The Start of Modern Astronomy

The Birth of Chemistry Dissolves Aristotle's Elements

- Chemistry and Thermodynamics emerge around the middle of the 18th Century
- Temperature is not Heat!
  - Temperature is what you measure with a thermometer, heat is a form of energy "stored" in an amount of substance
- Temperature scales
  - Fahrenheit, Celsius, Kelvin

The Delayed Scientific Revolution: Chemistry

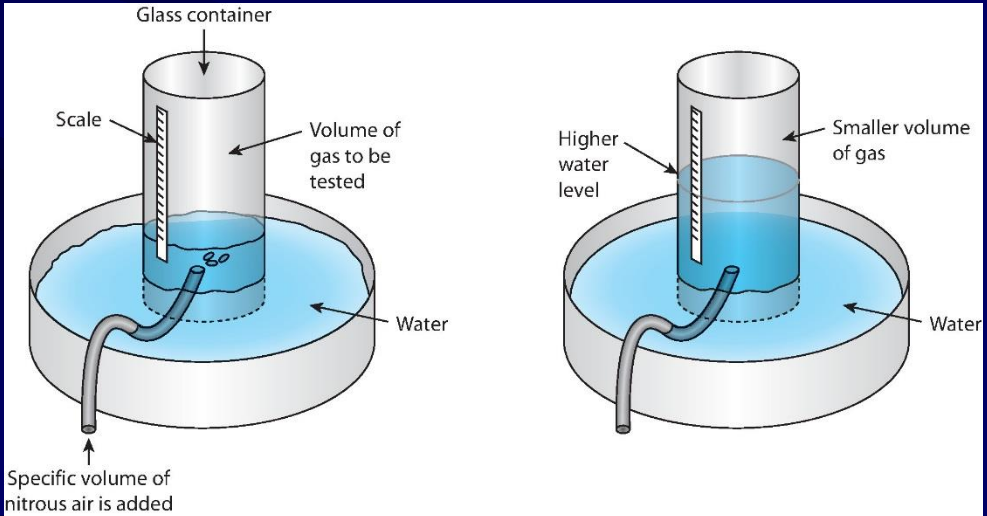
- Lavoisier's "*Methode de nomenclature de chimique*" (1787) appears 100 years after Newton's *Principia* (1687)
- In the 1770's Black, Lavoisier and Priestley discover that air is not an element, but consists of many "airs":
  - Oxygen, nitrogen, carbon dioxide
- Starting point: explain combustion process

From Phlogiston to Oxygen

- The epicycle theory of chemistry: phlogiston theory holds that a hypothetical substance (phlogiston) leaves the substance upon combustion
- Quite the opposite: oxygen enters the substance!

Priestley's "Good Air" Experiment

- Lavoisier claims that heating the calx of mercury (HgO) releases "good air" (normal air) using Priestley's good air test
- Priestley falsifies the theory by adding even more nitrous air (NO) and discovers oxygen



Lavoisier renames the Alchemistic Substances and starts Chemistry

- Lavoisier explains combustion: in an exothermic reaction (energy, heat released), substances combine with oxygen
- He names/labels the new elements for what they do (function)
  - Oxy-gen, i.e. generator of acids
  - Hydro-gen, i.e. water creator
  - Nitro-gen, i.e. soda creator
- This slick notation enables efficient work in chemistry, and really starts chemistry as a science

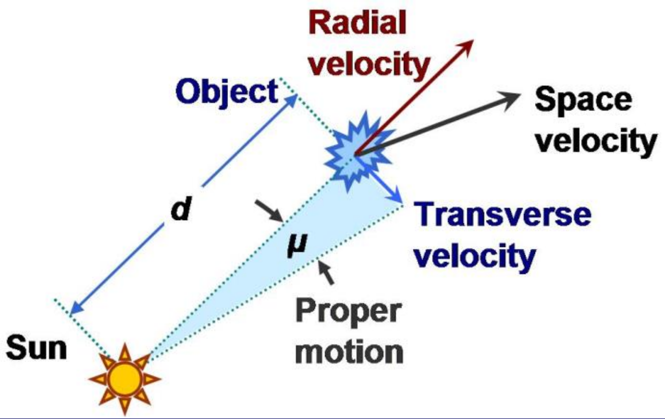
What became of Aristotle's Elements?

- Air → now a state of matter ("gaseous") or a mixture of gases (80% nitrogen, 20% oxygen)
- Water → a combination of two new elements (H_2O)
- Earth → a mixture of substances in their solid state
- Fire → the most enigmatic; eventually identified as heat or energy

The Deep Sky

- The universe beyond the solar system
  - Stars
  - Star clusters
  - Nebulae
    - Dark nebulae
    - Emission nebulae
    - Galaxies
    - Supernova remants
    - Planetary nebulae

The physical side of Stars



- Not just specks of light anymore in the 18th century!
- Halley: stars are not completely fixed, they move slowly wrt other stars
  - Sure, parallax, aberration, etc.? No, actual, physical motion in space → proper motion!
- Many stars have companions: double stars!
  - Stars obit other stars just like planets

Deep Sky Objects: Open Clusters

•Classic example: Plejades (M45)

•Few hundred stars

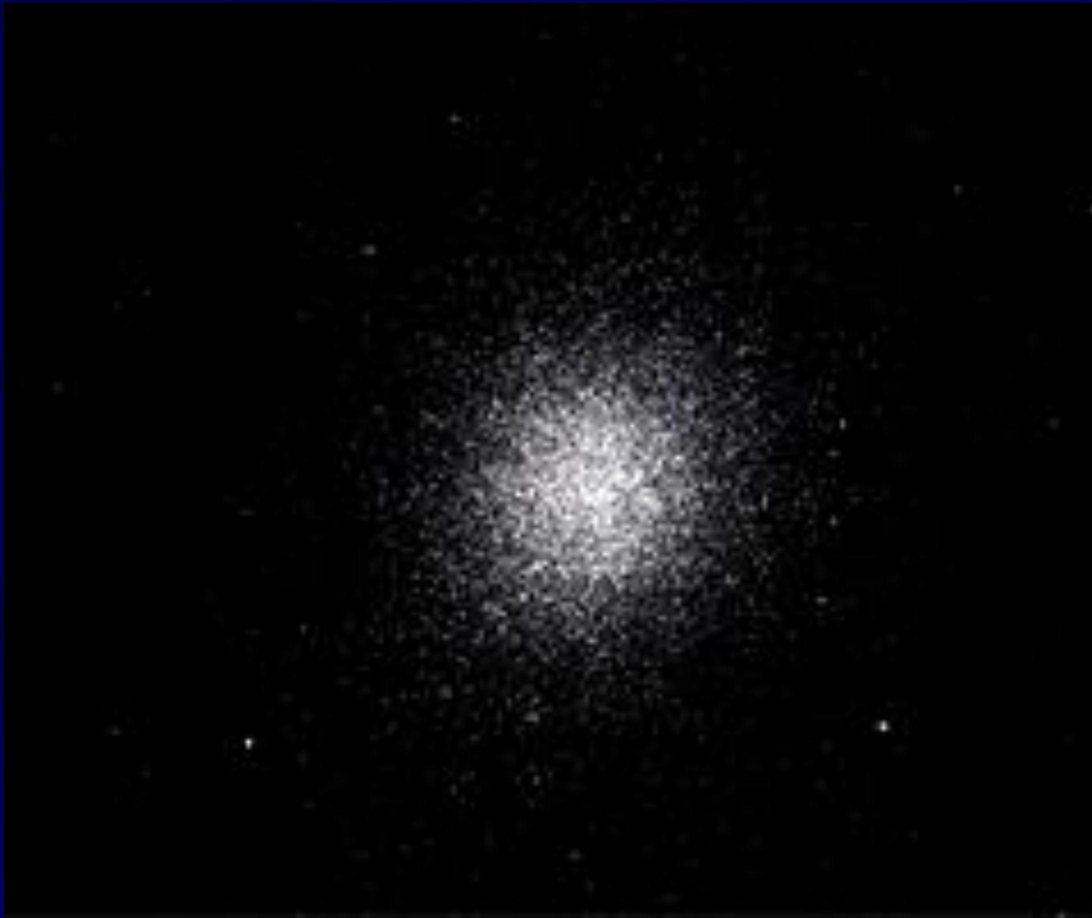
•Young: “just born”

→Still parts of matter around the stars

Deep Sky Objects: Globular Clusters

- Classic example: Great Hercules Cluster (M13)

- Spherical clusters
- may contain millions of stars
- Old stars
- Great tool to study stellar life cycle



Deep Sky Objects: Nebulae

Classic example: Orion Nebula (M 42)

- hot glowing gas
  Temperatures ~ 8000K
- Made to glow by ultraviolet radiation emitted by young O- or B-type (hot) stars located inside
- Color predominantly red, the color of a particular hydrogen emission line (“H_α”)

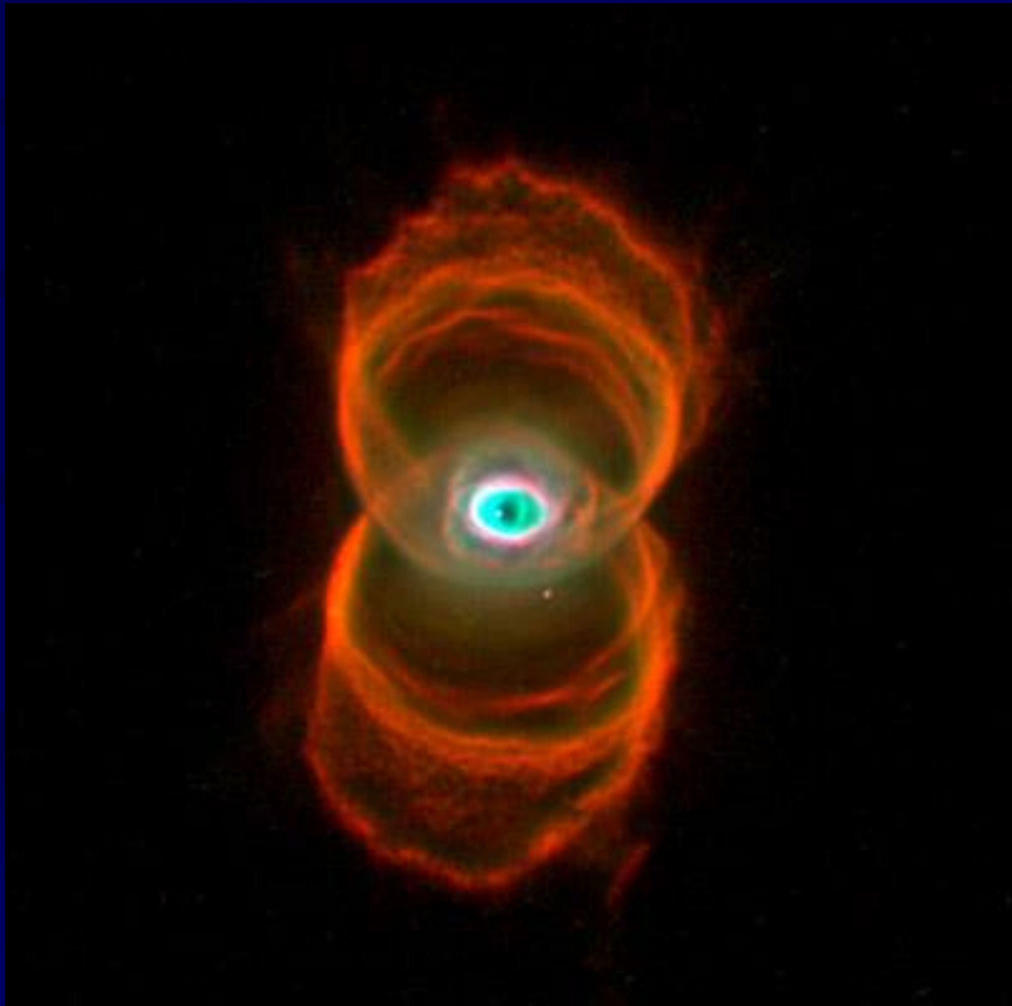
Dark Nebulae

- Classic Example: Horsehead Nebula in Orion

Deep Sky Objects: Planetary Nebulae

- Classic Example: Ring nebula in Lyra (M57)

  (Here: "Eye of God" Nebula)



- Dead, exploded stars
- We see gas expanding in a sphere
- In the middle is the dead star, a **"White Dwarf"**

Deep Sky Objects: Galaxies

- Classic example: Andromeda Galaxy (M31)

- “Island universes”
- Made out of billions of stars and dust
- Very far away (millions of ly’s)
- Different types:
  – Spiral, elliptic, irr.

Deep Sky Catalogues

- Some of the best deep sky objects can be found in the Messier Catalogue (e.g. M 31)
- Messier (around 1770) catalogued the objects not to confuse them with comets
- There are 110 Messier Objects

- Other catalogues:
  – NGC: new general catalogue (1880) lists 7800 objects
  – Caldwell list: 109 best non-messier objects
  – Herschel 400: from Herschel's famous list, early 1800's

Skylab Workshop

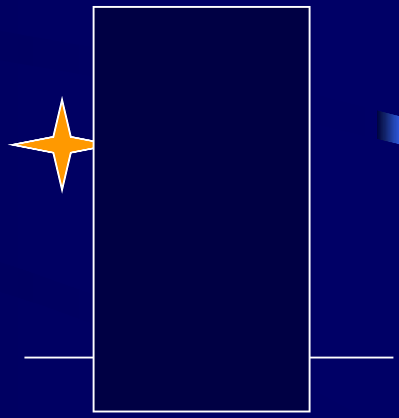
- Choose one of six possible projects
  - All involve observing
- May work in groups of up to four
- Hand in one report per group
- Due on last day of classes, first draft Wed Oct 18 Weather may be a problem, so **start early**!
  - If you wait and the weather turns bad, you will have to do the term paper
- Come ask me if you have questions

Making Measurements

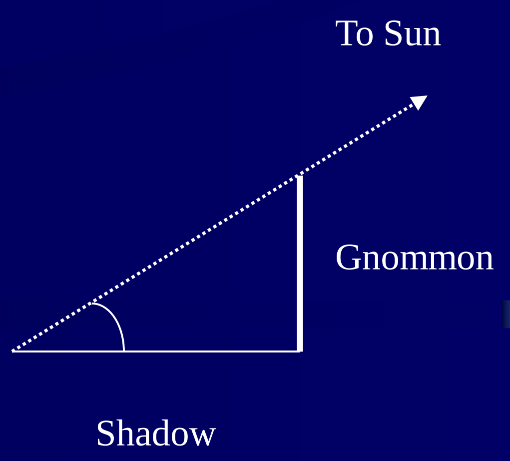
- Errors
  - Random
  - Systematic
- With every measurement, it is essential to provide an estimate of the uncertainty – the likely range of errors
- Example:
  - Using a ruler marked in mm, we round to the nearest marking – at most off by half a division, or 0.5 mm
  - Cite a measurement of 15 mm as 15 ± 0.5 mm to indicate that the real value of the length is likely to be anywhere between 14.5 mm and 15.5 mm
  - If a theory predicts a value of 15.2 mm, then a reading of 15 ± 0.5 mm is in agreement with the theory but a reading of 15 ± 0.1 mm is probably not

#1: Now where was I?

- Determining the difference between the *solar* and *sidereal* days
  - Understand the difference before you start
- Measure interval between times when a star returns to the same spot on the sky
- Measure times as accurately as possible (you should be able to get to within a second or so)
- Need 4–6 measurements, best if spread out with a few days between each measurement
- Ask if you have questions about the error analysis!



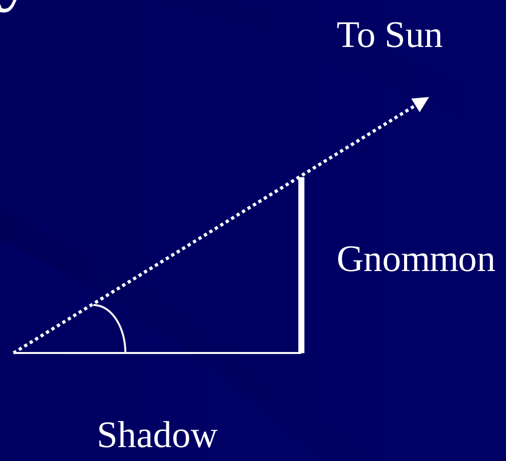
#2: Road Trip



- Measure the size of the Earth using Eratosthenes’s method
- Probably the most math of any of the projects (some trig)
- Need two sets of measurements separated (N–S) by 150 miles or so
  - Detroit or Lexington, say
  - Don’t go too far East or West (a little is okay)

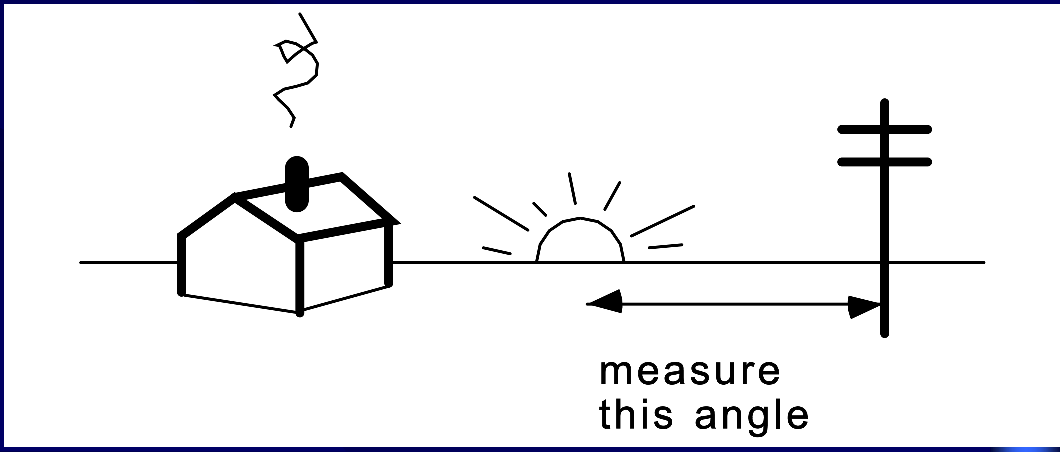
#2: Road Trip (cont'd)

- Need two sets of measurements separated (N–S) by 150 miles or so
  - Detroit or Lexington, say
  - Don't go too far East or West (a little is okay)
- Ask me if you want more details on the trig, or if you have questions about the error analysis
- Measurements should be as close as possible in time
  - Ideal would be on the same day by different group members



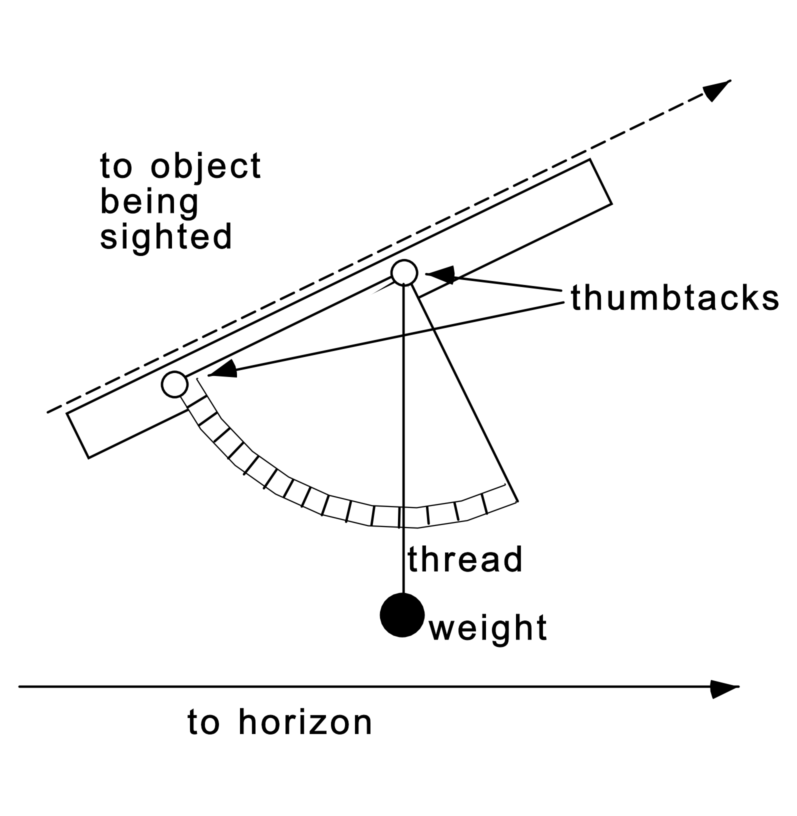
#3: Where did I put that chart?

- Study variation of the rising/setting points of the sun over time
- Need at least 10 sunrises or sunsets; more is better
- Measure time and azimuth (angle relative to North)
  - Note position of sunrise/sunset on horizon
  - Measure angle to that position relative to some fixed landmark (mountain, etc.)



#4: That thing is supposed to be a bear?

- Study the apparent motion of the stars in the night sky
- Requires one entire (clear) night
- Most involved equipment making of all the projects!
- Best to get out of the city; avoid bright moon
- Every hour, measure elevations of four stars in different constellations using a *quadrant*



#5 Take a Photo!

- take long exposure photographs of the night sky.
- stars appear to rotate once around the Earth in a day
- measure the duration of one rotation, this is the duration of a sidereal day
- Need camera capable of making long exposure photos and tripod to mount the camera absolutely stable.
- Time required: About an hour for a couple of nights which do not have to be adjacent.
- What to do: take photos of the night sky centered around the north pole star, Polaris. The stars will establish part of an arc around Polaris on the photo.

#6 Simulated Experiments

- In case weather becomes an issue
- Download manual and executable file from webpage
- Two choices:
  - Jupiter’s Moons
  - Hubble Law

Friedrich Wilhelm Herschel

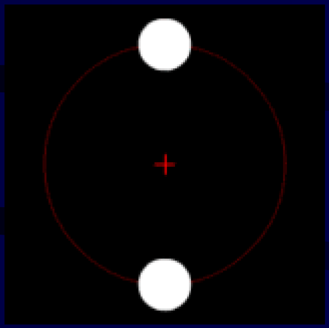
- Discoverer of Uranus (1781)
- Musician, then telescope maker
- Discovered thousands of galaxies, double stars
- Found a new form of light: infrared radiation

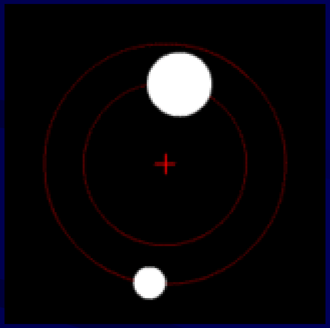
Binary Stars

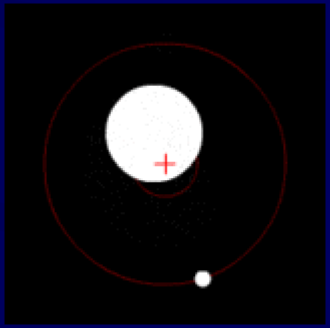
- Herschel sought to measure the parallax by finding close pairs of stars
- He assumed one is closer than the other
- Comparing their relative motion, he would then get a direct reading of the parallax of the closer star
- He found instead that the stars were often physically connected, gravitationally bound and orbiting each other → modern astronomy

Orbits depend on relative masses, so they reveal stars' masses

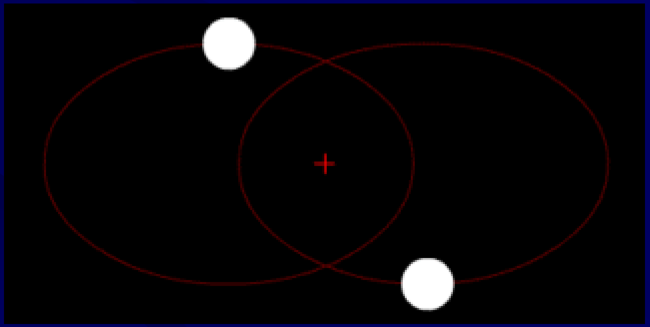
- Same mass 2m = M m<<M





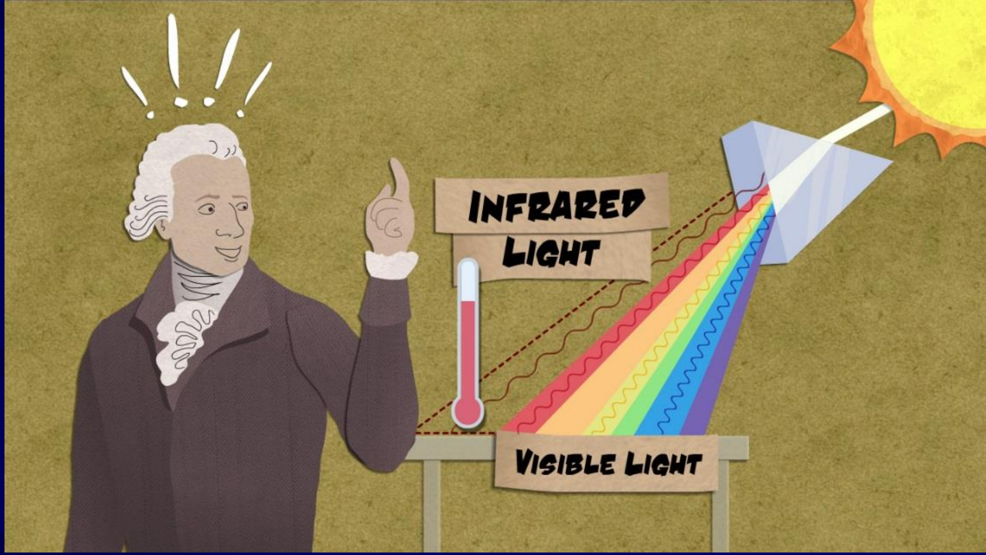


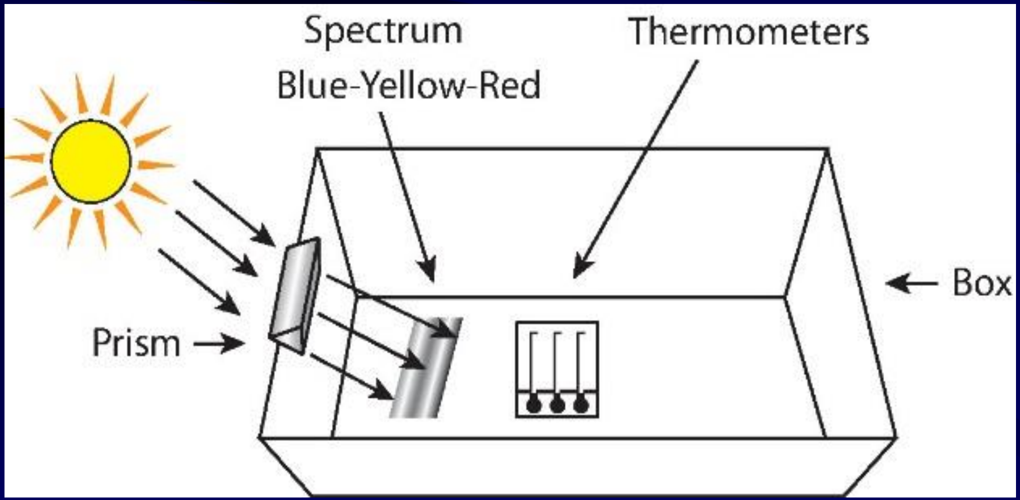
- Elliptical orbits:



(Wikipedia)

Herschel Discovers a new form of light – Infrared Radiation

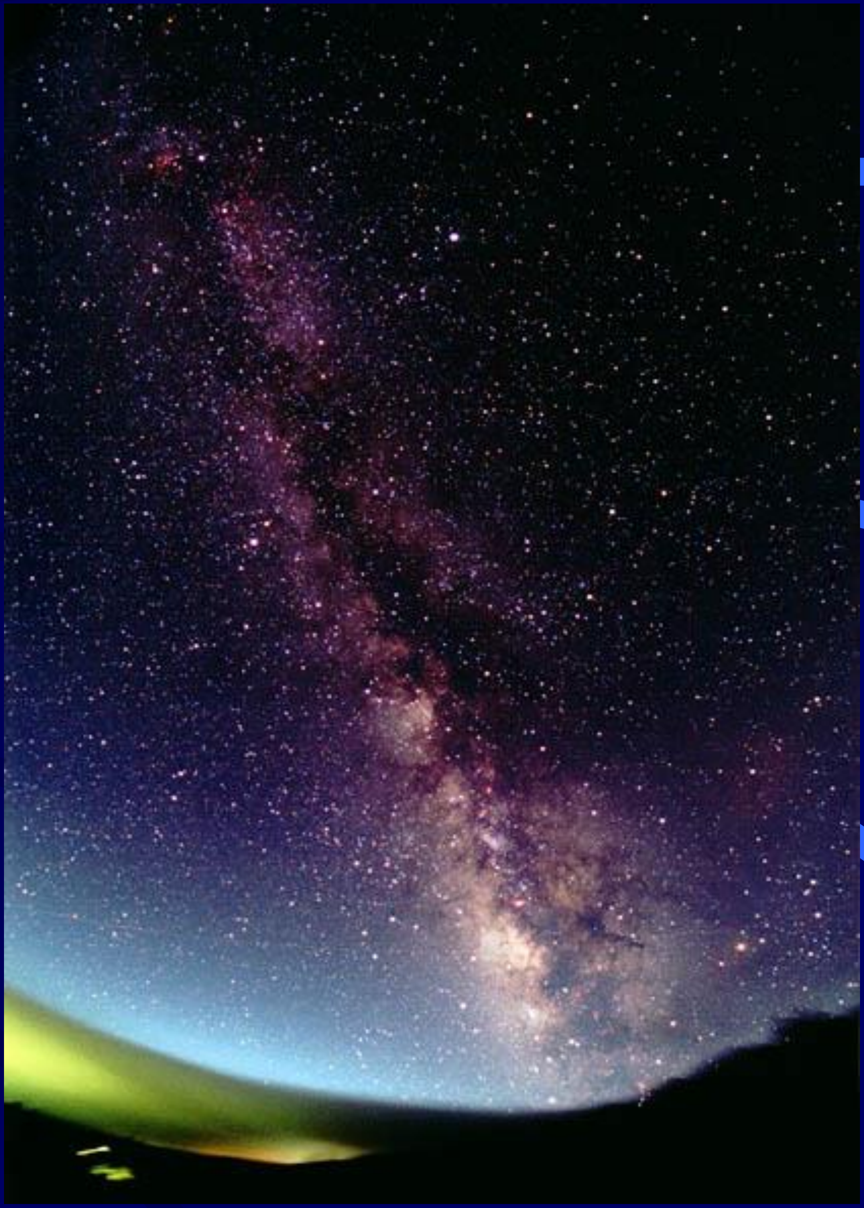




- In 1800 analyzes sunlight with a prism
- Finds it's hottest when it's redder than red: infra-red
- Ritter (1801): also violetter-than-violet light exists: ultra-violet

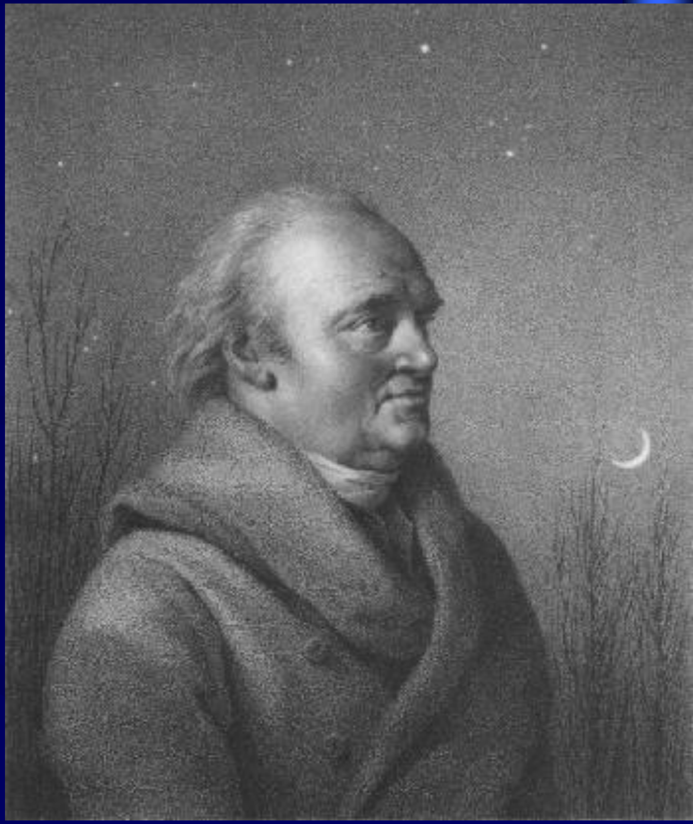
Exploring the Milky Way

- Appears as a milky band of light across the sky
- A small telescope reveals that it is composed of many stars (Galileo again!)
- Our knowledge of the Milky Way comes from a combination of observation and comparison to other galaxies



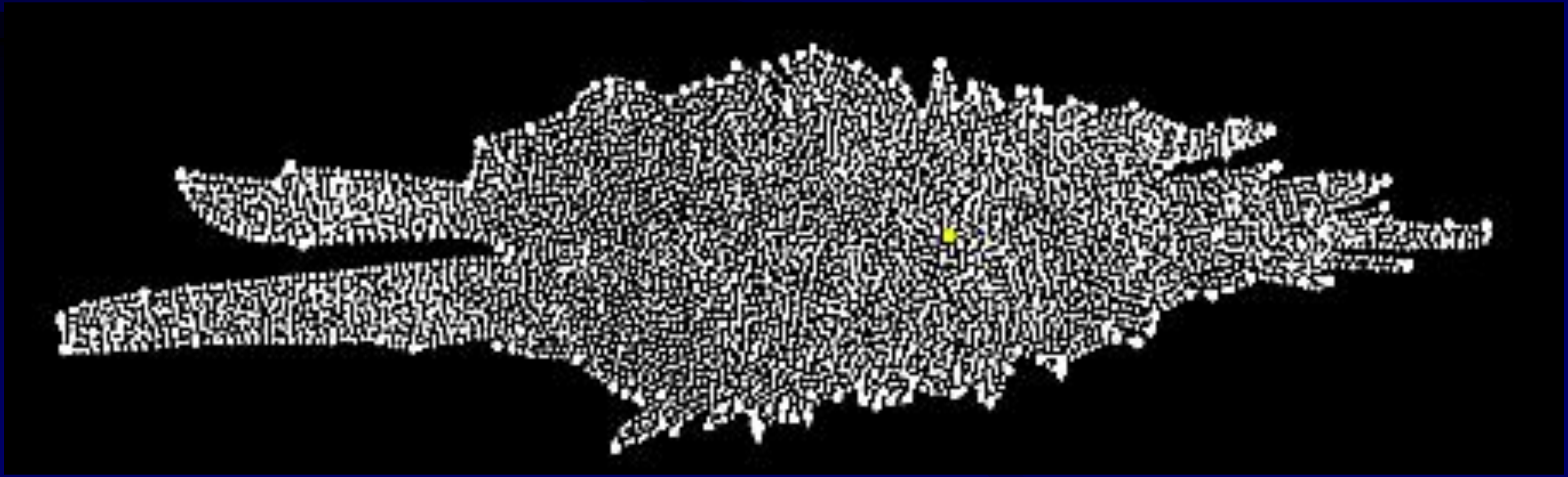
Herschel's Model of the Milky Way

- Simple model:
  - Assumed all stars have the same absolute brightness
  - Counts stars as a function of apparent magnitude
  - Brighter stars closer to us; fainter stars further away
  - Cut off in brightness corresponds to a cut off at a certain distance.
- Conclusion: there are no stars beyond a certain distance



Herschel's Findings

- Stars thinned out very fast at right angles to Milky Way
- In the plane of the Milky Way the thinning was slower and depended upon the direction in which he looked
- Flaws:
  - Observations made only in visible spectrum
  - Did not take into account absorption by interstellar gas and dust

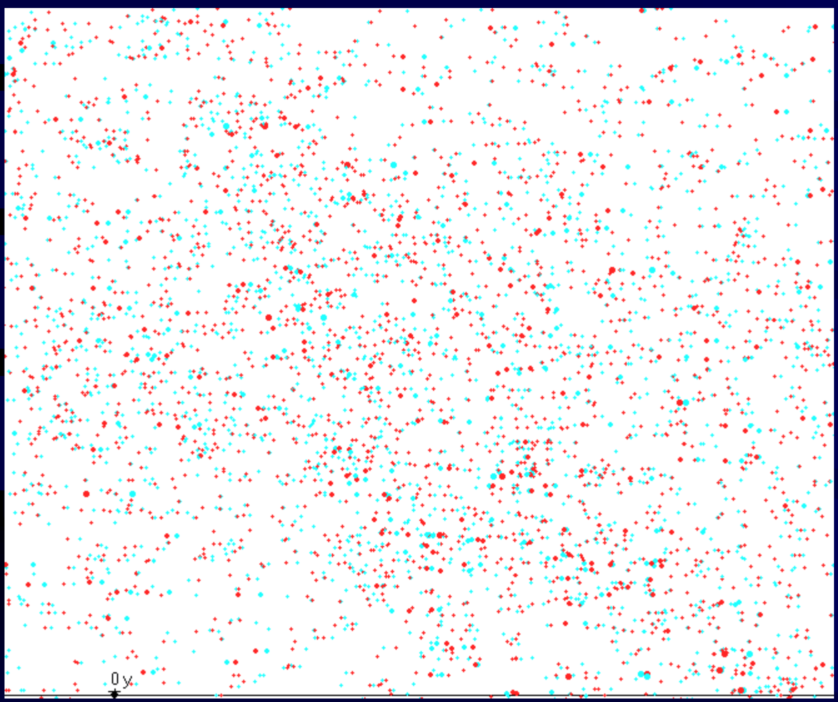


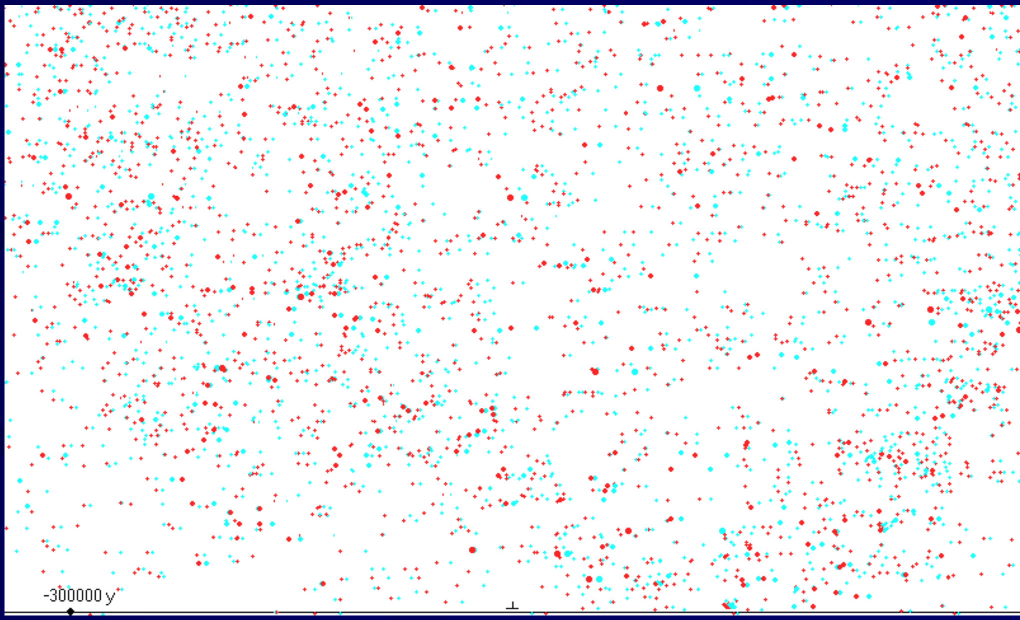
Herschel measures the Sun's velocity as it rotates around the center of the Milky Way

- Proper motion of stars is biased!
- Distribution of proper motions looks like snowflakes on the highway
- Seem to come from one point: the apex, or direction in which the sun is moving

- NOVA Video 4:23

Stars seem to drift away from the apex and towards the antapex





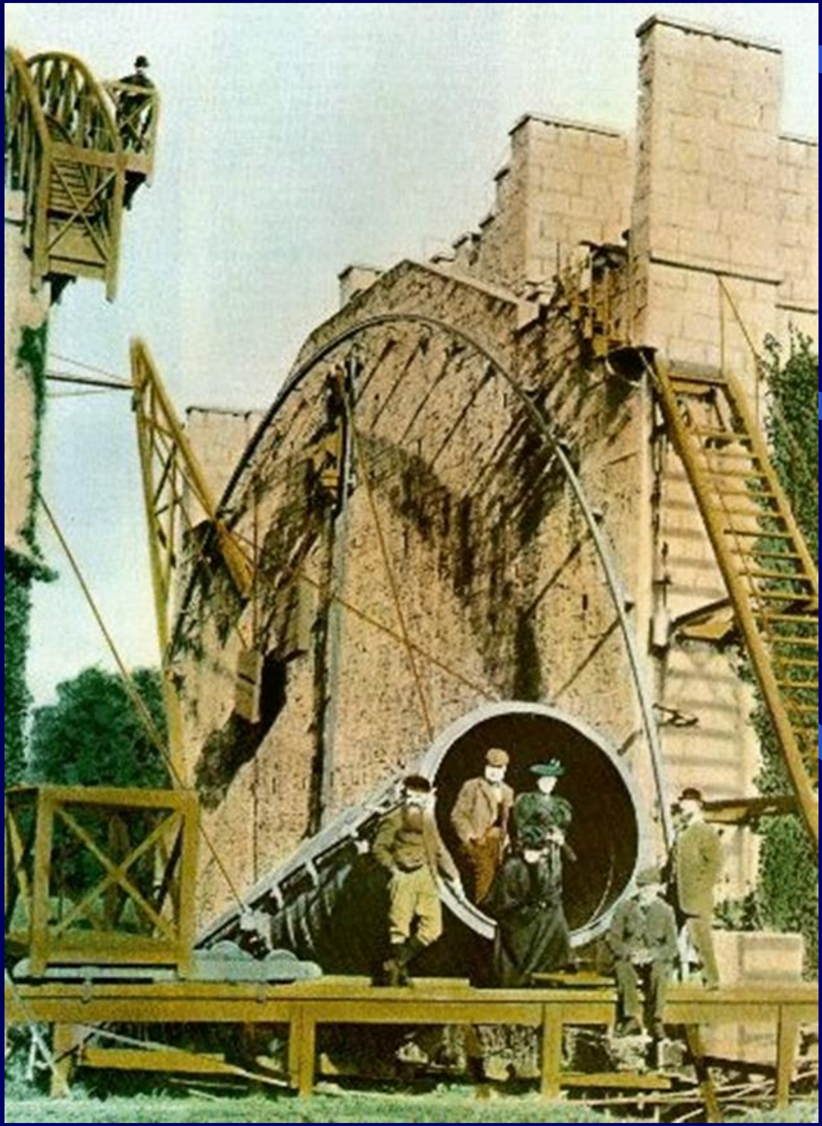
- The apex is the direction in which the sun is moving within the Milky Way (Wikipedia, Alexander Meleg)

Spiral Nebulae

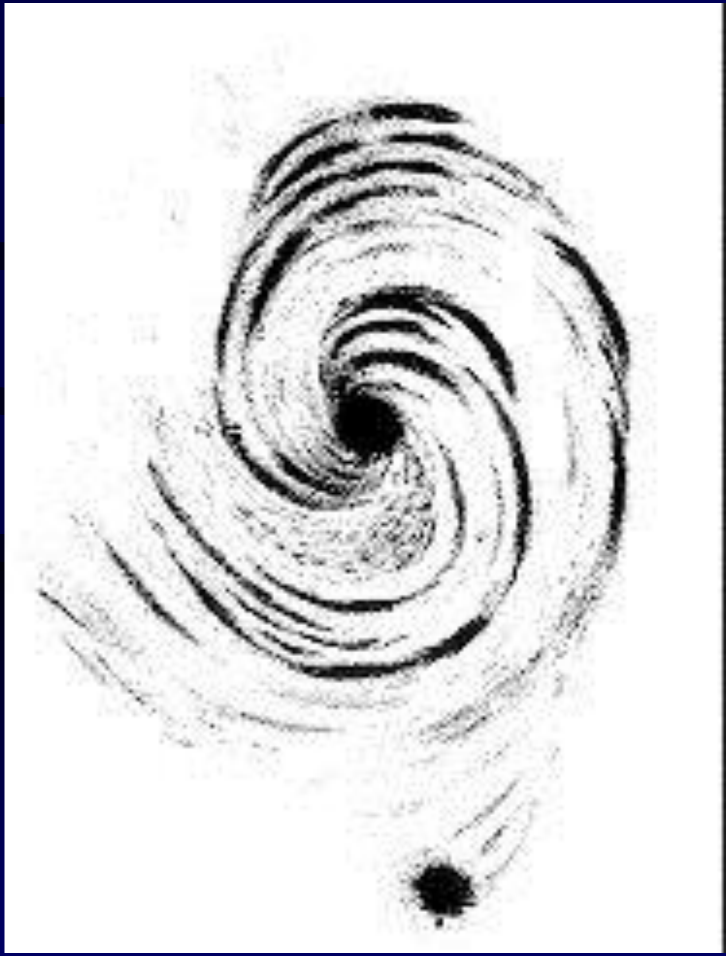
- Data: Lots of nebulous spots known in the night sky
- Questions: What are they? All the same? Different things?
- Need more observations!

➔Build bigger telescopes

(The Leviathan of Parsonstown shown, 1845
Biggest telescope of the World until 1917)

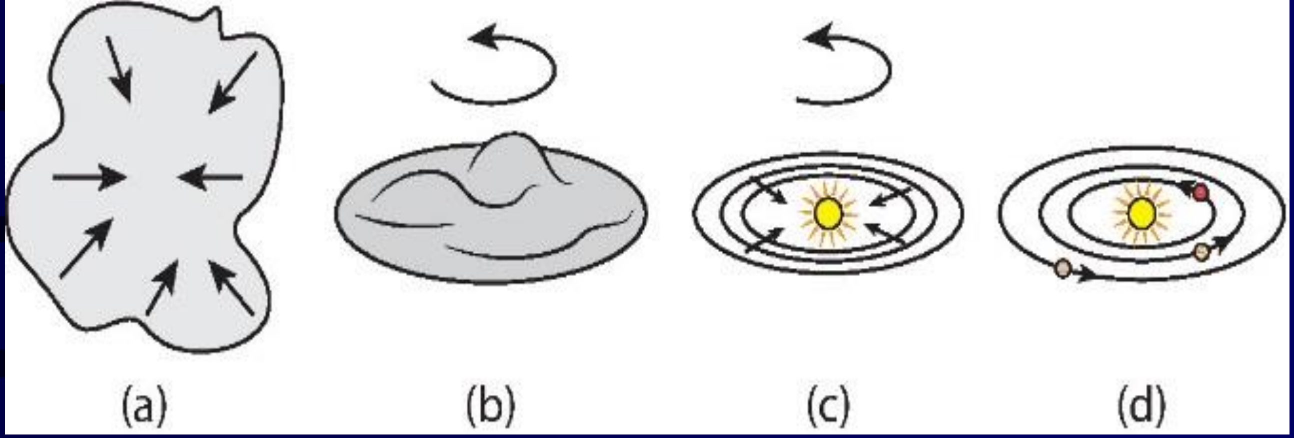


The first nebula discovered to have spiral structure: M51



First Toughts on the Formation of the Universe

- Maybe milky way is just one of many “island universes”?
- If the cosmos is physical, let’s think about how it developed, came to be, formed
- Ideas from Thomas Wright (Milky Way is a lenticular star system), Immanuel Kant and Heinrich Lambert (rotation stabilizes a Newtonian and hierarchical universe)



Kant's Nebular Hypothesis

- The galaxy and also the solar system may have formed from contraction and rotation of a giant gas and dust cloud
- The would explain why all planets orbit and spin counterclockwise
- Later extended by Laplace

The Southern Sky

- Stars below -50 declination (close to the SCP) not well known until the 18th century
- Halley in early 1700s observes from St Helena (16ºS)
- Lacaille (1750ies) and John Herschel (1830ies) observe from Cape Town, S Africa
- Lacaille introduces 14 new constellations
- J. Herschel catalogues southern deep sky objects