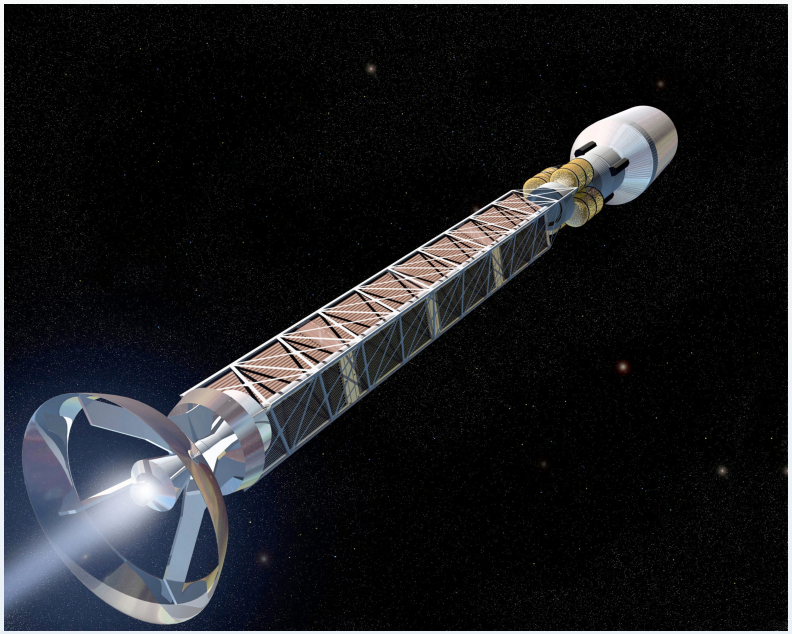


ROCKETS
A technological tour de force

Juan Rojo
VU Amsterdam & Theory group, Nikhef

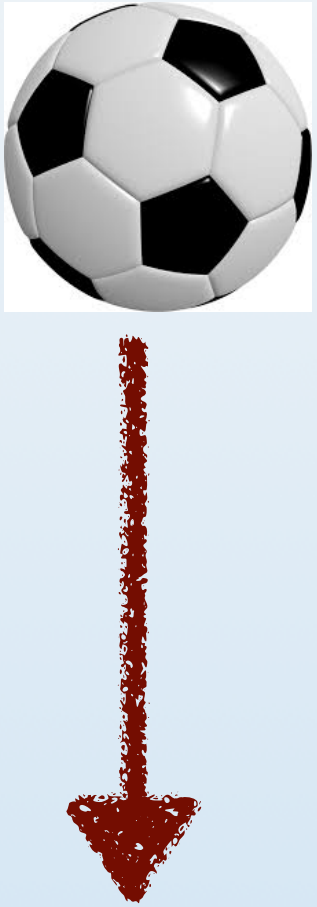
International School of Delft
Delft, 9/12/2016

Fighting gravity

- What happens if you **launch an object up in the air**?

Fighting gravity

- What happens if you launch something up in the air?
- …. that eventually **it will come down** to exactly the same point where the object was launched



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- But is this **always the case**? and more important, **why**?

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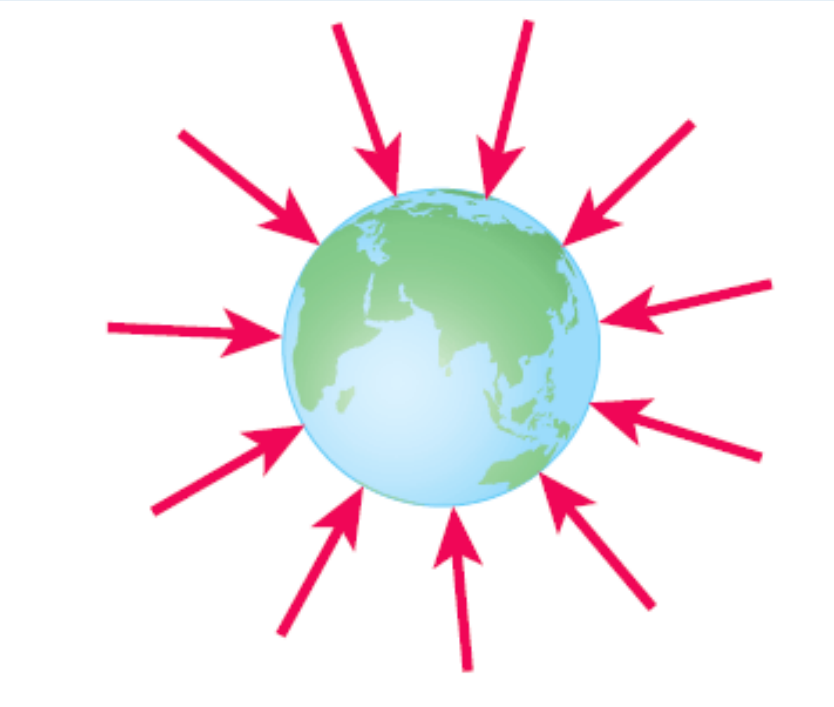

Because of **Gravity:** one of the four **fundamental forces in nature!**

The Earth attracts **any object with mass** towards its centre!

Fighting gravity

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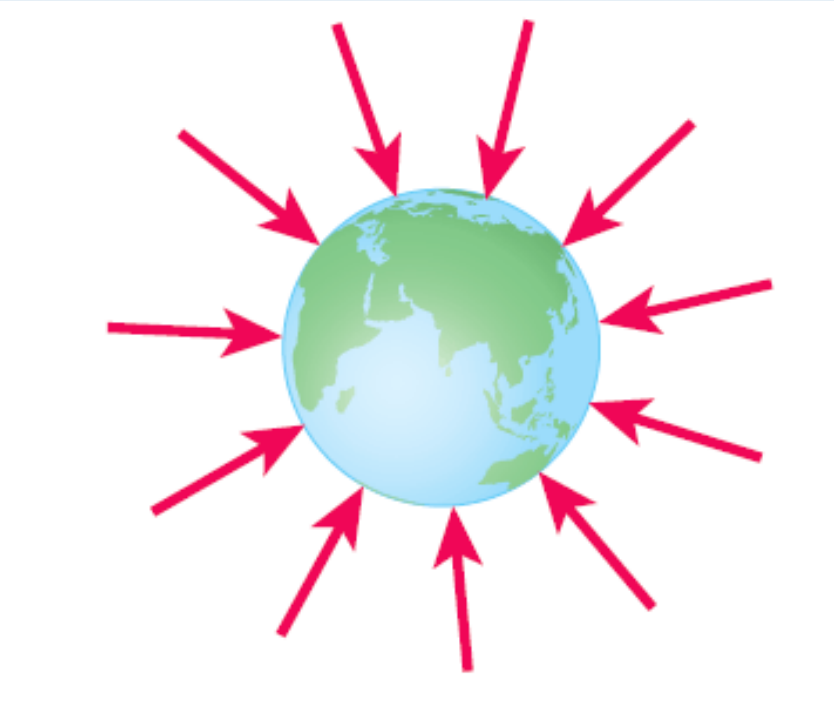


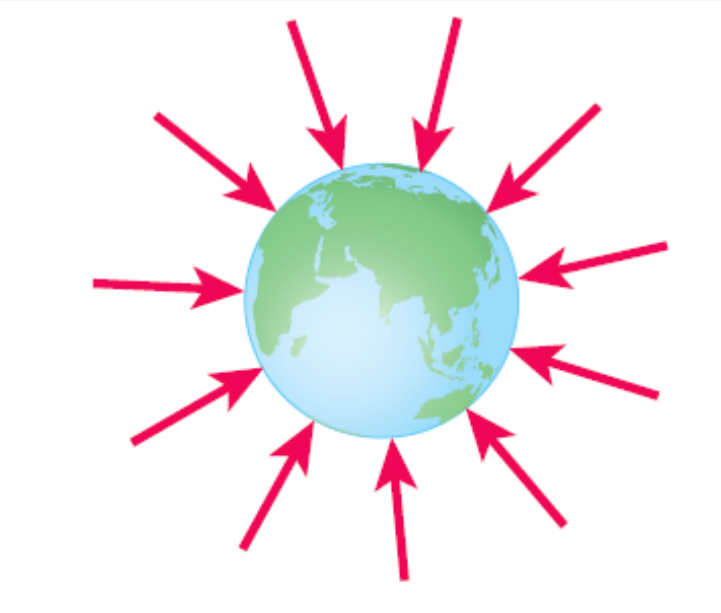
Because of **Gravity:** one of the four **fundamental forces in nature!**

The Earth attracts **any object with mass** towards its centre!

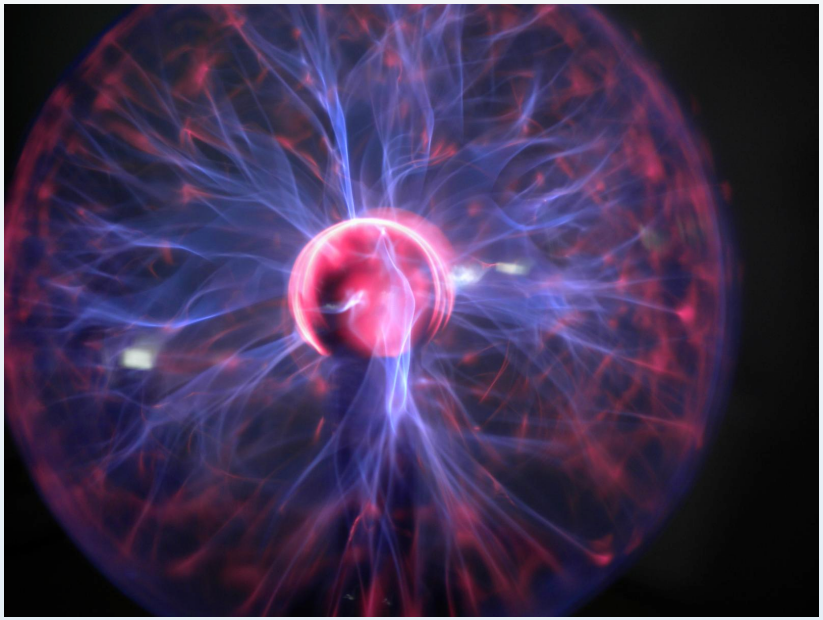
Do you know what are the other **three fundamental forces of nature** and what are their effects on us?

Four Forces to Bind us All

(1) **Gravity**

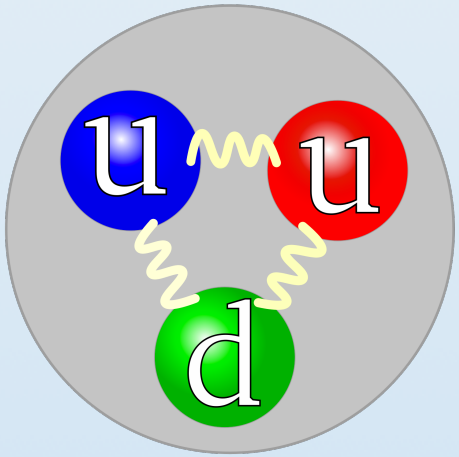


(2) **Electricity and magnetism**



(3) **Weak Nuclear Force**

(4) **Strong Nuclear Force**



Four Forces to Bind us All

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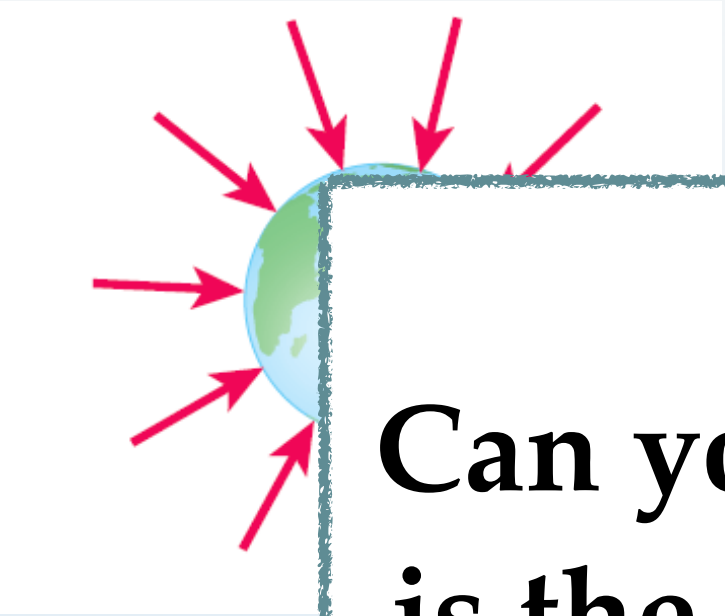

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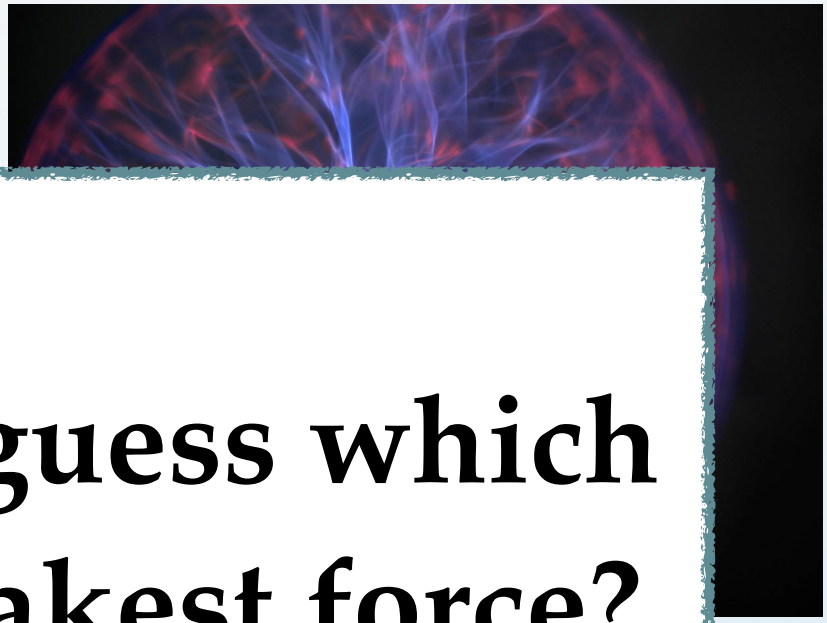
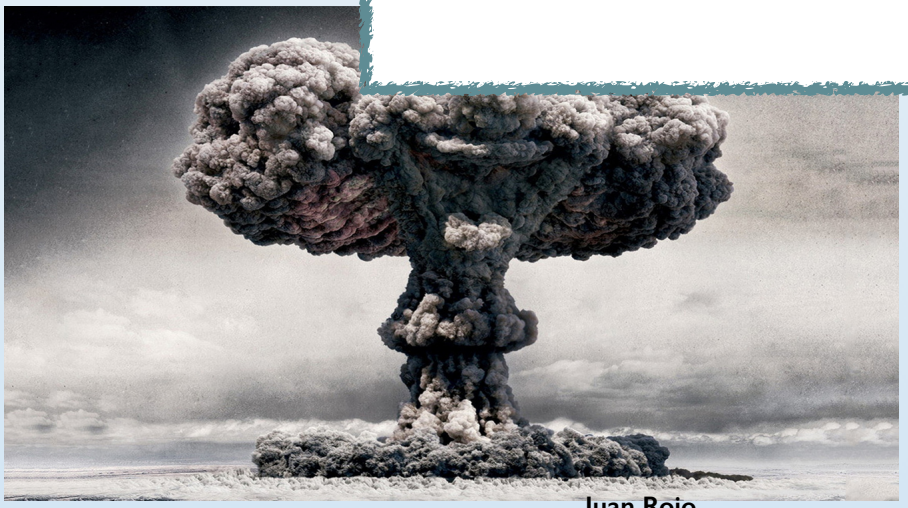
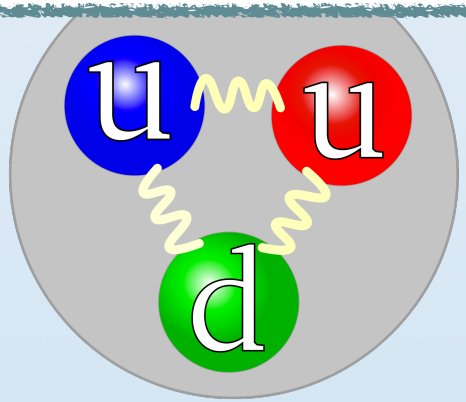


Can you guess which is the weakest force?

(3) **Weak N**





Four Forces to Bind us All

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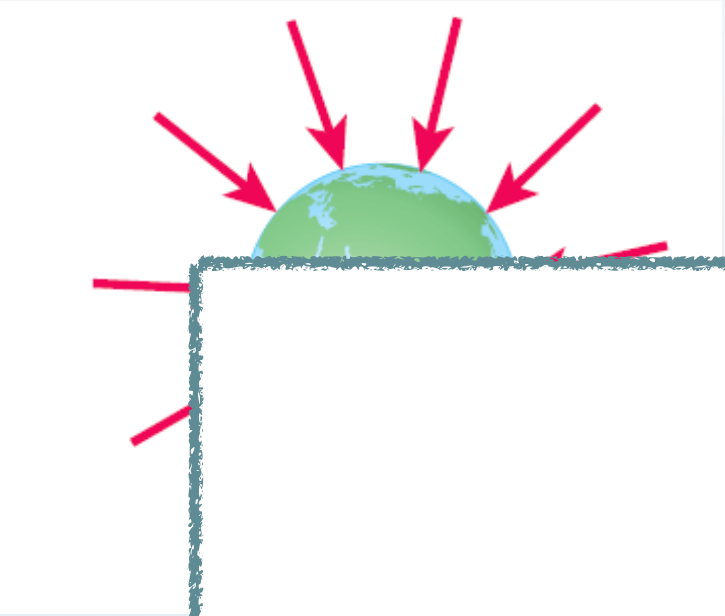

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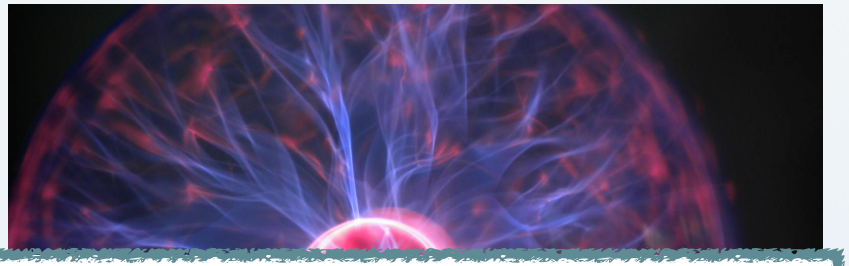
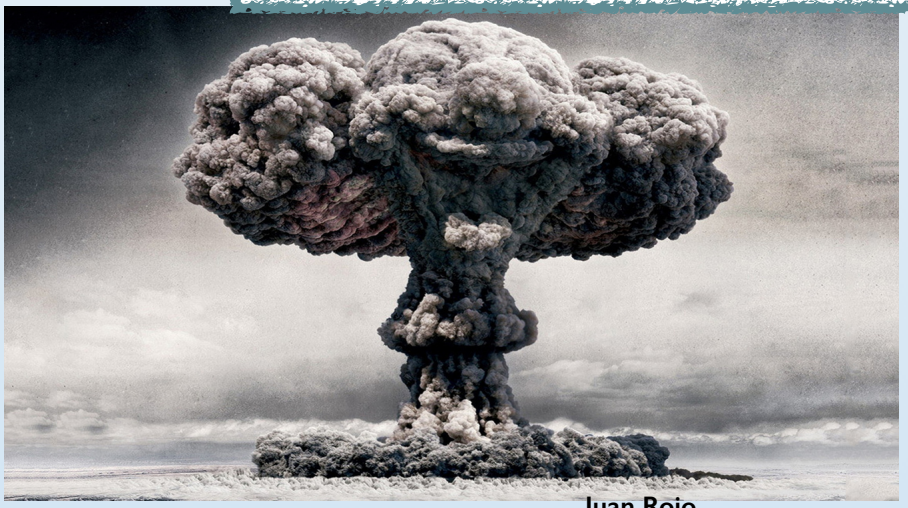
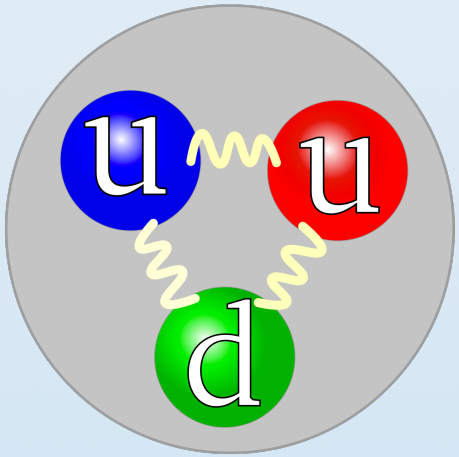


Gravity!

(3) **W**





Four Forces to Bind us All

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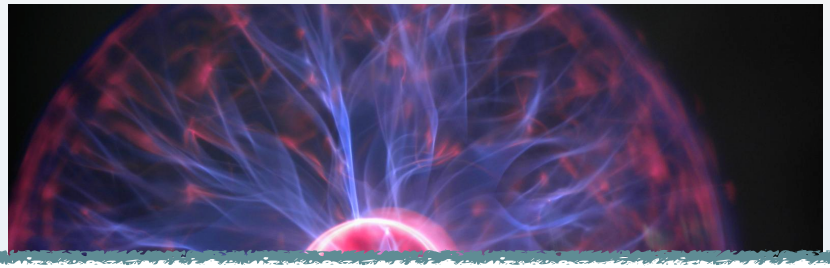
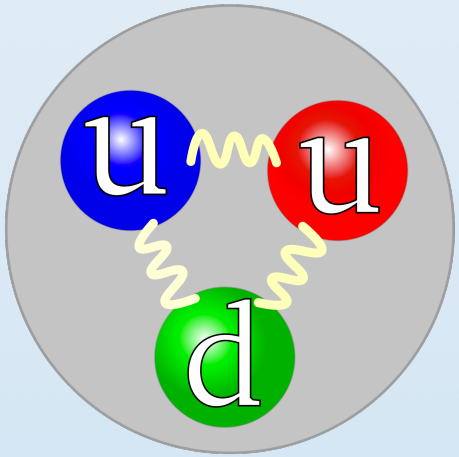


It appears the stronger simply because it is always attractive!

***eg* Electrical force can be attractive or repulsive ……**



Fighting gravity

- What happens if you throw something up in the air?
- …. that eventually it will come down to exactly the same point where the object was launched
- But is this **always the case**? and more important, **why**?

No!

If an object has enough speed, it will manage to **escape the Earth's gravitational attraction** an go to the Space!

Going Very Fast

- How fast do I need to launch something so that it goes to Space?
- This is called the **Earth's escape velocity**, and its value is

11 km/s = 40000 km/h

- This is a rather staggering velocity! Compare with something familiar to you ….

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Usain Bolt

Peak velocity: **50 km/h**

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Lamborghini

Peak velocity: **300 km/h**

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Supersonic Plane

Peak velocity: **4000 km/h**

Even this is too slow to reach Space!

Rockets

- So if we **want to go to space** we need to think of something else!

- But **how do rockets work?** How can they achieve **escape velocities**?

Action and Reaction

- The basic idea is one of the basic principles of **Mechanics: Action and Reaction**

If object A applies a Force to object B, then object B will apply the same force (opposite sign!) to object A

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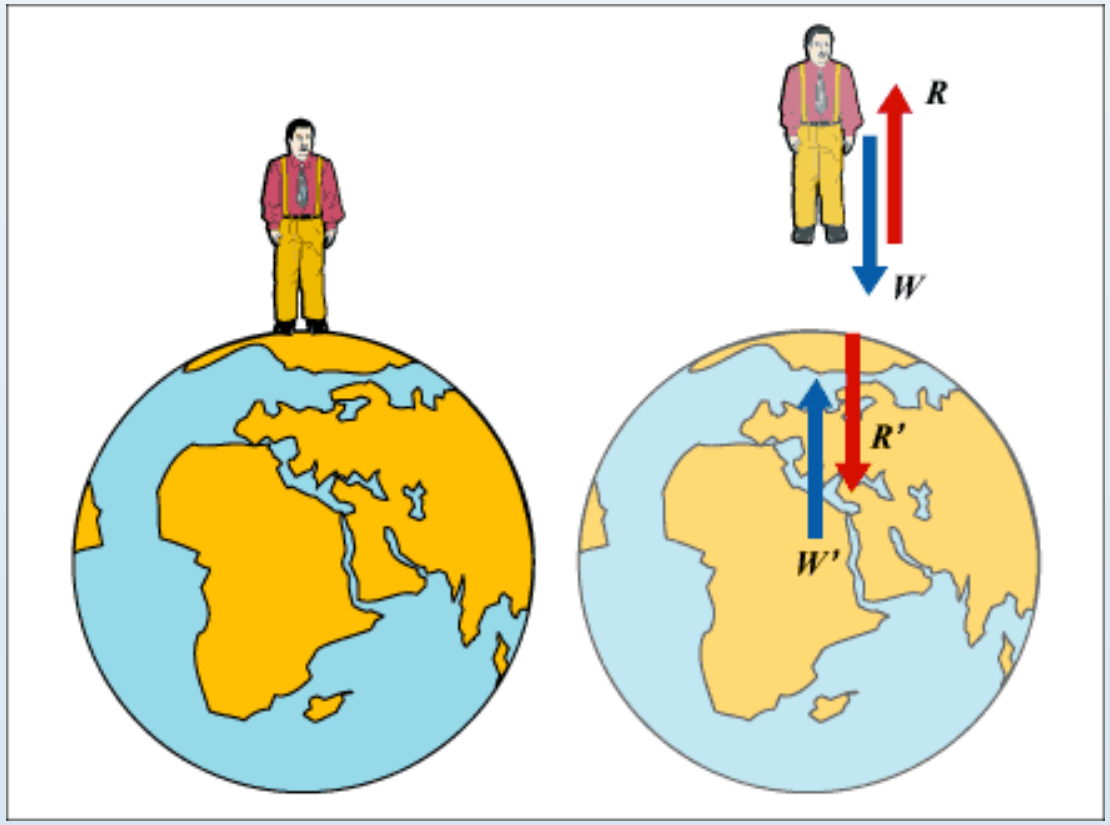

The Earth attracts me (Gravity!). Does this mean that **I also attract the Earth?** Then why does not the Earth move?

Action and Reaction

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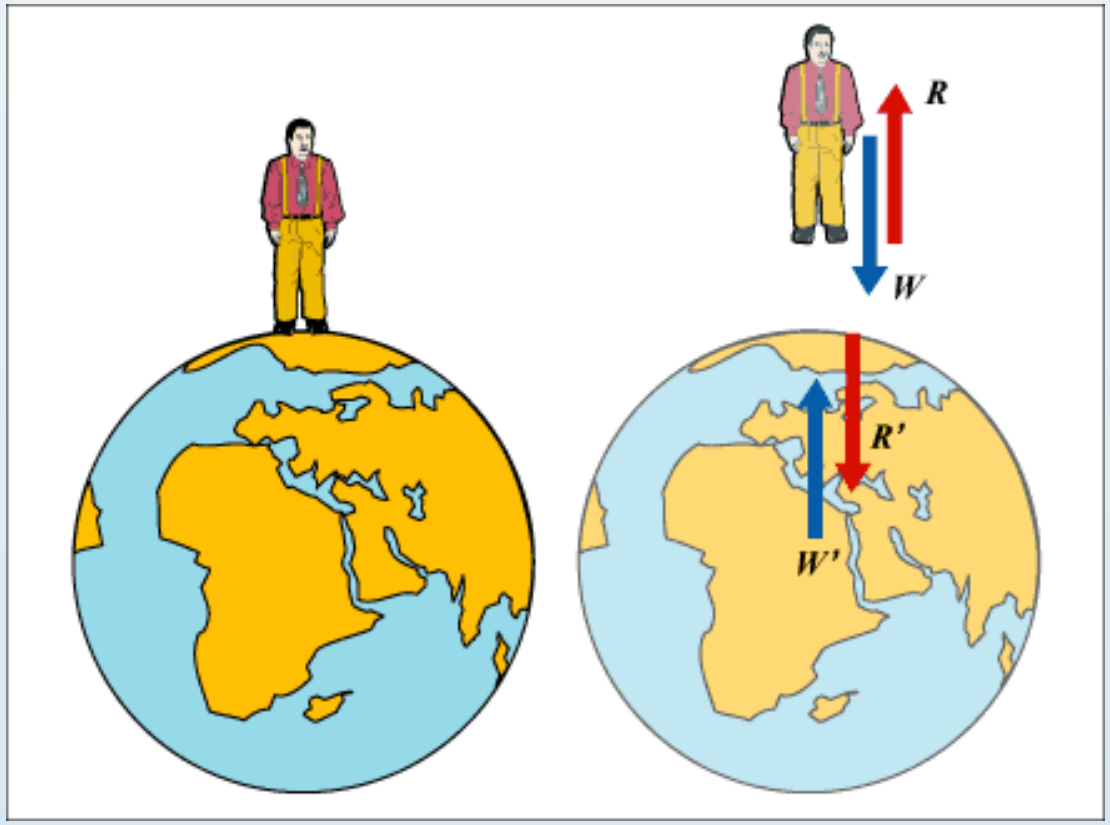

The Earth attracts me (Gravity!). Does this mean that **I also attract the Earth?** Then why does not the Earth move?

It does! But by a tiny tiny amount, since $\mathbf{M_{earth}} <<<< \mathbf{M_{myself}}$

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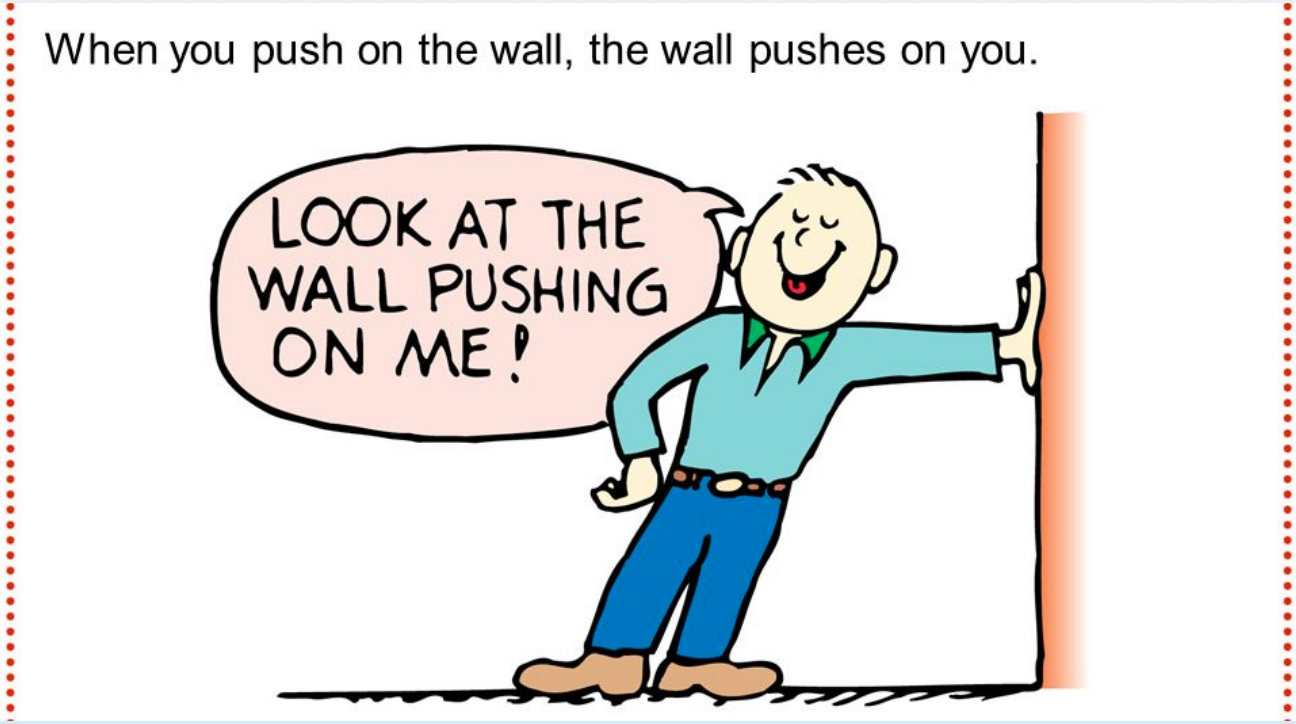

If you push a wall, the wall is also **pushing you back!**

(Else you would pass through the wall, which is unlikely ….)

Action and Reaction

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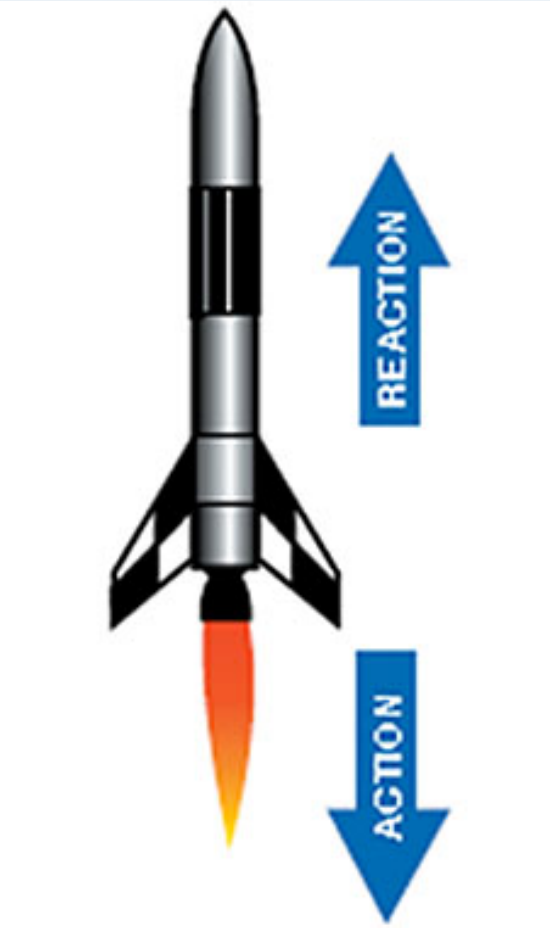

Rockets use this principle for their propulsion:

- **Before launch**: big mass of fuel available
- **During launch:** start to burn fuel, and expel hot gas (action) which causes r**ocket to accelerate** (reaction)
- **When all fuel is burnt**: peak velocity achieved - hopefully enough to escape the Earth!

- **Seems easy!**
- Then why it took so long to put rockets on orbit?

Challenges in Rocket building

- Ok then, so let's stuff the rocket with a **huge amount of fuel** so that it achieves very high velocities ……
- **Where is the catch?**

Challenges in Rocket building

- Ok then, so let's stuff the rocket with a huge amount of fuel so that it achieves very high velocities ……
- **Where is the catch?**
- We need another of the basic principles of **Mechanics**

If a Force F is applied to an object of Mass M, then the object will acquire an acceleration F/M

So for the same force applied, the more massive the object, the smaller acceleration

Challenges in Rocket building

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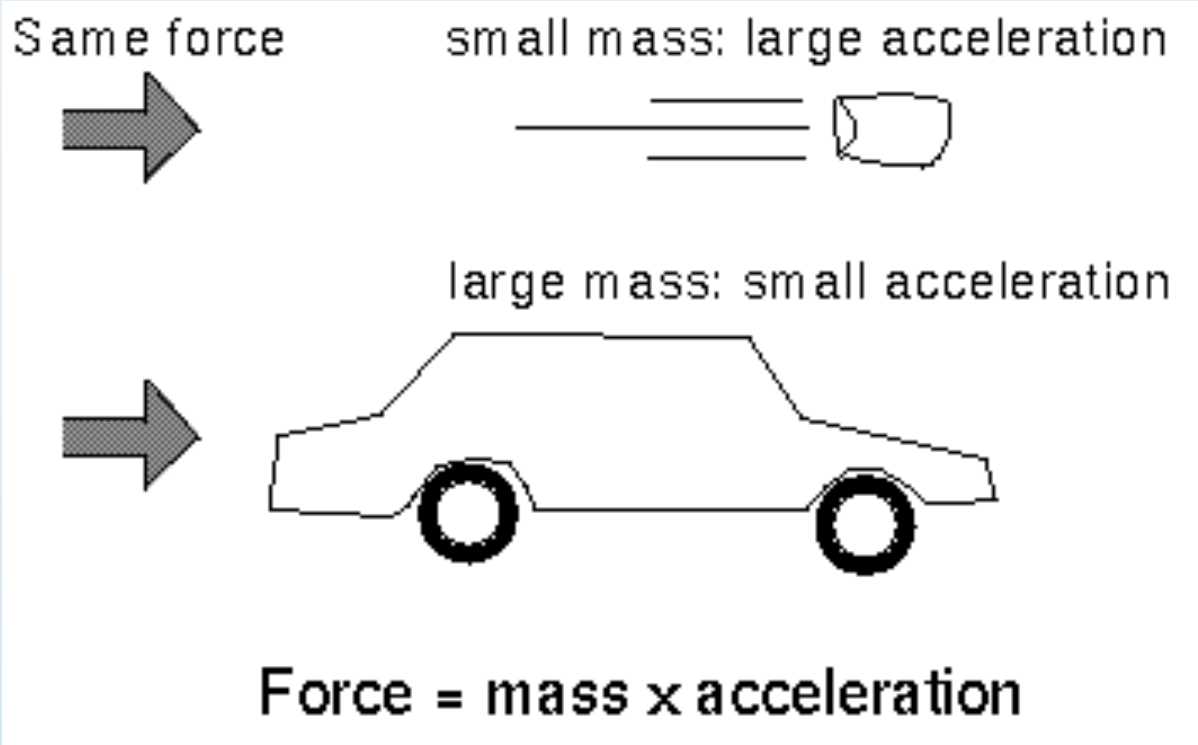

Challenges in Rocket building

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- Where is the catch?
- We need another of the basic principles of **Mechanics**

So for the same force applied, the more massive the object, the smaller acceleration

- So if the rocket is **too heavy (too much fuel)** the acceleration will be very small, and the maximum velocity will not be enough to escape Earth attraction

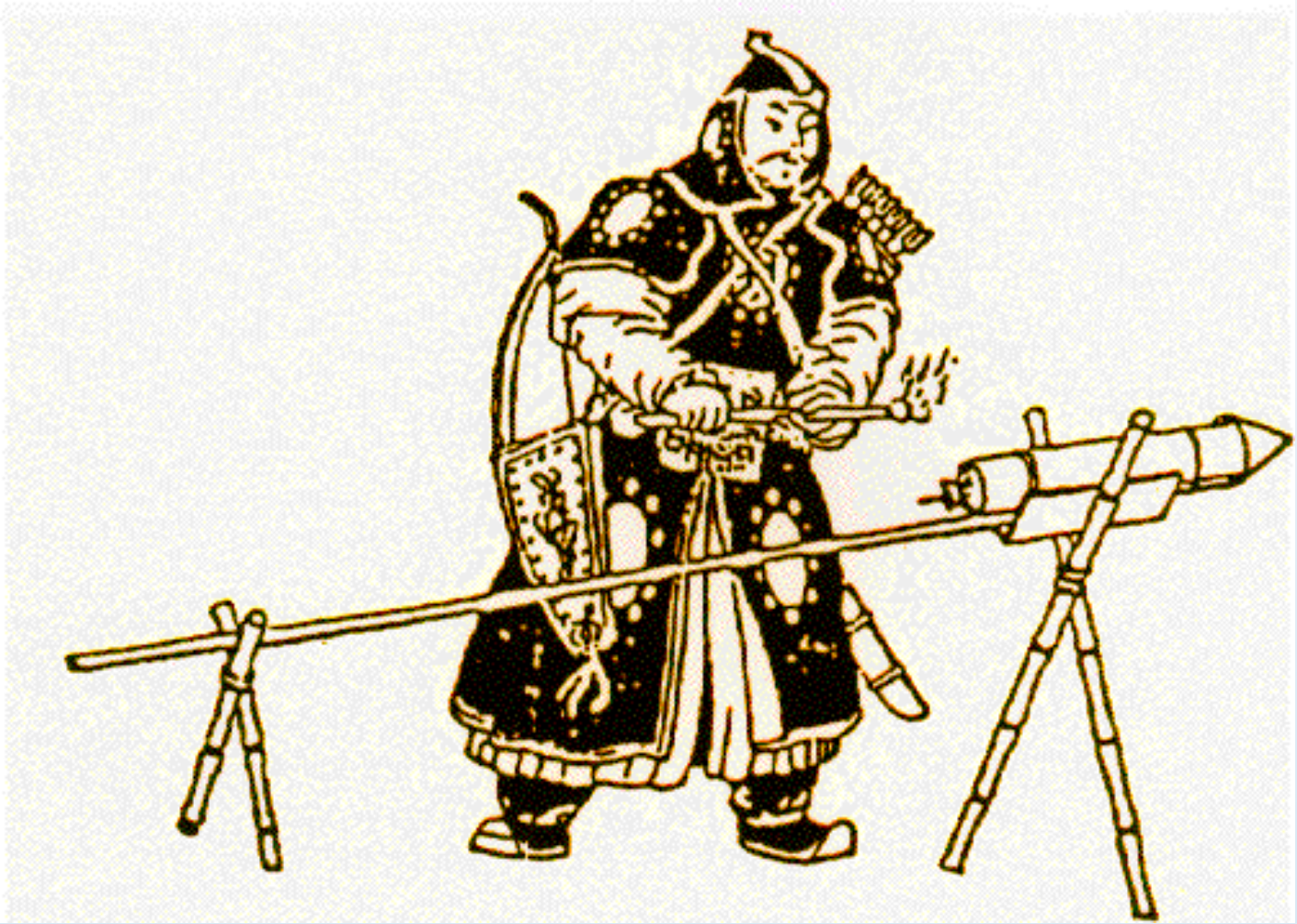
- It all comes down to the fuel then! Maybe we can find more efficient propulsion methods?

Challenges in Rocket building

Modern rockets use a clever **multi-stage system**: once part of the fuel is exhausted, the corresponding case is dropped to decrease the **total mass**

A brief history of rockets

As with many new technologies and inventions, rockets arose from **warfare requirements**



Chinese gunpowder rocket, circa 1200

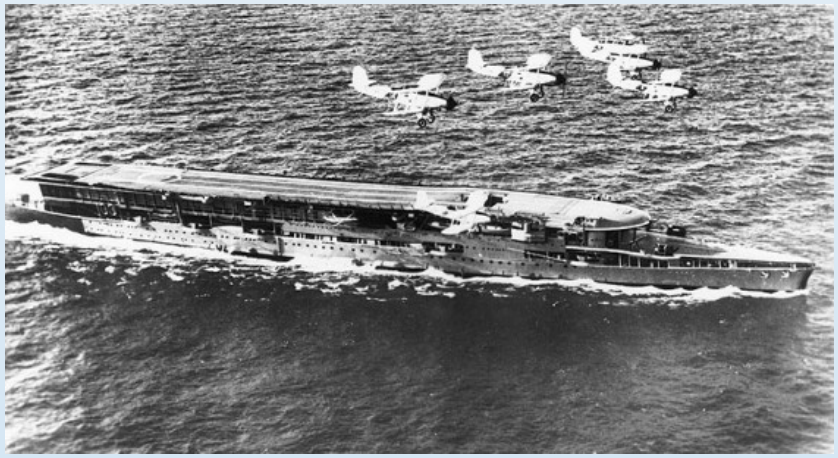
A brief history of rockets

Aside: other **crucial inventions driven by warfare efforts**

Radar

Nuclear power

Aircraft carriers



Drones

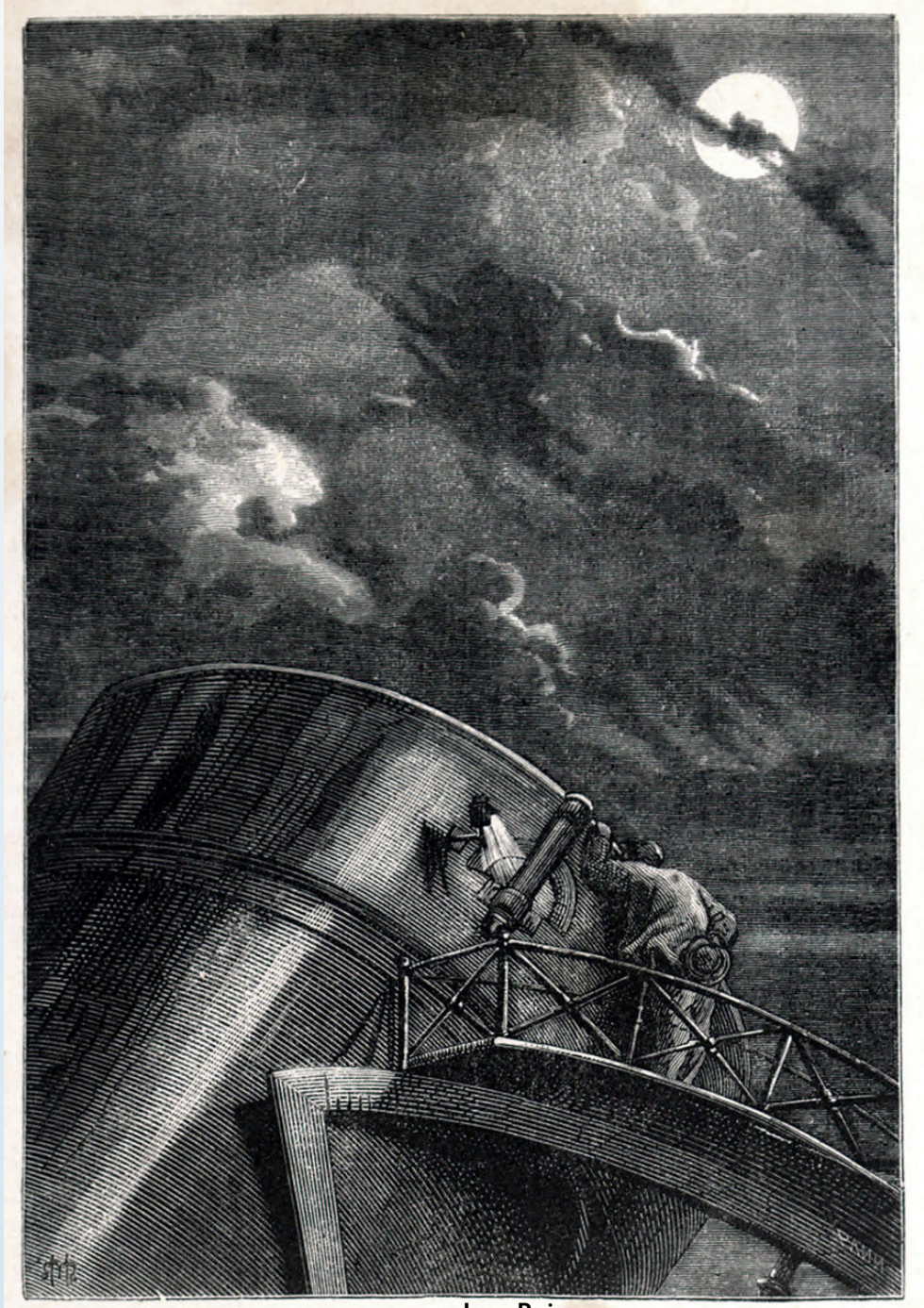
A brief history of rockets

The first rockets were **very small**, and powered by liquid fuel

Robert Goddard, 1920

Suggestions that using rockets one could **reach the Moon** were often ridiculised ….

A brief history of rockets



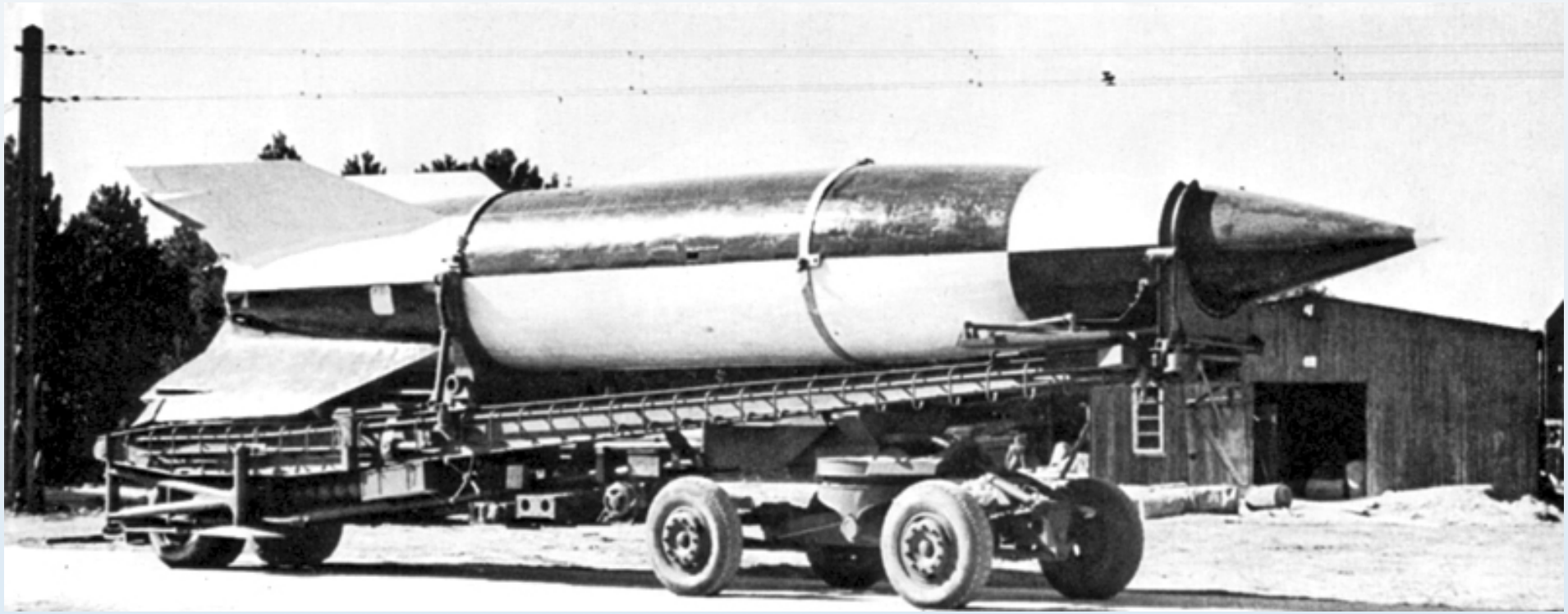
Juan Rojo

but the **dream of reaching the Moon** and beyond has been around long before …..

In *From the Earth to the Moon* Jules Verne imagined a huge cannon that **shot** a capsule with men to the Moon …..

A brief history of rockets

Rocket technology advanced rapidly during **World War II**, specially in **Nazi Germany**



At the end of the war, rocket technology **continued by the Allies**

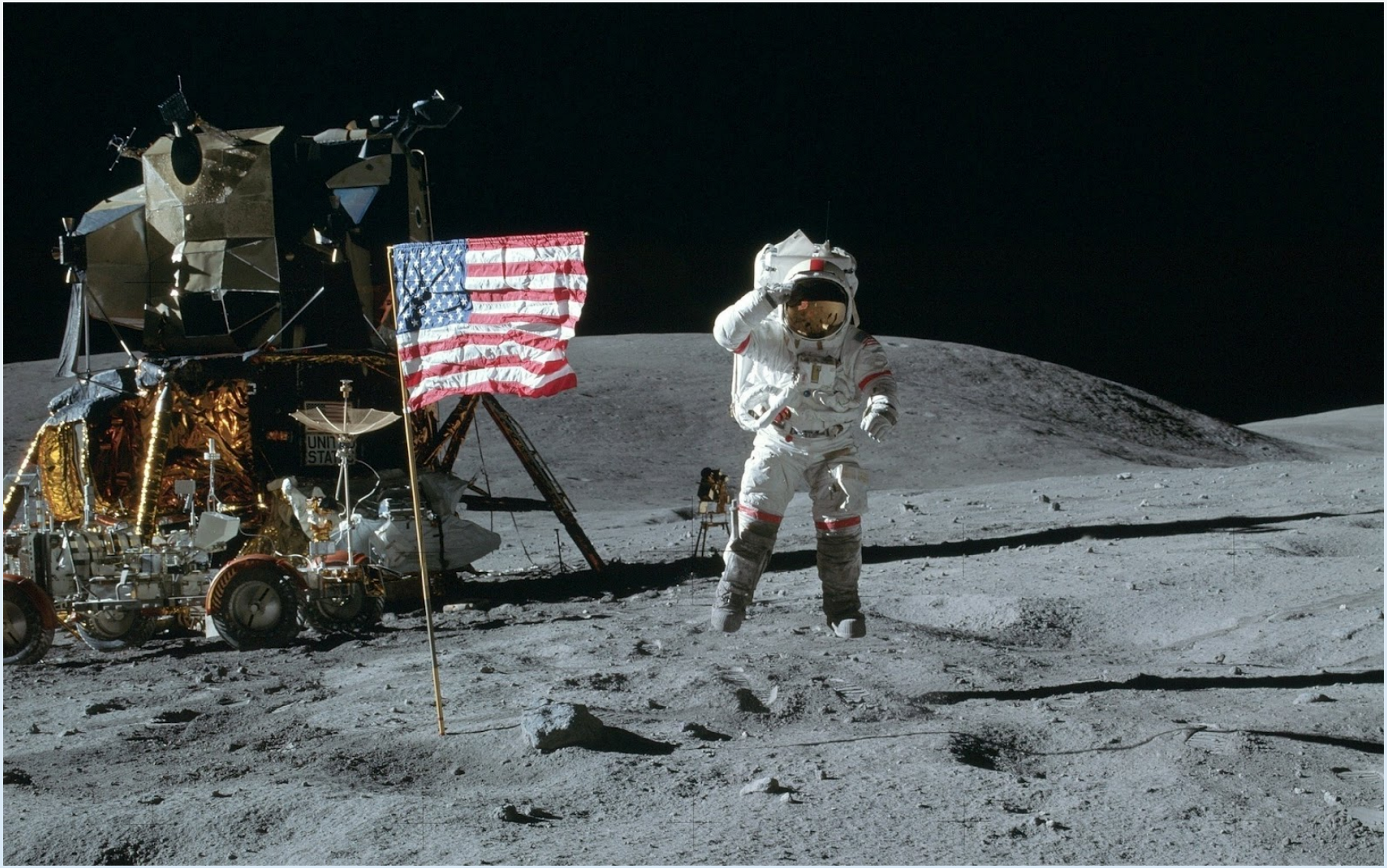
A brief history of rockets

In **1961**, the **Soviet Union** manage to put the first man ever in orbit around the Earth

This demonstration of **technological might** triggered a reaction in the USA

A brief history of rockets

So in **1969** the first men landed on the Moon thanks to the **Apollo rockets**



Unfortunately, **we have not left again the Earth's upper atmosphere since 1972**

What is next?

The natural next step for space exploration is **Mars!**

What are the main difficulties in **sending astronauts to Mars?**

What is next?

But if we are able to **colonize (and even terraform)** other planets, Mars will always be our first choice

Science usually starts as science fiction

Now, the **real challenge** would be to reach **other solar systems in nearby stars**

What is the main problem?

Even the nearest star, **Proxima Centauri,** is **very** far away

With current rocket technologies, it would take **1000 years to get there!**

Forget about getting back ….

So we need **better rockets**

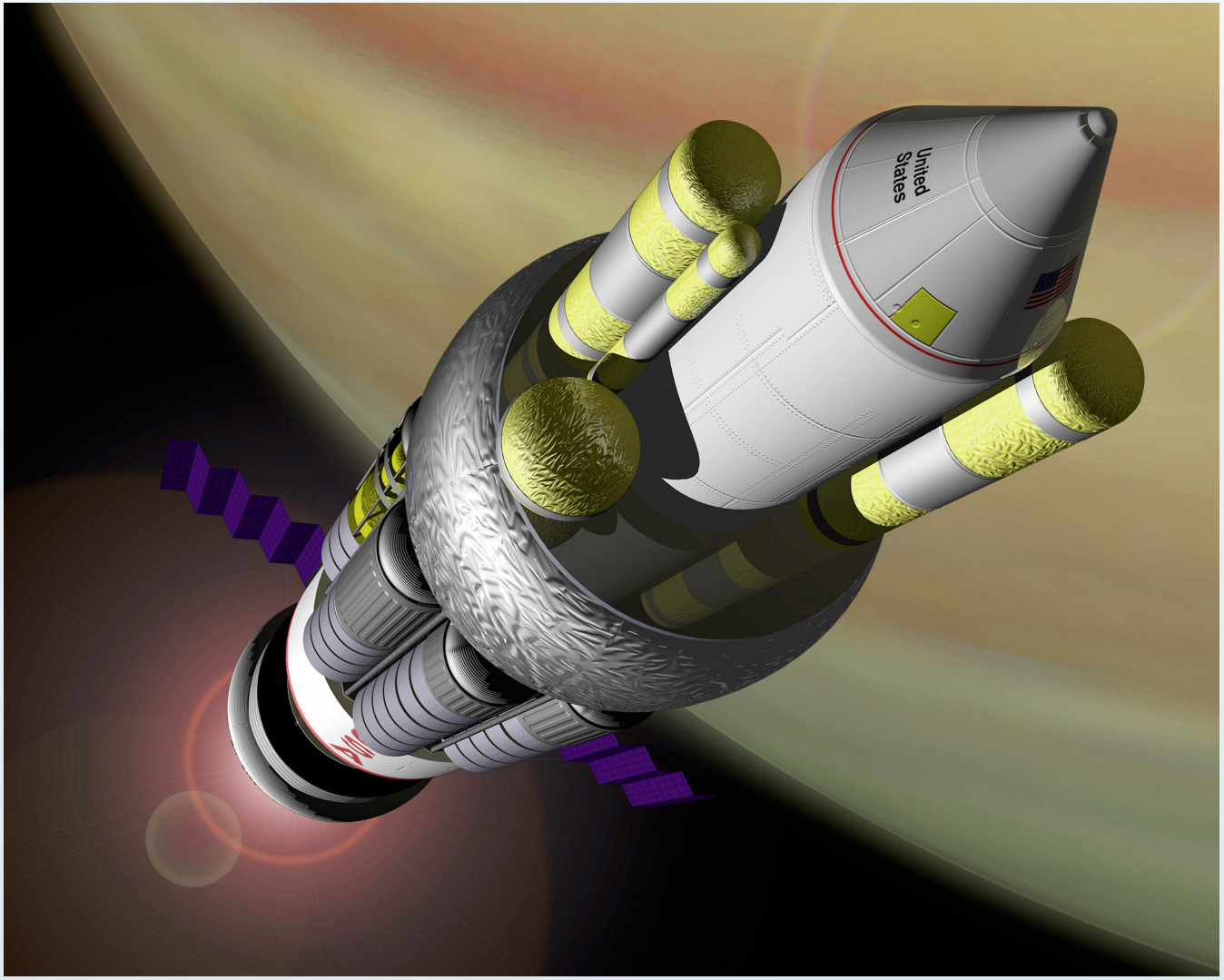
Science usually starts as science fiction

Now, the **real challenge** would be to reach **other solar systems in nearby stars**

Artist representation, European Southern Observatory

We just recently detected a possible habitable planet around within **only** 4 light years!

Nuclear-powered rockets



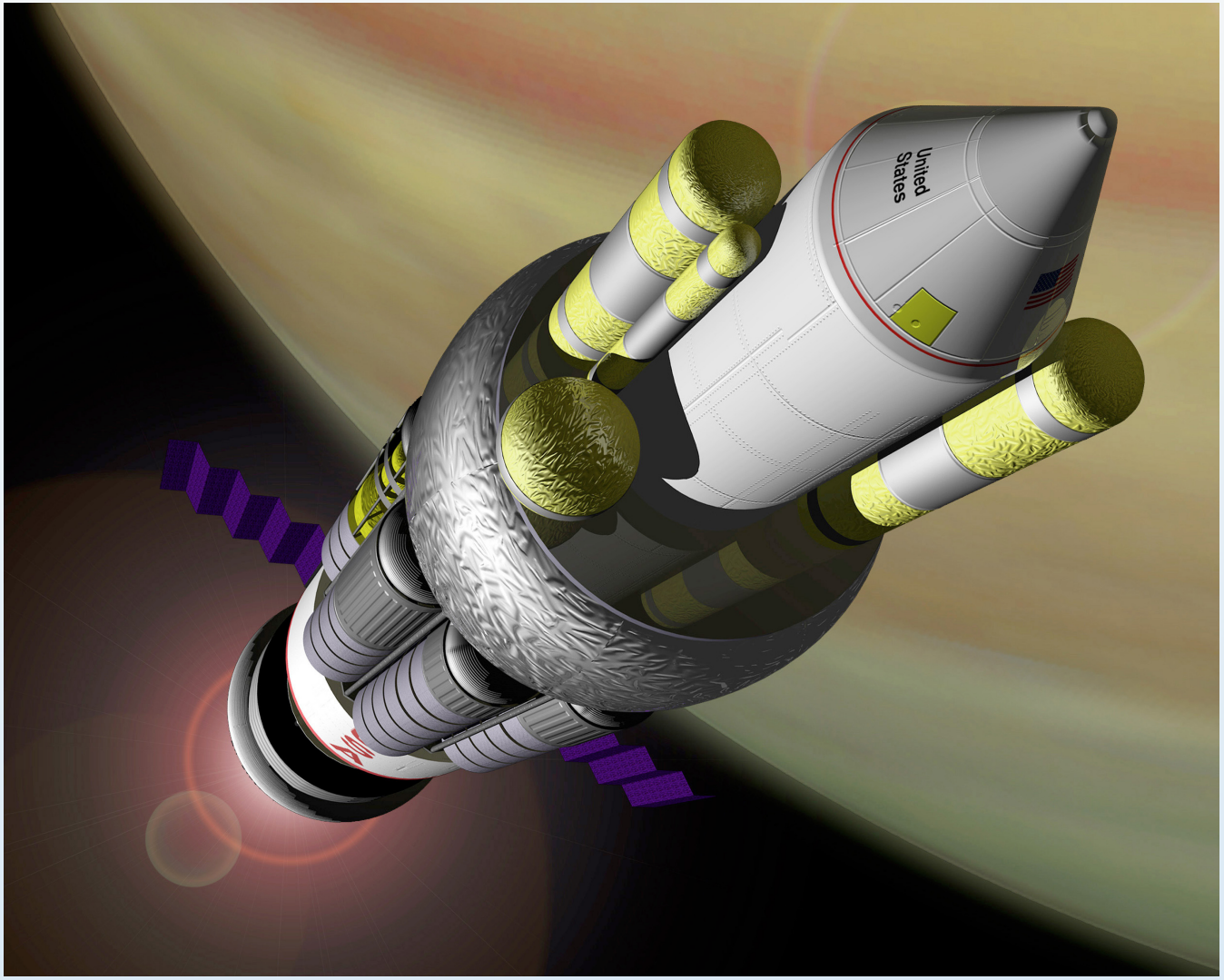
The **energy released in atomic explosions** is much more powerful that in the combustion of usual fuel (say petrol)

Very **high accelerations in short times** can be achieved (but don't try this at home!)

Proxima Centauri could be reach in 40 years of travel only!

So what are the problems?

Nuclear-powered rockets



Huge fuel cases to sustain **100s of nuclear explosions**

Very difficult to test, and even *small problems* can cause **catastrophic consequences**

Global security issues with 100s of nuclear bombs around ….

So what are the problems?

Solar-powered rockets

Can you guess the **advantages and disadvantages** of this type of propulsion?

Solar-powered rockets

Advantages:

Does not require **fuel** nor internal energy generator

Thus can be **lighter and carry more payload**

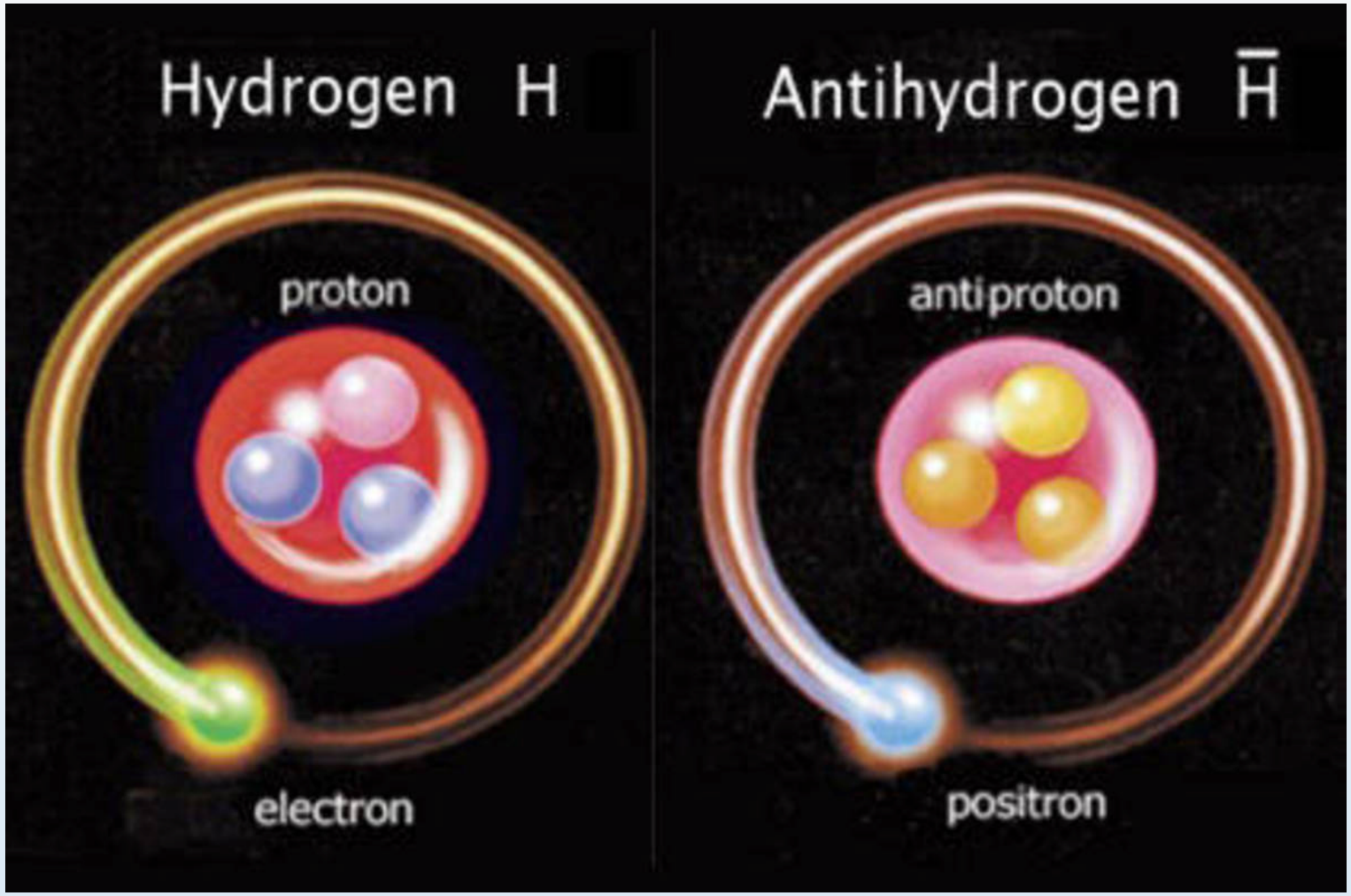
Solar-powered rockets

Disadvantages:

Very slow acceleration

Needs a nearby light source! Cannot be used for interplanetary travel ….

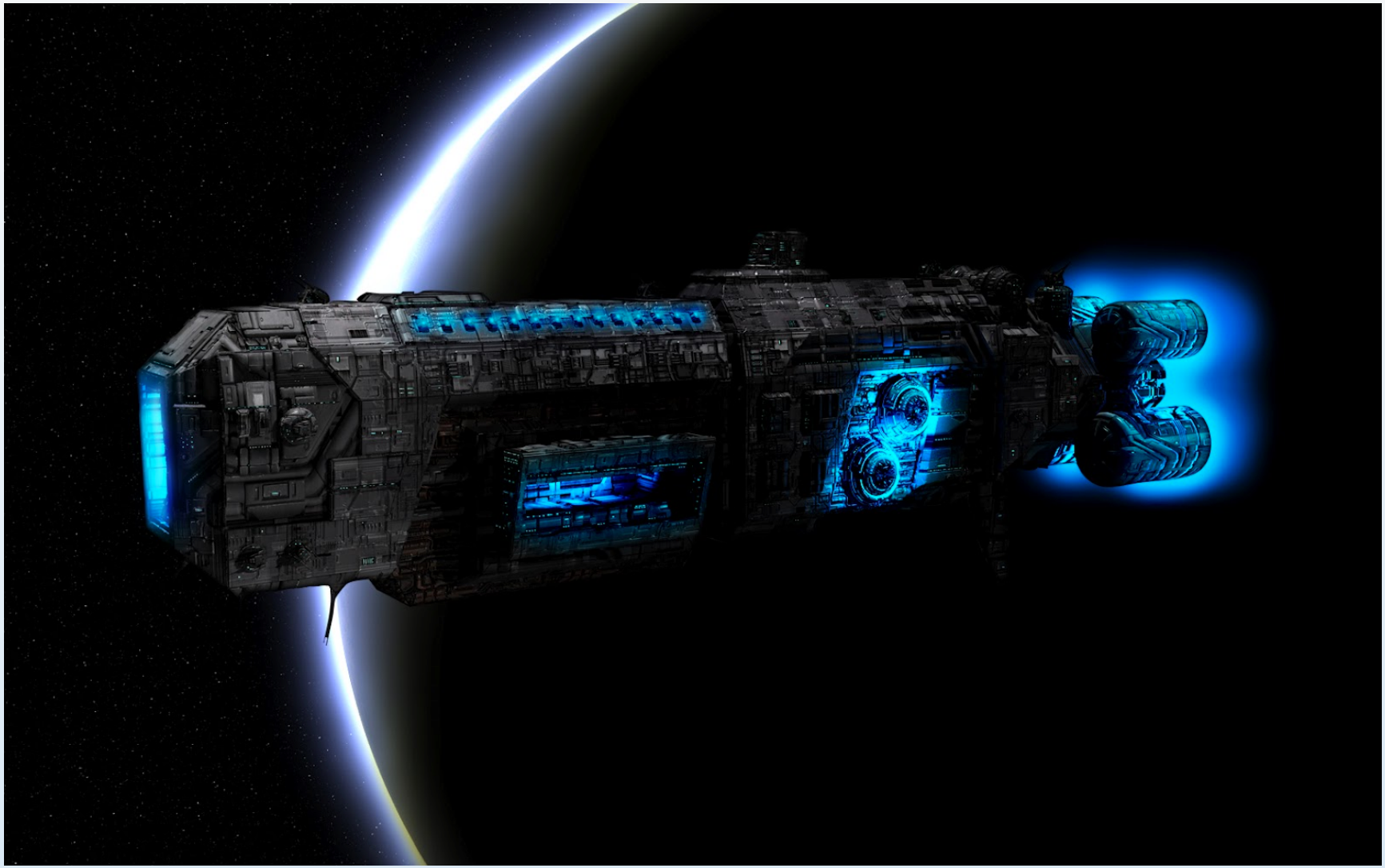
Antimatter-powered rockets



Each matter particle, say a **hydrogen atom**, has an antiparticle, its **mirror image**

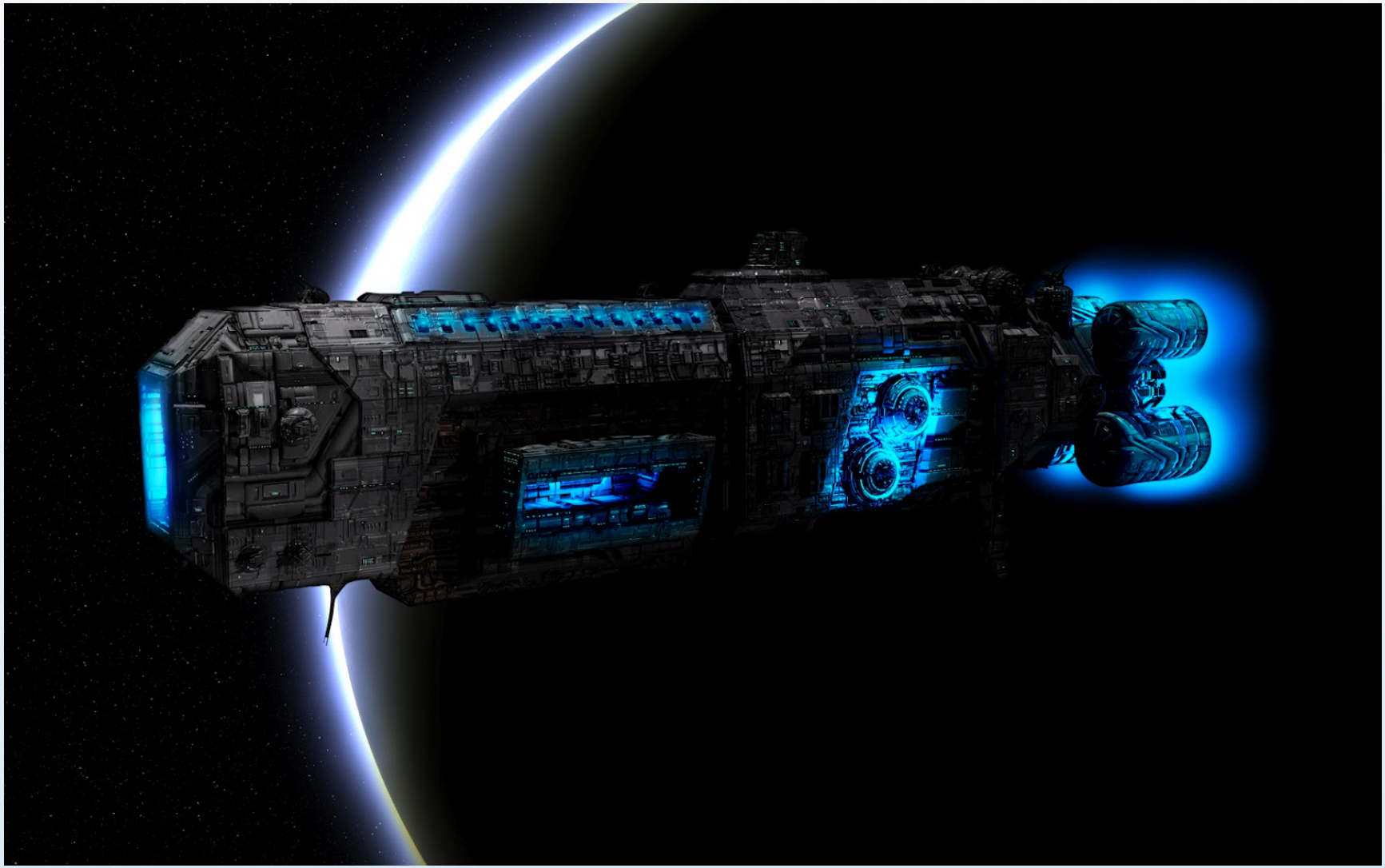
When particles and anti-particles meet, they **annihilate, releasing a huge amount of energy**

Antimatter-powered rockets



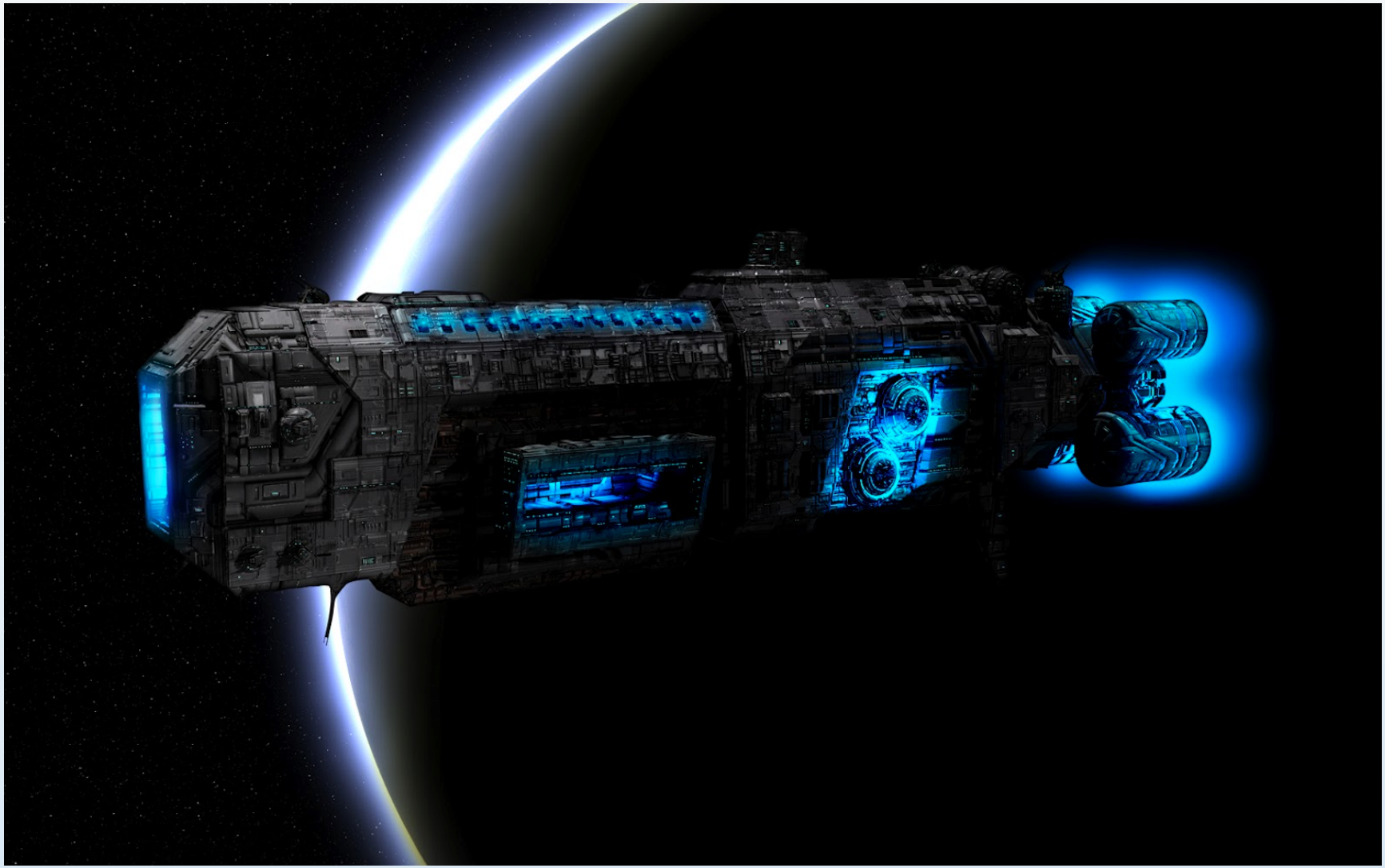
Why an **anti-matter rocket could be useful?**

Antimatter-powered rockets



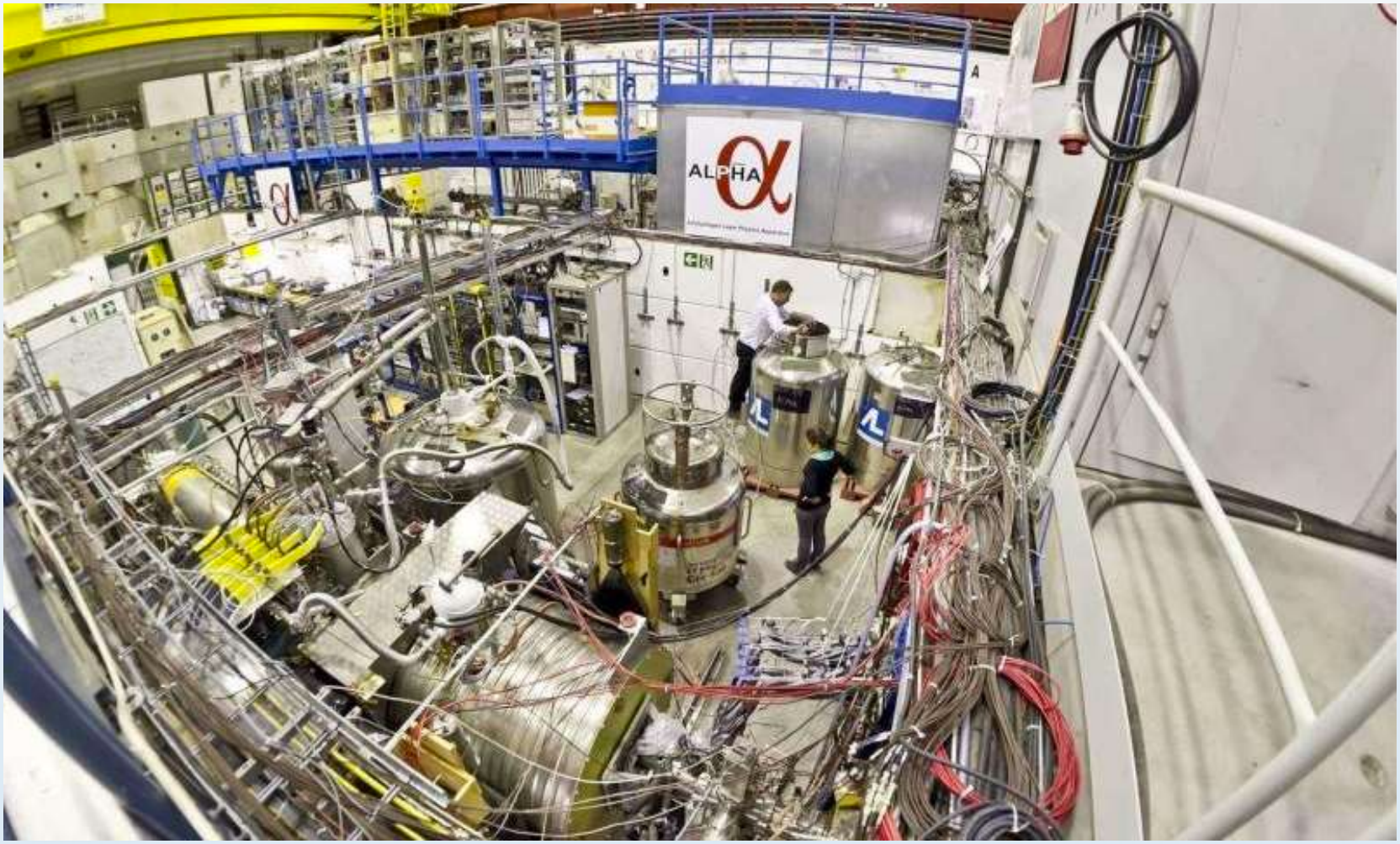
Advantages: very small amount of **fuel** needed (almost perfect energy conversion), very high velocities can be achieved

Antimatter-powered rockets



So why we have not build anti-matter rockets yet?

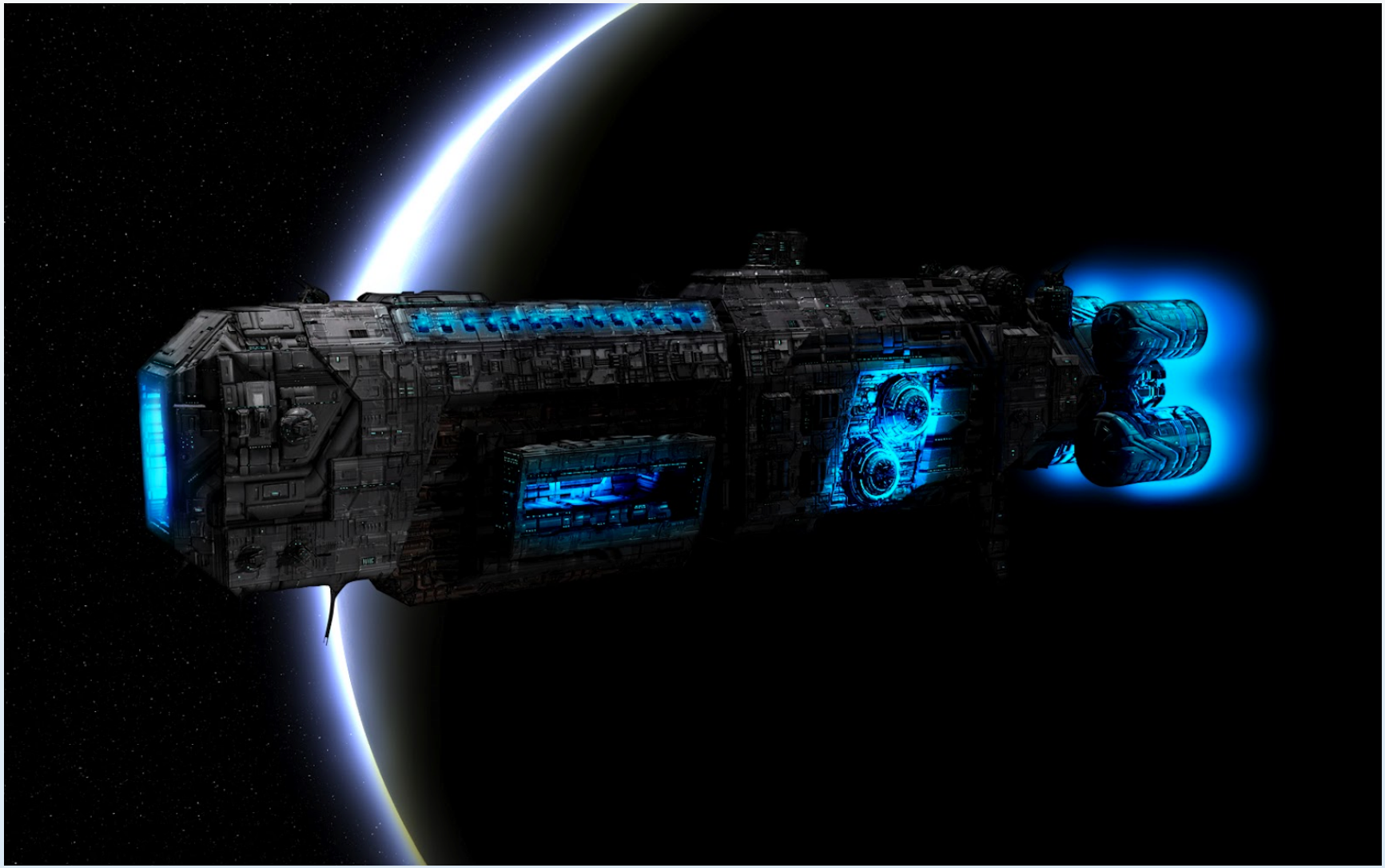
Antimatter-powered rockets



Producing antimatter is **very difficult and costly**

CERN experiments can produce and store anti-hydrogen, but only **few thousands of atoms** - you will not get to Proxima Centauri with this!

Antimatter-powered rockets



But the major problem is **trapping: how to we store anti-matter**? Any matter container with catastrophically explode if we put antimatter inside …

Staggering challenges, but also amazing opportunities

Maybe one of you will build the rockets

that will bring humankind to Mars and to other stars!