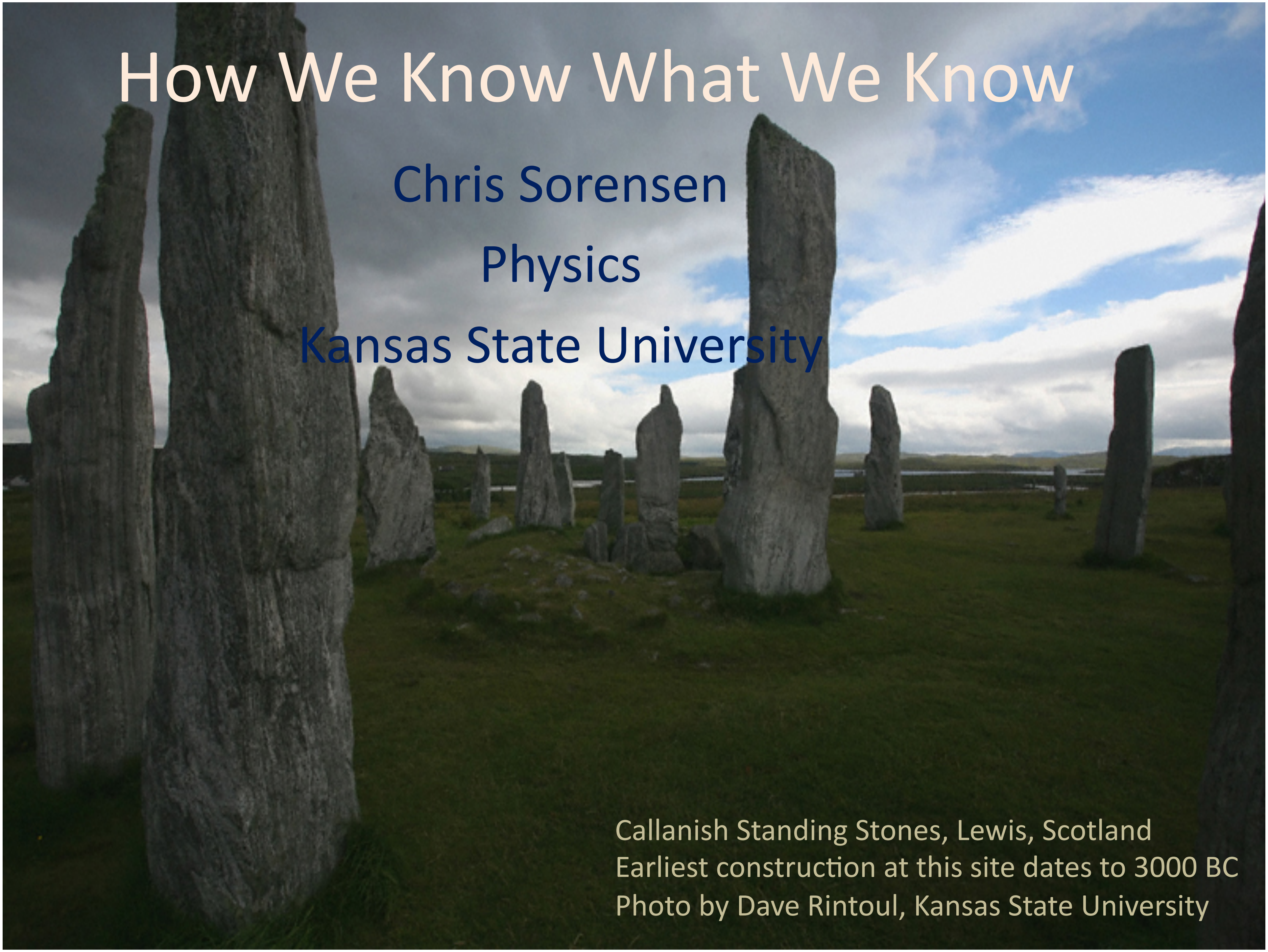
How We Know What We Know

Chris Sorensen

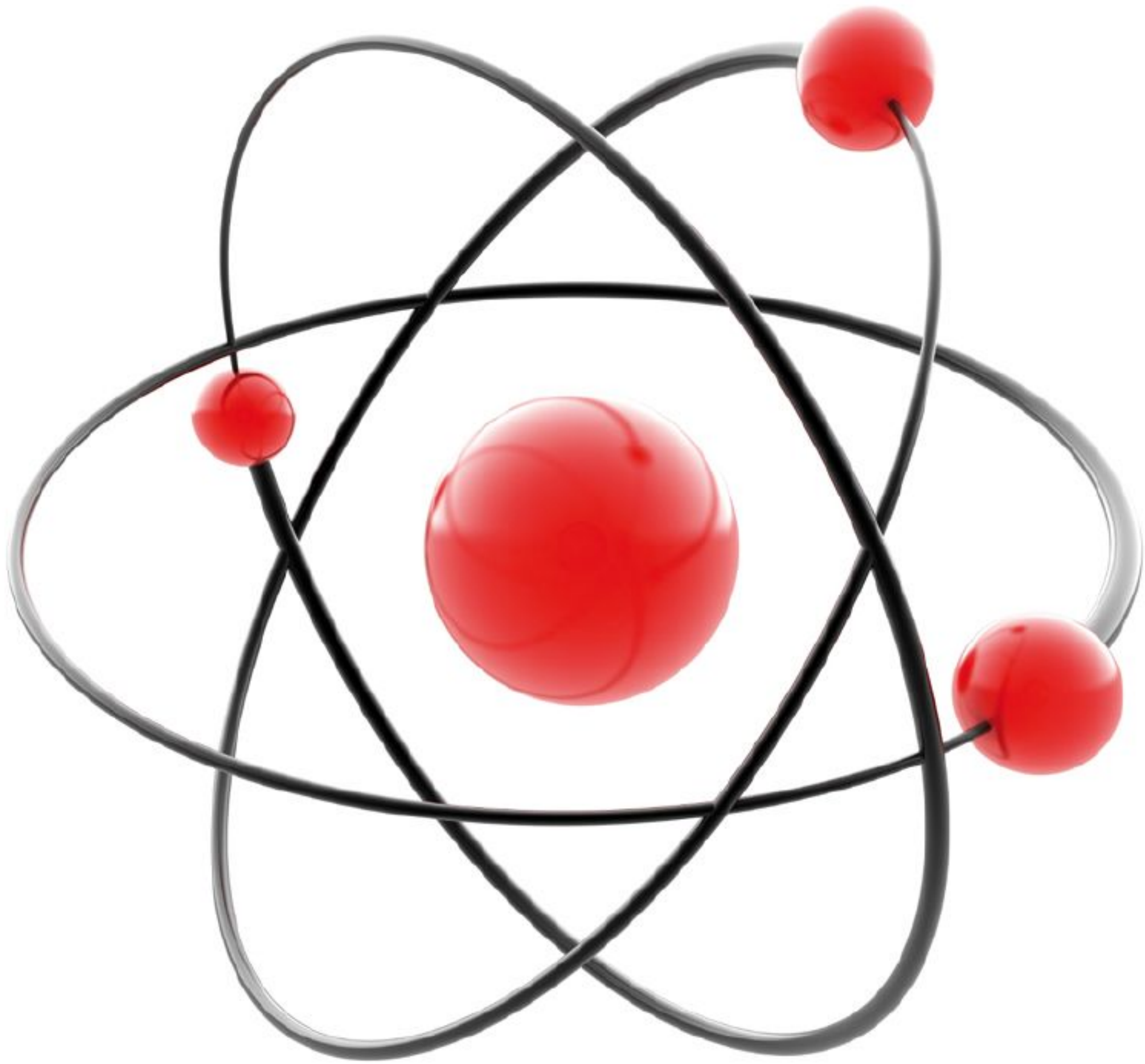
Physics

Kansas State University



Callanish Standing Stones, Lewis, Scotland
Earliest construction at this site dates to 3000 BC
Photo by Dave Rintoul, Kansas State University

How do we know atoms exist?



howitworksdaily.com

Ancient Speculations

The Atomic Hypothesis

Leucippus and Democritus, ca. 400 BC

Democritus

wikipedia

What if…

You cut a piece of iron in half?

“a-tomic” Greek for “non-divisible”

Let’s go dancing!

Dance 1. A ton of girls and a ton of boys.
After the dance, we find some changes.
There is now a new compound called “couples”
and there is 1.5 ton of couples.
We also find 0.5 ton of girls left over.

Dance 2. 1 ton of girls and 3 tons of boys.
After the dance, there is 3 tons of couples.
We also find 1 ton of boys left over.

Dance 3. 1 ton of girls and 2 tons of boys.
After the dance, there is 3 tons of couples,
and no one is left over.

Conclusion (not unique): Boys and girls combine in a 2:1 mass ratio to make couples. Why? Maybe girls and boys come in indivisible pieces of fixed mass with that ratio.

Let do some chemistry!! (and solve some puzzles)

React 1 gram of hydrogen (H) with lots of oxygen (O)
you get 9 grams of water and lose 8 grams of O.
i.e. 1 gram of H combines with 8 grams of O

Implies the "pieces" of O are 8 times as massive as
the "pieces" of H

React 1 gram H with lots of O and lots of sodium (Na).
You get 40 grams of lye and lose 16 grams of O
and 23 grams of Na.
This time 1 gram of H combines with 16 grams of O

Maybe the "pieces" of O are 16 times more massive than H,
and water had 2 H "pieces" for every O "piece".

John Dalton ca. 1800
The Laws of Definite
and Multiple Proportions

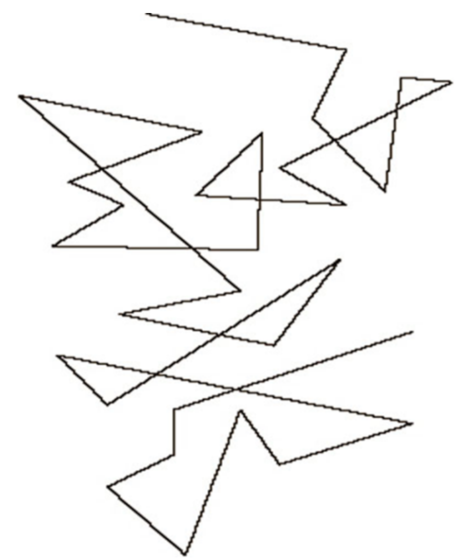
These laws imply that
matter comes in “pieces”
called atoms

chemheritage.org

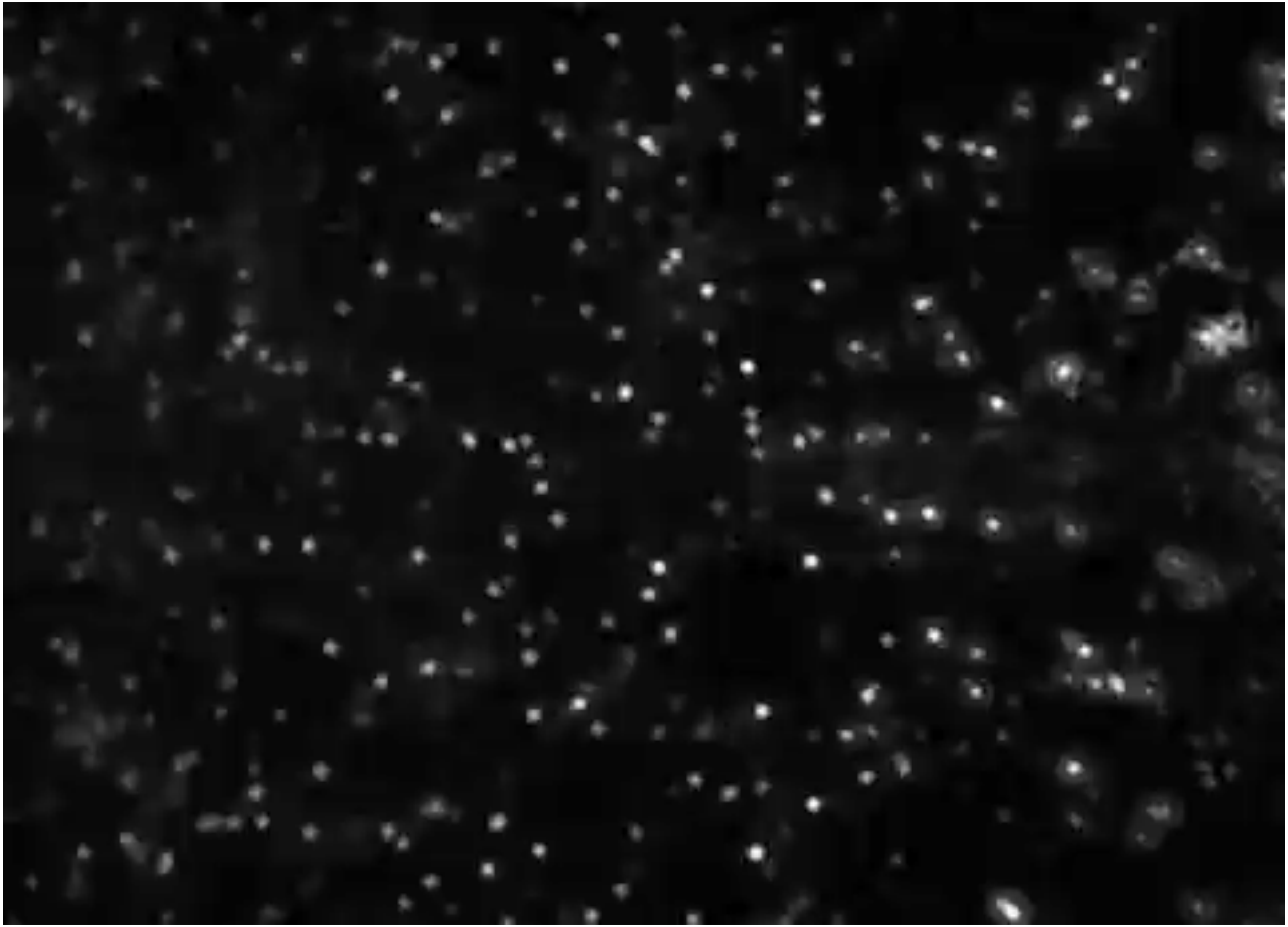
Brownian Motion

In 1827 Robert Brown, looking through a microscope at pollen grains in water, noted that the grains moved randomly through the still water.

Why?

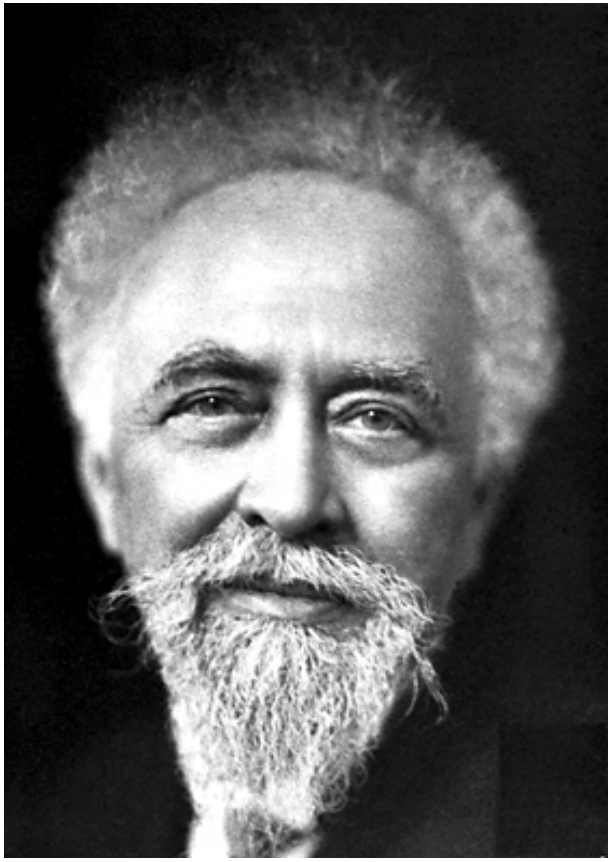


Random Path



Einstein (1905): the thermal motion of atoms!

Physical scientists of this pivotal period [early 20th century] did not for one minute assume … the discontinuity of the matter which underlies visible reality. In looking back upon the discoveries and theories of particles, one perhaps fails to realize that the focus was not simply upon the nature of the molecules, ions and atoms, but upon the very fact of their existence…
Mary Jo Nye



Einstein 1905
Perrin 1909
Bohr 1913

The Nobel Prize in Physics 1926
Jean Baptiste Perrin for his work on *the discontinuous structure of matter, and especially for his discovery of sedimentation equilibrium".*

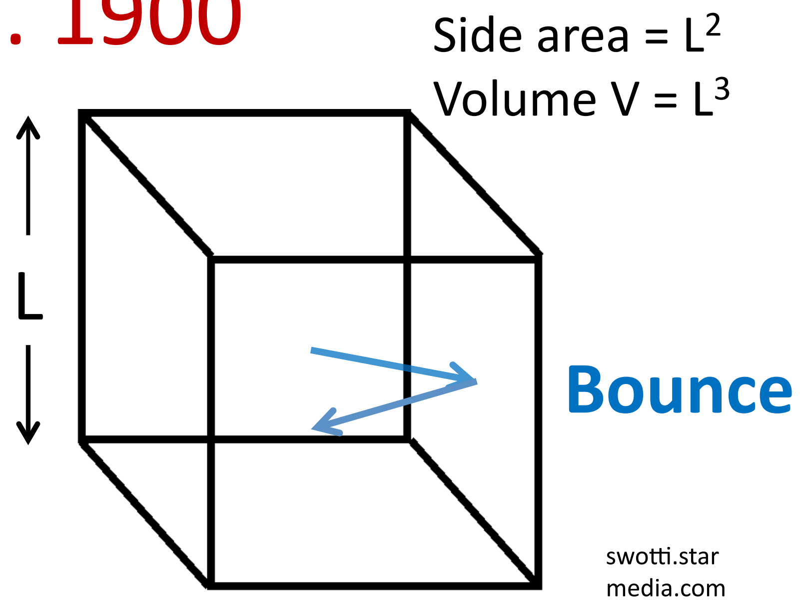
The Kinetic Theory of Heat
Boltzmann, ca. 1900

Heat is atomic motion

An atom of mass m
has a kinetic energy given by

$$E = mv^2/2 = 3kT/2$$

k is Boltzmann's constant
T is the temperature (absolute).



Pressure P due to bounce

Bounces increase with number of atoms, P ~ N

decease with time between bounces, P ~ 1/V

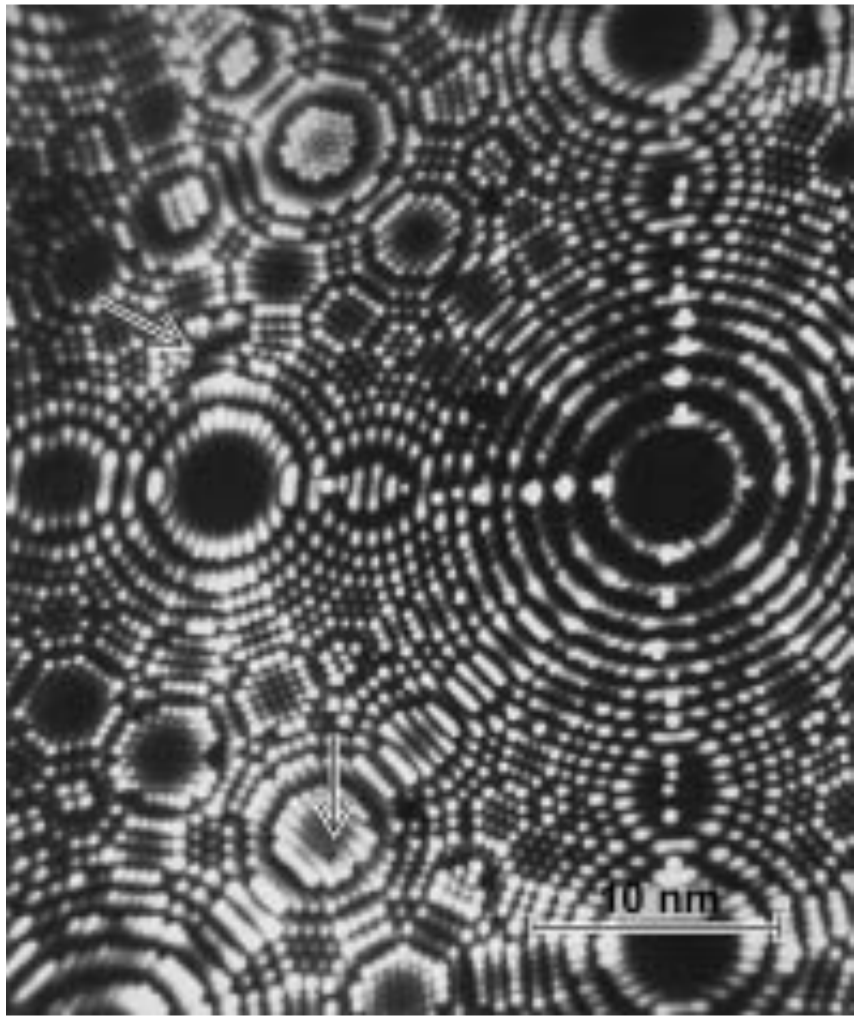
become stronger with atom energy, P ~ kT

Thus P ~ NkT/V, The Ideal Gas Law!

Boltzmann

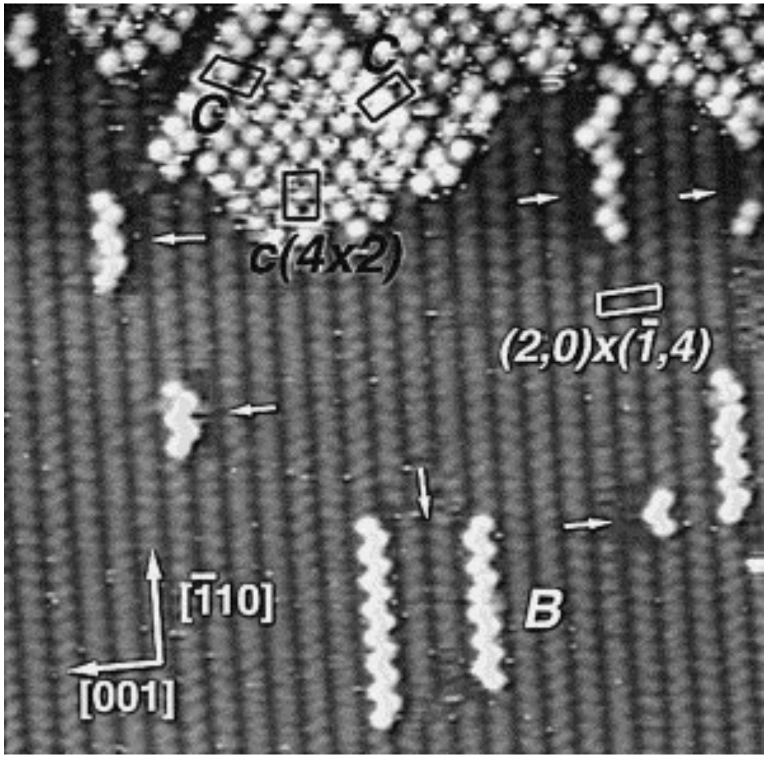
wikipedia.org/wiki/
File:Zentralfriedhof_Vienna_-
_Boltzmann.JPG

Fielded-Emission Microscope
Ca. mid 20th Century

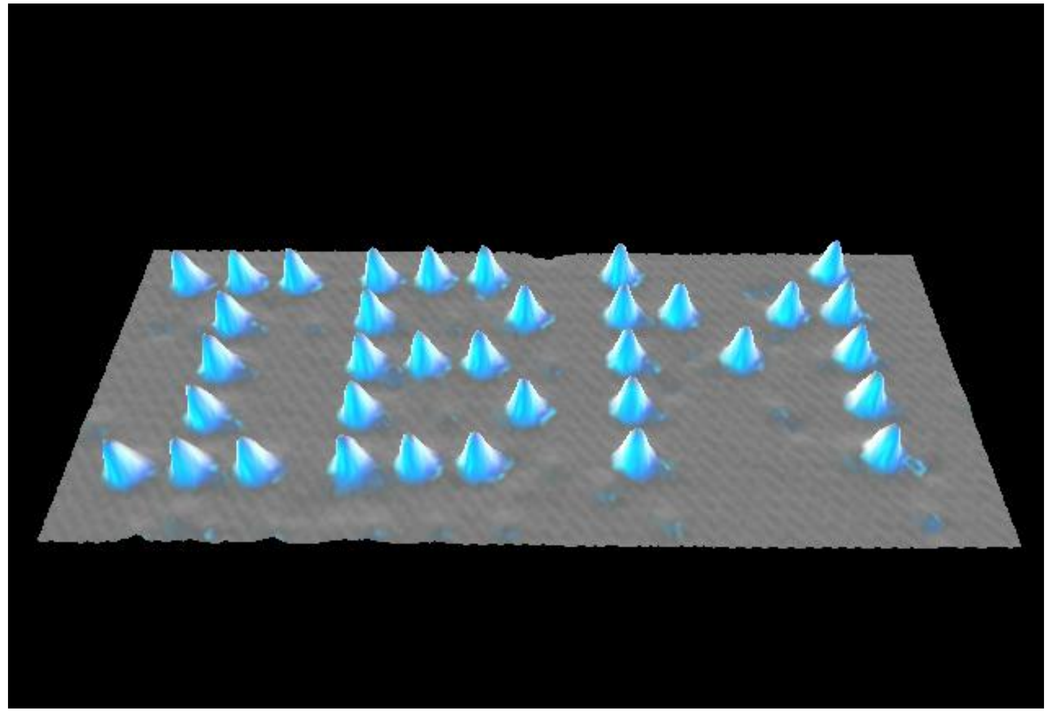


accessscience.com

Scanning Tunneling Microscope



Tin atoms (white) on Silicon surface (grey)

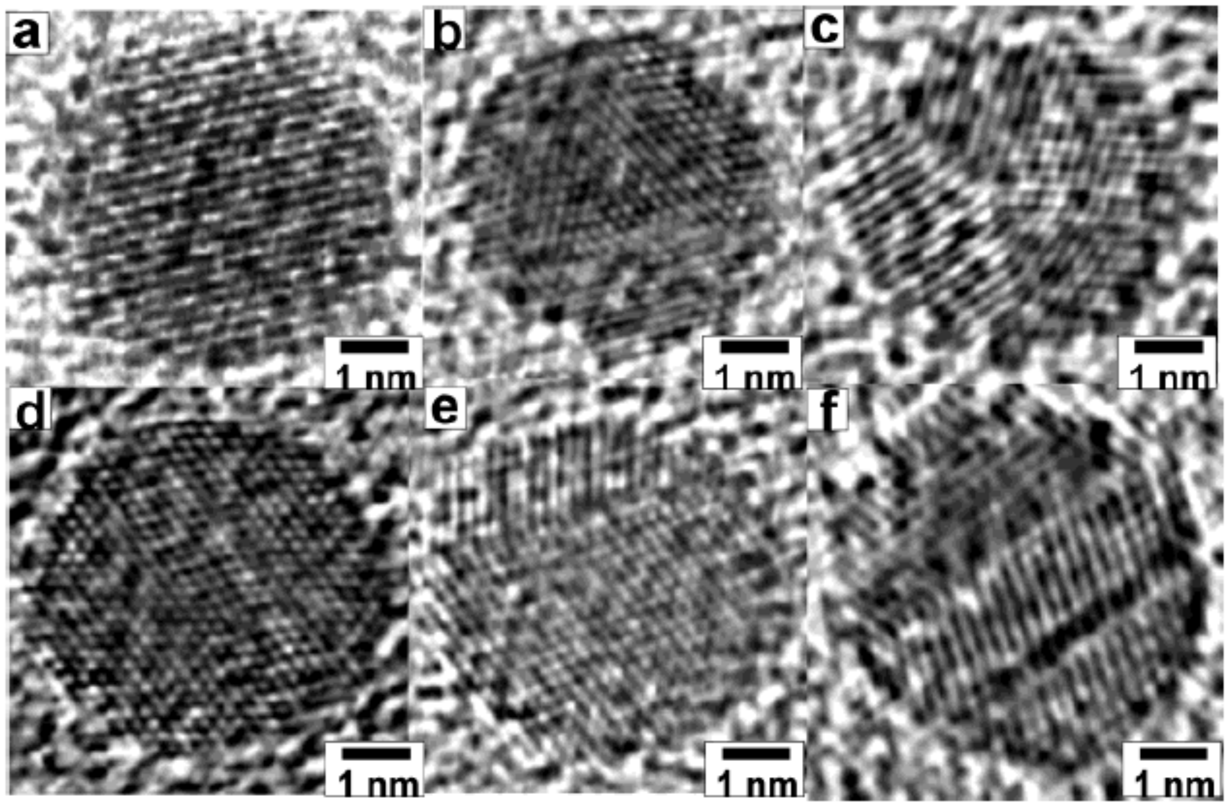


Xenon atoms manipulated to Spell IBM on silicon (unresolved).

sciencedirect.com/science An et al.

researcher.watson.ibm.com

High Resolution Transmission Electron Microscopy
HRTEM



Gold nanoparticles. Individual dots are gold atoms

Seeing is believing … I guess

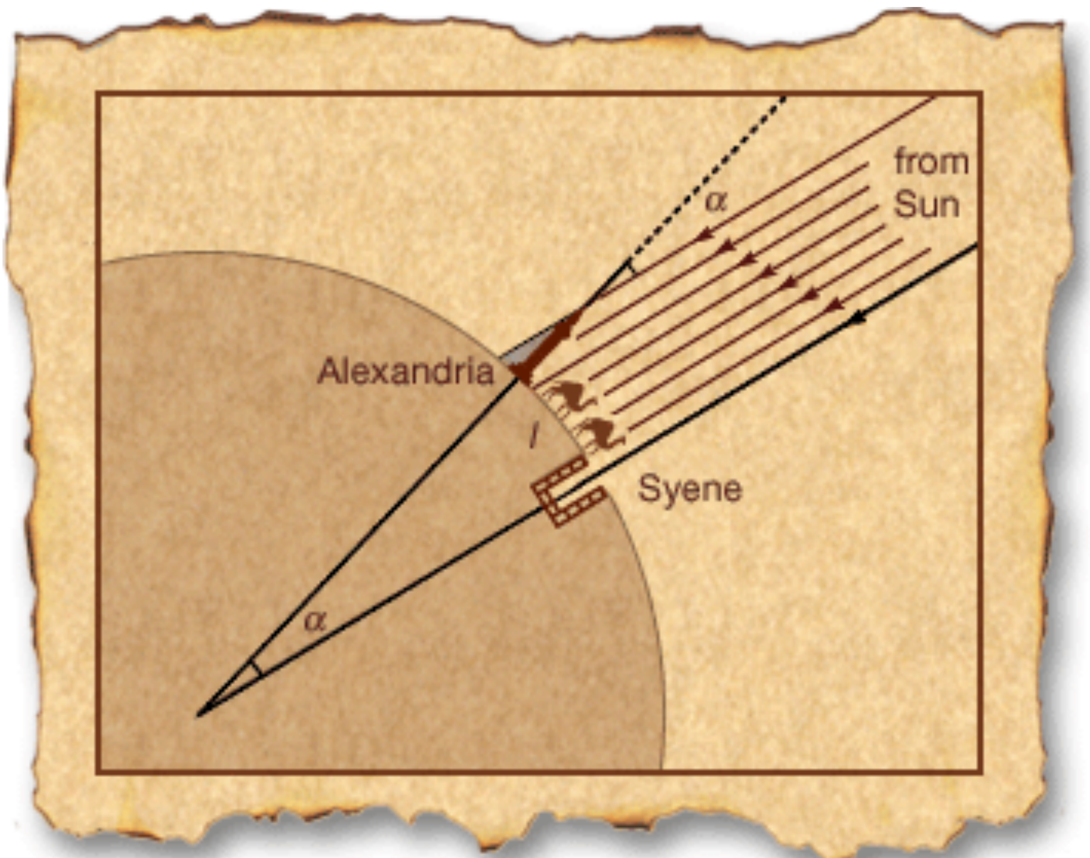
J. Phys. Chem. B 107, 7441 (2003)

How big is the Earth?

solarsystem.nasa.gov

The Earth's shadow during a lunar eclipse

Eratosthenes
Measuring the Earth
Ca. 250 BC



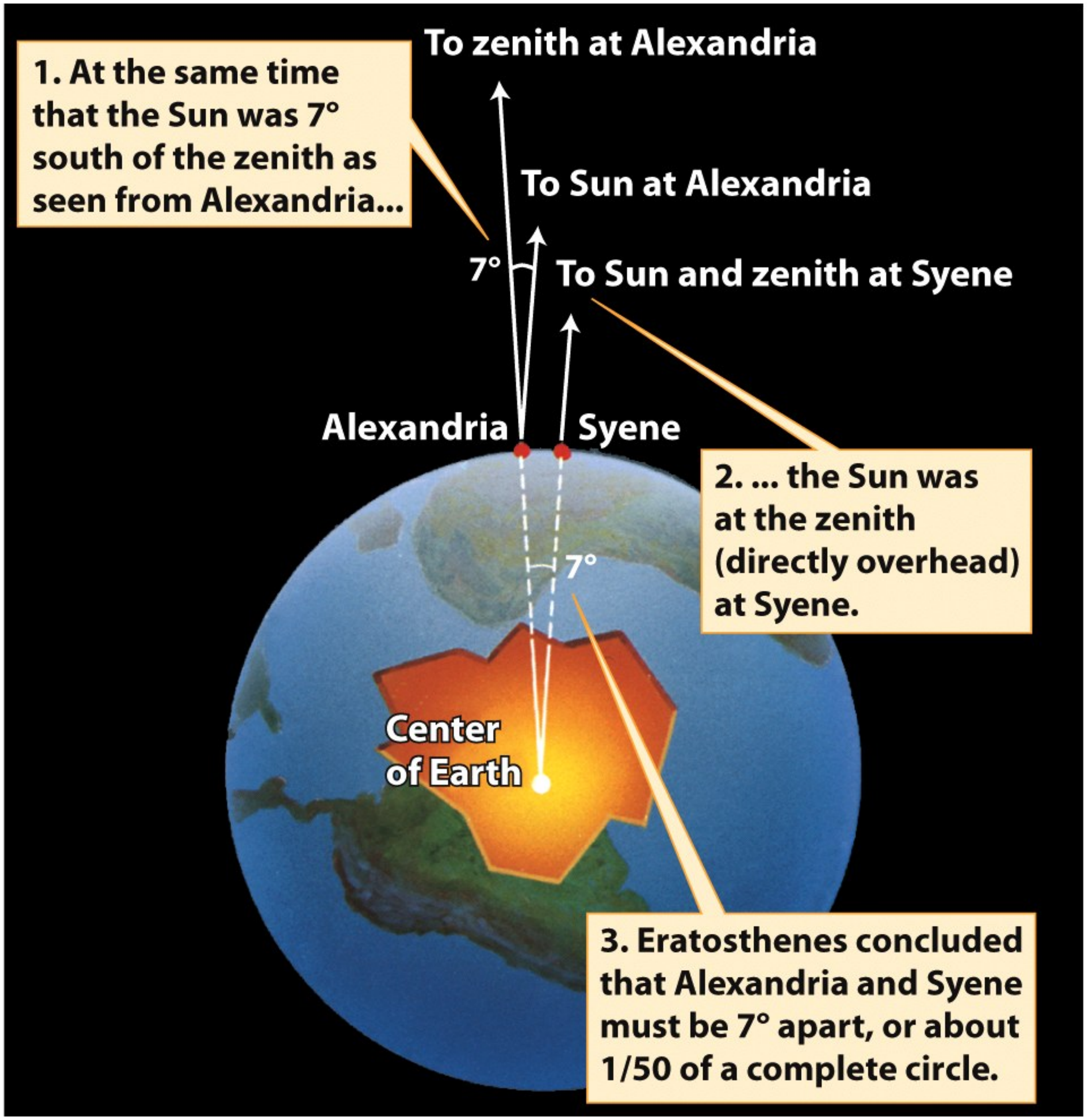


Figure 3-1
Investigating Astronomy

Weighing the Earth

Know the size, i.e. radius R (Eratosthenes ...)

Guess the density, e.g. water at $\rho = 1.0$ g/cc.

Calculate the mass:

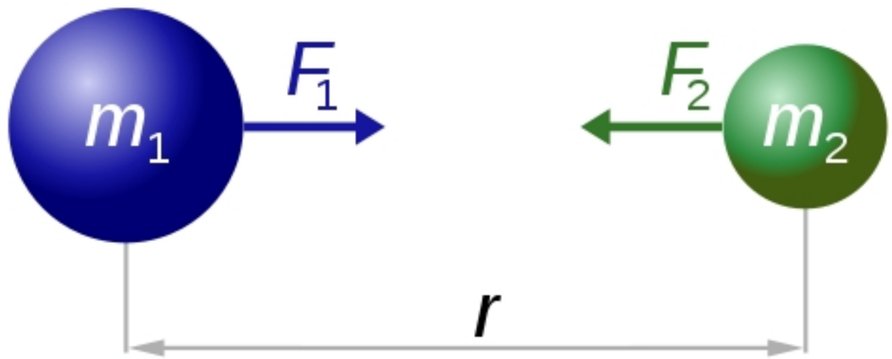
$$M = \rho\ 4\pi R^3/3$$

$$M = 10^3(12.56)(6.38\times10^6)^3/3 \quad \text{(SI units)}$$

$$M = 1.1\times10^{24}\ \text{kg}$$

Weighing the Earth (2)

Newton's Law of Universal Gravitation



$$F_1 = F_2 = G\frac{m_1 \times m_2}{r^2}$$

What is Big G?

The Physics of Falling

Ball

$F = Gm_bM_E/r^2$

Earth/ball distance is
Center-to-center distance
$r = R_E$

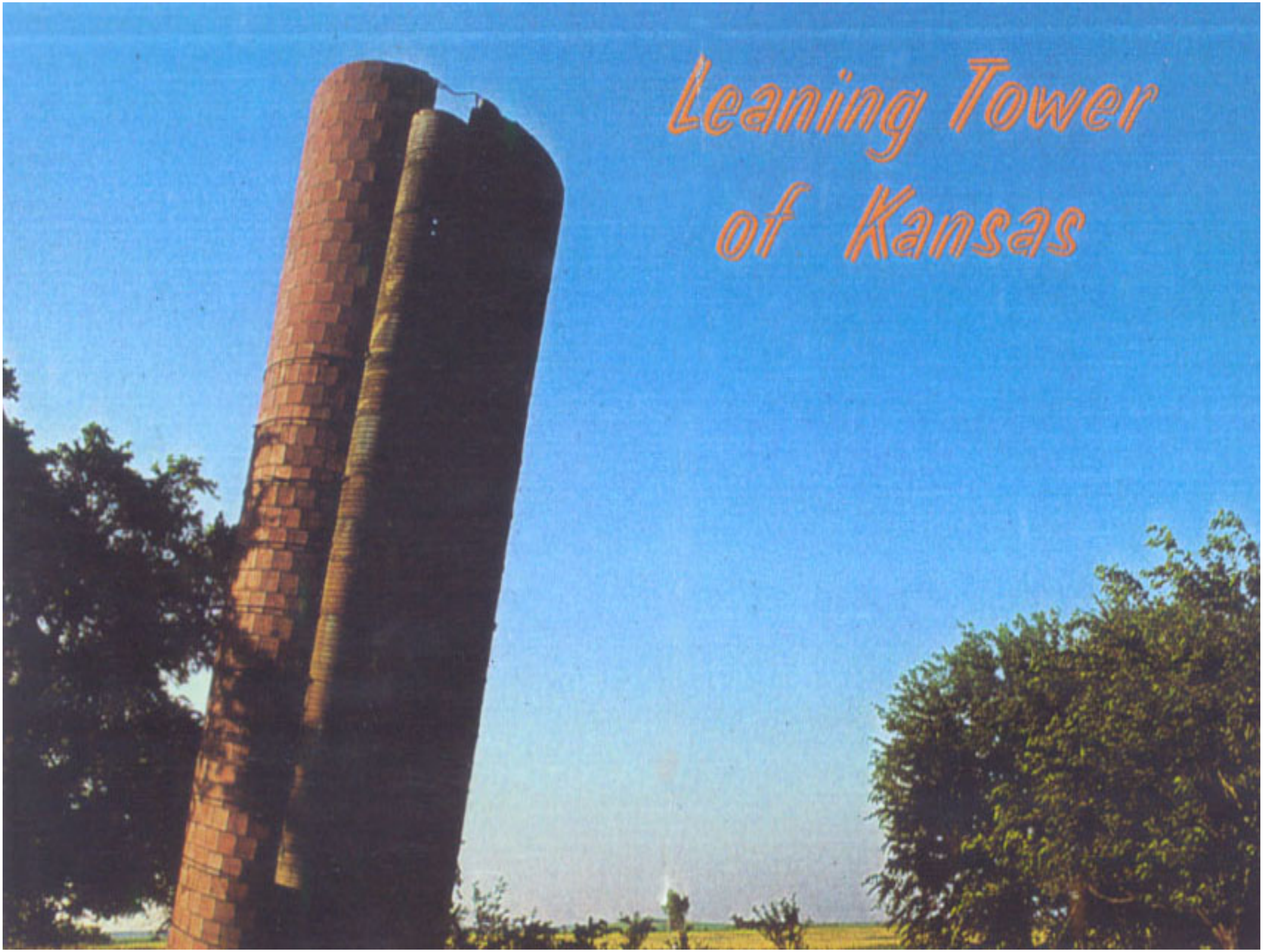
Newton's 2nd Law
$F = ma$

Combine
$m_b a = Gm_bM_E/R_E^2$
$a = GM_E/R_E^2$

And what is the acceleration a?

It's the acceleration of gravity $g = 9.8 m/s^2$!

Thus, $M_E = gR_E^2/G$


Leaning Tower
of Kansas

The Cavendish Experiment 1797-98

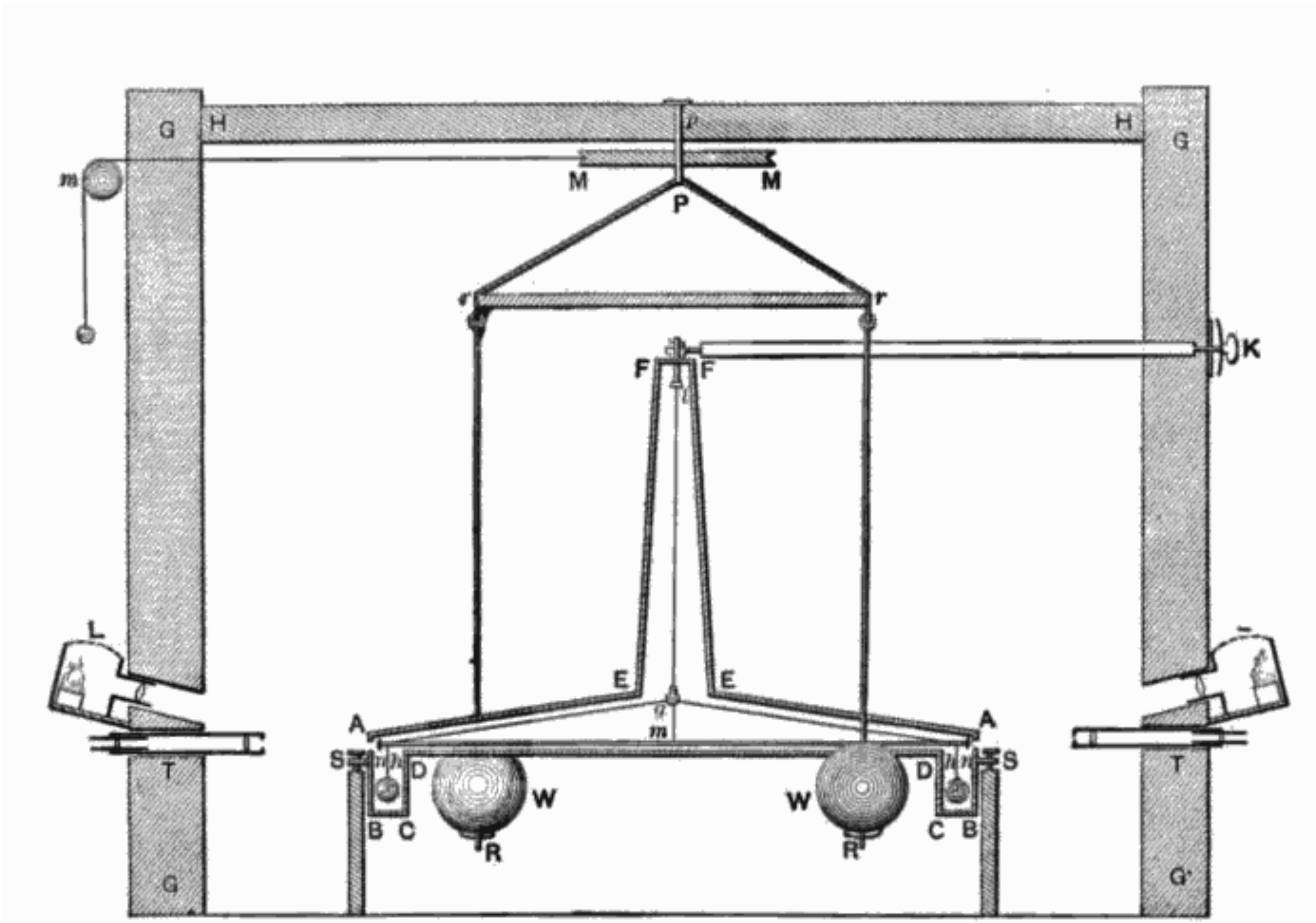
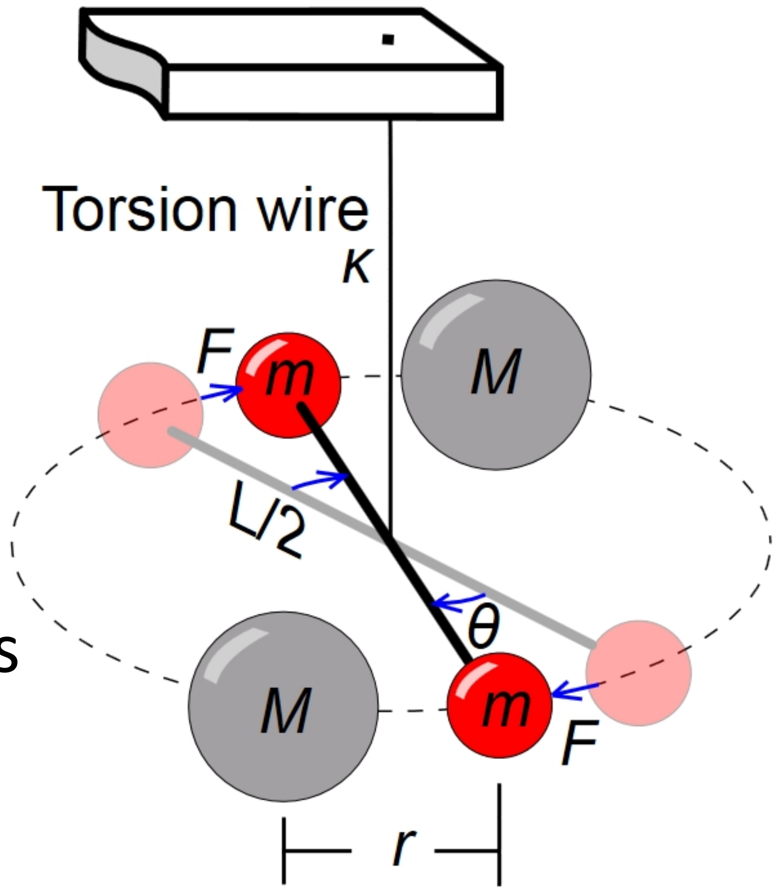


Fig. 1

wikipedia

Cavendish Schematic



M = 350 pounds
m = 1.6 pounds
r = 9”

F = 1.7 x 10^{-7}N equivalent to 17 micrograms!

wikipedia

$$M_E = gR_E^2/G$$
$$= 9.8(6.38\text{x}10^6)^2/6.67\text{x}10^{-11} \quad \text{(SI units)}$$
$$= 6.0\text{x}10^{24}\ \text{kg}$$


What are Stars?
Pinprick holes in a colorless sky?
--- *The Moody Blues*
http://www.wheretowillie.com


What are they…
where are they…
how far away?

Parallax

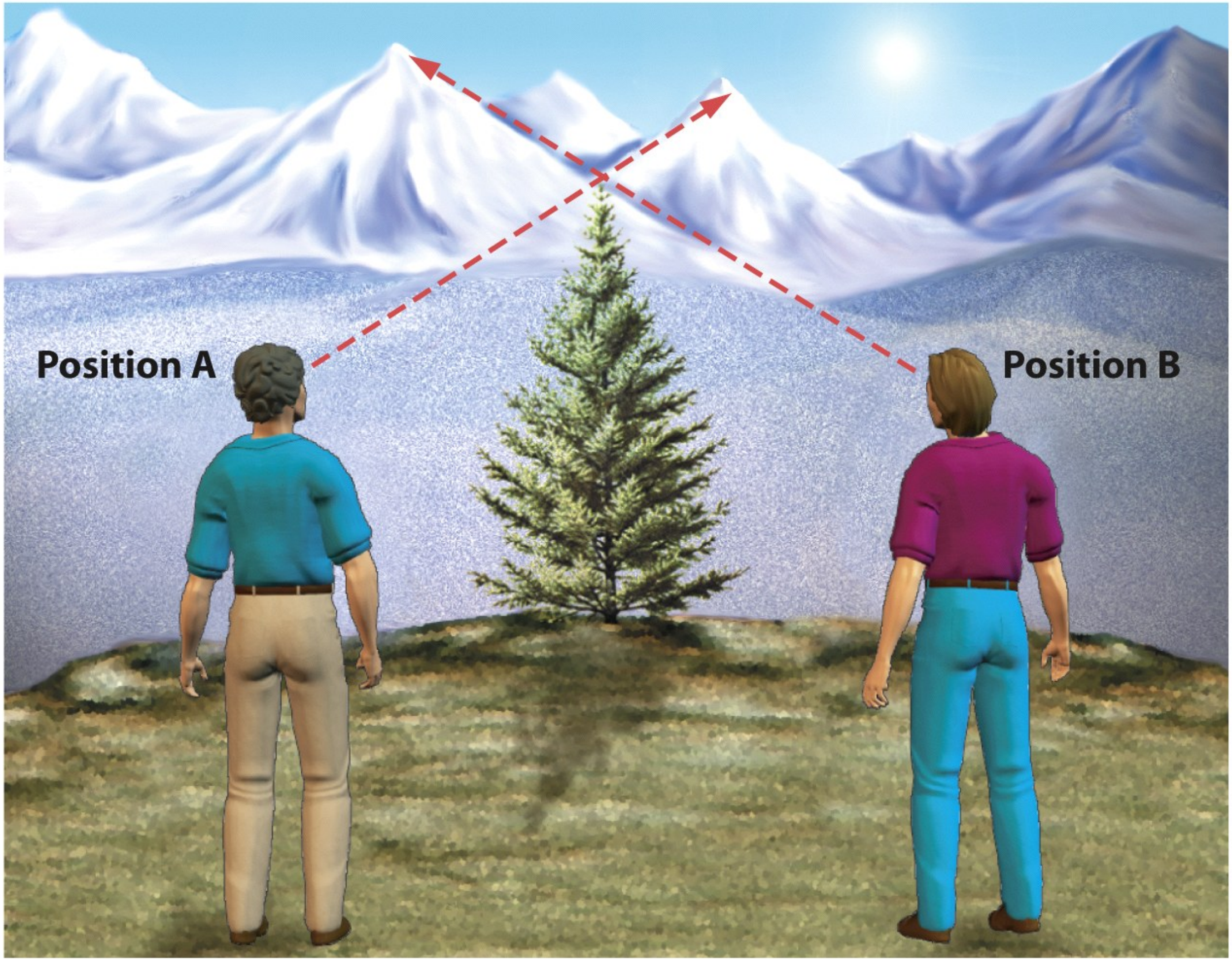
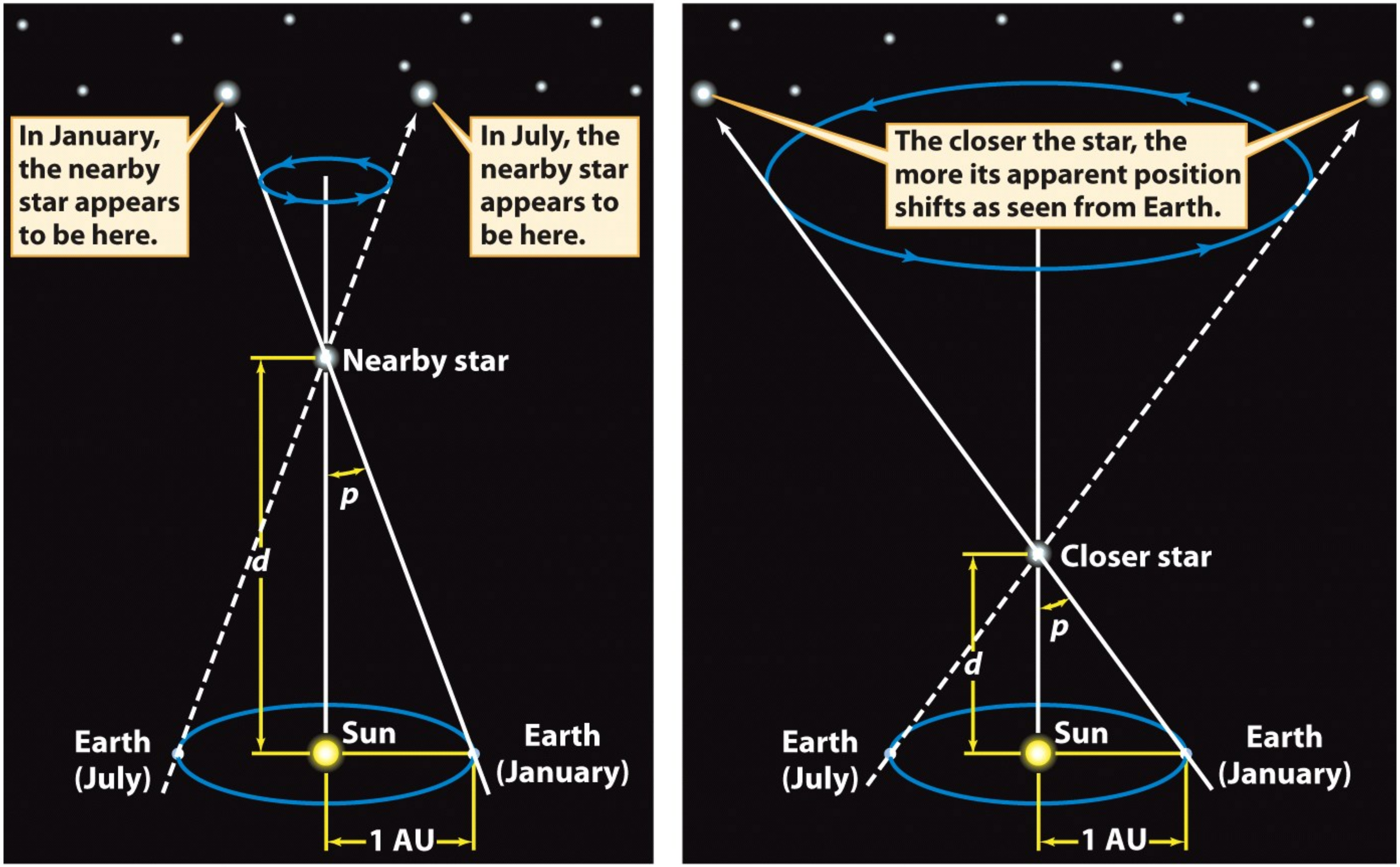


Figure 10-1
Investigating Astronomy

Parallax



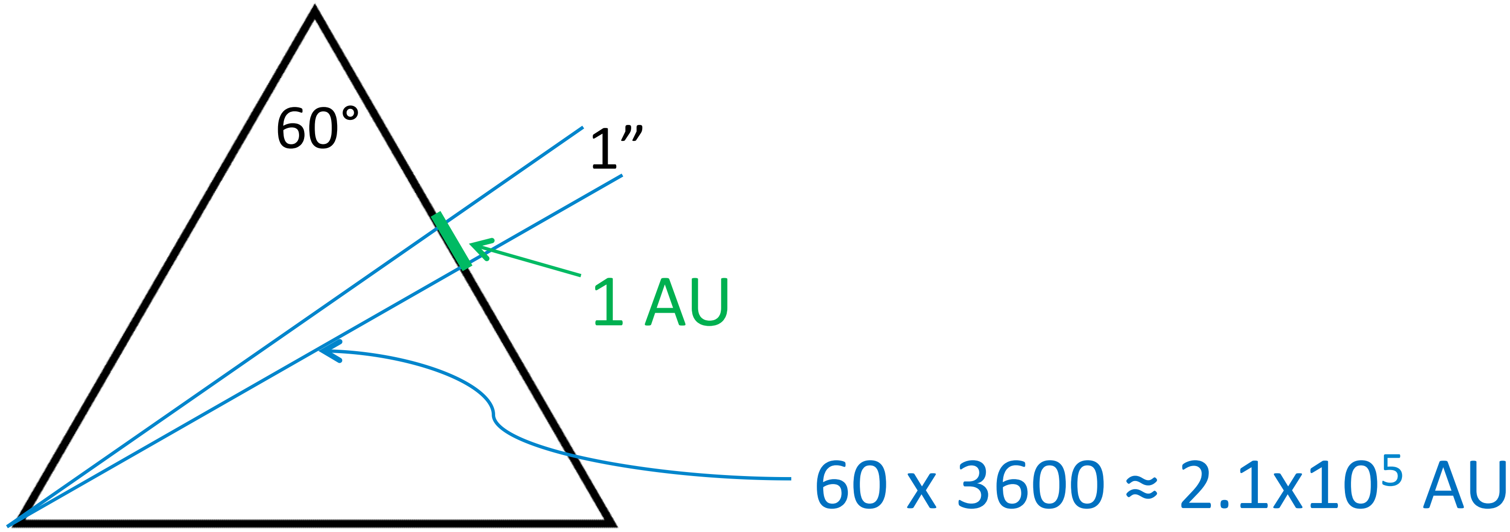
(a) Parallax of a nearby star **(b) Parallax of an even closer star**

Figure 10-2
Investigating Astronomy

All stellar parallax angles are <u>less than one second of arc</u>!

There are 60 sec in a minute and 60 min in a degree

1” = 1/3600 deg



2.1×10^{5} x 93,000,000 miles = 2×10^{13} miles!

$2\times10^{13}/(1.86\times10^{5} \times 3600 \times 24 \times 365) = 3.3$ years!!

All stars are farther than 3.3 light years away!

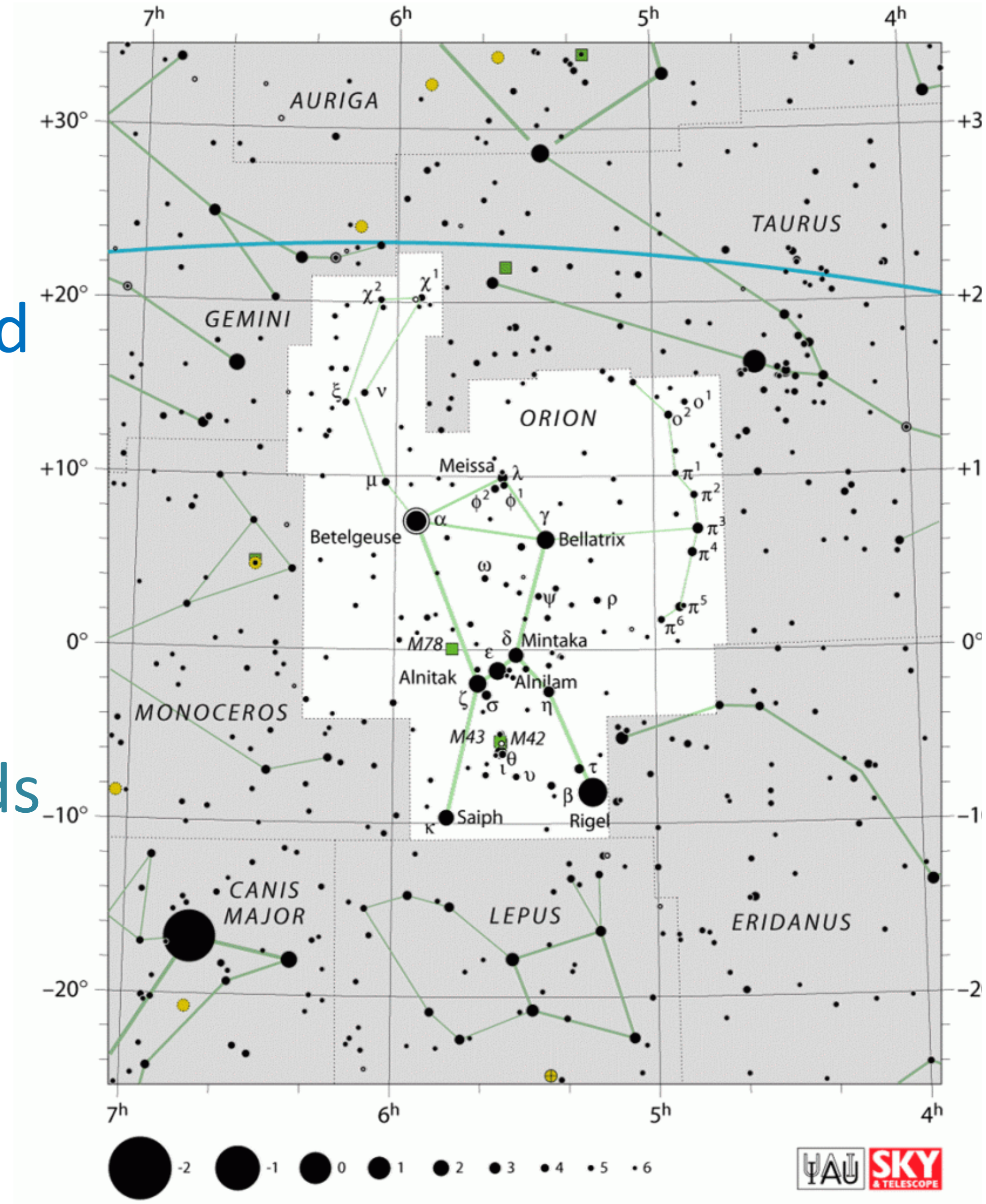
The Nearest Stars

Star	Distance (light years)
Alpha Centauri C ("Proxima")	4.2
Alpha Centauri A and B	4.3
Barnard's Star	6.0
Wolf 359	7.7
BD +36 degrees 2147	8.2
Luyten 726-8 A and B	8.4
Sirius A and B	8.6
Ross 154	9.4
Ross 248	10.4
Epsilon Eradinis	10.8
Ross 128	10.9
61 Cygni A and B	11.1
Procyon A and B	11.4

Stellar Brightness

Stellar brightness is measured with apparent magnitude. The smaller the magnitude, the brighter the star.

Apparent magnitude depends on intrinsic brightness and distance.



Absolute Magnitude (Intrinsic Brightness)

Given

- The apparent magnitude
- The distance
- The inverse square law: Intensity ~ $1/(\text{distance})^2$

One can calculate the <u>absolute magnitude</u>

which is the magnitude a star would have if it was ca. 30 light years (10 parsecs = 32.6 ly) away.

The Brightest Stars

Names		Dist(ly)	App Mag	Abs Mag
Sirius	Alpha CMa	8.6	-1.46	1.4
Canopus	Alpha Car	74	-0.72	-2.5
Rigil Kentaurus	Alpha Cen	4.3	-0.27	4.4
Arcturus	Alpha Boo	34	-0.04	0.2
Vega	Alpha Lyr	25	0.03	0.6
Capella	Alpha Aur	41	0.08	0.4
Rigel	Beta Ori	~1400	0.12	-8.1
Procyon	Alpha CMi	11.4	0.38	2.6
Achernar	Alpha Eri	69	0.46	-1.3
Betelgeuse	Alpha Ori	~1400	0.50 (var.)	-7.2
Hadar	Beta Cen	320	0.61 (var.)	-4.4
Acrux	Alpha Cru	510	0.76	-4.6
Altair	Alpha Aql	16	0.77	2.3
Aldebaran	Alpha Tau	60	0.85 (var.)	-0.3
Antares	Alpha Sco	~520	0.96 (var.)	-5.2
Spica	Alpha Vir	220	0.98 (var.)	-3.2
Pollux	Beta Gem	40	1.14	0.7
Fomalhaut	Alpha PsA	22	1.16	2.0
Becrux	Beta Cru	460	1.25 (var.)	-4.7
Deneb	Alpha Cyg	1500	1.25	-7.2
Regulus	Alpha Leo	69	1.35	-0.3
Adhara	Epsilon CMa	570	1.50	-4.8
Castor	Alpha Gem	49	1.57	0.5
Gacrux	Gamma Cru	120	1.63 (var.)	-1.2
Shaula	Lambda Sco	330	1.63 (var.)	-3.5

astro.wisc.edu/~dolan/constellations/extra/brightest.html

What does brightness depend on?

Size and Temperature

Blackbody Radiation

All dense objects emit electromagnetic radiation at any finite temperature.

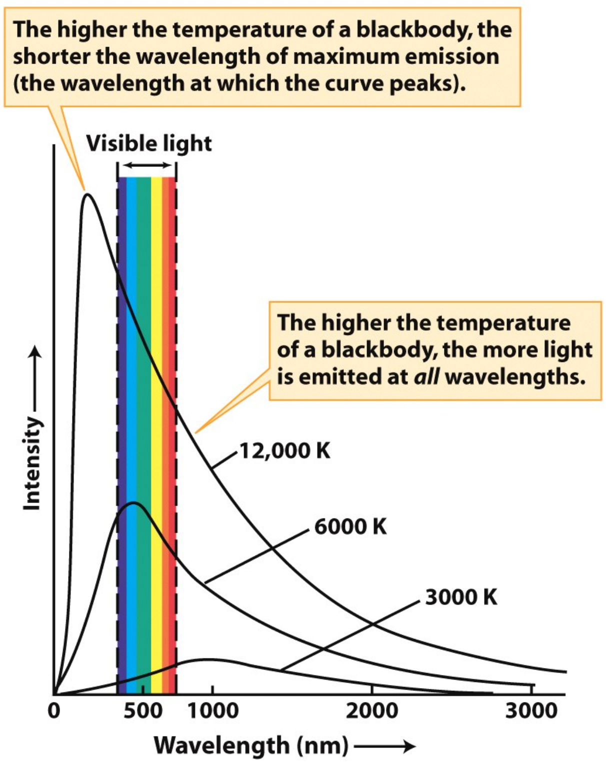
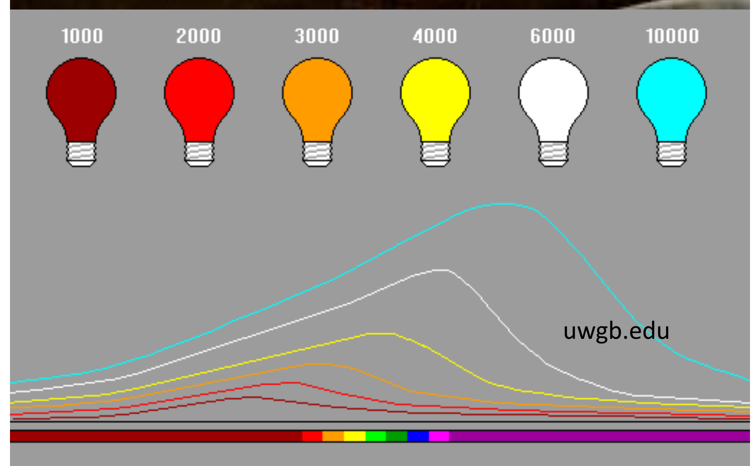
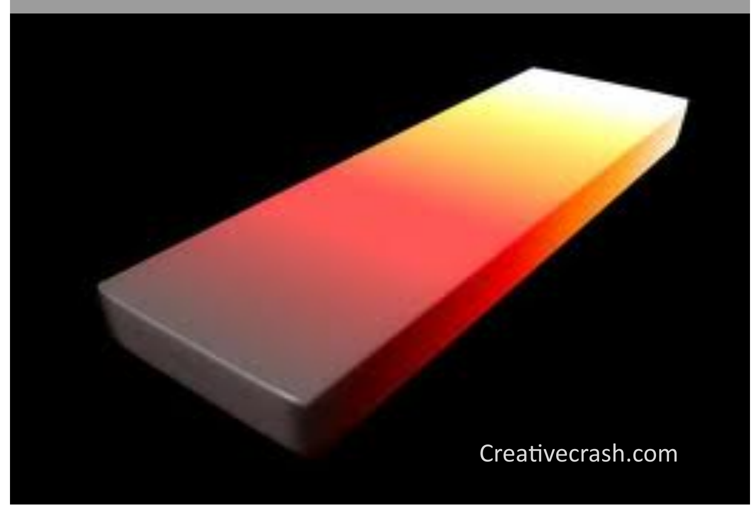


Figure 2-11
Investigating Astronomy





“Bluer” is hotter

“Bluer” is brighter


GE
energy smart
a smart way to save energy!
75
REPLACEMENT
LASTS 5 YEARS*
$44
IN ENERGY SAVINGS PER BULB**
2 PACK
20 WATT
ENERGY STAR
Soft White 2700K
energy used:
life:
contains:
1200
20
8000
2
(Spiral*)
20 WATT


Stars have color,
hence we can measure their temperatures!

Stellar Temperatures
and
Spectral Types

Apparent color

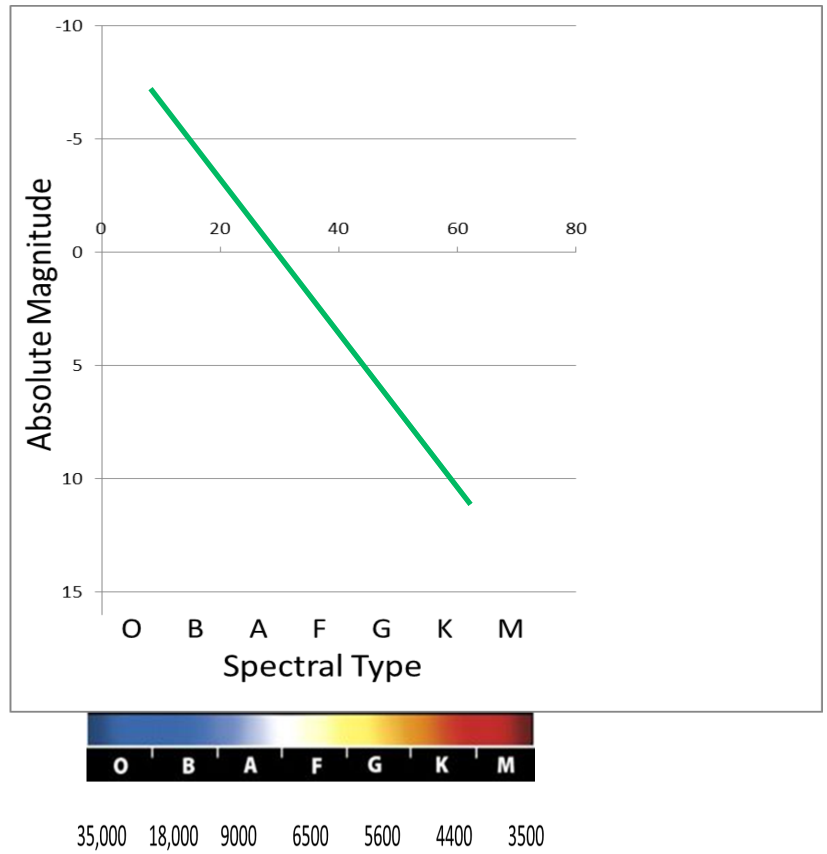
Spectral type

Temperature (K) 35,000 18,000 9000 6500 5600 4400 3500

Are bluer stars brighter, are redder stars dimmer?

Probably yes.

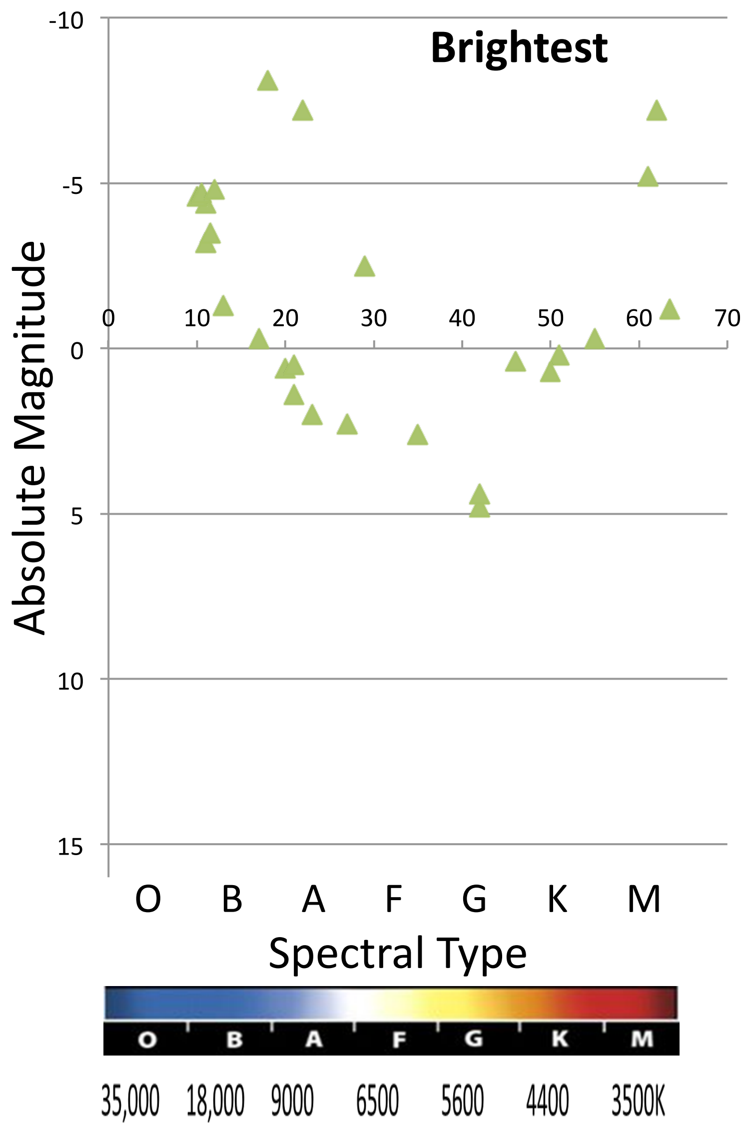
We expect



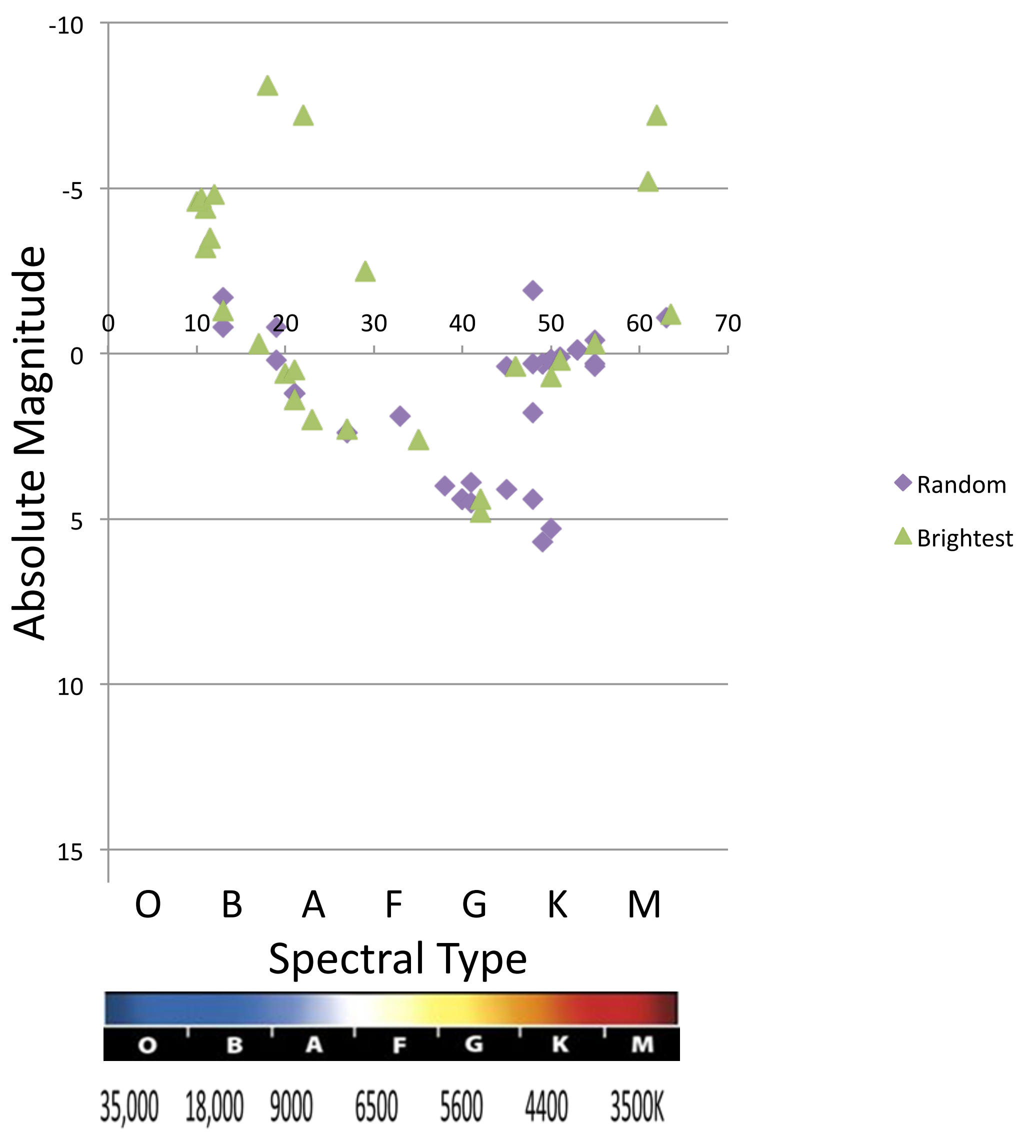
Is this in fact true?

We must test our hypothesis.

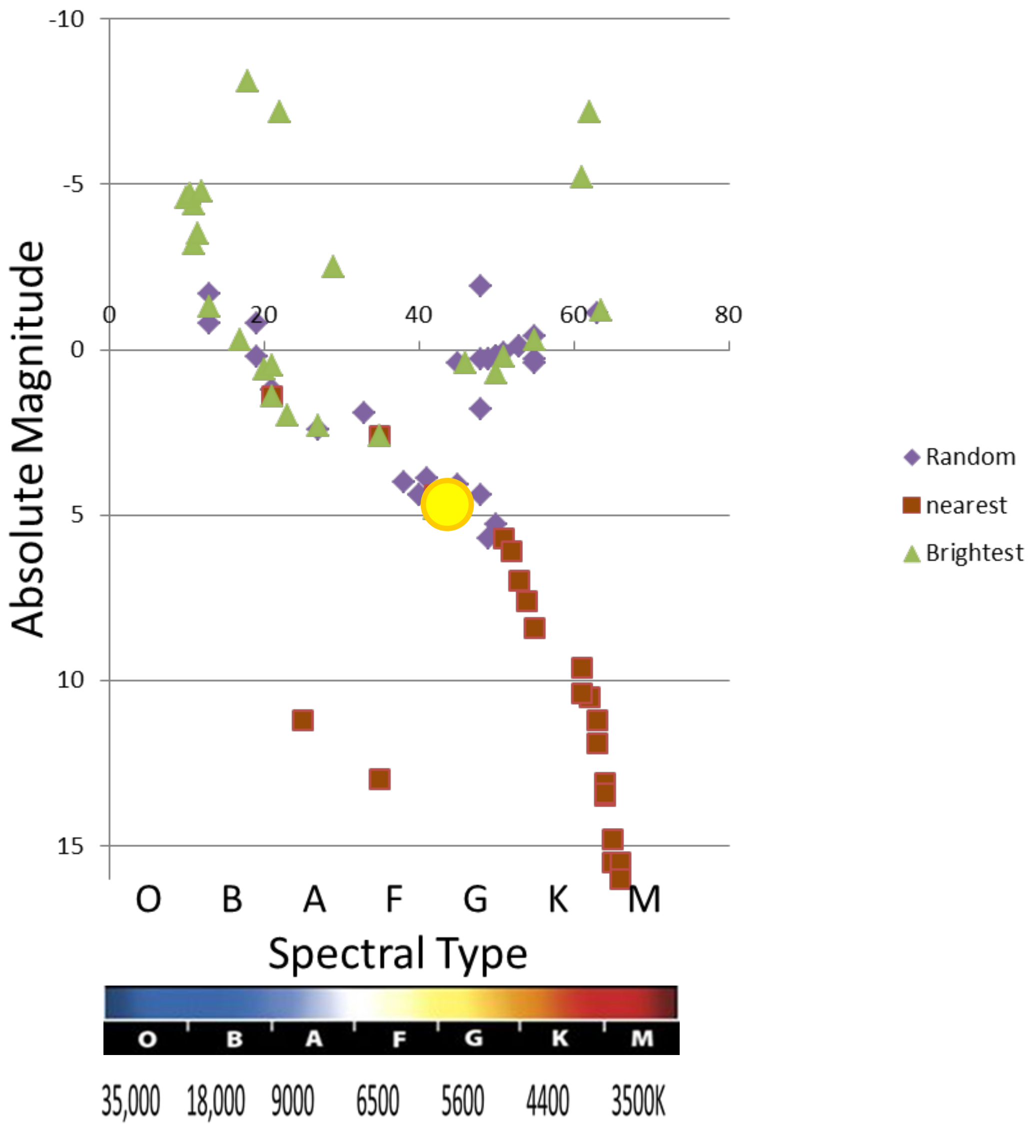
The Brightest Stars



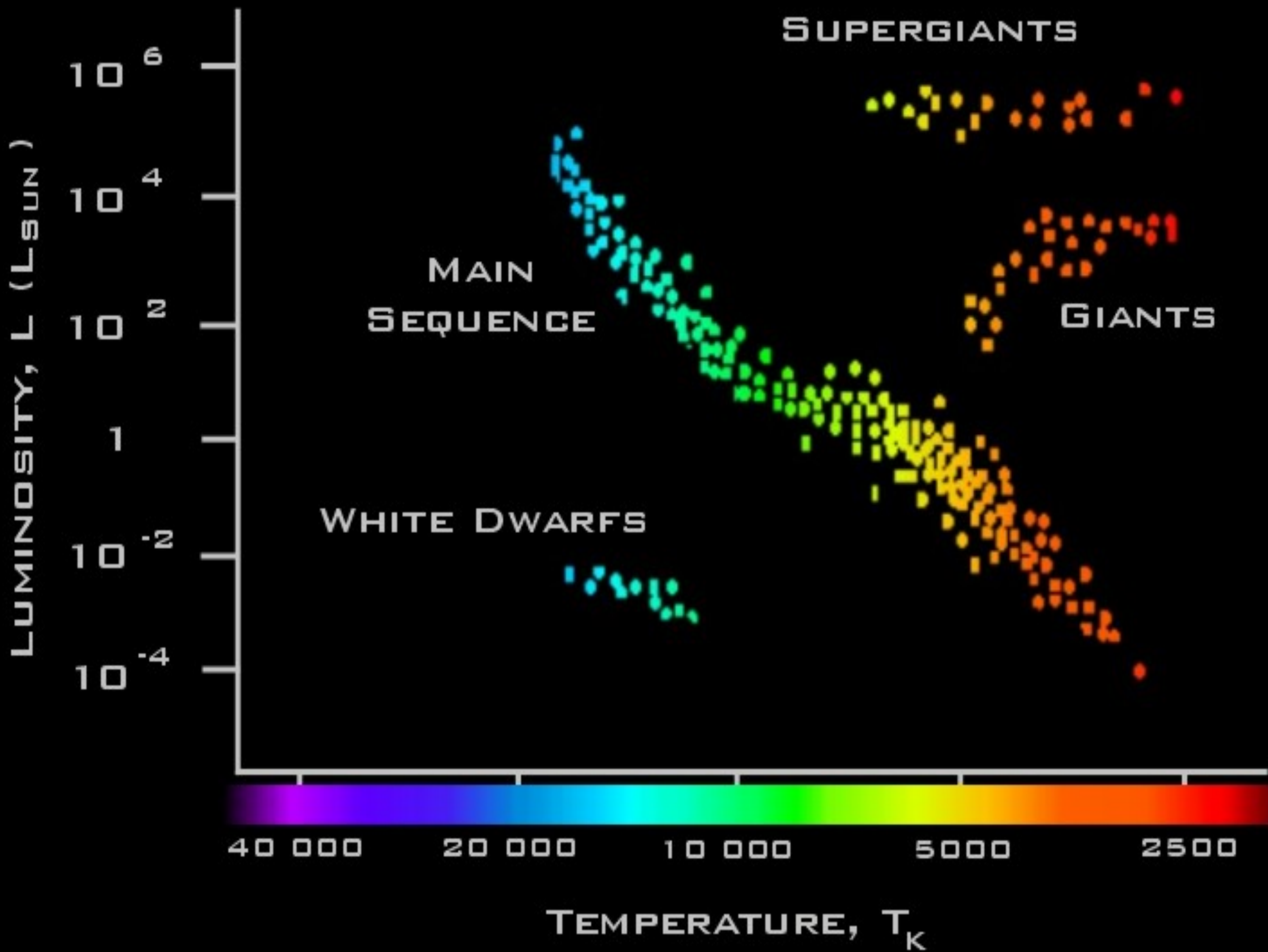
The Brightest and Randomly Picked Stars



The Brightest, Randomly Picked and Nearest Stars



The Hertzsprung-Russel Diagram



Faulkes

And now we find that we have, as Galileo advised, read “Nature like an open book”.

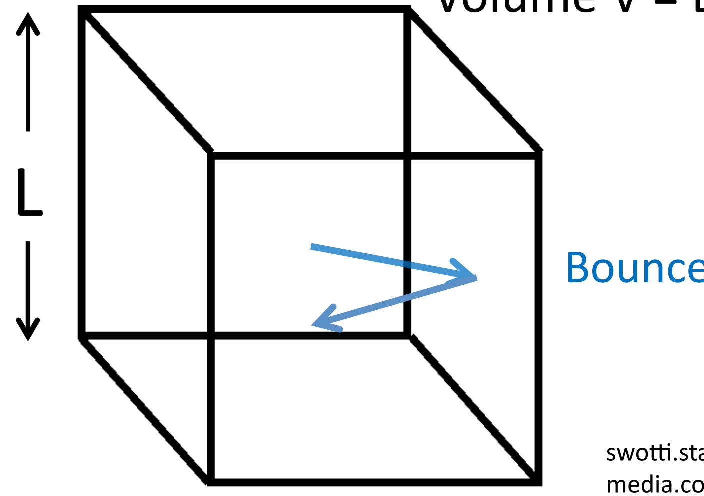
Stars are distant suns, and our Sun is one of many stars, and the possible stars are manifold to include many like our Sun but with widely ranging luminosities, and others that are giants of unimaginable proportions or dwarfs of enormous densities!

Yet, our quest continues (does it ever end?)!
We ask how do they shine? How were they formed?
Do their fires ever extinguish, and if so, how do they die?

These questions and others are accessible
via the method of science
and that’s how we know what we know!

The Kinetic Theory of Heat
Boltzmann, ca. 1900

Side area = L^2
Volume $V = L^3$



swotti.star
media.com

An atom of mass m
has a velocity v given by

$$v^2 = 3kT/m \quad (1)$$

k is Boltzmann's constant
T is the temperature (absolute).

Force due to one atom bounce

$$F = ma = m\Delta v/\Delta t = \Delta p/\Delta t$$
$$F = 2mv/(2L/v) = mv^2/L$$

$\Delta p = 2p = 2mv$
Round trip time
$\Delta t = 2L/v$
N atoms, N/3 moving along x-direction.

Pressure $P = F/L^2 = mv^2/L^3$
$P = mv^2/V = 3kT/V$

Total pressure $P = (N/3)3kT/V \Longrightarrow$ $PV = NkT$

The Ideal Gas Law