Astronomy 1: The Evolving Universe

Spring 2021

Prof. S. George Djorgovski

https://sites.astro.caltech.edu/ay1

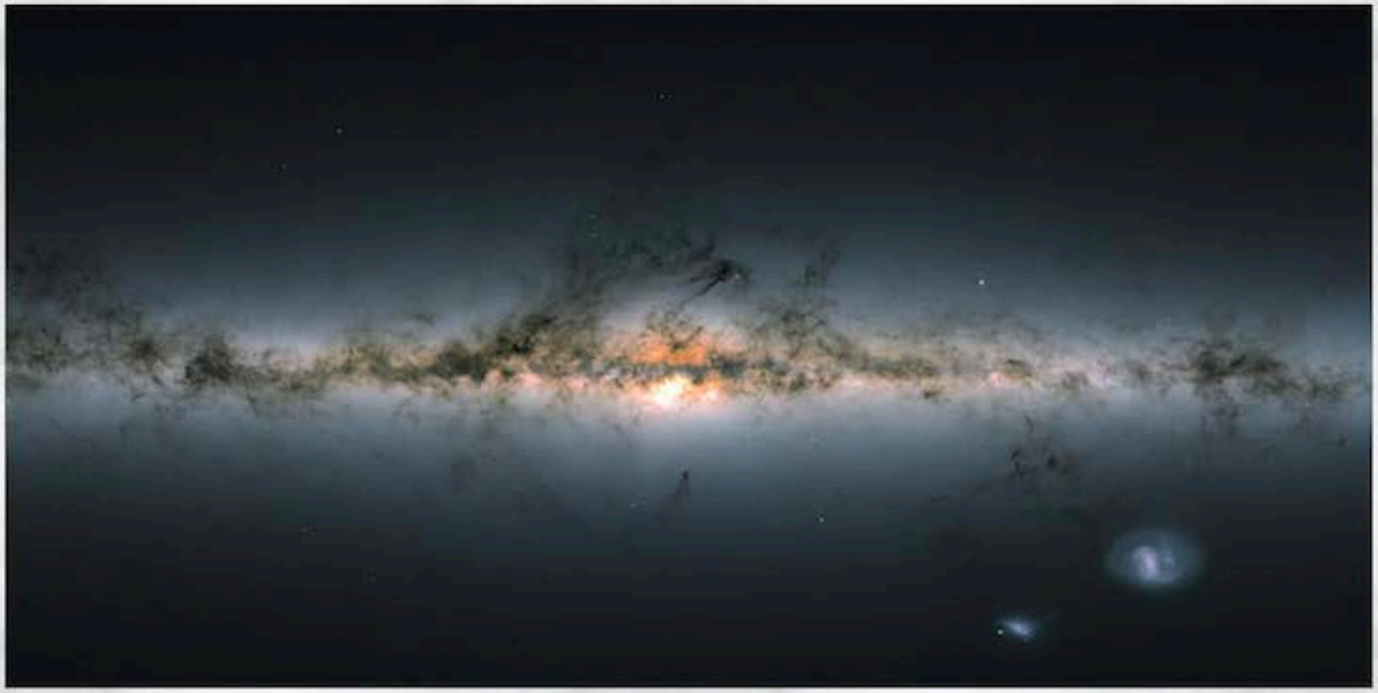
Milky Way as seen by *Gaia*

Some Class Logistics

- Class website: **https://sites.astro.caltech.edu/ay1**
  for the lectures (videos, slides), announcements, links.
  Canvas website for the assignments (homework, exams)
- A weekly summary lecture: Mondays 2-3 pm, on Zoom
  - Videos of the lectures from the previous years are linked on the class website, along with the pdfs of the slides. Along with posted readings and links, ***that is your "textbook"***
  - You can supplement them with ***any*** intro astronomy textbook you like, and our Library has a plenty of them, some of them available on line (see the website)
- Sections (mandatory!): Friday 2-3 pm on Zoom
- Weekly homework, except for the midterm and final weeks
- **Ask questions!**

Ay 1 - The Evolving Universe

Spring 2021



- Home
- About the class
- Class times+location
- The Evolving Syllabus
- Homeworks + exams
- Recitation
- Useful links
- Videos (YouTube)
- Facebook group

Lectures

Welcome to the Ay 1 - The Evolving Universe!

Please explore the links on the left.

Announcements:

- March 29: Welcome to the class! Please explore the links to the left. All lectures, slides, etc., will be posted here. All homeworks, solutions, and exams will be handled through the Canvas site. The first, introductory/summary lecture will be today, 2-3 pm; see the "times + location" tab.

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Lectures:

Lecture transcripts, in compressed folders: (pdf) * (txt). These are imperfect, but you may find them useful.

Lecture 1: Astronomy as a science

Some early history. Astronomy as a quantitative science, and as a branch of physics. Types of observations and their intrinsic limitations.

- Slides (pdf)
- Lecture videos:
  - Module 1.0: Introduction and Logistics
  - Module 1.1: The Oldest Science
  - Module 1.2: Astronomy as a Science
  - Module 1.3: Messengers from the Universe

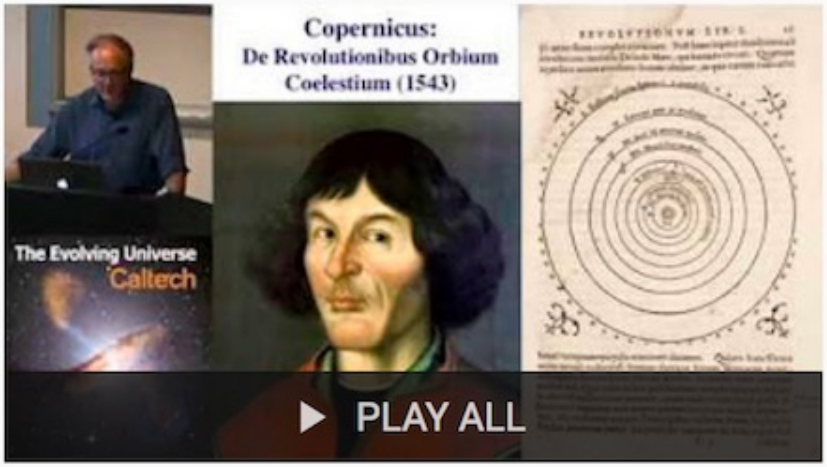
Lecture 2: Starting the Exploration

Some common units. Distances and parallaxes. An overview of scales and

https://www.youtube.com/playlist?list=PL8_xPU5epJdf-Ni1HSgxUUJhG6VBJMLOM

Gimg Gmail Gmaps Gtrans Duck Bing NYT WaPo NPR BBC FB WikiP Amzn Weather

Watch them on YouTube



Ay1001x - The Evolving Universe - George Djorgovski

90 videos • 10,351 views • Last updated on Aug 11, 2017

Unlisted

Caltech caltech SUBSCRIBE

1 

Ay1001x - Module 1.0
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4 

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5 

Ay1001x - Module 2.1
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Spring 2018

Some useful links:

More will be added, and suggestions are always welcome.

On-line education/outreach resources:

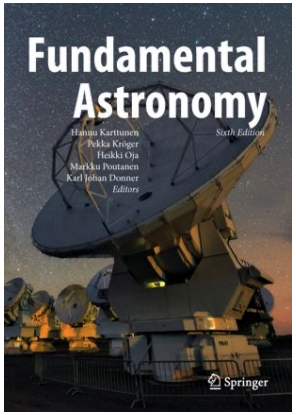
- Caltech astronomy outreach
- JPL (many popular astronomy links)
- The Library of Congress Astronomy Resources on the Internet
- Sky & Telescope Online Astronomy Links
- AstronomyOnline
- Imagine the Universe from the NASA GSFC
- CDS AstroWeb
- Griffith Observatory
- ispySpace.com
- StarDate
- PBS Astronomy Programs
- Popular astronomy links from UH/IfA
- Cornell astronomy links
- APOD educational links

Pretty pictures:

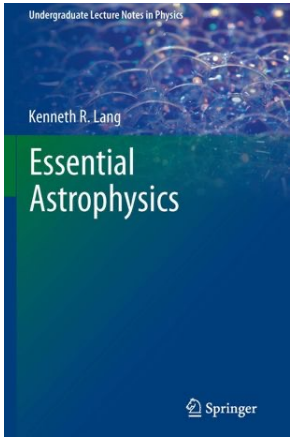
On-line Textbooks

Accessible from the caltech.edu domain

These can be used to ***supplement*** the classroom lectures (videos, ppts, links)



Karttunen, H., et al., "Fundamental Astronomy"



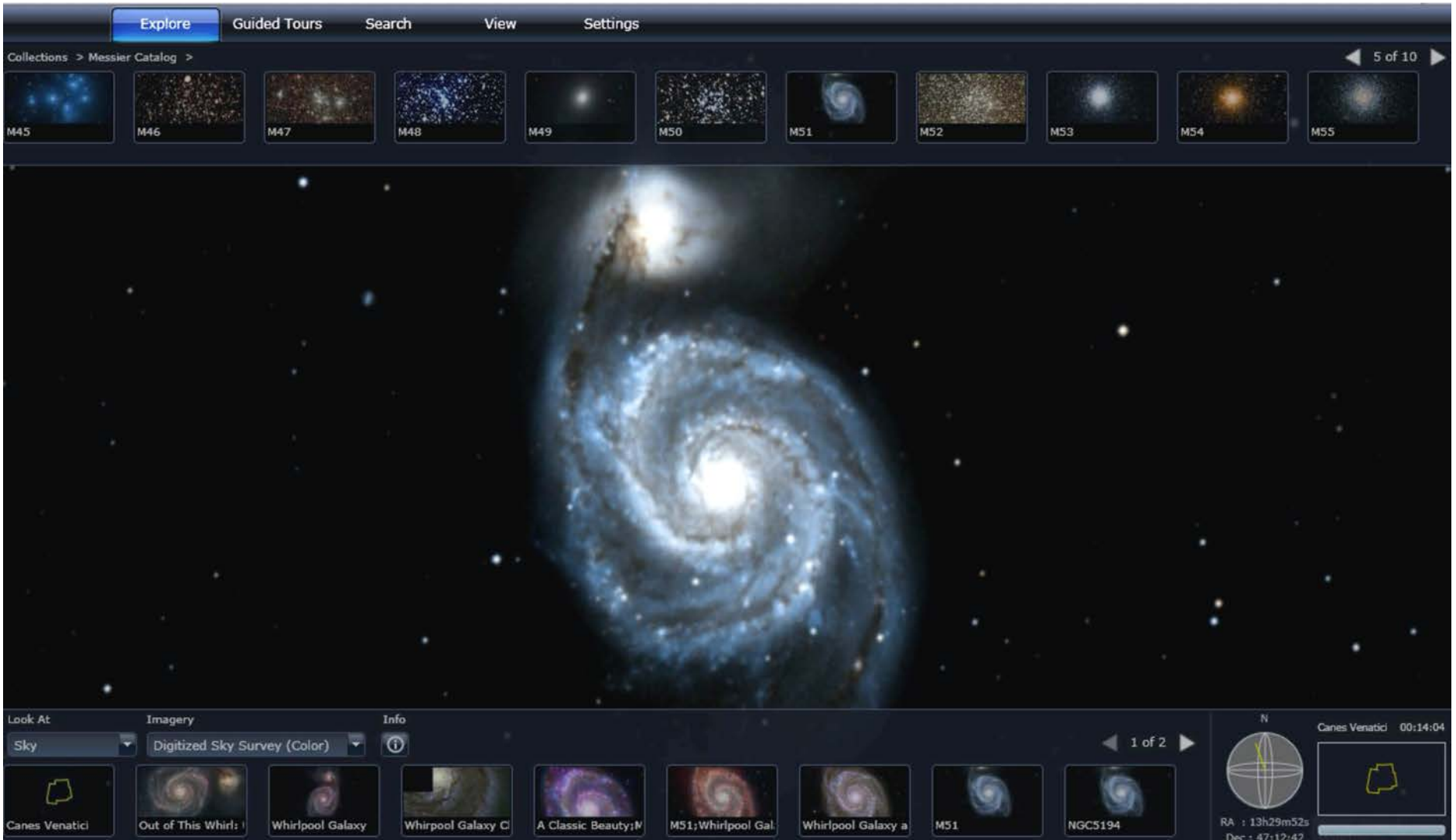
Lang, K., "Essential Astrophysics"

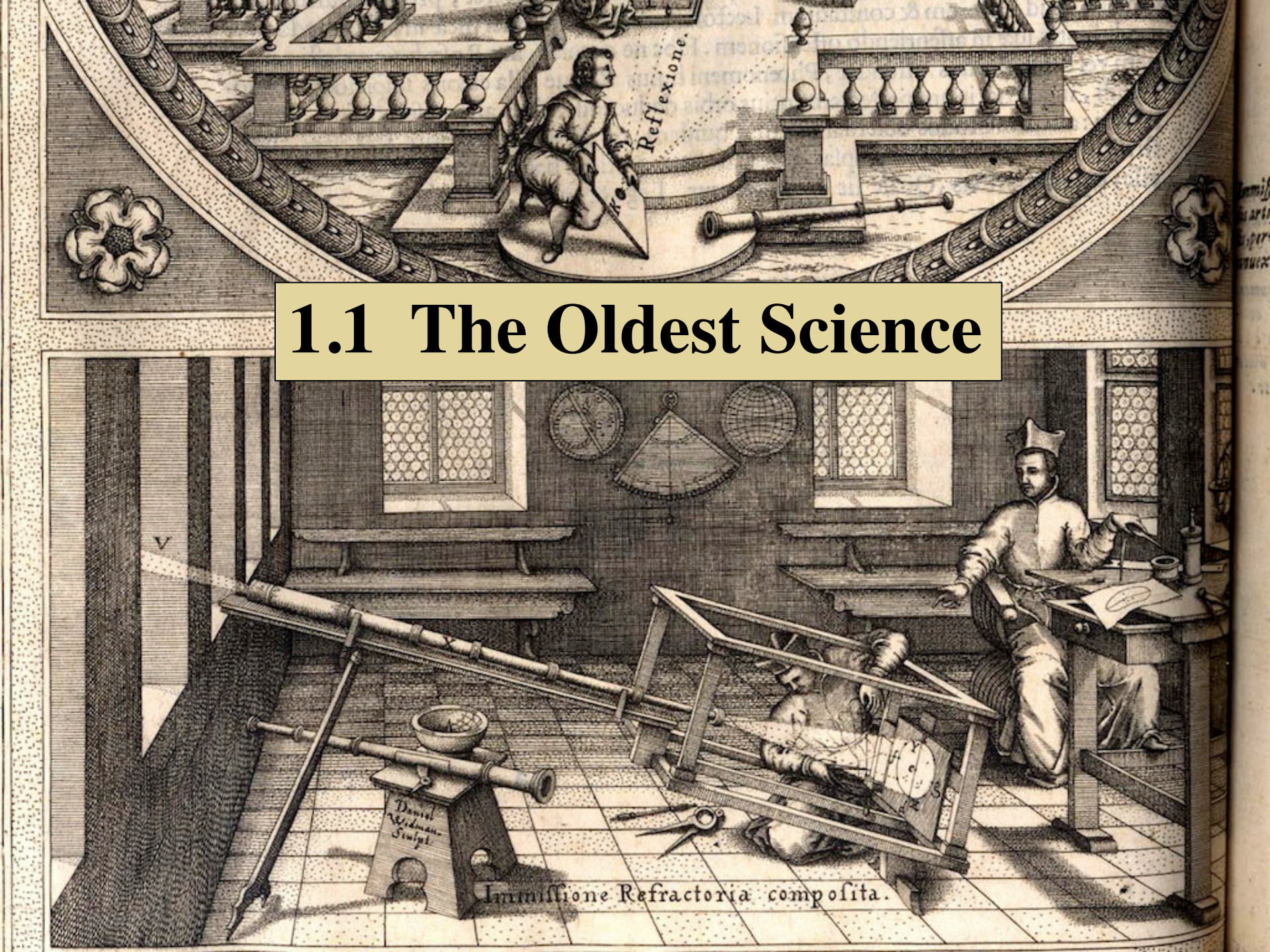
Fraknoi, A., Morrison, D., & Wolff, S., "Astronomy", [may be too elementary for this class]

Use the *WorldWide Telescope*

http://www.worldwidetelescope.org/webclient/

A great sky browser – try it!



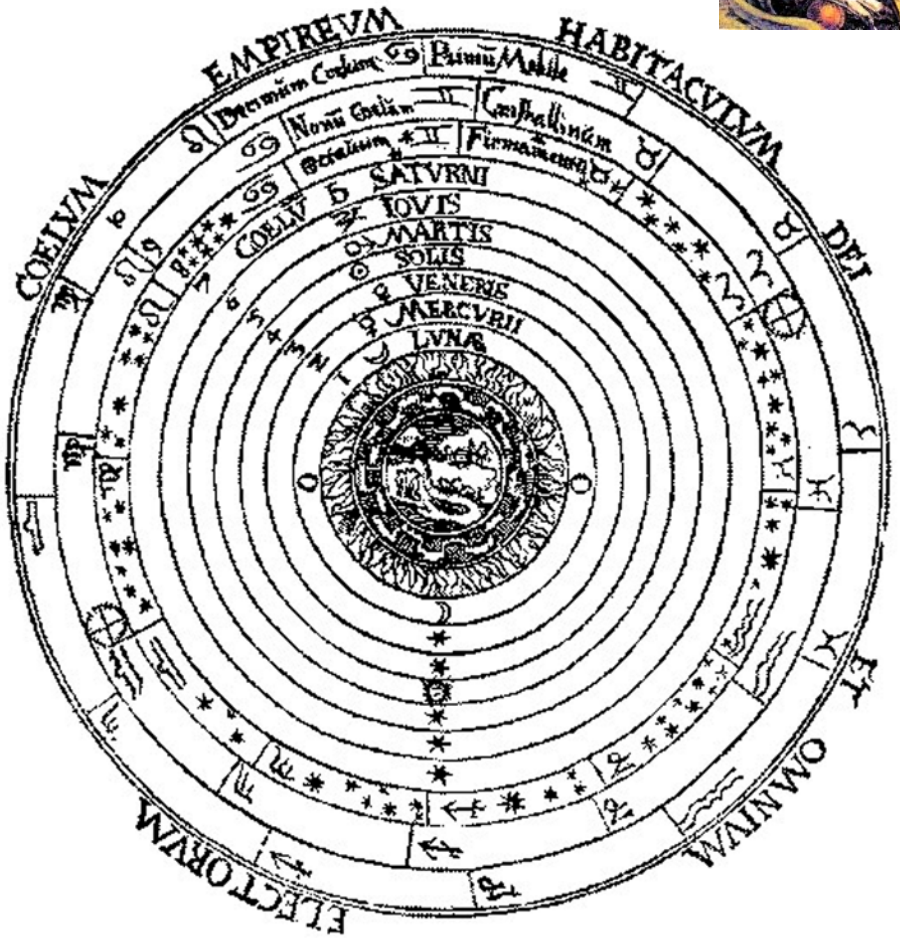


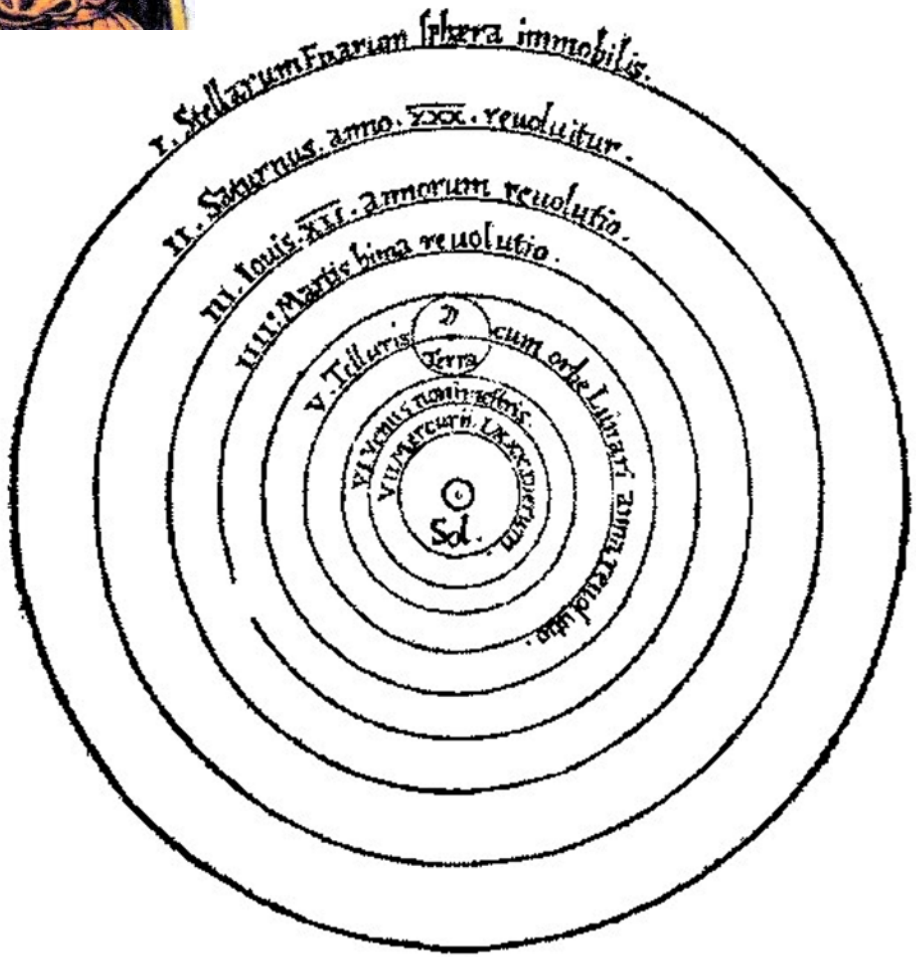
1.1 The Oldest Science

An Early 30-m Telescope

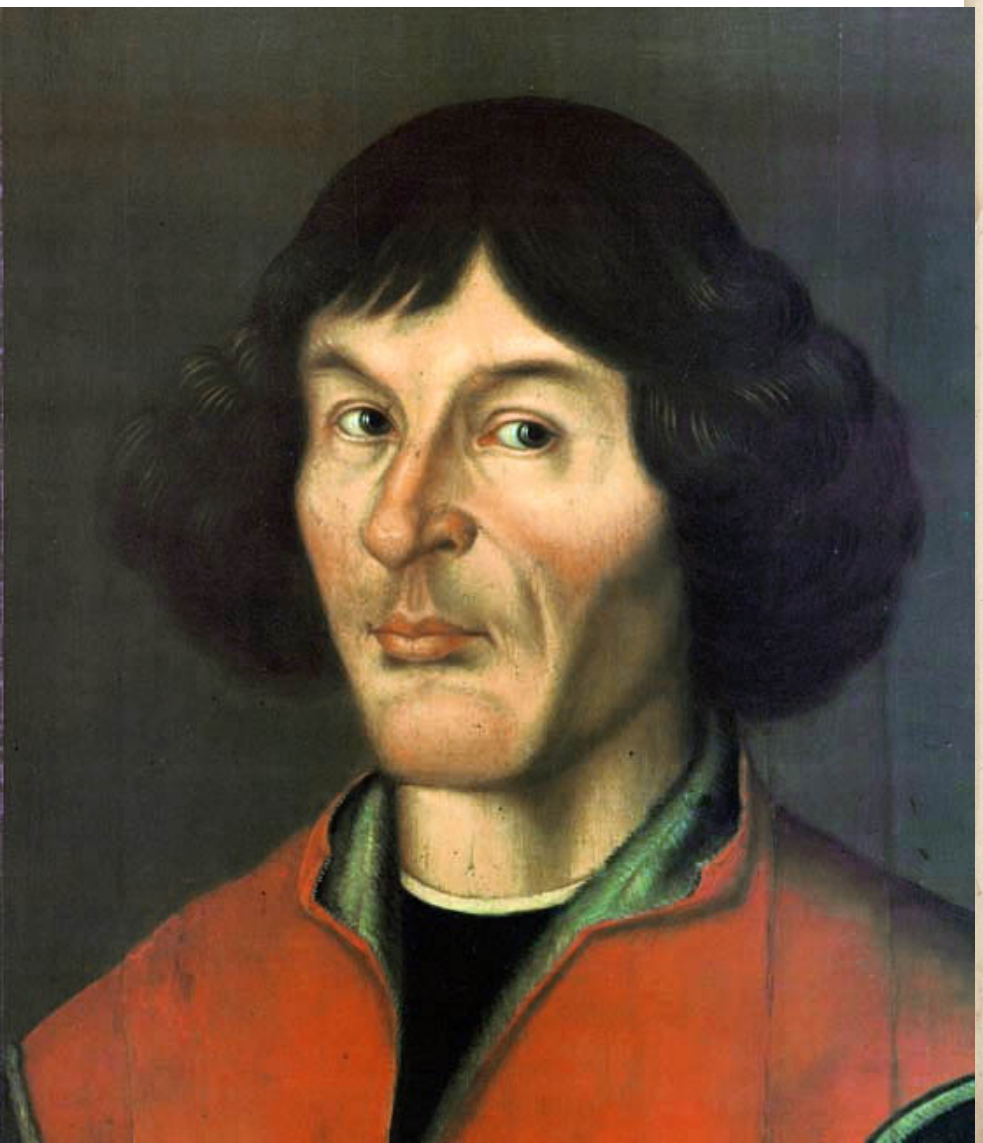
Ptolemaic System

~ 1st century





Copernicus:
De Revolutionibus Orbium Coelestium (1543)



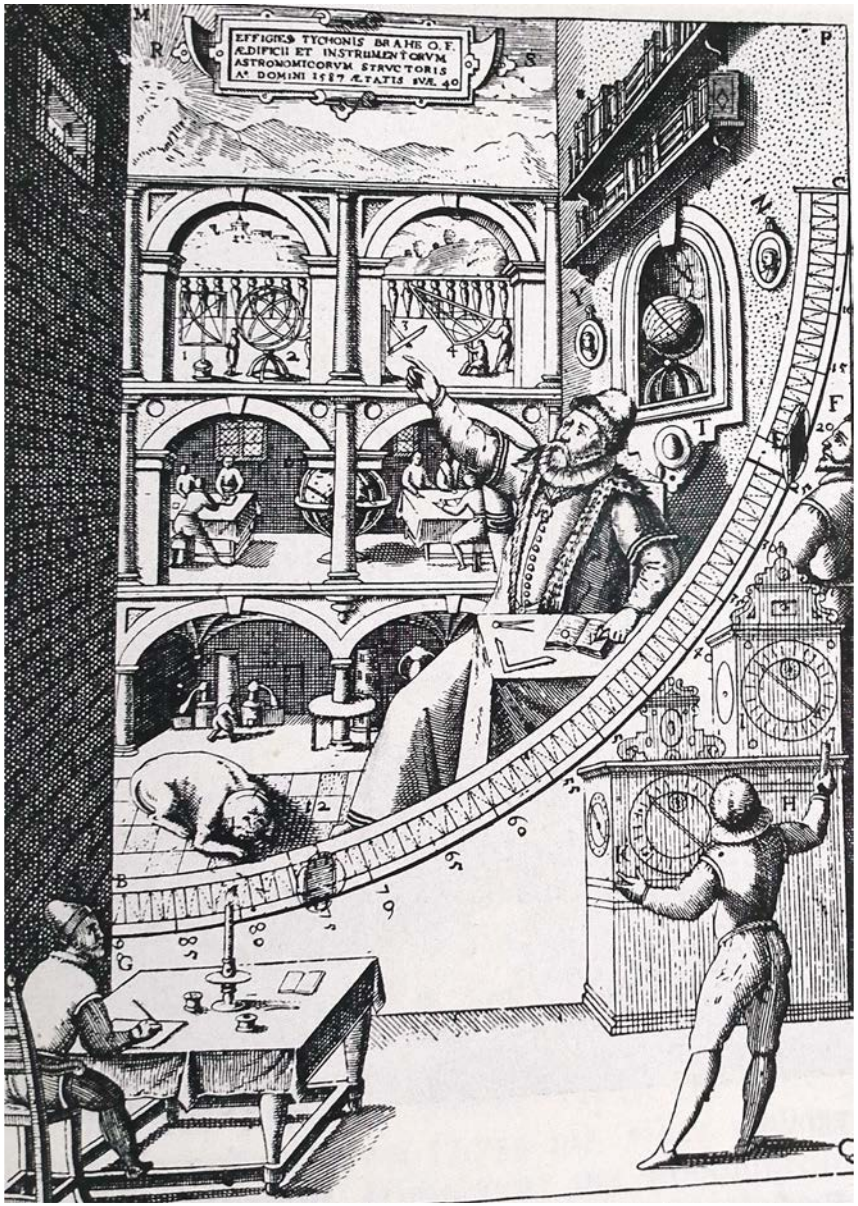
30 anno ſuum complet circuitum. Poſt hunc Iupiter duodecennali revolutione mobilis. Deinde Mars, qui biennio circuit. Quartum in ordine annua revolutio locum obtinet, in quo terram cum orbe

lunari tanquam epicyclo contineri diximus. Quinto loco Venus nono menſe reducitur. Sextum denique locum Mercurius tenet, octuaginta dierum ſpacio circum urrens. In medio vero omnium reſidet Sol. Quis enim in hoc pulcherrimo templo lampadem hanc in alio vel meliori loco poneret, quam unde totum ſimul poſſit illuminare? Siquidem non inepte quidam lucernam mundi, alij mentem, alij rectorem vocant. Trimeſgiſtus *viſibilem Deum*, Sophoclis Electra *intuentem omnia* Ita profecto tanquam in ſolio regali Sol

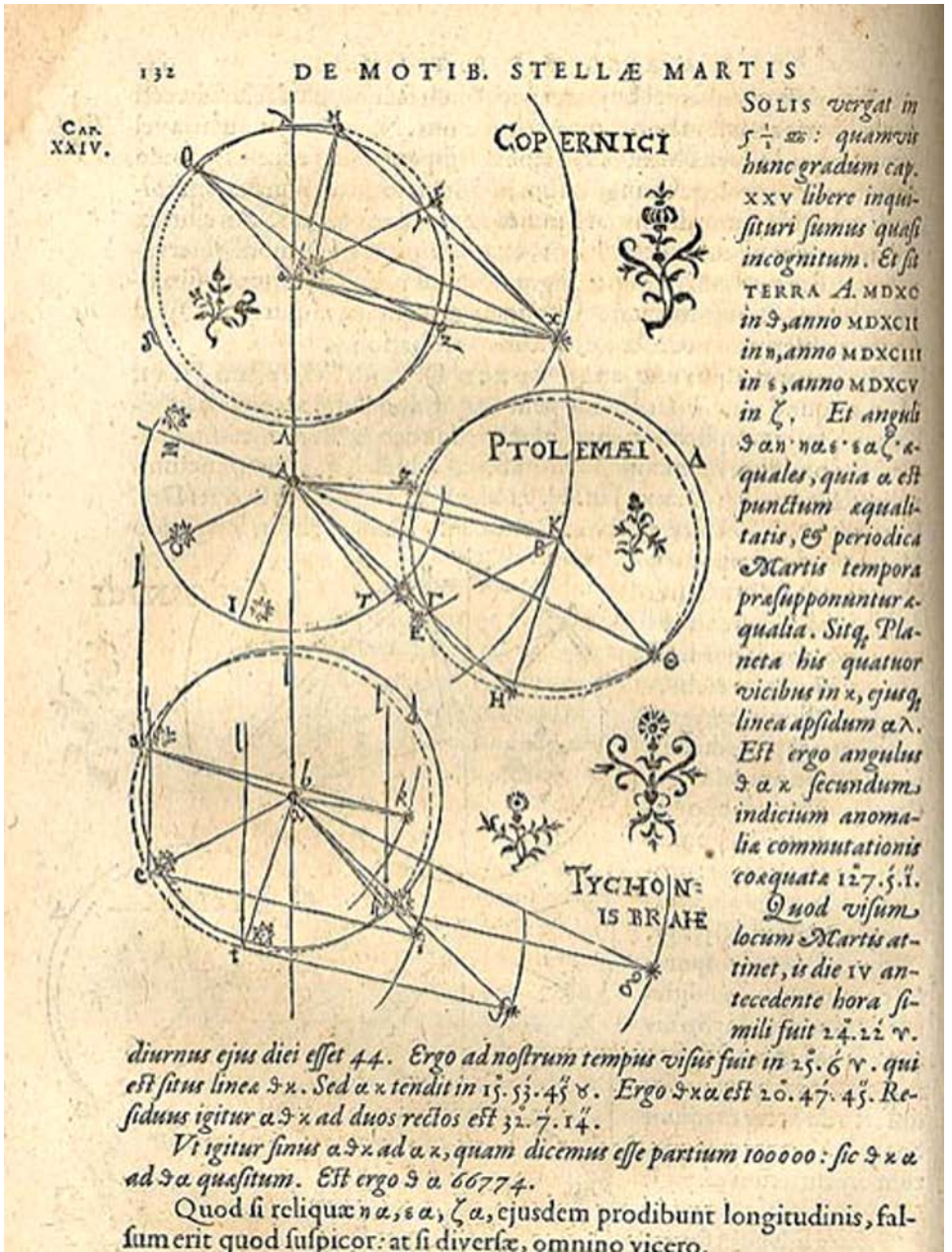
Solis nom. & ſeu attribut.

 reſidens

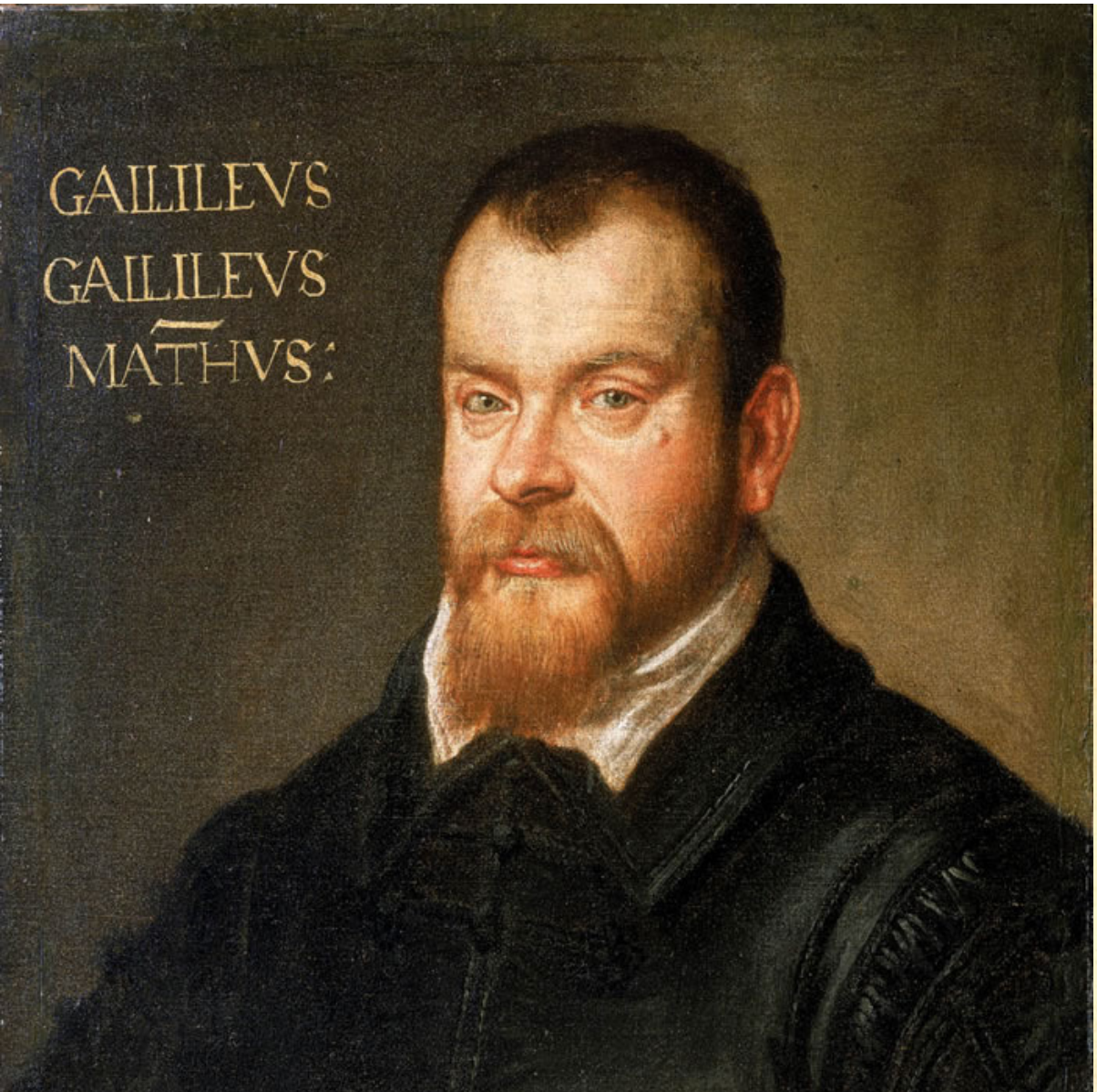
Tycho Brahe (1546-1601)

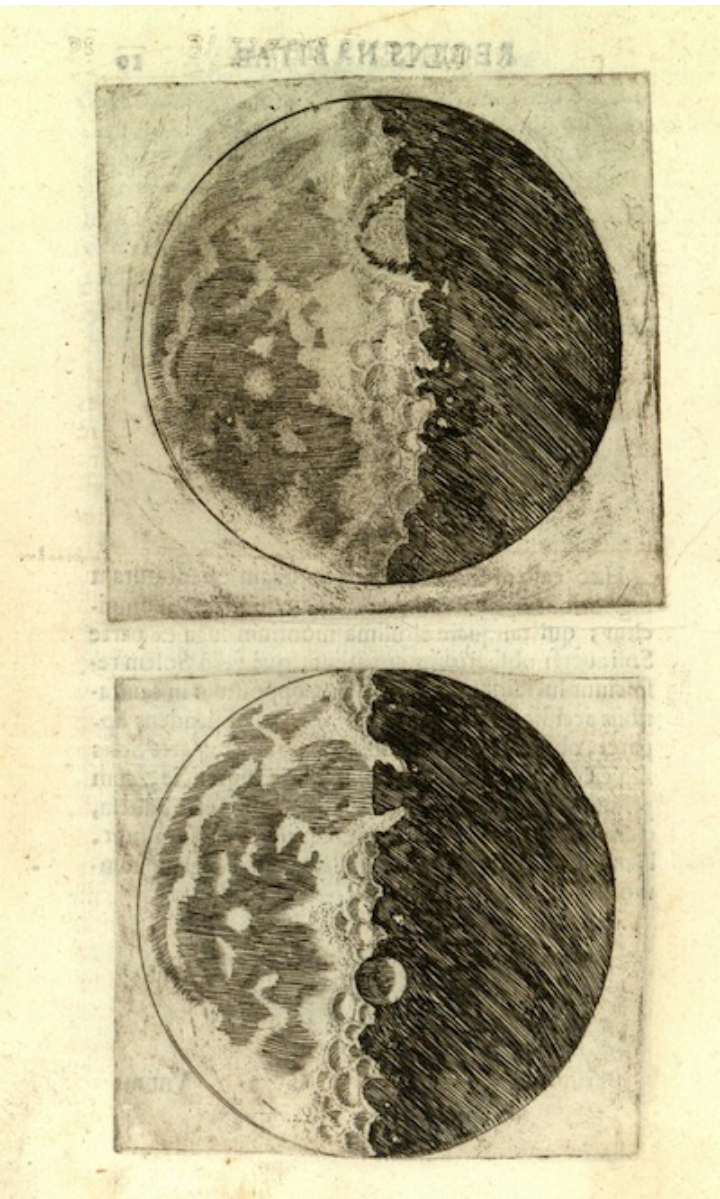


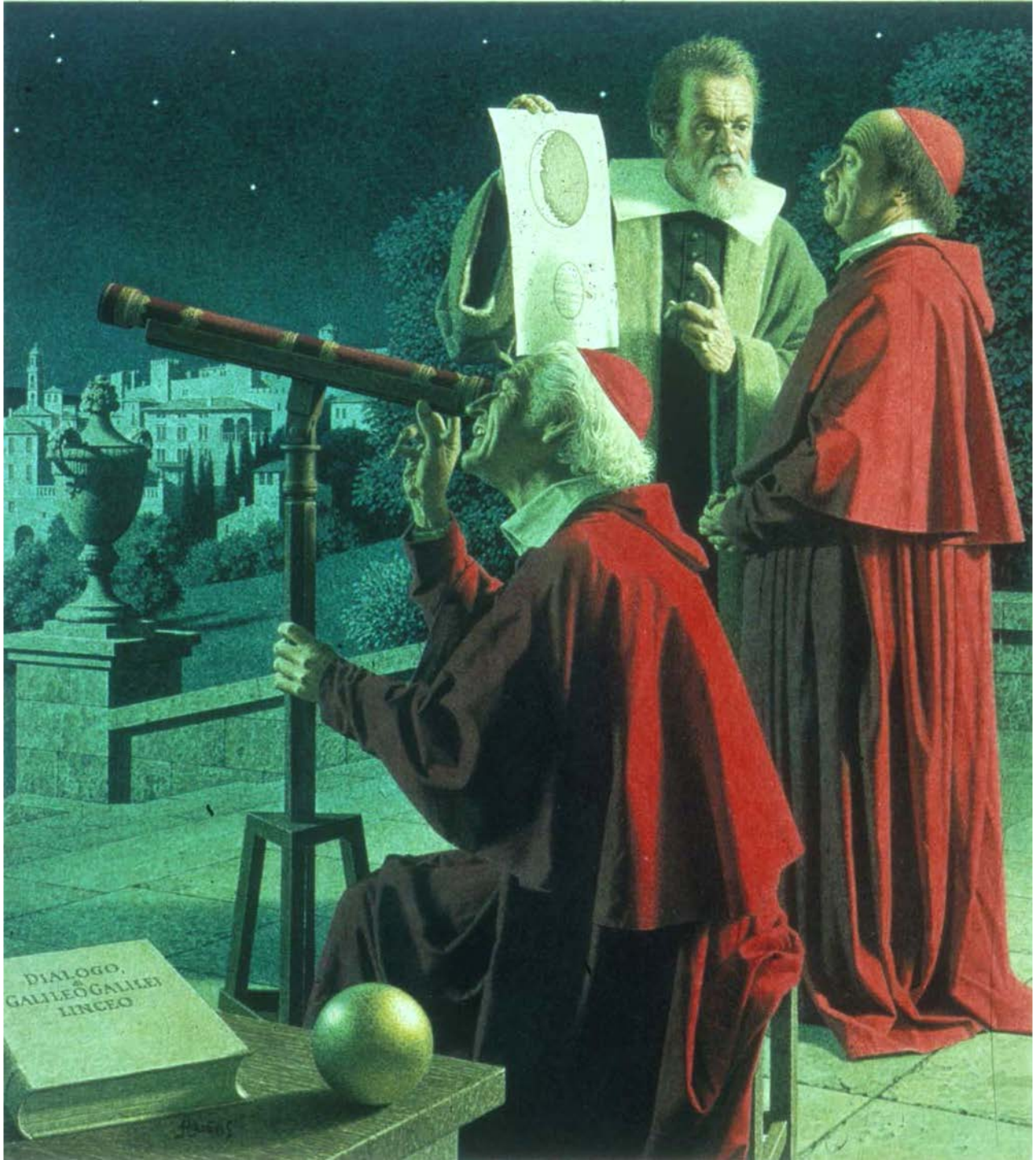
Kepler: Astronomia Nova (1609)



Galileo: Starry Messenger (1610), Dialogue Concerning the Two Chief World Systems(1632)



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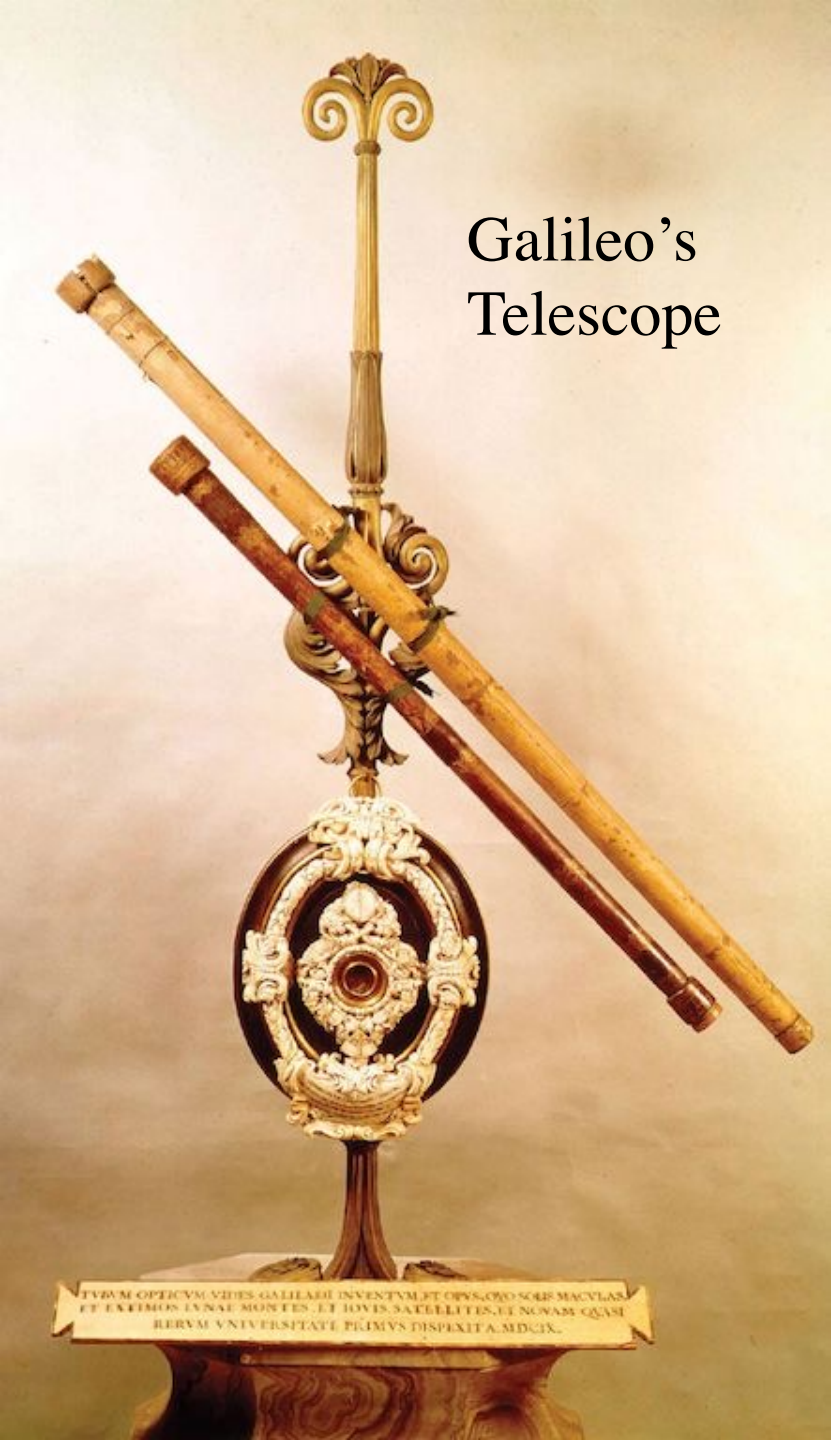
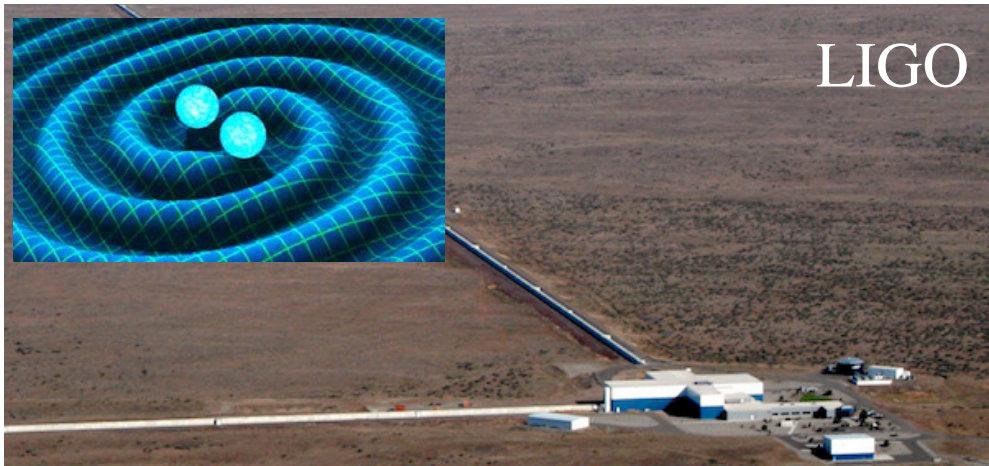
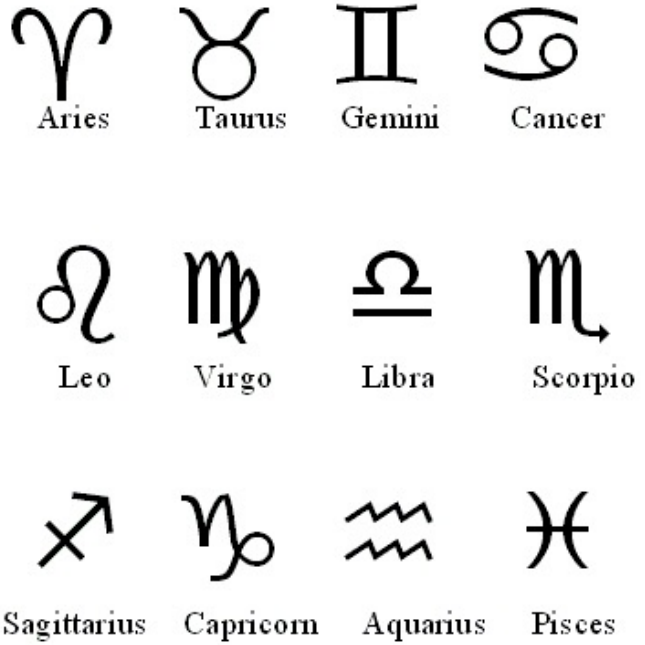

Galileo's
Telescope


Keck


HST


LIGO

Beautiful Lunar eclipse from our flat Earth



1.2 Astronomy as a Science

The Vast Scale of the Universe

If the Earth was the size of a grain of sand

... The Sun would be **5 feet away**

... The nearest star would be **250 miles away**

... Our Galaxy would be **10 million miles across**

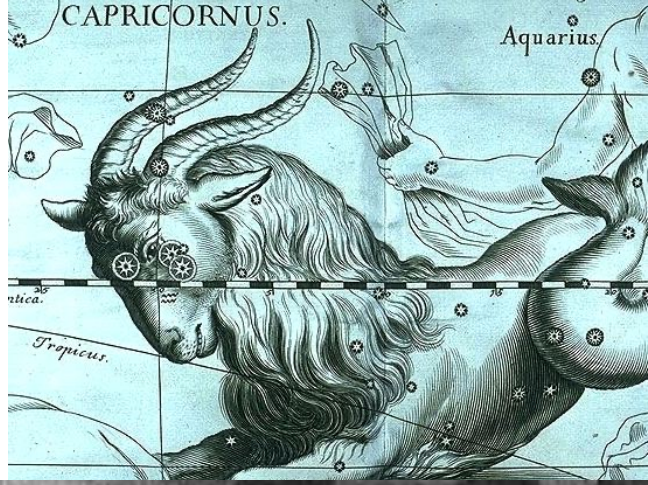
... The nearest other big galaxy (Andromeda) would be **130 million miles away**

If our Galaxy were the size of a frisbee …

... The most distant objects currently known would be about **100 miles away**

The Evolution of Astronomy

- From astrology to classical astronomy (~ positional astronomy and cellestial mechanics) to astrophysics



- A strong and growing connection with physics, starting with Newton … Today astronomy is one of the most exciting branches of physics

- Many important developments happened in Pasadena (Hale, Hubble, Zwicky, Baade, Minkowski, Sandage, …)

How is Astronomy Possible?

The universe is really, really big, and we cannot experiment in the lab with any of the objects in it

But we can use…

Data

+

Logic (~ math)

= Scientific method

… and use physics as an interpretative framework

The Nature of the Astronomical Inquiry

- The peculiar nature of astronomy as a science
  - Is it like history? Geology? Paleontology? (are there extinct species of astronomical objects?)
  - Observing vs. experiments, and repeatability
  - A single object of study: universe as a whole, CMBR… But the experiments are repeatable
  - Non-repeatable phenomena, e.g., SNe, GRBs, microlensing events… But there are *classes* of them
- Observing a narrow time-slice of the past light cone
  - Using "symmetry" principles (e.g., Copernican, cosmological) as a substitute for unobtainable information
  - t (astronomy) << t (universe) → inevitable biases
- Observing the past, or deducing it from the "fossil" information (e.g., galaxy formation and evolution)

Astronomy as a Branch of Physics

- Using the apparatus of physics to gather and interpret the data: assume that our physics is universal (and we can test that!)
- Astronomical phenomena as a "cosmic laboratory"
  - Relativistic physics (black holes, gravitational waves, $v \sim c$…)
  - Cosmic accelerators (HECR) and the early universe
  - Matter in extreme conditions (e.g., neutron/quark stars, GRBs, high & low density plasmas …)
- Astronomical discoveries as a gateway to the new physics (e.g., dark matter and dark energy; neutrino mixing; inflation; etc.)
- Progress driven by technology (telescopes, detectors, computing…)

Fundamental Limits to Measurements and Selection Effects

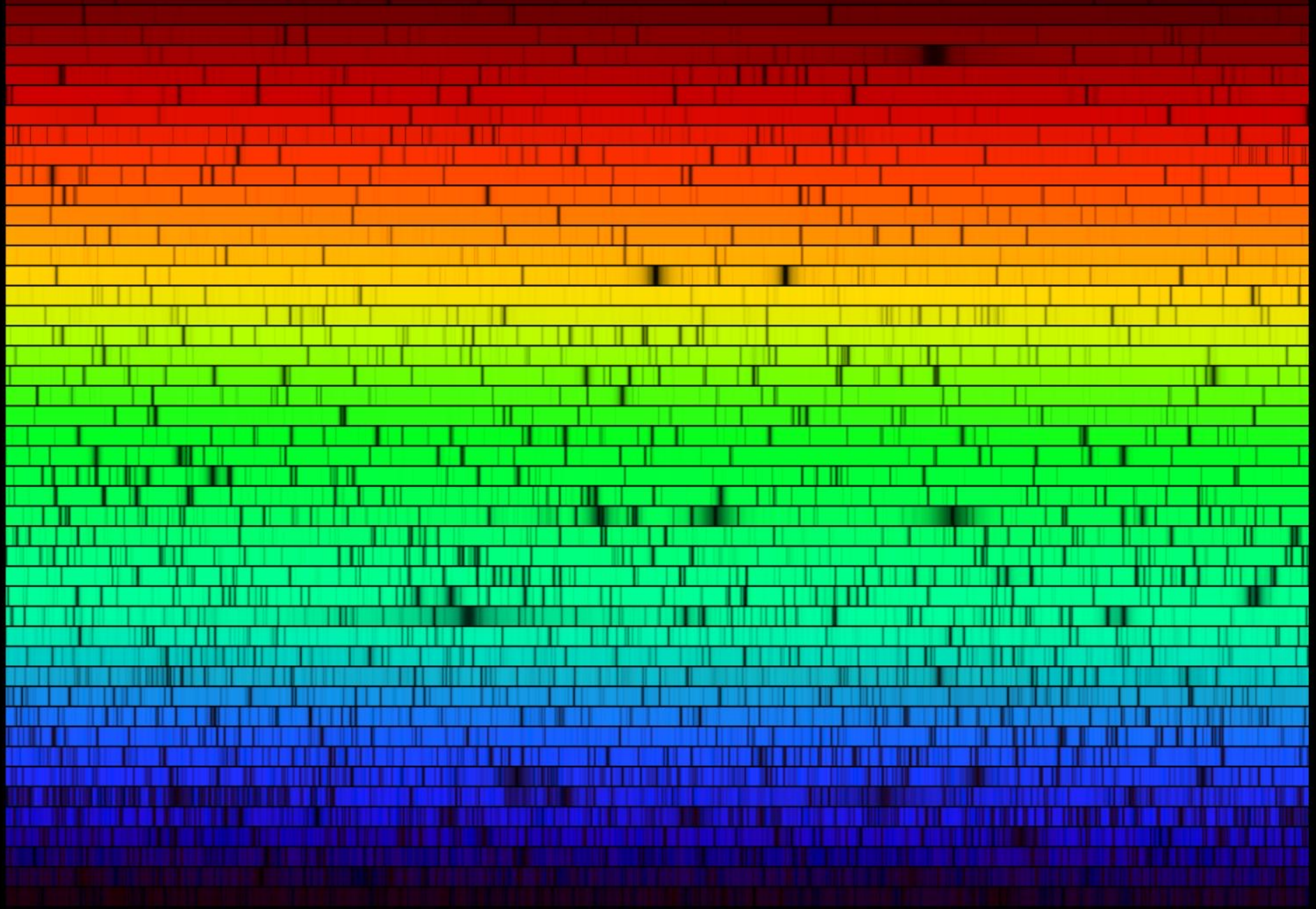
- S/N Poissonian and quantum limits of detection
- Geometrical optics limits of angular resolution
- Opacity of the Earth's atmosphere and the Galactic ISM (example: soft X-rays and the missing baryons)
- Obscuration by dust in galaxies
- Turbulence of the atmosphere/ISM: erasing the spatial information
- Convolved backgrounds and foregrounds (examples: CMBR, CIRBs)
- And the "un-natural" limits: politics, funding, social psychology …

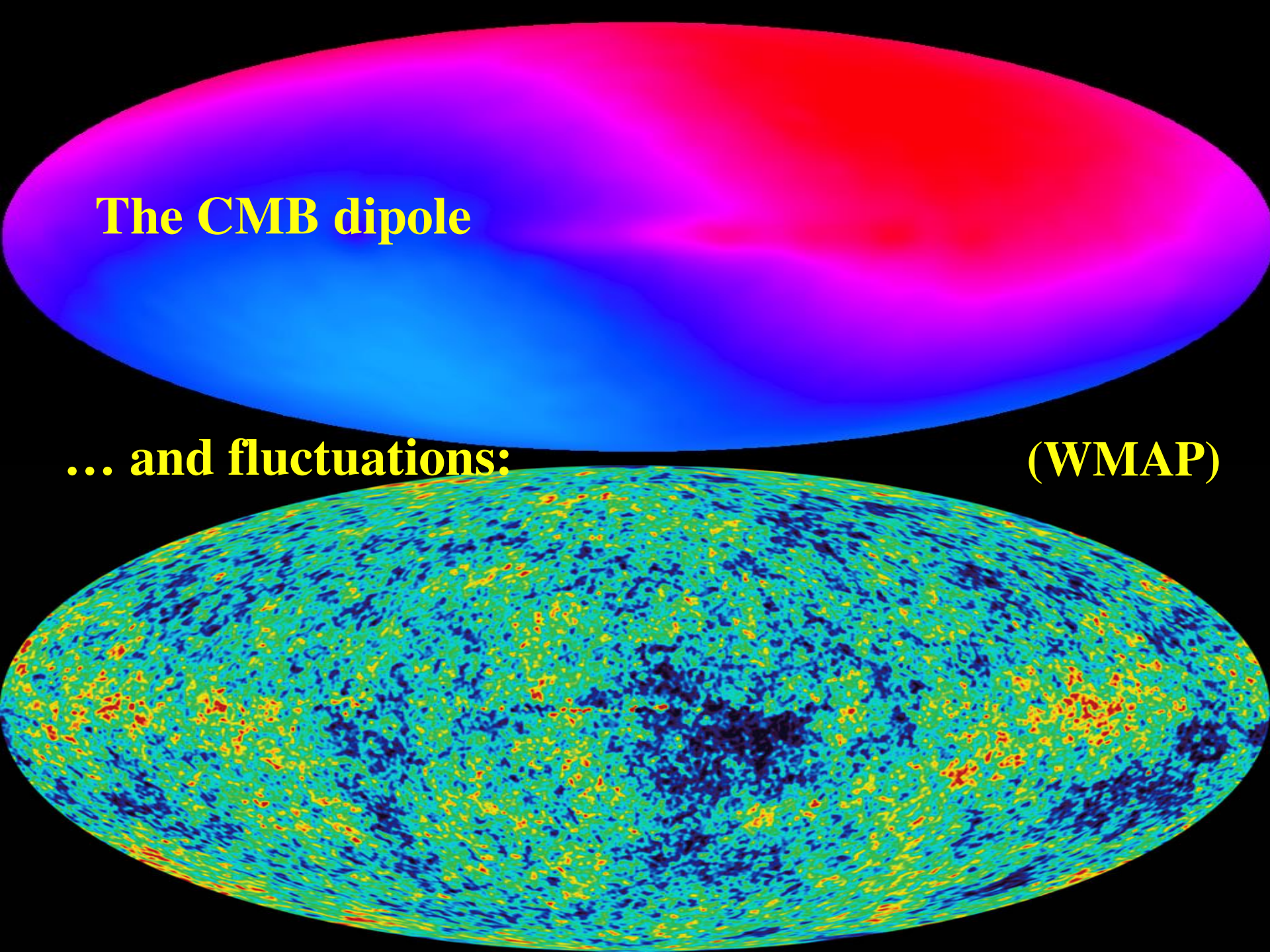
1.3 Messengers from the Universe

Information Flows in the Universe

- Physical parameters → Observables (but possibly in a very convolved manner - complex phenomena)
- Unresolved imagery/photometry: a very low information content; resolved imagery: morphology
- Spectroscopy is where most of the physics is!
- Primary continuum spectra (thermal, synchrotron…) : a low information content; abs./em. lines encode most of the interesting information
- Thermalization by dust erases information from the original energy flux (e.g., the power sources of ULIRGS)
- Different phenomena → different signals (some spectrum regions may be favored)

The Solar Spectrum

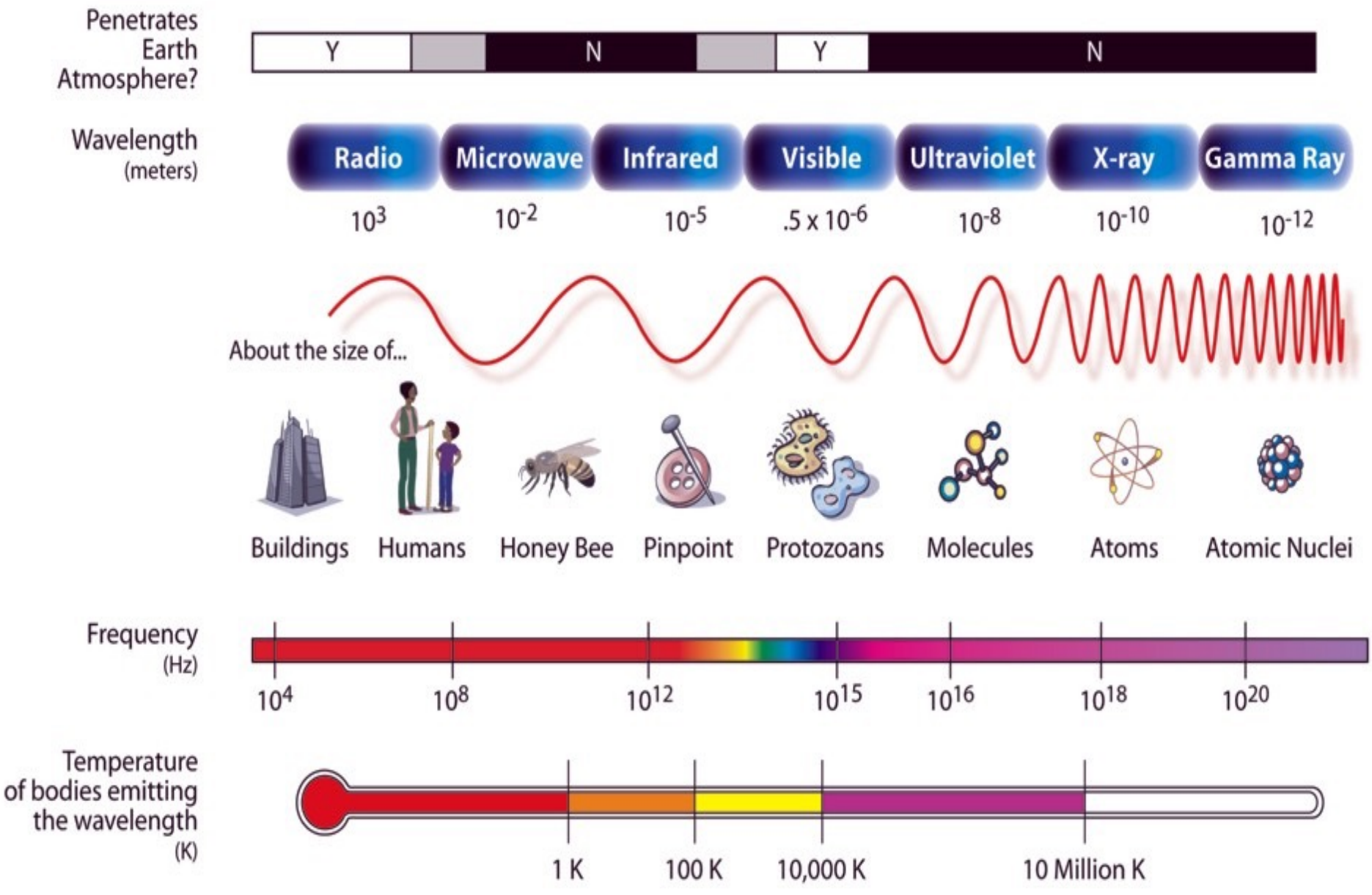



The CMB dipole
… and fluctuations:
(WMAP)

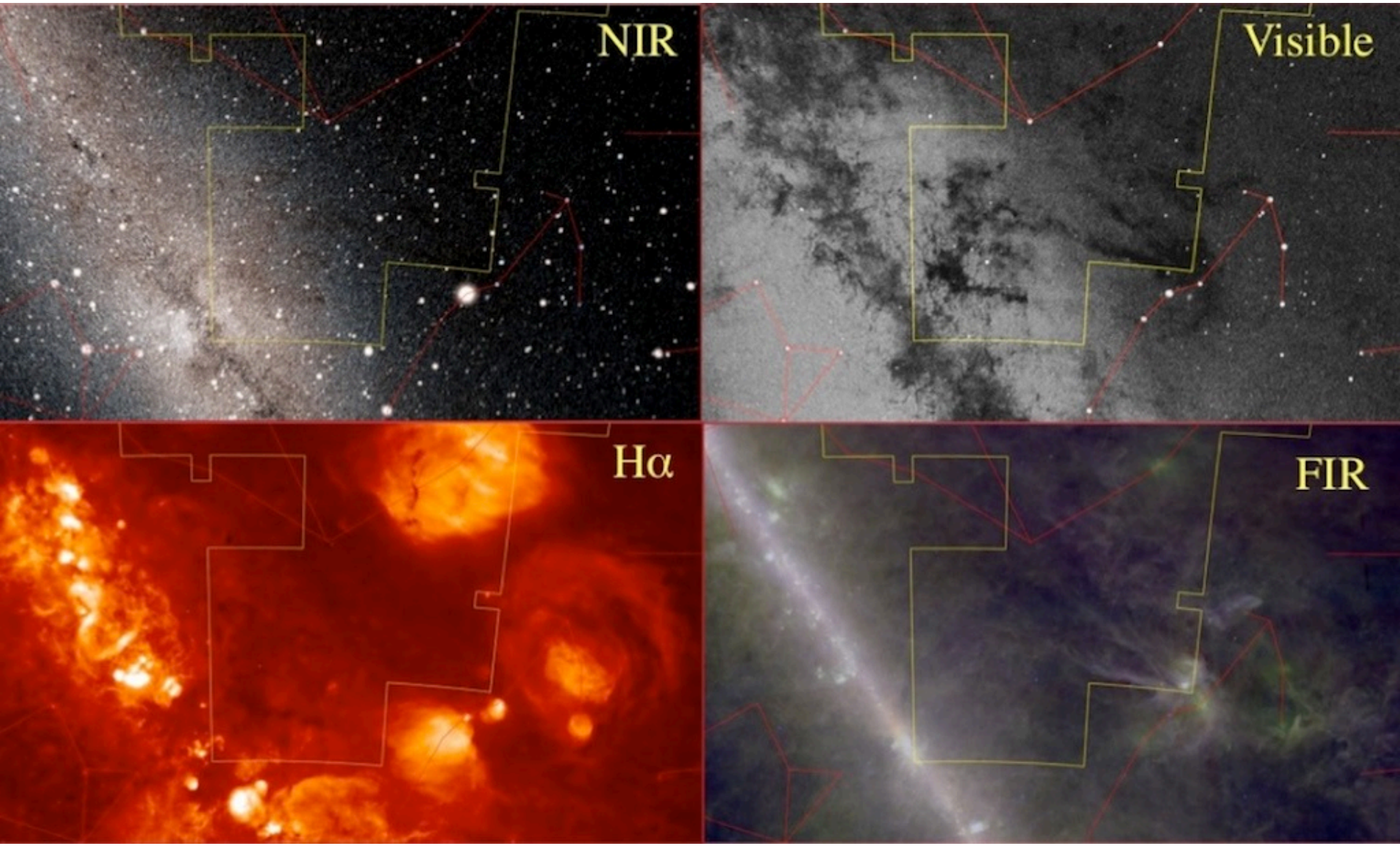
Information Channels in Astronomy

- Mostly electromagnetic! Methodologies:
  - Single-channel photometry
  - 2D imaging (photometry, morphology, positions/motions)
  - 1D spectroscopy
  - 2D (long-slit) spectroscopy
  - 3D data cubes (2 spatial + 1 spectro)
  - All can include polarimetry
  - All can be time-resolved (synoptic) or not
  - All can be single-dish, some (all?) can be interferometric
- Particles:
  - Cosmic rays: Cherenkov, particle detectors, geochemistry
  - Neutrinos: big tanks of something …
- Gravitational Waves: LIGO/LISA interferometers
- Dark Matter: lab detectors, gravitational lensing

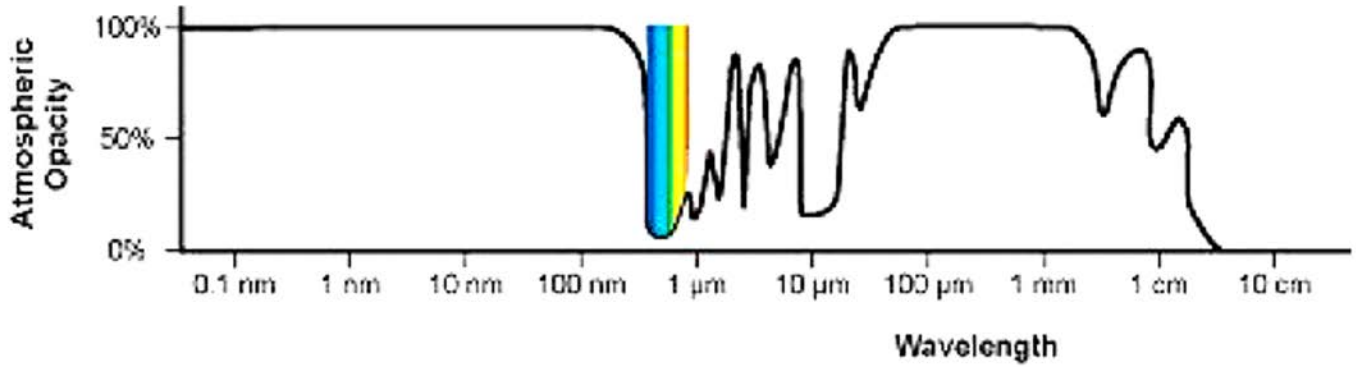
The Electromagnetic Spectrum



The Panchromatic Universe



Atmospheric Transmission Windows



Ionospheric cutoff

And that is why we need space observatories!

But there as an even more profound limitation:

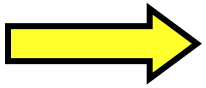
The Galactic "atmosphere" - the interstellar medium - also absorbs very long wavelengths, and hard UV / soft X-rays (the interstellar fog); and of course the dust absorbs the blue/UV light (the interstellar smog).

This may be very important: perhaps 90% of the baryons in the universe are in the form of a "warm" ($T \sim 10^5$ K) gas, which emits mostly soft X-rays

How Are Discoveries Made?

- **Conceptual Discoveries:** e.g., Relativity, QM, Inflation …
  Theoretical, may be inspired by observations
- **Phenomenological Discoveries:** e.g., Dark Matter, QSOs, GRBs, CMBR, Extrasolar Planets, Obscured Universe …

  Empirical, inspire theories, can be motivated by them

New Technical Capabilities  Observational Discoveries  Theory

Phenomenological discoveries are made by:

- Pushing along some parameter space axis
- Making new connections (e.g., multi-λ)

Different astrophysical phenomena populate different parts of the observable parameter space, and require different observables and measurement methodologies - and vice versa.