Astronomy 1: The Evolving Universe

Spring 2014

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http:// www.astro.caltech.edu/~george/ay1/

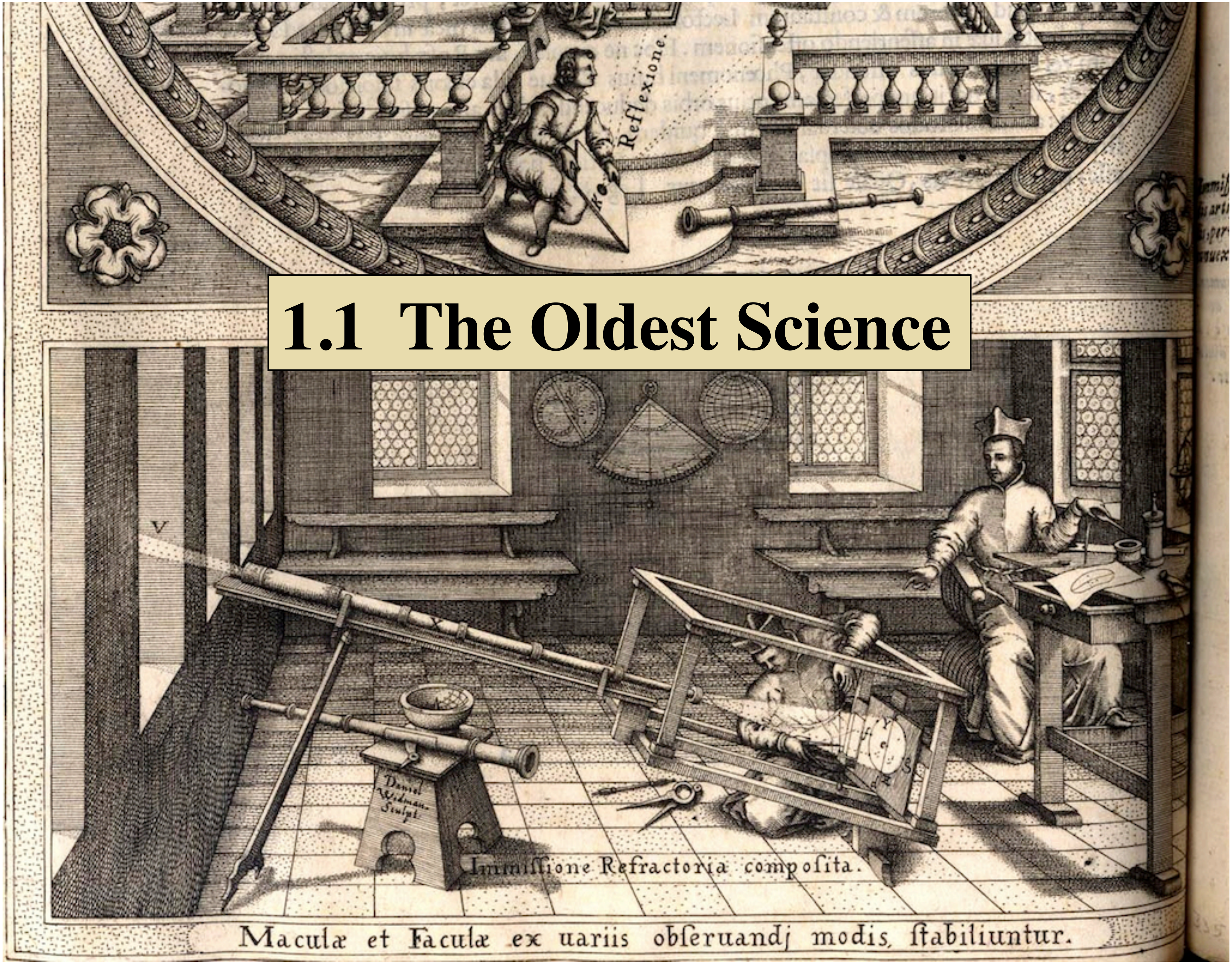
Some Class Logistics

- Class website: http:// www.astro.caltech.edu/~george/ay1/
  - *Everything* will be there
- Lectures MW 2-3 pm
  - Lectures are video recorded. Videos and slides will be posted on-line the same day. Along with posted readings and links, that is your "textbook"
  - These will also be offered as a MOOC with edX, with a 3 week delay
- Sections (mandatory!): various times & locations, sign up on line
- Weekly homework, except for the midterm and final weeks
- Class trip(s) to be arranged
- **Ask questions!**

Use the *WorldWide Telescope*

- Windows: download from http://www.worldwidetelescope.org
- Others: use http://www.worldwidetelescope.org/webclient/

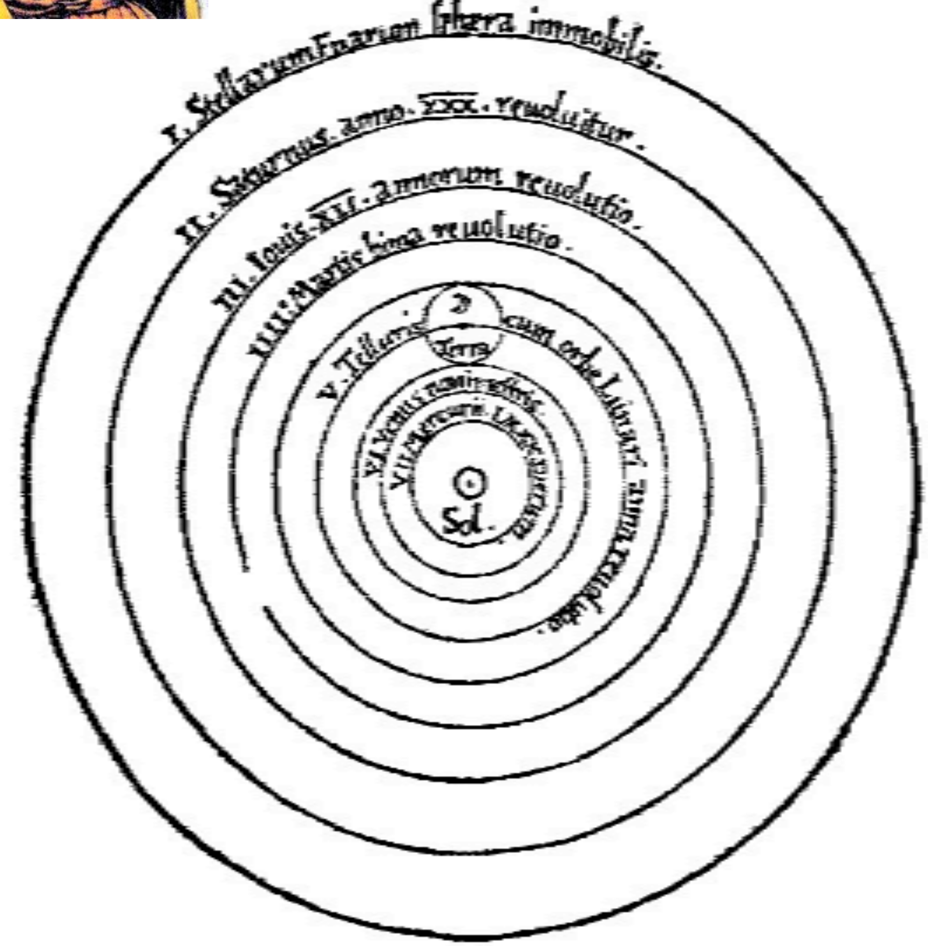
1.1 The Oldest Science



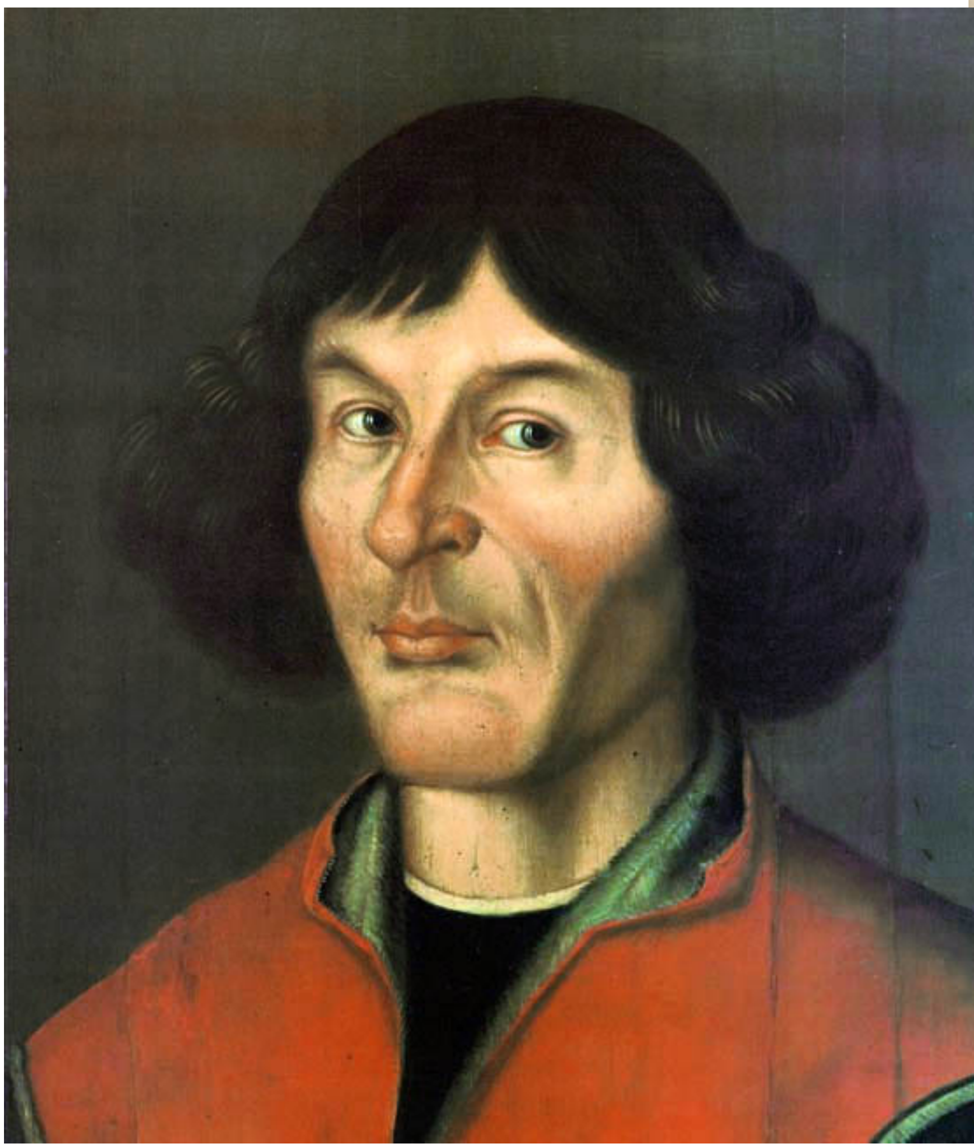
An Early 30-m Telescope

Ptolemaic System

~ 1st century



Copernicus:
De Revolutionibus Orbium Coelestium (1543)



REVOLVTIONVM LIB. I. 21

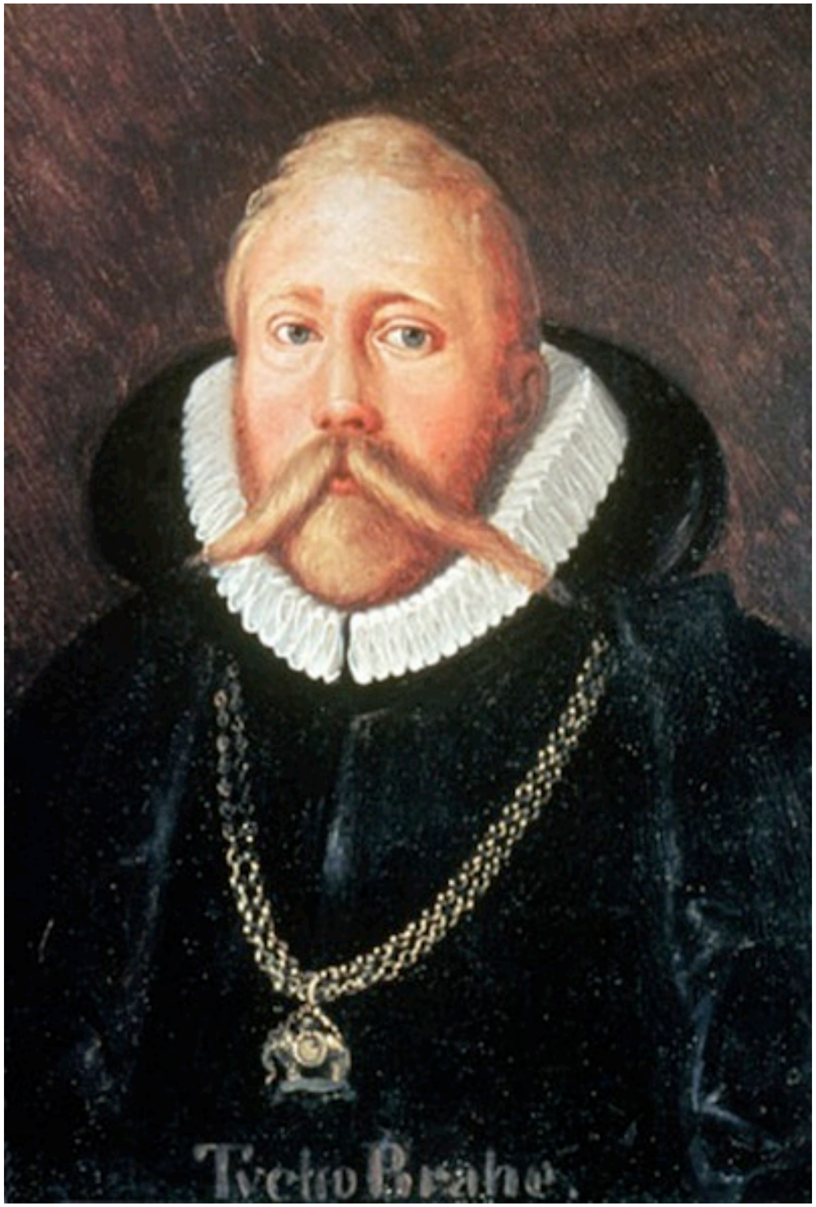
30 anno ſuum complet circuitum. Poſt hunc Iupiter duodecennali revolutione mobilis. Deinde Mars, qui biennio circuit. Quartum in ordine annua revolutio locum obtinet, in quo terram cum orbe

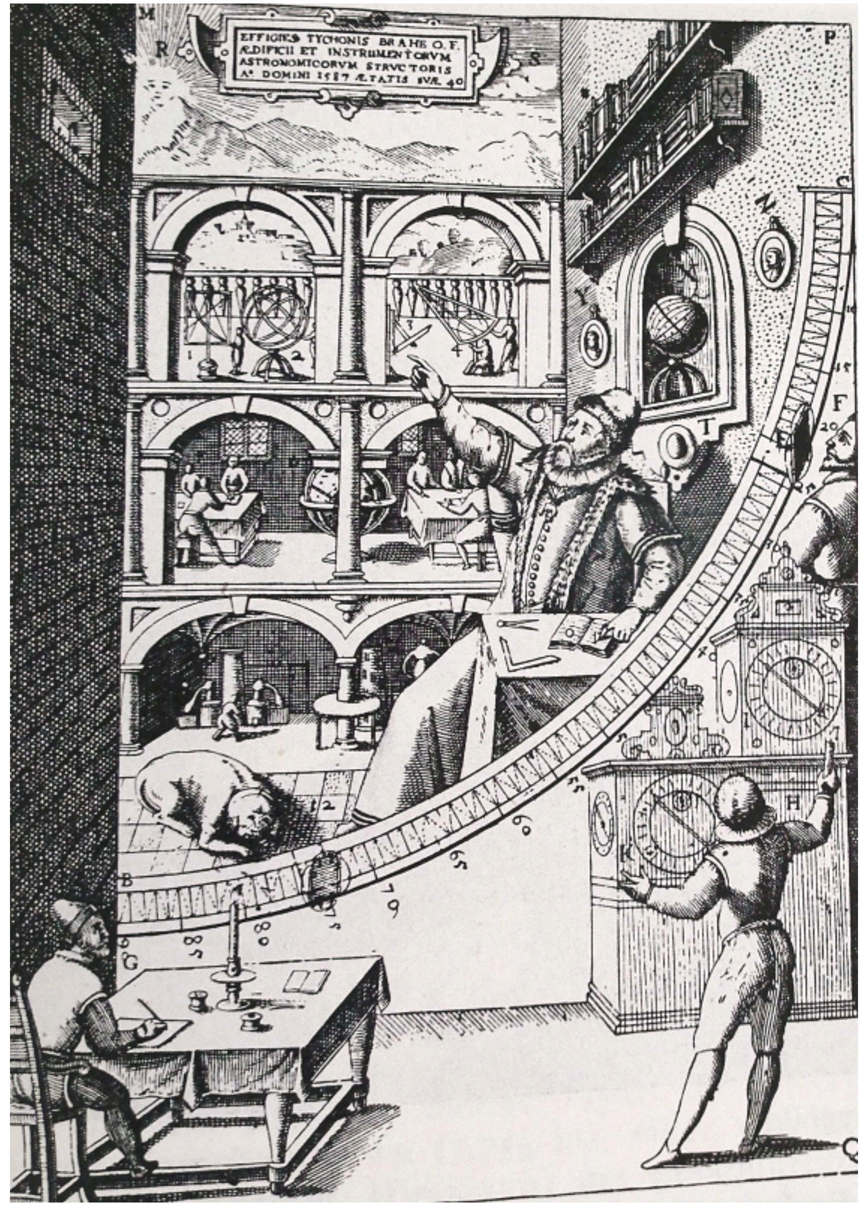
lunari tanquam epicyclo contineri diximus. Quinto loco Venus nono menſe reducitur. Sextum denique locum Mercurius tenet, octuaginta dierum ſpacio circum currens. In medio vero omnium reſidet Sol. Quis enim in hoc pulcherrimo templo lampadem hanc in alio vel meliori loco poneret, quam unde totum ſimul 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.

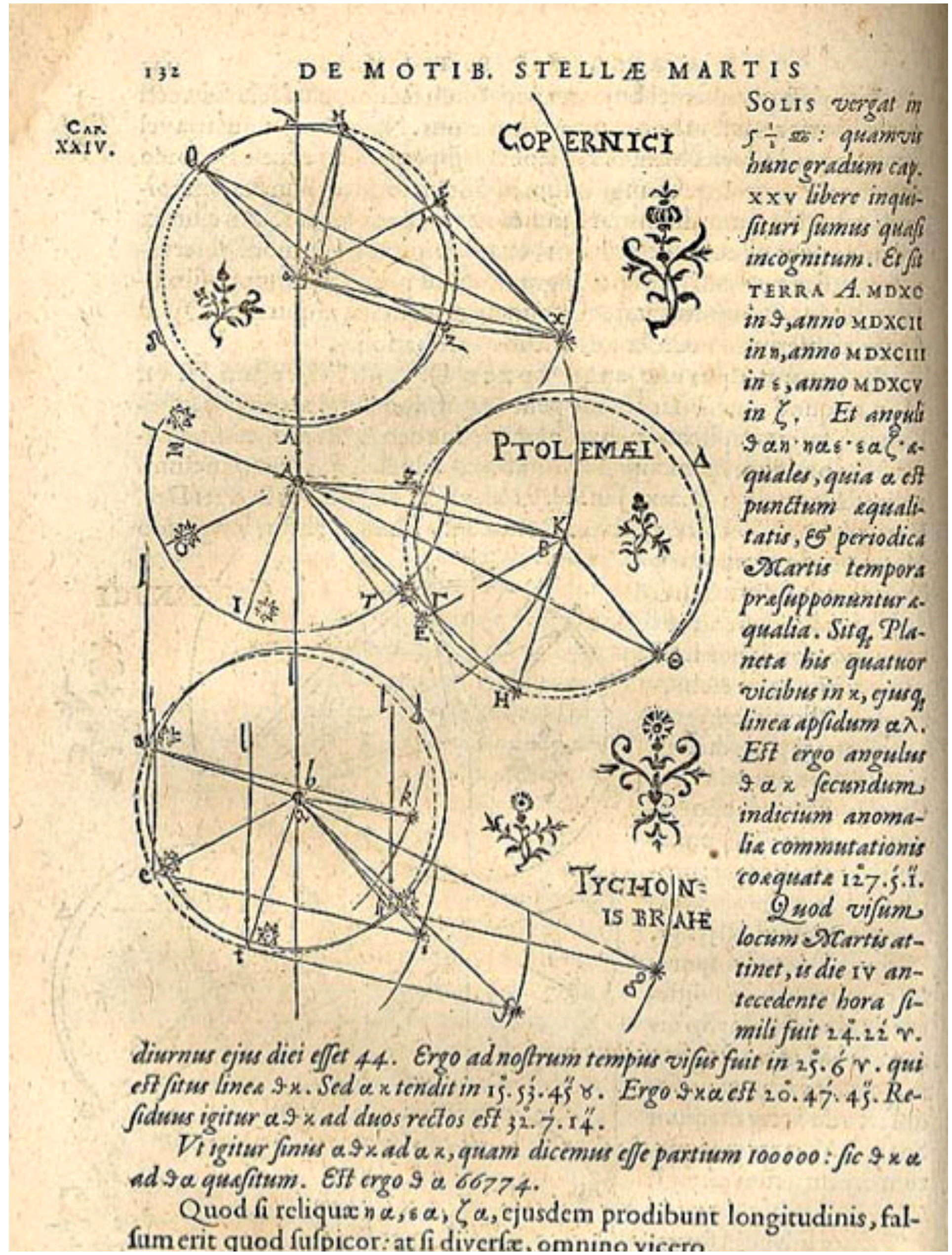
C 3 reſidens

Tycho Brahe


Tycho Brahe


EFFIGIES TYCHONIS BRAHE O.F.
ÆDIFICII ET INSTRUMENTORVM
ASTRONOMICORVM STRVCTORIS
Aº DOMINI 1587 ÆTATIS SVÆ 40

Kepler: Astronomia Nova (1609)



132 DE MOTIB. STELLÆ MARTIS

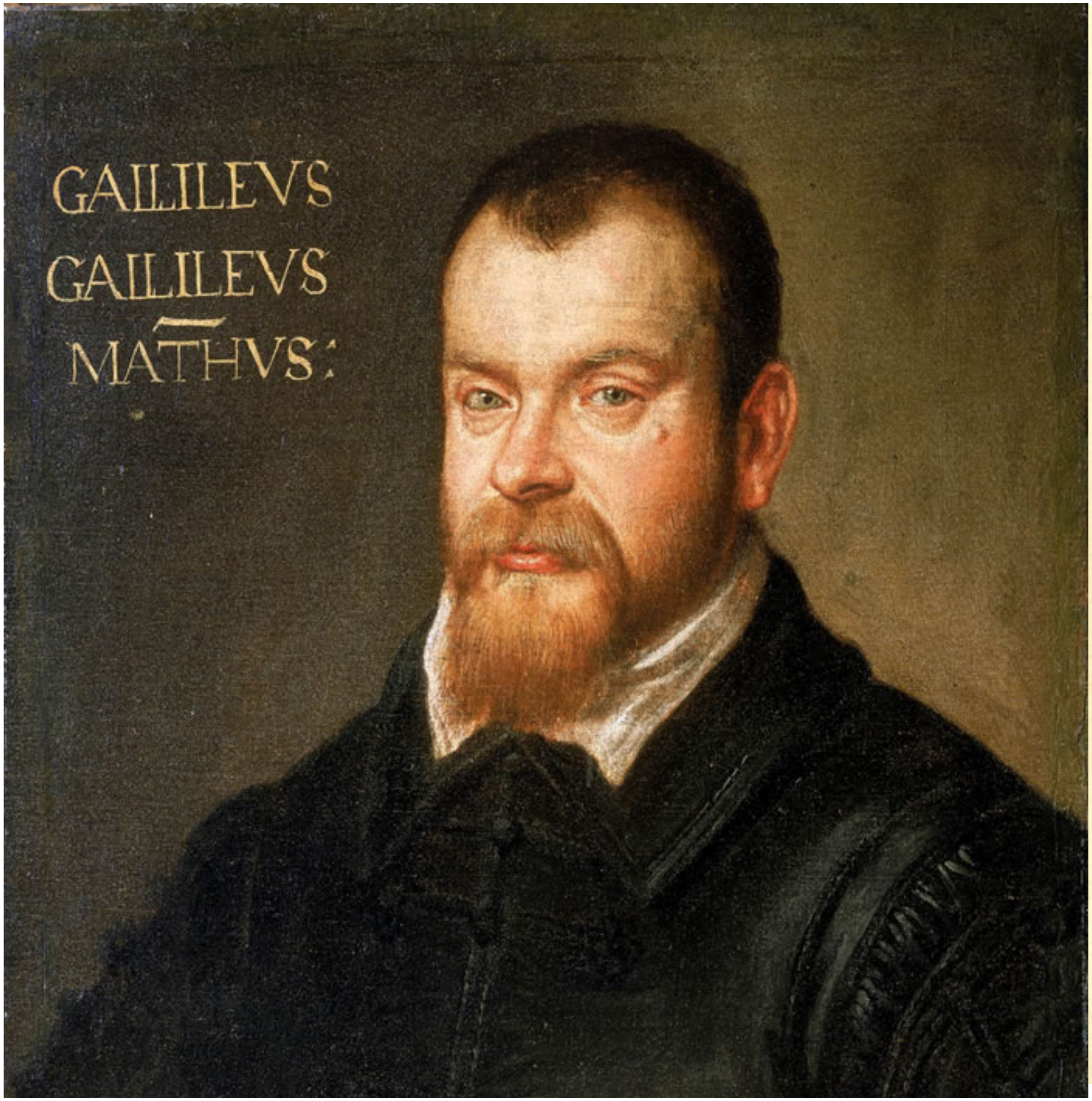
CAP. XXIV.

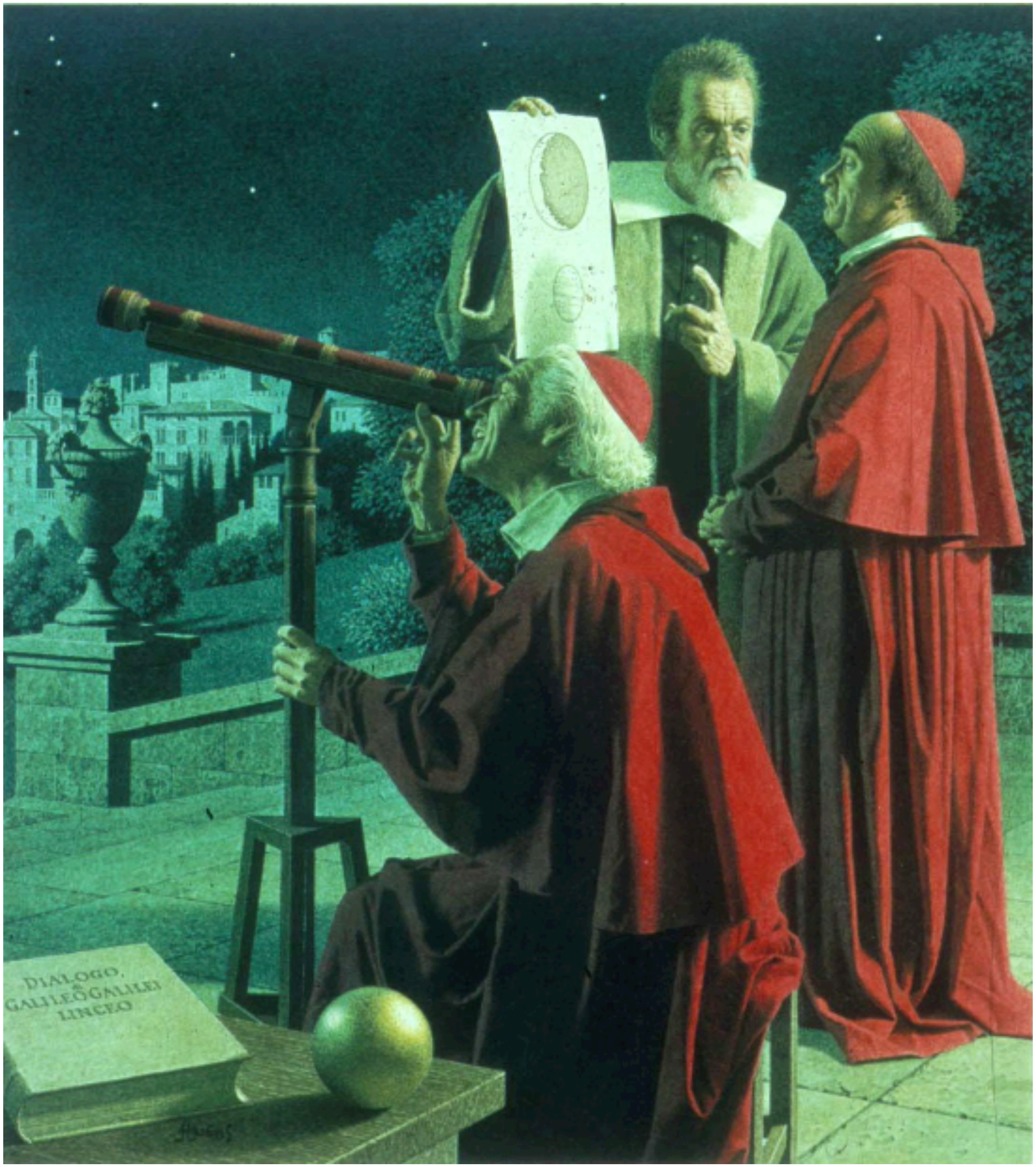
SOLIS vergat in 5 ½ ♒: quamvis hunc gradum cap. XXV libere inquisituri sumus quasi incognitum. Et sit TERRA A. MDXC in ϑ, anno MDXCII in η, anno MDXCIII in ε, anno MDXCV in ζ. Et anguli ϑαη·ηαε·εαζ· æquales, quia α est punctum æqualitatis, & periodica Martis tempora præsupponuntur æqualia. Sitq; Planeta his quatuor vicibus in κ, ejusq; linea apsidum αλ. Est ergo angulus ϑακ secundum indicium anomaliæ commutationis coæquatæ 127.5.1. Quod visum locum Martis attinet, is die IV antecedente hora simili fuit 24.22 ♈. diurnus ejus diei esset 44. Ergo ad nostrum tempus visus fuit in 25.6 ♈. qui est situs lineæ ϑκ. Sed ακ tendit in 15.53.45 ♉. Ergo ϑκα est 20.47.45. Residuus igitur αϑκ ad duos rectos est 32.7.14.

Vt igitur sinus αϑκ ad ακ, quam dicemus esse partium 100000: sic ϑκα ad ϑα quæsitum. Est ergo ϑα 66774.

Quod si reliquæ ηα, εα, ζα, ejusdem prodibunt longitudinis, falsum erit quod suspicor: at si diversæ, omnino vicero

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




DIALOGO,
&
GALILEO GALILEI
LINCEO

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**

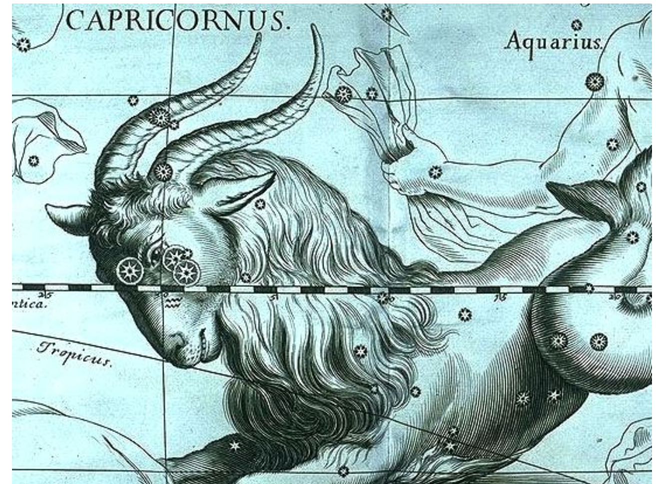
... Our Galaxy would be **10 million miles across**

... 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, high Γ, …)
  - 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

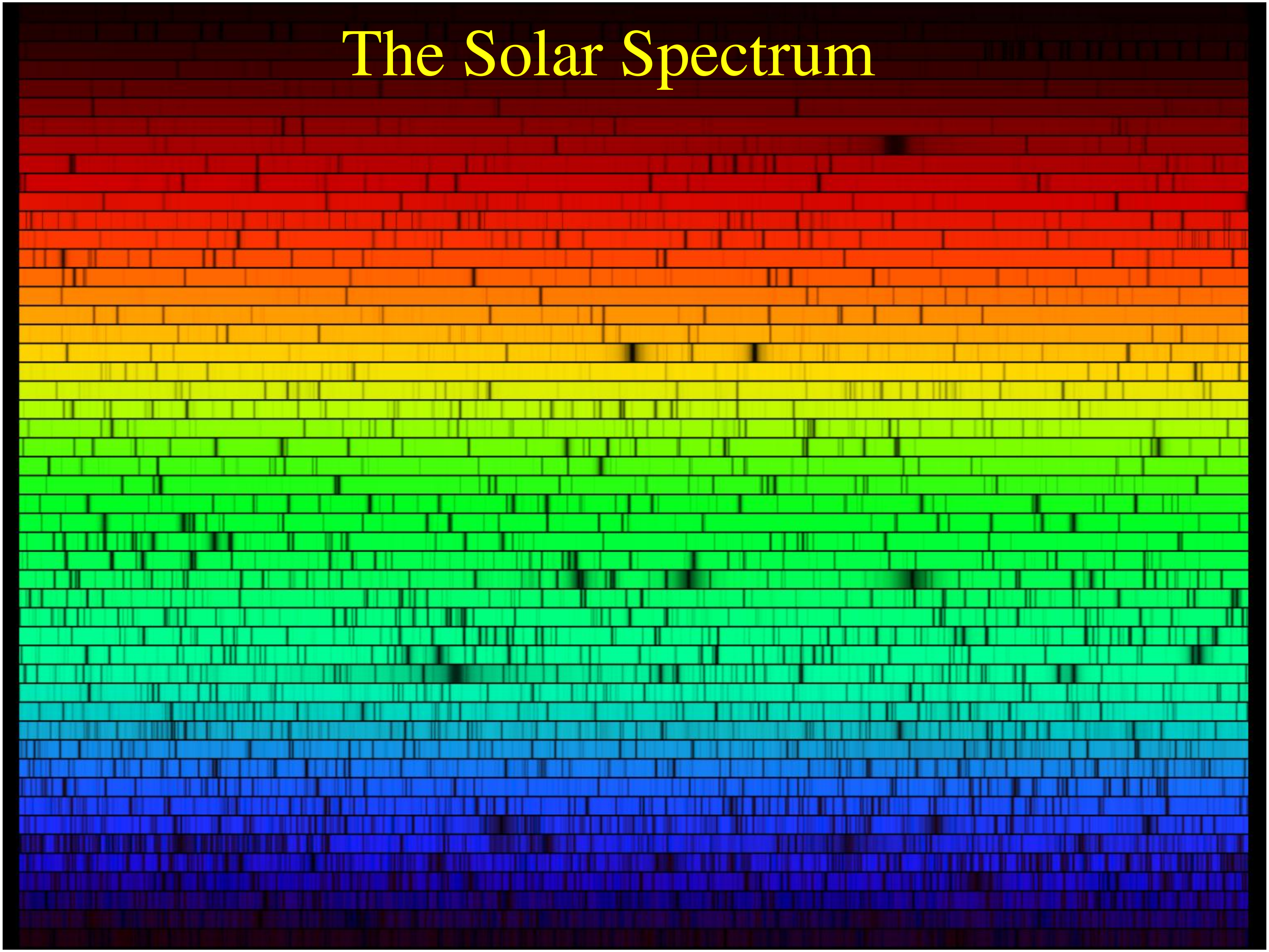
- S/N Poissonian and quantum limits of detection
- Geometrical optics limits of angular resolution
- Opacity of the Earth's atmosphere and the Galactic ISM (example: soft X-rays and the missing baryons)
- Obscuration by dust in galaxies
- Turbulence of the atmosphere/ISM: erasing the spatial information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


1.3 Messengers from the Universe

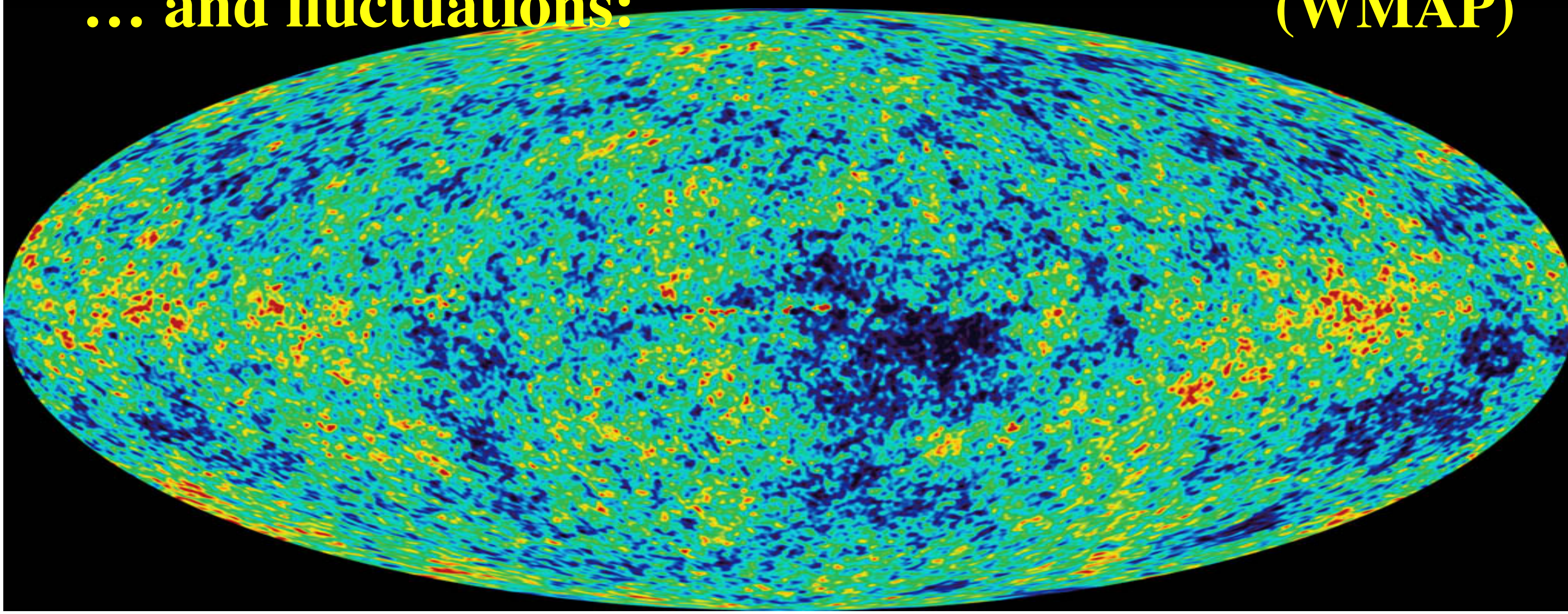
Information Flows in the Universe

- 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



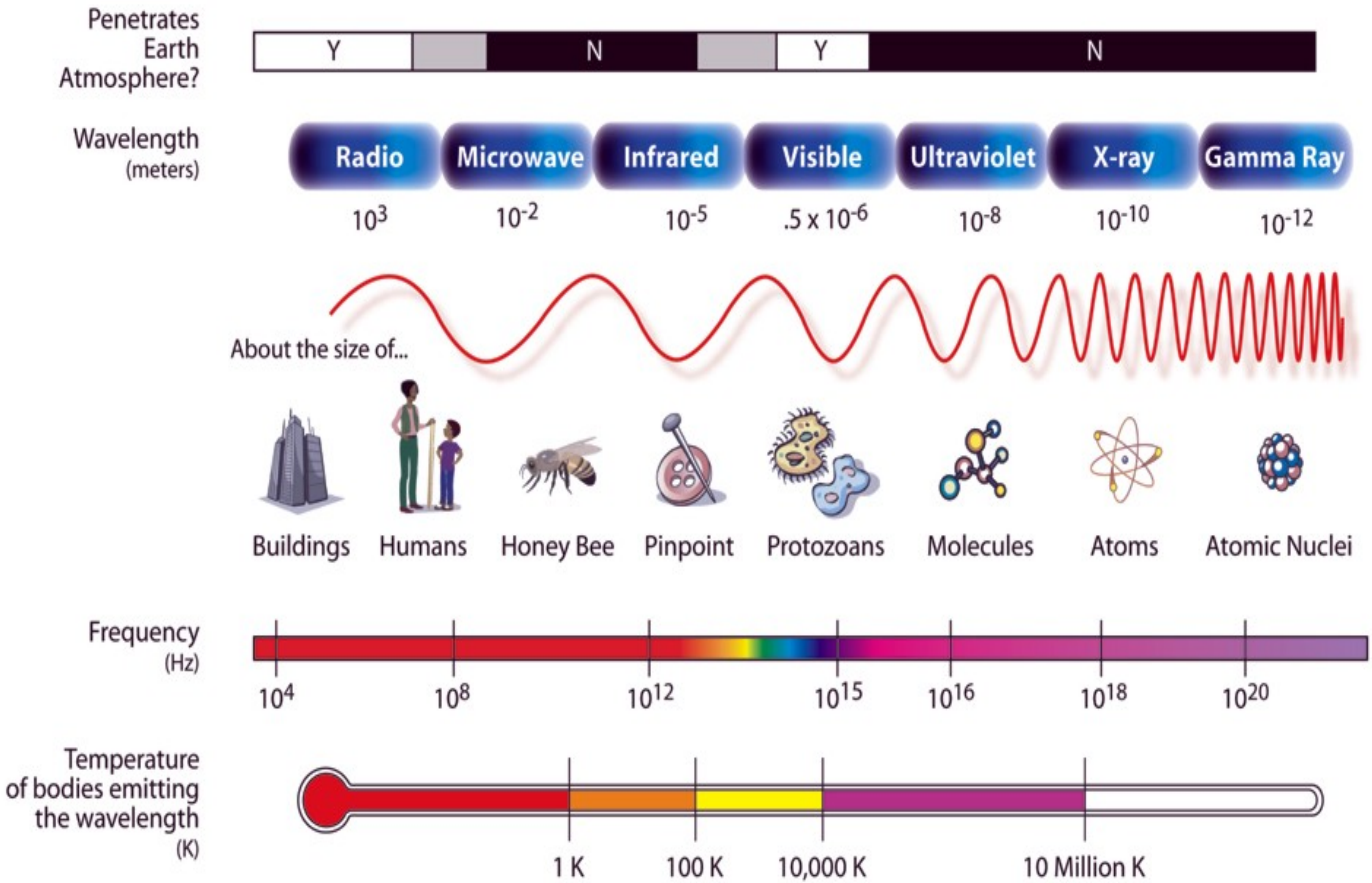
… and fluctuations: **(WMAP)**



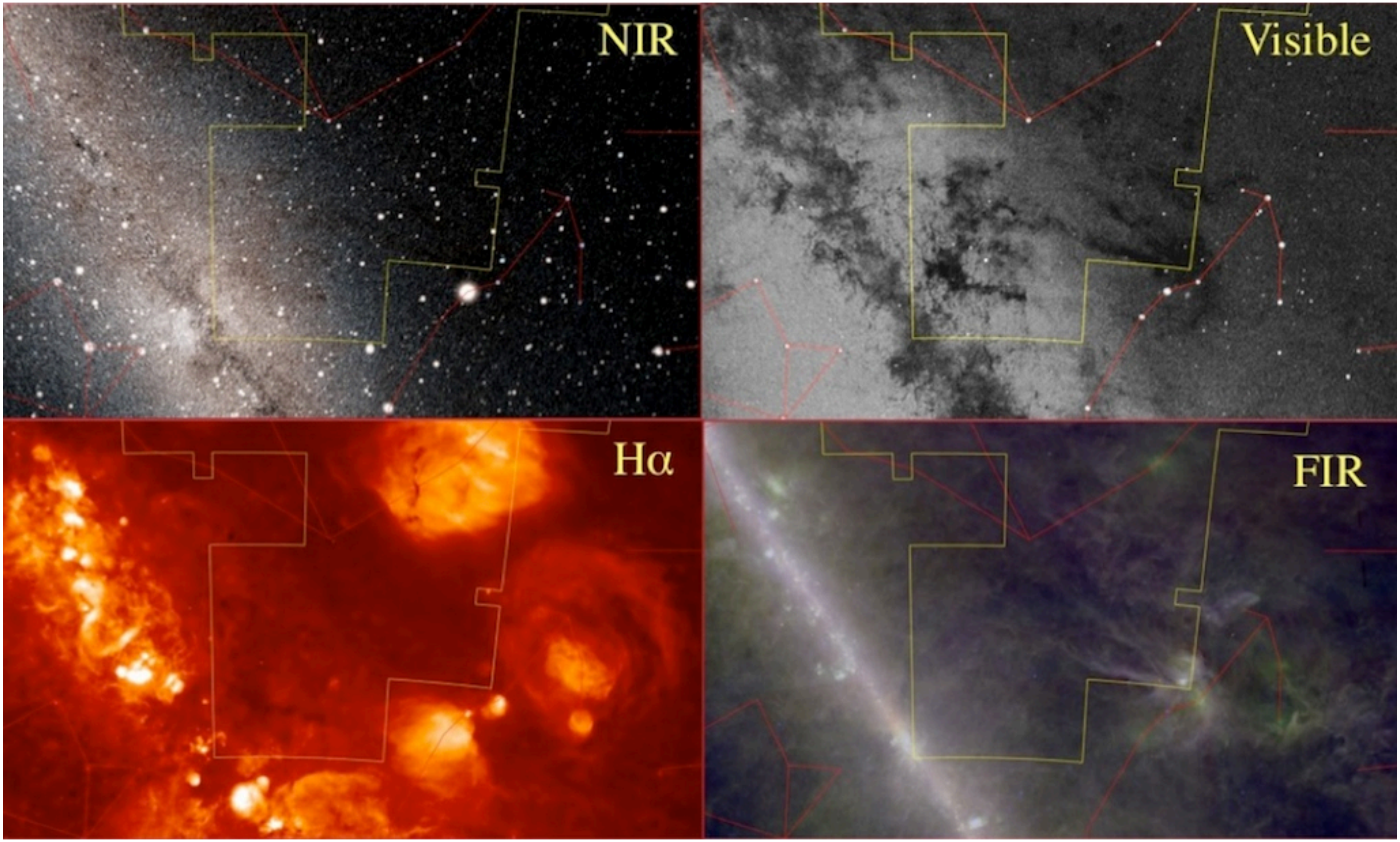
Information Channels in Astronomy

- 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 …
- Gravity Waves: LIGO/LISA type interferometers
- Dark Matter: lab detectors, gravitational lensing

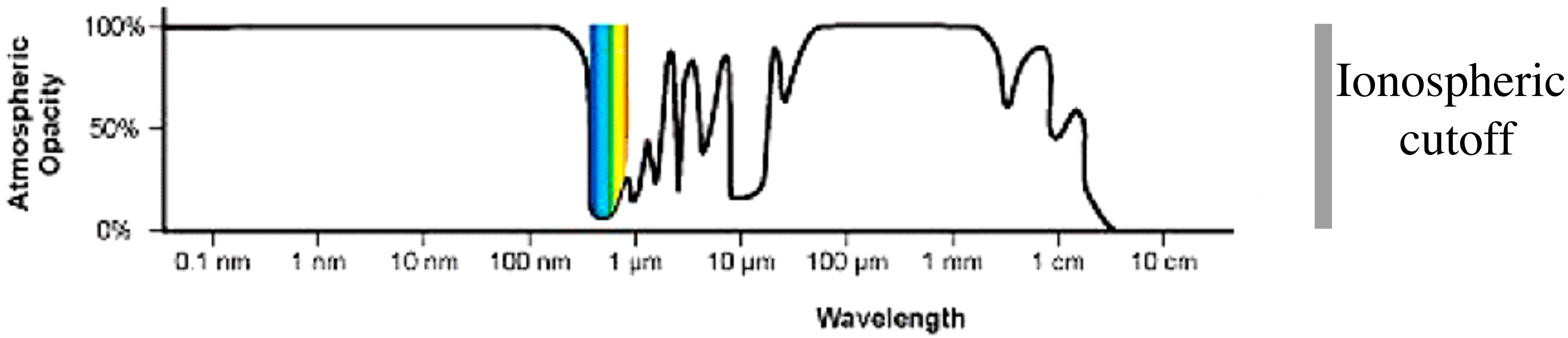
The Electromagnetic Spectrum



The Panchromatic Universe



Atmospheric Transmission Windows



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 ~ 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.