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Pineapples and Crabs: When Young Supernova Remnants Were Even Younger

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Abstract. If a "young" supernova remnant is less than 1000 years old, then all of them have aged at least 10% during the era of photographic astronomy. Nevertheless, historical investigations are, so far, probably telling us more about how astronomers behave than about how SNRs behave. The talk reviewed an assortment of firsts, lasts, and might-have-beens from roughly 5283 BCE to 2000 CE.

INTRODUCTION: NUMBERS OF YOUNG SNR AND METHODS OF RECOGNIZING THEM

The rate of discovery of extragalactic SNe is now in excess of 100 per year. Thus, if a young SNR is less than 1000 years old, there are at least 10^5 examples within telescope range. Another way of looking at the numbers is to note that there are supposed to be 10^{11} galaxies within a Hubble radius. Most of these are dwarfs, and so the rate of one event per 1000 years per galaxy [1] (an old Zwicky estimate) is probably about right, implying 10^{11} young SNRs in the observable universe. Of these, we know something about perhaps 100 and have interpretable data for about 10. Most of these are discussed in the later pages of this volume (and the rest are over-discussed).

The young SNRs about which something can be said are of two types: recoveries (at one or more wavelengths) of events in external galaxies and counterparts, from possible to probable to certain, of events recorded in the Milky Way by pre-telescopic observers. SN 1987A is the first example of what could eventually become a common third class, events that have never been lost (roughly for the same reason that elephants are not often found – they are so big they hardly ever get lost).

Recoveries date back only about a decade, beginning (at least as far as publication goes) with optical emission from 1957D in M83 reported by Long and his colleagues in 1989 [2]. Of the handful known, 1961V was probably not a real supernova; and 1885A (S And) is in absorption (elsewhere in this volume) against the bulge stars of

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the galaxy. SN 1923A, the oldest, is one of a comparable number of radio recoveries [3 and elsewhere in this volume]. X-ray recoveries have lagged a bit (mostly an angular resolution problem one suspects), beginning with 1978K in 1996 [4] and now including about four others plus about eight seen at the time of outburst (E. Schlegel, private communication). All the recovered events seem to be of the core collapse variety. Type I sites have, of course, also been searched at various times. Events whose apparent magnitude at peak luminosity was brighter than m = 10 include 1895B (in NGC 5253), 1937C, 1972E, and 1954A. This is also more or less an exhaustive list, and they are presumably the best bets for further study.

None of the recovered core collapse SNe shows strong evidence for a pulsar. The radio would be very weak, and the X-ray emission is in any case unresolved. Several pulsars have been reported at the site of SN 1987A, most recently one with a period of 2.14 msec [5].

The numbers of historical supernovae (meaning those seen by our pre-telescopic intellectual ancestors) or at least candidates for them are comparable. The standard authority on the subject is the 1977 book by Clark and Stephenson [6] – see [7] and [8] for partial updates. Of the 15 or so candidates, some can be dealt with very quickly. The three events of 1592 were probably sightings of Mira embellished. RCW 103 and MSH 11-54 appear to be supernova remnants not much more than about 1000 years old, but they would have been below the southern horizons of all the chroniclers whose records have been found so far. The event of 1408 is represented by only a single sighting and no indication of duration. Thus it was probably not a supernova, and whether the position was closer to the radio source CTB 80 or the X-ray source Cyg X-1 becomes irrelevant.

Schaefer [9] has presented evidence that the star of 185 CE was really the close juxtaposition of a nova and a comet. Supporting evidence is that the proper motions of the optical filaments at the location of putative radio SNR RCW 186 are less than 10% of what would be required by the supposed age, though one should not forget that much of the Cas A optical remnant consists of quasi-stationary flocculi. Petruk [10], however, still supports a connection and supernova identification. The event of 393 remained visible and, apparently, motionless for eight months. Not surprisingly, the position cannot be reconstructed accurately enough to distinguish between CTB 37 A and B as potential counterpart, and this event did not make the program as either an invited or contributed paper.

The remaining nine candidates are summarized in Table I. It is worth noting that two are quite recent additions to the inventory, SN 837 (regarded as a nova by Clark & Stephenson, [6] = SS 433 (proposed by Wang in 1996, 11, and somewhat earlier at other conferences), and SN 1523 = Kes 25. The three Chinese reports of a "po" star in summer, 1523 are translated and presented for the first time in a preprint by Wang [12]. Properties of the recently-discovered and rapidly slowing pulsar in Kes 75 appear elsewhere in this volume. If the 1523 event was as distant as the SNR appears to be, it may even have been a hypernova!

TABLE I

YEAR	REMNANT	REMARKS
386	G 11.2-0.3	pulsar, P = 0.54 sec
837	SS 433	high galactic latitude for SN (but SS 433 is there!)
1006	PKS 1459-41	VERY bright (record for Milky Way)
1054	Crab Nebula	pulsar, P = 0.033 sec, the "gold standard"
1181	3C 58	first SNR described as Crab-like, in Cas
1523	Kes 75	pulsar, P = 0.324, slowing down time = 700 yr
1572	3C 10	Tycho's event, B Cas
1604	G 4.5 + 68	Kepler's event
1680	Cas A	faint if seen by Flamsteed in 1680; even fainter if not seen at dynamical date of event, 1658 ± 3

Given the uncertainties of the candidates and the certainty that the list must be incomplete (Chinese reports of ominous events cluster near the ends of dynasties, [7]), I am not sure whether any significance at all should be attached to three of the tabulated events/objects being located in Cassiopeia!

The remainder of this introduction is arranged chronologically by events in our study of young SNRs, but divided into Crab Nebula, other historical remnants, and theory.

CHRONOLOGY: THE CRAB NEBULA

The photons (and presumably some neutrinos, gravitinos, etc.) left the progenitor in 5283 BCE (not, of course, known this precisely, but the distance to the nebula is probably within 10% of 2000 kpc, [13]). They arrived some time in 1054 CE, though just who saw them and when is still under discussion. The Chinese sighting on July 4, 1054 is in Biot's 1842 initial list [14], though not as one of the most promising events, and Duyvendak (of Leiden, an Orientalist, not an astronomer) provided a better, confirming translation [15]. A Japanese signting, of somewhat less certain date, was presented by Iba in 1934 [15a]. The report of Ibn Butlan from Baghdad [16] concurs with first appearance in July. As anyone who has ever

observed the nebula optically knows, it is a winter object (on the meridian at midnight on about 10 December), and Fourth of July must have been simply the first evening something "bright like Venus" became obvious against morning twilight. This has, of course, implications for the maximum brightness of the event, since it might well only have been caught past its peak. It has generally been claimed that Europe had particularly bad weather that year, but a recent suggestion is that the bad weather was political-religious, rather than meteorological. Collins et al. [17] have found several apparent European sightings that date from April and May (but nothing new from July onward), and suggest that the supernova was indeed seen, but that the subsequent failure of a last-ditch conference, aimed at holding together the Eastern and Western churches, transformed it into a bad omen, not to be talked about again.

Surprising as it may seem, a number of doubters over the years have suggested that NGC 1952 is not connected with the event of 1054. The basis most often has been either the measured expansion rate (which would place the event in about 1150 in the absence of acceleration) or the peak luminosity (too faint for a typical supernova, whatever that is). The standard responses are acceleration due to the pressure of magnetic field and relativistic particles and that not all supernovae are the same brightness (even if 1054 was caught at maximum).

A more generic response is that one would be surprised if two supernovae had occurred within a few hundred parsecs and a hundred years of each other, one of which was not seen and the other of which left no remnant. In contrast, it is legitimate to doubt that specific South West Indian petroglyphs record a sighting of SN 1054 near a crescent moon. It is true that the moon passed close to the SN position at a time when both were above the horizon at longitude 110° W and not when both were visible from 110° E, but anyone who has seen Venus close to a crescent moon, as is possible every few years, will have an alternative hypothesis.

SN 1054 faded below naked eye visibility in late 1055 and was not heard from again until 1731, when English phvsician-astronomer John Bevis recorded a fuzzy patch in Taurus. His publisher went bankrupt before his atlas could be published, but at. least one copy of the relevant plate survived. His version looks somewhat too large and too circular. The next drawing comes from Charles Messier, who saw the fuzzy patch on 12 September 1758, recorded it as a new discovery, and made a note of its position and appearance so as not to confuse it with Comet Halley, whose return was then expected any month or two, Messier appears in our folklore as a noted hunter for and discoverer of comets. Less widely known is that he became so as a result of being hired as a 21 year old assistant to Delisle of the Marine Observatory on the basis of his neat handwriting and drafting skills [18]. In case you wonder how the Halley story turned out, Messier did indeed recover it in January, 1759, about a month after an accidental discovery by a German amateur. But Messier's drawing was the first to show a nebula roughly the right size and somewhat elongated in the right direction.

Halley of course returned again in 1835, and seems to have left Edouard Biot curious about other perihelion passages. He carried out what he called "Recherches

faites dans le grande collection des historians de la Chine, sur les anciennes apparitions de la comete de Halley" in 1842-43 [14], identified the passages in 1222, 1145, 1066 (you know about that one), 989, 837, 684, 451 and -12. He also tabulated an assortment of guest, new, and broom stars, including that of 1054.

Also in 1842, William Parsons, later the third Earl of Rosse (whose descendent is a Lord Rosse to this day) cast the first mirror of his "Leviathan", with which, in due course, he observed M1 [19]. He is said to have assigned the name in 1844, but has left us two drawings, one nearly indistinguishable from a pineapple standing on its stem end, the other bearing some remote resemblance to a continuum-emission photograph of GC 1137 and/or to the larger claw of a Maryland crab. It seems mostly likely that the former drawing is a mislabeled representation of some other object (David Dewhirst of Cambridge has been promising for years to tell us which one), but when, many years ago, I read a Physics Today article by Philip Morrison on optical imaging which described "resolved objects" as ones that "look like crabs or pineapples" I knew he had contemplated the same pair of drawings. It is his impression (personal communication 2000) that the fruit-like image was done by an assistant, not Rosse himself [20]. Rosse shared the opinion, expressed earlier by Herschel [21] and others, that the nebula could be resolved into stars, and it was left to William Lassell, observing under the clearer skies of Malta, to conclude that the nebula was truly diffuse [22], indeed "very amorphous and indistinct."

Lassell's drawing is not especially Crab-like (put north to the left and it looks most like Caspar the Friendly Ghost), but his stars are real stars, down to the central, m = 15-16 pair, which is what has led me to wonder whether anyone has ever scanned drawings by him and his contemporaries of "extragalactic nebulae" for "guests stars", whose remnants would now be, say, 120-220 years old.

When was the Crab Nebula first photographed? In 1892, with a 20", by someone named Robertson, so says Shklovsky [23]. Unfortunately, he provides no reference and cannot now be queried. Casual investigation (that is, I looked in a few early volumes of Jahresberichte, indices of AJ, AN, and RAS publications from the late 19th century, and asked a few people with historical interests - Gingerich, Hoffleit, Hazen, Hodge) has not led to an identification for him or his reflector. The first photograph I have found documented and reproduced dates from 7 February 1896 and was taken on a Guilleminot plate in a 2 hour, 32 minute exposure, as part of regular astrograph work, by S. K. Kostinsky of Pulkova Observatory [24]. Kostinsky published his last paper in 1936 in the same issue of Pulkova Observatory Circular that carried the last paper by Gerasimovich [25]. It was not a good year at Pulkova for astronomers interested in international collaborations.

Thus the first images were about 20 years old when Vesto Melvin Slipher of Lowell Observatory began recording spectra [26] in 1913. He correctly described the split lines, but thought that a strong Stark effect was responsible. A few years later, Roscoe Sanford held on for a 48-hour exposure, but without doing much more than confirming some very large velocities by the standards of the times [27].

Carl Lampland, also of Lowell, reported the Crab as the fourth truly variable nebula in 1921 [28]. He was seeing the complex motions of continuum features (now

associated with the names of Scargle and Hester). But Duncan [29], with access to plates from the 60" at Mt. Wilson (exposed by Ritchey in 1909 and himself in 1920) soon spotted the systematic expansion, and later, its probable acceleration [30].

Also in 1921, Knut Lundmark [31] compared Biot's list of Chinese phenomena with the NGC catalog. His motivation was a firm conviction that novae were associated with nebulosity (not by expelling it, but more like being formed from it, an idea he attributed back to Tycho, whose new star indeed sits right on the edge of the murkiest bit of the Milky Way). Lundmark estimated a distance near 1 kpc from the expansion and spectral data [32] just in time for Hubble to use it in a careful, but non-technical discussion of the 1054-nebula association [33] in 1928. That same year, Adriaan van Maanen [34] first reported a large proper motion for what was then the "south preceeding" star and is now the pulsar. This does not seem to have played a very large part in anybody's thinking, perhaps because he was also the van Maanen of spiral galaxies with rotational motion in.the plane of the sky. Indeed when Baade [35] and Minkowski [36] point to that same star it is primarily because it lacks absorption features in its spectrum, though they also report a proper motion based on van Maanen's plates and later ones of their own.

It was from war-torn Holland that Oort and Mayall [37] and Duyvendak [15] submitted their discussions of the association between the guest star of 1054 and the expanding Crab Nebula. Since the technologies of both radio astronomy (via radar dishes and radar engineers) and X-ray astronomy (via captured German V-2 rockets) grew fairly directly out of World War II, this provides a natural break between sections!

THE NON-OPTICAL CRAB

Notoriously, the Crab Nebula was first or nearly first object outside the solar system to be recognized as a source of radio waves, X-rays, gamma rays, and so forth. Radio came first. Bolton and his Australian colleagues employed a virtual interferometer, of which the other arm was reflection from the ocean up to their cliff top to get a good enough position to permit optical identification [38], then as now the sine qua non of feeling that one might have begun to understand a non-optical source. The radio polarization was not measured until 1957 [39], after optical polarization had already been recognized (and this lives in the "theory" section, since it was predicted).

A high-resolution X-ray search of the vicinity was possible early because (and only because) the moon has the dubious taste to pass right across the face of the Crab a time or two every 19 years. Stu Bowyer and his colleagues managed to get a rocket aloft for the critical five minutes in 1963 [40], and their report had already triggered a countably infinite number of calculations of the cooling of neutron stars before a second flight the next year [41] demonstrated that the source was extended and so associated with the nebula as a whole rather than just the central star. To

that same year belongs the discovery of the first radio pulsar by Hewish and Okoye [42], only, of course, what they reported was a compact, low frequency radio source, their time resolution having fallen far short (or rather long) of the required 33 msec. Gamma-rays followed within a few years, and later reanalysis of those few photons provided a 1967 period for the pulsar that can never be bested as "first" by any method [43].

Other Crab "firsts" include the pulsar time derivative, a second derivative, optical and X-ray pulsations, and it remained unique until, one fine day [44] 3C 58 was declared to be "Crab-like" and NGC 1952 (3C 144, etc) became merely a prototype.

THEORETICAL CHRONOLOGY

The first theoretical statement that had to be made about supernovae is that they exist as a class distinct from that of the "common" novae. The suggestion came first from Knut Lundmark [45], who had both reconstructed the light curve of SN 1885 (S And) and estimated a distance of 200,000 pc to M31. The implied peak brightness for S And was M = -15, and, in their famous debate, Heber Doust Curtis interpreted this to mean that "a division into two magnitude classes is not impossible" while Harlow Shapley thought it ridiculous and a strong argument against the existence of island universes [46]. Incidentally, Lundmark [47] also coined the name supernova, though credit is generally given to Baade and Zwicky [48] writing two years later, whom you will meet again very shortly. The Gaposchkins, writing in 1938 [49], opined that the name was not very suitable but was also beyond repining. They suggested that the mechanism would prove to be continuous with that of the common novae. By 1957 she, at least, regarded the physics as distinct (partly because the brightest common novae were the fastest, [50]).

Once you accept existence, the next obvious question is energy sources. E. A. Milne provided a "prequel" hypothesis in 1931 [51] when he attributed the energy of common novae to the collapse of normal stars to white dwarfs.

This brings us to the "culture heroes" Walter Baade and Fritz Zwicky. Their 1934 paper [48], and an APS meeting abstract from December, 1933, make several critical points. First, supernovae exist and are different from common novae (with the inventory including S And, the 1054 event, Tycho's new star, and a handful of photographic discoveries between 1890 and 1930). Second, the energy source is the collapse of a normal star to a neutron star (a concept which they also probably invented). And, third, much of the available energy should go into accelerating cosmic rays. They were, of course, telling the truth (if not the whole truth) on all three points. They were not (also of course?) widely believed, and early papers on neutron star structure, like that of Oppenheimer and Volkoff in 1939 do not even cite them.

In fact, there was a giant step backwards, when, at a Paris symposium on novae and white dwarfs, Chadrasekhar associated supernovae with the expulsion of material from massive stars that would otherwise not be able to produce white

dwarfs, but then did so. This view was endorsed in print by Chandra himself [52], Minkowski [36], Baade [53], Baum [54], Schwarzschild and Spitzer [55], and various other custodians of received opinion right down to the first, 1964, edition of Abell's [56] pioneering text for non-science students of astronomy. Whichever text was used at UCLA just before Abell published his said the same thing, but the instructor in 1962, Thornton Leigh Page, made sarcastic remarks about mice and elephants' grave yards and was, in retrospect, at least a bit ahead of his time in returning to the neutron star camp, which Zwicky [1, 57] never abandoned. Indeed his last statement on the subject [58] emphasized the three points mentioned above, as well as a rate estimate of one per galaxy per 300 years, large expulsion velocities, and so forth.

After Minkowski separated the supernovae into two classes in 1940 [59], the was room for two mechanisms. Since we have already had core collapse (whether to white dwarf or neutron star), you already know with 20-20 hindsight that the other one is going to be a nuclear explosion of some kind. The standard "first reference" is Hoyle and Fowler in 1960 [60], though precursors in the work of Mestel, Schatzman, and others turn up in reference lists from time to time. Payne- Gaposhkin [50], as meticulous as any secondary source I have found, gives priority to a 1946 Schatzman paper [61], with Gurevich and Lebedinsky, submitted in 1946 but not published until 1947 [62] among the also-rans. One has, however, to suspect that she had not (or not lately) read through these papers. Schatzman's abstract says: "L'energie liberee au cours de l'explosion est due a la transformation de l'energie cinetique d'exclusion des electrons en energie d'agitation thermique." That is, freely translated, he proposes to claw back the energy that has been locked up in electron degeneracy and use it to power the explosion. The paper is explicitly titled "Theorie des Supernovae".

Later papers by Schatzman do, indeed, deal with nuclear burning under degenerate conditions, though it is sometimes a bit difficult to decide whether he is making novae or supernovae at a given time. Meanwhile, however, Gurevich and Lebedinsky [62] have already addressed both novae and supernovae, attributing both to "degenerated" nuclear explosions, with surface ignition (which the star survives) for novae and central ignition (which the star does not survive) for supernovae. No, they had not fully solved the problem, for they consider only hydrogen fusion (the only game in town then) and so decide that a nuclear explosion should occur early in the life of a star and a core-collapse event (for which their source is Gamow and Schoenberg in 1941, [63]) late in stellar lives. It becomes clearer how and why this was an issue if you recall that they were writing during the era in which star formation occurred "in the early universe, when conditions were very different from now," so that age and degree of evolution were not separable parameters.

Even earlier, Zwicky's 1940 review [57] had suggested that the exponentially declining late light curves displayed by many supernovae might be powered by the decay of some radioactive nuclide. Early suggestions included Be^7 (with the right half-life to electron capture but irrelevant if ionized) and Cf^{254} (which would give us a universe drowning in its decay products). The current "best buy" is Co^{56},

which comes from Ni^{56} in about 7 days and goes on to Fe^{56} in 70-some.

A second major theoretical issue was the photon emission process responsible for, initially, the optical and radio Crabs and, later, for other SNRs and X-rays all around. Let's dispose of X-ray bremsstrahlung in blast waves for non-Crabs immediately, with credit, rightly or wrongly to Carl Heiles [64]. And the rest, as no poet has said, is synchrotron. The word had already been whispered (with a slight accent) by Alfven and Herlofson in connection with radio emission from the plane of the galaxy, and the demonstration by Greenstein and Minkowski in 1953 [65] that the radio and optical emission from the Crab Nebula cannot both simultaneously be thermal is clearly part of the story. Several (former) Soviet astronomers have cast doubts on each others' share of the credit. The obvious citation is, however, Shklovski in 1953 [66a] because he explicitly predicted optical polarization as a consequence, and thereby inspired Dombrowski [67a] and Vashakidze [68a] to go out and look for it, successfully. Dombrowski spent most of the rest of his (relatively short) career searching for optical polarization, in other nebulae, typically with much less success. Vashakidze was presumably Georgian.

More detailed study of the polarized optical radiation by Oort and Walraven [69a] and by Woltjer [70a] made it clear that the electrons responsible for the optical synchrotron could have half lives of only about 200 years, implying either that the nebula must have been quite remarkably bright not long ago or that there must be some ongoing electron acceleration.

The solution was, of course, the P = 0.033 sec pulsar, and the measurement of its slowing-down rate and the first generation of models all date from the same year (1968) that I received my PhD with the second thesis ever devoted entirely to the Crab Nebula (Woltjer's was first, and R.E. Williams considered several other nebulae as well). Thus the rest of the story belongs to "current events" rather than to "history".

A different slant on the theoretical chronology can be gained from Shklovsky's book [23]. It is worth noting that (a) he was writing just before the discovery of pulsars and (b) he believed the 1054 event to have been of Type I. His own suggestion for the continuous power source was a neutron (or collapsed) star is an eccentric binary, whose dips into the atmosphere of the companion sent off the moving wisps first reported by Lampland. He favors nuclear over gravitational energy as the main power source, with lots of credit to Hoyle and Fowler [60] and none to Gurevich and Lebedinsky [62]. He accepts the potential existence and importance of neutron stars, but credits them to Oppenheimer and Volkoff [66]. Given that the book as a whole has strong overtones of "The refrigerator was invented by Westinghouski," it is probably significant that he does not attempt to credit neutron stars to Landau.

CHRONOLOGY: OTHER YOUNG SNRS

Supernovae were, in a sense, born with their remnants already attached, because the work of Barnard [67] on Nova Per 1901 and Nova Aql 1918 had firmly established within the astronomical folklore [68] the idea that an old nova ought to be surrounded by an expanding gas cloud, with time scale equal to the time since the outburst [69]. This was the context in which Hubble and Lundmark hunted for the remains of Z Cen = SN 1895B [70]. They were expecting both nebulosity and a hot white dwarf, and found neither. The same apply to Humason and Lundmark's 1924 search for a remnant of Tycho's new star [71] and to Baade's 1938 assault on Tycho [72]. Thus the Crab Nebula was the only "young supernova remnant" for several decades.

This changed in 1943 when Baade and Minkowski [53, 73] imaged a few wisps at the location of Kepler's new star of 1604 (Nova Ophiuchi) and obtained a spectrum. The optical remnant of Tycho's 1572 event, imaged by Baade in 1949, but not published at the time [74] is even less spectacular. Baade and Minkowski [53, 73] remarked upon the absence of a "white dwarf" at the Kepler site, and claimed that this was consistent with the event having been an SNI, in the newly-defined sense.

All the other observations pertain to supernovae whose locations and/or epochs are considerably less well known, and one must begin by asking the extent to which the reality of the events, their coordinates, and, therefore, the connection with assorted nebulosity, radio sources, and X-ray emission are to be trusted. Stephenson [75], shows the part of the sky extending from declination 55° to 75° and R.A. from 22.5 hours around through 0^{hr} to 3.5, on which he has placed the Chinese asterisms that define the location of SN 1181 and its proximity to radio source 3C 58. There are a dozen other 3C and comparable sources in that area (including, as it happens, Cas A and 3C 10, the remnant of Tycho's new star; and I remain uncertain about whether it is of any interest that the three were so close together; remember Tycho's SN was also called B Cas as a star name). Should we, therefore, trust the identification? I naturally think so, based, for instance, on the accuracy with which Venus can be located in Chinese descriptions relative to modern calculations of its motion [7]. Incidentally, the same Stephenson paper [75] lists another candidate historical supernova of 902, that was also in Cassiopeia. Perhaps the Chinese just liked that part of the sky, since it is circumpolar from mid to high northern latitudes.

Radio astronomy enters the picture chronologically with the cataloguing of Cas A by Graham Smith in 1951 [76], but logically not until 1952, when Hanbury Brown and Hazard [77] found emission at the Tycho site, leading to a correction in the position recorded by Brahe and so to increased confidence in the relevance of the optical wisps nearby. SNe 1572 and 1604 were, as should now be clear, along sight lines with much more optical obscuration than SN 1054. The radio counterpart of Kepler, however, was recognized after the optical counterpart by Shakeshaft et al. [78] in 1955, while for Tycho the radio counterpart came first, at least in the published literature. Given that the pioneers of radio astronomy typically did

not have backgrounds in traditional astronomy, one might be surprised that the observations and identifications came as quickly as they did. Brown recalled long after the fact [79] that he had been urged to turn his beam in the Tycho direction by Zdenek Kopal, a very traditional astronomer indeed.

With radio supernovae established as "a class" by the second example, it is not surprising that Shklovski almost at once attempted to identify other historical events with the handful of catalogued radio sources [80, 81]. Cas A = SN 369, though now known to be wrong, was perhaps the least improbable suggestion. In the same, 1954, time frame, Bolton et al. [82] reported radio emission from the general direction of Nova Aql 1918, and I have not checked on whether the identification is now generally regarded as correct.

This brings us to the first "large group" of optical identifications of radio sources by Baade and Minkowski in 1954 [93]. This paper is most often cited because the group included Cygnus A, the first recognized radio galaxy (described by them as "colliding galaxies" and so responsible for much theoretical work that should not be described as wasted). But they also found diffuse nebulosities in the (highly absorbed) directions of the radio sources Cas A, Pup A, and Cygnus X (NOT the same as Cygnus X-l, which is a black hole X-ray binary). They regard the first two identifications as reasonably firm (and doubted the third because the filaments show normal HII composition and small velocities). BUT they say with great confidence that "the random velocities are so large that they hide so far any expansion which may be present;" that "the conditions in the radio-source nebulosities are thus diametrically opposed to those in the filaments of supernova remants" (meaning 1054 and 1604); and that "Altogether, no observed fact supports the view that the radio source nebulosities are remnants of super-novae." Baade, at least, had changed his mind within a couple of years [84], and the identification of the radio Cygnus X with the optical Cygnus Loop re-established [85].

SN 1006 (unlike Tycho and Kepler) is still regarded as a Type Ia event. It joined the young SNR class with the discovery of readio emission from the location reported in European and Chinese records in 1965 [86]. The optical nebulosity, for which Minkowski obtained the first image and spectrum [87] is dominated by hydrogen emission. Nevertheless, van den Bergh [88] declared that it had been a type I explosion the same years, 1976, that Winkler and Laird [89] spotted the X-ray emission. It is expanding at the right rate [90] and most of the iron you expect from a nuclear supernova is still (or again!) cold and to be seen only in absorption [91].

Another word should be said about Cas A and S And. That the former acts precisely like a radio, optical, and X-ray supernova is not in doubt (it even, in the Chandra image shown at this meeting, seems to have a neutron star near its center). But we remain uncertain whether the event was witnessed. A star not otherwise to be found in today's skies was recorded on a chart from 1680 by Astronomer Royal John Flamsteed [92]. He seems to have been a fairly reliable chap – another of his phantom stars, from 1690, was a pre-discovery observation, of Uranus. On the other hand, Kamper and van den Bergh [93] have said quite firmly, on the basis

of measured proper motions of the nebula filaments, that the explosion must have happened about 20 years earlier. Modest deceleration of the expansion would, of course, reconcile their date of 1658 ± 3 with Flamsteed's star. Astronomers used to say that, when there was another astronomer as great as Kepler, there would be a supernova for him to see. Perhaps it is just that no-one wants to compete for the title of "greatest astronomer since Flamsteed."

For S And (SN 1885 in M31) a major outstanding puzzle has been the absence of expected radio emission, down to 1/15 or less that produced by the Tycho remnant [94]. A poster presentation here may have finally found the radio counterpart, but (like, the optical event that gave rise to Cas A) it is very faint.

And this brings us observationally down essentially to the modern era of optical recoveries, neutrino observations, hypernovae, and the rest. A major feature of that era is, of course, ever more powerful photon collectors, receivers, and processors, which have gradually extended the reach of Crab-like information as far as the LMC, yielding the remnant "more Crable than the Crab" [95, 96]. We can, in due course, look forward to that reach extending to M31 and beyond.

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