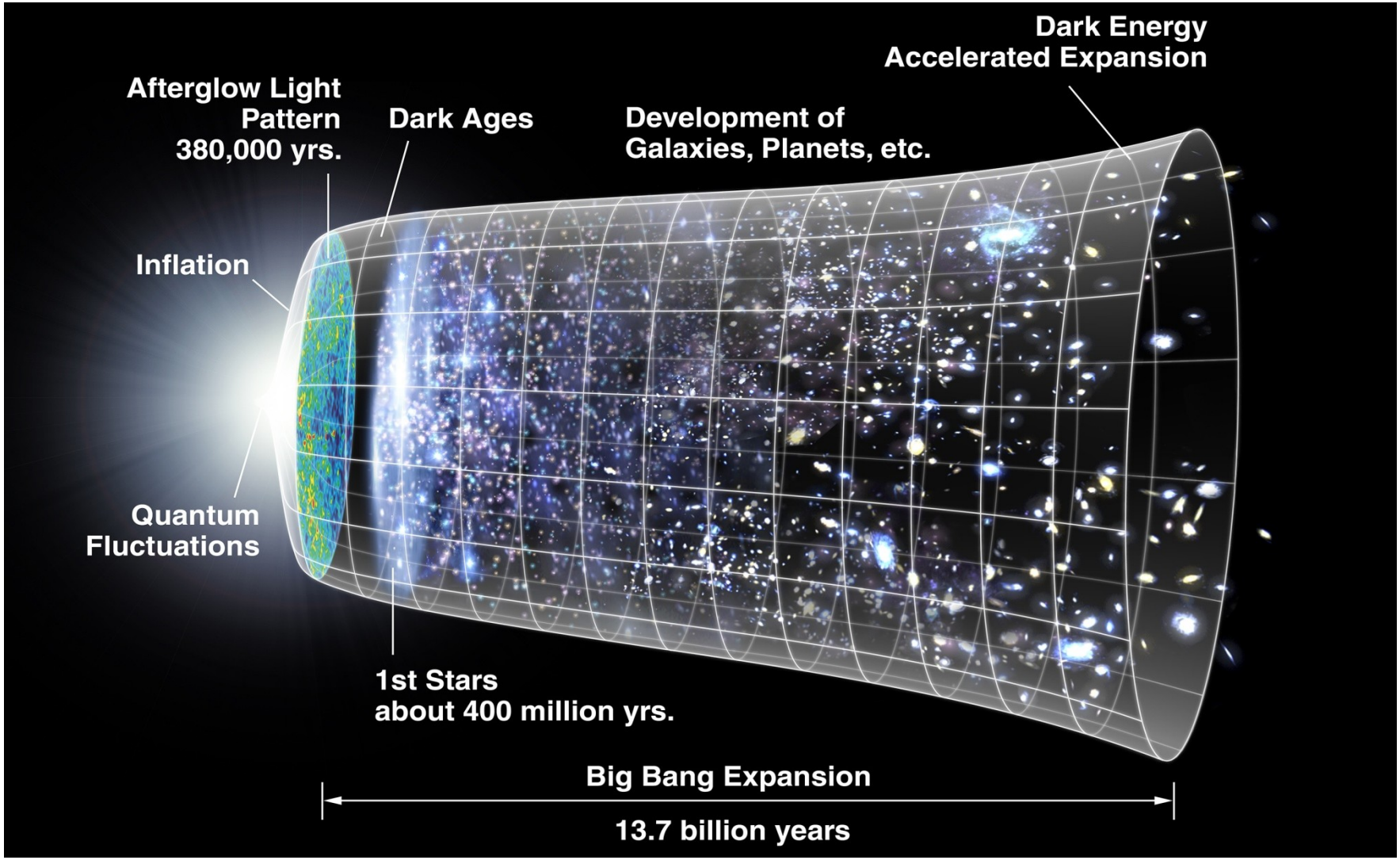
The Birth of the First Elements

THE LITHIUM CONUNDRUM

The Birth of the First Elements

COSMOLOGICAL LITHIUM PROBLEM

Universal Timeline



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Roughly three minutes after the Big Bang itself, the temperature of the Universe rapidly cooled from its phenomenal 10^{32} Kelvin to approximately 10^{9} Kelvin.

At this temperature, nucleosynthesis, or the production of light atoms, could take place.

The Origin of Chemical Elements

R. A. ALPHER*
Applied Physics Laboratory, The Johns Hopkins University, Silver Spring, Maryland

AND

H. BETHE
Cornell University, Ithaca, New York

AND

G. GAMOW
The George Washington University, Washington, D. C.

February 18, 1948

In their original paper and follow up articles Alpher, Betha and Gamow:

Formulated the theory of Primordial Nucleosynthesis

Calculated that this was completed by 20 minutes after the Big Bang.

current models and observations calculate this to have been completed 100 -1,000 seconds after the big bang.

Big Bang Nucleosynthesis (or **primordial nucleosynthesis**, abbreviated BBN) refers to the production of nuclei other than those of H-1 (i.e. the normal, light isotope of hydrogen, whose nuclei consist of a single proton each) during the early phases of the universe.

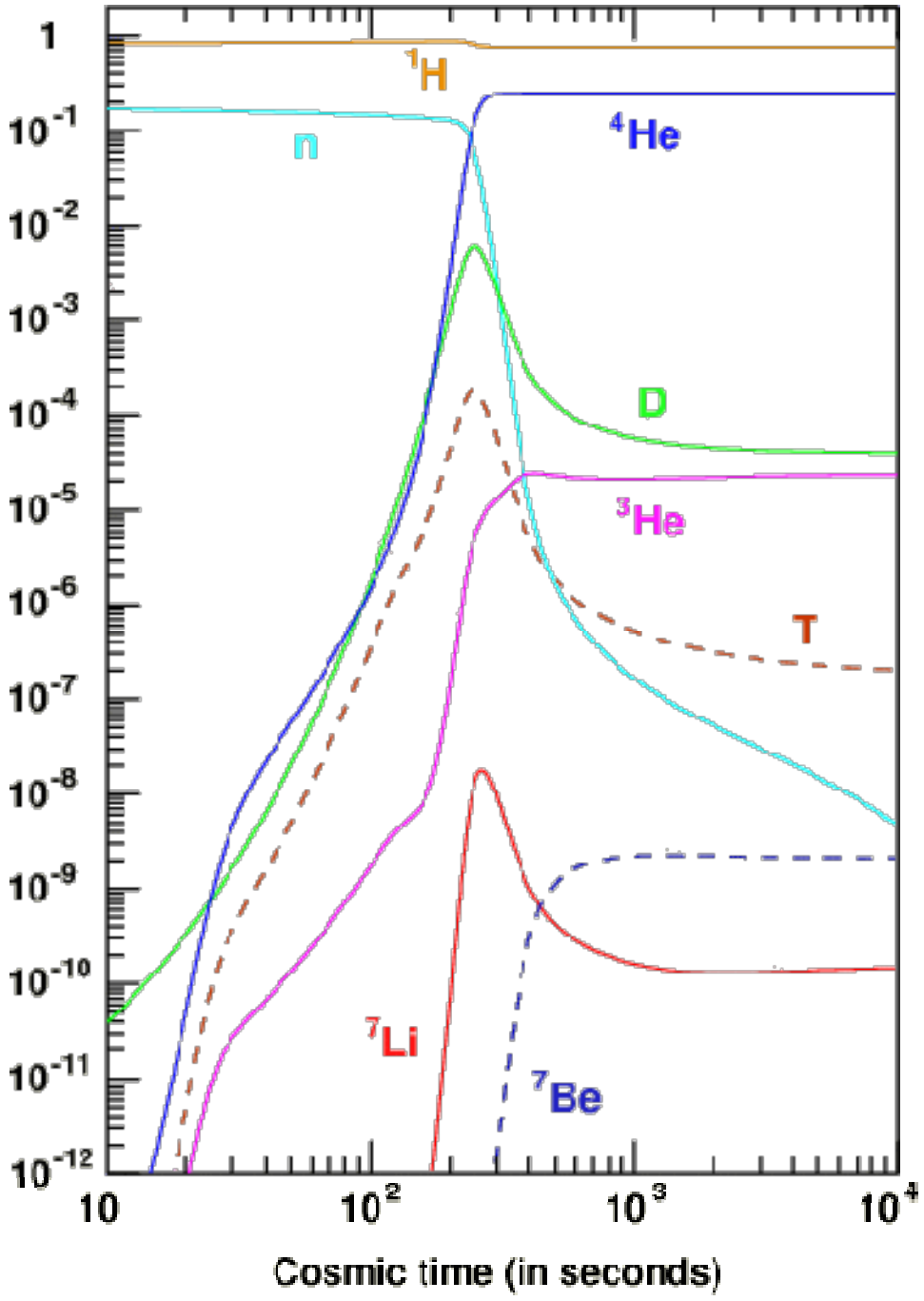
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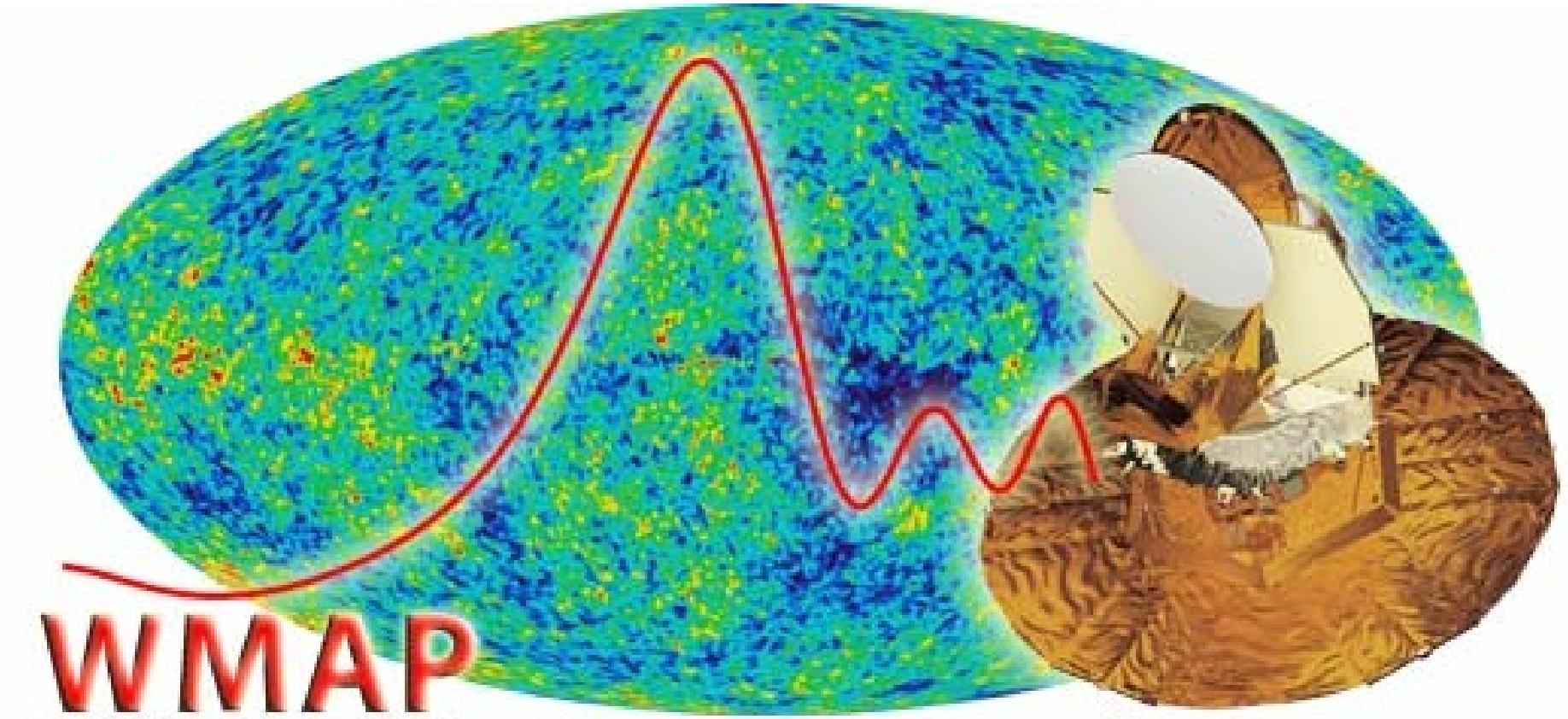
Big Bang nucleosynthesis is believed by many scientists to have taken place just a few minutes after the Big Bang and is believed to be responsible for the formation of a heavier isotope of hydrogen known as deuterium(H-2 or D), the helium isotopes He-3 and He-4, and the lithium isotopes Li-6 and Li-7 and beryllium Be-9.

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In addition to these stable nuclei some unstable, or radioactive isotopes were also produced during the BBN: tritium H-3; beryllium (Be-7), and beryllium-8 (Be-8). These unstable isotopes either decayed or fused with other nuclei to make one of the stable isotopes.


1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10
10^{2}
10^{3}
10^{4}
Cosmic time (in seconds)
^{1}H
n
^{4}He
D
^{3}He
T
^{7}Li
^{7}Be


WMAP
Wilkinson Microwave Anisotropy Probe

WMAP was launched on June 30, 2001 from the Cape Canaveral Air Force Base aboard a Delta II rocket.

The WMAP objective was to measure the temperature differences in the Cosmic Microwave Background (CMB) radiation. The anisotropies then are used to measure the universe's geometry, content, and evolution; and to test the Big Bang model, and the cosmic inflation theory.

As of October 2010, the WMAP spacecraft is in a graveyard orbit after 9 years of operations.

Observation of interstellar lithium in the low-metallicity Small Magellanic Cloud

Christopher Howk, Nicolas Lehner, Brian D. Fields & Grant J. Mathews

Nature 489, 121–123 (06 September 2012)

The primordial abundances of light elements produced in the standard theory of Big Bang nucleosynthesis (BBN) depend only on the cosmic ratio of baryons to photons, a quantity inferred from observations of the microwave background. The predicted primordial ^{7}Li abundance is four times that measured in the atmospheres of Galactic halo stars. This discrepancy could be caused by modification of surface lithium abundances during the stars' lifetimes or by physics beyond the Standard Model that affects early nucleosynthesis. The lithium abundance of low-metallicity gas provides an alternative constraint on the primordial abundance and cosmic evolution of lithium that is not susceptible to the *in situ* modifications that may affect stellar atmospheres. Here we report observations of interstellar ^{7}Li in the low-metallicity gas of the Small Magellanic Cloud, a nearby galaxy with a quarter the Sun's metallicity.

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The stars have approximately one quarter the heavier element abundance than our own star.



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Relative Abundance of Lithium (Li/H)			
Traditional BBN Model	Spectral Analysis	WMAP Cosmic Microwave Background	Howk *et al*
10^{-9}	$2\text{-}3\text{x}10^{-10}$	$2.4 \text{ x } 10^{-10}$	$10^{-8.99}$ (±0.13)

Astrophysical Solution

- The Big Bang model is correct, but older stars have destroyed lithium over time through internal mixing and burning.

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- HEAVILY DEBATED. Whilst stars are known to burn lithium in their cores primarily in the production of larger atoms, the uniformity of the plateau from the cosmic microwave background data makes it difficult to explain why largely different stars burn lithium at exactly the same rate.

Nuclear Physics Solution

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- The BBN model is incorrect, and the model overestimates the beryllium to lithium ratio.
- LARGELY RULED OUT. Data generated at CERN and other nuclear laboratories have replicated the BBN in controlled experiments and have re-measured the ratio. The nuclear data is highly precise and cannot account for the lithium depletion.

NEW PHYSICS BEYOND THE STANDARD MODEL

- “Exotic” physics or unknown particles selectively destroyed or hid lithium during the early universe without disrupting hydrogen, helium or beryllium.

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  - Lithium decayed into dark matter.

Light dark matter: A common solution to the lithium and H0 problems

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ABSTRACT

Currently, the standard cosmological model faces some tensions and discrepancies between observations at early and late cosmological time. One of them concerns the well-known H0-tension problem, i.e., a $\sim 4.4\sigma$-difference between the early-time estimate and late-time measurements of the Hubble constant, H0. Another puzzling question rests in the cosmological lithium abundance, where again local measurements differ from the one predicted by Big Bang Nucleosynthesis (BBN). **In this work, we show that a mechanism of light dark matter production might hold the answer for these questions. If dark matter particles are sufficiently light and a fraction of them were produced non-thermally in association with photons, this mechanism has precisely what is needed to destroy Lithium without spoiling other BBN predictions.** Besides, it produces enough radiation that leads to a larger H0 value, reconciling early and late-time measurements of the Hubble expansion rate without leaving sizable spectral distortions in the Cosmic Microwave Background spectrum

NEW PHYSICS BEYOND THE STANDARD MODEL

- “Exotic” physics or unknown particles selectively destroyed or hid lithium during the early universe without disrupting hydrogen, helium or beryllium

- THEORETICAL.
  - Lithium decayed into dark matter.
  - Discrete cosmic strings disintegrated lithium nuclei.

Cosmological Lithium Solution from Discrete Gauged B-L

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PHYSICAL REVIEW LETTERS 131 091003 (2023)

The cosmological lithium problem—that theory predicts a primordial abundance far higher than the observed value—has resisted decades of attempts by cosmologists, nuclear physicists, and astronomers alike to root out systematics. We reconsider this problem in the setting of the standard model extended by gauged baryon minus lepton number, which we spontaneously break by a scalar with charge six. Cosmic strings from this breaking can support interactions converting three protons into three positrons, and we argue that an "electric"-"magnetic" interplay can give this process an amplified, strong-scale cross section in an analog of the Callan-Rubakov effect. **We suggest such cosmic strings have disintegrated the primordial lithium nuclei, and lay out what is necessary for this scheme to succeed. To our knowledge this is the first new physics mechanism with microphysical justification for the abundance of lithium uniquely to be modified after big bang nucleosynthesis**

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No single explanation has achieved consensus.

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The problem remains one of the most significant open issues in Big Bang Nucleosynthesis