Dust Plasma

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What is dust plasma?

Dust plasma is an approximately equal number of positive and negative dust particles with perhaps a small numbers of electrons and ions.

$N_d^+ + N_d^- >> n_i + n_e$ Quasineutrality requires $N_d^+ \approx N_d^-$

Whereas,

Dusty plasma is a plasma of electrons and ions with a small number of dust particles.

$N_d^+ + N_d^- << n_i + n_e$

Question: What happens in a dusty space plasma if N_{dust} greatly exceeds n_i or n_e?

Case 1: Ionosphere:

ionization rate = recombination rate (no surface losses)

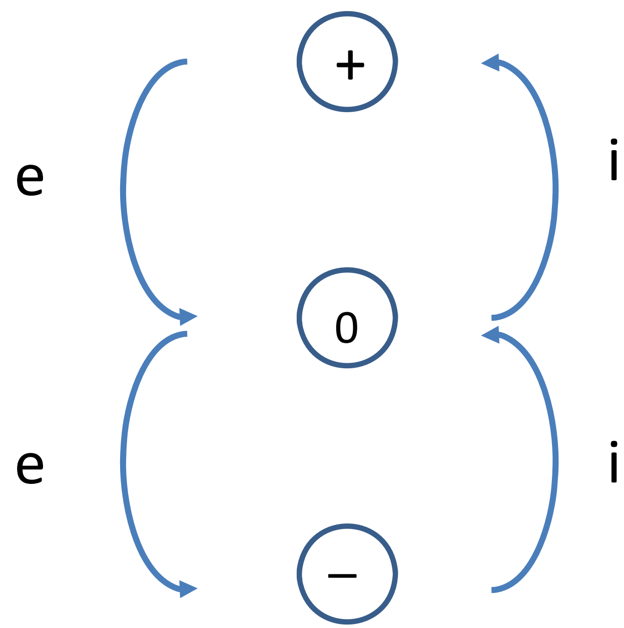
1. Quasineutrality require $N_{d+} = N_{d,-}$
2. Is the recombination on the dust particles?

Case 2: Lab Plasma

1. How can dust be levitated?
2. How can we get ionization?

The cartoon

Electrons
do this



Ions
do this

Model equations

Ionization rate

Electron-ion recombination

Electron-dust recombination, Z = -1, 0, +1

$N_{d,Z}$ number of dust particles with charge Z

$$\frac{d}{dt} n_e = R - \alpha_{ie} n_e n_i - n_e \sum_Z \alpha_{e,Z} N_{d,Z}$$

$$\frac{d}{dt} n_i = R - \alpha_{ie} n_e n_i - n_i \sum_Z \alpha_{i,Z} N_{d,Z}$$ ions likewise

With no dust, $R = \alpha_{ie}\, n_e\, n_i$ and thus $n_e = \sqrt{R/\alpha_{ie}}$

Rate equations for dust

1. Neutral dust created by discharging negative dust
2. Neutral dust lost by charging negative
3. Neutral dust lost by charging positive
4. Neutral dust created by discharging positive dust

1 2 3 4

$$\frac{d}{dt}N_{d,0} = \alpha_{i,-1}N_{d,-1}n_i - [\alpha_{e,0}n_e + \alpha_{i,0}n_i]N_{d,0} + \alpha_{e,1}N_{d,1}n_e$$

$$\frac{d}{dt}N_{d,1} = \alpha_{i,0}N_{d,0}n_i - [\alpha_{e,1}n_e + \alpha_{i,1}n_i]N_{d,1}$$

positive dust likewise

$$\frac{d}{dt}N_{d,-1} = -[\alpha_{e,-1}n_e + \alpha_{i,-1}n_i]N_{d,-1} + \alpha_{e,0}N_{d,0}n_e$$

negative dust likewise

Method of solution: Integrate in a spreadsheet

What are the assumed numbers?

For the ionosphere

R is a free parameter

$\alpha_{ie} = 10^{-12}$ m^{-6} s^{-1}

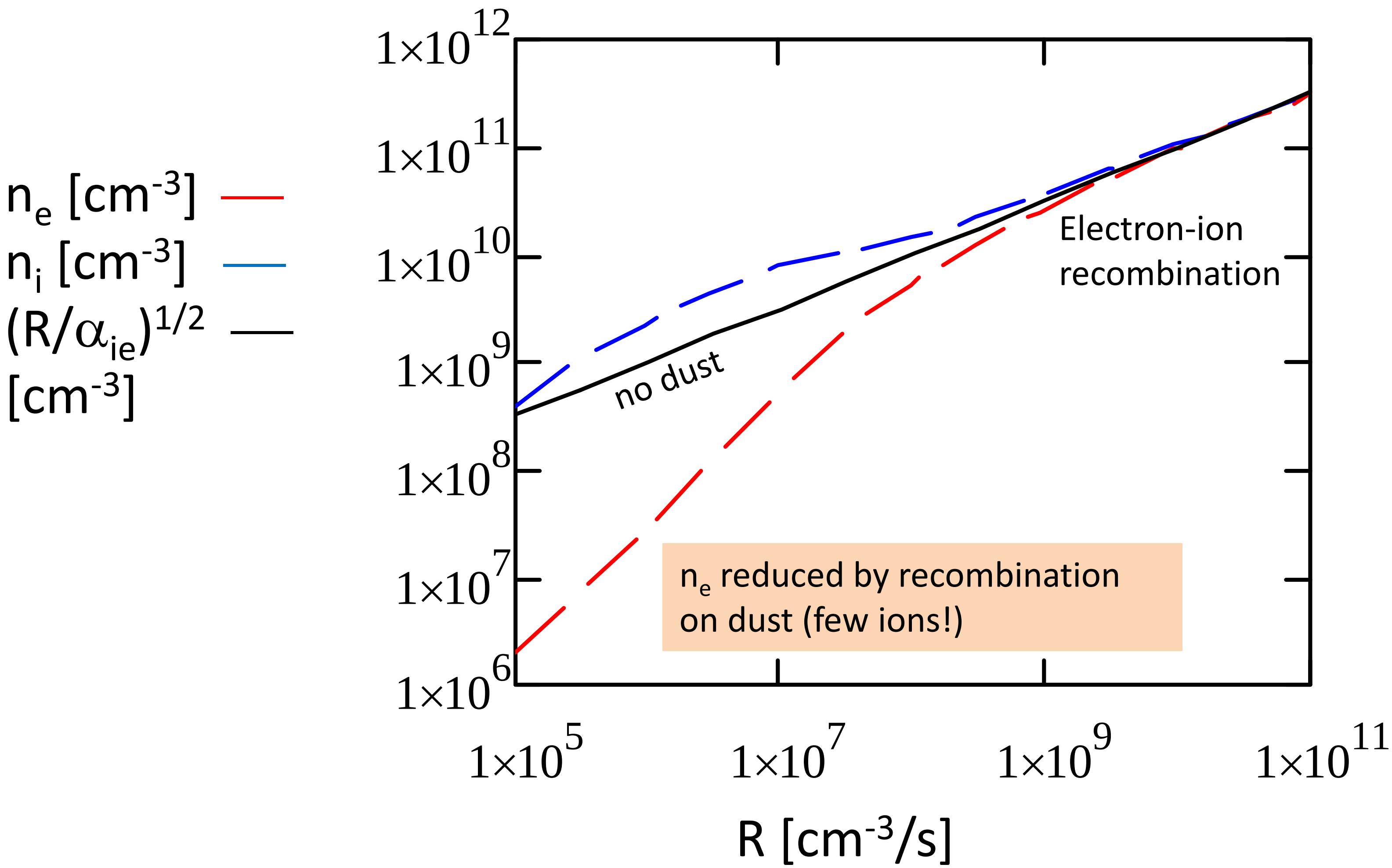
$N_{dust} = 10^4$ cm^{-3}

Dust charging cross sections

from Natanson's formulas, $T_i = T_e = 200$ K

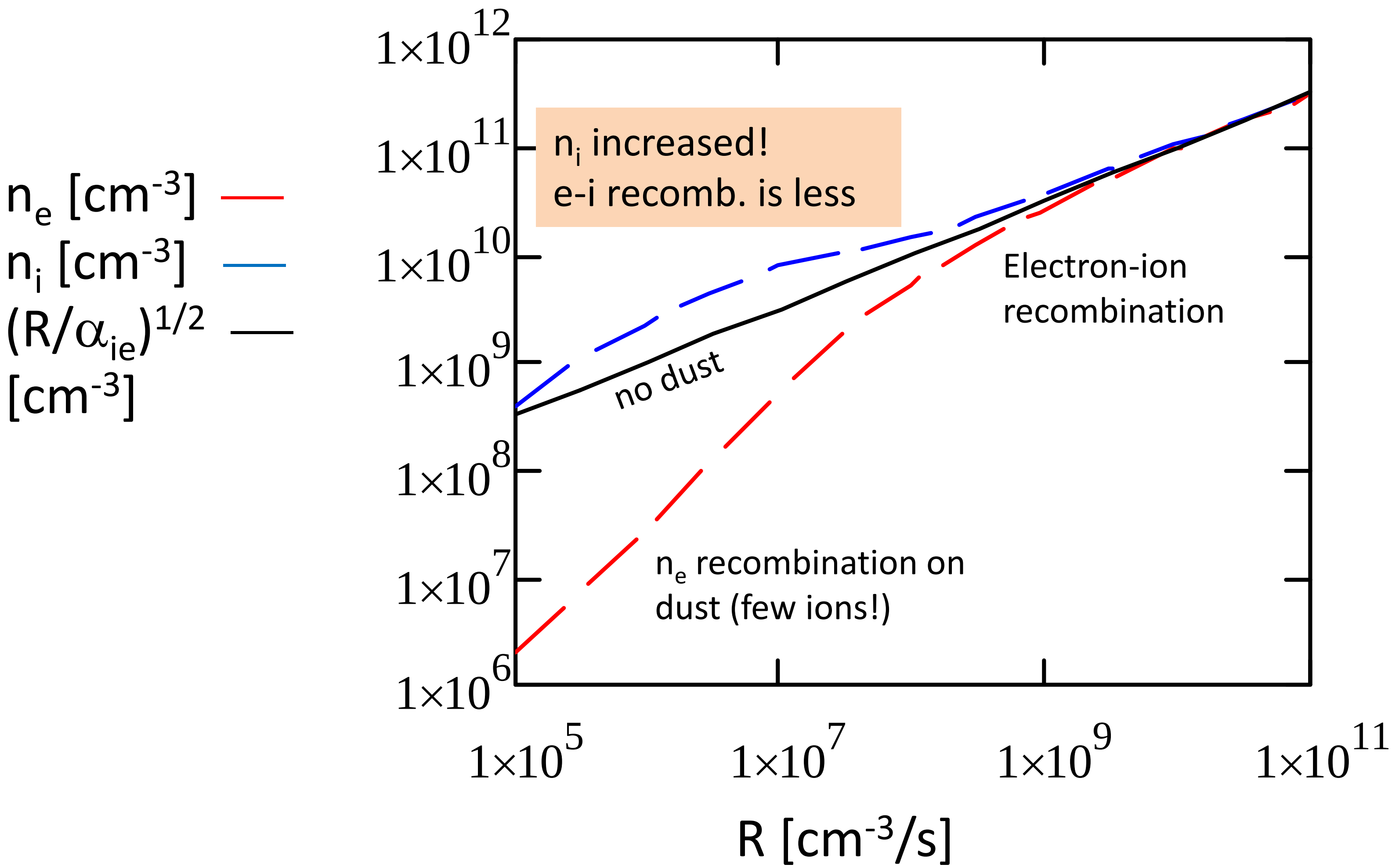
Result: Fewer electrons than expected at low *R*

Recombination on dust at low R exceeds electron-ion recombination

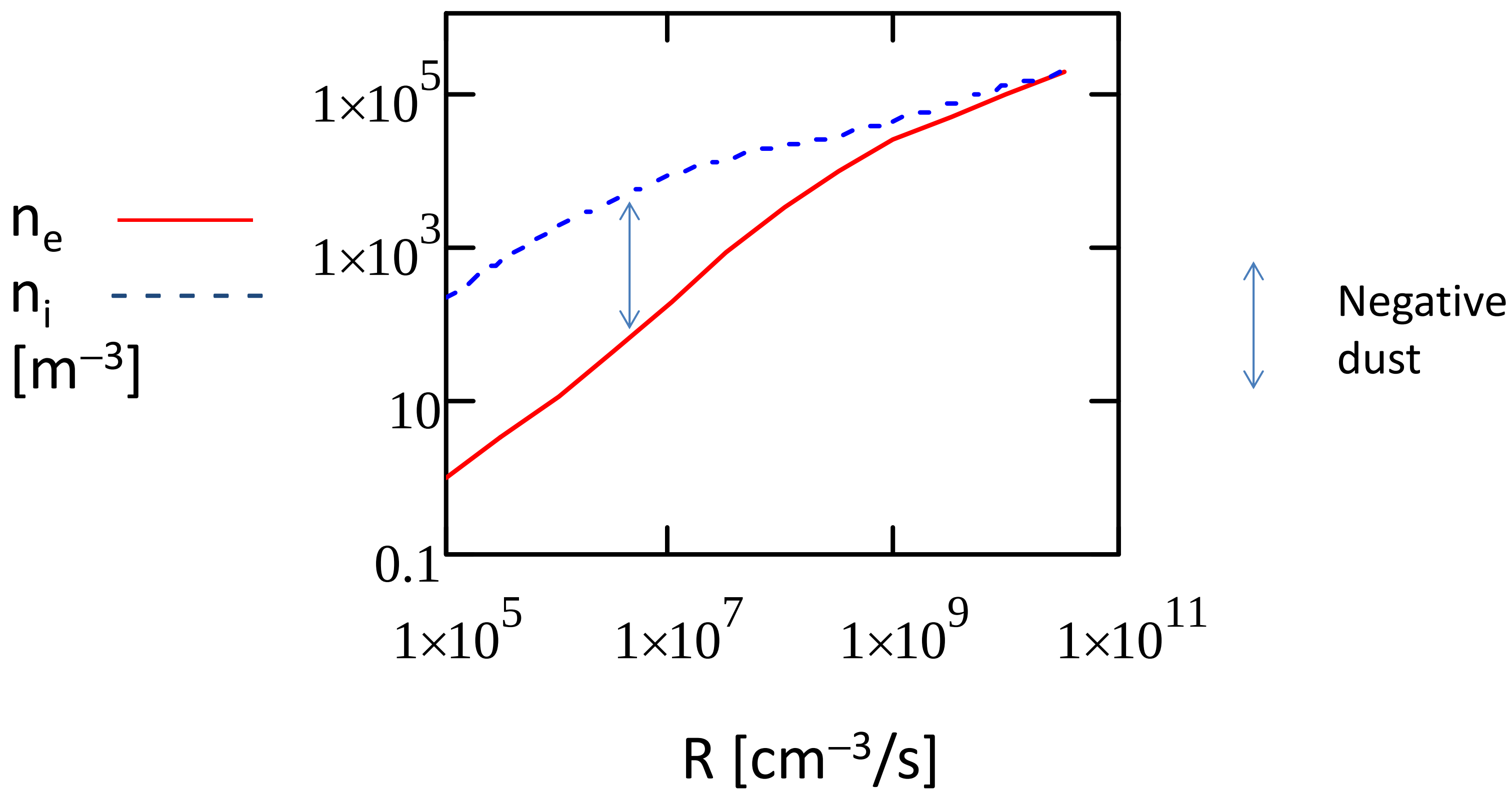


Result: More ions than expected at low *R*

electron-ion recombination is suppressed by dust because electrons are on dust particles and ion-dust recombination is small

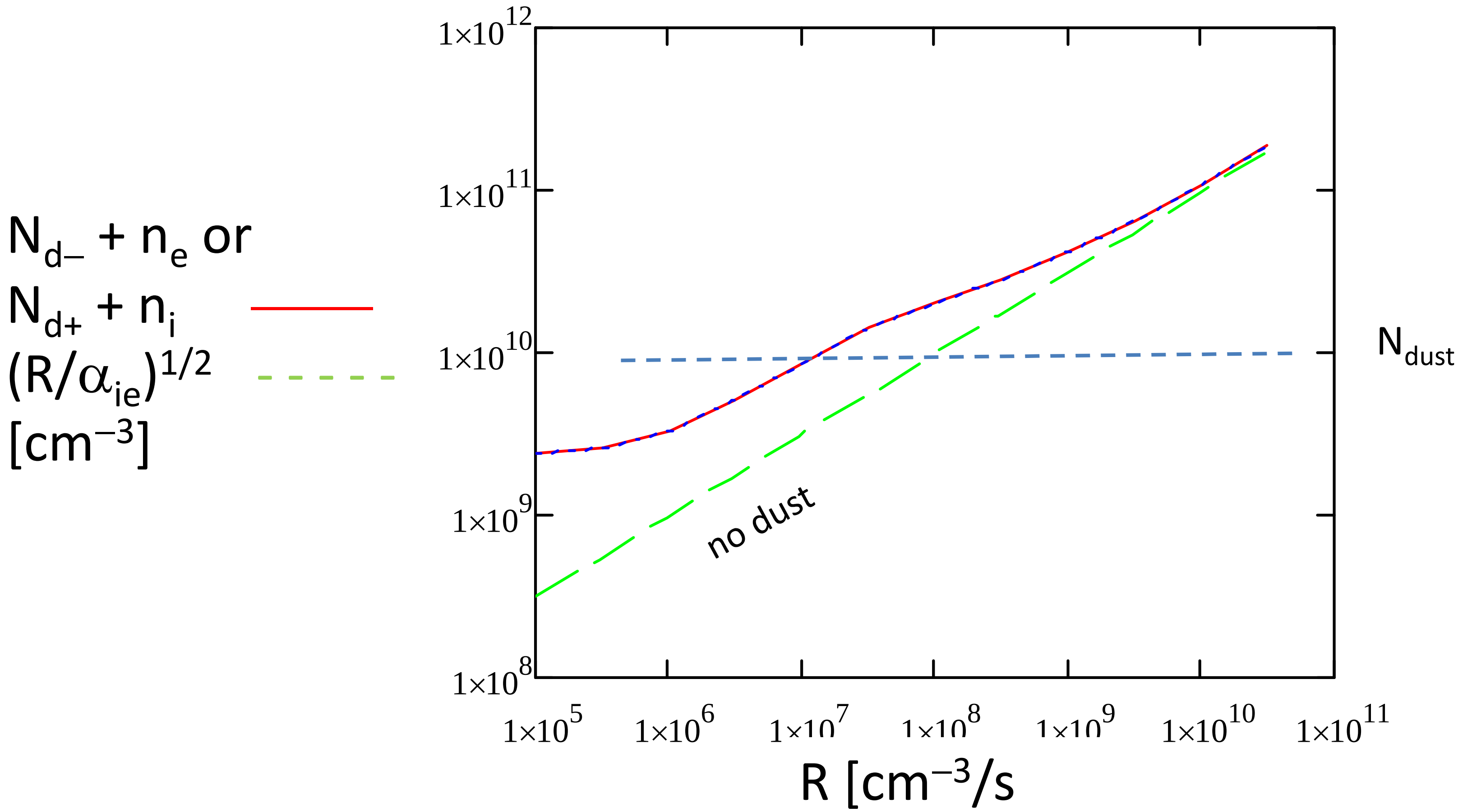


$n_i \neq n_e$ if $n_e < N_{dust}$



Adding dust increases the overall number of charges!

by suppressing e-i recombination



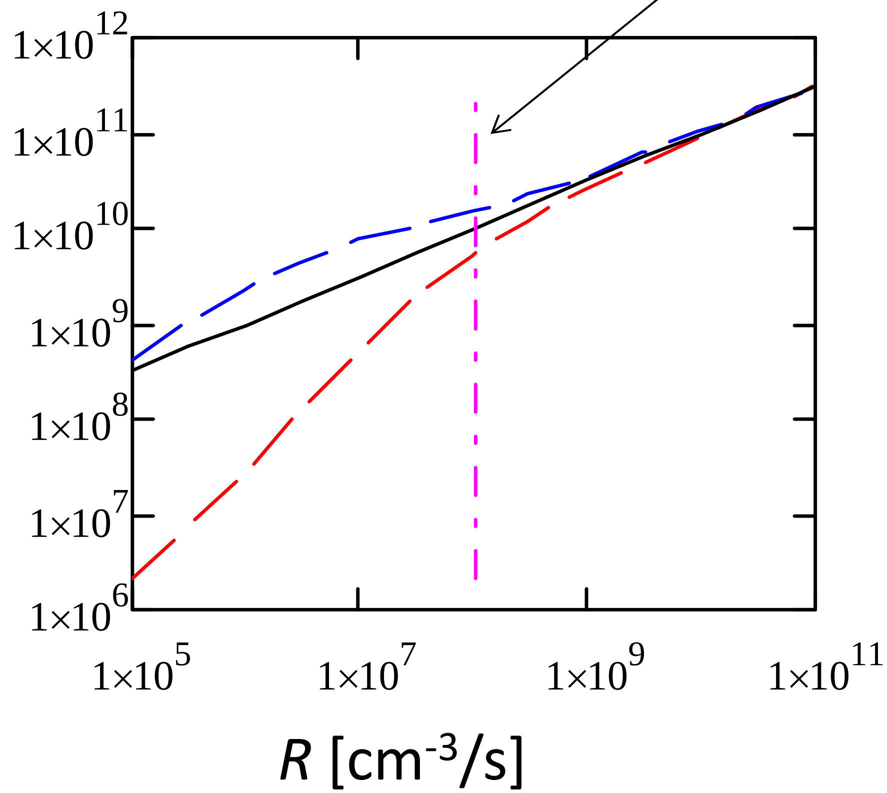
Q: At what density does dust affect recombination?

Ans: When $N_{d,-} \approx n_e \approx (R/\alpha_{ie})^{1/2}$ or $R = \alpha_{ie}\, N_{dust}^{2}$

n_e [cm^{-3}] —— (red)

n_i [cm^{-3}] —— (blue)

$(R/\alpha_{ie})^{1/2}$ [cm^{-3}] —— (black)



At very low R positive and negative dust have equal density

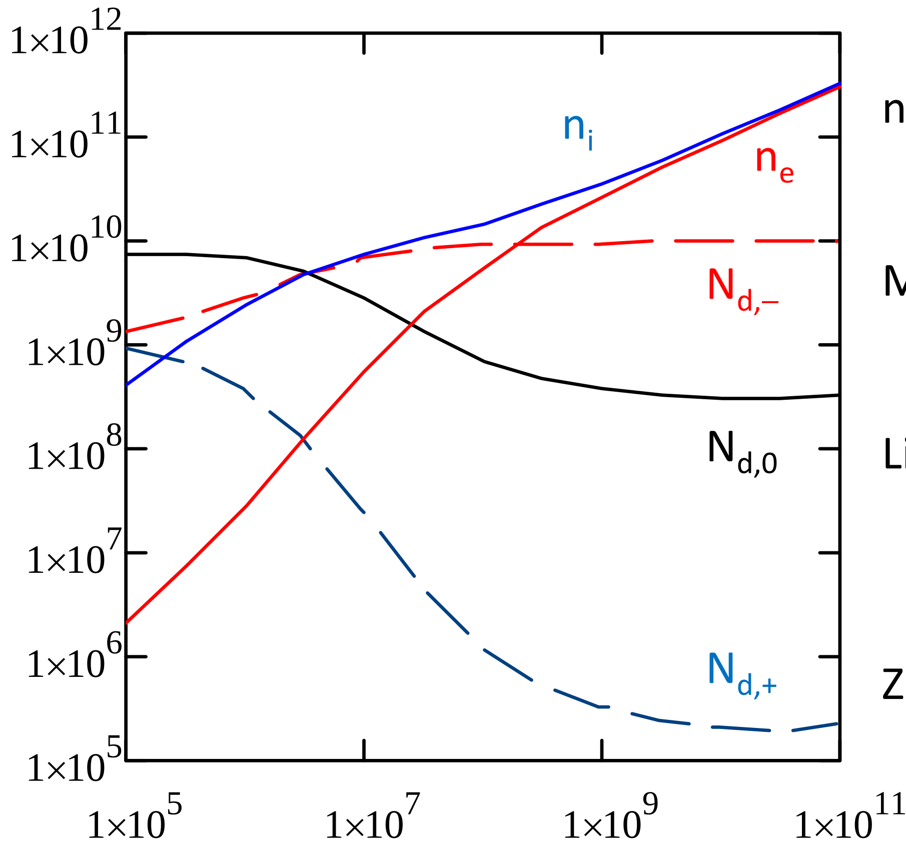
Low R

Density [cm^{-3}]

Mostly neutral dust

$N_{d,+} = N_{d,-}$

Zilch electrons



R [cm^{-3}/s]

High R

$n_i = n_e$

Most dust is negative

Little neutral dust

Zilch^2 positive dust

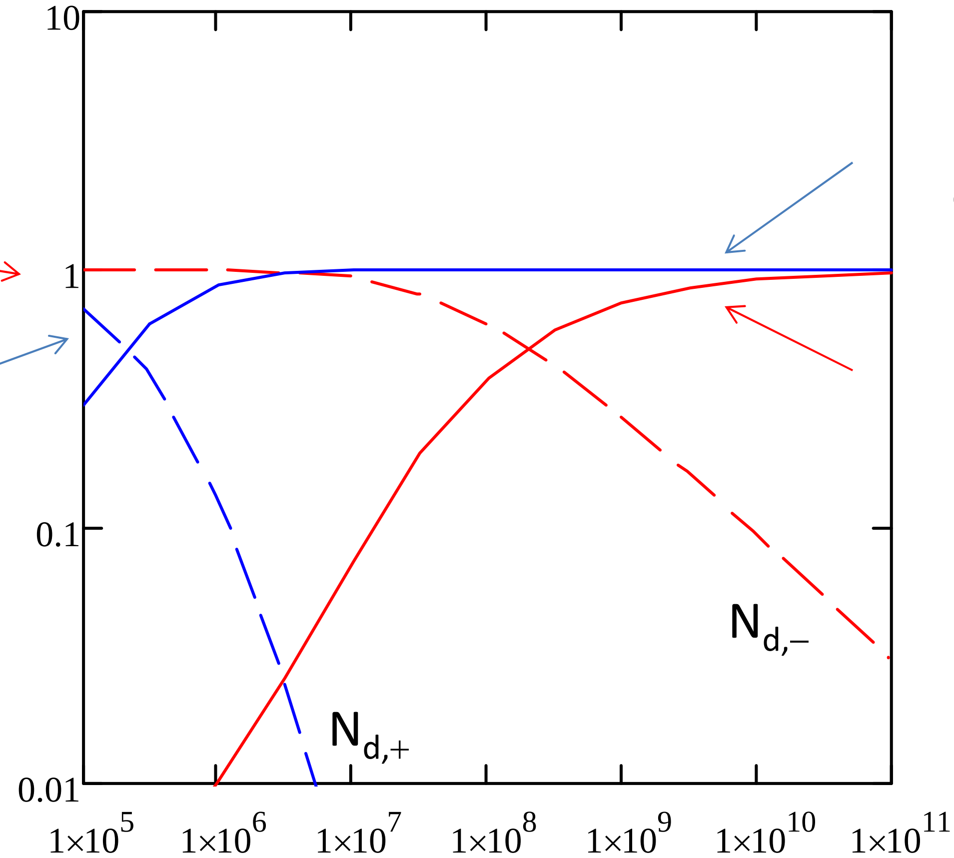
Very low R...

What fraction of the charge is where?

Dust share of negative charge

Dust share of positive charge

$N_{d,+} = N_{d,-}$



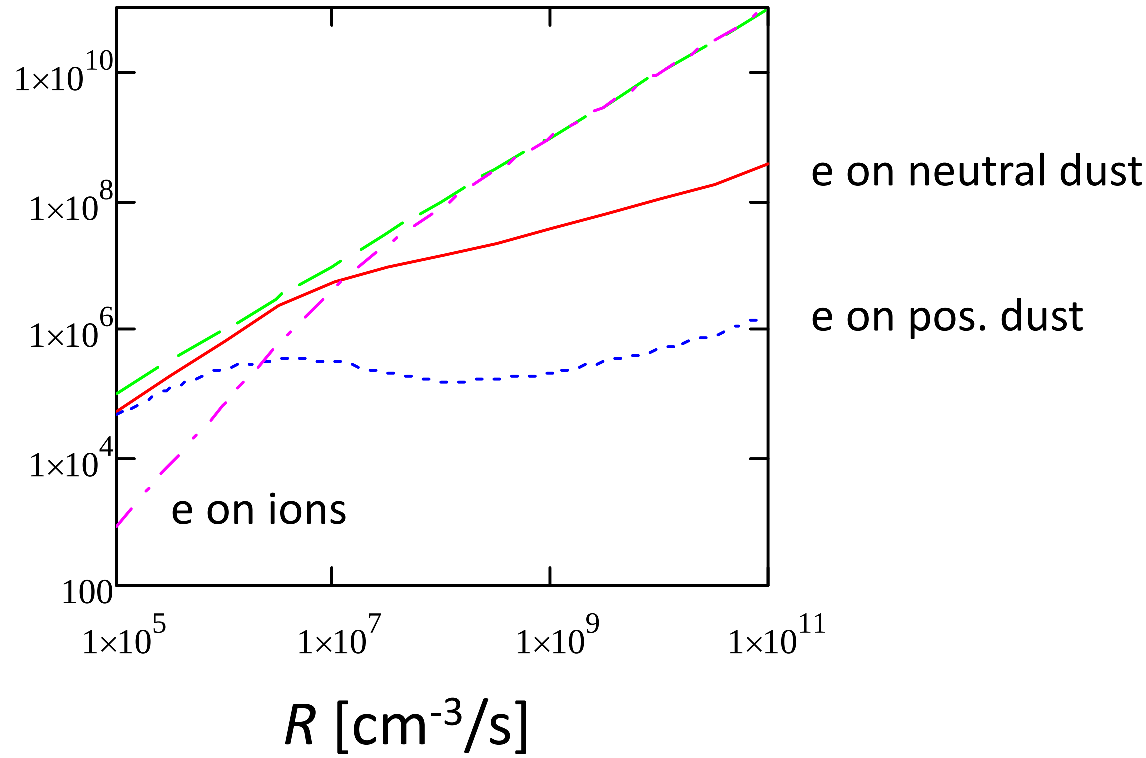
R [cm^{-3}/s]

Ion share of positive charge

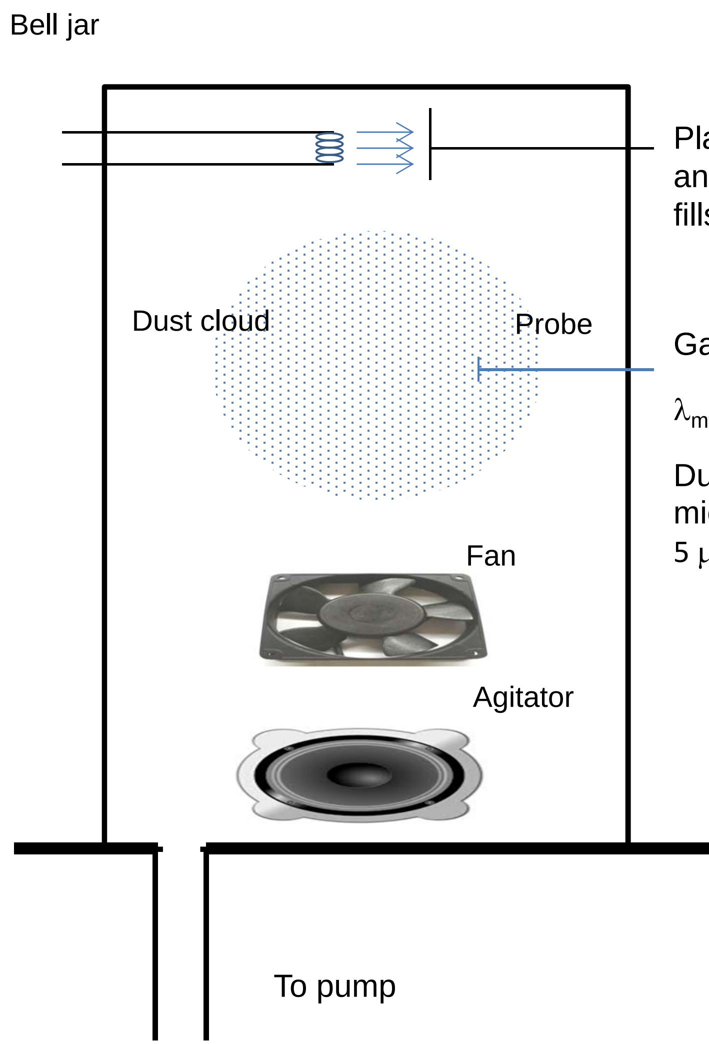
Electron share of negative charge

How are electrons lost? On ions? On dust?

e – $N_{dust,0}$ recomb.
e – $N_{dust,+}$ recomb.
e – i recomb.
[cm^{-3}/s]



Experiment to hold dust aloft – Filament ionization



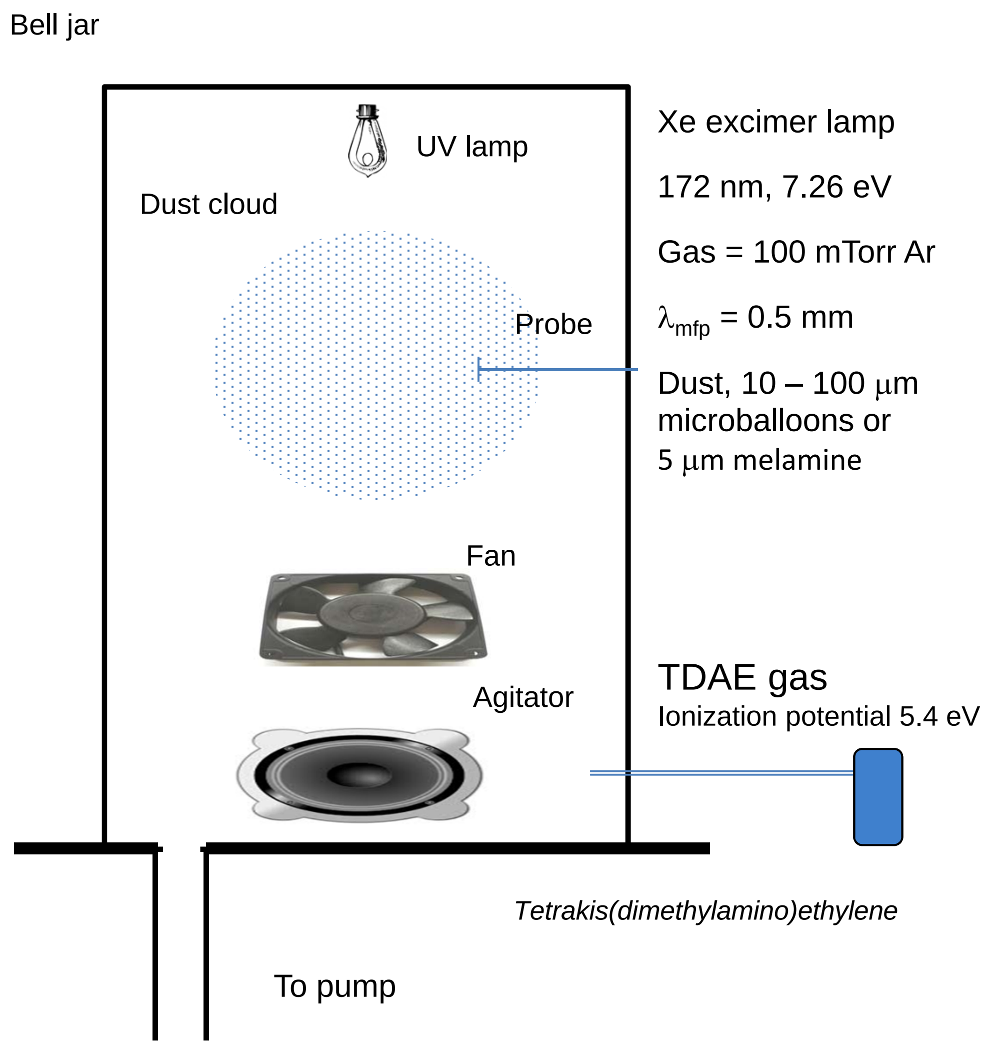
Plasma source is filament and anode – fills chamber by diffusion

Gas = 100 mTorr Ar

λ_{mfp} = 0.5 mm

Dust, 10 – 100 μm microballoons or 5 μm melamine

Experiment to hold dust aloft – UV ionization



Will it work?

Does the air speed from the fan at 100 mTorr exceed the dust falling speed?

Air speed
Fan area = 10 cm x 10 cm
Fan air volume speed 100 cfm = 0.05 m^3/s
Air speed = 5 m/s

Dust falling speed (Epstein formula)

Melamine spheres
Dust diameter = 6 microns
Falling speed = 5 m/s

Glass microballoons
Diameter = 6 microns
Falling speed = 4 m/s

Problem
Four sources of photoemission: gas, dust, walls, probe surface

What would you measure?

Case 1: Gas photoionizes, dust does not emit

Pulse UV on and off, Langmuir probe

1. Measure decay of electrons/ions by recombination on dust (fast)
2. Measure decay of + and – dust particles (slow)

Case 2: Dust has photoemission and photodetachment

Pulse UV on and off

Measure decay of + and – dust particles (slow)

Case 3: Wall photoemits, but not dust

Negatively charged dust lowers plasma potential and shields out the electrons from the wall

Conclusions

Model:

If dust density > plasma density

1. Quazineutrality says $N_{d,+} = N_{d,-}$
2. Electrons & ions recombine on the dust
3. More charges when dust is added
4. $n_i >> n_e$ (like adding SF_6)

Experiment:

1. Levitation seems possible at 100 mTorr
2. UV ionization of TDAE gas is possible