**1. Define a Problem**

* Discuss possible **problems** to address with your Advisor.
* What is the background of these **problems**?
* What is the motivation for their **solution**?
* Details of the problem may develop/change over the course of your Capstone.

Can a super solid quantum phase be achieved experimentally? What system is most appropriate to produce a super solid state? Is it easier to realize the super solid in a continuous or discrete position space? How low of a temperature must be reached to stabilize a super solid?

To date all experimental attempts to create a super-solid state have been in continuous systems. The most famous experimental attempts to produce a super solid state was conducted by Eun-Seong Kim and Moses Chan at Pennsylvania State University in 2004 and 2012. Their experimental apparatus made use of the non-classical rotational inertia that a super-solid would have. The apparatus would twist back and forth with the solid sample sitting on top. As the solid was cooled they looked for changes in its rotational inertia. Initially they observed that the 1-2% of the atoms were not contributing to the rotational inertia of the solid. However, in 2007 it was proposed that the strange rotational inertia observed in the experiment was due to elasticity of the solid and not due to any quantum effects. In 2012 Kim and Chan repeated the experiment with an improved apparatus and found no evidence of a super-solid state.

To date all computational/theoretical evidence for super solid phases has been in discrete systems, which can be approximately realized by optical lattice experiments.

It is well established that super-fluidity can appear in an optical lattice like experimental setup, if there were some way to impose a non-trivial crystalline arrangements of the particles in the optical lattice there is a good chance that a super solid state could form. If there were a long ranged repulsion between the particles in the lattice they may avoid being near each other and establish some solid order. An easy way to achieve such a long ranged repulsion is by making the particles dipoles.

To establish what physical parameters are needed to potential stabilize a super solid phase we will run computer simulations of an optical lattice filled with dipoles. We can then establish what dipole moments, lattice spacings, temperatures and contact potentials are necessary to experimentally produce a super solid state.

**2. Brainstorm**

* With your Advisor brainstorm possible smaller “**starter problems**” and steps toward the full **solution**.
* Develop preliminary ideas.
* Present ideas in an open forum.
* Record all ideas.

Firstly we will need to make some broad sweeps over parameter space to find which regions may warrant further investigations.

Additionally it will be worth some investigation as to whether it is necessary to calculate the full range of each dipole-dipole interaction or if the data will be accurate enough only considering the interaction of some near neighbors of each dipole.

**3. Research**

* Find good resources (text books, tutorials through papers) to introduce you to the background of the **problem**/ subject.
* Find resources directly associated with the **problem** itself.
* Are there solutions out there?
* Research solutions that may already exist (products available, patents etc.)
* Identify shortcomings and reasons why they aren’t appropriate to a given situation.
* Keep good notes/references, compile ideas and report findings to the team/Advisor.

I read some book about Monte Carlo simulations in Physics and also Lectures on Phase Transitions and Renormalization groups. Barbara sent me many articles about other peoples’ simulations of optical lattices and their evidences for super solid phases. Most/All of the other works which had been done only considered truncated long range interactions and were not able to simulate as large of system sizes as we will be able to. Our ability to do more comes from Barbara’s great FORTRAN code and the Quantum Monte Carlo Worm Algorithm Method.

**4. Identify Criteria and Specify Constraints**

* Identify what the **solution** should do and the degree to which the **solution** will be pursued.
* Identify constraints: *e.g.*, time/ cost/ size/ weight/ safety/ computation time *etc.*
* Make a brief summary.

As mentioned above we settled on doing Quantum Monte Carlo Worm Algorithm Simulations of an Extended Bose Hubbard Model of dipolar molecules in an optical lattice because we will be able to consider the full range of the forces and will be able to use large system sizes. Exactly how large of system size that we can use will depend on how much computing power we have and how long we are willing to wait for our simulations to run. We have access to about 150 cores on the local super computer and we are willing to wait some number of weeks for the simulations to finish. Thus we typically run ~50 simulations at a time with system sizes on the order of L~16 as the linear dimension of the simulation.

**5. Explore Possibilities**

* Consider further development of brainstorming ideas with constraints and tradeoffs.
* Explore alternative ideas based on further knowledge.

I am not sure what to put here. We have not had any appreciable changes in plan after the things I have previously described. Maybe we will put something here soon.

**6. Select an Approach**

* Review brainstormed information and answer any lingering questions.
* Narrow ideas down using a decision matrix.
* Decide on final idea, sometimes through consensus.

I guess I already talked about this. Our decision was to do Quantum Monte Carlo Worm Algorithm Simulations of an Extended Bose Hubbard Model of dipolar molecules in an optical lattice because we will be able to consider the full range of the forces and will be able to use large system sizes. The goal of this is to assemble a Zero Temperature Phase Diagram for our system and then do some rudimentary analysis into what temperatures these phases are stable through.

**7. Develop a Design Proposal**

* Explore the idea in greater detail (sometimes with annotated sketches).
* Make critical decisions such as: material types, manufacturing methods, or software .
* Generate through computer models detailed sketches to further refine the idea.

I am not sure what to put here either. I guess I should go back to the previous answers and spread them out more over all of these questions. I have already discussed our decision on the software to use and what computer simulations to run.

**8. Make a Model or Prototype**

* Make models to help communicate the idea, and study aspects such as shape, form, fit, or texture.
* Construct a prototype from the working drawings, so the solution can be tested.

The modeling of the physical experiment that we hope to run happened earlier and is described above. This is when we decided to use an Extended Bose-Hubbard model with soft core dipolar bosons to model an optical lattice experiment.

**9. Test/Evaluate Design**

* Design experiments and test the prototype in controlled and working environments.
* Gather performance data; analyze and check results against established criteria.
* Conduct a formal critique to flesh out areas of concerns, identify shortcomings, and establish any need for redesign work.

I guess that this phase of the process was collecting and analyzing the data from the simulations and constructing the phase diagram. I can discuss the data analysis techniques and the statistical thermodynamical theory behind them.

**10. Refine the Design**

* Make design changes; modify or rebuild the prototype.
* Make refinements until accuracy and repeatability of the prototype’s performance results are consistent.
* Update documentation to reflect changes.
* Receive user’s critique to provide outside perspective to help determine if established criteria have been met.

I am not sure here either.

**11. Create or Make Solution**

* Determine custom/mass production.
* Consider packaging.

No clue here.

**12. Communicate Processes and Results**

* Communicate the final solution through media such as PowerPoint, poster session, technical report.
* What remaining work needs to be done.

I have made several presentations for several different events. I presented the research to a group of physicists at OSU, I presented at DAMOP 2013 in Quebec, and I have presented for my Capstone class.