### Timeline: The Enlightenment Period

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
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<tbody>
<tr>
<td>1750</td>
<td>Death of J. S. Bach</td>
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<td>1751</td>
<td>First volume of <em>Encyclopédie</em> published</td>
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<td>1759</td>
<td><em>Voltaire, Candide</em></td>
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<td>1760–1820</td>
<td>Reign of George III of England</td>
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<td>1762</td>
<td><em>Rousseau, Le contrat social</em></td>
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<td>1774</td>
<td>First Continental Congress in Philadelphia</td>
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<td>1774–92</td>
<td>Reign of Louis XVI, king of France</td>
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<td>1775–83</td>
<td>American Revolution</td>
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<td>1776</td>
<td>Declaration of Independence</td>
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<tr>
<td>1776</td>
<td><em>Smith, The Wealth of Nations</em></td>
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<td>1778</td>
<td><em>La Scala opera house opens, Milan</em></td>
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<td>1781</td>
<td><em>Kant, Critique of Pure Reason</em></td>
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<td>1788</td>
<td><em>Gibbon, Decline and Fall of the Roman Empire</em></td>
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<td>1789–94</td>
<td>French Revolution</td>
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<td>1791</td>
<td><em>Death of Mozart</em></td>
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<td>1791</td>
<td>Boswell; <em>The Life of Samuel Johnson</em></td>
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<td>1791</td>
<td><em>Haydn, first London Symphonies</em></td>
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<td>1799</td>
<td><em>Beethoven, First Symphony</em></td>
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Question:
What is Enlightenment???
Enlightenment Philosophy

• Immanuel Kant (1724-1804)

• *Critique of Pure Reason* (1781):
  - Big Q: What can we know?

• *Theory of the Heavens* (1755):
  - “Island Universes” (galaxies)
“Enlightenment is man’s emergence from his self-imposed immaturity. Immaturity is the inability to use one’s understanding without guidance from another. This immaturity is self-imposed when its cause lies not in the Lack of understanding, but in lack of resolve and courage to use it without guidance from another. Sapere aude! [dare to know] Have courage to use your own understanding!— that is the motto of the Enlightenment.”

(Kant, 1784)
Enlightenment Philosophy

• Jean-Jacques Rousseau (1712-1778)

• *The Social Contract* (1762):
  
  - “Man is born free but everywhere is in chains”
  - Purpose of government: to ensure life, happiness, general welfare
  - Bad government: social contract is broken! Change of government legitimate!
Political Upheaval: American Revolution

“Life, liberty, and the pursuit of happiness…”
“Liberte, egalite, fraternite!”
Economical Upheaval: Industrial Revolution

- James Watt: Steam Engine (1774)

- beginnings of mass-production (Taylorism)

- Adam Smith (1776): *Wealth of Nations* (“Bible of Capitalism”)
  - Theory of the “invisible hand”
The Birth of Chemistry

- Antoine Lavoisier (1743-94), discoverer of oxygen
Big Q: Architecture of Stellar System?

• Q: How are stars arranged, and are they really fixed?
Newton’s A: Static, infinite Universe!

- Stars are fixed; i.e.: they don’t move!
But what about “Milky Way” band of stars?

• Q: How was Milky Way, and other galaxies, discovered?
But what about “nebulous patches” of stars?

- Many “islands of stars”!
Newton: A Static Universe

• Q: Is such a Universe possible (is it stable)?
Newton: A Static Universe

• Can stellar system be stable under gravity?

• A: No! Analogue: Balance infinitely many needles exactly on their tips! An unstable situation!
Newton: A Static Universe

• A: No, stars would begin to move around randomly!
Hunting for Stellar Motions

• Slow shift in angular positions → proper motions

• unsuccessful search initially

→ proper motions are exceedingly small due to large distance to the stars!
Hunting for Stellar Motions

- proper motion $\propto 1/d$
Serendipity: Bradley’s Discovery of Aberration

**The Aberration of Light**

- Apparent stellar positions are shifted because of Earth’s motion around Sun!
Bradley’s Proof for Earth’s Motion

- James Bradley (Astronomer Royal, 1693-1762)

- 1728: ‘Aberration of Light’

- Incontrovertible proof for Earth’s revolution around Sun (Copernicus was right!)
Serendipity: Bradley’s Discovery of Aberration

- Apparent stellar positions are shifted because of Earth’s motion around Sun!
Serendipity: Bradley’s Discovery of Aberration

- Apparent stellar positions are shifted because of Earth’s motion around Sun!
Q: How are Stars distributed in infinite Space?

• Stars are in motion, but what is architecture of stellar system?
Explaining the Milky Way!

- Thomas Wright of Durham (1711-86)
- An Original Theory of the Universe (1750)
- Concept of Milky Way as a `Galaxy’ (distinct system of countless stars)
Wright Explains the Milky Way!

Divine Center

Outer Darkness
Wright Explains the Milky Way!

- a disc-like appearance (like observed band of MW)!
Enlightenment Philosophy

- Immanuel Kant (1724-1804)

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  - Big Q: What can we know?

- *Theory of the Heavens* (1755):
  - “Island Universes” (galaxies)
Kant Postulates Disc-like Milky Way!

• basically correct picture for our Milky Way!

• direct proof: COBE, 1993 (infrared picture)
Kant’s Cosmogony:

Formation of disc-like systems!

- Kant-Laplace hypothesis!
Kant’s Hierarchy of Worlds

- Island Universes (galaxies)
- Systems of systems
- A fractal universe!
The Fractal Geometry of Nature

• Benoit Mandelbrot

• Fractal: self-similarity
The Fractal Geometry of Nature
Enlightenment Philosophy

- Pierre-Simon de Laplace (1749-1827)
  - *Exposition de System du Monde* (1796)

- **Laplace Demon:**
  - a being endowed with unlimited capability to compute
  - would be able to predict everything in past, present, and future
  - a completely deterministic universe!
Enlightenment Astronomy

- William Herschel (1738-1822)

- Discovery of Uranus (1781):
  - First planet not known in Antiquity

- Greatest telescope-builder of the age

- On the Construction of the Heavens (1785):
  - star counts
  - Map of the Milky Way
Herschel: From Musician to Astronomer

Organist in Bath (1766-82)

- Composer, conductor, oboist, organist

At age 35, Herschel turns to astronomy!
Herschel: Greatest Telescope-builder of the Age

40-foot reflector

Caroline Herschel (1750-1848)
Herschel: Discovery of Uranus (1781)

7-foot reflector

• First planet not known to the Ancients already!

Voyager 2 (1986)
Herschel: Mapping the Milky Way

- Using star counts to estimate distance to the edge of Milky Way

Shape of Milky Way Galaxy

~10,000 lightyears
Herschel: Discovery of Infrared Radiation (1800)

- Use prism to disperse sunlight into spectrum (blue-green-yellow-red)

- Place thermometer at “empty” place beyond red

- Detect heat there; there must exist energy (radiation) beyond red = Infrared
Great Task Ahead: What *are* the Stars?

• still unsolved: Need better physics and chemistry!
Enlightenment Astronomy (Kant/Herschel)

- First promising explanations for stellar architecture:
  - Milky Way
  - an infinite system of `island universes’ (galaxies)
  - maybe universe is a fractal (infinite regression of worlds)?
  - no incontrovertible proof yet: need stellar distances!

- Proof Earth’s motion around Sun:
  - Bradley’s `aberration of starlight’

- A mechanistic (clockwork) universe
  - Laplace’s Demon
  - a fully deterministic universe