

The Earth as a planet

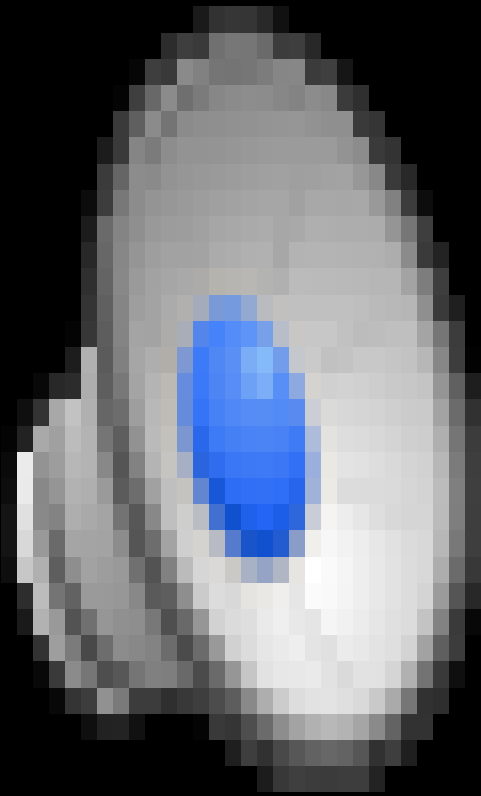


THE DAY THE DINOSAURS DIED

A young paleontologist may have discovered a record of the most significant event in the history of life on Earth.

By Douglas Preston March 29, 2019

Based on a sloppy and possibly
fraudulent paper by Robert de Palma of
a fossil site in the USA



Gulf of Mexico

Chicxulub crater

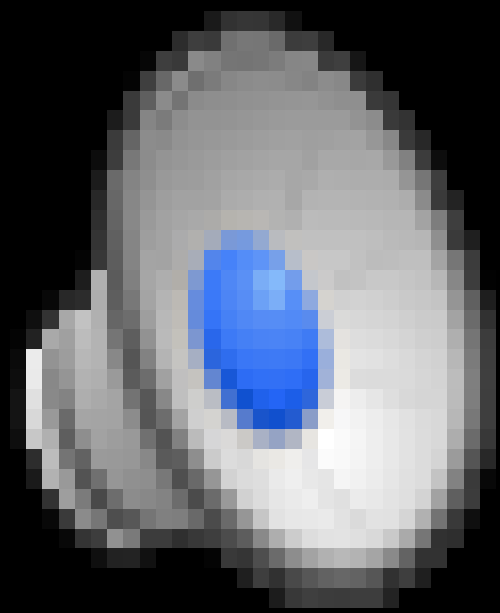


Yucatán
Peninsula

Mexico







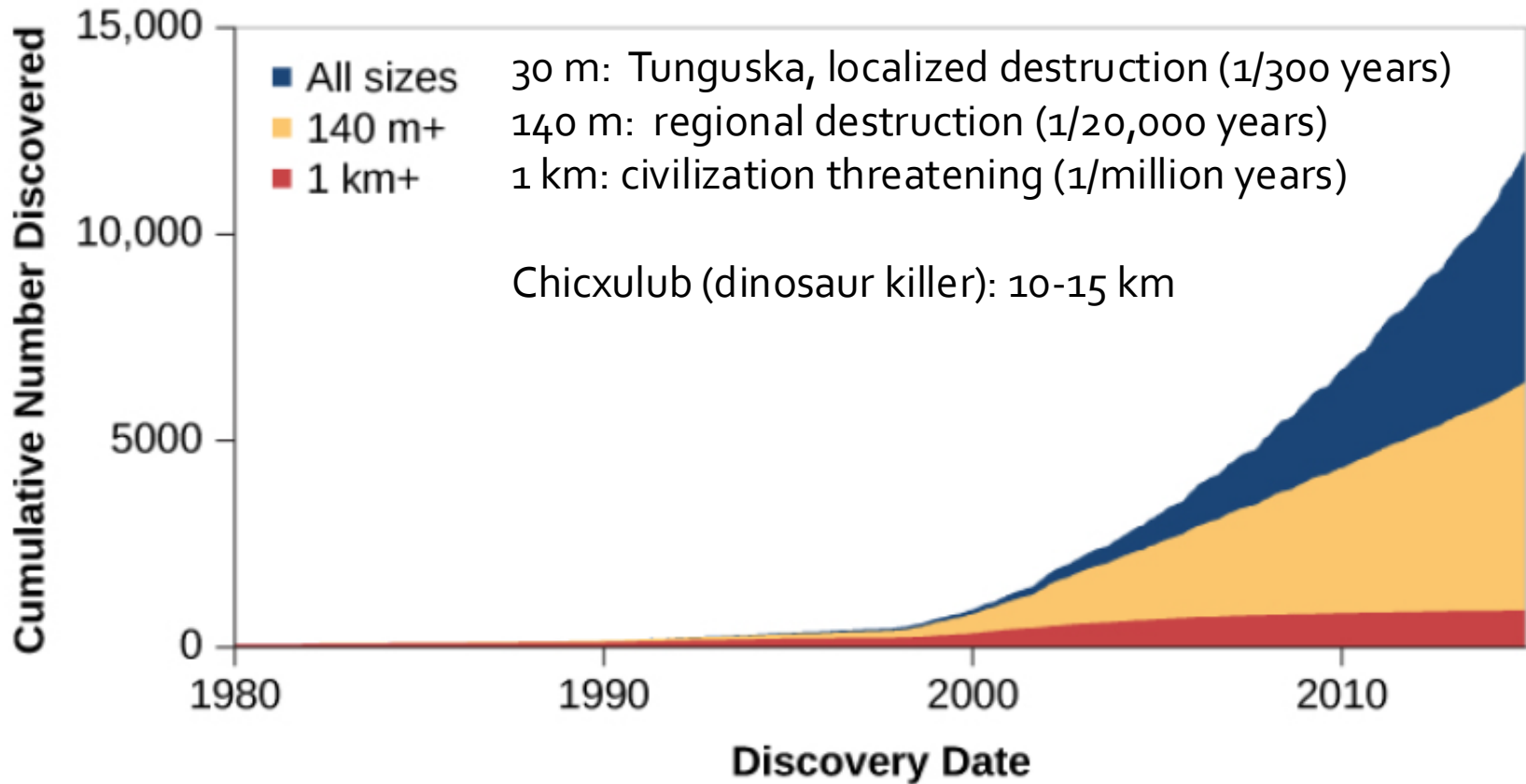


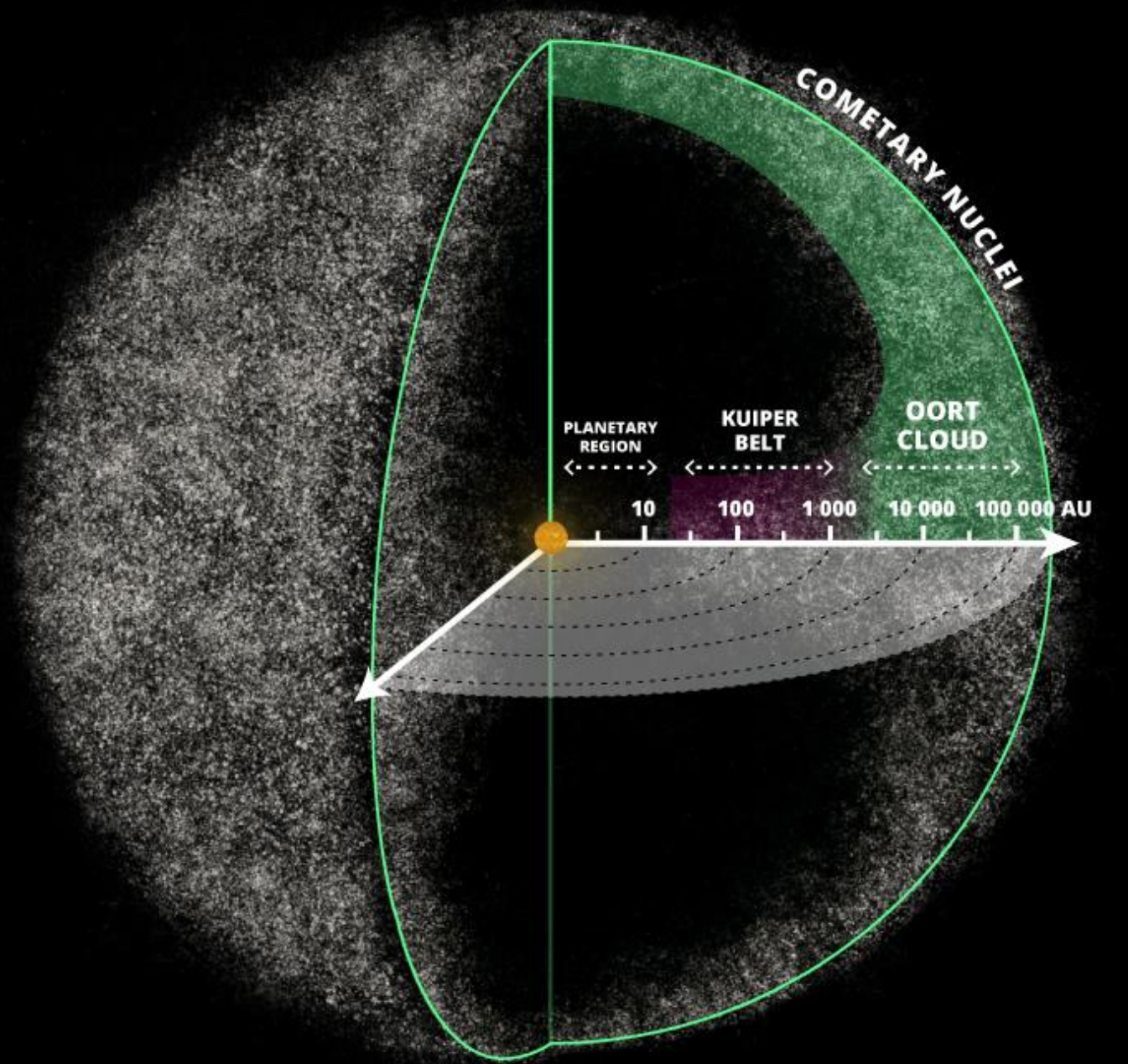
Tunguska event (Siberia, Russia, 1908)
trees knocked down across 2000 km²!

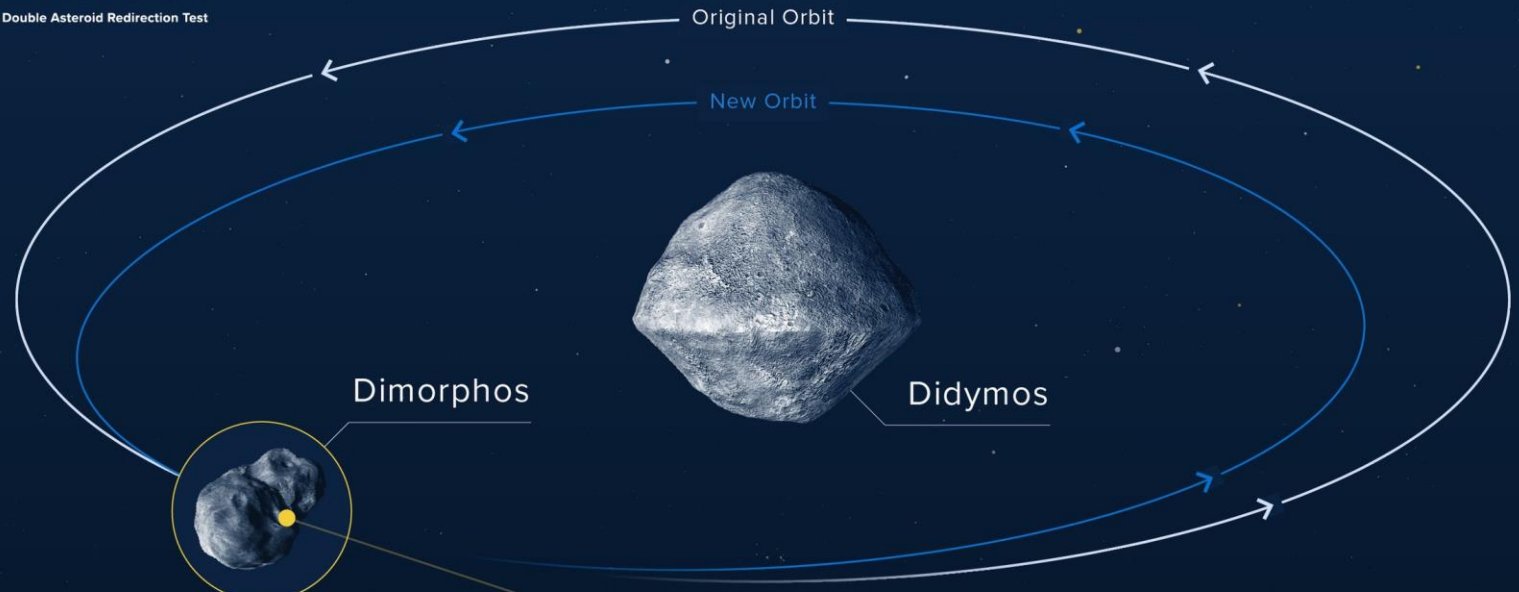


Photo from 1929

Near-Earth Asteroids Discovered







Dimorphos

Didymos

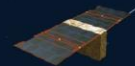
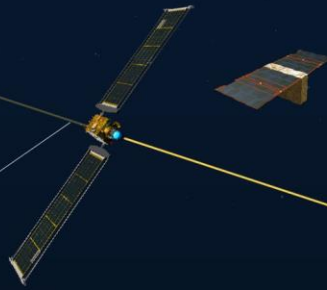
IMPACT

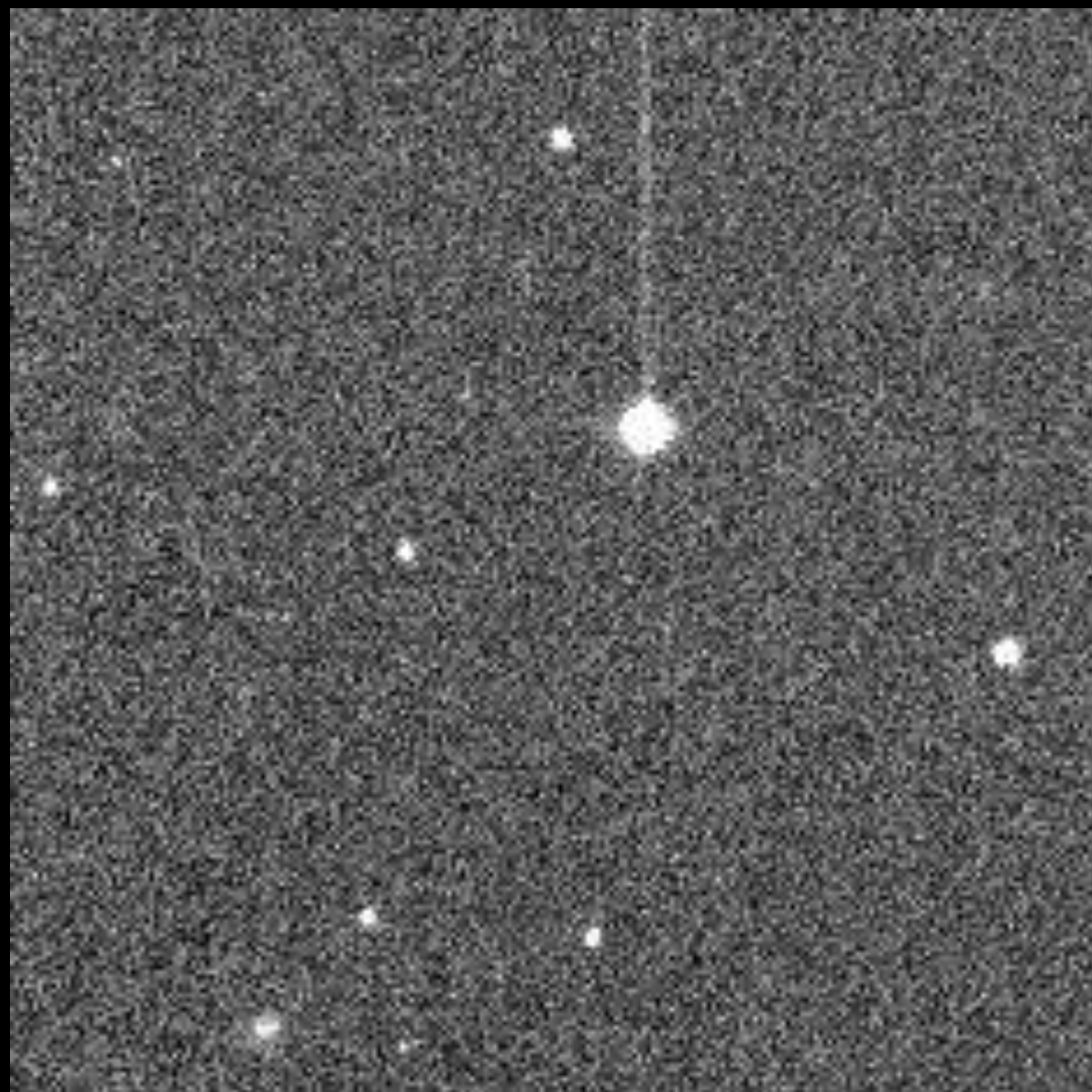
DART

LICIACube

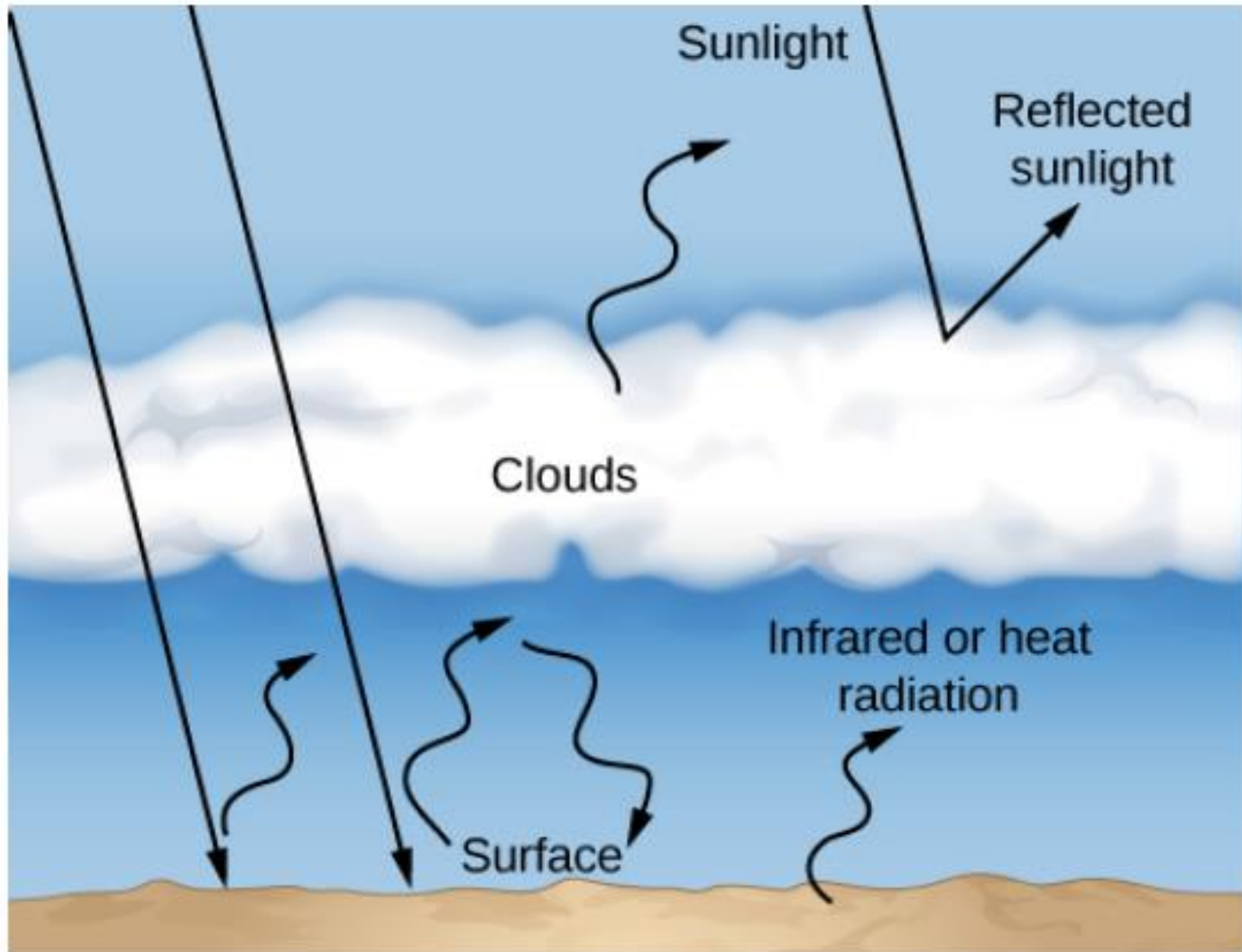


Earth-based observations

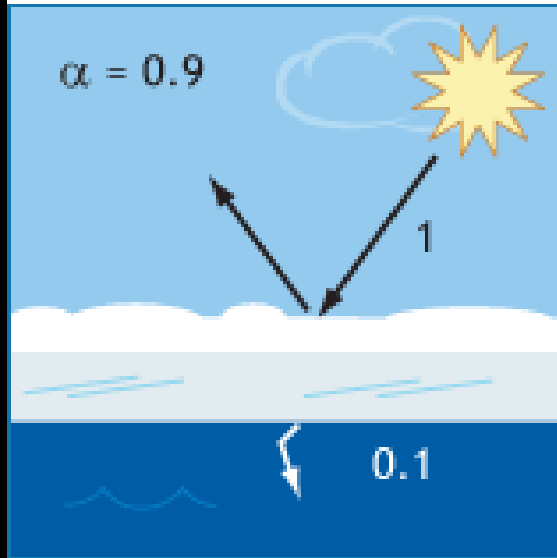




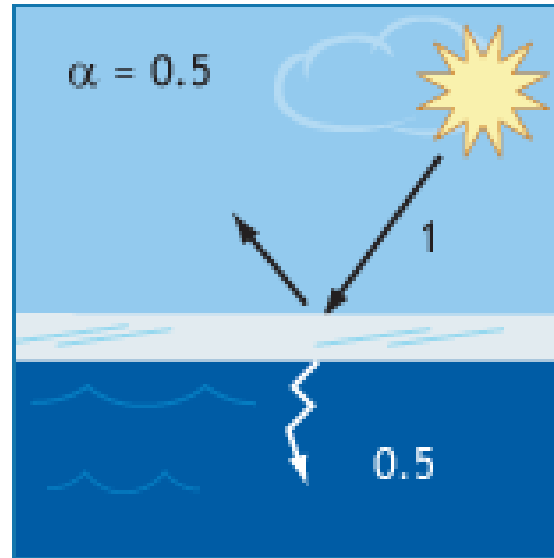
The Greenhouse effect



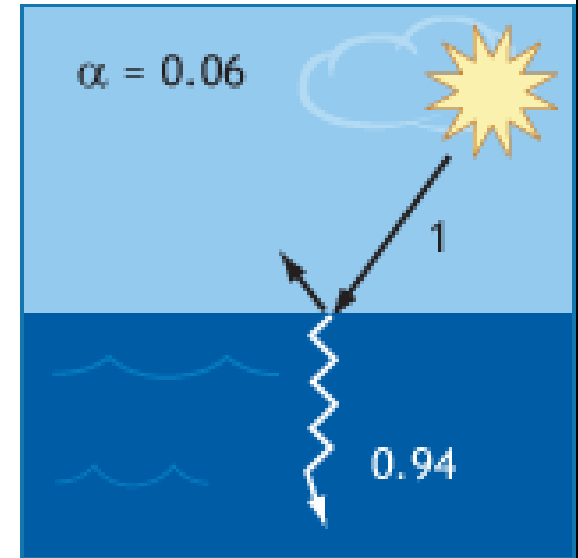
Ice with Snow



Bare Ice



Open Ocean

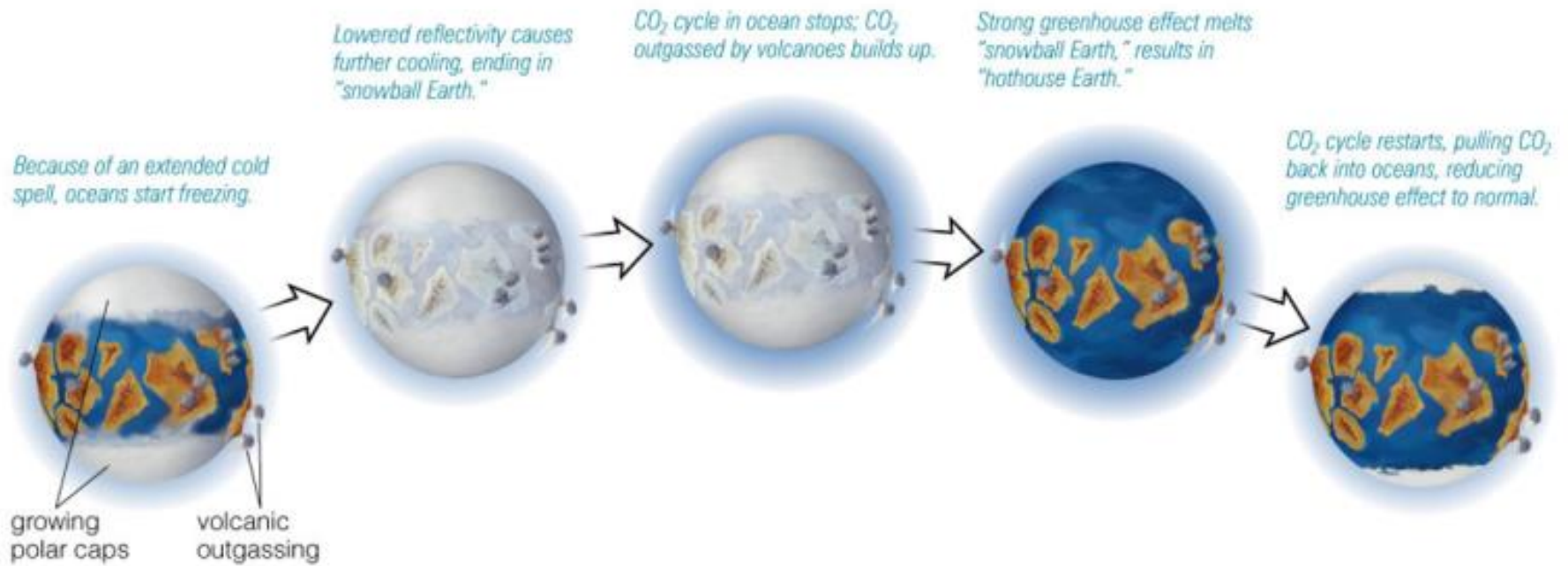


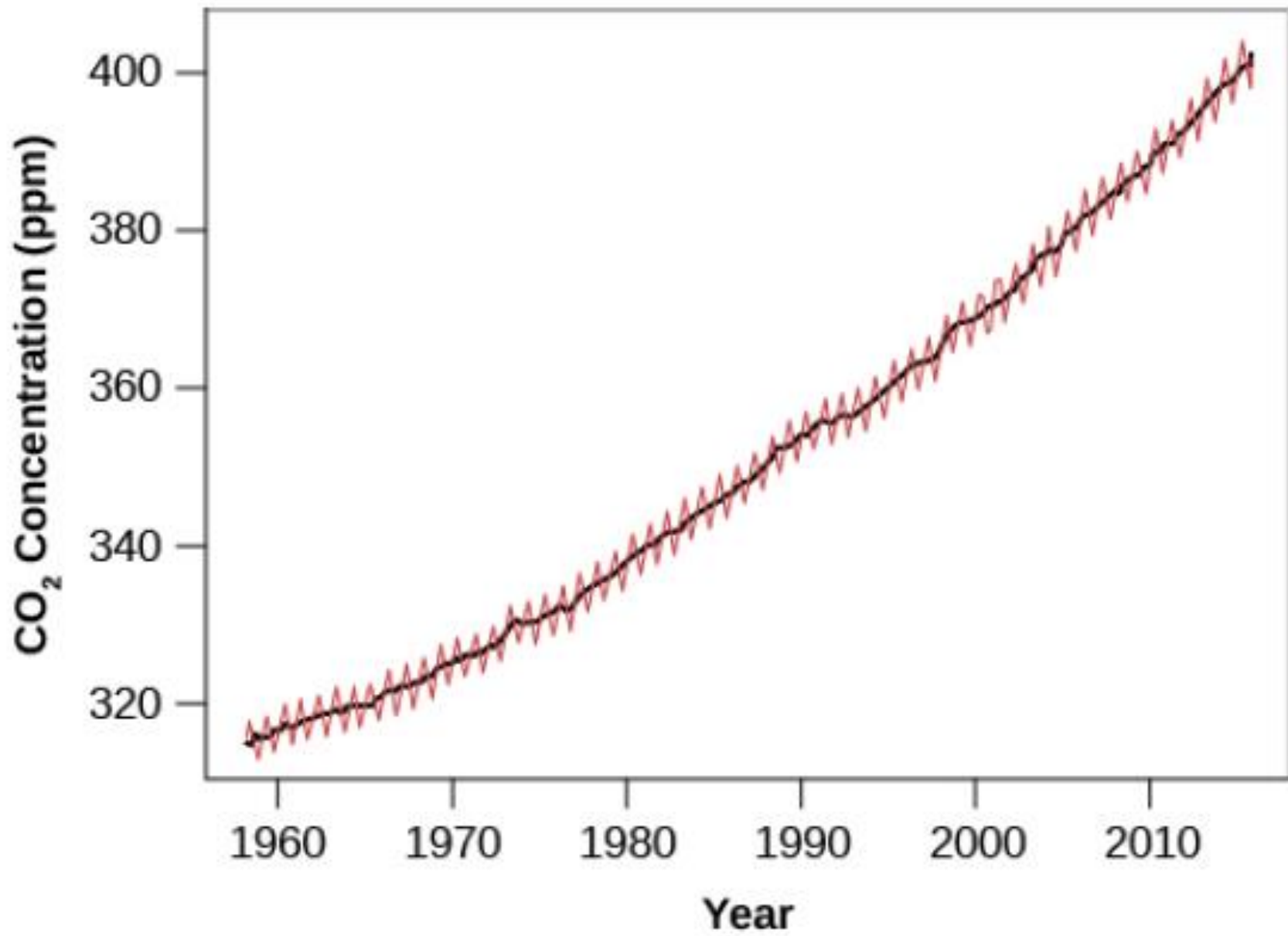
α : albedo = reflectance

Ice (and clouds) reflects energy = cooler planet



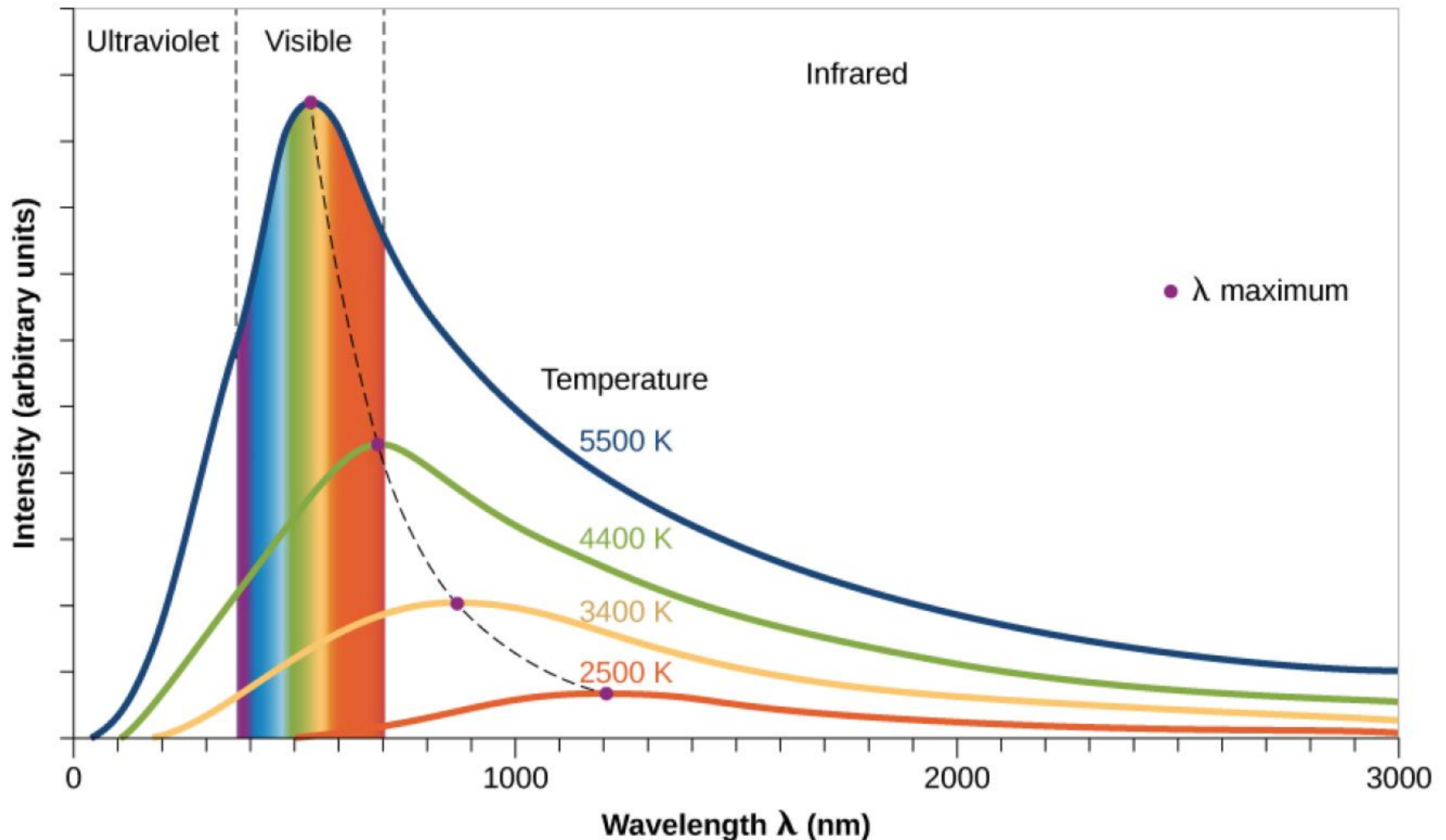
Five Stages of "Snowball" Earth



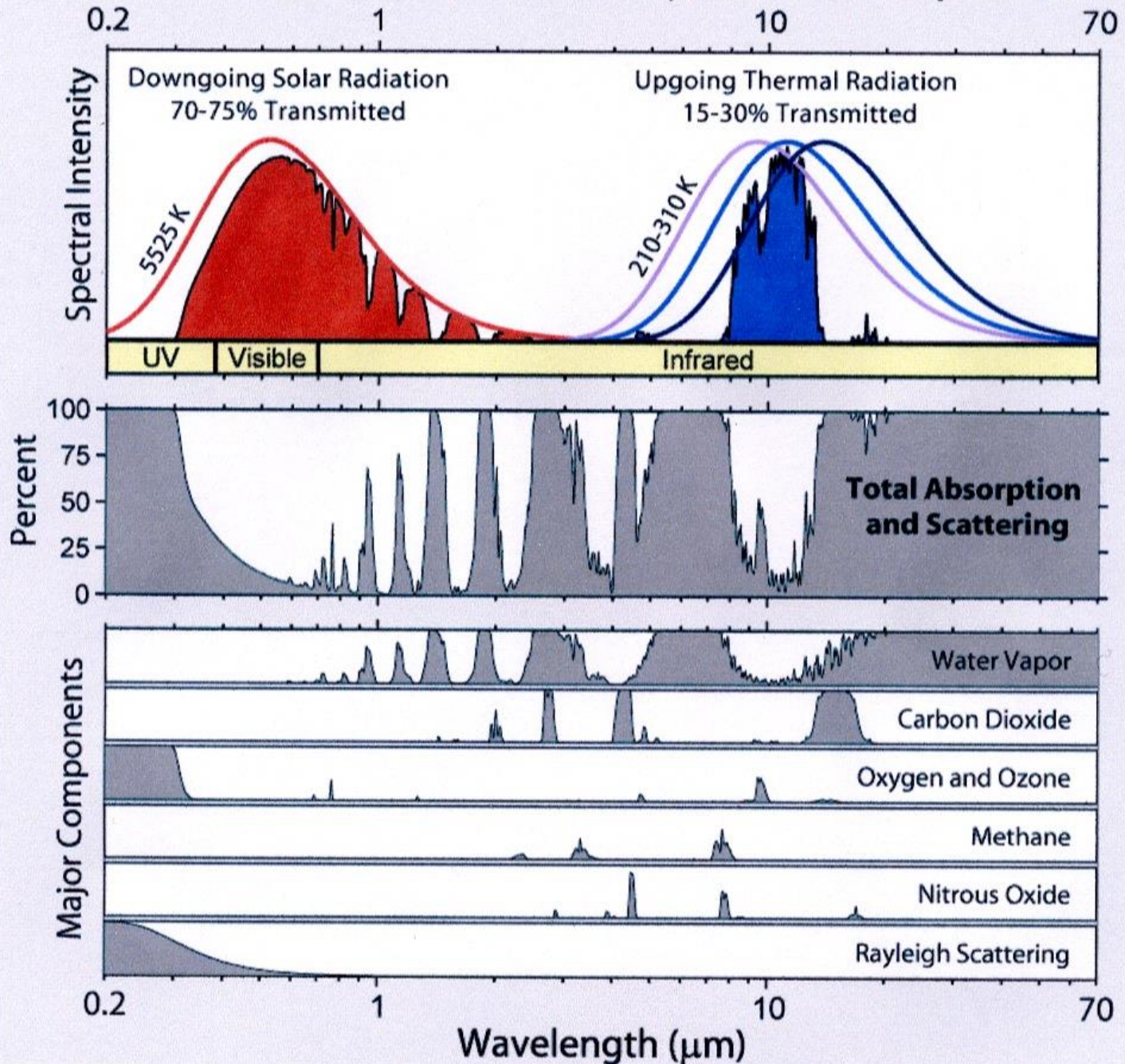


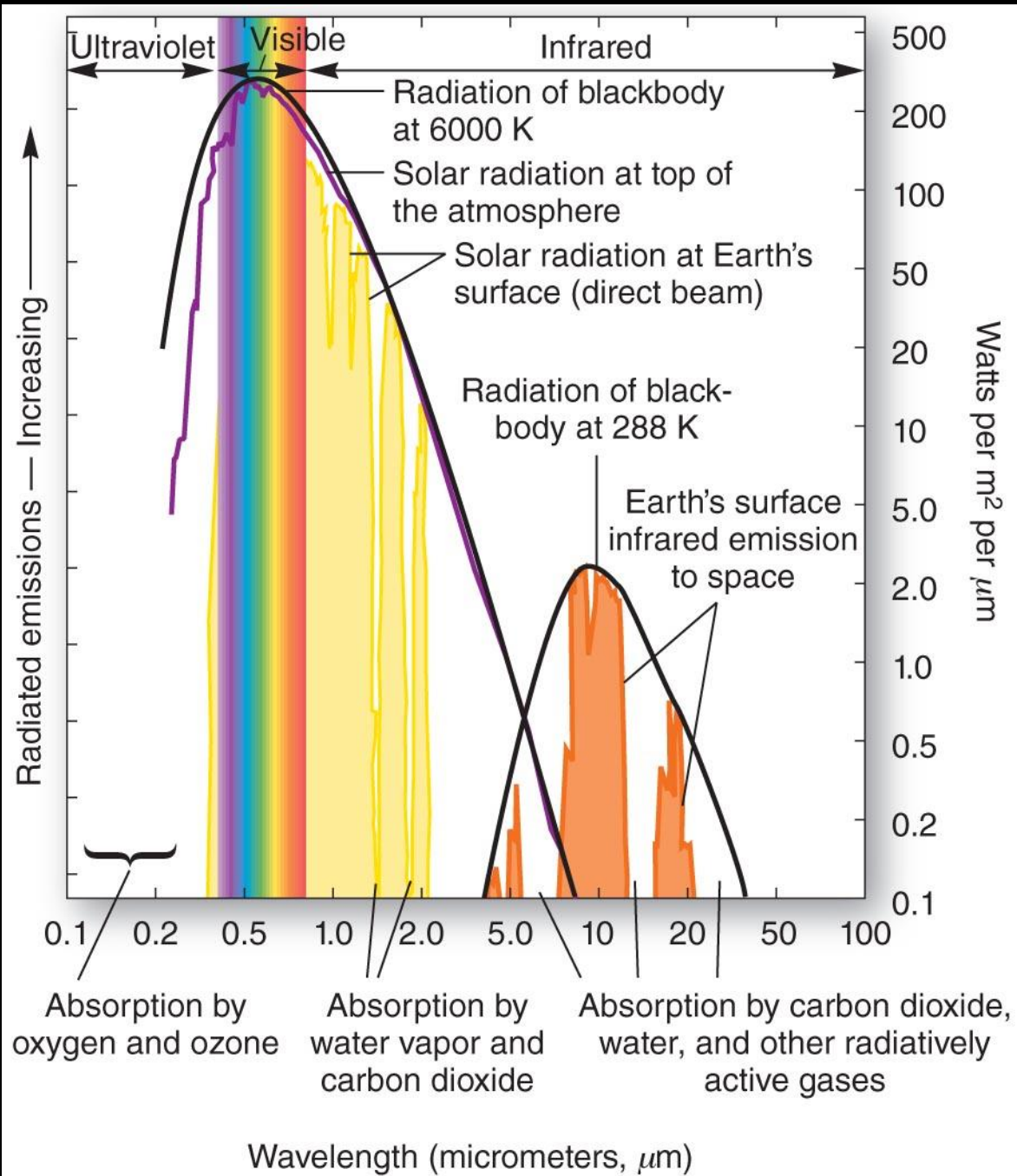
Blackbody emission: hotter things emit at higher energies
(=shorter wavelengths)

Peak of blackbody: $\lambda_{\max} \cdot T = 0.288 \text{ cm} \cdot \text{K}$



Radiation Transmitted by the Atmosphere





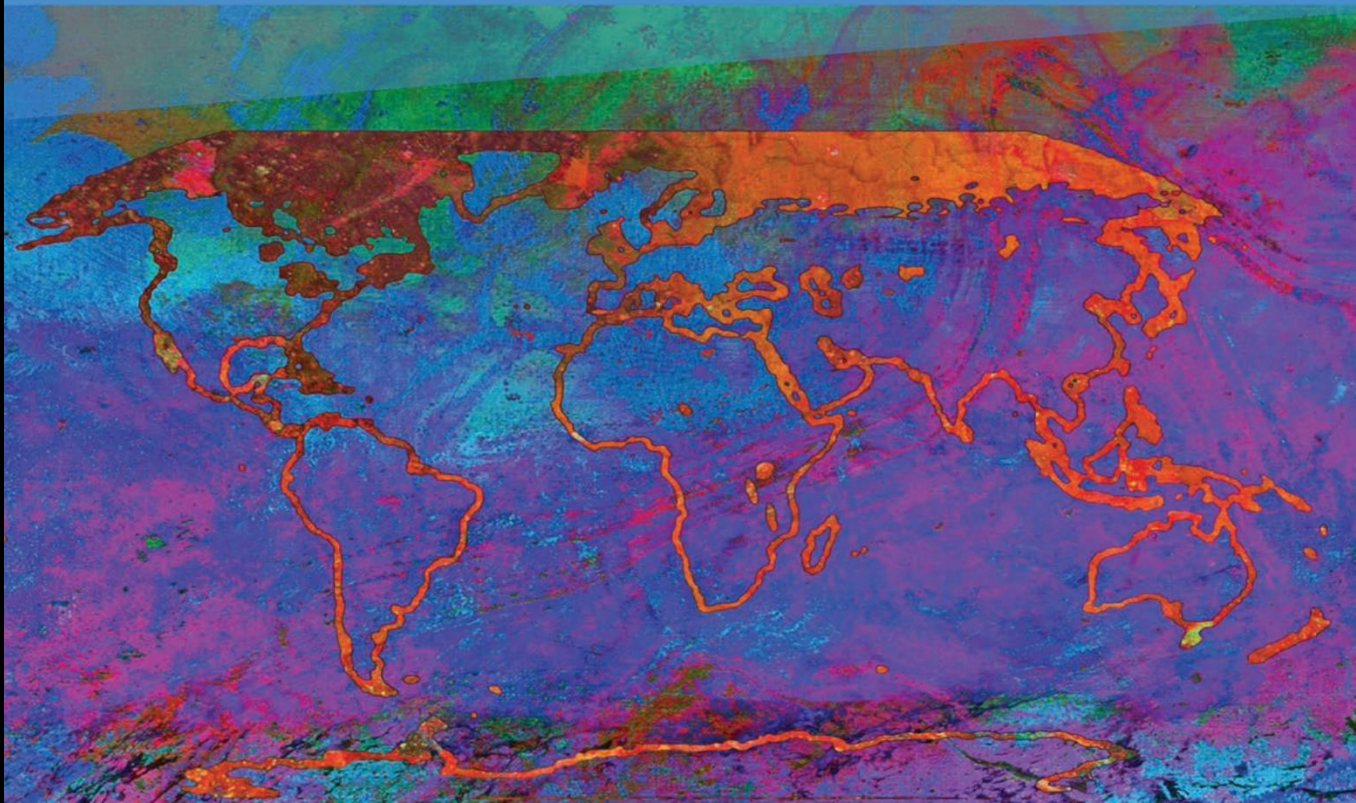
ipcc

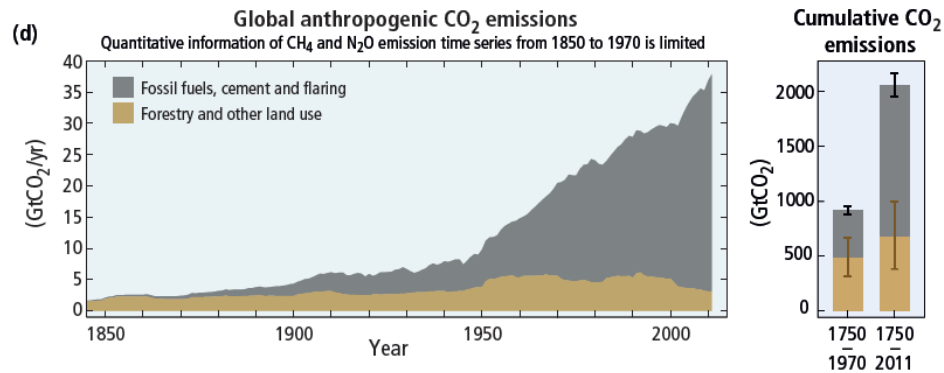
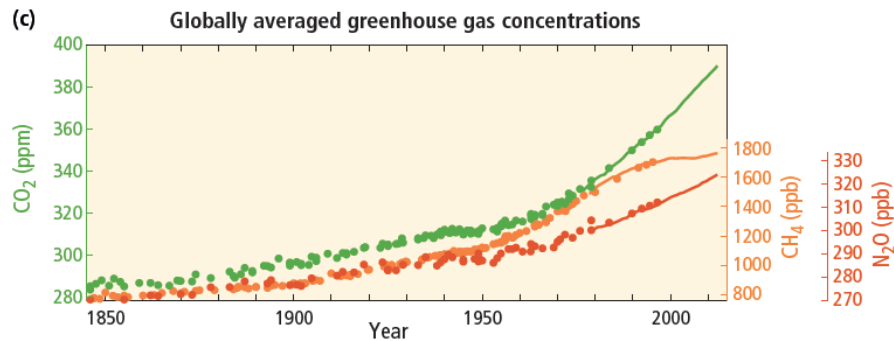
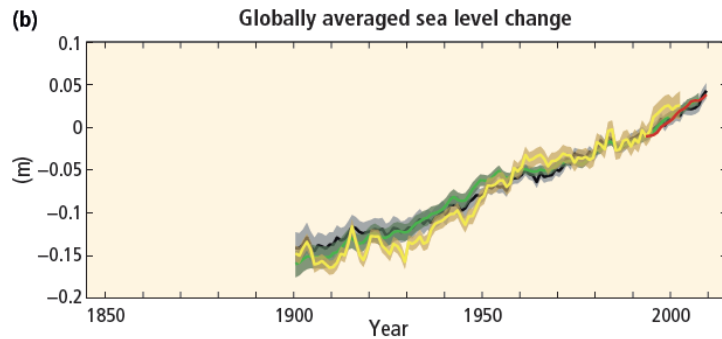
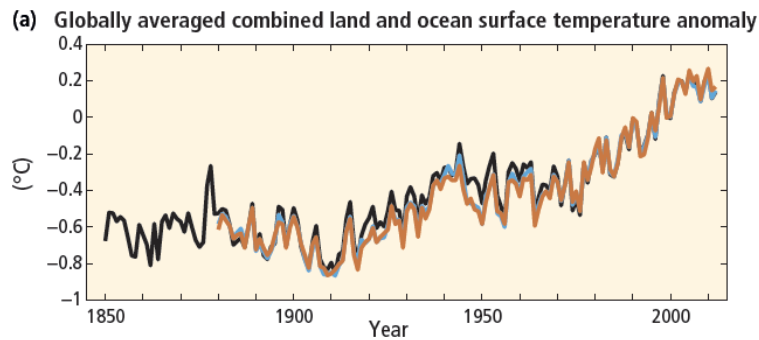
INTERGOVERNMENTAL PANEL ON climate change

Climate Change 2021

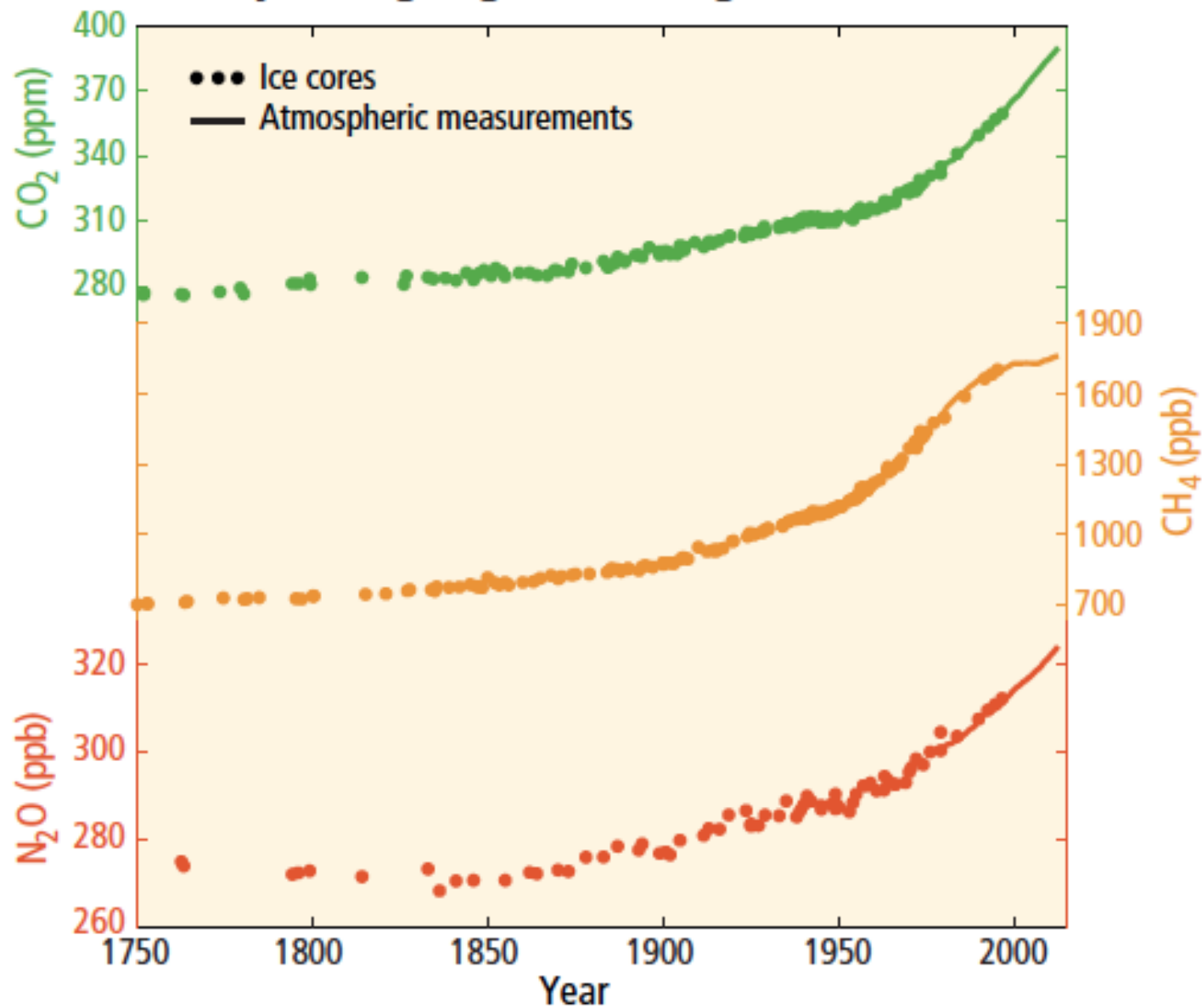
The Physical Science Basis

Summary for Policymakers



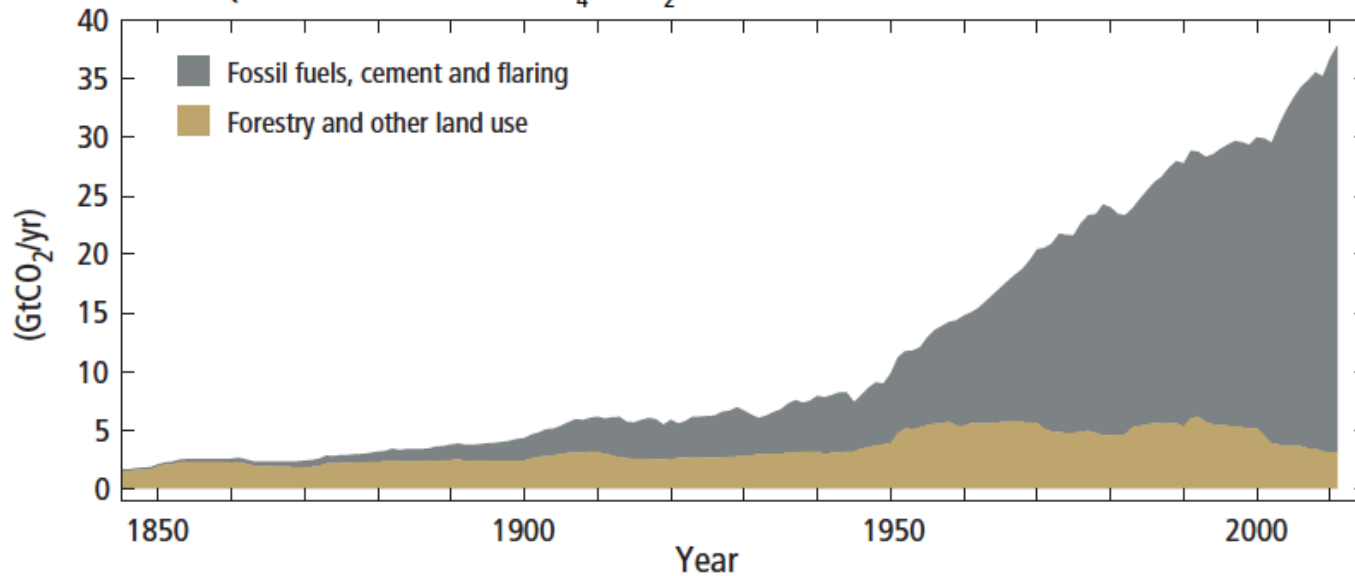


Globally averaged greenhouse gas concentrations

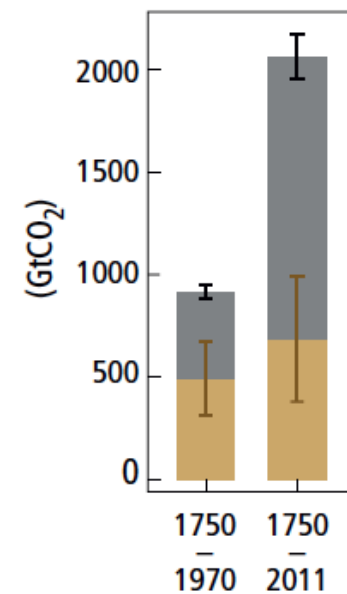


Global anthropogenic CO₂ emissions

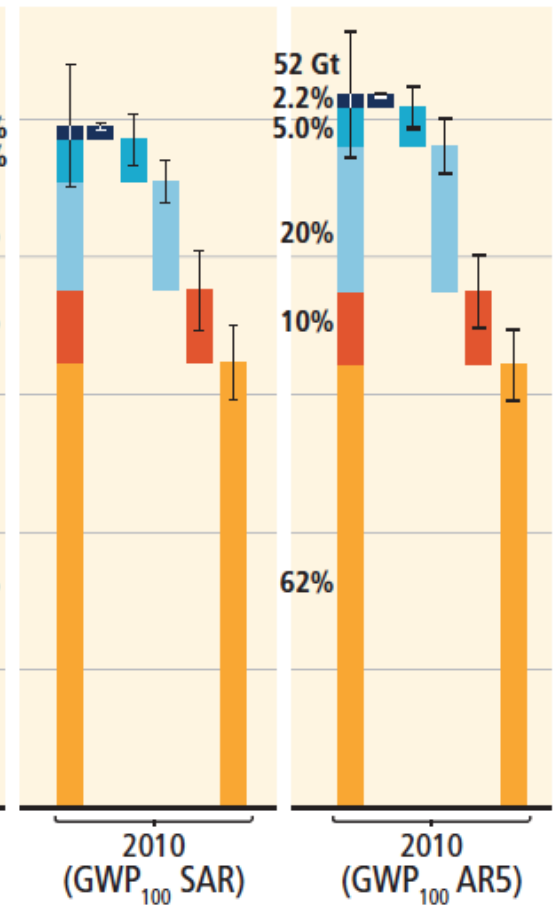
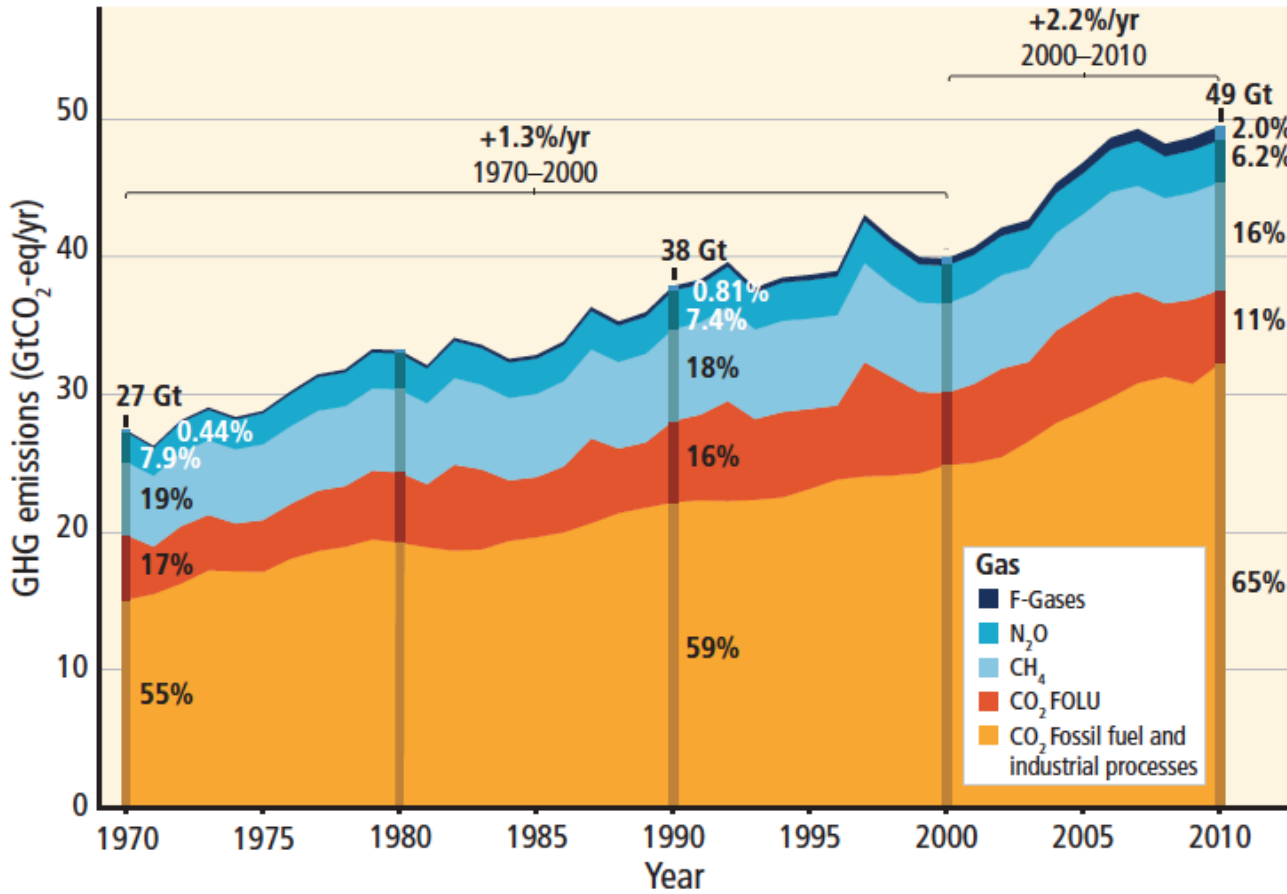
Quantitative information of CH₄ and N₂O emission time series from 1850 to 1970 is limited



Cumulative CO₂ emissions

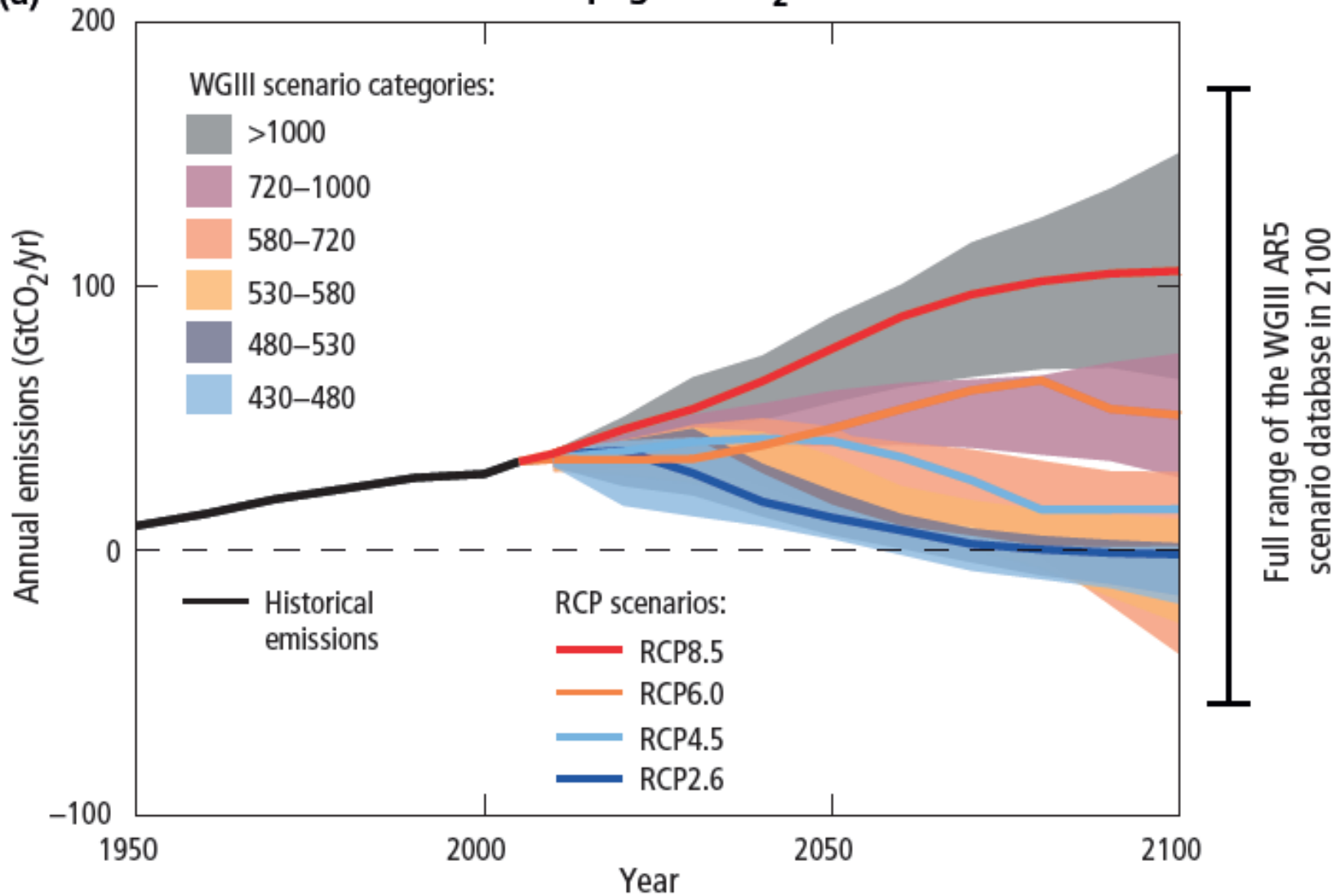


Total annual anthropogenic GHG emissions by gases 1970–2010



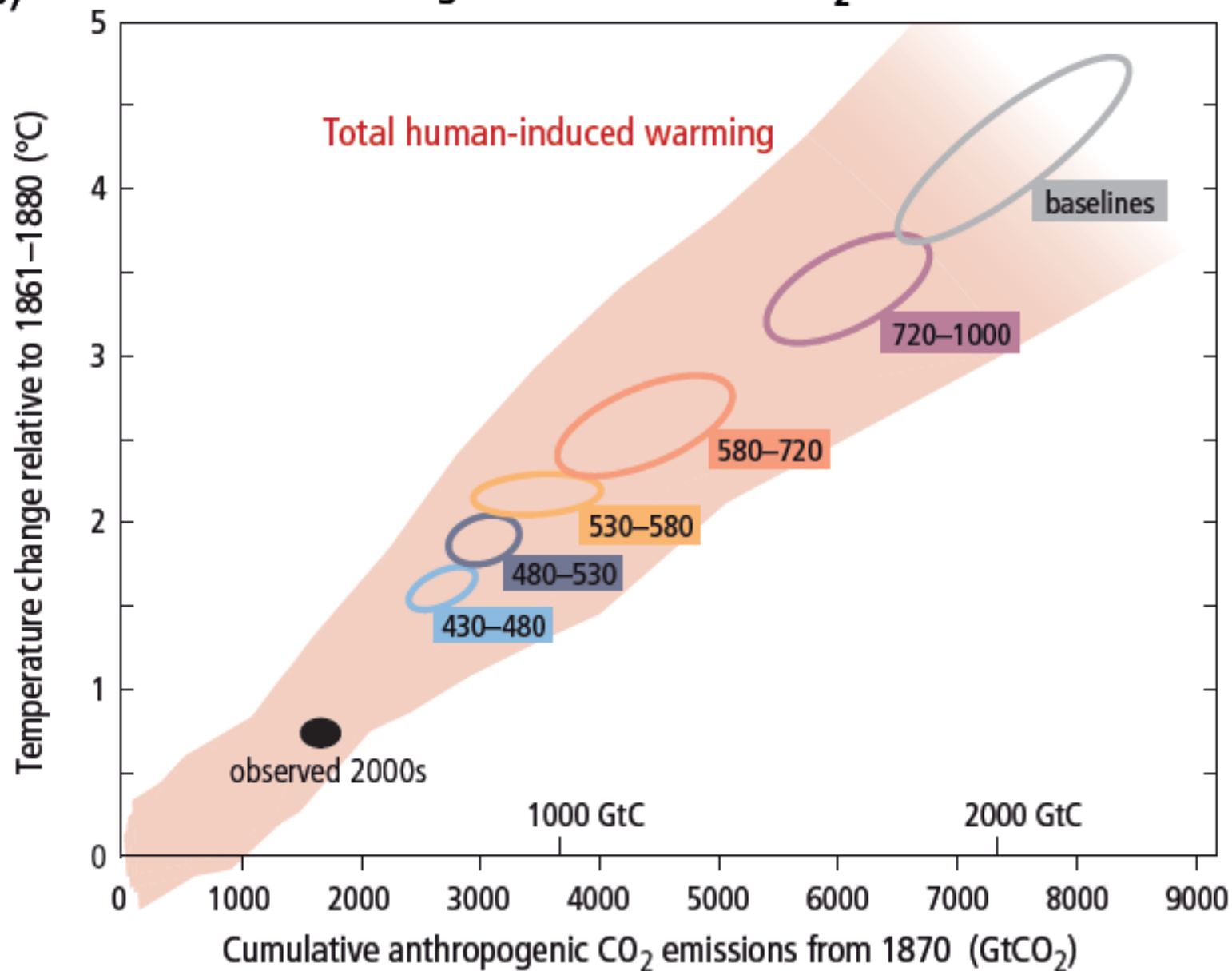
(a)

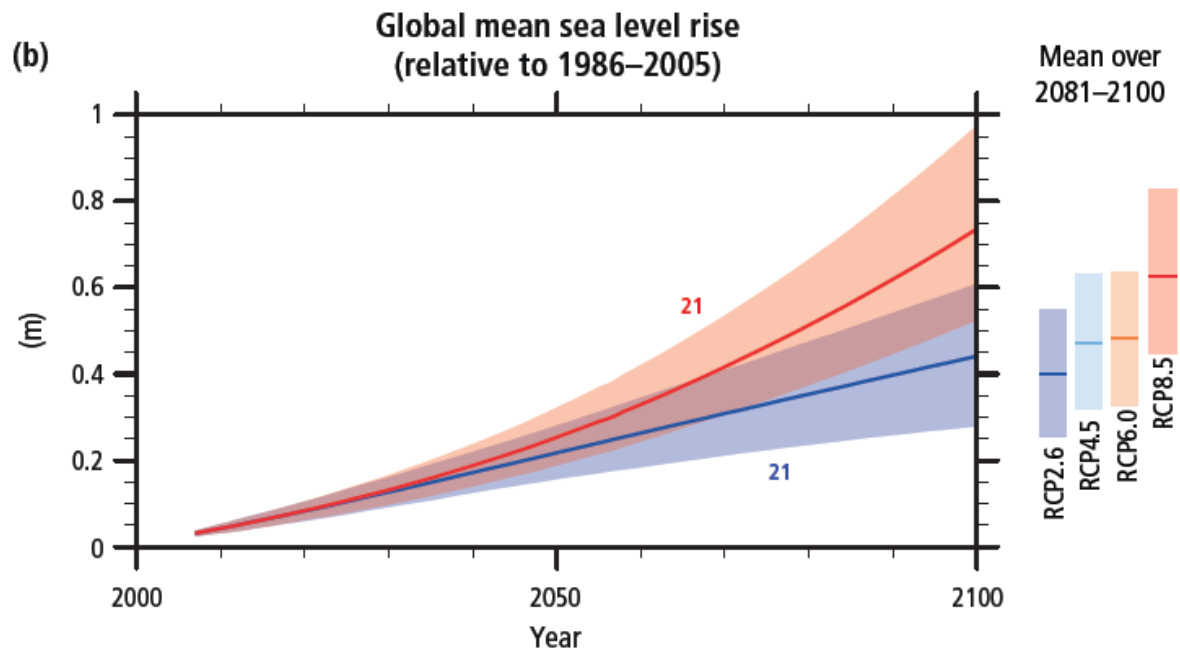
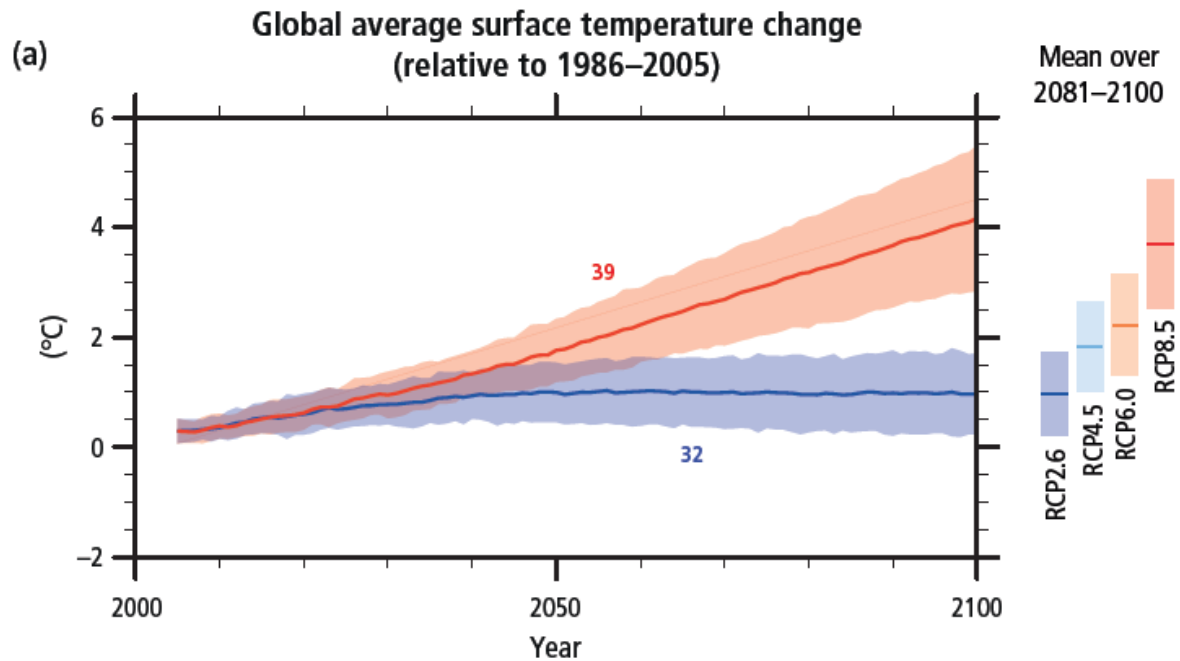
Annual anthropogenic CO₂ emissions

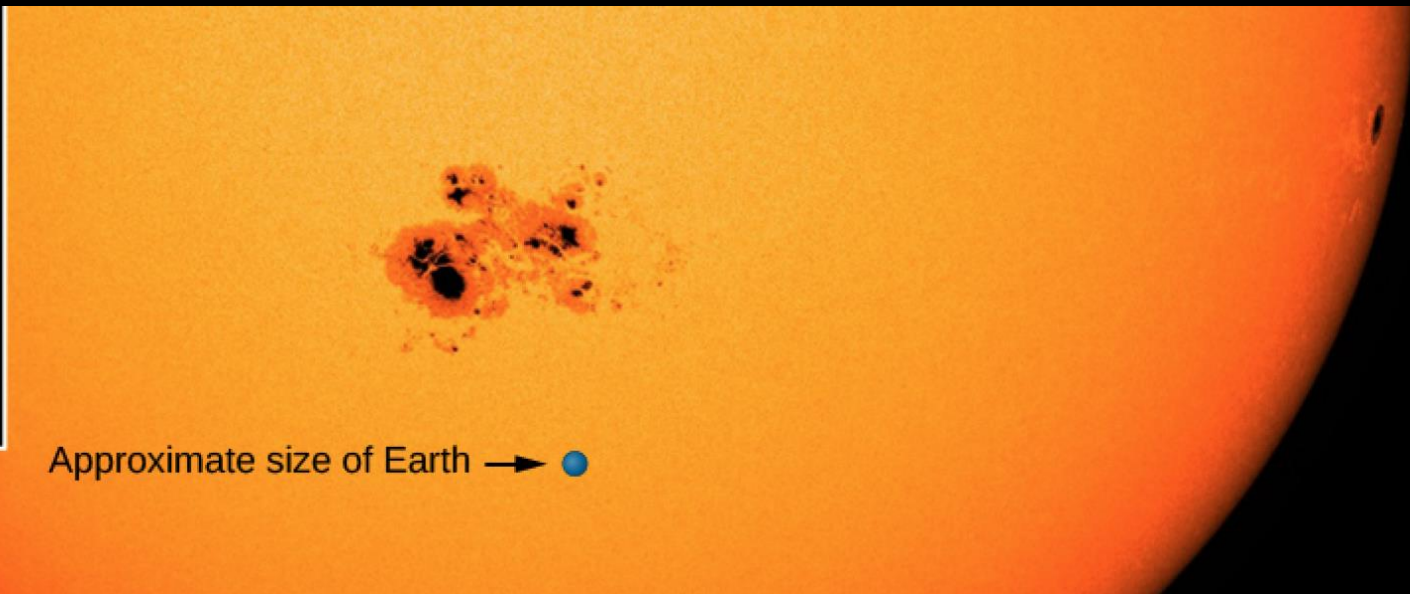
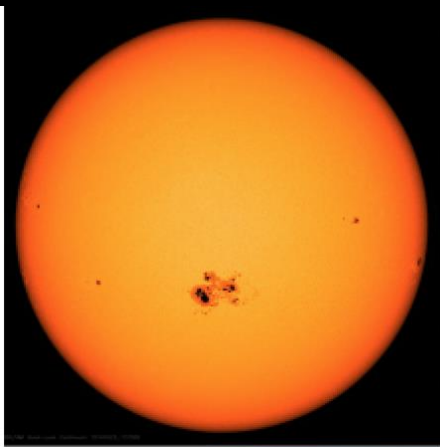


(b)

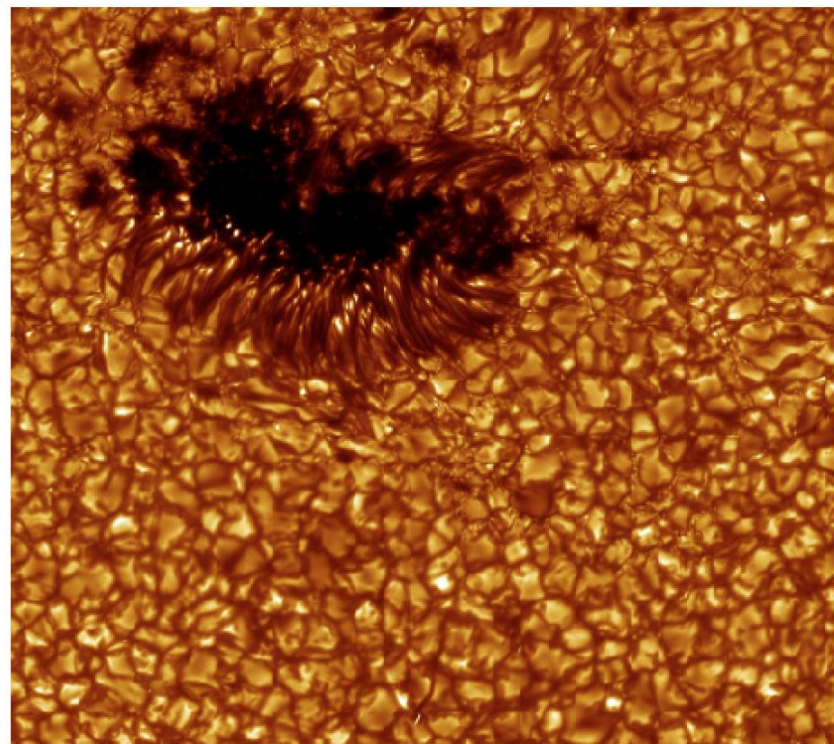
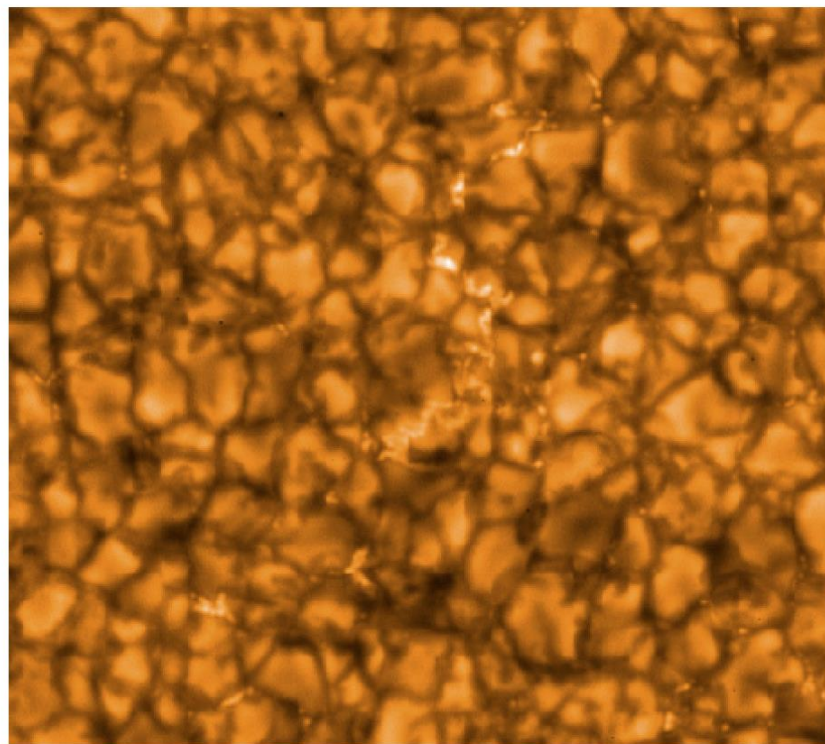
Warming versus cumulative CO₂ emissions

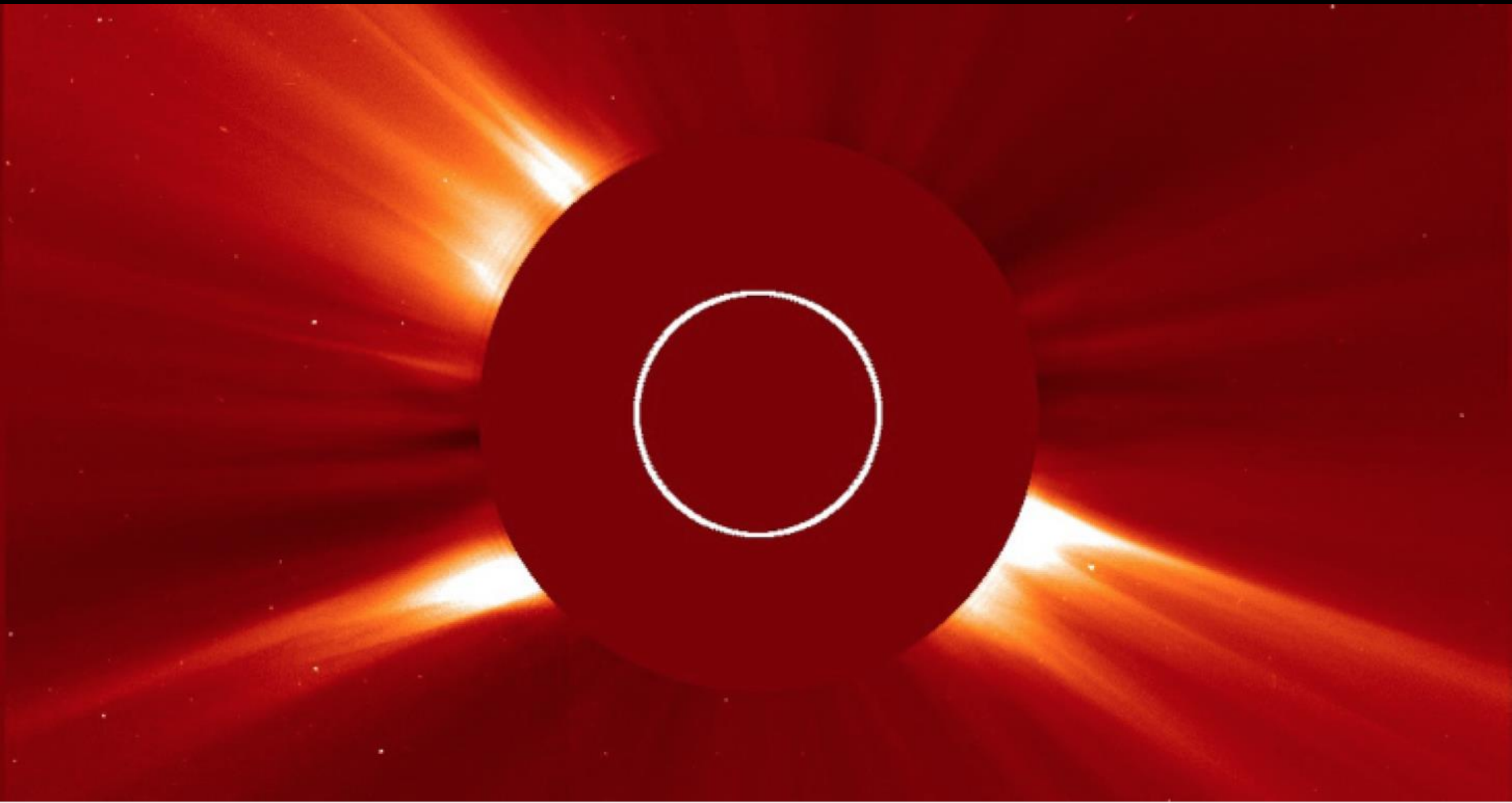




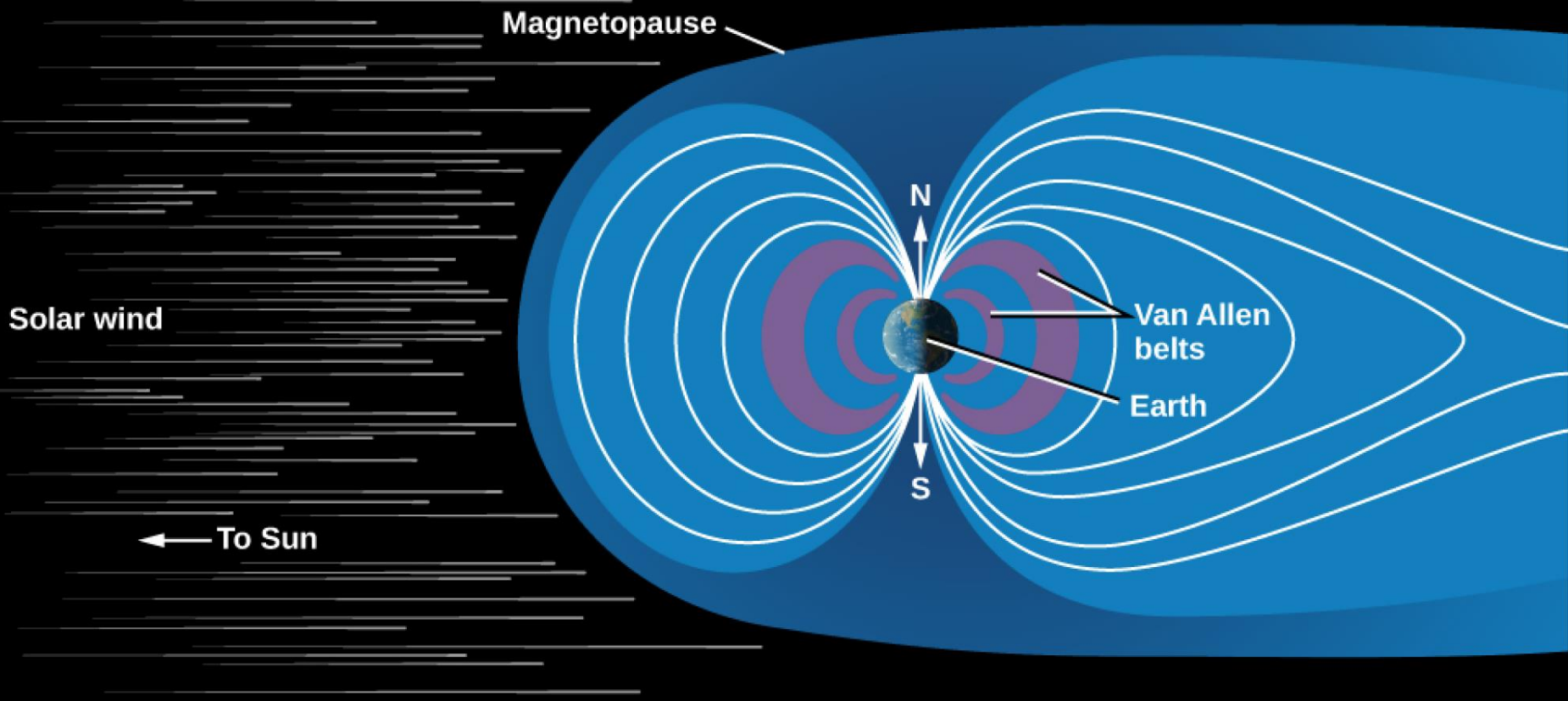


Approximate size of Earth → ●









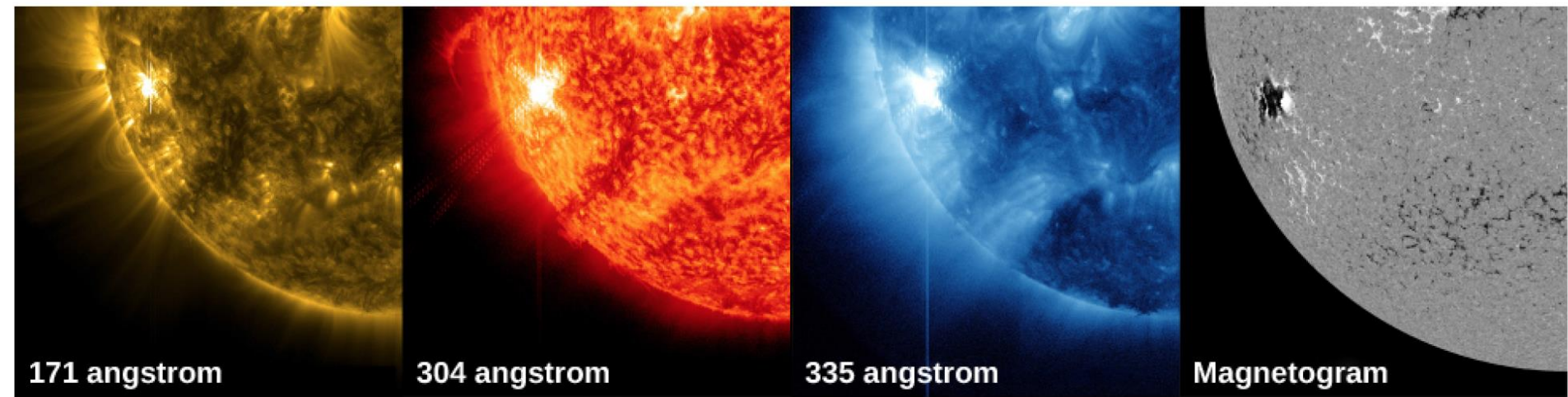


“WHITE SATIN”

© TODD SALAT
AURORAHUNTER.COM



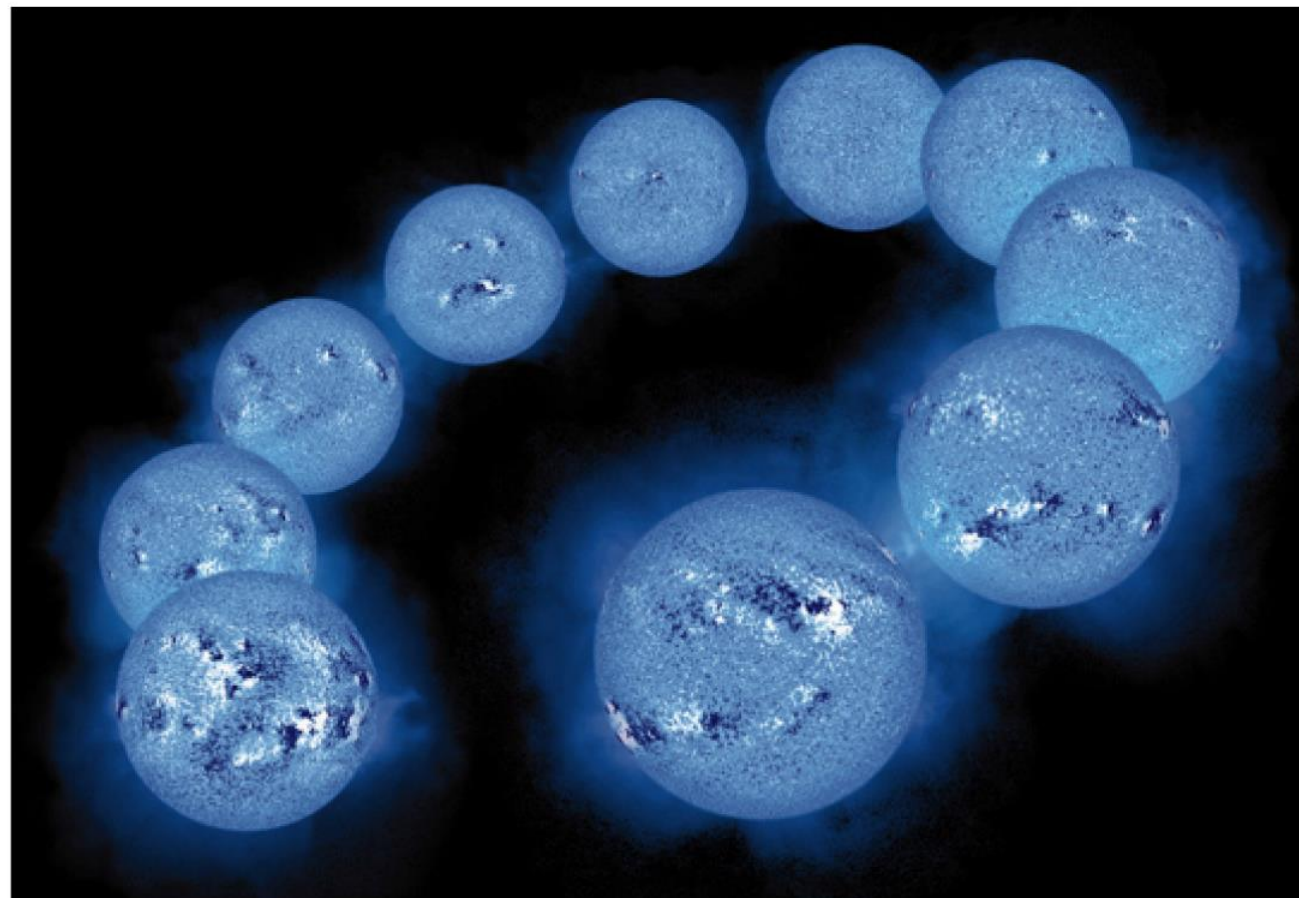




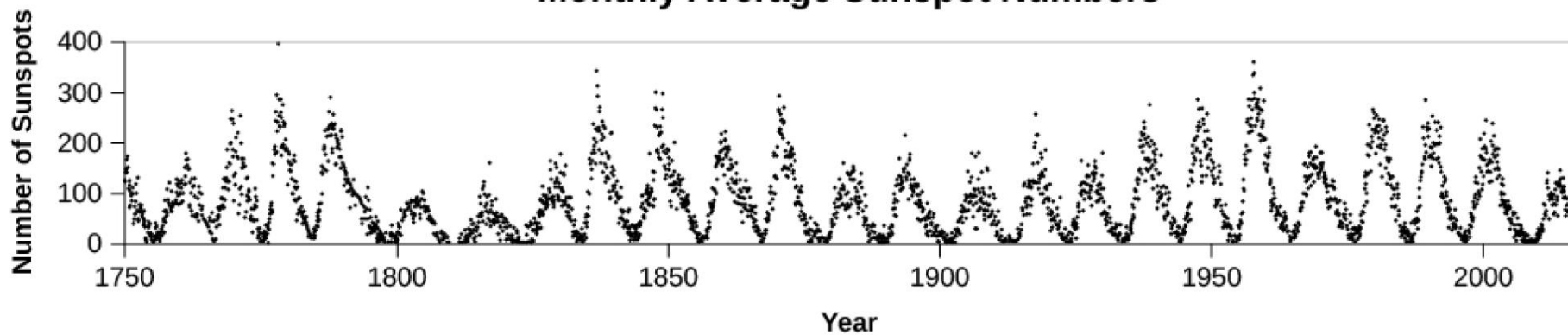
Sun: looks different at different wavelengths:
magnetic activity!


Flares, coronal mass ejections, corona

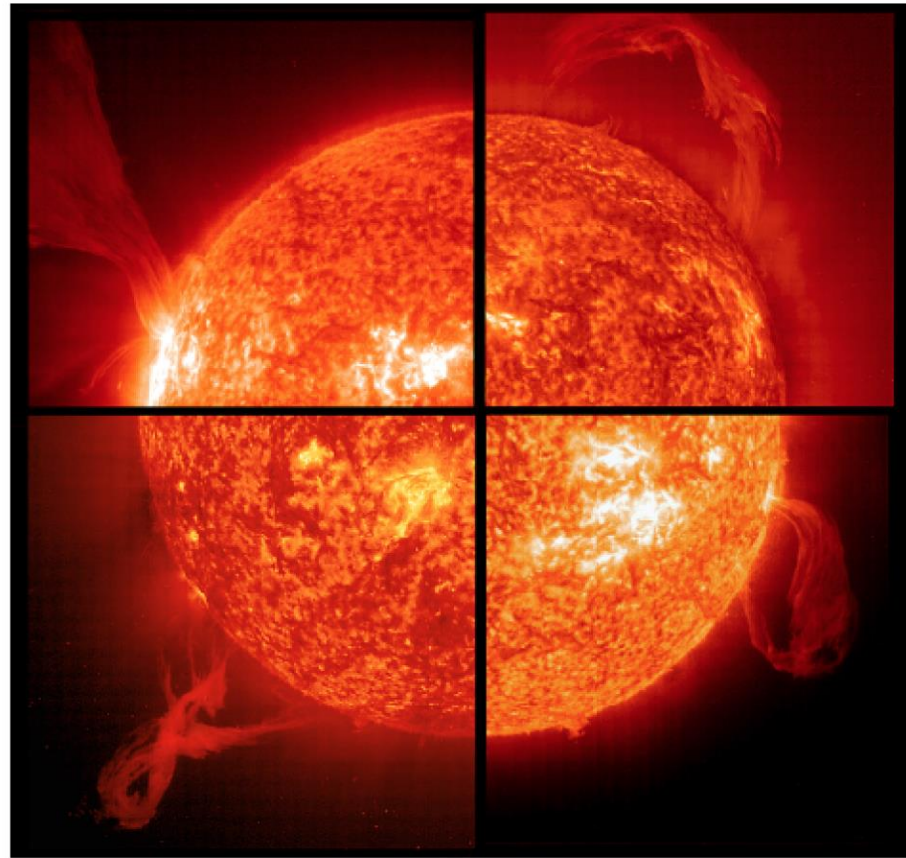
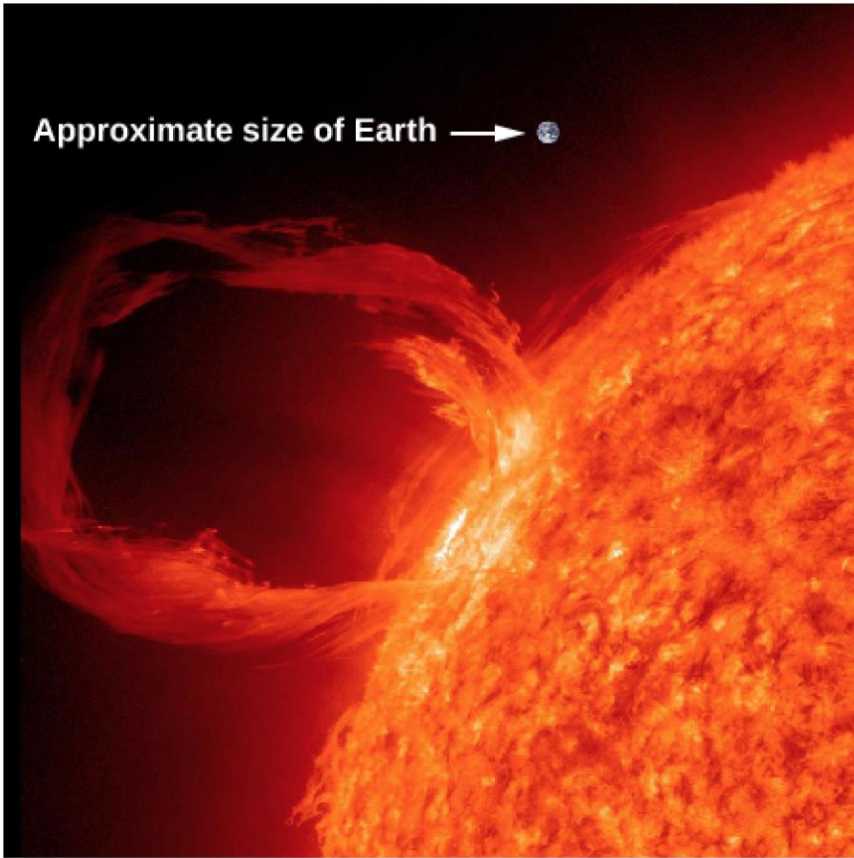
11 year
magnetic
cycles



Monthly Average Sunspot Numbers



Approximate size of Earth → 



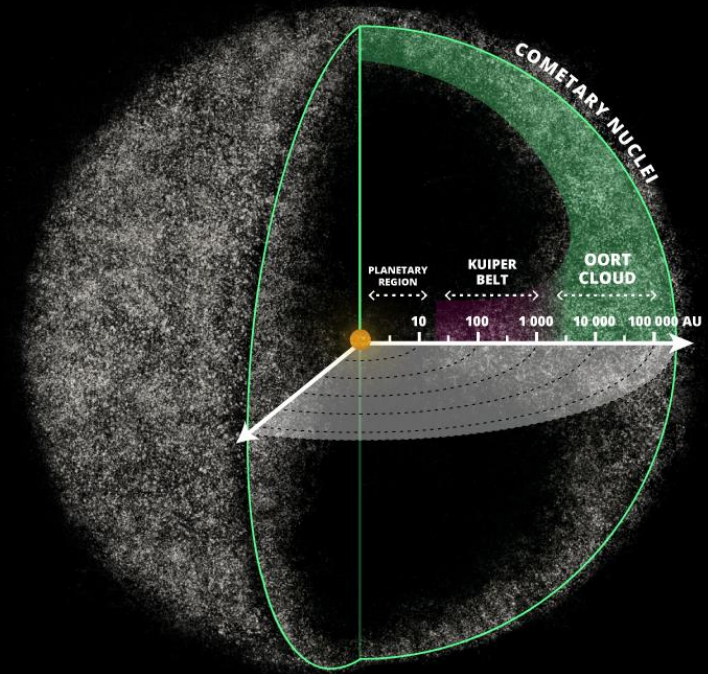
Solar storms

- Carrington event in 1869: huge solar storm
 - Estimated cost huge if happened today (1-10 trillion USD to world economy)
- 1989: solar storm knocked out power across much of Canada
- Possible superflare in 775 from C-14 isotopic evidence from trees
 - Similar event in 960

Satellite operators now build satellites to shield solar storm

Serious problems with technical solutions

- Need to control our own destiny
- Develop tech to move comets
 - Comet from Oort cloud on unpredictable orbit
 - Few months warning at most
 - Surveys like LSST help identify these objects
- Global Warming a significant challenge
 - Lots of solar, wind, nuclear power in China
 - Developing world needs more power
 - Many rich countries consume power w/o production
 - Rich countries: unwilling to sacrifice conveniences for long-term gains



Scientific Revolution

The history of the past ~500 years has been governed by the development of science and technology

Ancient Science

Lunar calendar

need 13th month!

driven by farming

Eclipses

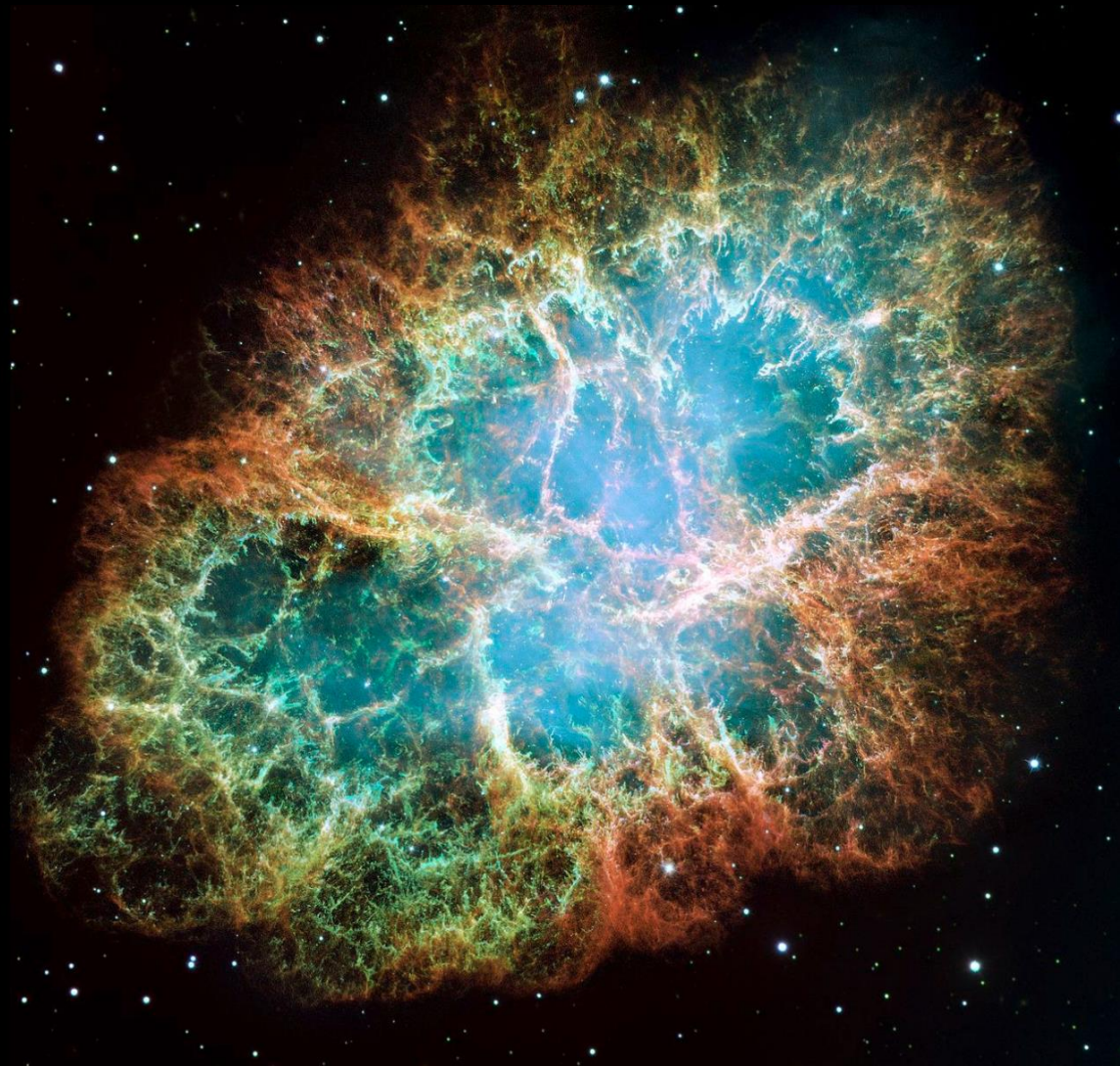
Comets

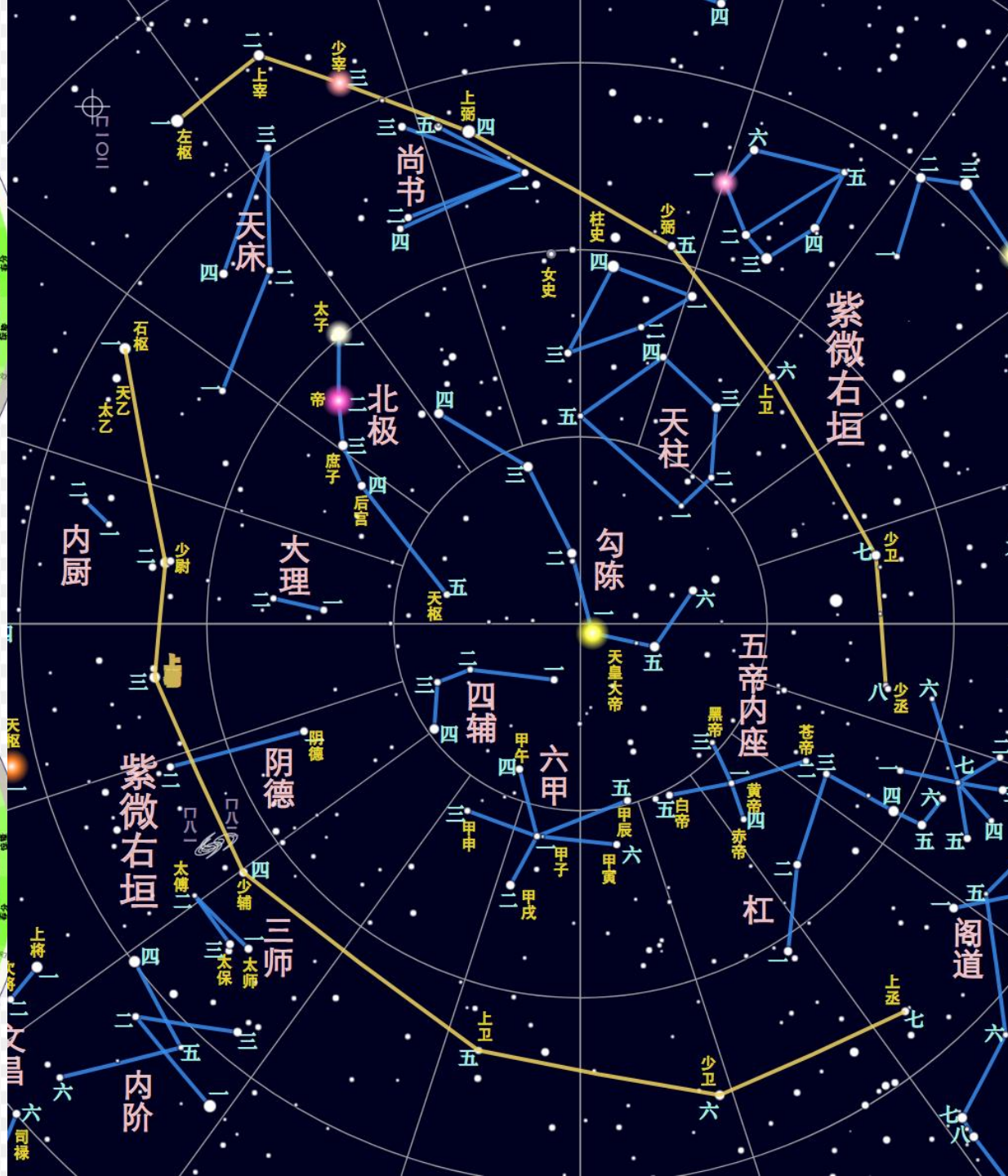
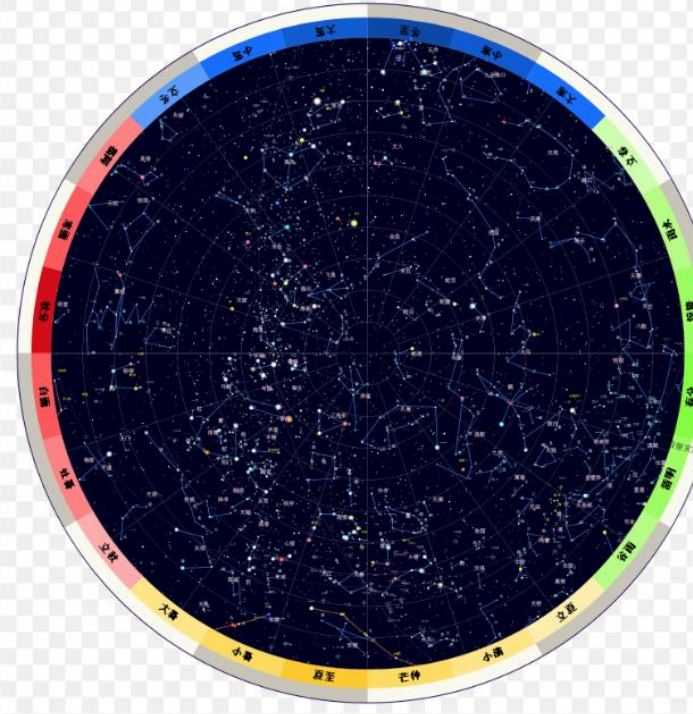
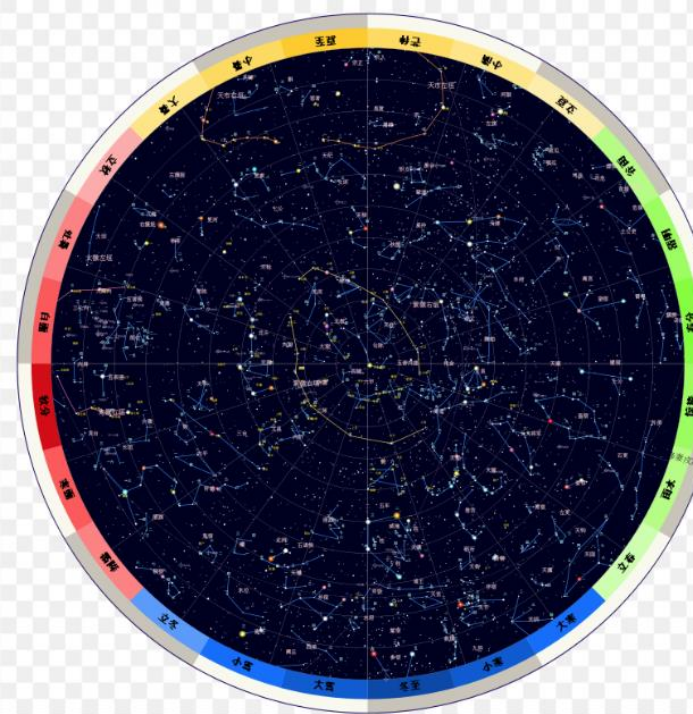
Supernova

Crab Nebula and Supernova 1054

Visible for ~2 years

kè xīng 客星





Horoscopes and astrology

Positions of sky determine your day/life

Born in the year of the dragon?

Pseudo-science

(includes superstitions, Traditional Chinese Medicine)

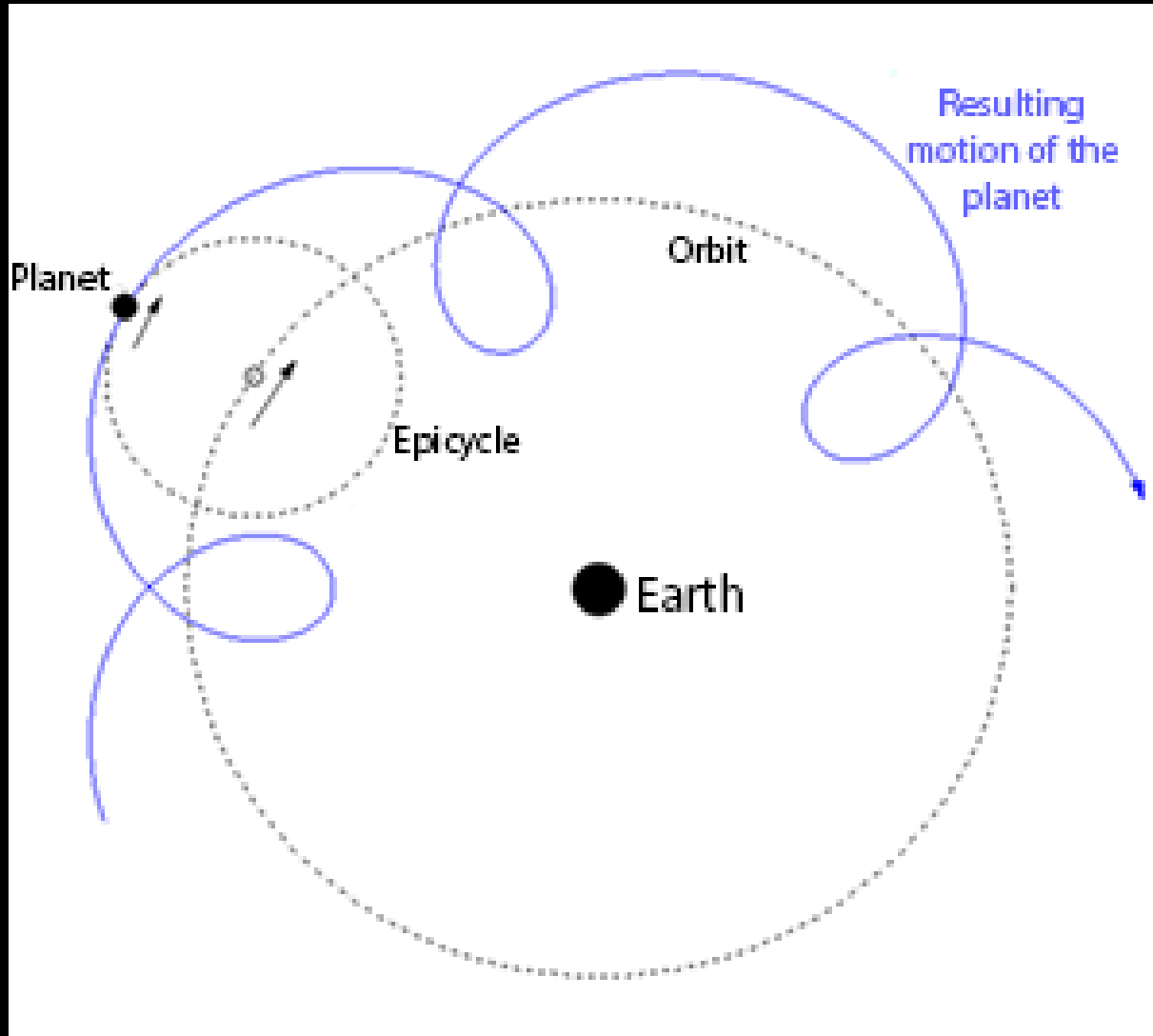
Scientific Method

- Prior approach: rationalism
 - Reason alone is the chief source of knowledge
 - Alternative was/is faith

 - Empiricism: use observations to test

 - Logic common to both
-

Epicycles: before heliocentric

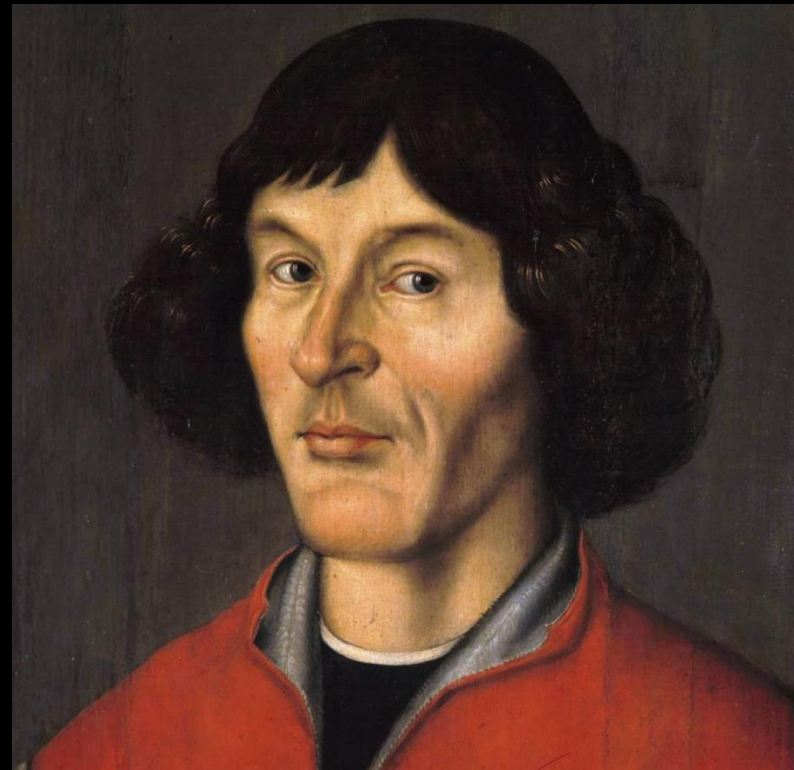


Copernican Revolution

Heliocentric model of the universe: sun is at the center

“helio” = sun in Greek

(Earth is not flat or center of universe)



Giordano Bruno

Burned at the stake for
support of Copernican
(heliocentric) view

Statue in Rome

Considered martyr for
science



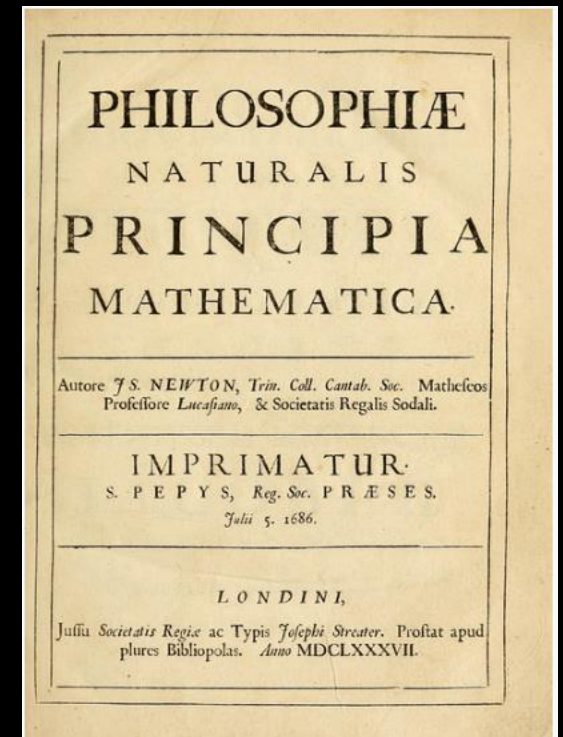
Newton's Principia

Mathematical Principles of
Natural Philosophy

Calculus

Planetary motion

Gravity



Empiricism

Inductive reasoning

Knowledge comes from testing

“There remains simple experience; which, if taken as it comes, is called accident, if sought for, experiment. The true method of experience first lights the candle [hypothesis], and then by means of the candle shows the way [arranges and delimits the experiment]; commencing as it does with experience duly ordered and digested, not bungling or erratic, and from it deducing axioms [theories], and from established axioms again new experiments.

Francis Bacon



Galileo

Telescope: Jupiter's moons!

Gravity



Galileo

Telescope: Jupiter's moons!
a different solar system (sort-of)

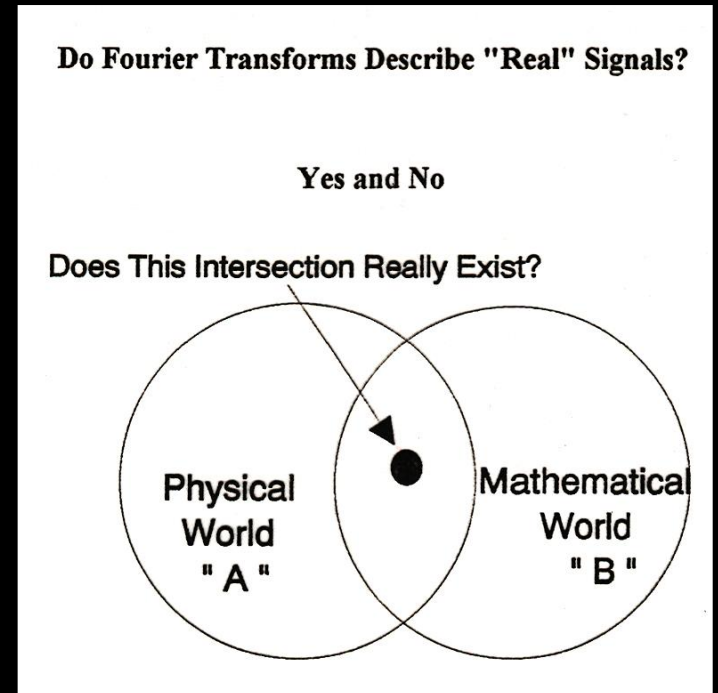
Gravity: drops two balls of
different masses, hit the ground
at the same time



Science

We want to understand our universe

What is the path to knowledge



Scientific method: testing!

Formulate a question

Hypothesis: guess at explanations

Prediction: what does the hypothesis predict?

Testing: obtain data from real world

Analysis: apply test to predictions

Dissemination: let others know

Scientific method: testing!

Formulate a question: why does the earth have seasons?

Hypothesis: earth is closer to the sun sometimes during the year

Prediction: northern and southern hemispheres have the same winter

Testing: winter is in June in Australia, Jan in Beijing

Analysis: prediction is very wrong

Dissemination: let others know

Scientific method: testing!

Formulate a question: why does the earth have seasons?

Hypothesis: earth's axis is tilted

Prediction: northern winter is southern summer

Testing: travel to southern hemisphere

Analysis: apply test to predictions

Dissemination: let others know

Occam's Razor

The simplest solution is more likely to be correct than complex ones

(fewer free parameters)



Falsifiability?

Does God exist? Cannot be tested

String Theory? Not sure

Do cigarettes cause cancer? Yes!

Scientific method: modern tweaks

Replication: can others repeat experiment?

External review: acceptance by others

Uncertainty: data has errors!

Data recording/sharing: papers, github

Astronomy: cannot control events

Physics laboratory: can determine everything about a test

Astronomy: observational (like economics)

Biases in science

- Confirmation bias: I interpret results based on my initial guess as to what is correct
- Publication bias: only publish positive/interesting results
- Simplicity/Occam's razor
- Ad hominem: person rather than argument
- Status quo bias: nothing should change
 - theories change when old people die
- Selection bias: sample not representative
- Over-criticism of others
- Conflict of interest: who is funding? Pharmaceutical industry

Replication crisis

- Scientific studies are difficult to replicate
 - Studies are difficult to replicate
 - Do vaccines cause autism? No, but long history
 - Erode public confidence in science
- Data: make public!
- Pre-registration of studies
- Funding for replication (no incentives)
- Better use of statistics

Examples of scientific ignorance

Horoscopes

Traditional Chinese medicine

Link between vaccines and autism

Nuclear power in Germany (and around the world)
after Fukushima

sometimes not considered “green” energy

How does science actually work: problem searching/solving

Always looking for problems

Always looking for ways to solve those problems

How does science actually work: problem searching/solving

Figure out a problem of interest

Get data (simulations or telescope)

Analyze data – usually different than expected

Write up results, often on a different problem

Peer review – referee and community acceptance

not perfect,



Brian Skinner @gravity_levity · 9 Aug 2018

1/ Who wants to hear some scientific intrigue?

A few weeks ago, a group of physical chemists posted a paper online announcing the observation of superconductivity at room temperature.

Today I posted a comment pointing out something funny in their data.
arxiv.org/abs/1808.02929

195 3.6K 7.2K



Brian Skinner @gravity_levity · 9 Aug 2018

2/ Room-temperature superconductivity has been a holy grail in physics for literally over 100 years. If we could find a material that was superconducting at room temperature, it would allow us to transport electrical power for free, and would revolutionize a bunch of industries.

6 34 463



Brian Skinner @gravity_levity · 9 Aug 2018

3/ There is no fundamental reason (that we know) why some material couldn't be superconducting at room temperature. But after a century of trying to find such material the best superconductor still needs to be cooled to 90 Kelvin (-183 Celsius).

6 24 335



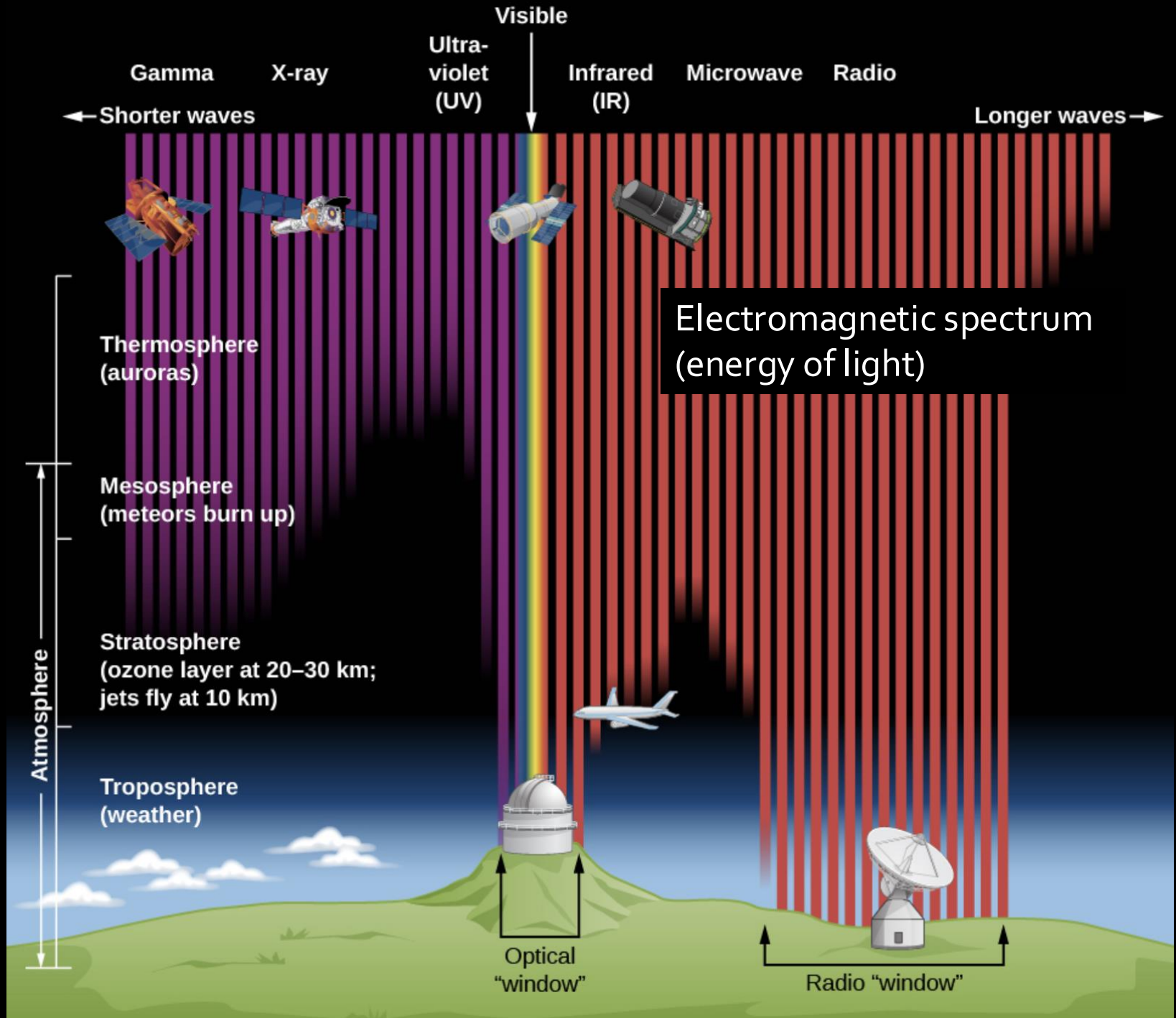
Brian Skinner @gravity_levity · 9 Aug 2018

3/ So you can imagine how exciting/shocking it was to see two people claim to have found it (arxiv.org/abs/1807.08572). This was a very surprising result, since neither of the constituent materials (gold and silver) are superconductors at any temperature.

7 19 342

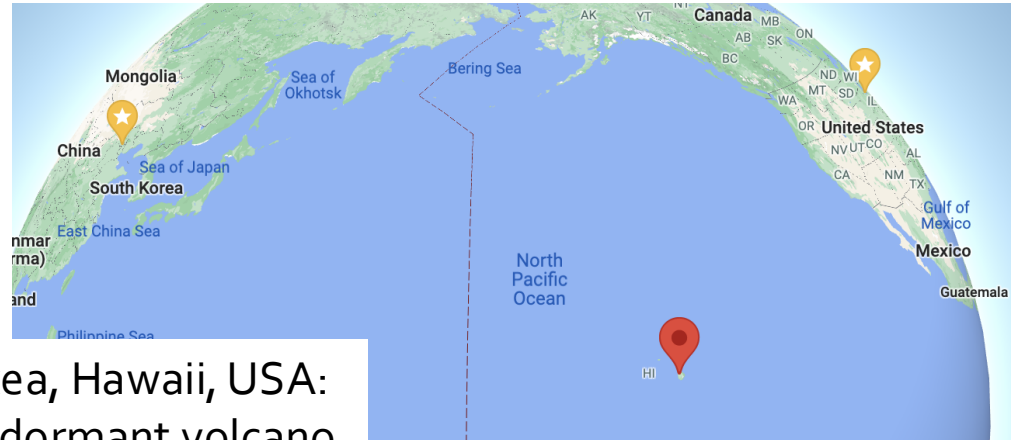
Telescopes

- The laboratory for observers
 - “experimentalist” in physics-hua
- Telescopes are adapted to different wavelengths
 - Some wavelengths only accessible in space
- Larger = better
 - Angular resolution proportional to diameter ($\propto D$: diameter²)
 - Number of photons proportional to diameter²
 - But more expensive!
 - Some advantages to small telescopes (monitor bright targets)
- Solar system: can send satellites/robots

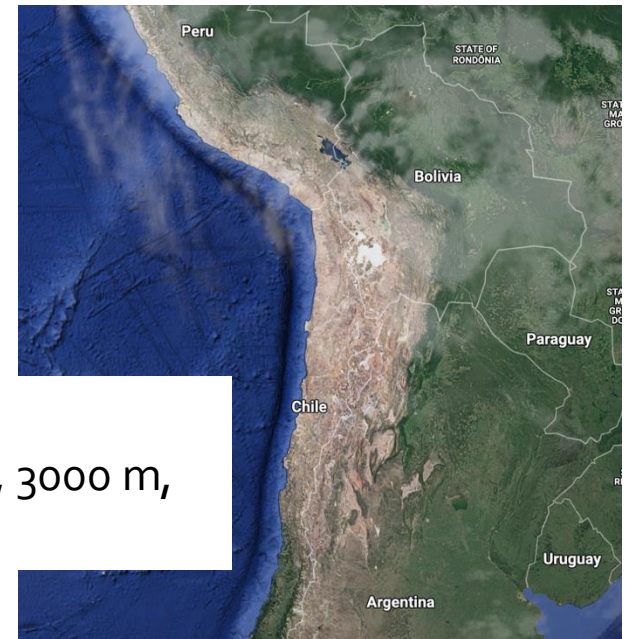


Where to build (optical) telescopes?

- High elevation
 - Above some of Earth's atmosphere
 - Smoother air currents
- Island/near ocean
- Sunny & dry
- Why go to space?
 - Some wavelengths not accessible
 - Stability of a stellar profile
 - Reduce background (especially in the infrared)



Maunakea, Hawaii, USA:
4000 m dormant volcano



Northern Chile
Andes mountains, 3000 m,
Very dry



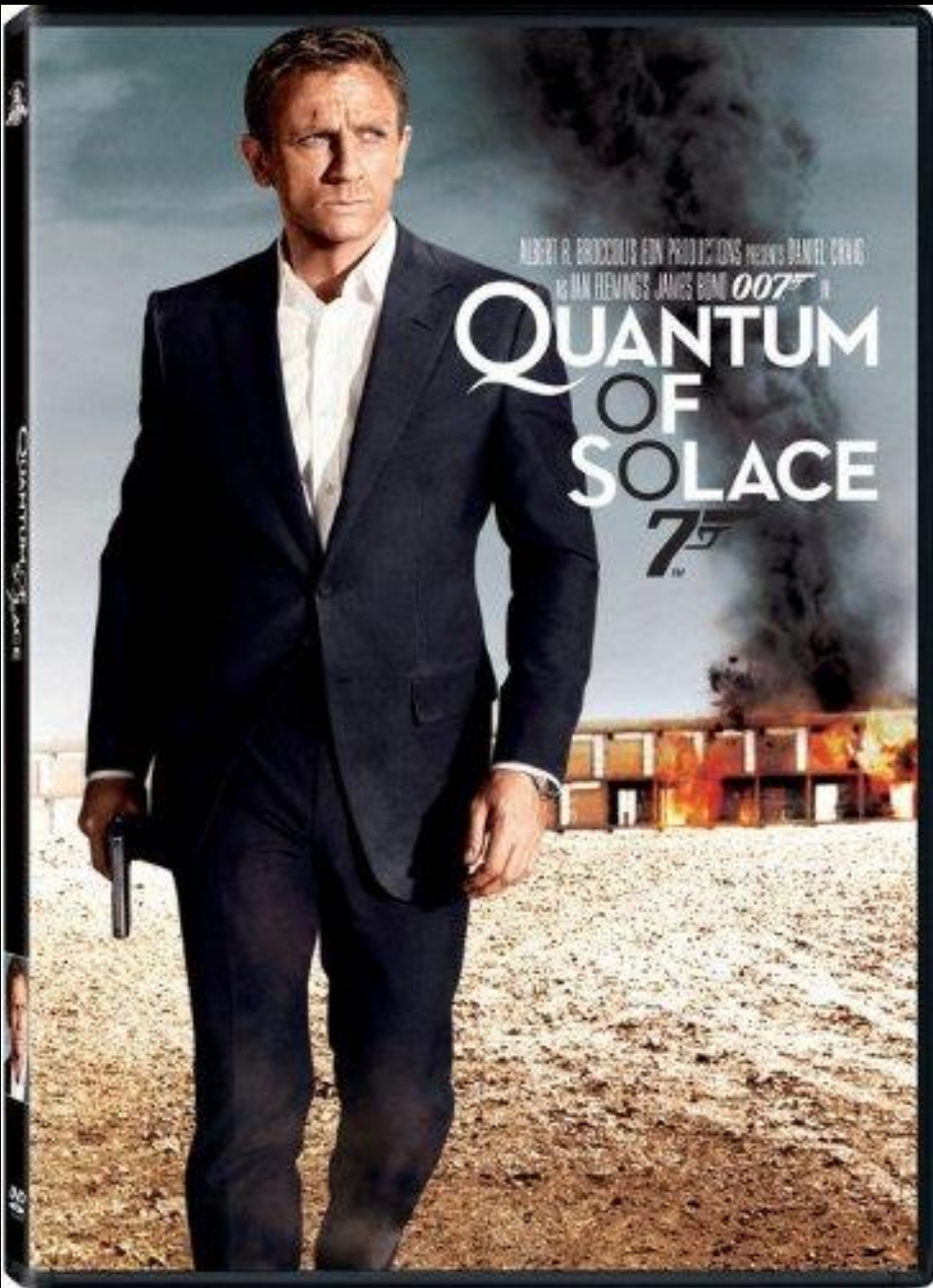
Maunakea, Hawaii



Maunakea, Hawaii



European Very Large Telescopes: Paranal, northern Chile



Optical Telescopes: Extremely Large Telescopes

- Three telescopes planned
“first light” in ~2030
- 25-40-meter diameters
 - Best current telescopes: 10-m
- \$2-3 billion USD each!
 - 100-150亿 RMB!
- Thirty Meter Telescope:
 - China is 10% partner



Optical Telescopes: Hubble Space Telescope

- Launched in 1991
- Four servicing missions for repairs and updated instruments
- Revolutionary telescope for science, general public



Unnamed replacement for Hubble

- US Science Community just announced support for a 6.5-m UV/optical/infrared telescope in space
- Cost: \$10B USD
- Launch: around 2045 (if lucky)

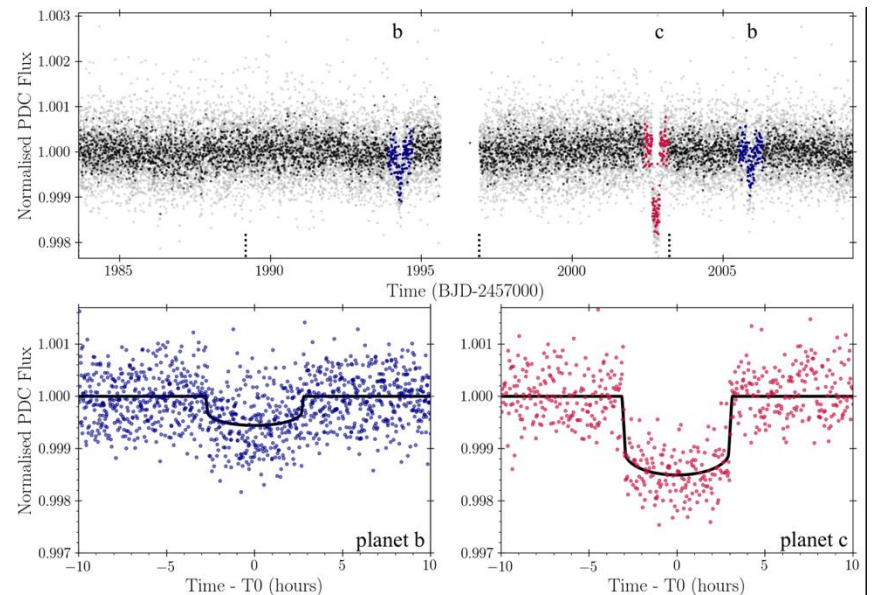
Optical Telescopes: Chinese Space Station Telescope

- Planned for 2024
- Hubble-sized telescope
- Much wider field of view
- Powerful new instrumentation
- CSST PKU Science Center!



Optical Telescopes: TESS

- Some (~5) small, mid-sized telescopes in space
- Kepler (2013): stared at same region of sky for 3 years to look for exoplanet transits (dips in light curve)
- TESS: All-sky search for exoplanets



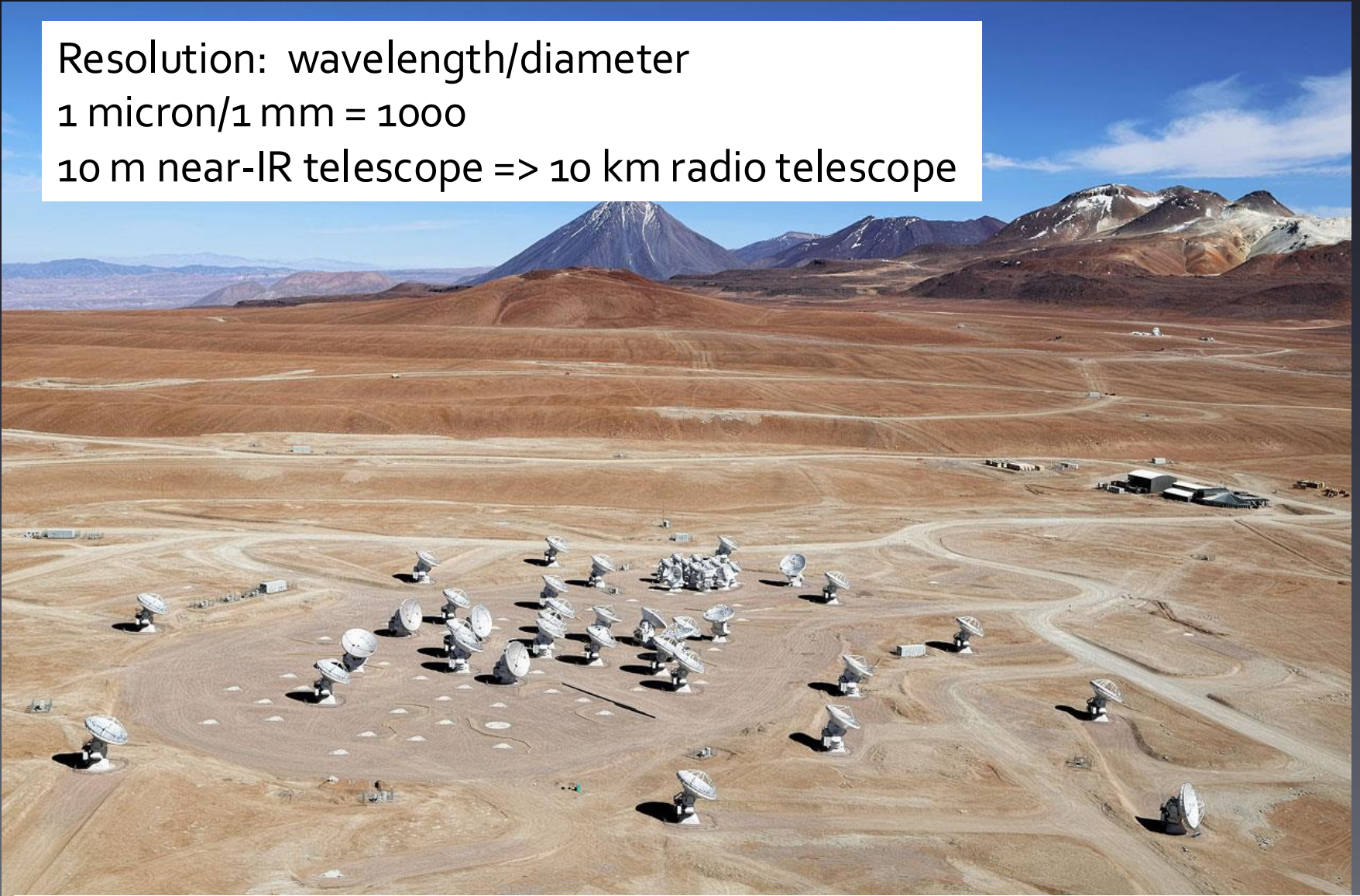
Infrared telescopes: JWST

- NASA/ESA James Webb Space Telescope
- 6.5m infrared telescope in space
- \$10B USD – most expensive telescope ever built
 - 650亿 RMB



Atacama Large Millimeter Array (ALMA)

Resolution: wavelength/diameter
1 micron/1 mm = 1000
10 m near-IR telescope => 10 km radio telescope



Sub-mm interferometer telescope; 5000-m elevation!



Complejo
de Puricó

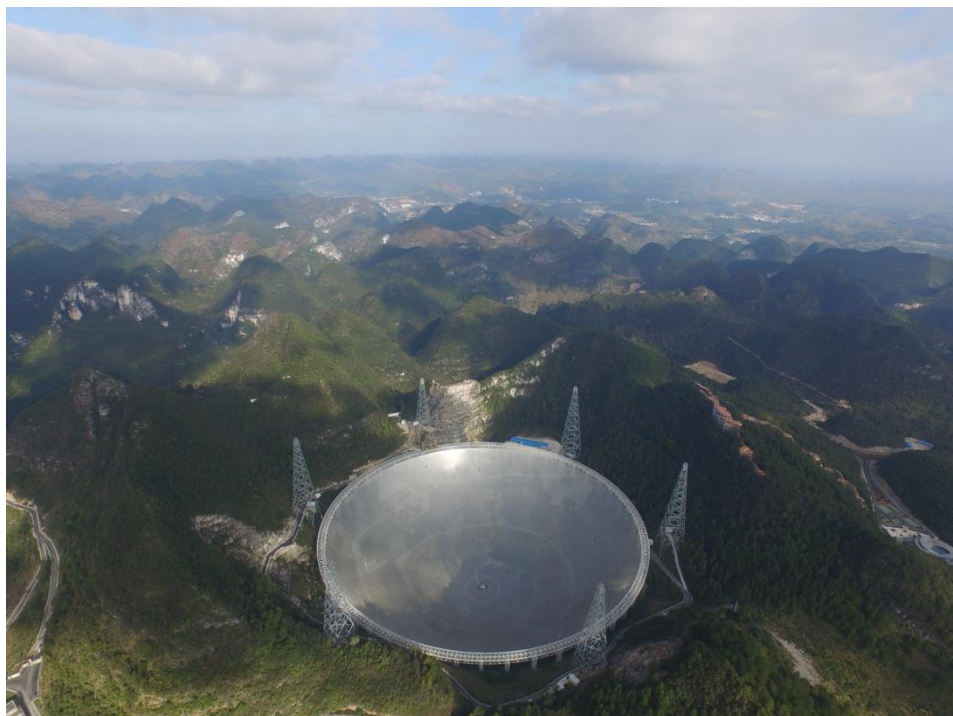


Atacama Large
Millimeter Array...



Radio Telescopes: FAST

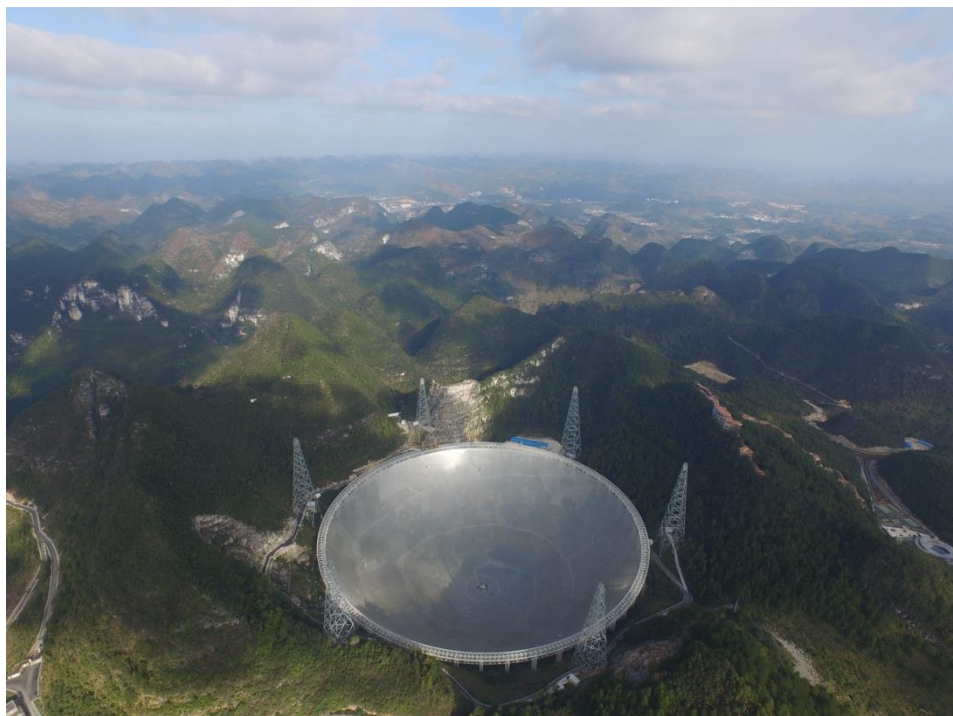
- Five-hundred meter aperture Spherical Telescope
- World's largest telescope in Guizhou
- Pulsars and interstellar gas
- Planned expansion in 2030
 - 6 linked dishes



Radio Telescopes: FAST

- Five-hundred meter aperture Spherical Telescope
- World
- Pulsars and interstellar gas
- Planned expansion in 2030
 - 6 linked dishes

我和我的家乡！

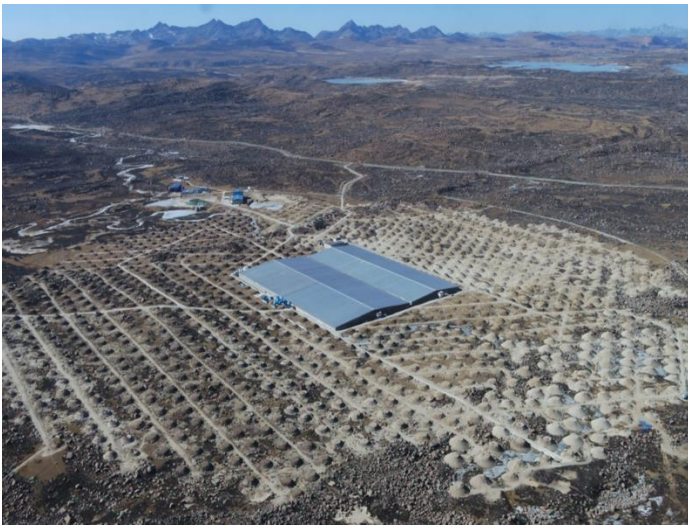




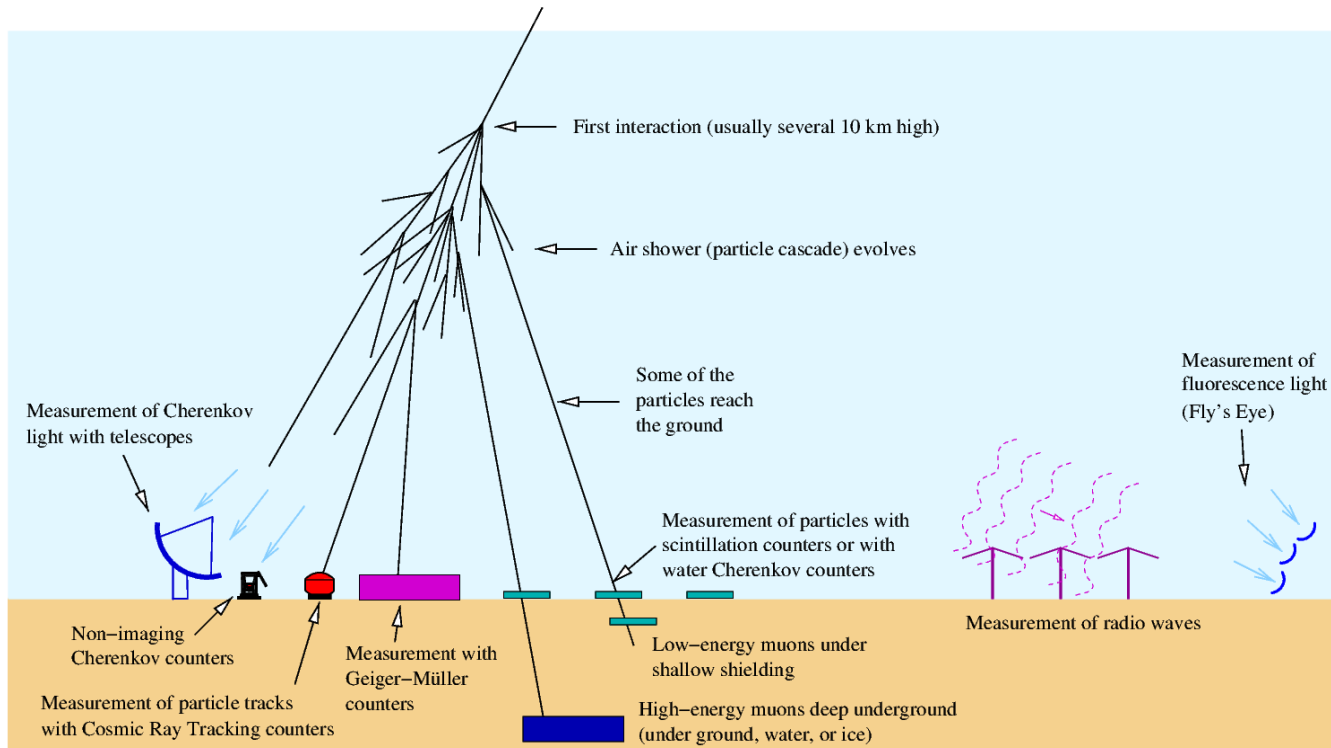
长春 汽车城嘛
Changchun, the city of cars.

LHAASO

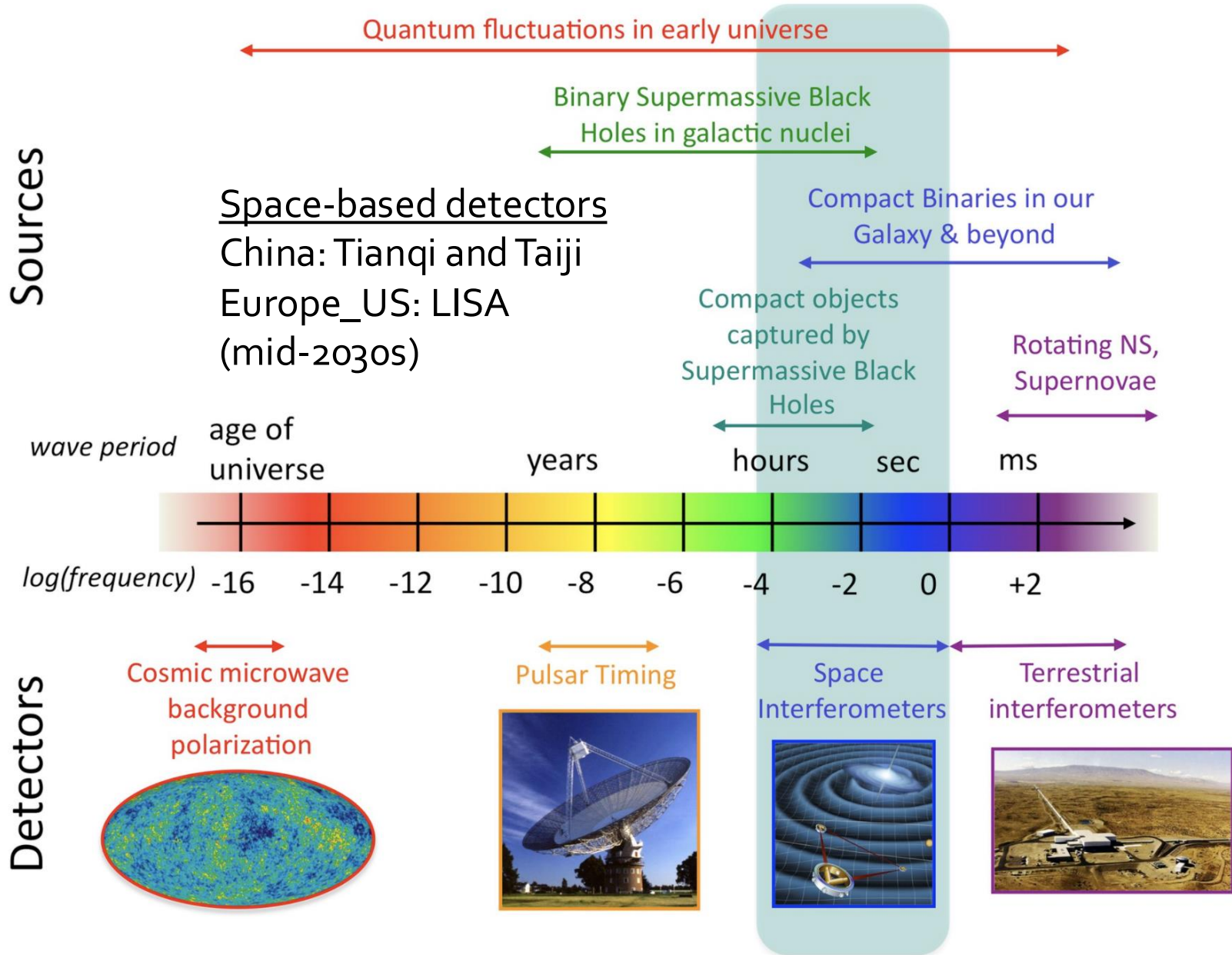
Cosmic rays, gamma rays



Measuring cosmic-ray and gamma-ray air showers



The Gravitational Wave Spectrum



Upcoming planetary missions

- Venus: NASA (2021) selected two missions for ~2030
- Dragonfly: drone to Titan!
- Europa Clipper: flybys of Europa
- Jupiter Icy Moons (JUICE): ESA (=European NASA)
- ESA: Comet Interceptor (2029)

Chang'e missions (嫦娥)

- Chang'e 1, 2 (2007, 2010): Lunar orbiter
- Chang'e 3 (2013): Lunar lander and Yutu rover
- Chang'e 4 (2018): first landing on far side of moon
- Chang'e 5 (2020): Lunar lander and sample return
- Chang'e 6 (2024): Lunar lander and sample return
- Chang'e 7 (2024): Drone!

Building to robotic lunar base and manned mission

Planetary missions from China

- Tianwen-1 (天问2021): Mars lander, Zhurong rover
- ZhengHe: sample return mission from comet
- Mars sample return missions
- Gan De (2030): Jupiter orbiter (and Callisto lander?)
- Mission to Uranus (2030s)?
- Other missions may include leaving the solar system

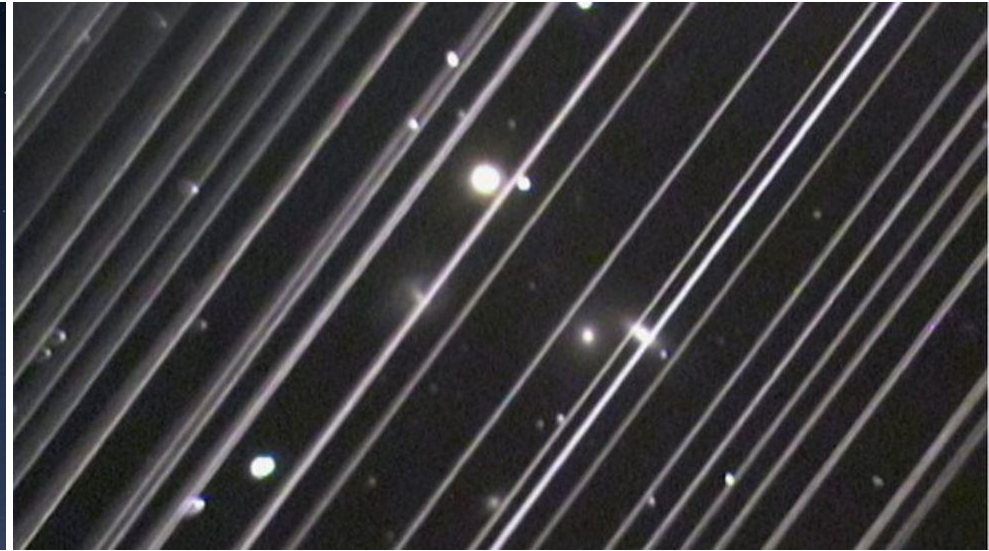
Crewed space missions

- Space Station
 - International Space Station
 - Tiangong Space Station
- Moon
 - Apollo program: Six US missions (last in 1972)
 - Chinese Lunar Exploration Program: 2030s
 - Chinese-Russian base on moon?
- Mars – 160 times further than moon at closest approach
 - US plans in mid-2030s, but unfunded
 - China plans in 2033



Constellations

- How to provide internet? Low earth orbit constellations!
(terrible for astronomy)



- Beidou (Chinese version of GPS)

Exciting decades for astronomy!

- Telescopes are expensive! Why build them?
- US and Europe are historical leaders in ground and space-based telescopes
 - FAST is best single-dish radio telescope
 - LHAASO is best cosmic-ray/gamma-ray observatory
 - Chinese Space Station Telescope will be best space-based optical telescope
- Space+launch technology: US, Europe also ahead
 - China starts out behind but is rapidly catching up
 - Should surpass the west in ~2030?