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Landau’s youthful sallies into stellar theory: Their origins, claims, and receptions

Astrophysicists are often in error, but never in doubt.
Lev Landau

DURING HIS TWENTIES Lev Landau, who even then was making his mark as one the greatest mid-century theoretical physicists, ventured into stellar-structure theory on three occasions. The resulting papers added only seven pages to his substantial publication record. Yet their histories deserve more attention than they have received, not because they attracted much notice at the time—for they did not—but rather because they shed light on Landau’s early career and his distinctive interdisciplinary style. They, or rather their subject matter, scarcely attracted him.


3. In his brief account of Landau’s papers on stars, Ter Haar (ibid., 2, 24–26) summarized all three but emphasized that they were “out of date.” Kenneth R. Lang and Owen Gingerich misread Landau’s first paper, which they reprinted, when they credited him “for first predicting theoretically in the context of modern physics the possible formation of a black hole.” See Lang and Gingerich, eds., A source book in astronomy and astrophysics, 1900–1975 (Cambridge, 1979), 456–459, on 456. By contrast, Kip Thorne has given an insightful account of the origin, content, and reception of Landau’s third paper in his Black holes and time warps: Einstein’s outrageous legacy (New York, 1994), 178–182, 184–187, 190–191. For a general account of

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He regarded the prevailing approach in the astronomical field of theoretical astrophysics as wrong-headed. Why then did young Landau devote time to the problems of stellar constitution? What conclusions did he present in his three papers? And how were these claims received when they appeared? The answers to these questions give a fuller picture of Landau as an exceptional figure among the upper echelon of those entering theoretical physics during the mid- and late-1920s. Consideration of his sallies into stellar theory also broadens our knowledge of the relations between the neighboring fields of theoretical physics and theoretical astrophysics during the 1930s.

Like my recent article on J. Robert Oppenheimer’s stellar theorizing, the present study of Landau’s astrophysical research during the 1930s builds on fragmentary evidence. I have had relatively little evidence to work with because Landau devoted even less time than Oppenheimer to thinking about the stars. Furthermore, I have not searched Russian archives for relevant information and only made limited use of Russian-language publications. Nevertheless, I have found enough pertinent material to provide a plausible reconstruction of the young Lev Landau’s situation-dependent reasons for thrice venturing into stellar theory, his stubborn disregard for the orthodoxies of theoretical astrophysics as he intermittently developed his dense-core model of stars, and his success, despite a generally negative response from gatekeepers, in stimulating a few theoretical physicists to develop his model.

1. THE FIRST TWO SALLIES, 1931–1933


4. In 1988, on the eightieth anniversary of Landau’s birth and the twentieth of his death, Isaak Khalatnikov brought out a valuable collection of earlier writings about and remembrances of Landau that includes some of the Landau-Bohr correspondence. See Khalatnikov, ed., Landau: The physicist and the man: Recollections of L. D. Landau, trans. J.B. Sykes (Oxford, 1989). Perhaps an archivally-based biography that does full justice to Landau’s remarkable life will appear by the one hundredth anniversary of his birth or, more likely, the fiftieth anniversary of his death.

Dmitry Ivanenko were at the center then of a talented circle of aspiring theorists. In spring 1927 this “Jazz-Band,” as they playfully called themselves, was joined by Matvei Bronstein, who not only shared his own side-interest in astronomical matters but also brought the young theoretical astrophysicists Viktor Ambartsumian and Nikolay Kozyrev into the group. Whatever Landau learned from these three about stellar theory was augmented in late spring 1929 upon Gamow’s return from a year of research in Göttingen, Copenhagen, and Cambridge. While abroad Gamow had served as a consultant to Richard d’Escourt Atkinson and Friedrich G. Houtermans in their application of quantum theory to the stellar-energy problem by suggesting that protons tunneling into nuclei at the high temperatures and pressures deep in stellar interiors powered the stars. Landau no doubt heard from Gamow, a great self-promoter, of the tunneling theory’s possible contribution to this recalcitrant astrophysical problem.

That summer Landau embarked on what became an 18-month round of Western Europe’s major research centers in theoretical physics. Early on, he gave vent to his frustration about the field’s current prospects when remarking to Yurii Rumer in Berlin that “All the nice girls have been snapped up and married, and all the nice problems have been solved. I don’t really like any of those that are left.” He soon changed his mind, at least about the problems. His interest in stellar structure was aroused during his two stays at Niels Bohr’s Institute in Copenhagen during 1930. In talking with Bohr and Gamow, who was back in Copenhagen, he learned that...
Bohr, puzzled by the variability in the energies of electrons emitted in the β-decay of specific radioactive species, had come to think that energy conservation might not apply within an atom’s nucleus or a star’s dense interior.\(^\text{15}\)

Toward the end of 1930 Landau made his way from Copenhagen to Wolfgang Pauli’s institute in Zurich to work with Rudolf Peierls, who had become a good friend during Landau’s visit there earlier in the year. While on a holiday skiing trip, the two found themselves frequently discussing Bohr’s ideas about the uncertainty principle and the limited validity of energy conservation. By the third week of January 1931, they had written a collaborative paper on relativistic quantum theory and begun circulating it for comments.\(^\text{16}\)

During the next few weeks, Landau independently followed up on this piece by focusing on Bohr’s intuition that stars depended on a different physics than any then known. He may have hoped that this foray into stellar theorizing would turn up something big in the way of a physical problem or insight. In any case, he soon wrote up a brief account of his results in English, which was then the chief language for research and debate in theoretical astrophysics. He probably intended to publish it in *Nature*, the field’s leading popular venue. As things turned out, however, he ended up carrying the manuscript back to the Leningrad Physico-Technical Institute when he returned to the Soviet Union that spring and submitted it to the new *Physikalische Zeitschrift der Sowjetunion* early the next year.\(^\text{17}\)

Landau opened his four-page paper by arguing that theoretical astrophysicists were wrong to analyze stellar structure with the aid of mathematically convenient, but physically unrealistic assumptions. He illustrated this point by commenting on Edward Arthur Milne’s ongoing campaign to overthrow Arthur Stanley Eddington’s orthodox model of stars as gas spheres in which inward gravitational pressure is counteracted by outward radiation pressure.\(^\text{18}\)

\(^{15}\) For Bohr’s earlier doubts about energy conservation, see Joan Bromberg, “The impact of the neutron: Bohr and Heisenberg,” *HSPS*, 3 (1971), 307–341, on 312–323.


that the opacity of stellar matter is “constant throughout [a] star, which assumption is made only for mathematical purposes and has nothing to do with reality.”

Believing that he had demonstrated the irrationality of “astrophysical methods,” Landau averred that it was “reasonable to try to attack the problem of stellar structure [with the] methods of theoretical physics.” His approach was to analyze stellar equilibrium in the absence of internal energy sources, in which case equilibrium would depend solely on the balance between the negative gravitational energy and the positive inner energy entailed by the stellar matter’s equation of state. His ensuing analysis indicated that, no matter what its mass, a hypothetical star consisting entirely of “classical ideal gas” would collapse to a point while one consisting mainly of a “non-relativistic Fermi-gas” would have a position of “stable equilibrium” in the presence of “quantum effects.” Turning, however, to what he regarded as the more realistic case of a star consisting mainly of an “extreme-relativistic . . . Fermi-distribution,” he found that one of low mass would have an equilibrium position, but that any star heavier than “a critical mass” of about 1.5 times the sun’s mass could not avoid “collapsing to a point.”

This result directly contradicted the astronomical fact that many stars have masses greater than 1.5 solar mass. That prompted Landau to argue like Bohr:

As in reality such masses exist quietly as stars and do not show any such ridiculous tendencies[,] we must conclude [that] all stars heavier than 1.5 [solar mass] certainly possess regions in which the laws of quantum mechanics . . . are violated. As we have no reason to believe that stars can be divided into two physically different classes according to [whether their mass is greater or less than the critical mass,] we may with great probability suppose that all stars possess such pathological regions. . . . It is very natural to think that just the presence of these regions [is what] makes stars stars.

Presuming that this was the case, Landau dropped the prevailing view among theoretical astrophysicists that energy generation in stars arose from the completely

19. Landau (ref. 17), 285. Later in the article, Landau criticized Milne for trying to replace Eddington’s model with one having a condensed core on the grounds that Milne’s reliance on an “equation of state [without] discontinuous transitions” made it impossible to explain “why such condensations could appear at all” (p. 286).

20. Ibid., 285–287. Landau based his result of 1.5 solar mass for collapse on the assumption that hydrogen was rather rare in the stars, the prevailing view among stellar theorists in 1931 even though evidence was mounting to the contrary. In 1932 the young Danish theoretical astrophysicist Bengt Strömgren and Eddington independently made compelling cases for hydrogen’s abundance in stellar interiors. Simon Olling Rebsdorf, “Bengt Strömgren: Growing up with astronomy, 1908–1932,” Journal for the History of Astronomy, 34 (2003), 171–199, on 186–194. According to Landau’s equation, stars with a high hydrogen abundance would have had a “critical mass” of between 3 and 6 solar masses.

21. Landau (ref. 17), 287. Landau’s grounds for dismissing the idea that stars beyond a certain “critical mass” would collapse indefinitely indicates an awareness of Eddington’s mass-luminosity relation.
unobserved process of electron-proton annihilation. He thought instead that Bohr was right in suggesting that stellar energy was the result of the “violation” of energy conservation that happens “when the laws of ordinary quantum mechanics break down.” In Landau’s opinion, “this must occur when the density of matter becomes so great that atomic nuclei come in close contact, forming one gigantic nucleus.”

He pictured a typical star as “a core of highly condensed matter, surrounded by matter in ordinary state.” These “pathological” and “normal” domains “must” be “separated by…a nearly discontinuous boundary between the two [where] some kind of nuclear attraction” was at play. In closing, he conceded that such a “theory of stellar structure [had] yet to be constructed” and that, until one was, the validity of his argument could not be assessed.

Landau’s paper elicited a meager response during the year following its appearance. Besides two young theoretical astrophysicists who published entirely descriptive abstracts of it, the only others to pay it any heed were Landau’s close friends Gamow and Bronstein. They seem to have been particularly intrigued by his view that stellar cores were “pathological” regions where some, or perhaps all, of the known laws of physics did not hold. In fall 1932 Gamow reported at a Leningrad physics conference on his efforts to build on the Bohr-Landau view that energy was not conserved in stellar interiors. Around the same time, Bronstein began exploring the relevance of Landau’s stellar model, which implied that much of the universe’s mass was in “pathological” stellar cores, for cosmology. In a discussion of Bronstein’s draft, however, Landau distanced himself from his earlier suggestion that energy was not conserved in atomic nuclei and stellar cores. Any such theory, he had come to think, was incompatible with Einstein’s theory of general relativity. It seems that he himself was no longer certain that the most ambitious claims that he had made for his stellar-core model would be sustained.

While Landau’s hope that Bohr was correct in surmising that unknown physical laws regulated stellar interiors inspired his first venture into stellar theory, his affinity for the ebullient Gamow inspired the second in August 1933. Their friendship, which had begun in Leningrad nearly a decade earlier, was based on their mutual enjoyment of talking physics, traveling, and joking. They had only seen one another on rare occasions during the preceding year because Landau had gone to Kharkov as head of the theoretical group in the recently founded Ukrainian Physico-Technical Institute. They were drifting apart politically because of Gamow’s increasing disaffection with the Soviet Union. Still, Landau accompanied Gamow and his wife that August on an outing to the mountain and lake district south of Murmansk. Gamow seems to have brought along a draft of a letter to *Nature* that he wanted Landau to co-author because it referred to the stellar-core model. On August 10 both signed the note entitled “Internal temperature of stars” at a summer residence for scientists on Lake Amendar in the Khibiny Mountains.

One of their starting points was Atkinson and Houterman’s idea that protons with thermal velocities will tunnel into and transform light elements in stellar interiors if the prevailing temperatures are high enough. Another was Gamow’s variant of Landau’s stellar model in which “the production of different elements takes place . . . in the internal regions of the star near the stellar nucleus.” A third was that diffusion would transport the elements produced in this transitional domain to the star’s surface. They proposed that the surface abundance of lithium could serve as an indicator of internal stellar temperature because lithium nuclei disintegrate into helium nuclei with increasing rapidity as incident protons attain higher thermal velocities. After laying

“Expanding universe” (ref. 26), 81–82; and Gorelik (ref. 16). This is the earliest evidence of Landau’s doubts about the non-conservation of energy and his return to the orthodox view of strict conservation. He surely knew that the latest experimental and theoretical work in nuclear physics was reaffirming this principle. See Kojevnikov (ref. 6), 95–96, who regards Landau’s first paper on stars as his last venture into foundational physics.

28. For Landau’s first years at Kharkov, see Alexander Akhiezer, “Teacher and friend,” in Khalatnikov (ref. 4), 36–56. Akhiezer suggested that Landau’s move to Kharkov was forced upon him as a result of irritation at his unrelenting criticism of an article on thin-layer insulation by Abraham Joffe, the director of the Leningrad Physico-Technical Institute; Akhiezer, “Recollections of Lev Davidovich Landau,” *Physics today*, 47:6 (1994), 35–42. Cf. Kojevnikov (ref. 6), 88–92.

29. Gamow chose this destination in the hope that after their vacation with Landau he and his wife could escape from the Soviet Union into Finland from a fjord near Murmansk. Gamow (ref. 6), 118–119.

30. Gamow and Landau, “Internal temperature of stars,” *Nature*, 132 (7 Oct 1933), 567. My suggestion that Gamow brought the draft with him is based on his having pulled the same trick earlier. Leon Rosenfeld, “Nuclear reminiscences,” in *Cosmology, fusion & other matters: George Gamow memorial volume*, ed. Frederick Reines (Boulder, 1972), 289–299, on 293–294. My thanks to Gennady Gorelik (ref. 1: 5 Nov), who suggested that the place name “Kasoochia Basa” [Bitch’s Base] given for the place of signing was Gamow’s crude way of making fun of the place in the Khibini Mountains where they were staying.
out equations for both the temperature dependence of the rate of breakdown and the distance of travel by diffusion before breakdown, they presented a table showing how, for temperatures running from $10^6$ to $10^8 \degree C$, the distance that the typical lithium atom would travel before disintegration decreased from $10^{13}$ cm to 1 cm. They concluded that there would be virtually no lithium present on the surfaces of stars whose internal temperatures exceeded “several millions of degrees.”

Their letter, which almost completely disregarded prior work on stellar elemental abundances, circulation mechanisms, and internal temperatures, elicited one, quite critical response from no other than Eddington, the era’s most distinguished theoretical astrophysicist. Just two days after the letter appeared in *Nature*, Eddington fired off a rejoinder. He conceded that the studies of elemental abundances they proposed would “probably be of great importance in the future development of astrophysics.” But their proposal mistakenly assumed that diffusion—“an exceedingly slow process”—is the main transport mechanism in stars. By comparison, vertical currents engendered by stellar rotation could bring lithium produced deep in stars much more rapidly to their surfaces than diffusion. This being the case, the upper limits for stellar interior temperatures could certainly be “of the order $10^7$ – $2 \times 10^7 \degree C$ found by astronomical methods, whilst negating any suggestion of considerably higher temperatures.” Whatever appreciation Eddington may have had for Gamow and Landau’s idea was overcome by his annoyance at their apparent ignorance of generally accepted stellar-structure theory.

2. THE THIRD SALLY, 1937–1938

At Kharkov during the mid-1930s, Landau bolstered his elite standing within the large cohort that entered theoretical physics after the quantum-mechanics revolution. His talent and versatility were attested by a stream of articles on photon scattering, collision-induced particle production, thermodynamic phenomena at low temperatures or near phase transitions, ferromagnetism, sound waves in solid media, and energy levels in atomic nuclei. Although often co-authored, his research articles were marked by a distinctive physical insight and mathematical agility. They enhanced not only his own standing but also that of his preferred venue, the *Physikalische Zeitschrift der Sowjetunion*.

31. Gamow and Landau (ref. 30).
33. My characterization of Landau’s research during these years is drawn mainly from Evgenii Lifshitz, “Lev Davidovich Landau (1908–68),” in Khalatnikov (ref. 4), 7–27, and Ter Haar (ref. 2), 2, 3–53. One of the attendees at Landau’s fiftieth birthday party brought a marble tablet upon which “the ten most important formulae derived by him” were inscribed. Four of the “ten commandments” came from work that he did while in Kharkov. See Isaak Kikoin, “Landau’s ten commandments,” in Khalatnikov (ref. 4), 284–285.
34. Landau placed 19 of the 21 articles that he published between early 1934 and mid-1937 in this journal, which was edited by a Kharkov colleague, the experimental nuclear physicist Alexander Leipunskii.
Meanwhile, Landau was building up a strong school of theorists by supervising a seminar that subjected the latest literature to trenchant critiques, by requiring every would-be theoretical physicist to pass stiff tests that enforced the “theoretical minimum” for acceptable work, and by scrupulously reading and editing his chosen disciples’ manuscripts. He soon wanted better advanced textbooks than those available. He and his disciple Evgenii Lifshitz set about writing some for a high-level course on theoretical physics, starting with a volume on “statistical physics.” During his third year in the Ukraine, Landau—then 27—was named professor of “general physics” at Kharkov University. This post made him responsible for experimental as well as theoretical physics. Drawing on his friends among the experimentalists in Kharkov, particularly the low-temperature physicist Lev Shubnikov, he created an introductory course of lectures dealing with the entire discipline.

Increasingly confident, Landau began playing a larger role in the highly charged arena of Soviet academic politics. In November 1935 he ventured into Izvestiia with an essay on the “bourgeoisie and contemporary physics.” There, besides dismissing Germany’s fascists for “peddling” Aryan physics and critiquing British physicists, including the astrophysicists Eddington and James Hopwood Jeans, for “peddling… spiritualism,” Landau distanced himself from Denmark’s “distinguished Bohr” for lending support to “bourgeois idealism” in his widely reprinted essay of 1932 on “Light and Life.” Only the Soviet government, he argued, offered any prospect of driving such idealism from physics. Soon afterwards, perhaps with the aid of this essay, Landau managed to persuade the local NKVD to release Moissey Koretz, a close friend who had recently been arrested for writing against the rise of classified

35. For Landau’s methods of mentoring aspiring theorists in his Kharkov group, see the testimonials in Khalatnikov (ref. 4).
research at the Kharkov Institute. In March 1936, during the Soviet Academy’s review of the Leningrad Physico-Technical Institute, Landau sharply criticized the leadership of the Institute’s eminent but old-fashioned director Abrahm Joffe. Koretz’s difficulties and Joffe’s ire seem not to have been his only concerns, for he wrote Bohr in April to explain that he had not applied for a visa to a Paris conference because he “had until recently a terrible number of things to worry about.”

In late spring Landau went beyond the cautious optimism that he had expressed in his Izvestiia essay and letter to Bohr. The occasion was Stalin’s announcement over the radios of plans for a new constitution. A student with Landau at the time later recalled that Landau, who then was still “red,” expected “a new, good era” was to follow. In actuality, the political situation was deteriorating. In November Landau informed Bohr that he would not be visiting anytime soon because “nothing seems to have come of my proposed trips.” Ever more isolated from theoretical work in Western Europe, he began to fear that he would “turn into a pathologist.” This was his way of telling Bohr, whom he regarded as near the apex of theoretical physicists, that he feared he might become one of the many in their field whose theorizing was so flawed or trivial that it was “pathological.” There was no hint, however, that he had any inkling then of the troubles ahead of him.

A heavy blow came in late December 1936 when, after a quarrel with Kharkov University’s rector, Landau was dismissed from his professorship. Despite a deep sense of shock, he still held his post at the Ukrainian Physico-Technical Institute and also his standing in the physics community, for the organizers of a conference on low-temperature physics that the Soviet Academy sponsored.

41. Landau to Bohr, 13 Apr 1936, in Khalatnikov (ref. 4), 308–309.
42. Akhiezer 1994 (ref. 28), 38. As late as September 1936, Landau told his Danish guest Christian Møller that liberalization was coming to the Soviet Union because Stalin was inaugurating elections. Gennady Gorelik, “Lev Landau, prosocialist prisoner of the Soviet state,” Physics today, 48:5 (1995), 11, 13, 15, 86, on 13.
43. Landau to Bohr, 10 Nov 1936, in Khalatnikov (ref. 4), 309–310.
44. Landau seems to have begun denouncing as “pathological” all theoretical work that he regarded as trivial or wrong soon after arriving in Kharkov. This epithet made a big impression on his students and colleagues. Khalatnikov (ref. 4), 13, 39, 211–212.
45. Landau’s quarrel with the rector probably concerned student complaints about the level of his teaching in the general physics course. However, the reason for his dismissal given by an official in Kiev to several associates who resigned in sympathy was that Landau was an “idealist” who opposed “dialectical materialism.” In January, the rector was arrested as a Trotskyite and never resurfaced. Akhiezer, “Recollections,” (ref. 28), 40; Kikoin (ref. 37); Kojevnikov (ref. 6), 97–98.
at the Institute in late January 1937 had assigned him the opening talk.\textsuperscript{46} It was fortunate for Landau that the low-temperature experimentalist Pyotr Kapitza, who directed the Soviet Academy’s Institute of Physical Problems in Moscow, was present. Kapitza had failed in two attempts to recruit someone to head up theoretical work at his Institute. He and Landau quickly agreed that Landau would come to Moscow to take the job.\textsuperscript{47} Disappearing from the Ukraine around the time that vicious infighting at the Kharkov Institute led to the arrest of his close friend Shubnikov and many others, Landau began work in Moscow in March 1937.\textsuperscript{48} The purges intensified everywhere, sweeping up, among many others, his longtime friend and former collaborator Bronstein that August.\textsuperscript{49} His own experiences in Kharkov and rumors about the arrests of close friends must have given Landau cause to worry about his own safety. In September during a nuclear physics conference whose Western European participants included his friend Peierls, the usually unrestrained Landau felt free to tell Peierls about his worries only when they were alone in a park.\textsuperscript{50}

At this juncture, after setting aside astrophysical research for four years, Landau revisited stellar-structure theory. His closest friend Lifshitz told Kip Thorne in an interview in 1982 that in doing so Landau was making, in Thorne’s poignant restatement, “a cry for help.” The relevant material that I have found supports, and enriches, this interpretation of the immediate background for Landau’s paper.\textsuperscript{51}

Two letters of early November 1937 signal Landau’s third sally into stellar theorizing. He first sent Bohr a note together with a short manuscript “on the subject of stellar energy.” He asked Bohr to forward the paper to \textit{Nature}, “if you think it makes physical sense.”\textsuperscript{52} Two days later David Shoenberg, quite possibly at the
behest of Landau who was his usual lunch companion then, reported in a long letter to theoretical astrophysicist Subrahmanyan Chandrasekhar:

Incidentally Landau is very excited about a new theory of stellar energy he has, which will appear in Nature in a few weeks. I think he will write to you about it, but in case he doesn’t the idea is that stars have a core of neutrons which grows at the expense of the combination of nuclei and electrons (this reaction gives out energy). I think he has proven that this sort of process will correspond reasonably with the luminosity & masses of the stars, though I haven’t understood the details. Incidentally, he is always declaiming against astrophysicists whom he considers “pathological” as making unreasonable assumptions—you will be pleased to hear (knowing his high standards for scientists other than himself) that he said you were one of the least harmful! Still, you probably have heard his views on these subjects yourself! Please let me know whether his neutronic state is plausible. Incidentally he asked me to ask for all your reprints, as he is quite unacquainted with your recent work on stellar structure and never sees the MN.

I shall be amused if you find his views “pathological” too.

Taken together these two letters reveal that Landau believed he had achieved a breakthrough on the stellar-energy problem by ignoring what he regarded as the astrophysicists’ physically nonsensical models. In addition, the letters’ near simultaneity, the addressees’ locations and reputations, and the decision to publish in *Nature* all bolster the idea that, in his predicament, Landau desired to draw international attention to his work. But why choose this particular problem, which was at some remove from his then recent work?

The developments of the next three weeks suggest the answer. About a week after Landau’s note to Bohr, Bohr wrote via Kapitza to say that he had read the paper on “stellar cores with greatest pleasure and admiration” and had sent it on to *Nature*. Around this same time Landau gave a talk or seminar on his paper at the Institute for Physical Problems.

53. During his stay at the Institute of Physical Problems from mid-1937 to mid-1938, Shoenberg had a cook. This made it easy for him to host Landau, who evidently appreciated the opportunity to converse with an outsider to the widespread hysteria of the time. Shoenberg (ref. 36), 224–225.
55. Shoenberg was referring here to the Royal Astronomical Society’s *Monthly notices*, which was the leading forum for theoretical astrophysics during the interwar years. Since Landau regarded the astrophysicists’ theorizing as “pathological,” he never looked at the journal.
56. Shoenberg to Chandrasekhar, 7 Nov 1937, Chandrasekhar papers, Special collections, University of Chicago Library.
57. Bohr to Kapitza, 13 Nov 1937, in Khalatnikov (ref. 4), 312. Bohr also told Kapitza that he would soon be writing him to invite Landau for a “visit.”
58. Landau’s report at the Institute, but not its date, was mentioned in [Editorial Office], “The problems of stellar energy sources: Work of Prof. L. Landau,” *Izvestiia* (23 Nov 1937), 4, trans. from Russian in Khalatnikov (ref. 4), 313. My thanks to Simon Werrett for a complete translation of this article.
by the aged academician Leonid Mandelstam to the Soviet Academy of Sciences for publication in its *Comptes rendus*. The Academy’s editors received it on November 16.  

That same day, thanks certainly to further arranging, *Izvestiia*’s editorial office wired Bohr to request his “opinion concerning [the] substance [of] Professor Landau’s work.”  

Bohr immediately wired back that “Professor Landau’s new idea of a neutron core in massive stars is most beautiful and promising” and inquired why his view was wanted.  

Responding the next day, the editorial office wrote that they wanted to quote Bohr’s opinion in a piece on Landau’s “latest work” that would soon appear in “our newspaper.”

The report that appeared in *Izvestiia* one week later was the work of unusually able and appreciative popularizers. Opening with a mention of Landau’s talk at the Institute, the authors gave a short history of the stellar-energy problem that began with Helmholtz’s gravitational-contraction theory, went on to Rutherford’s suggestion of radioactive processes, and ended by decrying the lack of “any definite positive results” from research along this line. They then summarized Landau’s “entirely new hypothesis” that attributed stellar energy “to the conversion of atomic nuclei and electrons into neutrons” as matter collapsed onto the dense neutronic cores of stars. The proposal, they reported, had already generated “much interest among Soviet physicists” because of its likelihood of serving as a key to many “of the most important questions in astrophysics.” Its author was “a young Soviet scientist” of 29 who had studied in Leningrad, Copenhagen, and Zurich, and was known for his research on the atomic nucleus, magnetism, and superconductivity. The report in *Izvestiia* concluded by announcing the imminent appearance of Landau’s paper in the Academy’s proceedings and quoting the “celebrated” Bohr’s praise for Landau’s “new idea.”

Taking my cue from this extremely well-placed and positive publicity, I think Landau made his initial “cry for help” to Bohr with the hope of just such an outcome. I believe that he chose the stellar-energy problem as his shield against potential detractors because he appreciated that a plausible solution to this long-standing conundrum would make a greater impression on Soviet elites than would any contribution he might make to one of the highly esoteric problems upon which he had recently been working.

Landau’s two-page paper appeared in the *Comptes rendus* in December 1937. As in his first two stellar papers, he supposed that dense cores lay in all stars. Now,
however, he eschewed any mention of his earlier idea—which he had entirely abandoned by 1933—that energy was not conserved in the core. Instead, he hypothesized that the core consisted of a gravitationally confined “Fermi gas” composed of neutrons. His proposal was that “We can regard a star as a body which has a neutronic core whose steady growth liberates the energy which maintains the star at its high temperature.” He gave a very preliminary analysis of this “growth.” The gravitationally-confined material just above a star’s core must be a gas of bare nuclei and electrons of much lower density than the core’s because of the electrons’ very low mass. Any neutron produced in this domain by the collision of an electron with a nucleus would, if it then fell inwards, liberate its acquired kinetic energy as radiation upon crashing into the neutronic core. This released energy, he reported, would exceed that required to form the neutron in the first place if the star had a core with a mass greater than .001 solar mass. The larger a star’s core and the more infalling neutrons, the greater would be the core’s rate of growth and energy liberation. If, as indicated by the relativistic interpretation of the galactic redshift, the sun was about two billion years old, his proposed “Fermi gas model” implied that the energy it radiated over this period would be produced by the “transition of only [0.3% of the sun’s mass] into the ‘neutronic’ phase.” This proposed source of energy struck Landau as quite ample. He anticipated that “the detailed investigation of such a model should make possible construction of a consistent theory of stars.”

Landau’s theory ran into considerable difficulties en route to its publication in *Nature*. Sending him the proof sheet in early December, Bohr reported discussions in Copenhagen that raised serious doubts about the “existence of a neutron core” in any star for which both the luminosity and mass had been observed. Bohr referred specifically to major review articles by Friedrich Hund on the thermodynamics of ultradense matter and Bengt Strömgren on stellar interiors and energy generation, which included comments on recent work by Chandrasekar bearing on the possibility of neutron cores. He suggested that Landau be given the opportunity to make whatever “corrections or additions” seemed desirable. Landau soon returned the proof sheet and a short note saying that he had added a reference to Hund and, as he did not have access to Strömgren’s article, asking Bohr to add “an appropriate note” about Chandrasekar’s work. Not willing to make the requested addition because he did not know how Landau would respond, Bohr returned the proof with a reprint of Strömgren’s article.

Impatient after “carefully” reading Strömgren,

65. Landau (ref. 59). Given his view of contemporary astrophysics, it is not surprising that Landau seems to have thought that he was the first to suggest how a “consistent theory of stars” might be constructed.


Landau shot back that it was “nothing more than astrophysical pathology” and hence not worthy of a reference. Doubtful, Bohr asked Christian Møller, a younger colleague who had visited Landau in Kharkov in 1936, to send Landau the exact page numbers of the pertinent passages. Completely exasperated, Landau wrote to Bohr that “Strömgren’s assertions are, alas, based on wild Eddingtonian pathology, which is known to be wrong not on one point but on all points.” This being the case, it would be “impossible to expose all this in a note to my letter in *Nature*.”

So Bohr mailed the proof sheet with its one small correction off to *Nature* and the paper appeared some two weeks later.

The several successes of Landau’s strategy—Bohr’s endorsement, Izvestiia’s publicity, and papers in the Soviet Academy’s *Comptes rendus* and in *Nature*—did not suffice to protect him. In late April 1938, he and his friends Koretz and Rumer were arrested by the NKVD. Angry, Kapitza wrote “Comrade Stalin” the morning of Landau’s arrest to request Stalin’s intercession in the case. By way of justification, he referred to Landau’s recent publication of a remarkable piece of work which for the first time indicated a new source of energy of stellar radiation. This makes it possible to determine why the energy of the Sun and the other stars does not decrease appreciably in the course of time and has not yet become exhausted. The great promise of these ideas of Landau’s has been acknowledged by Bohr and other leading scientists.

This courageous letter, which may well contain the last reference by a Russian during 1938 to Landau’s stellar research, opened Kapitza’s struggle for his junior colleague’s freedom. It resulted one year later in the release of Landau, who was nearly catatonic by then, into Kapitza’s custody. His experiences during captivity and the reliability of the extorted revelations about his political views and activities are fascinating subjects. But their bearing on my inquiry is only perplexity if
it is true, as Gennady Gorelik argues, that Landau helped prepare a prosocialist/anti-Stalinist leaflet for 1938’s May Day parade. He should have known that he was sacrificing whatever cover the successes of his 1937 strategy had given him.

During 1938 Landau’s neutron-core model of stars received considerably more attention beyond Russia than his earlier stellar papers. Most of the attention came in the form of abstracts and inconsequential references. But two elite theoretical physicists in Landau’s cohort—Gamow, Landau’s erstwhile friend who had left the Soviet Union in 1933 and landed a position at George Washington University the following year, and J. Robert Oppenheimer of the University of California [Berkeley] and the California Institute of Technology—scrutinized his model and found it wanting. Like Landau, both had a side-interest in stellar theory; unlike him, however, neither dismissed mainstream theoretical astrophysics. As early as late March, Gamow was persuaded by Chandrasekhar and Strömgren that the “astrophysical evidence” went against Landau’s latest core model except possibly for supergiants. A month later, Gamow and his colleague Edward Teller reported that “the extremely high…densities and temperatures in the neighborhood of [a star’s neutronic] core” would engender so many nuclear reactions that “the total energy production of the star [would be] many orders of magnitude greater than the observed radiation.” Later that spring, when Gamow learned privately of Hans Bethe’s breakthrough on the stellar-energy problem, he became completely convinced that giants were the only stars that might possibly have neutron cores.

When Oppenheimer, who had also been looking into the stellar-energy problem, learned that June of Bethe’s theory, he initially regarded it with such skepticism that he intensified what had been a desultory canvass of the neutron-core model’s prospects. Deciding during the summer that Bethe had indeed achieved a breakthrough, Oppenheimer began looking into whether neutron cores played a role in stars after they had exhausted their thermonuclear reserves. By December the studies

74. Gorelik (ref. 38).
75. Of the roughly ten relevant pieces here, the most thoughtful comments about Landau’s model appeared in McCrea, [abstract], Zentralblatt für Mathematik und ihre Grenzgebiete, 18 (21 June 1938), 188; Carl Friedrich von Weizsäcker, “Über Elementumwandlungen im Innern der Sterne. II” (received 11 Jul 1938), Physikalische Zeitschrift, 39 (15 Sep 1938), 633–646, on 637–638; Hans Bethe, “Energy production in stars” (received 7 Sep 1938), Physical review, 55 (1 Mar 39), 434–456, on 451; and McCrea, “Nuclear synthesis and stellar energy,” Observatory, 61 (Dec 38), 332–335, on 334–335.
78. Gamow, “Kernumwandlungen als Energiequelle der Sterne” (received 25 May 1938), Zeitschrift für Astrophysik, 16 (1 Aug 1938), 113–160, on 151–159.
carried out by Oppenheimer, his postdoctoral assistant Robert Serber, his doctoral student Michael Volkoff, and his colleague Richard Tolman indicated, contrary to Landau’s findings, that neutron cores were stable for such a narrow range of masses that virtually all exhausted stars must collapse either into white dwarfs or what are now called black holes. Following up on this result during the first half of 1939 with his student Hartland Snyder, Oppenheimer wrote what eventually came to be regarded as a classic study of relativistic gravitational collapse.  

Oppenheimer’s study had many roots, and one of them was the short paper emerging from Landau’s third sally into stellar theory. It seems fitting that, when the versatile Landau came across this study sometime during the year following his release from prison, he added it to his “golden list” of works warranting follow-up. Before the end of his life, some of his disciples were doing so.  

While fashioning my narrative, I have come to a better understanding of Lev Landau than I ever had during the decades when I was turning up evidence from the 1930s of his ventures into stellar theory and of the rare sparks that they struck. Earlier I supposed that a single motive—a desire to display his virtuosity—underlay these interdisciplinary forays. Now I believe that he had a variety of primary reasons—his driving hope to find fundamental results in 1931, his friendship with Gamow in 1933, and his fear of the purges in 1937—for his three interventions in astrophysics. Earlier I regarded his denunciations of the era’s astrophysical theory as an especially arrogant expression of theoretical physics’ imperialistic stance toward neighboring theoretical fields. Now I think of him as a maverick whose determination to do things in his own way was a source of his originality. And earlier I thought that contemporary astrophysical theorists paid him very little attention because he showed such ignorance of their very real achievements. Now I find myself also wondering whether their own theoretical commitments led them to pass too quickly over the insights that he threw into their midst.

79. Hufbauer (ref. 5).
80. Thorne (ref. 3), 219.
Landau’s youthful sallies into stellar theory: Their origins, claims, and receptions

ABSTRACT

Soviet physicist Lev Landau ventured into stellar theory three times during his twenties. In 1931 a hope of turning up fundamental results evidently inspired him to follow up Niels Bohr’s idea that the processes powering stars violated energy conservation. Two years later, friendship with George Gamow seems to have led him to sign on to a note about the relation between stellar central temperatures and surface elemental abundances. And in 1937 worries about the intensification of Soviet purges apparently motivated him to return to the stellar-energy problem. Here, as in 1931, Landau developed the view that stars have centrally condensed cores, this time proposing that such cores consist entirely of neutrons. While Landau’s idea enjoyed a positive reception from Izvestia and the Soviet Academy, this response was not sufficient to keep him out of Soviet jails. The idea did, however, play a major role in initiating Robert Oppenheimer’s research into relativistic gravitational collapse, research that would soon lead Oppenheimer to the idea of what would come to be called black holes.

KEY WORDS: Landau; Gamow; Bohr; Eddington; Oppenheimer; stellar theory; Soviet physics and purges