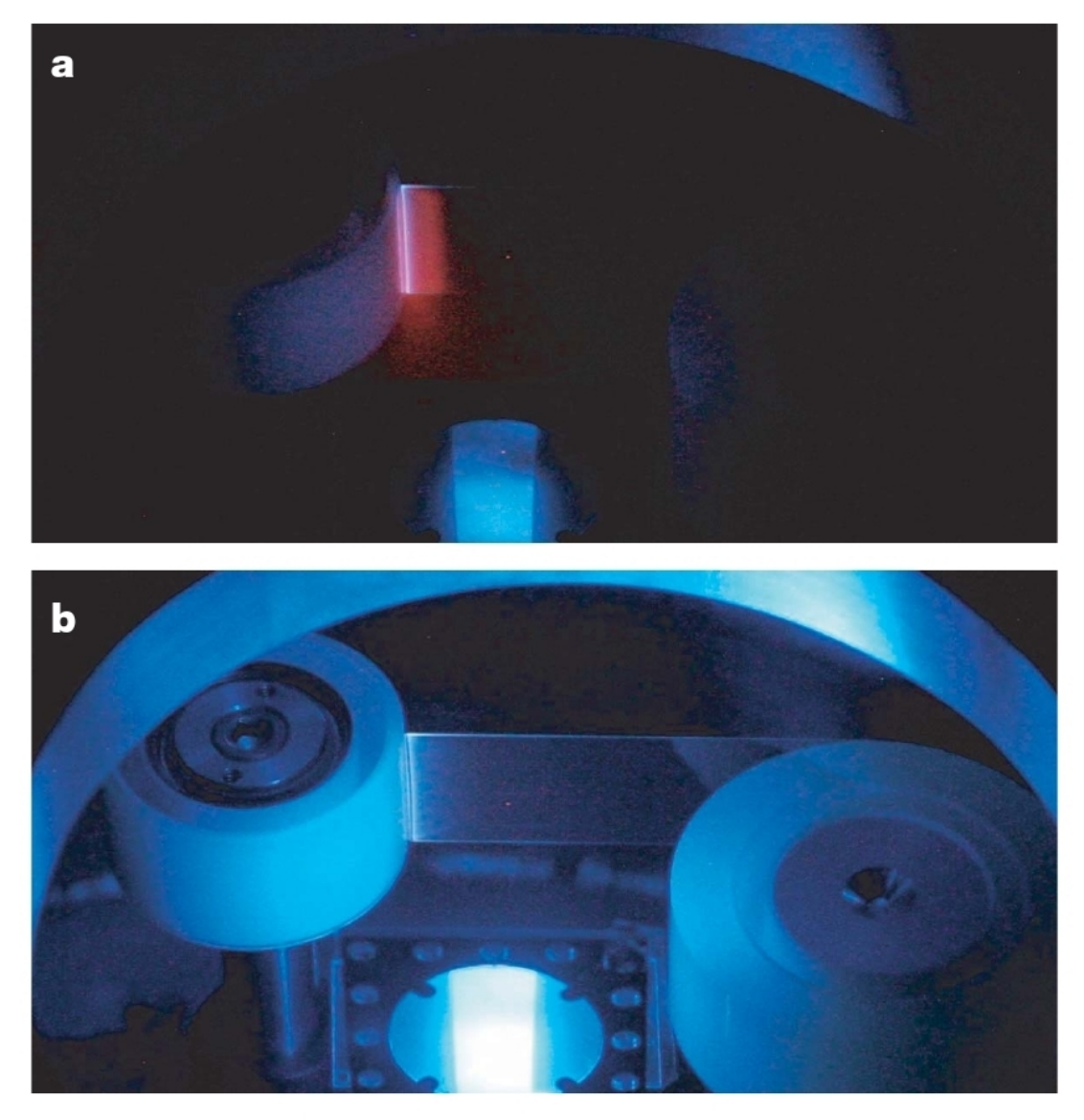
X-Ray Flashes from Scotch Tape

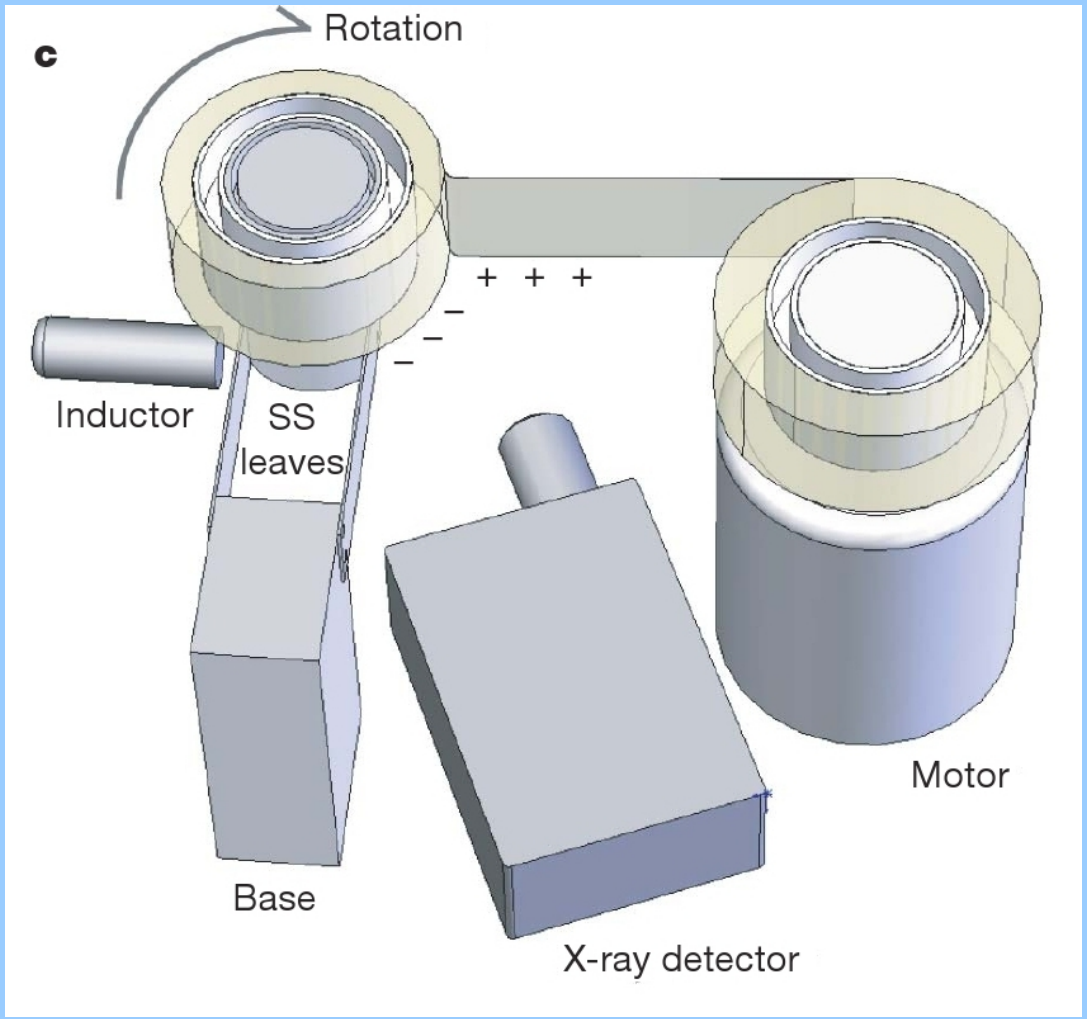


Moses Marsh Shpyrko Group 8/12/10

What is going on?

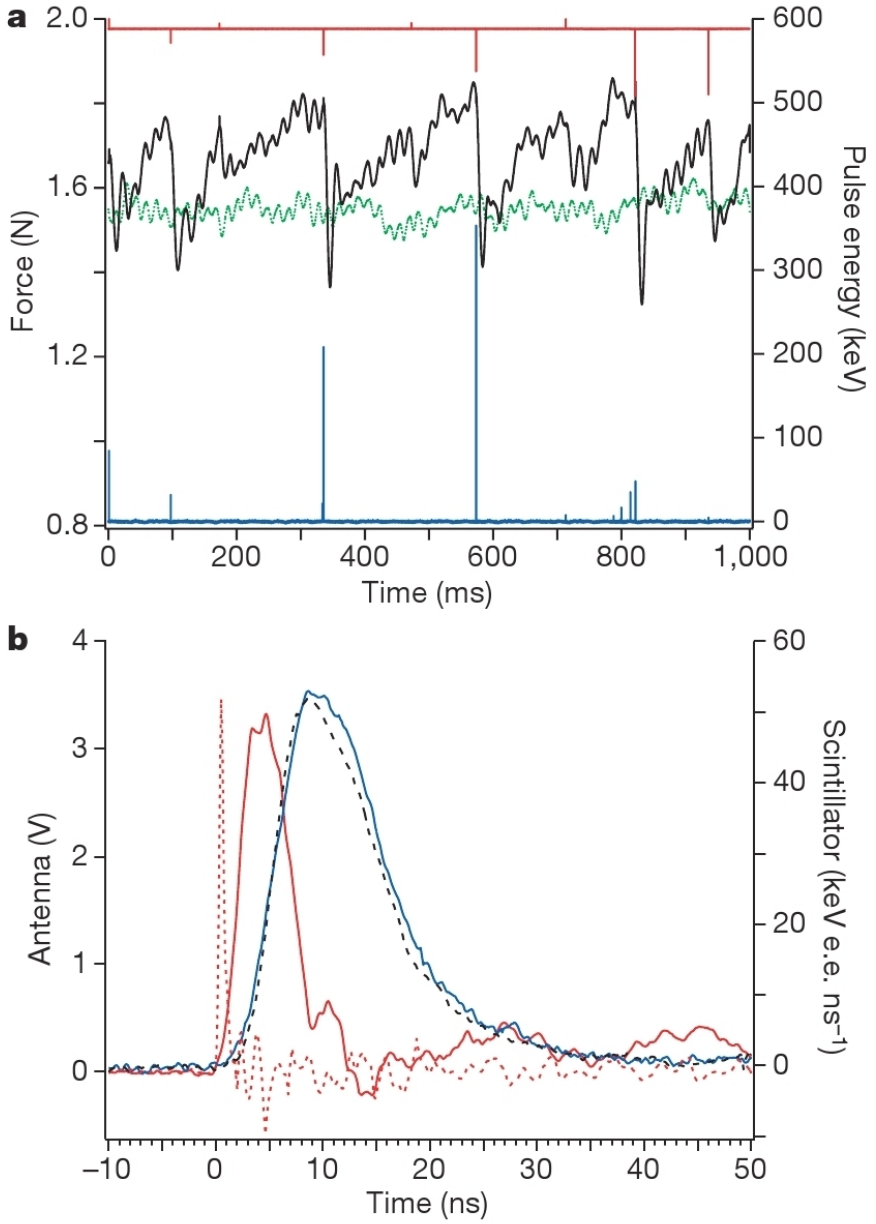
- ***triboluminescence*: emission of light when a material is crushed, rubbed, scratched, or pulled apart.**
- **Diffuse mechanical energy somehow concentrates huge charge densities over short time scales, resulting in high energy radiation during discharge**
- **Has been observed in sugar and quartz crystals for centuries**
- **Can also be seen as cracks form in ice cubes**
- **Possibly related to lightning, "earthquake lights," and gecko adhesion**

Experimental Setup



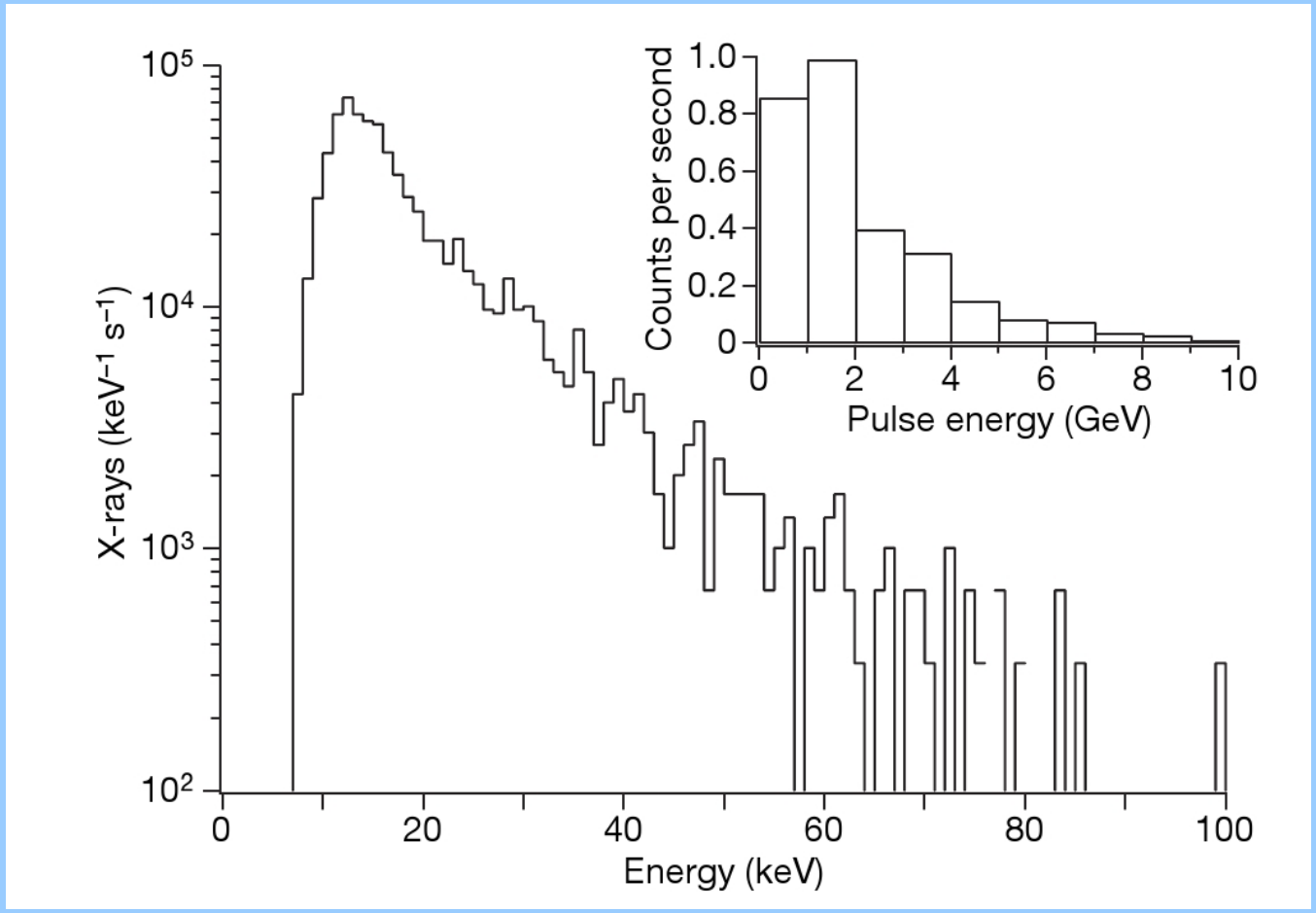
- **Peeling force measured**
- **X-rays emissions detected with scintillator**
- **Radio emissions detected with BNC antennae**

Data - Pulses



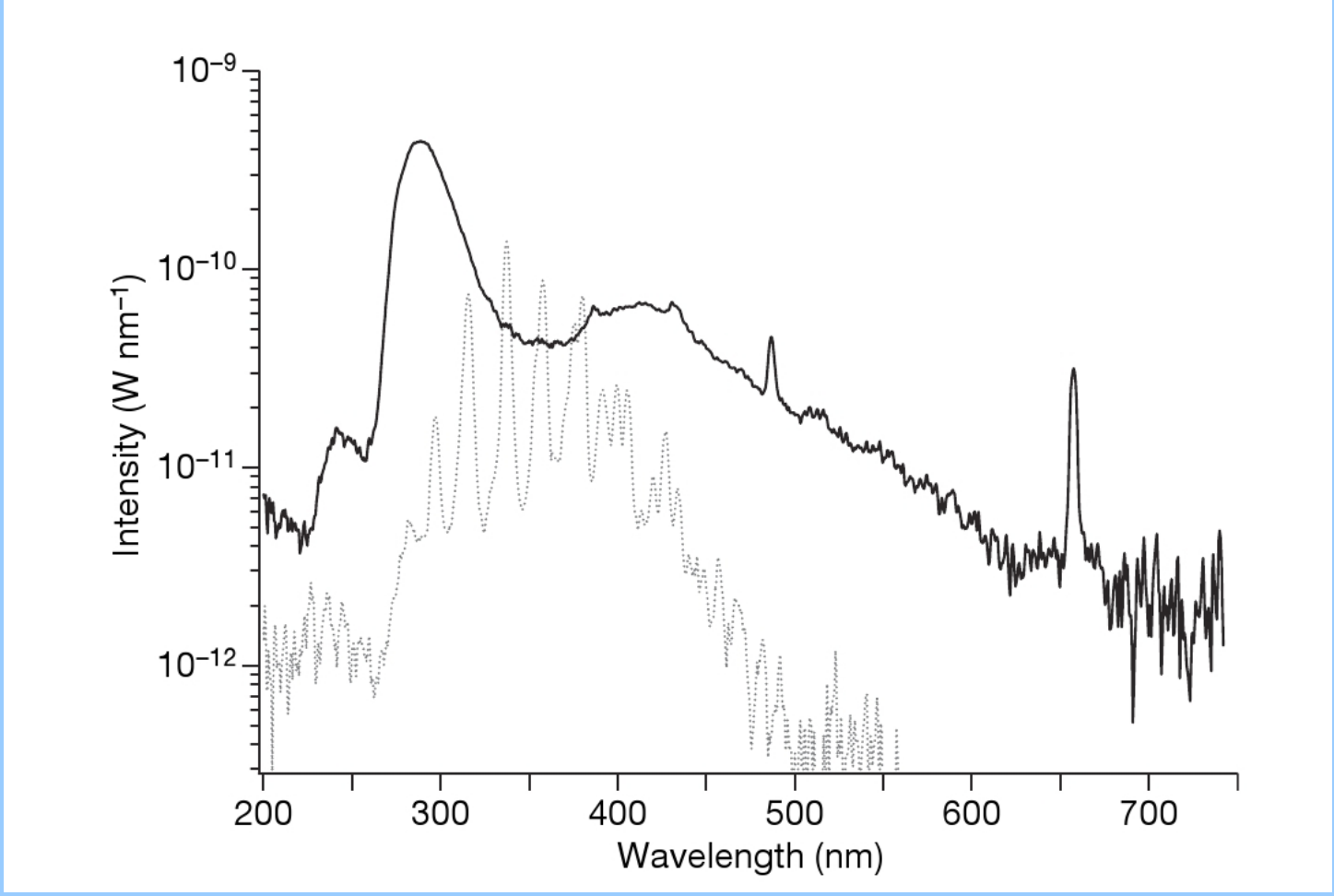
- **Slips in the peeling force (black) corresponded with x-ray (blue) and radio (red) emissions**
- **Bottom: comparison of x-ray and radio pulses**

Data – X-Ray Spectrum



- **Spectrum did not change significantly over 10 rewindings of the same roll of tape**

Data – Visible Spectrum



- **Black trace taken at 10^{-4} torr of air, gray at 1 atm.**

Power

- **At 1atm, it takes 50mW to peel tape at 3 cm/s.**
- **In vacuum, it takes an extra 3mW. Of this, at least 0.2mW goes into accelerating electrons to 30 keV, generating an average X-ray power of 2 nW. The power going into visible triboluminescence is 10 nW.**

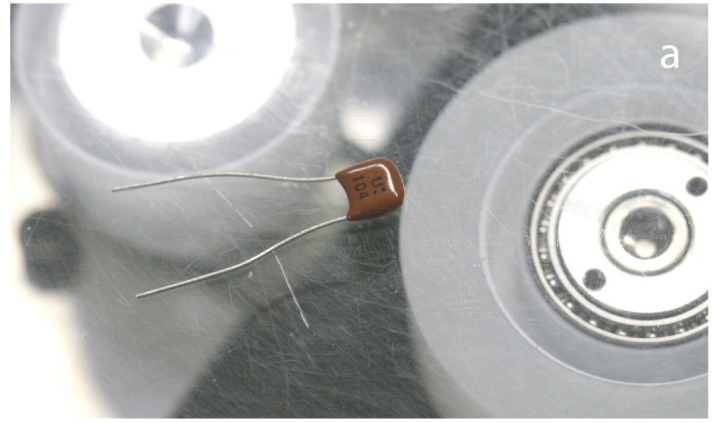
Theory

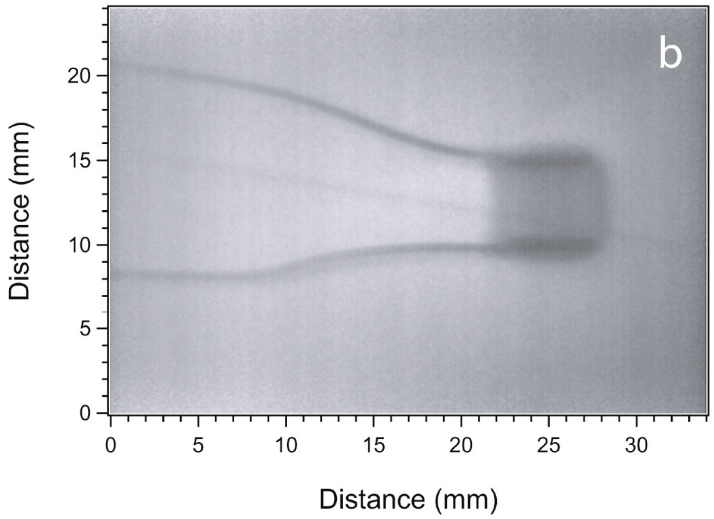
- **As the tape is pulled apart, the acrylic adhesive becomes positively charged and the polyethylene roll becomes negatively charged, until the electric field becomes strong enough to trigger discharge**
- **At low pressure, the discharge can accelerate electrons to high enough speed to generate Bremsstrahlung x-rays upon hitting the positive side of the tape**
- **Max E-field dictated by dielectric breakdown criterion of the intermediate gas, or, in vacuum, field emission criterion.**
  - **Air at 1 atm breaks down at E~30kV/cm.**
  - **In vacuum we are talking about fields ~1000 times greater.**

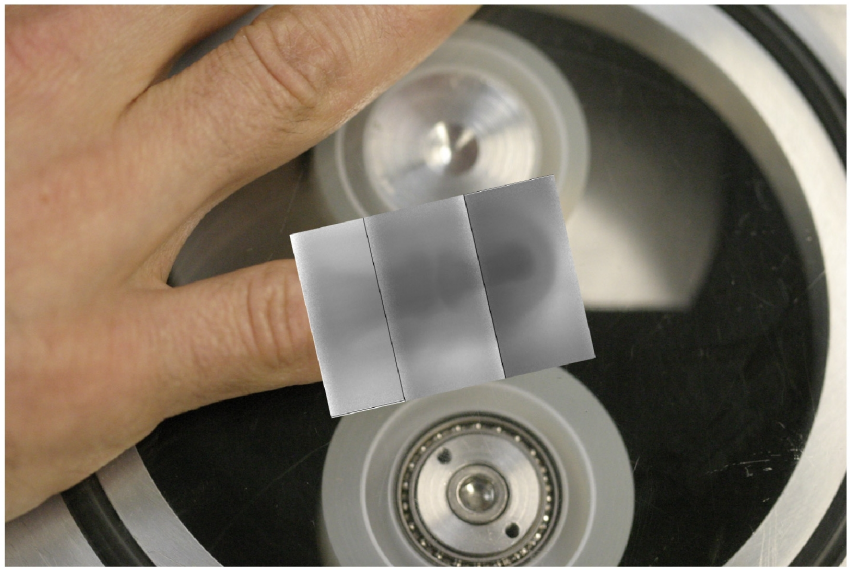
Theory

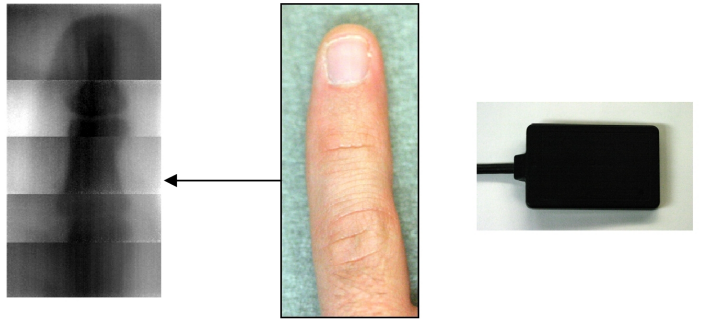
- **Multiple models for the discharge. Using the x-ray power spectra with these models lets us estimate the number of electrons being accelerated and thus the charge densities generated.**
  - **Kramers limit (thick target limit of Bremsstrahlung process): describes average charge density in agreement with previous tribocharging phenomena, but doesn't account for shortness of x-ray pulses**
  - **Townsend discharge (avalanche gas ionization)**
  - **Explosive plasma emission**
  - **The latter two can account for the necessary spikes in charge density**

X-Ray photography









- **Capacitor image: tape unwound at 20 cm/s, 5 s exposure**
- **Finger image: tape unwound at 10 cm/s, 20 s exposure**

References

- **Carlos G. Camara et al., "Correlation between nanosecond X-ray flashes and stick-slip friction in peeling tape," Nature 455, no. 7216 (October 23, 2008): 1089-1092**
- **Walton, A. J. Triboluminescence. Adv. Phys. 26, 887–948 (1977)**
- **Mesyats, G. A. Ectons and their role in plasma processes. Plasma Phys. Contr. Fusion 47, A109–A151 (2005)**
- **Putterman, S. J. & Weninger, K. R. Sonoluminescence: how bubbles turn sound into light. Annu. Rev. Fluid Mech. 32, 445–476 (2000)**
- **Gay, C. & Leibler, L. Theory of tackiness. Phys. Rev. Lett. 82, 936–939 (1999)**
- **Chervenak, J. G. & Liuzzi, A. Experimental thick target Bremsstrahlung spectra from electrons in the range 10–30keV. Phys. Rev. A. 12, 26–33 (1975)**