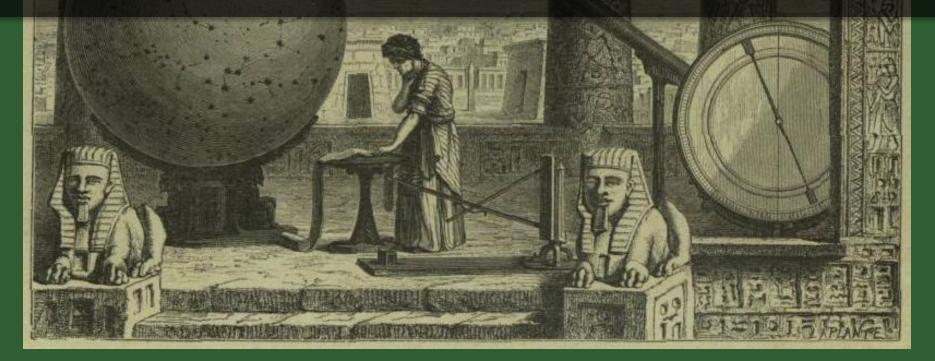# To Save the Phenomena

Prof. David Kaiser

Thursday, June 23, 2011, STS.003

Heavens unit

Overarching questions:

Are representations of astronomical phenomena *true* or merely *useful*?
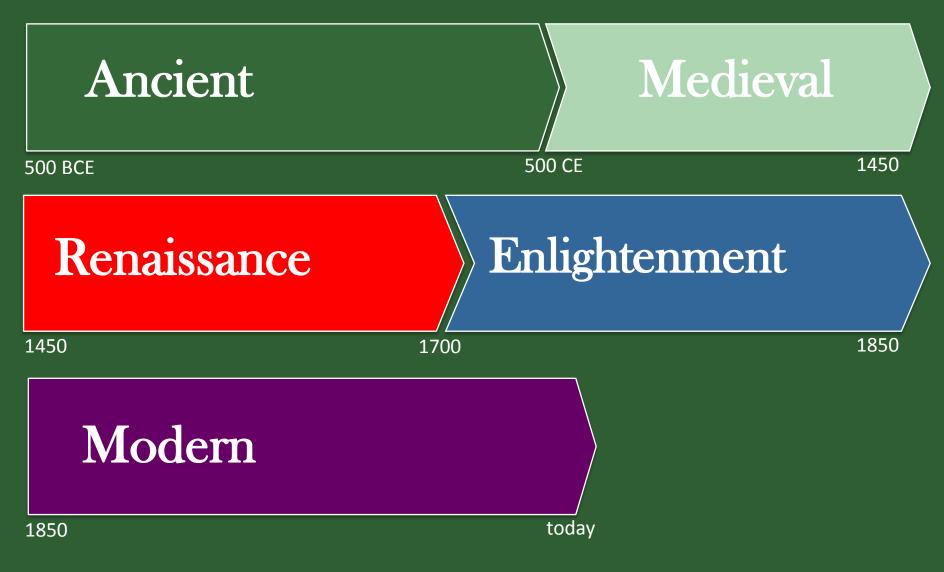
How does scientific knowledge travel?

I. Ptolemy and the Planets

II. Medieval Islamic Astronomy

III. Copernican Revolutions

Readings: Ptolemy, *The Almagest*, 5-14, 86-93;
Al-Tusi, *Memoir on Astronomy*, 194-222;
Lindberg, *Beginnings of Western Science*, 85-105.

Timeline

Ancient | Medieval

500 BCE | 500 CE | 1450

Renaissance | Enlightenment

1450 | 1700 | 1850

Modern

1850 | today

Thursday, June 23, 2011, STS.003

Puzzle of the Planets

"planet" = "wanderer"

1. Planets roughly follow the path of the sun (within 5° of the ecliptic).
2. They tend to move W to E over the year, but with varying speeds.
3. They sometimes display *retrograde motion*.
4. They appear brightest during retrograde.

Plato's challenge: "to save the phenomena." "By the assumption of what uniform and orderly motions can the apparent motions of the planets be accounted for?"

Retrograde Motion

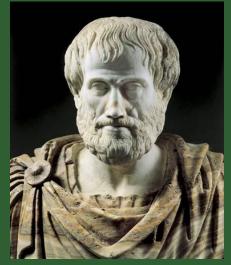Illustration explaining retrograde motion removed due to copyright restrictions.

Mars, 2003

Geocentrism

Nearly all of the ancient scholars assumed *geocentrism*: that the Earth sits at rest in the middle of the cosmos, while the sun, planets, and stars revolve around it.

Aristotle, ca. 330 BCE

"[Some people think] there is nothing against their supposing the heavens immobile and the earth as turning on the same axis from west to east very nearly one revolution a day. But it has escaped their notice in the light of what happens around us in the air that such a notion would seem *altogether absurd*."

"That the Earth does not in any way move locally" – Ptolemy, *Almagest*, 1:7

Aristotle, *De Caelo*

Flat Earth?

No! Nearly all Greek scholars *assumed* that the Earth was a perfect sphere. Aristotle gave arguments in his *De Caelo*, ca. 330 BCE; Eratosthenes even measured the Earth's circumference, ca. 250 BCE.

A

HISTORY

OF THE

LIFE AND VOYAGES

OF

CHRISTOPHER COLUMBUS.

BY

WASHINGTON IRVING.

Venient annis
Sæcula seris, quibus Oceanus
Vincula rerum laxet, et ingens
Pateat tellus, Typhisque novos
Detegat Orbes, nec sit terris
Ultima Thule.

Seneca, Medea.

IN FOUR VOLUMES.
VOL. III.

LONDON:
JOHN MURRAY, ALBEMARLE-STREET.

MDCCCXXVIII.

Peter Kohlbeck, *In Sight of the New World*, 1852

The "flat earth" myth was invented by Washington Irving in 1828, to heighten the drama of Columbus's voyage.
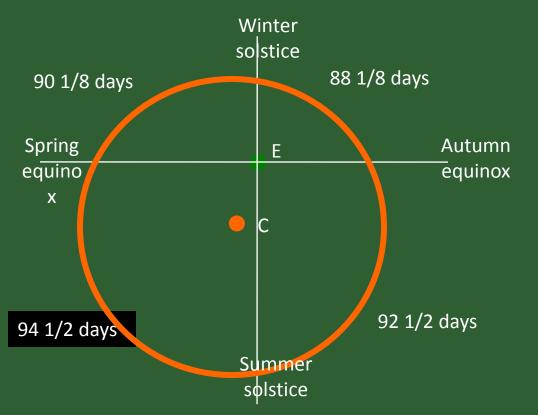
Eudoxan Spheres

Eudoxus (ca. 400 – 350 BCE), a student of Plato, invented a scheme of nested concentric spheres. If they rotated around different axes, and in opposite directions, a planet attached to both would trace out a *hippopede*: retrograde motion.
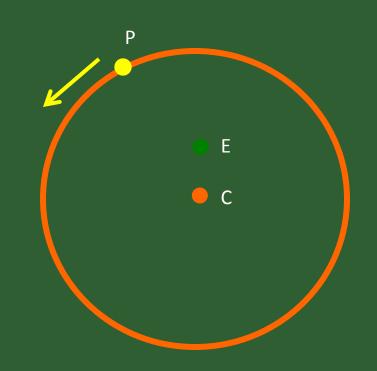
Image of a Eudoxan sphere removed due to copyright restrictions. See: hippopede.jpg.

But the hippopedes were of fixed size and shape. If one adjusted the parameters to match a planet's *speed* during retrograde, one couldn't match its arc, and vice versa.

Eccentric Circles

Apollonius (ca. 250 BCE): planet moves uniformly along a perfect circle, *but* the Earth is displaced from the center. So for us, the planet appears to change speeds.
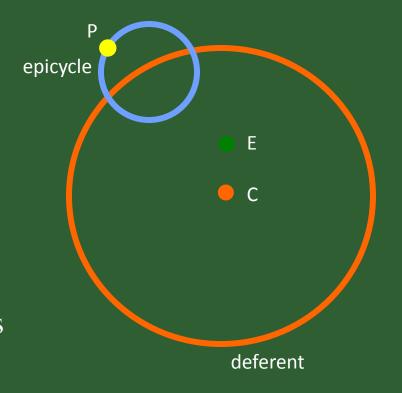
P

E

C

Winter solstice

90 1/8 days

88 1/8 days

Spring equino x

E

Autumn equinox

C

94 1/2 days

92 1/2 days

Summer solstice

Hipparchus (ca. 150 BCE) applied the eccentric circle to Babylonian observational data, e.g., to the path of the sun along the ecliptic.

Epicycle

Apollonius also invented the epicycle, ca. 250 BCE. He demonstrated that the effects of an eccentric circle could be equally well accommodated by an epicycle and vice versa, if one tuned the parameters correctly.

Ptolemy repeated the proof: "It must be understood that the appearances can be cared for interchangeably according to either hypothesis, when the same ratios are involved in each.... The same appearances agree with either hypothesis." (pp. 86-88)

Ptolemy

Claudius Ptolemy (ca. 90 – 168 CE) lived in Alexandria, the great center of learning and exchange. His last name (*not* to be confused with Egyptian royalty) indicates Egyptian and Greek heritage. His first name reveals Roman citizenship.
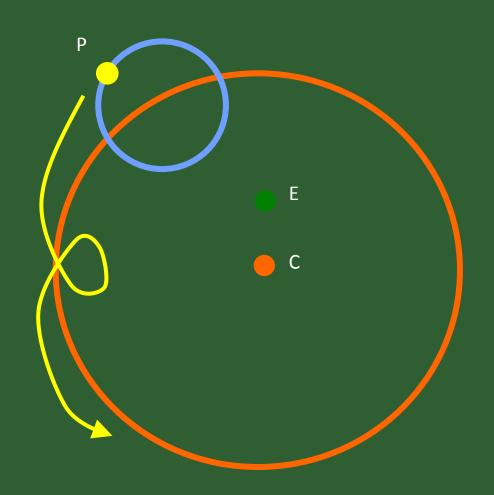
Baroque illustration of Ptolemy, ca. 1600

Almagest, 9th century Greek parchment.

His *Mathematical Syntaxis* (or *Compilation*) was translated into Arabic as "al Majisti" ("The Greatest"); and latinized as *The Almagest*. It defined the theory and practice of astronomy for 1400 years…

Retrograde Redux

Ptolemy demonstrated that by tuning the rate of rotation of the epicycle, one could produce retrograde motion.
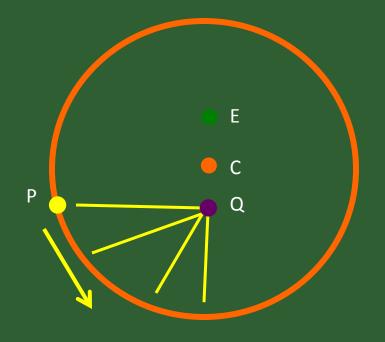
P

E

C

The same model explained why the planets appeared brightest during retrograde: that's when they were closest to us.

A Third "e"

In addition to Apollonius's eccentric circle and epicycle, Ptolemy invented a third device: the *equant*. A planet swept out equal angles in equal times with respect to the equant, rather than the true center of its circle.

Using all three 'e's, Ptolemy could match observed planetary motion to within 1° on the sky — unsurpassed until Tycho Brahe in the 1580s!

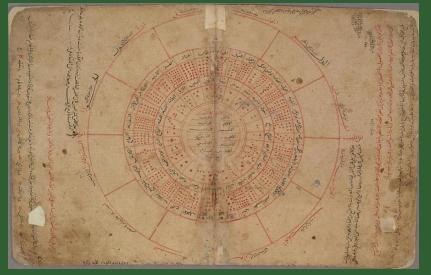But Ptolemy's equant broke with Plato's dictum (and Aristotle's physics) about uniform circular motion.

A New World Power

The Roman Empire fell ca. 450 CE.
Muhammed was born in Mecca in 570.
He was exiled to Medina in 622.
By 628, he had 10,000 followers.

Map of the Islamic Empire, ca. 750, removed due to copyright restrictions. See: islam_750.jpg.

Old Texts, New Ideas

Old view: The medieval Islamic scholars merely salvaged Greek learning and "transmitted" it to Latin Europe, without doing much to enrich it along the way.
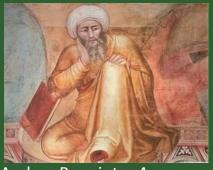

Book of Curiosities, Egypt, ca. 1020

New view: Period of deep originality. Massive *translation* efforts, ca. 750-900, followed by intellectual *appropriation*, *naturalization*, and — only later — *decline*.

Andalusian Astronomy

Andrea Bonaiuto, *Averroes*, ca. 1350

Averroes (d. 1198): "We should [seek] the true astronomy that is possible from the standpoint of physical principles. For nothing of the true science of astronomy exists in our time, the astronomy of today being only in agreement with calculations and not with what exists."

Al-Bitruji (d. 1217): "Ever since my youth I have followed the teachings of the ancients concerning the motion of the heavens, especially the teachings of the master of this science, Ptolemy. Yet I remained skeptical about those of Ptolemy's hypotheses which I found repugnant because Nature contradicted them."

Image of nested sphere's removed due to copyright restrictions.
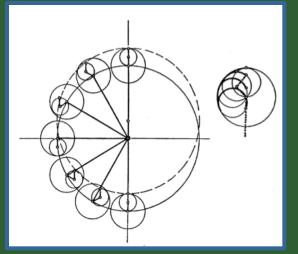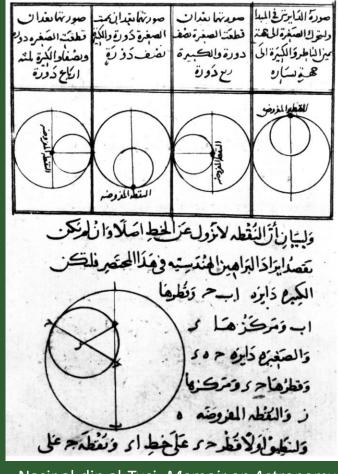See: physicallyRealPlanetarySystems3.jpg.

al-Bitruji's nested spheres

Group members were dedicated Aristotelians – philosophers first, most concerned with the question of physical causes. They focused on Ptolemy's physics, and found it wanting.

Maragha School

Founded in 1259. Rather than try to *replace* Ptolemy's system, they worked to *reform* it from within, saving his empirical results. To them, the equant was repugnant because it was *inconsistent* with Ptolemy's stated program.

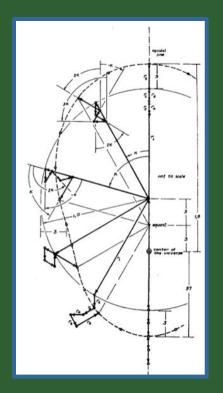
Nasir al-din al-Tusi, *Memoir on Astronomy*, ca. 1260

Al-Tusi demonstrated how to reproduce the effect of the equant using only uniform circular motion: the "Tusi couple."

Iranian postage stamp featuring al-Tusi, 1956

Stretch that Circle

Qutb al-din al-Shirazi (d. 1311) referred often to al-Tusi's writings. Using a *pair* of Tusi couples, al-Shirazi made the planet's path stretch at the ends and pinch at the midpoints.
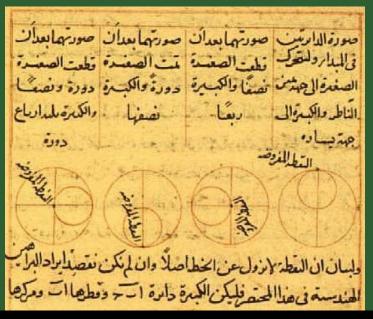
Al-Shirazi, *The Royal Present*, 1284

Al-Shirazi's planetary models were the first to consider deviations from purely circular orbital paths.
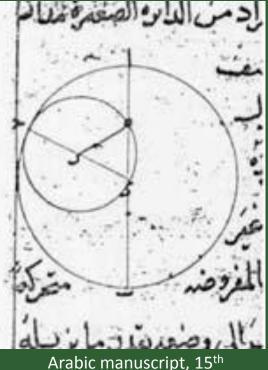
Paper Trail

Many Maragha manuscripts wound up in Padua by the late 1400s. Copernicus arrived there as a medical student in 1501.

Copernicus, *De Revolutionibus*, 1543
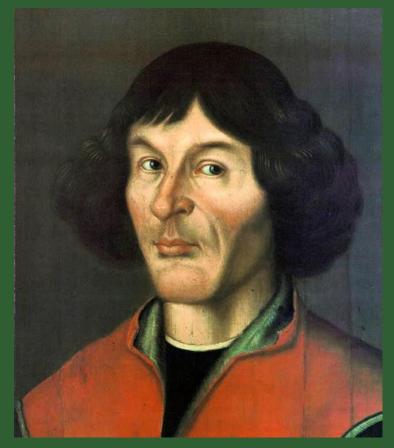

Arabic manuscript, 15th century

Arabic manuscript, 13th century, in Vatican library

Copernicus adopted the Tusi couple in his *De Revolutionibus* to avoid Ptolemy's equant, without attribution.

Enter Copernicus

Nicholas Copernicus (1473 – 1543) was the son of a wealthy merchant. He studied astronomy in Poland (1490s), before moving to Bologna to study canon (Church) law, and then Padua to study medicine. By 1503, he was back in Poland working as the assistant and physician to his uncle, the Bishop.

Nicholas Copernicus, ca. 1580

He worked on legal issues, taxes, currency reform... and, after hours, astronomy.
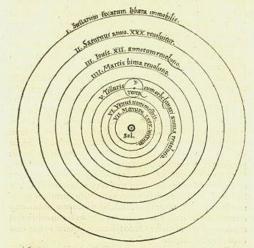
Heliocentrism

In 1510, Copernicus wrote a manuscript – the *Commentariolus*, not published until the 19th century – in which he introduced the idea of *heliocentrism*. Putting the Earth in motion would provide a simple explanation for *retrograde*.

It also provided a *reason* for the order of the planets: closest to sun orbited the fastest.

On the Revolutions...

Finally in 1543, Copernicus published his full treatment. *De Revolutionibus* is a strange admixture of quasi-Aristotelian arguments, Ptolemy-styled quantitative models, and fits to data.

If the Earth is at rest, then the distant stars must execute "vehement motions" for us to see them rise and set everyday.
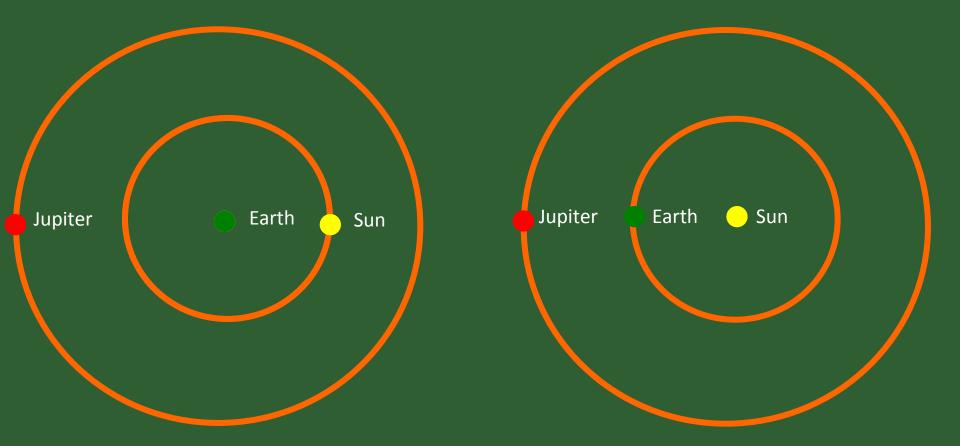
The Earth is a sphere, and "the motion appropriate to a sphere is rotation in a circle."

The sun belongs in the center: "At rest, in the middle of everything, is the sun. For in this most beautiful temple, who would place this lamp in another or better position than that from which it can light up the whole thing at the same time?"

NICOLAI COPERNICI TORINENSIS DE REVOLVTIONI-bus orbium cœlestium, Libri VI.

Empirical Regularities

It was well known that the outer planets appeared brightest when in *opposition* to the sun. No explanation within a geocentric cosmos; but it was an automatic outcome of heliocentrism.
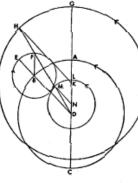
Renaissance Humanism

3. THAT THE HEAVENS MOVE SPHERICALLY

It is probable the first notions of these things came to the ancients from some such observation as this. For they kept seeing the sun and moon and other stars always moving from rising to setting in parallel circles, beginning to move upward from below as if out of the earth itself, rising little by little to the top, and then coming around again and going down in the same way until at last they would disappear as if falling into the earth. And then again they would see them, after remaining some time invisible, rising and setting as if from another beginning; and they saw that the times and also the places of rising and setting ge...

It is immediately clear that, on this hypothesis, angle *ADE* and angle *FBE* are always equal, and that the star will appear on the straight line *DF*.
I say also that, on the hypothesis of eccentricity, both if the eccentric circle is greater than the concentric circle and if it is less, with only the similarity of the relations and the isochronism of the returns assumed, the star will again appear on the same straight line *DF*.
For let the eccentric circle *GH* be drawn greater, as we said, with its centre at *K* on *AC*; and likewise *LM* less, with centre *N*. And producing *DMFH* and *DLAG*, let *HK* and *MN* be joined. Since
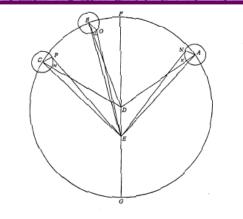*DB* : *BF* :: *HK* : *KD* :: *MN* : *ND*,
and since
angle *BFD* = angle *MDN*

THE UNIVERSE IS SPHERICAL   *Chapter 1*

First of all, we must note that the universe is spherical. The reason is either that, of all forms, the sphere is the most perfect, needing no joint and being a complete whole, which can be neither increased nor diminished; or that it is the most capacious of figures, best suited to enclose and retain all things; or even that all the separate parts of the universe, I mean the sun, moon, planets and stars, are seen to be of this shape; or that wholes strive to be circumscribed by this boundary, as is apparent in drops of water and other fluid bodies when they seek to be self-contained. Hence no one will question the attribution of this form to the divine bodies.

epicyclet's circumference in points *K*, *L*, and *M*. Take arc *KN* similar to *AF*, *LO* to *BF*, and *MP* to *FBC*. Join *EN*, *EO*, and *EP*. Then by [the preceding] computation arc *AB* = 75° 39', *BC* = 37° 51', *NEO* = the angle of apparent motion = 68° 23', and angle *OEP* = 34° 34'.

"To be sure, Claudius Ptolemy of Alexandria, who far excels the rest by his wonderful skill and industry, brought this entire art almost to perfection. [...] In my discussion, I shall adopt practically the same procedure as Ptolemy."

Copernicus, *De Revolutionibus*

Copernican Myths

Copernicus first argued for heliocentrism based on *simplicity*. But when he had to match real observations of planetary motion, he needed (nearly) as many epicycles as Ptolemy had used – his full model was *no simpler* than Ptolemy's system.

Nor did Copernicus match empirical data better than Ptolemy had done. He couldn't — Copernicus fit all of his parameters so as to *exactly reproduce Ptolemy's data*. So no observational differences whatsoever between the two systems.

So why did Copernicus bother? Because he thought heliocentrism was *real*.

Mixed Messages

Copernicus saw page proofs of *De Rev* on his deathbed. An anonymous preface was added to the published version — by the Lutheran theologian *Andreas Osiander*.

"The duty of the astronomer [is to] adopt whatever suppositions enable the motions to be computed correctly from the principles of geometry. These hypotheses need not be true nor even probable. On the contrary, if they provide a calculus consistent with the observations, that alone is enough. [...] If any causes are derived by the imagination, they are not put forward to convince anyone that they are true, but merely to provide a reliable basis for computation."

G. Pencz, *Andreas Osiander*, 1544

Philosophers, not astronomers or mathematicians, were to decide matters of cause and truth.

Lawsuit

When Copernicus's assistant saw the published version — complete with Osiander's preface — he sued the publisher for "breach of trust," and sought to force the publisher to issue a corrected version.

(1709)

Anno Octavo

Annæ Reginæ.

An Act for the Encouragement of Learning, by Vesting the Copies of Printed Books in the Authors or Purchasers of such Copies, during the Times therein mentioned.

The town council ruled in favor of the publisher: 100 years after Gutenberg's printing press, notions of authorship (let alone copyright) were still in flux, and quite different from today's standards.

Few knew that Osiander's (anonymous) preface hadn't been written by Copernicus — only revealed in print 80 years later. So most early readers took Copernicus's message to be that heliocentrism was merely *convenient*, not really *true*.

Rethinking "Revolutions"

The "Copernican Revolution" hardly happened overnight. In fact, it spanned at least a century and a half...

Photographs of "The Copernican Revolution" and "The Structure of Scientific Revolutions," both Thomas S. Kuhn, removed due to copyright restrictions.

... so was it a "revolution" or "evolution"?

STS.003 The Rise of Modern Science
Fall 2010