Eclipses and so Forth

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Goals

- Better understand Eclipses and how to predict them

- Better understand Solar System dynamics

History of Eclipses

- Ancient Greek noun ἔκλειψις (ékleipsis) - "the downfall"!

- 2300BC two Chinese astrologers behead for failing to predict and eclipse

- Herodotus claimed around 600BC that Thales predicted a solar eclipse
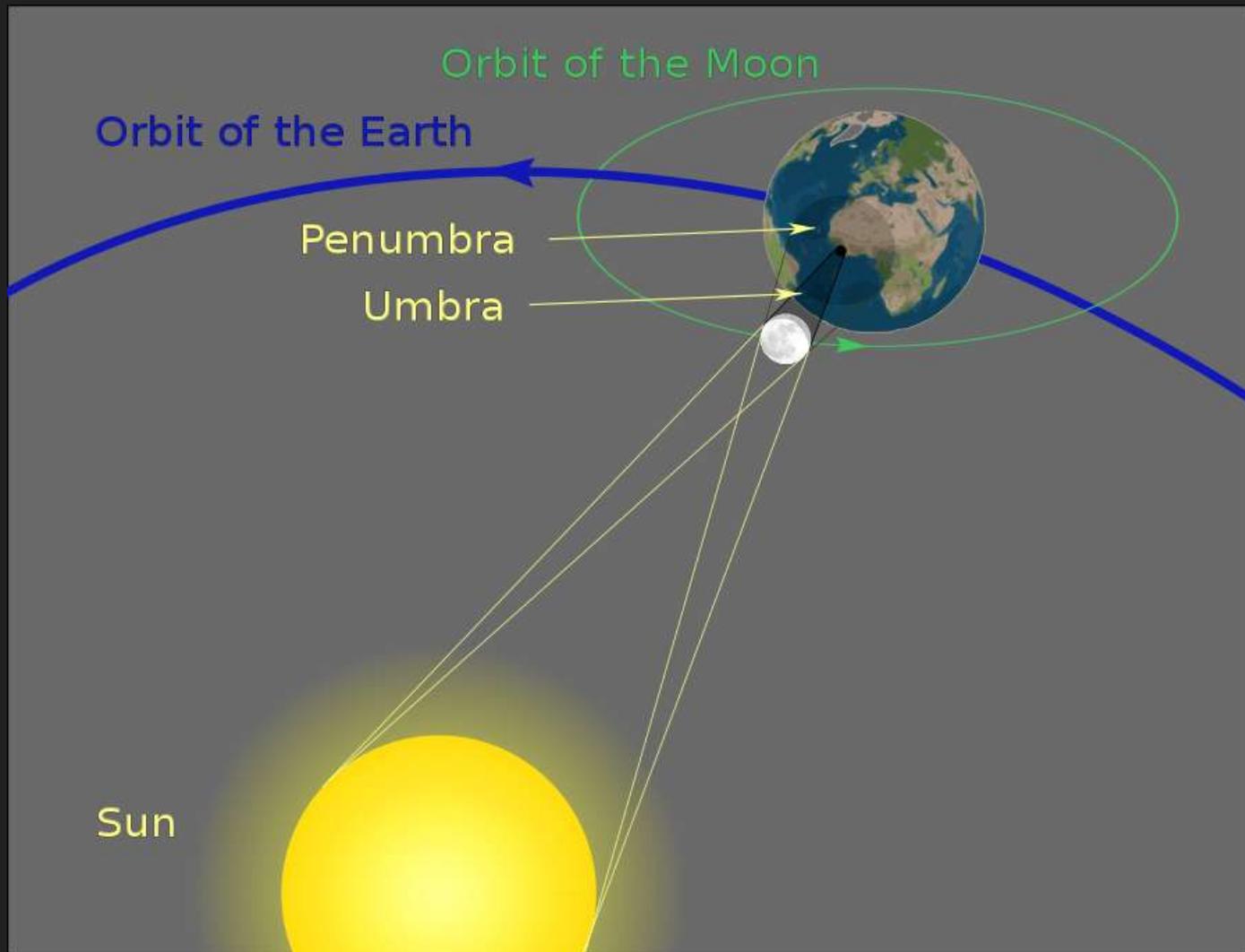
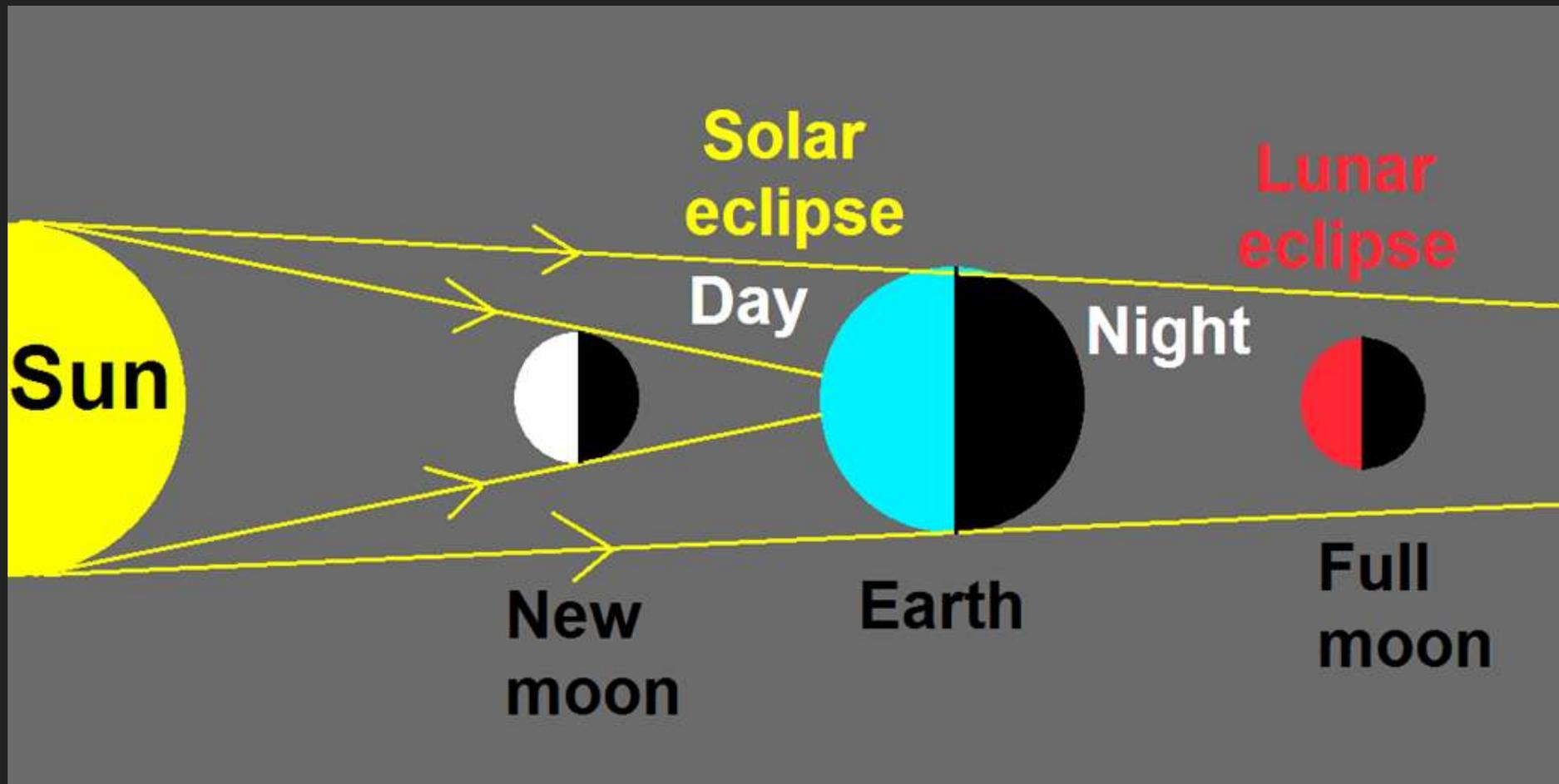# Antikythera Mechanism

Antikythera Mechanism
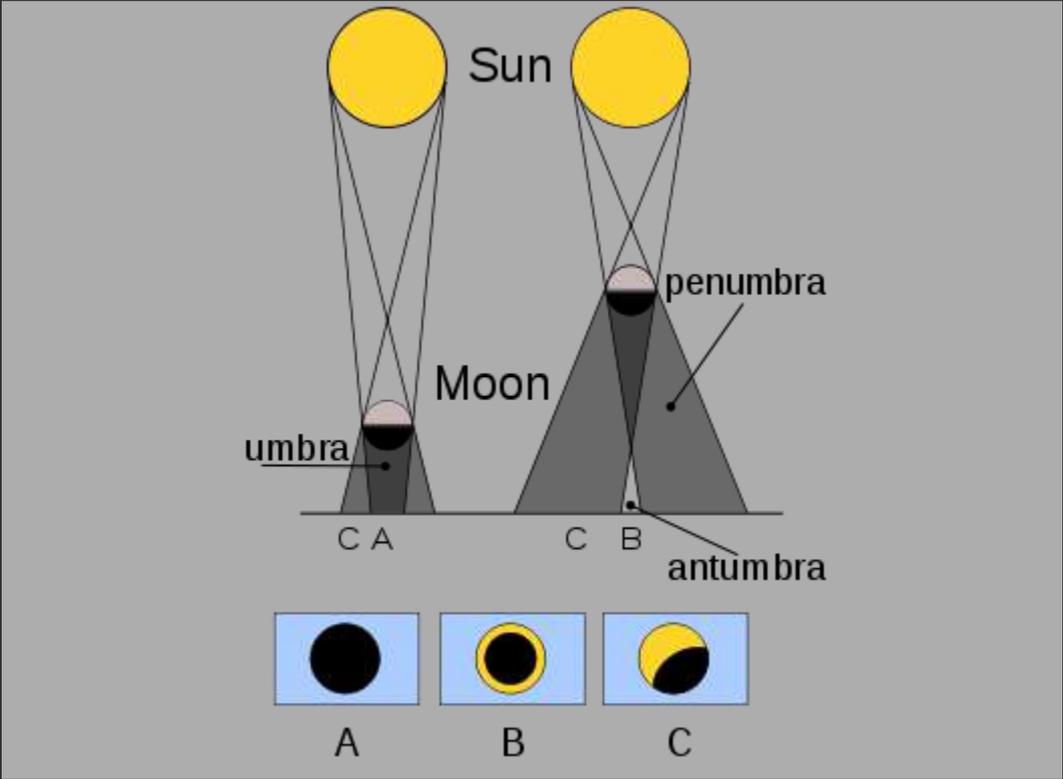
History of Eclipses

- February 29, 1504 - Columbus predicts lunar eclipse in Jamaica

- September 22, 1596 - Mateo Ricci predicts solar eclipse in China

- 1715 - Halley pushed back against contemporaries saying the eclipse: "foreshews the Destruction of the Fruits of the Earth, the Scarcity of Corn and Fruit, and a Danger of a Raging Pestilence."
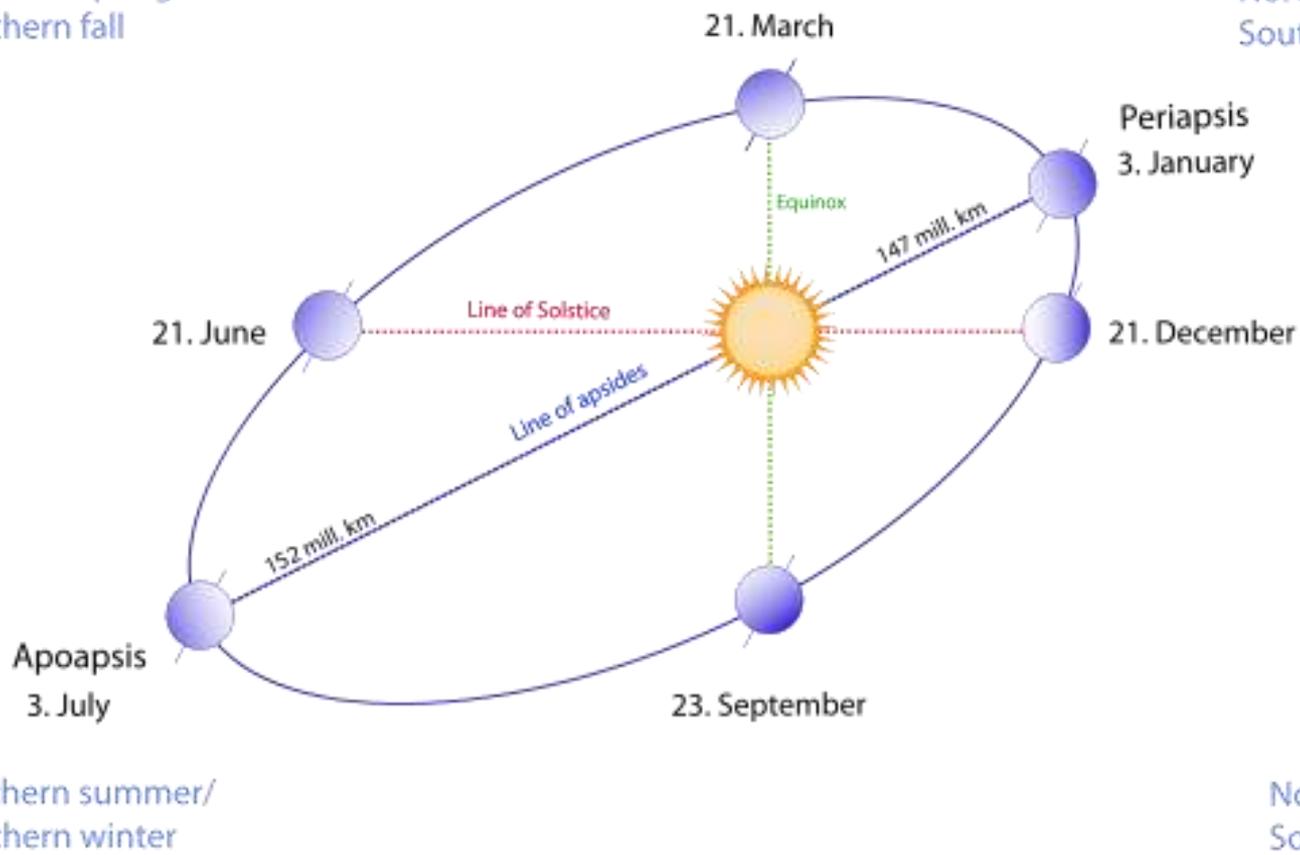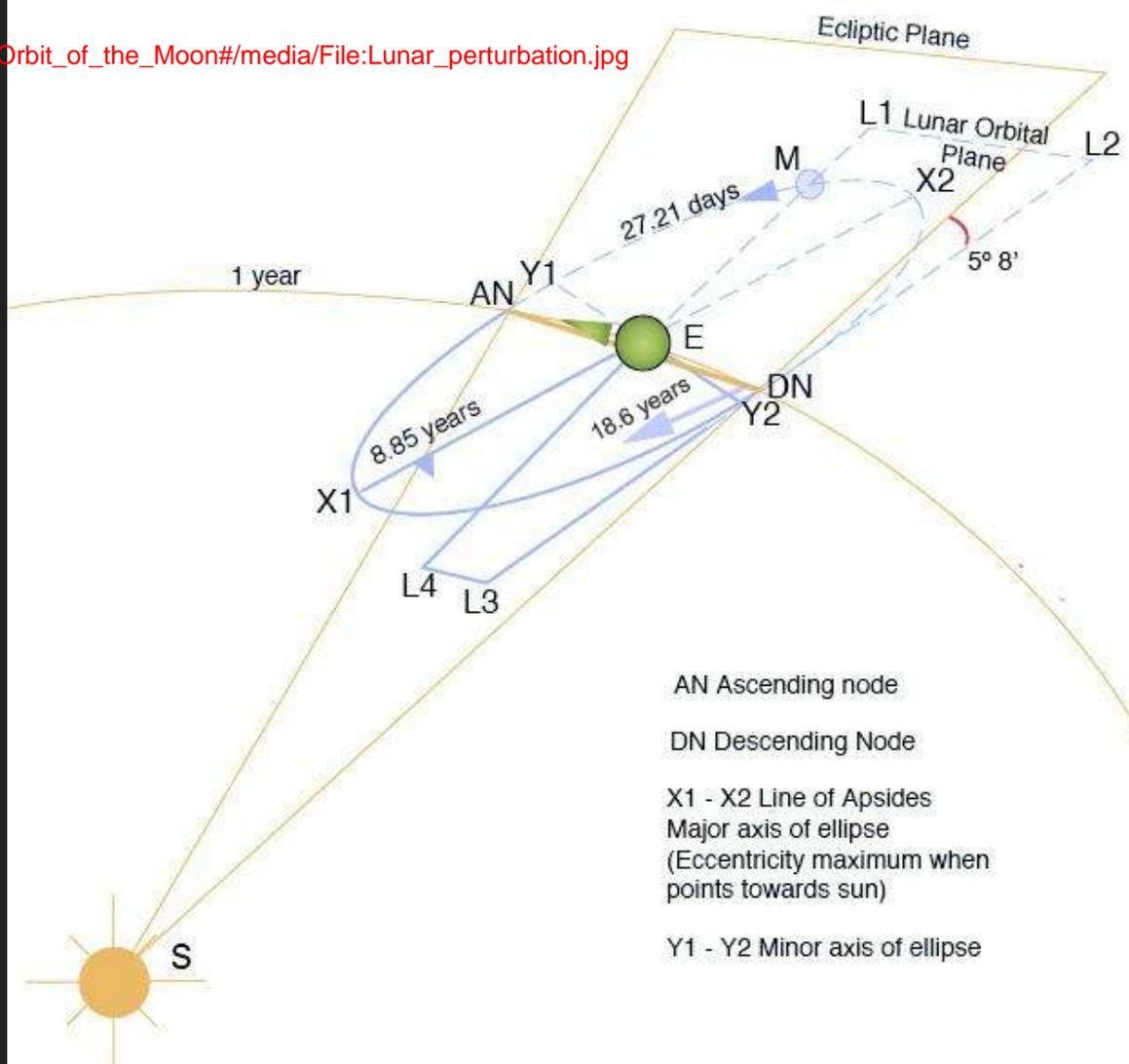
Orbit of the Moon

Orbit of the Earth

Penumbra

Umbra

Sun

https://upload.wikimedia.org/wikipedia/commons/0/0f/Lunar_eclipse_April_15_2014_California_Alfredo_Garcia_Jr1.jpg

Partial Eclipses

Ecliptic Plane

L1 Lunar Orbital Plane

L2

M

X2

27.21 days

5° 8'

1 year

AN Y1

E

DN
Y2

8.85 years

18.6 years

X1

L4 L3

S

AN Ascending node

DN Descending Node

X1 - X2 Line of Apsides
Major axis of ellipse
(Eccentricity maximum when
points towards sun)

Y1 - Y2 Minor axis of ellipse

Routes to Prediction

- Saros Cycle

  - 6,585.3 days between similar geometry

  - x3 for same location

- Other Formulas

- Simplified Model

- Leverage NASA Data!

JPL Ephemerides

- Data Online

  - ftp://ssd.jpl.nasa.gov/pub/eph/

- Planets

- Satellites

- Small Bodies

- Spacecraft

JPL - Development Ephemerides

- Caltech - Jet Propulsion Lab

- Dates at least to the 1960s

- DE(number)

- DE69 - 1969 replaced then common DE19

- Originally distributed on magnetic tape

- Geocentric coordinates of the Moon

- DE402 - 1995

- DE432 - April 2014 (Updated for New Horizons)

Ephemerides for Planets

- ftp://ssd.jpl.nasa.gov/pub/eph/planets/

- Position, Velocity, Acceleration

- Numerical Integration minimizing error against multiple data

- Takes relativistic effects into account

- Encoded as Chebyshev Polynomials

- Barycentric rectangular coordinates of Sun + 9 "planets"

Coordinate System

- Equatorial Coordinates

- X - Towards Vernal Equinox

- Y - 6h RA, 0 DEC

- Z - North Celestial Pole

- Centered on Solar System center of mass, excluding Earth
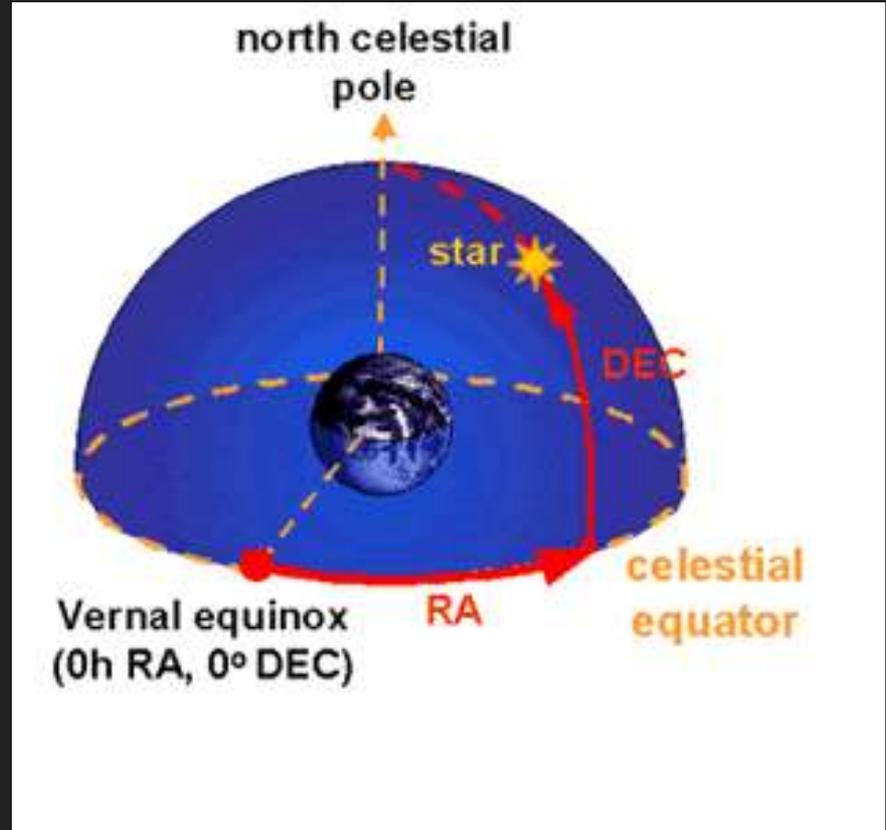
Julian Day

- Day 0:

  - January 1, 4713 BC, proleptic Julian calendar

  - November 24, 4714 BC

- Julian Period proposed by Joseph Scaliger, a classical scholar, in 1583

- Greenwich -> Alexandria

- Fractional part for portion of a day

- Many variations

Chebyshev Polynomials

$T_0(x) = 1$
$T_1(x) = 2x$
$T_n(x) = 2xT_{n-1}(x) - T_{n-2}(x)$

- Useful for good data fit

- Avoids ringing

- Easy to find derivatives for velocity + acceleration

- Easy to integrate over time

Format

- ASCII Text

- File with headers in "Groups"

- Separate data files per century

- Each Time sample prefixed with index and length

- Series of doubles

- Fortran +1.2345D+123 convention

Format

- Start time in Julian Days

- End time in Julian Days

- Mercury

  - N x Segments

    - M x Coefficients for X

    - M x Coefficients for Y

    - M x Coefficients for Z

- Venus

Fortran Code

- Converter from ASCII to binary (for lookup speed)

- Shockingly old and new (VAXes + updated in 2016)

- Uses number convention 1-9 for planets, 10 for Moon, 11 for Sun

- Meant to be library for other programs

Applying the Data

- Find "record" containing time period of interest

  - Uniform layout or binary search

- Find the start offset containing the body of interest

- Find the uniform sub-segment of interest

- Scale time to -1 to 1 for this sub-segment

- For each component

  - Calculate Chebyshev terms

 - Multiply by coefficients and tally

Visualization

- Show world map

- Show markers for celestial bodies (direction to them)

- Keys to move time

- Print time + date to console

Graphics + Text

- Use gforth

- Use xlib bindings and grf library from simplefont project

  - Get keystrokes + mouse events

  - Draw screen by filling buffer with 32-bit pixel values

- Use console for text

Equidistant Cylindrical Projection

- Marinus of Tyre (Syria) - 120AD

- Greek Geographer, credited by Ptolemy

- Latitude and Longitude map linearly
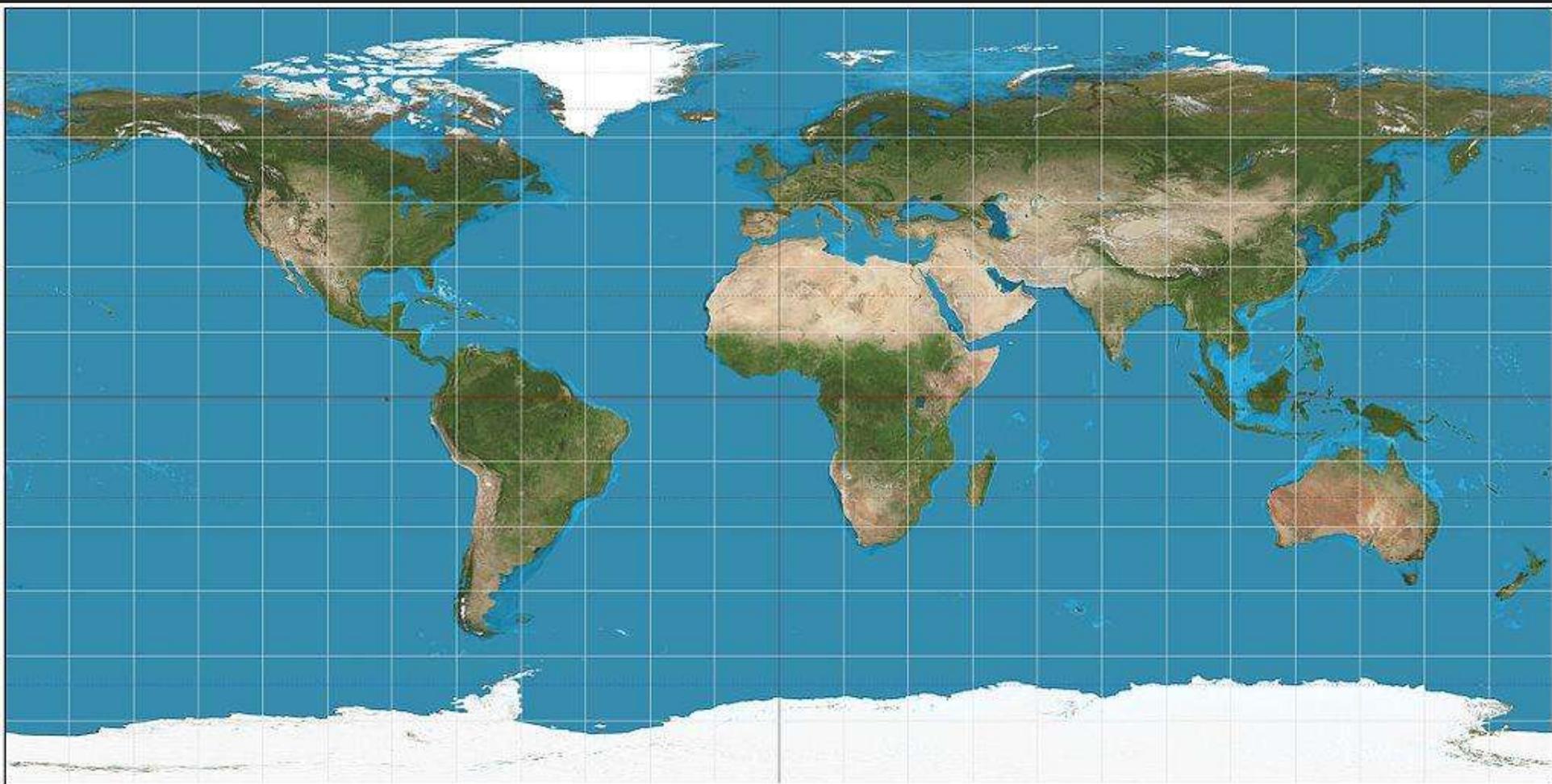
Conversion

- ImageMagick

- Convert to BGRA 4-bytes per pixel

Vectors

```
vector <name>
v+ v-
Vdot vdup
Vscale vunit vdist
v@ v!
```

Rays + Spheres

```
ray ( target origin -- )
sphere ( center radius -- )
intersect ( -- points )
hit ( -- closest )
```

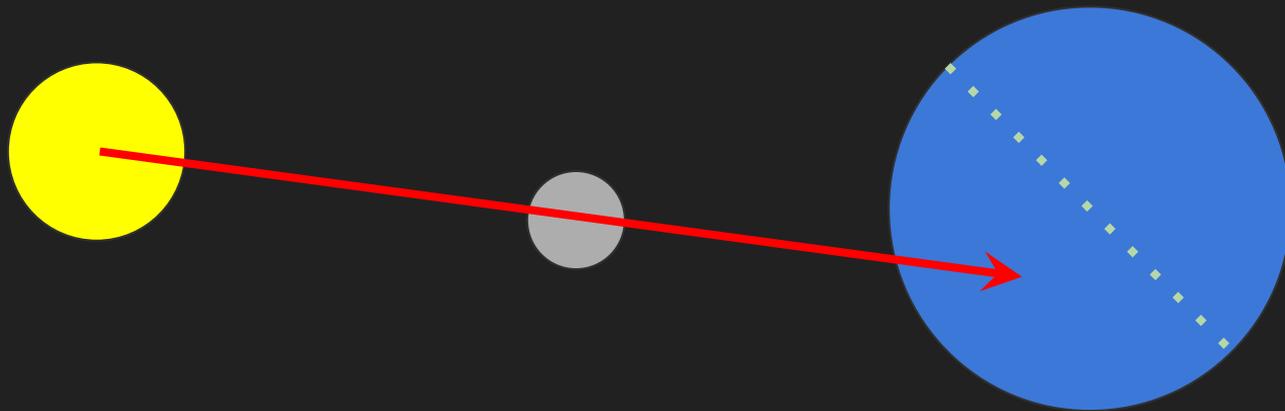# Ray Sphere Intersection
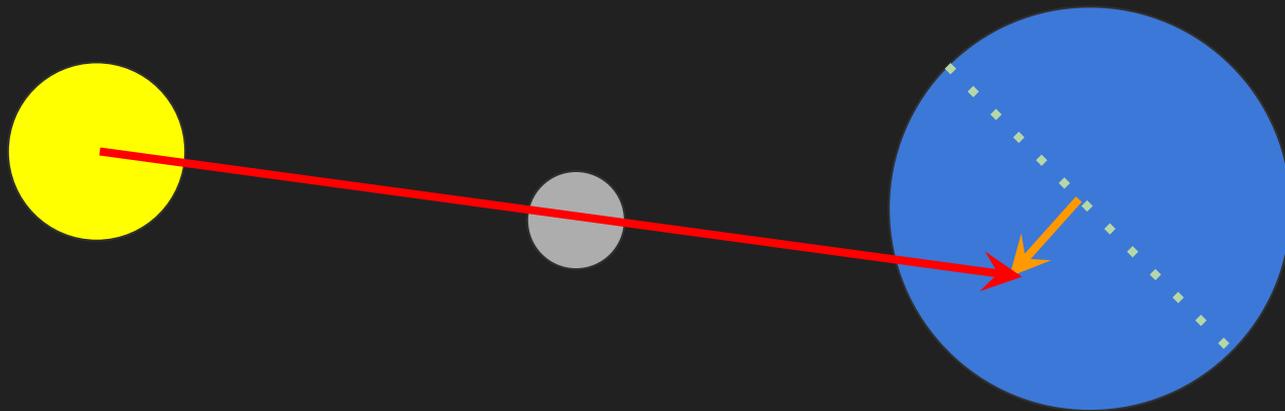
$x = p_x t + q_x$

$y = p_y t + q_y$

$z = p_z t + q_z$

$x^2 + y^2 + z^2 = r^2$

$(p_x^2 + p_y^2 + p_z^2) t^2 + 2(p_x q_x + p_y q_y + p_z q_z)t + (q_x^2 + q_y^2 + q_z^2 - r^2) = 0$

Detecting an Eclipse

Detecting an Eclipse

Nuances

- Radius of Earth (6,371 km) required

- Same approach applies to lunar eclipses

- Partial can be trickier (as this requires taking solar + lunar radius into account)

- Nutations of the Earth

Size of the Code

```
 58 convert.fs
139 eclipse.fs
100 eph.fs
206 grf.fs
 39 julian.fs
 28 math.fs
 27 ray.fs
 38 vector.fs
 88 xlib.fs
723 total
```

May 3, 1715
Haley's Eclipse

Questions?