We're scientists at the Max Planck Institute for plasma physics, where the Wendelstein 7-X fusion experiment has just heated its first hydrogen plasma to several million degrees. Ask us anything!

Wendelstein7-X [1] and r/Science AMAs[1]

[1]Affiliation not available

April 17, 2023

Abstract

Hi Reddit, we're a team of plasma physicists at the Max Planck Institute for Plasma Physics that has 2 branches in Garching (near Munich) and Greifswald (in northern Germany). We've recently launched our fusion experiment Wendelstein 7-X in Greifswald after several years of construction and are excited about its ongoing first operation phase. In the first week of February, we created our first hydrogen plasma and had Angela Merkel press our big red button. We've noticed a lot of interest on reddit about fusion in general and our experiment following the news, so here we are to discuss anything and everything plasma and fusion related! Here's a nice article with a cool video that gives an overview of our experiment. And here is the ceremonial first hydrogen plasma that also includes a layman's presentation to fusion and our experiment as well as a view from the control room. Answering your questions today will be: Prof Thomas Sunn Pedersen - head of stellarator edge and divertor physics (ts, will drop by a bit later) Michael Drevlak - scientist in the stellarator theory department (md) Ralf Kleiber - scientist in the stellarator theory department (rk) Joaquim Loizu - postdoc in stallarator theory (jl) Gabe Plunk - postdoc in stallarator theory (gp) Josefine Proll - postdoc in stellarator theory (jp) (so many stellarator theorists!) Adrian von Stechow - postdoc in laboratory astrophyics (avs) Felix Warmer (fw) We will be going live at 13:00 UTC (8 am EST, 5 am PST) and will stay online for a few hours, we've got pizza in the experiment control room and are ready for your questions. EDIT 12:29 UTC: We're slowly amassing snacks and scientists in the control room, stay tuned! http://i.imgur.com/2eP7sfL.jpg EDIT 13:00 UTC: alright, we'll start answering questions now! EDIT 14:00 UTC: Wendelstein cookies! http://i.imgur.com/2WupcuX.jpg EDIT 15:45 UTC: Alright, we're starting to thin out over here, time to pack up! Thanks for all the questions, it's been a lot of work but also good fun!

the WINNOWER

REDDIT

Science AMA Series: Hi Reddit, we're scientists at the Max Planck Institute for plasma physics, where the Wendelstein 7-X fusion experiment has just heated its first hydrogen plasma to several million

WENDELSTEIN7-X R/SCIENCE

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CORRESPONDENCE:

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Science AMA Series: Hi Reddit,

Just reading that article, it seems like there were lots of problems faced in the building of the Stellarator. What would you say was the hardest obstacle that you managed to overcome? And can you run through a(n extremely) simplified version of how you overcame it? Thank you.

had_a_beast

From the theoretical point of view it was necessary to understand the problems which result from three-dimensionality of the stellarator (loss of continuous symmetry and the related conservation laws). Regarding the construction the main problems were the construction of the superconducting non-planar coils. Also putting a big machine (about 700t) together with a tolerance of about 1mm is very demanding (e.g. wielding parts together will, if not done carefully enough, lead to a non-tolerable welding distortion). So, the most simplified version how to overcome construction problems is: work

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extremely carefully and constantly check quality (which will take time) (rk)

When do you think will fusion power become a reliable source of energy?

MrMemorie

According to the EFDA Roadmap it is planned that the demonstration reactor DEMO should produce first electricity 2050 (as usual: if everything works as expected). It will just be a prototype. After this one can start producing reactors on a large scale. So, the time when fusion power will become a reliable source of energy then depends how fast further reactors can be build. But roughly I would say, not before 2060. (rk)

What do you imagine the limits will be in terms of miniaturisation and portability?

WeaponsGradeHumanity

Regarding magnetic confinement fusion it will not be possible to do it with a small machine. The argument is roughly that we loose energy through the surface of the reactor by turbulence but energy is produced in the volume. So, we have to make the surface/volume-ratio small which can be done by making machines bigger (reducing turbulence is not possible). If a fusion reactor was to fit into a submarine we would not have to worry about money :-) (rk)

What do you imagine the limits will be in terms of miniaturisation and portability?

WeaponsGradeHumanity

Fusion reactors will always be big devices, so you will unfortunately probably never see a Mr. Fusion for your car. The reason is that a fusing plasma loses energy through its surface area (residual contact with the walls) and produces energy through in its volume. The larger your device, the better the ratio of volume to surface is, just like penguins are larger near the poles than the equator to compensate for the higher heat loss there.

ITER is going to be the first reactor that clearly passes the break-even mark, producing several times more fusion power output than heating power in - look at its size!

(avs)

How would you compare your approach to Lockheed Martin's?

What are the pros and cons of each?

shaim2

I have listened to a talk given by on of the Lockheed physicists. His main argument regarding the timeline was a management argument: they are a commercial company and can not afford to do research for decades since they have to make money. As a consequence they have to achieve fusion in about 5 years. He did not talk about the physical problems involved and how to get fusion in 5 years. The whole talk was just ridiculous. (rk)

How would you compare your approach to Lockheed Martin's?

What are the pros and cons of each?

shaim2

Honestly, we're quite sceptical concerning the very compressed timeline that Lockheed is proposing. Having been at the APS conference last November where they presented a lot of their work, many fundamental questions were left unanswered. How will they shield their superconducting magnets against neutron radiation? How will they suppress cusp end losses?

The stellarator and tokamak concepts are much more mature and the roadmap to fusion a much clearer path for these concepts.

We've written a short article about this here, check it out and let us know if you have more questions! (avs)

Could a fusion reactor ever be a good renewable source of helium? Or is the amount generated too small for practical use?

JimBroke

The amount of fuel fusion consumes, and hence the amount of helium produced, is very small. The helium we produce will be used in the reactor.

Thanks for all your efforts and all that you do to better understand our world, but could you possibly do an Eli5 on what this is for dopes like me? Thanks!

StopnFrisk

We want fusion reactions to create electric power.

The particles have to be very hot (hence fast) for them to do that - one hundred million degrees!

At those temperatures, everything is plasma, which is cool because we can control plasma with magnets. We think we've built just the right magnets to keep the plasma locked into our experiment and floating in mid-air. We're showing that we can keep these temperatures high for a long time (30 minutes!), so that in the future, others will be able to build a electricity-producing reactor from our design. (avs)

Hi,

What are the goals of the W7-X, i.e. what would be deemed success?

What's the next step for stellerators after W7-X? Could you guess how many iterations to a commercial reactor?

Thanks.

latecherry

The first objective is construction of the machine itself. The superconducting modular coils of this machine are a technological leap and W7-X has demonstrated that this can be done. The next important point in my opinion is the verification of the theory behind this design. W7-X is a so-called optimised stellarator and its design relies strongly on our numerical models and software. Demonstrating that our predictions are good would enable us to design the next machine. Finally, another very important point would be the investigation of steady state operation. this is one of the great advantages of the stellarator and very important for a reactor. In a project of this magnitude there are of course many other questions to be addressed, but these are, imho, the most important ones.

Hi, dear plasma physicists :). Today I read an interesting interview with Steve Cowley, the CEO of the U.K.'s Atomic Energy Authority. A short excerpt if I may:

With the recent news from Germany, and then China, it feels like fusion is gaining more public recognition as a realistic prospect— but exactly how realistic is it right now?

Those are both very good experiments, but they're not at the scale and power necessary to do fusion. They're not at the scale and power of JET. JET is the only one that can reach 200 million degrees.

So my question is: in your opinion or broad projections how far are you from reaching 200 million degrees Celsius hot plasma in Wendelstein 7-X?

Romulus13

Wendelstein 7-X is still in its infancy, and the energy we can stick in to the experiment is still limited. We're learning how to operate this new device and are setting new machine records daily. Right now, our electrons are at around 10 million degrees, the ions are about a factor 5 colder.

We do plan to reach the temperatures you mention, however Wendelstein 7-X is "only" a confinement experiment, which means that we're not going for fusion (which would require the radioactive tritium to do so effectively). Our goal is to demonstrate that we can reach these temperatures for an extended period of time (ultimately 30 minutes) as a major milestone on the roadmap to fusion power. In another comment, the eurofusion roadmap was mentioned, see that for more information! (avs)

I read that the plant will be operating and experimenting for decades. What are some experiments that you hope to do in 10 years or 20 years?

TheChickening

Always when a new large scientific facility is starting operation, the first focus is set on checking if all systems function correctly and to find and repair minor technical problems. For W7-X, this means currently, that diagnostics with which we can analyse the plasma are further taken in operation and calibrated. For such purposes we have limited the duration and heating power of the plasma. This is a continous progress and the device will be continously upgraded allowing us to extend the time we can hold the plasma and the achieved temperaure. While we currenlty achieve ~1 second, by 2020 we plan to reach 30 minutes. This is basically steady-state operation. The steady-state operation is important for showing, that the stellarator concept is suitable to be extrapolated to a Fusion power plant. In addition these long plasmas will be with high heating power, i.e. high temperatures and density -- both relevant for a power plant. After W7-X has demonstrated that the stellarator concept is suitable for power plant operation. After that we want to test different materials for the divertor (for the controlled particle and power) exhaust. For example tungsten could be an option for experiments beyond 2020. (fw)

I read that the plant will be operating and experimenting for decades. What are some experiments that you hope to do in 10 years or 20 years?

TheChickening

We want to demonstrate high plasma performance (high plasma temperature, high plasma density, good confinement) for discharges lasting as long as 30 minutes

What are the possible dangers associated with Fusion energy?

Joe_na_hEireann

Are you talking about dangers of a future fusion reactor?

The energy content in such a reactor is much too small for a catastrophic explosion as is in principle possible in a fission reactor. The amount of fuseable material in the reactor is tiny, it's basically a very dilute gas.

The largest danger lies in one of the materials that we will be using for fusion: Tritium is a (weakly) radioactive element that needs to be properly handled. One major risk is that there is a failure (or even an attack) at the tritium processing plant that would release this element to the atmosphere. Due to tight regulations on tritium handling, this is highly unlikely, but it's the worst case scenario we work with when doing risk assessment.

(avs)

Hi. I'm a physics student who is very interested in pursuing a career in the potential for fusion as an energy source after finishing university. What courses or extra curricula activities did you undertake to get where you are and would you recommend any specific opportunities to someone hoping to get a foot in the door in this area of physics?

BoogieTheHedgehog

Apply for an internship or a PhD position with us! http://www.ipp.mpg.de/hepp

Or get involved with any plasma physics lab, we're usually open to interns and there's always work to do! (avs)

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BoogieTheHedgehog

I can recommend you to visit the IPP Summer University for plasma physics taking part each September. It is intended for undergraduates and master students. Please visit http://www.ipp.mpg.de/summeruni/ there will be more information soon. (rk)

How close is the colaboration with others who work on projects in the same field? (for example ITER)

-5m

Within our community, collaborations are very close, since in the end we're all trying to solve the same problems. (jp)

What will it take for fusion power to overtake fossil fuel usage for power generation? How will fusion power affect existing alternative energy methods (solar, wind, hydro-electric, & wave/tidal)?

EnigmaticallySane

That's a difficult question, as it depends on the cost of a future fusion power plant itself and also the future development cost of generating electricity from alternative sources. A fusion power plant is a complex piece of technology and the capital investment will therefore be quite high. Still, current assessments suggests that fusion electricity should be competitive with power generation from renewable like wind and solar, and also fossils and nuclear if the negative external effects of these technologies are taken into account. Also, there is potential in fusion becoming a lot cheaper, if high temperature superconductors will become more advanced. (avs)

What will it take for fusion power to overtake fossil fuel usage for power generation? How will fusion power affect existing alternative energy methods (solar, wind, hydro-electric, & wave/tidal)?

EnigmaticallySane

I do not see any single source of energy on the horizon that would be able to satisfy the entire energy demand, and looking back at human history, I do not think there has ever been one. Fusion has a unique capacity to supply to a base load (which, I think, is a lot) and will, in the end, complement other sources and carriers of energy.

Will you be able to adapt the stellarator to account for the atomic and ionic turbulence that was discovered recently? Will this be a significant adjustment in terms of efficiency if the turbulence is accounted for?

sportsmc3

Thanks for sending the links! So this electron scale turbulence this article is talking about is notoriously hard to study, especially its interaction with ion scale turbulence (electron scales are a factor of 40 SMALLER than the ion scales, and even the ion scales need kinetic theory...), and in stellarator geometry we've only very recently started in tackling both scales. So soon (hopefully) we'll know enough and if this is the case we'll be able to optimise for it. (jp)

Will you be able to adapt the stellarator to account for the atomic and ionic turbulence that was discovered recently? Will this be a significant adjustment in terms of efficiency if the turbulence is accounted for?

sportsmc3

What recently discovered turbulence are you referring to exactly? (jp)

- Blackboard or whiteboard?
- GNU screen or tmux?
- Hot beverage of choice?
- Did you start doing plasma physics as an undergrad, or did any of you come from a different background? I love hearing stories about people making their own way across disciplines.

sedermera

whiteboard, tea I started as an astrophycist then I changed to plasma physics. (rk)

Can members of the public visit your Greifswald facility?

elpasorunway

Yes of course! See http://www.ipp.mpg.de/visitors for more information on how to set up a date for your visit. (jp)

1. As far as I see for the superconductor to work you need to come close to 0K which is many order of magnitude lower than the plasma inside. How do you isolate these two regimes? Is there any

experiment where comparable situations were achieved?

2. Do you have to take into account relativistic effects when simulating the plasma dynamics? Are your simulations based on some PDE/ finite elements machinery or are there reasons why this does not work?
3. If you build the machine far bigger, lets say 10x larger, would it still work or is it more feasible to build multiple machines with the same size? Thanks in advance!

vsilv

Answer to question 1: In W7-X we have reached plasma temperatures exceeding 50 million K with the superconductors staying at 4K. Other experiments like LHD in Japan or Tore Supra in France have achieved similar goals. This is done by having the plasma well confined by the magnetic field, and it touching components that are sufficiently water cooled to stay at at most a few hundred degrees C. A cooled wall sits behind these components and is not much more than room temperature. Outside this wall is a vacuum with special thermal insulation that allows the coils to be 4 K (-269 C) if cooled by a sufficiently powerful cryoplant. (ts)

Recently, the Chinese reported that their fusion reactor produced plasma at ~50 million degrees celsius for 102 seconds, while the Wendelstein X-7 achieved plasma at 80 million degrees for less than a second. While I know that the Wendelstein is planned to have plasma stabilized for 30 minutes, which would you say is more important to have an efficient, high energy-producing fusion reactor: temperature or time?

Obsidian_Phoenix

Please keep in mind, that W7-X started operation only in December last year -- and we already achieved such temperatures. The chinese device is operating since 2006!! For a power plant, we are aiming for steady-state operation -- so there is no time limit in energy production. The stellarator concept is exactly designed for steady-state. So, we reach the time and the temperatures!! Moreover, you need also a high plasma density. This can be achieved more easily in stellarators than in tokamaks. To summarise, you need high temperature, high density, good confinement of the plasma and operate this steady-state for high energy production. All of which stellarators are designed for. (fw)

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Obsidian_Phoenix

Both is important. To achieve fusion we need simultaneously a high temperature, a high density and a long energetic confinement time. Also the product of the three quantities has to cross some threshold for fusion to work (Lawson criterion). The energetic confinement time must not be confused with the time holding the plasma together. Even if we keep the plasma heated for 30min the energetic confinement time (some kind of cooling time) is much below 1s. We just started the Wendelstein experiments so it will take some time until we can reach the 30min. (rk)

While I know this device isn't designed for fusion, I was wondering if you could explain how one removes heat (for power) from a fusing plasma that is also being contained?

Where there any unexpected quirks of the five fold symmetry? Things that the simulations didn't predict?

Izawwlgood

In a power plant, the neutrons that are produced in the fusion reaction carry 4/5 of the energy that's released in the reaction in the form of kinetic energy. Since the neutrons are neutral, they don't care about the magnetic field and will fly onto the wall, where they'll be slowed down from the material. The material is heated up by this, and then you use this heat to run a steam engine.

Concerning the experimental results, we don't know enough yet to be able to tell whether there were any unexpected quirks, even though if there are, I doubt they'll have anything to do with whether Wendelstein 7-X has a five or six fold symmetry. (jp)

What do you think of ITER? Is it following the wrong track as compared to W7-X? Or are both projects complementary and necessary? What do you think of tokamaks in general?

loulan

Tokamak and Stellarator are complementary concepts. Its like diesel and gasoline. The more options, the better. :) In particular are synergy effects in developing technologies, such as superconductors. Of course we favour the stellarator, here, for its great advantages (intrinsic steady-state, no disruptions, higher density, ...) ;) (fw)

Looking into the future of fusion, do you believe it is theoretically possible to miniaturize fusion reactors, such as stellarators, to replace everyday sources of electromotive power, such as internal combustion engines and home generators, in our everyday life? What specific challenges would have to be overcome to achieve this?

skulduggeryplsnt

Heat losses in magnetic fusion devices are less and less of a problem with large devices. It is a sort of "economy of scale". Theoretically, a miniaturized fusion reactor would be possible if the causes of heat loss (for instance turbulence) were somehow eliminated. There is no known way to accomplish this. (gp)

Hey there, first - amazing work you do there!

Question - what materials do you anticipate to use as the radiation shielding on an industrial scale rectors?

I believe there is a big issue with the materials being consumed by radiation, and regulations saying that the half-life of the material afterwards must be low (I don't remember the exact number, something like 50 years).

Cheers!

MoltenSlag

A fusion power plant has two layers around the plasma. First is called "blanket". This is a complex technology component for which different concepts exist. A European concept is called Helium Cooled Pebble Bed (HCPB). The blanket absorbs nearly all the neutrons and using Lithium and Beryllium, the neutrons are used to produce our fuel -- tritium. And at the same time the energy of the neutrons is transported away by cooling the blanket. Only few neutrons pass the blanket. After the blanket is a shield. This shield could be just steel, which would be a cheap option to shield the remaining neutrons. Both the blanket and shield is slightly activated by the neutrons. However, the half-life time is only a few decades. So the activated material can be recycled after a few decades -- this is enourmously better than in fission, where there are long lived activation wastes with thousands of years half life time. So radiative waste is no real problem for a fusion power plant. (fw)

How many people are working at this project and did all people study physics? Did some study Engineering, oder Mathematics?

bene20080

We have around 500 employees in each branch (Garching with their tokamak, ASDEX and Greifswald with our stellarator, W7X). Many of these are engineers, technicians, even woodworkers, electrical engineers, software developers, all sorts! Since the experiment has completed construction gone online, we've seen a shift towards more physicsists, but we still need a ton of technical support.

(avs)

How many people are working at this project and did all people study physics? Did some study Engineering, oder Mathematics?

bene20080

In Greifswald there are about 400 staff members. Of those are about 100 scientists. The scientists are mostly physicsts, but also a few mathematicians. From the other staff there are quite a few enigneers and technicans. (fw)

Hi! Two questions:

1. MIT recently published work about successfully modeling and figuring out where plasma turbulence and heat loss is coming from. Will you be able to account for this in the current tokamak or stellerator designs or will a new design have to be created?
2. How small could we make a fusion reactor? Do you think we might ever be able to have transportable mini reactors say in a car or maybe ironman style or are they something that you anticipate due to requirements and constraints will always be giant?

Thanks!

masterfo0

To answer question 1: Turbulence and heat loss can indeed now be taken into account when designing stellarators (and also tokamaks, even though with tokamaks there's fewer degrees of freedom in the design). This is of course easier when you start from scratch, but also existing experiments (like Wendelstein 7-X or the small stellarator HSX in Madison, Wisconsin, USA) can change their magnetic fields with the aid of auxiliary coils, so that theoretically the turbulence can be reduced. It's quite tricky to do that though, because while you're optimising for turbulence other things might get worse, like the confinement of particles for example, so one has to take everything into account simultaneously.

Question 2 is being addressed in the response to https://www.reddit.com/r/science/comments/46k5y4/science_ama_series_hi_reddit_were_scientists_at/d05r0o2 (jp)

Would there be a difference between a stellerator on earth or one in space?

tijno_4

So, you're question started quite a vivid discussion amongst all of us :) As the main point: it would be aweseome. You'd get your vacuum for free :) But, most of the other components of the current machine would probably still be there, as you'd still need the magnetic field and the support structure for the coils. I think getting it up there might be challenging... (jp)

I'm a student planning to study computational electrodynamics and hopefully pursue a career in your field. There's not a lot of information below a PhD level concerning the challenges with designing a stellarator beyond "It's difficult to calculate because of the strange geometry".

Could you speak a bit on the simulations you used to design the Wendelstien? What method did you use? What were the complications you needed to overcome to design the reactor, and you did you get past them? How much do the twists change things compared to, say, a tokamak?

Bananawamajama

In a stellarator, you first want to design your coils such that the vacuum magnetic field has "magnetic surfaces", which are a necessary (but not sufficient!) condition for confinement. The first complication comes from the fact that once the plasma is formed, electric currents are self-generated inside the plasma, thus affecting the magnetic field. In order to know what will be the resulting equilibrium magnetic field, one has to solve a nonlinear "force-balance equation" (or alternatively, perform an energy minimisation) which is essentially the balance between the pressure force from the plasma trying to expand and the magnetic force compressing it. This is very hard to solve in 3D, while in 2D (e.g., in tokamaks) it is quite simple. Even then, one has to ensure that the equilibrium is stable (it could be an unstable equilibrium, like a pendulum standing vertically with the mass on top). This requires stability calculations using, e.g., perturbation theory. Finally, a magnetic stable equilibrium does not guarantee perfect confinement of particles in 3D. In fact, confinement is not perfect and some particles can be lost depending on their velocities. Then an optimisation can be carried out, e.g. by calculating which 3D magnetic configuration (there are families of possible configurations) has best confined particles. I hope you get a feeling of some of this challenges. If you are interested in the details, I can point you to some textbook (for example, Ideal MHD by J.P.Freidberg). (jl)

Do you think we will eventually see a tokamak/stellerator design plant producing energy or something completely different?

itssomeone

I believe, if we want to solve the future energy demand of humanity in a sustainable way, fusion power is very promising option. Its a complex technology and needs alot of research and technology development to achieve its goals. If we are able to solve all the technological requirements and learn enough about the physics, I believe we will see fusion power plants in the future.

There are also ideas, to use smaller fusion reactors as a drive for space ships, e.g. to intercept asteroids. (fw)

WHat private companies are showing the most progress/potential in the fusion race? If I belive in fusion, where should I invest my money? (put my money where my mouth is)

Fasterup

There are no private companies which earnestly follow fusion research.

It is too complex and time consuming for short-term profits.

But feel free to invest in one of the great research institute (like IPP ;)) or in education in general :) (fw)

In your estimation, how far away are we from having a sustainable fusion reactor that can outproduce the current fission reactors?

GentlemenBehold

This has been answered here

What qualifications do you need to work in a fusion lab? I start a physics degree in September and I'm curious.

Pizzadrummer

Studying physics or engineering is a good start, some knowledge on plasma physics is useful :) (jp)

Getting down to practicalities: if you were to achieve a self sustaining fusion reaction, how would you contain it? Even if it's kept floating in a magnetic field, there are going to be components exposed to massive heat and radiation. How do you keep them from melting?

oldforger

The energy from a fusing plasma comes out as 1. fast neutrons (will be absorbed in a specially designed radiation blanket that is cooled) 2. Photon radiation (light, x-rays...) is quite uniformly distributed over the plasma-facing components (which are also actively cooled) 3. Plasma outflow. The magnetic field will be designed such that the plasma flows out in a controlled way onto specially designed components, the so-called divertor, that must be efficiently cooled. The heat loads in the divertor can be up to 10 MW per square meter. For W7-X, divertor tiles that can take that amount of heat in steady state will be installed starting in 2018. (ts)