

# Introduction

- We'll take you through launching a rocket and landing it on a different planet
- Obviously: this is simplified

# Technicalities

## Jargon

**Orbit** An object rotating around another object is said to be in orbit

**Inclined** An orbit that is tilted relative to the plane of the parent body

## Delta-v

- Your fuel budget
- How hard can I accelerate/decelerate my rocket
- Depends on thrust to mass ratio

# Prepare for launch!

Stage	TWR (k)	$\Delta v$ (atm)	Time
1	2.10	279 m/s	12.9 s
2	2.07	322 m/s	15.0 s
3	2.04	380 m/s	17.8 s

Total  $\Delta v$ : 981 m/s

Stage	TWR (k)	$\Delta v$ (vac)	Time
4	4	198	3155 m/s
5	---	---	---

Stage	TWR (k)	$\Delta v$ (vac)	Time
6	6	135	2523 m/s
7	---	---	---

Stage	TWR (k)	$\Delta v$ (vac)	Time
8	8	115	2191 s

## 2 x Z-400 Rechargeable Battery

Mass = 20 kg  
Capacity = 400 e

## 2 x OX-STAT Photovoltaic Panel

Mass = 5 kg  
Electricity = 0.75 e/s

## 6 x 60° Liquid Fuel Booster

2-2-2 Asparagus Staging

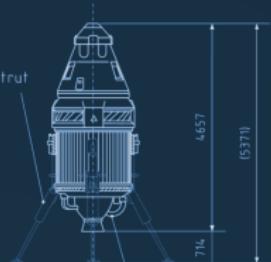
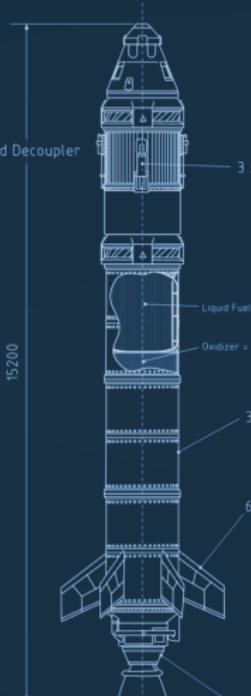
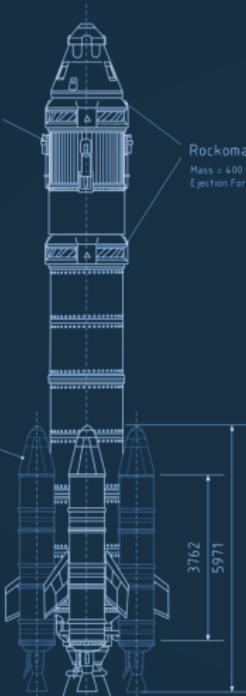
6 x NCS Adapter incl. Standard NC  
Mass = 400 kg

18 x FL-T400 Liquid Fuel Tank  
Mass = 250 kg  
Liquid Fuel = 180 L  
Oxidizer = 220 L

6 x LV-T45 Liquid Fuel Engine  
Mass = 1500 kg  
Thrust = 200 000 N  
Isp (atm) = 320 s

6 x Hydraulic Detachment Manifold  
Mass = 400 kg  
Ejection Force = 100 N

Total  $\Delta v$  (atm) = 5 404 m/s  
Total  $\Delta v$  (vac) = 6 826 m/s  
Total Mass = 131 390 kg  
Part Count = 78  
Total Cost = 64 820 ₣



Rockomax „Poodle“ Liquid Engine  
Mass = 2 500 kg  
Thrust = 220 000 N  
Isp (vac) = 390 s

Mk16-XL Parachute  
Mass = 300 kg  
Drag  
- Stowed = 0.22  
- Semi-Deployed = 1  
- Deployed = 500

Mk1-2 Command Pod  
Mass = 4 000 kg  
Required Crew = 3

# Staging



## How do we do it

- Split the rocket in different parts (stages).
- Each stage carries its own fuel and engine, and can be separated from the rocket in sequence
- For instance: booster stage, landing stage, transfer stage, ...



Mk1-2 Command Pod  
Mass = 4 000 kg  
Required Crew = 3

Rockomax „Mainsail“ Liquid Engine  
Mass = 6 000 kg  
Thrust = 1 500 000 N  
isp (atm) = 280 s  
isp (vac) = 330 s

Total  $\Delta v$  (atm) = 5 404 m/s  
Total  $\Delta v$  (vac) = 6 826 m/s  
Total Mass = 131 390 kg  
Part Count = 78  
Total Cost = 64 820 ₣

# Staging



## Why do we do it

- Rocket efficiency is inversely proportional to its weight
- Delta-v goes up as total mass decreases, so we want to carry as little mass as possible
- Throw away excess weight of unused engines and empty fuel tanks

6 x 60° Liquid Fuel Tank  
Mass = 200 kg  
Volume = 600 l  
Isp (atm) = 220 s  
Isp (vac) = 250 s

6 x 18 x 60° Liquid Fuel Tank  
Mass = 600 kg  
Volume = 1800 l  
Isp (atm) = 220 s  
Isp (vac) = 250 s

6 x 18 x 120° Liquid Fuel Tank  
Mass = 1200 kg  
Volume = 1800 l  
Isp (atm) = 220 s  
Isp (vac) = 250 s

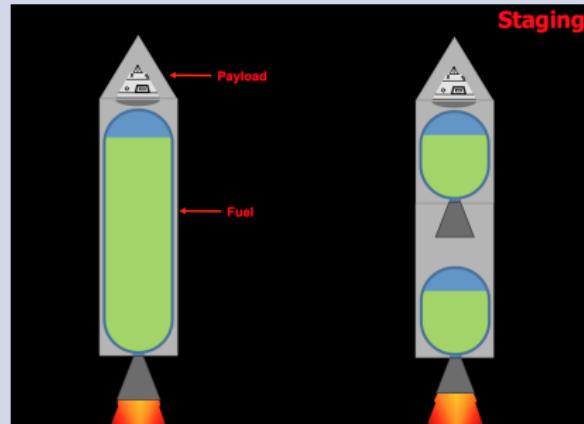
6 x Hydraulic Detachment Manifold  
Mass = 400 kg  
Ejection Force = 100 N



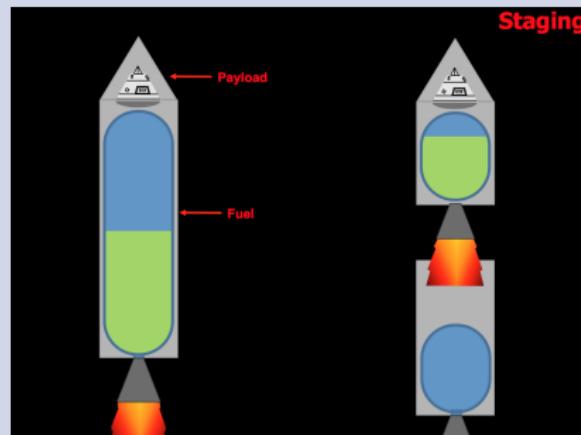
Rockomax „Mainsail“ Liquid Engine  
Mass = 6 000 kg  
Thrust = 1 500 000 N  
Isp (atm) = 280 s  
Isp (vac) = 330 s

Total Δv (atm) = 5 404 m/s  
Total Δv (vac) = 6 826 m/s  
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# Staging



# Staging

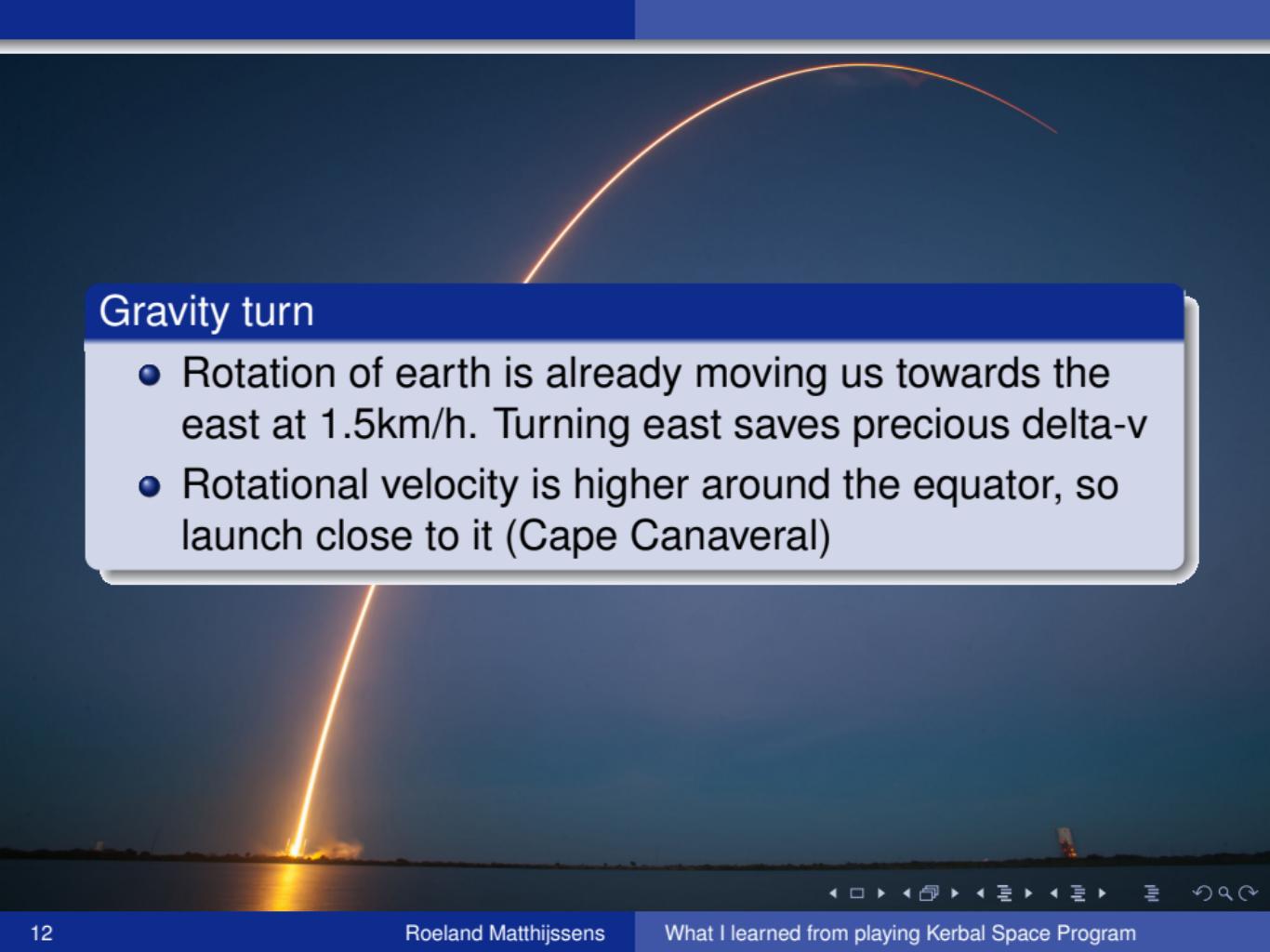




# Getting into orbit

## Why do we turn

- Going straight up gains altitude quickly
- But we would just fall down again
- To get into orbit we need to move lateral as well



## Gravity turn

- Rotation of earth is already moving us towards the east at 1.5km/h. Turning east saves precious delta-v
- Rotational velocity is higher around the equator, so launch close to it (Cape Canaveral)

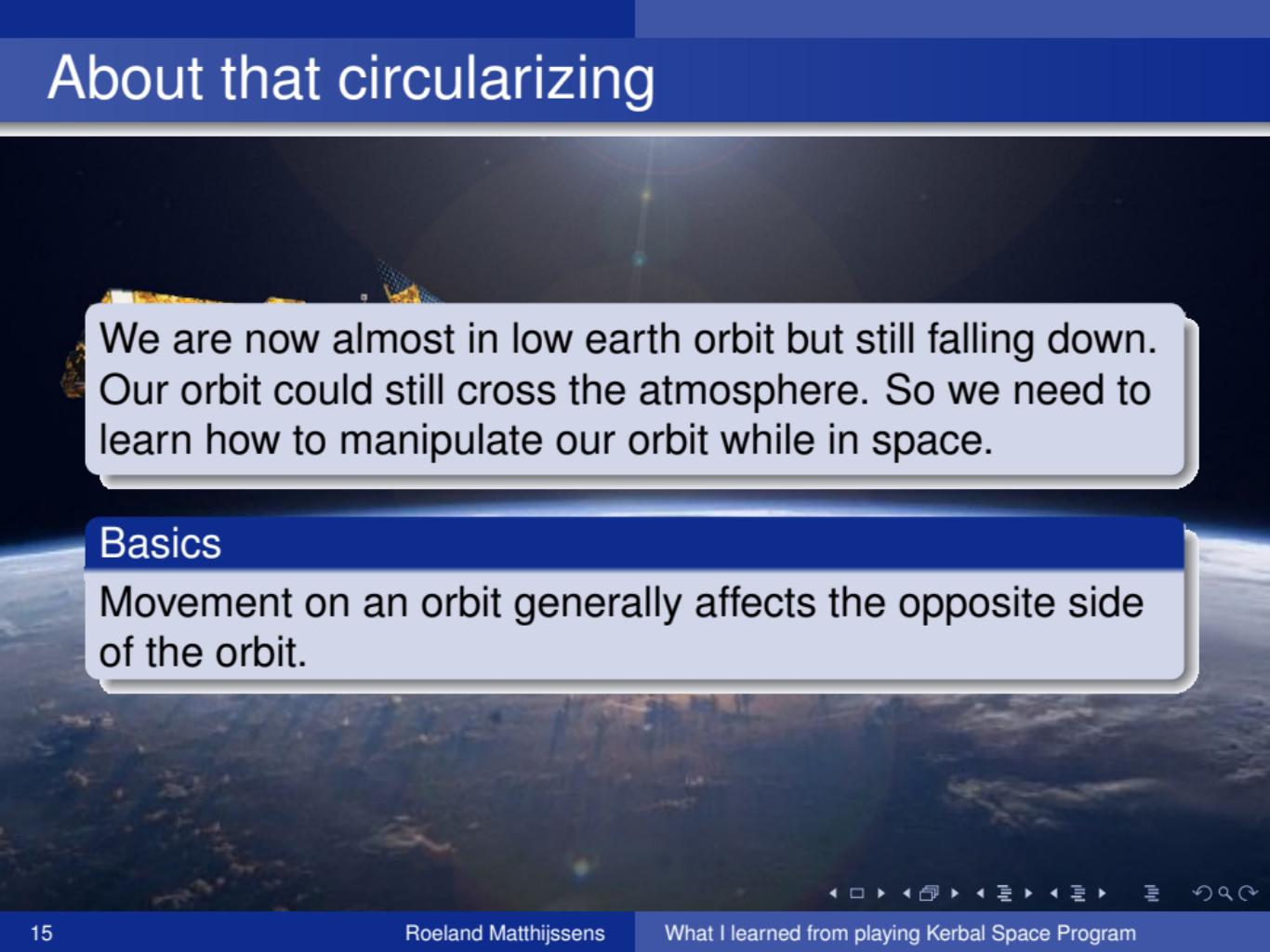
# Let's Launch

## How do we do it

- Point eastward (about 5 degrees)
- Fire rocket
- Don't. Touch. Anything. Let gravity do the work
- Activate staging at the appropriate times
- Circularize orbit
- It's easy, it's not ro... oh...



# About that circularizing



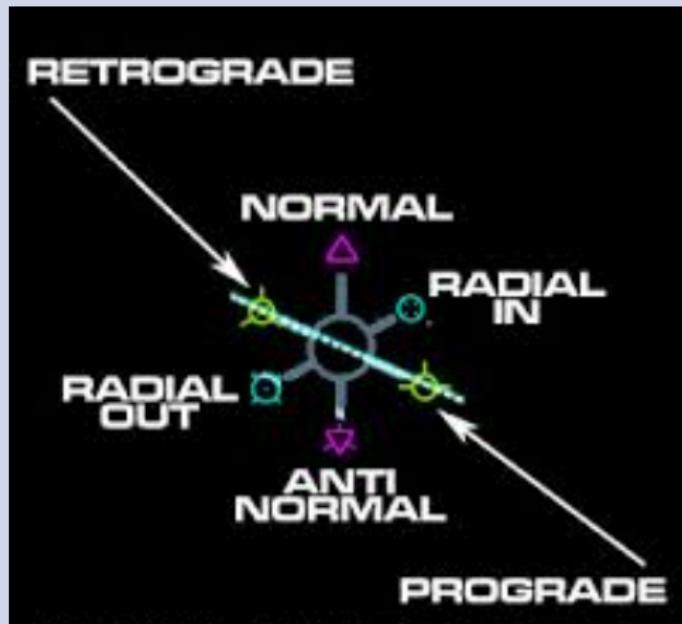
We are now almost in low earth orbit but still falling down. Our orbit could still cross the atmosphere. So we need to learn how to manipulate our orbit while in space.

## Basics

Movement on an orbit generally affects the opposite side of the orbit.

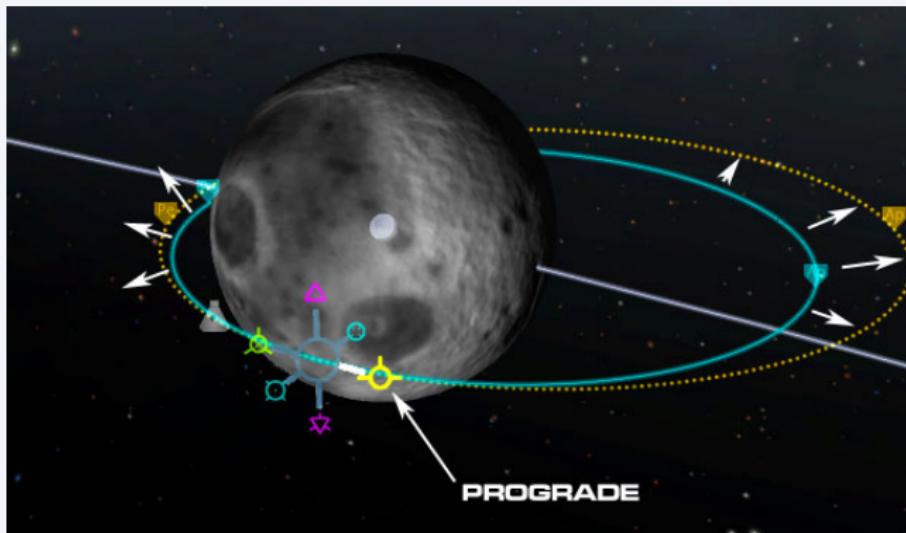
# Adjusting orbits

At any point on the orbit you can burn in 3 directions:  
up/down, left/right, forwards/backwards



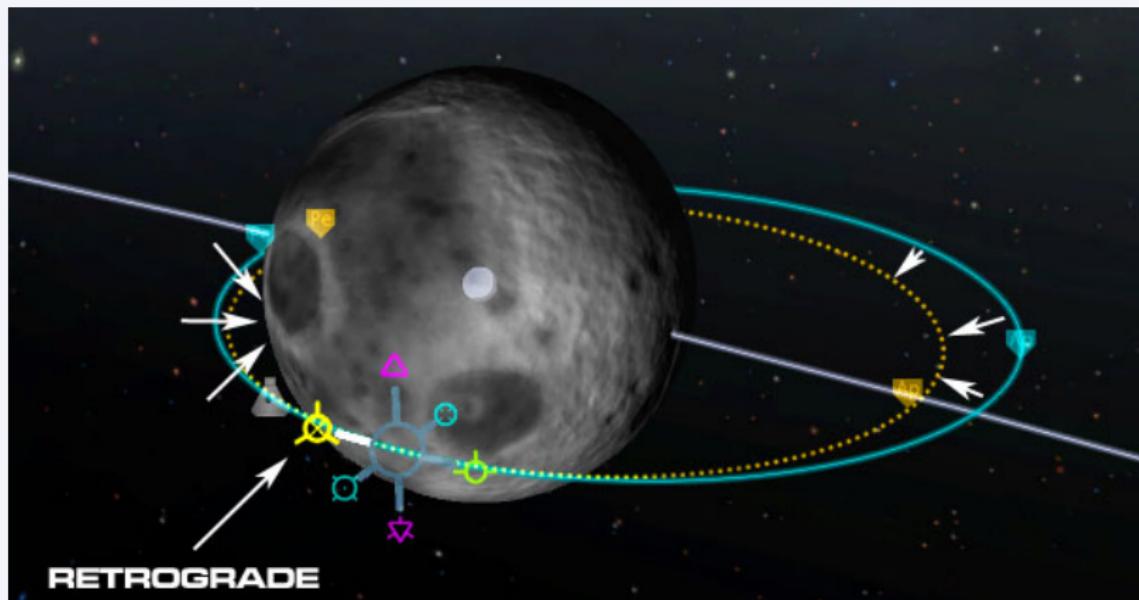
# Prograde

Burning in the prograde direction expands the size of the orbit, with the center of expansion at the current position.



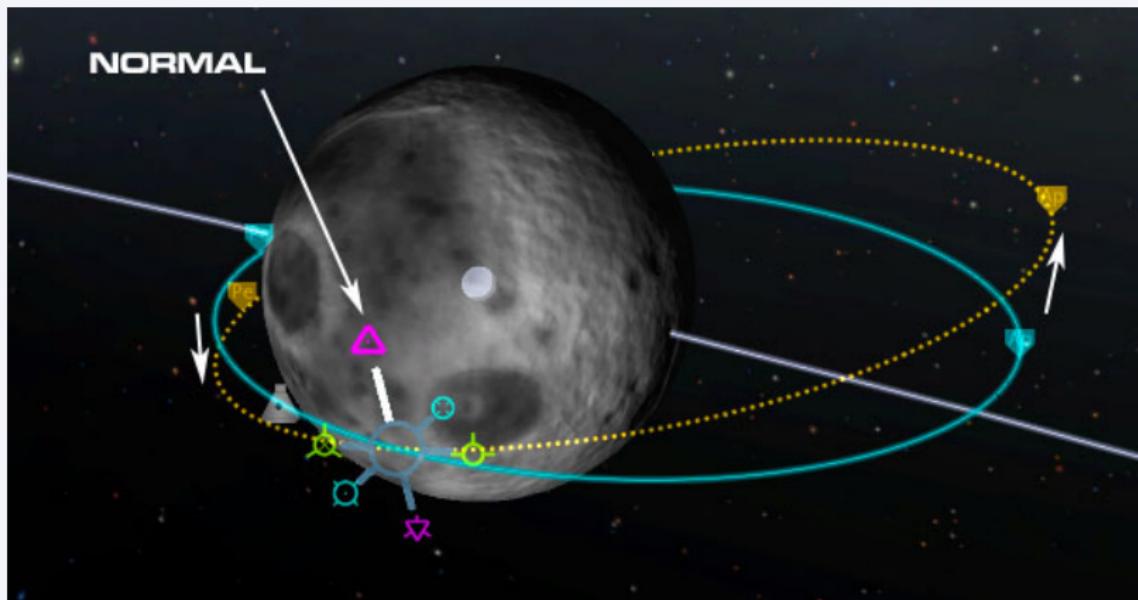
# Retrograde

Burning in the retrograde direction contracts the size of the orbit, with the center of contraction at the current position.



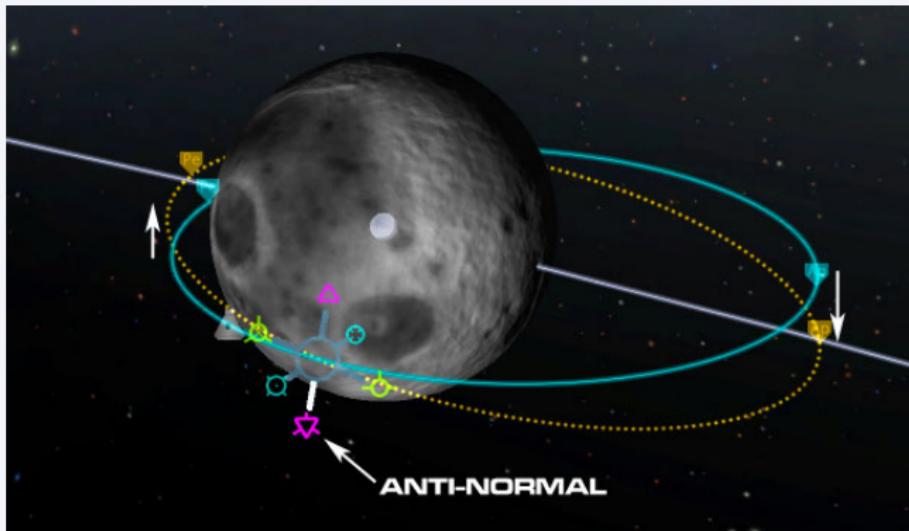
## Normal

Burning in the normal direction tilts the orbital plane counterclockwise on the axis determined by the current position and the planet's center.



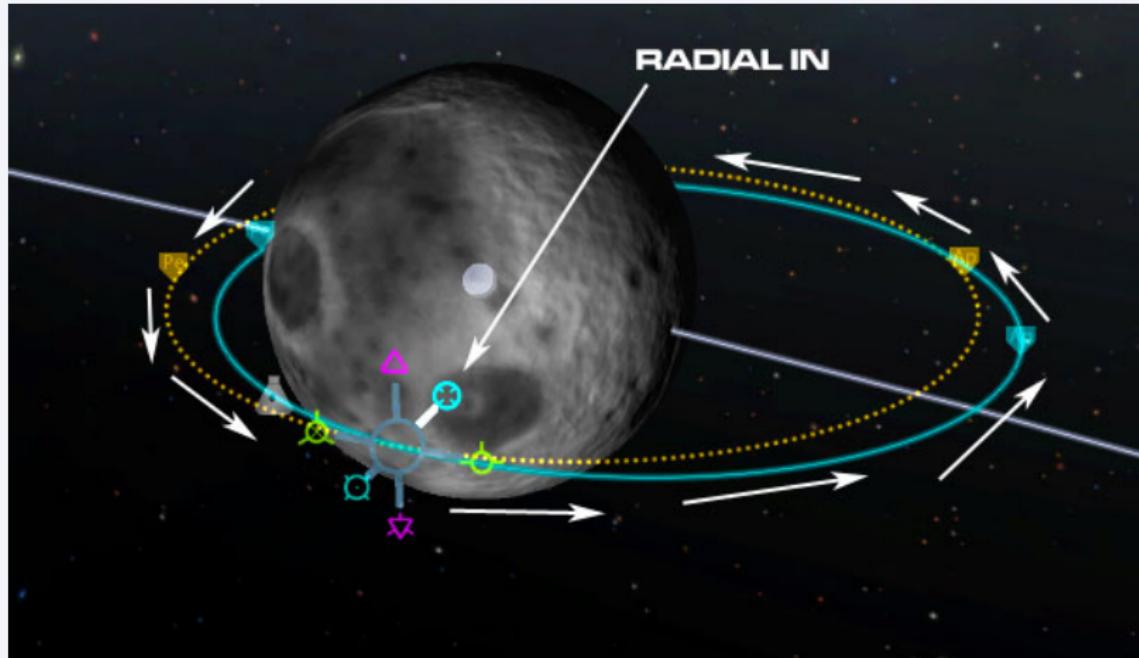
# Anti-normal

Burning in the anti-normal direction tilts the orbital plane clockwise on the axis determined by the current position and the planet's center.



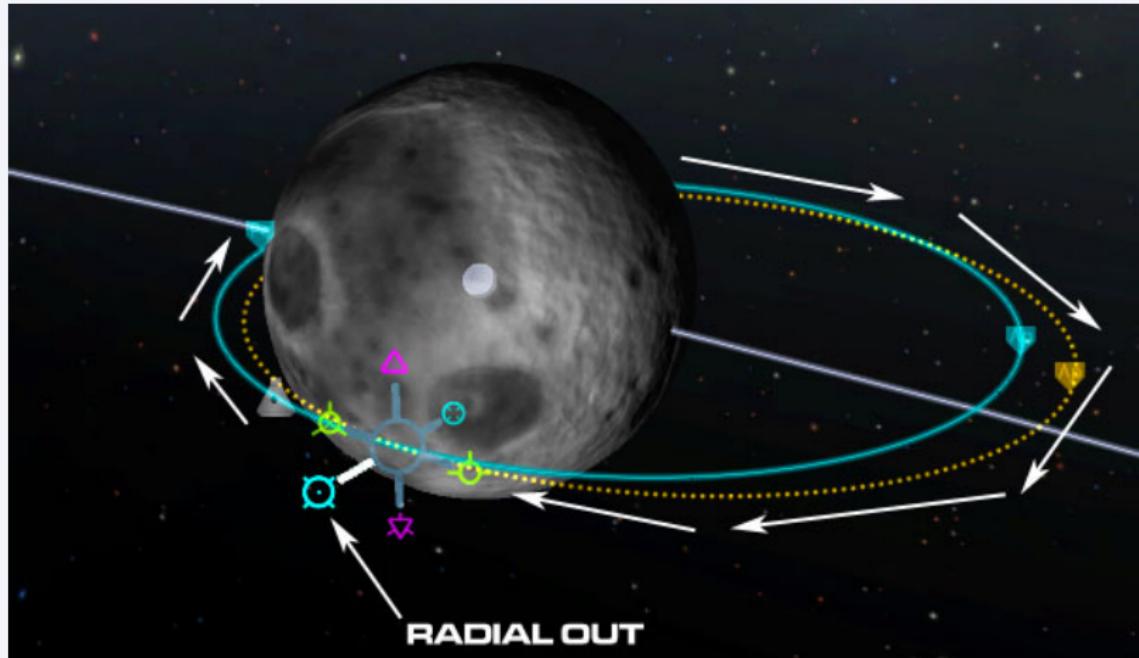
# Radial in

Burning in the radial-in direction rotates the orbital plane counterclockwise.



# Radial out

Burning in the radial-out direction rotates the orbital plane clockwise.



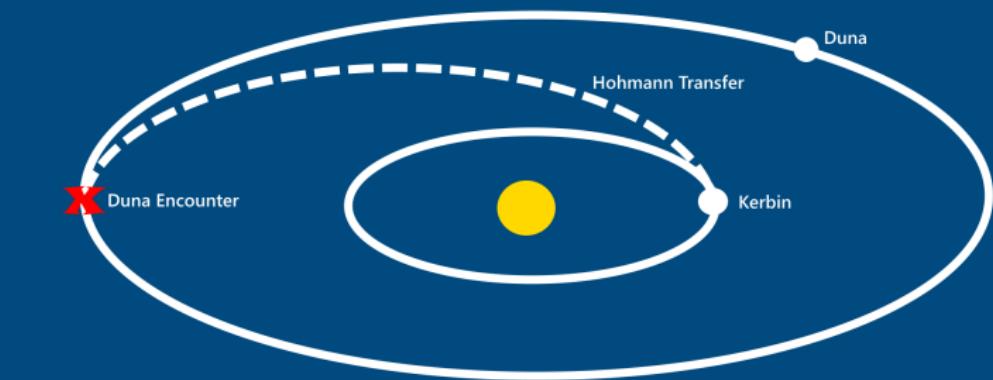
# Planning transfer

We finally achieved a stable low earth orbit. We need to plan our transfer to our target body



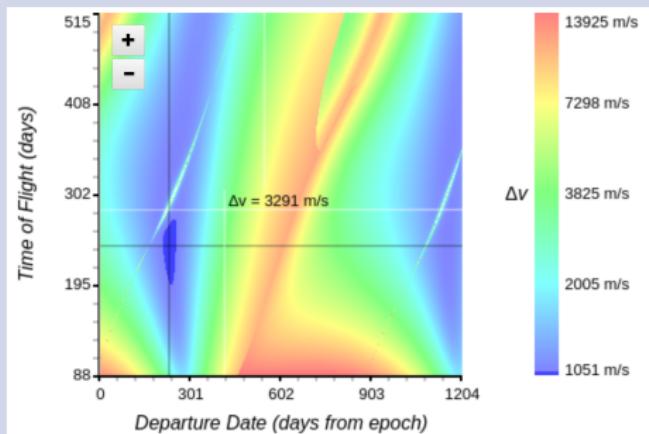
# Hohmann transfer

Now that we know our target and know the delta-v required to get there we need to plan the encounter



# Hohmann transfer window

To be able to transfer with the least amount of delta-v possible, we need to launch when the target body is at an optimal position. If we are on a strict delta-v budget we need to wait for a good window



# Oberth effect

$$V = V_0 + at$$

$$X = X_0 + V_0 t + at^2/2$$

$$V^2 - V_0^2 = 2a(X - X_0)$$

$$\bar{V} = \frac{V_f + V_i}{2}$$

$$\Delta X = \bar{V} \Delta t$$

~~$$\vec{F}_{\text{tot}} = m \vec{a}$$~~

$$W = F d_{\parallel} = F_I d$$

$$W_{\text{tot}} = \Delta(\text{KE})$$

$$\Delta U = -W_{\text{if}}$$

$$\frac{1}{2} kx^2$$

$$\omega = \sqrt{\frac{k}{m}}$$

$$p = m v$$

$$\vec{P}_{\text{init}} = \vec{P}_{\text{final}}$$

$$\left( \sum_i m_i \vec{v}_j \right) = \left( \sum_i m_i \vec{v}_j \right)$$

$$v_x = v \cos(\theta)$$

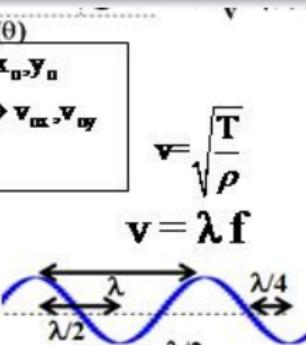
$$x \rightarrow x, y \quad x_0 \rightarrow x_0, y_0$$

$$v \rightarrow v_x, v_y \quad v_0 \rightarrow v_{0x}, v_{0y}$$

$$a \rightarrow a_x, a_y$$

$$\mu N$$

$$a = \frac{v^2}{R}$$



$$V = \omega r$$

$$a = \alpha r$$

$$\omega = \omega_0 + \alpha t$$

$$I = \sum_i m_i r_i^2$$

$$\theta = \theta_0 + \omega_0 t + \frac{1}{2} \alpha t^2$$

$$\omega^2 - \omega_0^2 = 2\alpha(\theta - \theta_0)$$

$$L = r_{\perp} p = m v r_{\perp}$$

$$L = I \omega$$

$$\tau = \frac{\Delta L}{\Delta t}$$

$$\tau = I \alpha$$

$$\frac{1}{2} I \omega^2$$

$$\sum_i \vec{F}_i = 0$$

$$\sum_i \vec{\tau}_i = 0$$

$$E = K + U$$

$$E_i = E_f$$

$$\frac{1}{2} m v^2$$

$$x = A \cos(\omega t) = \{ \text{or} \} A \sin(\omega t)$$

$$v = A \omega \sin(\omega t) = \{ \text{or} \} A \omega \cos(\omega t)$$

$$a = A \omega^2 \cos(\omega t) = \{ \text{or} \} -A \omega^2 \sin(\omega t)$$

$$\Delta Q = (\text{quant.}) C_{\text{cond.}} \Delta T$$

$$\Delta Q_{\text{intro}} = \Delta W_{\text{by}} + \Delta E$$

$$\frac{RT}{2} \mid_{\text{deg freedom}}$$

$$C_p = C_v + R$$

$$\Delta S \geq 0$$

$$\Delta Q = 1 \Delta (\text{quant.})$$

$$e = \frac{\Delta W}{\Delta Q}$$

$$PV = nRT$$

$$e = 1 - \frac{T_L}{T_H}$$

$$P = \frac{F}{A}$$

$$M = \rho V$$

$$P_1 = P_2$$

$$\Delta P = \rho g \Delta h$$

$$B = \rho_{\text{liqu}} V_{\text{disp}} g$$

$$A_1 v_1 = A_2 v_2$$

$$p + \frac{1}{2} \rho v^2 = \text{const}$$

$$\frac{GM_e}{R_e} = g R_e$$

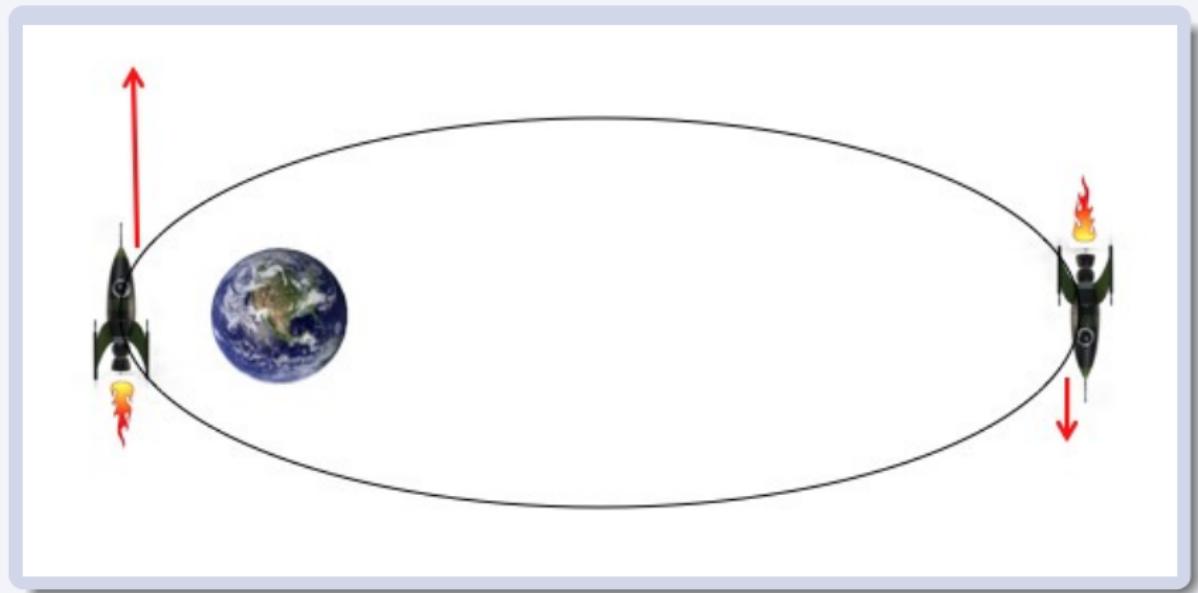
$$\frac{GMm}{r^2}$$

$$\frac{GMm}{r}$$

$$M_e = 5.97(10)^{24} \text{ Kg}$$

$$R_e = 6.37(10)^6 \text{ m}$$

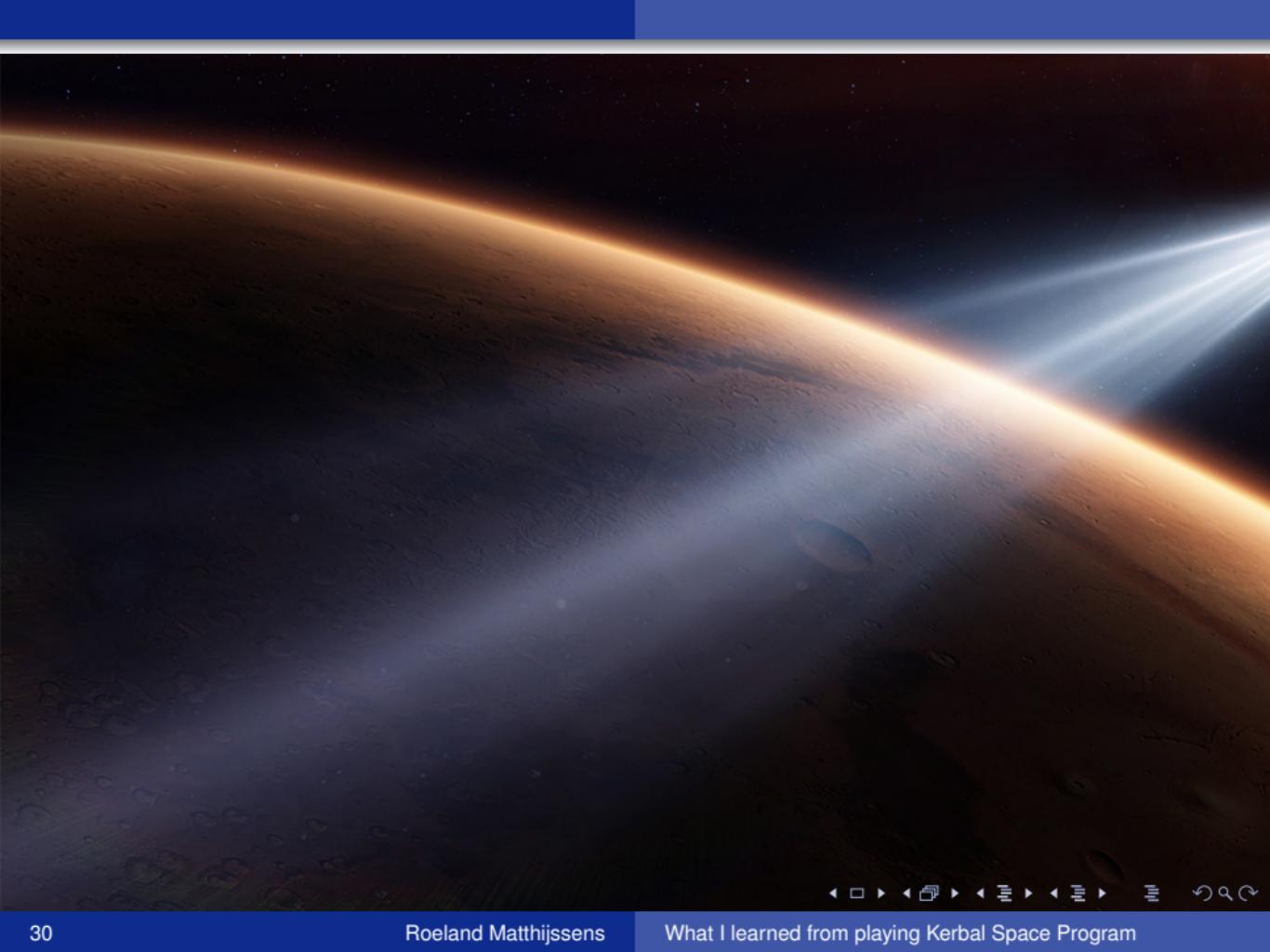
# jk, Oberth effect



# Escape

Now that we can make optimal use of the Oberth effect we can begin our escape burn and start our transfer orbit

- Decelerate to drop orbit deeper into the gravity well
  - Wait for lowest point of orbit (to make maximal use of Oberth effect)
  - Make transfer burn and coast to encounter



# Sphere Of Influence

Sphere Of Influence(SOI) is the region around a planet in which the gravitational pull from the planet is bigger than any other body's gravitational pull. Which planet/body has the most gravitational influence on you

- We are in the SOI of the sun
- The moon is also influenced by the gravity of the sun
- but it is close enough to earth so that our gravitational influence is higher than the sun's
- therefore we say that the moon is within the SOI of earth

# Intercept

When we are within the gravitational sphere of influence of the target planet we need to slow down to be captured by the planet.

- Burn retrograde to slow down
- Keep slowing down until you fall into a highly elliptical orbit
- keep dropping periapsis to desired height
- wait for periapsis and then circularize orbit

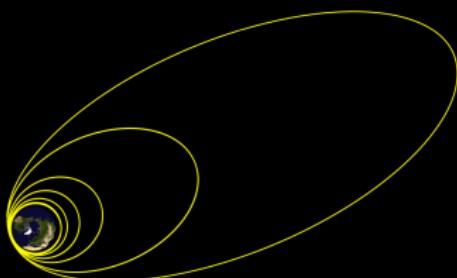
# Intercept

## Aerobreaking

Instead of having to circularize your orbit (which takes a fair amount of delta-v) we can make use of the body's atmosphere to slow down to do this you need to

- drop periapsis just inside of the atmosphere
- not too deep because you can burn up
- not too shallow because slowing down would take a very long time
- just wait a couple of orbits
- the apoapsis should drop on every orbit because atmospheric drag slows you down while at periapsis

# Aerobraking

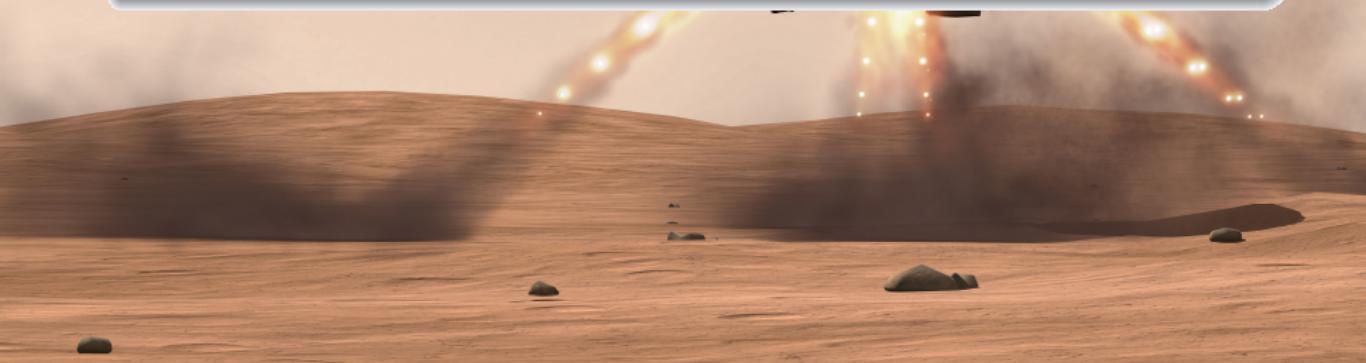




# Landing

## Entering atmosphere

- determine entry angle
- not to steep => too much atmospheric drag => burning up
- not to shallow => won't slow down quickly enough => skipping out of atmosphere



# Landing

## Suicide Burn

We need to slow down our descent before we hit the ground. At the last possible second we fire all engines at 100% throttle.

## Why?

- Gravity is an accelerating force adding  $\alpha m/s^2$
- Every second spent decelerating needs to be compensated for gravity
- Slowing down means burning an additional  $\alpha$  delta-v every second
- Slowing down quickly saves fuel.

