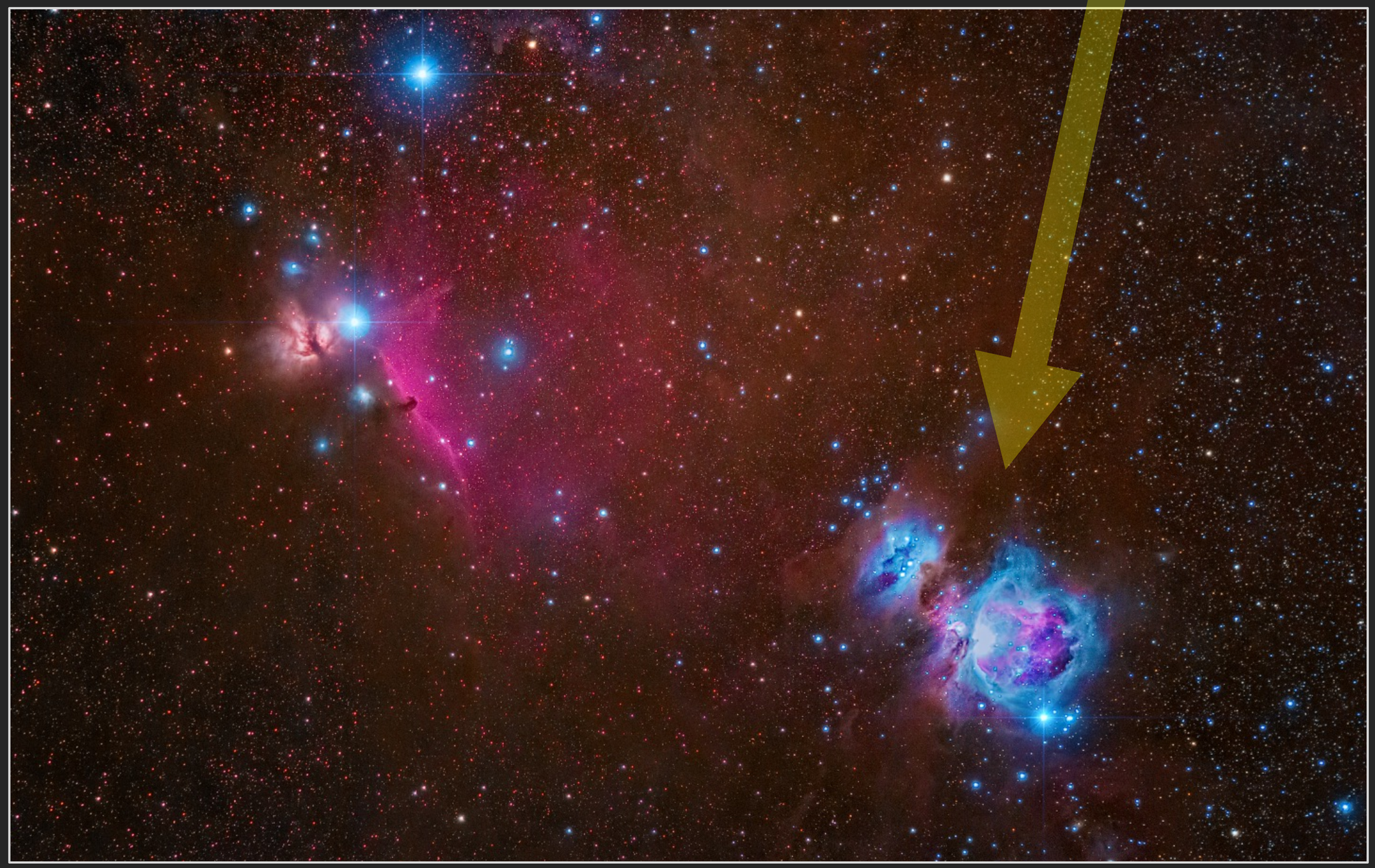
Alien Skies
Jan 26, 2022

Destination 6:
The Orion Nebula

Alien Skies
Jan 26, 2022

Destination 6:
The Orion Nebula



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- Many Bright, Blue Stars
- Dark ‘Holes’ in the Sky
- A Bright, Colorful Sky

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Destination 6: The Orion Nebula

Homeworks (new assignments):

- **Questions 10 and 11 will be posted today (both for Destination 6, Orion).**

- **HW 10 is due in one week, Feb 2, 4 PM; HW 11 due on FRIDAY, Feb 4, 11:59 PM.**

- **<u>As usual, these will be open for general discussion on Weds.</u>**

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Destination 6: The Orion Nebula

Homeworks (Grading Status):

- **HWs graded through HW 5.**
- **Grades (out of 1.0 points per question) are provided in the comments.**
- **NO VALID GRADES POSTED ON CANVAS. When you see 0 [zero] it means the assignment is graded.**

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Destination 6: The Orion Nebula

Other Assignments (Grading Status):

- **Bonus sets for Destinations 1 done; Destinations 2 and 3 soon.**
- **HWs 6 and 7 and Stellarium 1 graded by end of this week.**
- **Please defer asking about total points until next week . . .**

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Reminders:

- **Exam 1: Monday, Feb 7 (Weds of next week!). Starts at 4PM (normal class time) through 5:20PM. THIS ROOM (170 Weiser).**
- **Exam review topics to be posted within 24 hrs.**
- **Scavenger Hunt Deadline 1 is Friday, Feb 4.**

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Homework Review, Questions 8 and 9:

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Homework Review, Questions 8 and 9:

HW8: There are some LARGE numbers here! Be sure to use scientific notation and remember lots of significant digits are usually NOT needed: 1.20 is often fine while 1.202452993 is overkill.

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Homework Review, Questions 8 and 9:

HW9: Don’t forget to calculate the alternate wavelength/frequency/energy ranges.

Excel makes this chore a LOT easier!

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Most obvious thing:

Why the Bright Sky??

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Most obvious thing:

Why the Bright Sky??

On Earth: Our bright daytime sky is due to scattered sunlight.

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Most obvious thing:

Why the Bright Sky??

On Earth:
Molecules in the atmosphere do a lot of the scattering.

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The Orion Nebula

Most obvious thing:

But, especially obvious when there's added stuff, like smoke, in the air.

Why the Bright Sky??

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The Orion Nebula

But here, there is no atmosphere . . . it is ‘empty’ space that seems to glow.

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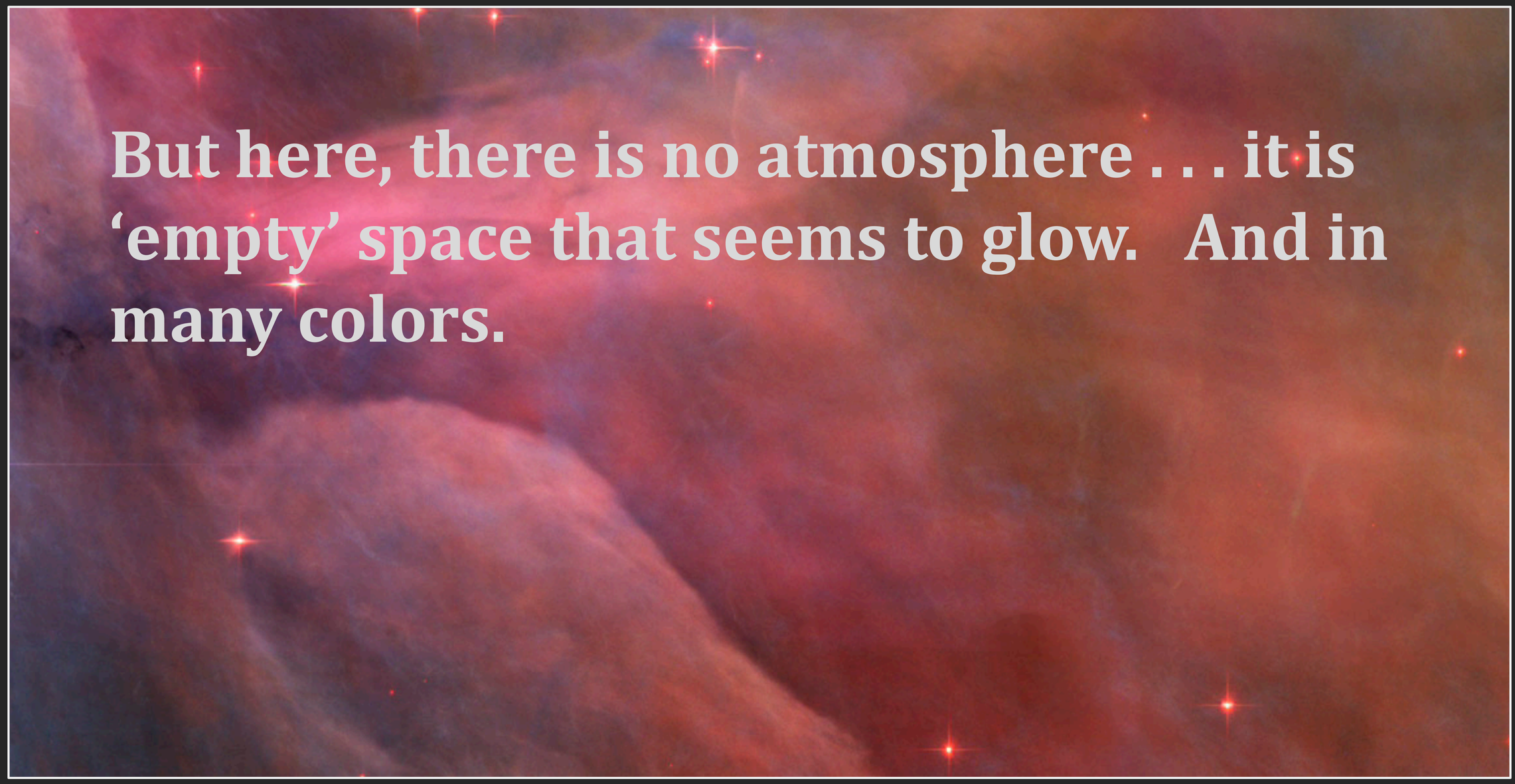
The Orion Nebula



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Destination 6:
The Orion Nebula

To analyze and ultimately understand this, we turn to

Spectroscopy

A *powerful* astronomical tool.

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Destination 6:
The Orion Nebula

To analyze and ultimately understand this, we turn to

Spectroscopy

In fact, pretty powerful in everyday life!

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Distinguishing colors is spectroscopy.

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Humans can do it . . .

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. . . and so
can birds!

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And we know that spectra can be produced in proper conditions.

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Different colors are different wavelengths, frequencies, energies of photons in the optical part of the Electromagnetic Spectrum .

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Splitting *any* type of EM radiation—not just visible light—into its constituent ‘colors’ is spectroscopy.

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The Orion Nebula

Using tools of spectroscopy, we find that the spectrum of stars in the Orion Nebula is similar to a rainbow: Light at all colors. Each is an (approximate) example of a

CONTINUOUS SPECTRUM

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Destination 6: The Orion Nebula

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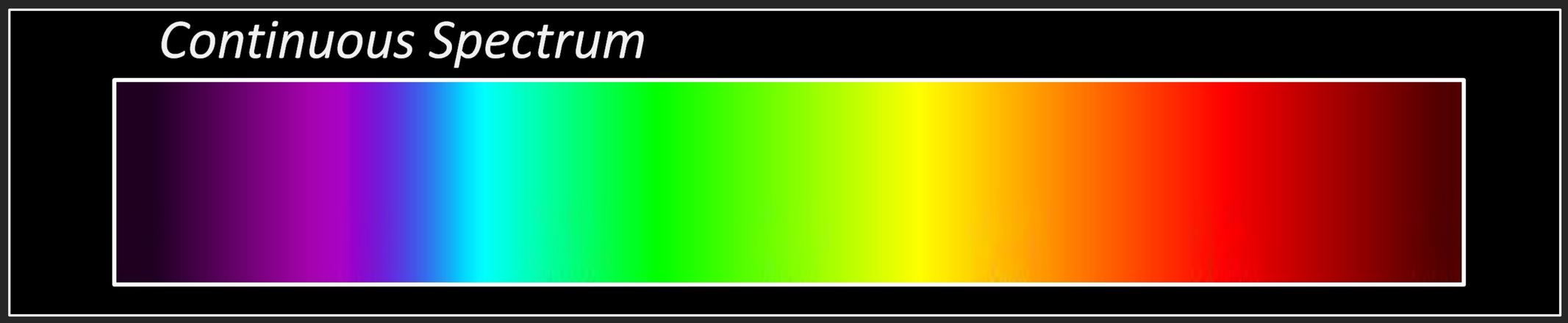

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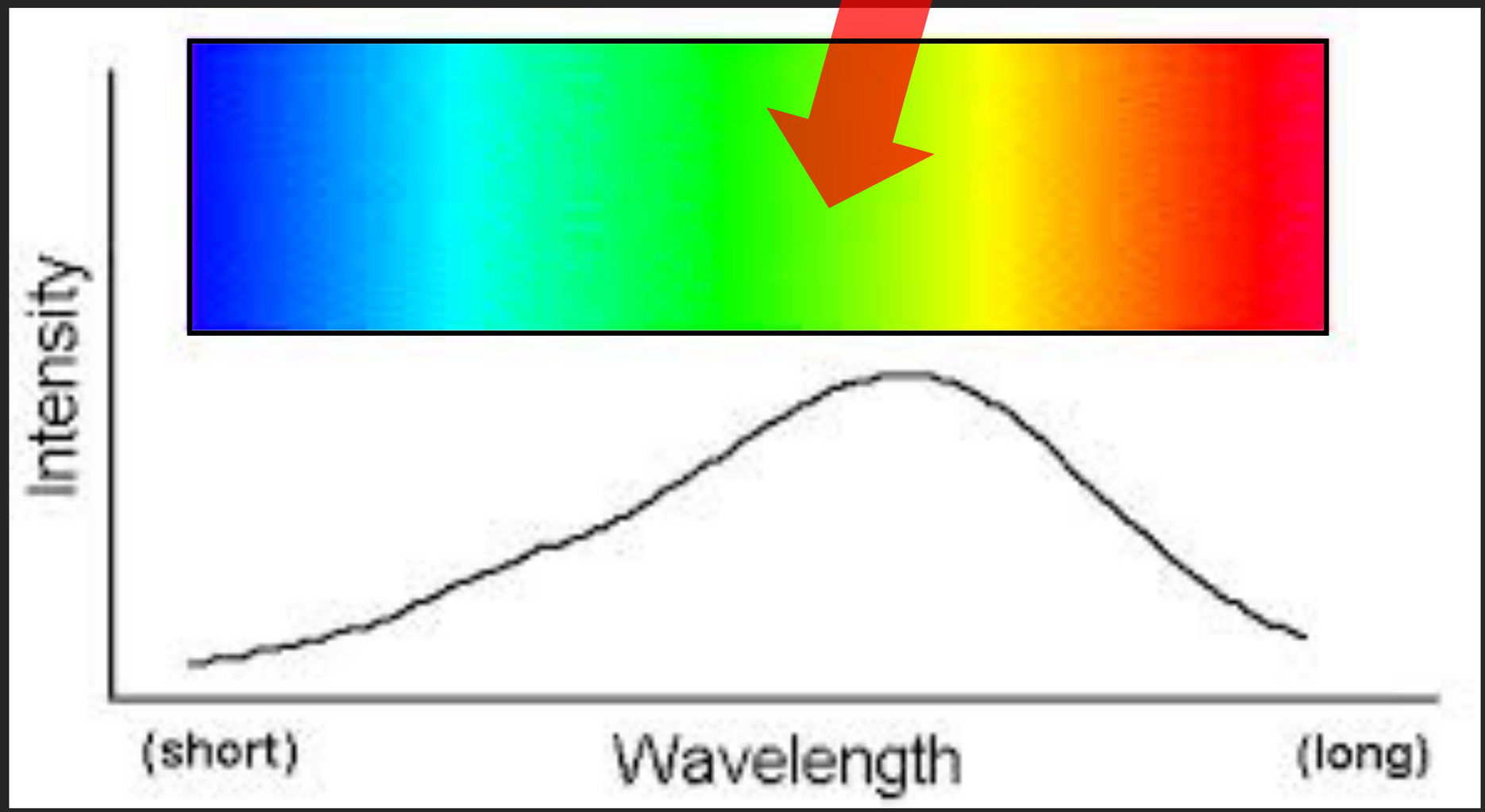
It looks like this to our eyes



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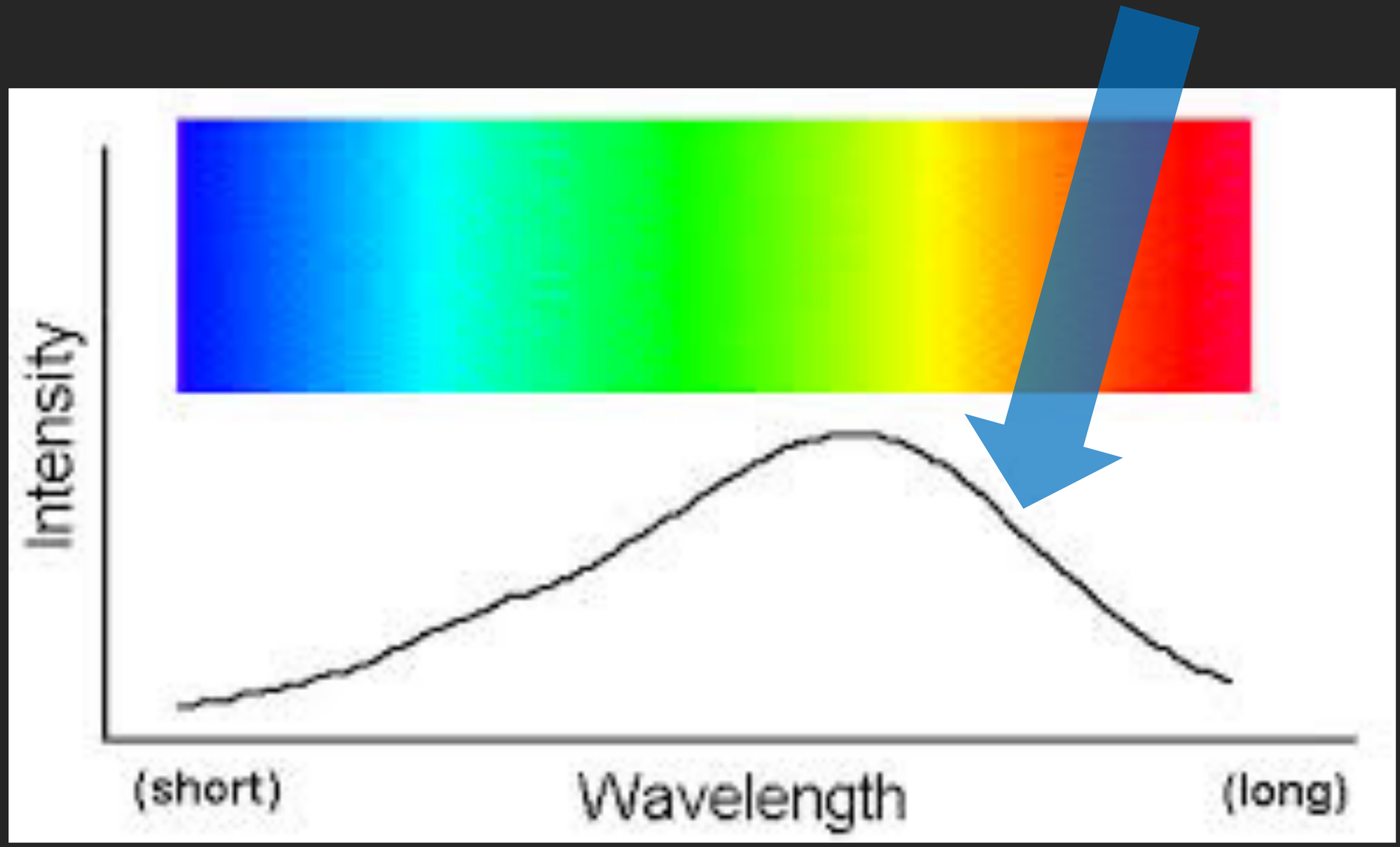
But a plot of Brightness vs Wavelength or Frequency or Energy is more quantitative and much easier to draw:



Alien Skies
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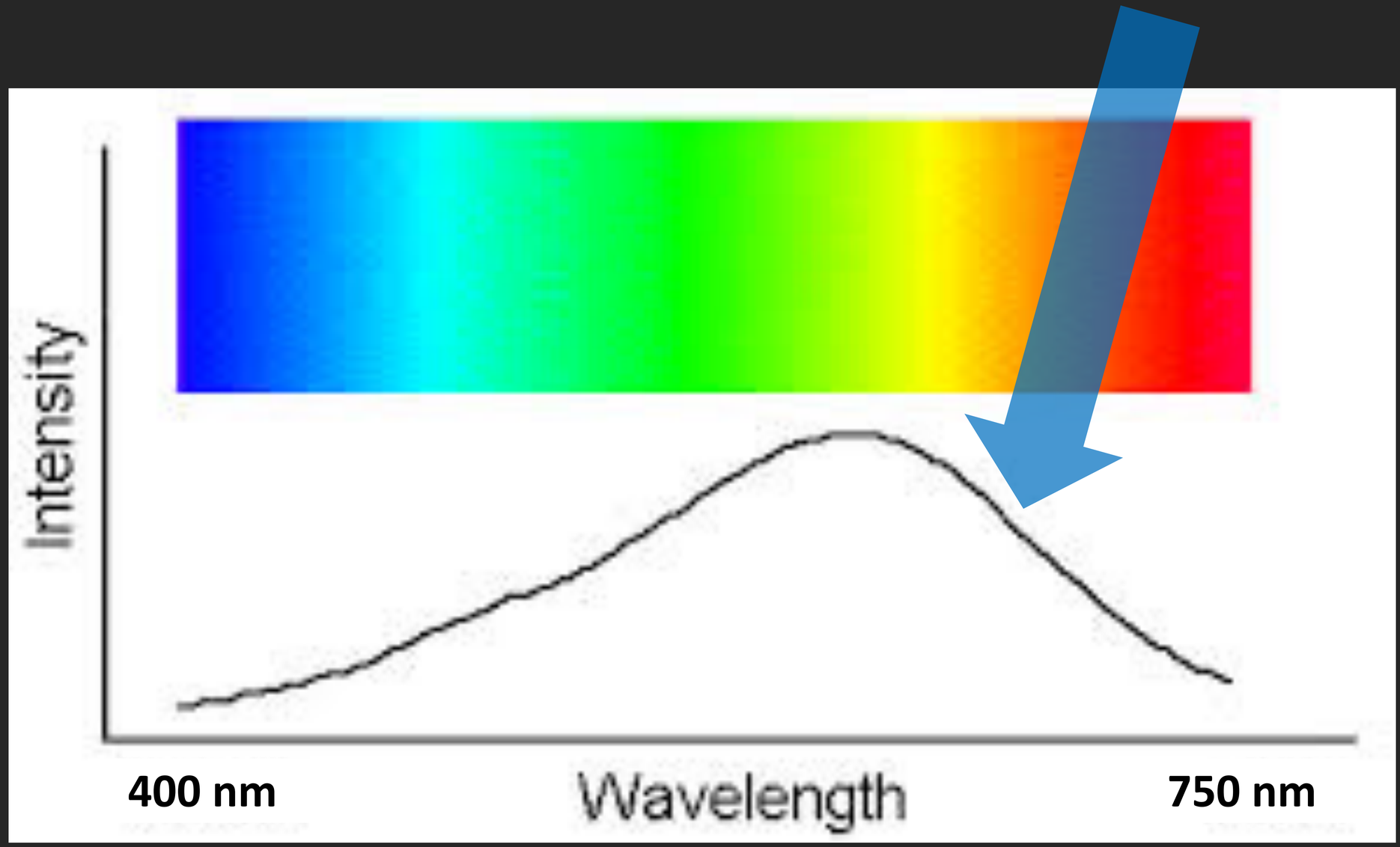

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Destination 6: The Orion Nebula

Many things emit continuous (or nearly continuous) spectra.

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Destination 6:
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Many things emit continuous (or nearly continuous) spectra.

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Destination 6:
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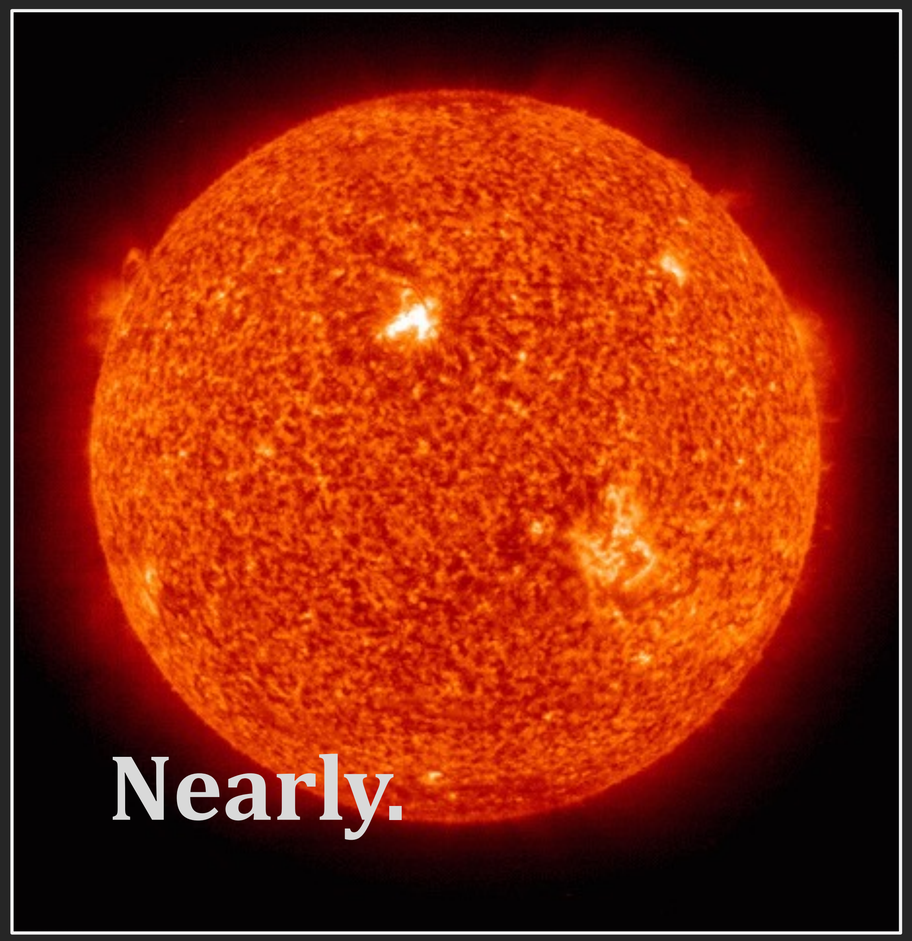
Many things emit continuous (or nearly continuous) spectra.



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Many things emit continuous (or nearly continuous) spectra.

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But this is NOT what we see here in the sky of the Orion Nebula.

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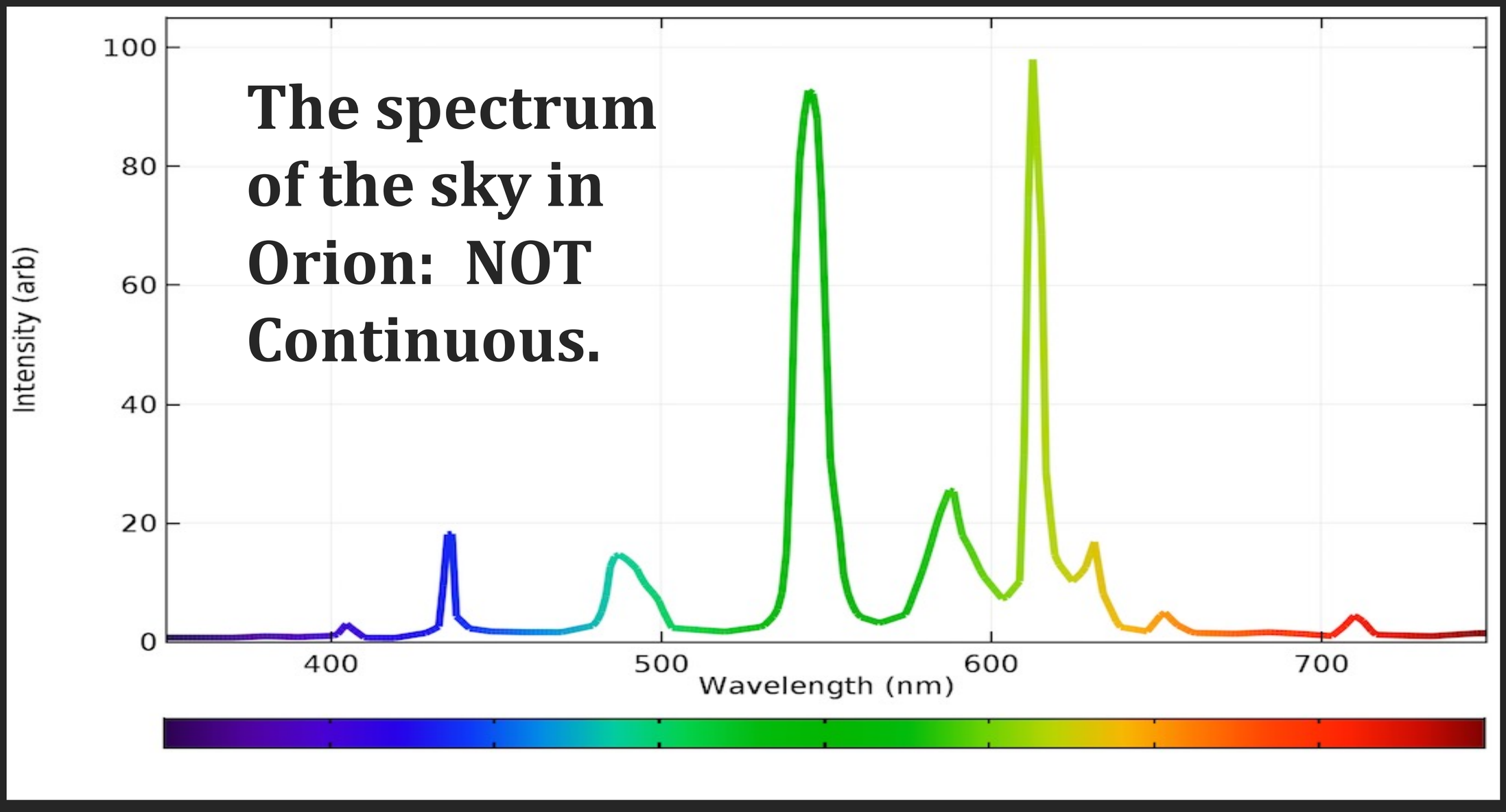

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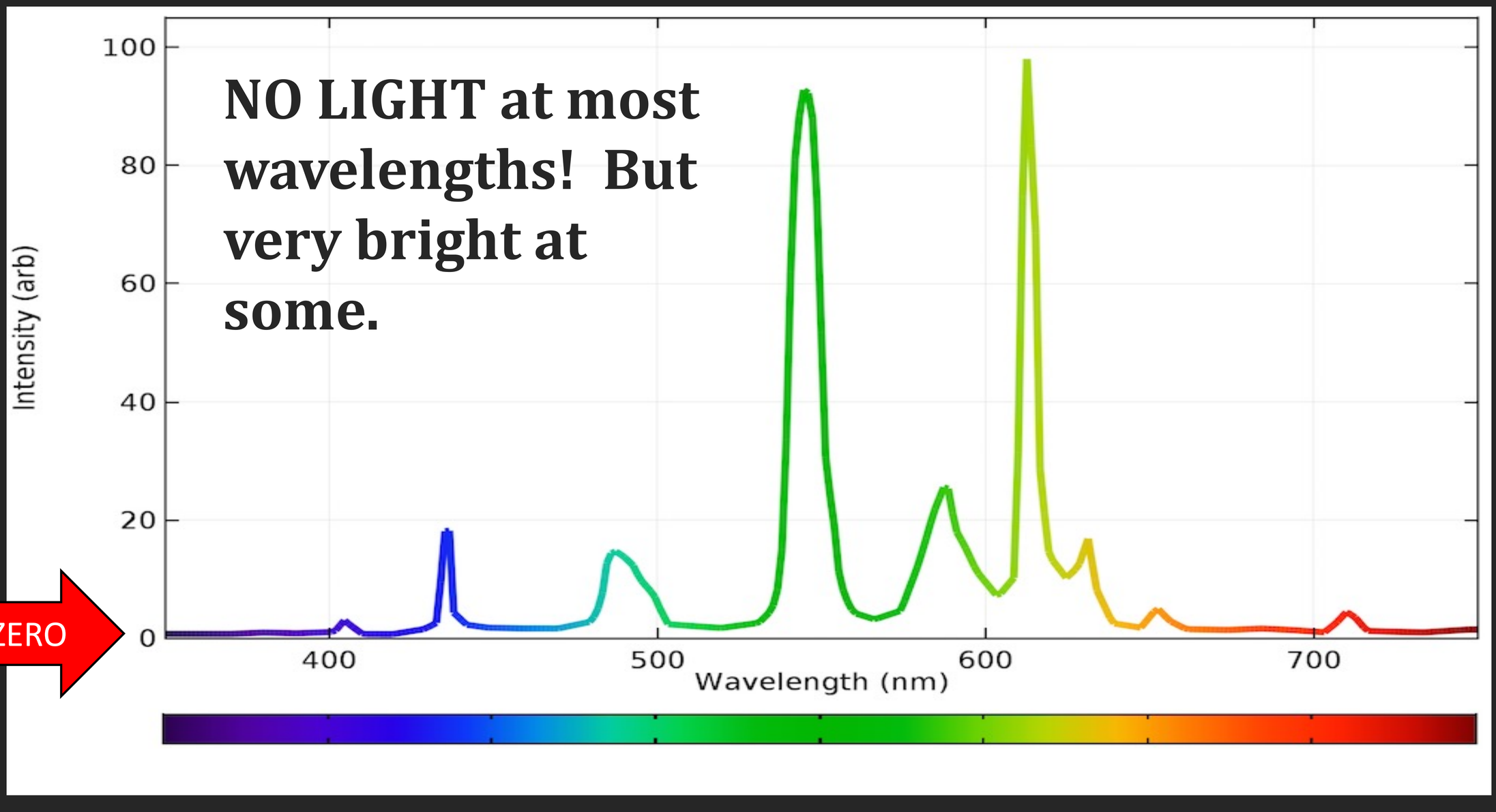
The Orion Nebula



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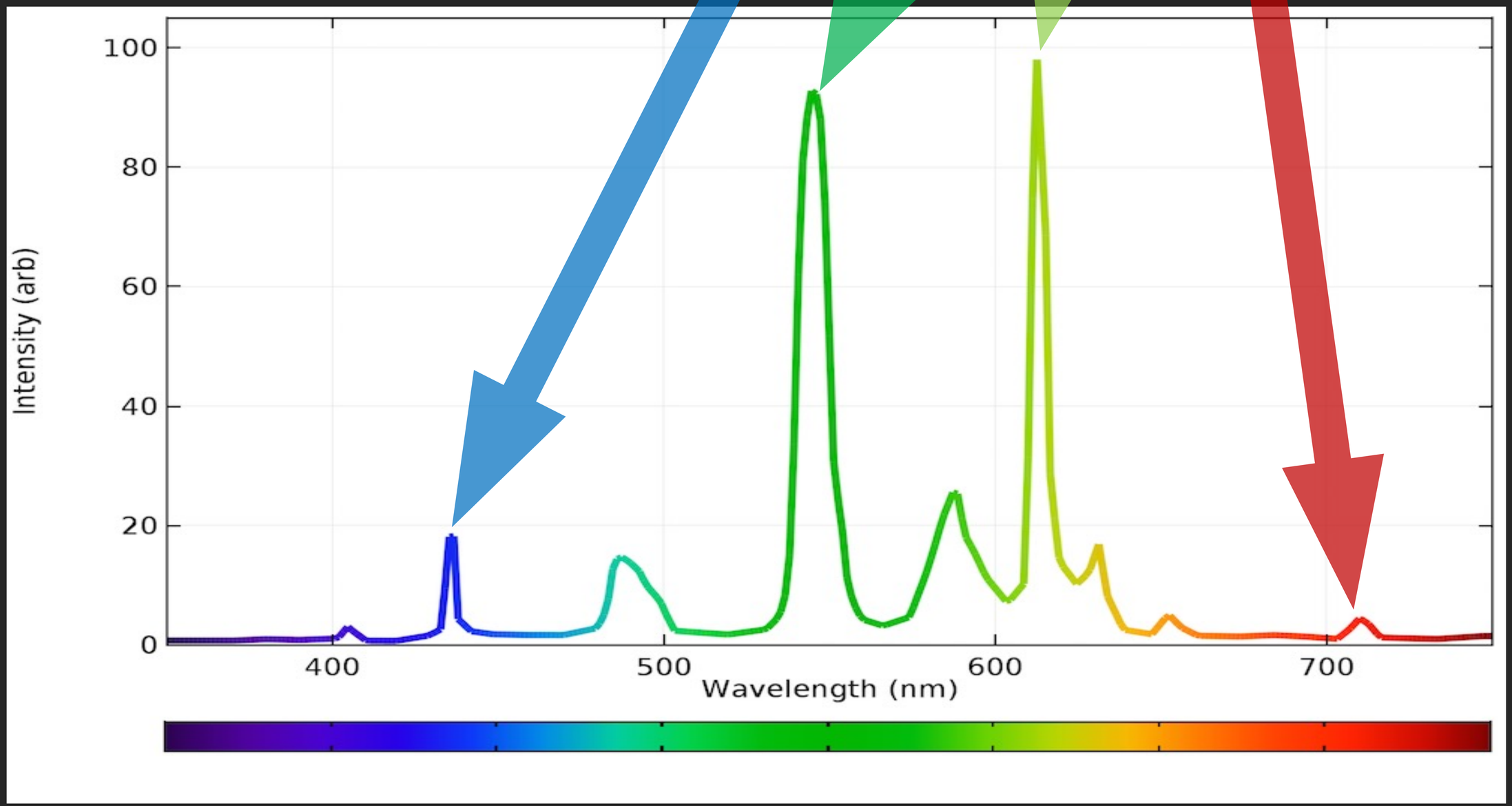

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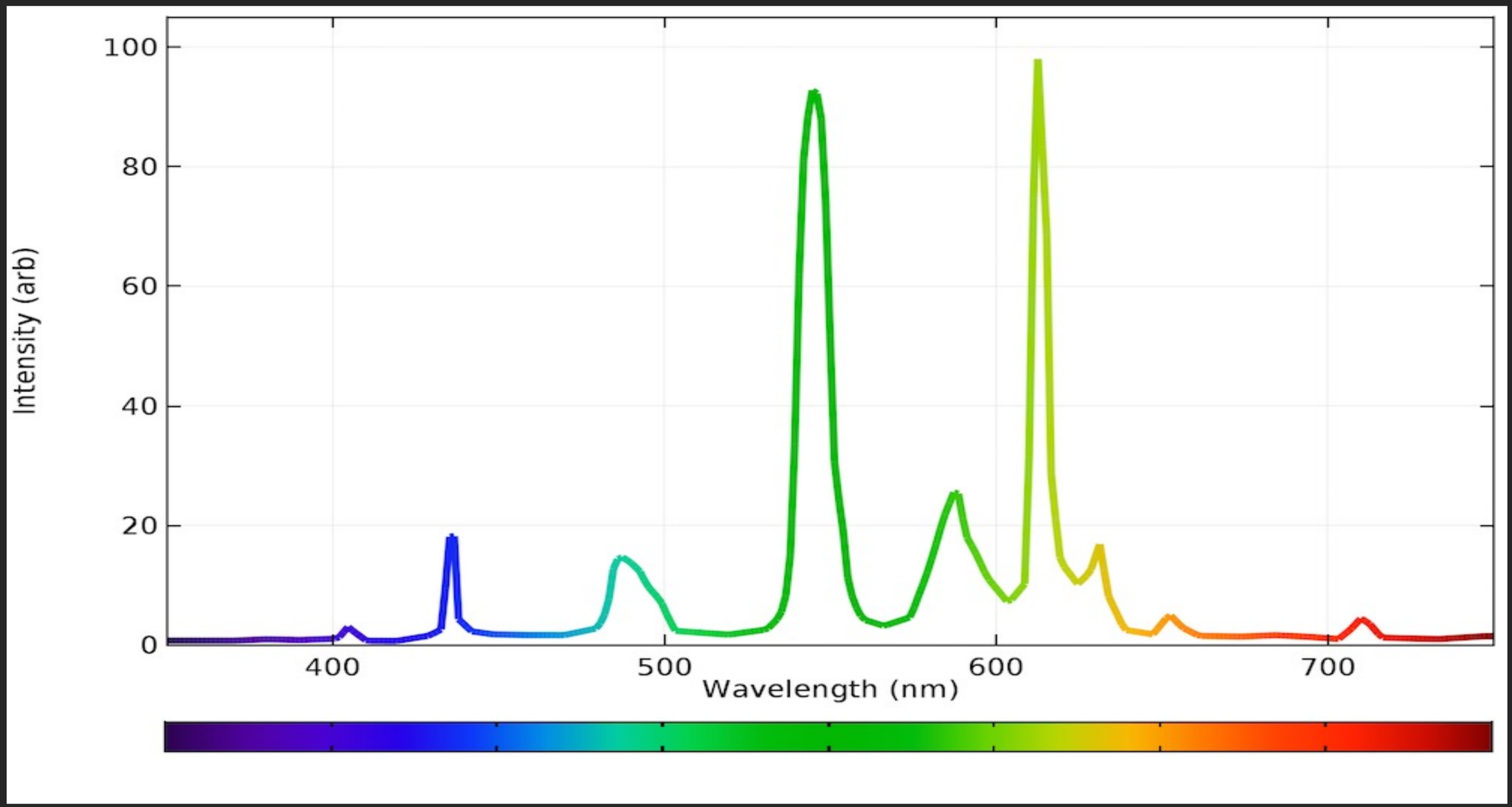
And this is an example of an
EMISSION SPECTRUM



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And this is an example of an
EMISSION SPECTRUM

See it for yourself!

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Destination 6:
The Orion Nebula

To understand why the sky here in Orion produces an emission spectrum, we need to revisit the Neutral Hydrogen Atom.

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Destination 6:
The Orion Nebula

To understand why the sky here in Orion produces an emission spectrum, we need to revisit the Neutral Hydrogen Atom.

- **One Proton:** Positive electric charge, the nucleus of the atom.

- **One Electron:** Negative electric charge, orbiting the nucleus (the proton).

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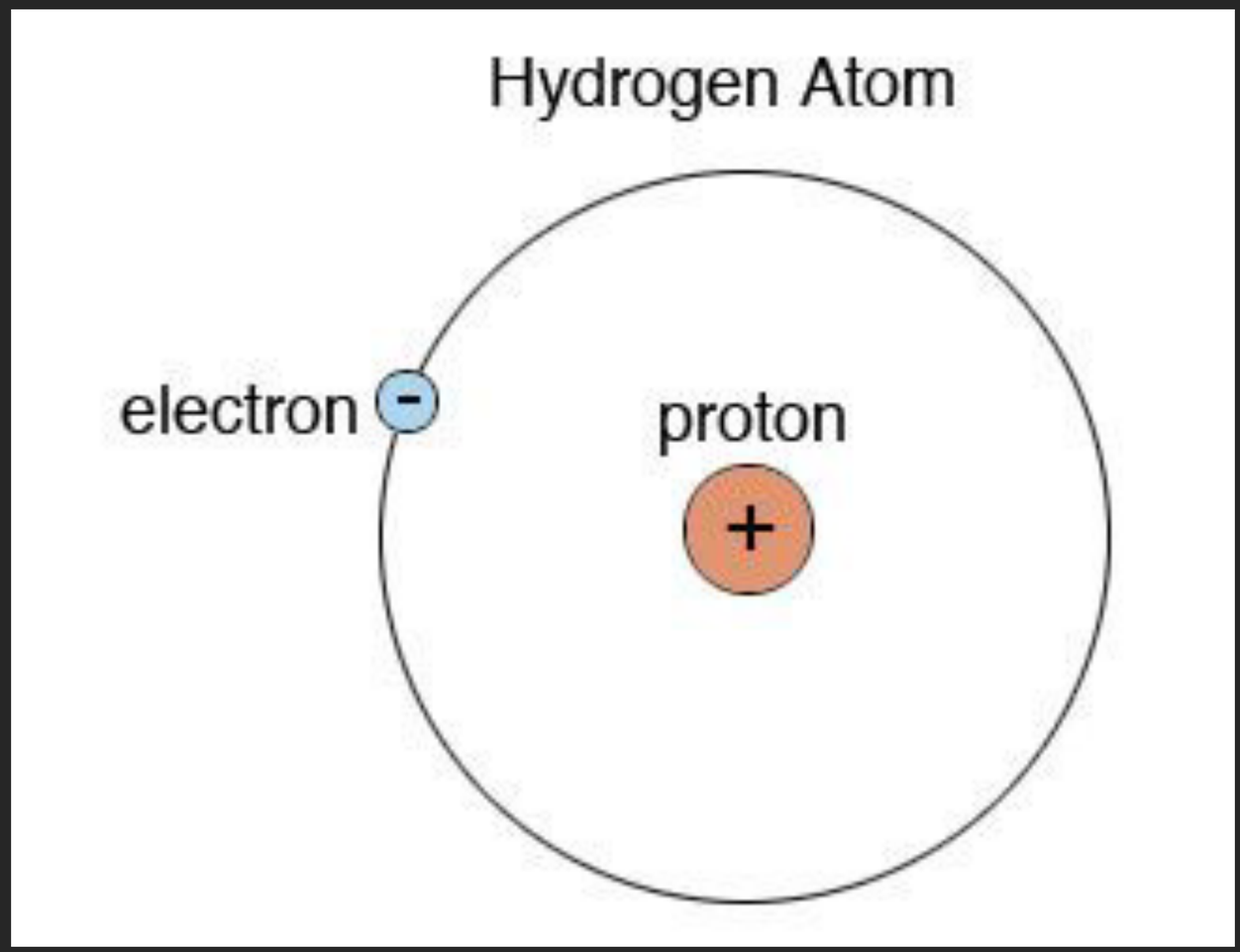

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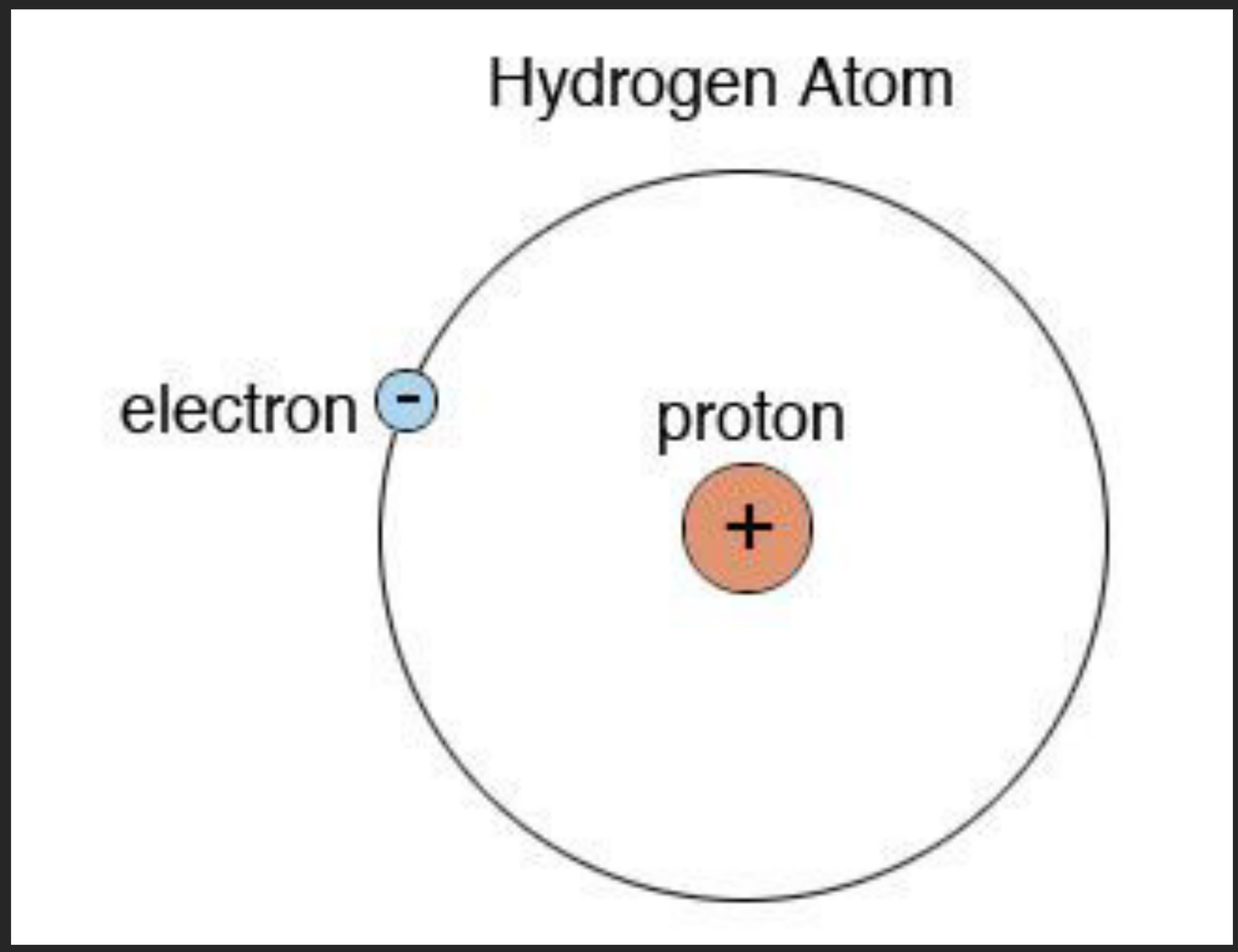

Aside: Not to scale! Think Sun and a star-sized object at 400 AU!!

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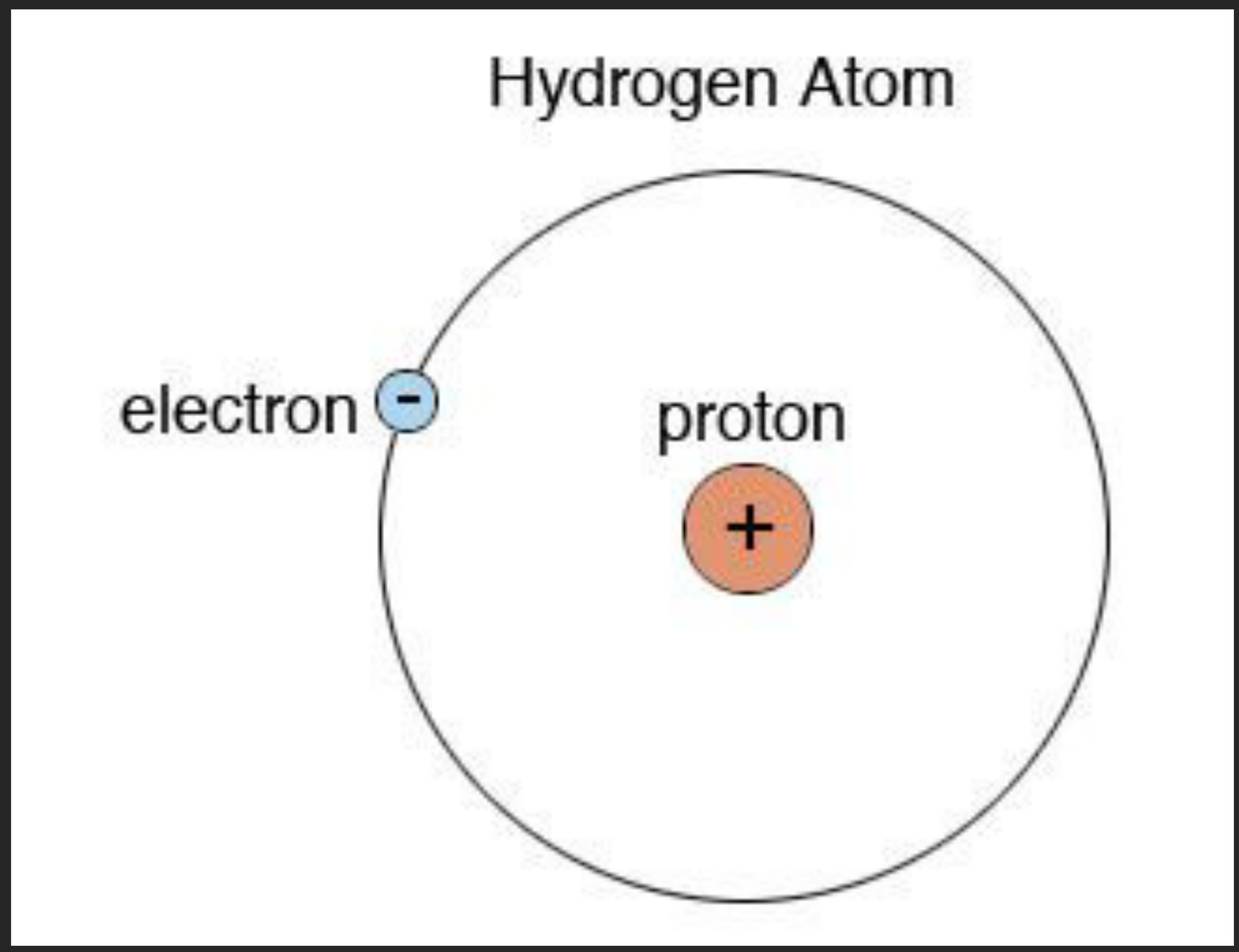
The Orion Nebula



Scale notwithstanding, there are some additional puzzles with this picture . . .

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Destination 6:
The Orion Nebula

Puzzle number 1:

- **Why doesn't the electron just fall into the nucleus? After all, unlike charges attract strongly.**

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Destination 6:
The Orion Nebula

Puzzle number 1:

- **Why doesn't the electron just fall into the nucleus? After all, unlike charges attract strongly.**

Puzzle number 2:

- **How does any of this atomic structure relate to emission lines in emission spectra?**

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Like we saw with photons—particles of EM radiation that exhibit BOTH wavelike and particle-like properties—subatomic particles like electrons are not quite simple to classify as they first seem.

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De Broglie Equation:

$$\lambda = h/p$$

λ is the wavelength
h is Planck's constant
p is the momentum

. . . of a particle!!!

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For 'normal' particles (with mass), $p = mV$, the particle's mass times its velocity.

This can be a photon of EM radiation.

This can be an electron.

This can be a baseball!

Wave-Particle Duality

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Super Key Point:

It means all particles can act like what we understand particles to be, but also like WAVES.

For everyday objects, their wave properties are minimal . . .

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Bonus 16 (a.k.a. Bonus 6.1):

Imagine a baseball moving at 75 mph. What is its deBroglie wavelength?

By what factor is the diameter of the ball larger than this wavelength?

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The Orion Nebula

But at subatomic scales, the wave nature of particles is significant. And this matters because waves act oddly . . .

Combined Wave

Input waves

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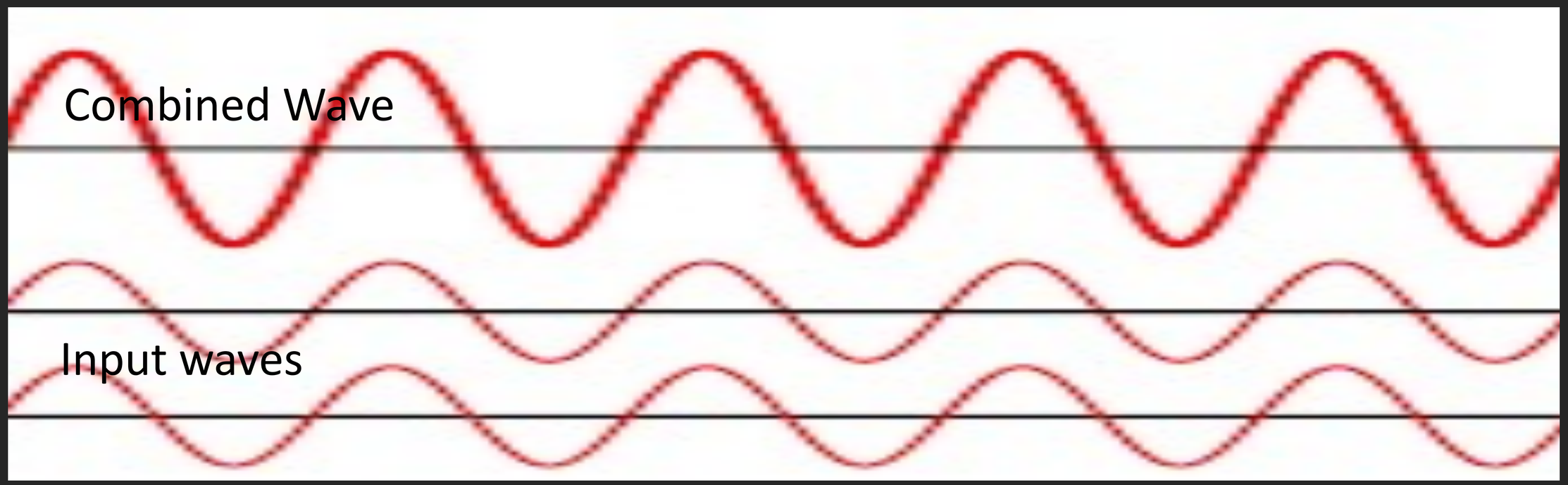
Particles ‘bounce’ but waves . . . Interfere.

Sometimes constructively:



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Destination 6:
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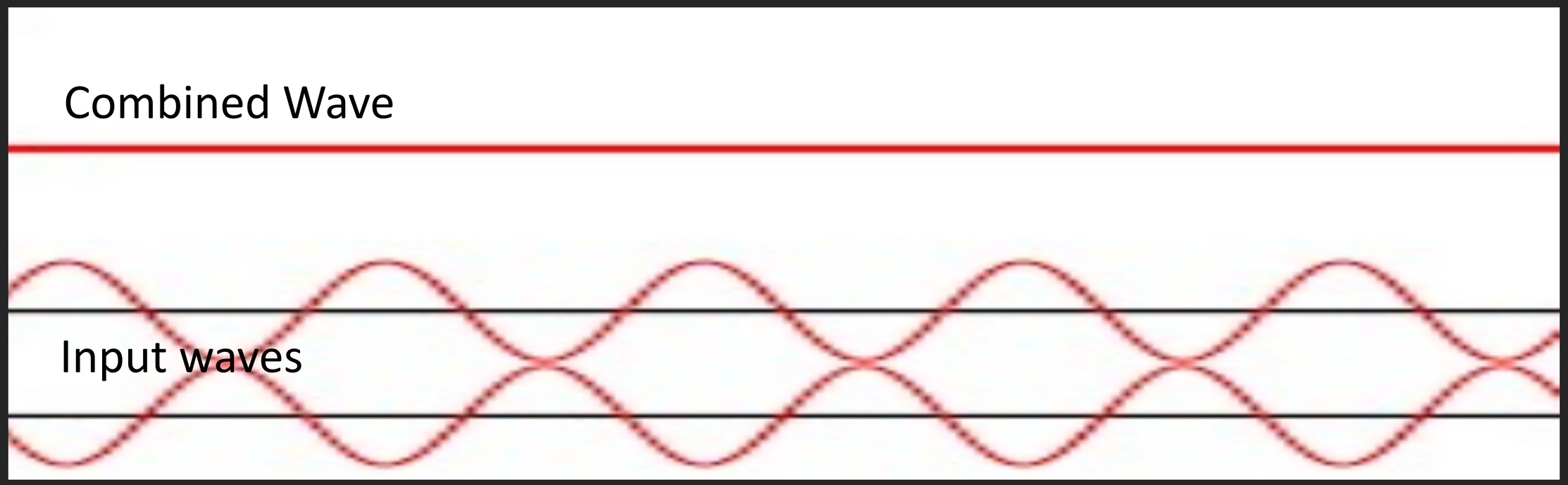
Particles ‘bounce’ but waves . . . Interfere.

Sometimes destructively:



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An electron in an atom is much more like a wave than a particle with a wavelength, λ_e .

- **Consequently, it can ONLY exist at specific orbits about the proton where the orbit circumference is such that the electron interferes with itself constructively.**

- **At any other orbits, it interferes with itself destructively.**

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The resulting orbits are labeled as

$n = 1:\ \ 2\pi R_1 = \lambda_e$ **'Ground Orbit' (smallest)**
$n = 2:\ \ 2\pi R_2 = 2\lambda_e$
$n = 3:\ \ 2\pi R_3 = 3\lambda_e$

. . . and so on to $n \to \infty$**.**

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The Orion Nebula

The resulting orbits are labeled as

$n = 1:\ \ 2\pi R_1 = \lambda_e$ **'Ground Orbit' (smallest)**
$n = 2:\ \ 2\pi R_2 = 2\lambda_e$
$n = 3:\ \ 2\pi R_3 = 3\lambda_e$

That is, the orbit circumference must be one electron wavelength, or 2, or 3, or any whole number of wavelengths.

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DEMO.

Combined Wave

Input waves

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Solving Puzzle 1:

The electron does not fall into the nucleus because its wave nature does not allow it to. As a wave, it cannot normally 'exist' in the atom's nucleus!

The $n = 1$ orbit is called the Ground State. The electron cannot get any closer until really extreme conditions occur.

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Solving Puzzle 2:

- **Each orbit corresponds to an ENERGY.**

Large orbits.

Small orbits.

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Solving Puzzle 2:

- **Each orbit corresponds to an ENERGY.**

This is a fall.

This is a trip.

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Solving Puzzle 2:

- **Each orbit corresponds to an ENERGY.**
- **Like stairs, moving from one orbit to another requires discrete changes of energy, E.**
- **An electron must absorb or emit a photon or EM radiation of a precise energy (wavelength, frequency, color) to change its orbit.**

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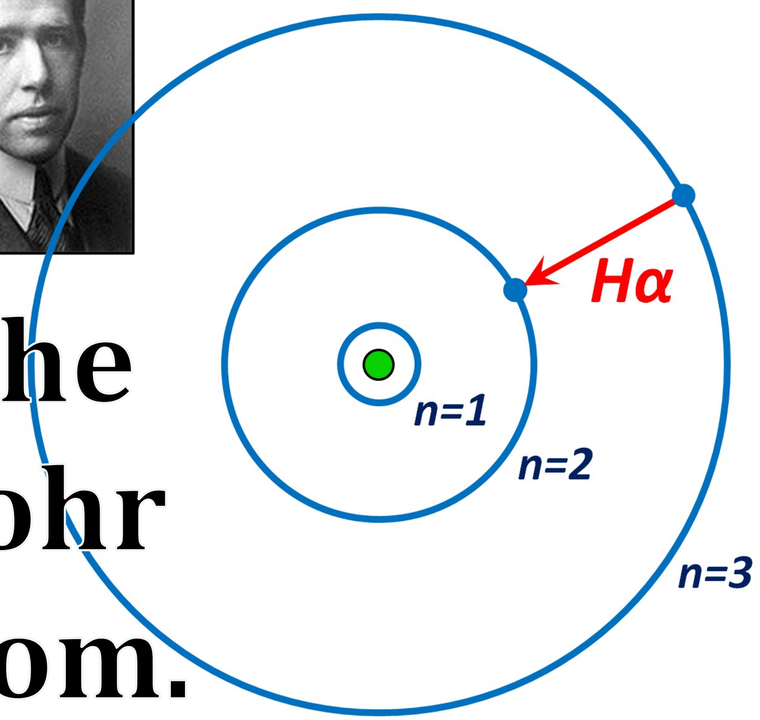
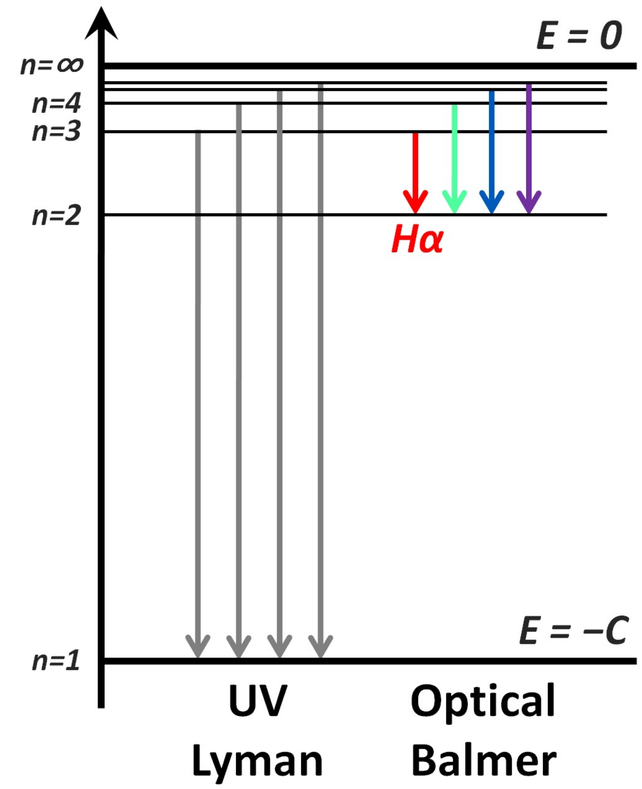
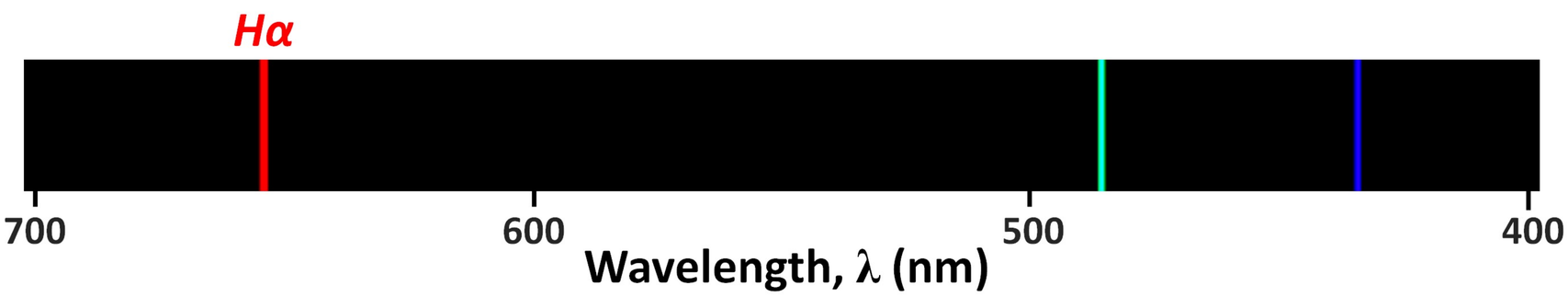
The Bohr Atom.







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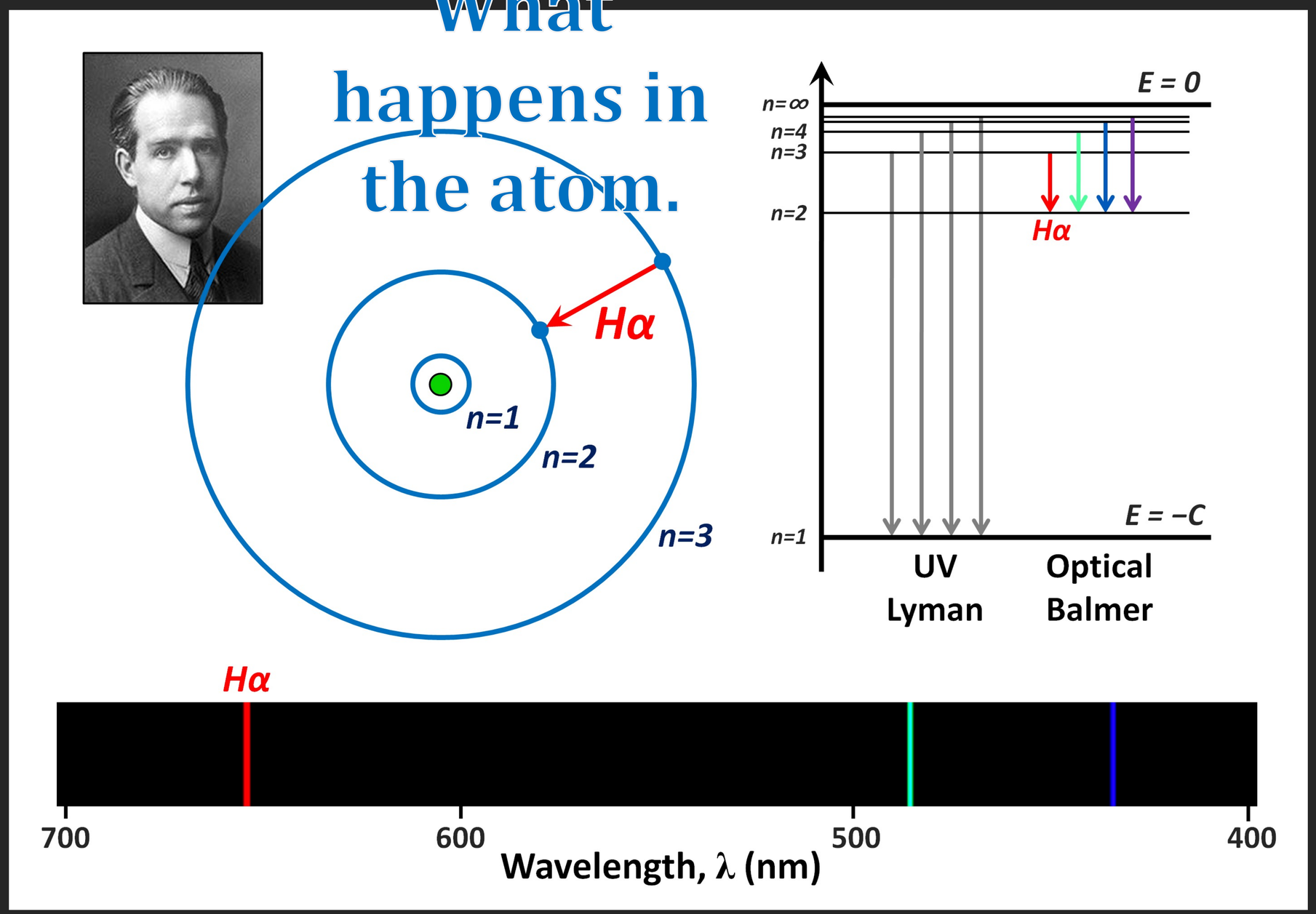

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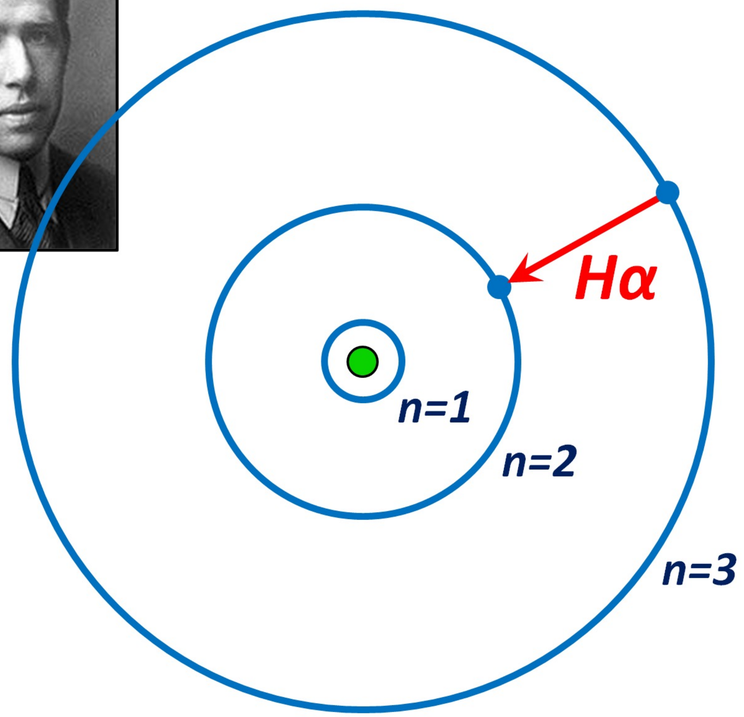
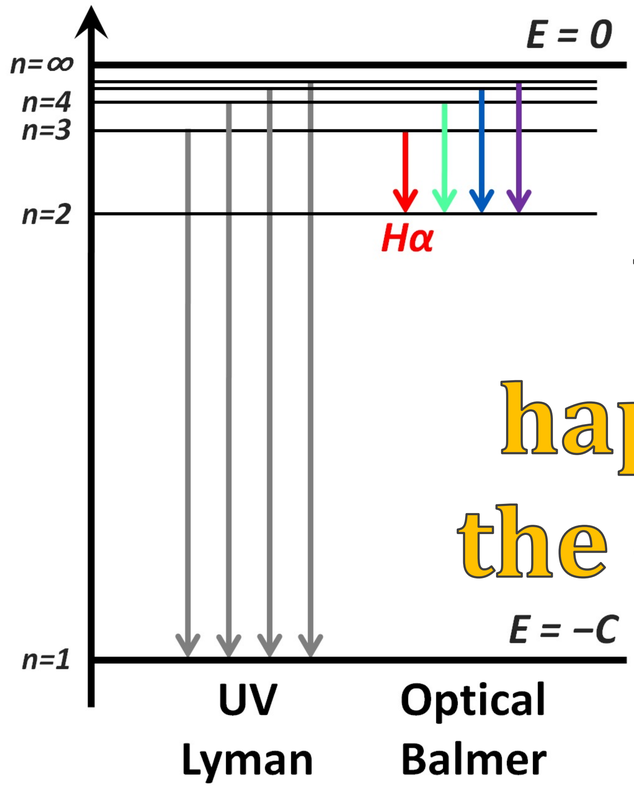
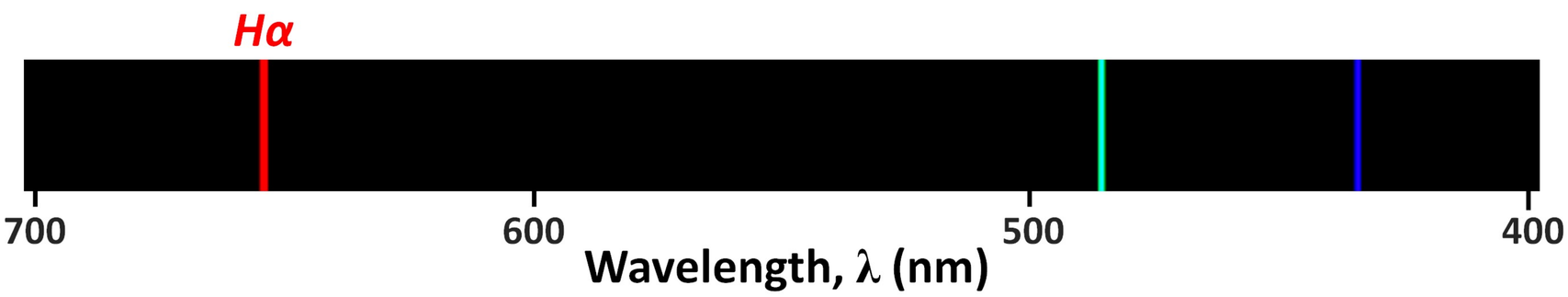




What happens to the energies.



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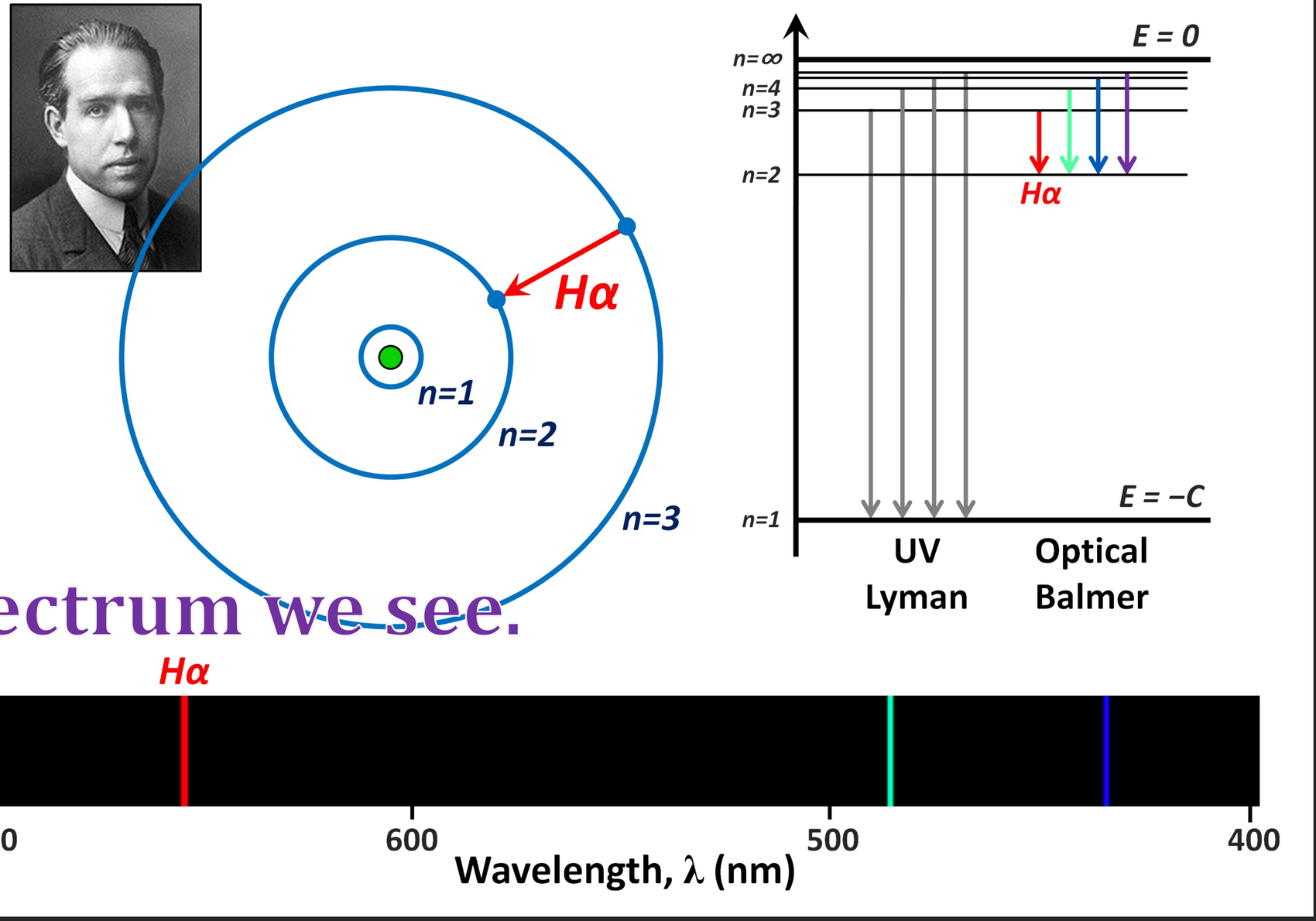

The spectrum we see.

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The H spectrum we see.

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Analyzing emission spectra can tell us the temperature and density of the gas. In places like Orion:

$$T \sim 10,000\ K$$

n (number density) is 0.01 to 0.1 cm^{-3}

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For the bright sky of Orion:

Temperature matters, because thermal energy and radiation can ‘excite’ or ‘de-excite’ electrons in atoms via emission and collisions.

Density matters, because it dictates the frequency of collisions between particles.

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This combination:

$$T \sim 10,000\ K$$

n (number density) is 0.01 to 0.1 cm^{-3}

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This combination:

$$T \sim 10,000\ K$$

n (number density) is 0.01 to 0.1 cm^{-3}

Reveals yet another ‘phase’ of the ISM:

The Hot ISM

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But there's more!

We can use emission lines to identify different Elements in the ISM. Each element has its own characteristic pattern of lines . . .

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Destination 6:
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But there's more!

We can use emission lines to identify different Elements in the ISM. Each element has its own characteristic pattern of lines . . .

In Orion, there's plenty of Hydrogen, but also Oxygen (O), Nitrogen (N), Neon (Ne), Helium (He), Sulphur (S) and many other elements visible in the emission spectrum of the sky of Orion!

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You can do spectral analysis too!
(Worth up to 1 class point)

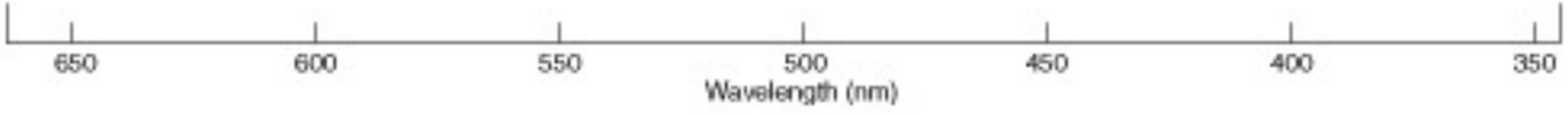
Hydrogen

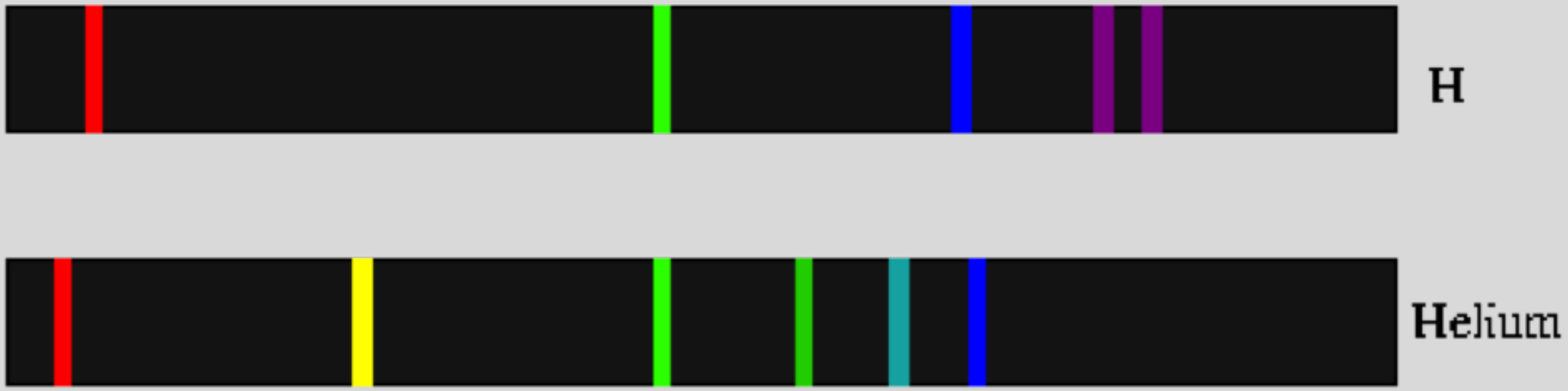
Sodium

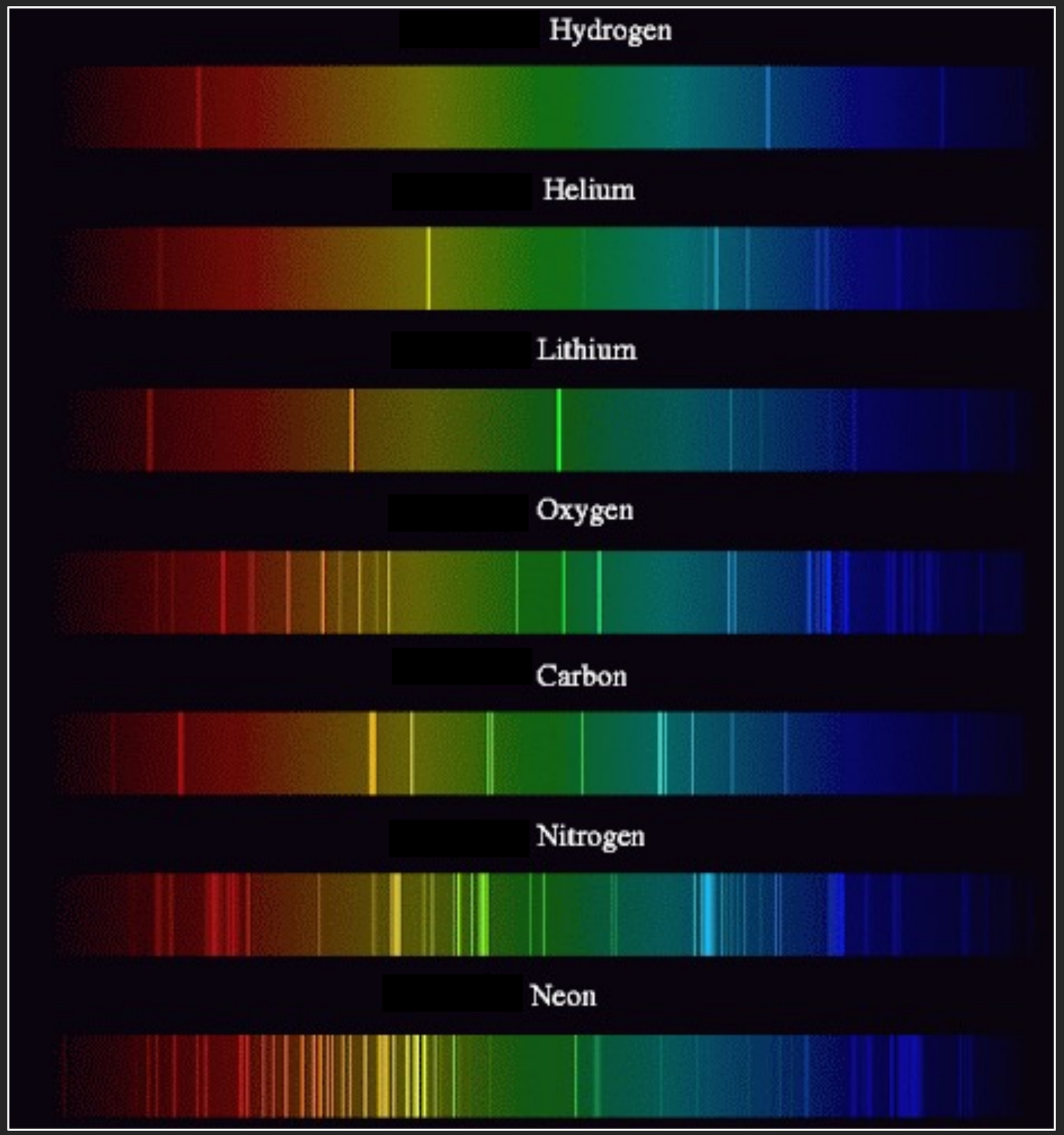
Helium

Neon

Mercury




H
Helium
Neon
Sodium
Mercury


Hydrogen
Helium
Lithium
Oxygen
Carbon
Nitrogen
Neon