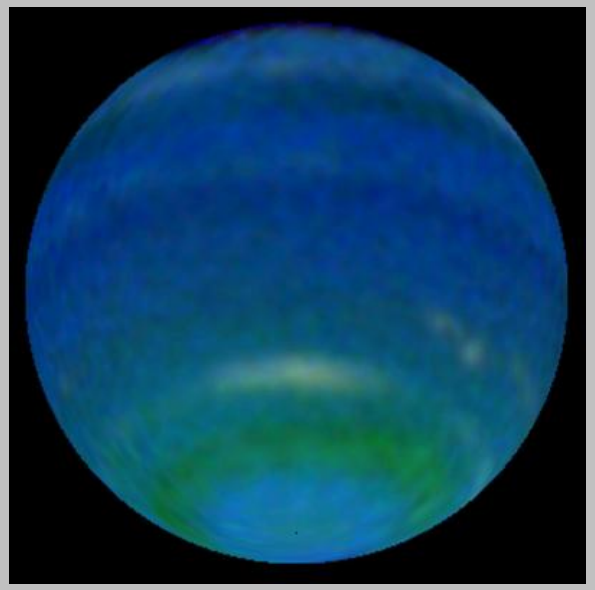
Neptune and Vulcan

Dark matter and modified Newtonian dynamics
in the Solar System



Dr. Rob Knop aka Prospero Frobozz
Meta-Institute of Computational Astronomy (MICA)
www.mica-vw.org
Second Life, 2009-04-18

Dark Matter

The substance that makes up ~30% of the energy density of the Universe. It is what holds together galaxies and galaxy clusters. It has been detected through the kinematics of galaxies and galaxy clusters, via gravitational lensing, and is needed to explain several cosmological observations.

dark matter

Something which has not been detected directly, but rather has only been detected due to its gravitational influence on other things we can detect directly.

Uranus

- Discovered 1782 by William Herschel
- First planet discovered with a telescope
- First planet beyond the classical six (*)

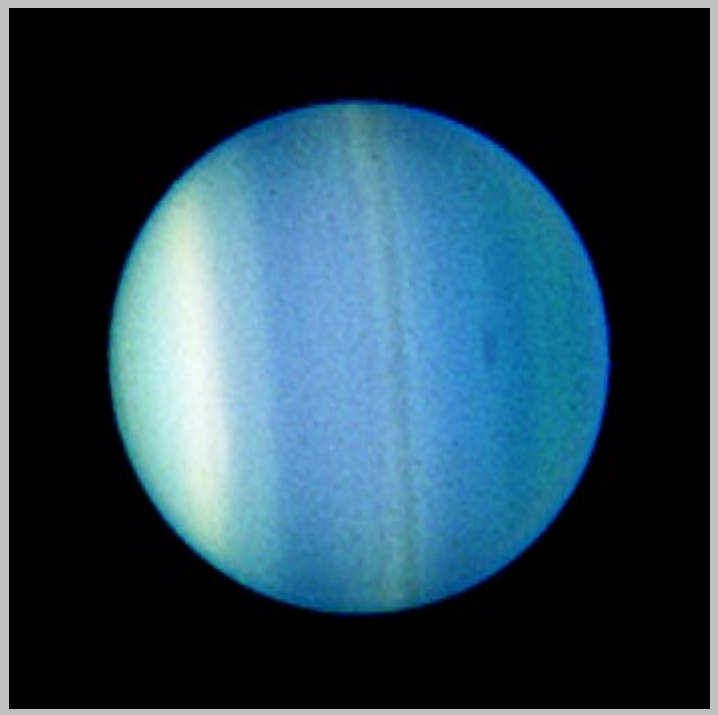


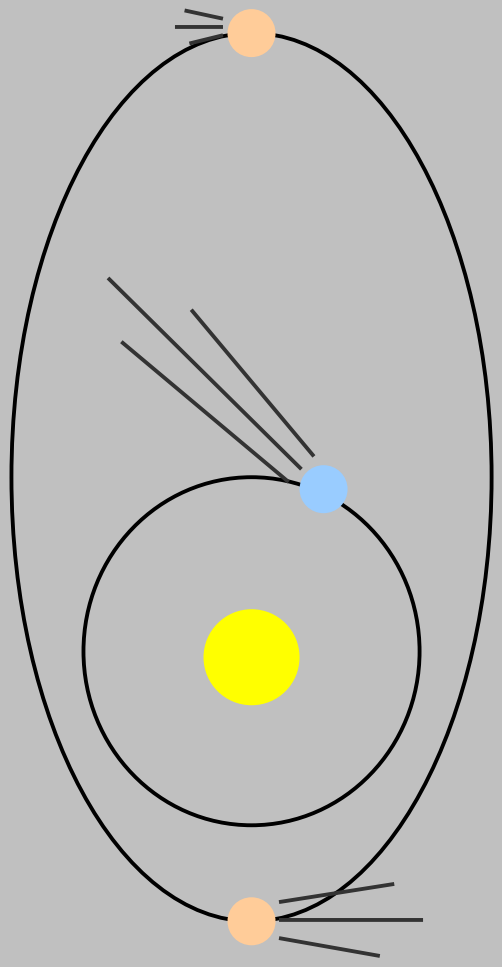
Image: http://hubblesite.org/gallery/album/solar_system/pr2006047b/

Describing Orbits in the Solar System:

Kepler's Laws

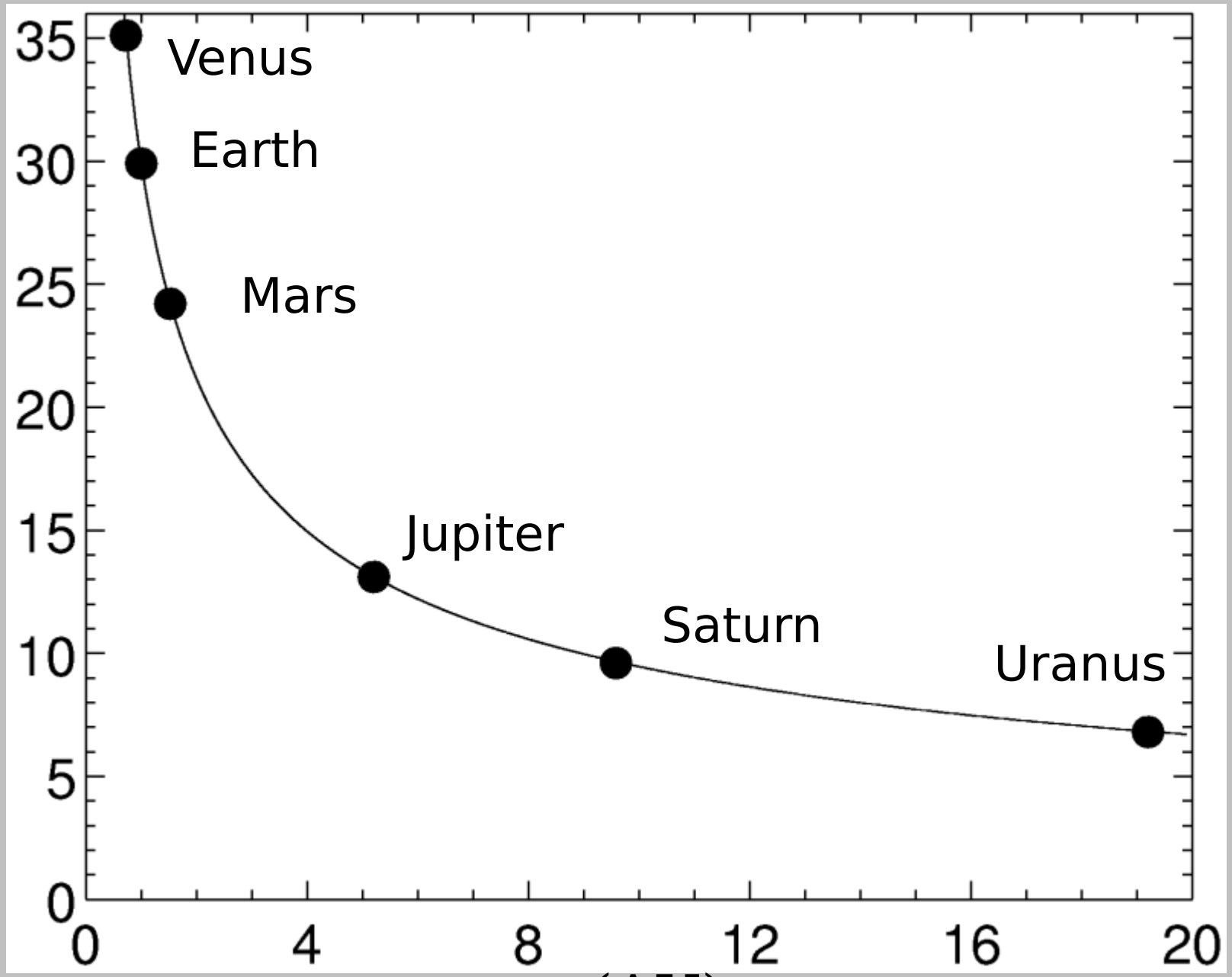
1605-1621

1. Planets orbit the Sun in ellipses with the Sun at one focus.
2. Planets move faster when closer to the Sun than when farther from the Sun (mathematical relationship).
3. Larger orbits have longer periods (mathematical relationship).



Keplerian Orbits

Observed & Kepler's Third Law



Newtons Laws of Motion

and

Newton's Theory of Universal Gravitation

Describe how things move-- inertia, change of motion with force, action/reaction.

Provide a physics of gravity that explain Kepler's laws... but also show their weakness!

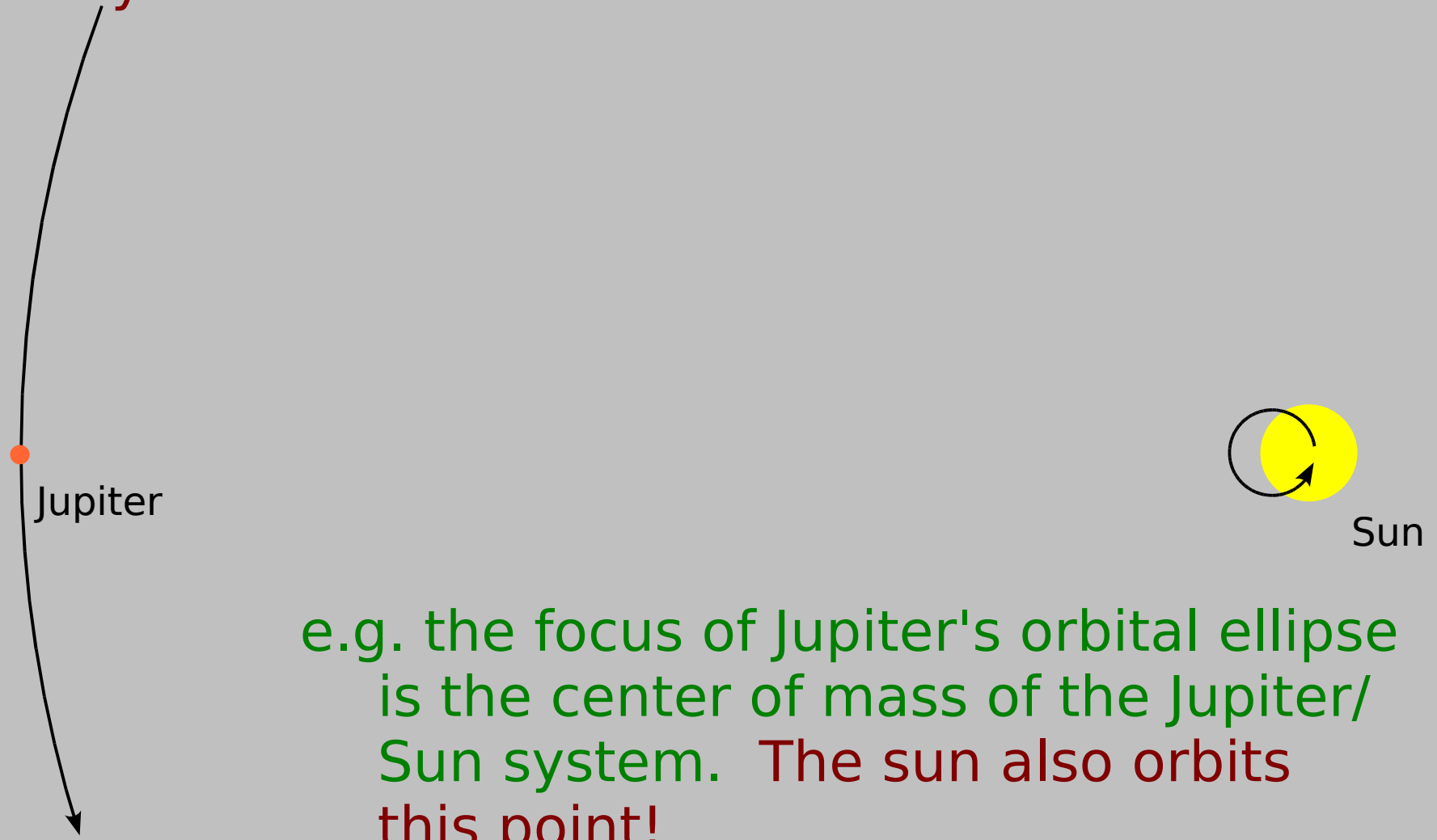
Kepler's laws can be mathematically derived from Newton's theory of motion and gravity!

$$F = m\,a$$

$$F = \frac{G\,M\,m}{d^2}$$

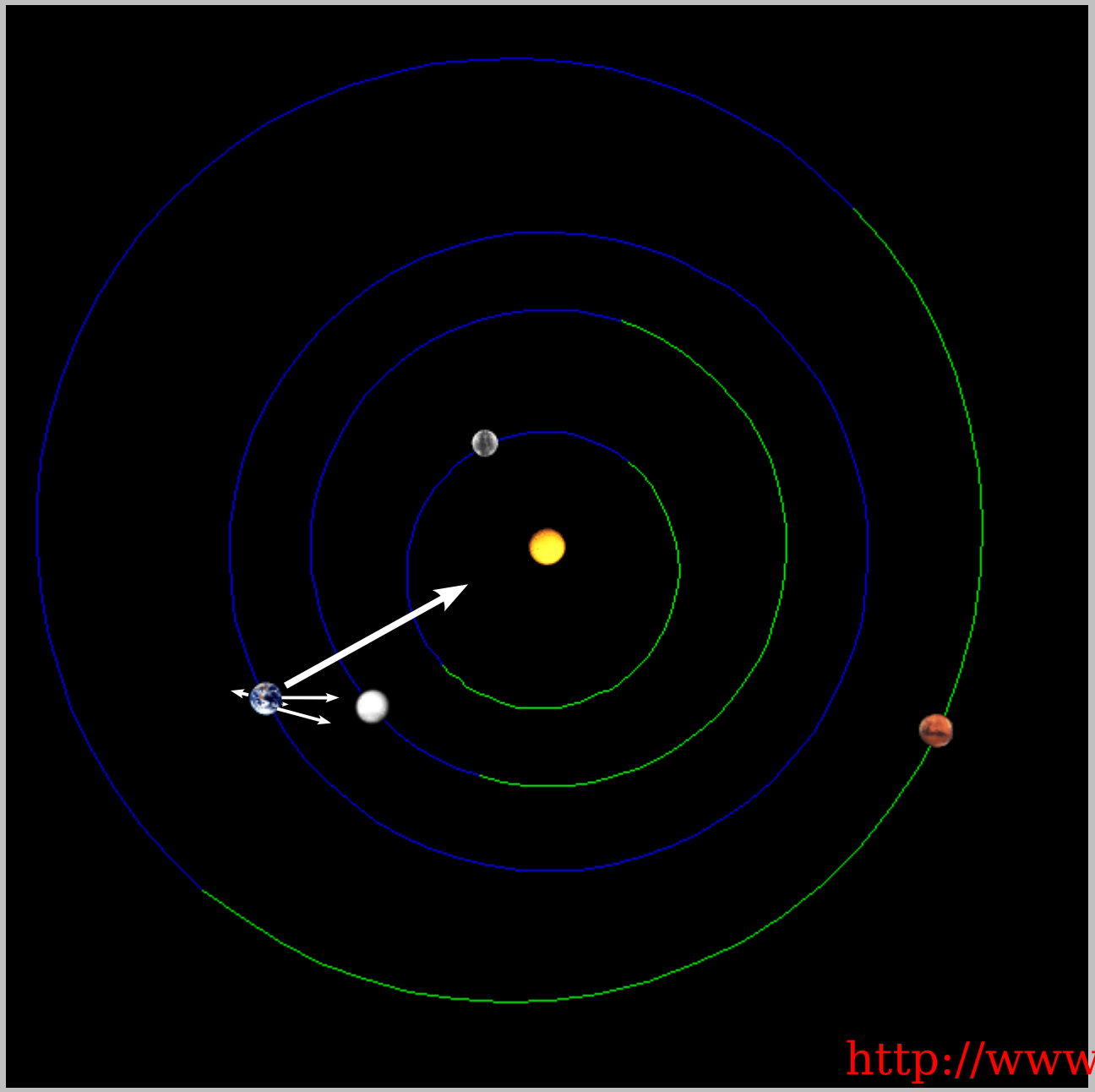
Kepler's Laws are the limit of Newton's Laws when the orbiting planets' masses are infinitesimal compared to the mass of the star.

This is only approximately true in our Solar System.



e.g. the focus of Jupiter's orbital ellipse is the center of mass of the Jupiter/ Sun system. The sun also orbits this point!

Newton's gravity also tells us that the planets' gravity affects *each other's* orbits!



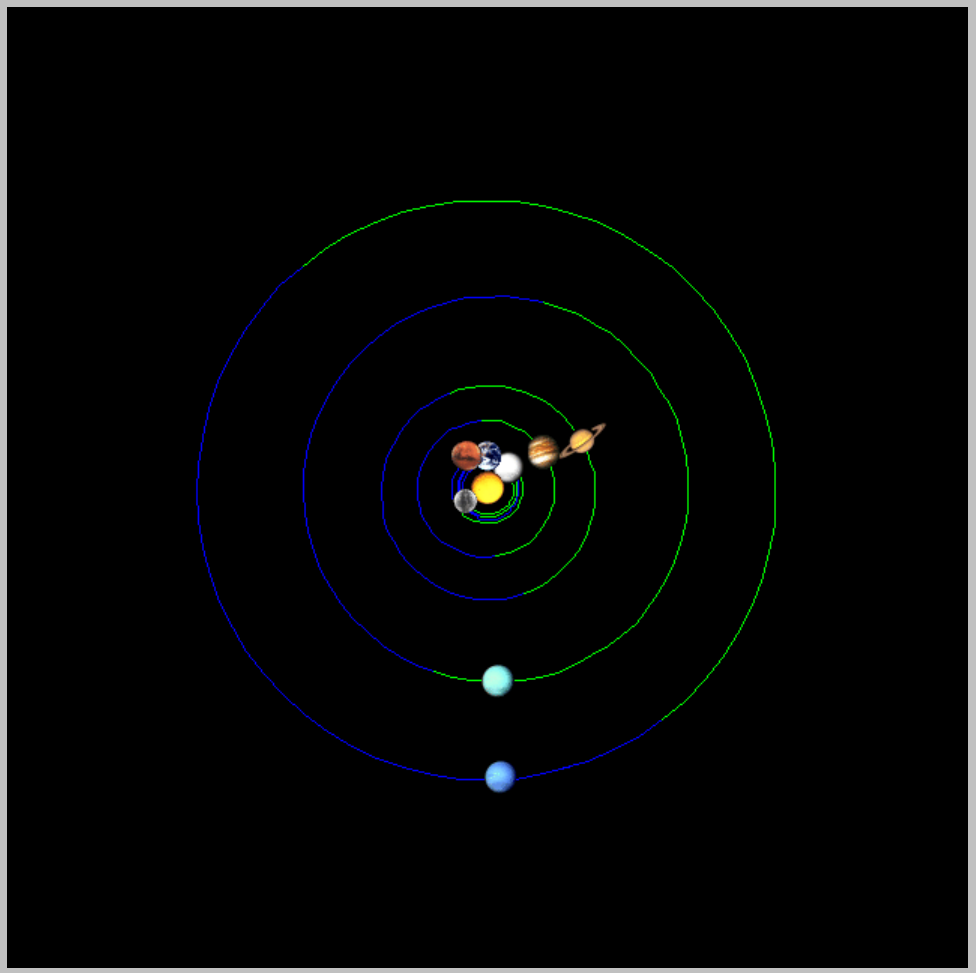
Sun's gravitational effect on Earth is ~30,000 times as strong as Jupiter's.

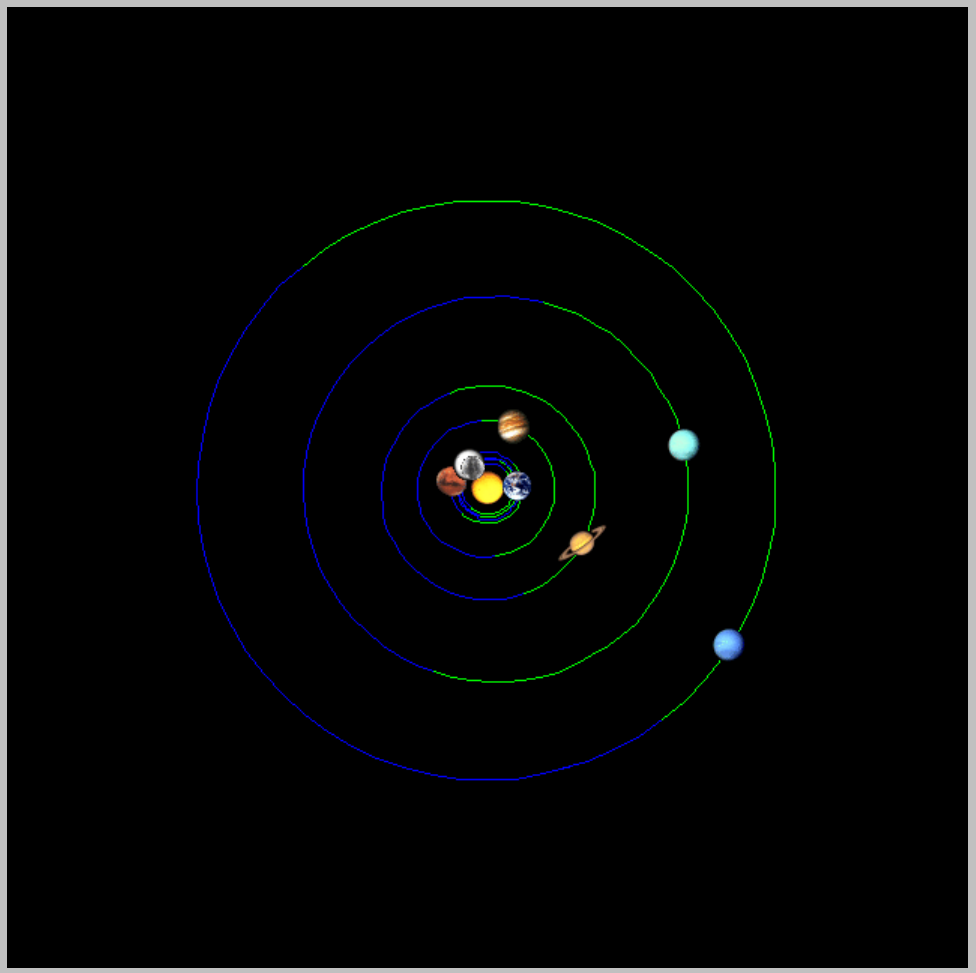
Planets at 10:20 SLT
2009/04/18

http://www.fourmilab.ch/cgi-bin/Solar

Uranus and Neptune

1821-1846





1821 – Alexis Boulvard calculates positions for Uranus, including the gravitational influence of the known planets. Uranus goes on to deviate a bit from those positions over the next several years, suggesting another planet out there.

Neptune – still unnamed at this point – can be said to have been discovered as dark matter....

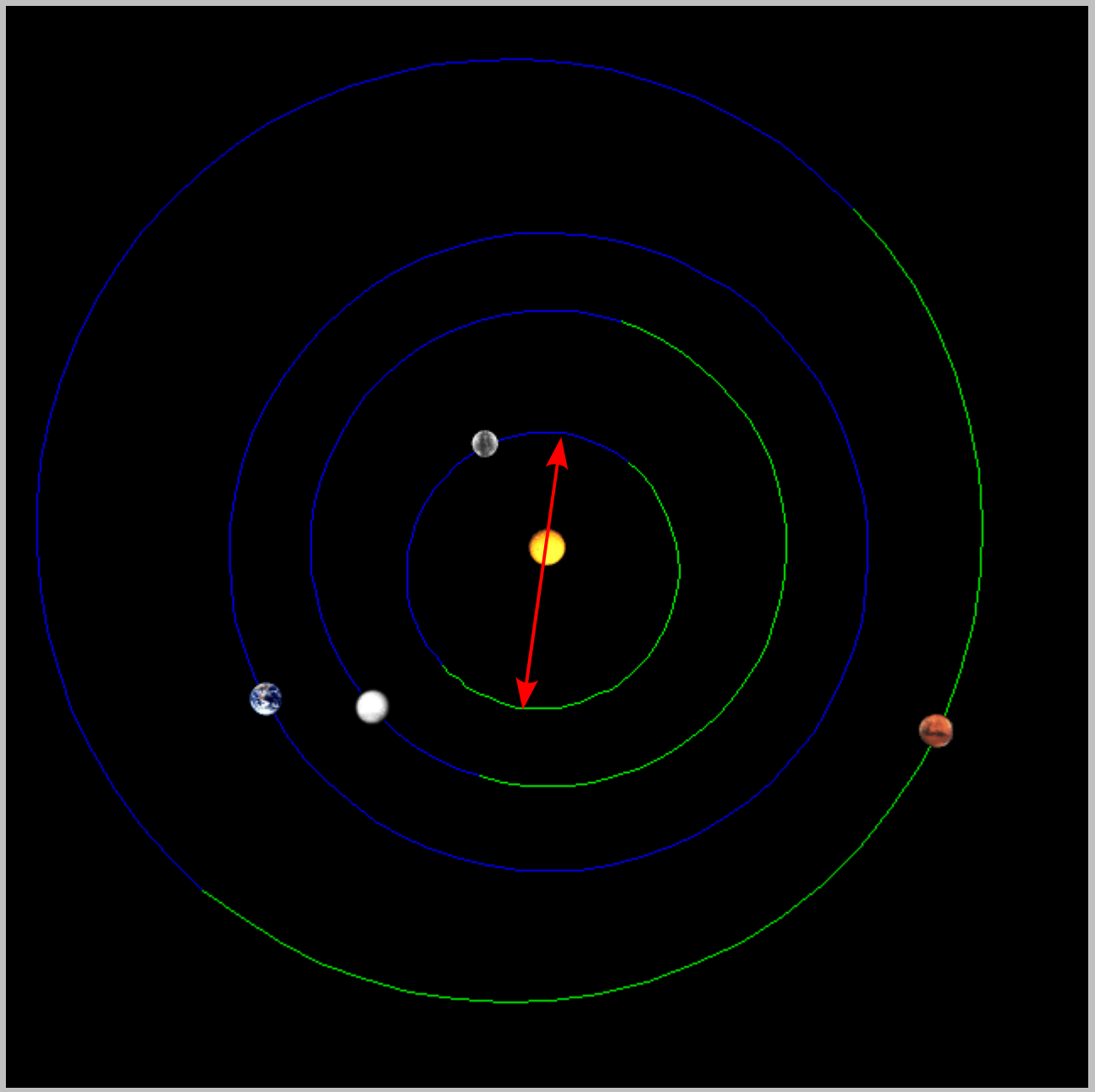
1821 – Alexis Boulvard calculates positions for Uranus, including the gravitational influence of the known planets. Uranus goes on to deviate a bit from those positions, suggesting another planet out there.

Neptune – still unnamed at this point – can be said to have been discovered as dark matter....

1845-1846 – John Couch Adams & Urbain Le Verrier calculate the position of Neptune based on Uranus' residuals.

1846 September 23 – Johan Gottfried Galle finds Neptune close to where Le Verrier predicted.

The Curious Case of Mercury's Orbital Precession

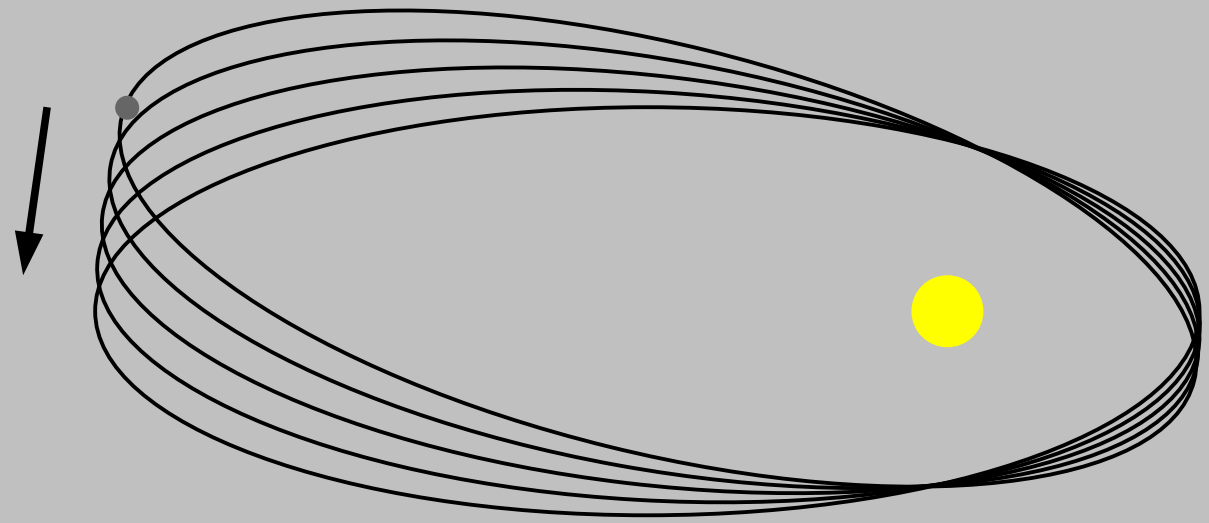


Indicated: the major axis of Mercury's orbit

Mercury's Orbit

First approximation : a constant ellipse dictated by the gravity of the Sun, described by Kepler's Laws.

Second approximation : a precessing ellipse, as a result of the gravitational interaction with the other planets (Venus, Earth, Jupiter, et al.).



Observed precession of Mercury : 1.38” per orbit
(0.00036 degrees)

Expected precession of Mercury : 1.28” per orbit

This is small, but an offset in Mercury's position of ~0.5” per (Earth) year could easily be observed after several years by 19th Century astronomers.

In particular, 1843 Mercury transit observations didn't match Le Verrier's predictions.

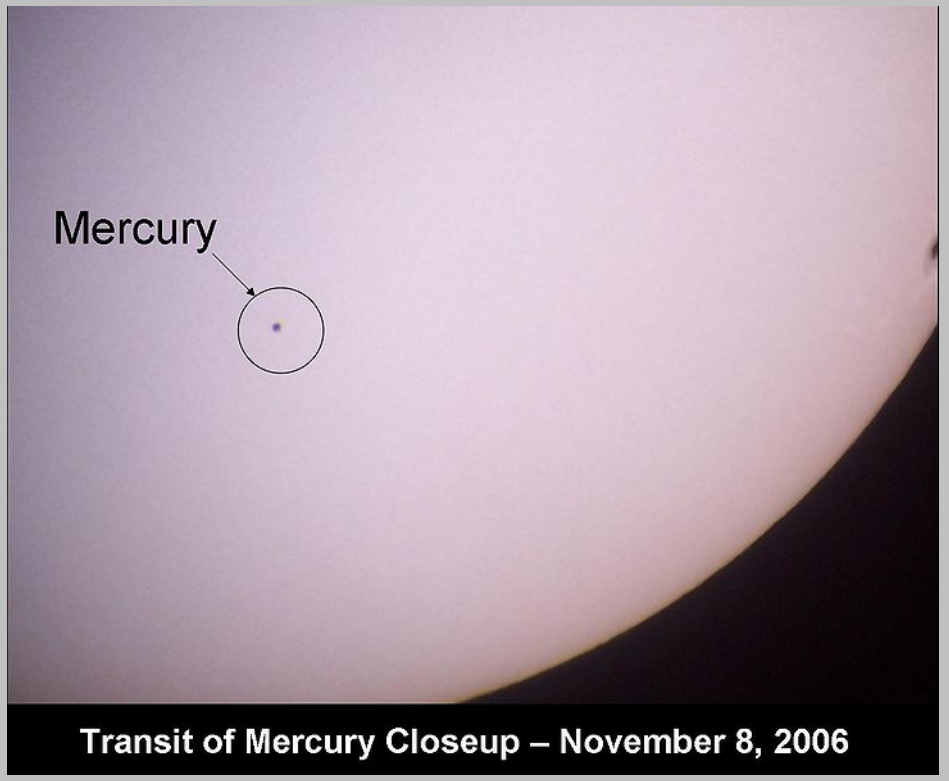


Photo: Eric S. Kounce

Vulcan – the dark matter that wasn't

- Proposed by Le Verrier in the 19th century to explain Mercury's anomalous precession.
- Several possible observations made over the next 50 years, none confirmed.
- Any sizeable planet (i.e. not just an asteroid) ruled out by the early 20th century....

So what's wrong with Mercury? Is it due to dark matter like today's Dark Matter – something we can't observe directly?

Or... is Newton's Gravity not right for Mercury?!?

Einstein, 1915 : General Relativity

- A completely different way to look at gravity. Instead of a force, it is the curvature of space-time.
- Massive objects cause spacetime near them to be curved.
- Objects move through spacetime along paths that are as close to straight lines as possible.
- The curvature of spacetime gives rise to the observed orbits.

Newton's Gravity is not wrong... it's incomplete.

Newton's Gravity is an increasingly good approximation to GR as long as:

- motion is not too close to the speed of light
- you are not too close to a very massive object

Note that even for Mercury (closest to the Sun), the relativistic corrections are less than 1/10 the corrections due to the gravity of the other planets!

The triumph of Newton's gravity : prediction of Neptune

The failure of Newton's gravity : there is no Vulcan.

Inspiration for this talk:
Is Pluto a Planet? by
David Weintraub