Plasma Research in Space – Applications on Earth

Gregor Morfill

Max-Planck Institut für extraterrestrische Physik

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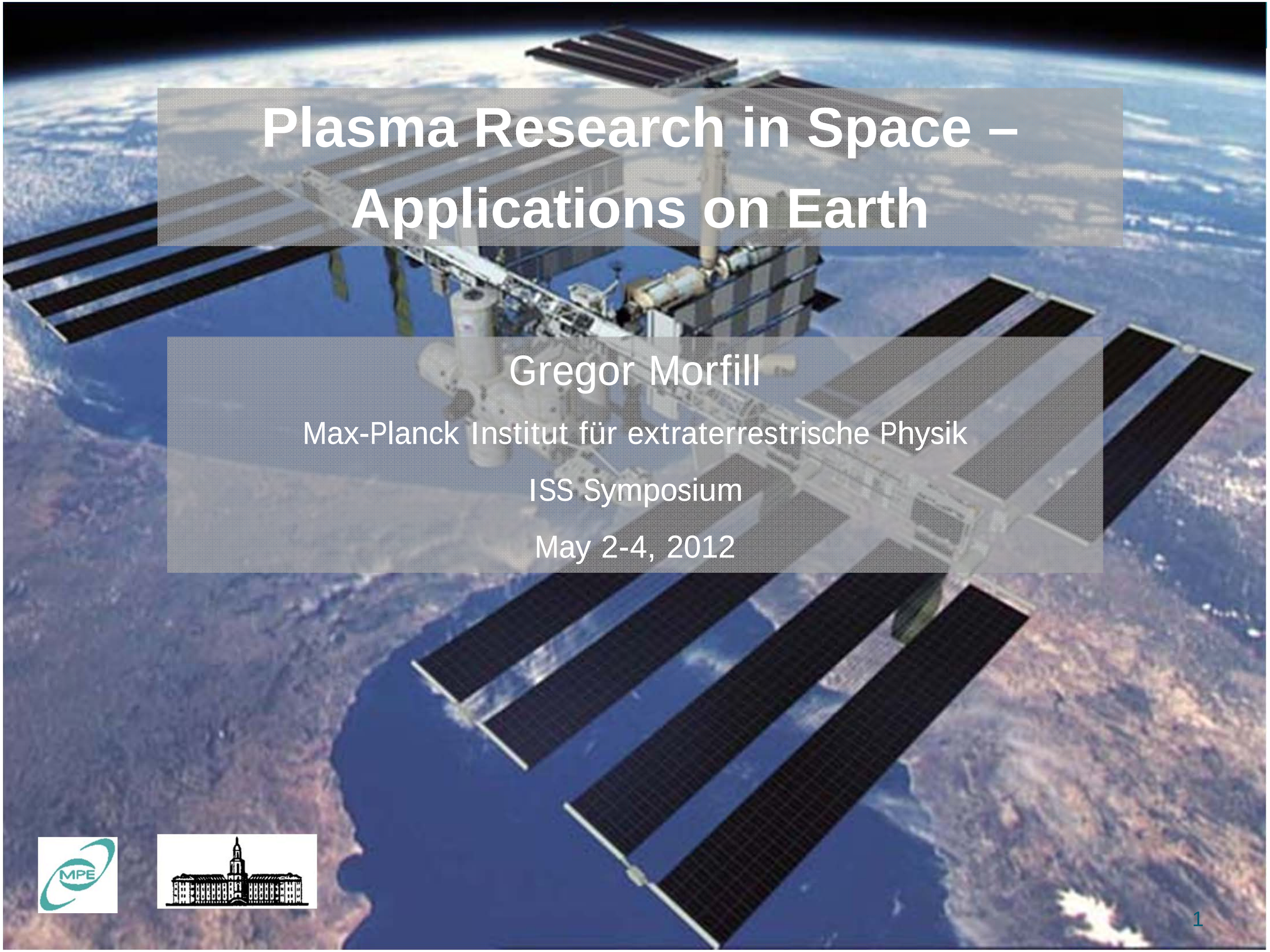

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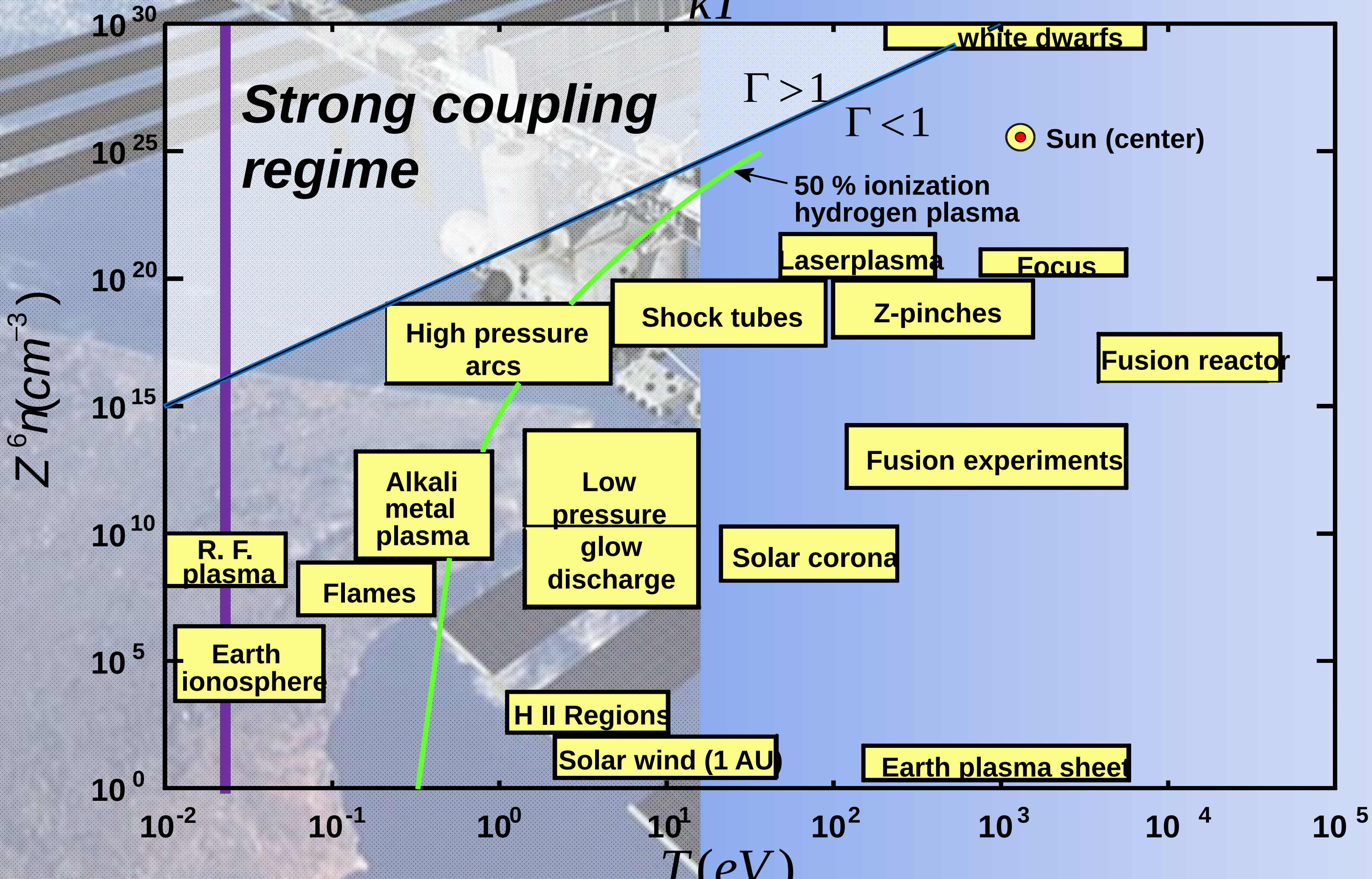
The Aims
I. Plasma Research in Space
II. Applications on Earth

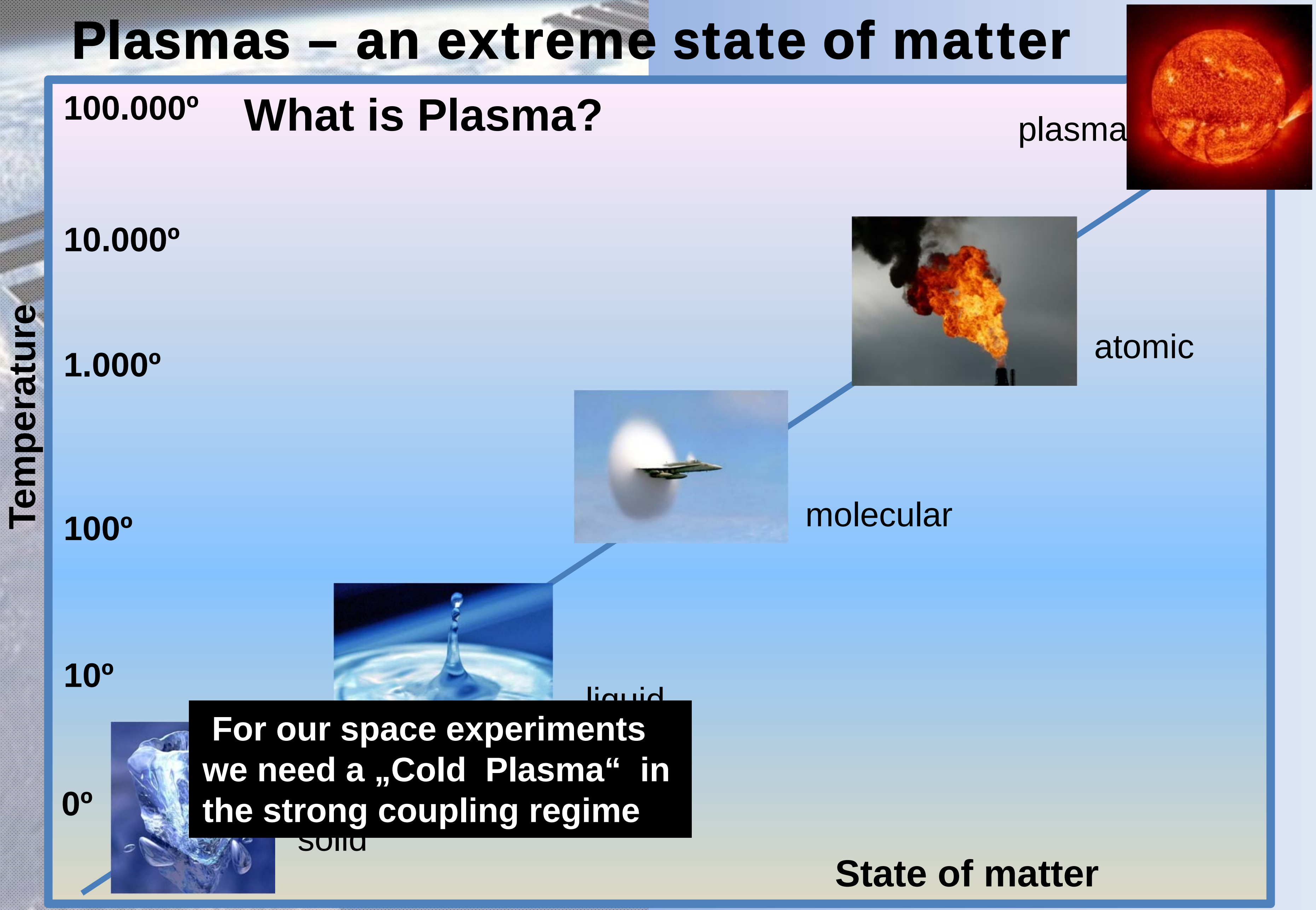
Aim 1. Extending the frontiers of plasma physics

$$\Gamma \equiv \frac{e^2}{kT}(Z^6 n)^{1/3}$$



Morfill and Thomas 1999

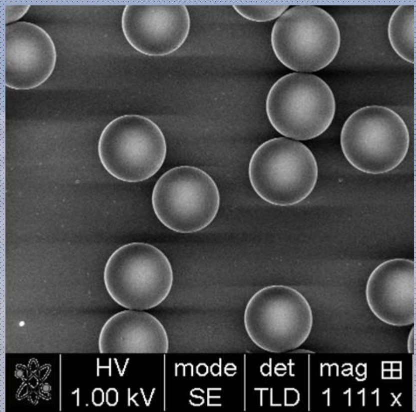
Plasmas – an extreme state of matter



A Problem?

- **A** highly charged cold plasma **is needed.**
- **Common wisdom: at low temperatures no (high) charges are possible.**
- **On the contrary, recombination sets in and matter becomes neutral.**

Problem solving…



Polymer (MF) microspheres:

diameter $d \approx 9\ \mu m$

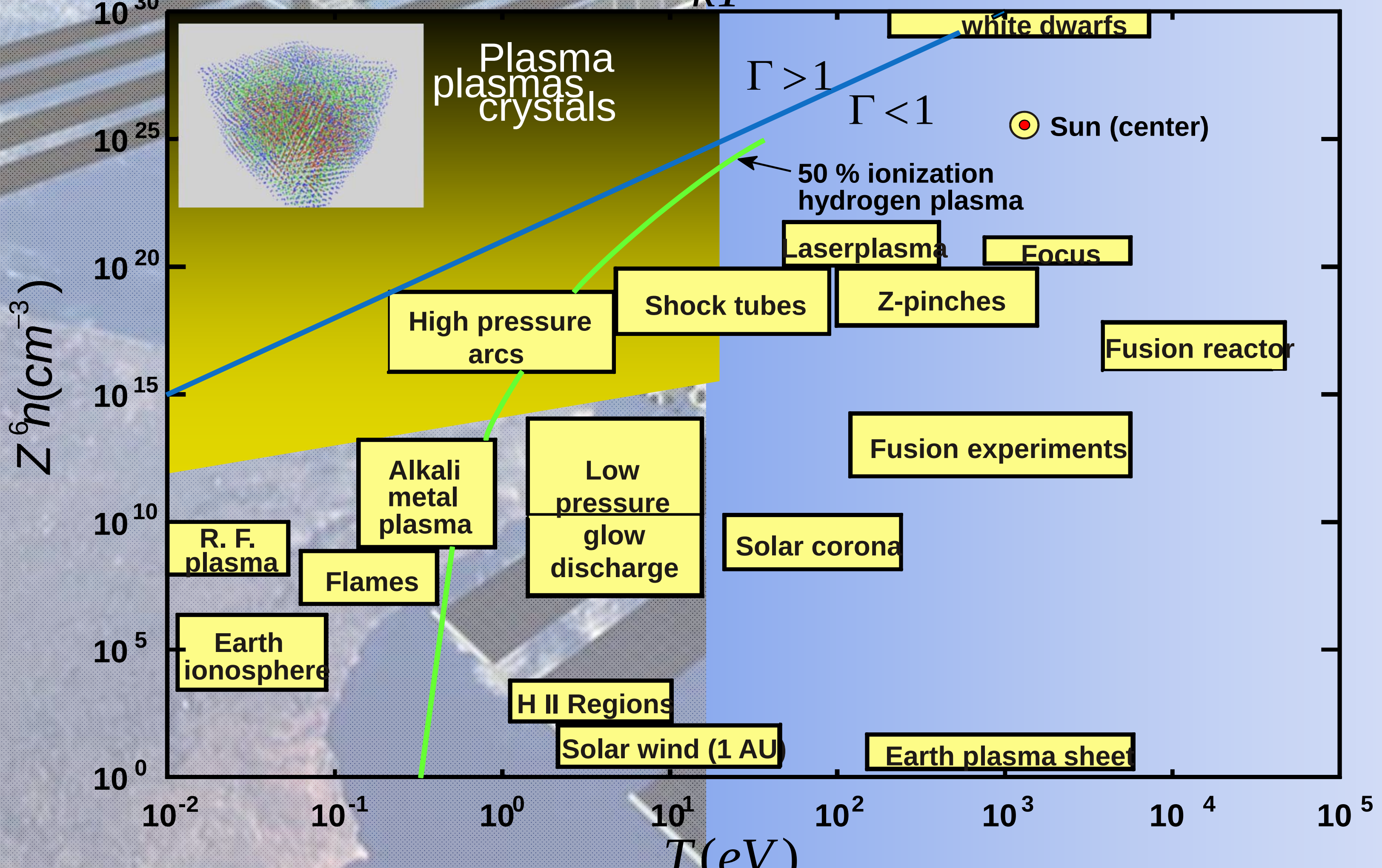
charge $Q \approx -10^{4}\ e$

spacing $a \approx 0.6$ mm

- **The solution is to produce a weakly charged (ionised) cold plasma and to add small microspheres – „*complex plasmas*“.**
- **These microspheres attain up to 1000s of elementary charges.**
- **They are lit up with laser light and are individually visible.**

Aim 1. Extending the frontiers of plasma physics

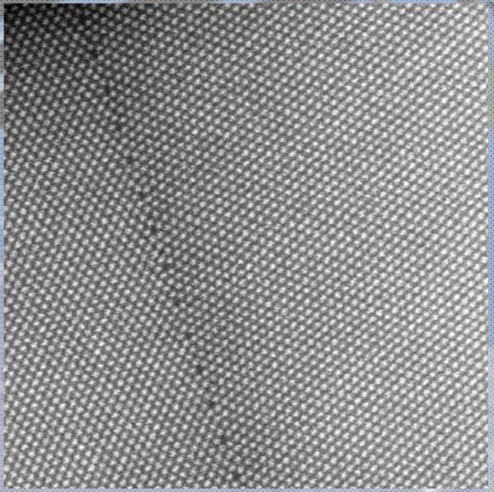
$$\Gamma \equiv \frac{e^2}{kT}(Z^6 n)^{1/3}$$



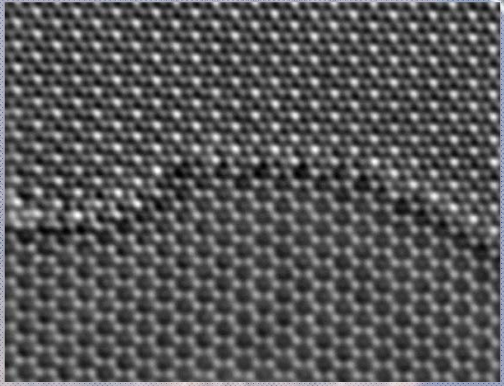
Morfill and Thomas 1999

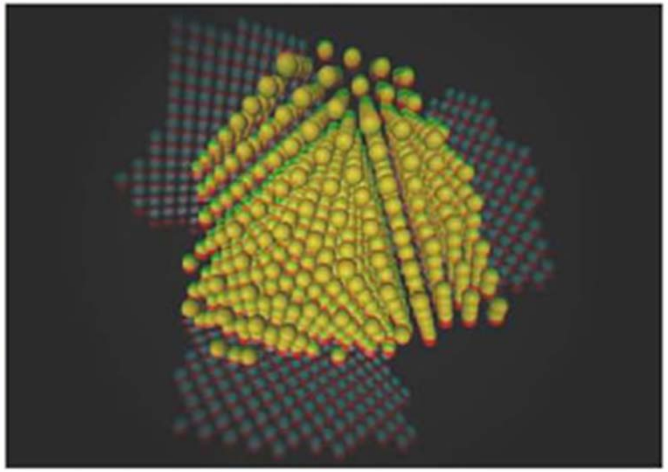
Aim 2. Structure and dynamics of matter at atomic scale resolution

Electron microscope: grain boundary in Gold



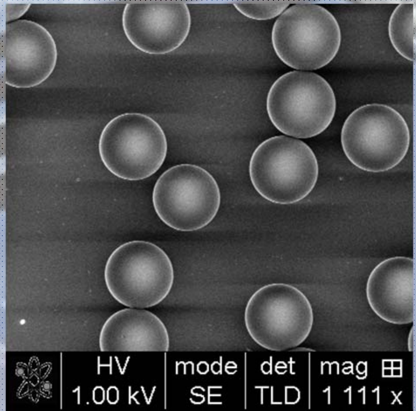
Single and bi-layer graphene





The atomic structure of an Ag nanoparticle in three dimensions. The particle is reconstructed by combining atom counting results obtained from different viewing directions (doi:10.1038/nature09741).

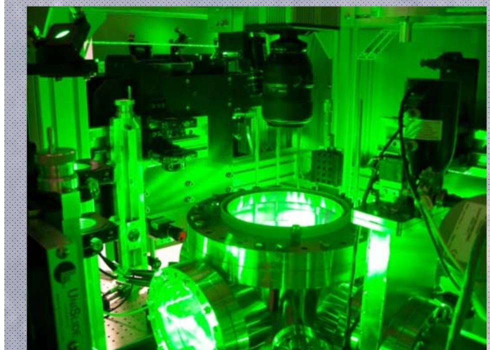
An alternative – bigger systems



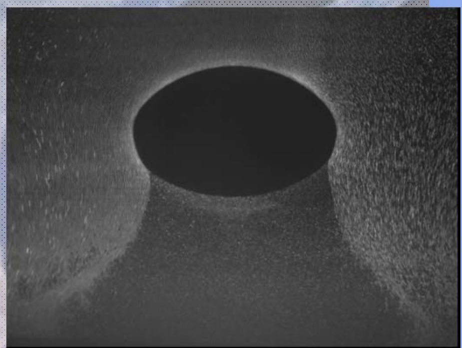
Polymer (MF) microspheres:
diameter $d \approx 9\ \mu m$
charge $Q \approx -10^4\ e$
spacing $a \approx 0.6$ mm

„Complex Plasmas“

Compared to atomic systems:
size amplified by 10 Million
velocities slowed to 1 Millionth
- studies at the extreme limits of natural phenomena are possible



2D Plasma Crystal



Turbulence

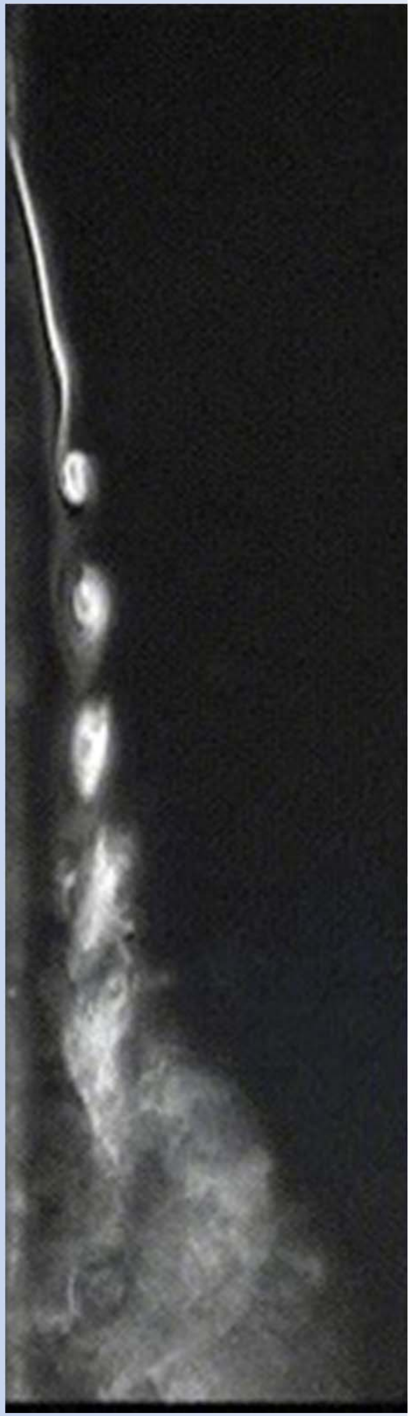
Phase separation

Electrorheology

Selected Topics

Turbulence - some quotes:

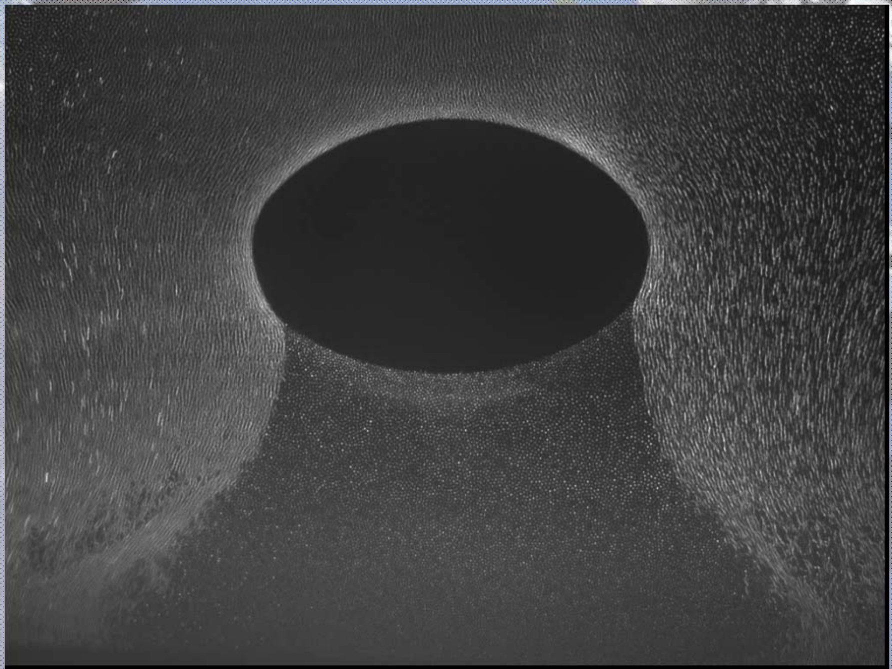
- **Feynman: "Turbulence is the most important and fascinating outstanding problem in fluid physics."**
- **Schober, Grewe and Fernholz (2004): "Investigations at the kinetic (particle) level have not been possible so far, but they could hold the key to this ubiquitous and generic phenomenon."**

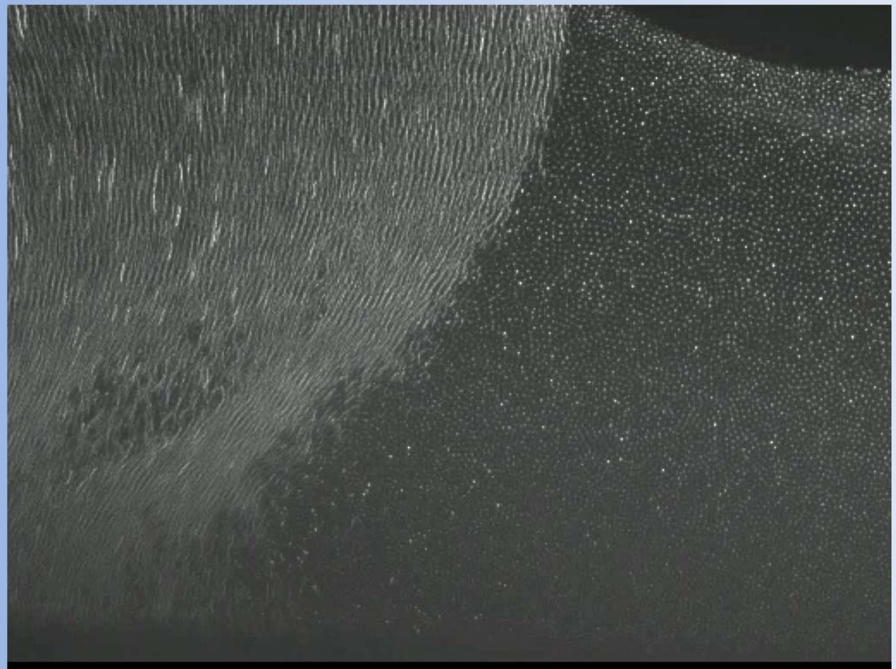


Ralf Heidemann et al. (2011)

First observation of laminar and turbulent flow at the individual particle (atomistic kinetic) level

Flow of a complex plasma around an obstacle.
Development of turbulence in the wake region.





2cm

1cm

Morfill et al. (Nature, 2004)

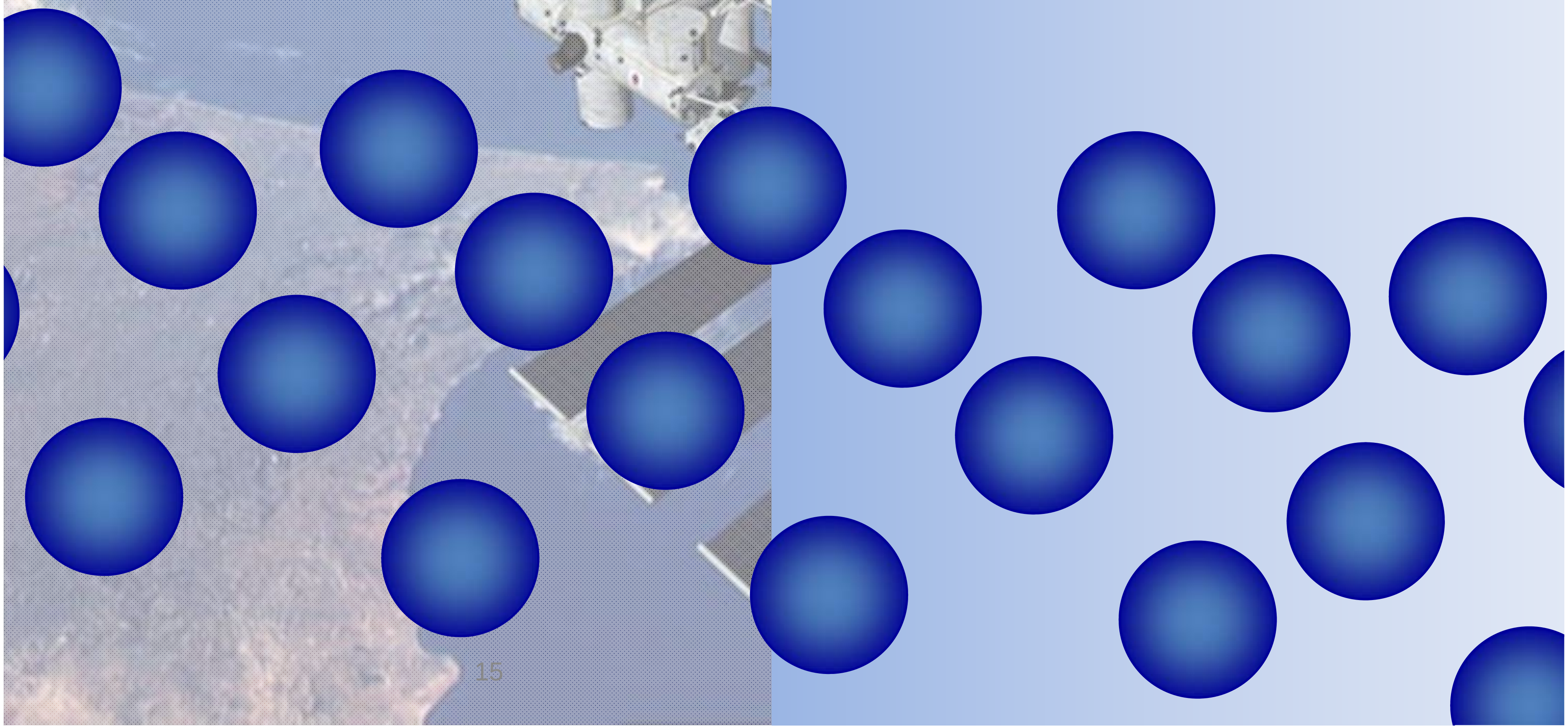
Science questions: Electrorheology

Electrorheological fluids **(or smart fluids) are soft matter fluids - suspensions of extremely fine electrically active particles in a non conducting liquid.**
The interparticle interaction (and hence the rheology) is determined by external electric fields.

- **If *electrorheological plasmas* exist, they will constitute a different class of electrorheology – which would make them interesting in their own right.**
- **Also, they would represent the first such system that is not overdamped – allowing dynamical studies of the associated phase transitions.**
- **Finally, it would be possible for the first time to investigate the (critical) processes at the cooperative limit.**

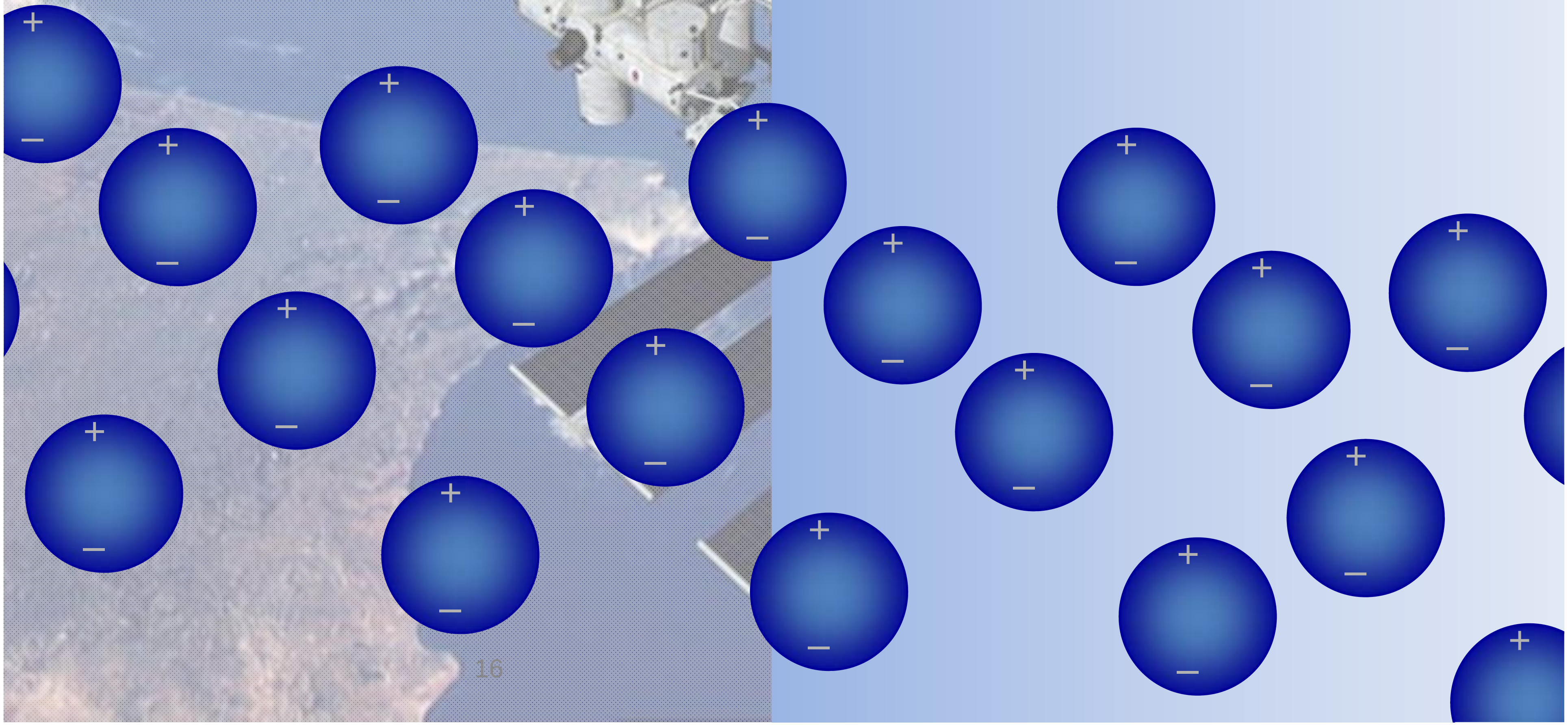
Electrorheological (ER) fluids

One theory to explain the electrorheological effect is the ´electrostatic theory´. This assumes a two-phase system (fluid and dielectric suspension).



Electrorheological (ER) fluids

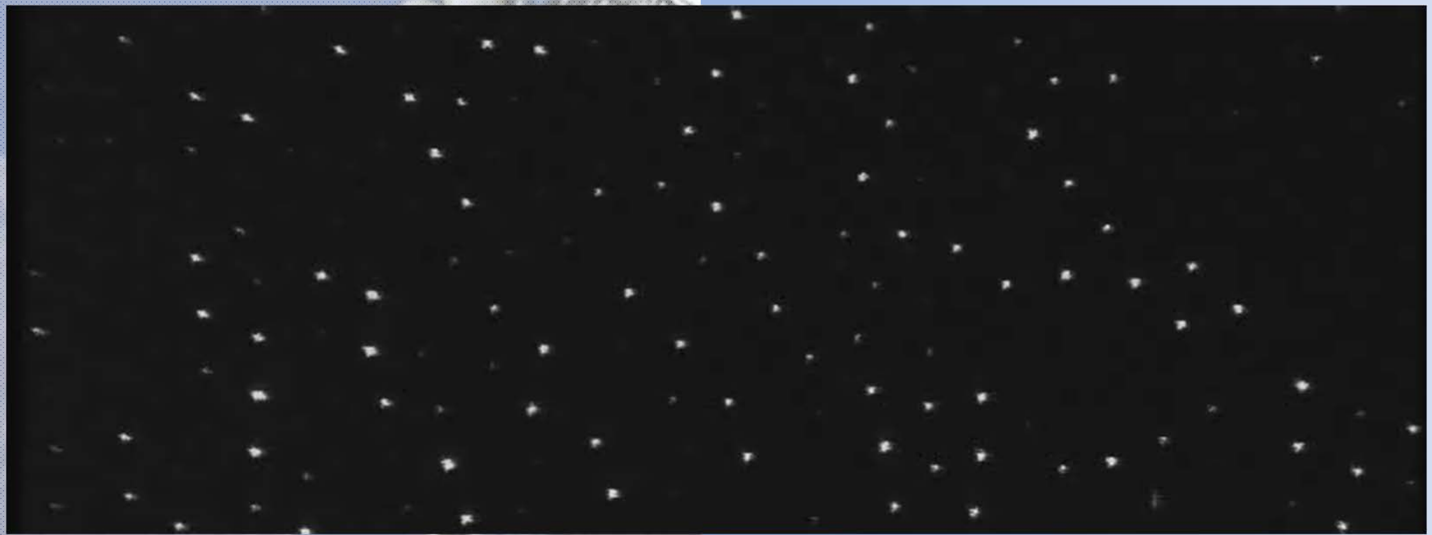
The particles develop induced dipoles in the presence of an external electric field and consequently align along this field.



Sequence with small modulating AC amplitude (26 Volts p-p) showing the characteristic complex plasma isotropic fluid phase

PK-3 Plus, Th. Reiter (2006)

Sequence with high modulating AC amplitude (66 Volts p-p). The first observation of the phase transition of an isotropic complex plasma fluid to an electrorheological ´string plasma´



PK-3 Plus, Th. Reiter (2006)

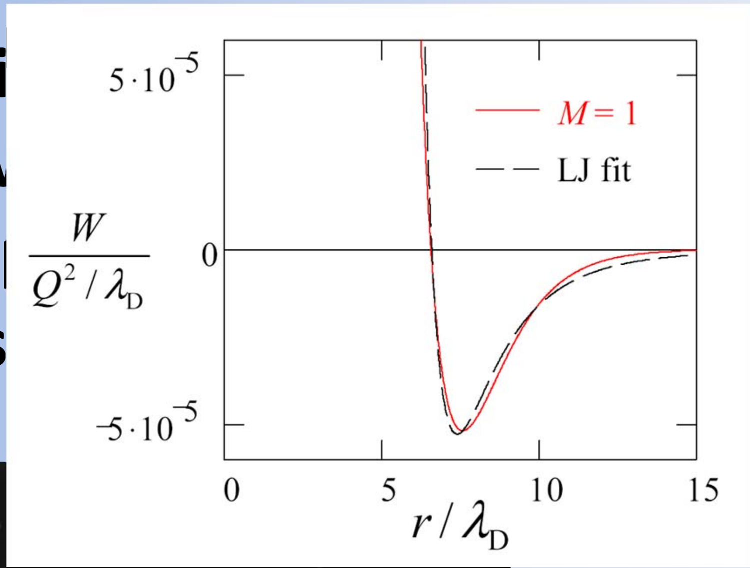
Sequence with high modulati

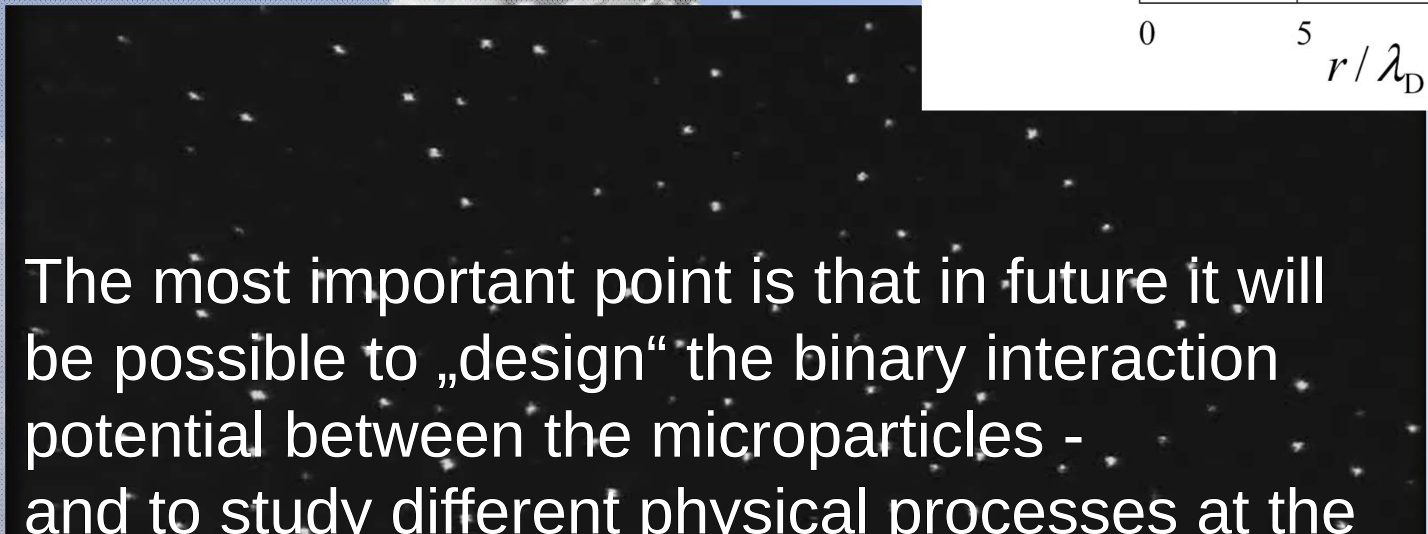
(66 Volts p-p). The first observ

transition of an isotropic com

electrorheological" string plas

Externally „designed" electrorheological binary interaction potential compared with the Lennard-Jones potential

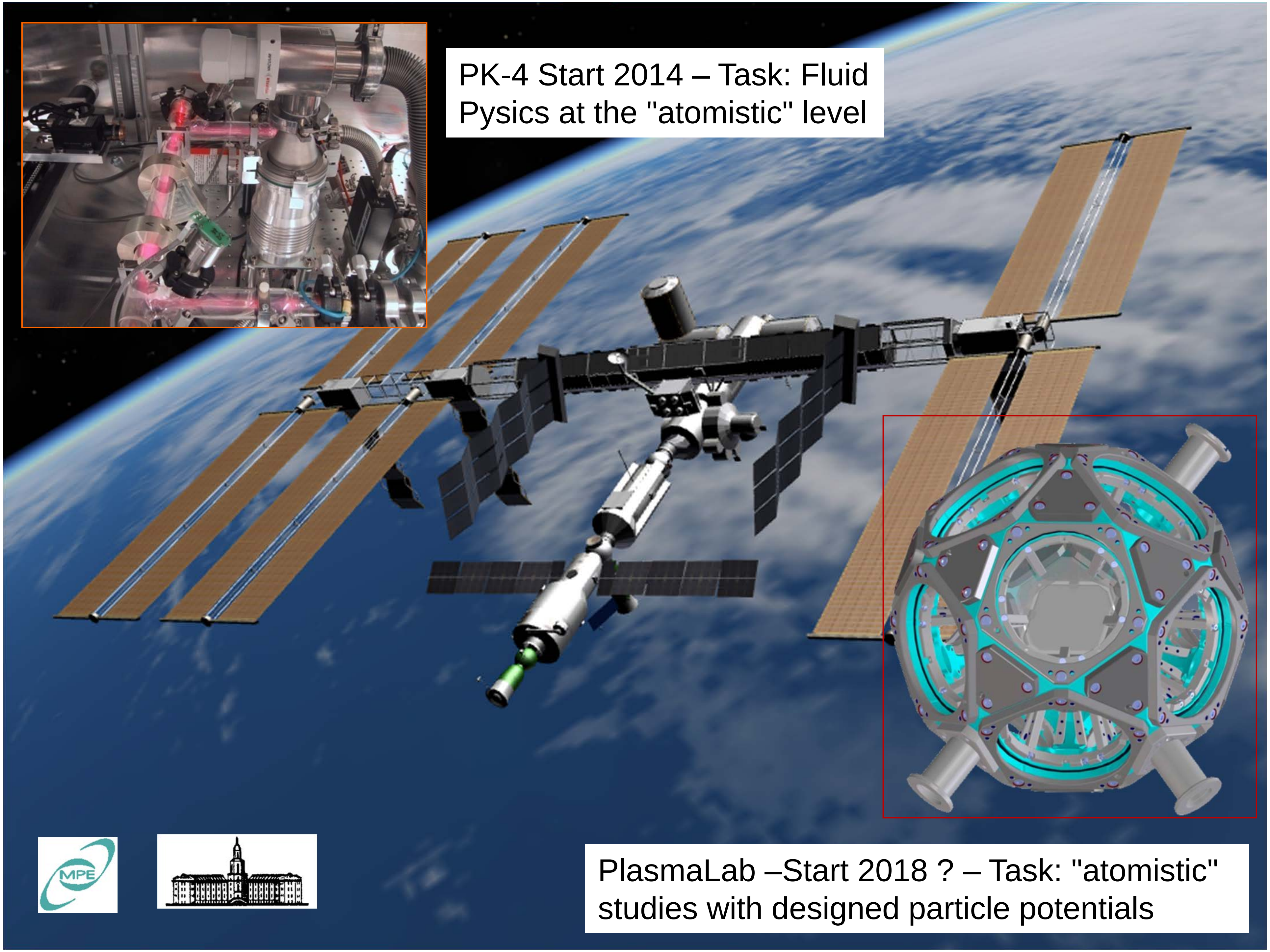


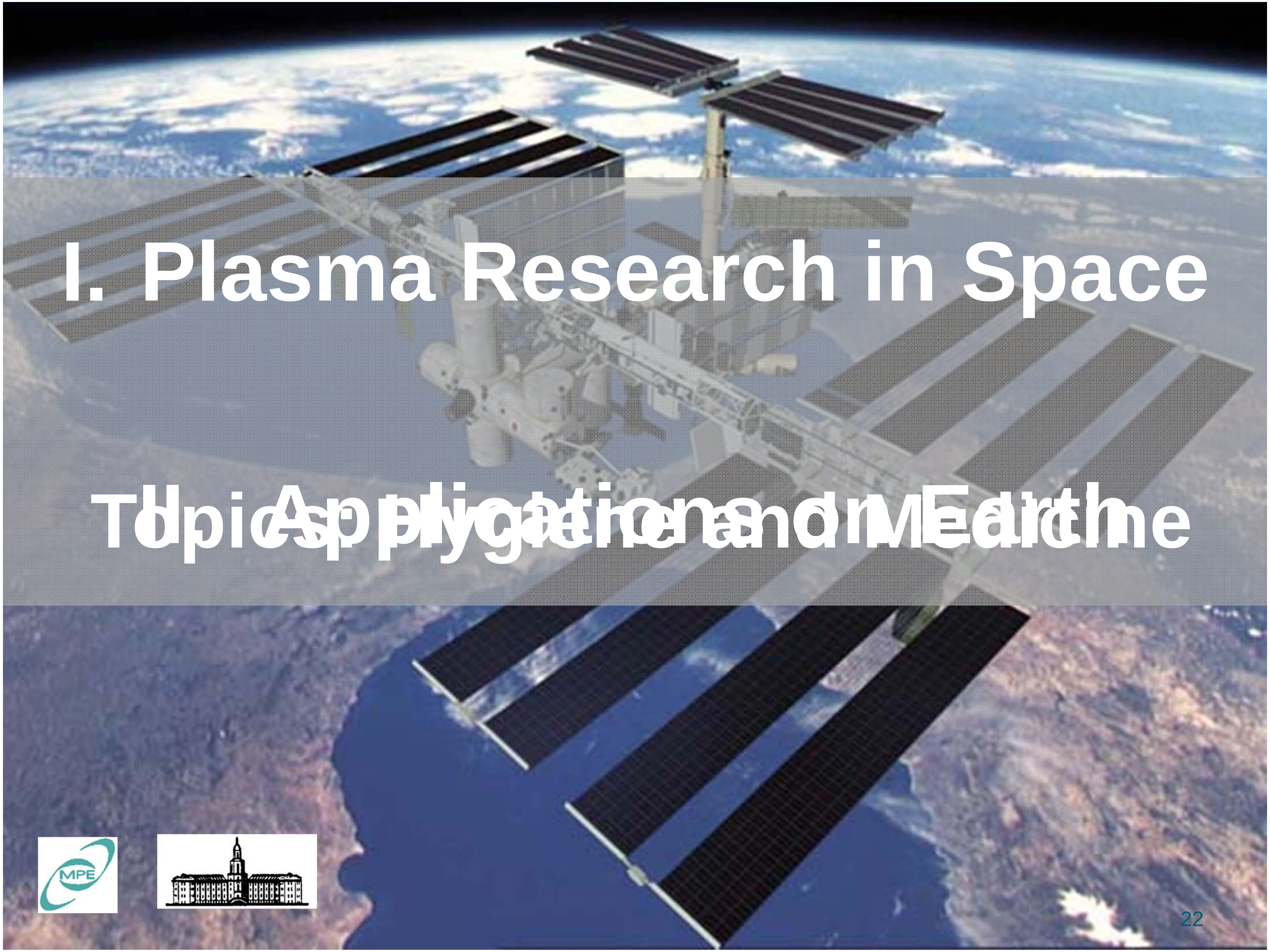


The most important point is that in future it will be possible to „design" the binary interaction potential between the microparticles - and to study different physical processes at the „atomistic" level for the first time using „realistic" potentials.

PK-3 Plus, Th. Reiter (2006)


The next ISS
laboratories


PK-4 Start 2014 – Task: Fluid Pysics at the "atomistic" level
PlasmaLab –Start 2018 ? – Task: "atomistic" studies with designed particle potentials



I. Plasma Research in Space

II. Applications on Earth

Topics: Hygiene and Medicine

Infection control – the issues

The experts warning:

More and more bacteria are developing increasing resistance to antibiotics.

More and more fungi are developing resistance to antifungal drugs.

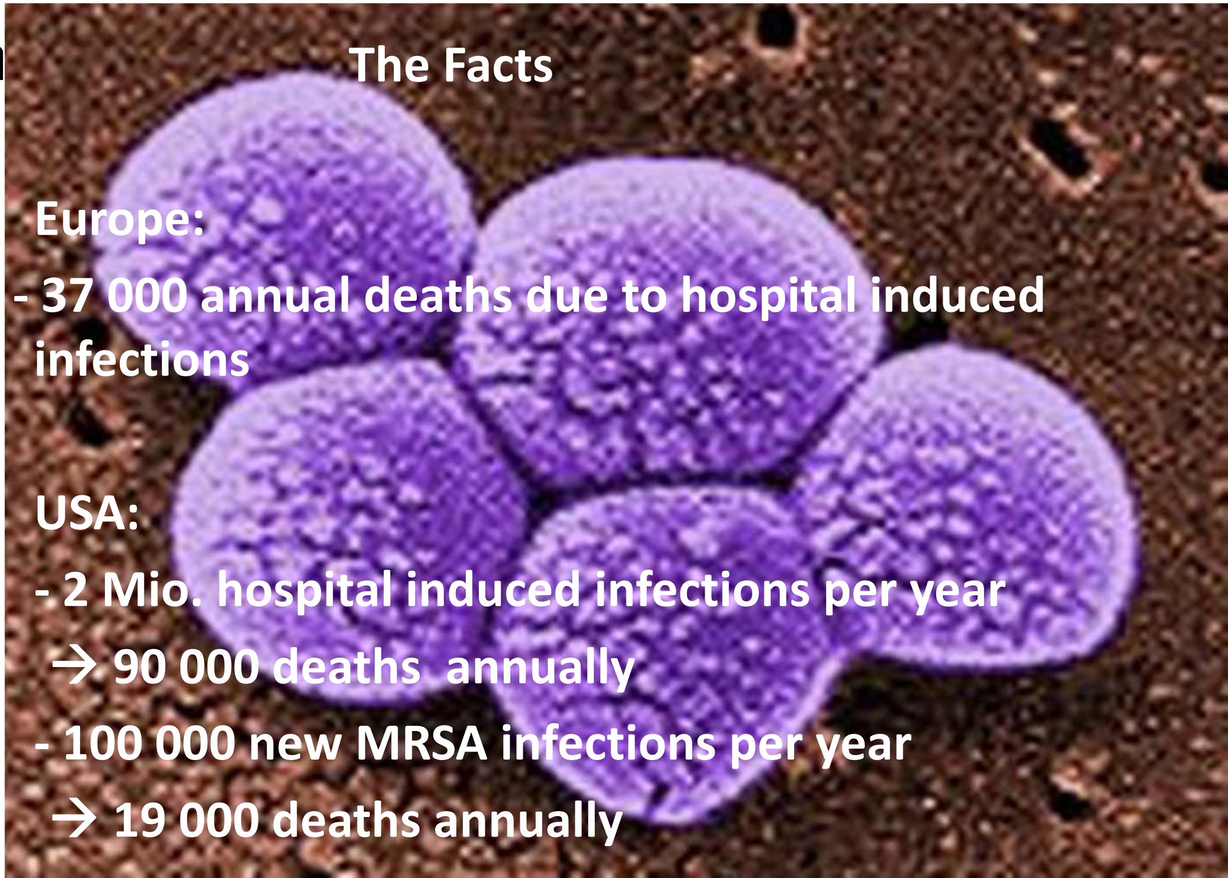
New methods for combating infectious diseases are urgently needed.

Der Spiegel, 2011 - Source: CDC/USA

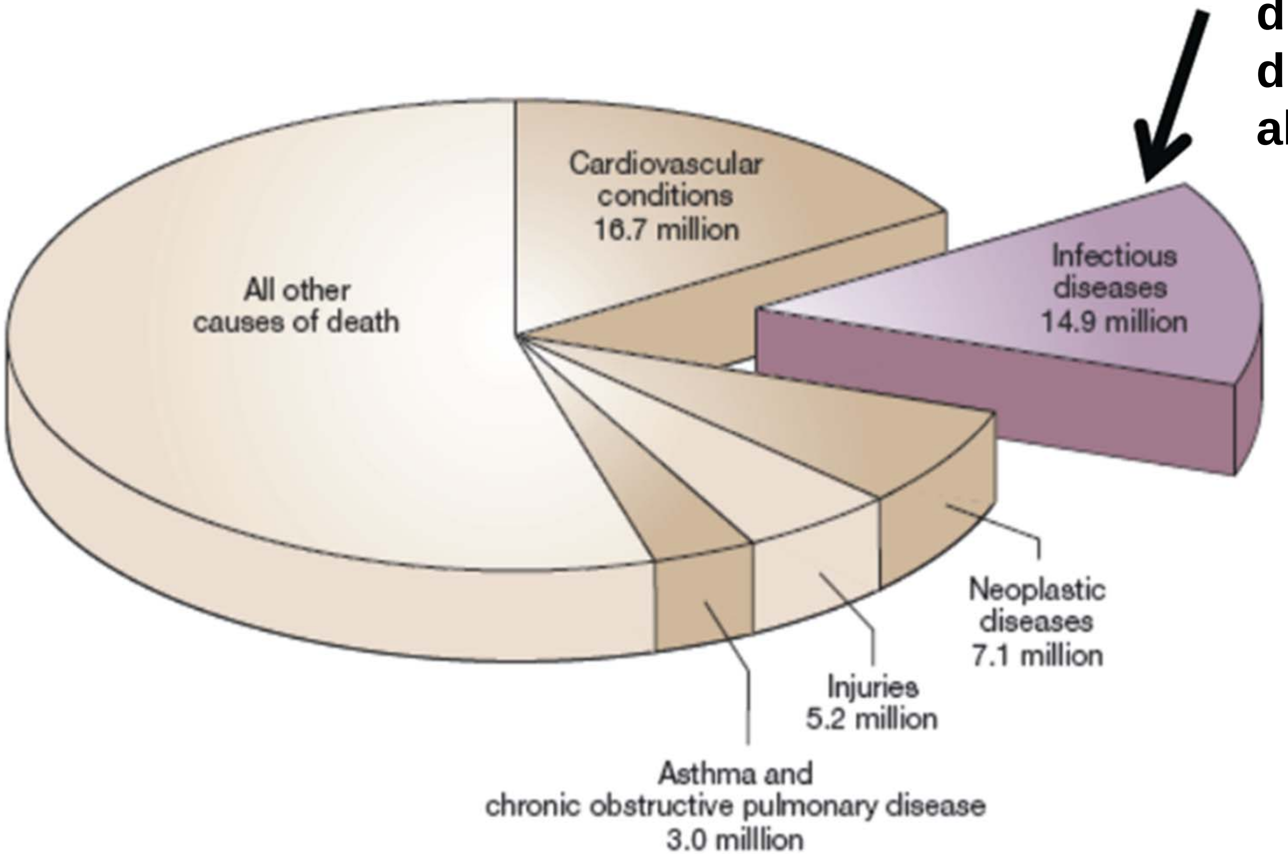
Infection control – the issues

Hospita

Percenta
of MRSA
samples
in 2008)



Infection control – the issues



Annual death toll due to infectious diseases – 15% of all deaths

Infection control – the issues

- To provide each person in Africa with only one application of liquid hand disinfection per day would produce a „plastic waste land“ of size 100 km^2 covered each year.

Cold Atmospheric Plasmas
Technology from Space - for a safer world

Our concept…

Hygiene at the touch of a button,

a 100% sustainable resource,

no residues,

no waste disposal,

always available,

gentle on your skin…

Morfill et al. NJP (2009), Kong et al. NJP (2009), Laroussi et al. (2012)

Cold Atmospheric Plasmas
Technology from Space - for a safer world

Our concept…

a technology designed to work in the same way as our own immune system,

which disinfects wounds,

controls secondary infections,

boosts wound healing,…

Isbary et al. (2010, 2012), Heinlin et al. (2012), Isbary et al. (2010)

Cold Atmospheric Plasmas
Technology from Space - for a safer world

Our concept…

a technology which fights fungal infections,

topical excema,

acne,

herpes,

and other skin ailments…

Maisch et al. (2012)

Cold Atmospheric Plasmas
Technology from Space - for a safer world

Our concept…

technology that can protect plant seeds against microbial infection,

increases the yield,

leads to faster plant growth…

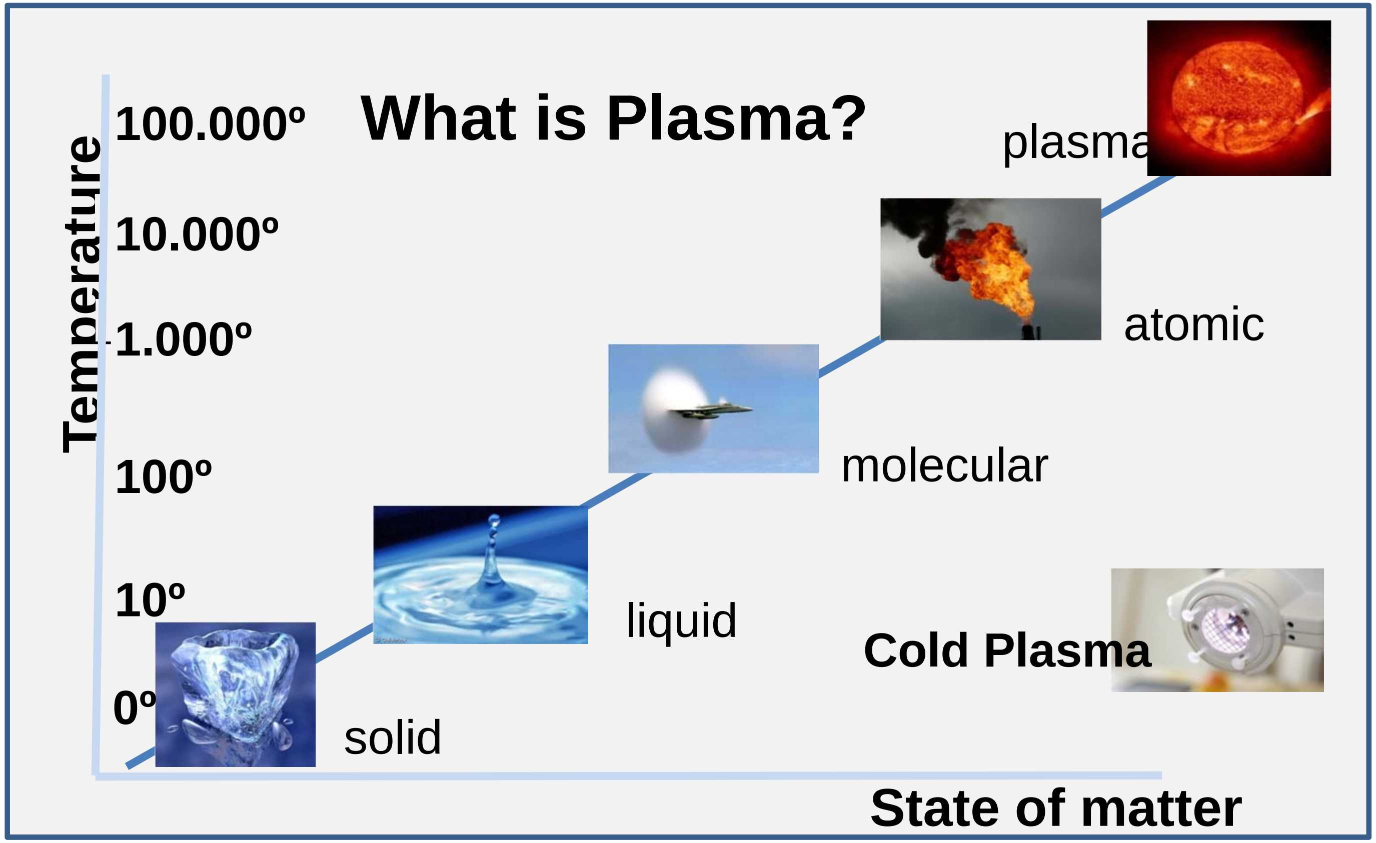
Mitra et al. (2012)

Cold Atmospheric Plasmas
Technology from Space - for a safer world

This concept now has a name:

„Cold Plasma Technology“

Cold Atmospheric Plasmas
Technology from Space - for a safer world



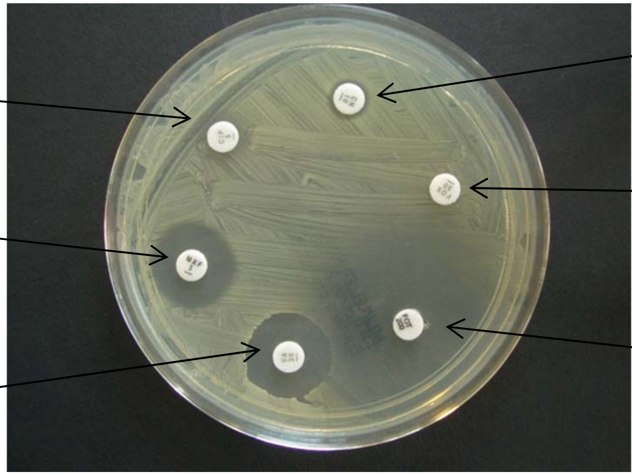
“Cold Plasma” is a partly ionised gas (or air).

Cold Plasma contains neutral gas, charged particles, excited atoms and molecules and reactive species.

It is produced at room temperature and atmospheric pressure.

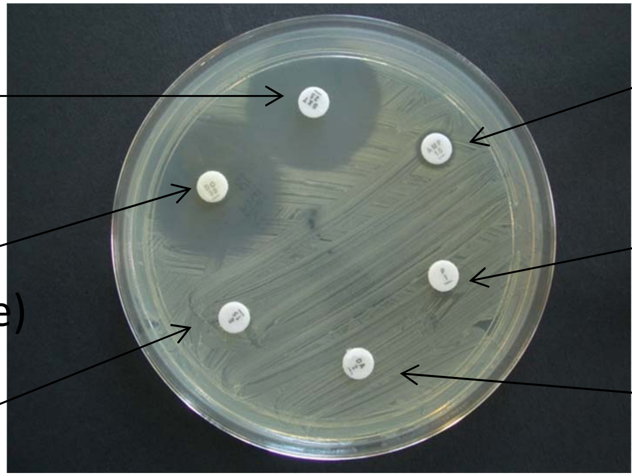
Plasma Inactivation of resistant bacteria

Drug-Resistance of the MRSA strain used



Ciprofloxacin
Moxifloxacin
Vancomycin
Gentamycin
Cefoxitin
Fosfomycin

First line drugs **bold** letters

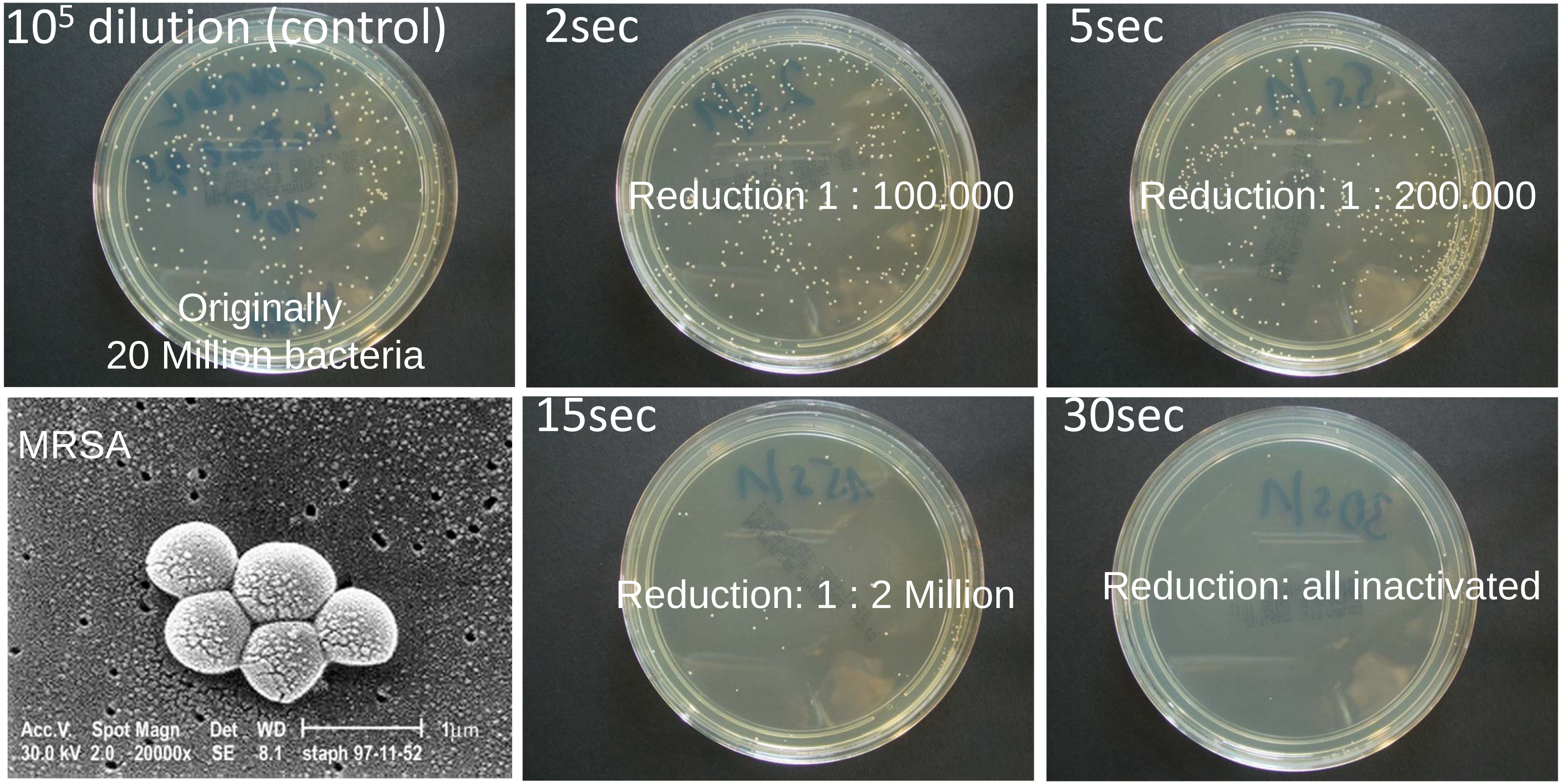


Co-Trimoxazole
Doxycycline (without hydrochloride)
Erythromycin
Ampicillin
Penicillin
Clindamycin

J. Zimmermann (2009)

Plasma Inactivation of resistant bacteria

Methilin-Resistant Staphylococcus Aureus (MRSA)



A project initiated by the Max-Planck Institut für extraterrestrische Physik

Plasma infection control - topics

Plasma for a safer world – reinventing hygiene

Hand disinfection
Surface disinfection
Laundry disinfection
Surgical tools sterilisation
Wound field disinfection

Personal hygiene
Public hygiene
Domestic hygiene
Epidemic control

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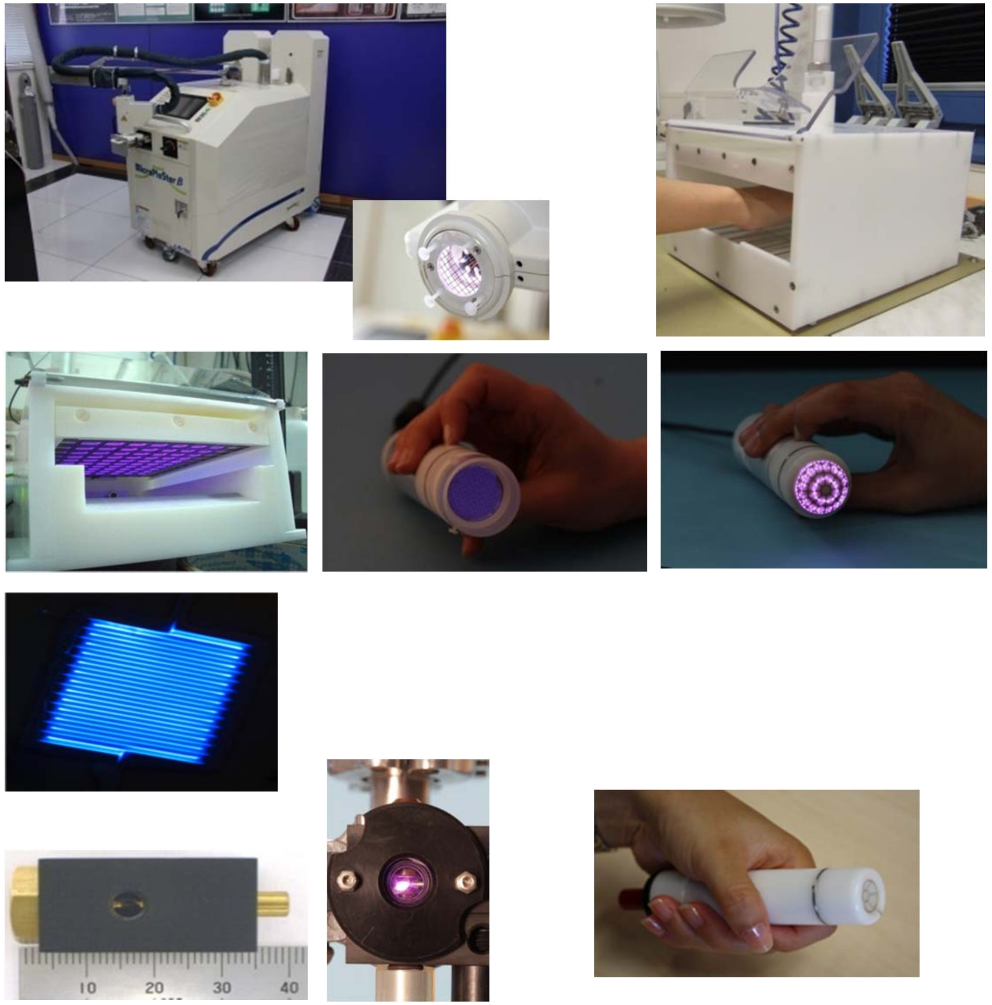
Technology from Space - for a safer world



„Cold Plasma Technology“ designed for many applications in health care and medical therapy

Based on research conducted in the Max Planck Institute for Extraterrestrial Physics (MPE) and the MPE plasma medicine network

Morfill et al. NJP (2009), Kong et al. NJP (2009), Shimizu et al. (2005), Maisch et al. (2012)

Plasma treatment of chronic wounds – clinical studies

Microwave driven cold atmospheric argon plasma device used for the **clinical phase II studies** on patients.

Technical details:

- used gas: Argon 2-4 l/min
- frequency = 2.45 GHz
- power = ca. 100 W

Developed in cooperation with Adtec Ltd. (Japan), Shimizu et al. Plasma Processes and Polymers (2008)

Plasma treatment of chronic wounds – clinical studies

In an add-on therapy more than 3000 plasma treatments so far showed a highly significant higher germ reduction (independent of the bacterial species and level of resistance).

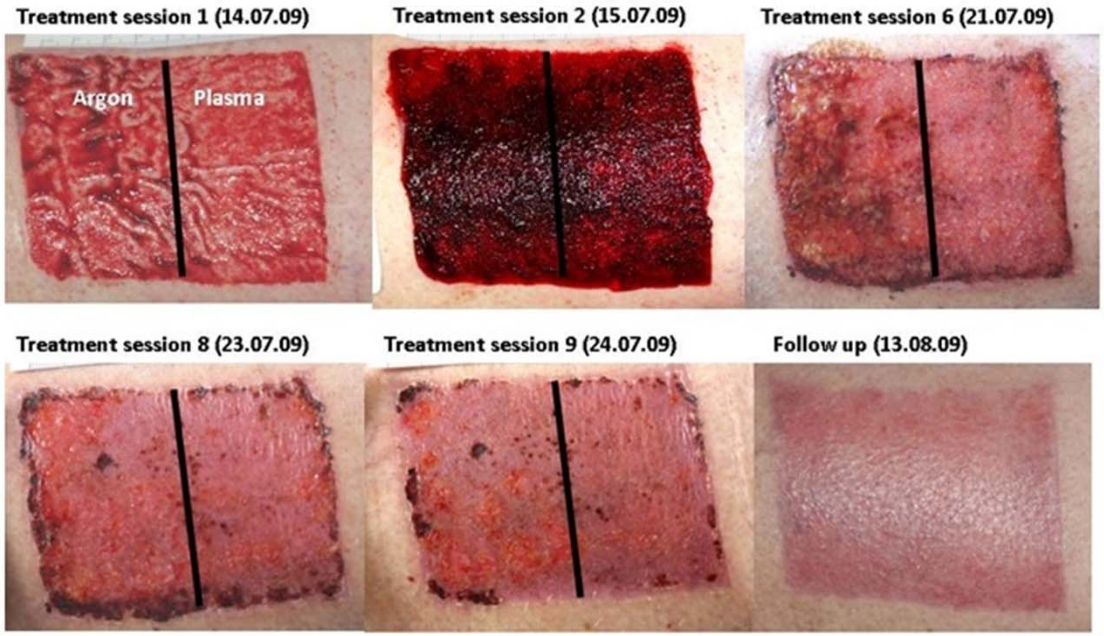
There were no negative side effects.

Wound healing seemed to be faster.

Example: Patient No. 72

Isbary et al. Brit. J. Dermatology (2010, 2012)

Skin graft wound healing – clinical studies



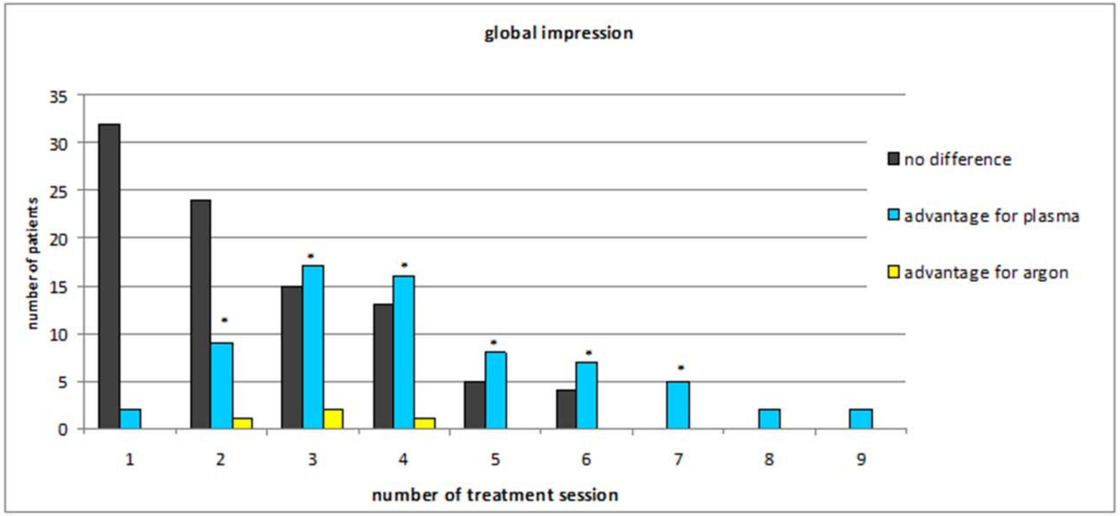
left side: treated with argon
right side: treated with plasma

Plasma treatment of acute wounds due to mesh grafts:

- One half of the wound was plasma treated in addition to the topical treatment.
- Assessment of the wound development was carried out by different medical experts based on different criteria (re-epithelialisation, fibrin layers, blood crust, wound surroundings).

Julia Heinlin et al. Submitted Arch. Derm. (2012)

Skin graft wound healing – overall result



Treatment session	1	2	3	4	5	6	7	8	9
advantage for plasma	2	9	17	16	8	7	5	2	2
no difference	32	24	15	13	5	4	0	0	0
advantage for argon	0	1	2	1	0	0	0	0	0
p-value	0.25	**0.011**	**<0.001**	**<0.001**	**0.004**	**0.008**	**0.031**	0.25	0.25

Plasma treatment leads to:

- improved epithelisation
- lower fibrin layers
- lower blood crusts

→**Faster wound healing!**

Julia Heinlin et al. Submitted Arch. Derm. (2012)

Plasma treatment Hailey-Hailey Disease

- syn: familial benign chronic pemphigus
- autosomal dominant inherited skin disorder
- mutation in the ATP2C1 gene on chromosome 3q21.1
- characterized by suprabasal acantholysis and leads to recurrent erosive and oozing skin lesions in intertriginous areas especially in summer periods and during sudatory work
- problem: frequent secondary infections
- Topical treatment: disinfectants, corticoids, antibiotics, antifungals, immunosuppressives

Isbary et al., Archives of Dermatol. (2010)

Plasma treatment Hailey-Hailey Disease

After 8 plasma treatments already a rapid clinical improvement in the axilla was observed.

The untreated ledge showed no improvement.

Isbary et al., Archives of Dermatol. (2010)


Interruption of treatment due to holiday

Plasma treatment Hailey-Hailey Disease

Resumption of the plasma treatment (after the holiday)

Isbary et al., Archives of Dermatol. (2010)

Next generation device for plasma therapy

This **rechargeable handheld** „skin treatment device“ is a universal household instrument. It can be used to:

- disinfect small wounds
- speed wound healing
- alleviate skin diseases caused by bacteria, viruses and fungi.

It is currently undergoing clinical phase I tests.

Maisch et al. PLoS One (2012), Boxhammer et al. submitted to Appl. Physics Letters (2012)

Next generation device for plasma therap

Clinical phase I tests:

1. Electrical safety tests according EN 60601-1
2. UV emission tests
3. Toxic gas emission tests
4. *In vitro* and *ex vivo* efficacy tests including the inactivation of various bacteria, viruses and fungi on different surfaces and skin
5. Biological safety tests *in vitro* and *ex vivo* including:

• toxicity tests in cell culture
• mutagenicity tests in cell culture
• blood analysis
• histology analysis of human skin
• detection for DNA double strand breaks (gamma H2AX) in human skin
• detection for DNA double strand breaks in mucosa cultures

→ Plasma is effective and safe!

Maisch et al. PLoS One (2012), Boxhammer et al. submitted to Appl. Physics Letters (2012)

Research to come

Outlook: plasma therapy

Plasma has a significant wound healing effect.

Plasma also alleviates skin irritations - from serious skin diseases, fungal infections to insect bites.

Plasma ions can function as new medically active agents (plasma pharmacology).

The plasma chemistry can be designed for personalised medical application and therapy.

Plasma can aid delivery and enhance the effectiveness of topical drug action.

Plasma is cell selective (e.g. cancer, normal cells)

Plasma therapy – the topics

Plasma for a safer world – a new approach in medicine

A comprehensive programme for plasma therapy:

Plasma drug action and design
Plasma aided drug administration
Plasma enhanced drug action
Plasma initiated cell selectivity
Plasma tumour action
Plasma dermatology
Personalised medicine and therapy

Cold Atmospheric Plasmas
Technology from Space - for a safer world

Scientific Cooperation Network

Germany:

- Max Planck Institute for Extraterrestrial Physics
- Max Planck Innovation GmbH
- Department of Dermatology, Hospital Schwabing, Munich
- Medizet Department Microbiology, Schwabing, Munich
- Department of Dermatology, University Hospital Regensburg
- Department of Neuropathology, TUM, Munich
- Institute of Experimental Oncology, TUM, Munich
- University of Veterinary Medicine, Hannover
- Department of Infectiology and Virology, University Heidelberg
- German Aerospace Center (DLR), Cologne
- German Aerospace Center (DLR), Bonn
- Ludwig-Maximilians-University, LMU, Munich

Russia:

- Joint Institute for High Temperature, RAS
- Institute for Biomedical Problems, RAS
- Institute for Epidemiology and Microbiology, RAMS
- Institute for Theoretical and Experimental Biophysics, RAS
- Shemyakin and Ovchinnikov Institute of Bioorganic, RAS
- Institute for Problems of Chemical Physics, RAS
- Institute for Physical Chemical Medicine, RAMS

USA:

- Department of Chemical Engineering, University of California, Berkeley
- Laser and Plasma Engineering Institute, Old Dominion University, Norfolk, VA

United Kingdom:

- Department of Electronic and Electrical Engineering, Loughborough University, Leicestershire
- ADTEC Europe Ltd.

Thank you