Afterword: Don't Shoot the Messenger Particles

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One summer in my teenage years (we are talking late 80s, here), I whiled away much of my holiday binge-reading a stack of old comics from the 70s. One particular comic featured a column about mysterious facts from around the world, phenomena and theories that I soon realised amounted to pseudoscience. One of the most recurring topics was 'Kirlian photography'. Evidently, it was deemed ideal fodder for all kinds of articles related to life after death, supernatural healing, ghosts, miracles, etc., as 'Kirlian pictures' supposedly taken with 'Kirlian cameras' sounded like the perfect fit for many of those unlikely claims. Kirlian photography demonstrated the existence of an otherwise invisible aura surrounding any living thing, and even many non-living ones (which, the authors implied, demonstrated that even non-living objects had some spiritual significance). Some pictures showed the aura in otherwise empty space: evidence for supernatural entities, invisible to the human eye? The aura was claimed to become brighter or dimmer depending on the health of the patient (Kirlian photography was even claimed to be actually used for diagnostics in many hospitals in the Eastern Bloc), and to be also correlated to emotional states. In a particularly remarkable example, a Kirlian camera captured the very moment of the death of a patient, showing part of the aura being displaced from the body: the moment when the soul was set free?

Too bad that most pictures were so blatantly fake. If the photo compositions had not been so irredeemably amateurish, perhaps I would have given them the benefit of the doubt, because the narrative was so powerful and uncannily coherent. Years later, I discovered that Kirlian photography is actually a thing. And although it may have once been popular in a particular niche of pseudoscience, its physical principles are well known to mainstream science. No mystery, no spirituality, no link with the soul, no correlation with health, mood, or the actual differences between animate and inanimate, spiritual and mundane. Once one knows what causes those 'auras', they actually become very boring. And sadly, in spite of Semyon Kirlian's hopes, no way was ever found to do medical diagnostics with them.

Apparently, many people in the world (across most cultures and religions) believe in the existence of ghosts. Probably, for those who believe in the concept of the soul, it is not too far-fetched to imagine that a soul can become detached from its body (in particular when the latter dies), and wander around. A soul, and a ghost, are allegedly invisible, at least most of the time. But if some mechanism links a particular soul to a particular body, there must be a physical interaction binding them; the atoms of a body (made of ordinary particles: quarks and leptons, mutually bound via electromagnetic and nuclear forces) and the atoms of a soul (made of some unknown particles, mutually bound by something unfathomable) must necessarily be aware of the existence of each other. The same mechanism, whatever it is, would make a soul or a ghost detectable, in principle. So, indeed, why not a tool conceptually similar to a Kirlian camera?

Mainstream physicists, like me, are much less keen to believe in ghosts than most other people. However, mainstream particle physicists, like me, also keep telling people that more research is needed because the Standard Model of particle physics is incomplete, meaning that there must be new phenomena, still unaccounted by the known Laws of Physics. (And let me stress: I didn't say 'there might be', I really said 'there must be'.) So, a layperson could ask, why not new phenomena related to souls, ghosts, and many other things that we currently dismiss as unscientific?

And to be more specific, we also say that there is compelling evidence from astrophysics (although not yet from laboratory experiments, alas) that we must be surrounded, and even compenetrated, by matter of an unknown nature that is invisible to us, which we call Dark Matter. Although its effects are subtle, Dark Matter is not rare: it is estimated to constitute about 80% of the matter of the universe. Could ghosts be made of Dark Matter? And could Dark Matter possibly explain other mysteries, while we're on the subject?

Recently, an ingenious answer to this whole set of questions was provided by my colleague, Brian Cox, speaking on a different BBC Radio show.[1] Cox's argument is more or less as follows: physical interactions between ghostly matter and standard matter cannot be part of the Standard Model; and the LHC has not found any new interaction up to very high-energy scales, hence *a fortiori* there cannot be any new interaction at the very low energy scales that are typical of the biological and chemical processes within our body.

I surmise that Cox's argument sounds way more compelling to the average particle physicist than to the average layperson. In fact, Cox's reasoning implicitly assumes, as most of the particle physics literature does, that unknown interactions should get more detectable as energy grows; but the average layperson has no reason to assume such a hypothesis. (One could ask: why not the other way around?) For once, the average layperson may be right. There is an entire niche of particle physics that has been booming recently, that you can find under the names of 'dark sectors', 'hidden sectors', 'hidden valleys', 'feebly interacting particles', etc., which explores the possibility that new interactions, new particles and new phenomena are more or less hiding in plain sight, and have not been found at the LHC or even in previous experiments just because we were blinded by our collective biases – including Cox's bias that any new physics should manifest more visibly as the energy grows. And although it is still a niche, it is beginning to be taken very seriously: it has already motivated some new experiments at the LHC,[2] upgrades of the existing ones, and original ways to re-analyse the already collected data.

This nightmare scenario – of having Nobel-Prize-worthy discoveries sat under our noses, but going unnoticed because our detectors are not optimised for them – is, to be honest, not so popular among my colleagues. However, there are historical precedents. For example, the string of revolutionary discoveries in the early 70s that imposed the reality of what we now call the Standard Model was achievable with the technology of several years earlier, if only particle detectors had been optimised for the kind of phenomena that this theory explains and that were not expected by the models that were mainstream at that time.[3] And some of those new phenomena, in hindsight, had probably been observed already in the 60s, and dismissed by general consensus as uninteresting fluctuations of the background.[4] Not unlike the 'bananas' discovered by the protagonist of Adam Marek's story. In that fictional universe, it takes a technological jump in MRI technology as well as an exceptional solar activity event to make the serendipitous discovery, but the bananas had always been there, and in hindsight, one could have recognised them in decades-old MRI data.

So let's separate the fact from fiction here: the Standard Model is an incredibly successful theory, precisely confirmed in almost every test that we could conceive in laboratory conditions, and yet we know it is incomplete. How do we know? Its fundamental parameters look too *ad hoc*, and most importantly it cannot account for a few established facts, such as the dominance of matter over antimatter in the Universe, or the existence of the aforementioned Dark Matter. That's why we believe it is just an approximation to the true Theory of

Everything (ToE), in the same fashion as Classical Physics is today regarded as an approximation to both Quantum Physics and the Theory of Relativity (that works best at low speeds and large scales). In a sense, the entire goal of Particle Physics is finding this ToE.

Something that's not established yet, but is a serious target of research, in the journey towards a ToE, is the Dark Sectors hypothesis. Suppose that the still unknown ToE is such that the various elementary particles are grouped (in the taxonomic sense) in well-defined 'sectors'; meaning that all particles within a sector easily interact with each other, but there is only some very tenuous interaction between particles belonging to different sectors. One such sector would be the Standard Model, i.e. all the particles that we already know, interacting through the forces that we already know (electromagnetism, weak nuclear force, strong nuclear force, and finally gravity which is by far the weakest force at the microscopic scale). Nothing excludes the possibility that other particles (from the other 'sectors') permeate the very same space that we occupy, without us noticing them because their interactions with us (i.e. with the Standard Model) are extremely feeble. However, all sectors are expected to feel at least gravitational interactions between each other and this would provide a neat explanation of the mystery of Dark Matter. If at least some of the particles in the hidden sectors (also known as 'hidden valleys') also have additional (non-gravitational) feeble interactions with the Standard Model particles, through some 'mediator particles' that act as a bridge, there is hope that one day we'll observe those interactions in a laboratory. This is a new idea and LHC data analysts have started looking for hints of hidden sectors, with some small, specialised experiments scheduled to take place very soon.[5] If we could find a way of seeing a hidden sector, maybe we could see hidden planets with an exotic chemistry and, of course, an exotic biology.

So, there would be three classes of particles: ordinary (those that physicists already know and that fit in the Standard Model), dark particles (i.e. those in the Dark Sector), and messengers. Ordinary particles and dark particles do not interact with each other directly, apart from gravity effects; but both can interact with the messenger particles. (And this interaction must be very, very faint, otherwise we would have noticed it before). In particular, ordinary particles can occasionally 'excite the vacuum' (i.e. transform kinetic energy into mass) and produce particle–antiparticle pairs of messengers. Presumably dark particles can do the same. But the messengers will probably be unstable heavy particles, meaning that they would soon decay into lighter particles, which in turn might be ordinary particles or dark particles, or both (e.g. a single messenger might decay into N particles, some of which are ordinary and the others are dark).

In Adam Marek's story, the exotic signals observed by the MRI machines intensify during the most intense solar activity events. This narrative trick (coming out of a brainstorming Zoom session between Adam and I) reposes on some plausible speculation. If the dark sector is ubiquitous, there must be dark particles also in the Sun. Given that gravity is the only force that can make a direct link between the Standard Model and the Dark Sector, where there is a big lump of ordinary particles held together by gravity (e.g. a star, a planet), there must be a big lump of dark particles as well, in the same place. Those dark particles presumably interact between each other a lot, just like the ordinary particles do, we just don't know how, because they're dark.

Now, imagine this dark part of the Sun that burns and boils, very energetically – just like the ordinary part of the Sun does – only in ways that are invisible to us. But suppose, from time to time, these tumultuous processes pass some threshold in energy and intensity and start producing messenger particles. The key point for the story is that this is not a continuous process, but more of an 'on/off' event, a collective phenomenon that only happens if a threshold is trespassed in some variable. Those messenger particles will interact with ordinary particles in the Sun, faintly, of course, but if they are temporarily produced in really humongous quantities, they might trigger similar processes in the ordinary part of the Sun. That would explain some of the extreme solar activity events.

If the above mechanism takes place, part of that huge flux of messenger particles would escape the Sun and flood the Solar System, and would reach us as part of the natural flux of cosmic rays. Some of those messengers would interact with the ordinary particles in the upper atmosphere, leading to the particularly intense auroras, stretching unusually far south, as mentioned by Adam's protagonist. Although only a tiny fraction of messenger particles interact with ordinary ones, during such exceptional events the flux would be enormous, so even a tiny fraction would become a significant number overall. And similarly, a very tiny fraction of those messengers would interact with the dark particles, transmuting them into ordinary particles with ordinary interactions with standard matter. In Adam's story, the new-generation MRI machines developed after a certain date include a new metamaterial, developed and optimised for other reasons, whose structure (by pure chance) resonates particularly well with photons of the frequency produced by those transmutations. This is a kind of serendipity that often happens in science: technological advances open new vistas into fundamental science. This idea of metamaterials came to Adam and not to me (ironically, as I was supposed to be bringing the science ideas), and I was initially hesitant. But then I found out that the Nobel Laureate and super-respected physicist Frank Wilczek is actually collaborating with some metamaterial expert in order to develop practically the same thing.[6]

But there are many other narrative possibilities offered up by the Dark Sector idea. It would be a science fiction feeding frenzy. Such is the disparity between the amount of Dark Matter and ordinary matter in the universe (cosmologists estimate a ratio of around four to one), that it's quite possible there are four hidden sectors out there to our own one, separated from each other as much as they are separated by us, and sharing roughly the same mass. Biology is based on chemistry and chemistry is based on the properties of what we know as electrons, photons, and to some extent also protons, so each sector could exist with its own independent biologies and ecosystems.

What's more, while our sector abides by the Standard Model, according to which all elementary particles that possess a non-zero mass obtain that from their interaction with the Higgs boson field; other sectors might abide by a completely different model, and obtain their mass from interaction with a different field. If the mass terms in the corresponding equations cannot be written as real numbers but as 'complex numbers', there would be an interesting consequence: 'tachyons' (i.e. hypothetical particles that move faster than light, from the ancient Greek word 'tachys', meaning 'fast'). In our reality, as Einstein demonstrated, the speed of light is the upper limit: massless particles travel at that speed, massive ones never reach it, but can only approach it as their energy grows. In the Tachyonic Sector, however, we would see the inverse: the speed of light would be the *minimum*, and massive particles would fly at infinite speed if they lack any kinetic energy. In practice, time in that sector would flow in the opposite direction with respect to us. And if any mediator particle would bridge a communication between them and us, then we would have a plausible mechanism for a new plot based on precognition.

Notes

1. *The Infinite Monkey Cage* (BBC Radio 4), as discussed in 'If Ghosts Were Real, Brian Cox Claims CERN would have Found them by Now,' *Wired*, 24 Feb, 2017. https://www.wired.co.uk/article/the-lhc-proves-ghosts-do-not-exist
2. In general, these new experiments are relatively cheap (at least by LHC standards) and are often hosted in ad hoc locations, exploiting infrastructure originally built for other purposes. For

example, milliQan is installed in an unused access tunnel leading to the CMS experiment (see https://u.osu.edu/milliqan/); Anubis will be hanging across the shaft of the cavern that hosts the ATLAS experiment (see https://www.hep.phy.cam.ac.uk/ANUBIS); Mathusla's large area detectors will cover an abandoned field at the surface 100 meters above the CMS experiment (see https://mathusla-experiment.web.cern.ch/).

3. As discussed thoroughly, for example, in *Constructing Quarks: a Sociological History of Particle Physics*, Andrew Pickering, University of Chicago Press, 1999

4. Examples of this might include the signatures of the Weak Neutral Currents and of the charm quark. The former was discovered by the Gargamelle experiment in 1973, but earlier neutrino experiments had observed an excess of events with the same characteristics. The existence of the charm quark was established in 1974 by collider experiments at SLAC and Brookhaven, but an experiment in 1968-1969 had already observed it in the form of an anomalous statistical distribution ('Lederman's shoulder') and, not being optimised for that observation, it lacked the mass resolution that would have been necessary to interpret it correctly. Moreover, some argue that the particles containing charm quarks had been first observed in 1971 in a cosmic-ray experiment.

5. Note this is different from the missing 'superpartner' particles of supersymmetry because in that case all new particles would be very heavy, otherwise they would have been found already. It also differs from the standard paradigm of Dark Matter which postulates the missing matter is constituted by a single very heavy particle, abundantly produced in the brief period after the Big Bang and then remaining as a sort of inert, relic molasses permeating the universe.

6. 'Physicists Propose New Way to Detect Dark Matter Particles,' *Sci-News*, 10 Oct, 2019: http://www.sci-news.com/physics/dark-matter-particles-07680.html