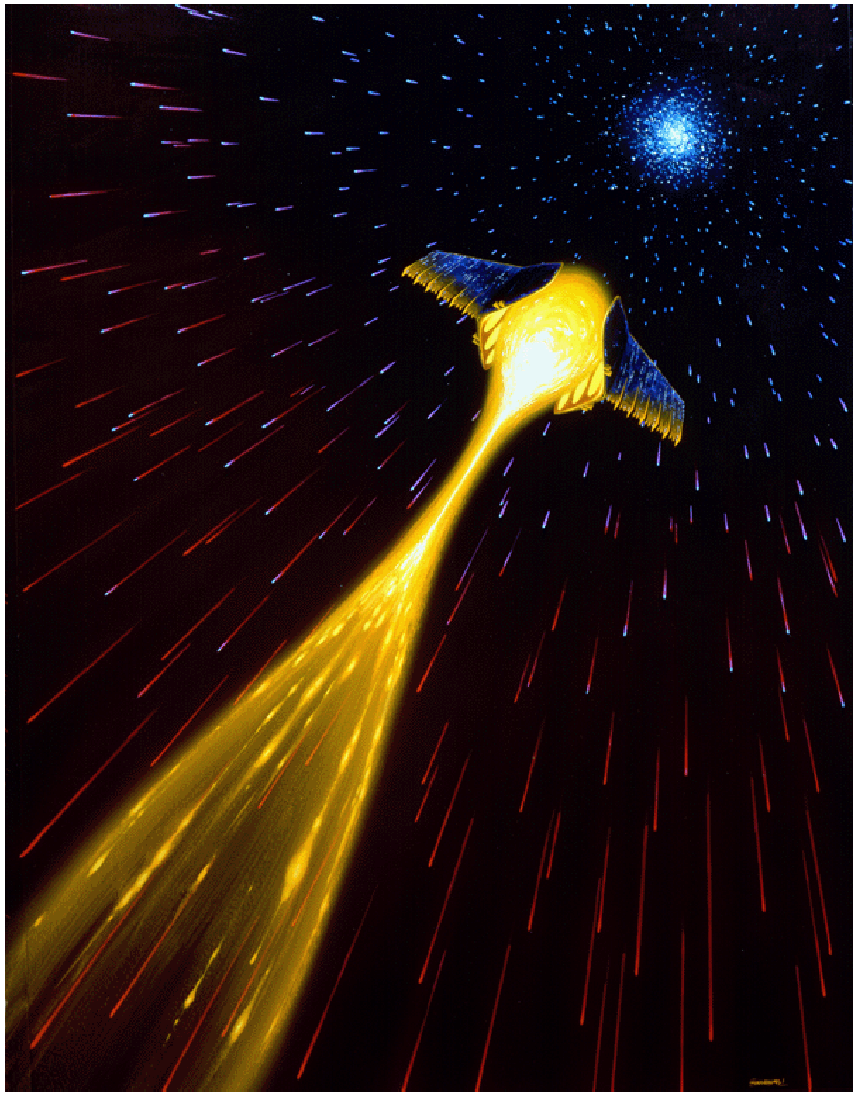


MOA: Magnetic field Oscillating Amplified thruster

The first technical application of Alfvén waves

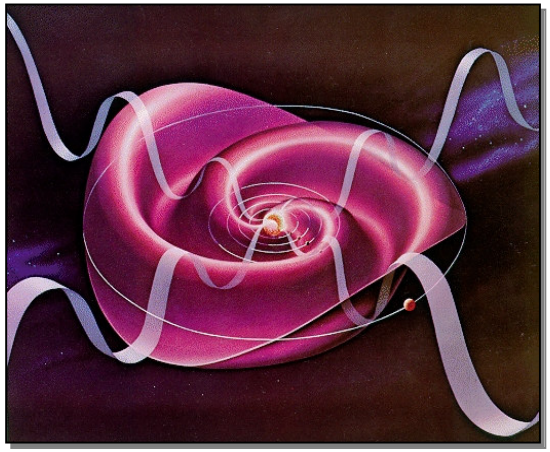
***N. Frischauf*, M. Hettmer, A. Grassauer, T. Bartusch, Prof. Otto Koudelka**

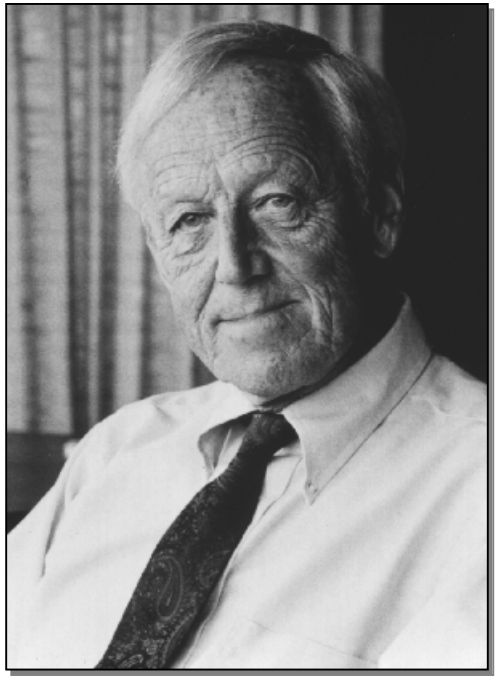
Outlook on this Presentation

- Introduction (Alfvén Wave Physics)
- Working Principle and Classification of the MOA Concept
- MOA in the Context of Advanced Propulsion
- Design and Test of the MOA Thruster
- Obtained Test Results
- Outlook
- Conclusion

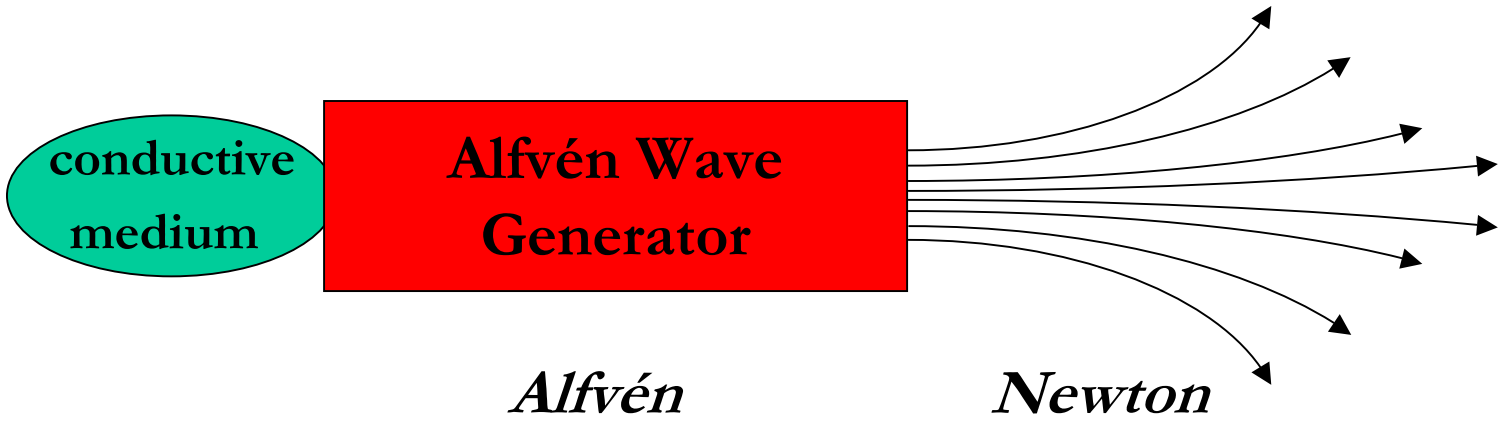
Introduction: Alfvén's Discovery

- ***Nature letter in 1942***
  - **Postulation that oscillating magnetic fields accelerate ionised matter via magneto-hydrodynamic interactions in a wave like fashion**
- ***Later observed in certain plasma phenomena, Wolf-Rayet stars and fusion reactors***





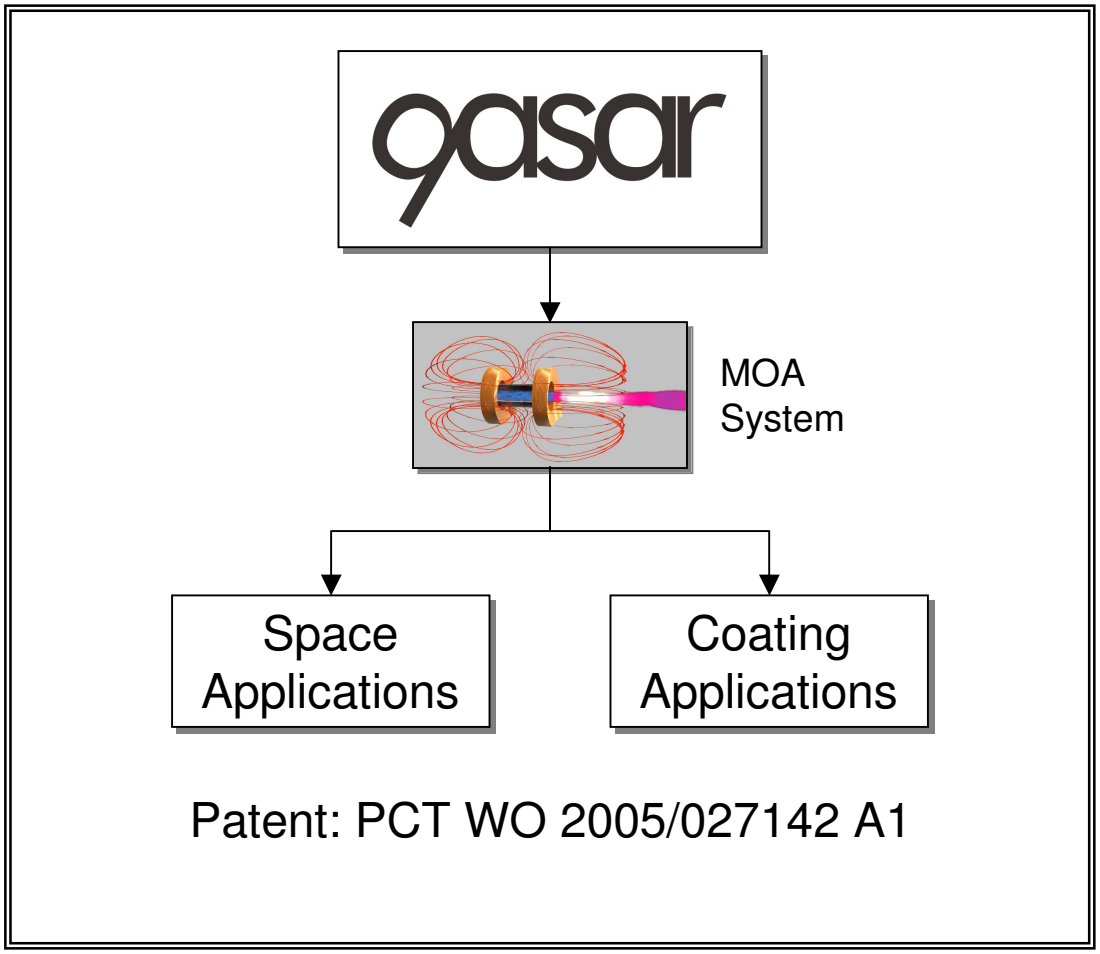
Working Principle and Classification of the MOA Concept



- The controlled use of a plasma source and two magnetic coils generates a periodically deformation of the system's magnetic field.
- This deformation generates Alfvén waves, which compress and transport the propulsive medium with high efficiency

⇒ **MOA is a thermo-electrodynamic accelerator!**

QASAR's Preliminary Products vs. potential Markets



MOA in the Context of advanced Propulsion (1/3)

- ***MOA is a flexible adv. Propulsion system***
  - **Different propellants can be used (N_2, H_2, Xe, etc.)**
  - **A real-time adaptation of MOA between the P, F and I_{SP} parameters is possible during flight**
  - **E.g. Xe-Thruster (simulation values):**
    - $P = 6.2\ kW;\ I_{SP} = 2411\ s,\ F = 236.5\ mN$
    - $P = 11.2\ kW;\ I_{SP} = 13116\ s,\ F = 12.9\ mN$
- ***MOA's superior I_{SP} can make a difference:***

Destination Planet	Total Velocity Increment [km/s]	Ratio of Fuel Mass to S/C Mass ($m_{Fuel}/m_{S/C}$)			
		Chemical Engine (SSME)	Nuclear Fission (NERVA)	MOA Concept	Nuclear Fusion (GDM)
		I_{SP} = 455 s	I_{SP} = 825 s	I_{SP} = 10000 s	I_{SP} = 126800 s
Moon	6,00	2,84E+00	1,10E+00	0,06	0,00484
Mars	25,00	2,70E+02	2,10E+01	0,29	0,02030
Saturn	70,00	6,47E+06	5,70E+03	1,04	0,05789
Pluto	180,00	3,26E+17	4,56E+09	5,26	0,15570

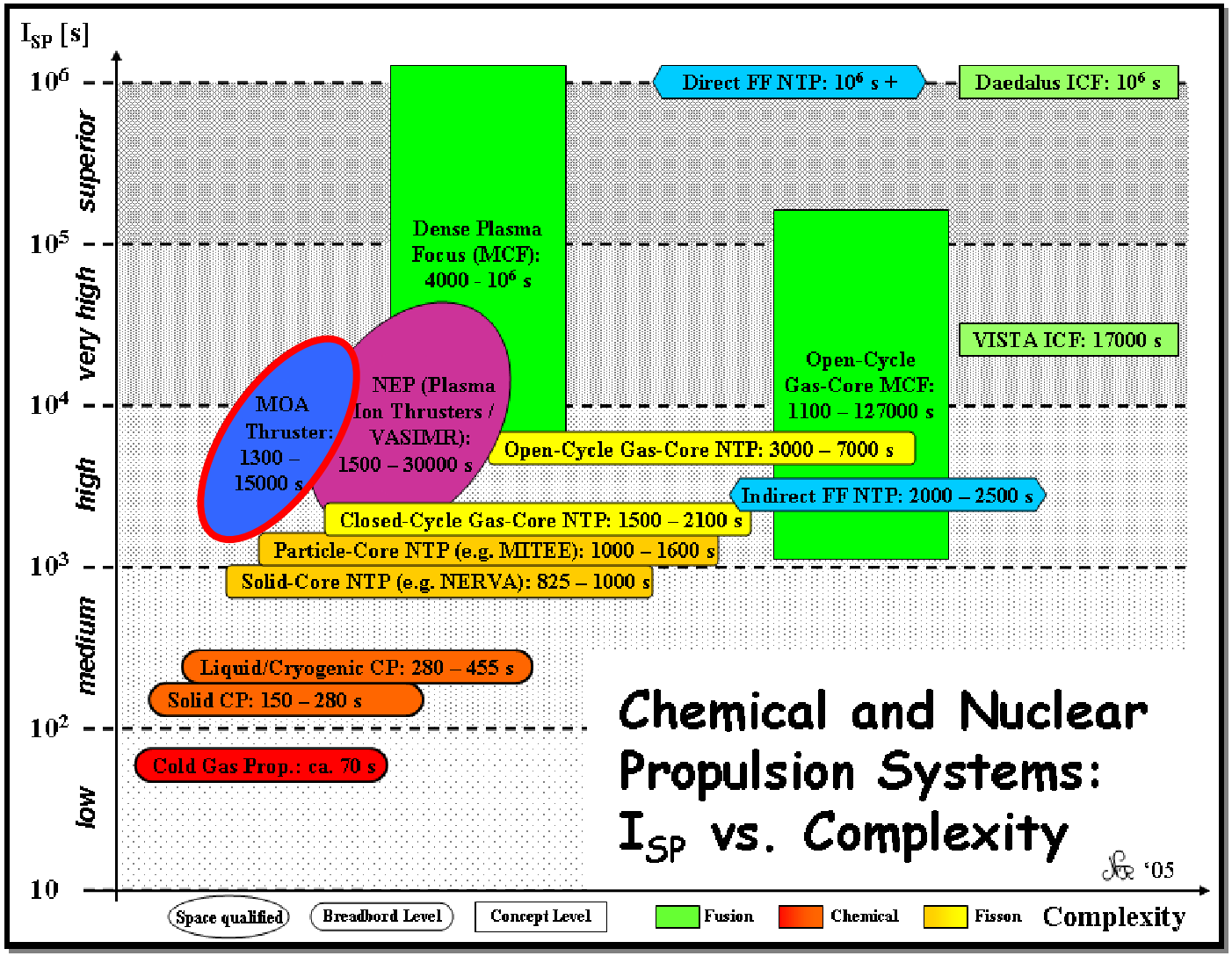
MOA in the Context of advanced Propulsion (2/3)

- ***MOA is suited for different applications:***
  - **Attitude Control System Thruster (ACST)**
  - **North South Station Keeping (NSSK)**
  - **Kick Booster**
  - **Thruster for deep space/interplanetary missions**
- ***Prof. Horst Löb has provided a positive expert opinion on the feasibility of the MOA concept***

MOA Thruster with H_2 propellant:	
Thrust:	80 mN
Beam Power:	1.6 kW
Specific Impulse:	4000 s
Specific Power Consumption:	20 W/mN

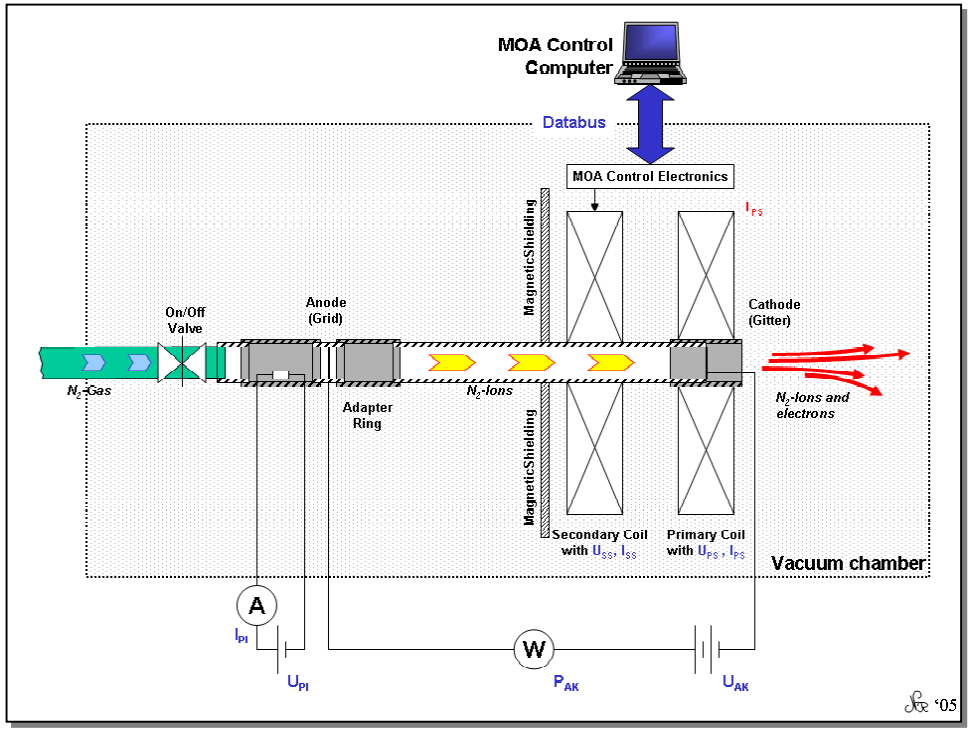
Table 1: Assumed Parameters of a MOA NSSK-System (Simulation Prof. Löb)

MOA in the Context of advanced Propulsion (3/3)

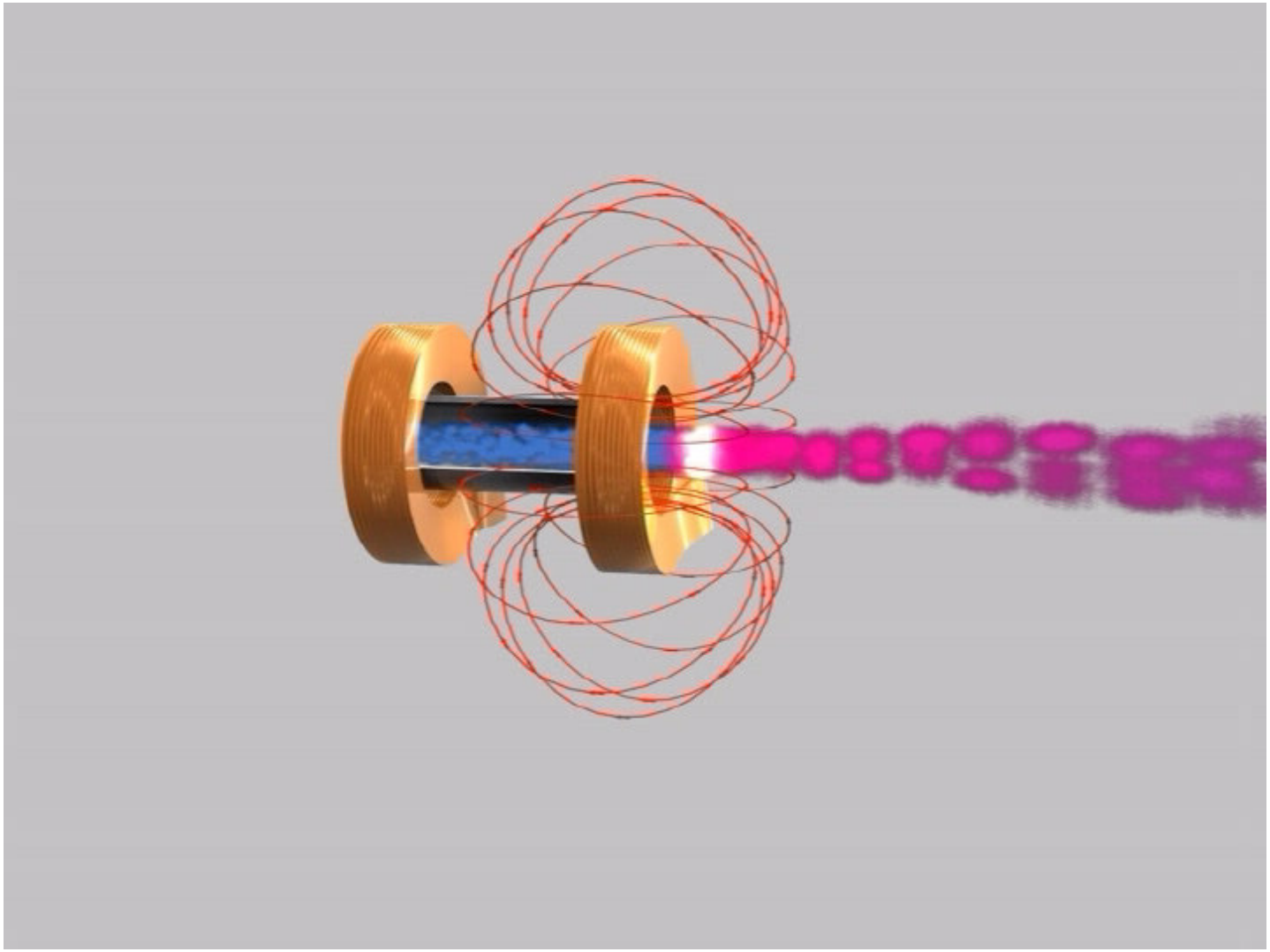


Design and Test of the MOA Thruster (1/3)

- ***MOA is the first technical application of Alfvén wave physics for adv. propulsion***
- ***MOA is comprised of five subsystems:***
  - **Plasma Generator**
  - **Central Tube**
  - **Primary Coil**
  - **Secondary Coil**
  - **Supply and Control Units**

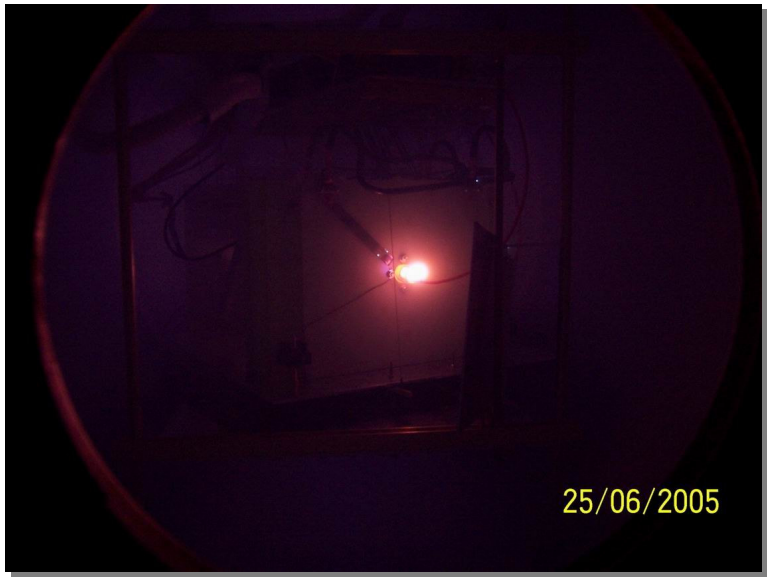


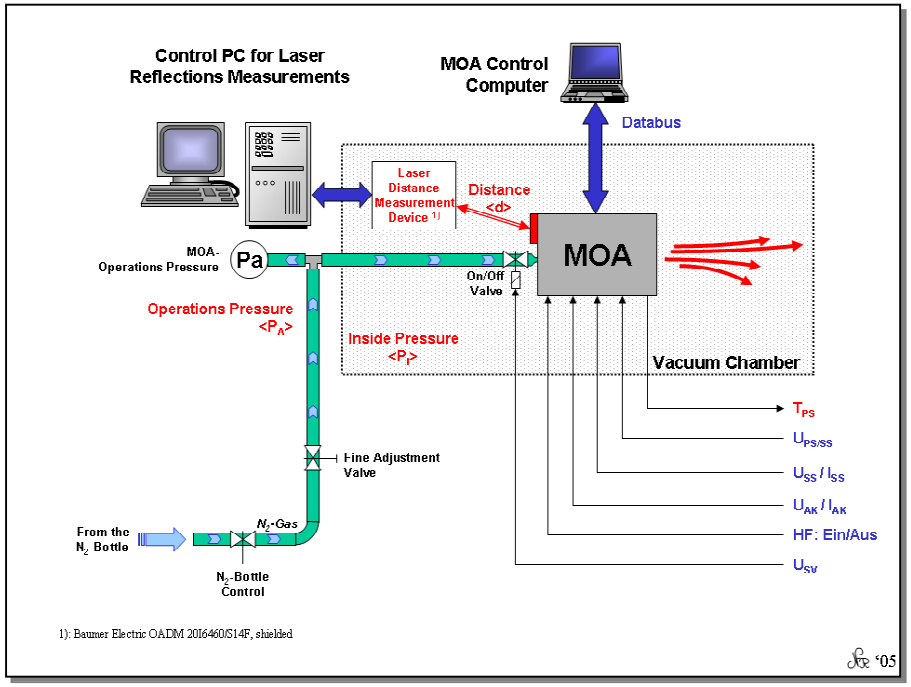
Design and Test of the MOA Thruster (2/3)



Design and Test of the MOA Thruster (3/3)

- ***MOA was tested in a vacuum chamber at 10^{-3} mbar ambient pressure***
  - **Friction less measurements via a laser triangulation sensor**
  - **N_2 as propellant**





Obtained Test Results

- ***2σ Calculations (95% confidence level) of 6 independent measurements with N_2:***
  - **Thrust (F): 8.09 +/- 3.57 mN**
  - **Power (P): 397.9 +/- 13.0 W**
  - **Specific Impulse (I_{SP}): 1042.5 +/- 431.9 s**

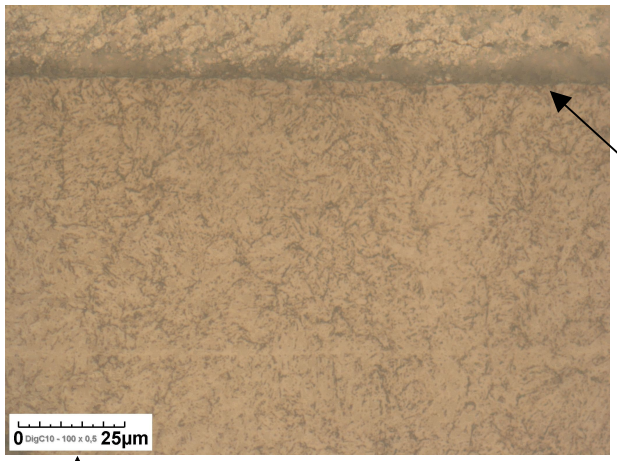
Measurement	Thrust	I_{SP}	Power	Ion Source		Spec. Power
Number 1; 18:32	7,19 mN	1114,5 s	393,1 W	96,0 W	1160 V	54,6 W/mN
Number 2; 20:15	10,89 mN	738,4 s	394,1 W	97,0 W	1150 V	36,2 W/mN
Number 3; 21:05	9,65 mN	833,0 s	394,1 W	98,0 W	1200 V	40,8 W/mN
Number 4; 15:32	7,53 mN	1075,8 s	397,1 W	100,0 W	1194 V	52,8 W/mN
Number 5; 17:00	6,22 mN	1306,2 s	398,2 W	100,0 W	1200 V	64,0 W/mN
Number 6; 20:30	7,05 mN	1187,3 s	410,5 W	106,0 W	920 V	58,2 W/mN
Average value:	8,09 mN	1042,5 s	397,9 W	99,5 W	1137,3 V	51,1 W/mN
Standard Dev.:	1,79 mN	215,94 s	6,50 W	3,56 W	108,60 V	10,59 W/mN

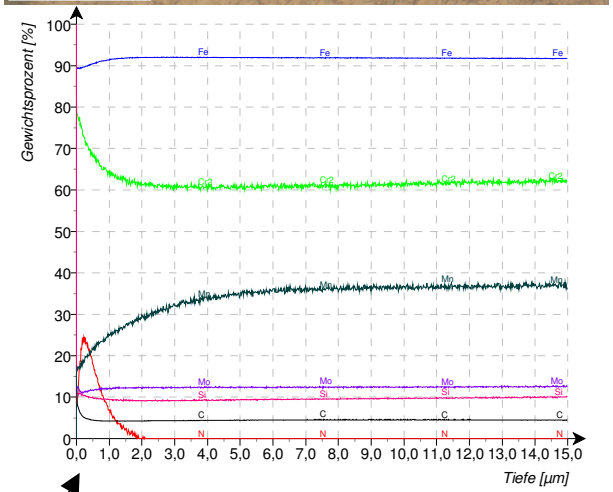
Coating: High Speed Plasma Nitriding

Polished working steel, code: 1.2343
MOA coating time: 10min

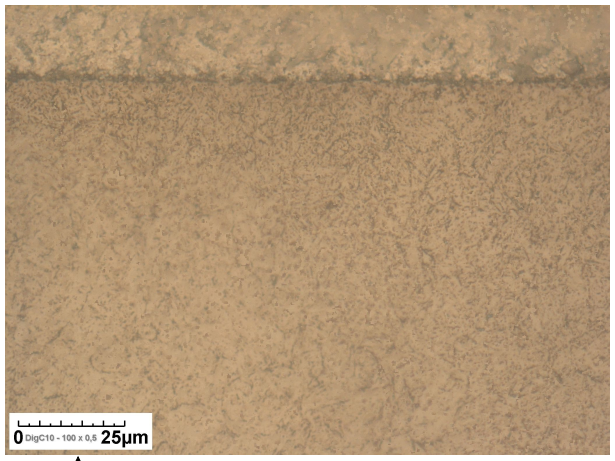
TiAl6V4 alloy
MOA coating: 10min

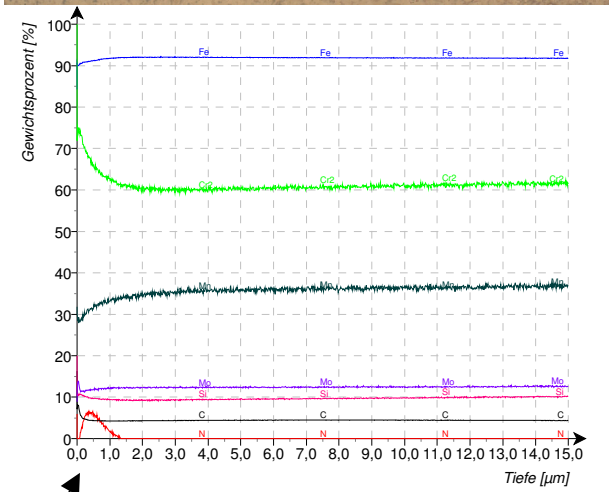
Coating: Polished working steel, Code: 1.2343





10min MOA nitrogen treatment





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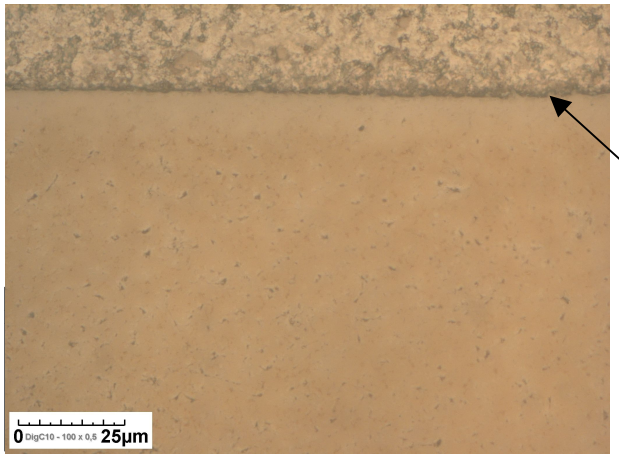
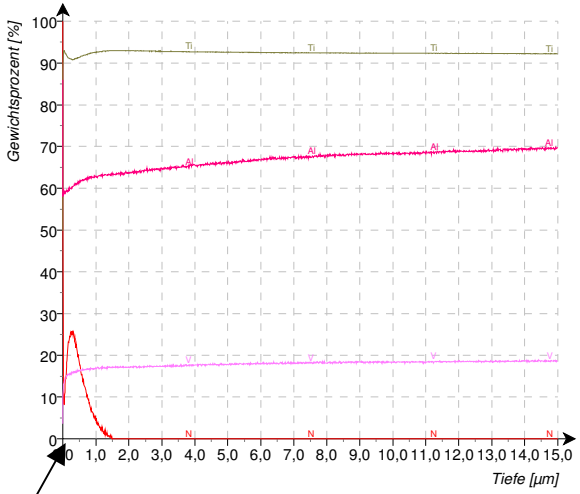
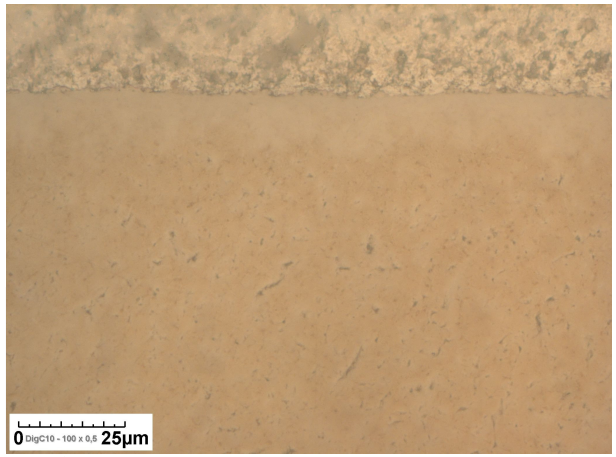
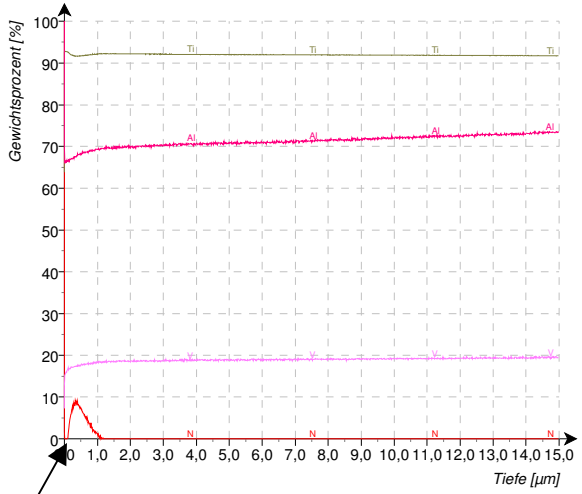
Coating: TiAl6V4 Alloy





10min MOA nitrogen treatment





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Outlook

- ***Current Technology Readiness Level: 5***
- ***R&D and structure has been set-up to enable a TRL of 7 in 2008***
- ***Further-on research:***
  - **Electronics upgrade**
  - **Plasma system upgrade**
  - **Additional propellant tests**

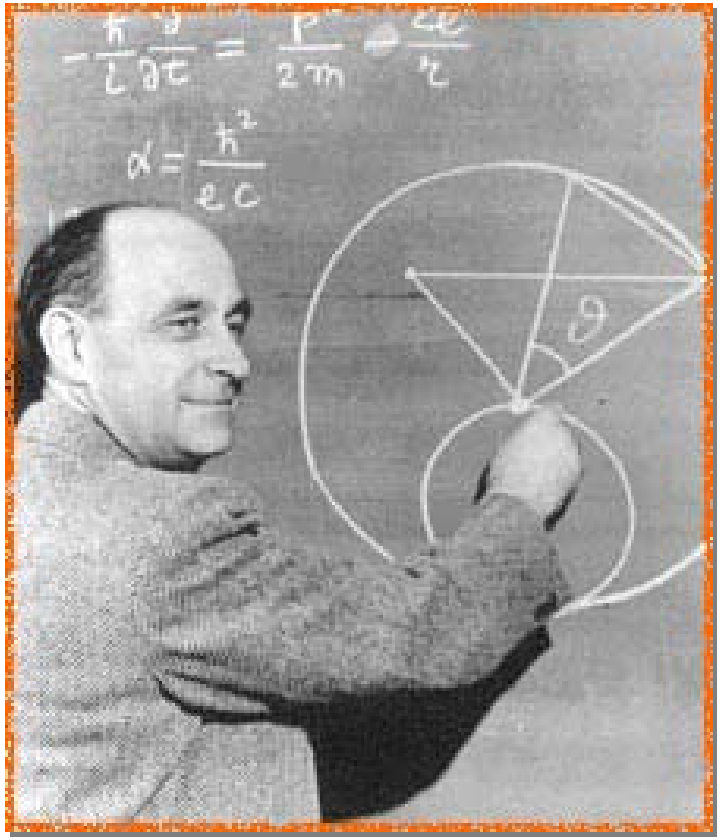
Technology Readiness Level

Phase	TRL	Maturity Level
System test, launch, and operations	9	System verified by successful mission
	8	System flight-qualified through test
Technology demonstration	7	System prototype demonstrated in space environment
System/subsystem development	6	System demonstrated in relevant environment (ground or space)
Technology development	5	Component and/or breadboard validation in a relevant environment
	4	Components validated in laboratory
Feasibility verification	3	Analytical and experimental critical function, characteristic proof-of-concept
	2	Technology concept and application formulated
Basic technology research	1	Basic principles observed and reported

Conclusion

- ***MOA is the first technical application of Alfvén wave physics for adv. propulsion***
- ***Current Technology Readiness Level: 5***
- ***Proven technical Feasibility***
  - **Simple modular set-up**
  - **Corrosion free behaviour**
- ***Numerous applications possible:***
  - **Attitude Control System Thruster (ACST)**
  - **North South Station Keeping (NSSK)**
  - **Kick Booster, Thruster for deep space missions**
  - **High-Tech Coating / Semiconductor Manufacturing**

MOA: A far reaching Technology



Enrico Fermi, Nobel Laureate of 1938, commented in 1948 on Alfvén's discovery by nodding his head, saying, "Of course…" The next day the entire world of physics said, "Oh. Of course."

Alex Dessler