SAMPLE

Cosmos Unveiled: The Lyman-Alpha Forest

Shadows of Ancient Gas

Aira Astralis

Free sample: Introduction & Chapter 1

putrabooks.github.io

Buy the full book:

Carousell carousell.sg/p/cosmos-unveiled-the-lyman-alpha-forest-ebook-pdf-1468105641

Payhip

Contents

Introduction

Chapter 01: The Line

Chapter 02: The Beacons

Chapter 03: The Discovery

Chapter 04: What the Lines Are

Chapter 05: Reading a Spectrum

Chapter 06: The Column Density Hierarchy

Chapter 07: The Thermal History

Chapter 08: The Metals

Chapter 09: The Surveys and the Cosmology

Chapter 10: The Gunn-Peterson Trough and the Edge

Chapter 11: The Damped Systems and the Galaxies

Chapter 12: The Proximity Effect and the Background

Chapter 13: The Three-Dimensional Forest

Chapter 14: The Frontier

Conclusion

This free sample contains the Introduction and Chapter 1. The complete book contains the full contents above.

Introduction

Spread the light of the most distant quasars across a spectrograph and the result is not a smooth spectrum but a ragged comb: a thicket of dark absorption lines crowded on the shortwave side of the quasar's own bright hydrogen line, hundreds of lines deep in the richest spectra, each one the shadow of a cloud of gas lying somewhere along the line of sight, between us and the beacon. Astronomers call that thicket the Lyman-alpha forest, and it is the subject of this book. The name is a nineteenth-century metaphor that stuck: the lines are the trunks and the gaps between them the foliage, and the metaphor, like the forest itself, rewards the patient walker.

The forest's importance is out of all proportion to its obscurity. The lines are the signatures of diffuse hydrogen gas in the space between galaxies, the intergalactic medium, and that gas is the universe's raw material: the stuff from which galaxies formed, the residue of the Big Bang, and the majority of the universe's ordinary matter for most of cosmic time. The forest is the only way to see this gas directly. Every line in the comb is a slice through the cosmic web, the foam-like structure of filaments and sheets that the universe builds its galaxies in, and a quasar spectrum is a core sample drilled through the web, one hydrogen cloud after another, from the earth to the edge of the observable universe.

The forest is also a measuring instrument. Because the absorption's strength depends on the gas's density, temperature, and ionization, the forest's statistics measure the intergalactic gas's physical state at every redshift, and because the gas's distribution follows the universe's dark matter, the forest's statistics measure the dark matter's clustering too. The forest has been used to weigh neutrinos, to constrain the dark energy equation of state, to map the baryon acoustic oscillation's imprint, to time the end of reionization, and to test the theory's cold dark matter foundation, and it does all this from lines that were once dismissed as noise.

This book tells the whole story. It begins with the physics: the hydrogen atom's ultraviolet transition, the line's cross-section, and the way redshift turns one spectral feature into a whole forest. It covers the discovery, from the first quasar spectra of the 1960s through the interpretation wars of the 1970s and 1980s, when the lines were argued to be everything from quasar ejections to primordial clouds. It sets out the modern theory: the forest as the cosmic web's transparent regions, the gas's thermal history, and the ionizing background that keeps it transparent. It covers the forest's use as a cosmological tool, the surveys that mapped it by the hundred thousand lines, and the exotic applications, from the Baryon Oscillation Spectroscopic Survey's

neutrino mass limits to the Gunn-Peterson trough's evidence for reionization. It ends with the damped systems where galaxies are caught in the act of forming, the metals that pollute the pristine gas, and the coming telescopes that will read the forest to the edge of the reionization era.

The reader should hold one image as the frame for everything that follows: a quasar is a lighthouse, the intergalactic medium is a fog bank, and the forest's lines are the fog's records, written in the lighthouse's light. The fog is not uniform; it is structured, by the dark matter's gravity, into the cosmic web, and the forest's statistics are therefore the cosmic web's statistics. The book's argument, developed over the chapters, is that the forest transformed cosmology's least visible component, the diffuse gas between the galaxies, into its most information-rich observable, and the chapters that follow are the account of how that transformation happened and what it taught.

The final framing idea is the forest's place in the universe's biography. The hydrogen the forest sees is the Big Bang's own leftover, and its history is the universe's history: hot and opaque at the beginning, cooling and transparent after recombination, reionized by the first stars, falling into filaments as structure grew, and slowly being condensed into galaxies as the cosmic age advanced. The forest's lines, read from redshift six to redshift zero, are the autobiography of the ordinary matter of the universe, the longest continuous record any observational technique holds, and the book that follows is that autobiography's reading guide.

The subject deserves one framing number before the chapters begin, because it sets the stakes. Everything visible, every star, galaxy, and cluster, is a rounding error beside the ordinary matter that exists as thin gas between them, and the forest is how that majority is seen. The book the reader is opening is therefore not a tour of exotica but an account of the universe's default state, told through the one spectral line that lets the near-nothing announce itself, and the chapters that follow move from a single dip of missing light to the largest completed maps of matter in existence.

Chapter 01: The Line

The forest is built from a single spectral feature, and this chapter is that feature's story: the hydrogen atom's Lyman-alpha transition, the line's physics, and the way the expanding universe multiplies one line into thousands.

The transition itself is the simplest atom's simplest notable act. A hydrogen atom's electron can occupy a set of energy levels, and the highest-energy member of the lowest, or ground, series, the transition from the first excited level to the ground state, is the Lyman-alpha transition. The energy difference corresponds to a photon of wavelength 121.6 nanometers, deep in the ultraviolet, and the transition is hydrogen's strongest: an electron in the first excited level will decay to the ground state by emitting a Lyman-alpha photon about a third of the time, and a hydrogen atom in the ground state will absorb a Lyman-alpha photon, jumping up to the first excited level, with the largest cross-section of any of its interactions with light. The line's strength is the forest's foundation: a gas of ground-state hydrogen is, at the right wavelength, an astonishingly efficient absorber, and the intergalactic medium, which is almost entirely ground-state hydrogen, absorbs at Lyman-alpha more strongly than at any other wavelength by orders of magnitude.

The line's astrophysical reach deserves a sentence too, since Lyman-alpha is not only a forest. The same transition is the universe's dominant cooling radiation: a hot ionized hydrogen gas, cooling, cascades its electrons through the levels, and the final step to the ground state emits a Lyman-alpha photon, so the line is the coolant of star-forming galaxies, the emitter of the high-redshift galaxies' signature, and the resonance that the modern cosmology's intensity-mapping experiments chase. The forest is the transition's absorption face, the galaxies' cooling is its emission face, and the same 121.6 nanometers threads through more of observational cosmology than any other wavelength, a fact the reader will meet again in the frontier chapters.

The cross-section deserves a paragraph, since its shape controls everything. The absorption's probability is not spread evenly over wavelength but concentrated in a profile: a sharp peak at the line's center, with a characteristic width set by the gas's temperature and turbulence and by the quantum uncertainty of the transition itself. A cold, still gas absorbs in a line a hundredth of a nanometer wide; a hot gas, broadened by thermal motion, absorbs over a wider band; and the profile's wings, though far weaker than the center, extend surprisingly far, the tail of the quantum mechanical resonance. The consequence is a hierarchy: a little hydrogen makes a narrow, weak line, more hydrogen makes a saturated line, and a lot of hydrogen, a dense cloud in the line of sight, makes a broad, black, wide absorption system. The forest's

lines are the small end of this hierarchy, and its rare dense systems, the damped Lyman-alpha absorbers, are the big end.

A note on the forest's red limit belongs here, since every forest has a boundary. The absorption never appears on the longwave side of the quasar's Lyman-alpha emission: by the redshift arithmetic, a cloud's absorption lands at wavelengths below the emitter's line, so the region redward of the quasar's emission is the forest-free comparison, and the quasar's redshift itself, the forest's starting point, is read from the emission lines' other features. The geometry has a second consequence: the absorption systems at redshifts close to the quasar's own crowd the spectrum's bluemost end, the proximity zone, where the quasar's own light dominates the ionization, and the forest's analysis treats this zone with special care, the next chapters' subject, since the ordinary forest's assumptions fail where the beacon's own light rules.

The redshift is the multiplier. Light from a distant quasar, traveling through the expanding universe, is stretched by the expansion, and the wavelength grows in proportion to the universe's scale factor. A photon that leaves the quasar at some wavelength passes, along its journey, through regions of the universe at every redshift, and each region's hydrogen absorbs at the wavelength that, in that region's rest frame, equals the Lyman-alpha wavelength. The observer receives a spectrum in which absorption appears not at one place but at many:

a cloud at redshift two absorbs at three times the rest wavelength, a cloud at redshift three absorbs at four times, and a line of sight through hundreds of clouds produces hundreds of lines, each at the wavelength that encodes the cloud's distance. The forest is therefore a map in wavelength, the stretch shortward of the quasar's own Lyman-alpha emission serving as a chronological strip, the nearest clouds on the red end and the most distant at the quasar's own redshift.

The line's ultraviolet home sets the technique's geometry. Lyman-alpha photons cannot cross the earth's atmosphere, so the forest cannot be observed from the ground for nearby gas; the atmosphere's ozone absorbs it. The trick that makes the forest observable is the redshift itself: gas at redshift two absorbs at about 365 nanometers, at the atmosphere's ultraviolet cutoff, and gas at redshift three and beyond absorbs in the visible, where ground-based telescopes work. The forest is therefore a technique for the distant universe by necessity, and the observable forest, the one ground-based astronomy can read, spans the redshift range from about two to the quasar limit near seven, the era from three billion years after the Big Bang to the first billion. The nearby forest, the gas in the present-day universe, requires space telescopes or surrogate lines, and its study is the field's modern frontier.

The chapter's summary is a single mechanism with three parts: hydrogen absorbs strongly at one ultraviolet wavelength, the expanding universe shifts that wavelength by the gas's distance, and the earth's atmosphere, by blocking the ultraviolet, restricts the observable forest to the distant universe. One line, multiplied by redshift, gives the forest; the forest's lines, ordered by wavelength, give a core sample; and the rest of this book is the account of what the core samples found.

The line has a human history too, and it runs through the laboratory before it reaches the sky. The ultraviolet series was measured in the first decades of the twentieth century, its discoverer a physicist who pushed spectroscopy into wavelengths the air itself refuses to transmit, evacuating his instruments to find the series that now carries his name, and the alpha line, the series' brightest member, entered the inventory of physics decades before anyone imagined it lighting the spaces between galaxies. The line then revealed itself twice over in near-earth space: in the Sun's own ultraviolet spectrum, and in the glow of the Earth's hydrogen halo, the geocorona, a diffuse envelope of our own planet scattering solar Lyman-alpha outward, one of the brightest ultraviolet signals in the solar system and a standing nuisance for space observatories.

The forest's line is therefore not an exotic of the deep universe but hydrogen's commonest signature, seen in the laboratory, in the Sun, in the Earth's outskirts, and finally, multiplied by expansion, in the gas between the quasars.

End of free sample. The full book is available at putrabooks.github.io

ABOUT THE AUTHOR

Aira Astralis is a science writer specializing in astronomy and space exploration. Her work spans the full breadth of humanity's relationship with the cosmos -- from the earliest naked-eye observations to the engineering marvels of modern space missions.

Her books are built on a foundation of primary sources: peer-reviewed research, mission archives, and direct engagement with the scientific community. She writes for readers who want to understand not just what we know about the universe, but how we came to know it.

She believes that the most important frontier is not out there but in the gap between what scientists discover and what the public understands. Her books exist to close that gap.