Abstract

Cosmic background (CB) radiation, encompassing the sum of emission from all sources outside our own Milky Way galaxy across the entire electromagnetic spectrum, is a fundamental phenomenon in observational cosmology. Many experiments have been conceived to measure it (or its constituents) since the extragalactic Universe was first discovered; in addition to estimating the bulk (cosmic monopole) spectrum, directional variations have also been detected over a wide range of wavelengths. Here we gather the most recent of these measurements and discuss the current status of our understanding of the CB from radio to \( \gamma \)-ray energies. Using available data in the literature, we piece together the sky-averaged intensity spectrum and discuss the emission processes responsible for what is observed. We examine the effect of perturbations to the continuum spectrum from atomic and molecular line processes and comment on the detectability of these signals. We also discuss how one could, in principle, obtain a complete census of the CB by measuring the full spectrum of each spherical harmonic expansion coefficient. This set of spectra of multipole moments effectively encodes the entire statistical history of nuclear, atomic, and molecular processes in the Universe.

Keywords

Cosmic background radiation, cosmology, electromagnetic spectrum, monopole

Introduction

If you look at the sky with relatively wide angular resolution, concentrating on radiation coming from beyond Earth's atmosphere, past the Solar System and outside the Milky Way galaxy, you would only see diffuse anisotropies on top of a homogeneous, isotropic background. This is known as the ''cosmic background'' (CB). The sources contributing to this background can range from astronomically small objects—such as atoms, nuclei, and dust grains—to stars, galaxies, and galaxy clusters, and are created by processes like nuclear fusion, gravitational collapse, and thermal radiation. As the CB is composed of photons ranging from hundreds of thousands to nearly 14 billion years old, its all-sky energy encodes the history of structure formation, energy distribution, and expansion in the Universe. It is an important tool in cosmology today and a huge amount of effort has been put into measuring, interpreting, and predicting its spectrum.

The CB can be observed over some 17 orders of magnitude in frequency (\(10^8\) – \(10^{25}\) Hz), which has required a plethora of detection techniques to measure and many different theoretical models to interpret; hence, we tackle this by splitting the spectrum into sections, or wavebands. Astronomers traditionally work in radio, microwave, infrared (IR), optical, ultraviolet (UV), X-ray, and \( \gamma \)-ray wavebands, each section unique in its radiation detection methods, units, and jargon, although the same physical quantity (namely the isotropic photon background) is being described. To construct the entire CB, it will therefore be necessary to perform a survey across effectively the whole astronomical discipline and to understand exactly how each measurement has been made, while translating the results into something mutually comparable.

Historically, the study of the CB took off in earnest with the discovery of the diffuse microwave component in 1965, although the first cosmic sources of X-rays were known slightly earlier than that and distant radio sources had been detected a couple of decades earlier still (although their interpretation was a long and complicated story, with direct detections of the radio background coming in the late 1960s). Moreover, it had been known since the early 20th century that we could see optical Department of Physics & Astronomy, University of British Columbia, Vancouver, BC, Canada

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Faint starlight in the brightest star-forming protoclusters
Galaxy clusters and protoclusters

Galaxy protoclusters: Collections of galaxies that will become a cluster at redshift 0.
Galaxy clusters and protoclusters

Protoclusters are in the most active phase of structure formation!

Peak of galaxy mergers/interactions.
The formation of the most massive galaxies.
The bulk of star-formation in the early Universe.
Finding and simulating galaxy protoclusters is hard, so little is known about this phase of structure formation.

When/why did galaxy environmental effects take place?

What drove the excess star-formation at high redshift?

Why did star-formation slow down (i.e. quench)?
The brightest objects in the cosmic microwave foreground

These sources are so bright, they can only be distant gravitational lenses or clusters of star-forming galaxies.

Experiments designed to map the CMB have also found the brightest submillimetre sources in the sky.
The South Pole Telescope proto-clusters

A sample of $z=4-7$ clusters of star-forming galaxies resolved from the South Pole Telescope (SPT) survey.

Large CMB angular resolution

Small follow-up angular resolution

Vieira et al. 2013
Spilker et al. 2016
Wang et al. 2020
The brightest star-forming protoclusters

SPT protoclusters were selected for their high star-formation rates.
The brightest star-forming protoclusters

SPT2349-56

SPT2349-56 is the brightest SPT protocluster at $z=4$, with a star-formation rate over 10,000 $M_\odot$/yr.

Brightest cluster galaxy (BCG)

Millimetre light sensitive to star formation

Miller et al. 2018
Rennehan et al. 2020
Rotermund et al. 2020
Hill et al. 2020
The brightest star-forming protoclusters

SPT2349-56

SPT2349-56 is the brightest SPT protocluster at $z=4$, with a star-formation rate over 10,000 M$_{\odot}$/yr.

100 kpc, size of Milky Way’s halo!
The brightest star-forming protoclusters

What happens when you cram 20 galaxies within 100 kpc?

0 Myr

?”

100 Myr
The brightest star-forming protoclusters

What happens when you cram 20 galaxies within 100 kpc?

Information about the ingredients of BCGs will become buried in the merger.

Mega merger!

N-body simulation, Rennehan et al. 2020
The brightest star-forming protoclusters

How any stars has this protocluster built up so far?

Millimetre light sensitive to star formation

Optical light sensitive to stars.
The brightest star-forming protoclusters

*Hubble* and *Spitzer* imaging of SPT2349-56 sees the light from the new stars.

- Optical light sensitive to stars.
- Infrared light sensitive to stars.

*Hubble* view shows protocluster galaxies.
Faint starlight in SPT2349-56

The galaxies in this dense environment look like galaxies in the field.

Star-formation rate $[\text{M}_\odot/\text{yr}]$

ALESS (da Cunha et al. 2015)
COSMOS (Scoville et al. 2016)
ALPINE (Khusanova et al. 2020)

z=4 field galaxies

z=4 protocluster galaxies

Star-forming rate versus stellar mass $[\text{M}_\odot]$
Faint starlight in SPT2349-56

Depletion timescale ($M_{\text{gas}}/\text{SFR}$) [Gyr]

Stellar mass [$M_\odot$]

The galaxies in this dense environment will use up their fuel faster than galaxies in the field.

z=4 field galaxies

z=4 protocluster galaxies

ALESS (da Cunha et al. 2015)
COSMOS (Scoville et al. 2016)
ALPINE (Khusanova et al. 2020)
Faint starlight in SPT2349-56

The protocluster core profile has a similar shape as a $z=1$ cluster profile...

Van der Berg et al. 2014

Stellar mass $[M_\odot]$

Radius [Mpc]

Core radius

$z=1$ cluster

$z=4$ protocluster
Faint starlight in SPT2349-56

This BCG will have formed by $z=4$!

Van der Berg et al. 2014

...until the core galaxies merge in 100 Myrs.
Thank you!
Questions?
Thank you! Questions?