BUBBLE GROWTH STUDIES FOR THE PICO EXPERIMENT

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DETECTING DARK MATTER WITH BUBBLES?
How Did Dark Matter Come To Be?
Galaxies Shouldn’t **Shine** This Way

Light ≠ Mass

\[ 2\langle T \rangle = -U \]  
**Virial theorem**

\[ M = \frac{r\langle v^2 \rangle}{G} \]  
**Mass of a cluster**

\[ L \approx M^{2.25} \]  
**Luminosity of a cluster**

Zwicky 1930’s¹

\[ M \text{ was off by a factor of } 400! \]

Image, https://ned.ipac.caltech.edu/level5/March02/Abell/Abell3_3.html
Stars Shouldn’t Move This Way

Vera Rubin 1970’s

Galaxies Shouldn’t **Collide** This Way

**Bullet Cluster**

Equivalent to

**Bullet Cluster Collision Simulation**
Detection Philosophy
How Do We Decide What’s This Missing Thing

Matter \rightarrow \text{Modification of dynamics} \rightarrow \text{MOND}

Standard model \rightarrow \text{Model extensions}

\text{MACHO} \rightarrow \text{WIMP}
The PICO Detection Principle

WIMP Interaction

Phase Transition

Acoustic Signal

\( \chi \) \( \chi \)

\( sm \) \( sm \)

\( R_{vap} \)

\( R_{liq} \)
The **PICO** Detection Principle

- **Background model**
- Alphas
- Neutrons

- **Expected bubble rates**

- **Detector run**

- **Bubble rates ≠ Expected bubble rates**

- **Dark Matter Detected!**
Background Discrimination: AP

Acoustic signal

AP Calculation Tool

Output value

Histogram of values

Neutrons and alphas are different!
What Am I Doing?
Bubble Growth

Governing Equations

\[
\frac{R}{2} \frac{d^2 R}{dt^2} + \frac{3}{2} \left( \frac{dR}{dt} \right)^2 = \frac{P'(T) - P_\infty(T)}{\rho''} - \frac{2\sigma(T)}{\rho''R} - \frac{4\mu}{\rho''R} \frac{dR}{dt} + \frac{\partial T}{\partial t} + \frac{R^2}{r^2} \frac{dR}{dt} \nabla_s T = \alpha \nabla_s^2 T
\]

How do You Make an **Acoustic Signal**?

Fourier Transform

A string frequency response

Sound you can hear!
Acceleration Curves’ Analysis

Acceleration Is equal to Force Is equivalent to Striking a piano string

Fourier Transform of acceleration curves

Key signatures in frequency

Improved AP

Optical Discrimination

Blue: curves are degenerate

Red: curves are non-degenerate!

THANKS!

References/Acknowledgements:
1. https://ned.ipac.caltech.edu/level5/March02/Abell/Abell3_3.html
3. 1 (Top) Deep Chandra image of the Bullet cluster. Shown in green are mass contours from weak lensing - reconstruction. From Clowe et al. 2006.
3. 2 (Bot) X-ray: NASA/CXC/CfA/M.Markevitch et al.; Optical: NASA/STScI; Magellan/U.Arizona/D.Clowe et al.; Lensing Map: NASA/STScI; ESO WFI; Magellan/U.Arizona/D.Clowe et al.
4. NASA/CXC/M. Weiss
Interface Acceleration Curves for Different Initial Conditions

In red: temperature disturbance of $10^{-5} \degree C$
In blue: temperature disturbance of $10^{-9} \degree C$

36 \degree C Superheated water at 1 atmosphere