COSMIC WEB

Catarina Aydar

notebooks
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Cosmic web

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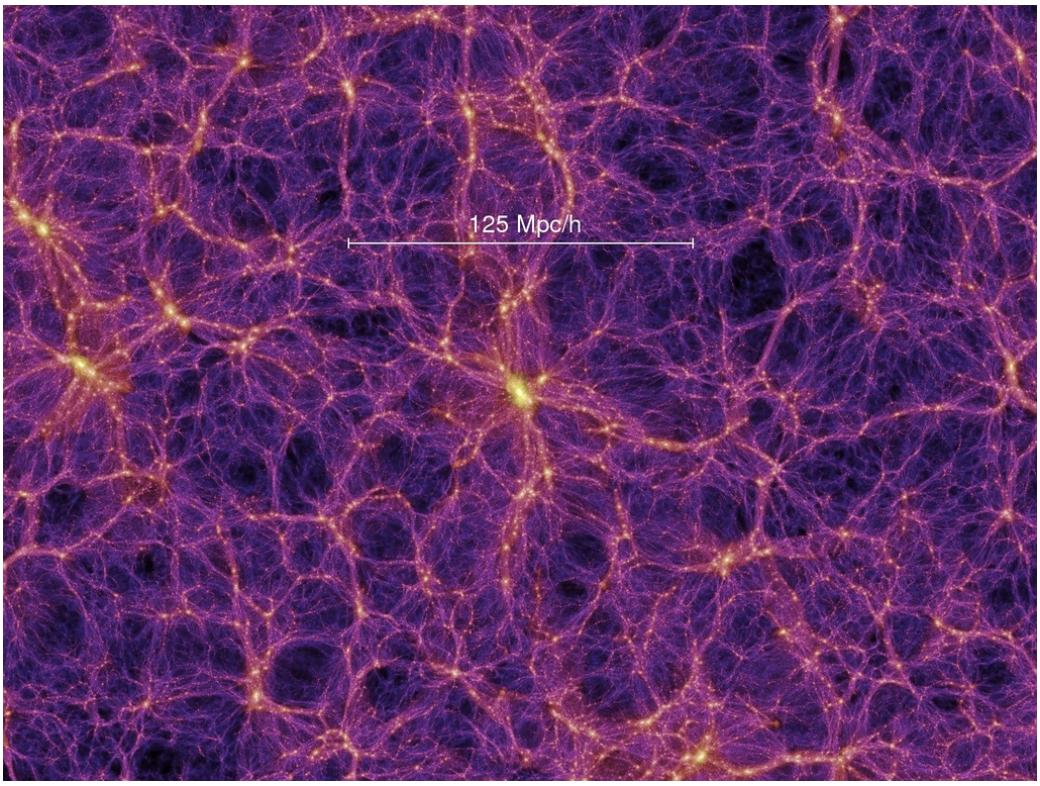
This notebook consists of the translation of the transcription of Catarina Aydar's talk about the Sun, filmed on 22 February 2024, at Teatro Oficina, in São Paulo. Catarina's video can be accessed here as part of the Sun Cycle, which comprises 17 talks.

It all started with a dot: a dot that was everything. Before this dot there was no before, because time and space emerged from this dot. But everything was too much to fit into only one dot, so this dot inflated in order to form a space, distributing everything that once was just one thing; creating difference. The differences, however subtle, were fundamental to define where there was going to be something and where there was going to be a void. Space continued to inflate, this time at a slower pace and, little by little, what was once a great mixture of things turned into a mixture of independent things: matter and energy. Matter is any body; it defines a presence there, in space. Energy flows in this space, transforming itself; its essence is to move, be it as light, as heat, as the very power of moving. So we formed the scenario as we have it today: matter and energy dancing in space-time, playing while they interact and transform, always influencing each other in their countless possibilities of connections.

As space continued to expand, things didn't want to be alone in the vastness of the Universe, which kept growing. Things wanted to be near other things, so they got together. Scientists don't really understand the Universe's desire to keep growing and things' desire to be together, so they call these tendencies 'dark energy' and 'dark matter'. We acknowledge that these effects happen, but we don't really understand how or why, so we call this invisible mystery 'dark'.

Once things wanted to be together, they began to form structures. The Universe, when seen from very far away, on its vast scale, is like

a cosmic web. It has nodes, where matter accumulates, with galaxies dancing and interacting with each other. It has filaments, which link these nodes like threads of a web. And there are many empty spaces, bubbles of nothing filling the everything.



Virgo Administrator, MPA-Garching. Springel et al. (2005)

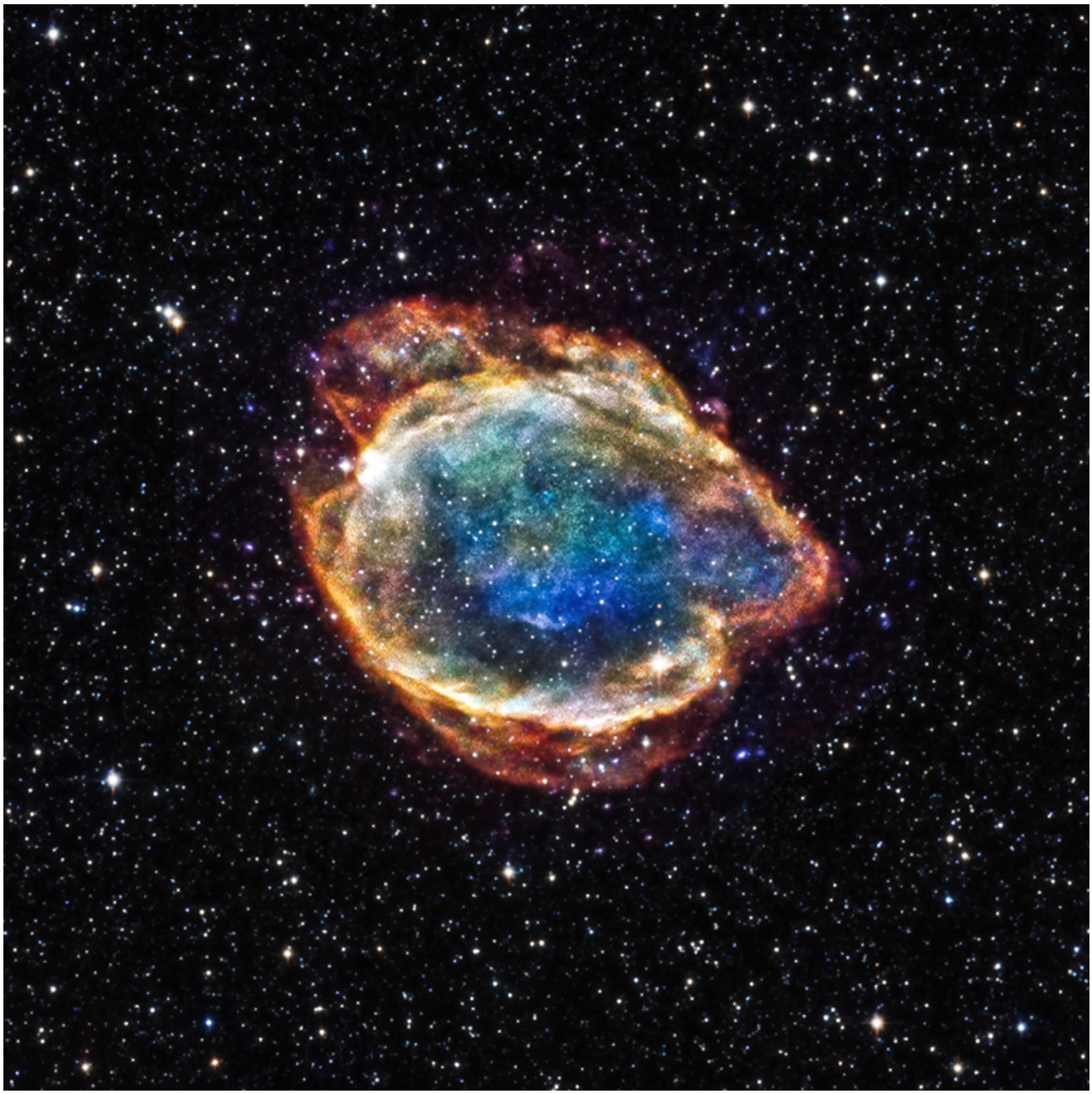
Simulation of the Universe on a large scale, showing the structures of nodes, filaments and voids in the cosmic web.

On the smallest scales (which are already immense), we find cycles similar to life, with births, developments and, in some cases, enough time for us to also witness deaths. Matter comes together in order to shine, but fades out once it runs out of fuel. A star, for example, appears when gas gathers into a hot ball, producing light and heat during its life-time. On a larger scale, galaxies are usually born from a lot of gas and very few stars, because the gas in them is still going to form the stars. These young galaxies are blue and spiral-shaped, with beautiful arms where stars are born, live and die.

NASA, ESA, Hubble, HLA; Processing & Copyright: Bernard Miller

Galaxies in interaction.
The larger one is spiral-shaped and blue, which indicates that it is younger and still forming stars, while the smaller one is elliptical and red, which indicates that it is older and has already turned most of its gas into stars.

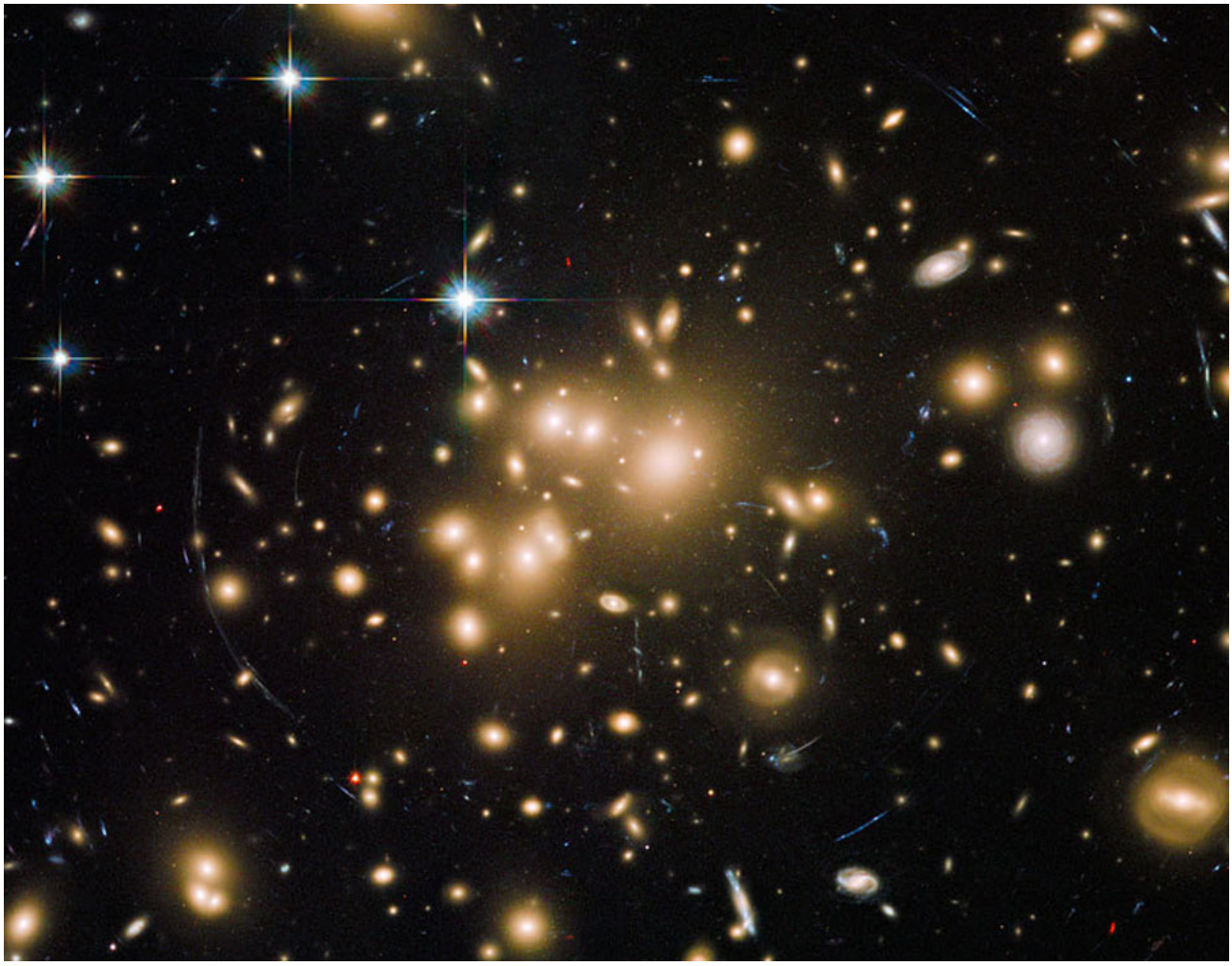
Stars have colours that depend on their size. A large star will be very hot and blue, and it will live very intensely and die early, due to an explosion followed by a collapse: what remains is a denser lump surrounded by the gas that once formed that star. A smaller star, on the other hand, will be cooler and redder, and its life will be less intense and much longer. It will transform its fuel into light little by little, and die less dramatically and explosively than its blue sisters.



X-ray: NASA/CXC/U.Texas/S.Post et al, Infravermelho: 2MASS/UMass/IPAC-Caltech/NASA/NSF

Supernova remnant.
When a massive star reaches the end of its life,
it explodes as a supernova and collapses becoming a central lump.
The image shows the debris from the explosion,
with gas slowly expanding in the form of a bubble.

When a galaxy gets older, it accumulates the history of many interactions. Most of its blue stars have lived out their lives and are no longer stars, after their death. So the older galaxies are redder, with older stars that burn slowly. And the shape of these older galaxies is rounder, because these galaxies have already mixed with other neighbouring galaxies that came from various sides. After so much eating, the galaxy is on a full stomach and round.



NASA, ESA, Hubble Heritage Team (STScI/AURA), e J. Blakeslee (NRC Herzberg, DAO) & H. Ford (JHU)

Cluster of galaxies in the centre and other galaxies in the background.
The dots with a crosshatched diffraction pattern are stars
from our Galaxy, and all the others are from another galaxy.

Our Galaxy, the Milky Way, is a teenager. The Milky Way still has spiral arms that form stars of all sizes and colours; and still dances with neighbouring galaxies, be they the Magellanic Clouds, which are gradually being swallowed up by and becoming part of the Milky Way, or the Andromeda galaxy, which is just as big as the Milky Way. When this great encounter happens, billions of years from now, they will certainly have a lot to exchange!

Carlos Eduardo Fairbairn

Long exposure photo of a night in Chile,
where we can see the structure of the Milky Way and,
between the mountains, the Magellanic Clouds.

Although we can predict what might happen in the Universe, we infer this from observations of what has already happened. Astronomy can only study the past, since information takes time to reach us. Light that has been emitted from a very distant star will take time to cross space and reach us, until someone on Earth is able to observe it and try to understand it. If the light coming from the Sun takes eight minutes to reach our planet, the light from the oldest galaxies in the Universe takes

billions of years to reach us, allowing us to study the beginning and development of the Universe up to the present moment.

Our Galaxy, like other galaxies of the present time, is made up of chemical elements that were formed inside stars or during the death of stars, in explosions we call supernovae. And since the Universe has been evolving for 13 billion years, we already have many different types of objects out there: stars, planets, moons, asteroids, comets, neutron stars, clouds of gas and dust, black holes... Faced with so much differentiation, will we ever be one, be a single dot again? Nobody knows about the future, but for now we're still in a growing Universe.

If nobody knows about the future, what is the point of astronomical knowledge? If we're dealing with such large scales of time and space, which don't affect our daily lives, what is this science for? We could resort to technological arguments, such as GPS and mobile phone chips, which have their origins in astronomical discoveries. But, after all, what do we do science for in general, if not to try to satisfy some of your curiosity about what exists? We continue to sketch out answers to basic questions such as: where are we? What surrounds us? Are we alone? And with every glimpse of an answer in this unravelling of Nature's fascination, we find more questions that continue to expand the frontiers of our knowledge. A plural knowledge that seeks dazzle and inspiration as we try to better understand what is this whole of which we are a part. After all, how many life-death-life cycles can we find when we observe the stars, the galaxies, the entire Universe?

By focussing on the life trajectory of stars and galaxies, perhaps the challenge for each being is to learn to chart their own paths in a balanced way, knowing the different ways in which life can manifest and thrive. We should be inspired by the Sun, that midsize star, which is neither too hot nor too cold, and from which we are neither too close nor too far away. This is the balance in which we manage to live while we explore the extremes and middle grounds in our journeys, and while we question how what's around us is also developing, on whatever scale.

Here on planet Earth, we still enjoy the blessing of a life that we don't know if it exists in other corners of this vast universe. We must not only thank the Earth, our mother who provides so many nutrients and

protections in the form of water, earth, air and fire, but also take care of her, acknowledging that without respect for our origin and our home, there is no place left for us to be. There is no other option on which to live, and yet part of humanity continues to treat life and the future with disregard, as if the abundance of this planet were resources to be exploited; as if life should be useful. We need day and night, activity and rest, adventure and care, in order to balance ourselves with grace and love in this cyclical Universe.

Catarina Aydar has a bachelor's degree in physics and a master's degree in astronomy from the University of São Paulo. She is currently studying for her PhD at the Max Planck Institute for Extraterrestrial Physics in Germany, where she is researching the co-evolution of galaxies and the supermassive black holes at their nuclei. Catarina is involved in scientific dissemination activities, such as *Astrominas*, and enjoys organising events. In addition to her work, she loves dancing, practising yoga and being in touch with nature.

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