ADAM GAZZALEY INTERVIEW PART ONE

Hello Ars Technica listeners. This is the latest serialization of an episode of the After On podcast here at Ars. We're splitting this one into three segments, starting today. And I'll be talking to UCSF neuroscientist Adam Gazzaley about brain plasticity. And the scientific potential of video games to treat, and perhaps one day even cure neurological afflictions like dementia, autism, and ADHD.

This is the second episode I ever created for my podcast. Which makes it a bit more than a year old – and I'm still something of a novice interviewer in it. Quite a bit has happened in Adam's world since we recorded it, and I'll give you a quick rundown on some of the exciting news connected to his work at the end of our second installment tomorrow.

Before we get started, a quick note: Throughout October, Medium.com is running a series of essays that I've written on the subject of existential risk. Which is to say, the grim, yet perversely fascinating possibility that our technological creations might just annihilate us.

Although I'm of course biased, I do think I have a novel take on all this, and present some arguments and analytic lenses that are new to the discussion about existential risks. If this might interest you, please go to Medium.com/@RobReid. That's medium.com; then a slash, followed by the @ symbol; followed by RobReid. There's also a link on the webpage that's hosting this player. The first article in the series went up last week. The second should go up sometime this week, and there will be a total of four by the end of the month.

I should note that Medium is running this in their editorially-curated, paid, members-only section. The goods news is, they give everyone access to three free articles per month with essentially zero friction. And since it's still quite early in October, there are good odds that you have not yet exhausted your allocation.

Anyway - onto my conversation with Adam Gazzaley.

TRANSITION MUSIC

Rob Reid: Adam Gazzaley, thank you so much for inviting me into this gorgeous lab of yours at UCSF.

Adam Gazzaley: Thank you. I'm excited to have a conversation with you.

Rob Reid: And before we talk about all the amazing things that are going on here, why don't we talk a little bit about your background, where you were born, where you grew up, what brought you down this educational path that has led here.

Adam Gazzaley: Sure. So I grew up in New York City, did all my training on the East Coast.

Rob Reid: Which borough?

Adam Gazzaley: I have occupied four of the boroughs.

Rob Reid: Whoa! Which borough did you not occupy? Staten Island?

Adam Gazzaley: Staten Island.

Rob Reid: How did I guess?

Adam Gazzaley: Staten Island.

Rob Reid: Okay, all but Staten Island.

Adam Gazzaley: Born in Brooklyn, grew up in Queens, went to high school in the Bronx and then spent my adult years in Manhattan and that's where I went to med school and did my PhD training.

Rob Reid: Well, you got to go back to Staten Island one of these days.

Adam Gazzaley: Close all five.

Rob Reid: Exactly, exactly. So undergrad was New York.

Adam Gazzaley: Undergrad was upstate New York.

Rob Reid: Was upstate.

Adam Gazzaley: And then med school and grad school in neuroscience, my PhD was at Mount Sinai. And then from there I went to Philly, I went to Penn for my residency training in neurology. From there to the west coast, figured I'd try out what was going on out here and went to Berkeley for three years to learn cognitive neuroscience methodology, brain imaging, brain stimulation those type of tools and wound up staying here and been here for 15 years now.

Rob Reid: Now, did you then come here to UCSF as a postdoc initially or was that post-post doc? Was that [crosstalk 00:03:37].

Adam Gazzaley: Yeah. So I did my post doc at UC Berkeley, and when I started at UCSF in 2005, I started as an assistant professor, so I started my first faculty position here at UCSF.

Rob Reid: So now you're 12 years here, and very big picture, tell us what you focus on. We'll get into the details in a moment but just sort of your ... not even elevator, your revolving door pitch.

Adam Gazzaley: Yeah, so my focus has evolved a lot over the years. It used to be really dedicated to understanding how the brain works and how it goes wrong in many different conditions including healthy aging, but now we're almost 100%, when I say 'we', my center here at UCSF called Neuroscape. Our team is pretty much 100% focused on not just understanding the brain, although that's still something that we pay attention to, but how we can build new technology or leverage existing technology to improve brain function.

Rob Reid: Yep. And this is a rather giant lab if I'm not mistaken. How many full timers work here?

Adam Gazzaley: We have around 30 full time people, which is pretty big for an academic group.

Rob Reid: Yeah, sounds very big.

Adam Gazzaley: Yeah, we have six faculty and with our volunteer staff, we have a very big internship program, we're around 100 people.

Rob Reid: You're kidding, 100 full time equivalent.

Adam Gazzaley: Yeah, so we're big group of people all dedicated to trying to figure out how we could use technology for good to help our brains.

Rob Reid: And now, what brought you to this? What inspired you to pursue this particular dimension of the many dimensions of medical science?

Adam Gazzaley: Well, as a neurologist, I felt a great degree of frustration as many of us do with our treatments. We have a whole set of tools that we reach for when someone comes in complaining of a memory problem, an attention problem, depression, anxiety, all the conditions of the mind and almost all of those tools are small molecules, what we call drugs or pharmaceuticals. The problem with them is that they are targeted to neurotransmitters systems in the brain, but they're not targeted to the underlying computational unit of the brain, which is the neural network. And so we have to boost our doses to very high levels to get the effects that we want, and then we get just as many side effects as effects. And that's just the world that we live in as physicians, and I was frustrated with that. I figured, there has to be a better way of improving how our brains function than relying on these nonspecific, non-personalized drugs.

Rob Reid: Now, this is a real novice question, but I guess I didn't realize this until now. Are you saying that substantially all or at least the overwhelming majority of drugs that people use for depression anxiety et cetera strictly operate on the neurotransmitter level and none of them are actually getting into the physical dimension of the brain of the neurons, [inaudible 00:06:24].

Adam Gazzaley: Yeah they act very ... well we think of almost like as a sledgehammer, blunt. These neurotransmitters, receptors that they target are diffusely located throughout the brain. And so if you want to have a certain effect, you have to really bring on a large quantity of these molecules, and then you're going to induce other effects that we call side effects. And they could be devastating and make the drug intolerable. So that is a very big challenge and something for 50 years that we've been trying to build better targeted molecular treatments, and we've really failed.

Adam Gazzaley: Now, I applaud the many scientists around the world, and many of whom are my colleagues that are working on cures for things like Alzheimer's disease, I want that to happen obviously. What I felt is that while that pathway is continuing along, we need to think out of the box about what else we can do to help improve brain function. And I was inspired in a lot of ways by another very traditional approach, which is the experience, that experience and by that I mean how we interact in the world around us, so even in the world within us, drives plasticity of the brain. The ability of our brain to modify itself at every level, its structure, its chemistry, its function all in response to how we interact with the world.

Rob Reid: So you can go beyond merely operating at the neurotransmitters level, or the receptor site level and get into the sinews of the brain itself by leveraging neuroplasticity, and you do that by way of experiences that people undergo?

Adam Gazzaley: Yeah. We know that experiences, unlike the drugs we use activate the brain selectively. They activate brain networks, that's the nature of how the brain works, is that when you engage in an environment in a certain way your brain responds selectively. And so this concept that we can use experiences to change the brain is an old one, it is the entire basis of our education system, it's the entire basis of all forms of therapy that have existed, and it's a completely non-contentious point in neuroscience that experience drives plasticity. So the foundations of the idea are very strong, that you could create an experience and lead to a positive effect.

Adam Gazzaley: And we know that an experience can lead to a negative effect, where you could go off overseas in a war and not get shrapnel in your brain but just witness a tragic moment, and that could detrimental impact the function of your brain for the rest your life. We call that post-traumatic stress disorder. So if you flip that concept around, then we can create experiences that are powerful enough to lead to improvement and not negative consequences. And so that was the sort of scientific foundation of the idea of not relying on drugs to improve attention and the other cognitive abilities that we study in the lab, but to create experiences.

Rob Reid: And of course the challenge with experiences is it's hard to come up with an experience that's as standardized as a molecule, an experience that's targeted, that studiable, that's validatable, that's repeatable et cetera. And therefore you came to ...

Adam Gazzaley: Video games.

Rob Reid: Somehow I knew you were going to say that.

Adam Gazzaley: Well, you know-

Rob Reid: We've known each other for a while.

Adam Gazzaley: Exactly, we go back. But you really laid it out beautifully. The problems with therapy and that it has had is that, some therapists are great and some are not so great. And some are, "You need a small dose." And some, "You need a bigger dose." It's the same thing with our educational system, teachers vary and so it is hard-

Rob Reid: Even if they don't vary, a particular teacher with a certain set of students is going to deliver a completely unique experience on Tuesday vs Wednesday, even teaching the same lesson, even teaching to identical twins of the people who were in the first class, you just can't have the standardization of experience that you can have with the standardization of the molecule.

Adam Gazzaley: Exactly.

Rob Reid: But a game you're right, can't replicate.

Adam Gazzaley: And the other thing is that it is a non-personalized experience. So a teacher speaking to a class, and we know that some students are picking up the information rapidly, and they're bored now, and other kids are struggling, and they're just not ever going to get there. The other problem with a lot of the experiences is that they're not really targeted to the individual, they're not personalized. So the idea of a video game was really attractive to me because it can be delivered reproducibly through a game engine, it can be delivered in a personalized way through adaptivity.

Adam Gazzaley: And we could talk more about that, that's one of our key features of our game development, and it can be delivered in a way that's targeted to a neural system that you want to optimize by the game mechanics. If it's an attention system that you're trying to improve, you could create a game environment, an interactive experience that challenges attention, and the brain responds selectively. And then of course there's another feature of games that's hard to ignore, is that they're fun.

Rob Reid: They are fun.

Adam Gazzaley: And they're engaging and they're immersive and that is exactly what any training program should be.

Rob Reid: I have heard that therapy is not necessarily fun.

Adam Gazzaley: It's not fun and medicine is often not considered fun, but it could be and thus video games had that other feature that we are horrible at in our current condition which is compliance. That even if a drug is a lifesaving, people do not often take them, that's just remarkable statistic.

Rob Reid: It is astounding. It is astounding. I've heard enough statistics from enough sources to certainly accept the fact that people ... some people when told, “Take that pill and you will not die,” end up watching Cheers and forget to do it.

Adam Gazzaley: It happens all the time. We have a very, very serious issue of compliance. And so, if we have a experience that's delivered reproducibly, targeted, personalized, that's fun, and not only that, we could monitor compliance remotely. We know when someone's taking their medicine in video game format because their data goes to the cloud to our lab and we could get notified if they didn't take their dose or if the trying to take too much of it.

Rob Reid: Take their dose, I love that. Did you take your dose of the video game today? So let's talk about your first game, Neural Racer, why did you decide to target distracted attention with your first major creation in this field?

Adam Gazzaley: Yeah, so you always work on what you know, and when I came up with this idea of building a video game, the first target that I chose was one that I knew very well, which was distraction. I have been studying distraction, the impact of multitasking on performance for many years. We have neural markers of it, we have expertise in how to engage it, so I came about this from a neuroscience perspective.

Adam Gazzaley: And so those abilities of resisting distraction, of being able to maintain your focus, of holding information in mind, something we call working memory, was the focus of my research for many years. They're also core to everything we do, they form essentially the base of the pyramid upon which all other cognitive abilities rest.

Rob Reid: This is like having good core muscles or something. It's useful in almost any activity.

Adam Gazzaley: Exactly. It's just, if you can pay attention, your language will be affected, your decision making, your emotional regulation. At every level you will be impaired and in the real world. And so it's a really great target because it could have broad positive consequences. The other reason it's a good target is pretty much every neurological psychiatric condition that impacts cognition, those patients have problems with attention, distraction, working memory. It's just pervasive. Again, you could affect many different populations in a positive way if you can improve those abilities.

Rob Reid: It was a well studied and well understood field, it was particularly well studied and well understood by you, so did that mean you were coming in with sort of I don't know like the equivalent of like an IQ test for attention? Was there some scale that you were trying to bring somebody from a three to a seven on?

Adam Gazzaley: Great question. So if you're going to build a game to improve these abilities, half the challenge is building a good game and that's not trivial. We could talk about that, the development process, you don't just build something and sprinkle some game dust on it. It's a baked in process from the beginning.

Rob Reid: So I kind of got ripped off of that game dust I bought online last week.

Adam Gazzaley: Yeah, it just doesn't work.

Rob Reid: It said, “Just sprinkle it on anything, and it becomes fun."

Adam Gazzaley: I know, simple colors and some rewards in that [inaudible 00:15:20].

Rob Reid: Oh men.

Adam Gazzaley: Yeah, so a lot of people fell for [crosstalk 00:15:22].

Rob Reid: I'm sending it back. I'm sending it back.

Adam Gazzaley: Yeah, it doesn't really work. So we could talk about game development in a moment but once you have something, my view is that, that's not the appropriate time to sell it and say it does what you think it should do. That's the appropriate time to do research.

Rob Reid: [inaudible 00:15:41].

Adam Gazzaley: You've got to figure it out. I mean that's just the way it works, you need to validate. And so to validate you need to have outcome measures that are sensitive and appropriate to document that. And so that's where we had a strong suit, is because we had been developing tests of attention and working memory, as well as the neural markers that go along with those abilities.

Rob Reid: 'We' meaning the [crosstalk 00:16:05].

Adam Gazzaley: ... UCSF.

Rob Reid: And these were tests like flashing light and reaction test.

Adam Gazzaley: Yeah, there're tests for example, a working memory test that we've studied for many years is you sit in front of a computer, you see a face and we ask you to remember that face. Seven seconds pass and we show you another face, probably similar face, you have to say is that the face or not. And sometimes we distract you during that and sometimes we make you multitask when you're doing that.

Rob Reid: Got it.

Adam Gazzaley: And we know that older adults, and here I'm defining that as older than 60 and healthy, no signs of Alzheimer's disease, they do very poorly on tests that have distraction and multitasking. Well documented by many labs including ours and dozens of papers. And so we wanted to improve that ability in older adults.

Rob Reid: Because they're more vulnerable, the effect is already evident in them.

Adam Gazzaley: Exactly. And also it is impairing the quality of life. They feel distracted, they feel like they're having trouble competing in the workforce because of it, and they desperately want to be more focused.

Rob Reid: So that's your measure tests, that test and others like.

Adam Gazzaley: Yeah.

Rob Reid: Very, very easy to quantify. Did they remember? Did they get 53% or they get 72%.

Adam Gazzaley: And it's beyond that, it's the speed of response which is a very sensitive indicator of how quickly they could recall these memories. Even if they get it right, how fast were they able to recall it? And then there are many other measures.

Rob Reid: Got it.

Adam Gazzaley: And what we do is during these tests, we record brain activity. Sometimes we do with functional MRI, sometimes we do with EG which records electrical metrics of brain activity. And in this particular study, this game is called Neural Racer, the outcome measure here ... First of all we were targeting older adults because as we said they are a vulnerable population when it comes to memory and attention and we felt that it would be a big win to improve it.

Adam Gazzaley: We recorded their brain activity while they were playing Neural Racer, the game itself. But also to understand how their attention and memory was improving outside of the game, so that was what's very important about these studies is not just to get better on the game.

Rob Reid: Sorry to interrupt you, but when you're watching them play the game were you in a sense saying, "Man if we could get this region to light up brighter, we know we're doing better and if we could get," or in the EG, "If we could get this particular brain wave to sound a little louder, we know we're doing better," or were you more recording that stuff so in the future go back and sort of get a sense of what you are looking for?

Adam Gazzaley: We do it after the fact, we go back.

Rob Reid: So you didn't know yet what you were looking for necessarily.

Adam Gazzaley: We had a hypothesis.

Rob Reid: You had a hypothesis.

Adam Gazzaley: So as we get older, the front part of our brain, the prefrontal cortex, the most evolved part of the human brain seems to diminish its ability to engage robustly when you're challenging yourself from an attentional point of view.

Rob Reid: So you might have thought if somebody went into an MRI and there were an older adult who was suffering from these things, that part of the brain would light up less.

Adam Gazzaley: We have shown that.

Rob Reid: You have shown that. Okay, got it.

Adam Gazzaley: Many times. We even showed it in our video game that when you play the game and your older, you engage the front part of your brain less. So the question was would training on the game, help you engage the front part of your brain more, have it light up more and who would that lead to improvement outside of the game play, into these other areas like face memory? And so, that was the study design that we engaged after the year of game development of building Neuro Racer.

Rob Reid: Got it. So you were building Neuro Racer based on highly educated guesses about distraction, probably associated to these things, "This is a distraction mechanic that we can have in the game, now let's take this distraction mechanic that we've come up with and try to make it fun." Et cetera.

Adam Gazzaley: Yeah, we call them hypothesis, right?

Rob Reid: Yeah.

Adam Gazzaley: Our hypothesis was that because abilities like multitasking and sustained attention and working memory all relied on common brain mechanisms that use the prefrontal cortex, that if we can improve one through adaptive gameplay, in this case multitasking, we would see improvements in those other abilities that relied on similar mechanisms. That was what our hypothesis behind this experiment was.

Rob Reid: Now, you also came away from this or perhaps went into it with a focus on a particular theta wave, correct? Was that something that was an area of interest before you started developing Neuro Racer or was that something that came as a result of Neuro Racer's development?

Adam Gazzaley: Yeah, so there is a low frequency vibration essentially of electrical brain activity that's generated from the prefrontal cortex when you are paying attention, when you're trying to resist distraction, when you're holding information in mind, we call that midline frontal theta. That's the name of it. So it's coming from the frontal region of the brain in the midline, and it's theta which is a low frequency like six Hertz.

Adam Gazzaley: That burst occurs in everyone's brain. If I asked you to focus, if you directed your attention, but it also occurs when you're holding information in mind, when you're doing working memory. It also occurs when you're multitasking. So it was an interesting metric to us because it is common across all these different types of abilities that we call cognitive control.

Rob Reid: And it's association with this diverse set of abilities was known by others before you started doing this work.

Adam Gazzaley: Correct.

Rob Reid: That was a part of the known landscape.

Adam Gazzaley: That was already known.

Rob Reid: So you were intrigued by this particular theta wave.

Adam Gazzaley: Yes.

Rob Reid: And is that something then you were tracking assiduously when people were playing Neuro Racer? Were you trying to see if midline ... Midline frontal theta?

Adam Gazzaley: Yep, correct.

Rob Reid: Whether that went up while people were playing or was that something you were tracking throughout [inaudible 00:21:58]?

Adam Gazzaley: Yeah. We have people come down to the lab, our participants, our older participants come down. We do multiple days of cognitive testing, and we record EG activity while the playing Neuro Racer. Then they train for a month-

Rob Reid: On Neuro Racer.

Adam Gazzaley: On Neuro Racer, one hour a day, three days a week for four weeks. Then they come back and then we recorded brain activity again and cognitive tests, so what improved outside of the game and what changed in their brain when they played Neuro Racer.

Rob Reid: Got it. And you saw essentially more frontal midline theta activity at the end of the month, than you saw prior.

Adam Gazzaley: We saw that that activity was reduced in an older adult compared to a 20 year old on day one, and afterwards it was indistinguishable from a 20 year old.

Rob Reid: And there's seems to be ... and correct me if this is oversimplification, but sort of my metaphorical brain is saying, so in a sense you kind of created a gym but instead of working, I don't know the bicep, it was working this frontal midline theta muscle. That muscle strengthened over the course of a month of workouts, and it seems that this muscle is used in the diversity of activities, now that it's been bulked up in a sense through this training, that muscle is available not merely when somebody is playing Neuro Racer but when they're doing a diversity of things that have to do with working memory, attention et cetera. Is that approximately-

Adam Gazzaley: That's our interpretation.

Rob Reid: That's your interpretation.

Adam Gazzaley: So we see that change occur. We also saw that working memory and sustained attention also improved in these older adults and-

Rob Reid: And those are things that are associated with frontal midline theta.

Adam Gazzaley: And we showed that if you do, what we call a cross participant regression analysis, which is a fancy way of saying those people that showed the biggest change in the midline frontal theta, we showed that they were also the people that showed the most improvement on the attention test.

Rob Reid: So it's correlation and [inaudible 00:23:50].

Adam Gazzaley: So we correlated it. That's how we mechanistically connect what we found in the brain with what we found in improved abilities outside of the game.

Rob Reid: That's amazing. Now that's the kind of thing that I would imagine might end up on the cover of a magazine. And it did, didn't?

Adam Gazzaley: It did.

Rob Reid: Leading question, [crosstalk 00:24:08] the ways I know the answer to that.

Adam Gazzaley: Yeah. So it's one of those life highlights because it was a five year study. At one point there were 50 people on our team involved in data collection, it took us a year to build this game working with friends of mine that worked at Lucas Arts. So, a year of development building Neuro Racer and then multiple studies and eventually in September of 2013, it was published as the cover story in Nature, which as a scientist it's as good as it gets.

Rob Reid: It's good as it.

Adam Gazzaley: Probably the most painful thing is that I probably won't have another cover of Nature in my life.

Rob Reid: Well, maybe you'll be on the cover of Science, which is almost as good.

Adam Gazzaley: That's possible. It's possible.

Rob Reid: So let's talk a little bit, we've mentioned various tools of your trade, I'd like to just talk, just briefly about ... I think it's the big three but if it's a big four, tell me about the fourth or the fifth. But MRI, EG and TACS or TMS. Why don't we just talk about them in sequence, like what they do, what they don't do. So MRI is probably something that people are most familiar with, what most folks probably don't know and again correct me if I'm wrong, is that MRI's super power is it can get under a very tiny scale but it super weakness is that it has a very ... has poor time resolution. Is that roughly correct?

Adam Gazzaley: Yeah, so MRI and EG are two tools that we use all the time because they have opposite strengths and weaknesses. As you said MRI has great spatial resolution, you could see ... I mean not compared to a microscope, but in a functioning human brain you could see data on a very tight spatial scale, [inaudible 00:25:41] like a millimeter. But what we're seeing functionally is a blood flow response of the brain which is sluggish, it takes place over seconds as opposed to brain activity which takes place over milliseconds. And so with EEG we're recording electrical signatures of the brain, not the blood flow, and so we see events as they're occurring in real time. It basically goes through the scalp with no time delay but it's spread spatially, so you can't see exactly where-

Rob Reid: It's excluded by the skull.

Adam Gazzaley: Yeah. It comes through but it gets diffused, it's like a filter. And so it doesn't change the timing but it changes your ability to localize where it's coming from.

Rob Reid: It blurs.

Adam Gazzaley: It blurs. And so basically we use FMRI to understand where activity is taking place, I need you to understand when. So we use them both as tools to give a more comprehensive picture of how the brain works and how it goes wrong and how it is improved by our interventions.

Rob Reid: But they couldn't be used simultaneously, right? Because the MRI, the magnets in the MRI-

Adam Gazzaley: We actually do-

Rob Reid: You can do it.

Adam Gazzaley: It's very challenging, they induce artifacts in each other and they're on such different time scales-

Rob Reid: People don't end up getting hauled across the room because of the magnetic-

Adam Gazzaley: No, no, no, no. We've put all sorts of things inside MRI scanners, EGs, we have joysticks that go inside MRI scanners so you could play video games.

Rob Reid: That's wild. So people are playing Neuro Racer and other games inside that machine. Now the EG, because most people probably don't know this, that is kind of like a bathing cap with a bunch of sensors on it.

Adam Gazzaley: Modern EGs like we use are delivered or the data is collected with a cap, that looks like a bathing cap that has many electrodes, usually we have 64, sometimes more and we have amplifiers at each electrode, so we could really have a sensitive detector of what's a very subtle signature, the electrical metrics that are generated by your brain activity.

Rob Reid: Yeah, and there's essential four waves or four big picture ...

Adam Gazzaley: There's a whole frequency spectrum, and we have drawn in many ways arbitrary lines between them to say alpha, delta, theta, gamma those are the ones you hear and they're just different frequencies along the spectrum.

Rob Reid: But they obviously come in a diversity of flavors because you focused on midline frontal theta.

Adam Gazzaley: Yeah.

Rob Reid: Or frontal midline theta [inaudible 00:28:10] whichever one it is.

Adam Gazzaley: [inaudible 00:28:12].

Rob Reid: Which is different from other forms of theta. And then finally there's TACS and other transcranial stimulation.

Adam Gazzaley: Yes.

Rob Reid: Which is funky stuff. Why don't you tell us a little bit about what that is, how it works and how well understood or misunderstood it is right now.

Adam Gazzaley: Well, TMS is used and has been used a long time. TMS is transcranial magnetic stimulation, you could use a very high powered magnetic field to induce an electrical current inside the brain which causes neurons to fire.

Rob Reid: So you're kind of giving it a flick in a sense.

Adam Gazzaley: Yes.

Rob Reid: You're flaking the brain.

Adam Gazzaley: Flicking the brain, yeah.

Rob Reid: It's like poking the brain.

END INTERVIEW ELEMENT OF PART ONE

Brain poking feels like a good note to end on, right? So with that cliff-hanger, we'll adjourn until tomorrow. If you can't wait to hear the rest of this conversation – or, if you'd like to browse my 36 other episodes, you can just head on over to my site, at after-on.com. Or, type the words After On into your favorite podcast player. Either way, you should then see my full archive of episodes in reverse chronological order - with Adam's interview slotted in all the way back at August 10th of last year.

In case you're interested, the show's current episode is an interview with Martin Rees: Who is Great Britain's Astronomer Royal. And that, by the way is the coolest title ever. Martin and I talk about the most eerie and violent phenomena in the known universe. Specifically, gamma ray bursts in the violent department; and fast radio bursts in the eerie department. We also spend a great deal of time discussing the existential risks society might face in the 21st century, which is also the topic of that article series I'm posting to Medium this month - which I mentioned at the start of this episode.

And with that, I hope you join me tomorrow here on Ars, for Part 2 of this conversation.

OUTRO MUSIC