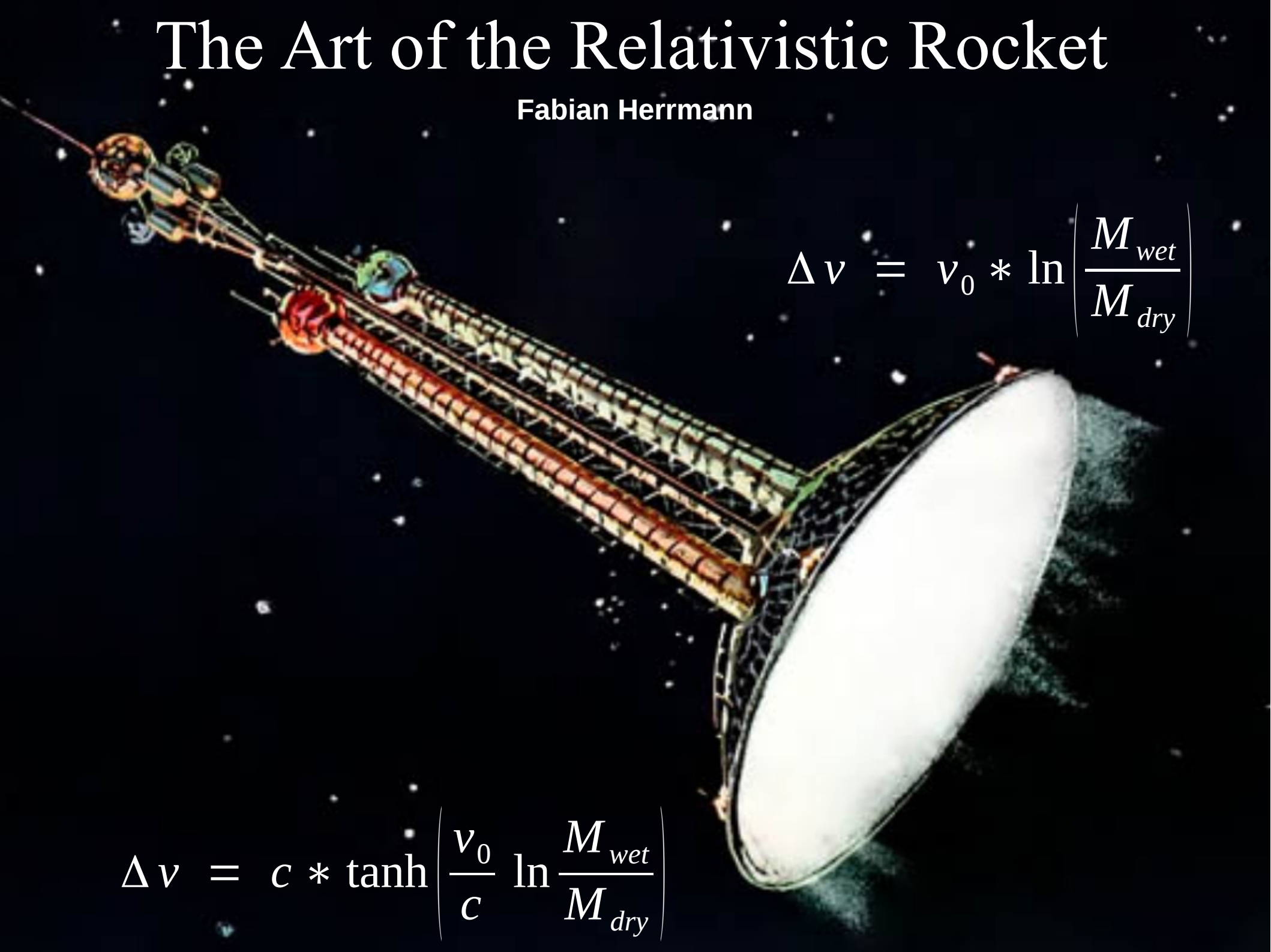
There is something strange about dream and waking. Occasionally – most happen to experience this as a small child only and forget about it in later life, some, like Annika, are capable of sensing it even when older – it happens, that Eerie Feeling, the scintillating, silent, floating sensation of strangeness, covering the world mantle-like, a separating layer between I and Object, which is invisble and mirage-like and extremely massive and lets one feel: The distinction between dream and reality is an artificial luxury, a practical myth for everyday life.

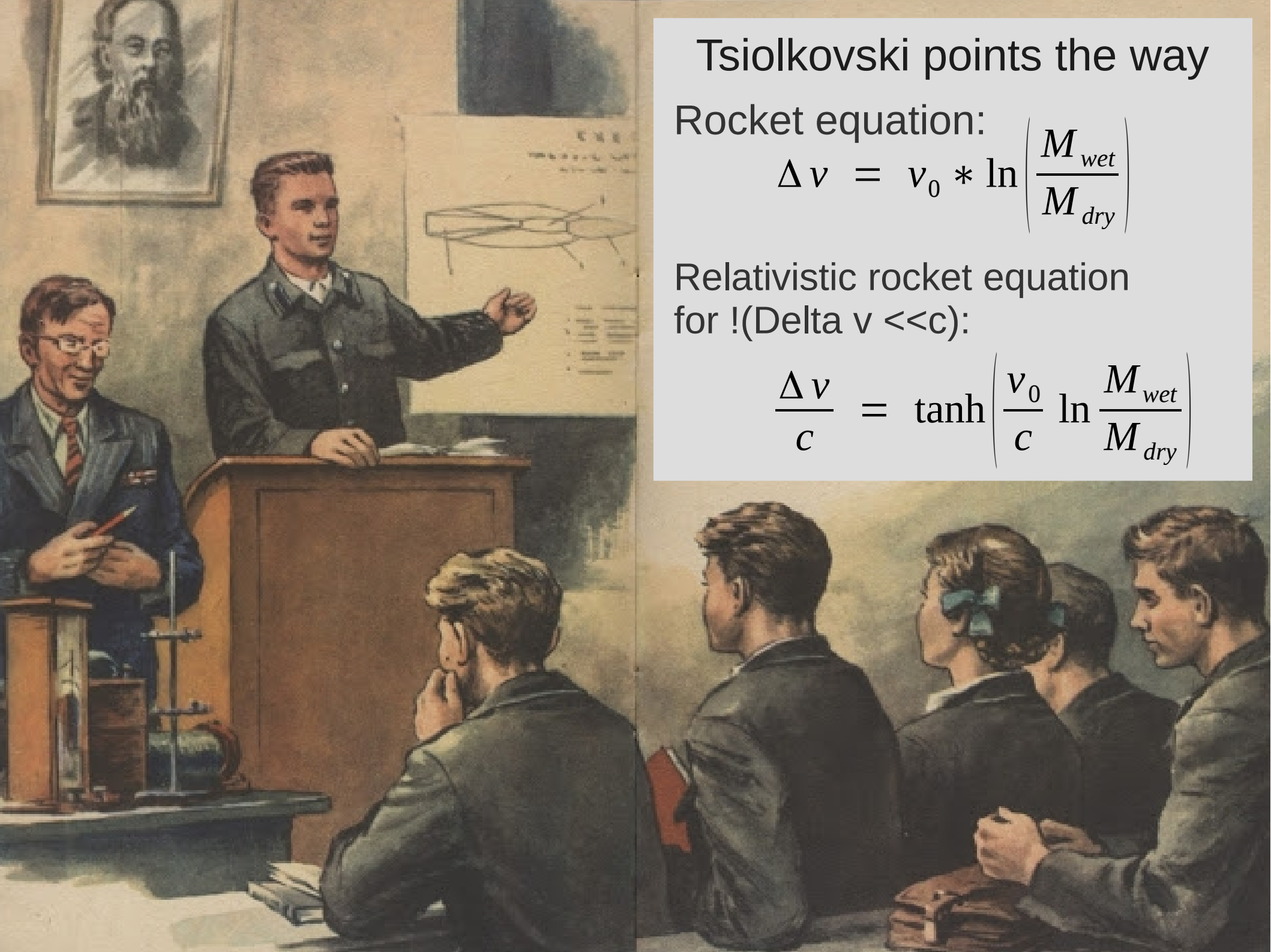
The Art of the Relativistic Rocket

Fabian Herrmann



$$\Delta v = v_0 * \ln\left(\frac{M_{wet}}{M_{dry}}\right)$$

$$\Delta v = c * \tanh\left(\frac{v_0}{c} \ln\frac{M_{wet}}{M_{dry}}\right)$$



Tsiolkovski points the way

Rocket equation:

$$\Delta v = v_0 * \ln\left(\frac{M_{wet}}{M_{dry}}\right)$$

Relativistic rocket equation for !(Delta v <<c):

$$\frac{\Delta v}{c} = \tanh\left(\frac{v_0}{c} \ln \frac{M_{wet}}{M_{dry}}\right)$$

Something is relative...

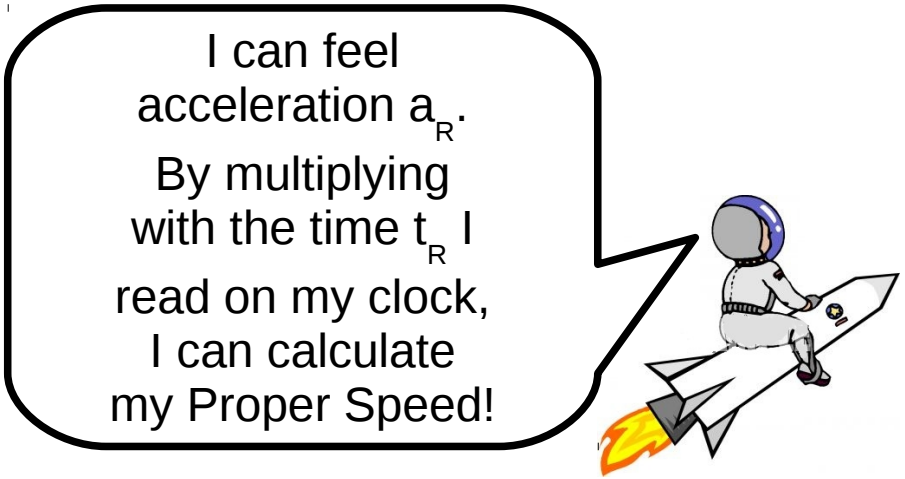
- **Velocity is relative!**
- No coordinate system in the universe can be said to be „at rest“.
- Everyone moves at near lightspeed – relative to someone else.

- **Acceleration is absolute!**
- It can be measured objectively and sensed by living beings.
- That's why rollercoasters have loops and sharp turns: a straight ride would be as thrilling as sitting in your livingroom.

Thus we can define **Proper Speed:**

$$d\delta := a_R(t) \cdot dt_R$$

„R“ subscripts mean: Observed aboard the rocket.

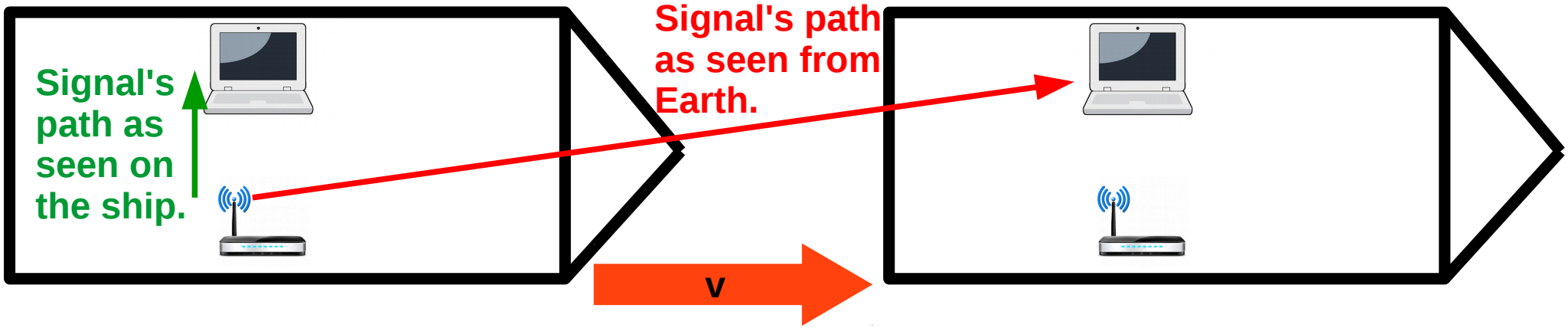


Something is relative...

Proper Speed: $d\delta := a_R(t) \cdot dt_R$

Theory and experiments in electrodynamics show: **LIGHTSPEED IS ALWAYS AND EVERYWHERE THE SAME!**

Let's suppose we have wifi set up on a spaceship:



When observed from Earth, **the wifi signal has to go sideways!**
But it still travels at c = 2.998 * 10^8 m/s.
As it has to cover a longer distance, **the Earth observer sees the computer receive data at a slower rate.** The astronauts don't notice, though – because speed is relative! You never know whether you're moving or not (unless you look outside).
This holds not only for routers+PCs, but **for any and all physical, biological, psychological phenomena.** This can only mean: **Time goes slower when you move!**

Something is relative...

Proper Speed: $d\delta := a_R(t) \cdot dt_R$

Theory and experiments in electrodynamics show: **LIGHTSPEED IS ALWAYS AND EVERYWHERE THE SAME!**

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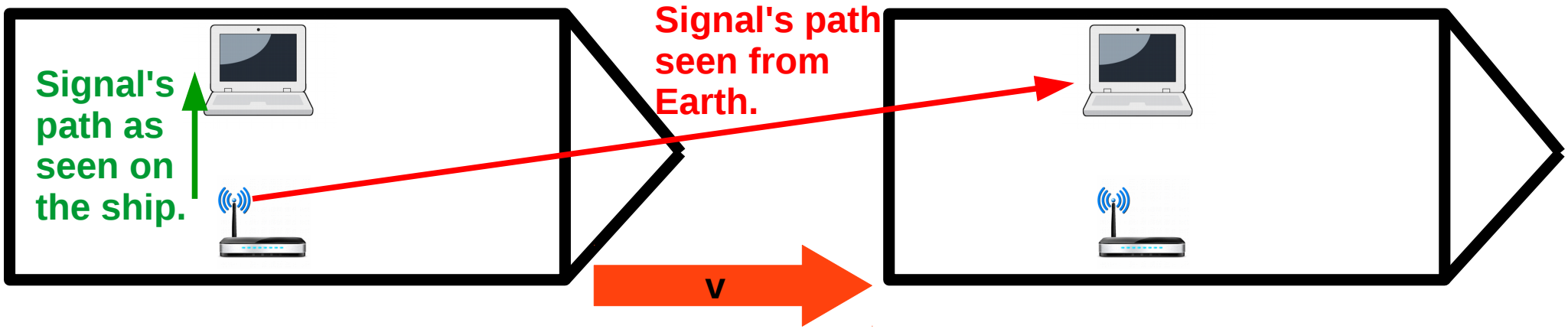


Time dilation: $d t_R = \frac{d t_E}{\gamma}$ $\qquad \gamma := (1-\beta^2)^{-1/2}$ $\qquad \beta := \frac{v}{c}$

Subscript „E“: Oberved from Earth.

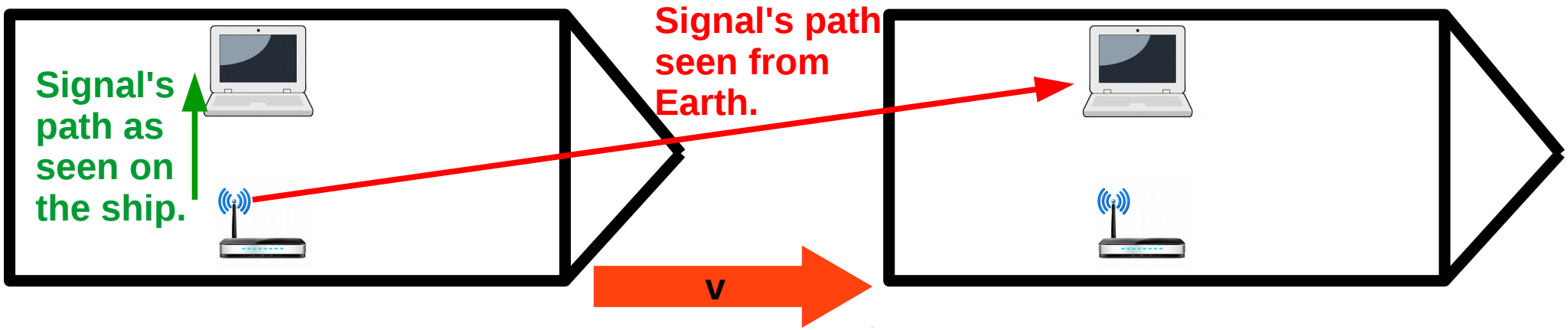
Problem 1: Derive this result from the wifi example. (Hint: Use Pythagoras!)

Something is relative...

Proper Speed: $d\delta := a_R(t) \cdot dt_R$

Theory and experiments in electrodynamics show: **LIGHTSPEED IS ALWAYS AND EVERYWHERE THE SAME!**

Let's suppose we have wifi set up on a spaceship:



Time dilation: $d t_R = \frac{d t_E}{\gamma}$ $\gamma := (1-\beta^2)^{-1/2}$ $\beta := \frac{v}{c}$

Subscript „E“: Oberved from Earth.

Another result:: $a_R = \gamma^3 a_E$ **Proper acceleration**

Tsiolkovski meets Einstein

Because velocity is relative – no experiment can tell me whether I am moving or not –, Proper Speed works exactly like classical speed: It can be added up linearly. Therefore, the Tsiolkovsky Equation can simply be carried over:

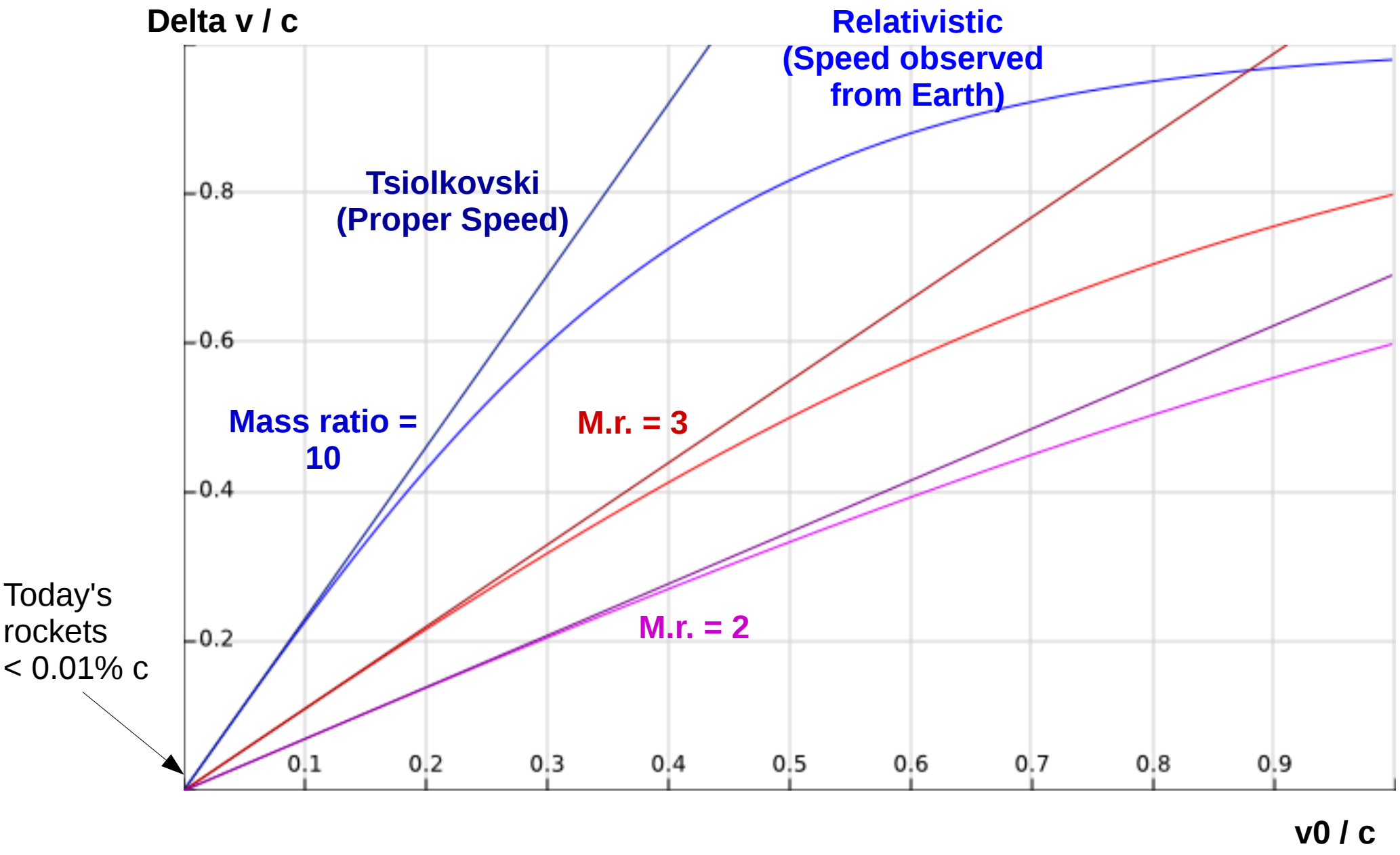
$$\Delta\delta = v_0 \cdot \frac{M_{wet}}{M_{dry}}$$

Problem 2: Derive the relativistic rocket equation in this form:

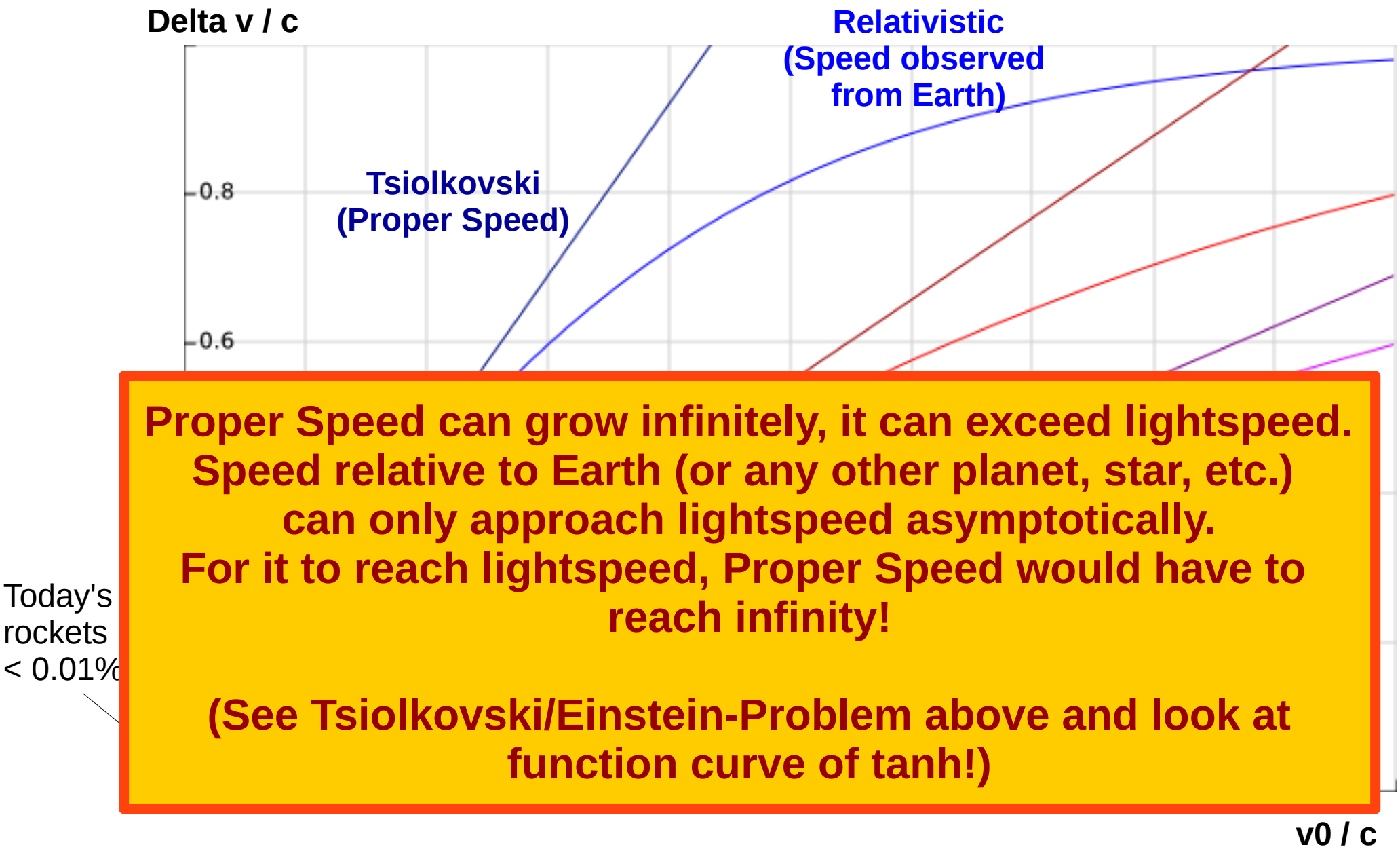
$$\frac{\Delta v}{c} = \tanh\left(\frac{v_0}{c}\ln\frac{M_{wet}}{M_{dry}}\right)$$

using $\delta(t_R) = \int_0^{t_R} a_R(t)\,dt$ and $dt_R = \frac{dt_E}{\gamma}$, $a_R = \gamma^3 a_E$, $a_E = \frac{dv}{dt_E}$

Delta v as function of exhaust jet velocity v0



Delta v as function of exhaust jet velocity v0



Proper Speed can grow infinitely, it can exceed lightspeed.
Speed relative to Earth (or any other planet, star, etc.)
can only approach lightspeed asymptotically.
For it to reach lightspeed, Proper Speed would have to reach infinity!

(See Tsiolkovski/Einstein-Problem above and look at function curve of tanh!)

A very common misconception:

„Rockets cannot exceede lightspeed because their mass grows infinitely as they approach it.“

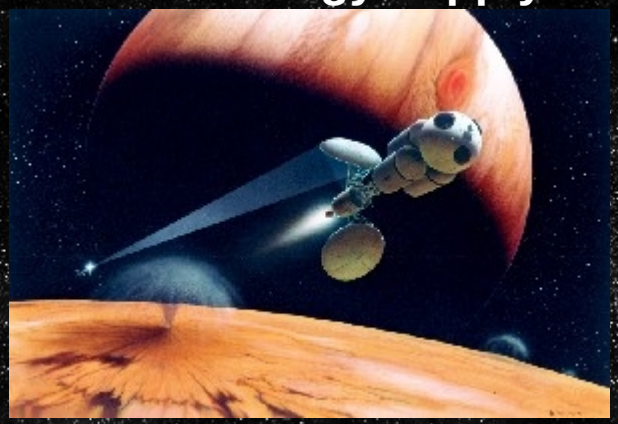
This is only true if the rocket is fed energy from an external source (light sail, laser, microwave beam, etc.).

„Ordinary rockets“ carrying their own energy supply onboard ***do not gain mass*** as they accelerate, because they do not gain any energy: it just gets shifted around inside the rocket – potential energy of the drive system into kinetic energy.

Their overall mass actually even decreases due to them emitting exhaust gases and energy.

In oder to reach lightspeed, they would have to turn their entire mass – including crew, cook and ship's cat – into drive energy.

External energy supply



Onboard source
(This is the normal case for rockets)

$E = m c^2$

Einsteins best known equation, probably the most famous equation in all of natural science!

It means: The mass of an object, when measured from outside, is proportional to its entire energy content, including any and all forms of internal energy.

The greatest part of this internal energy comes from the binding energy of the nuclear gluon field, which keeps protons and neutrons attached to each other as well as binds the quarks within them. *But the equation holds true for all forms of energy! Even an old mechanical alarm clock gets a tiny bit lighter as its spring runs down.*

Problem 3: What mass corresponds to the entire energy consumption of the US over one year? (320 mio people, 11 kW per person)

Over the Earth's Shadow

Alexa gave Annika a meaningful grin, raised her eyebrows: „We know a tiny bit more than just building some old breeder reactors and running them. What do you think?“

Annika's gaze wandered upwards, back to the bottom, slid back up again and came to rest on the pointed nose. Finally, she asked timidly: „What's its name?“

„Over the Rainbow!“ Alexa said loudly. „A so-called Shadow Jumper. Twelve gas-core engines, nuclear lightbulbs, they give us three thousand seconds of specific impulse! When one of these blasts off, you know you're going somewhere.“

Excitedly, Annika looked around for Dr. Korolyova. „Does this mean, we will... I will... now?“

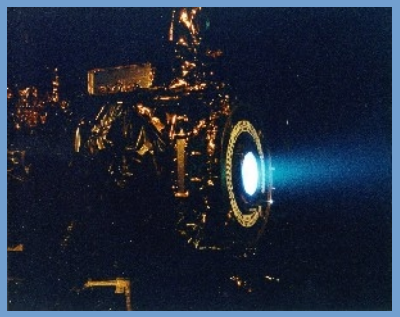
„Ya. »As long as you still feel the stars as an „Above-You“, you still lack the eye of one who understands.« Nietzsche. In Curiepolis you shall become one who understands, Annika, so you must grow closer to the stars. A little shadow jump at first, above the Earth's shadow – these rockets pack enough Delta-Vee to take them, for example, from Earth's surface to the moon's, set down a thousand tons of payload and back into Low Earth Orbit: without refuelling once! – but we mainly use them for rapid point-to-point transit on Earth. Parabolic, two hundred fifty kiolmeters apogee, thirty minutes from France to Curiepolis. For lunar – translunar destinations we prefer to cut orbit to orbit with our large thermonuclear pulsating clippers.“

The airlock resembles a barrel, a huge wine cask (I have never been in one, but I imagine... it's something like this!), through the inner bulkhead, up a narrow ladder, Carmen's miniskirt shines ahead, so fly you flaming, you red plaited cloth – we are future's loyal fighters, we are the scientists of Curiepolis, strapped into acceleration couches, inside the Shadow Jumper's cylindrical windowless passenger cabin, radially around the datastormflickering monitorsaiced central column, the straps fasten themselves (memory-metal fibers, according to Dr. Korolyova), tight tight oh so tight, feels like these meddlesome blood-pressure-thingies at the doctor's. The acceleration couch vibrates, I'm vibrating with it, the air my eyes vibrate, vibrate so tremendously to make everything roar! My body roars, shakes, my feet shake right in the shoes – I like my little boots, so nice and black and sturdy, the tiniest bit high-heeled, but robust, oh so robust! I like going cycling in them. Ah! „Mrs. Korolyova, what about my bike?“ „It's stowed away, don't worry.“ I wonder whether they have experience stowing bicycles in spaceships? Sure enough, the bike is now vibrating, too. Difficult to breathe when your own lung is roaring, just like the air you mean to inhale. Maybe I should take a nap, my eyelids are heave, terribly heavy. My little boots are heavy, it's probably difficult to stow a bicycle in a rocket so it won't tumble over when the rocket shakes quakes roars.

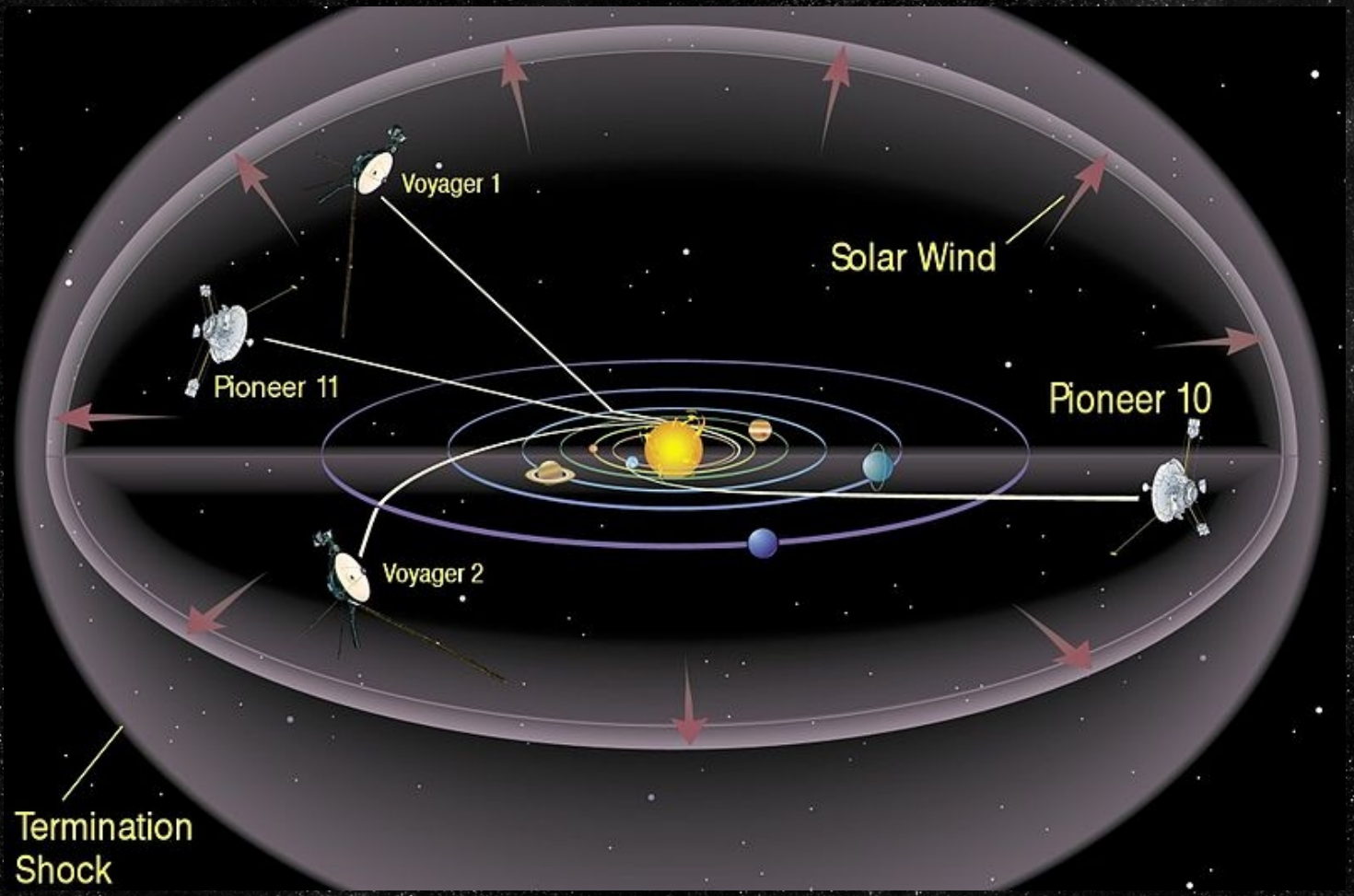
„Mrs. Korolyova... Alexa. Alexa, when will we take-off?“ „We broke the sound barrier half a minute ago. Just making for the tropopause.“

Rockets today

- Two main types:
- **Chemical**: low exhaust jet velocity (some km/s) but great thrust force (large mass flow). By staging, Delta v may be increased to several 10 km/s.
- **Electric (ion drives)**: Larger exhaust velocities (some 10 up to 100 km/s) but tiny thrust (very low mass flow).



Interstellar spaceflight as of 2016



Voyager 1 is the most distant artificial object from Earth (133 AU @ 2015).
She approaches the star Gliese 445 at 17 km/s and will reach it in around 40.000 years.

Building a Relativistic Rocket

Problem 4: A rocket has Delta V = 10% c = 30.000 km/s and a mass ratio of 10.

Use the Tsiolokvski Equation to determine the necessary exhaust jet velocity.

Problem 5: A rocket has Delta V = 90% c = 270.000 km/s, M.r. = 10.

Use the Relativistic Rocket Equation to determine exhaust velocity.

Building a Relativistic Rocket

Problem 4: A rocket has Delta V = 10% c = 30.000 km/s and a mass ratio of 10.

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Chemical rockets achieve around v0 = 4.5 km/s maximum.
Even electric rockets (v0 ~ 100 km/s) fall short.

We need to find physical effects allowing us to accelerate reaction mass to several 1000 km/s.

What about photons?

Light carries a certain amount of momentum.

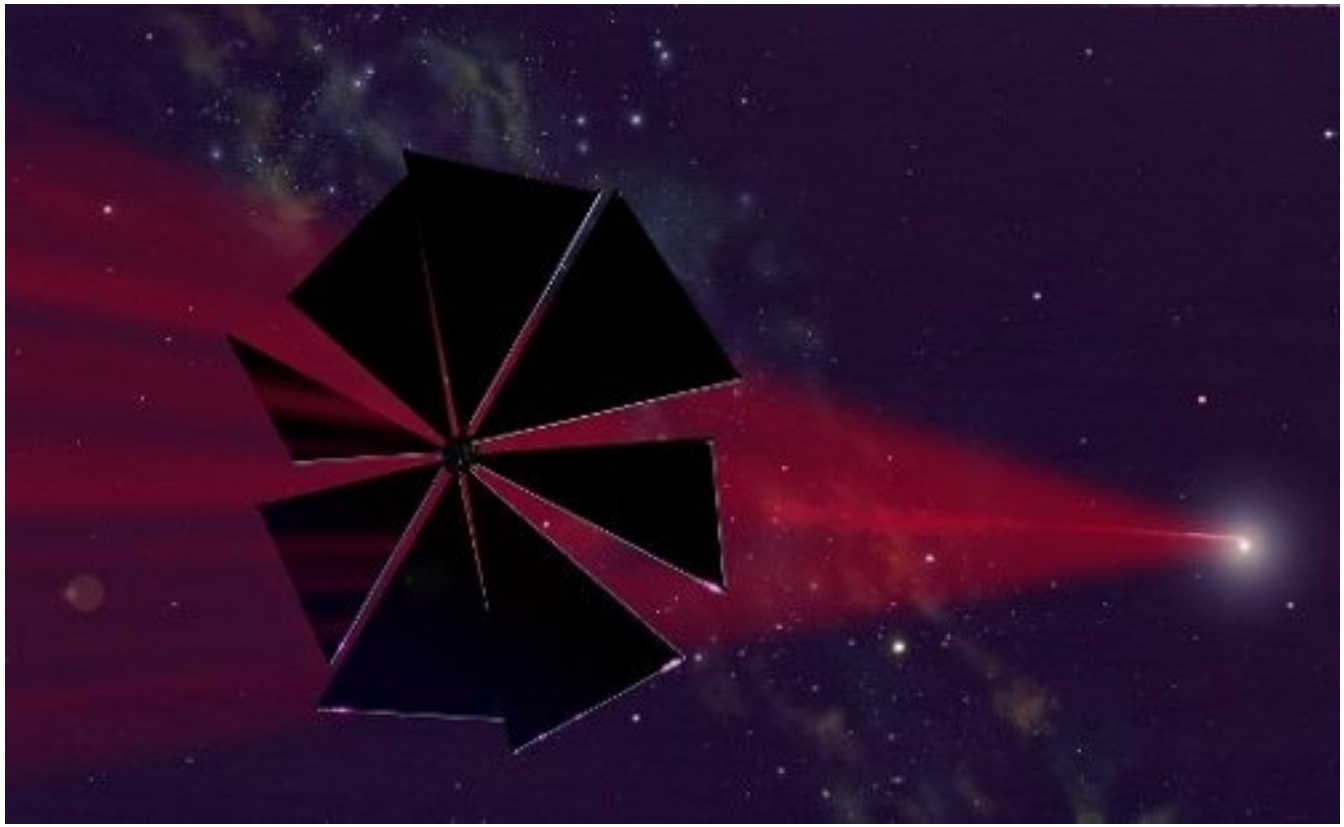
According to Einstein, everything that carries energy also contains (dynamic) mass and therefore momentum.

$$E = mc^2 \qquad \rightarrow m = E/c^2$$

$$p_{Light} = mc = E/c$$

Problem 6: Use these equations to derive the irradiation power (Watts) exerting a force of 1 N.

Light Sailing



The amount of irradiation needed even for modest thrust is staggering! The only practical solution is a huge light sail catching stellar radiation or lasers beamed by a massive power station in space.
Still we're talking about payloads the size of a smartphone or less.
Light sails are unsuitable for manned craft or accelerations close to 1 g.

The Holy Grail of Rocketry

For spaceflight beyond small unmanned probes and capsules the size of cupboards, we need to create what some may deem a paradox:

A rocket which:

* has a large exhaust velocity (specific impulse) and thus high Delta v, similar to ion drives or photon sails.

* creates high thrust forces like a chemical system.

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A rocket which:

* has a large exhaust velocity (specific impulse) and thus high Delta v, similar to ion drives or photon sails.

* creates high thrust forces like a chemical system.

Problem 7: Derive the power of a rocket motor
A.) as a function of exhaust velocity and thrust force.
B.) ...of thrust force, Delta v and mass ratio.

In order to build a high v0+high thrust rocket, massive engine power is needed!

The power has to be bundled into the rocket motor.

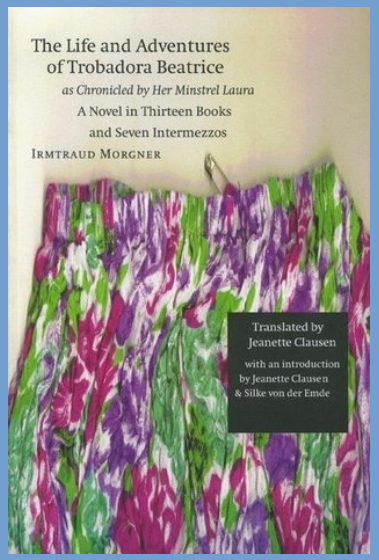
Advanced spaceflight is not a question of energy, but of energy flux density (or power density), measured in W/m² or W/m3 or W/kg.

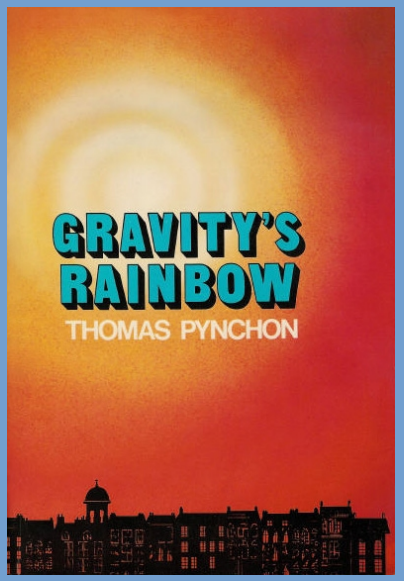
In science fiction, such rockets are sometimes known as „torches“.

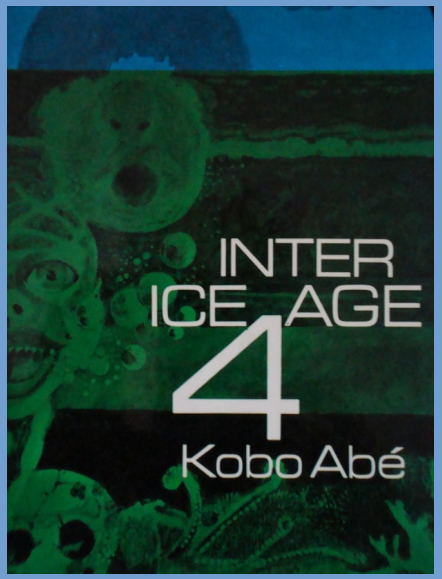
Above Limburg an der Lahn the computers switched off the Farnsworth-Hirsch-Fusors feeding the nuclear lightbulb with neutrons, causing the multiplication factor k to drop below one, zero point nine nine three, zero point nine five, zero point nine one, the raging fire of the plutonium plasma got cooler, milder. Annika shook her head to cast aside some hairs that were tickling her nose, but they kept flying around all the more, stroking skittishly her forehead, cheeks, chin. She tried to push them away with her hand, but the hand turned out to be unruly as well, rushed upwards, floated in the air, the arm stretched nearly to the utmost. A tiny drop of saliva, which had come loose from Annika's lower lip, turned into a minuscule shining bullet, rushed away on a dead-straight trajectory, hitting the hand on the soft fleshy bulge between thumb and index finger.

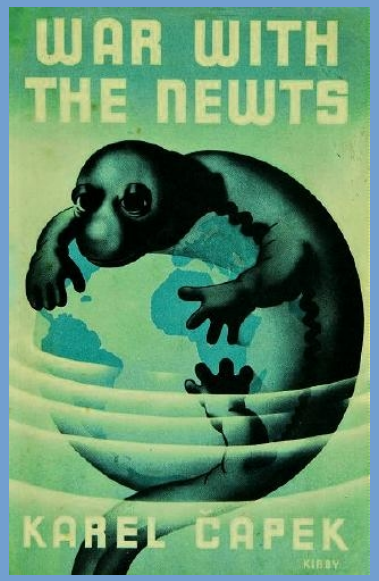
Dr. Korolyova said: „Look!“ Annika glanced into the appointed direction, towards one of the monitors on the cabin's central column: „How lovely. The clouds, their drifting shadows on the distant beloved Earth. The water – dark, slightly sparkling plains. The horizon! Abrupt transition into the complete blackness of space. Just a thin, blueish aureola surrounds the planet, changing outwards gradually into darkness, turquoise, dark blue, purple, black.“

Some futuristic novels

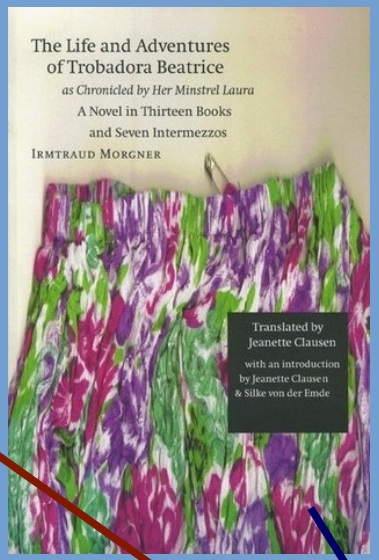


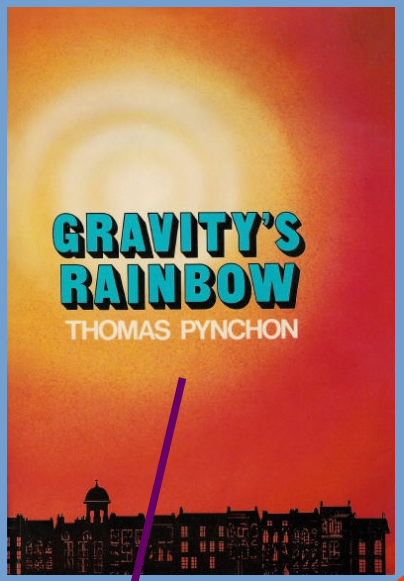


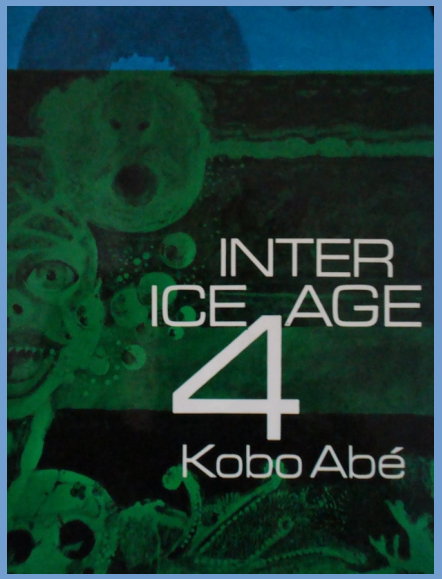


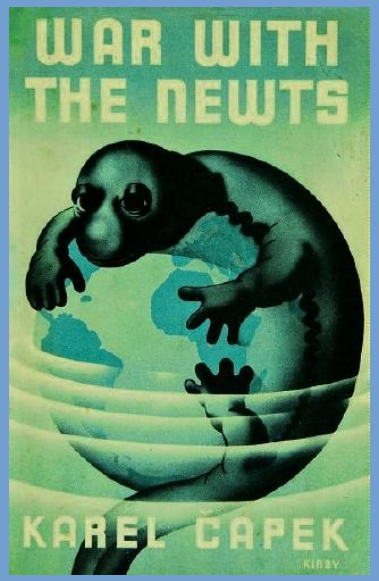


Some futuristic novels





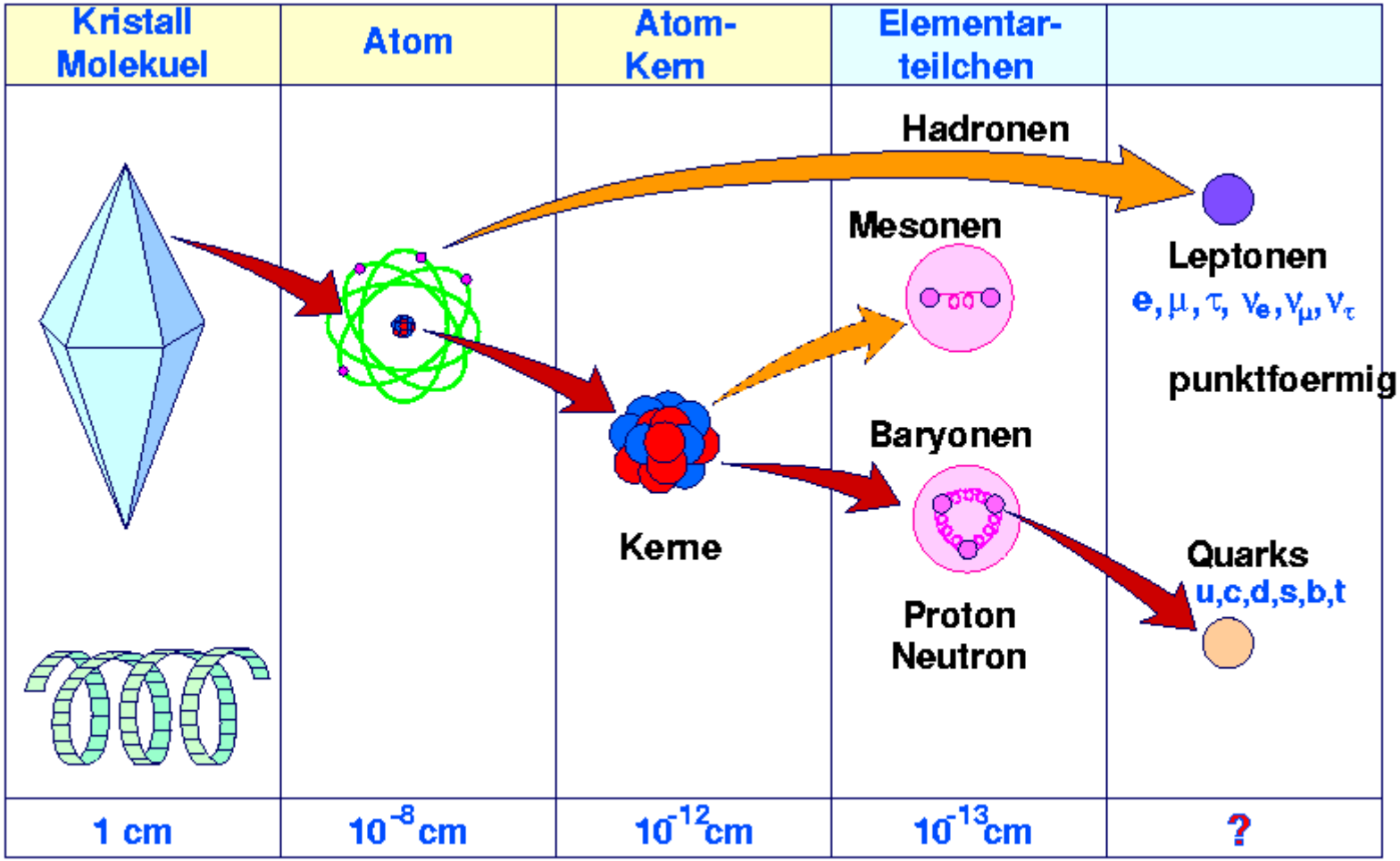




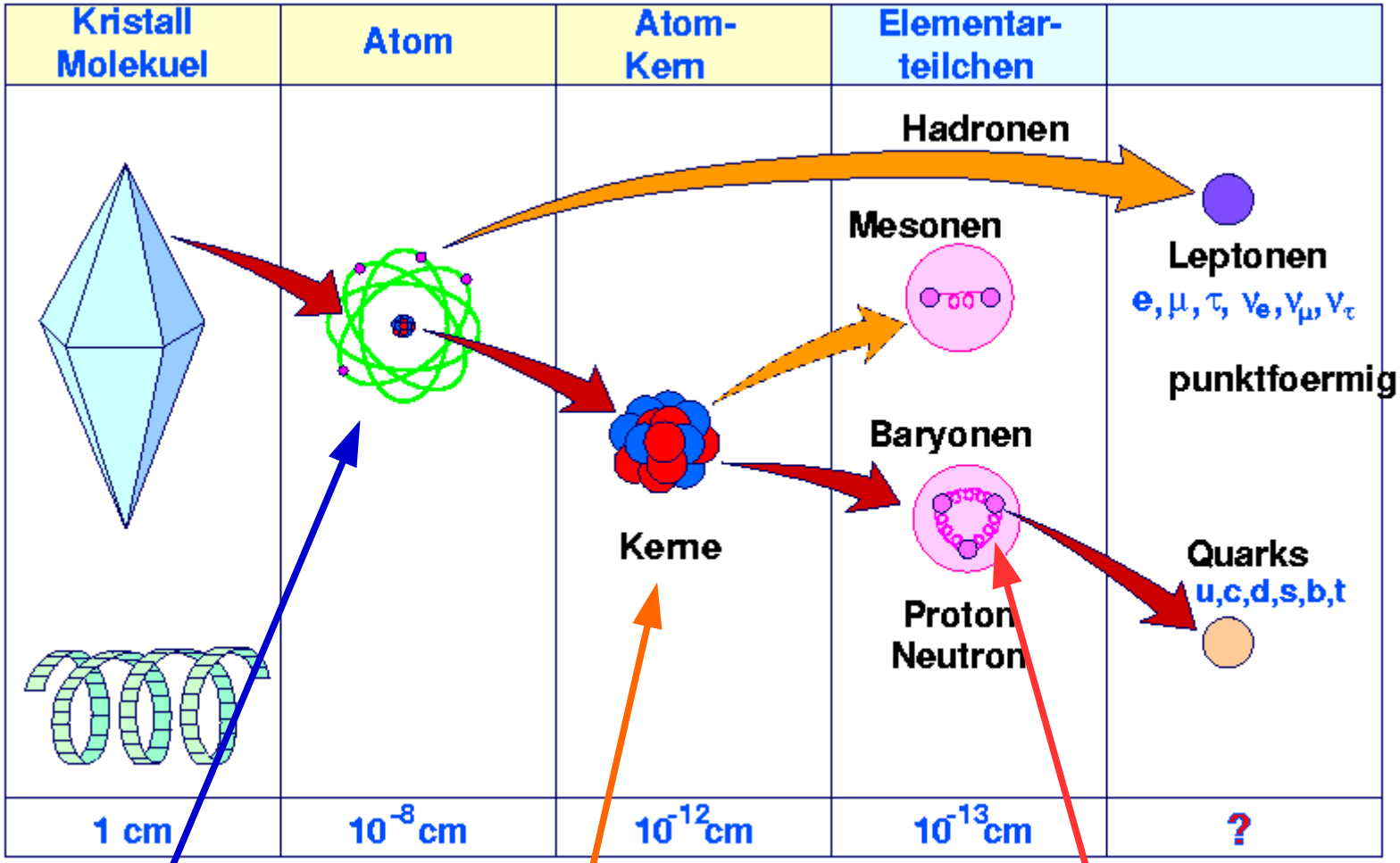
What's that: „Space“?

Space is black, silent, it is almost completely empty. Nearly everything which exists is space. Celestial bodies occupy a vanishingly small fraction of reality, their relative volume is vanishingly tiny. Space appears as a black hollow sphere – called „Hubble One“ by some –, within which thin veils of silvery star gauze float. Space is alien to the human eye. Our senses shy away from perfect darkness to which they can attribute neither size nor distance nor structure: „Division by zero“ says Alexa Nimitz dreamily, tracing the output line on the monitor affirmatively with her index finger. Earth, an almost perfect opal-blue sphere, trundles around in the neighborhood (just thirty-six thousand kilometers! a day and a half in an airplane, if those went beyond the Kármán-Line) of Port Terra, a metallic torus two kilometers in diameter, on which the Curiepolitan flag has been painted at regular intervals – „actually absurd“ – according to Carmen – „the other nations don't have manned spacecraft able to come up here, and we ourselves know it's ours!“

Forces of the Cosmos



Forces of the Cosmos



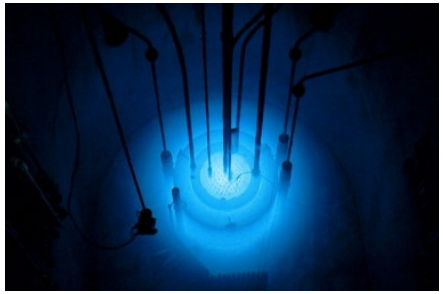
Electromagnetic.
Binding forces of chemistry.
Energy density: 1 eV/u.

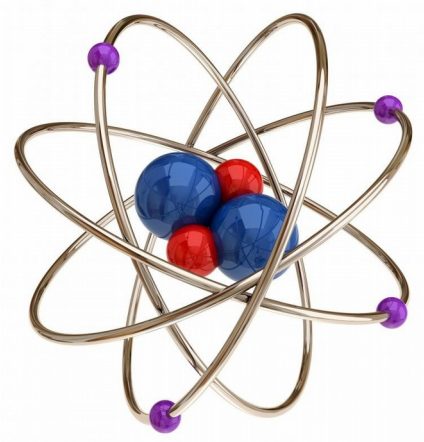
Outer Gluonic field.
Nuclear forces.
1 MeV/u.

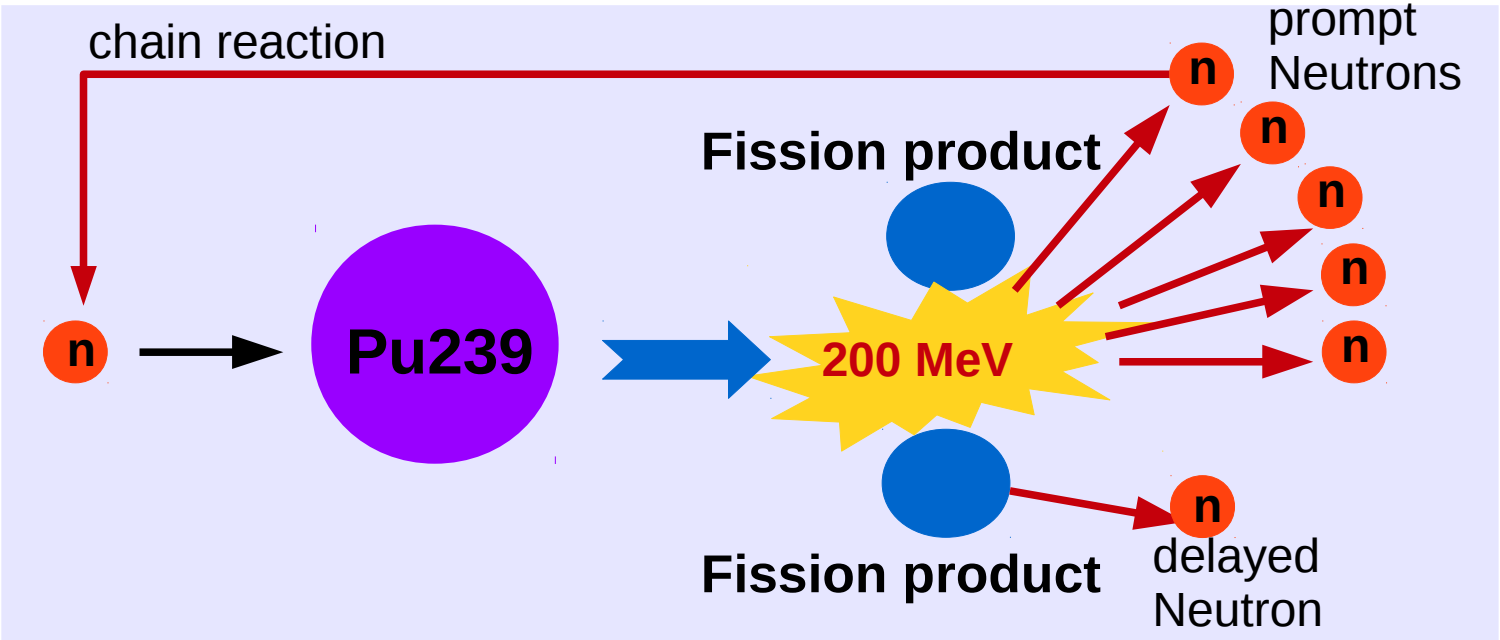
Inner Gluonic field.
Rest mass.
1 GeV/u.

Problem 8:
Calculate corresponding velocities!

Nuclear Fission

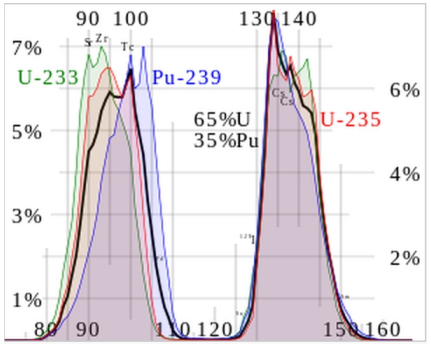






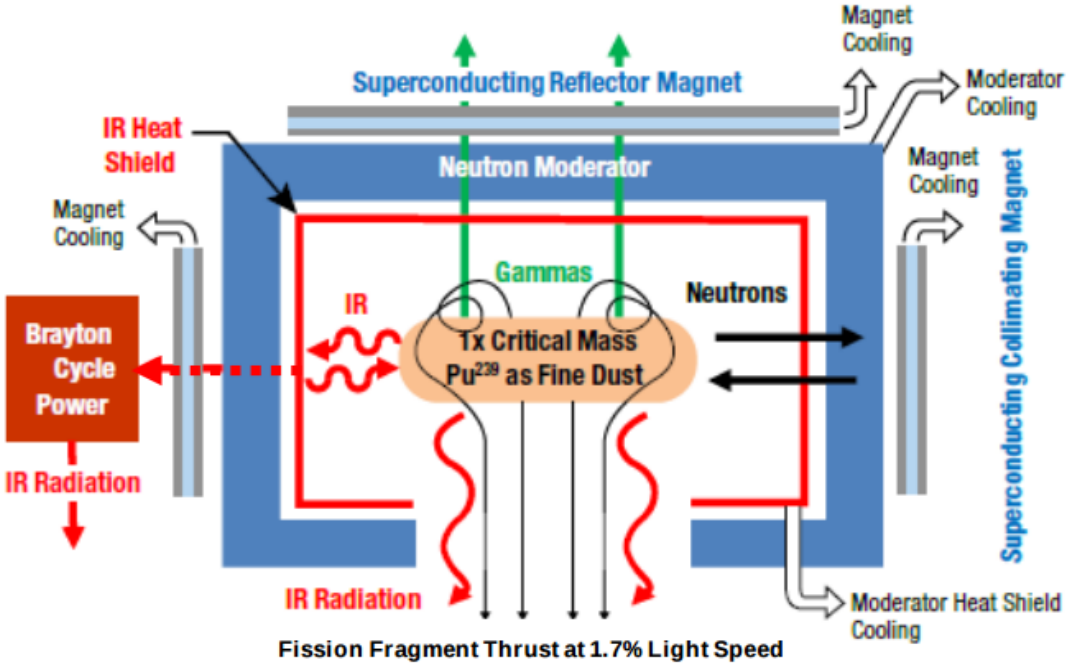
Enthalpy mostly goes into kinetic energy of daughter nuclei flying away at ~14.000 km/s. In a power reactor, they are used to heat a medium.

Could we use them as rocket reaction mass?



Fission product yields by mass for thermal neutron fission of U-235, Pu-239, a combination of the two typical of current nuclear power reactors, and U-233 used in the thorium cycle.

Fission fragment rocket



Fission fragment nuclei are directed out of a rocket nozzle by magnetic fields – direct use of nuclear energy without heat.

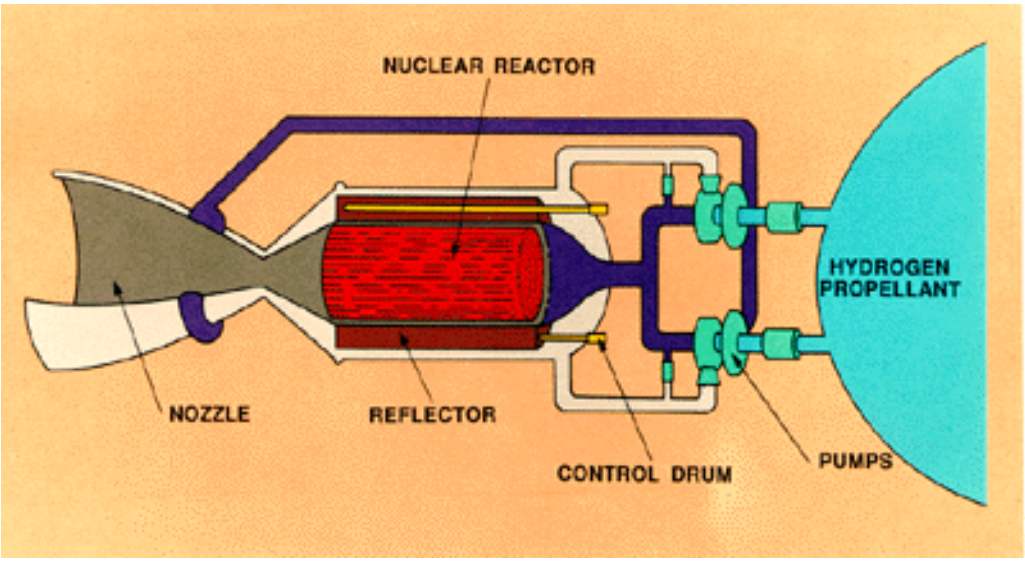
Problem 9: A power reactor has a thermal power of 3 GW. If all fission fragments were made to fly in a certain direction, how great would the thrust force be?

e.g. mass ratio 1.1: $\Delta v = 14.000 \frac{km}{s} \times \ln(1{,}1) \approx 1330 \frac{km}{s}$

How about more thrust?

Rockets can shift gears: Transfer energy to a larger mass portion. As thrust rises, exhaust velocity (specific impulse) shrinks.

Nuclear-thermal rocket (NTR):



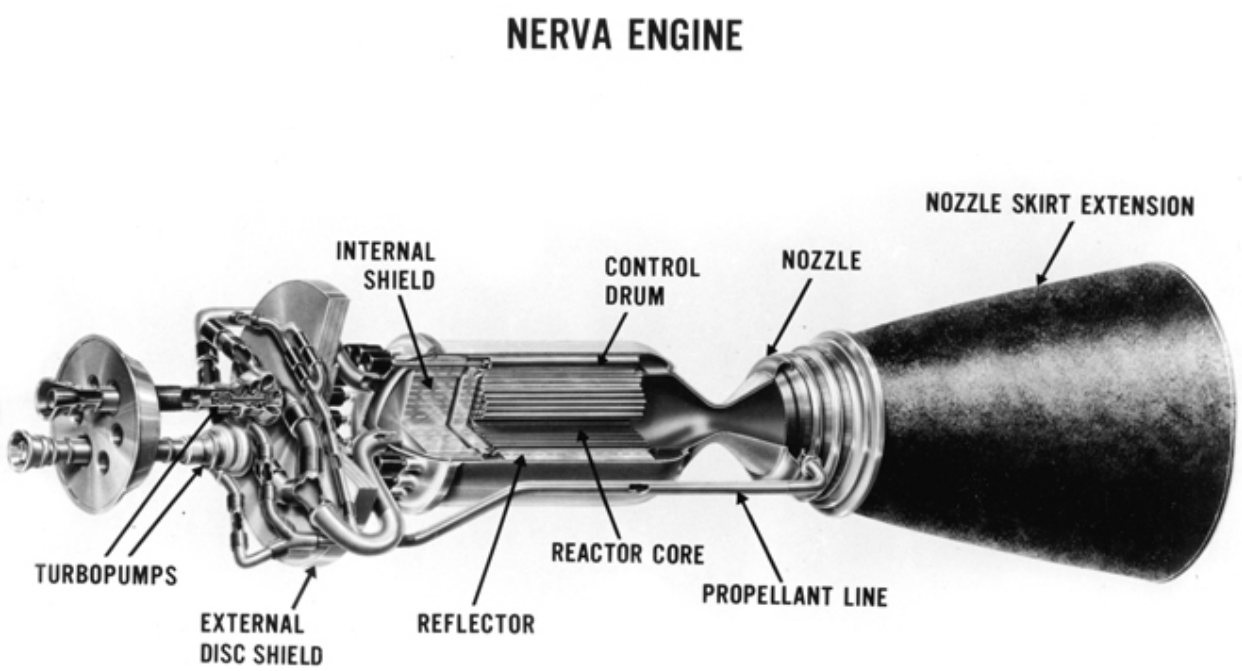
A gas (e.g. hydrogen) is heated by a reactor and streams out of a nozzle – like a nuclear power plant with an open cooling loop.

Exhaust velocity: $$v_0 = \sqrt{\frac{f\ T}{A}} \times 90\ \frac{m}{s}$$

E.g. H2: f = 5, A =2,
T = 3000 K → v0 = 7800 m/s

where T = Reactor temperature in Kelvin, A = Atomic weight of gas molecules,
f = Molecular degrees of freedom: 3 for single atoms, 5 for two-atom molecules with linear symmetry...

NASA projects Rover and NERVA
(Nuclear Engine for Rocket Vehicle Application)



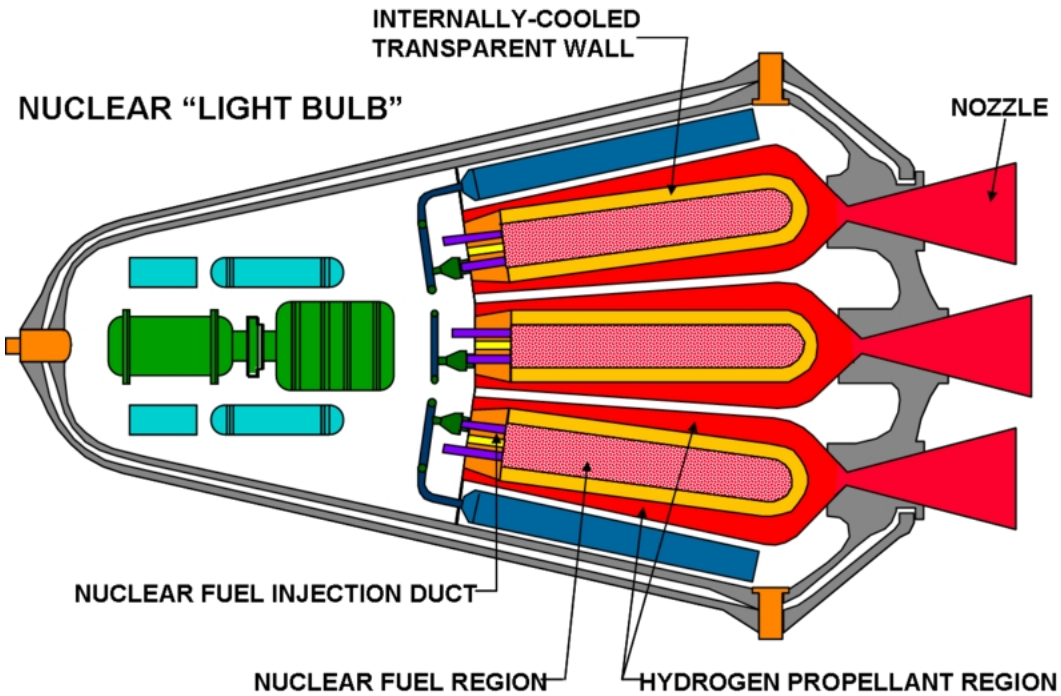
Ground testing of NTR by NASA from 1952 – 72.

Below right: Firing up KIWI (a flightless bird).

The experiments had promising results.

Don't let your reactor overheat! T = 4000 K → v0 = 10 km/s pushes the limit. → Any better possibilities?

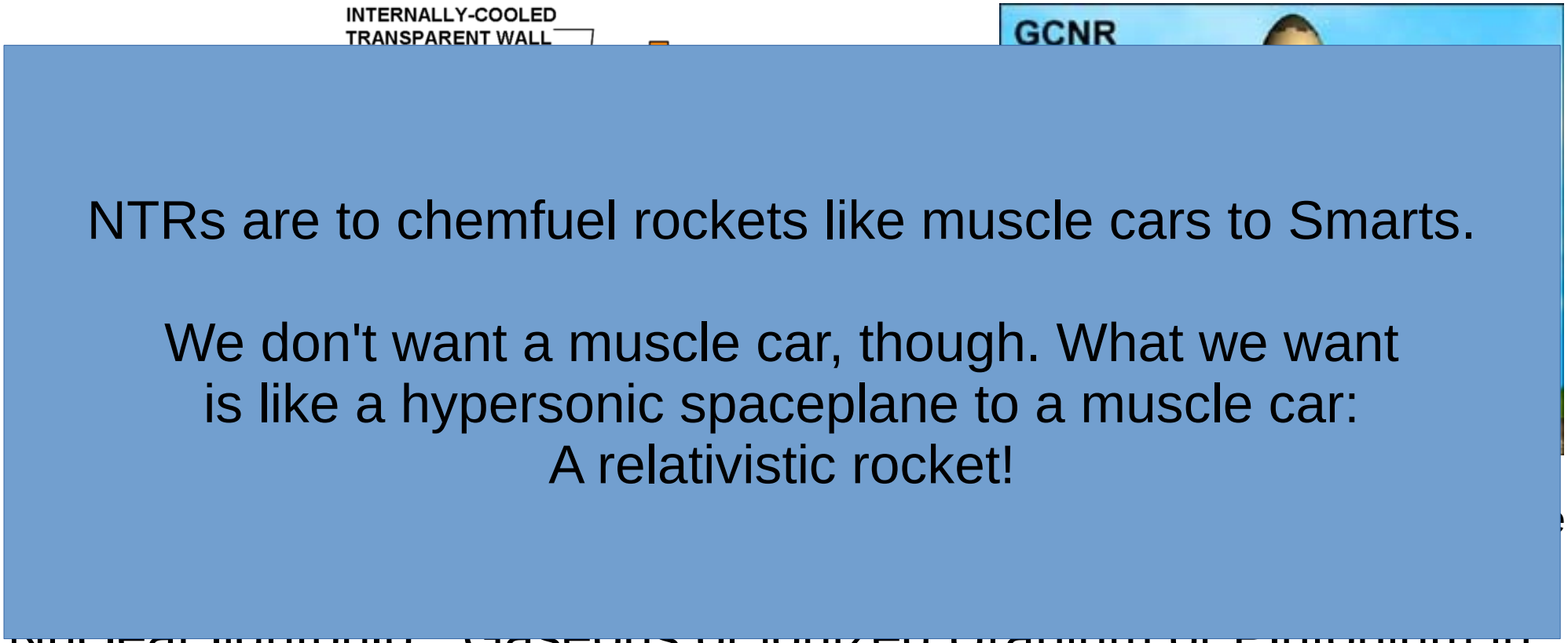
Liquid reactors are great for producing energy on earth! For rocket propulsion, let's climb up the ladder of matter states...



The „Liberty Ship" design.
1000 t payload to LEO with single stage + powered descend!

„Nuclear lightbulb": Gaseous or ionized Uranium or Plutonium in quartz glass flasks.
Cooling and reaction medium: Hydrogen at up to v0 = 30 km/s with chemfuel-like thrust.
Very powerful interplanetary rockets; not yet interstellar.

Liquid reactors are great for producing energy on earth! For rocket propulsion, let's climb up the ladder of matter states...

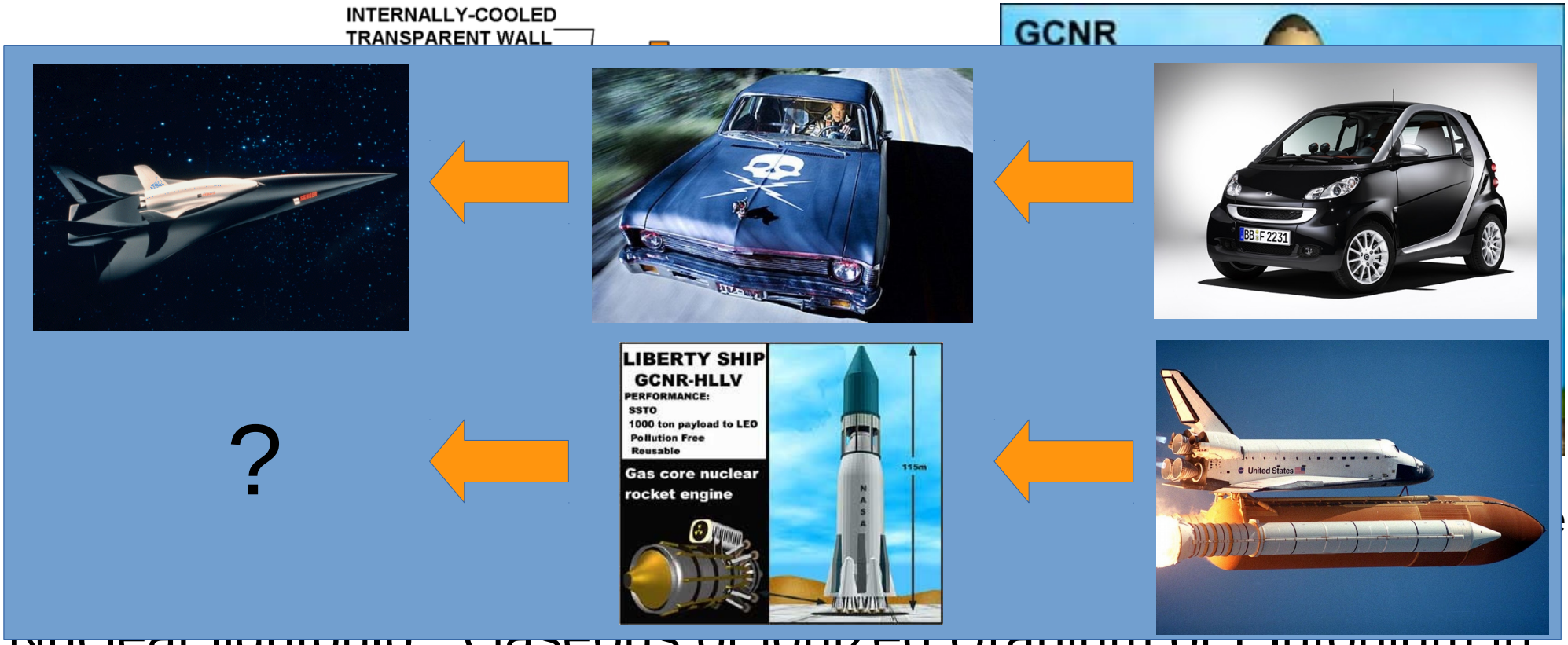


NTRs are to chemfuel rockets like muscle cars to Smarts.

We don't want a muscle car, though. What we want is like a hypersonic spaceplane to a muscle car: A relativistic rocket!

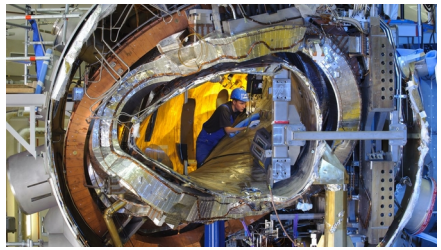
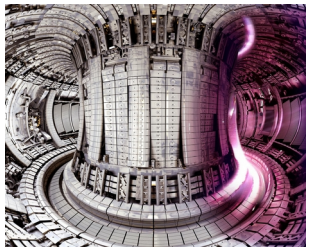
„Nuclear lightbulb": Gaseous or ionized Uranium or Plutonium in quarz glass flasks.
Cooling and reaction medium: Hydrogen at up to v0 = 50 km/s with chemfuel-like thrust.
Very powerful interplanetary rockets; not yet interstellar.

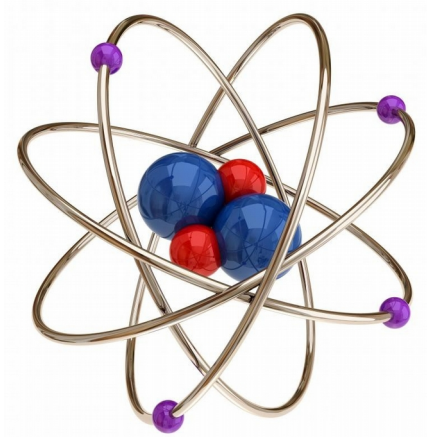
Liquid reactors are great for producing energy on earth! For rocket propulsion, let's climb up the ladder of matter states...

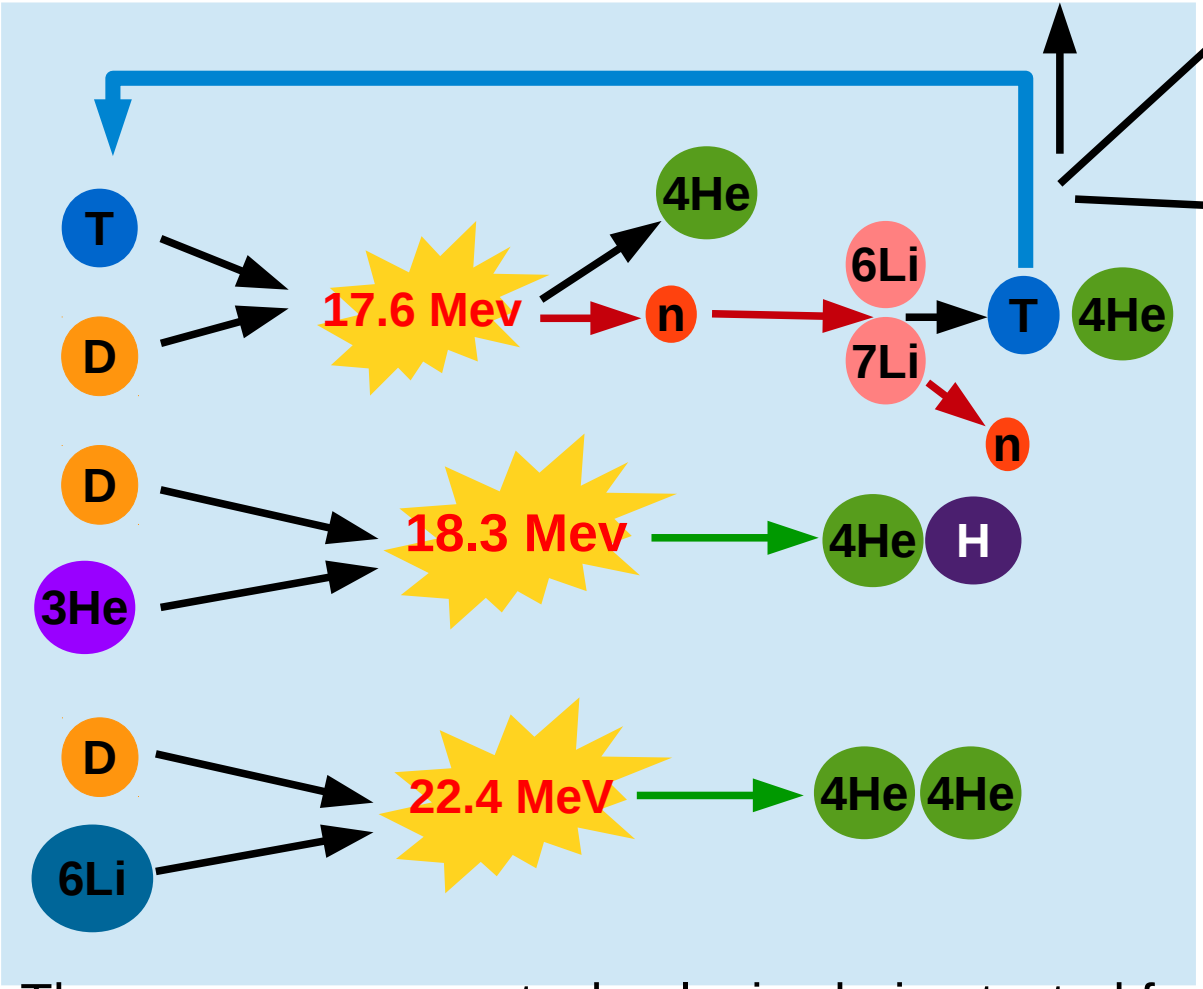


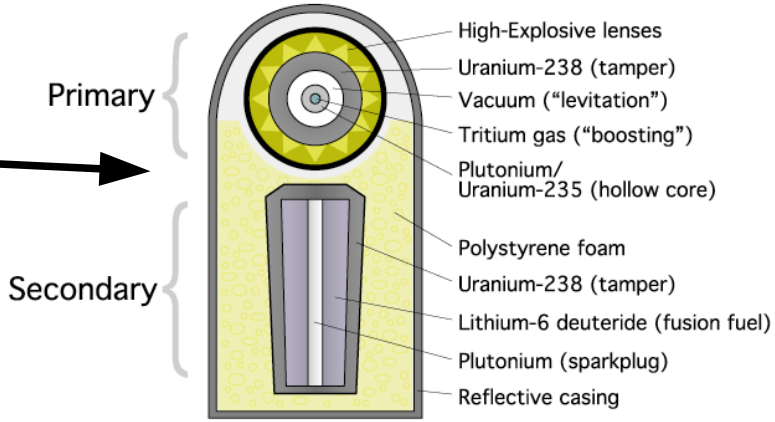
„Nuclear lightbulb": Gaseous or ionized Uranium or Plutonium in quarz glass flasks.
Cooling and reaction medium: Hydrogen at up to v0 = 50 km/s with chemfuel-like thrust.
Very powerful interplanetary rockets; not yet interstellar.

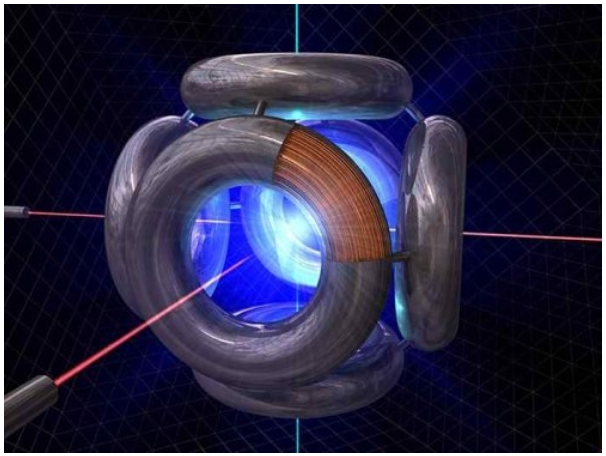
Nuclear fusion







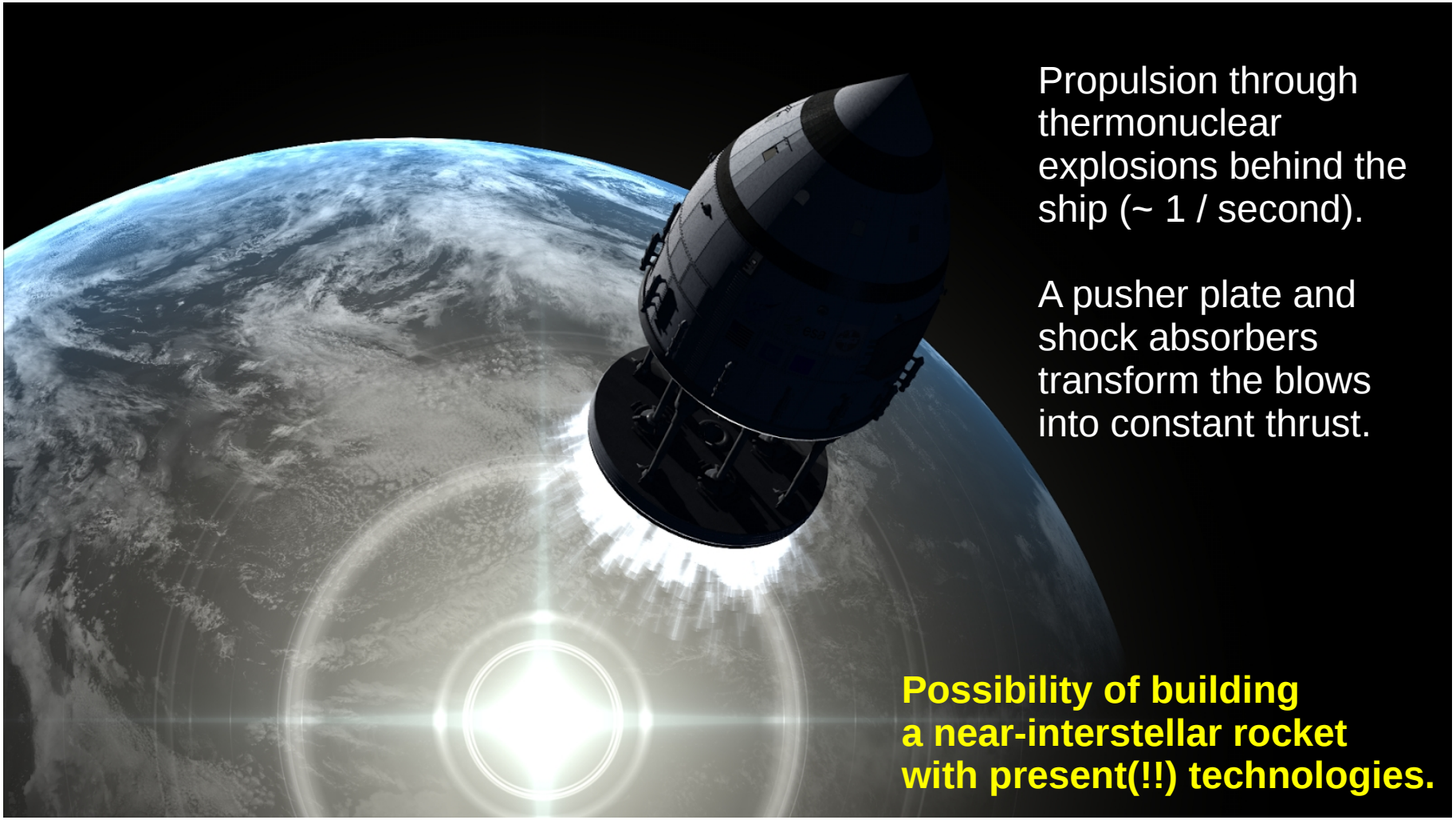


There are numerous technologies being tested for controlled fusion on Earth. Currently, energy production is only possible via explosive burning. Could explosions help us?

The „Trobadora Beatriz“

The experimental ship „Trobadora Beatriz“ has been towed some kilometers aside by Shadow Jumpers (which make quite sturdy orbital tugboats). From this vantage point, Port Terra is a radiant silvery sickle standing out from space's inexhaustible blackelation; different from the usual artillerygrenadoid-slamsquat thermonuclear pulsating clippers, the Trobadora is rather carmenheckenrosentallike tall and lean, with a bell nozzle at one end, which appears as tremendous as flimsy: for it is fashioned from an open lattice of magnetic coils, no solid matter would suffer focusing the fantastic heat of the plasma beam. Alexa: „The aim has always been to build something which in terms of specific impulse and thrust would draw even with good old boomboomboom [demonstrating by fist-into-hand two-three times], but doesn't go boomboomboom, burning steadily instead. Division by zero. It's that one include file, I think.“ „Why's it called tulipbulb.h?“ – Carmen, innocently. „Know something better?“ – Alexa, meanwhile rather gruff. „Sure. Pieinthesky.h.“ „Carmen, you seem bored, methinks. How about getting busy with the torch? Photocoupler T1136 doesn't respond like expected. Get your little cinneamon buttcheeks down there and grab a soldering iron.“

Nuclear pulse propulsion: Orion



Propulsion through thermonuclear explosions behind the ship (~ 1 / second).

A pusher plate and shock absorbers transform the blows into constant thrust.

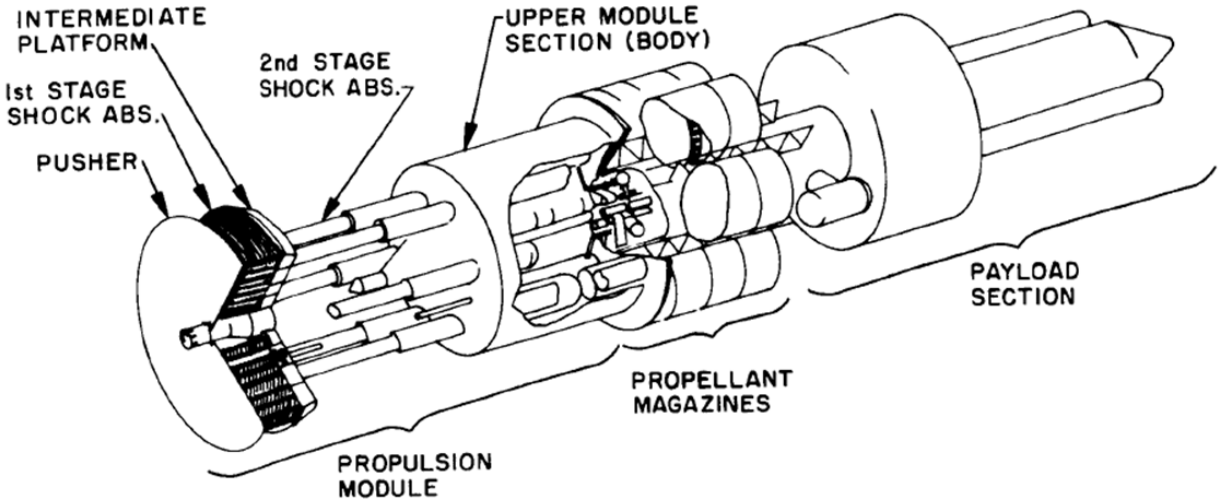
Possibility of building a near-interstellar rocket with present(!!) technologies.

Orion Pulse Drive

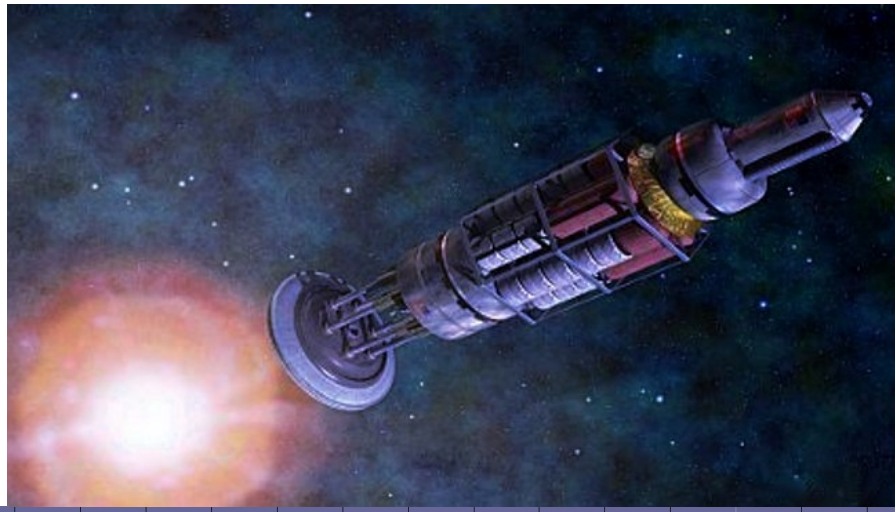
The mightiest of them all.

How mighty is it?

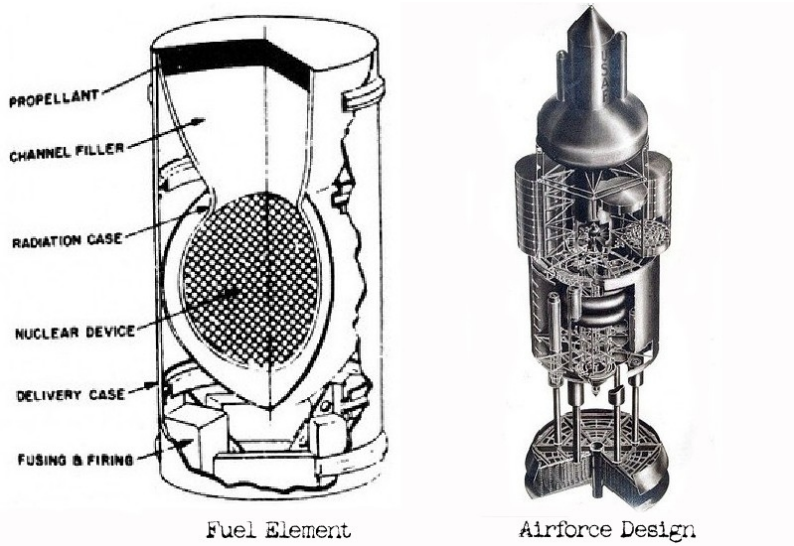
Energy density of Lithium deuterite:
50 kt TNT / kg LiD

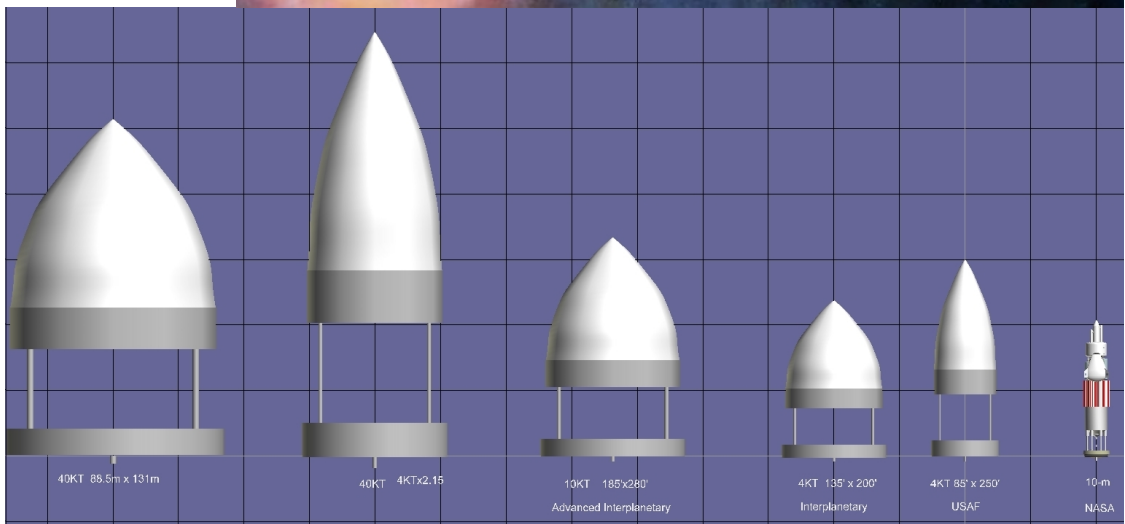


$$F_{thrust} = 300\sqrt{\frac{W_{bomb}}{kt} \times \frac{m_{bomb}}{kg}} \quad t \text{ at } 1\ g$$



$$\Delta v = 3000\sqrt{\frac{W_{bomb}/kt}{m_{bomb}/kg}}\ \ln\frac{M_{wet}}{M_{dry}}\ \frac{km}{s}$$





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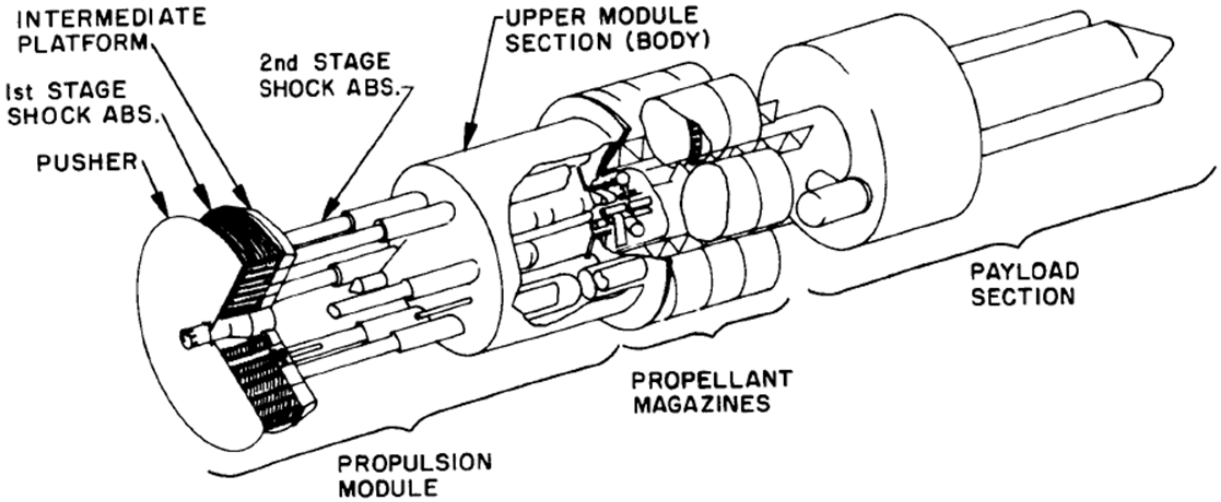
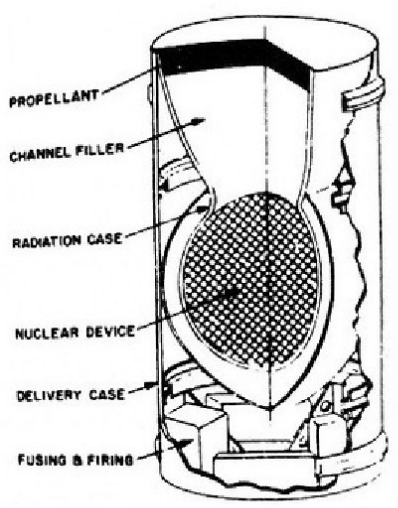


$$F_{thrust} = 300\sqrt{\frac{W_{bomb}}{kt} \times \frac{m_{bomb}}{kg}} \quad t \text{ at } 1\ g$$

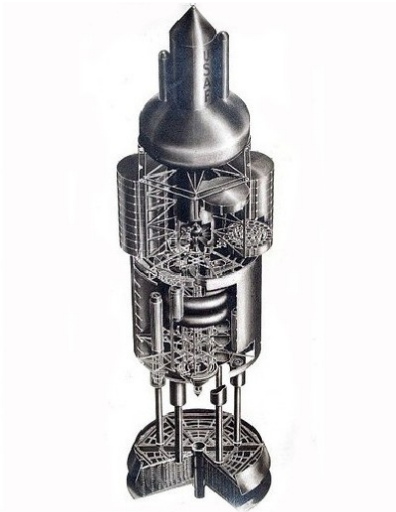
$$\Delta v = 3000\sqrt{\frac{W_{bomb}/kt}{m_{bomb}/kg}}\ \ln\frac{M_{wet}}{M_{dry}}\ \frac{km}{s}$$

Problem 10 A.: Derive these!

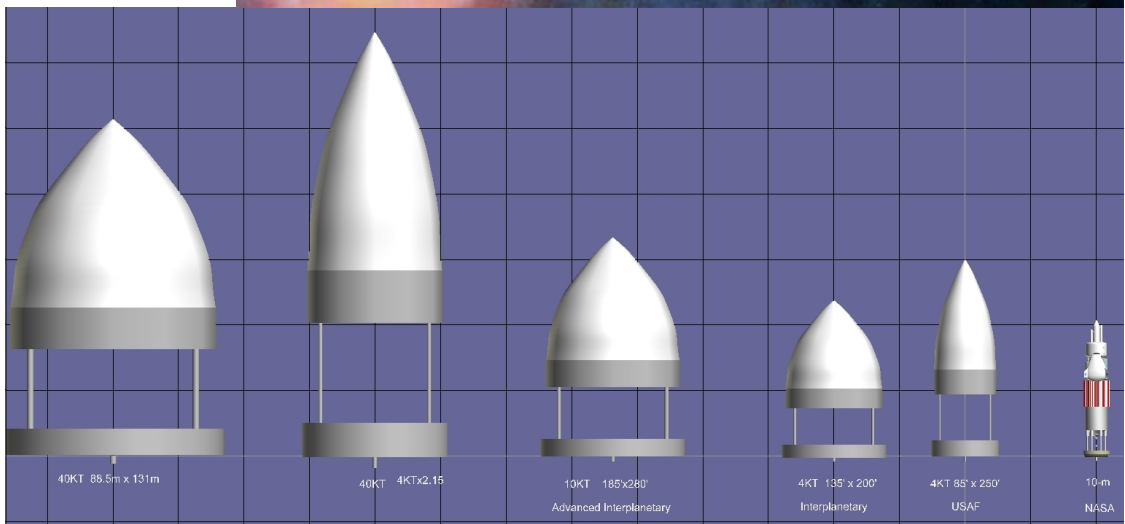
(W_{bomb} = Energy of bomb, m_{bomb} = bomb mass.)



Fuel Element



Airforce Design



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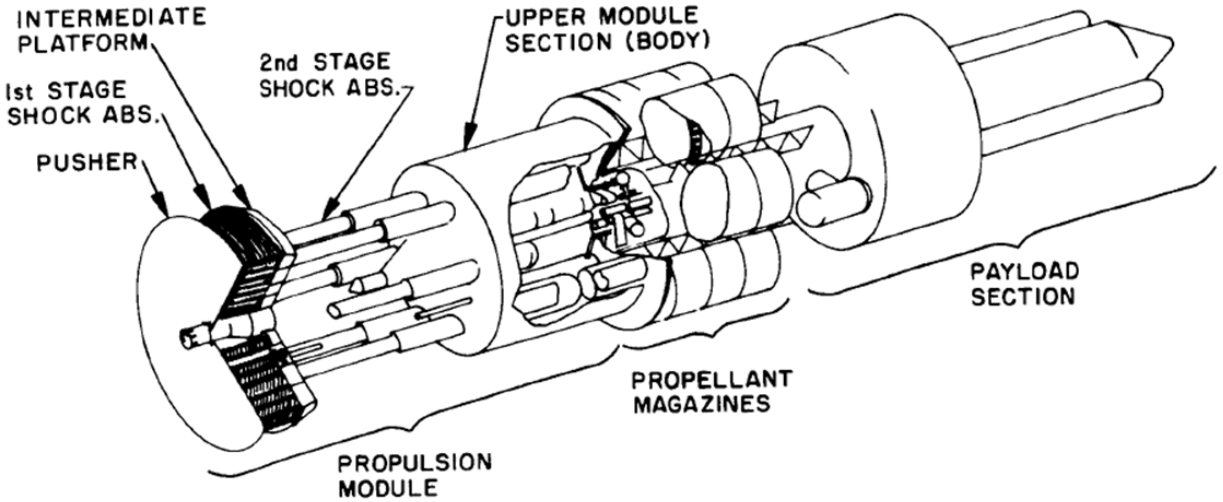
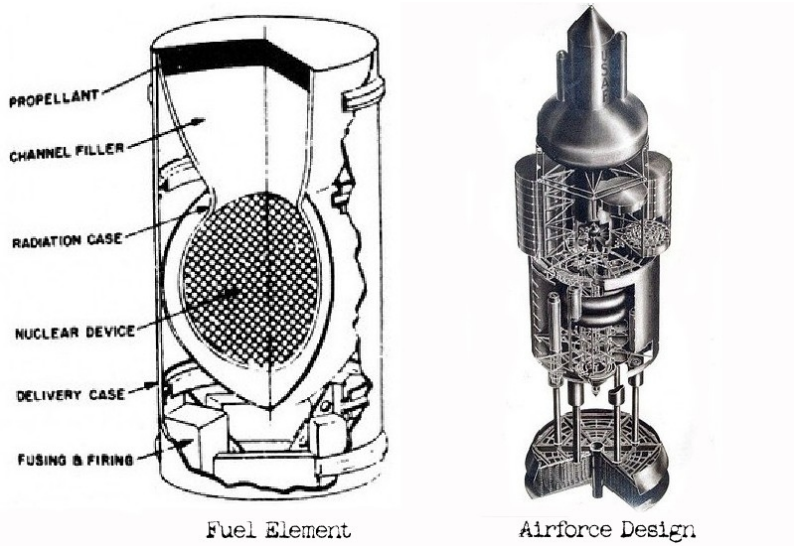


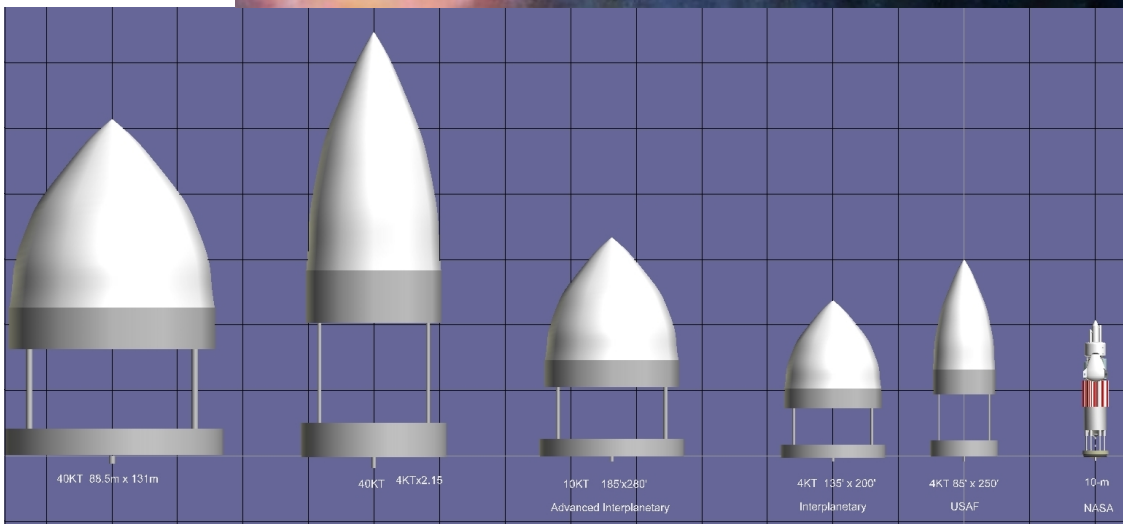
$$F_{thrust} = 300 \sqrt{\frac{W_{bomb}}{kt} \times \frac{m_{bomb}}{kg}} \quad t \text{ at } 1\ g$$

$$\Delta v = 3000 \sqrt{\frac{W_{bomb}/kt}{m_{bomb}/kg}} \ \ln \frac{M_{wet}}{M_{dry}} \ \frac{km}{s}$$

Problem 10 B.:

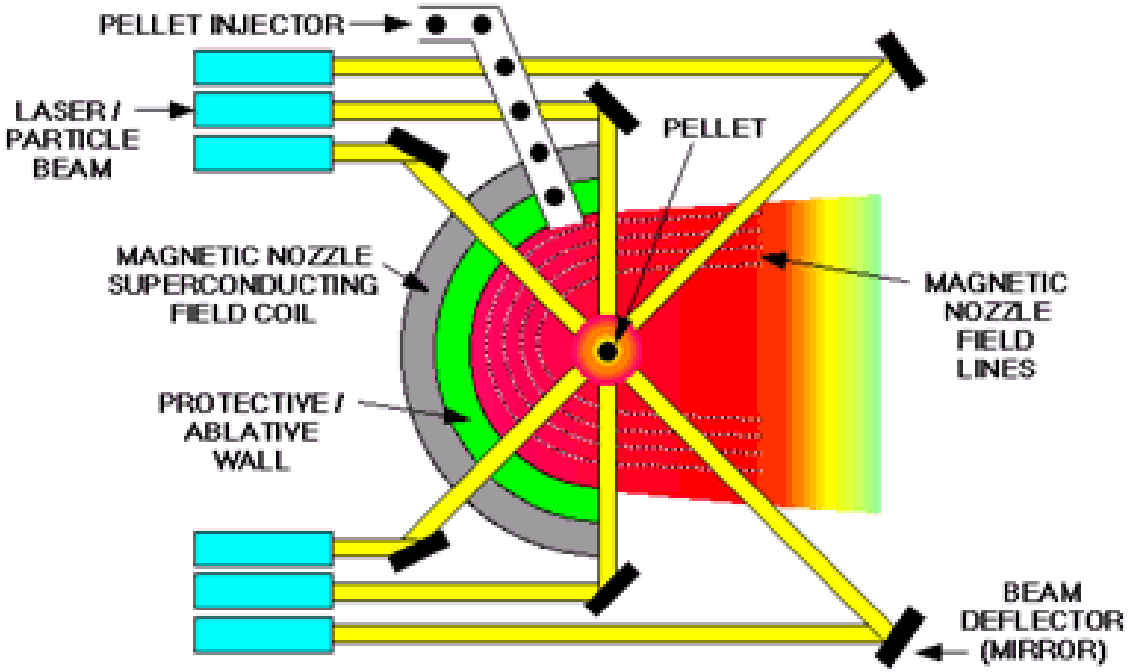
Design an Orion ship with Delta v = 10% c, Thrust = 1 Mio t @ 1 g.





Taking the „bomb“ out of Orion

Smaller pulse charges without a fission stage



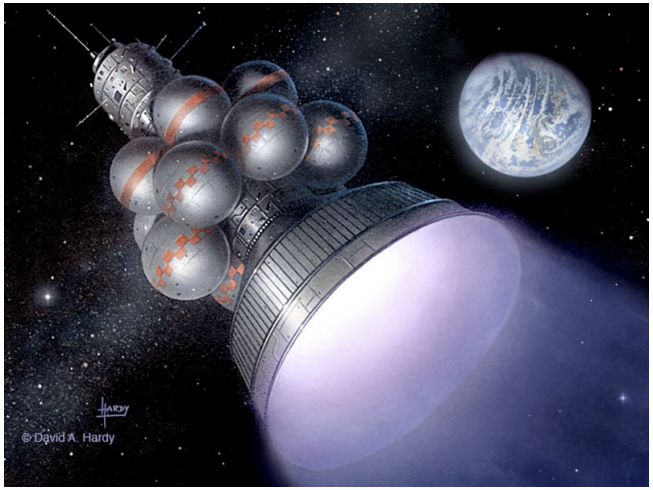
- Instead of full Teller-Ulam: **Small fusion fuel pellets (D+T, D+D, D+3He, D+6Li...)**
- Laser or particle beam ignition.
- Focusing the plasma via magnetic fields.
- Similar to inertial confinement fusion reactors (e.g. National Ignition Facility)

Exhaust velocity max. (D+3He): 9% c (!!)

$$\frac{\Delta v}{c} = \tanh\left(0.09 \ln \frac{m_{wet}}{m_{dry}}\right) \qquad \frac{m_{wet}}{m_{dry}} = 4 \rightarrow \frac{\Delta v}{c} = 0.12$$

Problem 11:
1 Mio t. ship, 1 g acceleration.
How much D+3He-fuel will it burn each second?
How much power?

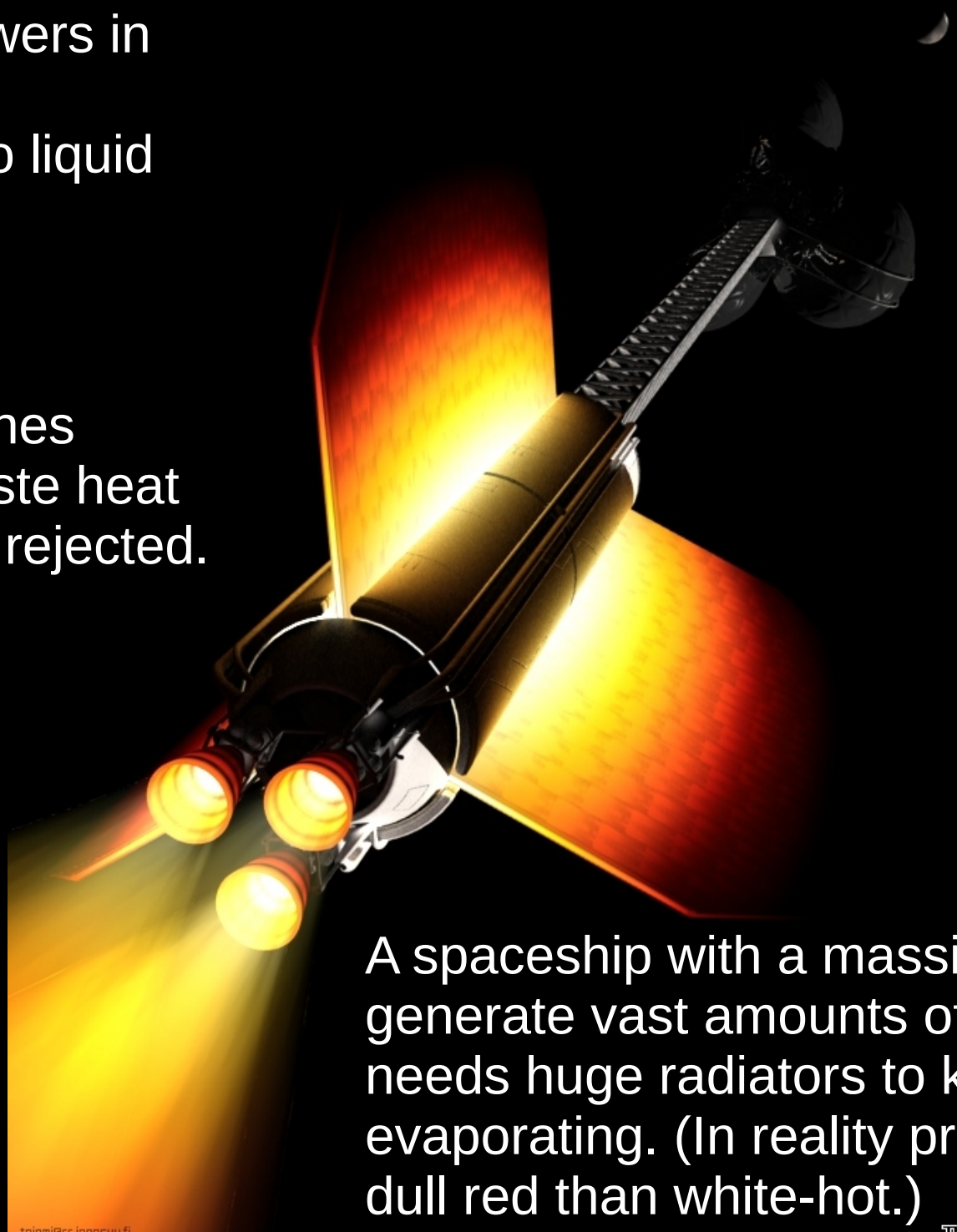
Project Daedalus/Icarus by BIS



Now, where's that photocoupler T1136? Carmen holds the replacement in her hand, soldering iron clipped to her uniform blouse's breast pocket. Where are you, coupler? Tut tut, come here, come to me, coupler. Carmen puckers her lips and whistles the Wilhelm Tell Overture (which tends to drive Alexa insane: „If you insist on whistling, at least expand your repertoire a bit!“ „But my name's Carmen, so I like that opera.“ „This isn't »Carmen«, it's Wilhelm Tell by Rossini.“ „I know.“) The gas core nuclear reactor, which – Carmen finds this almost hard to imagine – is situated just a few meters beyond the right-hand wall of the access well, contains in its inner workings a tube filled with a Heliumthree-Argon-mixture, to generate the x-ray laser beam igniting the Deuterium-Heliumthree pellets in the thrust chamber, the resulting heat, two and a half thousand megawatts, is enormous and must be rejected into space, to which end the Trobadora sports around her rear mothlike infrared radiators, stretching hundreds of meters into black nearvacuum.

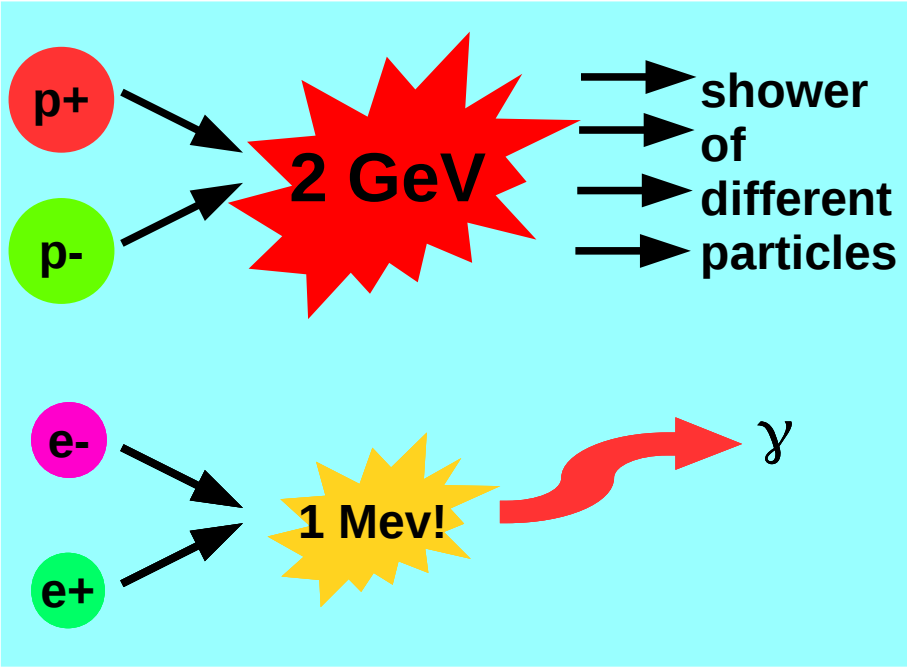
No cooling towers in space!
(As there is no liquid phase.)

All heat engines generate waste heat that must be rejected.



A spaceship with a massive engine will generate vast amounts of waste heat. It needs huge radiators to keep itself from evaporating. (In reality probably rather dull red than white-hot.)

Photon drive reloaded: Antimatter



A-mat ~ similar to everyday matter but with inverse electric charge.
Antiprotons – negative
Antielectrons (Positrons) – positive.

When in contact with matter:
Most powerful release of energy known to current physics:

$$E = (m1 + m2)\, c^2$$

(m1 = Mass of a-mat, m2 = Mass of ordinary mat.)

Issues:

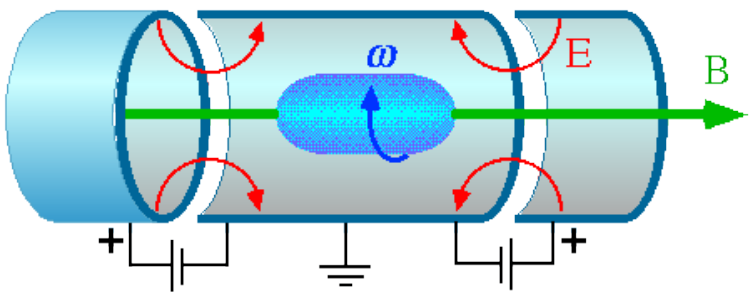
- No large amounts of a-mat found it nature – has to be produced using lots of energy. **Energy storage, not an energy source**.
- Store it, but DON'T TOUCH! Contact with tank wall results in nuclear bomb level explosions **(1 g = Hiroshima, 1 kg = Tsar Bomba, 50 Mt.)**

Types of a-mat drives:

- Reaction products as exhaust mass. **Only charged particles from p+/p- reaction can be magnetically focused (60%).**
- Use the reaction to heat a medium.
- Employ a-mat to catalyze other reactios, e.g. **a-mat-catalyzed fusion.**

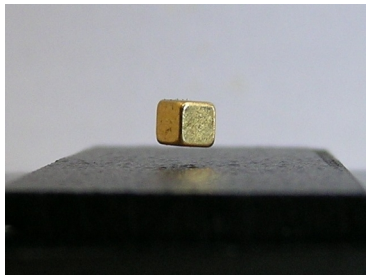
Taming the beast: Some a-mat storage options

Penning Trap



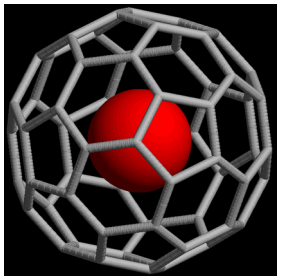
- Storage of charged a-mat particles in flask of superimposed electric and magnetic fields.
- Used presently to store minuscule amounts of antiprotons (some 1000s).
- Storage density not sufficient for a-mat-powered spacecraft.

Diamagnetic Floating



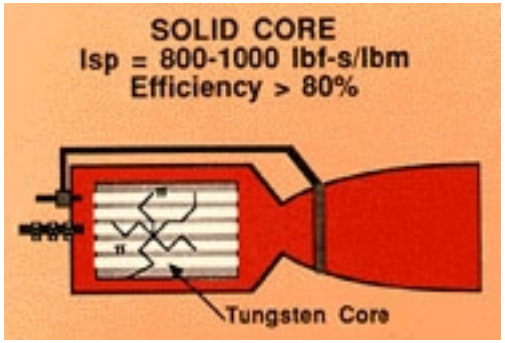
- Inhomogeneous magnetic field repels snowball made of frozen antihydrogen, which thus can be made to float without touching container walls.
- A-mat is removed by evaporating it with a laser.

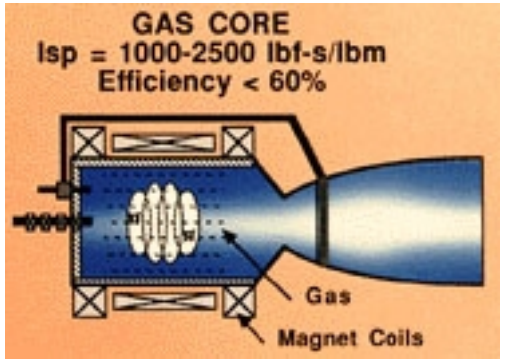
Trapping in Buckminster Fullerenes

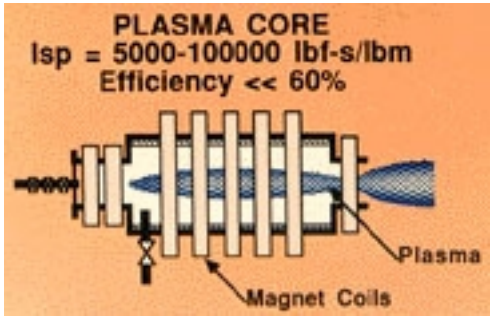


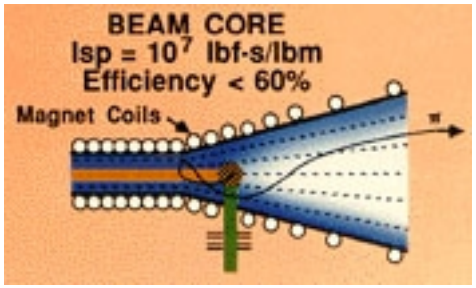
- Trapping a-mat particles in C60-balls.
- Earnshaw Theorem does not hold for quantum electrodynamics – stable storage possible!
- **Problem 12: Calculate energy density of Fullerite with one positron in every tenth molecule. Compare with TNT.**

Antimatter Rockets

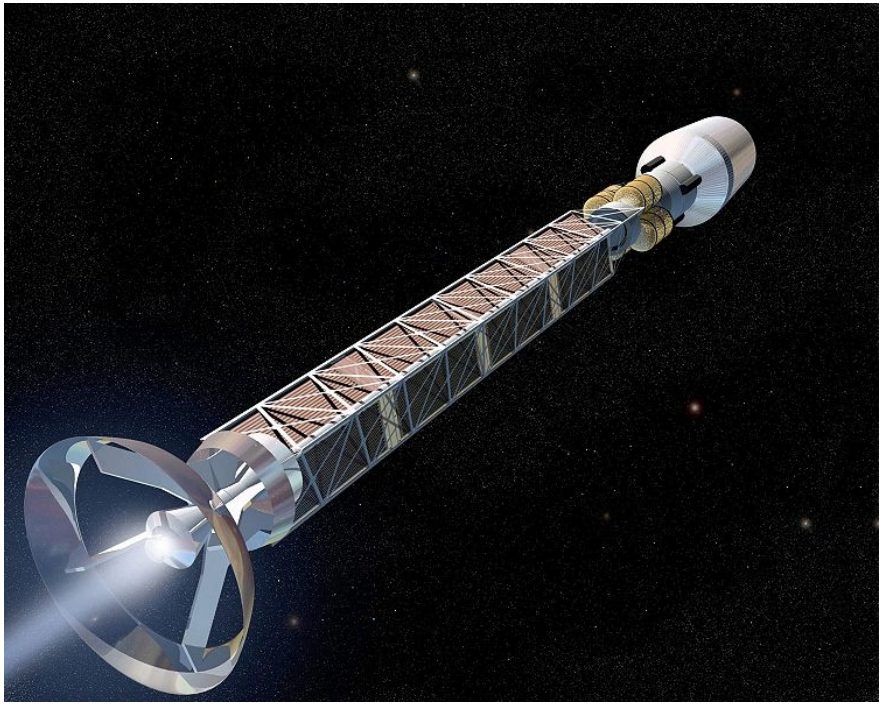


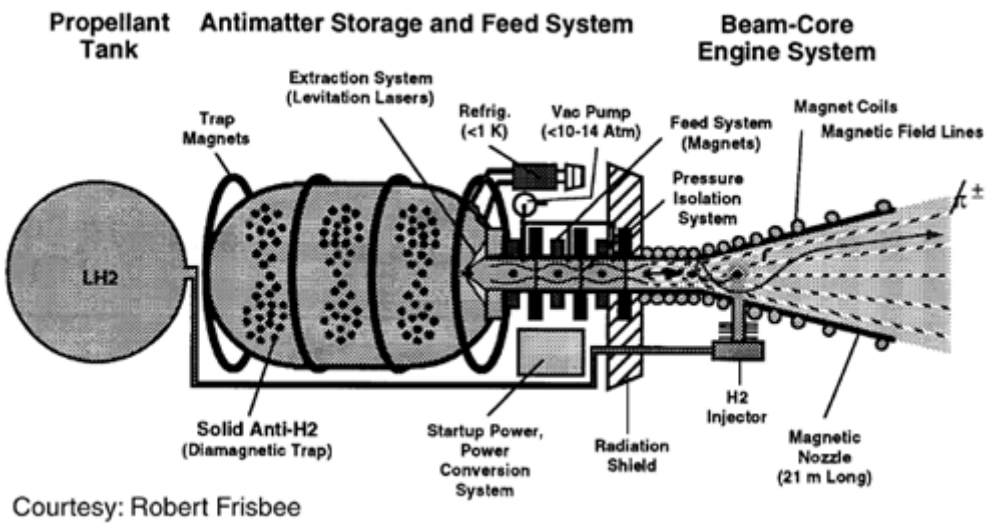






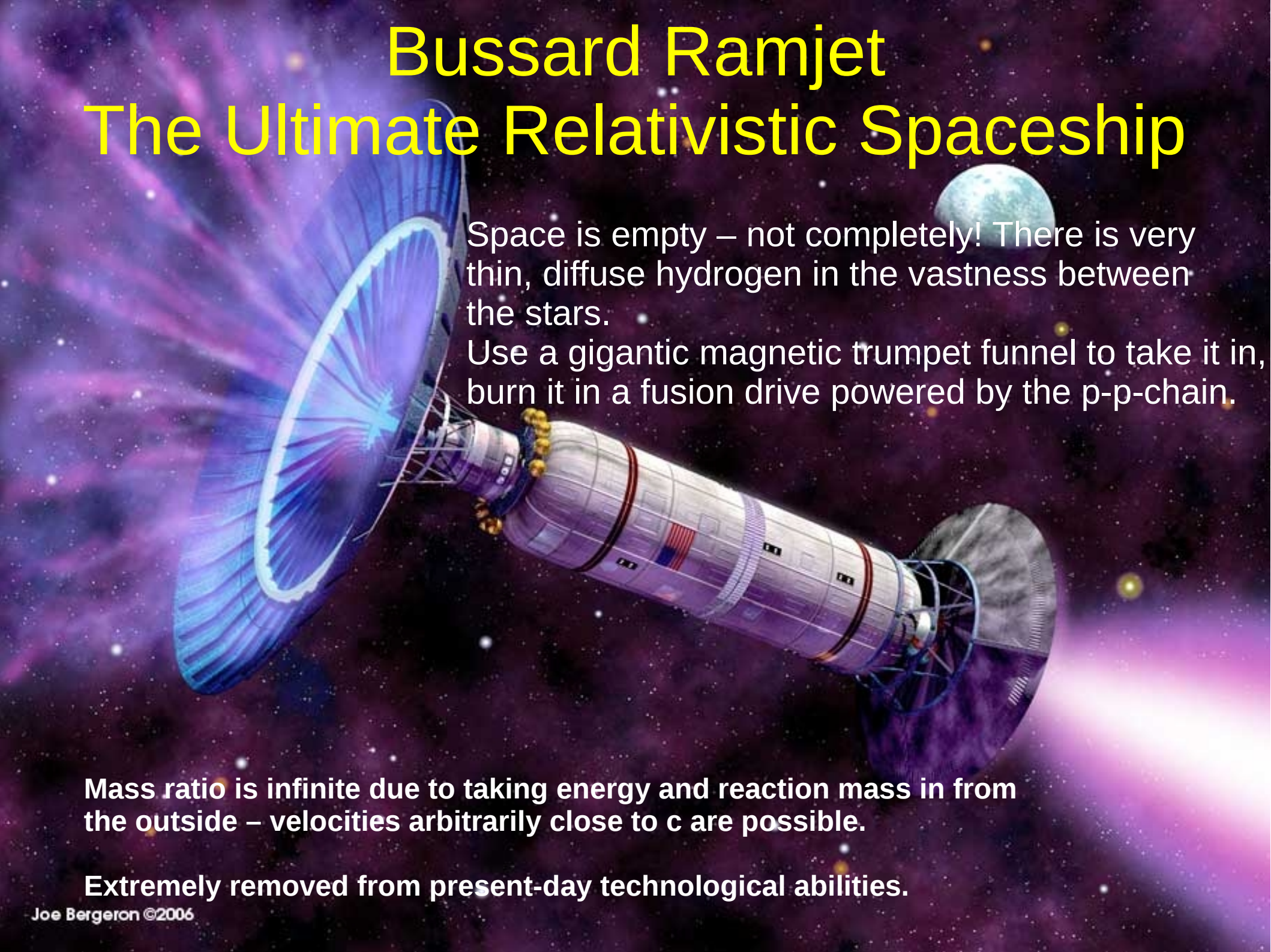
v0 ~ 10 km/s v0 ~ 25 km/s v0 ~ 1000 km/s v0 ~ nearly c





Courtesy: Robert Frisbee

Bussard Ramjet
The Ultimate Relativistic Spaceship



Space is empty – not completely! There is very thin, diffuse hydrogen in the vastness between the stars.
Use a gigantic magnetic trumpet funnel to take it in, burn it in a fusion drive powered by the p-p-chain.

Mass ratio is infinite due to taking energy and reaction mass in from the outside – velocities arbitrarily close to c are possible.

Extremely removed from present-day technological abilities.

Bussard Ramjet
The Ultimate Relativistic Spaceship

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Use a gigantic magnetic trumpet funnel to take it in, burn it in a fusion drive powered by the p-p-chain.

Problem 13:
Calculate...
A.) distance covered (in Earth's reference frame) as function of onboard time for a Bussard ship accelerating constantly at 1 g.
B.) Earth time passing as function of ship's time (distance).

Mass ratio is infinite due to taking energy and reaction mass in from the outside – velocities arbitrarily close to c are possible.

Extremely removed from present-day technological abilities.

Joe Bergeron ©2006

The Great Noon

Incredibly blue – blue like wind, like ice, like shimmering chromium steel; lightblue, rigelblue, Hertzsprung-Russel-topleft-blue; breathing blue, choral blue, sinfonia blue, brucknerblue, mendelssohnblue; waterblue, infinityblue, noonblue. Pacific everspring, Annika giggles, lies on her back, closes her eyes, licks her incisors, opens her eyes wide, Curiepolitan skyglow enters, rushes along nerve fibers, fills her brain with long quiet laughter. Opalclear the sky, just here-there so-tender feathercirruses: Annika recognizes the most delicate speck of cloud, almost every ice crystal floating sixteen kilometers up in the jetstream, breathchill powder of solid water, microscopic flakes, needles, splinters, from which sunlight rebounces joyfully. Immaculate crystal architecture, spires, castles, train station domes, pavilions, skyscrapers made of ice, so clear and flawless to seem to be made of pure light, lines, surfaces, columns, struttings of sleepyyellow and clinkingblue, slowly drifting tumbling coasting in thin icy air that streams around the globe, now and then thunderpierced by a climbing or descending rocket's, hypersonic deltaplane's heatflash . The Curiepolitans storm Olympus, towering top of the world and the eternal elationblackness full of stargems beyond. „Intelligence“, thinks Annika, „doesn't live well in the lowlands of the Earth's surface, the muddy fog-valleys of decay, of limitedness. Her world is height, expanses, silently vibrating laughing space, eternity sparkling with energy-richest radiation, weightless, happy, beautiful. Intelligence degenerates in a closed environment, she needs the ecstasy of infinity. Only if Intelligence succeeds in gaining as much of the universe as possible as her field of activity, she may have a chance – a very small chance, possibly – to win the final conflict with entropy at the end of time... or at least achieve a stalemate... Open the window of your cozy, claustrophile chamber: radiant luminosity rushes in, and cirrus-cold air that makes you shiver...“

Summerhand on goosebump skin: „Are you cold? Asleep? You okay, Annika? Like some tea?“ – Hikari. Annika turns her head, Hikari's bangs bobbing in the wind, thankfulglance backofhandpatpat. „Some riceballs left? One of the fried squid ones?“ Hikari nods, giggles, holds it for Annika's teeth, feed-chomp-gulp. One, two meadowcentimeters closer. Softfar noonnoises, mumblemuffled as if through a blanket woven of sunlight, but oh-so-clear, clear like the infinite sky. Strong puellae are the strongest when united, and happiest too.

Problem 14.
Write a short paragraph on why humanity should expand into space and become a multi-planet intelligence.

Thank you!

Lecture material on: http://geocities.ws/curiepolis/
Find me on Twitter: @NukeSqrrrl