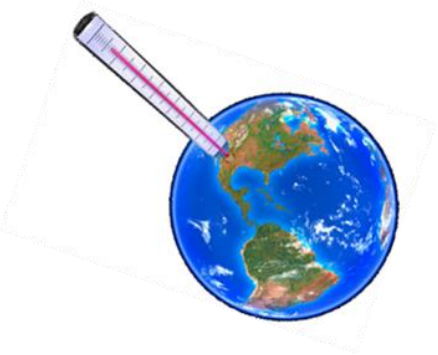
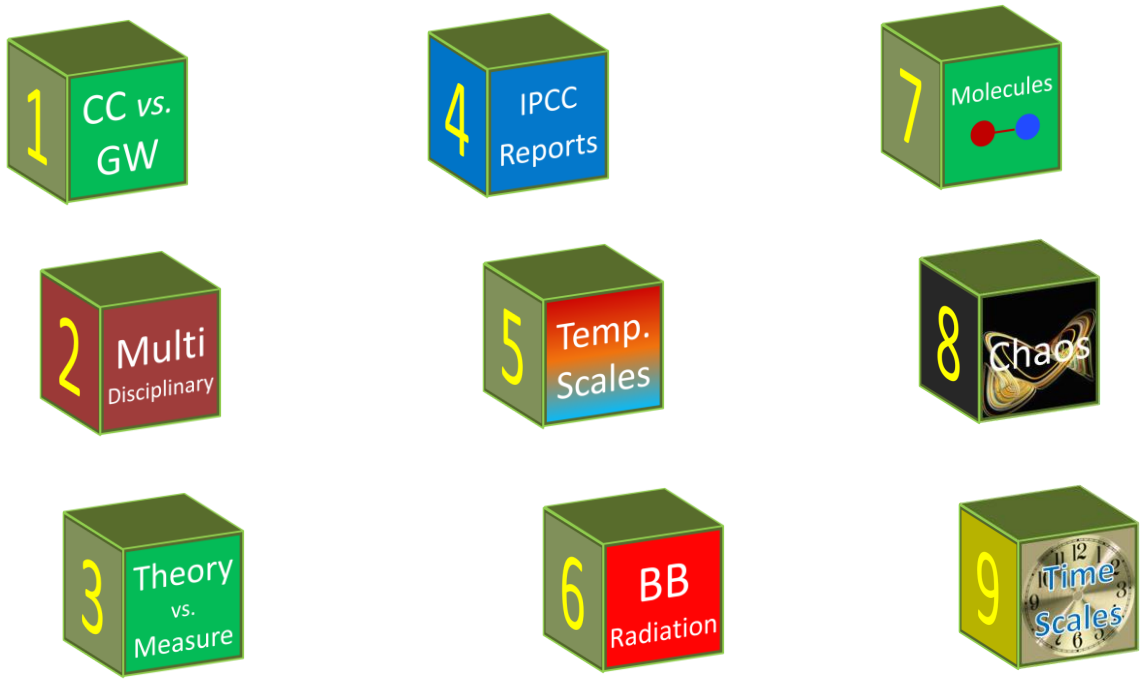
OSHER LIFELONG LEARNING INSTITUTE



Demystifying Climate Change



Session 1

Building Blocks

OLLI at Illinois

Spring 2021

D. H. Tracy

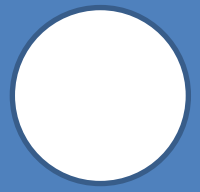
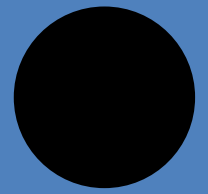
A Tale of Two Planets

77%	Albedo	30%
-51 °F	Effective *(Apparent Ave.)* Temperature	**-2 °F**

A Tale of Two Planets

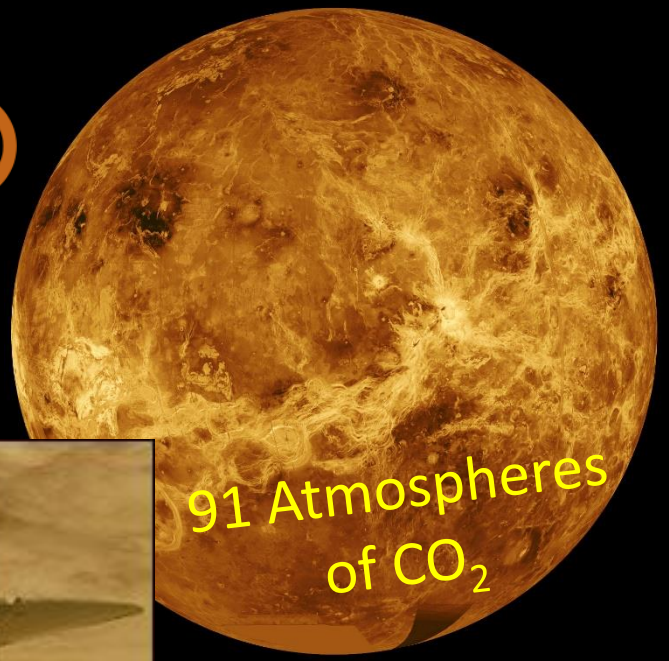
Albedo*:

Fraction of sunlight *reflected* by planet
(and therefore not absorbed)

1.0	.77	.30	.25	.11	0
					
No Absorption	Venus	Earth	Mars	Moon	100% Absorption

* Bond Albedo

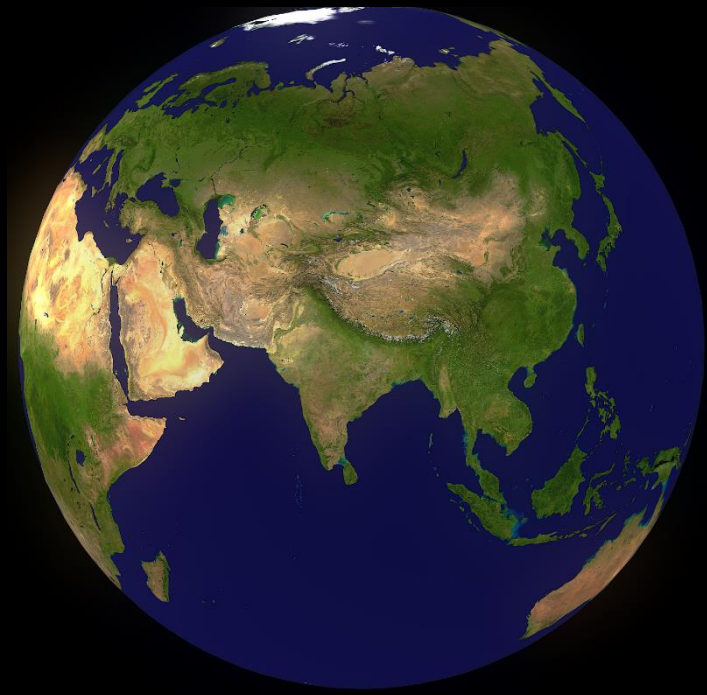
A Tale of Two Planets: Down at the Surface



Venera Landers

867 °F

Average Surface Temperature

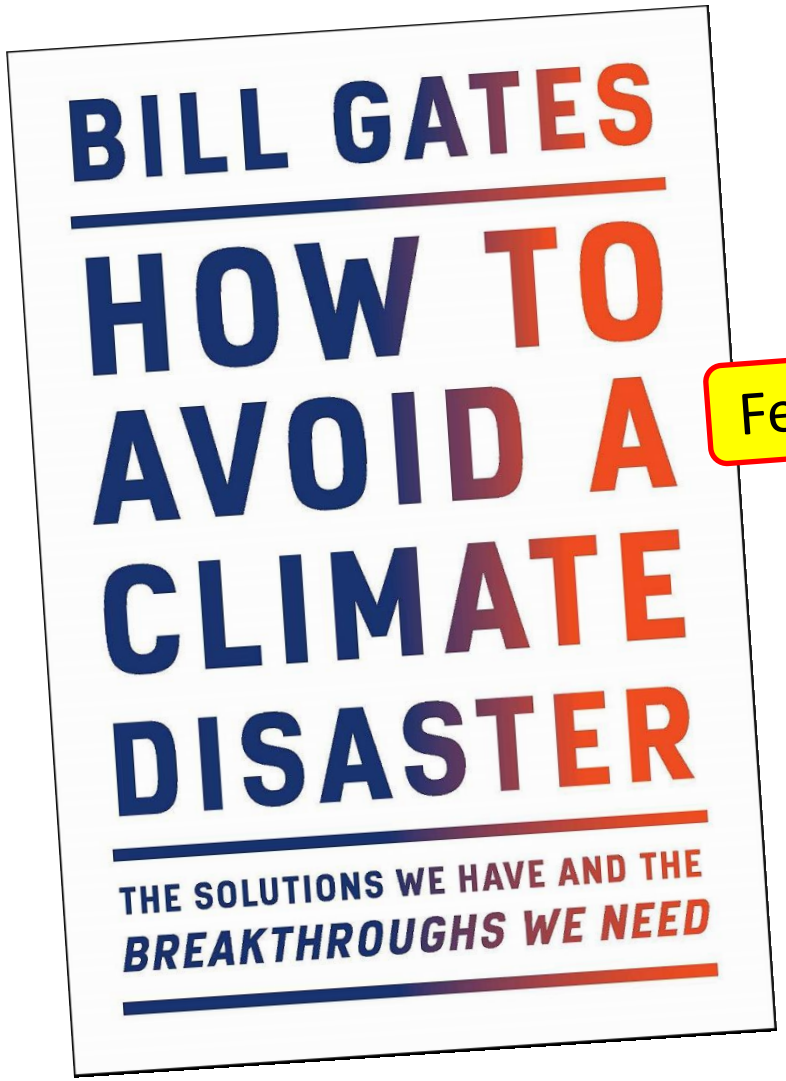


59 °F

Course Outline

1. **Building Blocks: Some important concepts**
2. Our Goldilocks Earth: a Radiative Balancing Act
3. The Role of the Atmosphere: Greenhouse Gases & Clouds
4. Dynamics of the Earth System: Oceans, Atmosphere, Biosphere, Cryosphere, People, Plate Tectonics
5. Natural Variability of the Climate, short and long term. Ice Ages
6. Carbon Dioxide and other Greenhouse Gases: where do they come from, where do they go, how are they regulated?
7. Impacts and Future Projections for Global Warming -- Uncertainties
8. Adaptation and Amelioration Strategies. The Climate debate. Policy options.

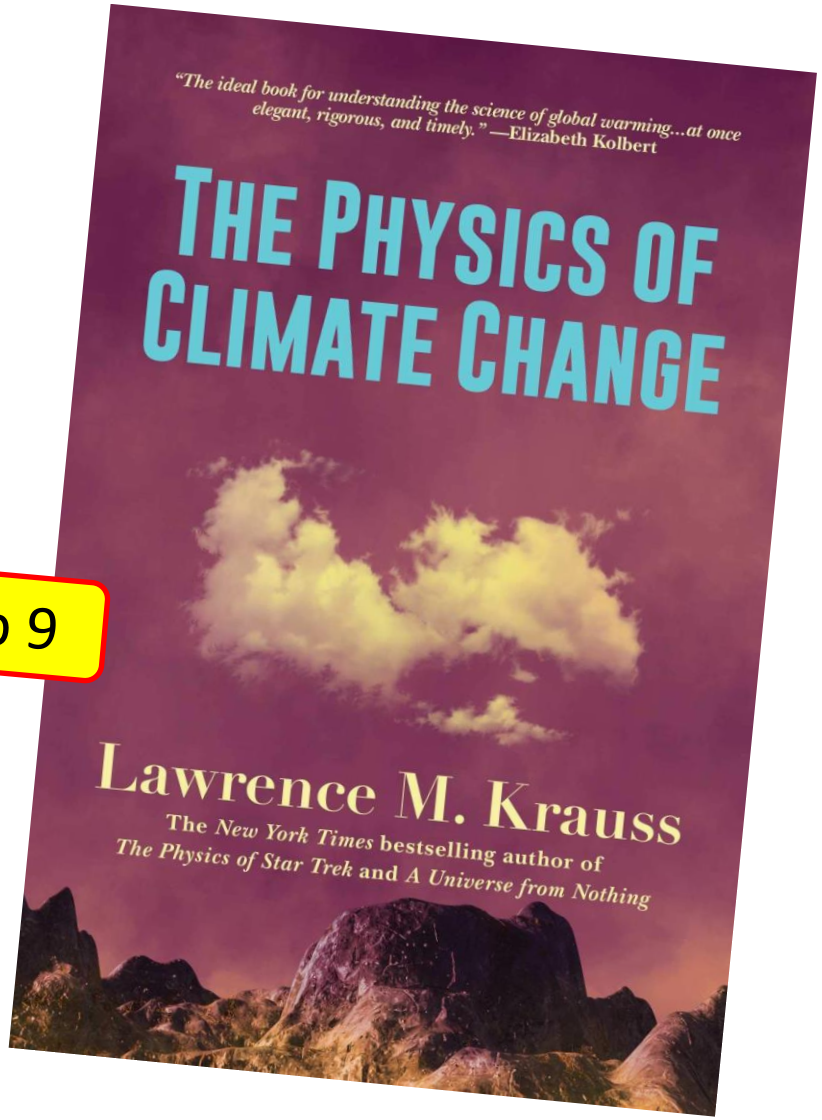
Upcoming Books of Interest



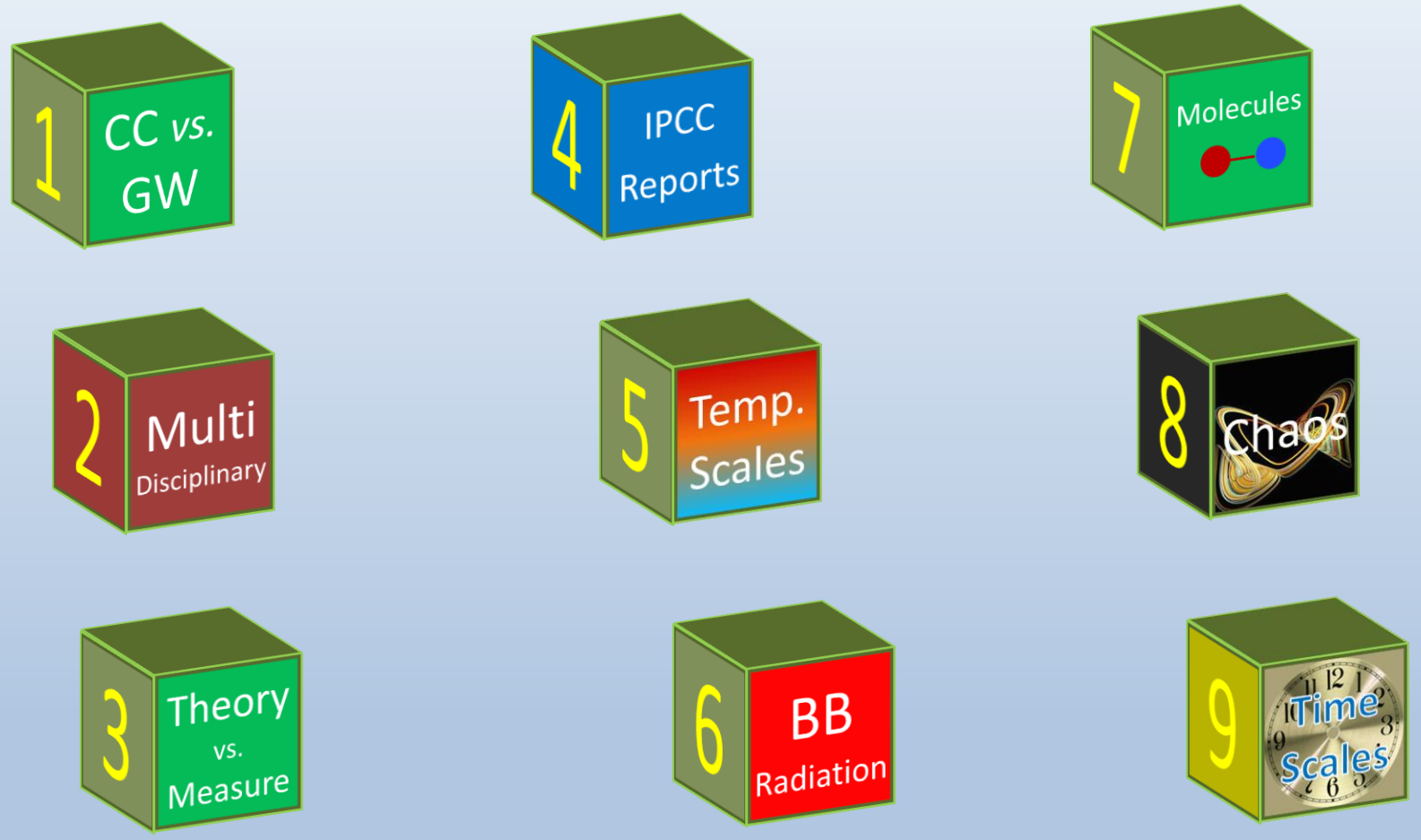
Feb 16

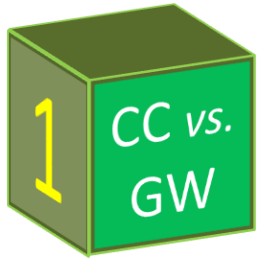
Check out Reference List on OLLI Course Download Site

Feb 9

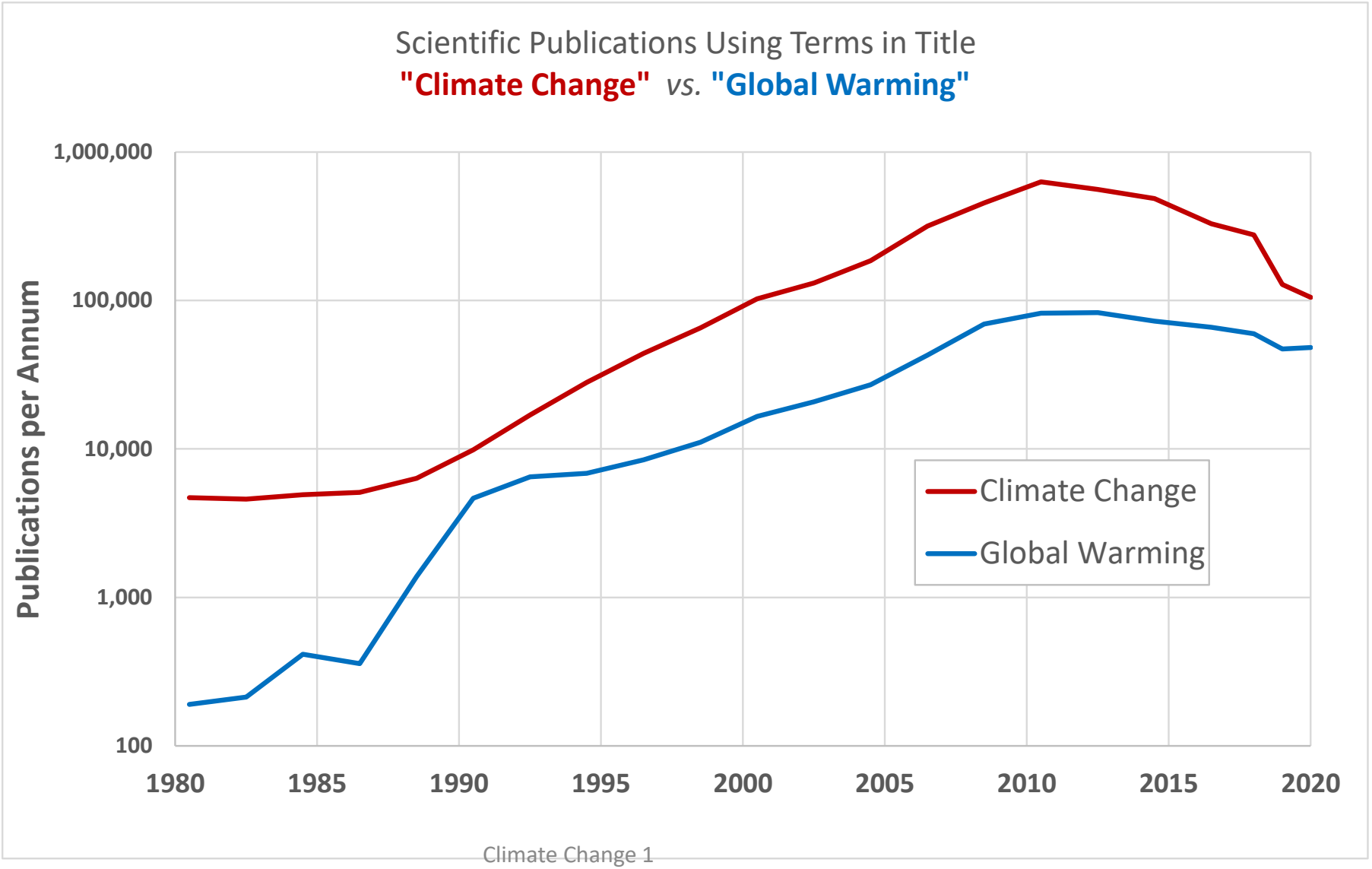


Session 1 Outline: Building Blocks

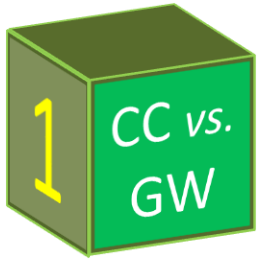




Is it **Climate Change** *or* **Global Warming**?



Source:
Year by year search in Google Scholar (12/3/20)



Is it **Climate Change** *or* **Global Warming**?

- Distinct meanings
- Global Warming:
  - Refers to global average surface temperature
  - Anthropogenic cause often implied (AGW)
- Climate Change:
  - Wide variety of impacts
    - Regional and seasonal variations
      - Precipitation, drought, extreme weather events
    - Changes in sea level, ice caps, vegetation, ocean circulation and chemistry, disease vectors, etc.

Climate Change is Complex and Multi-Disciplinary

1. Aerosol Physics
2. Atmospheric Chemistry
3. Bayesian Inference
4. Biochemistry
5. Biogeography
6. Climatology
7. Climate Science
8. Cloud Physics
9. Computer Science
10. Dendrochronology
11. Ecology
12. Economics
13. Fluid Dynamics
14. Geochemistry
15. Geology
16. Glaciology
17. Historical climatology
18. Hydrology
19. Meteorology
20. Molecular Spectroscopy
21. Non-linear dynamics
22. Numerical Modeling
23. Ocean Chemistry
24. Oceanography
25. Optical Scattering
26. Orbital dynamics
27. Paleoclimatology
28. Photosynthesis
29. Planetary atmospheres
30. Radiation transfer
31. Remote Sensing
32. Satellite Monitoring
33. Soil Science
34. Solar physics
35. Statistics
36. Thermodynamics
37. Volcanology

Et Cetera

Climate Change is Complex and Multi-Disciplinary

1. Aerosol Physics
2. Atmospheric Chemistry
3. Bayesian Inference
4. Biochemistry
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7. Clima
8. Cloud
9. Compu
10. Dendro
11. Ecology
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13. Fluid Dynamics
14. Geochemistry
15. Geology
16. Glaciology
17.
14. Oceanography
25. Optical Scattering
26. Orbital dynamics
27.
heres
g
olar physics
35. Statistics
36. Thermodynamics
37. Volcanology

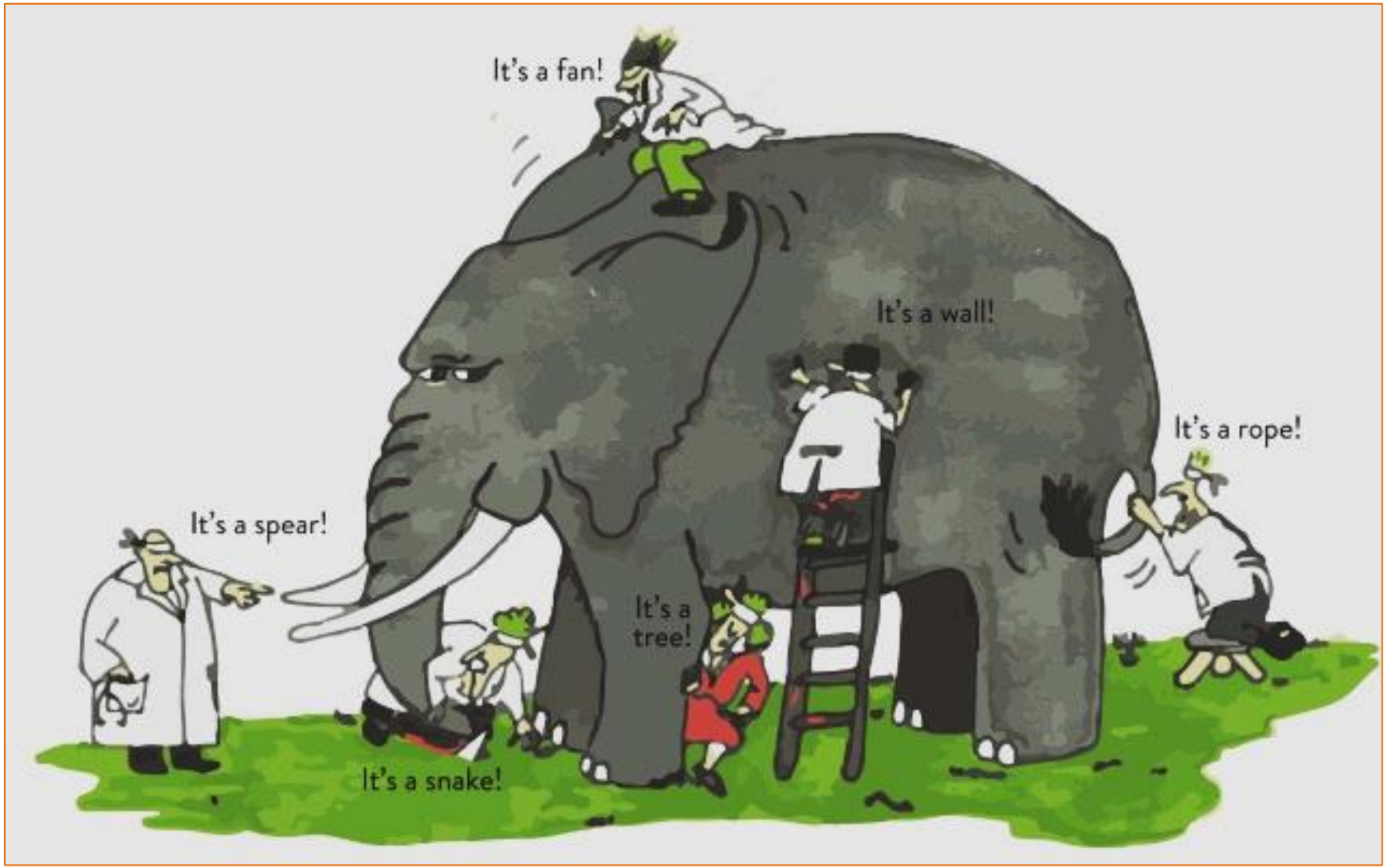
Et Cetera

Consequences:

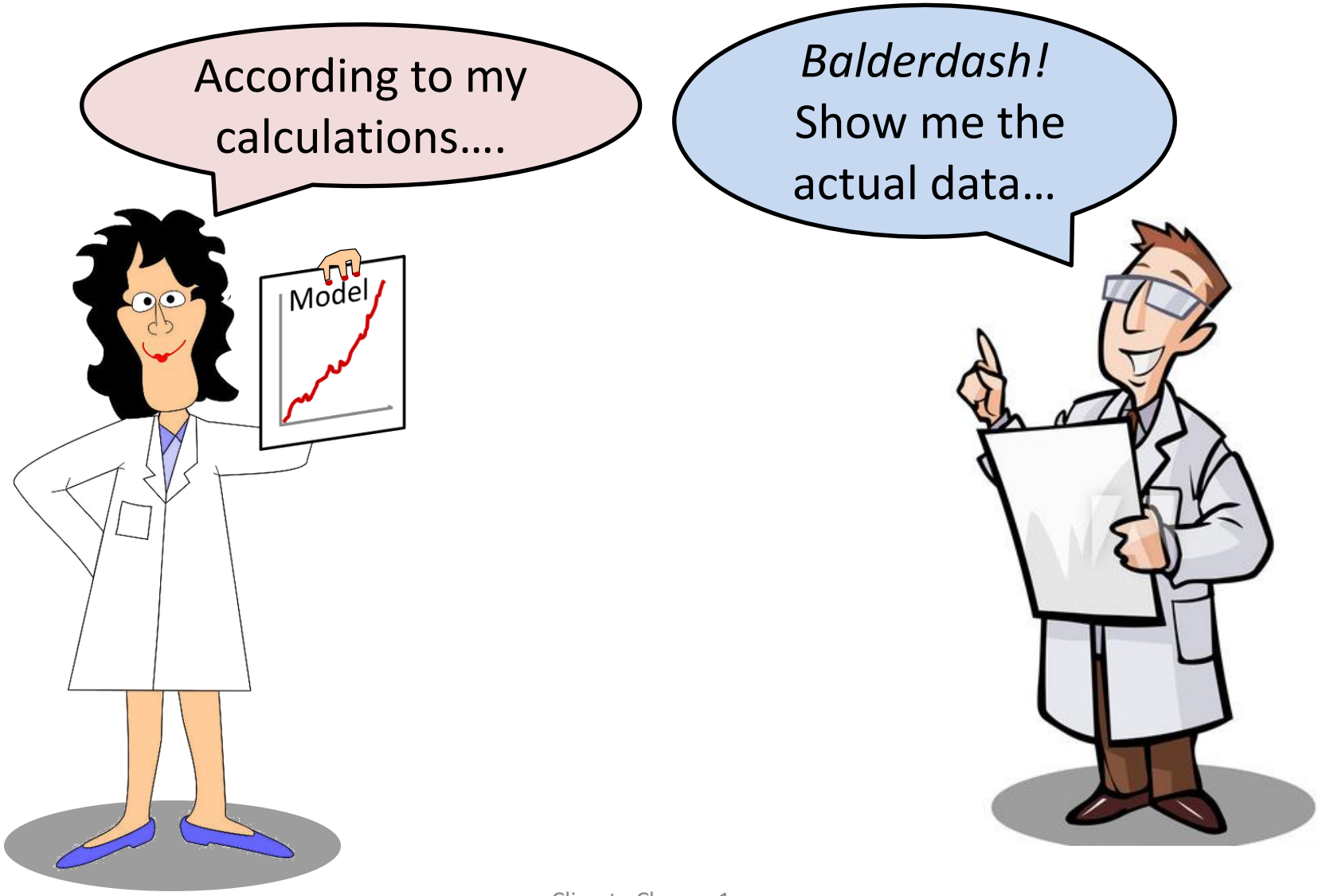
Almost

1. Nobody is likely to master it all.
2. Lots of opportunity for misunderstanding (*or mischief*)

Climate Change is Complex and Multi-Disciplinary



Theory *vs.* Empiricism



Theory *vs.* Empiricism

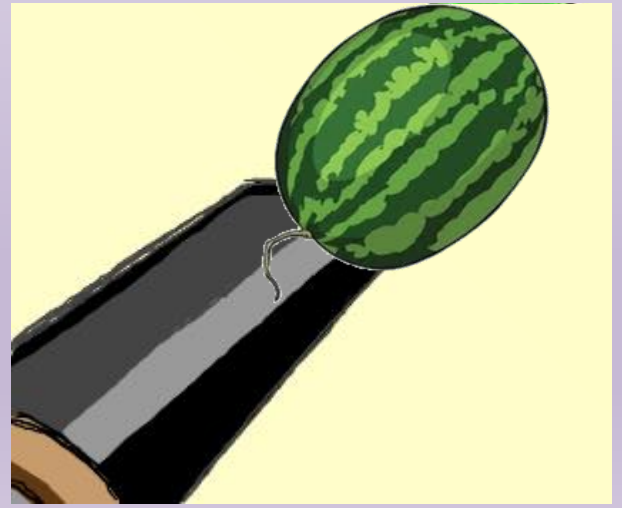
Silly
v
A Parable…

Theory *vs.* Empiricism

Silly
v
A Parable…

Theory *vs.* Empiricism

Silly
v
A Parable…



Theory *vs.* Empiricism

Silly
v
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Theory *vs.* Empiricism

Silly

A v Parable…

Theory *vs.* Empiricism

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v
A Parable…

Theory *vs.* Empiricism

Silly v A Parable…

Theory *vs.* Empiricism

Silly

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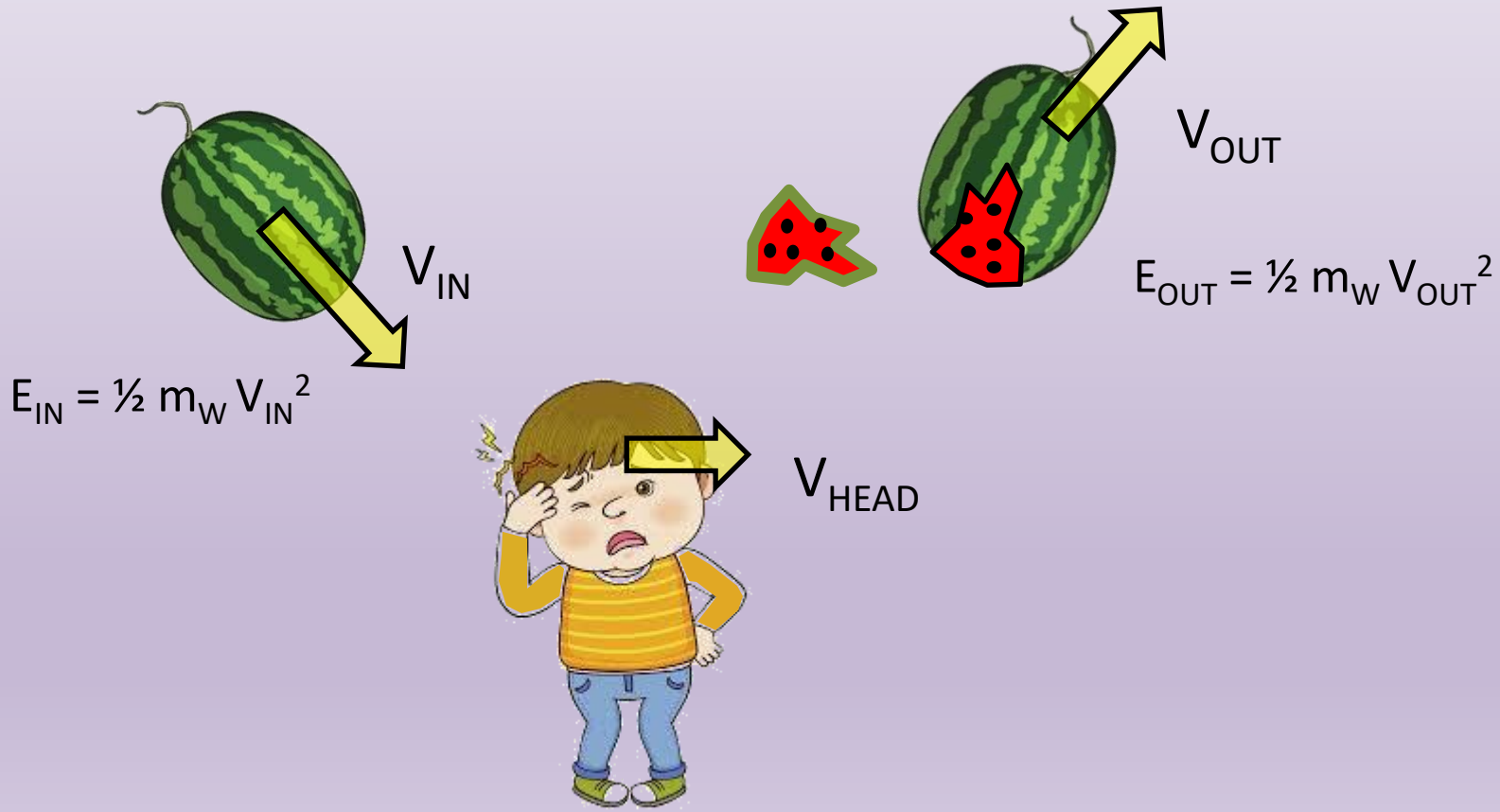
A Parable…

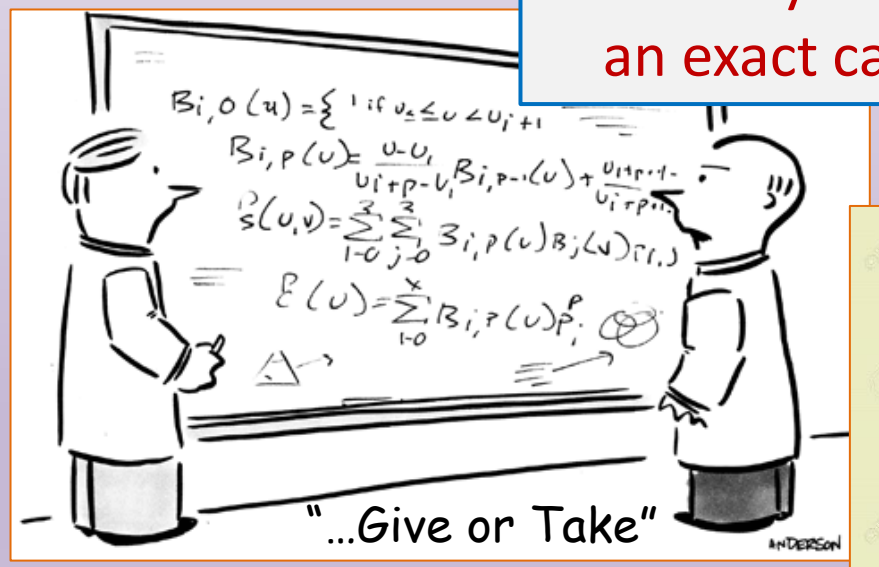


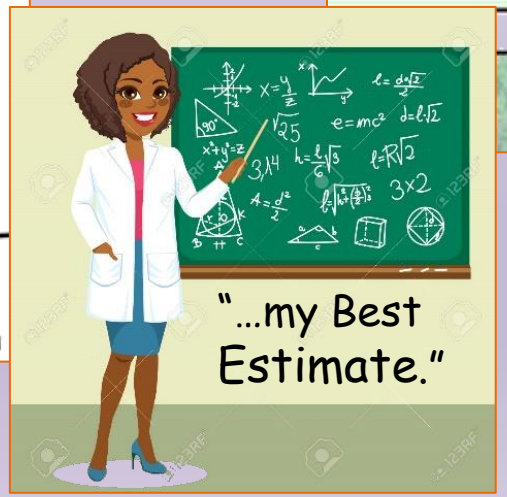
Theory *vs.* Empiricism

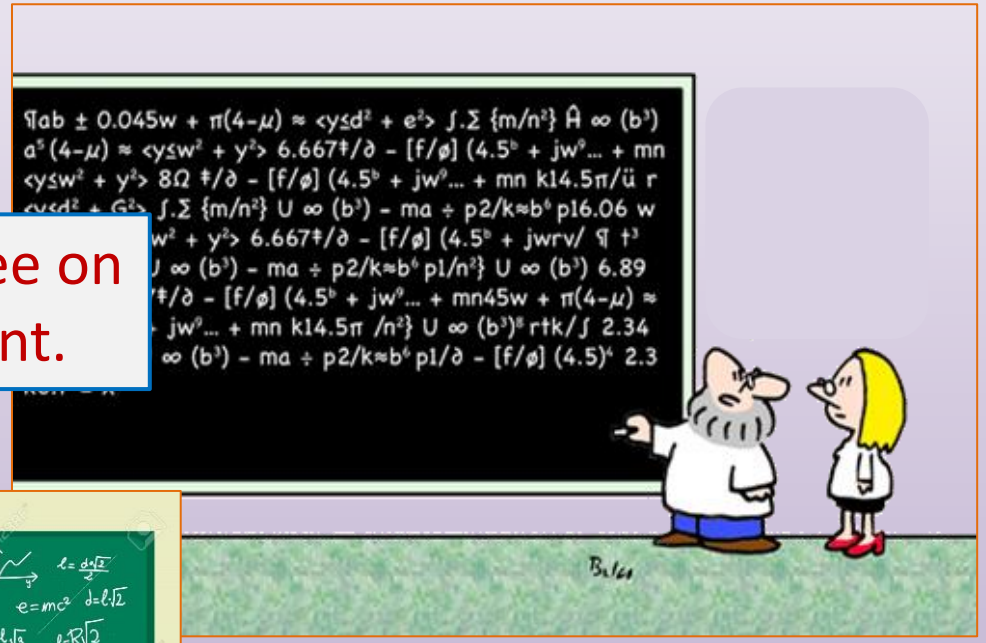
Silly v Parable…

Other modelers got to work…

…but they couldn't agree on an exact casualty count.





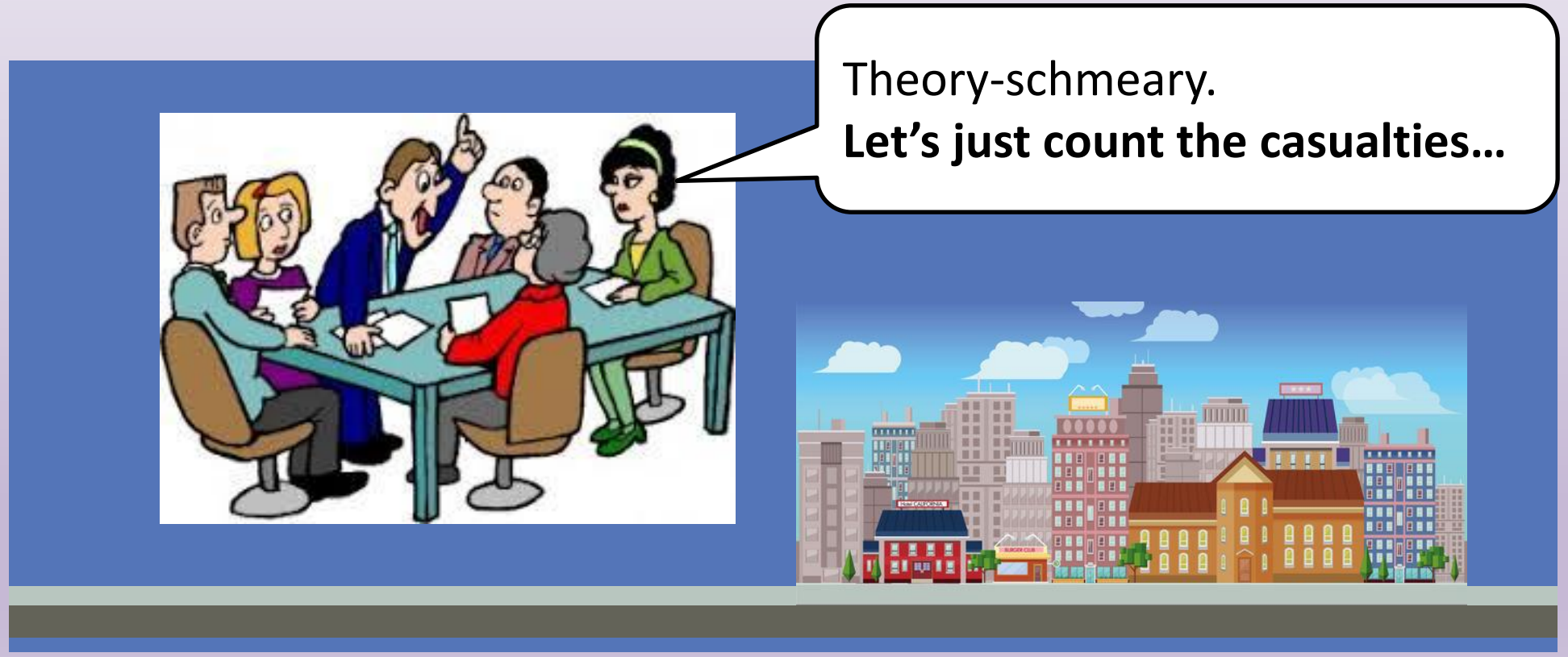


Theory *vs.* Empiricism

Silly

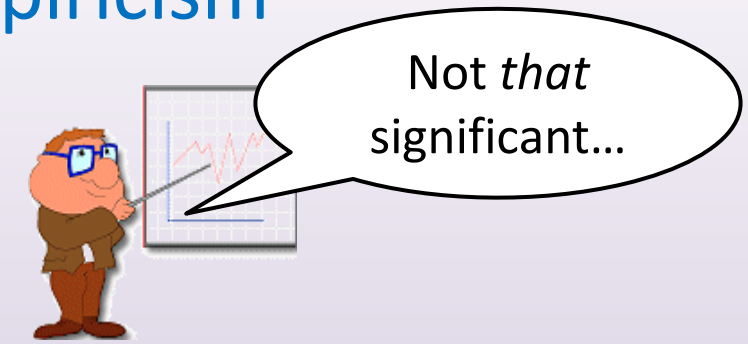
v

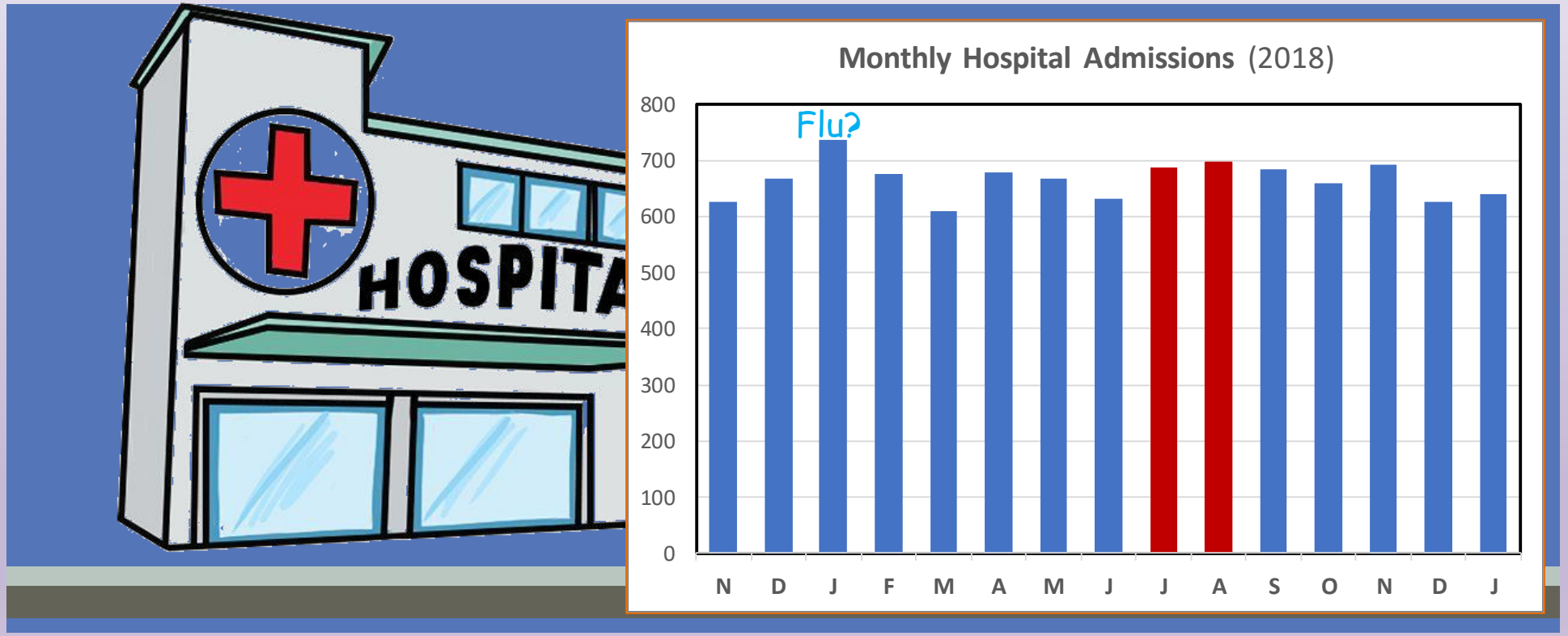
A Parable…



Theory *vs.* Empiricism

Silly
v
A Parable…





Theory *vs.* Empiricism

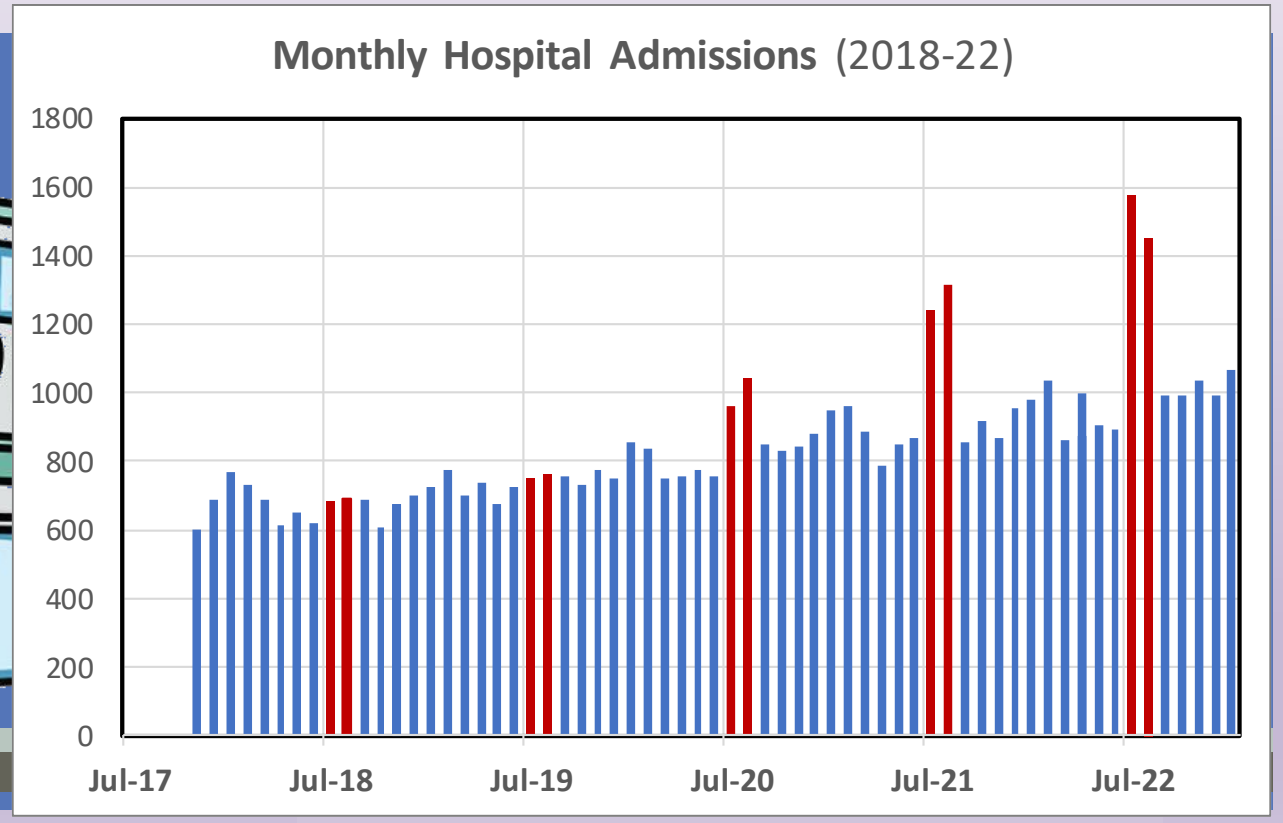
Silly
v
A Parable…

Epilogue…

Theory *vs.* Empiricism

Silly
v
A Parable…

5 years later…



IPCC

- Intergovernmental Panel on Climate Change
- Established 1988 by
  - World Meteorological Organization *and*
  - United Nations Environmental Programme
- Reviews and Assesses Literature
  - No original research
  - Thousands of volunteer scientists (Working Groups)
  - Reports reviewed by participating governments (~120)
  - Tendency for cautious consensus
- 5 major Assessment Reports (1990 – 2014)
  - **AR6** Due soon (April - October 2021, Summary 2022)
- Many Special Reports (2000-2020)

IPCC

- *Example:*
  Fifth Assessment Report (AR5)
- 3 main Components: (Working Groups)
  - WG I: The Physical Science Basis [Sept. 2013]
    - 800+ authors, over 2000 pages, 8K references
  - WG II: Impacts, Adaptation & Vulnerability [Mar. 2014]
    - 700+ authors, over 1800 pages
  - WG III: Mitigation of Climate Change [Apr. 2014]
    - 400+ authors, over 1400 pages, 10K references
  - Synthesis Report (SYR) [Nov 2014]
    - 150 pages

These are available online at, e.g.,
www.ipcc.ch/assessment-report/AR5/

- *Example:*
  Fifth Ass
- 3 main Cor
  - WG I: Th
    - 800+ a
  - WG II: I
    - 700+ a
  - WG III:
    - 400+
  - Synthes
    - 150 p

ar. 2014]

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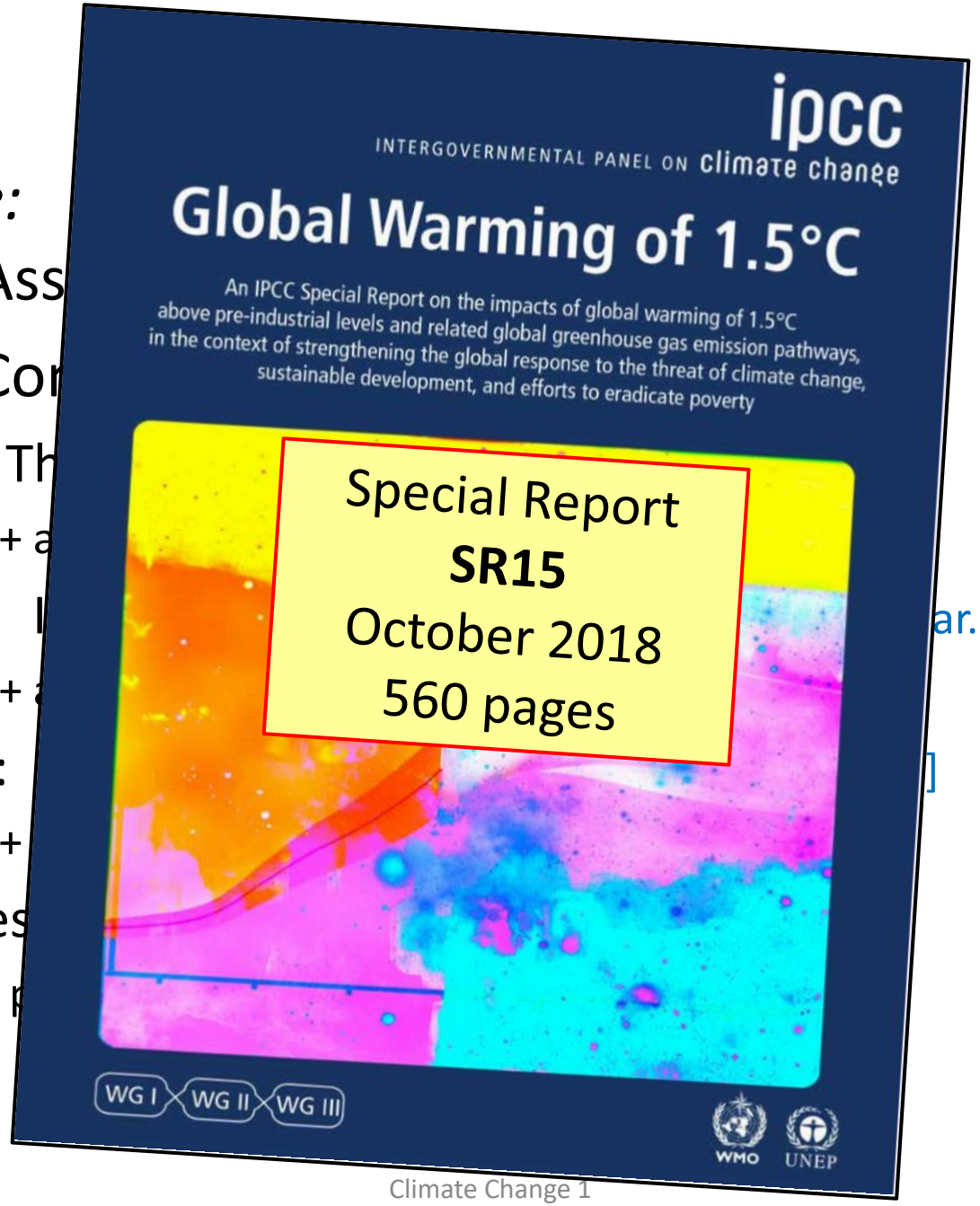
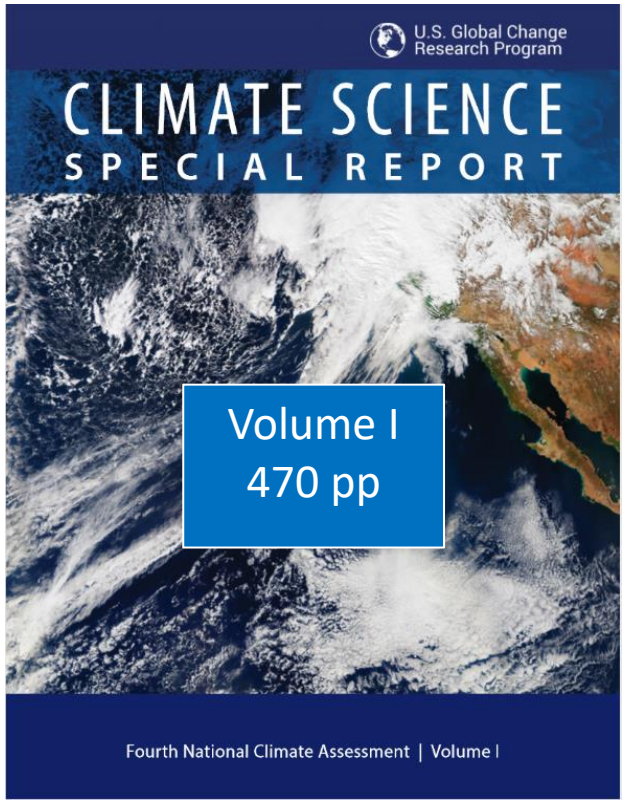
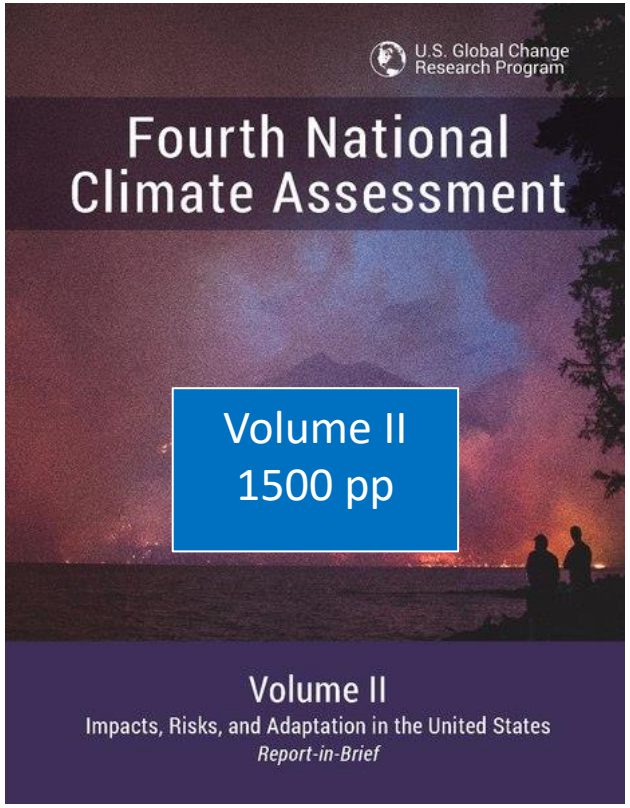


US National Climate Assessments

- 13 Federal Agencies (led by NOAA)
  - U.S. Global Change Research Program (USGCRP)
  - Pursuant to Global Change Research Act of 1990
  - https://GlobalChange.gov
- 4 Reports to date:
  - NCA1 (2000)
  - NCA2 (2009)
  - NCA3 (2014)
  - **NCA4** (2017/18)
  - NCA5 (due 2023)
- Tend to lean heavily on IPCC Assessments

°C → °F ☺





Changes at NOAA

The New York Times

Oct 28, 2020

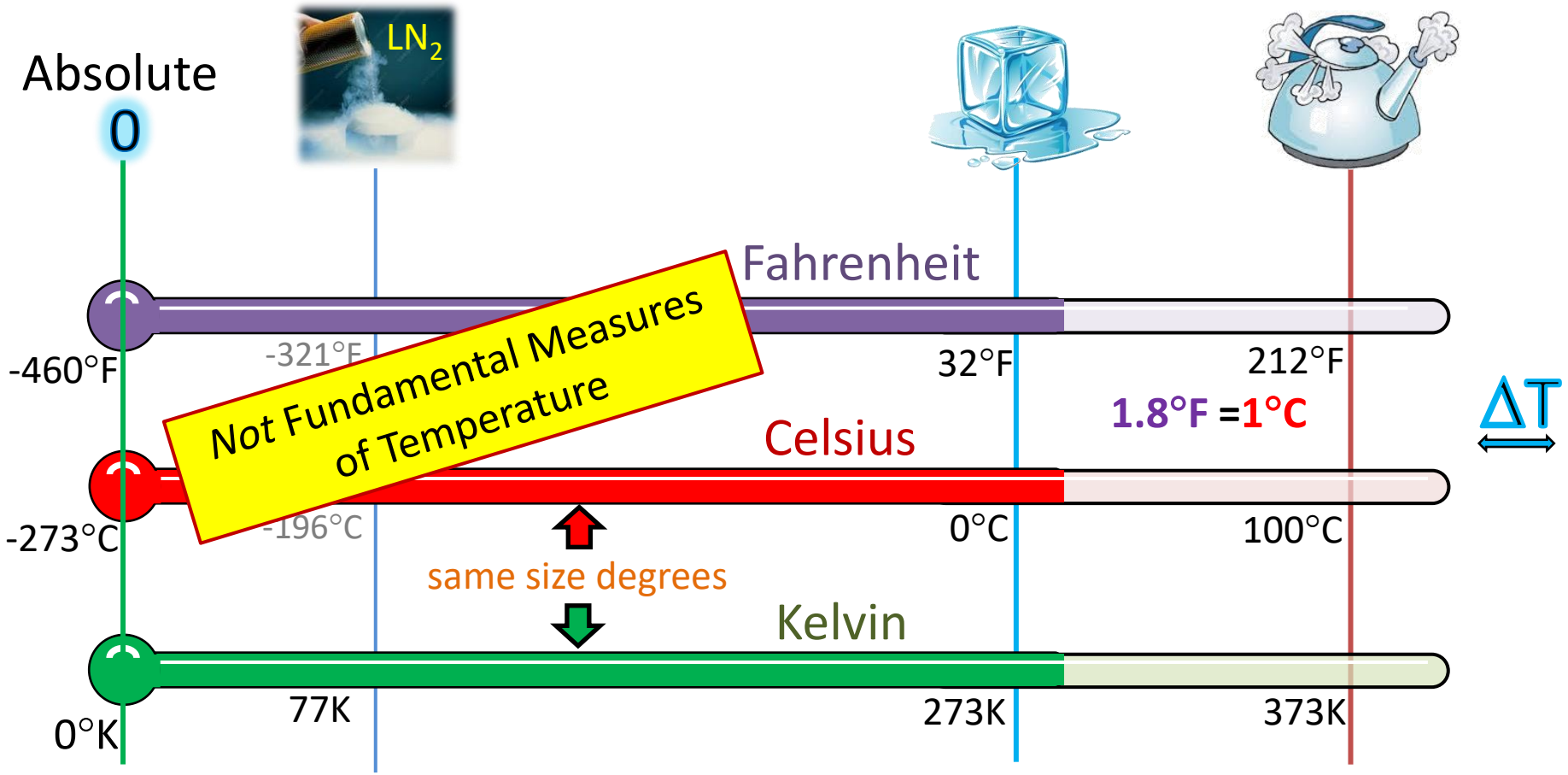
As Election Nears, Trump Makes a Final Push Against Climate Science

WASHINGTON — The Trump administration has recently removed the chief scientist at the National Oceanic and Atmospheric Administration, the nation's premier scientific agency….

Craig McLean, NOAA Chief Scientist fired September 2020.

Replaced by Ryan Maue
(ex-Cato Institute)

Temperature Scales for Global Warming



Temperature Scales for Global Warming

Absolute

0

Fahrenheit

-460°F

-321°F

32°F

212°F

1.8°F =1°C

ΔT

Celsius

-273°C

-196°C

0°C

100°C

same size degrees

Kelvin

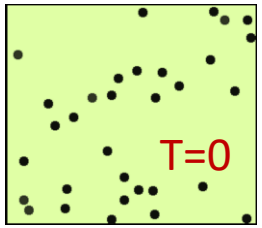
T

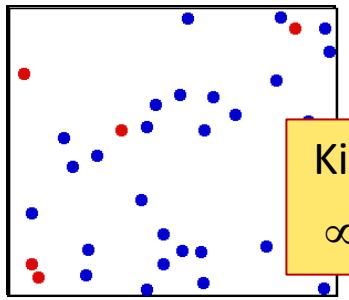
0°K

77K

273K

373K

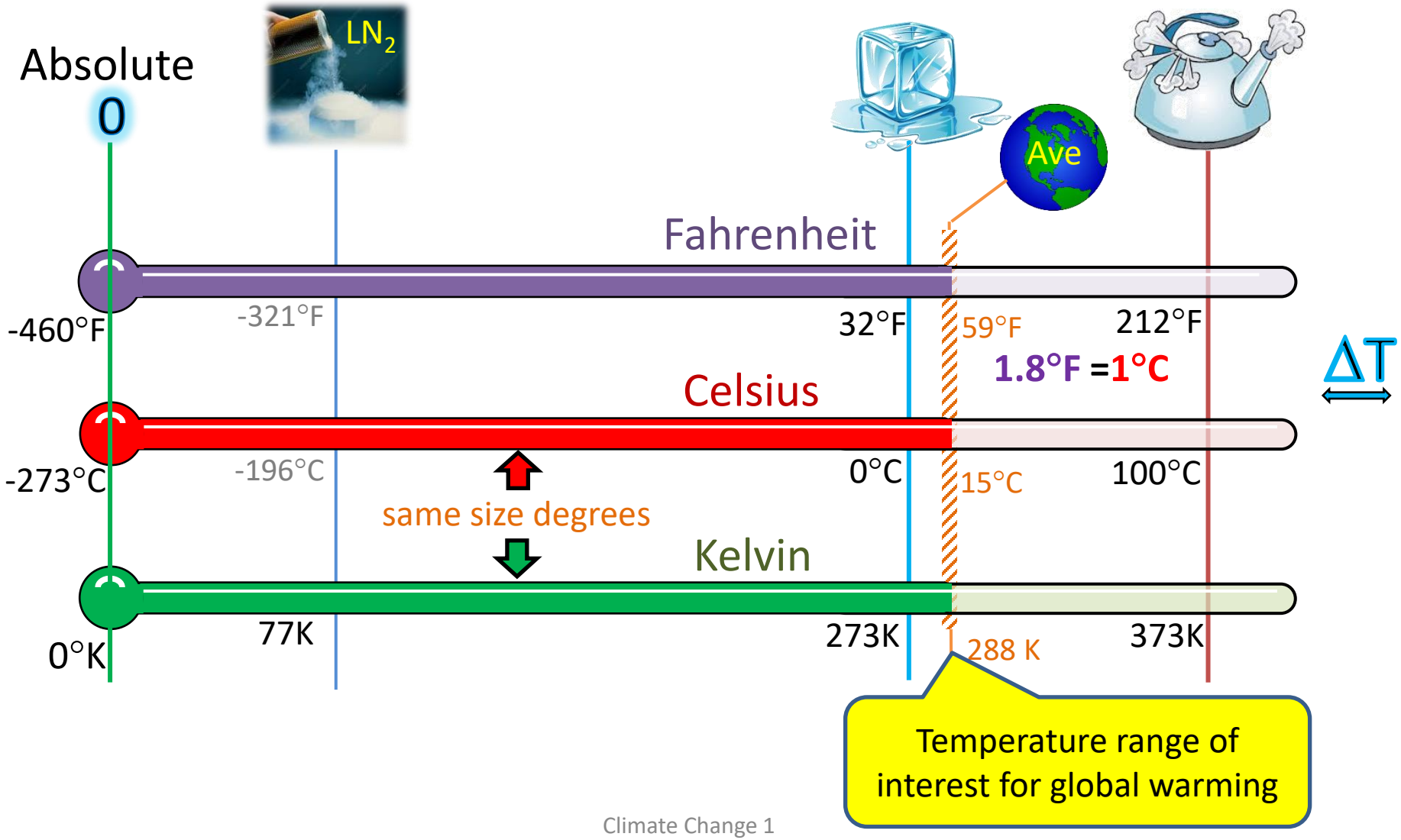




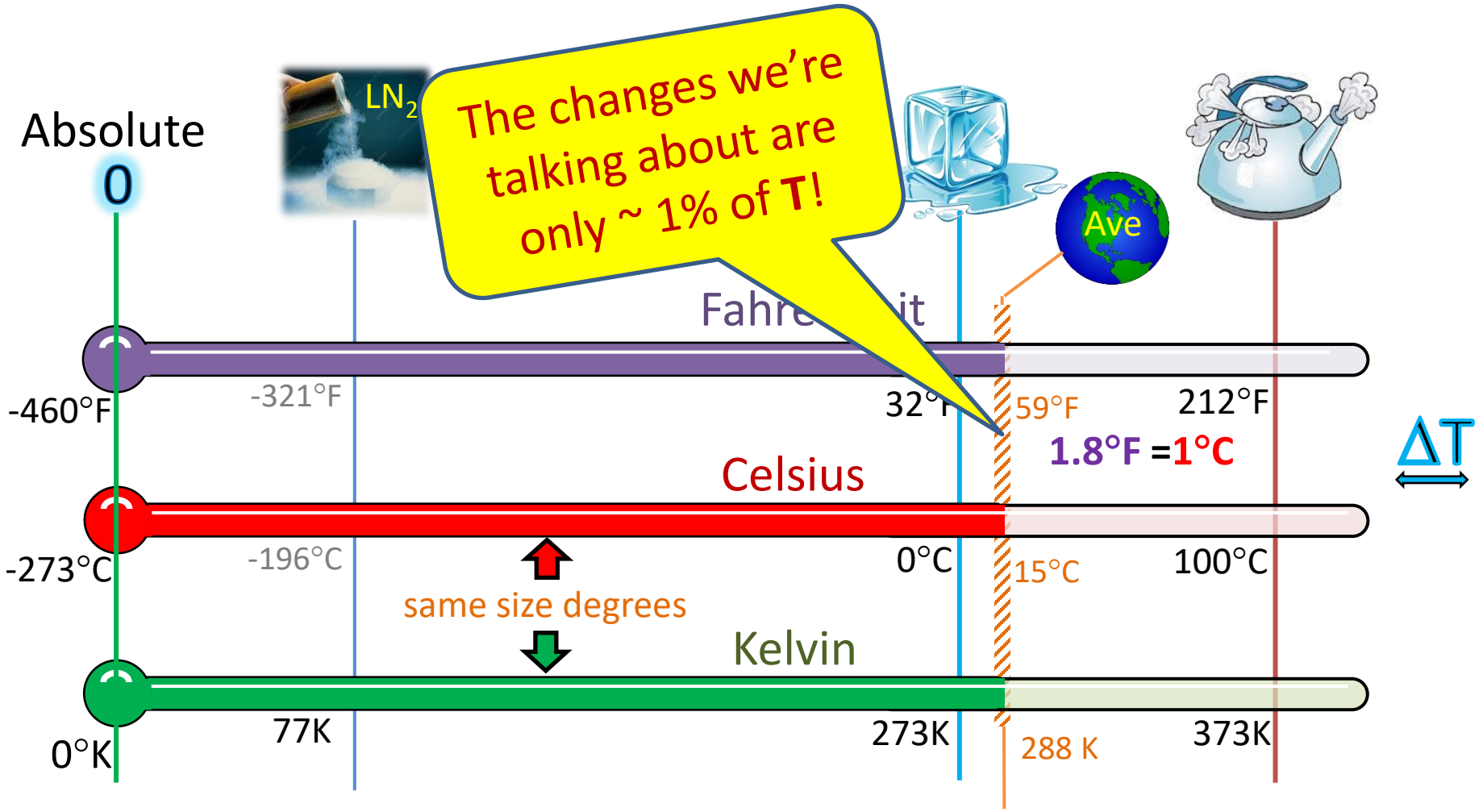
Kinetic Energy ∝ **T** (absolute)

The physically meaningful scale, used for most calculations

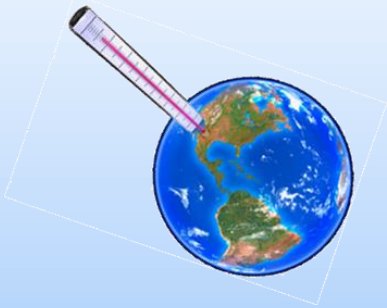
Temperature Scales for Global Warming



Temperature Scales for Global Warming



Questions So Far?



Blackbody Radiation

A key concept …

Blackbody Radiation

- Things glow
- Warmer things glow brighter
  - *much* brighter
- Warmer things glow bluer
  - Cooler things redder
- Black* things glow most
  -

Blackbody Radiation

- Things glow
- Warmer things glo
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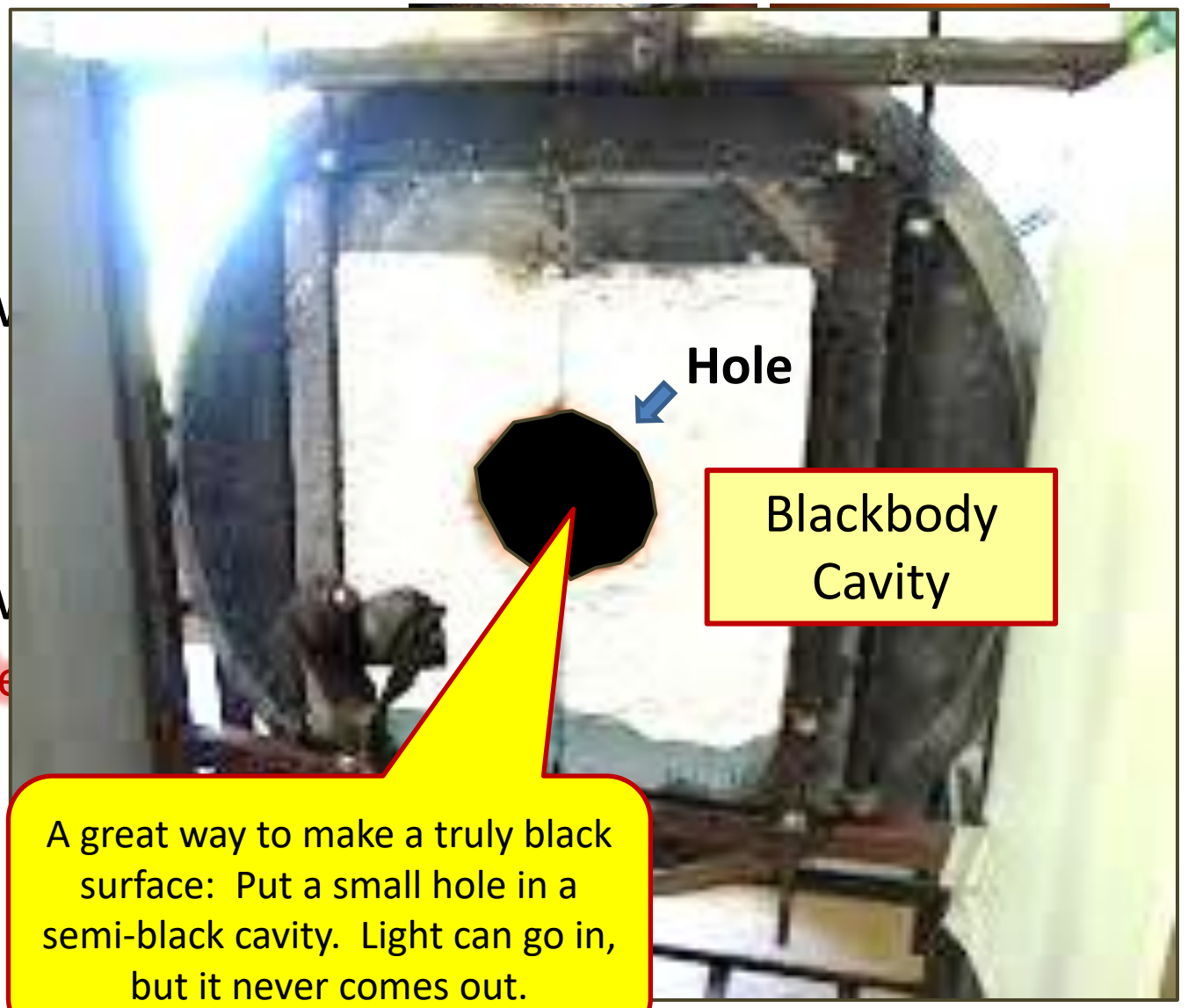
  - *much* brighter
- Warmer things glo
  - Cooler things redd
- Black* things glow
  -



Blackbody Radiation

- Things gl
- Warmer th
  brighter
  - *much* bri
- Warmer th
  - Cooler th
- Black* thin
  - white, tra
    reflective

Blackbody Radiation

- Things glow
- Warmer things glow brighter
  - *much* brighter
- Warmer things glow bluer
  - Cooler things redder
- Black* things glow most
  - white, transparent or reflective things glow less…. even if as hot.






Everything above Absolute Zero Glows…. even Ice Cubes

Our kitchen freezer drawer…..

Plywood left in for an hour to get very cold.

Ice cube on verge of melting placed there at the last minute…

Everything above Absolute Zero Glows…. even Ice Cubes

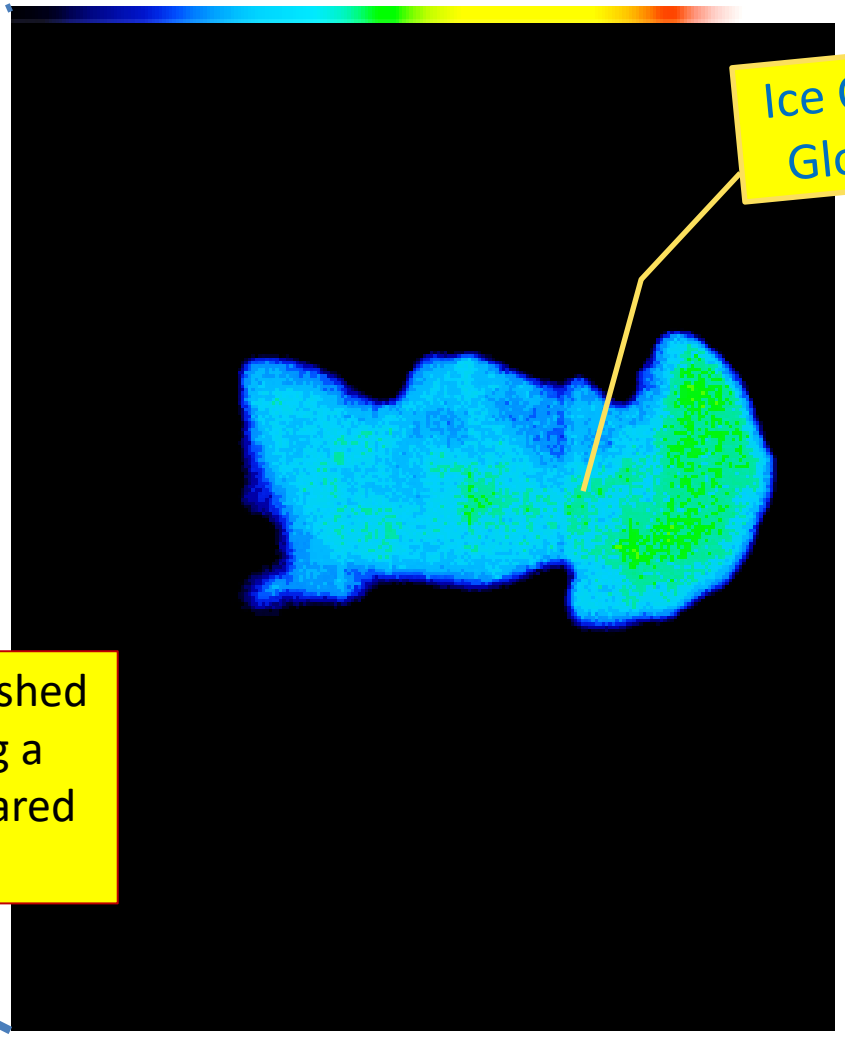
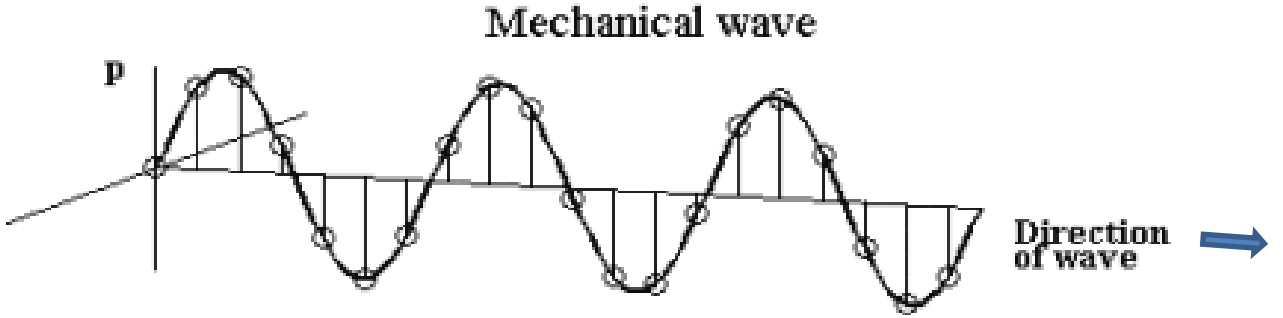


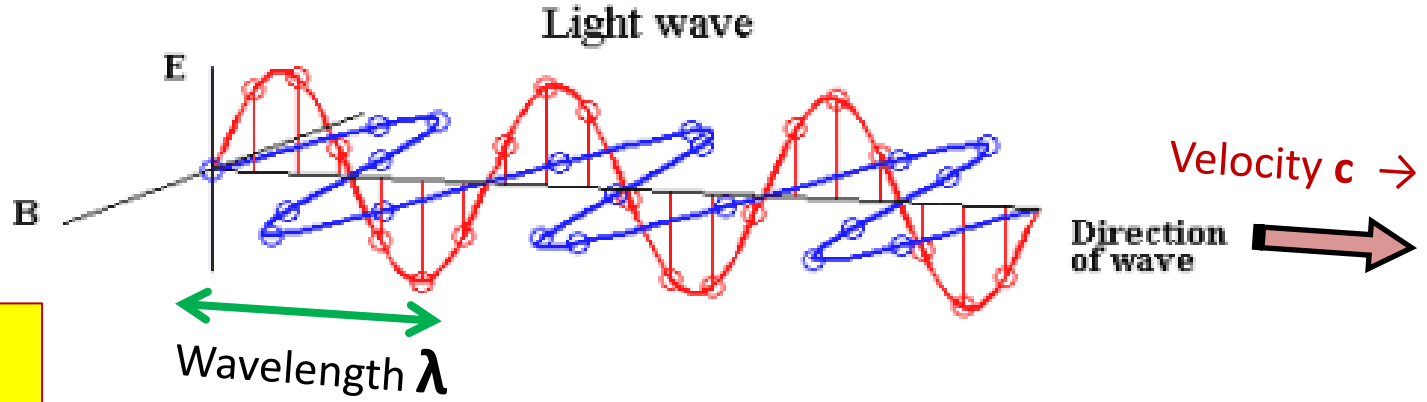
Image of dashed area using a special infrared camera

Radiation: Electro-Magnetic Waves

- James Maxwell
  Scot, 1831-1879

- What was "waving"?
  It was *electric* and *magnetic* fields

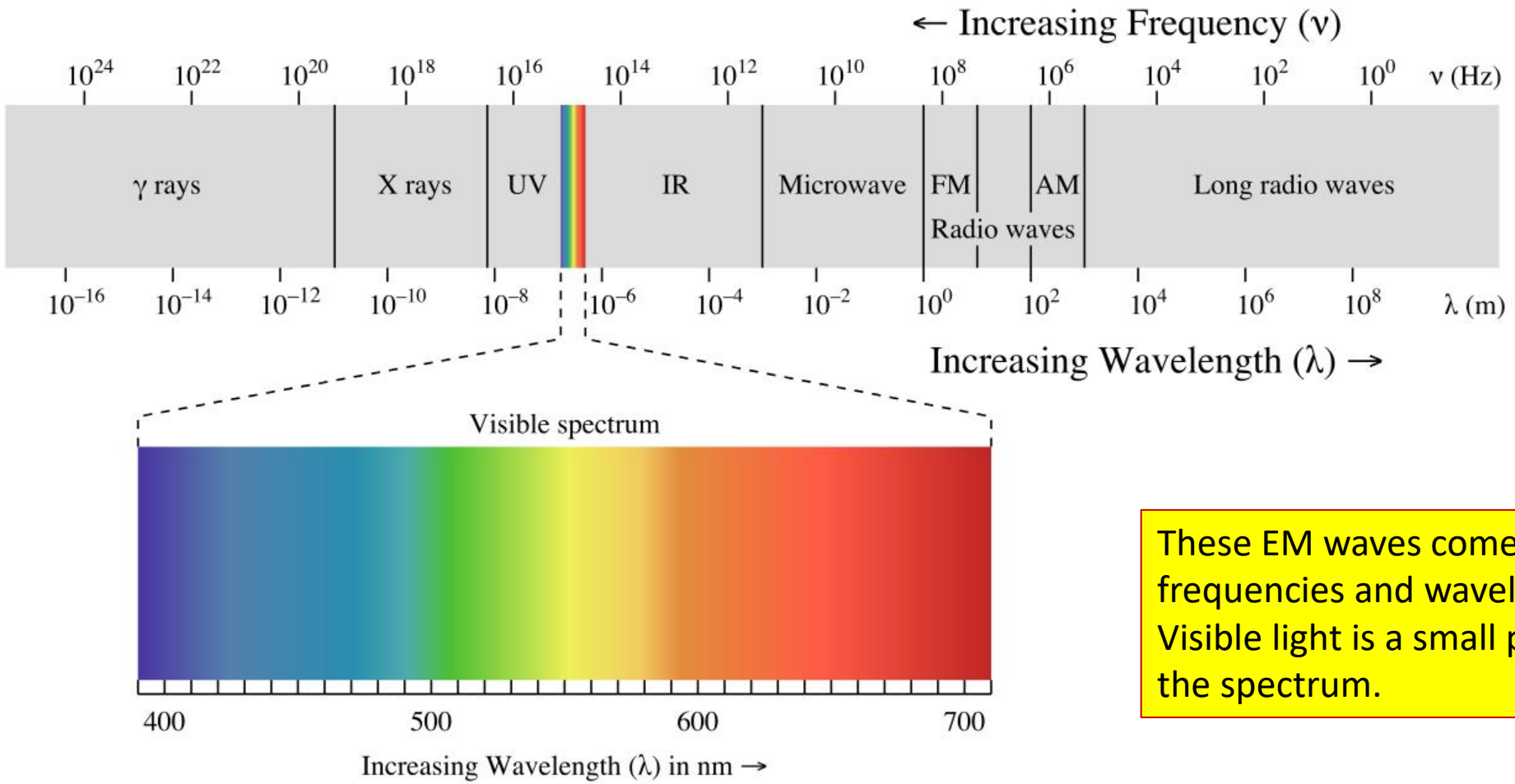




Institute of Sound and Vibration Research, U. of Southampton, UK

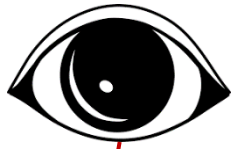
A vibrating electric charge generates EM waves (electric and magnetic fields) traveling at speed of light c.

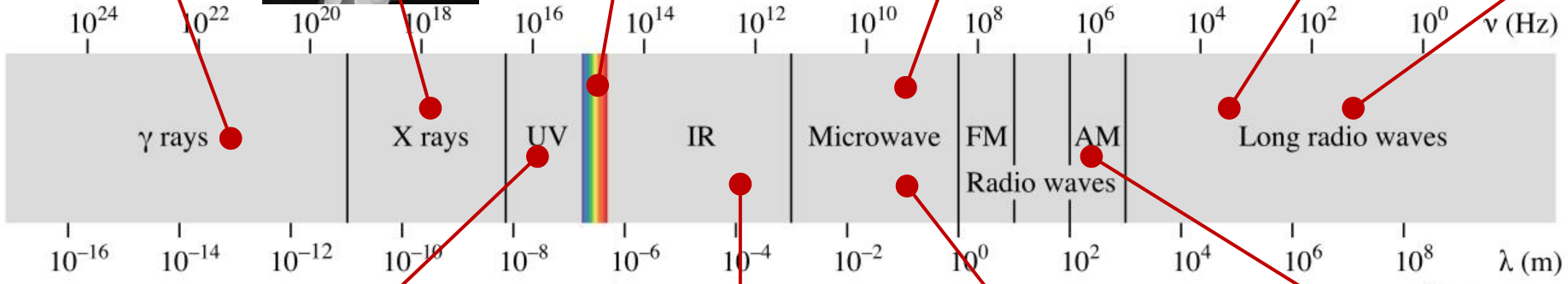
Very Broad EM Spectrum



These EM waves come in all frequencies and wavelengths. Visible light is a small portion of the spectrum.

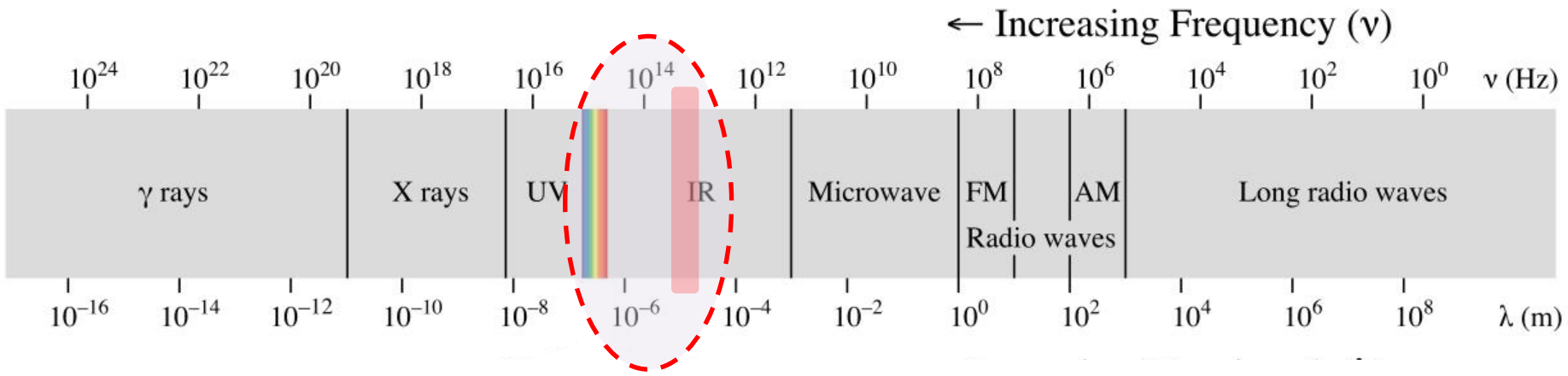
y Broad E n





Some examples of familiar EM waves

Very Broad EM Spectrum

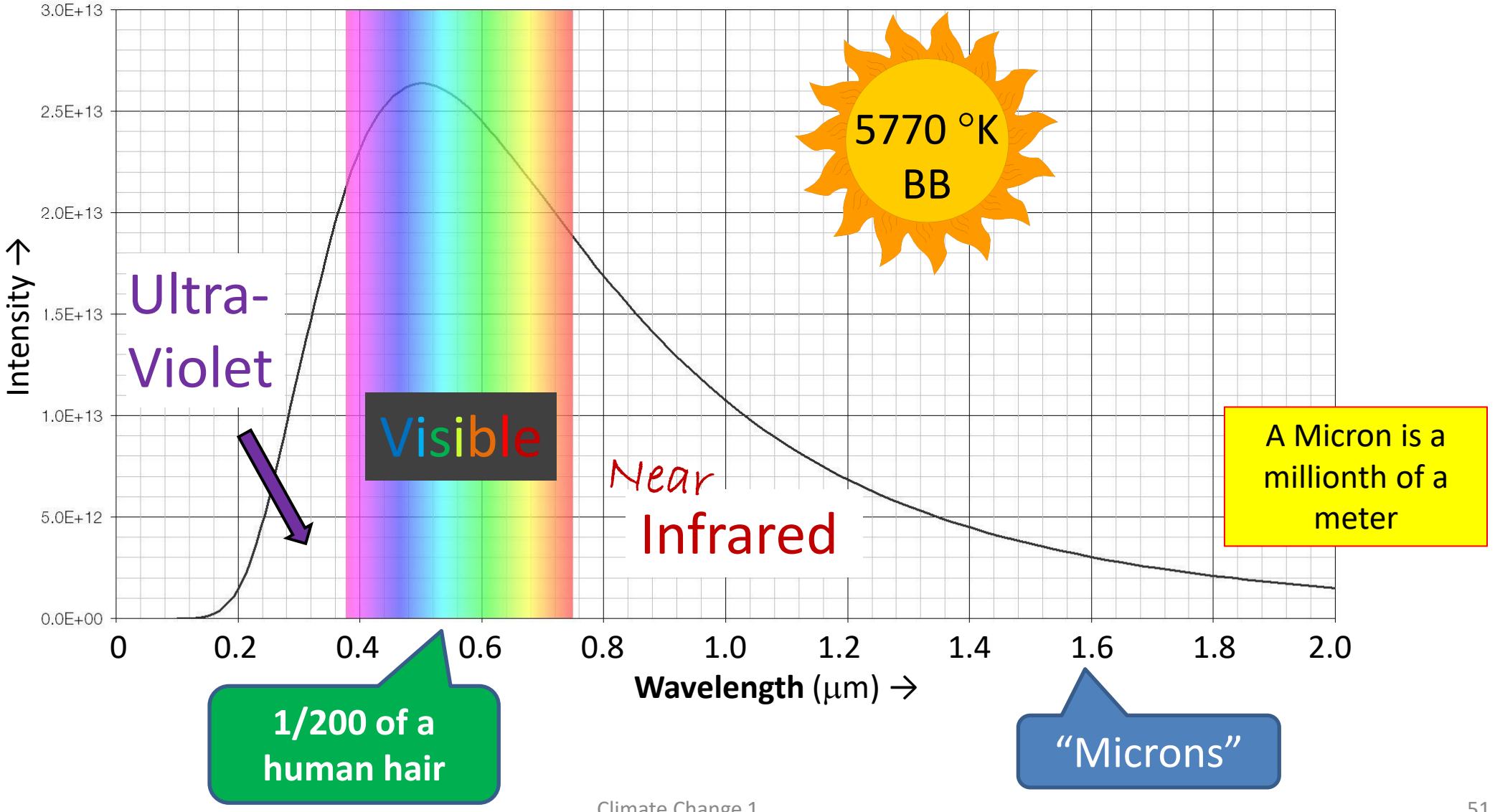


The important regions for Climate Change are these two:

1. The Visible range (and nearby UV and IR wavelengths) emitted by the sun, *and*

2. The Longwave IR emitted by Blackbodies at normal earth temperatures

The Solar Spectrum (Simplified)



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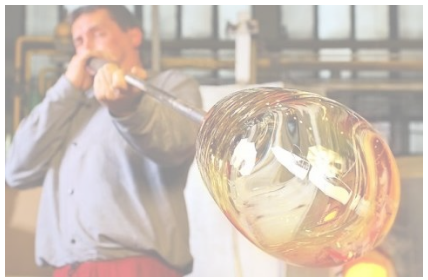
  - Cooler things redder
- Black* things glow most
  - white, transparent or reflective things glow less

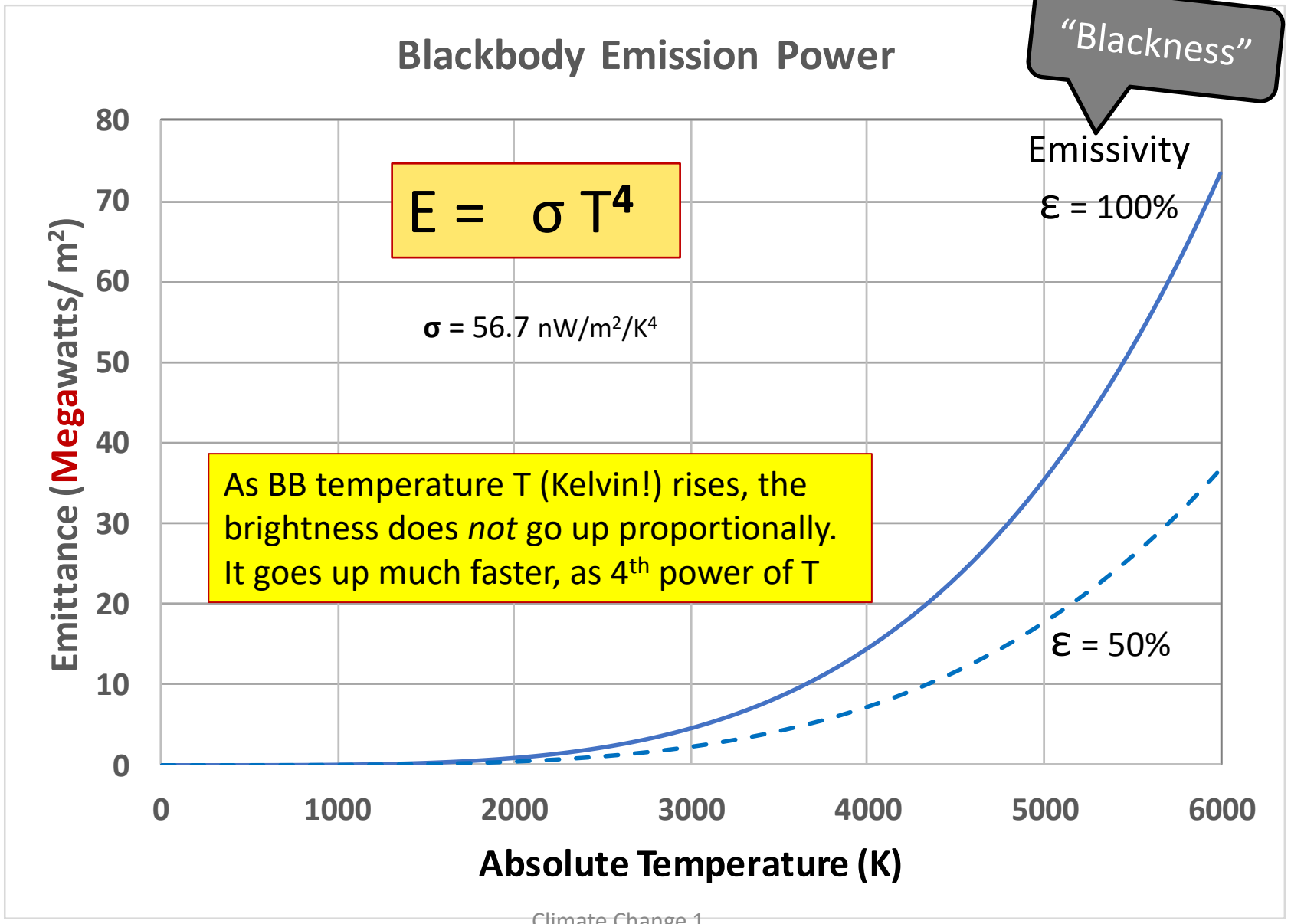




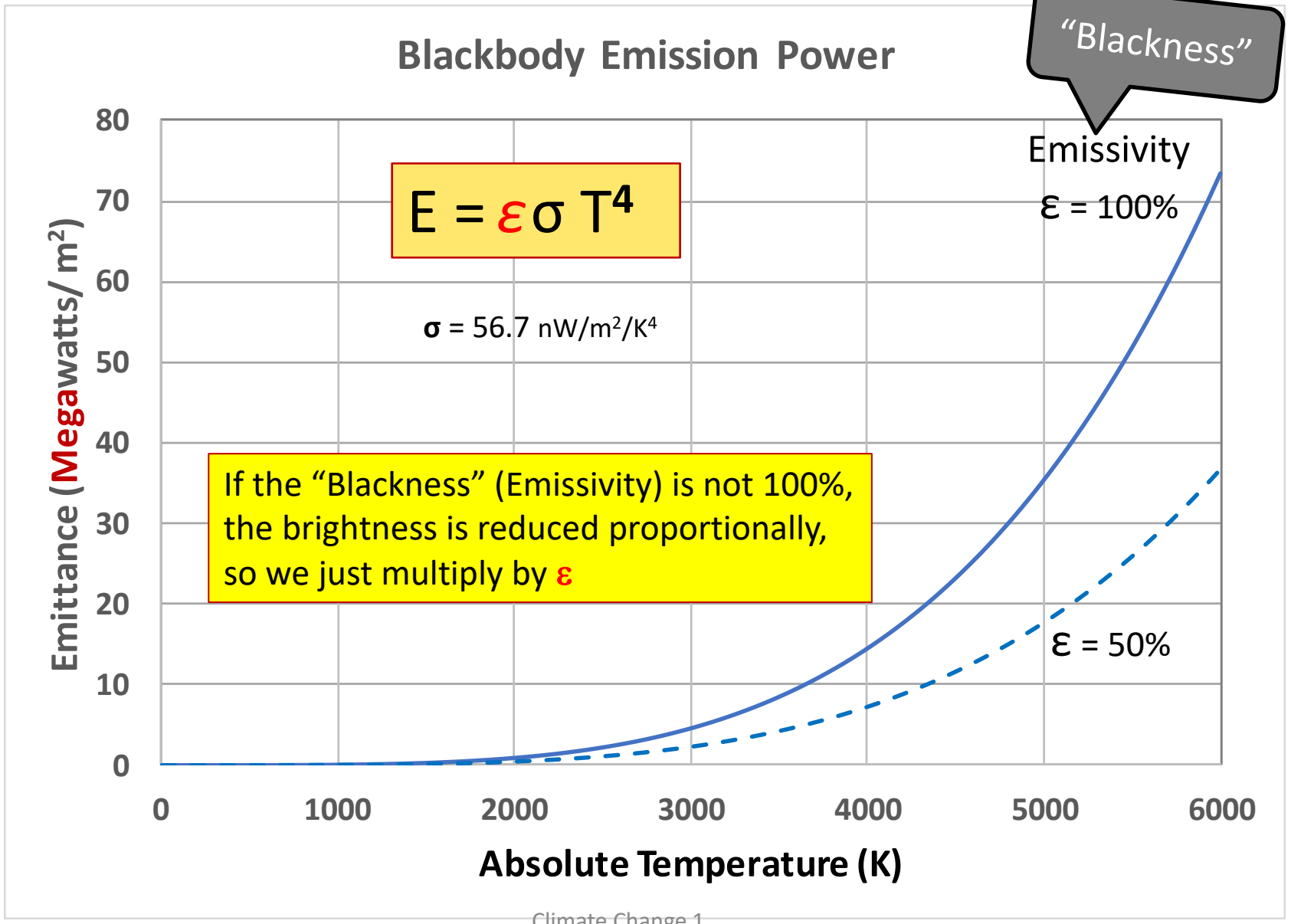


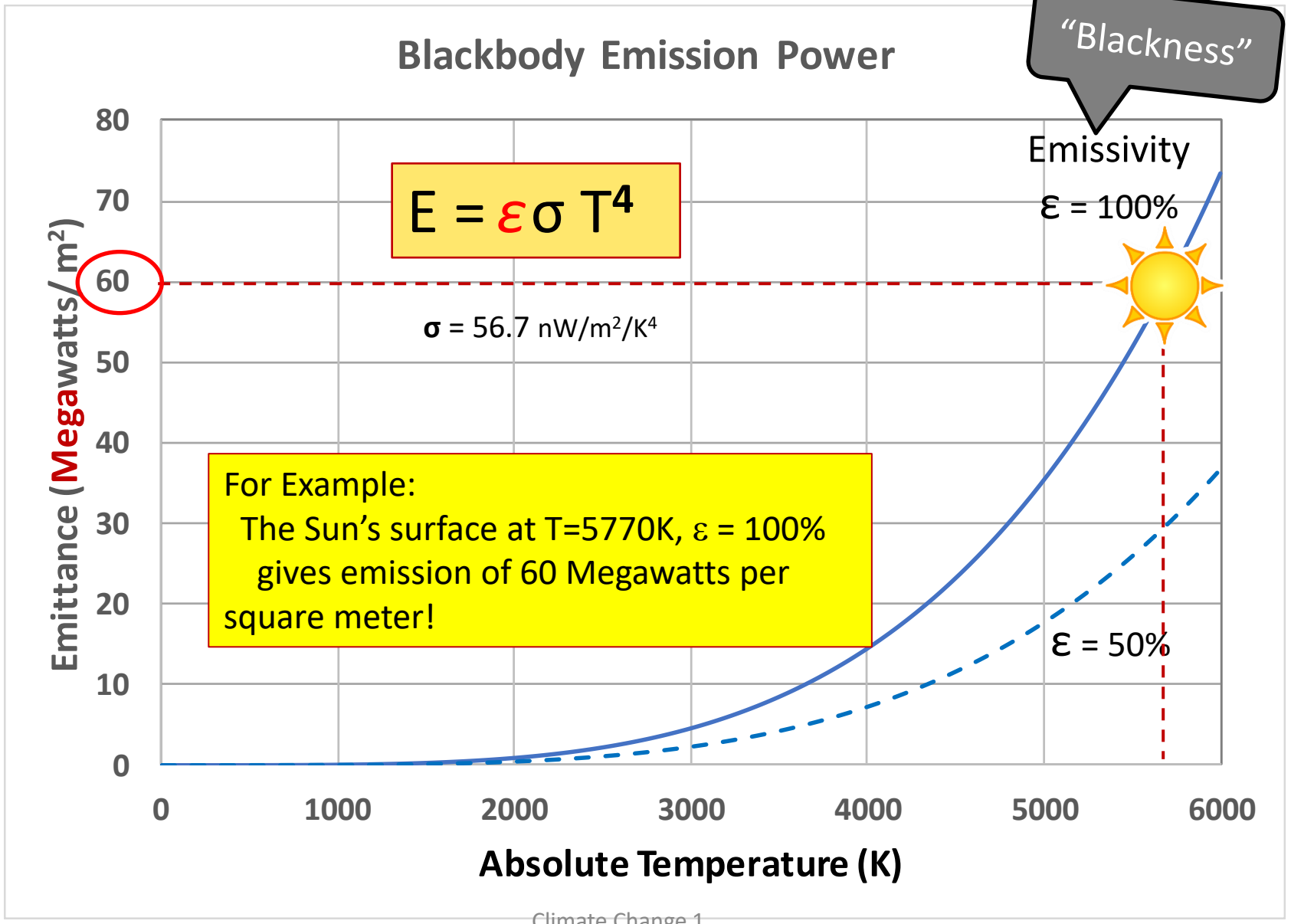
Stefan-Boltzmann Law



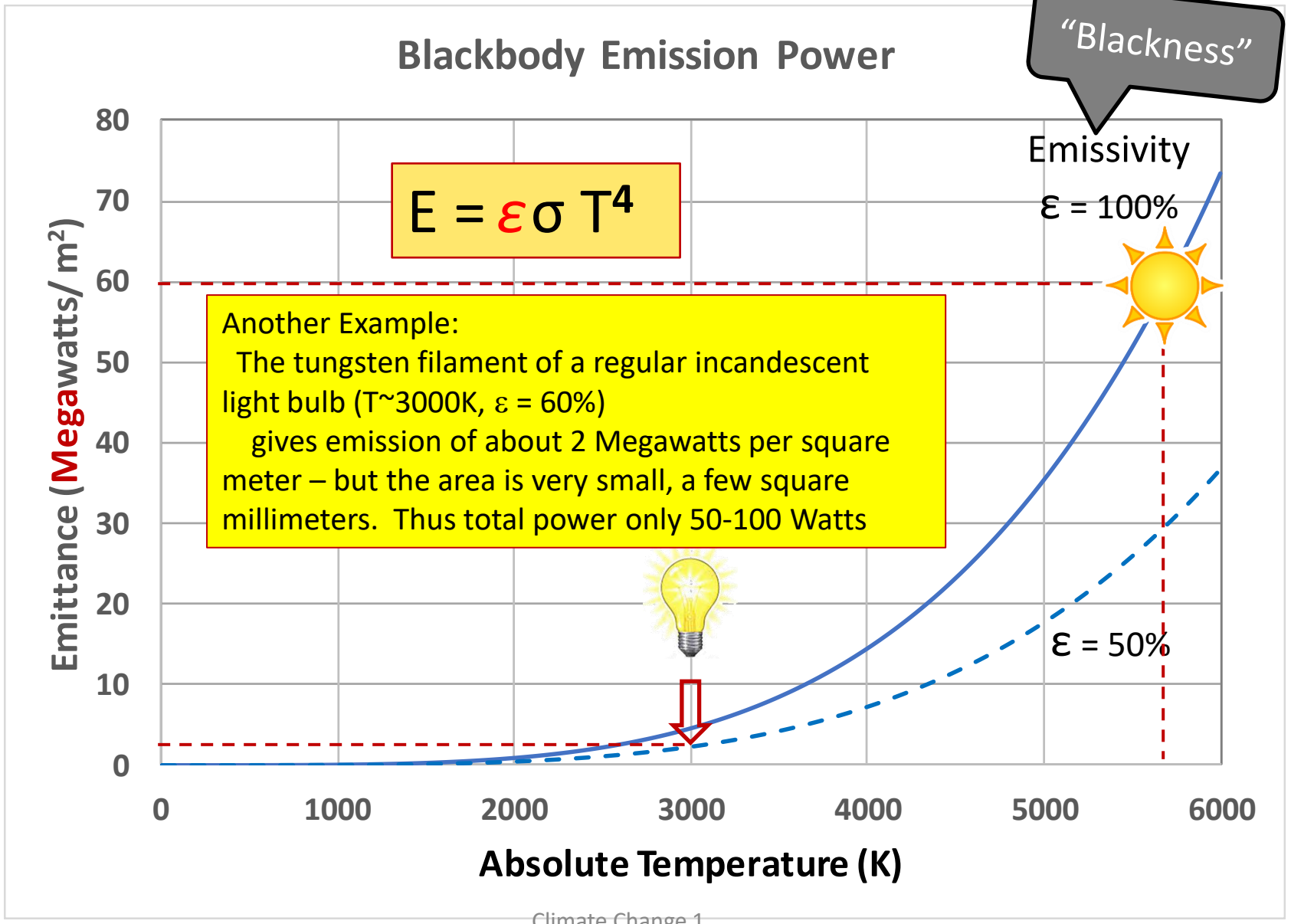
Stefan-Boltzmann Law



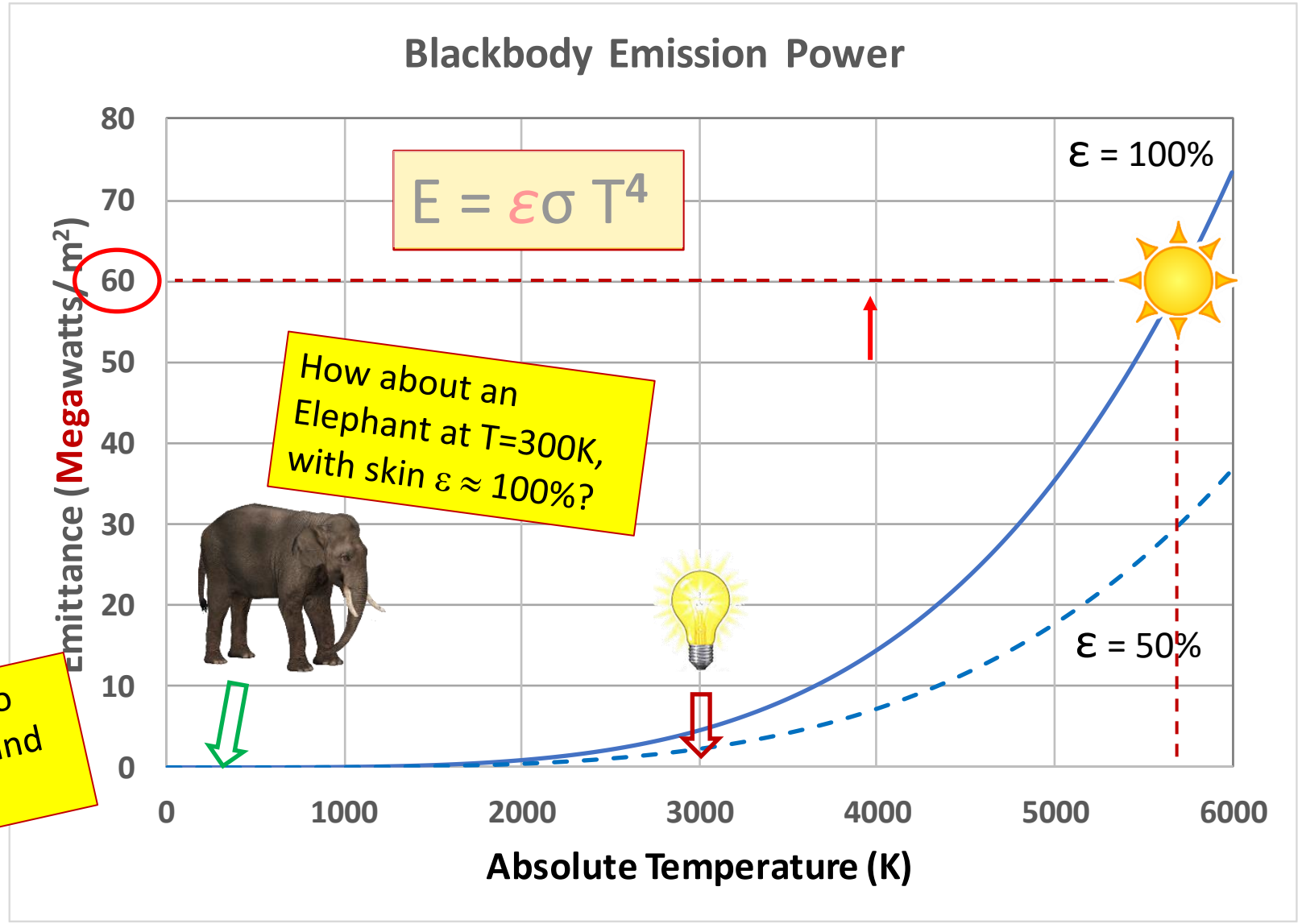
Stefan-Boltzmann Law



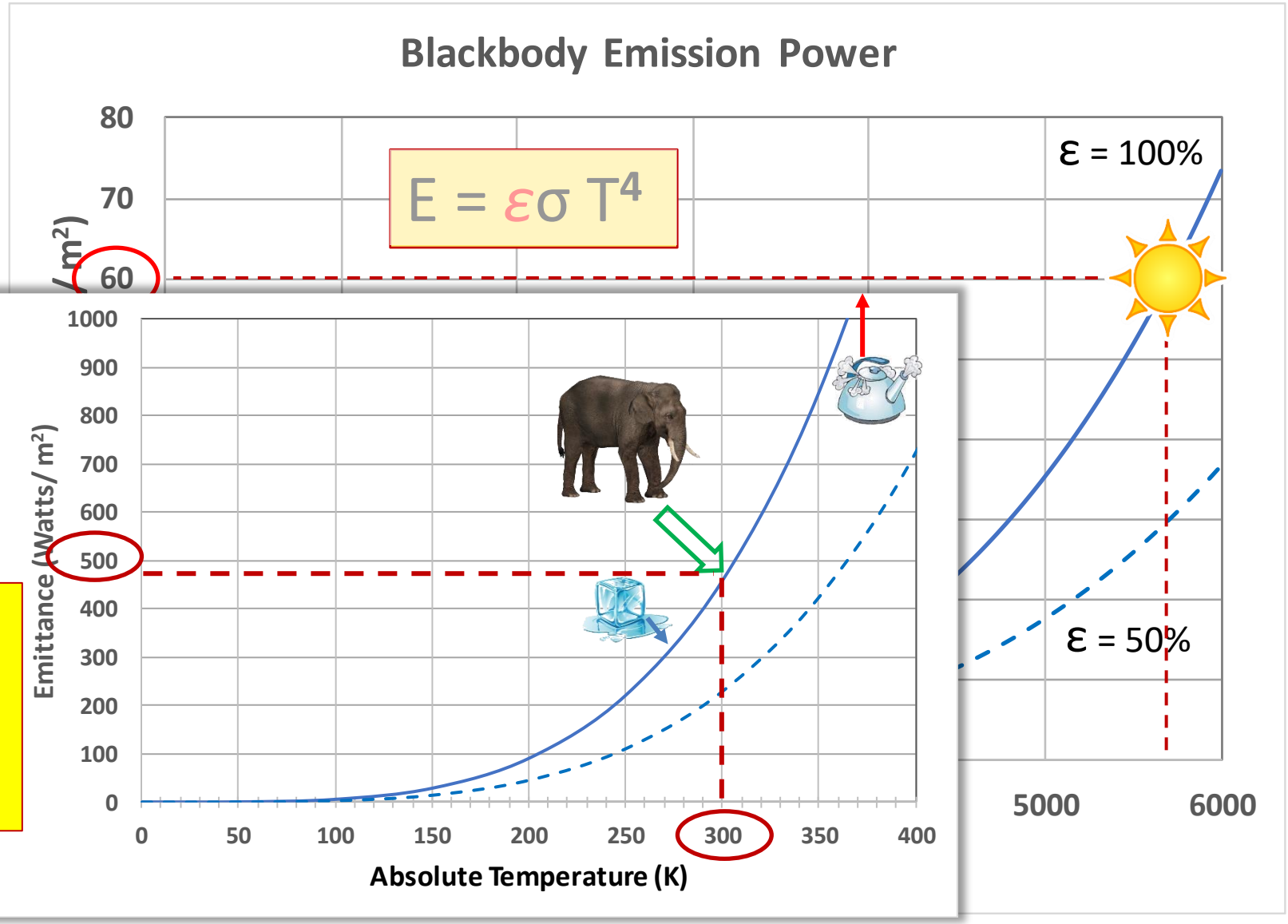
Stefan-Boltzmann Law



Stefan-Boltzmann Law



Stefan-Boltzmann Law



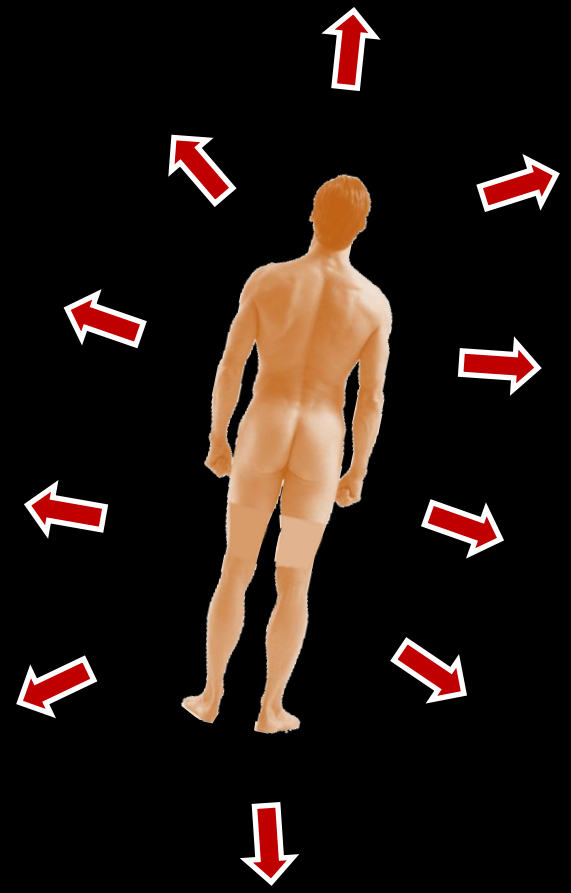
So the Elephant's skin emits about **500** Watts per m^2 of Blackbody Radiation

Human in Empty Space

T = 306 K (91° F)
E = 500 W/m^2

Area ≈ 1.7 m^2
Radiated Power
≈ **850 W**

Caloric
Requirement:
18,000 Cal/day



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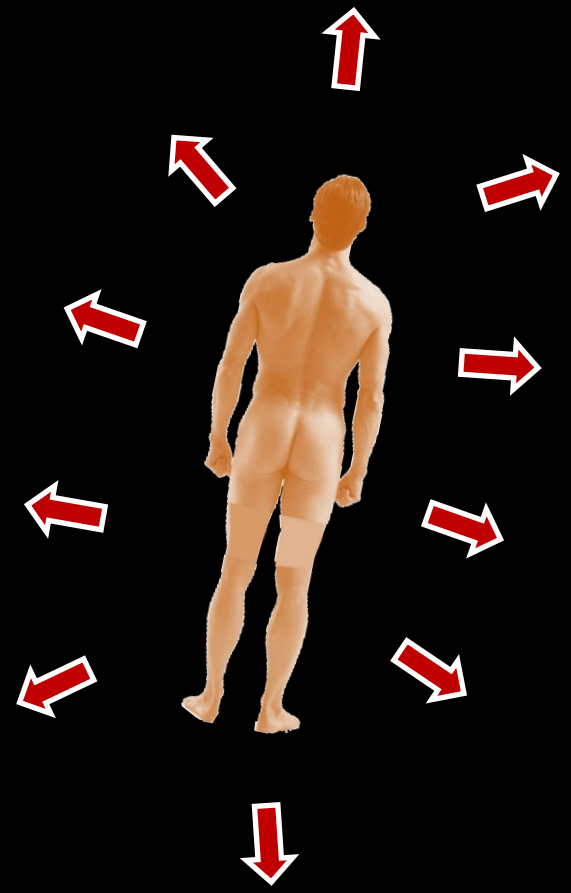


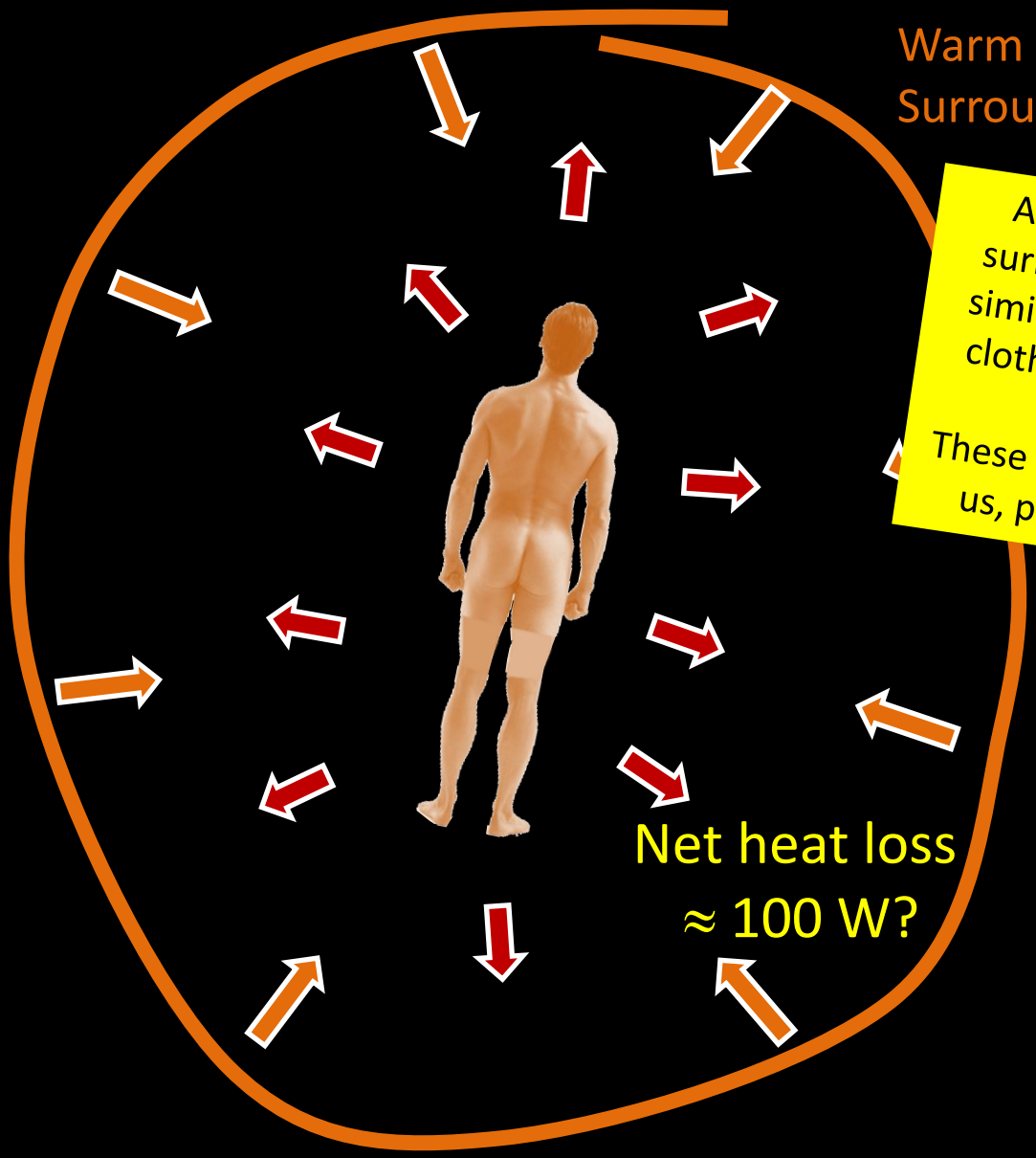
So how do we survive on 2000 Calories/day?

Human in Empty Space

T = 306 K (91° F)
E = 500 W/m^2

Area ≈ 1.7 m^2
Radiated Power
≈ **850 W**

Caloric Requirement:
18,000 Cal/day



Answer: We are always surrounded by surfaces at similar temperature (walls, clothing, the ground, even the sky.)
These radiate energy back to us, partly compensating.

Blackbody Radiation

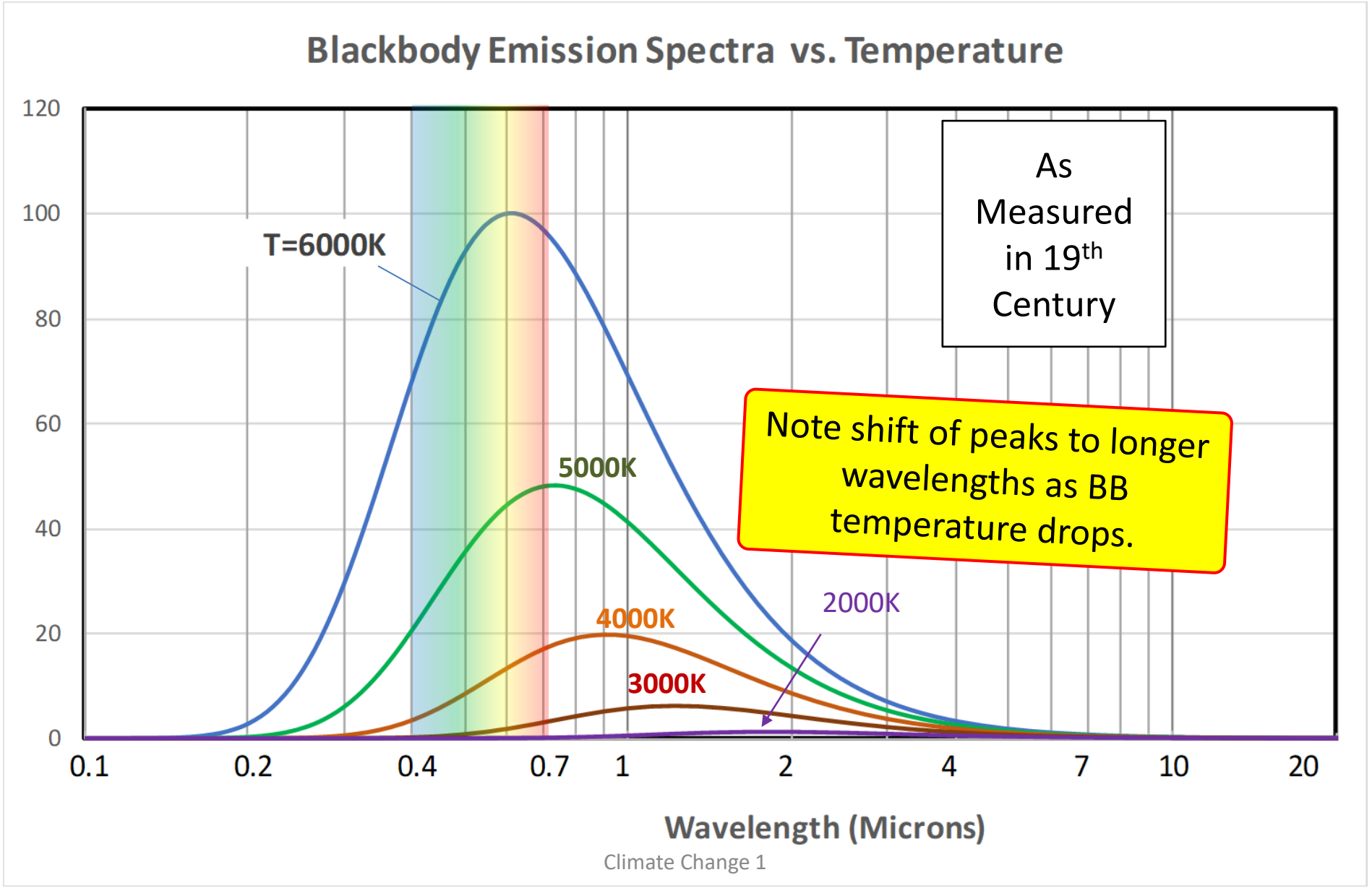
- Things glow
- Warmer things glow brighter
  - *much* brighter
- Warmer things glow bluer
  - Cooler things redder
- Black* things glow most
  - white, transparent or reflective things glow less



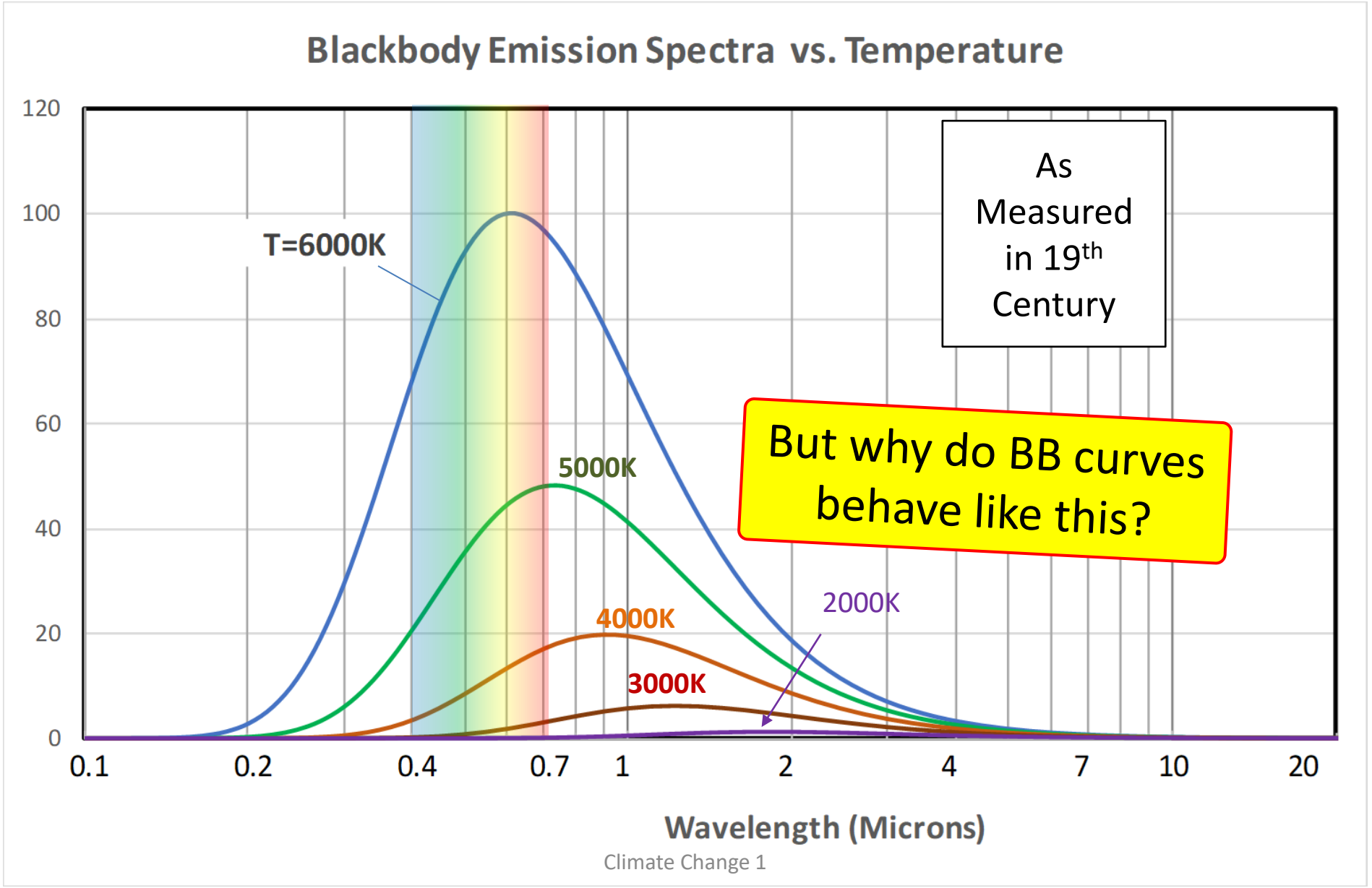




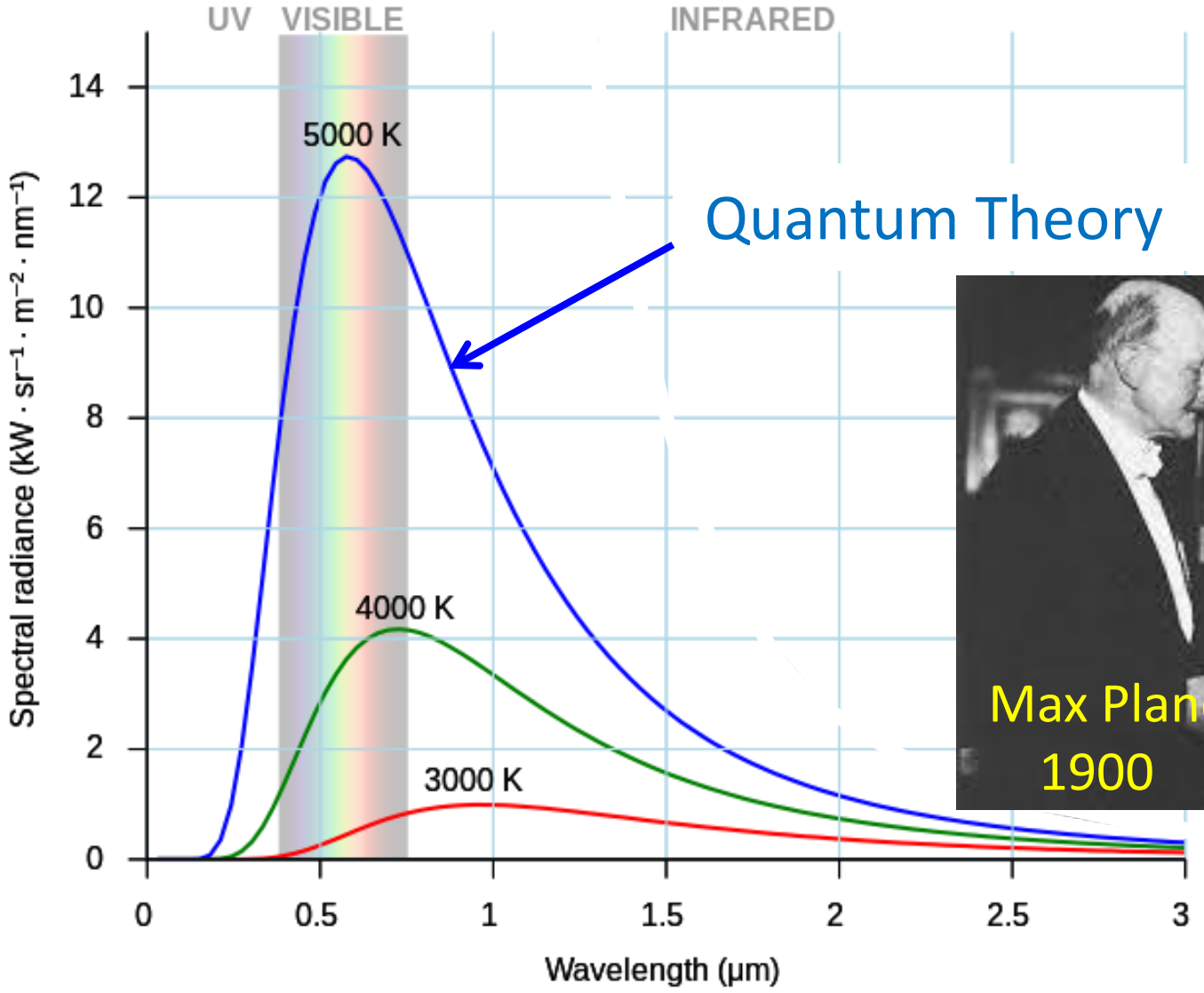

Blackbody Spectra



Blackbody Spectra



Answer was Quantum Theory



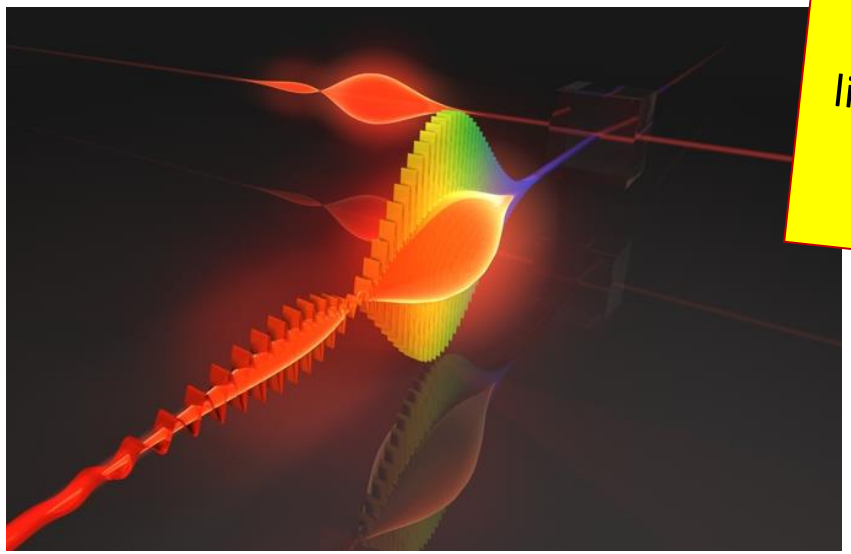
Quantum Theory

The Electro-Magnetic Waves Were Quantized as

Photons

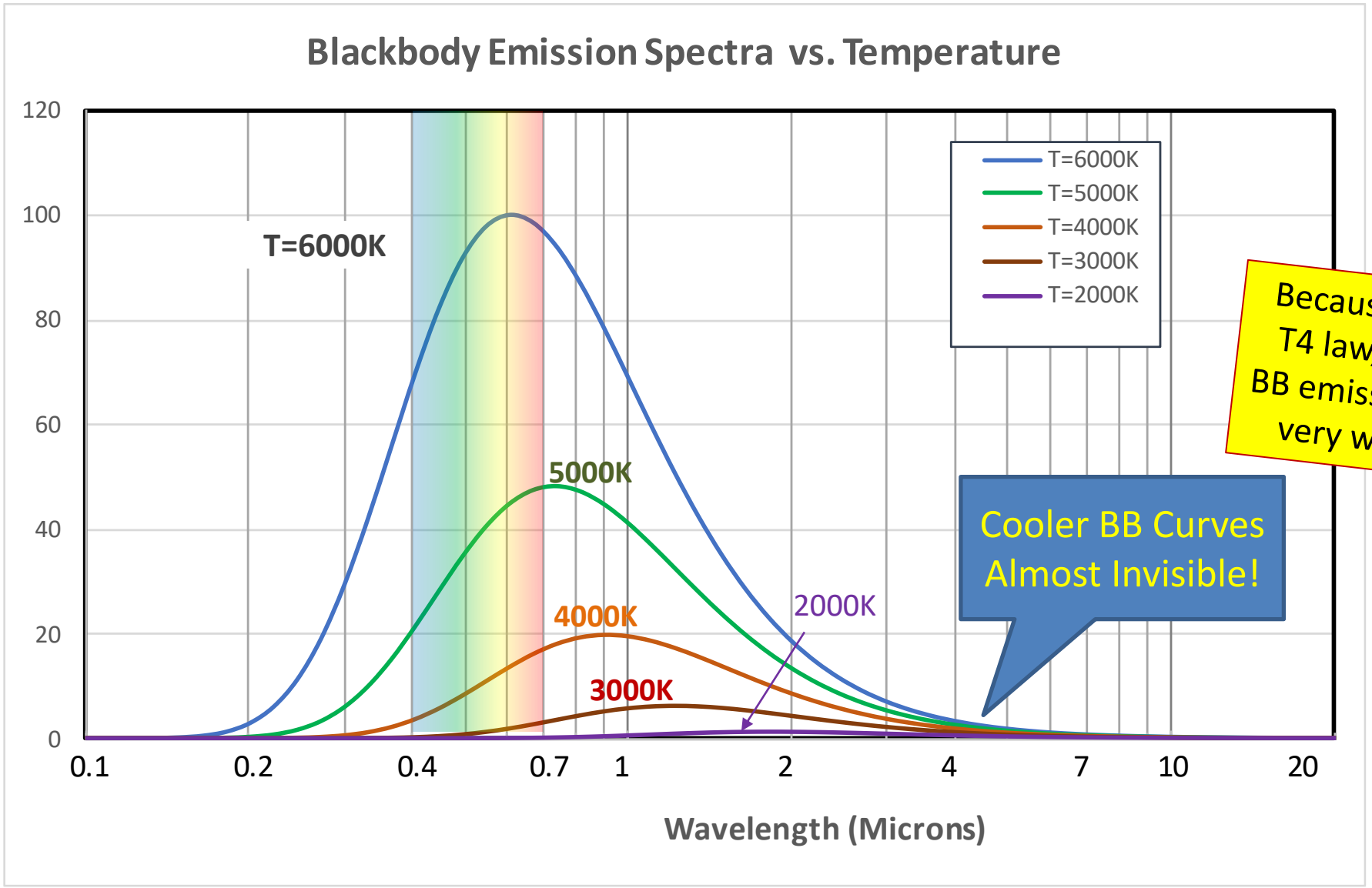
Duality:

- Part Wave
- Part Particle



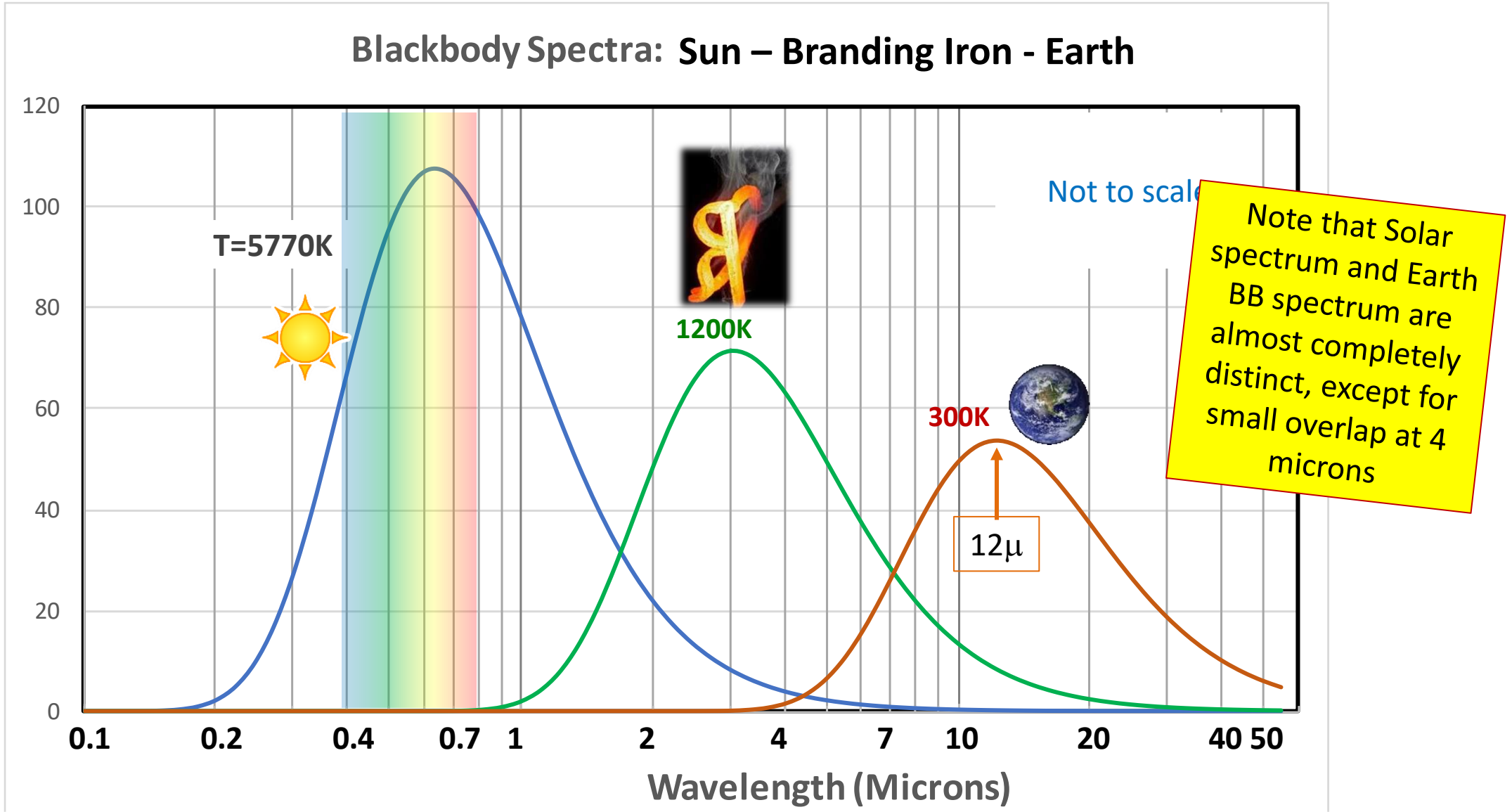
EM radiation, whether radio waves, IR, visible light, or x-rays, comes in discrete units called Photons.

Blackbody Spectra To Scale



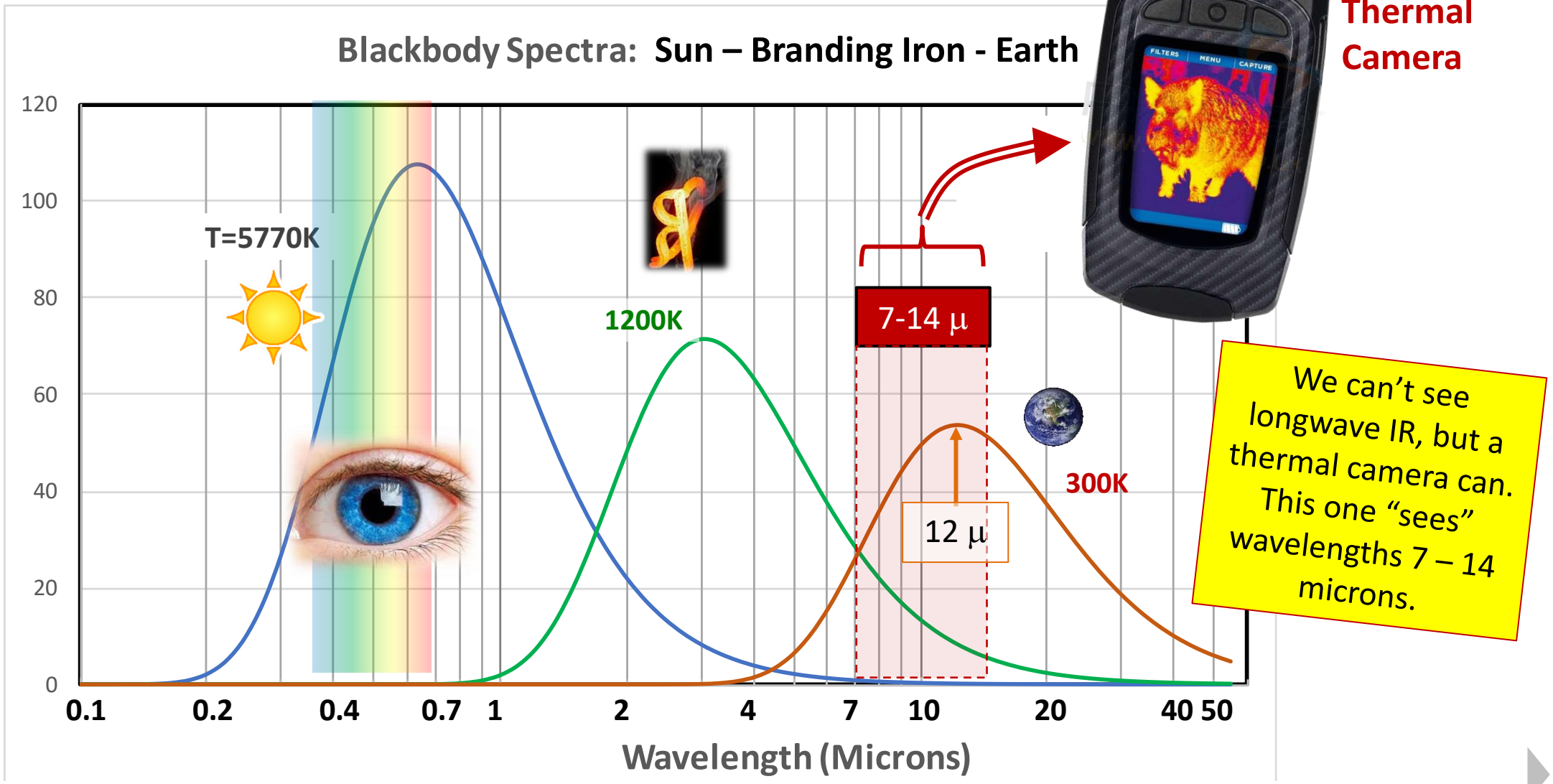
Blackbody Spectra (boosted)

Wide Temperature Range



Note that Solar spectrum and Earth BB spectrum are almost completely distinct, except for small overlap at 4 microns

Blackbody Spectra



Thermal Camera

We can't see longwave IR, but a thermal camera can. This one "sees" wavelengths 7 – 14 microns.

Emissivity ε

- For any material at a particular T and wavelength:
  Emissivity = Absorptivity Kirchhoff's Radiation Law
  - "Black" things both ***emit*** and ***absorb*** photons maximally: ε ≈ 100%
  - "White", Transparent or Reflective materials neither ***emit*** nor ***absorb*** photons: ε ≈ 0%

- *Examples at **visible** wavelengths:*

Hot charcoal
High ε ≈ 90%

Ash has lower ε

Its mostly transparent and glows relatively little.

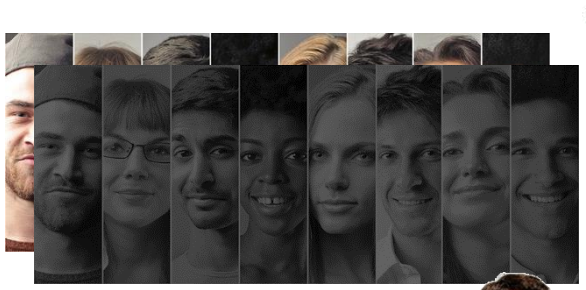
Hot glass
Low ε ≈ 5-10%

Emissivity ε

- For any material at a particular T and wavelength:
  Emissivity = Absorptivity Kirchhoff's Radiation Law
  - "Black" things both ***emit*** and ***absorb*** photons maximally: ε ≈ 100%
  - "White", Transparent or Reflective materials neither ***emit*** nor ***absorb*** photons: ε ≈ 0%
- *Examples at **LW Infra-red** wavelengths (7-15 μm):*

Most ordinary stuff is "black" in IR

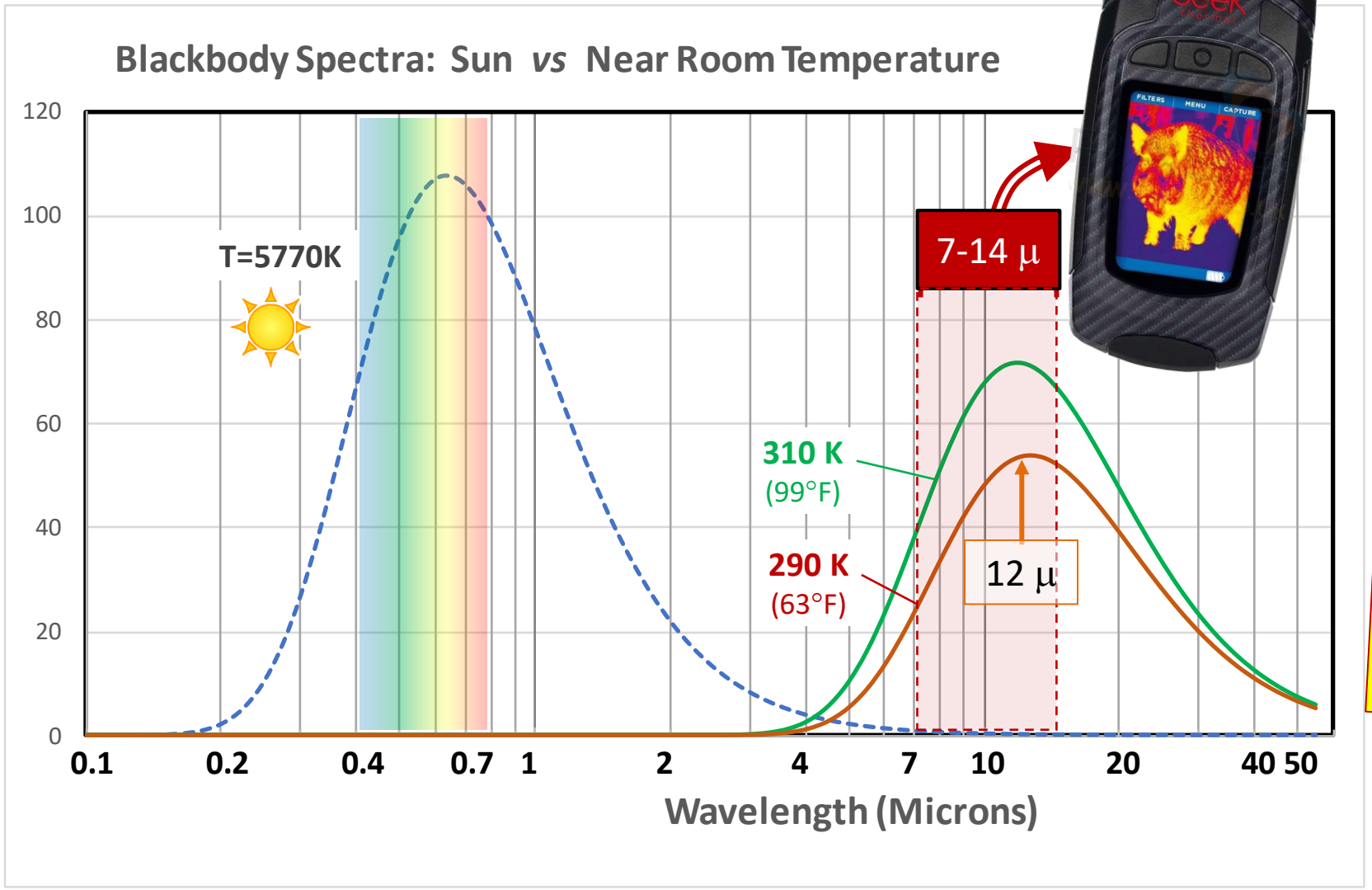
Skin, glass, plastic
High ε > 90%



Nitrogen, Oxygen gas
ε = 0

Aluminum
Low ε < 5%

Seeing in the Infrared



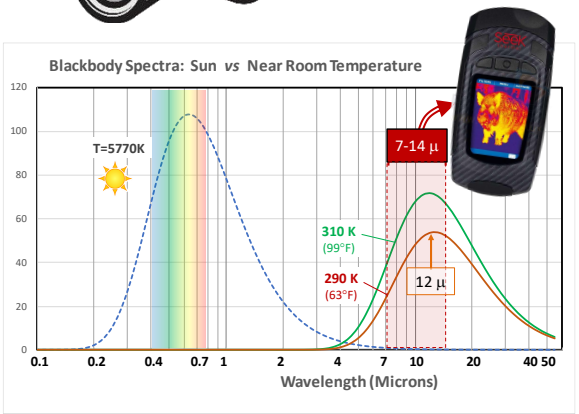
Thermal Infrared Camera (SEEK Pro)

Two slightly different temperatures have greatly different emission in 7-14μ band

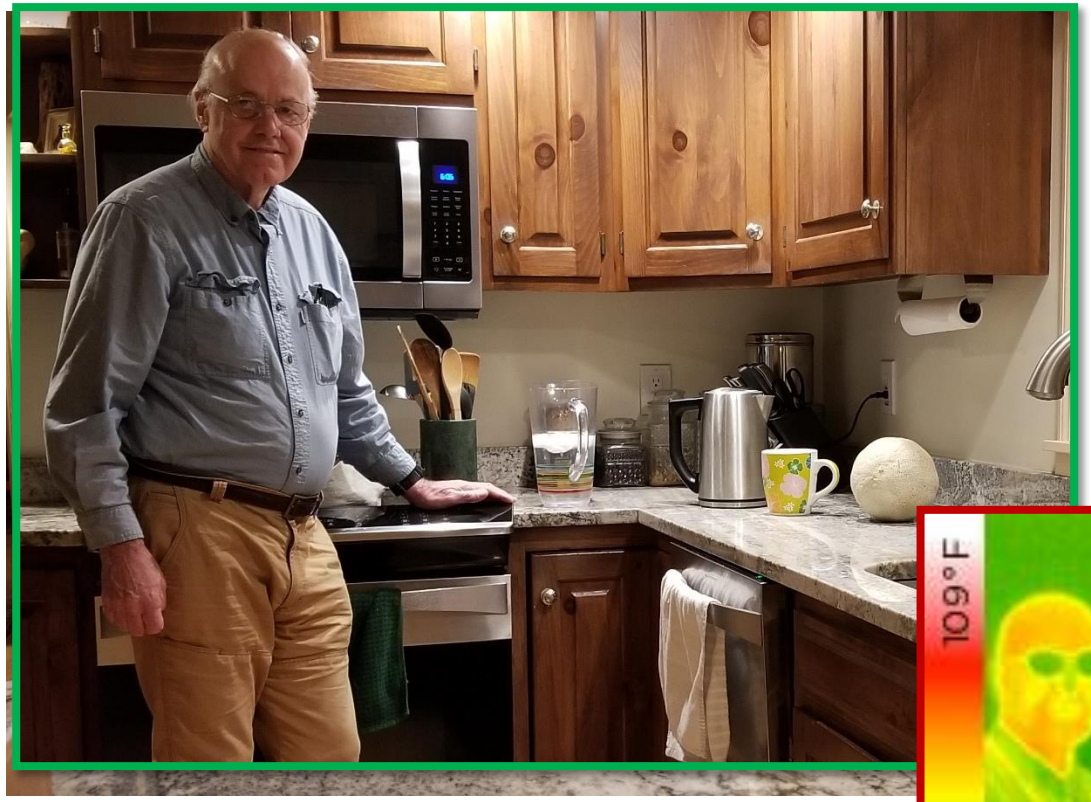
Seeing in the Infrared

VIS

IR



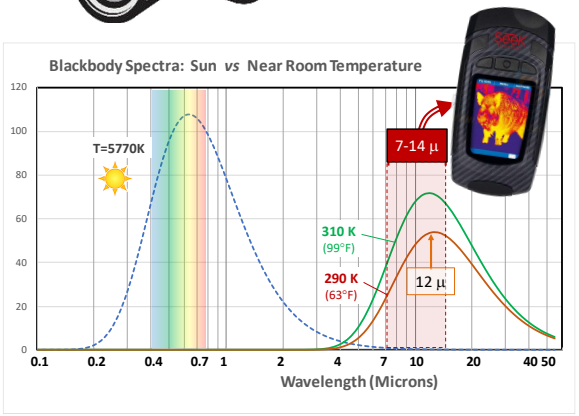
Seeing in the Infrared

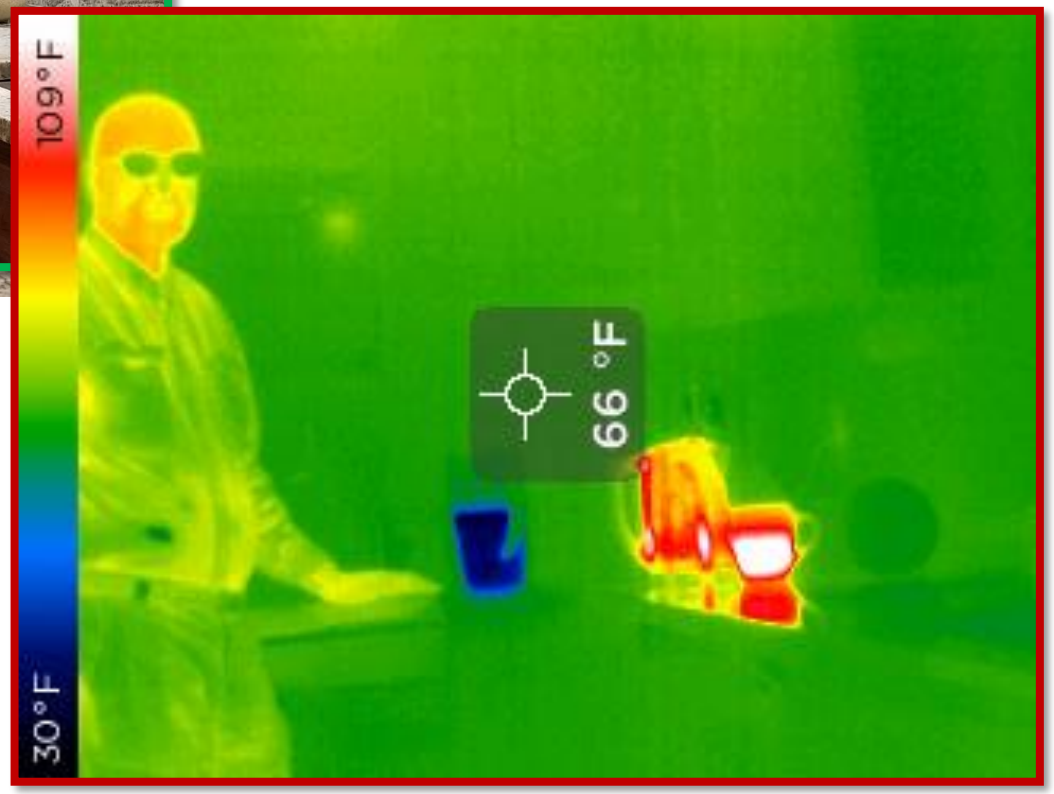


Note pitcher with ice water, electric kettle, and coffee cup half full of hot coffee. Everything else at room temperature, except my head.

VIS

IR

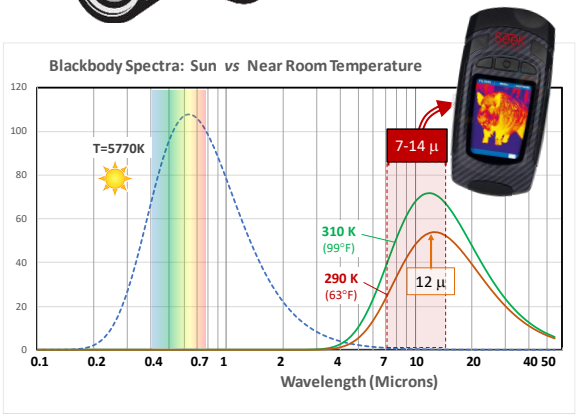


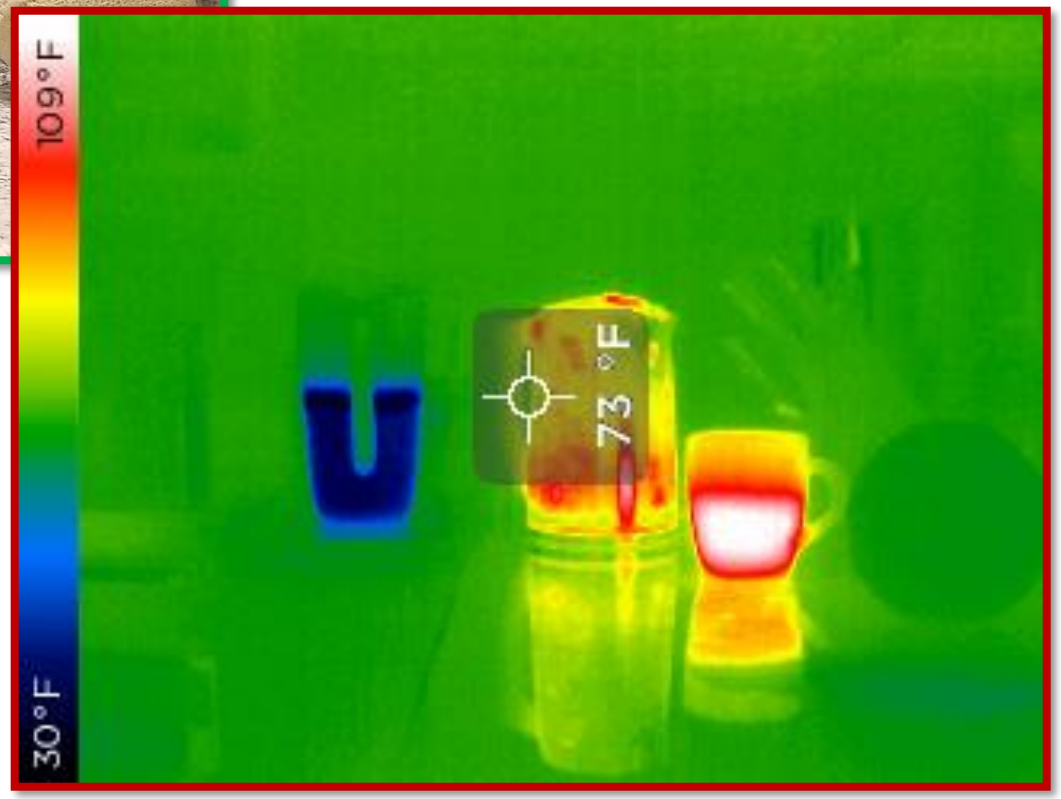


Seeing in the Infrared

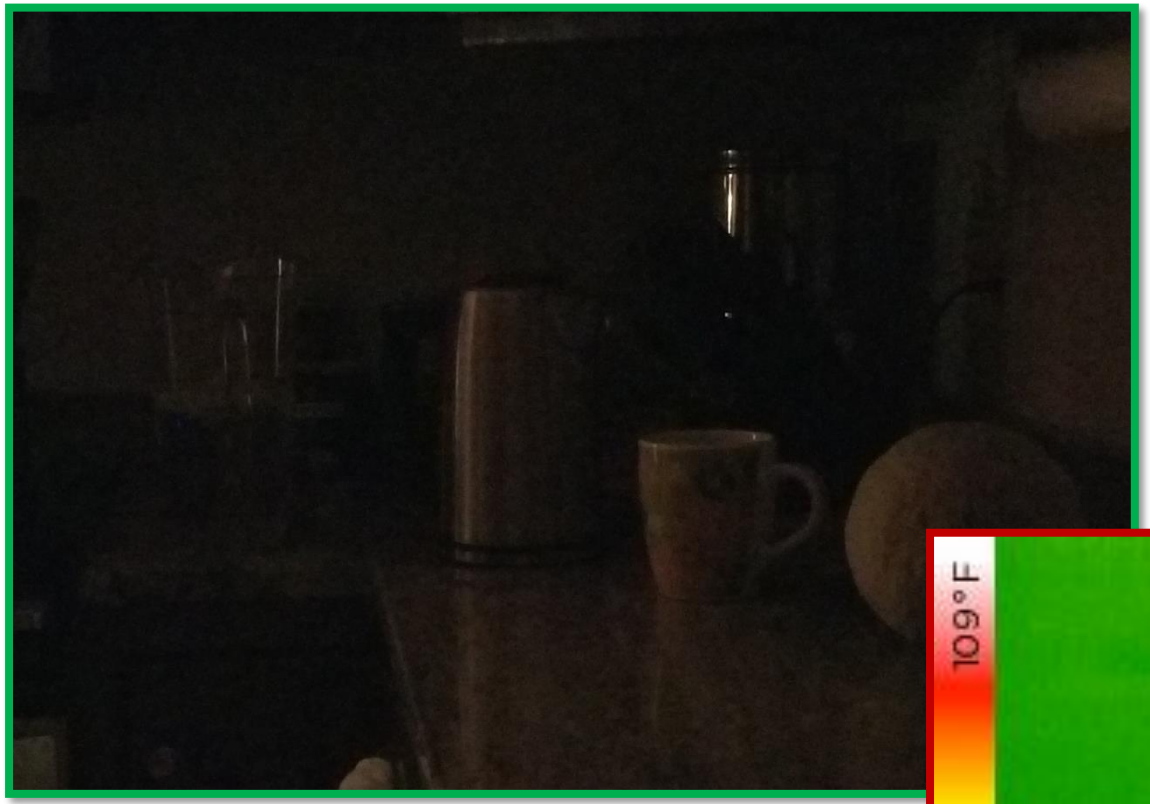
VIS

IR





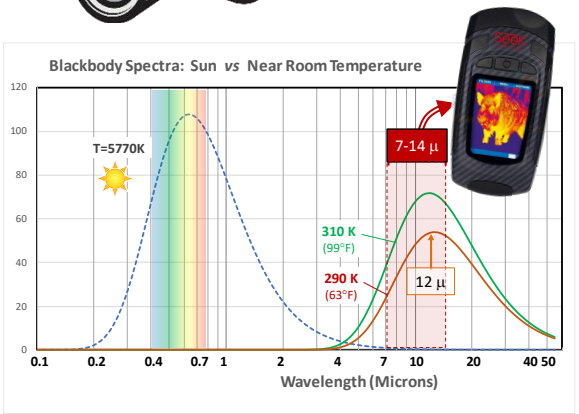
Seeing in the Infrared



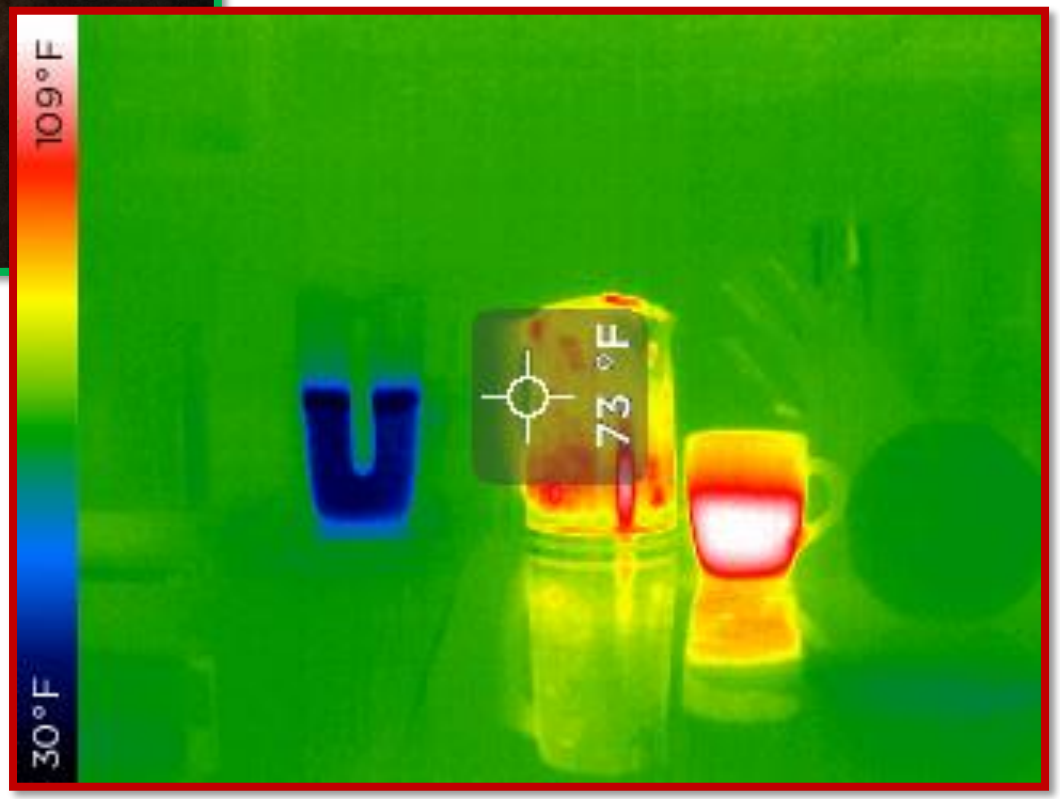
Room Lights Out…

VIS

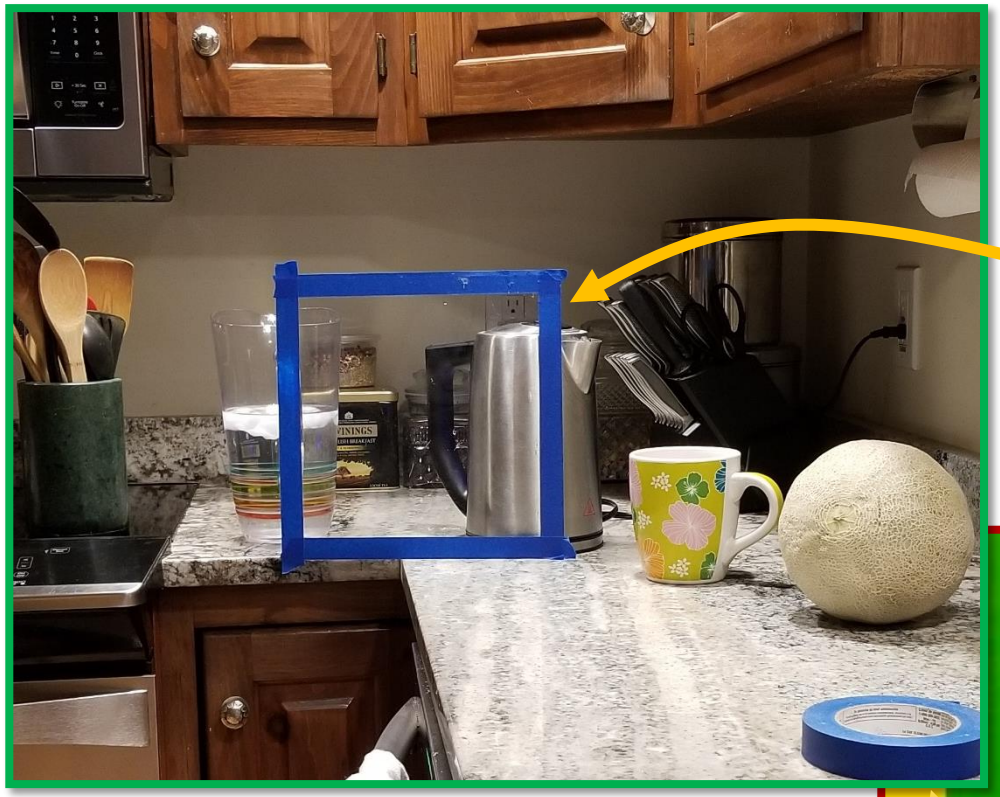
IR



Turning out the room lights has absolutely no effect on the IR Blackbody emission from all the stuff in the room!



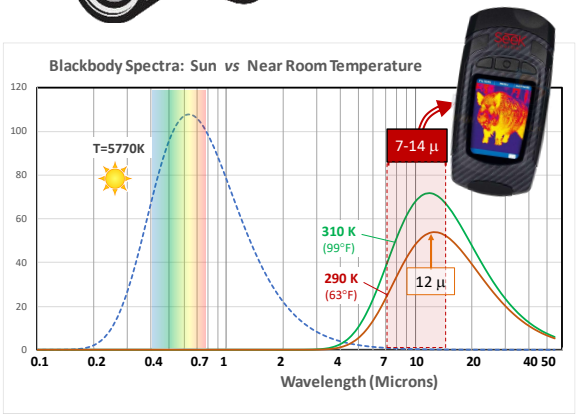
Seeing in the Infrared



Plexiglas Window

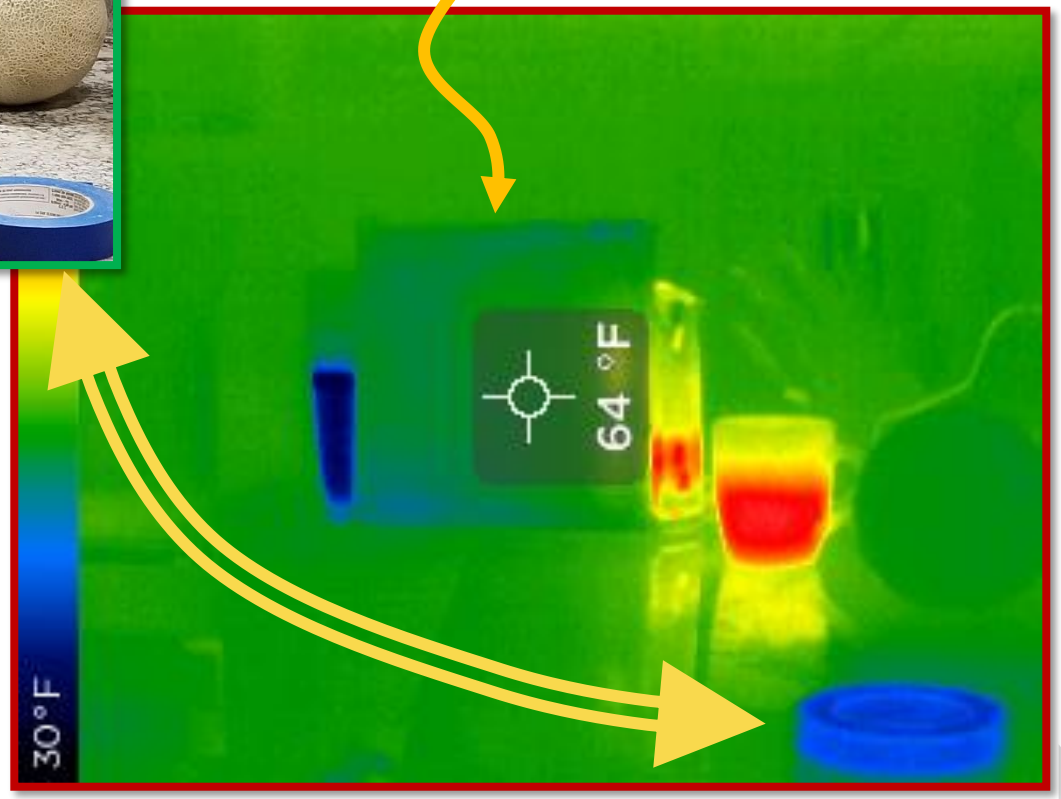
VIS

IR

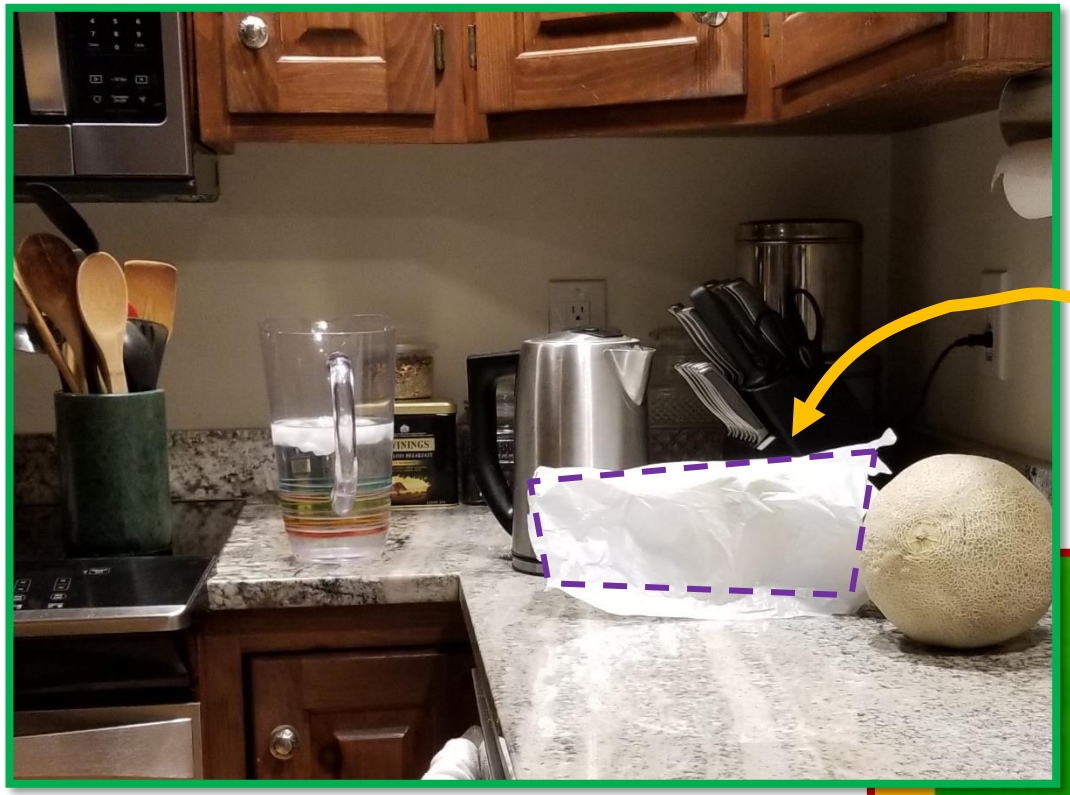


1/8” thick Plexiglass window is opaque to IR ($\varepsilon = 1$). Thermal camera can’t see through it.

[The roll of masking tape was very cold, just in from the garage!]



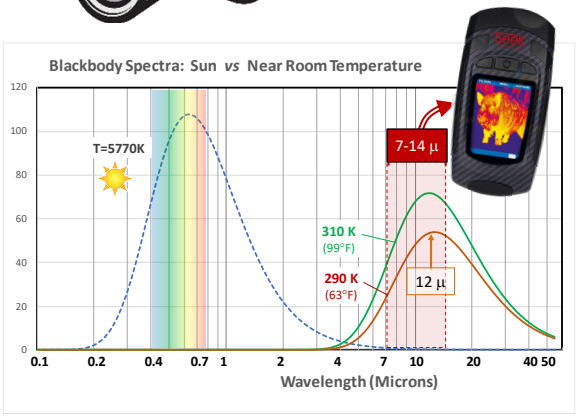
Seeing in the Infrared



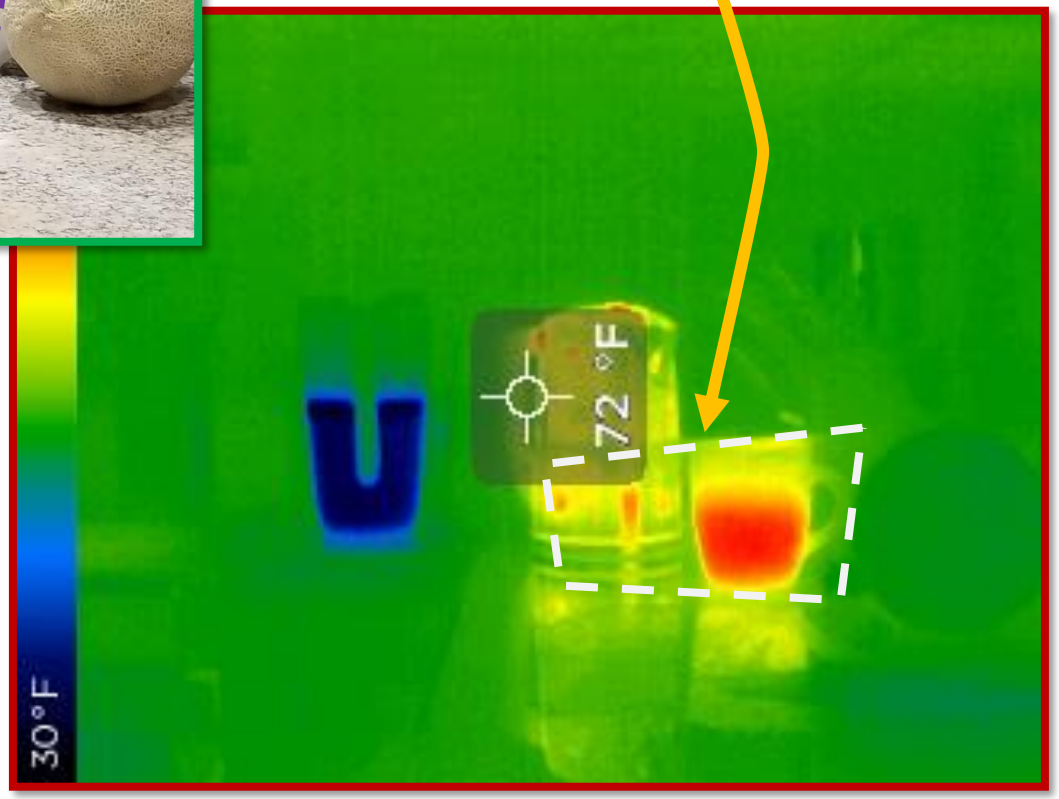
Plastic Bag
(Polyethylene)

VIS

IR



Thin plastic shopping bag is transparent to IR ($\varepsilon \approx 0$)., but opaque to visible light. Thermal camera sees right through it!

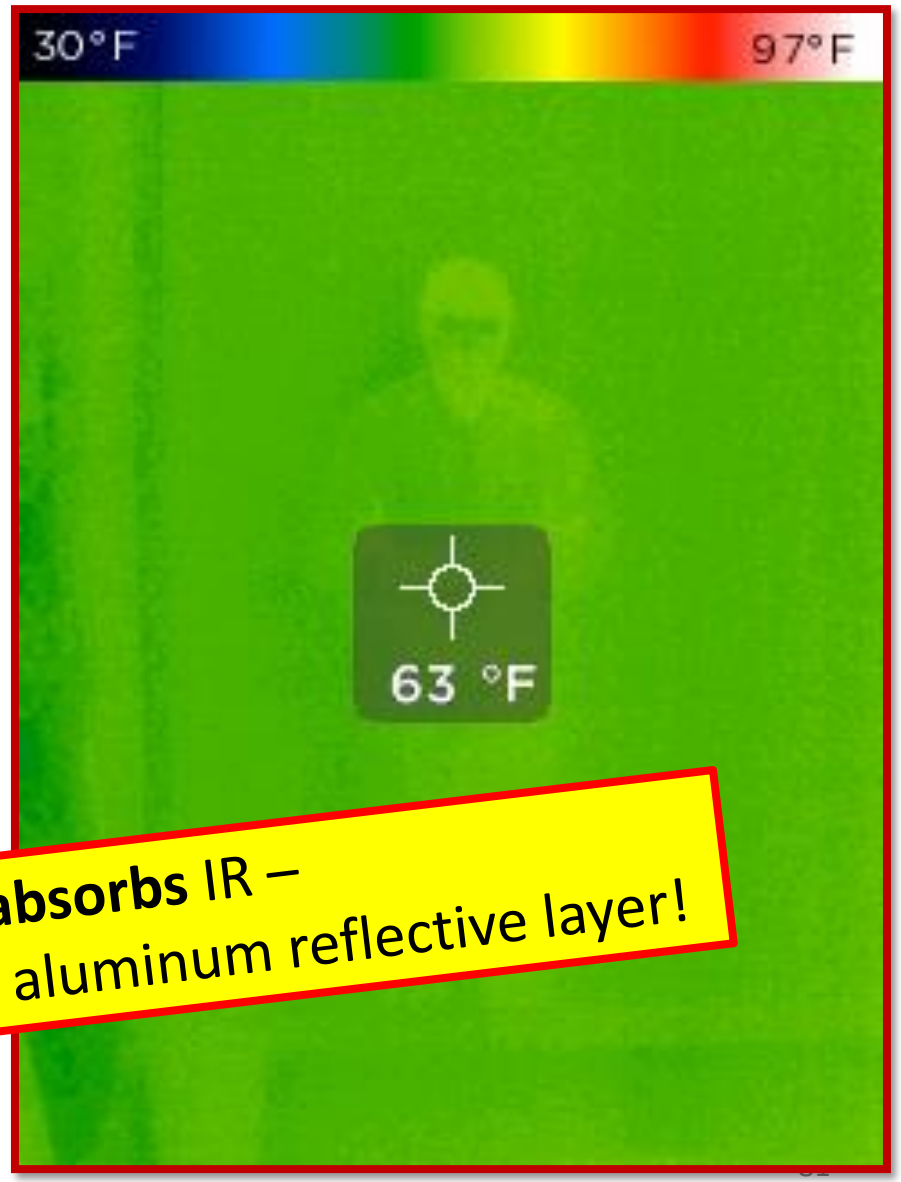


Seeing in the Infrared

VIS

IR

Glass Mirror

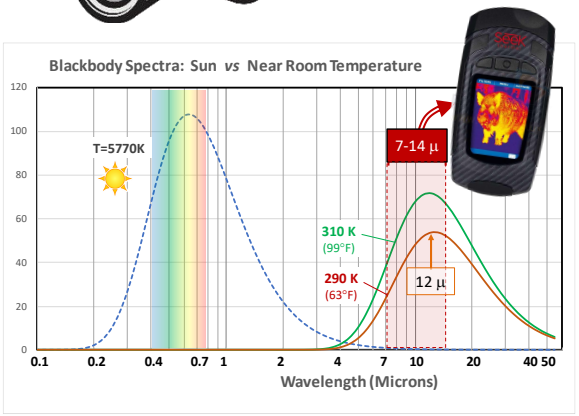


Glass front of mirror **absorbs** IR –
IR cannot reach the aluminum reflective layer!

Seeing in the Infrared

VIS

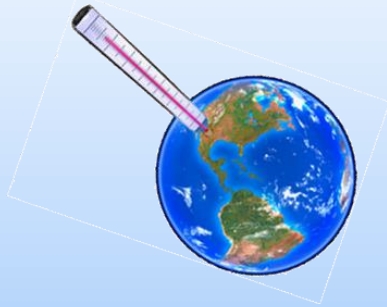
IR

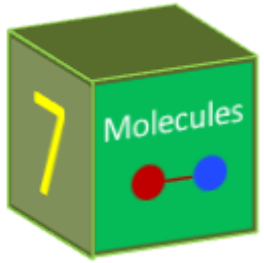


Stainless Steel Fridge

Brushed Stainless Steel is *too rough* to mirror VIS…
…but *smooth enough* for long wavelength IR!

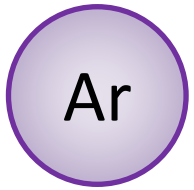
Questions about Blackbody Radiation?





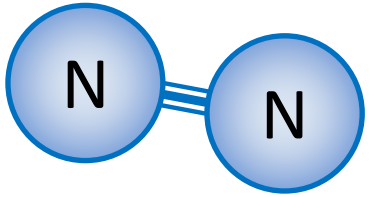
Some Gas Molecules in Air

- Monatomic

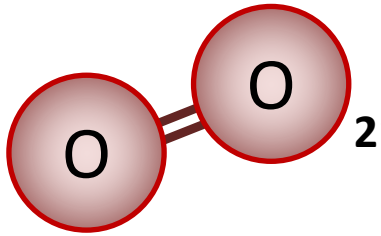


0.9%

- Diatomic
(homonuclear)

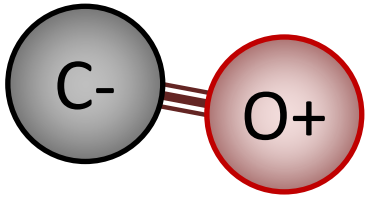


78%



21%

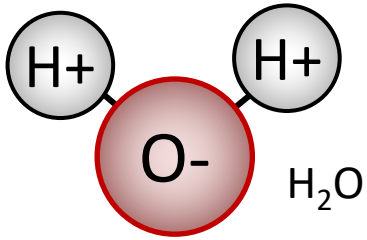
- Diatomic
(heteronuclear)



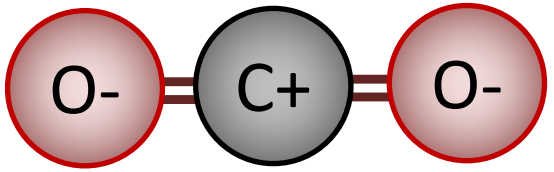
< 1 ppm

Carbon Monoxide

- Polyatomic

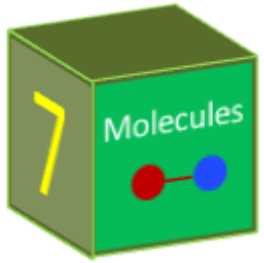


H_2O **0-4%**



CO_2 **400 ppm**

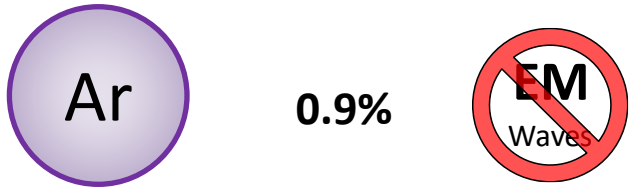
Note that CO2 is a Linear molecule – water is *not* linear.

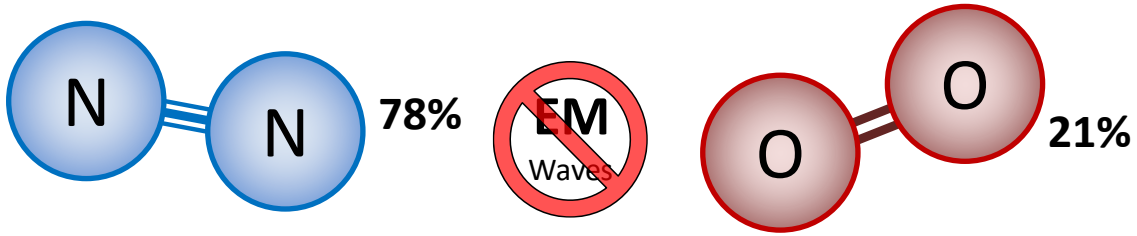


Gas Molecules in Air

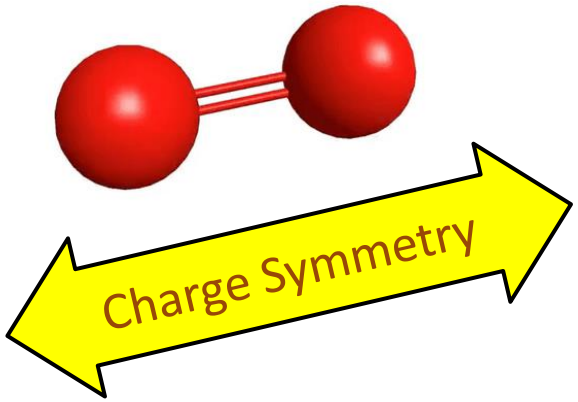
Do these Radiate at normal Temperatures?

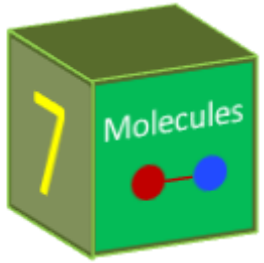
- Monatomic
- Diatomic
  (homonuclear)





Argon, Nitrogen and Oxygen do not emit or absorb IR electromagnetic waves, since there is no net wiggling of electric charges when they rotate or vibrate.





Gas Molecules in Air

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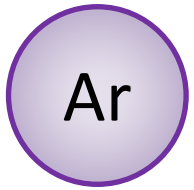
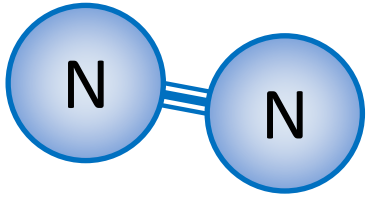
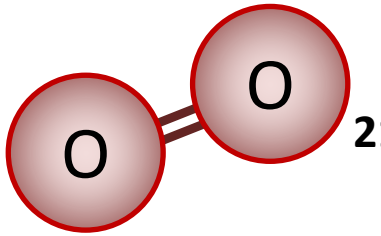


0.9%

- Diatomic (homonuclear)

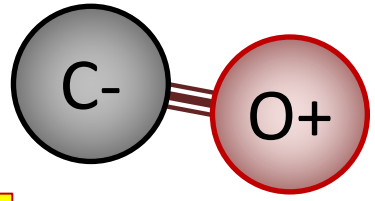


78%



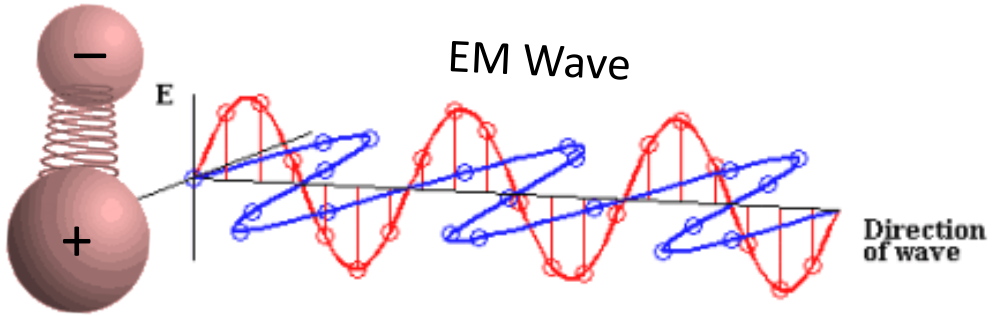
21%

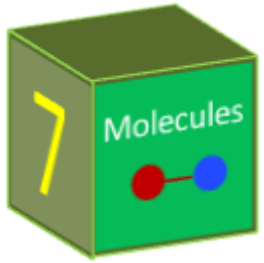
- Diatomic (heteronuclear)



< 1 ppm

Heteronuclear diatomic molecules like Carbon Monoxide do strongly absorb and emit IR.
However, there isn't much of them in the atmosphere.

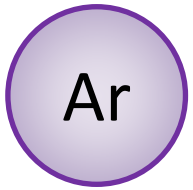




Gas Molecules in Air

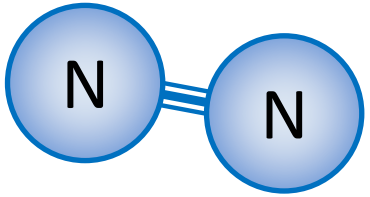
Do these Radiate at normal Temperatures?

- Monatomic

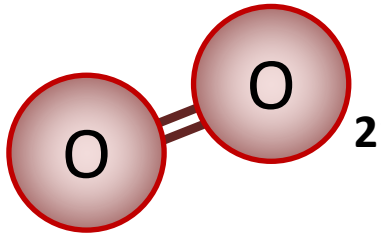


0.9%

- Diatomic (homonuclear)



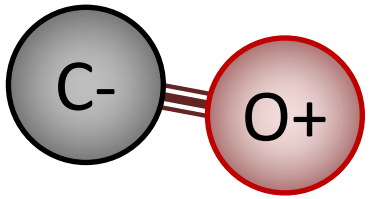
78%



21%

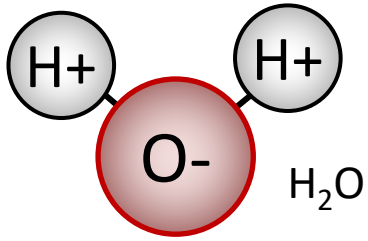
Water and CO_2 – as well as most other bigger molecules – also strongly absorb and emit IR. Moreover, there is quite of lot of them in the atmosphere.

- mic (nuclear)

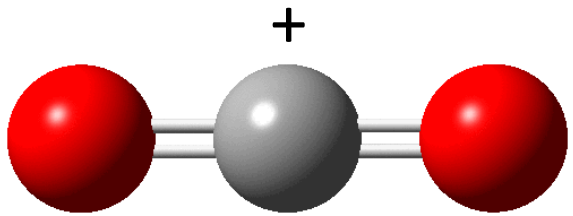


< 1 ppm

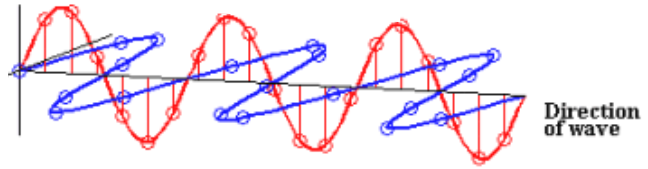
- Polyatomic



H_2O **0-4%**



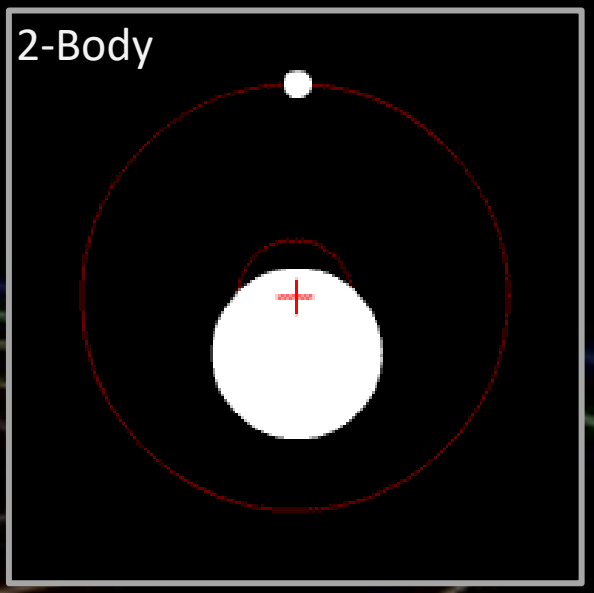
CO_2



Chaos

Jurassic Park (1993)

Chaos

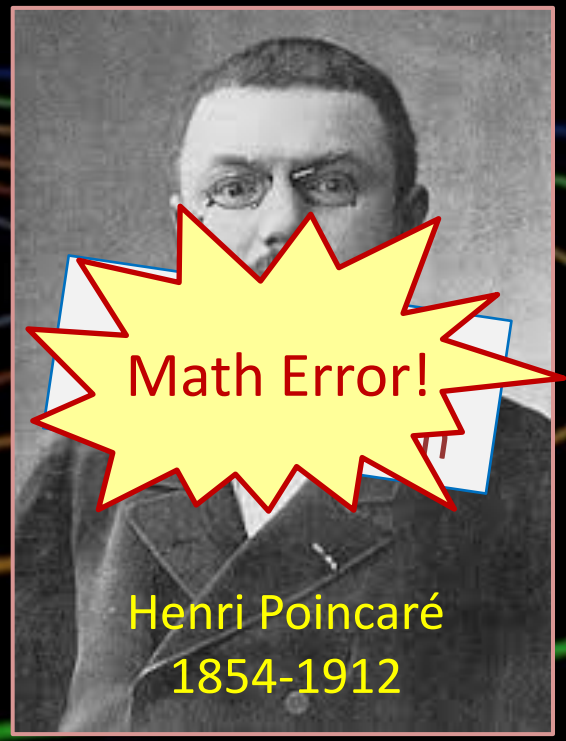


In the 19th century, the motions of the planets were mostly understood in terms of Newton's mechanics – especially for simple 2 body motion.

But some details involving multiple interacting planets were not understood and were a bit worrying….

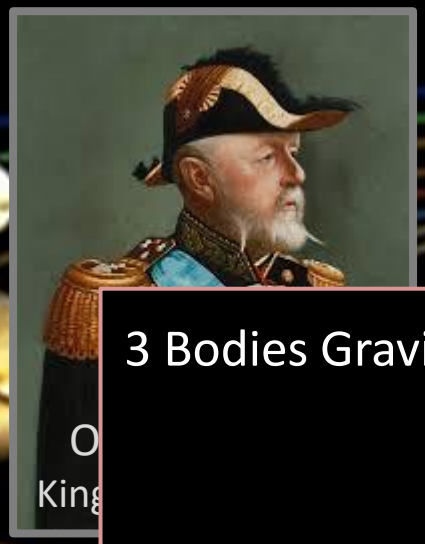
Chaos

King Oscar's
Prize of 1889
60th Birthday
Solve n-body Problem
(Prove Solar System
is Stable)

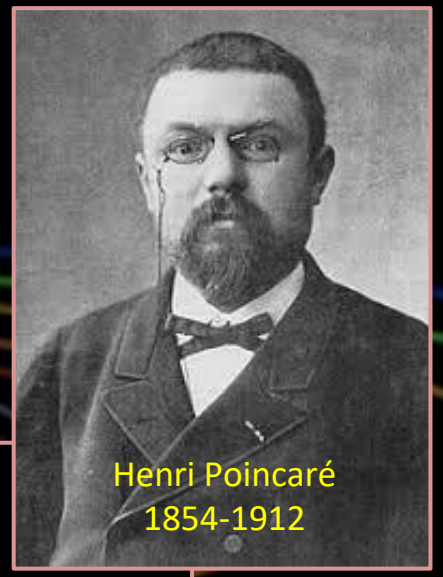


King Oscar II tried to get clarification and settle nerves by offering a prize. It was won by the mathematician Poincare, but just before the award ceremony Poincare discovered a major mistake and had to revise his work….

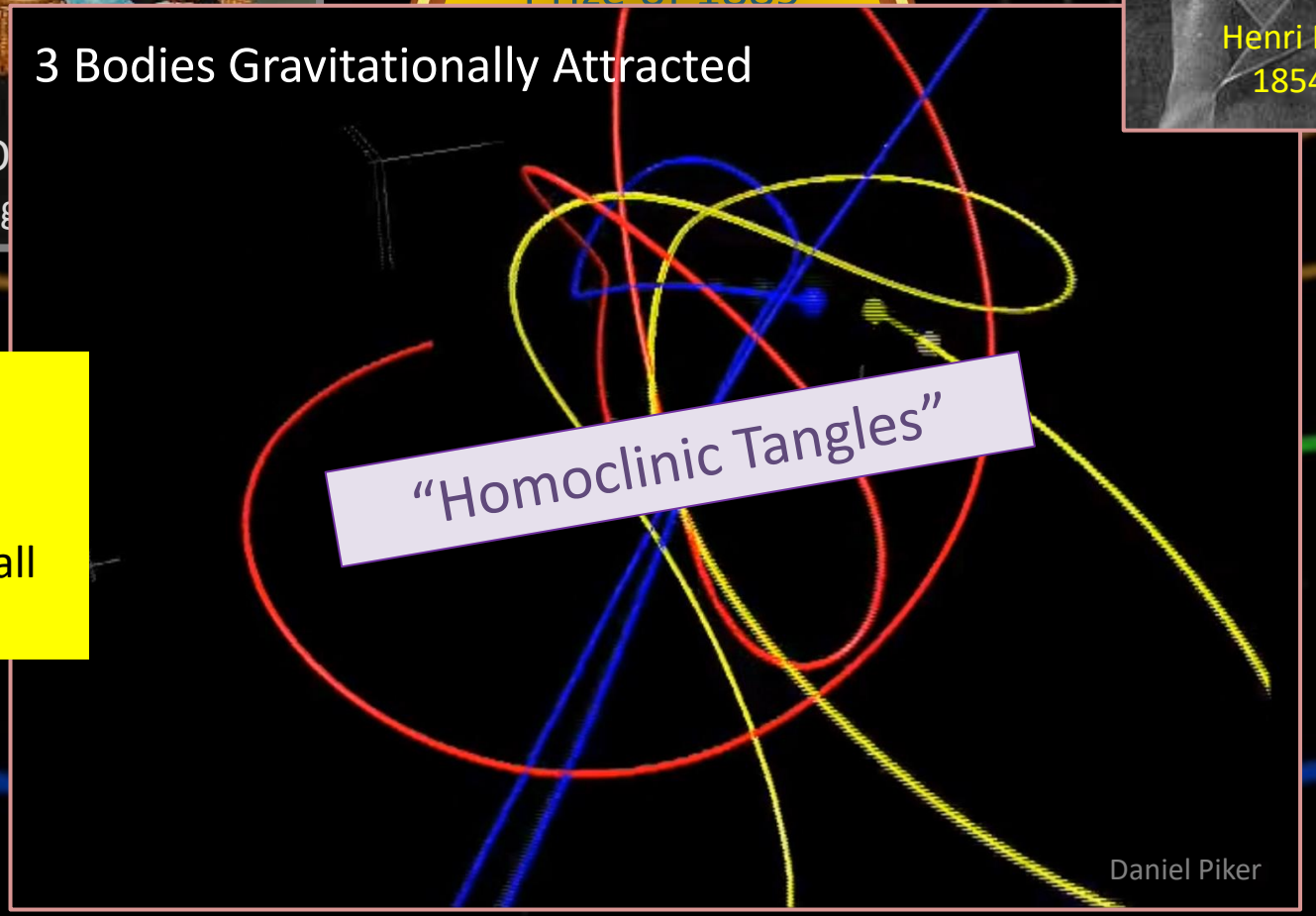
Chaos



King Oscar's Prize of 1889



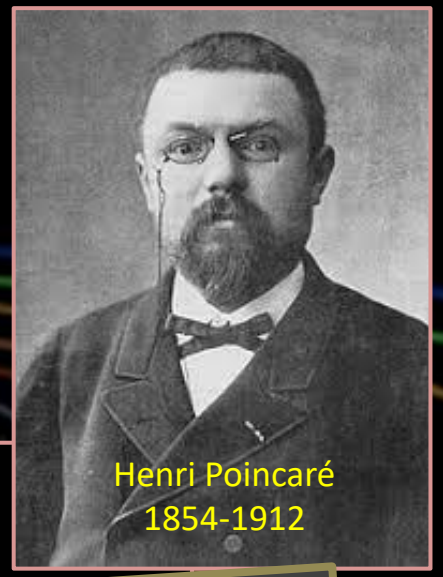
3 Bodies Gravitationally Attracted



Poincare found complications he called "Homoclinic Tangles" which we would now call signs of Chaos…..

Chaos

King Oscar's Prize of 1889



3 Bodies Gravitationally Attracted

"… it may happen that small differences in the initial conditions produce very great ones in the final phenomena."

Poincaré

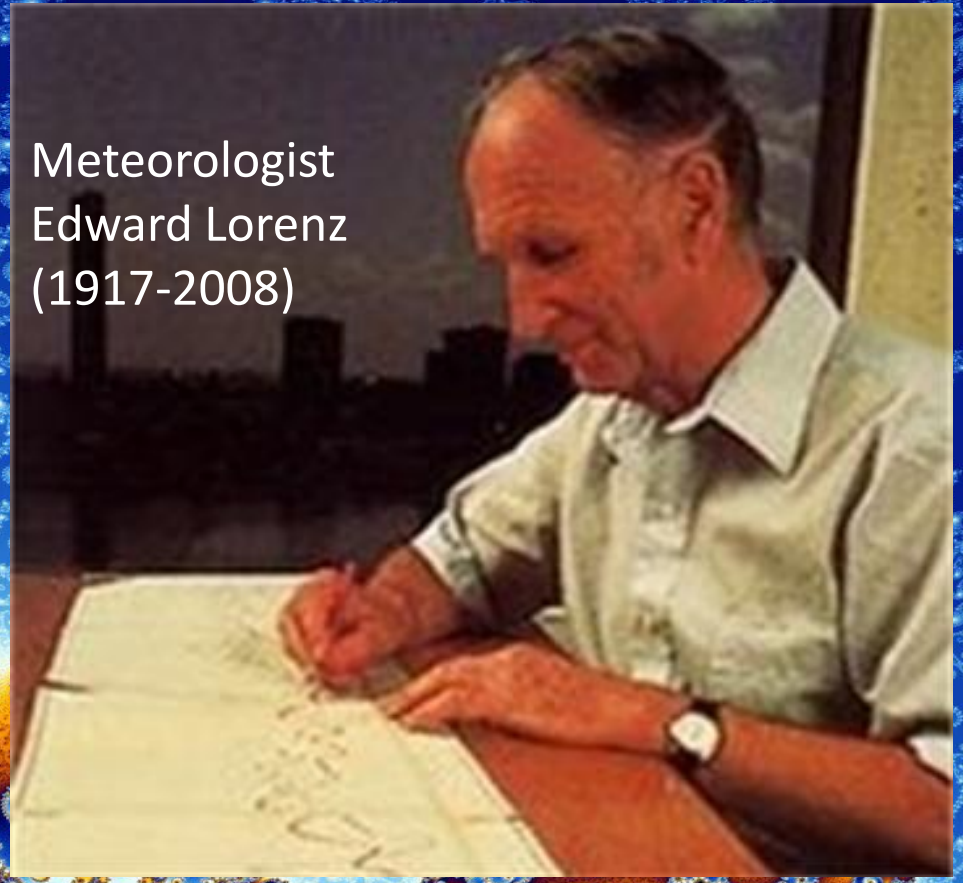
Daniel Piker

Chaos

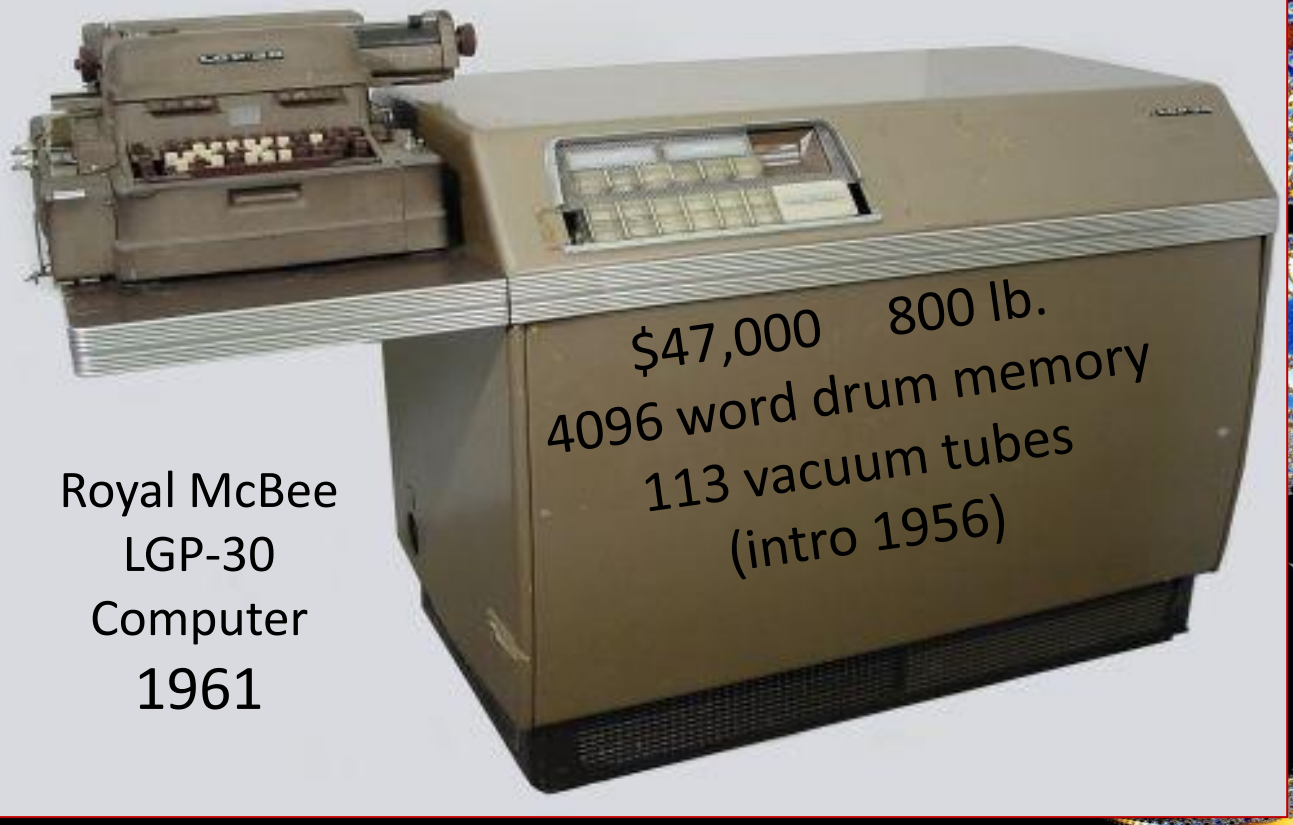
Meteorologist
Edward Lorenz
(1917-2008)

Fast forward to 1961….

Chaos



Meteorologist
Edward Lorenz
(1917-2008)

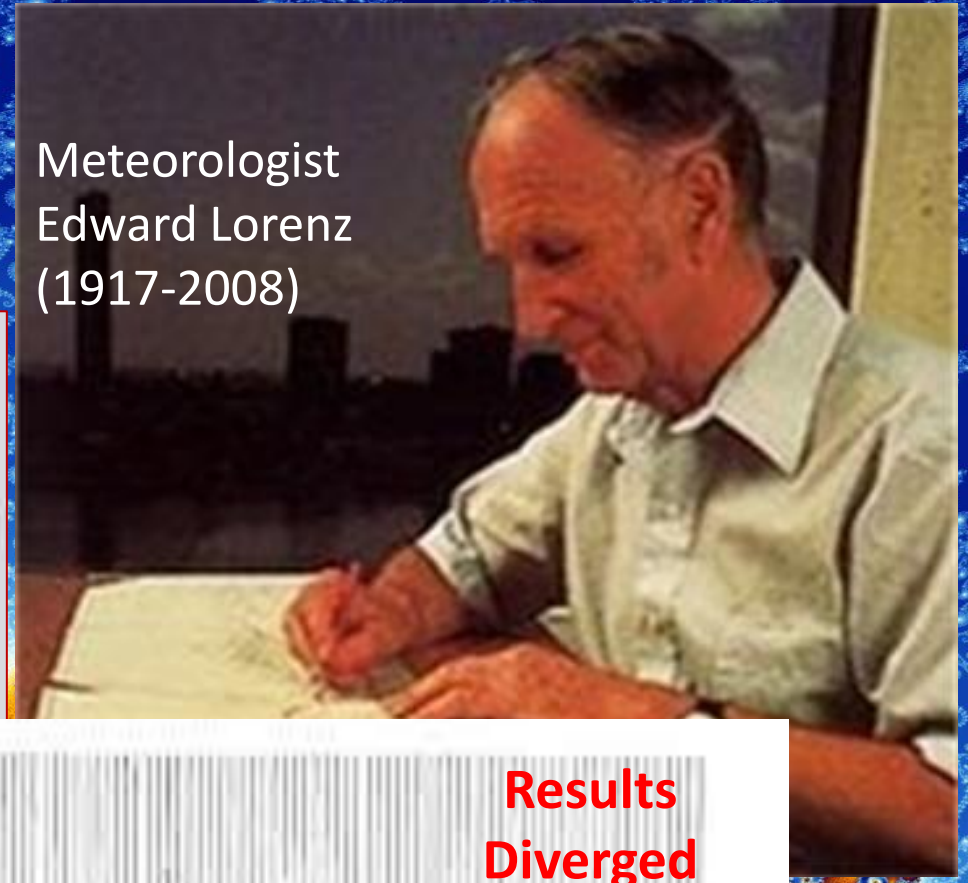


Royal McBee
LGP-30
Computer
1961

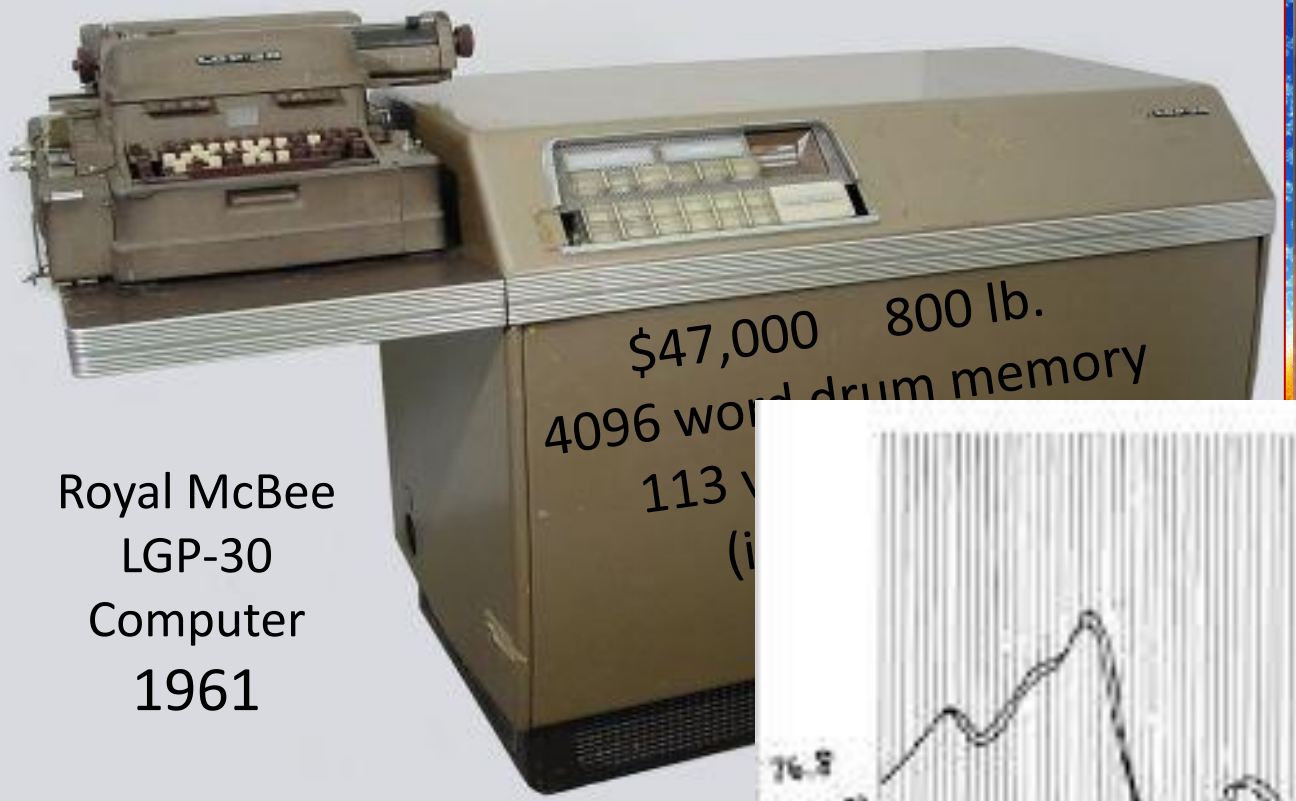
$47,000 800 lb.
4096 word drum memory
113 vacuum tubes
(intro 1956)

Lorentz attempted some of the first primitive numerical weather prediction calculations using an early computer….
He accidentally repeated a calculation with very slightly different starting conditions…..

Chaos

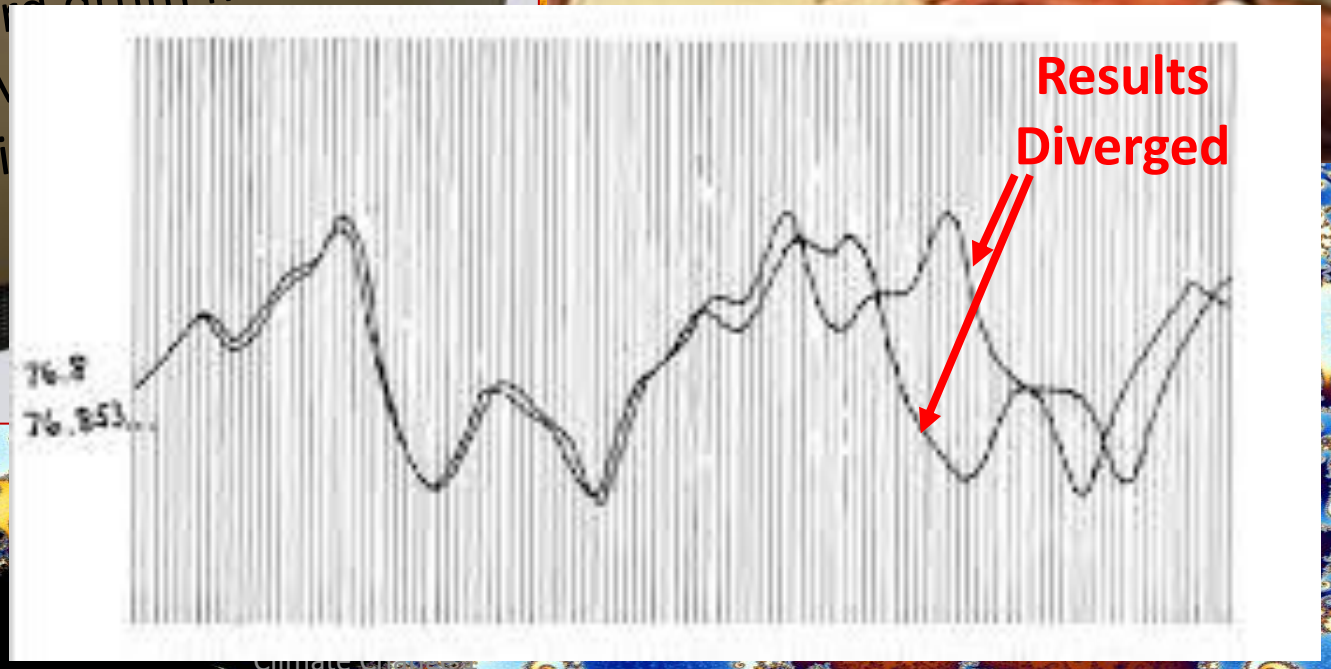


Meteorologist
Edward Lorenz
(1917-2008)

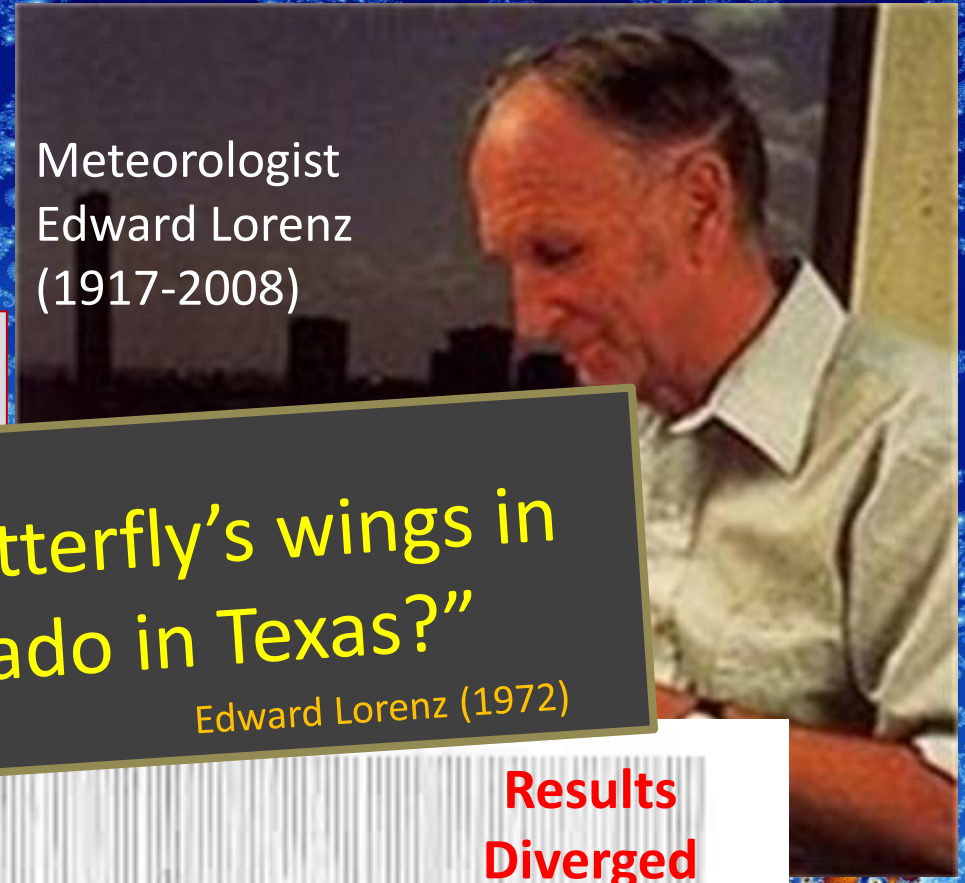


$47,000 800 lb.
4096 wo drum memory
113 v
(i

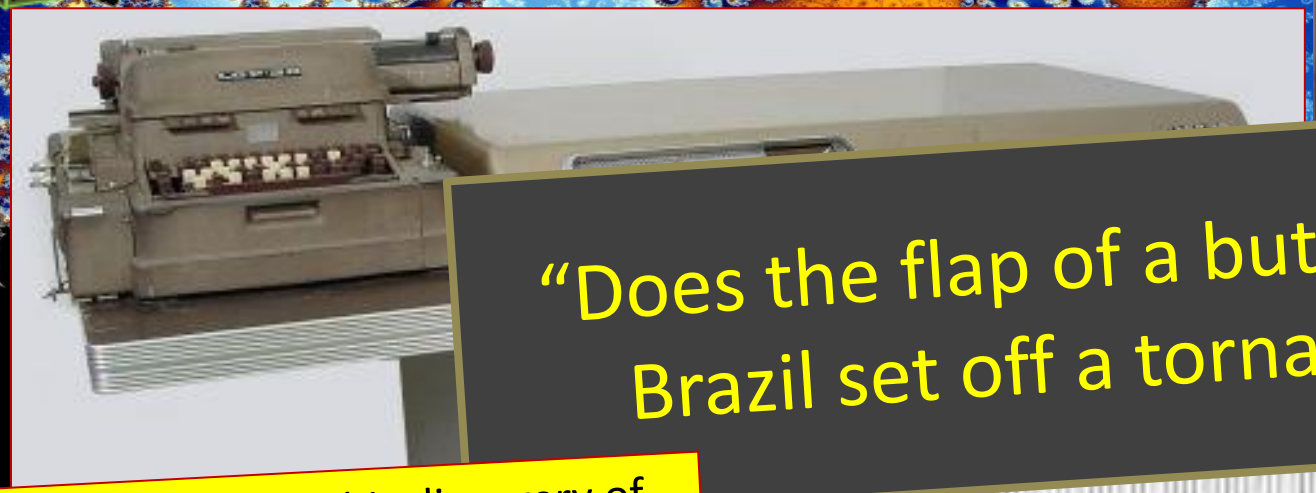
Royal McBee
LGP-30
Computer
1961



Chaos



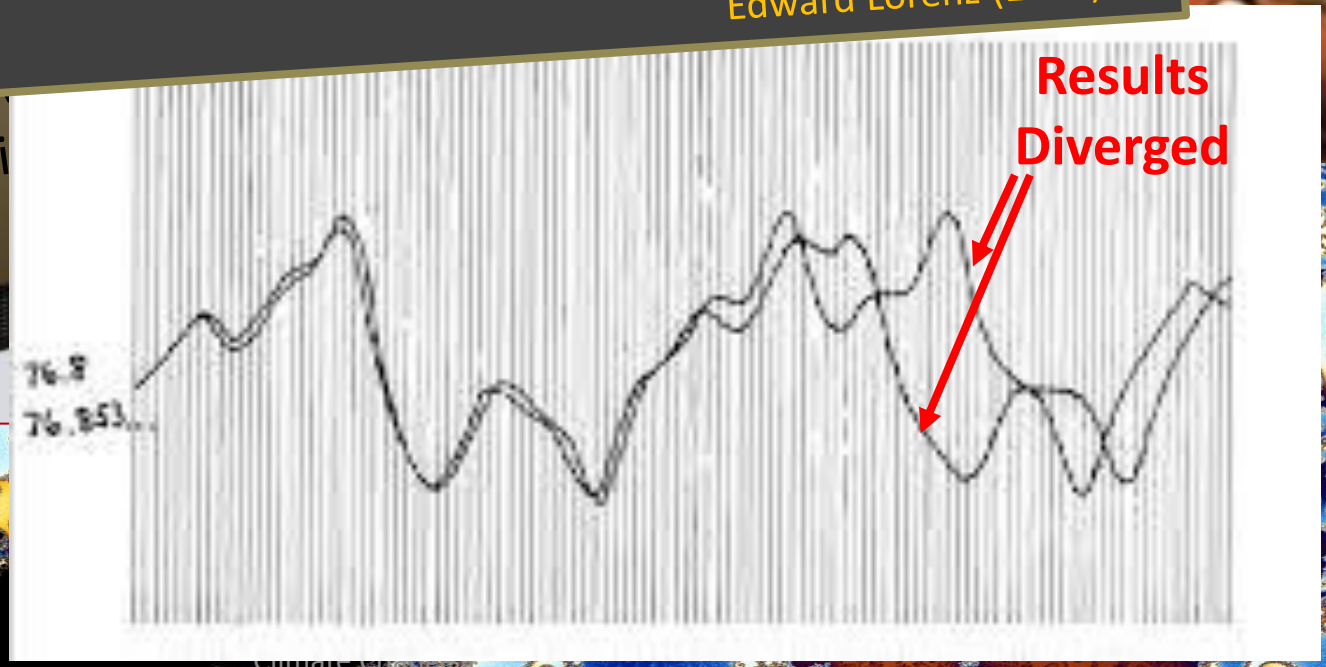
Meteorologist
Edward Lorenz
(1917-2008)



"Does the flap of a butterfly's wings in Brazil set off a tornado in Texas?"

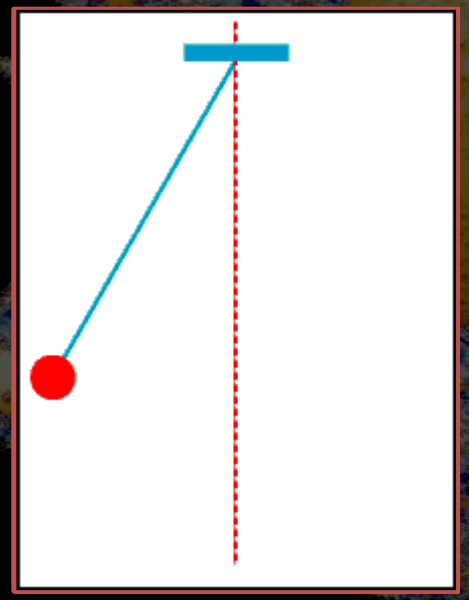
Edward Lorenz (1972)

He followed up on this discovery of sensitive dependence on the starting point, and spread the word…
This is the title of a talk he gave in 1972.
In 1975, another scientist coined the term **Chaos** to describe this behavior of complex models.



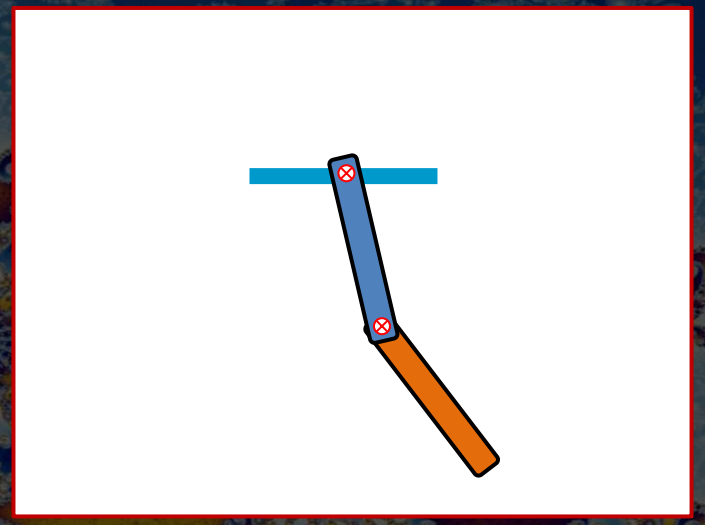
Chaos Demonstration

Simple Pendulum



Compound Pendulum

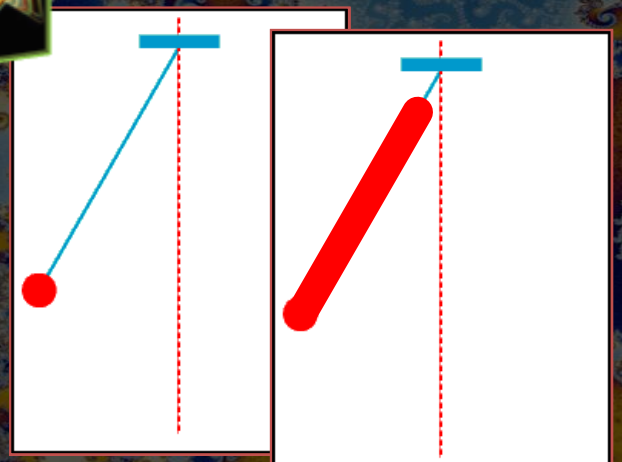
Double Pendulum



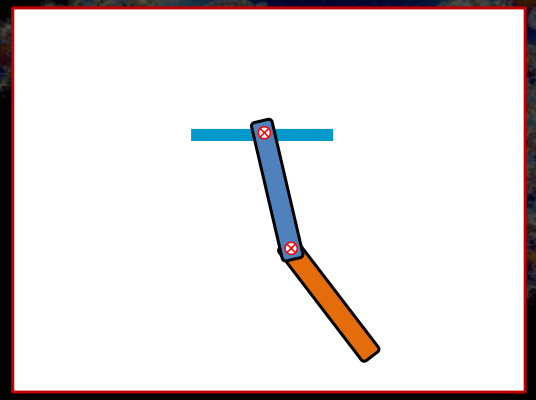
Chaos Demo

Simple Pendulum

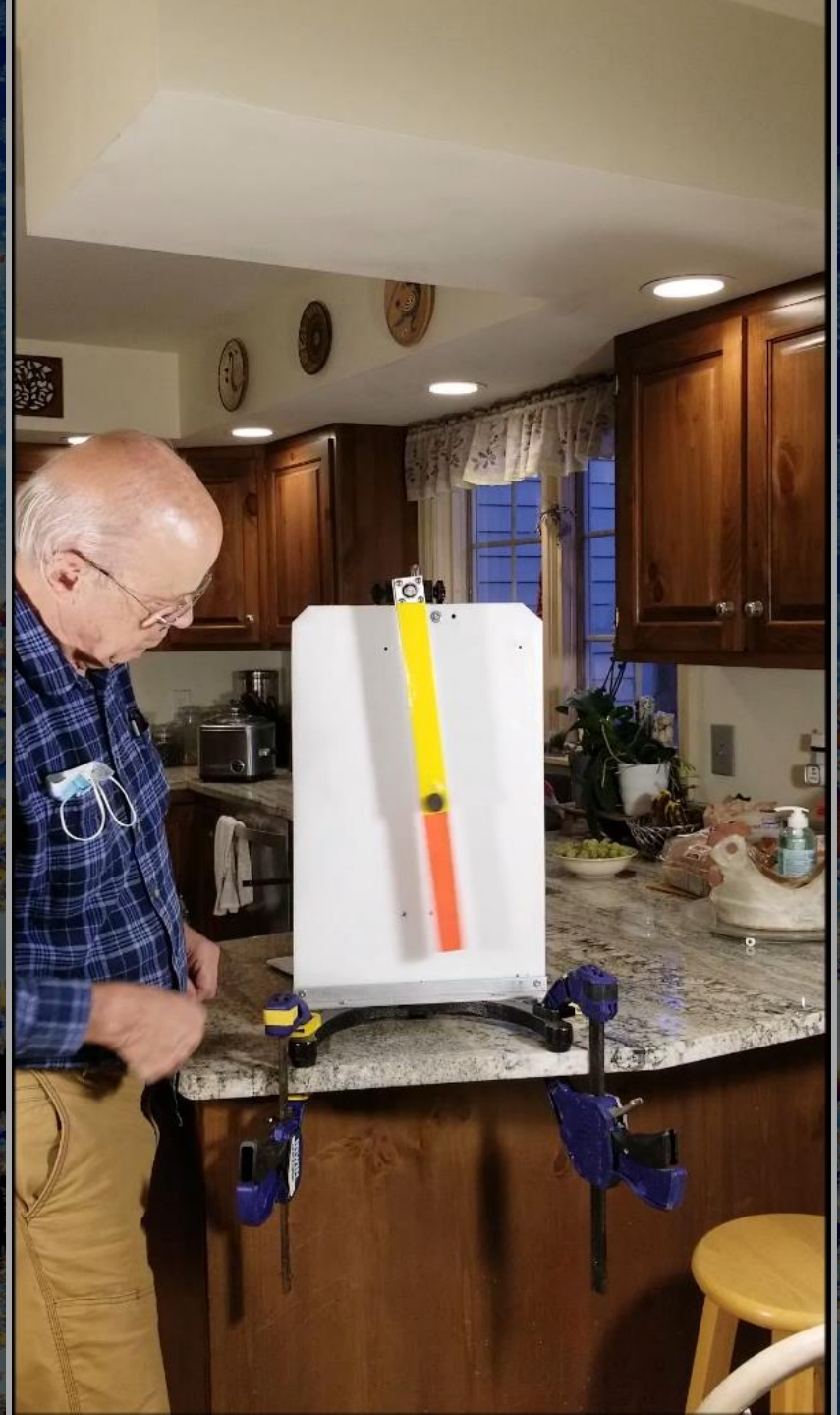
Compound Pendulum



Double Pendulum



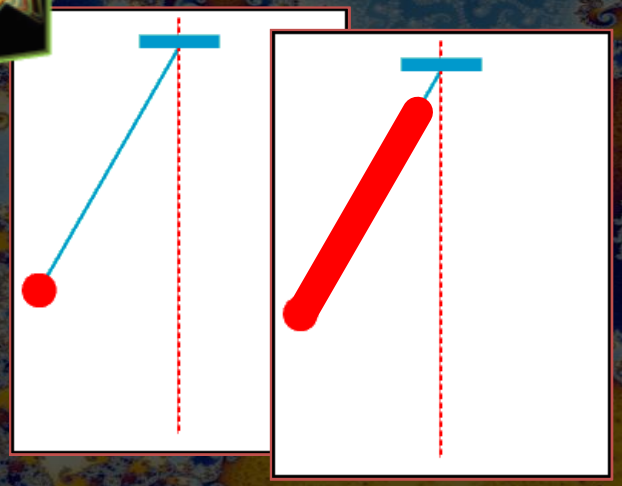
Video demo of behavior of a Double Pendulum – just 2 moving parts, and we get extreme Chaotic behavior.



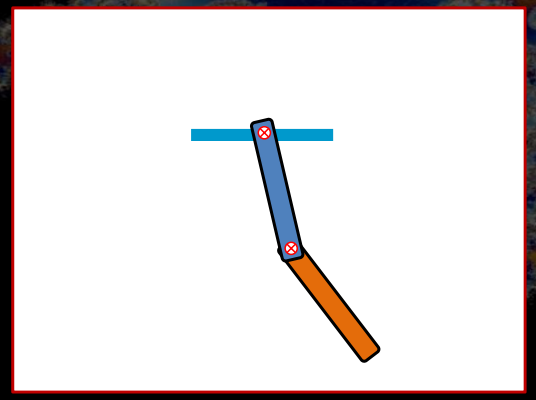
Chaos Demo

Simple Pendulum

Compound Pendulum



Double Pendulum



Double Pendulum Simulation

Chaos:

Tiny changes in starting conditions lead to ***huge*** changes in future behavior

Time Scales Vary Greatly

- Minutes
- Hours
- Days
- Weeks
- Seasons
- Years
- Decades
- Centuries
- Millenia
- 10 K years
- 100 K years
- Millions
- 100 Millions

Climate:
Average Weather over Decades

- Minutes
- Hours
- Days
- Weeks
- Seasons
- Years
- Decades
- Centuries
- Millenia
- 10 K years
- 100 K years
- Millions
- 100 Millions

Weather

Chaotic

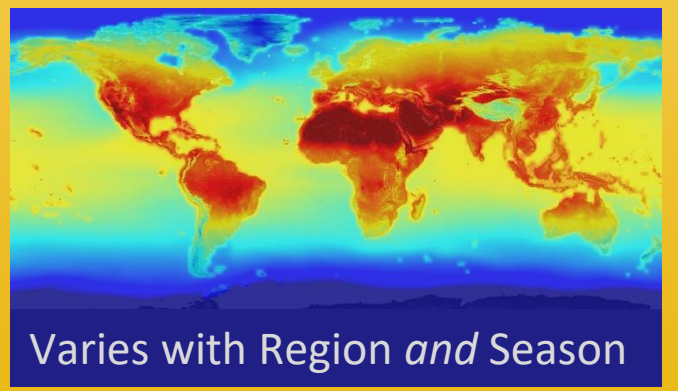
Annual Seasons

Some Chaos

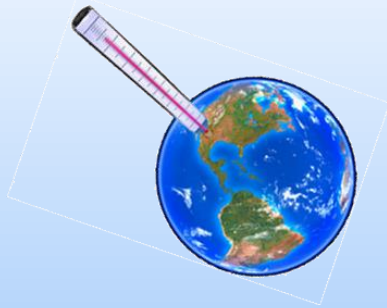
Climate

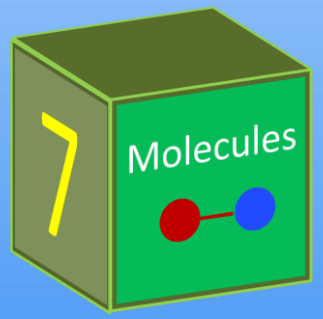
(30 year mean)

Chaotic?

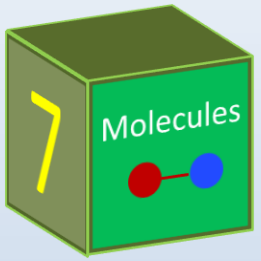


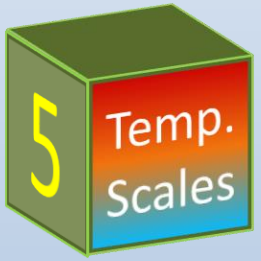
Questions?





Session 1 Outline: Building Blocks





Course Outline

1. Building Blocks: Some basic concepts ☑
2. Our Goldilocks earth: a radiative balancing act
3. The Atmosphere and its Gases. Modeling the climate system
4. Global Circulation and the roles of clouds and aerosols
5. The Dynamic Earth System: Oceans, atmosphere, biosphere, cryosphere, people, plate tectonics
6. Natural Variability of the climate, short and long term. Ice ages
7. Carbon Dioxide, Water and other greenhouse gases: Where do they come from, where do they go, how are they regulated?
8. Future Projections: Impacts of GW and the uncertainties. Amelioration strategies.