

MAC3: Multiscale Modeling and Nonlinear Analysis (since 2002)



Ute Ebert

At CWI since 1998
Prof. at TU Eindhoven



Willem Hundsdorfer

At CWI since 1984
Prof. at U Nijmegen



Jens Rademacher

**At CWI since 9/2006
(math cluster NDNS+)**

Docent at U Leiden

Joke Blom: MAC1 till 2006, MAC3 in 2007-08, MAC4 since 2009

Frank Bruggeman: **into CWI-MAC3 in 2007**-08, MAC4 since 2009

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Ute Ebert

**Nonlinear dynamics,
Monte Carlo models,
model reduction,
plasma modeling**



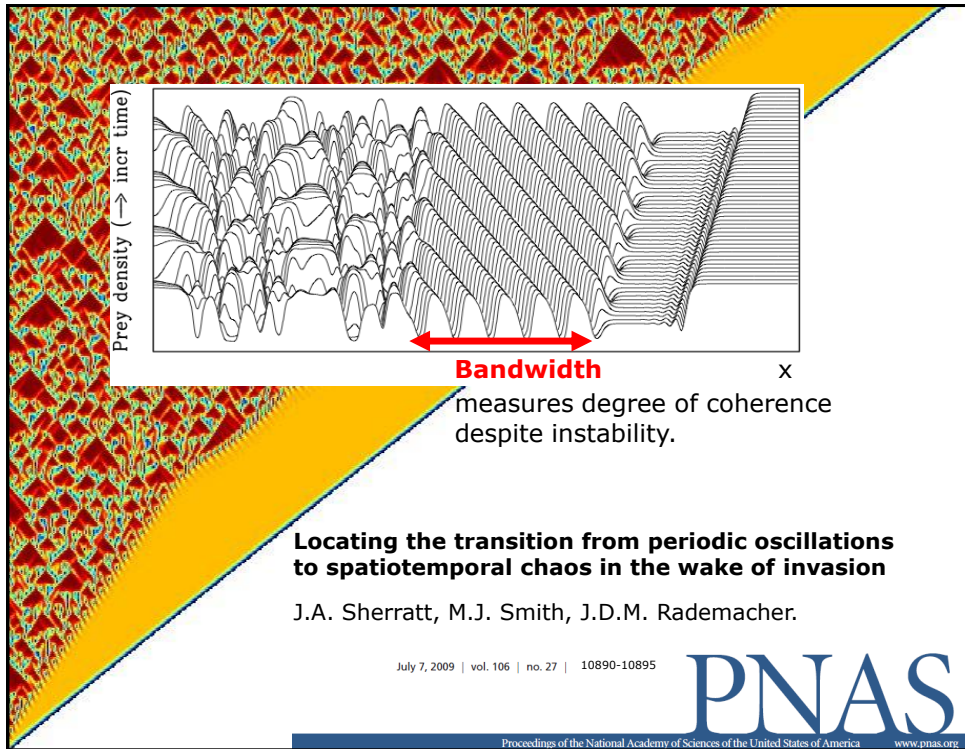
Willem Hundsdorfer

**Numerical methods for
time-dependent PDE's,
stability and
monotonicity
preservation**



Jens Rademacher

**Nonlinear dynamics,
coherent structures,
stability and bifurcations**



Large multiscale computations

Nonlinear dynamics, model reduction

Ebert's strategy since 2004

Spark formation in Nature and Technology

phys/techn.: Streamers

5 ns 5 μ s

geophysics: Sprite discharges

nature

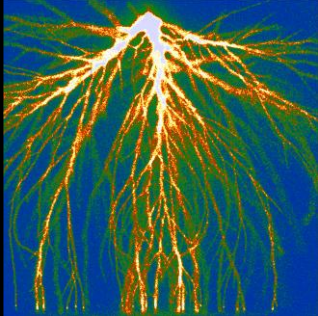
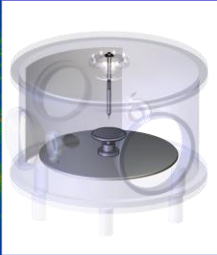

Charging up the ionosphere

Taste receptors: Flavonoid amino acids

Cosmology: Galaxies grow with the flow

Photoreceptor cells: A secret role for Crumbs

Main project partners on plasmas:

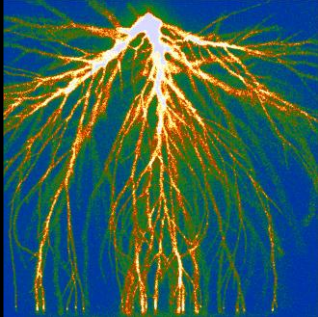
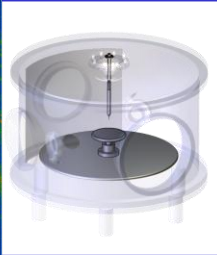

Plasma physics at TU Eindhoven

Electrical engineering at TU Eindhoven

2 joint projects finished, 4 running (750 000 €/project), 2 proposed

Internationally leading team combining

- unique facilities of plasma diagnostics and applications in Eindhoven,
- collaboration with international lightning research,
- *full MAC-expertise (unique for technical plasmas).*

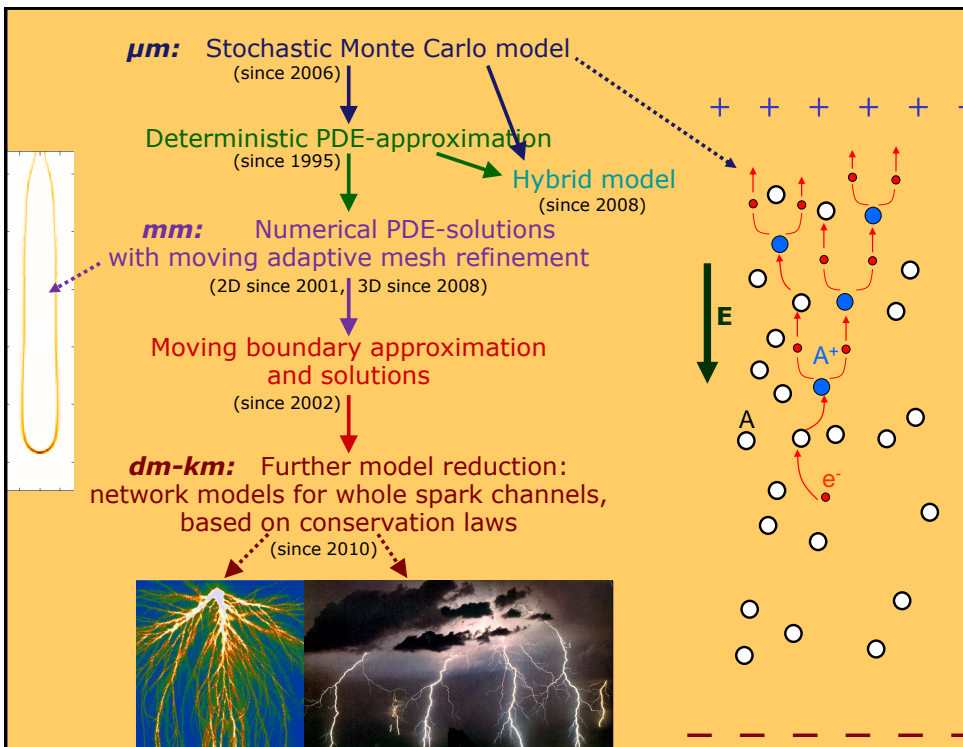
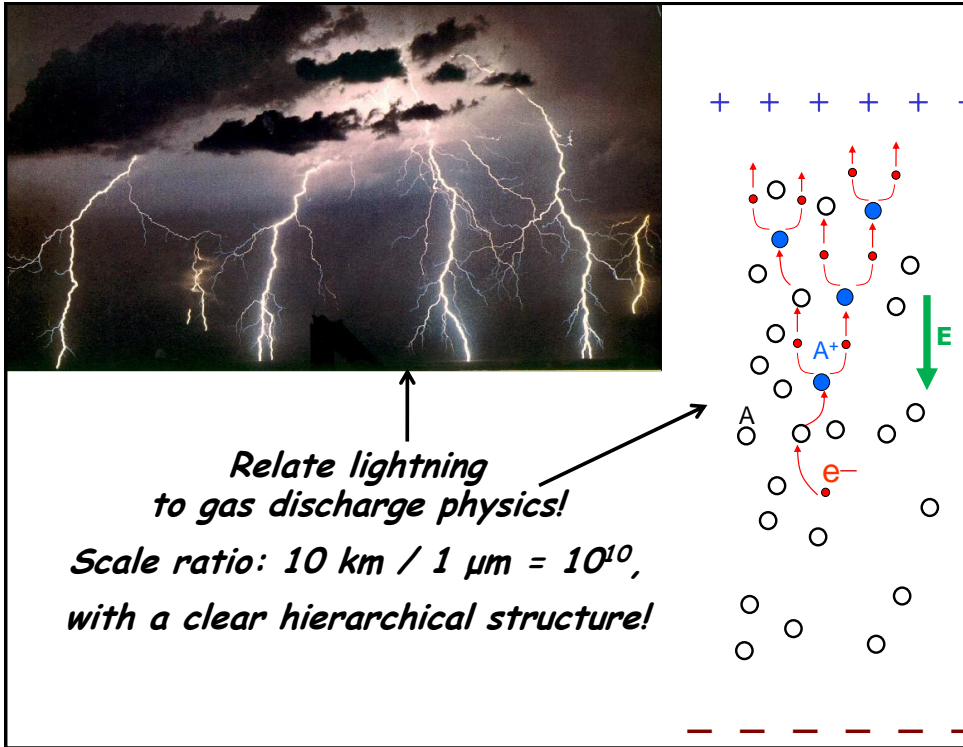
Plasma physics at TU Eindhoven

Electrical engineering at TU Eindhoven

Ebert's role in plasma community:

- Supervisor of two experimental PhD theses (Briels 2007, Nijdam 2011)
- Board member of research school "Plasma Physics and Radiation Technology"
- Board member STW-research program "Building on Transient Plasmas" (2009-14)
- Board member FOM-research program "Control Magnetohydrodynamics" (2009-15)
- Member MT of EU-COST-action P18 on Lightning (2005-09) and of ESF-program "Thunderstorm effects on atm.-ionosphere system" (2011-16)
- Associate editor of "Contributions to Plasma Physics" (2011-...), conferences ...

(I knew essentially nothing about discharges in 2000. A huge need of theory!)



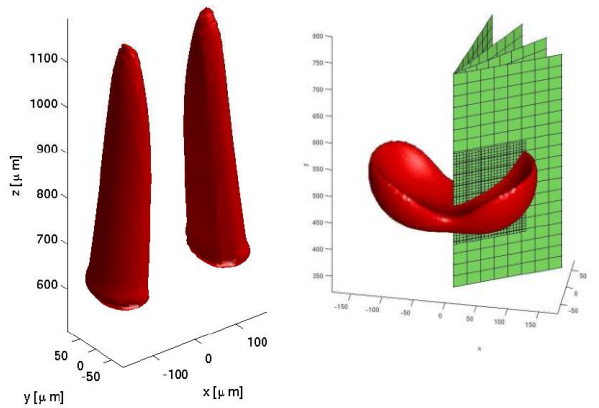
3D PDE-computations with 2.5D co-moving mesh refinement

PRL 101, 075005 (2008)

PHYSICAL REVIEW LETTERS

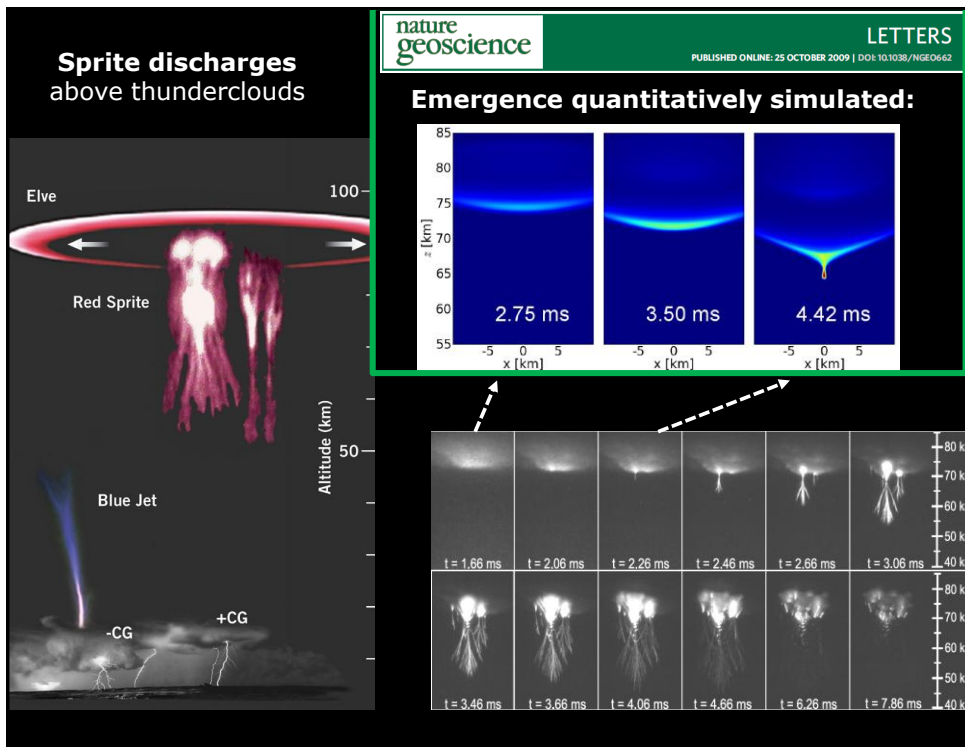
Interaction of Streamer Discharges in Air and Other Oxygen-Nitrogen Mixtures

A. Luque,¹ U. Ebert,^{1,2} and W. Hundsdorfer¹

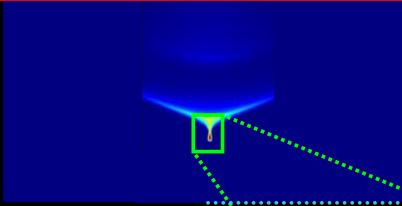


nature

Discussed in **RESEARCH HIGHLIGHTS** + more media

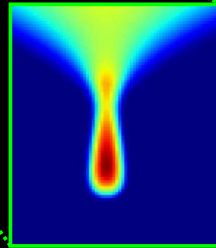


Ionosphere (85 km), equipotential



Air density $N(z) \sim e^{-z/7.2 \text{ km}}$
 Electron density $n_e(z) \sim e^{z/2.9 \text{ km}}$ above 60 km
 Gas discharge model for sprite and ionosphere

20 km



Finest numerical resolution: 3 m

Co-moving adaptive mesh refinement

Lightning:
(field calculated analytically)
 10 km
 ↓ $I = 30 \text{ kA}$

Ground, equipotential

PDE-computations

L

Moving boundary approximation for PDE-model derived and evaluated.

Relation to classical problem of applied analysis
 Laplacian growth (cf. viscous fingering).
 E.g., Saffman-Taylor finger with $\lambda = 1/2$,

$$x = \frac{L(1-\lambda)}{2\pi} \ln \left[\frac{1}{2} \left(1 + \cos \left(\frac{2\pi y}{\lambda L} \right) \right) \right]$$

fits space charge layer in discharge!

PRL 95, 195004 (2005) PHYSICAL REVIEW LETTERS

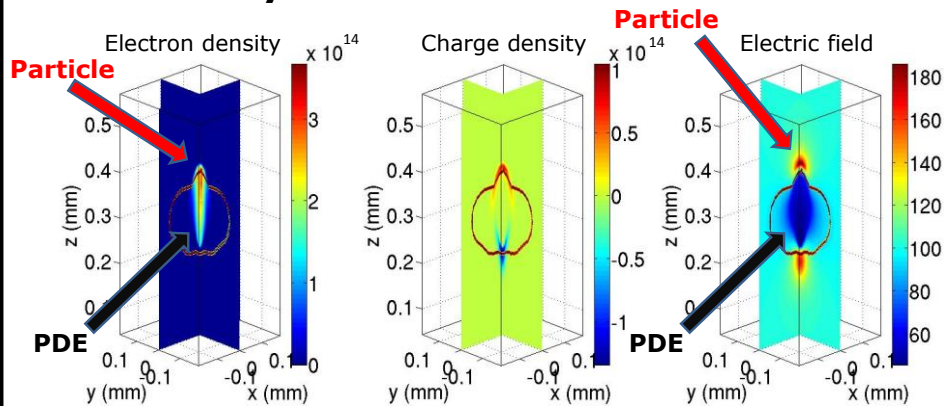
**Regularization of Moving Boundaries in a Laplacian Field
 by a Mixed Dirichlet-Neumann Boundary Condition: Exact Results**

Bernard Meulenbroek,¹ Ute Ebert,^{1,2} and Lothar Schäfer³

+ 10 papers + review [Nonlinearity 2011]

L

Hybrid model



PDE must approximate stochastic particle model well!

→ Analytical averaging reinvestigated.

Smooth curved buffer regions constructed at good location.

→ Conservation laws preserved everywhere!

[PhD Thesis Li 2009]

Now: Develop further and predict Terrestrial Gamma-Ray Flashes!

13

Applications of Multiscale (Plasma) Modeling:

- Plasma technology: **biofuel processing**, **discharge lamps**, **cleaning air from traffic exhaust**, **disinfection**
- Lightning protection
- **Lightning**: **Sprite discharges**, **green house gases**, **Terrestrial Gamma-Ray Flashes**
- **Fusion energy** (also in MAC2)
- **Vegetation patterns** as indicator of desertification
- **Safety and efficiency of high voltage electricity nets** (pending)
- **Plasma deposition for production of solar panels** (pending)
- **Plasma actuators for windmills and air planes** (planned)

Societal relevance:

- **Energy**: **Generation**, **transport** and **saving**
- **Earth Sciences**, **climate** and **environment**
- **Health**



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U



W



J

Output 2005 – 2010:

91 journal articles (51 on "plasmas")
 22 ref. proc. articles (19 on "plasmas")
 7 PhD theses
 4 plenary, 55 invited talks at int. conf.
 8 int. conferences co-organized
 7 articles for larger public
 13 talks for larger public
 20 media appearances
 (2 TV, 5 radio, 13 newspaper)
 8 PhD's + PD's into academia since 2002
 (7 in "plasmas")

Current PhD students:

Anna Mozartova (2007-2011, W)
 Sjors v/d Stelt (2007-2011, J+MAC1)
 Gideon Wormeester (2008-2012, U)
 Aram Markosyan (2010-2014, U+W)
 Christoph Köhn (2010-2014, U)
 Igor Savostianov (2011-2015, W)
 Delyan Zhelyazov (2011-2015, J+U)
 Eric Siero (2011-2015, J+Univ Leiden)
 Jannis Teunissen (2011-2015, U)

Current postdocs:

Chao Li (U+W)
 Diana Mikhailova (U)

All on external grants:

NWO (EW, Complexity, FOM), STW, KAUST

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Strengths:

Staff has complementary expertise. Intensive cooperation with experiments and observations; numerous application fields. Strong international research position. Success in funding, publications, invitations, media ... 8 former PhD students and postdocs on tenure (track) in academia (NL: 4, Belgium: 1, Spain: 2, Turkey: 1).

Weaknesses:

No strong expertise in high performance scientific computing.



**Hire
young
HPCN
expert!**

Numerous opportunities:

In geophysics, plasma technology, plasma medicine, electrical engineering; in 3D multiscale scientific computing, nonlinear analysis and model reduction.

Threats:

Loosing focus in view of numerous mathematical challenges and application fields.