Conflict in the Cosmos
Fred Hoyle's life in science
1915 - 2001

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About me ….

Current research: History of astronomy in 20th century

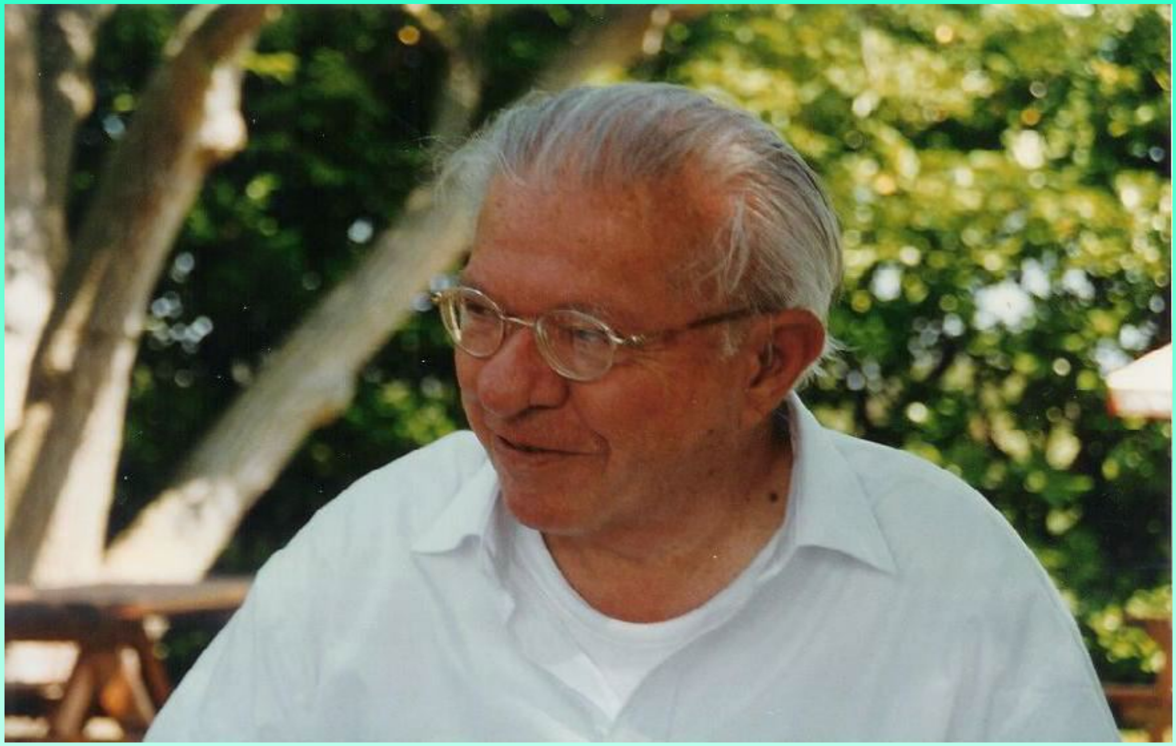
Current writing: Review articles in particle physics and astrophysics for journals, magazines, websites, podcasts …

Previous careers: astrophysics research, university administration, science publisher

St Edmund's College

UNIVERSITY OF CAMBRIDGE

Fred Hoyle 1915 - 2001



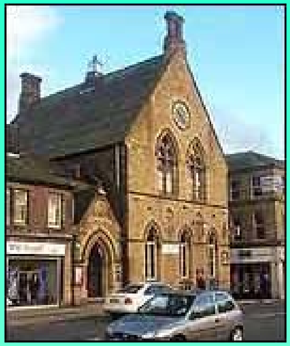
“Full of ideas and convictions; invariably kind to friends and cheerful with them; a dedicated baseball fan in later life; not terribly interested in things he had done in the past, but focused on the challenge at hand; and dismissive of critics.”

Martin Harwit, postdoc 1960-61

Childhood in Yorkshire

- Born 24 June 1915. Father an entrepreneurial cloth trader, mother teacher and pianist. Comfortably off: owned two substantial Victorian villas
- Place of birth Gilstead, on the edge of the moors near to Bingley West Yorkshire, the Bronte country
- Father enlisted in Machine Gun Corps, served 1915 - 1918. Returned a broken man. Lost employment during the Slump, and never worked again.Despised the government, the establishment, military top brass; these traits passed to young Fred
- Fred very unhappy at school. Frequently played truant and learned very little. Early starter at reading and arithmetic
- Spent a huge amount of time roaming the countryside, demonstrating a keen awareness for natural history.

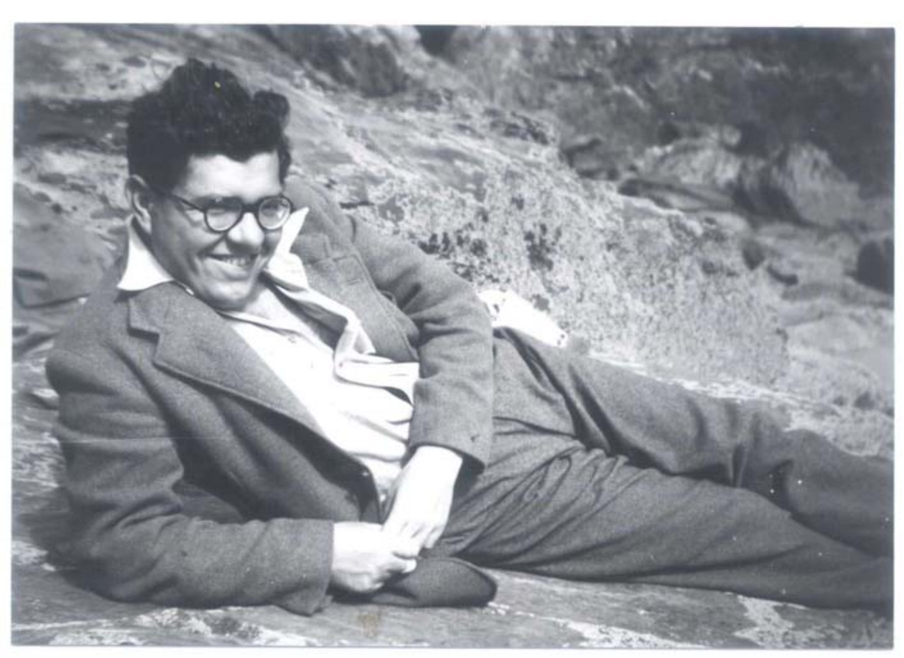
Education



- By the time he was ten he had settled down. He walked six miles a day to school in Eldwick
- He was the only child at his school to win a scholarship to Bingley Grammar School. Here he settled immediately as a very hard worker.
- His mother allowed him to conduct chemistry experiments in the kitchen and bought him an astronomical telescope. He made phosphine gas.
- In the public library, where he borrowed Jeans Mysterious Universe and Eddington's Stars and Atoms.
- From 16 - 18 he excelled at school. His headmaster picked him as one of two boys who should try for Cambridge.
- His first two applications failed.
- His headmaster pressed Emmanuel College very hard to find Hoyle a place. He won admission in 1933 to read Natural Science.

Cambridge undergraduate

- The ‘outsider’
- Switched to the Mathematical Tripos immediately. He felt strongly that to be a theorist he must study maths not laboratory physics.
- Played chess (half blue), canoed, climbed.
- Part I: first class honours and a College Exhibition.
- In his second year he proceeds straight to third year maths First class honours
- The summer of 1935: Reads Eddington and Dirac
- 1936 Part III Mathematics. Senior Wrangler, Mayhew Prize
- Accepted to do a Ph D. in nuclear physics. Supervised by Rudolph Peierls and Paul Dirac.



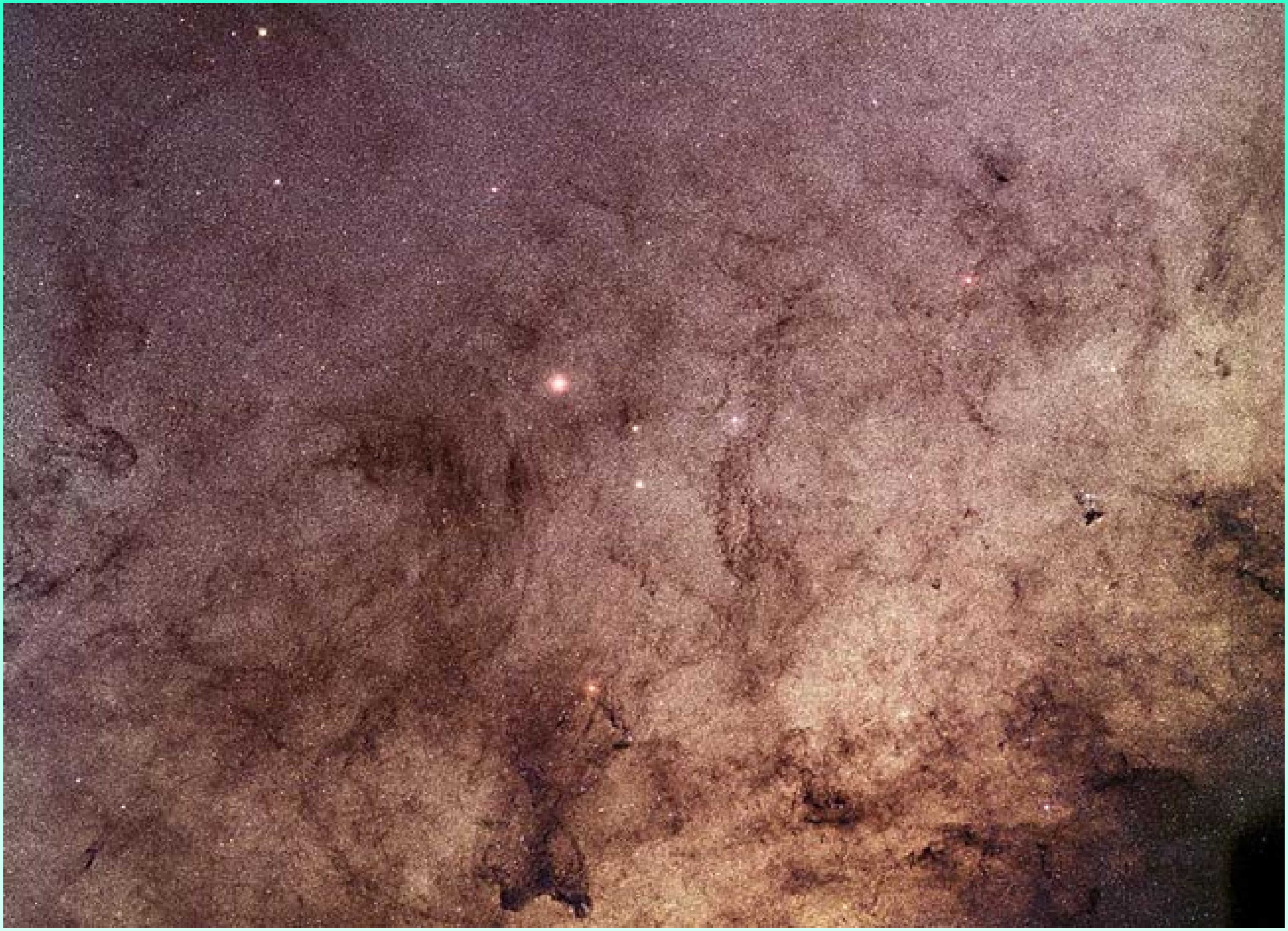
Cambridge postgraduate

- Accepted as a research student by the Cavendish Laboratory.
- Peierls sets him a project on Fermi's theory of beta-decay. Hoyle quickly learns the whole of nuclear physics.
- 1938 Won the Smith's Prize for his essay on beta-decay.
- Peierls goes to Birmingham. Hoyle supervised by Maurice Pryce then Paul Dirac FRS.
- 1939 papers on quantum electrodynamics win him a Research Fellowship at St John's College
- December 1939 marries Barbara.
- After the Joliot-Curies publish the principle of a chain reaction he determines not to work in nuclear physics but astrophysics. Meets Ray Lyttleton for the first time.
- Early in 1940 engaged by The Admiralty on war work. Portsmouth.

Wartime radar

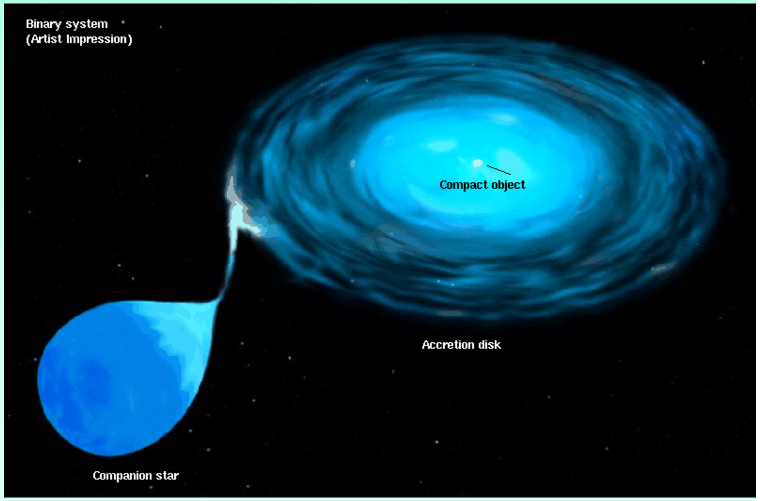
- Battle of the River Plate, 1939, has a direct effect on Hoyle's defence career.
- Admiralty recruitment 1940. Declines to fight the enemy with a soldering iron and opts for theory.
- **Quickly understands the principle of what later came to be known as the sea interferometer**. He devised a method of finding both the range and altitude of an incoming attacker at a time when the Royal Navy could not determine altitude. This undoubtedly saved numerous lives during the Royal Navy's campaigns in the Eastern Mediterranean. Later Hoyle conducts large-scale radar experiments on radio wave propagation. Secret work - no publications.
- In 1941 he recruited Hermann Bondi to his theory group. Bondi secures a post for Tommy Gold who had graduated at Cambridge with a Pass Degree in engineering. Gold was able to interpret blueprints of German submarines smuggled by the French Resistance.s
- They all work on astrophysics and cosmology in their spare time.

Accretion power in astrophysics



Accretion power in astrophysics

- **From late-1939 Lyttleton and Hoyle commence work on the physics of accretion.** Their emphasis is on mathematical analysis and solvable equations rather than realistic astrophysics.
- They discuss stellar evolution. Lyttleton believes that stars accrete matter on a continuous basis from the interstellar medium, and this how the nuclear fuel is replaced.
- In the period 1939 - 1945 they publish several papers on the physics of accretion.
- Enormous problems with the RAS Council because of the *ad hoc* guesswork concerning astrophysics.
- **Today Bondi-Gold-Hoyle accretion physics has major applications** in neutron stars, condensed objects, high energy astrophysics. Now among Fred's most highly cited work in physics.



Astrophysics with Lyttleton

- Late 1939 Hoyle is recruited by the Admiralty for theoretical work on radar, Lyttleton is hired as an expert in artillery dynamics by the Royal Artillery. For the next three years they hardly meet.
- The problems on which they worked on by correspondence were
  - **Internal constitution of the stars - corrects Eddington**
  - **Application of accretion physics to a variety of contrived astrophysical problems**
  - **Origin of the Solar System**
  - **Red giants**
  - **Cepheids**
  - **Sunspots and magnetohydrodynamics**
- Each and every one of these encountered massive problems with the referees of the Royal Astronomical Society
- The papers Secretary at the time, D. H. Sadler, said the theoretical astronomers on the Council were astonished at the range of problems that Lyttleton and Hoyle had assumed as their own. The “Government” astronomers at the Royal Greenwich Observatory were particularly hostile to the young ‘upstarts’ from Cambridge
- The correspondence shows that Lyttleton was extremely hostile and suspicious of Tom Cowling (Leeds), Plaskett (Oxford), Atkinson (Greenwich), David Thackeray (Cambridge), Harold Jeffreys (Cambridge), and Sydney Chapman (Oxford)

Visiting the USA, 1944

- The Admiralty sent Hoyle as one of two British representatives to a secret meeting on defence radar held in Washington
- Hoyle took advantage of this trip to visit H N Russell (Princeton Observatory) and Walter Baade (Mount Wilson Observatory, Pasadena)
- Russell stimulated Hoyle's interest in stellar evolution.
- Walter Baade stimulated Hoyle's interest in supernovae and nucleosynthesis. From late 1945 Hoyle sought an answer to the following question: why are the elements that cluster around iron so abundant, and where were they made?

Cosmology in a cinema

These three gentlemen went to the cinema every week.

They saw a movie *Dead of Night* which had no beginning or no end. (It starred Michael Redgrave and is available on DVD)

Gold (on the left of this 1960s photograph) joked “What if the Universe is like that? (Note that Hoyle is on the front row - his favourite location!

This led to the concept of a Steady State Universe, a notion that the three of them enthusiastically promoted.

Astronomers had to decide: Big Bang (sudden start), or, Steady State (has existed for ever)

Gold, Bondi, and Hoyle

The Universe - what was understood in the 1940s

- All astronomers agree that the universe is expanding. Recession of galaxies had been discovered by Vesto Slipher. Hubble discpvered that the expansion is uniform.
- All astronomers agree that Einstein's theory of general relativity - a theory of gravity - applies to the universe.
- Einstein and the cosmological constant
- Importance of Friedmann, Eddington, Lemaitre models - they incorporate expansion
- All astronomers agree that the universe has some limit
- Most cosmologists disagree with each other about the details
- George Gamow working in the USA goes further than Lemaitre with the idea that the universe began in an explosion out of nothingness. Gamow interested in element synthesis in the explosive universe.
- As we shall see, Hoyle named this model The Big Bang
- Today all astronomers accept that we live in a Big Bang universe. But getting that agreement was not easy, and it involved intense, protracted, and personal arguments in Cambridge.

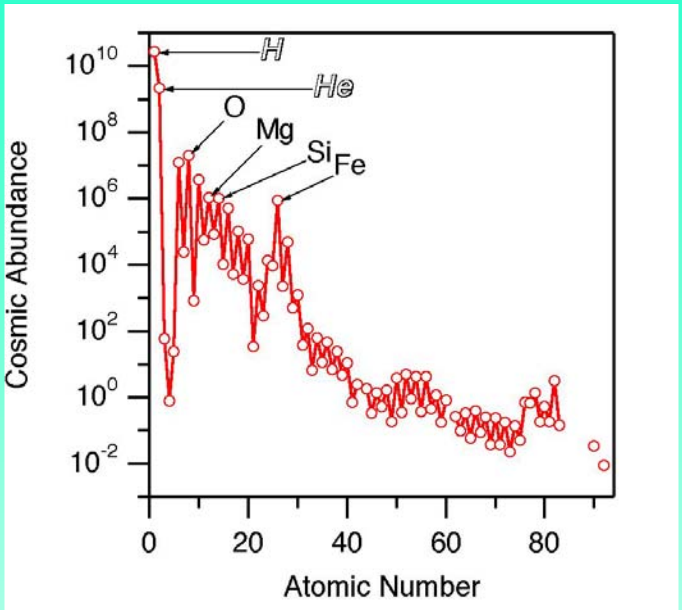
Continuous creation

- A new theory inspired by the movie: *The Dead of Night*
- The nature of cosmological theory in the early 1940s: several viable relativistic universes
- The age of the Galaxy is twice the age of the Universe! This was all Hubble's fault, but since only he had access to large telescopes his results went unchallenged.
- Hoyle: the physics of continuous creation. Explains how it could work. Deals with problems of conservation. Develops a field theory (the C-field).
- Bondi and Gold: the philosophy of the steady state universe
- They publish separate papers in 1945. Hoyle's paper initially rejected, as a result of which Bondi-Gold appears first
- The reception of the steady-state theory: (a) Britain, where the public loved it, the professionals hated it, and only two or three professionals took it really seriously; (b) everywhere else ignored it.
- Promotion of steady-state ideas at Royal Astronomical Society and international meetings. The spilling of blood at the RAS is nicely captured in the meeting accounts published in *Observatory*.

The nature of the universe - 1949 and 1950

- The radio broadcast of *28 March 1949*
- "I have reached the conclusion that the universe is in a state of continuous creation"
- The first use of the expression "a Big Bang", which was NOT pejorative
- The 1950 broadcasts on the *Third Programme* and the *Home Service*
- The broadcast produces a furious reaction, involving the Chairman of the Governors, the Archbishop of Canterbury, and the Astronomer Royal
- The correspondence in *The Listener*. The professionals begin to turn against him. They dislike the way in which he is promoting an unusual theory outside the Academy.
- Publication by Blackwell. Undreamed of wealth. Earns six times his university salary in 1950 alone. Launches his literary career.

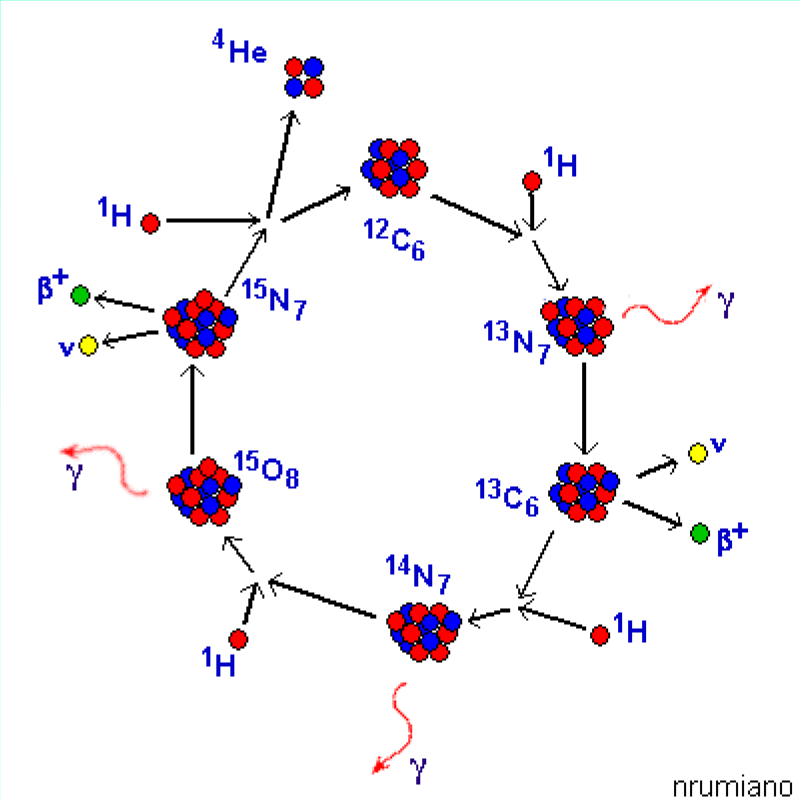
Nuclear processes in stars



$$O^{16}+He^{4}\rightleftarrows F^{19}+H^{1},\qquad F^{19}+H^{1}\rightleftarrows Ne^{20}+h\nu,$$
$$Ne^{20}+He^{4}\rightleftarrows Na^{23}+H^{1},\qquad Na^{23}+H^{1}\rightleftarrows Mg^{24}+h\nu,$$
$$Mg^{24}+He^{4}\rightleftarrows Al^{27}+H^{1}.$$

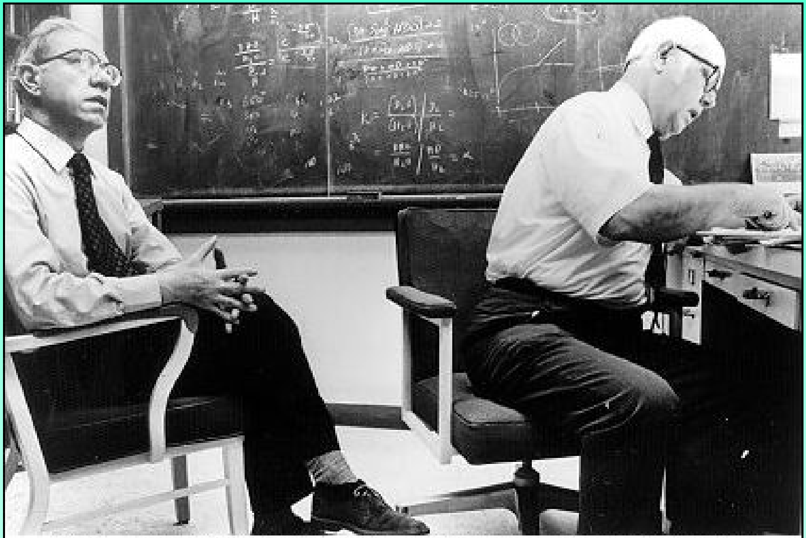
- He worked alone at this time, aided by the release of wartime data on the properties of individual nuclei.
- In November 1946 he cracked the physics of adding protons to a carbon nucleus one at a time
- The required a temperature exceeding 3 x 10^{9} K to overcome the electrical repulsion between the inbound alpha particle or proton and the target nucleus. Red giants provide this temperature.
- Hoyle used statistical physics to calculate the equilibrium composition. He assumed that the star would fragment rotationally in the late stages of evolution, scattering the nuclei to interstellar space.
- 1946 he produced the first paper to suggest that elements can be made in stars. Previously theorists thought they were made in the big bang. He gave a good account of the abundances as far as the iron peak.
- Work almost ignored for eight years, but not by the future Margaret Burbidge.

Nuclear processes in stars



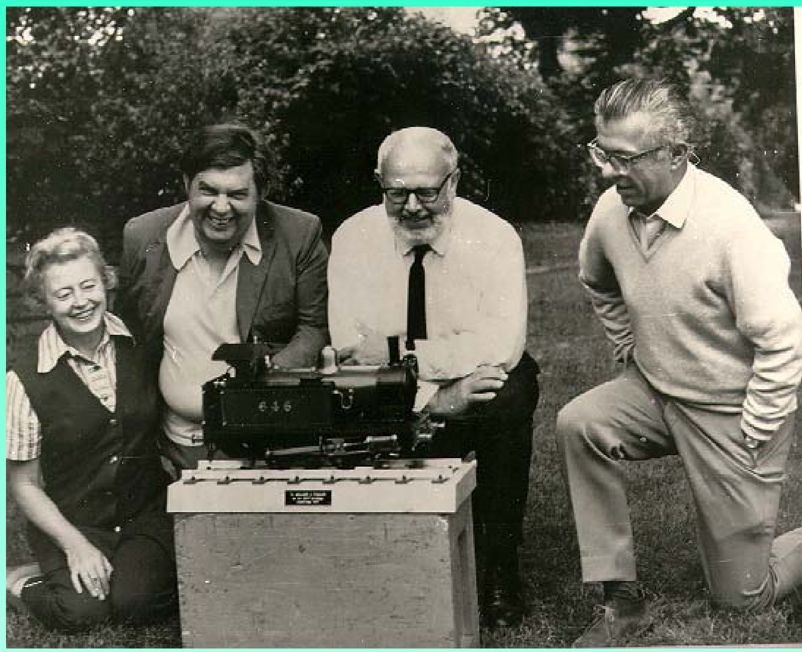
- Stars above about 1.2 solar masses undergo a reaction involving carbon, nitrogen, and oxygen. Baade had proposed this CNO cycle in 1938.
- The outcome is that four protons are fused to make one helium-4, as in the p-p chain
- When Hoyle started on the synthesis of the elements one problem nagged him: where did the carbon come from? In the atomic mass range 5 - 8 there are no nuclei that are stable long-term in stellar interiors.
- Hoyle therefore took the carbon as a ‘given’ in his 1946 nucleosynthesis papers.
- Nuclear astrophysicists knew that ^{12}C could not possibly be made by the simultaneous collision of three alpha particles.

The Carbon Puzzle



- Hoyle's 1946 paper built elements from carbon. But where did the carbon come from?
- Two helium nuclei can fuse to make beryllium-8. This is amazingly short-lived and decays back to helium.
- 1952 Ed Salpeter suggests an excited state exists in ^{8}Be. Hoyle shows that the reaction rate is too slow.
- 1953 Hoyle at Caltech suggests that ^{12}C has an excited state at 7.65 MeV, which would allow synthesis from three helium nuclei.
- Fowler confirms Hoyle's prediction, and "from then on we took Fred Hoyle very seriously" as a founder of nuclear astrophysics.
- Hoyle arranged his teaching so that he could spend at least four months every year at Caltech. This did not endear him to his Cambridge colleagues!

B^2FH 1957



- This paper in *Reviews of Modern Physics* is 108 pages long. It is still the foundation of nucleosynthesis. It gave substance to the new discipline of nuclear astrophysics which is still with us today. In 1957 there were three distinct theories of nucleosynthesis, all situated in the primordial universe.

- Hoyle's most highly cited paper. He appears to have been the most influential and productive of the four colleagues. Fowler worked on the light elements and the data. The Burbidges brought observational data (peculiar abundances in stars) to the collaboration.

- The unique example of a major contribution by Hoyle that did not involved controversy.
- The sad saga of the Nobel Non-Prize 1983

B^{2}FH 1957

(i) Hydrogen Burning

Hydrogen burning is responsible for the majority of the energy production in the stars. By hydrogen burning in element synthesis we shall mean the cycles which synthesize helium from hydrogen and which synthesize the isotopes of carbon, nitrogen, oxygen, fluorine, neon, and sodium which are not produced by processes (ii) and (iii). A detailed discussion of hydrogen burning is given in Sec. III.

(ii) Helium Burning

These processes are responsible for the synthesis of carbon from helium, and by further α-particle addition for the production of O^{16}, Ne^{20}, and perhaps Mg^{24}. They are described in detail in Sec. III.

(iii) α Process

These processes include the reactions in which α particles are successively added to Ne^{20} to synthesize the four-structure nuclei Mg^{24}, Si^{28}, S^{32}, A^{36}, Ca^{40}, and probably Ca^{44} and Ti^{48}. This is also discussed in Sec. III. The source of the α particles is different in the α process than in helium burning.

(iv) e Process

This is the so-called equilibrium process previously discussed by Hoyle (Ho46, Ho54) in which under conditions of very high temperature and density the elements comprising the iron peak in the abundance curve (vanadium, chromium, manganese, iron, cobalt, and nickel) are synthesized. This is considered in detail in Sec. IV.

(v) s Process

This is the process of neutron capture with the emission of gamma radiation (n,γ) which takes place on a long time-scale, ranging from ~100 years to ~10^5 years for each neutron capture. The neutron captures occur at a *slow* (s) rate compared to the intervening beta decays. This mode of synthesis is responsible for the production of the majority of the isotopes in the range $23 \leq A \leq 46$ (excluding those synthesized predominantly by the α process), and for a considerable proportion of the isotopes in the range $63 \leq A \leq 209$. Estimates of the time-scales in different regions of the neutron-capture chain in the s process will be considered later in this section, while the details of the nuclear physics of the process are discussed in Secs. V and VI together with the results. The s process produces the abundance peaks at $A = 90$, 138, and 208.

(vi) r Process

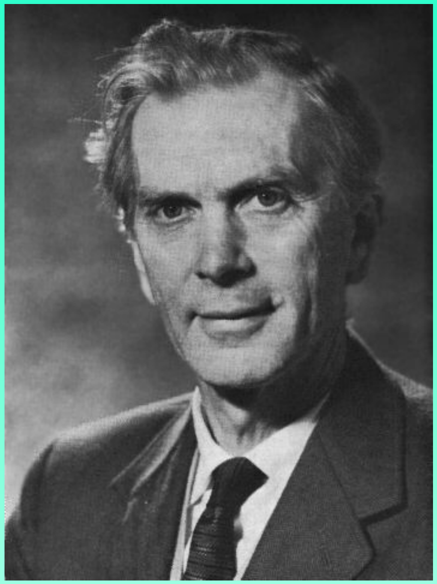
This is the process of neutron capture on a very short time-scale, ~0.01–10 sec for the beta-decay processes interspersed between the neutron captures. The neutron captures occur at a *rapid* (r) rate compared to the beta decays. This mode of synthesis is responsible for production of a large number of isotopes in the range $70 \leq A \leq 209$, and also for synthesis of uranium and thorium. This process may also be responsible for some light element synthesis, e.g., S^{36}, Ca^{46}, Ca^{48}, and perhaps Ti^{47}, Ti^{49}, and Ti^{50}. Details of this process and the results of the calculations are discussed in Secs. VII and VIII. The r process produces the abundance peaks at $A = 80$, 130, and 194.

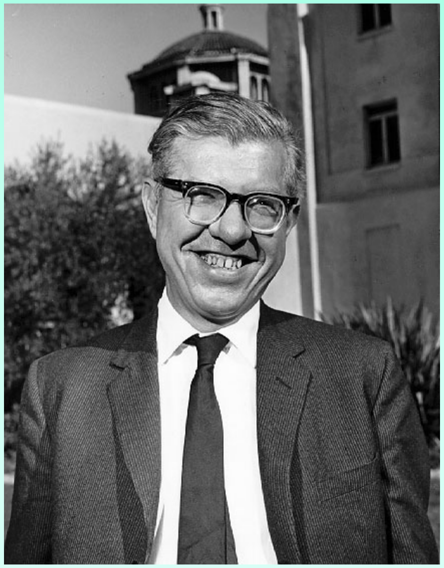
(vii) p Process

This is the process of proton capture with the emission of gamma radiation (p,γ), or the emission of a neutron following gamma-ray absorption (γ,n), which is responsible for the synthesis of a number of proton-rich isotopes having low abundances as compared with the nearby normal and neutron-rich isotopes. It is discussed in Sec. IX.

The Ryle-Hoyle clash

- Martin Ryle read physics at Oxford, had a distinguished wartime career on airborne radar, following which he joined the Cavendish Laboratory for ionospheric research. He had an engineer's distrust of mere theorists, whom he regarded as parasites. Ryle received the Nobel Prize for Physics in 1974 for his work on radio interferometry.
- 1949 first dispute between Ryle and Hoyle, on radio waves from sunspots, produces an over-reaction from Ryle.
- 1950: Ryle jumps to the conclusion that radio sources are a new class of star in the Milky Way. Gold and Hoyle press for an extragalactic interpretation after the identification of Cygnus A and Centaurus A. Ryle remains tenacious. Gold's Demonstratorship is not extended so he loses his university post at the Cavendish.
- 1952: Hoyle stage manages ridicule of Ryle at IAU in Rome when Baade produces Minkowski's spectrum of Cyg A.
- Radio astronomers now in the cosmology game. Ryle resolves to disprove Hoyle's steady state by counting radio sources, expecting to prove that the universe is evolving.



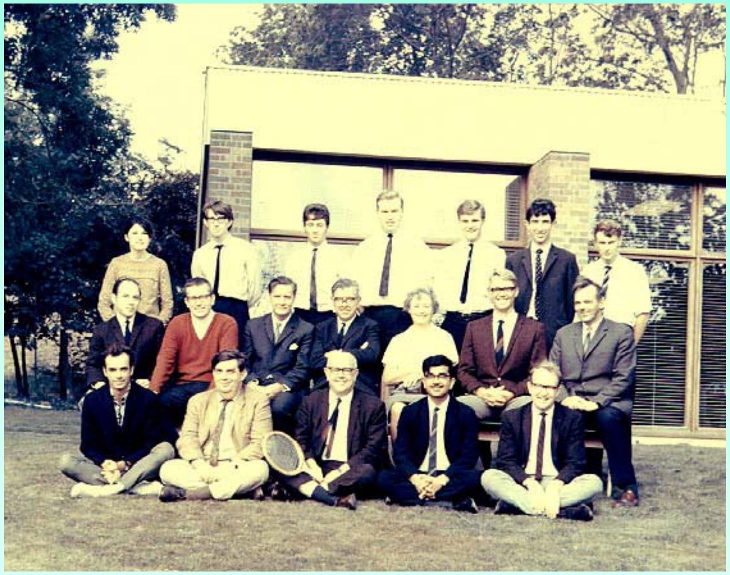


The Ryle-Hoyle clash

- Saga of the First and Second survey, which Ryle strongly promotes as having disproved the steady state theory. Ryle uses highly visible occasions to denigrate the steady state theory (Bakerian Lecture at Oxford, for example). Hoyle quickly loses all confidence in Ryle's surveys, the first two of which are in fact deeply flawed.
- The Third survey looks good from Ryle's point of view, and the Fourth is correct.
- Public humiliation of Hoyle stage managed by Ryle's publicist. Permanent rift, deeply damaging to UK astronomy, is the outcome.
- Hoyle has by now isolated himself from colleagues in DAMTP and well as the Cavendish. He aspires to having his own department, independent of physics and mathematics
- 1963 - Discovery of the microwave background

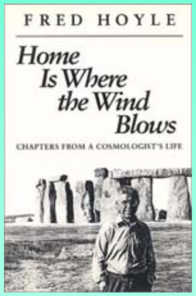
Institute of Theoretical Astronomy 67-72

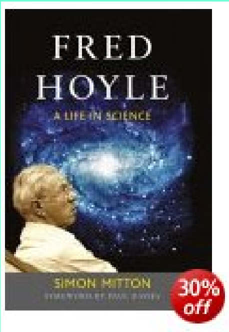
- The Institute opened in 1967, after a long saga of trials and tribulations.
- The idea of the UK having a national centre for theoretical astronomy was one which Hoyle took to heart. In this he was driven by his great respect for the position of theory in the leading American centres. The Royal Society became an important champion of the concept
- Putting together the funding took a great deal of time and a challenge for him. He had to play off many different actors: several universities, the research council, and foundations.
- The reality of an Institute in Cambridge was crystallized by Great Men of Cambridge. Lord Todd (Nuffield Foundation) and Sir John Cockroft (Wolfson Foundation) secured 80% of capital outlay.
- The immediate success of the Institute is Fred's enduring legacy. Through IoTA, with its imaginative programme of Visitor positions, he brought a new self-confidence to theoretical astronomy and cosmology in the UK.

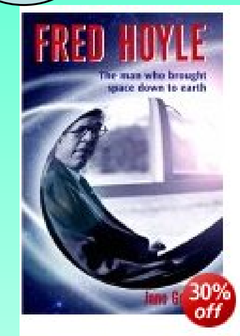


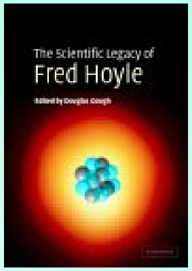
More about Fred: enjoy!

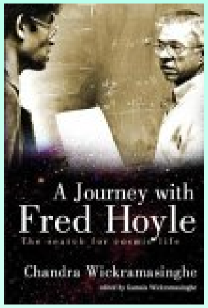
£5, signed











And finally ...

"Your years of toil,"
Said Ryle to Hoyle,
"Are wasted years, believe me.
The steady state
Is out of date.
Unless my eyes deceive me,

My telescope
Has dashed your hope;
Your tenets are refuted.
Let me be terse:
Our universe
Grows daily more diluted!"

Said Hoyle, "You quote
Lemaître, I note,
And Gamow. Well, forget them!
That errant gang
And their Big Bang—
Why aid them and abet them?

You see, my friend,
It has no end
And there was no beginning,
As Bondi, Gold,
And I will hold
Until our hair is thinning!"

"Not so!" cried Ryle
With rising bile
And straining at the tether;
"Far galaxies
Are, as one sees,
More tightly packed together!"

"You make me boil!"
Exploded Hoyle,
His statement rearranging;
"New matter's born
Each night and morn.
The picture is unchanging!"

"Come off it, Hoyle!
I aim to foil
You yet" (The fun commences)
"And in a while"
Continued Ryle,
"I'll bring you to your senses!"