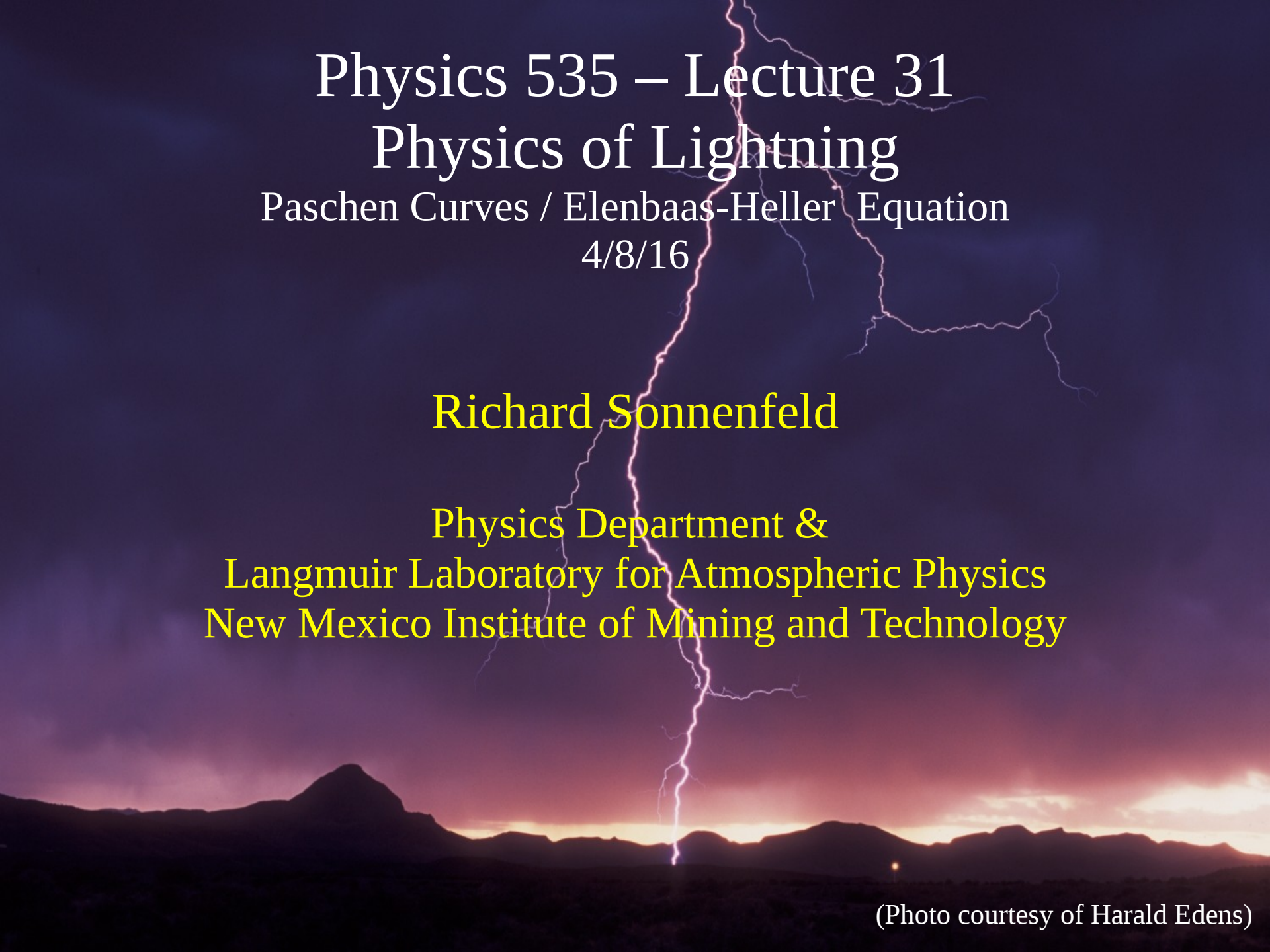
Physics 535 – Lecture 31
Physics of Lightning

Paschen Curves / Elenbaas-Heller Equation

4/8/16

Richard Sonnenfeld

Physics Department &
Langmuir Laboratory for Atmospheric Physics
New Mexico Institute of Mining and Technology



(Photo courtesy of Harald Edens)

Paschen Curves

Show dependence of breakdown voltage on gap and pressure.
Can be used for a spark, even where gap is not well defined.

Elenbaas-Heller Equation

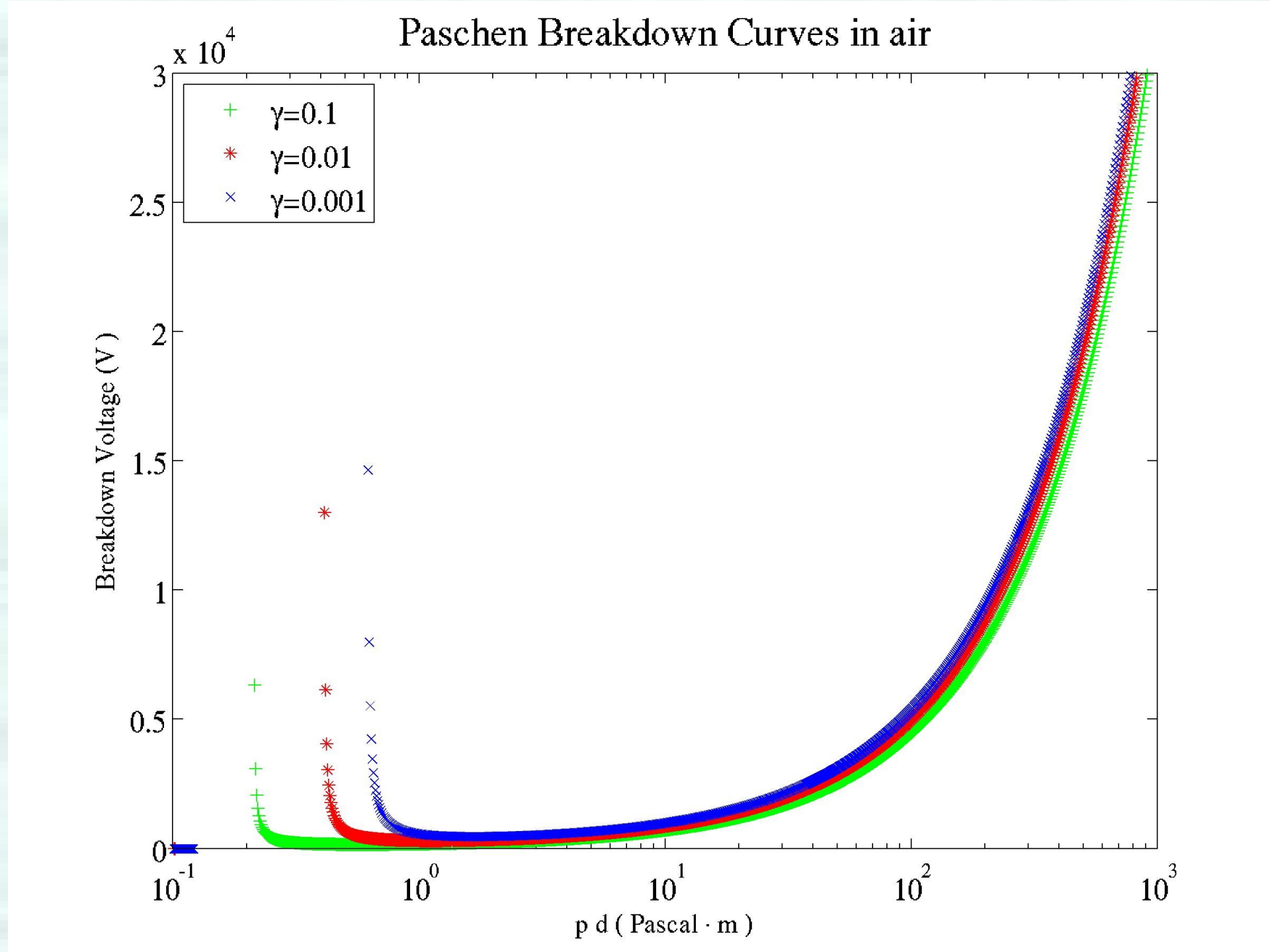
Equation for heat flow in cylindrical coordinates, assuming Joule heating.

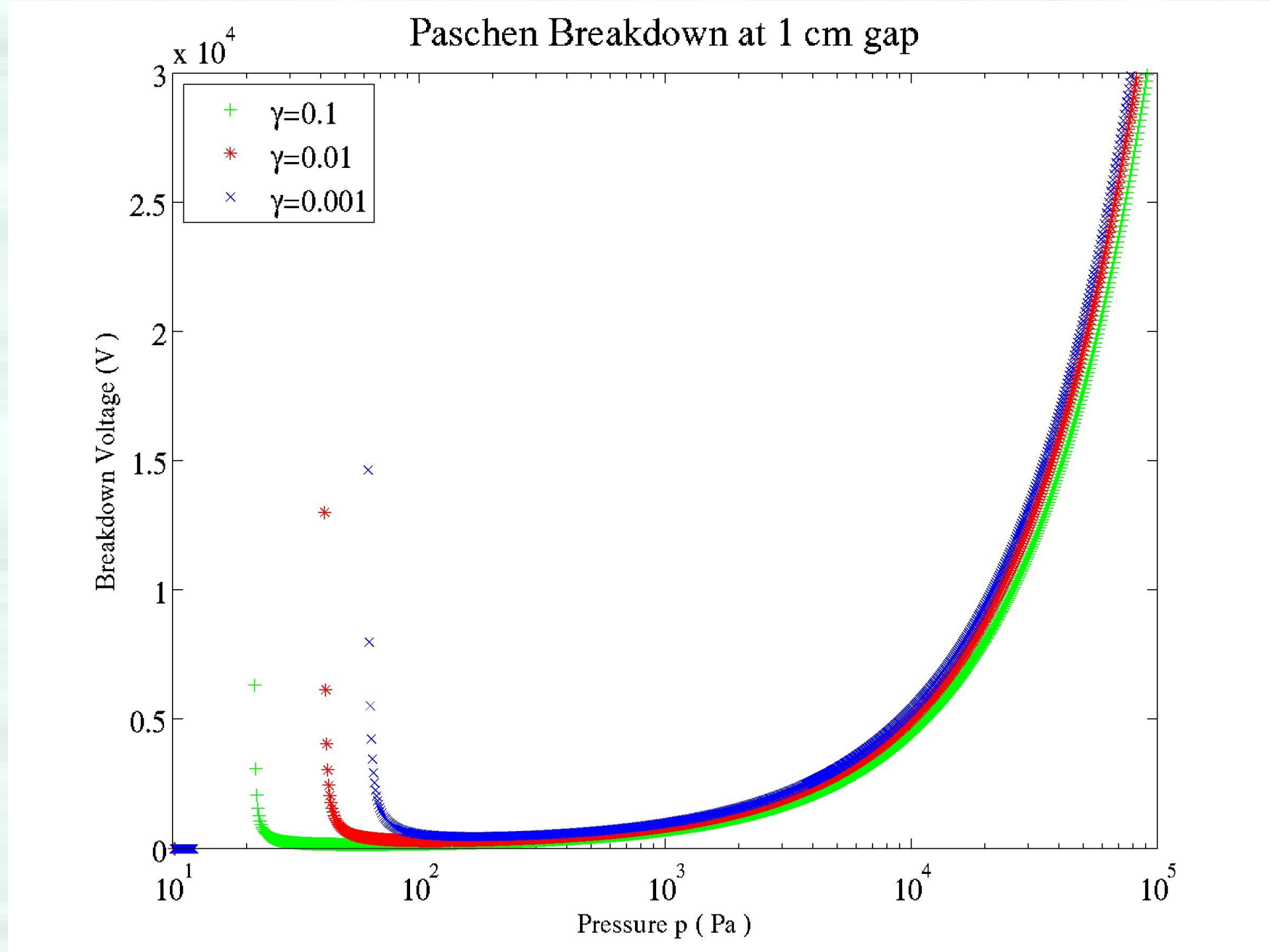
Paschen Curves

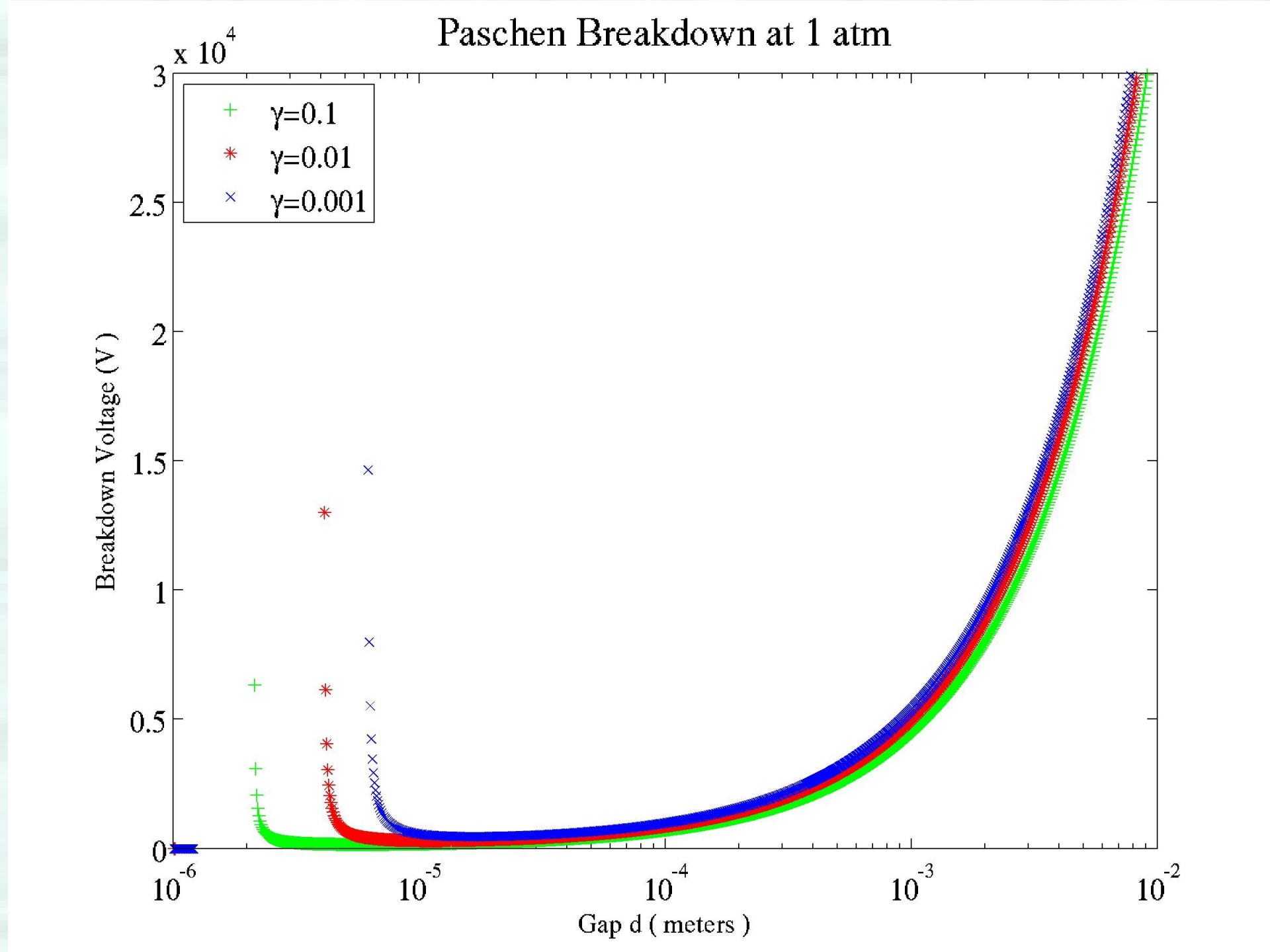
Show dependence of breakdown voltage on gap and pressure.
Can be used for a spark, even where gap is not well defined.

$$U = E\,d = \frac{B(p\,d)}{\ln(A\,p\,d) - D}$$

$$D = \ln\left(\ln\left(1 + \frac{1}{\gamma}\right)\right)$$


Paschen Breakdown Curves in air
x 10^4
3
2.5
2
1.5
1
0.5
0
γ=0.1
γ=0.01
γ=0.001
Breakdown Voltage (V)
10^-1
10^0
10^1
10^2
10^3
p d (Pascal · m)


Paschen Breakdown at 1 cm gap
x 10^4
3
2.5
2
1.5
1
0.5
0
γ=0.1
γ=0.01
γ=0.001
Breakdown Voltage (V)
10^1
10^2
10^3
10^4
10^5
Pressure p (Pa)


Paschen Breakdown at 1 atm
x 10^4
3
2.5
2
1.5
1
0.5
0
γ=0.1
γ=0.01
γ=0.001
Breakdown Voltage (V)
10^-6
10^-5
10^-4
10^-3
10^-2
Gap d (meters)

Elenbaas-Heller Equation

Equation for heat flow in cylindrical coordinates, assuming Joule heating.

$$\frac{dn}{dt} = D_A \nabla^2 n$$

$$\frac{dT}{dt} = \alpha \nabla^2 T$$

$$\frac{dT}{dt} = \frac{\alpha}{r}\left(\frac{\partial}{\partial r}\left(r\frac{\partial T}{\partial r}\right)\right) + \frac{\dot{q}}{\rho C_p}$$