Stanford Physics Qualifying Exam

Transcript

For my qualifying exam, I talked about the paper *Searching for Scalar Dark Matter with Compact Mechanical Resonators* using these slides. My committee consisted of two experts on these kinds of experiments, and a cosmologist. I prepared a 45 minute talk, and the entire exam took an hour, including questions and answers. They were:

- Slide 8: you say that $B - L$ is the only global symmetry of the Standard Model that can be gauged, but this isn't true. What are the others? (Answer: flavor-dependent symmetries such as $L_e - L_\mu$ are also nonanomalous.)
- Slide 16: where does the analogy between the dilaton field and a gravitational wave break down? (Answer: gravitational waves change distances between freely falling objects, while the dilaton changes the rest length of molecular bonds. If two objects aren't connected by such bonds, then gravitational waves still have a mechanical effect, but the dilaton won't.)
- Slide 16: would LIGO be sensitive to the dilaton? (Answer: sensitivity is significantly decreased because the dilaton's monopole effect would be cancelled out by LIGO's two arms.)
- Slide 26: how do you get your expression for the signal PSD? (Answer: I approximate it as a constant over a narrow frequency range so that it has the same total power. This gets the correct signal to noise ratio up to an order-one constant, but one could treat it more accurately using some model for the dark matter velocity distribution.)
- Slide 26: this is the scaling when t_{int} is long. How about when it is shorter than the dark matter coherence time? (Answer: in this case, the dark matter signal is effectively monochromatic, so we instead have $\text{SNR} \propto t_{\text{in}}$.)
- Slide 28: wouldn't a fully filled cylinder be insensitive to dilatons? (Answer: yes, the cylinder must be partially filled to have breathing modes that couple to the dilaton. The diagram I used is from a paper about gravitational waves, where the cylinder can be completely filled.)
- Slide 28: one of these challenges isn't like the others. (Answer: right, seismic isolation is about suppressing a new noise source, while the other three are about increasing the quality factor.)
- Slide 30: how do you scan over different dark matter frequencies? (Answer: either change the amount of helium in the cavity, or change the pressure to adjust the sound speed.)
- Slide 30: doesn't coupling to the readout decrease the quality factor, negatively impacting the results on slide 25? (Answer: yes, e.g. with critical coupling, which maximizes signal power, the quality factor is halved. However, it turns out that overcoupling can sometimes actually *increase* the reach of the experiment beyond the naive expectation, because of the increased scanning speed from broadening the frequency response, and the reduction of thermal noise. But that is beyond the scope of this talk.)
- Slide 31: these results do not account for a frequency scan. By how much would the sensitivity decrease if one had to scan over an octave in frequency? (Answer: because $Q_{\text{DM}} \sim 10^6$, we need to scan over 10^6 different frequencies. Because $h_{\text{min}} \propto t_{\text{int}}^{-1/4}$, the shorter integration time for each run weakens the sensitivity by roughly a factor of $10^{3/2}$.)

- Slide 31: would the dilaton induce oscillations of neutron stars? (Answer: yes, but probably not by the d_e or d_{m_e} coupling. A better option would be to search for couplings which affect Λ_{QCD}, such as the coupling to the gluon field strength, because these affect the neutron mass. Given such a coupling, oscillations could probably be excited at some low frequency, but (1) you would need to get lucky to have a mode at the right frequency to couple to the dilaton field, and (2) I'm not sure how high the quality factor would be.)
- Slide 31: would dilaton dark matter have a cosmological effect, such as on the CMB? (Answer: I had no idea about this one, and after a minute of stumbling, a different committee member pointed out that it was an open question. Apparently, he had worked on it earlier and thought the effects were too small to be observable.)

Afterward, the professors deliberated for a few minutes, and it was over. Their main critique was that my slides were pitched more for a seminar audience than for a colloquium; they could have used some more coverage of the basics.

Advice

- It usually takes about two weeks to prepare. I prepared for about a week and a half, since I had some earlier exposure to the subject through my particle physics knowledge.
- **Do practice runs!** I arranged to talk to the SITP and SLAC journal clubs. This helped me calibrate the length of the talk, and get used to answering questions during it.
- Don't worry too much about formality. Stanford's environment is very relaxed, even during exams. I put Spongebob memes in my slides for fun, and the professors didn't mind.
- The kinds of questions I got were similar to those given to seminar speakers, so it's good to attend lots of talks to see what kinds of questions come up, and how the speakers handle them. It's also good to look at your slides from the perspective of an audience member in a seminar, to see what questions you would like to ask about them.
- Understand your paper deeply. When I read the paper for the first time, I had lots of questions, which I answered for myself by following the citation chain backwards. I also derived every equation on my own, treating them like results to be shown on a problem set. This paid off, since many of the questions I got were precisely things I had looked into.
- You want to pick a topic which is rich in qualitative insights, not full of formalism. The paper I covered was only 4 pages long, with a handful of equations, but explaining the ideas took the full time. I think Physical Review Letters is the ideal journal to get topics from.
- The professors will enjoy your talk a lot more if you cover something new to them, such as a topic which links different fields together. For example, explaining the AdS/CFT correspondence would be the worst possible qual topic. Not only is it extremely technical, but your committee would consist mostly of professors who have been working on it for decades, and they'll have heard everything you're going to say a thousand times already.
- You don't have to use the exact same formalism as the paper you cover. My equations are shorter because I used different notation, with more simplifying assumptions. You can, e.g. set couplings to zero, work in one dimension, completely ignore subdominant terms, and generally do anything that makes the core idea clearer.