Interesting stuff Senthil has said to me

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1 (non) Fermi liquids

- non-fermi liquids should be describable by wormhole lattices. c.f. maldecena / qi for the two-site lattice case (wormhole rvb?!)
- a simpler example of bose metal is parton $b = d^\dagger_\alpha d_\beta \epsilon^{\alpha\beta}$, with a mean field ansatz that breaks $SU(2) \to \mathbb{Z}_2$. Since the $\mathbb{Z}_2$ gauge theory is much easier to treat than the U(1) gauge theory this bose metal is simpler
- for the $c = 1$ bosons, the nontrivial thing is the following: all non-forward scattering things are irrelevant. But there are now MULTIPLE TYPES of foreward scatterings: you can have density-density interactions, which are always marginal, as in a Fermi liquid. But you can also have current-current or density-current(?) foreward-scattering interactions, whose relevance depends on the scaling dimension of the boson. If they are irrelevant, can argue for stability by saying that the RG flow only occurs for a finite time, and therefore if the k_F gets renormalized, it only does so by a finite amount.
- why the patch construction? In standard FL, the different directions are uncoupled and the scattering between directions is irrelevant—this is why it makes sense to focus on single patches. but when you have a gauge field, the coupling between the fermions and the gauge field is relevant, and so there are defs gonna be scattering processes—hence why it makes sense to work with variables in which the scattering is easily formulated.
- is "some correln funcs have $2k_F$ oscillations" the same as "you can describe things with a bunch of 1+1D theories in momentum space"? Probably not; if you look at e.g. density-density correlators at $2k_F$, they need to be such that displacing the momentum difference in the y and x directions gives you different results for the way that the correlator changes, due to the curvature of the FS.
- the one coupled wire thing he would like to do: construct the fermi liquid from coupled wires. Apparently this is hard once you bosonize.

2 Cuprates

- how can we extract a notion of scattering rate for nfls, when qps aren't well defined? The only thing we have acess to is $\sigma(\omega)$. So try things like $(\int \omega\sigma)/\int \sigma$, which if σ has some kind of drude form is going to be proportional to the scattering rate. So can we use anything from quantum chaos / dynamics stuff to set a bound on transport in the cuprates? senthil now thinks that it's unlikely.

- Is transport just hydrodynamics? not for sure—in the cuprates it seems like you're not really in the hydrodynamical regime. Hydrodynamics works when scattering is on time scales long compared to system size—there were some irradation experiments done in the cuprates that suggested that the functional form of the linear in T resistivity doesn't change when disorder is varied.

- Maybe the $p \sim 0.19$ point is an unnecessary quantum critical point (even though it's in the superconductor).

3 Possible phase transitions / phases of matter

- kondo problem: there's some transition where we go from a large fermi surface with both the moments and the electron, to a small FS, where the local moments are localized. This transition changes the topology of the FS, BUT it may be continuous! If the magnetic ordering that accompanies the transition has some weird incommensurate wave vector, then the folding of the BZ that happens when the order is formed can complicate things—not a priori impossible to have a smooth transition.

- note that liquid metals are a thing (mercury), which is kind of crazy—the resistance doesn't really change appreciably in the solid-¿liquid transition, which is v. cool. So then there's a question: can you have a liquid mott insulator? Given that you can have a metal-insulator transition in a liquid metal as the liquid turns into a gas? Interesting to think about the fate of antiferromagnetism as you melt the liquid: since liquid has translational symmetry, there can be no order parameter with finite q, hence antiferromagnetism is strictly speaking impossible. But types of nematic spin order are possible. Can we have a liquid spin liquid? What happens to the TC if you make the lattice dynamical?

- our paper actually provides an example of a direct continuous transition out of a U(1) spin liquid (by considering our SU(2) theory and higgsing it down with a scalar in the SU(2) vector rep), even though the quantum numbers of the e and m particle are such that nothing can be condensed, and so a transition to the trivial phase naively seems impossible. (usually expect Higgs transitions to be first order; see e.g. coleman-weinberg potential)

- wants to solve phase transitions out of fracton phases: apparently he knows how to do a phase transition between a stack of 2d $\mathbb{Z}_n$ gauge theories and a 3d SF

- is it possible to have different order phase transitions at different points in momentum space (cuprates)?
- Consider transition where a roton minimum moves to the lowest energy. This would describe some sort of superfluid to supersolid transition, since we'd have ordering at some finite wavevector. Most people'd say this transition is first order, but who knows?
- When the brain enters the phase of sleep where you get the coherent neuron firing, is this a phase transition? What about phase transitions where a bunch of coupled oscillators synch up their oscillation frequencies? Is life a phase transition?!

4 Gauge theories / topological stuff

- why is an ordered state for SU(2) gauge theory at $\theta = \pi$ expected to not exist? Can start with spome spin problem on the square lattice in 3+1 dimensions and map it to an SO(5) sigma model; this can in turn be written as SU(2) gauge theory with theta=pi. Then the LSM theorem in the spin model precludes a trivial GS. Could form a spin liquid U(1) or $\mathbb{Z}_2$, or could break T.
- Can consider

5 RG stuff

- In the patch fermion approach to nfls, the point of the singular self energy to set up the RG flow is basically to take a "shortcut" on the RG flow away from the free fixed point: we are indeed not going to generate a singular term in RG, but we take inspiration from RPA to guess at a scaling form that we might have in the vicinity of the fixed point, which is a prohibitively long ways away from the free point. Once we've made that guess, we hope that the guess lands us near the fixed point we would have flowed to from the original nearly-free fixed point w/ only analytic terms.
- is it possible to have "symmetry-enforced symmetry breaking"? Seems like this is what goes on with the SU(2) T breaking example—hard to imagine that there could be a gapless symmetry-preserving state, given that preserving the symmetry means that the theory would be confining. (is EM a dumb example of this—i.e. is it possible to have a phase where both electric and magnetic dof are confined? well IDK, maxwell is always in the deconfined phase. Seems like you'd want to consider a gauge theory with both magnetic and electric 1-form symmetries, where a phase with both symmetries preserved is impossible. Seems reasonable for e.g. $SU(n)/\mathbb{Z}_m$ gauge theory)
- symmetry enforced symmetry breaking: consider any finite density of bosons, with all the symmetries you want: rotational symmetry, translation, U(1). Then the only known ground states are symmetry-breaking, viz a superfluid or a crystal. This is probably a promising place to look for sym-enforced sym breaking.

- how is mean field theory consistent with RG above four dimensions? After all, MFT says we can get ordered states, but RG says that the ϕ^4 term you'd need to stabilize the OP in LG theory is irrelevant... given that the vev of the OP is propto $1/\sqrt{\beta}$ where β is the coefficient of ϕ^4, how is RG consistent with a nonzero vev in the IR when ϕ^4 is irrelevant? The answer lies in the notion of a dangerously irrelevant operator—it modifies the flow of the ϕ^2 term sufficiently so that the IR is actually compatible with mean-field.

- anytime you have two marginal perturbations where one of them can be made negative, you have to worry about instabilities to first order transitions

- take two cfts and couple them with a relevant perturbation—how does the geometry evolve from two decoupled AdSs to a single thing?

6 Experimental things

- SuRu — the idea was to apply anisotropic strain in the xy direction to separate the px + ipy parts. When they did this T_c increased to 3K from 1K, which already was in tension with p+ip hypothesis. So wtf, there's a phase transition between p and s wave as a function of strain? Anyway, the 3K thing is easier to do NMR measurements on, since NMR needs a magnetic field and the low T_c means you have to use REAAAALY low B fields so as to not destroy SC. But anyway, new measurements show that you still don't have a zero NMR response and so yeah, p+ip is deadline

- apparently people have observed a roton minimum past the particle-hole continuum in He3!

7 TMDs, bilayer graphene, etc.

- The correlated insulator in tbg occurs at commensurate fillings. Therefore it can't be any kind of weak coupling thing; it must be because of interactions. Can hence ignore analyses that are predicated on being near weak coupling.

8 Random stuff

- If gravity is kinda like a non-abelian gauge theory (e.g. weinberg's book), what's the essential physical reason for why it's not confining? Probably something to do with anti-screening—gravitational charges can't be negative

- The orthogonality catastrophe is really just a statement about how classical mechanics emerges from quantum mech via decoherence: suppresses tunneling or something. it should also happen for e.g. a bath of oscillators. Also apparently there's a phase transition when you have a two-level system coupled to a bath of oscillators as a function of the coupling strength, where you go from a classical thing to some quantum thing; some sort of coherence-decoherence phase transition.

- replica symmetry breaking when doing the ashkin teller model or whatever—what does it mean? Should be able to do this using schwinger keldish and see all the replica symmetry breaking stuff in that language.
- Apparently there's a roton minimum in the quantum hall effect.

9 Life philosophy and academia

- research statements aren't very important for theorists, but experimentalists will take them seriously. Also, know that when getting hired people who don't work in your field will have a lot of say in the matter, so it's good to be able to talk to lots of different people. Best situation is one where everyone thinks that you're their guy. E.g. watanabe got the hep-th people to think he was theirs, and the cmt people to think he was theirs. This is ideal.
- what's the endgame in strongly correlated physics? Does it matter if there's not an endgame? some people do cmt cause they can do engineering and make cool shit, but that's not why we do it—we do it b/c it's fundamental physics! But still good to know what it means to "solve" a problem. Xiao-Gang said that when he was young, "solving" a problem meant getting a mean field theory for it. What do we mean now?
- There are three classes of theorists: calculaters, numerical people, and talkers. Senthil is a talker.
- Since my last progress report, I have been splitting my time between doing research and digging deeper into some of the foundational results in condensed matter theory and quantum field theory.

  Research-wise, I recently finished up a project with my adviser and a postdoc at MIT on a new way to think about what kinds of phase transitions are possible. The point of the paper is very simple, and in my opinion is the coolest project I've been a part of so far as a physicist. While the message of the paper is simple, some of the technical details that we needed to sort out were not, and the project ended up being a long effort than we anticipated. The paper is currently under review at PRX. I have also been working on a project with a grad student from Cornell on a topic relating to high energy physics

  This summer I attended the month-long TASI summer school on quantum field theory, which is a competitive summer school for grad students and postdocs in high energy theory. I met a lot of really great people there (including the student from Cornell that I'm currently working with), and learned a lot of things about quantum field theory that I hope will find applications in my future research work. Additionally, in December I gave an invited talk at a conference on quantum computation in Shenzhen.

  Although it likely is not germane to this report, I also spent a lot of time in the past year learning Chinese. I now speak fairly fluently, and have

For the coming year, I plan to spend my time fully on research, splitting up my time between working on problems that are 1) amenable to being solved with the high energy physics techniques that I've accrued over the last couple years, and 2) which are of greater relevance to current experiments. These two groups of problems are essentially disjoint sets, but I think that working on a relatively diverse array of questions will be a fun and rewarding research strategy.