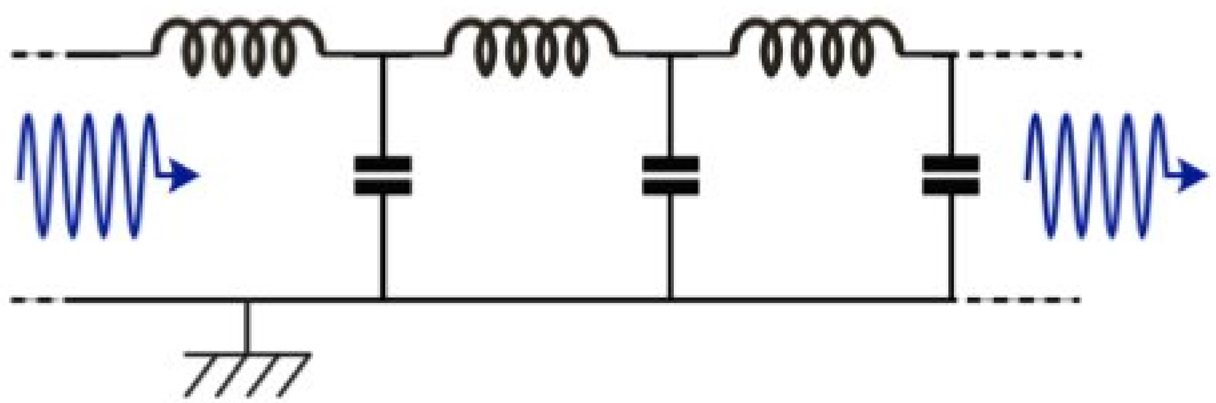
Quantum electrodynamics in 1D



$0.67 per ft.
Pasternack

$$Z = \sqrt{L/C} \approx \sqrt{\mu_0/\epsilon_0} = Z_{\text{vacuum}} \approx 377\ \Omega$$

$$R_Q = h/(2e)^2 \approx 6.5\ k\Omega$$

$$Z_{\text{vacuum}}/R_Q = 8\alpha, \alpha = 1/137.0$$

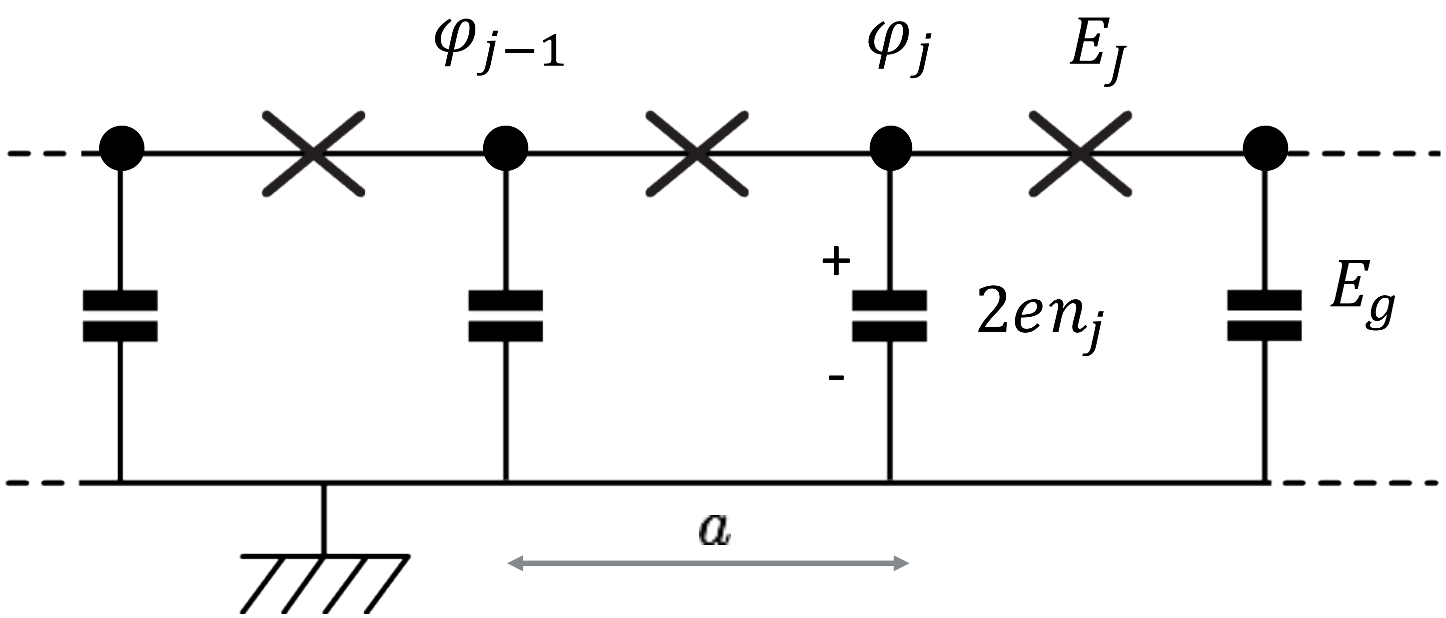
$Z_{\text{coax}} \approx 50\ \Omega$

(teflon and factors ~ 1)

Want fine structure constant >1?
Sure. Just make Z > 8R$_Q$!

Theory: BKT-type superconductor-insulator transition (SIT)

Long-wavelength limit:



$$\sqrt{\frac{E_J}{E_g}} = \frac{2}{\pi} \qquad Z = \frac{R_Q}{4}$$

$R_Q \approx 6.5\ k\Omega$

$$H = \sum_j \frac{E_g}{2} n_j^2 - \sum_j E_J \cos(\varphi_j - \varphi_{j-1})$$

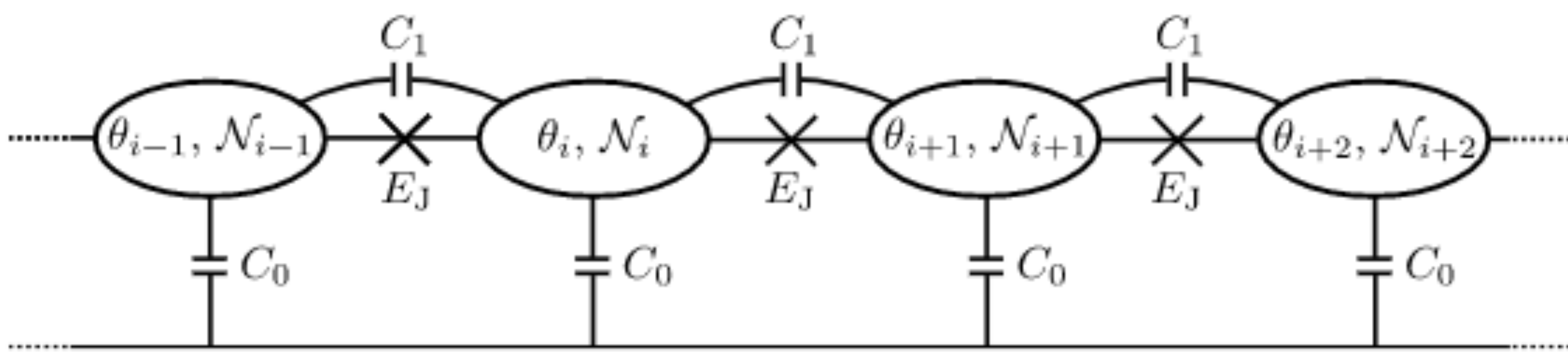
Equivalent to Superfluid - Mott insulator transition

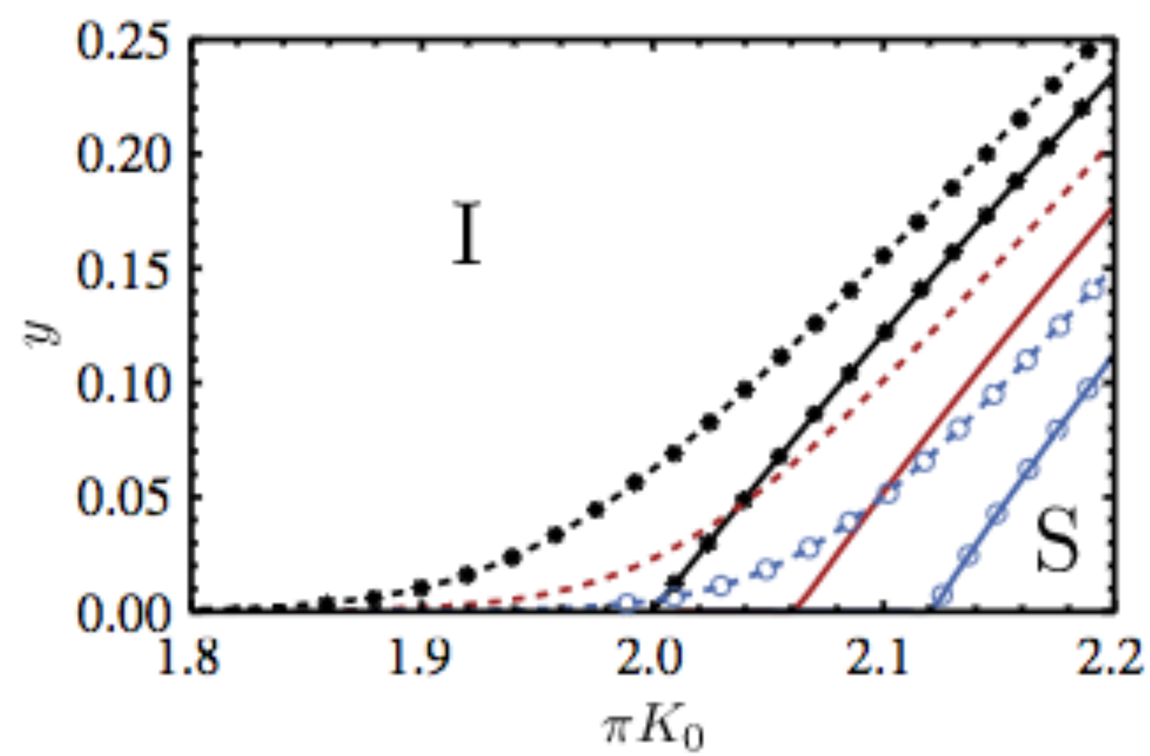
Quantum fluctuations do not allow Z > Rq/4 ~ 1.5 kOhm!

Bradley, R. M., & Doniach, S. (1984); Korshunov, S. E. (1989)

Superconductor-Insulator Transition in disordered Josephson junction chains

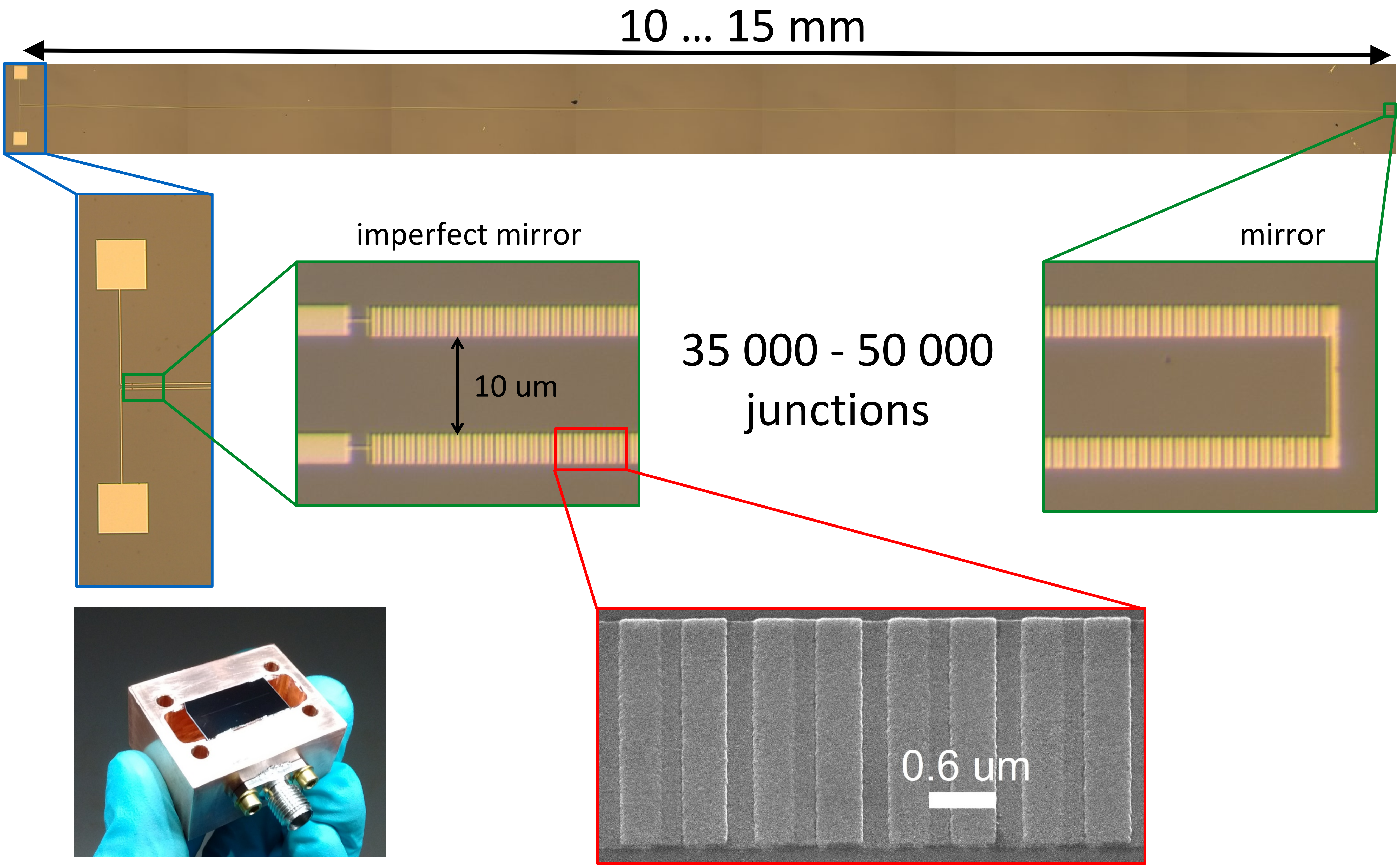
M. Bard,[1] I. V. Protopopov,[2,1,3] I. V. Gornyi,[1,4,3,5] A. Shnirman,[4,3] and A. D. Mirlin[1,4,3,6]





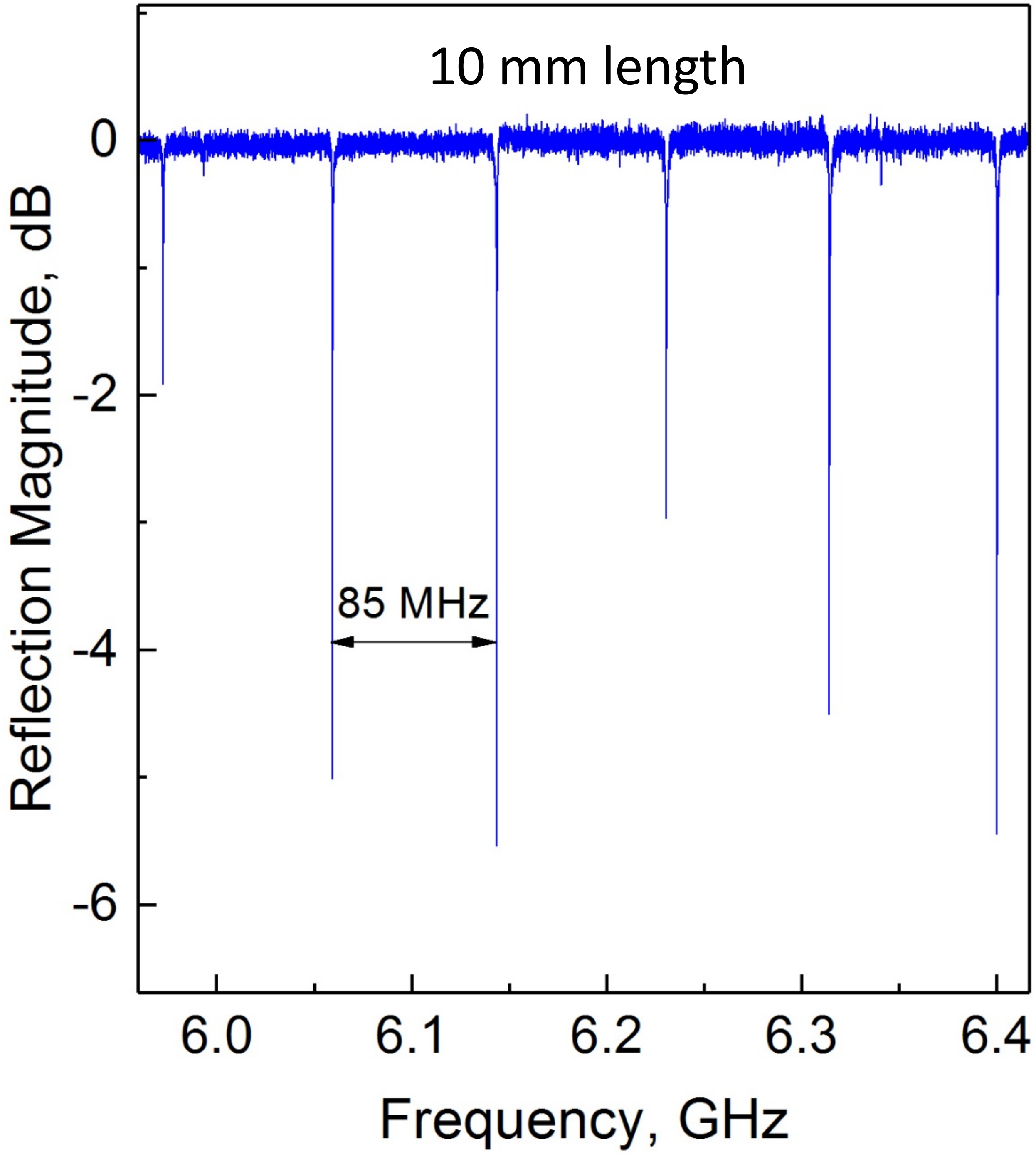
Intergrain capacitance & charge disorder do not change critical impedance much

High-impedance Josephson transmission line



Ultra-slow microwave "light"

Measured speed of light $c = 2.1 \cdot 10^6 \frac{m}{sec}$

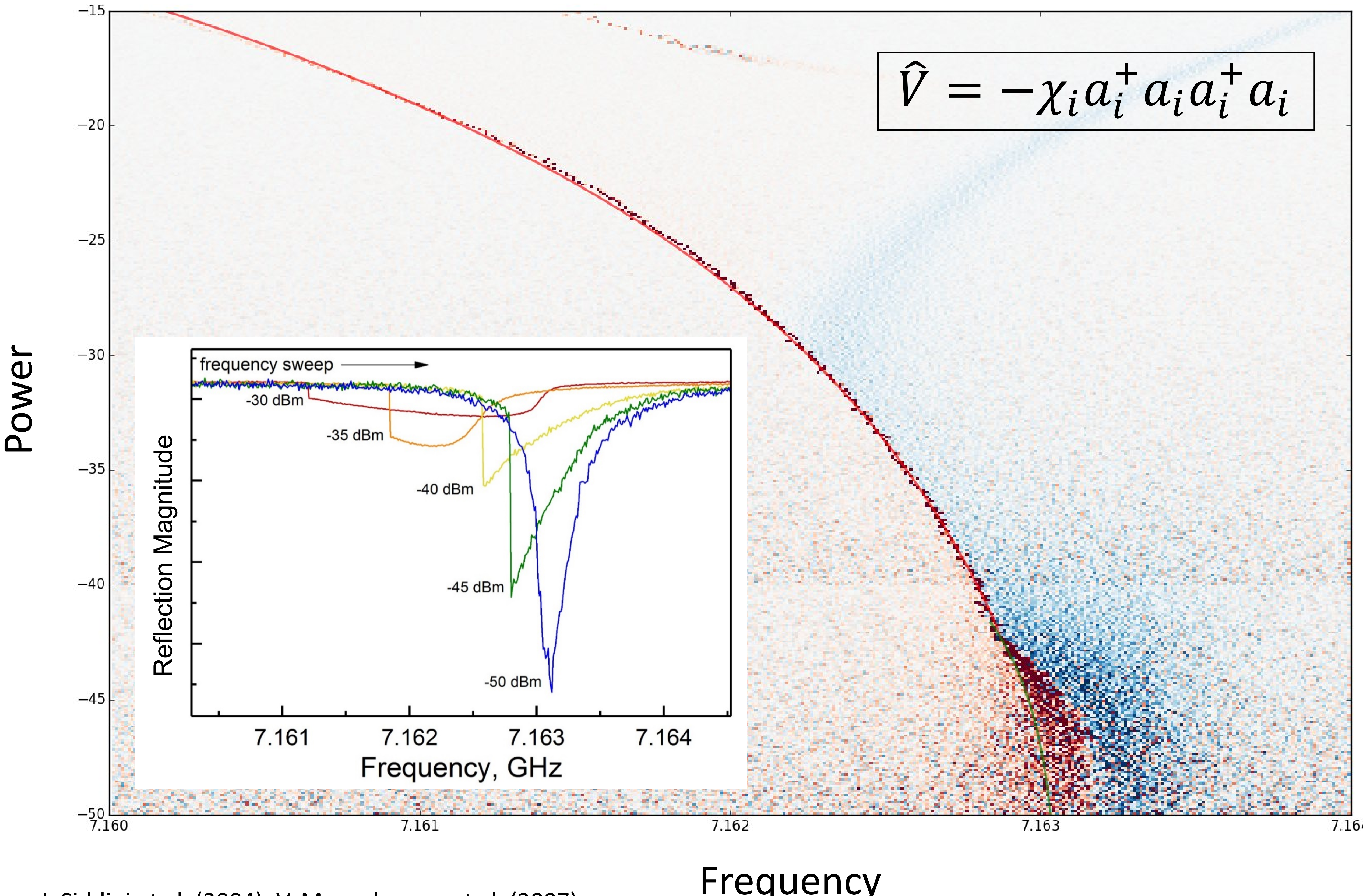


$$c \to c/150$$

$$\alpha \to \alpha \times 150$$

$$\alpha = \frac{1}{4\pi\varepsilon_0}\frac{e^2}{\hbar c} \approx \frac{1}{137}$$

Non-linear effects: Duffing bi-stability @ high power

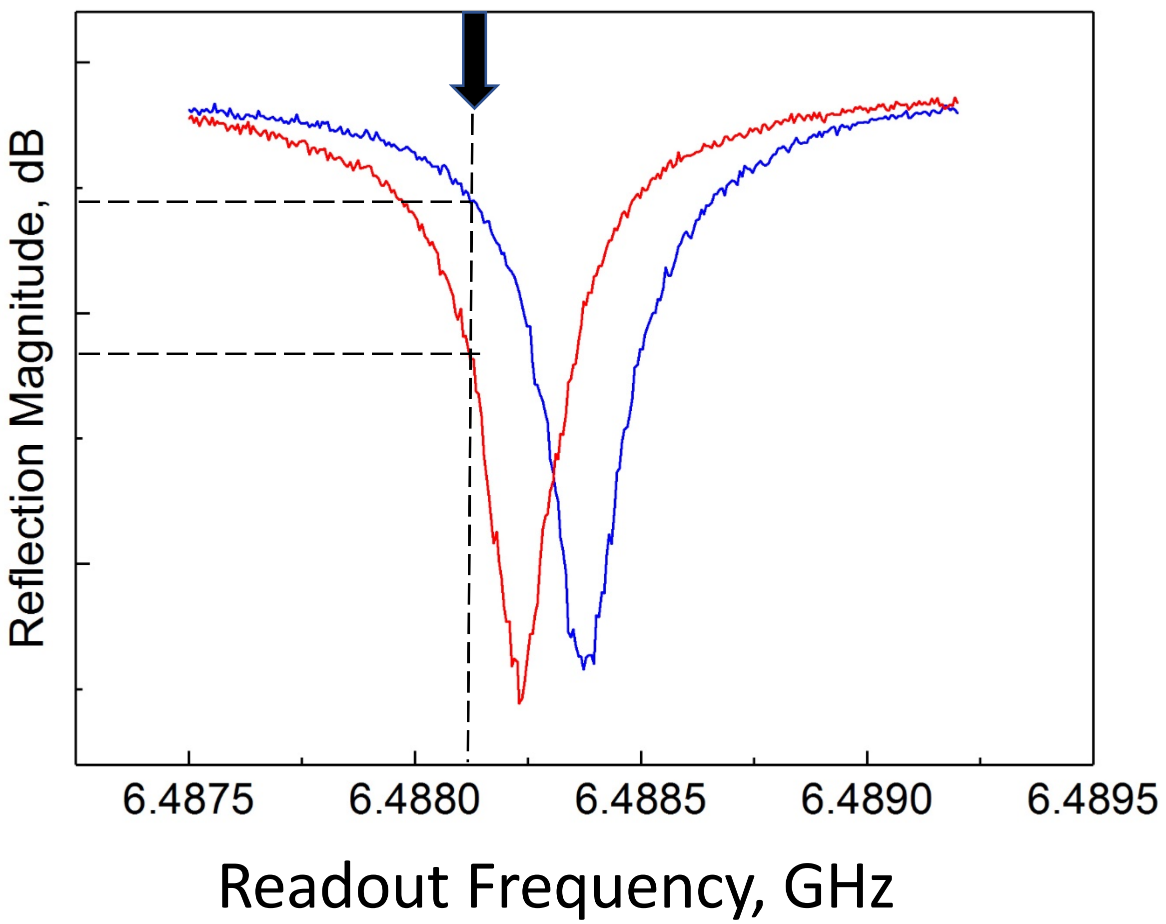


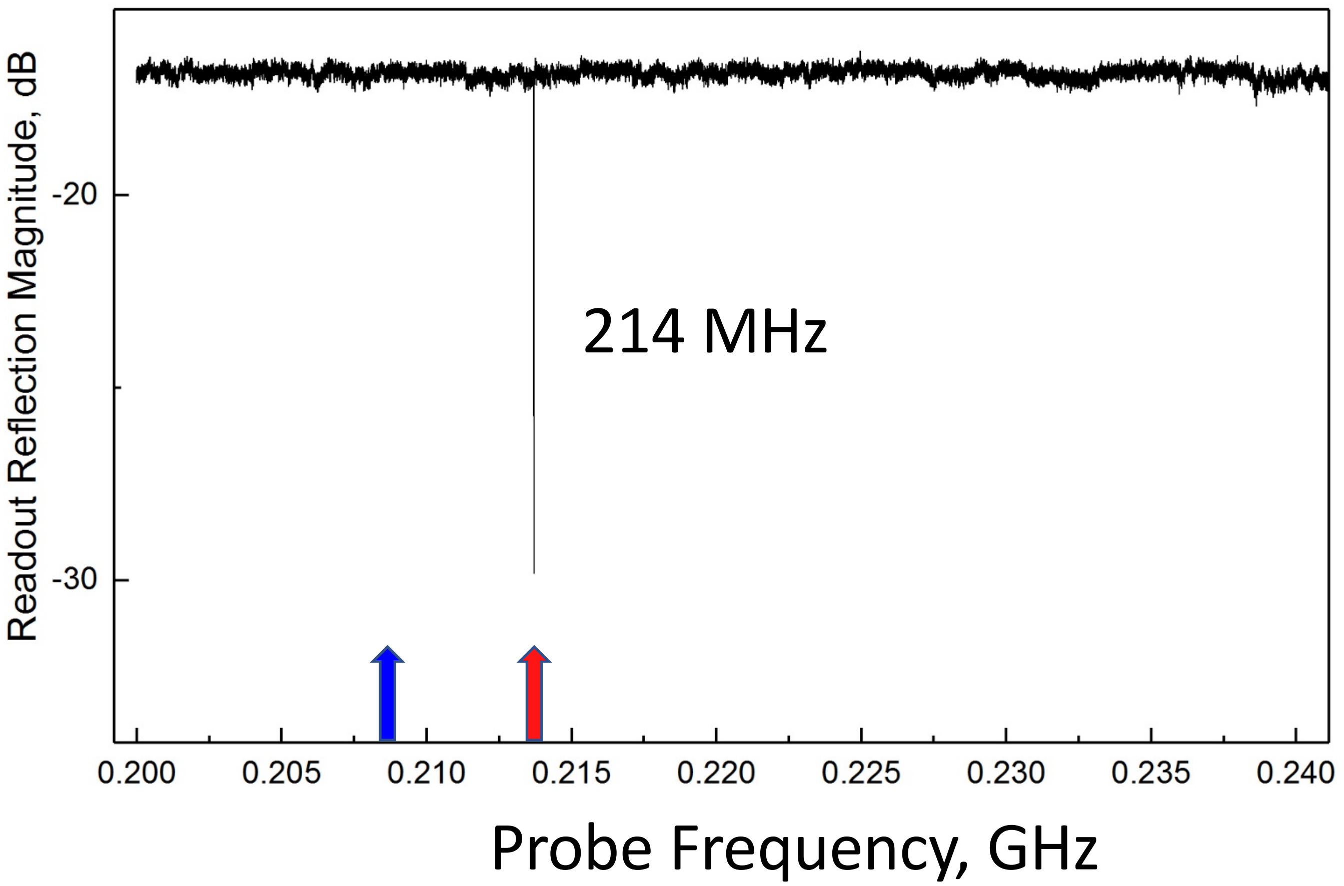
I. Siddiqi et al. (2004); V. Manucharyan et al. (2007);

Non-linear effects: dispersive mode interaction

$$\hat{V} = -\chi_{ij} a_i^+ a_i a_j^+ a_j$$

Choose this frequency for readout

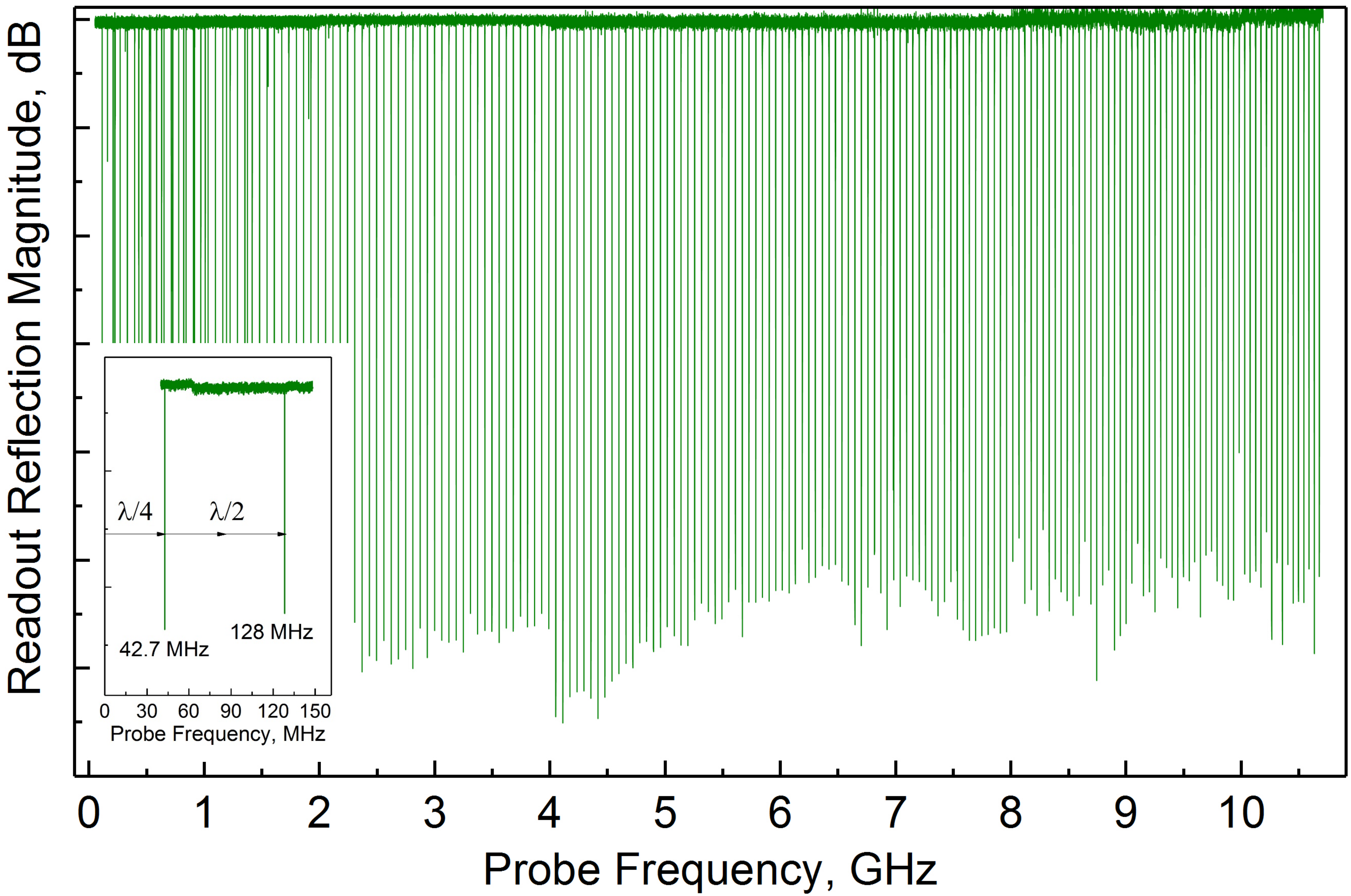




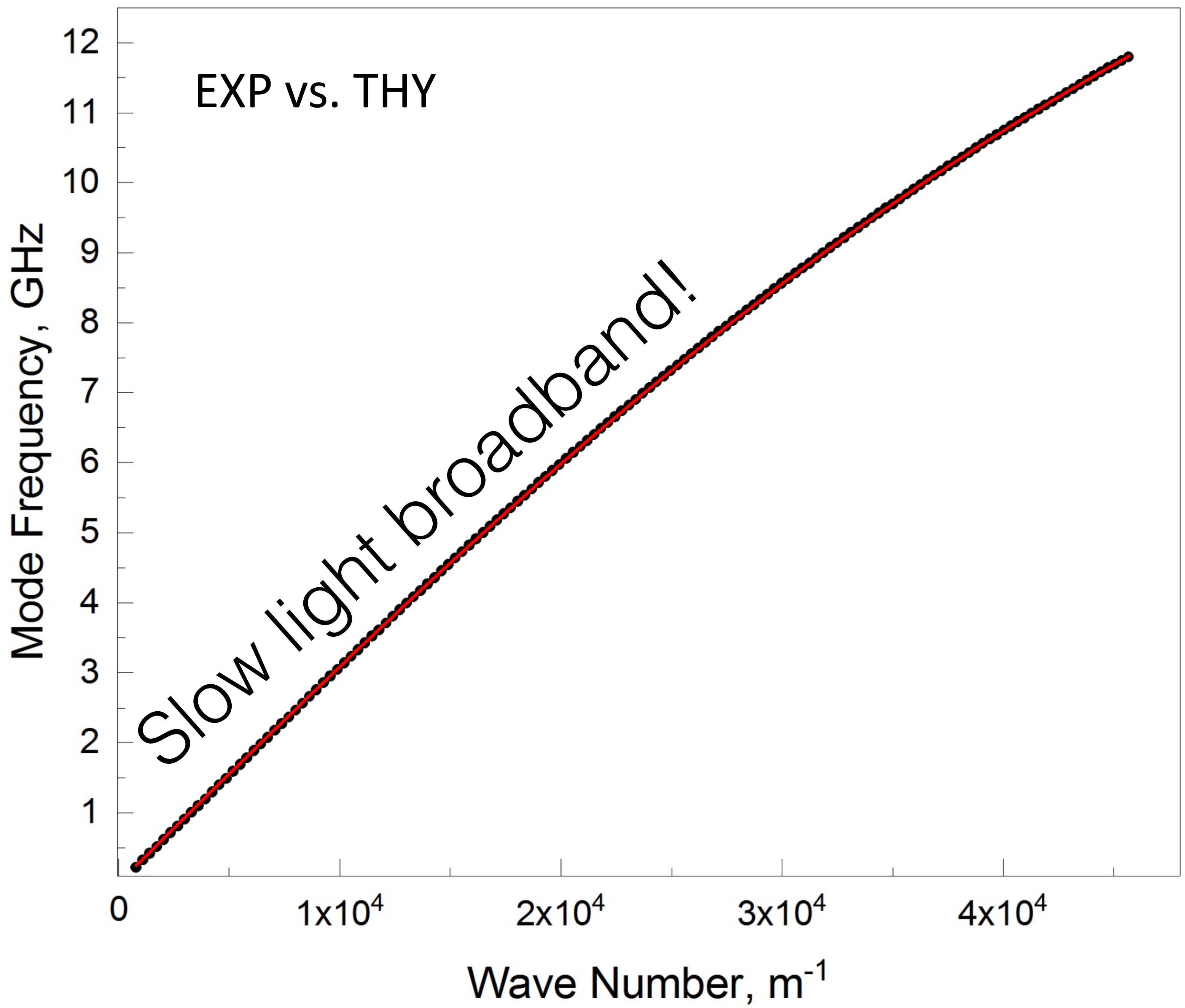
Detect modes outside the measurement band
by two-tone spectroscopy

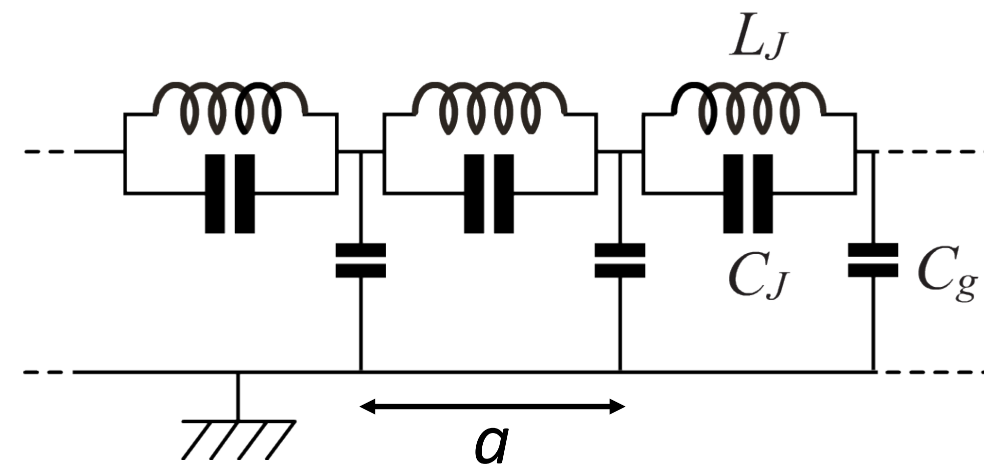
N. Masluk et al. (2012)

Many-body system of interacting photons



Dispersion relation: exp vs thy

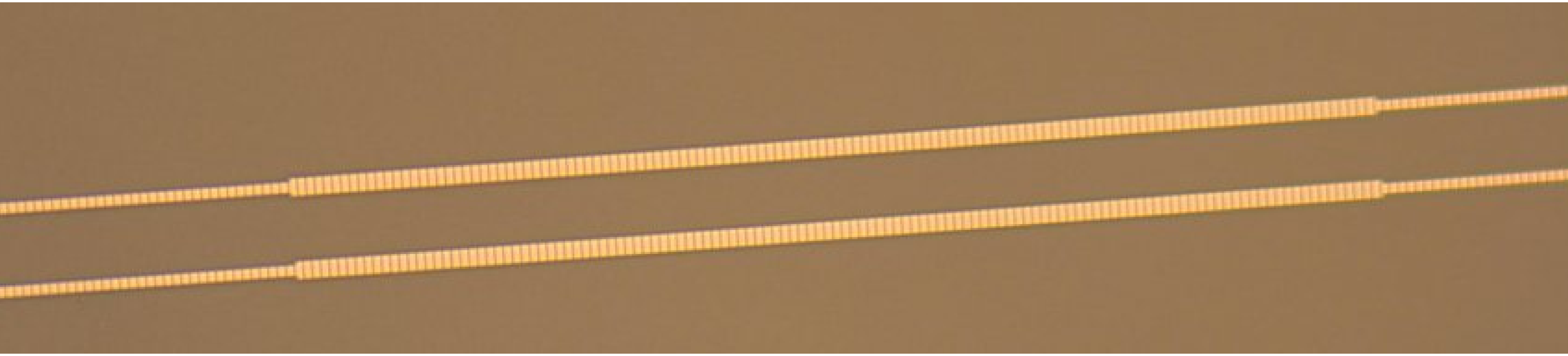


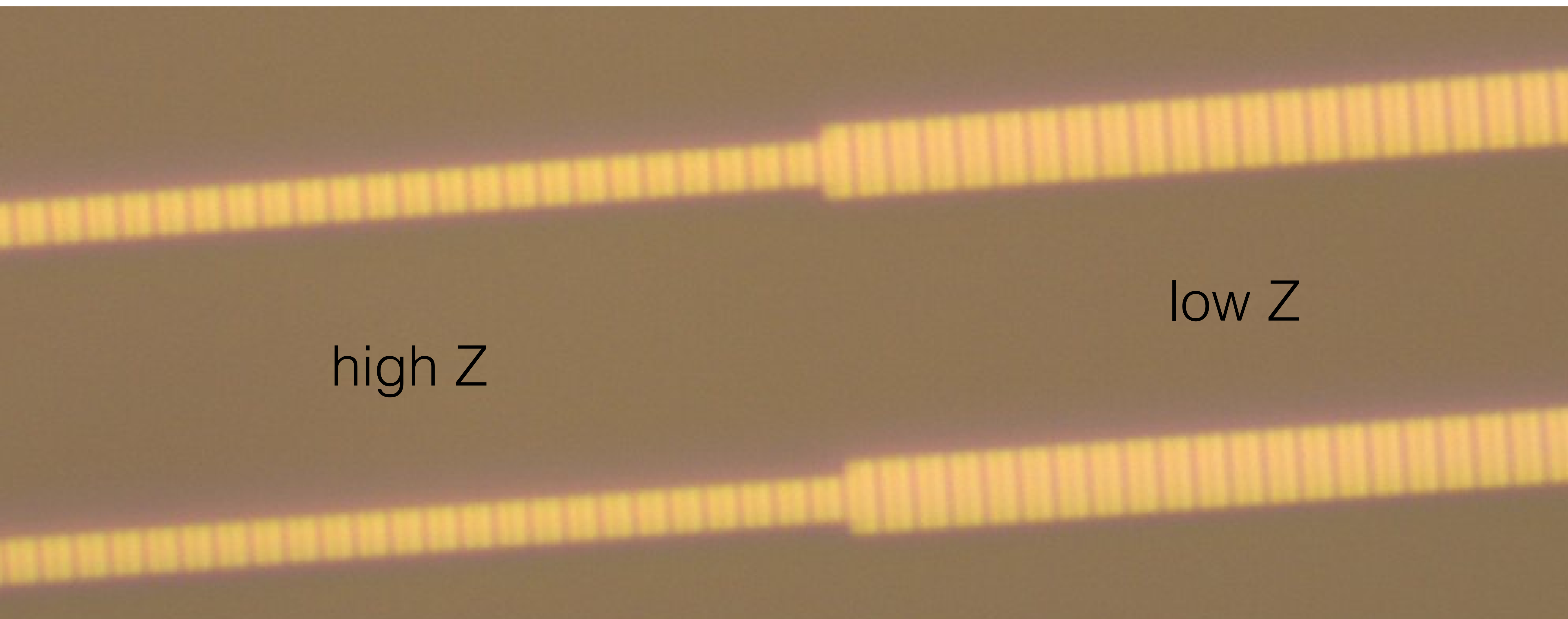


$$c = \frac{a}{\sqrt{L_J C_g}}, \quad \omega_p = \frac{1}{\sqrt{L_J C_J}}, Z = \sqrt{\frac{L_J}{C_g}}$$

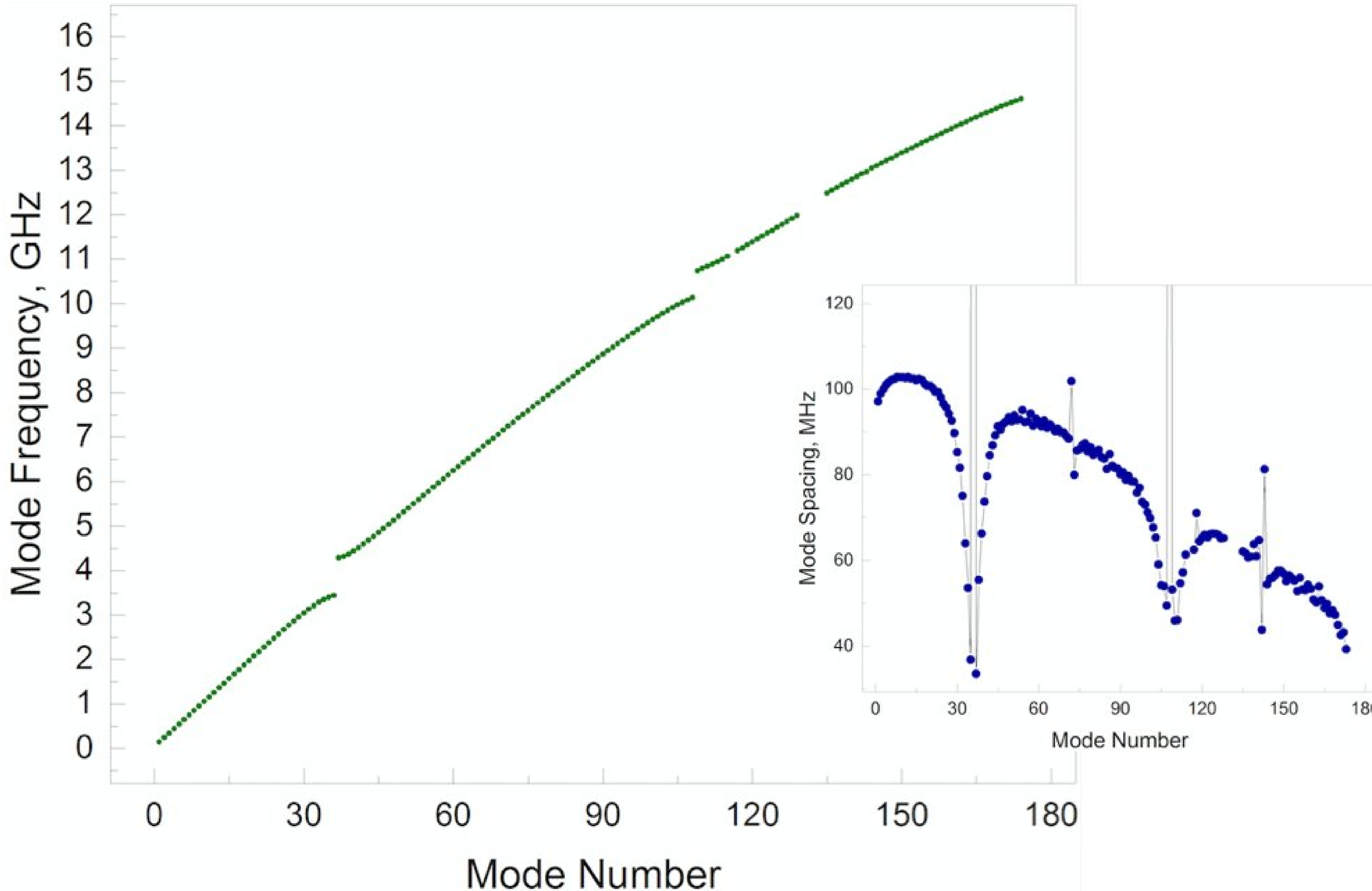
$$\omega(k) = \frac{ck}{\sqrt{1 + \left(\frac{ck}{\omega_p}\right)^2}}$$

(interacting) photonic crystal

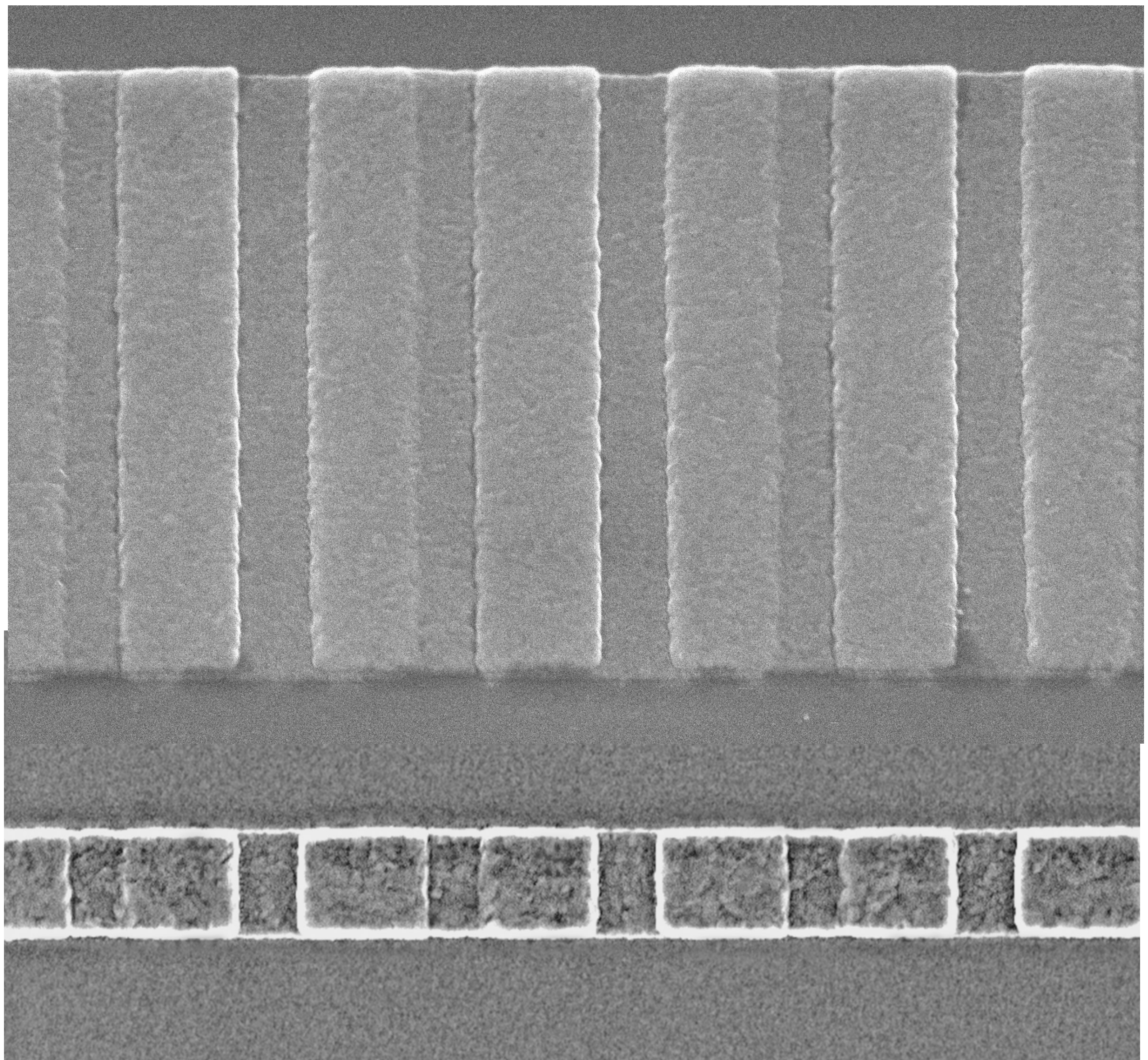




(interacting) photonic crystal



So,
how slow can the slow light be?
how high can the wave impedance be?

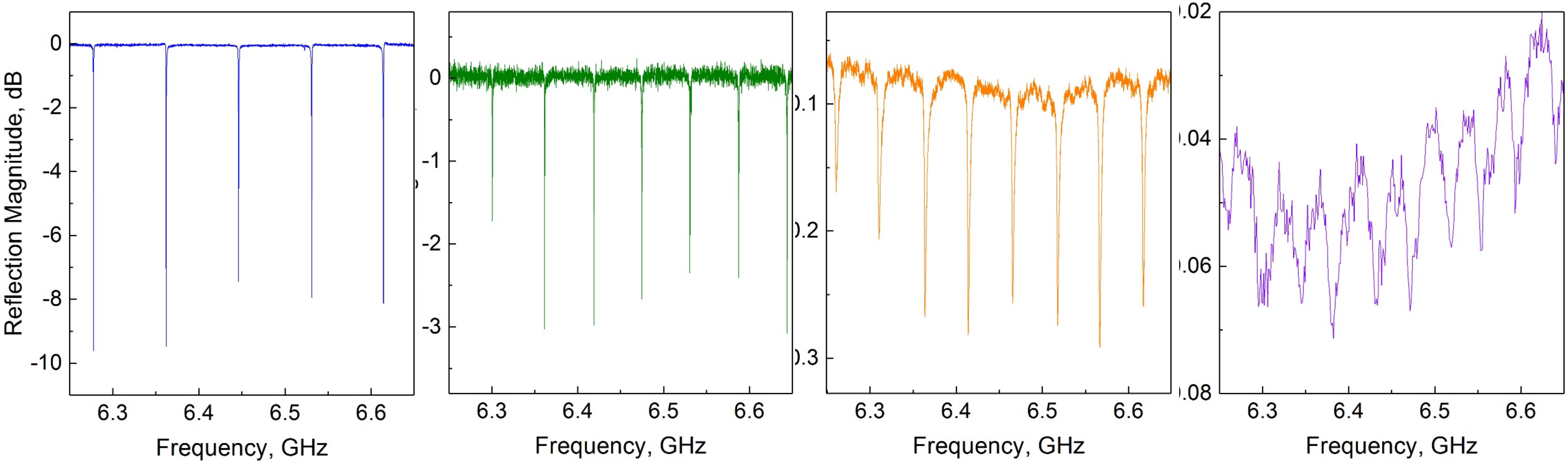


area ~ $(E_J/E_C)^{1/2}$

2 um

0.3 um

Raw data: this is how superconducting response is suppressed at a finite frequency



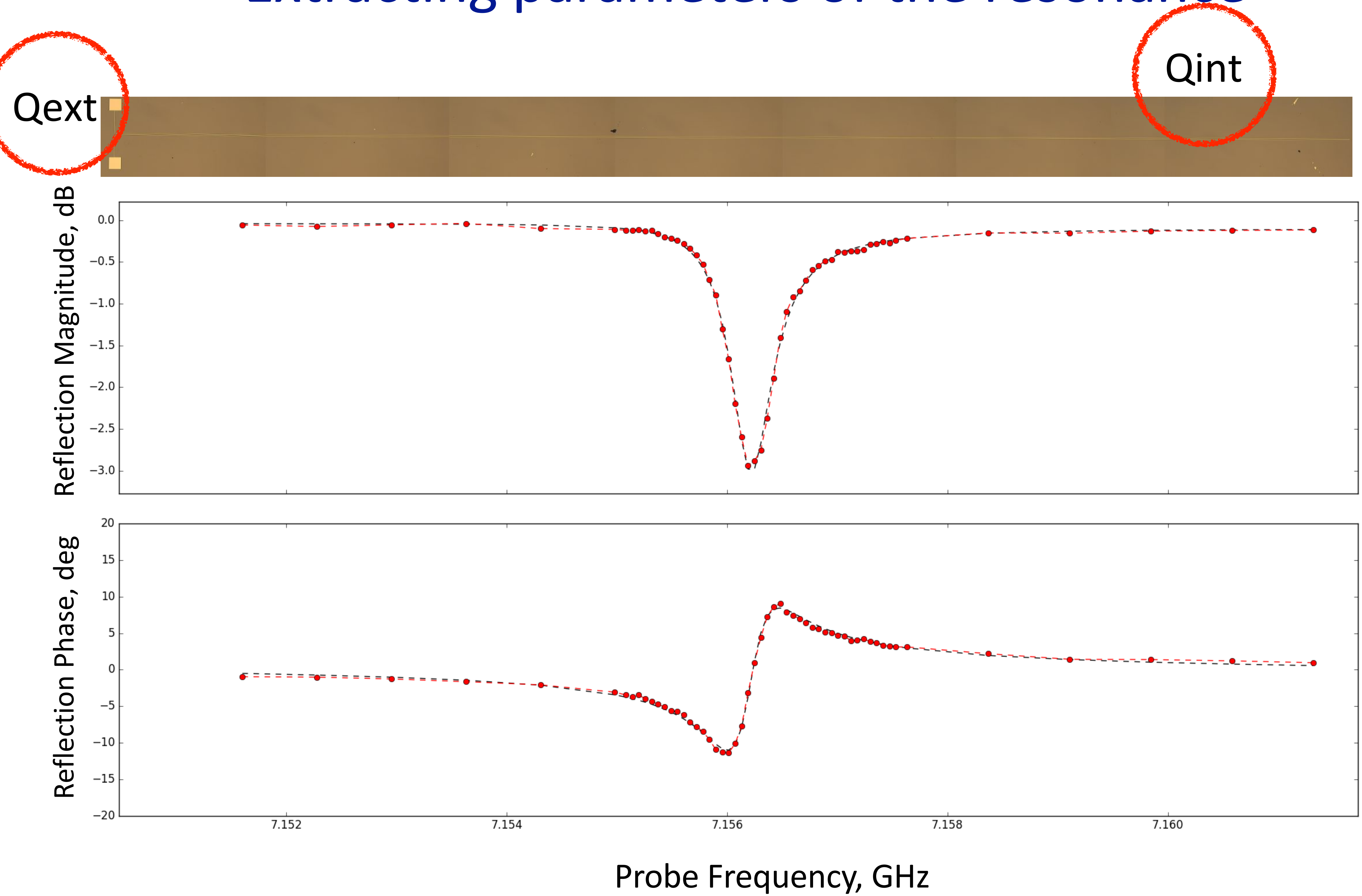
12.5 | 21.2 | 25.7 | ~30 | $Z, \mathrm{k\Omega}$

1.87 | 1.28 | 1.17 | < 1 | $c, 10^6 \frac{m}{sec}$

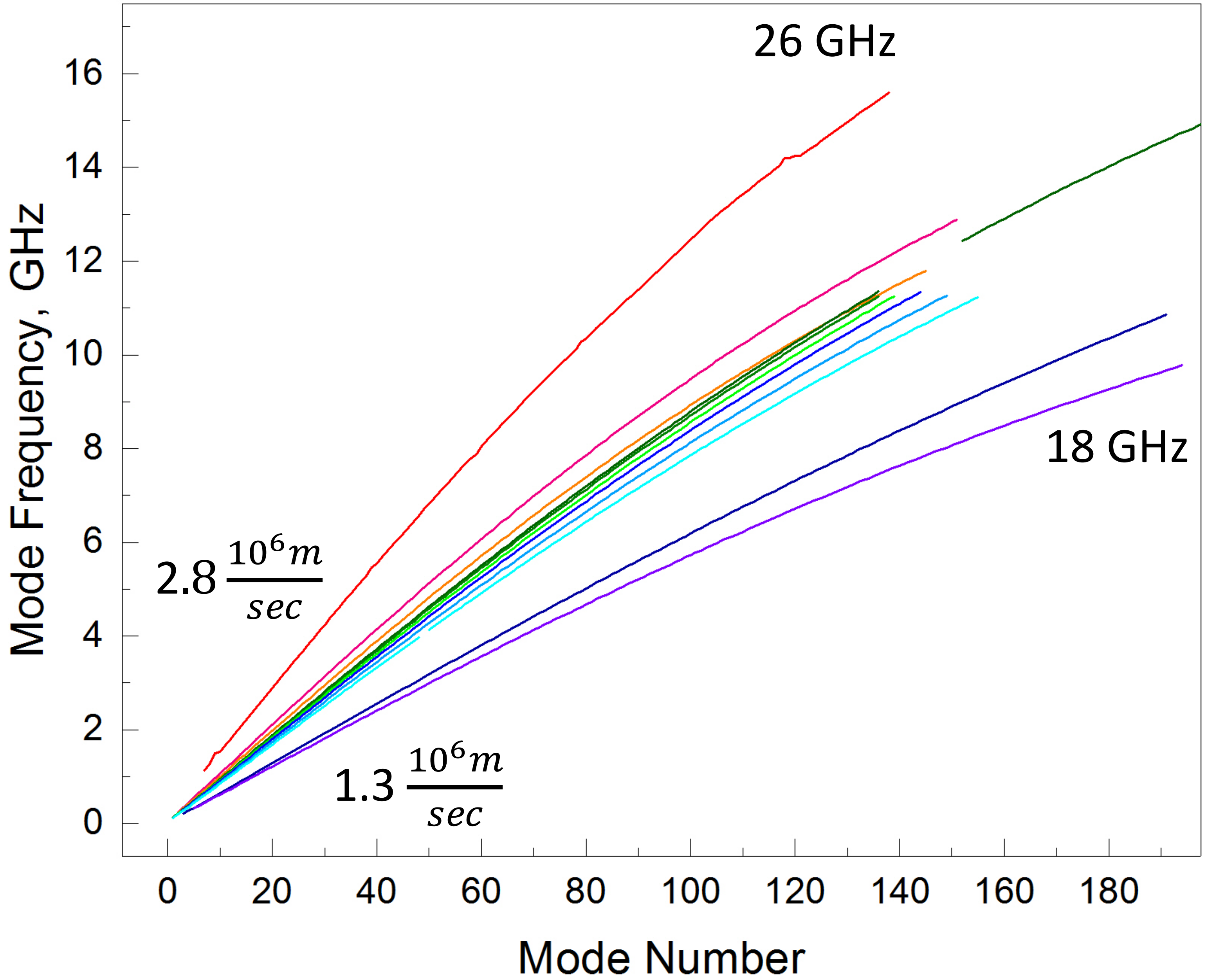
-Superconductivity persists at x10 larger impedance than theory predicts

-Something “damps” standing wave resonances

Extracting parameters of the resonance



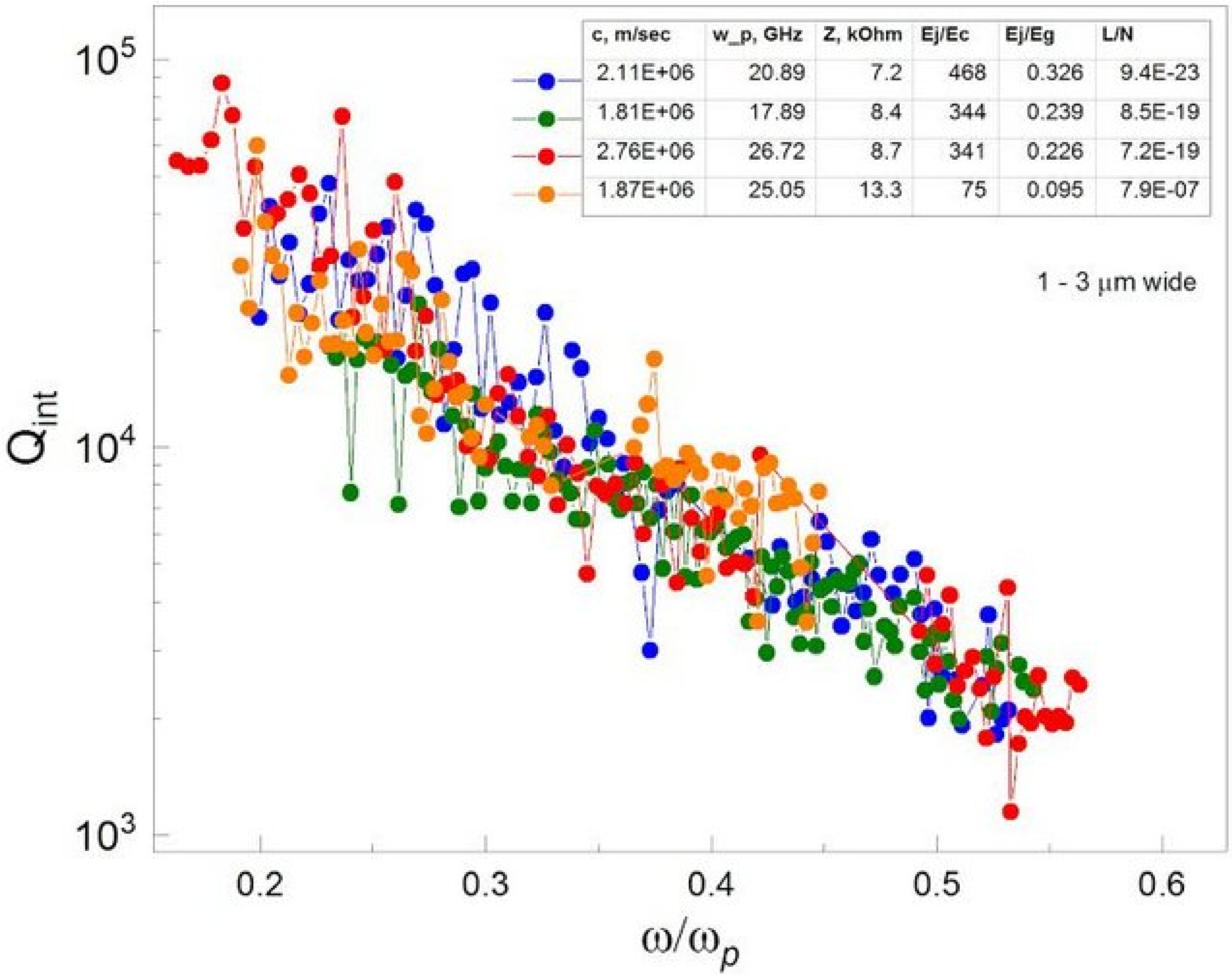
Tunable dispersion parameters



$c, \frac{m}{sec}$	$\frac{\omega_p}{2\pi}$, GHz	Z, $k\Omega$
$\mathbf{2.1 \cdot 10^6}$	21	6.8
$\mathbf{1.8 \cdot 10^6}$	18	7.9
$\mathbf{2.8 \cdot 10^6}$	26	8.1
$\mathbf{1.7 \cdot 10^6}$	23	13.8
$\mathbf{1.3 \cdot 10^6}$	24	21.2

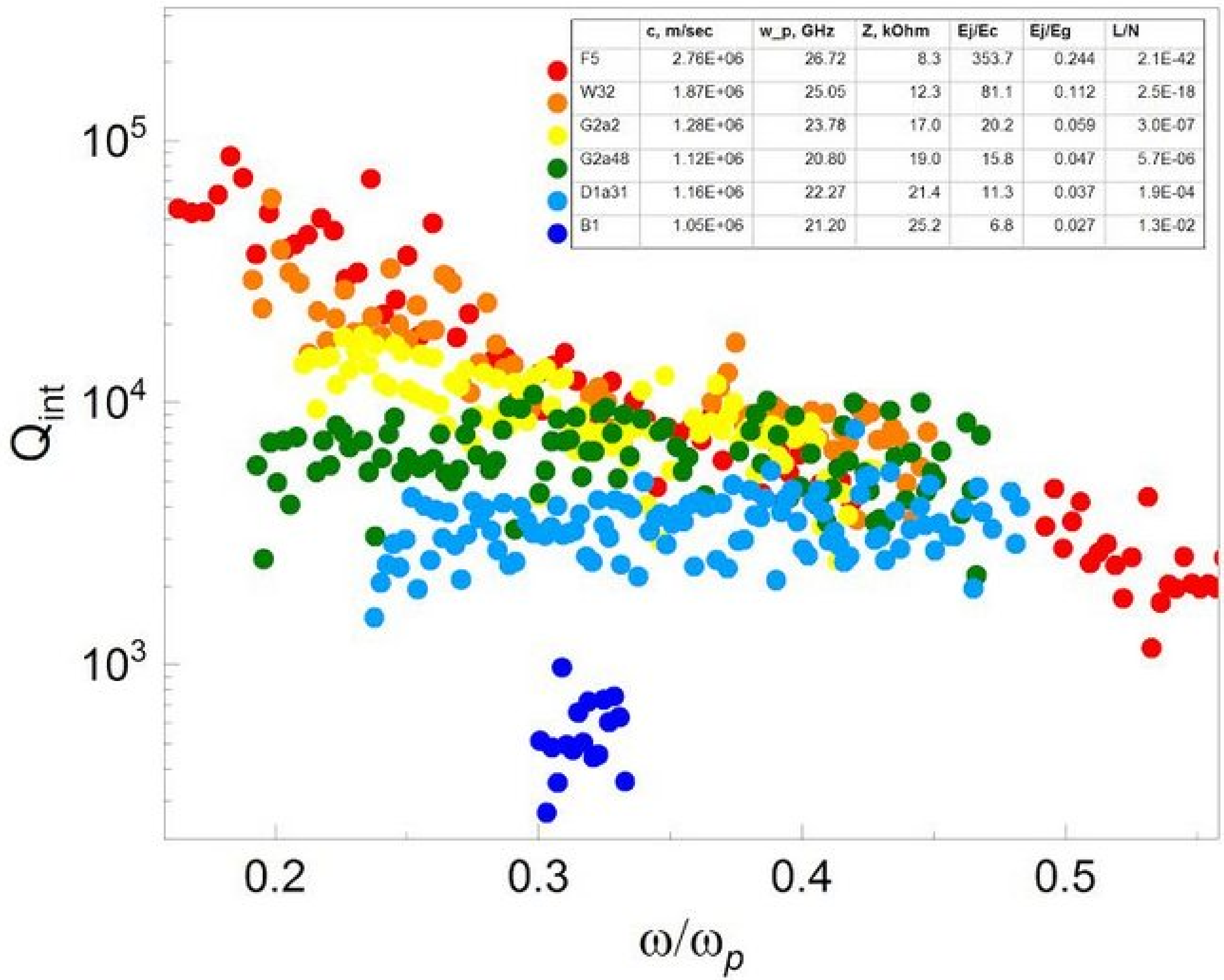
$R_Q = 6.5\ k\Omega$

Dissipation in chains for EJ/EC >>1



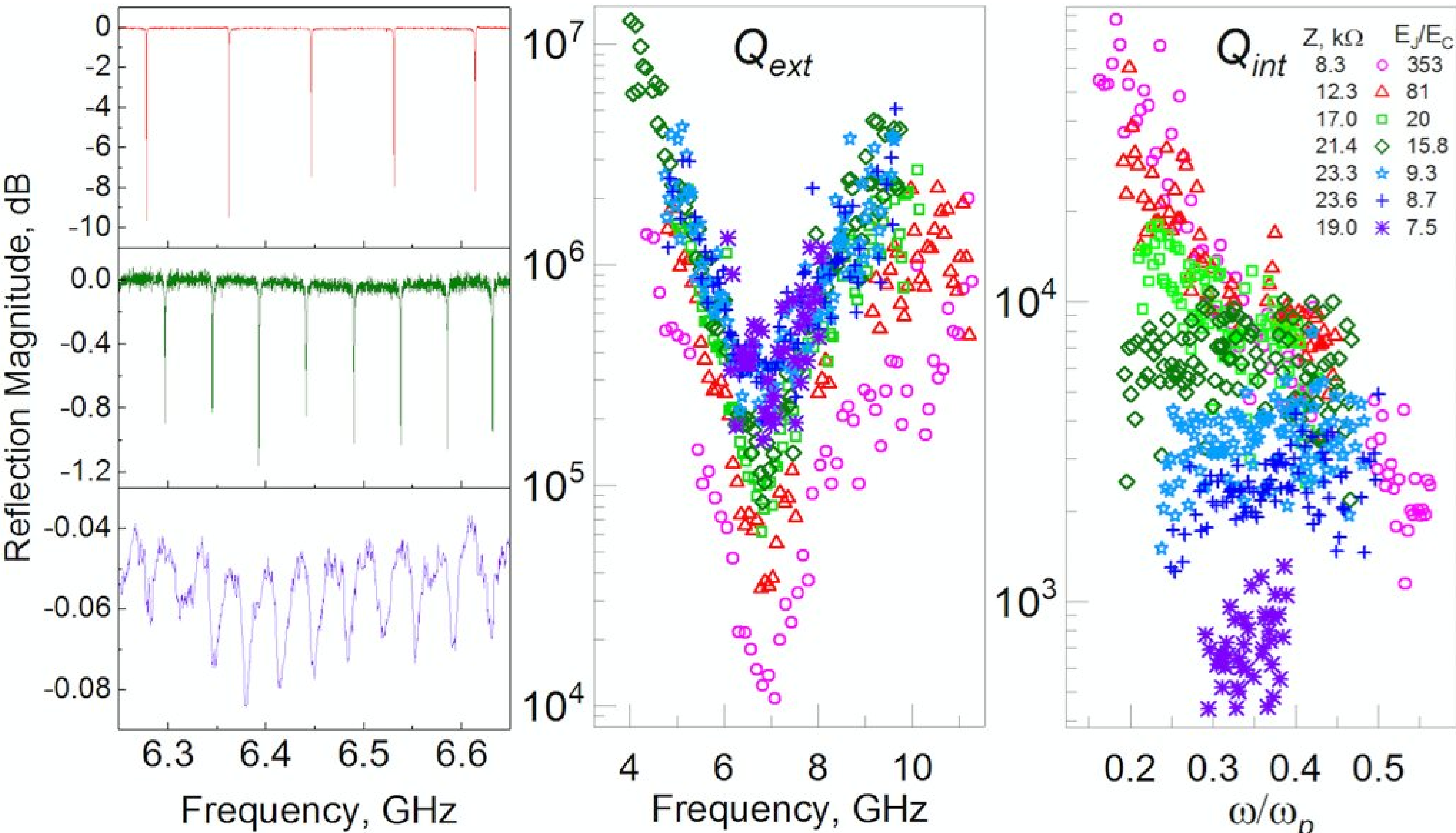
Losses in wide chains depend only on the plasma frequency.

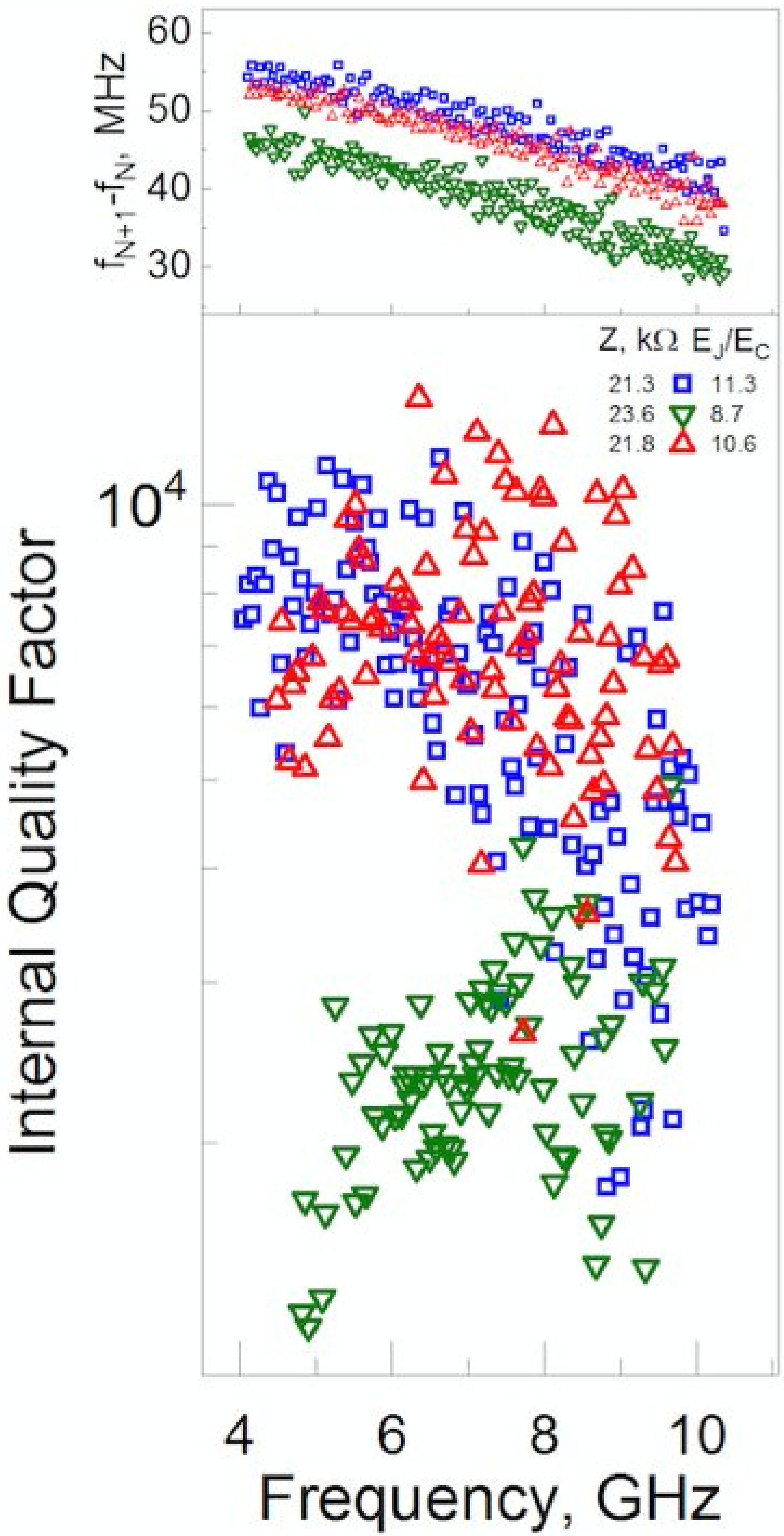
Dissipation drastically enhances for Ej/Ec < 20



Moreover, it appears that low frequencies are more damped than high frequencies at low Ej/Ec < 20. Is this how SIT looks at a finite frequency??

"SIT" at a finite frequency: summary

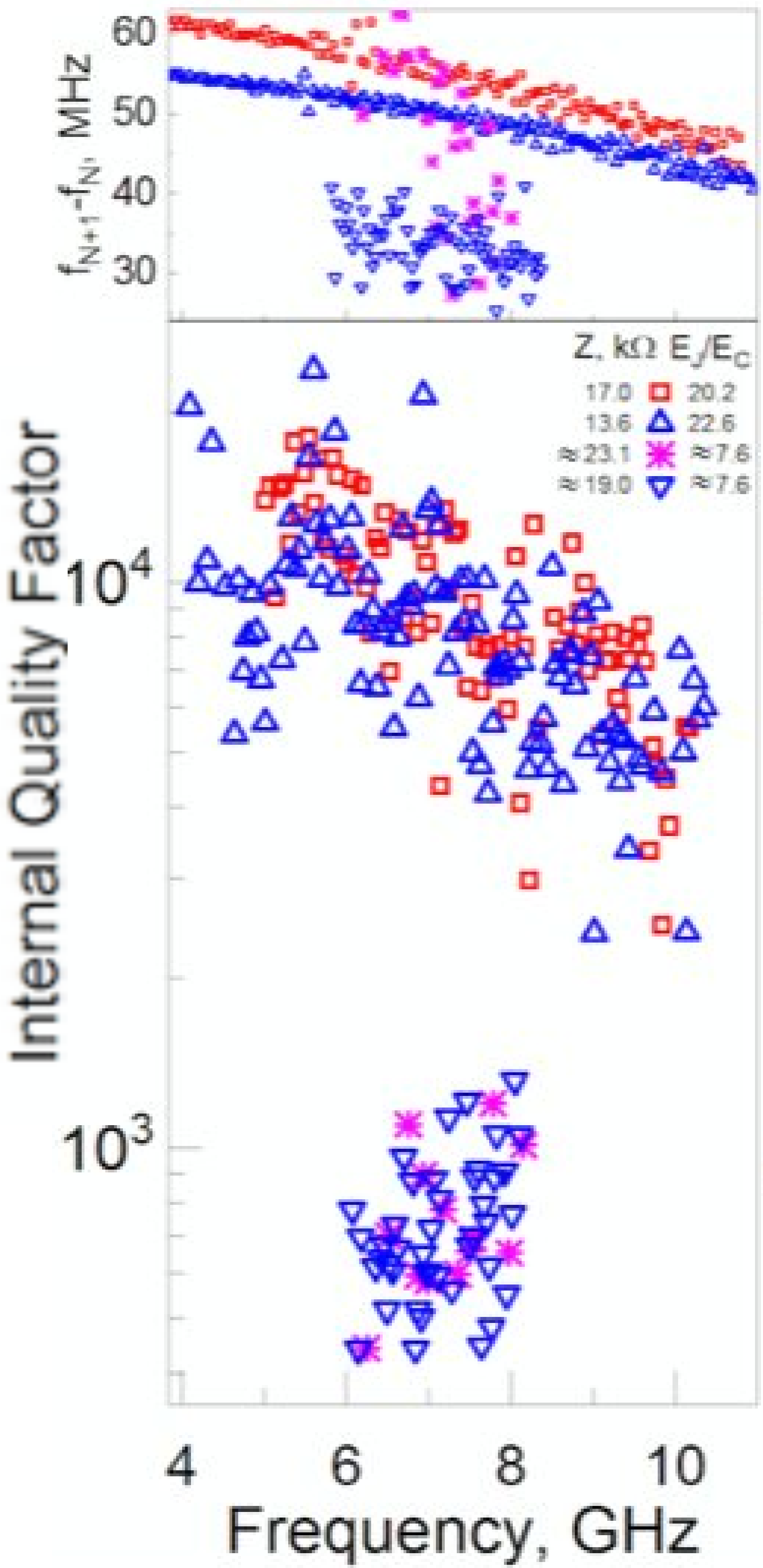




Aging test

Light velocity measures average Ej

“S” -> “I” -> “S”



Impedance test

Impedance is not
the control parameter for
“transition”

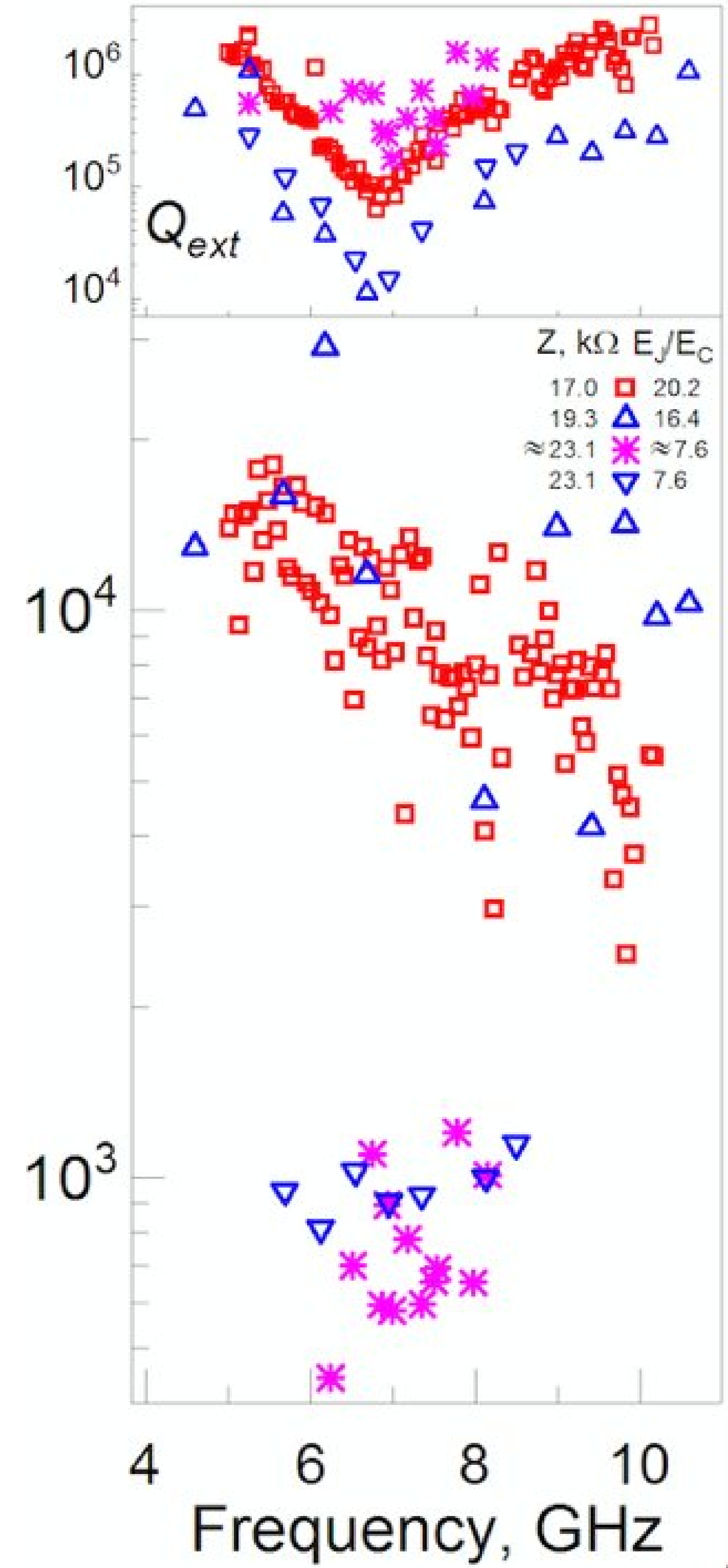
Length test

3000 junctions vs
30000 junctions

Sings of wave localization?

Decoherence is not affected!

Length test



Summary

Insulating phase superconducts @ finite frequencies!

Engineered artificial vacuum for 1D radiation:

Impedance > 24 kOhm
Speed of light < 7.5 x10^5 m/s
Fine structure constant ~ 1

Interaction of microwaves with phase-slips?

Next:

Quantum simulation of non-linear Luttinger liquids