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Fritz Zwicky: Novae Become Supernovae

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Abstract. The Swiss physicist Fritz Zwicky (1898-1974) dabbled in a plethora of disciplines, including astronomy and astrophysics. His dabblings were with vested interest and he has left quite an impact. His first great *success* was his nova research. In the early 1930s, while supermarkets and Superman were flying, he labelled the distinctly brighter nova *Supernova*. It had been believed that novae were the collision of two stars, but Zwicky came to recognize supernovae as a phenomenon quite distinct from novae. He and Walter Baade explained supernova by melding astronomy and physics and in this aim they created neutron stars, explained the origin of cosmic rays, initiated the first sky survey, and confirmed that a number of historical novae were indeed supernovae. This was truly an important work in the history of astrophysics.

1. Astronomy in the Thirties

The story of supernova that I am going to tell you takes place predominantly in the United States in the 1930s. World War I had left an impression on science and technology, such that science was being glorified for its influence on technology and its contributions to the war effort. But in 1930 America was changed, the stock market crashed in 1929 and the nation was hit with the Great Depression. Unemployment sky rocketed. Attitudes and lifestyles changed drastically in this decade.

Americans flocked to California to look for work in agricultural fields or in the West coast cities. However the image of poverty and the struggle for survival during the depression portrays only part of the history of this era. Paradoxically, this was also a time of great achievement in science and technology. For example, astronomy in California, which was already Big Science, did not particularly suffer from the depression. Astronomy at universities like Caltech grew.[1] In the 1920s, the discipline had been funded largely by individual philanthropists. The great observatories may be attributed to the rise of capitalism and personal wealth in the Western world. The eloquent George Ellery Hale was key in procuring the private funds for the construction of three great telescopes. And

[1] John Lankford attributes this to a change in funding decisions and policy objectives at the four different types of institutions: research factories, major Universities, second-order Universities, and Colleges. Research factories, like Mount Wilson Observatory funded by Carnegie Institute of Washington, waned in this era, Colleges remained static, while major and second-order Universities grew (see Lankford 1997, p. 141, and Geiger 1986, p. 246).

he used the duality of research goals to help him obtain private funding for pure science.[2]

2. The 200-inch Hale Telescope

Fortunately for those interested in astronomy in Pasadena, California, the International Education Board committed to the funding of a 200-inch telescope in the autumn of 1928, before the stock market crash of 1929. This telescope would be built on Mount Palomar and would be a part of the California Institute of Technology.

The opportunity to have access to what would be the largest telescope in the world would not be passed up, at least three physicists at Caltech would switch over to astronomy and astrophysics. These included Sinclair Smith[3] and John Strong.[4] At this time (and since the dawn of astronomical spectroscopy) physics was being applied more and more to astronomy but few astronomers had the physics background needed to take this very far. Richard C. Tolman also switched to astrophysics from physical chemistry, as did Josef Johnson after partaking in a number of solar eclipse expeditions.

3. Fritz Zwicky

The key character in the story that I have to tell was also amongst this group of physics turned astronomers. Fritz Zwicky (1898-1974) was born in Bulgaria in 1898. He was of Swiss nationality and he grew up in Switzerland, in the region of Glarus and then he studied in Zurich. He studied solid-state physics and worked in crystallography research before coming to California on an International Education Board post-doctoral fellowship in 1925.

You have probably all heard his name before. He is quite well-known for his work in astrophysics and rocketry. He is equally renowned for his *irascible* personality. However the incredibly wide range of his accomplishments is not so well known. He made an impact on supernovae theory and surveys, cosmic ray theory, neutron stars, extragalactic dark matter, gravitational lensing, dwarf galaxies, and jet propulsion. He had an important role in evaluating military research in post-war Germany and Japan, sending man-made objects into interplanetary space just days after Sputnik was launched, the founding of the morphological theory and his mountaineering exploits included innovating

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[2]The winning of the war had been perceived to be due to the marriage of pure and applied goals and he used this to his advantage. However, allegedly, until the beginning of World War II, "astronomy was the purest of sciences, almost devoid of practical application."(Struve & Zebergs 1962, p. 17; see also Hale 1928a; 1928b).

[3]Sinclair Smith (1899-1938) had worked on the 100-inch Hooker telescope as a draftsman at Mount Wilson and set almost immediately on the design of the 200-inch telescope. His radial velocity measurements of the Virgo cluster galaxies led to one of the first detections of dark matter in extra-galactic clusters.

[4]John Strong worked with infrared observations and would innovate evaporating aluminium films for telescope mirrors as a replacement for silver.

crampons and making the first winter ascent of the Aiguille du Gouter. The list goes on and on.

But you might be wondering how he got into astronomy and astrophysics from crystallography and solid-state studies? Well, as I mentioned before, he became a part of the faculty at Caltech in 1927, just in time to be part of the promise of the greatest telescope ever, Hale's 200-inch reflector. There was also the influence of his collaborator and boss, Robert A. Millikan who was applying physics to astronomy with his cosmic ray research. The crossover was perhaps natural. And needed, the 200-inch telescope was to be a part of Caltech, an institute that despite its strong physics faculty did not have an astronomy department! Zwicky witnessed the birth of the department and taught astronomy courses from the onset, although he was associate professor of theoretical physics (as of 1929) and only became a professor of astrophysics in 1942. His involvement may have been initially pedagogical, but his interest stretched far beyond this. Among his first astronomical research projects was the study of novae.

4. Novae

Interest in novae rose with the observation of a very bright nova in Andromeda 1885. It was immediately realized that this nova was exceptional; it could be seen with the naked eye! Observations and studies were pursued as the century turned. The innovations in photography and spectra studies in the latter half of the nineteenth century allowed the study of novae to be pushed further than ever.

In 1919, Knut Lundmark studied this nova. He had done a lot of work on star systems and estimated the distance of Andromeda to be 200 kpc and thus the peak absolute magnitude of the nova to be -15 (Lundmark 1919). By 1920, about ten novae had been observed. Lundmark suggested a distinction between the fainter *dwarf* novae that reached an absolute magnitude of -6.5 to -9 and *giant* novae that reached -17 to -19 at maximum brightness. He did not associate the distinction with distinct objects or mechanisms.

However, estimates of the unusual brightness of S And1885 varied with opinions concerning the distance of M31. The more distant the estimate, the brighter it would have to be. Distance determination was a major concern for astronomers at this time. Do not forget that it was only in 1924 that Edwin Hubble established that M31 was extra-galactic. Harlow Shapley, for example, thought an object of absolute magnitude -15 to be *inconceivable* and used this in his debate with Heber Doust Curtis on the distance scale of the Universe.

5. Three Publications. The Foundation of a New Field of Study

Walter Baade[5] and Fritz Zwicky presented a paper at a physics conference in November 1933 and at the December 1933 meeting of the American Physical

[5]Walter Baade (1893-1960) arrived in Pasadena, California from Hamburg in 1931. Upon his arrival he was primarily involved in photographing nebulae (both real nebulae and galaxies, although the distinction had not been made at this time) and star clusters. He was particularly concerned with determining distances with RR Lyrae variables and he used the 100-inch Hooker

Society titled *Supernovae and Cosmic-rays* (Baade & Zwicky 1933). This was followed up by a series of three papers on supernovae in 1934 (Baade & Zwicky 1934a,b,c). In a nutshell, they estimated their maximum brightness to be 63 million times the luminosity of the Sun, suggested that it was the source of cosmic rays, proposed that it was the final stage in the evolutionary process of a star and resulted in the creation of a neutron star. Their initial estimates were based on the supernova of Andromeda 1885 and that of 1572, which Tycho Brahe had observed in the constellation Cassiopeia. At the time only 12 supernovae had been observed. It was generally believed that they were the result of the collision of two stars, that cosmic rays were of interstellar origin, and neutrons had only been detected the previous year by Sir James Chadwick. So you can imagine that this was an incredible leap in the interpretation of the phenomena that yielded these bright objects. However, these suggestions did not come completely out of the blue. For instance, in 1926, Arthur S. Eddington estimated that a star has an incredible amount of stored energy (Eddington 1926, p 141) and, in 1930, Edward Arthur Milne suggested that novae resulted from the collapse of stellar cores, that is that ex-novae became white dwarfs or *dense stars* (Milne 1930, 1931).

Observational data were scarce and there was almost no evidence for their ideas. And Baade and Zwicky recognized this: "At the present time only a few underexposed spectra of super-novae are available, and it has not thus far been possible to interpret them" (Baade & Zwicky 1934b). In his book on supernovae, Laurence Marschall emphasized that "Informed opinion, therefore, did not favor Baade and Zwicky ... Based on the scarcity of supernova sightings at the time, Zwicky had little chance of success." (Marschall 1988, p. 107). Nevertheless these publications formed the foundation of supernova research as a field of study and subsequently a systematic search was coordinated.

6. The 18-inch Schmidt Telescope

This was essentially Zwicky's first observing experience. The survey began with a 3.5-inch Wollensak camera that Zwicky bought himself and mounted on the roof of the Robinson astrophysics building at Caltech. He acknowledged his colleagues' lack of confidence and stated that he was "accompanied by the hilarious laughter of most professional astronomers and colleagues at Caltech" (Zwicky 1974). And much to his dismay, he did not find any supernova in the first two years of observation, 1934-1936.[6]

He and Baade realized that a Schmidt telescope would be ideal for such a survey. A self-taught Estonian optician, Bernhard Voldemar Schmidt, invented the Schmidt telescope but it had never received much acclaim in Europe. Schmidt had worked at the Hamburg Observatory with Baade and they traveled to the

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telescope at Mount Wilson for these studies. Baade would later identify SN 1604 (the reason for our gathering today) as a supernova (Baade 1943).

[6]Hogg claimed that the systematic survey of rich nebular fields began at Mount Wilson in 1928 (Hogg 1937). I have not found any evidence of this. Zwicky and Baade did however search photographic plates from Mount Wilson that dated to 1901.

Philippines on a solar eclipse observing expedition together. Baade was quite familiar with this instrument and the advantages of its wide-angle field.

In 1935 Zwicky traveled to Hamburg to visit Schmidt. Upon his return to Pasadena, he and Millikan convinced Hale to allocate $25,000 of the Rockefeller grant for an 18-inch Schmidt, "on the pretext to the Rockefeller Foundation that it was needed as a scout instrument for the 200-in. telescope" (Zwicky 1974). It was constructed under the direction of John A. Anderson and put in operation on September 1936. Baade stated that this was "sooner than expected!" Perhaps this was a result of Zwicky's immediate visit to Hamburg and solicitation for funding.

7. A Systematic Search

The survey was a divided effort. Zwicky and Josef Johnson from Caltech observed and identified the supernovae with the 18-inch Schmidt at Palomar Mountain. While at Mount Wilson Observatory, Baade studied the light curves and Rudolph Minkowski[7] obtained the spectra with the 60- or 100-inch telescopes. Within the first year of observing with the Schmidt, they found three supernovae. The first supernova was found in NGC 4157 in March 1937, the second in IC 4182 in August, and the third in NGC 1003 in September of the same year (Zwicky 1937; Baade & Zwicky 1938; Minkowski 1939). They also found six supernovae on plates of the Virgo cluster taken between 1901 and 1931.

The observations had been directed at regions of clusters of galaxies (initially the Virgo cluster) with the idea that the greater the number of galaxies, the greater chance of observing a supernova. These observations would lead to Zwicky's work and the first dark matter hypothesis in clusters of galaxies.

By 1941, about 50 supernovae had been detected. But the survey, which had been interrupted by the Second World War, was only reestablished in 1957. And at this time, it went full swing. The 48-inch Schmidt telescope had been dedicated to the Palomar Sky Survey from its inauguration in 1949 until 1958, when Zwicky recommenced his systematic search for supernovae. In 1961, the supernovae count was up to 96 and in this year an IAU commission was formed and chaired by Zwicky. It came to include the participation of 15 observatories. By 1974, when Zwicky died, 380 supernovae had been detected.

8. Media Appeal

Later in his life, Zwicky himself claimed theirs to be "one of the most concise triple predictions ever made in science" (Zwicky 1971). Although he is reputed for his arrogant nature,[8] he was not alone in realizing that the theory was worthy

[7] Rudolph Minkowski (1895-1976) came to Pasedena in 1935. He had met Baade in Hamburg and solicited his aid in escaping anti-Semitic persecution in Germany. He was of Russian ancestry and born in Strasbourg. He worked at the Hamburg Observatory from 1922 to 1935.

[8] As an aside, there is an example of this arrogance that is quite appropriate as Galileo is very *present* today. Zwicky once compared himself to Galileo stating that they were the only two to know how to use a telescope properly (Bartusiak 1993, p. 193).

of attention. The media also thought these hypotheses to be quite spectacular. The New York Times published updates of Zwicky's supernova search on a regular basis. In 1934 he was featured in Literary Digest's "They Stand Out from the Crowd" column,[9] and in 1935 he gave a Science Service Radio Talk titled "Stellar Guests".[10] One headline that I thought to be particularly poetic was: "Supernova Hunt Set for Three Years: Twelve Such Orbs Discovered in a Thousand Nights by California Astronomer".[11]

A cartoon portrayal published on January 19, 1934 in the Los Angeles Times, in which Zwicky was named "Ol'Doc Dabble", recapitulated both his personality and the incredulity of the theory. It is interesting to see that supernova theory caught the eye of the population; though it is not surprising, these were spectacular phenomenon, almost science fiction-like in nature. I would like to suggest that the connection between science and culture is a two-way street. That is, there is equally influence of popular culture on science.

9. Why Supernovae?

So this gives you an idea of Fritz Zwicky's work on supernova. But why did he use this word? At the time that he became interested in the topic, it was quite clear that a distinction between the brighter and the fainter novae could be made. Zwicky and Baade first presented their theory in 1933; the abstract of their talk was published in January 1934 and they wrote the series of three articles in the following months. They called these objects "supernovae" (they spelled it with and without a hyphen until it was dropped in 1938.) They had been using the term since 1931 in seminars and in a lecture course on astrophysics at the California Institute of Technology (Zwicky 1940).

Officially, the term first appeared in publication in 1933 in an article dated December 31, 1932 by Knut Lundmark. He had visited Mount Wilson in the fall and winter 1932-1933, and Donald Osterbrock has suggested that it is likely that he heard the term being used.[12]

In the previous decade, a number of different descriptive terms had been used when talking about bright novae. In 1921, Lundmark and Curtis (independently) used the term "giant" novae. Edwin Hubble referred to these bright novae as "exceptional novae" in 1929 (Hubble 1929) and Walter Baade used the name "Hauptnovae" (chief novae) in a German handwritten manuscript on novae in

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[9]Literary Digest, "They Stand Out From the Crowd: Prof. Fritz Zwicky", (August 25, 1934) 118.

[10]The talk was named for the translation of the Chinese name (k'o-hsing) for supernovae. Fritz Zwicky, "Stellar Guests", The Scientific Monthly, 40 (May 1935) 461.

[11]The New York Times, "New Star Outdoes Sun 500,000,000 to 1", Section I (August 31, 1937), 14.

[12]In his 2001 book he gives credit to Lundmark (Osterbrock 2001a, p. 58) but in a poster at the 199th meeting of the AAS in 2002 (Osterbrock 2001b), and in private communication, Osterbrock mentions Lundmark's visit to California.

1929.[13] So, why did *super* catch on? It had been used in Baade and Zwicky's (1934a,b,c) publications (of immeasurable impact). Lundmark had used it prior to their publications. That this word was employed in articles that would shape the discipline is of no consequence. But I also think there is also an interesting reflection on culture and language to be made.[14]

There was a tendency to use the super- prefix in the 1920s and 1930s.[15] For example, in popular culture: supercar in 1920, supermarket in 1925, supercinemas in 1931, and Superman in 1938 (although he was first created in 1933). This tendency was not limited to popular culture. In political science, we find that: superstate appeared in 1918 and superpower appeared in 1921; and in Engineering: supertanker in 1921, superhighway in 1925, superblock in 1928. There are also examples to be found in physics and astronomy: superconductivity in 1913; supersonic in 1925; supercluster in 1930; superlattice in 1932. It thus comes as no surprise that in the 1930s, Fritz Zwicky coined the term supernova for the objects that were observed to be superbly bright novae, nearly as bright as the whole galaxy in which they originate. As a reflection of popular culture on science, this is very interesting.

10. Conclusion

At the time of his death, Zwicky had been working on a comprehensive catalogue of all known supernovae. 380 supernovae had been observed through the systematic search he had organized and, of these 270 were discovered by his group at Mount Palomar. Zwicky alone was responsible for 122. He held the record for the most observations until fairly recently; the first found in February 1937 and the last in January 1974. He published over 50 articles on supernovae[16] and wrote a number of review articles on supernovae; such as, an article titled "Novae", a chapter for the Handbuch der Physik, and the opening talk of a 1973 International Conference on Supernovae (Zwicky 1940).

Aside from the fact that Hubble did not give recognition of the theories, or even of the supernovae phenomenon in his influential book *The Realm of the Nebulae* of 1936 (Hubble 1936), Baade and Zwicky's theories concerning supernovae were quite well received. Freeman also attributes Zwicky with being "the first astronomer who imagined a violent universe" (Freeman 1996). The idea of a violent universe had been met with some resistance. In particular, Henry Norris Russell and A.S. Eddington disagreed with the idea of "implosive

[13] Osterbrock (2001a) refers to an article titled "Extragalacktishe Nebel als Sternsysteme: Habilitationvorlesung". I do not know if this article was published.

[14] I do not claim this reflection for my own. Marschall (1988) mentioned that the term coincided with the appearance of superman and was shortly followed by supermarkets and supersales. I thought it intriguing and have pursued the idea.

[15] Etymological information from The Compact Oxford English Dictionary, 2nd Edition. (Oxford: Clarendon Press, 1991).

[16] A search on the Astrophysical Data Service (adsabs.harvard.edu) yields 47 articles with supernova/super-nova in the title; 54 with it in the abstract.

processes" (Zwicky 1974). Conversely, the media caught on to the violent and spectacular nature of the supernova phenomenon.

Zwicky's interest in supernovae led him to search for them. This systematic survey became "a prototype for all the later skysurveys carried out with bigger instruments and bigger budgets" (Freeman 1996). He, quite effectively, combined theoretical and observational approaches to astronomy and set the stage for understanding supernovae.

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