AY 1: Introduction to the Cosmos

This is a one-term introductory course on astronomy and astrophysics covering the basic history, content, and fate of the universe.
These topics require knowledge of simple mechanics and basic laws of radiation, quantum mechanics, and nuclear & particle physics, which we will develop as we go along.

AY 1: Introduction to the Cosmos

- Instructor: Mike Bolte ISB 333
- Lectures: T/Th 5:20pm – 6:55pm Sections: homework problems will be answered and discussed in sections and people who attend the sections do better in the class!
- Book: There isn't one
- iClickers: get one!
- Everything related to the class can be found at https://astro1.sites.ucsc.edu

Grades

- Grades will be based on:
  - four quizzes
  - comprehensive final exam
  - clicker-based participation

The worst of the four quiz grades will be dropped.

- Homework questions will be assigned but not graded, however, some of the quiz questions will taken from the homeworks

TAs:

- Tiffany Hsyu: ISB XXX, thsyu@ucsc.edu
- Grecco Oyarzun: ISB355, goyarzun@ucsc.edu

Class Goals

- Understand the process of scientific investigation
  - Very important question to ask all the time "what is the evidence that supports that conclusion?"
- Learn or review some physics and mathematics
- Use the physics and mathematics to understand the Universe and its history

CLASS TOPICS

- Scale of the Universe: Space and Time
- Tools of astronomy: Telescopes, computers
- Things related to astronomy that everyone should know
  - Seasons
  - Motions of objects in the sky
- Physics: electromagnetic radiation
- Solar System
- Extra-solar Planets
- Stars
  - Properties (mass, size, energy output, temperature)
  - Power sources
  - Lifecycle
  - Physics: thermo-nuclear fusion, gas laws, quantum physics applied to
  - White Dwarfs and Neutron Stars, General relativity and Black Holes
- Galaxies
  - Structure
  - Evolution
- Dark matter
- Supermassive black holes
- The Expansion of the Universe
- The Hot Big Bang
- The current-day distribution of matter in the Universe
- Growth of large scale structure
- Fate of the Universe
- - Expansion history
  - Dark Energy
  - The last three minutes

Quantitative vs Qualitative

- How would the appearance of the Sun change if it were moved to twice its current distance?

  Qualitative answer: *It would get fainter.*

  Quantitative answer:

$$I = I_0 / d^2$$

Intensity at distance "d" ← I

Original intensity ← I_0

distance ← d

<u>It would be 1/(2x2)=1/4 as bright</u>

Math phobic's nightmare

Clickr Quiz

Q. Astronomy is most closely related to:

a) Cosmetology
b) The Human Genome Project
c) Astrology
d) Physics

Q. While `at' the telescope, most astronomers wear:

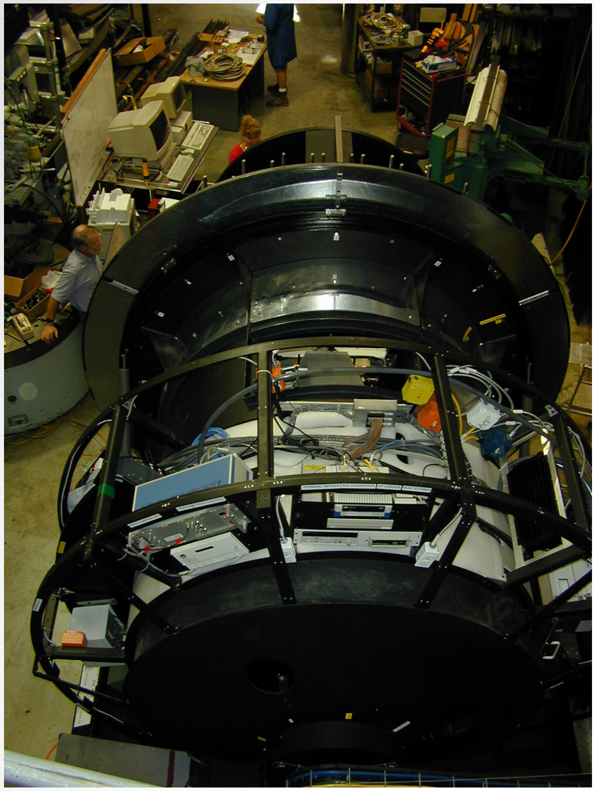
a) Patagonia Down Sweaters in "outlet" colors
b) White shirts and skinny ties
c) Politically incorrect animal furs
d) Bermuda shorts and aloha shirts

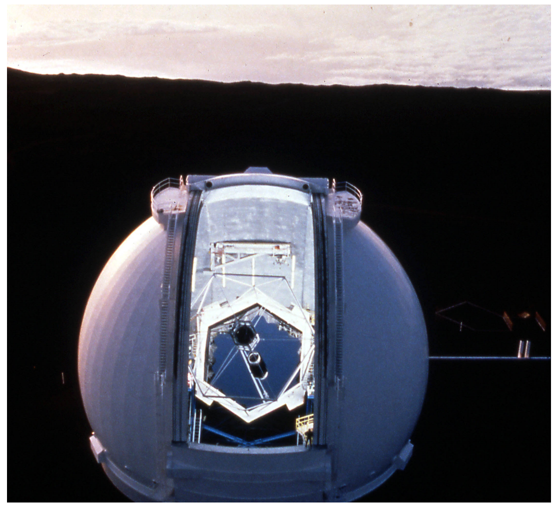
W.M. Keck Obs control room, Waimea, HI

Astronomy as a Career

- Typical path to astro-career
  - Undergraduate degree in Physics
  - 5 to 7 years in graduate school in A&A leading to PhD
  - 3 to 6 years as a research postdoc
  - Faculty position at some University
- Around 40% head in other directions
  - Aerospace, software, financial markets

University of California Observatories





UCO is a UC Multi-Campus Research Organization with headquarters at UC Santa Cruz. UCO develops and manages the astronomical optical/IR facilities for UC astronomers and is a major research center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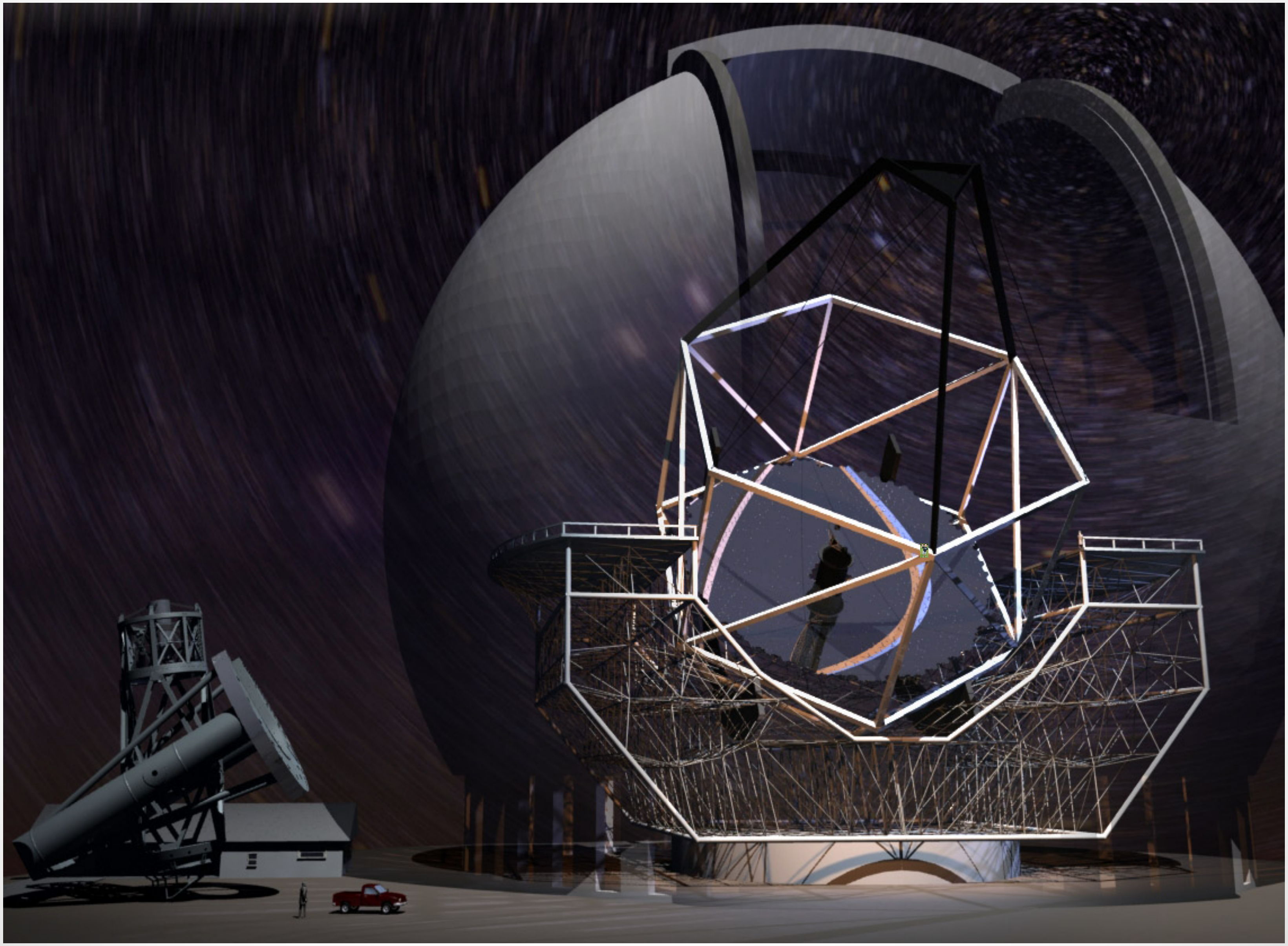
Keck Telescopes:

- 10-meter diameter mirrors
- UC design: joint ownership UC and Caltech

Rick Peterson image

The Future: Thirty-Meter Telescope



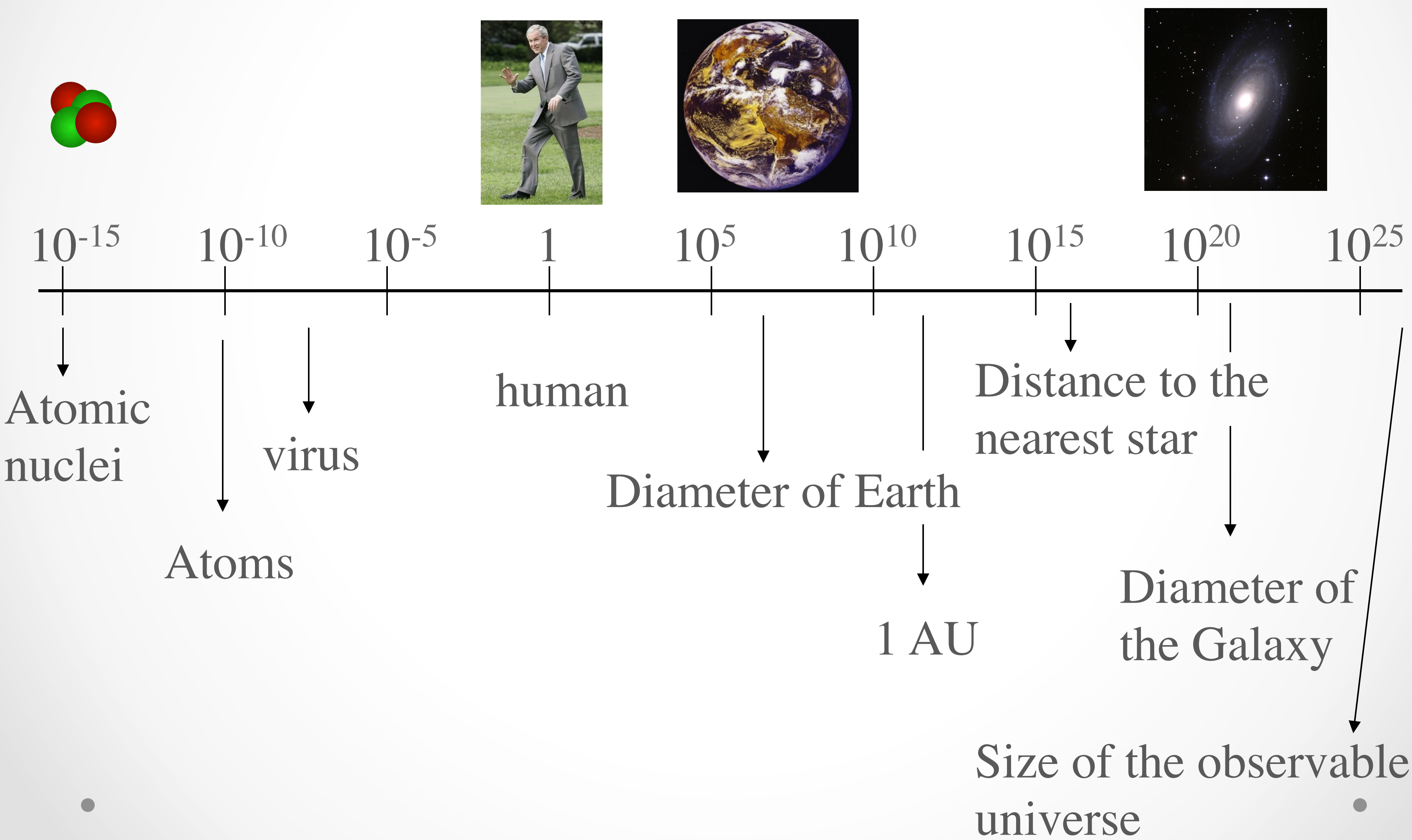

2009
Laureates
T. Boone Pickens
Lotfi A. Zadeh
The Franklin Institute
Awards
April 23, 2009
J. Frederick Grassle

Powers of 10

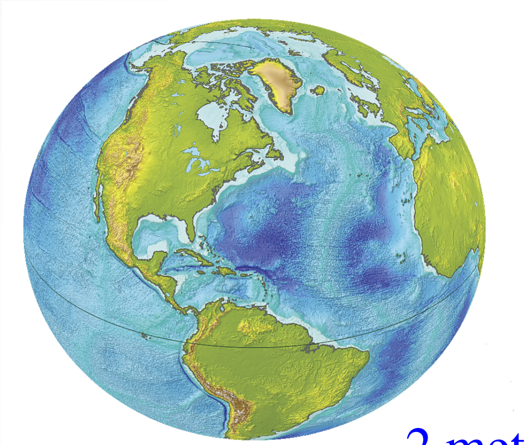
- Will use scientific notation throughout the class
- $100 = 10^2$
- $2.5 \times 10^4 = 2.5 \times 10000 = 25,000$
- $0.01 = 10^{-2}$

Getting Oriented in Space-time

Our Place in Size Scales



Scale of the Universe



- How many 2-meter tall students laid end-to-end would it take to encircle the Earth at the equator? (hint, Earth radius= 6400km)
    a. 2,000
    b. 20,000
    c. 200,000
    d. 2,000,000
    e. 20,000,000

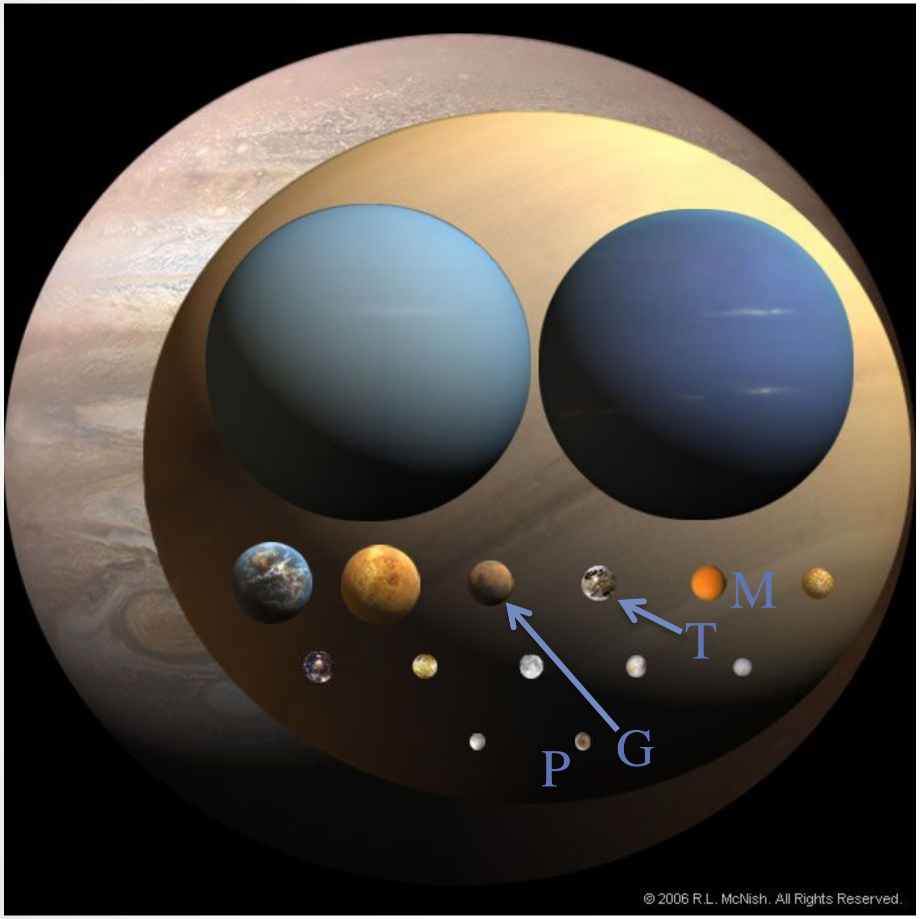
Distance around the Earth at equator:

$$2\pi r = 2 \times 3.14 \times 6400\cancel{\text{km}} \times 1000\,\frac{\text{m}}{\cancel{\text{km}}} = 40{,}212{,}385\text{m}$$

Number of students

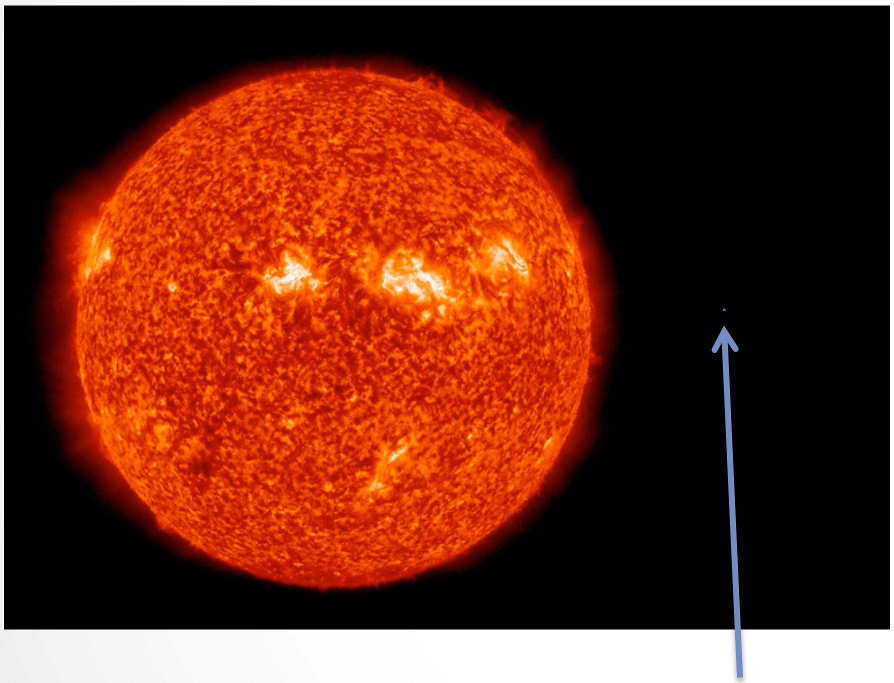
$$\frac{40{,}212{,}385\cancel{\text{m}}}{2\cancel{\text{m}}\,/\,\text{student}} \approx 20 \times 10^{6}\,\text{students}$$

Solar System Objects



In the Solar System the Earth is much smaller than the Sun and "gas giant" planets

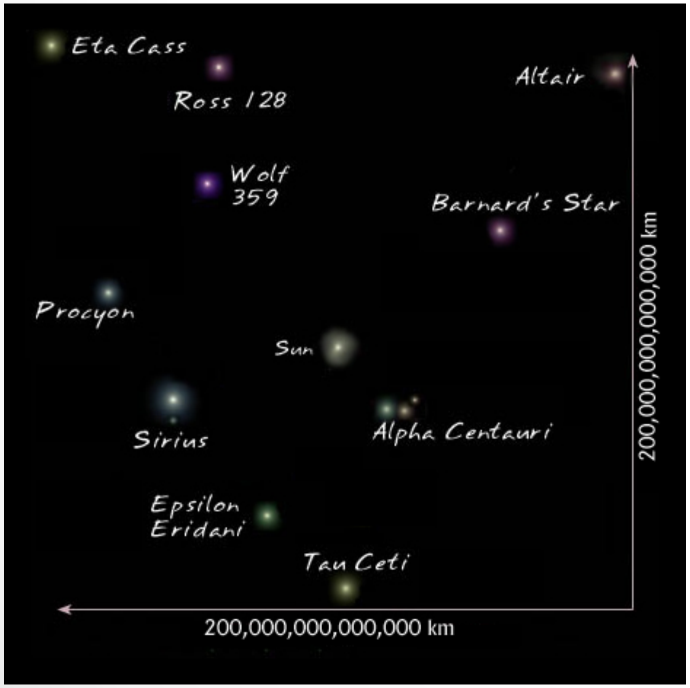
Solar System Scale



Earth x 5

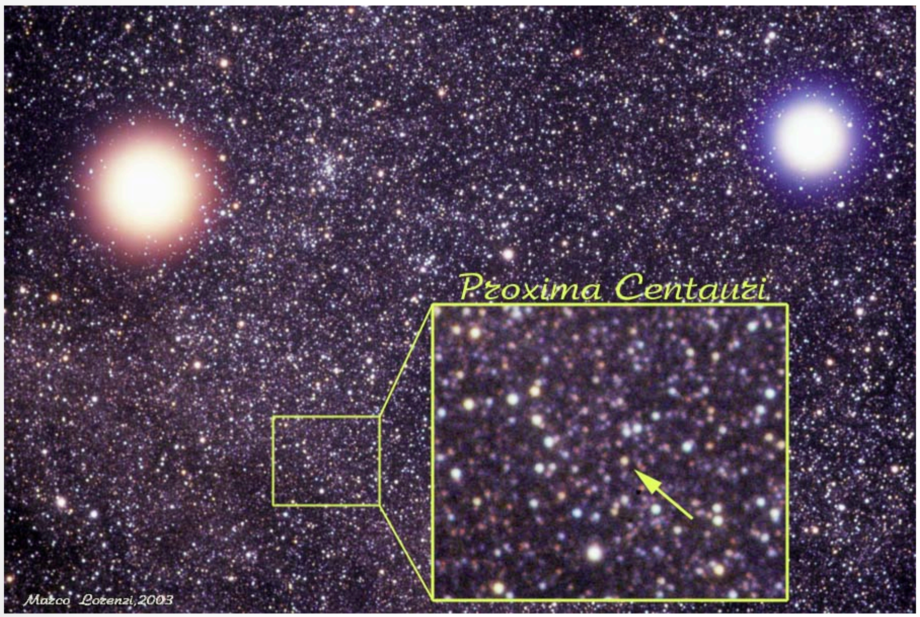
- Sun has a diameter of 1.4 million km. It would take 1.3 million Earths to fill up the Sun
- Sun has a mass of 1.99×10^{30} or 332,946 x mass of the Earth
- At speed of a 747 in flight it would take 17 years to go from the Earth to the Sun
- Light takes ~ 8 minutes

Solar Neighborhood



- Look at the sky at night other than a few planets and three galaxies all the points of light are stars in the Milky Way Galaxy
- Nearest stars to Sun are ~4×10^{16} m distance: 4.22 "light years" (LY)away. Sun is 8 light minutes distant

Solar Neighborhood



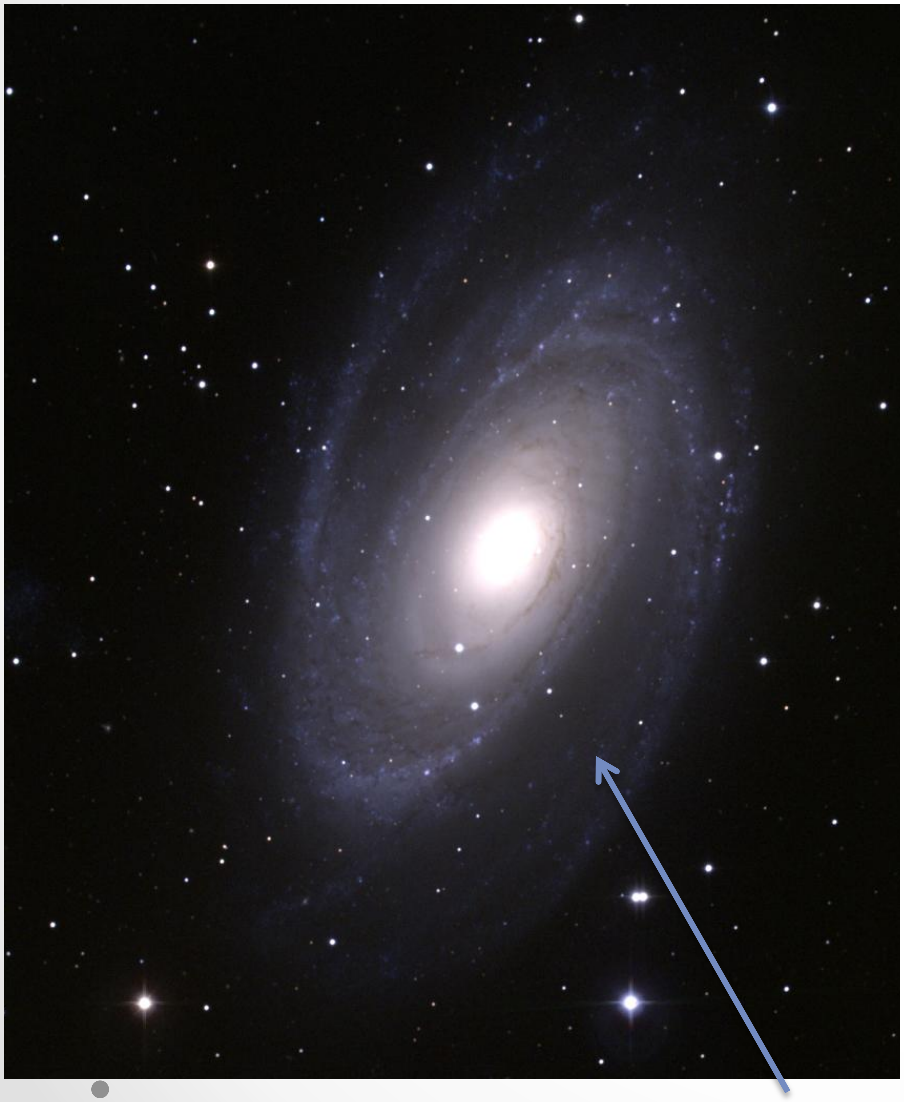
- In a 747 at 600 miles/hour, how long would it take to fly to Proxima Centauri 4 x 10^{13} km away?

Time = Distance/Speed

$$T = \frac{4 \times 10^{13}\,\text{km}}{600\,\text{miles/hr}} \times \frac{0.62\,\text{miles}}{1\,\text{km}} = 4.1 \times 10^{10}\,\text{hr}$$

$$4.1 \times 10^{10}\,\text{hr} \times \frac{1\,\text{day}}{24\,\text{hr}} \times \frac{1\,\text{yr}}{365\,\text{day}} = 4.7 \times 10^{6}\,\text{yr}$$

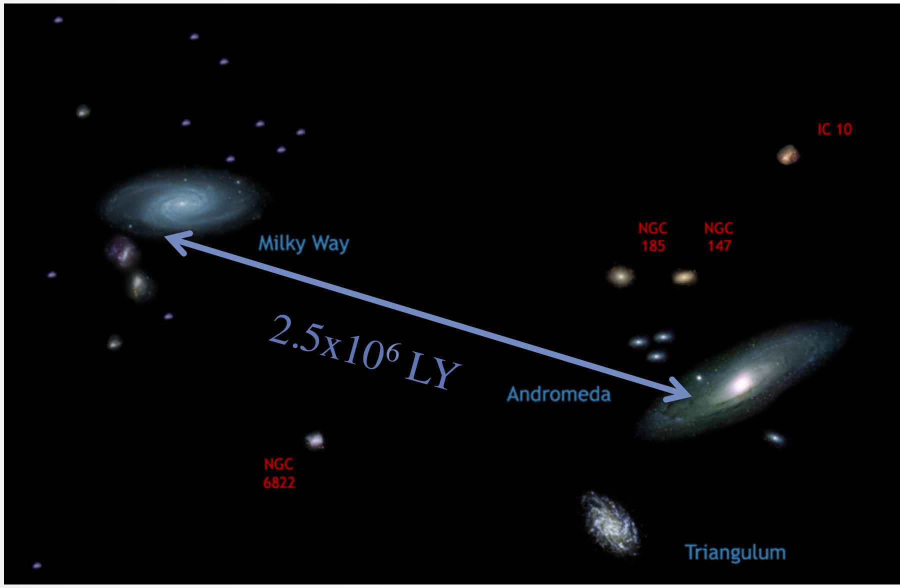
Milky Way Galaxy



- A large spiral galaxy like the Milky Way Galaxy contains around *[200 billion]* stars.
- We live in the suburbs of the Galaxy
- MW Galaxy is ~100,000 LY in diameter

- A good question is how do we know what kind of galaxy we live in
- This is what it looks like from Earth

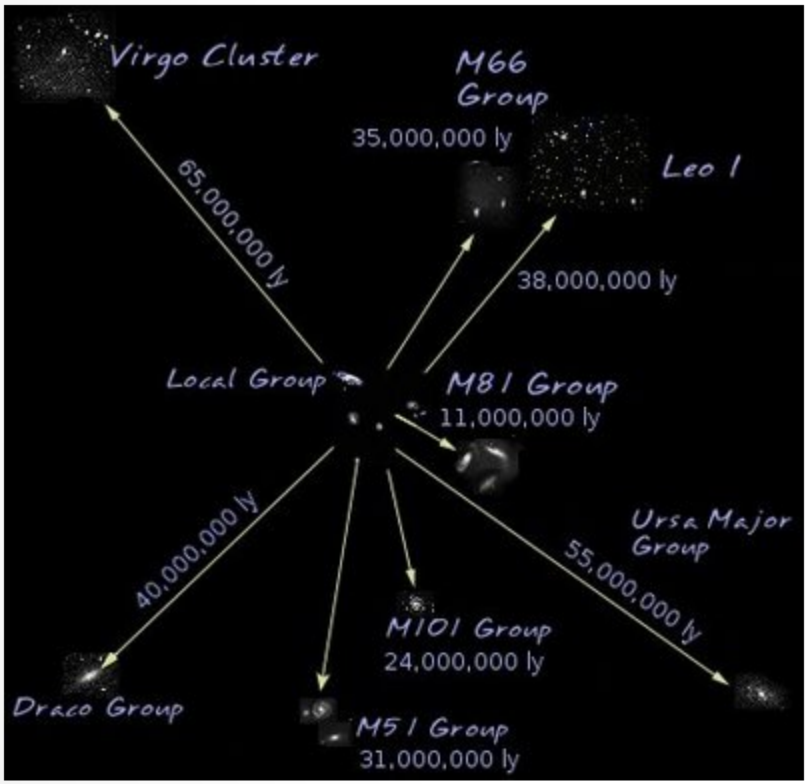
Local Group of Galaxies



The Milky Way Galaxy has a small complement of "dwarf" galaxy companions and

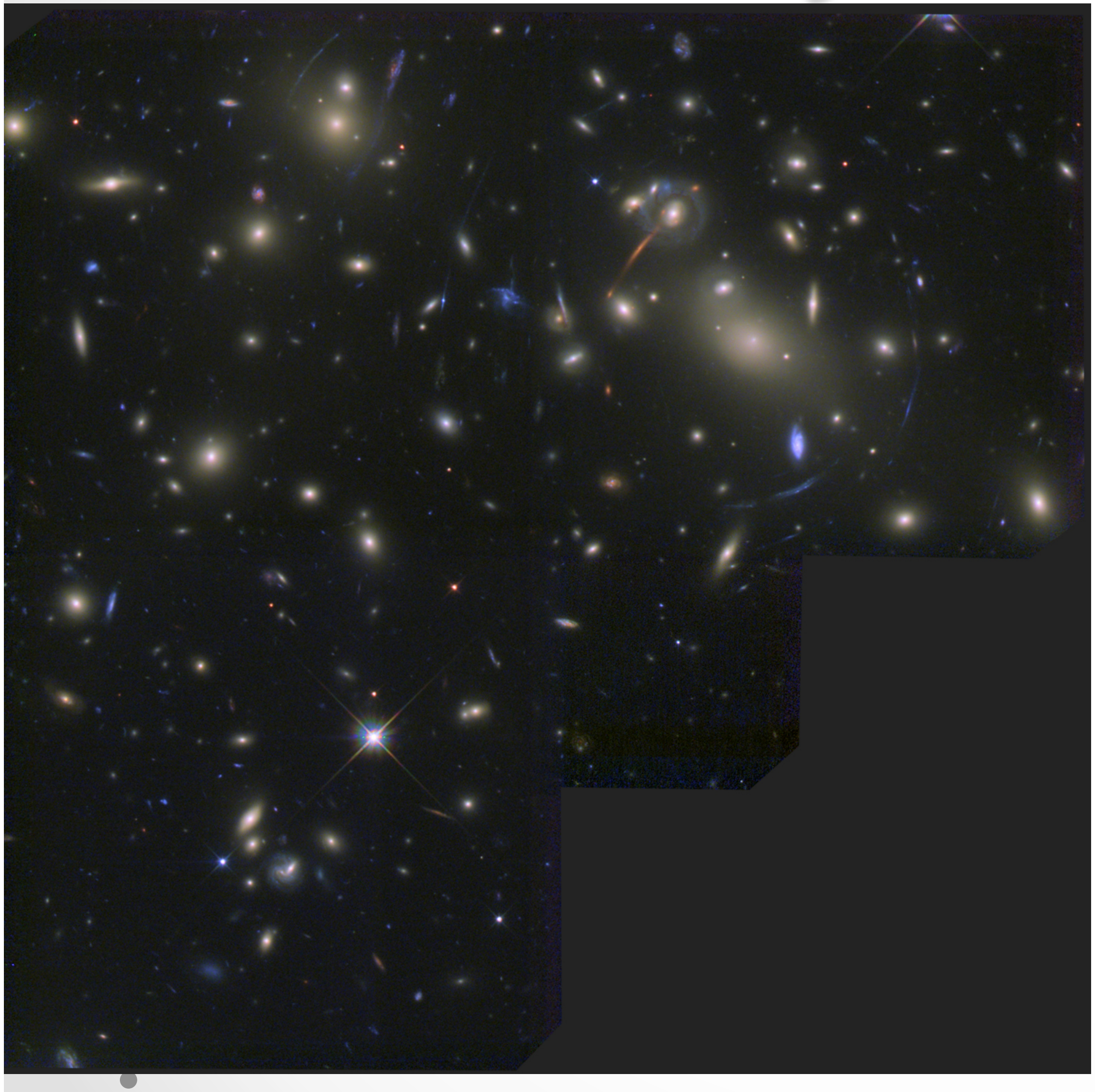
is a member of the "Local Group" of galaxies.

Galaxy Groups



- Local Group is one of many galaxy groups within a radius of ~50 million light years
- Each group is a gravitationally-bound entity
- Most, including the Local Group are flying toward the Virgo Cluster of Galaxies

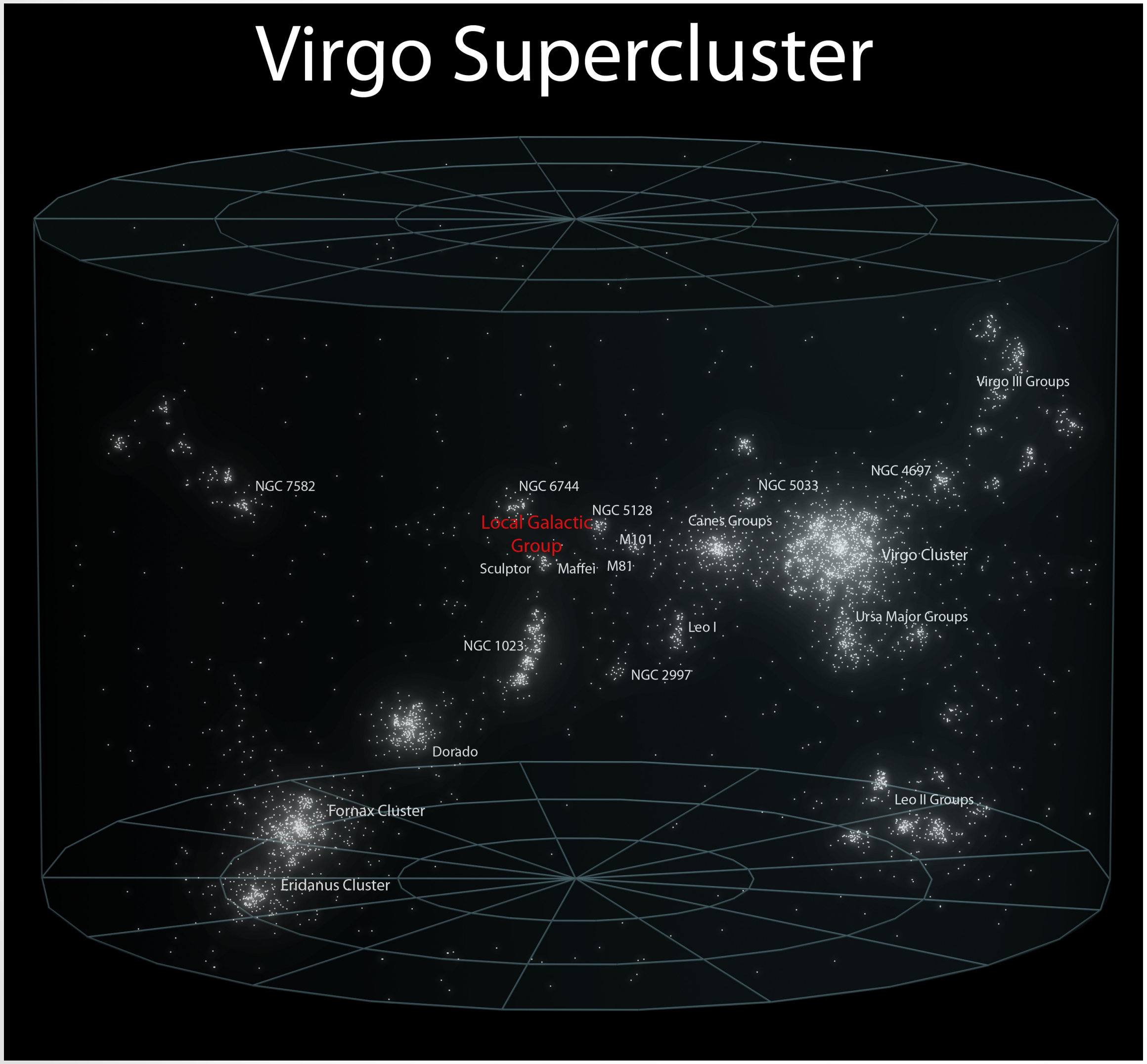
Galaxy Clusters



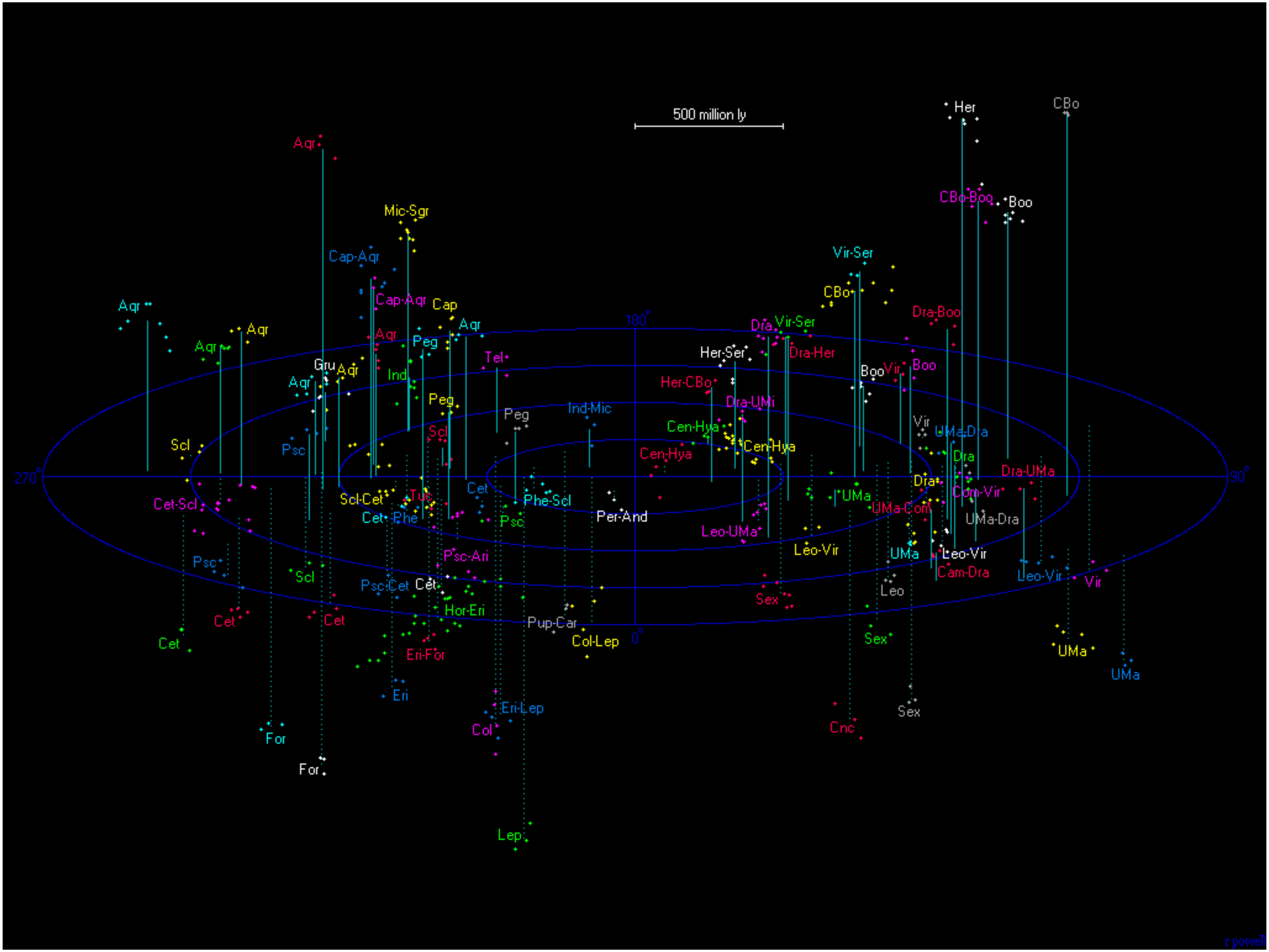
There are many clusters of galaxies, some much larger than the Virgo Cluster

These group together in super clusters…

Super Clusters



- Galaxy clusters cluster into super clusters
- Nearest is the Virgo Supercluster


500 million ly
Her
CBo
Aqr
Mic-Sgr
CBo-Boo
Boo
Cap-Aqr
Vir-Ser
CBo
Cap-Aqr
Cap
Dra-Boo
Aqr
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Aqr
Aqr
Peg
180°
Dra
Vir-Ser
Gru
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Tel
Her-Ser
Dra-Her
Aqr
Ind
Boo
Vir
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Her-CBo
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Ind-Mic
Dra-UMi
Cen-Hya
Vir
UMa-Dra
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Com-Vir
Cet
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UMa-Com
UMa-Dra
Leo-UMa
Psc-Ari
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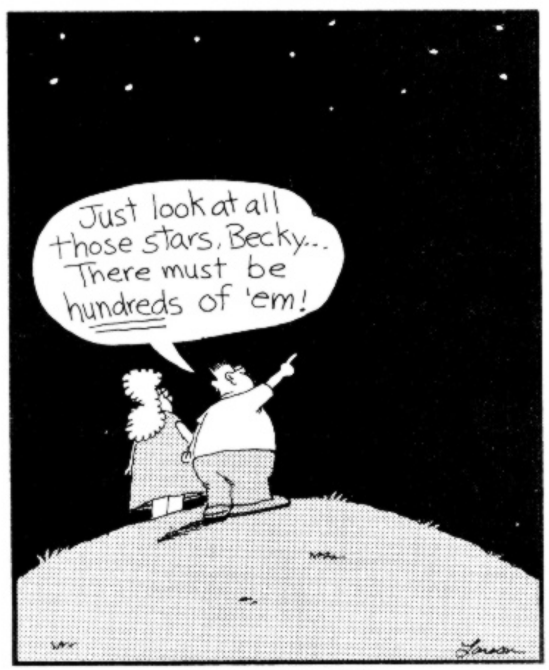
r.powell

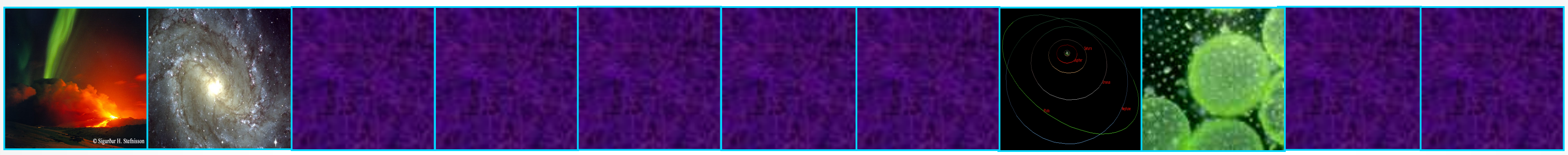
- Number of super clusters in the observable Universe*: 10 billion
- Number of Milky Way-sized galaxies in the observable Universe: 350 billion
- Total number of galaxies in the observable Universe: 7.5 trillion
- Total number of stars in the oU: 3×10^{22} (30 billion trillion)



Carl Sagan as a kid

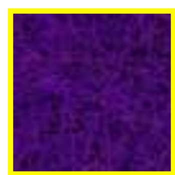
Our Place in Time

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov



13.5 billion years: Big Bang

12.5 billion years: formation of the Milky Way Galaxy



Dec

4.5 billion years: formation of the Sun and Solar System

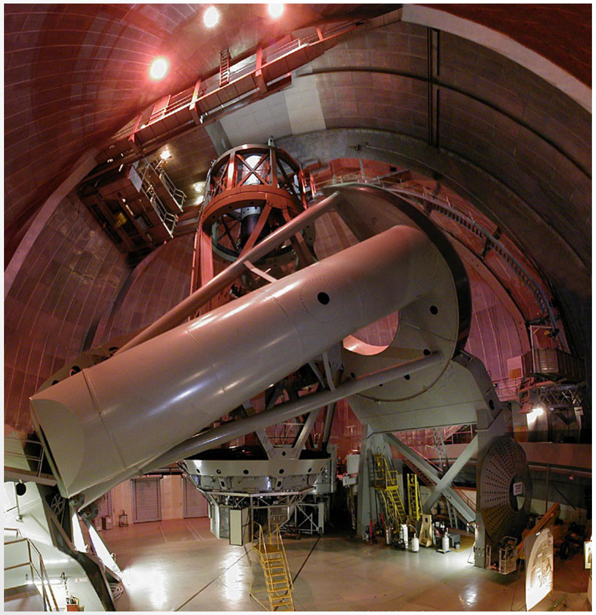
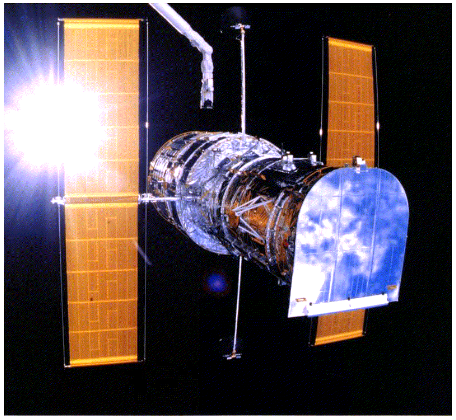
Life on Earth

December of the Cosmic Year

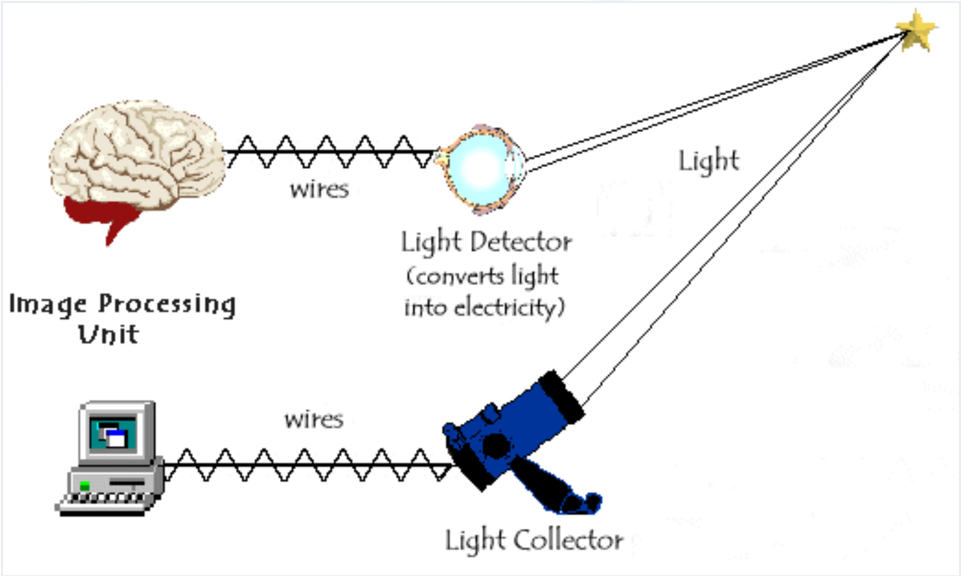
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16 First vertebrates	17	18 First land plants	19 First amphibians	20 First reptiles	21
22	23 The Great Dying	24 First Dinosaurs	25 First Mammals	26	27 First birds	28
29 First primate, Asteroid wipes out Dinos	30	31 9:24pm - First human ancestor to walk upright 11:30pm - Fire becomes human tool 11:54pm - Homo Sapiens appears 11:59:50pm - The pyramids are build 11:59:59pm - Columbus sails to the New World				

Tools of Astronomy




Telescopes



Telescopes only have a few jobs:

1) Point to a particular point on the sky
2) Collect lots of light and focus it onto a detector
3) Follow the apparent motion of the object

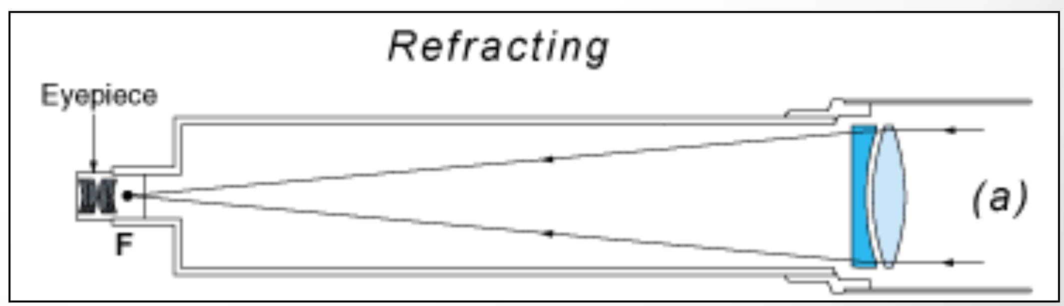
A short history of telescopes: Galileo to the TMT

Galileo

- 1608 Hans Lippershey applied for a patent for "*seeing things far away as if they were nearby*"
- 1609 Galileo had built a 1″ diameter refracting telescope with 3x magnification and made observations of celestial objects

Refractor

Up to the early part of the 20th century the largest telescopes used a lens and refraction to focus the gathered light



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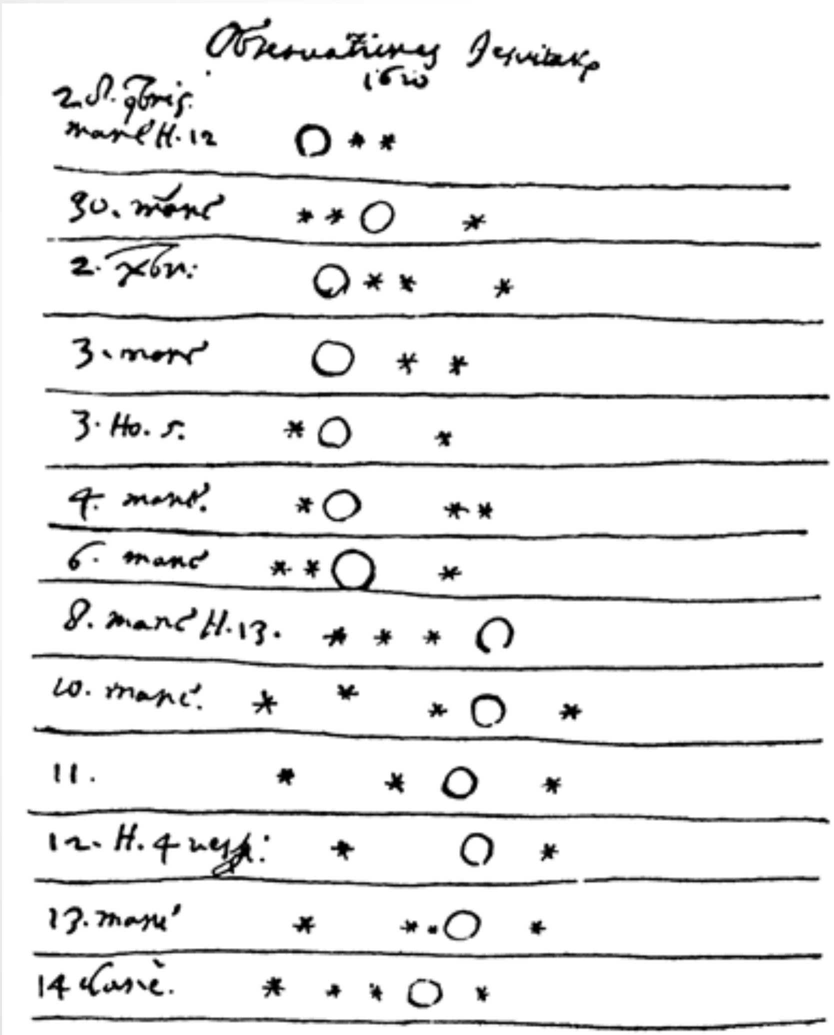
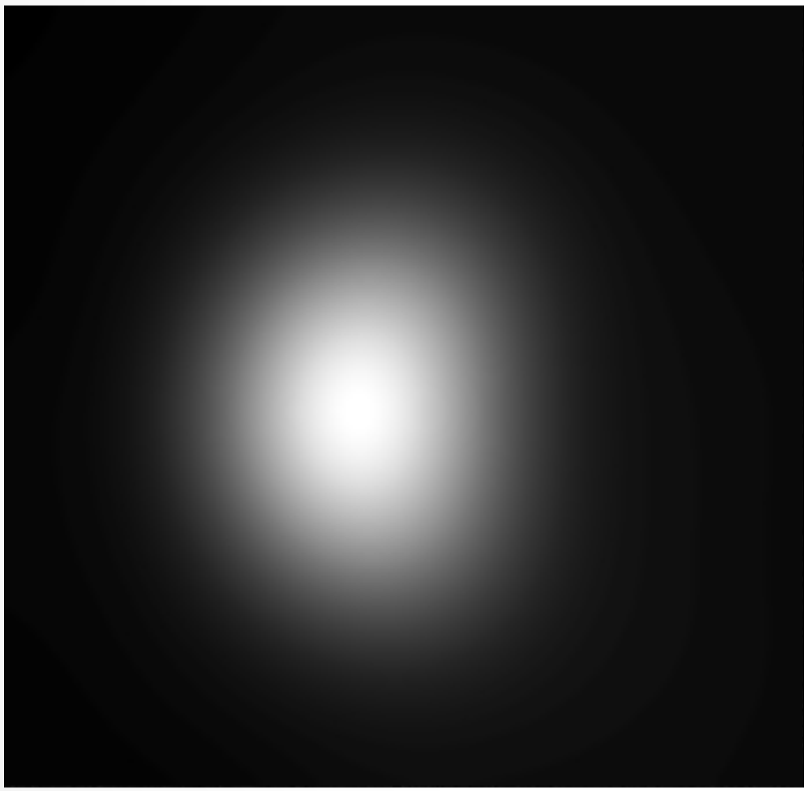
Galileo's Observations



- With his telescopes Galileo could see *fainter* objects and with *higher spatial resolution*
- Observed four faint objects that over time were shown to orbit Jupiter

- Galileo observed imperfections on the surface of the moon and the Sun
- Perhaps most importantly, with the improved spatial resolution of his telescopes, Galileo observed that Venus showed different phases

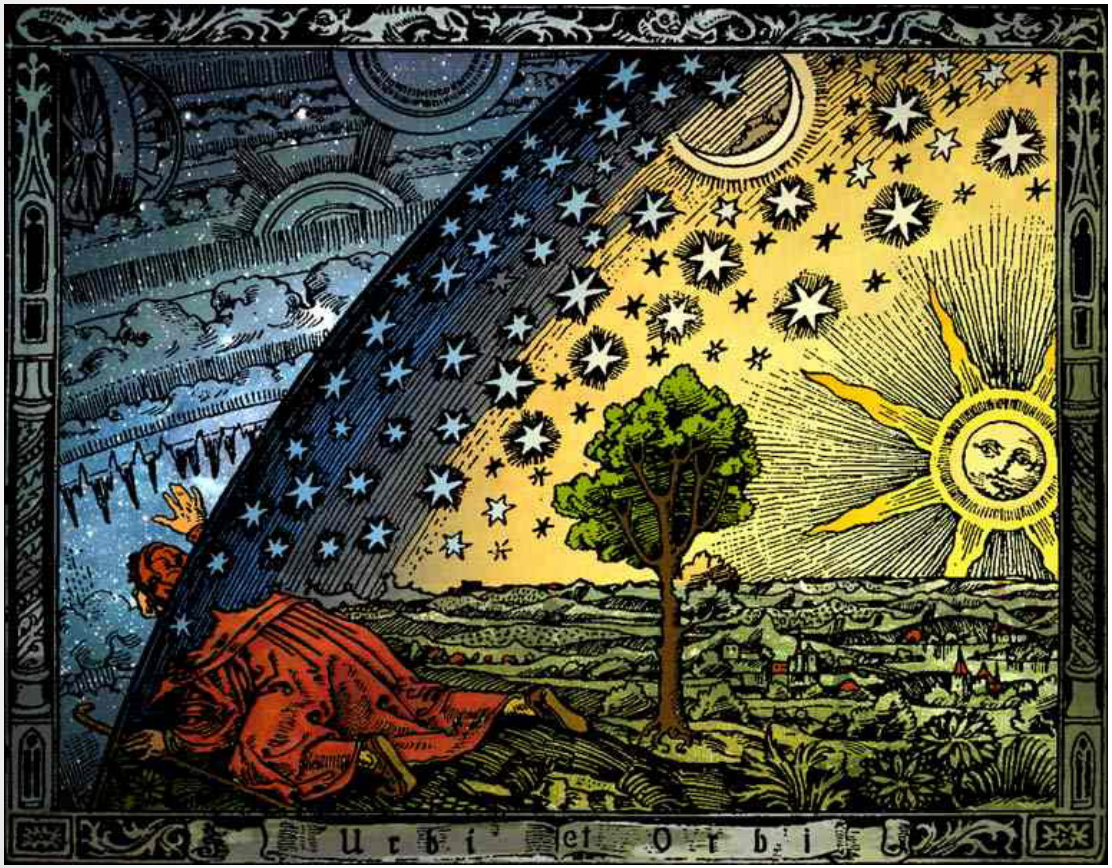
Galileo and Venus



The key observation that demonstrated at least one object in the Solar System orbited the Sun was observing Venus go through different phases

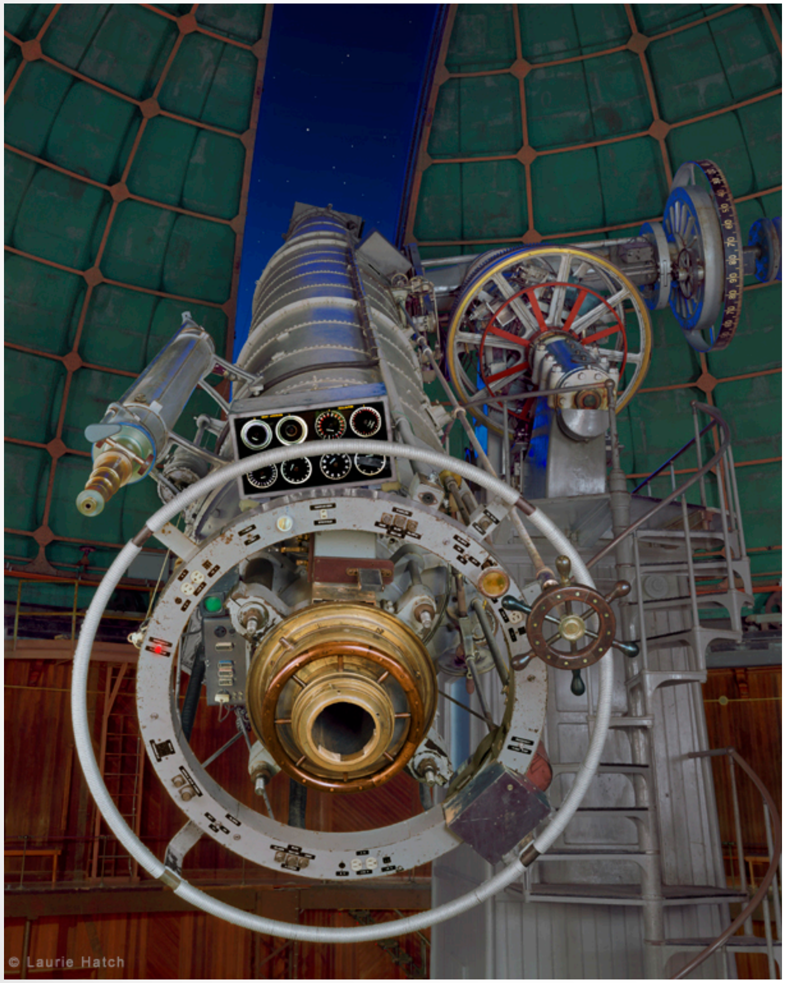
A New World View

- *The technological advancement of a simple combination of two lenses to make a telescopes led to a profound discovery*
- *The Earth was not the center of the Universe!*



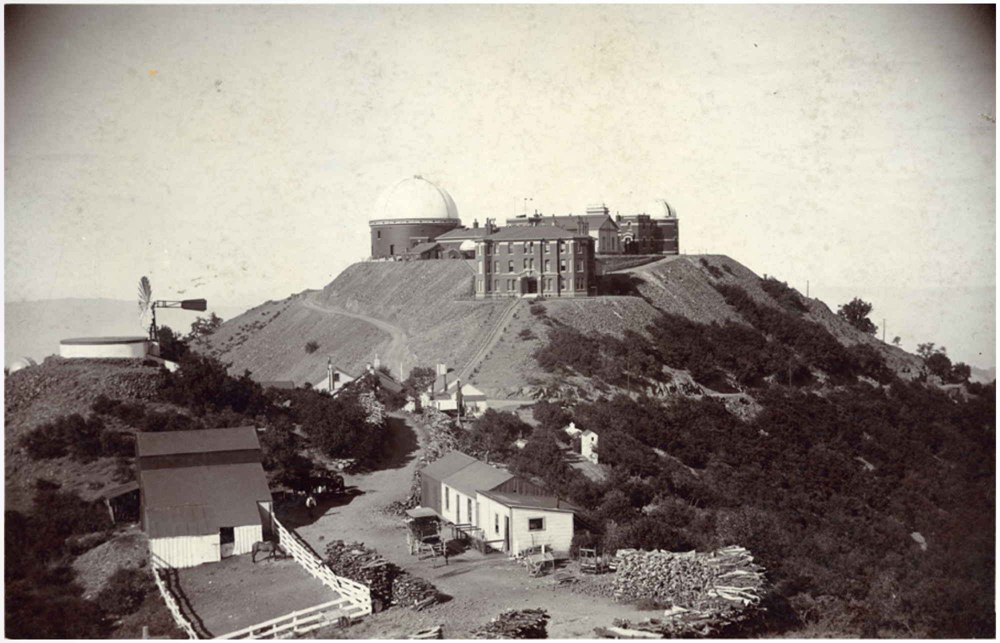
- This story of discovery following the invention of new and better tools has been repeated many times since Galileo's time

Telescopes 1609-1888



- Refracting telescopes grew in size (diameter of the lens) through the end of the 1800s
- 1888 the 36″ refractor was completed at Lick Observatory: largest steerable telescope in the world

Lick Observatory



- First mountaintop observatory in the world in 1888
- First observatory to completely embrace photography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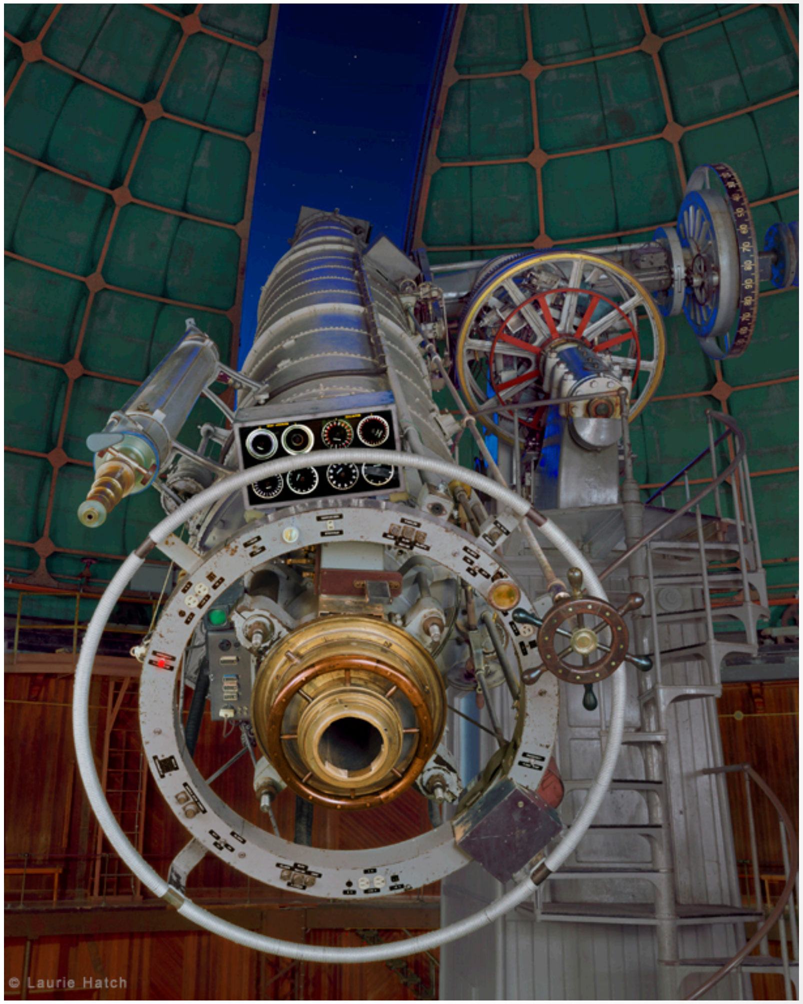
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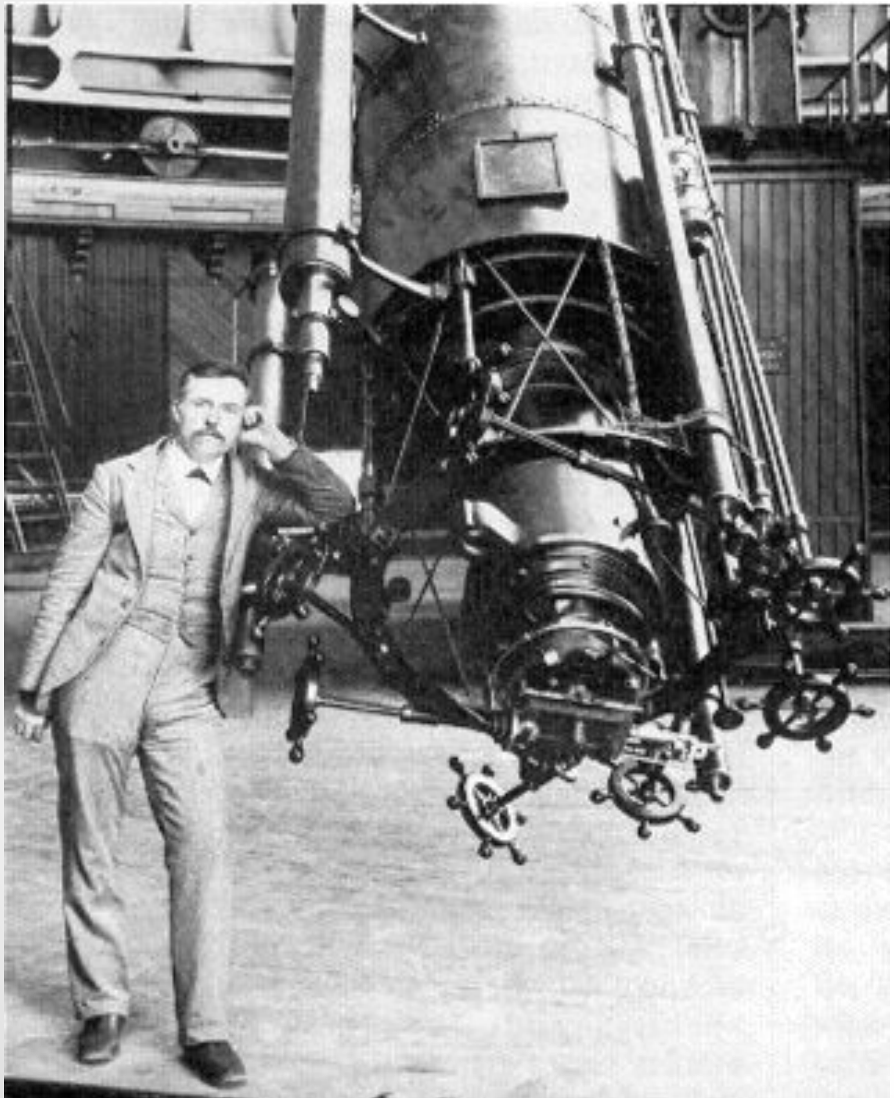
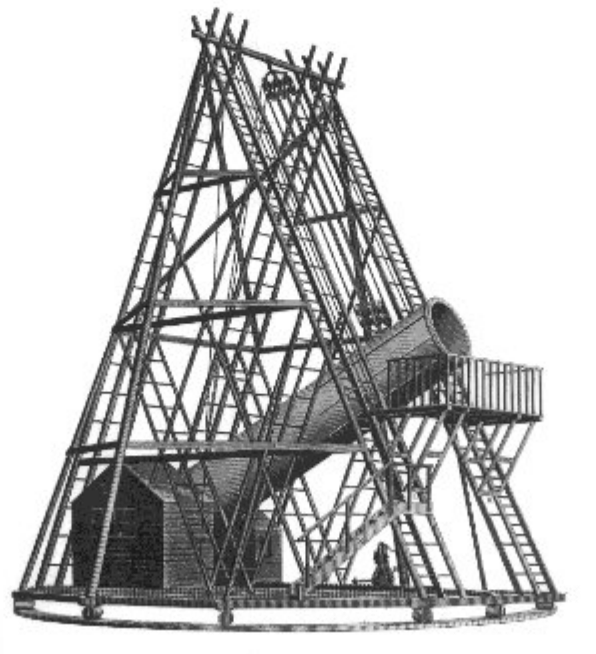
Early Work at Lick Observatory



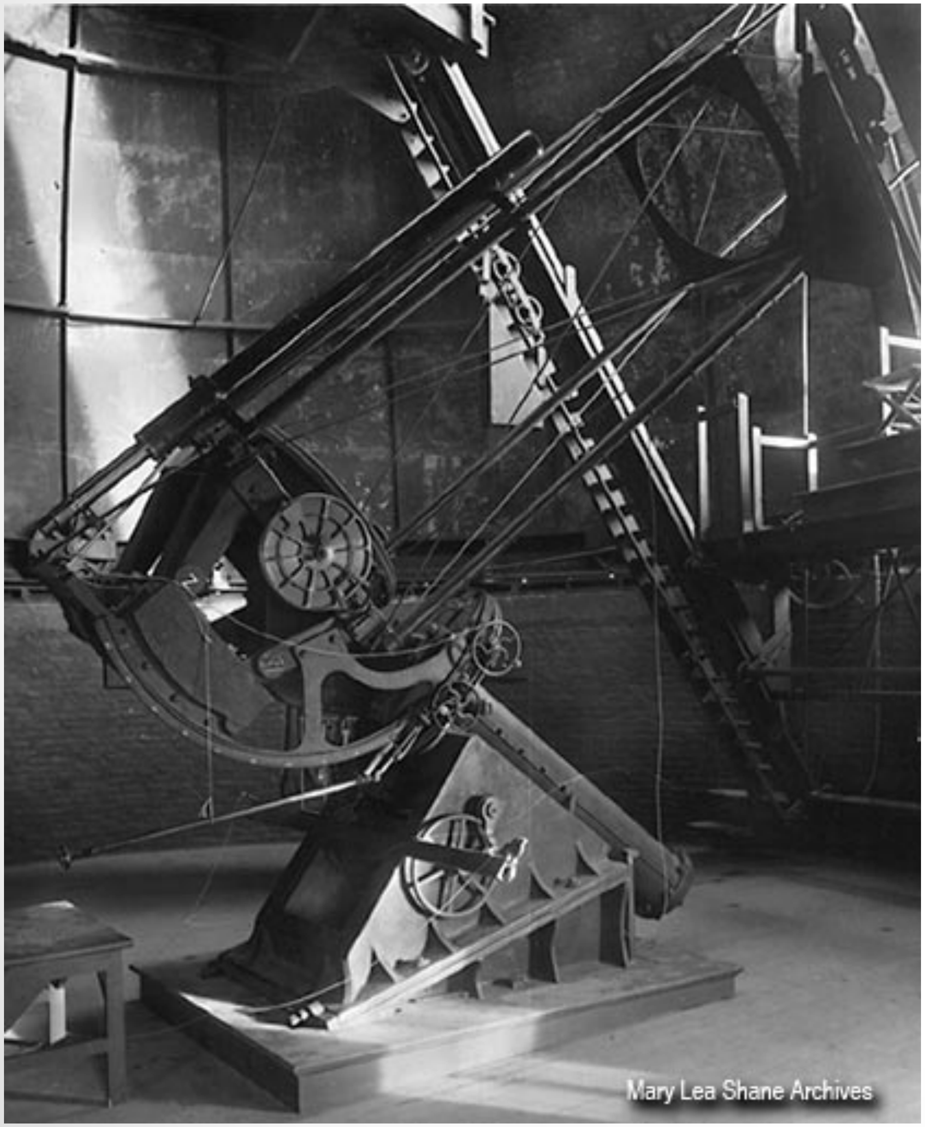
- First photographic mapping of the Milky Way and source of much debate about the nature of the dark regions
- Discovered many comets
- Measured motions of stars
- Measured binary star orbits and masses of stars

Reflecting Telescopes

- Newton proposed telescopes using mirrors rather than lenses
- no chromatic aberrations, "faster" optics and possibilities of building larger and larger mirrors (can support mirrors from behind)

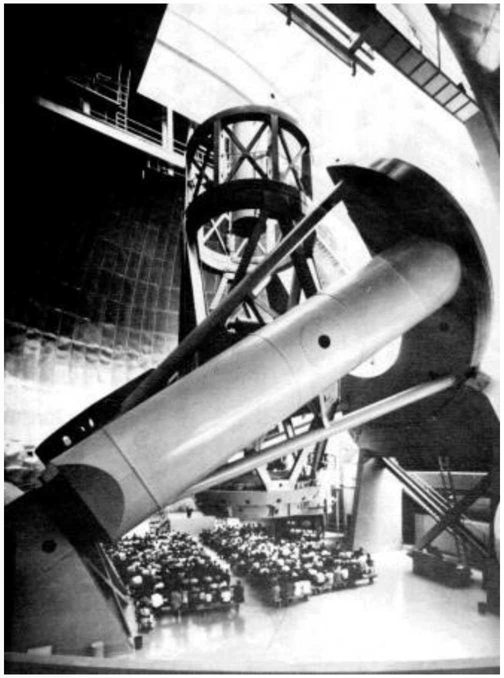


The Rise of the Reflectors



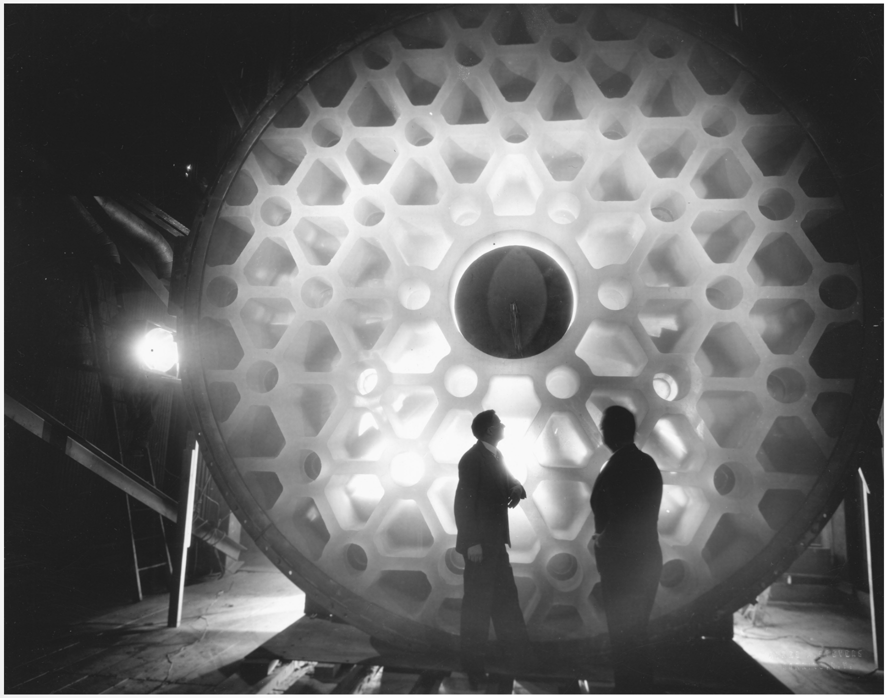
- 1896 the 36″ Crossley Reflecting Telescope arrived at Lick Observatory
- Using a complicated hand-guiding mechanism, exposures could be made that lasted hours

The End of an Era



- The Palomar 5m was completed in 1949
- Established the extra-galactic distance scale, discovered stellar populations, discovered quasars and led to the birth of observational cosmology

The Trouble with Big Telescopes



- 5m Pyrex Mirror weighted 14.5 tons and the support structure almost the same
- Surface is polished to ~1/10 micron (1/200,000″) over 11 years of grinding
- Very difficult to maintain that exquisite figure for different orientations

Evolution of Telescopes

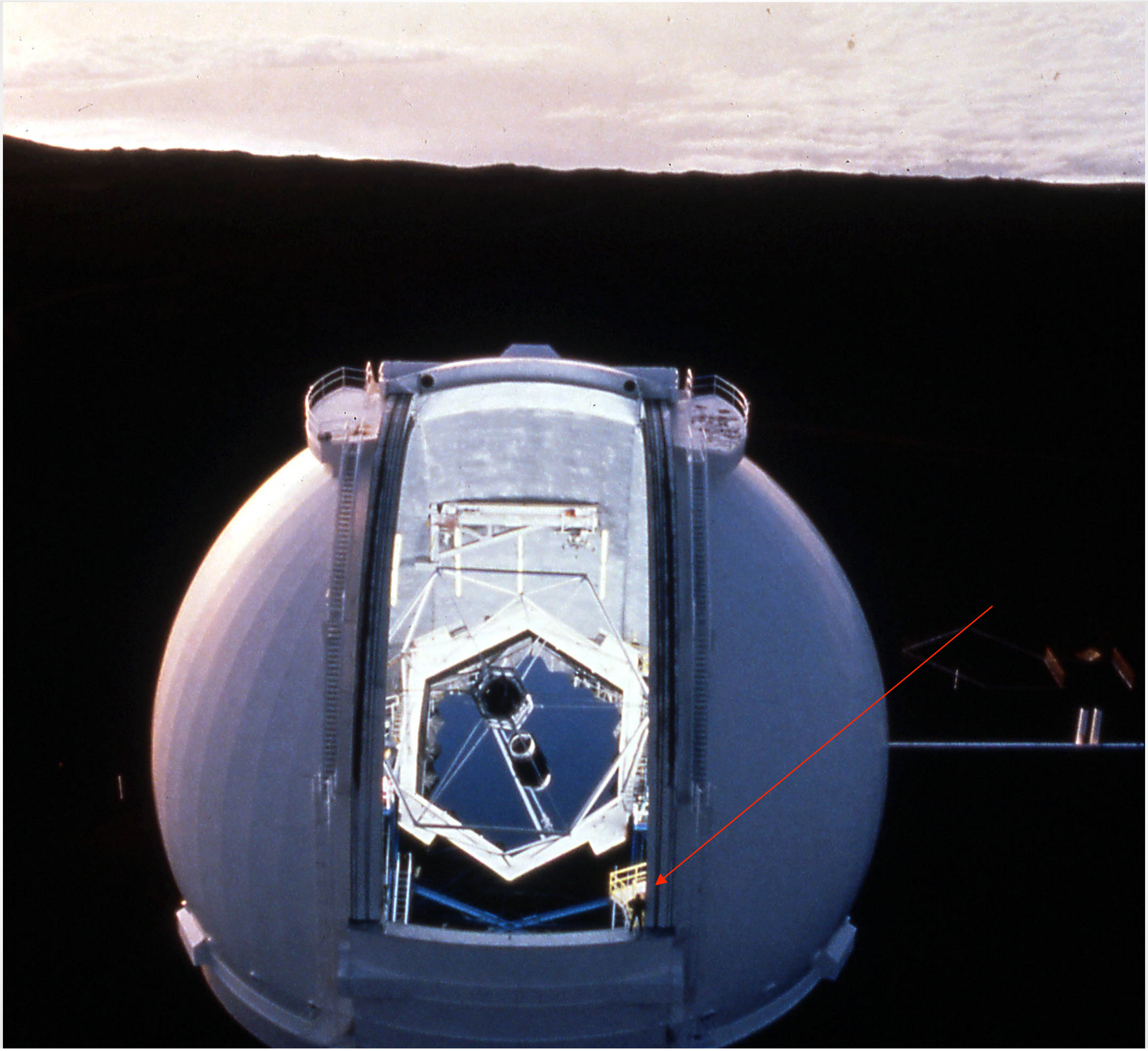
Not obvious that this would work

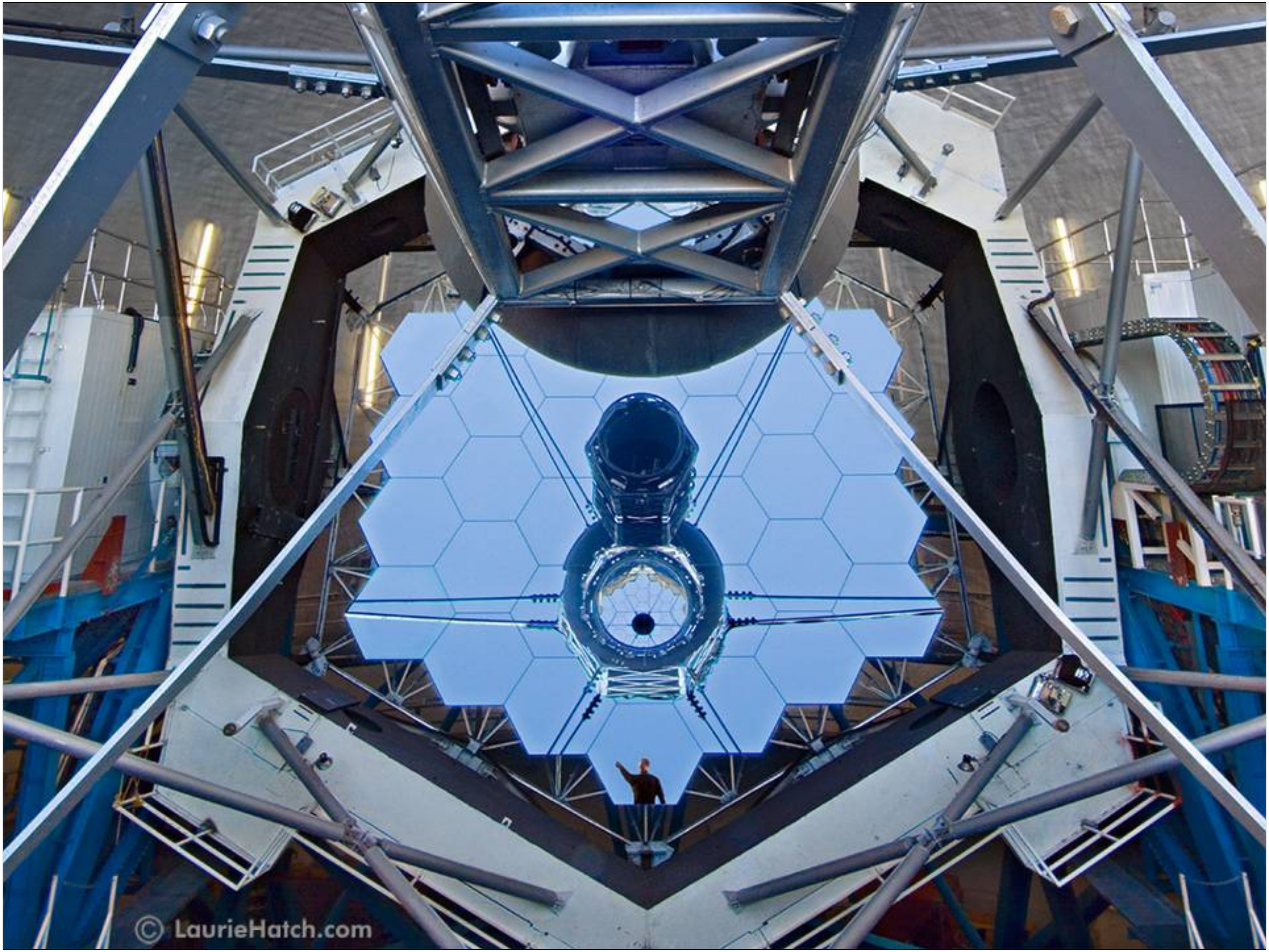
- Control system/precision
- Manufacturing segments

- In the 1980s, two University of California physicists, Jerry Nelson and Terry Mast, proposed a new approach to building giant mirrors using segments that fit together and are controlled very (very) precisely

Keck Observatory

- Nelson/Mast concept became an observatory via gift from the Keck Foundation to Caltech and partnership between Caltech and the University of California
- "prototype" Keck 1 was a spectacular success
- One attractive aspect to segmented approach was scalability of the concept to even larger primary mirrors

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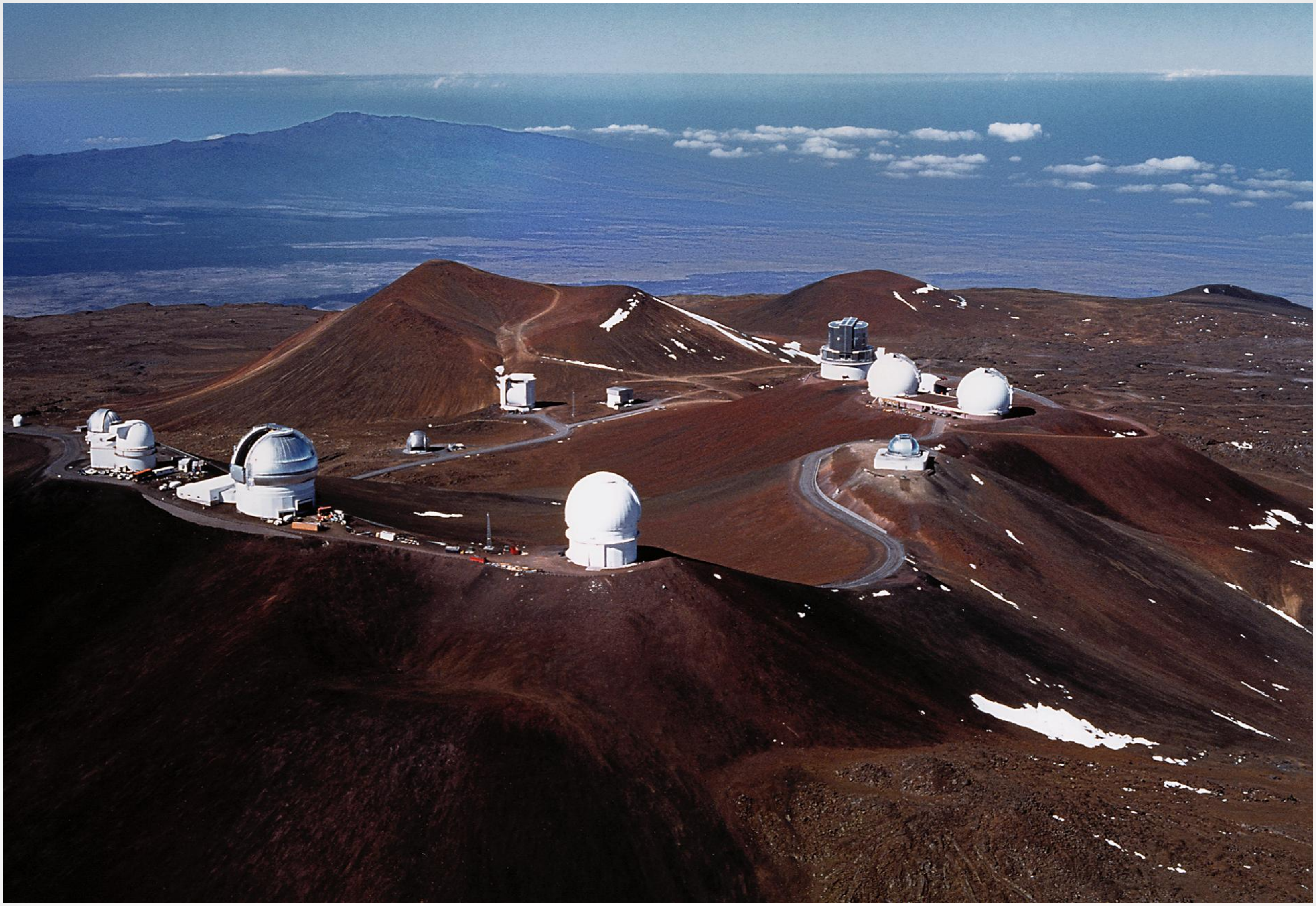
Telescopes Cities

- The US operates optical national facilities in Chile, near Tucson, on Mauna Kea (Hawaii) and near Sunspot, NM.

Kitt Peak National Observatory
near Tucson

ESO Very Large Telescope Array



Mauna Kea, HI

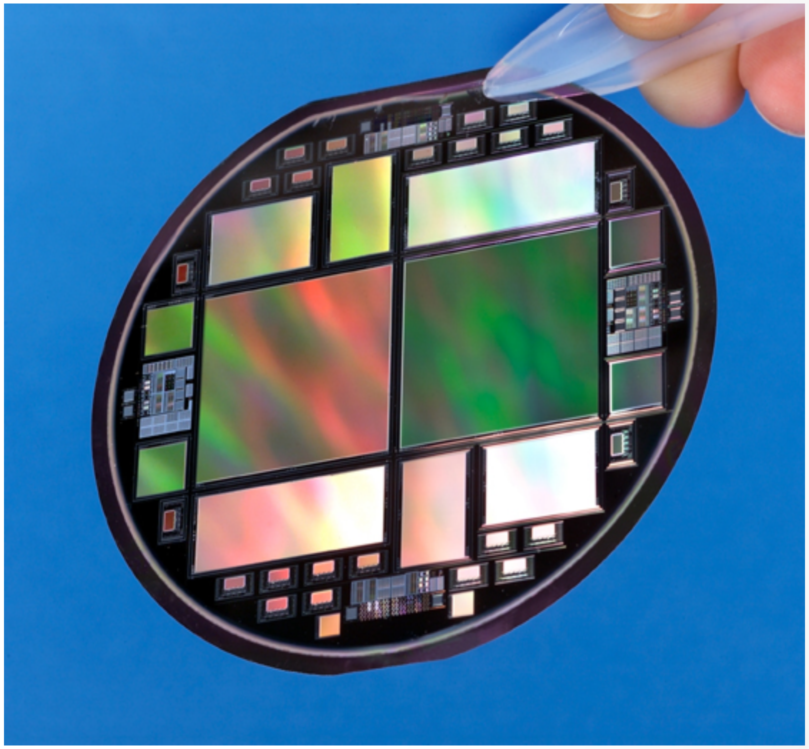
JCMT

What makes a good site

- Dark skies
  - Increasingly difficult!
- Clear (no clouds) weather
- High altitude
- Low precipitable water vapor
- Laminar wind flows
- Hawaii, northern Chile, islands off Europe

Detectors

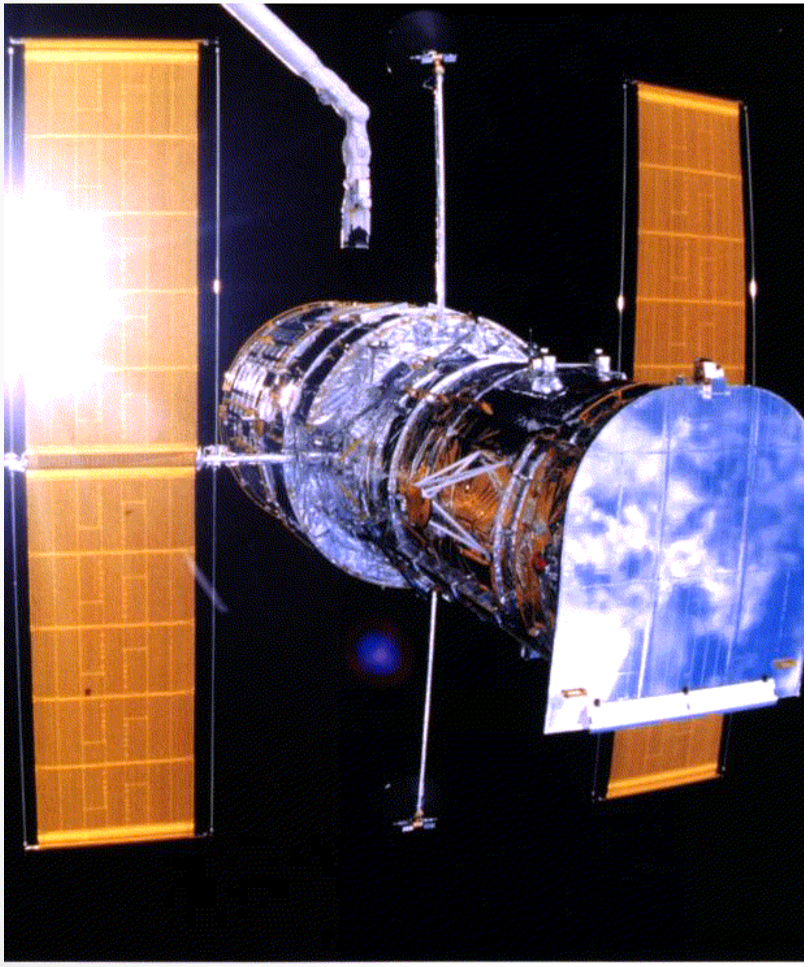
- "visual" observations till 1880s
- Ever better photographic emulsions till mid-1980s
- Silicon-based electronic detectors since 1985: nearly a factor of 100 higher sensitivity



Radio Telescopes

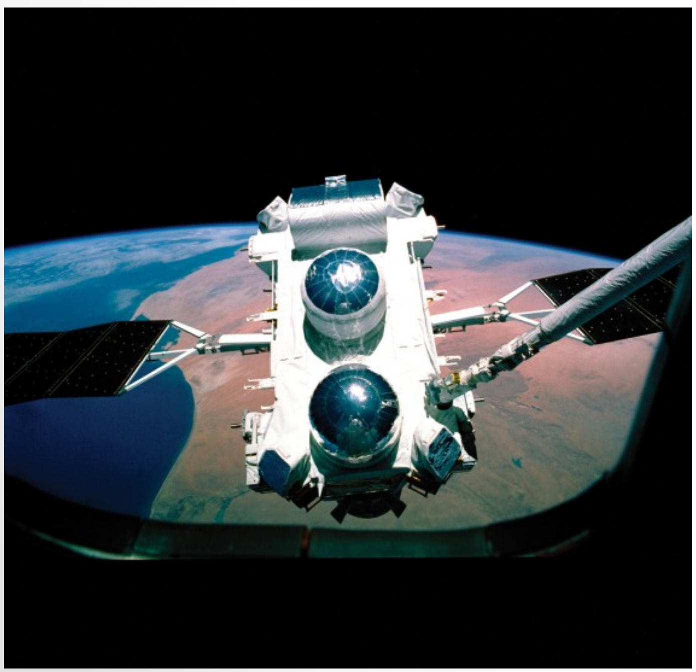
- As we will talk about later, there are many different types of signals from the Universe.
- Radio telescopes are sensitive to long wavelength electro-magnetic radiation

Space Telescopes

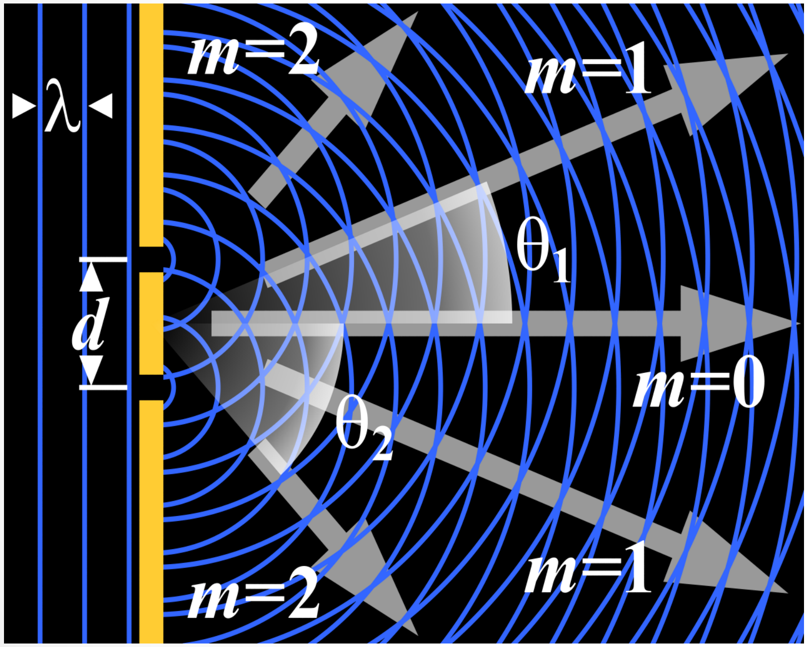


- No distortion from the atmosphere
- No absorption or emission background from the atmosphere:
  - X-ray telescopes
  - far infrared telescopes
  - gamma-ray telescopes have to be in orbit
- A little pricey, can't always do upgrades

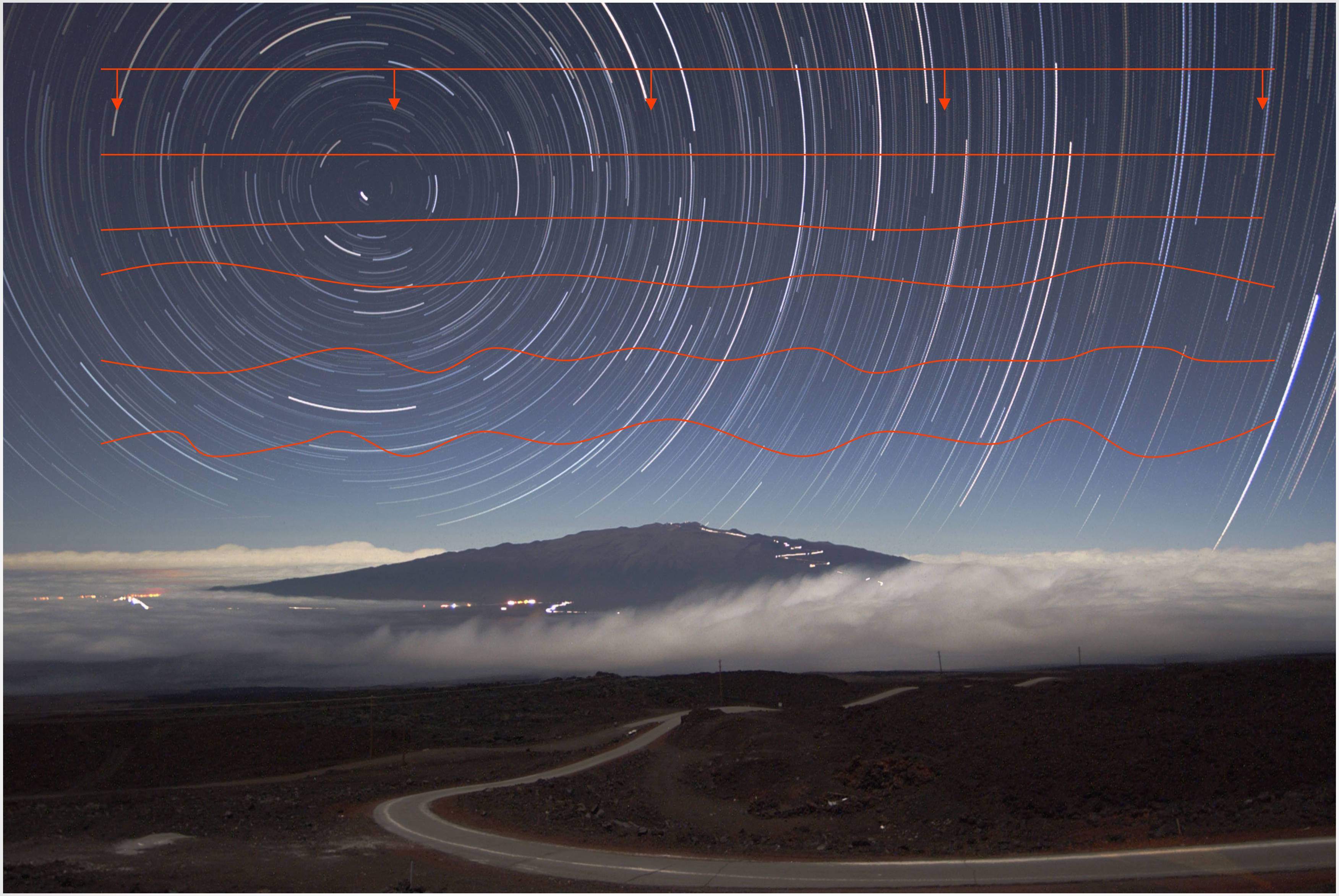
The Space Age



Adaptive Optics

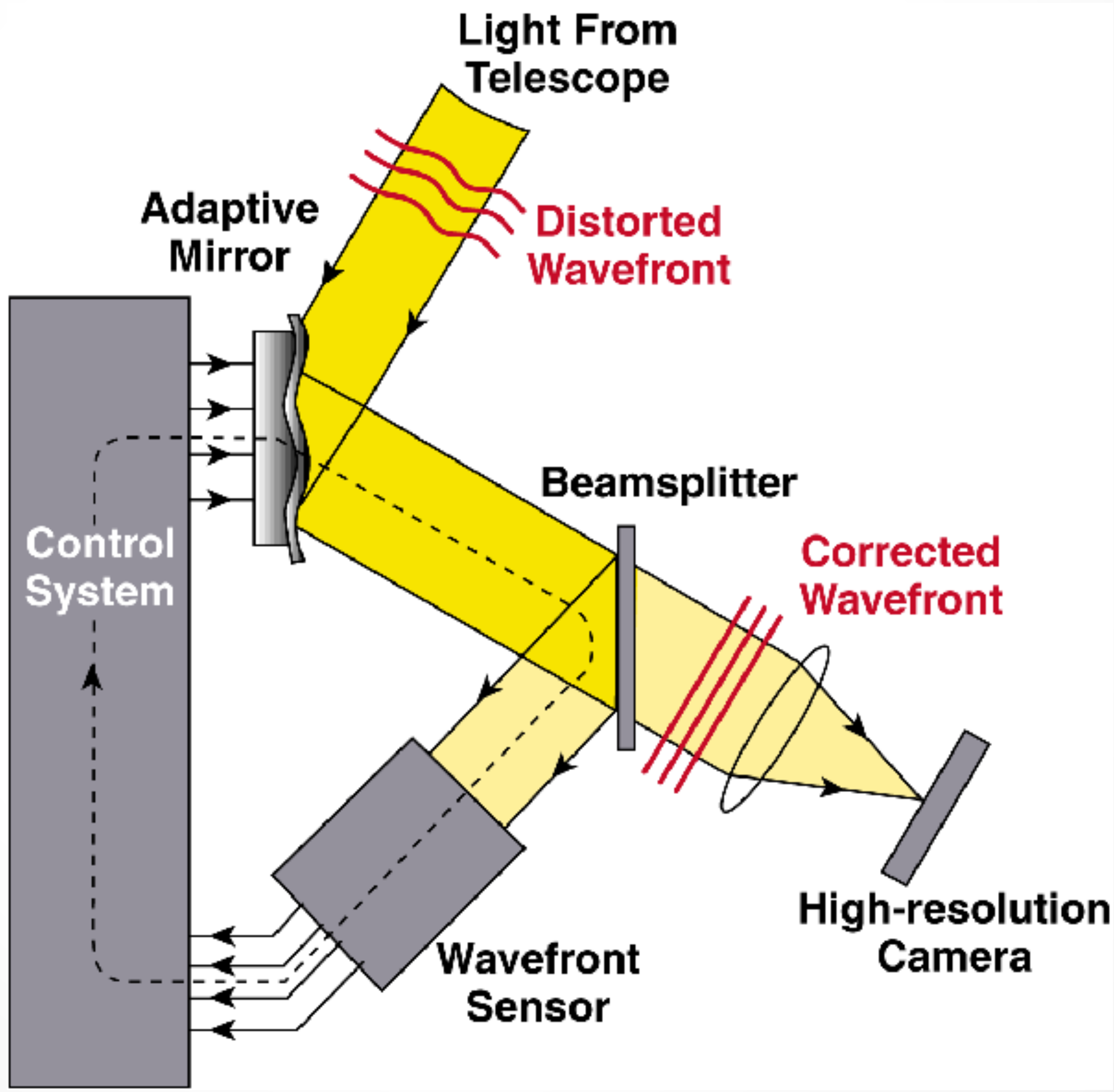


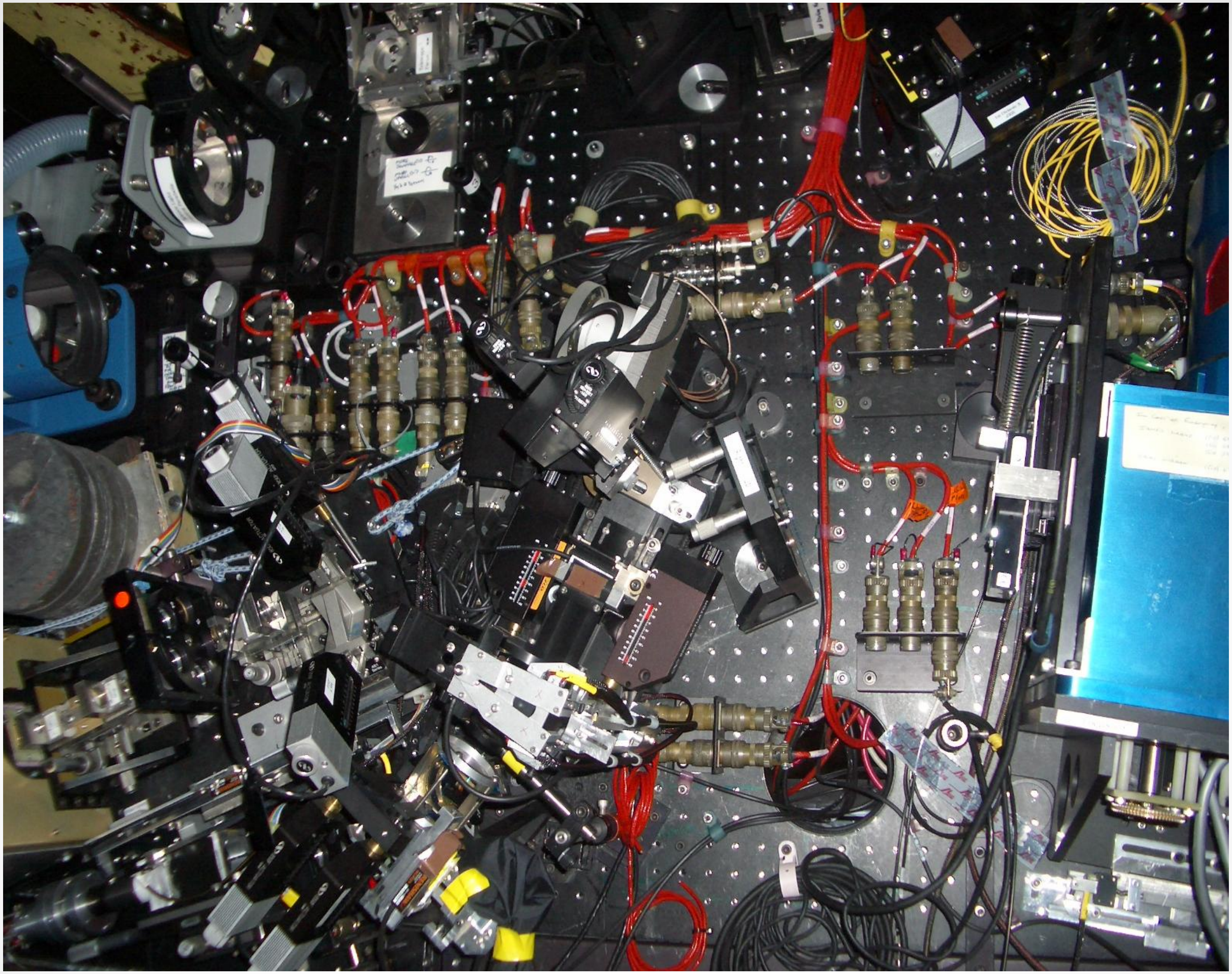
- Theoretical resolution is set by mirror diameter and a property of light called diffraction
- For telescopes at the surface of the Earth, resolution is set by blurring of the atmosphere to ~1 arcsecond, equivalent to a 6-inch telescope



Adaptive Optics

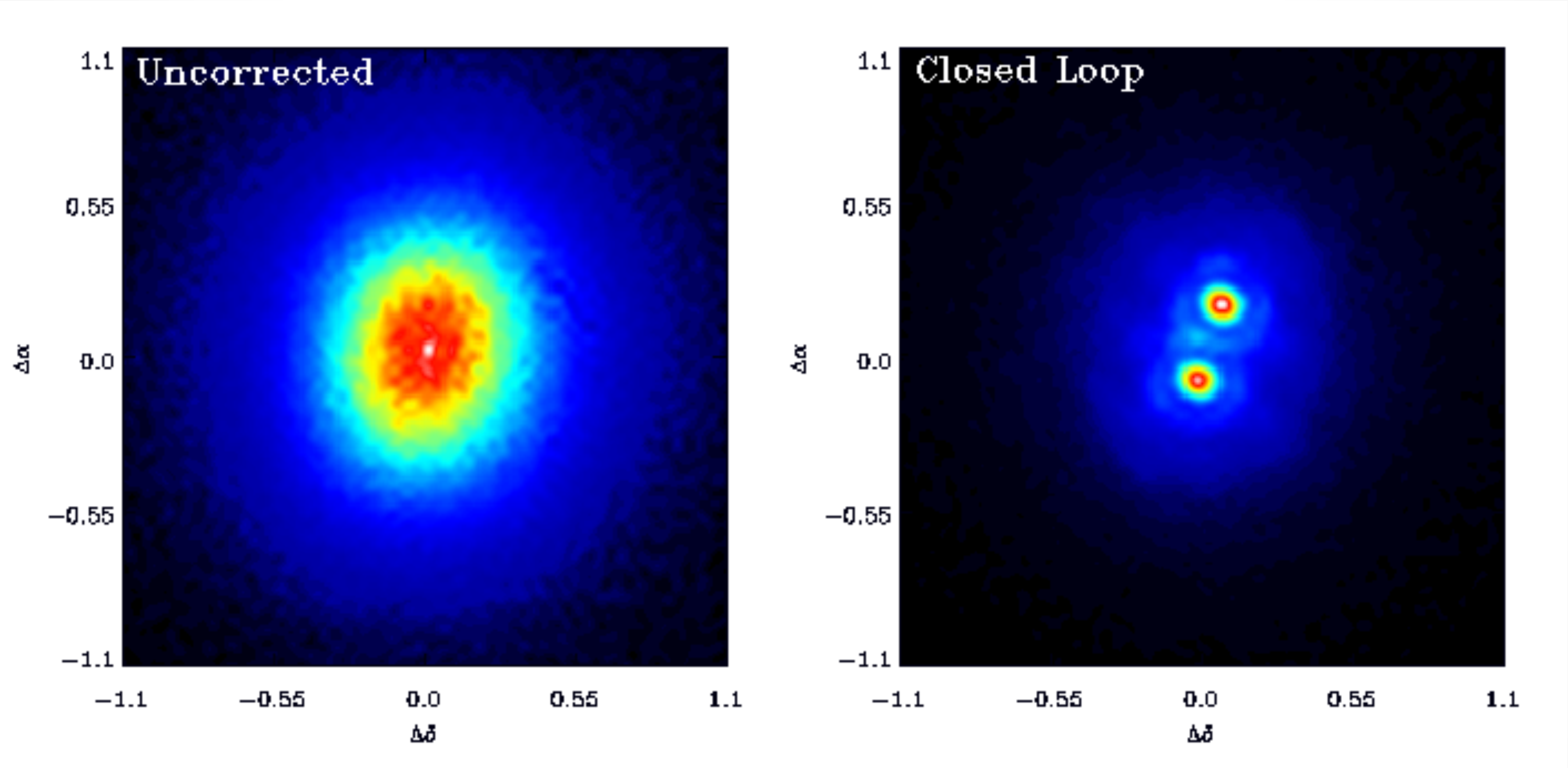
Feedback loop: next cycle corrects the (small) errors of the last cycle



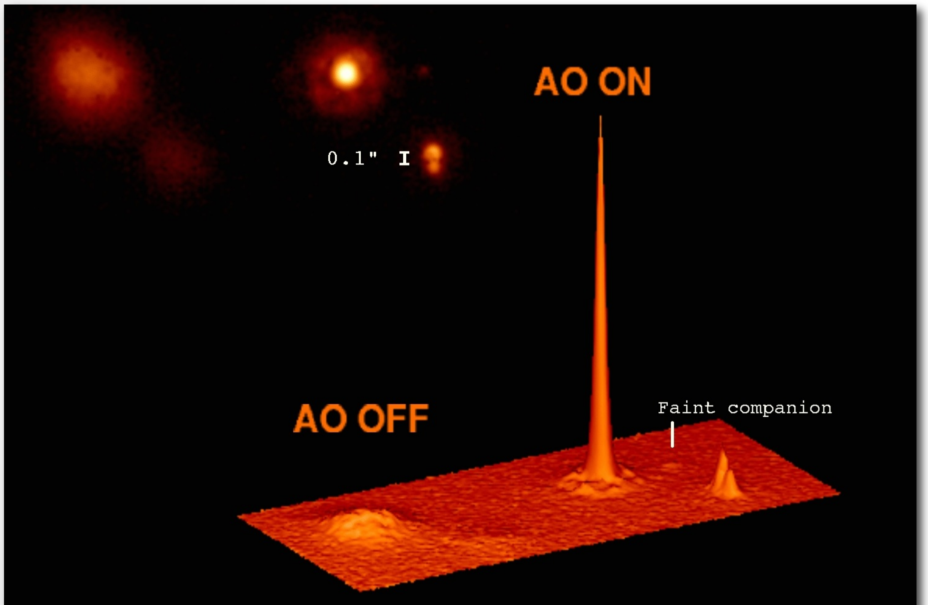


Lick 3m Cassegrain AO bench(!)

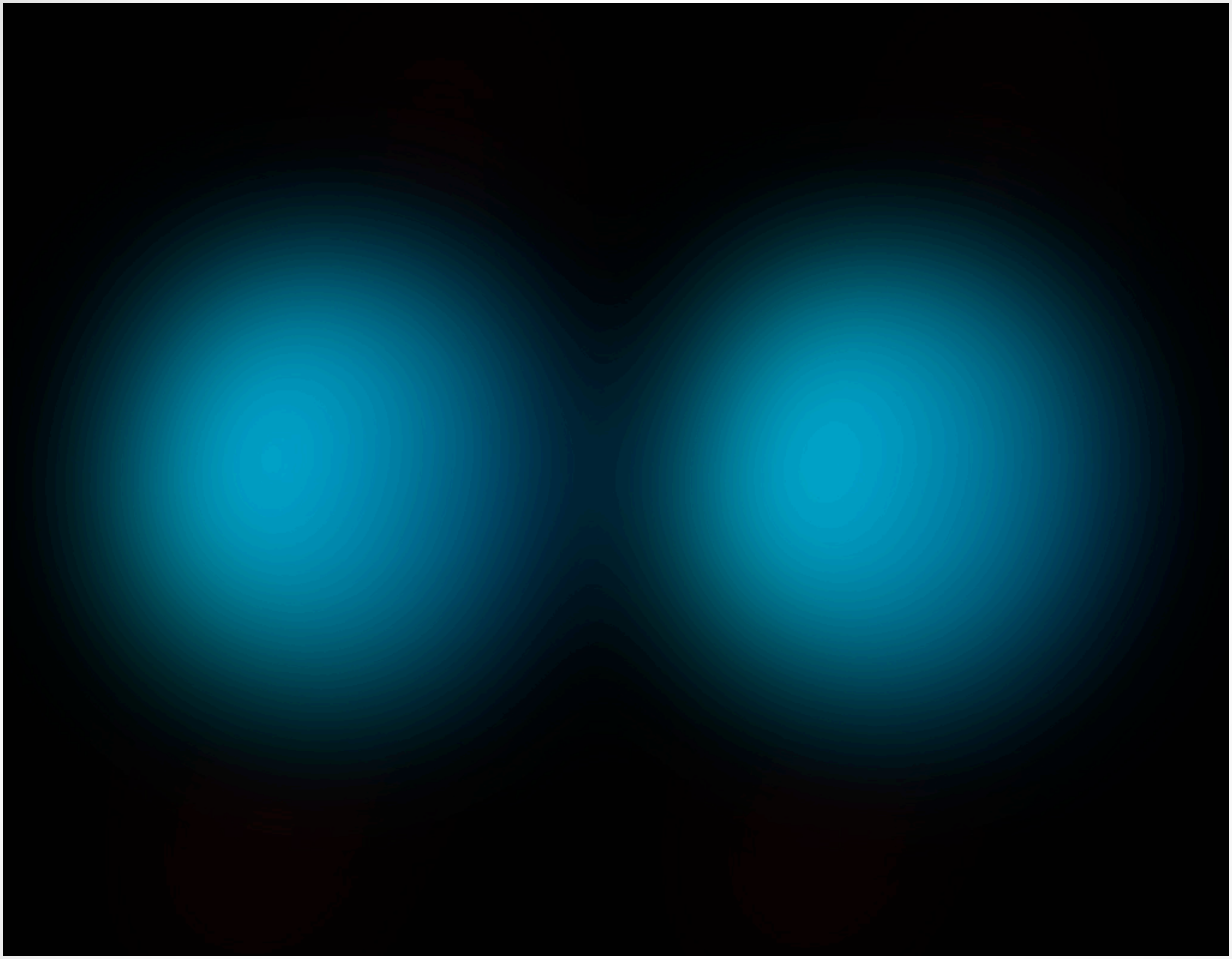
AO works!

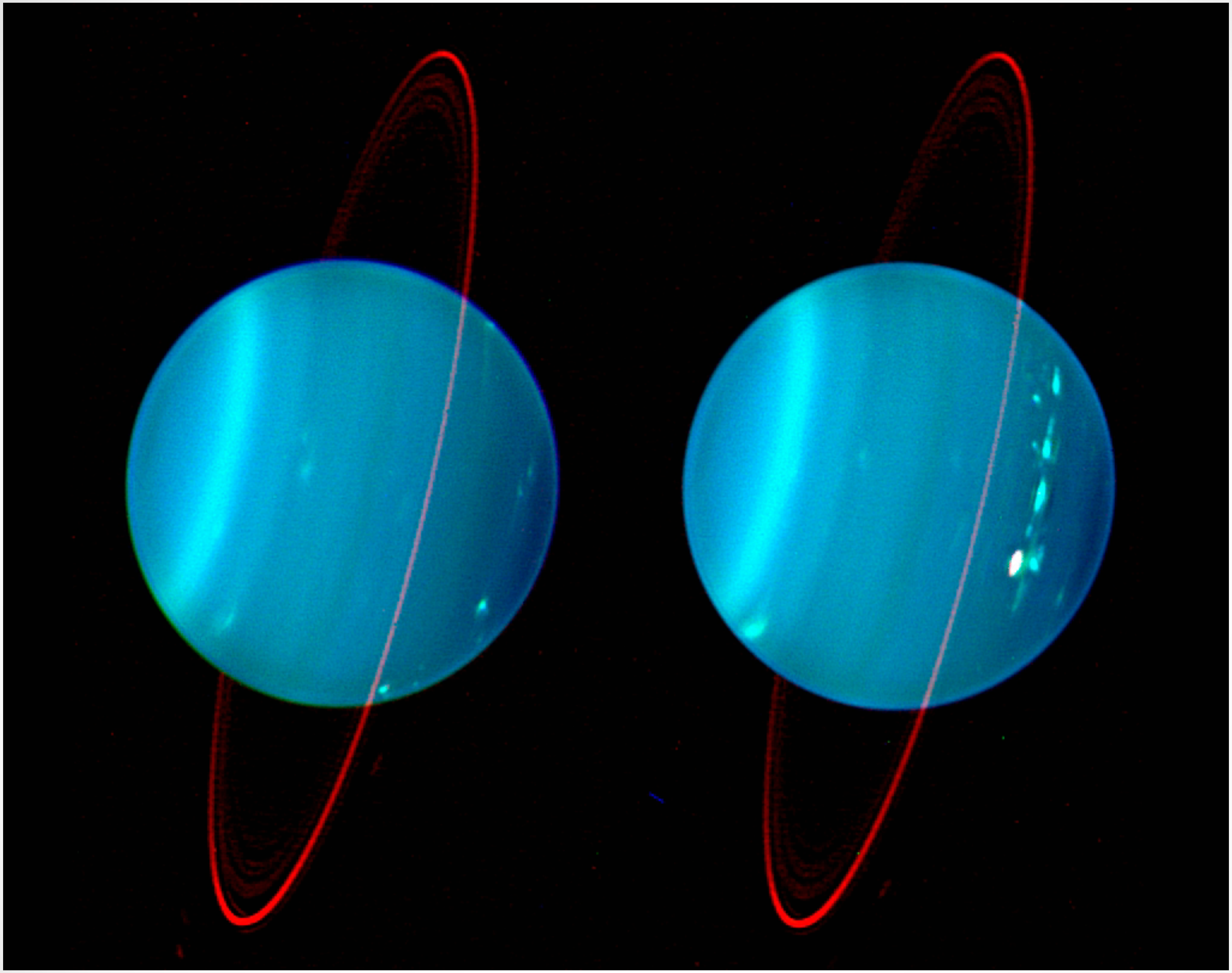


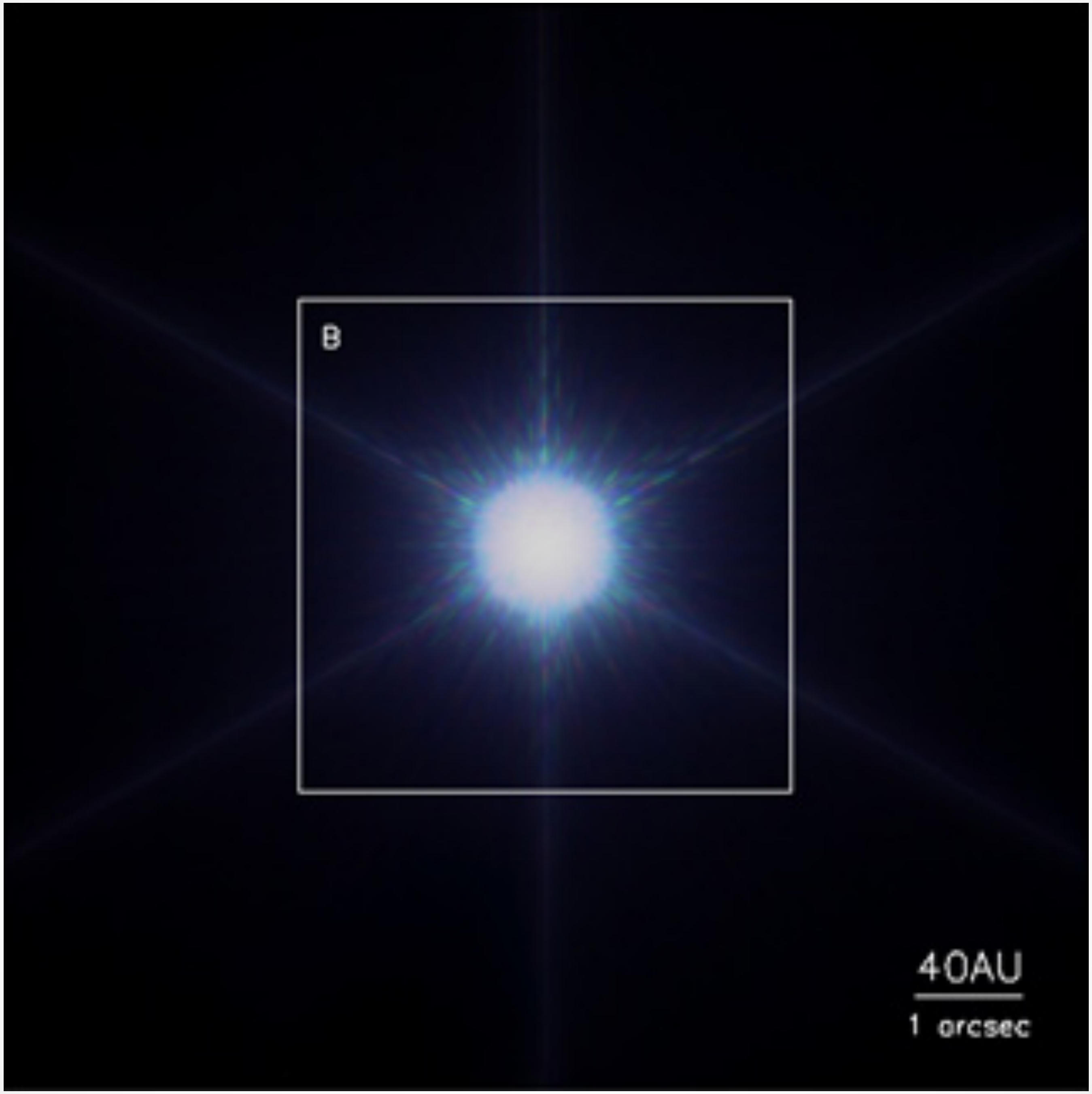
AO works II

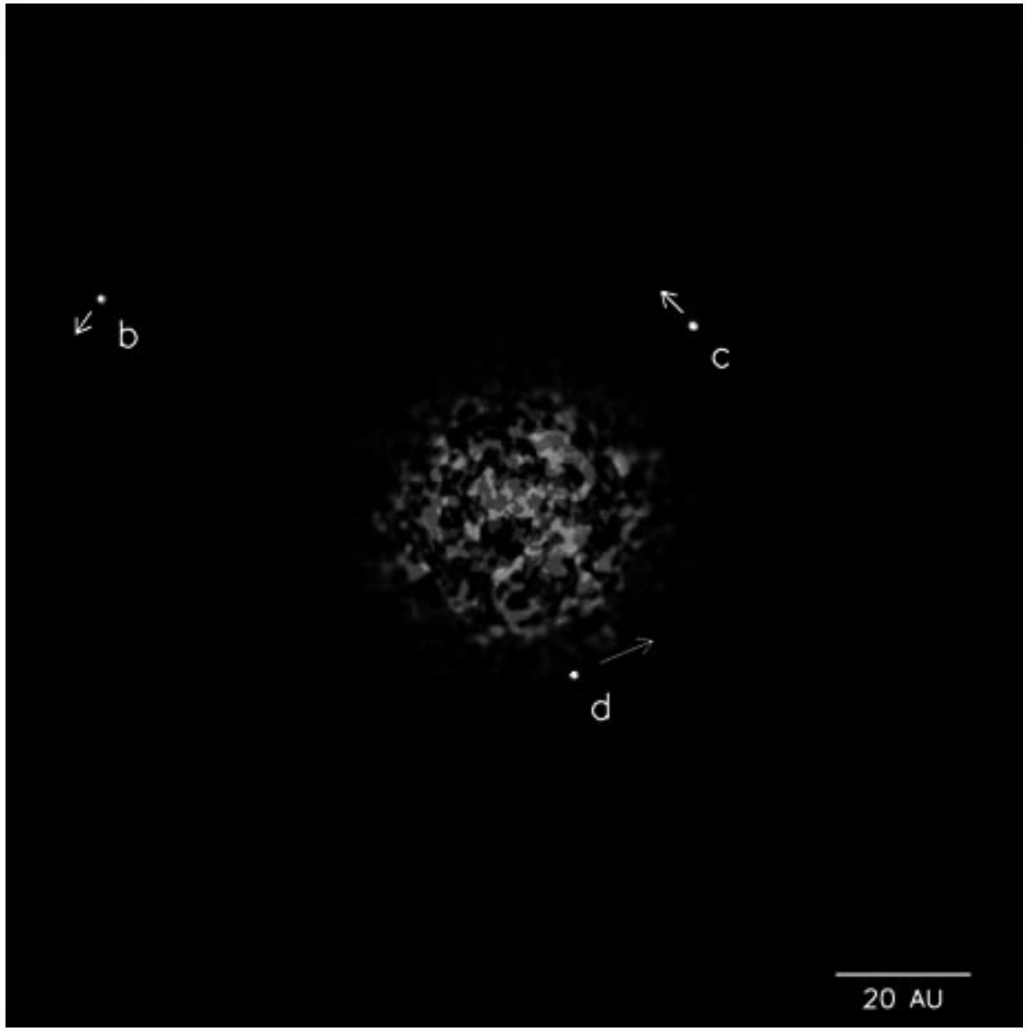


- Correction is easier and better for wavelengths > 1μ
- At most sites, need to correct at 50Hz or faster
- For 10m, diffraction limit is 0.02″ @ 1μ
- *Need a bright guide star (<13^m)*

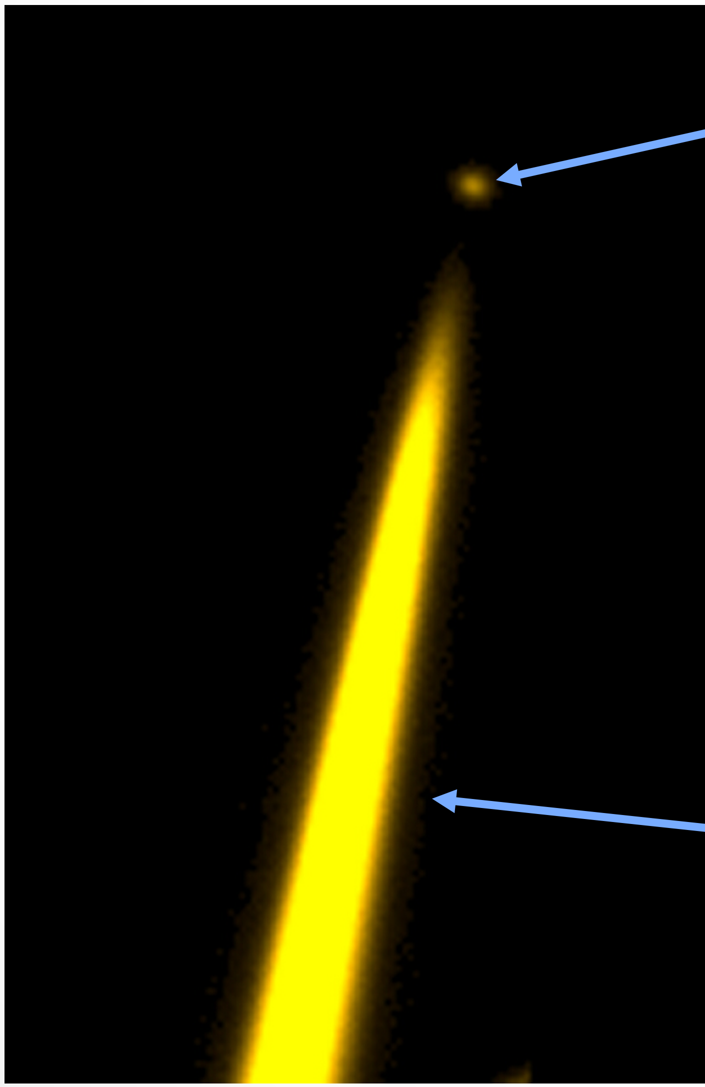





B
40AU
1 arcsec


b
c
d
20 AU

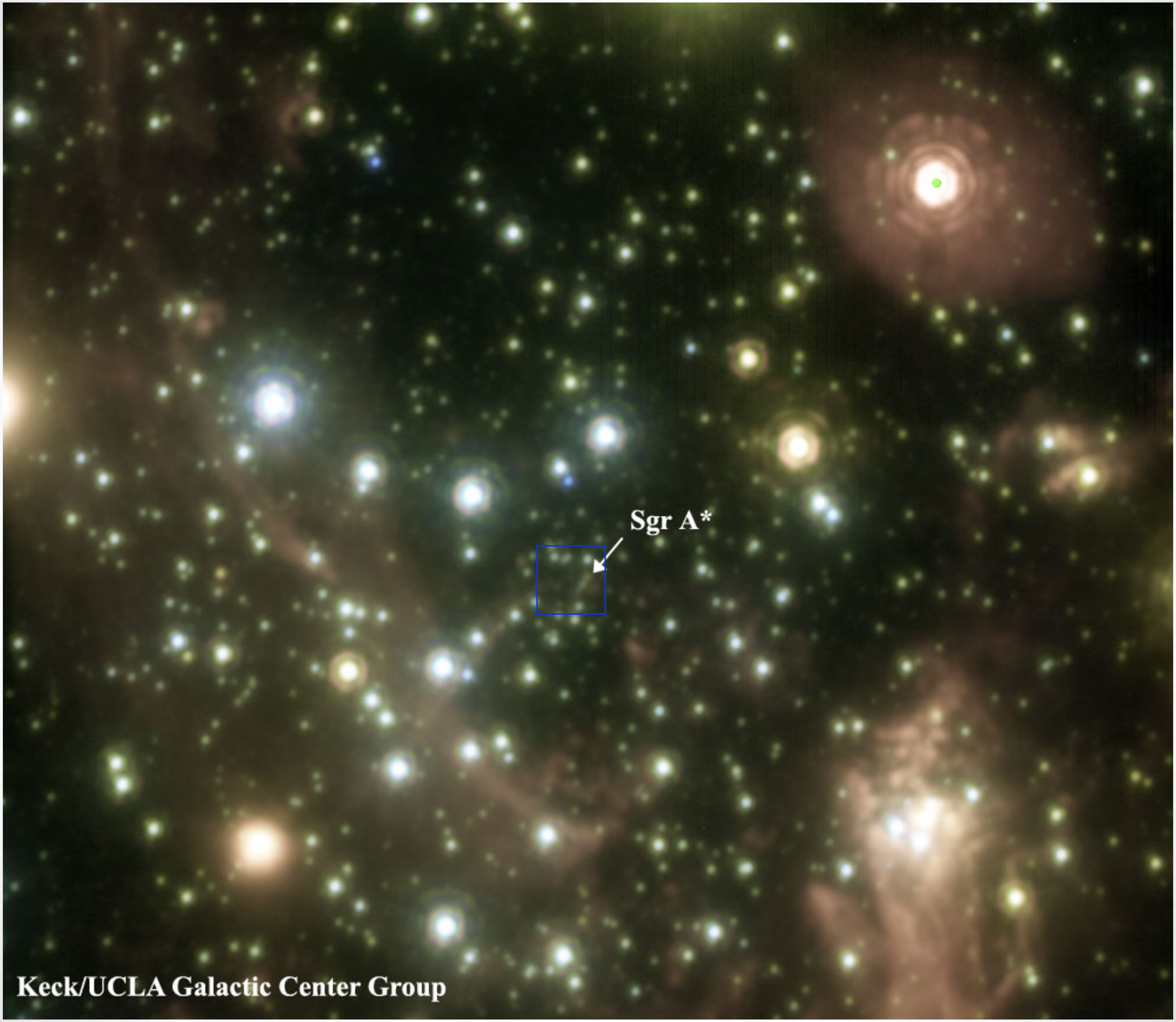
[redacted]

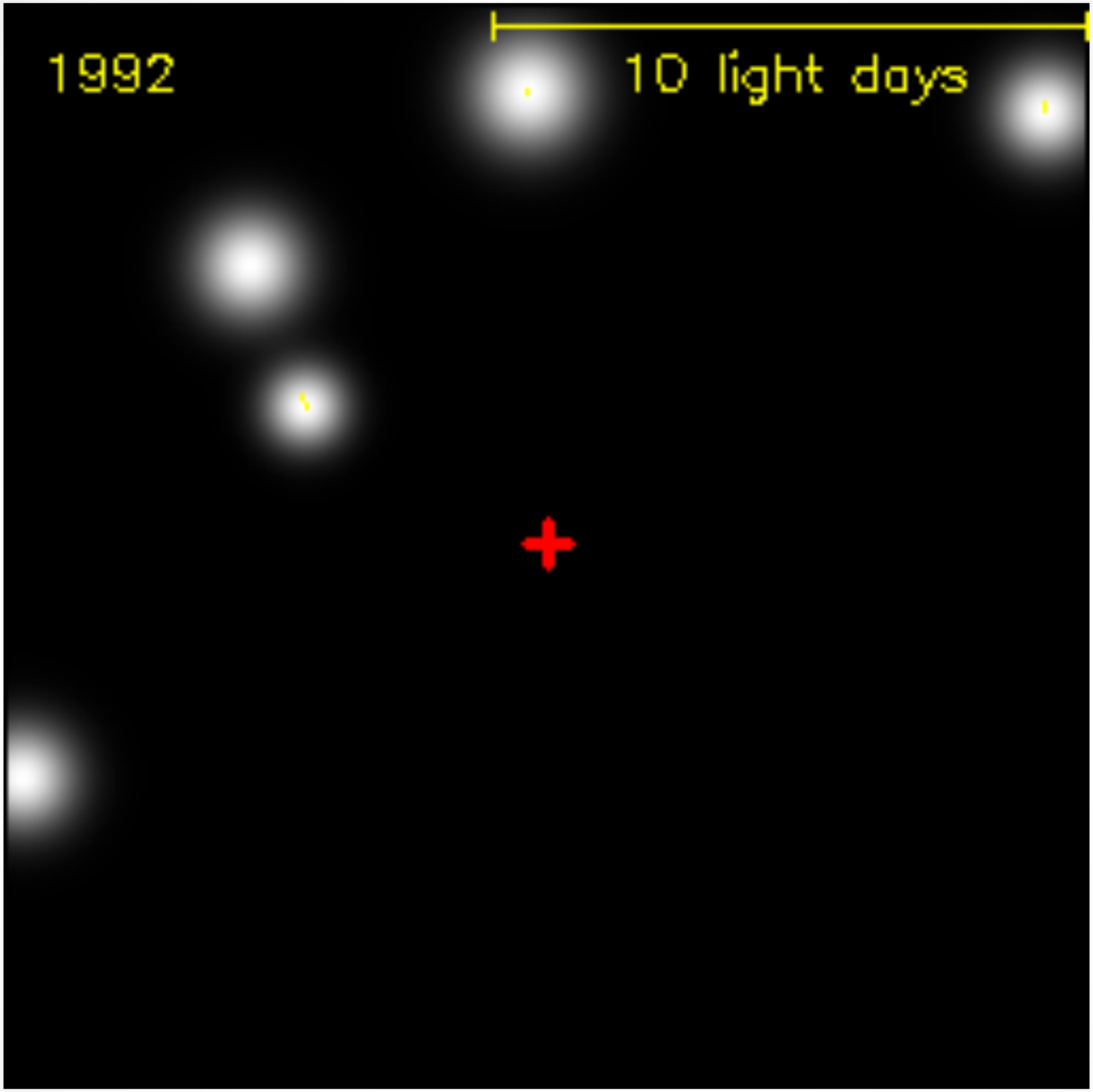


Guide star in sodium layer at ~ 90 km

Scattered light from low in atmosphere

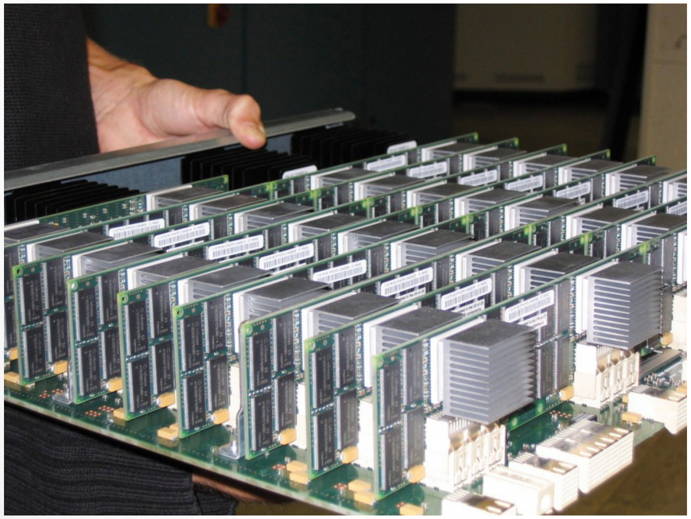
- First AO system used for astronomy purposes was completed at Lick Observatory 1994
- First Laser Guide star implemented at Lick Observatory in 1996
- Both systems are the basis for the systems at Keck Observatory


Sgr A*
Keck/UCLA Galactic Center Group



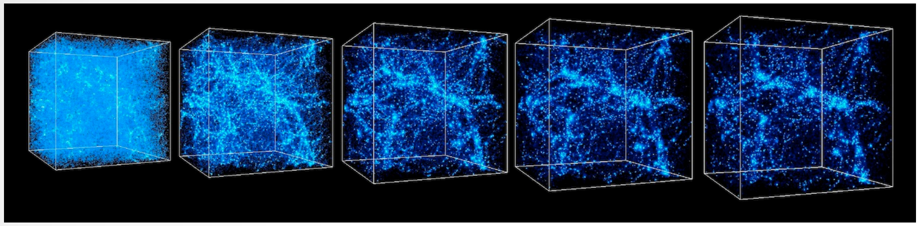
Courtesy of Andrea Ghez, UCLA

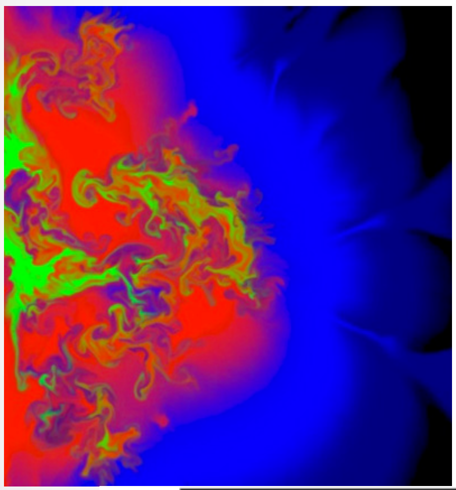
Tools of Astronomy II

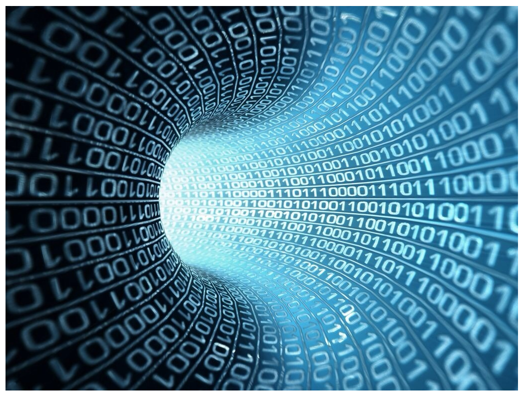


- Computers are a key part of modern astronomy
- Telescope/instrument control
- Data analysis
- Modeling and simulations

Computational Astrophysics







- Evolution of structure in the Universe
- Stellar structure, stellar explosions
- Complex nucleosynthesis
- "Big Data" for giant astronomy surveys
- Etc, etc.