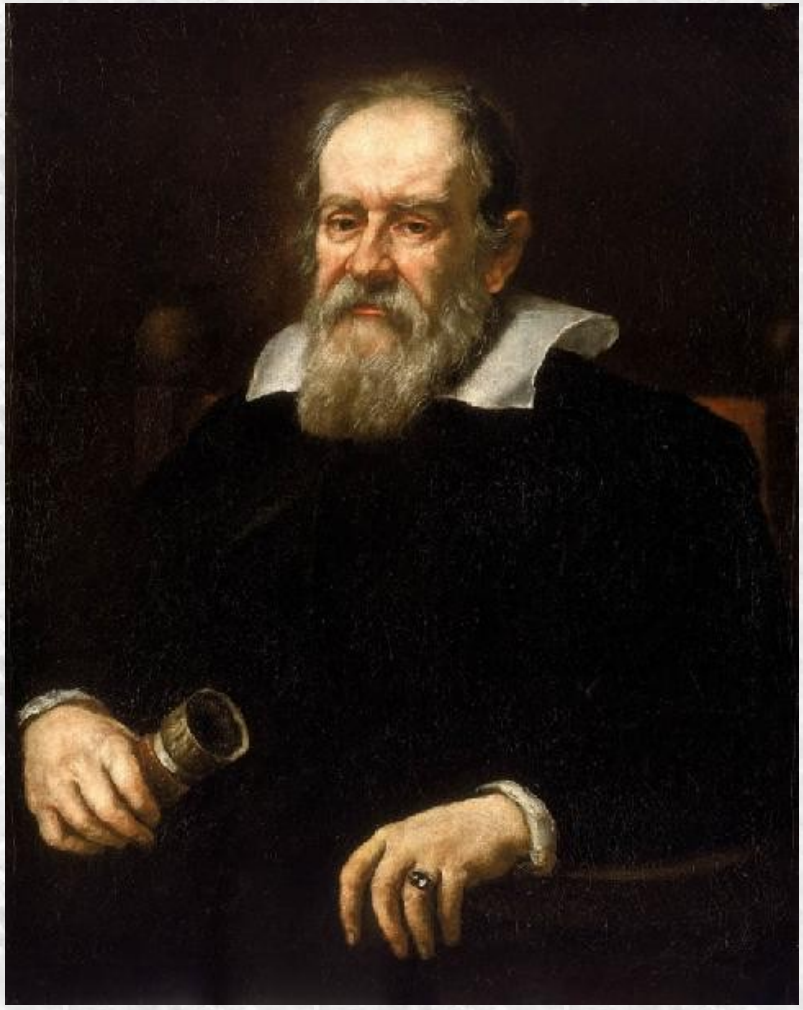
Galileo's Legacy

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

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

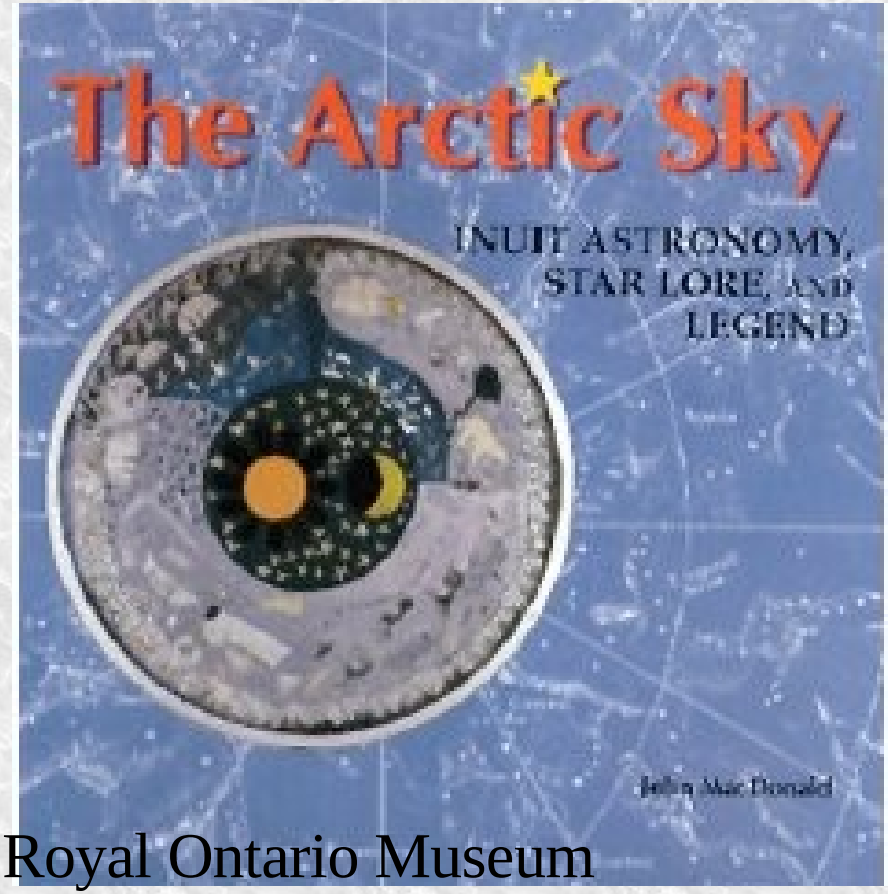
Goals for this Presentation

- 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

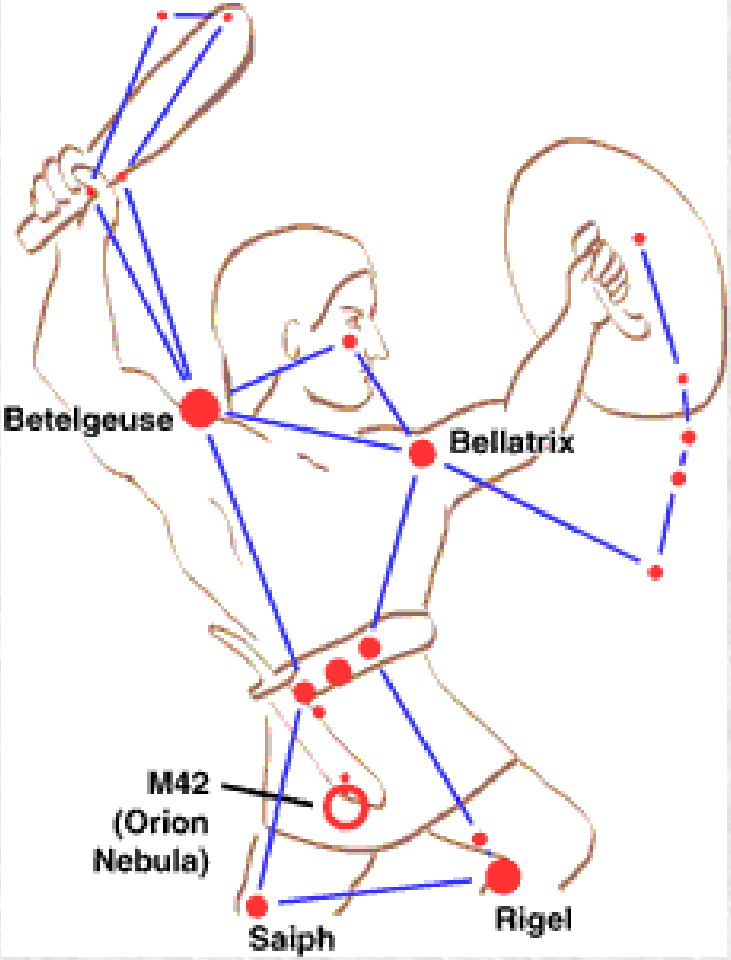
Practical Astronomy



Royal Ontario Museum

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

Constellations and Culture



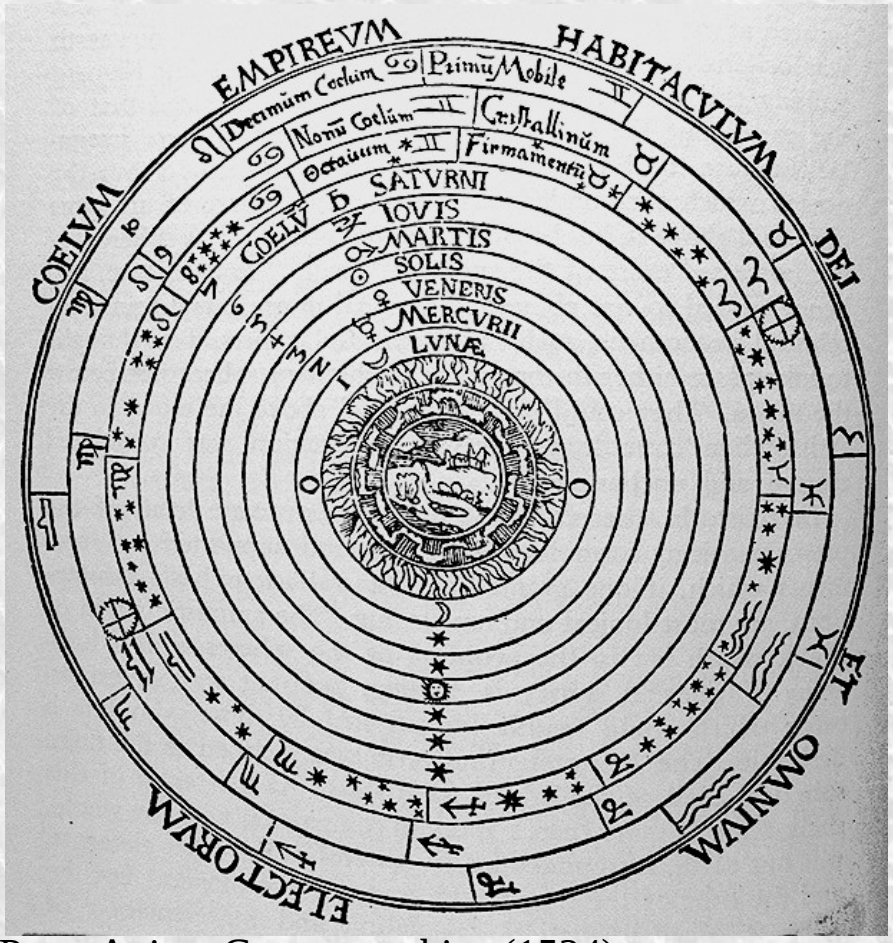
StarDate, University of Texas

- 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?

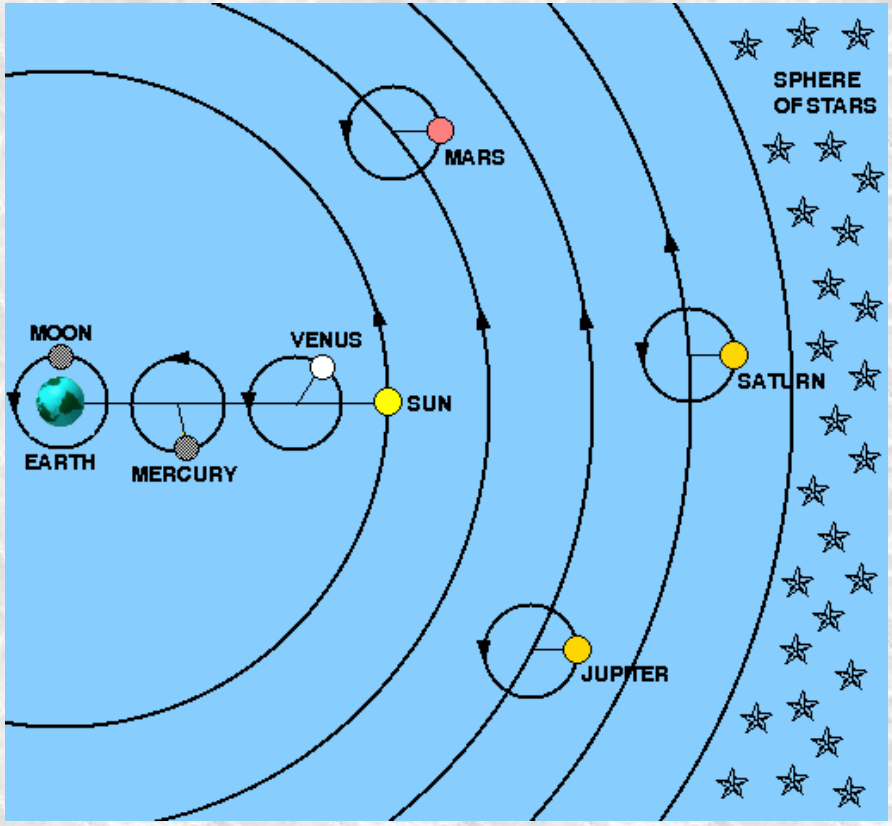
Aristotle's Model of the Universe



Peter Apian, Cosmographica (1524)

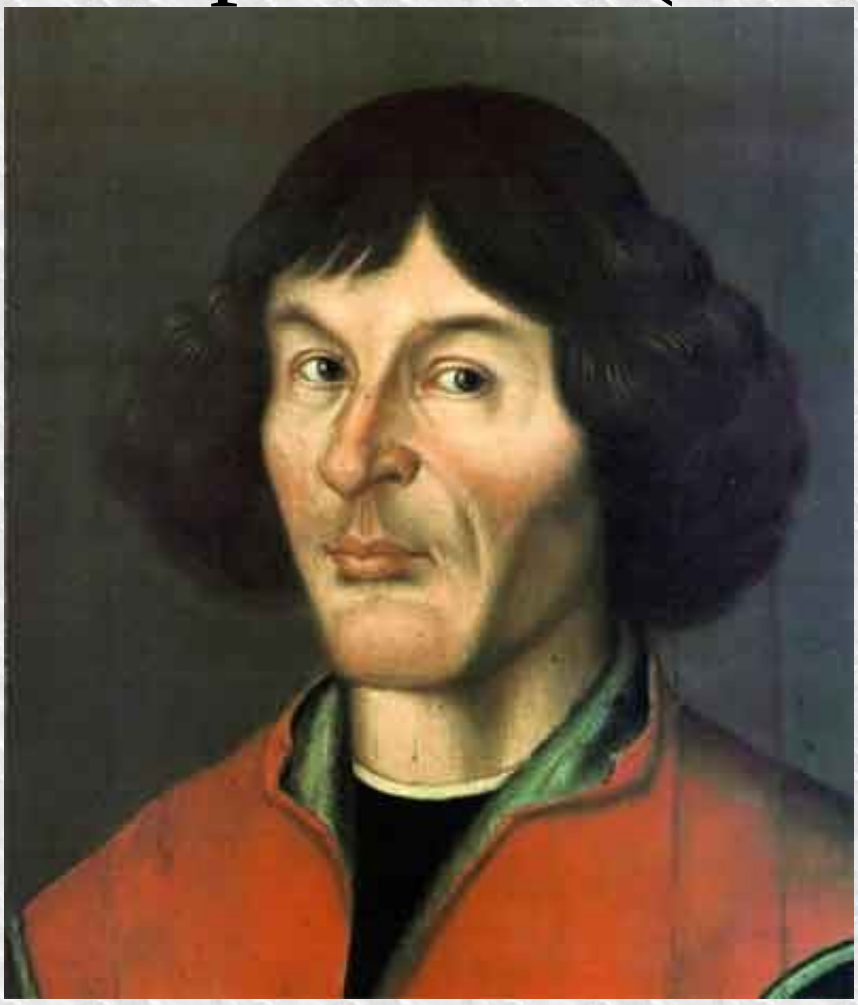
- The four elements: earth, water, air, and fire.
- The perfect and unchanging heavens: quintessence.
- The motions (and music) of the spheres.

Ptolemy's Model of the Solar System



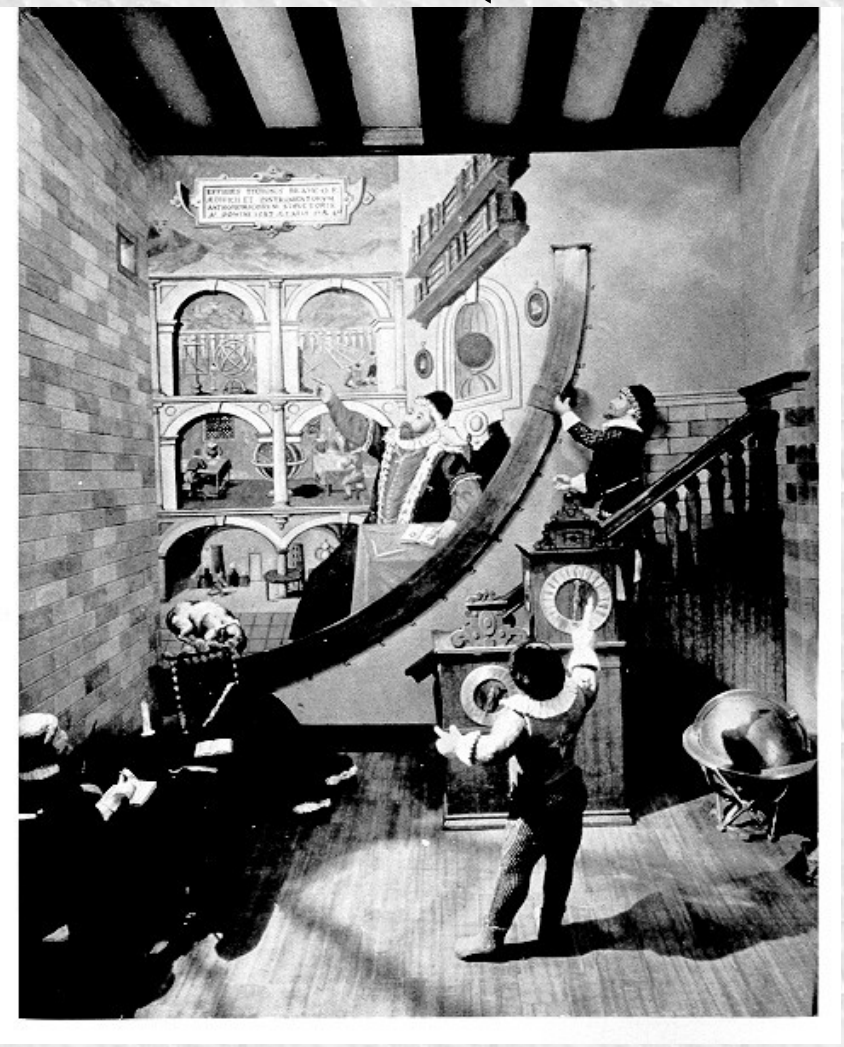
- Earth and the centre.
- All motions on circles (on circles, on circles)
- Predictions fit the observations for over a thousand years!

Nicolaus Copernicus (1473-1543)



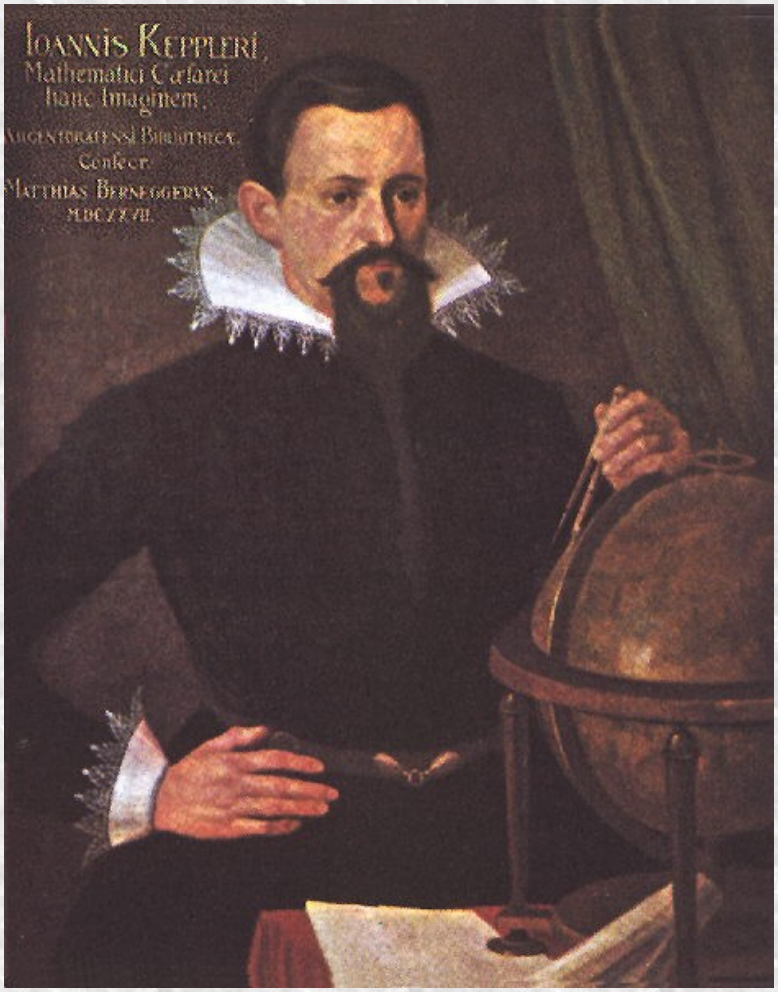
Copernicus Museum, Frombork

Tycho Brahe (1546-1601)



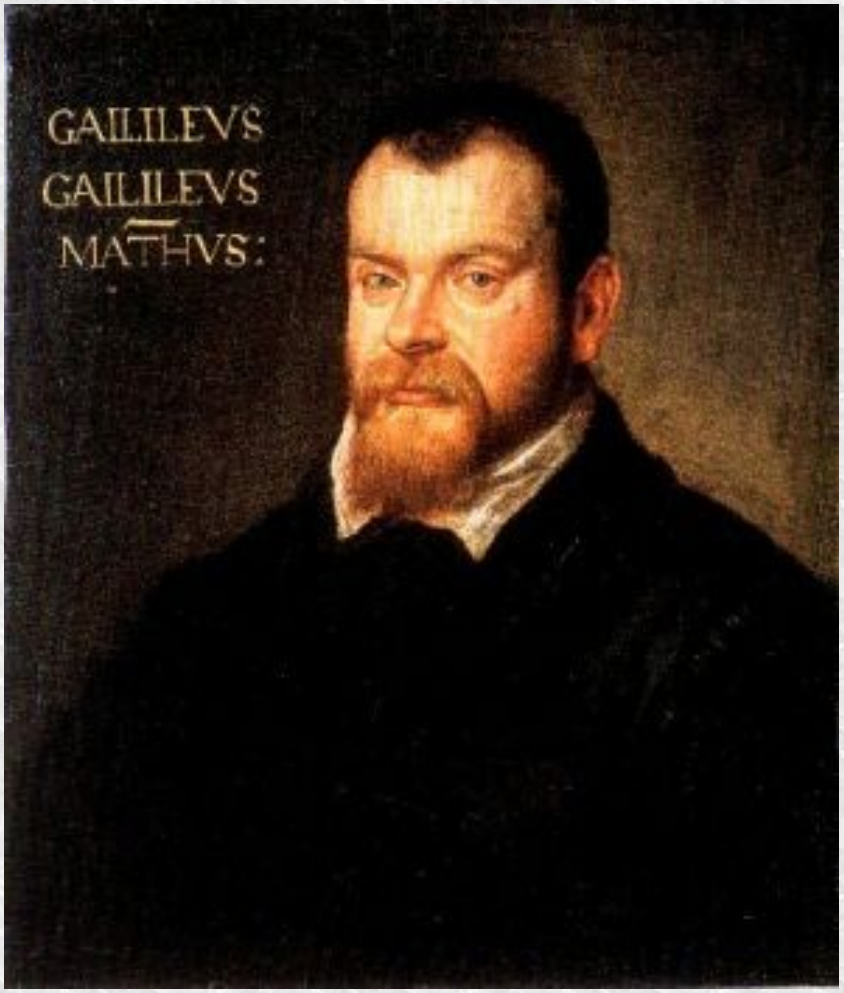
Buhl Planetarium, Pittsburg.

Johannes Kepler (1571-1630)



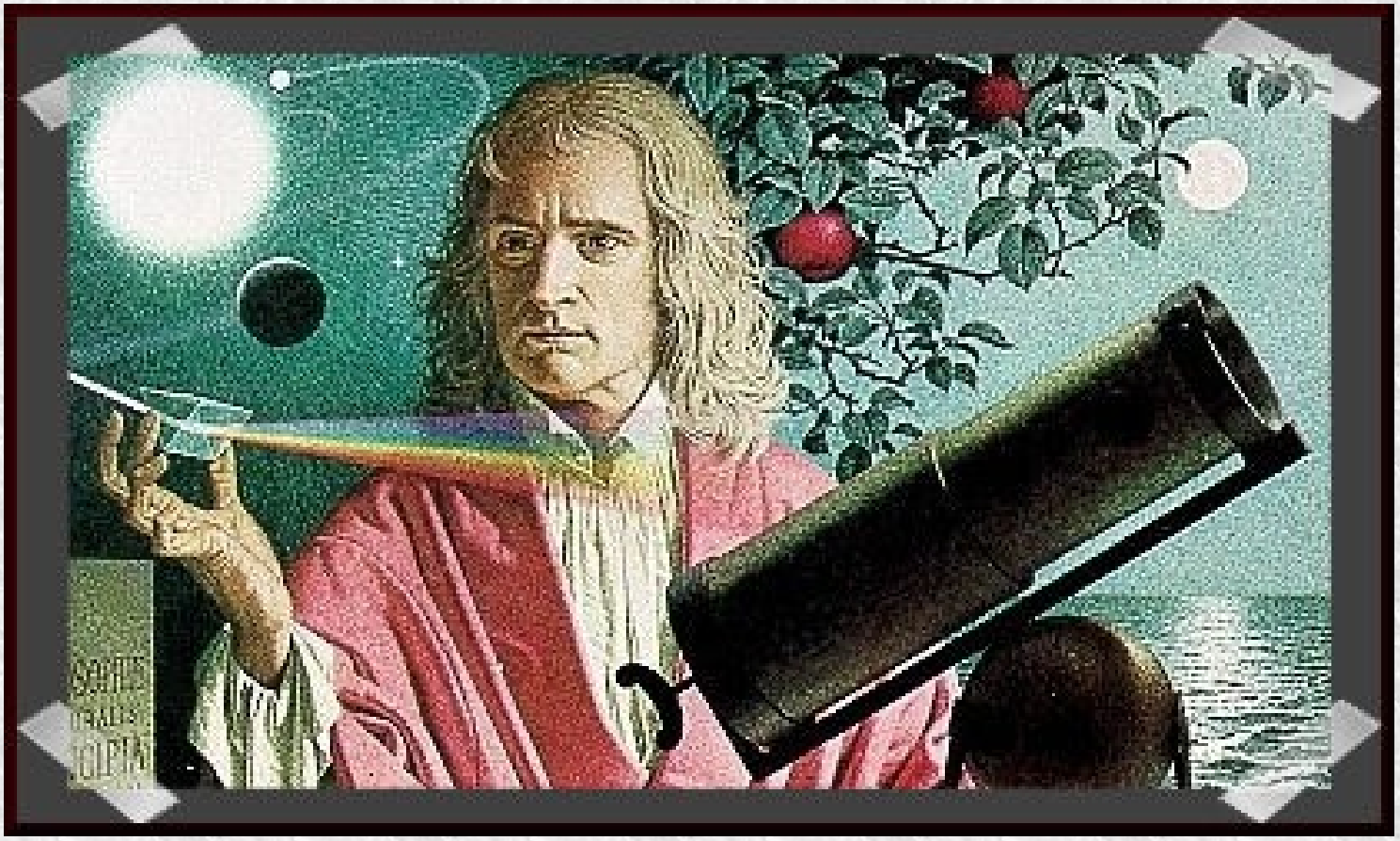
Joachim Reinhardt, Frankfurt

Galileo Galilei (1564-1642)



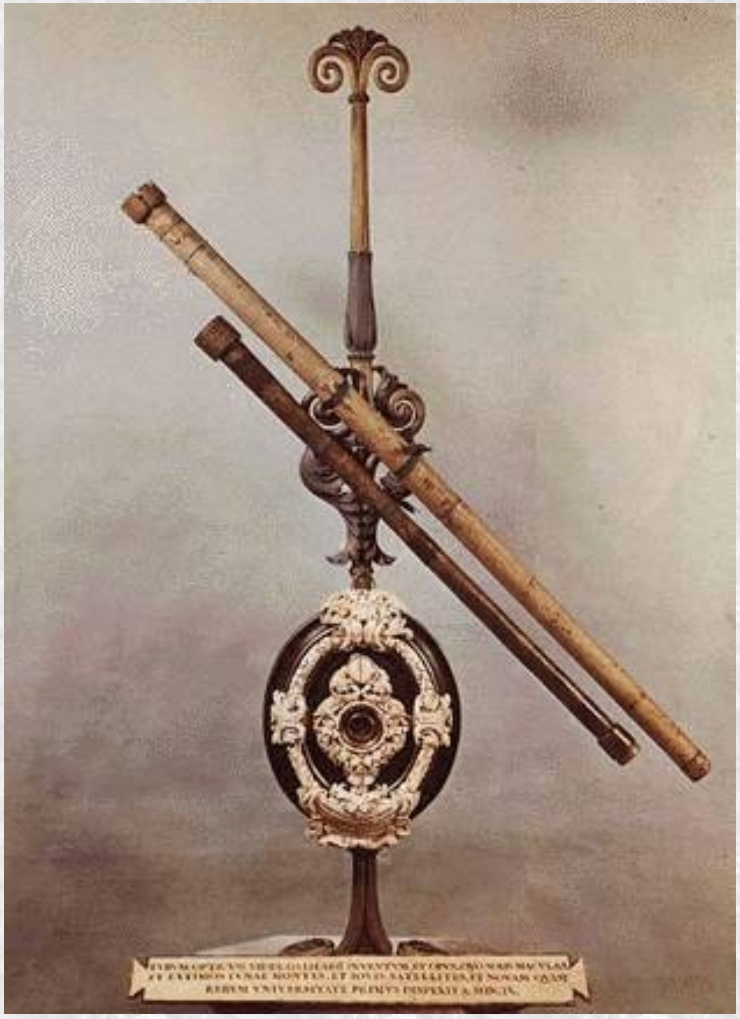
National Maritime Museum UK

Isaac Newton (1642-1727)



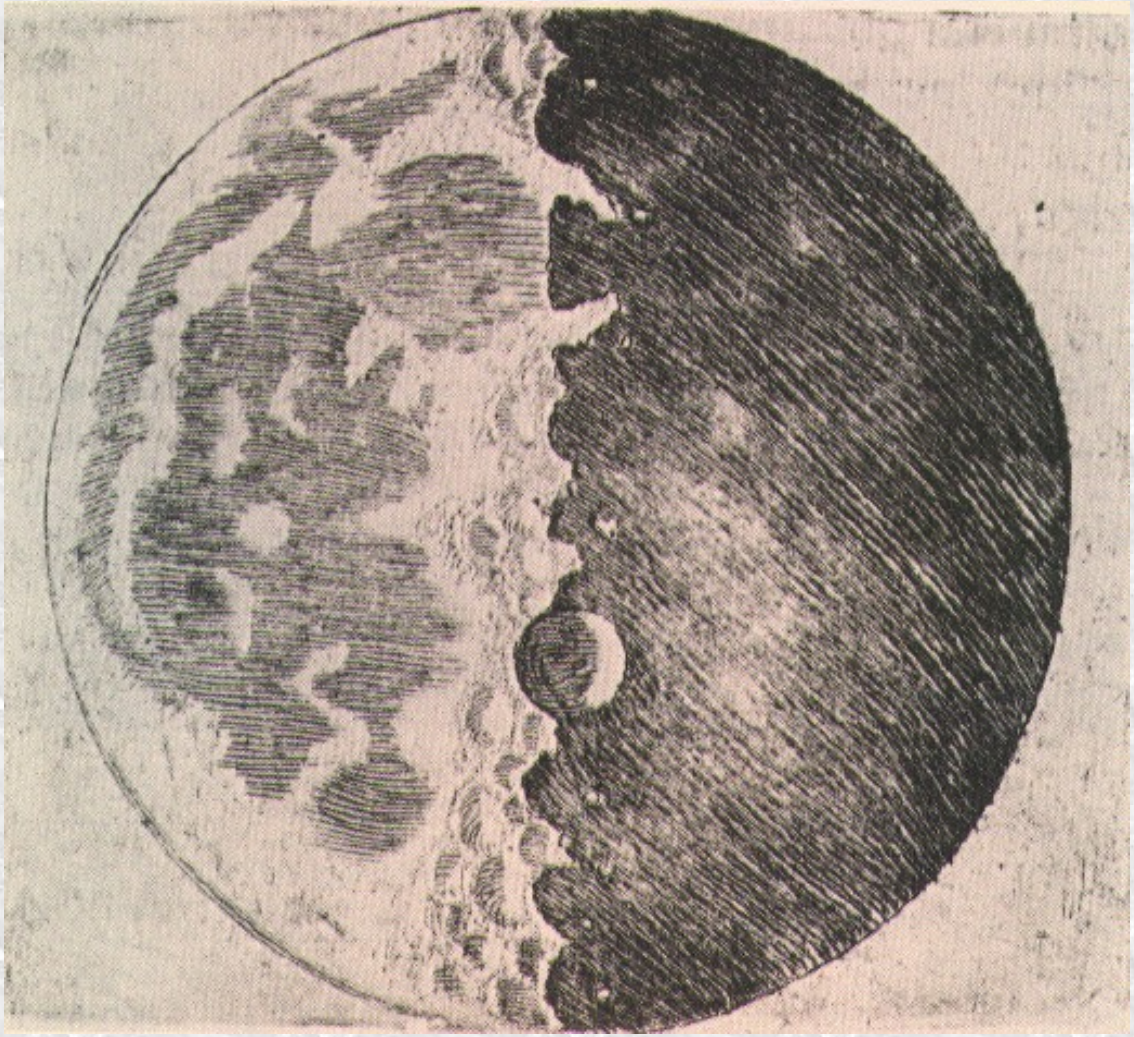
Rice University, Texas

Galileo's Telescope



Museum of the History of Science

Galileo's Observations: The Moon



Galileo's Observations: Jupiter

36 OBSERVAT. SIDERAE

Stella occidentaliori maior, ambæ tamen valde conſpicuæ, ac ſplendidæ: vtraque diſtabat a Ioue ſcrupulis primis duobus; tertia quoque Stellula apparere cœpit hora tertia prius minime conſpecta, quæ ex parte orientali Iouem ferè tãgebat, eratque admodum exigua. Omnes fuerunt in eadem recta, & ſecundum Ecliptiæ longitudinem coordinatæ.

Die 5. primum a me quatuor conſpectæ fuerunt Stellulæ in hac ad Iouem conſtitutione. Erant tres occidentales, & vna orientalis; lineam proximè.

Ori. * * * * Occ.

rectam conſtituebant; media enim occidentalium paululum a recta Septentrionem verſus deflectebat. Aberat orientalior a Ioue minuta duo: reliquarum & Iouis intercapedines erant ſingulæ vnius tantum minuti. Stellæ omnes eandem præ ſe ferebant magnitudinem, ac licet exiguã, lucidiſſimæ tamen erant, ac fixis eiuſdem magnitudinis longè ſplendidiores.

Die 14. nubiloſa fuit tempeſtas.

Die 15. hora noctis tertia in proxime depictæ fuerunt habitudine quatuor Stellæ ad Iouem;

Ori. * * * * Occ.

occidentales omnes ac in eadem proxima recta linea diſpoſitæ; quæ enim tertia a Ioue numerabatur, paululum in boream attollebatur; propinquior Ioui erat omnium minima, reliquæ conſequenter maiores apparebant; interua lla inter Iouem,

RECENS HABITAE. 37

Iouem, & tria conſequentia Sydera, erant æqualia omnia, ac duorum minutorum: at occidentalius aberat a ſibi propinquo minutis quatuor. Erant lucida valde, & nihil ſcintillantia, qualia ſemper tum ante, tũ poſt apparuerunt. Verũ hora ſeptima tres ſolũmodo aderant Stellæ, in huiuſ

Ori. * * * Occ.

cemodi cum Ioue aſpectu. Erant nempe in eadẽ recta ad vnguem, vicinior Ioui erat admodum exigua, & ab illo ſemota per minuta prima tria; ab hac ſecunda diſtabat min. vno; tertia verò a ſecunda min. pr. 4. ſec. 30. Poſt vero aliam horam duæ Stellulæ mediæ adhuc viciniores erant; aberant enim min. ſc. vix 30. tantum.

Die 16. hora prima noctis tres vidimus Stellas iuxta hunc ordinem diſpoſitas. Duæ Iouem

Ori. * * * Occ.

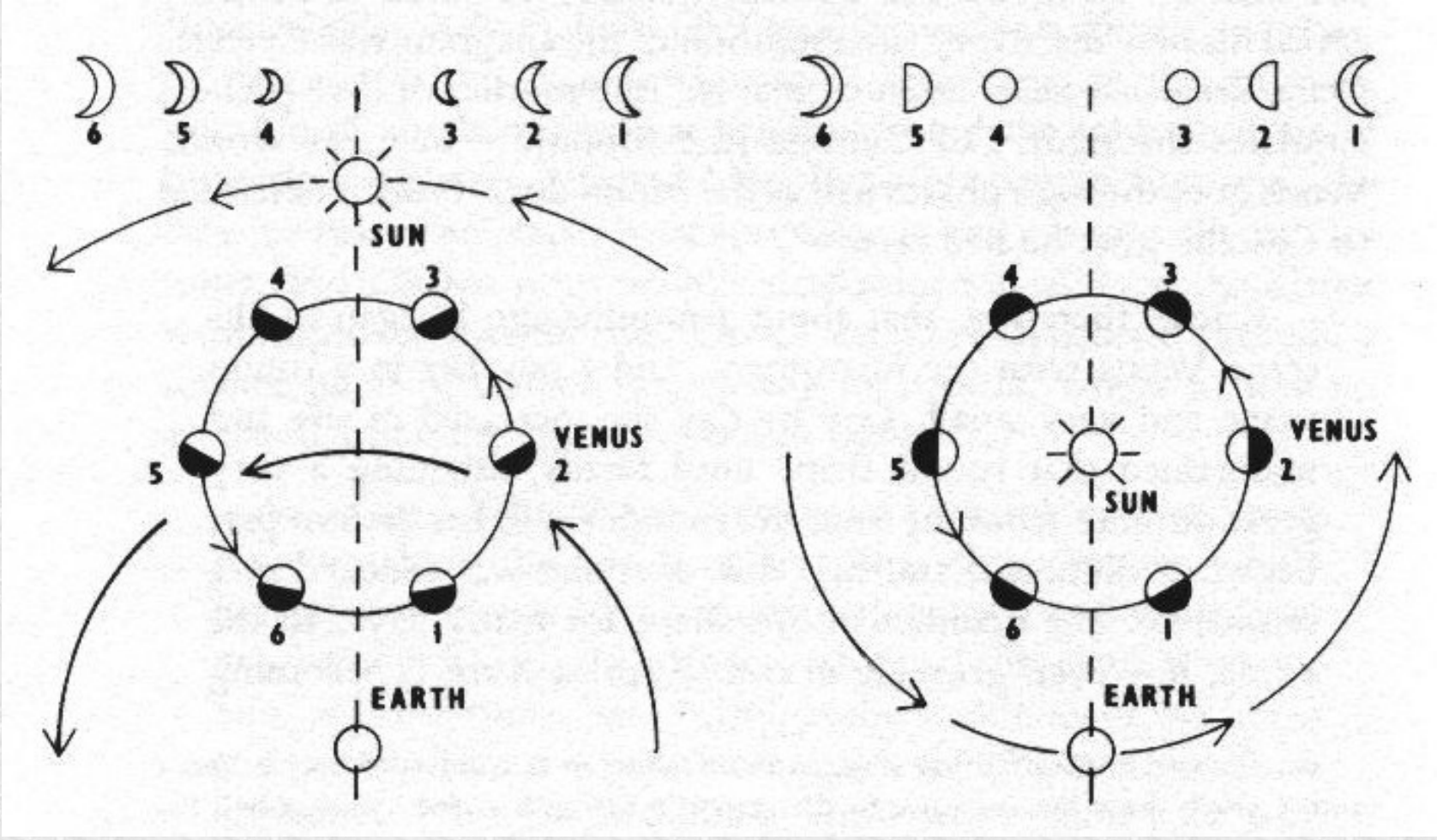
intercipiebant ab eo per min. 0. ſec. 40. hinc inde remotæ, tertia vero occidentalis a Ioue diſtabat min. 8. Ioui proximæ non maiores, ſed lucidiores apparebant remotiori.

Die 17. hora ab occaſu 0. min. 30. huiuſmodi fuit configuratio. Stella vna tantum orientalis a

Ori. * * Occ.

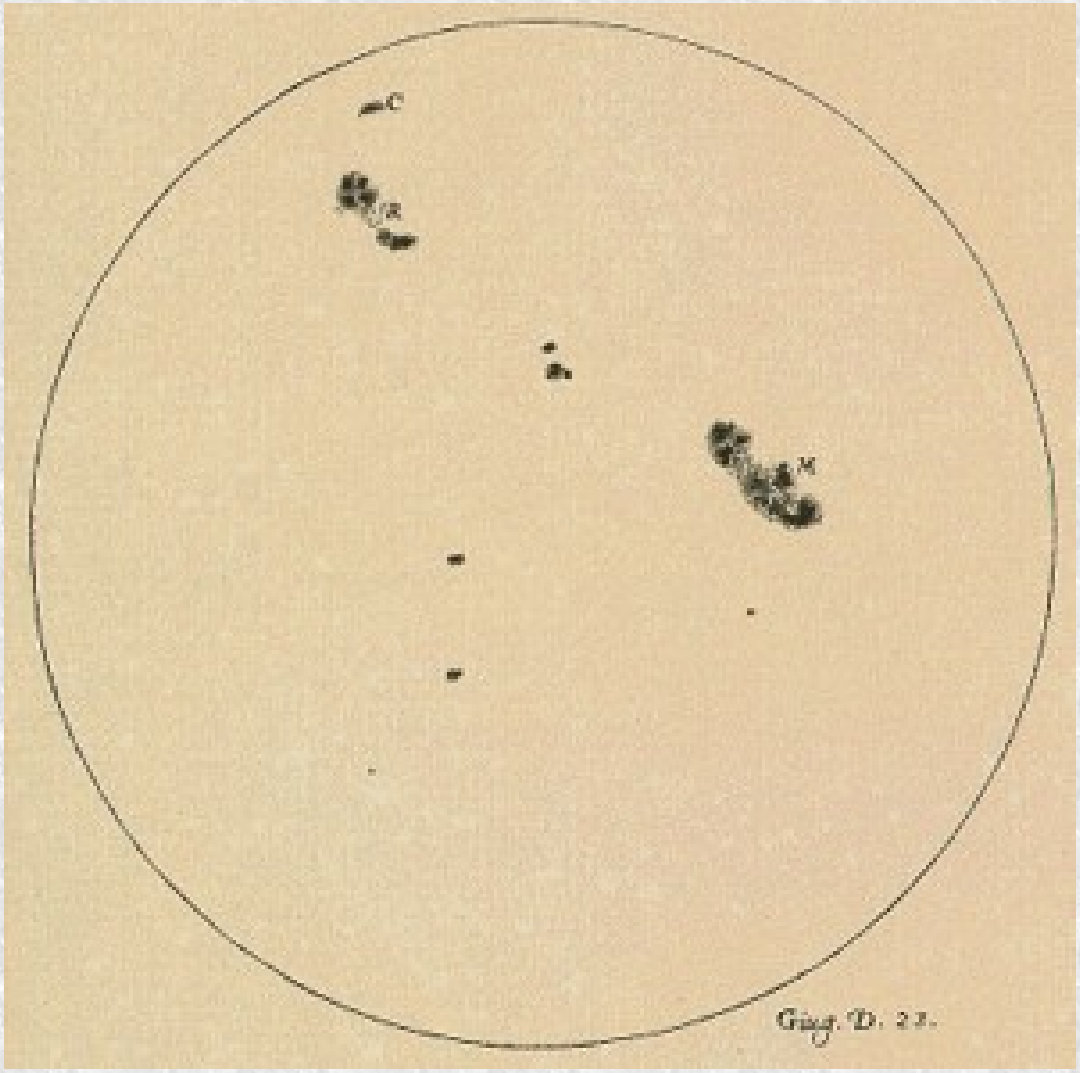
Ioue diſtabat min. 3. occidentalis pariter vna a Ioue diſtans min. 11. Orientalis duplo maior apparebat occidentali; nec plures aderant quam iſtæ duæ. Verum poſt horas 4. hora nempe proxime quinta, tertia ex parte orientali emergere cœpit, quæ antea, vt opinor, cum priori iun[illegible]

Galileo's Observations: Venus

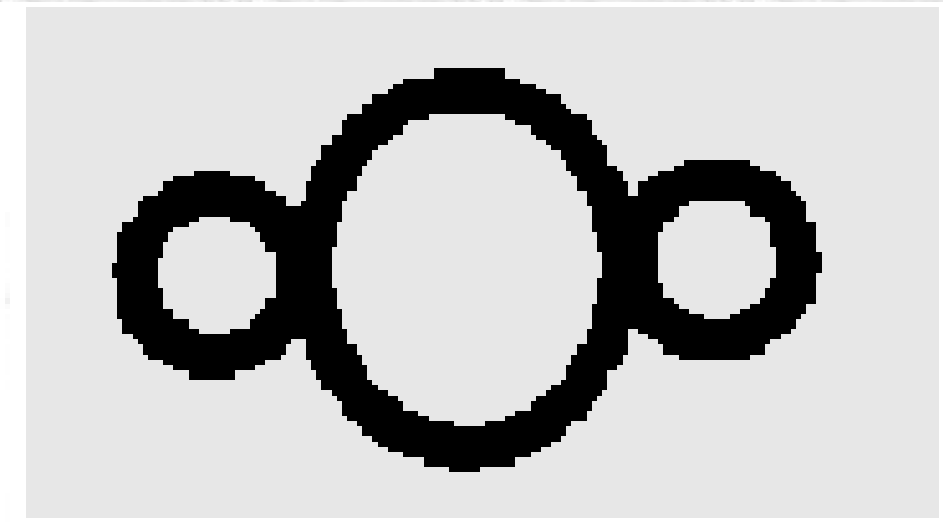


Albert Van Helden

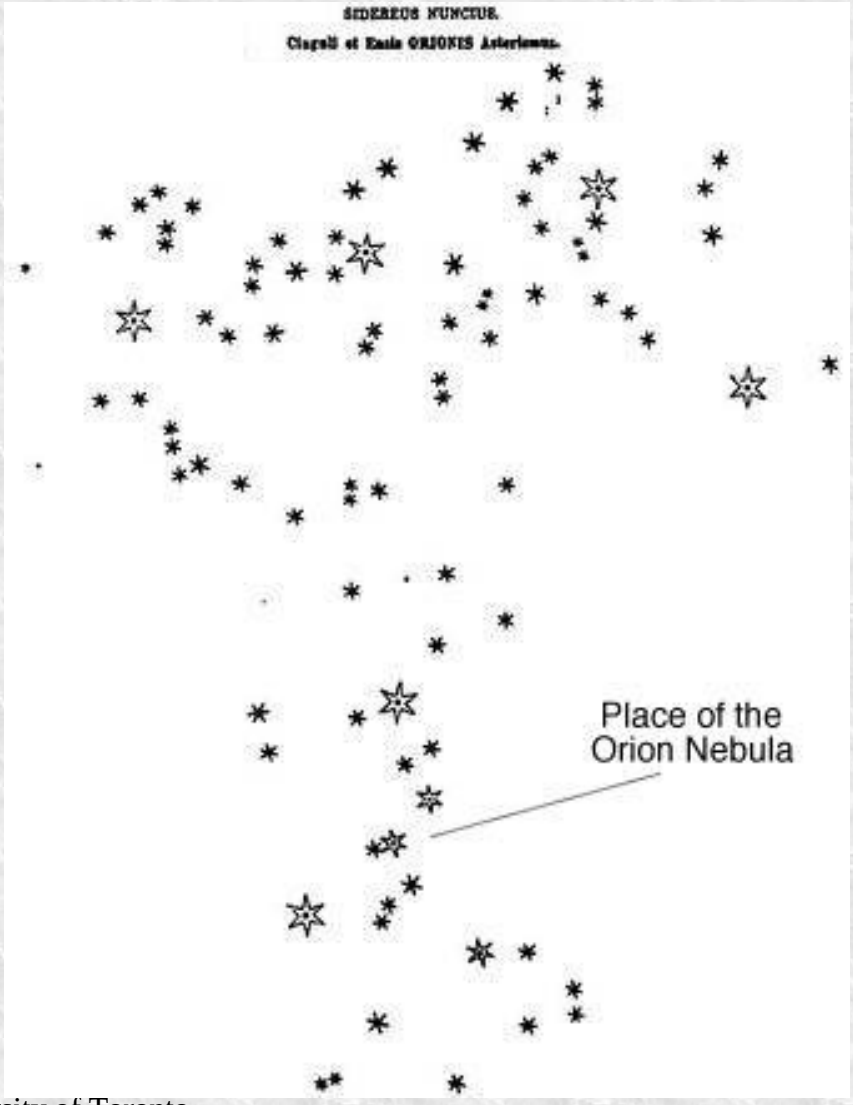
Galileo's Observations: The Sun



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).

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

Harlow Shapley (1885-1972)

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

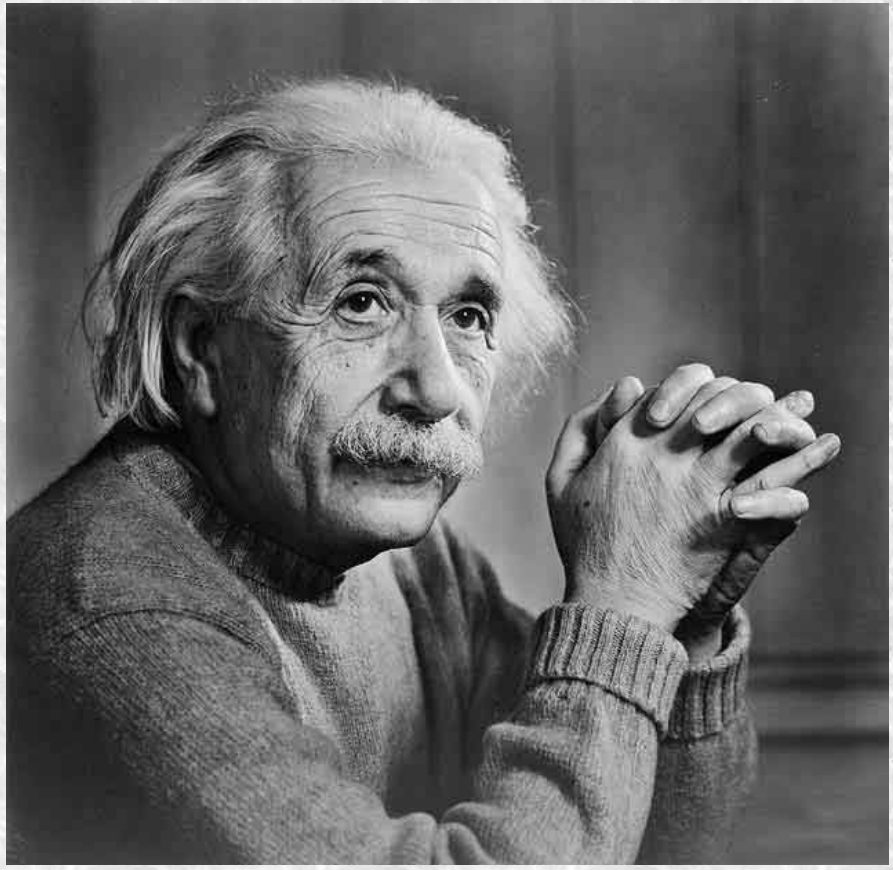
- Determined the size and shape of the Milky Way, and our position within it.
- Expert on stars and star clusters.
- Administrator and popularizer of astronomy.

Edwin Hubble (1889-1953)

Hale Observatories

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

Albert Einstein (1879-1955)



Karsh of Ottawa

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

Newton's Mirror (Reflecting) Telescope

Royal Society, London

Astronomical Photography

Kitt Peak National Observatory

- More information
- Objective information
- Permanent information

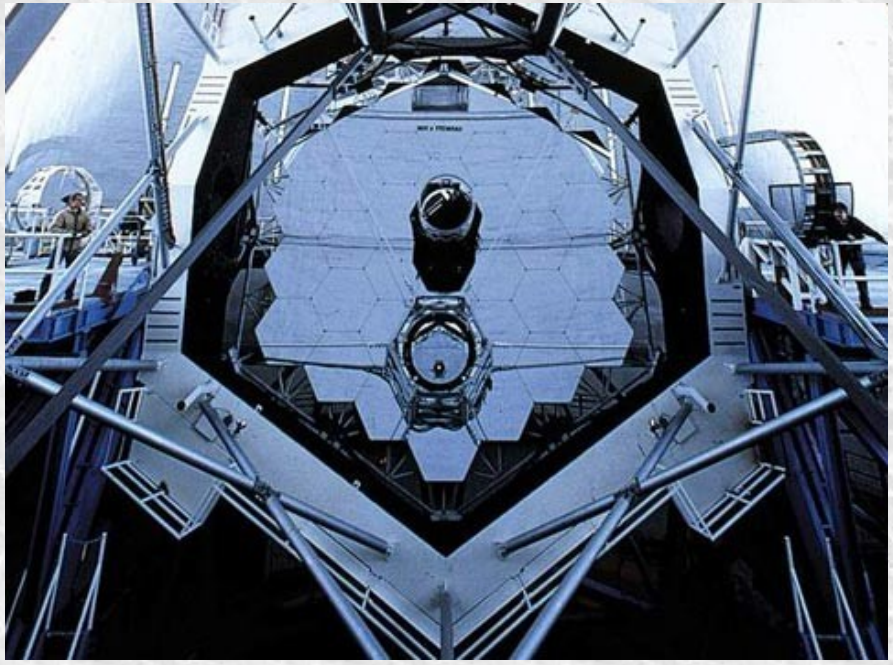
Telescope Mountings

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

- 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

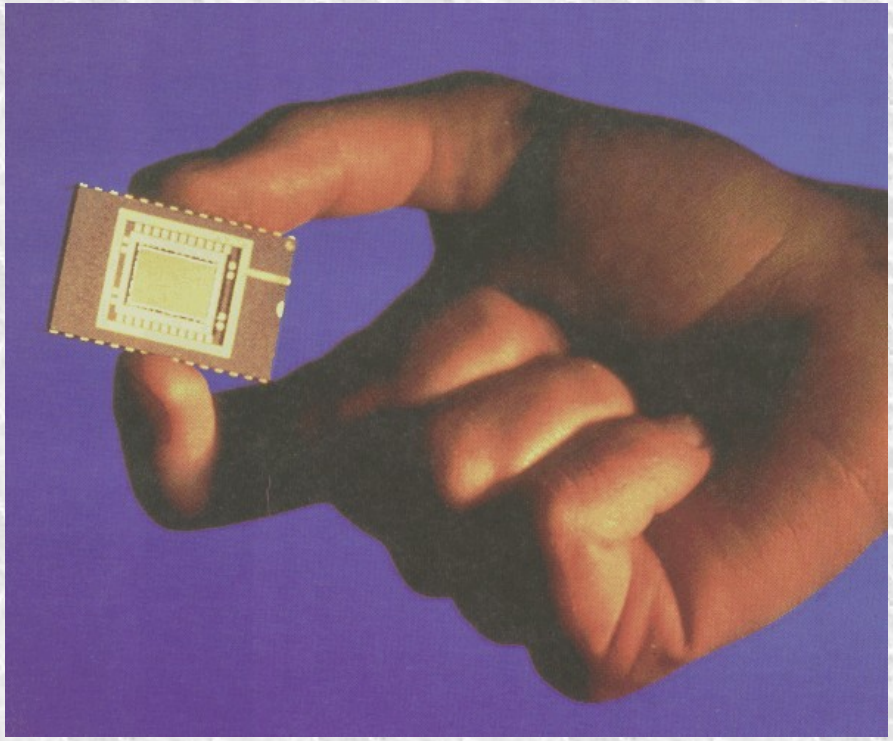
Larger Telescope Mirrors



Lawrence Livermore Laboratory

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

Digital Electronic Detectors

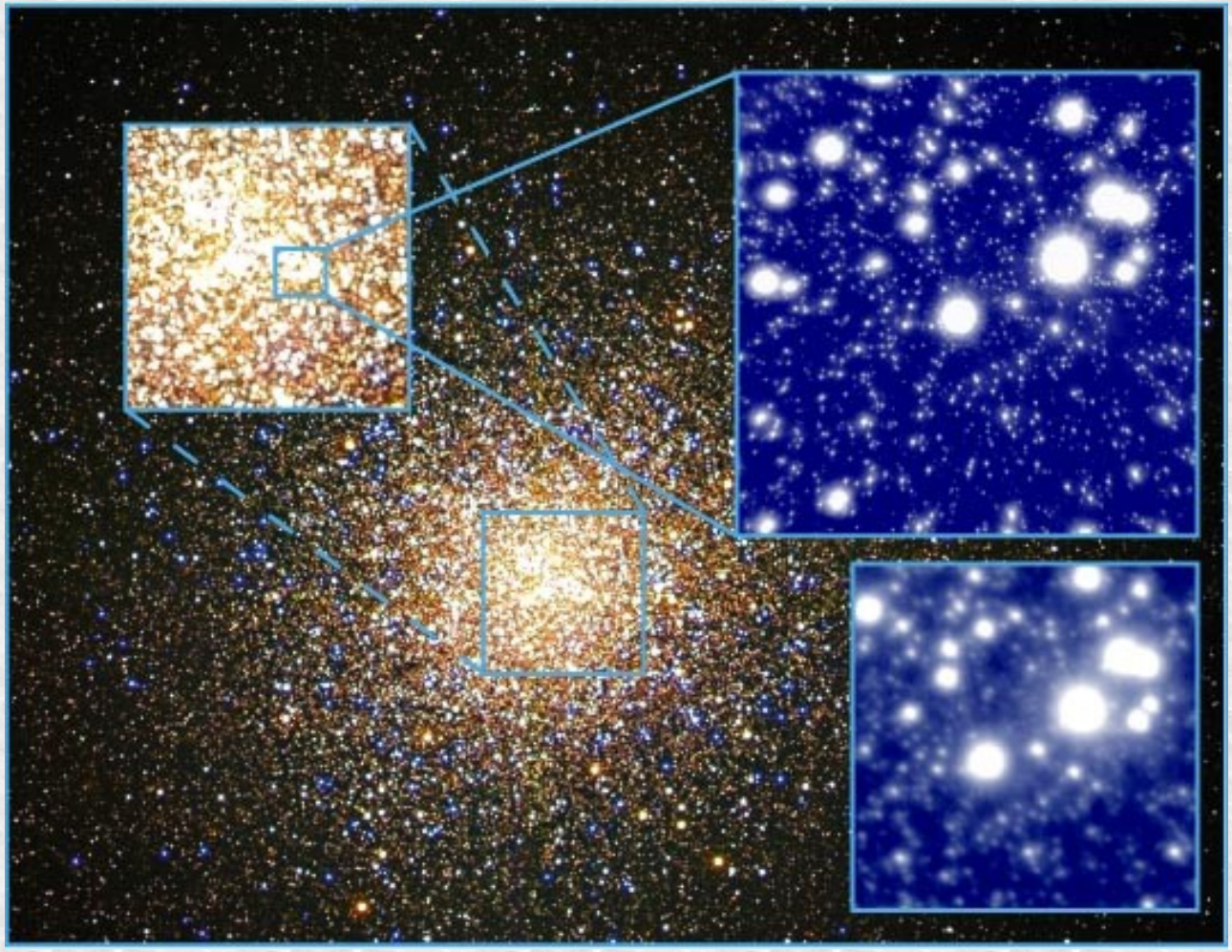


Smithsonian Astrophysical Obs'y

- 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.

Best Astronomical Sites (Mauna Kea, Hawaii, and Chile)

Adaptive Optics
On the Gemini Telescope



Gemini Obs'y

Telescopes in Space

Telescopes to Study Wavelengths other than Light

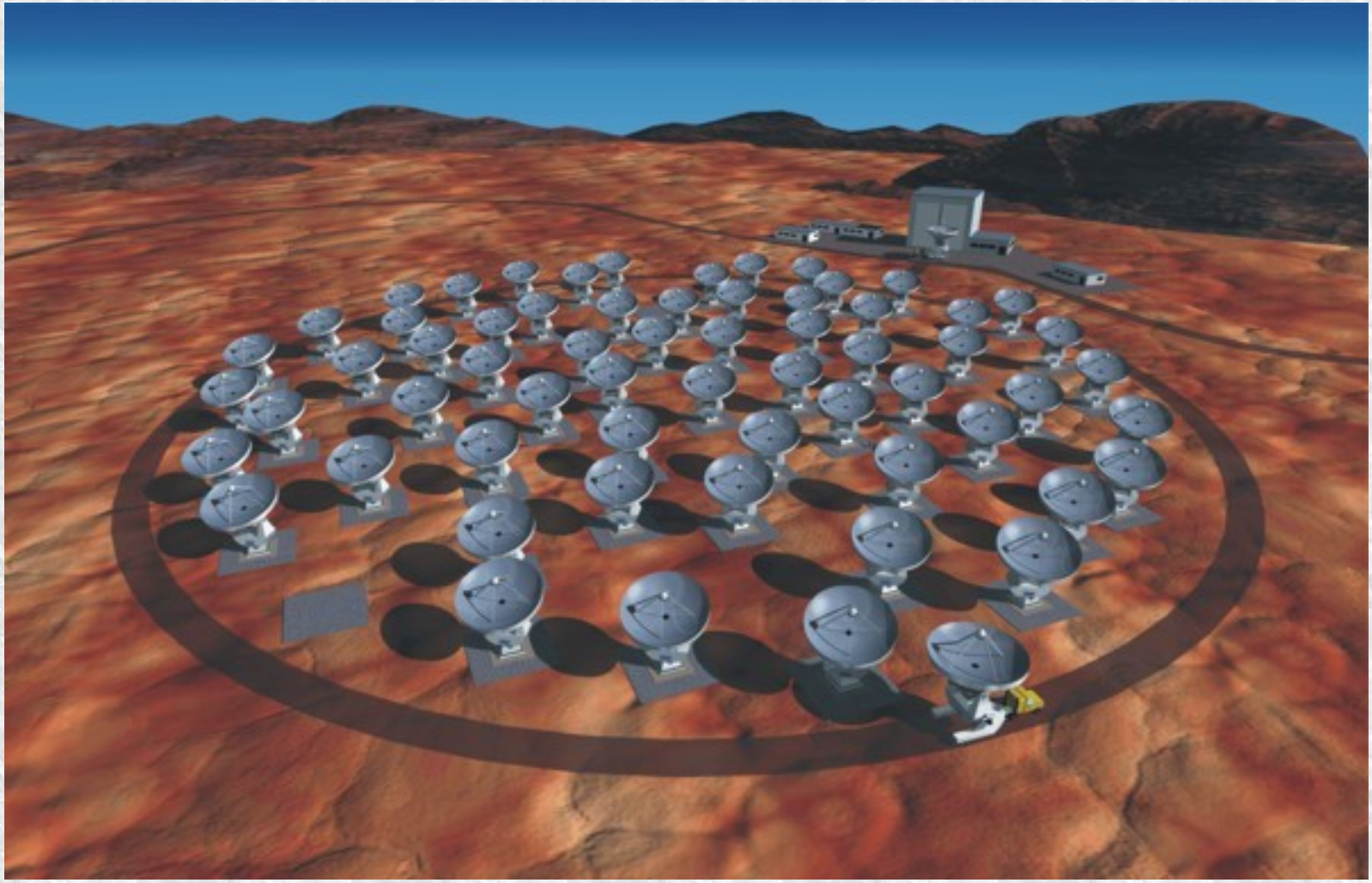
Galileo's Legacy, John R. Percy, University of Toronto

NRC Canada

“Chandra” X-Ray Telescope

NASA

Atacama Large Millimetre Array
ALMA



NRC Canada

James Webb Space Telescope
JWST

Thirty-Metre Telescope

TMT Corporation

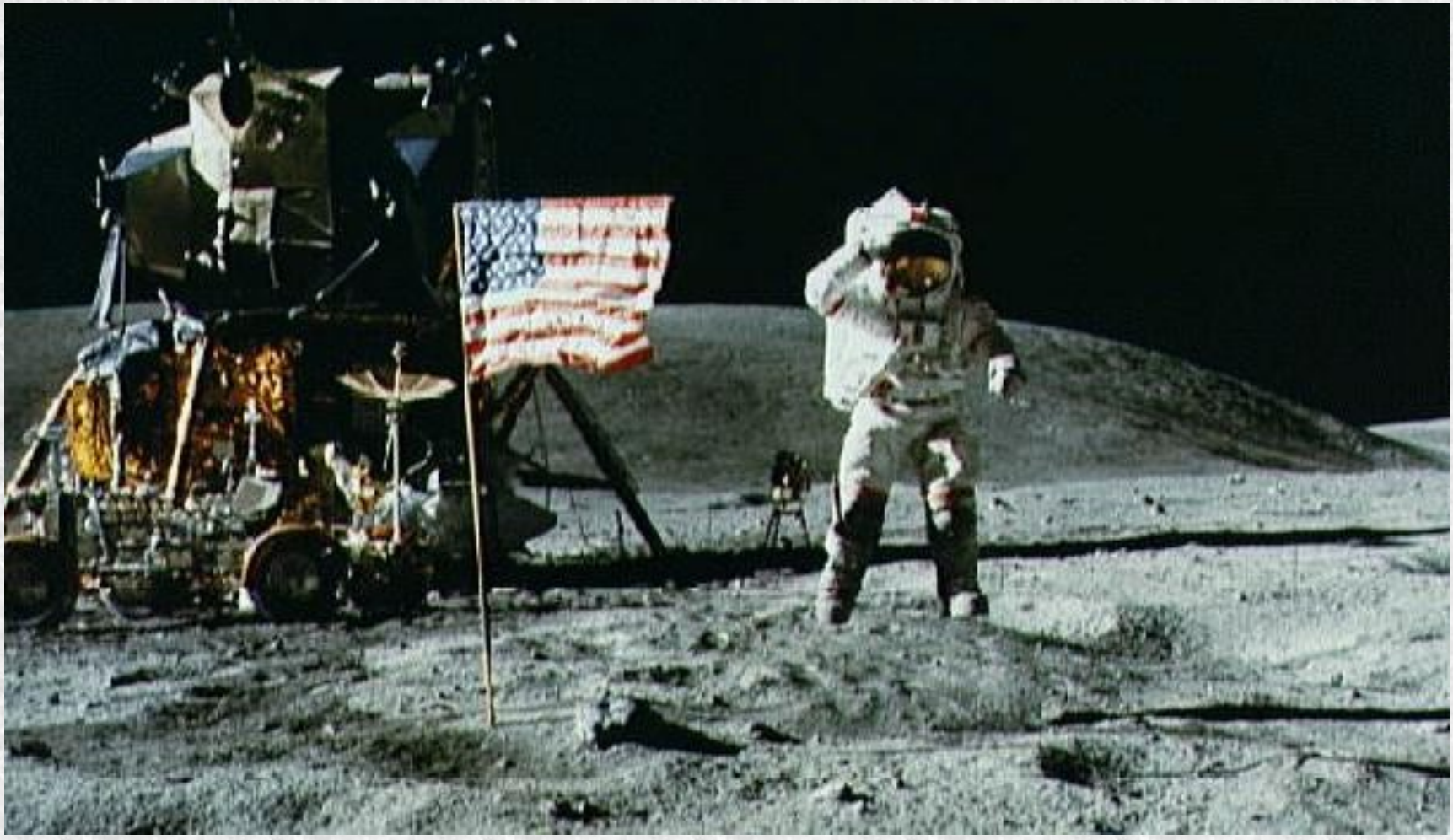
T

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 ingrediants 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 are 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”.

Humans Have Walked on the Moon

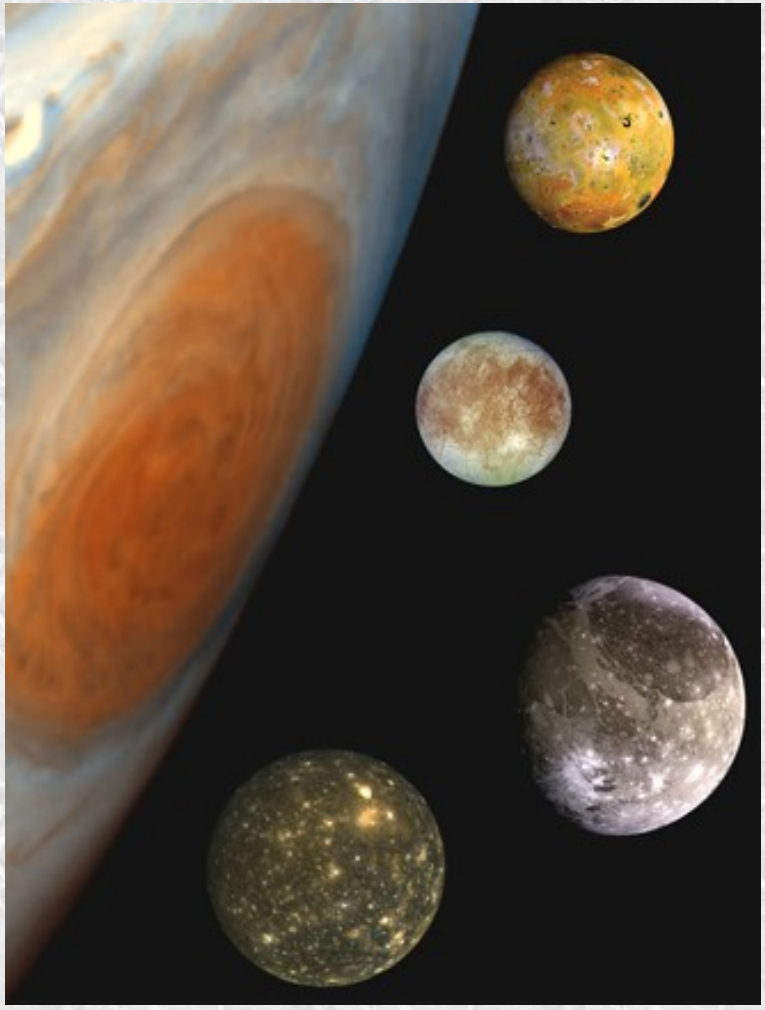


Spacecraft Have Explored Other Planets

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

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

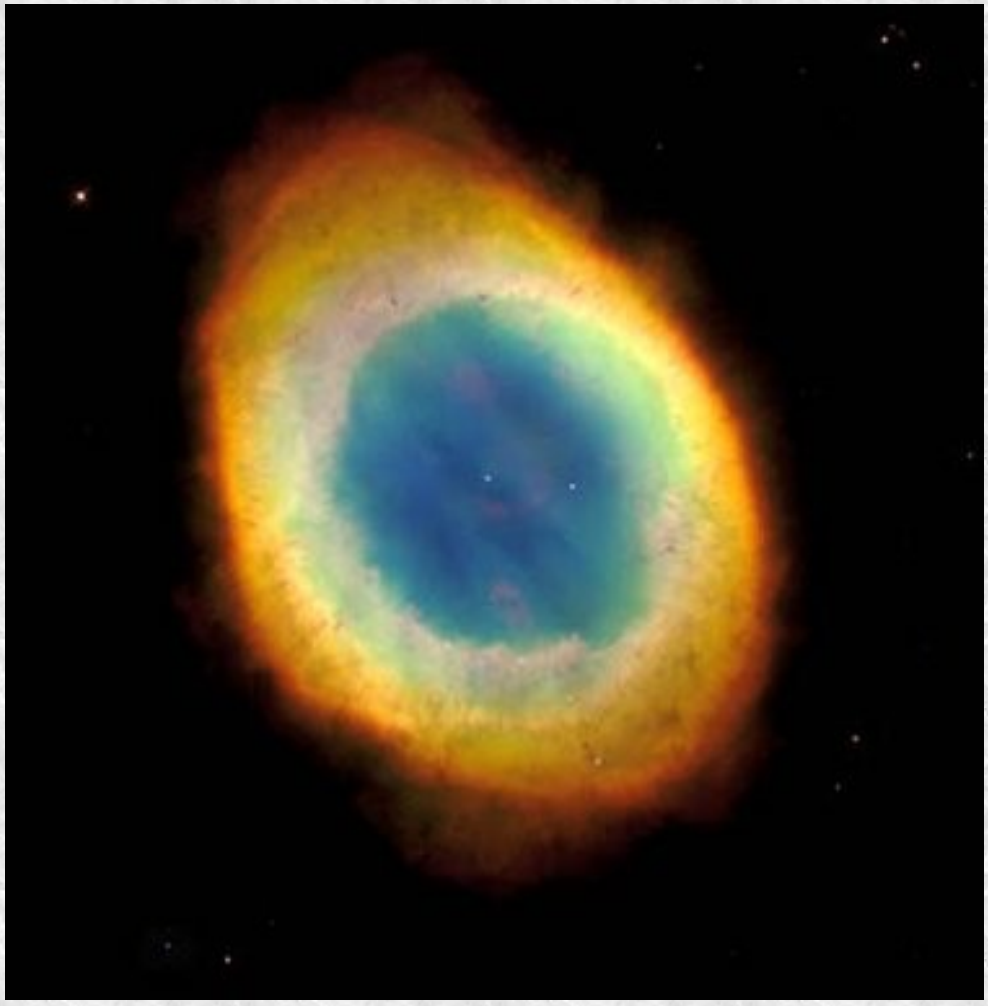
The “Galilean Satellites” of Jupiter



- Jupiter and its Great Red Spot (left)
- Io
- Europa
- Ganymede
- Callisto

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

The Death of a Sun-like Star
A Planetary Nebula ("The Ring")



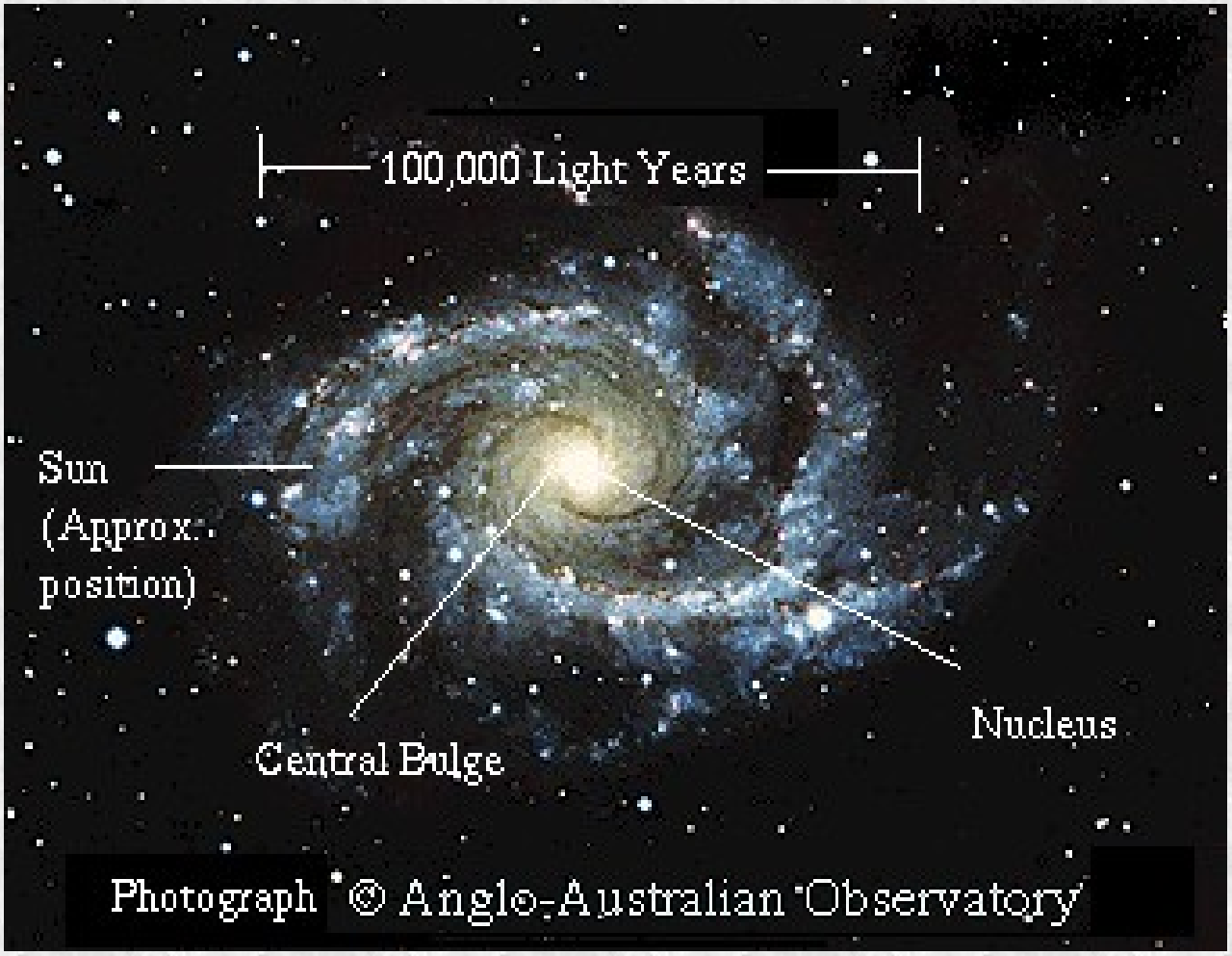
The Death of a Massive Star
A Supernova Remnant ("The Crab")

NASA

The Birth of Stars and Planets
The Orion Nebula

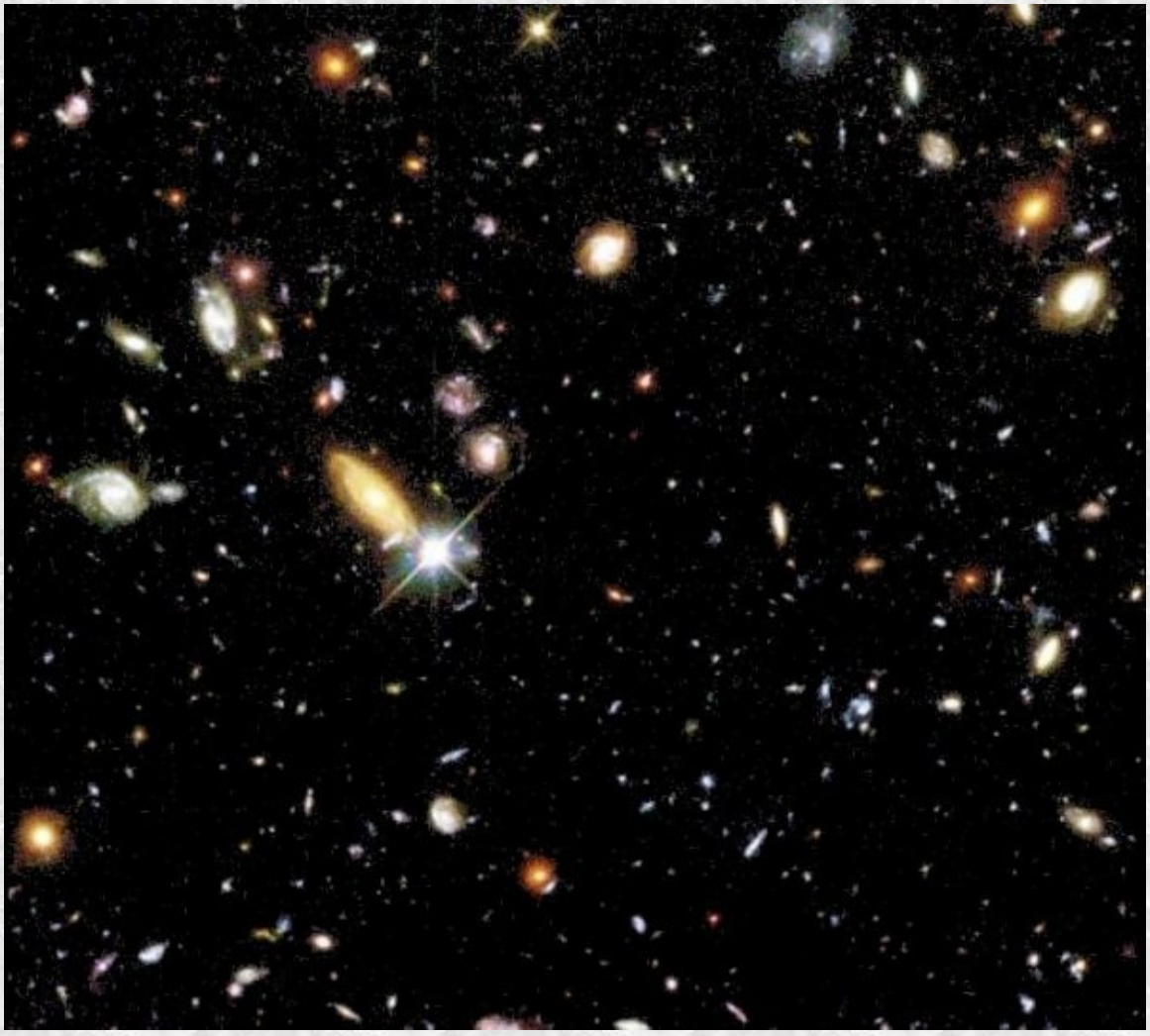
NASA

Our Milky Way Galaxy
300 Billion Stars



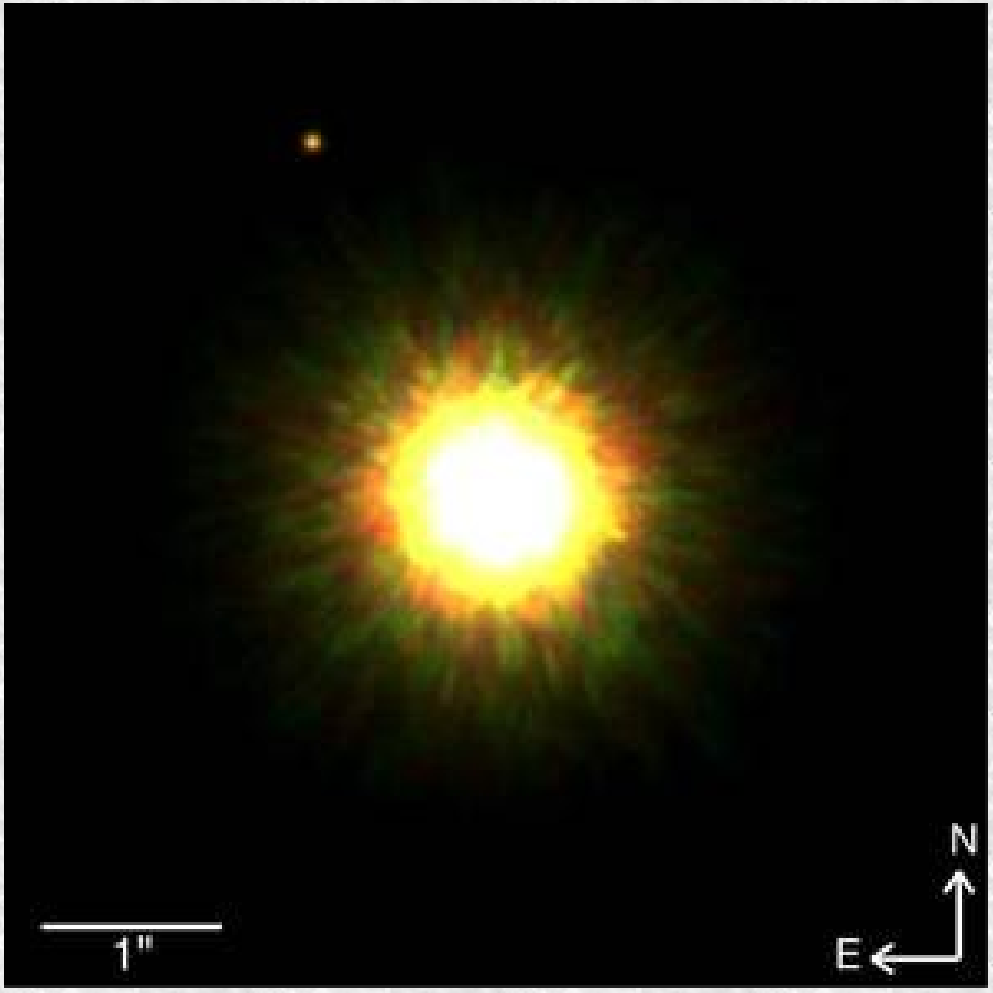
Billions of Other Galaxies

The Hubble Ultra-Deep Field



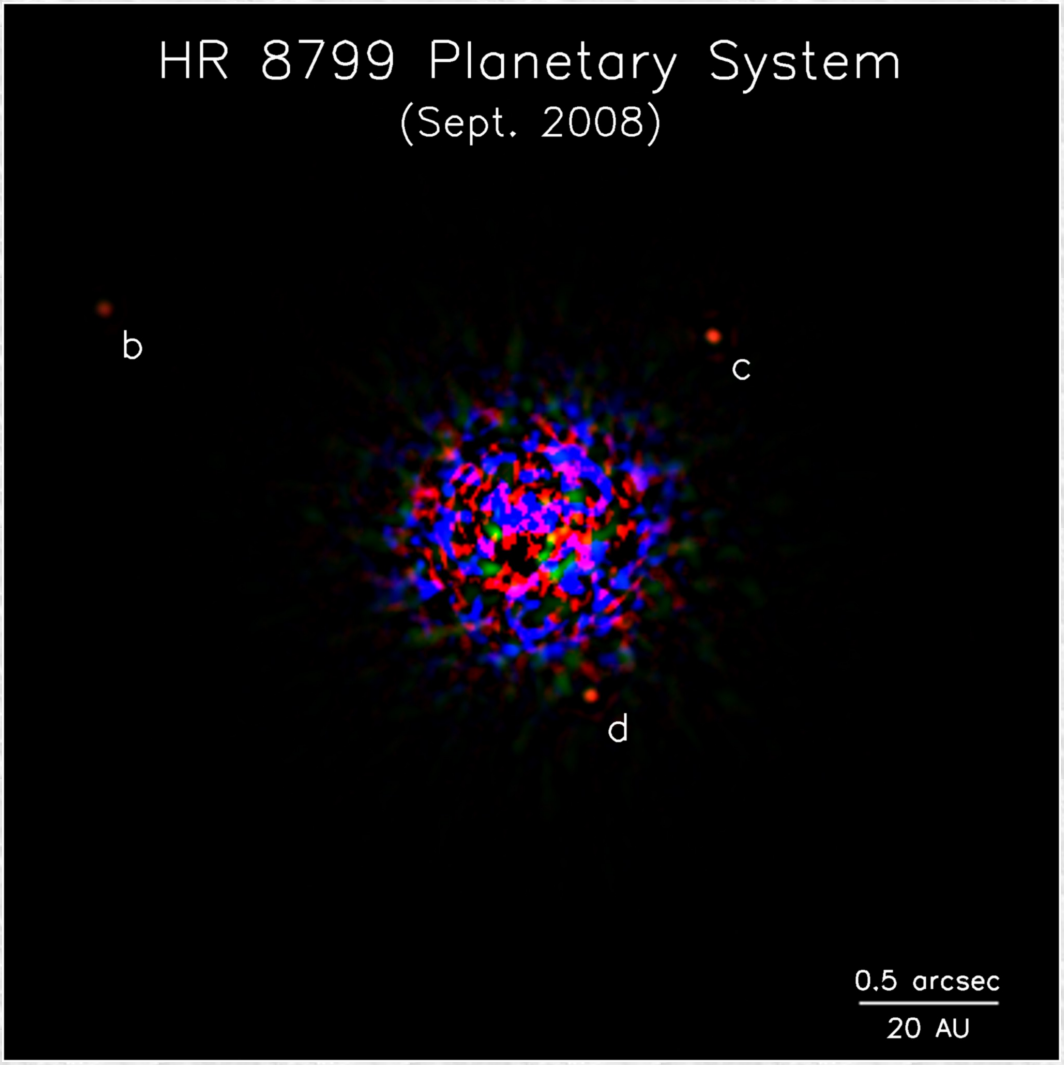
NASA

Exoplanets
Planets Around Other Stars



Gemini Observatory

Exoplanetary Systems



NRC Canada

Life in the Universe

NSF/NAIC/Arecibo

- 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!

The Value of Astronomy

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

Henri Poincare´