Fundamental Physics Tests with Atomic Interferometry

SLAC Theory
Collaboration

SLAC
Theory
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Theory
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Atomic Experiment
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Atomic Interferometry


- unprecedented precision: 16 digit clock synchronization
- many possibilities for improvement
- can test e.g. time variation of fundamental constants

How can we use this new tool to test fundamental physics?
## Fundamental Physics Tests

<table>
<thead>
<tr>
<th>Category</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Gravitational Waves</strong></td>
<td>$h \sim 10^{-22}$ at frequencies $\sim 1 \text{ Hz}$</td>
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<tr>
<td></td>
<td>compact binaries (BH, NS, WD) in local galaxy cluster, cosmological sources (phase transitions, cosmic strings, inflation,...)</td>
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<tr>
<td><strong>Short-Distance Gravity New Forces</strong></td>
<td>$\alpha \geq 10^{-5}$ for $100 \mu m \leq \lambda \leq 10 \text{ m}$</td>
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<td></td>
<td>extra dimensions, QCD axion, light moduli,...</td>
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<tr>
<td><strong>Atom Neutrality</strong></td>
<td>charge per nucleon $\sim 10^{-30}$</td>
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<tr>
<td></td>
<td>current bound $\sim 10^{-22}$</td>
</tr>
</tbody>
</table>
colocated $^{85}\text{Rb}$ and $^{87}\text{Rb}$ clouds test Principle of Equivalence initially to $10^{-15}$ in controlled (lab) conditions
Other Prospects

General relativity and extensions (equivalence principle, DGP)

Modifications of quantum mechanics (e.g. Weinberg ’89)?

New ideas?
Gravitational Wave Sensitivity

experimental sensitivity for continuous sources

waves from solar mass binaries:

\[ h \sim \frac{(GM)^2}{rR} \]

L~10 m and LMT \hspace{1cm} h \sim 10^{-17}
L~10 km \hspace{1cm} h \sim 10^{-20}
Heisenberg statistics \hspace{1cm} h \sim 10^{-22}

on earth \( \omega \sim 1 \text{ Hz} \)
in space \( \omega \sim 10^{-3} \text{ to } 1 \text{ Hz} \)

maybe IMBH \( \rightarrow h \) up to \( 10^5 \) larger

galaxy \hspace{1cm} h \sim 10^{-18}
cluster \hspace{1cm} h \sim 10^{-21}
universe \hspace{1cm} h \sim 10^{-23}

opens a new window for stochastic gravity wave searches from phase transitions, inflation, cosmic strings...
Short-Range Force Sensitivity

## Future Prospects

<table>
<thead>
<tr>
<th>Experimental Precision for:</th>
<th>Principle of Equivalence</th>
<th>GR effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>current limits</td>
<td>$10^{-13}$</td>
<td>$10^{-4}$ - $10^{-5}$</td>
</tr>
<tr>
<td>AI initial</td>
<td>$10^{-15}$</td>
<td>$10^{-1}$</td>
</tr>
<tr>
<td>upgrade</td>
<td>$10^{-16}$</td>
<td>$10^{-2}$</td>
</tr>
<tr>
<td>future</td>
<td>$10^{-17}$</td>
<td>$10^{-4}$</td>
</tr>
<tr>
<td>far future</td>
<td>$10^{-19}$</td>
<td>$10^{-6}$</td>
</tr>
</tbody>
</table>

- 10 m experiment
- 200 $\hbar k$ beamsplitters
- 100 m experiment
- Heisenberg statistics