Institute of Applied Physics
Russian Academy of Sciences

XIXth International Workshop on ECR Ion Sources
ECRIS 2010
LPSC Grenoble, France, August 23 – 26, 2010

PREGLOW PHENOMENON ORIGINS AND ITS SCALING FOR ECRIS

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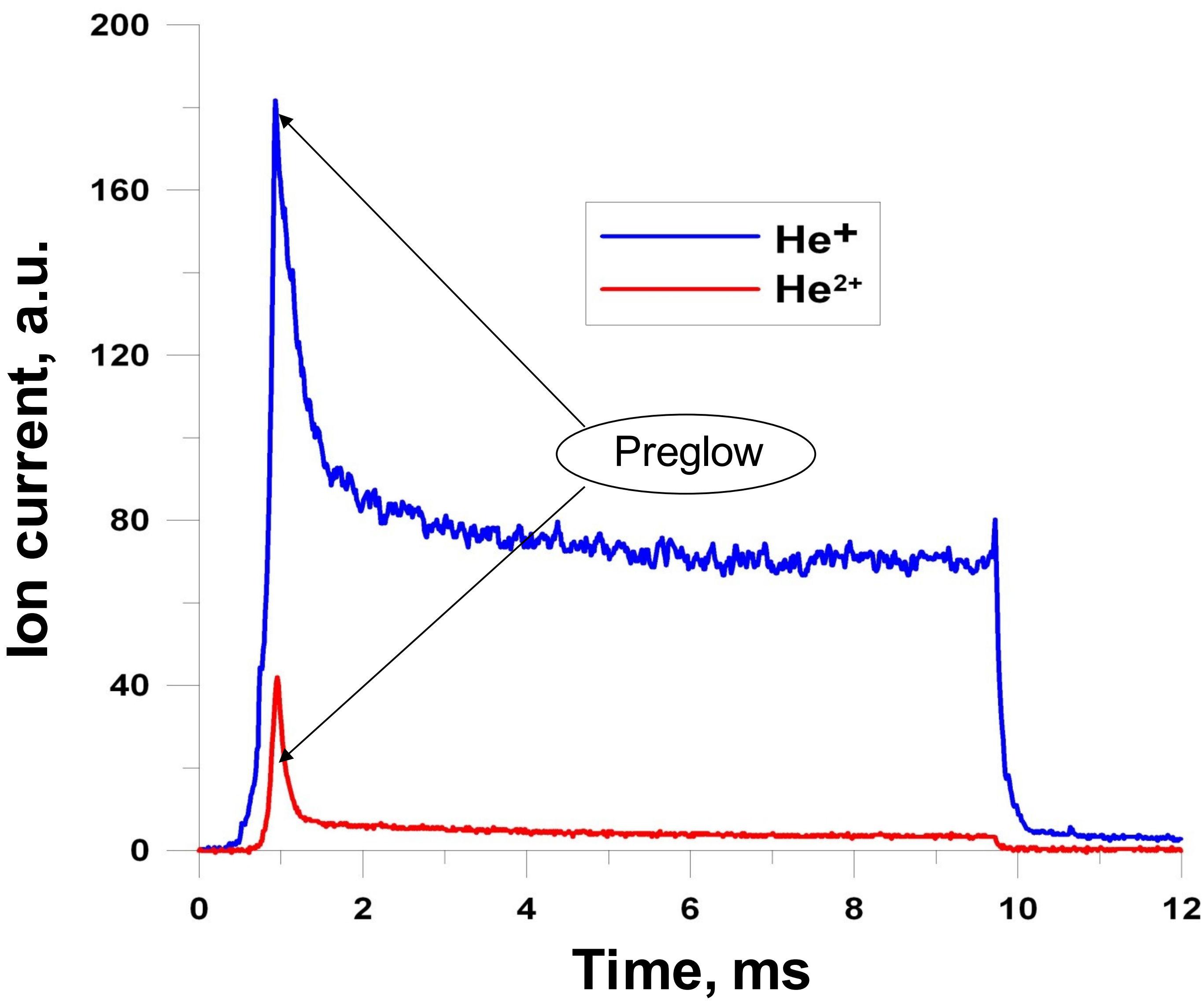
Outline

- Theoretical model and main equations
- Physical interpretation of Preglow phenomenon
- Numerical simulation: Preglow vs experimental conditions
- Universal parameter defining existence of Preglow
- Frequency scaling of Preglow

What is "Preglow"?



Theoretical model [1,2]

$$\frac{dN_i}{dt} = (k_{i-1,i}N_{i-1} - k_{i,i+1}N_i)\cdot N_e - \frac{N_i}{\tau_i}$$ Ions

$$\frac{dN_e}{dt} = N_e \cdot \sum_{i=0}^{n-1} k_{i,i+1}N_i - \frac{N_e}{\tau_e}$$ Electrons

$$\frac{dN_0}{dt} = I(t) - k_{0,1}N_0N_e$$ Neutrals

$$\frac{1}{\tau_e} = \frac{1}{N_e}\sum_{i=1}^{n}\frac{iN_i}{\tau_i}$$ Condition of quasi-neutrality

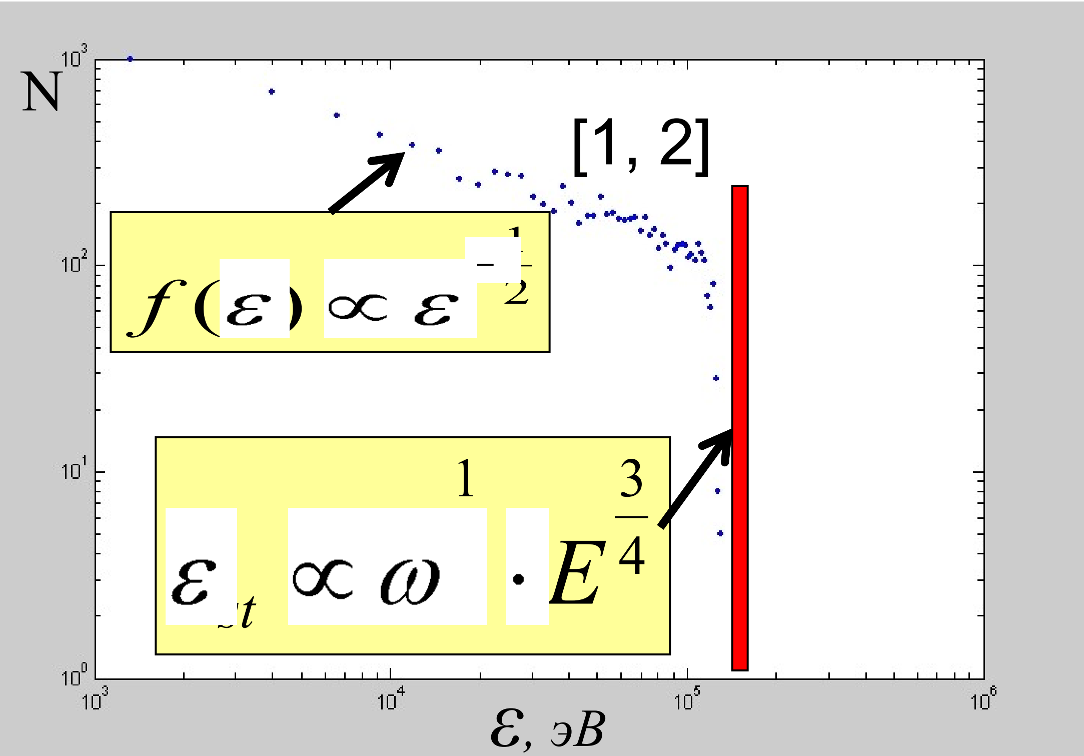
$$\frac{3}{2}\cdot\frac{d(N_e\cdot T_e)}{dt} = \frac{P}{L} - \frac{N_e}{\tau_e}\cdot(T_e+\varphi_0) - \sum_{i=0}^{n-1} k_{i,i+1}\cdot N_e\cdot N_i\cdot E_i$$ Balance of energy

$$k = <\sigma v> = \frac{\int F(\varepsilon)\sigma(\varepsilon)v(\varepsilon)d\varepsilon}{\int F(\varepsilon)d\varepsilon}$$ Ionization rate

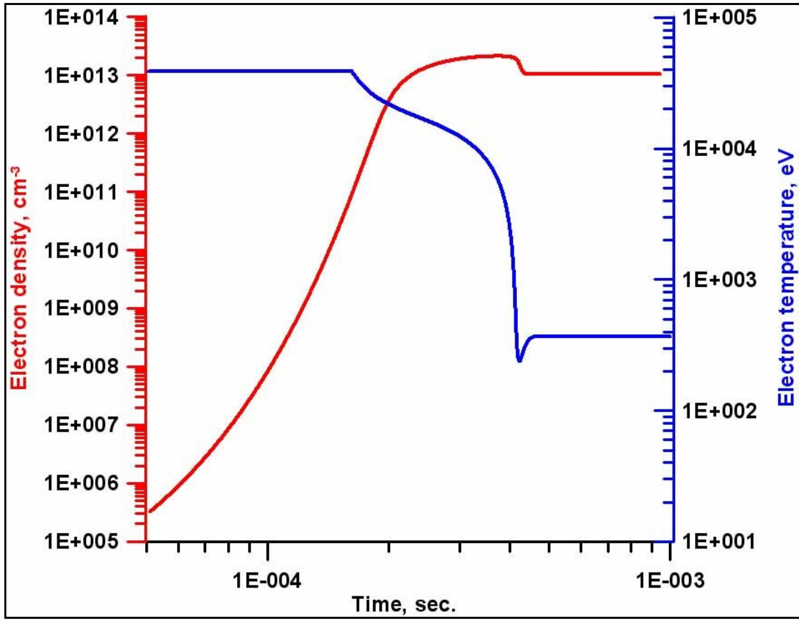
Free parameters of the model:
- ***Gas density***
- ***Microwave absorption coefficient***

[1] S.V. Golubev, I.V. Izotov, S.V. Razin, V.A. Skalyga, A.V. Vodopyanov, V.G. Zorin. Multicharged Ion Generation in Plasma Created by Millimeter Waves and Confined in a CUSP Magnetic Trap. Transactions of Fusion Science and Technology, v. 47, n. 1T , fuste8, p. 345-347, 2005.
[2] V. Skalyga, V. Zorin, V. Izotov, A. Sidorov, T. Lamy, P. Sortais, T. Thuillier. Gas Breakdown in ECR ion Source. Review of Scientific Instruments. v.77, n3, p. 03A325-1 – 03A325-3, 2006.

Superadiabacity effect



Non-maxwellian EEDF!



[1] E. V. Suvorov and M. D. Tokman, Sov. J. Plasma Phys. **15, 540 1989.**

[2] Edgell D.H. et all. Modeling of electron cyclotron resonance ion source plasmas. Proceedings of Particle Accelerator Conference, USA, 2001.

E_e - N_e *plane* [1]

Coulomb electron scattering into the loss-cone

$$\tau_e = \ln R/\nu_{ei}$$

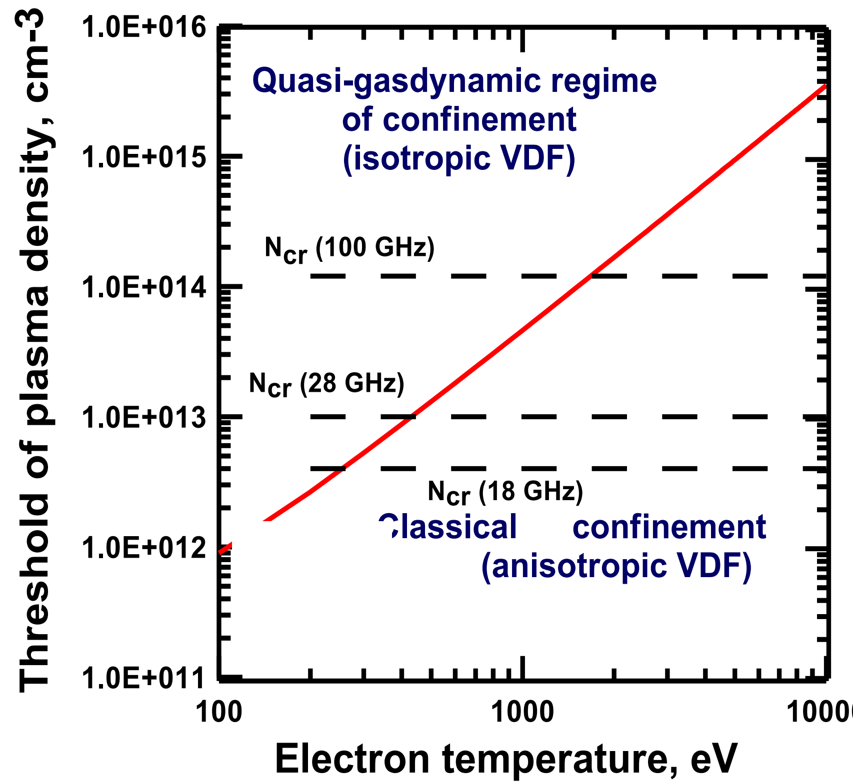
$\tau_e > \tau_g$ (collisionless)

$\tau_e < \tau_g$ (collisional)

Duration of plasma escape

$$\tau_g = L_{eff}/V_s$$

Doesn't depend on VDF

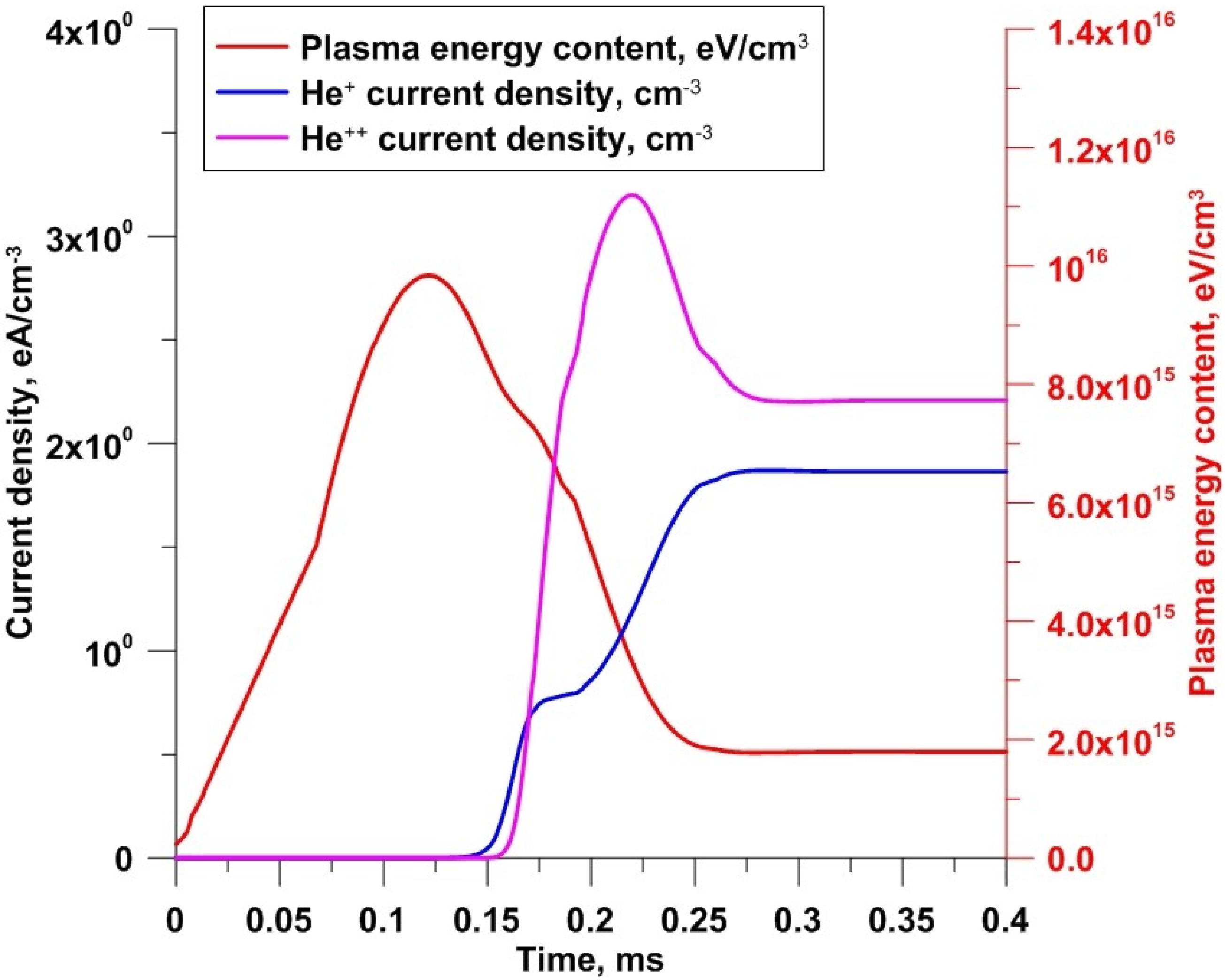


V_s – ion sound velocity

L_{eff} – effective trap length

[1] V. Semenov, V. Skalyga, A. Smirnov, V. Zorin. Review of Scientific Instruments. v. 73, #2, p. 635 – 637. 2002.

Physical interpretation of Preglow



Energy content:

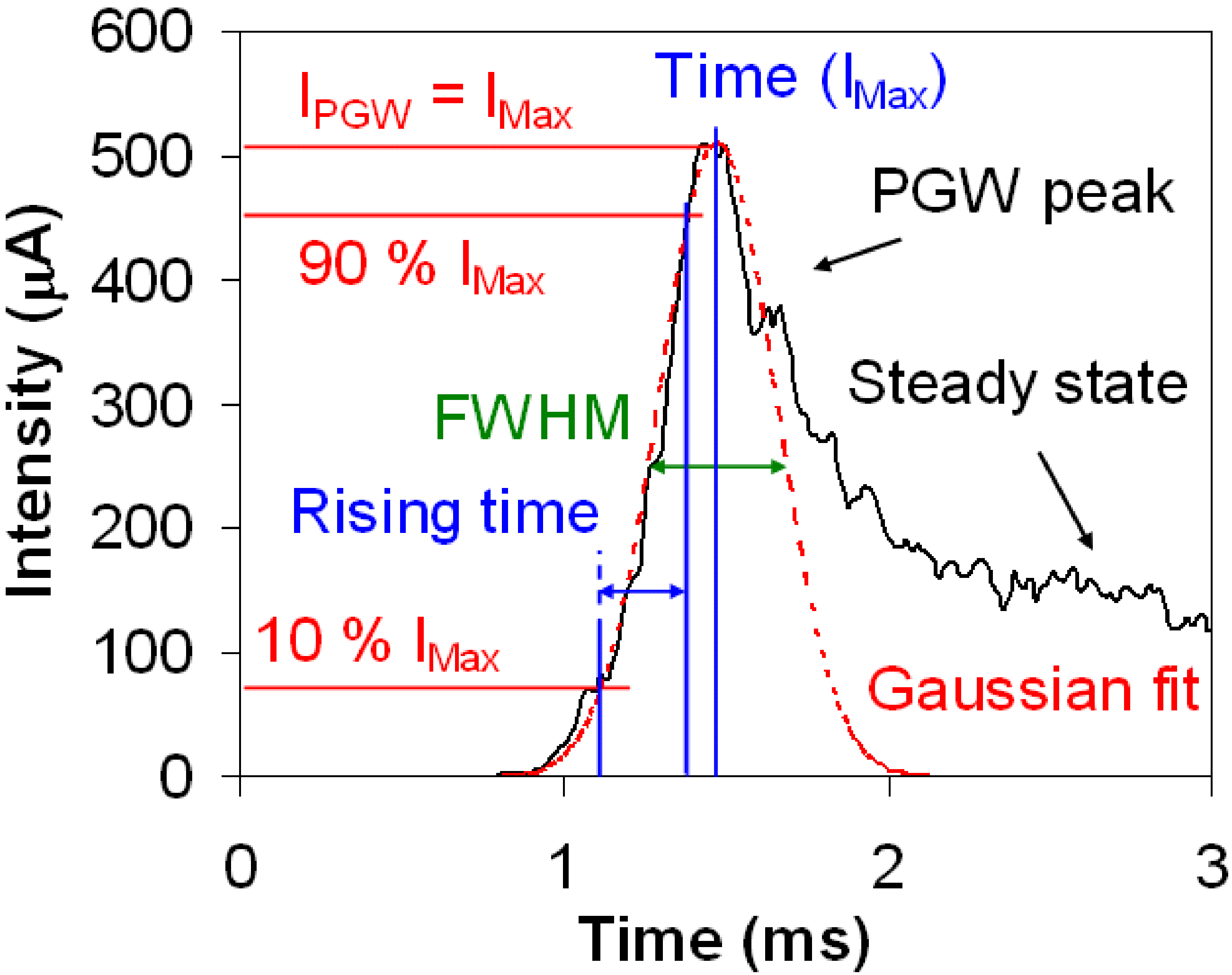
w=<E>*Ne

<E> - average electron energy over EEDF

Ne - electron concentration.

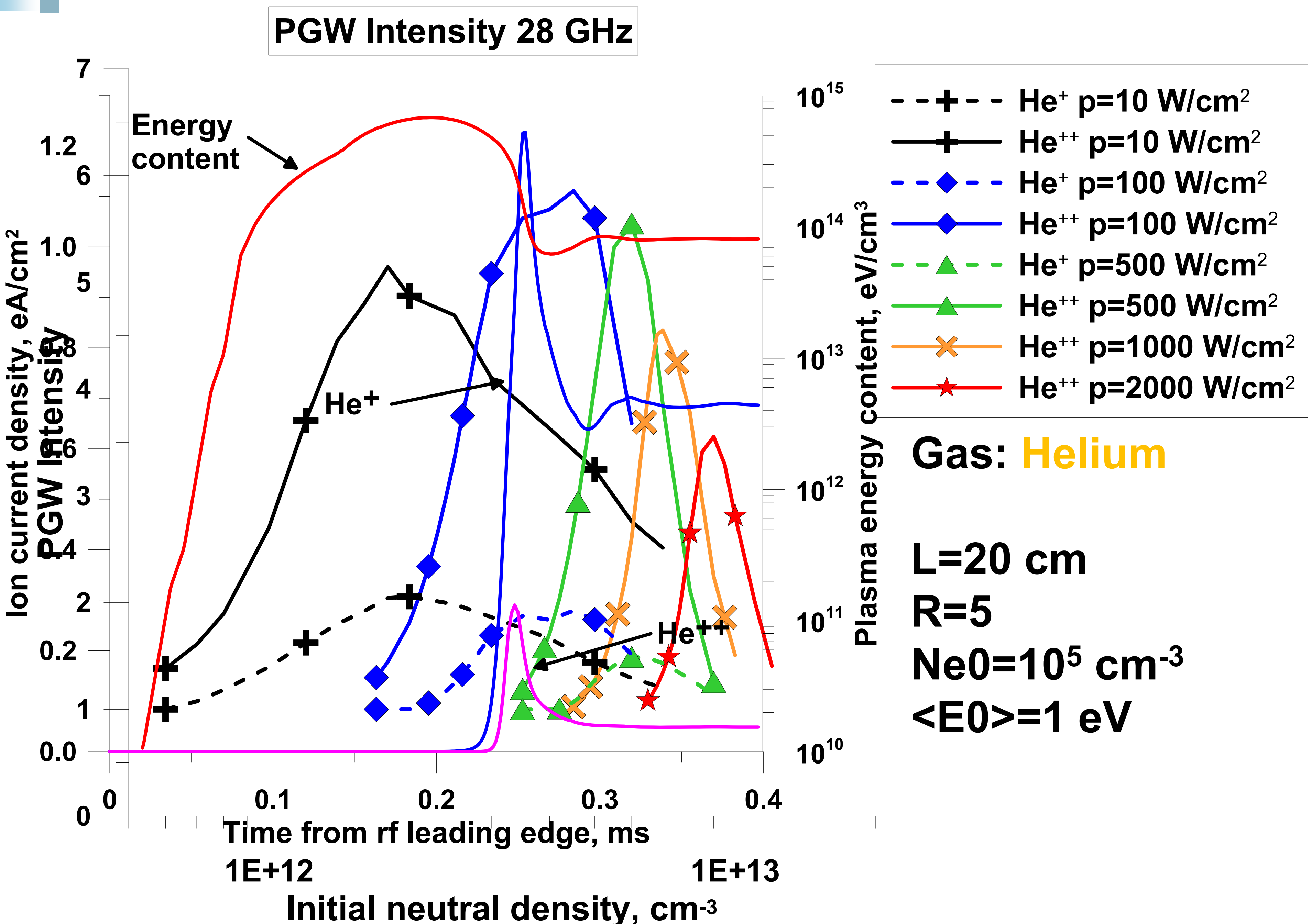
Plotted for:
SMIS`37
37.5 GHz
100 kW

Preglow parameters definition



Intencity:
Int=Imax/
I(steaty-state)

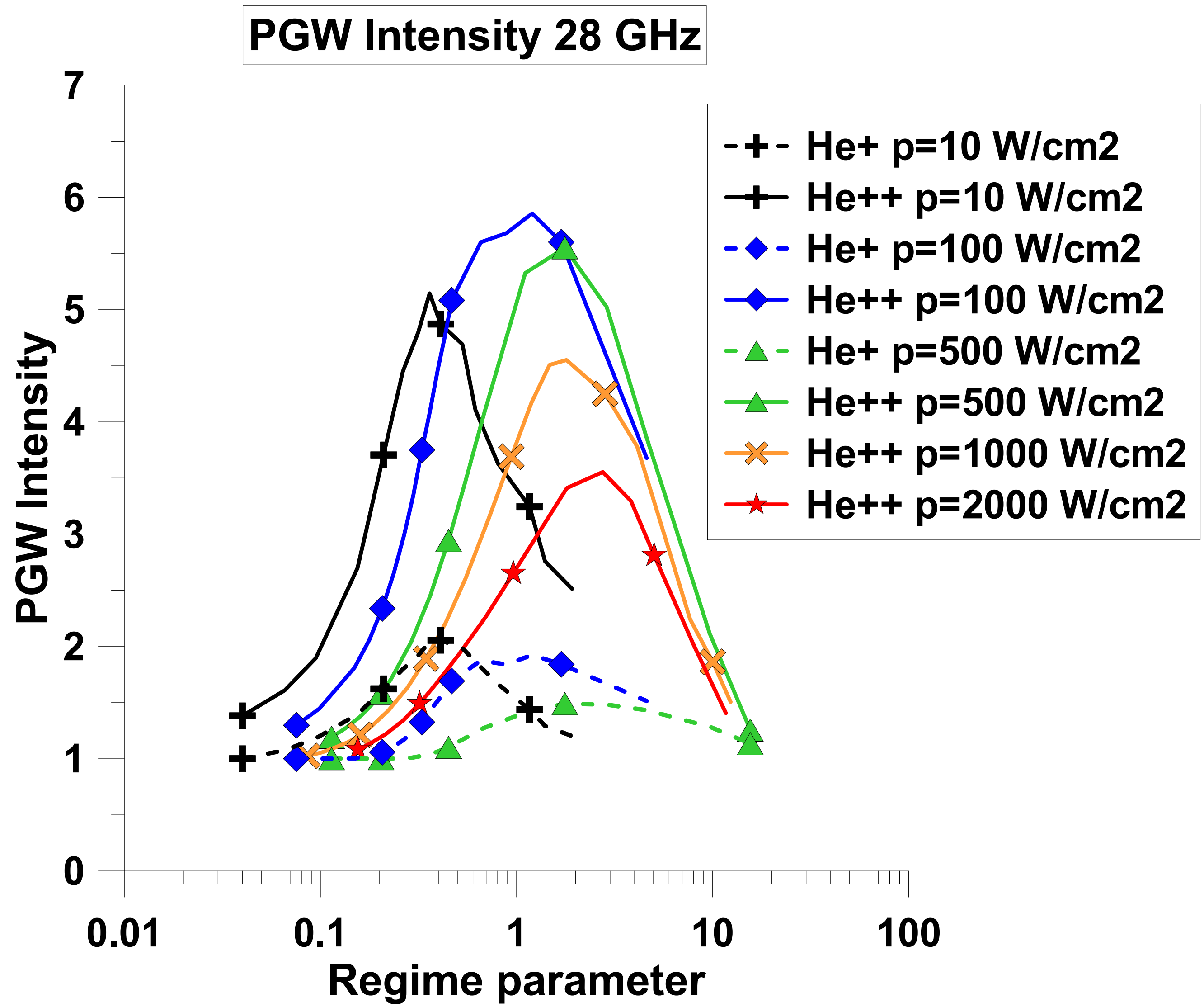
T. Thuillier et all. R.S.I., 79, 02A314, 2008

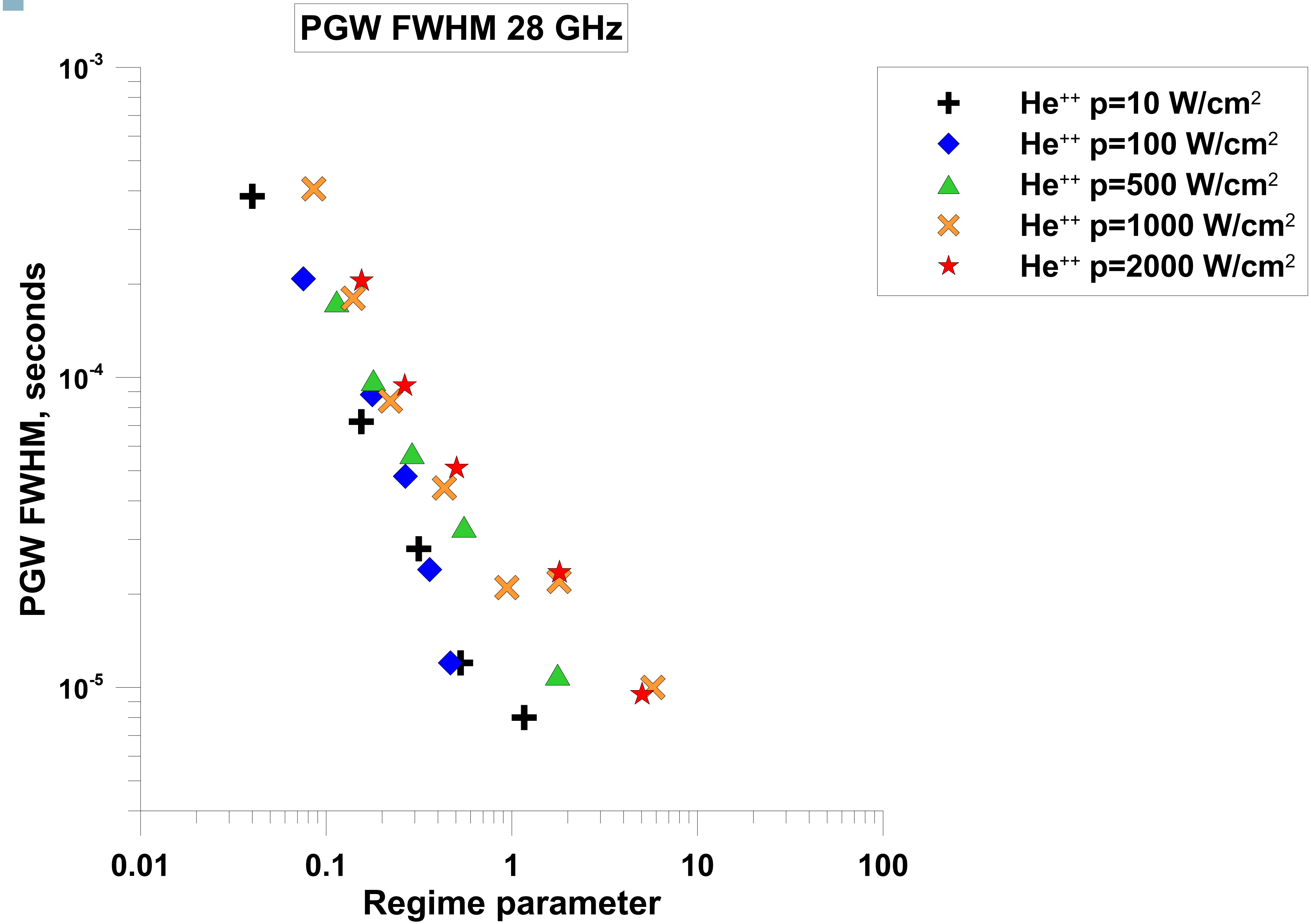


PGW Intensity 28 GHz
Energy content
He+
He++
Ion current density, eA/cm2
PGW Intensity
Plasma energy content, eV/cm3
Time from rf leading edge, ms
Initial neutral density, cm-3
1E+12
1E+13
0
0.1
0.2
0.3
0.4
0.0
0.2
1.0
1.2
0
1
2
3
4
5
6
7
10^10
10^11
10^12
10^13
10^14
10^15
He+ p=10 W/cm2
He++ p=10 W/cm2
He+ p=100 W/cm2
He++ p=100 W/cm2
He+ p=500 W/cm2
He++ p=500 W/cm2
He++ p=1000 W/cm2
He++ p=2000 W/cm2
Gas: Helium
L=20 cm
R=5
Ne0=10^5 cm-3
<E0>=1 eV

$RP \equiv \tau_g / \tau$

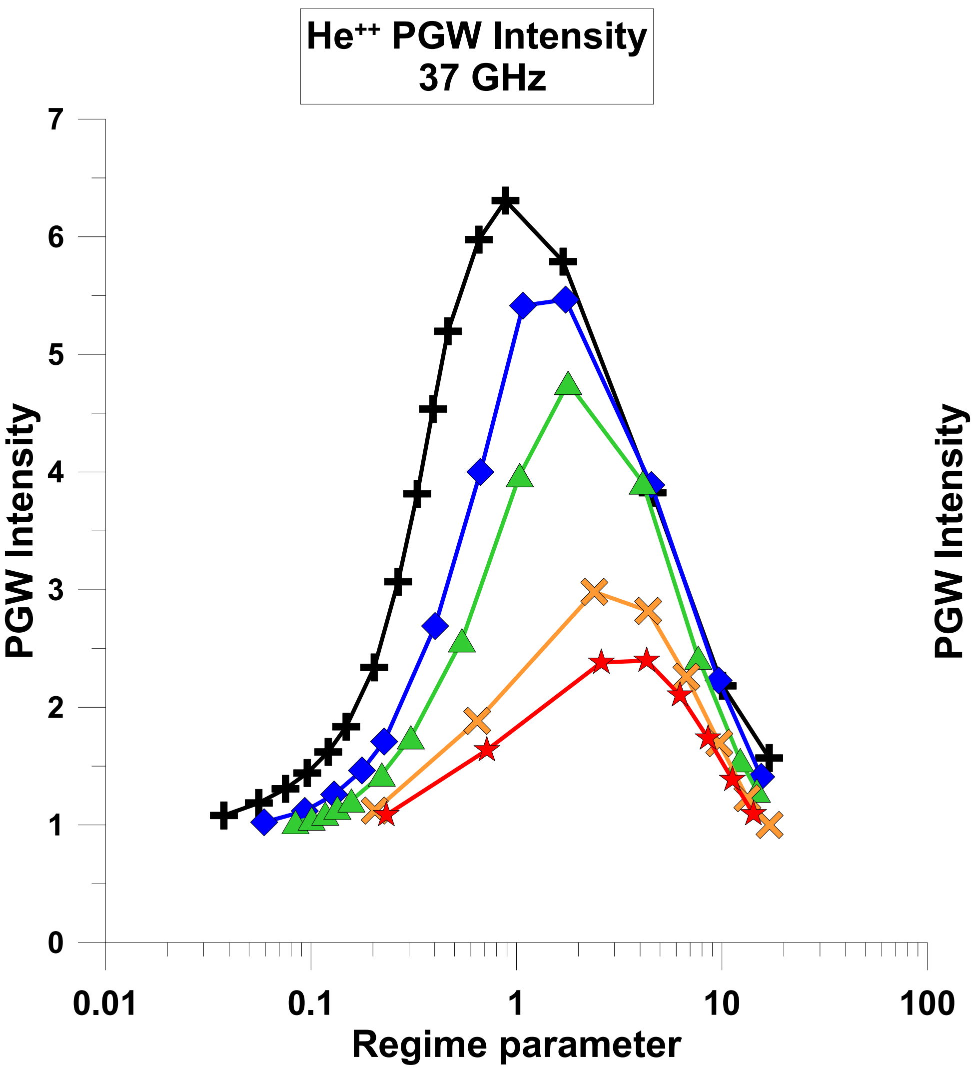
RP<<1 – classical confinement,
RP>>1 – gasdynamic confinement

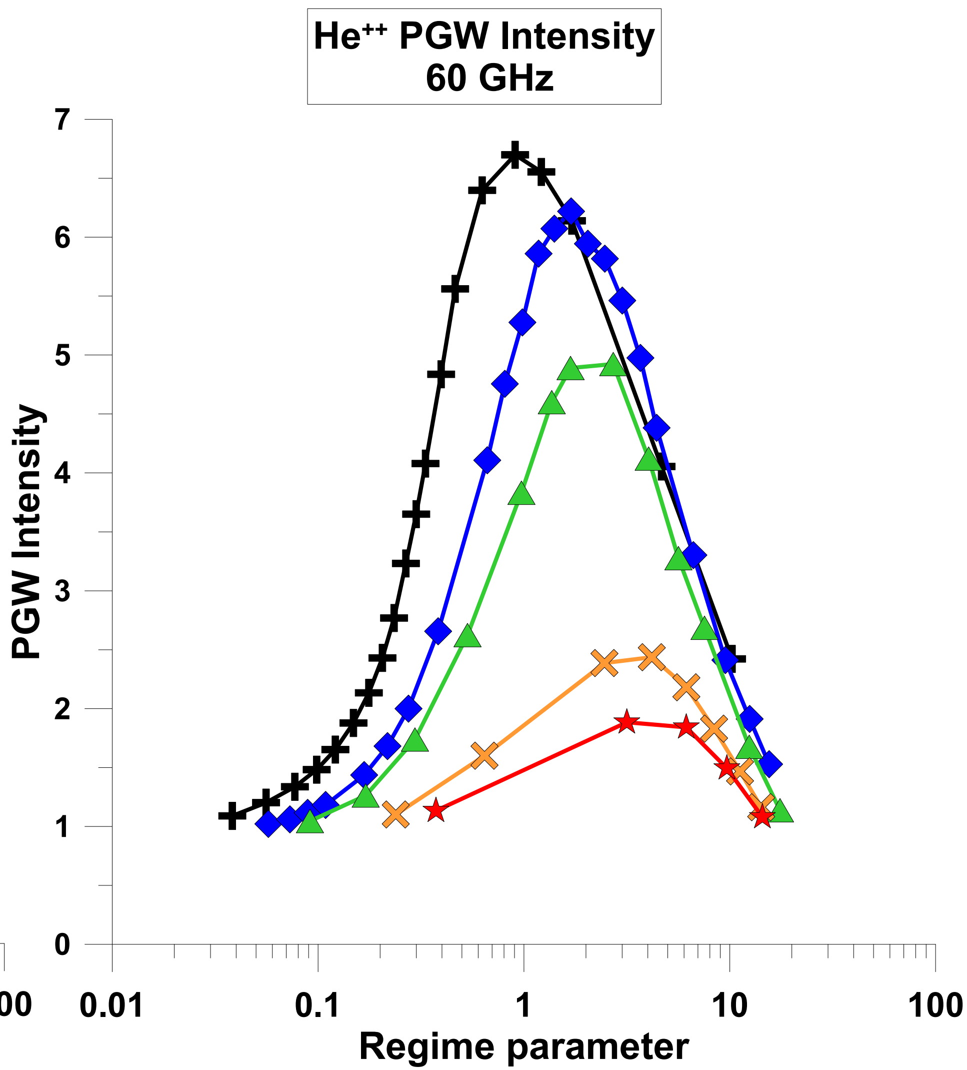


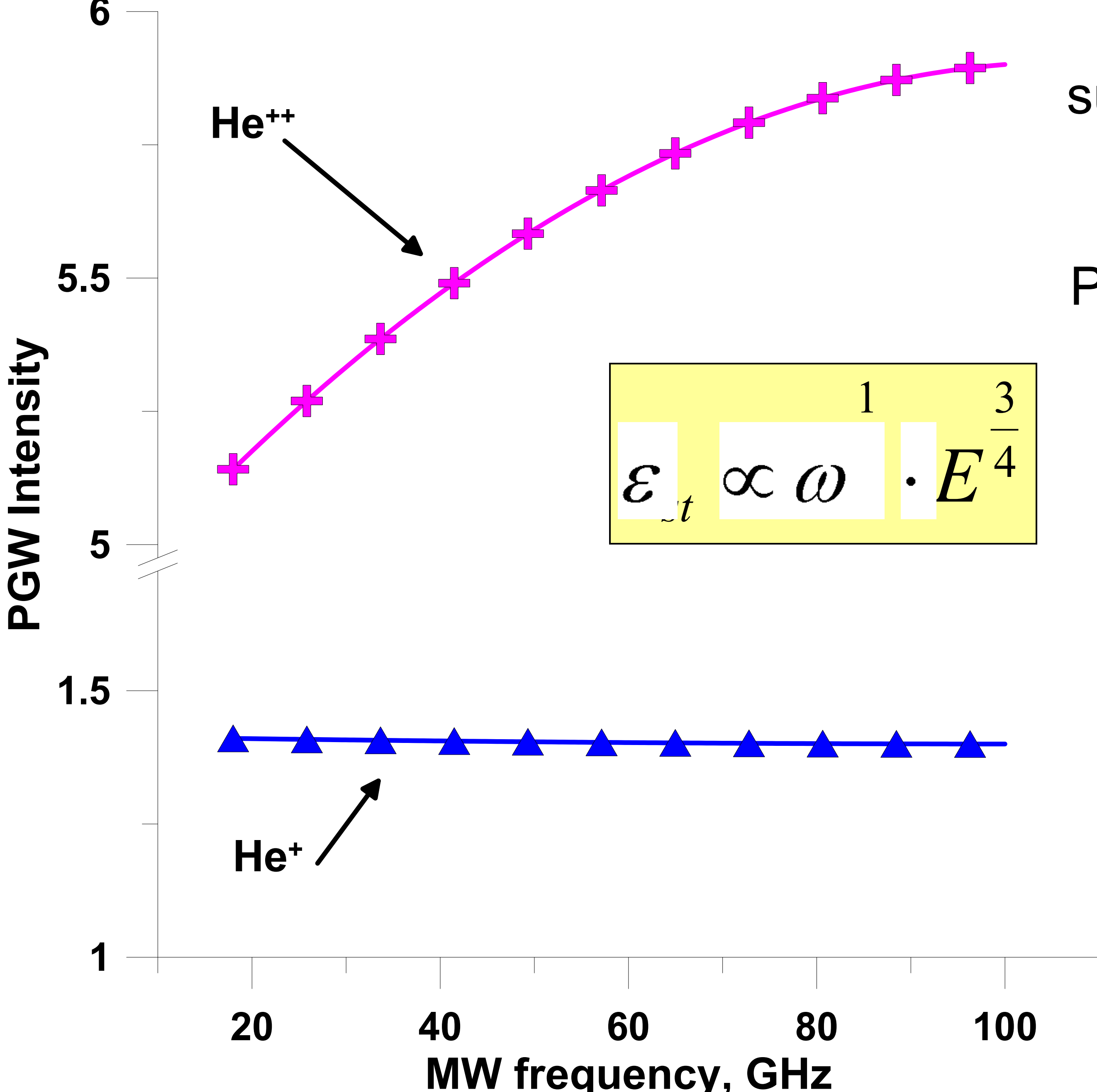


PGW FWHM 28 GHz
PGW FWHM, seconds
10-3
10-4
10-5
0.01
0.1
1
10
100
Regime parameter
He++ p=10 W/cm2
He++ p=100 W/cm2
He++ p=500 W/cm2
He++ p=1000 W/cm2
He++ p=2000 W/cm2

Weak dependence of Preglow Int on Frequency



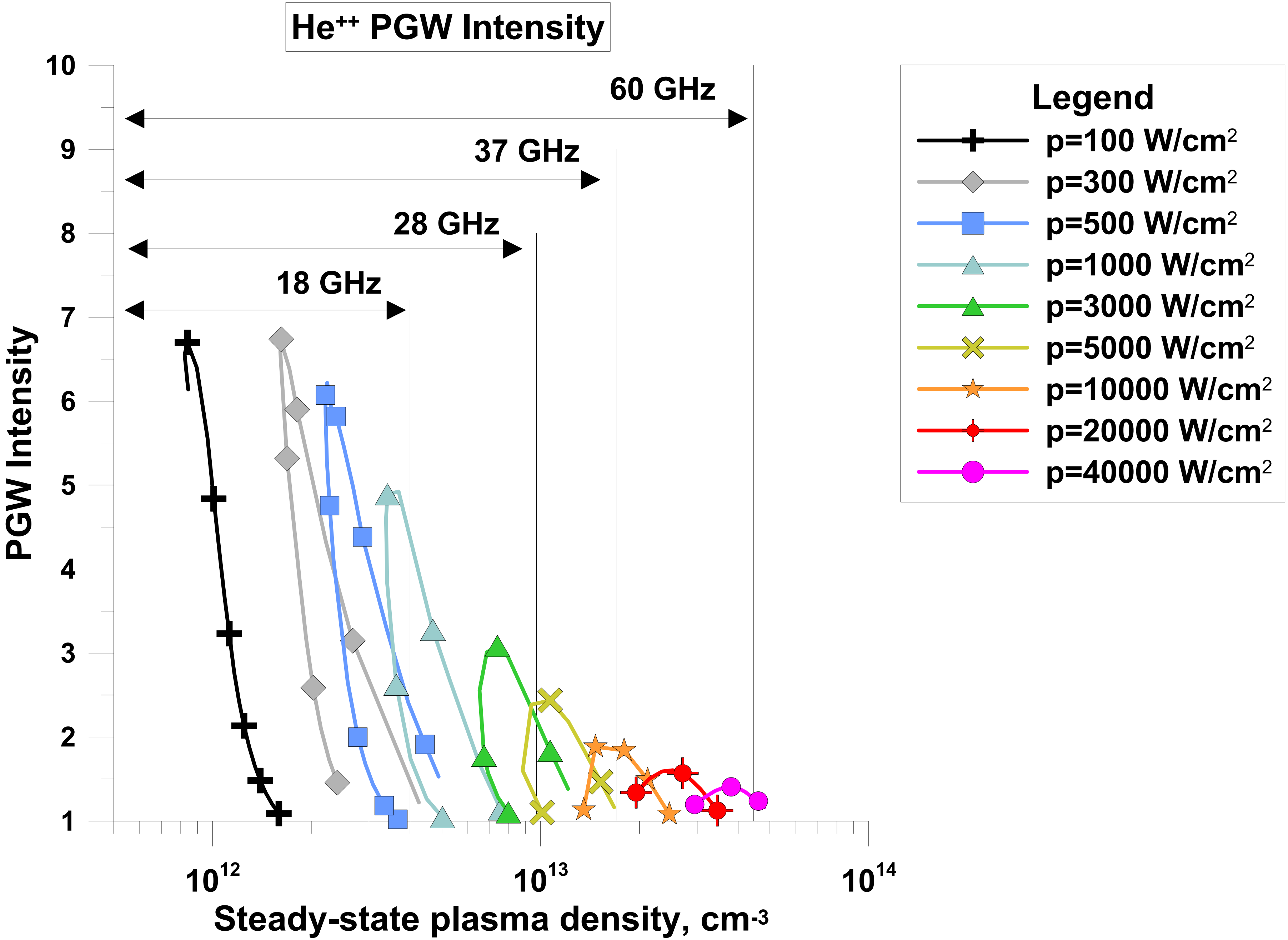


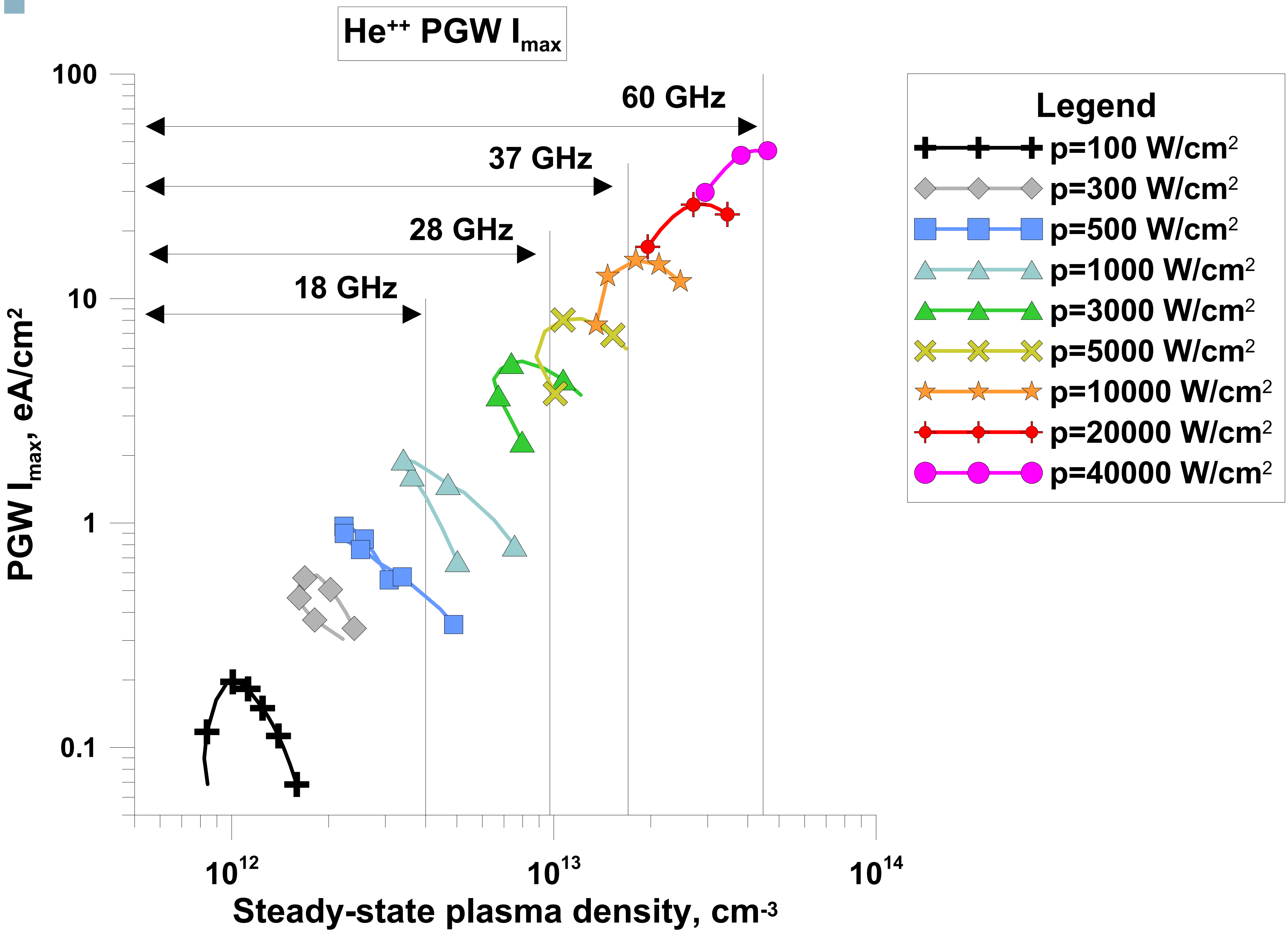


Stored at superadiabatic mode energy, which determines further Preglow, has a weak dependence on a heating frequency

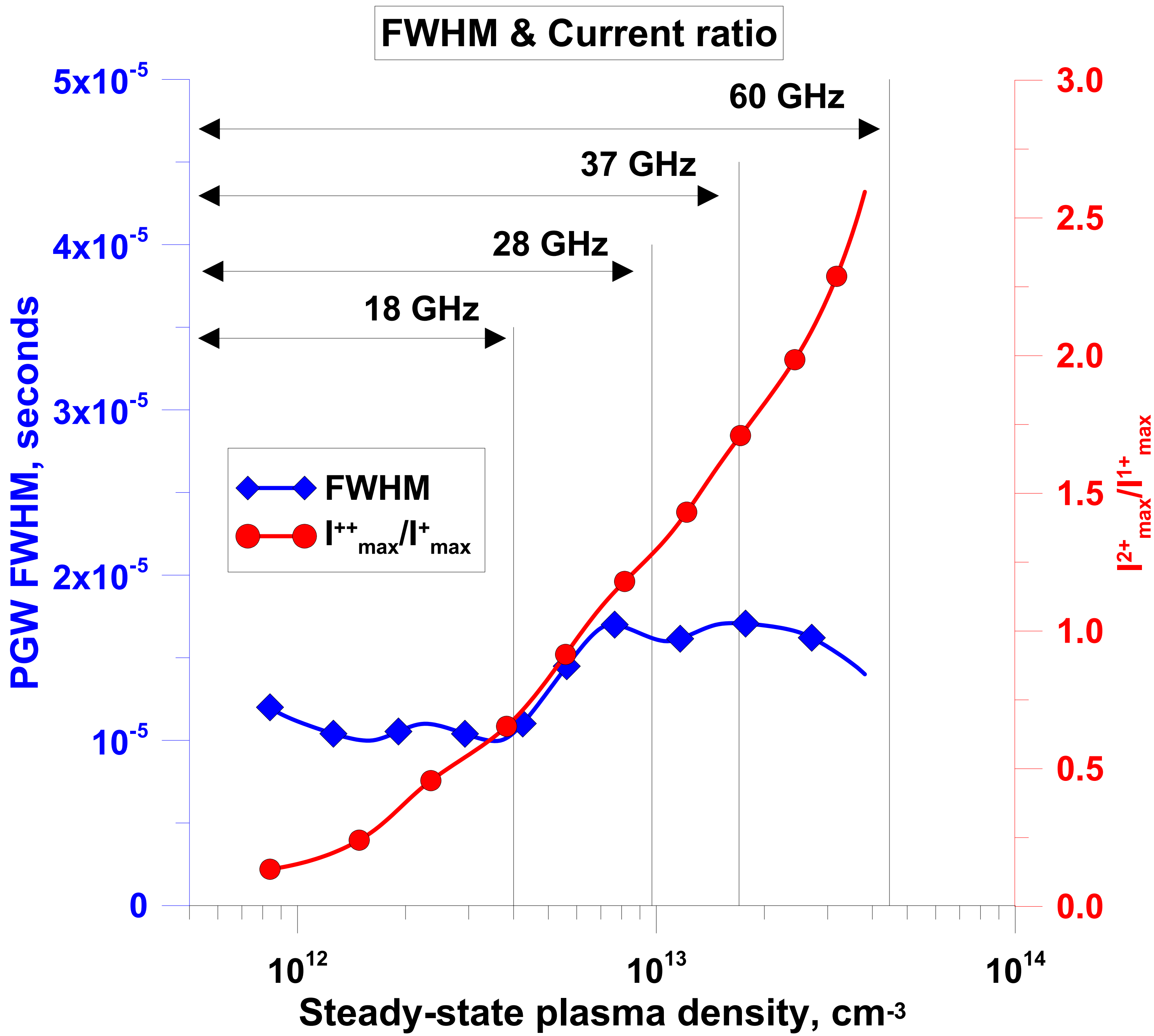
L=20 cm
R=5
Ne0=10^5 cm^{-3}
Te0=1 eV

RP=1.1
(Na0=5.5E11, p=500W/cm^2)


He++ PGW Intensity
PGW Intensity
10
9
8
7
6
5
4
3
2
1
60 GHz
37 GHz
28 GHz
18 GHz
10^12
10^13
10^14
Steady-state plasma density, cm-3
Legend
p=100 W/cm2
p=300 W/cm2
p=500 W/cm2
p=1000 W/cm2
p=3000 W/cm2
p=5000 W/cm2
p=10000 W/cm2
p=20000 W/cm2
p=40000 W/cm2



He++ PGW I_max
100
10
1
0.1
PGW I_max, eA/cm2
10^12
10^13
10^14
Steady-state plasma density, cm-3
60 GHz
37 GHz
28 GHz
18 GHz
Legend
p=100 W/cm2
p=300 W/cm2
p=500 W/cm2
p=1000 W/cm2
p=3000 W/cm2
p=5000 W/cm2
p=10000 W/cm2
p=20000 W/cm2
p=40000 W/cm2


FWHM & Current ratio
PGW FWHM, seconds
5x10^-5
4x10^-5
3x10^-5
2x10^-5
10^-5
0
60 GHz
37 GHz
28 GHz
18 GHz
FWHM
I++max/I+max
3.0
2.5
2.0
1.5
1.0
0.5
0.0
I2+max/I1+max
10^12
10^13
10^14
Steady-state plasma density, cm-3

Conclusion

- New, more physical explanation of Preglow phenomenon is suggested.
- Provided results show dependence of Preglow principal parameters on experimental conditions.
- Preglow effect may be observed in almost every ECR source; a proper choice of initial conditions may ensure the phenomenon existence.
- The proposed scaling demonstrates that an ECR source with plasma heating by radiation at a high frequency (37 GHz and higher) seems to be the most effective to generate pulsed beams of multicharged ions with current density of several eA/cm2 and higher and duration less than 50 μs.
- The next step is experimental investigation of the preglow effect on the SMIS`37 facility with 37.5 GHz @ 100 kW pumping.