Blast Analysis: Further Study

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PHYS 21900 Final Project

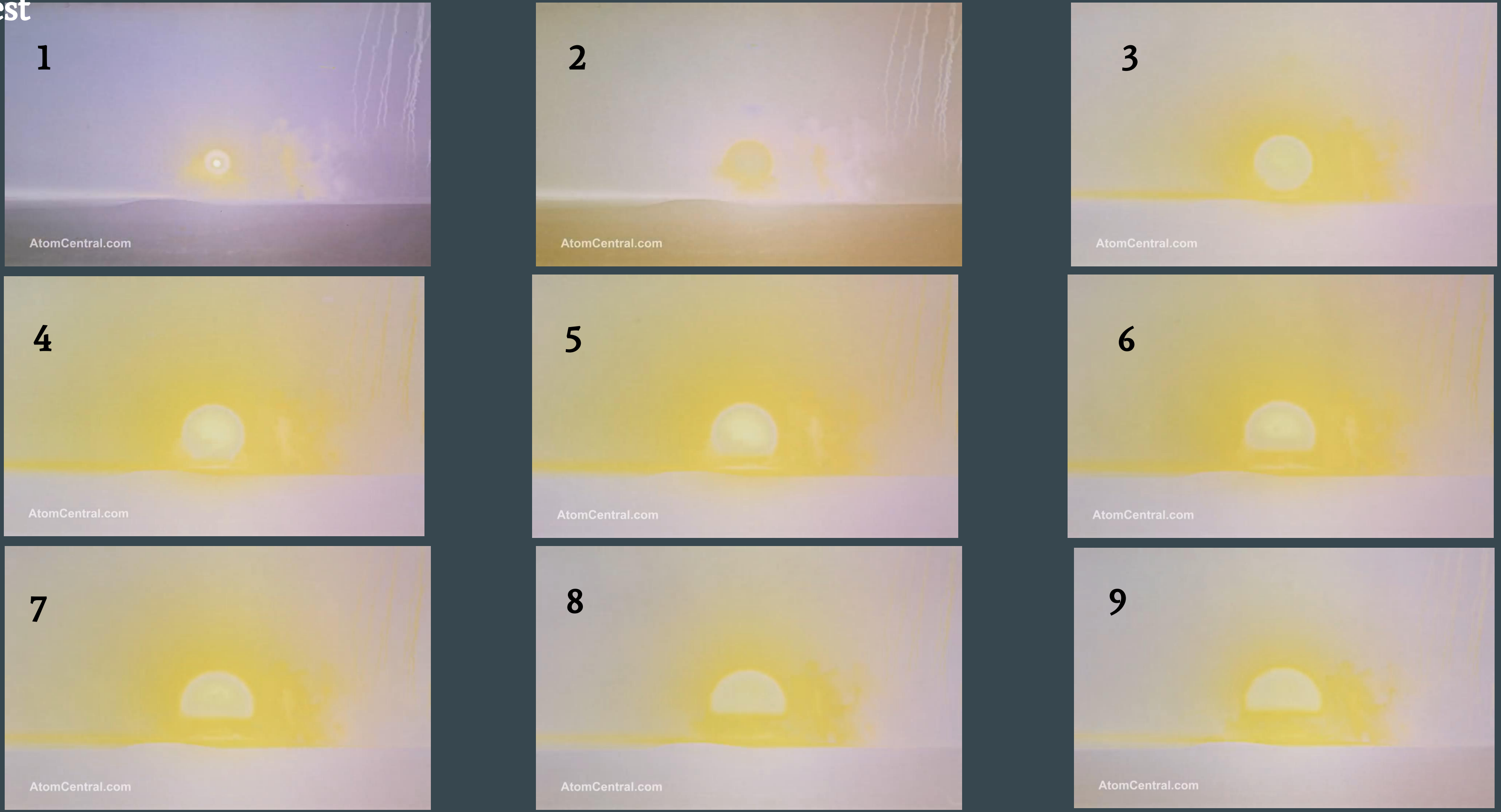
Goals

- Analyze the power law relationship we derived for point-like blasts
- Expand analysis to other systems
- Make inferences of missing physics

Explosions Analyzed

- Shot Grable of Operation Upshot-Knothole (nuclear artillery shell)
- Ivy Mike test of a thermonuclear device
- Two videos of fireworks
- Footage of a car explosion after a motor vehicle accident
- 1 million match heads lit on the show MythBusters
- 855 lbs of ANFO in an RV detonated on MythBusters

Data Collection Example: Shot Grable Test



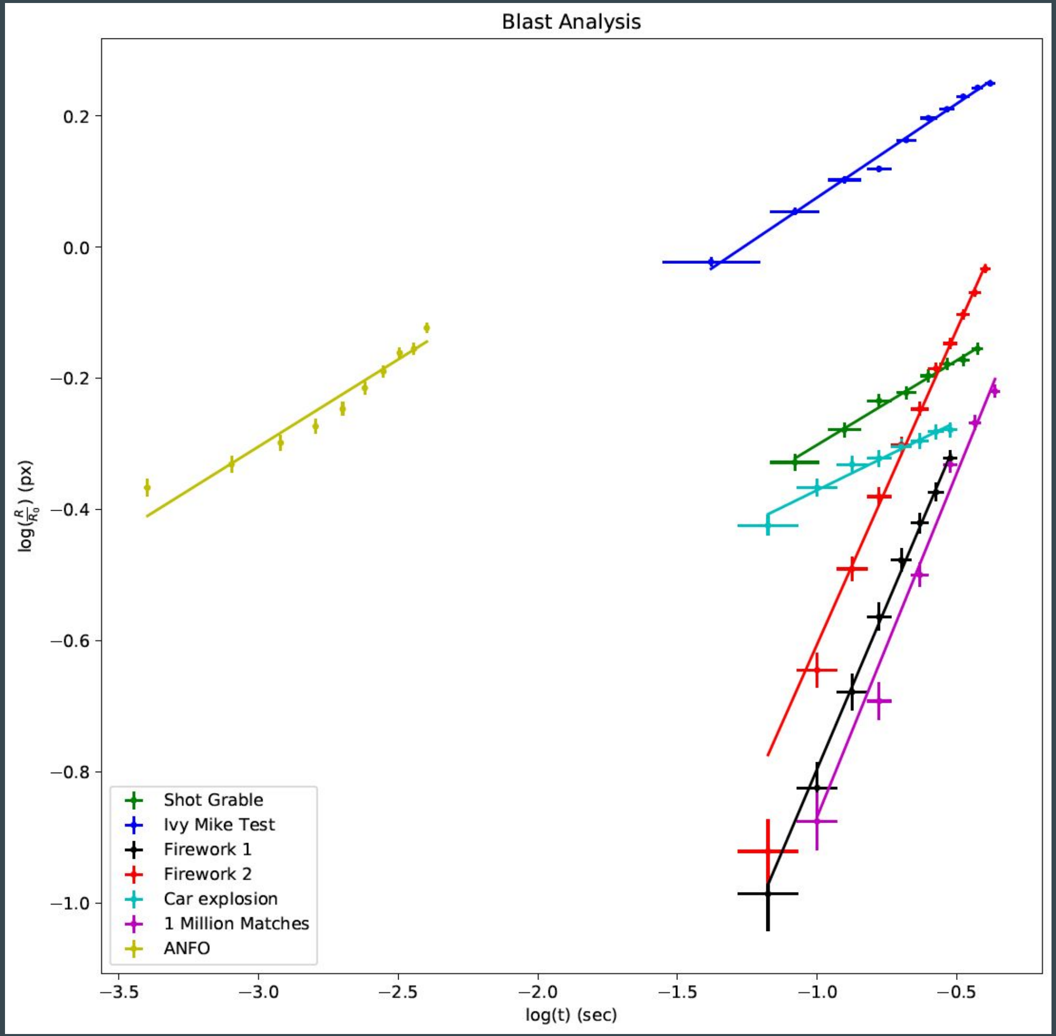
Shot Grable Test: Crop Example

Error Propagation and Normalization

- dt = 0.5 fps
- dp = 2 px
- R_0 = 150 px

$$\delta(log(R/R_0)) = \frac{\delta(R/R_0)}{R \cdot ln(10)}$$

$$\delta(log(t)) = \frac{\delta t}{t \cdot ln(10)}$$



Radius Calculation:

$$R \propto \left(\frac{Et^2}{\rho}\right)^{1/5}$$

$$\frac{5}{2}log(R) \propto log(t) + \frac{1}{2}log(\frac{E}{\rho})$$

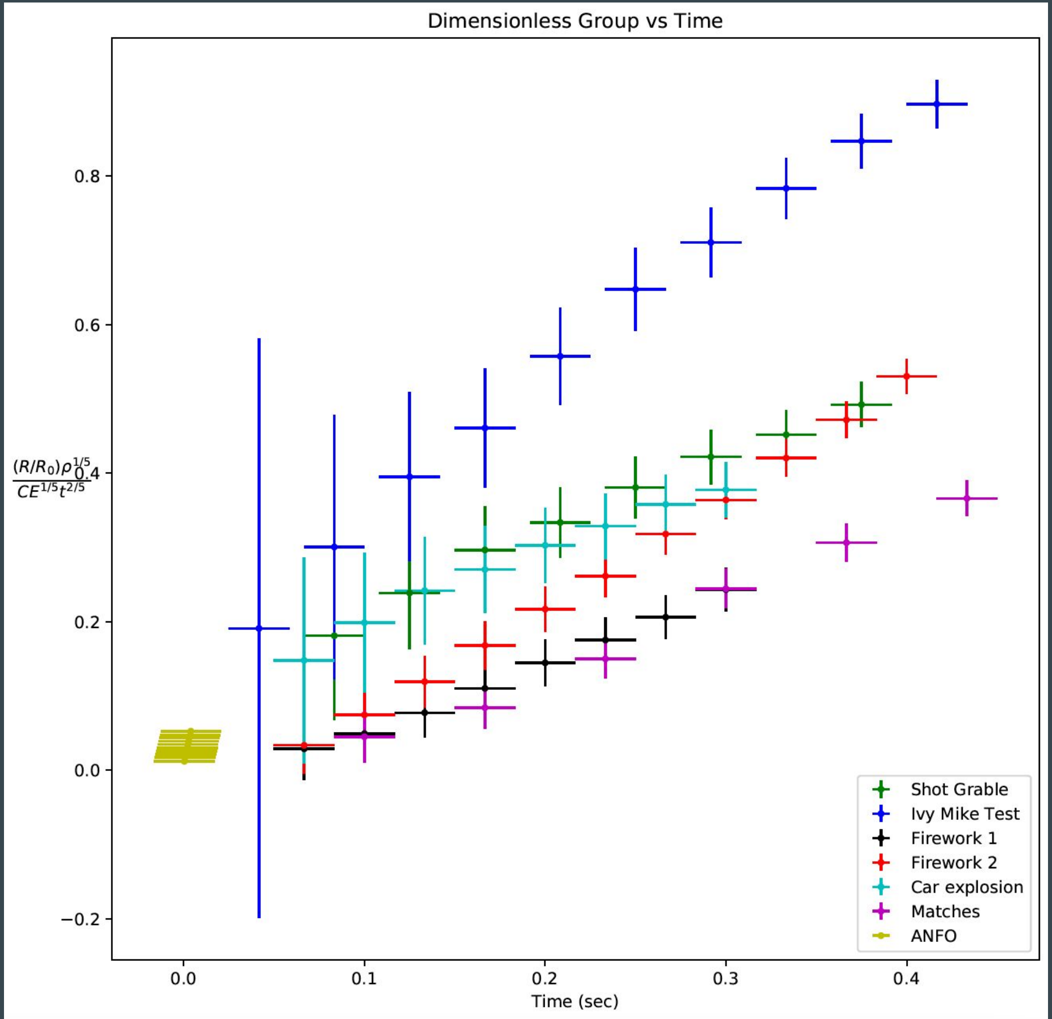
Energy Calculation:

$$b = C \cdot \frac{1}{2} log(\frac{E}{\rho})$$

$$E \cdot C = 10^{2b} \rho$$

Dimensionless Group:

$$\left[\frac{R\rho^{1/5}}{E^{1/5}t^{2/5}}\right] = 1$$



m ~ 1 or m ~ 0.2

TABLE I: Blast Fit Values

over or under estimating errors

Blast	Fit Equation	Reduced Chi-Squared	$E \cdot C$ (kg px^2/t^2)
Shot Grable	$\log(R/R_0) = (0.257 \pm 0.009) \log(t) + (-0.044 \pm 0.006)$	0.336	1.005
Ivy Mike Test	$\log(R/R_0) = (0.286 \pm 0.002) \log(t) + (0.362 \pm 0.002)$	3.971	6.509
Firework 1	$\log(R/R_0) = (1.00 \pm 0.02) \log(t) + (0.21 \pm 0.02)$	0.373	3.203
Firework 2	$\log(R/R_0) = (0.96 \pm 0.01) \log(t) + (0.354 \pm 0.006)$	1.955	6.289
Car Explosion	$\log(R/R_0) = (0.21 \pm 0.01) \log(t) + (-0.162 \pm 0.009)$	0.514	0.584
1 Million Matches	$\log(R/R_0) = (1.05 \pm 0.02) \log(t) + (0.18 \pm 0.01)$	4.561	2.812
ANFO	$\log(R/R_0) = (0.266 \pm 0.006) \log(t) + (0.49 \pm 0.02)$	3.978	11.914

Discussion: Slopes

- Nuclear vs chemical explosions
  - Strong nuclear force vs electromagnetic force
- Not point-like sources

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Discussion: Outliers

- Car explosion and ANFO
  - Systematic errors, large energy

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Discussion: Error

- Over and under-estimation of variables $\Rightarrow$ more rigorous data collection technique needed

Other Potentially Relevant Quantities

- Shape of explosive
  - $[V] = L^3$
- Force associated with explosive
  - $[F] = MLT^{-2}$
- Radius
  - $[R] = L$
- Energy
  - $[E] = ML^2T^{-2}$
- Density
  - $[\rho] = ML^{-3}$
- Time
  - $[t] = T$

$$\left[\frac{RF^4V}{E^4}\right] = 1$$

$$\left[\frac{RF}{E}\right] = 1$$

$$\left[\frac{RE^3\rho}{F^4t^2}\right] = 1$$

$$log(R) \propto 2log(t) + log\left(\frac{F^4}{E^3\rho}\right)$$

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Chemical regime:

$$log(R) \propto 2log(t) + log\left(\frac{F^4}{E^3\rho}\right)$$

Nuclear regime:

$$log(R) \propto \frac{2}{5}log(t) + \frac{1}{5}log(\frac{E}{\rho})$$

Conclusions

- Further study to determine why slopes are uniformly off by a factor of 2
- Unaccounted physics might be force of explosion
- Exploration of transition between two regimes and how energy scales effect blast radius is needed

Works Cited

https://www.acs.org/content/acs/en/education/students/highschool/chemistryclubs/activities/fireworks.html

http://sciexplorer.blogspot.com/2015/01/chemical-explosions-versus-nuclear.html#:~:text=Chemical%20explosions%20are%20chemical%20reactions,the%20nuclei%20of%20the%20atoms.&text=It%20consists%20of%20two%20protons%2C%20two%20neutrons%20and%20two%20electrons.

https://sciencing.com/match-head-made-of-5948585.html

https://www.youtube.com/watch?v=Jgi7WgB05Jo

https://www.youtube.com/watch?v=AhUVp3xAYYY

https://www.youtube.com/watch?v=S7wUIJJpvcE&t=105s

https://www.youtube.com/watch?v=ts34UxRfTx8