Nature's Design

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This page is for the "Designing Matter" Common Course. To get the most out of my contribution as Session 13 : "Astronomy", I strongly recommend reading and pondering the following questions, as well as reading the article: "A Brief History of Matter" which you can find on my web page at http://www.astro.virginia.edu/∼dmw8f under public outreach.

This course concerns "Designing Matter". For the most part, the designers have been either humans or the biosphere. Lets step back and look more broadly at the presence of matter in the Universe, and consider Nature's role in the design of matter. Afterall, all we can do is tinker with the products of its creation.

1) Perhaps understandably, most of human attention is focused on molecular matter. How common are molecules in the Universe? Consider just the solar system. What fraction of matter in the solar system is in the form of molecules? What fraction is in the form of single atoms? To help answer this question, imagine what would happen to you if you inadvertently fell into the sun — can your molecules or even your atoms survive, and if not why not? What about the presence of molecules in the galaxy. Where, besides planets, might you expect to find them? What factors might limit the size and complexity of these extraterrestrial molecules?

2) Why stop at atoms or molecules: what fraction of the mass in our Universe is basically atomic (protons/neutrons/electons)? If you have not heard of it, look up "dark matter" on the web to find out the answer. Pushing even further, what fraction of the Universe is composed of matter, as opposed to energy? Again, if you have not heard of it, look up "dark energy" on the web.

From (1) and (2) you should learn that we live and breath in a world made from an **exceedingly** rare form of matter. We are myopically focused on a small scrap of paper when all the world's books lie waiting to be read.

But the material content of the Universe is only the beginning of our investigation. What about the way that matter is arranged: it is **structure** that we most associate with design and creativity.

3) When it comes to creating structures from matter, our methods have many limitations: temperatures, densities, energies, pressures, durations. Contrast some of these limitations with what is available in Nature's laboratory, the Universe. For example, what are the densities, temperatures and pressures found at the centers of stars, which one can think of as the ultimate pressure

cookers. Near black holes, essentially all process occur at "relativistic energies" — what does this mean, and are these conditions easily achievable on Earth? What about designing life: a billion year experiment in molecular evolution covering an entire planet — will we ever be able to explore this creative avenue? Or perhaps the chemical factories found in planetary interiors — to what extent can we replicate these kinds of environments? Such questions reinforce the notion that compared to our own facilities, Nature's laboratory is vast, powerful, and ancient. Even if there are no scientists to man it, it is so huge and so old that many extraordinary and wonderful things have been "designed" and constructed, most of which we could never hope to reproduce ourselves.

4) The richness of our own world stems in large part from the variety of chemical elements that make it up — from the metals in your car, to the carbon in your bones, to the silicon in your computer. We take these elements for granted, as we do our high-school pictures of the periodic table. But there was a time when **none of these elements existed. Not one**. If you think humans are clever when they design molecules, reflect on how clever Nature has been to design and create the chemical elements, to which all molecules owe their life. How did the Universe do this wonderful thing? What properties allow such creativity to emerge? Having made these elements, why are they so unique and varied in their properties — the perfect starting point for further construction? You can find an extended account of this wonderful branch of astrophysics on my web page: http://www.astro.virginia.edu/∼dmw8f – go to the public outreach section, and then "A Brief History of Matter".

5) Continuing this theme, the main reason why life can exist is that molecules can combine to form endlessly complex arrangments. Why doesn't nuclear matter form similarly complex structures (only 200 nuclear isotopes exist) ? Why doesn't gravitating matter form complex structures (stars and galaxies are simple systems by comparison)? What's special about atomic matter that allows complexity to develop?

6) Not by itself, however. When humans assemble complex structures they requre energy to do so. How does energy enter our discussion of the creation of the biosphere, including the evolution of ourselves? What is the ultimate source of this energy? If you think it is the sun, think again — it is much deeper than that.

7) When the Universe designed its matter, it chose to construct four basic buidling blocks: nuclei, atoms, stars/planets, galaxies. Why four and not five, or ten? Why aren't there other natural building blocks? On a related theme: since we owe our existance to these building blocks, what role has each played in creating us and the world in which we live?

8) It may seem obvious to you that the Universe is filled with structure: stars, planets, people, rocks. But why isn't the Universe just smooth matter, spanning the vastness of space, expanding with the Big Bang? Why is there ANY structure? How did structure begin, and once begun, how did it grow into

the exceedingly rich distribution it now has? Afterall, we know from looking at the microwave background that about 400,000 years after the big bang, the Universe was just a hot (3000 K), dilute (100,000 atoms/cm^3), glowing (bright orange), UNIFORM (smoother than the surface of a bowling ball), expanding (500 km/s/Mly), gas of protons, helium nuclei, electrons and photons. Where the hell did galaxies, stars, planets, and people come from? As you may already know, we think that structure emerged from primordial SOUND: the hiss of the quantum world was amplified by cosmic expansion and gravity to become the sound waves from which all cosmic structure condensed. Rather poetically, "In the Beginning was the Word" may have renewed meaning in this context.

9) Moving further into the philosophical, why is there something and not nothing? Humans may succeed at rearranging pre-existing matter, but how did Nature create that matter in the first place? Why not a Universe of pure energy & light — it would have been much simpler, and possibly more beautiful, but of course there would be no-one to know that. You may already know that thanks to a tiny quirk of physical law, we narrowly avoided a Universe just like that — devoid of ANY matter. Even more confounding: both ourselves and the structures we design are inherently embedded in space and time. How and why were these bizarre entities created — an intangible framework in which all things find their place and moment.

Faced with such acts of creation, we should feel humbled in our stumbling attempts at "Designing Matter", and thankful for Nature's gift of magic building blocks and a stage on which to play our games. These gifts are absolutely dazzling, created by processes so subtle and powerful that we have only just begun to recognize them for what they are.