Or: Why Rockets Are Hard

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What is SpaceX?

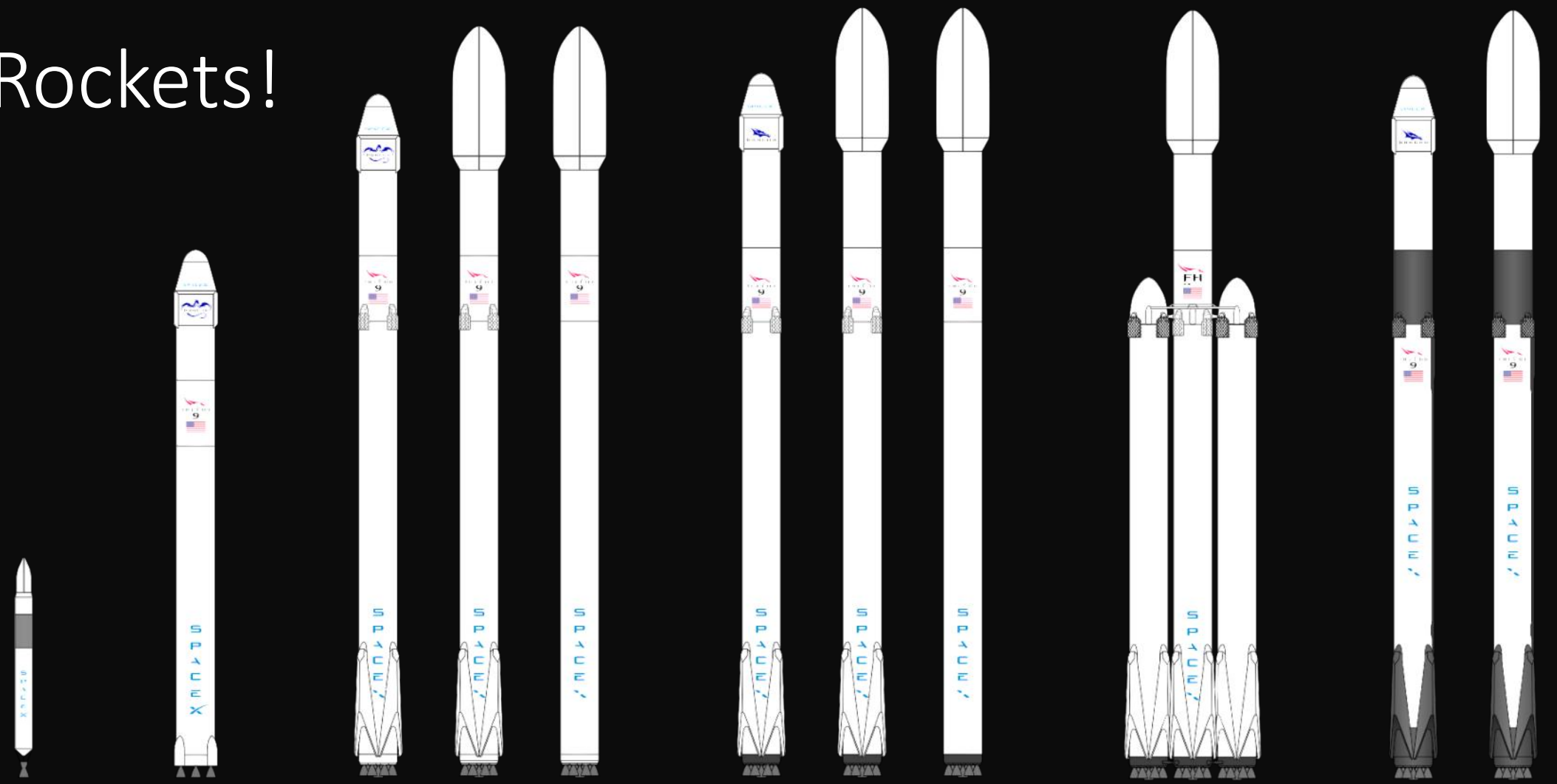
An Introduction

SpaceX

- Private US company
- Design, build & fly spacecraft
- You buy a ride, not the rocket:
  - Satellites
  - Space station cargo
  - Science payloads
  - Tourists…?

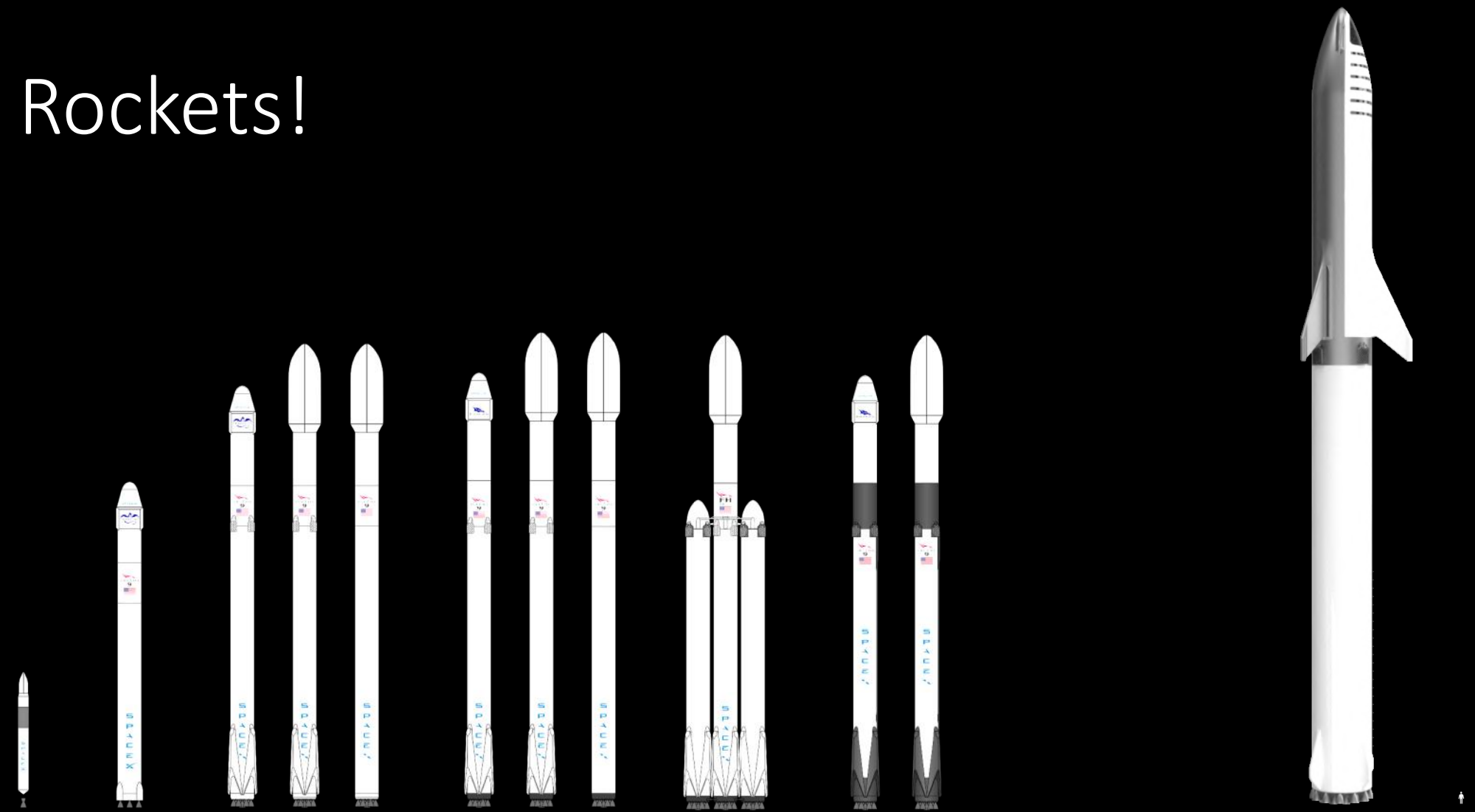
2002 - The Beginning

Rockets!



Start 2002 | Falcon 1 2006-09 | Falcon 9 v1 2010-13 | Falcon 9 v1.x 2013-16 | Falcon 9 FT Block IV 2015-18 | Falcon Heavy 2018- | Falcon 9 FT Block V 2018- | Now

Rockets!

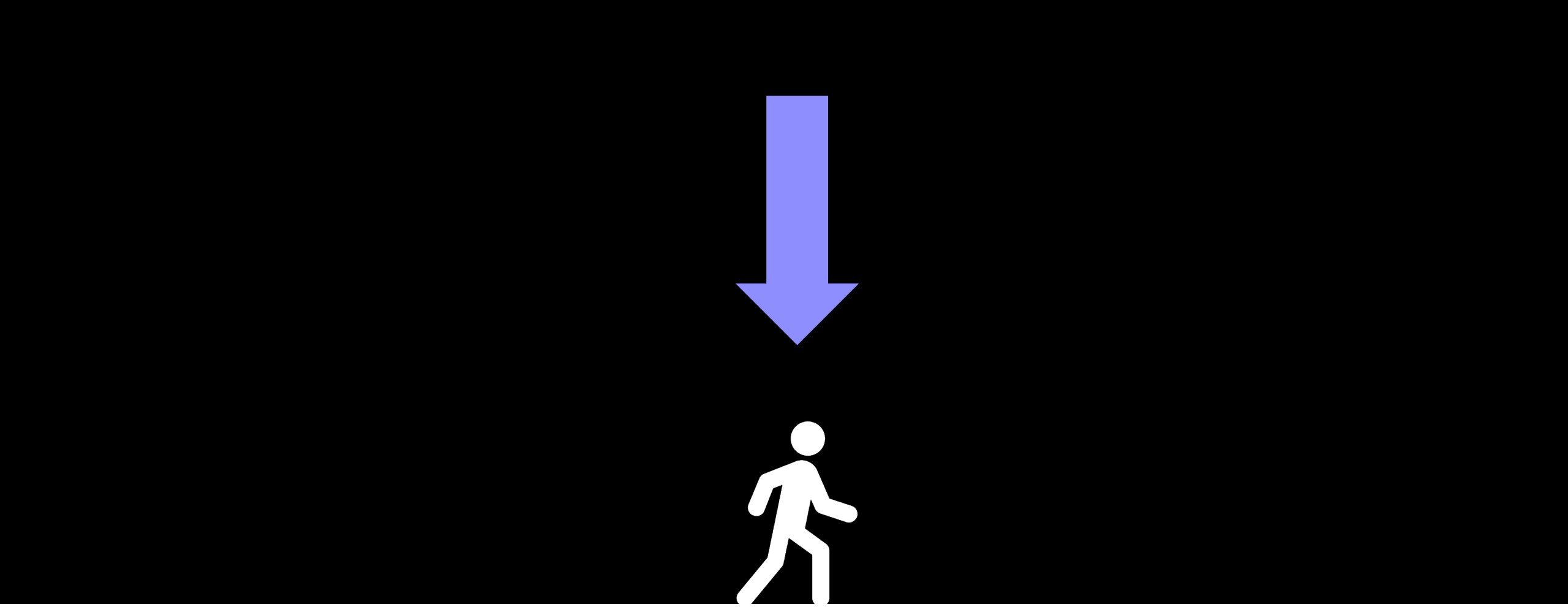


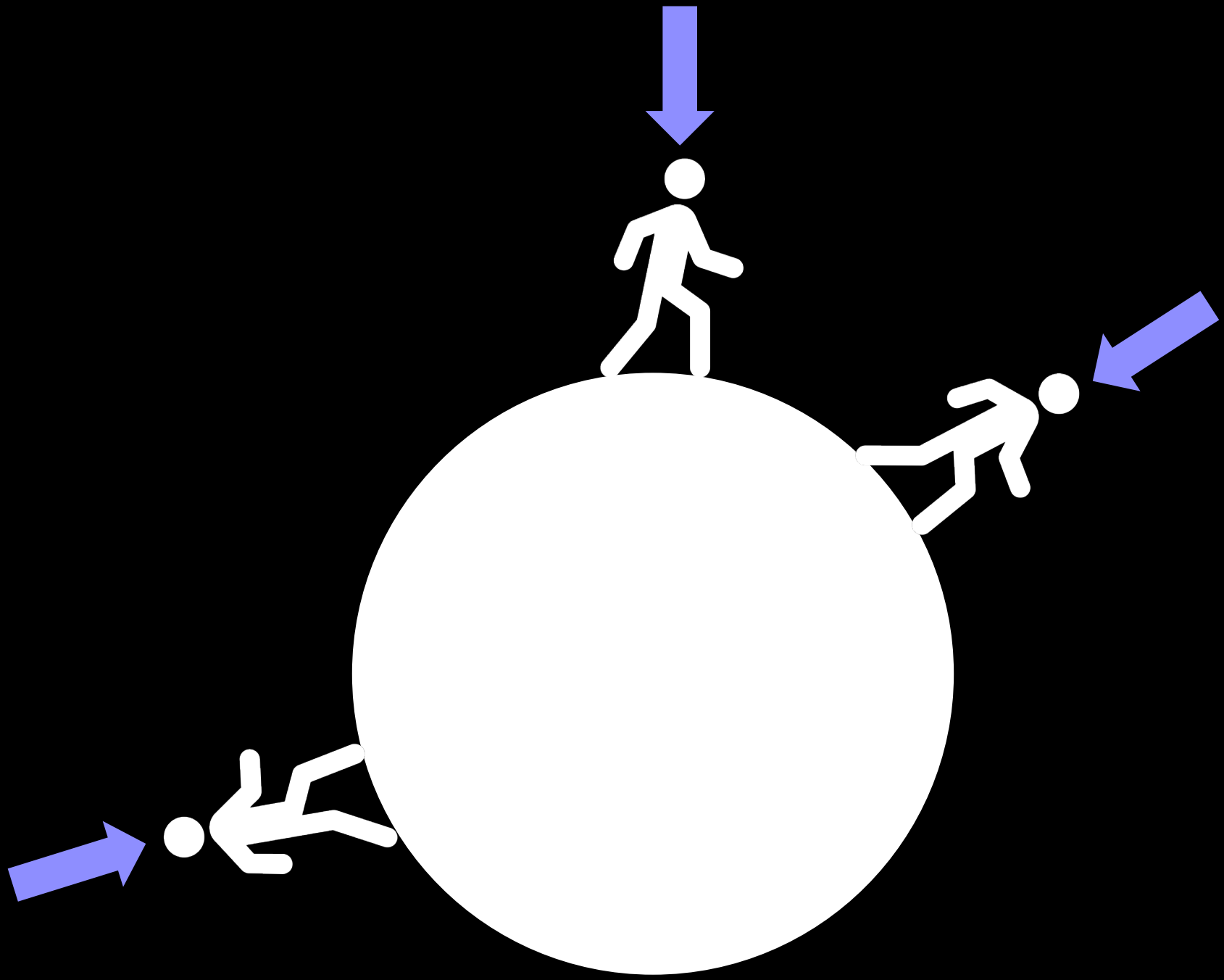
Start
2002

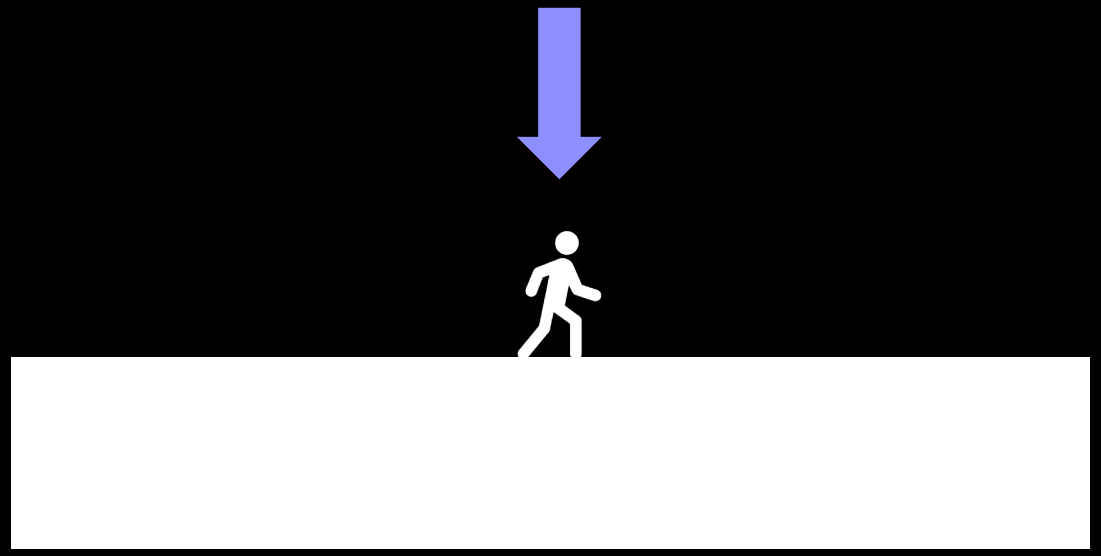
Now

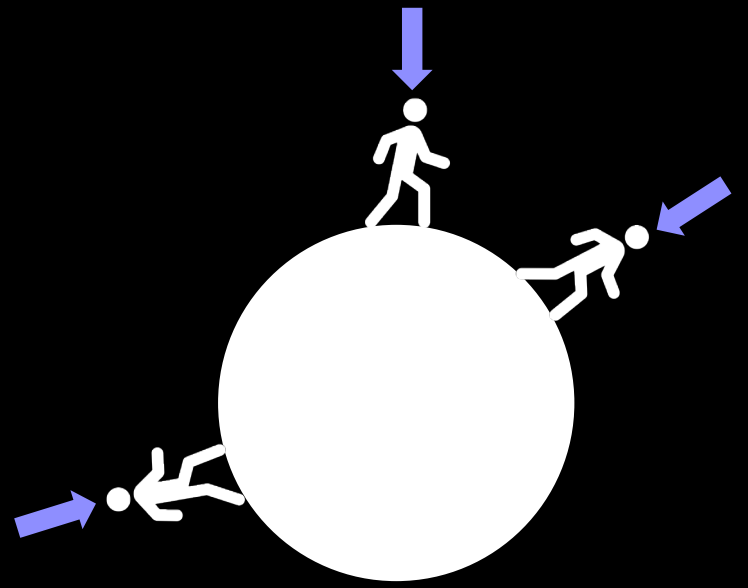
BFR
2020?

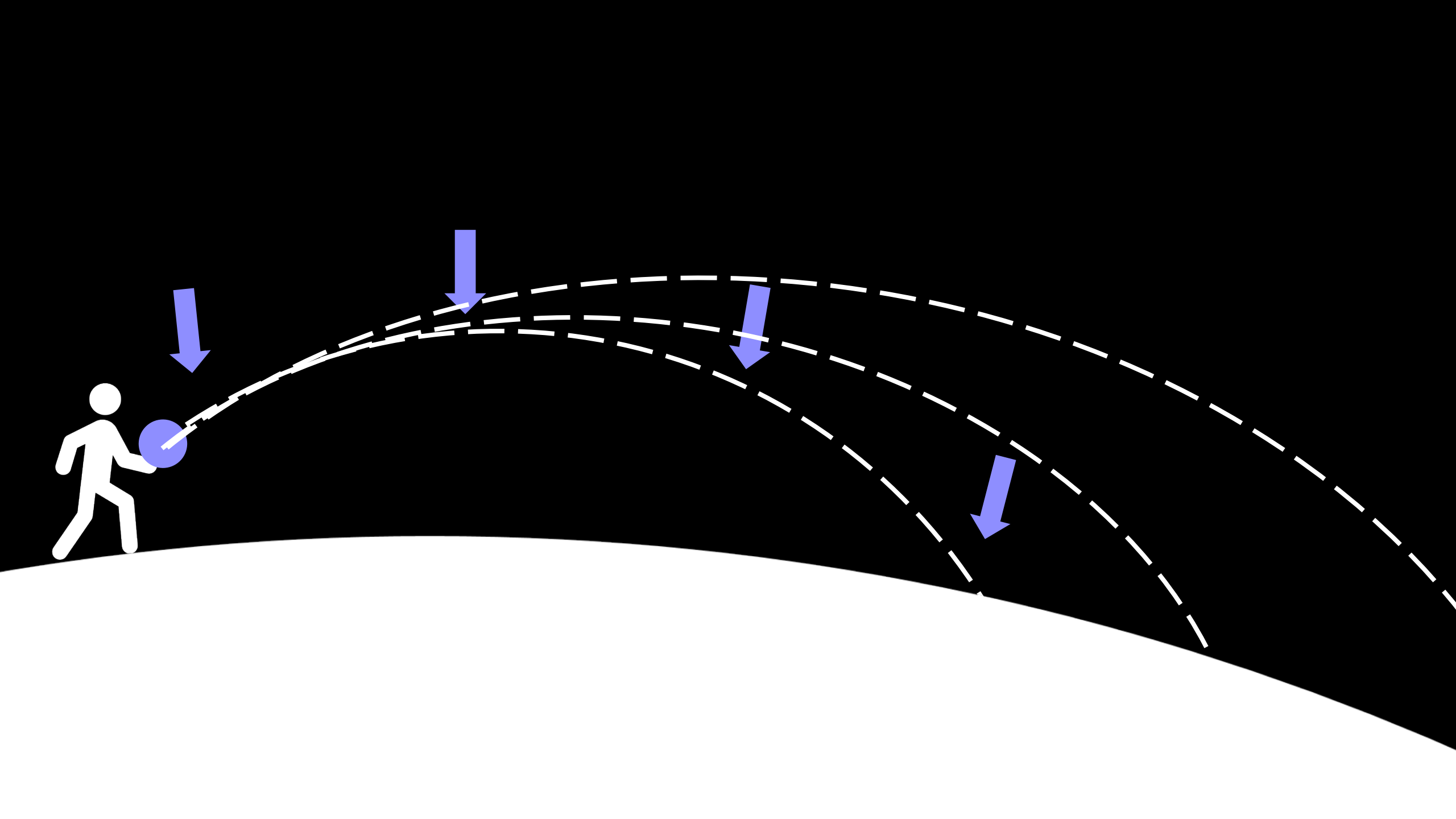
Orbit

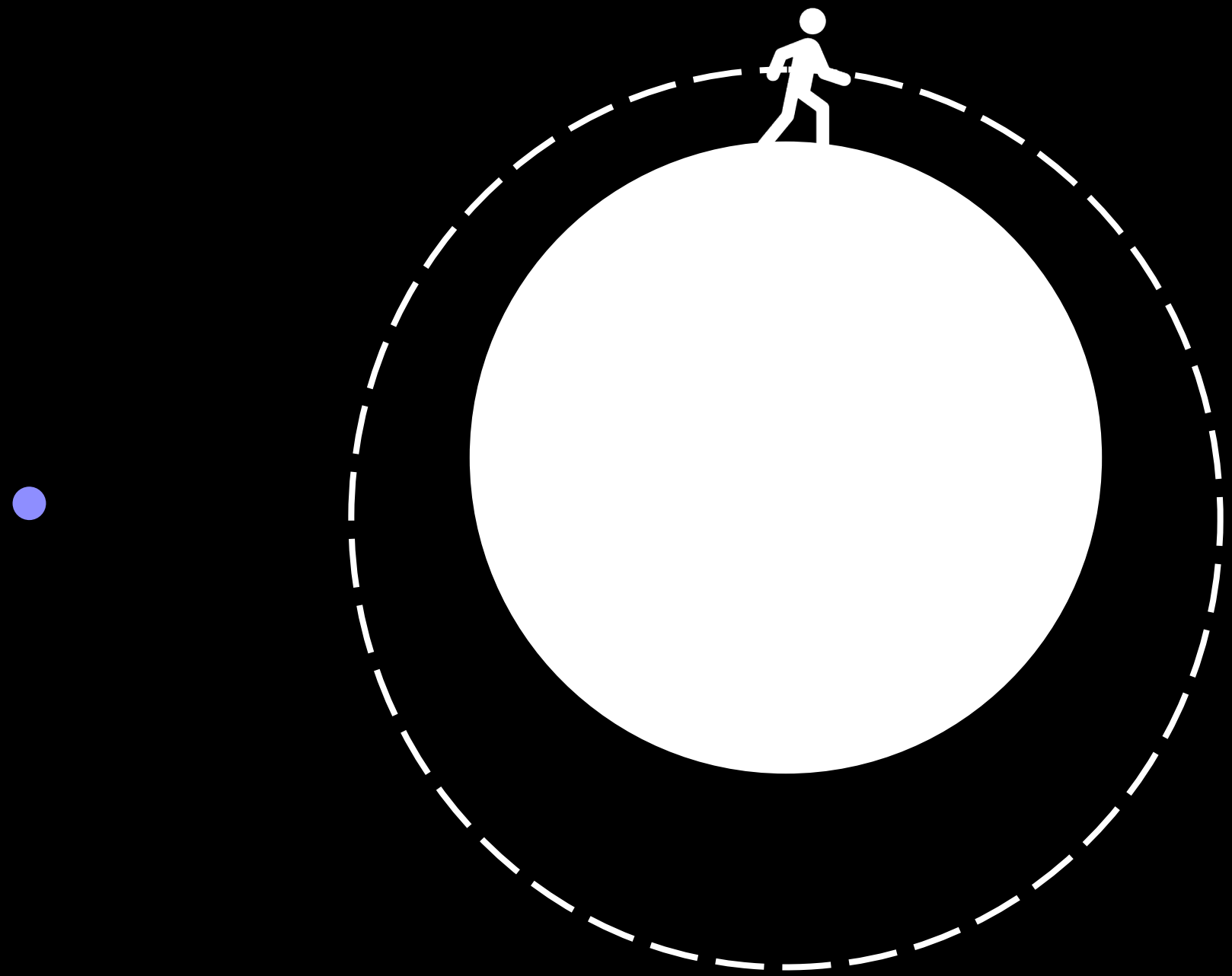










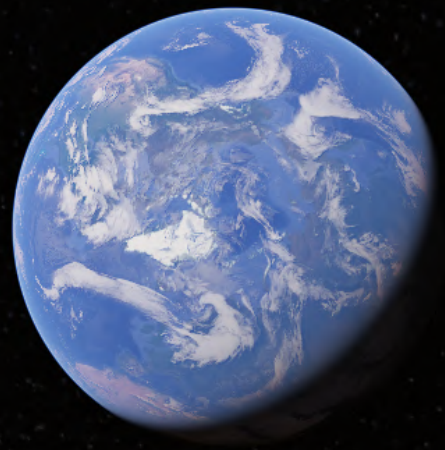


$r_E = 6370$ km
$M_E = 5.972 \times 10^{24}$ kg

$$v_o \approx \sqrt{\frac{GM}{r}}$$

Orbital Velocity

$200km \Rightarrow 7.8kms^{-1}$
$2{,}000km \Rightarrow 6.9kms^{-1}$



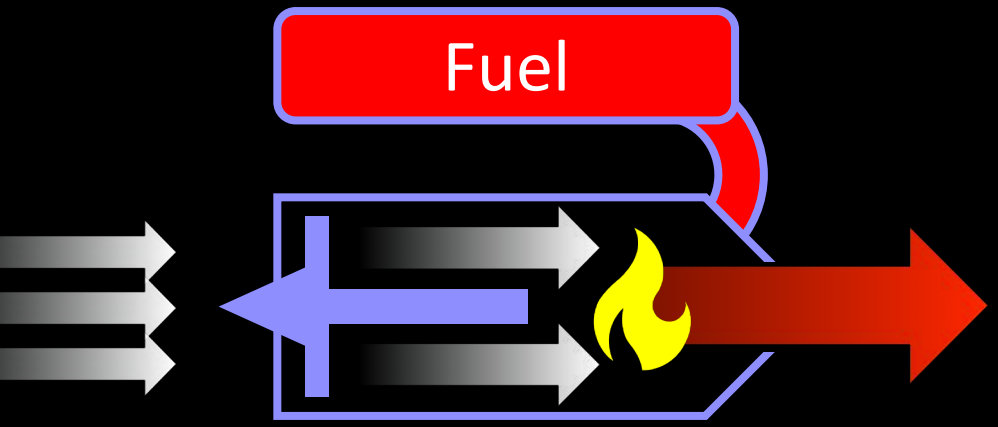
The Earth is big. *[citation needed]*

The Rocket Equation

Jets & Rockets:

“Because you can’t use a jet engine in space!”

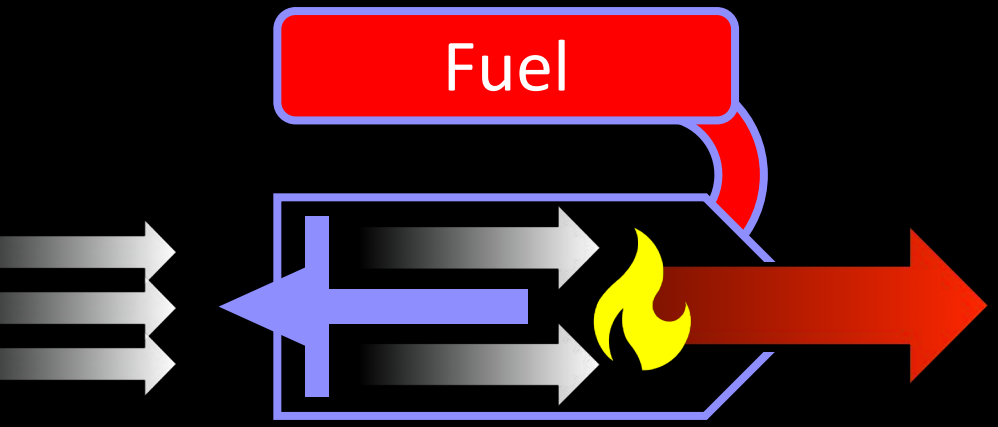
Jets & Rockets:



Air = Reaction Mass

“Because you can’t use a jet engine in space!”

Jets & Rockets:



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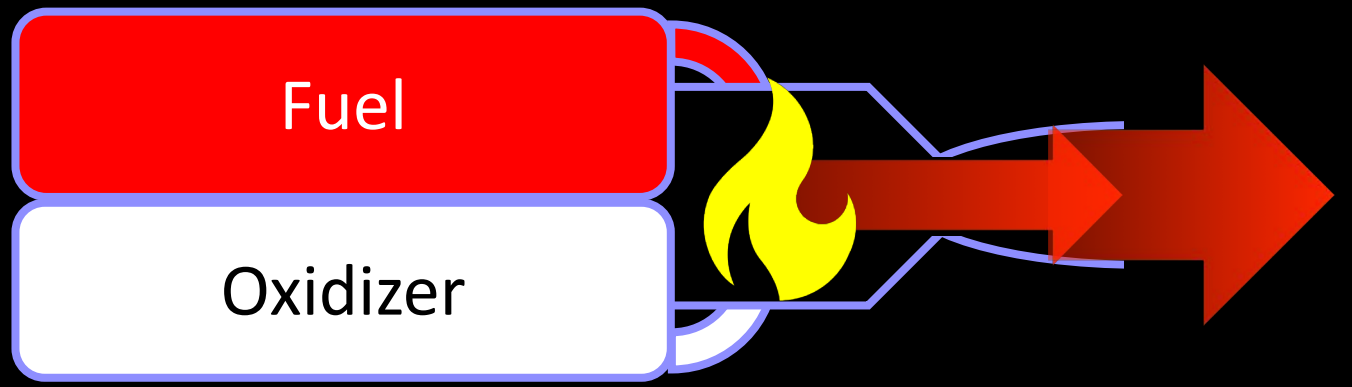
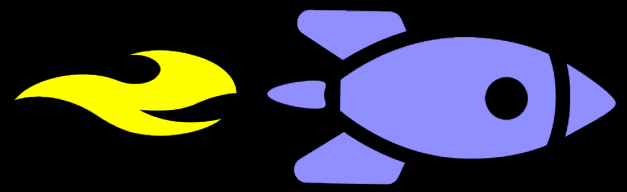


Fuel = Reaction Mass

“Because you can’t use a jet engine in space!”

Delta-v

$$\Delta v = \ln\left(\frac{M_{wet}}{M_{dry}}\right) \cdot I_{sp} \cdot 9.81 ms^{-2}$$



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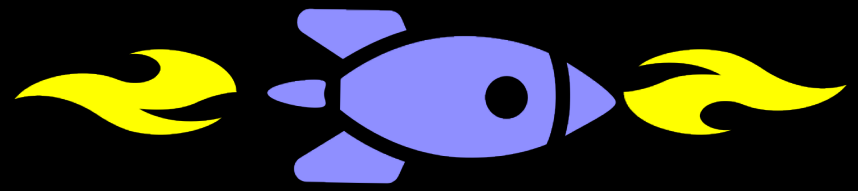
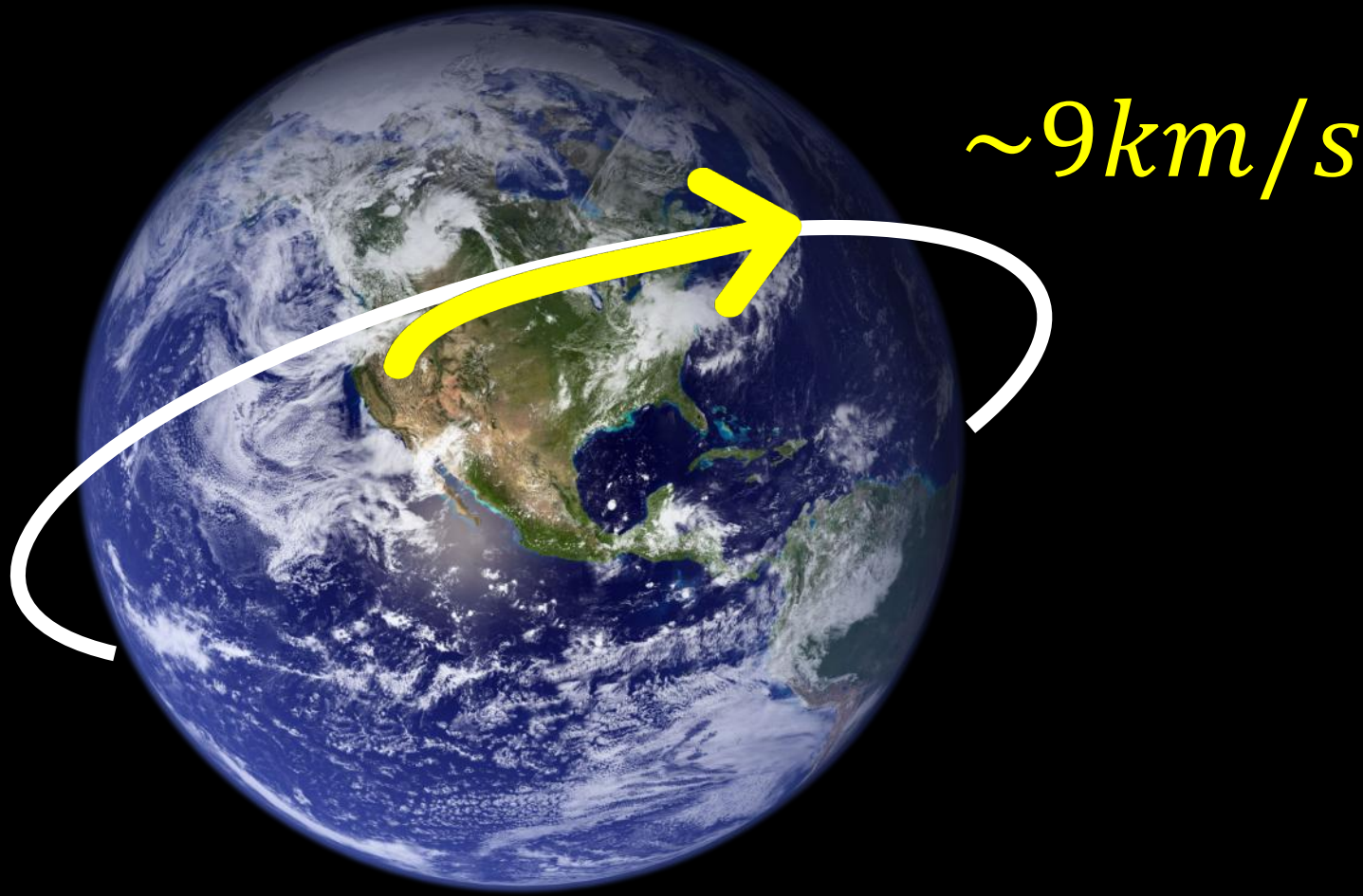
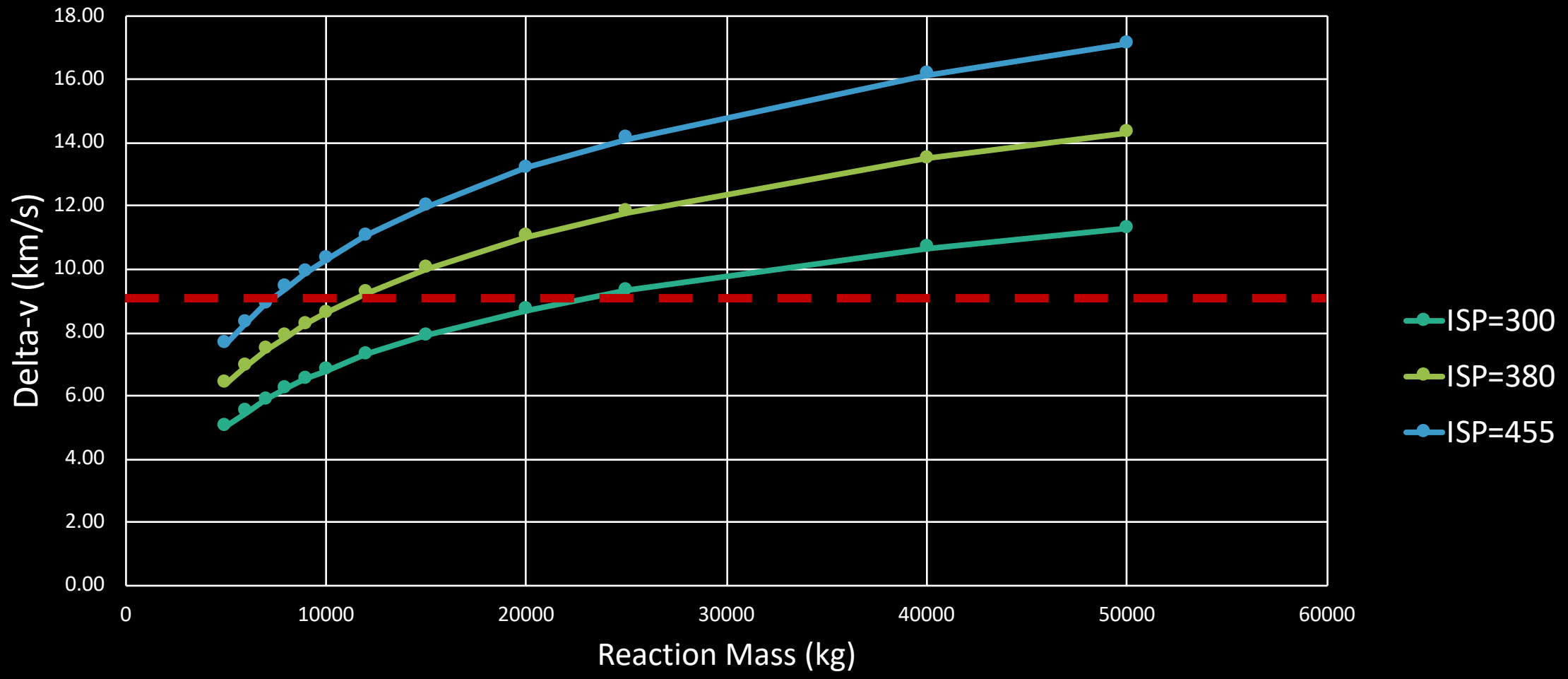


Delta-v



Rocket Performance

100 kg Payload
1 tonne Rocket
5-50 tonnes Fuel



rockets are hard

Normal Solutions

Staging

Rocket initially needs **high thrust**

- Less time with drag
- Starts heavy!

Drop used rocket hardware

- Empty fuel tanks
- Big high-thrust engines

Upper stages use **light, efficient engines**

- Can optimize to work in Vacuum
- Don’t need TWR > 1

Specific Impulse

Rocket “efficiency” mentioned earlier

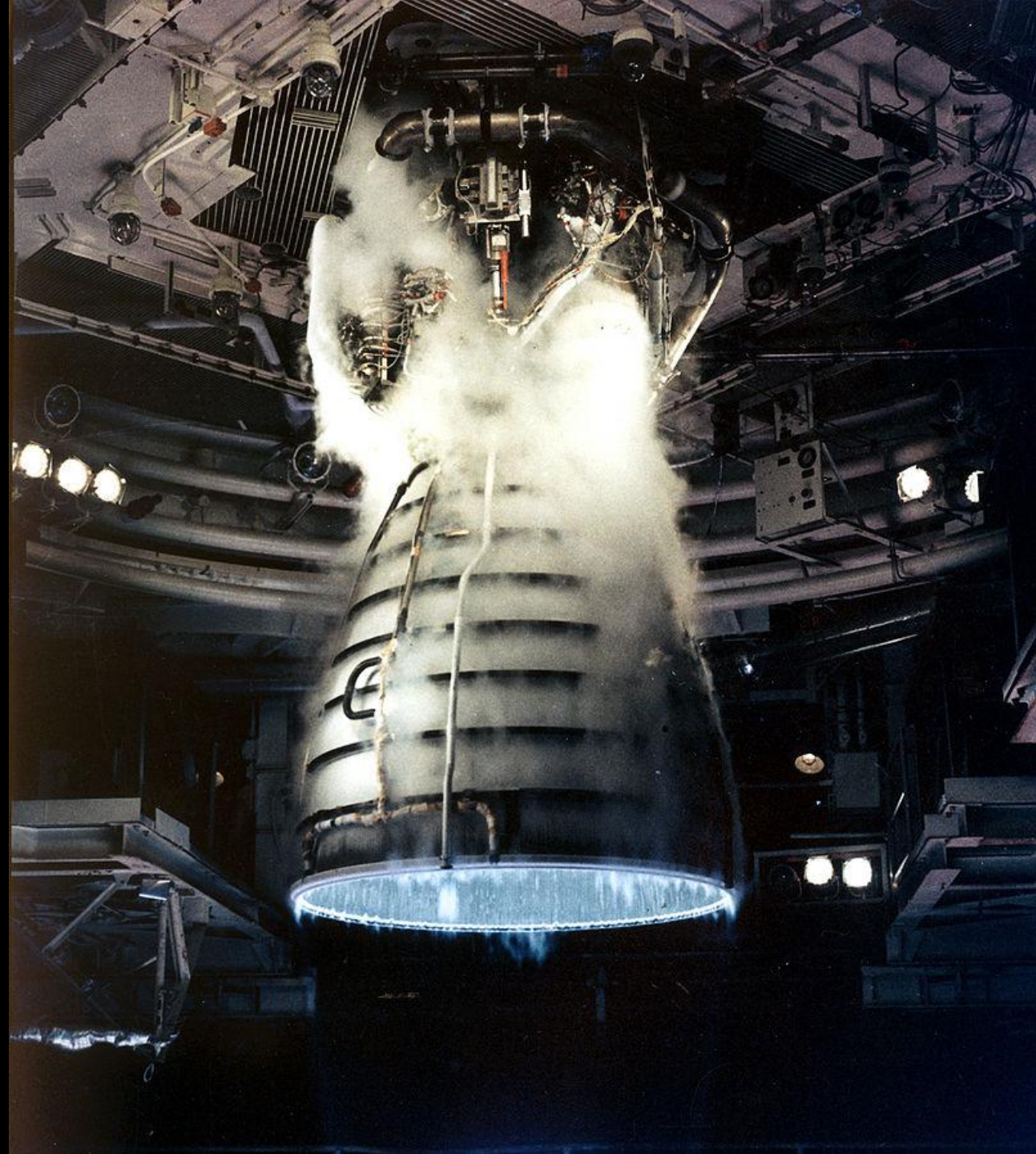
- High exhaust velocity = more Isp

Different fuels have different Isp ranges

- Lighter is better
- Hydrogen + Oxygen is the “best” chemical fuel

Nozzle shape

… engineering makes up the rest



SpaceX Solutions

Goals

High Mass-Ratio

- Ultra-lightweight engines
  - GOAT thrust-to-weight ratio – nearly 200x
- Densified propellants
  - Same fuel tank mass, more fuel
- Manufacturing techniques
  - Single-skin super-light tanks
  - Use of composites – Carbon Fibre

Partial Reusability

Partial Reusability

- Land the first stage(s)
  - 90%+ of the rocket's cost
  - Retropropulsive landing works on Mars
- Fairings? Maybe?

Partial Reusability

- Streak of 24 successful landings for Falcon 9
- Zero reuse failures

Road to Mars

Goals

Go Big or Go Home

Go Big or Go Home