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Measuring darkness

Abstract:

Up to now, simulations of dark matter resemble shapes seen in the vast cosmic web that scientists have drawn to depict the universe. That is, the gaseous knots, filaments, and voids which link galaxies betray the shapes of what dark matter is thought to look like. But this mimicry stutters when the centres of those knots, filaments, and voids are observed, and the precise nature of dark matter—particles which make up 80% of the known universe—remains elusive. The task is to find a way to describe the spaces in-between, because in the heart of the web pattern hunting breaks down; knowledge peters out.

One clue to the mapping and describing of dark matter might be in the shape and shaping of stellar halos. These ghostly remnants of interactions between galaxies surround observable galaxies as faint halos of starlight. As with the moon and tides, galaxies push and pull each other, their great gravities shaping the fabric of their neighbours and vice-versa: galaxies are cannibals, and the larger ones strip the thinning edges of smaller, star-massed bodies. These surrounding edges—made up of stars and gasses escaping the rims of the galaxies in which they were born—build up stellar halos. Within this cloud must be, somewhere, dark matter: that is the only current explanation for the terrific mass which is measurable and impactful within and without stellar halos, but which remains unseen. Chris's research attempts to understand the differences latent in the maps we make of the universe, with the aim of producing a phenomenological model that matches observed data with theoretical models. The big question is something like this: Using models of what we can already observe in the universe, can measurements be made to pin down what dark matter is? Perhaps, this questions suggests, by drawing maps, something impossible to describe can be sensed.

Daniel, as a creative writer, is inspired by a differing interpretation of phenomenology: he is looking for clues to aid both his descriptions of the past, and his understanding of how the past is formed in consciousness. Thus, this dialogue on the shape and form of matter will dwell on how constructions of the past are shaped; it will linger on vastness which cannot yet be described—the 80% of the universe which is dark matter, and the mysterious shapes of the past behind us. The gravitational pull of dark matter moves galaxies, forces them to touch and kiss and burst; the dark shapes of the past push and pull the present, and make patterns yet to be understood.

Biographical notes:

Chris Power is a Research Associate Professor and ARC Future Fellow at the University of Western Australia. His research interests span a broad range of topics in dark matter and galaxy formation, which he tackles with a combination of simple pen-and-paper and sophisticated supercomputer models.

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Creative Writing - Dark Matter – Anne Lister – Pattern Hunting

Provocation

Chris Power

Up to now, simulations of dark matter resemble shapes seen in the vast cosmic web that scientists have drawn to depict the universe. That is, the gaseous knots, filaments, and voids which link galaxies betray the shapes of what dark matter is thought to look like. But this mimicry stutters when the centres of those knots, filaments, and voids are observed, and the precise nature of dark matter—particles which make up 80% of the known universe—remains elusive.

One clue to the mapping and describing of dark matter might be in the shape and shaping of stellar halos. These ghostly remnants of interactions between galaxies surround observable galaxies as faint halos of starlight. As with the moon and tides, galaxies push and pull each other, their great gravities shaping the fabric of their neighbours and vice-versa: galaxies are cannibals, and the larger ones strip the thinning edges of smaller, star-massed bodies. These surrounding edges—made up of stars and gasses escaping the rims of the galaxies in which they were born—build up stellar halos. Within this cloud must be, somewhere, dark matter: that is the only current explanation for the terrific mass which is measurable and impactful within and without stellar halos, but which remains unseen. The big question is something like this: Using models of what we can already observe in the universe, can measurements be made to pin down what dark matter is? More precisely, this stimulus considers how extended stellar components might help pin-down the nature of dark matter. The data is taken from an article published by C. Power and A.S.G Robotham: ‘The Extended Stellar Component of Galaxies the Nature of Dark Matter’, in *The Astrophysical Journal*, 825:31 (10pp), 2016 July 1.

Galaxies are surrounded by faint stellar halos, streams, and shells. The conjecture is that the properties of these ‘extended stellar components’ (ESCs) might be used to test dark matter. After simulating different dark matter models—Cold Dark Matter (CDM), Warm Dark Matter (WDM), and Self-interacting Dark Matter—one conclusion is ‘that [the] mass scale at which differences between plausible dark matter models is most likely to be evident—at or below the scale of the satellites of the Milky Way—is also the mass scale at or below which galaxy formation is inefficient and apparently stochastic’ (Power and Robotham 2016, p.1)—that is, random, and impossible to predict precisely.

Results suggest that, provided a galaxy can form, the properties of the galaxy that we observe are likely to be shaped by the physics of galaxy formation rather than the physics of dark matter. Arguably this is not so surprising, when one considers the relative dominance of baryonic [a baryon is a kind of subatomic particle] material for the central gravitational potential in all but the most dark matter dominated galaxies, and the relatively short timescales (e.g., crossing times, cooling times) in these regions. What about the outskirts of galaxies, where timescales are long and the influence of dark matter dominates that of baryons? Could these regions offer a test of the underlying dark matter model? (ibid p.1)

Stellar halos are predicted to arise naturally in hierarchical galaxy formation models, built up, at least partially, by the merger and accretion events that drive galaxy assembly; partially, because cosmological galaxy formation simulations have demonstrated that such halos likely have a dual origin, comprising of a component that formed in situ, in addition to the accreted component that formed via tidal disruption of satellite galaxies and star clusters. The in situ component is believed to originate in dynamical heating of the stellar disc at early times, and so it dominates at smaller galacto-centric radius; in contrast, the outer halo is dominated by the accreted component. (ibid p.2)

The paper published in *The Astrophysical Journal* investigates ‘how the underlying dark matter model might influence this accreted component by exploring the spatial and kinematic structure of stellar halos of simulated galaxies’ (ibid p.2).

We do not expect the dynamics of subhalos to differ significantly between CDM and WDM models. The orbital distribution will be preferentially radial, while the orbits of lower mass subhalos and their satellites will require many pericentric [arranged around a centre] passages to decay; this implies that tidally stripped stars from a low-mass satellite can be spread over large galactocentric distances [a star’s distance from the centre of a galaxy], and the greater the number of low-mass satellite undergoing such tidal stripping, the greater the radial extent of the resulting ESC. We make the reasonable assumption that the physical processes that govern galaxy formation (e.g., cooling, star formation, feedback) should not depend on the underlying dark matter, consistent with previous studies. This means that differences in the properties of the accreted component of the ESC should reflect differences in the abundance of satellites, which depends on the subhalo abundance. (ibid p.2)

The paper presents an exploration of the above using ‘cosmological zoom simulations’ of Milky Way mass systems. Each of the Milky Way mass halos was simulated with both dark matter and gas. While it’s beyond the scope of this ‘stimulus’ to provide in-depth analysis of the results, a number of images and graphs were presented which suggest that ‘the low surface brightness surroundings of galaxies could contain the observable imprint of dark matter’ (ibid p.7). Here are some examples of what the images and graphs look like:

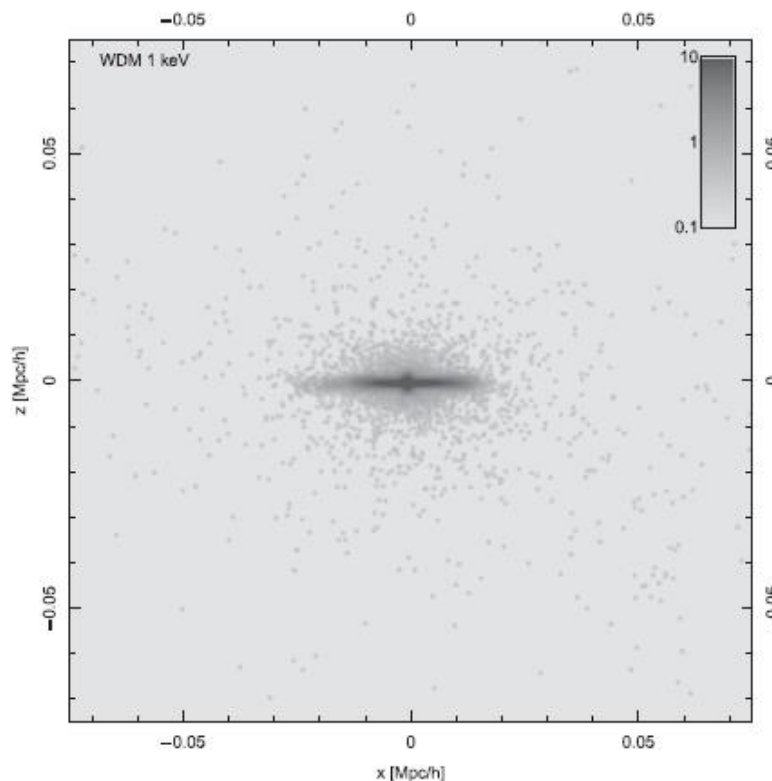


Figure 1: From Figure 1: a Warm Dark Matter case

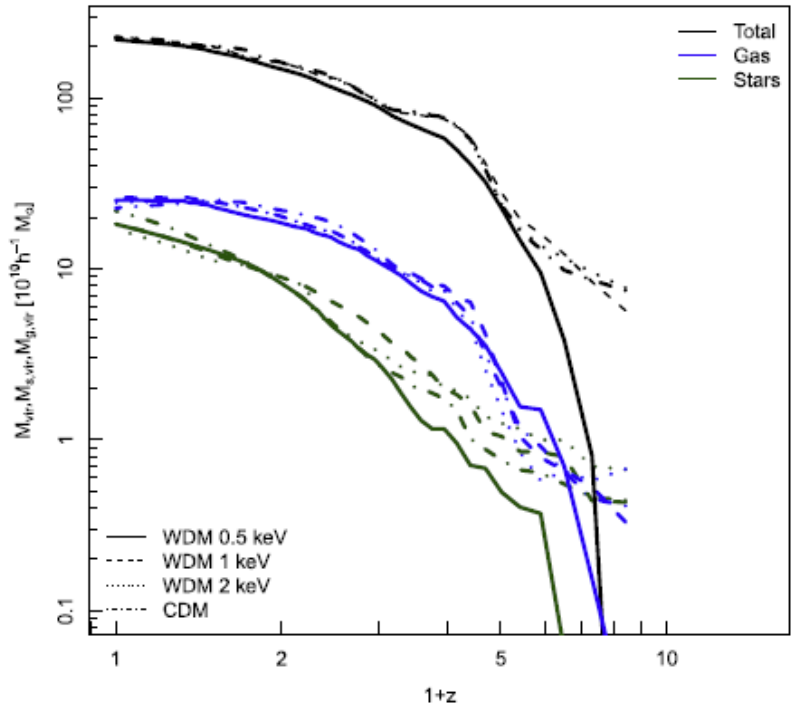


Figure 2: Figure 4 in the article: Growth of Viral Mass with Redshift

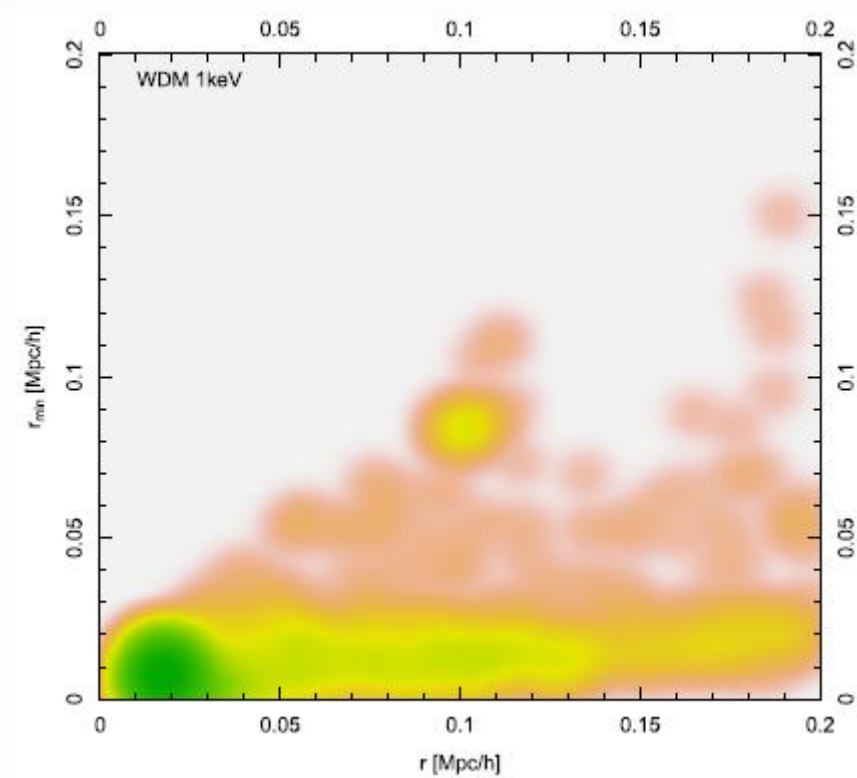


Figure 3: From Figure 7: An orbital eccentricity of the extended stellar component

In Figure 7 we check if differences in the spatial structure of the ESC reflect differences in the kinds of orbits traced out by the progenitors of the material that composes in the ESC.

The key point here is that there is no systematic difference between the distributions in the four models [in Figure 7 in the article]; orbits are preferentially radial and there is no compelling reason why the distribution should differ between CDM and plausible WDM models, as is

borne out by numerical simulations—material funnels from the cosmic web and into the potential of the halo, which does not differ substantially between models. (ibid p.7)

In summary, ‘the nature of dark matter should be more centrally concentrated in WDM models with lower particle masses (i.e., warmer dark matter)’ (ibid, p.7). And, even if the work done remains ‘a challenging test of dark matter’,

There is good reason to expect that we can use properties of the ESC to explore the mass assembly histories of galaxies, tracing merger and accretion events using material in the outer halo, and placing limits of the growth of galaxies in the context of their larger scale environment. (ibid p.9)

That is, it should be possible to use what’s left or visible to explore the history of galaxies.

Creative Response

‘Simulation’

Daniel Jukes

...the ‘three steps’ business so in my mind, I seemed coolish, I daresay, & formal. Spoke very low & little. Said I was sleepy. Went upstairs at ten. M— came & talked to me.

Anne Lister, *The Secret Diaries of Miss Anne Lister*, p.316.

I find it difficult to think constructively about stars, let alone what lies behind, around, and within them. I am not so good in the abstract, and that is, sometimes, what stars seem to be. Galaxies are, of course, the next stage of that abstraction, a zoomed-out substructure nested within—apparently—something even larger, interconnected, and webbed.

When I think of a web I think of something trembling, fragile—even if the shapes and branches and hollows of it are formed by material stronger than anything it’s possible for non-spiders to manufacture. And I think of the web which has existed, in its slowly-deteriorating way, in a corner above my front door; of the spider once strung tightly to it, who slept during the daytime, in-between bricks, just next to the doorbell. Now she is gone, but there is still a small amount of debris, some bugs trapped in the silk, though soon the wind will take even it and them away. For a while I could follow two thin strands which led from the web’s heart to where she lay; they were hard to spot at first, but when eyes adjusted and the twinned, taut strands appeared over a background of window and peeling paint, it felt a little like a secret revealed. Perhaps this is how Chris feels when he wonders on the secrets in extended stellar components? Perhaps not.

The metaphor of the web is a well-travelled one. That might be because it is not quite a metaphor: in one of Charles Darwin’s scribbled notebooks, strung with crossings-out and those spangled diagrams which branch off and off and off, the naturalist wrote (underlining the words, and crossing his last ‘t’ with a flourish), that ‘We may be all netted together’ (1837-8). And here, in Chris’s picture of the universe, is something similar: a cosmic web made of intangible—at least, to me—yet solid material. We are netted together in it, within its endless intricacy, and somehow the shapes of it—brief dustings, great clouds, its branches, streams, and shells—have and hold secrets like those it might be possible to see in the wisps of stars or in the webs of spiders.

There is a generous kind of density to the language of physics, a solidity which I do not think exists in the language of words and letters strung in sentences—at least those words and sentences I can understand. Without some quick-to-function Rosetta stone, or years penetrating the depths of symbols and concepts, the language of physics enforces a kind of comprehension (even if that comprehension is nestled nowhere near the truth). Without the ability to penetrate its shapes and hollows, the language in the provocation—the language I’ve tried to familiarise myself with over the course of this dialogue—feels impenetrable. It’s a flip-sided density, whereby equations become shapes themselves, self-evident polygons which stand for things in the same way words do.

Of course, the truth is that language—any kind of language—only seems this way. Those who can and do decipher complex mathematics can read between the lines in a way which is, perhaps, second nature. But from a distance the words used to describe the web of stars and galaxies and more-than-galaxies which is the universe seem like hieroglyphics on a pyramid wall: that is, definite constructions, or pictograms of singular essence. The ambiguities are only apparent when the construction is peered at closely, and with the right kinds of knowledge, such as the findings gleaned from the fading star-edges which are Chris’s business. I’ve been

able to glimpse less than a skerrick of the truths embedded in the language I've been working with and bouncing from. But that small insight has helped me to see this way of describing the world in a dual kind of light, albeit glimpsed sidelong and only following hard, sometimes-failing focus. The world on Chris's page is still solid, distant, and pictographic, but I can see too the way it trembles and refracts just slightly: it threatens to move. I can understand how its shifts and ambiguities might function a little like the language I understand and write in. By extension, those shifts and shakings within the model represent a fragile and solid universe being understood. It is webbed in more ways than one.

The web of the universe is a kind of ever-expanding thing. I think Chris and I approach it with a similar goal in mind, but from entirely opposite directions. He aims at the invisible from the more macro-scaled things which make up that web, and I try to use the invisible to describe the patterns and forces of some of those scales. Of course, we mean different things by 'patterns and forces'. No doubt we even mean different things by the word 'invisible'. But I hope to make a contribution on a scale I can only describe as micro (even if, ironically, it is not quite as micro as the one Chris is hoping to be able to detect). I'm interested in moments of the past that, for a while, are invisible, but which become relevant through a kind of simulation; through the examination of some of what remains, the cold and still skerricks of what was. By cross-hairing time on a micro-scale I hope to reify the potentials in each 'sussuric' machination of the atoms which build our bodies and everything else. I hope, sincerely, that that does not seem too grand a claim to make.

A fixation on particular words, whether because of their shape, sound, or meaning, was crucial to my attempts to decipher the paper abbreviated above. 'Stochastic' is one such word, and 'kinematics' another. Kinematics is a branch of mathematics dealing with pure motion. It discounts mass. And, of course, that still means not much to me. I tried to drill down into words like these to attempt to excavate meaning, but this level of attention only ever results in ambiguity too, even if something is solidified at the same time in a simultaneous ravelling and unravelling, a little like the way dark matter is both evident and elusive in simulations of it. Perhaps this erratic—stochastic?—approach is fruitful, perhaps not. One thing it's typical of is the way I've taught myself to work, of the historical method I've employed in the past for writing like this: an unflinching focus on random particulars, in order to elucidate all the extending ripples of moments, people, and things. Again, a grand claim. But I must emphasise it is just that: a claim.

This feels, though, like a method borne of the very workings of literature, which is something like a literal attempt to describe a web—a story is a flashing, partial, ephemeral simulation of the things which make up life. In *Middlemarch*, George Eliot embraces the web as metaphor. Her novel is an incredible simulation of the very threads which link hearts and minds together, and she talks directly to the theme I want to evoke here, in this response: that an obscene focus on the particular might work to describe something larger, that there are secrets in each and every substructure of the universe, that zooming in and out—playing between scales—is a method for sensing something of the whole. I'll present a test case momentarily. Eliot says, of her focus, that 'All the light I can command must be concentrated on this particular web, and not dispersed over that tempting range of relevancies called the universe' (1871-2/2003: 141). The particularities of Eliot's web are the people of the provincial town she created. In my practice, those particularities are the moments, people, and things which I can trace in my past—even the most stochastic of them. Especially those. It's like picking a star at random and hoping to find something telling about the history of galaxies. But it is possible to do that sometimes, isn't it? Even if picking a star at random might prove difficult.

In trying to keep my focus as precise as possible, I only ever fail. But I find that the more ephemeral, the more fleeting those past-essences are, the better the effect. Ephemerality is one way a kind of kinematics can be sensed: not a kinematics of solid (or un-solid) objects, but one of influence and essence and personality. I think this approach is compatible with Chris's work, but only in the sense that one might be a metaphor for the other. Of course, I'm not really describing the workings of the universe, but if it's possible to make it seem as if I am, then I'll consider the simulation a success. That success—and the driving force behind each and every word I pin to the page—is elusive, because of the always-shifting cosmic web we are caught by.

I tend to start with my past, because it is my own, because it is mostly uneventful, and because it is—by dint of this web—partly yours too. I have not lived what you would call an explosive life, and cannot be accused of causing much in the way of repercussions. But part of the claim I want to make here is that smaller collisions—each event, in fact—do have consequences for the web in which we are netted. I am also, I must confess, a little enamoured by the potential of illuminating something of myself to myself. In any case, I always seem to end up in the places where my memories were made, whether in my writing, or in a more embodied sense. I take myself there—into memories—because I like feeling the way they flicker, the way they force footsteps and allow a sense of something it might be possible to chase. Perhaps it is one bulwark against randomness? Certainly, in considering the shapes produced by past collisions, it would have been remiss of me to go anywhere else.

Despite the fact that I have lived in Australia for much of my life, most of my memories were made in a valley in the north-west of England—the Calder Valley. I have been unable to loosen my grip on that small, green, stony patch of the planet. Only this valley could give me the firm foundation needed to respond to Chris's initial sally of dialogue: how else could I form a reply to writing in which I found barely a thing to hold onto, besides dreams of galaxies clashing, spuming, revealing, and odd words I could love, like 'subhalo', or 'baryon'?

That day I let my impulse take me. I found myself tracking back to a stately home in a park next to my grandparents' old house. The stately home was Shibden Hall, in Halifax, West Yorkshire. There is, perhaps, something in the way the place sits at the crest of a hill: the act of looking upwards is possibly some kind of reaction to the starstruck experiments detailed in the first section of this dialogue, a hint at the movements of memory. Then again, perhaps not. What's true is that once this memory settled as the one to explore, it was difficult to shift, and, since that decision, I have merely spent my time working out how to write towards what I knew, know, and have learned of Shibden Hall.

I visited the Hall only by chance, the last time I was in England. As I said, I had aimed for the house in which my grandparents used to live: 'Fairclough', the name of which is carved into the stone at the top of a driveway that butts onto the road to Hipperholme. My brother and I would go to Fairclough every Friday, and enjoy the sort of routine which only ever excludes memory: each trip, now, has become the same as the others, split only occasionally with an intervening sharpness: the sting of a wasp hiding in the lock of a window, or an argument in which my name is shouted. In my mind the rest is rote and wonderful: swimming, McDonald's, television, bed.

Going back was a way to test my memory, to see what came up when I visited, and to attempt to understand those shapes which emerged. There were flashes and pulses of things: mostly summertime memories, of a sun house (which had disappeared when I visited), of a barbeque surrounded by crunching stones, and of an armchair in which my brother and I would sit together to watch whatever we had chosen to watch on that particular night. (Every Friday we would drive along the road at the top of the driveway, into Hipperholme, to a video shop in that

village, and my brother and I would take turns to pick a film.) I wonder sometimes exactly how my brother reconstructs those days, how my Nanna and Grandad do: the string of things I recall cannot be what they have inside their heads.

In England this last time I didn't dare walk down Fairclough's driveway, nor did I knock on the door. I can never quite bring myself to those kinds of actions when I play these memory games. This is possibly an indication of my true feelings towards the intangible, and of how they might differ to Chris's. Instead, I watched the house work for a while, from the main road looking down onto it. I let the things I remembered play out, and play again.

When I was there I realised I had forgotten precisely how the green of the place was broken up by speckles and freckles of yellow and white: daisies and buttercups covered the grass of the lawn and of the fields opposite, on the other side of the road. But the trees closed above in the same way, even felt taller; midges and gnats swarmed and tried to sneak into the corners of my mouth, of my nose.

Alongside the house, separated from it by a hedge, was a path leading down into the bottom of the valley—into Shibden Park. The stone of the steps on the path had not had time to do more than crack a little more. The walls either side of those steps were crammed and crazed, sometimes bulging in, and always mossy and threatening. Stinging nettles surged over the tops of the bricks, and thorns and thick brambles were massed either side. My grandad used to keep the hedge tidy; I remember it was important that the thing be thick and heavy, so that people might not be tempted to crawl under or through it.

The stone stairs dropped down to the lower end of the park, which was waterlogged, and coursed with streams that rung and clattered. The whole place is dangled with green in my memory, groves and grottoes leading up the edge of the park, and up to the road next to Fairclough. It was like that when I returned. I followed the path downwards, and reached the lake where we had hired small boats to row around the brown and still water, where we watched for geese and ducks, and where each time a waterboatman landed on its bouncing surface, the water would crease and then support it. At the bottom of the path you passed a kind of fountain, perhaps just a waterfall, and the curved track of a miniature railway. There were swings, a slide, and the spinning barrels I loved the most, on which you could run forever and never move an inch. The playground had changed—the barrels were gone—but the fountain was the same, and the tracks of the train were there in the ground.

I walked through the park, listening to it, trying to remember where I was. There was a football pitch, and a paddling pool, and a pair of crows hopping on the rail of a bench. The ground started to incline, and I realised I was at the bottom of the hill we had once come down on sledges, in the snow: I had been scared I would not be able to stop myself before I reached the lake, but the ride had petered out long before that became a problem. Then—there, at the top of the hill—was the Hall.

I left my memories behind and headed up the incline towards the building. And this is, of course, the problem with chasing memories: we are always inevitably involved in the process of making new ones. Perhaps an old desire was murmuring, one I'd held since then—since the time before—a desire to see inside the Hall, to know what the place looked like from behind its walls. So I paid the entrance fee and worked my way through its rooms. I looked closely at the bookcases, which were behind glass, and held shelves of leather volumes. All the walls of the place were dark brown and wood panelled, and I remember a clock which had more dials on it than I knew how to read. The beds were small but grand, and there was a courtyard with carts and carriages, a tiny pub, and a chiselled bit of stone commemorating the remains of a gibbet, found on the site, which had been used for the beheading of fifty-three people. There

were secret passageways, small doors, and an exhibition about a woman who had once owned the property: Anne Lister.

Anne lived between 1791 and 1840, and inherited Shibden Hall from her aunt. She was responsible for the way much of the building looked when I wandered through it—she built at least some of the secret passageways, and she also kept a diary for most of her life, often for much the same purpose as those passageways. The diary stretched over four million words, and large chunks of it were recorded in what Anne called ‘crypthand’, a coded mixture of Greek letters and other symbols which she dropped into when the subject matter became more necessary to conceal. At Anne’s death, the diary was hidden inside the walls of the Hall, until its rediscovery in 1887. The code was cracked by the last member of Anne’s family to own Shibden, John Lister—helped in the task by his friend, Arthur Burrell—who decided to put the documents back into hiding. Initially Burrell had wanted to burn them, writing that, ‘The contents of this cipher ... is an intimate account of homosexual practices among Miss Lister and her many “friends”; hardly any one of them escaped her’ (Whitbread introduction, in Lister 1988/2013: xiv). The journals are full of life: of domesticity, of business, of illness, anger, and banality. They are painstaking in their detail, in their revelation, and are crammed with love, sex, and misery. They stayed hidden until the 1930s, and even then Anne’s secrets were kept until the 1980s, when Helena Whitbread began the laborious task of deciphering them. And, thus, the wisps of the past are made visible in the present. I thought of Anne when I read Chris’s provocation; of the way she’d somehow lasted, and how all she’d done in that house would have had the same impact on me even if I did not go into Shibden Hall that day.

Anne had a number of partners, but perhaps the love of her life was Mariana Belcombe (M—in the journals). The tragedy of their story is not the focus of this essay, but it is the subtext. It is part of the tempting range of relevancies I have tried to skirt, a part of the moving, whorling knotted weaves of the past behind me.

One day in August, 1823, Anne and Mariana were to meet and spend the night together in York. But, according to Whitbread, Anne could not bear to wait for M—’s coach to arrive in Halifax. Instead, she set off ‘to walk over the moors to meet the coach on its way from Lancashire’ (ibid 300). The story is told in Anne’s journal entry for Tuesday, August 19:

Only one house (& that 2 miles off), the inn at the top of Blackstone Edge, looking down on Littlebrough & Rochdale. The drizzling went off, the prospect cleared & I walked forward, enjoying the clear mountain air. Between the 9th & 10th milestone, passed the division stone between the counties of York & Lancaster. A dreary mountain moor-scene, the river but a small stream murmuring on my left; the lake-like reservoir of the Rochdale canal on my right. A dreary prospect. A countryman observed in passing, ‘It’s but a wildish place, this.’ (ibid 300)

Anne spied the carriage carrying M— winding up towards the inn. She recorded her joy, and (precisely) her speed: she had walked 10 and a half miles in 3 hours and 10 minutes, ‘at a rate of a mile in 18 minutes’ (ibid 301). What happened next, according to Anne, was that she leapt into the carriage, surprising a dozing M—, and shocking a man, a maid, and the post-boys, jumping the three coach steps in a proverbial single bound. In her diary Anne records some of the incident in her strange, invented code, and Whitbread tips the writing into italics to show Anne slipping into cipher, saying that M— would have been ‘horror-struck. Why did I say I had walked from Shibden? ... how fast I talked! Why did I come so far? Why walk?’ (ibid 301-302). Whitbread says that Anne’s decision to take her walk across the moors, to leap—suspended for a moment, gravity-defying—into M—’s carriage, ‘was to have fateful consequences for the relationship between the two women. Anne’s bizarre and wild appearance in the middle of nowhere ... provoked [M—] to respond in a way which Anne never forgave’ (ibid 300). Back in plainhand—what Anne called her non-coded text—she admits: ‘I did talk

fast. My words flew from me as tho' disdainful to touch on utterance' (ibid 302). The words of her diary flow fast and free, and she admits that 'I felt—yes—unutterable things.' And even though she tried to laugh it off (what she began then to call the 'three steps business'), it was clear that something was settling in Anne's mind: that moment at the cusp of her walk across the moors had shifted her world a little. And, believe it or not, her leap up those three steps is intended to be the shimmering, ephemeral focus of this essay. Think how a longish stride up three steps into a carriage might have set the world rolling in a particular direction—might have shaped the web of us all in ways we aren't quite sure of. How each moment trembles off another and another, as if silk-linked; how the histories of galaxies of influence might be glimpsed in the preservation of a moment like this.

On the carriage now, and less than happy, Anne arrives with M— at Tadcaster. Despite their tempers, Anne reports in her diary that, 'Soon began the erotics last night'. She also records the moment she cribbed down those thoughts in cryptand: Thursday 21 August, 3.55 p.m., 1823. But she cannot balance the way she feels about M— with the way that she perceives, or is beginning to perceive, M— feels about her. 'My heart still lingers in its old abiding place, thoughtless of its broken bowers, save when some sudden gust blows thro', & screeching memory is disturbed' (ibid 306). The next day Anne copies up her thoughts: 'I only meant to have written a few lines of rough draft but thoughtlessly got into the midst of the thing & could not, did not like to, stop till I had done it, for if I once break the thread of my ideas I can never get on so well afterwards' (ibid 306-307). I am familiar with the feeling.

The crux of that business with the three steps was that M— was embarrassed by Anne. The moment Anne set out that day from Shibden Hall, on her stochastic walk across the moors to Blackstone Edge, and the instant she hurdled into M—'s carriage, were catalysts for all that came afterwards: her leap into thin air caused a journal entry to be written on August 21. This in turn pulsed a new, sad kind of life between Anne and M—, a life which enforced the shapes they both made for the rest of their days. And each time the journals were hidden, found, read, written; each time I walked with my family in the park which Anne had built; and each time I have remembered that place, the same thing has happened: shapes have been added and bridges have been built in the web which both locks us down and frees us, which we are trapped by, but can pluck at. Of course, the strings are not so tight, and this is metaphorical. But I wonder sometimes how it felt for Helena Whitbread to find this story hidden among the millions of Anne's words that she deciphered. I wonder how it felt to know that this thing happened, that the ache Anne felt was once not quite a simulation, that something like the truth lingers, and limbers up, in all we have left of what was. And that the past pulls at us when we see it like this, when the force of each decision made is enough to shape a web which quickly becomes less and less particular, which trembles and ripples with each and every breath taken and leap made, in every nook and cranny of the cosmos, filled with dark and void.

Exegesis

Chris Power

At first glance on a clear, dark evening, stars appear to be scattered at random across the sky. Some are brighter than others, some twinkle orange, others red. Any obvious design is a design imposed—the hunter and his dogs, the twins, the creatures of myth—telling tales that thread through time. The stars and their stories are some of my earliest memories of enchantment, as a child growing up in a rural Ireland, just over the Irish Sea from the English North-West of Daniel's childhood. Memories abide; the dim, ruddy glow of Dublin to the East; the nip of cold in my fingers as I sharpened the focus on my binoculars; the gasp of breath as, even then, I comprehended the beauty, the scale, the sublime, the sense of something greater.

We often talk of our lives as tapestries, as we impose a narrative, a logic of design, but the web that Daniel perceives is arguably a more accurate one. The strands can snap, our lives shift in response; the design and its logic need not be visible, but we often sense it and seek it. So it is that I find myself half a world away from my childhood, divining our past and present in the stars and in those runic symbols that so intrigue Daniel, equations, that act to shape the world we live in.

Stepping outside on a clear, dark evening, it takes a few moments for my eyes to discern design—a faint band of nebulosity running across the sky, the disc of the Milky Way. Our Solar System is embedded within this disc of stars, billions of times more massive than our Sun, completing an orbit about the centre of our galaxy every 220 million years or so, an astronomical timescale in the true sense of the word.

Yet if we continue to peer upwards, out of the plane of the disc, we see that the Galaxy is enshrouded in a ghostly halo, a relic of its assembly. Astronomers are galactic archaeologists, sifting through ancient light to piece together the story of how galaxies have come to be. Within this ghostly halo we see the remnants of galactic companions past, wispy tendrils of stars that were stripped and shorn out as these smaller companions fell towards and were cannibalised by our Milky Way's ancestor. Through the prism of their light, we can both track the motions of these stars and piece together their histories in their host galaxies, from the enormous clouds of gas and dust that gave birth to them. These are relics of ancient galaxies, building blocks of the Galaxy that we live in today.

Gravity is both creator and destroyer. It draws together matter, dark and light, over cosmic distances, and builds galaxies, confining them and funnelling fresh matter towards them. It is why our Universe, which was smooth and featureless 14 billion years ago, now contains stars, planets, indeed complex life itself. It is why our galactic companions, distinct galaxies drawn to our own, suffered a demise that allowed our Galaxy to grow. The stars ripped from those unfortunate companions by the Galaxy's tides as they plunged towards their doom continue to trace out their host galaxy's orbit, an almost anthropomorphic response to the trauma of their host's destruction.

Using detailed computer models, we can reconstruct the kinds of orbits these long-gone companions once followed. What these models reveal tells us not only about orbits, but also about cosmic dark matter. The laws of nature, those of everyday experience and intuition, falter when we consider the motions of stars and galaxies—their speeds strongly hint that either our theory of gravity breaks down, or there is matter present that we cannot see. Unseen, 'dark' matter is the favoured interpretation, favoured by many lines of evidence. How much dark matter is present and what kind of particle it is—analogueous to the protons, neutrons, and electrons that comprise the ordinary matter of everyday experience—will impact the numbers of galactic companions we might expect to find around a galaxy like the Milky Way, and

computer models reveal that the structure of ghostly halos has the nature of the dark matter imprinted on it.

Mapping the ghostly halo of a galaxy as we change the nature of the unseen dark matter reveals that the masses of the most massive galactic companions are similar across different models, but there are many more low mass companions in currently favoured theories of dark matter. The orbits of these low mass companions decay on a much longer timescale than their more massive brethren, and they can spread their stellar material over much larger scales. The result: that light from ghostly halos in alternative theories of dark matter should be more concentrated around galaxies, providing an interesting observational test accessible to the latest generation of telescopes. A little, perhaps, like the way the past can persist in hidden diary entries.

Works cited

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