Orbital quest for mysterious matter

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Can the existence of antimatter and dark matter be proven? Is it necessary to go to the International Space Station to do so?

By Marco Trovatello

The Alpha Magnetic Spectrometer (AMS), a seven-ton, four-metre-high particle detector installed on the International Space Station (ISS), is being used to help a team of researchers from all over the world come a step closer to solving riddles about our Universe and, by extension, our own existence. The experiment addresses questions concerning the existence of antimatter and dark matter, and could lead to ground-breaking discoveries. In this interview Stefan Schael, an experimental physicist and the German project lead for AMS, explains how the instrument is being used and the discoveries it could lead to, and shares the story of the long road leading to its launch and commissioning.

Professor Schael, could you start by describing the operating principle of the Alpha Magnetic Spectrometer and the aim of the experiment in simple terms?

People often speak of it as a 'dark matter camera', but it is not a camera in the normal sense, is it? I could give a two-hour lecture on this question alone. I will begin with a few basic considerations that led to the AMS experiment. One of the problems in physics today is that a number of recent cosmological observations are not compatible with current theories. This means that there are phenomena in our natural environment, the Universe, which we do not fully understand. Some of the fundamental questions in physics include: Why do we exist? Why does it appear that equal amounts of matter and antimatter were not formed after the Big Bang? Why is the Universe not made of light alone?

When you say 'we', you mean matter?

Yes, that is correct. This has nothing to do with the question of why there are intelligent beings like us in the Universe. Of course, the fact is that matter is needed in order for us to be here, but we do not even understand why matter exists in the Universe!

A second, more fundamental problem is that we observe our Sun, along with the planets in the Solar System, moving around the centre of the Milky Way in a stable orbit. We can even measure the speed at which the Solar System is orbiting he centre of our galaxy. But when we calculate whether the gravity of the Milky Way is sufficiently strong to keep the Solar System in its orbit, we come to the conclusion that the Sun should theoretically be flung out of the galaxy. If that happened, there would be no life on Earth. This leads us to the question: why do Earth and the other planets exist?

Are you hoping to use the AMS experiment to help answer these questions?

Exactly. We do have a physical model that might explain this phenomenon. What we refer to as dark matter plays an important role in this model. We presume that the answer must be a new type of elementary particle that we have not yet detected. If we were to find it, we might understand why the Sun does indeed orbit the centre of the galaxy in a stable path.

So AMS is intended to help us find dark matter?

Yes, that is right. But I would like to say a few words about antimatter and follow up on your opening question. One currently valid model assumes that antimatter was left over after the Big Bang. In this scenario, there could be galaxies made of antimatter, but they would look exactly the same as our Milky Way. The stars would shine in exactly the same way as in our own galaxy, and they would die off every so often in a huge, yet brief supernova explosion. In this way, antimatter particles would be accelerated to high energies and, since the Universe is a near-perfect vacuum, they would reach us, pass through our spectrometer and we could observe them. If we were able to detect such particles, we would know that the Universe consists of as much matter as antimatter and we would have solved this puzzle.

Why must the particles be detected in space or, more accurately, on the ISS, 350 kilometres above Earth? Have we not already been trying to track down antimatter for some time now, using particle accelerators like the one at CERN, the European Organization for Nuclear Research?

Yes. In fact, we have been investigating the asymmetry between matter and antimatter for 50 years, but the experiments we are carrying out on Earth have not revealed enough for our needs. In this regard, AMS is a pioneering experiment, as it will increase the measuring sensitivity by a factor of over a thousand. And that is only possible in space…

Why?

Here on Earth, we are only able to identify neutral particles such as photons because the atmosphere and magnetic field protect us from charged particles, which are one component of cosmic radiation and dangerous for all living things. If we were not shielded from them, there would be no life on Earth. This is why we have to go into space, to the ISS, to encounter such charged particles.

Let's come back to antimatter. Do you think you will be able to find evidence of its existence?

If we do not detect any antimatter, we will be able to assume there is a high probability that it does not exist anywhere in the Universe. Speaking personally, I would be surprised if we do find antimatter, but as a scientist one needs to be careful making such predictions; an experiment with this level of sensitivity has never been performed. But one way or another, the conclusions drawn at the end of the AMS mission will be groundbreaking.

If you don‘t find any antimatter, physics textbooks will need to be rewritten…

Not actually rewritten, but we have been trying to build on incomplete theories that lie at the heart of the standard model of particle physics for over 30 years. We still have not managed to use these theories to solve the mysteries of the Universe and answer the question about our existence. Nevertheless, it is very clear that we are not currently advancing our theoretical understanding. To do so, we need new experiments and new observations…

… and new data from experiments such as AMS?

Yes, we need new experimental data. This is precisely what we, as experimental physicists, are trying to do; develop and construct measuring instruments with much higher accuracy - and then hope that we can unravel the next mystery, or at least the clue to the next step that lies within the range of these experiments.

How is this highly sensitive spectrometer working thus far?

AMS is working superbly, as well as we had hoped it would. The measurements that we are getting are extremely precise, even better than expected. We have not been able to achieve this accuracy with particle accelerators on Earth yet. I find that fantastic. We are running at 100 percent - everything has worked as planned. It is a tremendous technical and engineering achievement. But we are also facing a dilemma. The data we are recording is so precise that it would not do it justice to publish it prematurely before its calibration is thoroughly tested. It would not be fair to the instrument. In effect, we need to understand our instrument better than originally expected. This means there is a great deal of detailed work ahead of us.

Have you found anything of significance yet?

Before creating any expectations, one must demonstrate that the measuring instrument - the basic physics - is working properly. We are already making good progress and anticipate a first publication as early as 2012 or 2013. I cannot say today whether we will have found dark matter or antimatter by then, or whether we will perhaps have found something else entirely, but I can tell you that we will have some excellent results. We will definitely meet the expectation of obtaining measurements 1000 to 10,000 times better than with previous experiments. Currently, we are fully engaged in guaranteeing the operation and functioning of AMS. In this regard, we have already agreed a financing package for the next three years with the DLR Space Administration. At this point I must say that our DLR colleagues have done a great job here. AMS was and is not a simple project - some really difficult decisions have had to be made, and DLR‘s assessment has been correct. It is thank to this that we have been able to develop such a wonderful instrument and are now in a position to carry out excellent research on an international scale.

Let‘s talk about the duration of the mission. Is it true that 11 years will be the optimal length of time, so that you are able to take measurements throughout a complete solar cycle?

This is a difficult question. Of course we have asked ourselves for how long AMS will keep taking measurements. The current forecast is about 20 years. The space agencies in the other countries involved have committed themselves to operating the ISS until at least 2020, and there is even a statement of intent that the ISS will continue to operate until 2028. Ideally, we would take measurements for more than 11 years, precisely because of the solar cycle. We are doing this work in a totally unknown environment in which we are unable to control the acceleration mechanisms responsible for the incoming particles. We are measuring everything there is in the Universe and there are a few rare results that might lead us to finding something completely new. For example, a supernova explosion in our galaxy cannot be predicted. If this type of event were to take place, it would be a shame if our unique measuring instrument were no longer there to witness it. My opinion is that we would do well to keep AMS operational for as long as possible - not least because operational costs are rather low in comparison to those related to development and construction. If everything goes to plan, after 10 or 12 years we will have data that achieves excellent levels of precision in terms of statistical averages.

Let’s take another look at the technology. What was especially challenging about constructing the AMS instrument?

This was mainly a matter of the magnetic field required. AMS detects charged particles and has been designed to be used in space - these are the basic requirements. To determine whether particles are positively or negatively charged, a magnet is used to deflect these particles along a path whose direction depends on their charge. When such a magnet flies in low Earth rbit on a space shuttle or the ISS, its magnetic field interacts with Earth's magnetic field. Consequently, great caution must be taken when designing the magnet, otherwise the interaction between these forces might be so large that attitude control cannot be maintained and the ISS might begin to tumble. Naturally, the first thing that NASA and DLR said was 'show us that it works'. This is what we did with AMS-01, our precursor experiment that spent 10 days on board the Space Shuttle Discovery in 1998. We not only proved that we had built an instrument - incorporating a magnet - whose interaction with Earth’s magnetic field did not affect the con trol of the Shuttle or the Space Station, but also that it was sufficiently robust and mechanically stable to survive a shuttle launch, installation on the ISS and take highly precise measurements.

Why is AMS also referred to as a dark matter camera?

This is because it has a semiconductor detector similar to those found in digital cameras. What we are doing is photographing the charged particles that enter the instrument. So the comparison is not so far off the mark? No, it is actually quite good. But we are acquiring up to 6000 images per second, and this just from cosmic radiation. We measure this with 300,000 separate channels.

Let's talk about the German contribution to AMS. At RWTH Aachen, you are concerned with, not just scientific research, but also with the development and construction of the new types of instruments required, such as AMS.

That is correct; it makes up a good 50 percent of my work as a Professor and Chair for Experimental Physics. We perform experimental physics. If you want to discover something new in this field, you need a new, even more precise measuring device. Designing and building one is the first task. Take the Hubble Space Telescope as an example. You build a telescope, launch it into space and acquire the most incredible data above Earth's atmosphere. But nobody can build the new instrument that we need for our experiments, so we have to do it ourselves, according to our own specific requirements. It is not something you can buy off the shelf.

Which components of AMS were designed and built in Germany?

Development work took place at two locations in Germany, at RWTH Aachen and at the Karlsruhe Institute of Technology (KIT).

With AMS-01, we already had two important subsystems: the Laser Alignment System and the Anti-Coincidence Counter - both important components of the track detector, which analyses the incoming particles. With AMS-02, in addition to these components, we built the Transition Radiation Detector, which sits above AMS, so to speak, and weighs around 500 kilograms. We built the whole detector ourselves and KIT contributed the data acquisition system.

In summary, it can be said that here in Germany, with comparatively limited financial resources, we managed to produce an independent detector for this measuring instrument. This was a great achievement, for which the basics were set up by my predecessor, Klaus Lübelsmeyer, and DLR. I think that we are now playing a leading role in this project. It turns out that our Transition Radiation Detector is the key instrument for research into the nature of dark matter. Even in science, such an effort is not fully predictable, but requires good fortune. Clearly, we are very lucky to have been in the right place at the right time with the right instrument.

Let's talk about the history of AMS. Everything moved quite quickly following the launch on 16 May 2011. AMS was switched on for the first time after just two hours in the shuttle payload bay; it was installed on the ISS on 19 May, began recording data and, as you have already said, is functioning perfectly. But getting there was a long, drawn-out journey…

Correct. Samuel Ting, Nobel Prize winner and the 'father' of AMS, approached Daniel Goldin, NASA Administrator at the time, and made him aware of the need to carry out fundamental research on the ISS. Goldin understood immediately; the space agencies from other countries, including DLR, came on board, and today AMS is on the ISS. It is by far the biggest and most publicised fundamental research experiment on the ISS. From my perspective, it adds to the legitimacy of building a structure like that up there. Basic research, as another Nobel Prize winner, Steven Weinberg, said, involves discoveries that can change the world. AMS has the potential to change the world with its discoveries.

In Germany, Klaus Lübelsmeyer set the project, which I have led since the year 2000, in motion. In 1996, DLR providedthe funding for AMS-01 in its capacity as the Federal Government's space agency. Two years later, AMS-01 spent 10 days on board the Space Shuttle Discovery as a technology demonstrator. In 1999 DLR committed to the funding for AMS-02, and a launch date of 2003 was planned. But things worked out differently as there were no shuttle launches for four years. In 2005, when the problems concerning the NASA Space Shuttle programme intensified, we were informed that there would no longer be a flight slot available for AMS…

And that was the low point of the project. You had invested years of work…

More than five years, and the instrument was ready. In addition to this, the space agencies of the other participating countries decided to reduce support for the project. Ultimately it was Samuel Ting and leading European politicians who persuaded the US government to reverse NASA's decision; DLR also decided to go ahead on behalf of the German Federal Government and allowed us to carry on. Here, Peter Hintze, Parliamentary State Secretary in the German Federal Ministry of Economics and Technology, and Johann-Dietrich Wörner, Chairman of the DLR Executive Board, made strong personal commitments.

Did you ever consider using a European Ariane heavy lift rocket as a platform for getting AMS to space on board a satellite?

AMS has high power consumption and communications requirements, for example in terms of data down- and up-linking. This does not mean that an appropriately sophisticated platform could not have been built to operate AMS as a free flying satellite, but why would we do this when we already had the infrastructure for such a sophisticated platform in the form of the ISS? From my perspective, the ISS is the ideal platform for running experiments such as AMS in space.

Back to AMS' long journey to space…

Well, it took until 2008 for the STS-134 mission to gain approval, taking AMS with it to the ISS.

And that only happened in May 2011. Why did it take so long?

Mainly because we needed to rebuild AMS after such a long interval. Originally, AMS was only supposed to operate on the Space Station for three years and then be brought back to Earth. Of course, with the discontinuation of the shuttle programme, that became unlikely, so we had to adapt the magnet and detector components for a longer mission, to optimise the scientific return.

The results of the AMS experiment will be made generally available. How exactly will that happen?

I believe that whenever we carry out research to understand how the Universe originated, many people want to know how we have reached our conclusions – not the technical details, but certainly the results and what implications these have for individuals.

What implications are these?

First of all, the insight is of value in itself, because it gives rise to intellectual freedom. One does not have to decide between belief system A, B or C, rather, in the ideal case, science will tell us how the Universe originated. This gives society freedom; it becomes more difficult to manipulate it. Just as it gave society freedom once it became understood that Earth orbits the Sun, not the other way around. We are not the pinnacle of creation; Earth is not the centre of the Universe. Results like these are the basis for an open and free society and, consequently, can change all our lives. In the medium term, the findings of fundamental research in physics tend to lead to new technologies. Think back 100 years to the development of quantum mechanics and then consider the semiconductors, lasers, solar cells, computers, the Internet and smartphones that are the result.

So communicating these results is as important as the results themselves?

Yes, if you like. Another part of my job is to communicate the knowledge we have acquired in the last decade and that which we can anticipate for the future. I do this in presentations and articles aimed at the general public. If we make exciting discoveries, I will ensure that the public is informed about the aspects that have wider significance, while the scientific community will learn the details in specialist publications.

About the interviewee

Stefan Schael was born in 1961 in Leverkusen and is head of the I. Physics Institute B at RWTH Aachen (Rheinisch-Westfälische Technische Hochschule Aachen). He studied physics in Bonn and Heidelberg, obtained his PhD at the University of Karlsruhe and qualified as a professor at the Ludwig Maximilian University in Munich. Following a research period at CERN (the European Organization for Nuclear Research) and work as a scientific staff member at the Max Planck Institute of Physics in Munich, he moved to RWTH in early 2000. His research interests include particle and astroparticle physics. Besides the AMS experiment, he has worked on various different international research projects, such as CMS, a detector at the CERN Large Hadron Collider. Schael is married and has two children.

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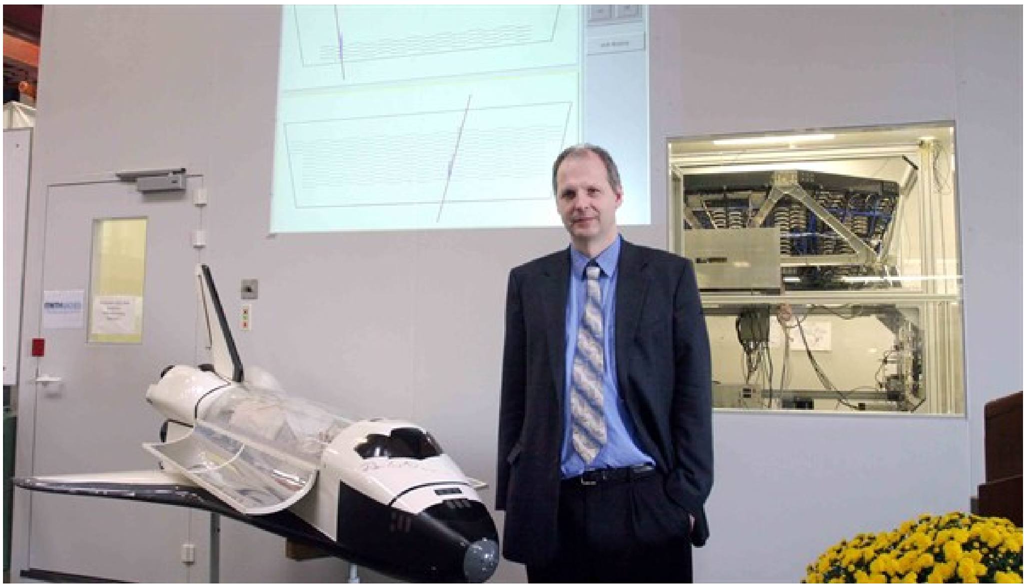
AMS-02 after installation on the ISS

AMS after installation on the International Space Station‘s Starboard Truss. To the right is the docked Space Shuttle Endeavour, which carried AMS into Earth orbit.

Credit: NASA.

Stefan Schael



Stefan Schael, German project leader for the Alpha Magnetic Spectrometer experiment.

Credit: DLR (CC-BY 3.0).

Astronauts Greg Chamitoff and Andrew Feustel install AMS-02

NASA astronauts and STS-134 mission specialists Greg Chamitoff (left) and Andrew Feustel (right) install AMS on the ISS exterior structure.

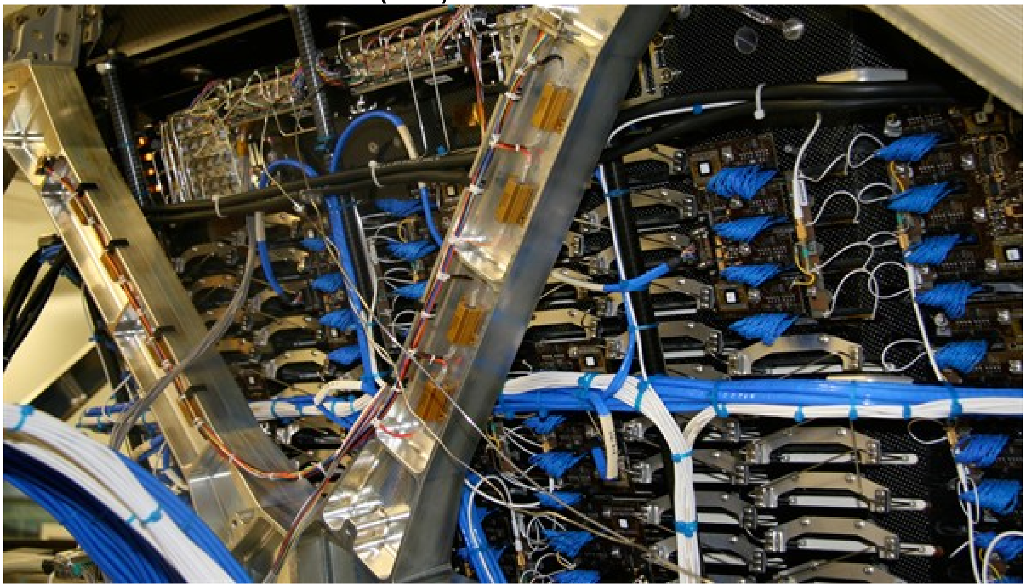
Credit: NASA.

Members of the AMS team during preparations for the launch of AMS

Samuel Ting (middle), Stephan Schael (fifth from right) and the other members of the AMS team in the Payload Changeout Room, during preparations for the launch of AMS on board Space Shuttle Endeavour.

Credit: Stephan Schael.

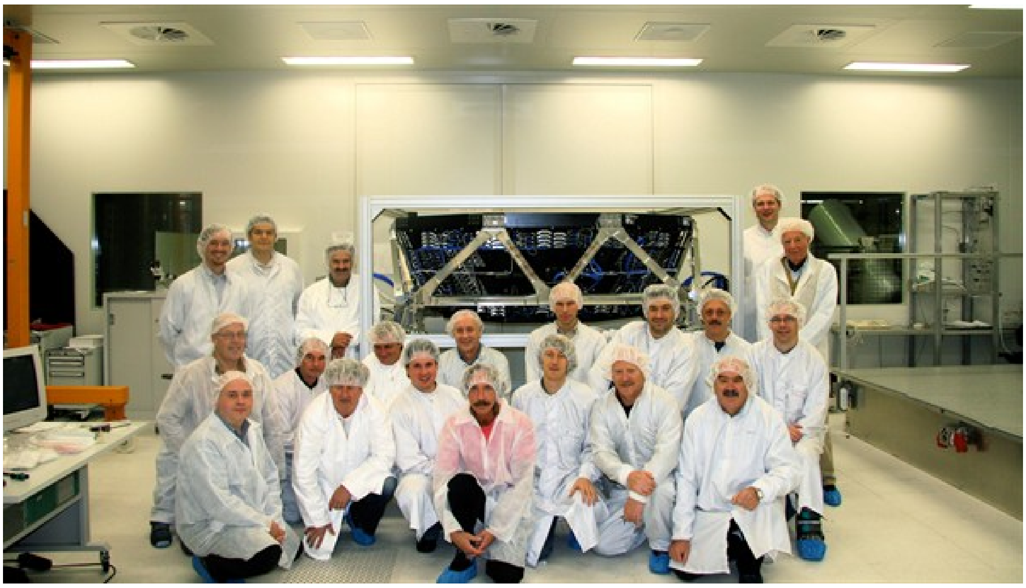
Transition Radiation Detector (TRD)



Detail of the German-built Transition Radiation Detector (TRD), which plays a key role in studying the existence and nature of dark matter.

Credit: Stephan Schael.

Part of the German AMS team



Part of the German AMS team in the clean room of the I. Physics Institute RWTH Aachen. Visible in the background is the Transition Radiation Detector.

Credit: RWTH Aachen.

Spaceshuttle Endeavour

AMS inside Space Shuttle Endeavour‘s payload bay

Credit: NASA.

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