Plasmas for in-situ resource utilization on Mars

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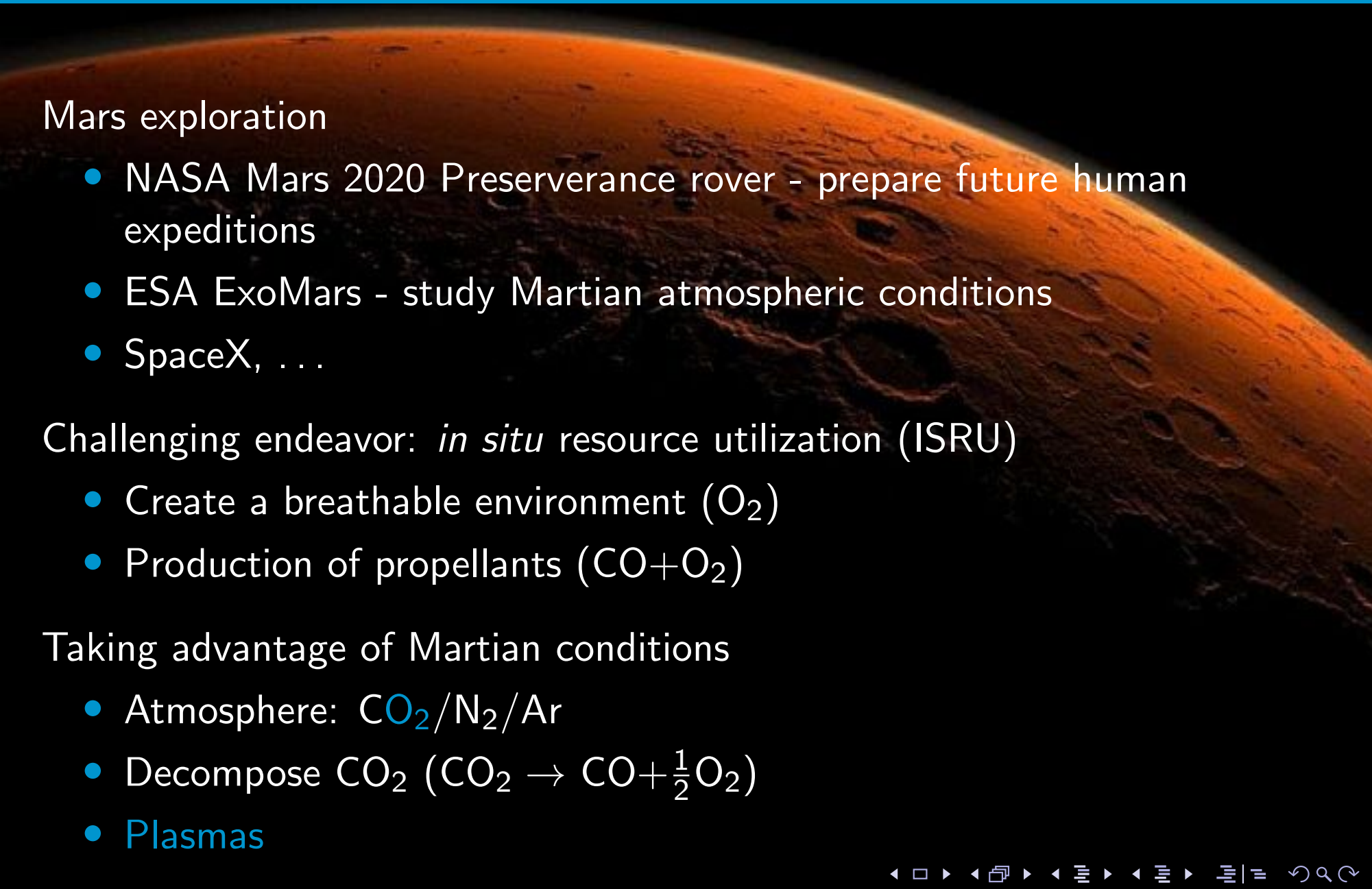
Travelling to Mars



Mars exploration

- NASA Mars 2020 Preserverance rover - prepare future human expeditions
- ESA ExoMars - study Martian atmospheric conditions
- SpaceX, ...

Challenging endeavor: *in situ* resource utilization (ISRU)

- Create a breathable environment (O_2)
- Production of propellants ($CO+O_2$)

Taking advantage of Martian conditions

- Atmosphere: $CO_2/N_2/Ar$
- Decompose CO_2 ($CO_2 \rightarrow CO+\frac{1}{2}O_2$)
- Plasmas

Looking ahead

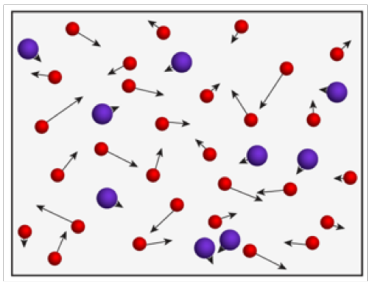
Martian atmosphere: $CO_2/Ar/N_2$

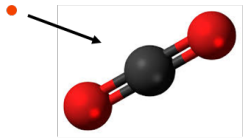
- Oxygen and nitrogen are the building blocks to produce nitrogen-based fertilizers
- Carbon
  - also a fertilizer
  - manufacturing of carbon structures
  - synthesis of organic molecules

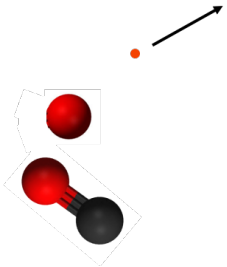
Decomposing CO_2: why plasmas?

Selective use of energy!

- Free electrons are easily accelerated
- Ions and neutrals remain "cold"
- Unique channels to break the C=O bond

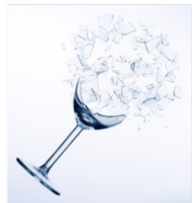


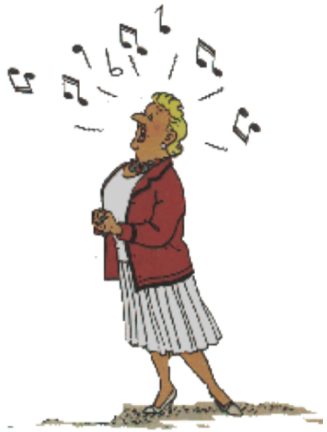




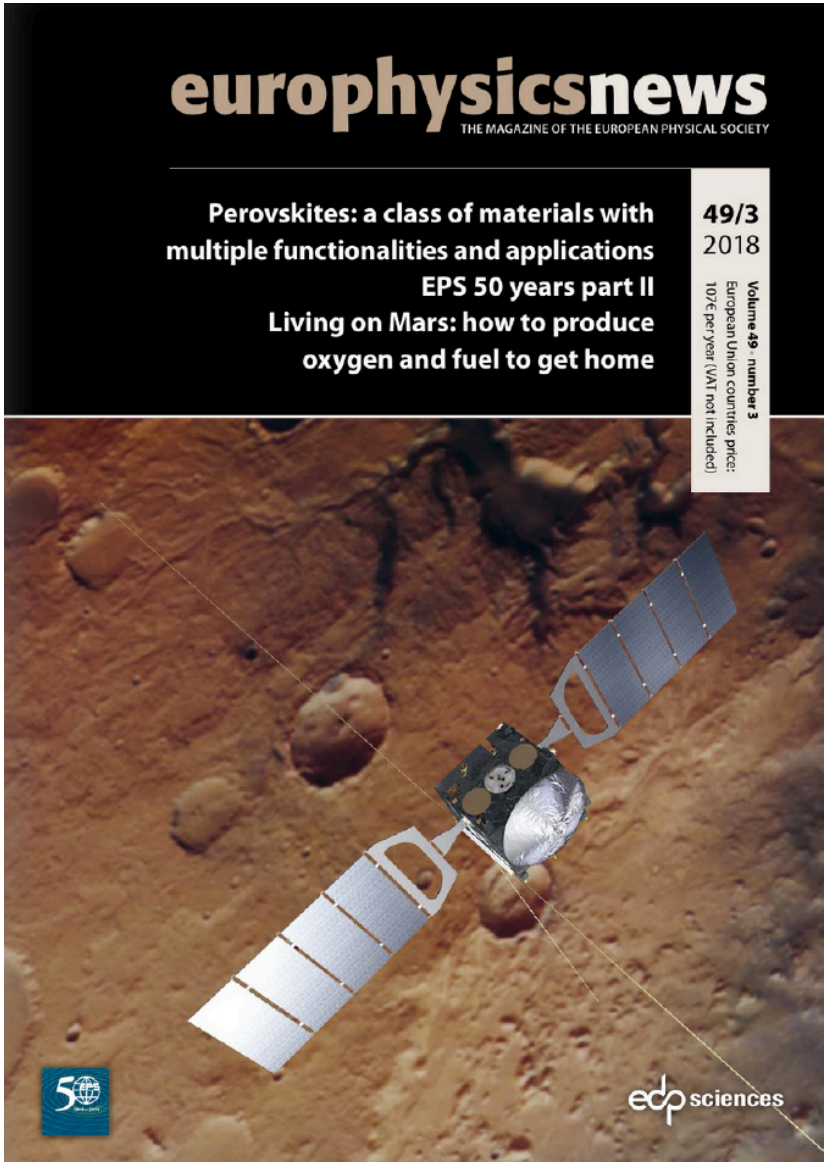
- Direct collision is inneficient
- But it is easy to make the molecule vibrate...

  ...and we can make it "sing"!





ISRU on Mars



Mars has excellent conditions for *In Situ Resource Utilisation* by plasma!

- $\sim$ 96% CO_2 atmosphere
- Traces of N_2 and Ar
- Lower pressures
- Lower temperatures

[V. Guerra *et al*, *PSST* **26** (2017) 11LT01]

[V. Guerra *et al*, *EPN* **49** (2018) 15-18]

Subsequent work:

- prove these ideas!
- joint experimental / modelling investigation

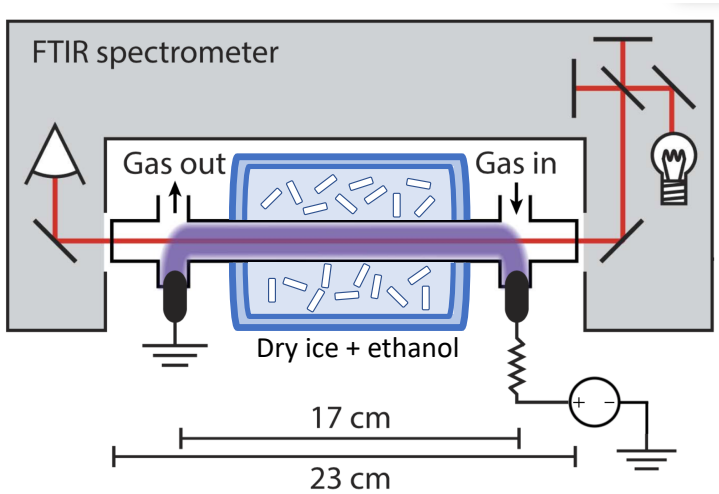
[P Ogloblina *et al* *PSST* **30** (2021) 065005]

DC discharge in Martian conditions

Fourier Transform Infra Red spectroscopy

DC discharge
$I = 10 - 50$ mA
$p = 1 - 5$ Torr
Mixture of ethanol and dry ice ~ 200 K
Temperature of the gas $\sim 220 - 230$ K

Experiments performed @ LPP (O.Guaitella)

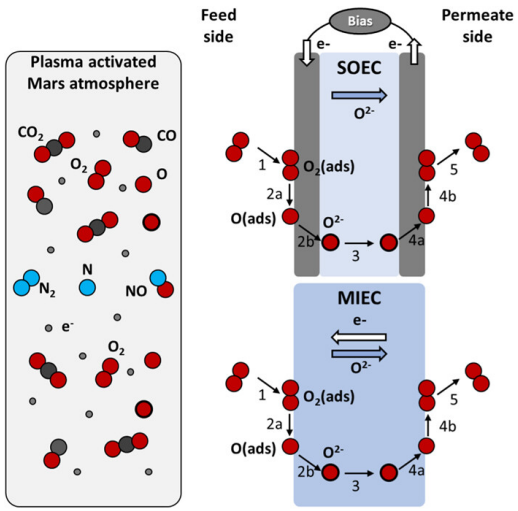


Dissociation fractions ~30%

Recent developments: product separation

Critical steps: decomposing CO_2 & separation

- Coupling plasmas with a separation membrane (SOEC or MIEC)...
  ...solves both challenges at the same time!
- A true synergy!
  - Removal of O and O_2 prevents back reactions forming back CO_2
  - Plasma enhances the performance of the membrane
  - Plasma provides the heat to heat the membrane
  - Development @ DIFFER (R. van de Sanden & M. Tsampas)



Plasmas for *in situ* resource utilization on Mars: Fuels, life support, and agriculture

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COLLECTIONS

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Plasmolysis *vs* electrolysis

MOXIE: Mars OXygen In situ resource utilization Experiment

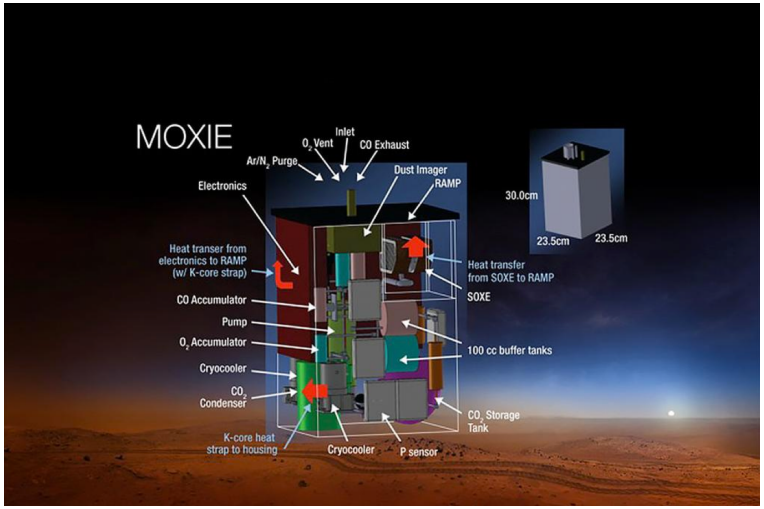
- 5.5g of O_2 per hour for $P = 300$ W
- 17 kg ; $24 \times 24 \times 31$ cm
- High temperature and high pressure

\+ Robust and ready technology

– Very low energy efficiency of $\sim 15\%$

– Scarce and expensive rare-earth metals

- 0.32 g O_2 per hour per kg



Plasma technologies

- Recently achieved energy efficiencies of $\sim 50\%$ for CO_2 decomposition
- 14g of O_2 per hour for $P = 250$ W
- 5 kg ; $25 \times 20 \times 5$ cm

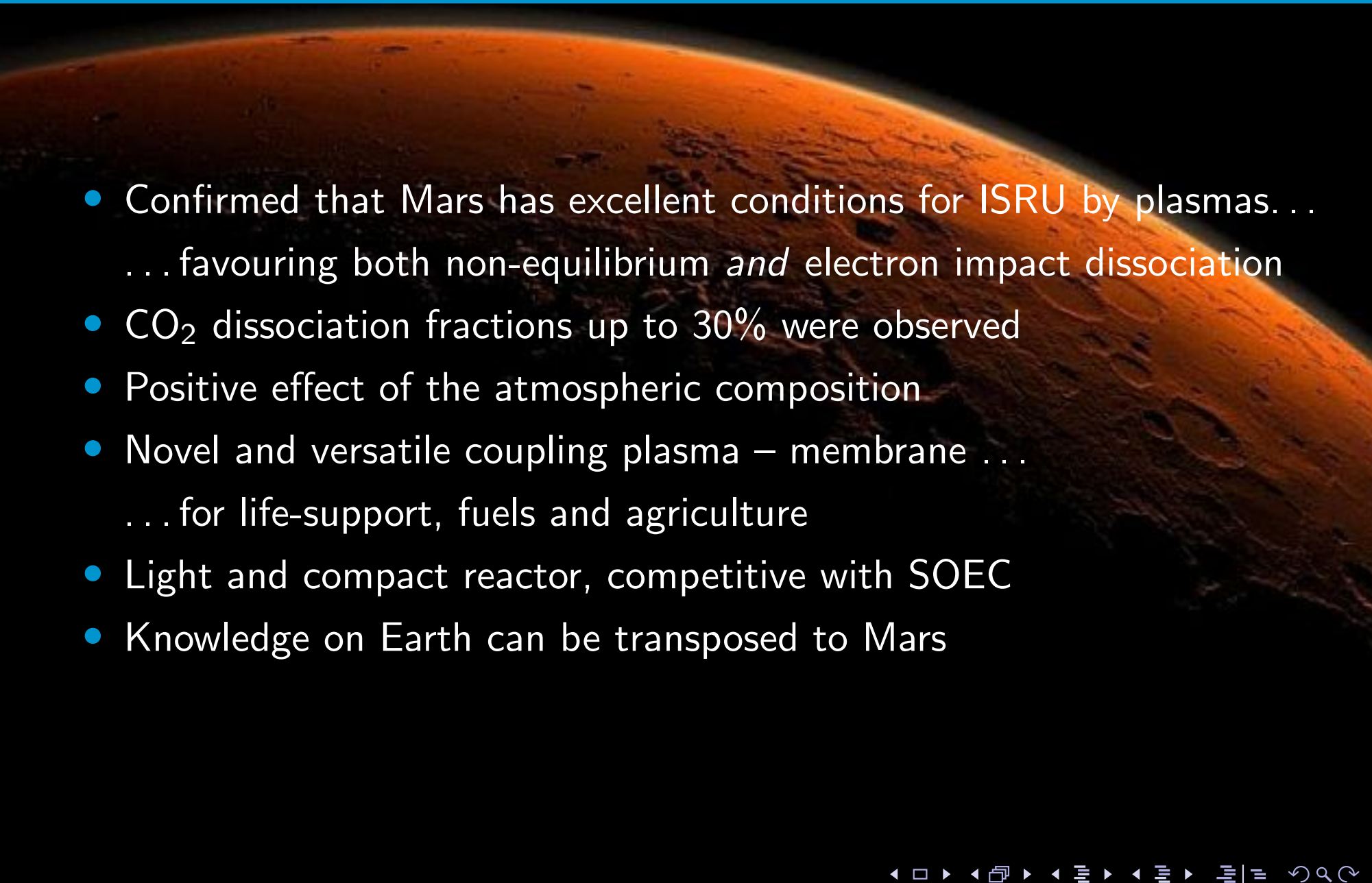
\+ Scalability and adequate for intermittent operation

\+ Versatility: the same device can be used to produce NO_x (and arrive at C)

– Product separation is still challenging

- 3.5 g O_2 per hour per kg

Conclusions



- Confirmed that Mars has excellent conditions for ISRU by plasmas...
  ...favouring both non-equilibrium *and* electron impact dissociation
- CO_2 dissociation fractions up to 30% were observed
- Positive effect of the atmospheric composition
- Novel and versatile coupling plasma – membrane ...
  ...for life-support, fuels and agriculture
- Light and compact reactor, competitive with SOEC
- Knowledge on Earth can be transposed to Mars