KU LEUVEN

TU Delft
Delft University of Technology

Space: to boldly go and see what happens (or maybe rather not)

Absolventská GJH prednáška

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Krátky úvod

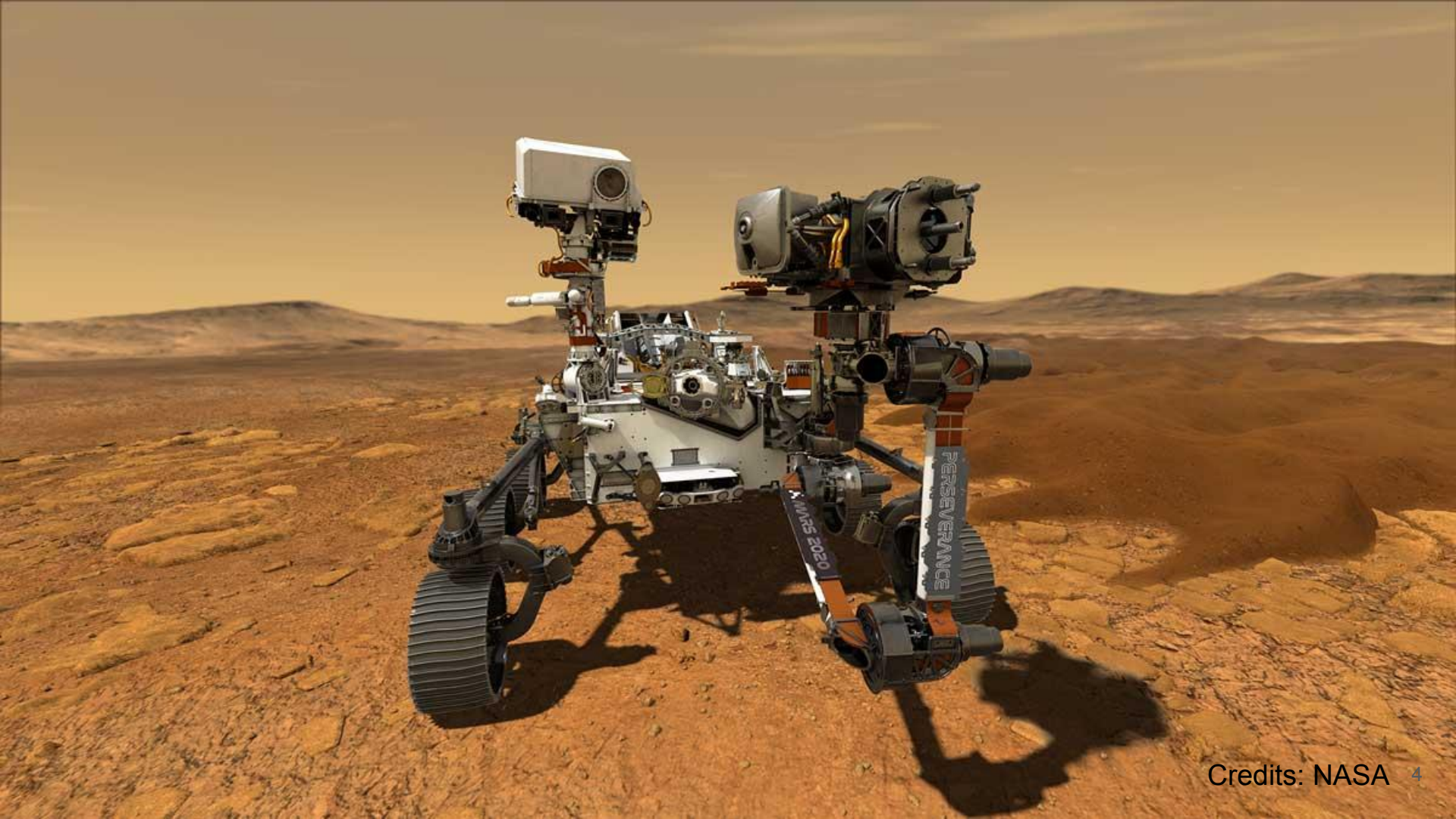
- do 2013 : basketballový gympel na Hubeného 23

- 2013 - 2015: IB GJH

- 2015 - 2020: TU Delft
  - BSc, MSc aerospace
  - 2015-2017: DARE
  - 2017: ESA, Noordwijk
  - 2019: DLR, Goettingen

- 2020 - 2024: KU Leuven
  - PhD plasma mathematics

Čo treba k úspešnej vesmírnej misii?



Credits: NASA

Čo treba k úspešnej vesmírnej misii?

1. Vyletieť
2. Preletieť
3. Doletieť
4. Prežiť

Čo treba k úspešnej vesmírnej misii?

1. **Vyletieť**
2. Preletieť
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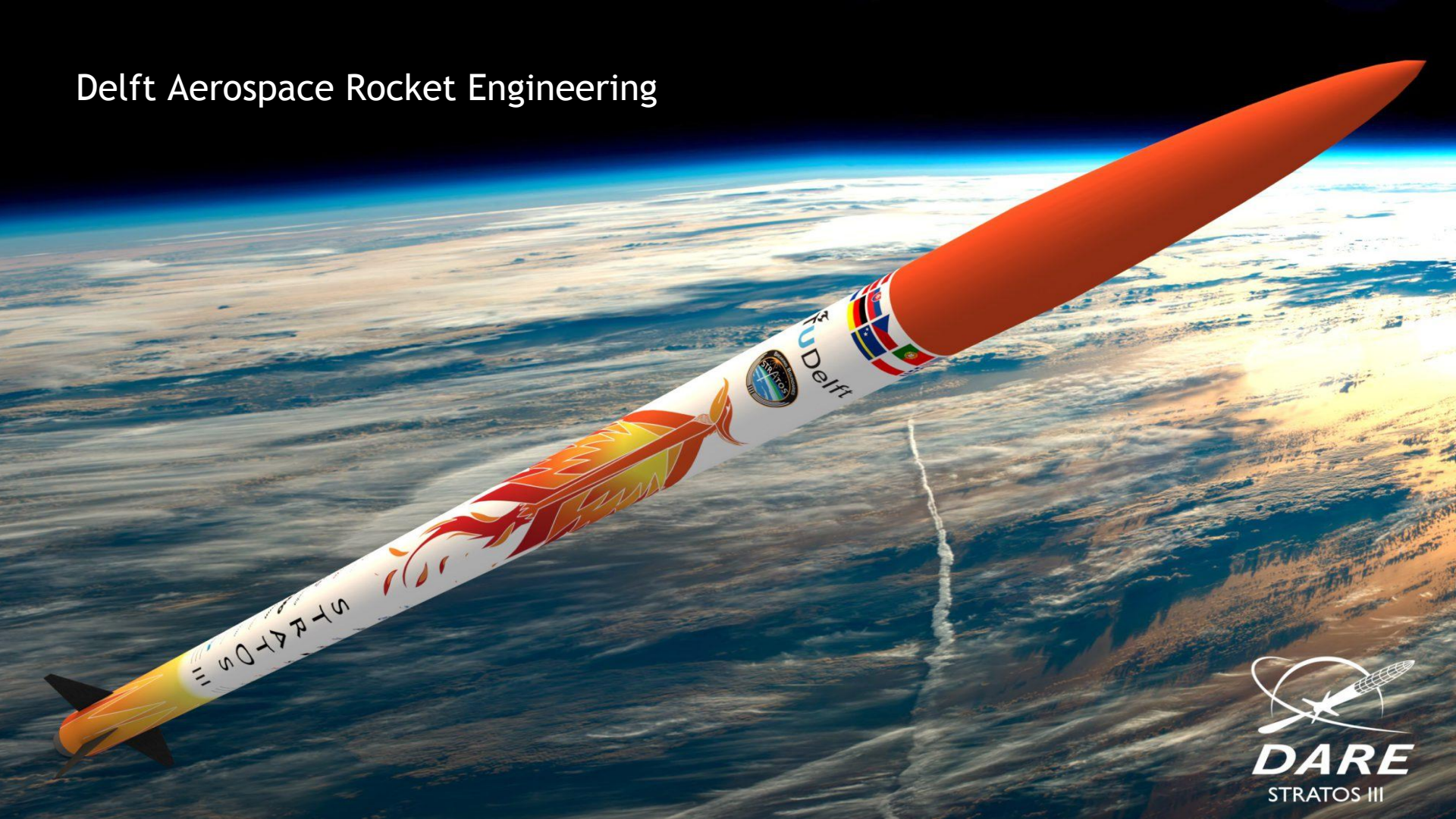
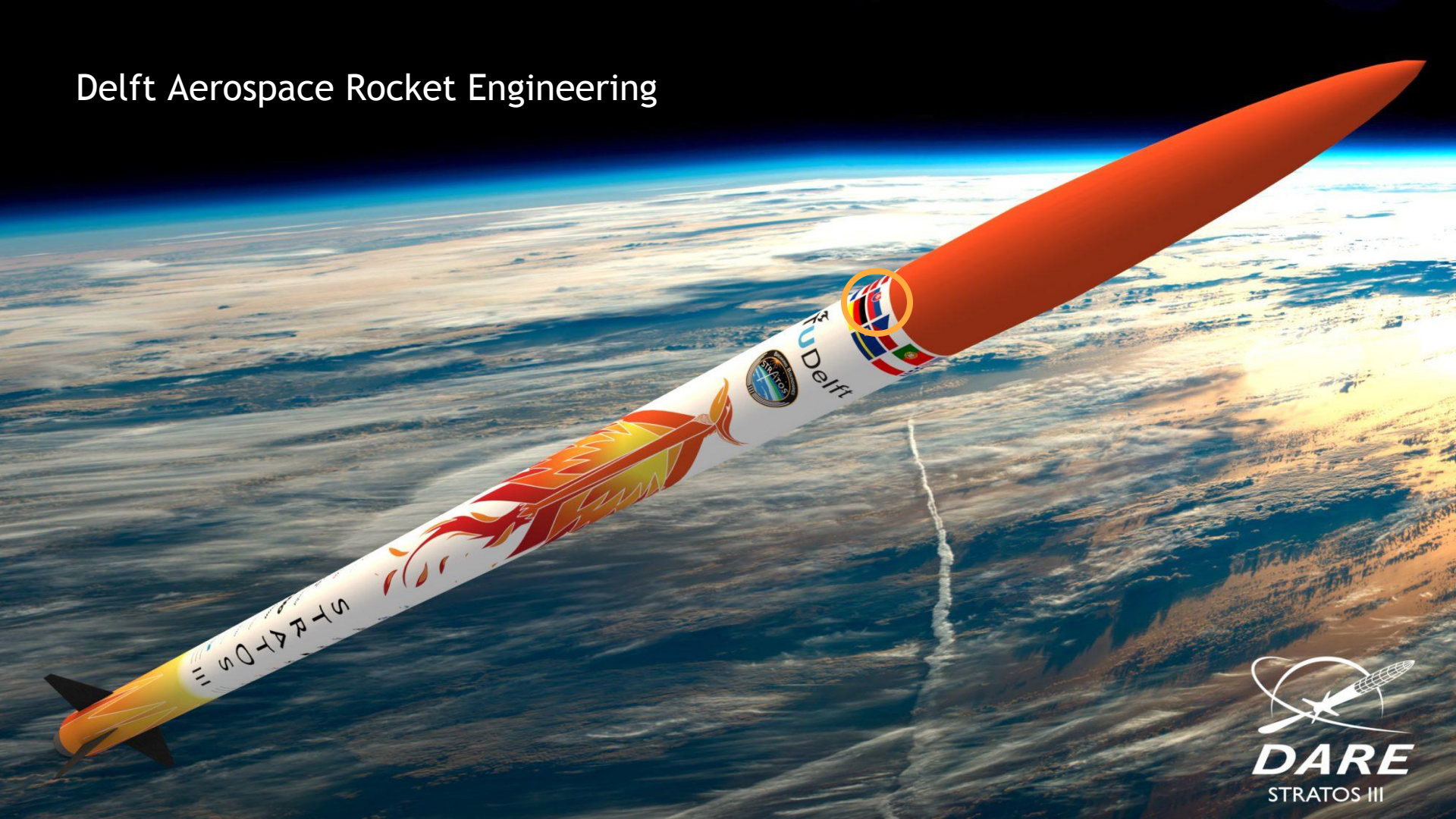
Delft Aerospace Rocket Engineering

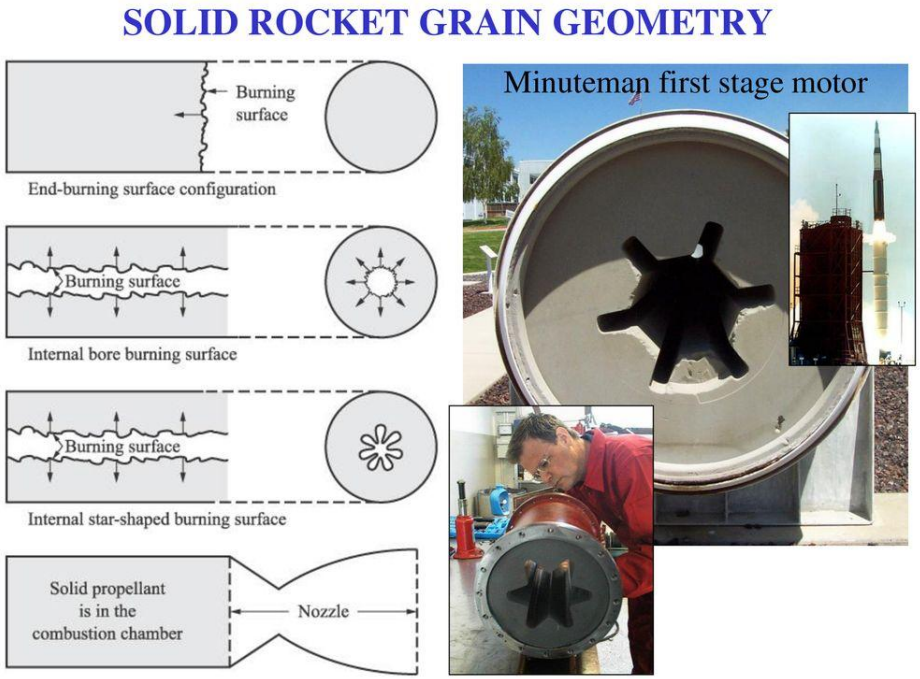


Delft Aerospace Rocket Engineering

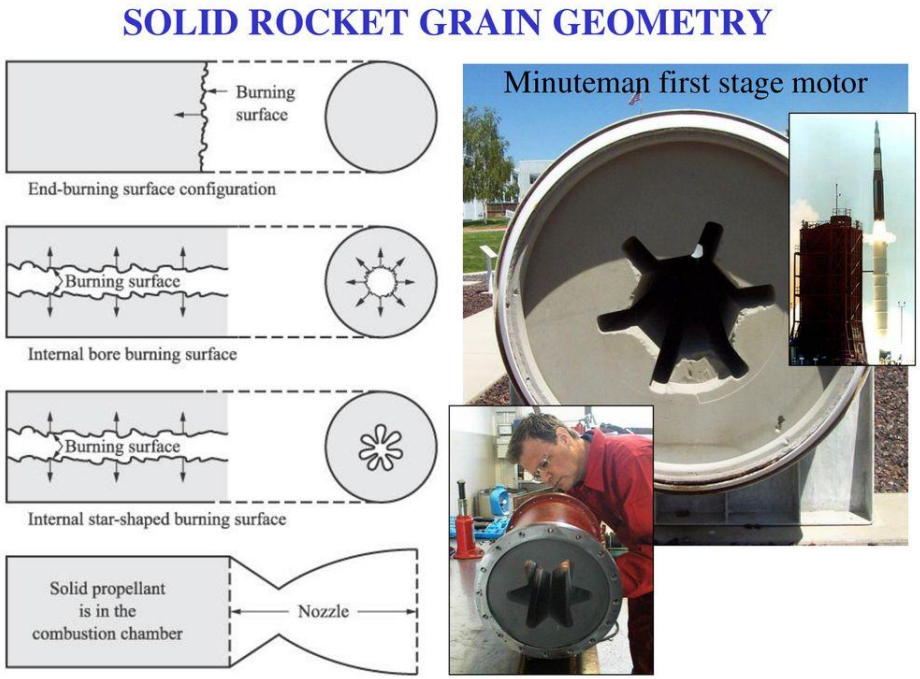


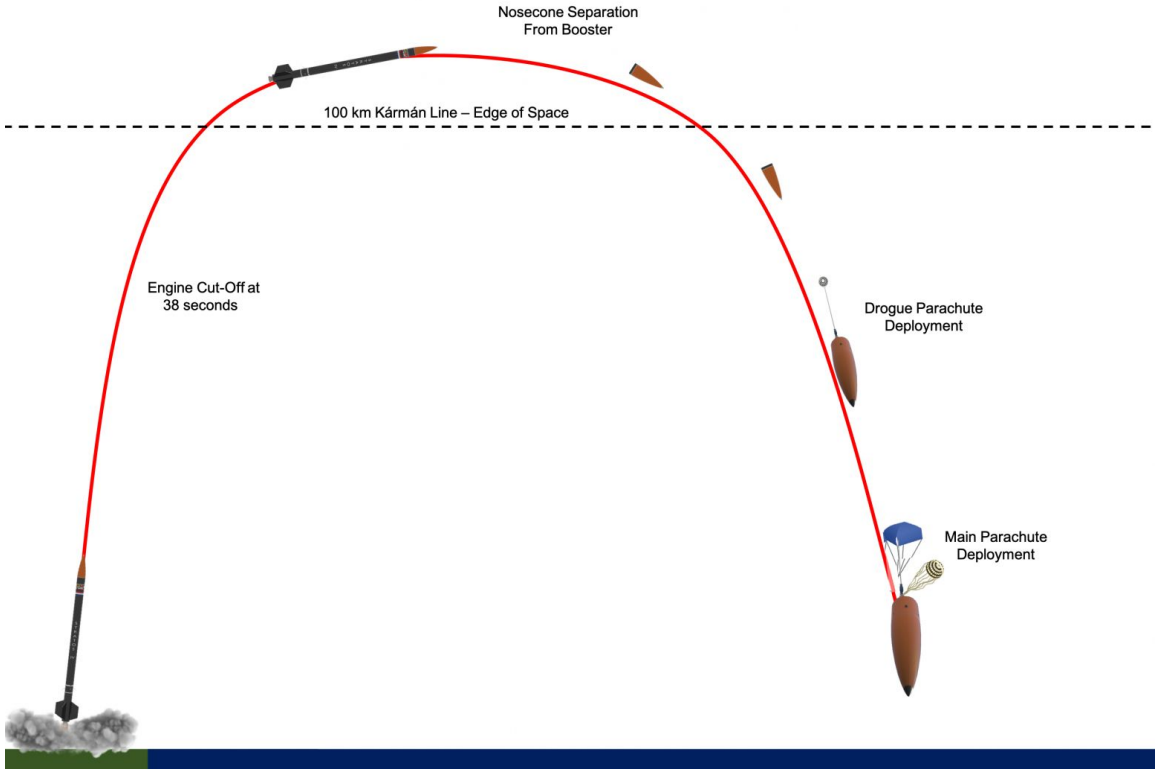
LIBRATUS PER MODERATIONEM
ADVANCED CONTROL
DARE
ELECTRONICS
CAPSULE TEAM
SUCCESSUS ACET IN FORTYITUDINE
SOLID SIX
PER VERAS
S 6
IGNIS AD ASTRA
SIC ITUR AD ASTRA
PROJECT AETHER

Raketa?


SOLID ROCKET GRAIN GEOMETRY
Burning surface
End-burning surface configuration
Burning surface
Internal bore burning surface
Burning surface
Internal star-shaped burning surface
Solid propellant is in the combustion chamber
Nozzle
Minuteman first stage motor

Alebo drahý ohňostroj?




Nosecone Separation
From Booster
100 km Kármán Line – Edge of Space
Engine Cut-Off at
38 seconds
Drogue Parachute
Deployment
Main Parachute
Deployment

Čo treba k úspešnej vesmírnej misii?

1. Vyletieť
2. **Preletieť**
3. Doletieť
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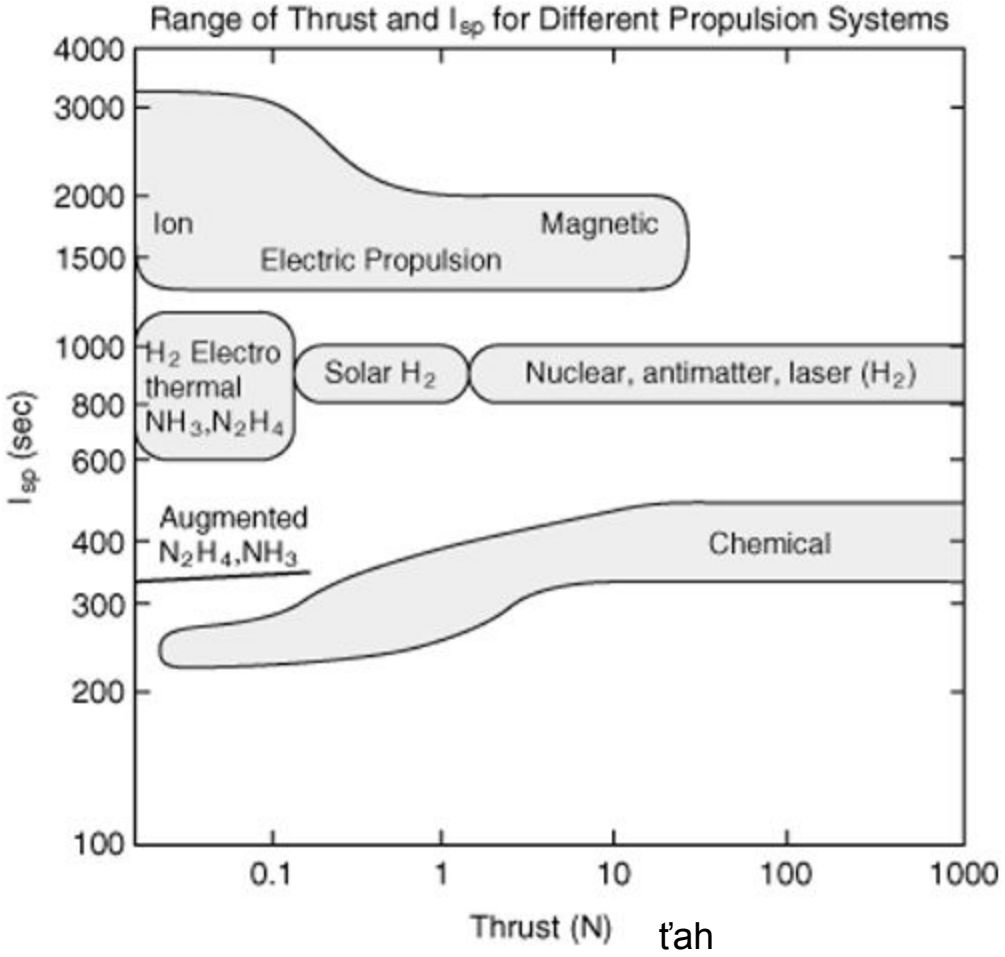
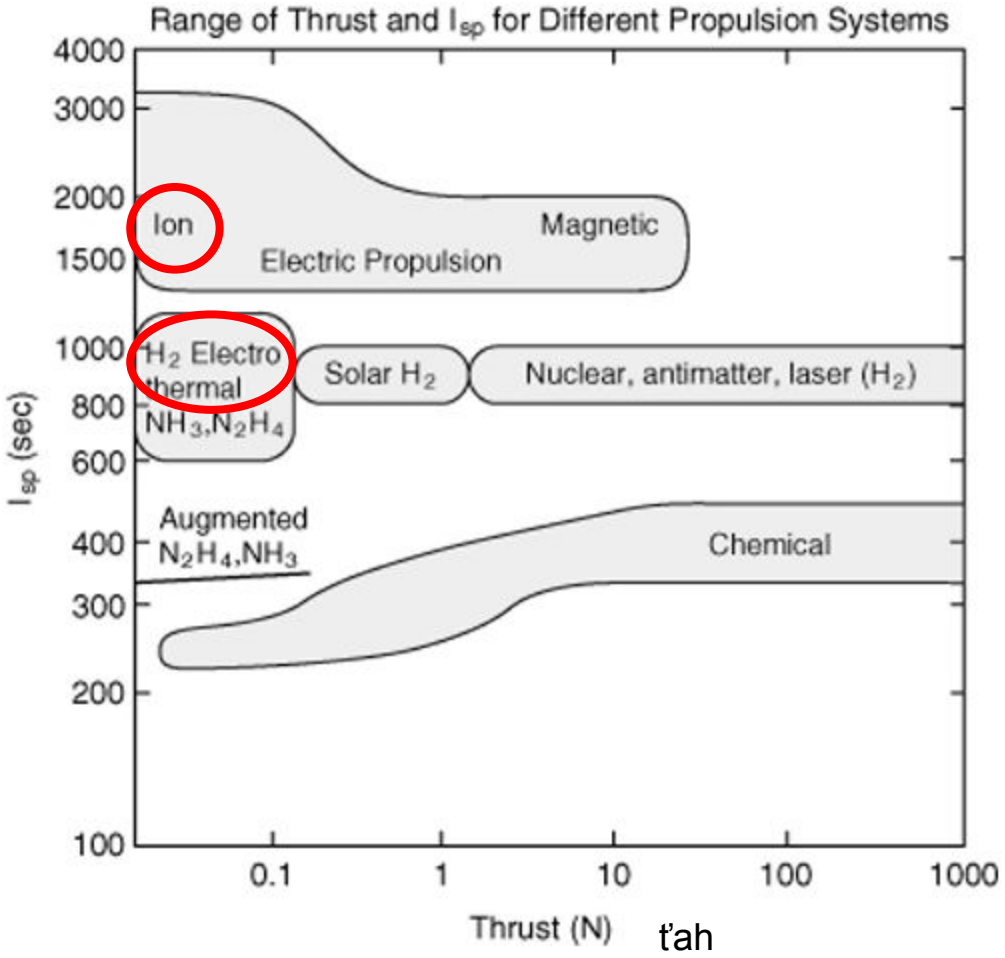


"efektivita" (dajme tomu)

ťah

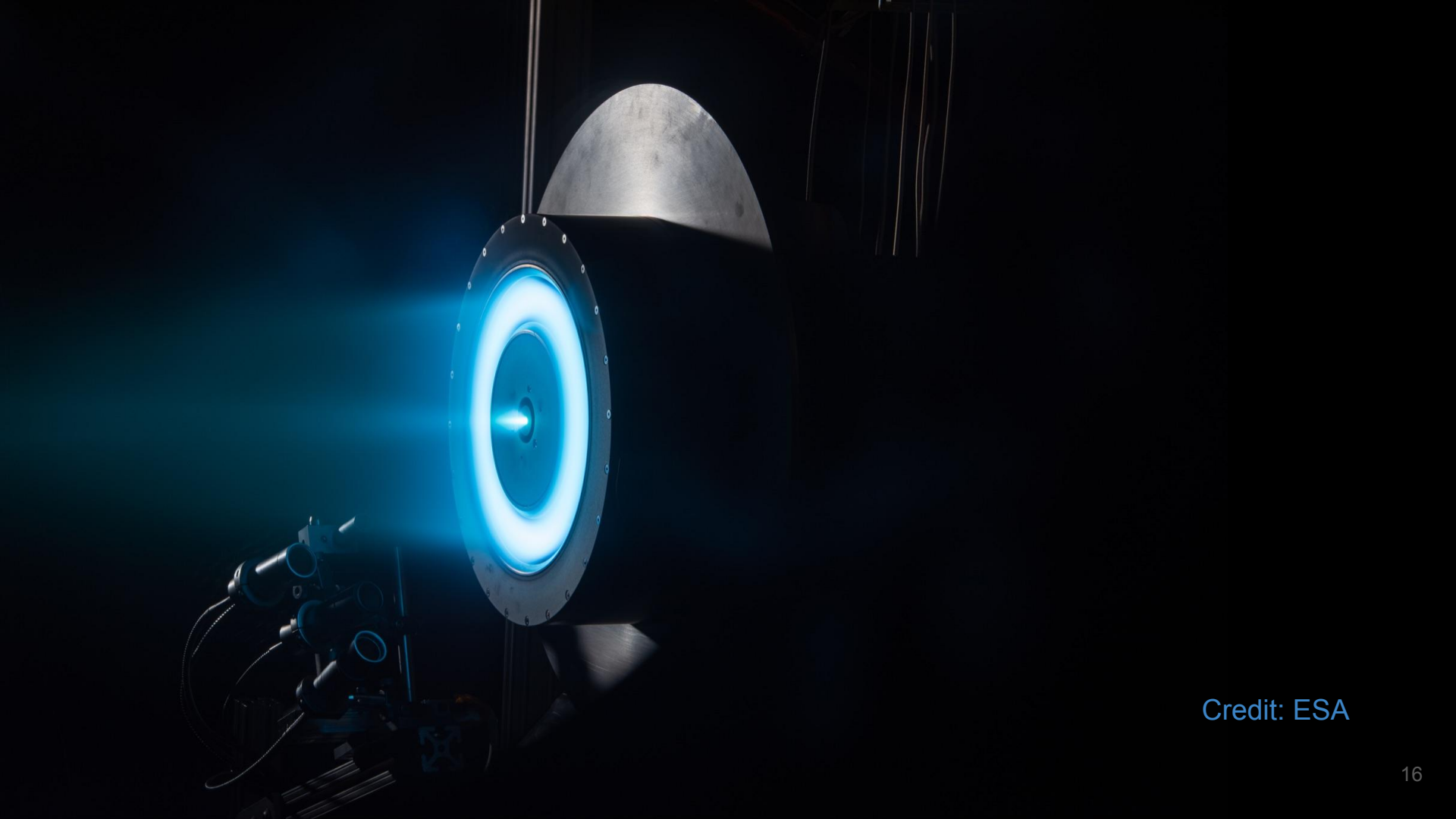
Credit: NASA

“efektivita” (dajme tomu)

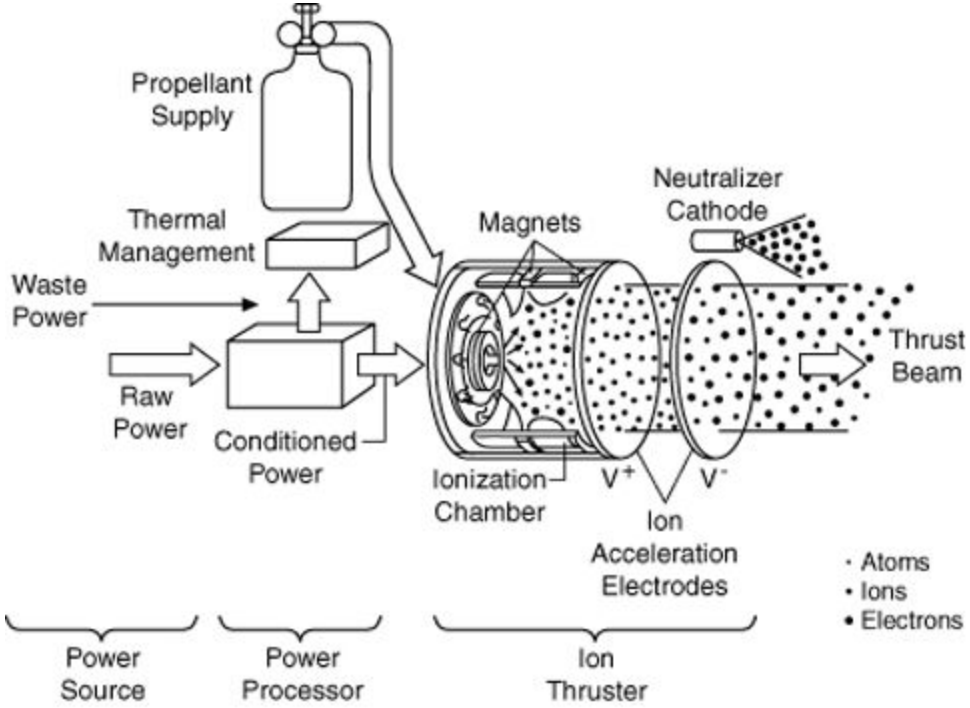


ťah

Credit: NASA



Credit: ESA



Credit: DAWN Aerospace

Credit: DLR

https://youtu.be/HMcJ1Mml6yc

Čo treba k úspešnej vesmírnej misii?

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3. **Doletieť**
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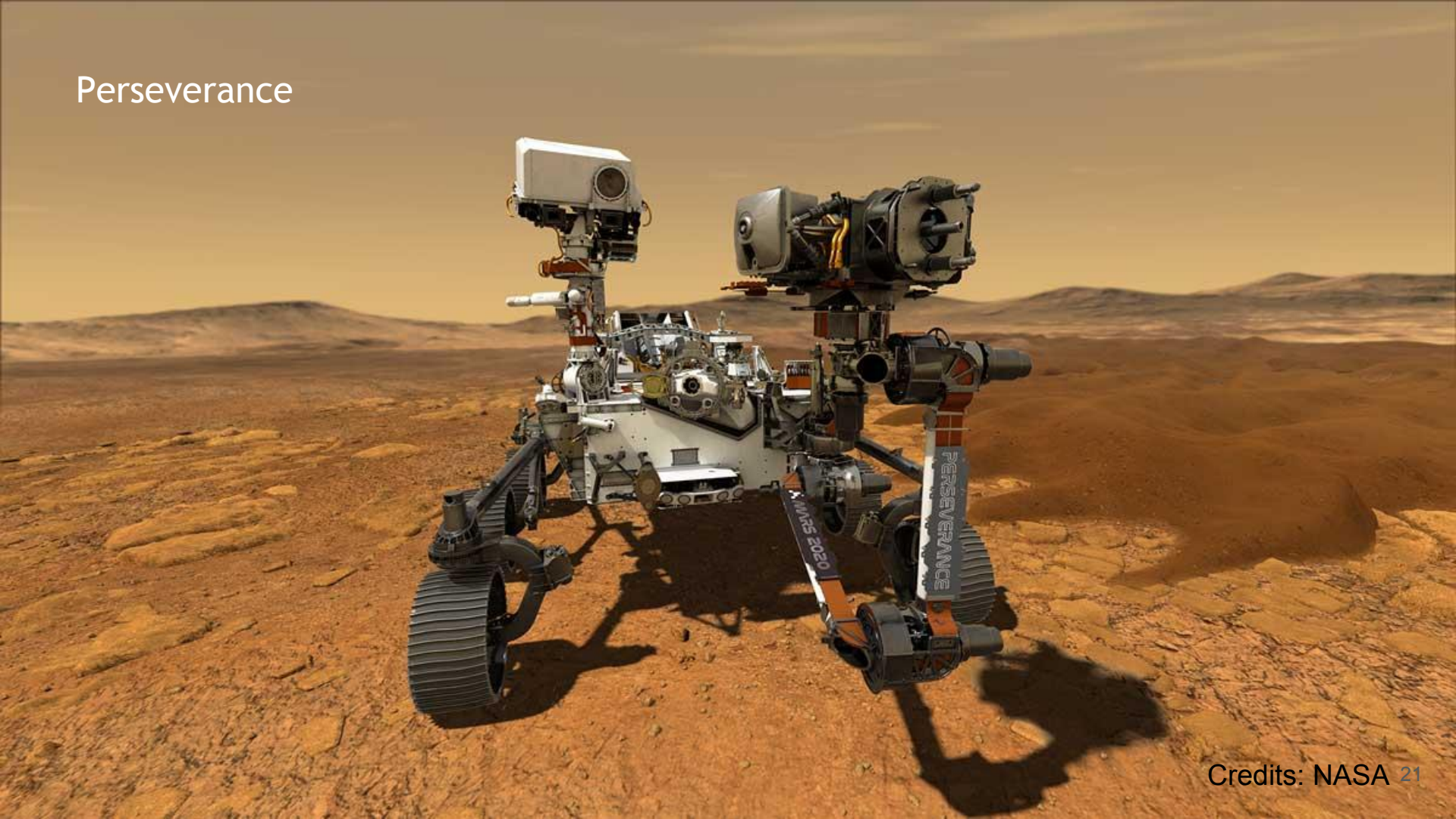
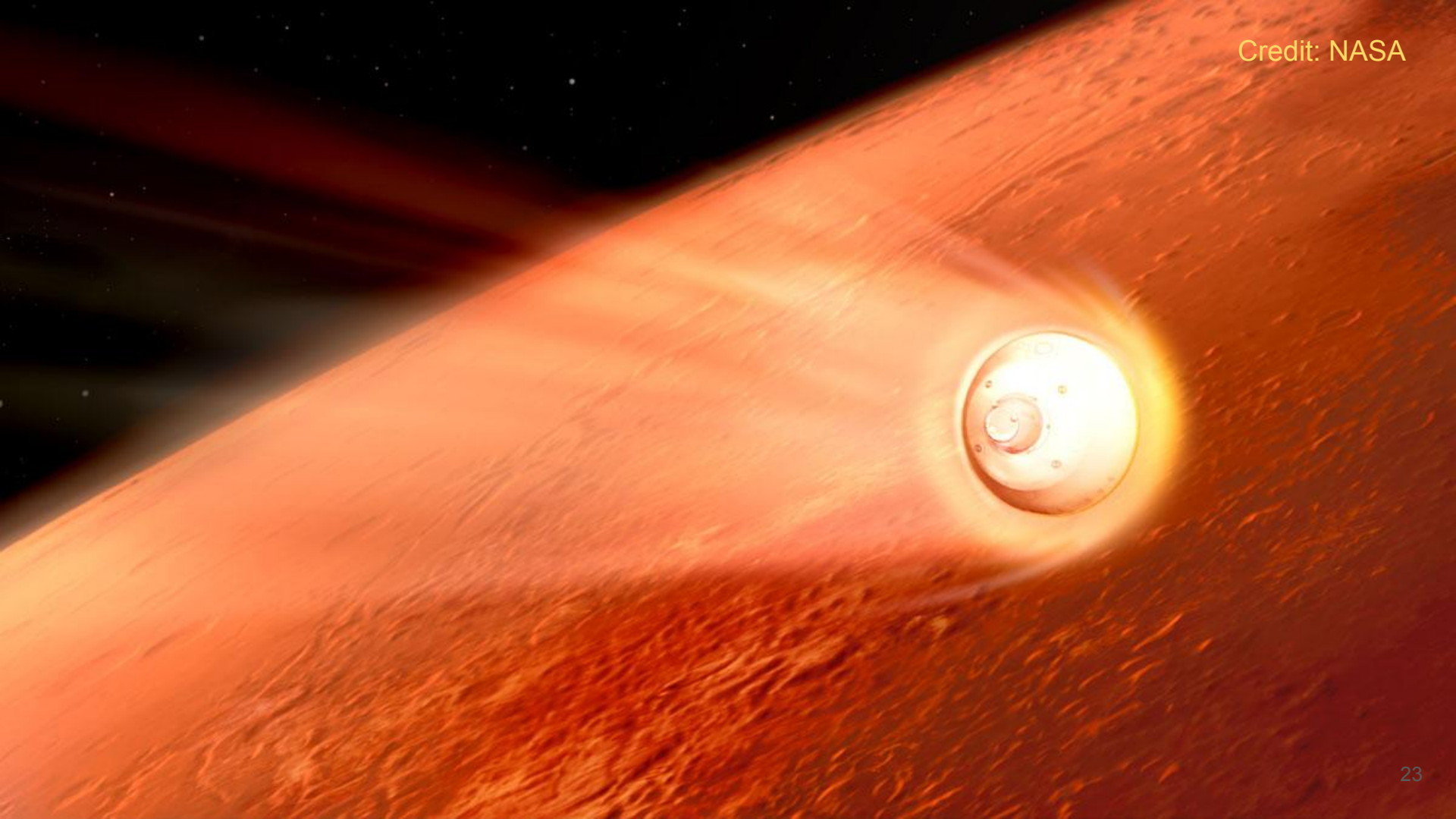
Perseverance

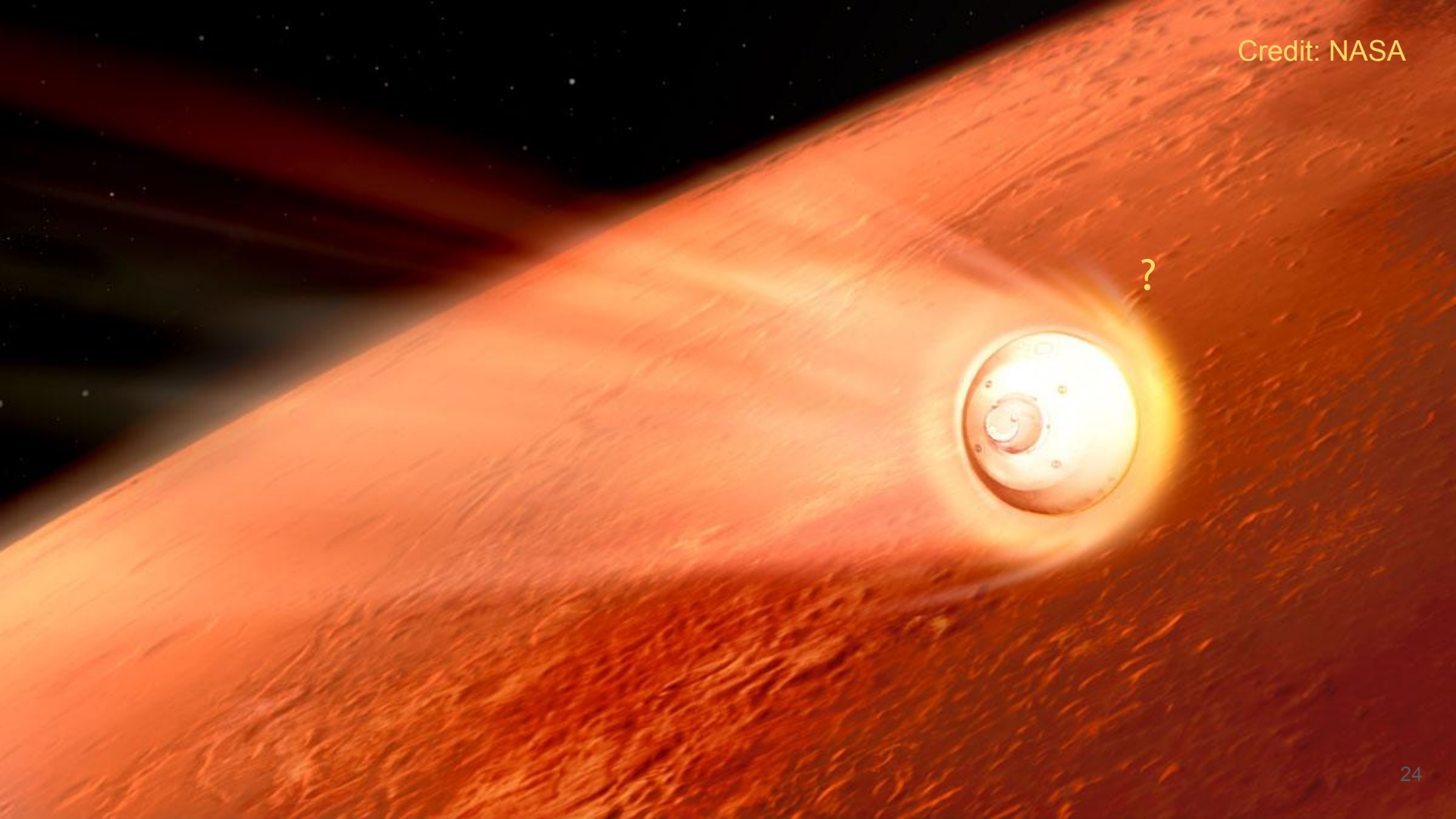


Credits: NASA

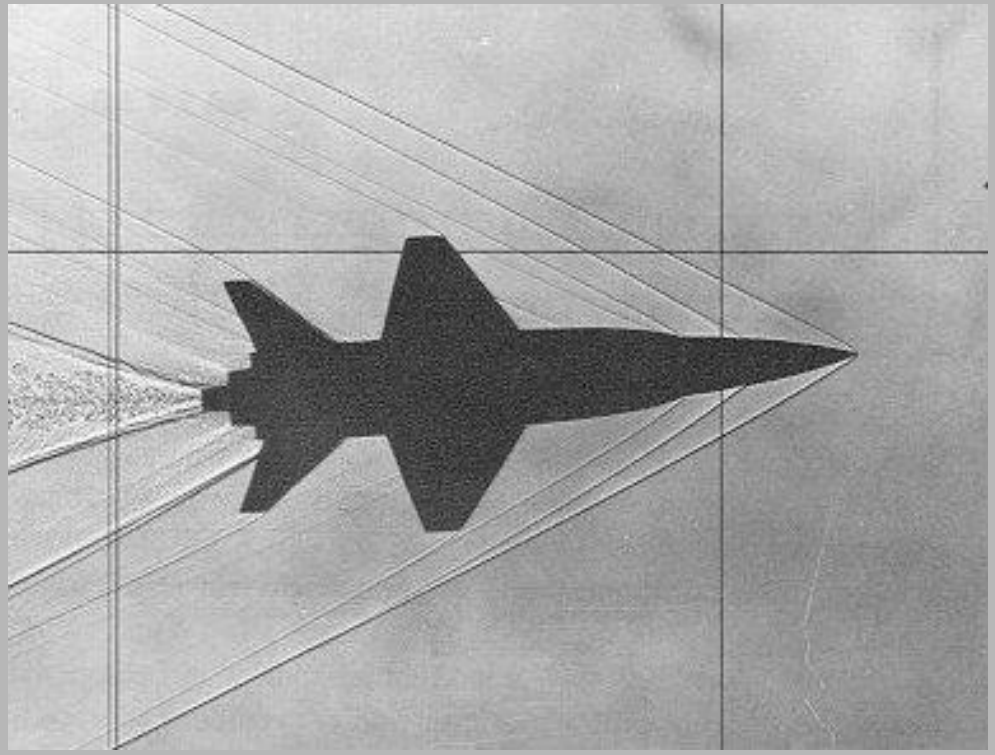
MARS 2020



Credit: NASA

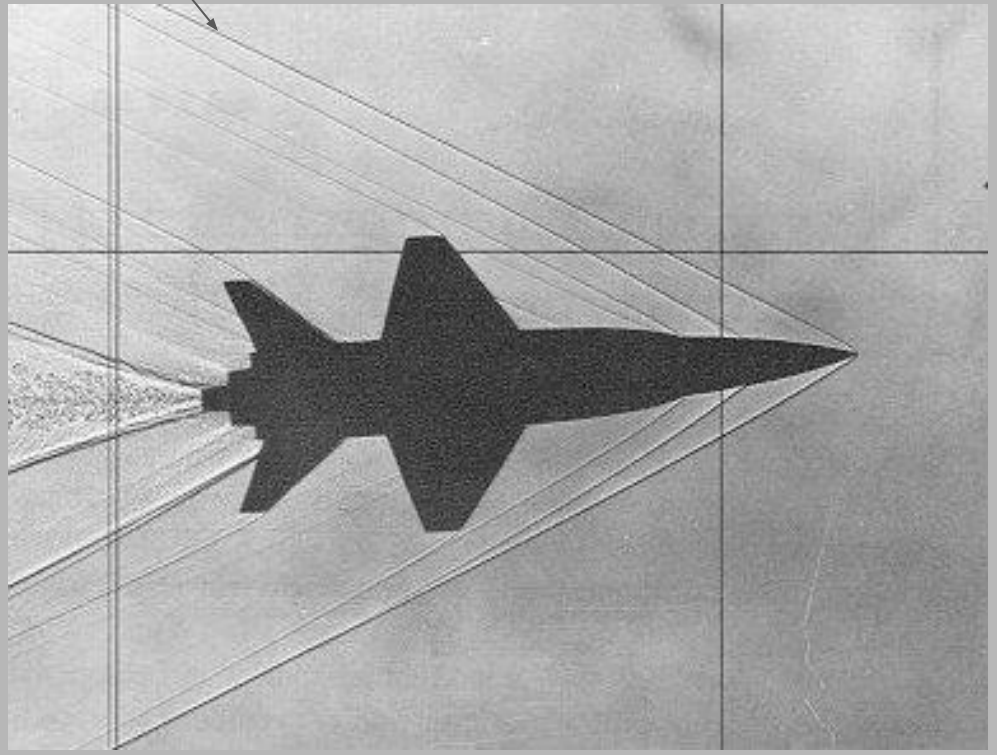

Credit: NASA
?

Credits: Getty Images



Šoková vlna - ideme rýchlejšie ako rýchlosť zvuku

Supersonický: Mach > 1
Hypersonický: Mach > 5

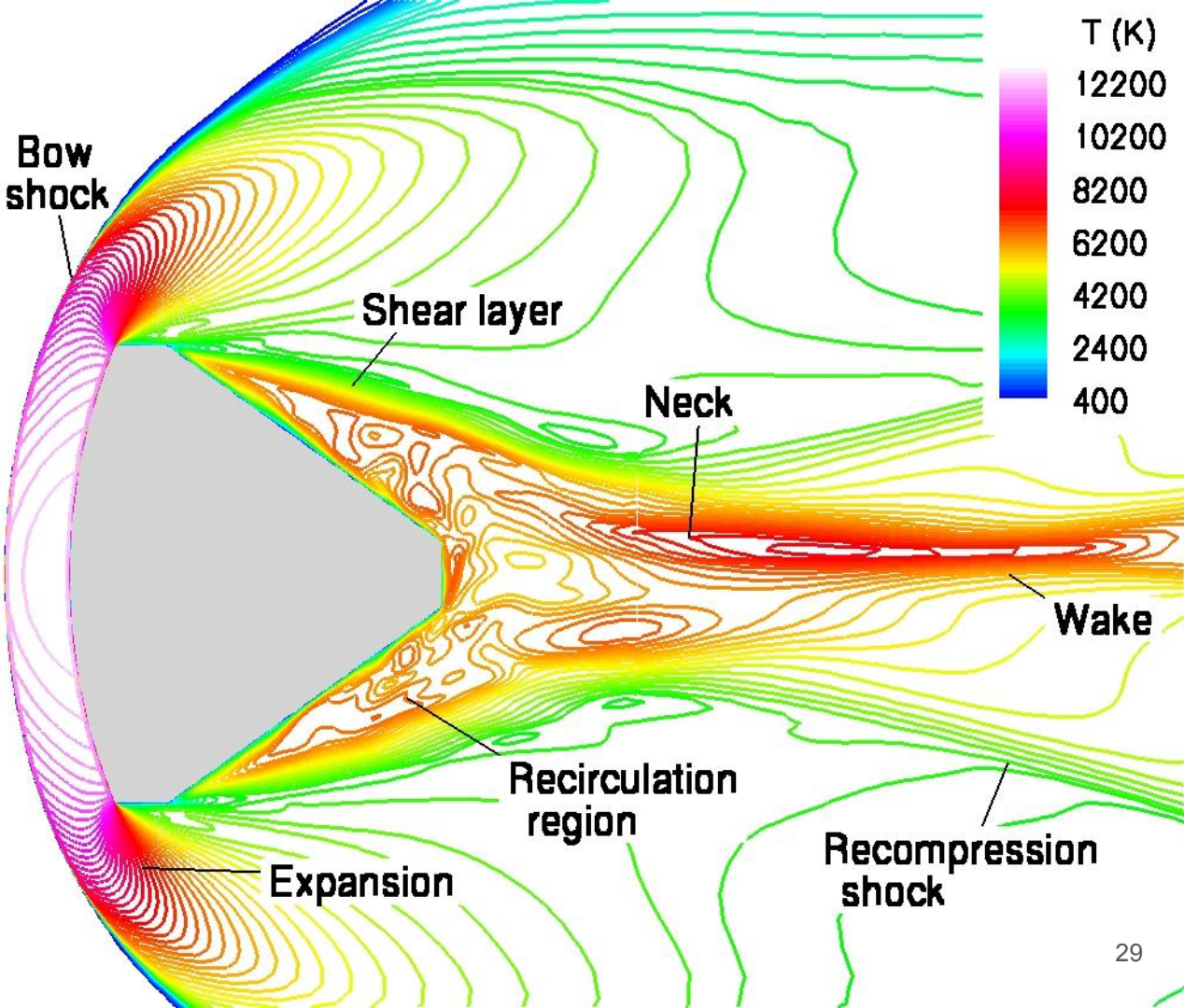


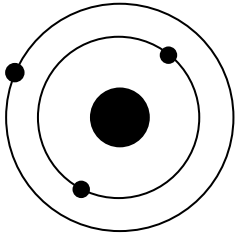
Columbia, 2003

Credits: NASA

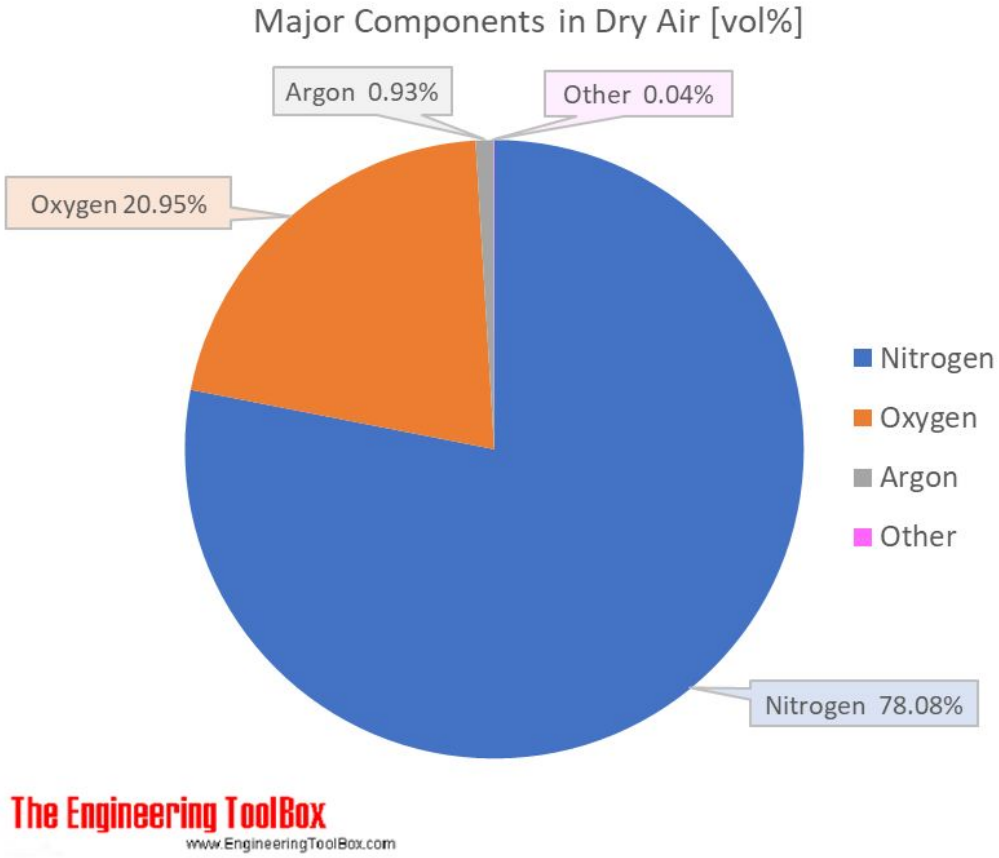
Credits: NASA

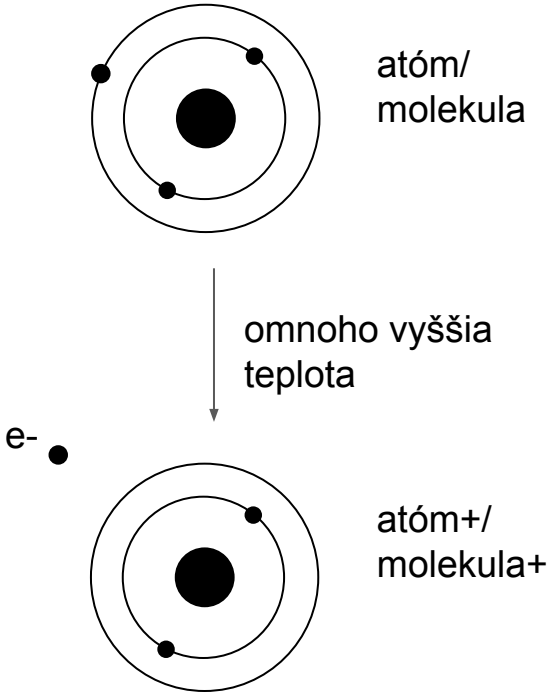
Zloženie?

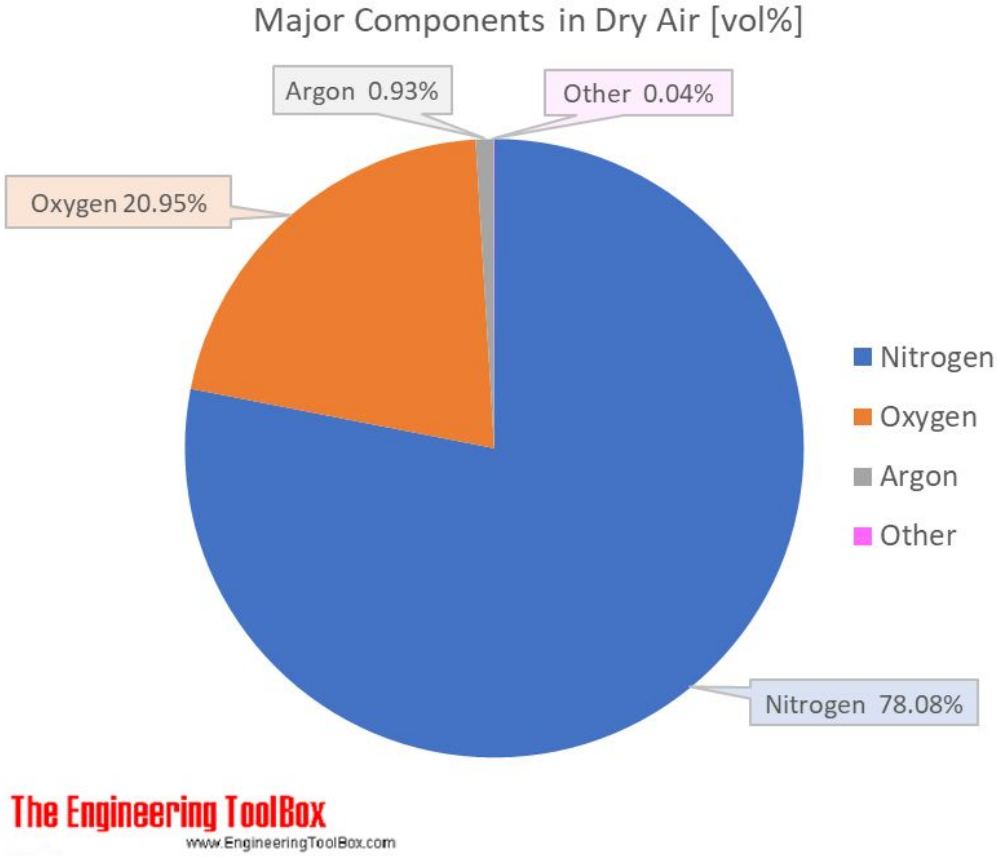




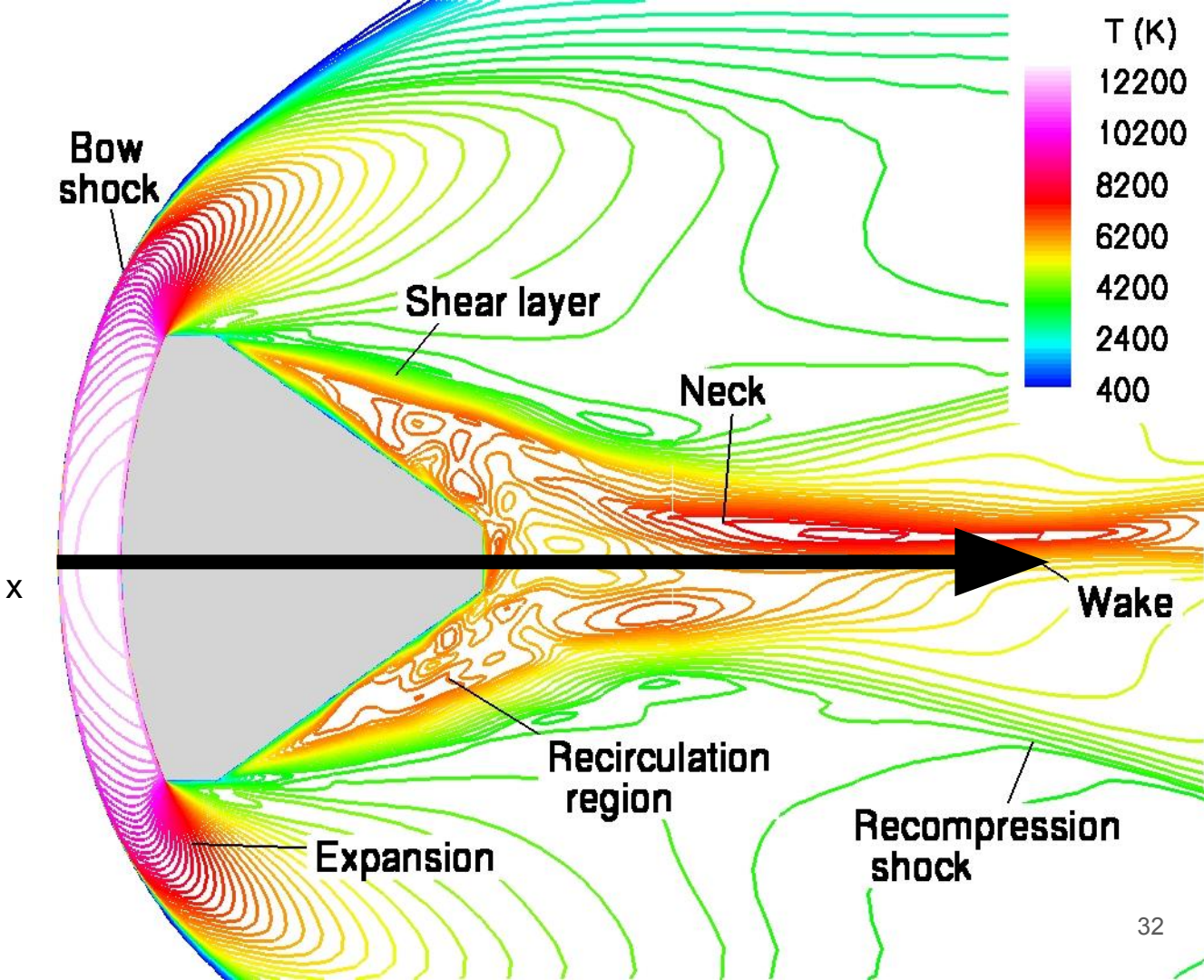
atóm/
molekula

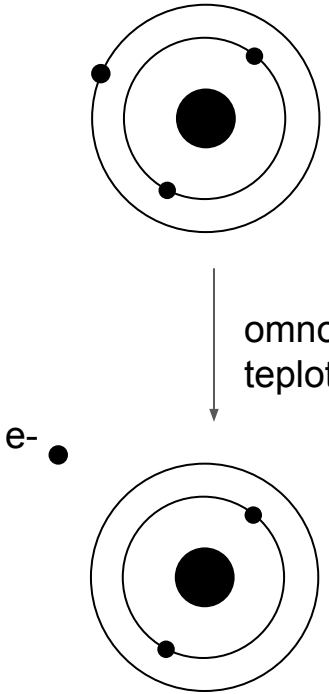



atóm/
molekula
omnoho vyššia
teplota
e-
atóm+/
molekula+

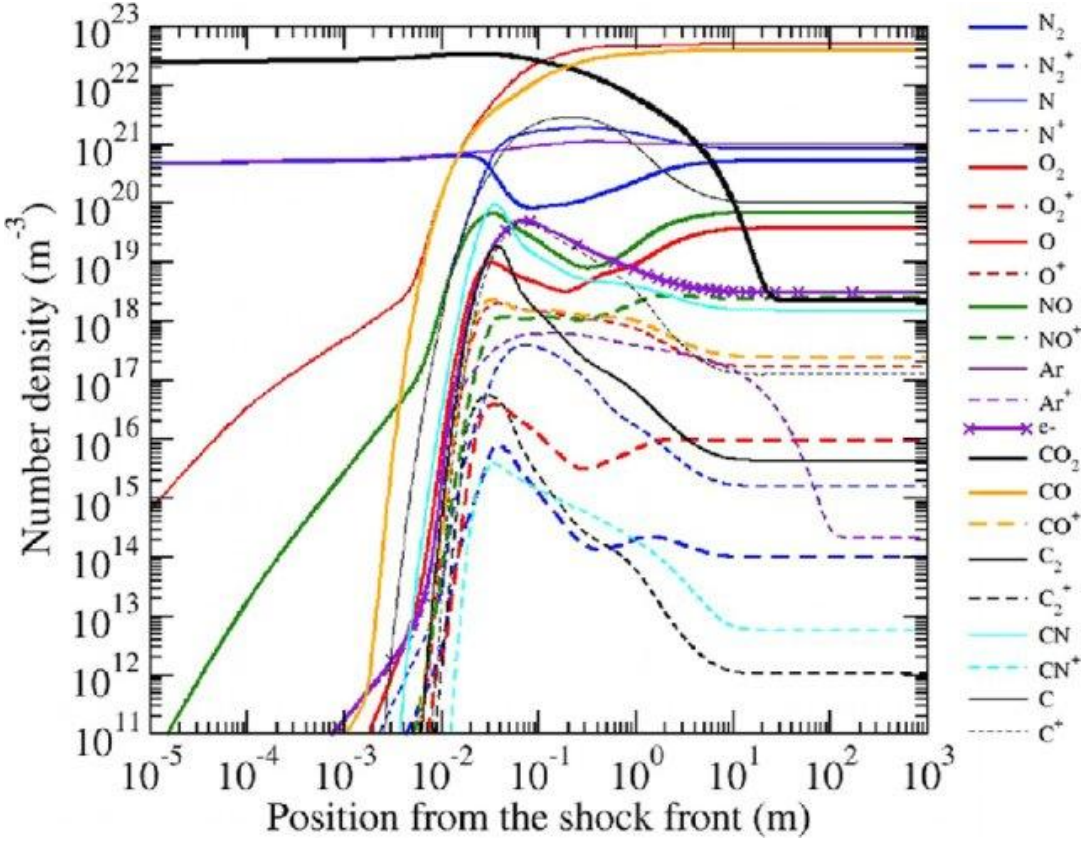

Major Components in Dry Air [vol%]
Argon 0.93%
Other 0.04%
Oxygen 20.95%
Nitrogen 78.08%
Nitrogen
Oxygen
Argon
Other
The Engineering ToolBox
www.EngineeringToolBox.com

Zloženie?

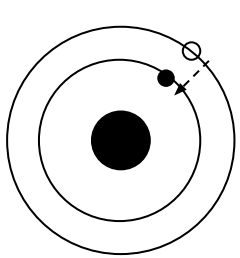

T (K)
12200
10200
8200
6200
4200
2400
400
Bow shock
Shear layer
Neck
x
Wake
Recirculation region
Recompression shock
Expansion



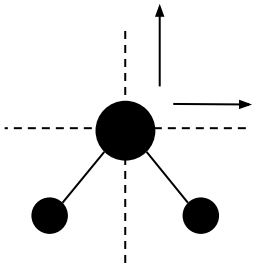
Annaloro & Arnaud Bultel 2019



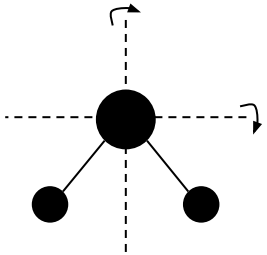
Čo je vôbec teplota?



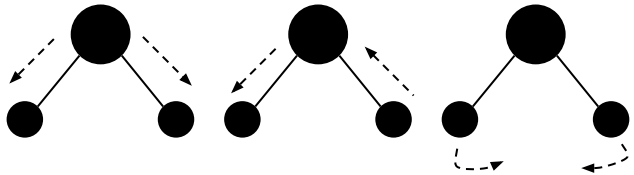
Elektronická energia



Translačná energia



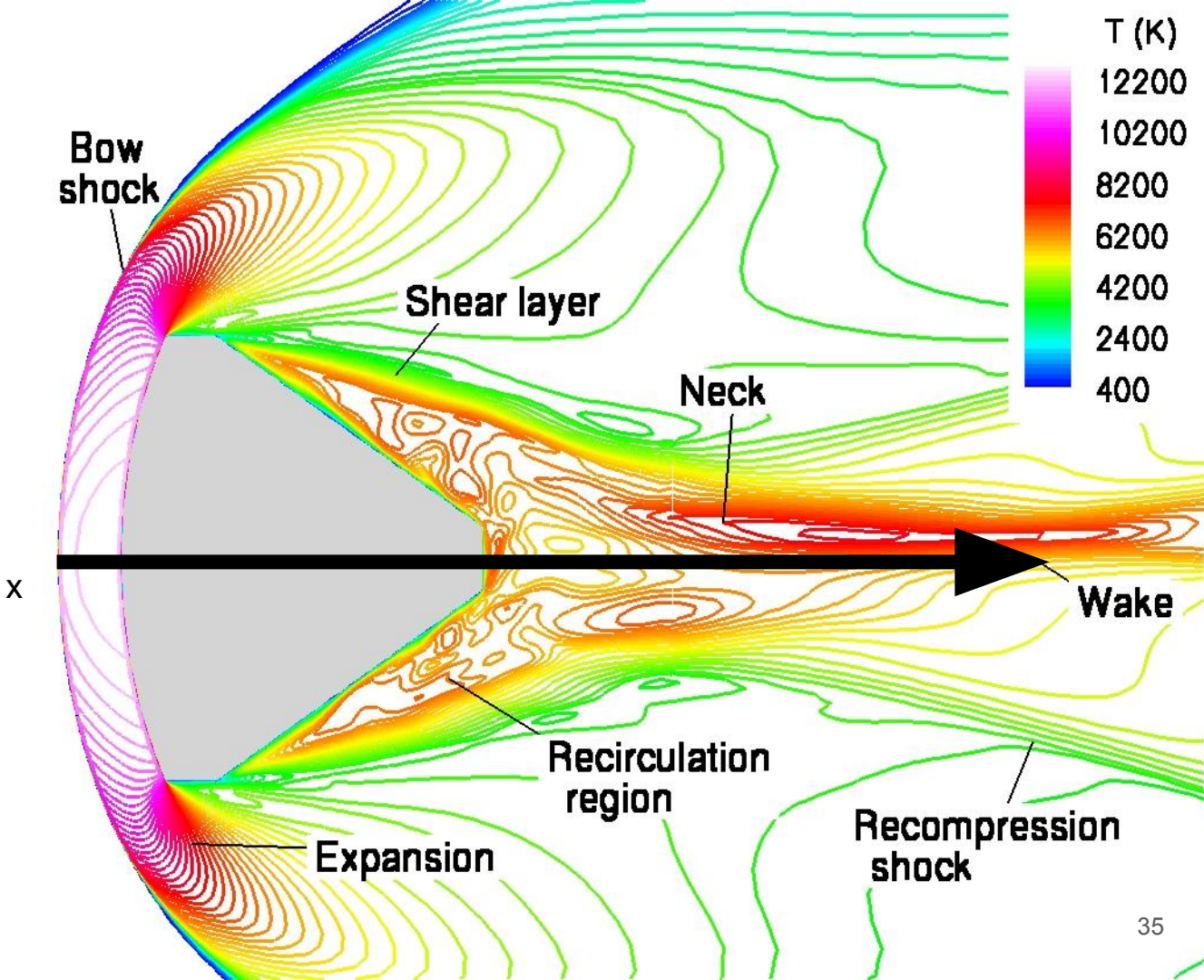
Rotačná energia



Vibračná energia

- Ak tieto nie sú v rovnováhe, koncept teploty stráca zmysel
- Teplota je potom definovaná ako elektronická, translačná, rotačná, vibračná a špecificky pre každý typ látky

Zloženie?


T (K)
12200
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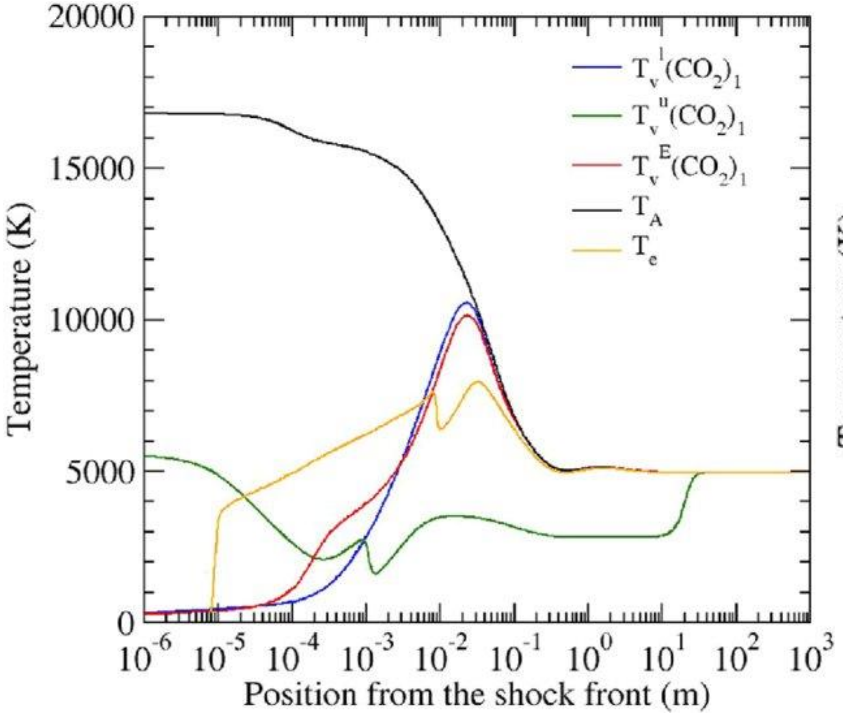
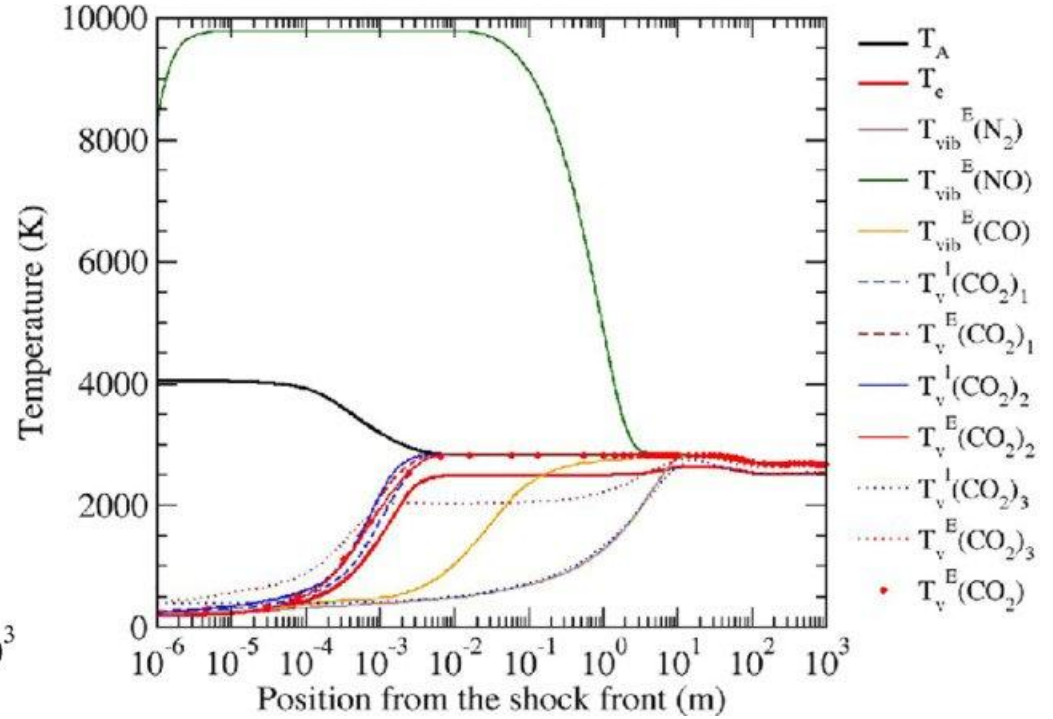
Annaloro & Arnaud Bultel 2019



Annaloro & Arnaud Bultel 2019

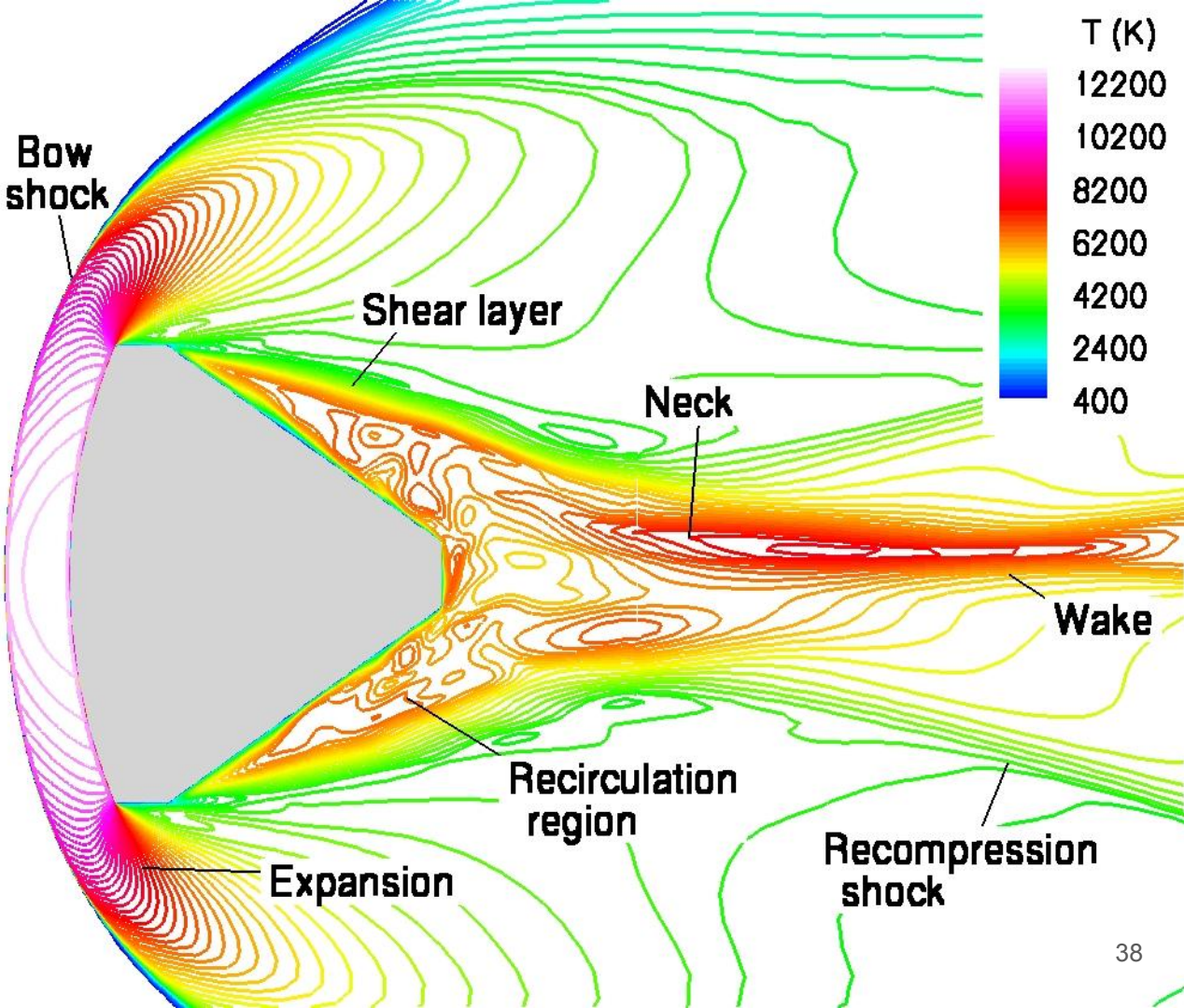


Model len dusíka v atmosfére Zeme

Elementary processes	Parameters of the rate coefficient $k(T_A) = A\,T_A^{\alpha}\exp(-B/T_A)$ expressed in $m^3\,s^{-1}$: A ($m^3\,s^{-1}\,K^{-\alpha}$)	α	B (K)	References
$CO_2(X^1\Sigma_g^+) + CO_2(X^1\Sigma_g^+) \rightarrow CO_2(^3\Sigma_u^+) + CO_2(X^1\Sigma_g^+)$	7.443×10^{-26}	1.069	40854	Equation (12) of Ref. 1
$CO_2(X^1\Sigma_g^+) + CO_2(X^1\Sigma_g^+) \rightarrow CO_2(^3\Delta_u) + CO_2(X^1\Sigma_g^+)$	6.995×10^{-26}	1.078	45089	Equation (12) of Ref. 1
$CO_2(X^1\Sigma_g^+) + CO_2(X^1\Sigma_g^+) \rightarrow CO_2(^3\Sigma_u^-) + CO_2(X^1\Sigma_g^+)$	6.467×10^{-26}	1.064	49311	Equation (12) of Ref. 1
$CO_2(^3\Sigma_u^+) + CO_2(X^1\Sigma_g^+) \rightarrow CO_2(^3\Delta_u) + CO_2(X^1\Sigma_g^+)$	1.073×10^{-24}	1.466	2996	Equation (12) of Ref. 1
$CO_2(^3\Sigma_u^+) + CO_2(X^1\Sigma_g^+) \rightarrow CO_2(^3\Sigma_u^-) + CO_2(X^1\Sigma_g^+)$	2.531×10^{-25}	1.408	6800	Equation (12) of Ref. 1
$CO_2(^3\Delta_u) + CO_2(X^1\Sigma_g^+) \rightarrow CO_2(^3\Sigma_u^-) + CO_2(X^1\Sigma_g^+)$	1.067×10^{-24}	1.465	3005	Equation (12) of Ref. 1
$CO_2(i) + CO(X^1\Sigma^+) \rightarrow CO_2(j) + CO(X^1\Sigma^+)$	$k_{CO_2(i)+CO(X^1\Sigma^+)} = 1.134 \times k_{CO_2(i)+CO_2(X^1\Sigma_g^+)}$			
$CO_2(i) + O(^3P) \rightarrow CO_2(j) + O(^3P)$	$k_{CO_2(i)+O(^3P)} = 1.370 \times k_{CO_2(i)+CO_2(X^1\Sigma_g^+)}$			
$CO(X^1\Sigma^+) + CO_2(X^1\Sigma_g^+) \rightarrow CO(I^1\Sigma^-) + CO_2(X^1\Sigma_g^+)$	1.131×10^{-26}	1.097	87895	Equation (12) of Ref. 1
$CO(X^1\Sigma^+) + CO_2(X^1\Sigma_g^+) \rightarrow CO(D^1\Delta^-) + CO_2(X^1\Sigma_g^+)$	1.032×10^{-26}	1.102	88990	Equation (12) of Ref. 1
$CO(X^1\Sigma^+) + CO_2(X^1\Sigma_g^+) \rightarrow CO(a^3\Sigma^+) + CO_2(X^1\Sigma_g^+)$	2.648×10^{-26}	1.054	75823	Equation (12) of Ref. 1
$CO(X^1\Sigma^+) + CO_2(X^1\Sigma_g^+) \rightarrow CO(d^3\Delta) + CO_2(X^1\Sigma_g^+)$	1.678×10^{-26}	1.075	82791	Equation (12) of Ref. 1
$CO(X^1\Sigma^+) + CO_2(X^1\Sigma_g^+) \rightarrow CO(e^3\Sigma^-) + CO_2(X^1\Sigma_g^+)$	1.235×10^{-26}	1.092	86815	Equation (12) of Ref. 1
$CO(X^1\Sigma^+) + O(^3P) \rightarrow CO(i) + O(^3P)$	$k_{CO(i)+O(^3P)} = 1.297 \times k_{CO(i)+CO_2(X^1\Sigma_g^+)}$			
$CO(X^1\Sigma^+) + CO_2(X^1\Sigma_g^+) \rightarrow CO^+(X^2\Sigma^+) + e^- + CO_2(X^1\Sigma_g^+)$	1.202×10^{-26}	1.817	14479	Equation (12) of Ref. 1
$CN(X^2\Sigma^+) + CO(X^1\Sigma^+) \rightarrow CN(D^2\Pi) + CO(X^1\Sigma^+)$	3.320×10^{-24}	1.050	73953	Equation (12) of Ref. 1
$CN(X^2\Sigma^+) + CO(X^1\Sigma^+) \rightarrow CN(E^2\Sigma^+) + CO(X^1\Sigma^+)$	2.201×10^{-24}	1.067	80608	Equation (12) of Ref. 1
$CN(X^2\Sigma^+) + CO(X^1\Sigma^+) \rightarrow CN(F^2\Delta) + CO(X^1\Sigma^+)$	2.063×10^{-26}	1.070	81556	Equation (12) of Ref. 1
$CN(X^2\Sigma^+) + O(^3P) \rightarrow CN(i) + O(^3P)$	$k_{CN(i)+O(^3P)} = 1.167 \times k_{CN(i)+CO(X^1\Sigma^+)}$			
$C_2(X^1\Sigma_g^+) + CO(X^1\Sigma^+) \rightarrow C_2(a^3\Pi_u) + CO(X^1\Sigma^+)$	1.150×10^{-22}	1.498	488	Equation (12) of Ref. 1
$C_2(X^1\Sigma_g^+) + CO(X^1\Sigma^+) \rightarrow C_2(b^3\Sigma_g^-) + CO(X^1\Sigma^+)$	3.086×10^{-25}	1.403	7136	Equation (12) of Ref. 1
$C_2(X^1\Sigma_g^+) + CO(X^1\Sigma^+) \rightarrow C_2(A^1\Pi_u) + CO(X^1\Sigma^+)$	2.060×10^{-23}	1.364	9885	Equation (12) of Ref. 1
$C_2(X^1\Sigma_g^+) + CO(X^1\Sigma^+) \rightarrow C_2(c^3\Sigma_u^+) + CO(X^1\Sigma^+)$	1.325×10^{-25}	1.276	17056	Equation (12) of Ref. 1
$C_2(X^1\Sigma_g^+) + CO(X^1\Sigma^+) \rightarrow C_2(C^1\Pi_g) + CO(X^1\Sigma^+)$	8.859×10^{-26}	1.072	46841	Equation (12) of Ref. 1
$C_2(X^1\Sigma_g^+) + CO(X^1\Sigma^+) \rightarrow C_2(e^3\Pi_g) + CO(X^1\Sigma^+)$	7.263×10^{-26}	1.049	55493	Equation (12) of Ref. 1
$C_2(X^1\Sigma_g^+) + CO(X^1\Sigma^+) \rightarrow C_2(D^1\Sigma_u^+) + CO(X^1\Sigma^+)$	6.450×10^{-24}	1.044	59371	Equation (12) of Ref. 1
$C_2(X^1\Sigma_g^+) + O(^3P) \rightarrow C_2(i) + O(^3P)$	$k_{C_2(i)+O(^3P)} = 1.161 \times k_{C_2(i)+CO(X^1\Sigma^+)}$			
$C_2(X^1\Sigma_g^+) + O(^3P) \rightarrow CO(X^1\Sigma^+) + C(^3P)$	7.760×10^{-14}	−0.541	0	Equation (12) of Ref. 1
$C_2(X^1\Sigma_g^+) + O(^3P) \rightarrow CO(a^3\Pi) + C(^3P)$	6.272×10^{-14}	−0.541	11936	Equation (12) of Ref. 1
$C_2(X^1\Sigma_g^+) + O(^3P) \rightarrow CO(a'^3\Sigma^+) + C(^3P)$	5.331×10^{-13}	−0.541	21831	Equation (12) of Ref. 1
$C_2(X^1\Sigma_g^+) + O(^3P) \rightarrow CO(d^3\Delta) + C(^3P)$	1.137×10^{-14}	−0.541	29406	Equation (12) of Ref. 1
$C_2(X^1\Sigma_g^+) + O(^3P) \rightarrow CO(e^3\Sigma^-) + C(^3P)$	6.037×10^{-14}	−0.541	33849	Equation (12) of Ref. 1
$C_2(X^1\Sigma_g^+) + O(^3P) \rightarrow CO(D^1\Delta^-) + C(^3P)$	4.163×10^{-13}	−0.541	36262	Equation (12) of Ref. 1
$C_2(d^3\Pi_g) + O(^3P) \rightarrow CO(X^1\Sigma^+) + C(^3P)$	7.662×10^{-12}	−1.259	−14466	Rate coefficient[55]
$O_2(X^3\Sigma_g^-) + C(^3P) \rightarrow CO(a^3\Pi) + O(^3P)$	9.606×10^{-17}	0	348	Rate coefficient[56]
$O_2(X^3\Sigma_g^-) + C(^3P) \rightarrow CO(a'^3\Sigma^+) + O(^3P)$	8.118×10^{-17}	0	1024	Equation (12) of Ref. 1
$O_2(X^3\Sigma_g^-) + C(^3P) \rightarrow CO(d^3\Delta) + O(^3P)$	1.732×10^{-16}	0	1782	Equation (12) of Ref. 1
$O_2(X^3\Sigma_g^-) + C(^3P) \rightarrow CO(e^3\Sigma^-) + O(^3P)$	9.291×10^{-17}	0	1919	Equation (12) of Ref. 1
$O_2(X^3\Sigma_g^-) + C(^3P) \rightarrow CO(D^1\Delta^-) + O(^3P)$	6.314×10^{-18}	0	2127	Equation (12) of Ref. 1

Elementary process	Parameters of the rate coefficient k of Eq. (1), $m^3 \cdot s^{-1}$: A	α	B	Reference
$N_2(X^1\Sigma_g^+) + e^- \rightarrow N_2(A^3\Sigma_u^+) + e^-$	2.233×10^{-18}	0.717	71,493	A, α, and B derived from [30], VRP
$N_2(X^1\Sigma_g^+) + e^- \rightarrow N_2(B^3\Pi_g) + e^-$	3.977×10^{-16}	0.280	85,958	A, α, and B derived from [30], VRP
$N_2(X^1\Sigma_g^+) + e^- \rightarrow N_2(W^3\Delta_u) + e^-$	1.063×10^{-18}	0.843	85,327	A,α and B derived from [30], VRP
$N_2(X^1\Sigma_g^+) + e^- \rightarrow N_2(B'^3\Sigma_u^-) + e^-$	1.430×10^{-17}	0.492	95,079	A, α, and B derived from [30], VRP
$N_2(X^1\Sigma_g^+) + e^- \rightarrow N_2(a'^1\Sigma_u^-) + e^-$	6.802×10^{-19}	0.788	98,471	A, α, and B derived from [30], VRP
$N_2(X^1\Sigma_g^+) + e^- \rightarrow N_2(a^1\Pi_g) + e^-$	2.305×10^{-17}	0.529	99,272	A, α, and B derived from [30], VRP
$N_2(X^1\Sigma_g^+) + e^- \rightarrow N_2(w^1\Delta_u) + e^-$	9.319×10^{-17}	0.330	103,923	A, α, and B derived from [30], VRP
$N_2(X^1\Sigma_g^+) + e^- \rightarrow N_2(G^3\Delta_g) + e^-$	4.960×10^{-14}	−0.119	127,901	A, α, and B derived from [30], VRP
$N_2(X^1\Sigma_g^+) + e^- \rightarrow N_2(C^3\Pi_u) + e^-$	4.413×10^{-14}	−0.111	129,395	A, α, and B derived from [30], VRP
$N_2(X^1\Sigma_g^+) + e^- \rightarrow N_2(E^3\Sigma_g^+) + e^-$	1.562×10^{-20}	0.907	137,419	A, α, and B derived from [30], VRP
$N_2(X^1\Sigma_g^+) + e^- \rightarrow N_2^+(X^2\Sigma_g^+) + 2e^-$	2.750×10^{-19}	1.500	178,027	A, α, and B derived from [30], VRP
$N_2(X^1\Sigma_g^+) + e^- \rightarrow N_2^+(A^2\Pi_u) + 2e^-$	2.953×10^{-18}	0.714	193,623	A, α, and B derived from [30], VRP
$N_2(X^1\Sigma_g^+) + e^- \rightarrow N_2^+(B^2\Sigma_u^+) + 2e^-$	3.817×10^{-19}	0.822	216,810	A, α, and B derived from [30], VRP
$N_2(X^1\Sigma_g^+) + e^- \rightarrow N_2^+(D^2\Pi_g) + 2e^-$	1.888×10^{-18}	0.603	255,026	A, α, and B derived from [30], VRP
$N_2(X^1\Sigma_g^+) + e^- \rightarrow N_2^+(C^2\Sigma_u^+) + 2e^-$	2.200×10^{-18}	0.599	273,610	A, α, and B derived from [30], VRP
$N_2(a'^1\Sigma_u^-) + e^- \rightarrow N(^2D) + N(^2D) + e^-$	2.254×10^{-11}	−0.500	71,166	Eq. (3)
$N_2(a^1\Pi_g) + e^- \rightarrow N(^2D) + N(^2D) + e^-$	2.013×10^{-11}	−0.500	69,426	Eq. (3)
$N_2(w^1\Delta_u) + e^- \rightarrow N(^2D) + N(^2D) + e^-$	2.052×10^{-11}	−0.500	65,470	Eq. (3)
$N_2(G^3\Delta_g) + e^- \rightarrow N(^2S) + N(^2D) + e^-$	7.922×10^{-12}	−0.500	15,683	Eq. (3)
$N_2(E^3\Sigma_g^+) + e^- \rightarrow N(^2S) + N(^2D) + e^-$	7.789×10^{-13}	−0.500	3,202	Eq. (3)
$N_2^+(a^4\Sigma_u^+) + e^- \rightarrow N(^4S) + N^+(^2P) + e^-$	1.743×10^{-11}	−0.500	64,312	Eq. (3)
$N_2^+(D^2\Pi_g) + e^- \rightarrow N(^4S) + N^+(^3P) + e^-$	1.114×10^{-11}	−0.500	26,438	Eq. (3)
$N_2^+(X^2\Sigma_g^+) + e^- \rightarrow N_2^+(a^4\Sigma_u^+) + e^-$	— —	— —	— —	Eq. (6)
$N_2^+(X^2\Sigma_g^+) + e^- \rightarrow N_2^+(D^2\Pi_g) + e^-$	— —	— —	— —	Eq. (6)
$N_2(X^1\Sigma_g^+) + N_2(X^1\Sigma_g^+) \rightarrow N_2(W^3\Delta_u) + N_2(X^1\Sigma_g^+)$	— —	— —	— —	Eq. (7), VRP
$N_2(X^1\Sigma_g^+) + N_2(X^1\Sigma_g^+) \rightarrow N_2(B'^3\Sigma_u^-) + N_2(X^1\Sigma_g^+)$	— —	— —	— —	Eq. (7), VRP
$N_2(X^1\Sigma_g^+) + N_2(X^1\Sigma_g^+) \rightarrow N_2(a'^1\Sigma_u^-) + N_2(X^1\Sigma_g^+)$	— —	— —	— —	Eq. (7), VRP
$N_2(X^1\Sigma_g^+) + N_2(X^1\Sigma_g^+) \rightarrow N_2(a^1\Pi_g) + N_2(X^1\Sigma_g^+)$	— —	— —	— —	Eq. (7), VRP
$N_2(X^1\Sigma_g^+) + N_2(X^1\Sigma_g^+) \rightarrow N_2(w^1\Delta_u) + N_2(X^1\Sigma_g^+)$	— —	— —	— —	Eq. (7), VRP
$N_2(X^1\Sigma_g^+) + N_2(X^1\Sigma_g^+) \rightarrow N_2(G^3\Delta_g) + N_2(X^1\Sigma_g^+)$	— —	— —	— —	Eq. (7), VRP
$N_2(X^1\Sigma_g^+) + N_2(X^1\Sigma_g^+) \rightarrow N_2(C^3\Pi_u) + N_2(X^1\Sigma_g^+)$	— —	— —	— —	Eq. (7), VRP
$N_2(X^1\Sigma_g^+) + N_2(X^1\Sigma_g^+) \rightarrow N_2(E^3\Sigma_g^+) + N_2(X^1\Sigma_g^+)$	— —	— —	— —	Eq. (7), VRP
$N(i) + (N_2 \text{ or } N) \rightarrow N(j) + (N_2 \text{ or } N)$	— —	— —	— —	Eq. (8)
$N^+(i) + (N_2 \text{ or } N) \rightarrow N^+(j) + (N_2 \text{ or } N)$	— —	— —	— —	Eq. (8)
$N(i) + (N_2 \text{ or } N) \rightarrow N^+(j) + (N_2 \text{ or } N) + e^-$	— —	— —	— —	Eq. (8)

Ako takéto niečo riešime?



Čo funguje v tekutinách?

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- Nevzniká nová hmota (1x)
- Nevzniká nová hybnosť (3x)
- Nevzniká nová energia (1x)
- Platia Maxwellove rovnice (4x)

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- Chceme zistiť chemické zloženie, rýchlosti, teplotu, tlak…

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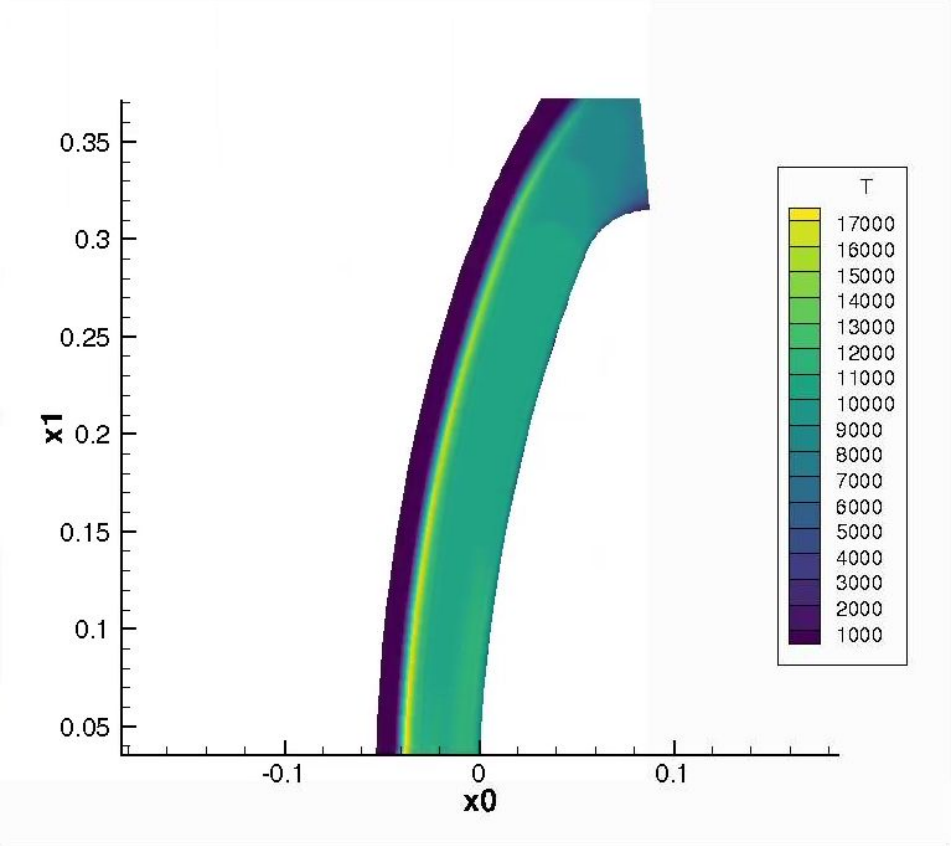
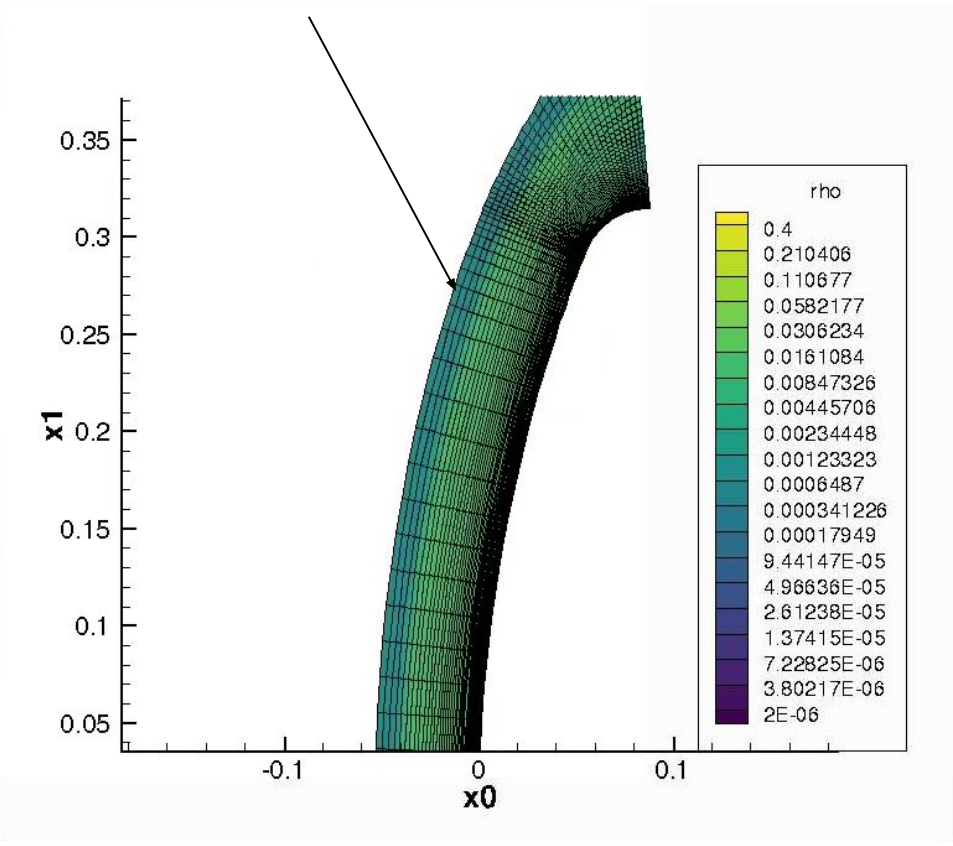
- Chceme zistiť chemické zloženie, rýchlosti, teplotu, tlak…
- Tie sa líšia z miesta do miesta, ale možno si geometriu vieme rozdeliť na malé kúsky, v rámci ktorých sa moc nemenia

Tie rovnice riešime v týchto malých “bunkách” geometrie





Credits: VSC

Egzostive 2020 - Brussels Motor Show

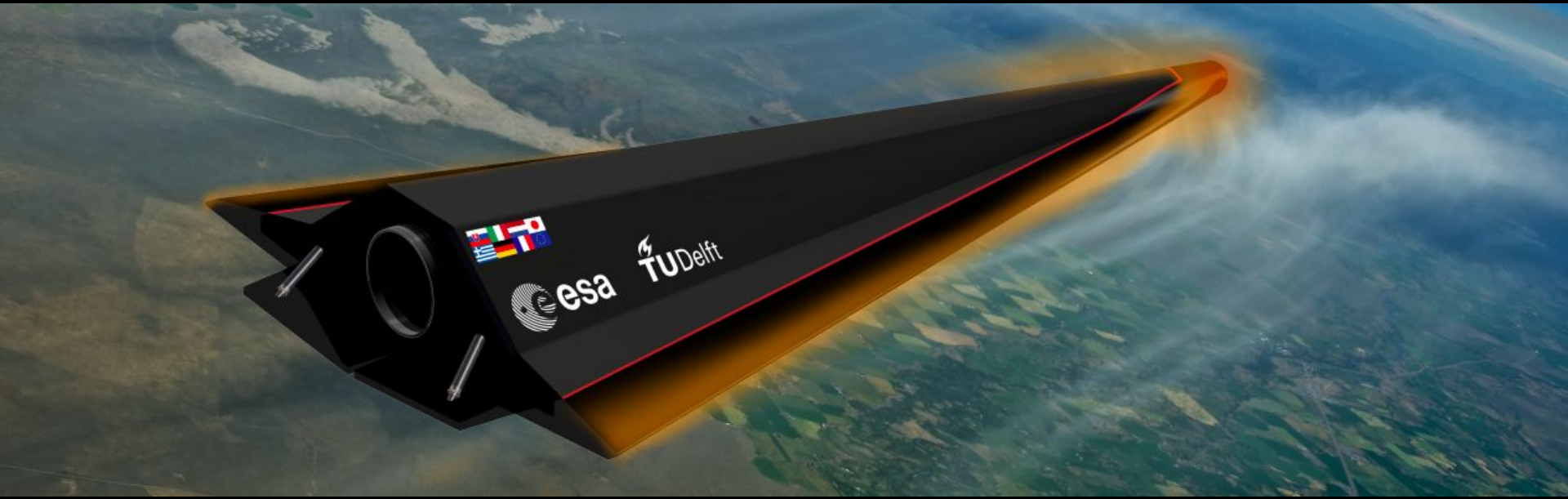
Credit: REUTERS

Credit: ROSKOSMOS

Credit: SpaceX

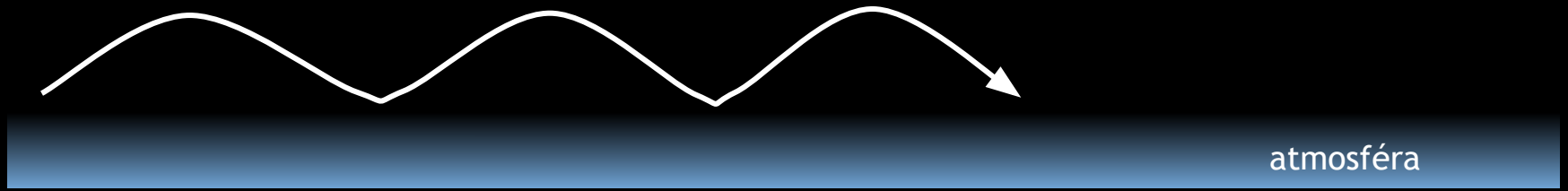
Credit: Blue Origin

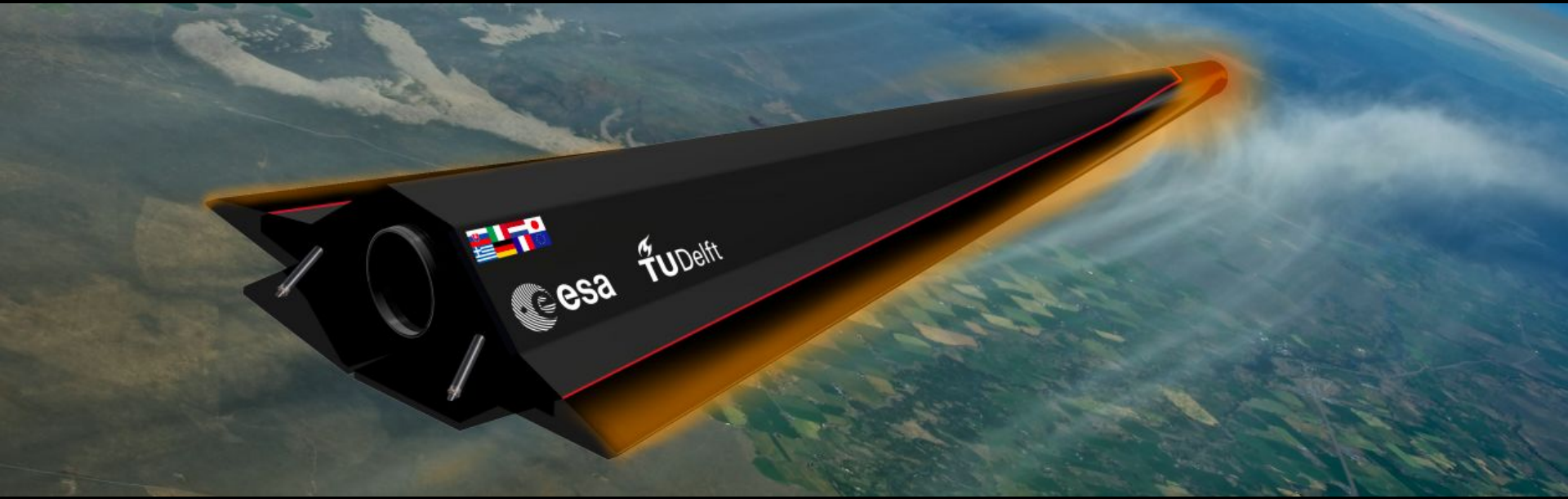
Bakalárska práca, 2018



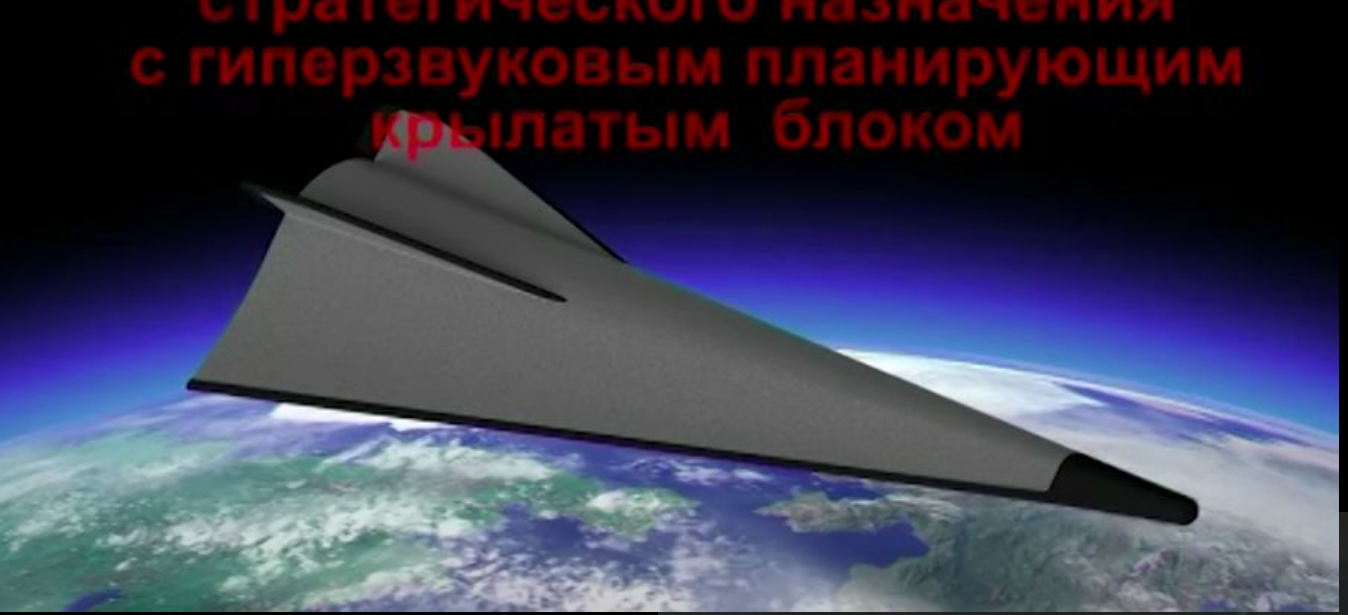
Hlavné požiadavky na design:

- Vedieť obehnúť Zem aspoň raz bez poriadneho pohonného systému
- Vedieť “sa odrážať” od atmosféry
- Hmotnosť do 500kg
- Cena do 120e6 dolárov
- Znovu-použiteľné

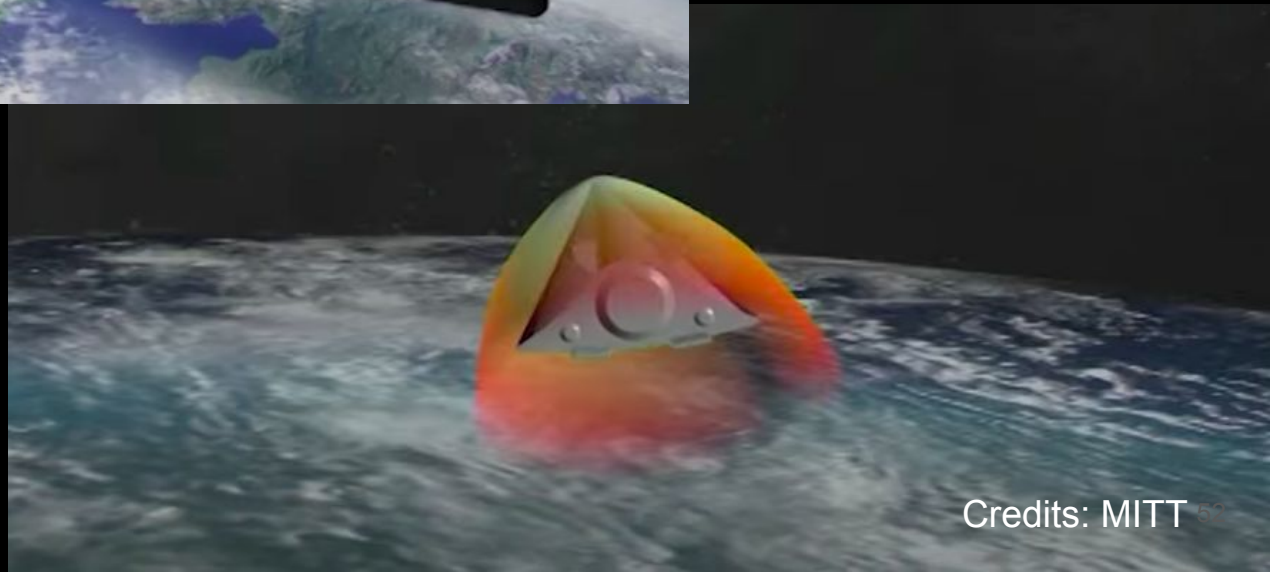



esa
TUDelft

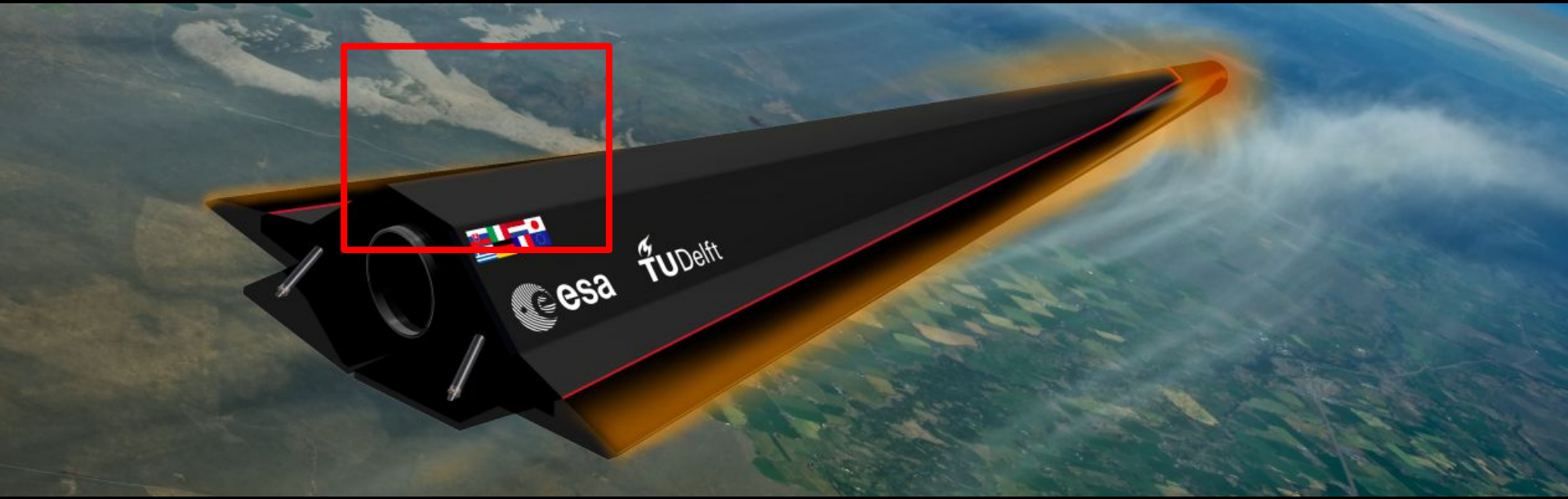
Concurrent



Ruský Avangard
2018



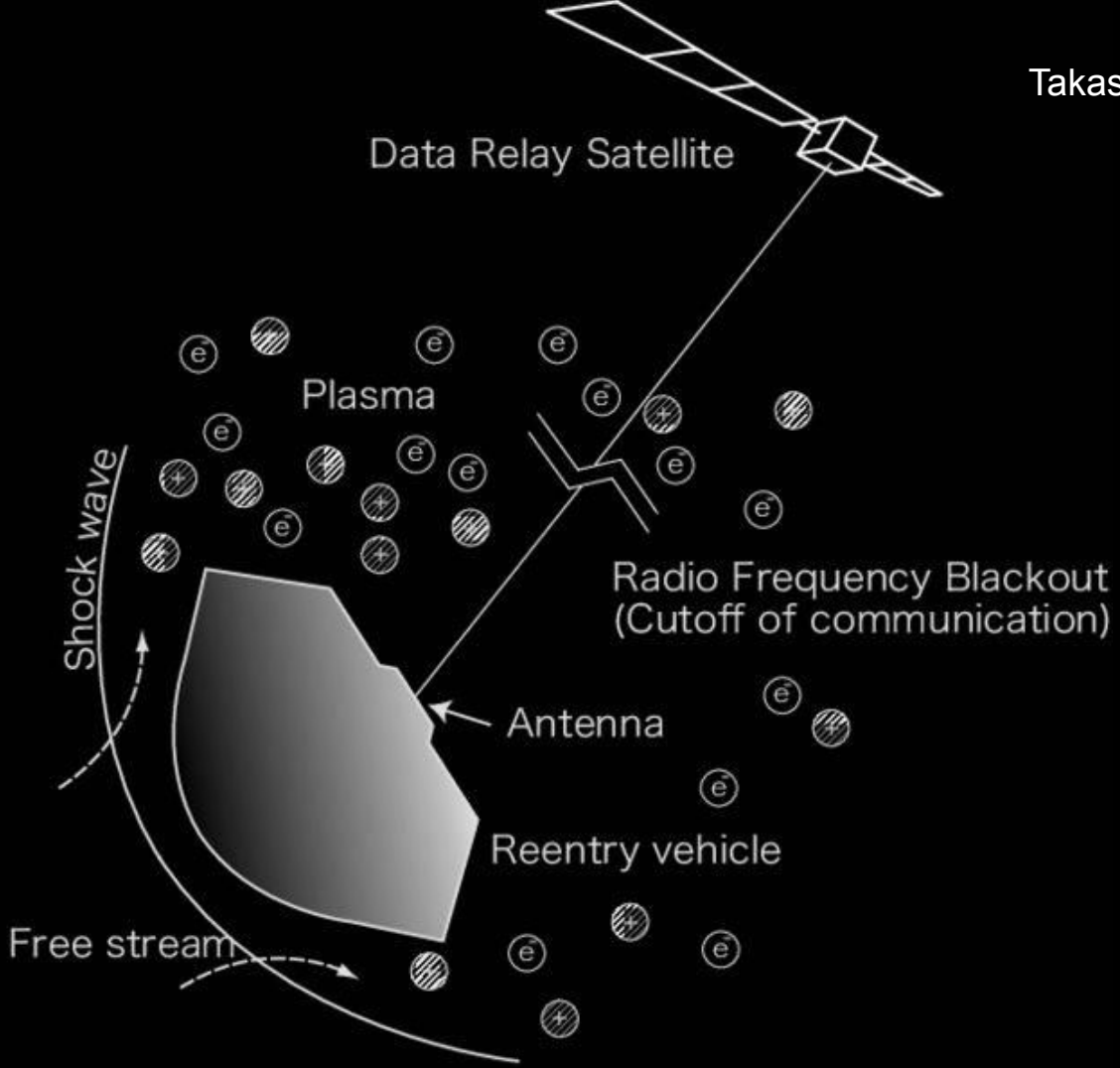
Credits: MITT

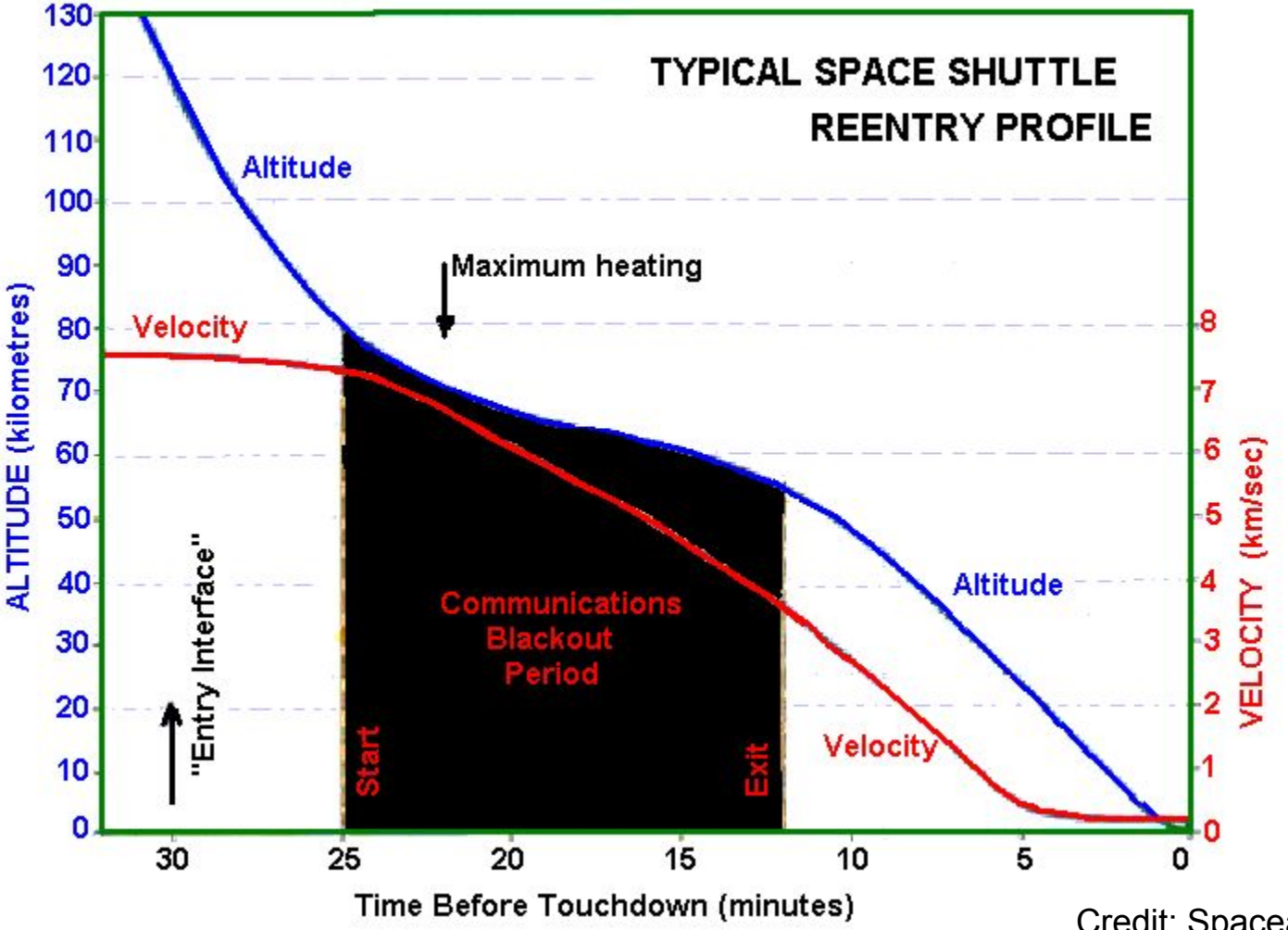

esa
TUDelft

Credit: NASA

Credit: NASA

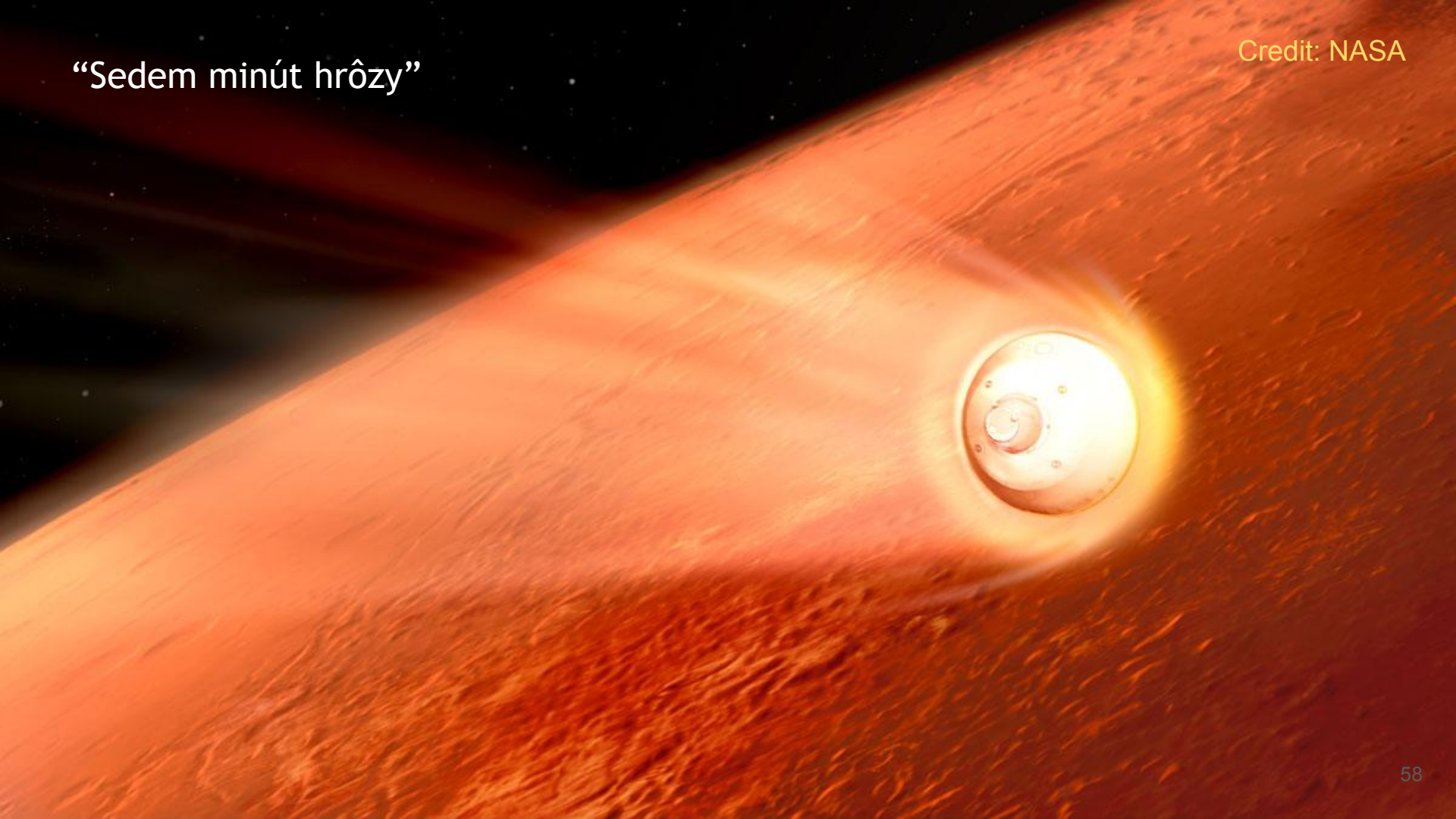
Takashi et al. 2016





Credit: Spaceacademy,net

“Sedem minút hrôzy”



Credit: NASA

Credit: NASA

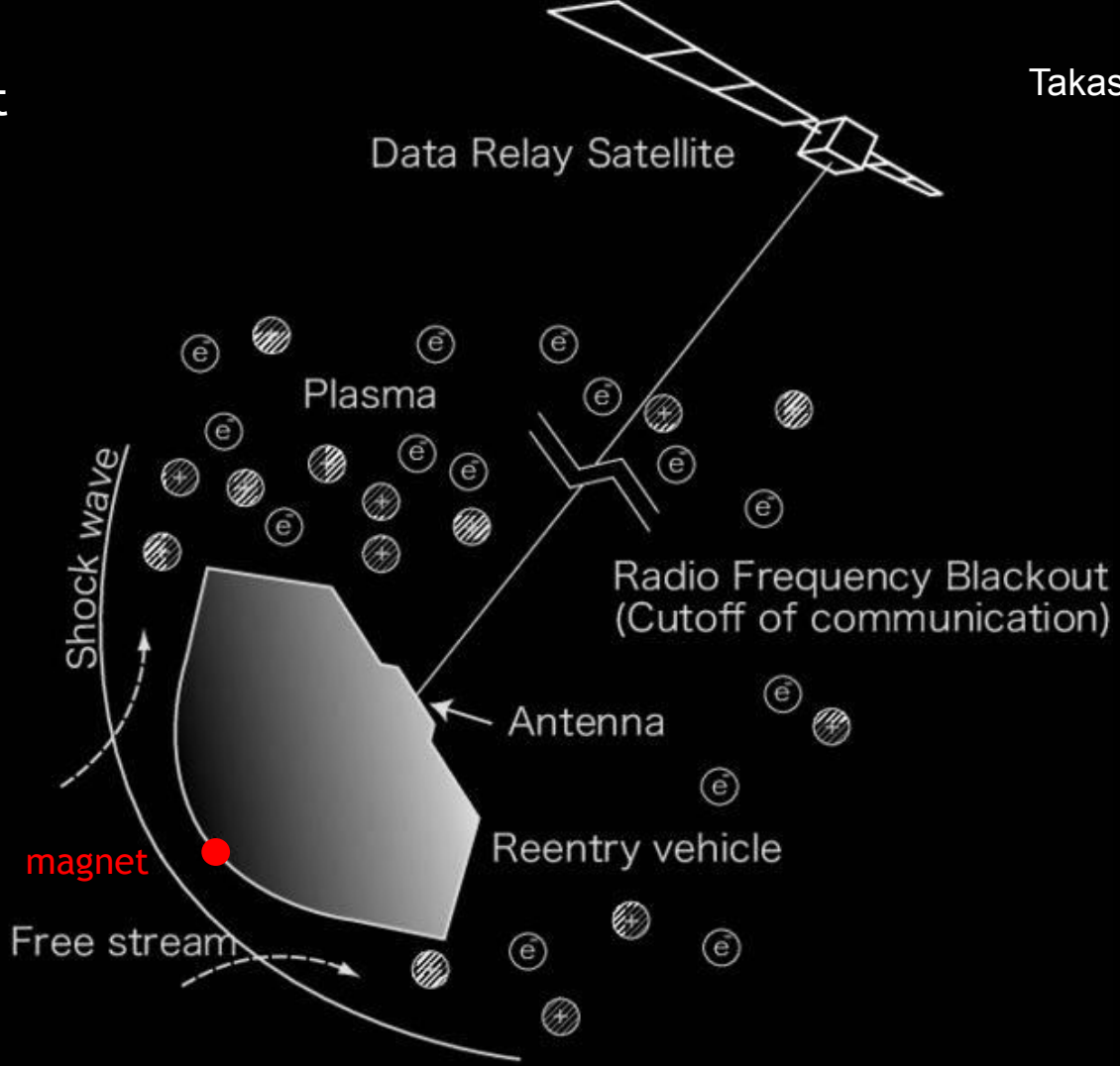
“Sedem minút hrôzy”

- Posun kvôli vzdialenosti
- Neschopnosť komunikácie
- Obrovské zahrievanie

Vieme s tým niečo spraviť?

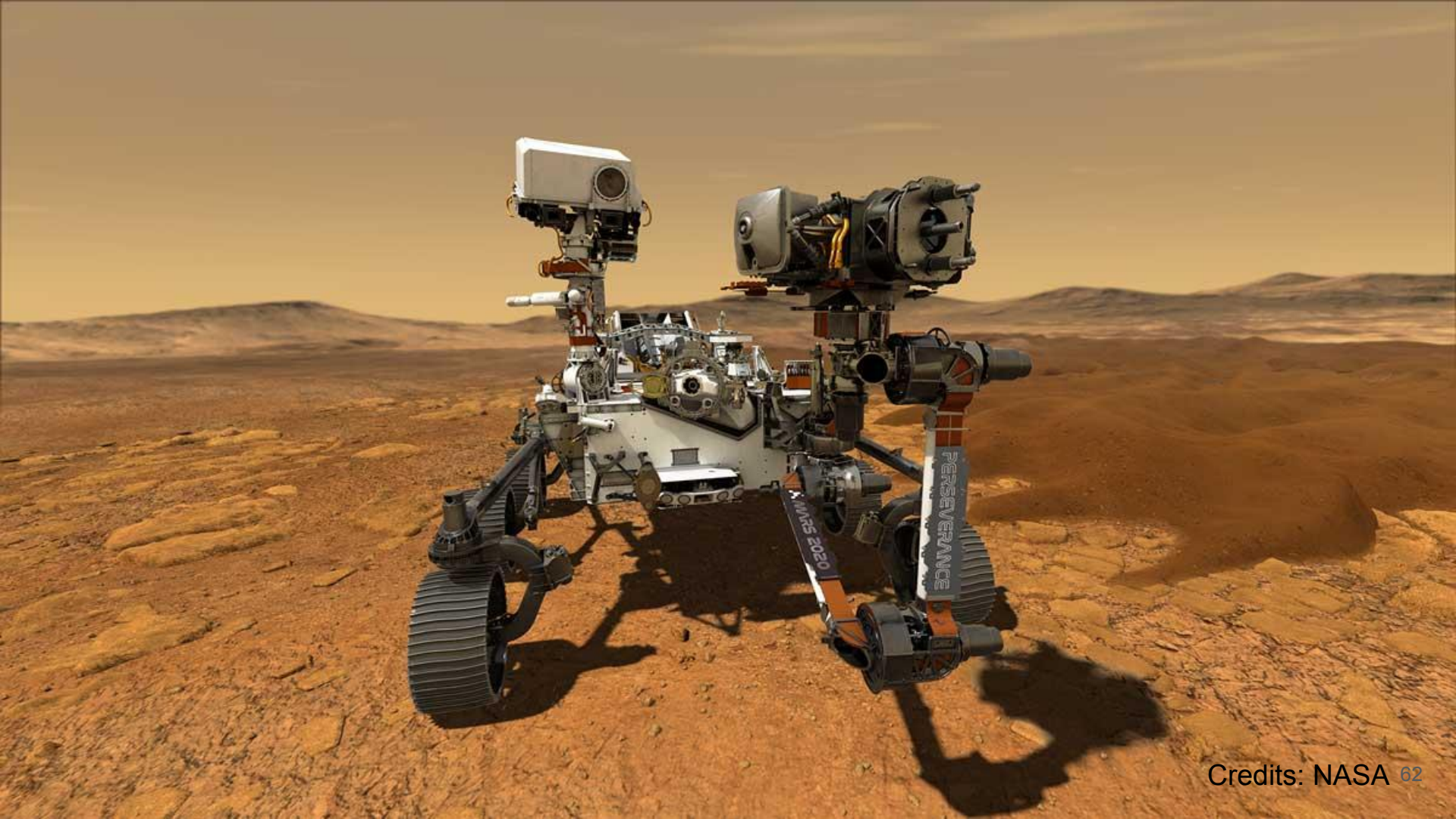
MEESST project

Takashi et al. 2016



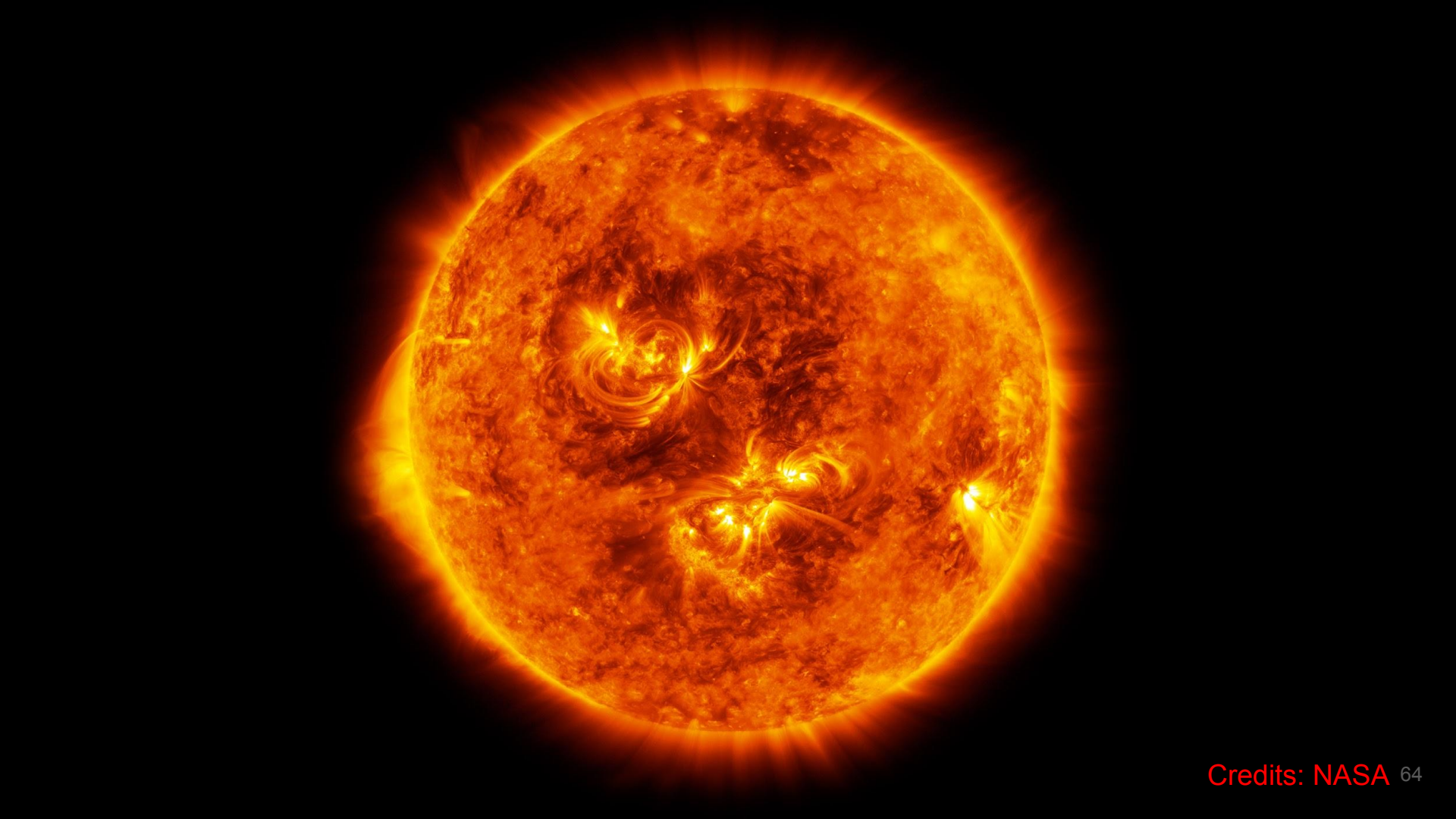
Čo treba k úspešnej vesmírnej misii?

1. Vyletieť
2. Preletieť
3. Doletieť
4. **Prežiť**



Credits: NASA

Credits: wp.com



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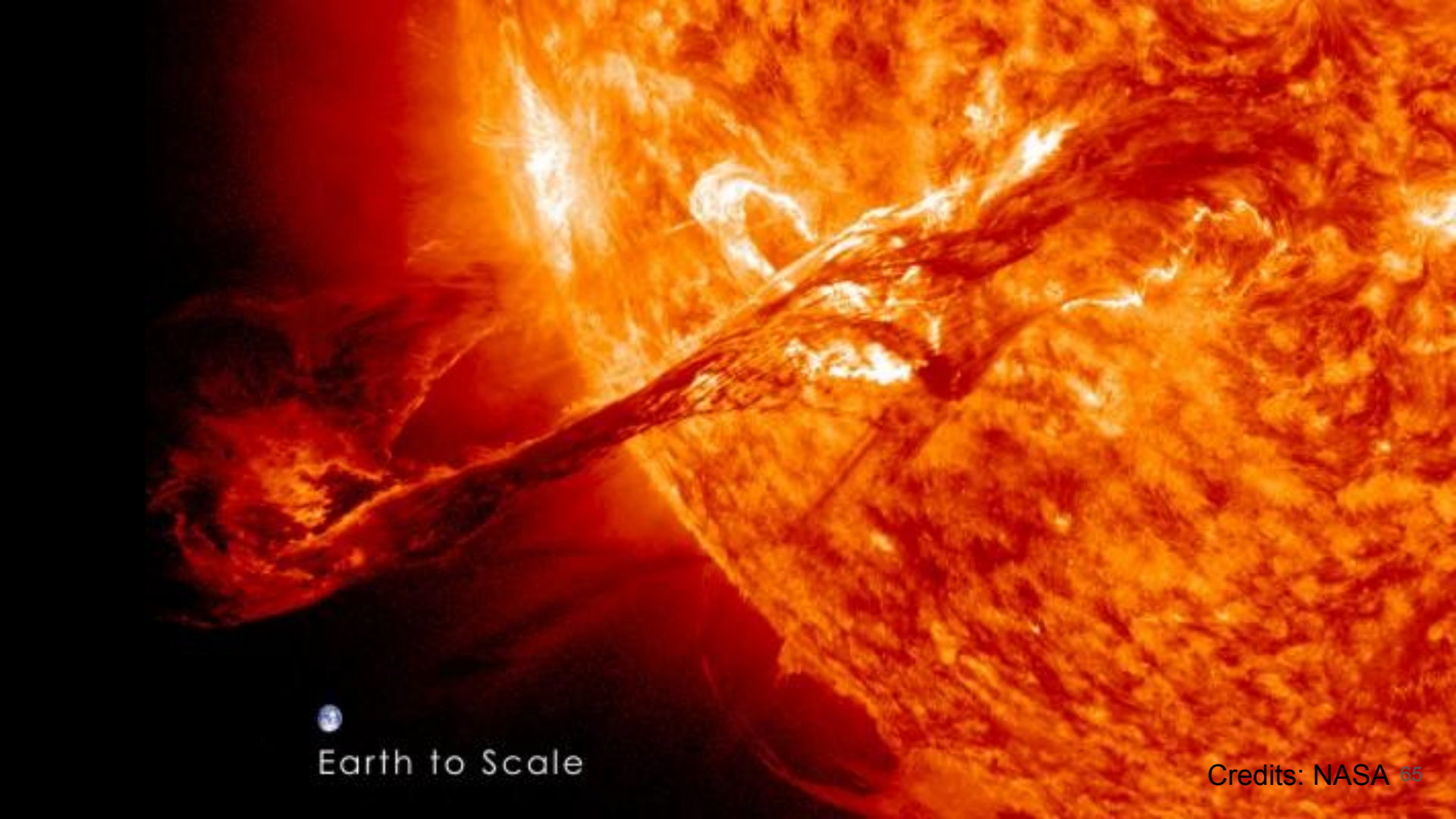
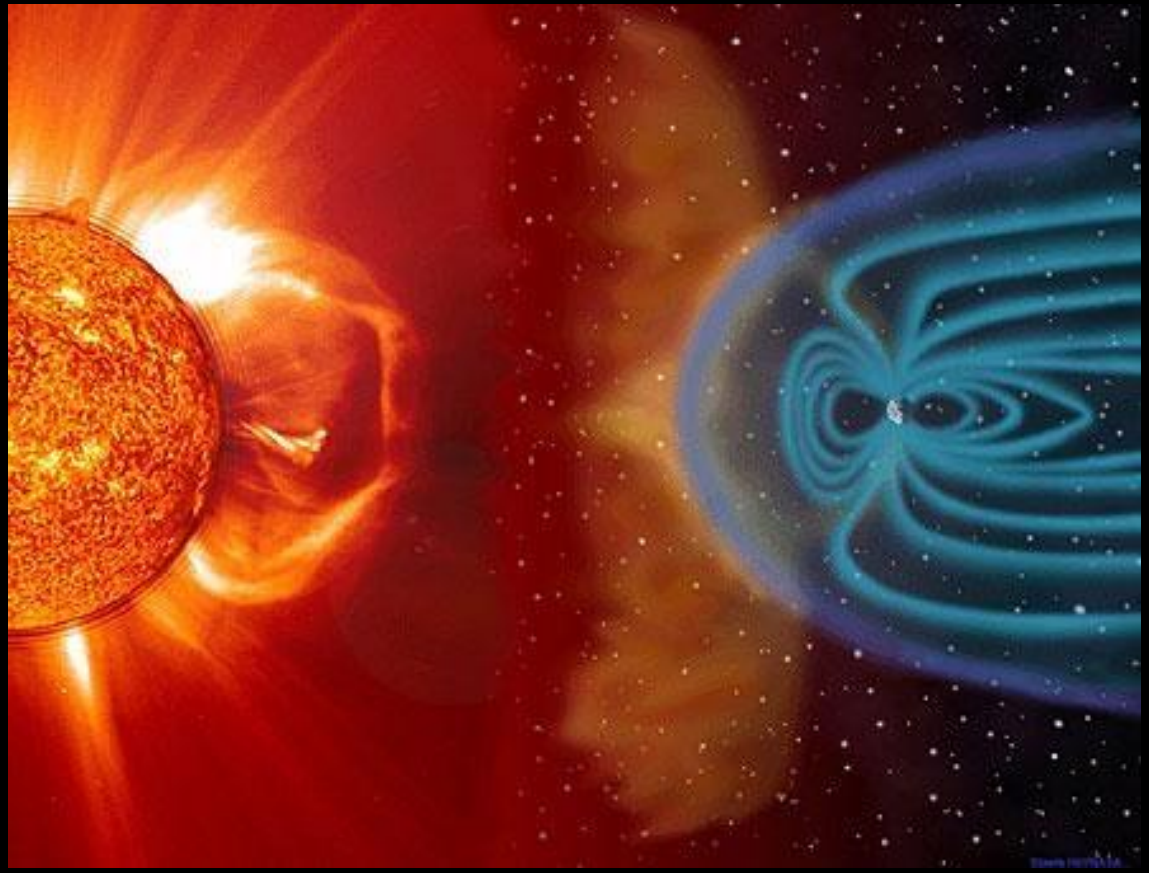


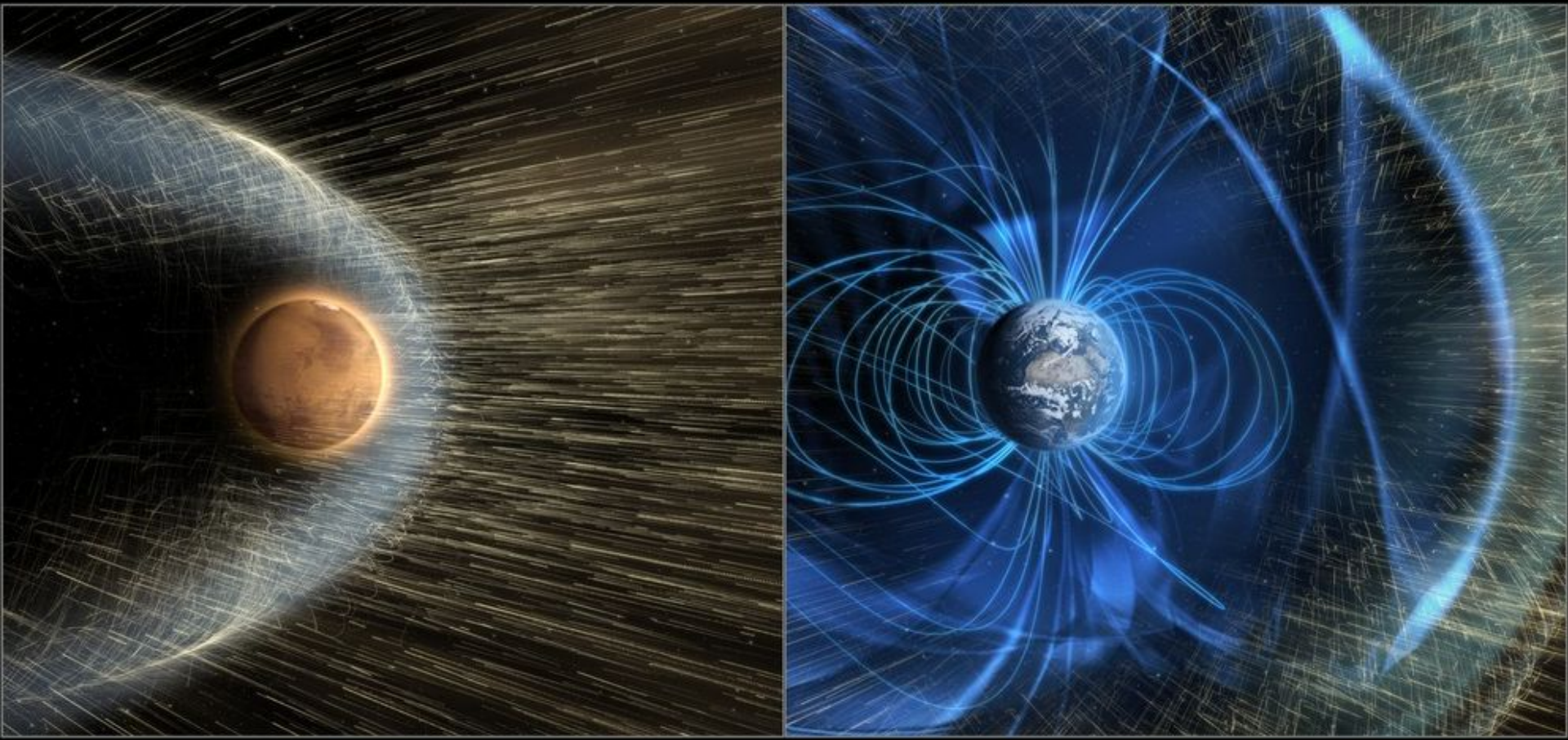
Credits: NASA

“Slnečný vietor”



Credits: NASA

Credits: Getty Images



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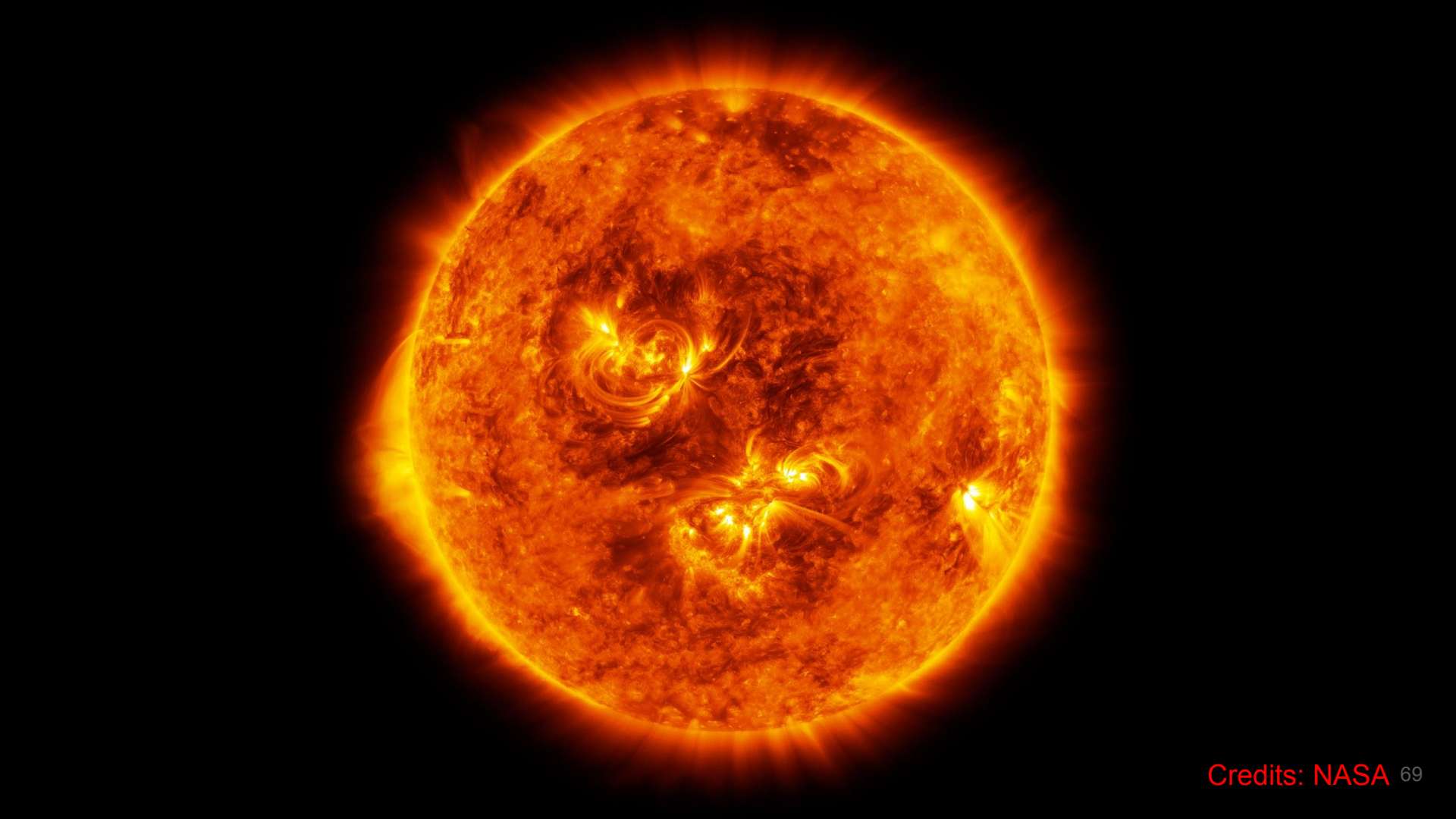


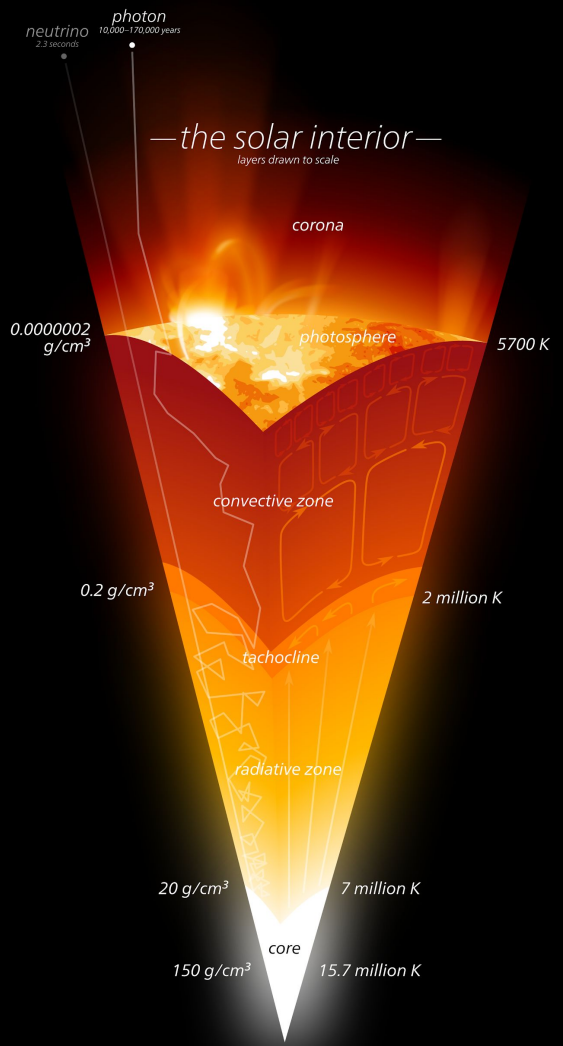
Credits: NASA

1 milión deg C

5000 deg C

2 milióny deg C

16 miliónov deg C



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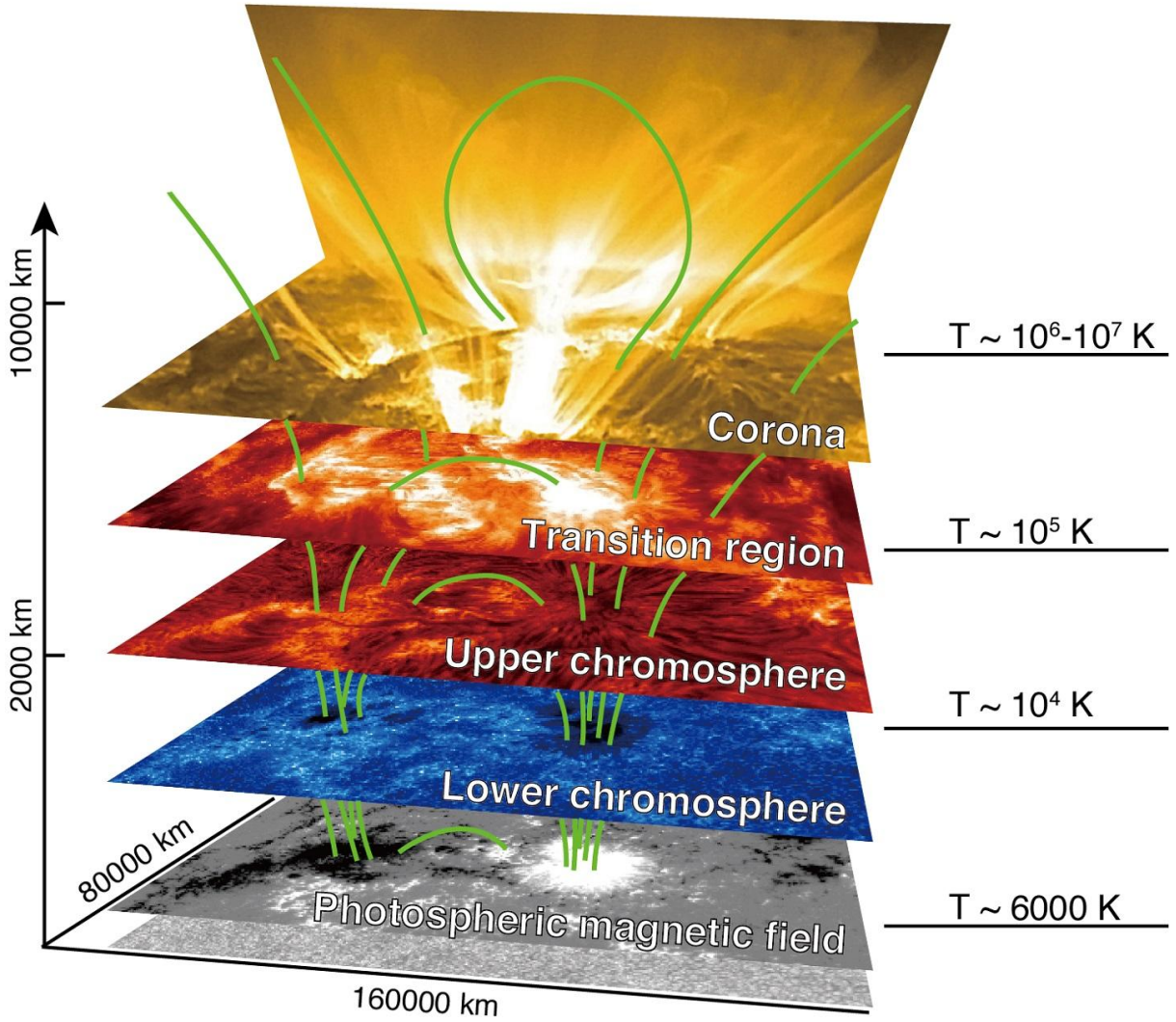
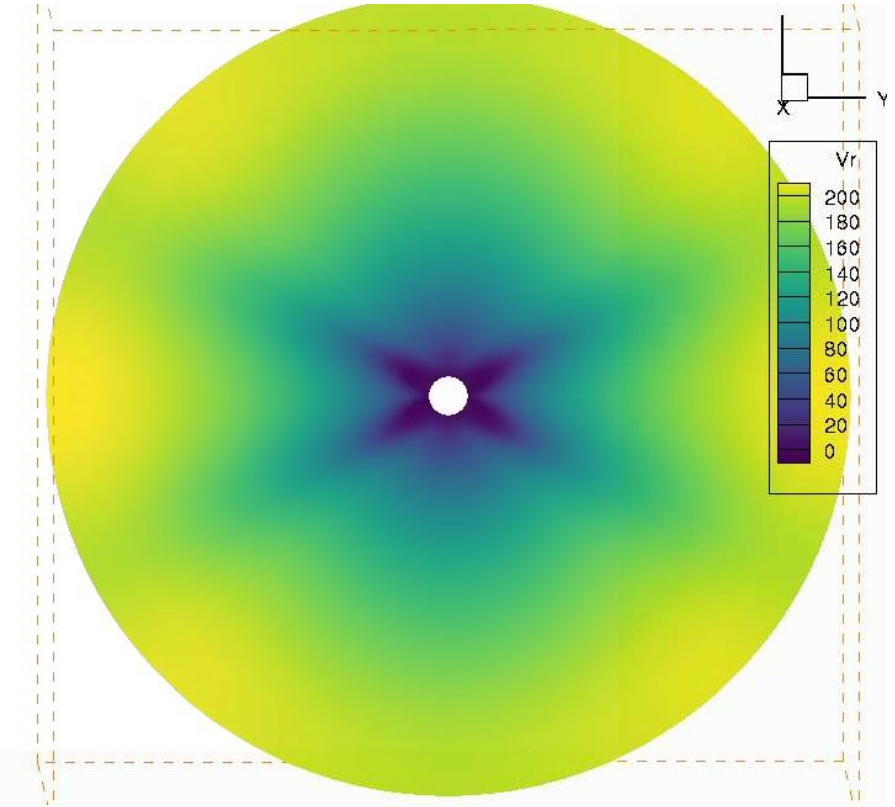
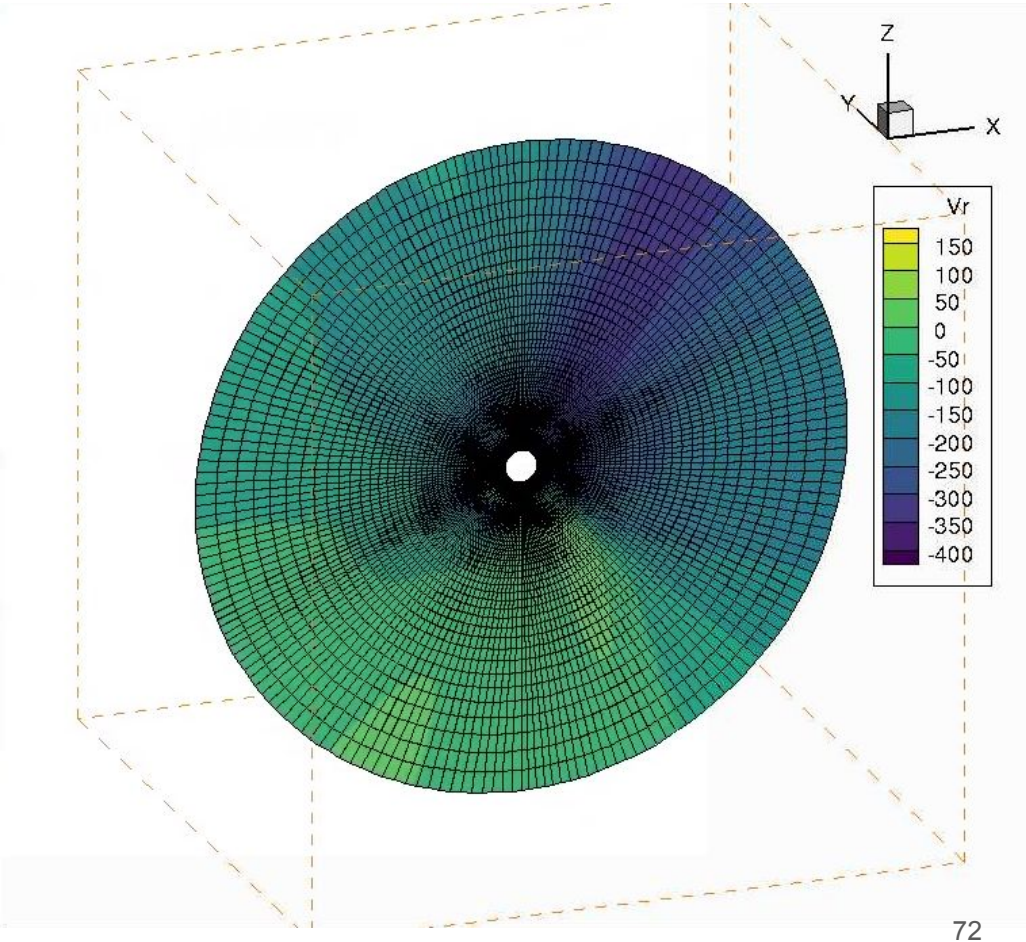
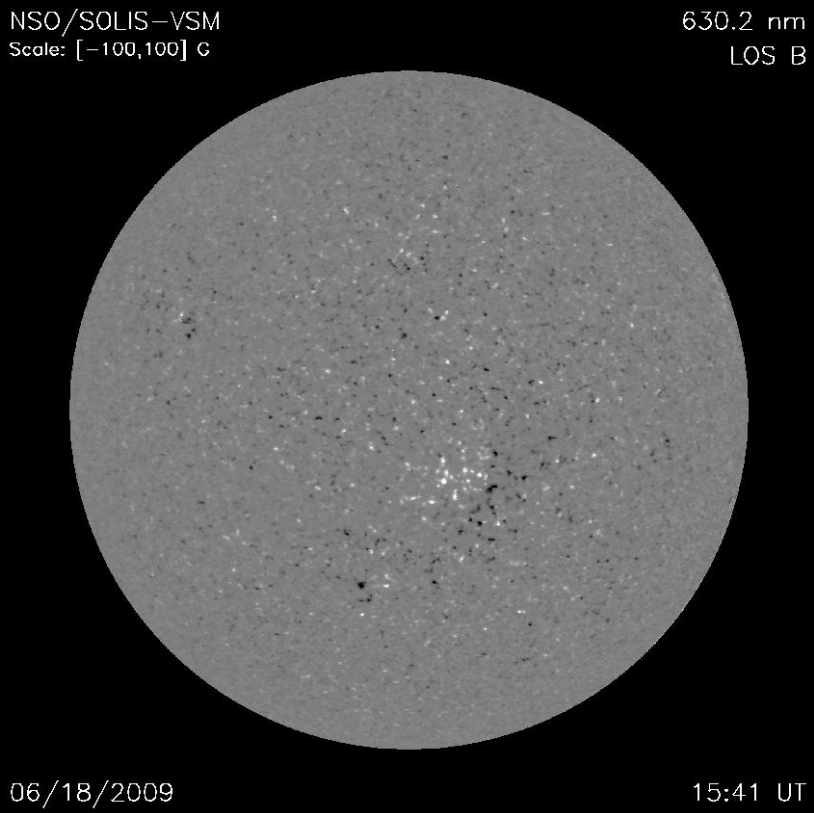


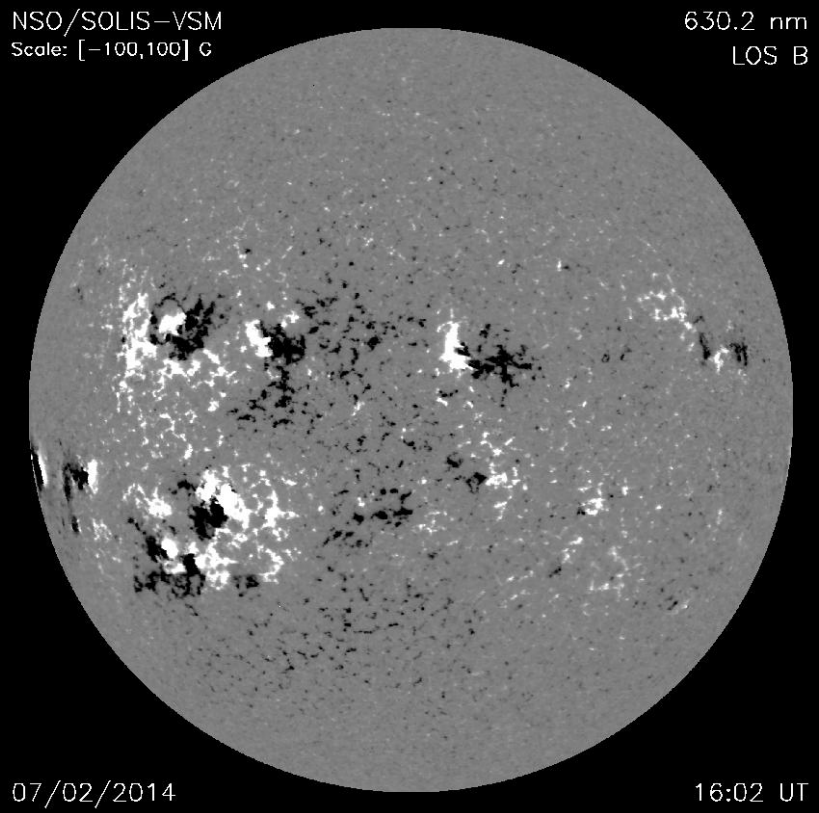
Credits: NASA

Numerické modelovanie





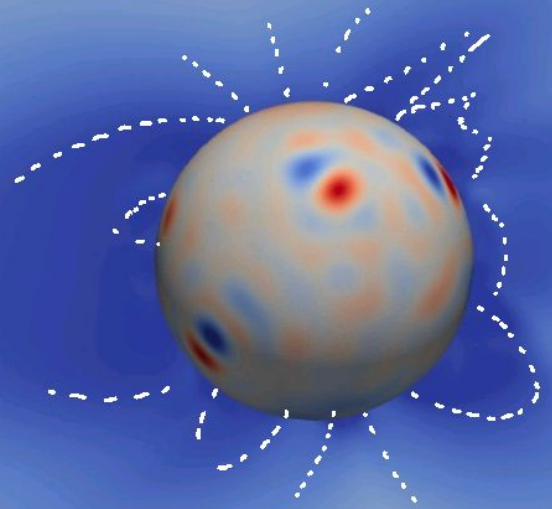


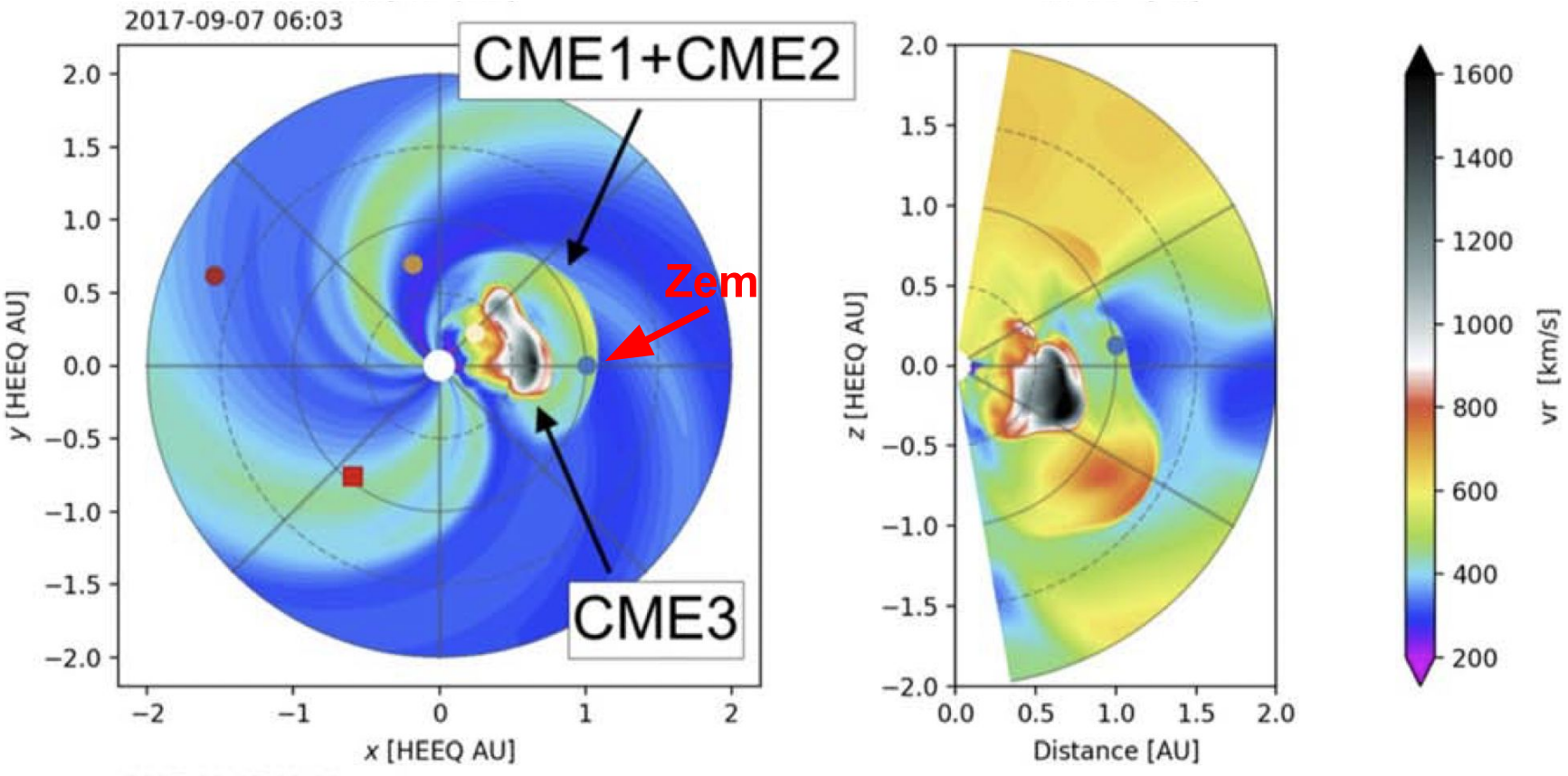


Credits: NSO/SOLIS

Zatmenie Slnka 2021

Numerický model

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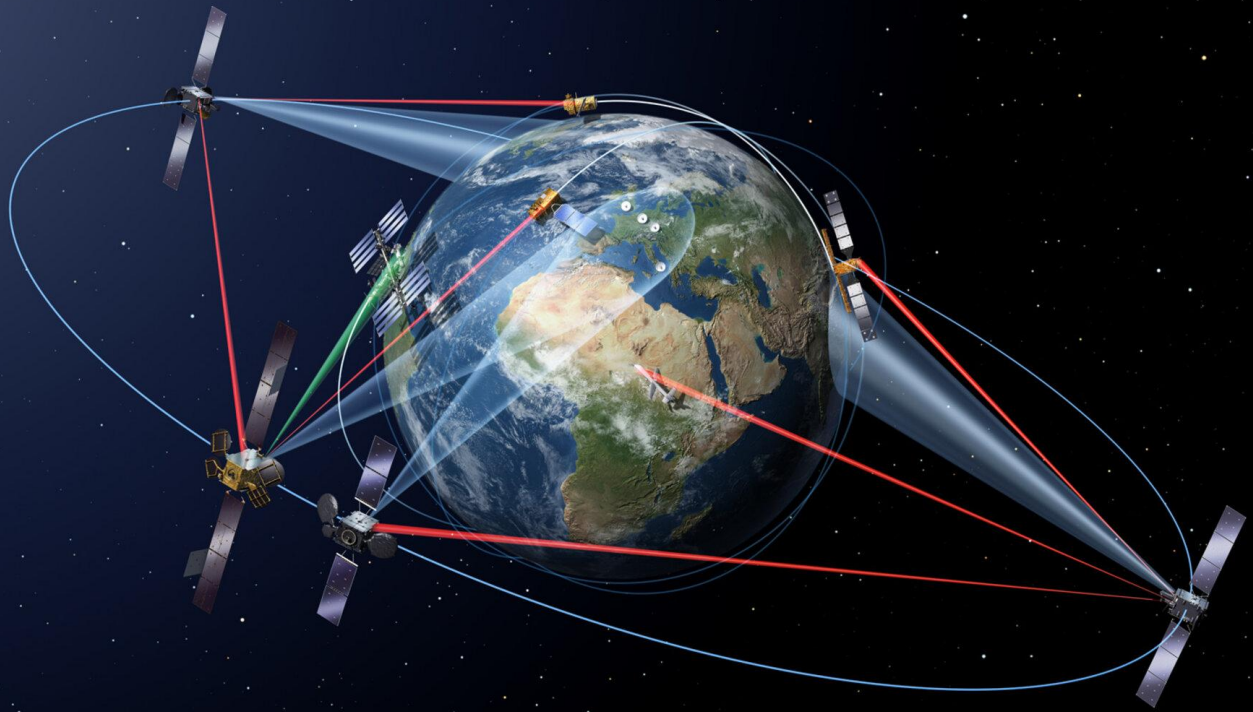


Credits: NASA

KU LEUVEN

TU Delft
Delft University of Technology

Ďakujem za pozornosť!

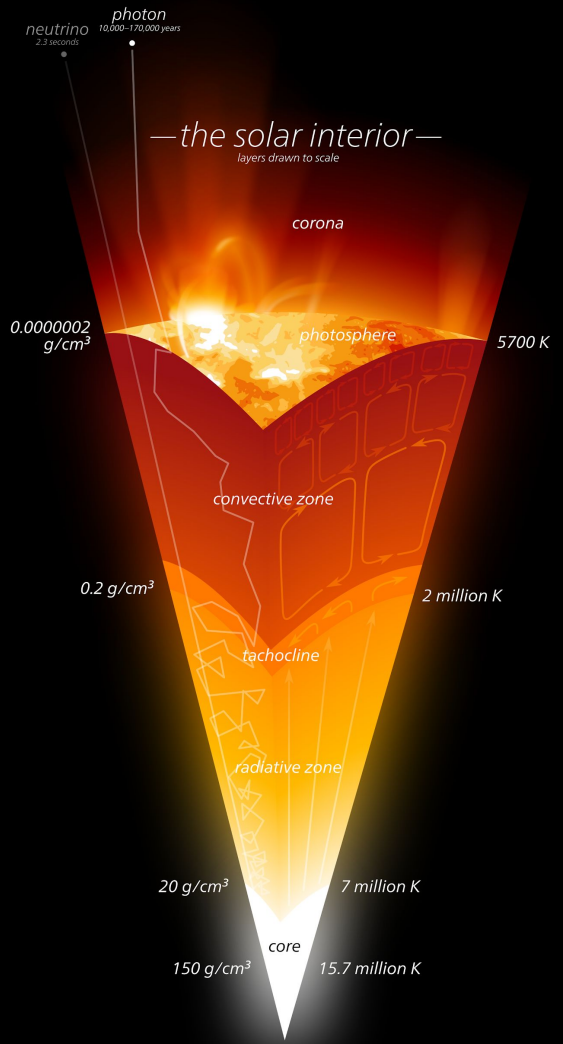
michaela.brchnelova@kuleuven.be

1 milión deg C

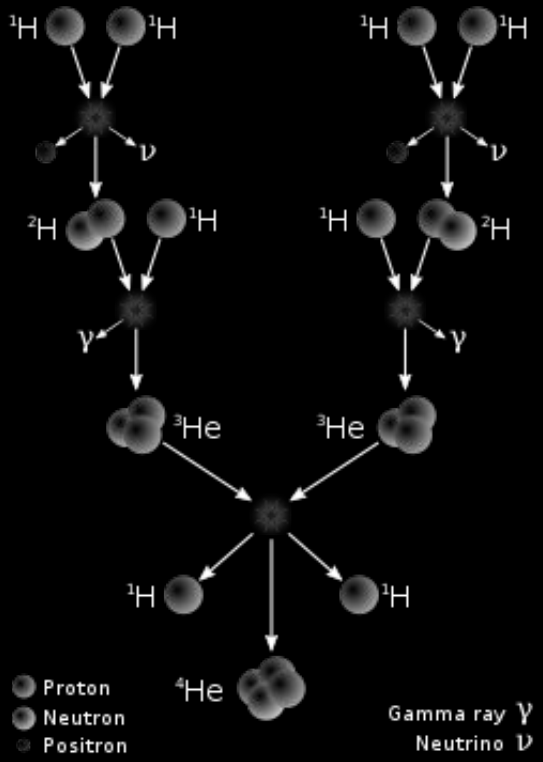
5000 deg C

2 milióny deg C

16 miliónov deg C

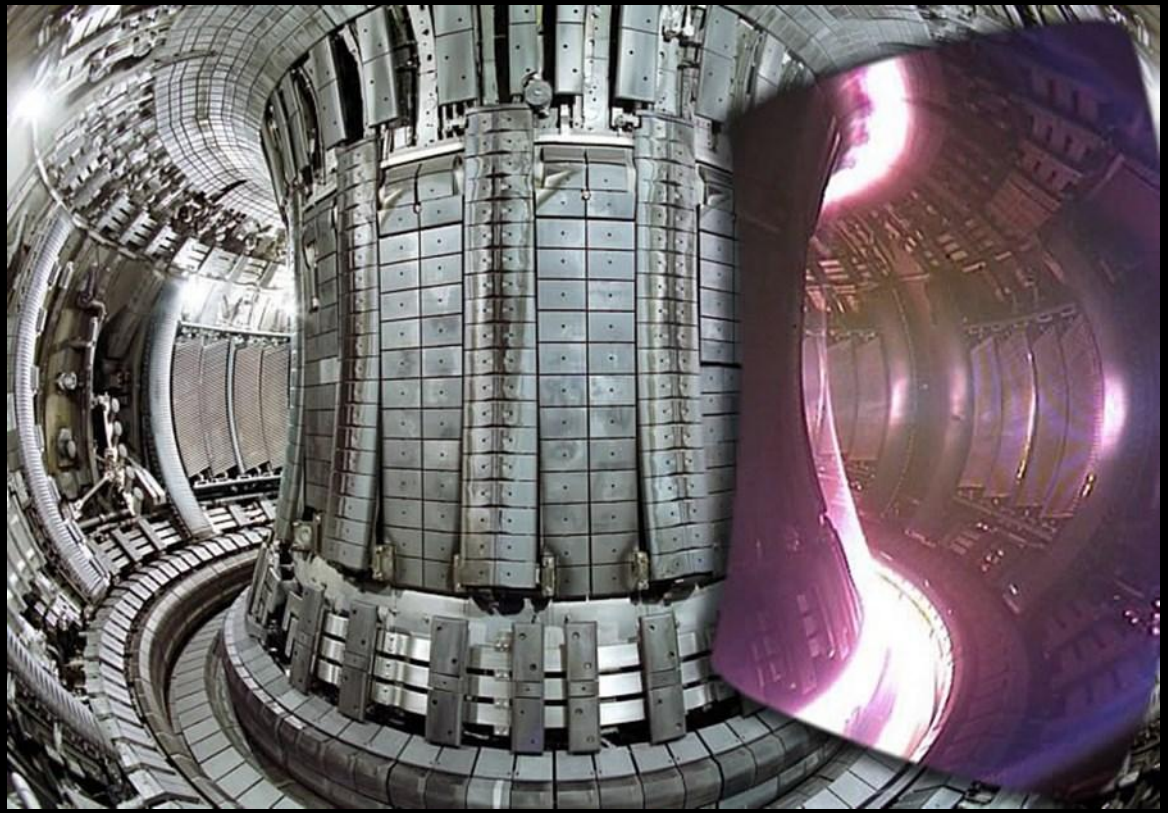


H → He

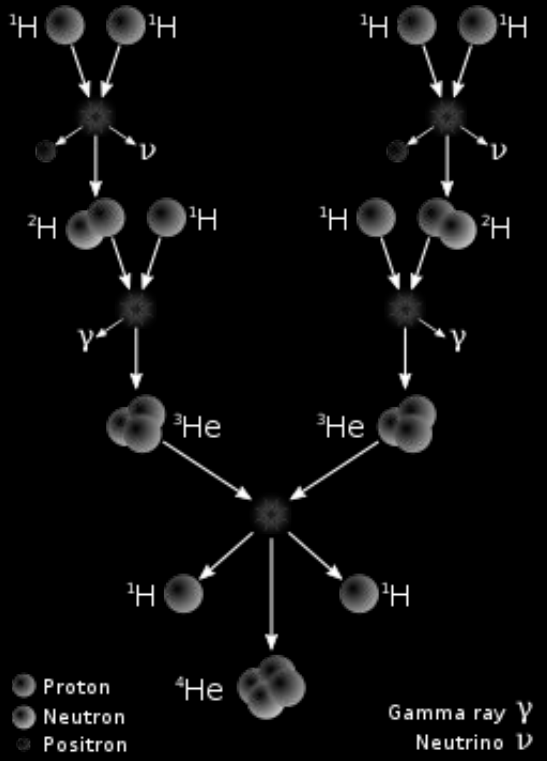


Credits: NASA

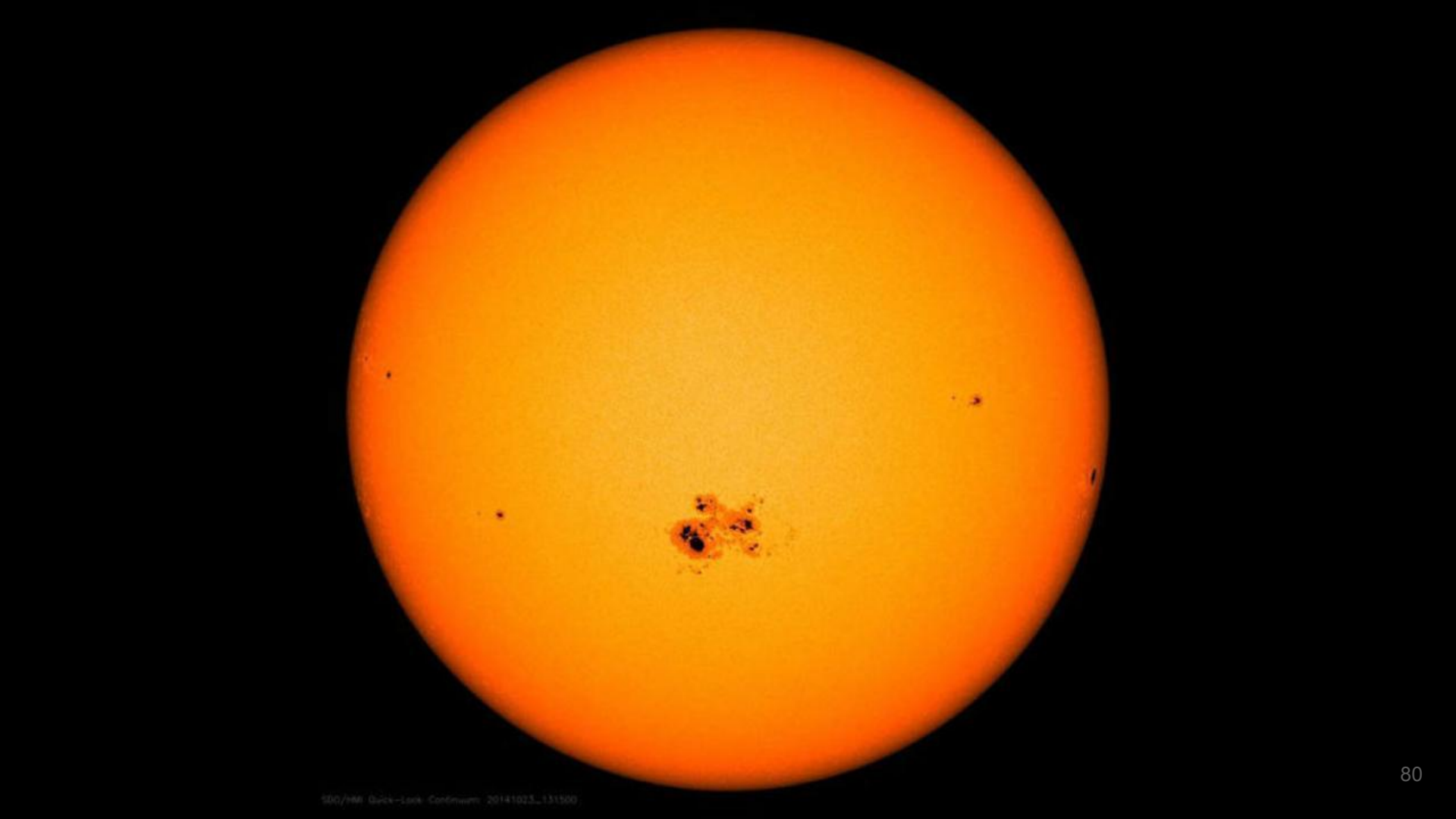
Trítium + Deutérium → Hélium + neutrón + 17.6 MeV

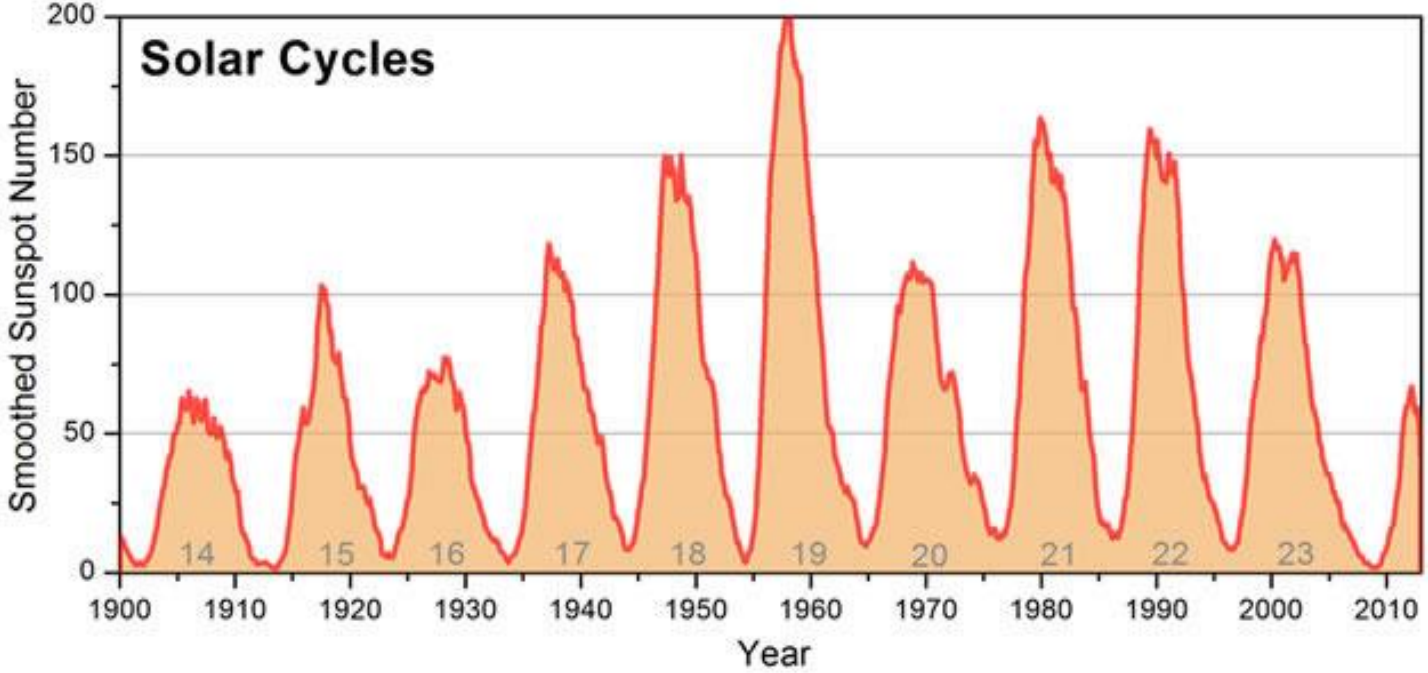


H → He



Credits: ITER


SDO/HMI Quick-Look Continuum 20141023_131500


Solar Cycles
Smoothed Sunspot Number
200
150
100
50
0
14
15
16
17
18
19
20
21
22
23
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Year