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The engine began to growl as my old Land Cruiser crawled its way up and out of the valley. A column of dust was suspended in the air behind me exposing my route of travel and I watched it trace the contours of the landscape through my rearview mirror as I climbed. Cobbled river rocks gave way to a deeply rutted two track, which slowly morphed into something more befitting of a mountain. You know you are heading in the right direction when the rocks in the road begin to surpass your minimum ground clearance. This is a good road. A Wyoming sort of road.

I was looking forward to ascending to loftier heights and escaping the heat below. Though seasonally we were squarely into autumn, my thermostat was having philosophical differences with the date on the calendar. And so I climbed - out of the gritty high desert and into the cool embrace of Engelmann spruce and subalpine firs that ringed a high mountain lake.

The real object of my desire was not so much an escape from the unseasonal heat though, as it was to locate an osprey nest that I had been watching over the summer. Two weeks prior, I had waded out into this small lake to climb atop of a rock and watch a pair of these birds pull fish from the water. On the opposite bank was a towering condominium of sticks and branches where two chocolate brown and speckled juveniles shouted their demands. An idyllic place if there ever was one. This was an osprey Shangri-La, and I admit that I was jealous.

Upon finally reaching the lake however, the nest was empty. No birds floated overhead riding out invisible thermals. Nor was there signs of freshly caught sushi smeared across the males preferred perch. Instead, I found mallards – refugees in the process of hopscotching their way down the Rocky Mountain Flyway, fleeing some distant cold front up north. The migration was here, and my ospreys were now well on their way to some place as far south as Venezuela to spend the winter lounging around in cahoon palms and dining on peacock bass.

The seasonal mass movement of animals is one of the most extraordinary natural phenomena that we play witness to. Each year, around five billion birds undergo a mass exodus out of North American. Some, such as the arctic tern for instance, log an average of forty four thousand miles a year traveling back and forth between Greenland and the Weddell Sea in Antarctica, chasing an endless summer. Mammals do it. Reptiles do it. Even the insect world catches the fever with the likes of the monarch butterfly who travels 2,500 miles over the course of four generations only to return back to the exact same tree in Mexico from which their great grandparents left the year before. And here in Wyoming, just about every species that calls this state home undergoes some sort of migration before the winter snows begin to fall – even salamanders.

This nest will sit empty through the winter. Snow will build to towering heights. Howling winds will put structural integrity to the test. And for eight long months, this entire scene will be encased in white.

But once the mountains begin to thaw, the ospreys will return. And they will do so to the exact same nest from which they started from - a feat that deserves pause. As for their offspring however, the intoxication of the neotropics will hold them hostage a little longer. But after spending the next two years in tropical bliss, they too will return back to this same place - having only made the journey once before when they followed their parents south shortly after fledging.

These birds will fly thousands of miles, and cross international borders again and again. Peering down from their vantage amongst the clouds, they will witness a landscape ever changing. Development will spread. Mountains will be removed for resources. Great storms will rearrange the coast lines. And forests will be cleared. Yet, they will stay the course. Year after year, they will make their journey undismayed by the improbability of distance, and each time with a precision that the GPS in my vehicle cannot match.

Answering the question of why animals migrate is simple enough. Of all the many factors that we face in life, only two of them are powerful enough to force these animals to leave their hard earned territories and roll the cosmic dice of surviving such an arduous journey. Food and sex. The need to sustain yourself, and the need to sustain your species. Urges that drive all life on Earth. The greatest natural phenomena on the planet can be simplified down to just those two words. A calculable percentage of individuals who migrate will not make it back. They will be shot, caught in storms, starve to death, preyed upon, or who knows. Elegies are not written for dead ospreys. You simply find an empty nest come spring. The need to feed and the need to breed are the only things worth risking one's life over.

But how do they do this? That is the million dollar question that ties the proverbial knot in the stomachs of researchers. How exactly do the meadowlarks that sing to us in the springtime find their way back to the same territories they left last year? How do ospreys fly from Venezuela to the very same dead tree they departed from eight months before in the Gros Ventre Mountains? Are they following landmarks? The polarity of the sun? The stars? Smell? Memory? All of these have merit. Yet none explain how animals move across continents when landmarks change, when both stars and sun are obscured by clouds for days on end, and storms blow them far off track. And what of bears and wolves who are translocated hundreds of miles from home, far beyond any known landscape, only to reappear in the very same area that they were originally removed from? For this to occur, there must be some sort of constant, some kind of unwavering feature that is perceptible regardless of location, weather, knowledge, or distance.

Enter: geomagnetism.

We have known for some time now that buried deep inside of the beaks and brains of various animals is a collection of microscopic magnetic rods that we have termed biogenic magnetite. Intricately connected to the nervous system, these little magnets dispatch signals to the brain that help orient its carriers. Basically, this is an internal compass of sorts with the magnetic poles of the Earth pulling at the ends of the rods. Even humans have deposits of this stuff in their brains, though it would seem that some of us are paying more attention than others.

But a compass is just a compass. At the very best, it will only let you know in what general direction that magnetic north is. To get to my house though, you need a little more information than simply, "its north of Mexico."

As the esteemed Harvard biologist E.O. Wilson revealed in his book Consilience, one of the biggest hurdles that faces science in general is the fact that there is often times little to no synthesis between the different disciplines. Each genre of scientist specializes in their given topic of interest. This gives us deep insight into those topics of course, but often times it does not allow for out of the box thinking, or for seemingly disconnected pieces of a puzzle to come together.

Our understanding of the role that the Earth's magnetic field plays in migration has been no exception. By the late 1960s, we knew that birds and other animals were somehow tapping into the magnetic field, but biologists didn't quite understand how. That is, until Klaus Schulten and Thorsten Ritz did the unthinkable in the late 1990s and began looking at the mystery of migration through the lens of quantum physics.

Quantum physics, or more appropriately, quantum mechanics, is the really heady science that dabbles in concepts of multidimensional universes, string theory, and where exactly electrons go when they simply disappear and then reappear. This realm of science is more famously working on questions like the origins of the universe and black holes. But this is exactly the type of thinking that it took to begin questioning the biophysics of migration, and more specifically the discovery of cryptochromes in the eyes of birds.

The paper that Schulten and Ritz would publish on their findings was a game changer. What they discovered was that cryptochromes, a protein that played a role in the eyes' sensitivity to light in general, were also uniquely reactive to blue waves of light. When this color spectrum of light entered the eye and bathed the cryptochromes, stable pairs of electrons split apart into free radicals that became sensitive to the Earth's magnetic field. I am simplifying some pretty complex science here, but they were able to show that in theory, this should create a sort of light and dark banding across the field of vision that corresponded directly with variations in the magnetic field. In other words, birds may actually see the geomagnetic field that wraps around our planet.

This is biology, brought to you by the same field of science that discovered dark matter.

Now let's skip ahead several years to a researcher working out of Goethe University in Germany named Katrin Stapput. Curious as to what degree vision really is related to bird's ability to sense the magnetic field, she began working with European robins to test Shulten and Ritz's findings. What Stapput found was that when you cover the right eye of these birds during the migration, they became disoriented and flew in completely random directions. When the right eye was uncovered however, and therefore the cryptochromes within it were exposed to light, the birds were all able to orient perfectly and completed their migrations.

If a species could actually see, or sense the magnetic field, and not just tell north from south, then they would also be able to identify subtle variations in that field as well. And the world is full of these little disparities. In fact, just about every place on the planet has its own unique geomagnetic address thanks to these variations. Jackson Hole is going to have a different magnetic signature than that of Cheyenne, which is going to have an even greater difference than Cape Hatteras National Seashore along the coast of North Carolina. So whether you are a meadowlark returning to your windswept summer haunts near the Black Hills, a sandhill crane trying to find Greys Lake, or a tundra swan simply passing through on your way back north to the arctic tundra, knowing the magnetic address of your destination will help to get you where you are going. Add to this an internal compass of biogenic magnetite that is ever pointing

northward, and in essence you have a neuro global positioning system continuously reading latitudinal and longitudinal coordinates.

Life began at sea. So when the ancestors of today's avian and terrestrial species came crawling out of the primordial soup, they carried with them the genetic memory of life once lived within the watery embrace of the ocean. And it was here, in the vast openness of the sea where species traveled across entire ocean basins to exploit seasonal food sources, that all of this began. In this world where no stars exist, where the polarity of the sun is hidden, where geographic features sit many thousands of feet below, the magnetic field was the only reliable constant from which to navigate by.

It should be of no surprise then, that when it comes to studies related to animals' ability to tap into this magnetic field, that much of what we do know is based upon pelagic species. Whales, sea turtles, sharks, and salmon have been something of the epicenter of research. But as we have seen with recent discoveries of the quantum mechanics of cryptochromes, the details of avian migration are slowly beginning to be teased from the story as well. Yet, for the wholly terrestrial tribes of animals, this realm is still *Terra incognito*, and stands as mysterious and unknown as Yellowstone was when John Colter lost himself and his mind there after parting ways with Louis and Clark.

To what extent do animals as diverse as salamanders and gray wolves utilize the Earth's magnetic field to navigate the world? The evidence suggests that they may be orienting themselves through their perception of geomagnetism, but how and to what end?

In 2008, researchers from the University of Duisburg-Essen, Germany made international headlines when they released the findings of their study utilizing Google Earth to document the phenomenon that cows and deer tend to orient themselves with magnetic north when resting. And another team has recently shown that all of that spinning you see when your dog heads out in the morning to do their business, is actually them attempting to line up with the magnetic poles in preparation to take a squat.

And then there is the red fox. After a two year-long study of their hunting success, researcher Jaroslav Červený, along with a twenty three member team, found that red foxes had a mind bending 73% success rate at pouncing on mice when they were oriented with magnetic north. The success rate fell to just 18% when facing other directions, a rate that is more typical of carnivores in general. Červený hypothesizes that red foxes may be using geomagnetism as a sort of rangefinder based upon the downward tilt of the magnetic field toward the north. Huh?

Like I said, *Terra incognito*.

Despite the fact that scientists have been studying the effects of the Earth's magnetic field on species since the 1960s, our understanding is still rudimentary at best. Much like a Russian Matryoshka doll, where picking up one doll only reveals another below it, in the field of animal magnetism, each question that is finally and painstakingly answered, only creates new and more complex questions. This is very much a biophysical rabbit hole that we find ourselves just now beginning to peer down into.

Given the legendary skittishness of migrating waterfowl, I opted to remain in my Land Cruiser and observe the raft of twenty plus mallards that loafed about on the lake from a distance. As I adjusted the diopter on my binoculars, their reddening legs seemed to almost glow beneath the water's surface. This

was a sign that hormone levels in these birds were beginning to change as their breeding season was just over the horizon.

Soon, these high mountain lakes would be inundated with waterfowl stopping over on their journey south. All of them following geomagnetic meridians in science fiction like fashion. Down in the valleys, the first roughed legged hawk had already been seen - a sign that changes were in the air. Red winged black birds were vacating their now brown and dying cattail haunts and congregating in mass across agricultural fields. Soon, the unseasonably warm temperatures will break and elk will begin funneling out of these mountains and down to their ancestral winter ranges. Animals all over the northern hemisphere are in motion now. The migration is in full swing. And forces are at work all around us that we have only begun to understand.