

Science AMA Series: I'm Jena Meinecke, an Oxford fellow studying the origins of magnetic fields in the universe. Next week I'm doing an experiment with the world's largest laser at Lawrence Livermore N

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Abstract

Hi, Reddit! I've literally prepared for years and travelled around the world for an experiment I'm doing next week. And I'm super excited to geek out with you all about it. I'll be using the world's largest laser – the National Ignition Facility (NIF) at Lawrence Livermore National Laboratory in California – to figure out how magnetic fields came into existence in our universe. It's a question that's consumed me and driven years of research: I've used other high-energy lasers to create scaled galaxy clusters and supernovas that could fit in the palm of your hand. Using these cosmic objects, I've generated seed magnetic fields—the “grandparent” fields of our universe and amplified them to current observations. But to be able to understand the origins of magnetic fields, I'll need to measure one of the most coveted phenomena in laboratory astrophysics: turbulent dynamo. There's only one laser on Earth that can tell us the origins of magnetic fields in our universe, and that's the NIF laser. We have three shots to gather our data, and next week we will take our first shot! So that's what gets me up in the morning. I'm incredibly excited to share our journey with YOU! What would you like to know? AMA!!! Bio: <https://www2.physics.ox.ac.uk/contacts/people/meinecke> Publications: https://www.researchgate.net/profile/J_Meinecke/publications Epic laser: <https://lasers.llnl.gov/> I'll be back at 1 pm EST (10 am PST, 6 pm UTC) to answer your questions, ask me anything! I'm here at the Lawrence Livermore National Laboratory and the National Ignition Facility, THE BIGGEST LASER ON EARTH, is just across the road!!! Your questions are WONDERFUL and I'll start answering them now. UPDATE: We are wrapping up here and there are many people with pizza sitting close to me. I need to deal with this... I LOVED your questions and wish I could keep the conversation going. Please feel free to follow my updates on Twitter: https://twitter.com/Jena_Meinecke. SIX MORE DAYS UNTIL SHOTS!!! I will definitely be tweeting. Look out for updates!

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JENA_MEINECKE [R/SCIENCE](#)

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Bio: <https://www2.physics.ox.ac.uk/contacts/people/meinecke> Publications:

https://www.researchgate.net/profile/J_Meinecke/publications Epic laser: <https://lasers.llnl.gov/>

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Jena_Meinecke , r/Science ,
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Thanks for doing this AMA. Please could you explain more about the process of creating "scaled" galaxy clusters or supernovae? How do you do this using lasers?

[reformed_nice_guy](#)

You're welcome! I'm super excited to share our work today.

The field of laboratory astrophysics is really new! Thanks to the invariance of magnetohydrodynamic equations, we can create scaled astrophysical objects in the laboratory that are identical to objects we observe in the universe. For instance, we can create supernovas that could fit in the palm of your hand!!! So instead of waiting around hundreds or thousands of years for these events to develop, we can watch their entire lifespan in fractions of a second, on tabletop scales.

So let's discuss the recipe:

week I'm doing an experiment with the world's largest laser at Lawrence Livermore N, *The Winnower* 3:e145527.79401, 2016, DOI: [10.15200/winn.145527.79401](https://doi.org/10.15200/winn.145527.79401)

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Step #1: Pick your astrophysical event. Do you want to create a supernova, a jet, or galaxy clusters? I choose turbulent dynamo-- the phenomena that explains the origins of magnetic fields in our universe. Turbulent dynamo occurs in (you guessed it!) turbulent plasmas where the magnetic energy is on par with kinetic energy. What does that mean? That the magnetic fields play an IMPORTANT role in the dynamics of the plasma.

Step #2: Pick an appropriate laser. The BIGGER the BETTER. We want hot, fast moving plasmas. For that we have to use the biggest lasers on Earth. Cue NIF! So why NIF?? This is the ONLY laser on Earth that can create plasmas hot and fast enough to generate TURBULENT DYNAMO-- the "holy grail" of laboratory astrophysics. NIF can generate plasmas with large magnetic Reynolds numbers $R_m \gg 1$ AND $R_m \gg Re$. This is the goal.

Step #3: Carefully, ever-so carefully, make a delicate target that is within 50 micron tolerance. Check out our previous target designs (which are not so different for NIF): goo.gl/SD1aey

Step #4: DESTROY your target with the most powerful laser on Earth!!

Step #5: Collect pretty pictures and data from your various diagnostics.

Step #6: Now comes the hard work. What does it all mean??? We spend a lot of time here.....

For more information about our work, check out this link:

<http://physicsworld.com/cws/article/news/2014/jun/06/lasers-ignite-supernovae-in-the-lab>

Are magnetic fields a separate physical entity from electric fields? Some textbooks say that magnetic fields are "just relativistic electric fields" and imply that the only "real" thing is the electric field, which seen by a moving observer "looks" magnetic. Other textbooks talk about magnetic fields, or the electromagnetic field, as having its own independent reality in which case the electric field can't be "all there is." I'd love any insight you could shed on this question!

Edit: textbooks

[peterfreed](#)

This is a great question and certainly not an easy one to answer. Magnetic fields and electric fields have a very special relationship. They are separate entities but very much linked. For instance, when you have a moving charge, you necessarily have a magnetic field.

In our experiments, we generate "seed" magnetic fields by something called the Biermann Battery mechanism. What actually happens is:

(1) Asymmetrical shock waves are driven by lasers, focused onto a carbon rod target, in a gas-filled chamber.

(2) Misaligned density and temperature gradients then generate a magnetic field. For this, we look back to our (oh so favorite) Maxwell's Equations.... let's leave this as an exercise for you....

(3) These magnetic fields are transient-- so we have to work hard to keep them alive!! This is easy if we use a big laser.

So in answering your question, for our work, you can think of currents (and therefore electric fields) being generated and manipulated in the plasma. These currents GENERATE magnetic fields. So BOTH phenomena are important.

Hi Jena and greetings from IPP! Glad to see you're still going strong on this subject and got a grant for

NIF usage!

My question is about singling out the turbulent dynamo in your experiments:

- 1) How do you separate the dynamo effect from a ton of other stuff (Weibel, Biermann battery) that might be going on?
- 2) Is the setup of this experiment similar to what you did for your Nature paper, just on a larger scale?
- 3) And what are your diagnostics in place to see all this crazy stuff going on at once, especially since you've got just three shots to get things right?

[burningbunny](#)

Hi there IPP! These are great questions-- I get asked these ALOT.

(1) Separating out the dynamo effect is really important. There are two culprits which like to make life hard for us here: Weibel instabilities and return currents. Luckily, return currents happen very quickly and dynamo develops over much longer times (nanoseconds). Weibel instabilities grow in collisionless plasmas where the long-range electromagnetic forces dominate local collisions to point where these collisions can be neglected. We have carefully designed a target and laser assembly that will generate COLLISIONAL plasmas, so the Weibel contribution will be very minimal. As a sanity check, we run powerful FLASH simulations to verify the dominate mechanism. In our experiment, we will first generate the magnetic fields with Biermann Battery, but then turbulent motions will take over and dynamo will snuff out all other effects. In this paper (Meinecke et al. PNAS) I have great data to confirm this effect. Check it out!

(2) Without giving too many details, the setup is based on both the Nature Physics and PNAS paper. So colliding plasma jets that are made turbulent with a plastic grid.

(3) We are using x-ray cameras to image the turbulent structures, polarimetry and proton radiography to assess the magnetic fields, and a few other minor diagnostics as sanity checks. Let's hope they work!!

Thanks for doing this AMA. Why do you have only 3 shots for doing this experiment? Is there a short window of time or is it because of funding? Also, what are your controls to know that you are in fact looking at a significant result.

[bowlofpetuniass](#)

We are so happy to have 3 days to squeeze in as many shots as possible!! Each shot day is 24 hours- get as many as you can! For us, that means 2-3 shots per day.

The #1 goal of NIF is to support stockpile stewardship, so those shots take priority (and therefore a lot of time). However, the lab sees the importance of discovery science and has generously offered 8 teams time to do their experiments. There is a call for proposals each year, and teams compete to get their science to NIF. Check out the procedure here: <https://lasers.llnl.gov/for-users/nif-user-group>

It's hard to get more than 3 discovery science shots in a day because there are ALOT of things that have to be done in preparation. For instance, target alignment can take hours for a complicated platform. Fingers crossed ours doesn't take that long!!

What is it about the NIF laser system that makes it particularly well-suited for this type of research over any of the other world's most powerful lasers? Is it the radial symmetry of the NIF system? Could

similar experiments be carried out with, say, LCLS (the free electron laser at SLAC), the BELLA Petawatt laser at Berkeley, or the Texas Petawatt Laser?

[yoitspoe](#)

Great question!!

We want lasers that are high ENERGY which tend to be long-pulse systems. The most energetic laser on Earth is NIF, so it only makes sense to go for it! There are a few lasers with high energy too (not nearly as much as NIF) that have been used for previous experiments that led up to this: Omega (NY), Vulcan (UK), LULI (France), and Gekko (Japan) to name a few. However their delivered laser energy is less than tens of kilojoules. NIF can deliver megajoules!

I have two questions one personal and one scientific. For the personal question: I know that physics is unfortunately still a male-dominated field. Have you faced much sexism in your journey to become a physicist? Do you have any ideas or thoughts on how to increase the enrollment of female physics students?

Second question is scientific. I personally believe that putting too much faith in these analog systems can be dangerous. I know that PIC code runners will say that as long as your normalized plasma parameters are the same then your analog system should exhibit the same physics. However, I know from experience that this isn't true from a practical perspective (there's a big difference between gas and solid targets even if you scale lambda such that the critical density is the same, for example). What are the main differences between your analog system and the real deal? Are you worried that what you see, while very interesting, may not correspond to what's going on in the big universe?

[aggressively_laser](#)

(1) So true. I've been very lucky, in that I never feel sexism in our group. However, I have felt the stinging pain of unconscious bias. At larger meetings sometimes, people will accidentally (almost out of habit) ask the man next to me for an answer instead of me. Also, it's easy to feel isolated. I find the best solution is having GREAT female friends who support your work (even if they're not scientists) and communicating your concerns to people-- awareness is important. (Also, videos of pugs jumping up stairs never fails to elevate my mood)

(2) This is the most difficult step to make. Dimitri Ryutov has a phenomenal paper (<http://iopscience.iop.org/article/10.1086/313320/meta>) that highlight a laundry list of criteria for making scaled astrophysical objects. In practice, we want to make sure our magnetic Reynolds number and Reynolds number are very high. These two parameters are the ones that are different from the real thing, but still close enough to make an analogy. Also check out any of Alexander Schekochihin's papers-- they are fantastic!

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Well I'd have to put in a budget proposal first.... but this project might cost "One MILLION dollars!" and tell your "not so evil" friend, sharks are all ready scary enough-- they need no further advantage.

What advice would you give to young kids entering the field of science?

[deathless_lich](#)

BE PASSIONATE!! There is nothing better than loving what you do. People notice! I love being a physicist-- everyday-- and that enthusiasm encourages others to appreciate your work too.

Laboratory astrophysics is amazing. Using large lasers is incredibly stressful and rewarding-- all at the same time. When the sirens are ringing and you're preparing for a shot, there's this adrenaline rush that's addictive. Who knew science could be so exciting??

Furthermore, creating supernovas is deeply important. Our physical bodies are made up of stardust that was spread throughout our universe by a supernova explosions. The iron in your blood, calcium in your bones, and air you breathe are all here because of supernovas. AND I GET TO CREATE THEM!! That's why I love science.