

# **Star Stuff**

How We Know What's in Space

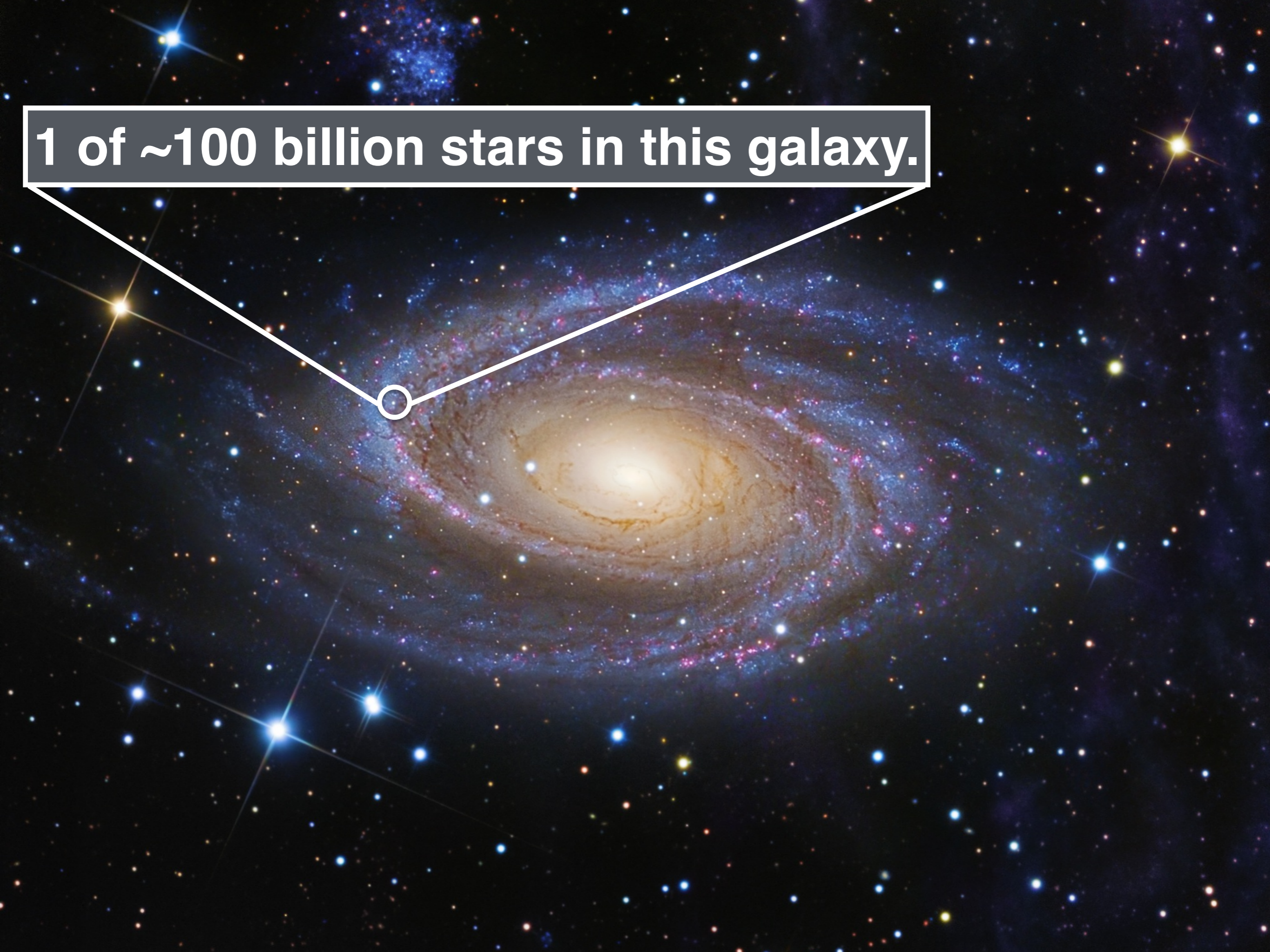


(I work here)



(I study things like this)

**1 of ~100 billion stars in this galaxy.**



# Big Questions

- What is a star?
- How can we learn what they're made of?
- Why do we care?

# Big Questions

- What is a star?
- How can we learn what they're made of?
- Why do we care?

***You will learn the answers!***

A dark, starry night sky with numerous stars of varying colors (white, blue, orange) and sizes. The text "What is a star?" is centered in a white, serif font.

What is a star?





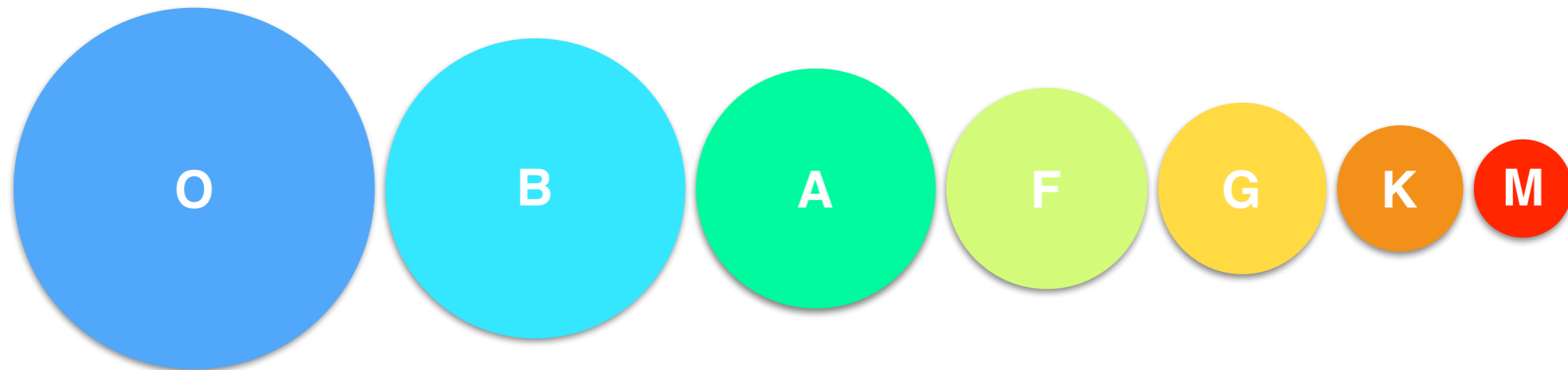
# Stars are diverse

- Come in **O, B, A, F, G, K, M** flavors:



# Stars are diverse

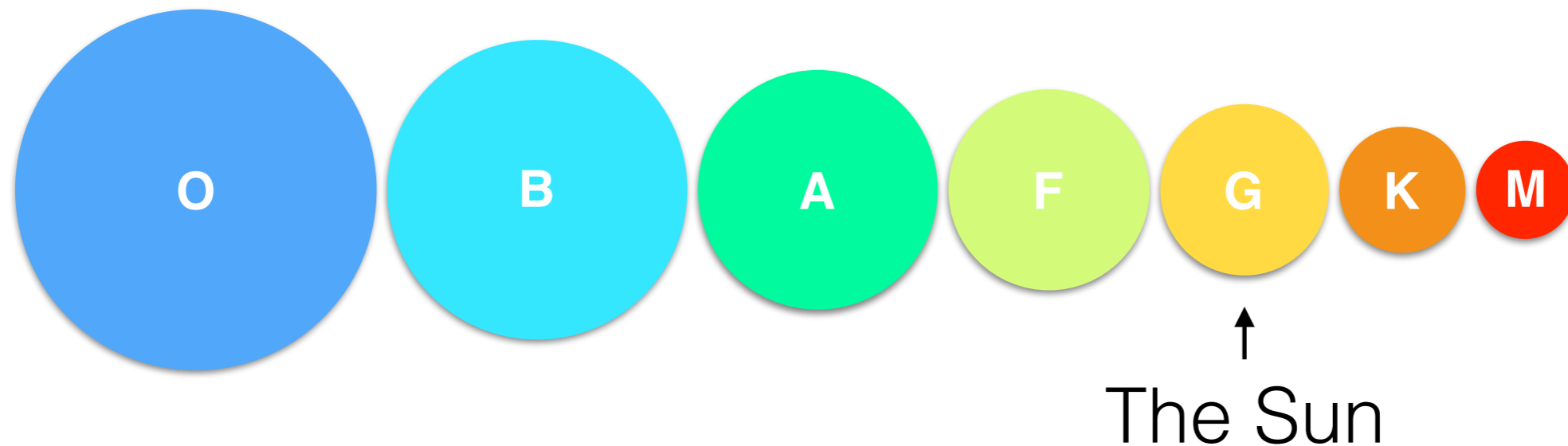
- Come in **O, B, A, F, G, K, M** flavors:



- “**Oh Be A Fine Girl and Kiss Me!”**

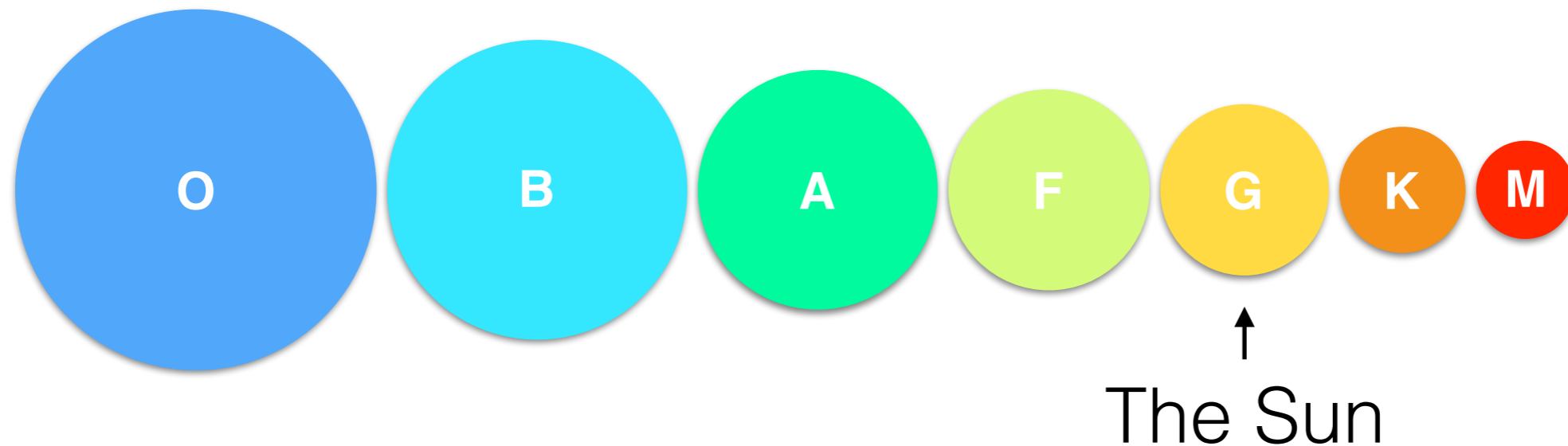
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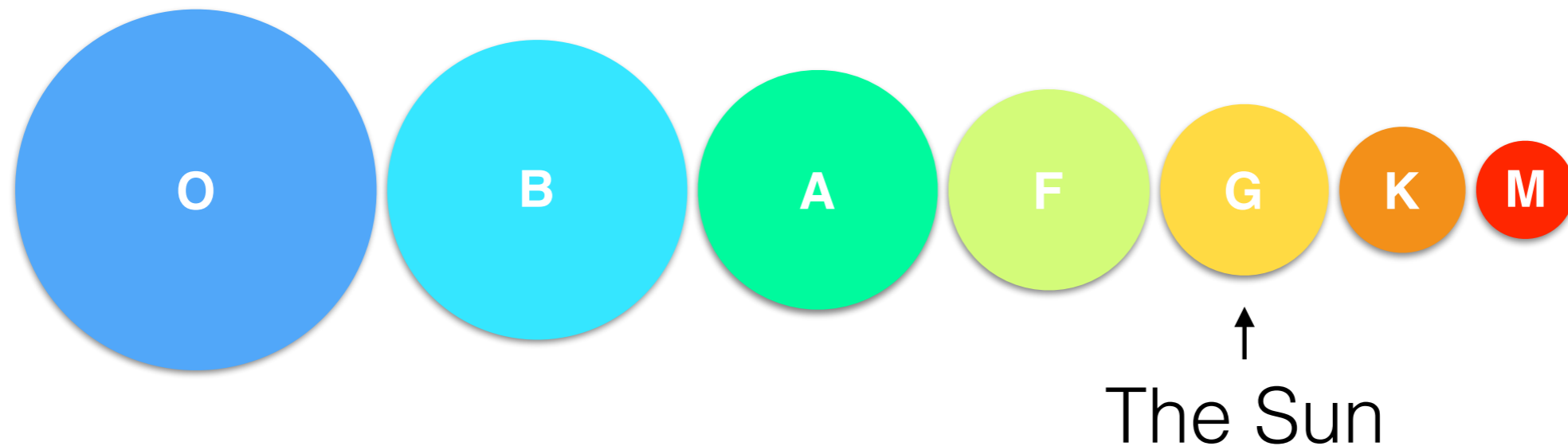
- “**Oh Be A Fine Girl and Kiss Me!”**

# They are big and bright



~ 1 **million miles** across  
100 **trillion-trillion watts!**

# They are big and bright



20x **wider**

10,000x **brighter**

~ 1 **million miles** across

100 **trillion-trillion watts!**

# They are big and bright



2x smaller

10x fainter

↑  
The Sun

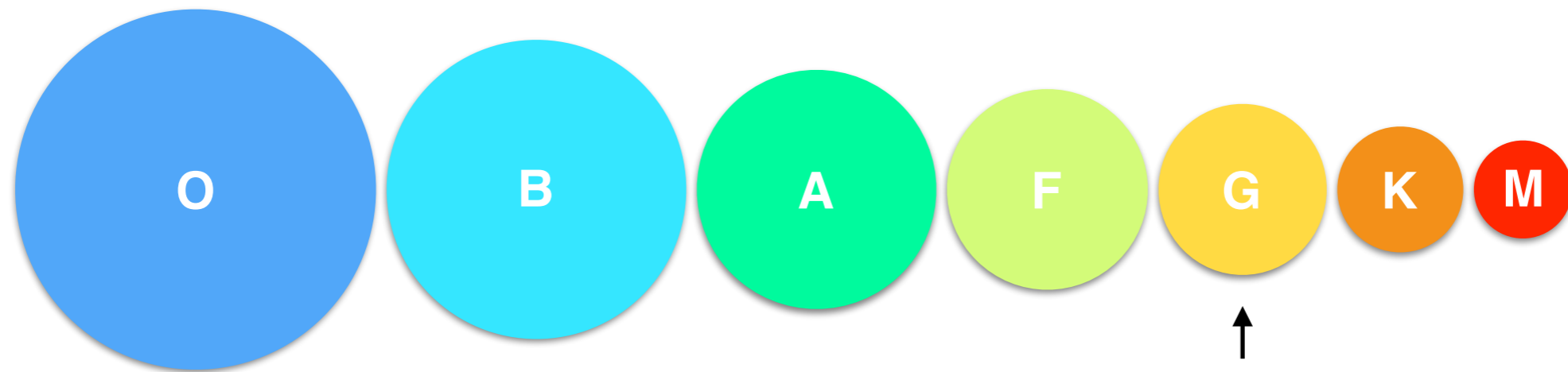
20x wider

10,000x brighter

~ 1 million miles across

100 trillion-trillion watts!

# They are old and young



↑  
The Sun

lives 10 **billion** years

# They are old and young



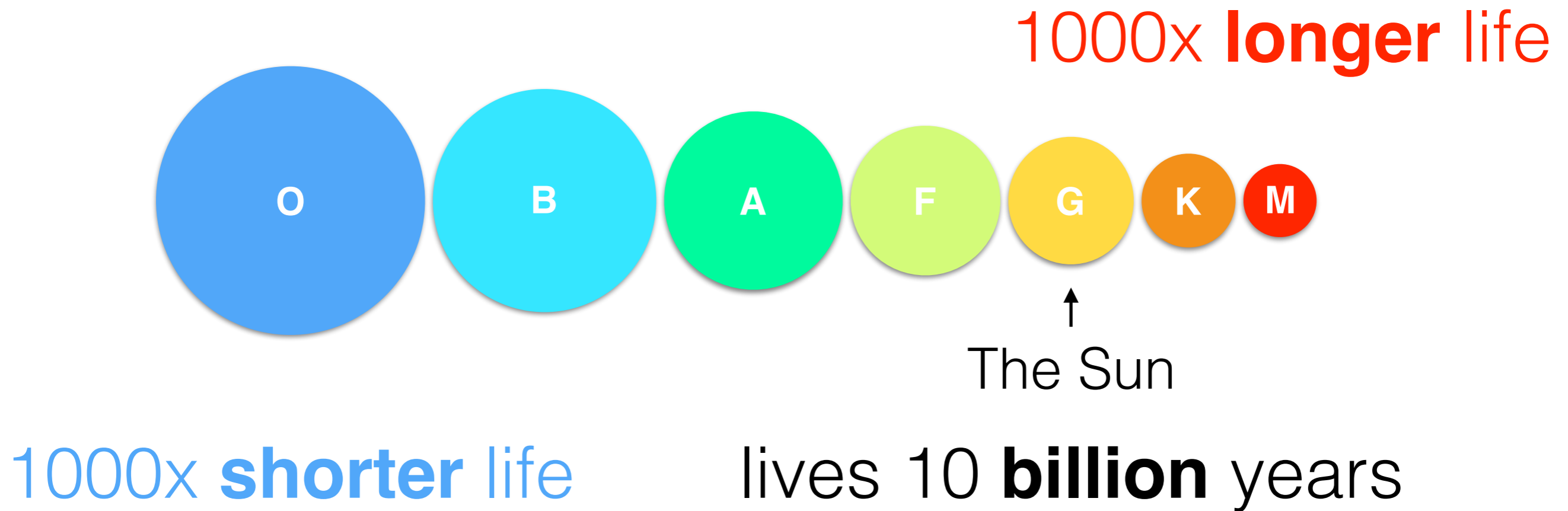
↑  
The Sun

1000x **shorter** life

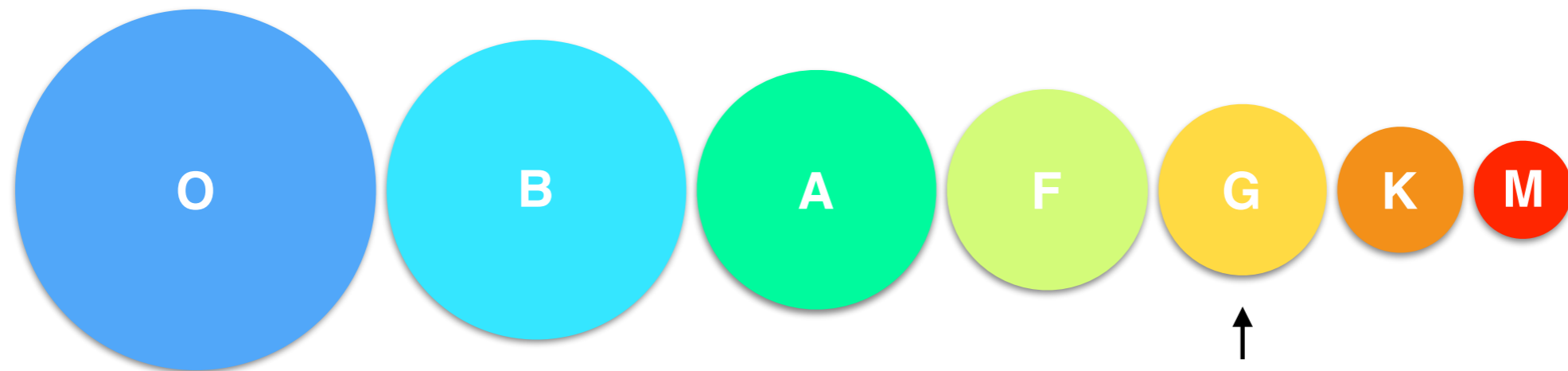
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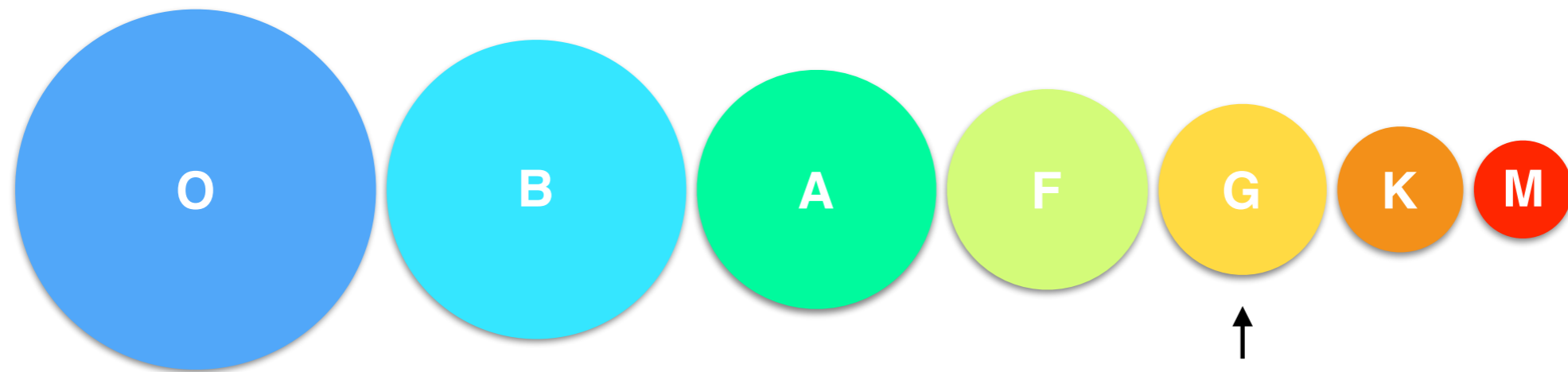
# They are hot and...less hot



The Sun

5000 **degrees**

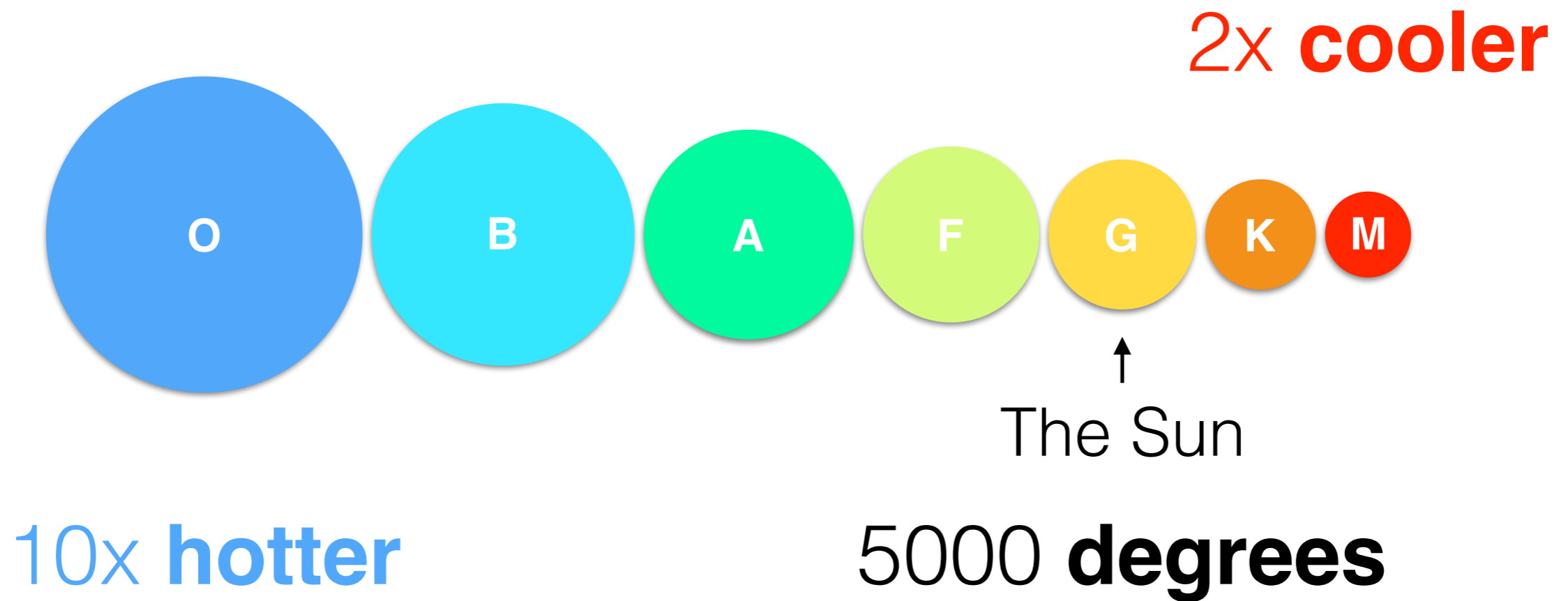
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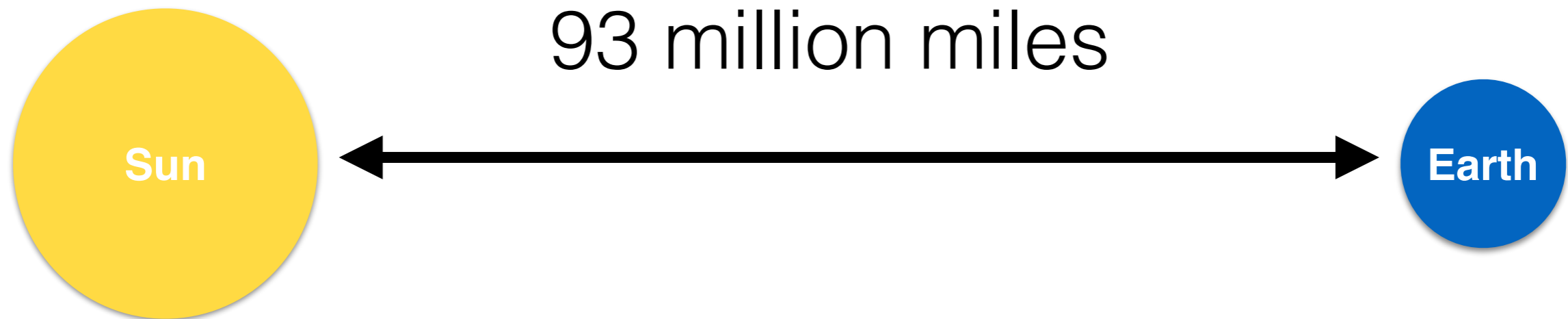
# They are hot and...less hot



They are *really* far away



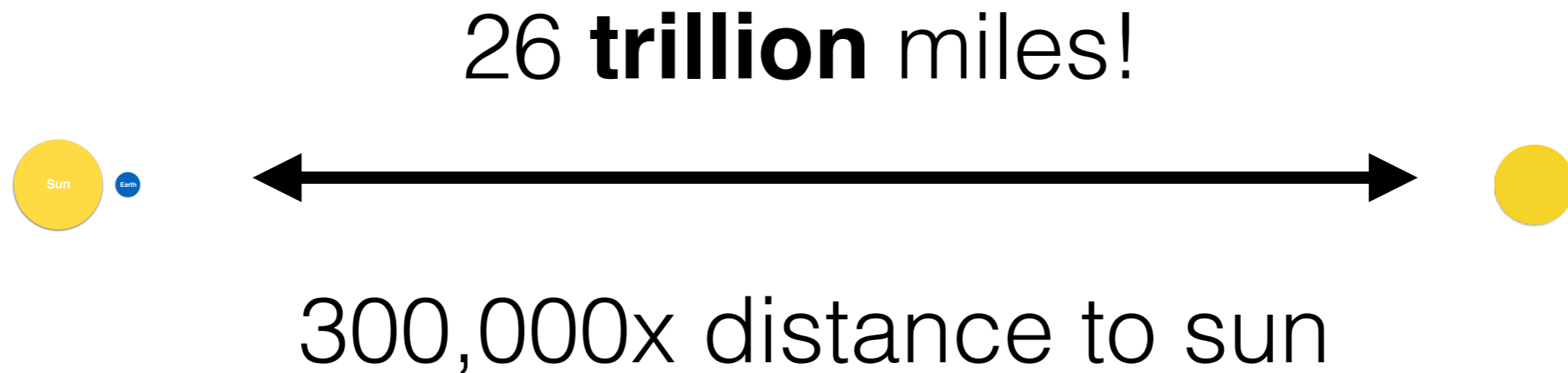
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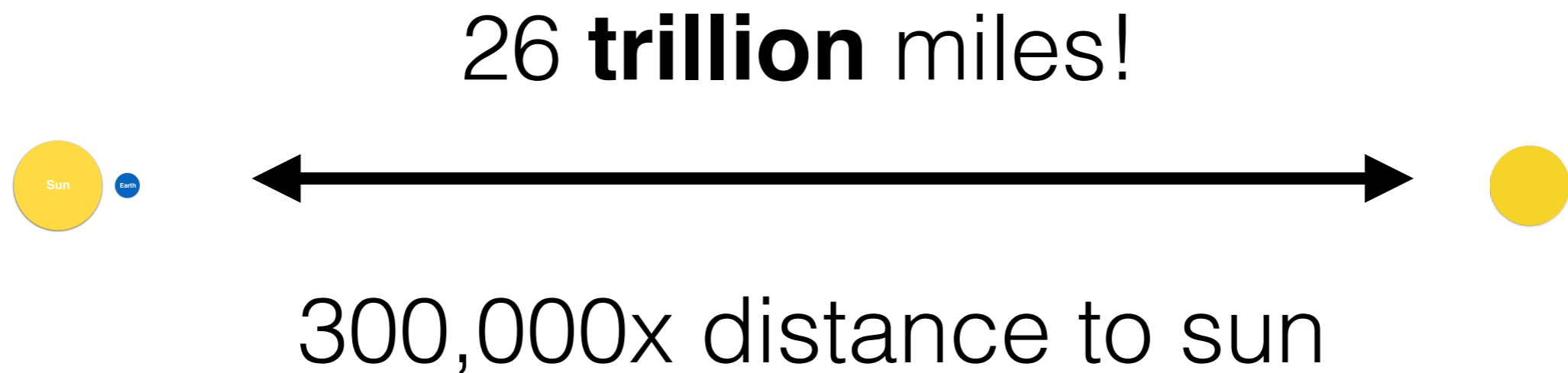


# They are *really* far away





# They are *really* far away



(And that's to the next *nearest* star!)



A vast field of stars in a dark night sky, with the text "Just imagine the rest..." centered in a white serif font.

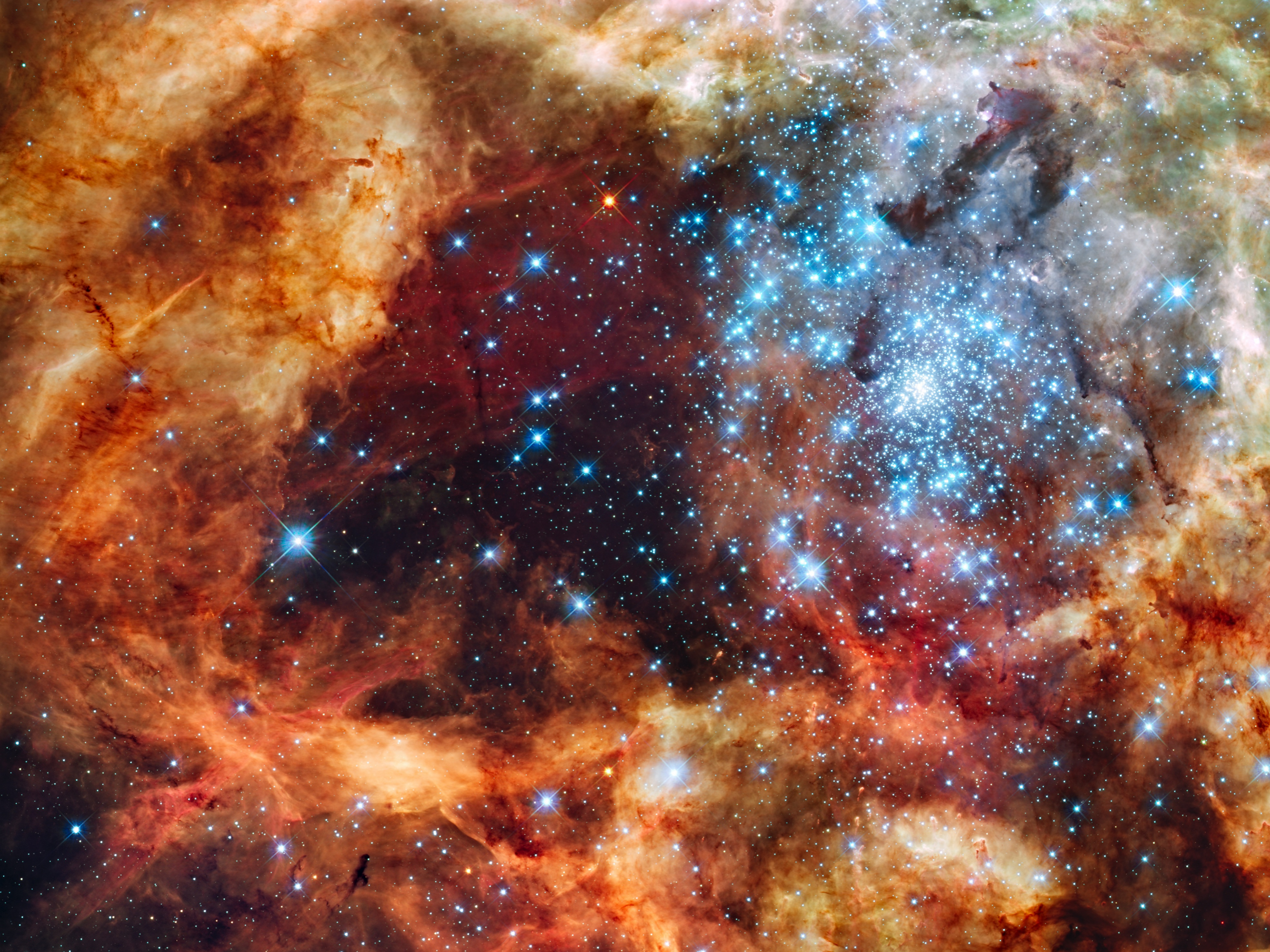
**Just imagine the rest...**

They have life cycles

**Birth**



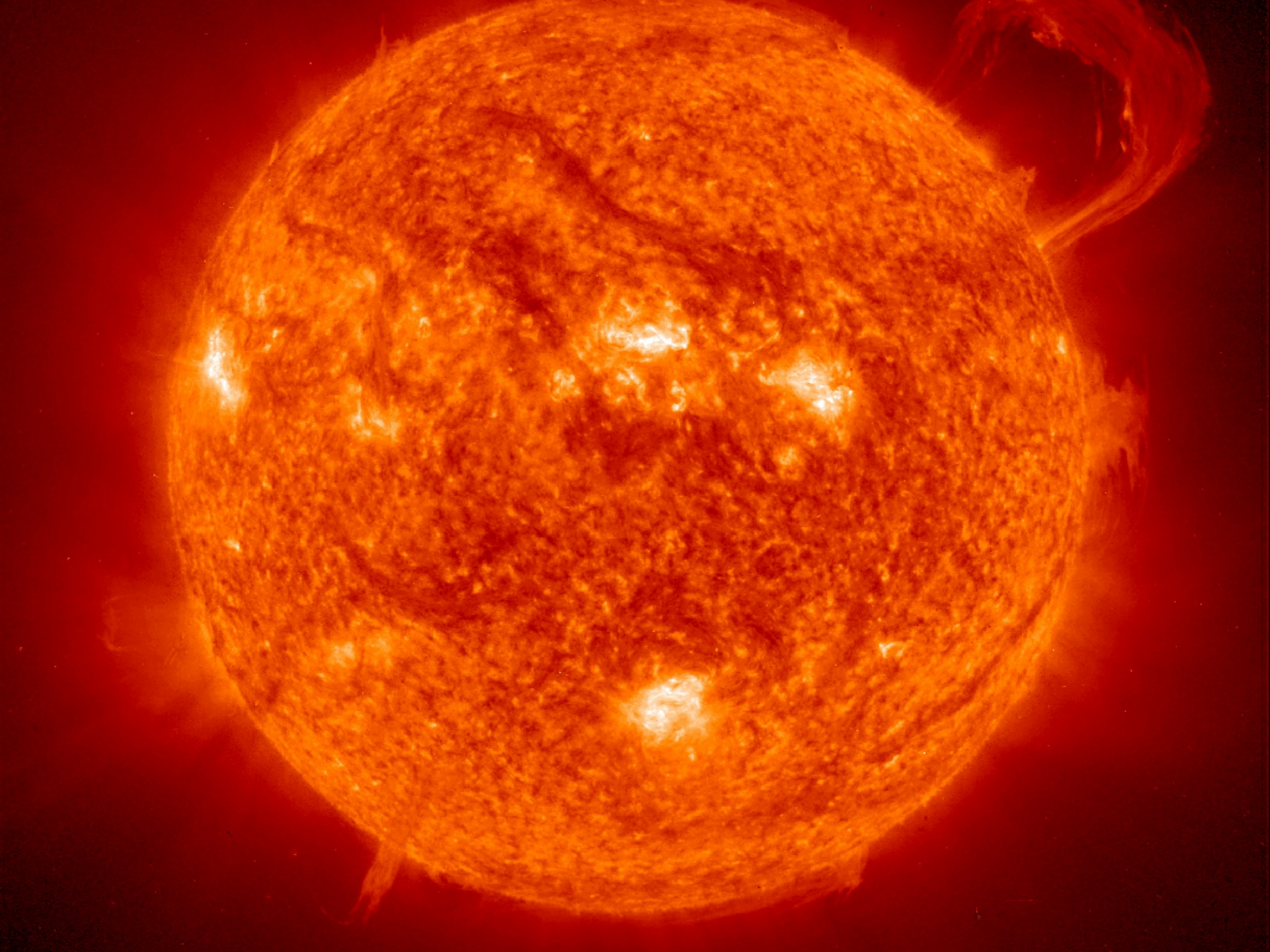








Life









How did they get here?

In the beginning...



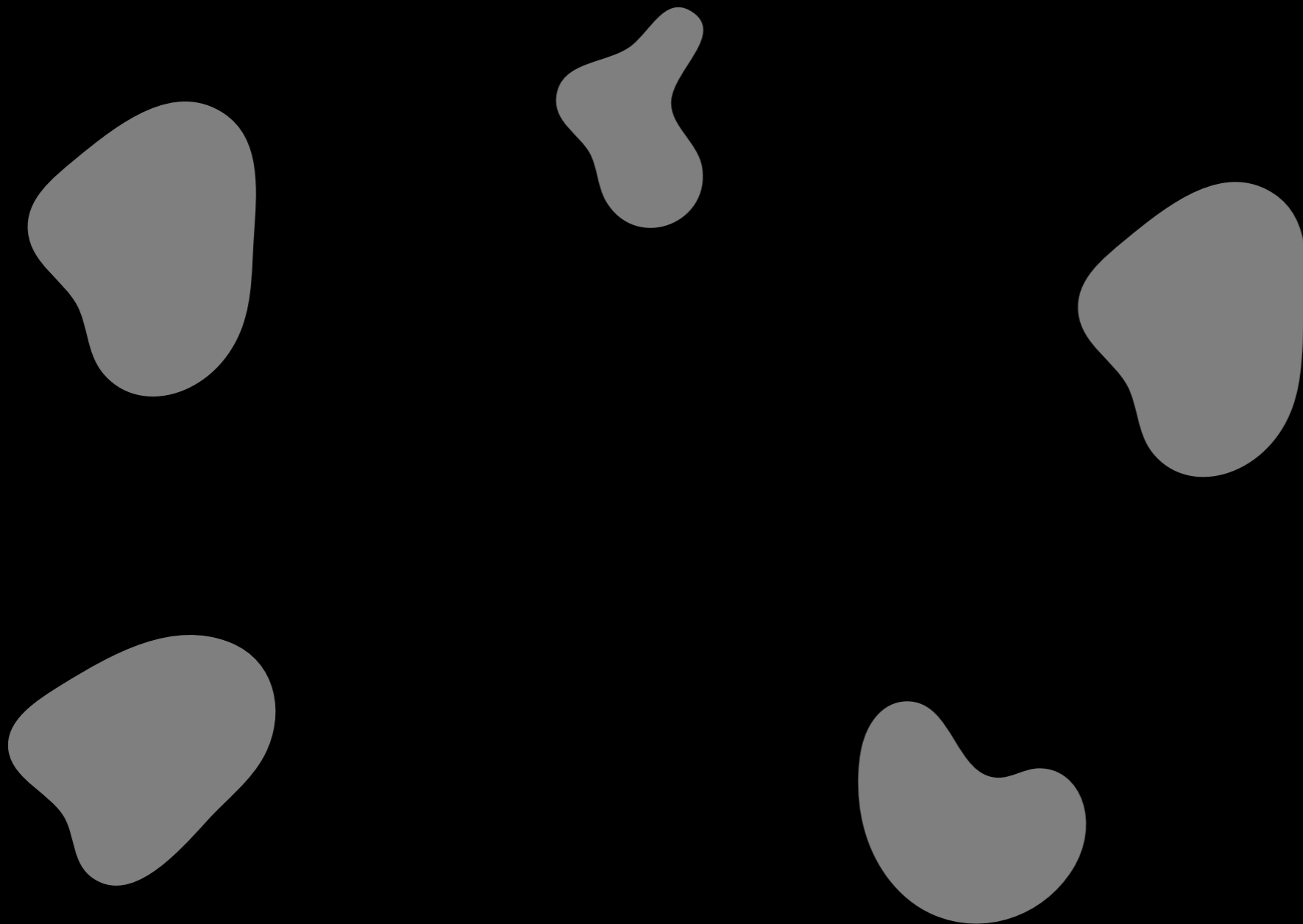
# In the beginning...

- (There were no stars)

# In the beginning...

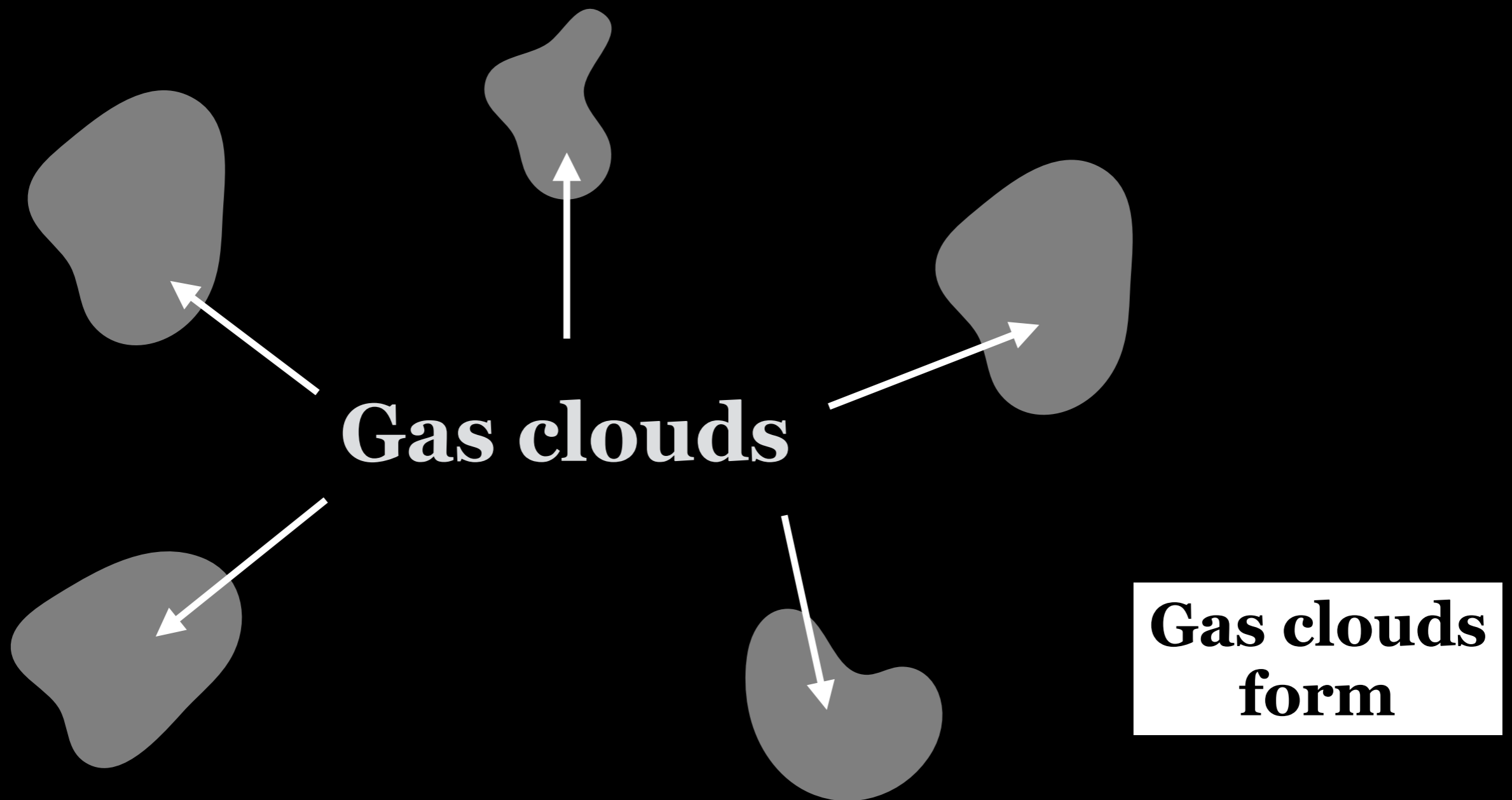
- (There were no stars)
- But! There was a lot of gas ...

Slightly after the  
beginning...

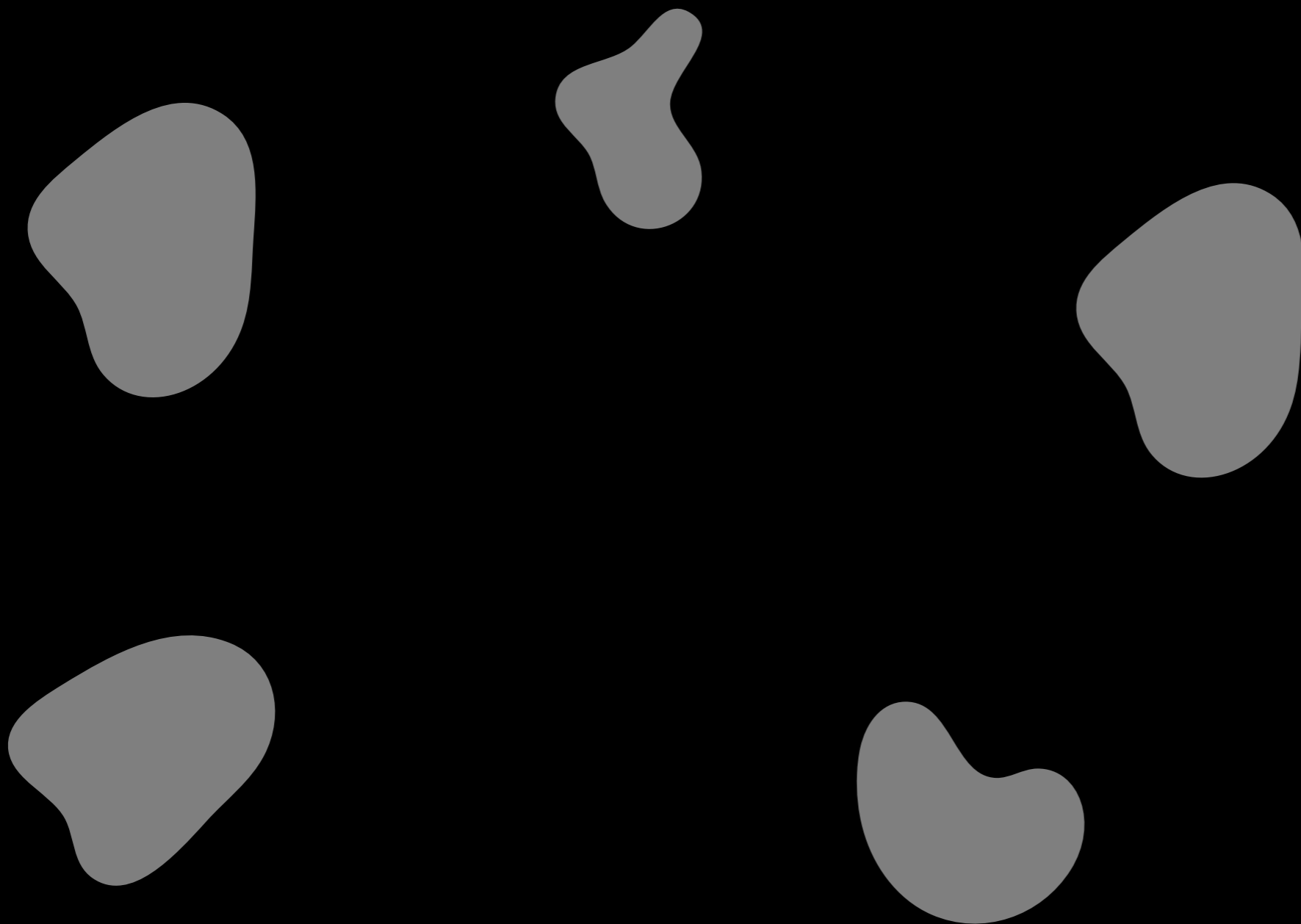


**Gas clouds  
form**

Slightly after the beginning...

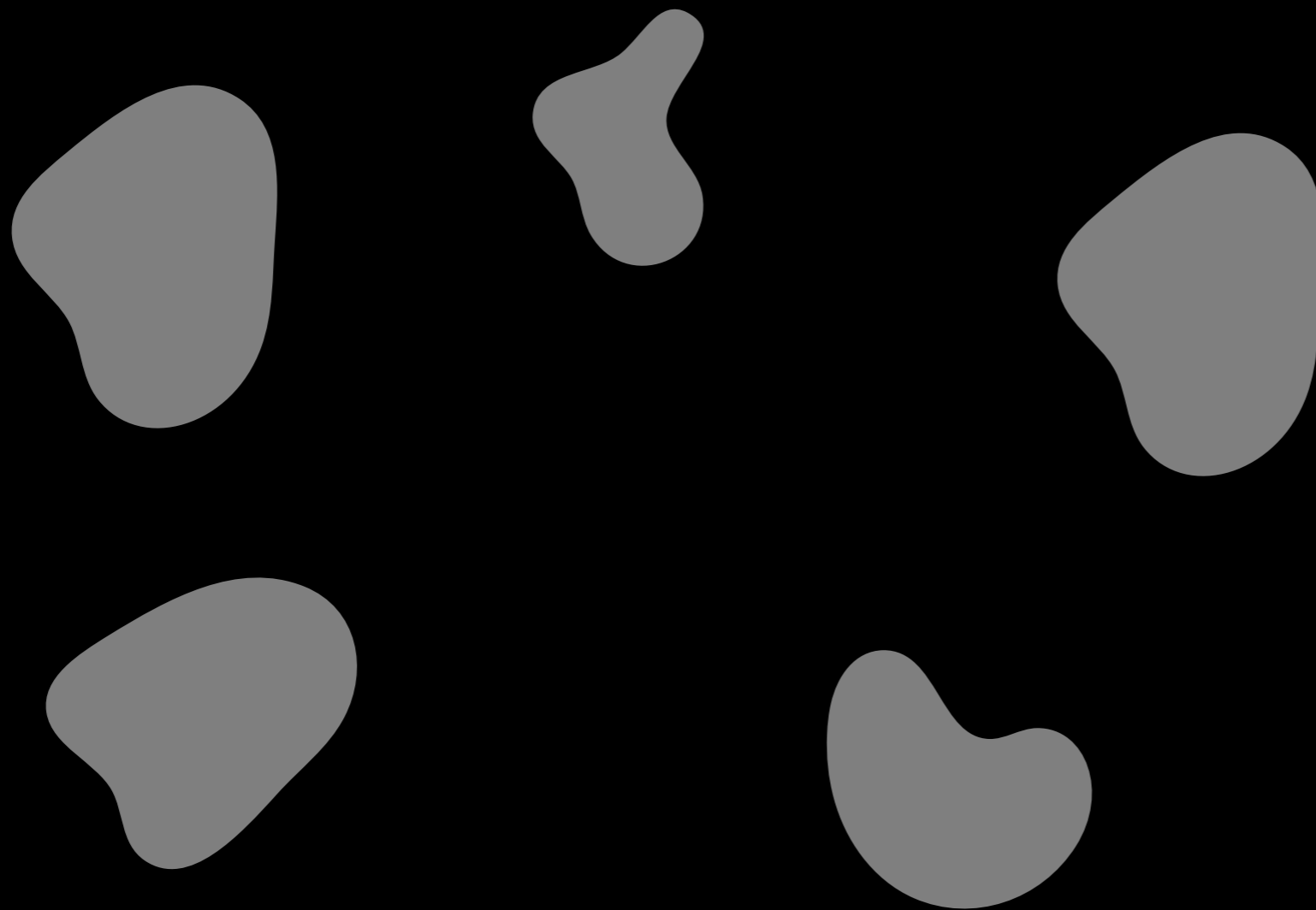


Slightly after the  
beginning...



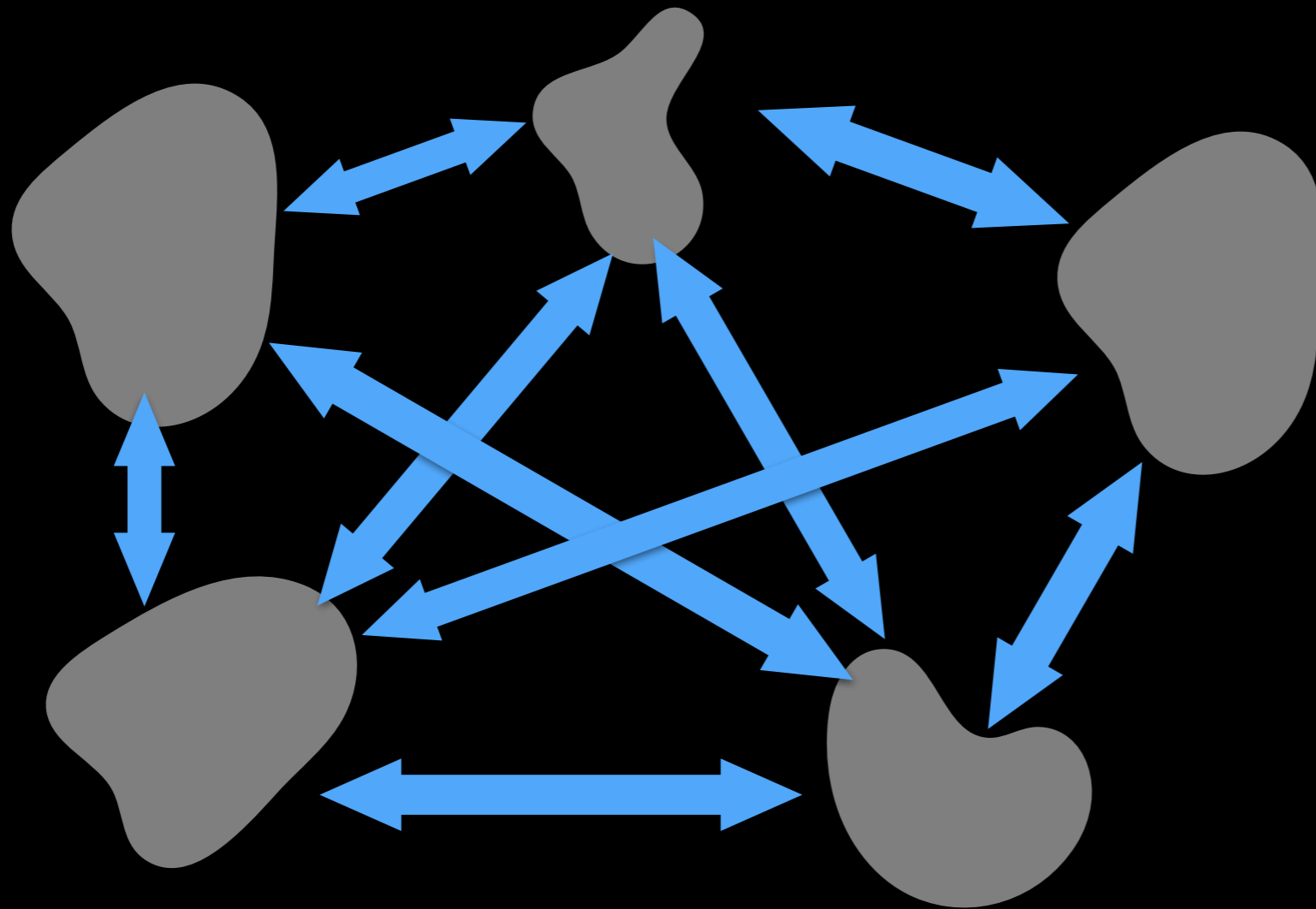
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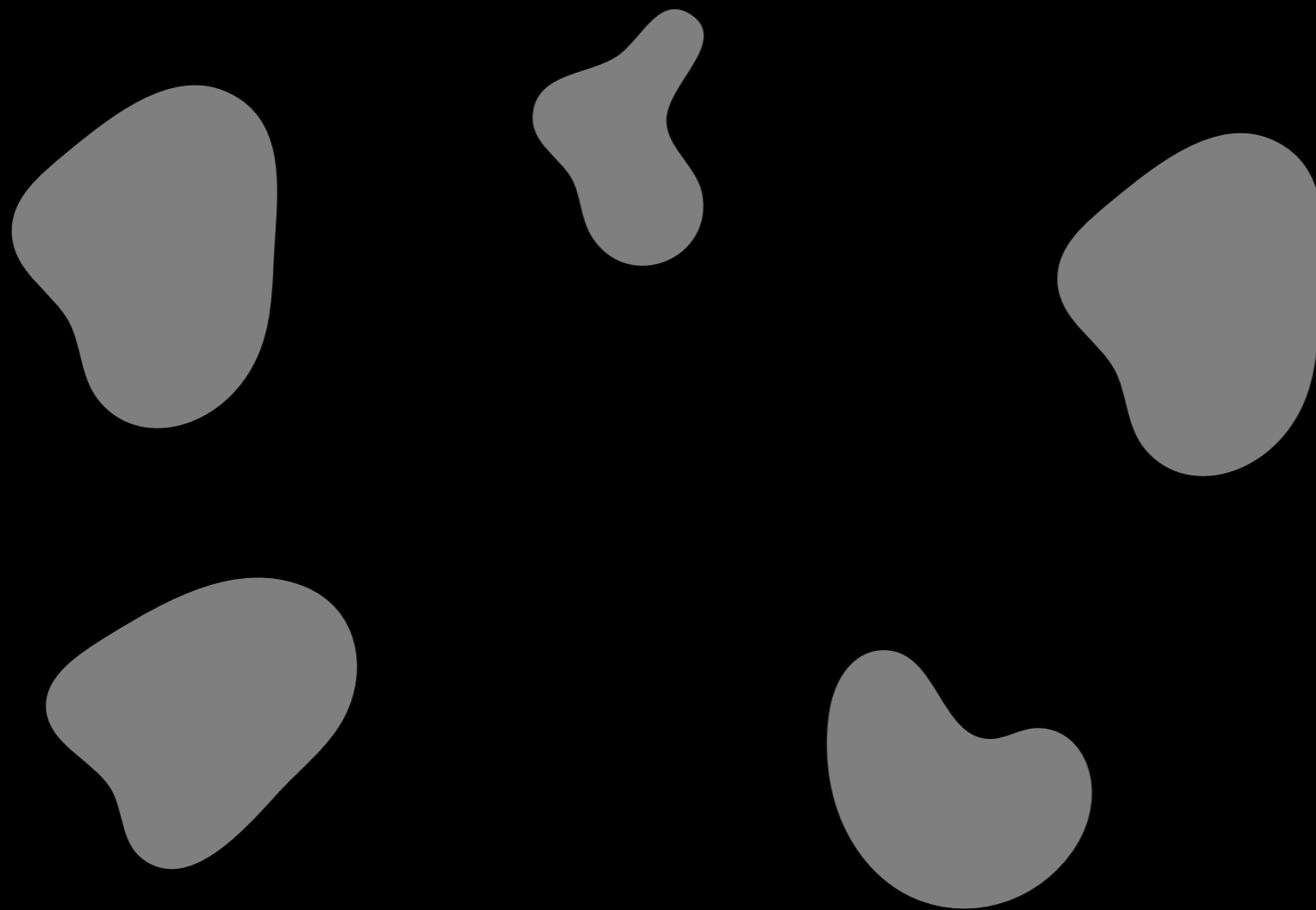
**Gravity pulls  
gas clouds  
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Slightly after the  
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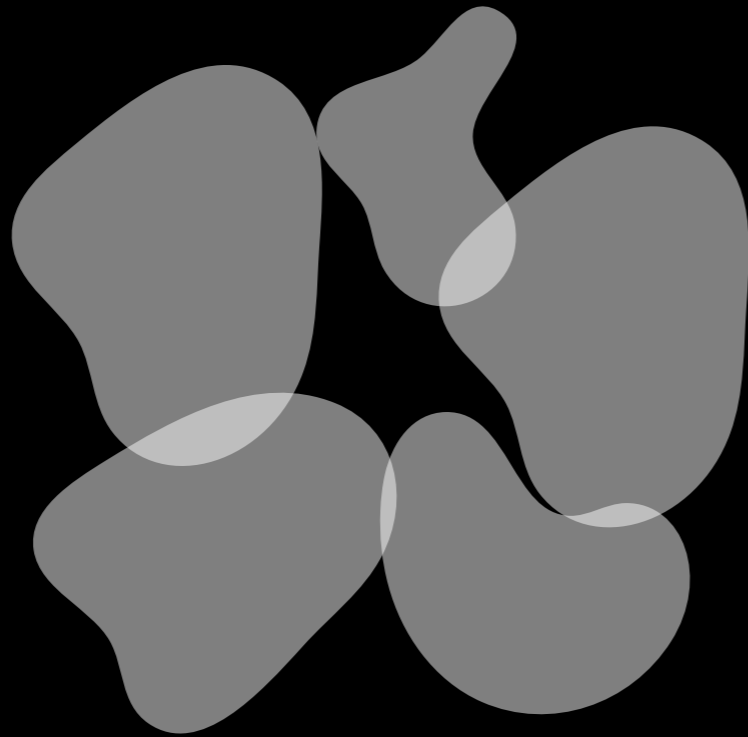
Slightly after the  
beginning...



**Gravity pulls  
gas clouds  
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Slightly after the  
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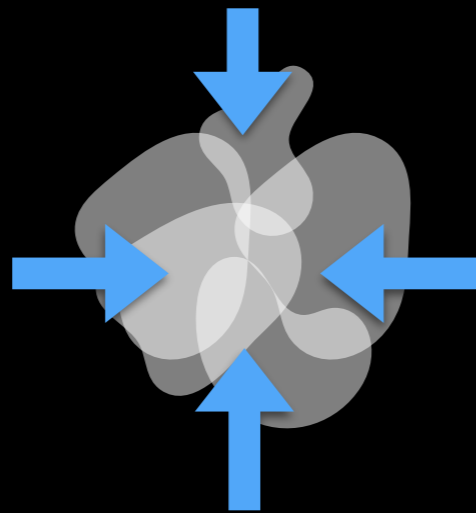
**Gas clouds  
begin to merge**

# A little later...



**Gravity  
compresses  
the cloud,  
making it  
*denser***

# A little later...



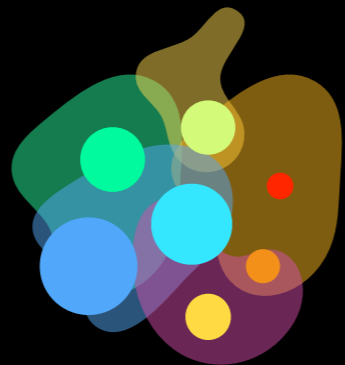
**Gravity  
compresses  
the cloud,  
making it  
*denser***

# A little later...



**Gravity  
compresses  
the cloud,  
making it  
*denser***

And then...



**Stars  
are  
born!**

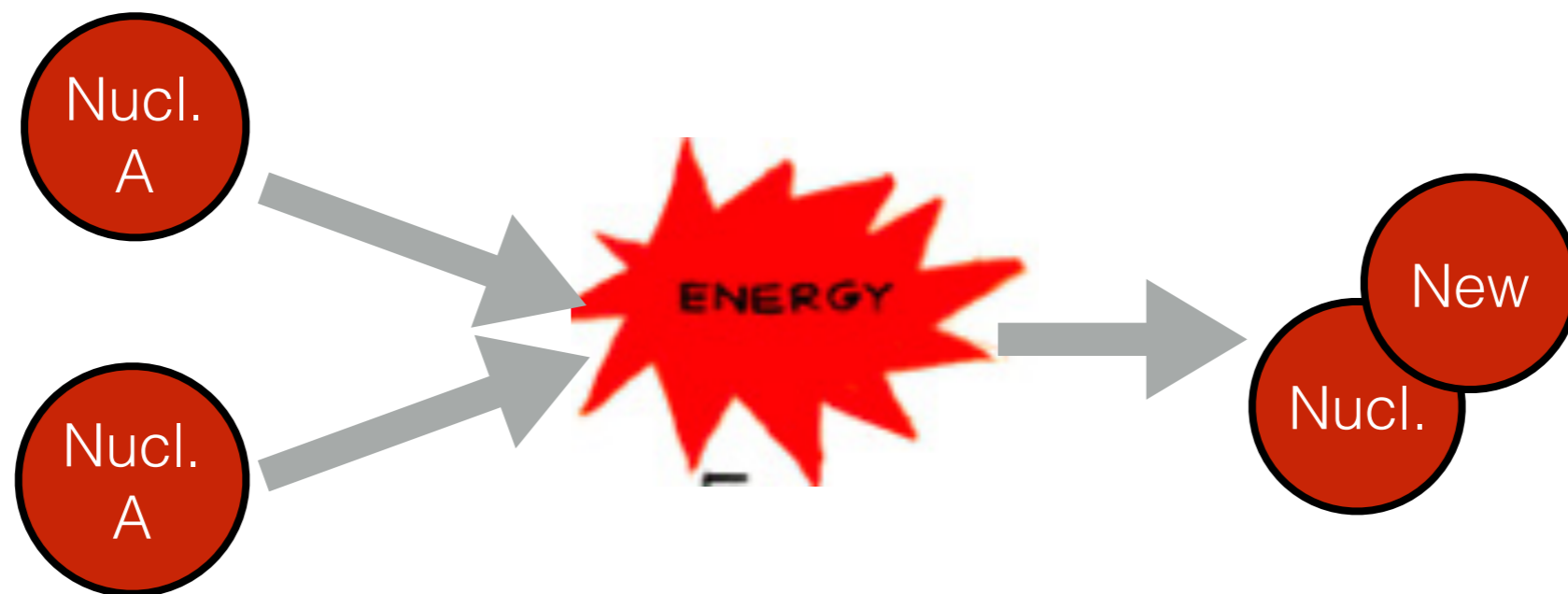


# How do stars shine?

- **Stars are dense**, so atoms are close together.
- **Stars are hot**, so atoms are flying *really fast*.
  - ➔ Atoms hit each other...**really hard!**

# How do stars shine?

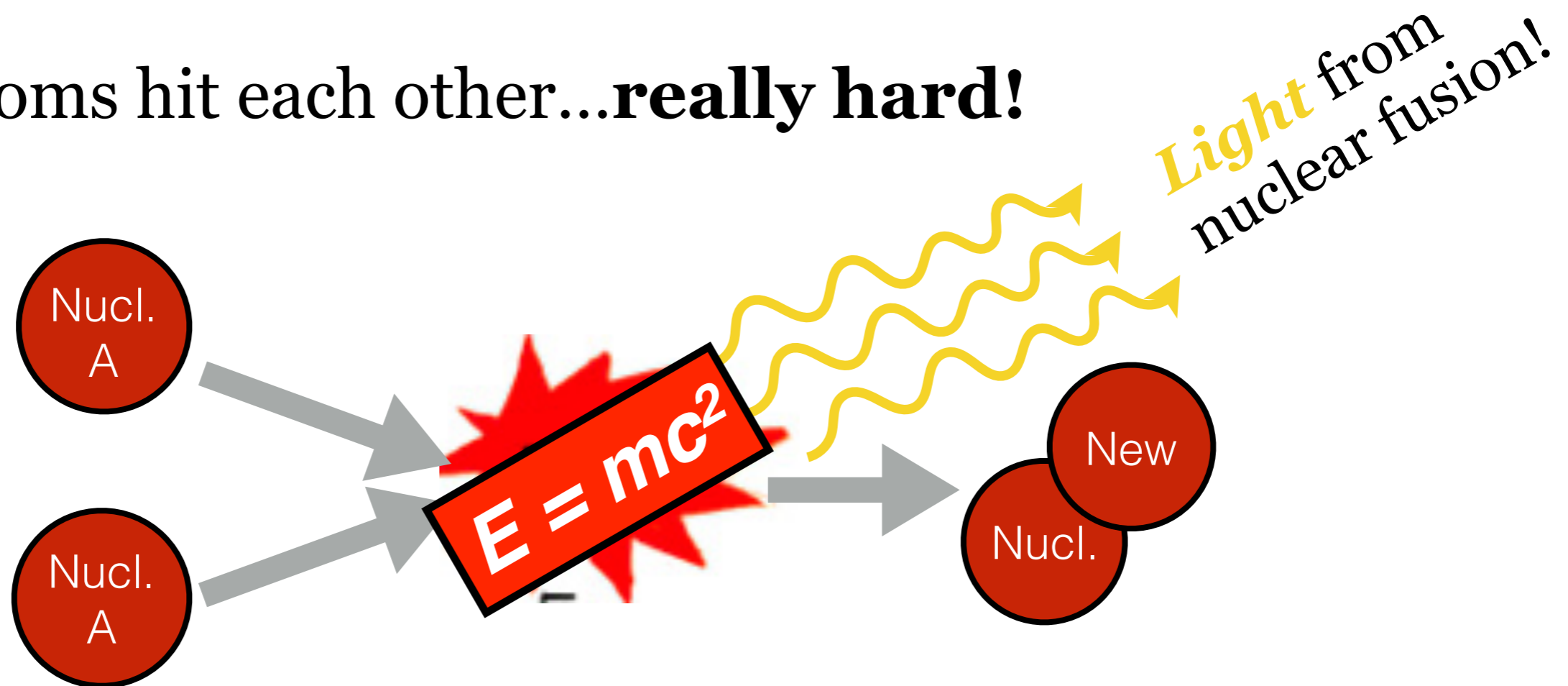
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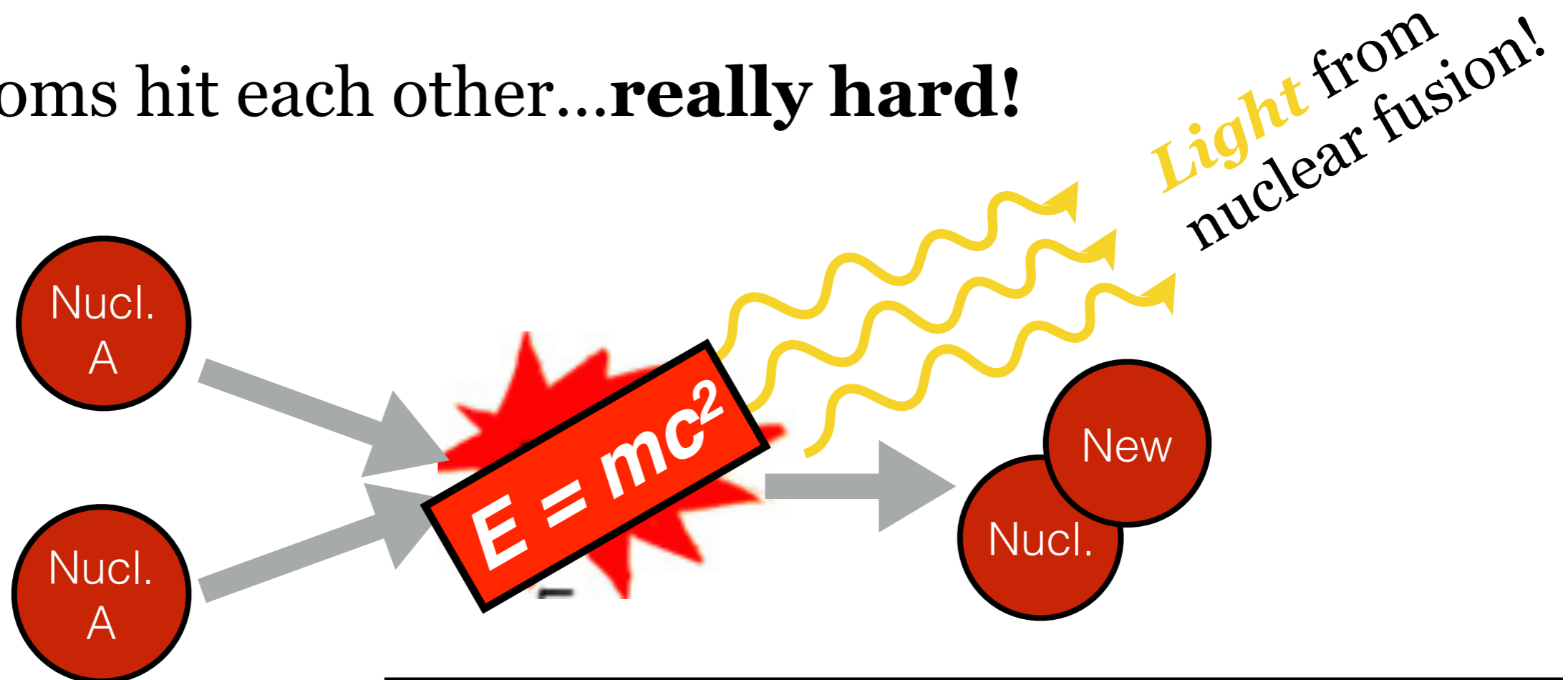
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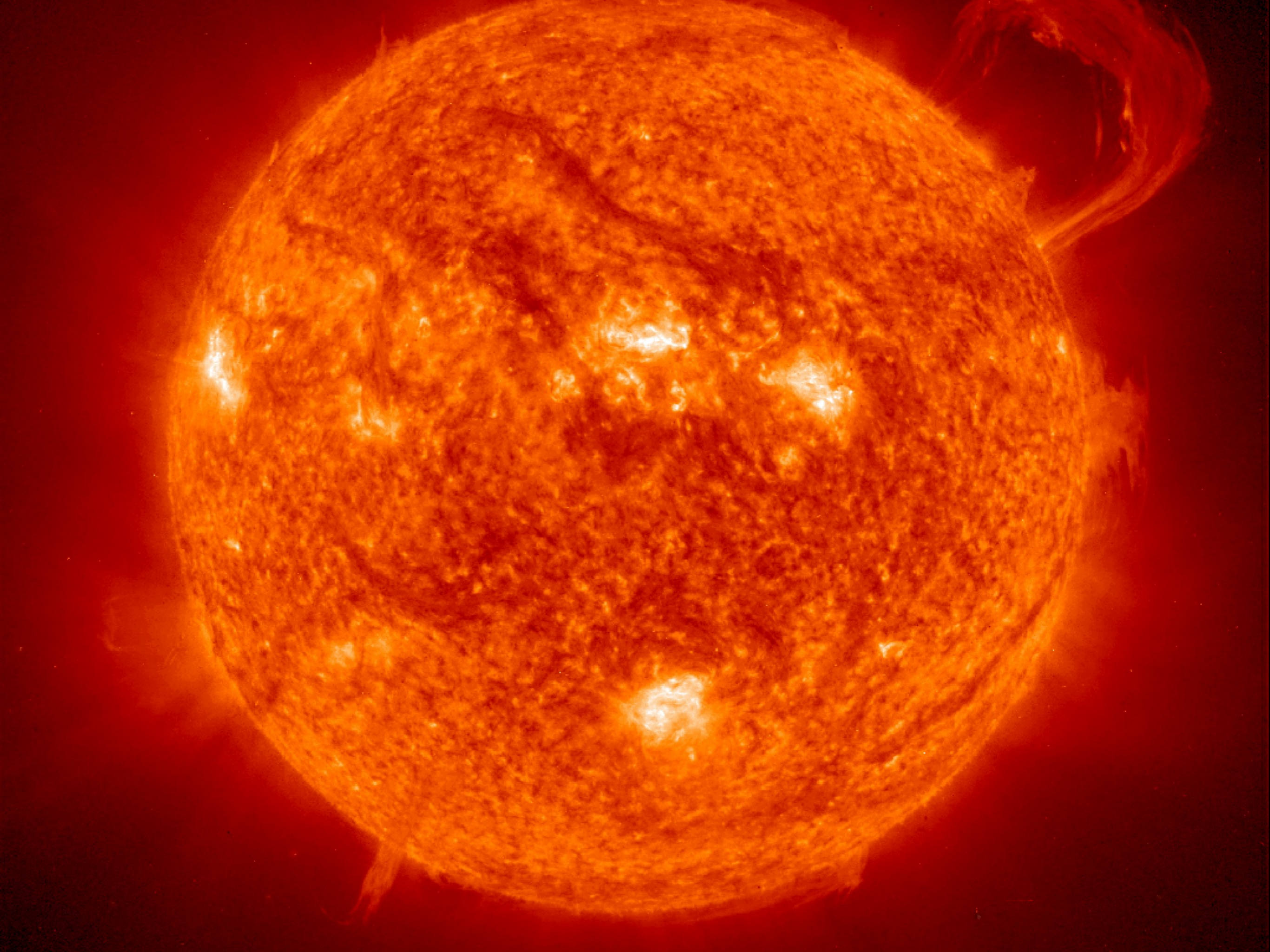
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**Figured out in 1938 by Hans Bethe**







*Let there be light*



**How do we know  
all that stuff?**



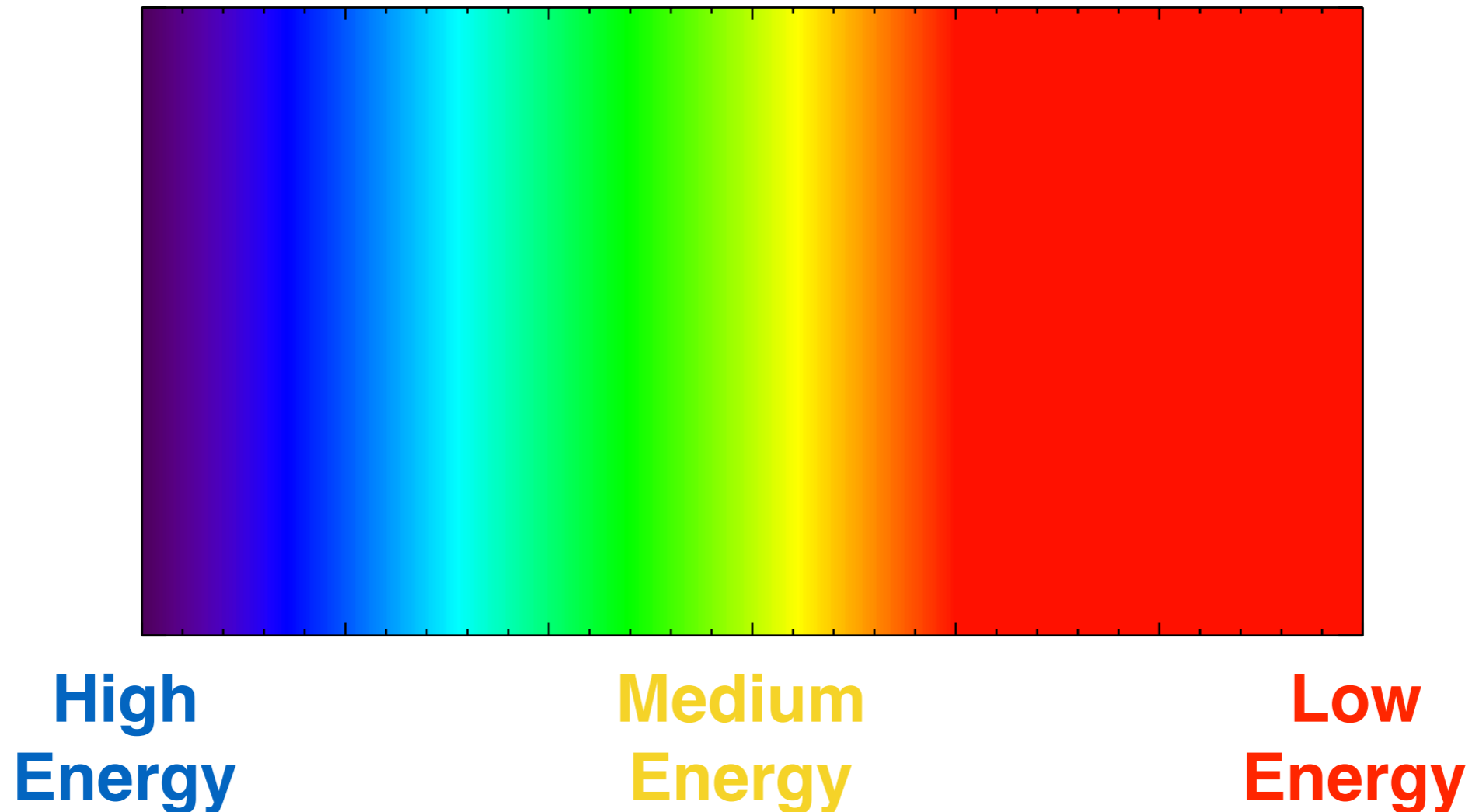




Like this.

# Rainbow power

- Light carries energy:

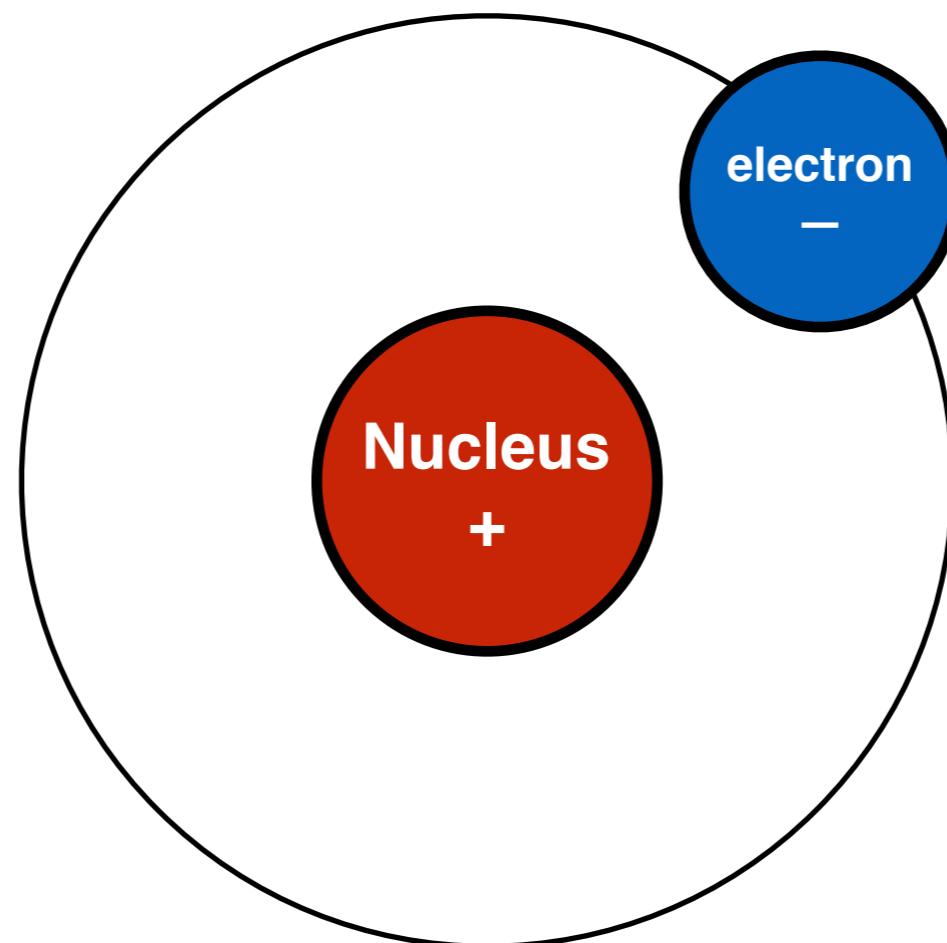


# More on atoms

- Gas is made of atoms.
- An atom is made of:

# More on atoms

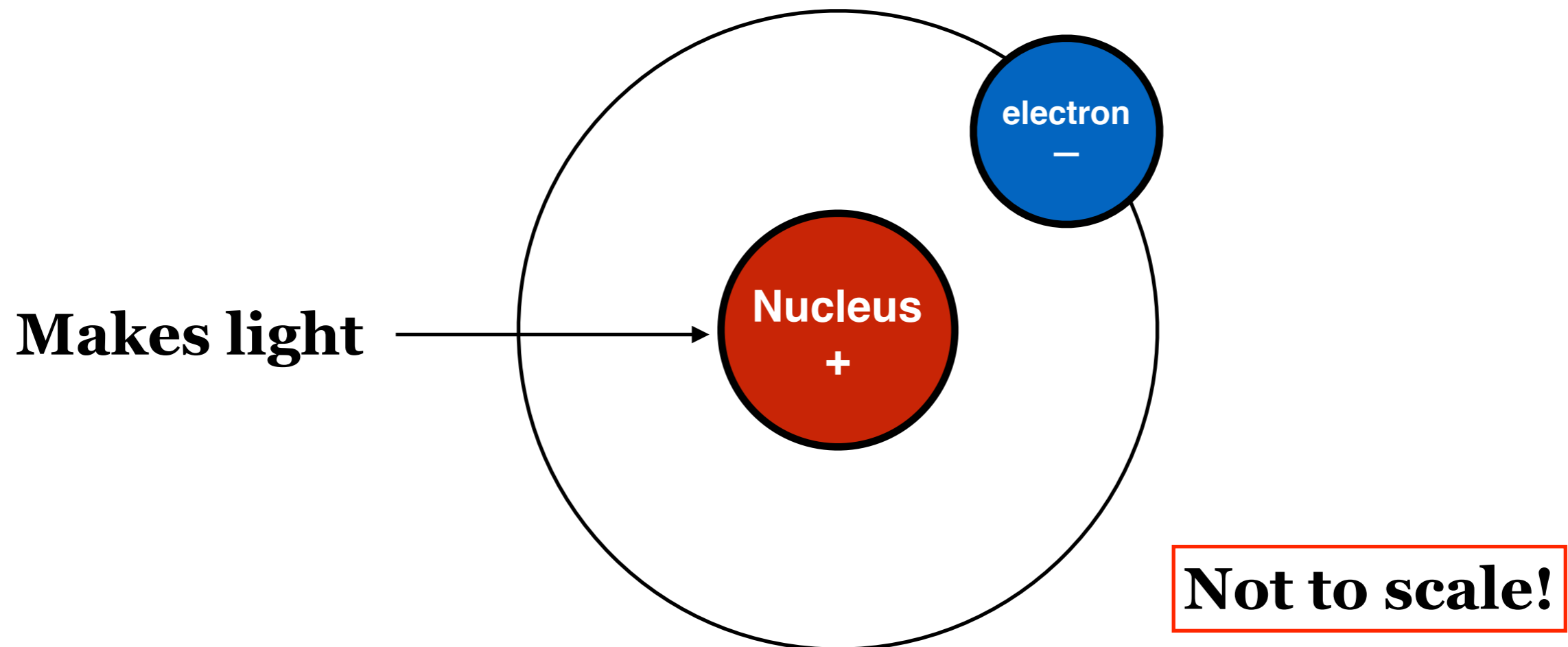
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**Not to scale!**

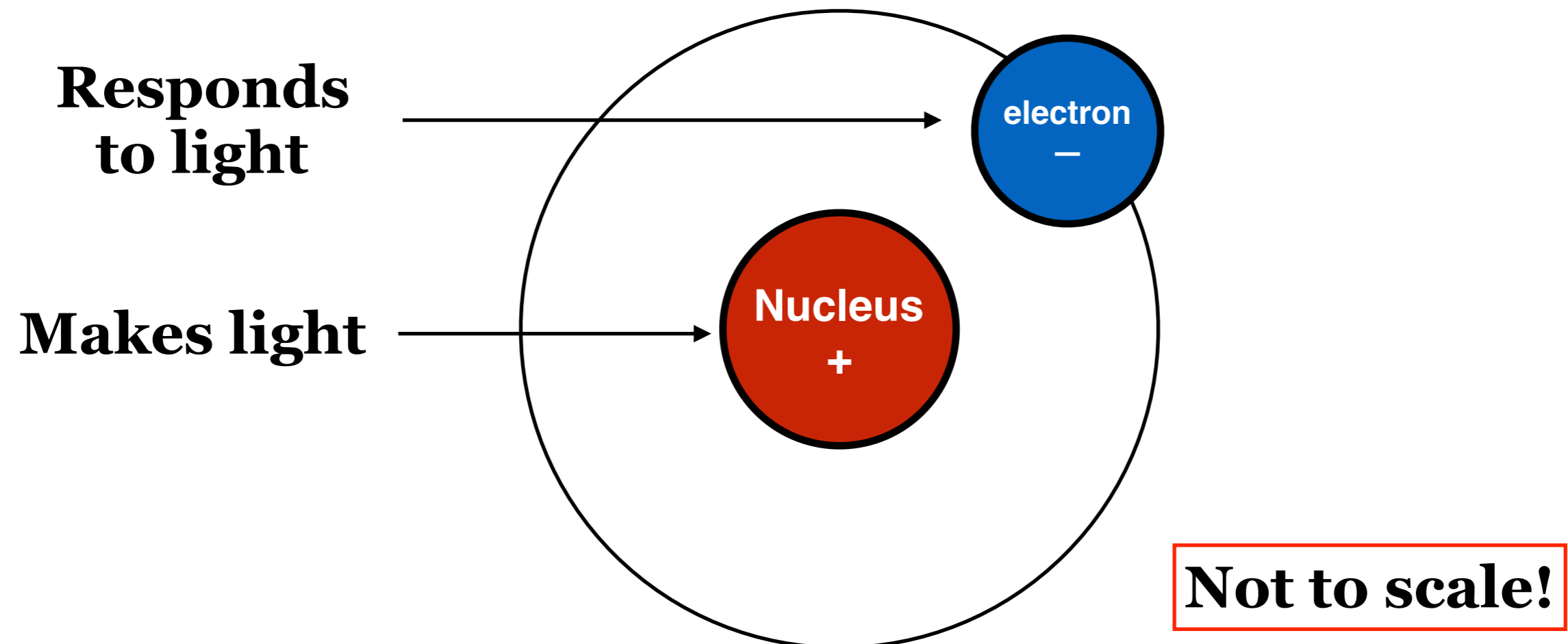
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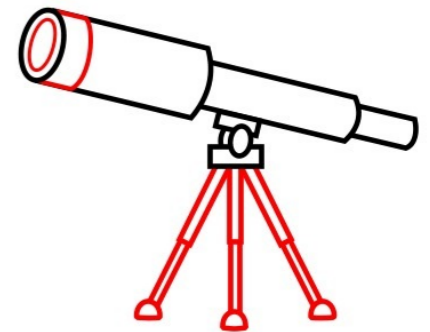
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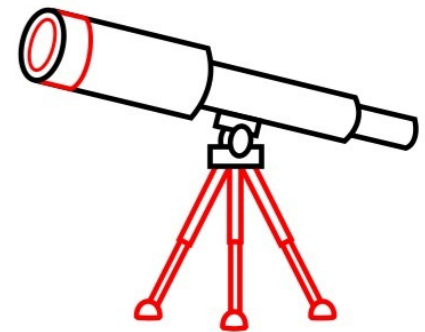
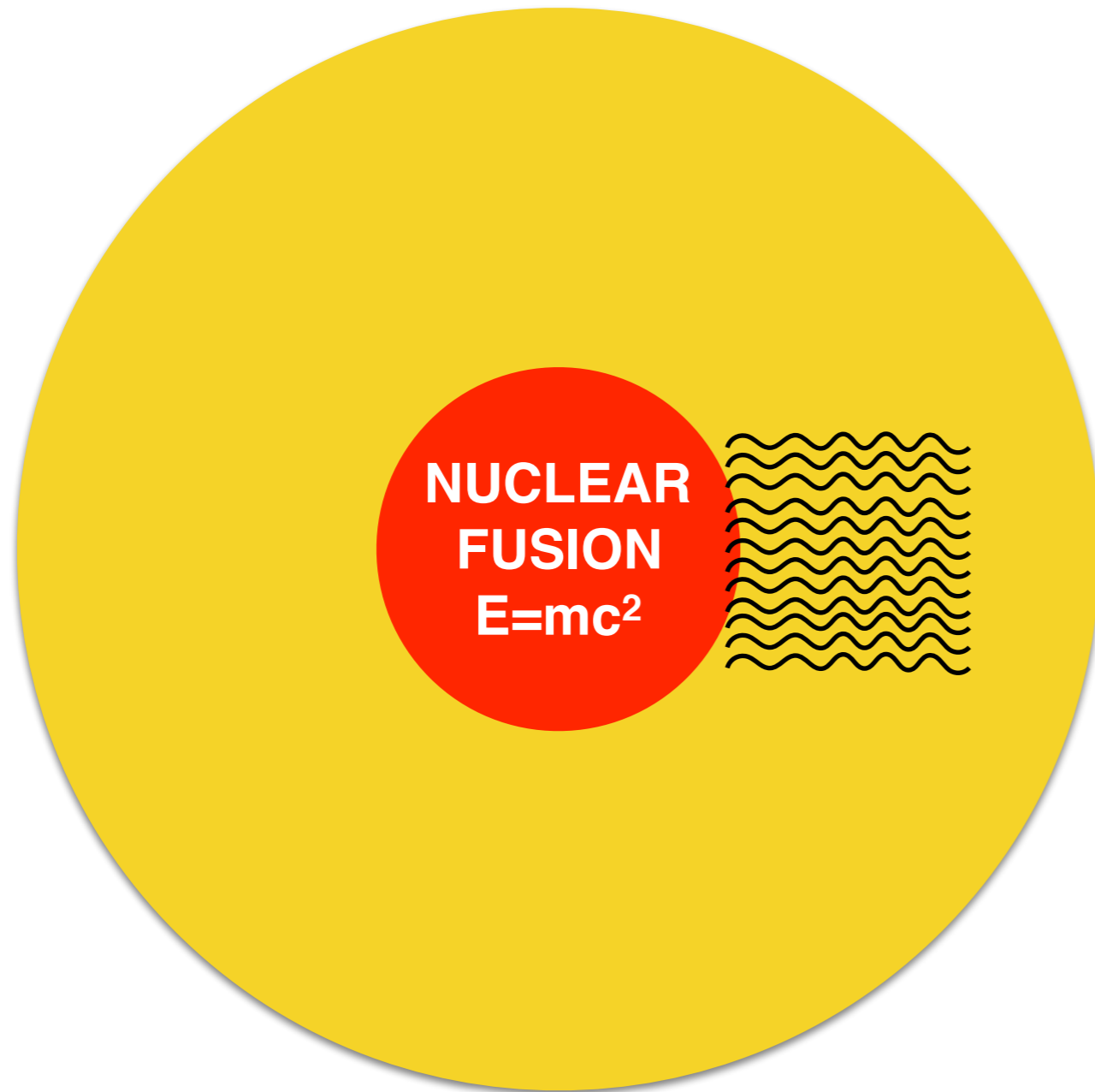


# In a star...

**NUCLEAR  
FUSION  
 $E=mc^2$**

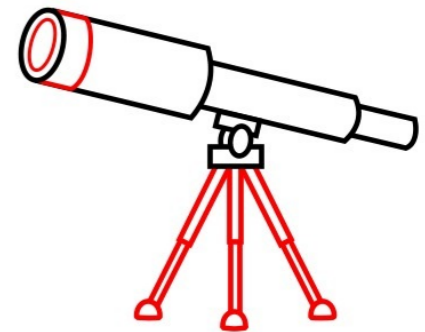
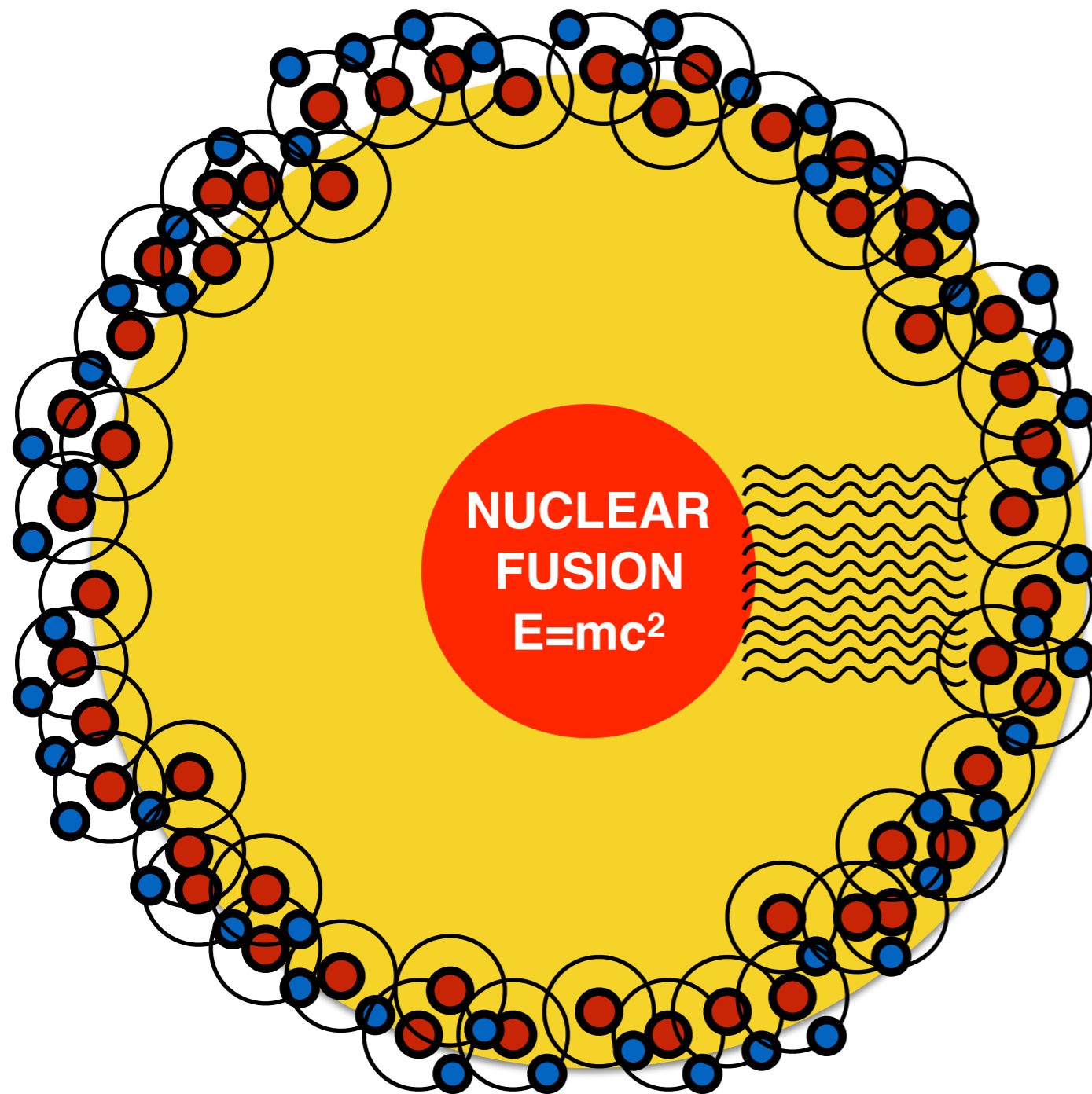


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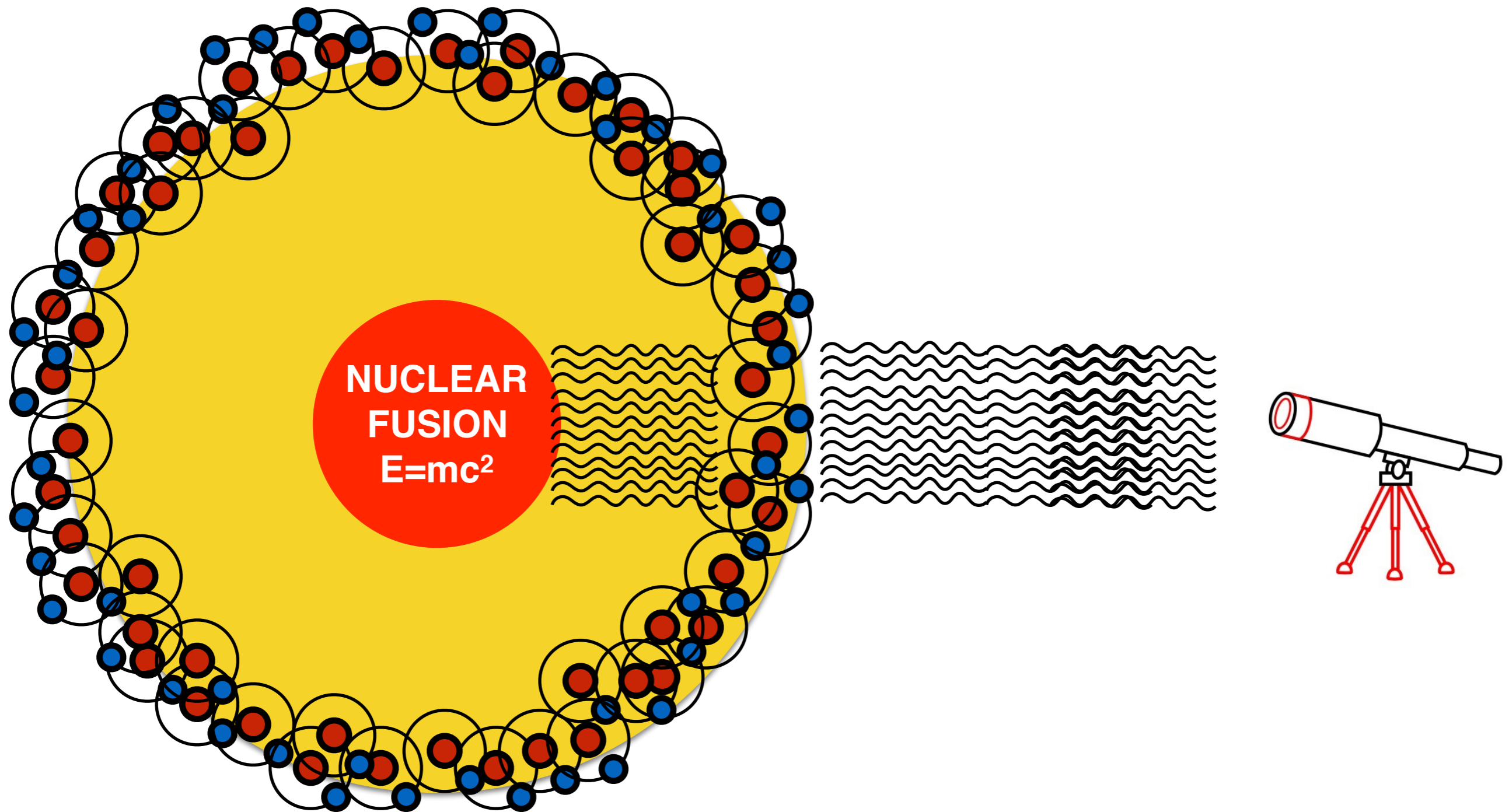




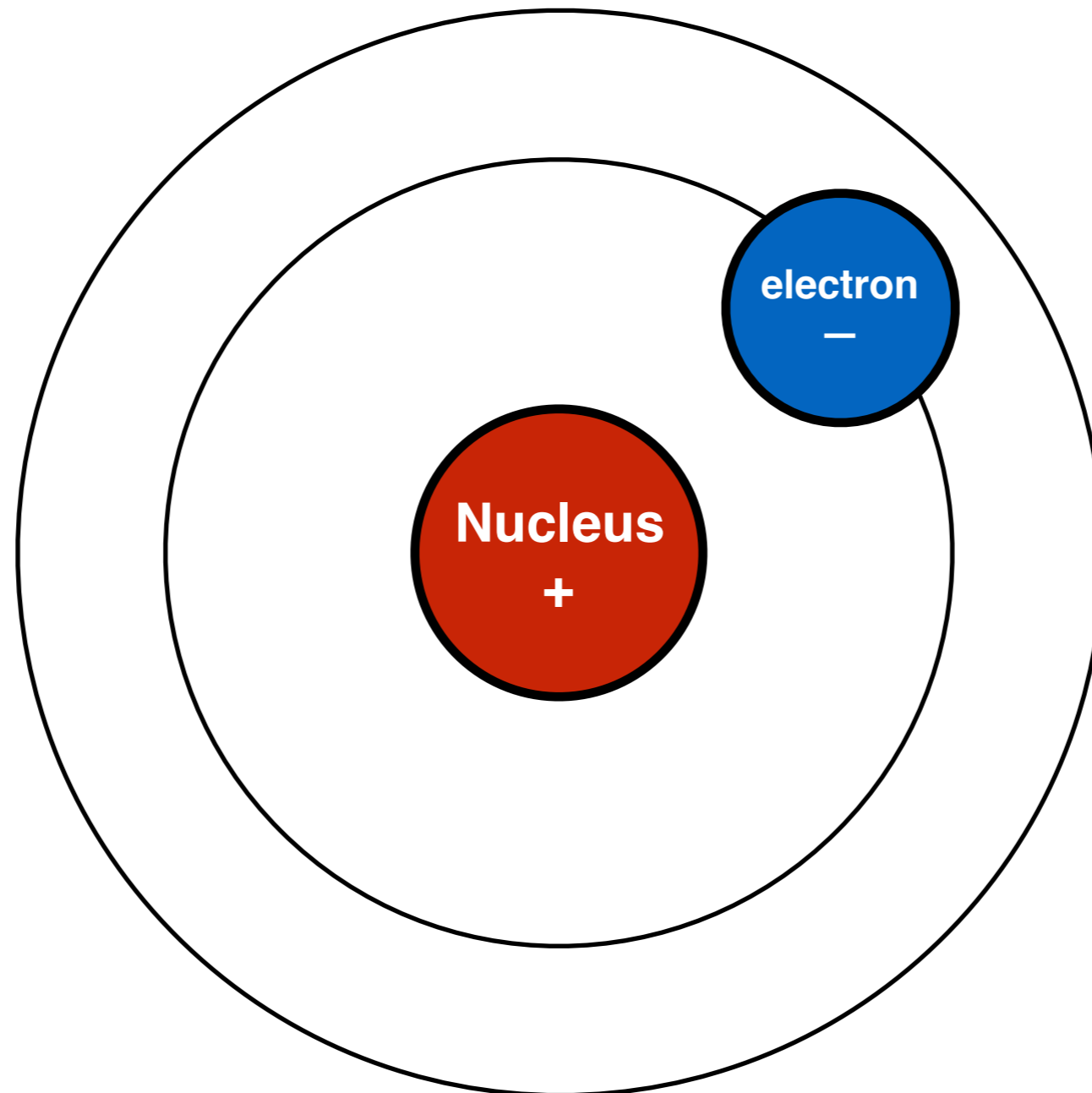
# In a star...



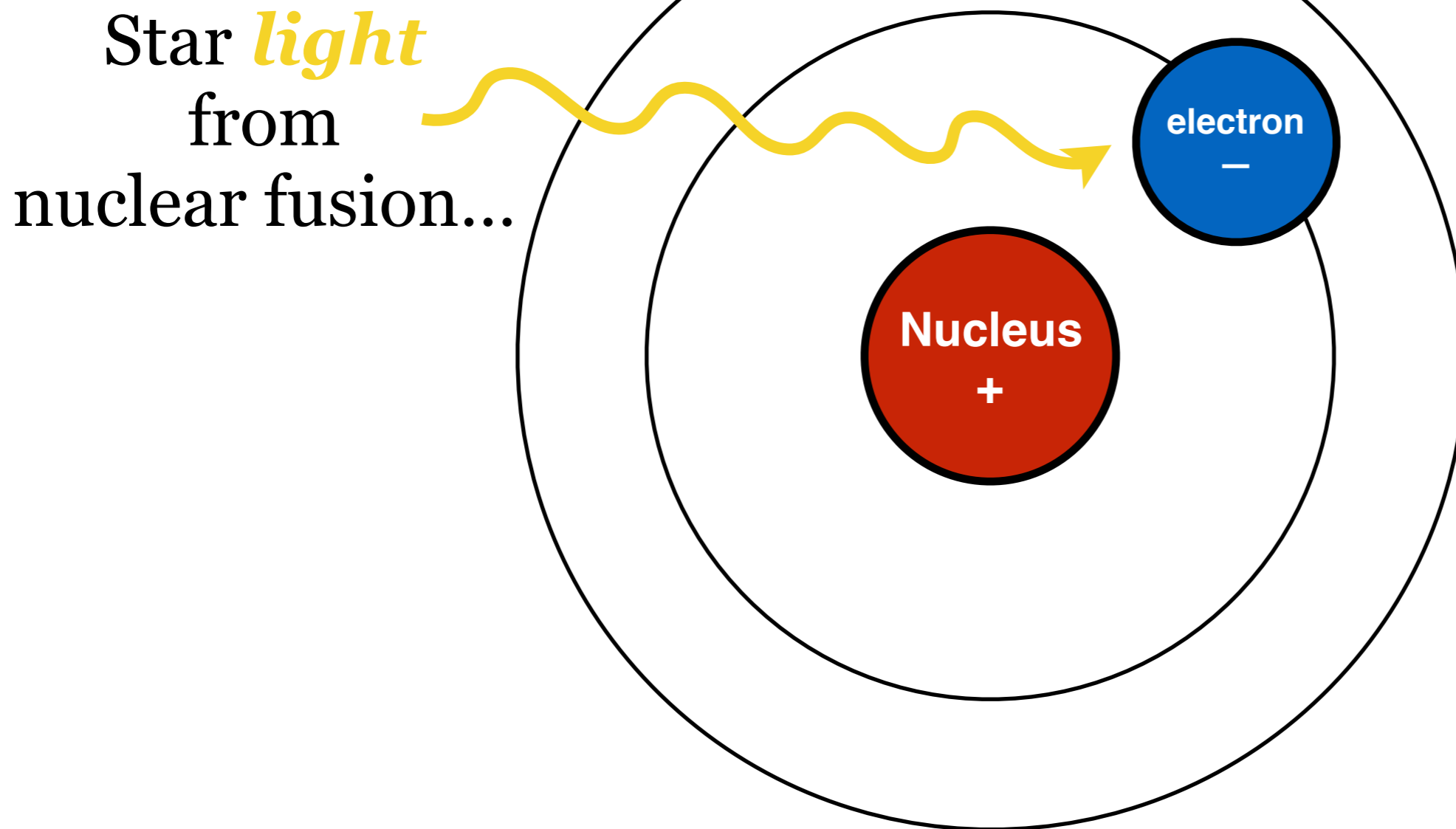
# In a star...



# More on atoms

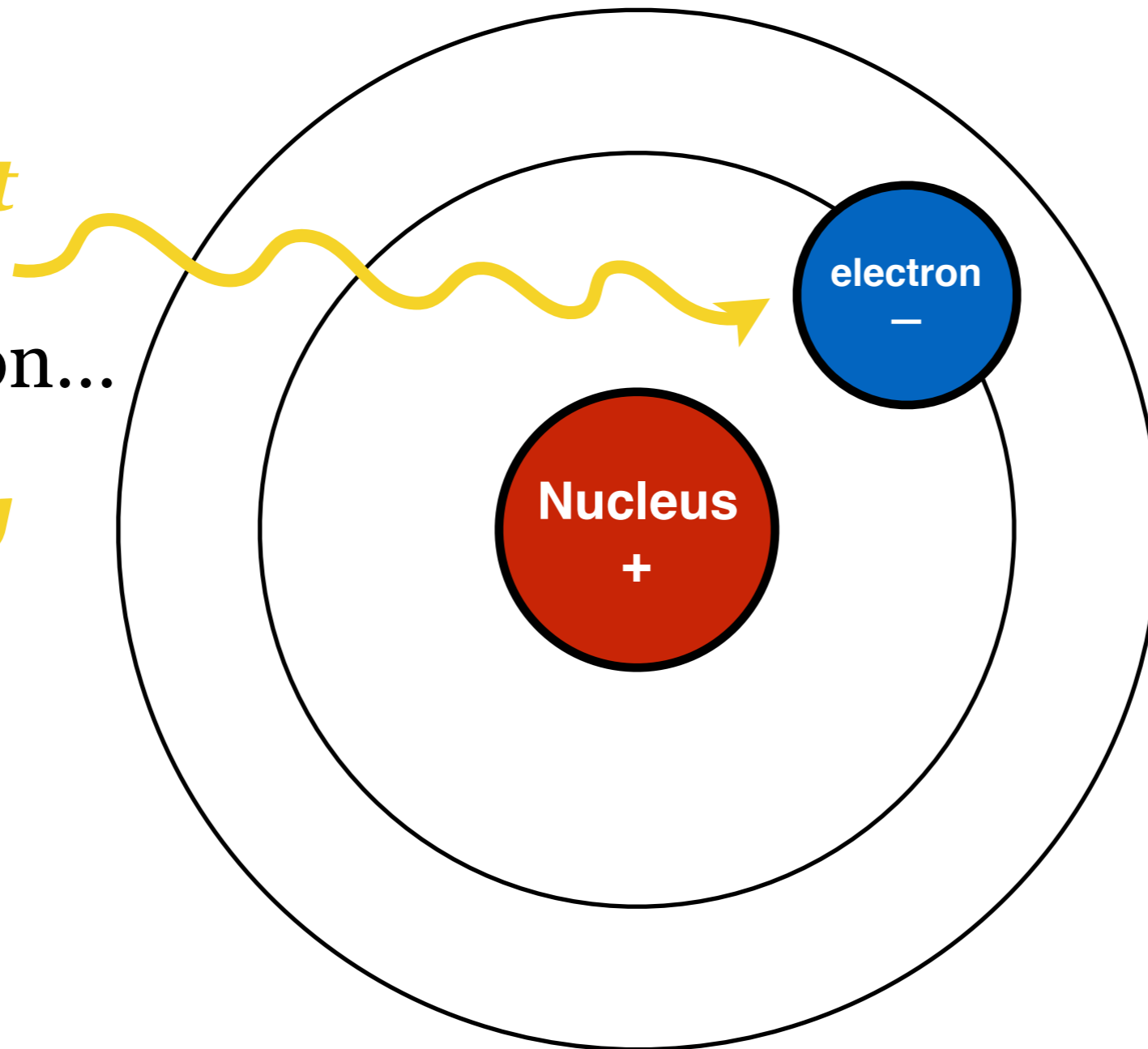


# More on atoms



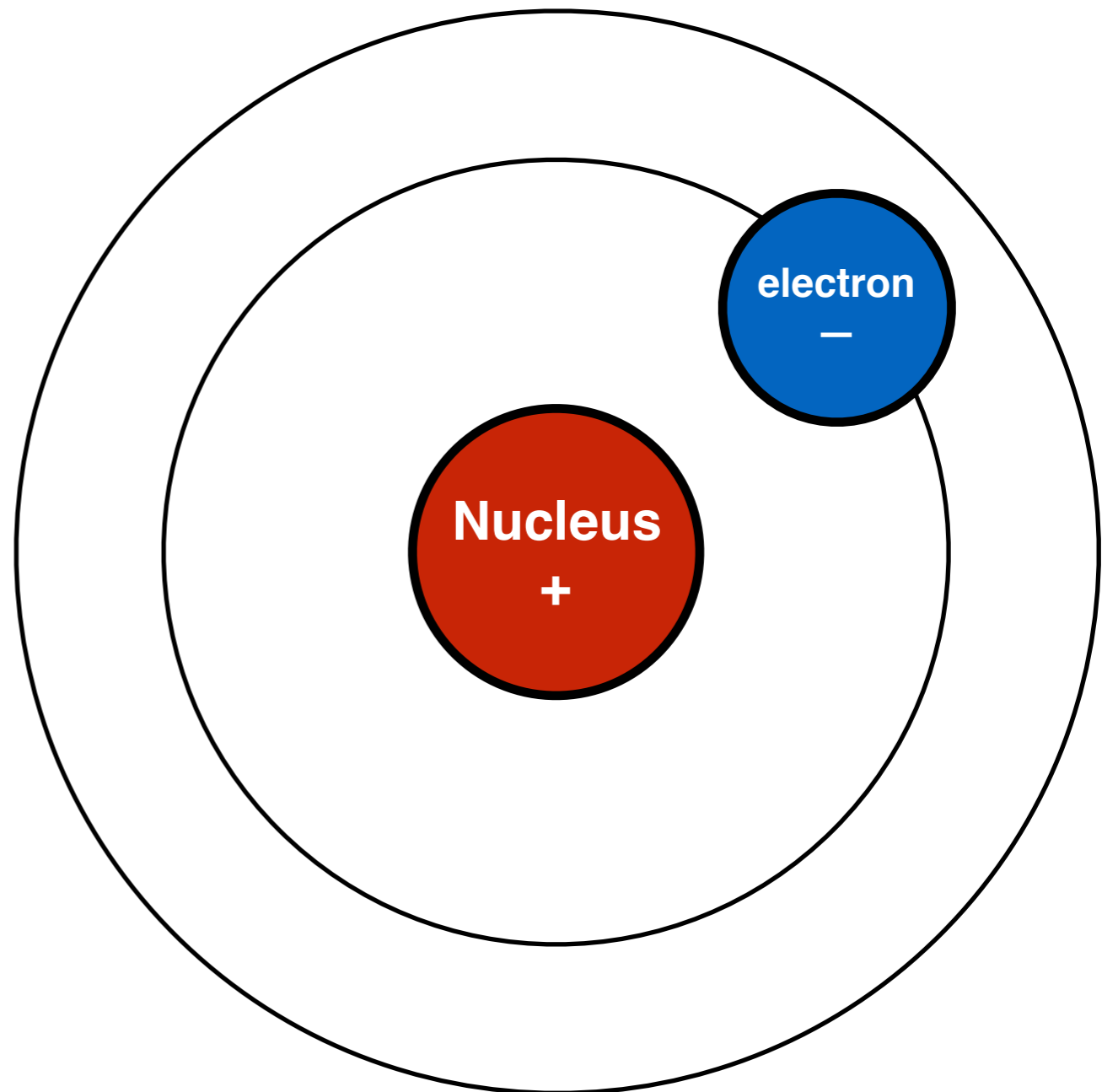
# More on atoms

Star *light*  
from  
nuclear fusion...  
  
= *energy*



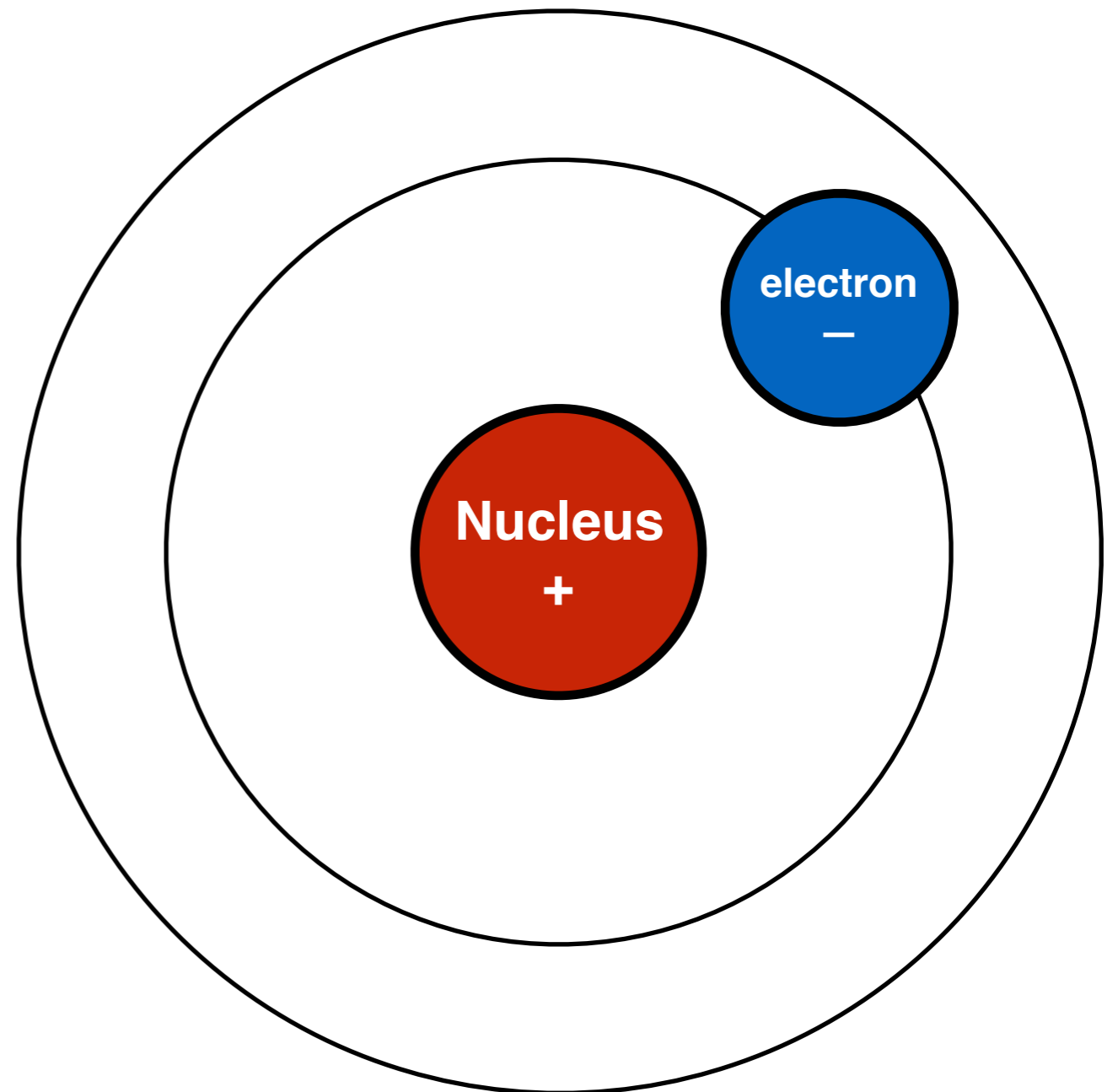
# Atoms & light

- Electron “orbits” have specific energies



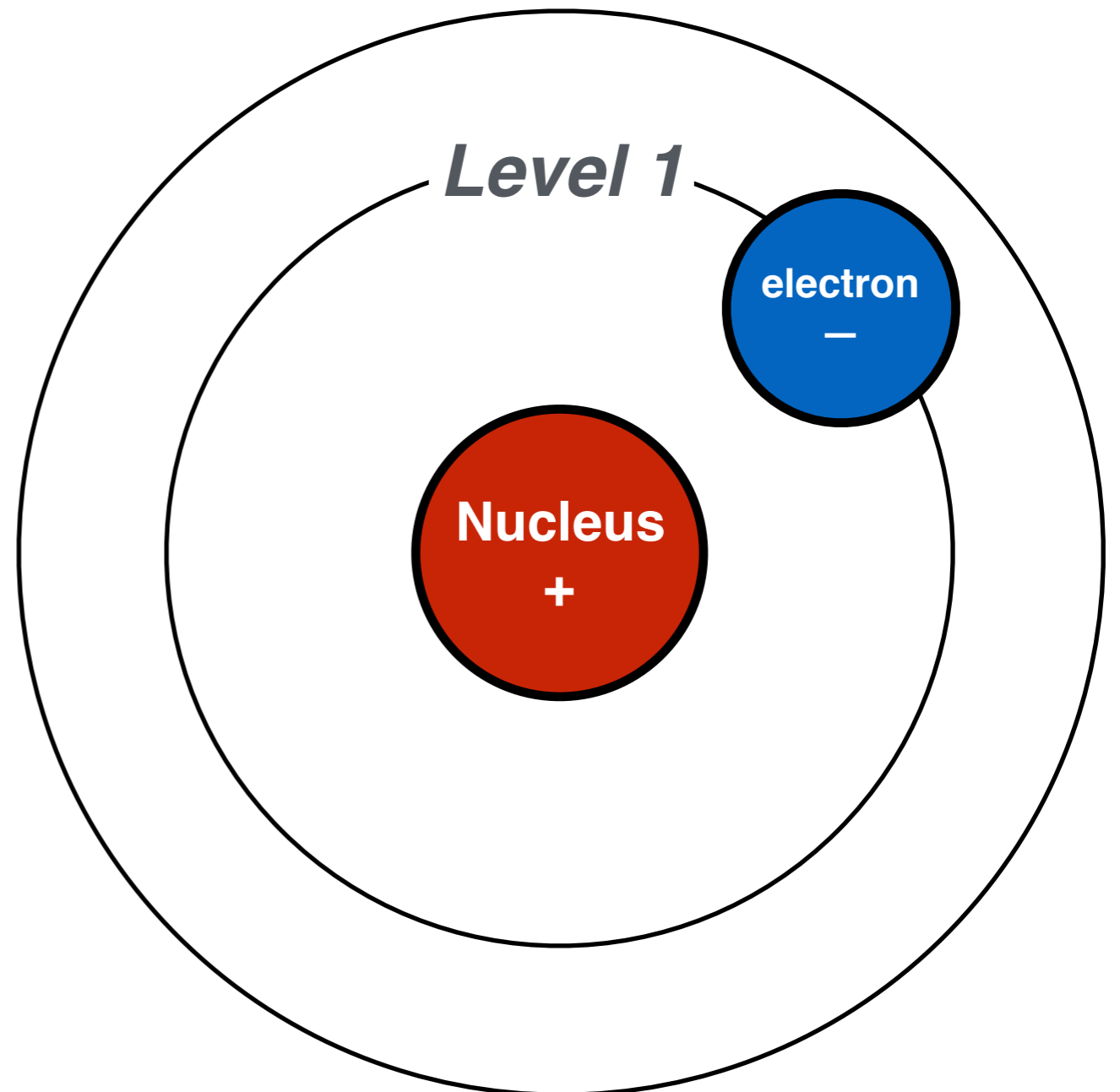
# Atoms & light

- Electron “orbits” have specific energies
- Separated like stairs on a staircase.



# Atoms & light

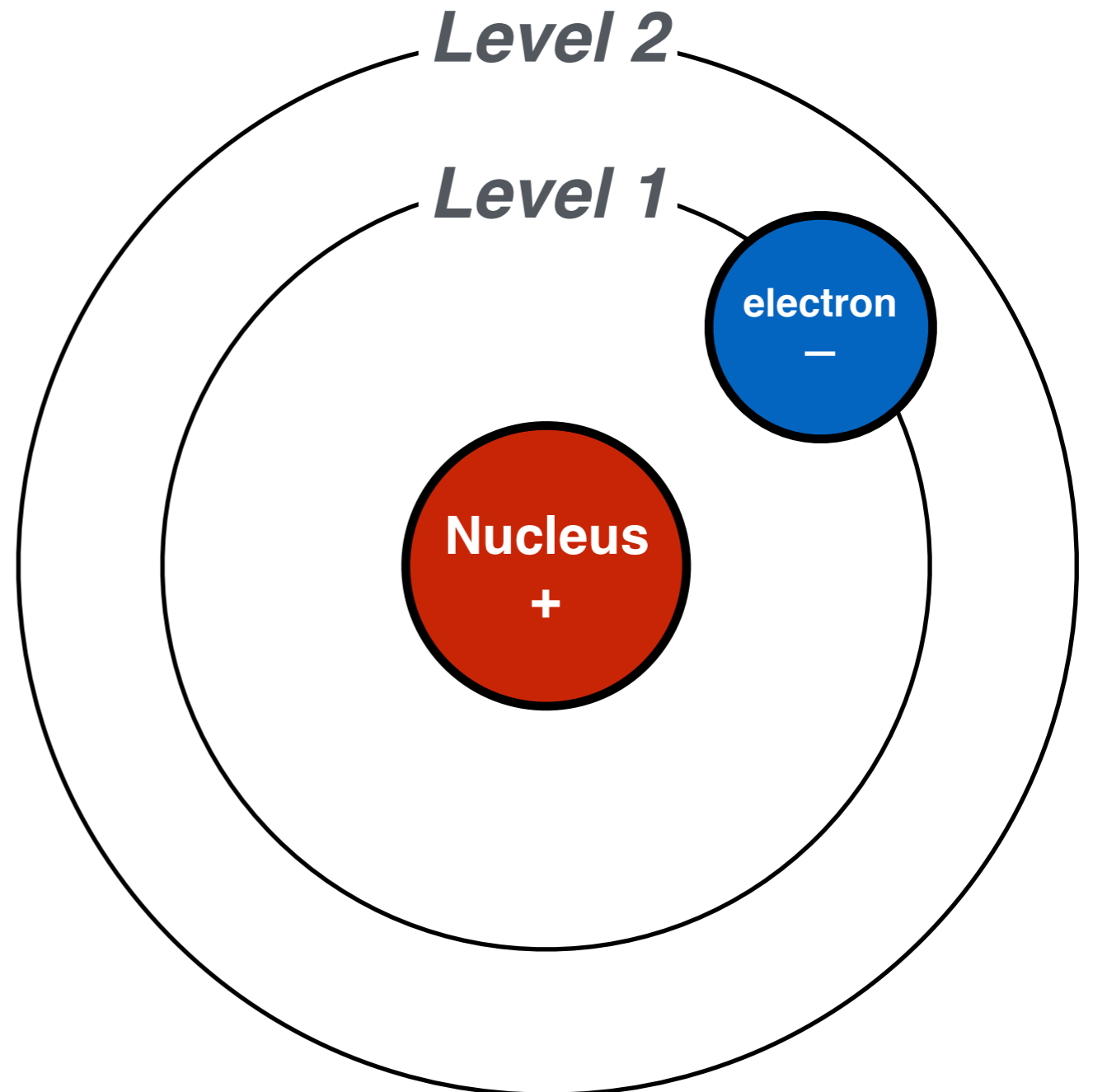
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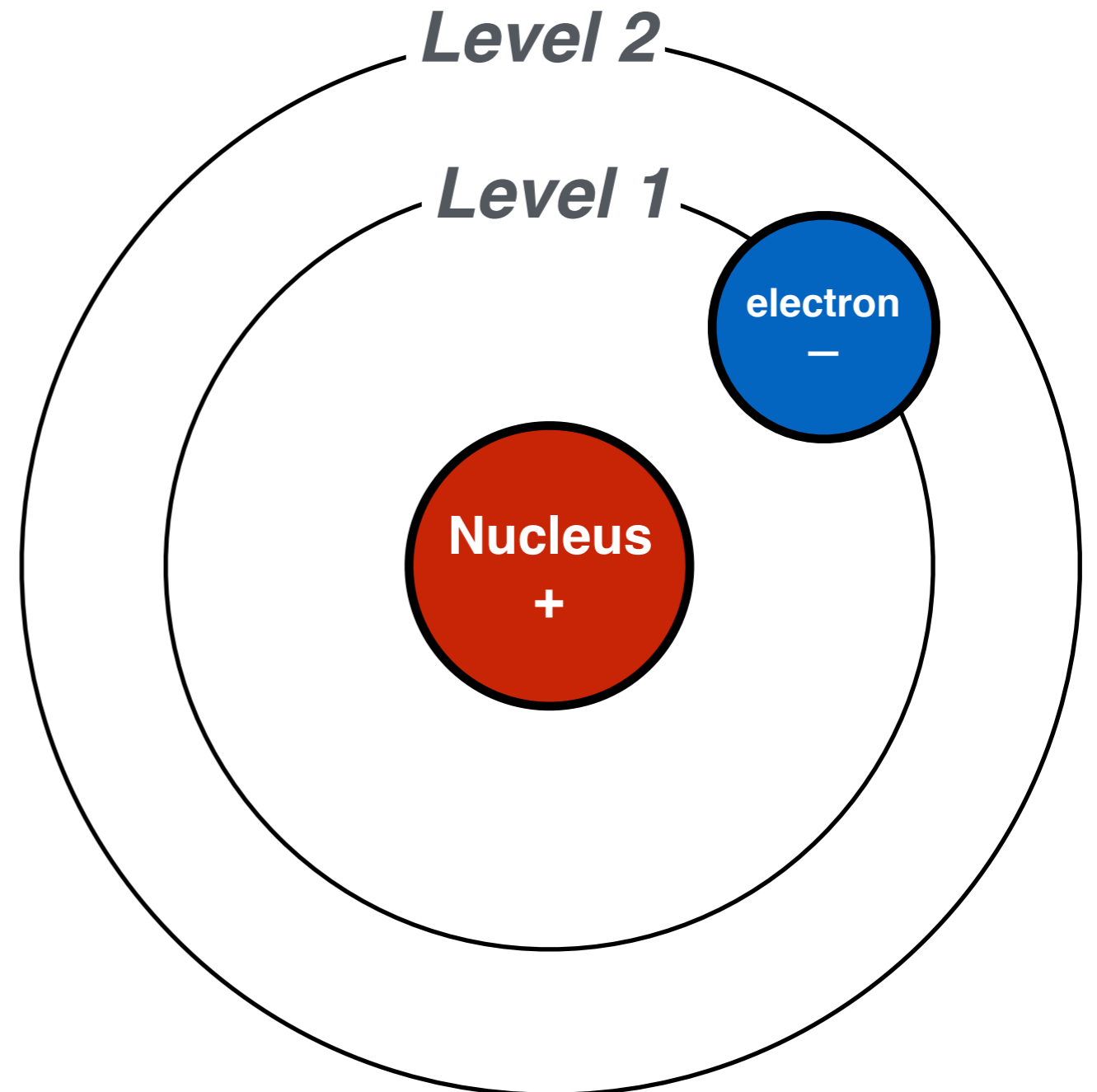
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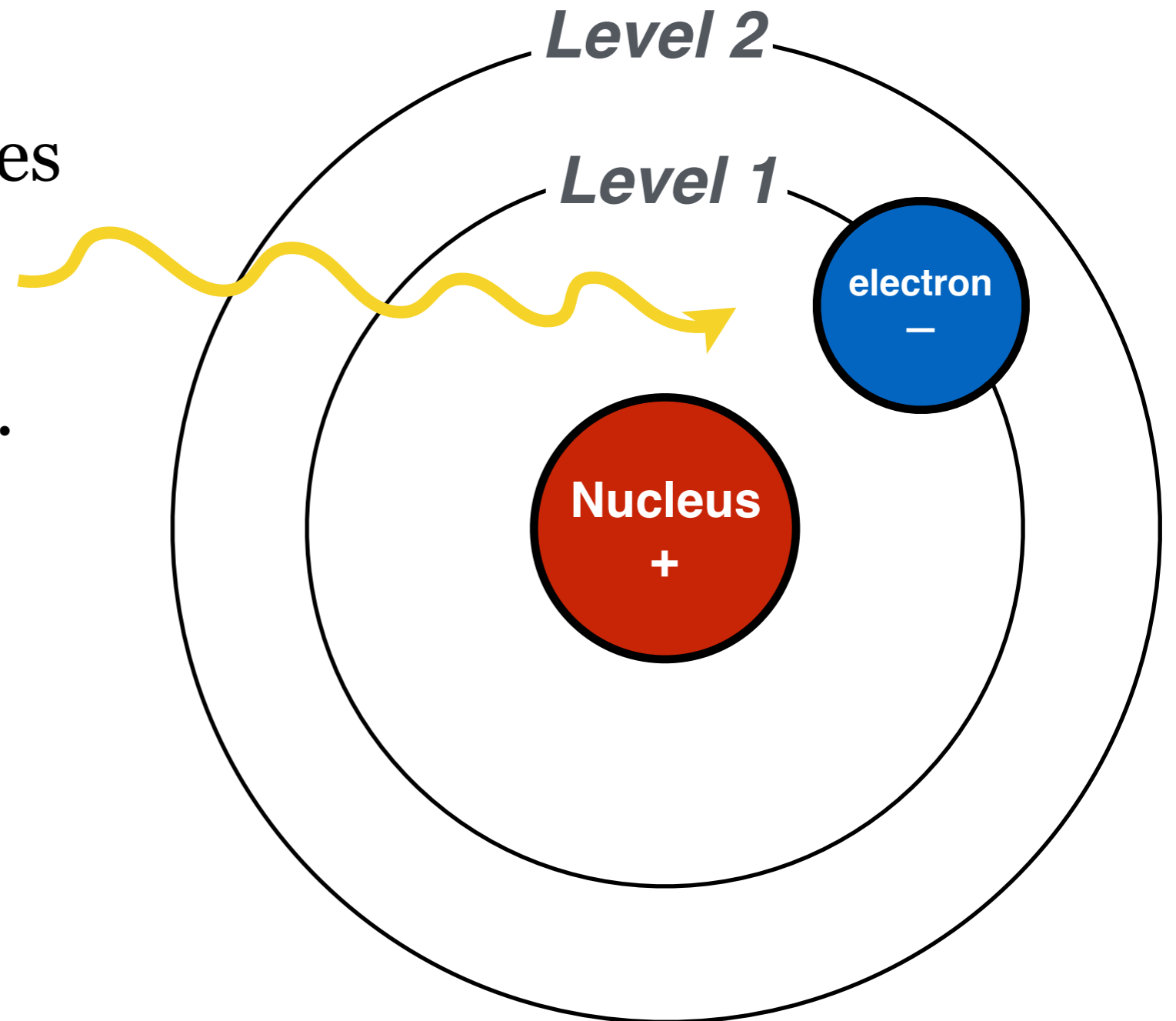
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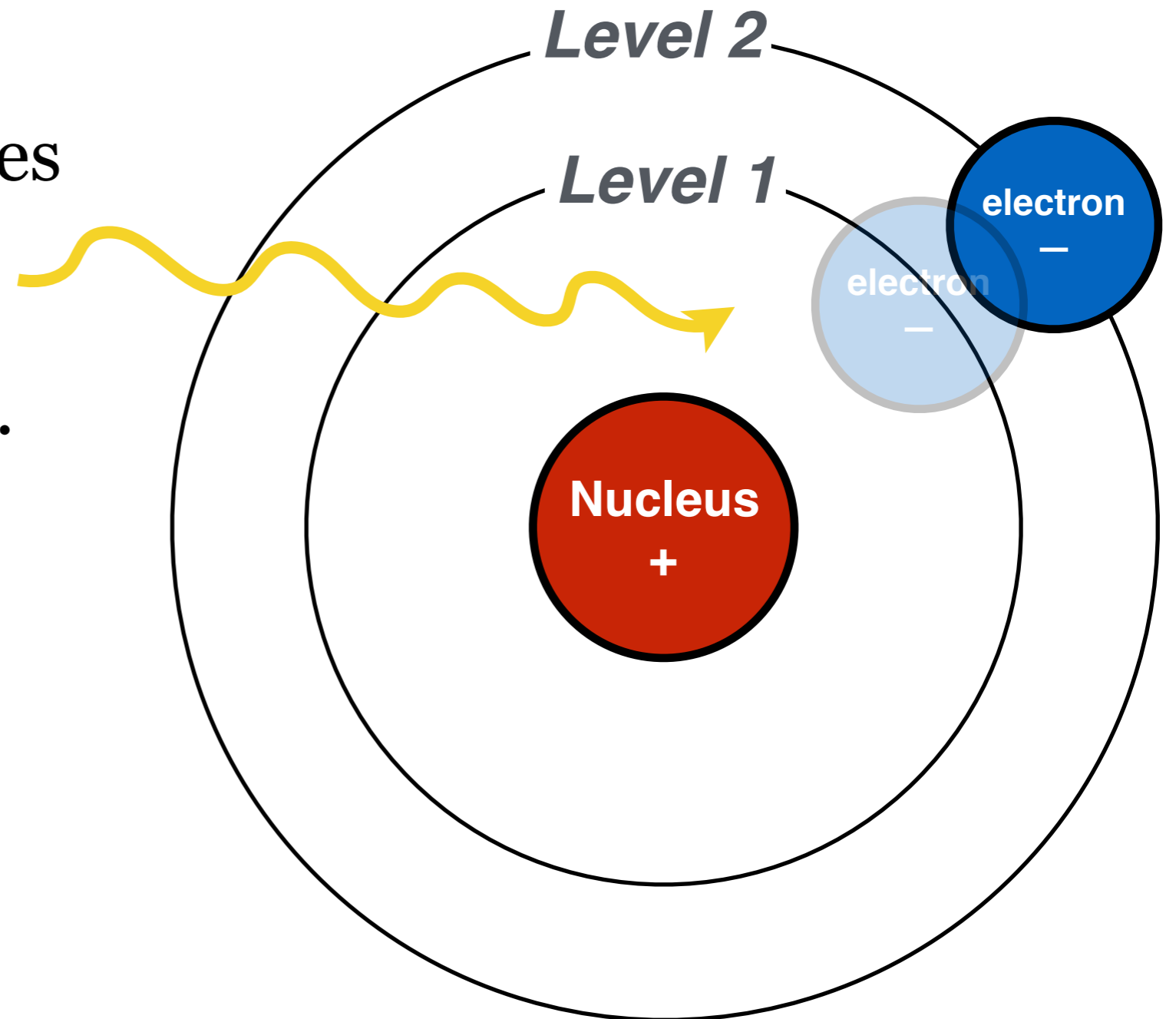
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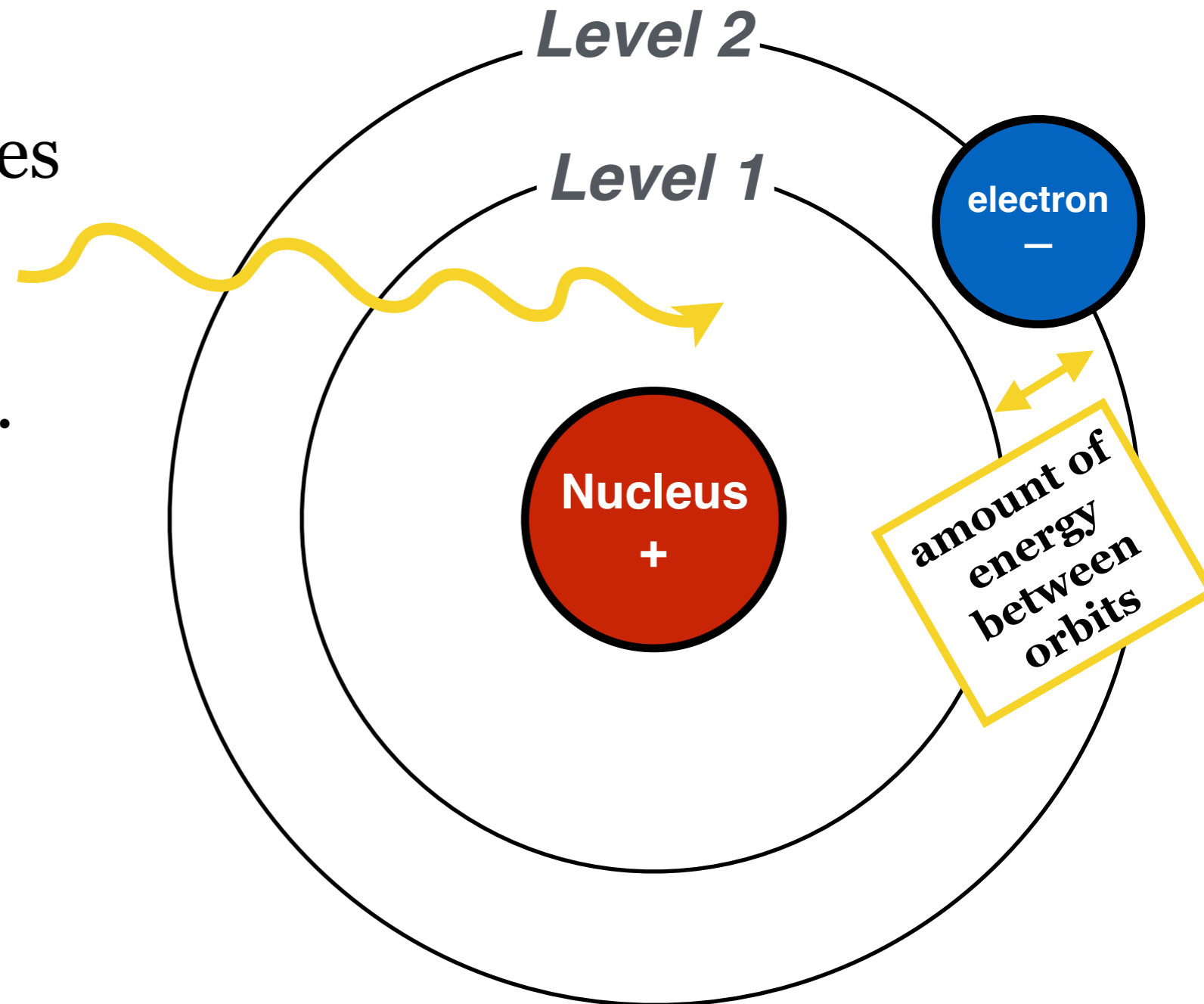
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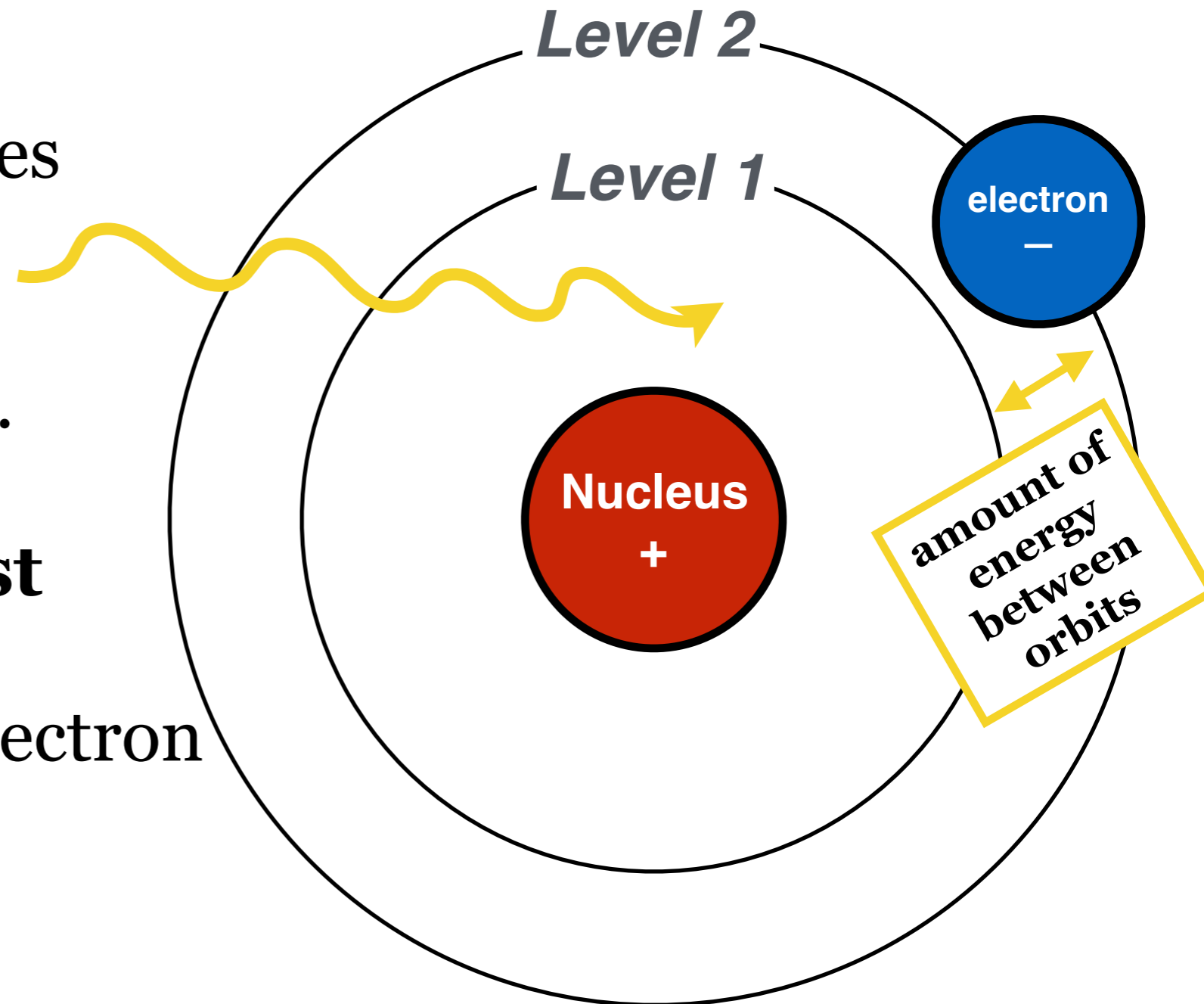
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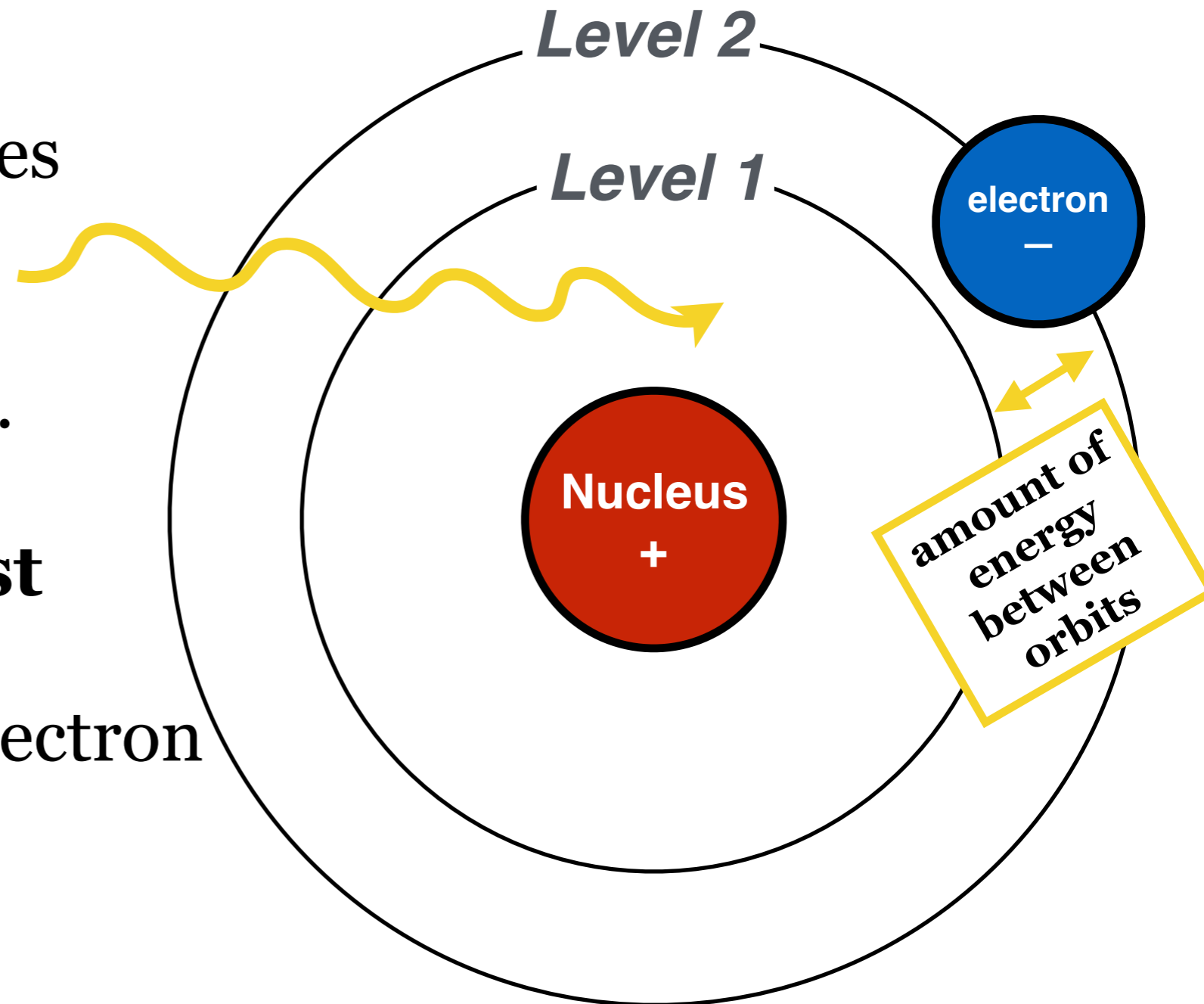
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- Electron “orbits” have specific energies
- Separated like stairs on a staircase.
- Light must have **just the right color** (energy) to bump electron



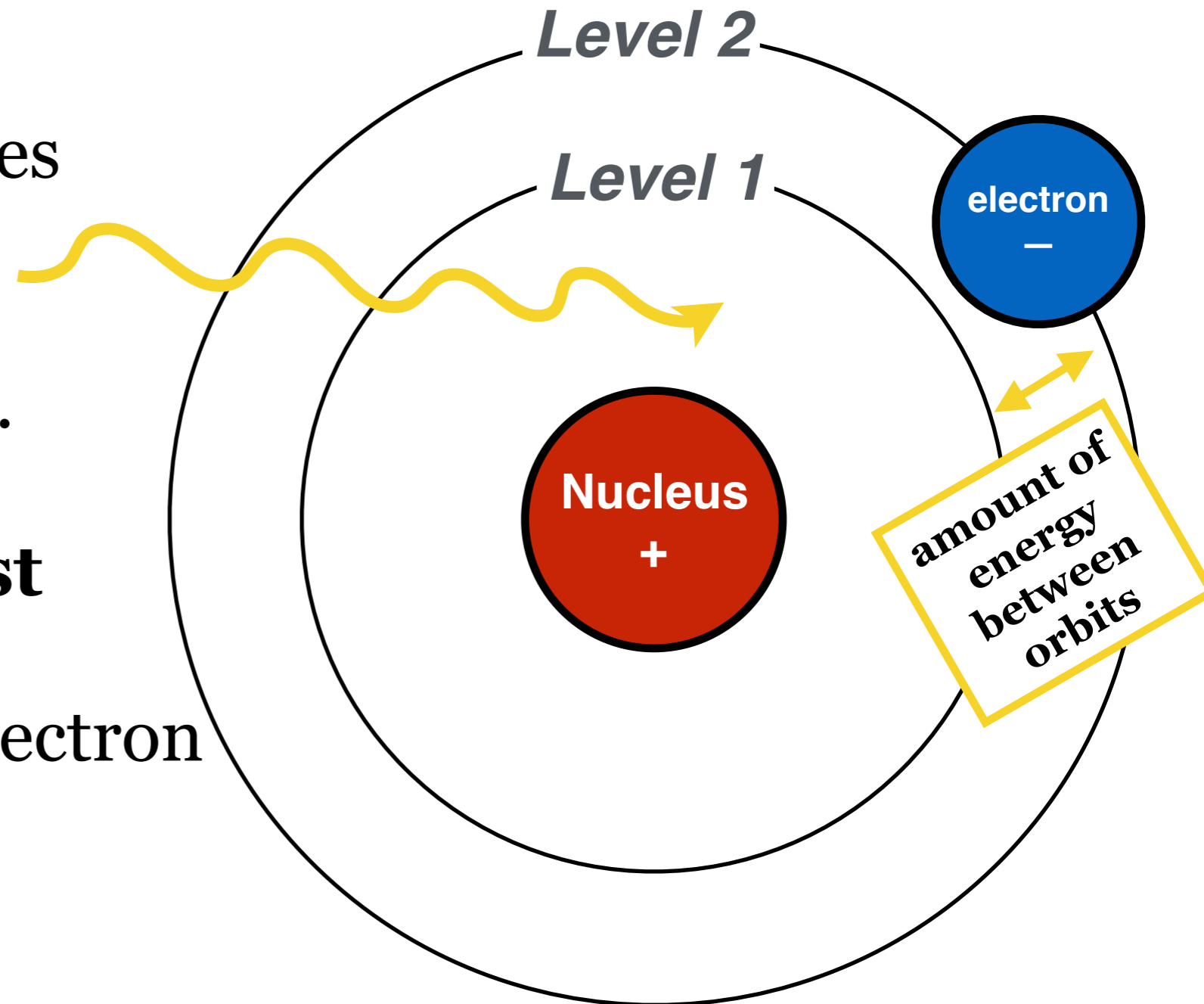
# Atoms & light

- Electron “orbits” have specific energies
- Separated like stairs on a staircase.
- Light must have **just the right color** (energy) to bump electron
  - Not too **much!**



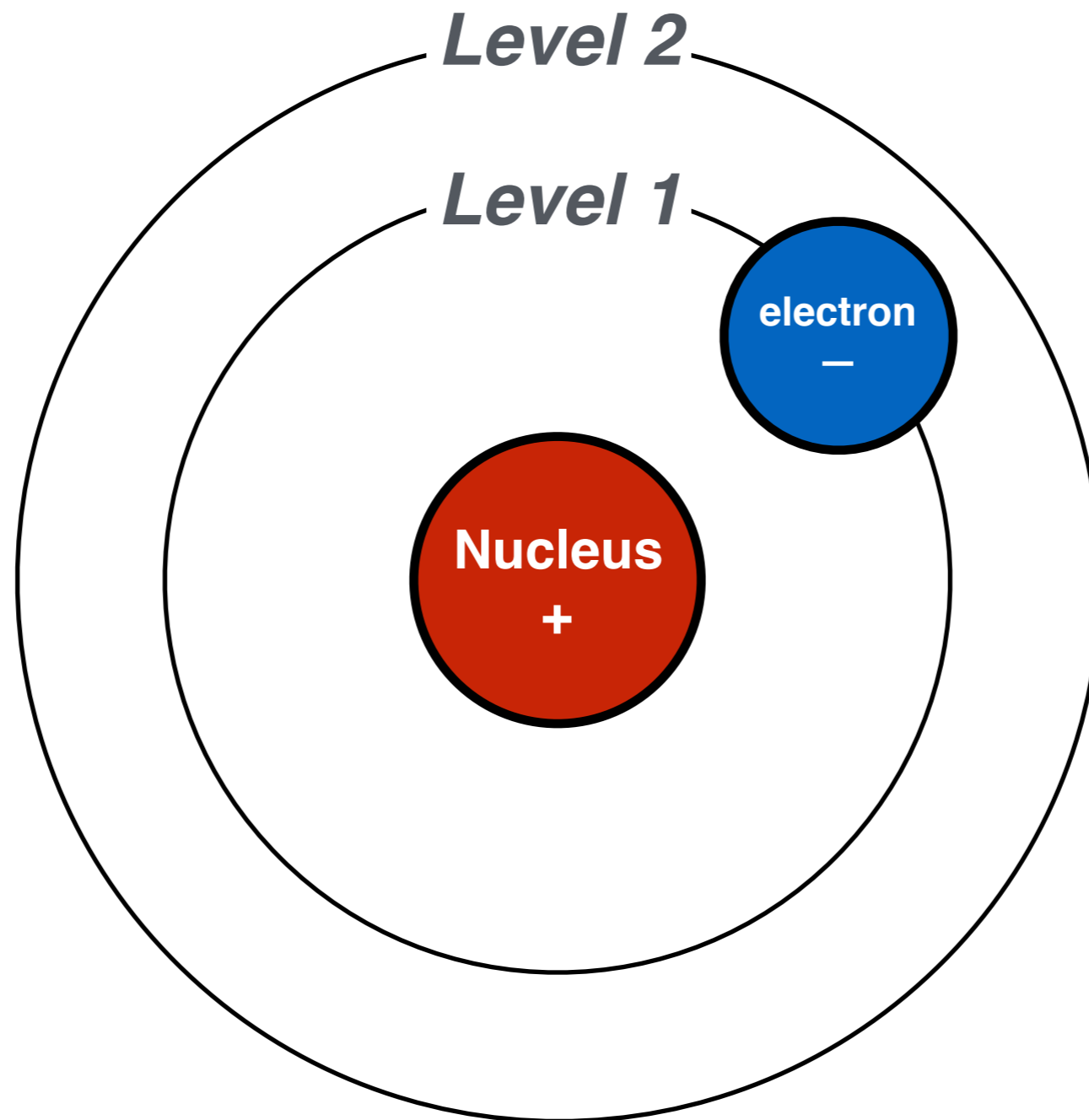
# Atoms & light

- Electron “orbits” have specific energies
- Separated like stairs on a staircase.
- Light must have **just the right color** (energy) to bump electron
  - Not too **much**!
  - Not too **little**!

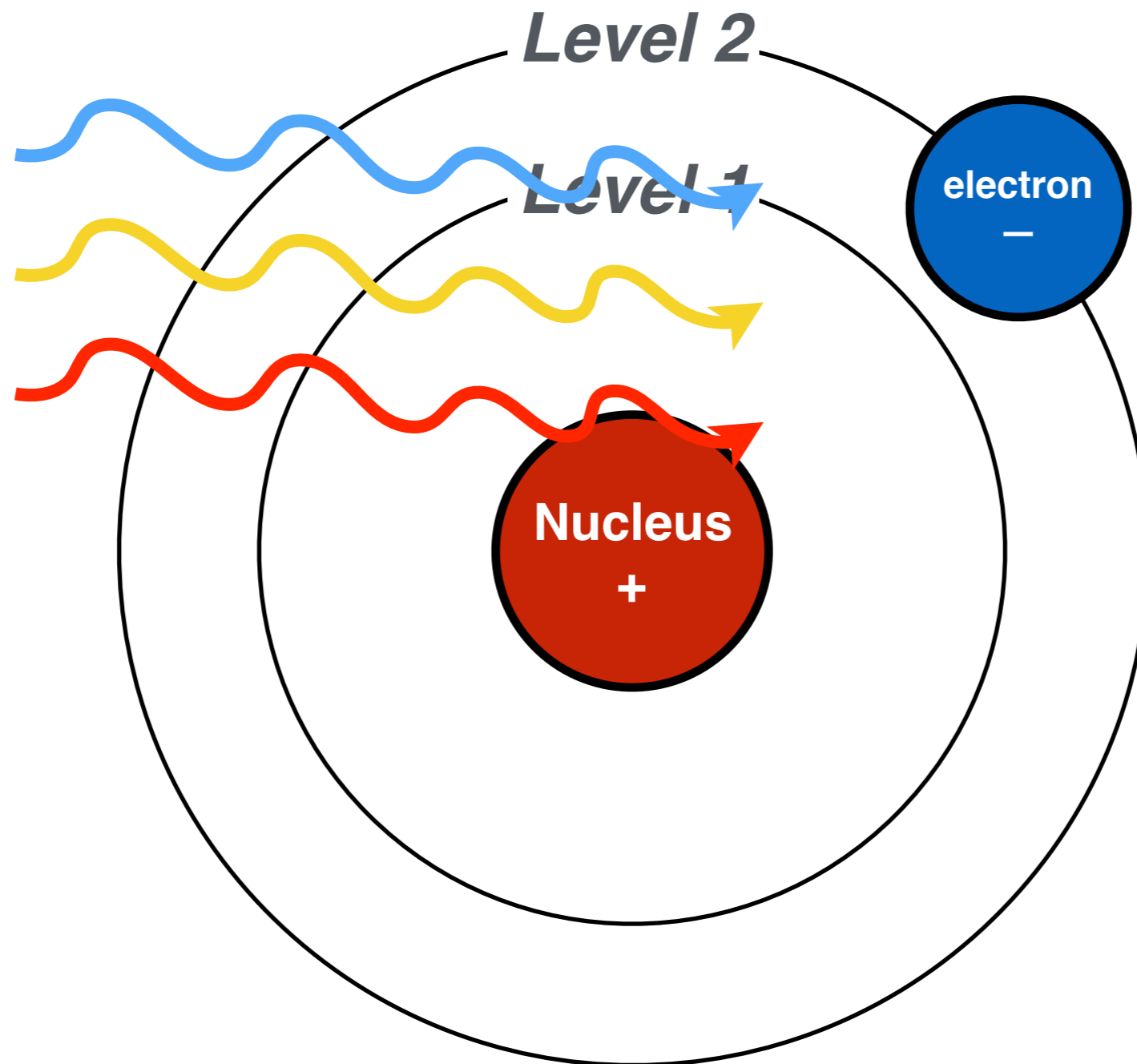




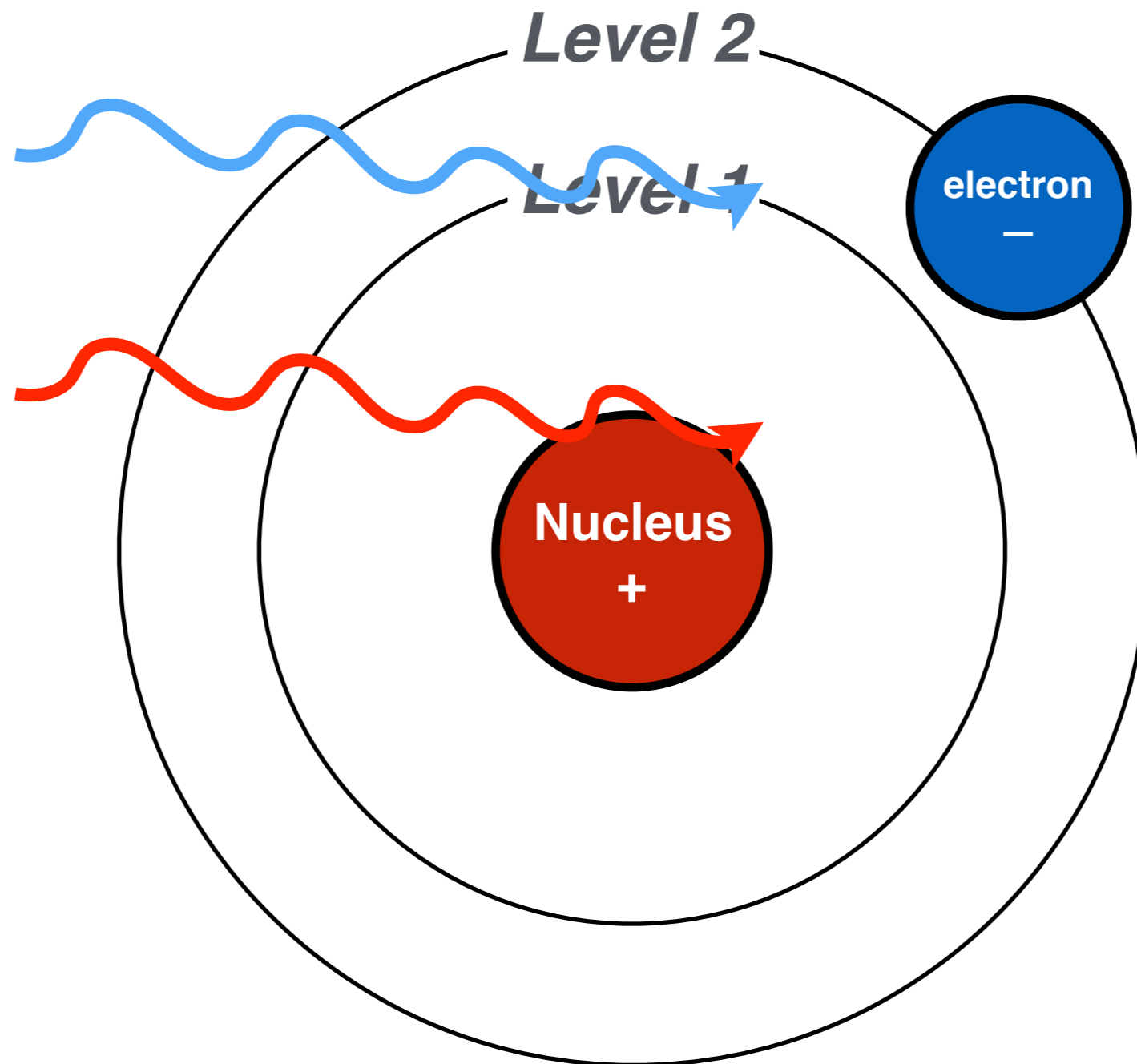
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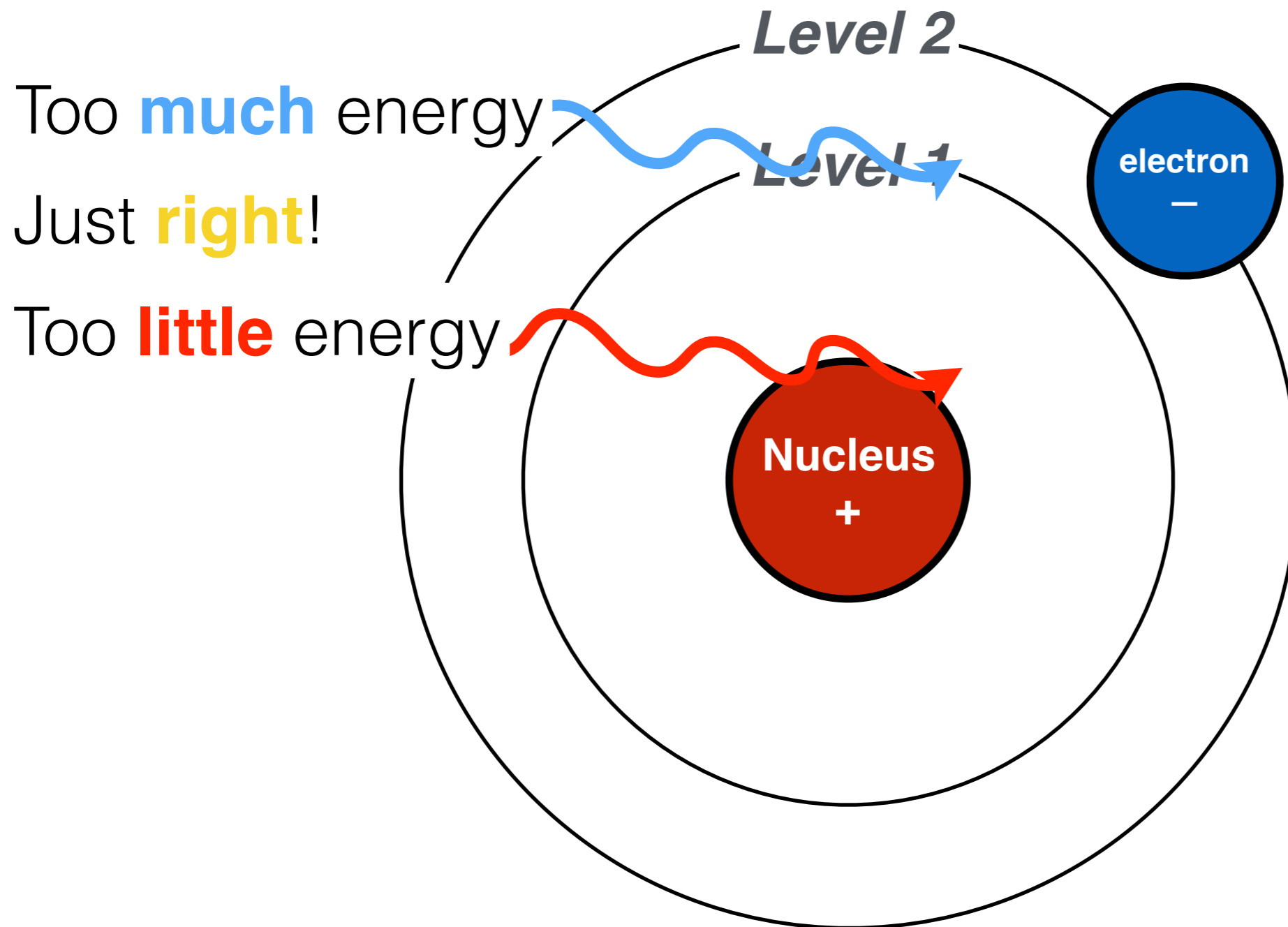
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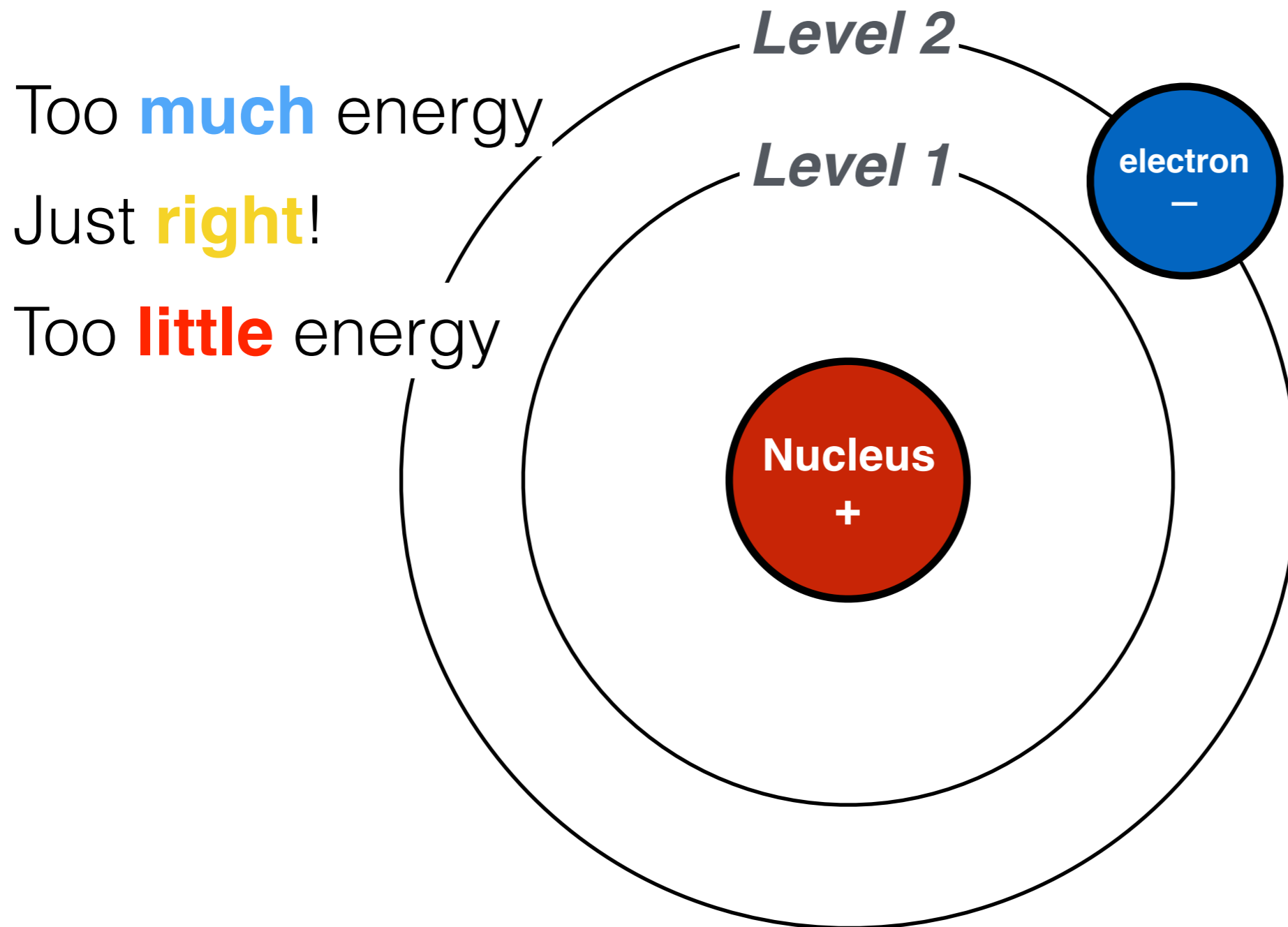
# Atoms & light



# Atoms & light



# Atoms & light



# Atoms & light

- Colors going **in**:
- Colors coming **out**:

# Atoms & light

- Colors going **in**:



- Colors coming **out**:

# Atoms & light

- Colors going **in**:



- Colors coming **out**:



# Atoms & light

- Colors going **in**:



- Colors coming **out**:

# Atoms & light

- Colors going **in**:



- Colors coming **out**:



# Atoms & light

- Colors going **in**:



- Colors coming **out**:

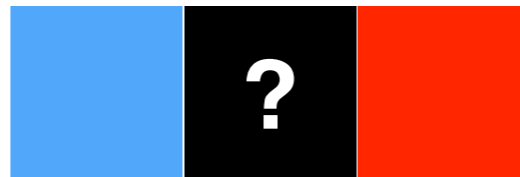


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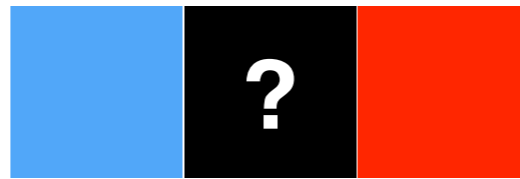


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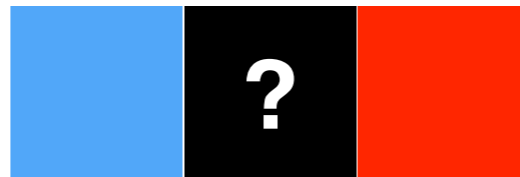
**Yellow** light was **absorbed** by electron!

# Atoms & light

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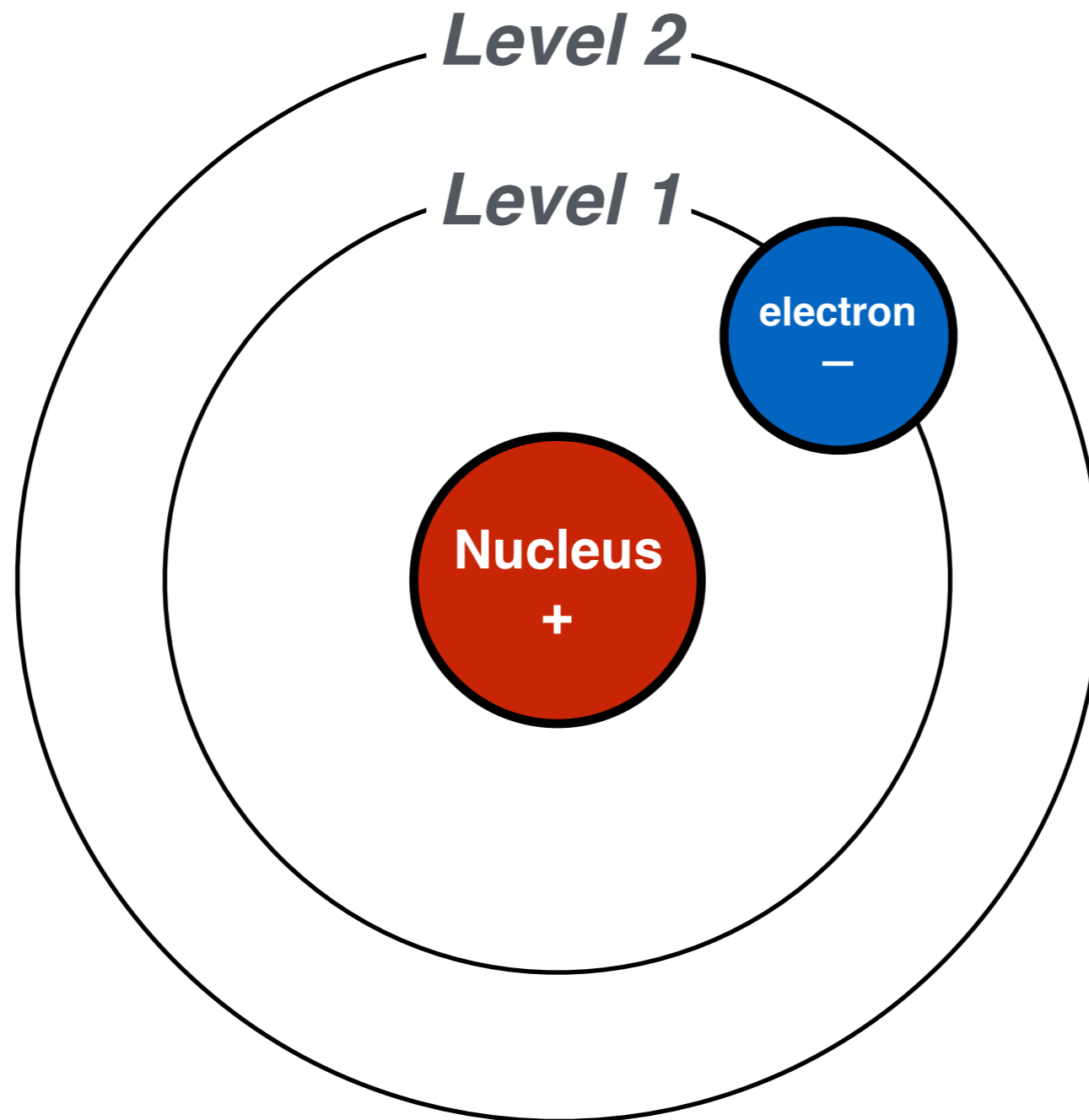
- Colors coming **out**:



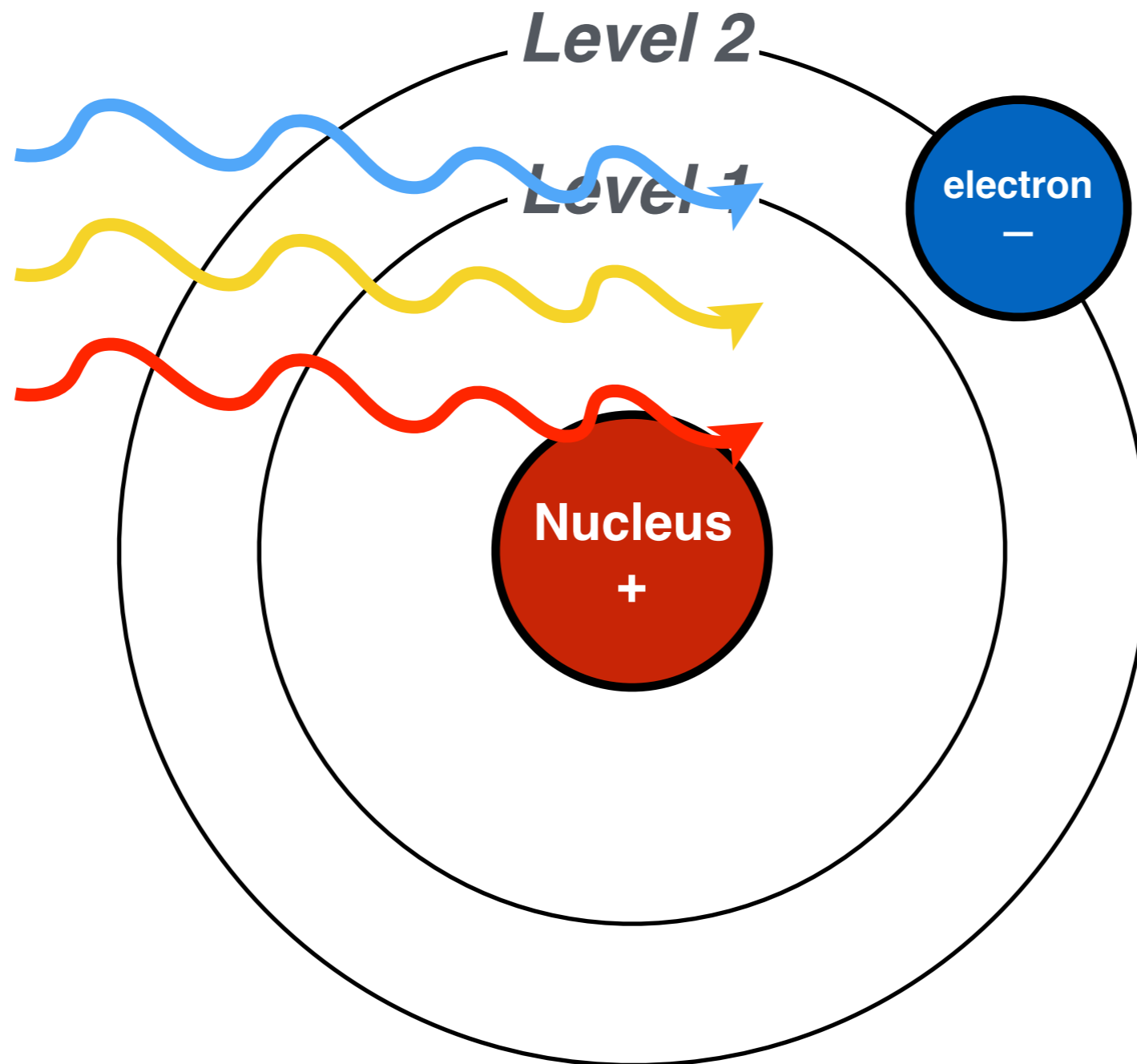
**Yellow** light was **absorbed** by electron!

Its energy was used to “boost” the electron **up** one orbit.

# Atoms & light

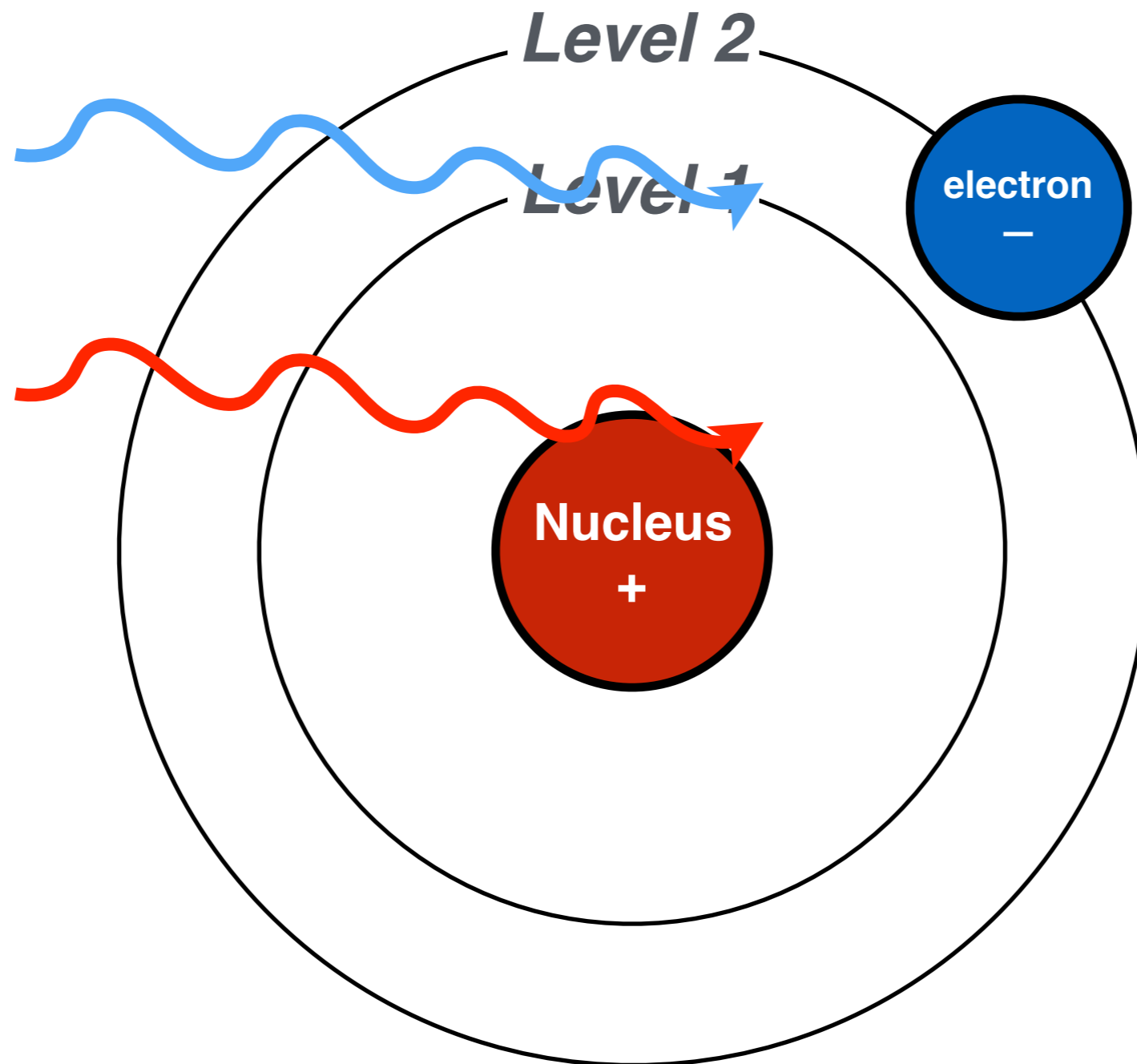


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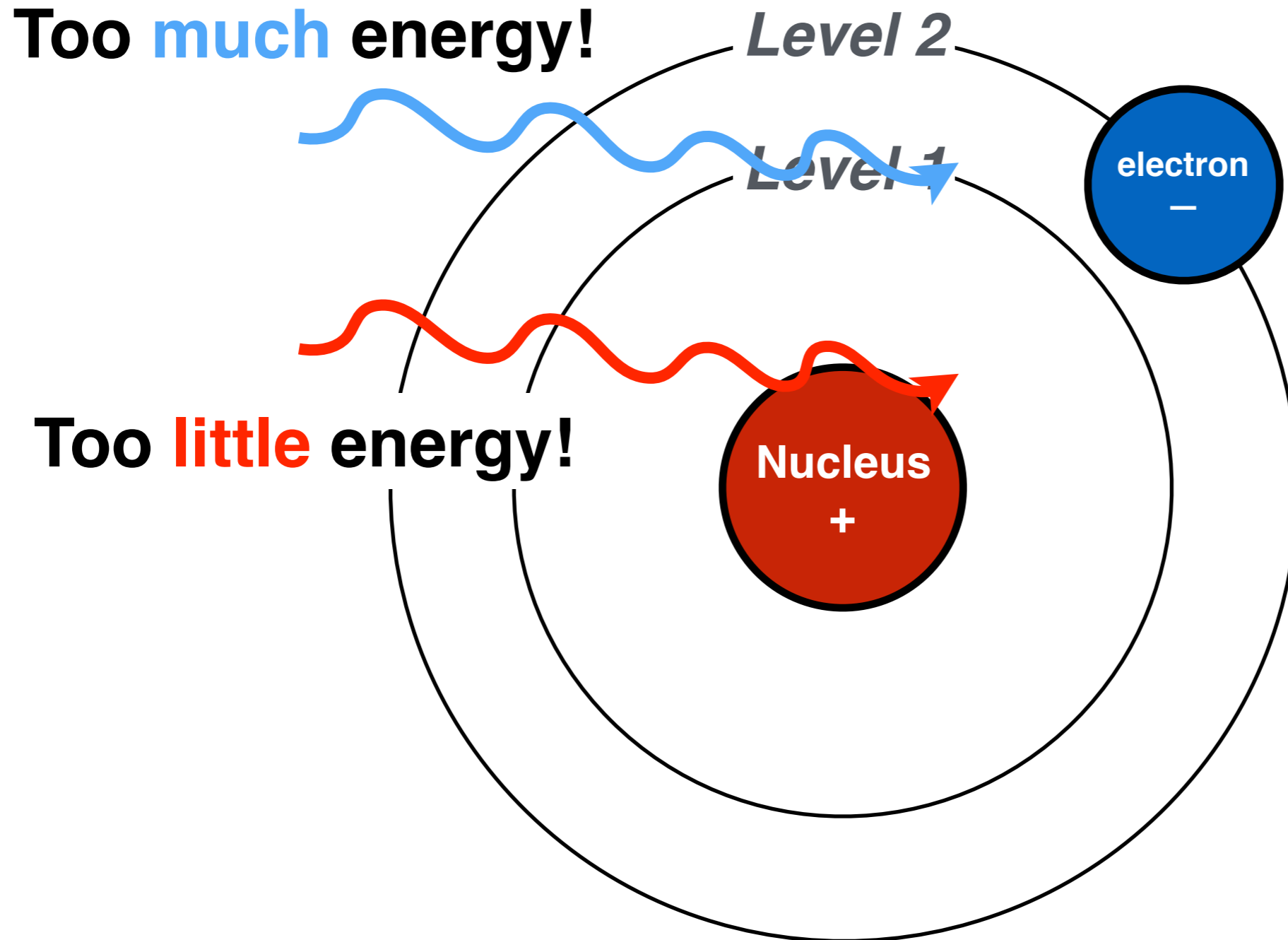




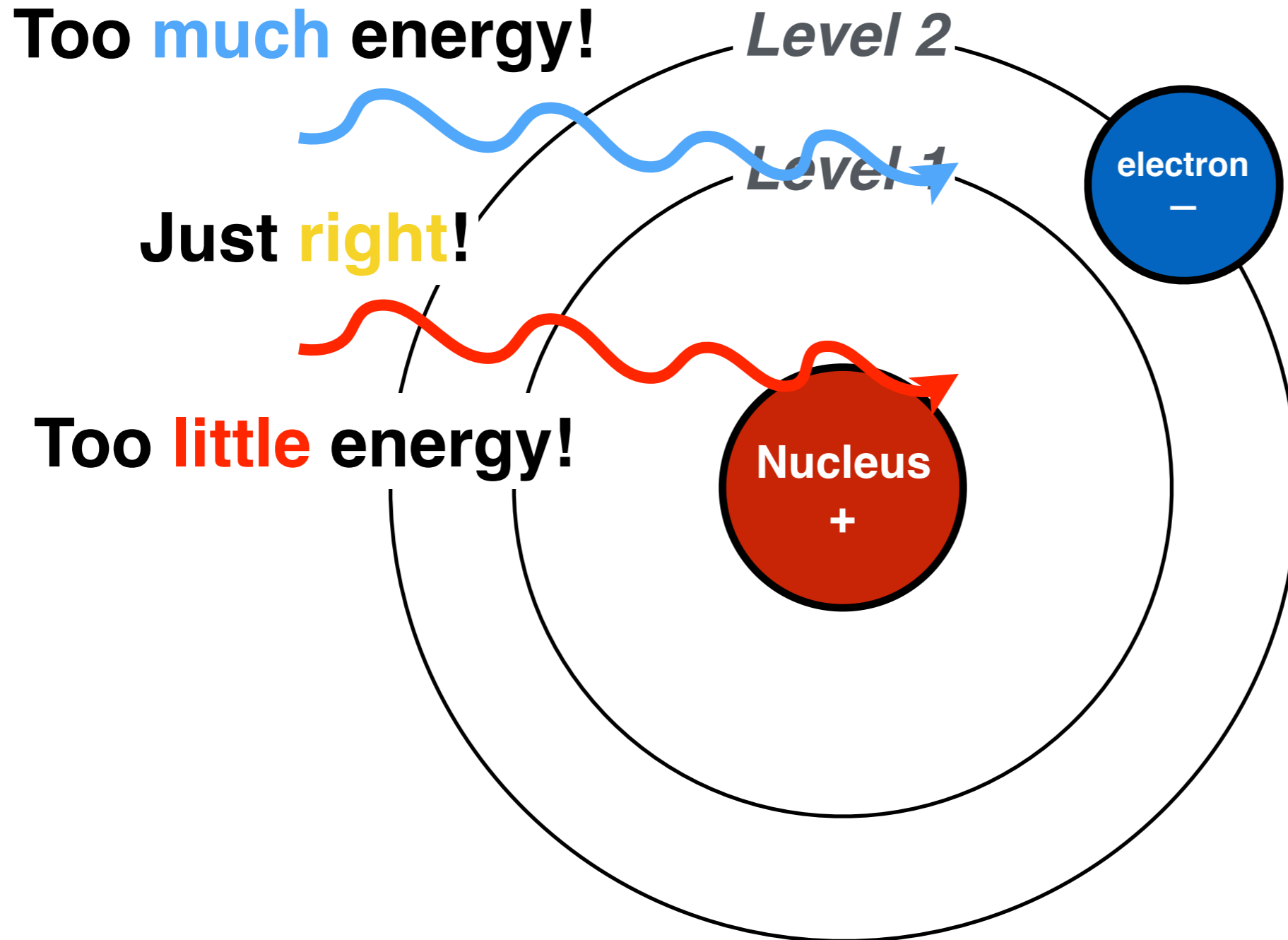
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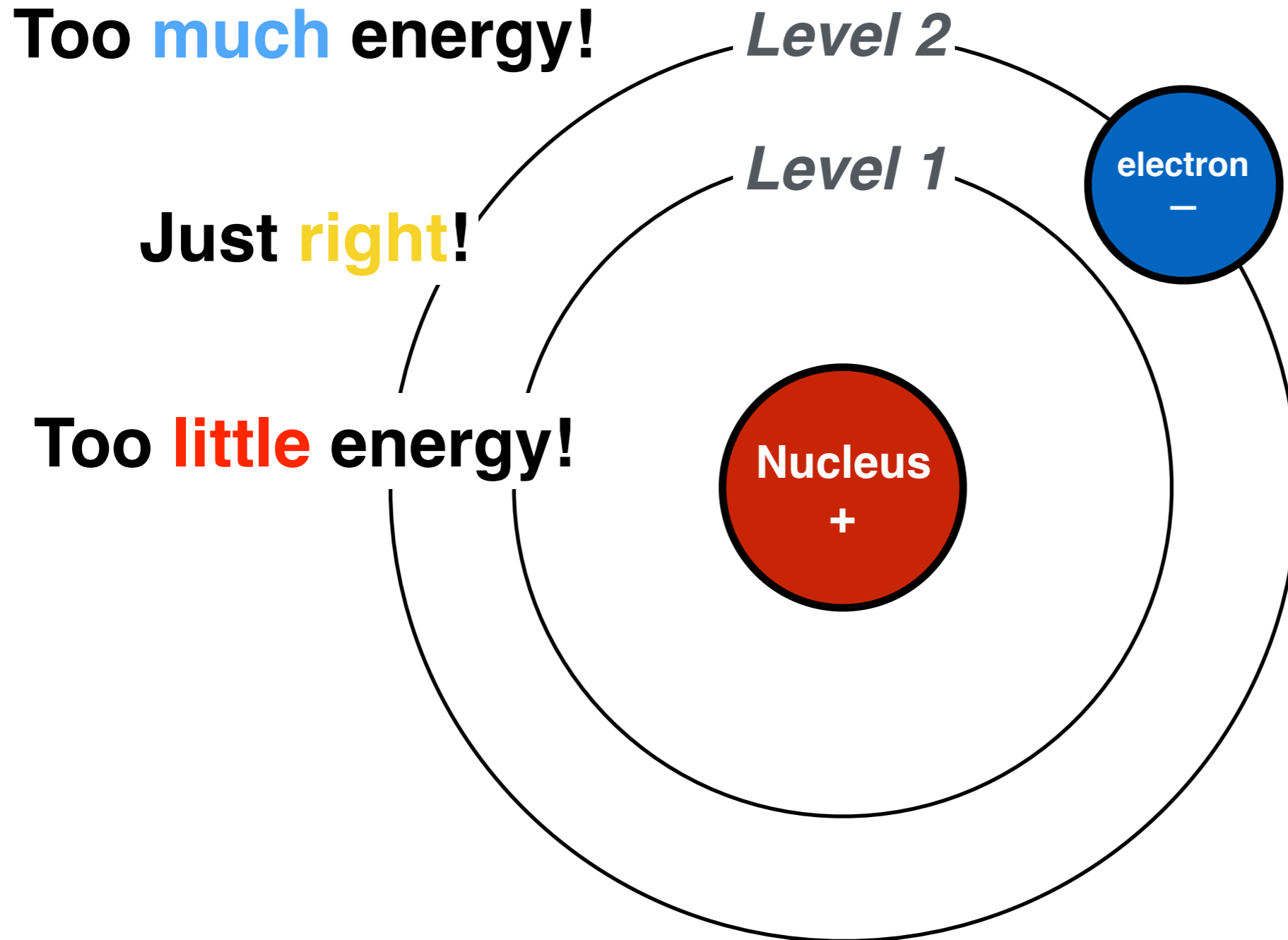
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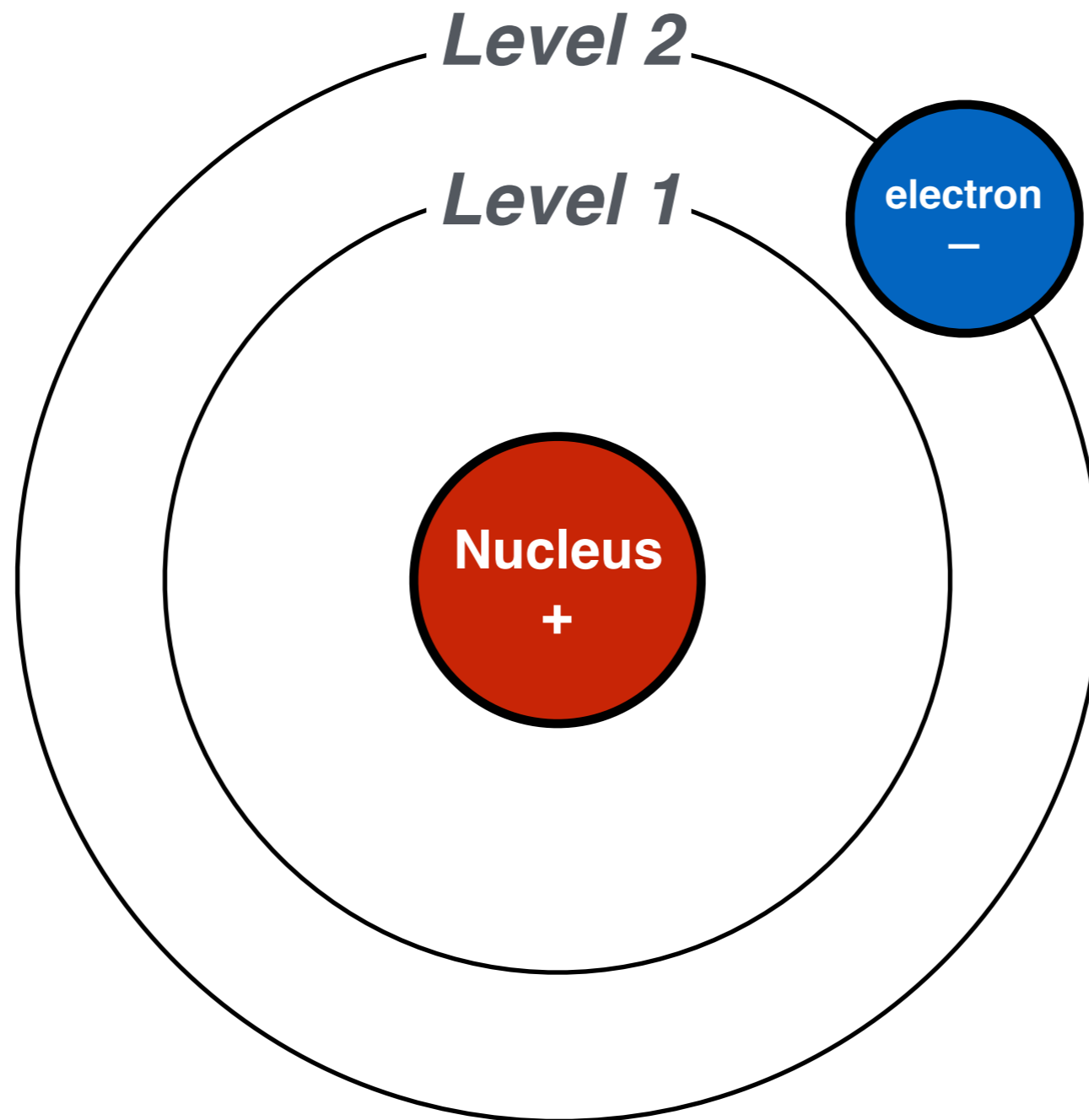
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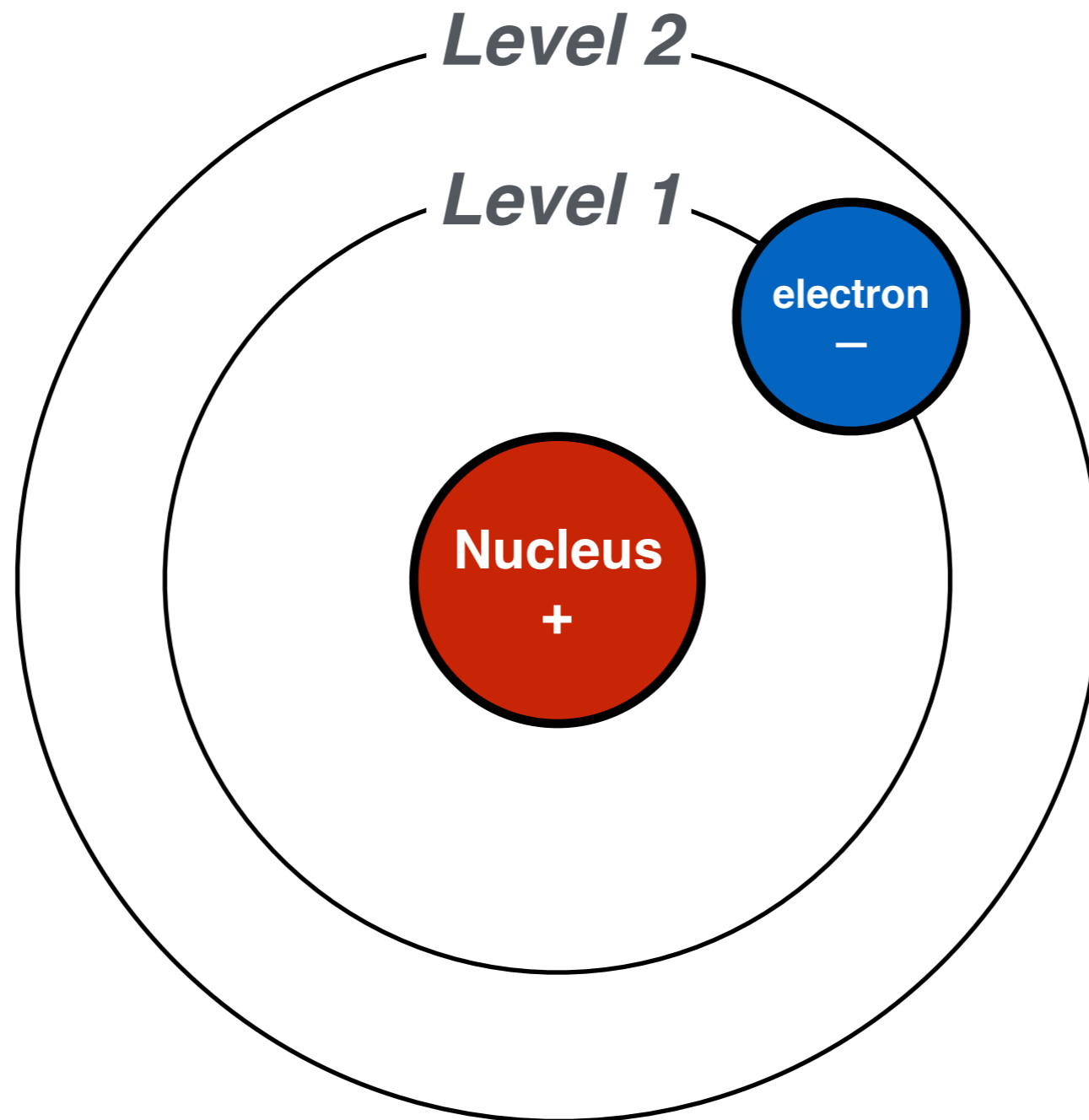
# Atoms & light



# Also happens in reverse



# Also happens in reverse



Also happens in reverse

*Atoms emit the  
same color that they  
absorb!*

# Upshot

- A star's **colors** tell us what **atoms** it is made of.



# Upshot

- A star's **colors** tell us what **atoms** it is made of.

  $\Rightarrow$  **stellar composition**

# Atoms & light

- Colors going **in**:

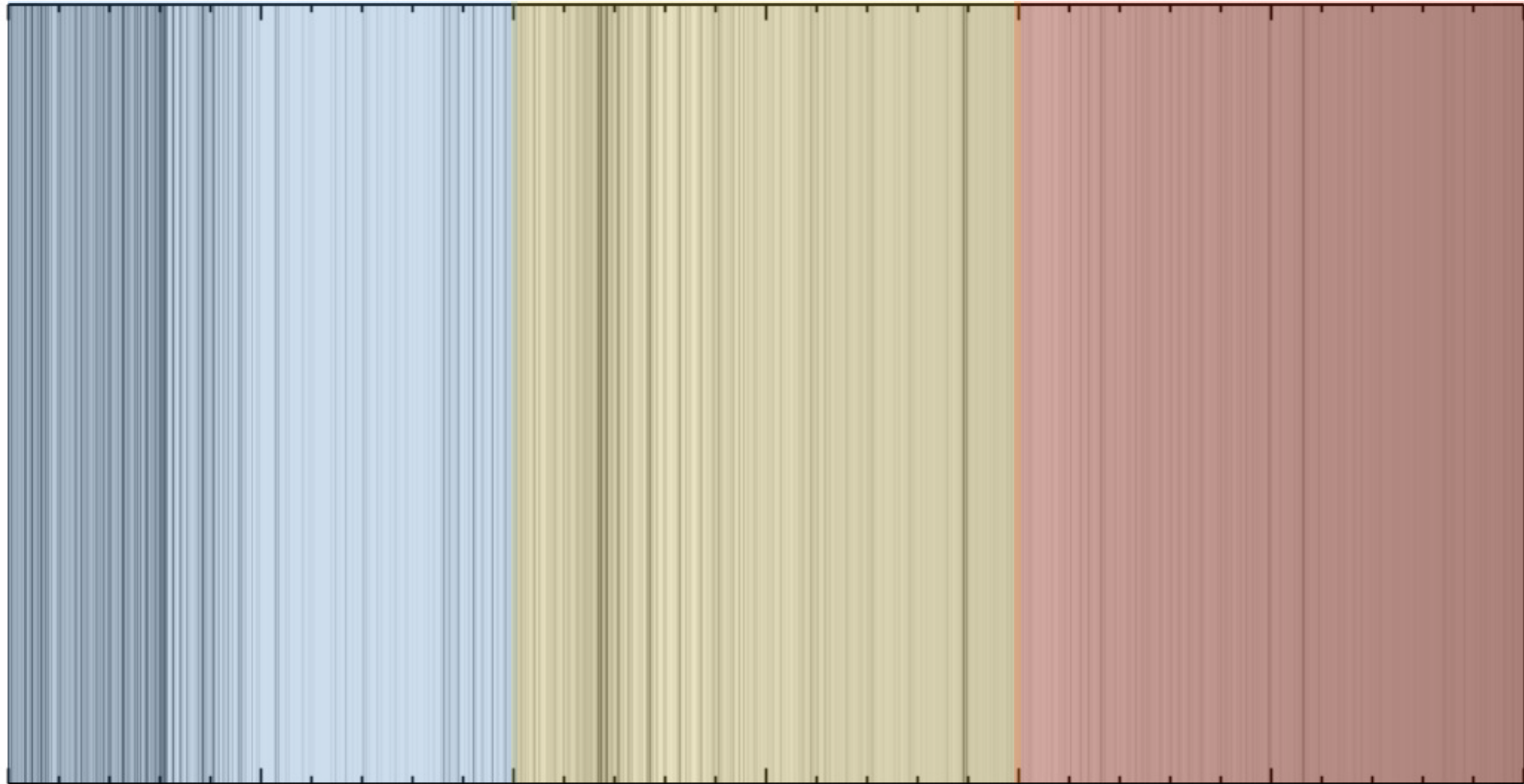


- Colors coming **out**:



- *Missing light is the shadows of electrons!*

# Example spectrum of a star



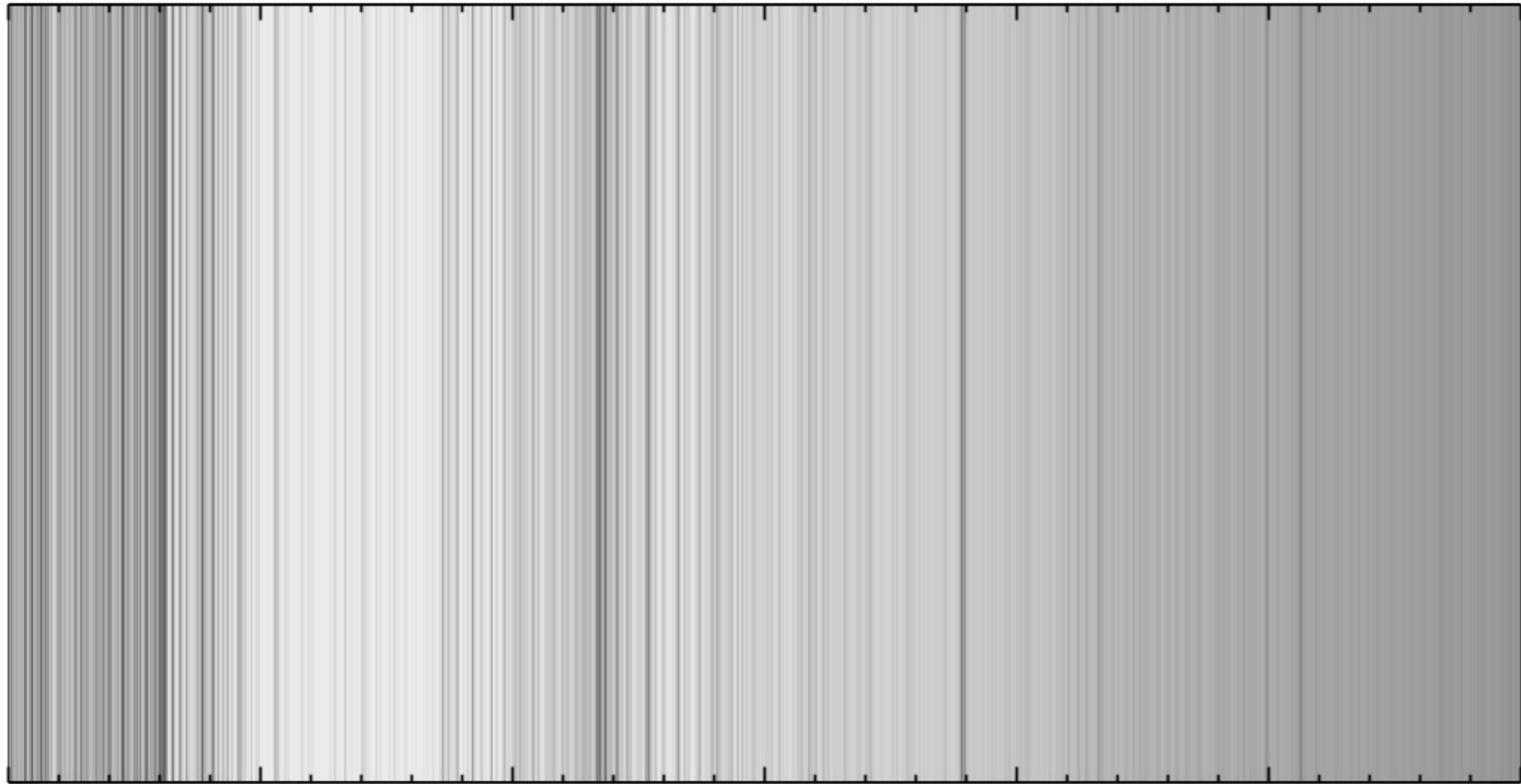
**Blue**

**Yellow**

**Red**

**Color of light**

# Example spectrum of a star



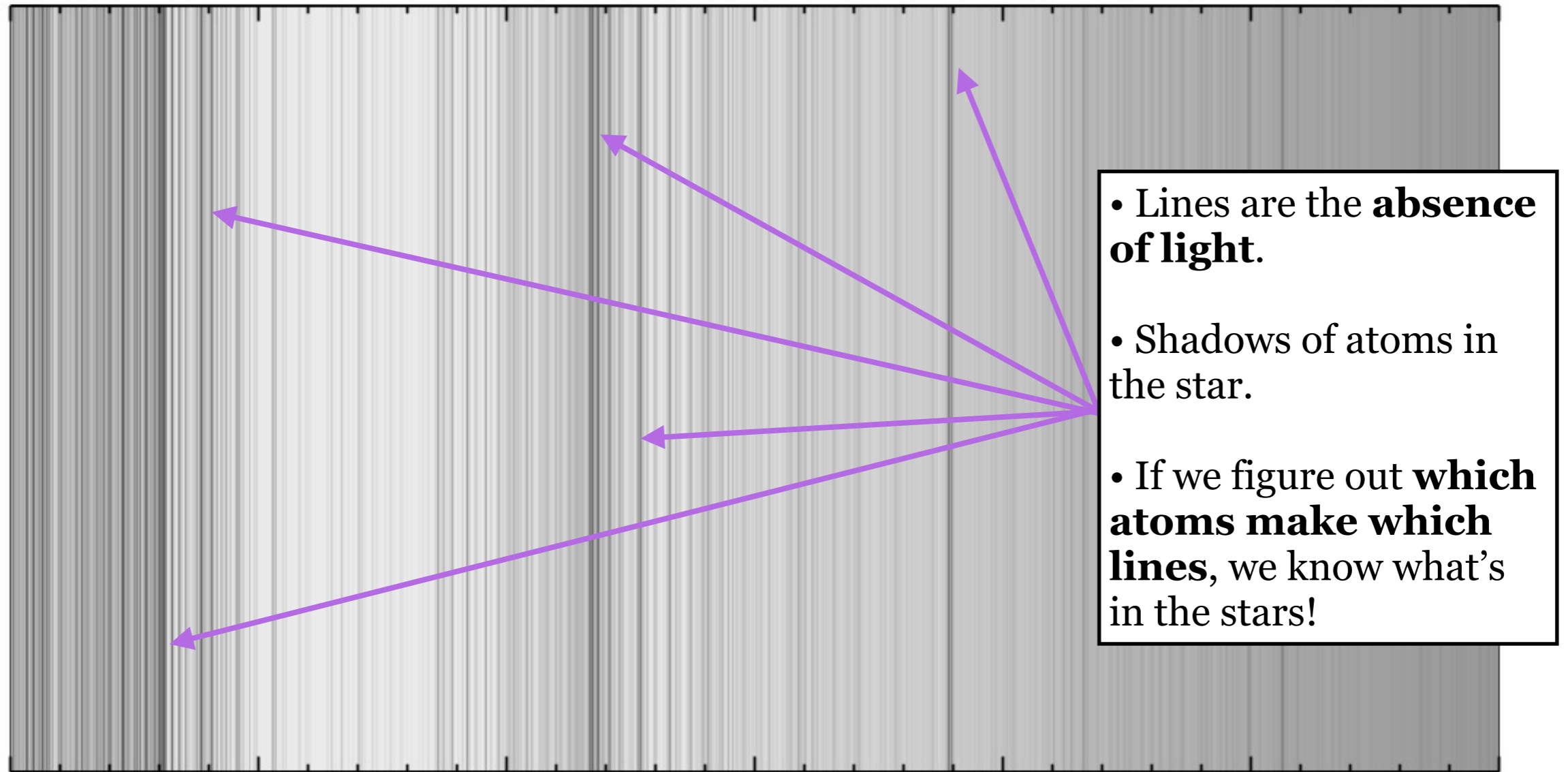
**Blue**

**Yellow**

**Red**

**Color of light**

# Example spectrum of a star



**Blue**

**Yellow**

**Red**

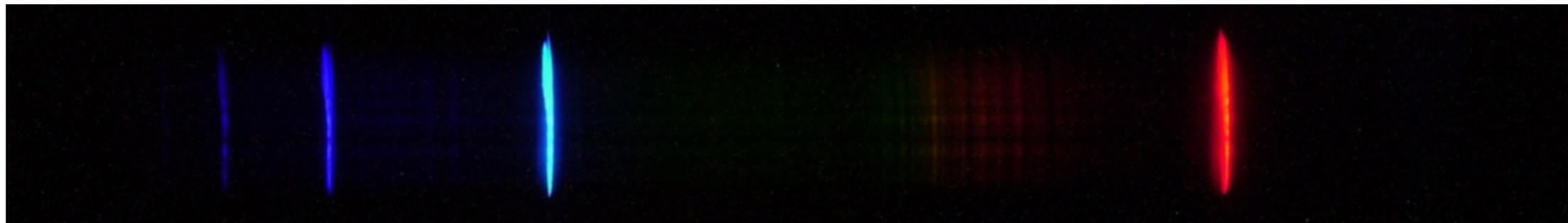
**Color of light**

**Let's try it!**

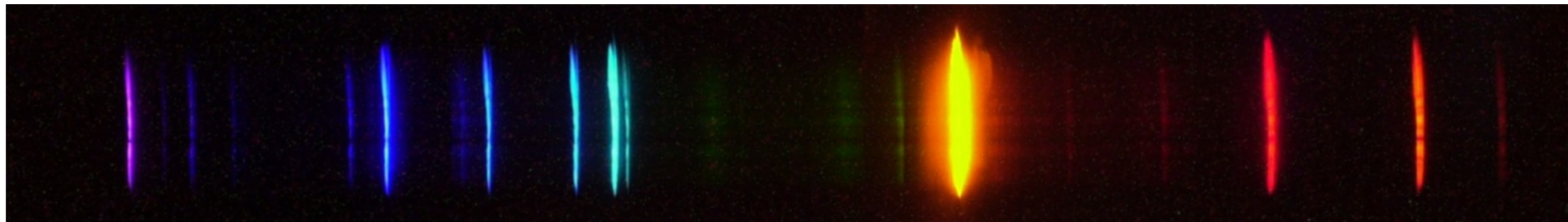
(Do some spectroscopy)

(What you should've  
seen...)

**H**ydrogen



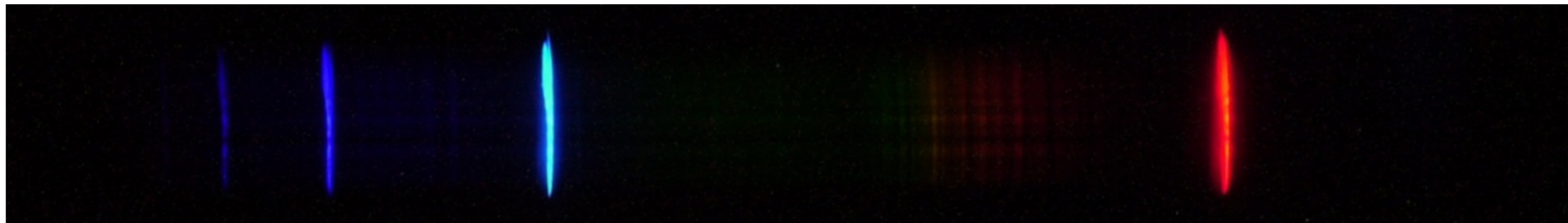
**H**elium



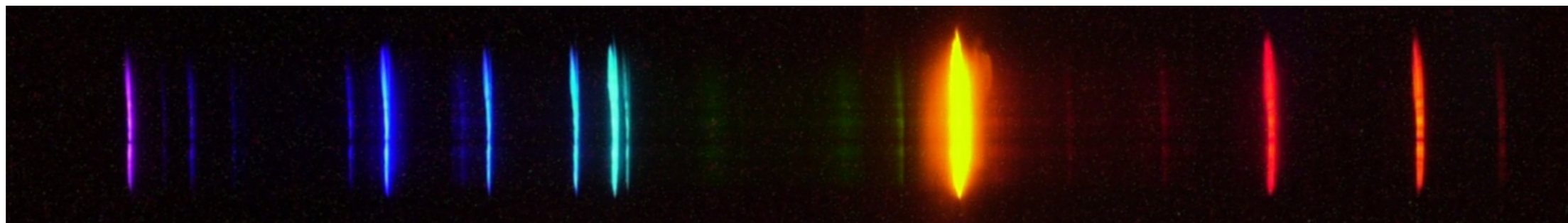


(What you should've  
seen...)

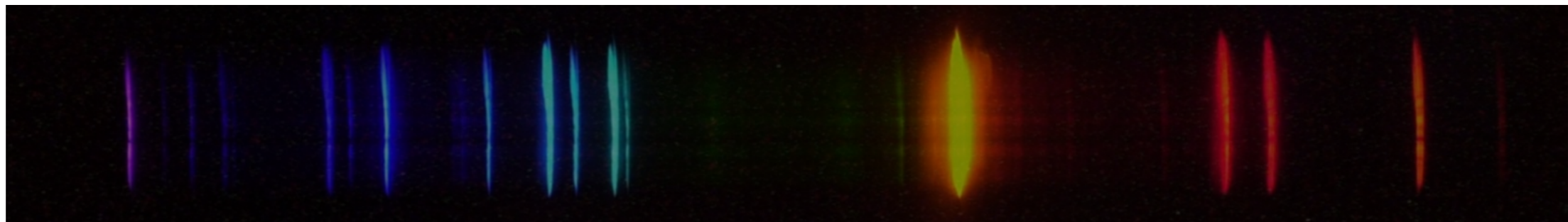
**H**ydrogen



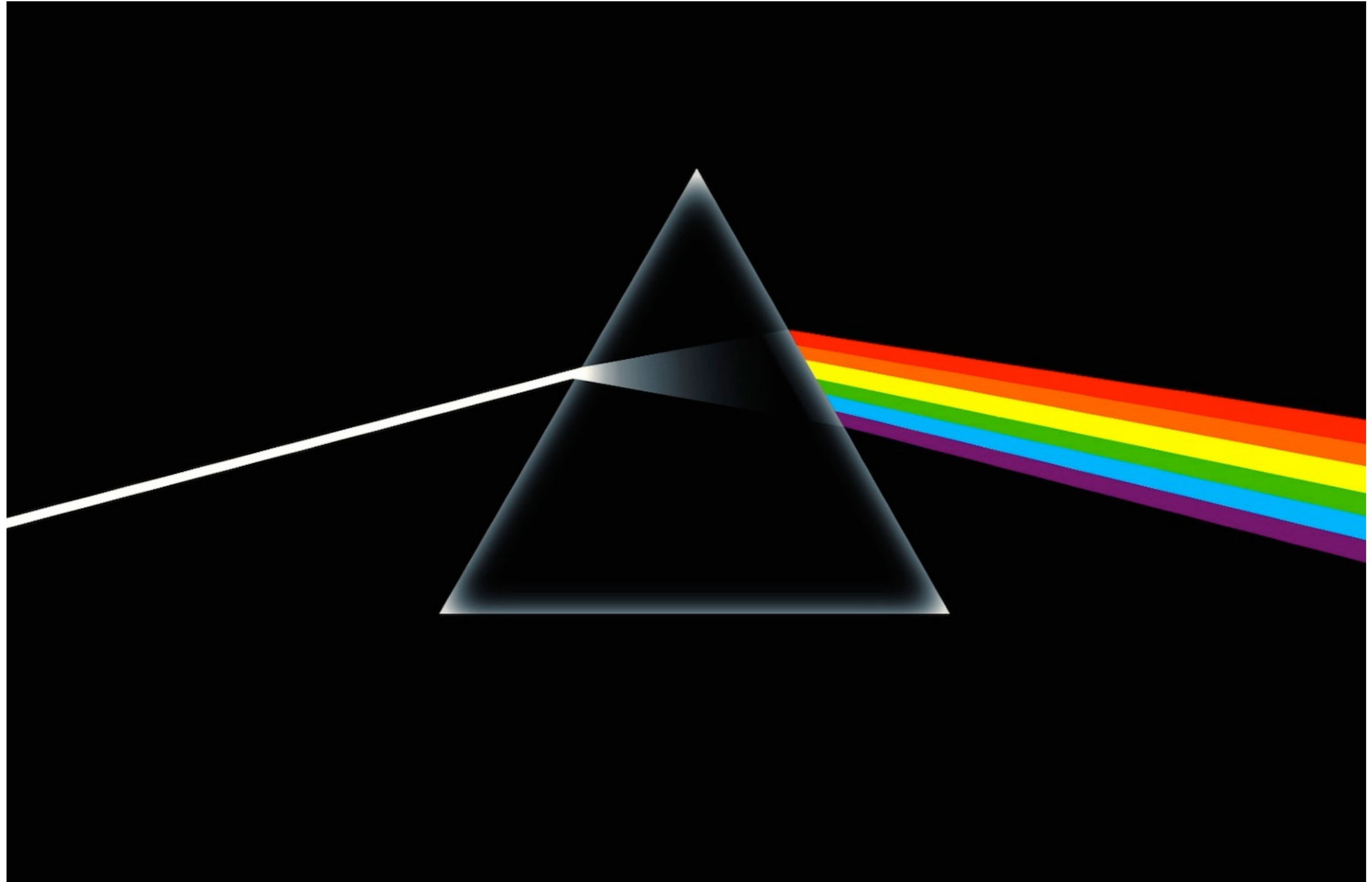
**He**lium



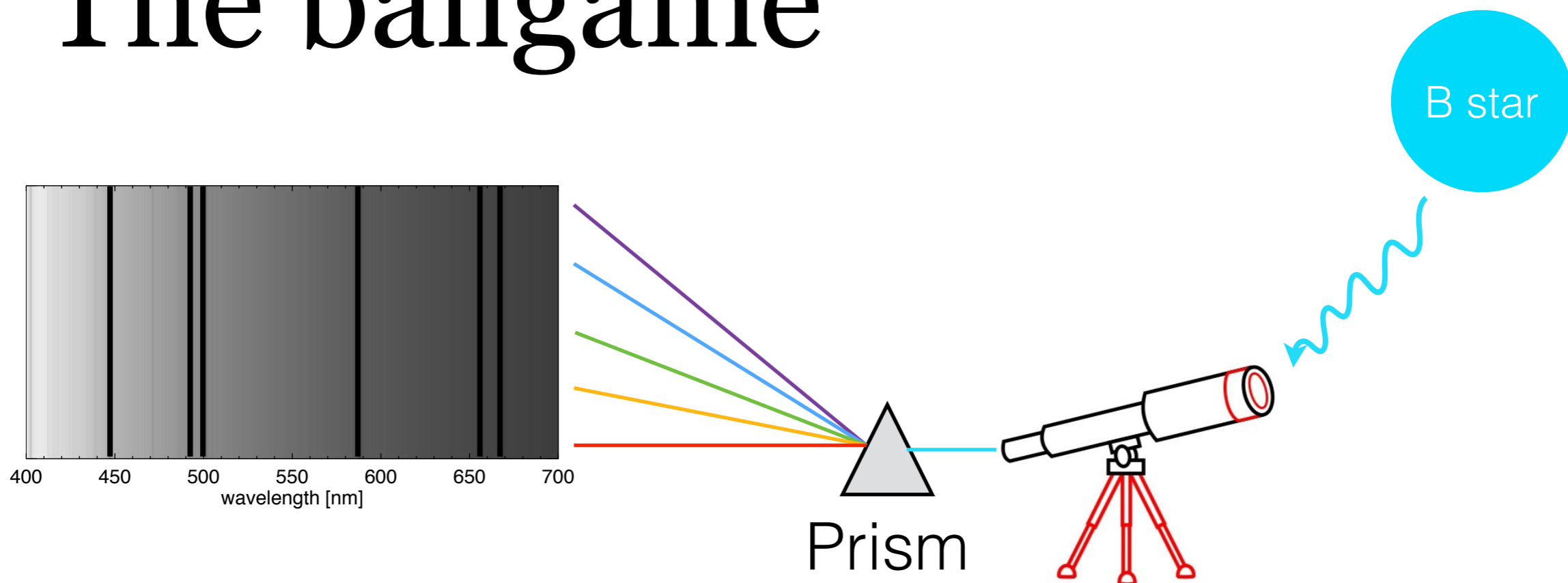
**H+He...**



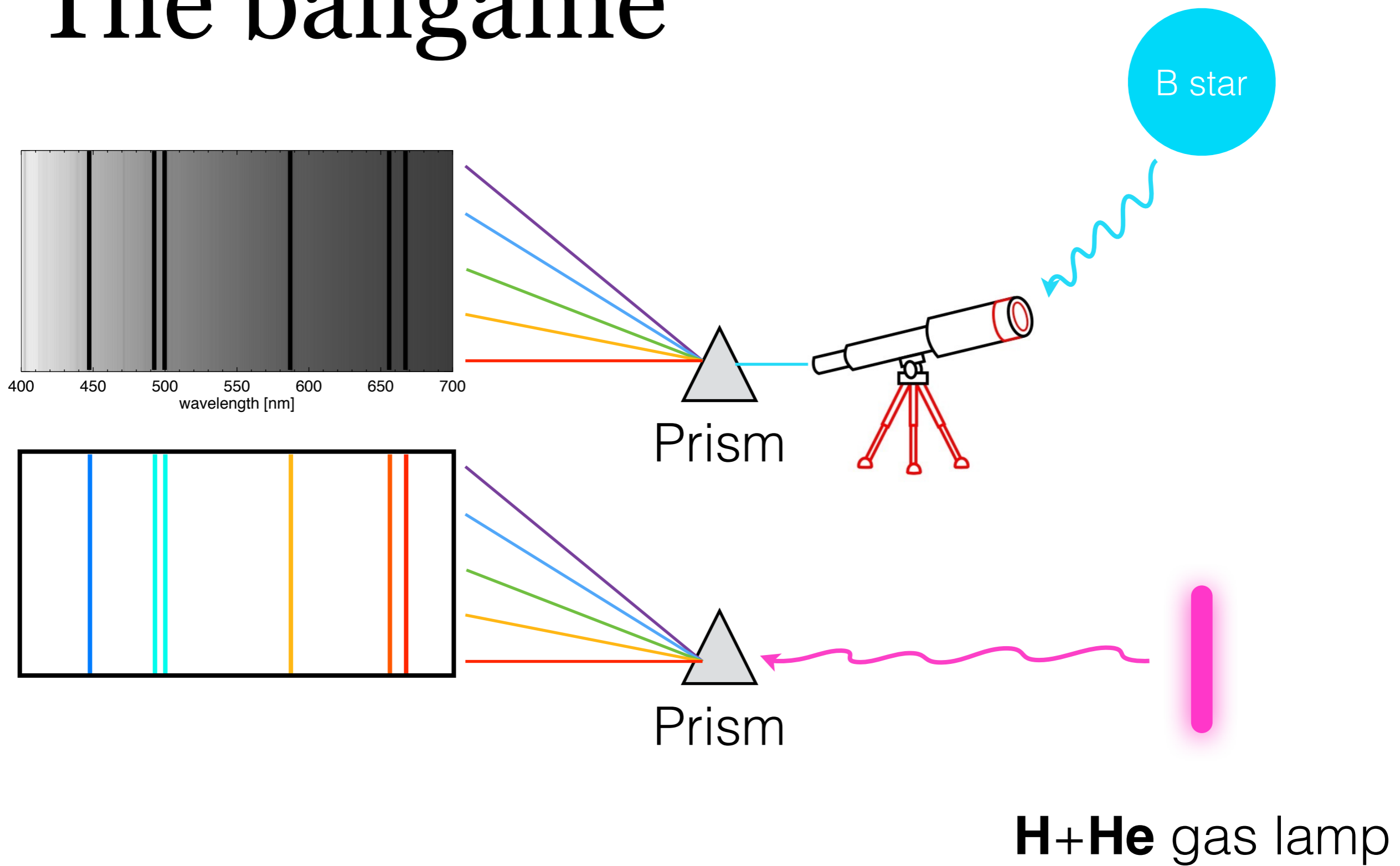
# Breaking up light



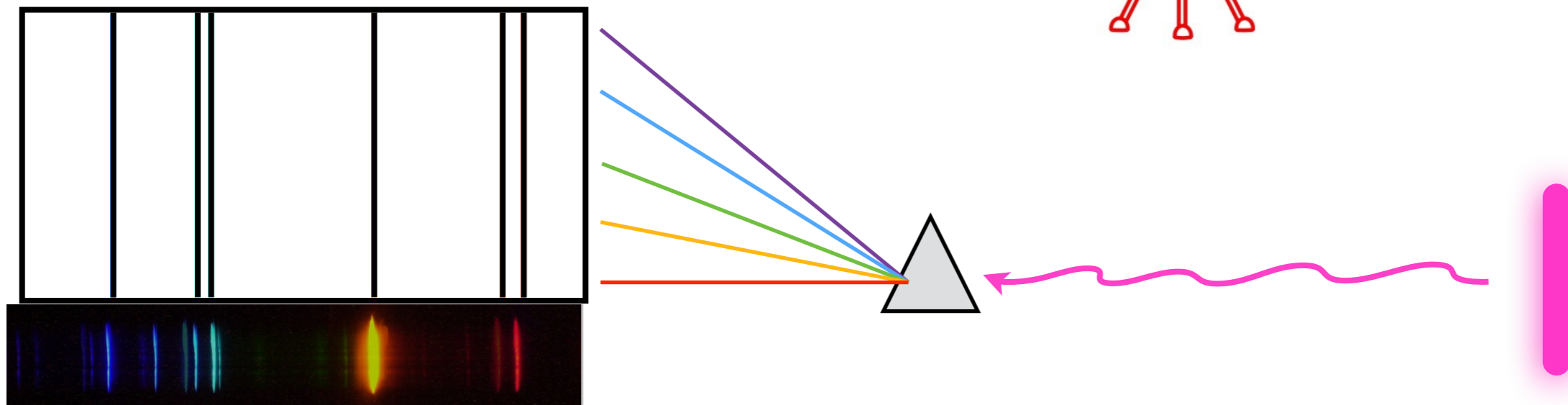
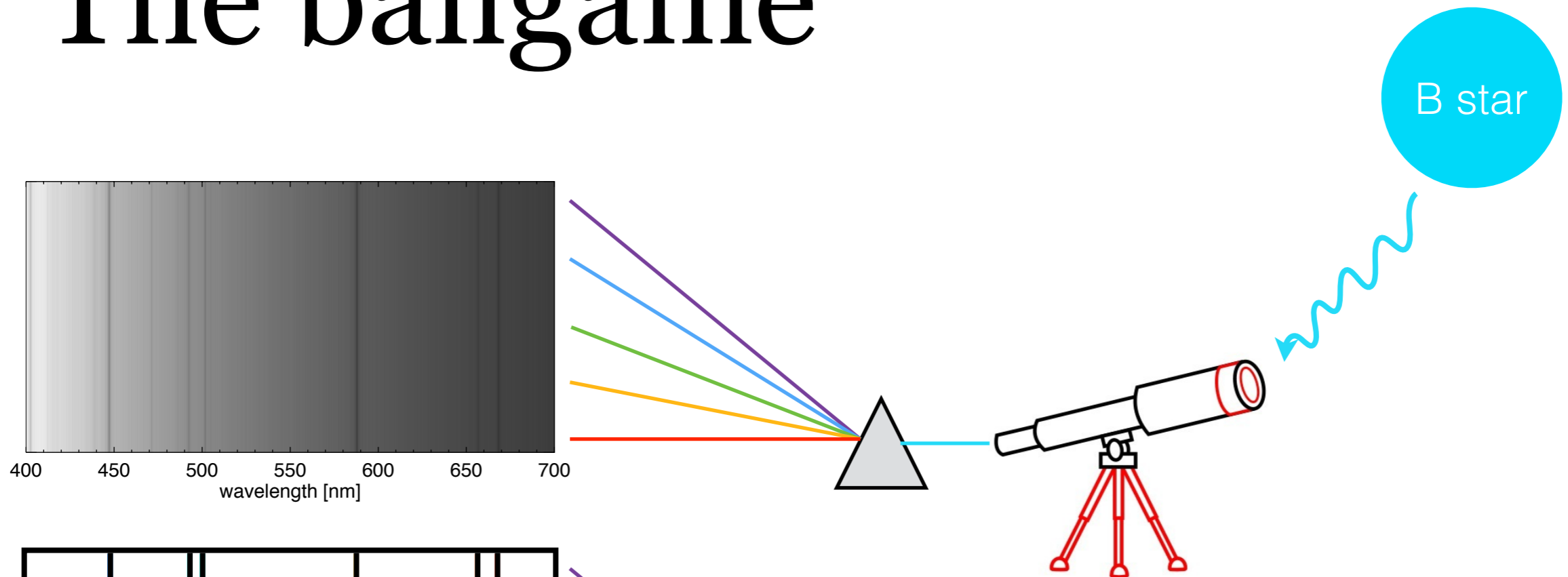
# The ballgame



# The ballgame



# The ballgame

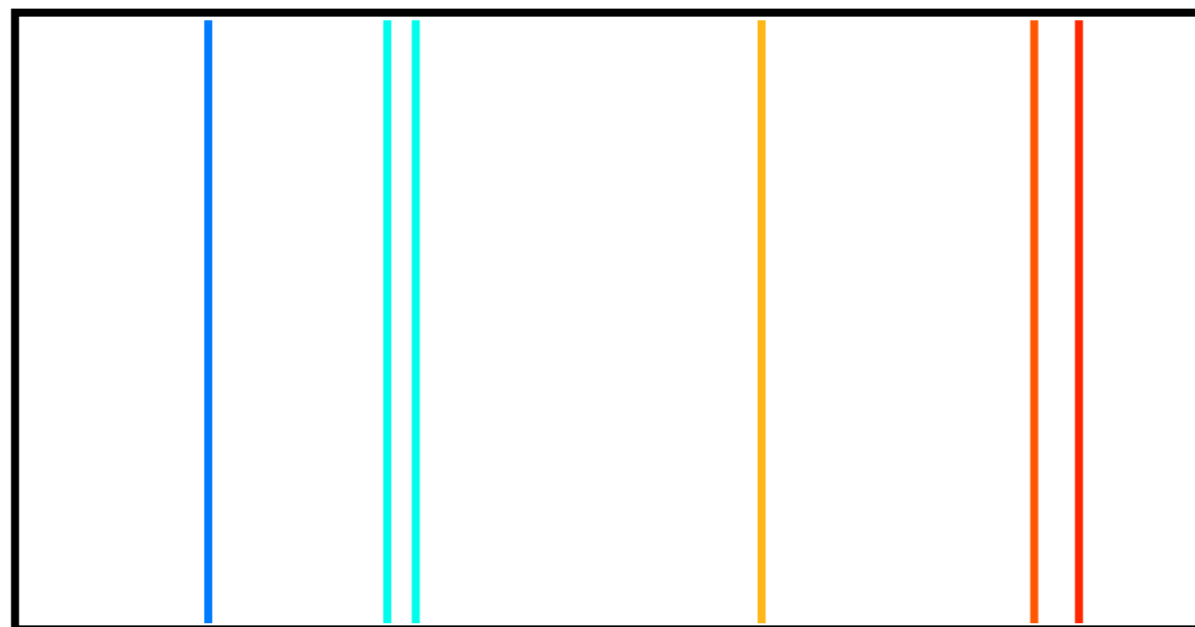
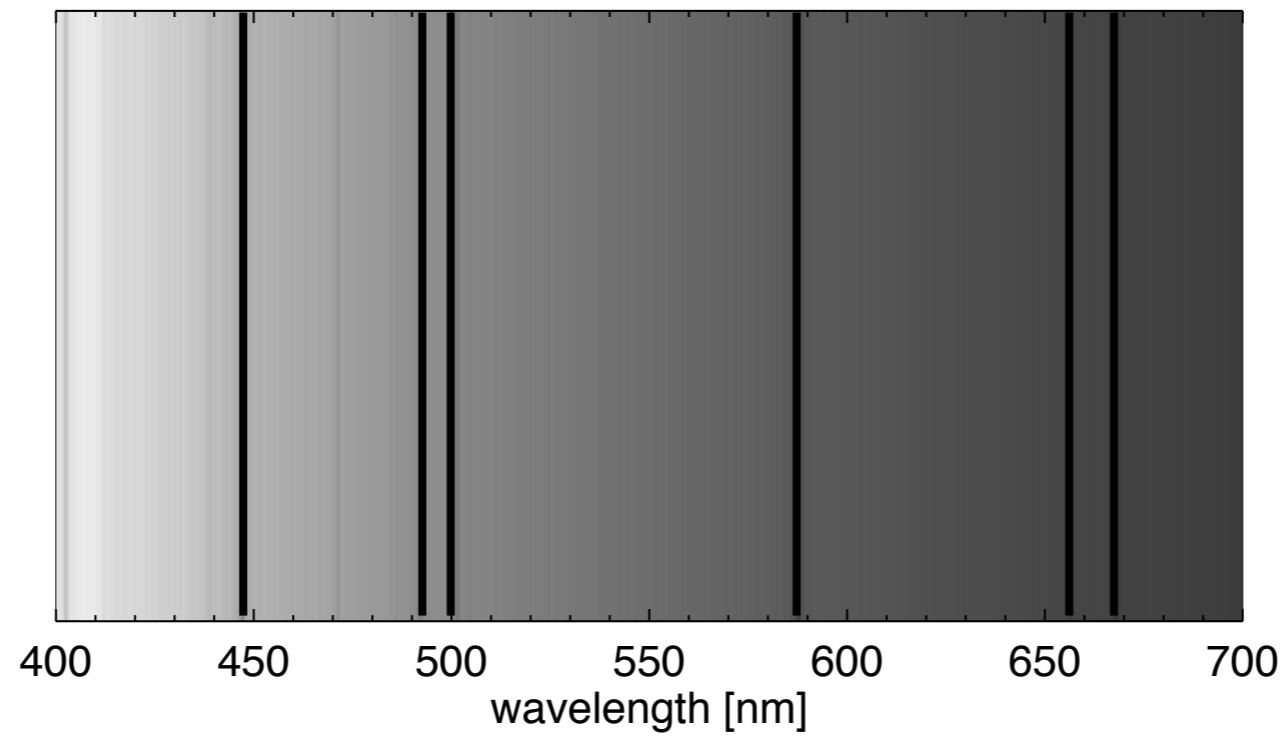


The star is made of  
**Helium** and **Hydrogen!**

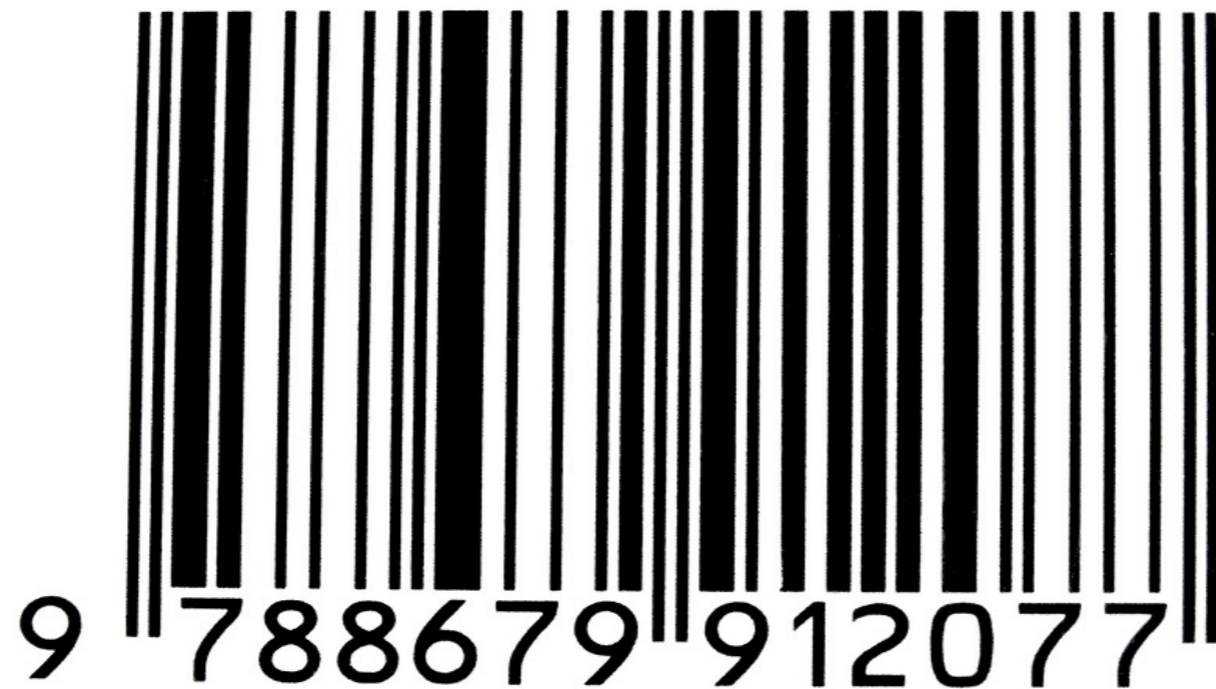


**H+He** gas lamp

# The ballgame



# The ballgame



# The ballgame

**We barcode the stars  
to learn what they're made of!**



**But why?**



Earth

( 1 )



**Telescopes**  
(+ spectrographs)

**Earth**



*The Milky Way  
(our neighborhood)*

**Telescopes  
(+ spectrographs)**

**Earth**

# THE UNIVERSE

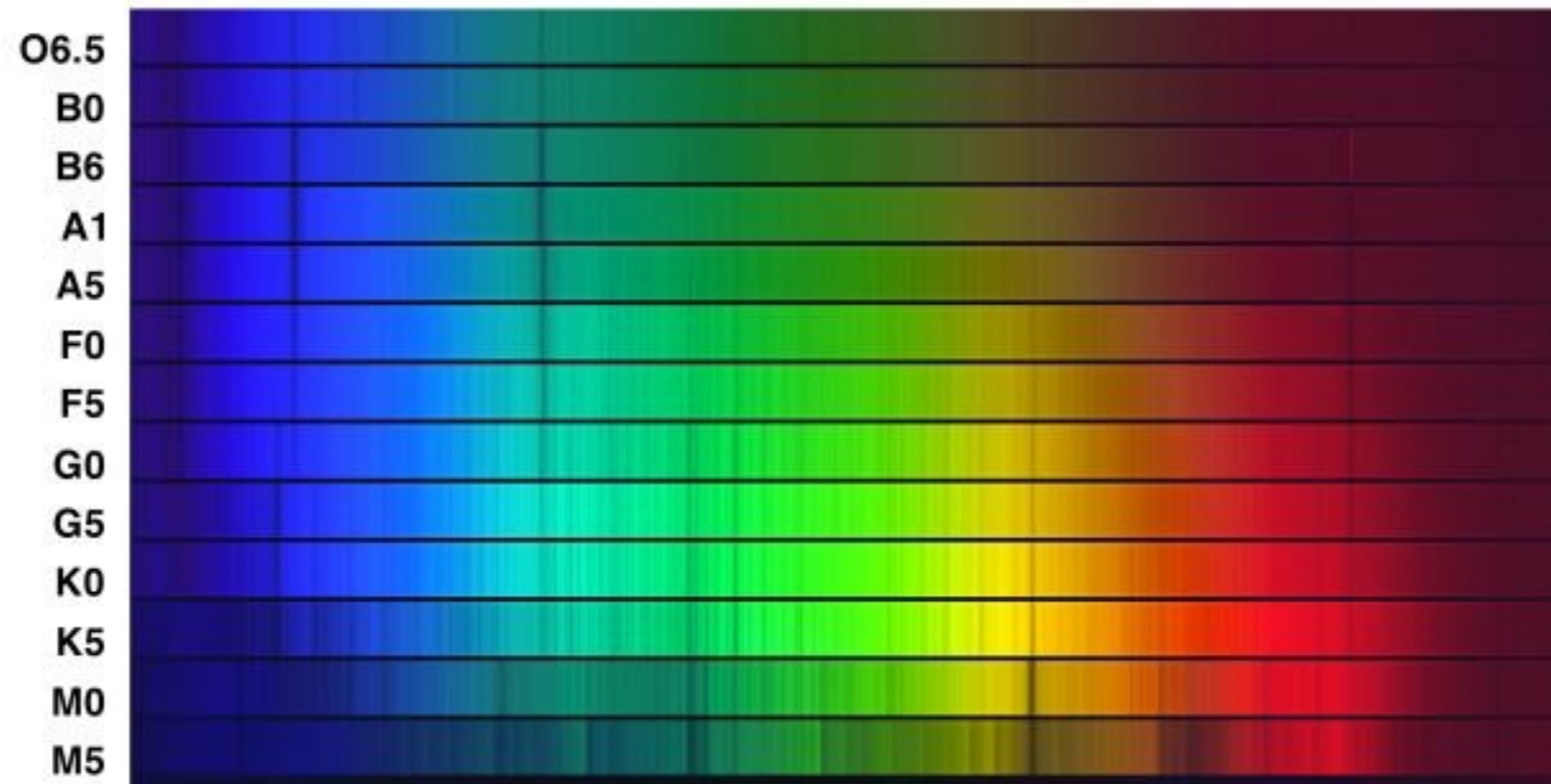
*The Milky Way  
(our neighborhood)*

**Telescopes  
(+ spectrographs)**

**Earth**

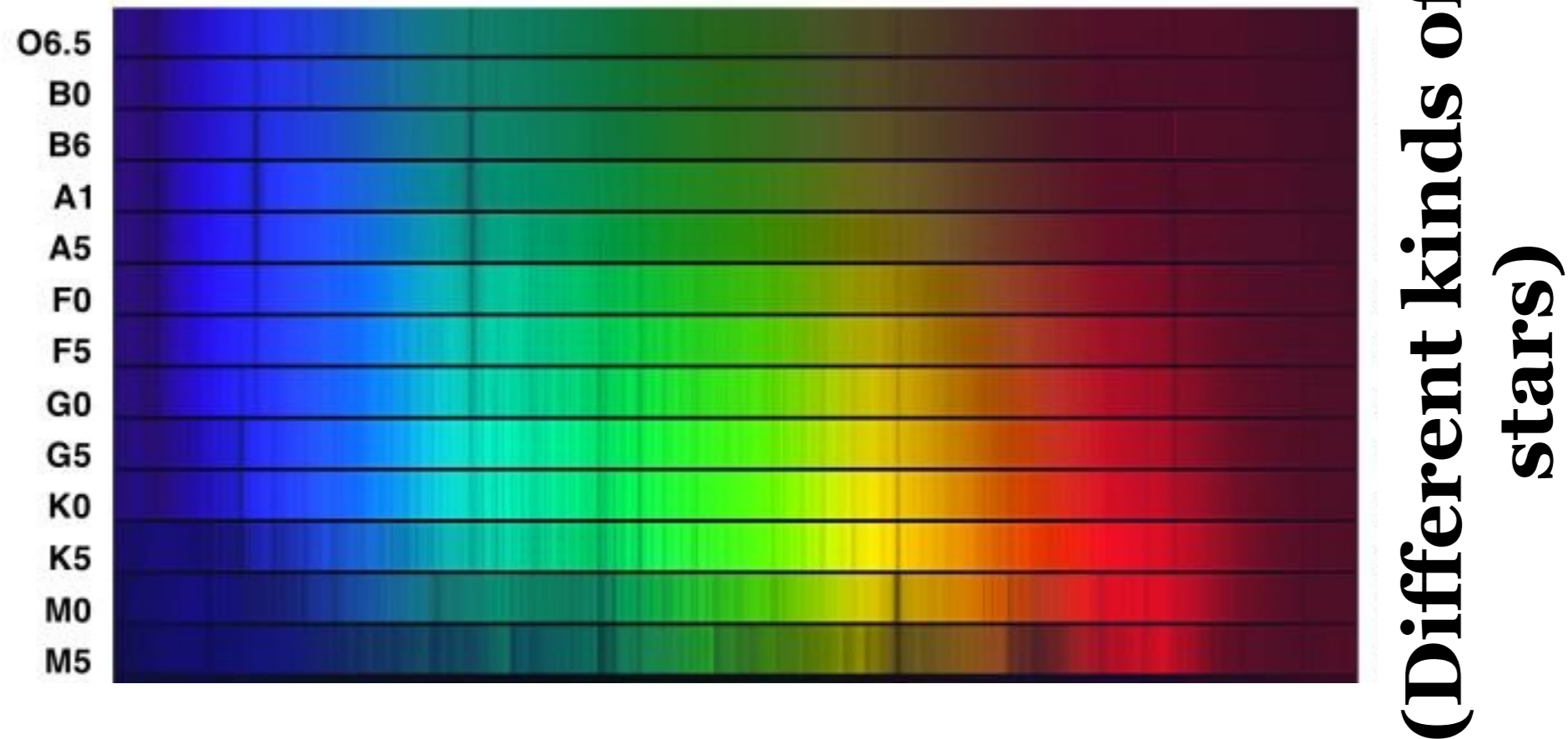


# Looks like just a bunch of lines ...



**(Different kinds of  
stars)**

**Looks like just  
a bunch of lines ...**



**...but...**



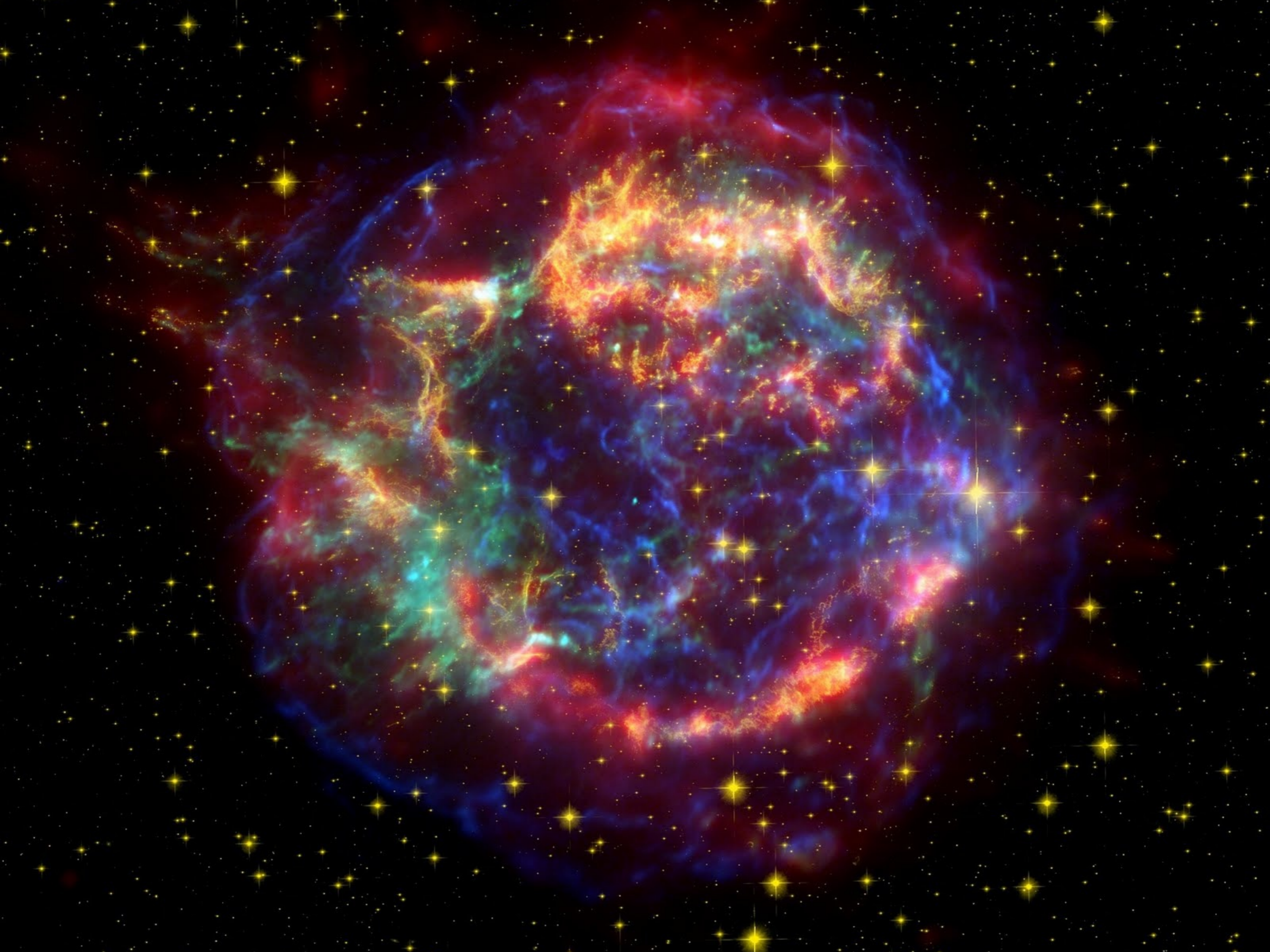


**This stuff is in us!**

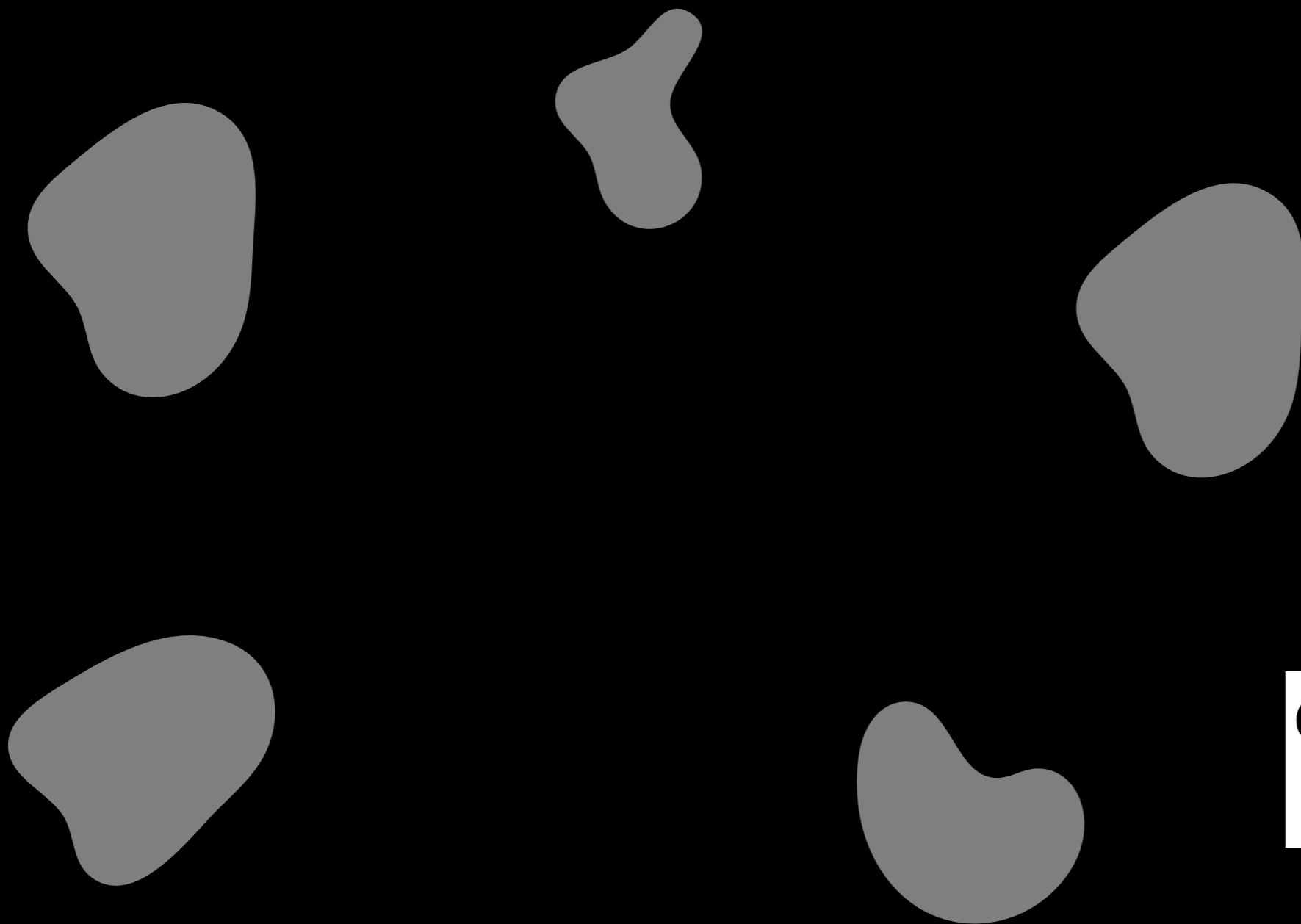








They tell us about the  
beginning of time!



**Our original  
“stuff”**



**This is the stuff we're  
made of.**