The Light Elements in Astrophysics

An historical perspective

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An observer's perspective

David L. Lambert
The W.J. McDonald Observatory
The University of Texas at Austin

Cast of Stable Characters

^{1}H ^{2}H

^{3}He ^{4}He

^{6}Li ^{7}Li

^{9}Be

^{10}B ^{11}B

Omitting ^{10}Be
(half-life = 1.5 Myr)

Hydrogen has the title role – usually

- Stars

  1925 "Stellar Atmospheres" – Ceclia Payne*

  1928 "Solar chemical composition" – A. Unsöld

*It is undoubtedly the most brilliant Ph.D. thesis ever written in astronomy.

Otto Struve

Hydrogen has the title role - usually

Gaseous nebulae

1935 "The Spectrum and Composition of the Gaseous Nebulae" – I.S. Bowen

> "A study of nebular line intensities in the light of the forgoing process indicates that *H* is the most abundant element and He is the second. *N, O, Ne, S* – and possibly *C* and *A* – are present but are very much rarer. The lines of these heavier elements are strong, not because the elements are very abundant but because they are able to make use of large sources of energy that are not available to the predominant *H* and *He*. Lines of *F, Na, Si, P, Cl, K,* and *Ca* are missing."

1945 "Physical Processes in Gaseous Nebulae XVIII" – L.H. Aller and D.H. Menzel

Helium often has the role of a dark character

- Cool-warm stars

  - not detectable in photospheric spectra – GUESS!

  - are there mildly He-rich stars?

ALL OTHER CHARACTERS HAVE VERY MINOR ROLES, BUT SOMETIMES A LOT TO SAY

Atomic Facts of Life

H I				
He I	**He II**			
Li I*	**Li II**	**Li III**		
Be I	**Be II***	**Be III**	**Be IV**	
B I*	**B II***	**B III***	**B IV**	**B V**

*Generally, strongest resonance lines only

A PERSONAL SELECTION:

SETTING THE STAGE 1957-1982

1957 E. M. Burbidge, G. R. Burbidge, W. A. Fowler, and F. Hoyle

"Synthesis of Elements in Stars"

BUT

"We have made some attempt to explain possible modes of production of deuterium, lithium, beryllium, and boron, but at present must conclude that these are little more than qualitative suggestions." [x-process]

A. G. W. Cameron

"Nuclear Reactions in Stars and Nucleogenesis"

"Not formed in stellar interiors. Possibly made by nuclear reactions in stellar atmospheres."

1964 F. Hoyle & R. J. Tayler

"The Mystery of the Cosmic Helium Abundance"

"There has always been difficulty in explaining the high helium content of cosmic material in terms of ordinary stellar processes. The mean luminosities of galaxies come out appreciably too high on such a hypothesis. The arguments presented here make it clear, we believe, that the helium was produced in a far more dramatic way. Either the Universe has had at least one high-temperature, high-density phase, or massive objects must play (or have played) a larger part in astrophysical evolution than has hitherto been supposed."

1964 I. Iben, Jr.

"The Surface Ratio of N^{14} to C^{12} during helium burning opened continuing era of theoretical and observational studies of dredge-ups by red giants"

" It is the purpose of this note to point out that the ratio of N^{14} to C^{12} at the surface of a star undergoes a significant increase during the rise into the red-giant region immediately preceding the phase of helium burning in the core. A spectroscopic verification of this enhancement would provide direct evidence for the occurrence of the reaction $C^{12}(p, \gamma)N^{13}(\beta^+ \nu)$ $C^{12}(p, \gamma)N^{14}$ in the stellar interior."

1965 A. A. Penzias & R. W. Wilson

"A measurement of excess antenna temperature at 4080 Mc/s"

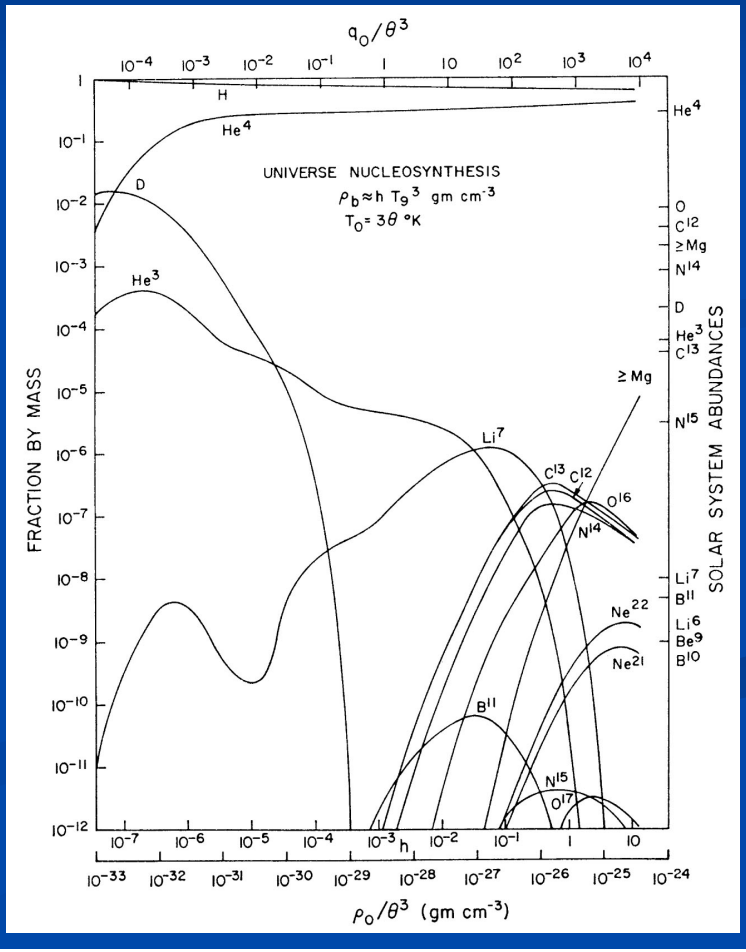
3°K cosmic microwave background radiation ⟶ Hot Big Bang

1967 R. V. Wagoner, W. A. Fowler & F. Hoyle

"On the Synthesis of Elements at Very High Temperatures"

"A detailed calculation of element production in the early stages of a homogeneous and isotropic expanding universe as well as within imploding-exploding supermassive stars has been made. If the recently measured microwave background radiation is due to primeval photons, then significant quantities of only D, He^3, He^4, and Li^7 can be produced in the universal fireball.

It is found that very low abundances of He^4, as recently observed in some stars, can be produced in a universe in which the electron neutrinos are degenerate."



1970 H. Reeves, W. A. Fowler & F. Hoyle

"Galactic Cosmic Ray Origin of Li, Be, and B in Stars"

Reeves (1992) remarked that:

"In 1969, I presented these conclusions in a seminar at the former IOTA (Institute of Theoretical Astronomy) in Cambridge (UK). During my seminar, Fred Hoyle kept on talking to Willie Fowler. I could overhear some of his words: "I've been repeating that to you for many years. You should have listened to me." Later on, he told me that he had considered this scenario for a long time. We published a paper together on this subject." (Reeves, Fowler and Hoyle 1970)

^{7}Li and ^{11}B require a supplement

1970 G. Michaud

"Diffusion processes in Peculiar A star"

1971 A. G. W. Cameron & W. A. Fowler

"Lithium and the s-process in Red-Giant Stars"

- Li synthesis by

  $^{3}He(^{4}He, \gamma)^{7}Be(e^{-} \nu)^{7}Li$ on the AGB

- neutron source:

  $^{12}C(p, \gamma)^{13}N(e^{+} \nu)^{13}C(\alpha, n)^{16}O$

1972 L. Searle & W. L. W. Sargent

"Inferences from the Composition of Two Dwarf Blue Galaxies"

"The emission spectra of two dwarf compact galaxies, I Zw 18 and II Zw 40, which were earlier described as "isolated extragalactic H II regions," have been analyzed. Oxygen and neon have lower abundances (relative to hydrogen) than does the interstellar gas near the Sun, while helium has a normal abundance. These galaxies are the first metal-poor systems of Population I to be discovered: the normal helium abundance is taken as evidence that this abundance is primordial."

1973 H. Reeves, J. Audouze, W. A. Fowler & D. N. Schramm

"On the Origin of Light Elements"

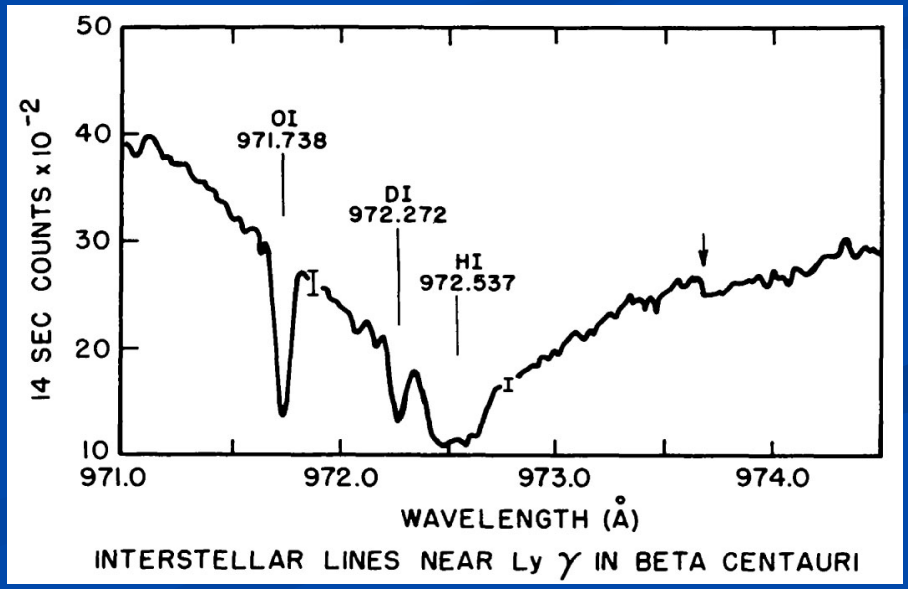
The deuterium can only be produced pregalactically either in the big bang or in some pregalactic event.

1973 J. B. Rogerson & D. G. York

"Interstellar Deuterium Abundance in the direction of β Centauri"

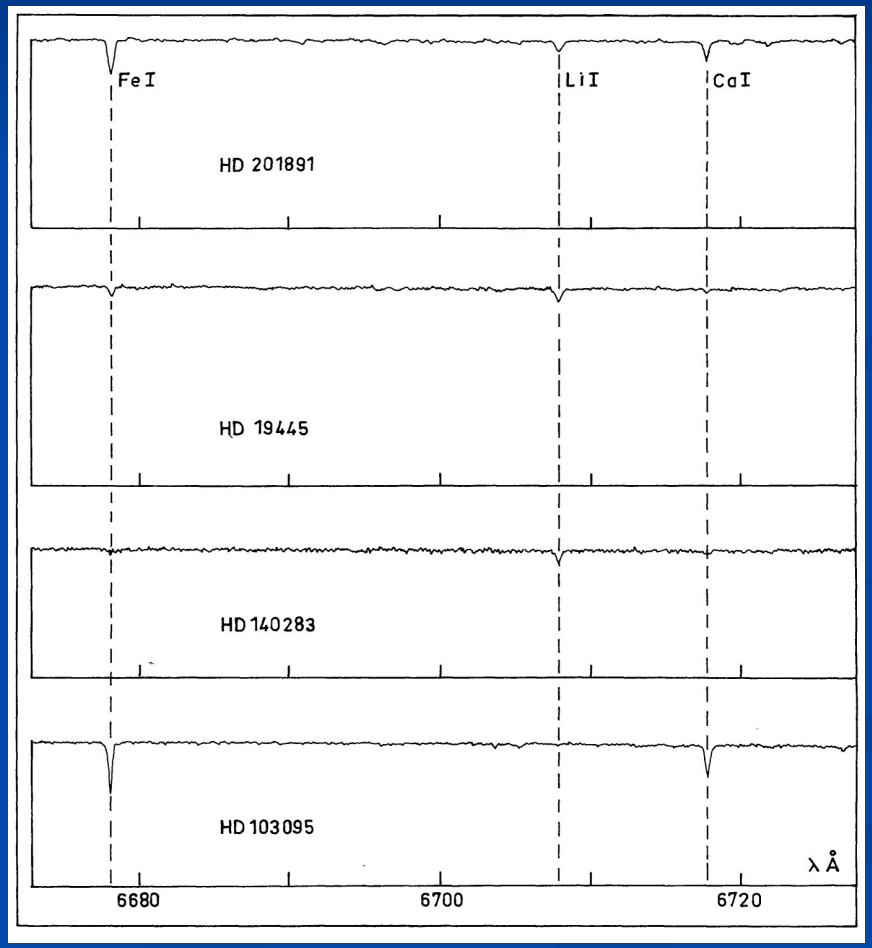
1976 T. Adams

"The Detectability of Deuterium Lyman α in QSOs"



1982 F. Spite & M. Spite

"Lithium abundance at the formation of Galaxy"



The Foci of Contemporary Studies

^{1}H – "Primeval" – $B^{2}FH$ (1957)

"It seems probable that the elements all evolved from hydrogen, since the proton is stable while the neutron is not."

True!

The Foci of Contemporary Studies

D/H - Big Bang nucleosynthesis and
QS0 absorption lines

- Astration and Galactic Chemical Evolution

- Interstellar molecules and fractionation

The Foci of Contemporary Studies

^{3}He - Big Bang nucleosynthesis and H II regions

- Stellar yields of ^{3}He and planetary nebulae

- Diffusion and chemically peculiar stars (3 CenA)

The Foci of Contemporary Studies

^{4}He - Big Bang nucleosynthesis and extragalactic H II regions

- Stellar mixing and mass loss with He often off-stage

- Diffusion and chemically peculiar stars

The Foci of Contemporary Studies

^{6}Li - Is it out there in unexpected places?

- Synthesis by spallation via cosmic rays

($^{6}Li/Be \approx$ ok)

The Foci of Contemporary Studies

- ^{7}Li - Big Bang nucleosynthesis and Li in warm halo dwarfs
- Stellar astration: PMS, MS, RG
- Lithium synthesis and survival
  - Li-rich red giants and AGB stars
  - Exotic places
- Synthesis by spallation via cosmic rays

The Foci of Contemporary Studies

^{9}Be - Synthesis by spallation via cosmic rays

- Pure spallation product
- Calibrator for Li, B from spallation
- Search for a Be plateau

The Foci of Contemporary Studies

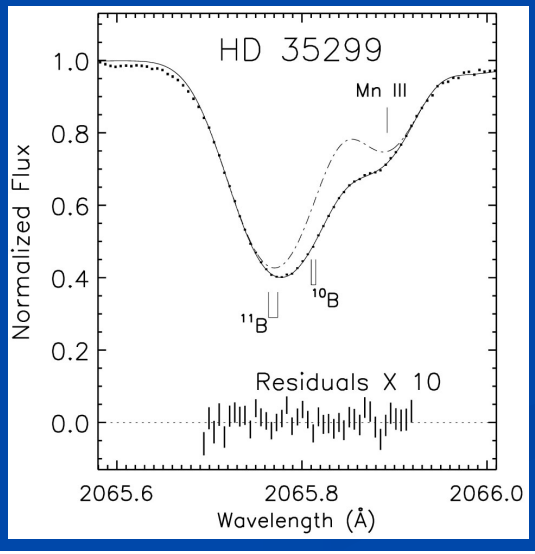
B - Synthesis by spallation via cosmic rays

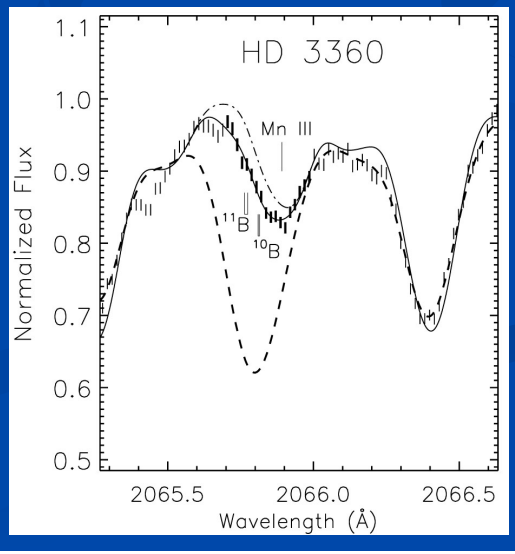
Search for B plateau

- Supernova ν - process for ^{11}B?

($^{10}B/Be$ = ok)

- Monitor of mixing in B-type stars





Progress is driven by …

- People – bright ideas, lucky strikes
- New open windows

  UV – D/H, B/H
  Radio – ^{3}He
- Larger telescopes

  D/H, ^{4}He/H, Li/H, Be/H

BUT …

Old spectroscopists forget a lot

But they do remember their lines

Sir Harry Kroto

2009, in *Frontiers of Molecular Spectroscopy*