Happy New Year from SSX!

There's a lot of stuff here... not all of it pertains to everyone but I wanted the whole plan for the next few months in one place...

I can only hope that 2002 is as successful as 2001 was! We had some success with the 3D magnetic probe array on SSX, we re-designed and re-configured the machine to make SSX-FRC (with collaborator Mike Schaffer), we got nice numerical results from TRIM and the particle code (with Bill, Gang, and Slava) and we got some nice results in the sodium experiment (with Amy). We submitted and/or published six very solid papers in 2001 on our 3D reconnection results, energetic particles, simulations and liquid sodium results (note the heavy undergraduate participation... 5 different students!)...

1. M. R. Brown, C. D. Cothran, M. Landreman, D. Schlossberg, and W. H. Matthaeus, "Observation of energetic ions accelerated by three-dimensional magnetic reconnection activity", Science (submitted 12/01).

2. C. D. Cothran, M. Landreman, W. H. Matthaeus, and M. R. Brown, "Three dimensional structure of magnetic reconnection in a laboratory plasma", Phys. Rev. Lett. (submitted 12/01).

3. M. R. Brown, C. D. Cothran, M. Landreman, D. Schlossberg, W. H. Matthaeus, G. Qin, V. S. Lukin, and T. Gray, "Energetic particles from three-dimensional magnetic reconnection events in SSX", Phys. Plasmas (to appear, 5/02).

4. G. Qin, V. S. Lukin, C. D. Cothran, M. R. Brown, and W. H. Matthaeus, "Energetic Particles and Magnetohydrodynamic Activity in the Swarthmore Spheromak Experiment", Phys. Plasmas **8**, 4816 (2001).

5. V. S. Lukin, G. Qin, W. H. Matthaeus, and M. R. Brown, "Numerical Modeling of Magnetohydrodynamic Activity in the Swarthmore Spheromak Experiment", Phys. Plasmas **8**, 1600 (2001).

6. A. B. Reighard and M. R. Brown, "Turbulent Conductivity Measurements in a Spherical Liquid Sodium Flow", Phys. Rev. Letters **86**, 2794 (2001).

We modified SSX in November by removing the plates at the midplane and allowing full merging (forming an FRC or doublet-CT). We had a nice

visit from Tim Gray just before we shut down SSX at the end of the year. We got some new 3D magnetic data correlated with density data from the He-Ne interferometer (stay tuned). The struggle is that without the backwalls, we need to rely on magnetic pressure balance east to west. Also, the RGEA signal is much broader in time and (likely) not as locallized spatially. We'll rely on SXR in the future (see below).

Plans for the New Year

1. **Experimental agenda:** Initially, we'll run with the large (50 cm) flux conserver and the 3D probe array with the He-Ne interferometer. I'd like to get some (more) data correlating current channel width (without back plates) and density (see below). Next step will be the 50 cm flux conserver and the distributed 3D array (assuming we get enough probe stalks wound by Andrew and Mike, see below). After we learn how to plot field lines and flux surfaces there, we'll swap in the new, tighter SSX-FRC 40 cm flux conserver (with the distributed array and He-Ne interferometer). Finally, we'll install the reconnection control coil and associated power supply with SXR and Mach probes (see below).

2. **SSX-FRC flux conserver (MB, Steve):** I need to re-confirm the length of the new outer electrode (long enough to reach from the flux conserver to the high current flange... allowing for a 1" gap at the midplane... taking into account the recesses at the flange and FC... see below). We'll weld the copper flanges to them then ship them out for tungsten coating (at Plasma Technology Inc in CA unless Steve has an alternative plan). When we get them back, we'll weld them to the flux conservers, weld on bosses for the supports and install in SSX.

   Details for Steve only (I have drawings for all this... but maybe check my reasoning here): We basically want to maintain the same 1.0" gap between flux consevers for SSX-FRC as we did for SSX. SSX-FRC doesn't have the back wall that SSX had so the outer electrode (sometimes called the entrance region) needs to be a bit longer to make up the difference. Something I'd like to verify is that the length of the new copper cylinders is 12.00" like the old ones (as designed). So... we re-measured the length the old outer electrodes (from the copper plate to the flange) and we got 10.57" (on average, for both east and west). The re-measured length of the flux conservers themselves was 12.175"

on average (12.0" for the cylinder plus end plates minus recesses) so the overall length of the whole unit was 22.745". For SSX-FRC, we need the same overall length. The new length of the SSX-FRC flux conservers will be 12.0" + 0.125" (one plate) - 0.065" (new depth on large groove) = 12.06". So 22.745" - 12.06" = 10.685" (new distance from copper plate to the flange... about 0.115" longer than before). Now to figure out how long the tube should be cut... $L_{cylinder}$ = 10.685" + insert into plate - recess into flange = 10.685" + 0.065" - 0.125" = 10.625" (ie 10 5/8"). In the end, not too different from the old one but we'd like to make dimensions at the merging region the same as before so we can make comparisons.

3. **SSX-FRC probe array (Andrew/Mike):** Everything is in place to begin winding the new probe array (25 stalks). Steve is finishing up the Delrin coil forms (first two are done now). The new forms are 50% bigger than the old ones (3/16" vs. 1/8" diameter) so our signal should be a factor of 2.25 bigger with the same number of turns. The rectangular x,y pair went from 1/4 x 1/8" to 3/8 x 3/16" (.031 in^2 to .07 in^2). The round z probe went from $(\pi/4)(1/8)^2$ to $(\pi/4)(3/16)^2$ (.0123 in^2 to .0276 in^2). In the old setup, we partially compensated on the z probe by winding 10 turns (compared to 5 for x,y) so the old probes had total area of 0.156 in^2 for x,y and 0.123 in^2. Everything gets balanced in calibration.

   We can further boost the signal by winding more turns. We need to worry about fitting more wire inside the thin wall tubing so Andrew and Mike will need to experiment a bit (we have some skinnier wire but it's a pain to work with). You could balance x,y with z a bit better by winding 6:15 for example (would boost overall signal by factor of 3 but might be too fat to fit in the SS tube). You're basically trying to find a rational approximation to π or actually $\pi/8 \cong 6/15$. I think it would be useful to wind some prototypes with different number of turns (and maybe different wire) and compare to the old set. We have a test stand all set to do this. Stainless steel tubes and flanges are here (Steve will begin machining those for the welder as soon as the forms are done). We need to finish the new housings (aluminum tube, Delrin cap and new 50-pin connectors, we order these from TK wire and cable, Jim). New probes could be ready to use with the old flux conservers in a month or so.

4. **SSX-FRC reconnection control coil (Steve and welder Nick A):** We decided after re-measuring the ID of SSX (23.5" not 24") and after the nice new flux conservers arrived (precisely 16.00" ID and 16.25" OD) that the RCC ID should drop to 17". This will give us only 3/8" clearance to the flux conserver (which is better from a physics standpoint) but 7/8" to the SSX inner wall (which is better for ceramic supports, etc). The RCC is all re-designed, we need to get together with welder Nick A at Custom Vacuum, get a final quote on the vacuum jacket and wind the coil. I guess a remaining issue is whether we can do the RCC sidewalls ourselves (electron beam cutting?).

5. **SSX-FRC RCC power supply (Jim):** We could start ordering electronics right away. This will involve a high current, 100 V charging supply (few amps so we can fill up the caps with 50 C of charge in a few minutes... I have a Sorenson that might do the trick), plus SCRs, diodes (capable of 300 A pulses), lots of caps (0.5 F worth), buswork, support stand... all triggered optically. I've already mentioned some of this to Jim. There will be some art to this since (among other things) the inductance of the RCC could vary by a factor of two. If the pair (N turns each) are close together then the inductance goes like $(2N)^2$. If they are far apart, it goes like $2N^2$. Anyway, the power supply should be flexible so we can add caps if neccessary.

6. **SXR and Mach probes (MB):** Once items 2-5 are on their way, I'll get back to the SXR and Mach probe design. We have permanent magnets and vacuum hardware for the SXR, I need to finalize the design (some tricky alignment issues). SXR flux is low in SSX but Paul Bellan had good luck with a similar design at Caltech. I think we'll have to rely on this diagnostic for energetics in the future. This is actually an excellent student project (Andrew made some headway on this two summers ago)... I'll be on the lookout for someone. We have a prototype Mach probe on loan from Princeton. We need to install it (maybe in the 50 cm flux conserver) and test out electronics (differential amp).

7. **RSI paper (Matt):** Matt should take the lead on this with Chris' help. Working title is "Novel multiplexed measurement of a magnetic field in three dimensions for turbulent plasmas". There are potentially lots of figures and lots of text available (see Mark Kostora's notes plus

bits from earlier papers for background). Matt should get together with MB and Chris to develop 12-18 figures or so including the best data from the Helmholtz coil and pulsed line current experiments. We'll also need photo/schematic of 3D array, probe schematic, MUX schematic, flow chart for system, raw de-MUXed data, etc.

8. **Next big paper (Chris, Bill, Phil E):** lots of topics for the next 3D reconnection paper(s)... we want to analyse our 40 shot data (Bill has offered to help Chris with this... maybe Phil E can help with 3D statistics too), Chris has some analysis of a χ^2 measure of $\nabla \cdot \mathbf{B}$, we have some initial results of merging with the interferometer... I'd like to get a plot of current channel width vs density (interesting if it scaled like $n^{-1/2}$), it'll be interesting to compare merging with and without the plates at the midplane, we have lots of other old scans to look at (esp east/west timing delays), etc.

9. **Other new papers and presentations (AAPT, ICC, CT):** I'm giving an invited talk at the American Association of Physics Teachers (AAPT) meeting Jan 21. Chris and I go to Maryland for the Innovative Confinement Concepts meeting 1/22-25. We need to send our contributions to Alan Hoffman for the FRC talk. We need to arrange for travel to the CT workshop in Seattle in Feb 25-27. At some point, Bill, Gang, Chris, Slava and I should re-visit our "paper 3". I'd like Chris, Tim and Slava to work on a "density diagnostics on SSX" paper (before Tim's and Slava's theses get too old). Chris and I are taking the SSX show on the road this spring to U. Maryland 3/13/02, U. New Hampshire 3/18/02, Dartmouth 5/10/02 (maybe U. Wisconsin and U. Iowa too). I'm sitting on an NSF panel Mar 4-5 in DC.

10. **Matt's thesis:** Matt's taking a credit for thesis writing this winter so he should have time to synthesize all this material. A big part of the thesis will be the RSI paper so that will serve double duty. Matt: remind me to send you my revised reference list... your thesis should have 100 references easy.

11. **MAYA rendering (Jean, Nick O):** Prof. Jean Griffin (CS dept) and senior physics major Nick Ouellette (CS honors minor) will be working on rendering some of our 3D data using a very high end program called MAYA. MAYA has been used in movies like Shrek, Jurassic

Park, Matrix, etc.

12. Φ_{gun}**:** We need to check our stuffing flux circuits. I'm still puzzled as to why west spheromak is wimpier than east (for the same bank energies). I wonder if we're not getting as much flux to the west. Chris and I will re-measure the gun flux when we get back (with simple flux loops).

13. **E-mail list:** Finally, we need to come up with a way to diseminate our results. Maybe we can zip together the PoP, Science and PRL papers and e-mail them off. Here's my list (17 so far, Bill: do you have Field, Chandran, Blackman e-mails handy plus any additions?)...

    1. Paul Bellan 2. Bob Rosner 3. Amitava Bhattacharjee 4. Steve Spangler 5. Spiros Antiochos 6. Terry Forbes 7. Jim Drake 8. George Field 9. Ben Chandran 10. Eric Blackman 11. David Montgomery 12. Walter Gekelman 13. Reiner Stenzel 14. Eugene Parker 15. Masaaki Yamada 16. Hantao Ji 17. Dana Longcope

SSX is powered down (on Christmas eve) and the power to Dupont went out on the day after Christmas (as expected). Power was back up in Dupont when I checked on Friday 12/28. We'll get SSX back on the air in January sometime.

cheers and happy new year, mb