Journal of Astronomical History and Heritage, 20(1), 2–12 (2017).

IS THE UNIVERSE EXPANDING? FRITZ ZWICKY AND EARLY TIRED-LIGHT HYPOTHESES

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Abstract: The recognition that the Universe is in a state of expansion is a milestone in modern astronomy and cosmology. The discovery dates from the early 1930s but was not unanimously accepted by either astronomers or physicists. The relativistic theory of the expanding Universe rested empirically on the redshift–distance law established by Edwin Hubble in 1929. However, although the theory offered a natural explanation of the observed galactic redshifts, these could be explained also on the assumption of a Static Universe. This was what Fritz Zwicky did when he introduced the idea of "tired light" in the fall of 1929. Hypotheses of a similar kind were proposed by several other scientists but their impact on mainstream astronomy and cosmology was limited. The paper offers a survey of tired-light hypotheses in the 1930s and briefly alludes to the later development.

Keywords: Expanding Universe, tired light, redshifts, Fritz Zwicky, cosmology

1 HUBBLE'S UNIVERSE

Edwin Hubble (1889–1953; Figure 1; Christianson, 1995) is often, if mistakenly, considered the discoverer of the Expanding Universe (Kragh and Smith, 2003; Nussbaumer and Bieri, 2009). The claim rests on Hubble's seminal paper published in March 1929 and in which he established the fundamental velocity–distance law named after him. The law can be stated as

$$v = c\frac{\Delta\lambda}{\lambda} = Hr \qquad (1)$$

Here $\Delta\lambda/\lambda$ denotes the redshift of a receding galaxy and *r* its distance; v is the radial velocity on the assumption that the observed redshifts are Doppler shifts, and *H* is the Hubble constant or parameter (Figure 2). It may come as a surprise that the same year, Hubble (1929: 96) left no doubt that he preferred a non-recession explanation of the galactic redshifts. In a popular account of his discovery, he wrote:

> It is difficult to believe that the velocities are real; that all matter is actually scattering away from our region of space. It is easier to suppose that the light-waves are lengthened and the lines of the spectra are shifted to the red, as though the objects were receding, by some property of space or by forces acting on the light during its long journey to the Earth.

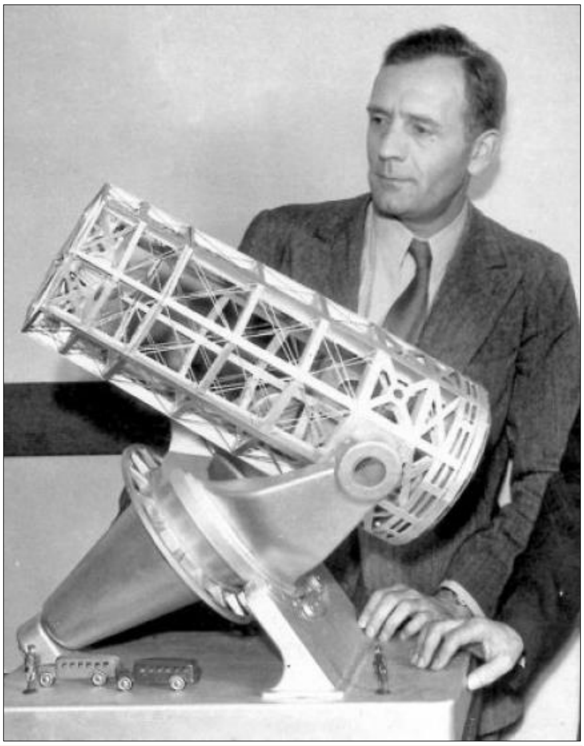

Figure 1: Edwin Hubble with a model of the proposed 200-in telescope, this is a cropped version of a photograph that appeared in the *New York Sun* on 18 June 1931 (adapted from citizensvoice.com/news/silvered-stargazer-1.1869195).

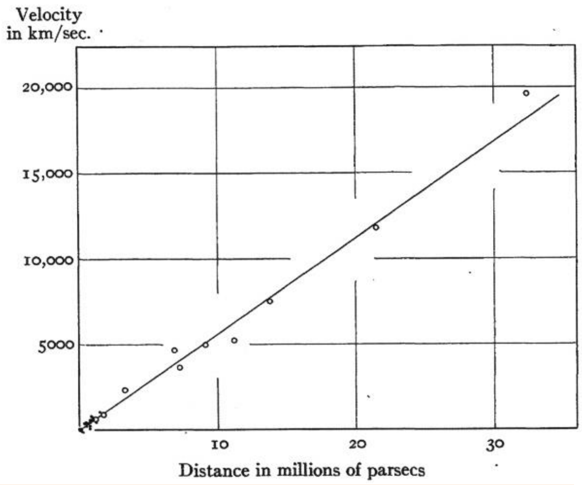

Figure 2: The Hubble law (after Hubble & Humason, 1931: 74).

In his later writings Hubble was more ambiguous and he never clearly endorsed alternatives to the recession theory. One of the first scientists to comment on Hubble's discovery was the Bulgarian-born Swiss-American astronomer Fritz Zwicky (1898–1974; Figure 3; Knill, 2014), who from 1925 had worked at the California Institute of Technology (Caltech). Zwicky knew Hubble personally and was part of the discussion club consisting of astronomers and physicists that regularly met at Hubble's home (Christianson, 1995: 197) and which also included Richard Tolman (1881–1948), Milton Humason (1891–1972) and Walter Baade (1893–1960). There is little doubt that Hubble, when referring to the possibility of "… forces acting on the light …", had in mind Zwicky's still unpublished explanation of the redshifts in terms of aging light. Zwicky submitted his paper on the subject in late August 1929 and it appeared in the October issue of the same journal as Hubble's paper, the *Proceedings of the National Academy of Sciences*.

Zwicky was the founder of 'tired light' mechanisms, a term that in general refers to the idea that photons slowly lose energy on their journey through space and therefore (since $E = h\nu = hc/\lambda$) arrive at the observer with an increased wavelength. According to this view, the galactic redshifts are not cosmological in nature and not peculiar to the galaxies; the light from all celestial objects will be redshifted proportionally to their distances from the Earth. The name 'tired light' is sometimes ascribed to Tolman, but always without a proper reference. It may have been coined by Howard Percy Robertson (1903–1961; Figure 4; Bogdan, 2014b) who, in a semi-popular address on the Expanding Universe, referred to the hypothesis that "… the observed red shift would be due to the properties of 'tired' light rather than the nebulae themselves." (Robertson, 1932: 226). Robertson found explanations of this kind to be unsatisfactory and *ad hoc*. The name may have been used informally at earlier occasions, for the Princeton astrophysicist John Quincy Stewart (1894–1972; Mumford, 2014) referred to "… what has been called the 'fatigue' of light quanta." (Stewart, 1931). Note that Zwicky did not use the term in any of his publications between 1929 and 1940.

In a little-known paper published shortly after Zwicky's, the Russian astronomer Aristarkh Belopolsky (1854–1934; Figure 5; Bogdan, 2014a) independently suggested that the Hubble redshifts might not be due to nebular recession (Belopolsky, 1929). A pioneer in the use of spectroscopy for the study of stellar motion, Belopolsky was a respected and internationally-oriented astronomer (Struve, 1935). In a brief note dated September 1929, 75-year-old Belopolsky questioned whether the redshifts were really to be understood as Doppler shifts of receding nebulae:

> If we only look at the spectral shifts we have to relate the phenomenon – the generally positive shifts – to light itself and the dilatation of waves or a diminution of its frequency. It follows that the celestial objects closer to us exhibit a smaller diminution of the vibrations of the ether particles than distant objects and that the diminution is proportional to the distance. To phrase it differently, if the light quantum at the source is $h\nu$, an observer at distance r from the source will receive it as $h\nu/r$. (Belopolsky, 1929).

The following year Belopolsky (1930) published a paper in a Russian astronomical year-

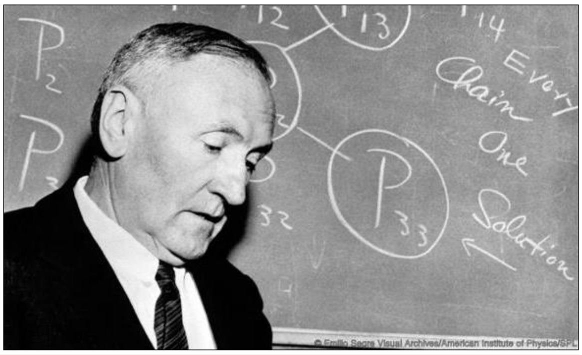

Figure 3: Fritz Zwicky (courtesy: Emilio Segrè Visual Archives/American Institute of Physics).

book in which he summarized Hubble's 1929 paper and again called attention to the interpretation of the redshifts (Tropp et al., 1993: 221). Although he admitted that the redshifts could be explained in terms of recession, he was more inclined to the hypothesis that they were due to some unknown quantum factor causing the wavelength to increase with the distance traversed by the light.

Figure 4: Howard Percy Robertson (courtesy: Emilio Segrè Visual Archives/ American Institute of Physics).

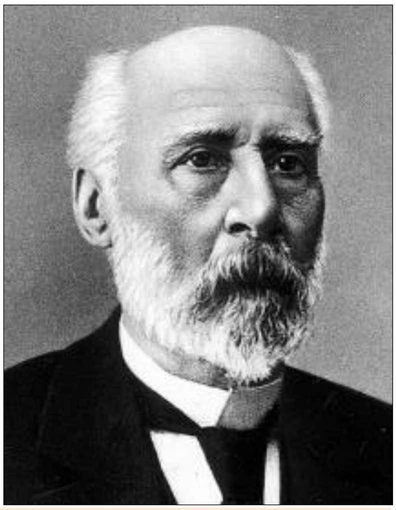

Figure 5: Aristarkh Apolionovich Belopolsky (WikiVisual).

2 ZWICKY'S GRAVITATIONAL DRAG HYPOTHESIS

Until 1929 Zwicky had mostly worked in areas of physical chemistry, such as the quantum theory of crystals and electrolytes, and he had only recently become interested in astrophysics. Realizing that Hubble's discovery was greatly important for "… the future development of our cosmological views …", Zwicky (1929a: 773) discussed a number of possible explanations of the spectral shifts. The 'curious phenomenon' might conceivably be due to an ordinary gravitational shift of spectral lines or Compton scattering of photons on free electrons, but these explanations he dismissed as inadequate. As a better alternative Zwicky focused on what he called "… a gravitational analogue of the Compton effect." (Zwicky, 1929a: 776). According to the theory of relativity a photon of frequency ν has a gravitational mass $h\nu/c^2$ and therefore should be able to transfer momentum and energy to an atom. As a result of the recoil the photon's frequency would be diminished. Zwicky calculated that according to this mechanism a photon travelling a distance r would be redshifted by the amount

Figure 6: Paul Willem ten Bruggencate (http://dutchgenie.net/bruggencate/brugg-e-o/ p4381.htm).

$$\frac{\Delta\nu}{\nu} = \frac{1.4G\rho D}{c^2} r \qquad (2)$$

The quantity $D >> r$ is a measure of the distance over which the gravitational 'drag' operates, and ρ is the average density of matter in the Universe, which Zwicky took to lie in the interval $10^{-25} > \rho > 10^{-31}$ g/cm^3. Estimating D to be of the order 10^3 R, where R ~ 1 Mpc is the mutual distance of the galactic systems, he got $D \sim 3 \times 10^{27}$ cm. Zwicky thus arrived at a frequency shift of

$$3 \times 10^{-2} > \frac{\Delta\nu}{\nu} > 3 \times 10^{-7} \qquad (3)$$

Comparing this estimate with Hubble's value of approximately 1.7×10^{-3} for R ~ 1 Mpc, Zwicky suggested (1929a: 779) that his explanation was in "… qualitative accordance with all of the observational facts known so far." As a possible test he remarked that an absorption line shifted due to gravitational drag would be asymmetrically broadened toward the red. His theory was admittedly just a 'rough idea' which in its further development needed to be based on the General Theory of Relativity and possibly include the effects of "… absorption of gravitational waves." (Zwicky, 1929a: 778).

It should be noted that at the time Zwicky did not present his theory as an alternative to the relativistic view of the Expanding Universe. This view was still in the future, if not for long. Moreover, Zwicky solely proposed a rival interpretation of the redshifts and not, either in 1929 or in his later papers, a new cosmological model. Although the literature on cosmology contains references to 'Zwicky's model', there never was such a model (Hetherington, 1982).

In a follow-up paper later in the year Zwicky (1929b: 1623) admitted that he had made a mathematical error, which "Professor Eddington kindly informs me in a letter." As a result of Eddington's criticism, he stressed that his derivation of the gravitational drag of light needed to be "… derived or disproved by the general theory of relativity." (Zwicky, 1929b: 1624). Zwicky again referred to gravitational waves propagating with the speed of light. Moreover, he discussed observations which might possibly confirm his theory and distinguish it from the Doppler theory of receding galaxies. It followed from Zwicky's hypothesis that the redshift should depend on the distribution of matter in space and one would therefore expect that "… an appreciable effect should also be observed in our galaxy." (Zwicky 1929a: 774). Moreover, the redshifts from within the Milky Way should depend on the direction. According to the cosmological view, there should be no such direction effect, indeed no distance-related redshifts within the Milky Way at all.

For observational support of his theory Zwicky referred to discussions with the young Dutch-German astronomer Paul ten Bruggencate Figure 6; Broughton, 2014), who at the time was working at Mount Wilson Observatory and was acquainted with the results obtained by Hubble and Humason. Inspired by Zwicky, ten Bruggencate (1930) studied the radial velocities of globular clusters on the assumption of the gravitational drag hypothesis. From his study he concluded that the number of stars required to bring the observed redshifts into agreement with the hypothesis was justified. It was "… of the right general order of magnitude to reconcile the observed red-shift with Zwicky's prediction." (ten

Bruggencate, 1930: 117). Several years later, after taking up the position as chief observer at the Potsdam Solar Observatory, better known as the Einstein Tower, ten Bruggencate (1937) returned to the question of the origin of the redshifts. However, his study of the luminosity–redshift relation for galaxies failed to discriminate clearly between the Expanding Universe and a static one with redshifts caused by a tired-light mechanism.

During the 1930s Zwicky published two more papers on his theory characterized by a redshift that depended not only on the distance but also on the amount and distribution of cosmic matter. Zwicky (1933), published in German in a Swiss physics journal, has today the status of a scientific classic because of its bold prediction of dark matter (English translation in Zwicky, 2009). But Zwicky (1933: 121) also reviewed the galactic redshift problem, now distinguishing between two alternatives, one of which was cosmic expansion and the other "… an interaction of light and the matter in the universe." Zwicky did not conclude that his own tired-light explanation was superior but only that it was no less unsatisfactory than the relativistic theory of the Universe. Both theories, he wrote,

> … have been developed on a most hypothetical basis, and none of them has succeeded to uncover any new physical relationships. (Zwicky, 1933: 124).

This was also Zwicky's message in 1935 when he listed a number of methodological and other objections to the relativistic theory of galactic redshifts. It is, he said,

> … scientifically more economical *not* to link the redshift from nebulae with any *purely hypothetical* curvature and expansion of space. (Zwicky, 1935: 803).

Zwicky did not claim that his own theory was better but rather recommended cautiousness, not unlike what Hubble did. Astronomers should not "… interpret too dogmatically the observed redshifts as caused by an actual expansion …" but wait for more experimental facts which "… is badly needed before we can hope to arrive at a satisfactory theory." (ibid.). In Zwicky's mind the gravitational-drag hypothesis had one advantage over the expansion hypothesis, namely that it was empirically testable:

> An initially parallel beam of light, on this theory, will gradually open itself because of small angle scattering. Observational tests on this point will be important. (Zwicky, 1935: 806).

Although Zwicky did not stress the connection between his tired-light hypothesis and the Static Universe, there is no doubt that he preferred the latter model over the Expanding Universe model. In a paper of 1939 he challenged the Expanding Universe on one of its weak points, namely that it led to an age of the Universe smaller than the age of stars and galaxies. According to Zwicky's analysis, the time of formation for a large cluster out of a random distribution of nebulae was more than 10^{18} years, immensely longer than allowed by most models of the Expanding Universe. This and other observations, he wrote, "… rule out any possibility of interpretation of the nebular red-shift on the basis of an expanding universe." (Zwicky, 1939: 607). Vera Reade (1905–1986; Kinder, 2009), a British amateur astronomer, reported on Zwicky's arguments in the *Journal of the British Astronomical Association*. She wrote:

> It may seem bold to challenge the expansion universe theory, but some observational facts pointed out by Dr. F. Zwicky seem to warrant this. (Reade, 1940: 162).

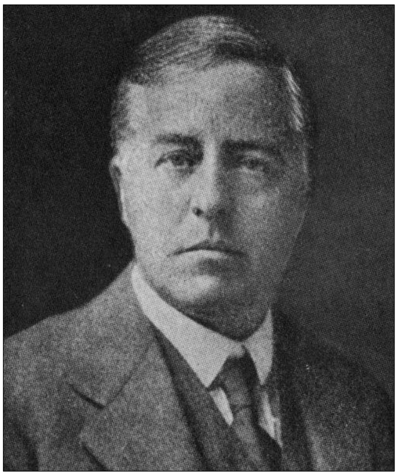

Figure 7: Sir James Hopwood Jeans (en.wikipedia.org).

Three years later Zwicky listed a number of observations which, to his mind, favoured the Static Universe over the hypothesis of the Expanding Universe. Zwicky (1942) argued that models of the Expanding Universe contradicted observed features of the large-scale distribution of matter.

3 TESTING TIRED LIGHT

Zwicky was a recognized scientist and his theory of redshifts attracted considerable interest among his peers. Although frequently rejected as inadequate, speculative or *ad hoc*, it was well known and taken seriously enough that proponents of the relativistic Expanding Universe often commented on it. As mentioned, Eddington did it informally, in a private letter. Sir James Jeans (1877–1946; Figure 7; Milne, 1952) dealt in some detail with Zwicky's theory in his popular book *The Mysterious Universe*. He obviously found the theory to be attractive and thought that it received support from ten Bruggencate's study of globular clusters. According to Jeans (1930:

87), most of the reddening of the spectral lines "... may be attributed to the effects suggested by Zwicky, or to some similar cause."

As Zwicky had argued for his theory in methodological terms, so Robertson (1932: 226) criticized it from a methodological point of view by invoking Occam's principle of simplicity and economy. Referring to "... a group which would attribute the observed red shift … to a property of light which has traveled the tremendous internebular distances ...", he singled out Zwicky's hypothesis. But, he concluded,

> ... in the lack of further facts I should prefer to wield Occam's razor on all ad hoc explanations of the red shift and accept that one which follows so naturally from our present views of the nature of the physical world.

Richard Tolman (Figure 8; Kirkwood et al., 1952), another mainstream cosmologist and advocate of the Expanding Universe, argued theoretically that the frequency of light could not be appreciably affected by passing the gravitational fields of particles on its way from source to observer. He consequently concluded that Zwicky's gravitational-drag hypothesis was "... improbable." (Tolman, 1934: 288).

This seems also to have been the view of Albert Einstein (1879–1955; Figure 8), who spent the first two months of 1931 in Pasadena. He met with Zwicky and most likely discussed cosmological issues with him. Einstein at the time was aware of the Expanding Universe, but he still hesitated in converting to the new theory. He believed that the nature of the galactic redshifts was "... a mystery ...", according to a *New York Times* report on a meeting that took place at Mount Wilson Laboratory on 11 February 1931. On the other hand, Einstein did not accept Zwicky's tired-light explanation of redshifts. According to the report,

> He [Einstein] said the red shift might be interpreted as the light quanta getting redder by losing energy as they went long distances. 'But no man can get a picture of how this happens', he said. (Nussbaumer, 2014: 50).

The reference obviously was to Zwicky's hypothesis.

Not only did ten Bruggencate's luminosity–redshift test fail to distinguish observationally between an Expanding and a Static Universe, but the same was the case with an extensive investigation undertaken by Hubble and Tolman (1935; see also Peebles, 1971). For the variation of a galaxy's surface brightness *S* with redshift $z = \Delta\lambda/\lambda$ they found different relations for simple expanding models (E) and tired-light models (TL), namely

$$S_{\mathrm{E}} \propto (1+z)^{-4} \quad \text{and} \quad S_{\mathrm{TL}} \propto (1+z)^{-1} \qquad (4)$$

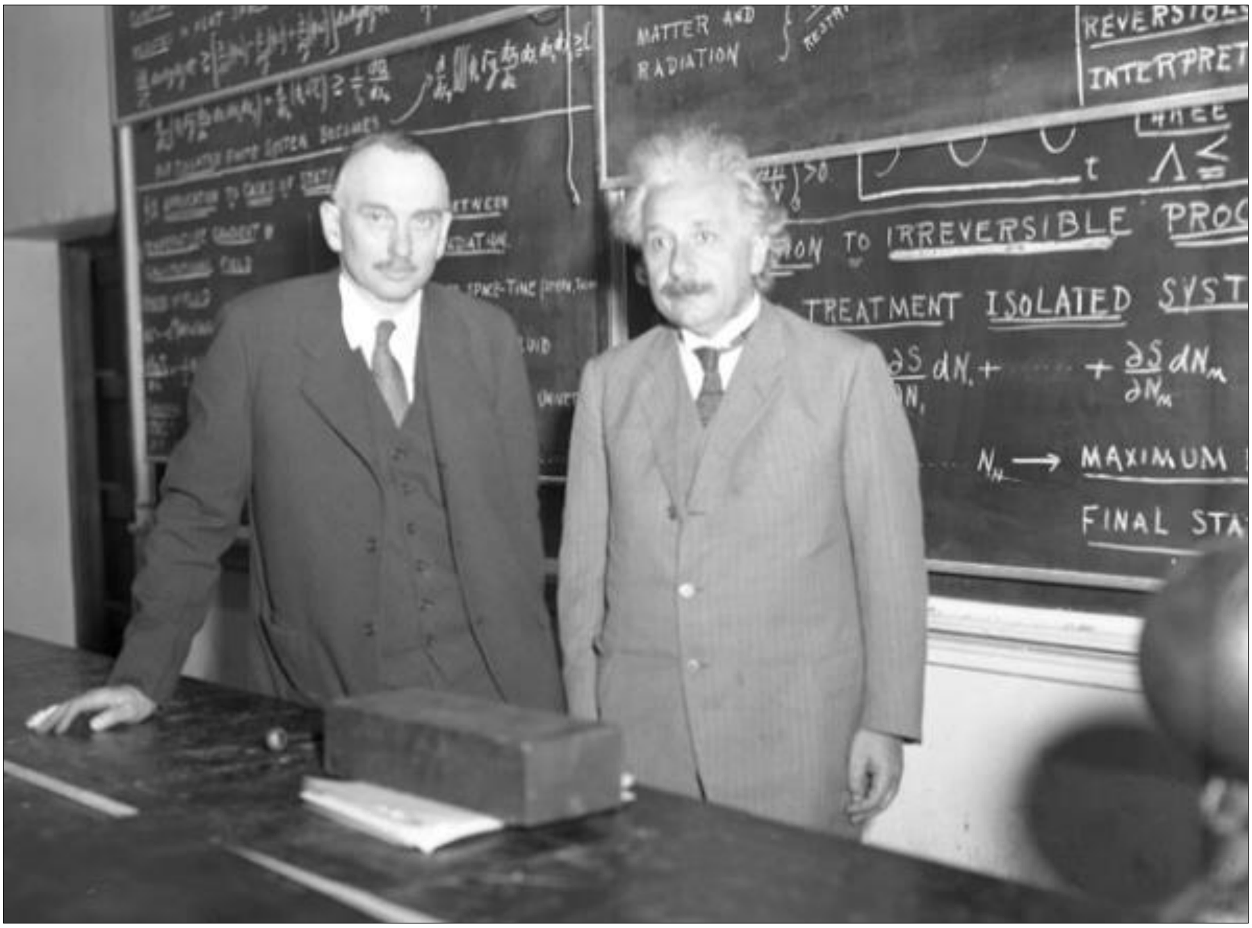

Figure 8: Richard Chase Tolman and Albert Einstein at Caltech in 1932 (en.wikipedia.org).

However, due to lack of reliable data neither this test nor other tests proposed by Hubble and Tolman provided a clear answer. As Hubble and Tolman (1935: 303) noted,

> The possibility that the redshift may be due to some other cause [decrease of the energy of galactic photons] ... should not be neglected; and several investigators have indeed suggested such other causes, although without as yet giving an entirely satisfactory detailed account of their mechanism.

Hubble and Tolman did not refer to the names of the investigators, but presumably they thought of Zwicky in particular.

If observations were of little use, perhaps tired-light hypotheses could be subjected to experimental testing. According to Roy Kennedy and Walter Barkas (1912–1969) at the University of Washington, experiments proved that Zwicky's hypothesis was wrong. The aim of Kennedy and Barkas (1936) was to test whether or not the 'Hubble–Humason law' could be reproduced on the basis of a tired-light hypothesis assuming that a photon loses energy to free electrons in proportion to its frequency. Let the photon's initial frequency be ν_0 and the density of the medium of free electrons through which it passes be ρ. From the Beer–Lambert law

$$\mathrm{d}\nu = -k\rho\nu\mathrm{d}x \qquad (5)$$

where k is an unknown constant, it follows that

$$\nu = \nu_0 \exp(-k\rho x) \qquad (6)$$

or approximately

$$\frac{\Delta\nu}{\nu} = \frac{\nu_0 - \nu}{\nu_0} = k\rho x \qquad (7)$$

This is an expression similar in form to Hubble's relation. To test the expression experimentally Kennedy and Barkas needed a very high value of ρ to compensate for the small value of x = 40 cm in the experiment. This they obtained by using an ionized helium gas of $\rho = 5 \times 10^{12}$ electrons per cc, whereas they estimated the electron density in the intergalactic medium to be $\rho \geq 5 \times 10^{-4}$ per cc. Their interferometer showed a null result from which they concluded that "... the nebular redshift is not to be attributed to interstellar electrons in a static universe." (Kennedy and Barkas, 1936: 451). To make a Static Einstein Universe comply with their data it had to be unrealistically small, of a radius less than 10^8 light-years. Moreover, Kennedy and Barkas failed to detect the asymmetric broadening toward the red in absorption lines that Zwicky's theory required. Because it was published in *Physical Review* the Kennedy–Barkas experiment was well known, but neither Zwicky nor other proponents of tired-light hypotheses responded to it.

4 OTHER PHOTON-DECAY HYPOTHESES

Although Zwicky's gravitational drag hypothesis was the best known and most elaborated alternative to the relativistic interpretation of the galactic redshifts, it was far from the only one. During the 1930s more than twenty scientists or amateur scientists suggested alternatives to the Expanding Universe, many of them belonging to the tired-light category (see Table 1). I shall mention just a few of the ideas.

Table 1: Alternatives to the Expanding Universe, 1929–1939

Name	Year	Nationality	Profession	Comment
Zwicky, F.	1929	Swiss-American	astronomer	see text
Belopolsky, A.	1929	Russian	astronomer	see text
Stewart, J.	1931	American	astrophysicist	see text
MacMillan, W.	1932	American	astronomer	see text
Buc, H.	1932	American	engineer	tired light
Arx, W.	1932	American	amateur astronomer	tired light
Mason, W.	1932	American	author	classical gas theory
Eigenson, M.	1932	Russian	astronomer	galactic mass decrease
Schier, H.	1932	Austrian	amateur astronomer	decreasing speed of light
Kaiser, F.	1934	German	amateur astronomer	gravitational redshift
Gramatzki, H.	1934	German	amateur astronomer	varying speed of light
Northtrop, F.	1934	American	philosopher	Whitehead's gravitation theory
Wold, P.	1935	American	physicist	varying speed of light
Underwood, R.	1935	American	amateur astronomer	tired light
Chalmers, J. and Chalmers, B.	1935	British	physicists	variation of Planck's constant
Gunn, R.	1935	American	physicist	classical radiation forces
Halm, J.	1935	German-British	astronomer	modification of optical theory
Nernst, W.	1935	German	chemist	see text
Haas, A.	1936	Austrian-American	physicist	photon decay
Sambursky, S.	1937	American	physicist	see text
Lorenz, H.	1937	German	amateur astronomer	classical gas theory
Freeman, I.	1938	American	physicist	varying gravity
Arnot, F.	1938	British	physicist	inspired by Milne's cosmology
Kalmar, L.	1938	Hungarian	amateur astronomer	modification of classical mechanics
Gheury de Bray, M.	1939	British	amateur physicist	varying speed of light

Figure 9: John Henry Reynolds (en.wikipedia.org).

The first to propose a tired-light hypothesis after Zwicky and Belopolsky was Princeton's John Quincy Stewart, who was known as the co-author, together with R.S. Dugan and H.N. Russell, of the widely-used textbook *Astronomy*. From manipulations with the fundamental constants of nature, among which he counted Hubble's constant, Stewart (1931) suggested that photons lost their energy $E = h\nu$ in proportion to the distance r from the source. Confusingly, instead of using the standard definition of Hubble's constant H he took it to be the corresponding length given by c/H. Re-written in the conventional form, Stewart (1931) proposed that

$$\nu(r) = \nu_0 \exp\left(-\frac{H}{c}r\right) \quad (8)$$

This simplest possible form of the tired-light hypothesis was to reappear several times over the next decade. While Zwicky's tired-light hypothesis assumed nebular photons to interact with intergalactic matter, according to Stewart's proposal photons just lost energy without any external agency.

Figure 10: Walther Nernst (en.wikipedia.org).

Inspired by quantum mechanics, other hypotheses in the period supposed that a photon of energy $h\nu$ might spontaneously split into two or more photons of lesser energy and frequency (Halpern, 1933). The reduction in energy would on the average be proportional to the distance travelled by the photon through empty space.

> Is the Doppler effect the only possible interpretation? If the slowing down of light over vast distances is a possibility, shifts toward the red should be expected.

This is how the British astronomer John Reynolds (1874–1949; Figure 9; Johnson, 1950), a specialist in galactic astronomy, ended a survey paper on the evidence for the Expanding Universe (Reynolds, 1932: 462). He referred to a recent proposal by his colleague in Chicago, Astronomy Professor William Duncan MacMillan (1871–1948), who had long advocated an eternal, stationary and self-perpetuating Classical Universe (Kragh, 1995). MacMillan (1932) supposed that if

> ... there is a leakage of energy from the photon in its long journey over millions of years, due perhaps to an inherent instability in the photon, or, possibly, to collisions with other photons.

From this he derived the same frequency–distance relation as Stewart, commenting that

> ... the assumed tendency of the energy of the photon to evaporate in its long journey through space leads to a law of frequency which is indistinguishable from the law of Doppler effect as given by Hubble and Humason.

MacMillan's conception of the Universe was to a large extent shared by the German physical chemist and Nobel Prize Laureate Walther Nernst (1864–1941; Figure 10; Bartel and Huebener, 2007), who during the 1930s turned from chemistry to astrophysics and cosmology. Nernst's tired-light explanation of the redshifts, essentially the same as the one of Stewart and MacMillan, led to a redshift–distance formula of the form

$$c\frac{\Delta\nu}{\nu} = Hr \quad (9)$$

According to Nernst (1935), the constant H was not really a constant of the Universe but a 'quantum constant' giving the decay rate of photons.

Other tired-light proposals in the period were based on the assumption that one or more of the constants of nature varied slowly in cosmic time. For example, Samuel Sambursky (1900–1990; Figure 11) at the Hebrew University in Jerusalem suggested that

> ... a static universe with a quantum of action decreasing with time is equivalent to an expanding universe with a constant quantum of action. (Sambursky, 1937: 336).

Sambursky assumed that Hubble's constant H and the variation of Planck's constant h were related, since

$$H = -\frac{1}{h}\frac{\mathrm{d}h}{\mathrm{d}t} \qquad (10)$$

From this it followed that

$$\mathrm{d}h/\mathrm{d}t \cong 10^{-50}\ \mathrm{J} \qquad (11)$$

Although there was not the slightest empirical evidence that the constants of nature varied in time, Zwicky welcomed the hypothesis. He believed that it might contribute to "... a deeper understanding of the redshift of light from distant nebulae and other astronomical phenomena." (Zwicky, 1938). On the other hand, he denied that the speed of light depended on the age of the Universe, a hypothesis which at the time was suggested by several writers (Table 1). According to some versions of the hypothesis, as proposed by Gheury de Bray in England, Hugh Gramatzki in Germany, and Peter Wold in the United States, a decreasing speed of light might explain the redshifts on the basis of a Static Universe (North, 1990: 231).

5 THE STATUS OF NON-EXPANDING HYPOTHESES

Astronomers in the 1930s realized that observational evidence for the Expanding Universe was limited to the galactic redshifts and the Hubble law. They were aware of the alternative, a Static Universe supplied with a redshift mechanism, and consequently some astronomers adopted an agnostic attitude. Hubble was among them, and he was followed by his colleague at Mount Wilson Observatory, the stellar spectroscopist Olin Wilson (1909–1994; Apt, 2002), who wrote:

> At the present time it is not possible to decide observationally whether the red shift is a true Doppler effect, representing relative motion, or whether it is a hitherto unrecognized phenomenon of a different kind, such as, for example, the gradual dissipation of photonic energy. (Wilson, 1939: 634–635).

However, most mainstream physicists and astronomers accepted that the galactic redshifts were due to recession, if not necessarily to the relativistic expansion of space. When they referred to the static alternative it was not because they found it attractive but because it offered a solution to the serious time-scale problem of the Expanding Universe. The British astronomer Harold Knox-Shaw (1885–1970; Wilds, 2014), President of the Royal Astronomical Society during 1931–1932, probably spoke for the majority of astronomers when he said:

> Some doubt has been expressed as to whether the red-shifts in their [the nebulae's] spectra should be interpreted as a Doppler effect, but in the absence of any satisfactory alternative explanation I consider that we are justified in expressing them in terms of velocity. (Knox-Shaw, 1933: 308).

Astronomers had for decades been used to stellar Doppler shifts and could therefore regard the galactic redshifts as just an extension of previous practice. This is what Richard Richardson at Mount Wilson Observatory suggested in a comment on what he called "... the greatest puzzle facing astronomers today." According to Richardson (1940: 332),

> Astronomers hesitate to believe that displacements of spectral lines toward the violet or red on which they have relied so long do not indicate real velocities of approach or recession.

The core group of relativist cosmologists conceived the alternatives to be speculative and based on arbitrary assumptions with no support in known physics. According to them, the redshifts followed naturally from relativistic cosmology whereas tired-light theories were contrived, *ad hoc* and unnecessary. This judgment was later expressed in much stronger language by the French astronomer Paul Couderc (1899–1981; Marché, 2014) from Paris Observatory. Describing those who denied the expansion of the Universe as 'conservative spirits', Couderc (1952: 97) wrote:

Figure 11: Samuel Sambursky (en.wikipedia.org).

> The vanity and sterility of twenty years' opposition to recession is characteristic of a poor intellectual discipline. To hunt for an *ad hoc* interpretation, to search for a means of sidestepping a phenomenon which is strongly indicated by observation simply because it leads to "excessive" conclusions is surely contrary to scientific method worthy of the name. As long as there is no precise, concrete phenomenon capable of casting doubts on the reality of the recession and of explaining the shifts differently, I maintain that it is *a priori* unreasonable to reject recession.

By and large, and despite the reservations expressed by Hubble and a few others, by 1940 the Static Universe was no longer part of mainstream astronomy. On the other hand, it had not yet been replaced by the Expanding Universe in the sense of relativistic cosmology.

6 A GLANCE INTO LATER DEVELOPMENTS

Although redshift alternatives to the Expanding Universe were not held in high regard after WWII, a large number of tired-light hypotheses continued to be proposed. In 1954 the German-born British astronomer Erwin Finlay-Freundlich (1885–1964; Figure 12) revived interest in the tradition initiated by Zwicky. Finlay-Freundlich, whose name was originally Freundlich, was a former collaborator of Einstein and by 1954 he served as Professor of Astronomy at St. Andrews University in Scotland (Batten, 2014). For stellar redshifts he suggested a linear redshift–distance law which he believed was valid also for

Figure 12: A painting of Erwin Finlay-Freundlich by Ernest Mandler (courtesy: Art UK).

the galactic redshifts and whose physical mechanism might be a kind of photon–photon interaction (Finlay-Freundlich, 1954; Born, 1954). With r denoting the distance light passes through a radiation field of temperature T, he stated the formula as

$$\frac{\Delta\lambda}{\lambda} \propto T^4 r \qquad (12)$$

Finlay-Freundlich's proposal attracted considerable interest and during the following three decades a large number of tired-light hypotheses were published by physicists, astronomers and amateur scientists.

However, according to nearly all mainstream astrophysicists and cosmologists they are untenable. Not only are they in conflict with observations, but they also rested on unverifiable assumptions of an *ad hoc* nature. Consequently, tired-light alternatives to the Expanding Universe are no longer found in reputable journals devoted to research in astronomy and cosmology but are largely relegated to journals and internet sites of a more speculative nature. Still, in 1986 the prestigious *Astrophysical Journal* included a paper arguing a tired-light alternative to the Expanding Universe. The author, a recent Ph.D. graduate from Portland State University writing from a private home address, concluded in favour of

> ... a cosmology in which the universe is conceived of as being stationary, Euclidean, and slowly evolving, and in which photons lose a small fraction of their total energy for every distance increment they cover on their journey through space. (LaViolette, 1986: 552).

Zwicky's spirit was still alive!

7 CONCLUSION

Tired-light hypotheses for the origin of the galactic redshifts are still considered as possible alternatives to the Expanding Universe, but they are no longer taken seriously in mainstream cosmology. The situation in the 1930s was different, with Hubble and a few other astronomers expressing interest in the hypotheses. The first and most influential proposal of a tired-light mechanism, Zwicky's gravitational drag hypothesis of 1929, was followed by a dozen similar but less detailed proposals. In most cases the *raison d'être* was to retain a Static Universe and avoid the conclusion that galaxies were receding at very high velocities. The cool response from astronomers was in part based on methodological arguments and in part on comparison with observations. It is worth noting that many astronomers at the time subscribed to a Doppler interpretation of the redshifts without accepting the expansion of the Universe associated with the new theory of relativistic cosmology.

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