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The Role of Breakdown Data in Atmospheric Studies

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A&M DATA 2023, Palić, Serbia

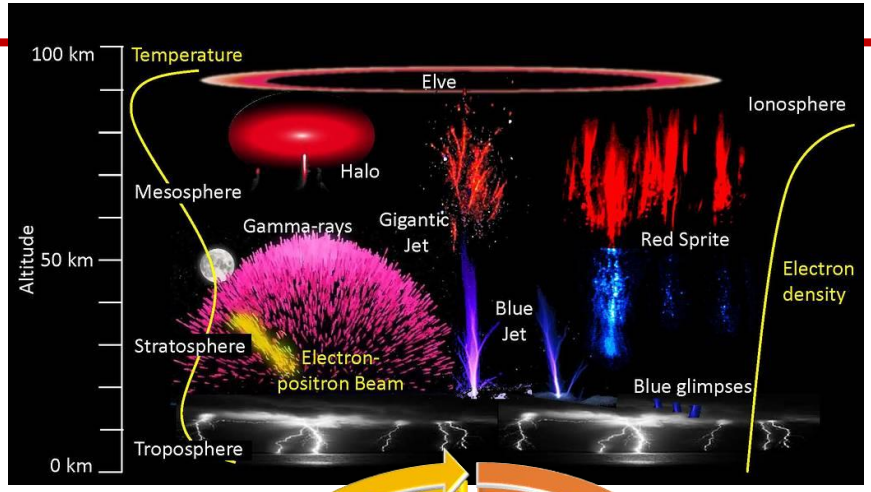
Motivation

Experiment

Results

- Discharge in alcohol vapors
- Discharge in water vapor
- Discharge in low GWP and ODP gases

Summary



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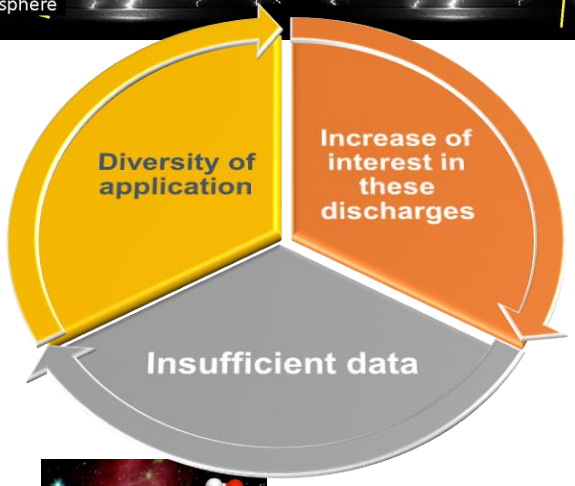
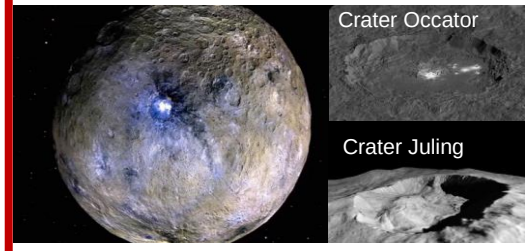
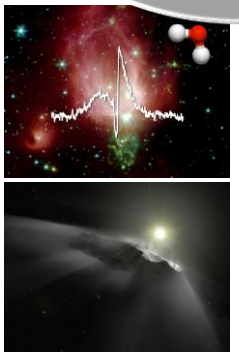


H_2O footprint in space

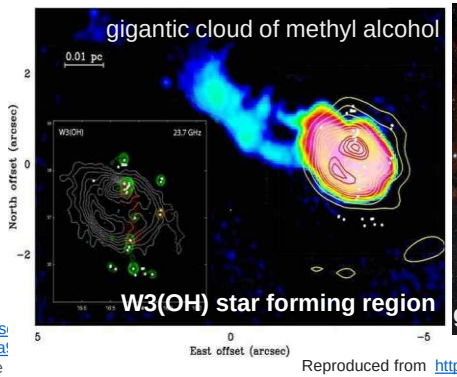


Reproduced from https://photojournal.jpl.nasa.gov/ ; Image Credit: *NASA/JPL-Caltech/UCLA/MPS/DLR/IDA* Accessed on 7 Septembre 2023.



Reproduced from https://www.nbcnews.com/mach/s asteroids-may-be-spreading-life-across-galaxy-ncna Image Credit: ESA/Hubble, NASA, ESO, M. Kornme Accessed on 7 Septembre 2023.

Alcohol footprint in space



Reproduced from https://www.universetoday.com/8098/deep-space-alcohol/; Image Credit: JIVE Accessed on 7 Septembre 2023.

Experimental Set-up

Motivation

Experiment

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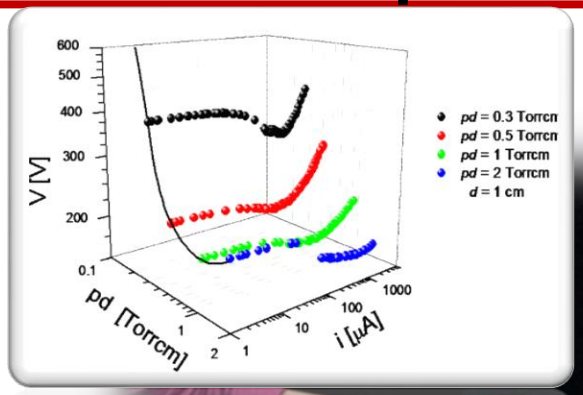
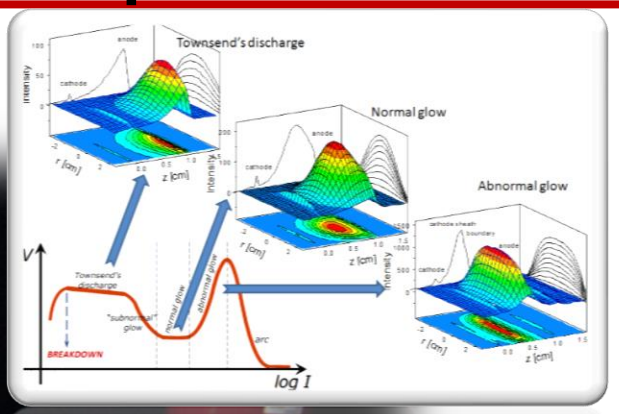
Discharge in alcohol vapors

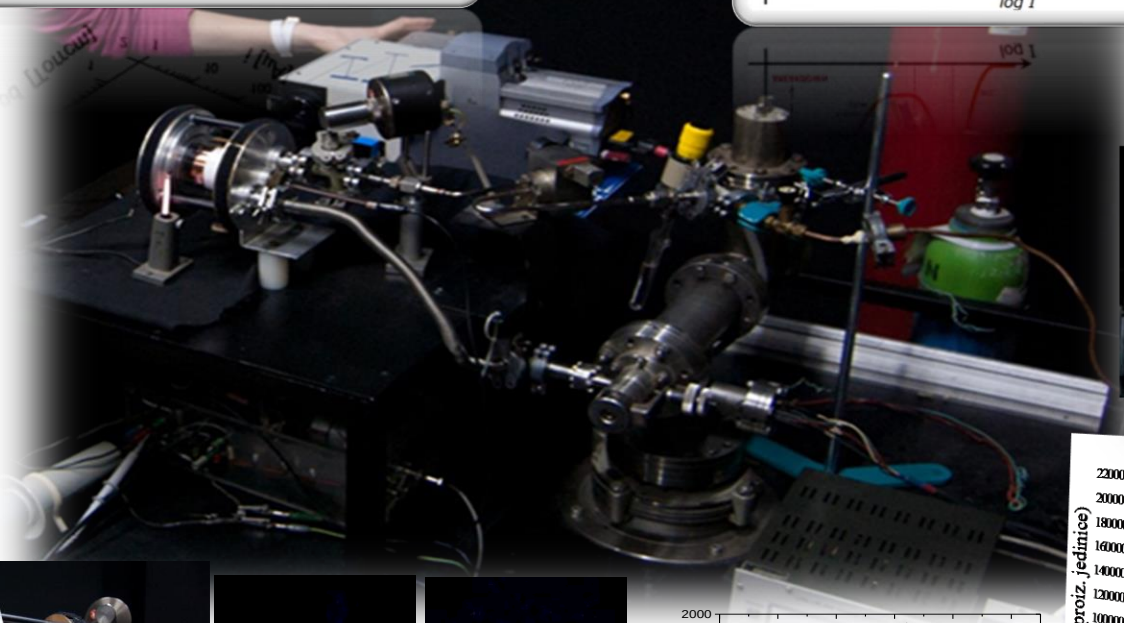
Discharge in water vapor

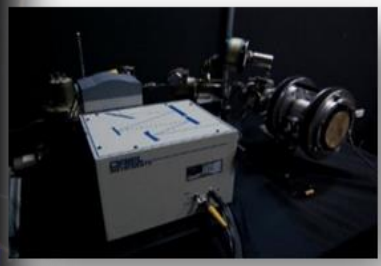
Discharge in low GWP and ODP gases

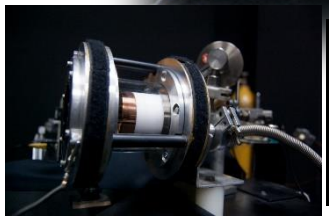
Summary

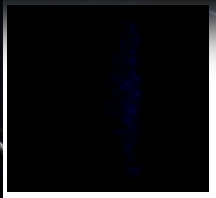




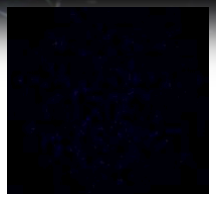




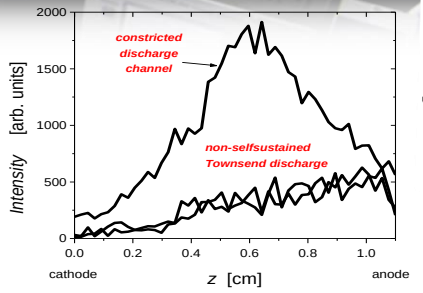


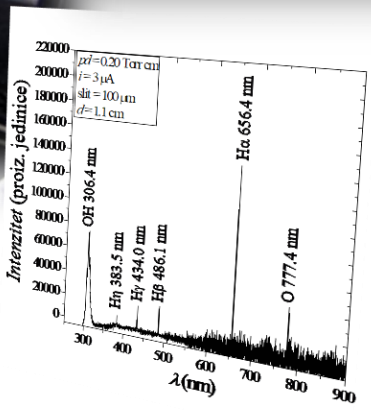


Side-on view



End-on view





Elementary processes data

Modelling

Experimental measurements of macroscopic observables

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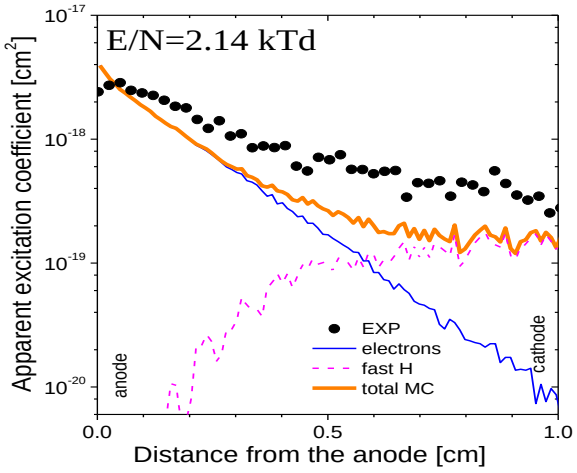
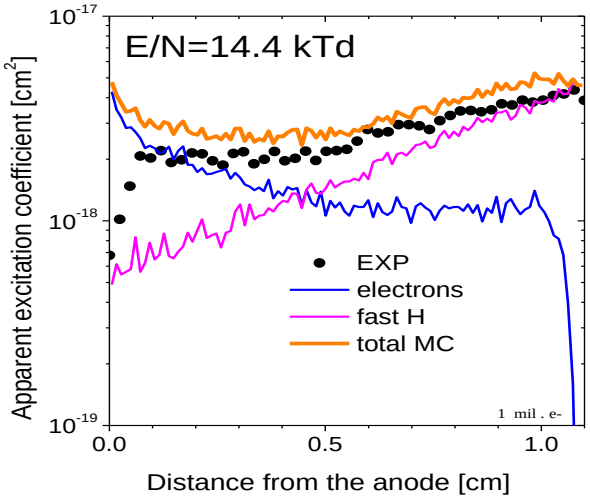
DC Breakdown Measurements

Spatial profiles of Ha emission in H_2O discharge – exp vs model

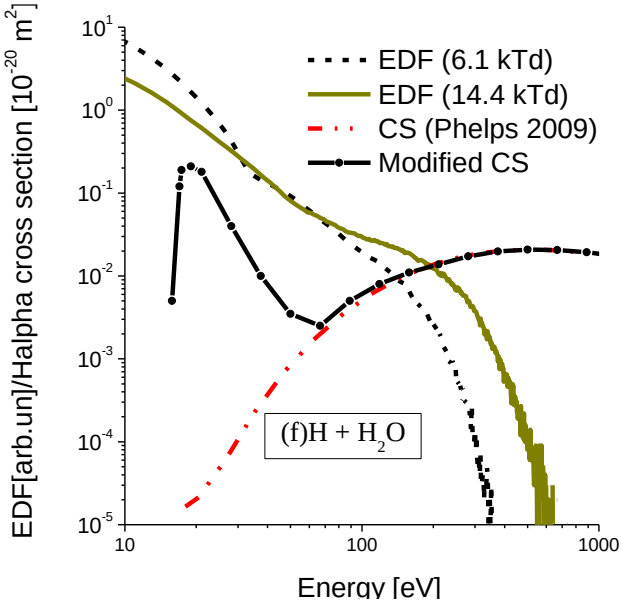
Dominant ions H_2O^+, OH^+, H^+ and H_3O^+





Total Hα emission signal obtained from MCS (sum) consists of a sum of electron component **e-(d+b)** direct and including backscattered electrons (b), and fast H component [**(f)H**] which accounts also for all fast H reflected back from the cathode.

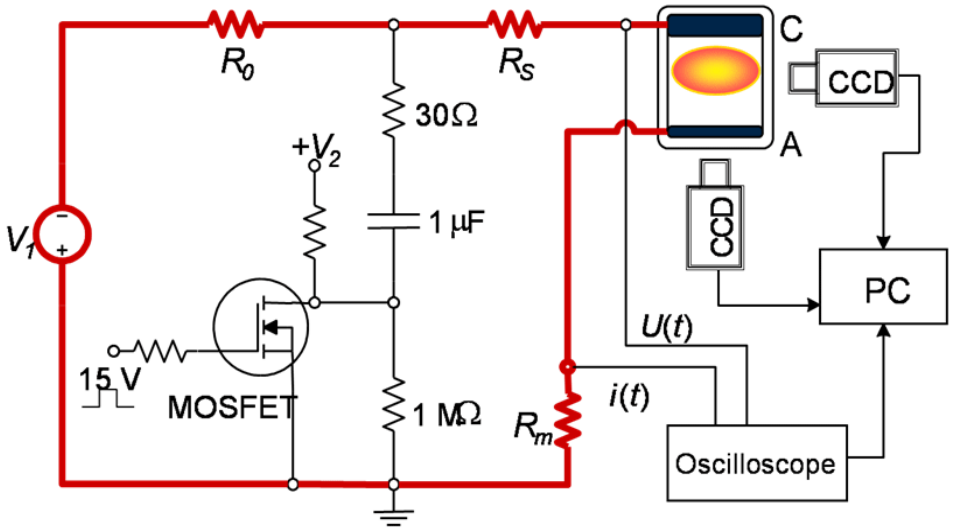
Hα emission from fast H: CS and EDF



Vladimir Stojanović, Nikola Škoro, Jelena Sivoš, Gordana Malović, Dragana Marić and Zoran Lj. Petrović, Modeling Emission from Water Vapor DC Discharge at Low Pressure
28th Summer School and International Symposium on the Physics of Ionized Gases (SPIG) ,August 29- September 2, 2016, Belgrade, Serbia, p. 328-331

Cross sections for Hα emission/EDF as a function of energy. Energy distribution function (EDF) of fast H particles 0.5 cm from the cathode

Experimental Set-up



1Torr = 133.32 Pa = 1.316 x 10^{-3} atm
1 Td = 10^{-21} Vm^2

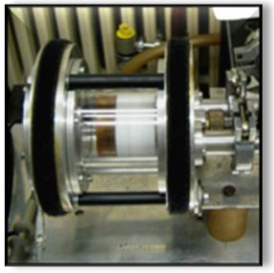
Vapour:

bi-distilled de-ionized water
99 % methanol
95 % ethanol
99 % isopropanol
99 % n-butanol

Gases:

1,1,1,2-tetrafluoroethane R-134a
2,3,3,3-tetrafluoropropene HFO-1234yf

Discharge Chamber → parallel-plate electrode geometry

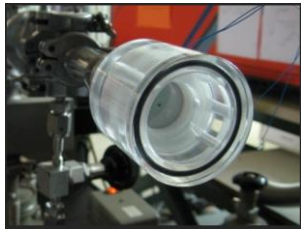


Cathode copper

Anode transparent Pt film & Al

→ *diameter* 5.4 cm

Electrode gaps = 0.5, 1.1 and 3.1 cm



Cathode SST

Anode transparent ITO film & Al

→ *diameter* 2 mm

Electrode gaps = 0.5 and 1 mm

Vapour pressure:

Methanol @ 25°C, p = 127 Torr
Ethanol @ 25°C, p = 59 Torr
Isopropanol @ 25°C, p = 44 Torr
n-Butanol @ 25°C, p = 7 Torr
Water @ 25°C, p = 24 Torr
R-134a @ 25°C, p = 4230 Torr
HFO-1234yf @ 25°C, p = 5122 Torr

DC Breakdown Measurements

Motivation

Experiment

Results

Discharge in alcohol vapors

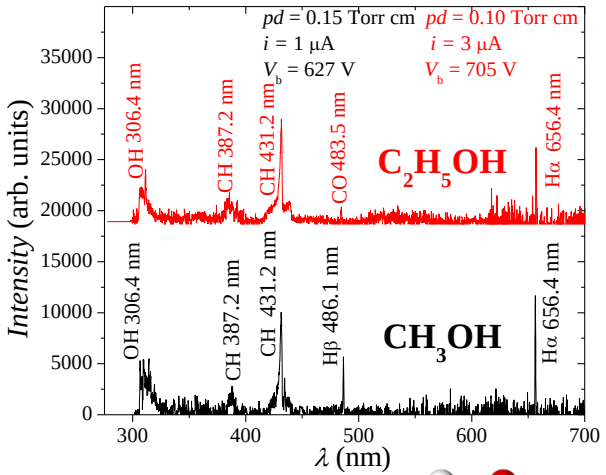
Discharge in water vapor

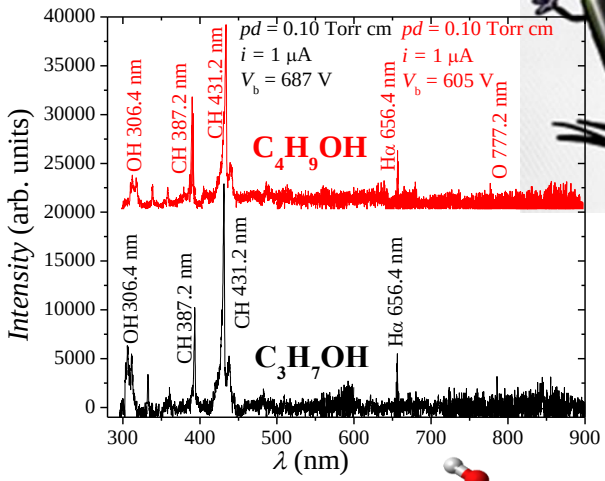
Discharge in low GWP and ODP gases

Summary

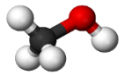
Emission spectra

d = 1.1 cm
Slit = 100 µm

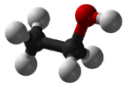




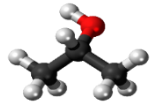
methanol



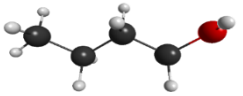
ethanol



isopropanol

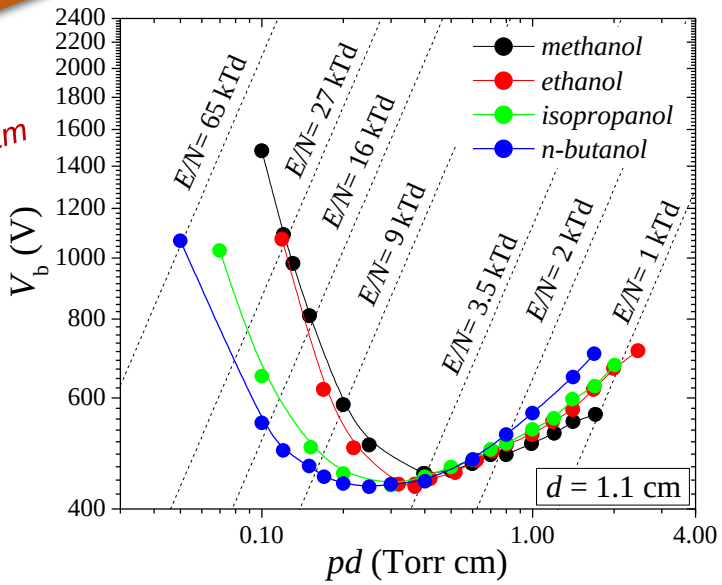


n-butanol



Paschen curves

1Torr = 133.32 Pa = 1.316 x 10^{-3} atm
1 Td = 10^{-21} Vm^2



MeOH $(V_b)_{min}$ = 455 V @ pd = 0.40 Torr cm

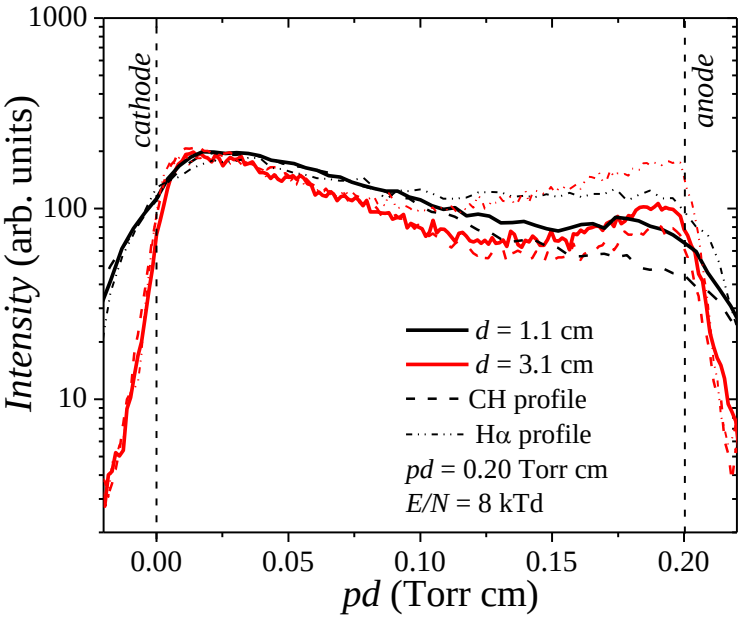
EtOH $(V_b)_{min}$ = 435 V @ pd = 0.35 Torr cm

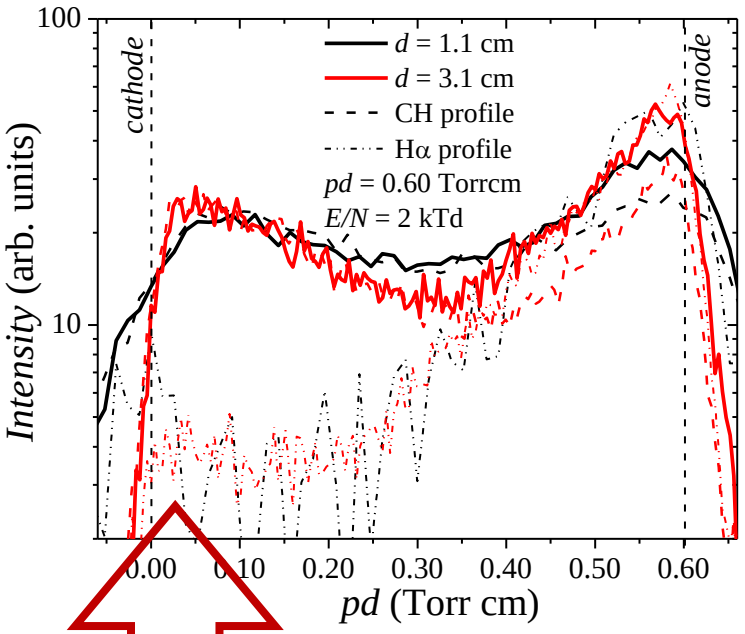
Isoprop. $(V_b)_{min}$ = 436 V @ pd = 0.30 Torr cm

n-BuOH $(V_b)_{min}$ = 434 V @ pd = 0.25 Torr cm

DC Breakdown Measurements

Axial emission profiles from Townsend discharge in MeOH vapour

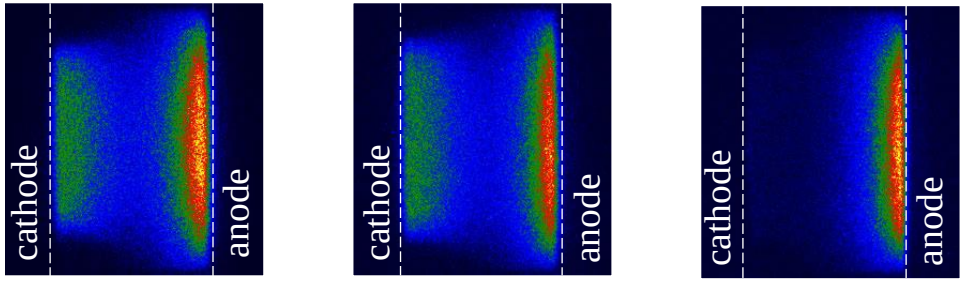




Optical filters

CH band at 431.2 nm

Hα line at 656.4 nm



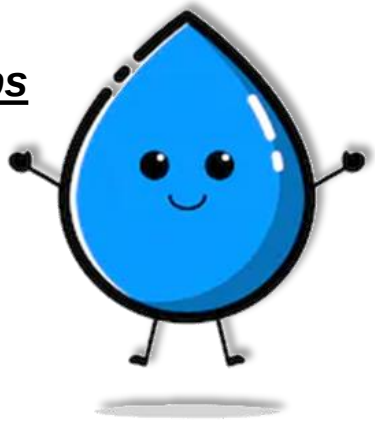
Integrated visual | filter at 431 nm | filter at 656 nm

2D structure of discharge in MeOH vapour at *pd* = 0.60 Torr cm, *E/N* = 2 kTd & *d* = 3.1 cm

DC Breakdown Measurements

Micro-discharge

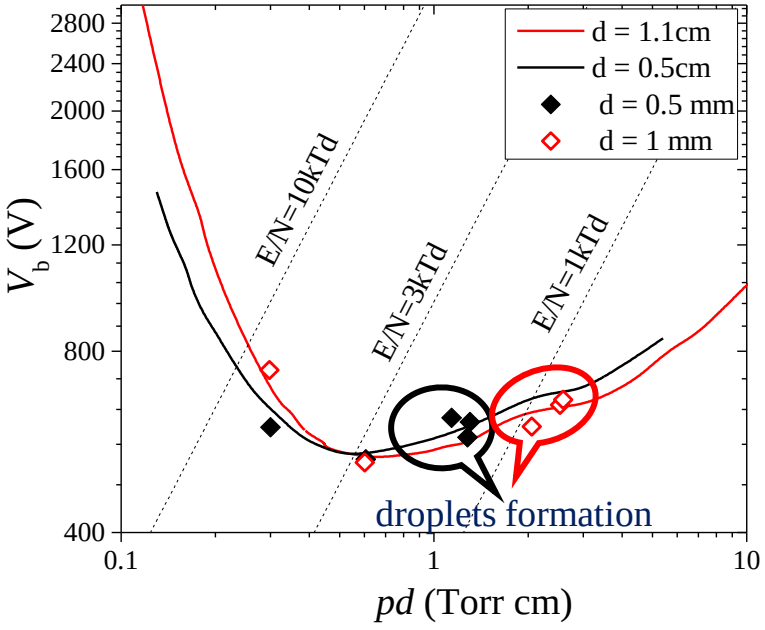
Pressures above vapor pressure– formation of liquid drops



vapor pressure for water at 22°C → 19.8 Torr

droplet formation at *pd* ≥ 0.99 Torr cm & *d* = 0.5 mm

≥ 1.99 Torr cm & *d* = 1 mm

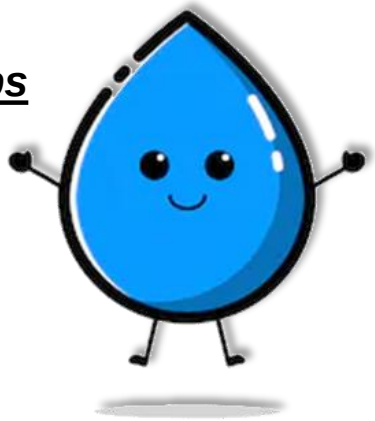


Discharge chamber at room temperature 22°C

DC Breakdown Measurements

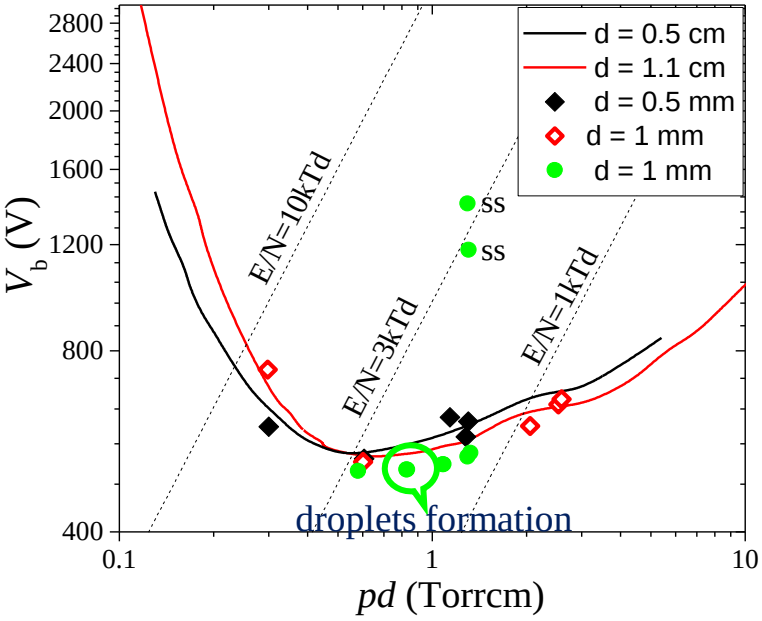
Micro-discharge

Pressures above vapor pressure– formation of liquid drops



vapor pressure for water at 8°C → 8.1 Torr

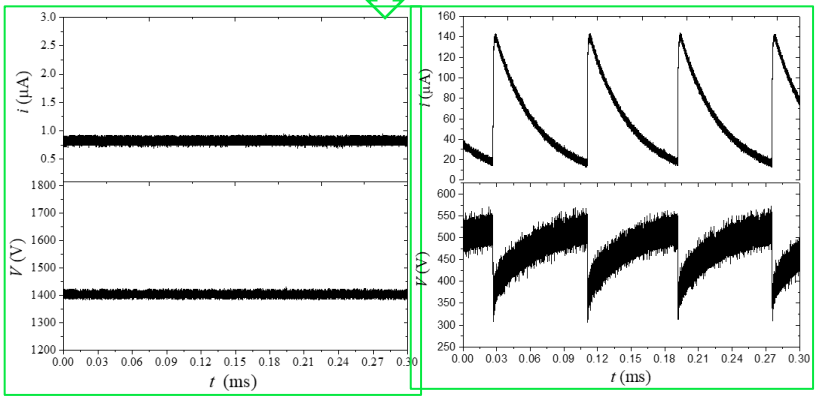
droplet formation at $pd \geq 0.81$ Torr cm & $d = 1$ mm



SS (steady-state) discharge at

1.29 Torr cm; V_b = 1177 V

1.33 Torr cm; V_b = 1405 V

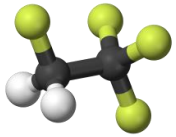


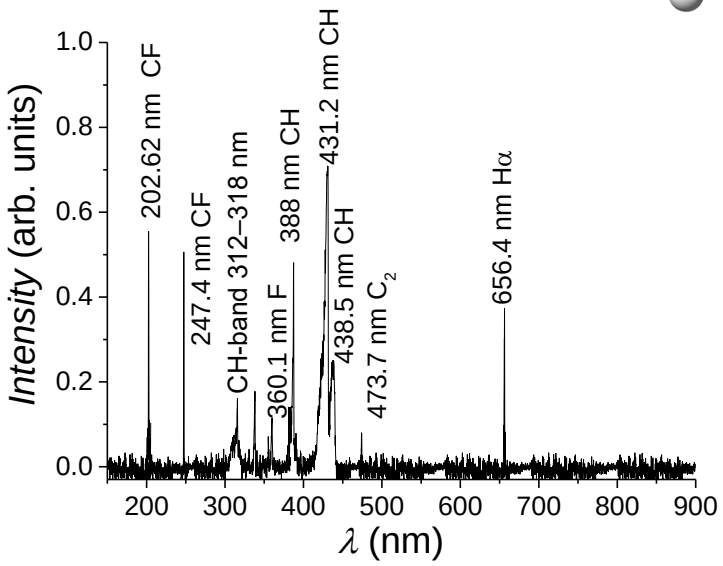
Discharge chamber at 8°C

DC Breakdown Measurements

Emission spectra

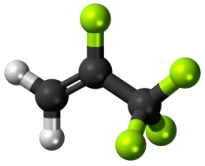
1,1,1,2-tetrafluoroethane / R-134a

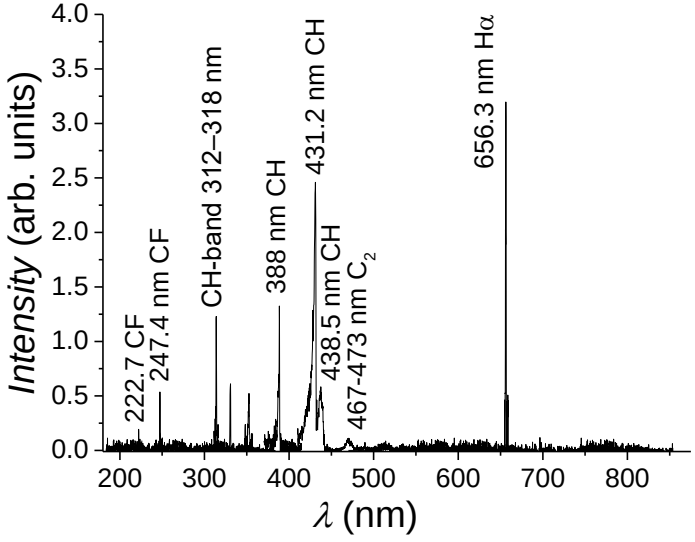




d = 1.1 cm
pd = 0.2 Tor cm
Slit = 50 μm
I = 20 μA
T = 21 °C

2,3,3,3-tetrafluoropropene / HFO-1234yf

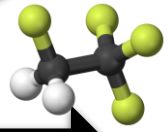




d = 1.1 cm
pd = 0.2 Tor cm
Slit = 50 μm
I = 20 μA
T = 21 °C

DC Breakdown Measurements

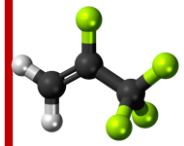
Paschen curves



R-134a

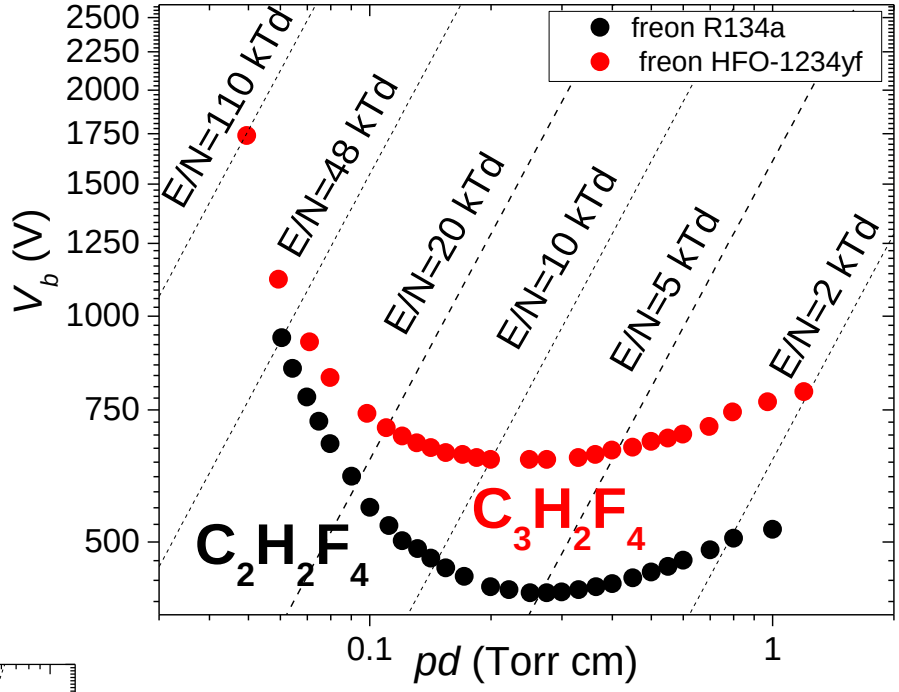
$(V_b)_{min}$ = 428 V @ pd = 0.28 Torr cm

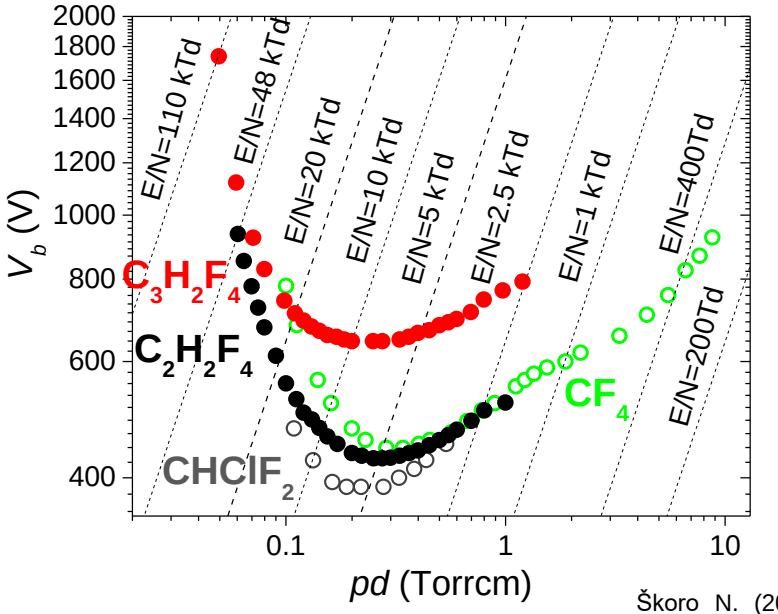
d = 1.1 cm
T = 21 °C
i = 1 μA



HFO-1234yf

$(V_b)_{min}$ = 644 V @ pd = 0.25 Torr cm





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1 Td = 10^{-21} Vm^2

Škoro N. (2012), Doktorska disertacija: *Proboj i formiranje gasnih pražnjenja od standardnih do mikroskopskih dimenzija* (Fizički fakultet, Univerzitet u Beogradu).

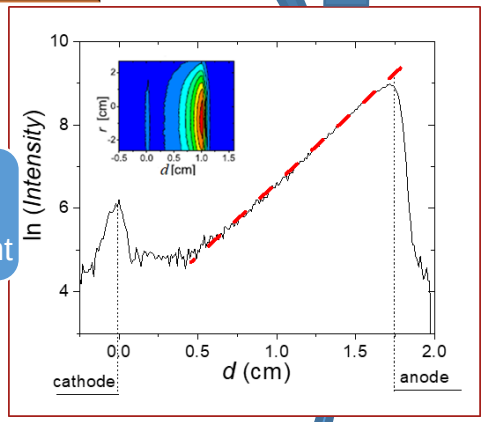
DC Breakdown Measurements

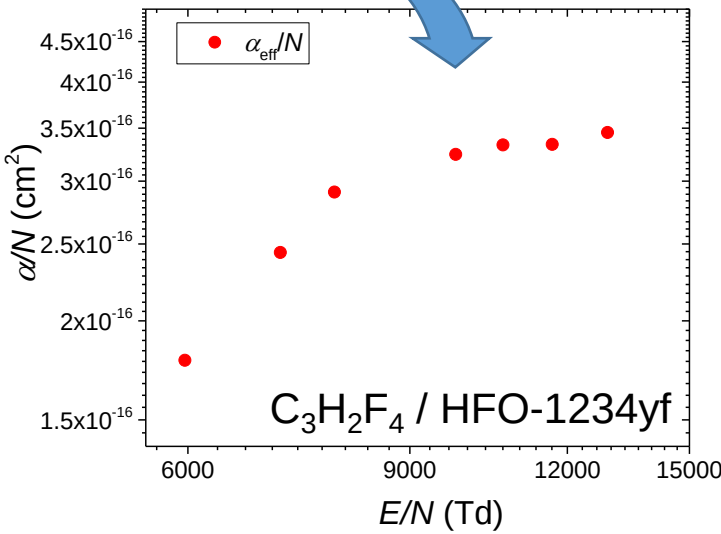
Ionization Coefficients and Secondary Electron Yield

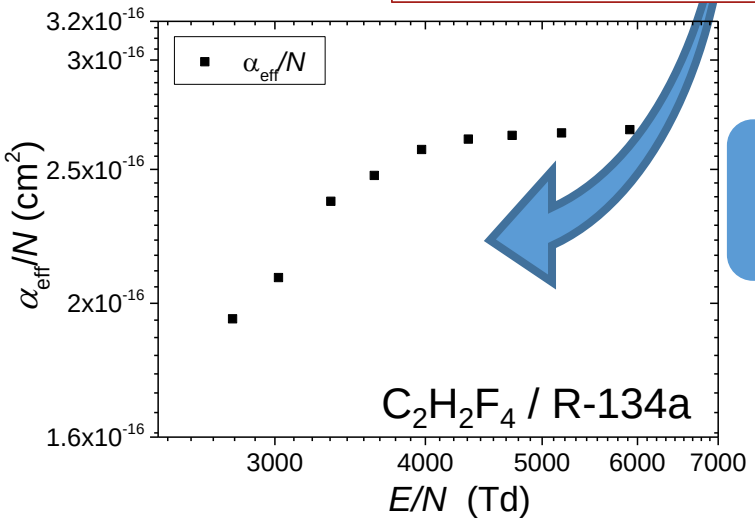
Determination of ionization coefficient

breakdown
i.e.
no space charge
i.e.
field is uniform!!!

Exponential slope corresponds to the ionization coefficient







Ionization coefficient

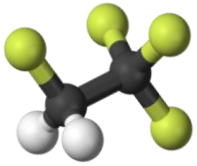
α_{eff}/N obtained from Ha emission profiles

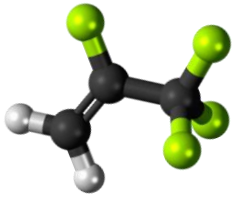
DC Breakdown Measurements

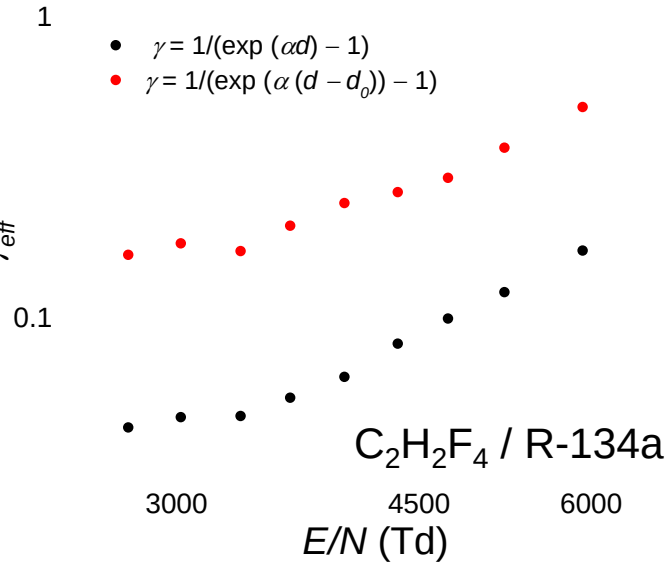
Ionization Coefficients and Secondary Electron Yield

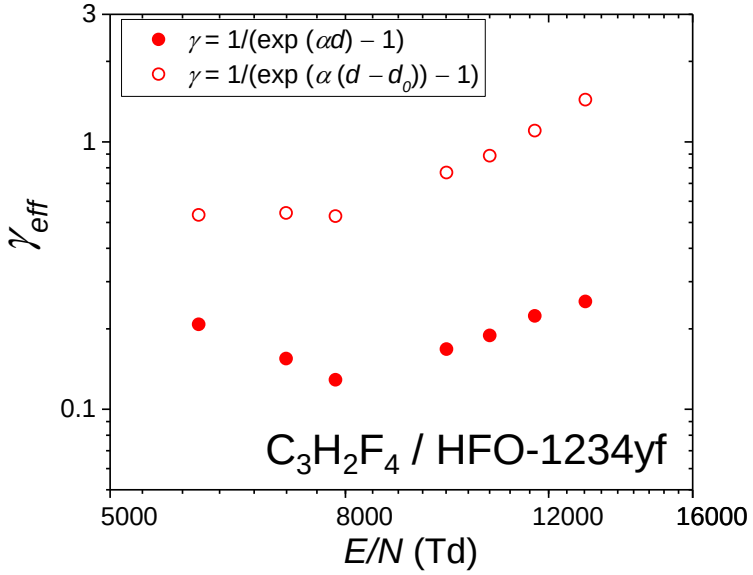
Determination of secondary electron yield

$$\gamma_{eff} = \frac{1}{\exp(\alpha(d-d_0))-1}$$









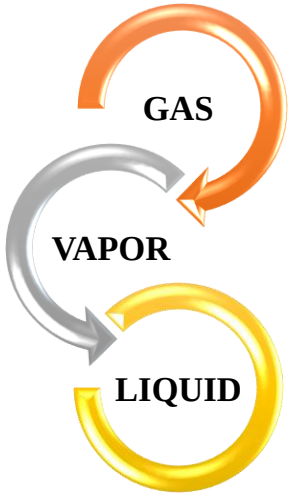
Summary

- Breakdown voltages vs *pd's* / Paschen curves recorded for H2O, alcohols, R-134a and HFO-1234yf
- Obtained axial emission profiles – enable insight in dominant processes that participate in discharges
- Our measurements have enabled extending the range of ionization coefficient towards higher *E/N* values
- Breakdown voltages and ionization coefficients enable obtaining of the secondary electron yields
- Emission spectra are recorded from 200 – 900 nm. Some heavier dissociation fragments (OH and CH radicals) and H atoms play main role in heavy particle processes of collisional excitation and ionization
- Recordings with optical filters reveal some of elementary processes that participate in breakdown

providing basis for describing breakdown in vapors of liquids & low GWP gases

establishing the benchmarks *tests*

modelling the breakdown and discharges in studied vapors/gases



… next step **RF breakdown measurements**

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THANK YOU