Proceedings of the 22nd International Conference on Gas Discharges and Their Applications

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Vol. 1

PROCEEDINGS OF THE XXIIND INTERNATIONAL CONFERENCE ON GAS DISCHARGES AND THEIR APPLICATIONS

- VOLUME 1 -

2nd - 7th September 2018

Novi Sad, SERBIA

Serbian Academy of Sciences and Arts
&
Institute of Physics, University of Belgrade

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Panacomp Wonderland Travel

22nd International Conference on Gas Discharges and Their Applications

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Electron transport in strongly attaching gases in radio-frequency electric and magnetic fields

J. Atić, D. Bošnjaković, Z.Lj. Petrović, J. de Urquijo, R.D. White and S. Dujko

LABORATORY FOR GASEOUS ELECTRONICS
INSTITUTE OF PHYSICS BELGRADE

САНУ

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MOTIVATIONAL FACTORS

The need for electron transport data in radio-frequency E(t) and B(t):

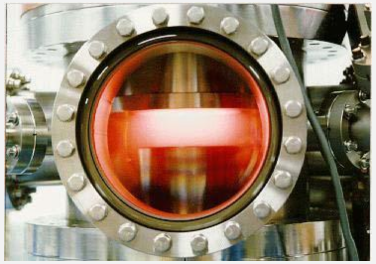
Input data

FLUID MODELS OF RF PLASMA DISCHARGES

Transport data as function of:

- frequency
- amplitude of E(t) and B(t)
- phases between E(t) and B(t)

MODELING OF ICP REACTORS



High voltage technology

SENSORS FOR ELECTROMEGNETIC WAVES DETECTION

CURRENT ISSUES IN MODELING :

1. lack of publicly available codes

- Boltzmann equation based codes
- Monte Carlo codes

2. no swarm experiments

THEORY AND CODES

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SIMULATION TECHNIQUES

NUMERICAL SOLUTION OF BOLTZMANN'S EQUATION

$$\frac{\partial f}{\partial t}+\mathbf{c}\cdot\frac{\partial f}{\partial \mathbf{r}}+\frac{q}{m}\left(\mathbf{E}+\mathbf{c}\times\mathbf{B}\right)\cdot\frac{\partial f}{\partial \mathbf{c}}=-J\left(f,F_0\right)$$

We apply the moment method

1. The angular dependence of f(**r**,**c**,t) in velocity space: expansion in spherical harmonics

$$f\left(\mathbf{r},\mathbf{c},t\right)=\sum_{l=0}^{\infty}\sum_{m=-l}^{l}f_m^{(l)}\left(\mathbf{r},c,t\right)Y_m^{[l]}\left(\hat{\mathbf{c}}\right)$$

2. The space dependence of f(**r**,**c**,t): powers of the density gradient operator

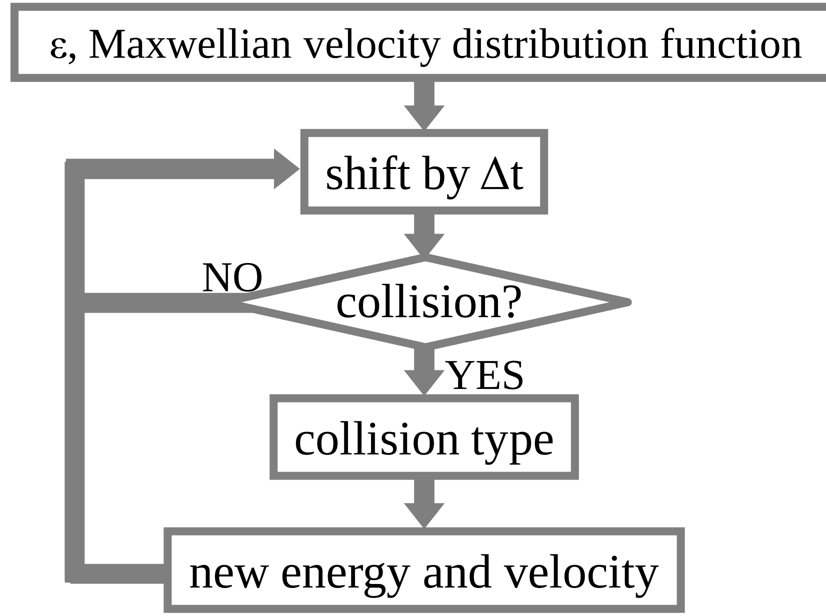
$$f_m^{(l)}\left(\mathbf{r},c,t\right)=\sum_{s=0}^{\infty}\sum_{\lambda=0}^{\infty}\sum_{\mu=-\lambda}^{\lambda}f\left(lm\,|\,s\lambda\mu;c,t\right)G_\mu^{(s\lambda)}n(\mathbf{r},t)$$

3. The speed dependence of f(**r**,**c**,t): Sonine polinomes

$$f\left(lm\,|\,s\lambda\mu;c,t\right)=\omega(\alpha,c)\sum_{\nu=0}^{\infty}F\left(\nu lm\,|\,s\lambda\mu;\alpha,t\right)R_{\nu l}\left(\alpha c\right)$$

moments of f(**r**,**c**,t) → **flux and bulk** transport coefficients, f(**r**,**c**,t)

MONTE CARLO SIMULATION TECHNIQUE



dynamic properties: ε, <x>, <v>,..

flux and bulk transport coefficients

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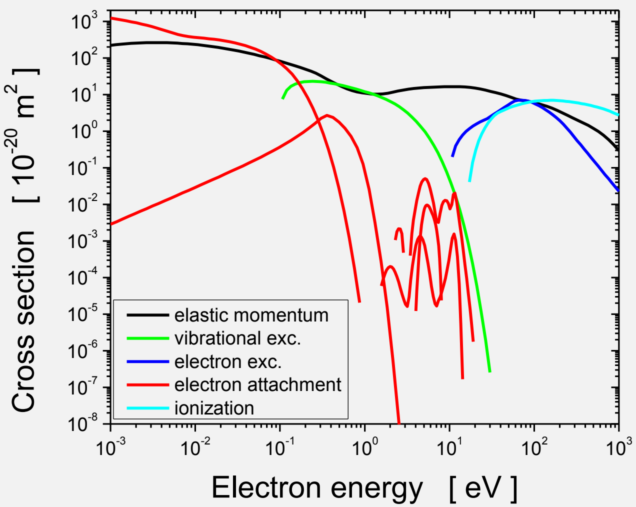
STRONGLY ATTACHING GASES:

Rescaling procedures for electron compensation

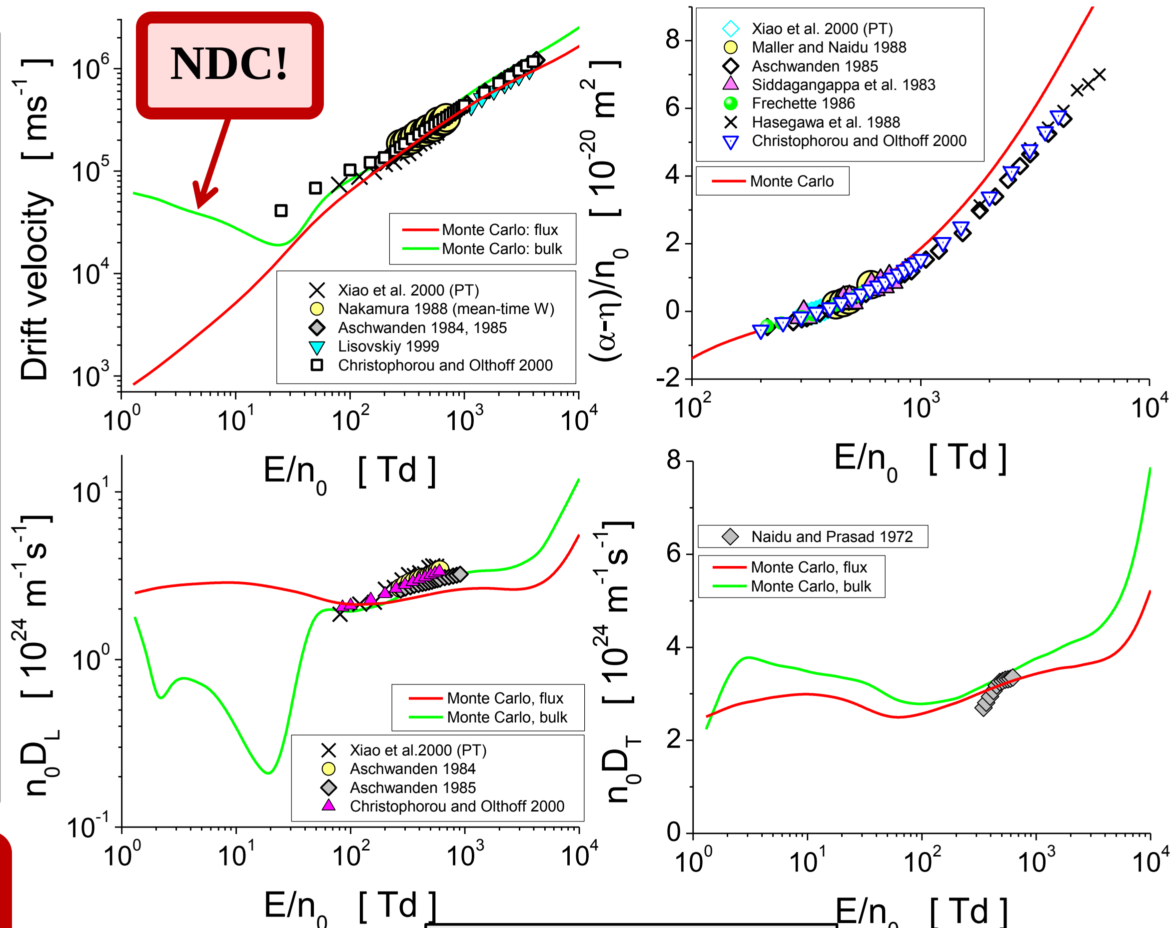
Mirić et al. *Plasma Source Sci. Technol.* **25**, 065010 (2016)

CROSS SECTIONS AND ELECTRON TRANSPORT IN SF_6

Cross sections for electron scattering in SF_6



Itoh et al. *J. Phys. D: Appl. Phys.* **26**, 1975 (1993)

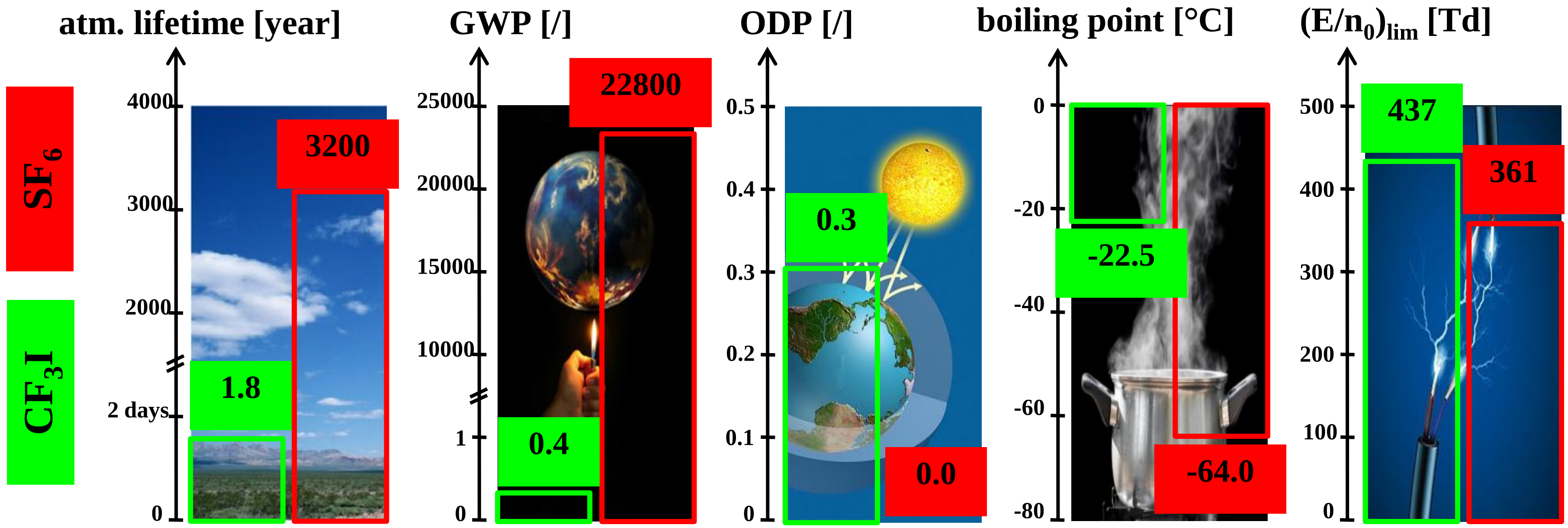


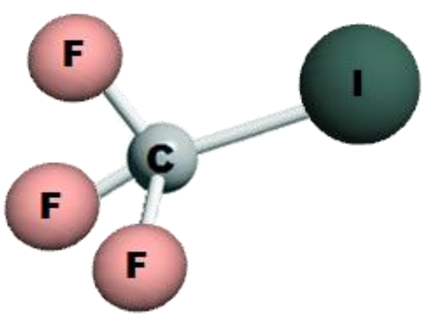
$1\ Td = 1\times10^{-21}\ Vm^{-2}$

First calculations of swarm data for the lower values of E/n_0!

- Measurements vs. our calculations: the agreement is good for the intermediate range of E/n_0.
- **Bulk drift velocity:**
  1. dominates the flux drift velocity over the entire range of E/n_0,
  2. exhibits a very strong **negative differential conductivity effect (NDC)**.

PROPERTIES OF CF_3I AND SF_6





CF_3I shows promising insulation properties

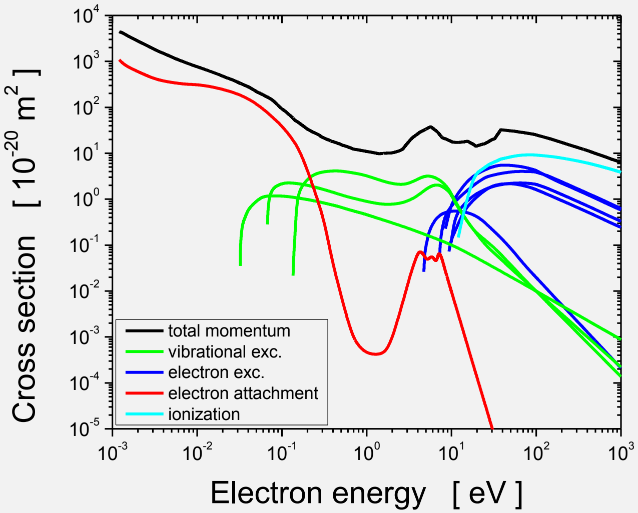
→

POSSIBLE REPLACEMENT FOR SF_6!

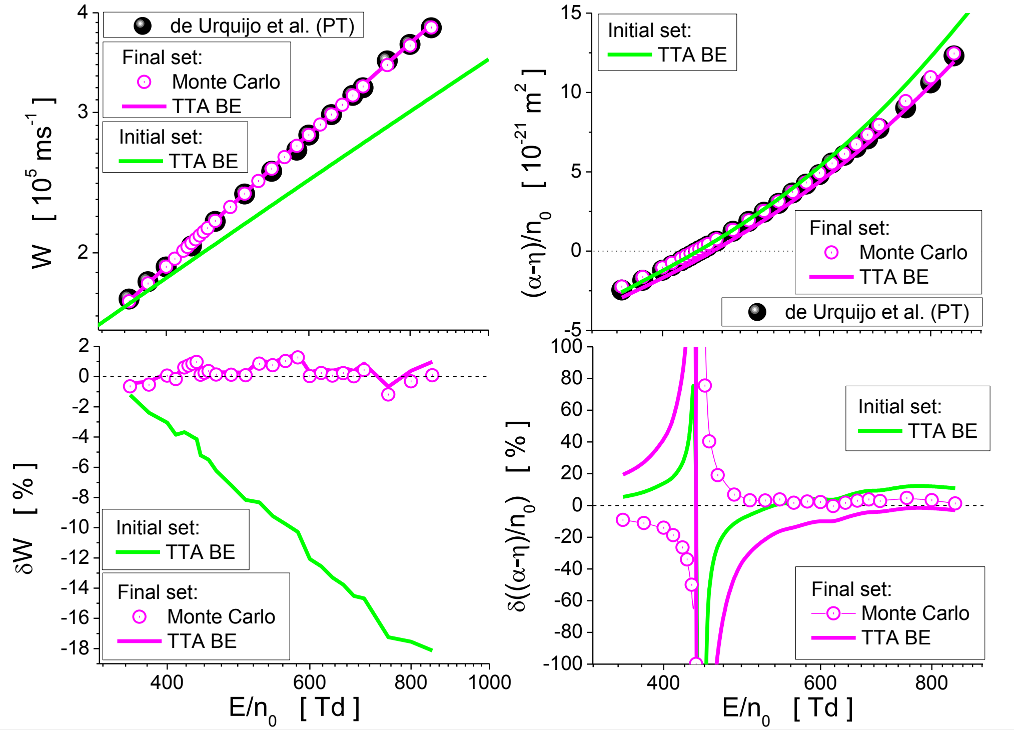
GWP (***global warming potential***) – amount of heat trapped in the atmosphere; reference gas: carbon dioxide (CO_2).
ODP (***ozone depletion potential***) – potential to destroy ozone; reference gas: chlorofluorocarbon-11 (CFC-11).

CROSS SECTIONS AND ELECTRON TRANSPORT IN CF_3I

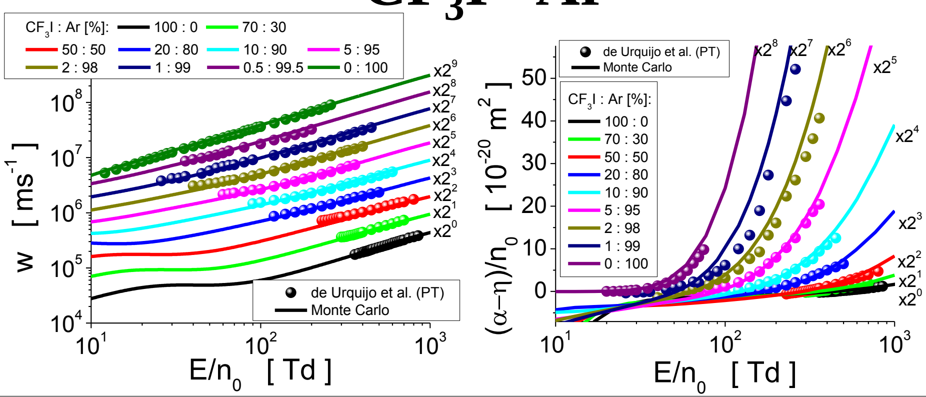
Cross sections for electron scattering in CF_3I



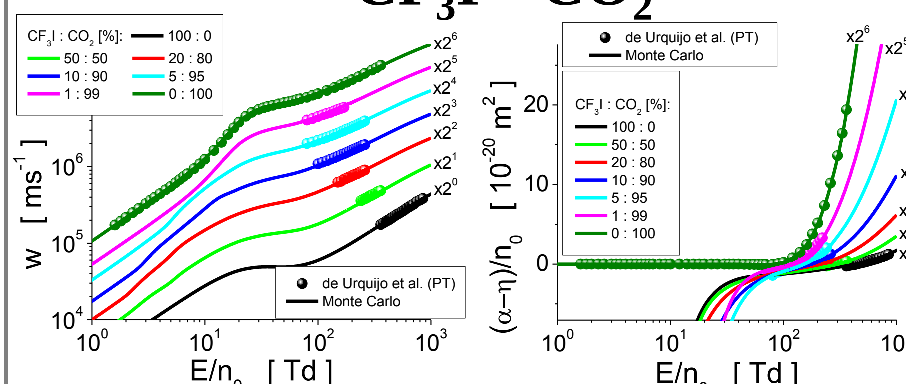
Pure CF_3I



CF_3I - Ar



CF_3I – CO_2



M. Kimura, Y. Nakamura, *J. Phys. D: Appl. Phys*. **43**, 145202 (2010)

Measurements under the pulsed Townsend conditions are performed by Prof. J. de Urquijo and his co-workers.

HOW DOES THE FIELD FREQUENCY AFFECT ELECTRON TRANSPORT?

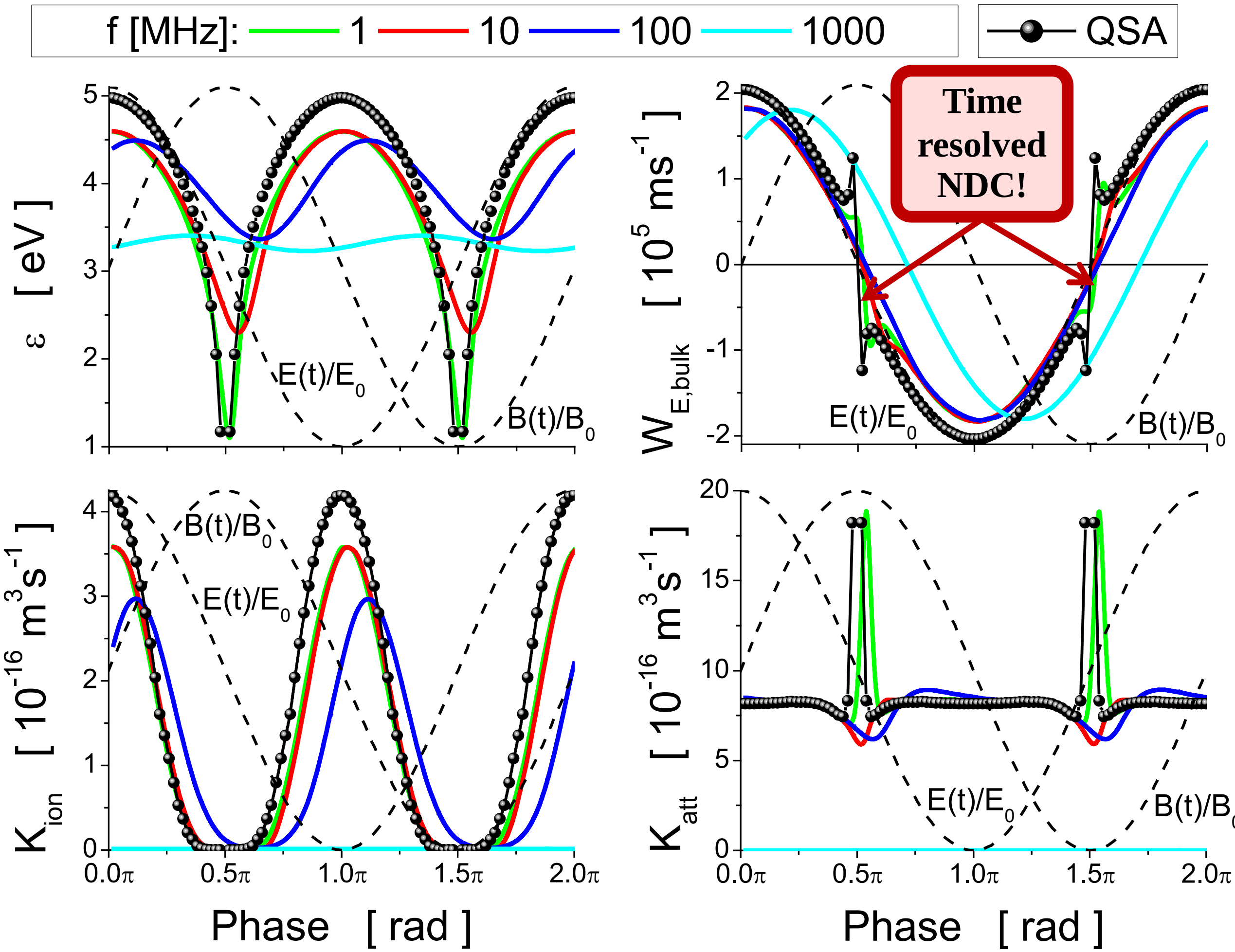
- Modulation amplitude decreases with increasing frequency.
- Phase-shift of the temporal profiles with respect to the **E** field increases with frequency.

Quasi-static approximation (QSA):

- instantaneous relaxation of energy and momentum
- corresponding temporal profiles are constructed from the DC data
- **QSA is not valid for the higher field frequencies!**

Time-resolved NDC:

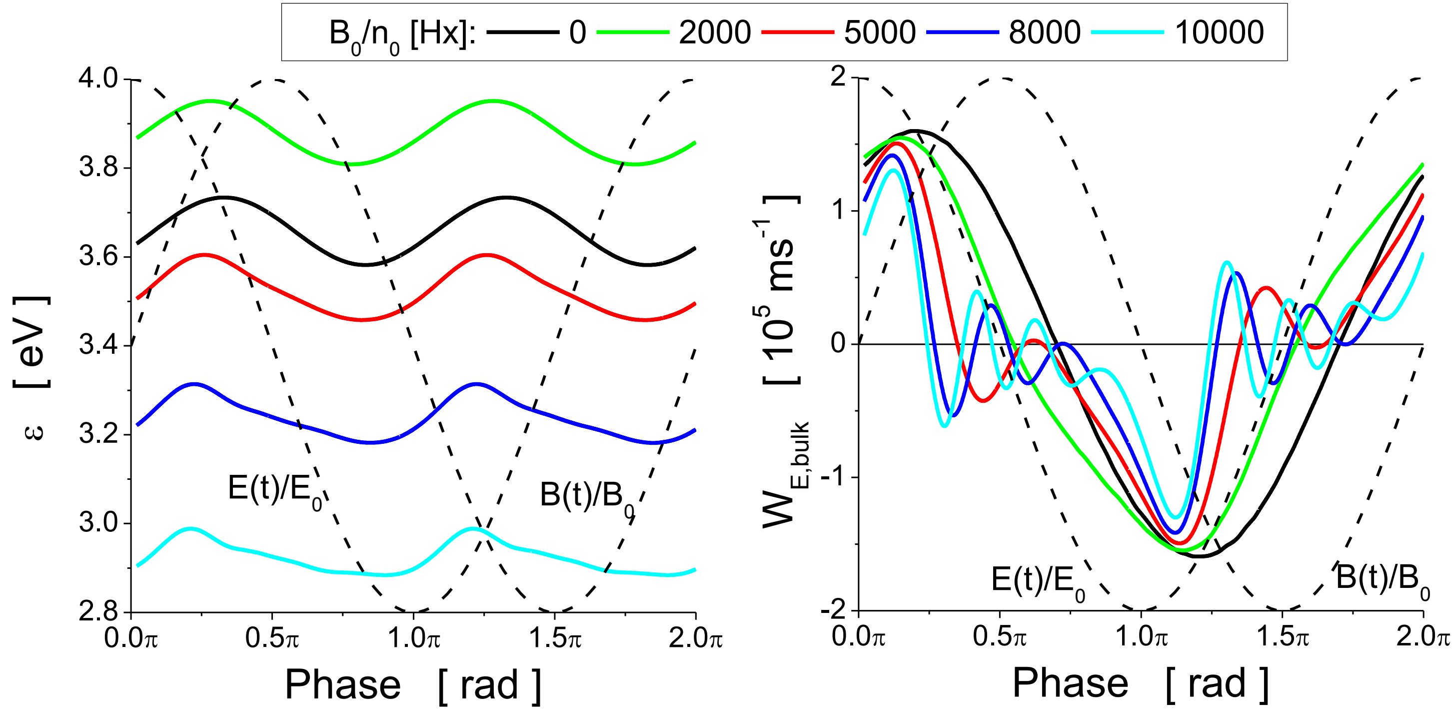
- QSA predicts instantaneous NDC
- **inability of momentum to fully relax + explicit effects of electron attachment**: just one of the sub-maximums stays



Simulation conditions: pure CF_3I, E_0/n_0 = 350 Td, B_0/n_0 = 0 Hx

HOW DOES THE MAGNETIC FIELD AMPLITUDE AFFECT ELECTRON TRANSPORT?

- Mean energy could be increased by applying the time-varying magnetic field.
  Never observed in DC electric and magnetic fields!
  Dielectric characteristics can be improved by B_0/n_0!
- There is a transition from a sinusoidal to the non-sinusoidal (triangular) profile.
- For B_0/n_0 less than 2000 Hx the phase-shift of the drift velocity with respect to the applied electric field is decreased.
- Strong oscillations are induced due to cyclotron motion.

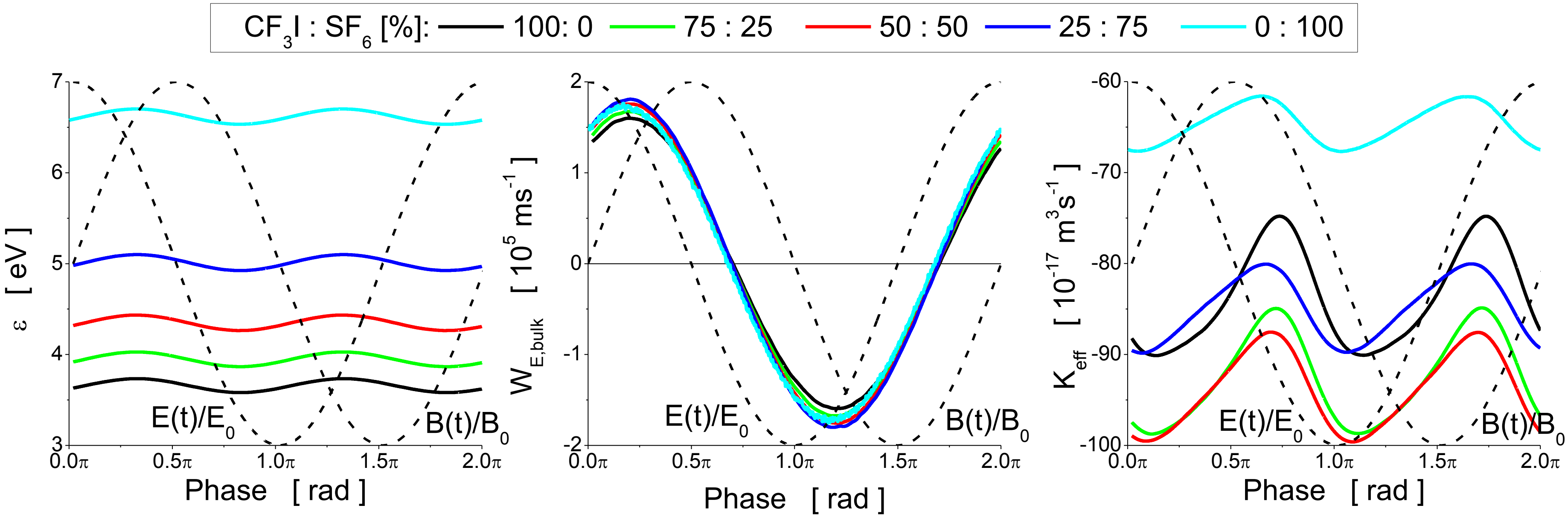


Simulation conditions: pure CF_3I, E_0/n_0 = 350 Td, f = 1 GHz

1 Hx = 1×10^{-27} Tm^3

ELECTRON TRANSPORT IN SF_6-CF_3I MIXTURES

- Mean energy is reduced by adding CF_3I in the mixture.
- Attachment rate does not follow the mean energy.



higher abundance of CF_3I → **lower ε** → **more efficient attachment of electrons**

BETTER GASEOUS DIELECTRIC
from the microscopic physical picture
(to be checked in real-life applications)

Simulation conditions:
E_0/n_0 = 350 Td,
B_0/n_0 = 0 Hx,
f = 1 GHz

CONCLUSION

OUR CONTRIBUTION:

- CF_3I: we have developed a **complete set of cross sections for electron scattering**
  Standard swarm procedure
  Measurements of swarm properties, PT conditions
- Electrons in SF_6 and CF_3I:
  Rescaling procedures for electron compensation → **the first calculations at low E/n_0!**

WE HAVE OBSERVED:

- Strong NDC in SF_6 and CF_3I in DC fields induced by electron attachment
- QSA: valid in the limit of the lowest frequencies
- Temporal profiles of transport coefficients:
  The increase of the mean energy with B_0/n_0
  Time-resolved NDC in the profile of the bulk drift velocity: inability of momentum to be fully relaxed + explicit effects of electron attachment

ЗАВРШНА ТРИБИНА У ГО ЧУКАРИЦА

завршној трибини у оквиру пројекта „ММА- знаменита Српкиња“, одржаној 8.јуна 2016.године у Свечаној сали ГО Чукарица, приказан је целокупан пројекта, са многобројним различитим активностима, сусретима учесника пројекта из основних и средњих школа Београда. Присуствовали су офесори и ученици из Земунске гимназије, Техничке школе из Железника, ОШ Веселин Маслеша, као и представници Канцеларије за младе ГО карица, ДКЦБ-а и чланови Друштва физичара Србије.

есници трибине су имали прилику да добију одговор на питање ***Зашто је важно проучавати природне науке?*** Свој пут од школске клупе до ска у свет науке изложиле су Александра Димић и Јасмина Мирић.

ивој дискусији, ученици основних и средњих школа показали су заинтересованост за свет природних наука и ових младих амбициозних научница, и су примери заиста инспиративни.
о је ово био завршни сусрет пројекта „Милева Марић Ајнштајн – знаменита Српкиња„ учесници пројекта су се осврнули на активности планиране и ализоване током пројекта, уручене су захвалнице учесницима пројекта, сарадницима на пројекту и партнерима пројекта: Канцеларији за младе ГО карица и Дечијем културном центру Београда.