Timekeeping

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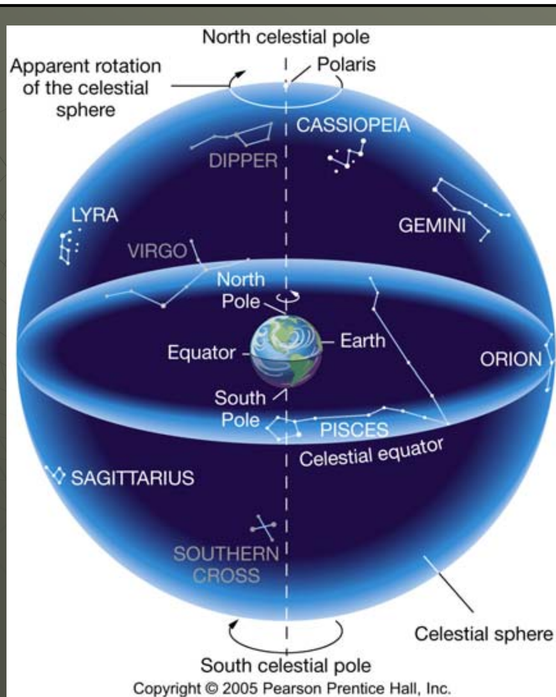
The Solar System: Our Home in the Universe

Universe, University → unum vertere
"to flow into one"

Alma Mater Studioru Universitas Bonomiensis"
(Bologna 1088)
"turning all studies into one"
The place where the free cultivate
the liberal arts



Because of the Earth's rotation, distant objects such as stars appear to move in the sky along circular paths with center along the Earth's rotation axis. Stars very near the poles (e.g. Polaris) appear to practically not move at all.

Since Earth rotates about its axis once every 23h 56m, to a stationary observer on Earth it appears as if stars were "pinned" on a distant, fictitious sphere, which rotates about Earth with a period of 23h 56m, hence the term "sidereal day". That fictitious sphere is referred to as the "celestial sphere".

The changing aspects and relative locations of the Sun, Moon, planets and stars in the sky, as perceived by the naked eye, are due to:

1. The daily rotation of Earth on its axis
2. The annual revolution of Earth around the Sun
3. The rotation of the Moon on its axis (*)
4. The revolution of the Moon around Earth (*)
5. The orbital motions of planets around the Sun

These are motions of periodic nature which have been used through history for timekeeping purposes.

(*) Those two motions take place with the same period, so we always see the same face of the Moon.

1. Earth rotates about its axis every 23h 56m (*sidereal day*); however, the Sun transits every 24h 00m (*solar day*).
2. Earth revolves about the Sun every ~365.25 days. The projection of the plane of its orbit onto the celestial sphere is the *ecliptic.*
3. The axes of rotation and revolution of Earth are tilted wrt each other by 23deg 27'. This tilt and the orbital motion cause the Earth's *seasons.*
4. The Moon revolves about Earth once every ~27.3 days and rotates about its axis in exactly the same time, hence we see always the same face of the Moon.
5. Because Earth moves along its orbit as the Moon revolves about Earth, the time required for repetition of the Moon's phases is ~29.5 days (*synodic period*).
6. The plane of the Moon's orbit is tilted to that of the ecliptic by 5deg; thus the Moon can be found anywhere within +/- 5deg from the ecliptic, explaining why eclipses do not occur every month.

Our ability to keep track of time has historically increased in the measure by which our understanding of the motions of cosmic objects has matured. The accuracy with which we can predict the periodicities associated with those motions – and the departures thereof – has determined the quality of our clocks and calendars.

On the other hand, progress in technology provides more accurate instruments to measure time and thus better understanding – and testing - of the physical laws, as well as satisfying increasingly demanding social needs.

Astronomy, technology and social needs are tightly bound in the process of **Timekeeping.**

The predictable recurrence of sunset and sunrise, the phases of the Moon, the flow of the seasons: these are events that anchor our perception of time, and "stamp" the sequence of our acts.

- We can safely predict that the Sun will rise again in some number of hours
- Ancient farmers learned that seeds needed to be planted at a specific time of the year, e.g. after the Spring equinox
- Children are born about 9 months after conception
- Our Sun has nuclear fuel to last only for 4.5 billion years
- 15-Euro "vignetten" let you drive on Austrian highways for 15 days
- There are 86,400 seconds in a civil day

What is a year?... what is a day?... What is a month? What is a second?

There are several different ways to define hour, day, month, year, as Martha told us yesterday.

Gary Cooper may not have cared for the exact definition of "High Noon": whether it was meant to be solar noon, civil noon or something else. Shooting a few bad hombres did not require millisecond readiness.

Plane geometric surfaces that contain the Earth's polar axis are called *meridional planes.*
The meridional plane that passes through the local Zenith is referred to as the *local meridian.*

When a celestial object crosses the local meridian we say it *transits.*
The Sun transits at noon. Given two locations on Earth apart from each other in the East-West direction, the Sun will transit by then at different times

"meridian" ➔ from Latin *medius dies* which means "half day"

a.m. ➔ *ante meridiem*, Latin for "before the meridian"
p.m. ➔ *post meridiem,* Latin for "after the meridian"
(referring to the position of the Sun)

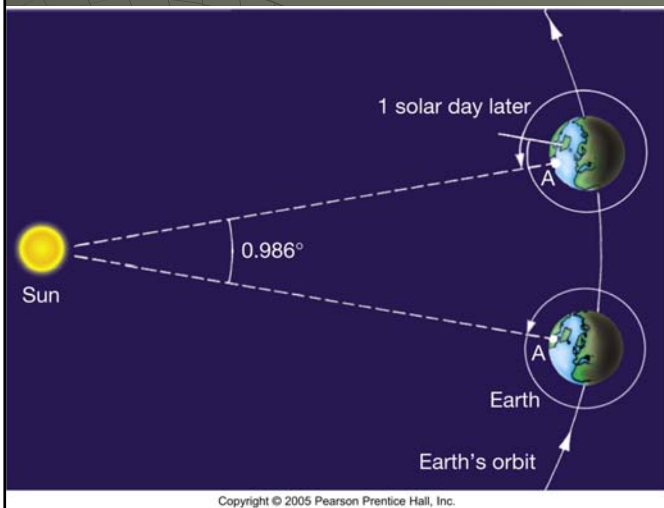
Because at northern latitudes an observer of the Sun, at noon, faces the South, the word "noon" in some languages is synonym with "South" (e.g. French *midi*, Italian *mezzodi' or mezzogiorno or "meridione";* folks who live in southern Italy are commonly referred to as meridionali*).*

A day is the time between to successive transits of a celestial object

If such celestial object is very far away – e.g. a star – then we call that day sidereal. If such object is the Sun, we call it a solar day.

However, the duration of a solar day is not the same as that of a sidereal day…

What is a "solar day"?



Earth rotates about its axis once every sidereal day (23h 56m) and revolves about the Sun once every ~365.25 solar days.

➔ Between one sidereal day and the next, Earth has moved about 1 deg along its orbit around the Sun.

So for the Sun to be aligned with the local meridian (transit) two successive times, Earth has to rotate and extra ~1 deg, wich takes an extra 4 minutes

➔ Thus the solar day lasts 24h.

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If such celestial object is very far away – e.g. a star – then we call that day sidereal. If such object is the Sun, we call it a solar day.

However, the duration of a solar day is not the same as that of a sidereal day…

Moreover, the duration of the solar day is not the same at all times of the year…
The reason for that is that the shape of Earth's orbit about the Sun is not circular, but elliptical (Kepler's first law); hence (second law), Earth's orbital speed is variable: faster near perihelion and slower at aphelion. Thus the difference in time between successive transits of the Sun at different orbital configurations.

➔ So we create an arithmetic fictitious but convenient unit: the "civil day"

Each "civil day" of the year is defined to have exactly the same length, equal to that of the average solar day across the year. Thus, it is not necessary to have clocks that run at different speeds at different times of the year.

We subdivide the civil day in 24 hours: 12 hrs before transit of the Sun (noon) and 12 hrs after the transit. Each hour is exactly of the same length as another: 60 minutes of 60 seconds each(*). And each second has the duration of 9192631770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the Cesium 133 atom.

(*) But it wasn't always so: ancient Egyptians divided day time in 12 hours and night time in 12 hours. Because the time the Sun is above the horizon is different at different seasons, day time hours had different length than night time hours.

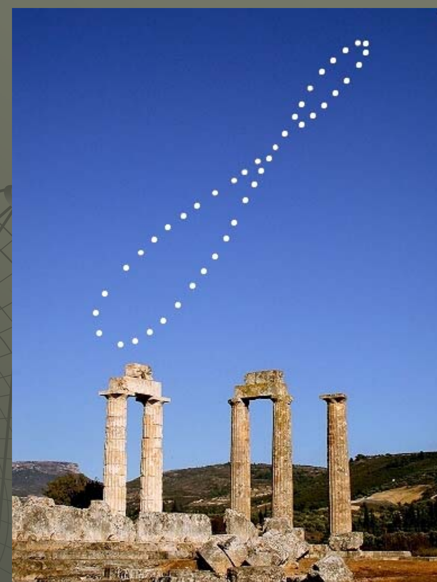
Each civil day consists of exactly 60x60x24=86,400 seconds. Since the solar day has variable duration, the civil time sometimes runs slightly ahead and sometimes slightly behind the Sun. The difference between civil and solar time, i.e. between a clock that ticks civil seconds and, e.g. a sundial, which displays actual solar time, is referred to as the "Equation of time".

"Thought" Experiment:

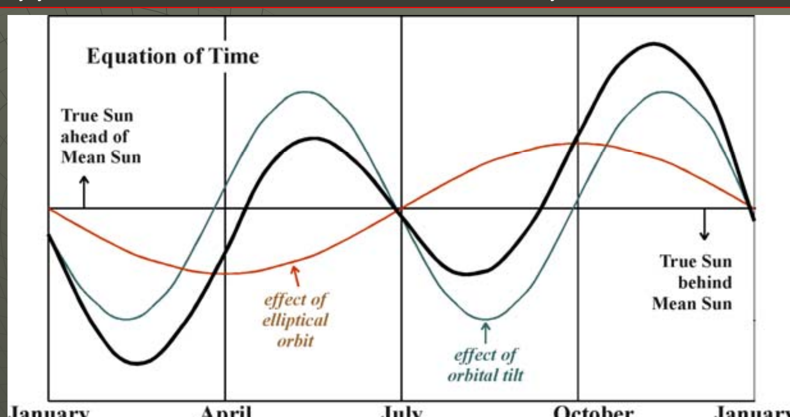
Every day, at exactly noon by our watch, we take a picture of the Sun, in exactly the same direction and foreground scenery. After one year, what will the sum of all the images look like?

- If the orbit of Earth were perfectly circular and the rotation axis of Earth exactly perpendicular to the plane of that orbit
- If the orbit of Earth were perfectly circular and the rotation axis had a tilt to the plane of its orbit

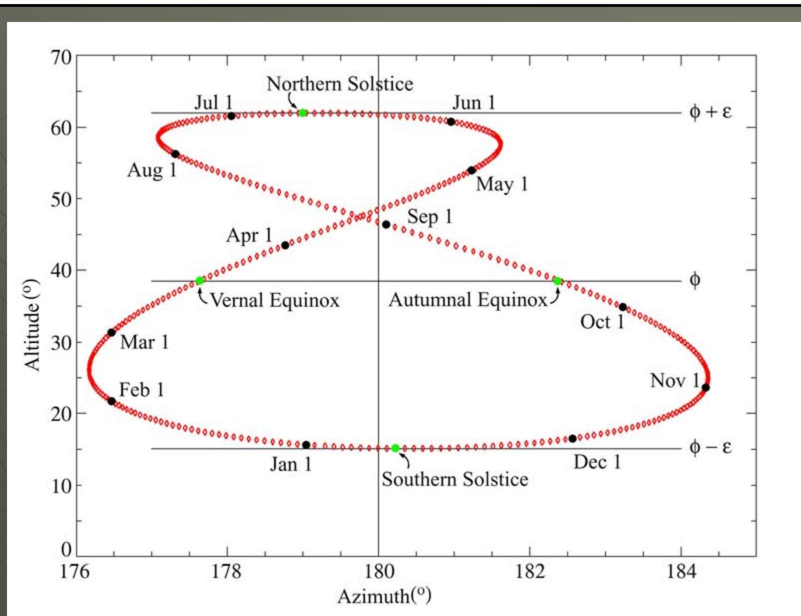
ANALEMMA !

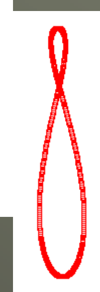


The difference between the mean solar time and the apparent solar time is known as the "equation of time"



The "equation of time" provides the East-West component of the Analemma graph. The North-South component of the Analemma corresponds to the seasonal apparent displacements of the Sun.





Analemma as seen at noon from Greenwich. X-axis expanded x10 ^ ^

Analemma downtown Parma

The Pew Sundial at Cornell

It consists of a semi-circular band with a graduated scale and a gnomon – a thin wire parallel to the polar axis of Earth and containing the center of curvature of the semi-circular band. The shadow of the gnomon on the band's scale marks the time with better than 1 min accuracy.

Sundials were the most accurate time measuring devices until modern times.

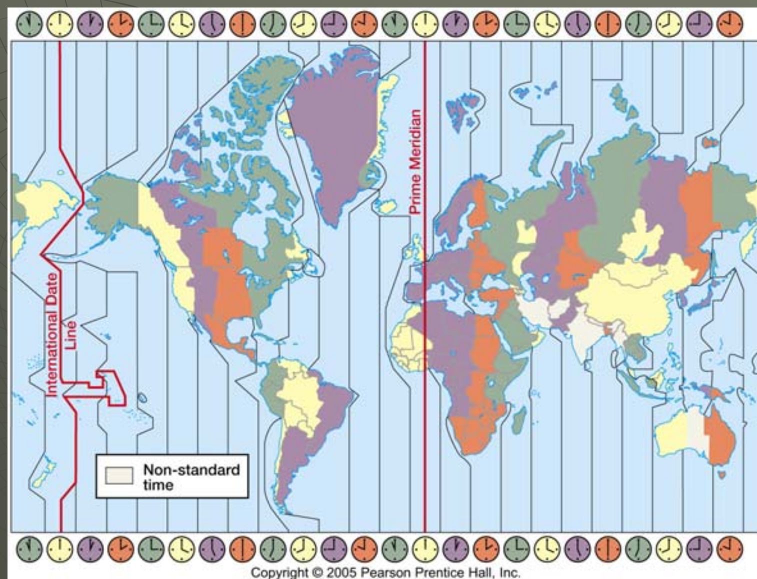
One of the most respected and popular "manuals" for the design and construction of sundials was written by astronomer and mathematician Giuseppe Biancani, born in Bologna in 1566.

His work was censored by the catholic church for containing description of the ideas of Galileo Galilei.

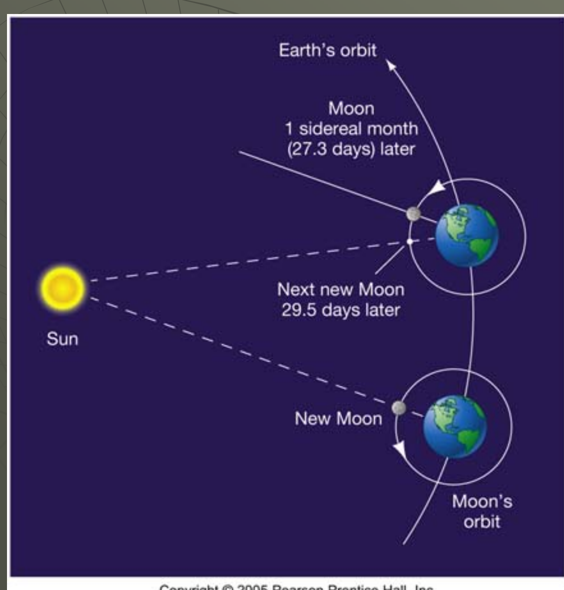
Civil time: Time agreed to by governments' fiat

- By convention, time is associated with terrestrial longitude, which is referenced to Greenwich, England
- Around the globe, there are 24 time zones.
- All clocks within a time zone keep time as if they were all located at the central longitude of the zone.
- The time zones are spaced approximately every 15° in longitude; the exact boundaries are set by governments, for convenience. Thus, solar noon (transit) can take place quite apart from 00 hours civil time.
- Daylight savings time was introduced as an energy saving convenience.

Time zones of the world



What is a "month"?...

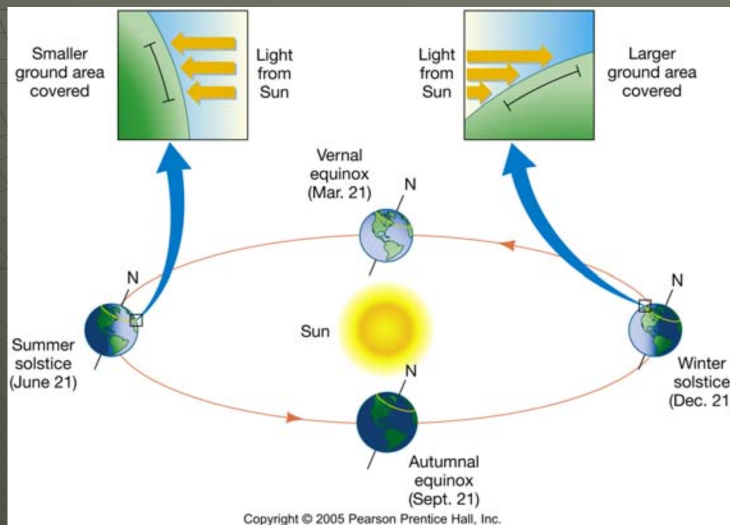


While the Moon revolves around the Earth once every 27.3 days, the Earth has moved part of the way on its orbit around the Sun.

Thus, in order for two successive "New" phases to occur, the Moon has to go an extra fraction of an orbit around Earth.

Hence, Moon phases repeat with a period of 29.5 days (synodic period).

What is a "year"?



Seasons result from the fact that the axis of Earth's rotation and that of its revolution about the Sun are inclined wrt each other by 23deg 27'. A period that matches exactly the repetition of the seasons is called a "tropical year".

On Making Calendars

Problem in attempts to build an efficient calendar:

➔ The ratios between the duration of year, month, day and precession period are not integer numbers
e.g.

1 sidereal year = 365.245366 solar days

1 synodic month = 29.53069 solar days

So either we make calendar years not last an integer number of days (very impractical) or make the duration of the calendar year change from one year to the next.

The year is 365.245366 days long. Suppose your calendar rounds off duration to the nearest integer number of days, e.g. – as the Egyptians did, adopt a calendar year of 365 days:

- After the first year, the calendar will be off by about one quarter of a day,
- After ten years, calendar will be off by 4 days
- After one century, calendar will be off by 40 days, a very noticeable fraction of a full season

➔Some ancient civilizations kept calendar with reference to the Moon. The 12 months of our calendar are a remnant of that practice

➔ Because the synodic month is not an integer number of days, but the sum of two months is very near to an integer (59 days), earlier "lunisolar" calendars had months of alternating duration of 29 and 30 solar days.

➔12 synodic months of 29.5 days each add up to 354 days, about 11 days short of a full year; 13 synodic months are about 19 days too long. The Babylonians, for example, adopted a basic cycle of 235 lunar months, which includes very closely to 7 yrs of 12 months and 12 yrs of 13 months

The Babylonian calendar was very accurate; their recorded events can be dated to within a day.

The Greeks kept calendar poorly – note Thucydides' troubles in reporting the Peloponnesian Wars.

The Egyptian Calendar

From an early date, the ancient Egyptians adopted a calendar consisting of 12 months of 30 days each, plus 5 additional days. There were no leap years or intercalations.

With a duration of 365 solar days, it was about a quarter of a day too short. Every 4 years, it lagged by 1 day. It "lapped" around after 1460 years. In spite of the obvious slide, attempts by the rulers to update the calendar to account for the mismatch were not supported by religious leaders and the populace.

Julian Calendar-1

Up to the last century BCE – and of the Republic – Romans used a lunisolar calendar of 12 months (of variable , but average duration of 29.5 solar days, that of a synodic month). The total length of the calendar year was then 355 days, about 10 and a quarter days too short.

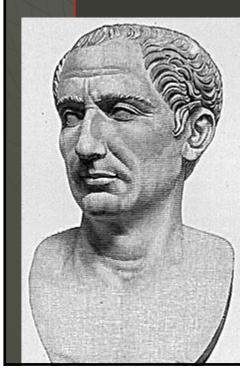
This would accumulate to substantive mismatch with the seasons in just a few years.

Aware of this problem, roughly every other year, they would add an "intercalary" month, called *intercalaris, or Mercedonius,* of 27 or 28 days. On the average, their calendar year duration was 366 days, about ¾ of a day too long. A year of 13 months was referred to as an "embolistic year".

The officer in charge of managing the calendar had the title of *Pontifex Maximus..*

Julian Calendar-2

On the year 68 BCE, Julius Cesar was appointed Pont
With the "technical" support of Sosigenes, a Greek ast
Alexandria, he adopted a purely solar calendar, which
days spread across the older system's months, plus an
day" to be added to February every 4 years, for an a
of the Julian year of 365.25 solar days.



ndar began to operate in 45 BCE, referr
mplementation of the required changes, especially by
Cesar's assassination in 44 BCE, was poor, and
to intervene to correct errors.

death, the Senate honored his memory by renaming
Quintilis after Cesar, hence July.

Ancient civilizations with "substandard" calendars (or complex ones not repeating exactly from one year to the next) used other means to pin down the precise "season time": e.g. the heliacal rising of one or more bright star.

The heliacal rising of a star occurs when the star is first seen rising above the eastern horizon just before sunrise, after months of invisibility (up during the day).

Egyptians monitored the heliacal rising of Sirius and of 36 bright stars, spaced about 10deg from each other, for that purpose and to tell time at night.

Julian Calendar Month Names

-The Roman year started in March, and most of the names were plain ordinals; some remain to date:
➔ September, October, November, December

The name of the 5th month (Quintilis), was changed to honor Cesar ➔ hence July

His successor, Augustus Octavianus named the sixth month after himself ➔ hence August

Since July was a month of 31 days and August had 30, Augustus took a day off February and tagged it into August, not to be outdone by Cesar. Also note *ferragosto = feriae augustae*

Julian Calendar Month Names

January	after *Janus*, Roman god of beginnings and endings
February	after *Februa*, a Roman festival of purification
March	after the god of war, Mars
April	month of aperture, of sprouting vegetation
May	after *Maia*, Earth godess of growth
June	after *Juno*, *queen* of the gods
July	month of Julius Cesar, reformer of the calendar
August	month of Augustus Octavianus
September	plain ordinal [surprisingly claimed by no one]
October	plain ordinal "
November	plain ordinal "
December	plain ordinal "

… but it's still 11 minutes too long. Excess accumulated at this rate would add to 1 day every 130 years: by year 1500 seasons and calendar out of phase by more than 10 days.

Days of the week

There is no astronomical periodicity associated with the duration of the week. The astronomical connection is with the fact that in ancient times 7 "planets" were known: the Sun, the Moon, Mercury, Venus, Mars, Jupiter and Saturn. The name of the days of the week still reflect the "planetary" association, both in the Romance and Norse-influenced languages:

Monday	Moon (=Luna) day, Lunedi, Lunes
Tuesday	Tiu (=Mars) day, Martedi, Martes
Wednesday	Woden (=Mercury) day, Mercoledi, Miercoles
Thursday	Thor (=Jupiter, Giove) day, Giovedi, Jueves
Friday	Freya (=Venus=Venere) day, Venerdi, Viernes
Saturday	Saturn day
Sunday	Sun day

Gregorian Calendar

So, what do we do with the fact that a year of 365.25 solar days is 11 minutes too long?

In order to correct the accumulating mismatch between calendar and seasons, Pope Gregory XIII introduced a new modification to the calendar in 1582:

➔The key modification was to skip the leap year occurring on century years, unless they are also divisible by 400; i.e. 1600 and 2000 were leap years, but 1700, 1800, 1900 were not

Gregorian Calendar

The average Gregorian calendar year is only 38 sec off the duration of the tropical year. It would take 2274 years for that difference to accumulate up to 1 day.

Modern revisions of the Gregorian calendar, by making the years 4000, 8000, 12000, etc. *non-leap*, produce an average year such that the accumulated error will only add up to 1 day in 20,000 years.

Pope Gregory the XIII – leader of the calendar reform still used today – was born Ugo Boncompagni in Bologna in 1502. Upon becoming Pope in 1572, he responded to the urging of Luigi Giglio – astronomer and physician – and Christopher Clavius – Jesuit astronomer – instituting the new system in October 1582. The transition was simple: the day following October 4 was called October 15.

Catholic countries immediately adopted the new calendar. However, the Protestant North and Orthodox East refused to go along for centuries. Denmark did not change until 1700, Great Britain not until 1732, Russia not until 1918; the Russian Orthodox Church still uses the Julian calendar.

This gave rise to confusion. E.g., the Russian "October (per Julian calendar) Revolution" took place in November (per Gregorian).

The Birthdate of George Washington

The Washington Bible preserved in Mt Vernon reads:

"George Washington, Son to Augustine and Mary his Wife was Born ye 11th Day of February 1731/2 about 10 in the Morning & was Baptiz'd on the 30th of April following."

However, historically his birthday is celebrated on February 22nd.

* In 1732, Virginia was still a British colony, thus using the Julian calendar (until 1752). The day of February 11th in the Julian calendar is also February 22nd in the Gregorian one.

* On the meaning of 1731/2: the initial date of the year was not universally agreed. The most common practices were December 25th, January 1st, March 1st and March 25th. The "style" used in Great Britain at the time was March 25th, while most of Europe already used January 1st. Hence "1731/2" meant "in the year 1731, March 25th style, and in the year 1732, January 1st style".