Physics of transition scattering and some recent observations

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V. L. Ginzburg conference 2012 .
V. N. Tsytovich . Physics of transition scattering .Forewords.

Most of participants have an opportunity to know **V.L.** personally or to work with him or at least to be impressed by the style of his wide range papers. **Personally I** was impressed several times- **first** as a student **in 1948** reading the first in my life scientific papers and those were the papers of **V.L.** (and I. E. Tamm , I. M. Frank) on Cherenkov emission (I cannot even imagine at that time that my future scientific activities will be close related with interest of **V.L.** and that I will have the opportunity to work with **V.L.**) ,- **second in 1951** preparing my first scientific paper on synergetic effect of synchrotron and Cherenkov emission by relativistic particles (both topics have been top top activities of **V.L.**)-**third in 1959** when I was invited to P. N. Lebedev Institute and started to give regularly presentations on famous **V. L.** seminar as basic for my second (after PHD) **doctor** degree defined **in 1962** where **V.L.** was my general **opponent , fourth –when** we started to work together with **V.L**. **in 1973,** the year when **V.L.** invite me to teach on his chair **"Problem of Physics and Astrophysics"** Moscow Institute of Physics and Technology, and I nave the pleasure to work Professor in this chair up to present . The main our with **V.L.** theoretical work has been related to generalisation of famous work V. L.Ginzburg and I.M.Frank on **Transition radiation (1946)** which results in a theory of effect **Transition scattering (**V. L. Ginzburg and V. N.Tsytovich **1973)** having at present **many new applications** which will be the subject of **this presentation.** This activity was summarized in 3 monographs (one of them is substantially enlarged monograph "**Transition Radiation and Transition Scattering" ,Adam Hilger 1990**)

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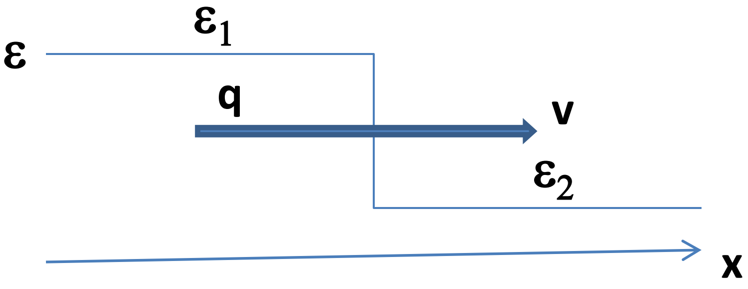
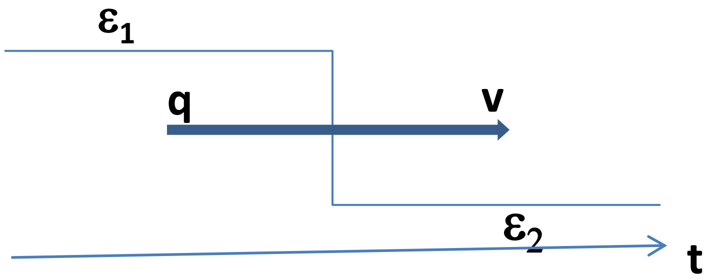
General features of transition scattering physics.

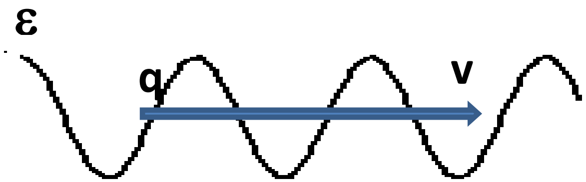
Transition radiation of particle moving through boundary of two media V. L.Ginzburg and I.M.Frank (1946) .Change of self-energy. Global conservation of energy and momenta



Transition radiation of particle with sudden change of dielectric constant in time. Emission Is present for v =0



Simplest case where the dielectric constant is changed both in time and space is the wave Of dielectric constant **$\varepsilon=\varepsilon_0+\varepsilon_1\cos(\omega t-kx)$ –transition Scattering. Emission Is present for v =0**



The main problem is cross-section of transition scattering which is estimated as **$Q=Ze$; $\sigma=Z^2\sigma_T$ Emission exist for very heavy particles- ions . For many thermal heavy particles the Doppler width is extremely small $\Delta\omega/\omega$ about $v_T/c=(T/mc^2)^{1/2}$. For coherent structures the rate of emission is determined by square of coherent electrons**

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General features of transition scattering physics.

The conditions for effective scattering by ions (wavelength larger than screening length) is fulfilled for rather high frequencies $\omega<\omega_{pe}c/v_T$ and specially for small angle of scattering θ and small frequency difference $\Delta\omega=|\omega_{inc}-\omega_{scat}|$

$$\frac{\Delta\omega}{\omega} < \theta^2 \cdot \frac{v_T}{c} < \frac{\omega_{pe}}{\omega} \qquad \text{or} \qquad \theta^2 \cdot \frac{v_T}{c} < \frac{\Delta\omega}{\omega} < \frac{\omega_{pe}}{\omega}$$

The effect of ion scattering in these conditions is big. Natural questions are
1) Does there exist straightforward derivation ? Yes 2)is this effect observed ? Wildly observed but sometimes not recognized

1.Field of incident wave $\mathbf{E}_{inc}$ excites both the current of particle oscillations $\mathbf{j}_{ocs}$ proportional to $\mathbf{E}_{inc}$ and the nonlinear current $\mathbf{j}_{nl}$ proportional to the field $\mathbf{E}_q$ of uniformly moving charge **q** and $\mathbf{E}_{inc}$. The nonlinear responses for high frequencies are determined only by electron mass $\mathbf{m}_e$ and therefore the nonlinear current excites the transition scattered wave with amplitude of Thomson cross-section for scattering on free electrons. For electrons the interference of both usual and transition scattering decreases since added are not the cross-sections but amplitudes (matrix elements) and for ions the oscillating current is negligible and only transition current creates the scattered wave. The given above conditions correspond to dominations of scattering on ions and are thus confirmed by such simple calculations

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Long term existing myth on difference of scattering in media on fluctuations and sum of scattering on individual particles

Theory of scattering of high frequency of electromagnetic waves on plasma fluctuations was created in 60-s E.E.Salpeter *Phys.Rev.*,**120**, 1528 (1960), **122** (1961) M. N. Rosenbluth and N.Rostoker *Phys.Fluids*,**5**, 776 (1962) reviewed in excellent book J.Sheffield *Plasma Scattering of Electromagnetic Radiation*, Academic Press, New York, San Francisco, London, 1975 and used in many experiments on plasma diagnostic by laser scattering in fusion devices and numerous other experiments on scattering of electromagnetic radiation in plasmas.

$$n_0^{(e)} S(\mathbf{k}_-,\omega_-) = 2\pi \left|1 - \frac{G_-^{(e)}}{\epsilon_-}\right|^2 \int \Phi_0^{(e)}(v^{(e)})\delta(\omega_- - \mathbf{k}_-\cdot\mathbf{v}^{(e)})d\mathbf{v}^{(e)}$$

$$+2\pi (Z^{(i)})^2 \left|\frac{G_-^{(e)}}{\epsilon_-}\right|^2 \int \Phi_0^{(i)}(v^{(i)})\delta(\omega_- - \mathbf{k}_-\cdot\mathbf{v}^{(i)})d\mathbf{v}^{(i)}$$

$$\omega_- = \omega_{(inc)} - \omega_{(sc)},$$

$$\mathbf{k}_- = \mathbf{k}_{(inc)} - \mathbf{k}_{(sc)}$$

$$n_0^{(i)} = n_0^{(e)}/Z^{(i)})$$

In fact correspond to usual Thompson scattering of single electron correspond to amplitude of transition scattering on electrons and corresponds to transition scattering on ions. In beginning **Sheffield stated that scattered can only electrons** and the additional terms in fluctuation approach are due to correlations with electrons shielding ions and is used for that

$$\epsilon(\mathbf{k},\omega) = 1 + G^{(e)}(\mathbf{k},\omega) + G^{(i)}(\mathbf{k},\omega)$$

$$G^{(e)}(\mathbf{k},\omega) = \int d\mathbf{v} \frac{4\pi e^2}{k^2(\omega - \mathbf{k}\cdot\mathbf{v} + i0)}\left(\mathbf{k}\cdot\frac{\partial\Phi^{(e)}}{\partial\mathbf{p}}\right)$$

$$G^{(i)}(\mathbf{k},\omega) = \int d\mathbf{v} \frac{4\pi (Z^{(i)})^2 e^2}{k^2(\omega - \mathbf{k}\cdot\mathbf{v} + i0)}\left(\mathbf{k}\cdot\frac{\partial\Phi^{(i)}}{\partial\mathbf{p}}\right)$$

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Proof that the scattering is produced also by ions

The statement that really ions are scattering can be checked by considering the influence of scattering on distributions of ions. At present the equation for ion distribution $\Phi^{(i)}$ taking into account the influence of the incident and scattered waves can be found using nonlinear currents of third order in fields including the fields created by free particles and Find the conservation laws of energy and momentum. The second term describing the transition scattering on ions satisfies the conservation laws with ion distribution which is a direct proof that the energy and momentum in this scattering process is transferred to ions.

$$\frac{dW_{sc}}{dt}+\frac{dW_{inc}}{dt}+\frac{dE^{(i)}}{dt}=0 \quad \frac{d\mathbf{P}_{(sc)}}{dt}+\frac{d\mathbf{P}_{(inc)}}{dt}+\frac{d\mathbf{P}^{(i)}}{dt}=0; \quad \mathbf{P}^{(i)}=\int \mathbf{p}\Phi^{(i)}_{\mathbf{p}}\frac{d\mathbf{p}}{(2\pi)^3}.$$

In general case with first term of scattering taking into account both electrons and ions take part in conservation laws. **The scattering in plasmas is simple a sum of scattering on electrons and ions** and the fluctuation theory only reflects this fact and with transition scattering taken into account the scattering can be described by simple physics not referring to fluctuations. This **physical approach is important** since its very rare that the particle distributions in plasmas are thermal and different effects are responsible for changes of the distribution functions.

Thus the correct interpretation deals not with correct formulations but with appropriate physics which can change the results obtained in observations

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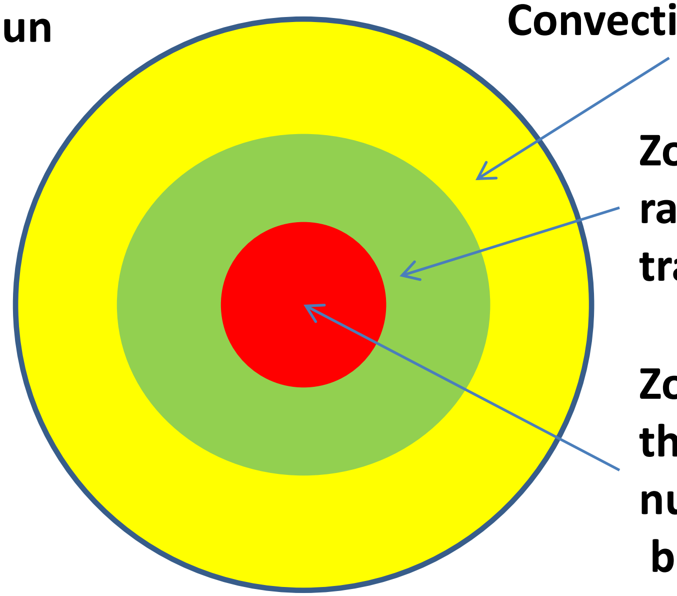
Interpretation of observations

In all fusion experiments and other scattering diagnostic experiments the observers are dealing with total scattered waves including the transition scattering. The measuring of features of ion distributions is possible only because of transition scattering.

The observed resonance features of scattering in the case where ε_- is close to zero correspond to **Mandelshtamm- Brillouin** or **Raman** scattering obviously are present due to transition scattering process.



Sun

Convective zone

Zone of radiative transfer

Zone of thermo-nuclear burning

The ratio of optical to neutrino emission depends on solar opacity depending on radiative transfer which As due to radiation scattering on electrons and ions. From 20% to 60% the radiation is scattered by ions (Boerker DB). For given optical emissivity the opacity determines the temperature at the centre and therefore determined the emissivity of **high energy neutrino.**

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Scattering of radio waves in ionosphere and PMSE

1.Diognostic of ionosphere is usually made by scattering of radio waves similarly as diagnostic of fusion devices by lasers.

2. Transition scattering can be due to massive macroscopic objects if there size is of the order or less than the wave length - emission is proportional to the square of coherent electrons in the structure. Candidates are dust particles or even dust clouds with the size less than wave length

3.PMSE-Polar Mesospheric Summer Echo – Facilities EISCAT, PMVE- Winter Echo -

Main features 1)The intensity of backscattered signal from the height 80-85 km is two orders of magnitude larger when PMSE is present

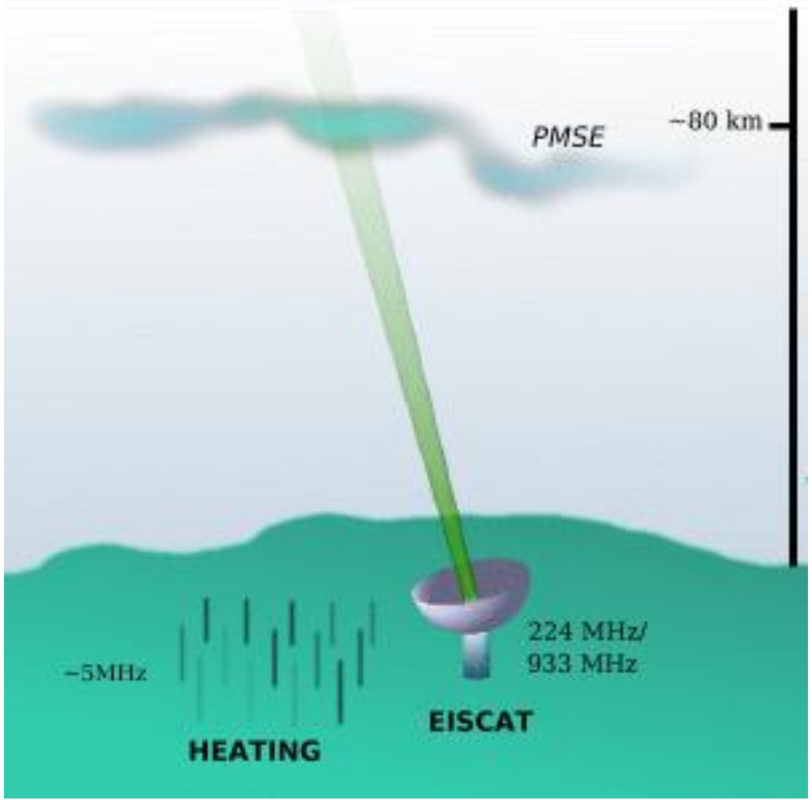
2.The frequency width of reflected signal is Very small $\Delta\omega$**<1MHz**

UHF 933 MHz

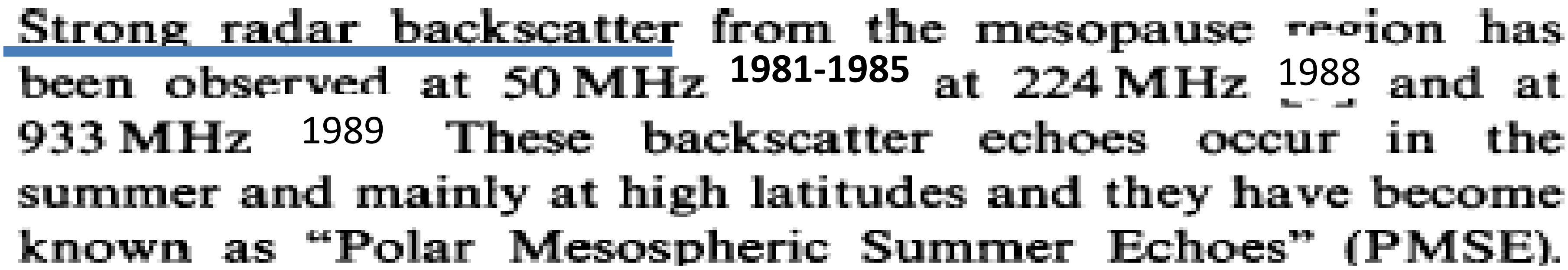
VHF 224 MHz

$\Delta\omega/\omega < 10^{-9}$

T=(110-140)K^0



V.L.Ginzburg conference 2012. V.N.Tsytovich . Radar scattering from mesospheric clouds



Strong radar backscatter from the mesopause region has been observed at 50 MHz 1981-1985 at 224 MHz 1988 and at 933 MHz 1989 These backscatter echoes occur in the summer and mainly at high latitudes and they have become known as "Polar Mesospheric Summer Echoes" (PMSE).

Ecklund, Czechowsky, Hopps, Roetger, Havnes at al.

Noctilucent clouds (NCL) at this height (about 80-85 km) have been observed by centuries ago but their intensity and duration Is increases in time after industrial revolution -the effect is certainly regulated by dust in these clouds . The region is the coldest in the Earth vicinity and the grains are coated by ice. PMWE have been discovered only recently and can be seen only in radar scattering.

RECENT ACTIVE EXPERIMENT- Ionosphere heating at the PMSE and MNSE

Havnes at al

Combination of high intensity of scattering and very narrow frequency width of scattered signal REQUIRES mechanism of TRANSITION SCATTERING for EXPLANATION

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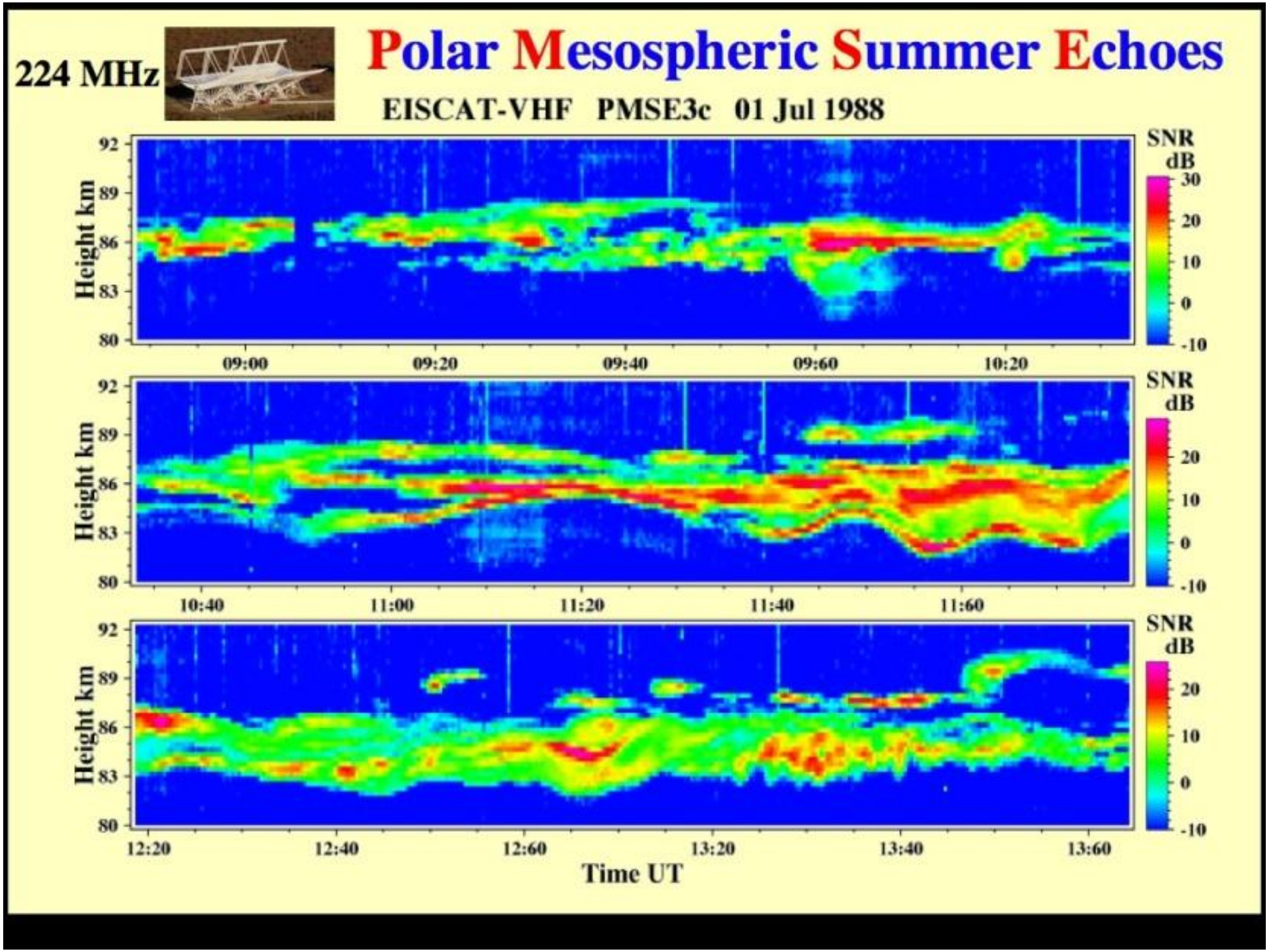

NCL- Noctilucent clouds

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1.The wave length is larger than the ion Debye screening length and although in backscattering transition scattering on ions is dominant the observations cannot be explained by ion scattering

a)even for low temperatures T_i=140K ; $\Delta\omega/\omega\sim v_{Ti}/c$=**8.7 10^{-7}**

b)enhancement of scattering is determined only by n_i and it is improbable that in presence of dust the ion density in the dust cloud region increases by factor**100**

2.Transition scattering by dust proposed 1990 by Havnes et all at present also cannot be used for explanation. The enhancement factor $\mathbf{Z_d^2 n_d = Z_d(Z_d n_d) < Z_d n_i}$ since $\mathbf{n_e = n_i - Z_d n_d > 0}$ **–**all electrons cannot be attached to the grains, so $\mathbf{Z_d}$ should be about **100** which implies the grain size to be larger than **(5-8)μ** .Direct size measurements by rocked started by Havnes and by Robertson –**the size are smaller** . The size was measured in active experiments by launching dust counters on rockets (Robertson 2008), but large grains are splitting by counters , the number of grains decreases with their size and cannot be properly counted, so no accurate measure of grain with largest size exist. The dust density $\mathbf{n_d}$ measured for **0.1 μ** grains is about **10^{-3}cm^{-3}** The recent measurements certainly **exclude individual grains to produce the scattering enhancement by 2 orders of magnitude** It is believed that PMSE – are ice particles **covering dust grains 0.01-0.1 μ**; $\mathbf{Z_d}$ is about **3-5** and so the **enhancement factor** can be **less 3-5**

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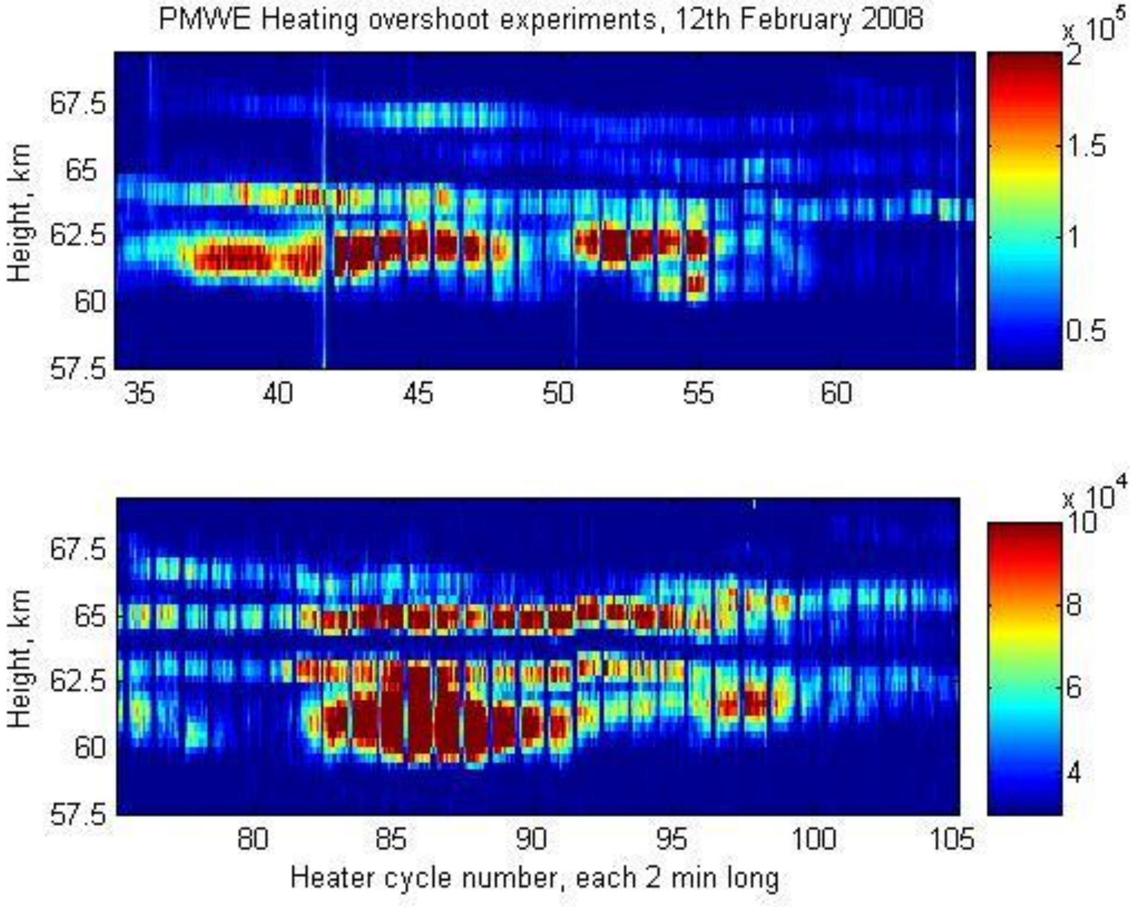
Similar arguments can be applied for interpretation of PMWE Observed 2008

PMWE –probably is prodused by

very small (3-5 nm),

meteoric smoke particles (??). Can not be observed visually from ground, only with radars. The straght lines correspond to substantial decrease of scattering during heating (discussed later)Seen *August-May* – fairly rare, and weak.



V.L. Ginzburg conference 2012. V.N.Tsytovich . Most probable explanation is by transition scattering of dust clusters.

In the case when the whole dust cloud is divided by **dust clusters** the total number of **coherent electrons Z_{cl}** in the cluster can be large and transition scattering enhancement factor **$Z_{cl}{}^2 n_{cl}$** **is quitesufficient** since similar to previous estimated for individual grains **Z_{cl} n_{cl}** is about n_i and the enhancement factor is about **Z_{cl}** which for10-100 cm cluster could be much larger than 100 even for weak clustering .

Required conditions:

1.The size of the cluster should be much larger than the wave length

2.The clusters should be relative stable

Present state of art

1.The wave length used for radar scattering –several cm up to 3-5m can satisfy this conditions

2.Dust clumps and dust holes (dust voids) of the size about 1m have been detected in recent rocket dust detection mission to PMSE, PMWE;

3. Modern general dusty plasma investigations provides the physics, laboratory evidence, theoretical and computational support of universality of dust clump and dust void formation called as dusty plasma as structurization .

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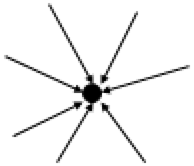
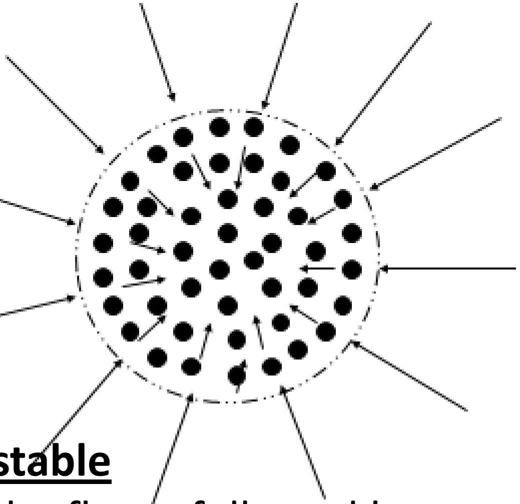
Individual dust grain charges are formed by continuous by **plasma fluxes** on individual grains



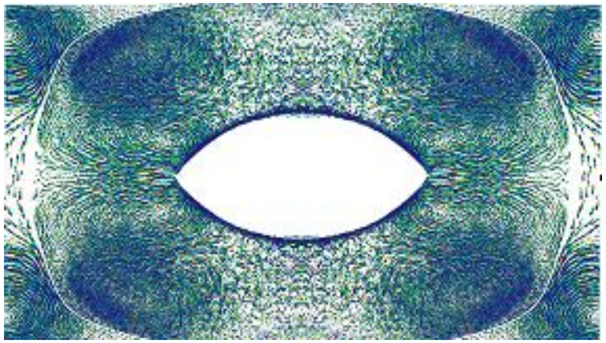
Collection of grains create collective fluxes - can confine grains, create potential well for ions and Lesage grain attraction



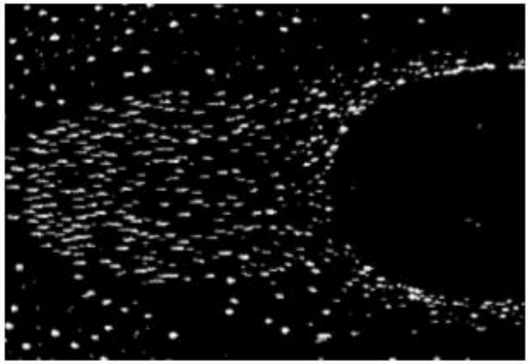
In **linear theory** homogeneous dust distribution is **universally unstable to create structures-** any enhancement of dust density increases the fluxes followed by an increase of dust and ion density (Angelo1988 Morfill Tsytovich 2000).For conditions in PMSE only linear approach exist predicting maximum growth rate at **(1-3)m** (Tsytovich ,Havnes 2002)

Both dust **clumps** and **voids** are often observed in laboratory experiments and **on board of ISS**

Void and vortices



Dust clump close to dust void



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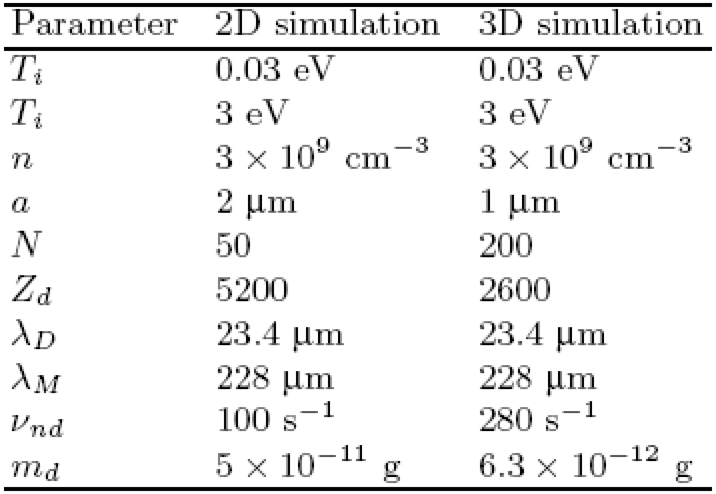
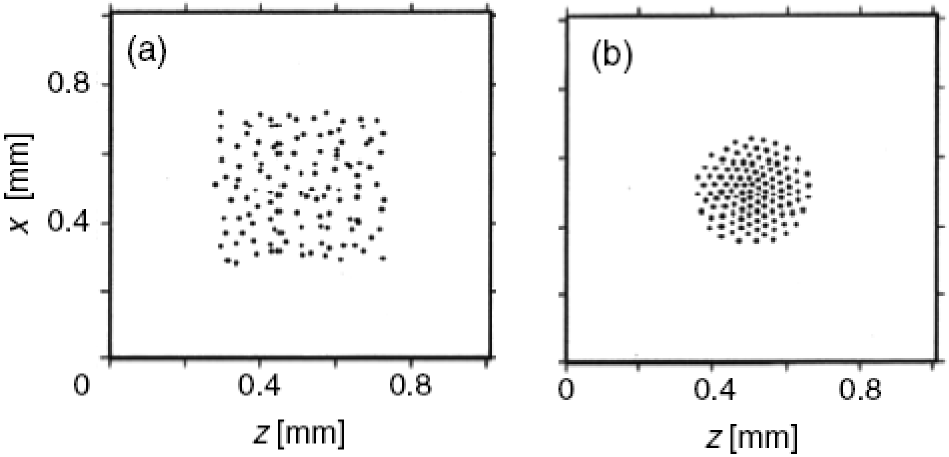
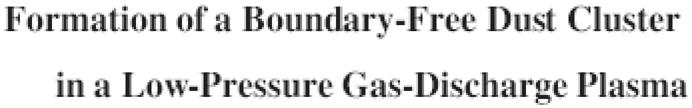
Predicted **2001** (Khodataev et all) by PIC computations with dust Lesage attraction (due to flux shadowing)



Parameter	2D simulation	3D simulation
T_i	0.03 eV	0.03 eV
T_i	3 eV	3 eV
n	3×10^9 cm^{-3}	3×10^9 cm^{-3}
a	2 µm	1 µm
N	50	200
Z_d	5200	2600
λ_D	23.4 µm	23.4 µm
λ_M	228 µm	228 µm
ν_{nd}	100 s^{-1}	280 s^{-1}
m_d	5×10^{-11} g	6.3×10^{-12} g

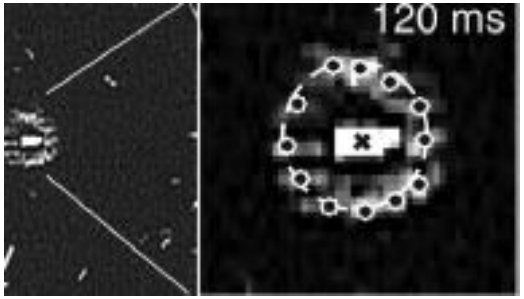


Laboratory observations 2009 (Kasachev and PK4 micro-gravity team)

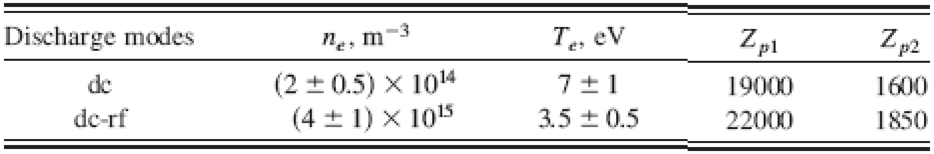


Formation of a Boundary-Free Dust Cluster in a Low-Pressure Gas-Discharge Plasma

Observed cluster with 12 particles cluster size 160µ



Parameters of discharges



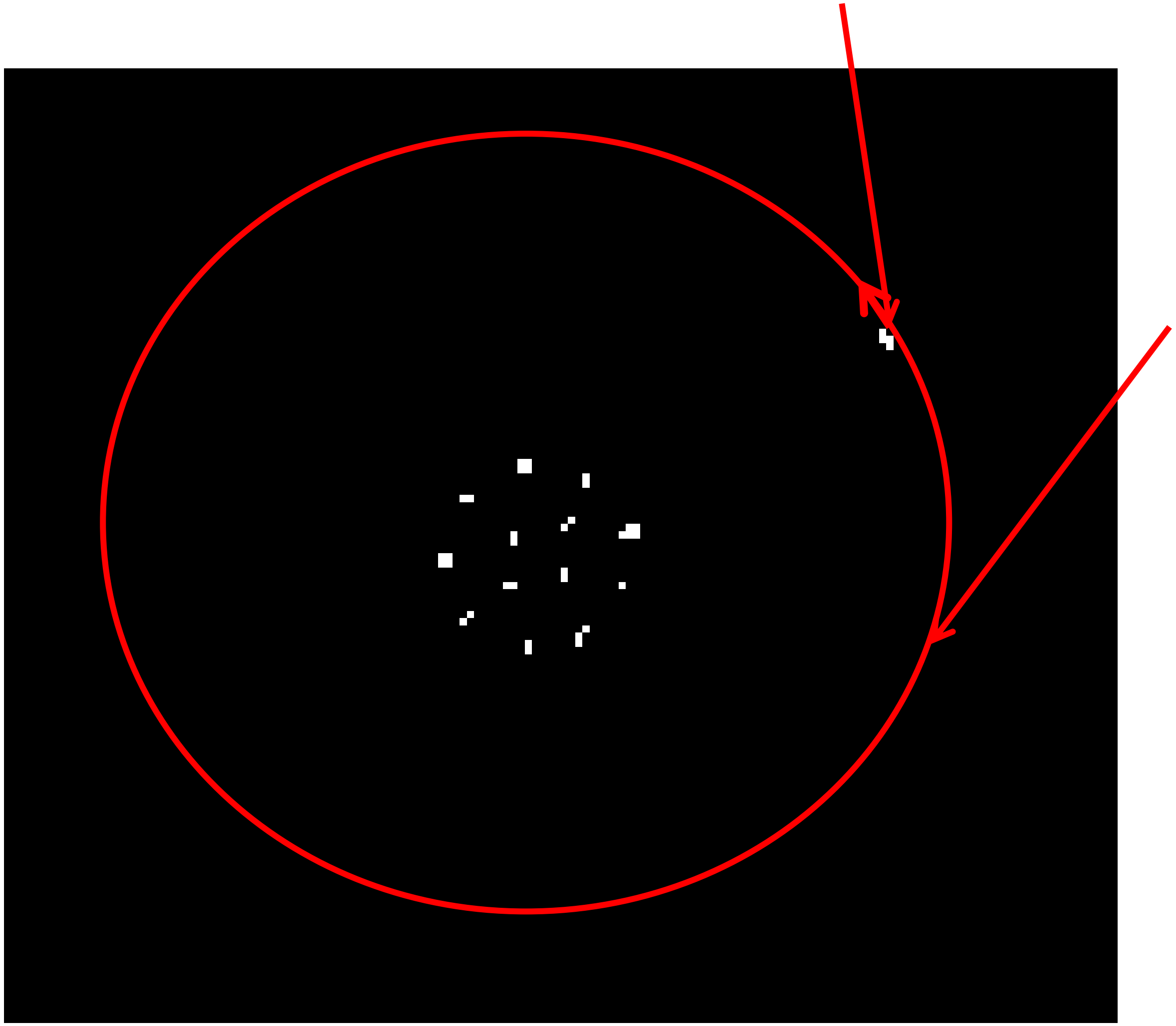
Discharge modes	n_e, m^{-3}	T_e, eV	Z_{p1}	Z_{p2}
dc	$(2 \pm 0.5) \times 10^{14}$	7 ± 1	19000	1600
dc-rf	$(4 \pm 1) \times 10^{15}$	3.5 ± 0.5	22000	1850

Grain size
a_{p1}=6µ
A_{p2}=0.6µ

V.L. Ginzburg conference 2012. V.N.Tsytovich . Experimental prove for existence of plasma fluxes around boundary free cluster

Fast particle **circulating** around boundary free cluster

First experiments,



ALLen

Annaratone (1998)

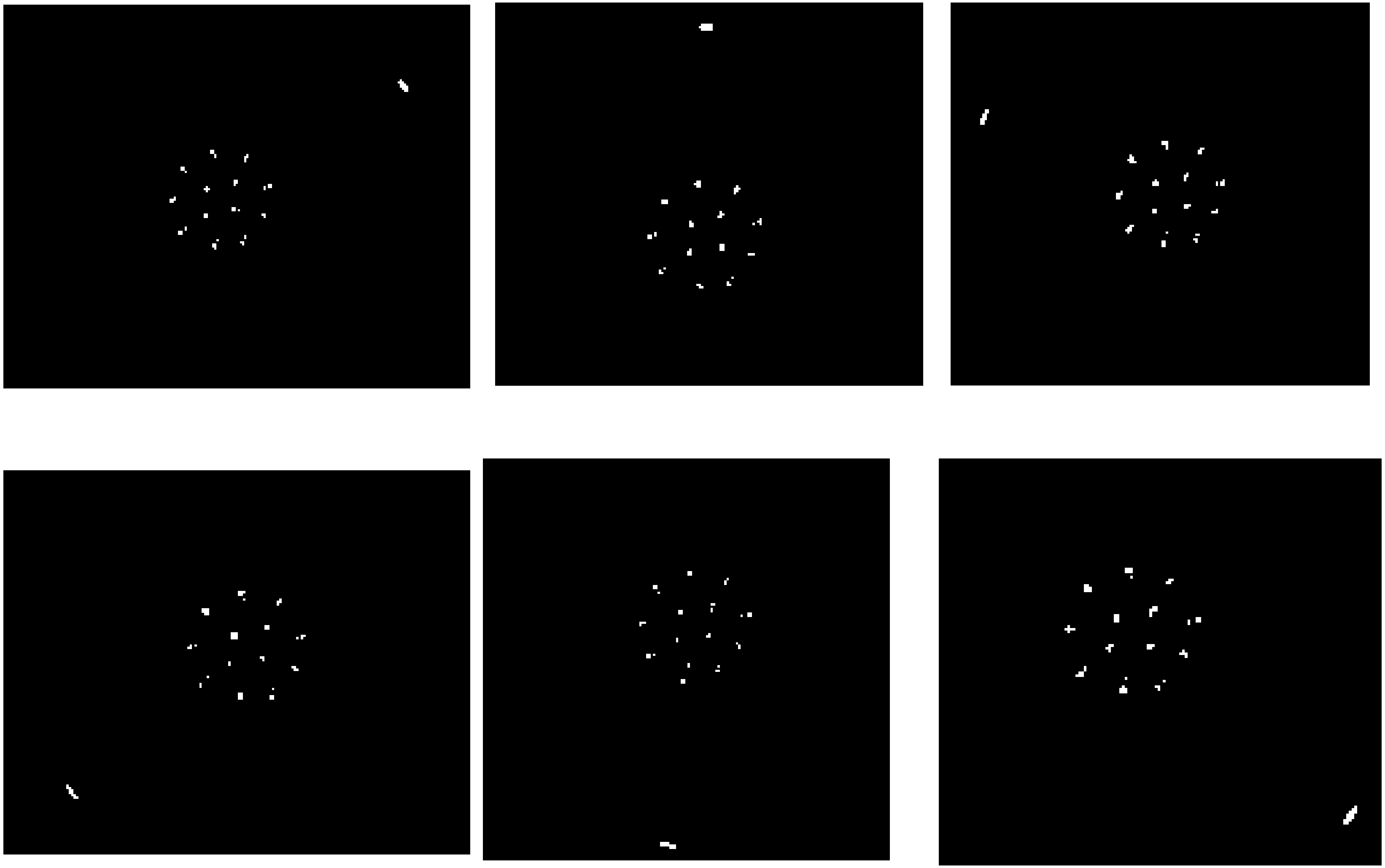
Last experiments

Woerner (2012)

Trajectory of fast

Grain period 3sec

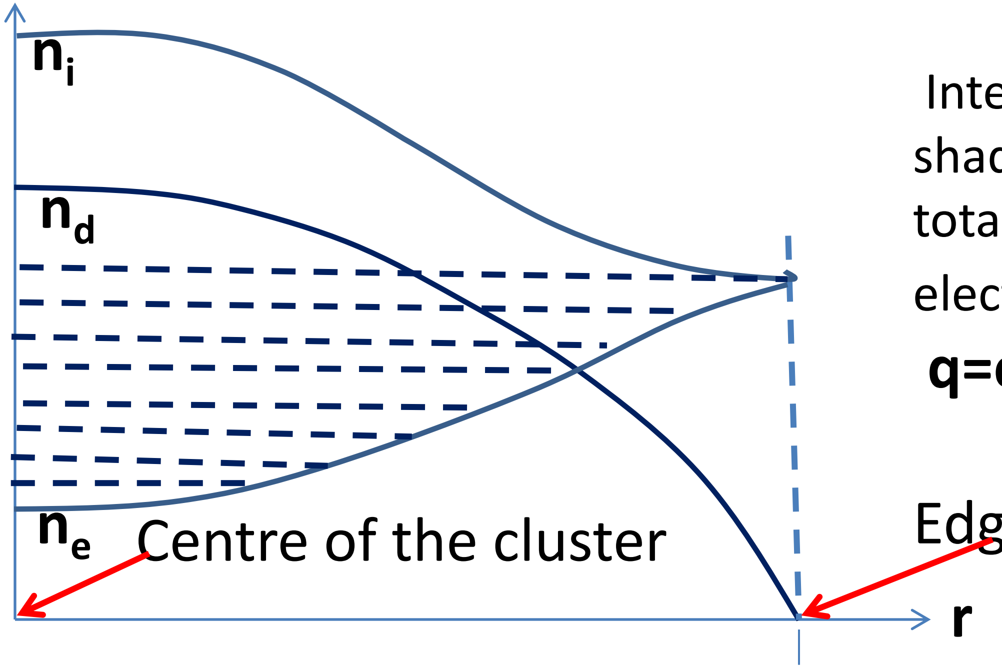
V.L. Ginzburg conference 2012. V.N.Tsytovich . Experimental prove for existence of plasma fluxes around boundary free cluster



6 frames from movie of Woerner L. experiment

V.L. Ginzburg conference 2012. V.N.Tsytovich . Main features of selforganized dust clusters and their consecuencis

Typical distributions of dust ,electrons and ions obtained by numerical solutions of Master equations . Shadowed is the region of coherent **hole electrons**



Integration electrons over the shadowed region gives the total number of coherent electrons **Z_{cl} – positive charge $q=e Z_{cl}$ with electron mass .**

The size of clusters **R_{cl} is inverse proportional to the grain size**

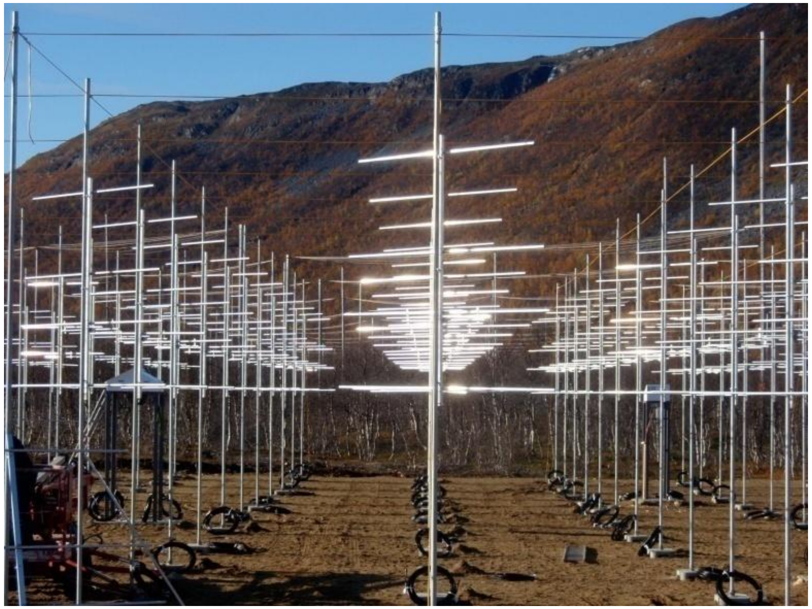
In PVSE the grains with charges >0.02 μ are **negative** photo-electron charging is small

Two predictions 1) for small grains the cluster size is increased and coherency can be lost (PMWE)2) sudden increase of electron temperature decreases electron density gradients ,shadowed area and decreases Z_{cl} - radar signal should decrease

V.L. Ginzburg conference 2012. V.N.Tsytovich. Active experiments on electron heating in the region of PMSE (Havnes 2003-2004)

The ”overshoot” technique, an active effect found in 2003-04 to analyze the summer radar clouds(PMSE)

HF sender (Heating) with frequency 4 til 8 MHz



The heater affects electrons only

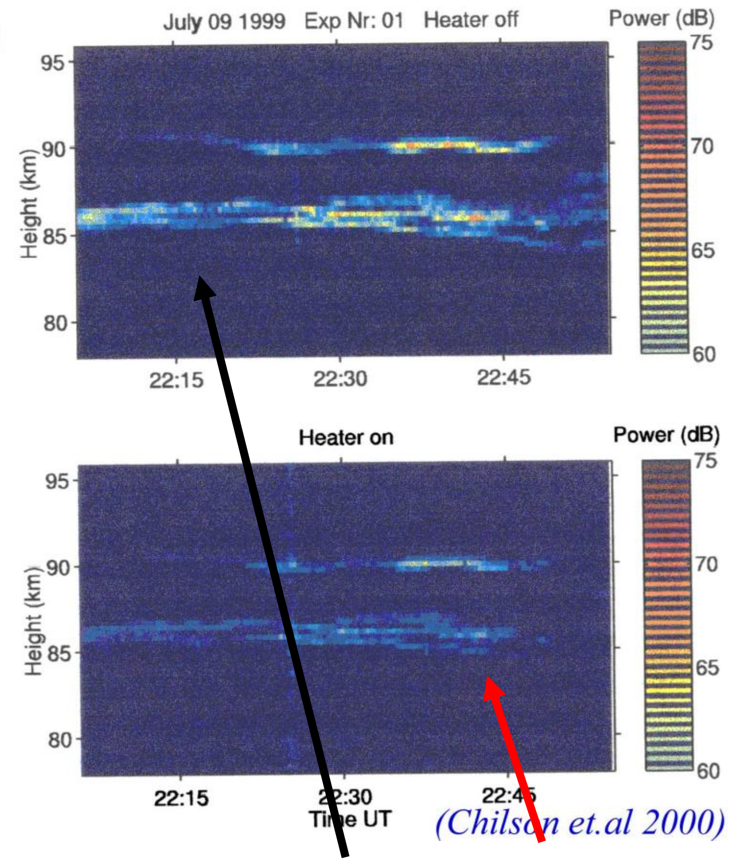
❑ Electrons are heated within a few milliseconds

❑ The electron density below the PMSE/PMWE layer control how much heater wave power which reach the PMSE layer.

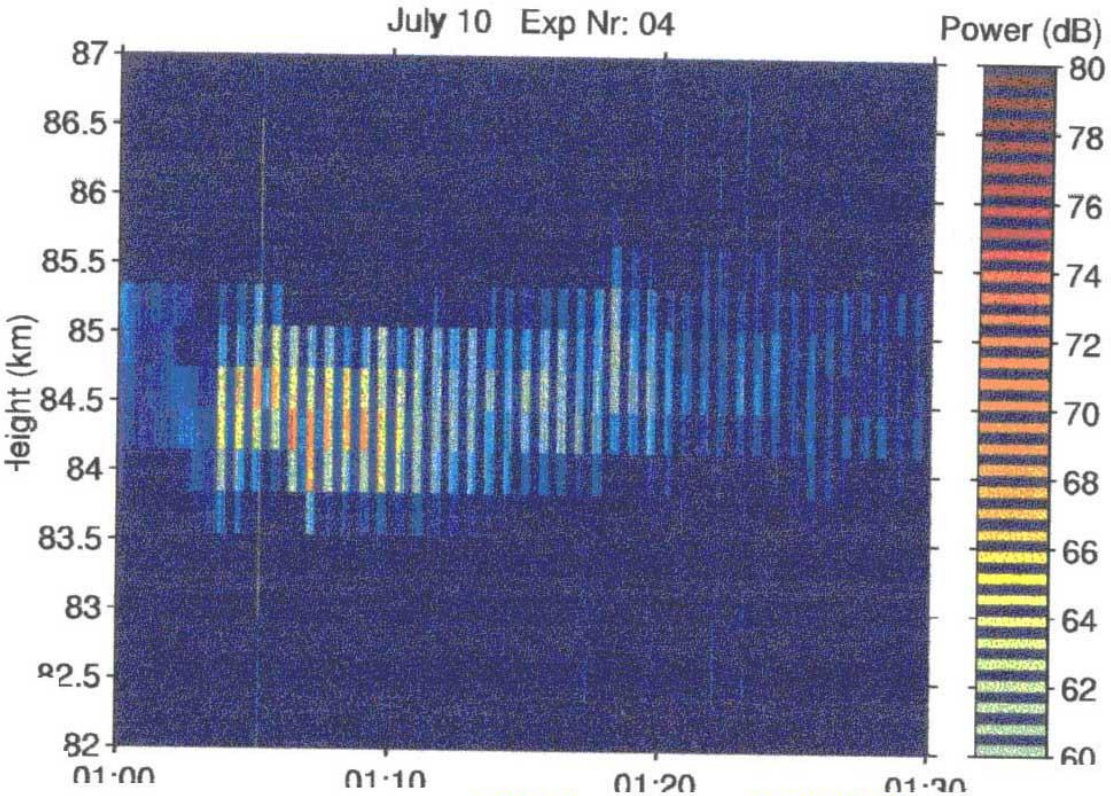
❑ The electron heating in the PMSE layer may be (theoretically) from negligible to around 2500 – 3000 K.

V.L.Ginzburg conference 2012. V.N.Tsytovich .Observation of Havnes O.

Discovery of the electron heating effect on PMSE. Observations by the EISCAT VHF at 224 MHz



(Chilson et.al 2000)

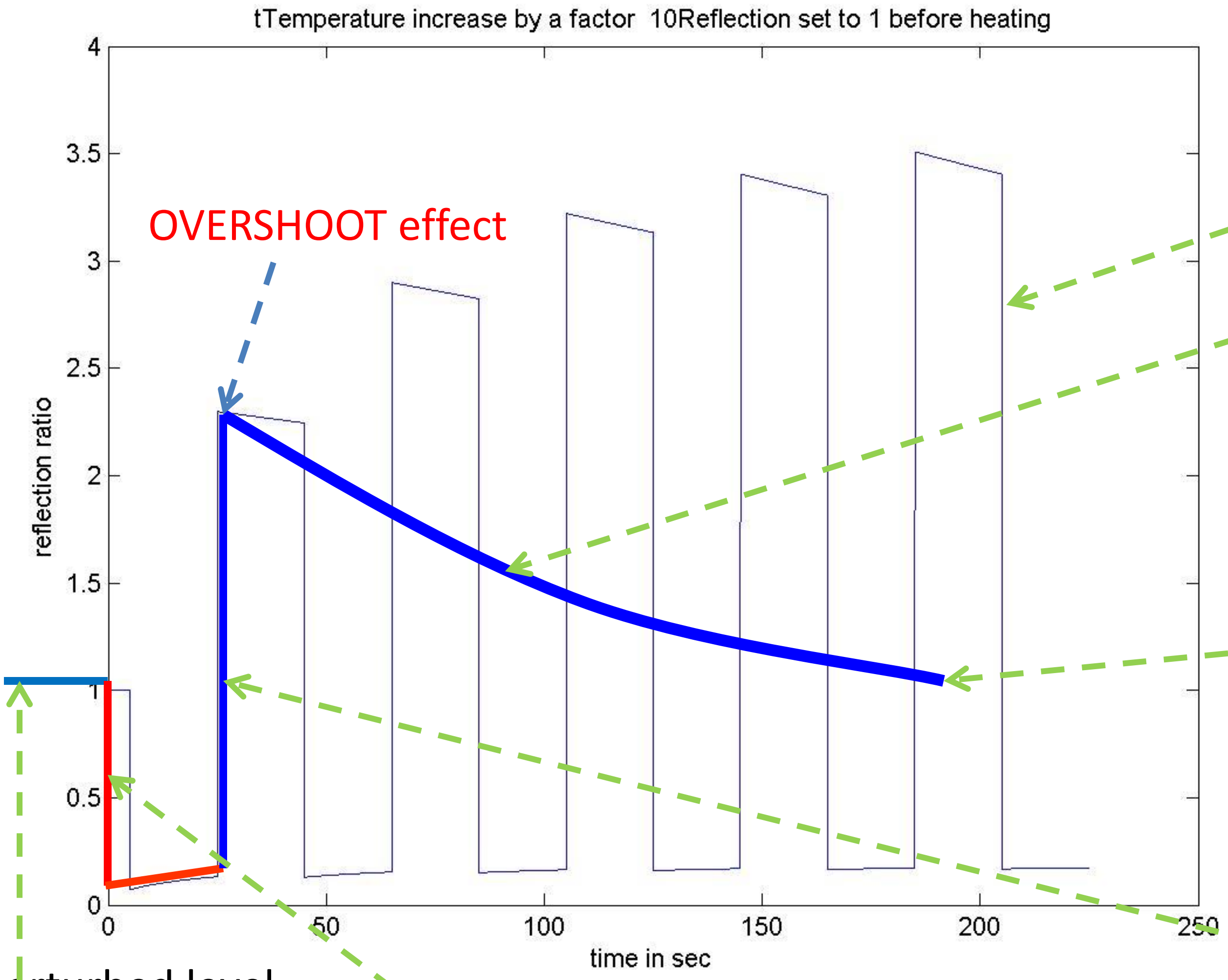


(Chilson et.al 2000)

Heater: OFF ***ON***

Heater : OFF 20 sec – ON 20 sec

V.L. Ginzburg conference 2012. V.N.Tsytovich. Typical active experiments results (Havnes 2004)



OVERSHOOT effect

By changing the Heater cycling from:

20 sec ON and 20 sec OFF

to for example

20 sec ON and 160 sec OFF

Relaxation to undisturbed level

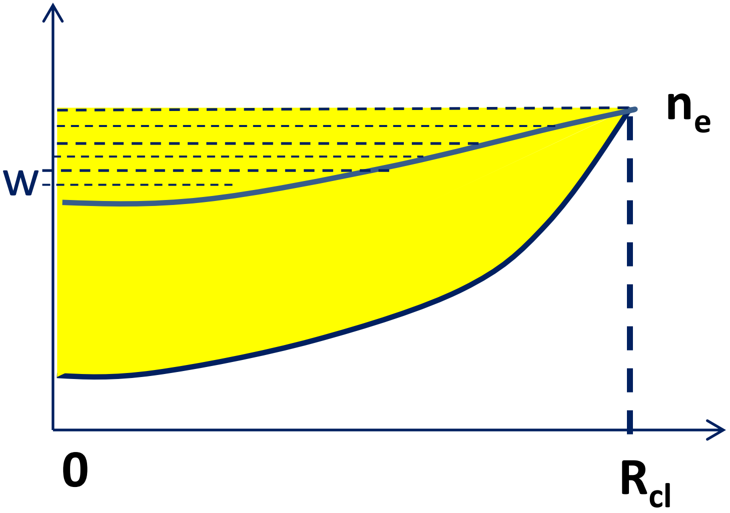
Increase of Scattering after stop of heating

Unperturbed level before heating

Drop of reflection after heating

V.L. Ginzburg conference 2012. V.N.Tsytovich. Possible explanation by cluster transition scattering

1. During the heating disturbed are only electrons and other parameters of the cluster are not disturbed $T_e\,(dn/dr) = const$.



2.After heating (dn/dr) decreases resulting in decrease of total number of coherent electrons (from total yellow area wand to shadowed area)

3. Results – the electron heating decreases the scattering power

4. Z_d being proportional to T_e **is** increases, the electron flux increases and after the heating is switched of the electrons with smaller temperature are reflected by the grains

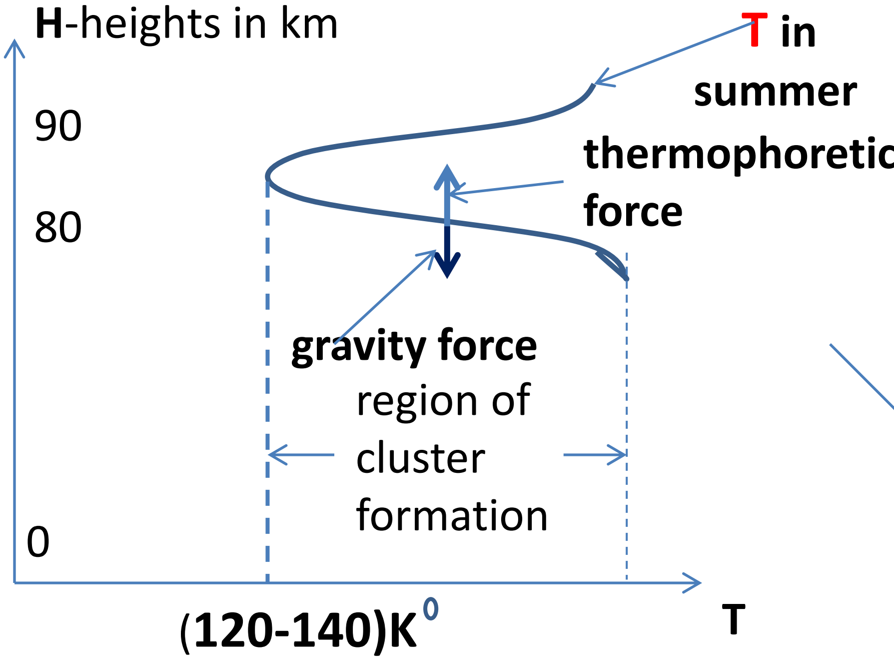
5.This leads overshoot effect

6. The relaxation is due to ion current to the grain which requites longer time

7 .Estimates is this relaxation time are of the order of that observed

V.L.Ginzburg conference 2012. V.N.Tsytovich . MPSE and vorteces in mesosphere

1.Balance of gravity and thermophoretic forces- proportional to **–dT/dr**
2.Laboratory experiments give evidence that **such balance exists** but degree of ionization is much larger
3.Convection in upper atmosphere is related to system of vortices in neutral gas with velocity about several hundred **meters per second-** this creates a Doppler shift much less than the width of transition **scattering** by clusters which Is **less than cm/s.**
4 Planned by EC in future -
A)3D rocket measutments of dust in PNSE
B) Scattering facilities to be build in Norway



Transition scattering serves as a tool for Investigation of turbulence in upper atmosphere

Thank you for attention

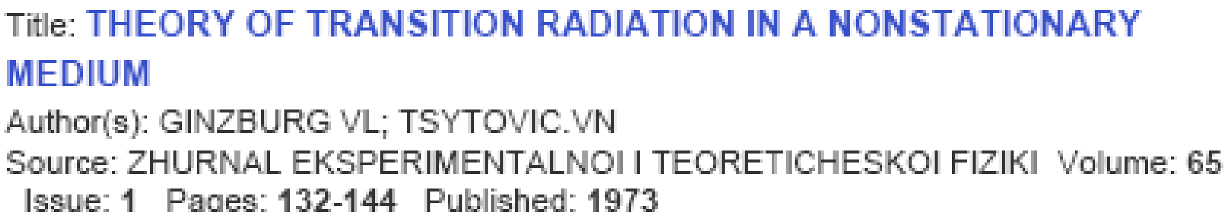
List of references –in Appendix

V.L.Ginzburg conference 2012. V.N.Tsytovich .

APPENDIX :References

Papers on transition radiation

1. **Title** Transition radiation of fast particles
authors **Ginzburg V. L. and I. M. Frank I. M.,** *Zh.Exp.Teor.Fiz.,*volume **16**, page15 **,(1946)**

2.

Title: THEORY OF TRANSITION RADIATION IN A NONSTATIONARY MEDIUM
Author(s): GINZBURG VL; TSYTOVIC.VN
Source: ZHURNAL EKSPERIMENTALNOI I TEORETICHESKOI FIZIKI Volume: 65 Issue: 1 Pages: 132-144 Published: 1973

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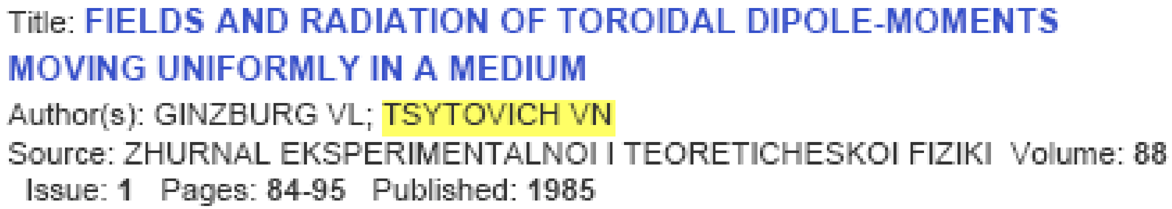
Title: FIELDS AND RADIATION OF TOROIDAL DIPOLE-MOMENTS MOVING UNIFORMLY IN A MEDIUM
Author(s): GINZBURG VL; TSYTOVICH VN
Source: ZHURNAL EKSPERIMENTALNOI I TEORETICHESKOI FIZIKI Volume: 88 Issue: 1 Pages: 84-95 Published: 1985

Papers on transition scattering general

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Title: TRANSITION SCATTERING
Author(s): GINZBURG VL; TSYTOVIC.VN
Source: ZHURNAL EKSPERIMENTALNOI I TEORETICHESKOI FIZIKI Volume: 65 Issue: 5 Pages: 1818-1824 Published: 1973
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2. *Induced resonance scattering of radiation in medium,*
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3.

Title: Transition scattering in electrodynamics and general relativity
Author(s): Ginzburg V.L.; Tsytovich V.N.
Source: Izvestiya Vysshikh Uchebnykh Zavedenii, Radiofizika Volume: 18 Issue: 2 Pages: 173-84 Published: 01 1975

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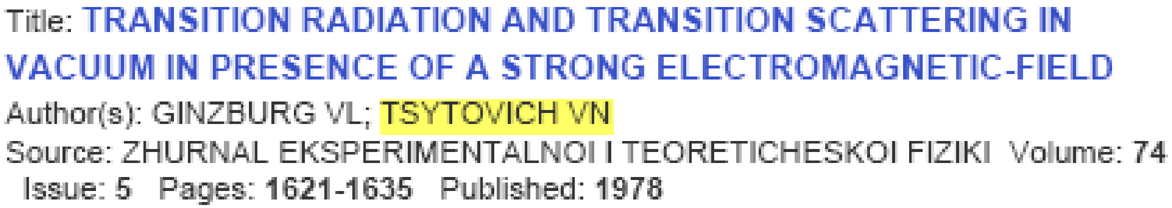
Title: TRANSITION RADIATION AND TRANSITION SCATTERING IN VACUUM IN PRESENCE OF A STRONG ELECTROMAGNETIC-FIELD
Author(s): GINZBURG VL; TSYTOVICH VN
Source: ZHURNAL EKSPERIMENTALNOI I TEORETICHESKOI FIZIKI Volume: 74 Issue: 5 Pages: 1621-1635 Published: 1978

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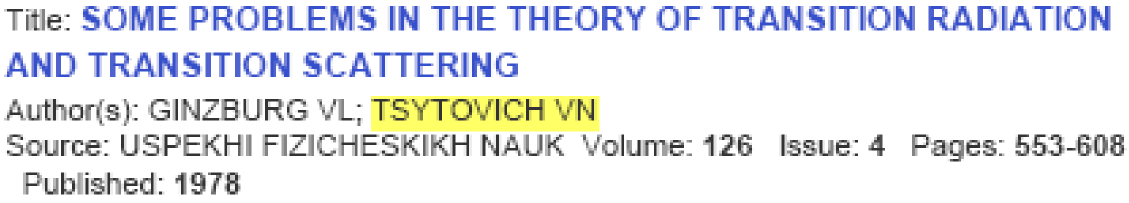
Title: SOME PROBLEMS IN THE THEORY OF TRANSITION RADIATION AND TRANSITION SCATTERING
Author(s): GINZBURG VL; TSYTOVICH VN
Source: USPEKHI FIZICHESKIKH NAUK Volume: 126 Issue: 4 Pages: 553-608 Published: 1978

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Title: ON THE DERIVATION OF THE TRANSITION RADIATION INTENSITY
Author(s): GINZBURG VL; TSYTOVICH VN
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Title: Quantum theory of transition scattering
Author(s): Khorev A.B.; Tsytovich V.A.
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Author(s): Tsytovich VN; de Angelis U; Bingham R; et al.
Source: JOURNAL OF QUANTITATIVE SPECTROSCOPY & RADIATIVE TRANSFER Volume: 69 Issue: 1 Pages: 9-11 DOI: 10.1016/S0022-4073(00)00039-X Published: APR 1 2001

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Title: Collective plasma processes in the solar interior and the problem of the solar neutrinos deficit
Author(s): Tsytovich V.N.; Bingham R.; de Angelis U.; et al.
Source: Physics-Uspekhi Volume: 39 Issue: 2 Pages: 103-28 Published: Feb. 1996

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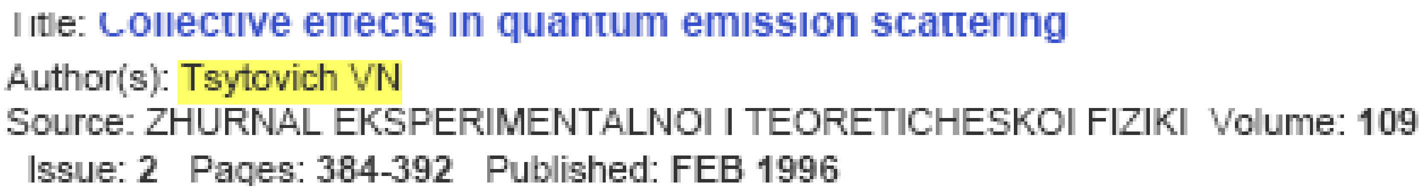

Title: Collective effects in quantum emission scattering
Author(s): Tsytovich VN
Source: ZHURNAL EKSPERIMENTALNOI I TEORETICHESKOI FIZIKI Volume: 109 Issue: 2 Pages: 384-392 Published: FEB 1996

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Author(s): Tsytovich VN; Bingham R; deAngelis U; et al.
Source: PHYSICA SCRIPTA Volume: 54 Issue: 3 Pages: 312-320 DOI: 10.1088/0031-8949/54/3/011 Published: SEP 1996

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Author(s): TSYTOVICH VN

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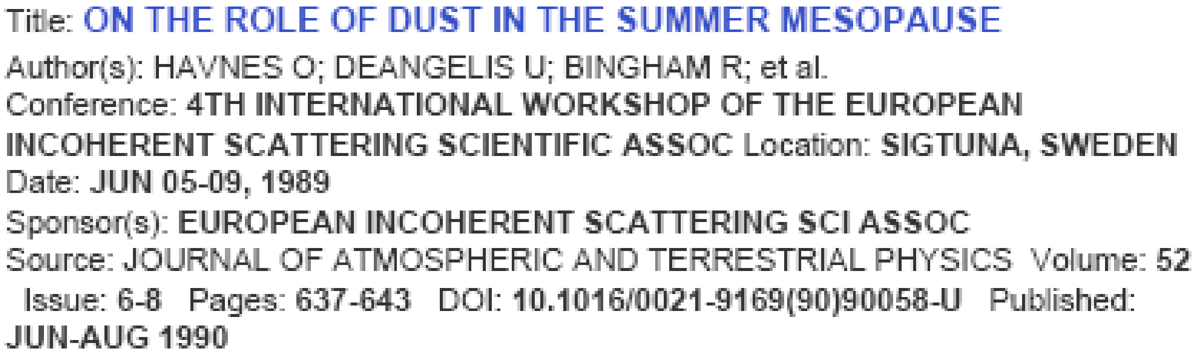
2. 

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Author(s): HAVNES O; DEANGELIS U; BINGHAM R; et al.

Conference: 4TH INTERNATIONAL WORKSHOP OF THE EUROPEAN INCOHERENT SCATTERING SCIENTIFIC ASSOC Location: SIGTUNA, SWEDEN Date: JUN 05-09, 1989

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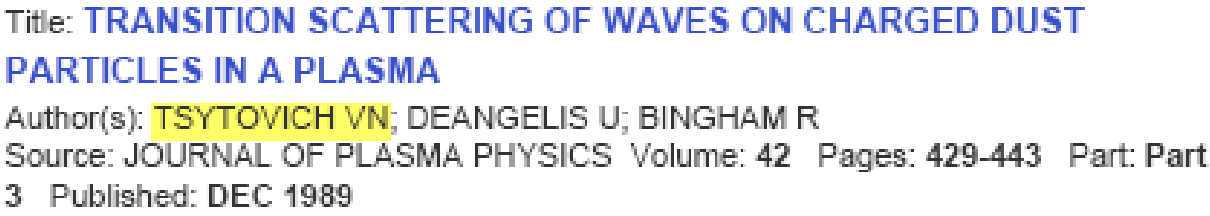
Source: JOURNAL OF ATMOSPHERIC AND TERRESTRIAL PHYSICS Volume: 52 Issue: 6-8 Pages: 637-643 DOI: 10.1016/0021-9169(90)90058-U Published: JUN-AUG 1990

3. 

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Author(s): TSYTOVICH VN; DEANGELIS U; BINGHAM R

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Authors:

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authors : O. Havnes and K. Messaret

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Author(s): Khodataev YK; Bingham R; Tarakanov VP;Tsytovich VN and Morfill GE
Conference: International Topical Conference on Plasma Physics Location: TRIESTE, ITALY Date: JUL 03-07, 2000
Source: PHYSICA SCRIPTA Volume: T89 Pages: 95-100 DOI: 10.1238/Physica.Topical.089a00095 Published: 2001

2. Title: Ionization instability and dusty plasma structurization
Author(s): Morfill G; Tsytovich VN
Source: PLASMA PHYSICS REPORTS Volume: 26 Issue: 8 Pages: 682-690
DOI: 10.1134/1.1306997 Published: AUG 2000

3. Title: Formation of a Boundary-Free Dust Cluster in a Low-Pressure Gas-Discharge Plasma

Authors:

A. D. Usachev,[1,*,†] A. V. Zobnin,[1] O. F. Petrov,[1] V. E. Fortov,[1] B. M. Annaratone,[2] M. H. Thoma,[3] H. Höfner,[3] M. Kretschmer,[3] M. Fink,[3] and G. E. Morfill[3]

PRL 102, 045001 (2009)

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Authors: J. R. Heinrich, S. -H. Kim, R. L. Merlino

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Authors :A). Annaratone B. and Allen J. ***Privet communication Oxford Univ.(1997)***

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Thank you
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