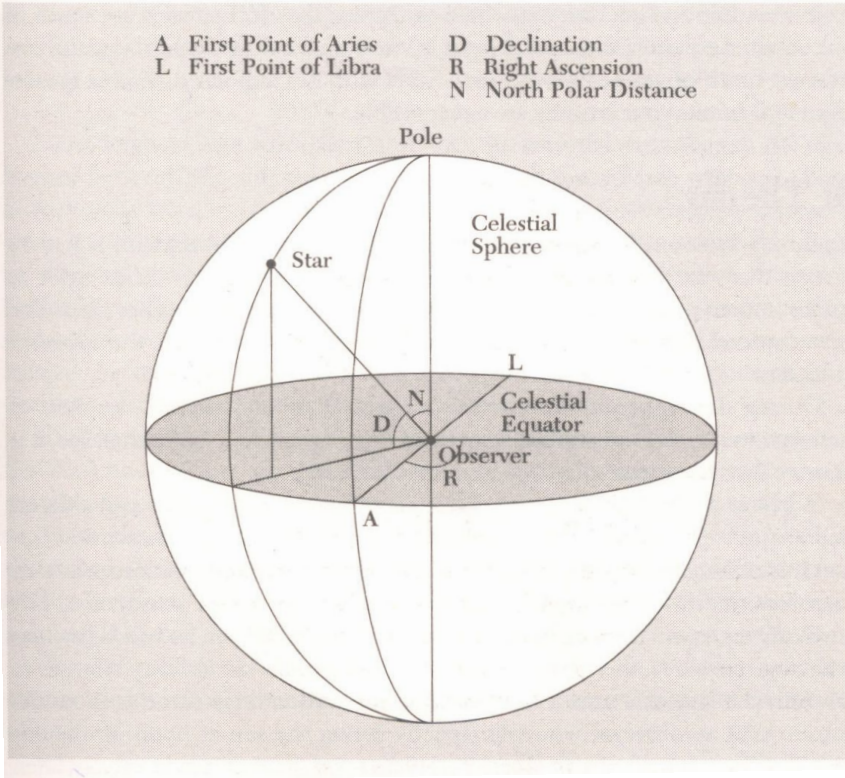

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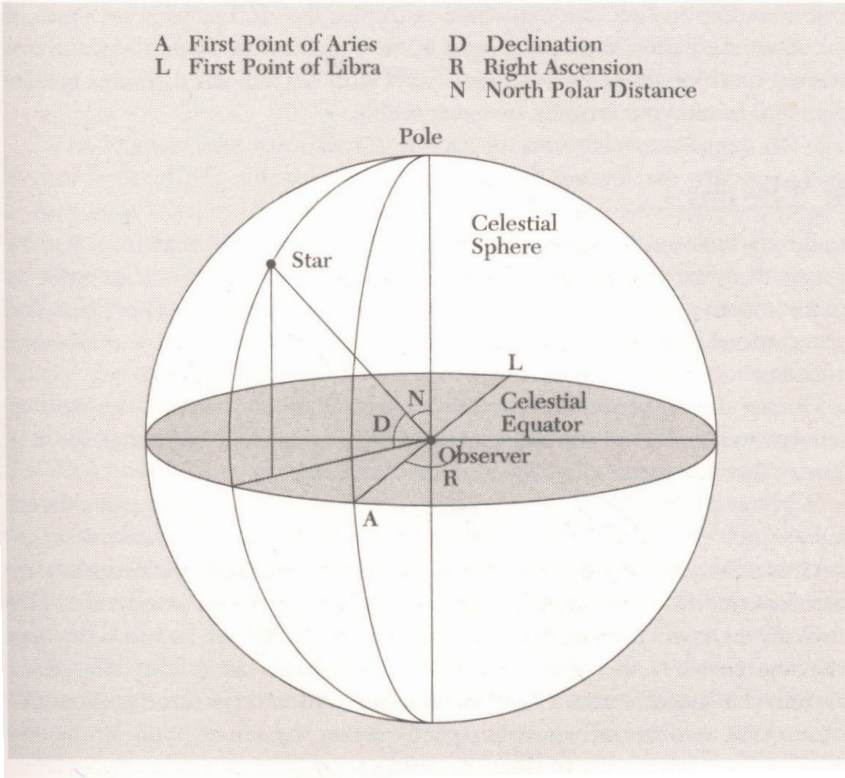

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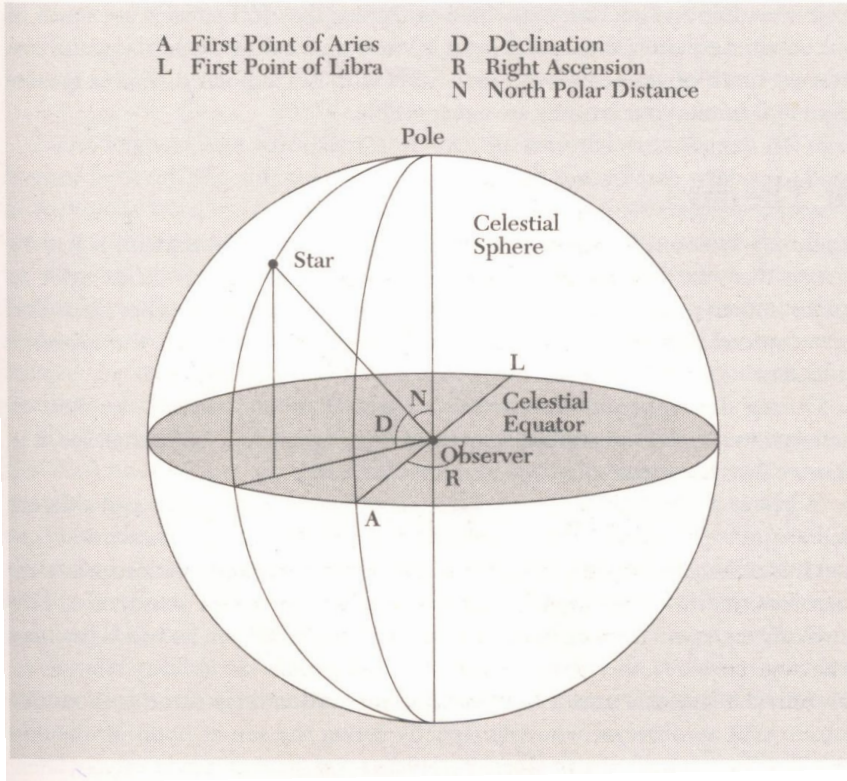

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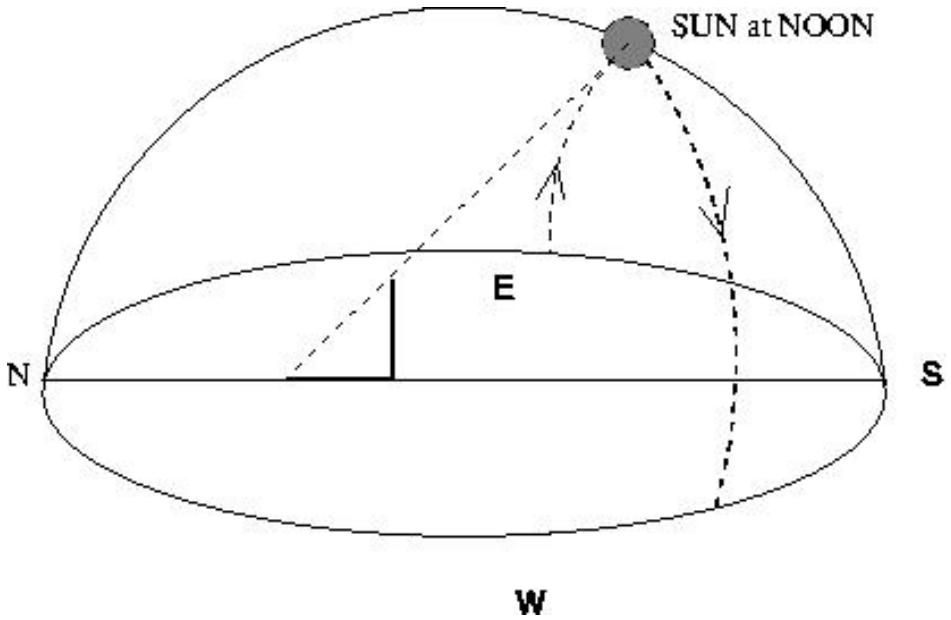
The Length of a Day

- Apparent Solar Day: Successive transits of the sun through the local meridian – e.g. noon to noon when sun is highest in the sky
  Easy to measure with a gnomon – shadow points north and is shortest at that point in the day – "sundial" time.



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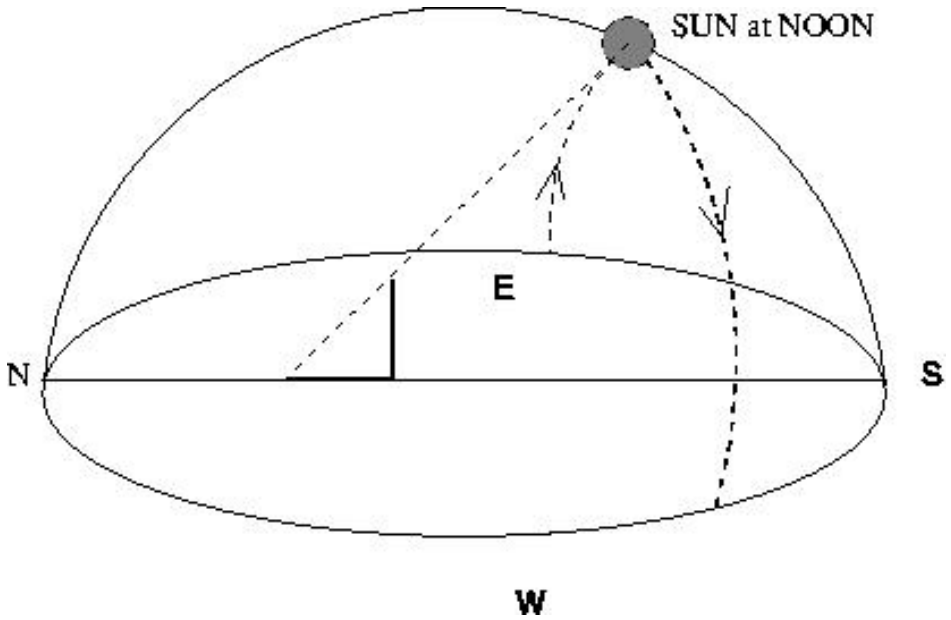

Sidereal Day

- Sidereal Day: Two successive transits of a particular star
- Different because after one full rotation (say noon to noon) earth has also moved by about 1^o in its orbit $\Rightarrow$ same point no longer facing sun – must move an extra 1/360 of a day (1^o) or 4 minutes...
- Non-uniform movement of the earth in its orbit $\Rightarrow$ apparent solar day varies substantially (over 50 seconds)
  $\Rightarrow$ "sundial time" and watch time vary in a complicated way.
- To solve this problem, the "mean solar day" was invented

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Mean solar day

Artificial (fixed) clock time adjusted via diurnal rotation of the stars to agree with average apparent solar time
$\Rightarrow$ exactly 24 hours.

As the celestial sphere rotates about the earth, "mean" sun sweeps through every observer's meridian once each day, but now the intervals between successive transits are (made to be) constant $\Rightarrow$ 86,400 s.
$\Rightarrow$ apparent solar day can vary upto 50 s from this which can build up to as much as 17 min too early or 14 minutes too late.
$\Rightarrow$ the difference is called $\Rightarrow$ equation of time (known to Babylonian astronomers from the first millennium BCE)

From mid second millennium BCE water clocks used, till mid first millennium BCE when diurnal rotations of the stars were used against which clocks were corrected.

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- The seasons arise because the axis of the earth is at an angle of about 23.5 degrees from the vertical.
  (As the earth goes around the sun, the earth alternately tilts towards and away from the sun.)
- Summer solstice:June 21 $\Rightarrow$ tilt is maximum towards the sun
- Winter solstice:December 22 $\Rightarrow$ tilt is maximum away from the sun.
- Equinoxes: Earth is not tilted with respect to the sun.
  - Vernal equinox: March 21
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To keep track of the cycle of the seasons accurately, need to measure the time between corresponding equinoxes (or solstices) $\Rightarrow$ tropical year$\rightarrow$ different from the sidereal year.

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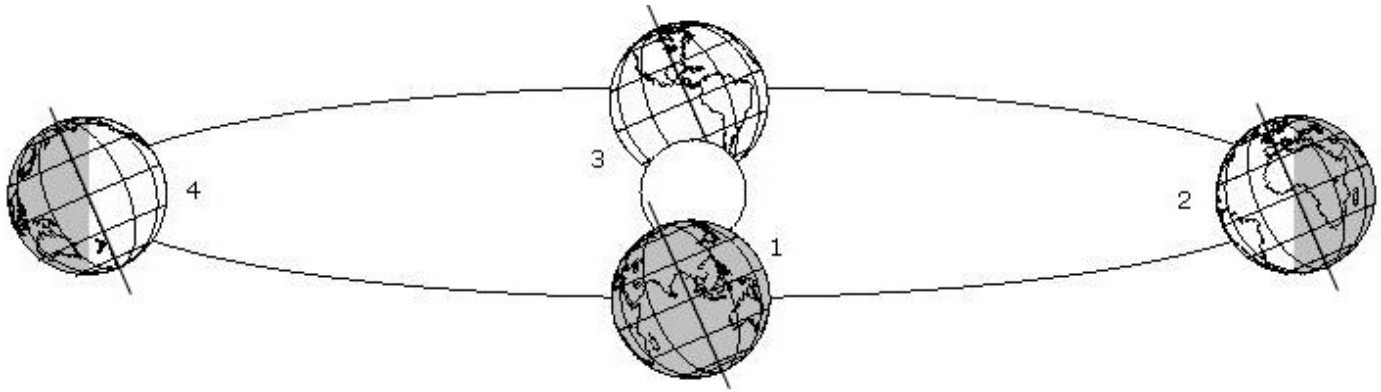
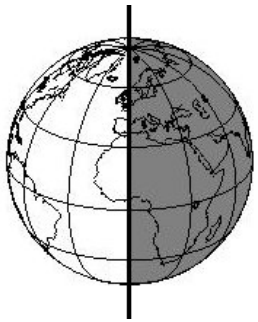
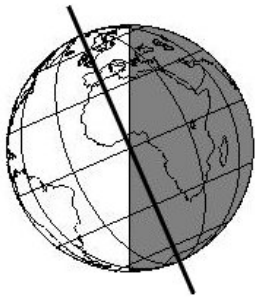
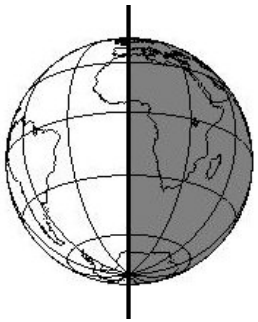




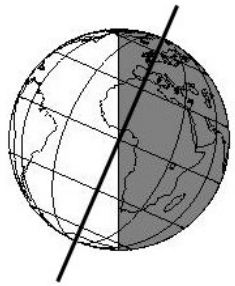
Vernal Equinox



Summer Solstice



Autumnal Equinox



Winter Solstice

The Tropical and Sidereal Year

Tropical year: Time between corresponding *equinoxes* or *solstices*

Tropical year: 365.242199 days (365d, 5h, 48',46")
$\Rightarrow$ This is the length of the year used by the present Western (or Gregorian calendar) and is different from...

Sidereal year: 365.2564 days (365d, 6h, 9', 13")
$\Rightarrow$ measures the time the earth takes to complete a revolution around the sun. This is the year length used in almost all Indian (and many ancient) calendars and accounts for the relative shifting of dates between the Indian and Gregorian calendars.

But why are these two year-lengths different...?

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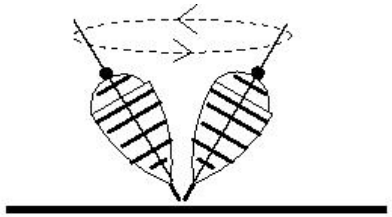

A spinning top that is not entirely vertical "wobbles" around the vertical
$\longrightarrow$ the centre point at the crown of the top describes a circle around the vertical line above the point where it is balanced$\longrightarrow$ precession
Similarly, the earth's axis which is tilted, precesses, describing a large circle in the sky.
Periodicity $\longrightarrow$ 25,868 years
So what does this mean for the sidereal year?

One sidereal year after an equinox, the earth's axis will have moved 1/26000 of the way around this large circle due to precession
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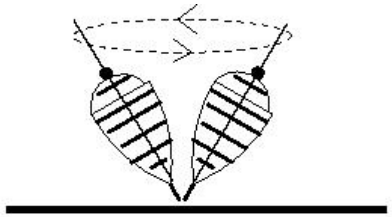

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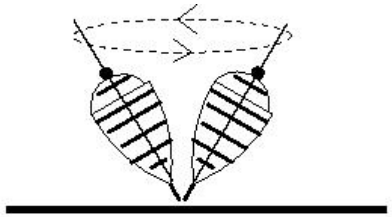

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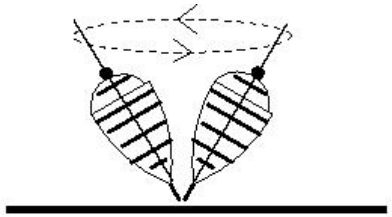

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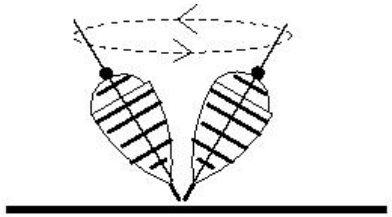

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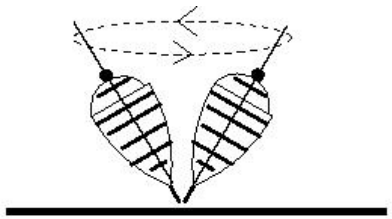

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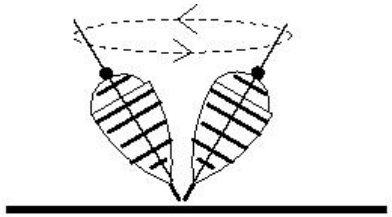

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The Tropical and Sidereal Year – again. . .

Tropical Year $<$ Sidereal Year

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365.2422 vs. 365.2564 days

$\Rightarrow$A calendar based on the sidereal year (like virtually all Indian solar calendars) will gradually begin to err with respect to the seasons

The "real" equinoxes and solstices will gradually shift away from the original dates specified by the calendar.

Examples:

Makara Sankranti (January 14) and Mesha Sankranti (April 14) originally meant to denote the winter solstice and vernal equinox respectively

$\Rightarrow$ however since these dates were fixed, the equinoxes (and solstices) have shifted "back" by about 24 days due to precession.

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Types of Calendars

Essentially three types of calendars:

- Solar: Based of perceived seasonal changes and therefore synchronized to the apparent motion of the sun (or the stars)

  Example: Gregorian, Persian, some Indian calendars

- Lunar: Synchronized to the motion of the moon

  Example: Islamic

- Luni-solar: Synchronized both to the motion of the moon and the apparent motion of the sun/stars – and therefore the most complicated

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Solar Calendars

Tropical solar calendars reckon the position of the earth (or sun) with respect to the equinox. The calendar year is the tropical year.

Dates tied to the seasons and therefore to the declination of the sun.

They have 365 days, occasionally extended by adding an extra day to form a leap year $\Rightarrow$ Gregorian calendar

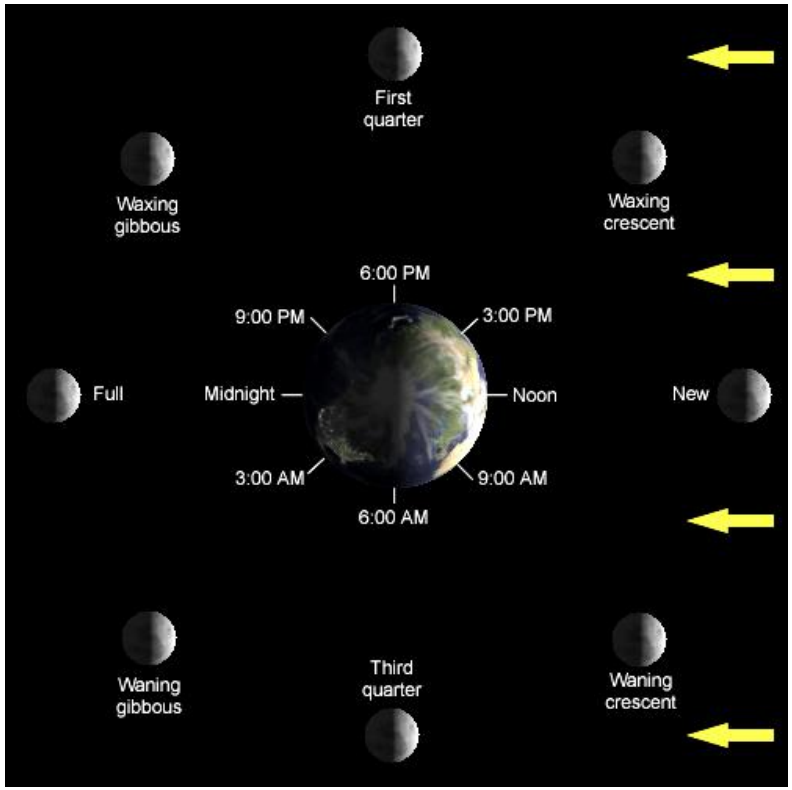
Sidereal solar calendars reckon the position of the earth (or sun) with respect to the stars.

The calendar year is the sidereal year.

Dates indicate the constellation near which the sun may be found $\Rightarrow$ All Indian calendars

Lunar and Luni-Solar Calendars

Month corresponds to a lunation
$\longrightarrow$ a specific day represents a moon phase.
In some cases, may also indicate the season as well
$\longrightarrow$ a lunisolar calendar
$\longrightarrow$ all Indian calendars, Jewish calendar, the Chinese calendar. . . but it need not (pure lunar calendar)
$\longrightarrow$ Islamic calendar.



Indian (Hindu) Calendars

There are many Indian calendars!

Stick to the most common structure – the luni-solar Indian calendar(s)
$\Rightarrow$ tries to fit together, the cycle of lunar months and the solar(sidereal) year in a single framework.

Recall:12 lunar months add up to less than a year, 13 are more than a year.To solve this, define a normal year to have 12 lunar months; an extra lunar month is intercalated every few years to keep in step with the solar year

Seven extra lunar months over a period of nineteen years gives a very close approximation to nineteen solar years (*Metonic cycle* from Babylonian astronomy)

How exactly does this work?

Need to understand the definitions of the month and year in the solar and lunar calendars – the day being the same

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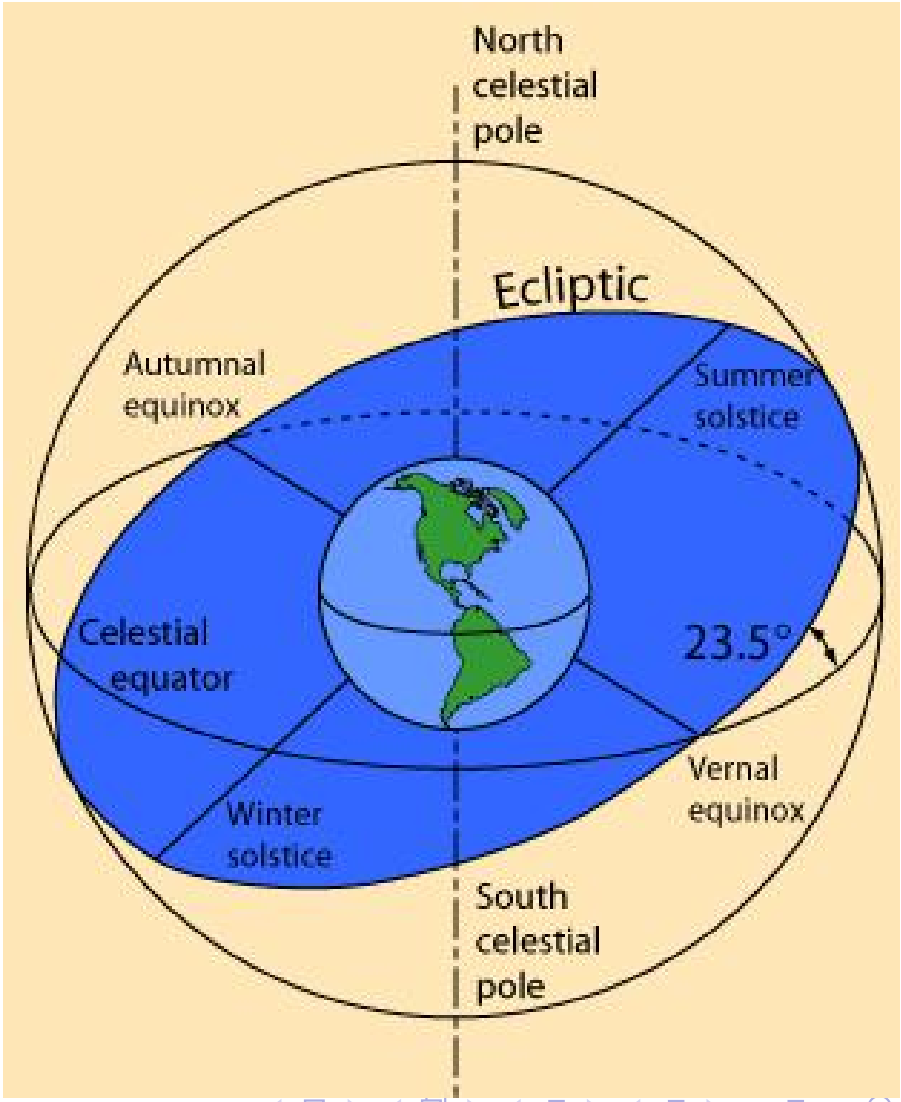
Ecliptic:The apparent path of the sun as it moves against the background of the stars

Solar year:A full circuit of the sun along the ecliptic (against the star background) $\Rightarrow$ ecliptic is divided into twelve equal segments, (each associated with a constellation – signs of the zodiac).

Solar month: Time taken for the sun to pass through one of the twelve segments:$\longrightarrow$ Sankranti – marking the beginning of the solar month.



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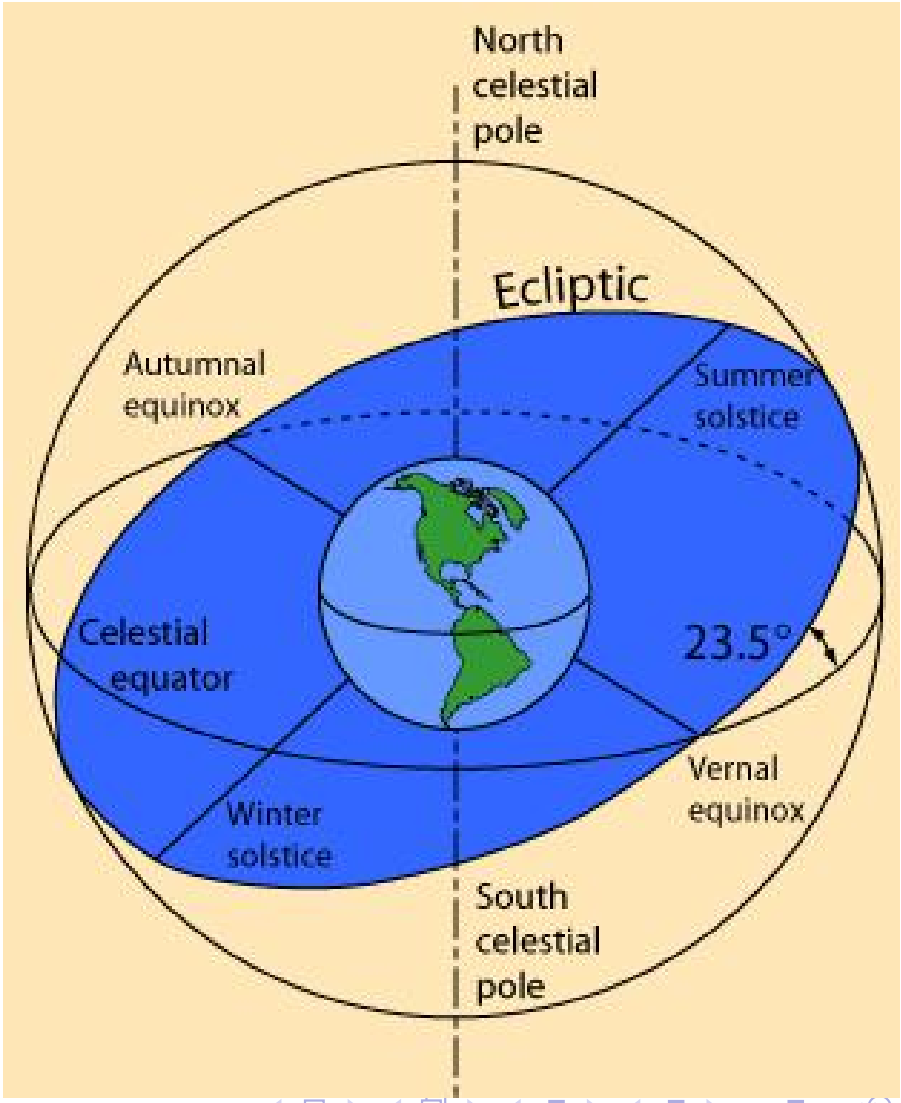

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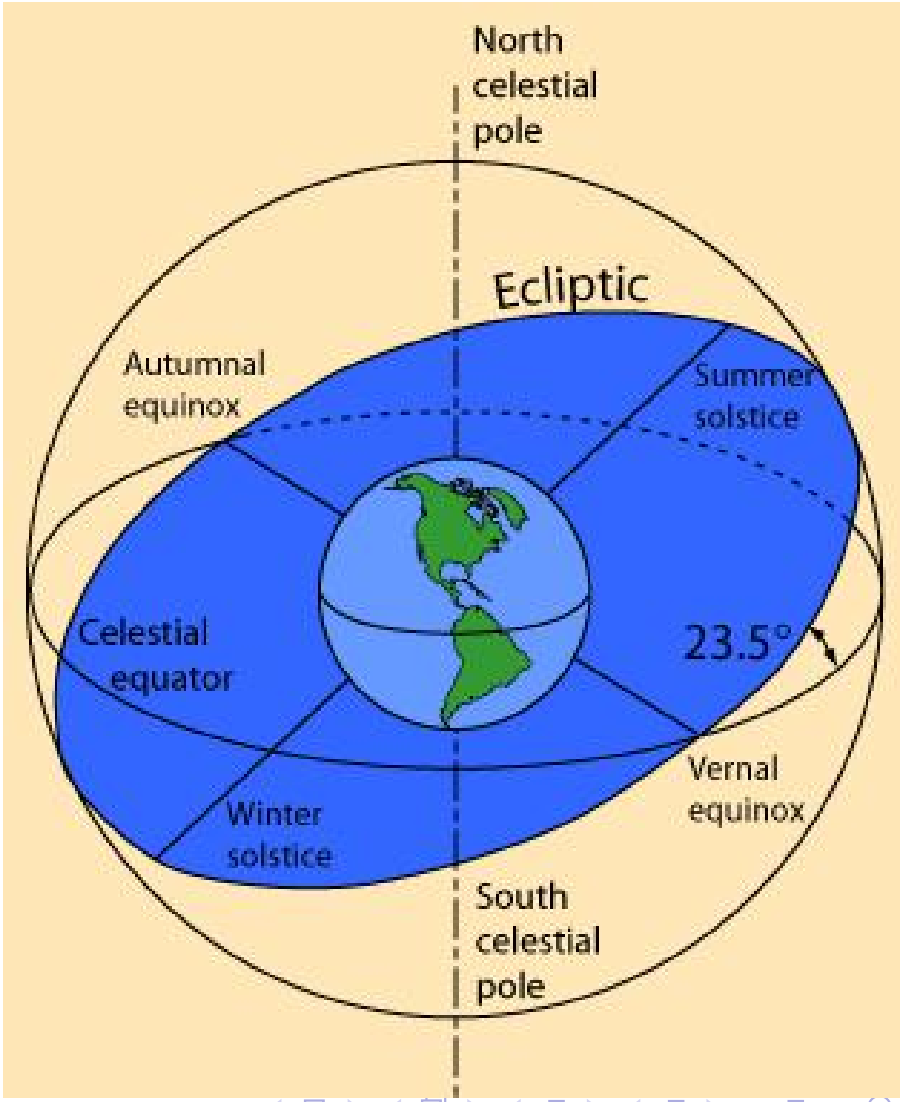

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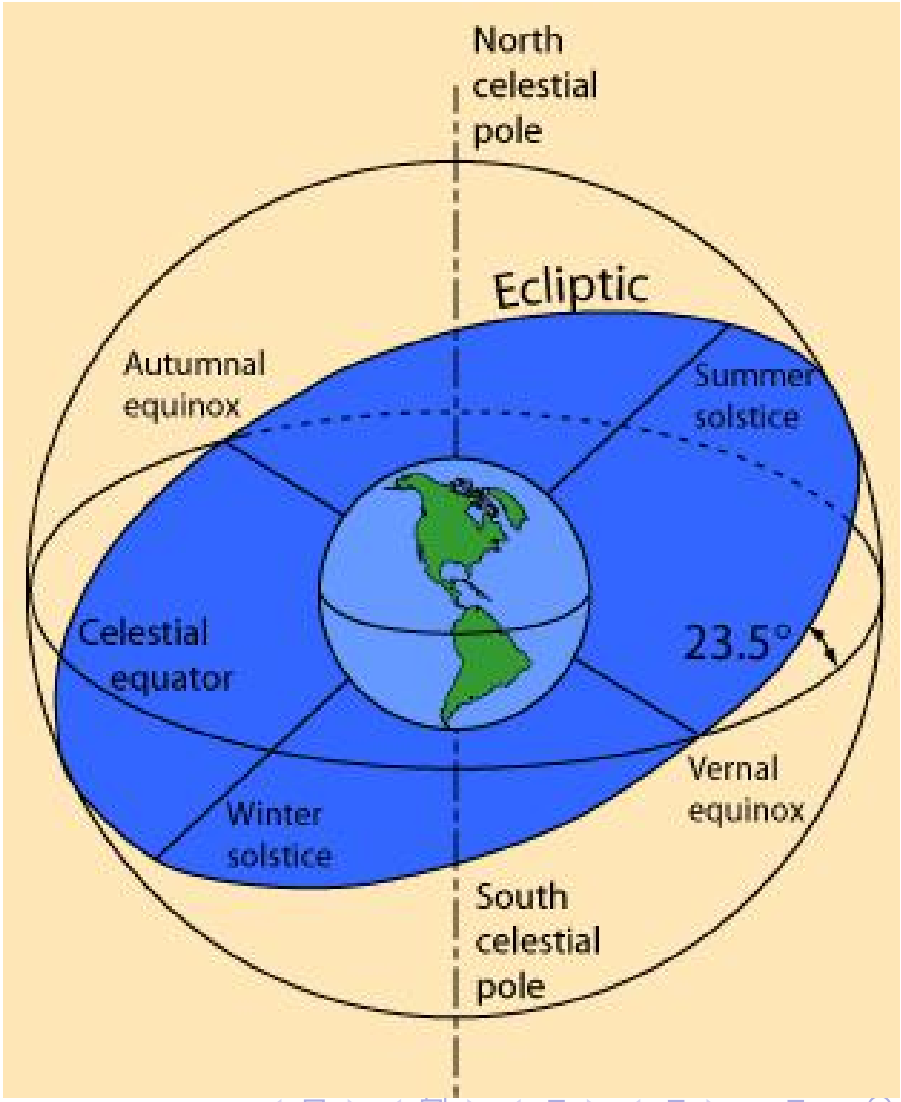

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The year starts with Mesha Sankranti, April 14 (Chittrai). Since this is a solar calendar, the date with respect to the Gregorian calendar also remains fixed (almost!).

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The Sun and the Zodiac

This way of relating the sun's motion to its passage through the constellations ("zodiac") originated with the Babylonians...

The signs of the zodiac – Latin names translated from Greek

Babylonian	Latin	Sanskrit	English	Season
Hired hand	Aries	Mesha	The Ram	Spring
Star	Taurus	Vrishabha	The Bull	
Twins	Gemini	Mithuna	The Twins	
...	Cancer	Karka	The Crab	Summer
Lion	Leo	Simha	The Lion	
Furrow	Virgo	Kanya	The Virgin	
Balance	Libra	Tula	The Scales	Autumn
Scorpion	Scorpio	Vrischika	The Scorpion	
...	Sagittarus	Dhanus	The Archer	
Goat-fish	Capricorn	Makar	The Goat	Winter
...	Aquarius	Kumbha	Water Carrier	
Tails	Pisces	Mina	The Fish	

The Indian Lunar Calendar

The lunar months are related to the solar months (with the same names) and

- either begins and ends with the new moon (*amavasya*)
  - as in AP, Karnataka, Maharashtra and Gujarat – the first lunar month Chaitra beginning with the last *amavasya* before Mesha Sankranti and therefore
  - The next lunar month Vaisakha begins with the first *amavasya* during the solar month Vaisakha. Subsequently, each *amavasya* falling between two *sankrantis* marks the beginning of the successive lunar months.
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Relationship of the Solar and Lunar Months

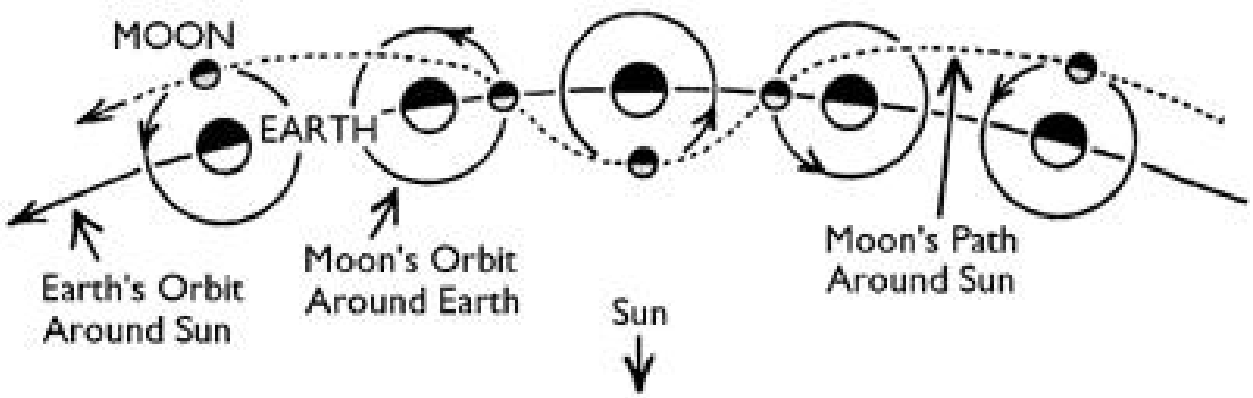
Meena
Mesha
Vrishabha
Mithun
Kataka
Simha
Kanya
Tula
Vrishchika
Dhanus
Makara
Kumbha

Horizontal lines $\Rightarrow$ *Sankrantis or Amavasyas*

Types of Lunar Months

There is more than one way to measure the lunar month:

- Sidereal Lunar Month: Time taken by the moon to pass a fixed star on the celestial sphere
  $\Rightarrow$ this is the moon's rotation period = orbital period = 27.32 days (27d 7h 43' 11.6")
  Origin of the 27 stars or constellations through which the moon passes – "a constellation a day!"
- Synodic month: Time period from new moon to new moon = 29.53 days (29d 12h 44' 2.8")



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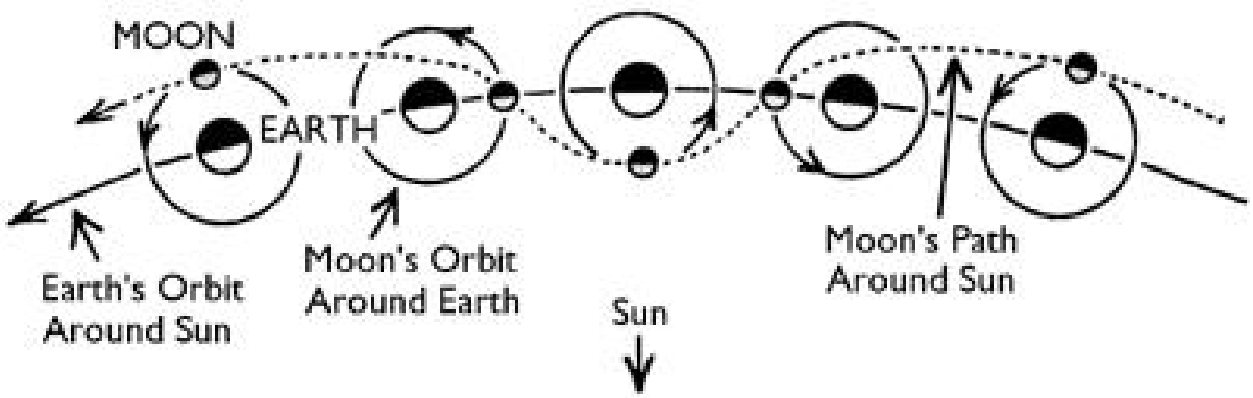
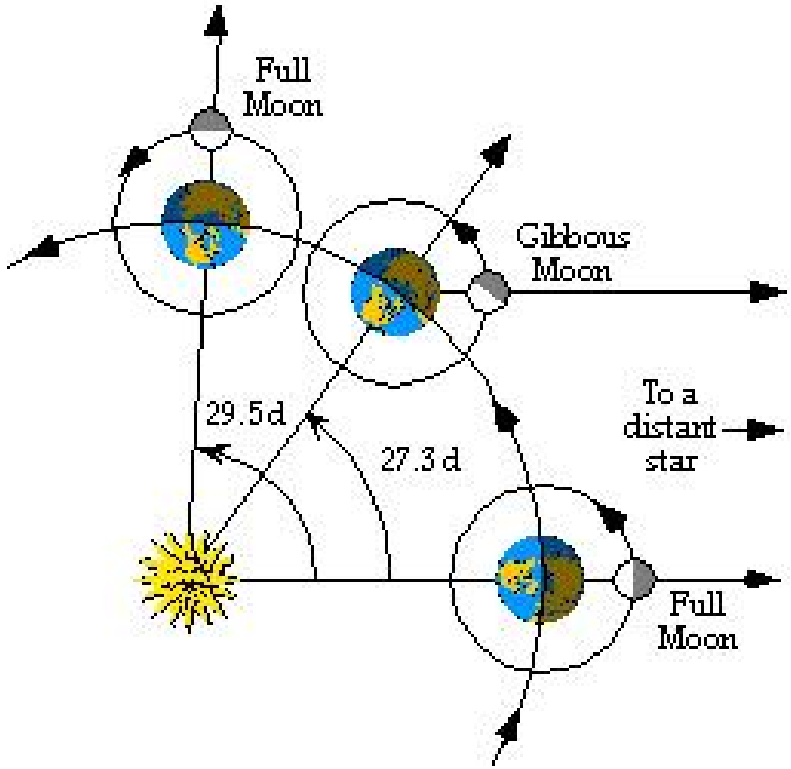


Sidereal vs. Synodic

Since earth-moon system orbits the sun in the same direction as the moon orbits the earth
synodic period $>$ sidereal period by about 2.1 days
$\Rightarrow$ most common way of expressing the lunar cycle and is the one used in the Indian calendars



Tracking the Lunar Month

27 (approx.) days of the sidereal lunar month are marked by the 27 (or 28) nakshatras (constellations) located around the ecliptic (at $13^{o}20'$) intervals.

- The moon travelling around the ecliptic during a lunation passes close by each one which thus marks the day of the lunation
- The nakshatras are grouped into twelve sets ("lunar" zodiac) each containing about 2 or 3 nakshatras
- The names of each of the 12 lunar months is derived from a nakshatra in each of these zodiac regions (Chaitra from Chitra, Vaisakha from Visakha...)

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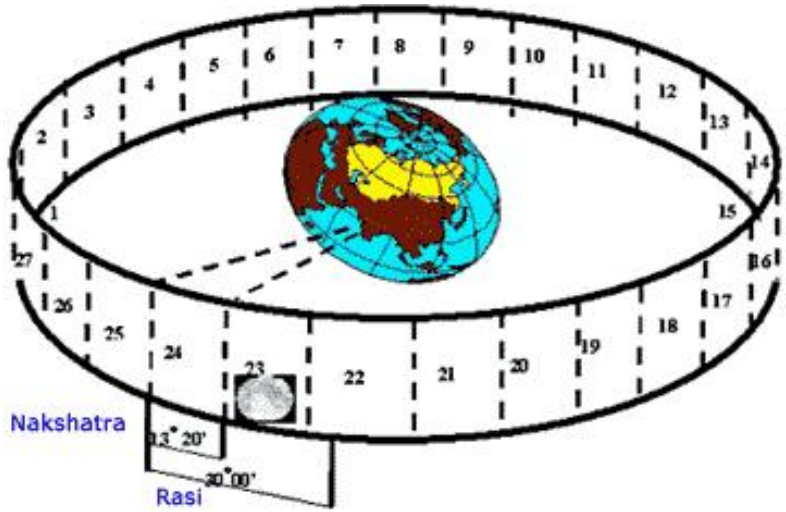

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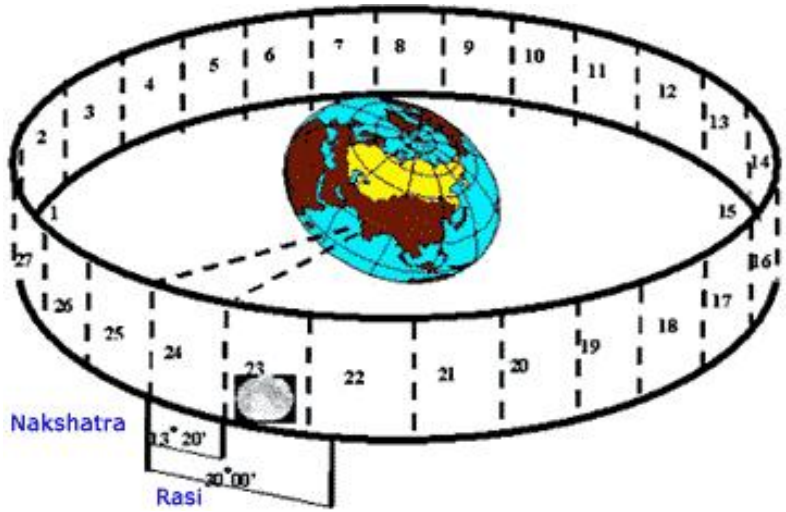

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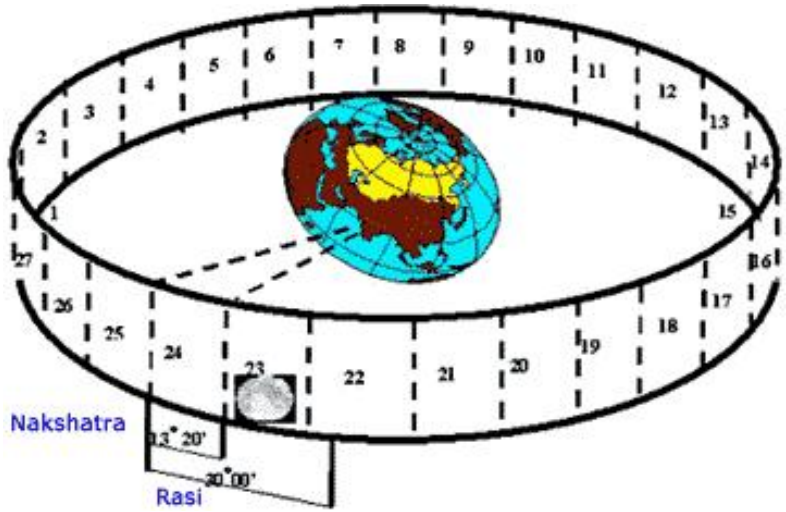

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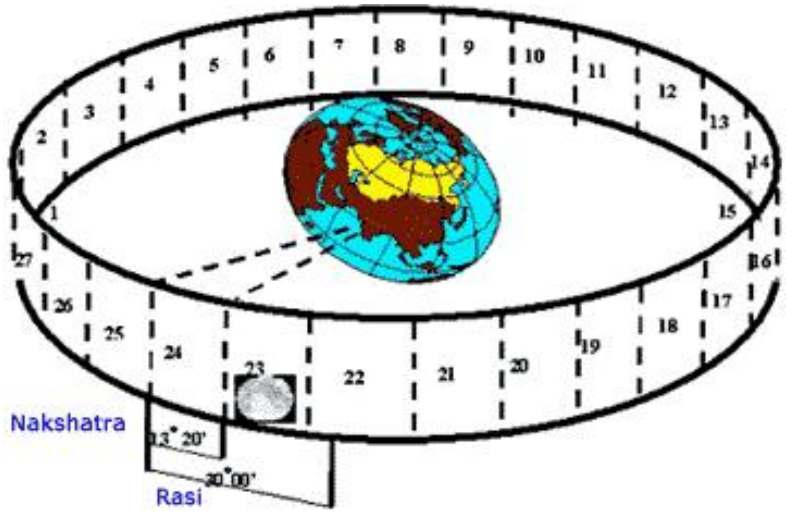

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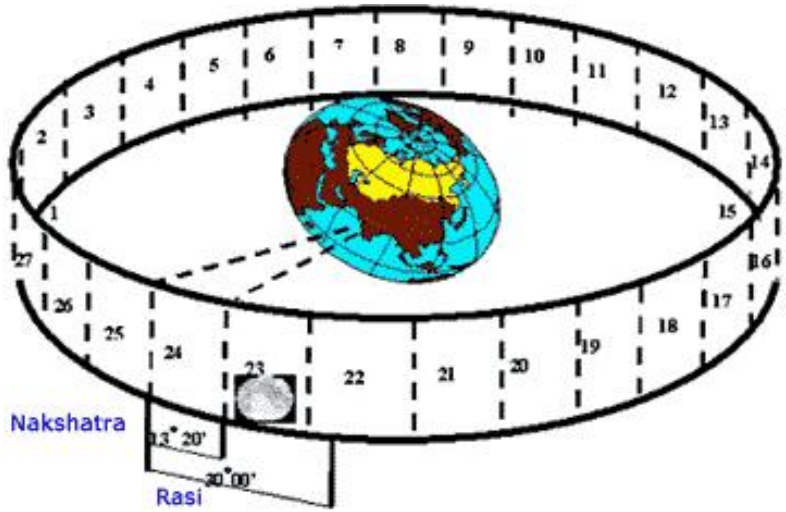
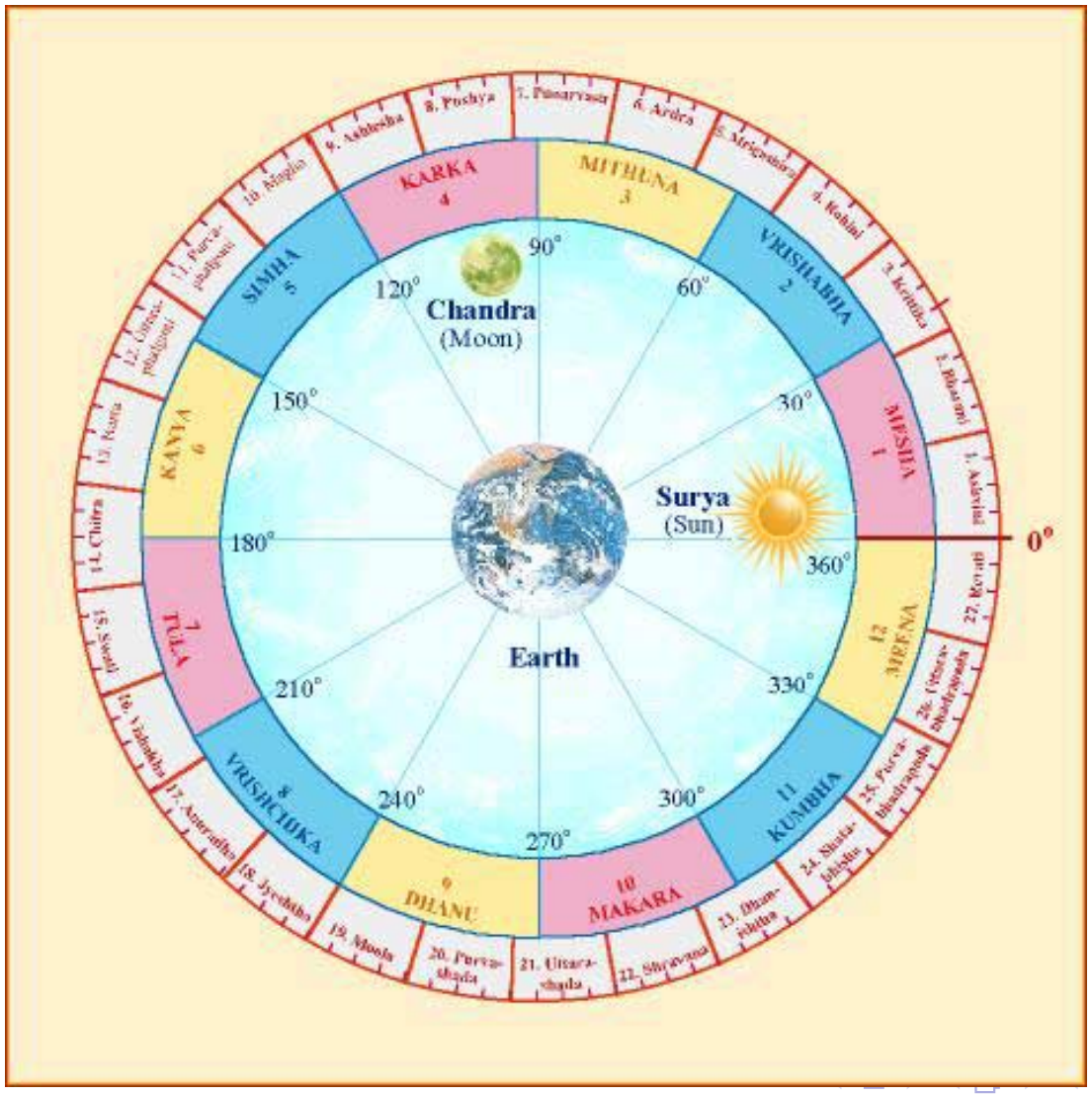


The Full Monty!



Nakshatras and their equivalents

Ashvini	β and γ Arietis
Bharani	35, 39, 41 Arietis
Krittika	Pleiades
Rohini	Aldebaran
Mrighashirsha	$\lambda$and ϕ Orionis
Ardra	Betelgeuse
Punarvasu	Castor and Pollux
Pushya	γ,δ, θ Cancri
Ashlesha	$\delta, \epsilon, \eta, \rho, \sigma$ Hydrae
Magha	Regulus
Purva Phalguni	δ, θ Leonis
Uttara Phalguni	Denebola
Hasta	α, ϵ Corvi
Chitra	Spica

Swati	Arcturus
Visakha	$\alpha, \beta, \gamma, \iota$ Librae
Anuradha	β, δ, π Scorpionis
Jyestha	α, σ, τ Scorpionis
Mula	$\epsilon, \zeta, \eta, \theta, \iota, \kappa, \lambda, \mu, \nu$ Scorpionis
Purva Ashadha	δ, ϵ Sagittarii
Uttara Ashada	ζ, σ Sagittarii
Shravana	α, β, γ Aquilae
Shravishta	α to δ Delphinis
Shatabhishaj	γ Aquarii
Purva Bhadrapada	α, γ Pegasi
Uttara Bhadrapada	γ Pegasi,α Andromedae
Revati	ζ Piscium

Divisions of the Lunar Month

A unique feature of the Indian lunar month:

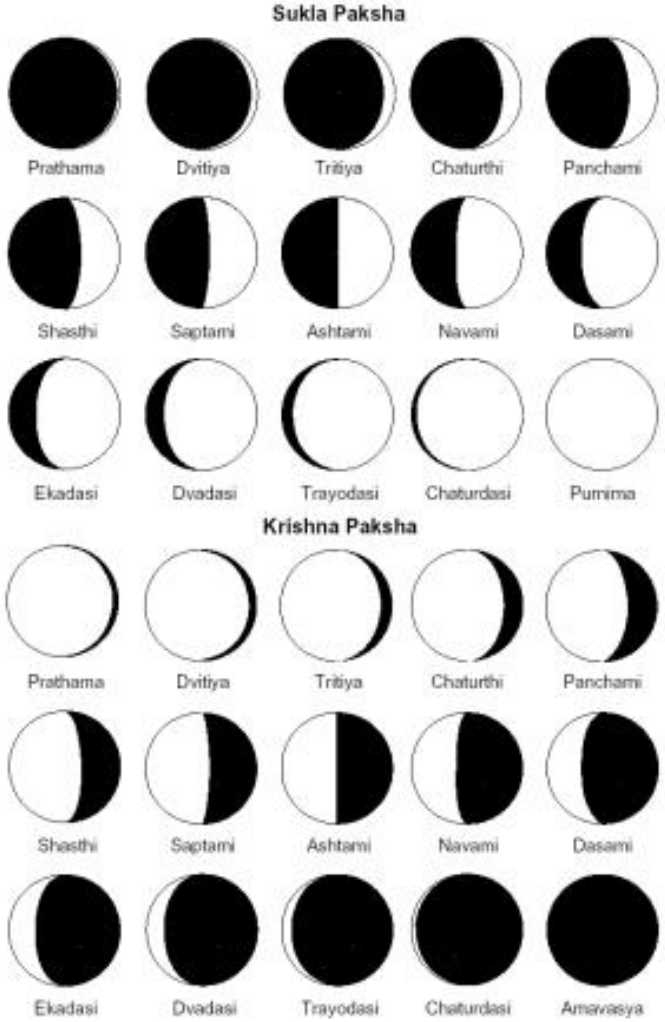
Tithi: The time taken for the angular separation of sun and moon to change by 12^o exactly (conjunction to conjunction 360^o – divided by 30.)

$\Rightarrow$ Mean synodic period divided by 30 = 0.984353 days = 23h 37'.

Tithi number of a day in a lunar month is that of the *tithi* in force at dawn.

Actual time taken for the moon to pass from one *tithi* to another varies from 19 to 26 hours which has interesting consequences...

360 *tithis* in 12 lunar months, but 354 days!!



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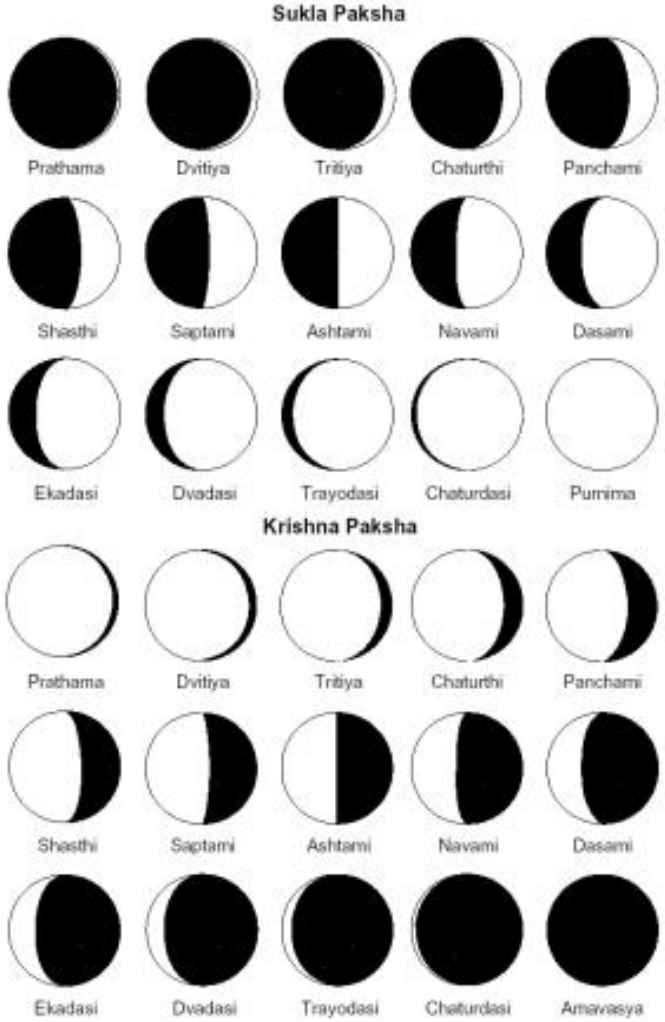

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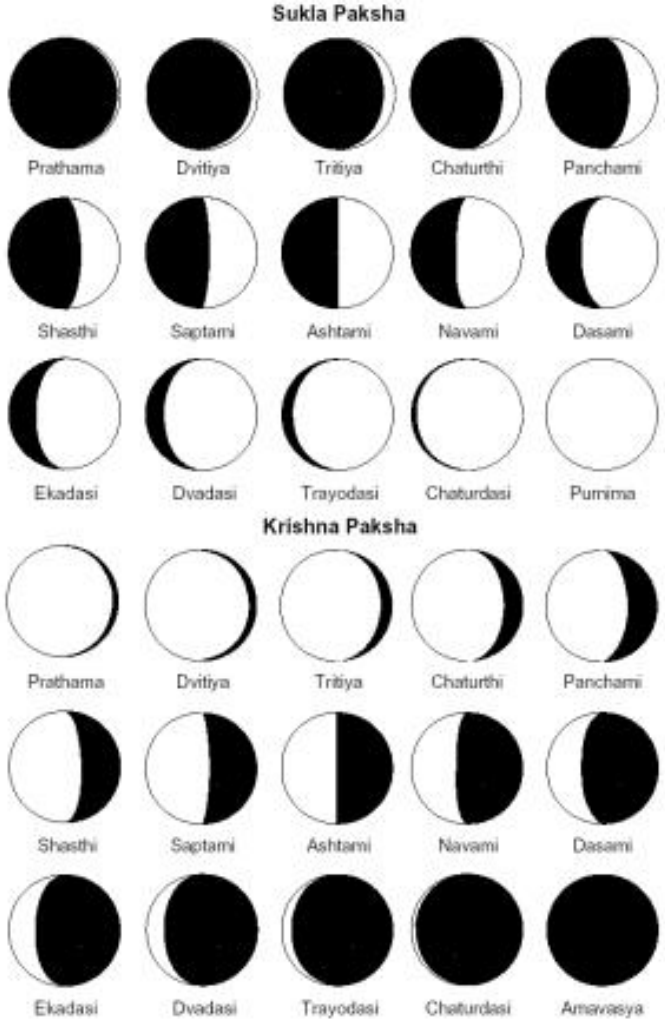

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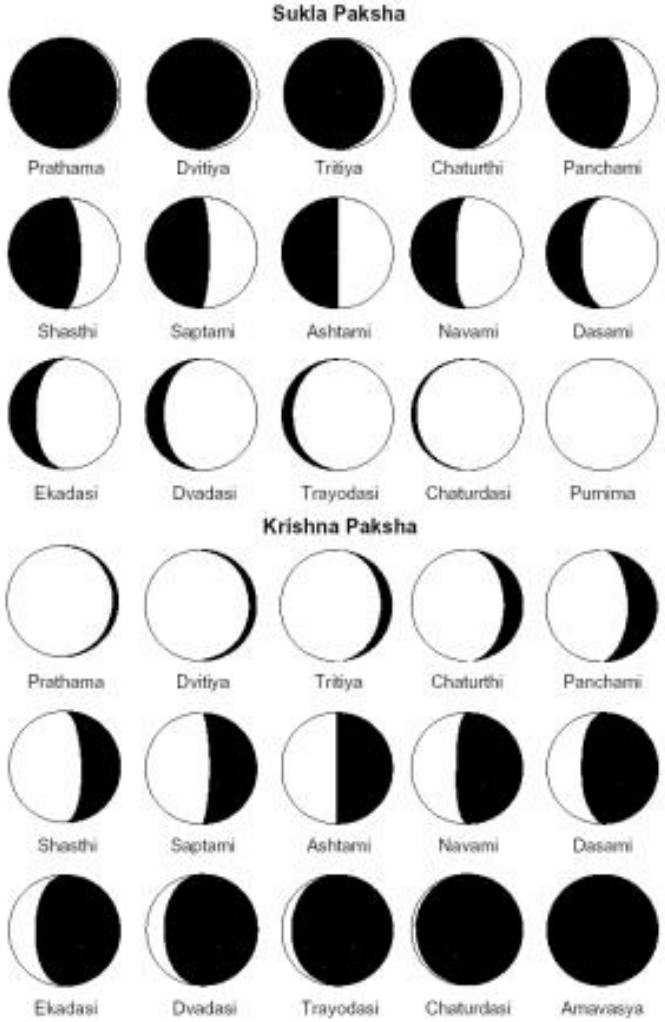

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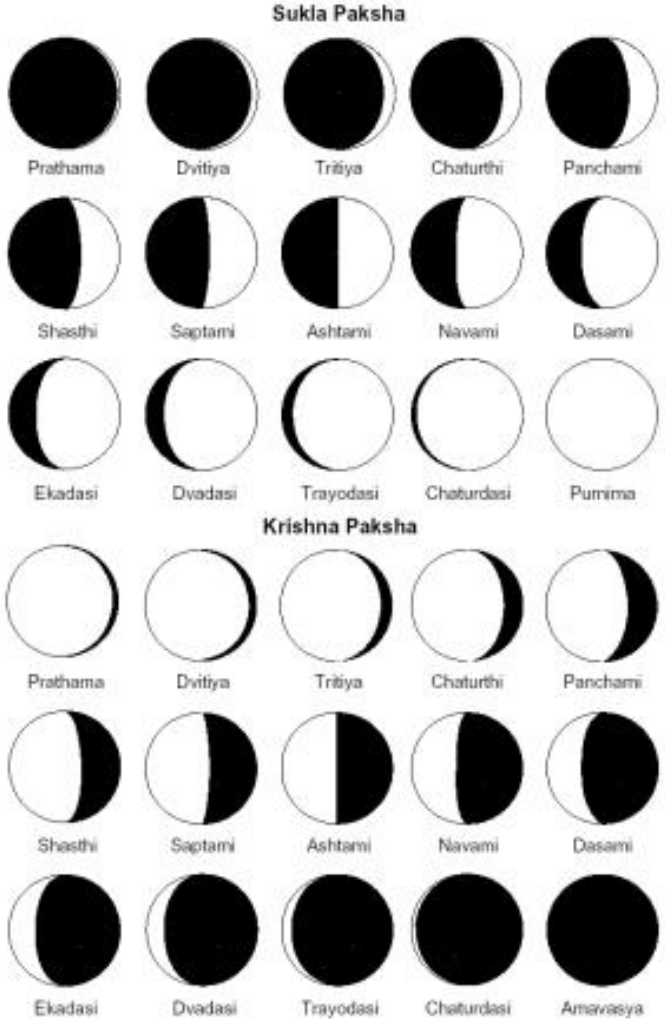

Relationship of the Solar and Lunar Months

- Meena
- Mesha
- Vrishabha
- Mithun
- Kataka
- Simha
- Kanya
- Tula
- Vrishchika
- Dhanus
- Makara
- Kumbha

Horizontal lines $\Rightarrow$ *Sankrantis or Amavasyas*

Problems with Matching

A solar month usually has 30-31 days, a lunar month is about 29.5 days long! $\Rightarrow$ As the year goes by, each lunar month starts a little earlier within the corresponding solar month.

$\Downarrow$

Eventually an entire lunar month will lie within a solar month!

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Two amavasyas between a pair of sankrantis! $\Rightarrow$ we get an extra intercalated month called *adhika maasa* .

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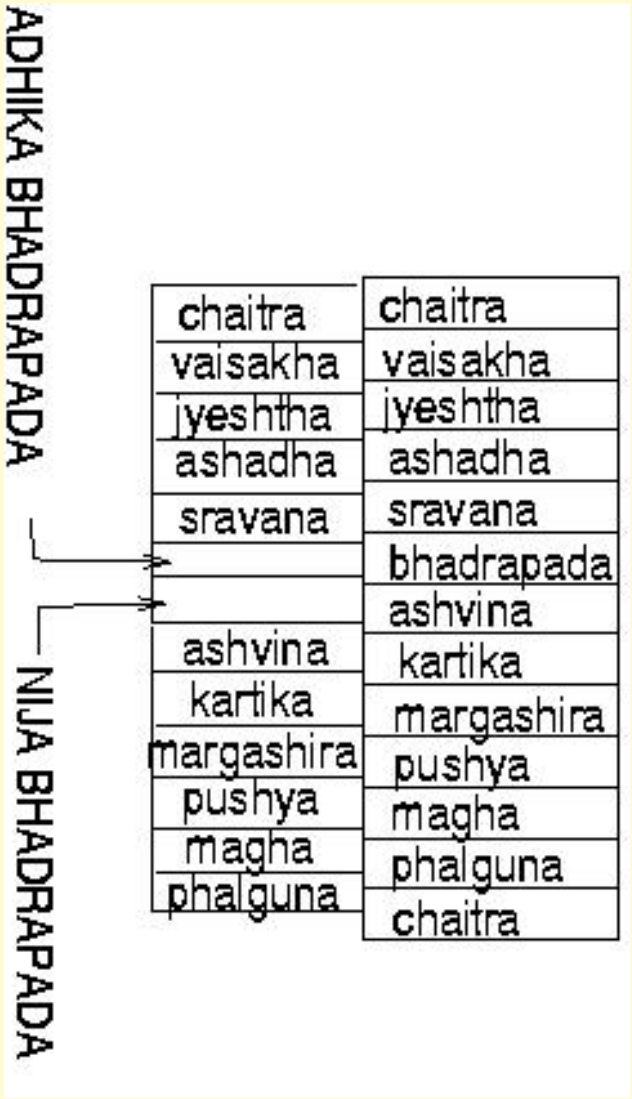
Example



Two amavasyas within solar month Bhadrapada $\Rightarrow$ First amavasya begins extra month *Adhika Bhadrapada* and the second one begins the "real" month *Nija Bhadrapada*

A Peculiar Case

Usual to have about 7 adhika maasas in 19 years. (Recall: Metonic cycle in Babylonian astronomy). However the opposite can also happen (very occasionally).

$\Rightarrow$ A lunar month spans **two** sankrantis e.g. in 1991-92, there was **no** amavasya during solar month Magha.

$\Rightarrow$ The lunar month Magha was "lost" $\longrightarrow$ it became a *kshaya maasa*!

Very unusual since solar month ($\sim 30 - 31$ days) is usually larger than a lunar month (~ 29 days) – so it cannot "fit" inside a lunar month.

Sun's motion along ecliptic is not uniform – in some sections when it is moving faster, it may pass through a sign of the zodiac in less than a lunar month – sometimes in as little as 29.4 days

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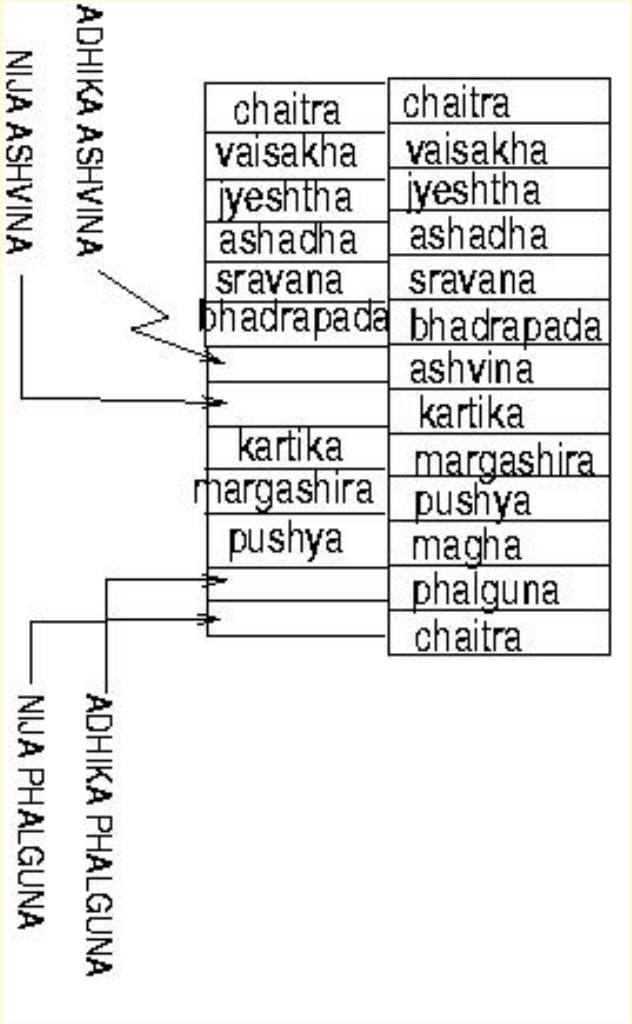

Lunar month Pushya spans **two** sankrantis – no amavasya during solar month **Magha**
$\Rightarrow$ no lunar month of **Magha** (*kshaya maasa*) but two *adhika maasa* – **Ashvina and Phalguna**:
A year with a *kshaya maasa* always has one or more *adhika maasa*.

Summary of the Indian luni-solar system

- Reasonably complicated (*adhika maasa, nija maasa, kshaya maasa*), but copes well with reconciling the solar and lunar calendar.
- Like the solar and lunar months both of which vary, the *tithi* and the mean solar day also vary
  $\Rightarrow$ sometimes a tithi number is repeated (*adhika tithi*) or one will be skipped (*kshyay tithi*).
- This system (Nirayana) does not keep track of the precession of the earth's rotation.$\Rightarrow$ it moves forward by one day in about 70 years...(the precession is included in the Sayana system which is rarely used)$\Rightarrow$ equinoxes coincided in 285 CE with First point of Aries (Mesha) or First point of Ashwini nakshatra.

Most other calendars (Babylonians, Egyptians, Assyrians...) use similar or different algorithms to reconcile the lunar and solar movements. There is however still a widely used calendar which is purely lunar...

The Islamic calendar

The Islamic calendar: This is purely lunar with no corrections for the solar year
$\Rightarrow$ 11 extra days intercalated in each cycle of 30 years of 12 months each
$\Rightarrow$ 19 years of 354 days + 11 leap years of 355 days gives average month of $(19 \times 354 + 11 \times 355)/360$ lunar months $= 29.530555$ days (compare average lunation 29.530589 $\longrightarrow$ discrepancy of 1 day in 2500 years).

Since the Islamic calendar is shorter than any solar calendar (. . . Gregorian) by about 11 days, Ramadan migrates throughout the seasons e.g.

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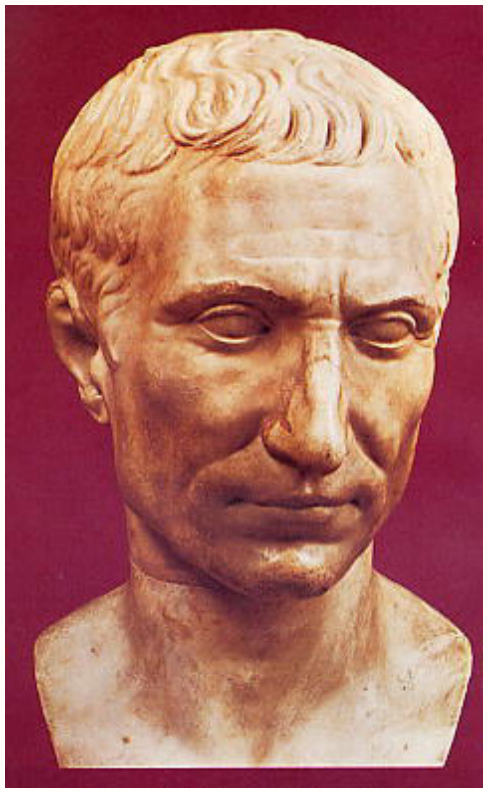
The most familiar calendar in this world is the legacy of two people



Julius Caesar
and
Pope Gregory
XIII

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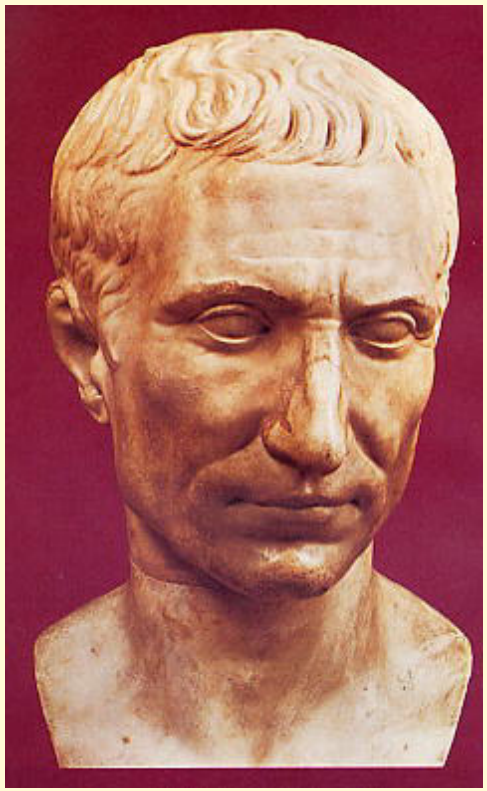

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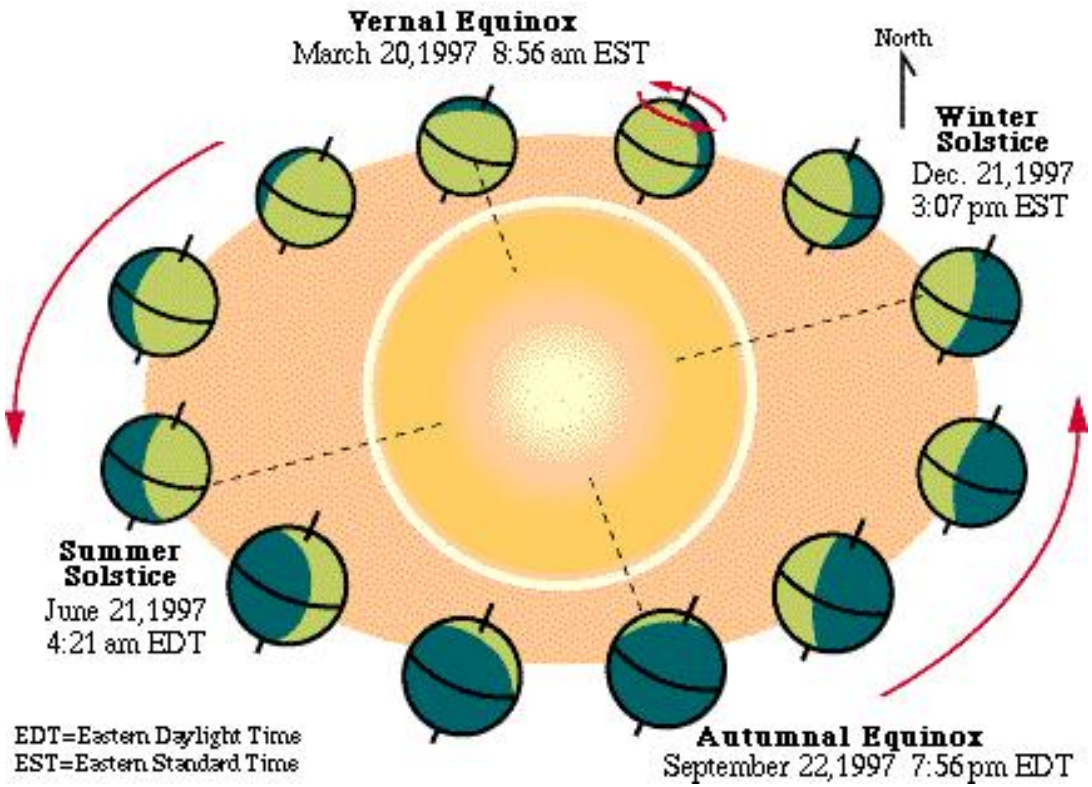
Basics of the Gregorian Calendar

Unlike luni-solar calendars, the Gregorian calendar directly uses the tropical year as its basis.

This keeps the equinoxes and solstices fixed and hence the relationship of the year to the seasons



Basics of the Gregorian Calendar

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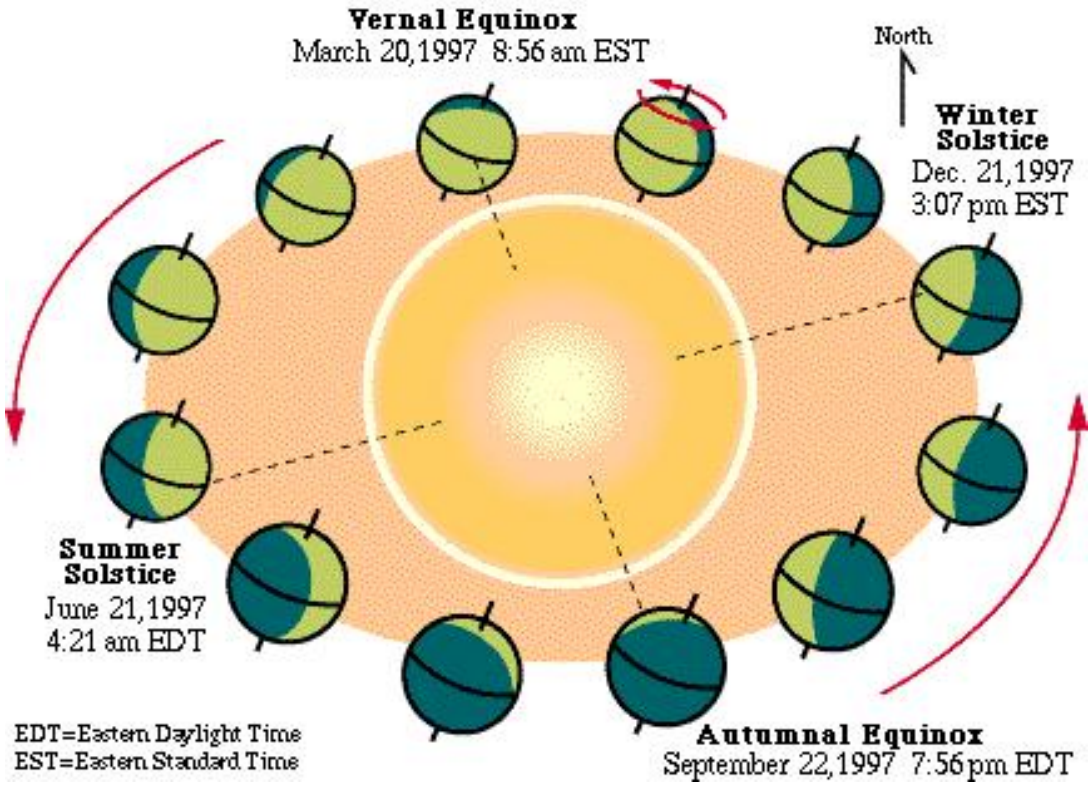

Genesis of the Gregorian Calendar –Julian Calendar

- Originates from the ancient calendars of Babylon, Egypt and Greece
- By 50 BCE, the observed equinox had drifted from the predicted equinox by about three months
- Julius Caesar, on the advice of the Egyptian astronomer Sosigenes, added 67 days to the year 46 BCE to reset these dates and, on his advice
- Reformed the calendar, completely decoupling it from the lunar cycle

In this new Julian calendar. based on a measurement of 365.25 days, Caeser began the practice of normal years of 365 days and an extra day added every fourth year. The year begins with January 1 and the vernal equinox falls on March 21.

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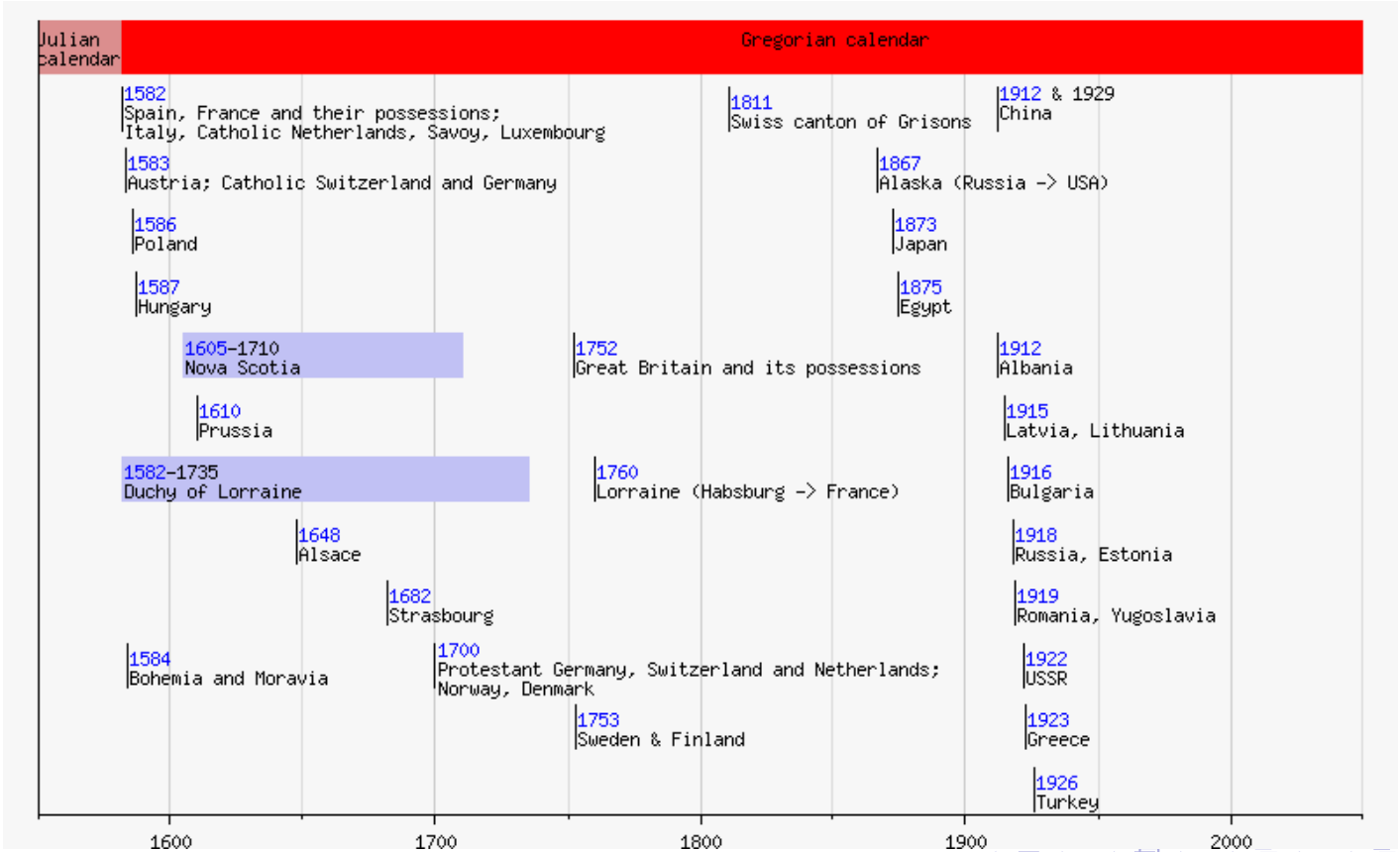
Acceptance of the Gregorian Calendar

Took almost 400 years to be accepted around the world – many Protestant countries (England, Americas) considered it a Catholic conspiracy and accepted it only in 1752. . . by which time it had to be corrected for 11 days (2/9/1752 followed by 14/9/1752).



Gregorian Calendar today

Gregorian calendar used in almost all countries as the *civil* calendar

Many countries like India follow their own calendars for other purposes like religious festivals.

With the fine tuning of the calendar to make 4000 CE, 8000 CE non-leap years, the Gregorian calendar is in synchrony with the tropical year to an accuracy of one day in 20,000 years.

One final complication: the slowing down of the earth.

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The Gregorian Calendar and Easter

Some Christian Festivals

New Year's Day	January 1
Ash Wednesday	46 days before Easter Sunday
Good Friday	2 days before Easter Sunday
Easter Sunday	First Sunday after 14th day of the moon occuring on or immediately after 21 March
Ascension Day – Holy Thursday	39 days after Easter Sunday
Christmas Day	December 25