



October 30, 2025

Press Release

Keio University

**ALMA Confirms a Hotter Early Universe with Record-Precision
Measurement of the CMB**
**—The most accurate CMB temperature measurement far beyond the
Milky Way reinforces the standard model of cosmology—**

A research team has precisely measured the temperature of the cosmic microwave background radiation (CMB) at redshift $z=0.89$ —corresponding to about 7 billion years ago—by analyzing archival data from the Atacama Large Millimeter/submillimeter Array (ALMA) toward the quasar PKS1830–211. The team consisted of Keio University researchers, including doctoral student Tatsuya Kotani from the Graduate School of Science and Technology, and Professor Tomoharu Oka from the Faculty of Science and Technology Department of Physics, in collaboration with the National Astronomical Observatory of Japan. The team determined the CMB temperature at that epoch to be 5.13 ± 0.06 K, the most precise measurement ever obtained at intermediate redshift. This temperature is roughly twice the current CMB temperature (≈ 2.7 K) and is in agreement with the underlying prediction of big bang cosmology that the CMB temperature increases in proportion to $(1 + z)$ when looking back in time. This result provides a stringent observational test of the standard cosmological model and places important constraints on our understanding of the universe’s thermal history.

This research was published on October 29, 2025, in *The Astrophysical Journal*.

1. Main Points of Research

- The team analyzed publicly available ALMA^{*1} data toward the quasar^{*2} PKS1830–211, enabling a precise measurement of the CMB temperature 7 billion years ago.
- The resulting temperature, 5.13 ± 0.06 K, is the most accurate determination at intermediate redshift^{*3} to date.
- The measurement is in agreement with the prediction of standard big bang cosmology.

2. Background of Research

The universe is thought to have begun as an extremely hot and dense “fireball” and evolved into its present low-temperature, low-density state through adiabatic expansion. This is known as the “big bang model”, which has served as a leading framework for cosmic evolution since the 1960s. However, in recent years, several alternative cosmological models have also been proposed.

The CMB is faint radiation uniformly filling the sky in the microwave^{*4} range. It is believed to be the cooled remnant of the hot blackbody radiation^{*5} that once permeated the early universe, providing strong observational evidence for the big bang model. In the standard cosmological framework, the CMB temperature is predicted to increase in proportion to $(1 + z)$ when looking

back to earlier cosmic times. Therefore, precise measurements of the CMB temperature at different epochs offer a powerful means of testing cosmological models.

One effective approach to measuring the past CMB temperature is to use the absorption of radiation from bright background sources, such as quasars, by tenuous atoms and molecules residing in distant galaxies. The energy levels of these atoms and molecules are influenced by the CMB prevailing at that epoch, producing characteristic absorption features in the background spectrum. By analyzing the strength of these absorption lines, the CMB temperature at that time can be inferred. Because the light from such distant systems takes billions of years to reach Earth, the observed absorption signals provide a direct record of the physical conditions in the early universe. Thus, studying molecular absorption in distant galaxies enables astronomers to estimate the CMB temperature in the distant past.

3. Results

The team analyzed ALMA archival data toward the distant quasar PKS1830–211, which exhibits numerous molecular absorption lines ideal for probing the CMB (Figure 1). From these archival observations, they successfully detected multiple absorption lines of hydrogen cyanide (HCN; Figure 2 [a]). Based on these data, the team performed a refined analysis that accounts for several important effects: the non-uniform distribution of the absorbing gas, time variations in absorption strength, and the partial coverage of the background source by the absorbing gas. These factors had not been considered in the earlier CMB temperature measurement toward the same object at the same redshift, conducted in 2013. Through this detailed analysis, the researchers determined that the CMB temperature at the epoch when the absorbing gas existed—about 7 billion years ago—was 5.13 ± 0.06 K (Figure 2 [b]). This is approximately 40% more precise than previous studies, and the most reliable CMB temperature measurement ever obtained at intermediate redshift. Furthermore, the measured value is in agreement with the underlying prediction of standard big bang cosmology (Figure 2 [c]), confirming that the universe was indeed hotter 7 billion years ago.

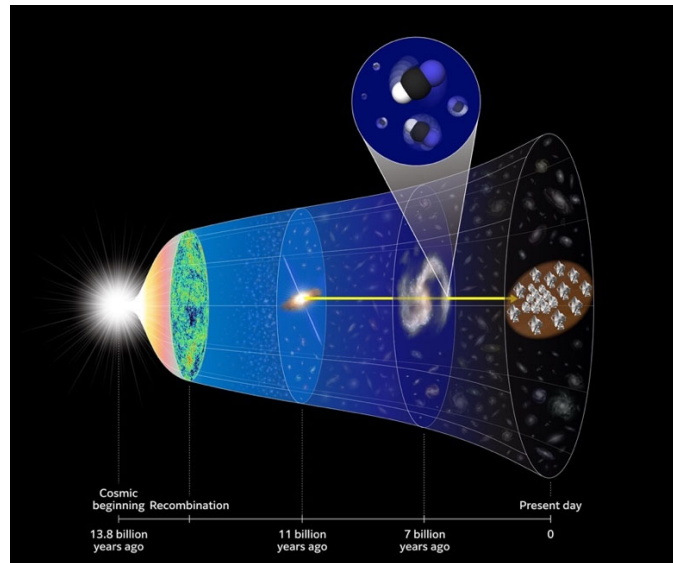


Figure 1

Schematic illustration showing the relative positions of the background quasar (PKS1830–211), the foreground galaxy producing HCN absorption, and the observer (ALMA).

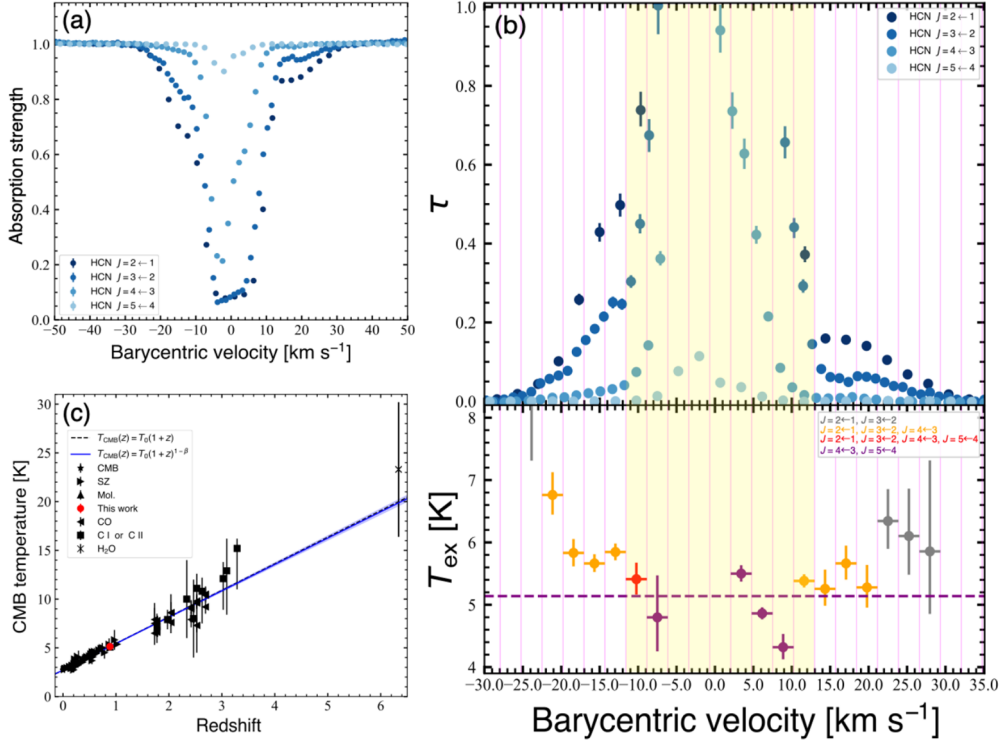


Figure 2

(a) Absorption spectra of hydrogen cyanide (HCN) obtained with ALMA. Four absorption features corresponding to transitions between different energy levels of HCN are shown in shades of blue. (b) Profiles of optical depth (top) and excitation temperature (bottom) derived from the absorption strength. The excitation temperature was calculated for each velocity bin (shown in magenta) and color-coded according to the transition used. The purple dashed line indicates the value predicted by the standard cosmological model (5.14 K). The weighted average within the central absorption region (highlighted in yellow), 5.13 ± 0.06 K, is considered to best represent the CMB temperature at that cosmic epoch. (c) Dependence of the CMB temperature on redshift. The red data point shows the measurement obtained in this study, while the black points represent previous results. The blue solid line and shaded region show the best-fit model and its uncertainty. The measured value agrees with the prediction of the standard model (black dashed line) within uncertainties, demonstrating that the big bang theory has been tested in the universe as it was 7 billion years ago.

4. Future Prospects

This achievement represents an important step toward future quasar observations aimed at measuring the CMB temperature at even higher redshifts. In particular, precise determinations of the CMB temperature at redshifts $z > 1$ —corresponding to a look-back time of more than 8 billion years—will allow for an even more stringent test of big bang cosmology. The team plans to conduct new molecular absorption-line observations toward additional quasars using the ALMA. If these forthcoming observations yield new CMB temperature measurements at high redshift, they are expected to enable sensitive tests for subtle deviations from the standard cosmological model with unprecedented precision. Furthermore, this achievement opens the path toward future CMB temperature measurements with next-generation radio observatories, such as the Square

Kilometre Array (SKA) and the next-generation Very Large Array (ngVLA), which will further extend our ability to probe the thermal history of the universe.

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Details of Journal Article

Title: “A New Precise Measurement of the Cosmic Microwave Background Radiation Temperature at $z = 0.89$ toward PKS1830–211”

Authors: Tatsuya Kotani¹, Tomoharu Oka^{1,2}, Rei Enokiya³, Kazuki Yanagihara¹, Miyuki Kaneko¹, Ryo Ariyama¹

1. School of Fundamental Science and Technology, Graduate School of Science and Technology, Keio University
2. Department of Physics, Faculty of Science and Technology, Keio University
3. National Astronomical Observatory of Japan

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References

Tomoharu Oka-Laboratory, Department of Physics, Faculty of Science and Technology, Keio University, <http://aysheaia.phys.keio.ac.jp/index.html>

Glossary

- *1. ALMA (Atacama Large Millimeter/submillimeter Array): A world-class radio telescope located at an altitude of about 5000 m in the Atacama Desert of northern Chile. It is an international collaboration among East Asia (led by NAOJ), North America (NRAO), and Europe (ESO).
- *2. Quasar: A distant, intensely luminous point-source that appears star-like in optical images.
- *3. Redshift (z): An index that represents how much the wavelength of light emitted from an object has been stretched before reaching the observer. Light from very distant object is stretched due to the cosmic expansion, making redshift a key indicator of the cosmic age.
- *4. Microwave: Electromagnetic waves with frequencies between 300 MHz and 300 GHz; a subset of radio waves.
- *5. Blackbody radiation: Radiation emitted by photons in a state of thermodynamic equilibrium.

*Please direct any requests or inquiries to the contacts listed below in advance of any press coverage.

*We have sent this news release to the MEXT Press Club, Science Press Club, and the science departments of other media outlets.

- Inquiries about research

Professor Tomoharu Oka

Department of Physics

Faculty of Science and Technology

Keio University

Phone: 045-566-1833

Email: tomo@phys.keio.ac.jp

- Source of this release

Office of Communications and Public Relations (Masuda)

Phone: 03-5427-1541

Fax: 03-5441-7640

Email: m-pr@adst.keio.ac.jp <https://www.keio.ac.jp/>