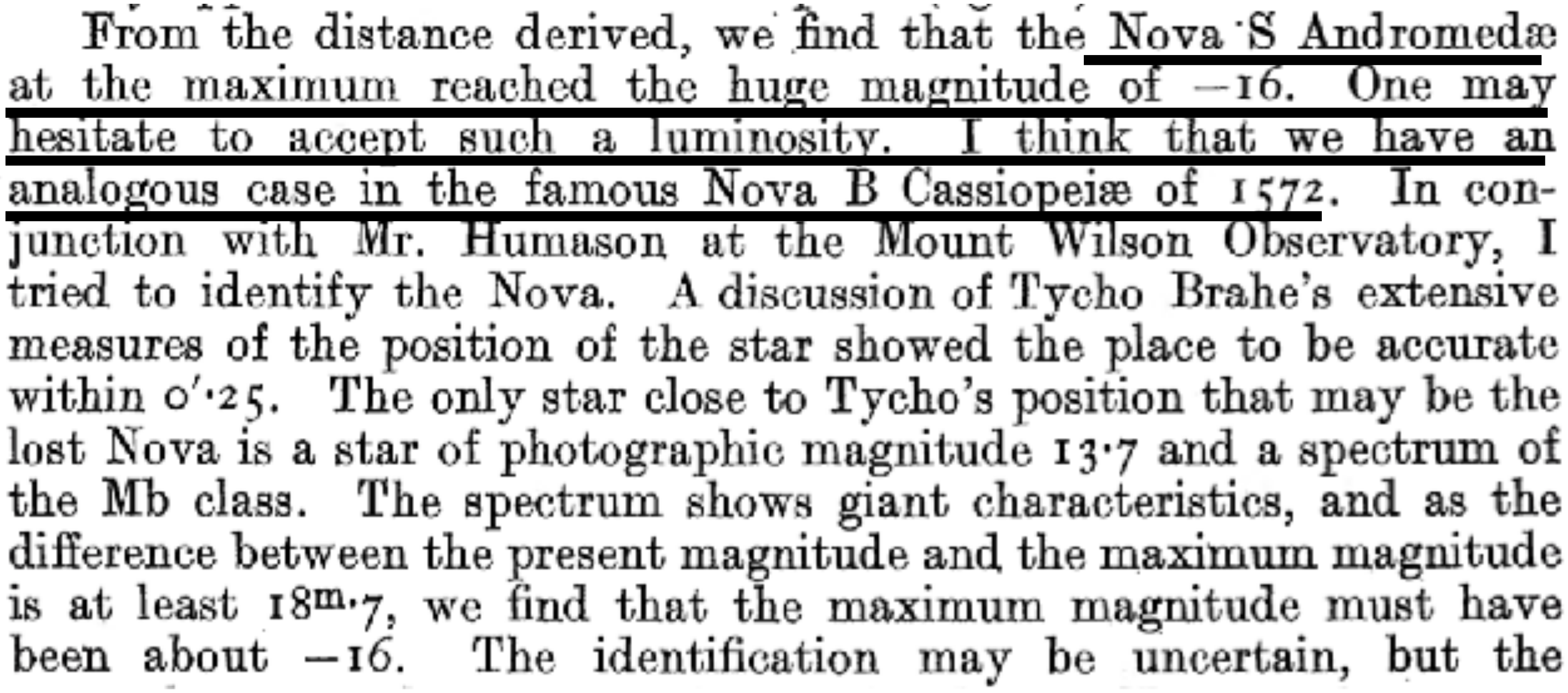
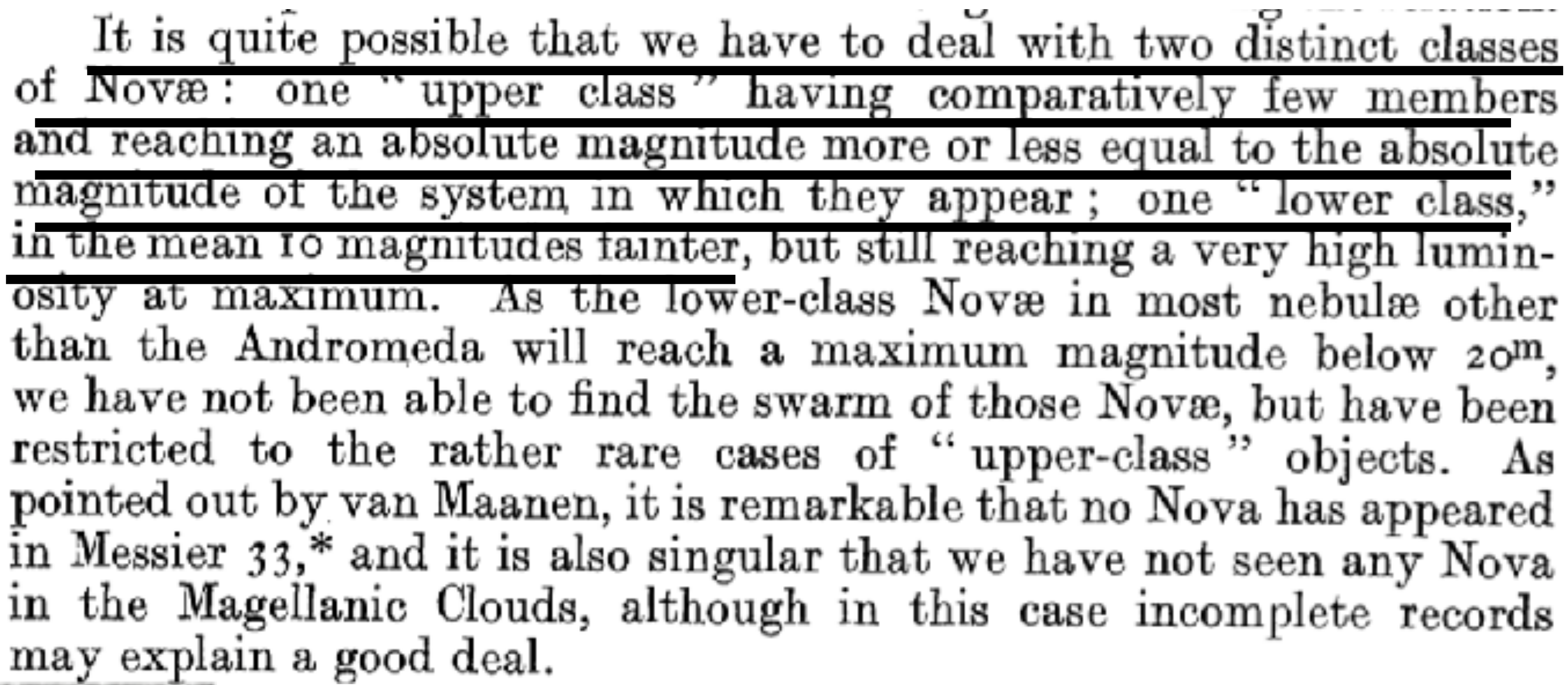
Knut Lundmark 1925: There is something very bright out there

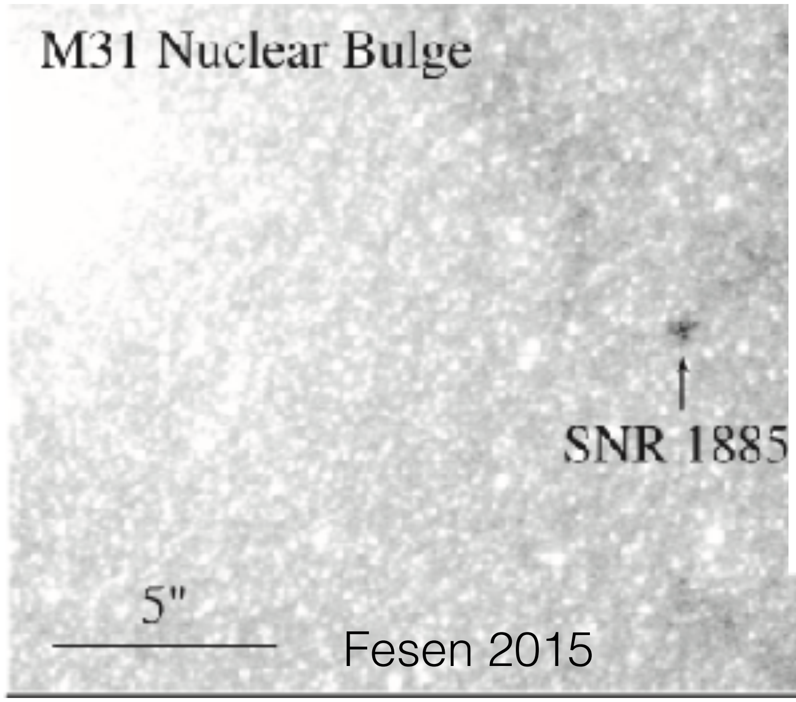


From the distance derived, we find that the Nova S Andromedæ at the maximum reached the huge magnitude of −16. One may hesitate to accept such a luminosity. I think that we have an analogous case in the famous Nova B Cassiopeiæ of 1572. In conjunction with Mr. Humason at the Mount Wilson Observatory, I tried to identify the Nova. A discussion of Tycho Brahe's extensive measures of the position of the star showed the place to be accurate within $0'\cdot25$. The only star close to Tycho's position that may be the lost Nova is a star of photographic magnitude 13·7 and a spectrum of the Mb class. The spectrum shows giant characteristics, and as the difference between the present magnitude and the maximum magnitude is at least $18^{m}\cdot7$, we find that the maximum magnitude must have been about −16. The identification may be uncertain, but the

KNUT LUNDMARK
Foto LUB

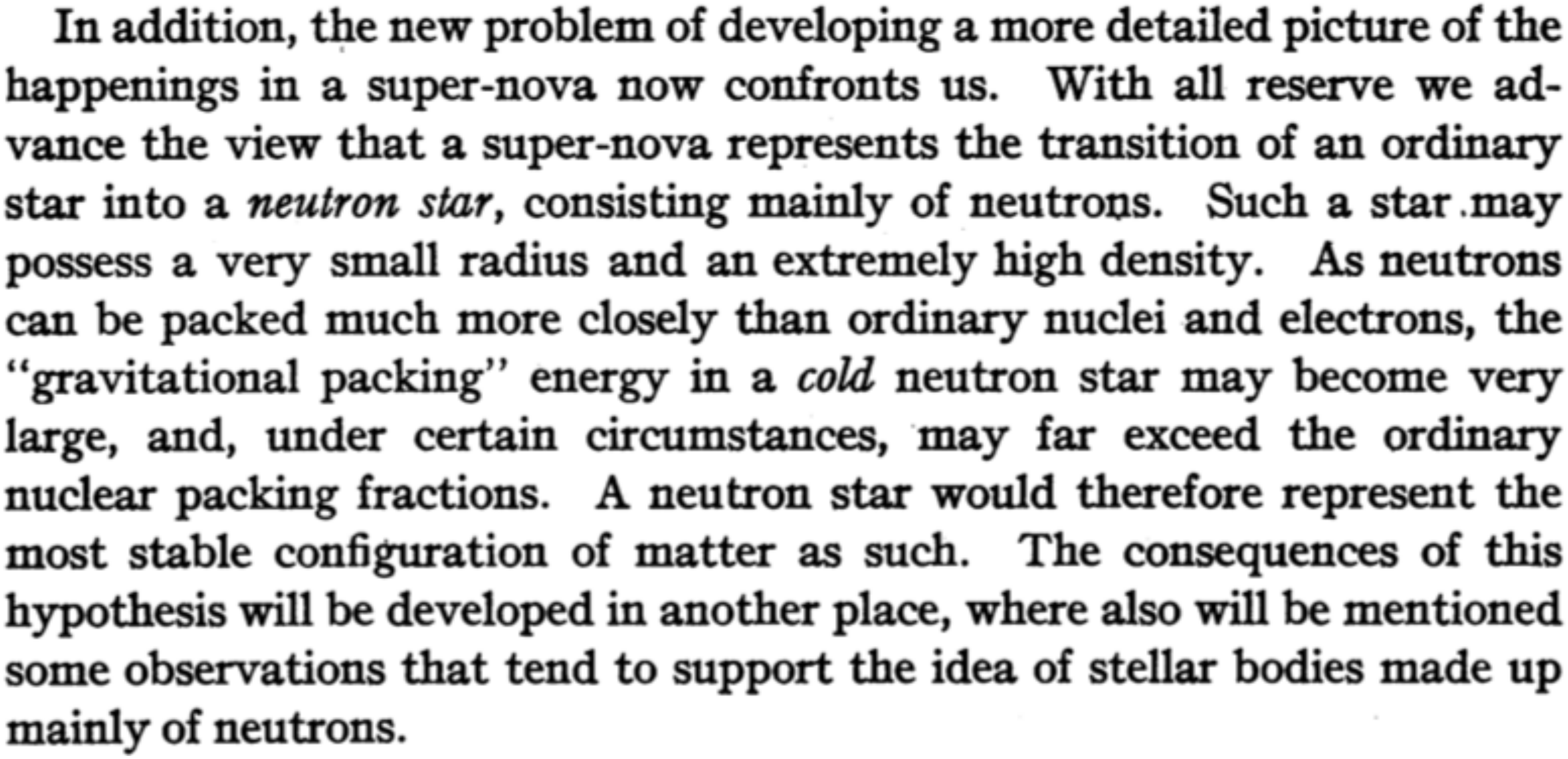


It is quite possible that we have to deal with two distinct classes of Novæ: one "upper class" having comparatively few members and reaching an absolute magnitude more or less equal to the absolute magnitude of the system in which they appear; one "lower class," in the mean 10 magnitudes fainter, but still reaching a very high luminosity at maximum. As the lower-class Novæ in most nebulæ other than the Andromeda will reach a maximum magnitude below 20^{m}, we have not been able to find the swarm of those Novæ, but have been restricted to the rather rare cases of "upper-class" objects. As pointed out by van Maanen, it is remarkable that no Nova has appeared in Messier 33,* and it is also singular that we have not seen any Nova in the Magellanic Clouds, although in this case incomplete records may explain a good deal.



Fesen 2015

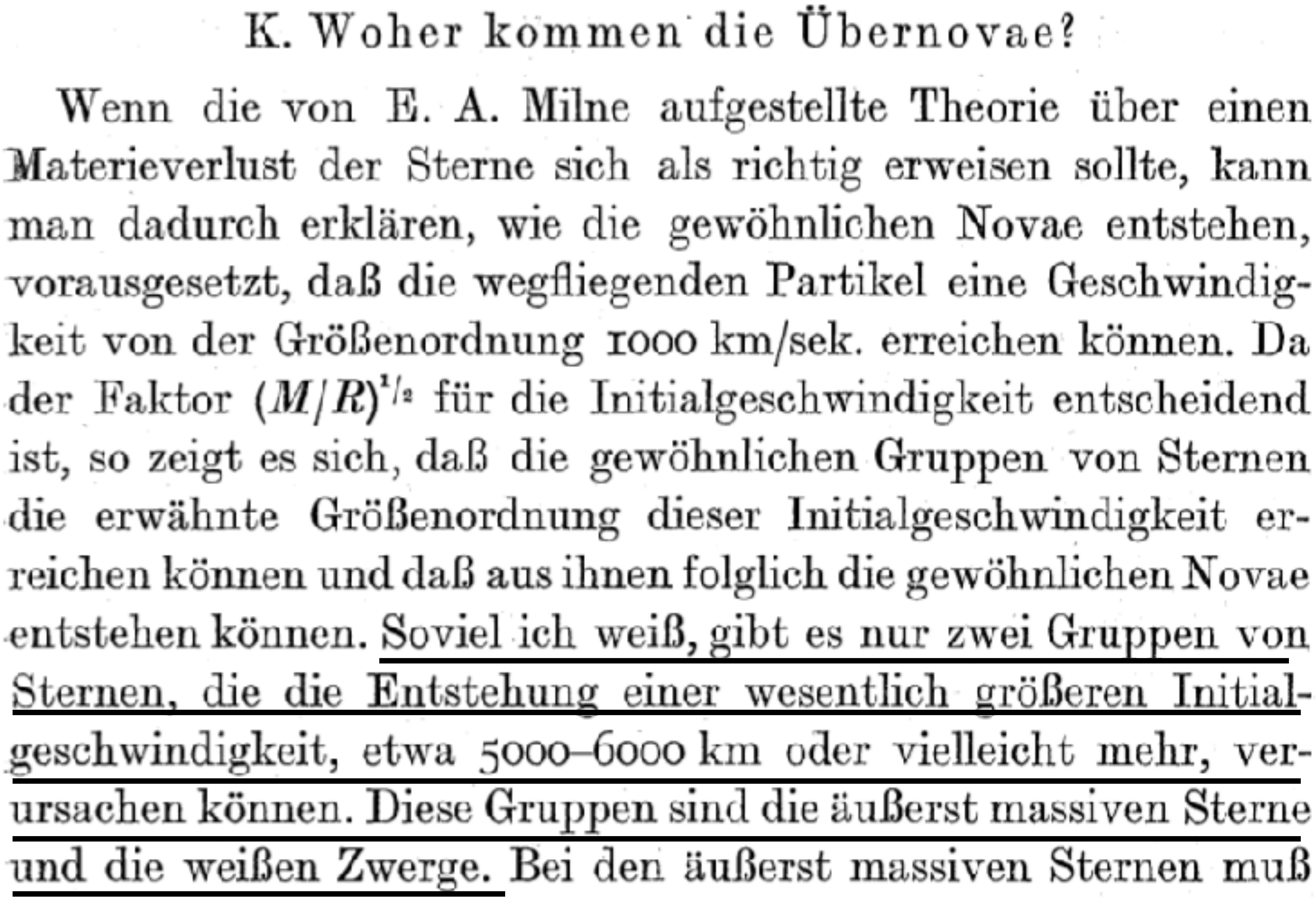
Baade & Zwicky 1934: a rabbit out of a hat?



In addition, the new problem of developing a more detailed picture of the happenings in a super-nova now confronts us. With all reserve we advance the view that a super-nova represents the transition of an ordinary star into a *neutron star*, consisting mainly of neutrons. Such a star may possess a very small radius and an extremely high density. As neutrons can be packed much more closely than ordinary nuclei and electrons, the "gravitational packing" energy in a *cold* neutron star may become very large, and, under certain circumstances, may far exceed the ordinary nuclear packing fractions. A neutron star would therefore represent the most stable configuration of matter as such. The consequences of this hypothesis will be developed in another place, where also will be mentioned some observations that tend to support the idea of stellar bodies made up mainly of neutrons.

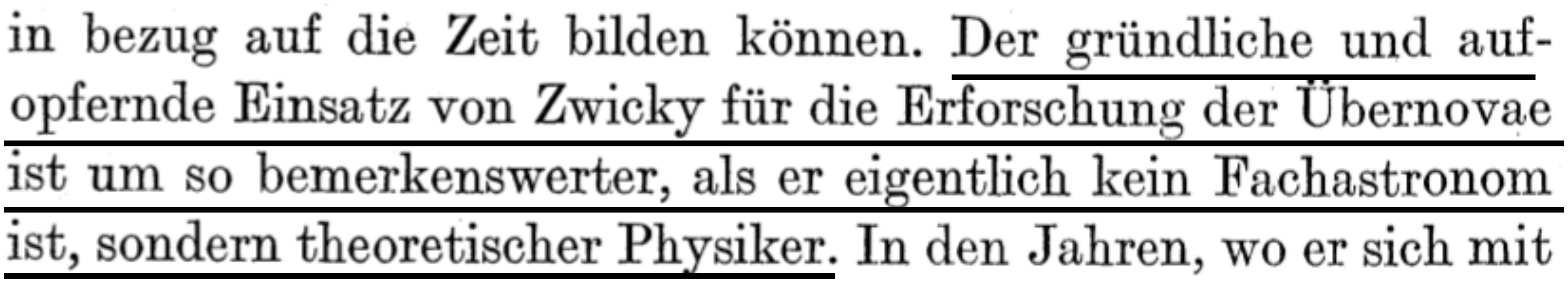
Ironically, all the SNe Baade and Zwicky had observed were Type Ia.

Lundmark 1939



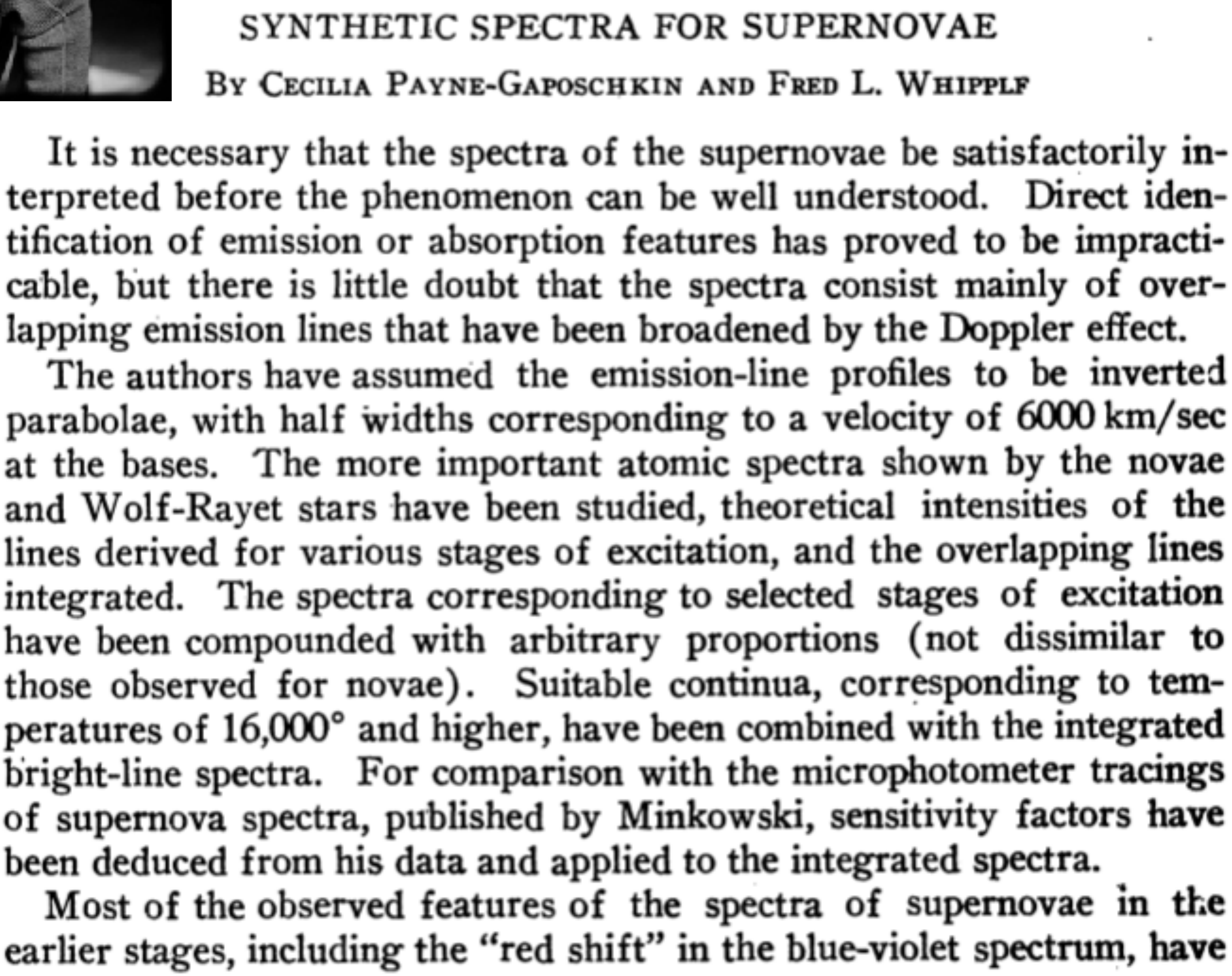
K. Woher kommen die Übernovae?

Wenn die von E. A. Milne aufgestellte Theorie über einen Materieverlust der Sterne sich als richtig erweisen sollte, kann man dadurch erklären, wie die gewöhnlichen Novae entstehen, vorausgesetzt, daß die wegfliegenden Partikel eine Geschwindigkeit von der Größenordnung 1000 km/sek. erreichen können. Da der Faktor $(M/R)^{1/2}$ für die Initialgeschwindigkeit entscheidend ist, so zeigt es sich, daß die gewöhnlichen Gruppen von Sternen die erwähnte Größenordnung dieser Initialgeschwindigkeit erreichen können und daß aus ihnen folglich die gewöhnlichen Novae entstehen können. Soviel ich weiß, gibt es nur zwei Gruppen von Sternen, die die Entstehung einer wesentlich größeren Initialgeschwindigkeit, etwa 5000–6000 km oder vielleicht mehr, verursachen können. Diese Gruppen sind die äußerst massiven Sterne und die weißen Zwerge. Bei den äußerst massiven Sternen muß



in bezug auf die Zeit bilden können. Der gründliche und aufopfernde Einsatz von Zwicky für die Erforschung der Übernovae ist um so bemerkenswerter, als er eigentlich kein Fachastronom ist, sondern theoretischer Physiker. In den Jahren, wo er sich mit

Cecilia Payne 1940
First model spectra



SYNTHETIC SPECTRA FOR SUPERNOVAE

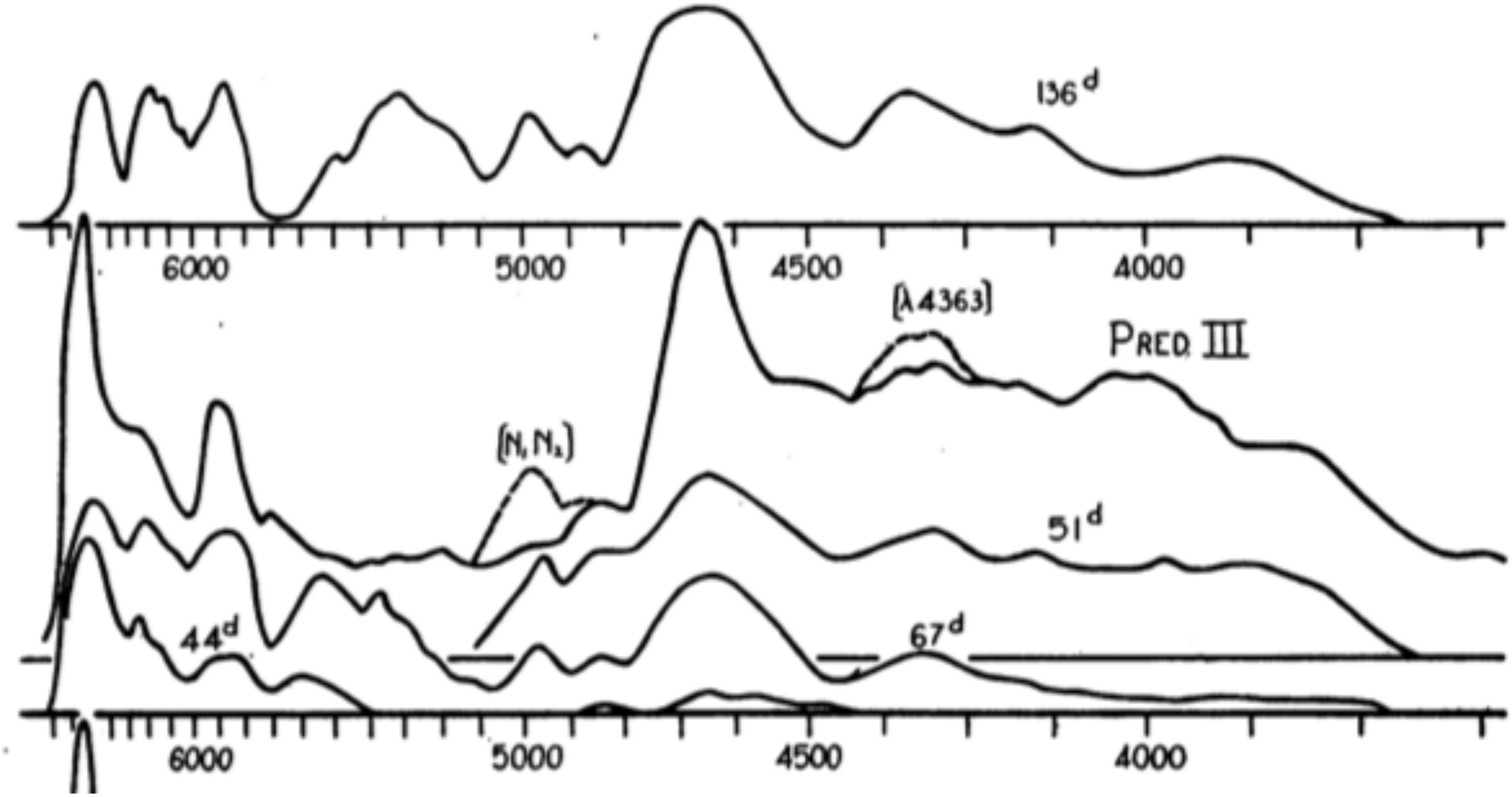
By Cecilia Payne-Gaposchkin and Fred L. Whipple

It is necessary that the spectra of the supernovae be satisfactorily interpreted before the phenomenon can be well understood. Direct identification of emission or absorption features has proved to be impracticable, but there is little doubt that the spectra consist mainly of overlapping emission lines that have been broadened by the Doppler effect.

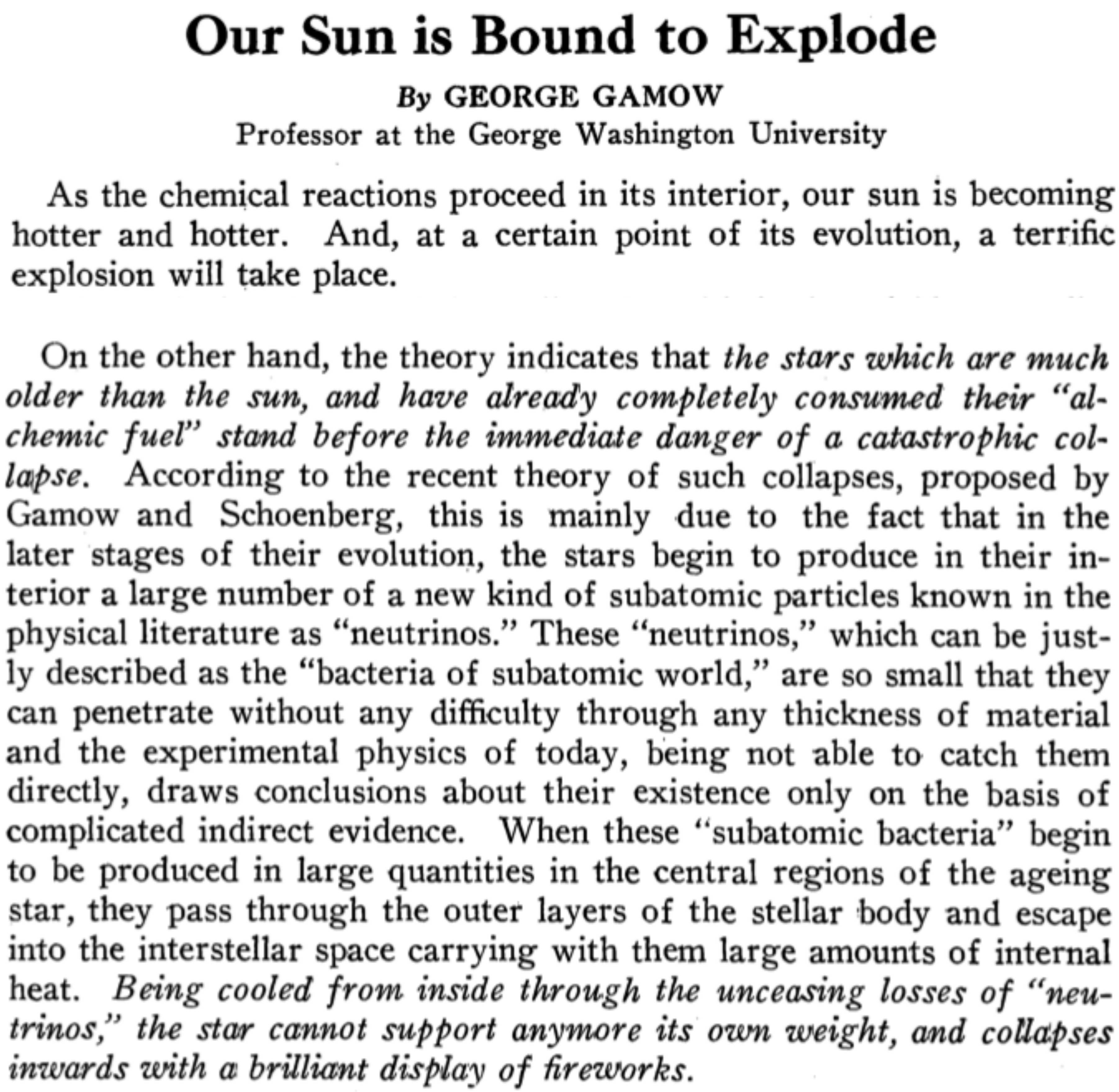
The authors have assumed the emission-line profiles to be inverted parabolae, with half widths corresponding to a velocity of 6000 km/sec at the bases. The more important atomic spectra shown by the novae and Wolf-Rayet stars have been studied, theoretical intensities of the lines derived for various stages of excitation, and the overlapping lines integrated. The spectra corresponding to selected stages of excitation have been compounded with arbitrary proportions (not dissimilar to those observed for novae). Suitable continua, corresponding to temperatures of 16,000° and higher, have been combined with the integrated bright-line spectra. For comparison with the microphotometer tracings of supernova spectra, published by Minkowski, sensitivity factors have been deduced from his data and applied to the integrated spectra.

Most of the observed features of the spectra of supernovae in the earlier stages, including the "red shift" in the blue-violet spectrum, have

Modelling of SN IC 4182 (SN 1937C)



Gamow 1941



Our Sun is Bound to Explode

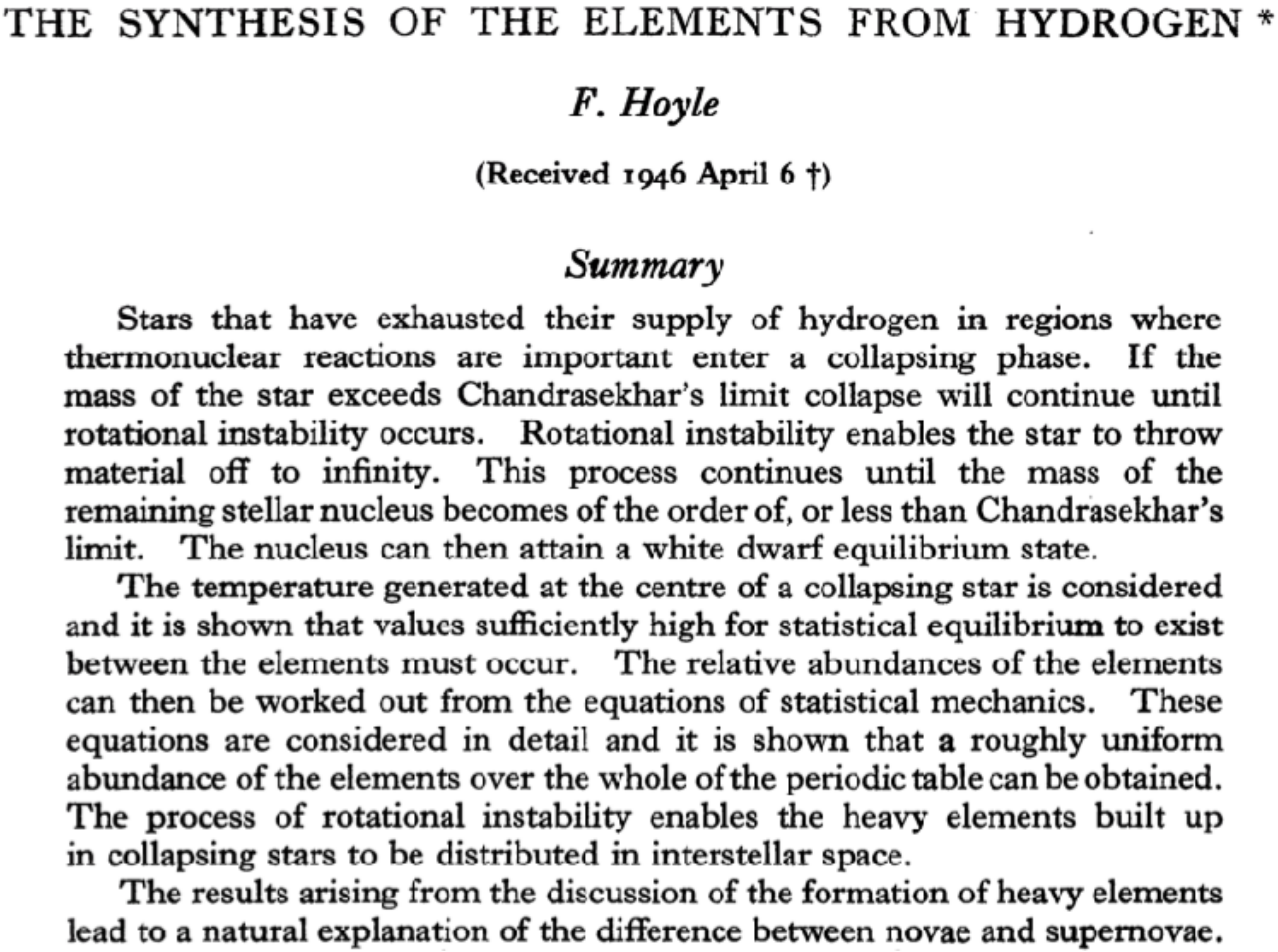
By GEORGE GAMOW
Professor at the George Washington University

As the chemical reactions proceed in its interior, our sun is becoming hotter and hotter. And, at a certain point of its evolution, a terrific explosion will take place.

……

On the other hand, the theory indicates that *the stars which are much older than the sun, and have already completely consumed their "alchemic fuel" stand before the immediate danger of a catastrophic collapse.* According to the recent theory of such collapses, proposed by Gamow and Schoenberg, this is mainly due to the fact that in the later stages of their evolution, the stars begin to produce in their interior a large number of a new kind of subatomic particles known in the physical literature as "neutrinos." These "neutrinos," which can be justly described as the "bacteria of subatomic world," are so small that they can penetrate without any difficulty through any thickness of material and the experimental physics of today, being not able to catch them directly, draws conclusions about their existence only on the basis of complicated indirect evidence. When these "subatomic bacteria" begin to be produced in large quantities in the central regions of the ageing star, they pass through the outer layers of the stellar body and escape into the interstellar space carrying with them large amounts of internal heat. *Being cooled from inside through the unceasing losses of "neutrinos," the star cannot support anymore its own weight, and collapses inwards with a brilliant display of fireworks.*

Fred Hoyle 1946
First idea that stars make the elements



THE SYNTHESIS OF THE ELEMENTS FROM HYDROGEN *

F. Hoyle

(Received 1946 April 6 †)

Summary

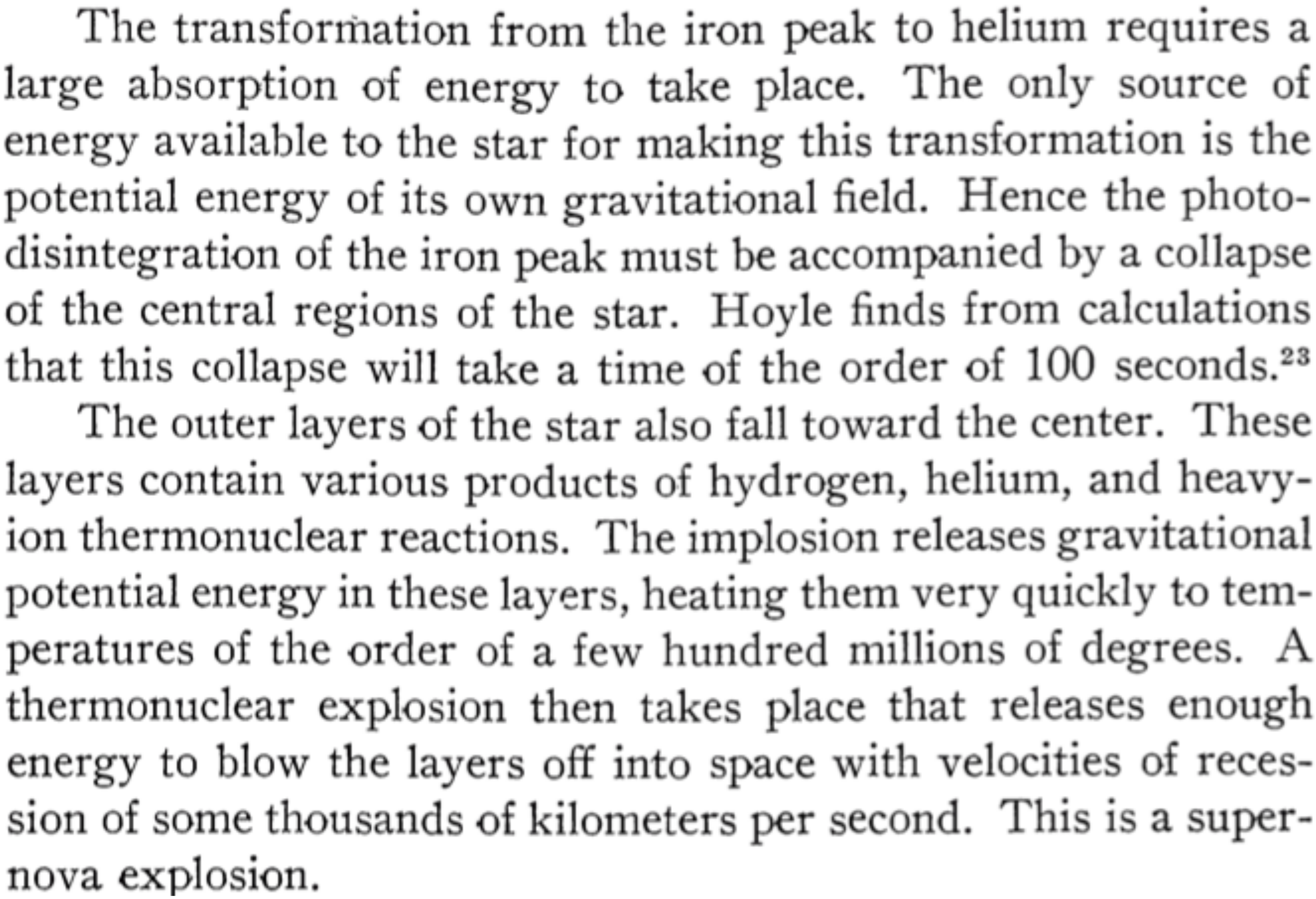
Stars that have exhausted their supply of hydrogen in regions where thermonuclear reactions are important enter a collapsing phase. If the mass of the star exceeds Chandrasekhar's limit collapse will continue until rotational instability occurs. Rotational instability enables the star to throw material off to infinity. This process continues until the mass of the remaining stellar nucleus becomes of the order of, or less than Chandrasekhar's limit. The nucleus can then attain a white dwarf equilibrium state.

The temperature generated at the centre of a collapsing star is considered and it is shown that values sufficiently high for statistical equilibrium to exist between the elements must occur. The relative abundances of the elements can then be worked out from the equations of statistical mechanics. These equations are considered in detail and it is shown that a roughly uniform abundance of the elements over the whole of the periodic table can be obtained. The process of rotational instability enables the heavy elements built up in collapsing stars to be distributed in interstellar space.

The results arising from the discussion of the formation of heavy elements lead to a natural explanation of the difference between novae and supernovae.

1950s: Hoyle, Cameron, G. Burbidge, M. Burbidge, Fowler lay the foundation for stellar nucleosynthesis

Alistair Cameron 1957: Revives theories for SNe

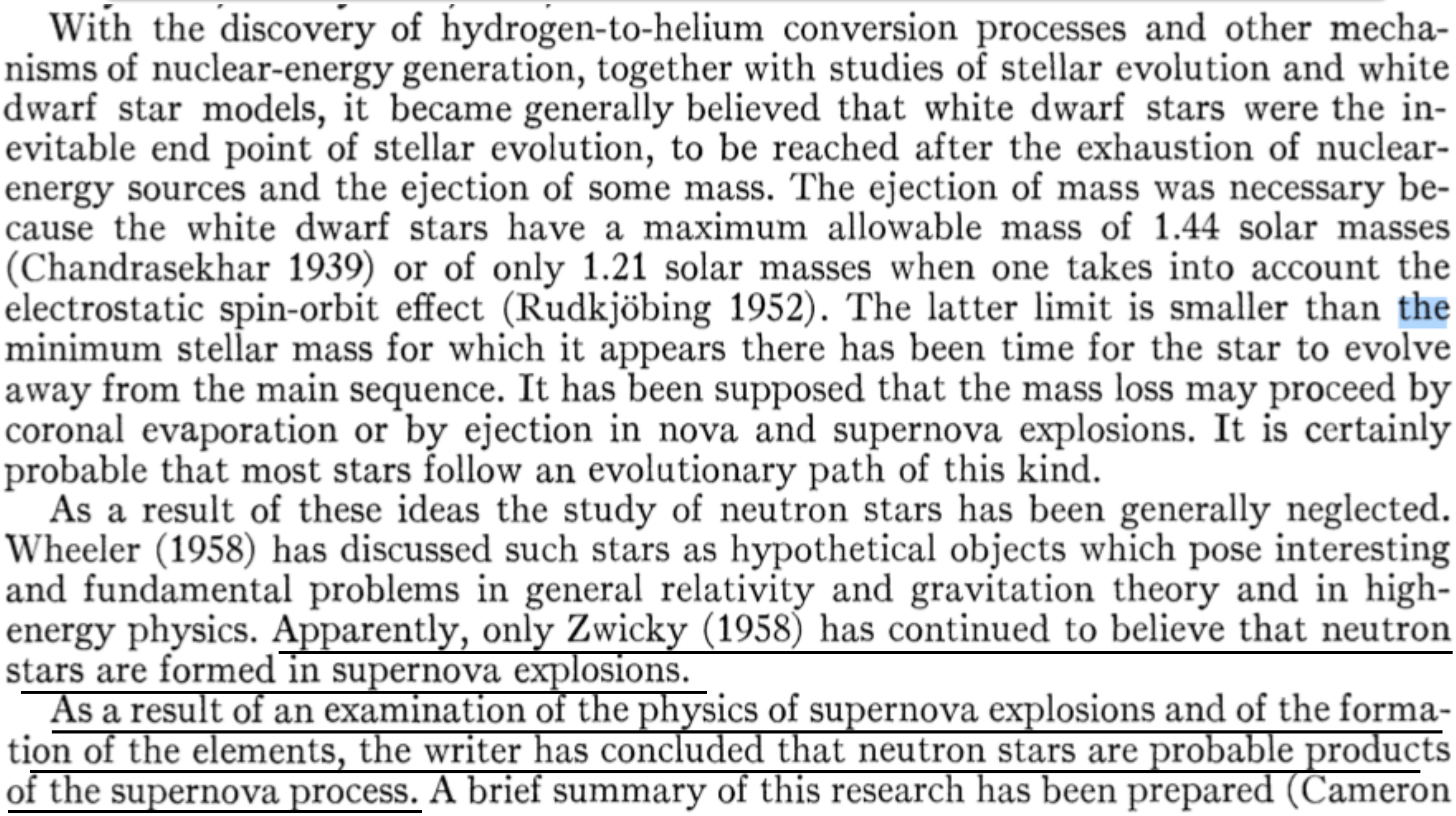


The transformation from the iron peak to helium requires a large absorption of energy to take place. The only source of energy available to the star for making this transformation is the potential energy of its own gravitational field. Hence the photodisintegration of the iron peak must be accompanied by a collapse of the central regions of the star. Hoyle finds from calculations that this collapse will take a time of the order of 100 seconds.[23]

The outer layers of the star also fall toward the center. These layers contain various products of hydrogen, helium, and heavy-ion thermonuclear reactions. The implosion releases gravitational potential energy in these layers, heating them very quickly to temperatures of the order of a few hundred millions of degrees. A thermonuclear explosion then takes place that releases enough energy to blow the layers off into space with velocities of recession of some thousands of kilometers per second. This is a supernova explosion.

Does not address collapse to what.

Cameron 1959 : Solves problem that Oppenheimer/Volkoffs MNs_max < M_WD_max

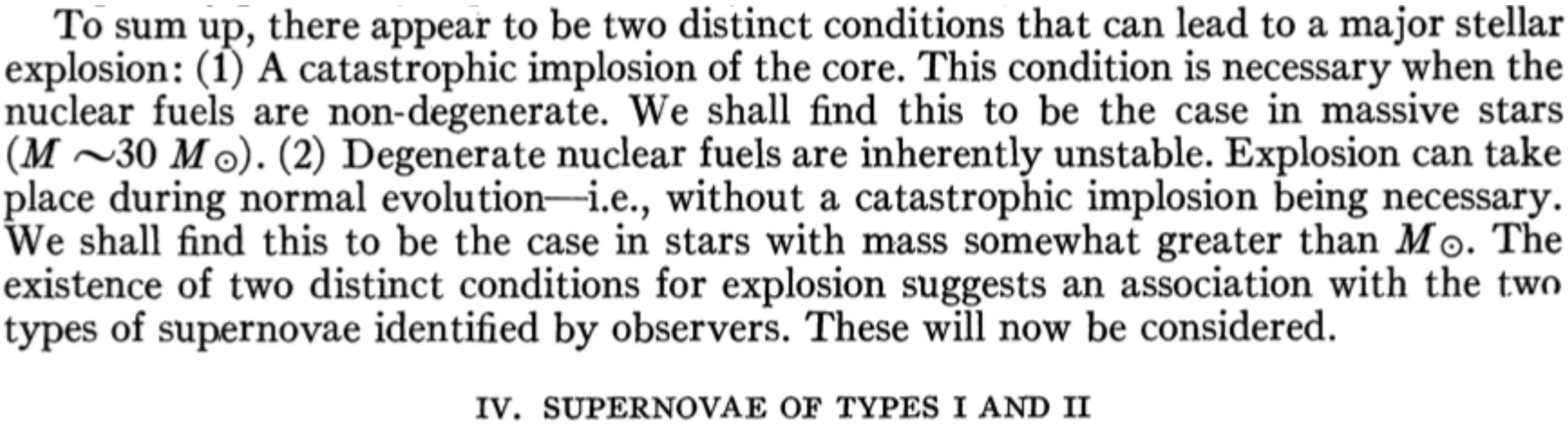


With the discovery of hydrogen-to-helium conversion processes and other mechanisms of nuclear-energy generation, together with studies of stellar evolution and white dwarf star models, it became generally believed that white dwarf stars were the inevitable end point of stellar evolution, to be reached after the exhaustion of nuclear-energy sources and the ejection of some mass. The ejection of mass was necessary because the white dwarf stars have a maximum allowable mass of 1.44 solar masses (Chandrasekhar 1939) or of only 1.21 solar masses when one takes into account the electrostatic spin-orbit effect (Rudkjöbing 1952). The latter limit is smaller than the minimum stellar mass for which it appears there has been time for the star to evolve away from the main sequence. It has been supposed that the mass loss may proceed by coronal evaporation or by ejection in nova and supernova explosions. It is certainly probable that most stars follow an evolutionary path of this kind.

As a result of these ideas the study of neutron stars has been generally neglected. Wheeler (1958) has discussed such stars as hypothetical objects which pose interesting and fundamental problems in general relativity and gravitation theory and in high-energy physics. Apparently, only Zwicky (1958) has continued to believe that neutron stars are formed in supernova explosions.

As a result of an examination of the physics of supernova explosions and of the formation of the elements, the writer has concluded that neutron stars are probable products of the supernova process. A brief summary of this research has been prepared (Cameron

Hoyle & Fowler 1960 get the story spot in



To sum up, there appear to be two distinct conditions that can lead to a major stellar explosion: (1) A catastrophic implosion of the core. This condition is necessary when the nuclear fuels are non-degenerate. We shall find this to be the case in massive stars ($M \sim 30\ M_\odot$). (2) Degenerate nuclear fuels are inherently unstable. Explosion can take place during normal evolution—i.e., without a catastrophic implosion being necessary. We shall find this to be the case in stars with mass somewhat greater than $M_\odot$. The existence of two distinct conditions for explosion suggests an association with the two types of supernovae identified by observers. These will now be considered.

IV. SUPERNOVAE OF TYPES I AND II