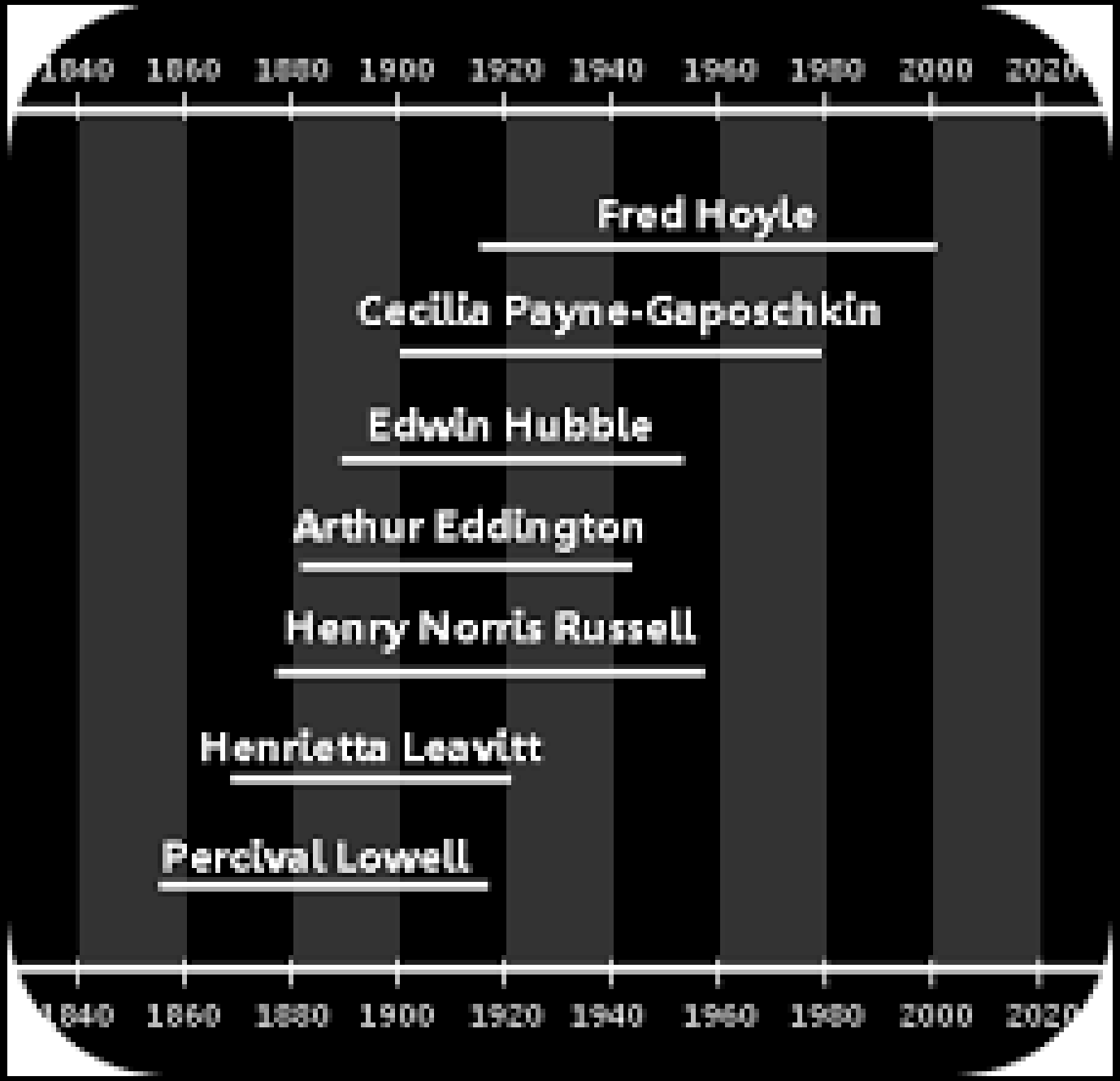
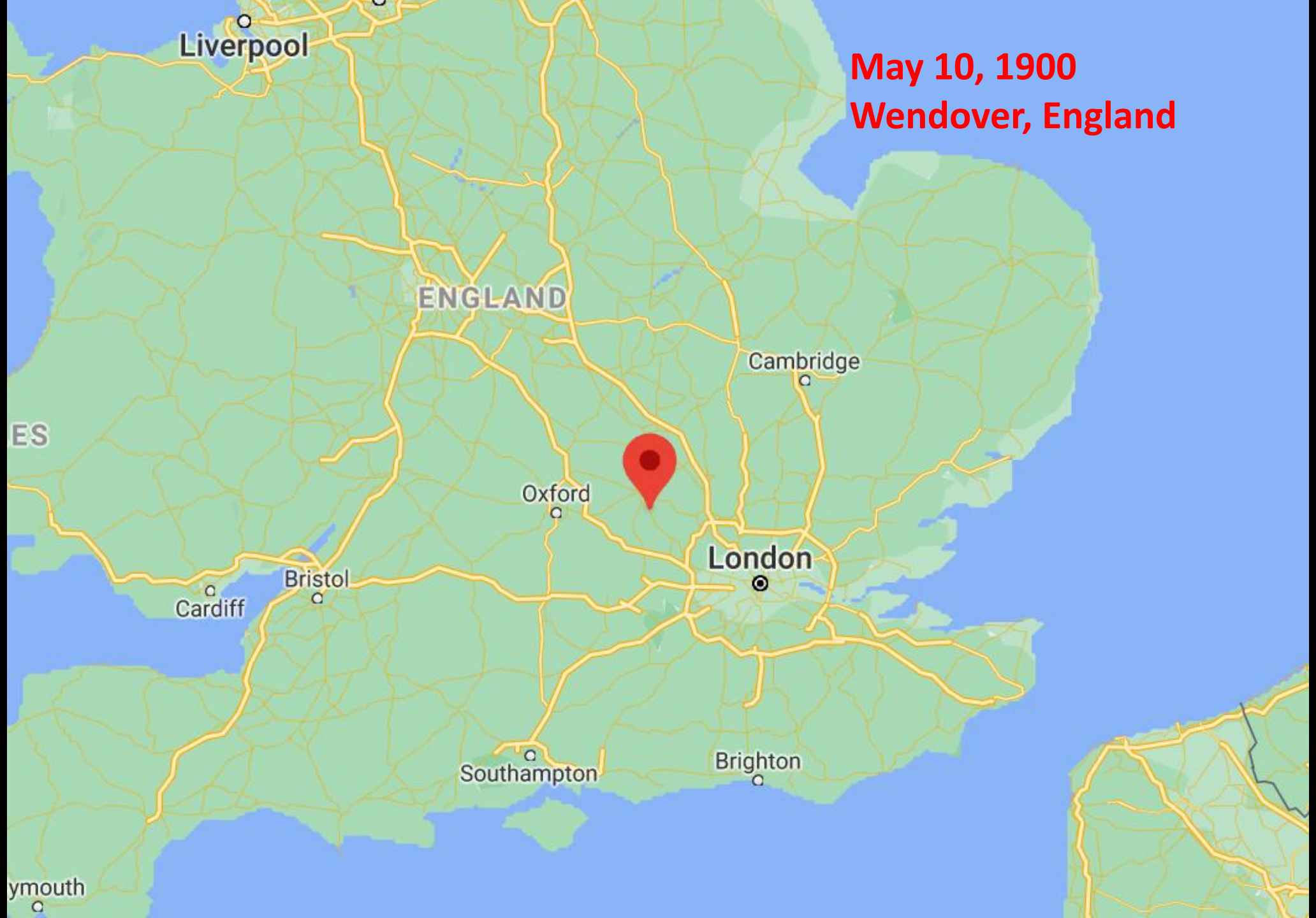
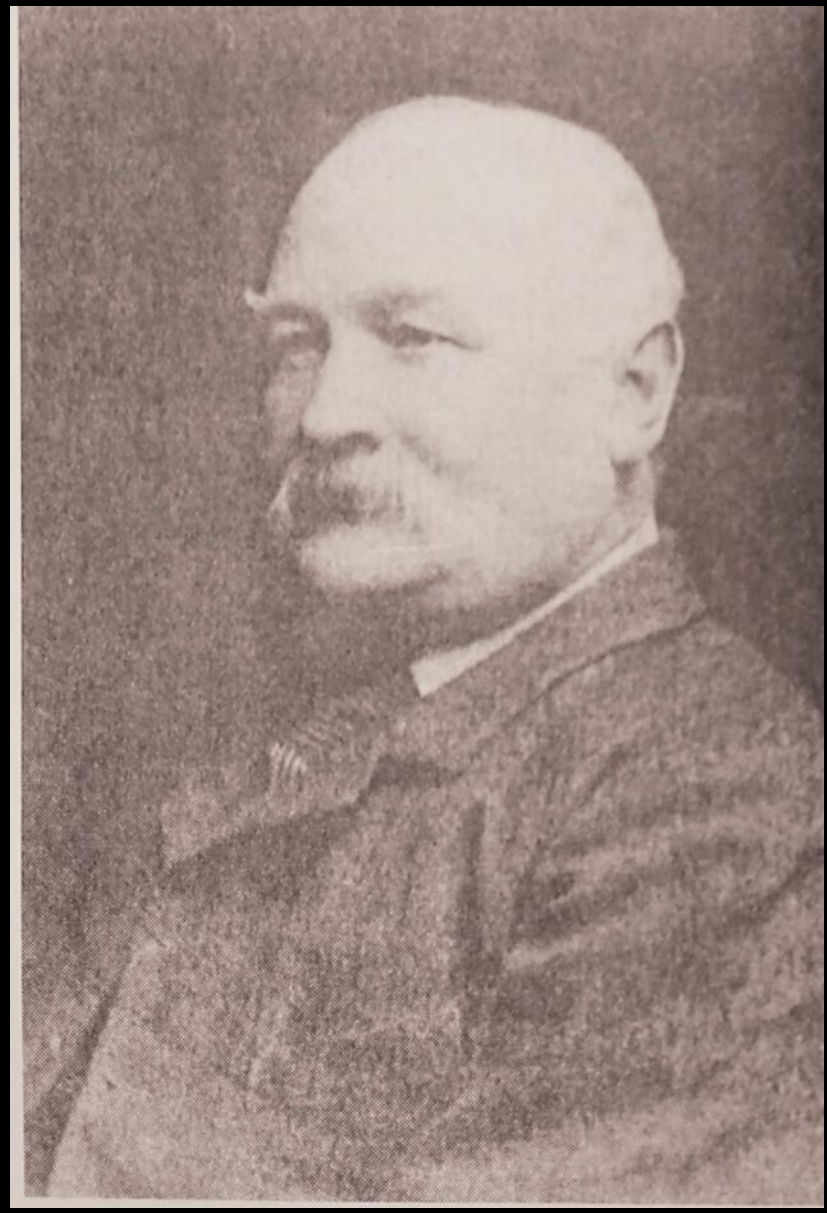
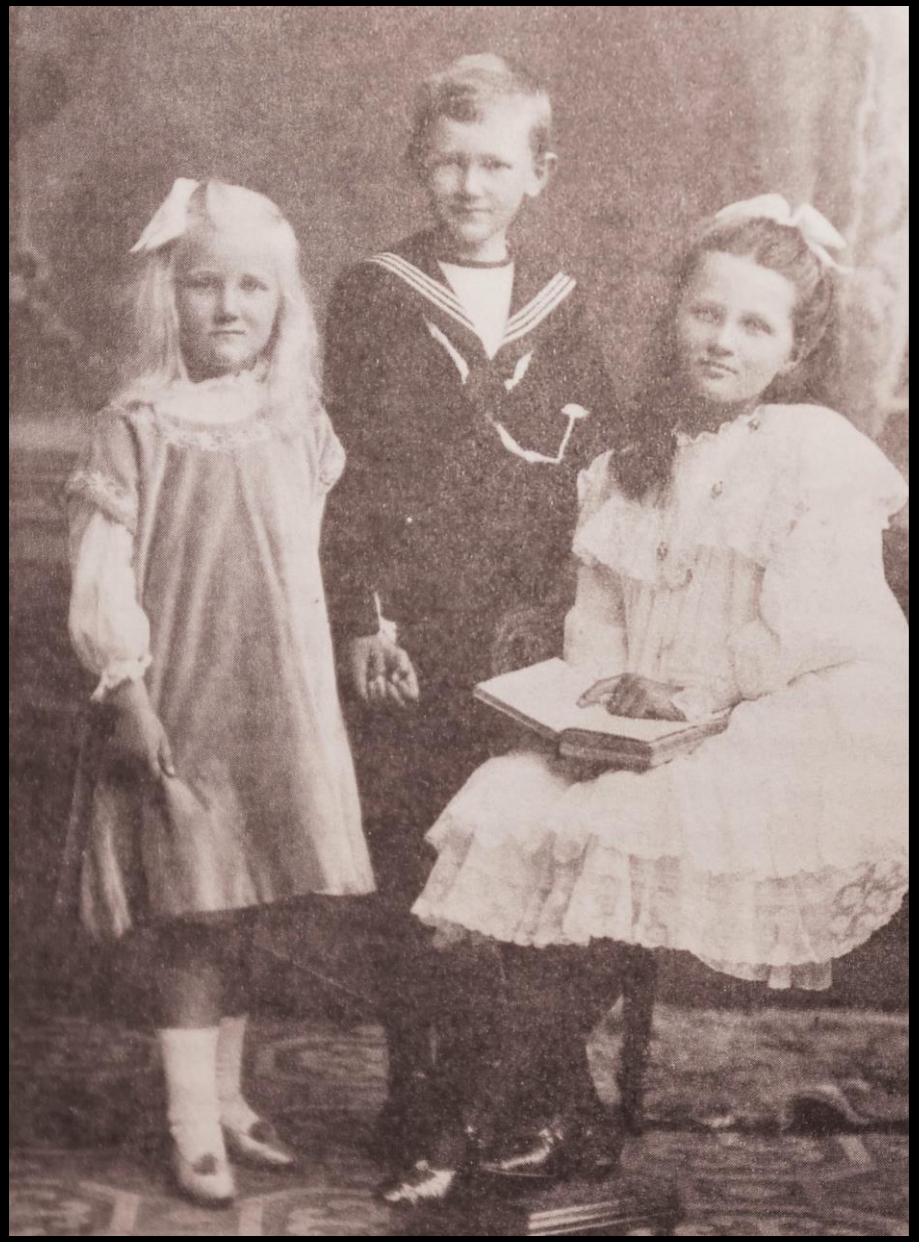
Cecelia Payne-Gaposchkin

. . . . and the Composition of the Stars


1840
1860
1880
1900
1920
1940
1960
1980
2000
2020
Fred Hoyle
Cecilia Payne-Gaposchkin
Edwin Hubble
Arthur Eddington
Henry Norris Russell
Henrietta Leavitt
Percival Lowell


May 10, 1900
Wendover, England
Liverpool
ENGLAND
Cambridge
Oxford
London
Bristol
Cardiff
Southampton
Brighton



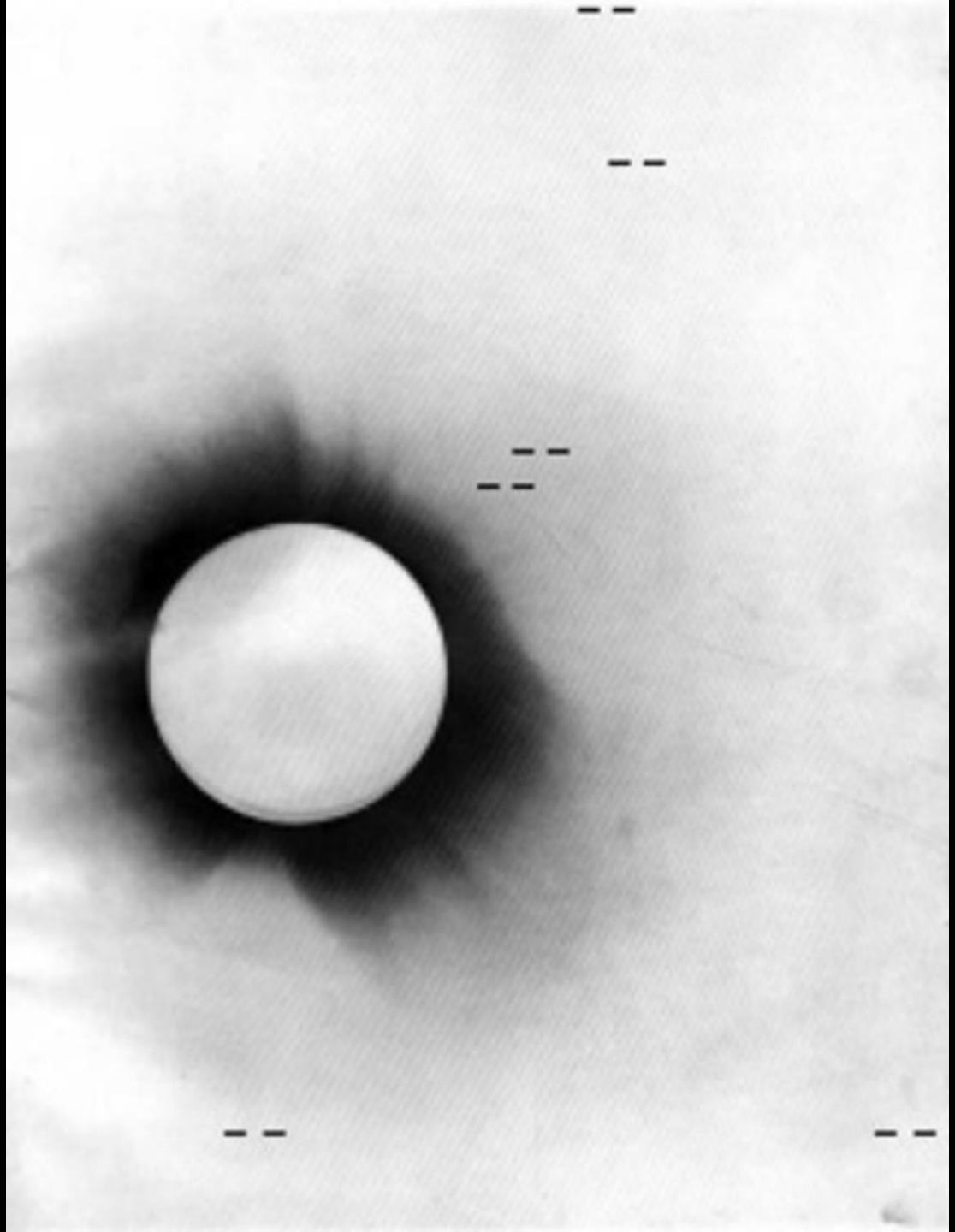


St. Paul’s School for Girls

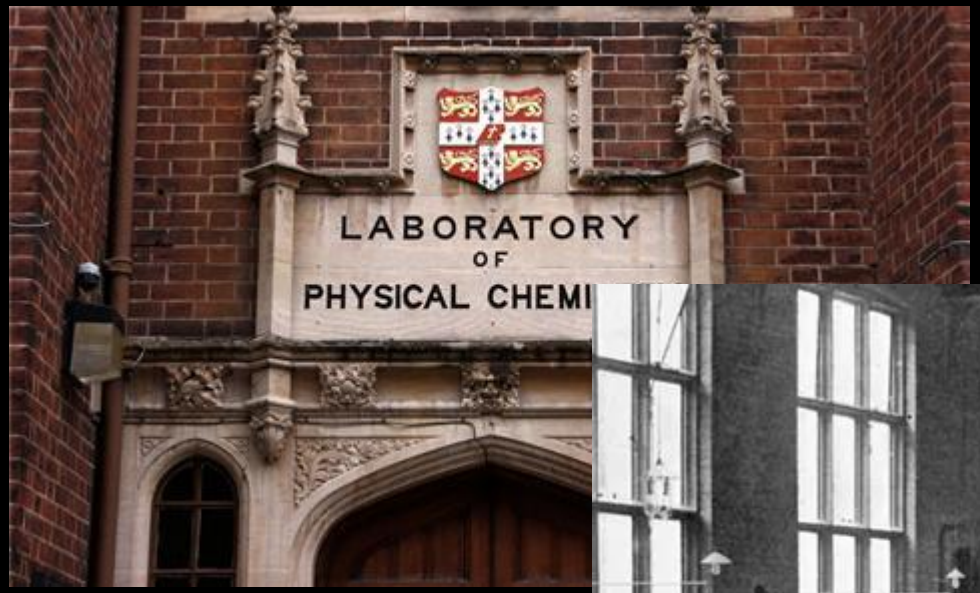
Newnham College - 1919

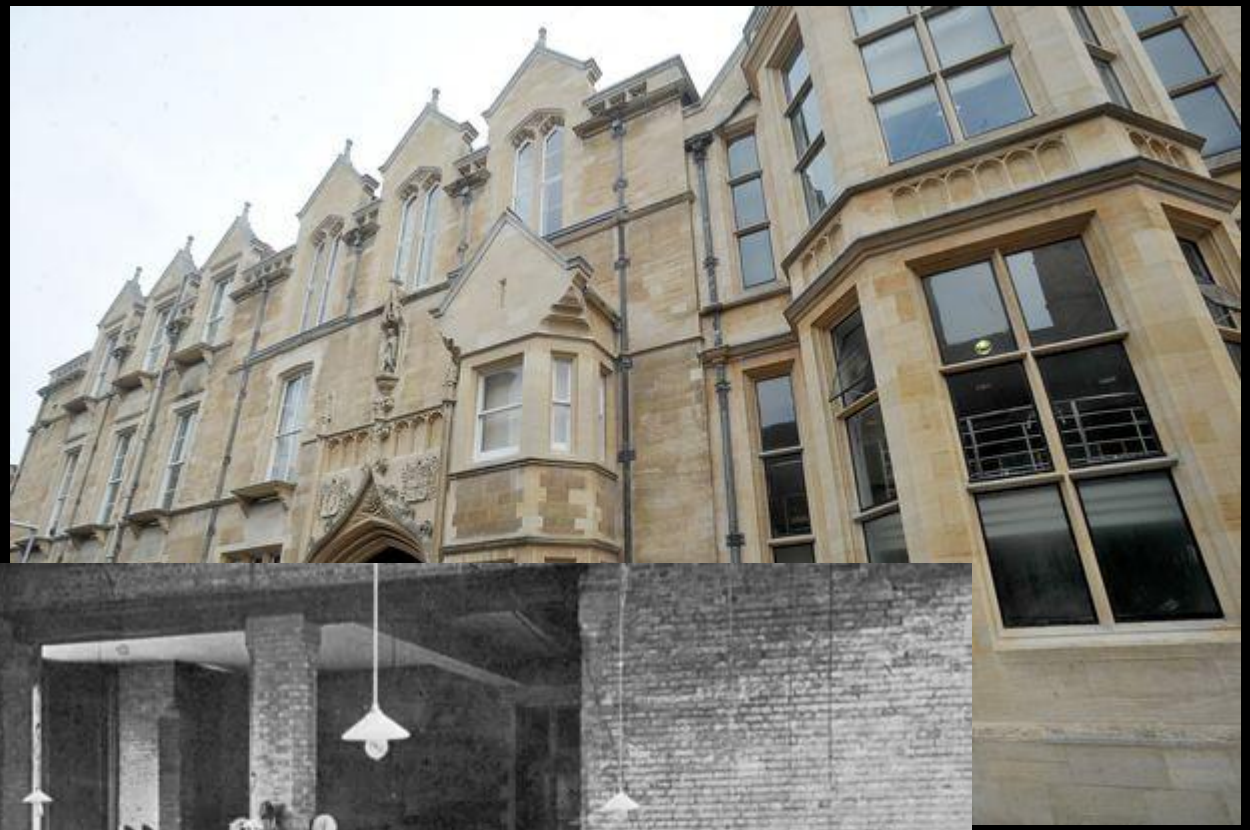
William Bateson, botanist

Sir Arthur Eddington

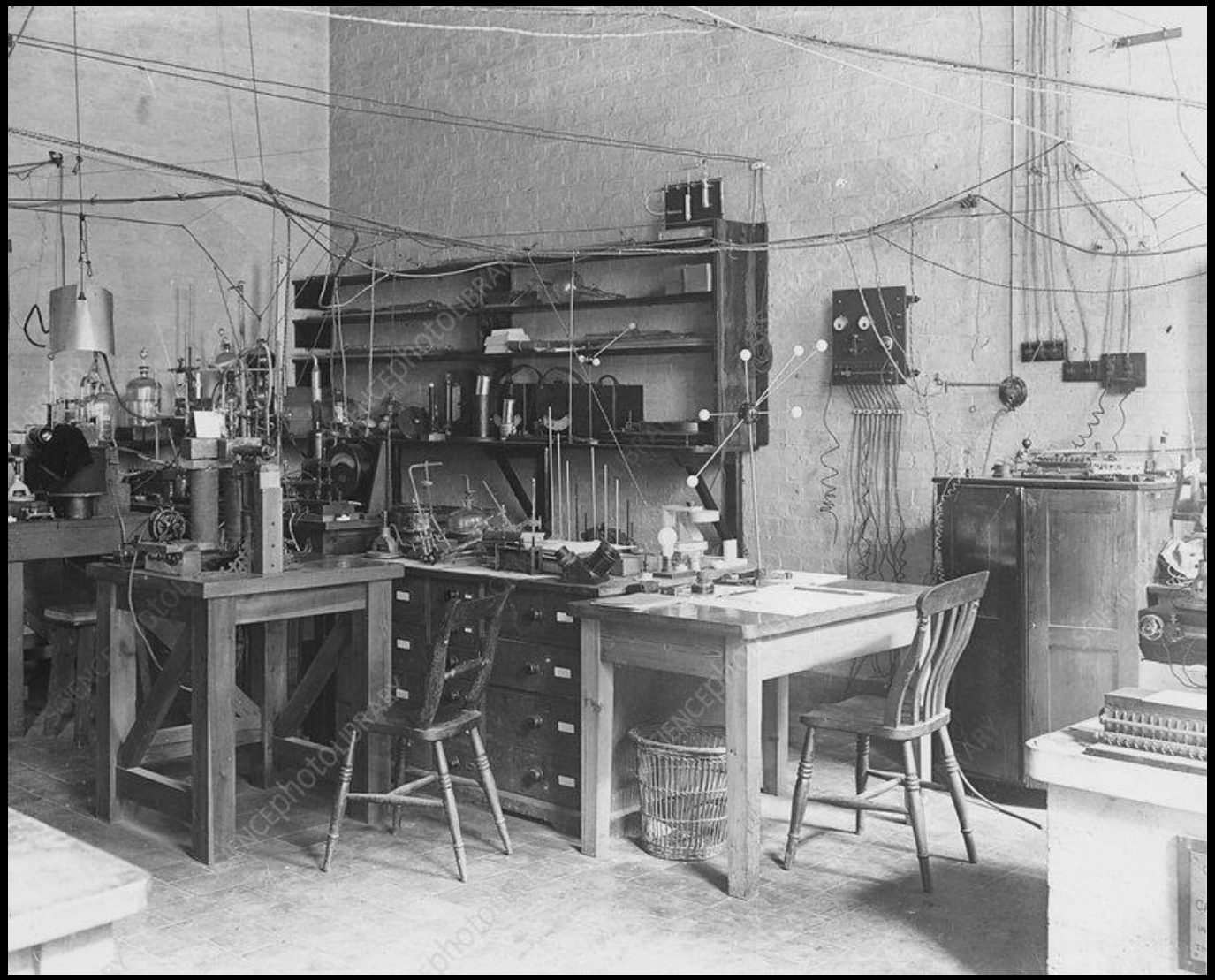


Cavendish Lab

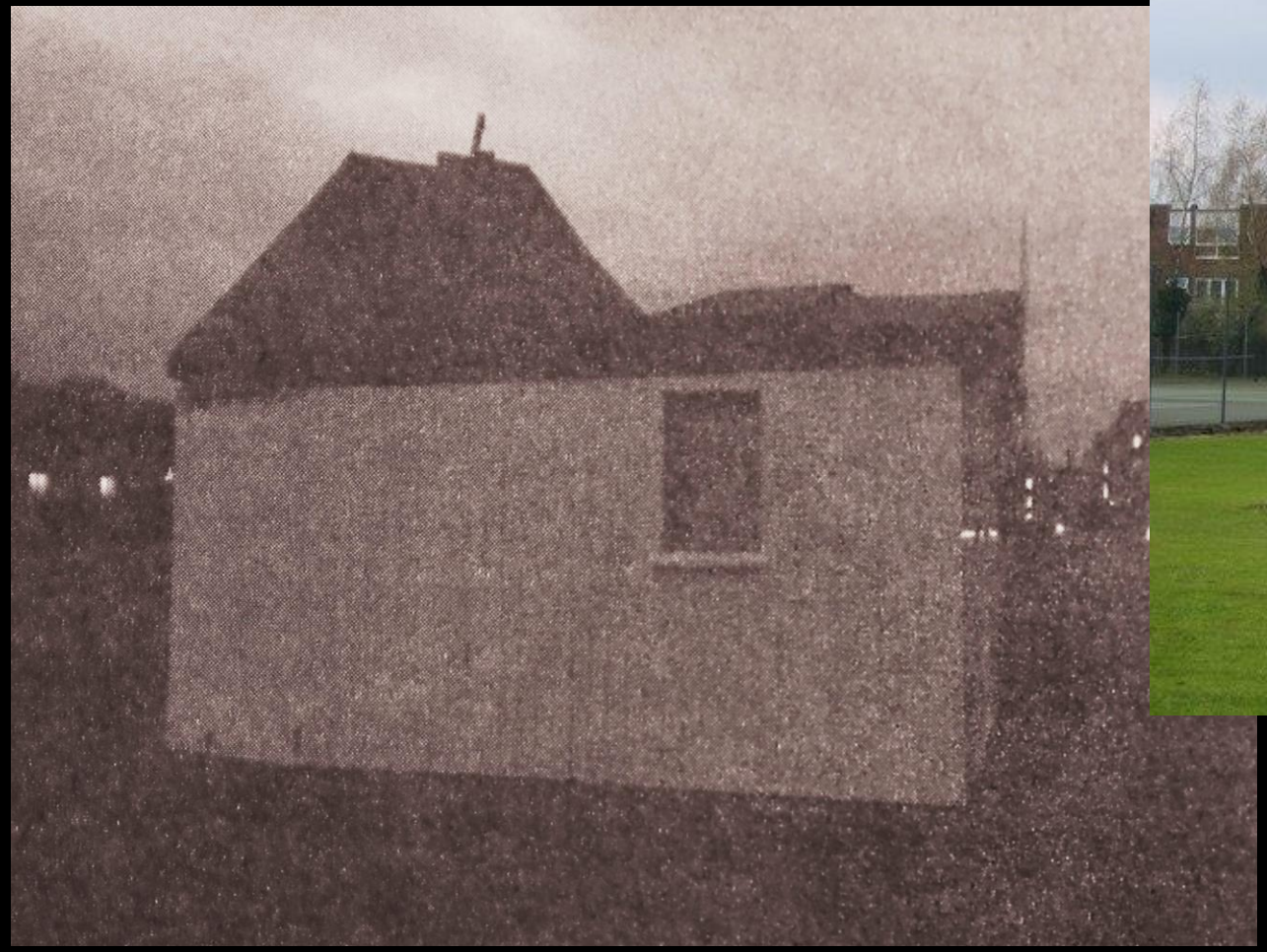


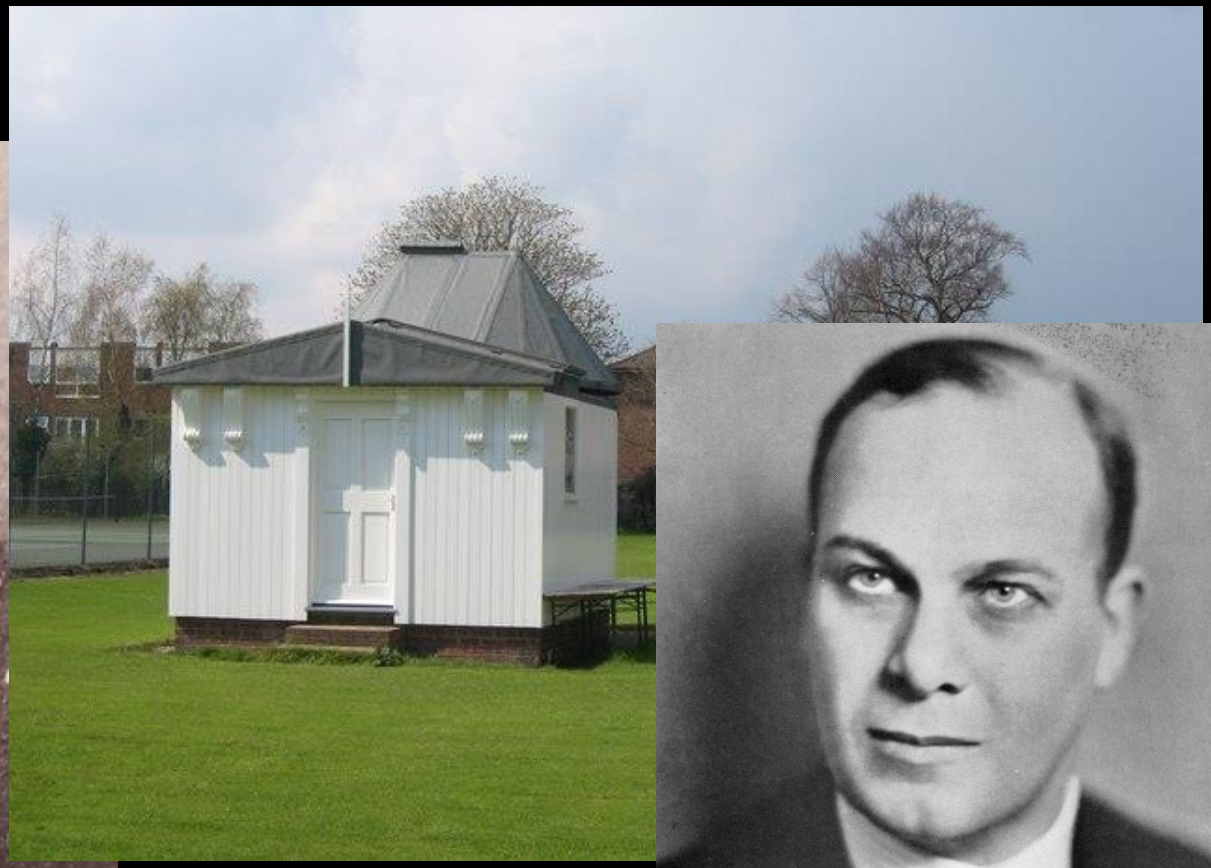


George Searle, lab manager

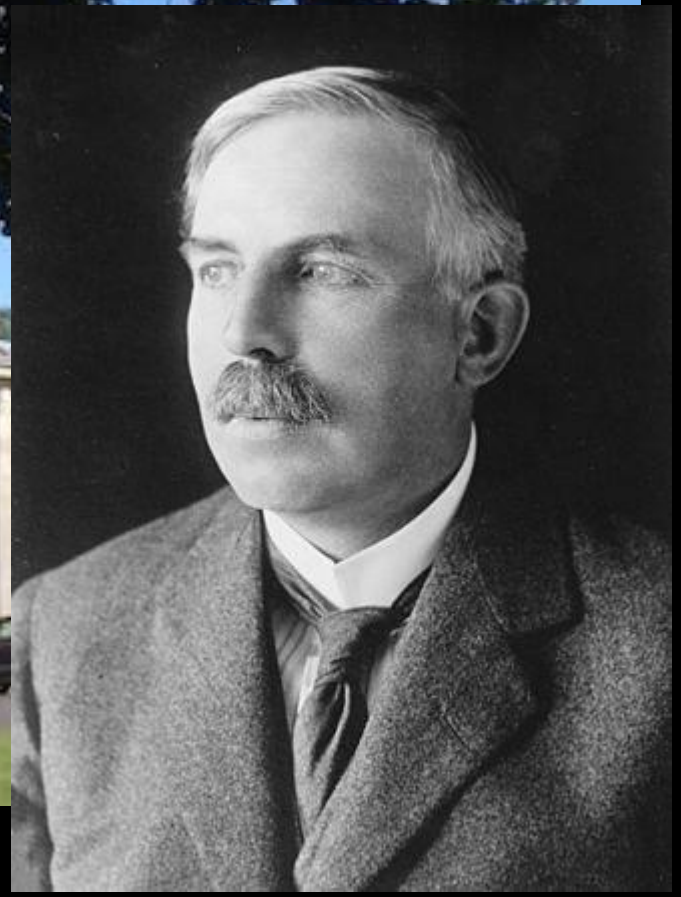


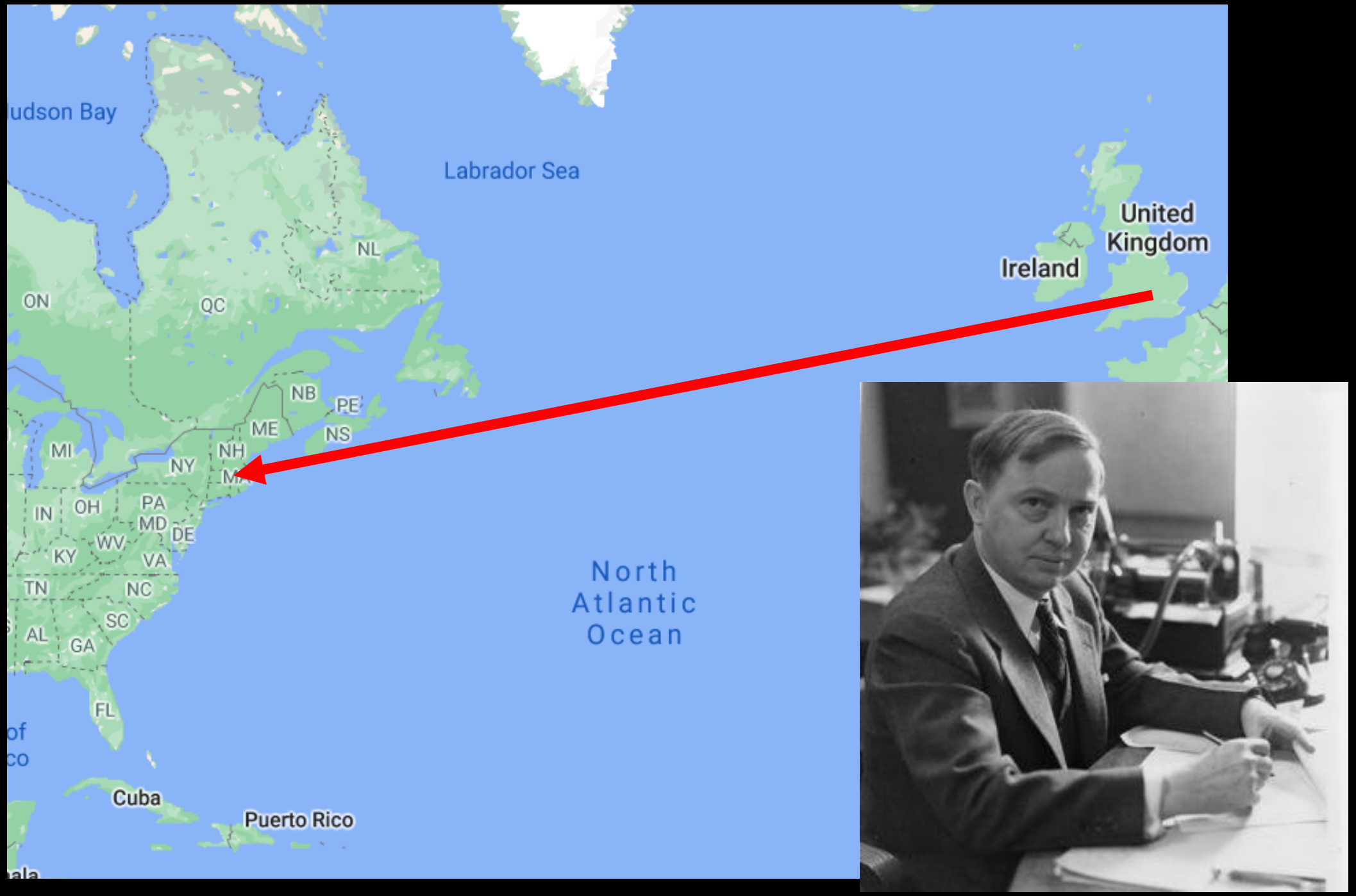
Newnham Observatory

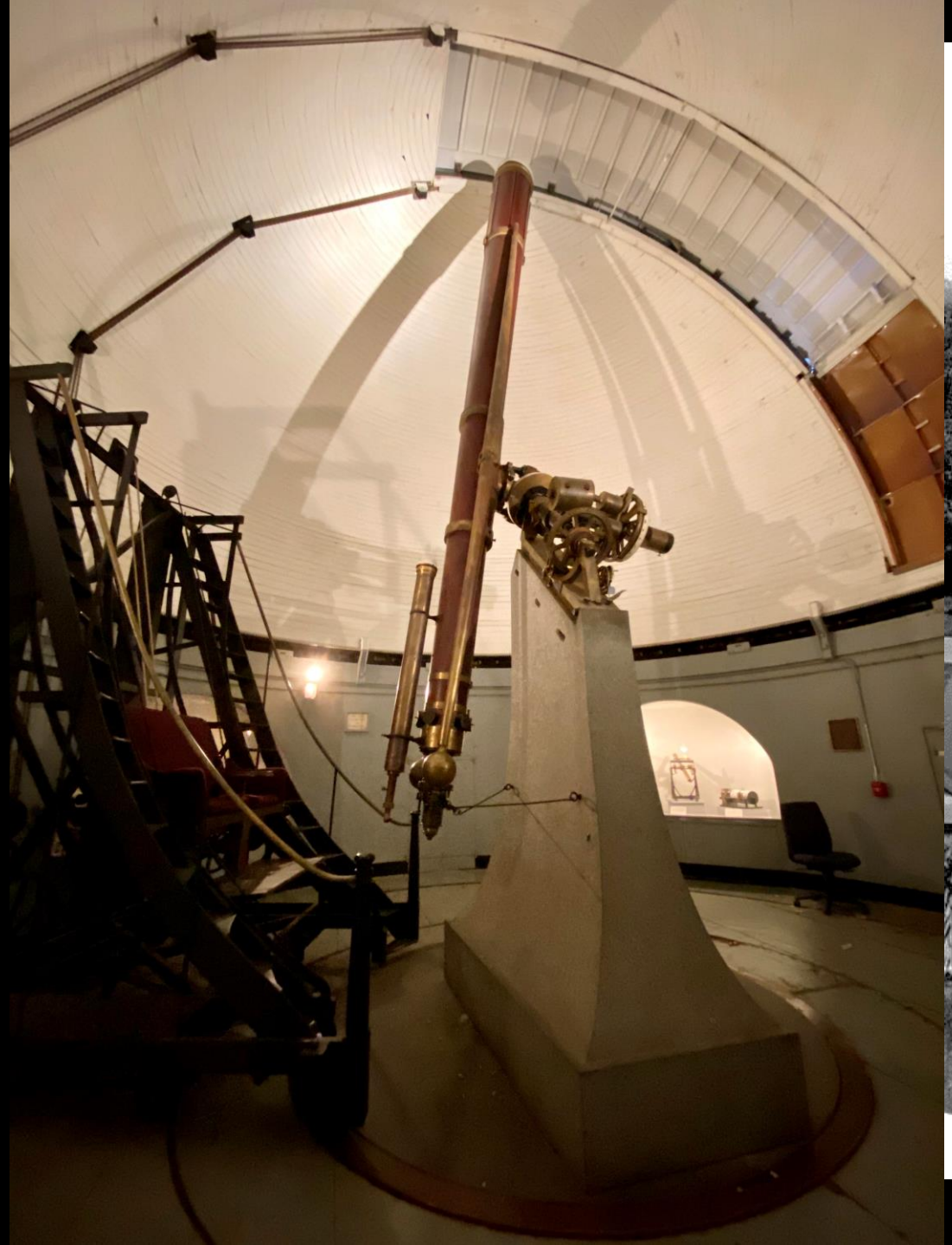


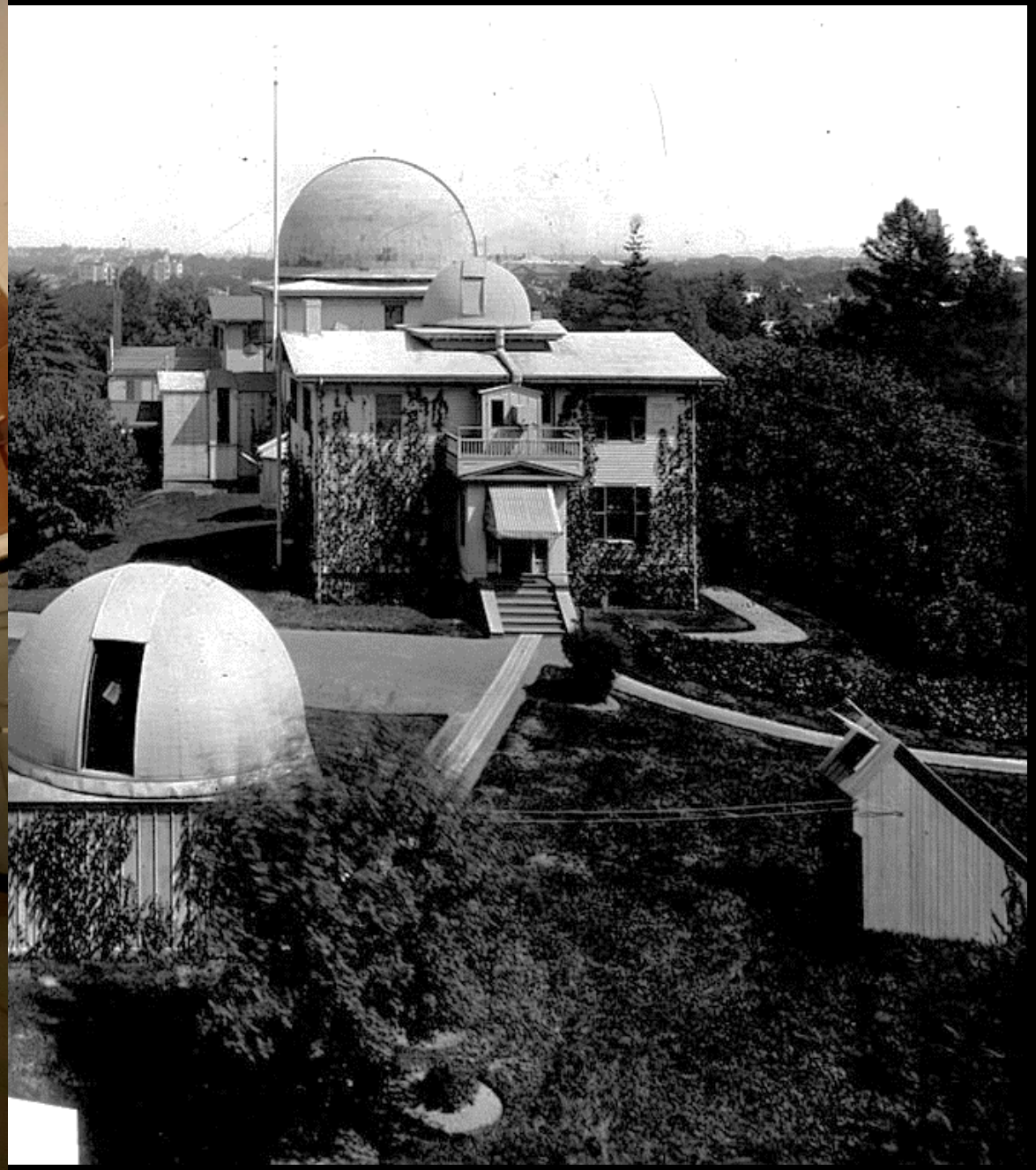


Cambridge Observatory (England)

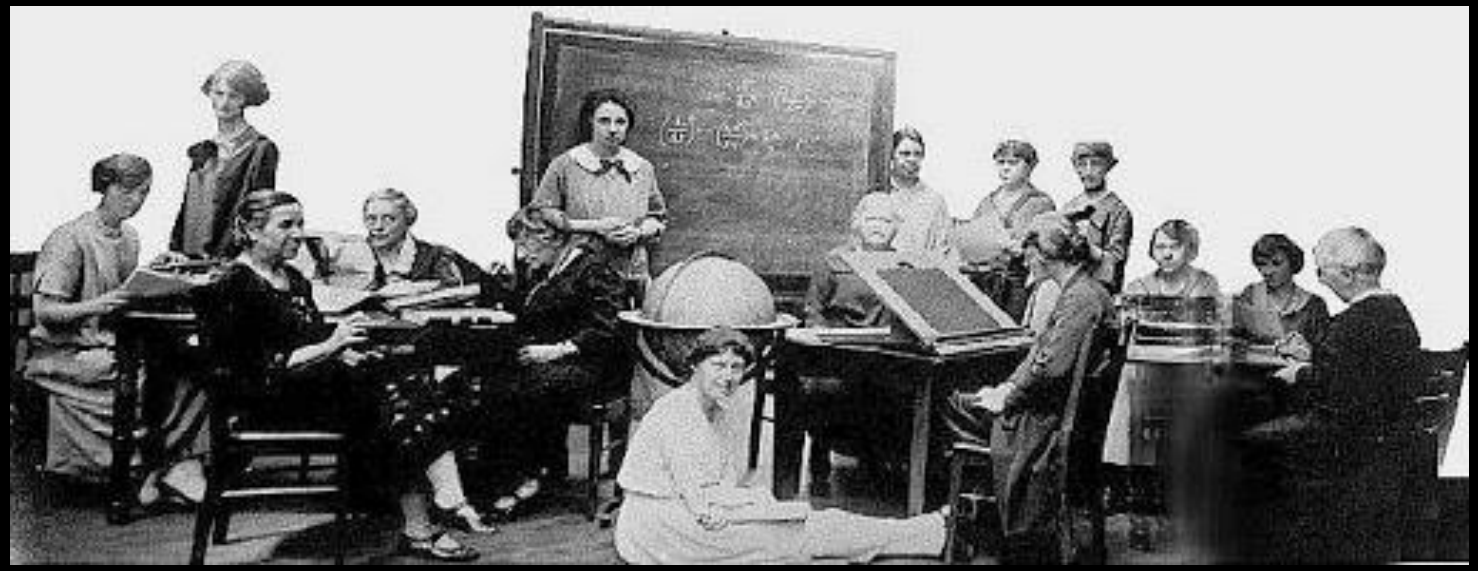



udson Bay
Labrador Sea
United Kingdom
Ireland
NL
ON
QC
NB
PE
NS
ME
MI
NH
NY
IN
OH
PA
MD
DE
WV
KY
VA
TN
NC
SC
AL
GA
FL
North Atlantic Ocean
Cuba
Puerto Rico



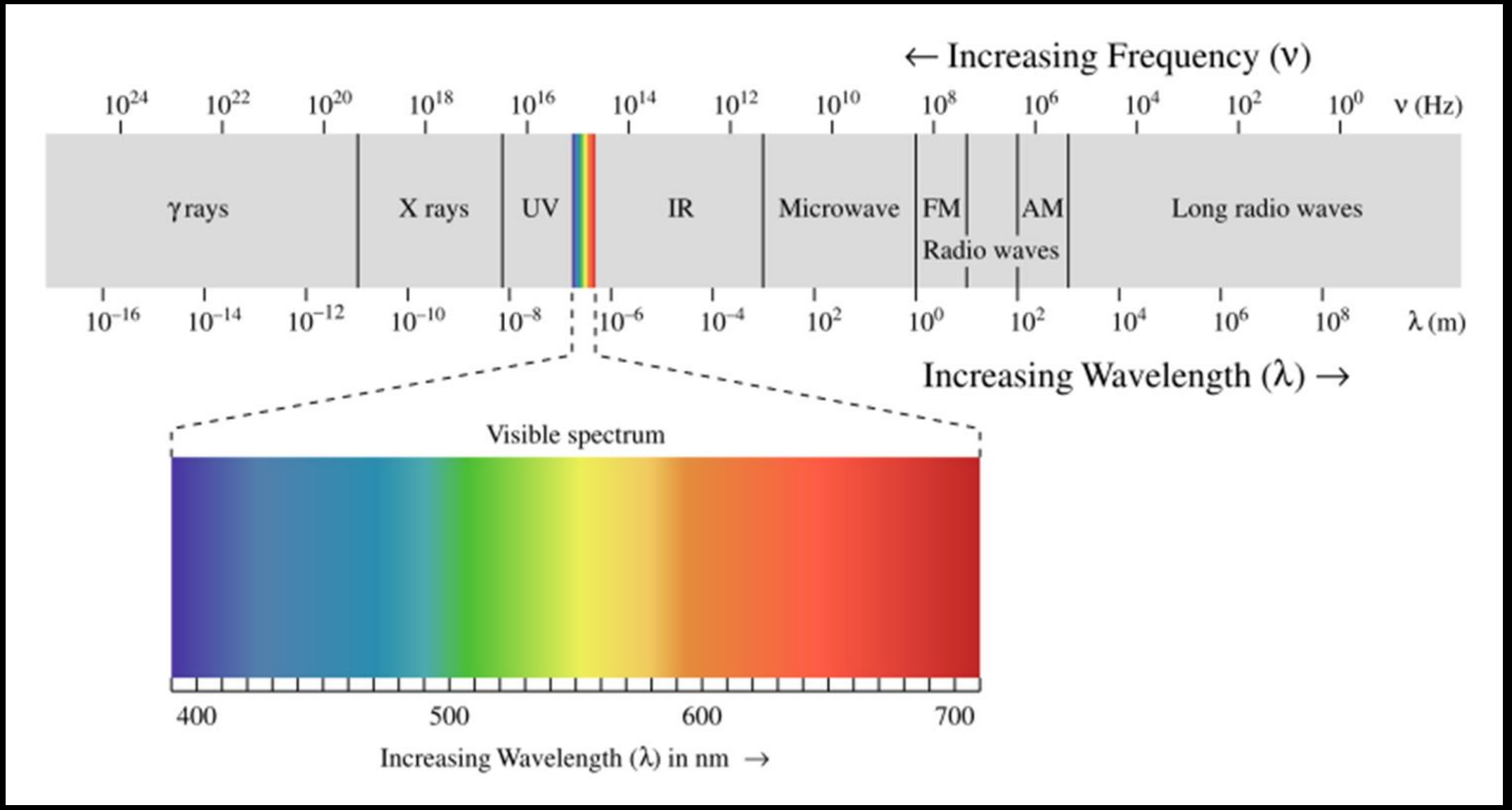


Antonia Maury

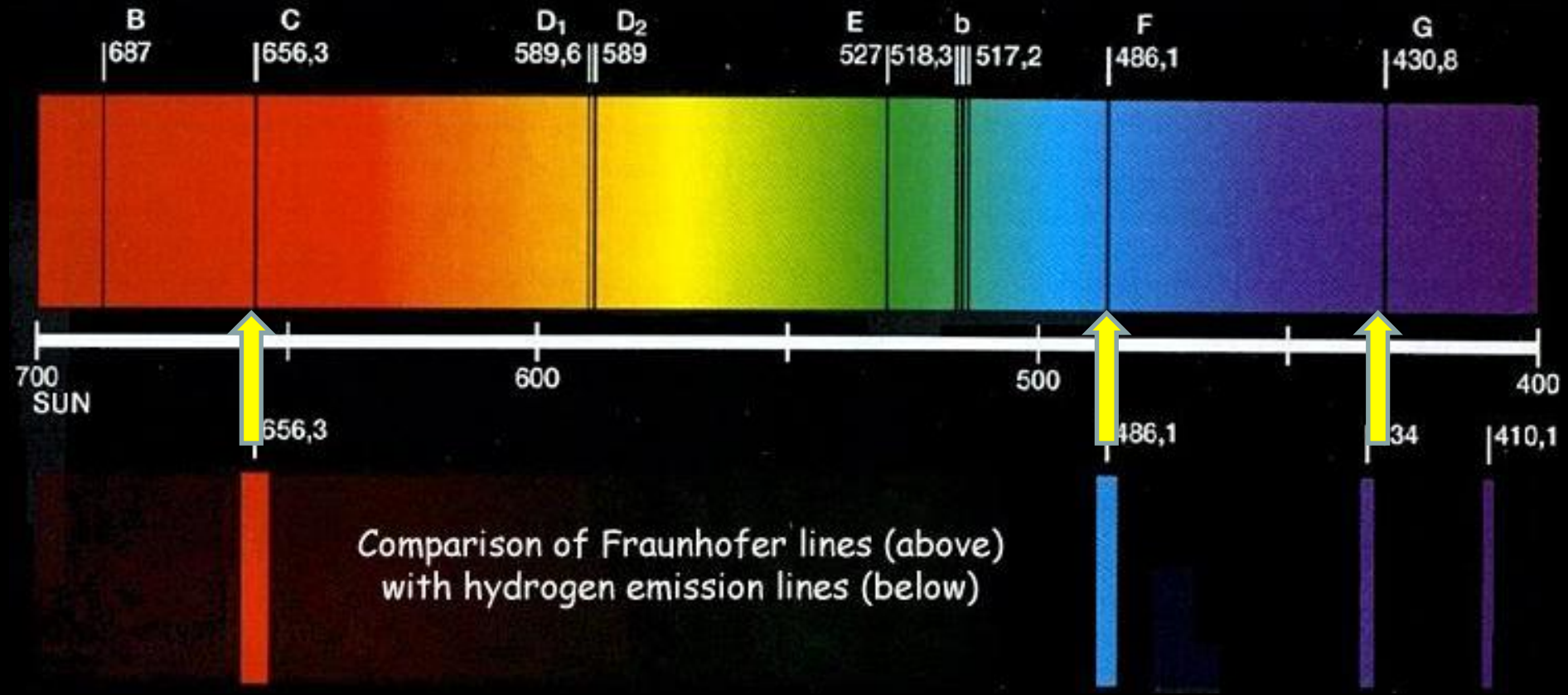



C

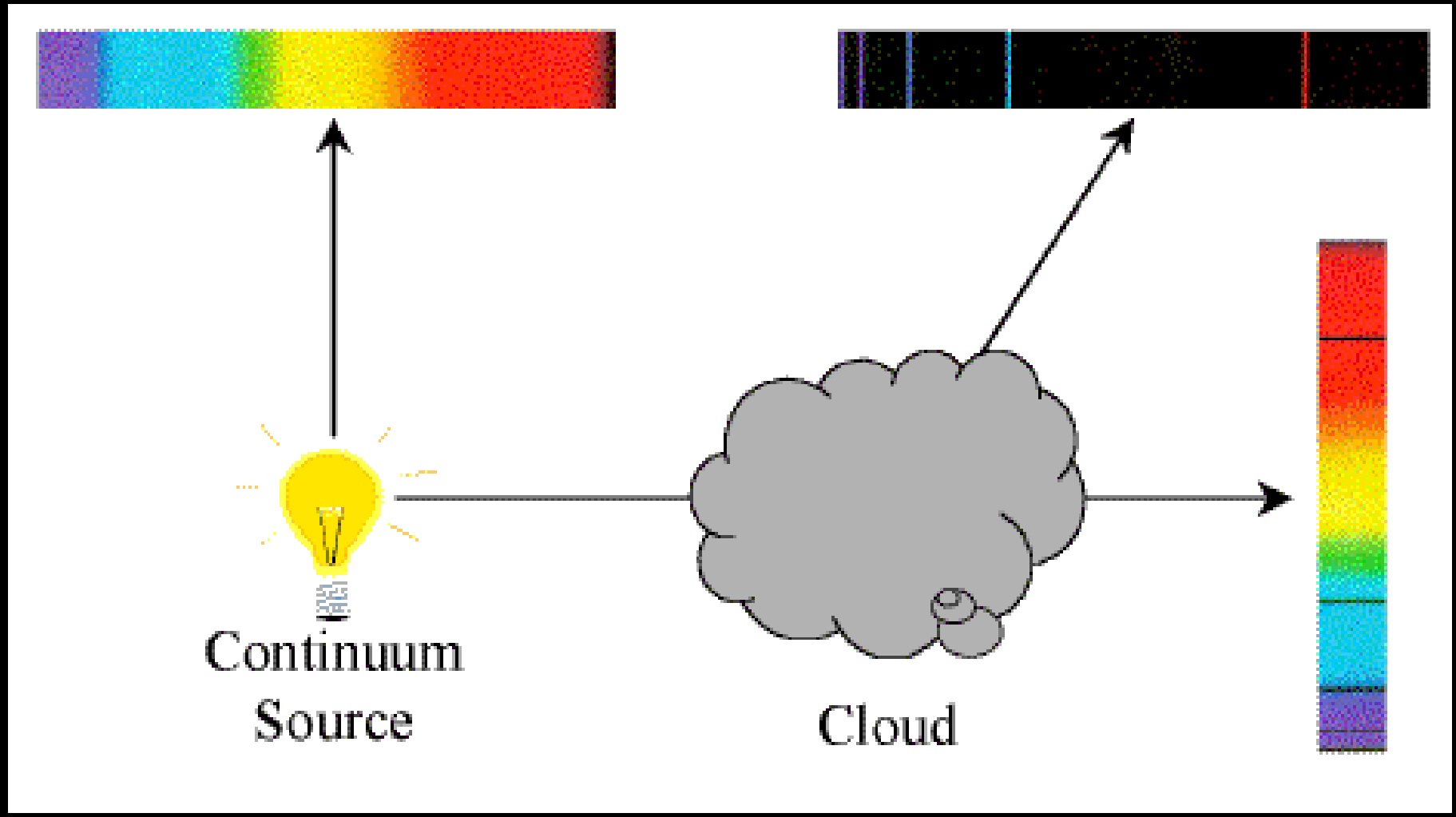
Somewhere over the rainbow. . .

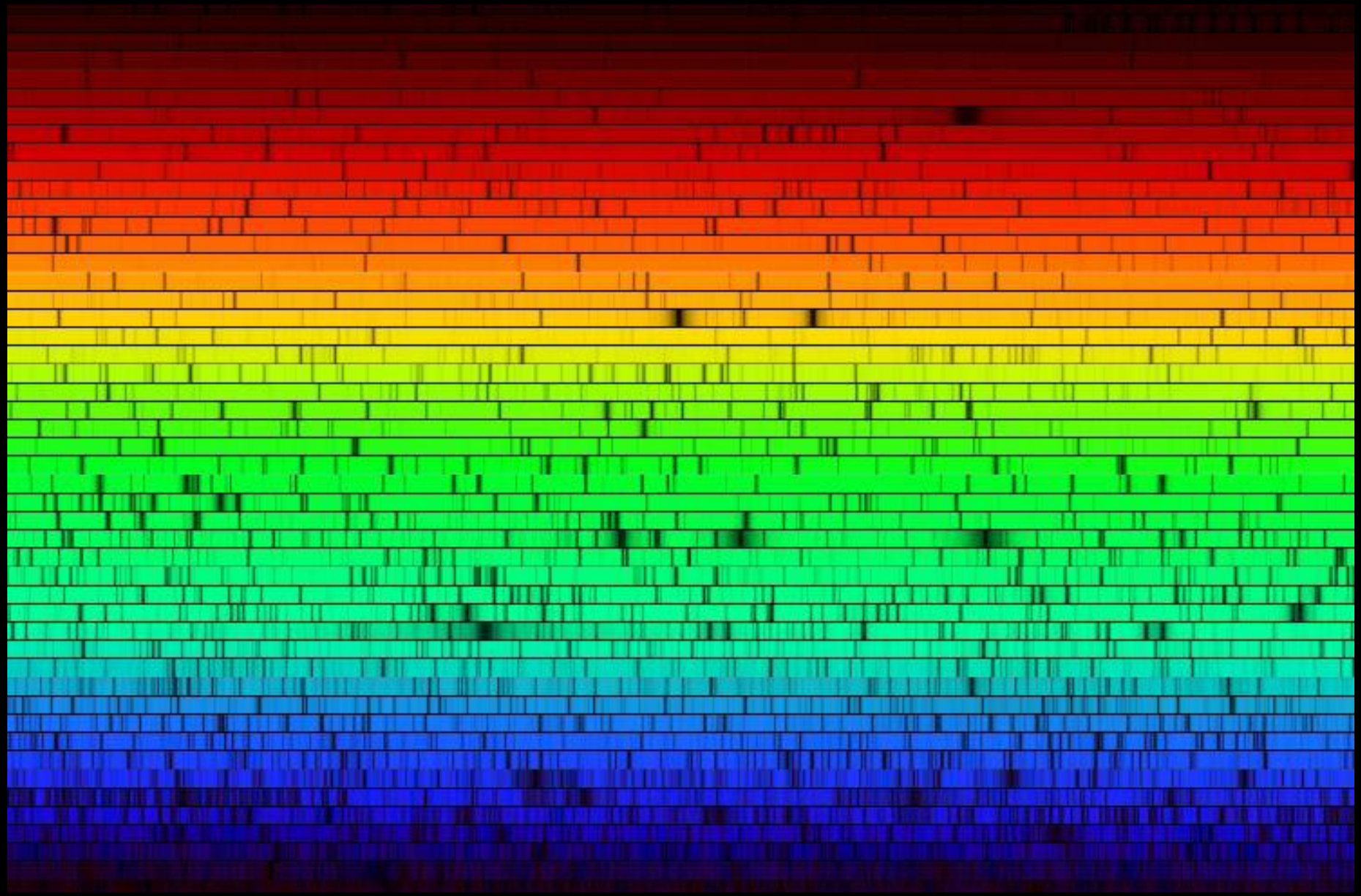



Hydrogen
Helium
Neon
Sodium
Mercury


B
687
C
656,3
D1
589,6
D2
589
E
527
b
518,3
517,2
F
486,1
G
430,8
700
SUN
600
500
400
656,3
486,1
34
410,1
Comparison of Fraunhofer lines (above)
with hydrogen emission lines (below)

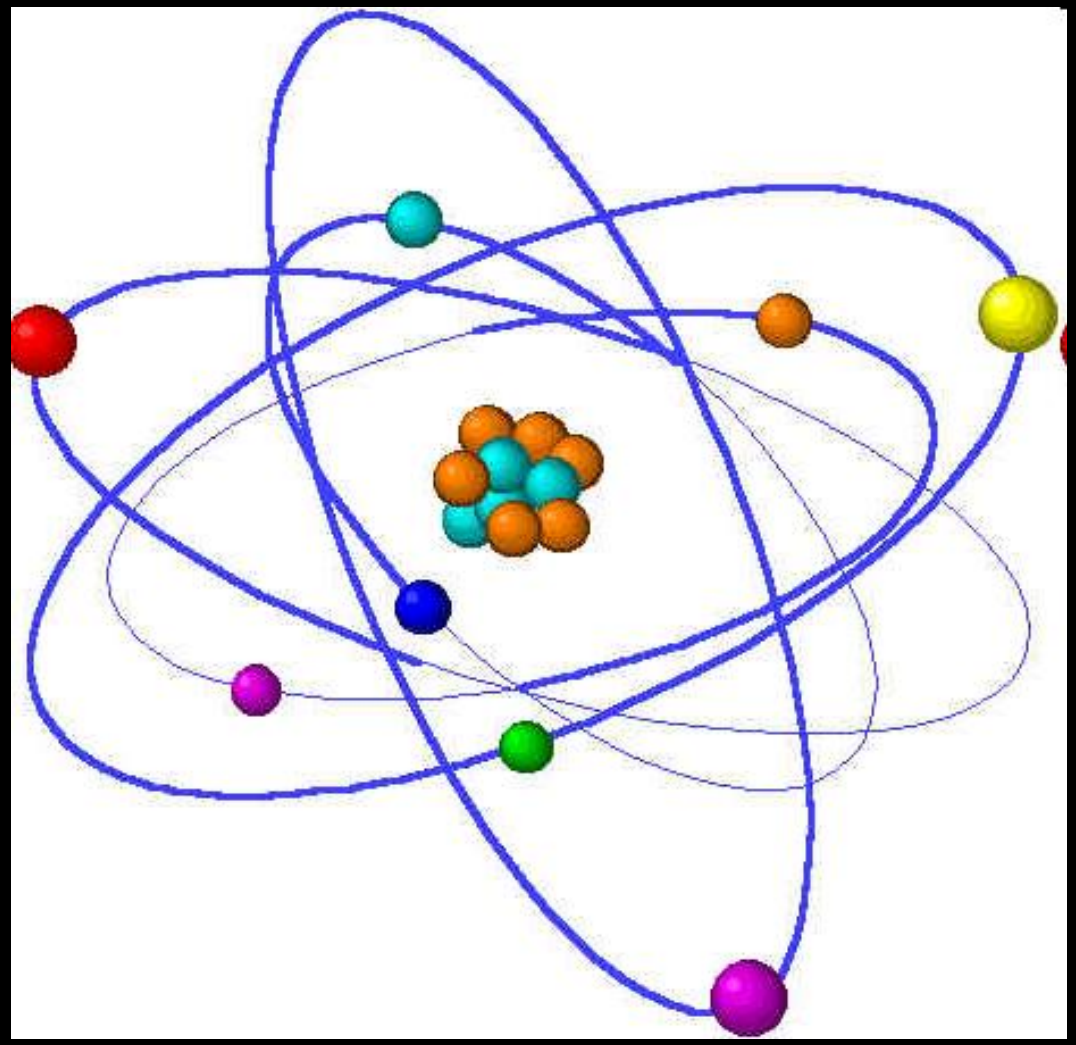
Kirchoff's Laws



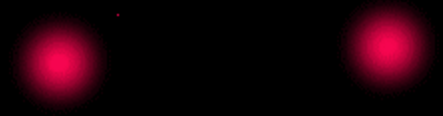


Gambling in Chicago

A Story . . . . . .

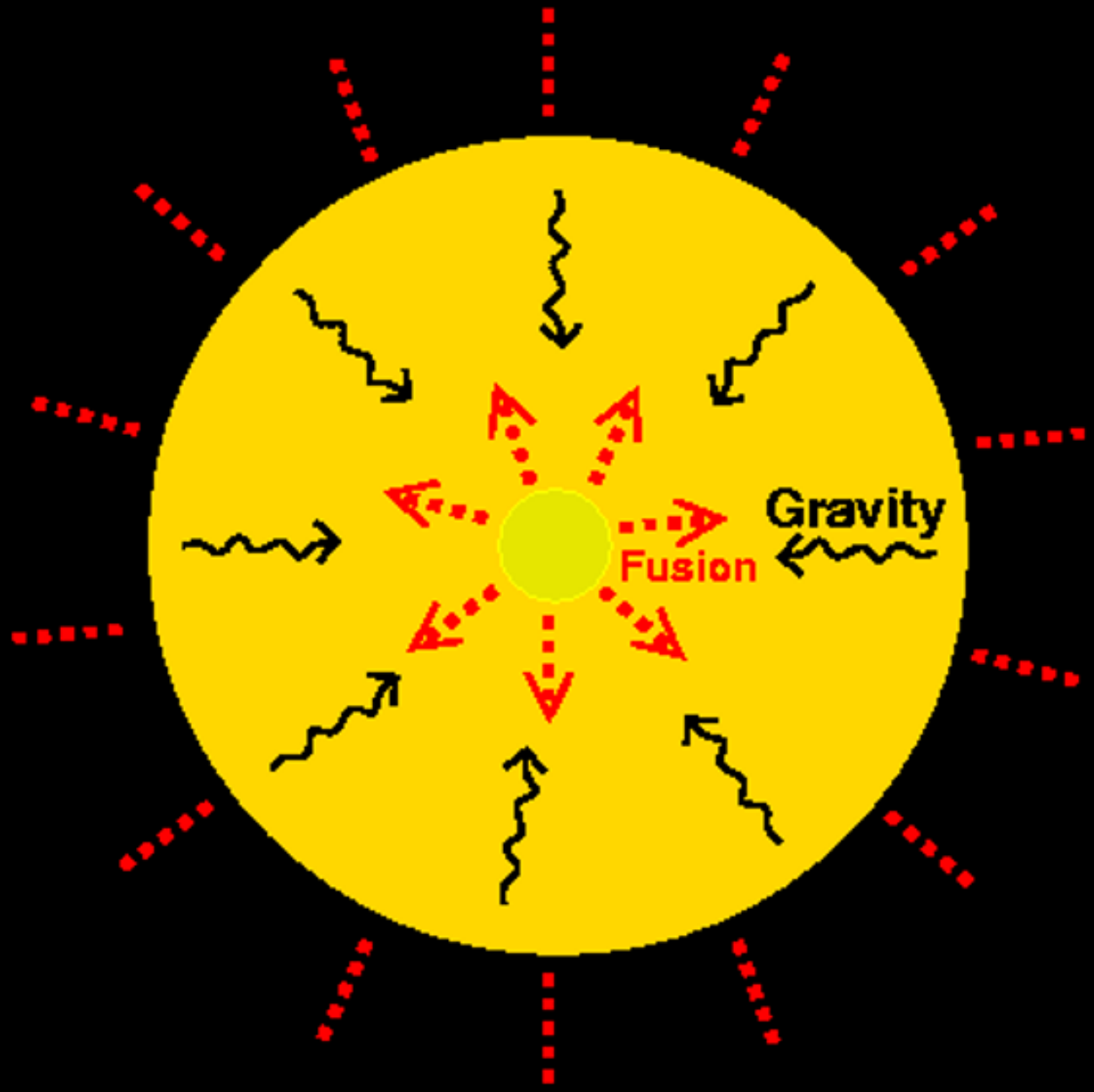


Fusion in the Core

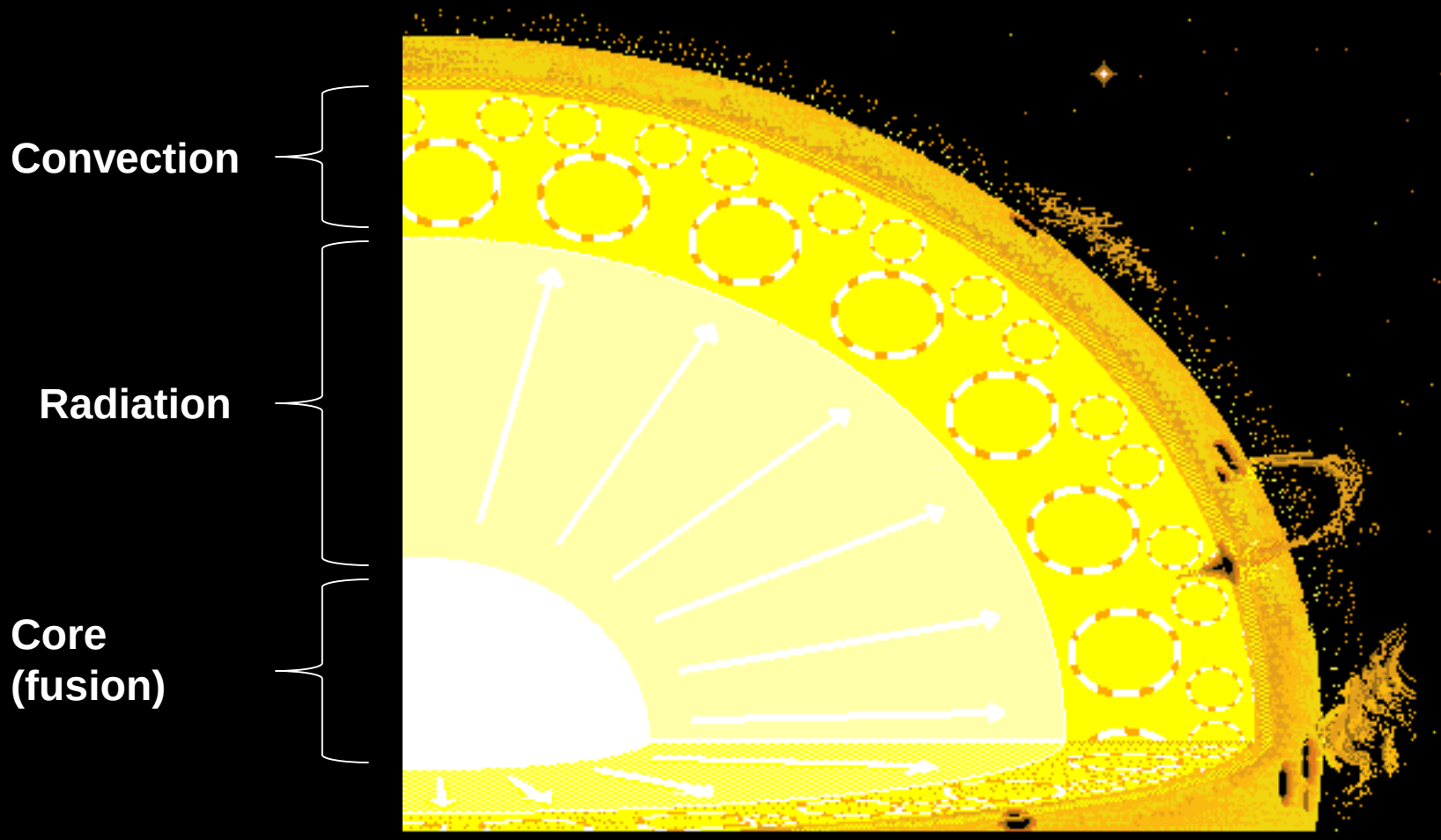


$$E = mc^2$$

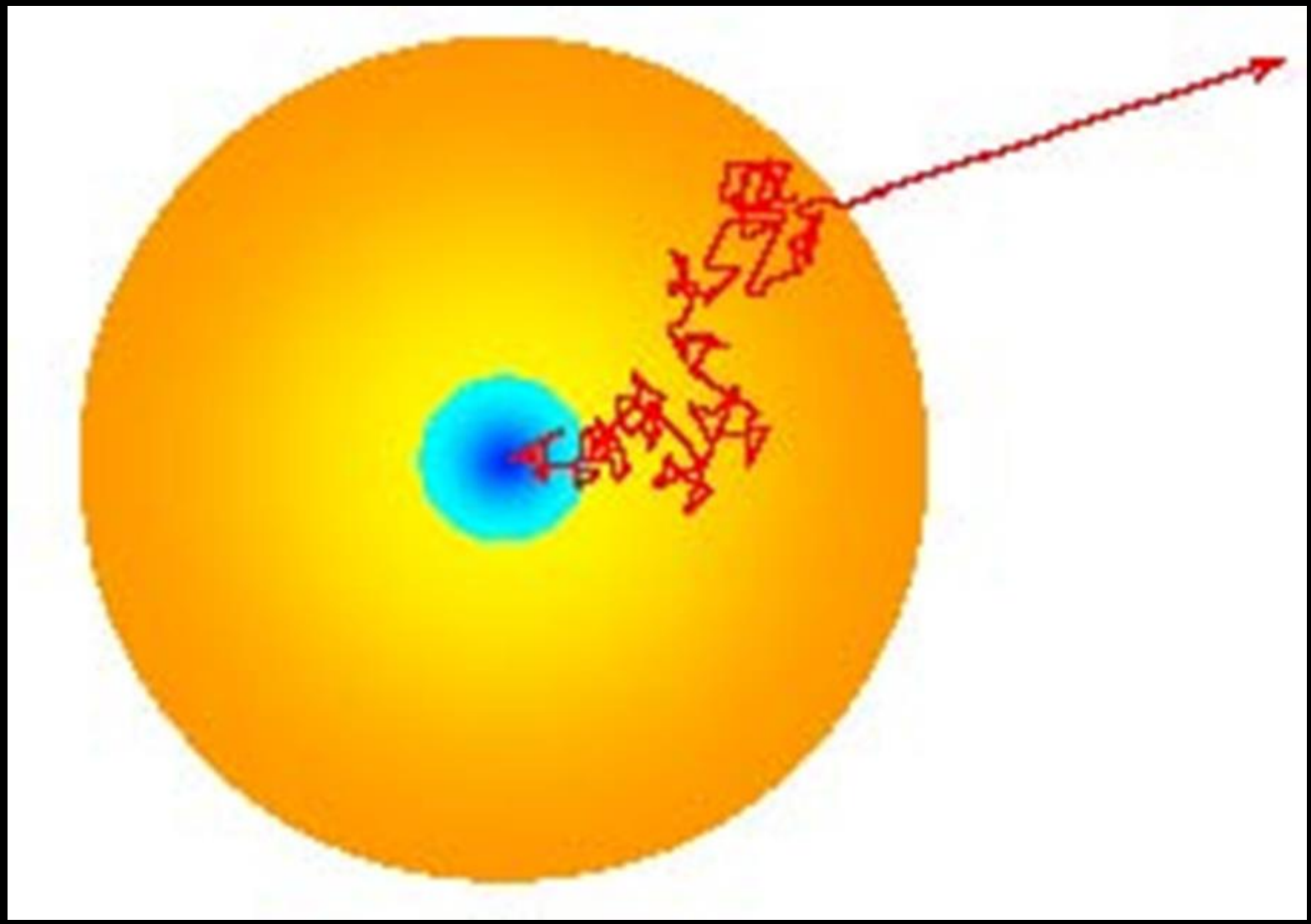
Final result . . . . . 4 H atoms ⟶ 1 Helium atom


Gravity
Fusion

How does light get out of the Sun?



How does light get out of the Sun?



Stellar Spectra

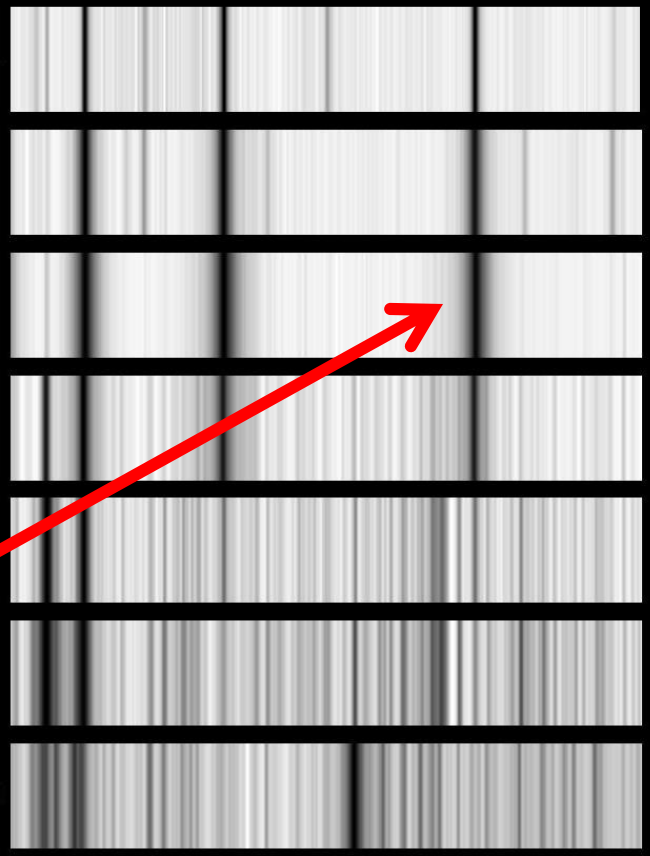
- First measured in 1860
- Absorption lines!
- 1896 Henry Draper Catalog – spectra of 200,000 stars . .
- . . .but what to do with them?

Williamina Fleming

λ 4861
λ4481 — 3
MgII λ4471 — 6
He λ4471
λ4388 HE — 5
λ4340 — 13
λ4267 C — 4
λ4144 HE — 1
λ4131 Si
λ4130 HE
11
λ4026 HE — 8
λ4009 HE
-HE 3970
H & K
H5

Annie Jump Cannon

- 1924 – classification scheme based on hydrogen absorption lines

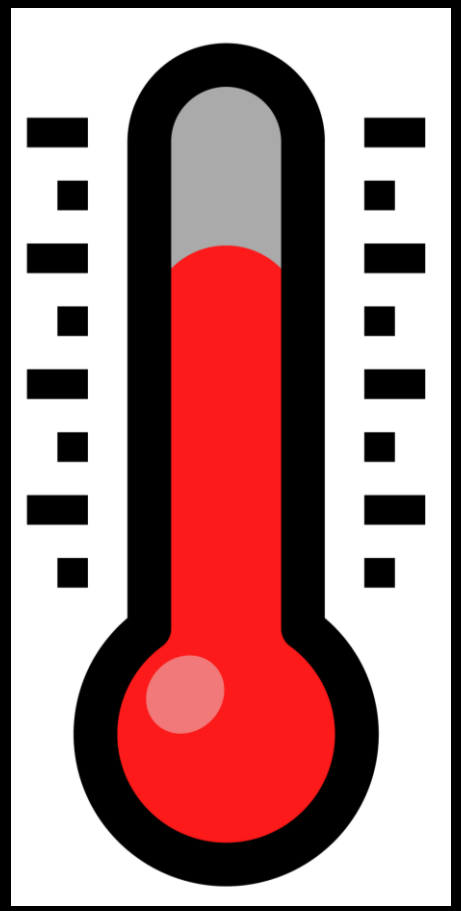


Classification of Spectra

- “A stars” – strongest hydrogen lines
- “B stars” – next strongest hydrogen lines

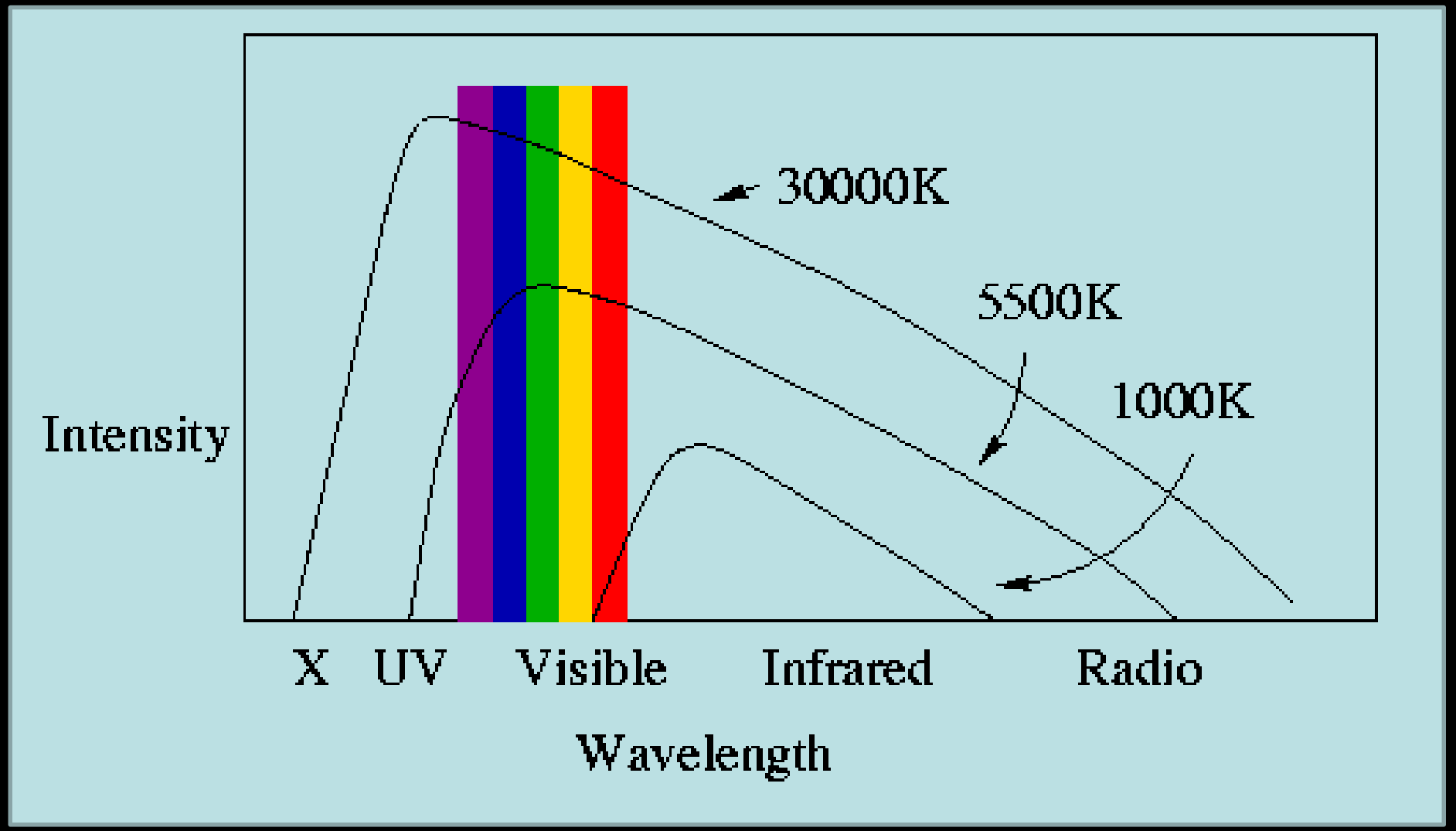
.

.

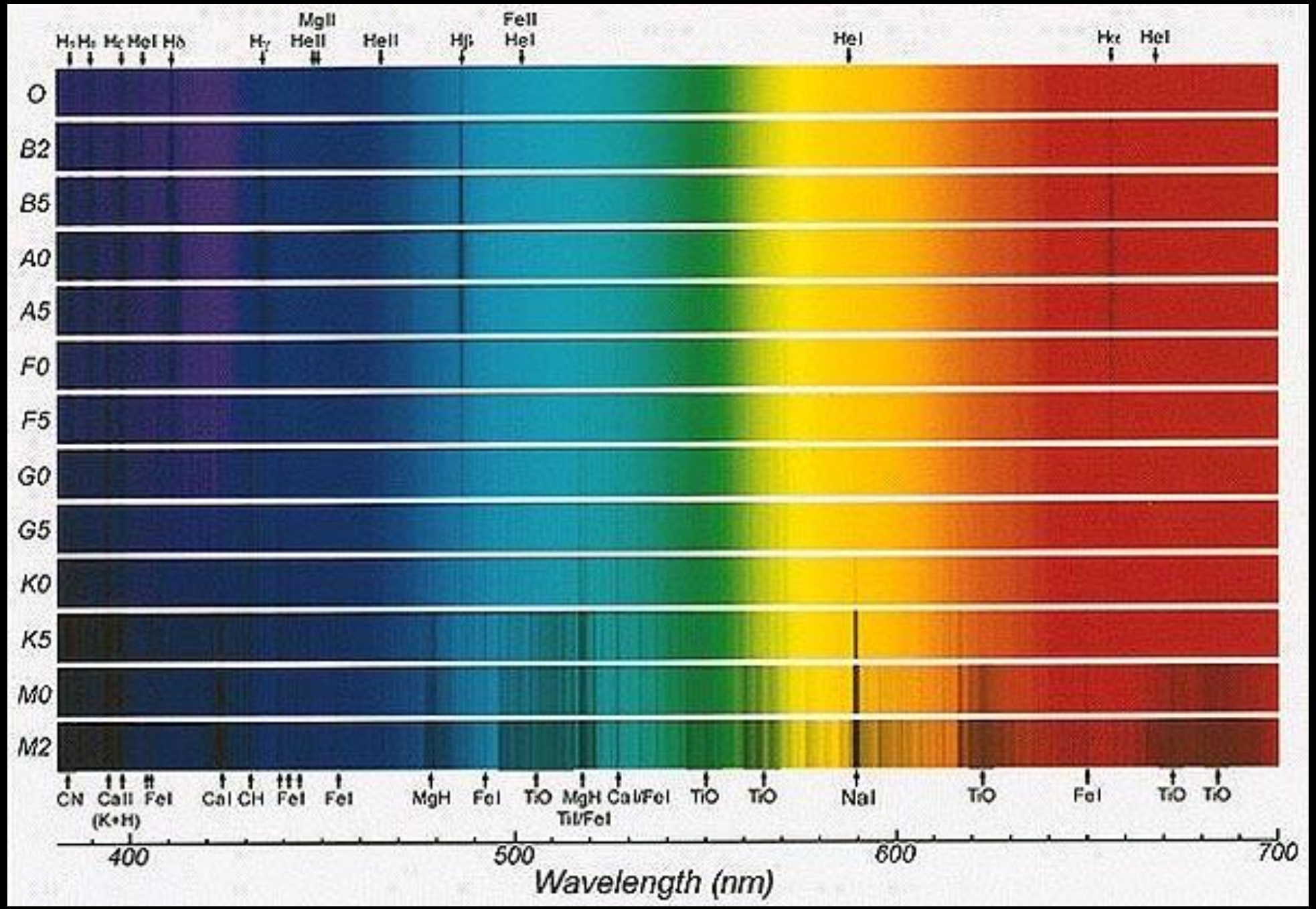


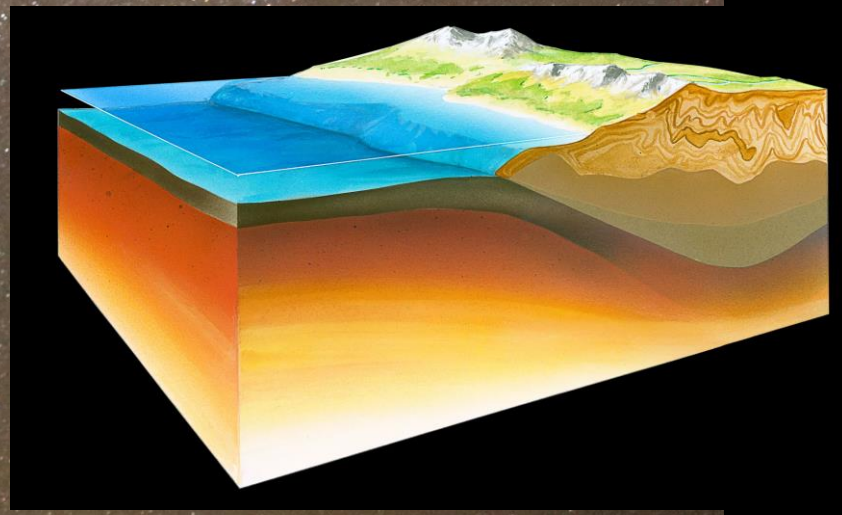
Q: If stars are all made of about the same stuff . . . Why are their spectra different

A: TEMPERATURE!



Star colors ⟶ temperature!

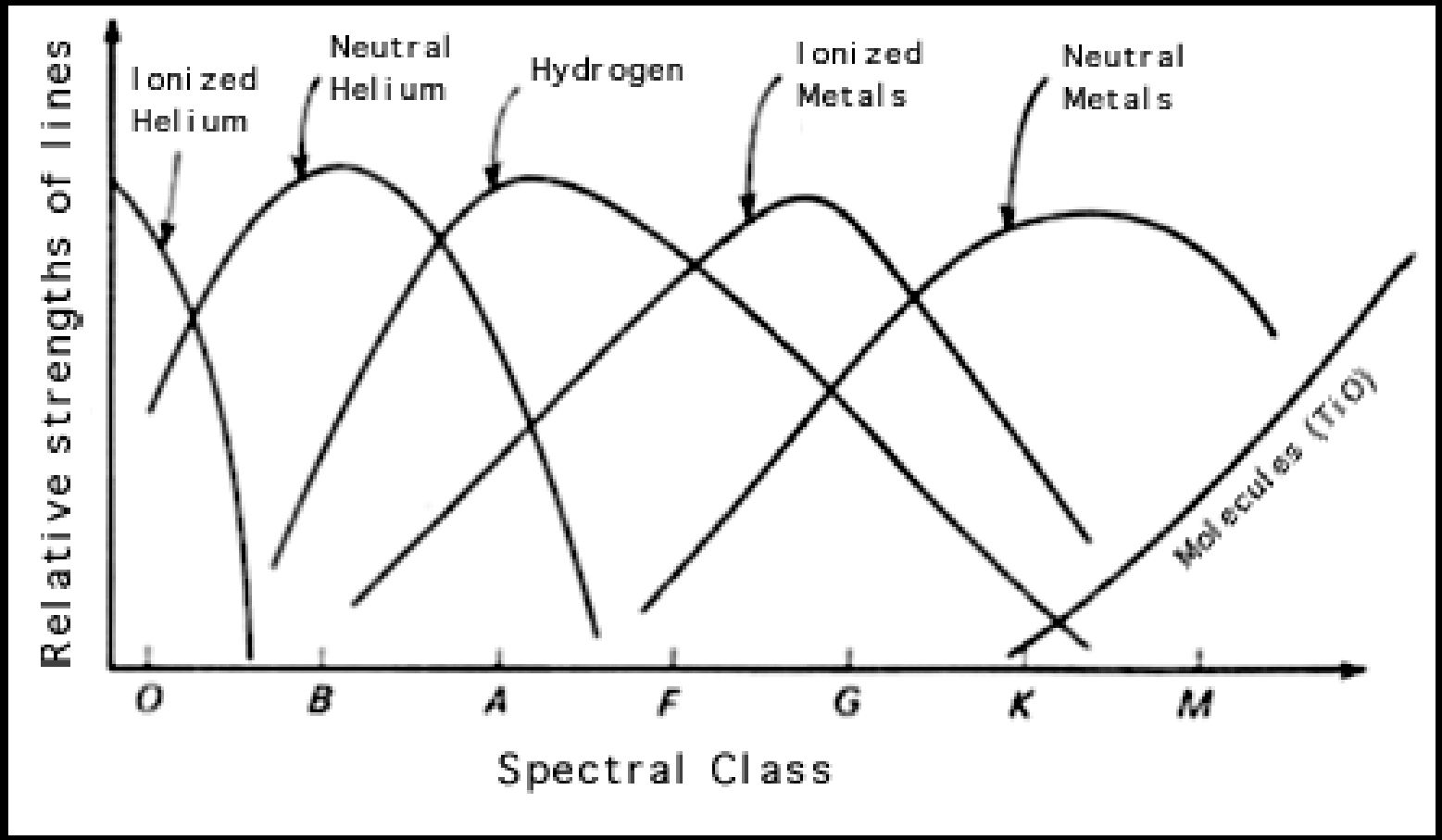

O
B2
B5
A0
A5
F0
F5
G0
G5
K0
K5
M0
M2
CN
CaII (K+H)
FeI
CaI
CH
FeI
FeI
MgH
FeI
TiO
MgH TiI/FeI
CaI/FeI
TiO
TiO
NaI
TiO
FeI
TiO
TiO
400
500
600
700
Wavelength (nm)



Class	Color	Prominent Spectral Lines
O	Blue	Ionized helium, hydrogen
B	Blue-white	Neutral helium, hydrogen
A	White	Hydrogen, ionized sodium and calcium
F	White	Hydrogen, ionized and neutral sodium and calcium
G	Yellow	Neutral sodium and calcium, ionized calcium, iron, magnesium
K	Orange	Neutral calcium, iron, magnesium
M	Red	Neutral iron, magnesium, and neutral titanium oxide

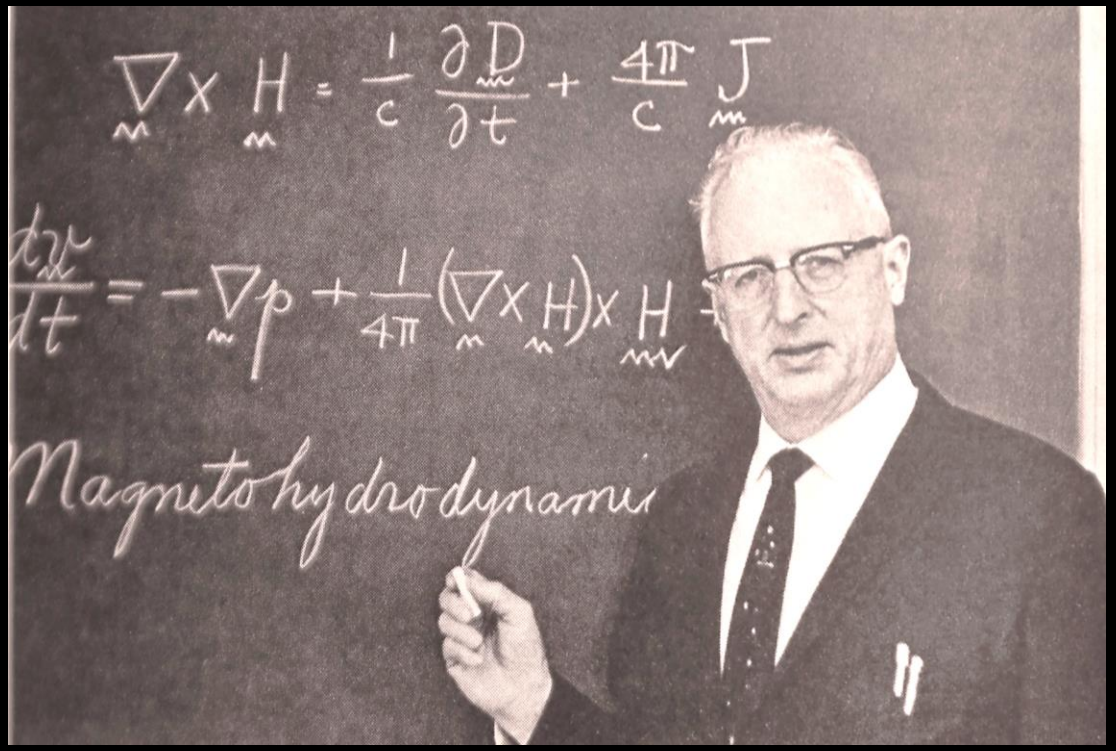
Meghnad Saha

- Born: 1893 in India
- Work relates the degree of ionization of a gas to temperature & pressure of the gas (1920)
- Had no access to Harvard spectral data.


Relative strengths of lines
Ionized Helium
Neutral Helium
Hydrogen
Ionized Metals
Neutral Metals
Molecules (TiO)
O
B
A
F
G
K
M
Spectral Class

HOTTER!!

Class	Color	Prominent Spectral Lines	Surface Temp. (K)
O	Blue	Ionized helium, hydrogen	> 25,000 K
B	Blue-white	Neutral helium, hydrogen	11,000 – 25,000 K
A	White	Hydrogen, ionized sodium and calcium	7,500 – 11,000 K
F	White	Hydrogen, ionized and neutral sodium and calcium	6,000 – 7,500 K
G	Yellow	Neutral sodium and calcium, ionized calcium, iron, magnesium	5,000 – 6,000 K
K	Orange	Neutral calcium, iron, magnesium	3,500 – 5,000 K
M	Red	Neutral iron, magnesium, and neutral titanium oxide	< 3,500 K


$\nabla \times H = \frac{1}{c}\frac{\partial D}{\partial t} + \frac{4\pi}{c} J$
$\frac{dv}{dt} = -\nabla p + \frac{1}{4\pi}(\nabla \times H) \times H$
Magnetohydrodynamics

Henry Norris Russell

Doctoral thesis: “”*Stellar Atmospheres; a Contribution to the Observational Study of High Temperature in the Reversing Layers of Stars."*

. . . . "the most brilliant PhD thesis ever written in astronomy“ – *Otto Struve*

HARVARD OBSERVATORY MONOGRAPHS
HARLOW SHAPLEY, EDITOR

No. 1

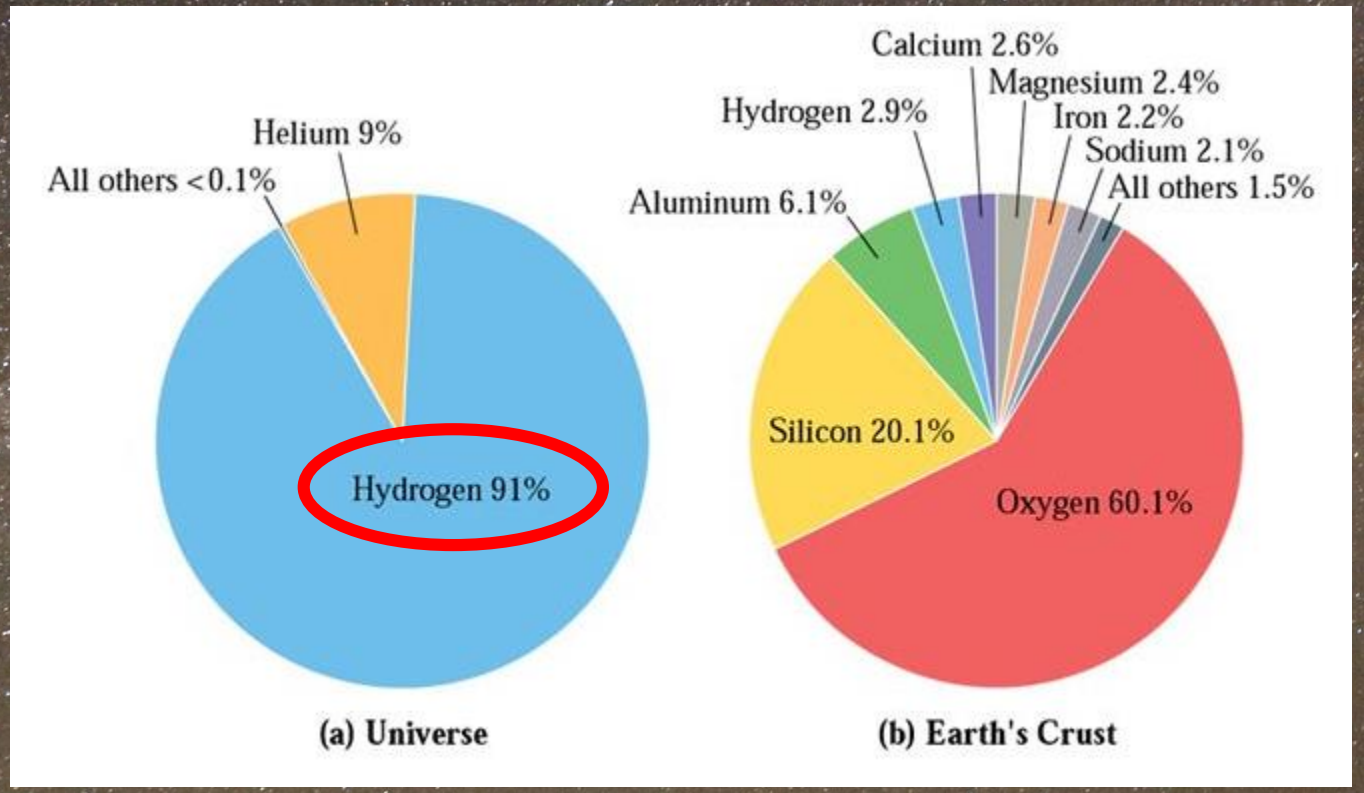
STELLAR ATMOSPHERES

A CONTRIBUTION TO THE OBSERVATIONAL STUDY OF HIGH TEMPERATURE IN THE REVERSING LAYERS OF STARS

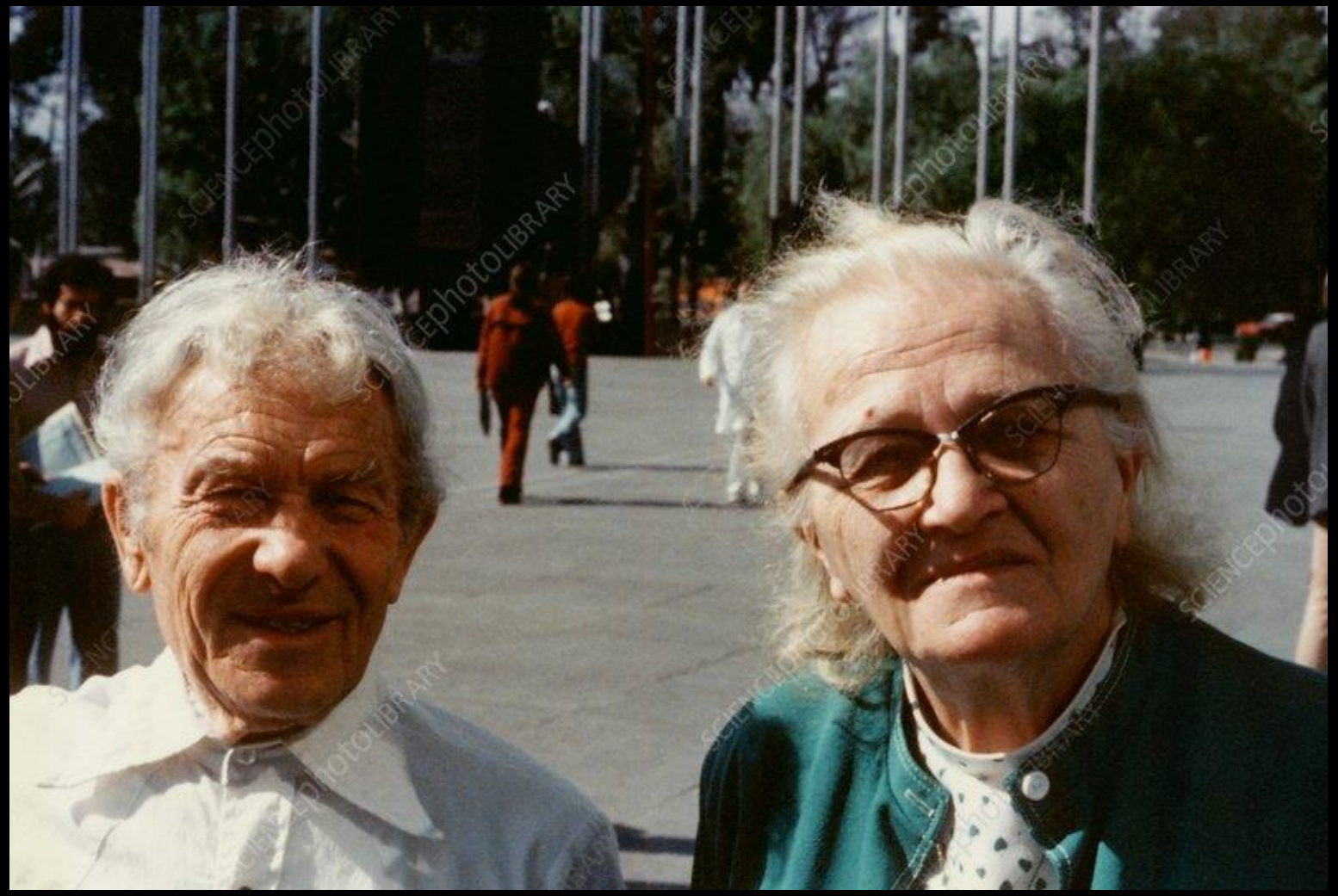
BY

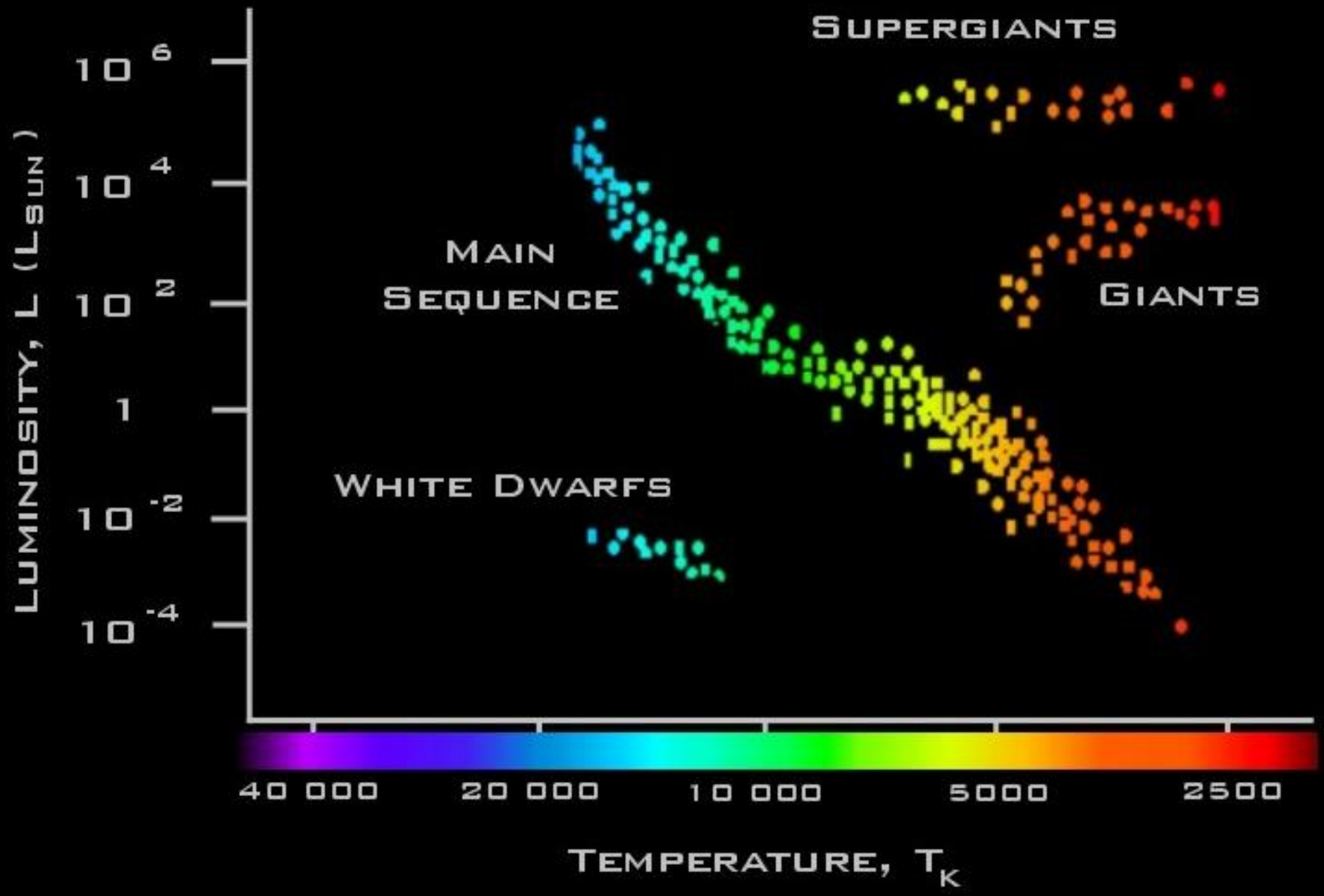
CECILIA H. PAYNE

PUBLISHED BY THE OBSERVATORY
CAMBRIDGE, MASSACHUSETTS
1925


Helium 9%
All others <0.1%
Hydrogen 91%
(a) Universe
Calcium 2.6%
Magnesium 2.4%
Hydrogen 2.9%
Iron 2.2%
Sodium 2.1%
All others 1.5%
Aluminum 6.1%
Silicon 20.1%
Oxygen 60.1%
(b) Earth's Crust

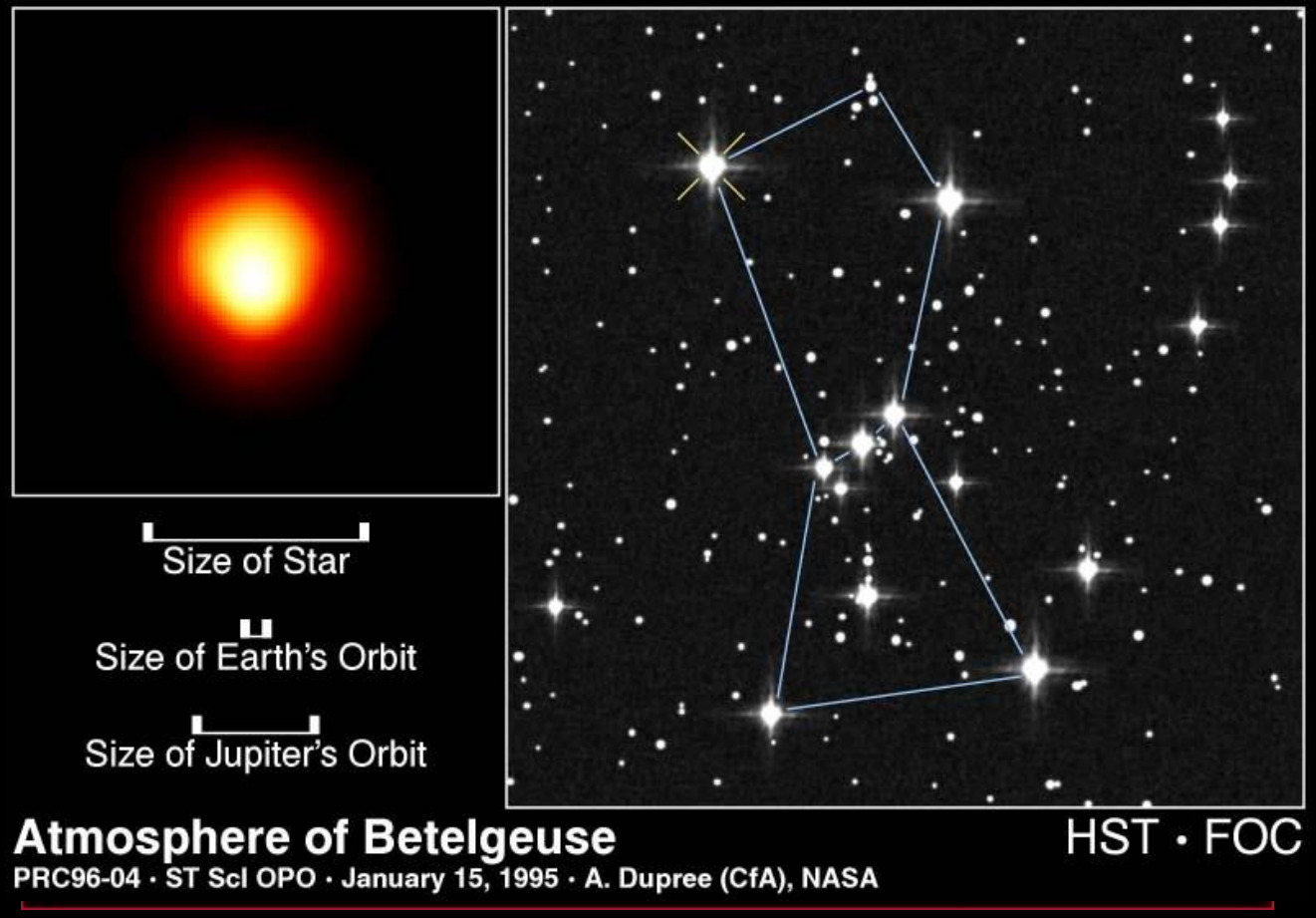
Sergei Gaposchkin




Supergiants
Main Sequence
Giants
White Dwarfs
Luminosity, L (Lsun)
10 6
10 4
10 2
1
10 -2
10 -4
40 000
20 000
10 000
5000
2500
Temperature, TK

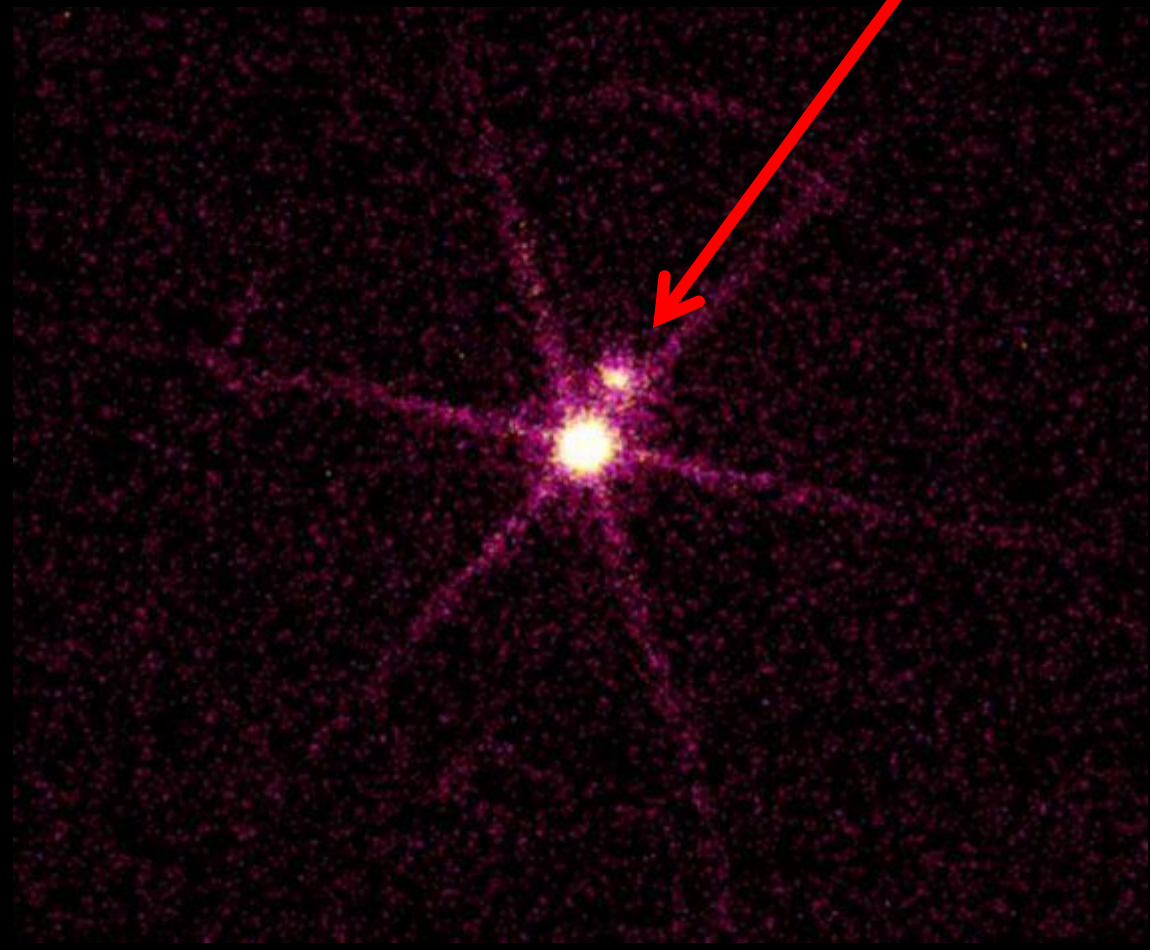
“Supergiants:

- Betelgeuse (Orion) = 216 million miles diameter!
- 3000K



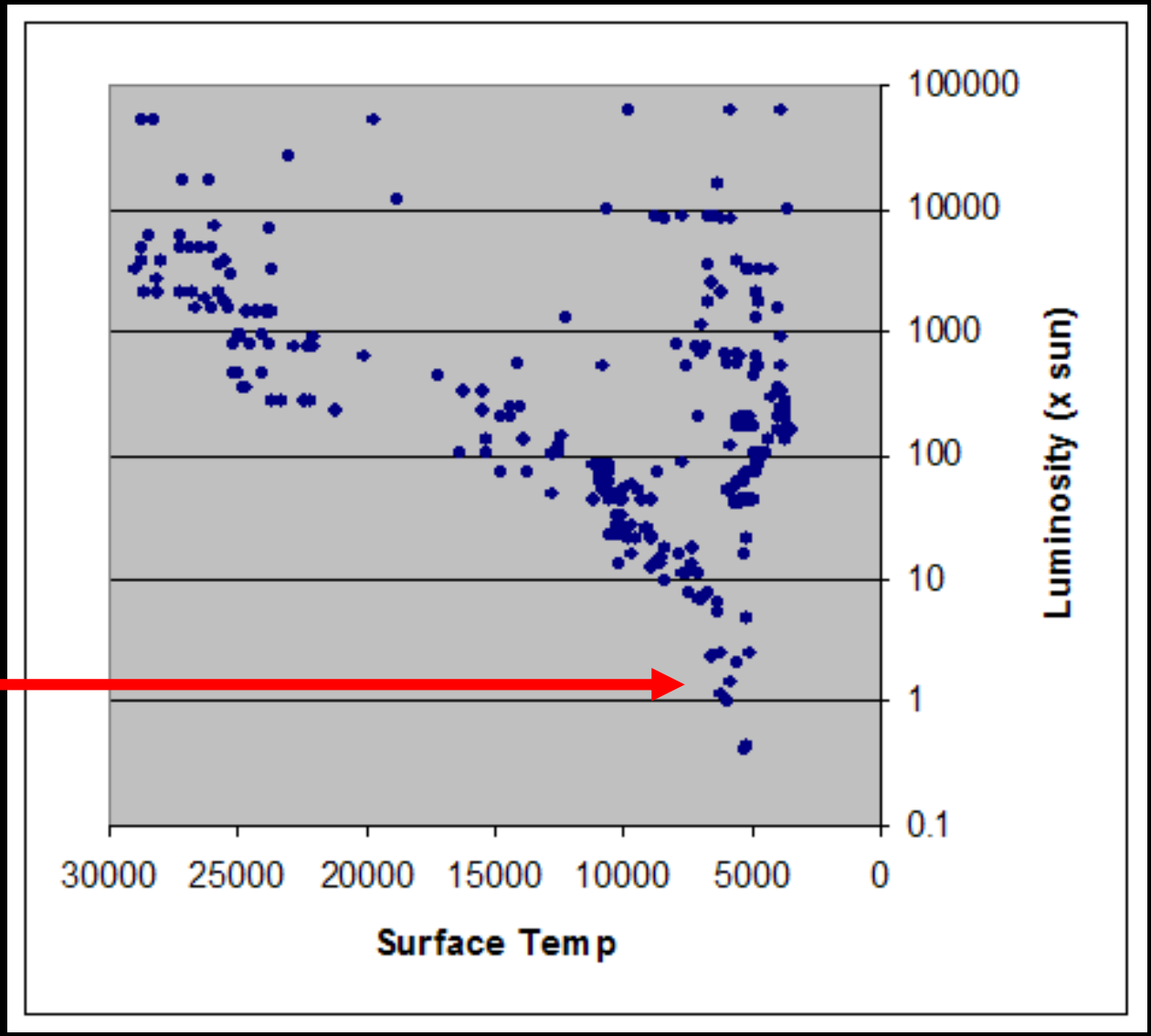
White Dwarfs

- Sirius B (Canis Major) = ¾ size of Earth 53,000K
- Disc. 1862

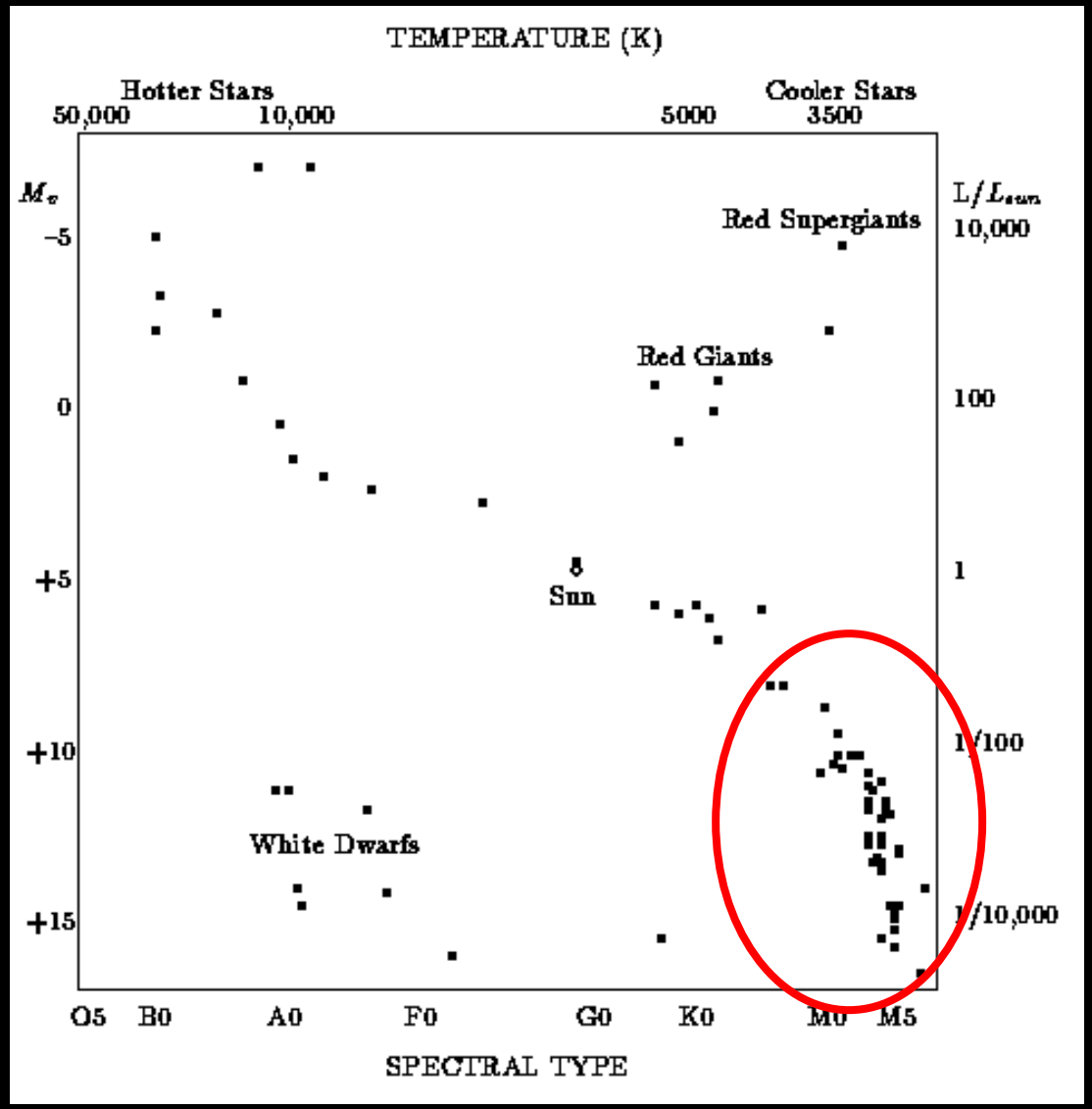


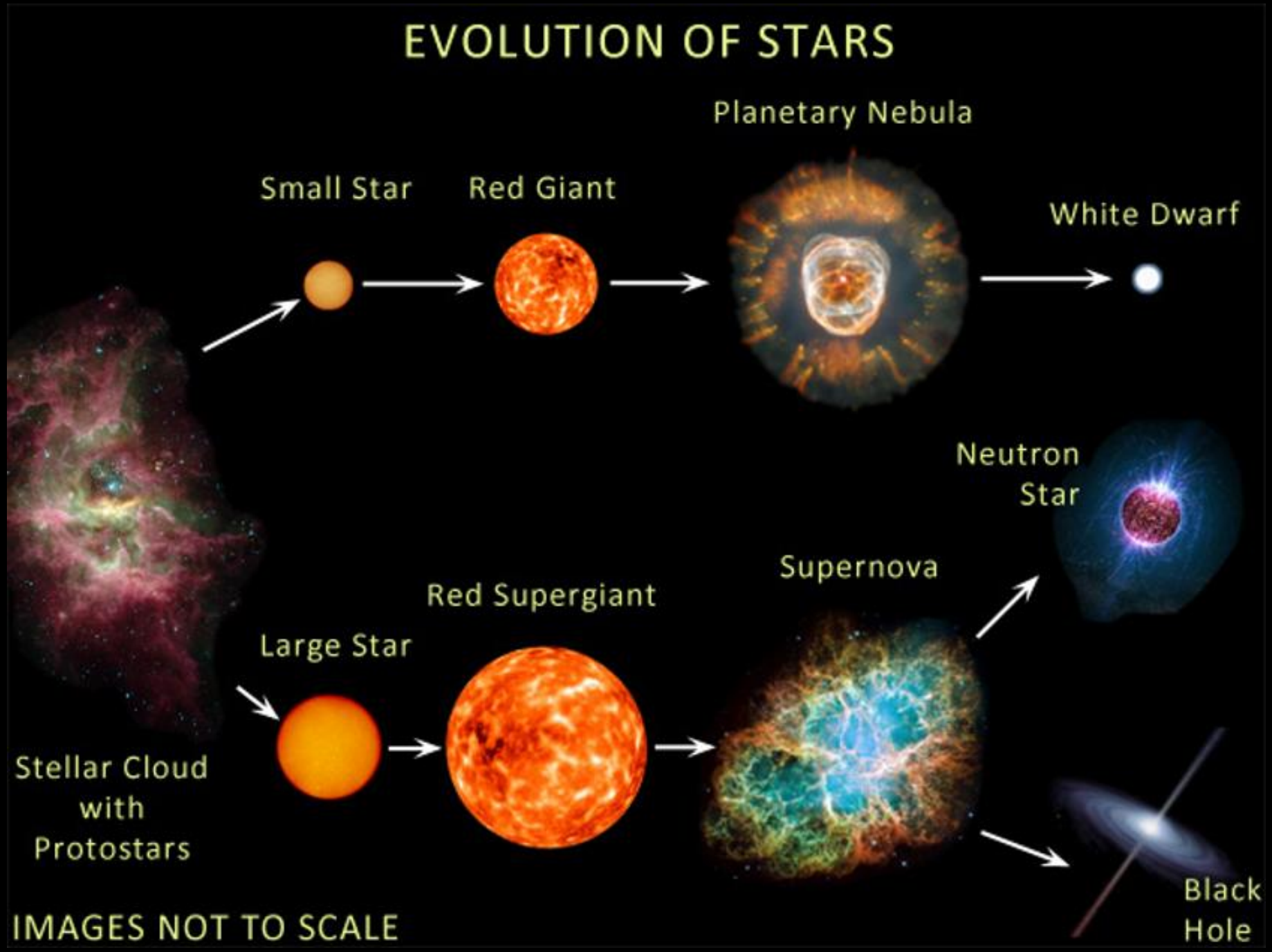
The stars in our sky . . .

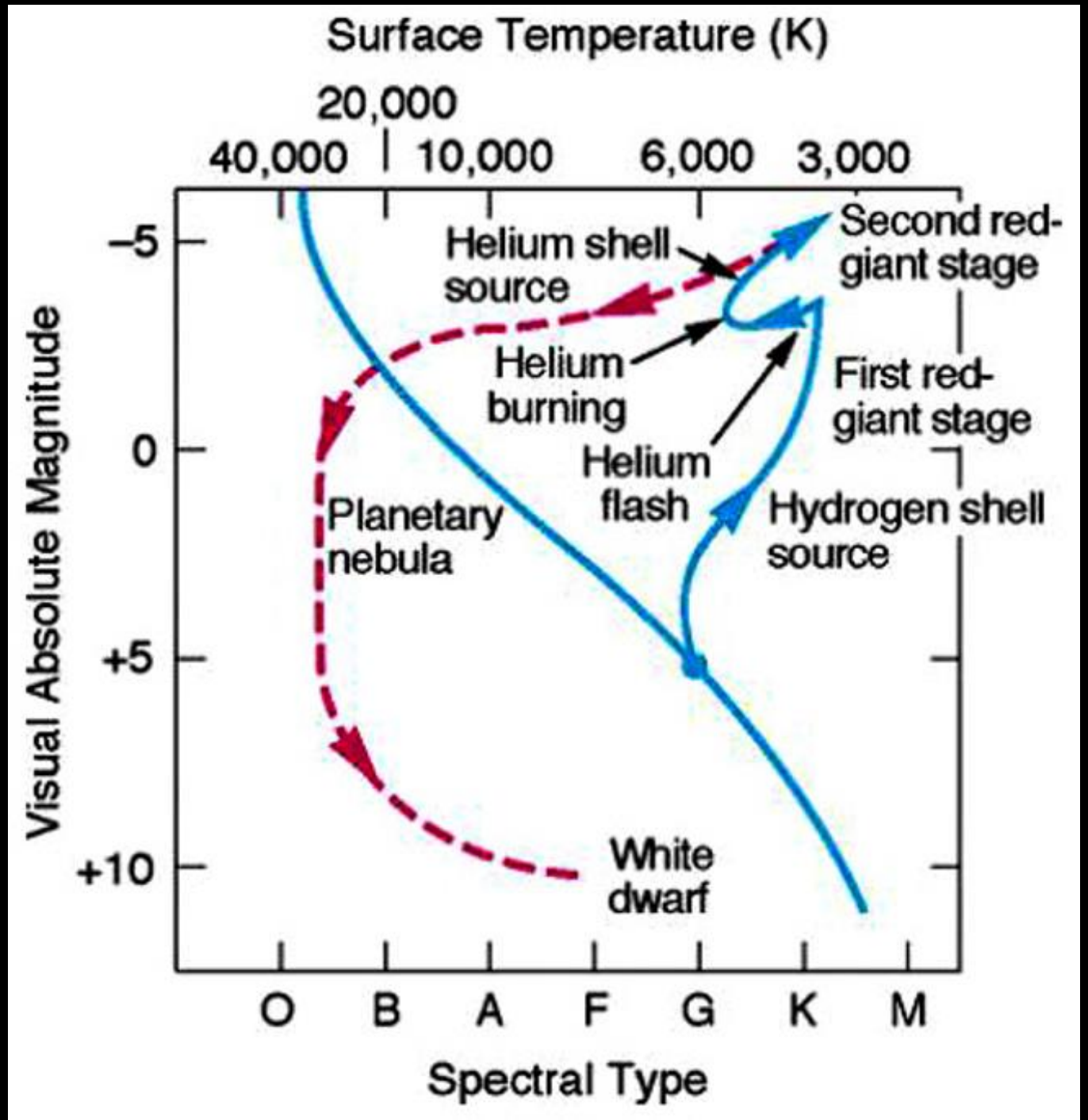
Sun

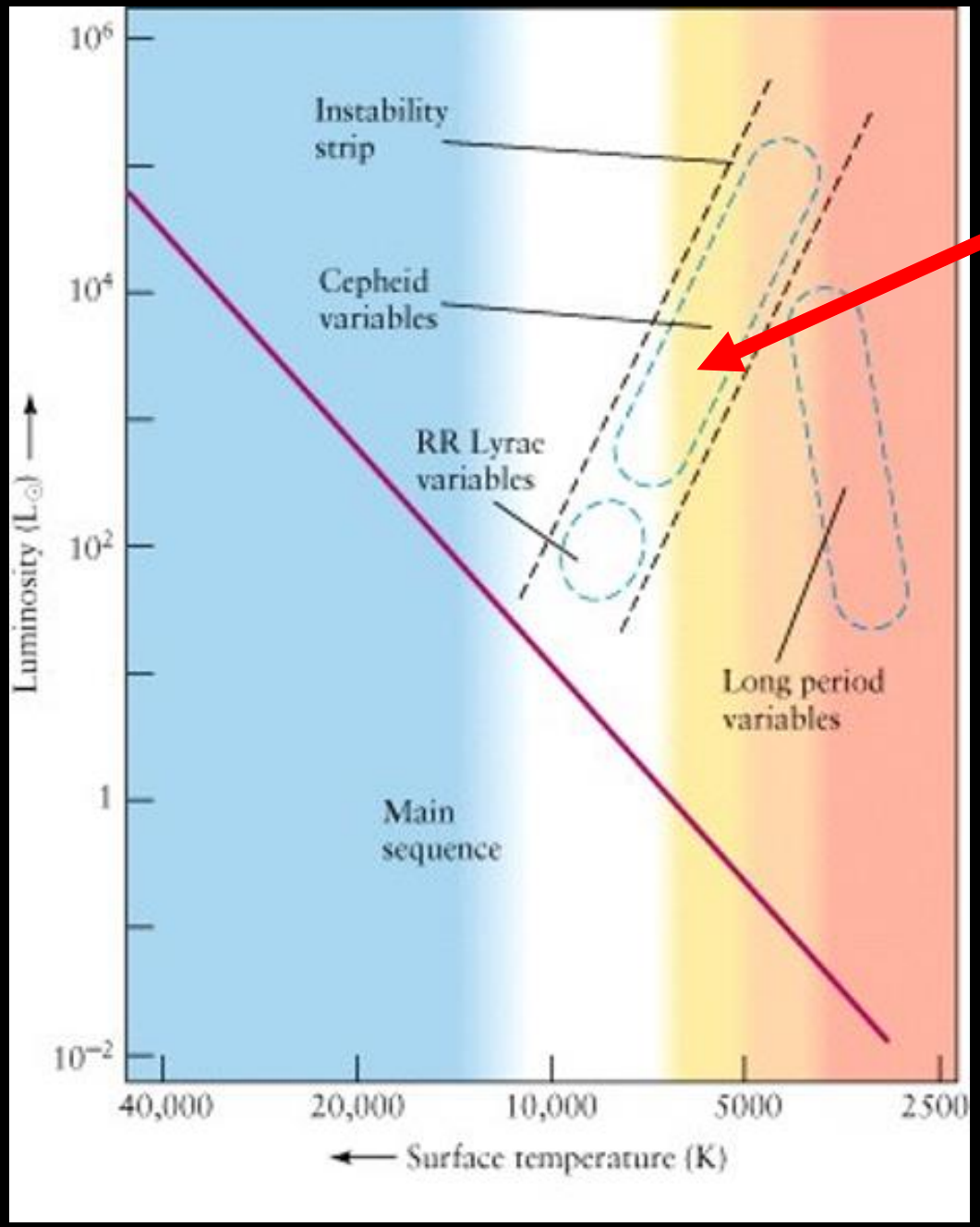


The nearest stars . . . .



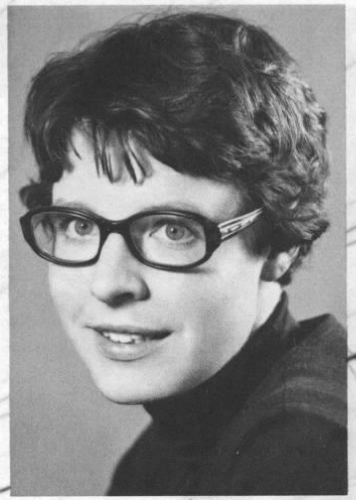

EVOLUTION OF STARS
Planetary Nebula
Small Star
Red Giant
White Dwarf
Neutron Star
Supernova
Red Supergiant
Large Star
Stellar Cloud with Protostars
Black Hole
IMAGES NOT TO SCALE


Surface Temperature (K)
20,000
40,000
10,000
6,000
3,000
–5
0
+5
+10
Visual Absolute Magnitude
Helium shell source
Second red-giant stage
Helium burning
First red-giant stage
Helium flash
Hydrogen shell source
Planetary nebula
White dwarf
O
B
A
F
G
K
M
Spectral Type



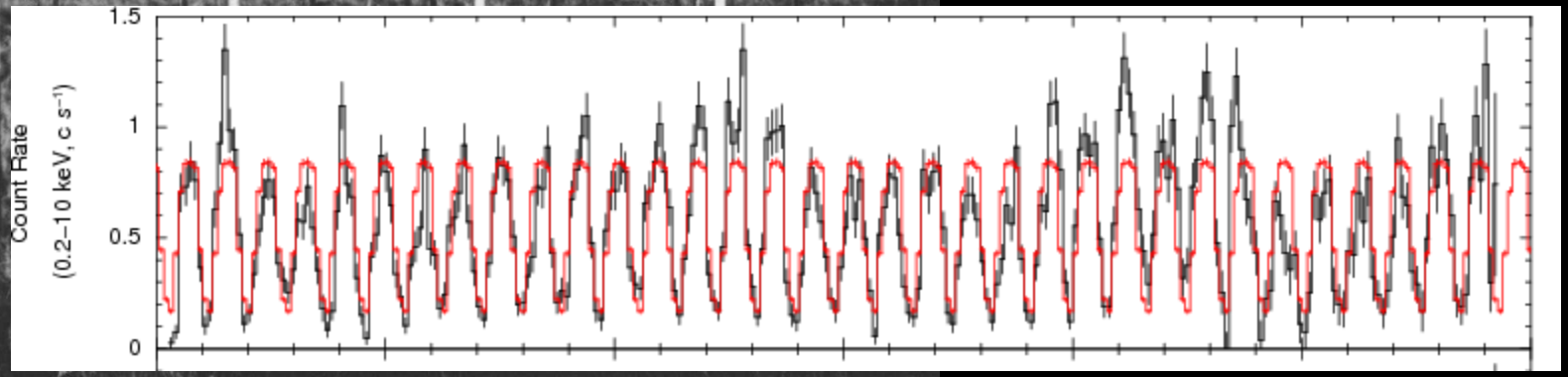
"Instability Strip"

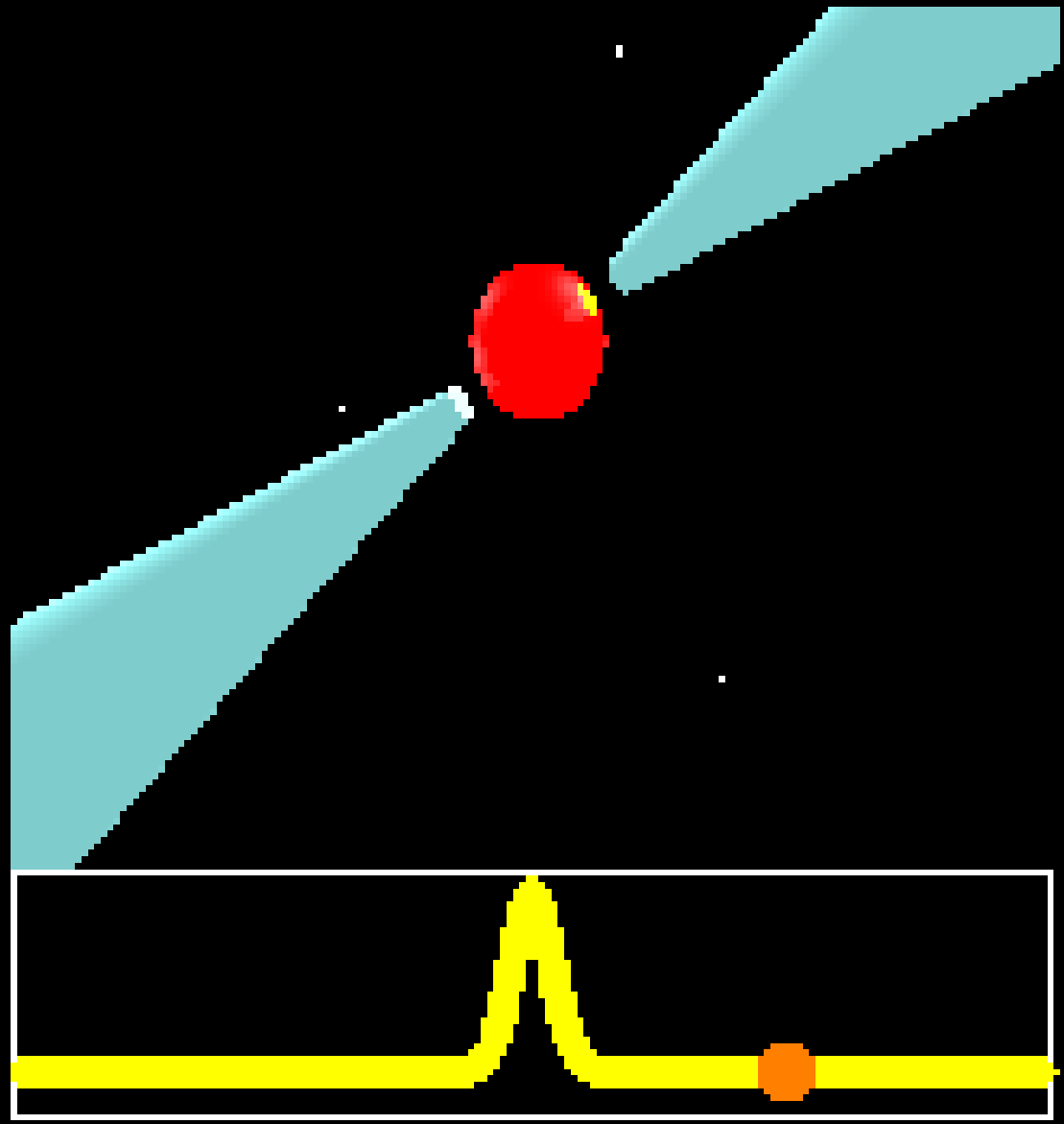
S. Jocelyn Bell Burnell was born in northern Ireland in 1943. After receiving a B.S. degree in physics from Glasgow University, Scotland, she went to Cambridge University, England, where she earned her doctorate in radio astronomy in 1969. Since then she has done research in the newest branches of astronomy involving gamma-rays and x-rays. In 1978 she received the American Tentative Society Award for her pulsar research. Currently she is a research scientist at the Mullard Space Science Laboratory of the University College London.

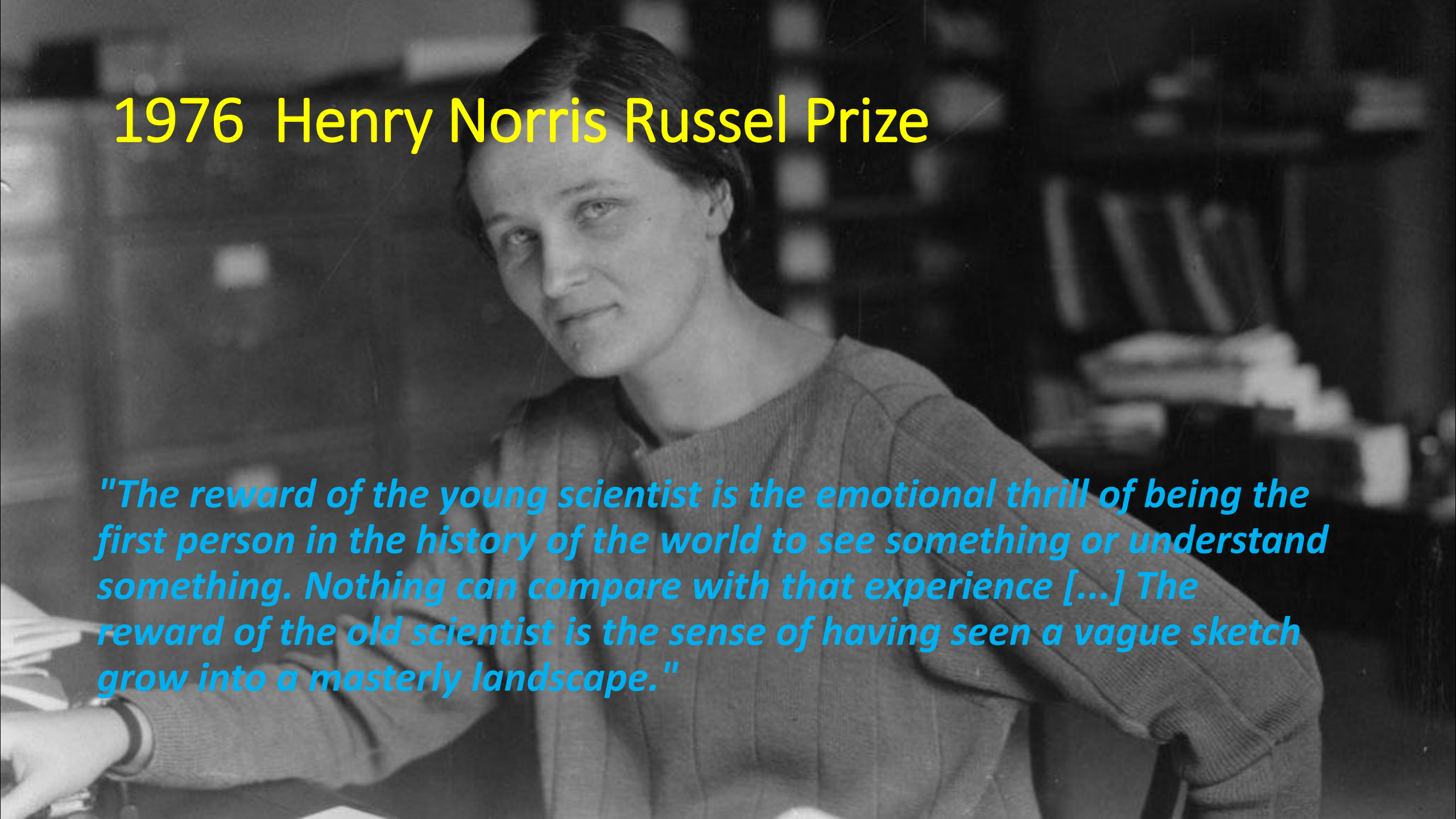


Burnell

Jocelyn Bell (1967) “LGM-1”

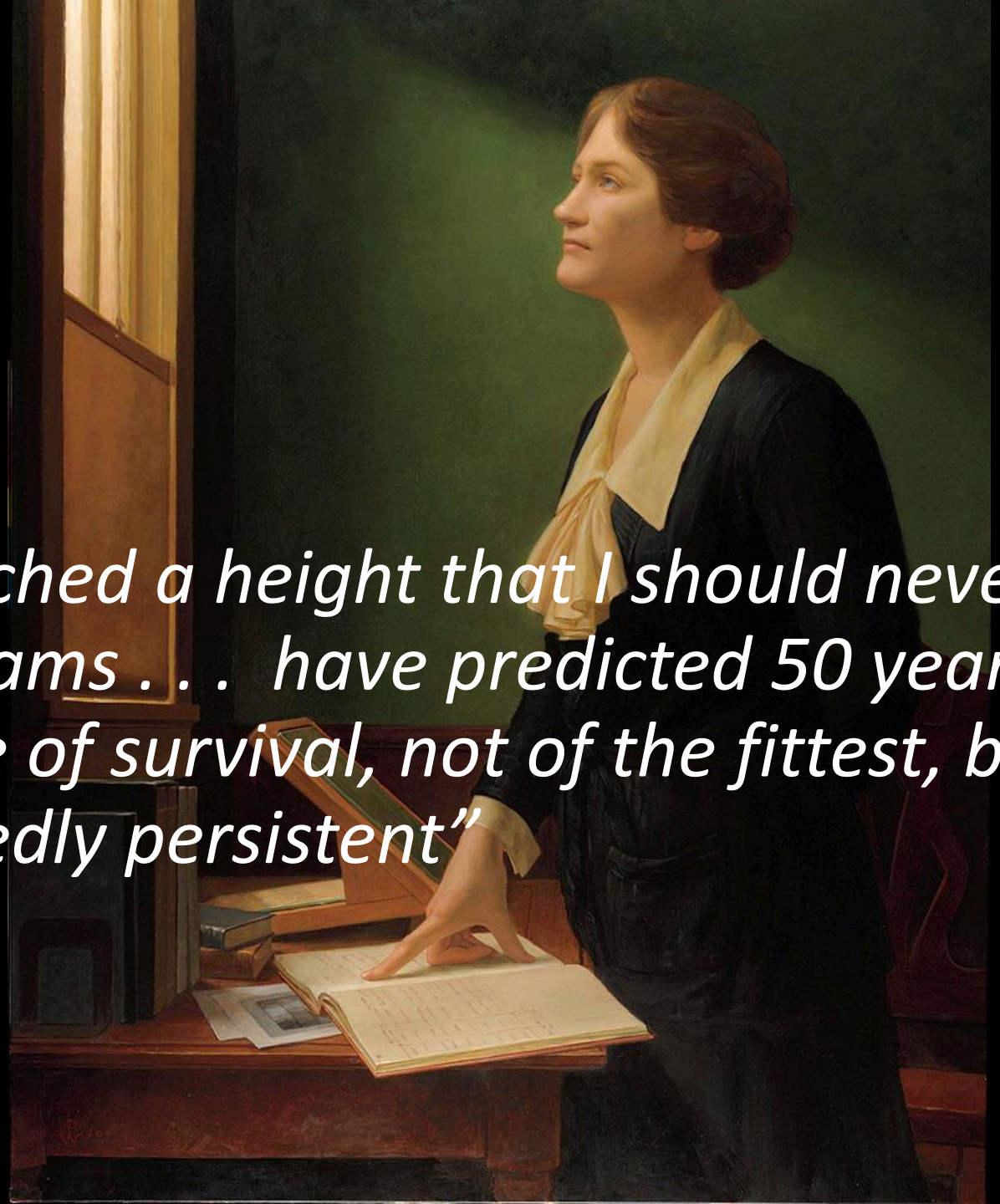






1976 Henry Norris Russel Prize

"The reward of the young scientist is the emotional thrill of being the first person in the history of the world to see something or understand something. Nothing can compare with that experience [...] The reward of the old scientist is the sense of having seen a vague sketch grow into a masterly landscape."



“I have reached a height that I should never in my wildest dreams . . . have predicted 50 years ago. It has been a case of survival, not of the fittest, but of the most doggedly persistent”