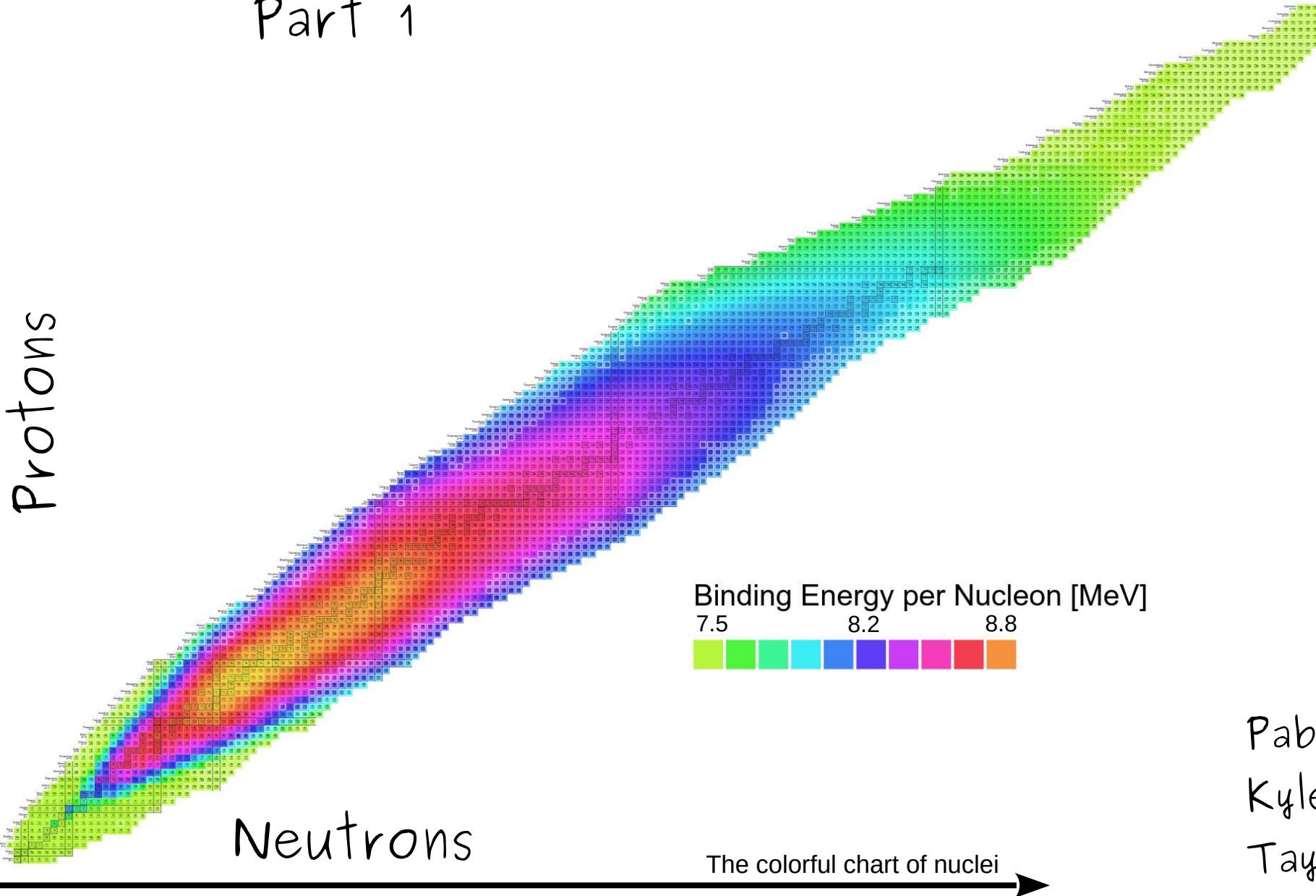




# Nuclear Models

Part 1



Pablo G.  
Kyle G.  
Taylor W.

# For today

## Building a nuclear model

- Physics models
- Binding energy
- Coding time

## Nuclear Structure

- Building (better) models
- Shell model

## Nuclear Reactions

- Intro to scattering
- Optical potentials

# For today

## Building a nuclear model

- Physics models
- Binding energy
- Coding time

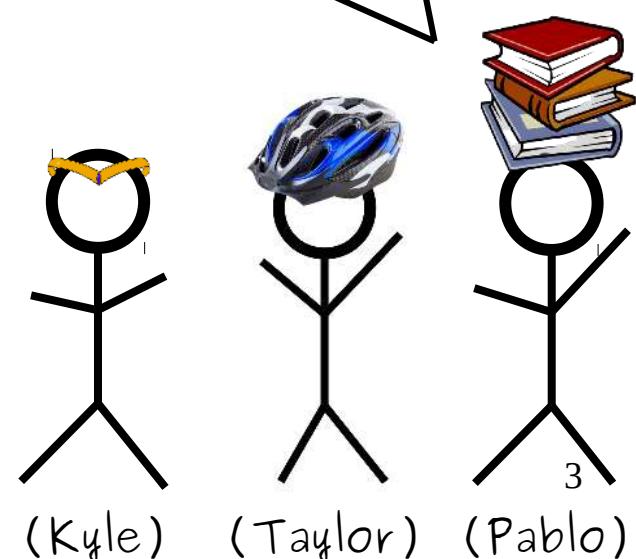
## Nuclear structure

- Building (better) models
- Shell model

## Nuclear Reactions

- Intro to scattering
- Optical potentials

Ask  
questions



# For today

## Building a nuclear model

- Physics models
- Binding energy
- Coding time

1 question =



## Nuclear structure

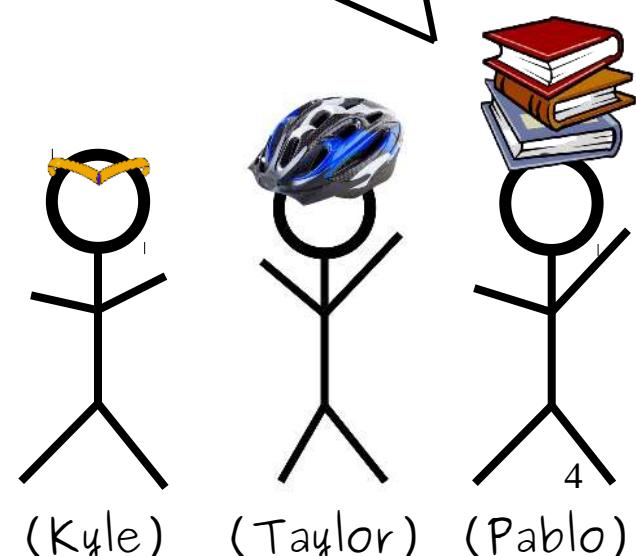
- Building (better) models
- Shell model

## Nuclear Reactions

- Intro to scattering
- Optical potentials

Ask

questions



# Building models (planets)

XVII century



# Building models (planets)

XVII century



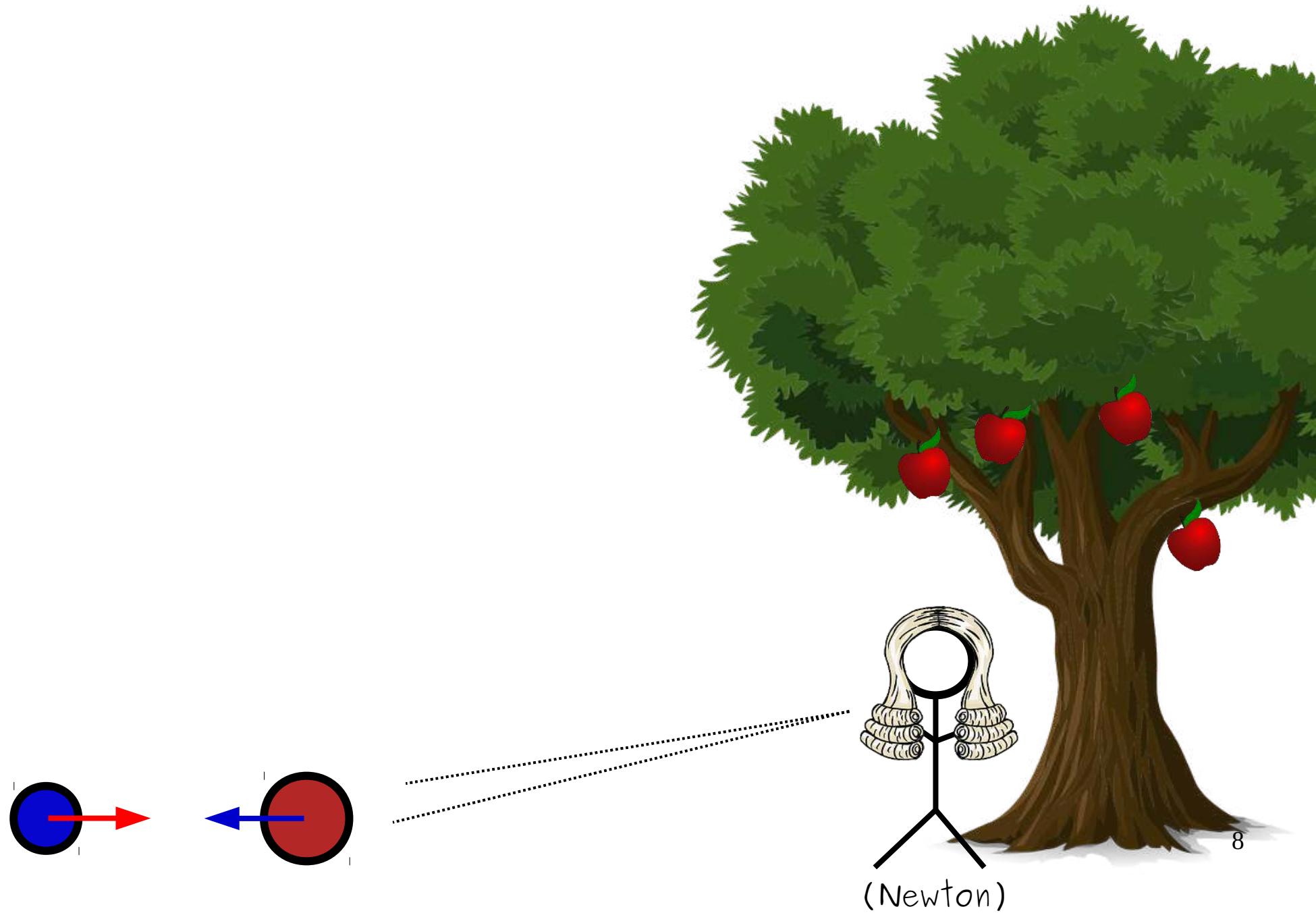
# Building models (planets)

XVII century



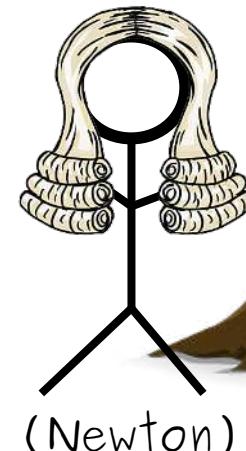
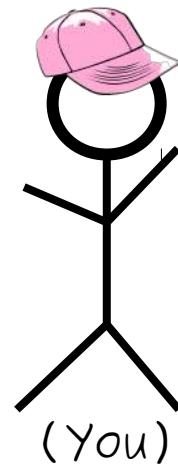
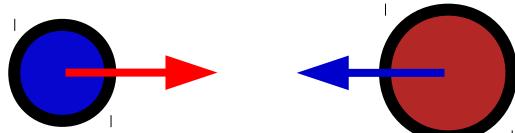
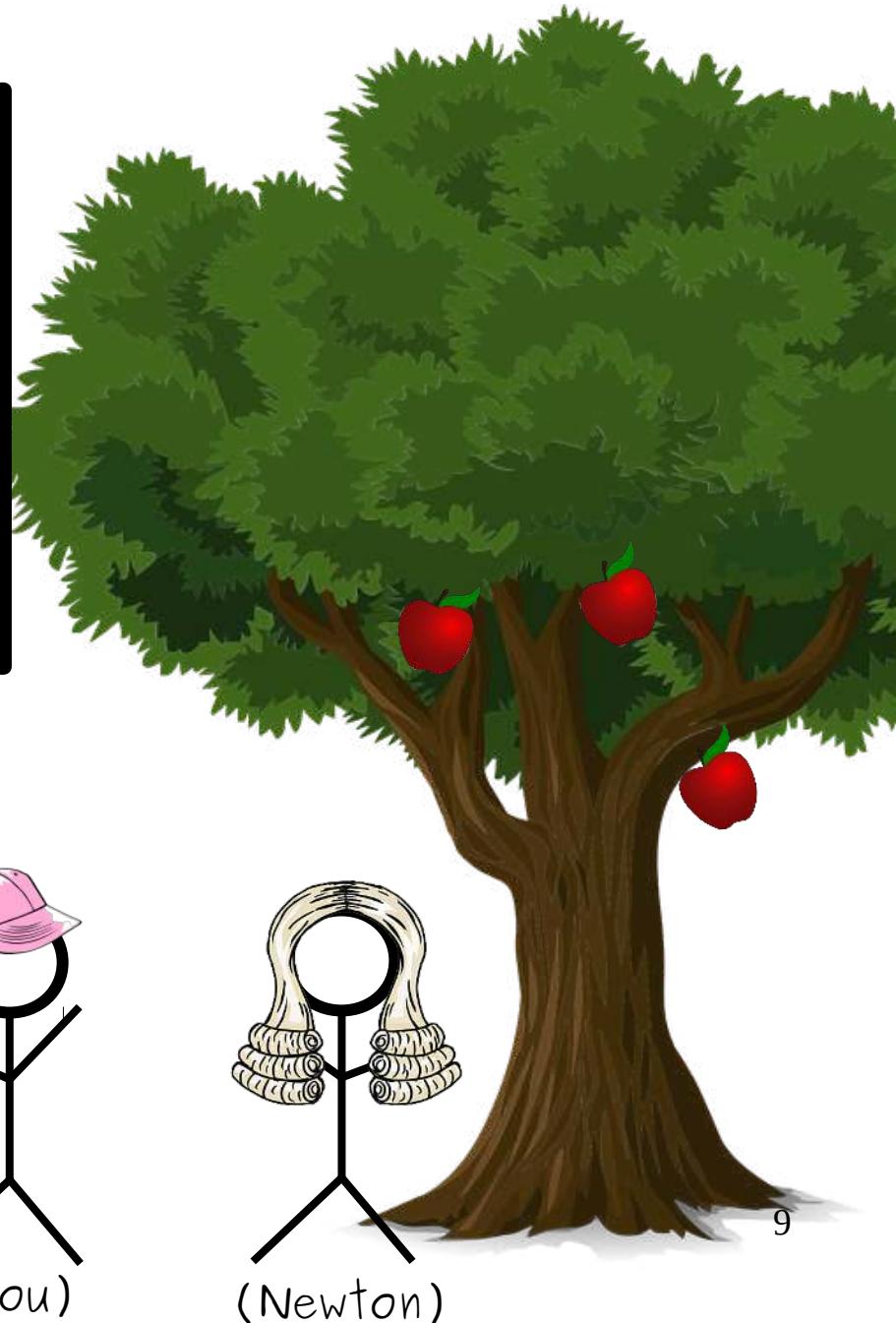
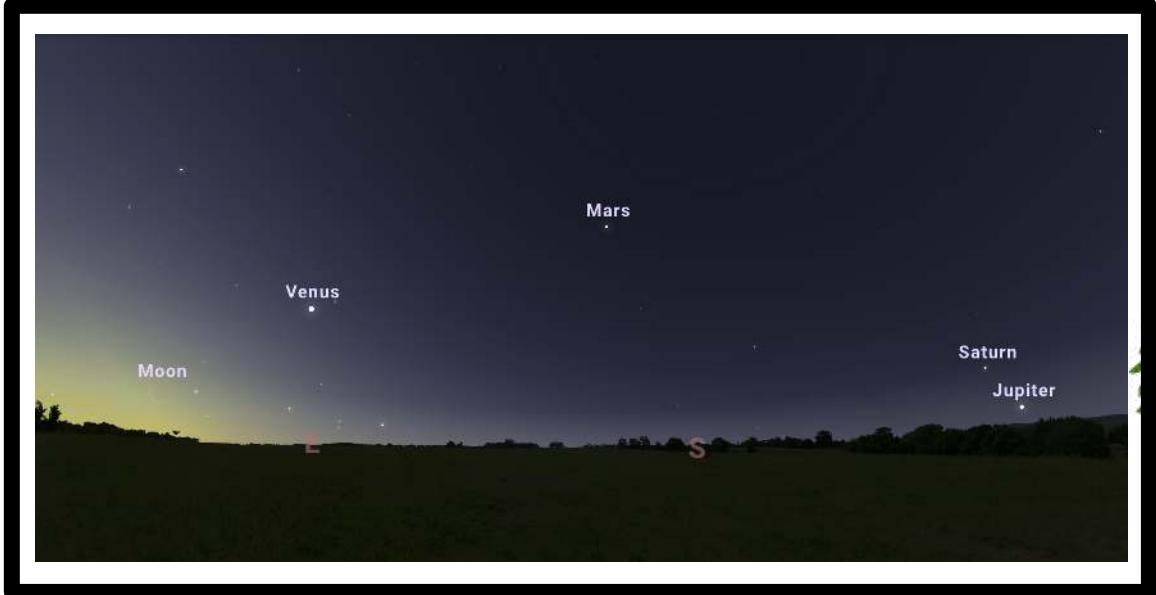
# Building models (planets)

XVII century



# Building models (planets)

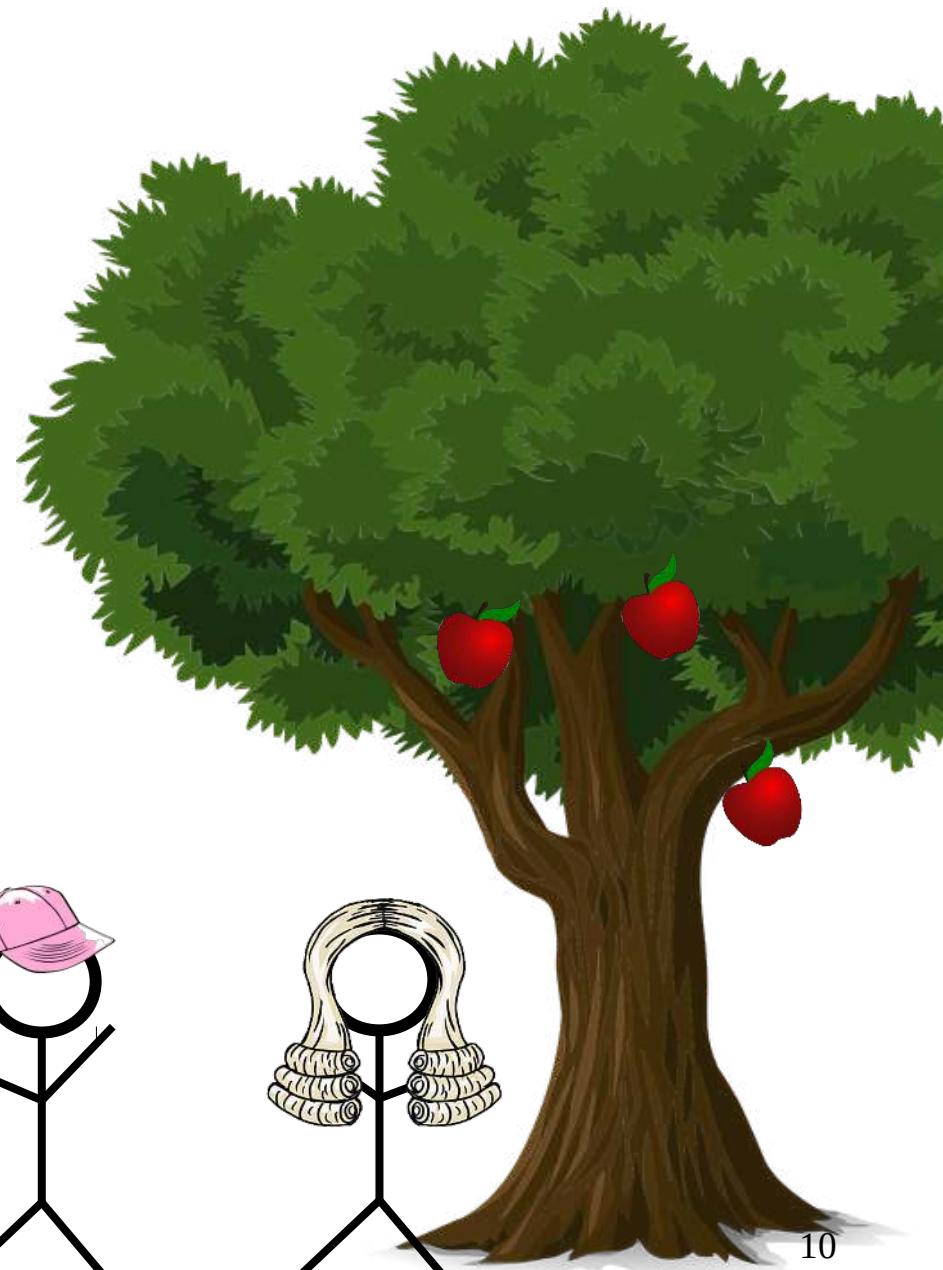
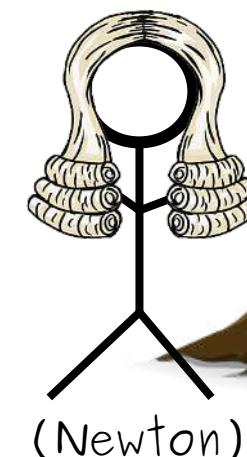
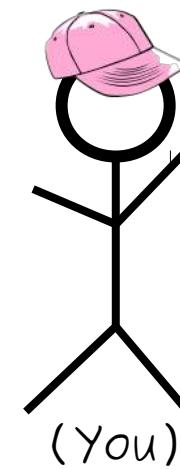
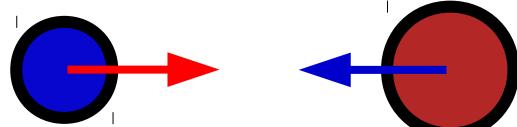
XVII century



# Building models (planets)

XVII century

Behaviors:

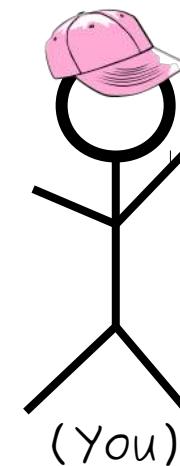
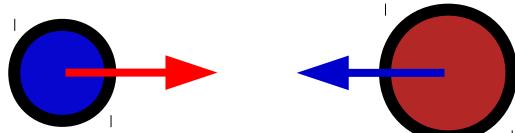


# Building models (planets)

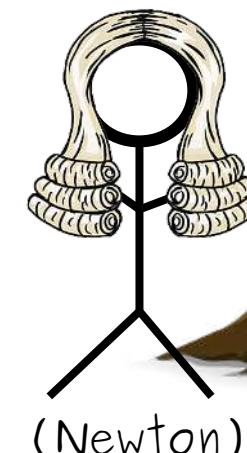
XVII century

Behaviors:

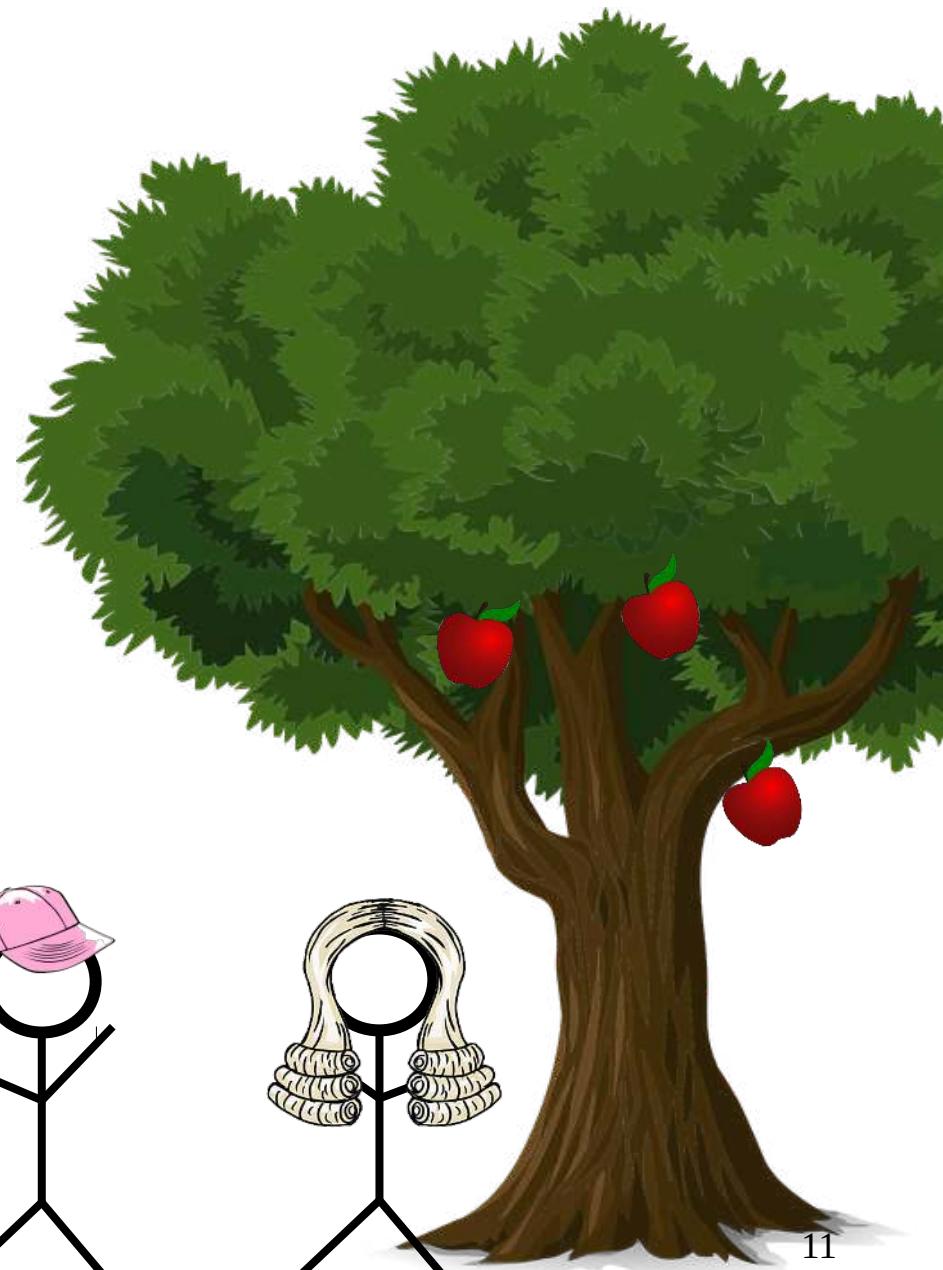
- Trajectories



(You)



(Newton)

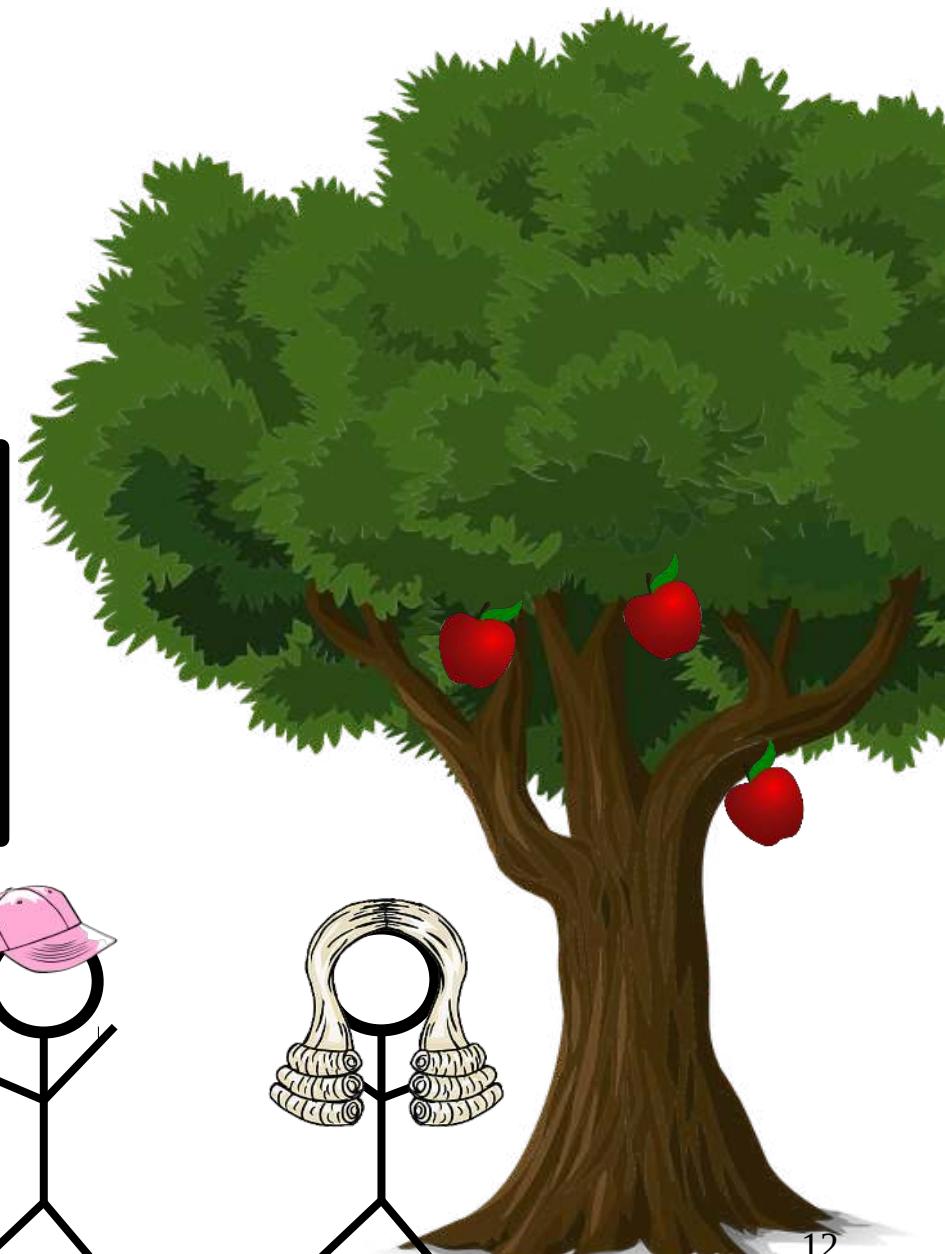
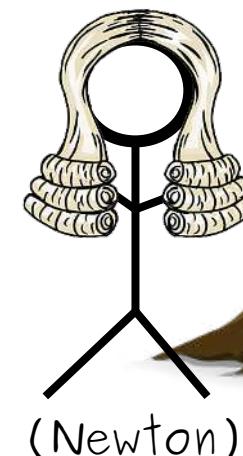
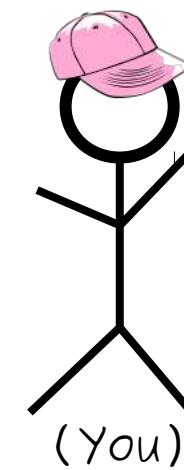
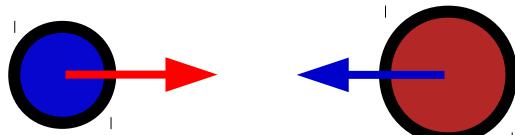


# Building models (planets)

XVII century

Behaviors:

- Trajectories
- Structure

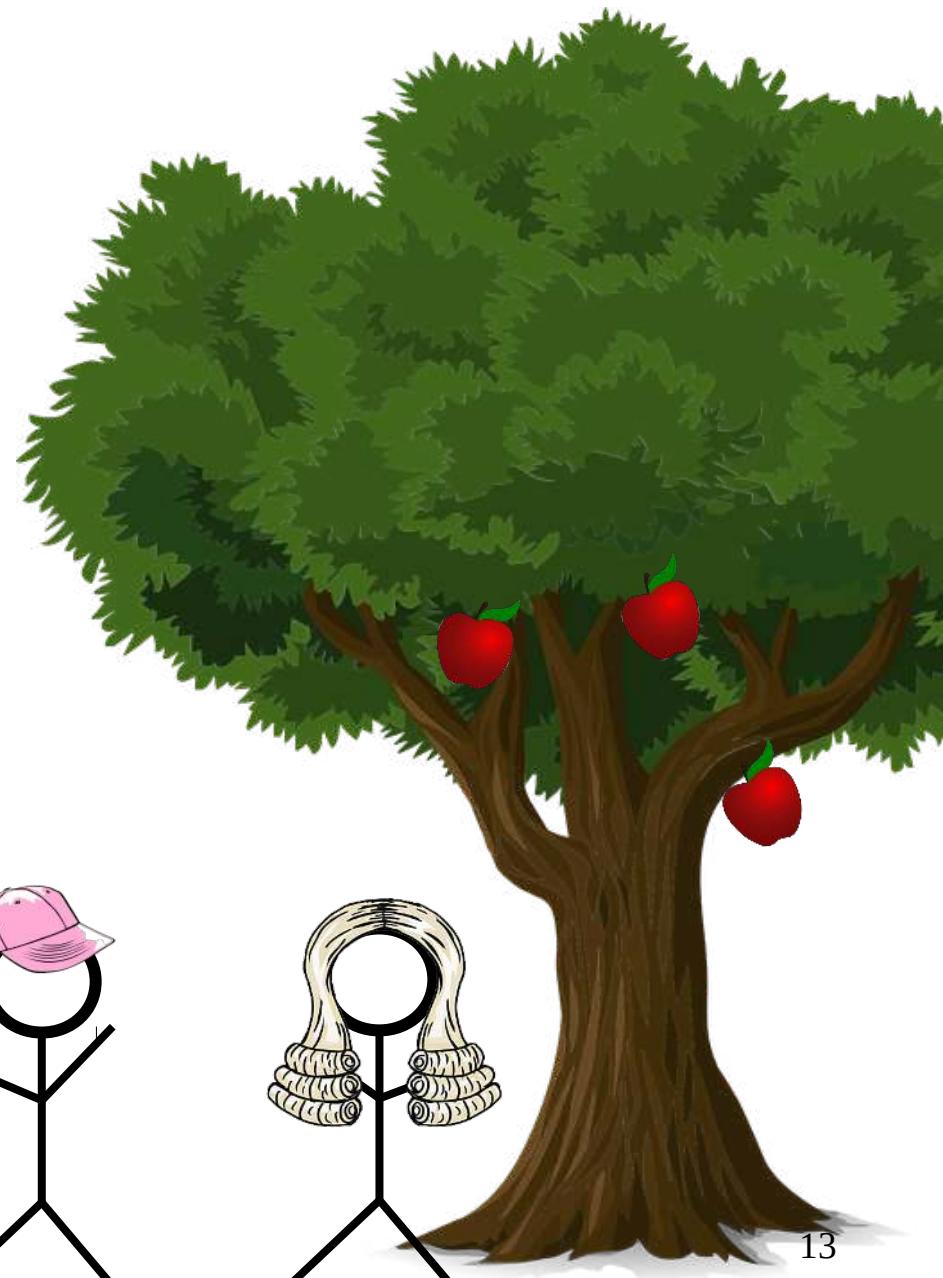
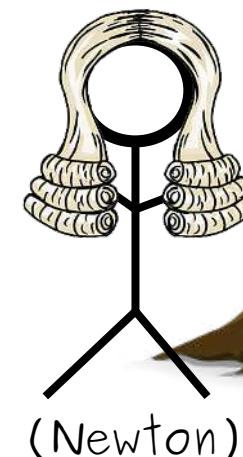
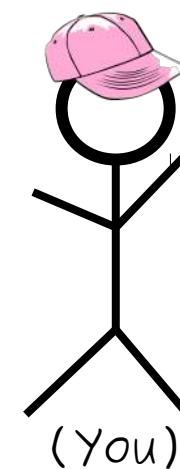
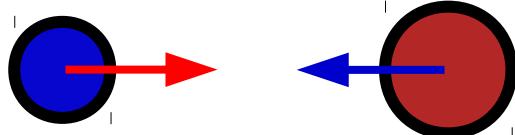


# Building models (planets)

XVII century

Behaviors:

- Trajectories
- Structure
- Brightness



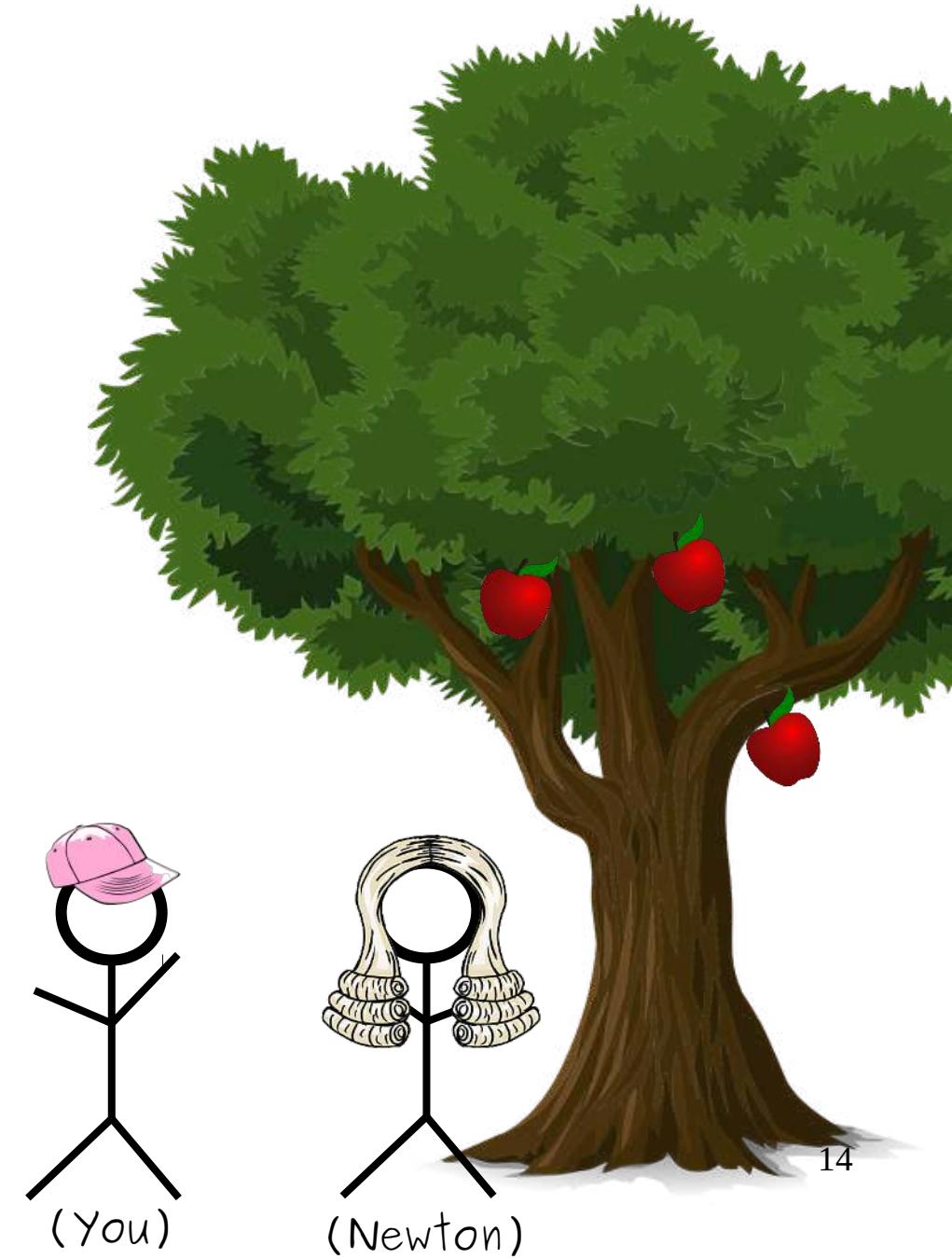
# Building models (planets)

XVII century

Behaviors:

- Trajectories
- Structure
- Brightness

?



# Building models (planets)

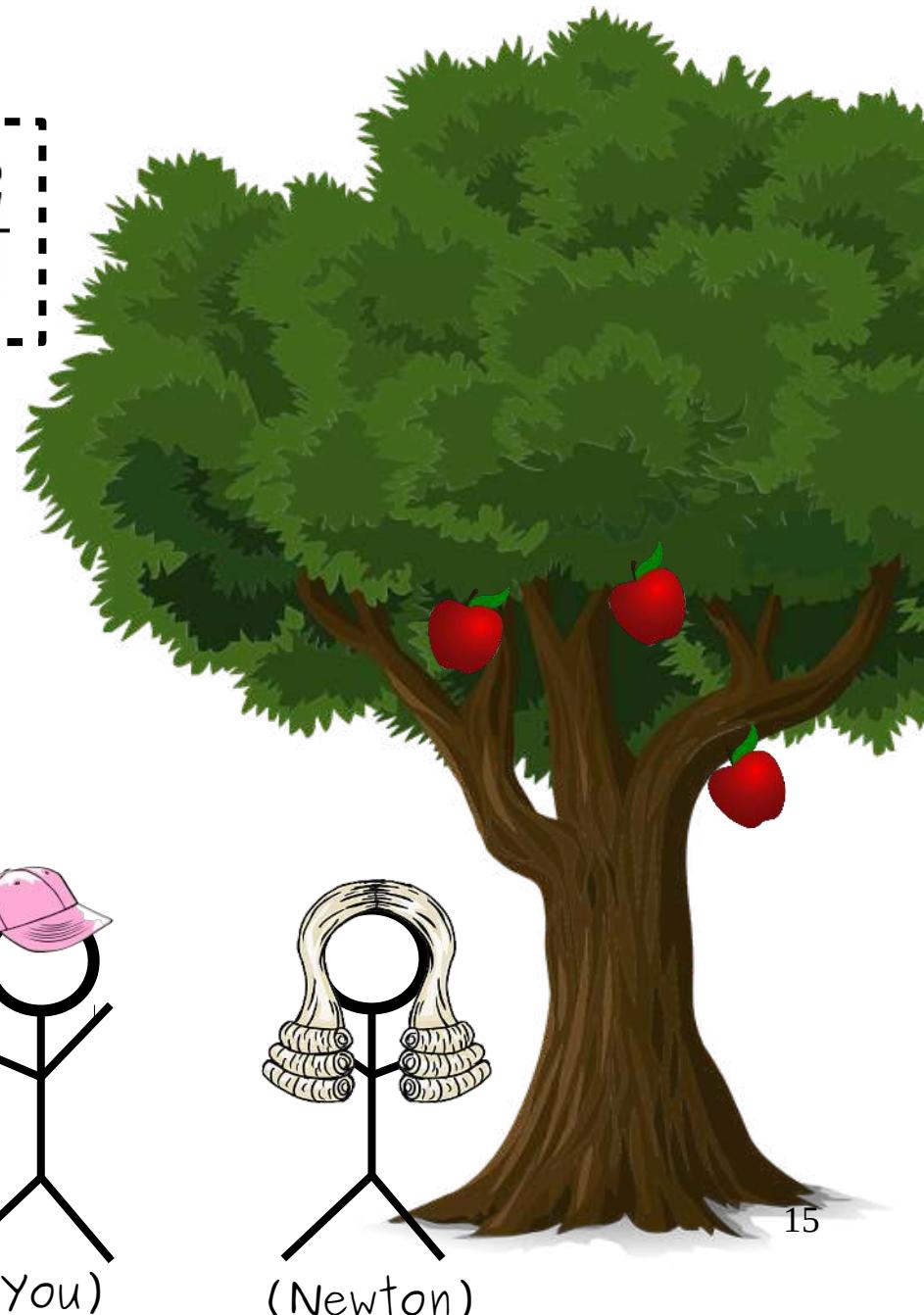
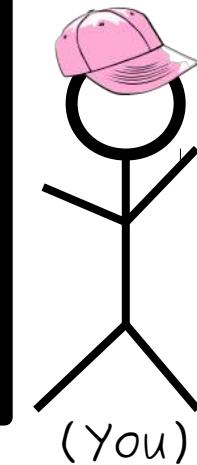
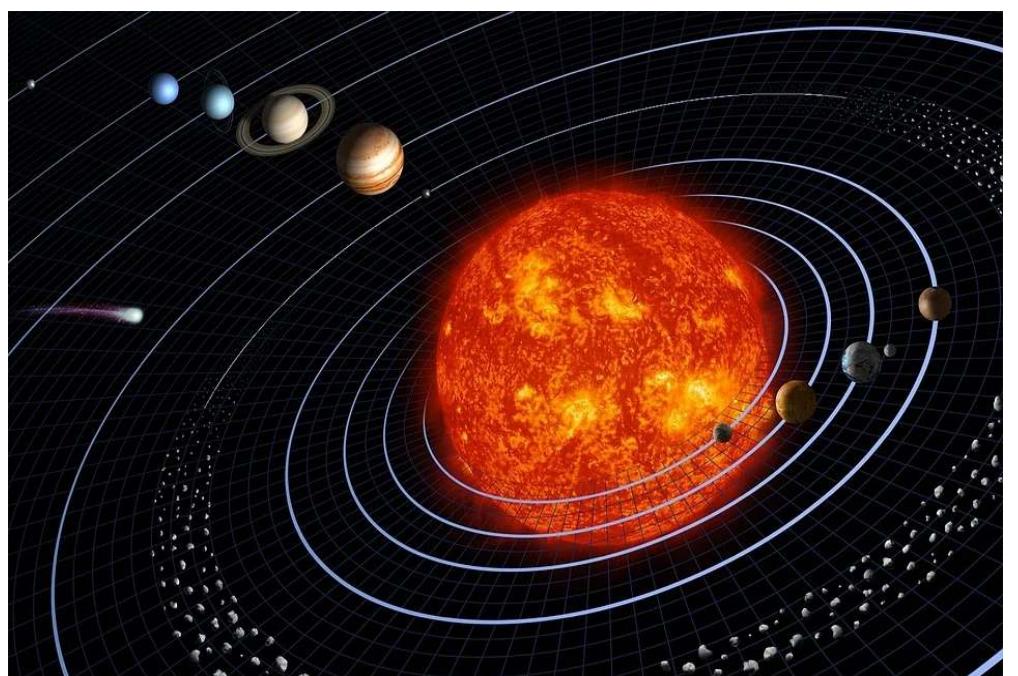
XVII century

Behaviors:

- Trajectories
- Structure
- Brightness

$$F = G \frac{m_1 m_2}{r^2}$$

model



# Building models (planets)

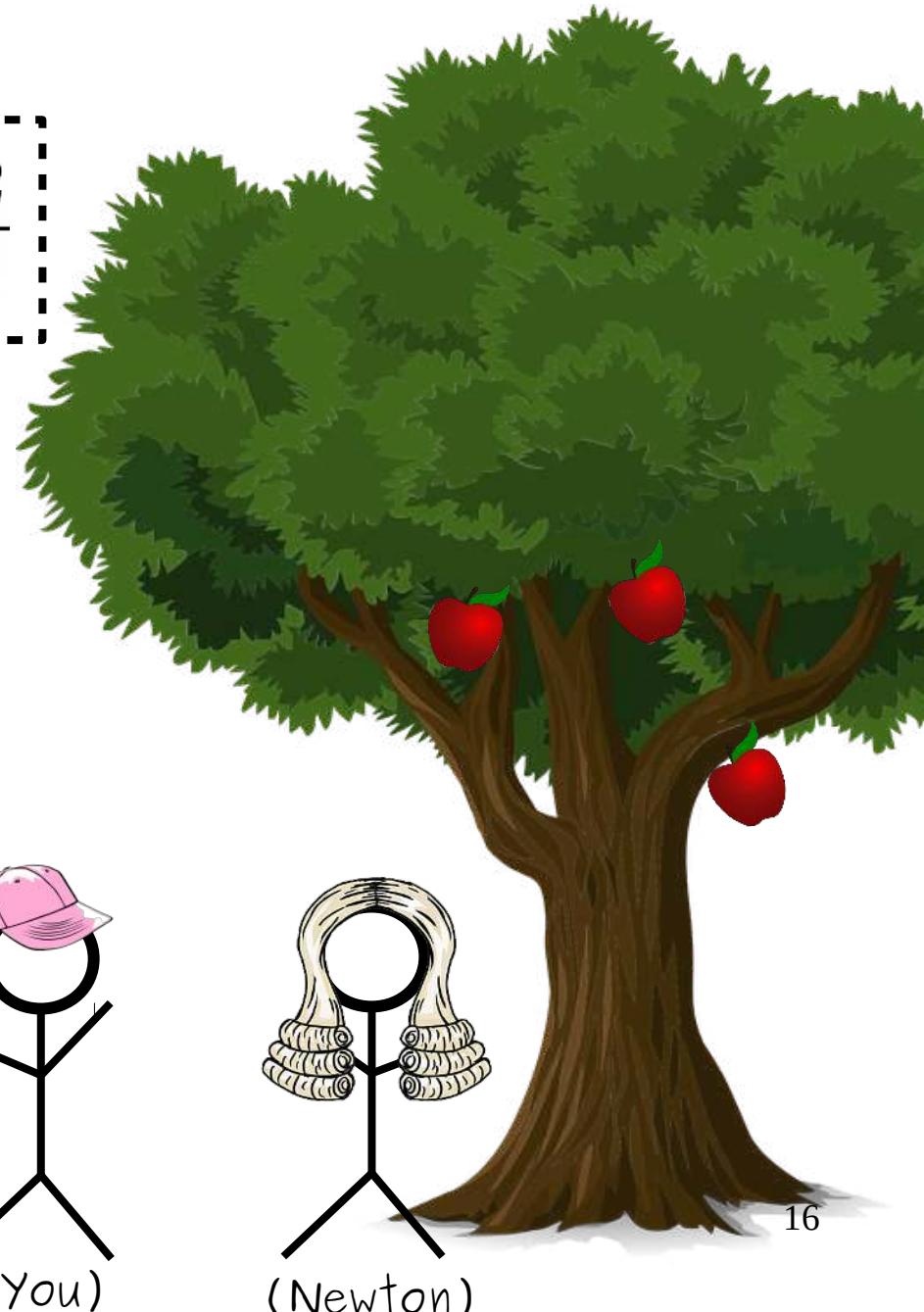
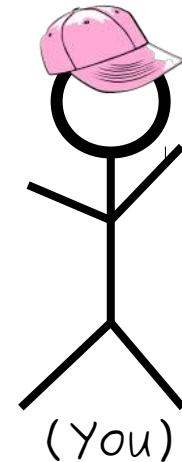
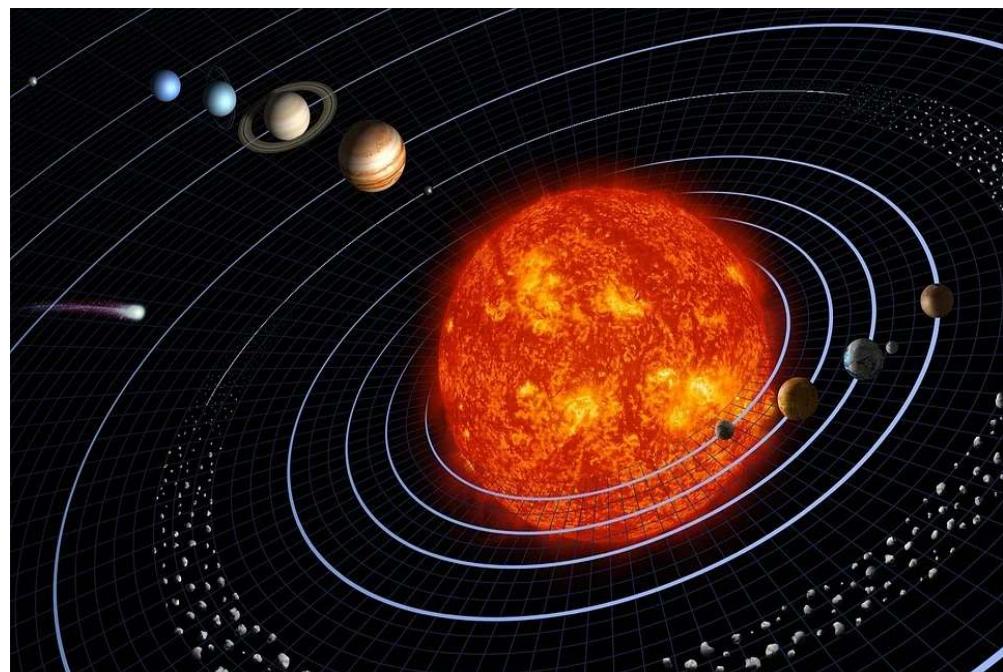
XVII century

Behaviors:

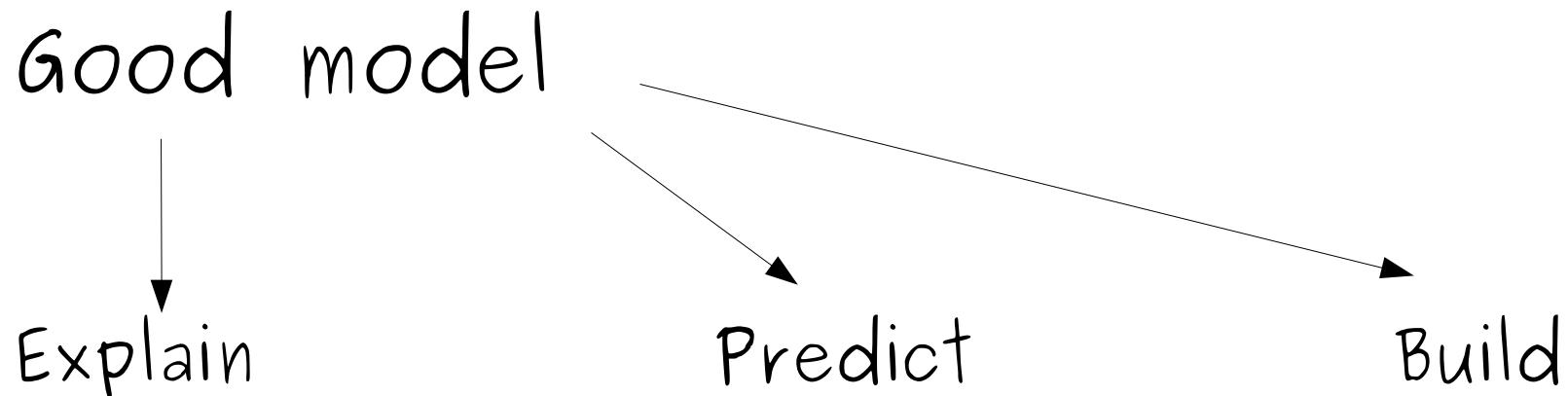
- Trajectories
- Structure
- Brightness

$$F = G \frac{m_1 m_2}{r^2}$$

Good model



# Building models (planets)



# Building models (planets)

Good model

↓  
Explain

Predict

Build



“Retrograde”

# Building models (planets)

Good model

↓  
Explain

Predict

Build



"Retrograde"



Halley's comet

# Building models (planets)

Good model

↓  
Explain

Predict

Build



"Retrograde"



Halley's comet



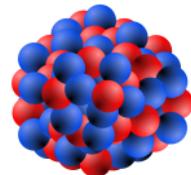
space shuttle

# Building models (nuclear)

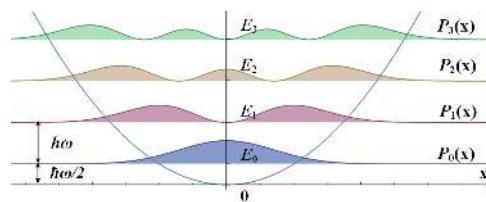
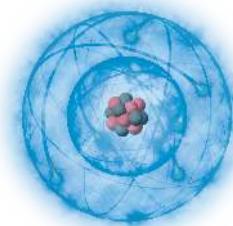
XXI century

Behaviors:

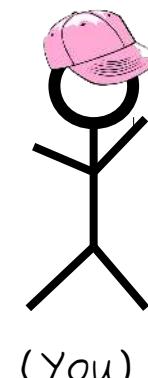
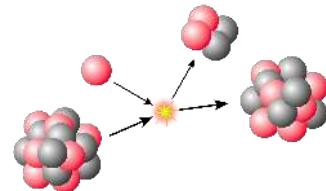
- Binding energy (energy "debt")



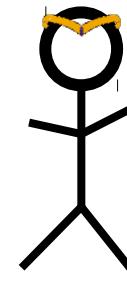
- Structure (arrangement of nucleons)



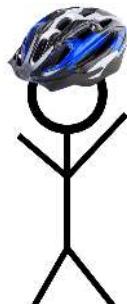
- Reactions (smashing nuclei)



(Pablo)



(Kyle)



21

(Taylor)

# Building models (nuclear)

Good models

↓  
Explain



Predict



Build



Kilonova after  
merger

# Building models (nuclear)

Good models

↓  
Explain

Predict

Build



Burning Sun



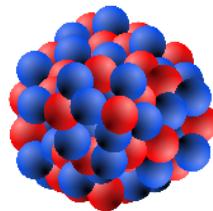
Kilonova after  
merger



Nuclear energy

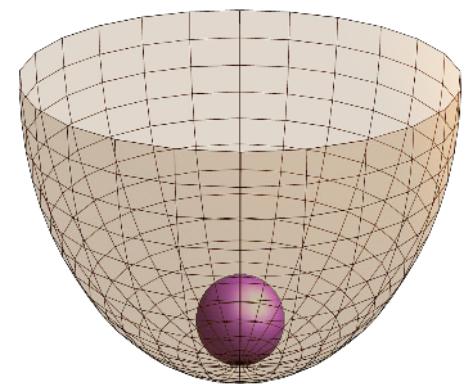
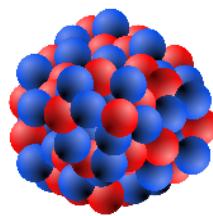
# Binding energy

→ Energy needed to break it apart



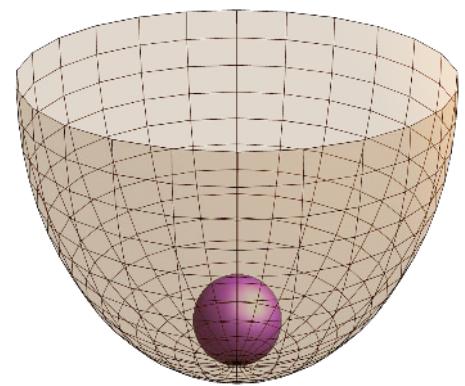
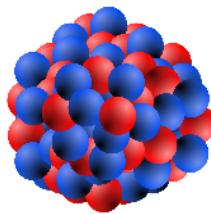
# Binding energy

→ Energy needed to break it apart



Binding energy → Energy needed to break it apart

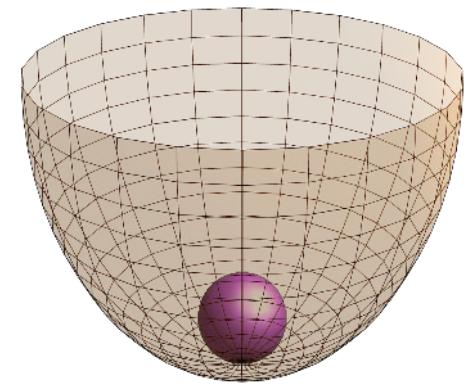
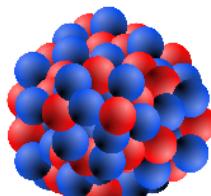
$$m = Zm_p + Nm_n - \frac{BE}{c^2}$$



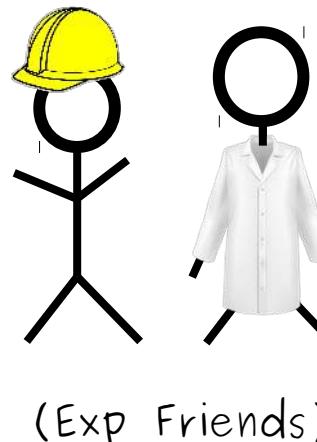
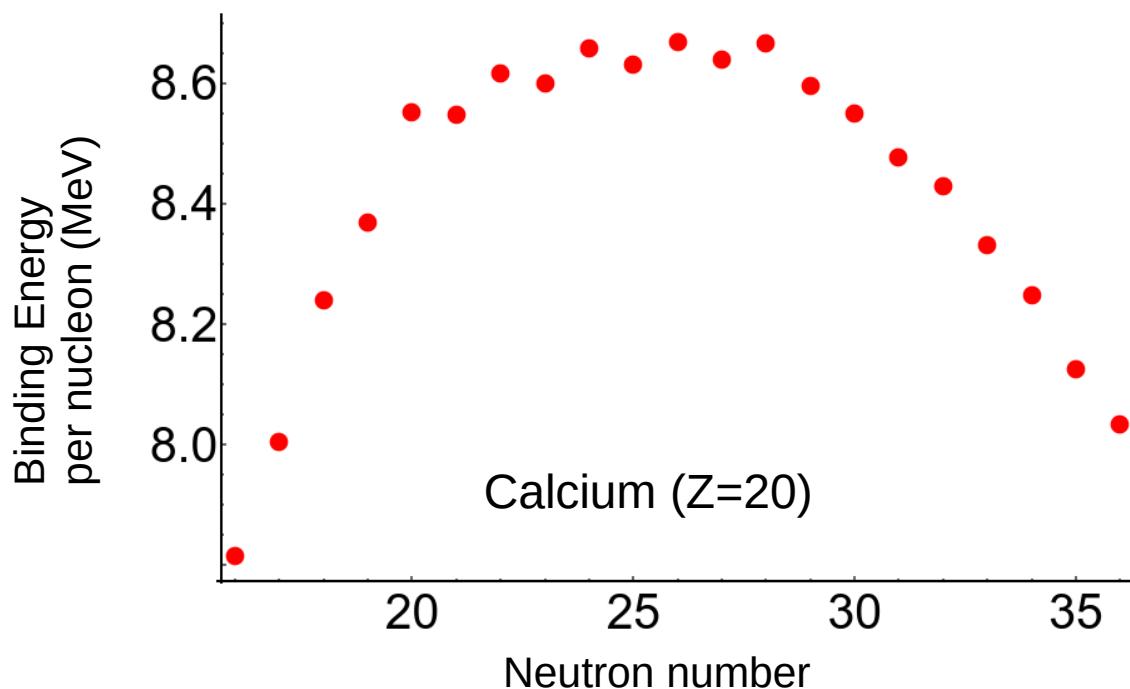
# Binding energy

→ Energy needed to break it apart

$$m = Zm_p + Nm_n - \frac{BE}{c^2}$$



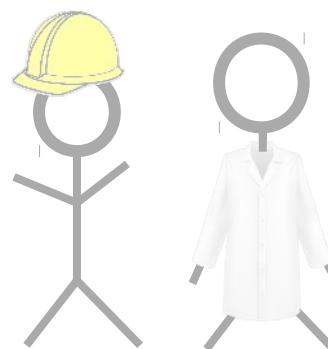
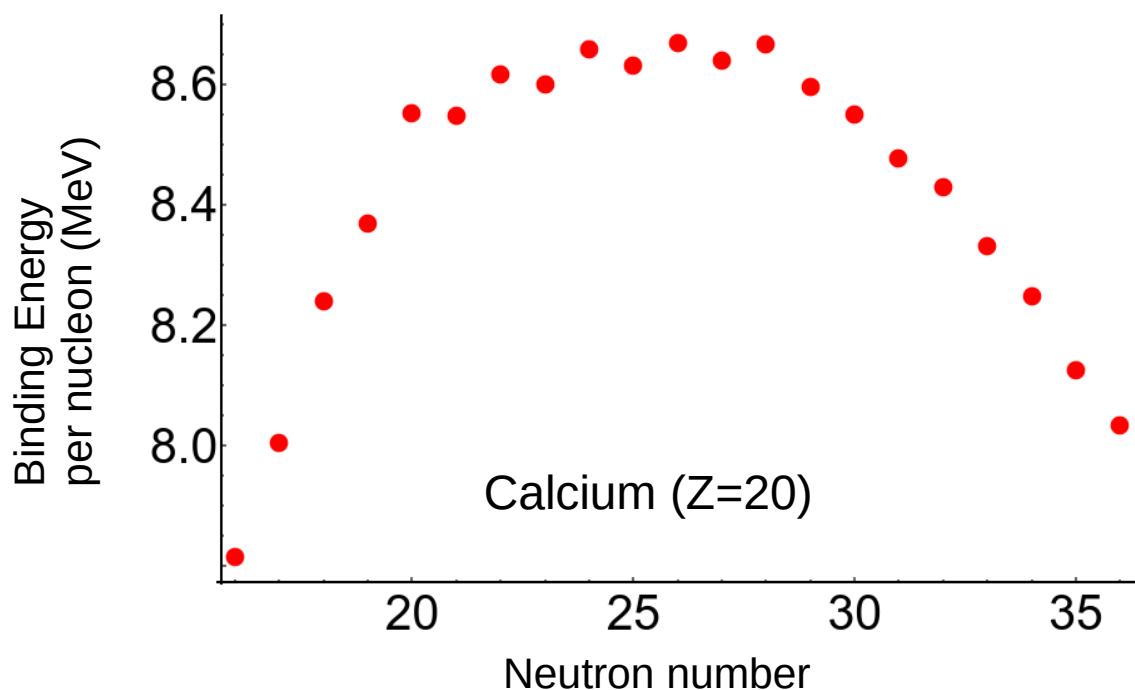
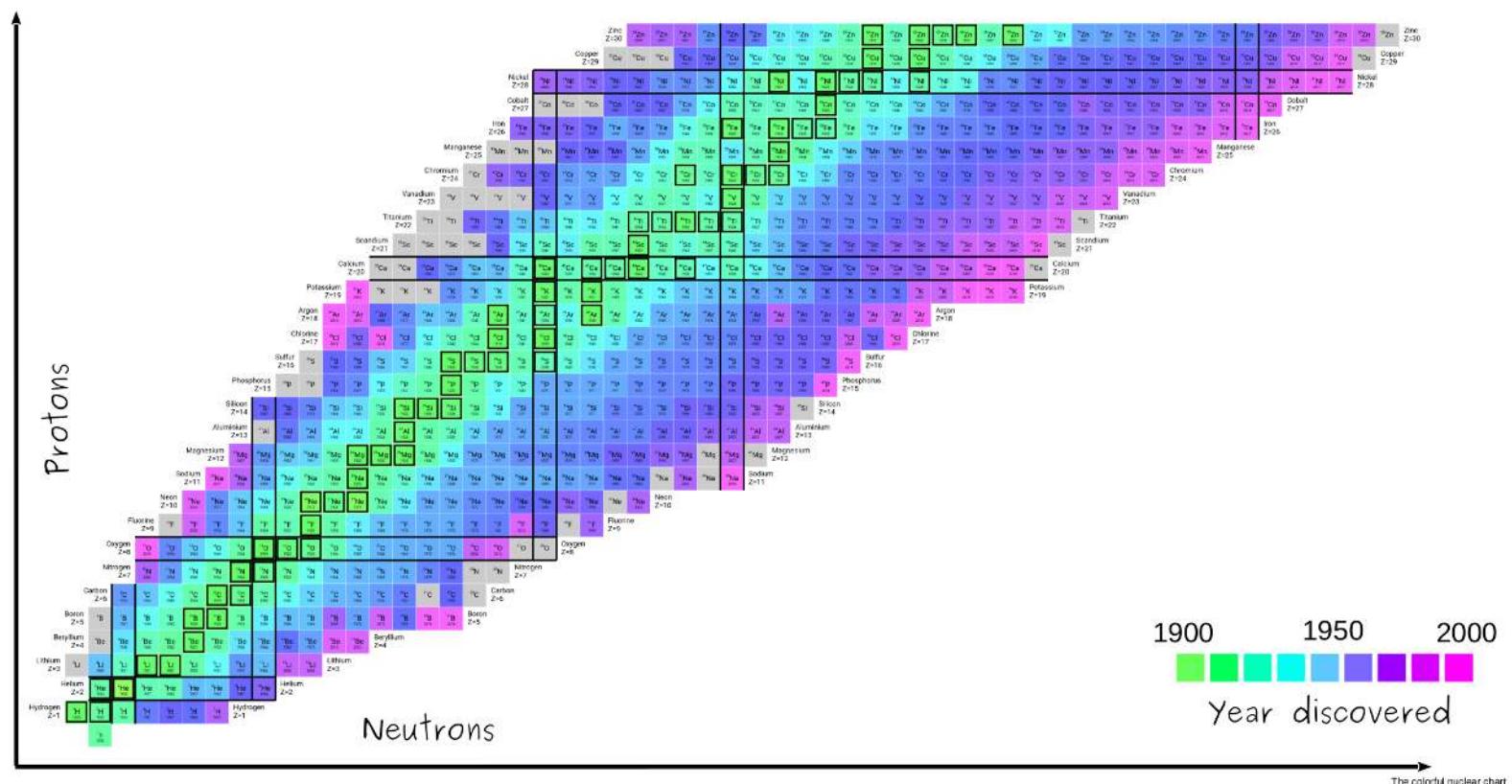
Behavior:



# Binding

$$m = Z m_p$$

# Behavior:

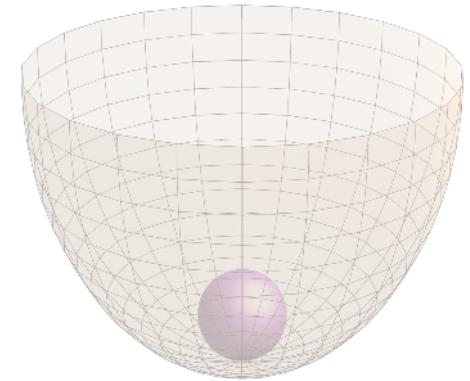
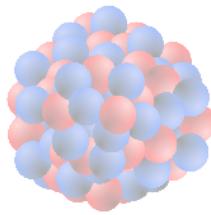


## (Exp Friends)

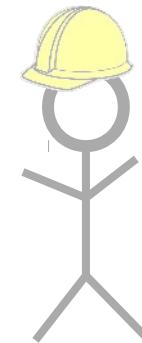
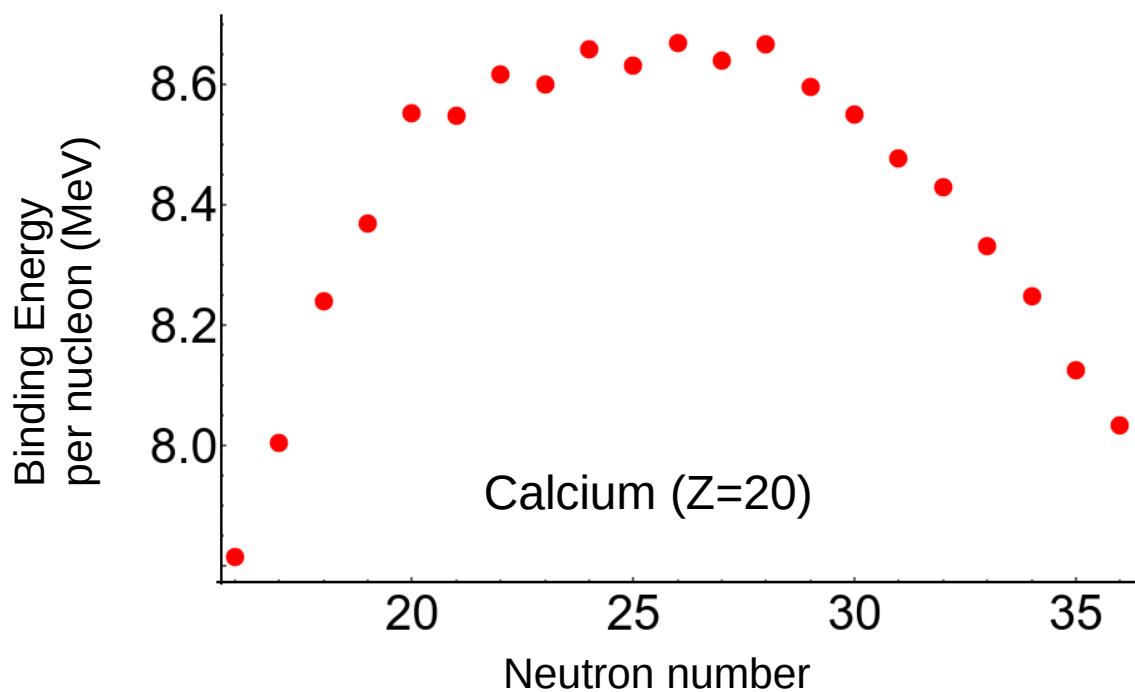
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→ Energy needed to break it apart

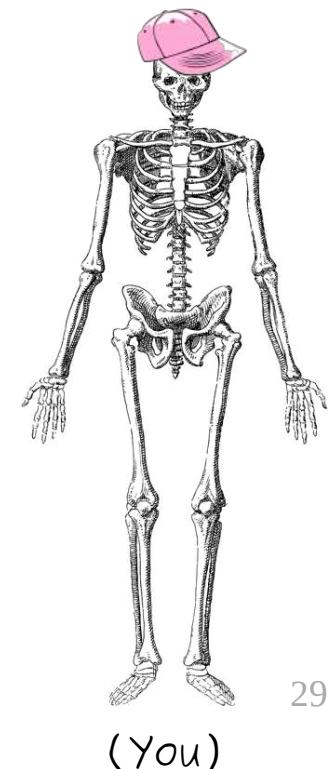
$$m = Zm_p + Nm_n - \frac{BE}{c^2}$$



Behavior:



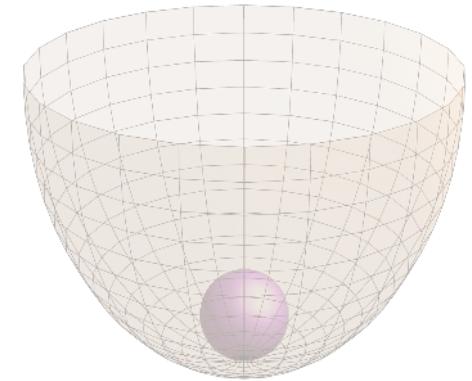
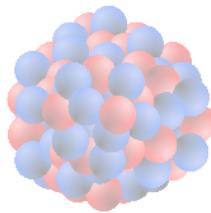
(Exp Friends)



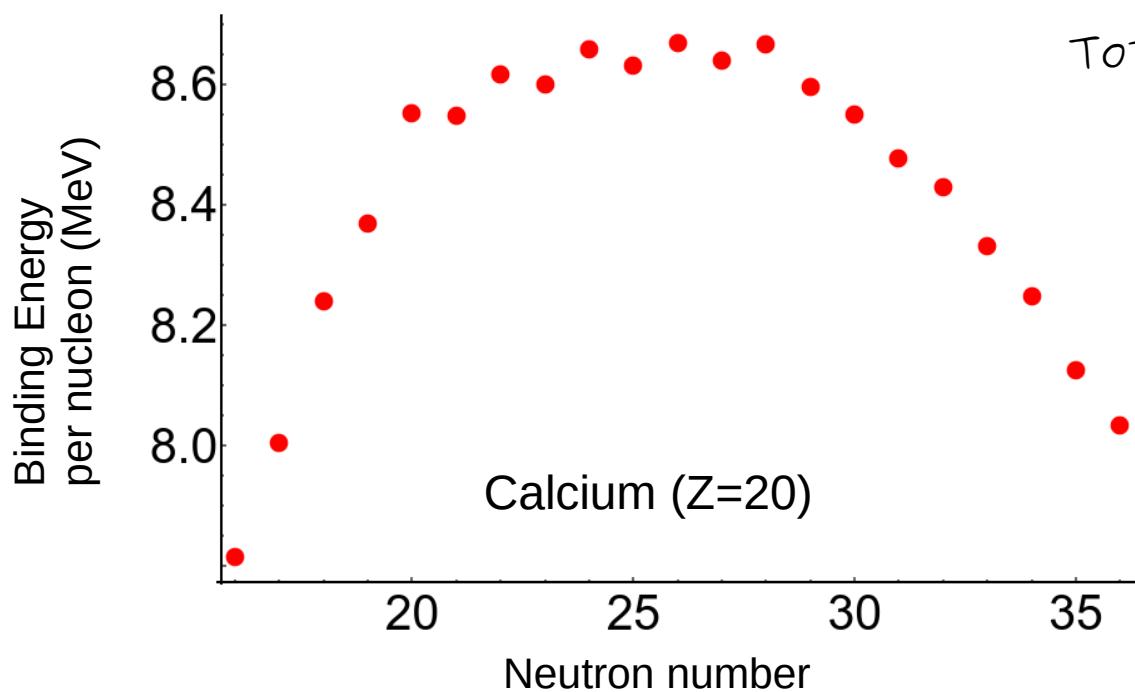
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→ Energy needed to break it apart

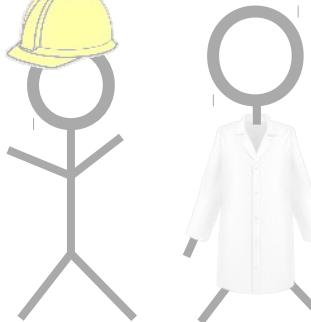
$$m = Zm_p + Nm_n - \frac{BE}{c^2}$$



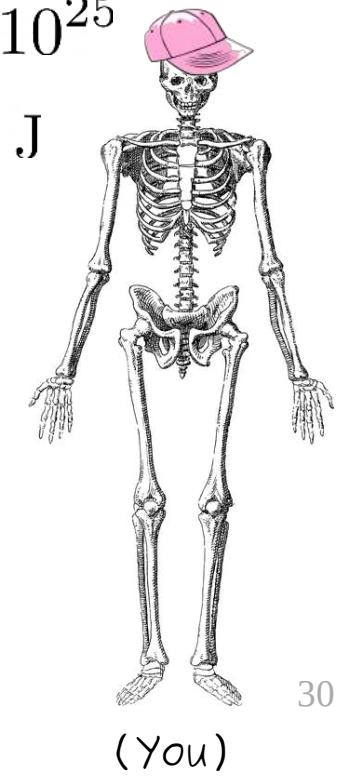
Behavior:



Total calcium  $\sim 1.6 \times 10^{25}$   
Total energy  $\sim \times 10^{15} \text{ J}$



(Exp Friends)

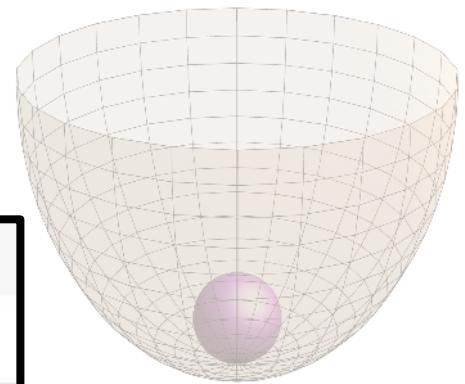
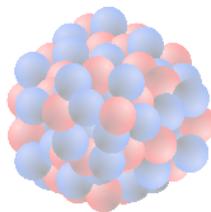


30  
(You)

# Binding energy

→ Energy needed to break it apart

$$m = Zm_{\alpha} + Nm_{\alpha} - \frac{BE}{c^2}$$

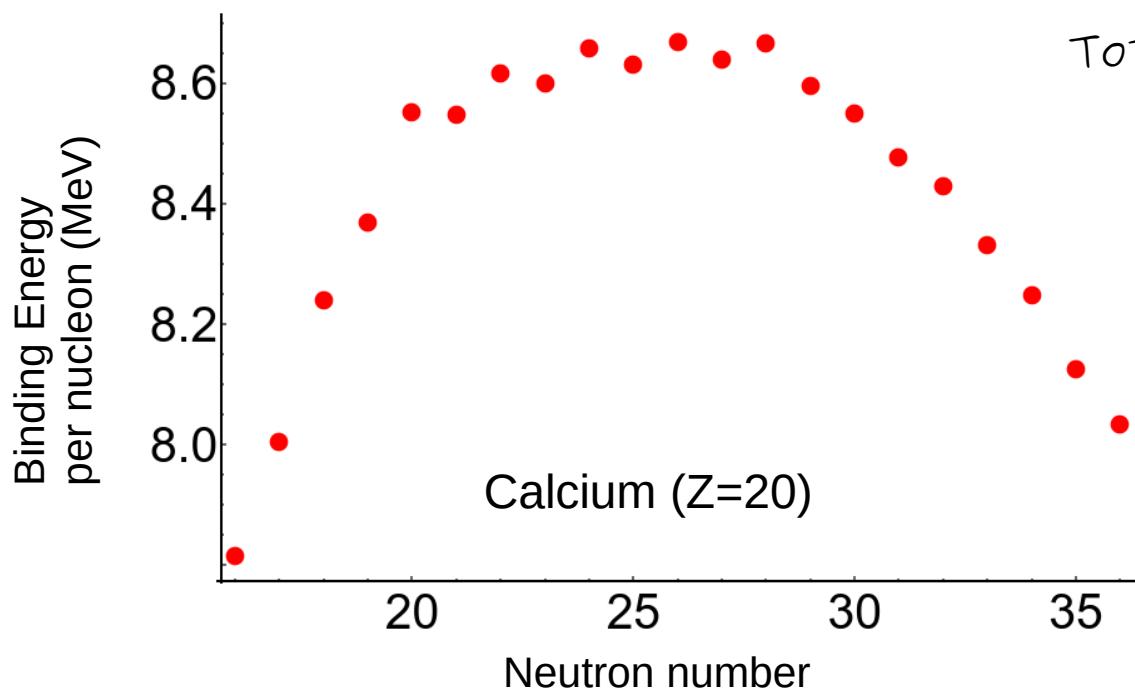


Comparisons as energy

$\approx (0.09 \approx 1/11) \times$  impact energy forming Meteor Crater, Arizona ( $\approx 1 \times 10^{16}$  J)

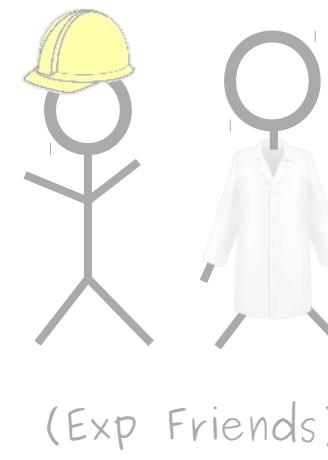
$\approx$  energy released by a hurricane in 1 second ( $\approx 6 \times 10^{14}$  J)

Behavior:

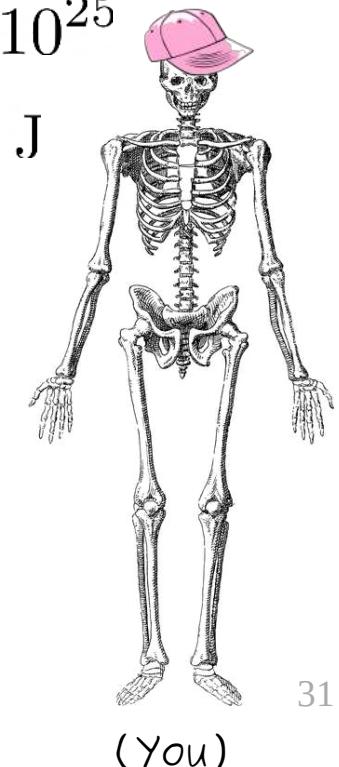


Total calcium  $\sim 1.6 \times 10^{25}$

Total energy  $\sim \times 10^{15}$  J



(Exp Friends)

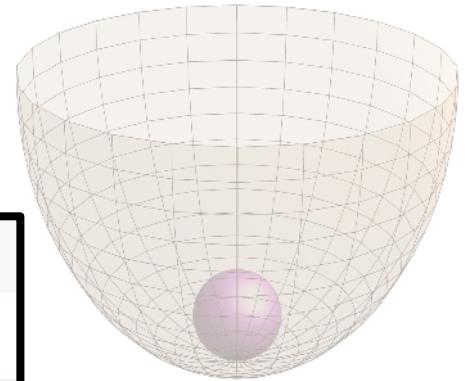
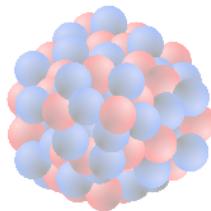


(You)

# Binding energy

→ Energy needed to break it apart

$$m = Zm_{\alpha} + Nm_{\nu} - \frac{BE}{c^2}$$

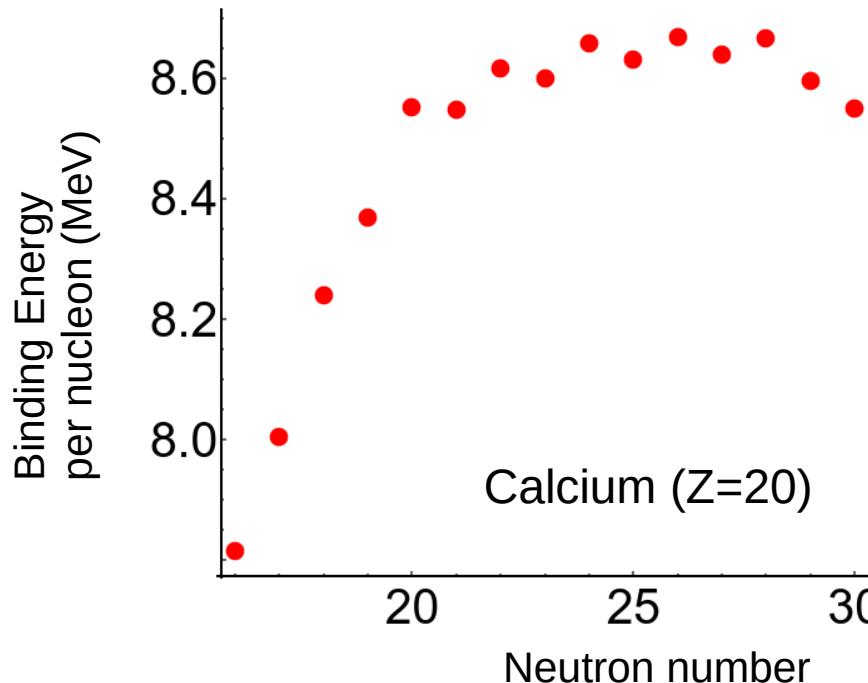


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Behavior.

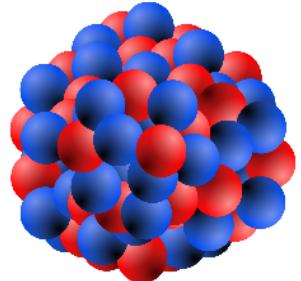


Total calcium  $\sim 1.6 \times 10^{25}$

Total energy  $\sim \times 10^{15}$  J



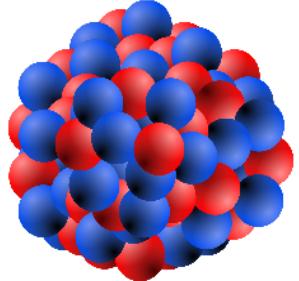
# Binding energy



Liquid drop  
model



# Binding energy

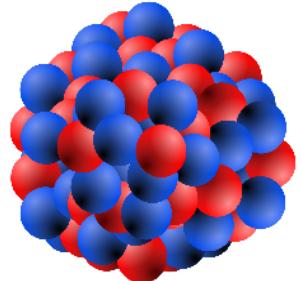


Liquid drop  
model



$$\text{BE}(N, Z) =$$

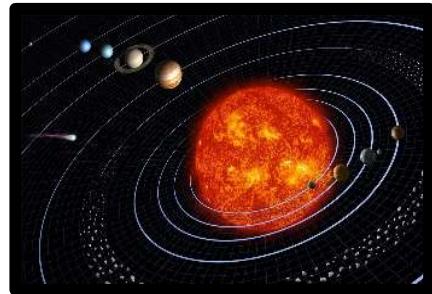
# Binding energy



Liquid drop  
model

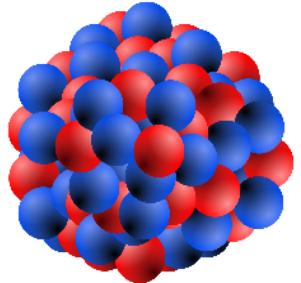


$$F = G \frac{m_1 m_2}{r^2}$$



$$\text{BE}(N, Z) =$$

# Binding energy



Liquid drop  
model

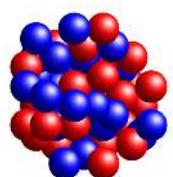


$$F = G \frac{m_1 m_2}{r^2}$$



$$\text{BE}(N, Z) =$$

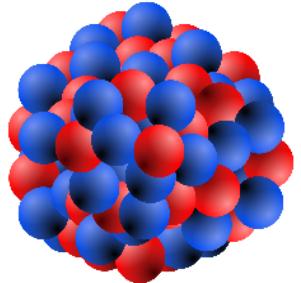
More nucleons



BE



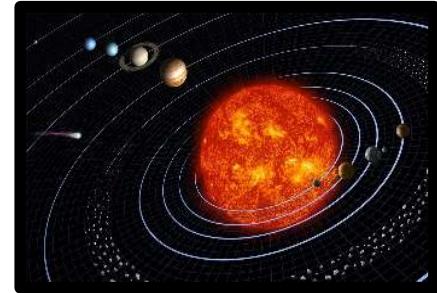
# Binding energy



Liquid drop  
model

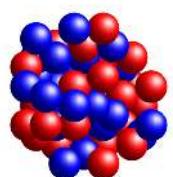


$$F = G \frac{m_1 m_2}{r^2}$$



$$\text{BE}(N, Z) = a_V(N + Z)$$

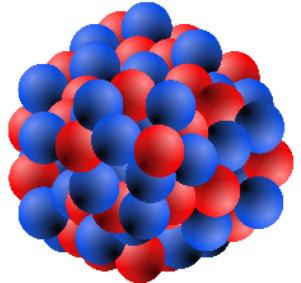
More nucleons



BE



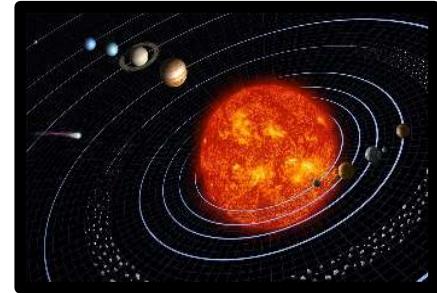
# Binding energy



Liquid drop  
model



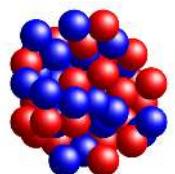
$$F = G \frac{m_1 m_2}{r^2}$$



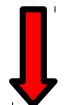
$$\text{BE}(N, Z) = a_V(N + Z)$$

More nucleons

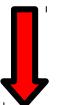
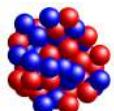
More surface



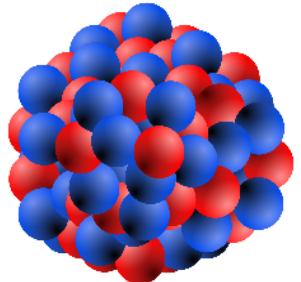
BE



BE



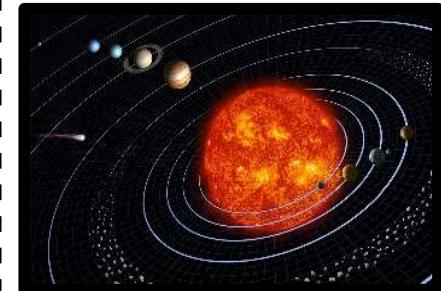
# Binding energy



Liquid drop  
model



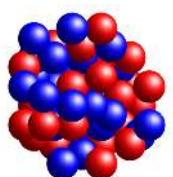
$$F = G \frac{m_1 m_2}{r^2}$$



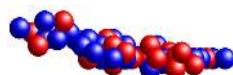
$$\text{BE}(N, Z) = a_V(N + Z) - a_S(N + Z)^{2/3}$$

More nucleons

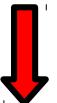
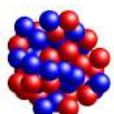
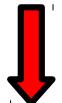
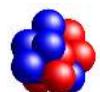
More surface



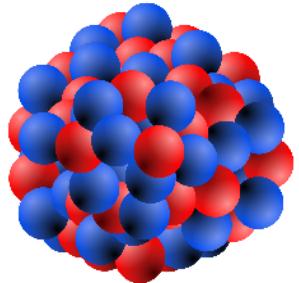
BE



BE



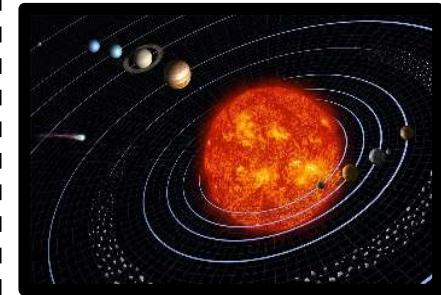
# Binding energy



Liquid drop  
model



$$F = G \frac{m_1 m_2}{r^2}$$

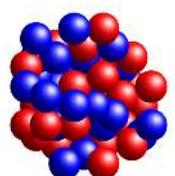
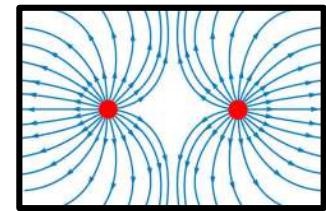


$$\text{BE}(N, Z) = a_V(N + Z) - a_S(N + Z)^{2/3}$$

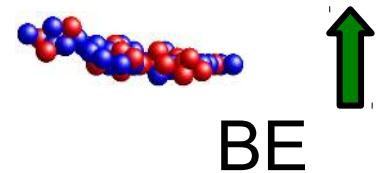
More nucleons

More surface

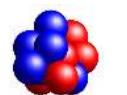
More protons



BE



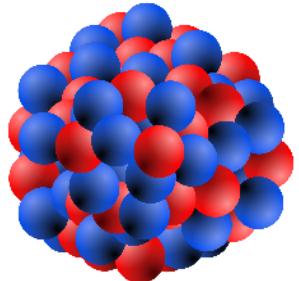
BE



BE



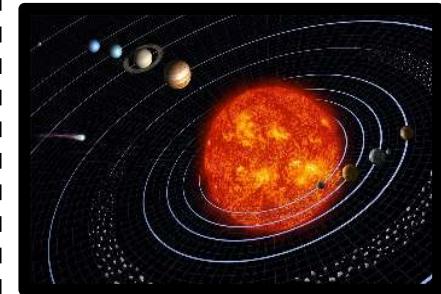
# Binding energy



Liquid drop  
model

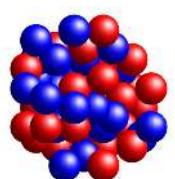


$$F = G \frac{m_1 m_2}{r^2}$$



$$\text{BE}(N, Z) = a_V(N + Z) - a_S(N + Z)^{2/3} - a_C \frac{Z^2}{(N + Z)^{1/3}}$$

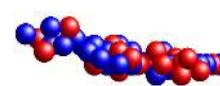
More nucleons



BE



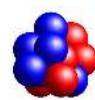
More surface



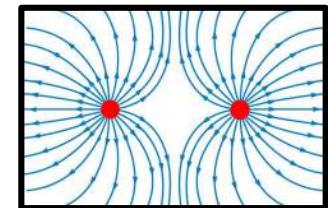
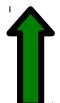
BE



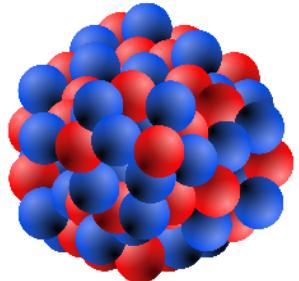
More protons



BE



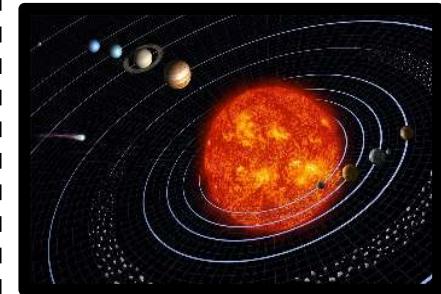
# Binding energy



Liquid drop  
model



$$F = G \frac{m_1 m_2}{r^2}$$



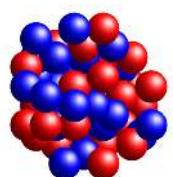
$$\text{BE}(N, Z) = a_V(N + Z) - a_S(N + Z)^{2/3} - a_C \frac{Z^2}{(N + Z)^{1/3}}$$

More nucleons

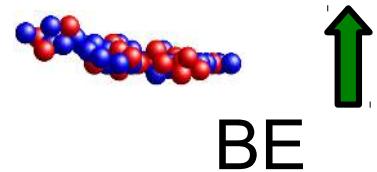
More surface

More protons

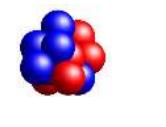
More asymmetry



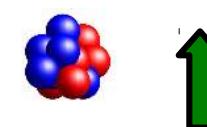
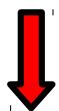
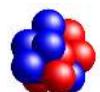
BE



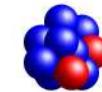
BE



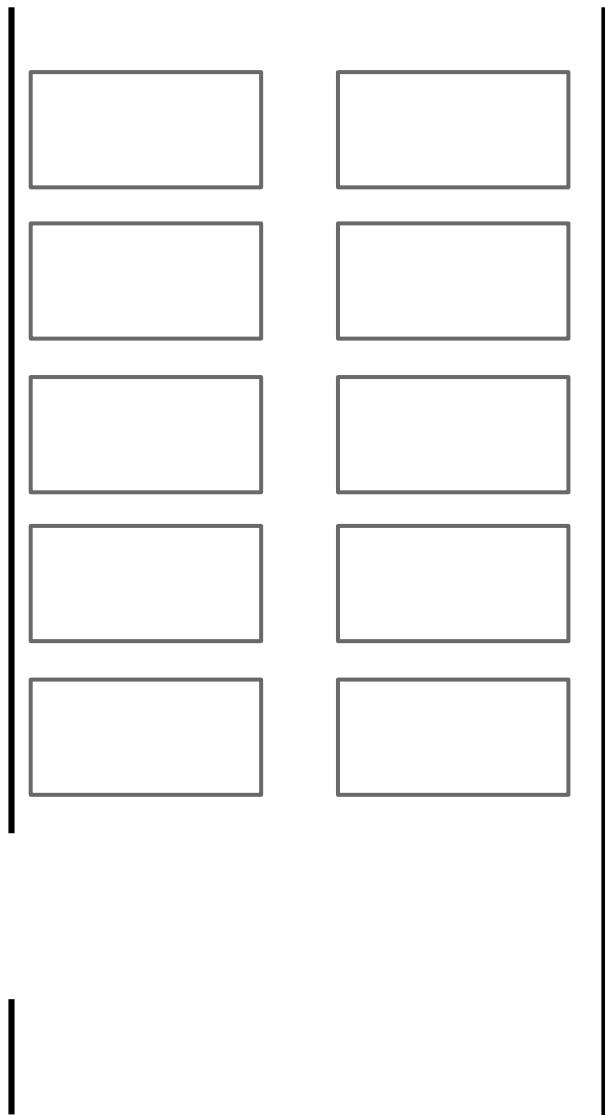
BE



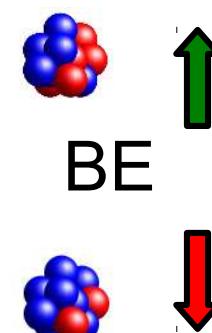
BE



# Binding energy (Asymmetry parenthesis)



More asymmetry

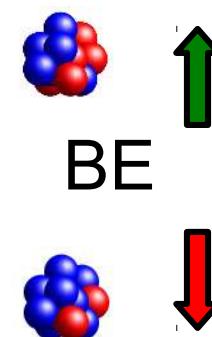


# Binding energy (Asymmetry parenthesis)

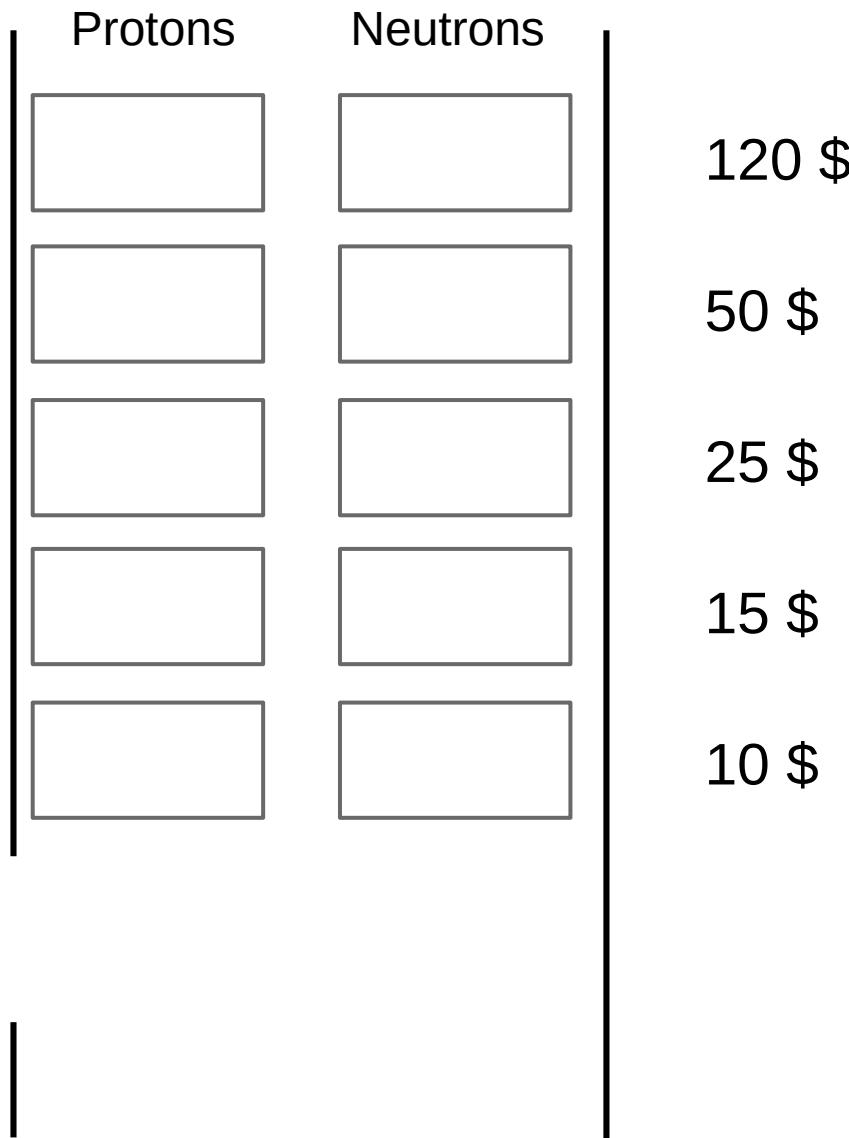
Protons	Neutrons



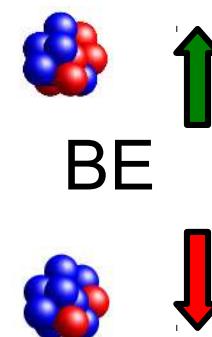
More asymmetry



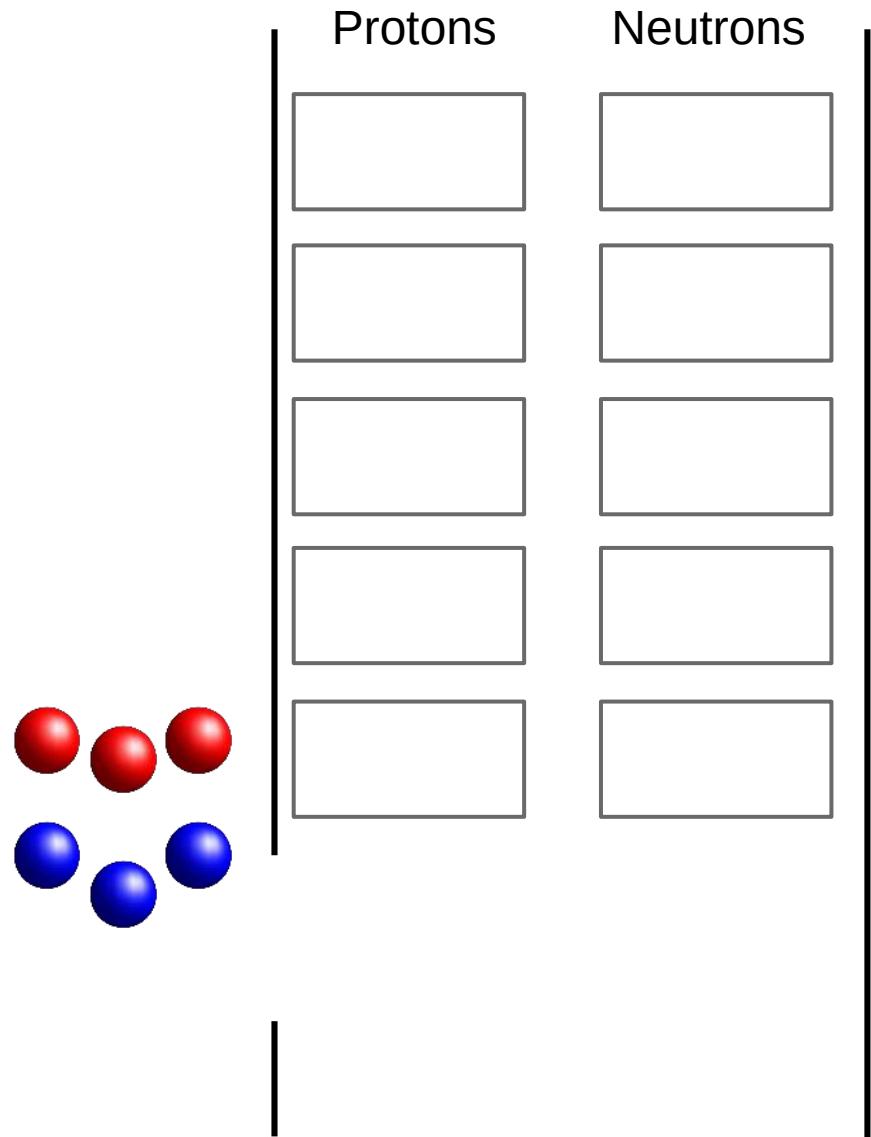
# Binding energy (Asymmetry parenthesis)



More asymmetry



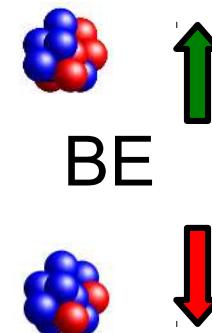
# Binding energy (Asymmetry parenthesis)



120 \$  
50 \$  
25 \$  
15 \$  
10 \$

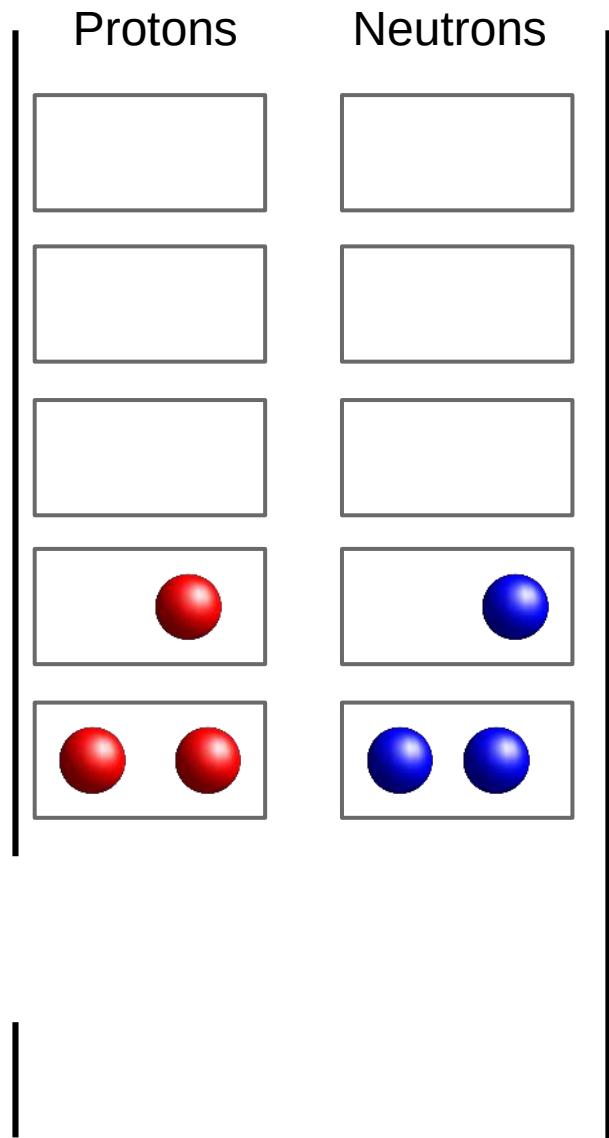


More asymmetry



46

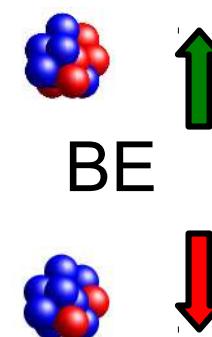
# Binding energy (Asymmetry parenthesis)



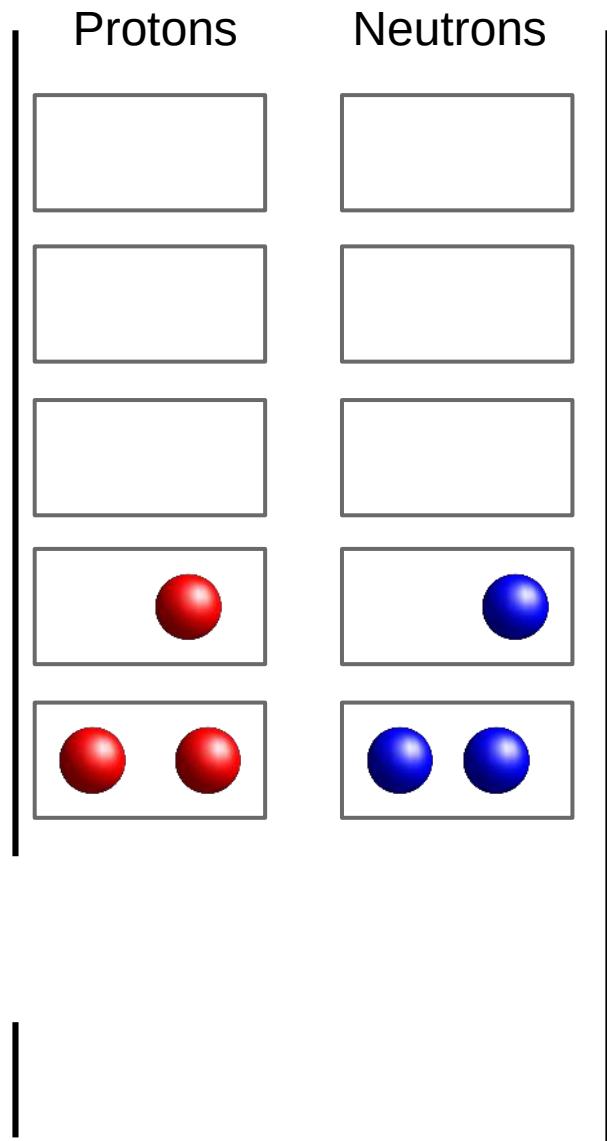
120 \$  
50 \$  
25 \$  
15 \$  
10 \$



More asymmetry



# Binding energy (Asymmetry parenthesis)

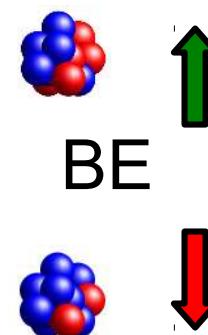


120 \$  
50 \$  
25 \$  
15 \$  
10 \$

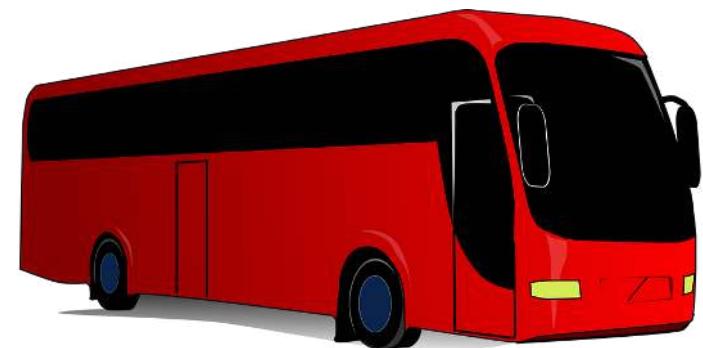
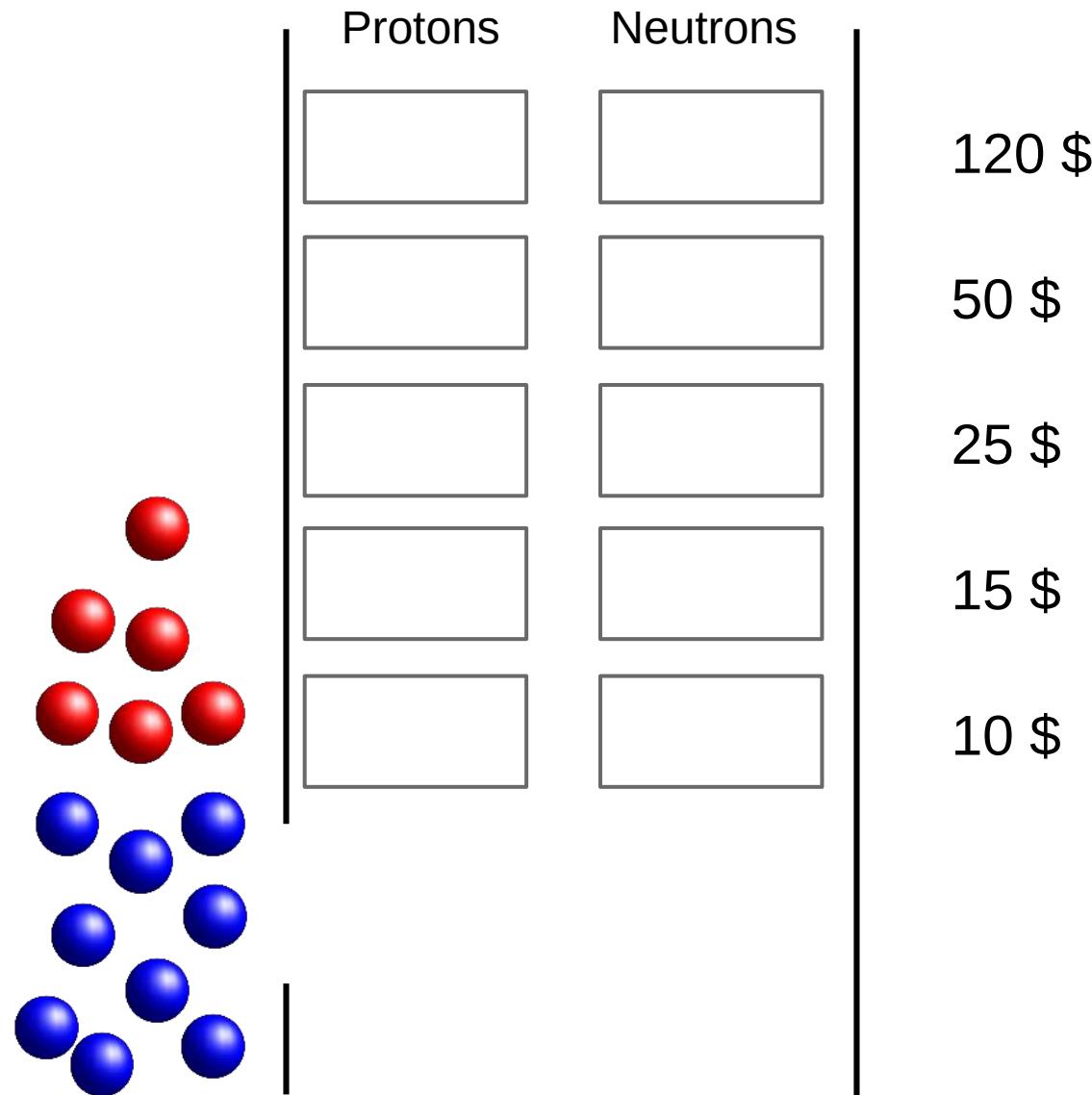
Total = 70 \$



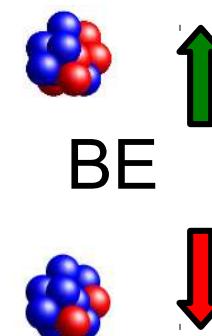
More asymmetry



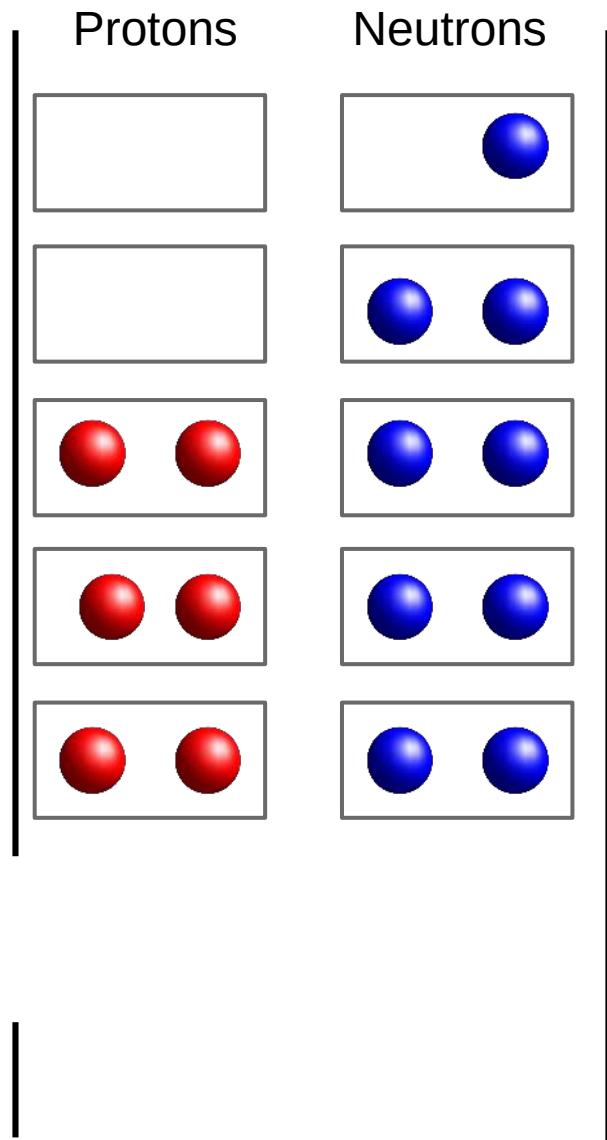
# Binding energy (Asymmetry parenthesis)



More asymmetry



# Binding energy (Asymmetry parenthesis)

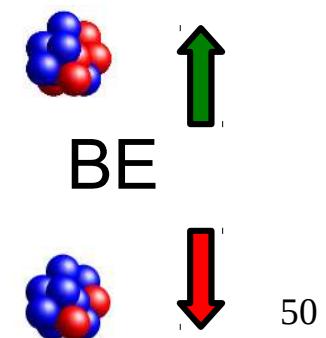


120 \$  
50 \$  
25 \$  
15 \$  
10 \$

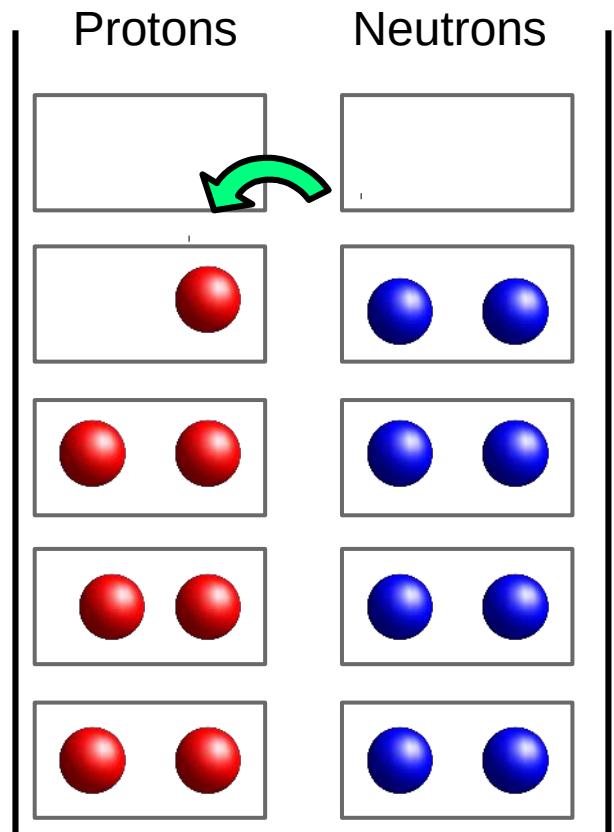
Total = 420 \$



More asymmetry



# Binding energy (Asymmetry parenthesis)



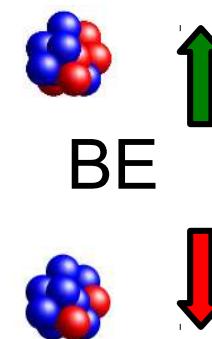
120 \$  
50 \$  
25 \$  
15 \$  
10 \$



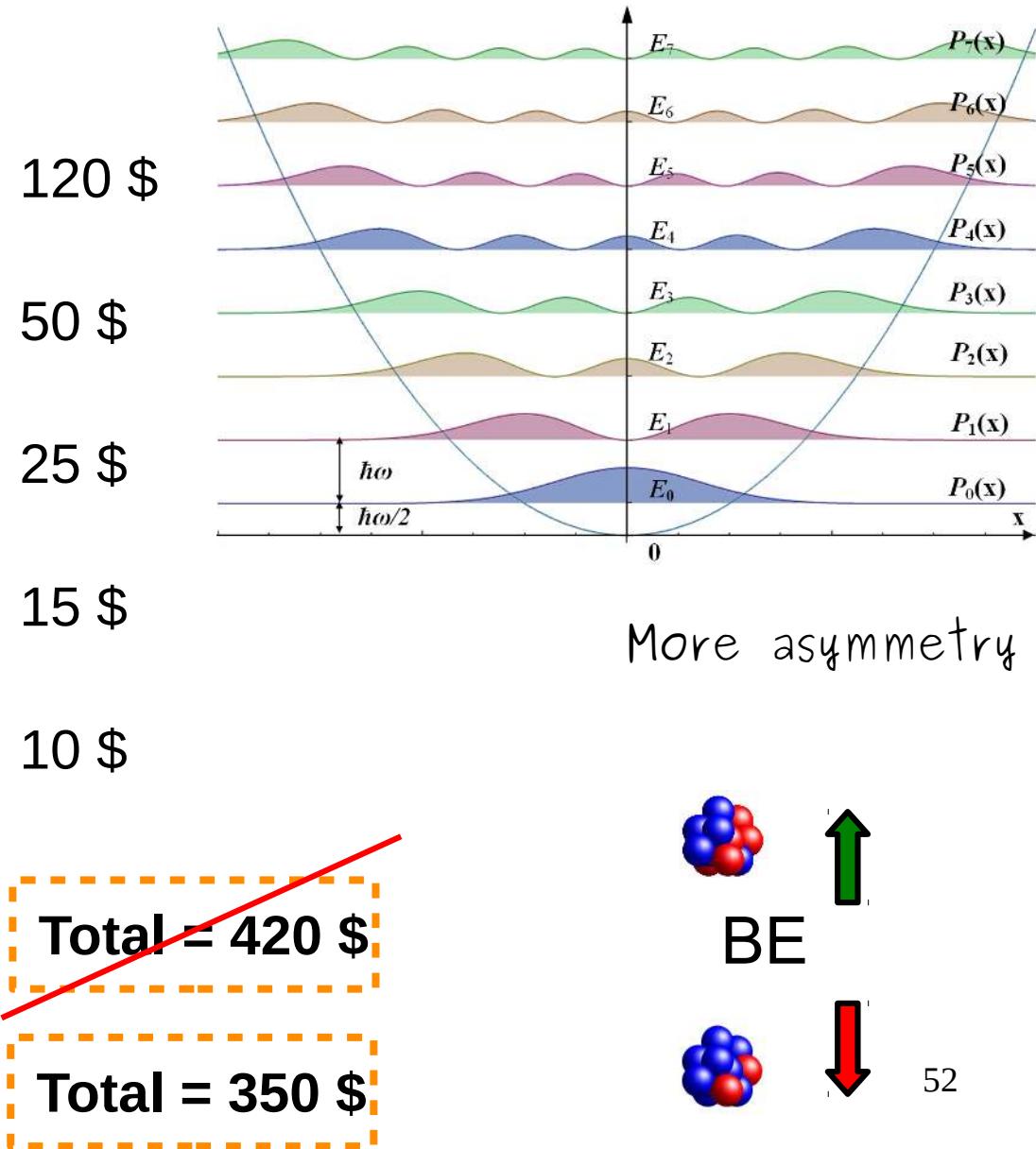
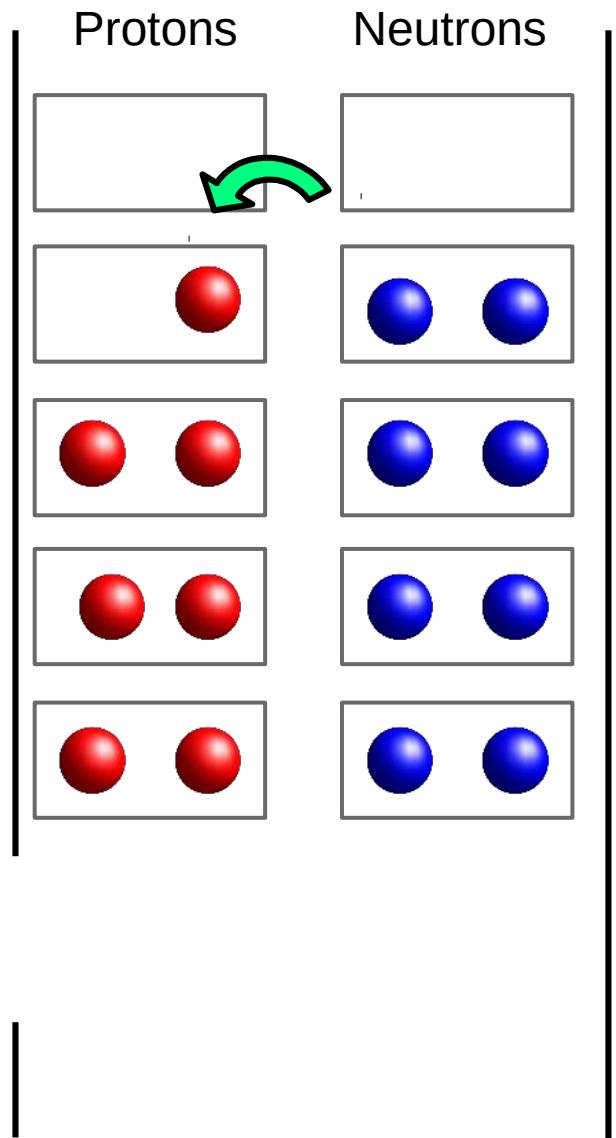
More asymmetry

Total = 420 \$

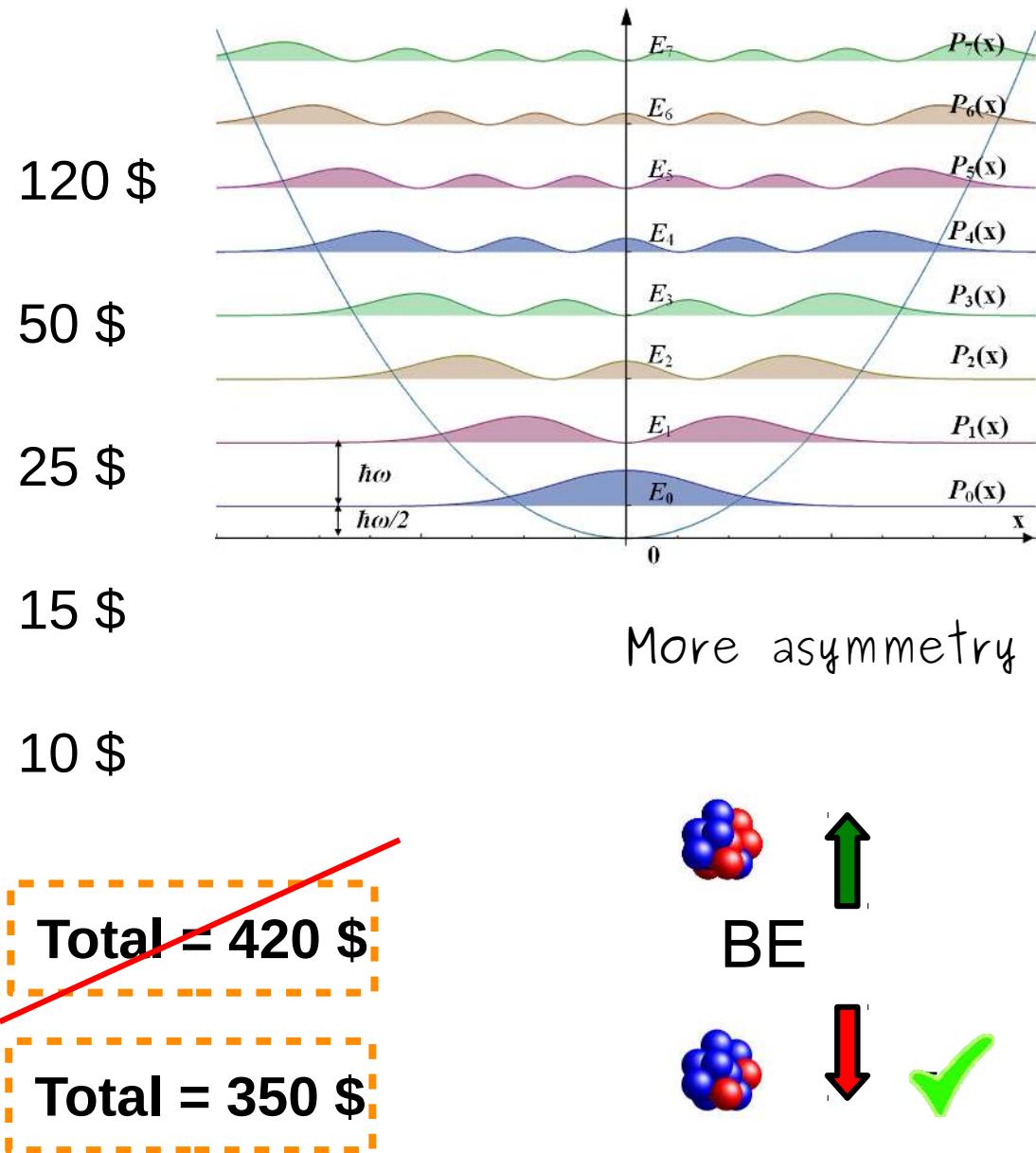
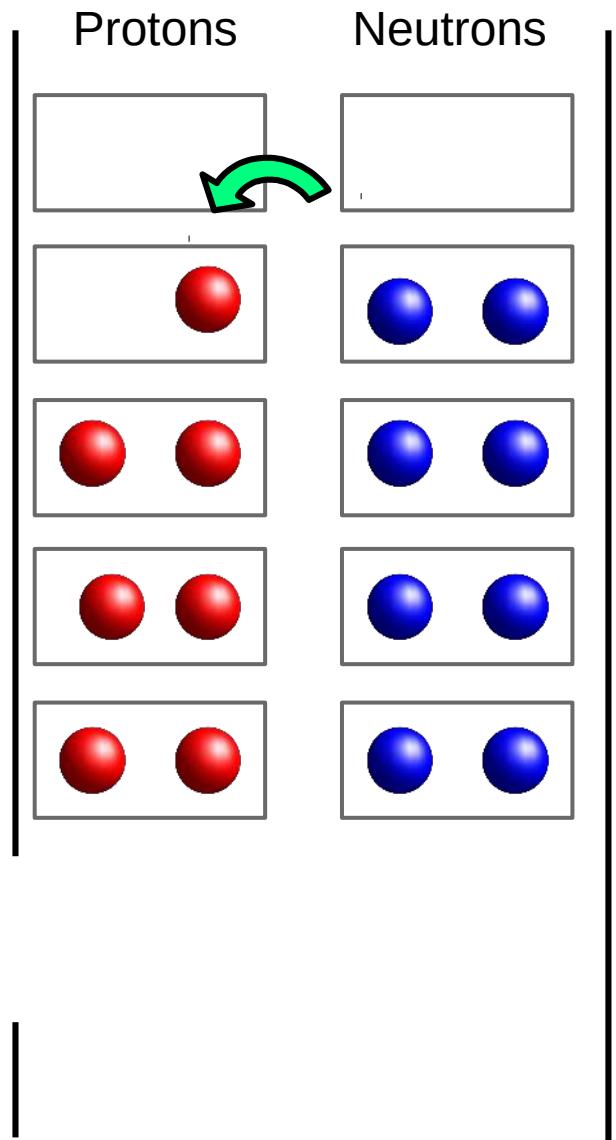
Total = 350 \$



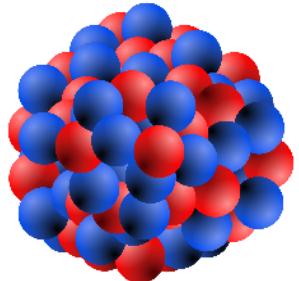
# Binding energy (Asymmetry parenthesis)



# Binding energy (Asymmetry parenthesis)



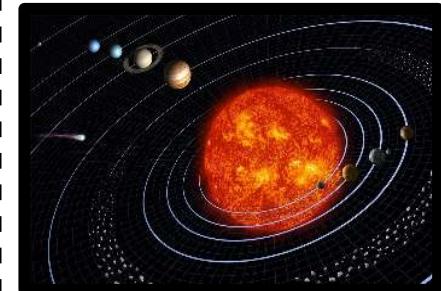
# Binding energy



Liquid drop  
model



$$F = G \frac{m_1 m_2}{r^2}$$



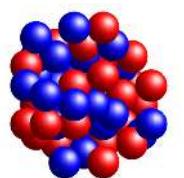
$$\text{BE}(N, Z) = a_V(N + Z) - a_S(N + Z)^{2/3} - a_C \frac{Z^2}{(N + Z)^{1/3}} - a_A \frac{(N - Z)^2}{N + Z}$$

More nucleons

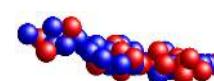
More surface

More protons

More asymmetry



BE



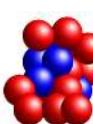
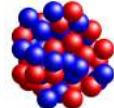
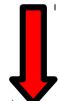
BE



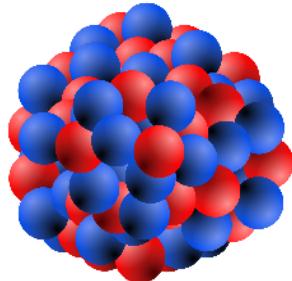
BE



BE



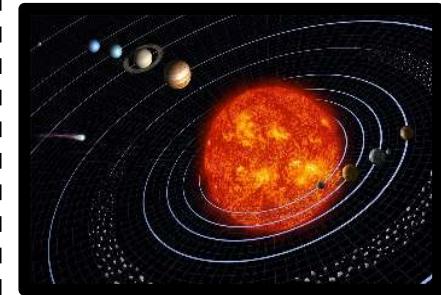
# Binding energy



Liquid drop  
model

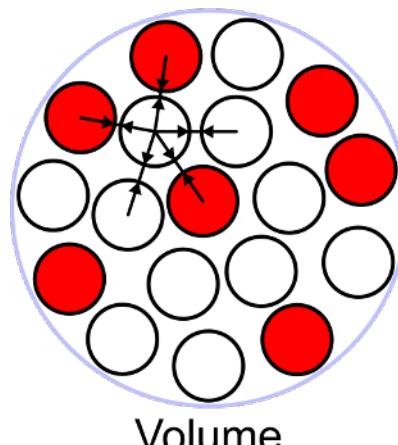


$$F = G \frac{m_1 m_2}{r^2}$$

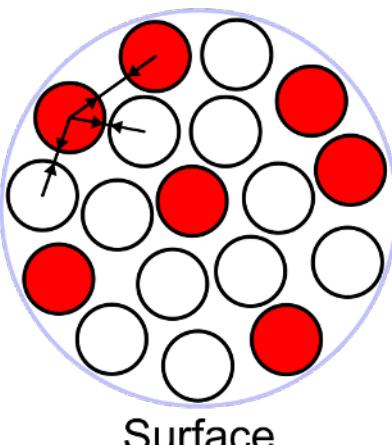


$$\text{BE}(N, Z) = a_V(N + Z) - a_S(N + Z)^{2/3} - a_C \frac{Z^2}{(N + Z)^{1/3}} - a_A \frac{(N - Z)^2}{N + Z}$$

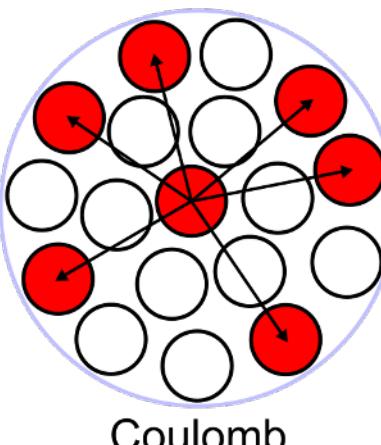
More nucleons



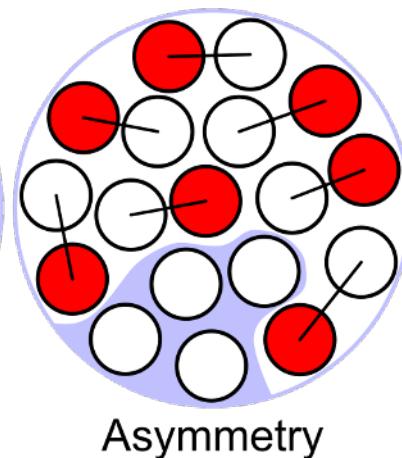
More surface



More protons



More asymmetry

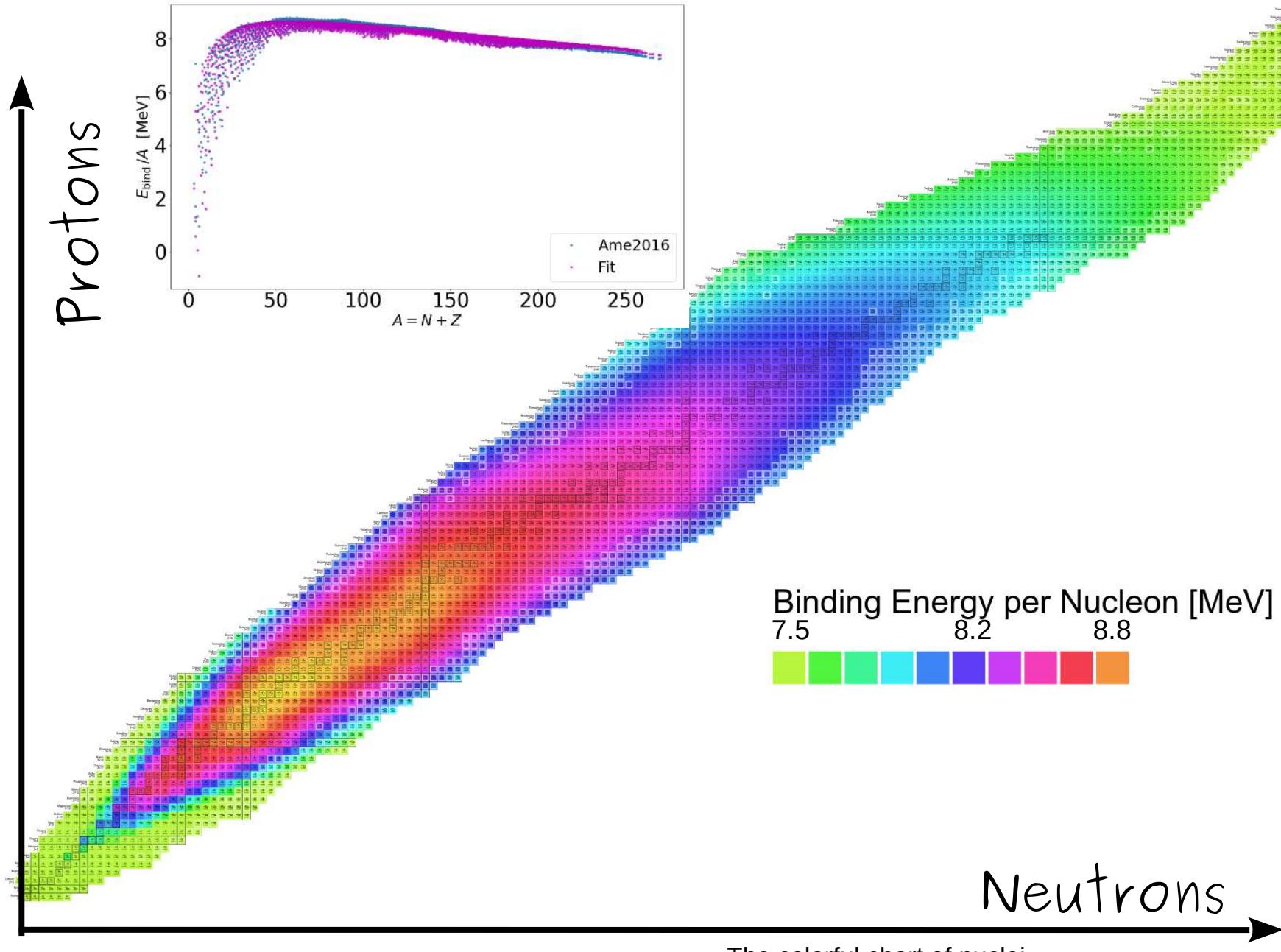


# Binding energy

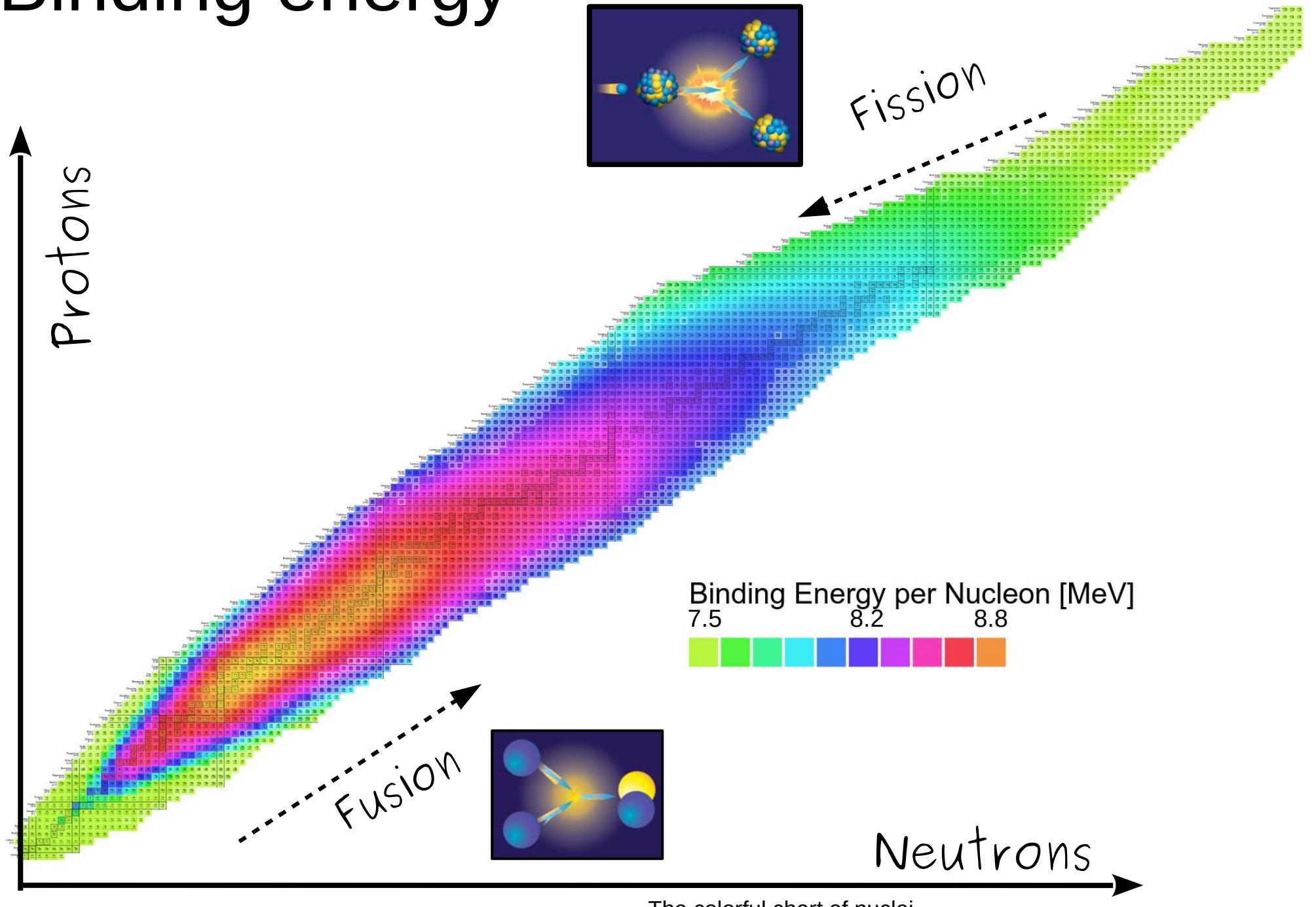
Lets code!



# Binding energy



# Binding energy

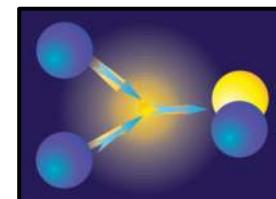


# Binding energy

Protons

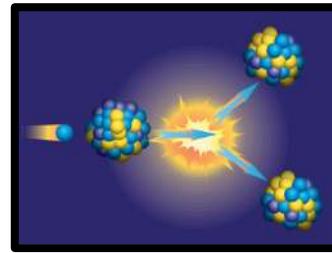


Fusion



Neutrons

The colorful chart of nuclei



Fission

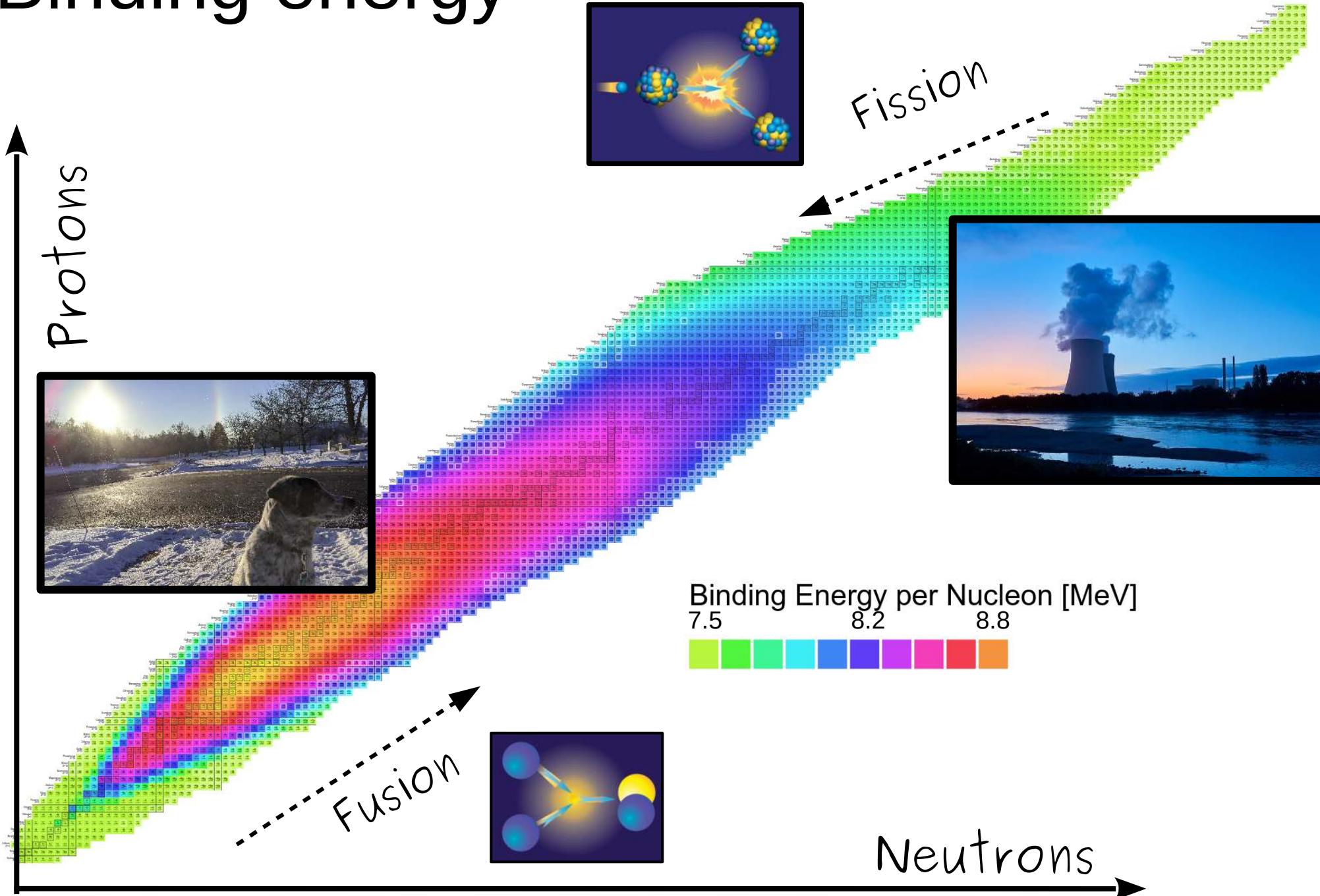


Binding Energy per Nucleon [MeV]

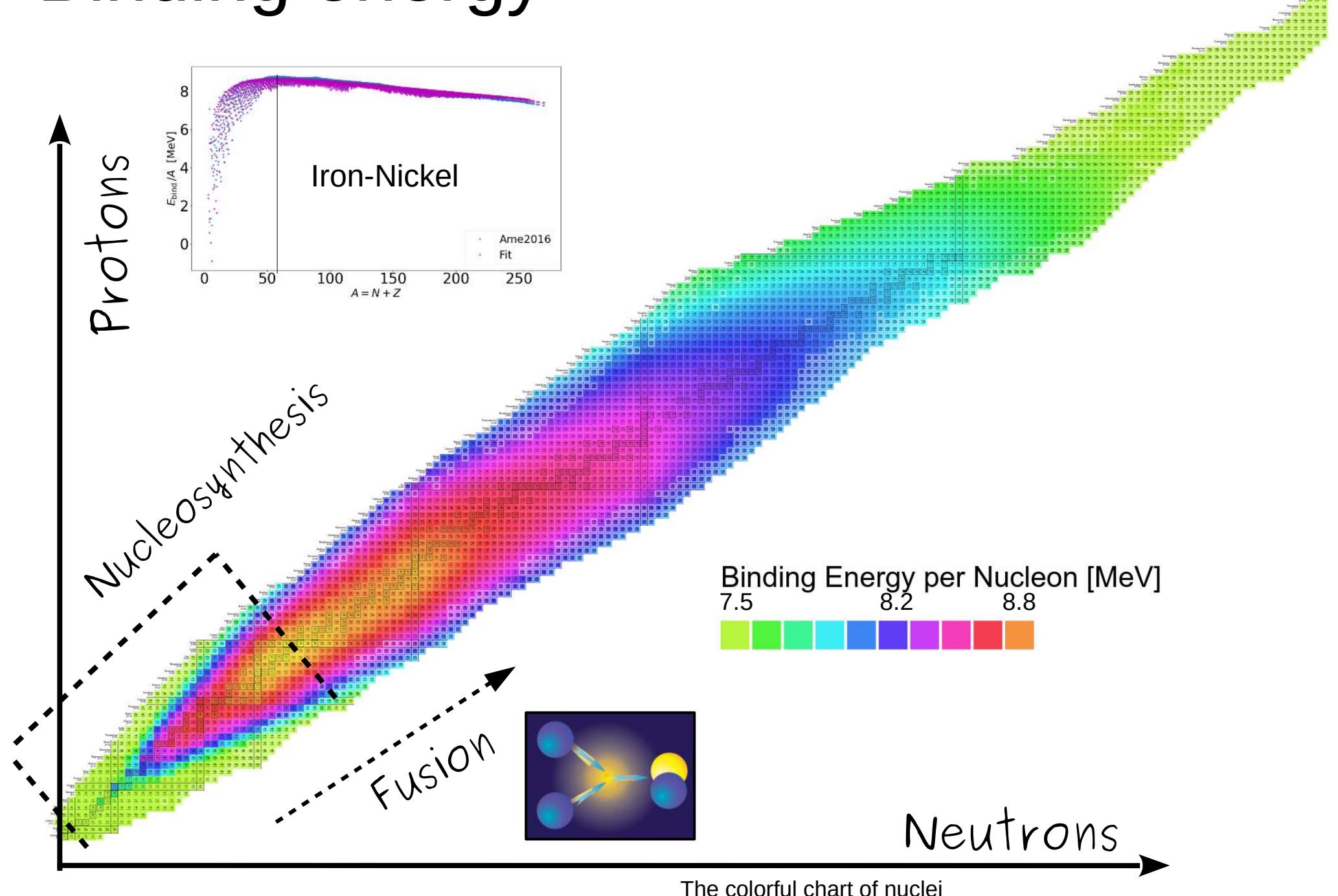
7.5

8.2

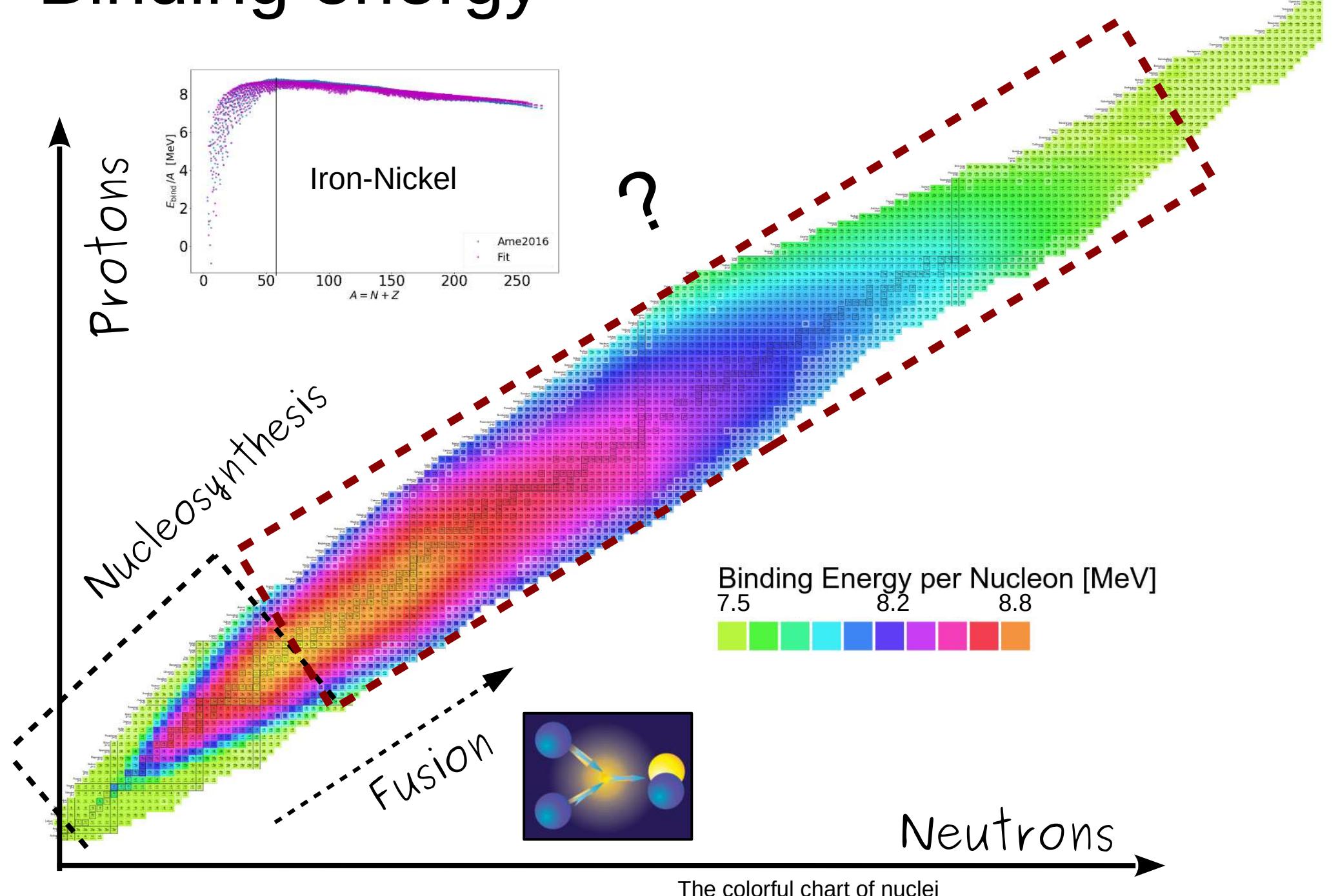
8.8



# Binding energy

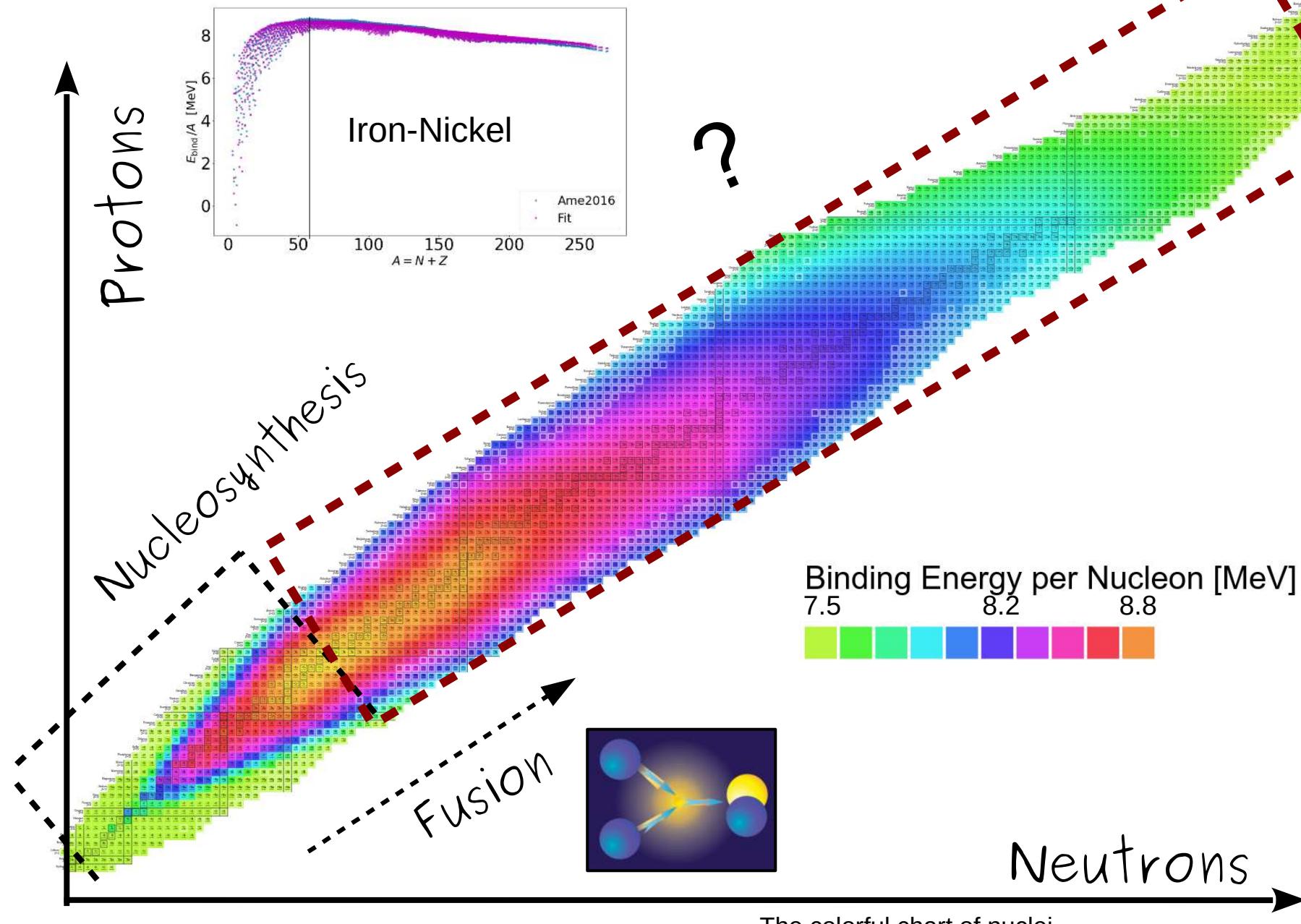


# Binding energy



# Binding energy

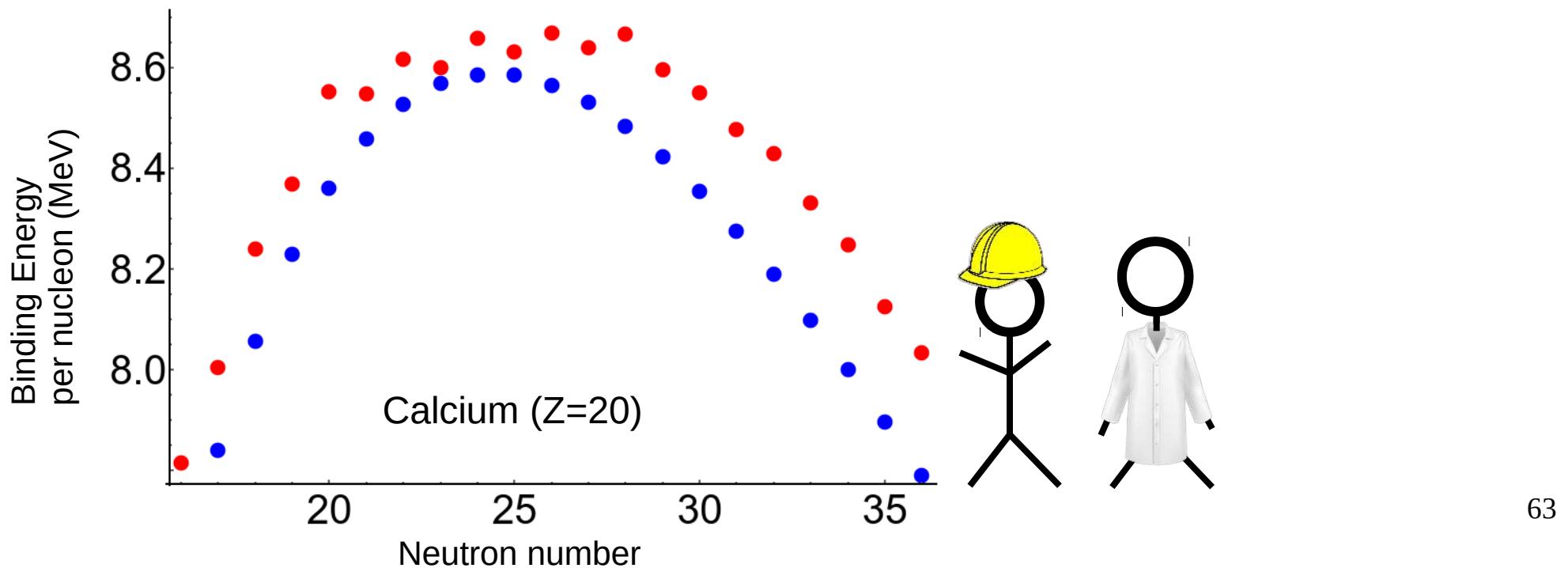
Where do heavy elements come from?



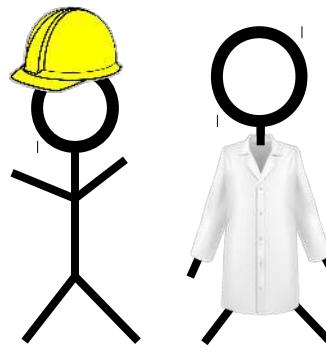
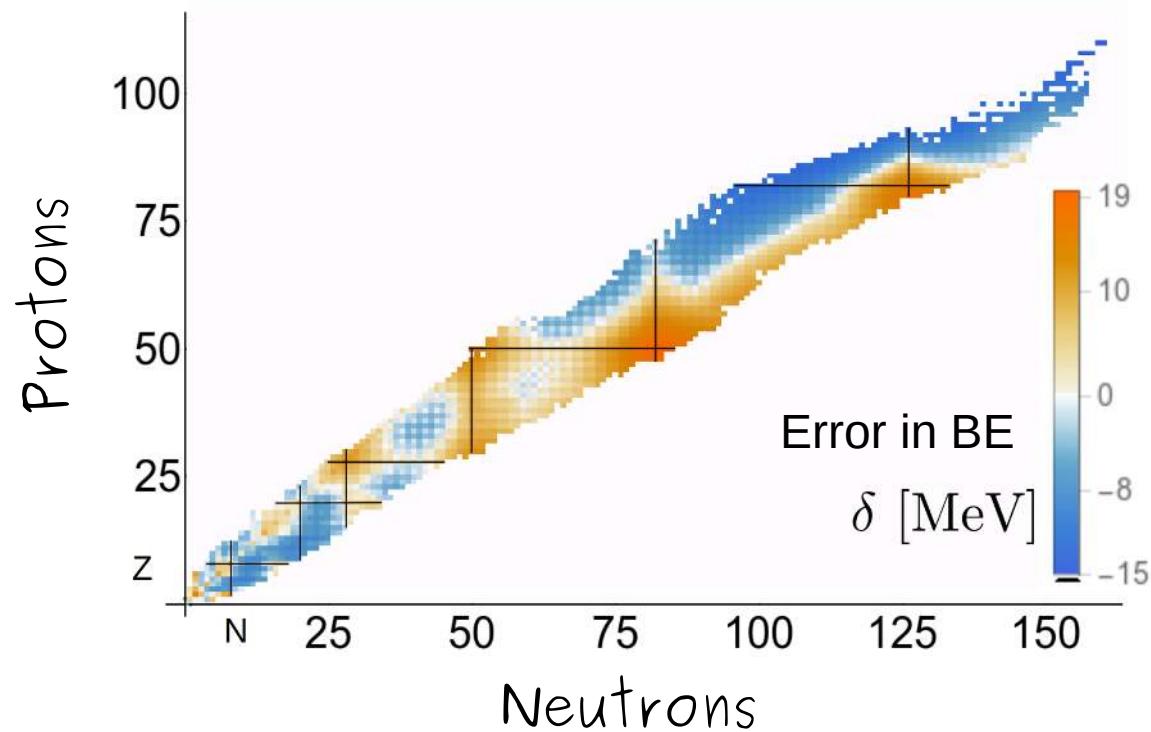
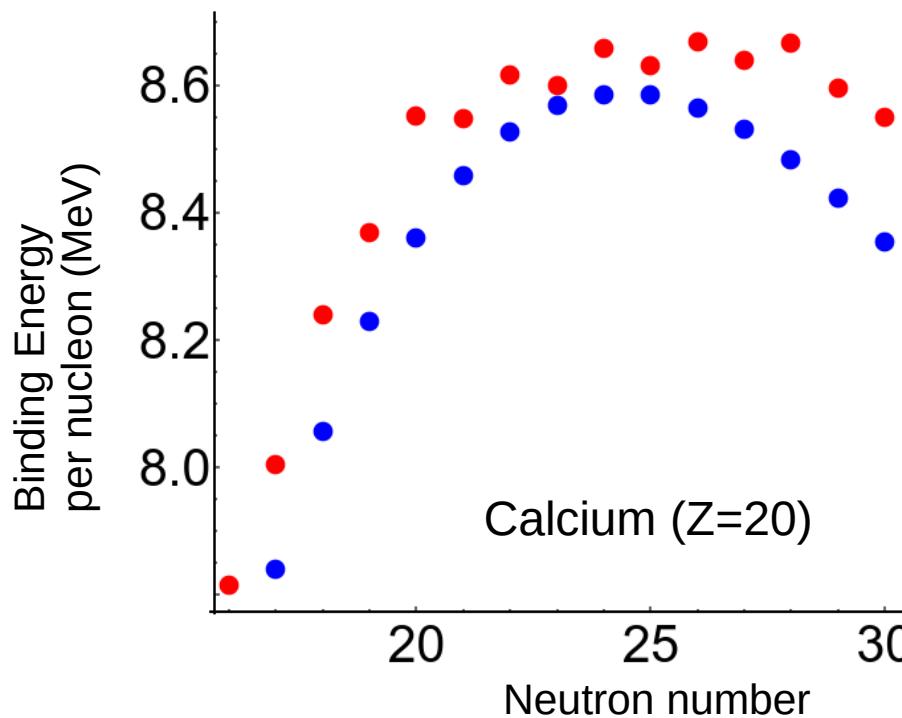
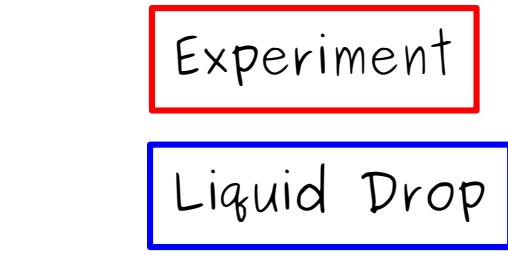
# Binding energy

Experiment

Liquid Drop

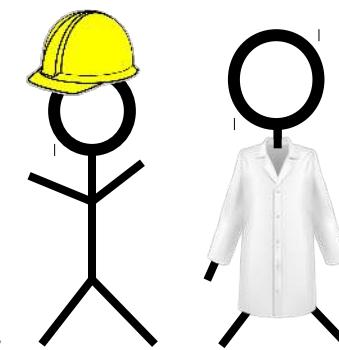
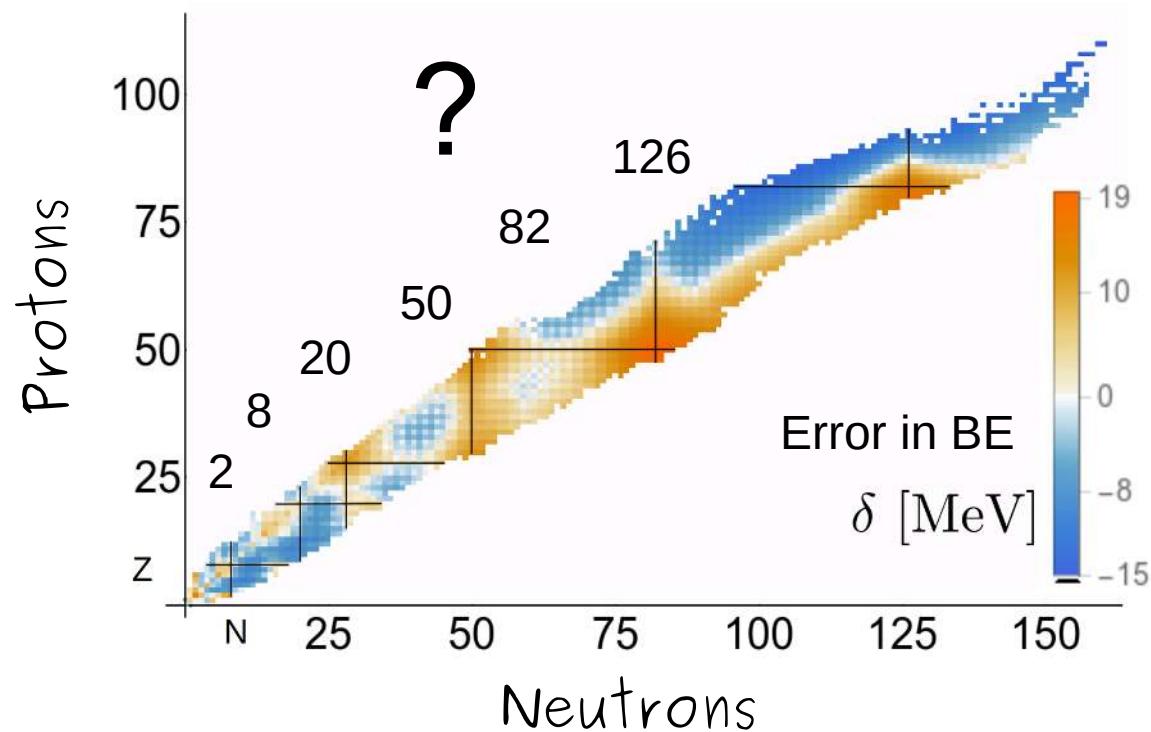
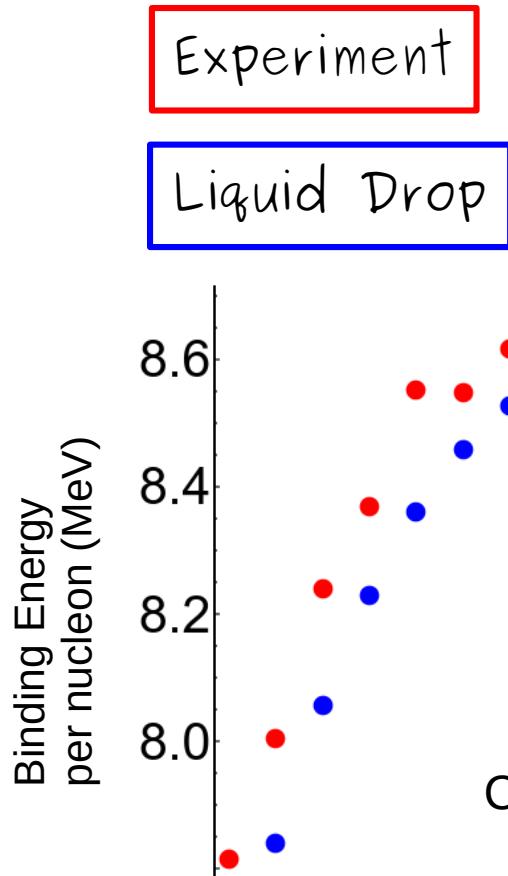


# Binding energy



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# Binding energy

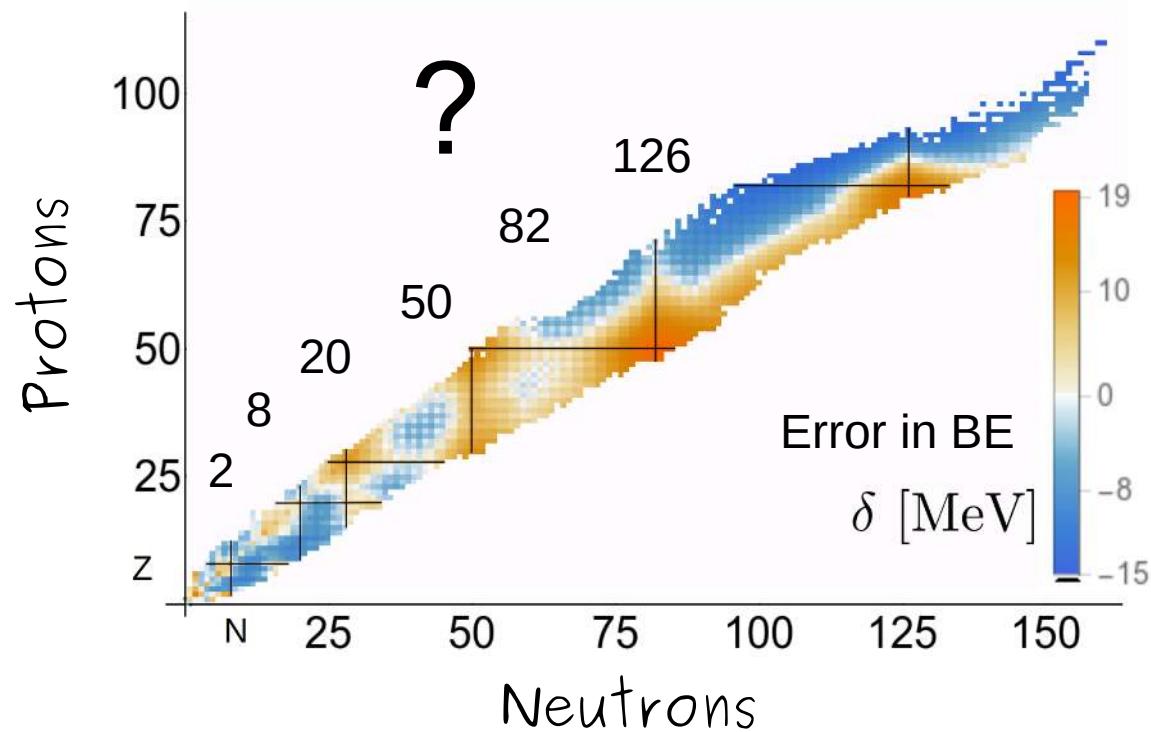
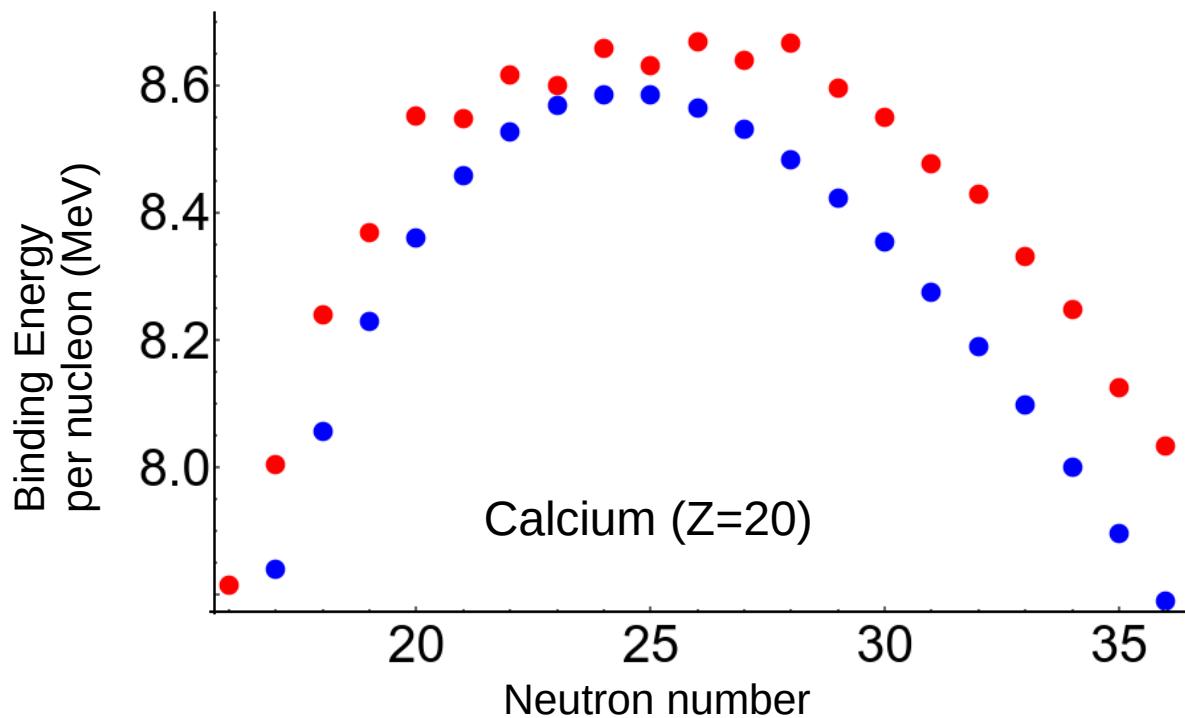


65

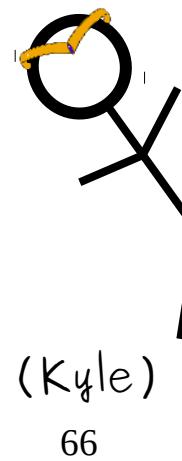
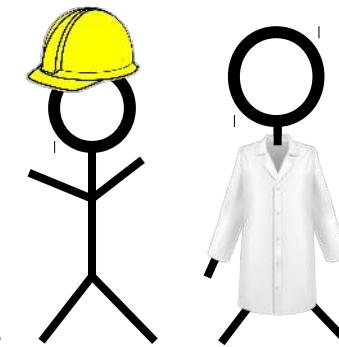
# Binding energy

Experiment

Liquid Drop



I can help!



# Key insight

Good science always  
leaves you with more  
questions

