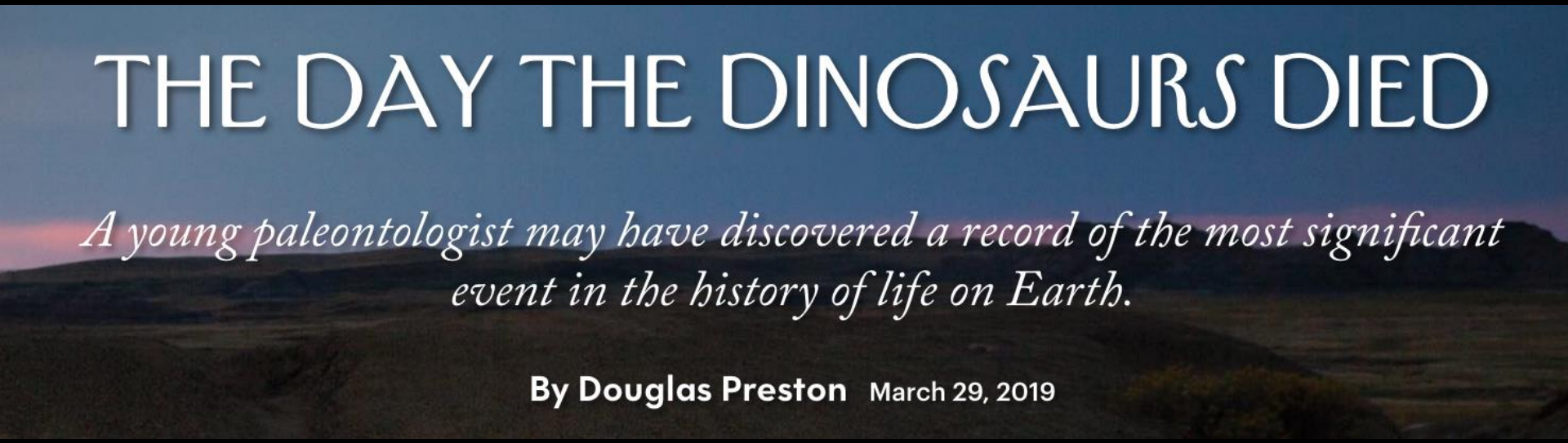
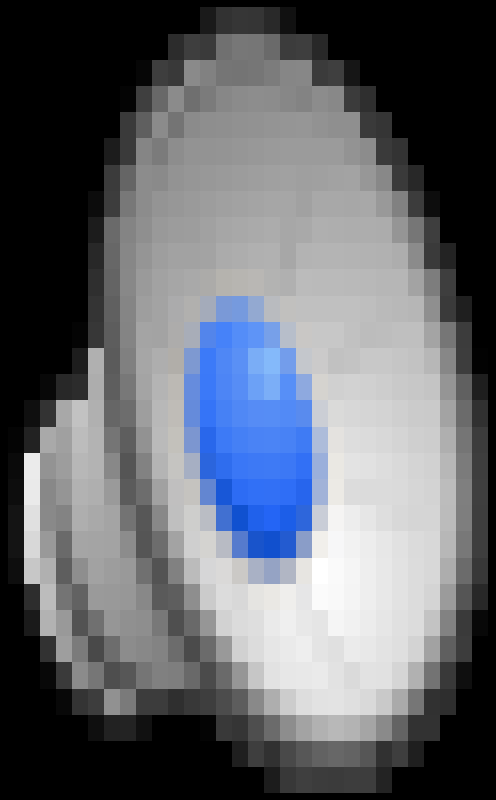
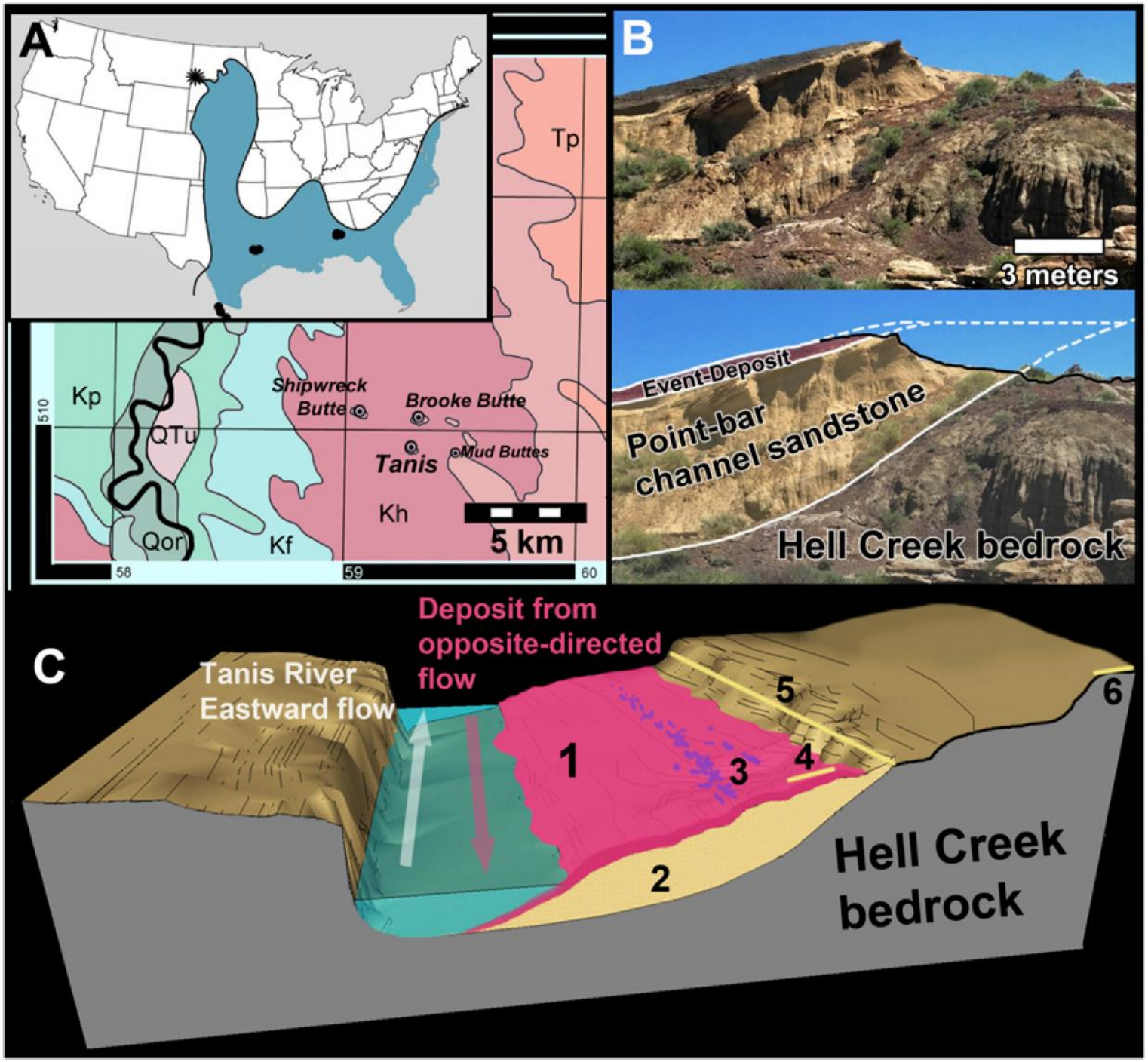
The Earth as a planet

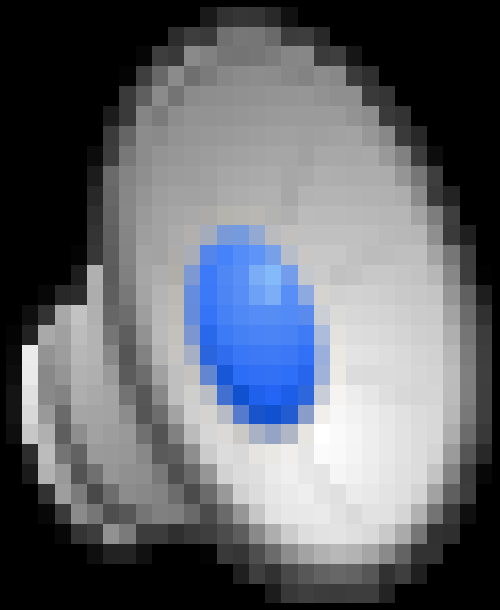


Based on a (sloppy and possibly fraudulent) paper by Robert de Palma of a fossil site in the USA




Gulf of Mexico
Chicxulub crater
Yucatán
Peninsula
Mexico

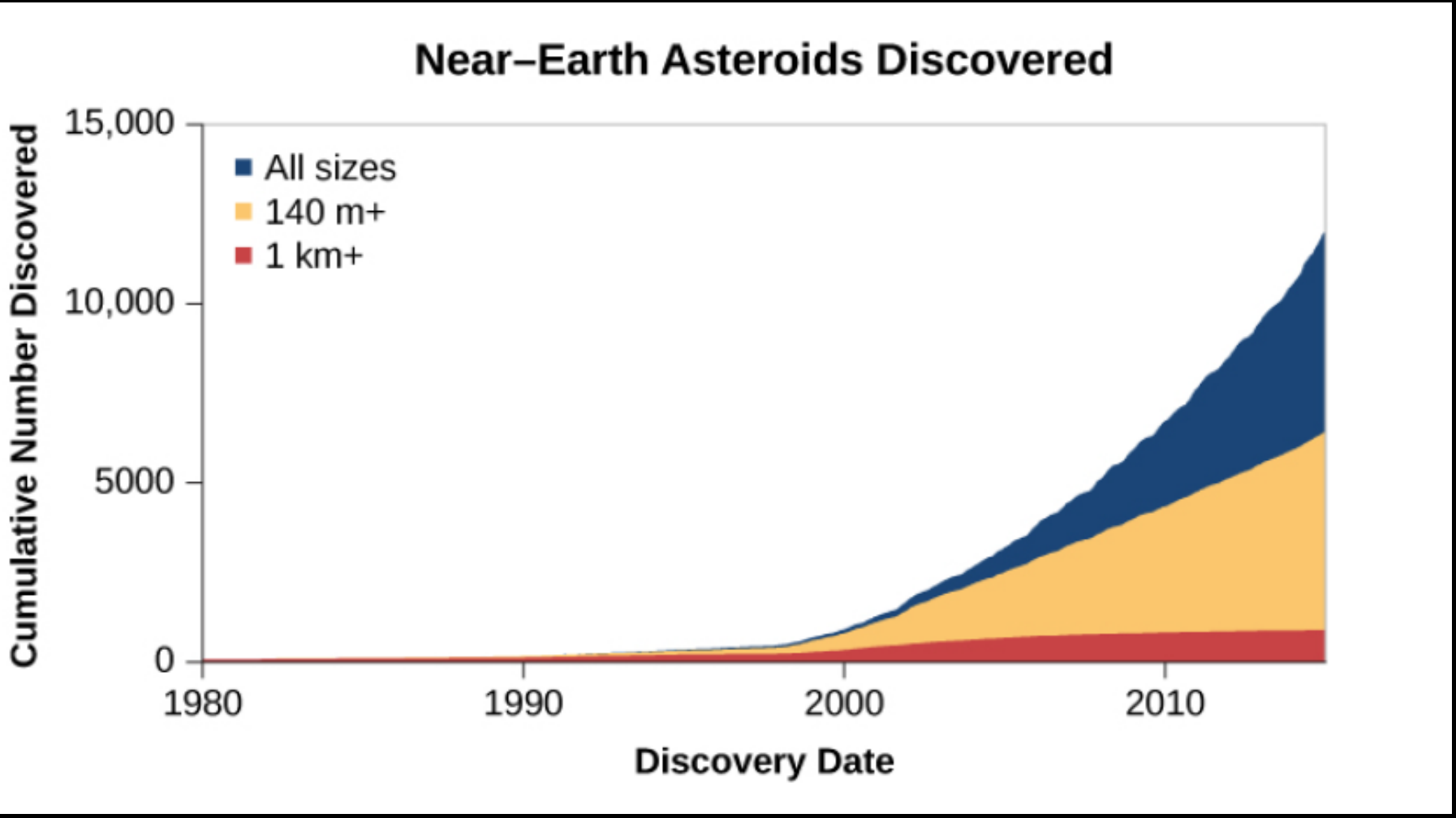

A
Tp
Kp
QTu
Qor
Kf
Kh
Shipwreck Butte
Brooke Butte
Tanis
Mud Buttes
510
58
59
60
5 km
B
3 meters
Event-Deposit
Point-bar channel sandstone
Hell Creek bedrock
C
Tanis River Eastward flow
Deposit from opposite-directed flow
1
2
3
4
5
6
Hell Creek bedrock

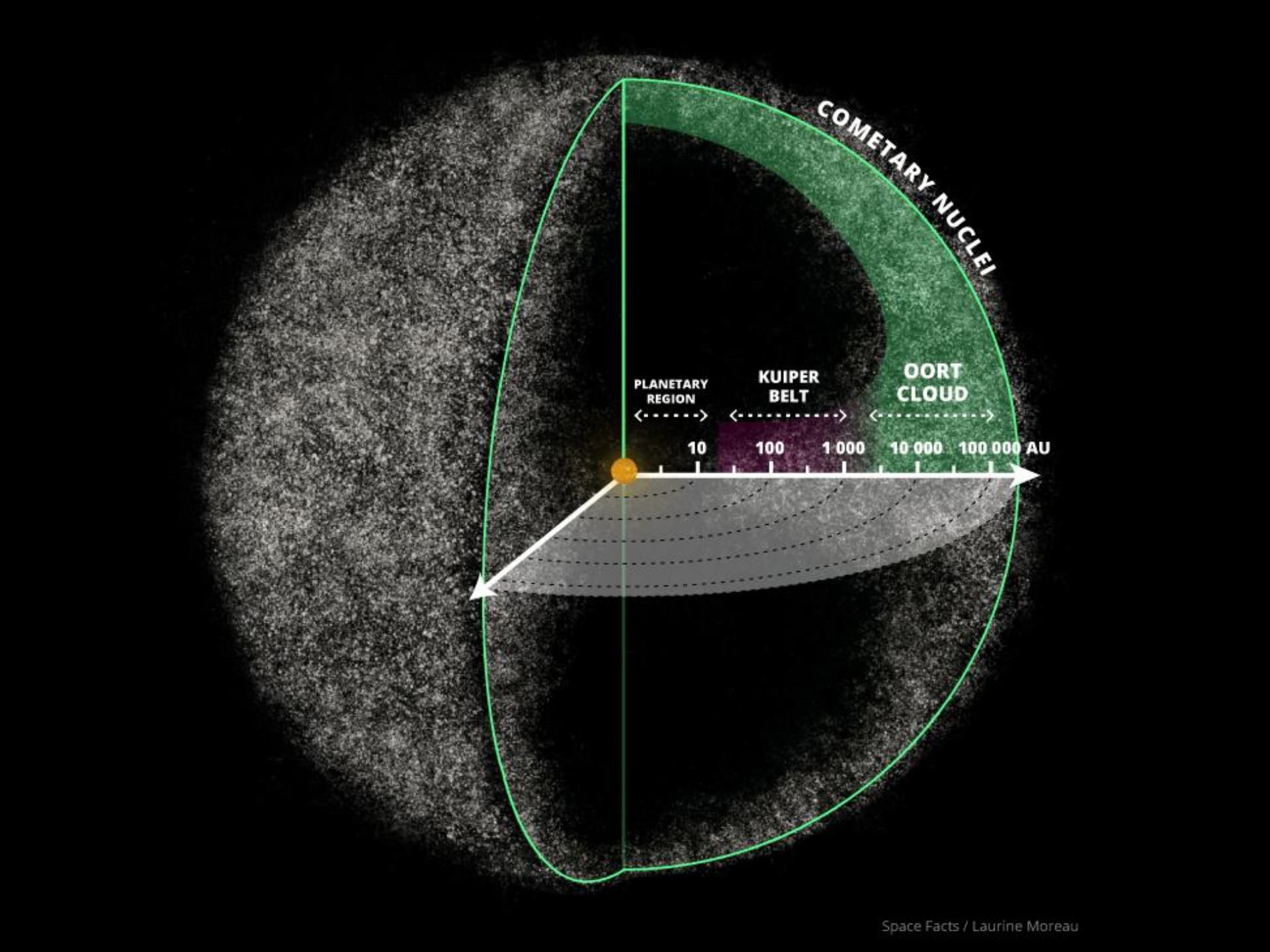



0 300 600 km
0 300 600 mi
ARCTIC OCEAN
Barents Sea
Bering Sea
Sea of Okhotsk
NORTH PACIFIC OCEAN
Black Sea
Caspian Sea
Aral Sea
Lake Baikal
Providenlya
Anadyr'
Kaliningrad
Murmansk
Vyborg
Petrozavodsk
Saint Petersburg
Arkhangel'sk
MOSCOW
Nizhniy Novgorod
Kazan'
Rostov
Novorossiysk
Volgograd
Tuapse
Sochi
Astrakhan'
Yekaterinburg
Chelyabinsk
Omsk
Novosibirsk
Krasnoyarsk
Irkutsk
Noril'sk
Yakutsk
Magadan
Petropavlovsk-Kamchatskiy
Khabarovsk
Kholmsk
Nevel'sk
Nakhodka
Vostochnyy
Vladivostok
Tunguska Event
SIBERIA
URAL MTS
CAUCASUS MTS
KAZAKHSTAN
CHINA
JAPAN
MONGOLIA
N. KOR.
KURIL ISLANDS
UKRAINE
BELARUS
POLAND
FIN.
SWE.
NOR.
GER.
IRAN
U.S.
U.S.S.R.

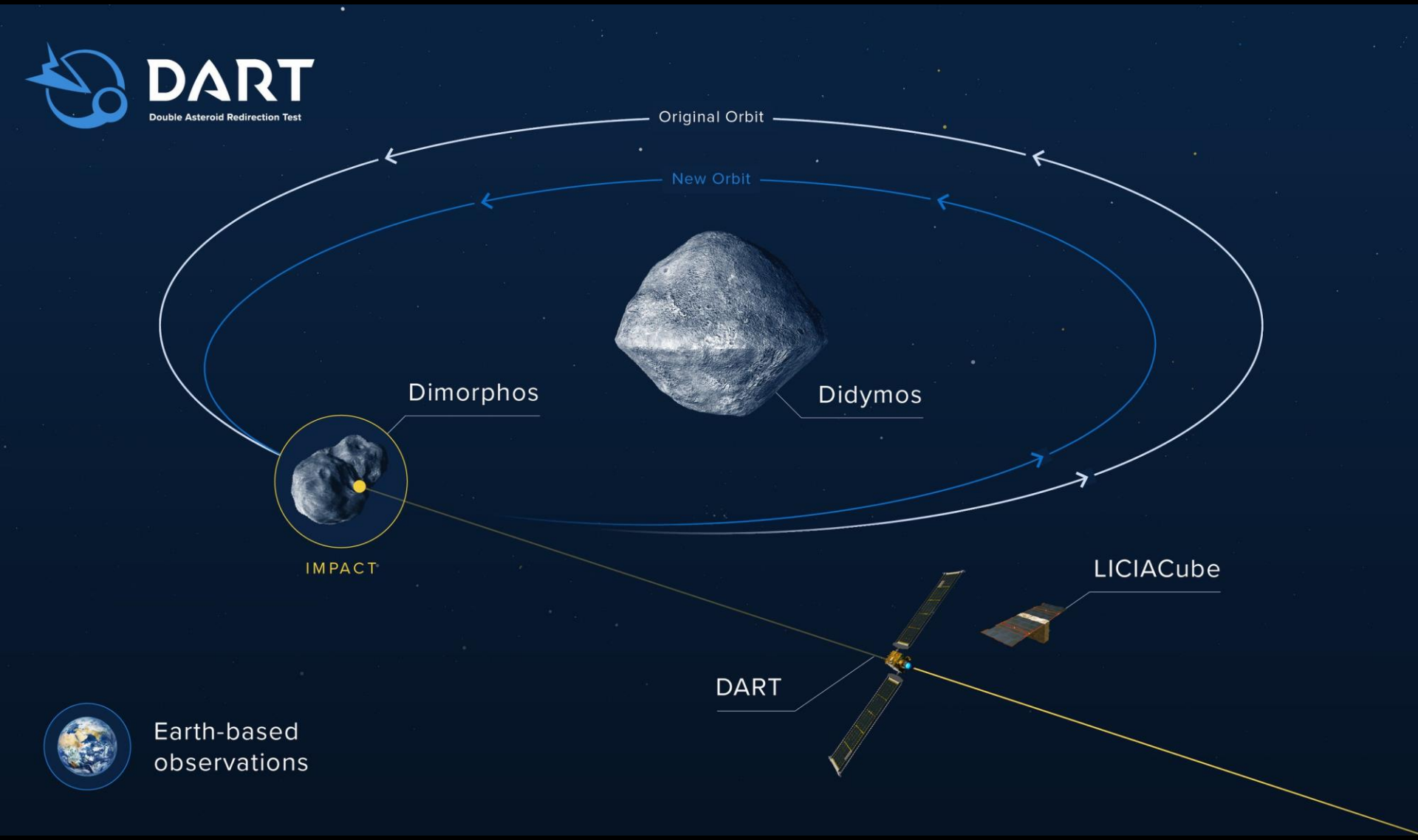
Tunguska event (Siberia, Russia, 1908) trees knocked down across 2000 km^2!

Photo from 1929

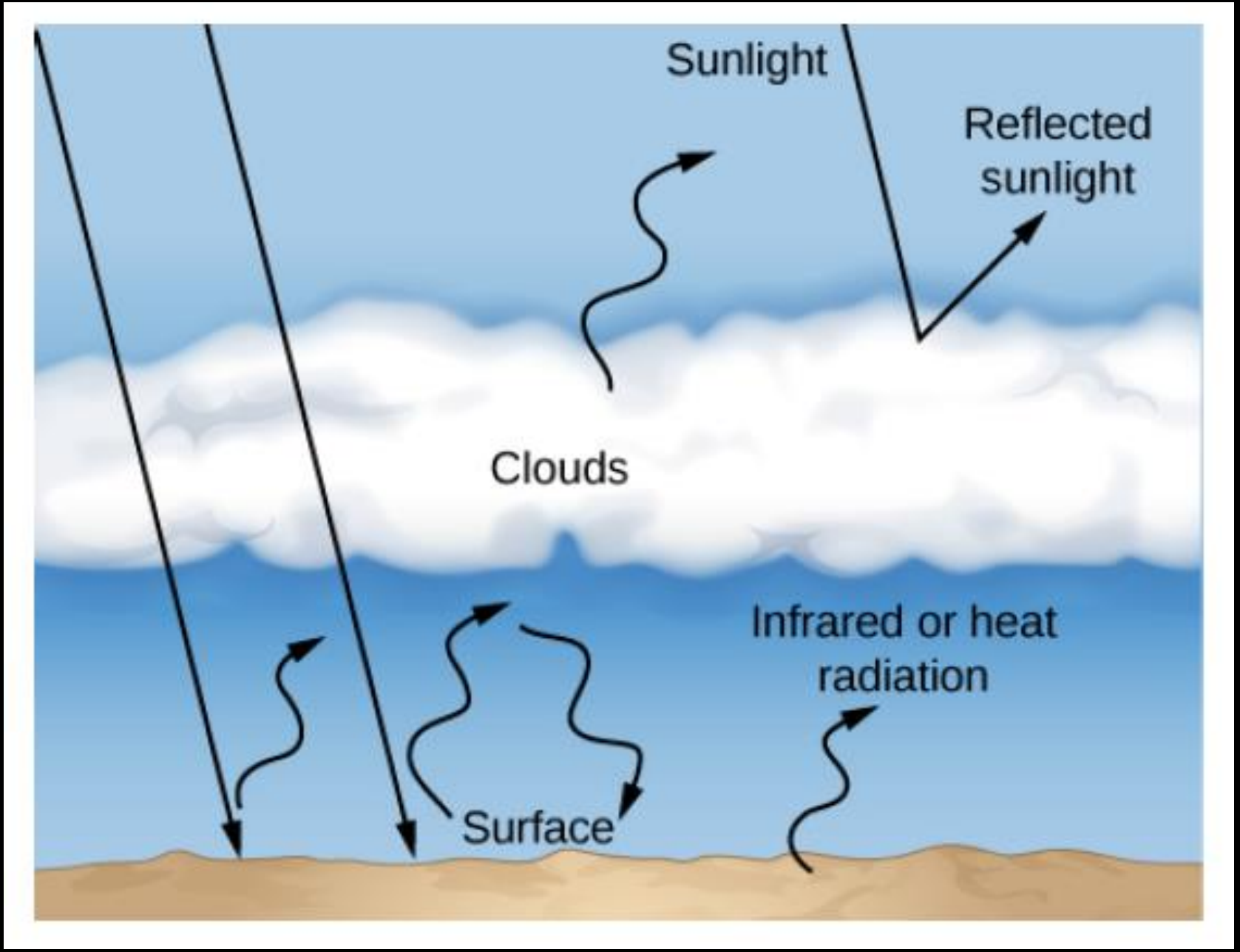

Near–Earth Asteroids Discovered
Cumulative Number Discovered
15,000
10,000
5000
0
All sizes
140 m+
1 km+
1980
1990
2000
2010
Discovery Date

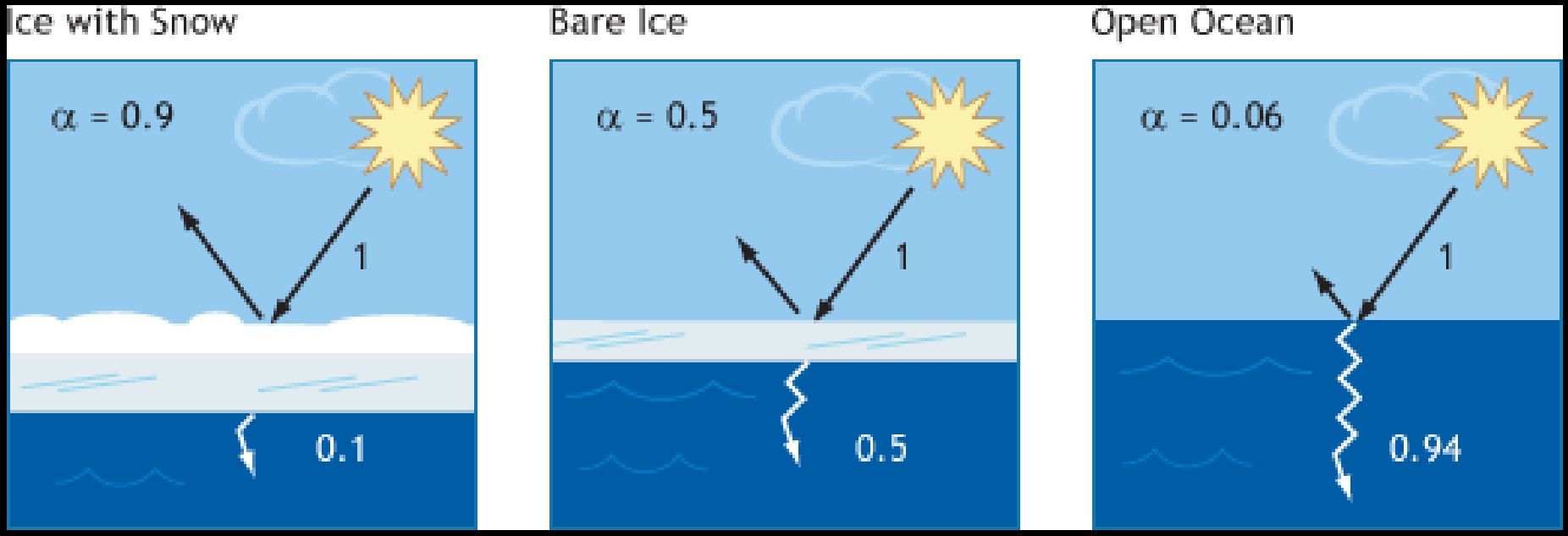


Space Facts / Laurine Moreau


DART
Double Asteroid Redirection Test
Original Orbit
New Orbit
Dimorphos
Didymos
IMPACT
LICIACube
DART
Earth-based
observations

The Greenhouse effect

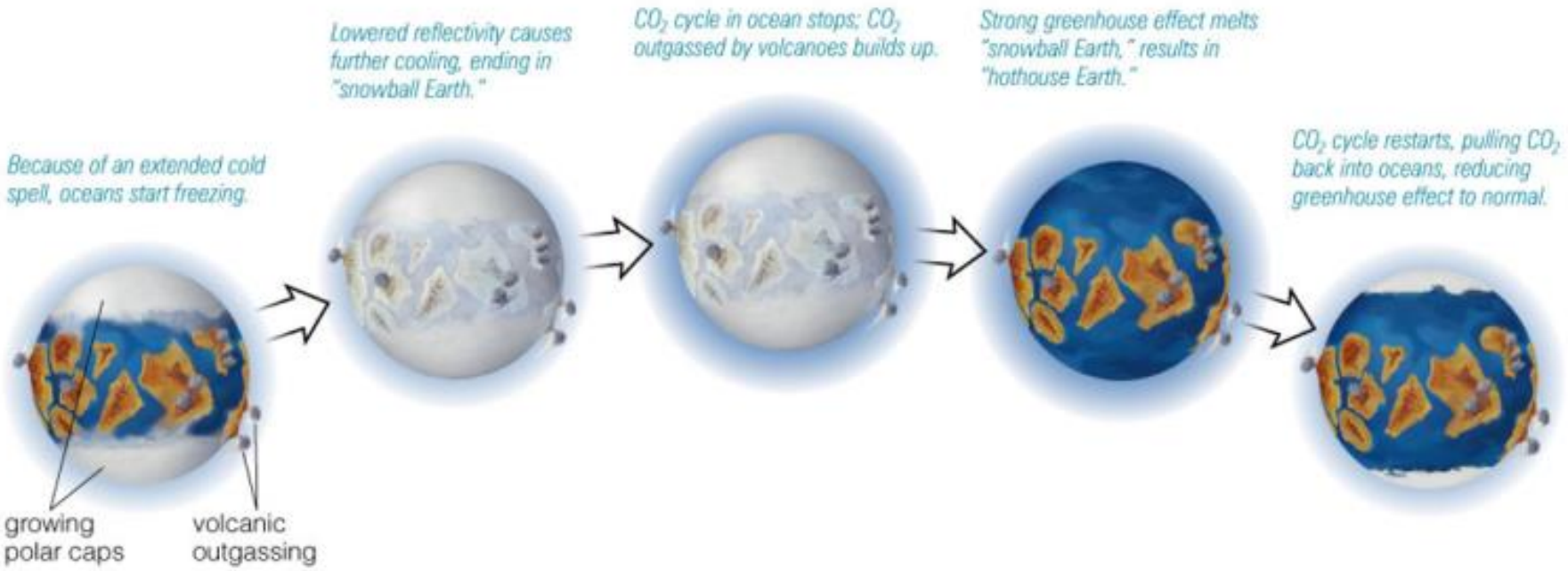


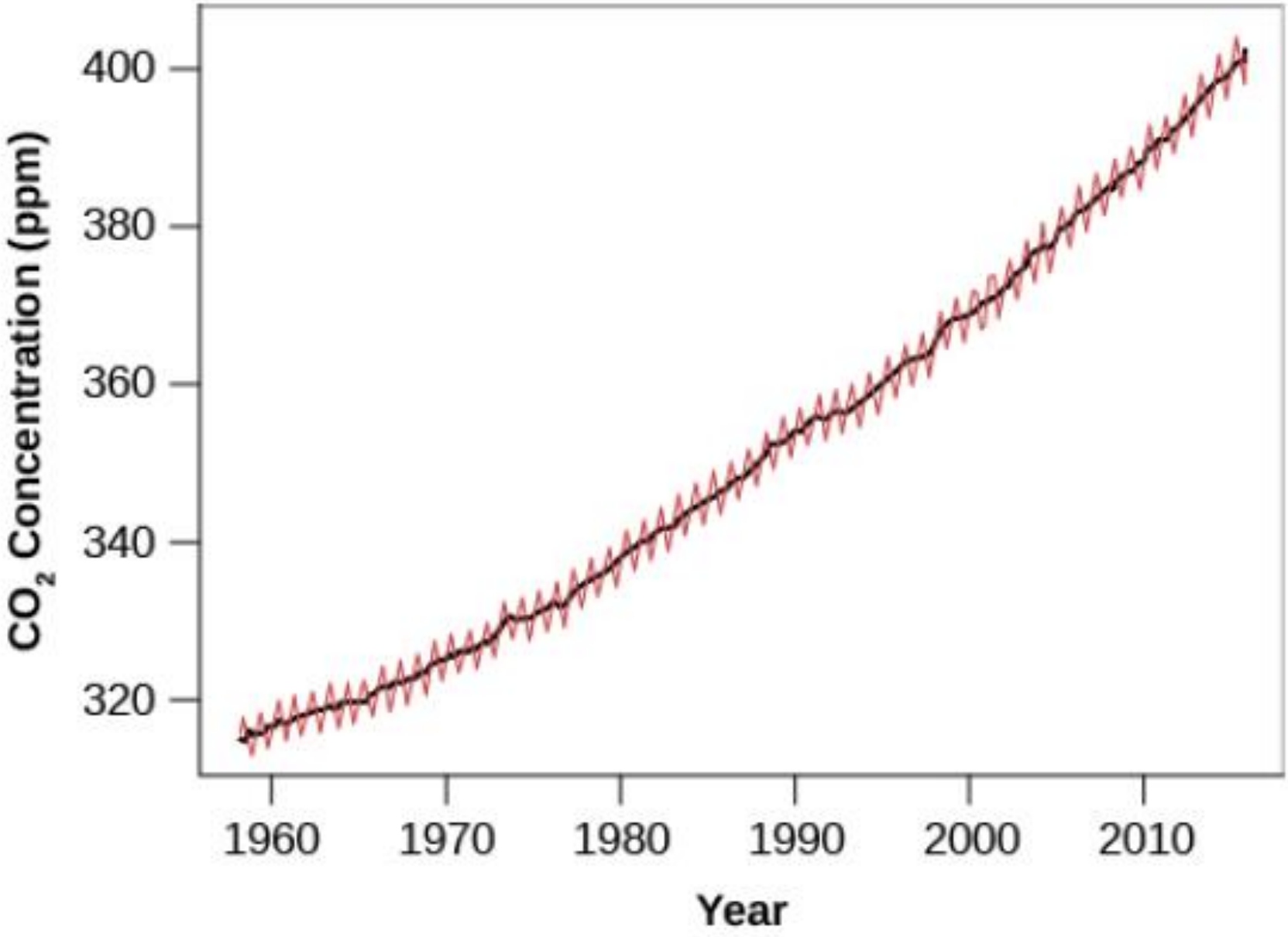


α: albedo = reflectance

Ice (and clouds) reflects energy = cooler planet

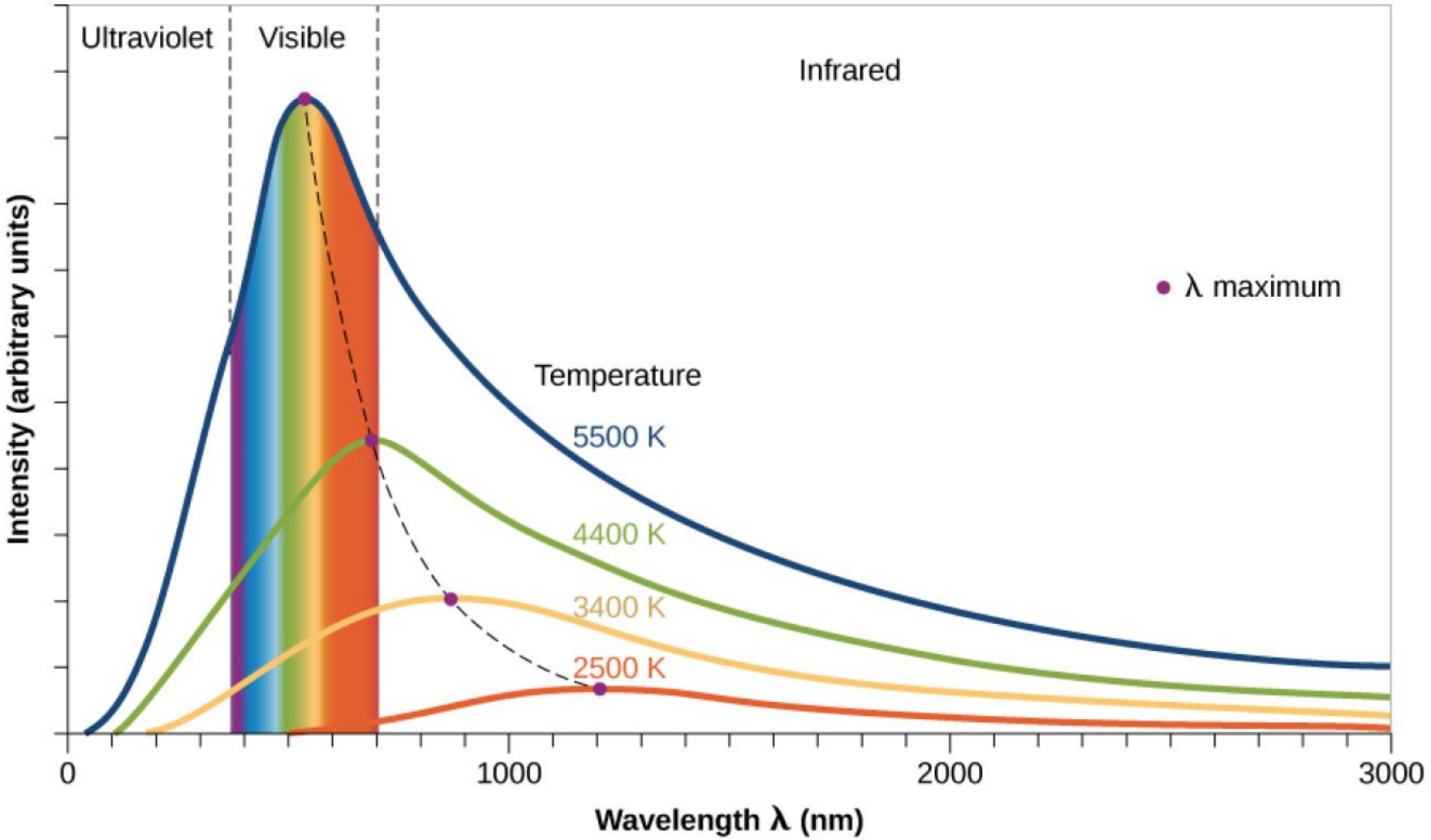
Five Stages of "Snowball" Earth



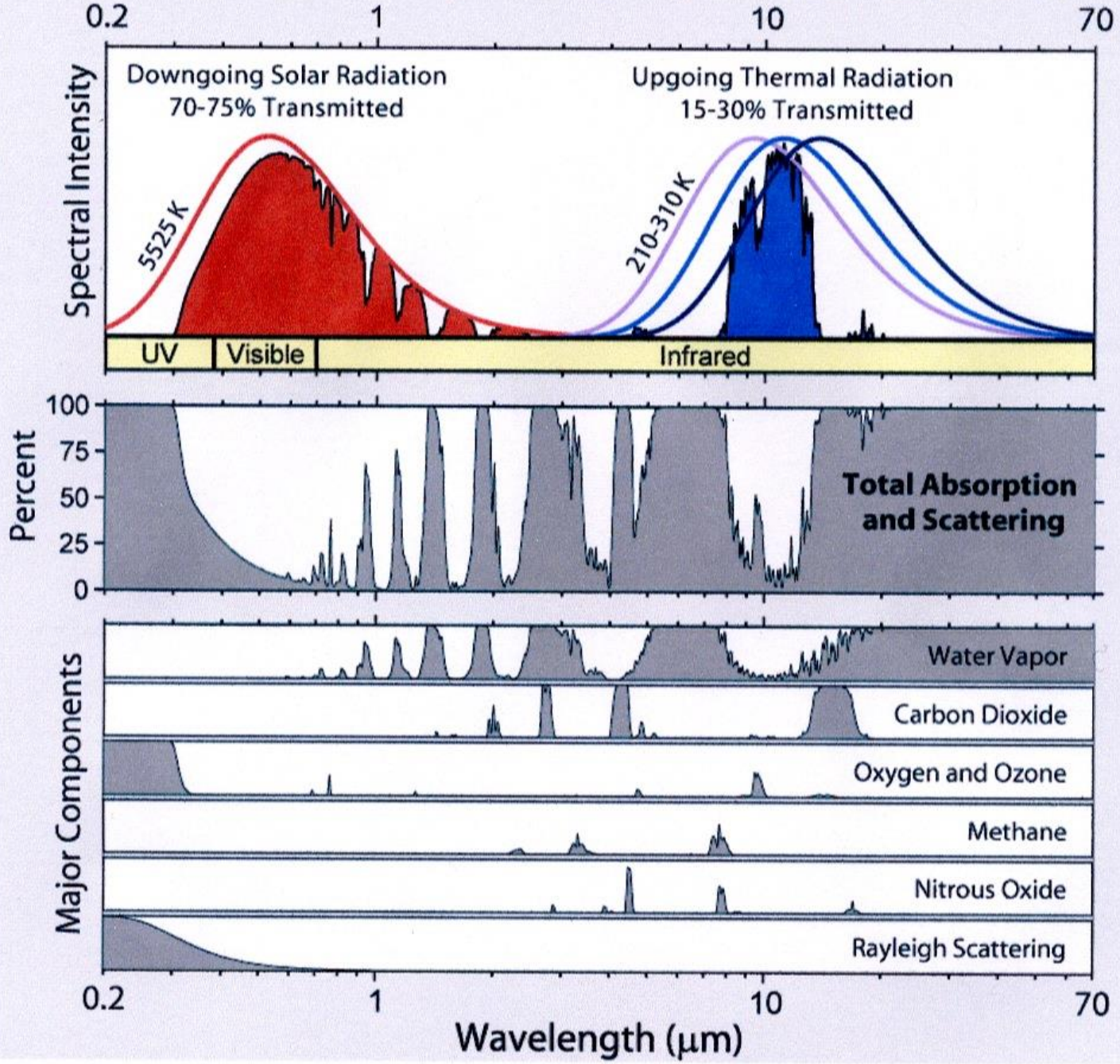

400
380
360
340
320
CO_2 Concentration (ppm)
1960
1970
1980
1990
2000
2010
Year

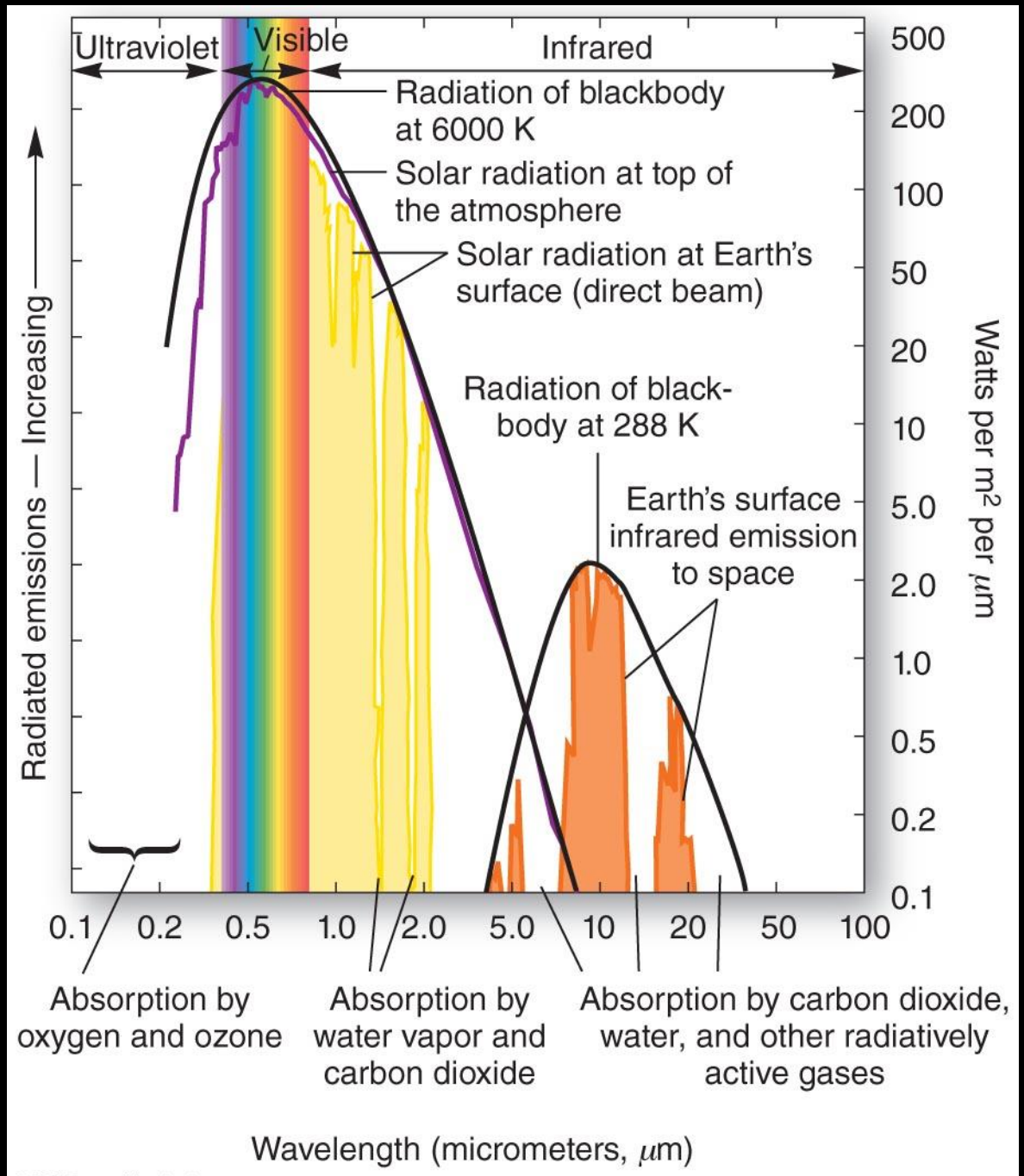
Blackbody emission: hotter things emit at higher energies (=shorter wavelengths)

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



Radiation Transmitted by the Atmosphere





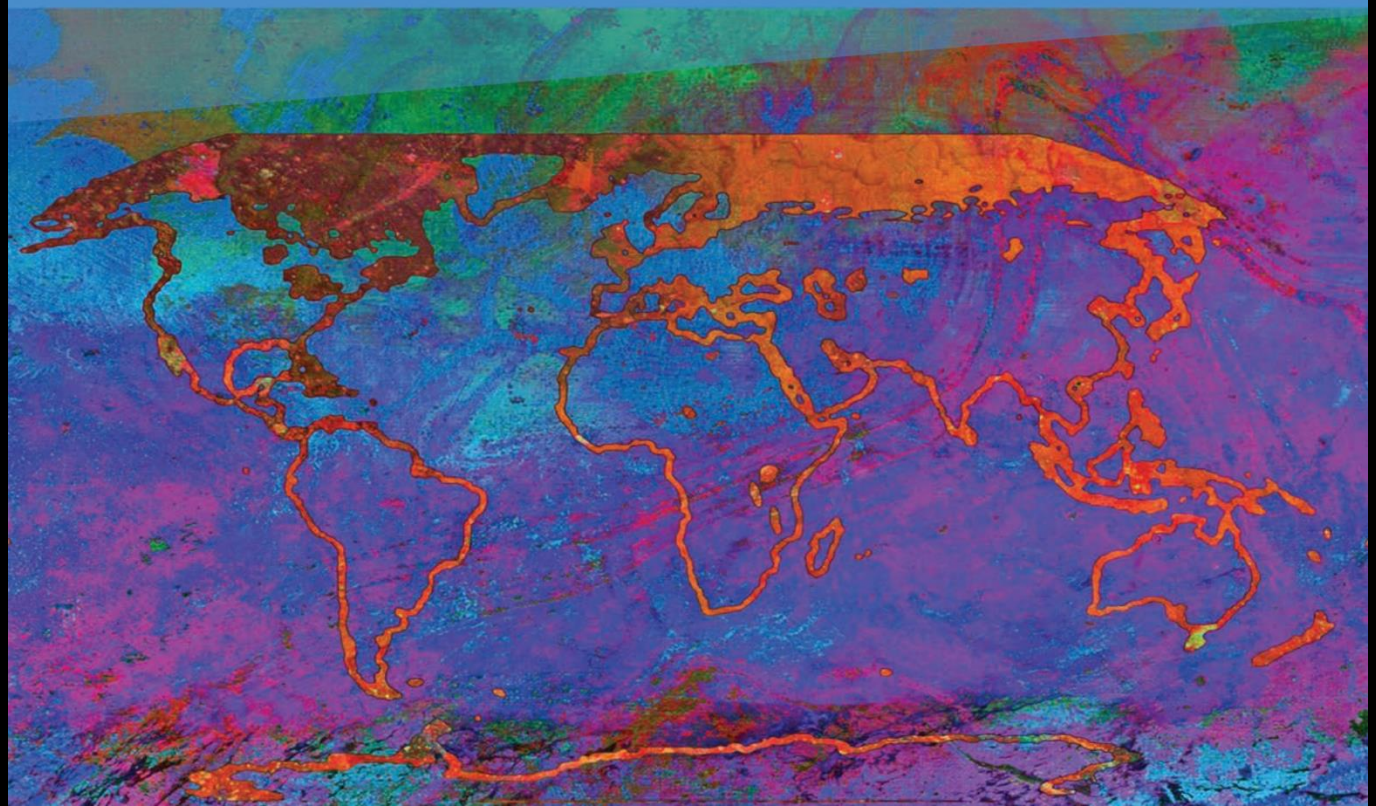
ipcc

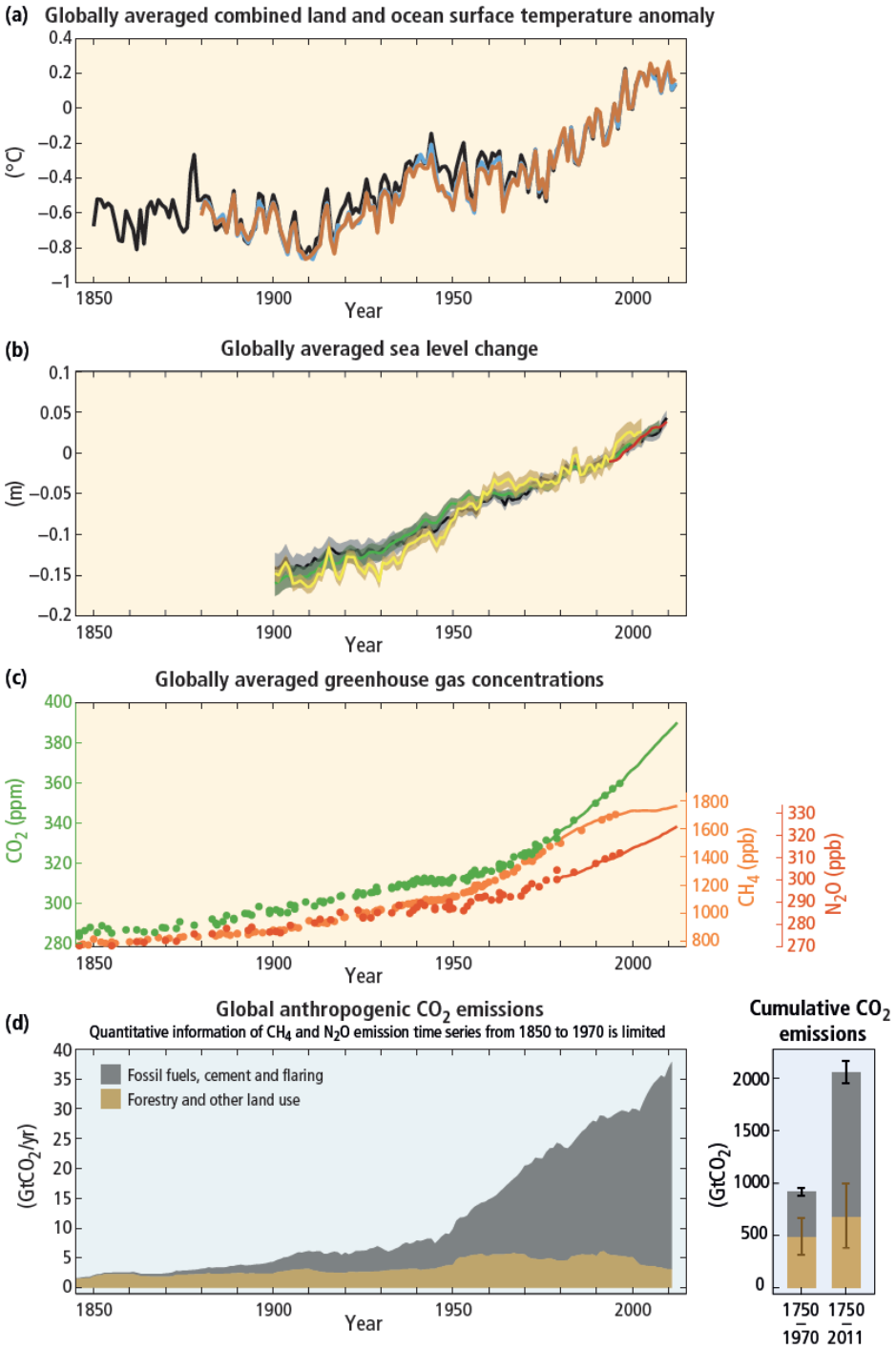
INTERGOVERNMENTAL PANEL ON climate change

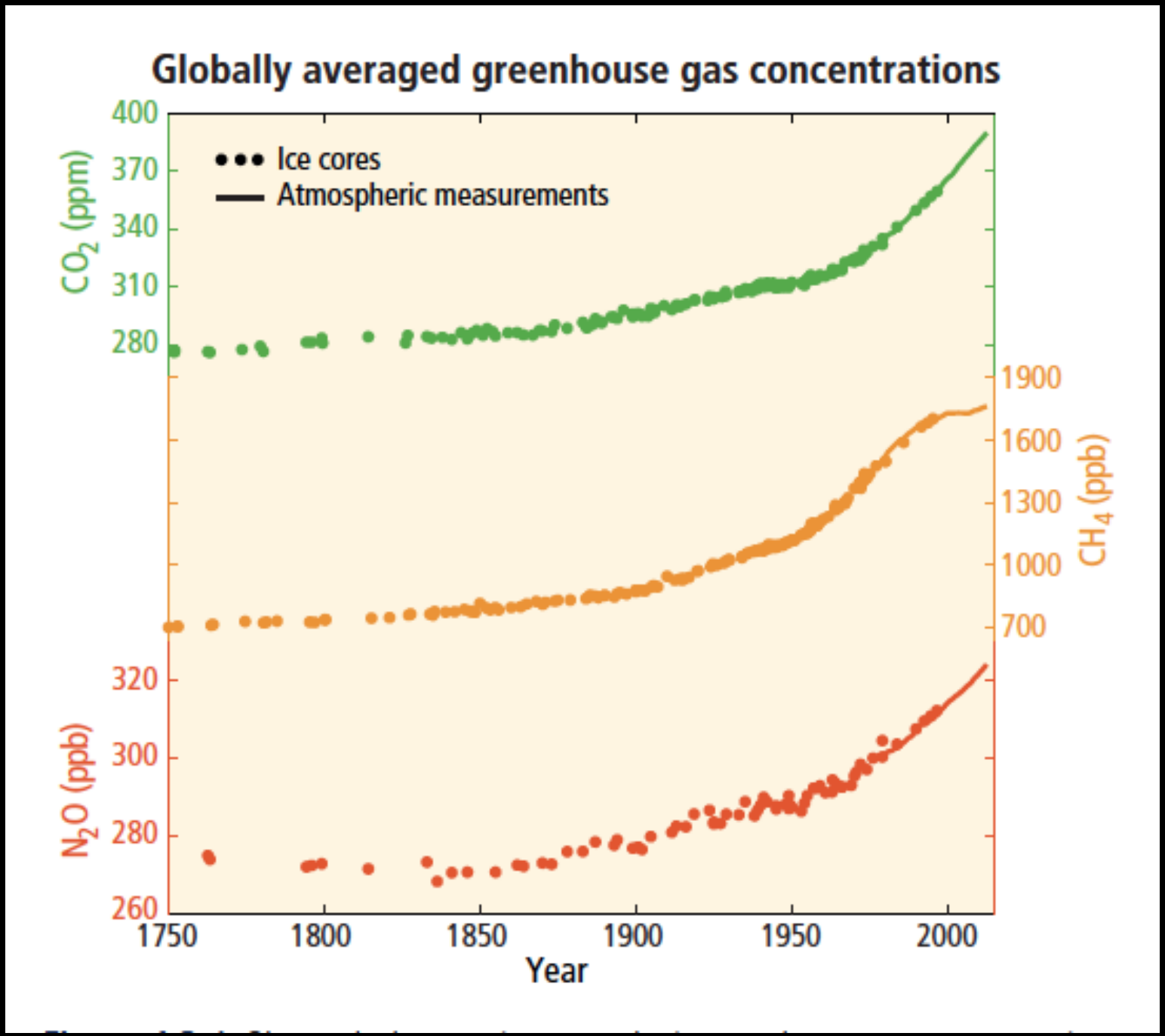
Climate Change 2021

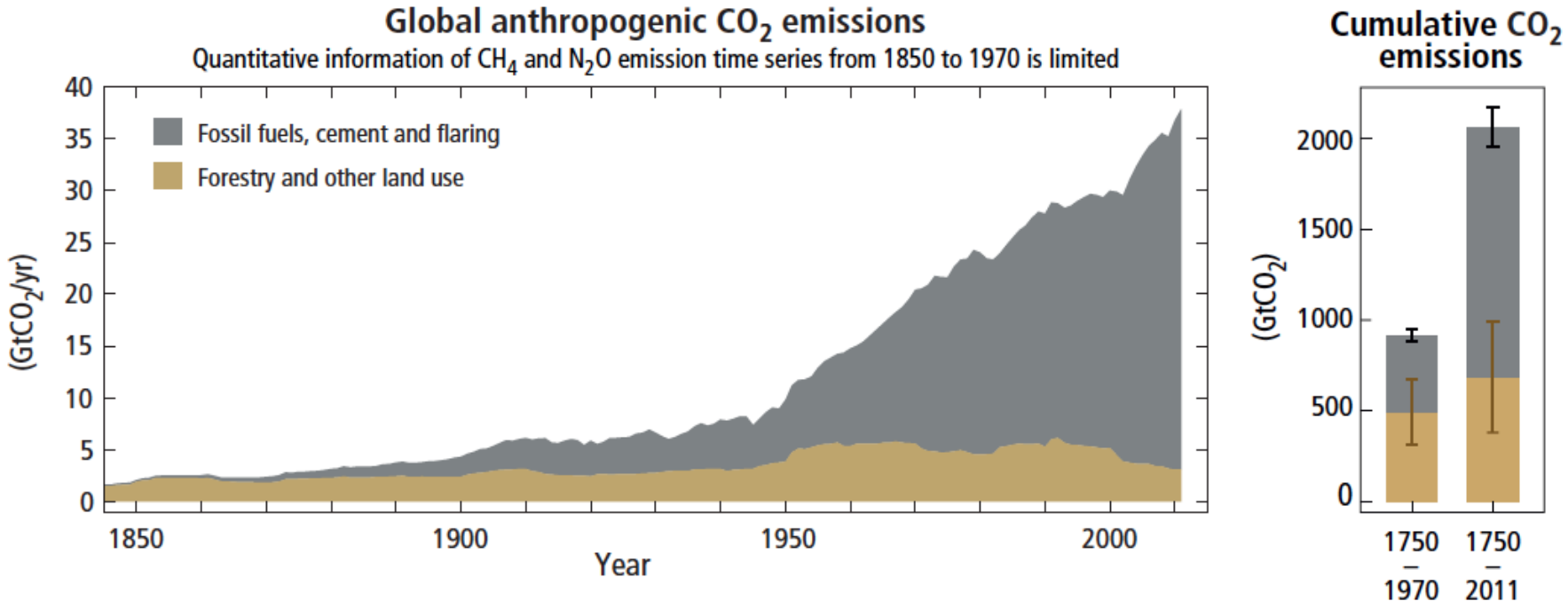
The Physical Science Basis

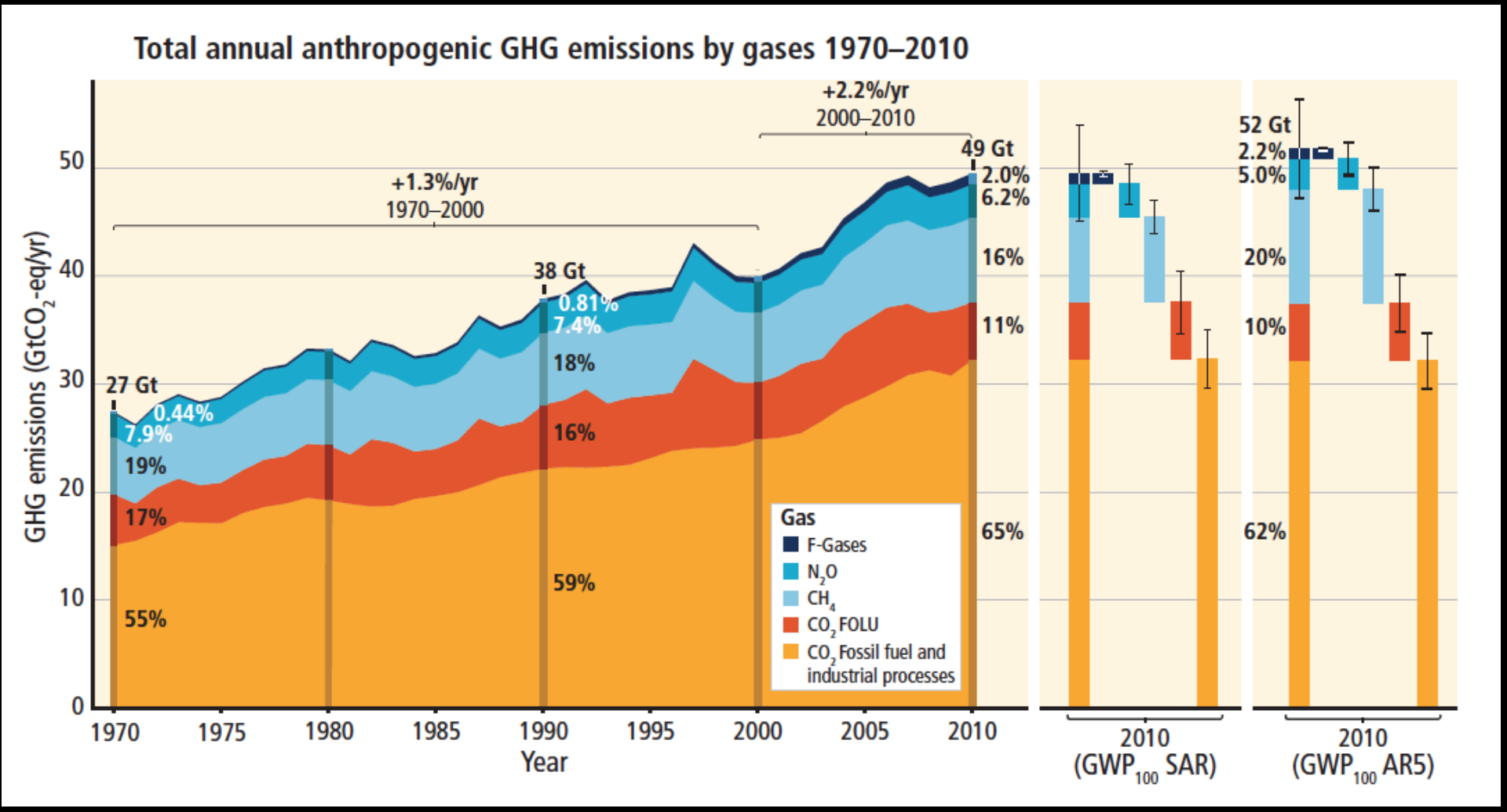
Summary for Policymakers

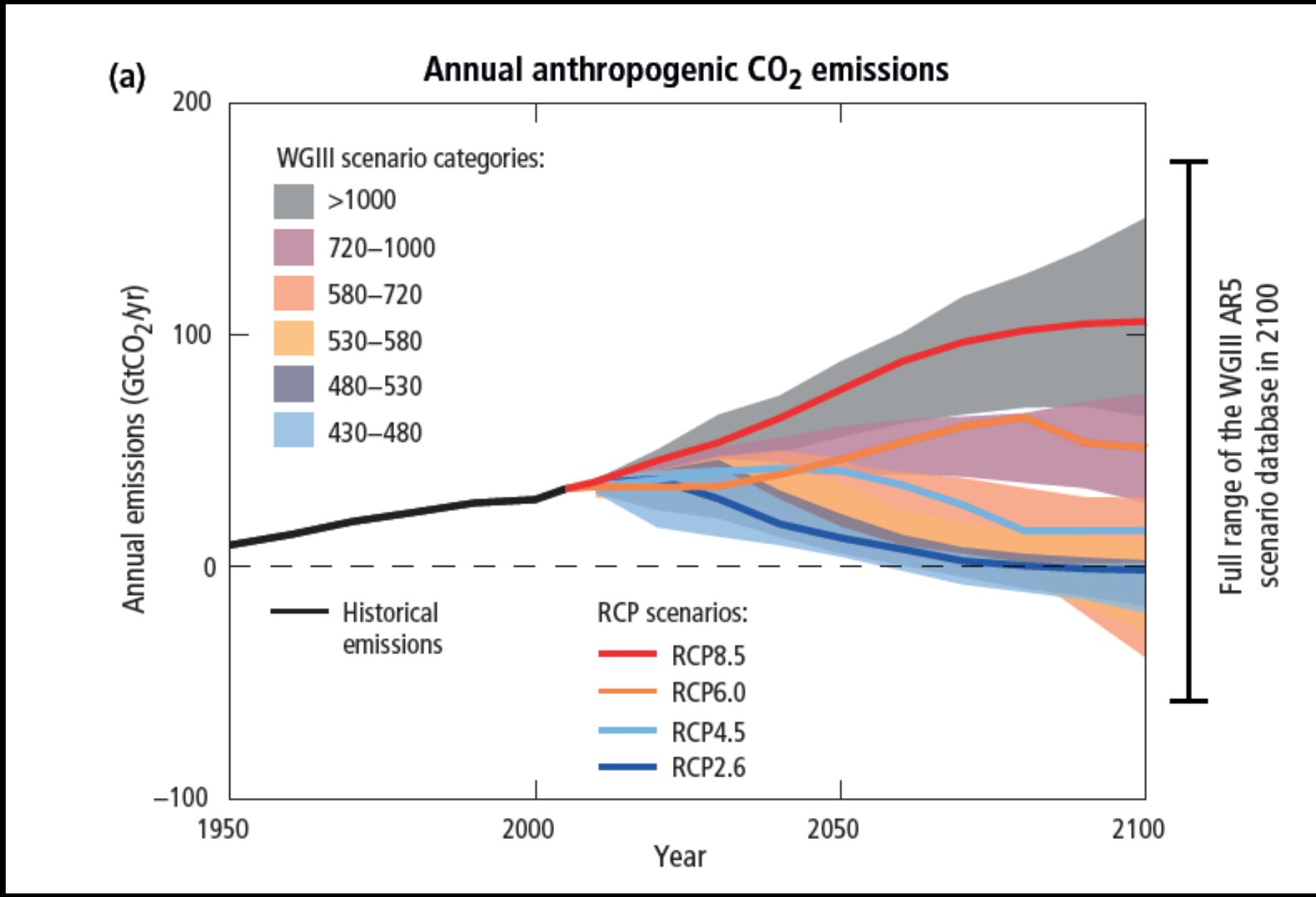


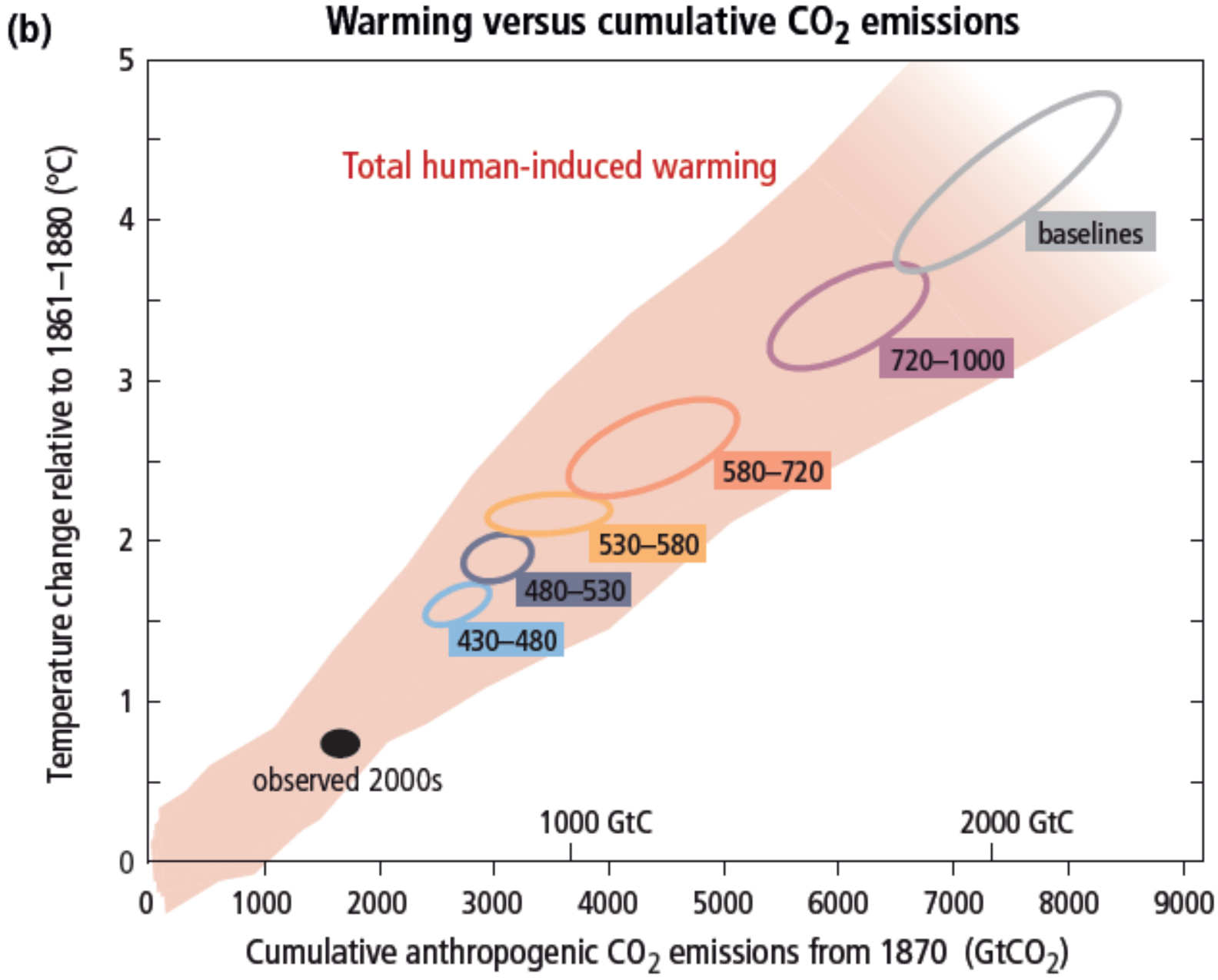

(a) Globally averaged combined land and ocean surface temperature anomaly
(°C)
0.4
0.2
0
−0.2
−0.4
−0.6
−0.8
−1
1850
1900
1950
2000
Year
(b) Globally averaged sea level change
(m)
0.1
0.05
0
−0.05
−0.1
−0.15
−0.2
1850
1900
1950
2000
Year
(c) Globally averaged greenhouse gas concentrations
CO2 (ppm)
400
380
360
340
320
300
280
CH4 (ppb)
1800
1600
1400
1200
1000
800
N2O (ppb)
330
320
310
300
290
280
270
1850
1900
1950
2000
Year
(d) Global anthropogenic CO2 emissions
Quantitative information of CH4 and N2O emission time series from 1850 to 1970 is limited
Fossil fuels, cement and flaring
Forestry and other land use
(GtCO2/yr)
40
35
30
25
20
15
10
5
0
1850
1900
1950
2000
Year
Cumulative CO2 emissions
(GtCO2)
2000
1500
1000
500
0
1750–1970
1750–2011

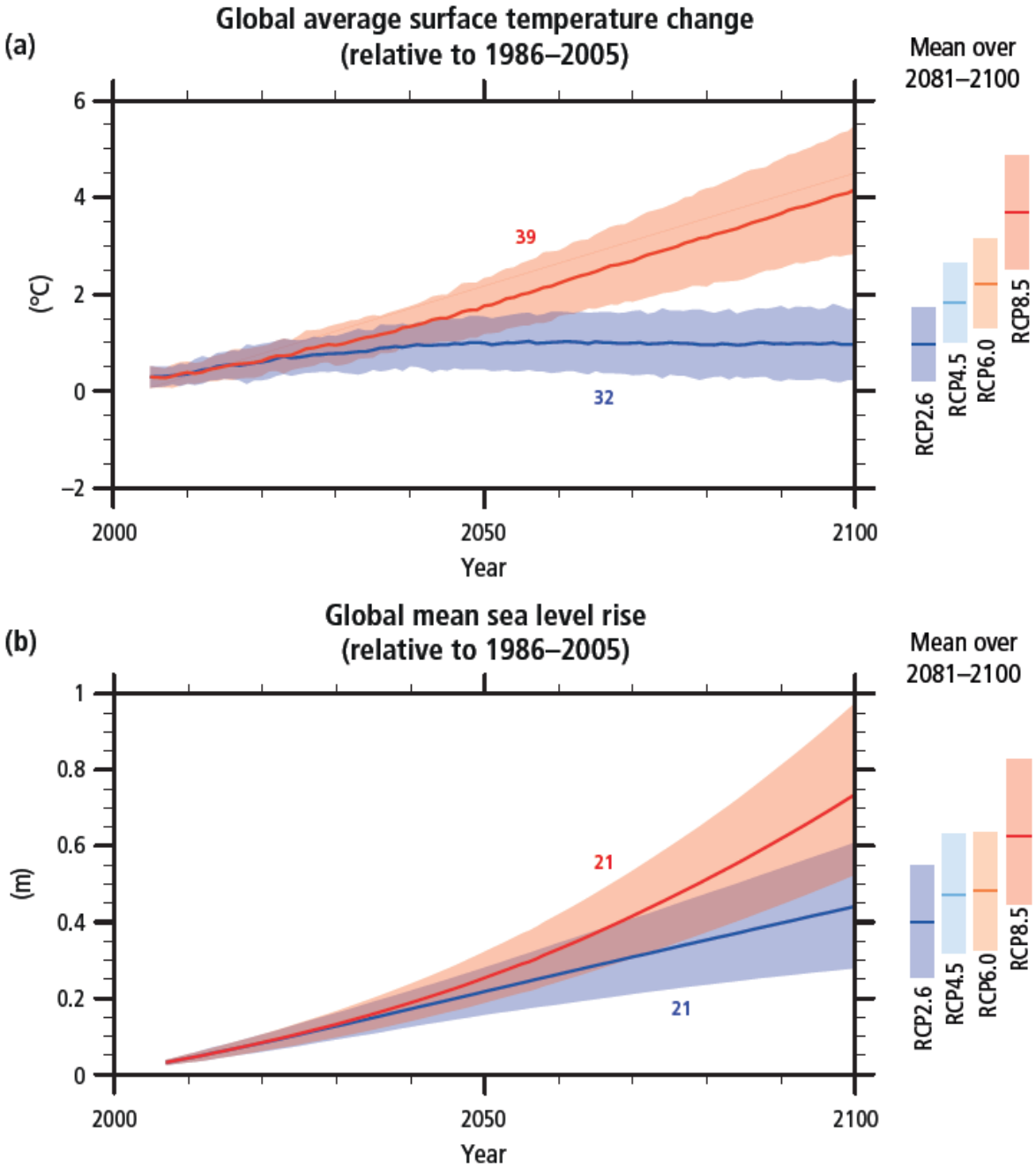

Globally averaged greenhouse gas concentrations
Ice cores
Atmospheric measurements
CO_2 (ppm)
400
370
340
310
280
CH_4 (ppb)
1900
1600
1300
1000
700
N_2O (ppb)
320
300
280
260
1750
1800
1850
1900
1950
2000
Year


Global anthropogenic CO_2 emissions
Quantitative information of CH_4 and N_2O emission time series from 1850 to 1970 is limited
Fossil fuels, cement and flaring
Forestry and other land use
$(GtCO_2/yr)$
40
35
30
25
20
15
10
5
0
1850
1900
1950
2000
Year
Cumulative CO_2 emissions
$(GtCO_2)$
2000
1500
1000
500
0
1750 – 1970
1750 – 2011

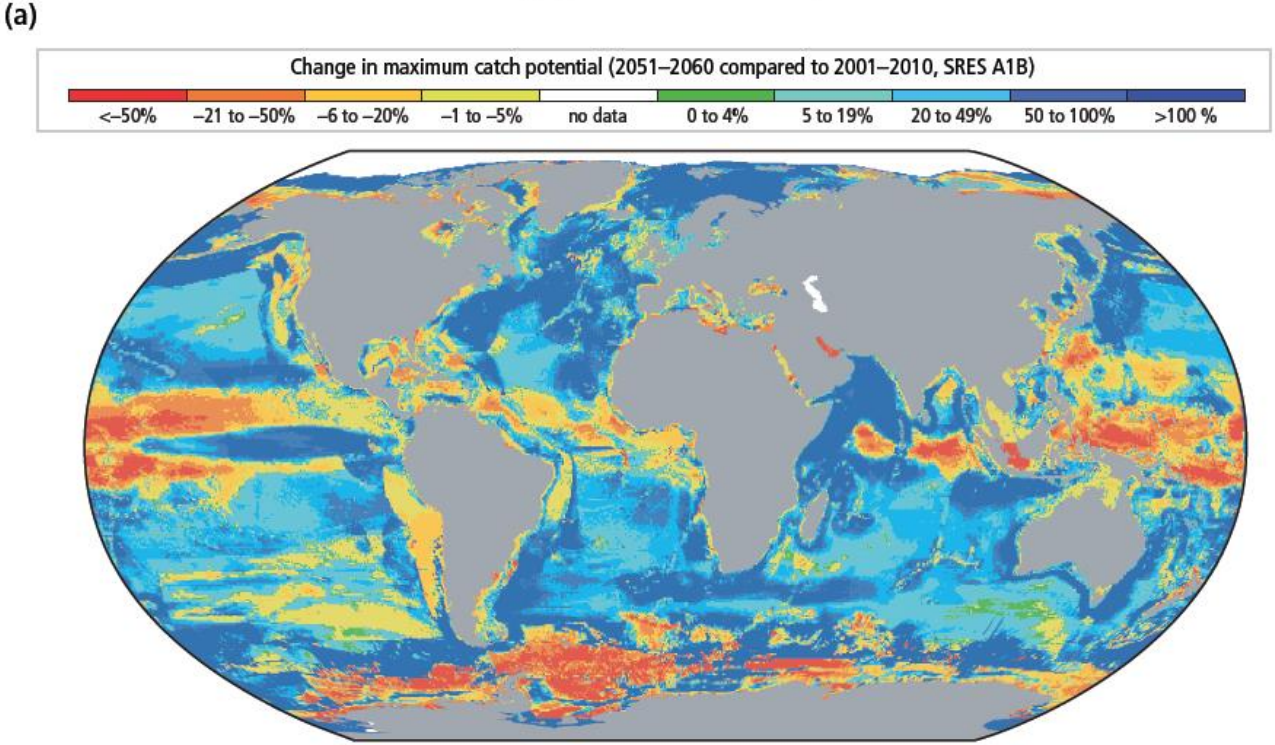

Total annual anthropogenic GHG emissions by gases 1970–2010
GHG emissions (GtCO2-eq/yr)
+2.2%/yr
2000–2010
+1.3%/yr
1970–2000
49 Gt
38 Gt
27 Gt
2.0%
6.2%
16%
11%
65%
0.81%
7.4%
18%
16%
59%
0.44%
7.9%
19%
17%
55%
Gas
F-Gases
N2O
CH4
CO2 FOLU
CO2 Fossil fuel and industrial processes
Year
52 Gt
2.2%
5.0%
20%
10%
62%
2010 (GWP100 SAR)
2010 (GWP100 AR5)

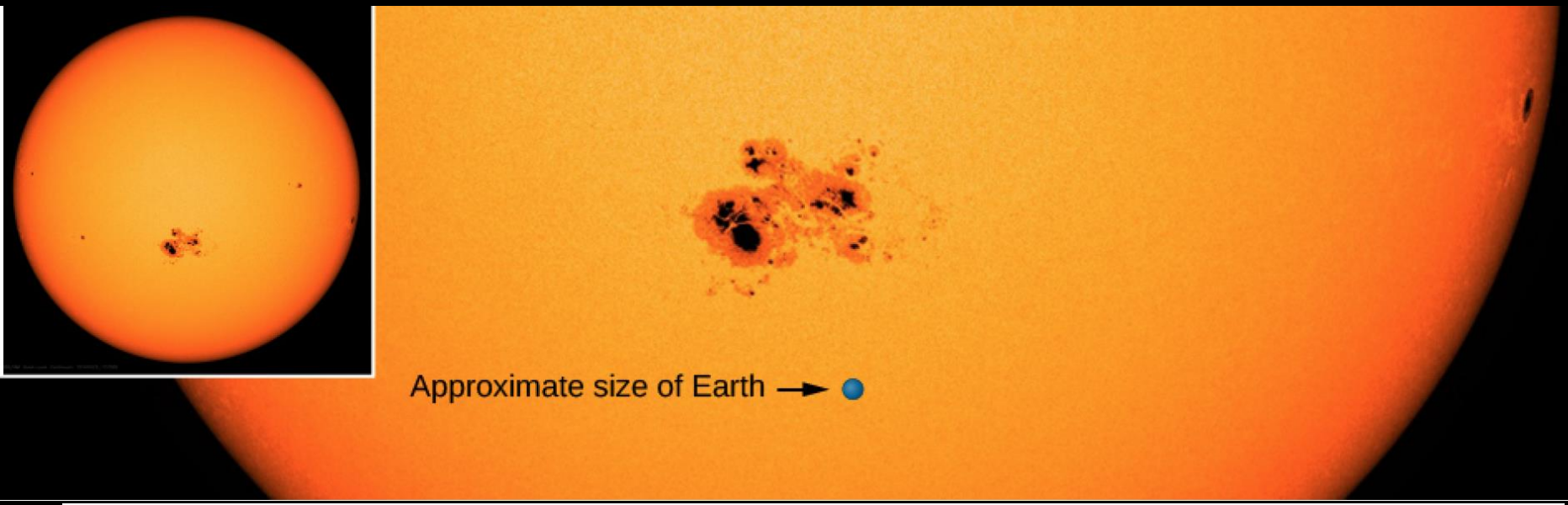

(a)
Annual anthropogenic CO_2 emissions
Annual emissions ($GtCO_2$/yr)
200
100
0
−100
1950
2000
2050
2100
Year
WGIII scenario categories:
>1000
720–1000
580–720
530–580
480–530
430–480
Historical emissions
RCP scenarios:
RCP8.5
RCP6.0
RCP4.5
RCP2.6
Full range of the WGIII AR5 scenario database in 2100

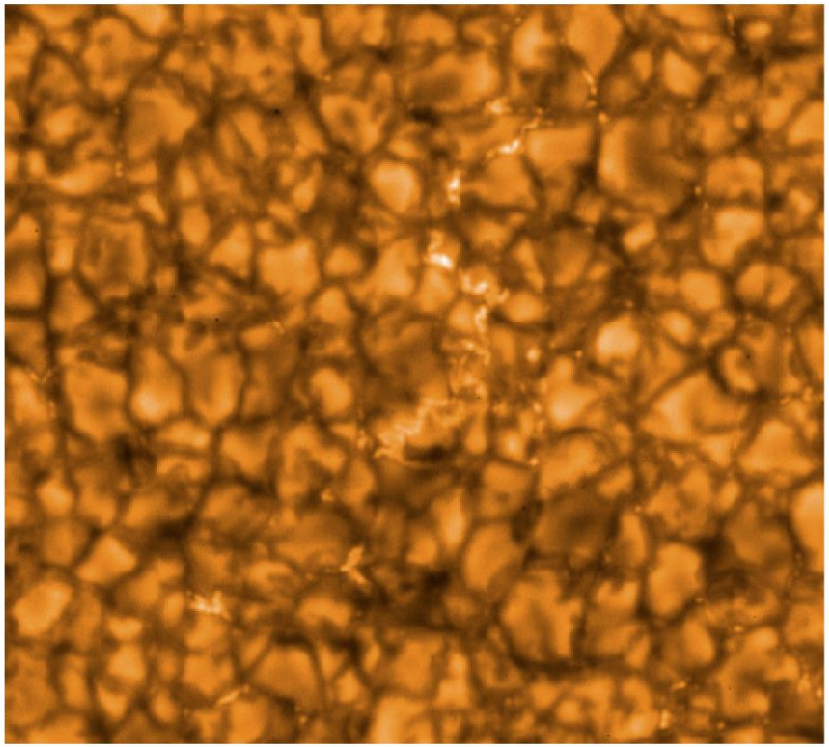

(b)
Warming versus cumulative CO_2 emissions
Total human-induced warming
baselines
720–1000
580–720
530–580
480–530
430–480
observed 2000s
1000 GtC
2000 GtC
Temperature change relative to 1861–1880 (°C)
Cumulative anthropogenic CO_2 emissions from 1870 ($GtCO_2$)
0
1
2
3
4
5
0
1000
2000
3000
4000
5000
6000
7000
8000
9000

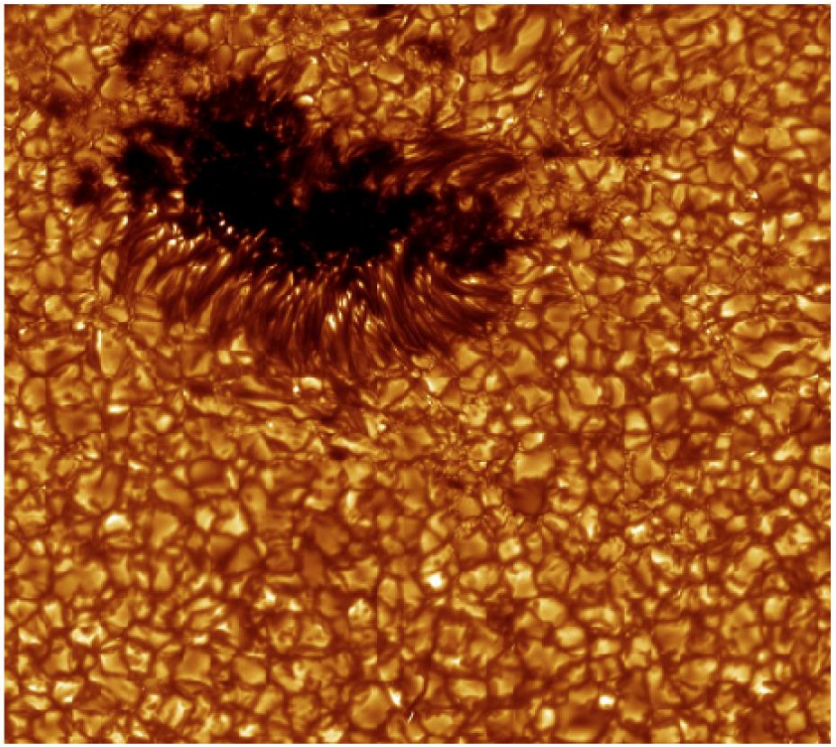

(a)
Global average surface temperature change
(relative to 1986–2005)
Mean over
2081–2100
6
4
2
0
–2
(°C)
39
32
2000
2050
2100
Year
RCP2.6
RCP4.5
RCP6.0
RCP8.5
(b)
Global mean sea level rise
(relative to 1986–2005)
Mean over
2081–2100
1
0.8
0.6
0.4
0.2
0
(m)
21
21
2000
2050
2100
Year
RCP2.6
RCP4.5
RCP6.0
RCP8.5

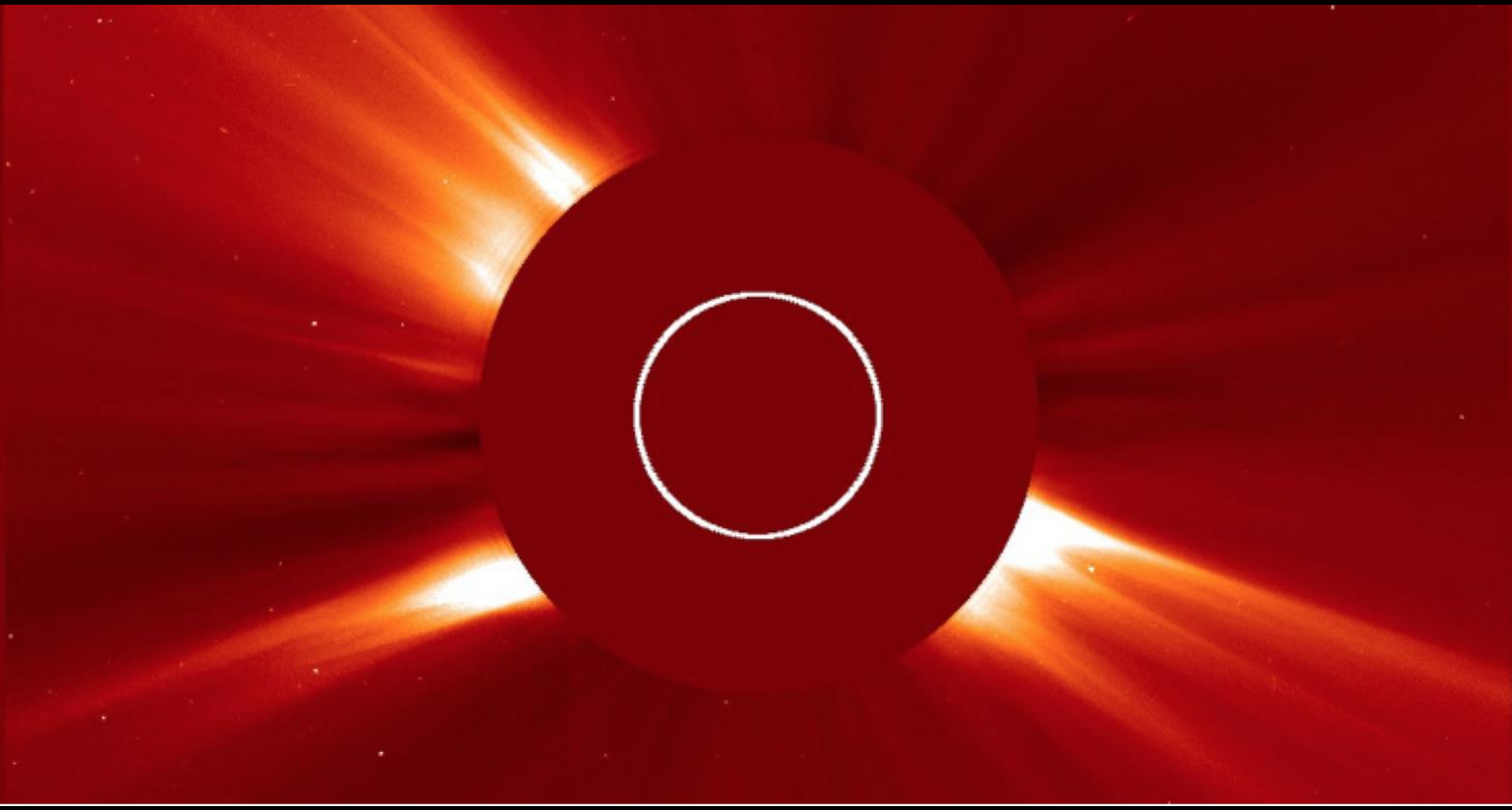
Climate change poses risks for food production

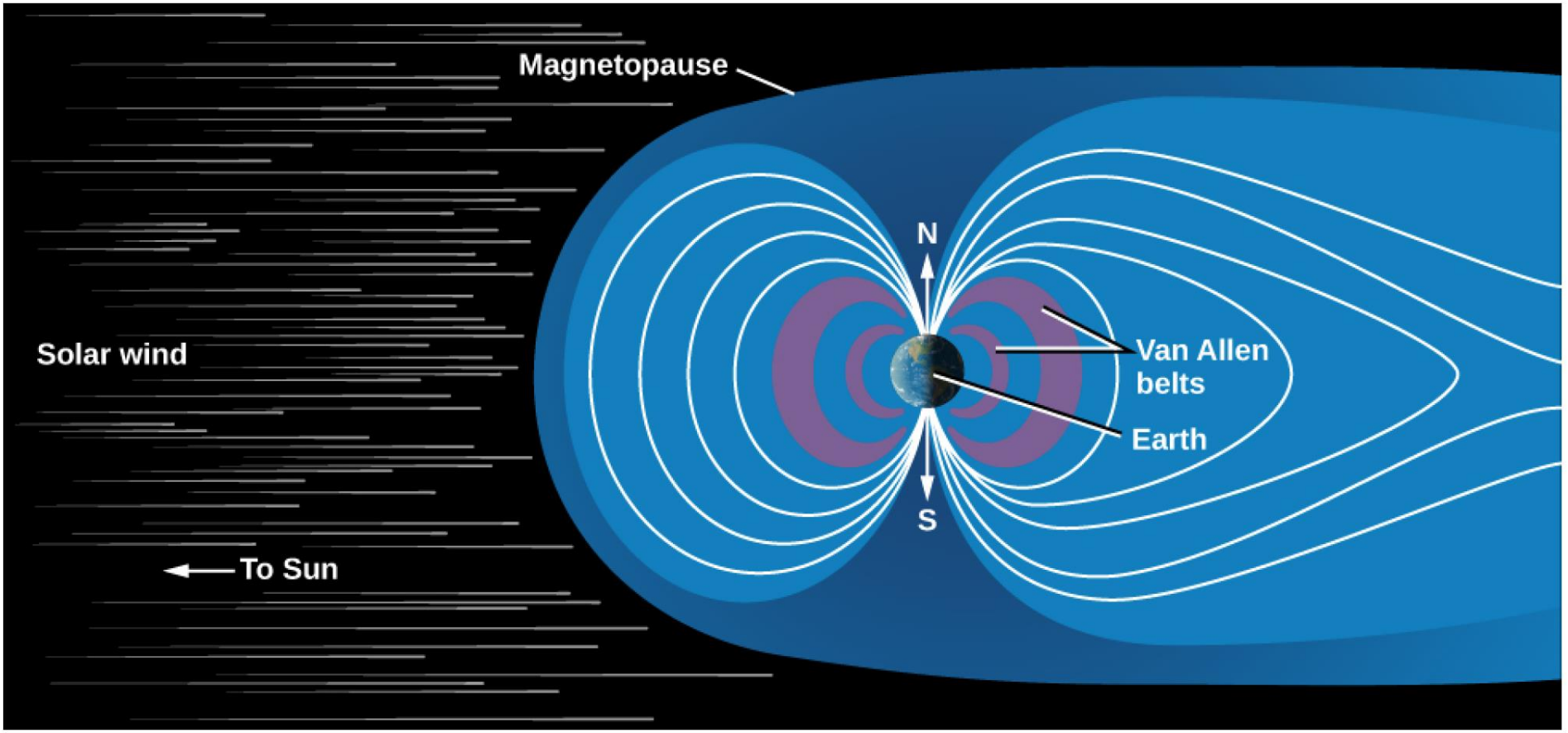



Approximate size of Earth

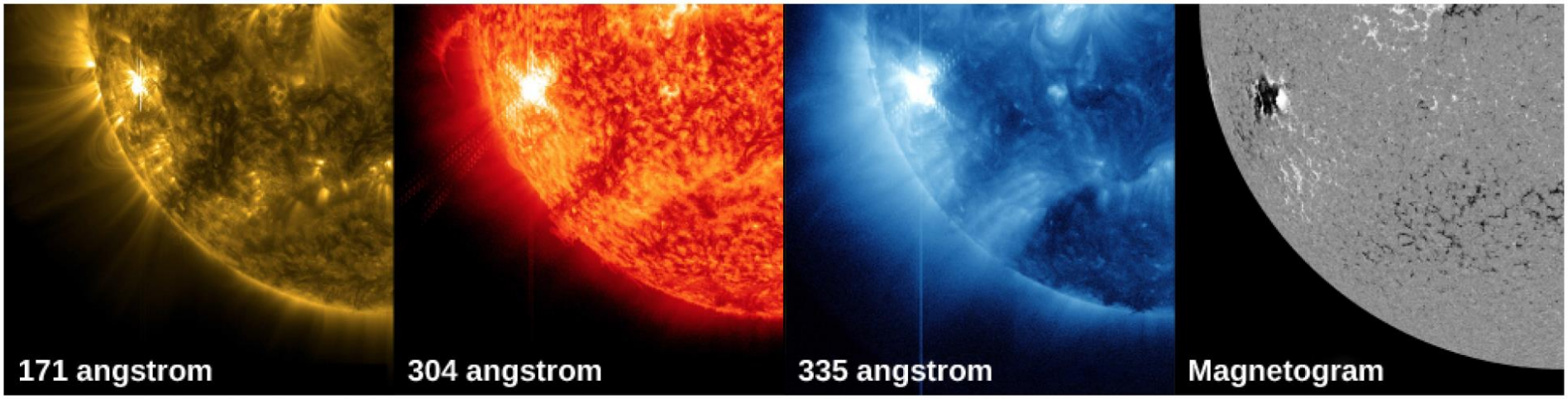







Magnetopause
N
Solar wind
Van Allen
belts
Earth
S
To Sun

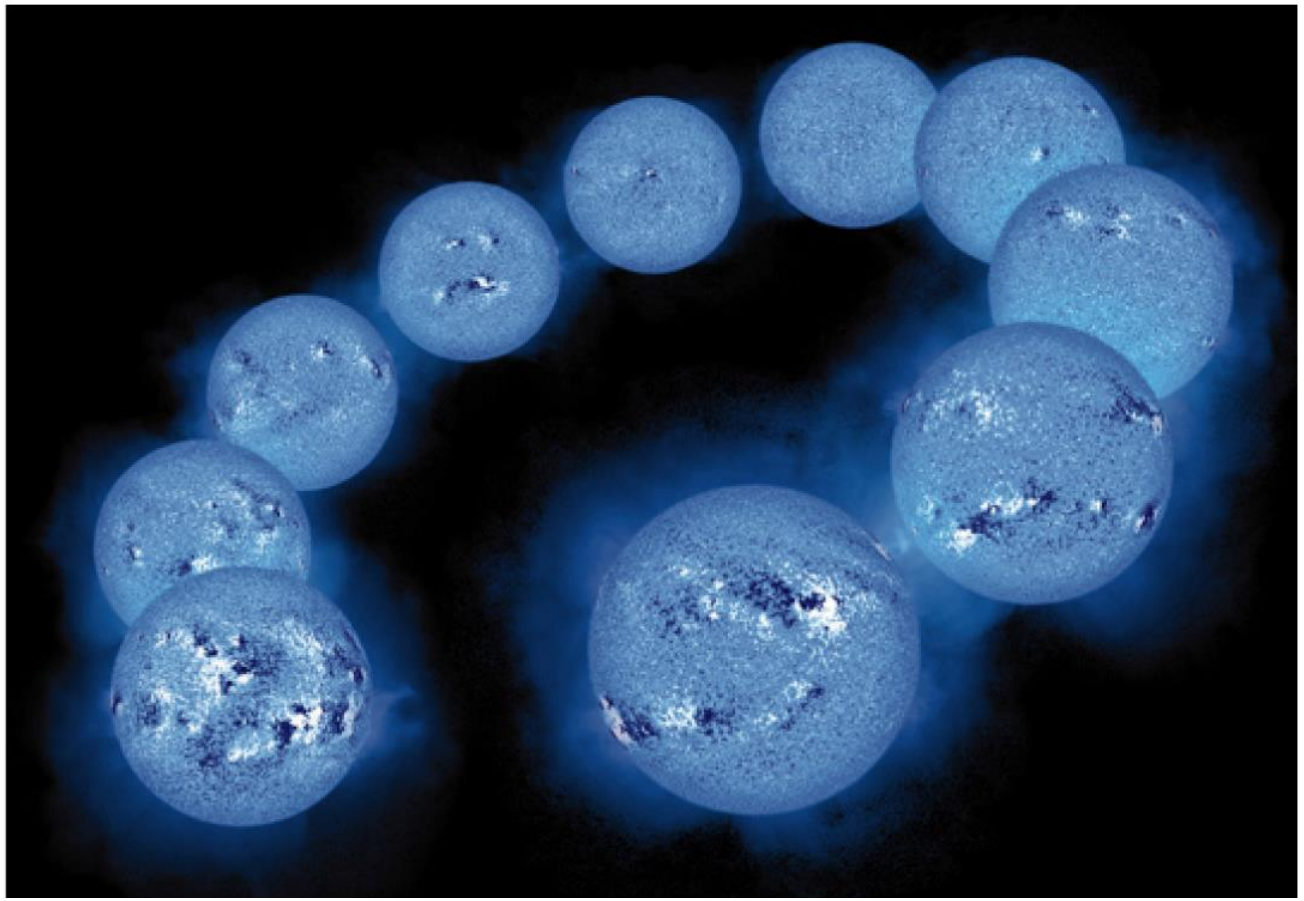

"White Satin"
© Todd Salat
AuroraHunter.com

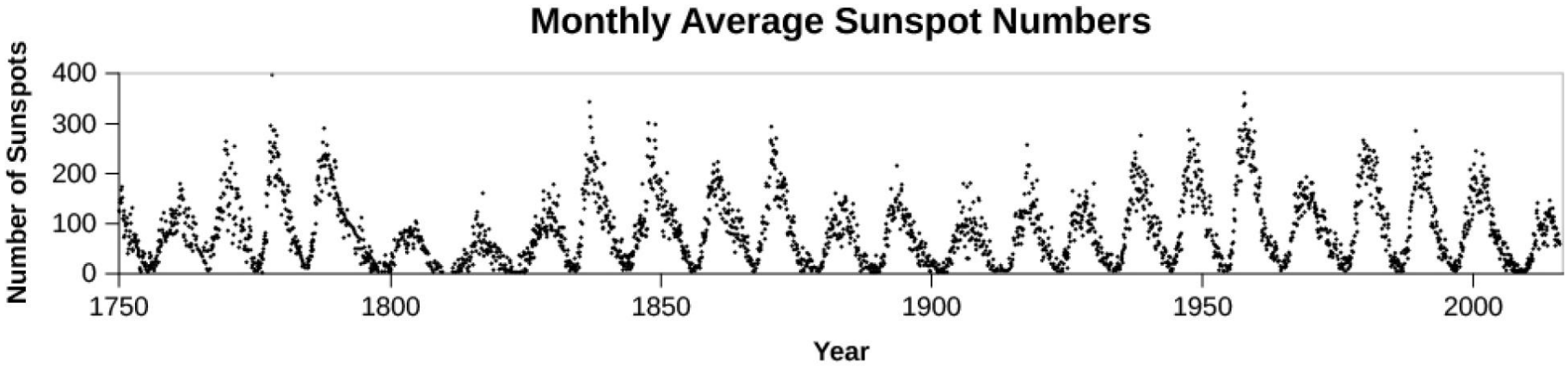


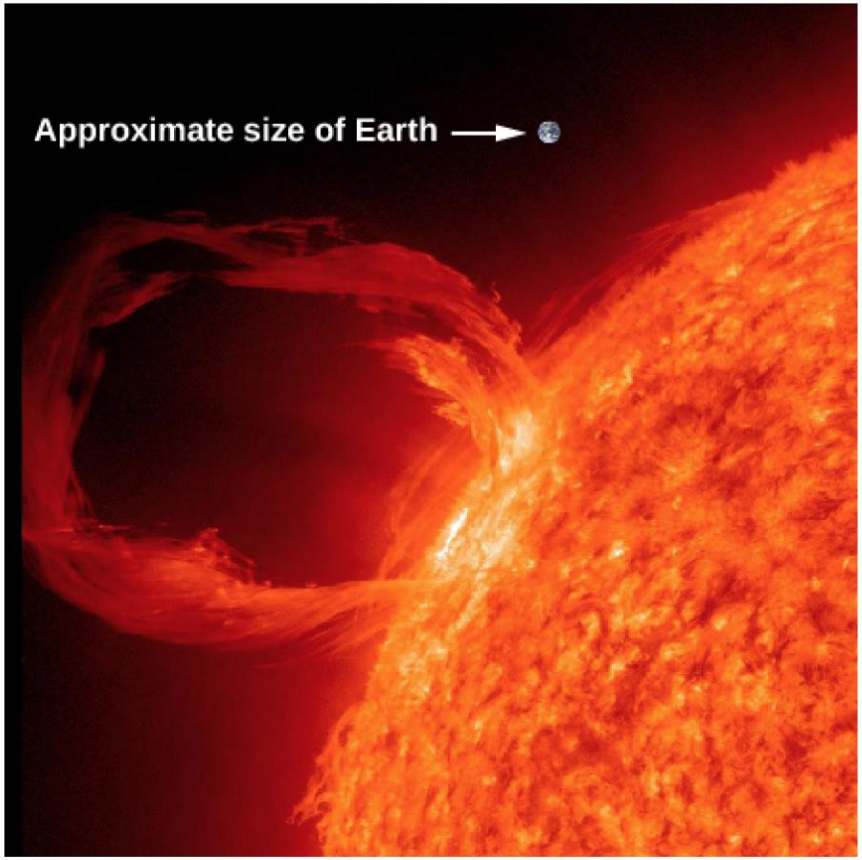
Sun: looks different at different wavelengths: magnetic activity!

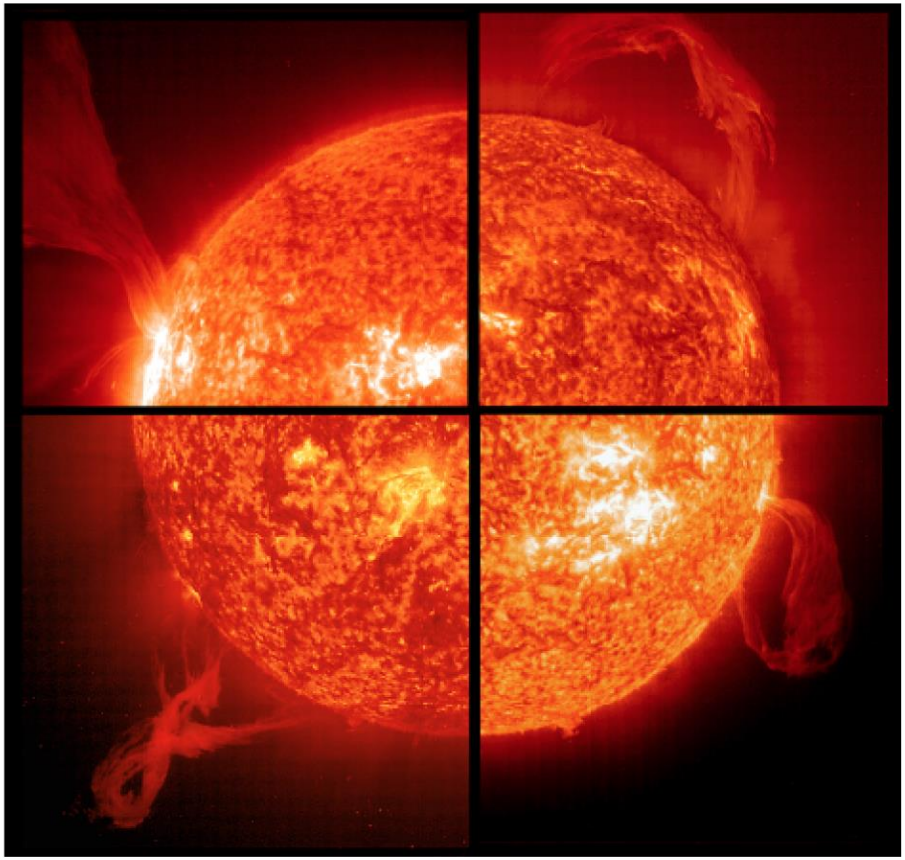
Flares, coronal mass ejections, corona

11 year magnetic cycles






Approximate size of Earth



Solar storms

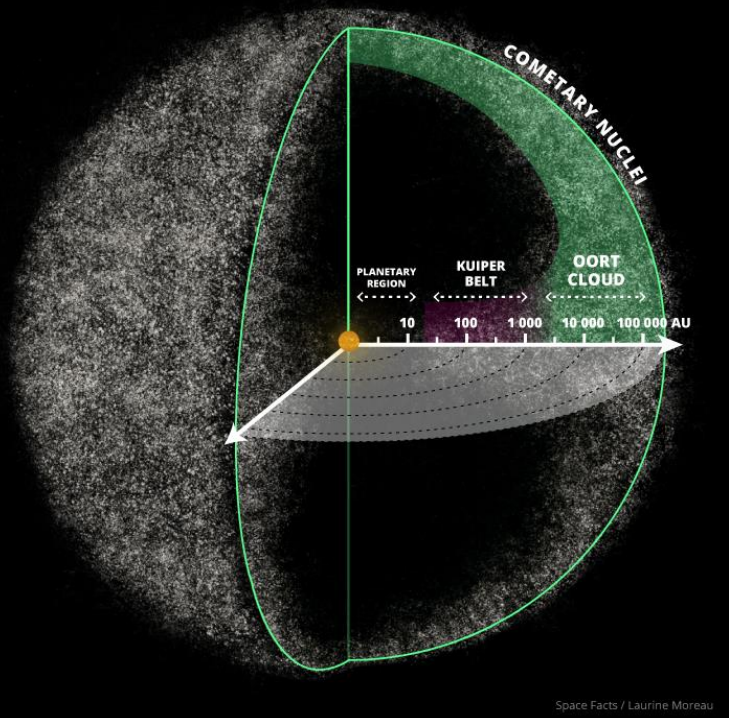
- Carrington event in 1869: huge solar storm
  - Estimated cost huge if happened today (1-10 trillion USD to world economy)
- 1989: solar storm knocked out power across much of Canada
- Possible superflare in 775 from C-14 isotopic evidence from trees
  - Similar event in 960

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
  - China recently pledged to stop funding coal plants
  - 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

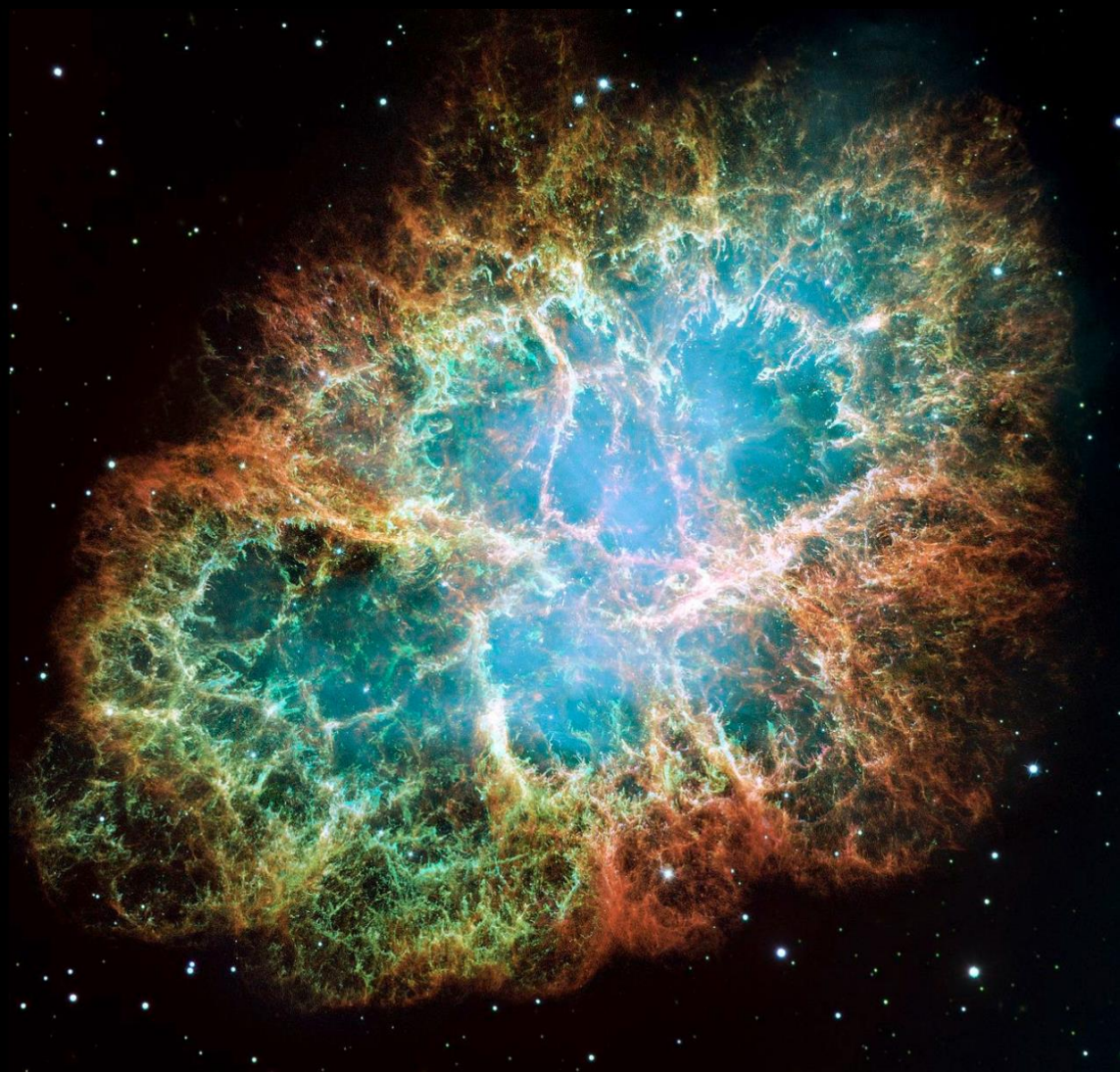
Comets

Supernova

Crab Nebula and Supernova 1054

Visible for ~2 years

kè xīng 客星



G7.7-3.7: a young supernova remnant probably associated with the guest star in 386 CE (SN 386)

PING ZHOU (周平),[1,2] JACCO VINK,[1,3,4] GENG LI (黎耕),[5,6] AND VLADIMÍR DOMČEK[1,3]

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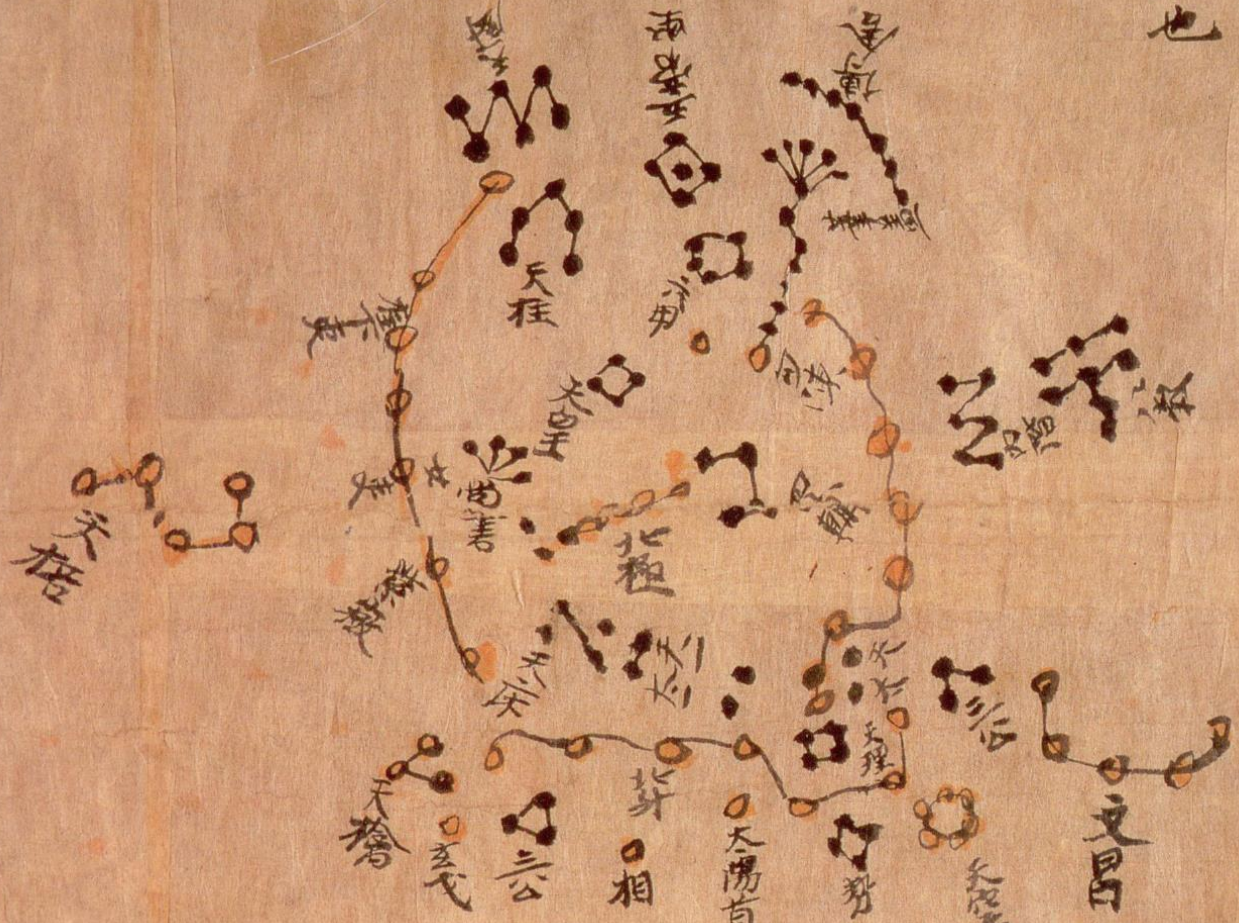
[2] *School of Astronomy and Space Science, Nanjing University, 163 Xianlin Avenue, Nanjing, 210023, China*
[3] *GRAPPA, University of Amsterdam, Science Park 904, 1098 XH Amsterdam, The Netherlands*
[4] *SRON, Netherlands Institute for Space Research, Sorbonnelaan 2, 3584 CA Utrecht, The Netherlands*
[5] *National Astronomical Observatories, Chinese Academy of Sciences, 20A Datun Road, Chaoyang District, Beijing 100101, China*
[6] *School of Astronomy and Space Science, University of Chinese Academy of Sciences, No.19A Yuquan Road, Shijingshan District, Beijing 100049, China*

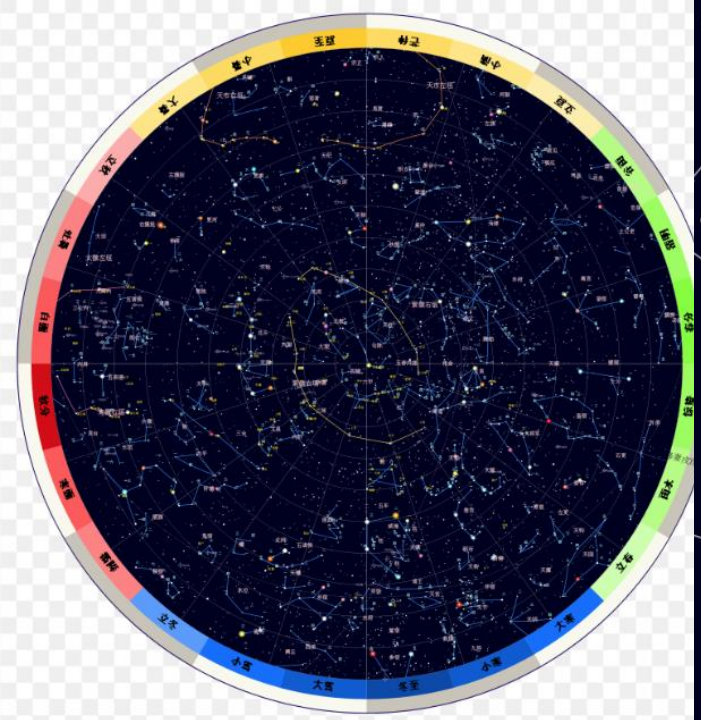
Submitted to ApJL

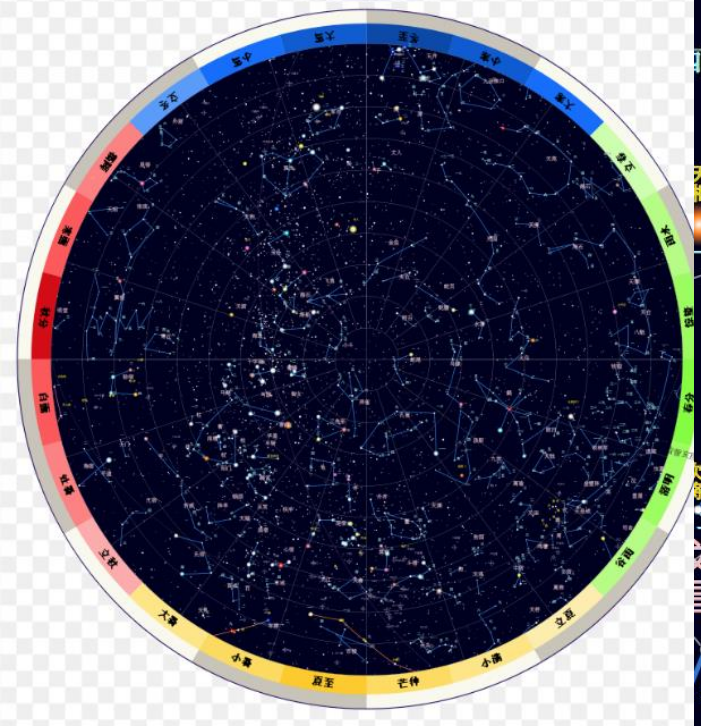
ABSTRACT

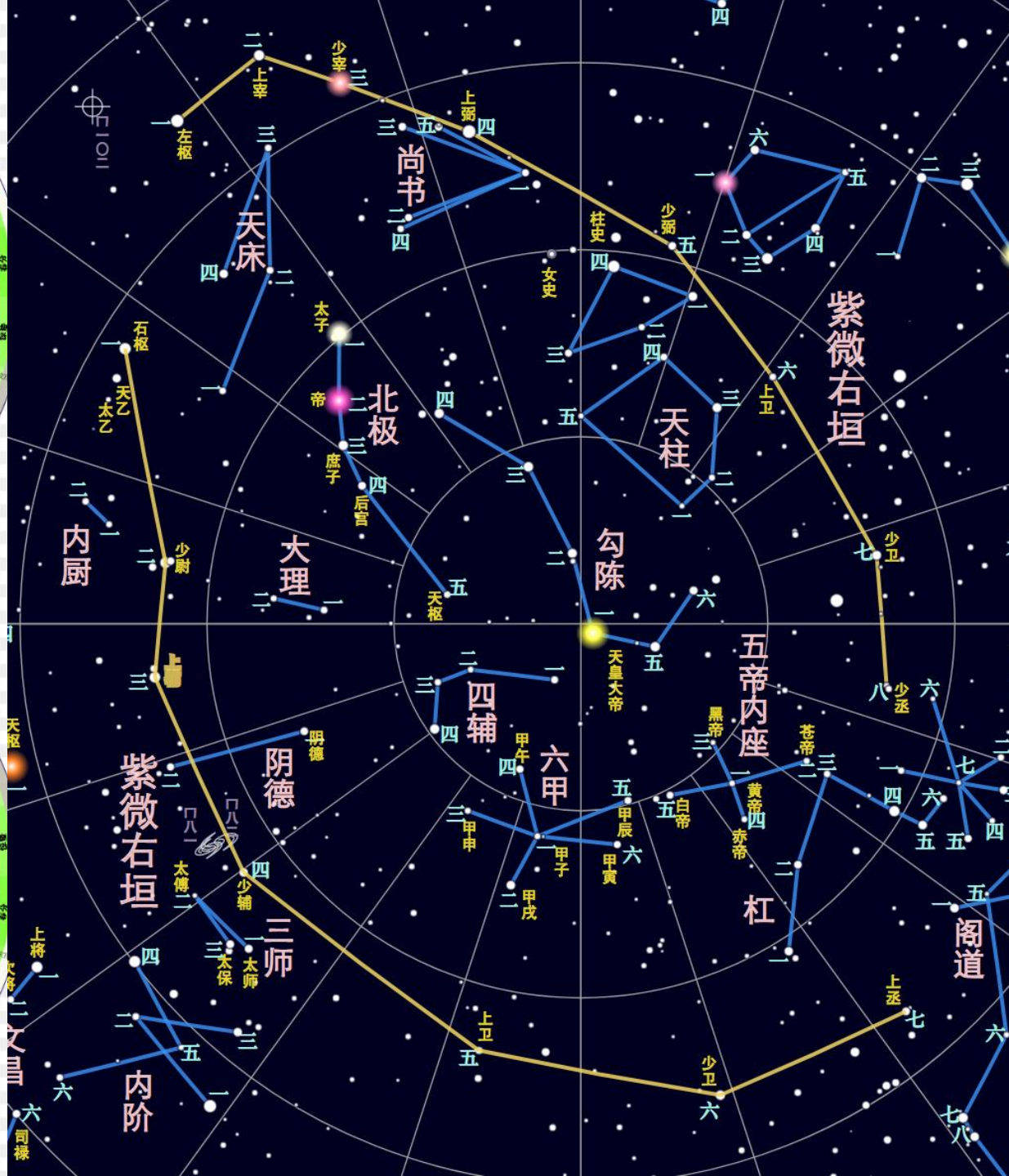
Although the Galactic supernova rate is about 2 per century, only few supernova remnants are associated with historical records. There are a few ancient Chinese records of "guest stars" that are probably sightings of supernovae for which the associated supernova remnant is not established. Here we present an X-ray study of the supernova remnant G7.7−3.7, as observed by *XMM-Newton*, and discuss its probable association with the guest star of 386 CE. This guest star occurred in the ancient Chinese asterism *Nan-Dou*, which is part of *Sagittarius*. The X-ray morphology of G7.7−3.7 shows an arc-like feature in the SNR south, which is characterized by an under-ionized plasma with sub-solar abundances, a temperature of 0.4–0.8 keV, and a density of $\sim 0.5(d/4\ \mathrm{kpc})^{-0.5}\,\mathrm{cm}^{-3}$. A small shock age of $1.2 \pm 0.6(d/4\ \mathrm{kpc})^{0.5}$ kyr is inferred from the low ionization timescale of $2.4^{+1.1}_{-1.3} \times 10^{10}\ \mathrm{cm}^{-3}\,\mathrm{s}$ of the X-ray arc. The low foreground absorption ($N_{\mathrm{H}} = 3.5 \pm 0.5 \times 10^{21}\ \mathrm{cm}^{-2}$) of G7.7−3.7 made the supernova explosion visible to the naked eyes on the Earth. The position of G7.7−3.7 is consistent with the event of 386 CE, and the X-ray properties suggest that also its age is consistent. Interestingly, the association between G7.7−3.7 and guest star 386 would suggest the supernova to be a low-luminosity supernova, in order to explain the not very long visibility (2–4 months) of the guest star.

自井二度抵牛七度於辰在丑為星之記者言統己万物之終故曰星
越之分也








少宰
上宰
左枢
尚书
上弼
天床
柱史
少弼
女史
紫微右垣
太子
石枢
天乙
太乙
帝
北极
庶子
后宫
上卫
天柱
内厨
少尉
大理
天枢
勾陈
少卫
天皇大帝
五帝内座
四辅
黑帝
苍帝
甲午
六甲
黄帝
白帝
赤帝
甲申
甲辰
甲寅
甲子
甲戌
杠
少丞
阴德
明德
紫微右垣
太傅
少辅
三师
太保
太师
阁道
上将
内阶
上丞
上卫
少卫
文昌
司禄

Horoscopes and astrology

Positions of sky determine your day/life

Born in the year of the dragon?

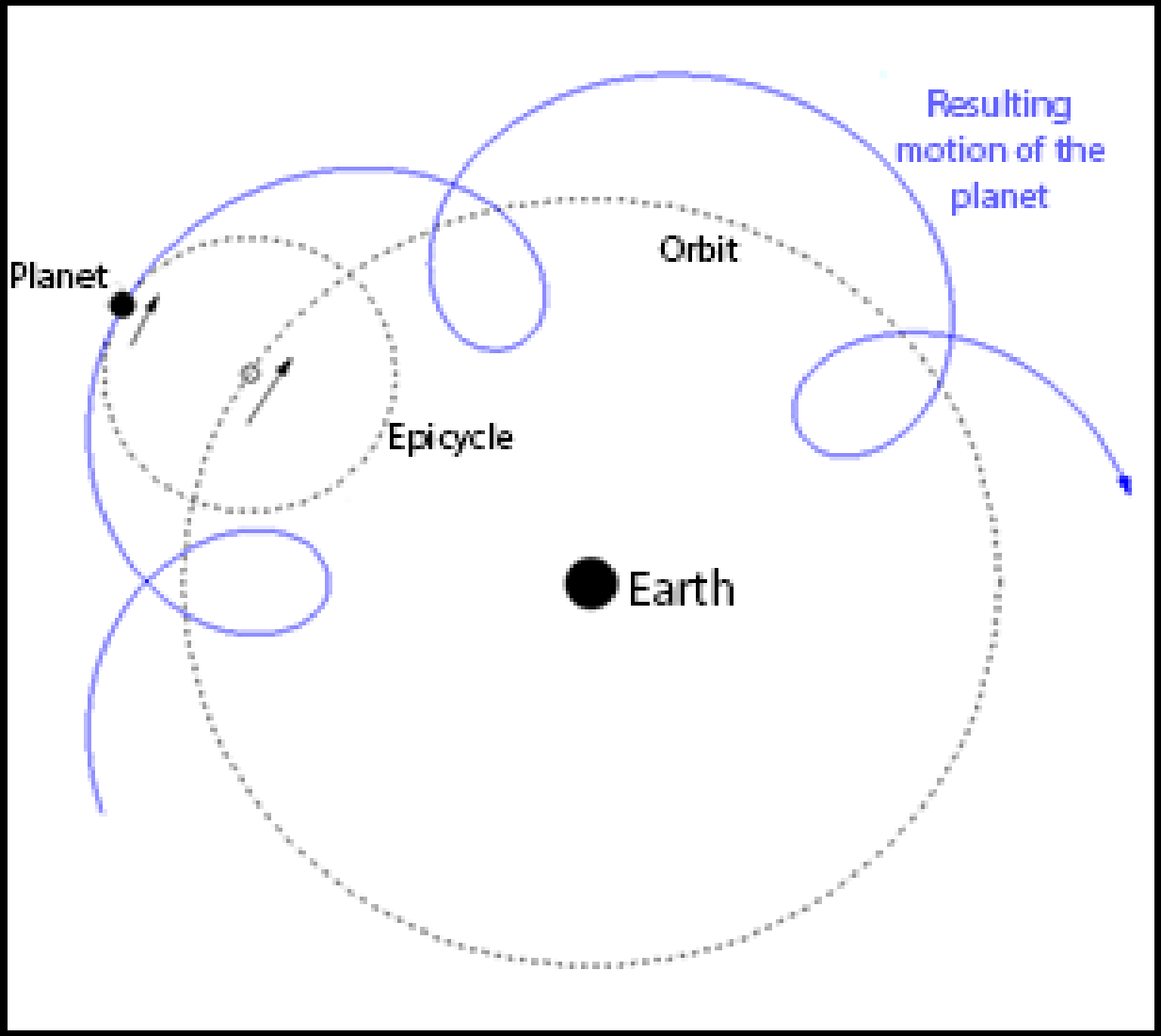
Pseudo-science

(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

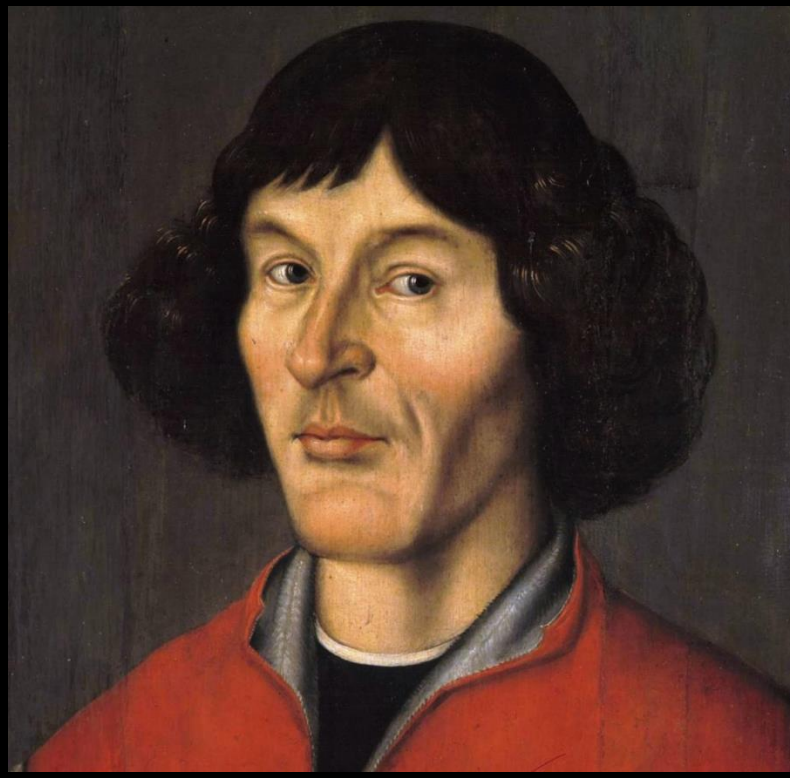


Copernican Revolution

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

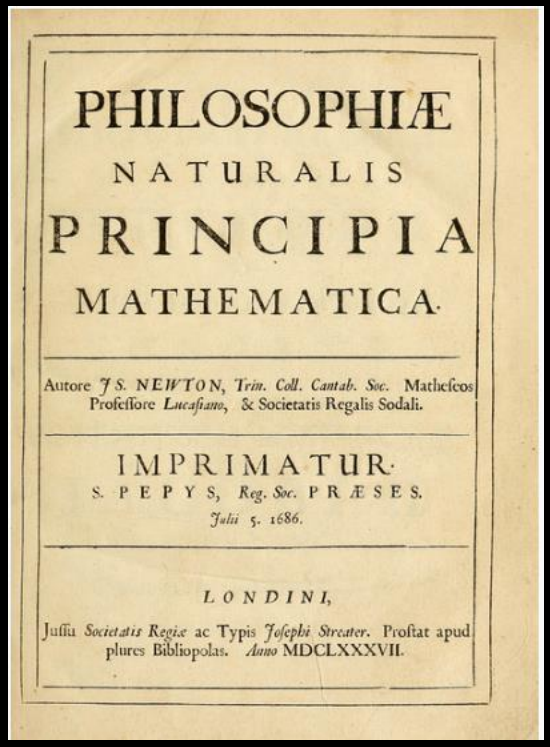
Newton's Principia

Mathematical Principles of Natural Philosophy

Calculus

Planetary motion

Gravity



PHILOSOPHIÆ
NATURALIS
PRINCIPIA
MATHEMATICA.

Autore *J S.* NEWTON, *Trin. Coll. Cantab. Soc.* Matheſeos Profeſſore *Lucaſiano*, & Societatis Regalis Sodali.

IMPRIMATUR.
S. PEPYS, *Reg. Soc.* PRÆSES.
Julii 5. 1686.

LONDINI,
Juſſu *Societatis Regiæ* ac Typis *Joſephi Streater*. Proſtat apud plures Bibliopolas. *Anno* MDCLXXXVII.

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!

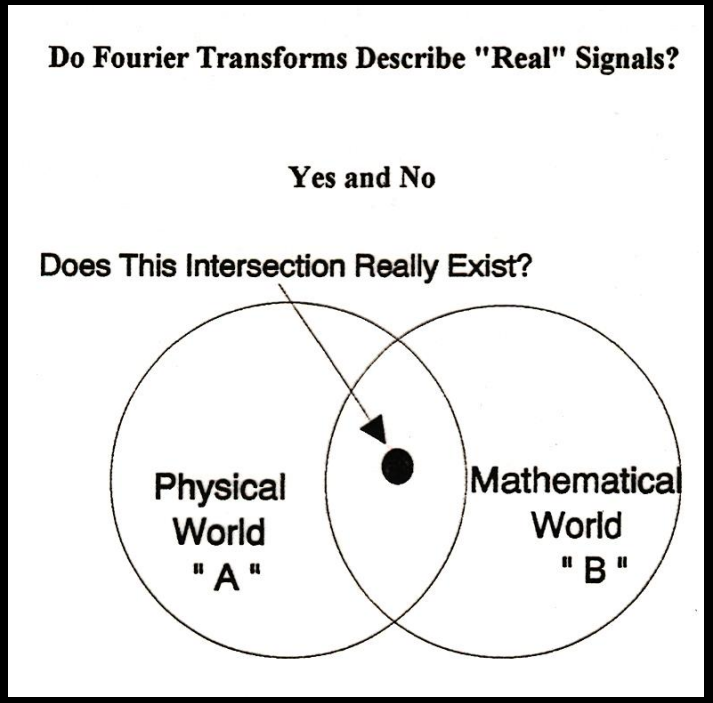
a different solar system (sort-of)

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)

William of Ockham depicted on a stained glass window at a church

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

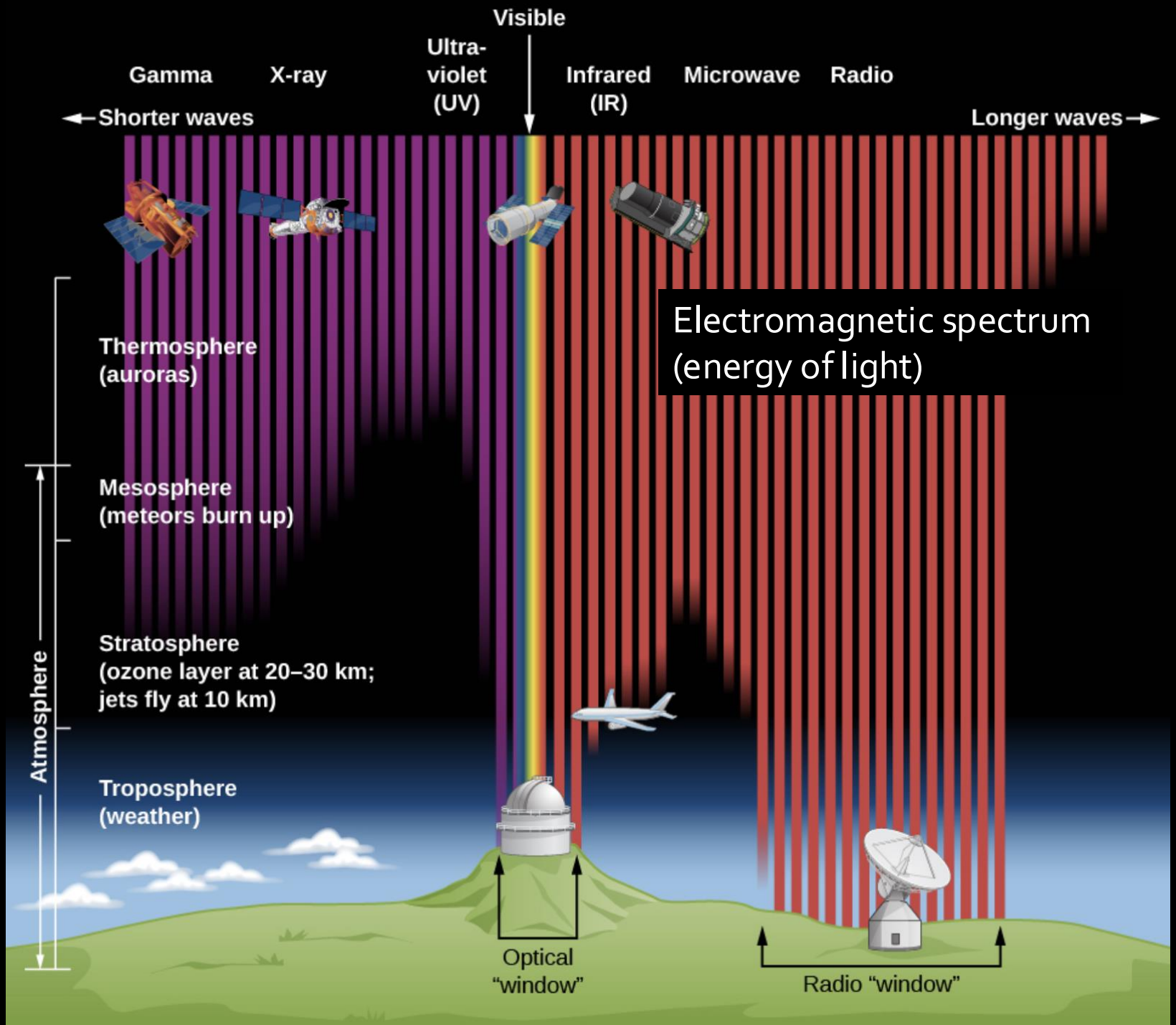
Brian Skinner @gravity_levity · 9 Aug 2018

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

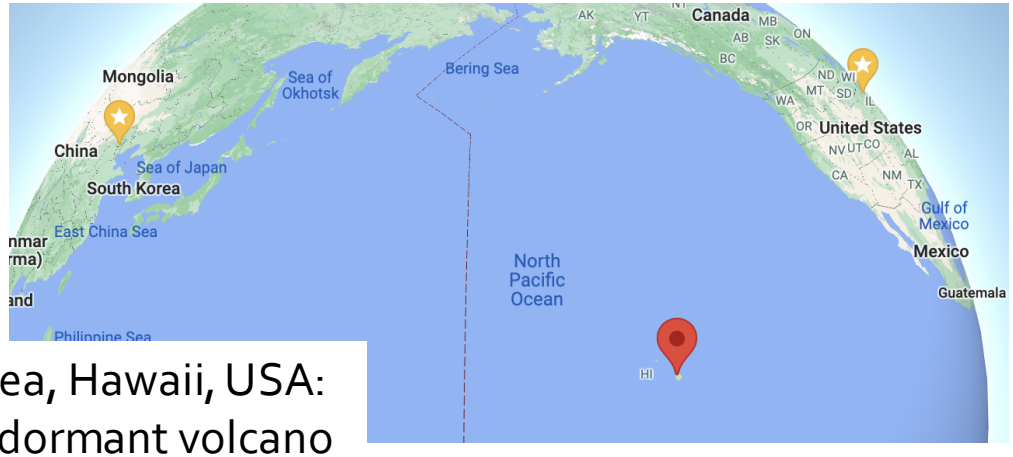
- The laboratory for observers
  - "experimentalist" in physics-hua
- Telescopes are adapted to different wavelengths
  - Some wavelengths only accessible in space
- Larger = better
  - Angular resolution proportional to diameter (2D: diameter^2)
  - Number of photons proportional to diameter^2
  - But more expensive!
  - Some advantages to small telescopes (monitor bright targets)
- Solar system: can send satellites/robots



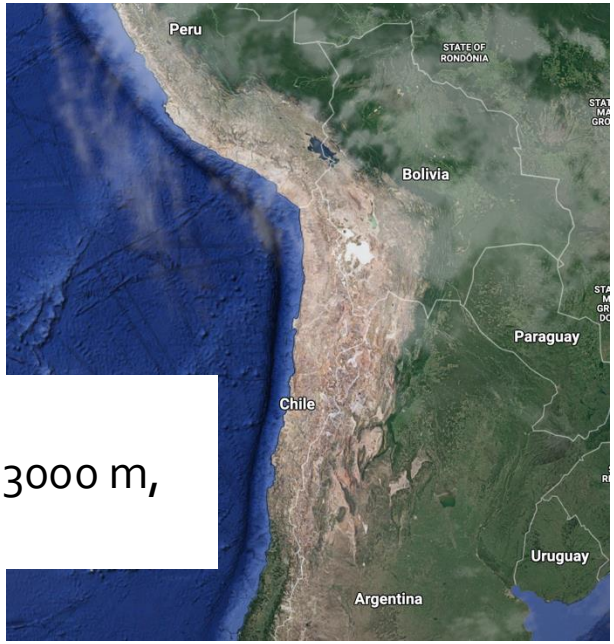
Electromagnetic spectrum (energy of light)

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

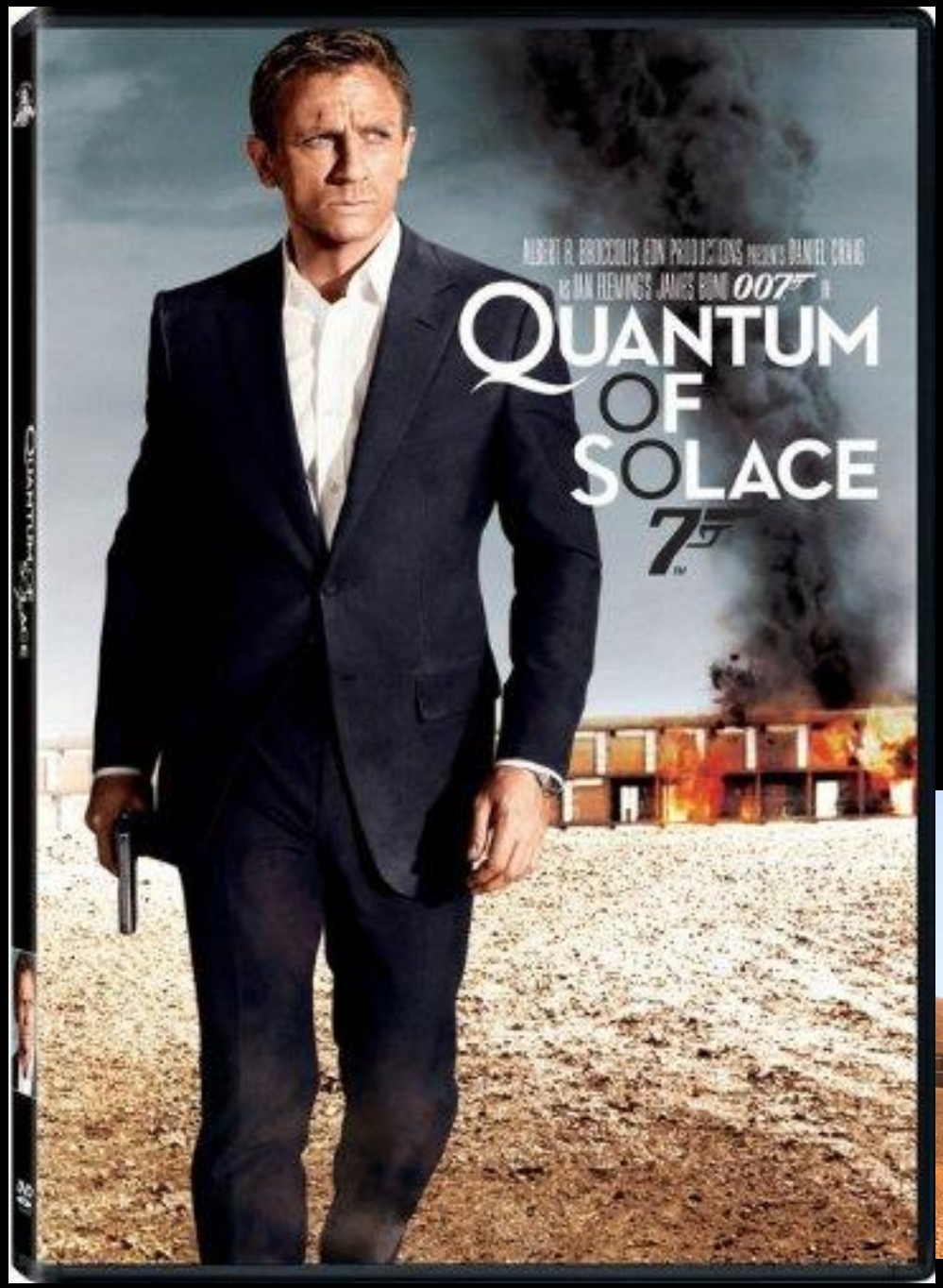


Northern Chile
Andes mountains, 3000 m,
Very dry

Maunakea, Hawaii

Maunakea, Hawaii

European Very Large Telescopes: Paranal, northern Chile


QUANTUM
OF
SOLACE

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

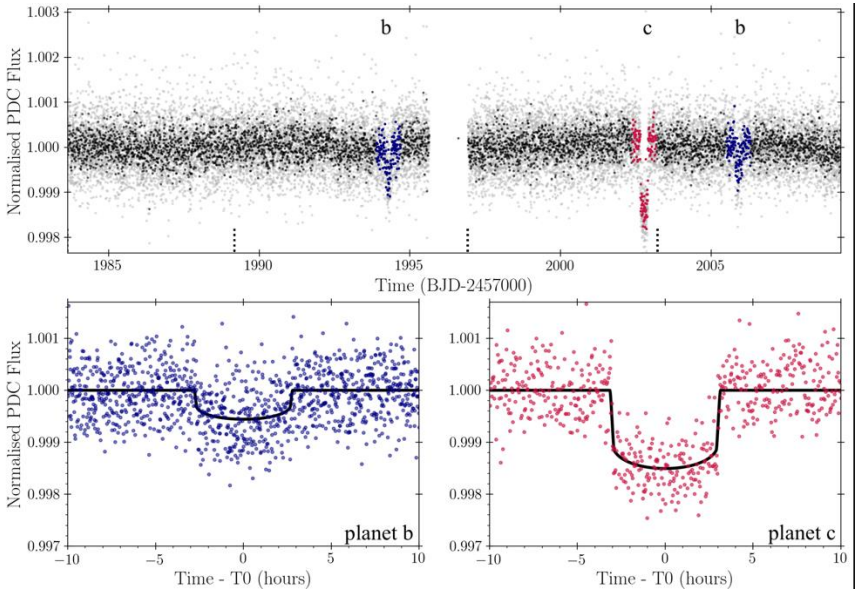
- US Science Community just announced support for a 6.5-m UV/optical/infrared telescope in space
- Cost: $10B USD
- Launch: around 2045 (if lucky)

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

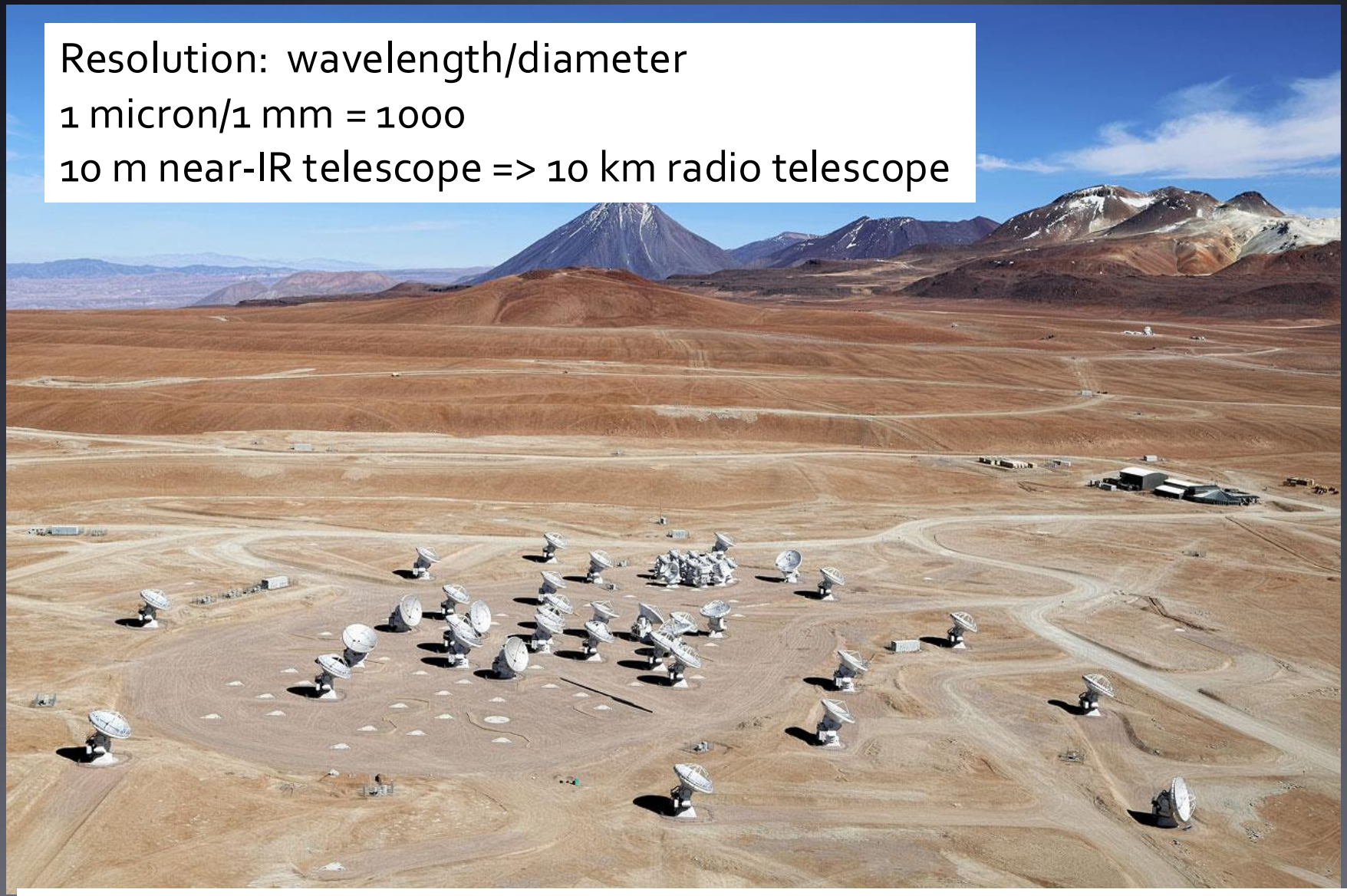
- Some (~5) small, mid-sized telescopes in space
- Kepler (2013): stared at same region of sky for 3 years to look for exoplanet transits (dips in light curve)
- TESS: All-sky search for exoplanets



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)



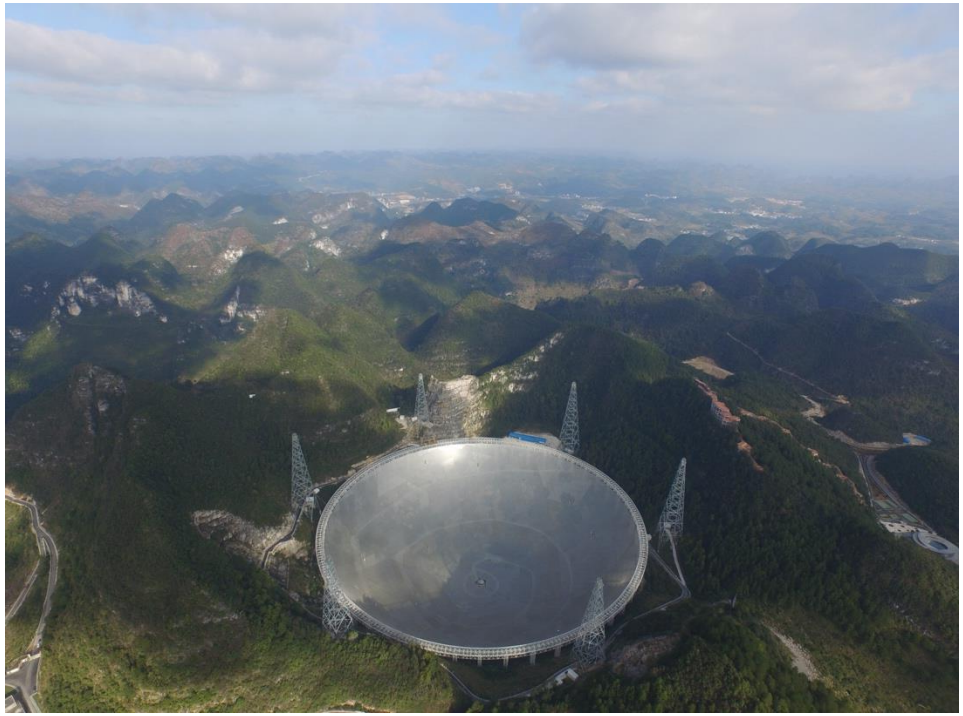
Sub-mm interferometer telescope; 5000-m elevation!


Cali
Colombia
Guyana
French Guiana
Quito
Ecuador
STATE OF RORAIMA
STATE OF AMAPÁ
STATE OF AMAZONAS
STATE OF ACRE
STATE OF PARÁ
Peru
Brazil
Lima District
STATE OF RONDÔNIA
STATE OF CEARÁ
STATE OF MATO GROSSO
STATE OF TOCANTINS
Bolivia
STATE OF BAHIA
STATE OF GOIÁS
Salvador
Atacama Large Millimeter Array...
STATE OF MINAS GERAIS
Paraguay
Asunción
STATE OF SÃO PAULO
Chile
STATE OF SANTA CATARINA
Córdoba
Santiago
Uruguay
Argentina
Montevideo


Complejo
de Puricó
Atacama Large
Millimeter Array...

Radio Telescopes: FAST

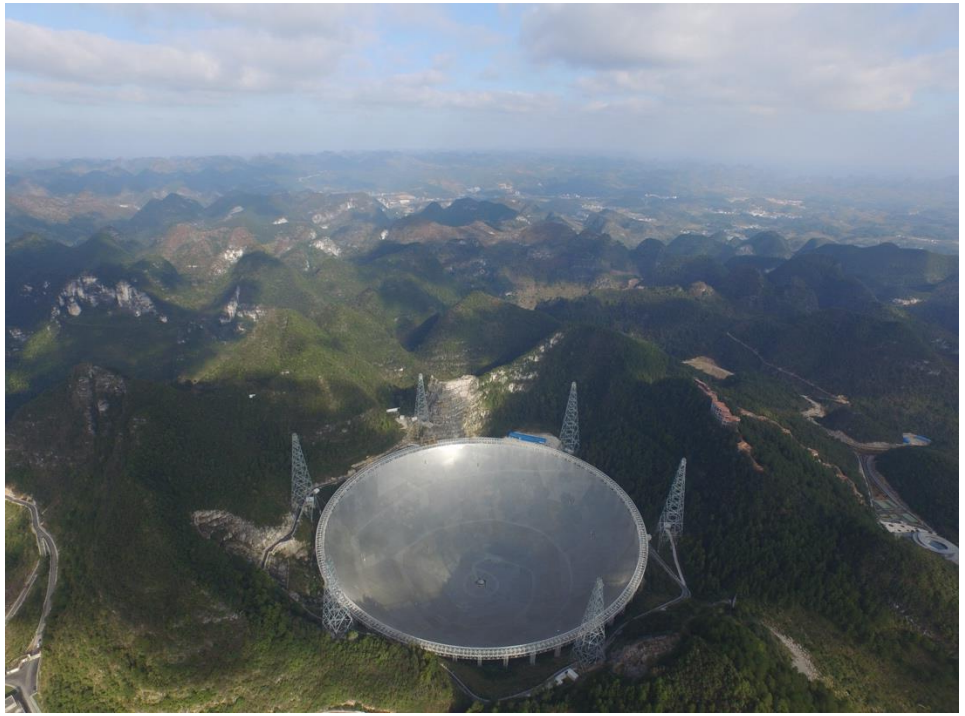
- Five-hundred meter aperture Spherical Telescope
- World's largest telescope in Guizhou
- Pulsars and interstellar gas
- Planned expansion in 2030
  - 6 linked dishes



Radio Telescopes: FAST

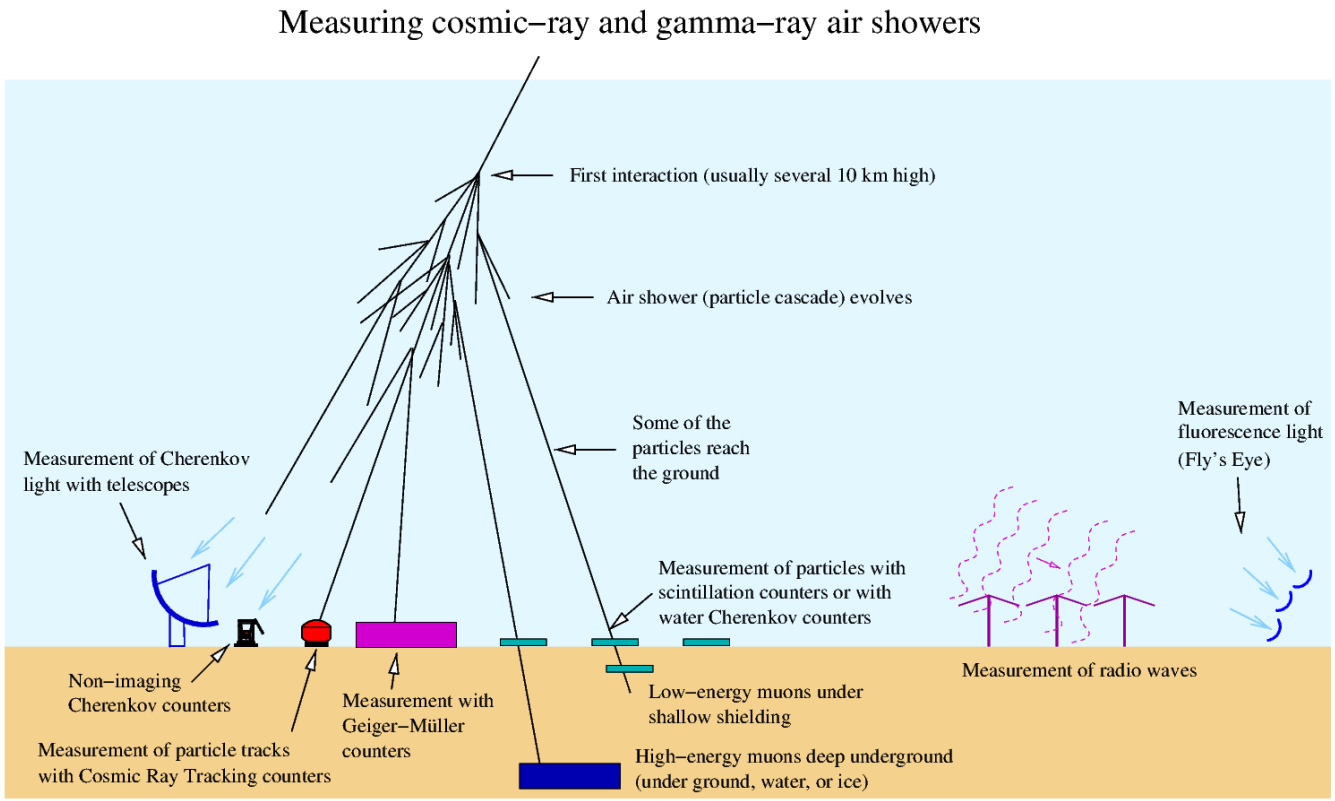
- Five-hundred meter aperture Spherical Telescope
- Worl
- Pulsars and interstellar gas
- Planned expansion in 2030
  - 6 linked dishes

我和我的家乡！

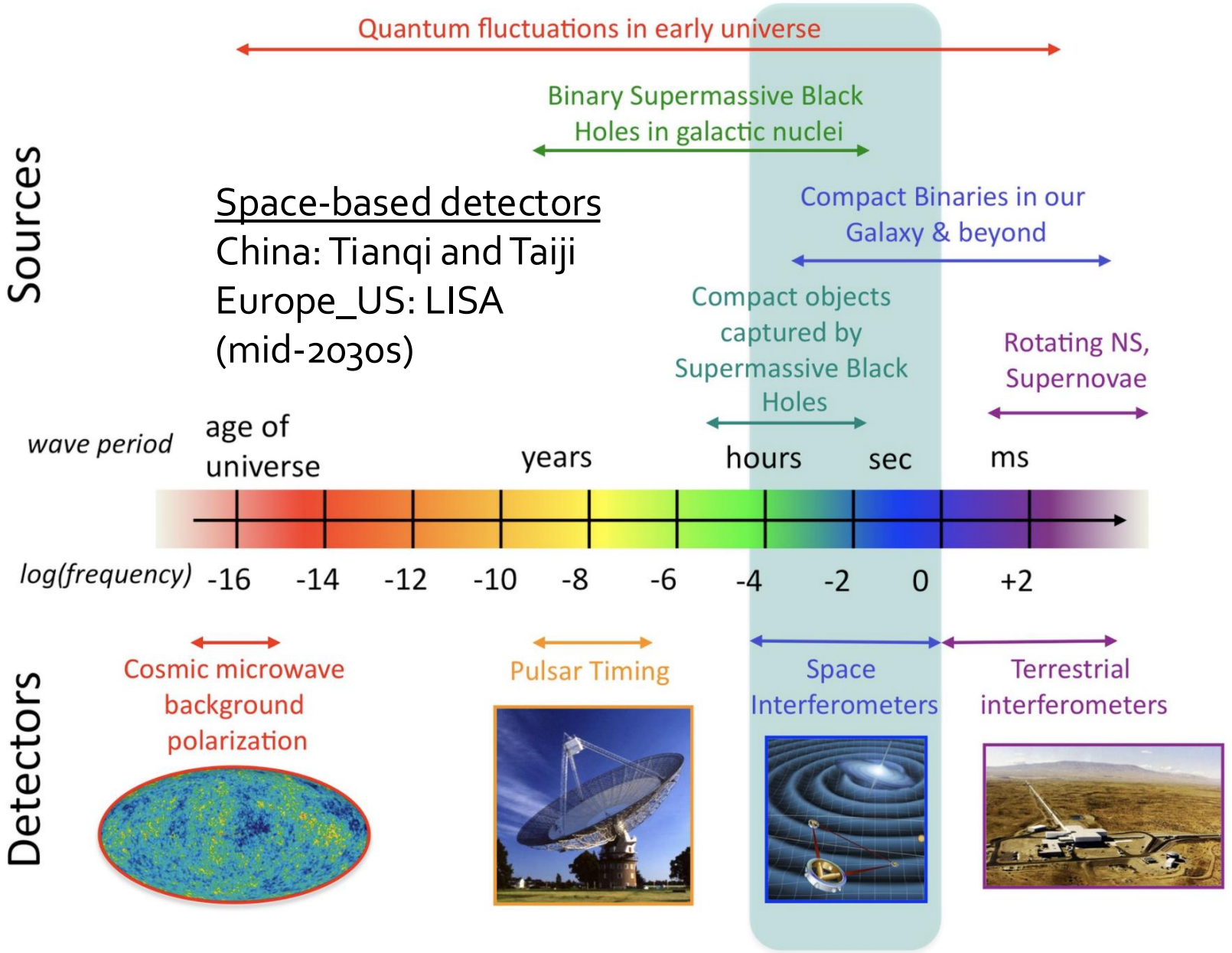



长春 汽车城嘛
Changchun, the city of cars.

LHAASO
Cosmic rays, gamma rays



The Gravitational Wave Spectrum



Upcoming planetary missions

- Venus: NASA (2021) selected two missions for ~2030
- Dragonfly: drone to Titan!
- Europa Clipper: flybies 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

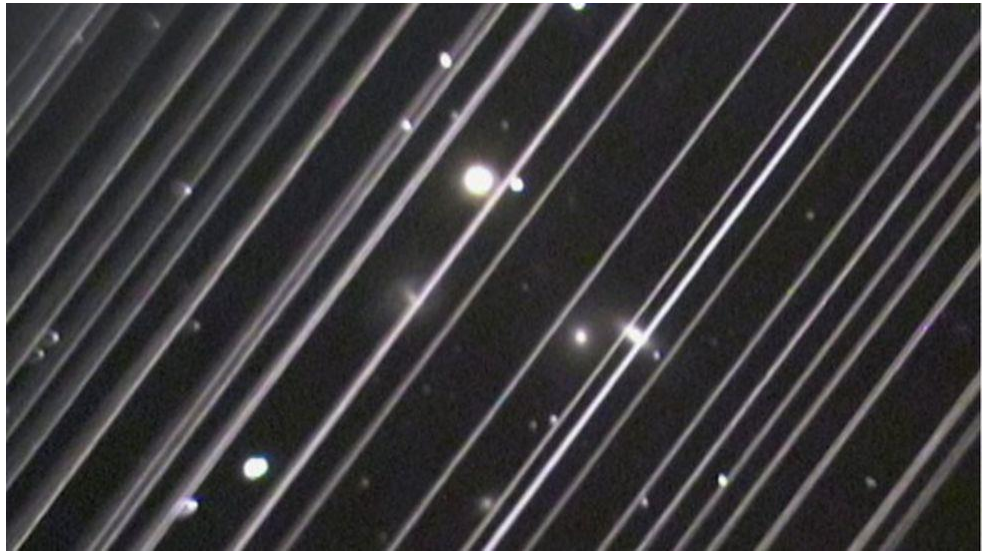
- Tianwen-1 (天问2021): Mars lander, Zhurong rover
- ZhengHe: sample return mission from comet
- Mars sample return missions
- Gan De (2030): Jupiter orbiter (and Callisto lander?)
- Mission to Uranus (2030s)?
- Other missions may include leaving the solar system

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?