Galileo's Legacy

John R. Percy
Department of Astronomy and Astrophysics
and
Ontario Institute for Studies in Education
University of Toronto

Email: john.percy@utoronto.ca
Galileo Galilei (1564-1642)

- Galileo developed and used the astronomical telescope.
- He made observations that revolutionized our understanding of the universe.
- He advanced what we now call “the scientific method”.

National Maritime Museum, London UK
International Year of Astronomy 2009

THE UNIVERSE YOURS TO DISCOVER

INTERNATIONAL YEAR OF ASTRONOMY 2009
IYA Canada Committee

• “to offer an engaging astronomy experience to every person in Canada ...

• [especially underserved communities]

• ... and to cultivate partnerships that sustain public interest in astronomy”

• http://www.astronomy2009.ca

• “Beyond IYA”: new and underserved audiences
Goals for this Presentation

- Scientific and philosophical background to Galileo's work
- Its context: Copernicus, Brahe, Kepler, Galileo, and Newton
- Galileo's contributions
- The evolution of the telescope since then
- Our present conception of the universe
- Questions and discussion!
The Awe and Wonder of the Sky

Photograph: Terence Dickinson

Galileo's Legacy, John R. Percy, University of Toronto
Practical Astronomy

- time-keeping
- season-keeping
- navigation
- the inuit were skilled users of the day and night sky for practical and ceremonial purposes

Royal Ontario Museum
Constellations and Culture

- We use the constellation figures of the Greeks and Romans, with Arabic star names

- Other cultures use different figures and different names
Astronomy and Culture

• Daily and yearly motions of the sky
• Mythology in the sky
• Seven days of the week: sun, moon, planets
• Connection of sun, moon, and planets with gods
• Astrology (varies from culture to culture)
• The size and scale of the earth, moon, and sun
• What causes their motions?
Aristotle's Model of the Universe

- The four elements: earth, water, air, and fire.
- The perfect and unchanging heavens: quintessence.
- The motions (and music) of the spheres.
Ptolemy's Model of the Solar System

- Earth and the centre.
- All motions on circles (on circles, on circles)
- Predictions fit the observations for over a thousand years!
Nicolaus Copernicus (1473-1543)

Copernicus Museum, Frombork
Tycho Brahe (1546-1601)

Buhl Planetarium, Pittsburg.

Galileo’s Legacy, John R. Percy, University of Toronto
Johannes Kepler (1571-1630)

Joachim Reinhardt, Frankfurt
Galileo Galilei (1564-1642)

National Maritime Museum UK
Isaac Newton (1642-1727)

Rice University, Texas
Galileo's Telescope

Museum of the History of Science
Galileo's Observations: The Moon
Stella occidentali maiori, ambre tamen vale conquisca, ac splendida, tur qua disblat a lune scupulis primus duobus, tertia quoque Stellula apparere coepit hora tertia prinum minime conspecta, que ex parte orientali loundem feretagebat, etaque admodum exigua. Omnes furent in cadem recta, & secundum. Ellipse longitudinem coordinata.

Die 15. primum a me quatuor conspecta fuerunt Stellulae in hac ad louem consititutione. Erant tres occidentales, & una orientalis; lineam proxime.

1. Ori. ** * * * 

rectam constituant; media enim occidentali paulumum a recta Septemtrionem versus deflectebat. Abarat orientali a louem minuta duo reliquarum & loundem intercapedines erant singularius tantum minuti. Stellae omnes cadem praeferebant magnitudinem, aclect exigus, lundissima tamen erant, ac fines eiusdem magnitudinis longe splendidiores.

Die 14. nubulosa fuit tempetas.

Die 15. hora noctis tertia in proxime ditecta fuerunt habitudine quatuor Stellae ad louem;

Ori. ** * * * 

occidentales omnes in cadem proxima recta linea dispositae; que enim tertia a loundem numerabantur, paululum in boream atollubahat; propinquius loundem erat omnium minimis, reliquis consorteriores apparabant; interella inter loundem.

Die 16. hora prima noctis tres vidimus Stellae inusta hunc ordinem dispositas. Dux loundem

Ori. ** * * 

interciaphantes tab co per min. o. sec. 40. hincinde remotas, tertia vero occidentalis a loundem disblat min 8. loundem proxima non magiores, sed luciories apparabant remotior.

Die 17. hora ab oscasu 0. min. 30. huiusmodi fuit consortium. Stella vna tantum orientalis 3

Ori. * 

loundem disblat min. 3. occidentalis pariter vna a loundem distans min. 11. Orientalis duplo maior apparabant occidentalis nec plures aderunt quam illa duce. Verum post horas 4. hora nemo proxime quinta, tertia ex parte orientali emergens, quaeante, et opinor, cumpriorius...
Galileo's Observations: Venus
Galileo's Observations: The Sun
Galileo's Observations: Saturn
Galileo's Observations: Milky Way
Galileo's Contributions to Physics

- Developed the basic laws of motion, later formalized by Isaac Newton.
- Observed that objects of different masses fell at the same rate (from the Leaning Tower of Pisa?)
- Attempted to measure the speed of light – 300,000 km/sec!
- Many contributions to technology, in addition to the astronomical telescope.
William Herschel (1738-1822)

- Built large mirror telescopes.
- Studied objects beyond the solar system.
- Discovered Uranus.
- Discovered infra-red radiation (heat).
Harlow Shapley (1885-1972)

- Determined the size and shape of the Milky Way, and our position within it.
- Expert on stars and star clusters.
- Administrator and popularizer of astronomy.
Edwin Hubble (1889-1953)

- Determined that there were galaxies other than the Milky Way ...
- ... and that the universe of galaxies was expanding.
- Established a classification system for galaxies.

Hale Observatories

Galileo's Legacy, John R. Percy, University of Toronto
Albert Einstein (1879-1955)

- Developed Special and General Theories of Relativity.
- Made fundamental discoveries of the nature of light, and molecular motion.

Karsh of Ottawa
Newton's Mirror (Reflecting) Telescope

Royal Society, London
Astronomical Photography

- More information
- Objective information
- Permanent information

Kitt Peak National Observatory
Galileo's Legacy, John R. Percy, University of Toronto
Telescope Mountings

• Telescope mountaings enable the telescope to track objects for many hours, as they move from east to west, making long time exposures possible, so that fainter objects can be studied.

U. Toronto
Larger Telescope Mirrors

- Larger mirrors, and segmented (multiple) mirrors enable the telescope to gather more light, and study fainter objects.

Lawrence Livermore Laboratory
Digital Electronic Detectors

- Unlike photographic films, which are only 1% efficient, CCD's (charge coupled devices) are almost 100% efficient.
- Their output can be directly studied with computers.

Smithsonian Astrophysical Obs'y

Galileo's Legacy, John R. Percy, University of Toronto
Best Astronomical Sites
(Mauna Kea, Hawaii, and Chile)
Adaptive Optics
On the Gemini Telescope

Galileo's Legacy, John R. Percy, University of Toronto

Gemini Obs'y
Telescopes in Space
Telescopes to Study Wavelengths other than Light
Atacama Large Millimetre Array
ALMA
James Webb Space Telescope
JWST
Thirty-Metre Telescope
Canada's “Humble Space Telescope”
MOST
Microvariability and Oscillations of STars
Our Present Conception of the Universe

- Astronomy is based on observation, theory, and simulation.
- Astronomy is deeply embedded in every culture.
- Earth is one of dozens of “worlds” in the solar system.
- Planets exist around stars outside the solar system.
- The stars are distant suns, with life cycles of birth, life, and death.
- The ingredients of life are widespread in the universe.
- Our sun is one of hundreds of billions of stars in our Milky Way galaxy, which is one of tens of billions of galaxies in the universe.
- We see distant galaxies as they were, billions of years ago.
- The universe is expanding at an ever-accelerating rate.
- The universe consists mostly of “dark matter” and “dark energy”.

Galileo’s Legacy, John R. Percy, University of Toronto
Humans Have Walked on the Moon
Spacecraft Have Explored Other Planets

- The Huyghens probe, carried by the Cassini spacecraft, landed on Titan, the largest moon of Saturn, and the only moon with a thick atmosphere. The temperature was -180°C!

- NASA/ESA Image
The “Galilean Satellites” of Jupiter

- Jupiter and its Great Red Spot (left)
- Io
- Europa
- Ganymede
- Callisto
The Death of a Sun-like Star
A Planetary Nebula (“The Ring”)

Galileo’s Legacy, John R. Percy, University of Toronto
The Death of a Massive Star
A Supernova Remnant ("The Crab")
The Birth of Stars and Planets
The Orion Nebula
Our Milky Way Galaxy
300 Billion Stars
Billions of Other Galaxies
The Hubble Ultra-Deep Field
Exoplanets
Planets Around Other Stars
Exoplanetary Systems

HR 8799 Planetary System
(Sept. 2008)
Life in the Universe

- The ingredients of life are widespread.
- Most stars are older than the sun.
- Is the origin of life a natural process?
- Is the evolution of intelligence a natural process?
- We can communicate with intelligent life!

NSF/NAIC/Arecibo
The Value of Astronomy

Astronomy is useful because it shows how small our bodies, how large our minds.

Henri Poincare´