

Monday, August 25, 2014

## **Of Dark Matter, And Resonance Across Scales**

**by Tasneem Zehra Husain**

I'm a total pushover when it comes to stories of connection. I am delighted by accounts of barriers breaking down and disparate people uniting in purpose, of ideas coalescing and theories fusing to reveal the common threads that underlie diversity. As I look back upon the history of physics, what reaches out and grabs me are the moments of unification when strands long thought separate are suddenly braided together in a whole that is stronger and more beautiful than the sum of its parts.

Sometimes we uncover hidden affinities by exploring a motif repeated in apparently unrelated contexts; at other times, we are compelled by circumstance to form alliances with those we may have neglected, to put our heads together and come up with a solution acceptable to all. The conundrum of dark matter falls solidly in the latter category.

For several decades, cosmologists and astronomers had been growing progressively distant from their particle physics colleagues. As one group craned their necks further out into uncharted space, the other crawled deeper into the recesses of the atom. The disciplines began to seem as divergent as the scales upon which they operate, but there is a surprising resonance between the minute and the colossal. Even objects of cosmic proportions are built from subatomic particles. The discovery of dark matter was a reminder that no part of the universe can be completely understood by those who turn their backs on the rest.

Discussions of dark matter (and dark energy) are often front-ended by a startling admission of ignorance: the entire gamut of matter particles we conventionally study - quarks and leptons combined - forms less than 5% of the known universe. There is about five times as much dark matter out there, we are told, while the rest of the universe is made up of dark energy. But, since neither dark matter nor dark energy can be seen, how do scientists justify this shocking claim? An analogy might help. The mechanism of human



vision is such that we see objects only when they reflect light. But if you find yourself in a pitch dark room, you don't immediately conclude that just because nothing is visible, the room must be empty. You simply realize that sight is no longer a reliable guide under these circumstances, and you must lean on sounds and smells, and touch (and taste?) to probe your surroundings. For lifeforms less dependent on vision, the darkness is multi-textured and alive with variety. Consider bats, for instance. Where we rely on light hitting objects and bouncing back, bats bank on sound. They emit high frequency calls, inaudible to human ears, and use the resulting echoes to construct a sonic map of their surroundings (the further an object is, the longer it takes for the echo to come back). The moral of the story is this: as long as there is a way for you to interact with an object, you can "sense" its presence.

In physics, we sense things through their response to the four fundamental forces - gravity, electromagnetism, and the two nuclear forces - strong, and weak. To be visible, an object must feel the electromagnetic force. We are so used to translating our dependence on light into an inability to see in the dark, that we don't often stop to think about its corollary: even when light is present, only those objects that reflect it can be seen. In other words, if there is an object that is oblivious to light, it is quite literally, invisible. For a long time, we thought that all matter was visible, but it turns out that is not quite true. How do we know this? There are several pieces of evidence, but I will mention only two: a discrepancy between the observed and expected rotation speeds of astronomical objects, and an optical trick called gravitational lensing.

Measuring the orbital velocities of galaxies in the early 1930s, Fritz Zwicky called upon "hidden" matter to make sense of what he saw. In several cases, the observed speed of rotation was so fast that the galaxy simply could not have been held together by the gravitational force of the visible stars - it should, by rights, have flown apart. The only way out of this apparent contradiction was to postulate the existence of clumps of invisible matter, clustered at the center of the galaxy. The idea fell into oblivion for about four decades, until astronomer Vera Rubin noticed similarly perplexing behavior: stars at the outer edge of a galaxy were rotating as fast as those close to the center. Since most of the visible mass of the galaxy is clustered at the core, the gravitational pull should decrease as one moved further out, resulting in slower motion for stars around the edges. To make up for the discrepancy between observation and expectation, Rubin conjectured that the gravitational effect of the "luminous matter" was supplemented by that of a "dark matter" halo surrounding the galaxy.

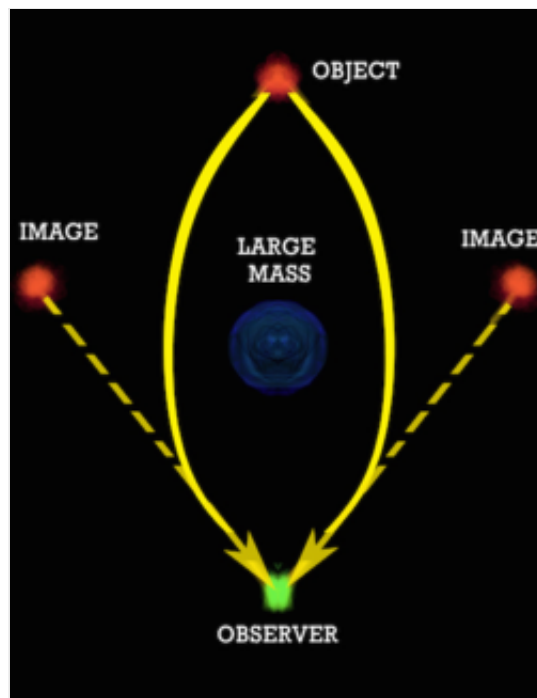
In order to understand gravitational lensing, we need to take a detour through general relativity. We'll go the quick route, by virtue of John Wheeler's elegant aphorism: "Matter tells space(-time) how to curve, Space(-time) tells matter how to move." The theory is far more complicated, of course, but this statement suffices for our present purpose. While classically, space and time were thought of as a fixed, rigid background, general relativity says that space-time is dynamic and responsive to the presence of matter.

Much as a rubber sheet is depressed by a heavy object, space-time curved by the presence of mass; when the stage changes shape, the play is naturally modified. A marble might roll straight across a stretched, taut rubber sheet, but if the sheet is curved, the path of the marble will be adjusted accordingly. What we call gravity, said Einstein, is merely a response to the space-time curvature caused by mass.

In the days before general relativity, gravity was thought of as an attraction that existed between two objects that had mass. If Einstein was correct, gravity would be exerted only by massive objects, but the resulting space-time deformations would be felt by all. Thus, even massless particles (like those of light) which had previously been thought to remain unaffected, would succumb to the gravitational pull. The claim was audacious, but luckily it could be tested. In 1919, in the now famous Eddington expedition, stars close to the sun - not usually visible during the day - were photographed during a total eclipse. Comparing these day-time positions to their known, recorded night-time positions, a slight discrepancy was found.

The excitement could scarcely have been greater had the stars actually moved in the heavens, but of course the apparent shift was only an optical illusion. Our visual apparatus has evolved to construct images based on the assumption that the light rays impinging on our retinas have travelled in straight line paths from the object - and in the terrestrial environment where we live, this is an eminently sensible approximation. When light rays converge or diverge (as through a lens, or on a shiny curved surface, like the back of a spoon) or otherwise deviate from straight line paths (through the refraction that occurs at the boundary of air and water in a drinking glass, for instance), the eyes do not know how to compensate; the brain extrapolates the incident rays to be straight lines, thus creating a distorted image. The Eddington expedition caused an international commotion because the difference between the "day-time" and "night-time" positions of the photographed stars was precisely what general relativity had predicted it would be, if light rays were curved as they passed by the sun. The discovery was heralded by sensational headlines in newspapers all around the world, and Einstein was catapulted into instant celebrity.

Besides ensuring immortality for Einstein, light's engagement with gravity has many other consequences. After all, if the mass of the sun can cause measurable visual aberrations, we would expect light coming around heavier masses to result in severely unreliable images, and in fact such effects have been observed. The phenomenon is called gravitational lensing - since mass serves to alter the path of light, much as an optical lens would. In fact, if gravity is strong enough, light rays from the same object can come and hit us from different sides, resulting in multiple images of the same object.



*(In the figure above, light rays reflected from the object reach the observer after being curved by a strong gravitational field. The observer constructs images under the assumption that the light rays have traversed straight line paths, and hence miscalculates the position of the object.)*

Working backwards from these distorted - or repeated - images, we can calculate the strength of the gravitational field that gave rise to these effects. When this is found to be far larger than the field that can be generated by visible objects, we are forced once again to attribute the missing mass to dark matter.

Convinced by astronomical observations that dark matter exists, we turn to particle physics for an explanation. Regardless of how it behaves on a cosmic scale, dark matter must be made up of something - but there is nothing in the standard particle physics repertoire with the requisite properties. Astronomers and particle physicists alike conclude that our existing understanding of the universe is astonishingly incomplete, and that - at least with dark matter - we have run into a problem that must be tackled simultaneously by both teams. As to the subatomic origin of dark matter, there are several conjectures for candidate particles, but no conclusive proof has yet been obtained. The search is on at various places, including the LUX dark matter detector, and of course the Large Hadron Collider at CERN. There is hope that once the LHC is turned on again, in early 2015, at higher energies than before, some evidence of dark matter may turn up.

Like most physicists, I am excited at the prospect of what we might uncover. We form - and follow - conjectures, we wonder how this new mystery will be resolved. But for now, perhaps it is enough that dark matter has shaken us out of our complacency. As a race, we have a propensity for pausing, every so often, to think we have it all figured out. Each time, the universe reminds us of its almost unfathomable vastness. "Inventions have long since reached their limit and I see no hope for further development"

declared Julius Sextus Frontius, a Roman Engineer, two millenia ago. It is scarcely possible to list all the 'further developments' that have occurred since.

At the turn of the twentieth century, several physics professors attempted to dissuade their brightest students from pursuing the subject, since the end was eminently near. Max Planck too, was told that "Possibly in one or another nook there would perhaps be a dust particle or a small bubble to be examined and classified, but the system as a whole stood there fairly secured, and theoretical physics approached visibly that degree of perfection which, for example, geometry has had already for centuries." And then, quantum mechanics was unleashed. In some ways, the discovery of dark matter - the revelation of the magnitude of our ignorance - might be the biggest jolt yet. Or, it could be the biggest gift, depending on how you look at it.

Personally, I've begun to think of knowledge as a fractal. Rich and intricate worlds lie between points that appear adjacent. The circumscribed area may well be finite, but the boundary is infinitely long. Out on the perimeter, we can walk forever and never run out of places to explore. What could possibly be better?

ShareThis Facebook Tweet Reddit LinkedIn Pinterest Email

Posted by Tasneem Zehra Husain at 01:00 AM | [Permalink](#)