Casimir Friction

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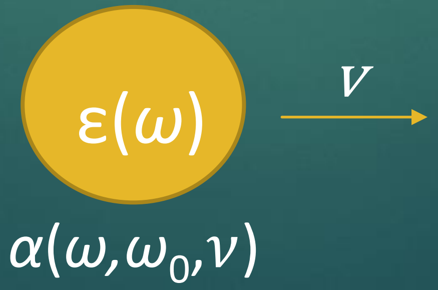
Background

- Short-range electromagnetic force
- Quantum interpretation involves dipole and field fluctuations
- Sign of the force can vary

Scenario

- Isotropic spherical particle moves through vacuum
- Particle is made of polarizable dielectric
- Constant velocity
- Force in direction of motion represents friction (if negative)
- Particle and background temperatures can be different



Polarizability Equation

- Lorentz oscillator model:
- $\alpha(\omega) = \frac{4\pi}{3} a^3 \frac{\omega_p^2}{\omega_1^2 - \omega^2 - i\omega\nu}$
  - a is radius, ω_p is plasma frequency, ν is damping parameter, ω_1 is shifted resonance frequency $\left(\omega_1 = \sqrt{\omega_0^2 + \frac{1}{3}\omega_p^2}\right)$
- $Im[\alpha(z)] = \frac{4\pi}{3} a^3 \frac{(\beta' \omega_p)^2 zy}{(x^2 - z^2)^2 - y^2 z^2}$
  - $x = \beta'\omega_1,\ y = \beta'\nu,\ z = \beta'\omega, r = \beta/\beta'$
  - β is inverse temperature of background, β' is inverse temperature of particle

Force Equation

- Force in direction of motion given by:
- $F = -\frac{1}{2\pi^2\gamma^2\beta'}\int_0^\infty dz\ z^4\ Im[\alpha(z)]\int_{-u_-}^{u_+} du\ u\ \left(\frac{1}{e^z-1} - \frac{1}{e^{rz(\frac{1}{\gamma}+Vu)}-1}\right)$
  - v is velocity, $\gamma = \frac{1}{\sqrt{1-V^2}}$
  - $u_+ = \sqrt{\frac{1+V}{1-V}},\quad u_- = \sqrt{\frac{1-V}{1+V}}$
- Overall factor of $-\frac{2a^3}{3\pi}\frac{\omega_p^2 y}{\gamma^2\beta'}$ neglected in results that follow

Method

- Numerical integration of force equation
- Interested in conditions that lead to sign change
- Fixed β' = 40 eV^{-1} for simplicity
- Looked at critical value of r for v = 0.1 and v = 0.9
- Looked at critical value of v for r = 0.1

Method

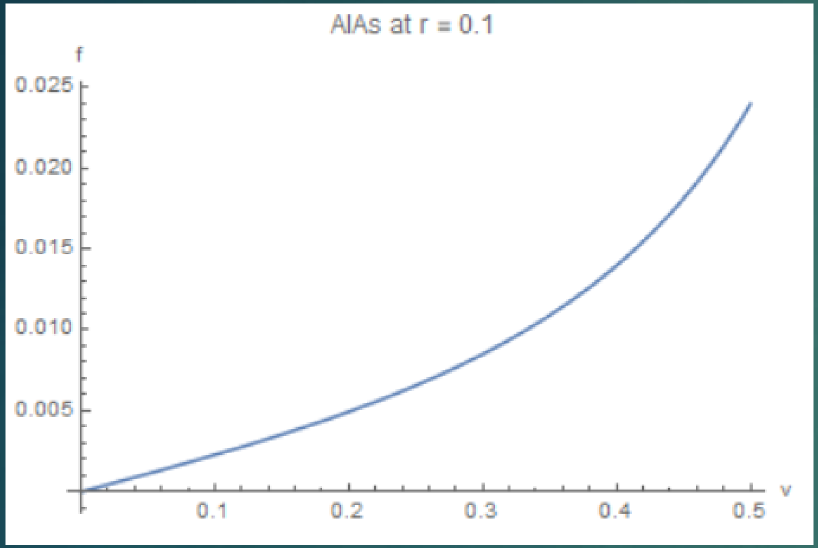
- Considered 17 different substances
- Many “typical” values, a few outliers

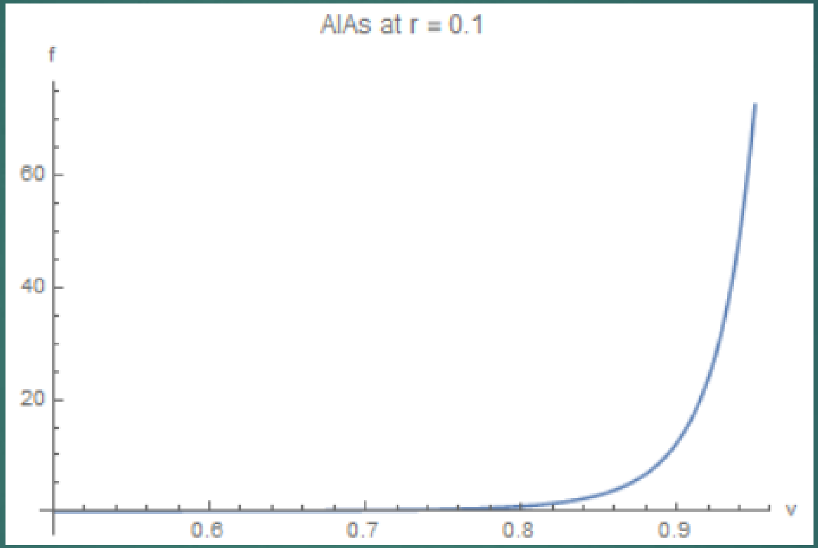
	y = 1-10	10-50	50-100	100-350
x = 0-100		1		
100-300	1	1	1	
300-500	1	3	2	1
500-700	2	1		
700-900		2		1

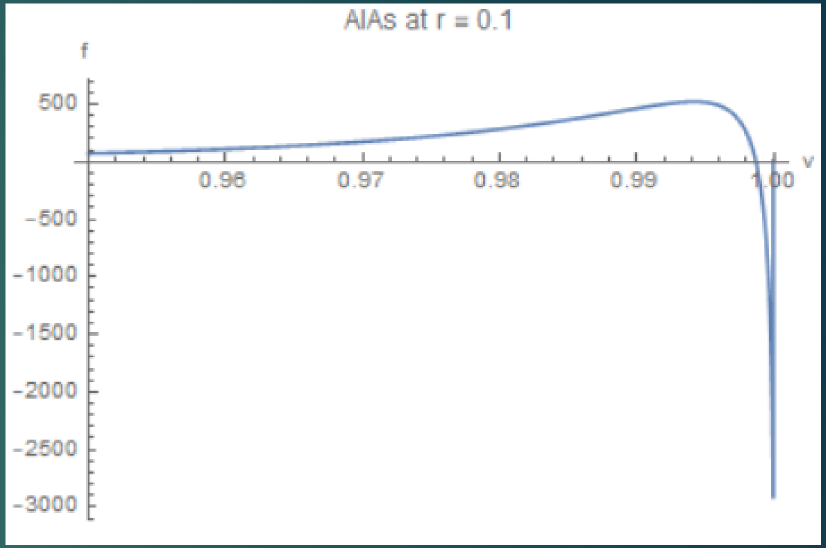
- Minimum x = 78.95, maximum x = 890.49
  - Minimum y = 4, maximum y = 336.64

Example: AlAs

- Force vs. velocity for $r = 0.1$:



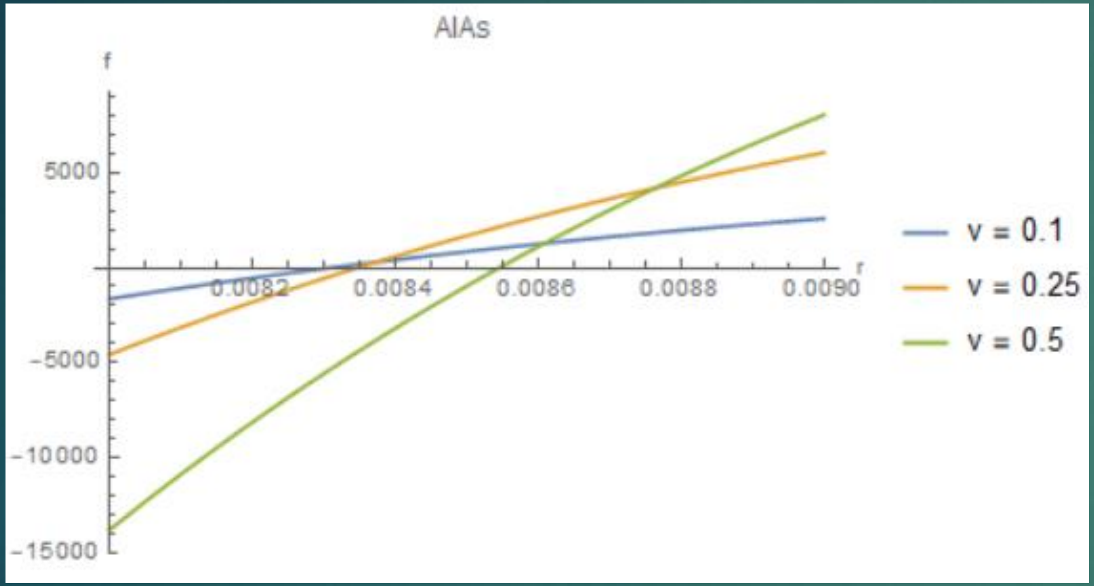


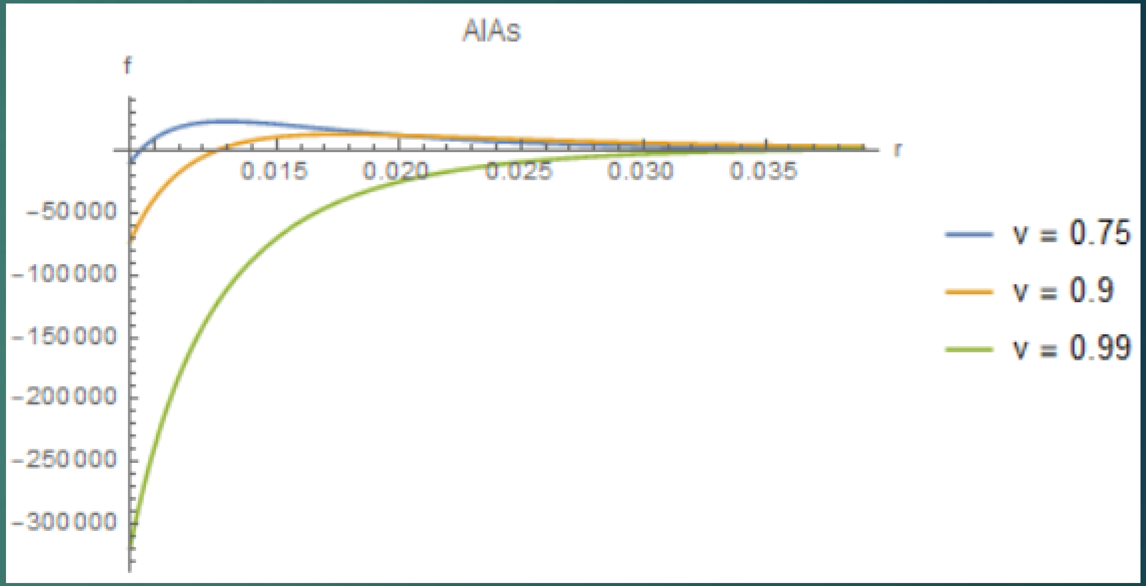


- Force is reduced by overall factor of $-2.04 \times 10^{-8}\,\gamma^{-2}$
- x = 334.45, y = 15.12
- Peak at 520.917 for v = 0.994204
- Negative at ultra-relativistic velocities, v > 0.998697

AlAs

- Force near critical value of r for various v:

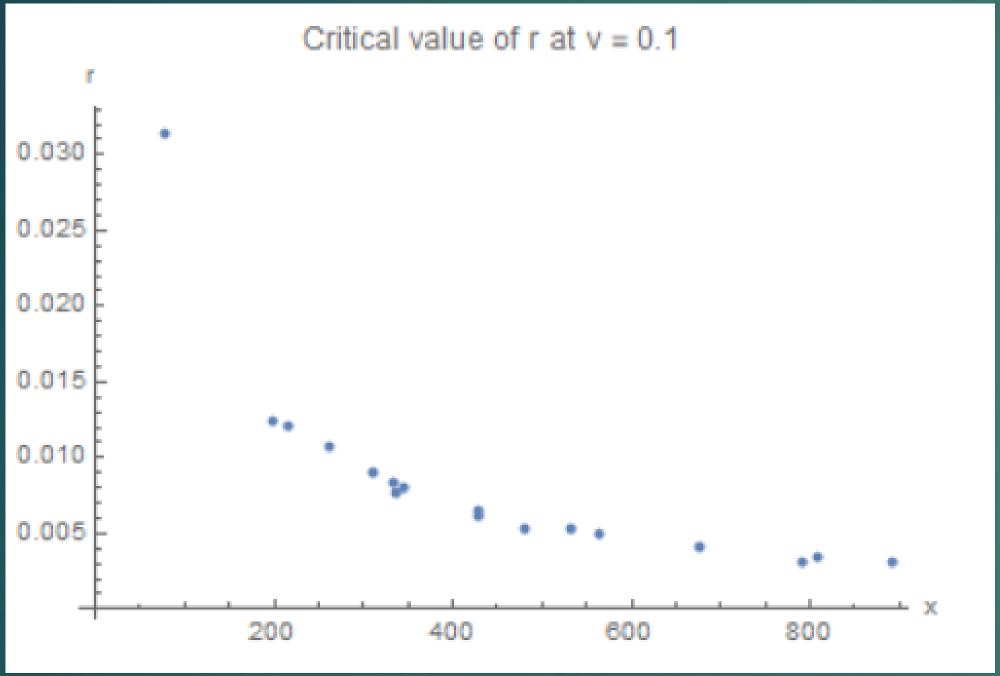


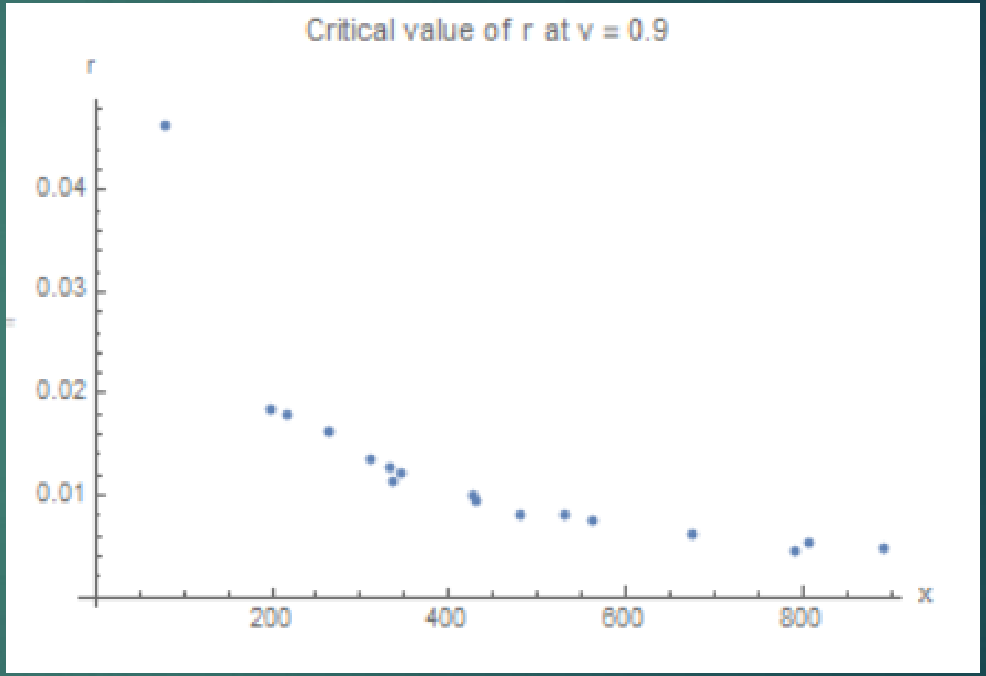


- Critical value of r increases with velocity
- Increases faster at higher velocities

Results

- Critical value of r vs. x at fixed v

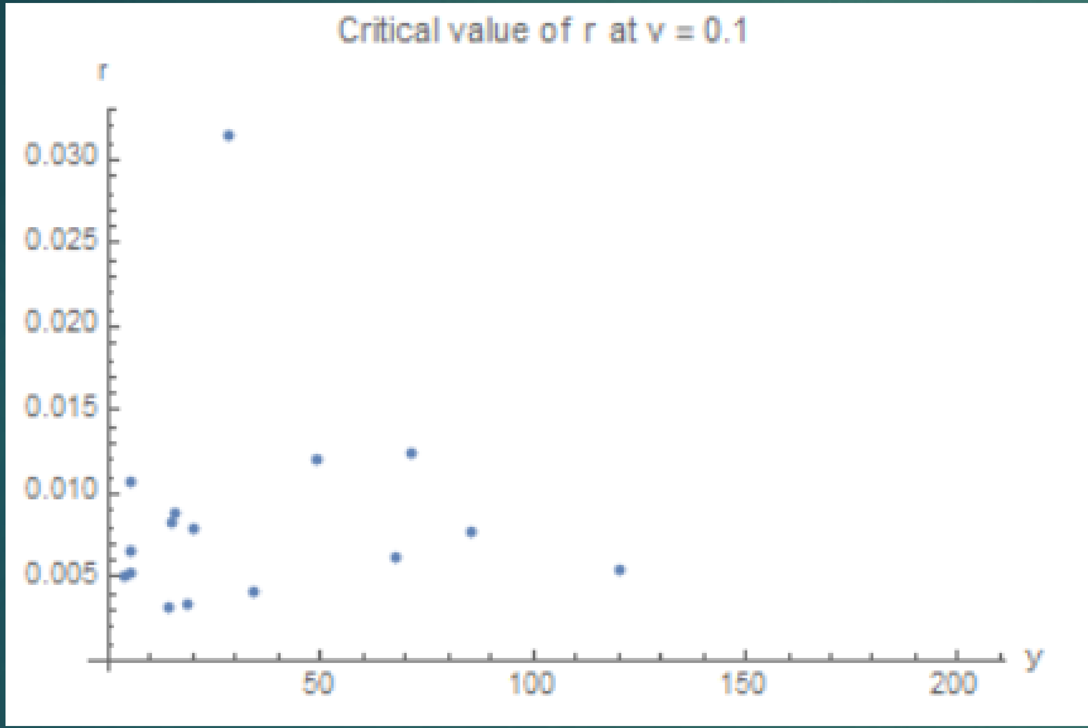


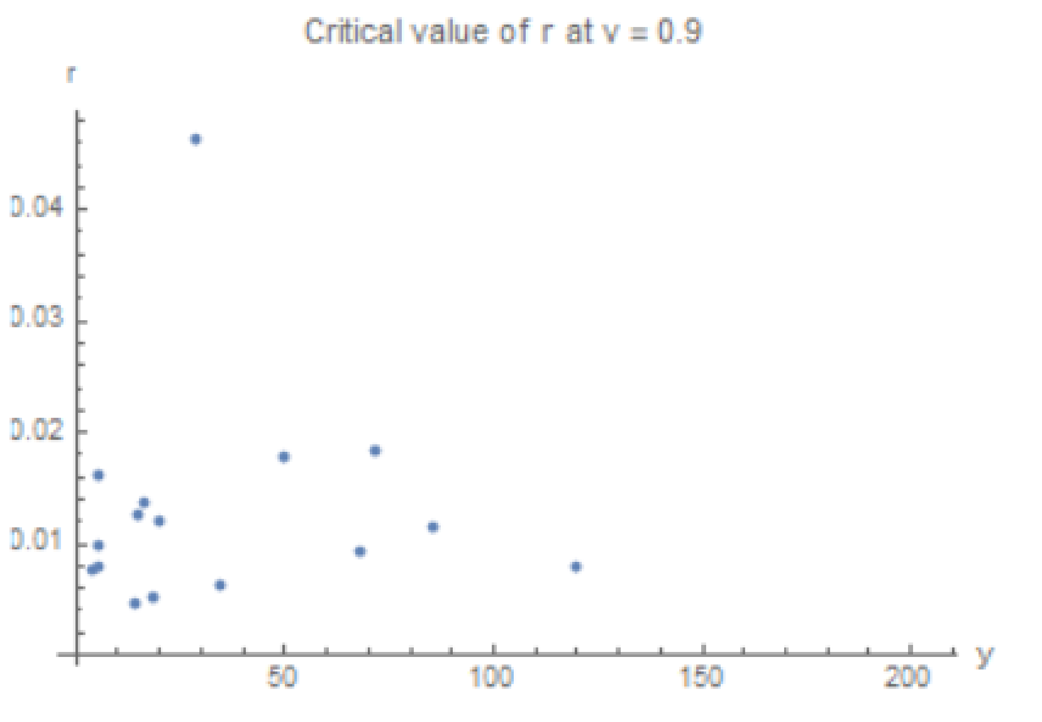


- Critical value of r increases with decrease in x

Results

- Critical value of r vs. y at fixed v

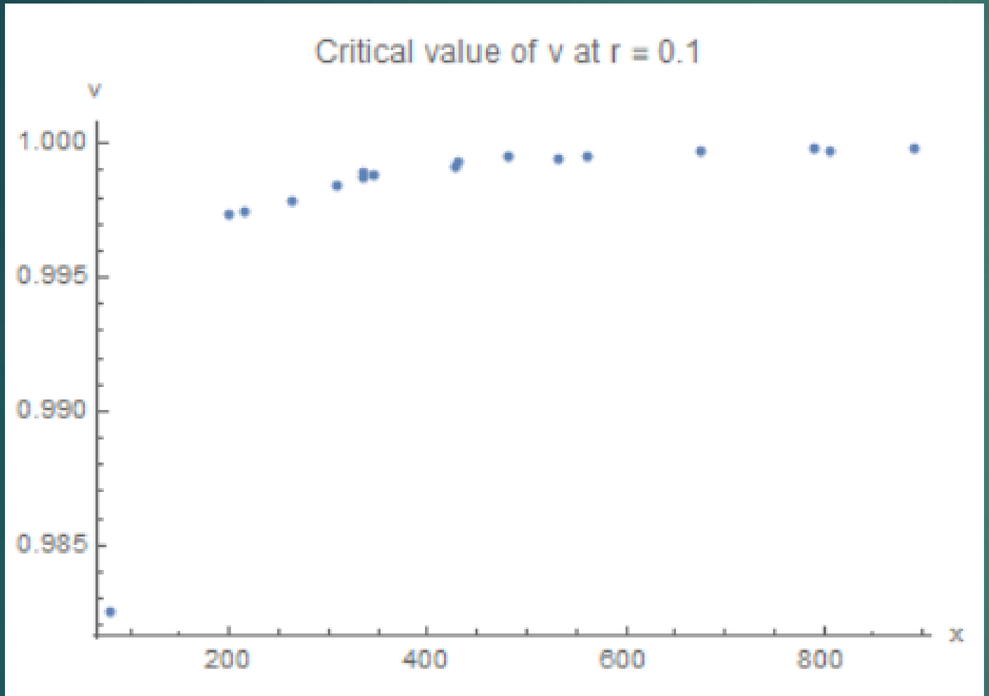




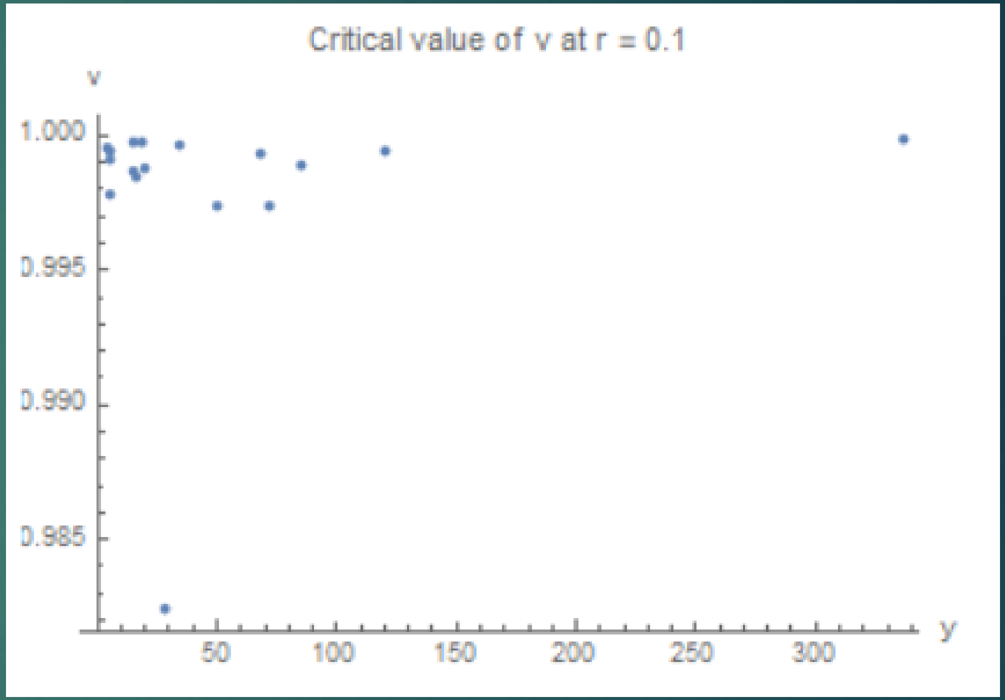
- Critical value of r not well-correlated with y

Results

- Critical value of v vs. x at $r = 0.1$



Critical value of v vs. y at $r = 0.1$



- Critical value of v increases slightly with x
- Not well-correlated with y

Conclusion

- Force typically changes sign at high v and/or low r (environment hotter than particle)
- Critical values appear to be more strongly dependent on x than y
- Critical values are less extreme at low x (low resonance frequency and/or high particle temperature)

Acknowledgments/References

- **Acknowledgments**
- Dr. Milton and his group
- Dr. Abbott and Dr. Strauss

- **References**

- K. A. Milton, H. Day, Y. Li, X. Guo, G. Kennedy, "Self-force on moving electric and magnetic dipoles: dipole radiation, Vavilov-Čerenkov radiation, friction with a conducting surface, and the Einstein-Hopf effect" (2020) [arxiv:2006.15375 [hep-th]].
- Horiba, Ltd., "Lorentz Dispersion Model," TN08 (2006).

Questions?