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Fitting the Crab Supernova with a Gamma-Ray Burst

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Abstract: Here, we reconsider the historical data, assuming a gamma-ray burst (GRB) as its source. A Supernova correlated with the GRB explains well the fading time observed by the ancient Chinese astronomers in the daytime and the nighttime, while the GRB power law explains the present X-rays and GeV emission of the Crab. On the grounds of a recent understanding of the first episode of binary-driven hypernova GRB (BDHN GRB) in terms of the collapse of a ten solar masses core, we propose the possible identification of the real Supernova event at an earlier time than Chinese chronicles. This work allows a new understanding of the significance of historical astronomical observations, including a fireball due to gamma-ray air shower observation and a plague of acute radiation syndrome, documented with several thousands of victims in the Eurasian area (Egypt, Iraq, and Syria).

Keywords: supernova (SN1054); gamma-ray burst (GRB190114C); binary-driven hypernova

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1. Introduction

A panorama of the current historiography on the Supernova of 1054 is outlined in the classical texts of Shklovsky (1968) [1] and Murdin (1985) [2] show how the interpretation of this phenomenon converged on a Supernova event. The Crab Nebula is the remnant of a powerful phenomenon that occurred in 1054, and it was carefully observed and reported by the Chinese imperial astronomers. The attentive scrutiny of the sky by them has not surprised us: the legend of the beheading of the astronomers Hi and Ho after missing the prediction of an eclipse that occurred reliably in 2159 BC [3] illustrates the high status required to be imperial astronomers in China.

Here we are considering a GRB as a possible Crab Nebula progenitor, using GRB 190114C as a prototype. Here, starting from the historical documents, we extrapolate the GRB light curve for nearly 1000 years or 3×10^{10} s. Ten Supernova-rise occurred in GRBs have been studied [4], and here, we formulate new inferences on the event of 1054, which originated the Crab.

In particular, we formulate the possibility of a very strong event visible at dawn in America, at noon time in Europe on 3 July 1054 11 UT, and appearing to the Chinese astronomers only at the dawn of the following day. This is considered the first episode (episode one) of a Supernova explosion of a ten solar masses CO-core introduced in the BDHN GRB model [4,5].

2. Historiography of the Crab Supernova

Shklovsky (1968) [1], Trimble (1968) [6], and Murden and Murden (1985) [2] carefully analyzed the literature on the Crab Nebula, where the comprehension of it as a Supernova remnant, expanding since 1054, appears gradually in the first three decades of the XX century. The knowledge of the Chinese and Japanese sources became available in the XIX century, and their translations were discussed and improved, as we can see in the now classical books of Shklovsky (1968) [1], Murden and Murden (1985) [2], and Stephenson and Green (2002) [7]. These studies became the present "*Vulgata*" of the Supernova of 1054. Some European sources with possible accounts of observations that referred to this particular event have been scrutinized, as by Polcaro et al. (2006) [8]. We present a rapid sketch of the present situation in historiography about the European sources as integrations of the Chinese and Japanese ones.

2.1. Shklovsky and the Supernova Fit of 1054 Observational Data

The news about a "guest star" in the right position of the present Crab Nebula has been found in Chinese sources. The astronomical bureau of the Emperor was supposed to record any information coming from the sky with great precision, and these ancient astronomers did it carefully. Shklovsky quoted the studies of J. J. Duyvendak (1942) [9], who paved the way to exploit the Chinese historical astronomical sources.

Skhlovsky (1968) [1] fitted the Chinese data (23 days of daytime visibility after 4 July, 1054, and 21 months of total visibility) with a Supernova, possibly observed also by the Japanese in its rising phase.

From the Sung-shih [Annals, of the Sung Dynasty] (Astronomical Treatise, chapter 56):

> *"On the 1st year of the Chi-ho reign period, 5th month, chi-chou (day) [July 4, 1054], a guest star appeared approximately several inches to the south-east of Tian-kuan [Aldebaran]. After a year and more it gradually vanished."*[1]
>
> *From the Mei Getsuki Japanese source:*
>
> *"After the 2nd third of the 4th month, the second year in the Ten Ki period of Japan at the time of Chuou, a guest star appeared three times at the Hsiu Tsui (Turtle). It was seen in the east, with Ten Kwan Hsing, as big as Jupiter.*
>
> *"In the middle of the ten-day period of the fourth Moon of the second year in the Ten-ki period, [between May 20–30, 1054] and in the following days, a guest-star was observed in the orbit of Orion. It was seen in the Eatern horizon. Its radiation resembled a comet with short rays in T'ieng-K'uang and it was about the size of Jupiter."*

Shklovsky did not cause problems with shifting the Japanese dates of one month forward, from the end of May to the end of June 1054, without considering that the Chinese should have been forced to be precise in monitoring the sky.

"We may see from the light curve that this may be the magnitude (-1.3, equal to Jupiter) of a supernova, about one week before its maximum. This is in full agreement with the text of the Japanese chronicles". (Shklovsky 1968, p. 55, [1]).

2.2. Arabic Source and Criticism on European Sources

The Arabic source of the 1054 event is Ibn Batlān, a physician and astrologer who lived in Constantinople at the time of the Supernova and who linked that star to the plague spread after its appearance, also in Egypt and Iraq for some years after; Ibn Batlān's account is reported in Murden and Murden (1985, p. 8) [2].

> *One of the well-known epidemics of our time is that which occurred when the spectacular star appeared in Gemini in the year 446 after the Hegira (from April 12, 1054 to April 1, 1055). [. . .]*
>
> *As this spectacular star appeared in the sign of Gemini, which is the ascendant of Egypt, it caused the epidemic to break out in Old Cairo when the Nile was low, at the time of its appearance. Thus Ptolemy's prediction became true: Woe to the people of Egypt when*

one the comets appears threateningly in Gemini. Then when Saturn descended into the sign of Cancer, the destruction of Iraq, Mosul and Jazira was complete. [...] And this confirmed the wisdom of Ptolemy in saying: when Saturn and Mars are in conjunction in the sign of Cancer, the world will be shaken."

The position of the bright new star is only defined by its ecliptic coordinate λ (in Gemini, say $60^\circ \leq \lambda \leq 90^\circ$) and the date to the nearest lunar year (446 after Hegira). Stephenson and Green (2003) [10] also considered Arabic sources, but they ruled out other European sources. Several authors, quoted in Collins et al. (1999) [11] and revisited in Polcaro et al. (2006) [10], presented the European accounts of celestial phenomena possibly related to the 1054 Supernova. Stephenson and Green (2002) [9] considered the European accounts dates for the 1054 event as very inaccurate compared with total eclipses European reports; the phenomena described are too generic, and the positions in the sky are ambiguous; moreover, they consider all the studies on these European accounts biased by the desire to show a European primacy on the Supernova observations.

We reconsider these European sources and their historiography in Section 3.

2.3. The Chinese "Vulgata"

After Dyuvenok's (1942) [9] studies on Chinese sources, there is a further translation of Ho (1972) [12], and the more coherent information is the Sung dynasty annals. Taking the translation offered in Stephenson and Green (2003) [10], the Supernova that appeared on 4 July, 1054, was visible for 23 days in the daytime and disappeared on 6 April, 1056, after 21 months of visibility. It appeared several inches southeast of the star Beta Tauri, near Zeta Tauri. Other Chinese sources present conflicting dates, as late as 27 August; in particular, Stephenson and Green [10] mentioned in the total eclipse account (dated unambiguously 10 May, 1054) that the new star near Pleiades was not necessarily seen during that eclipse but may have been seen after.

The Sung-shih hsin-pien text (prepared by K'o Wei-ch'I in the XV century) recites:

"During the eight month [of the 23rd year of the Chung-his reign period, 1055] the King passed away... Previously there was a solar eclipse at midday [10 May 1054] and a guest star appeared within the Mao [lunar mansion, the Pleiades]. The Assistant Officer in the Bureau of Historiography, Liu I-shou, said "Isn't this an omen that [the King of Ch'I-tan] Hsin-tsung will die?

The prediction did come true. The same passage is give in Liao-shih-i."

It remains difficult, as Skhlovsky and Stephenson and Green already declared, to avoid an "identification game" with such ancient data based on modern translations from ancient Chinese to English of transcriptions made two centuries (and more) after the event. The "identification game" can also be the fit of the data (23 days daytime and 21 months of visibility) with a precise Supernova-type light curve, following Skhlovsky.

3. Fitting the 1054 Event with a GRB

GRBs are the most energetic sources known in the Universe [13]; their gamma prompt emission would put at risk the Earth's life if they occurred in our galaxy, not screened by the galactic plane's dust [14,15].

GRBs show typical power-law decay, and in many cases, they overlap a Supernova light curve [4]. The connections between GRBs and Supernovae have been documented several times. The cosmological distances of GRBs made the observations of the related SN very difficult because they can be immersed in the GRB optical afterglow, but some well-documented cases exist [16].

3.1. GRB190114C Physical Parameters

This GRB, which exploded at 1.1 Gpc from us, was associated with the SN2019jrj [17], and we used this system to "fit" the Crab SN remnant present luminosity and the 1054 SN luminosity with its light curve, extrapolated some 10^{10} s after the GRB, say 1000 years.

The present X-ray and gamma-ray luminosities of the Crab, as well as the optical one, are in good agreement with the extrapolation of the corresponding power laws of such GRB, with the isotropical energy released ranging around $E_{ISO} = 3 \cdot 10^{53}$ erg with a luminosity of $L_{ISO} = 10^{53}$ erg/s. The Supernova associated with the GRB190114C peaked 15 days post-burst, with episode one of the Supernova-rise lasting 0.79 s in the rest frame, and it was released as energy as 3.5×10^{52} erg; its black body temperature was 40 KeV or 464 million °K [4]. These parameters set the GRB190114C among the BdHN model of type I, the most energetic ones [4]. The GRB triggered by the Supernova exploded within 5 min, the orbital period of the neutron star orbiting around the carbon–oxygen stripped core of a massive star. The initial fireball is due to the GRB produced by the fast-rotating black hole, created by collecting the mass of the ejecta of the Supernova over the orbiting neutron star during an orbital period. There is enough time for the orbiting neutron star to get the critical mass for creating the black hole.

3.2. Magnitude Scaling at 2 Kpc, the Distance of the Crab from Earth

A power law is a typical energy decay law, general for natural phenomena. The total energy of the phenomenon is related to the initial luminosity by an integral equation.

For a luminosity $L_0 = 10^{46}$ erg/s at the distance of the Crab 2.0 ± 0.5 Kpc, it is associated with an apparent magnitude of $m_v = -16.2$, as seen from the Earth, with nearly 30 magnitudes scaling from 1.1 Gpc distance of GRB190114C to 2 Kpc. This luminosity is similar to the solar corona, brighter than the full Moon ($m_v = -13.6$) and much brighter than Venus ($m_v = -4.5$), so it is indeed visible in the daytime.

The Sun's absolute magnitude (at 10 pc, 200 times closer than the Crab) is $M_v = +4.8$.

The GRB irradiates 10^{13} times the flux of the Sun, using Pogson's law and the inverse square law of the flux at increasing distance, the flux of that GRB would be $10^{13}/200^2 = 2.5 \times 10^8$ = 21 magnitudes brighter than a +4.8-magnitude star, $m_v = -16.2$ mag.

3.3. Daytime Visibility of the Supernova

The 23 days of daytime visibility of the "guest star" in 1054 can also be obtained with a GRB starting at a much brighter luminosity, as the $m_v = -16$ mag. The steep optical power law allows a 10-magnitude drop in about $2 \cdot 10^6$ s, which is 23 days, after which the luminosity was about $m_v = -6$, easily visible in the daytime. We remark that Venus is theoretically visible, such as Jupiter, in the daytime, but only when looking in the exact position and near a far reference, like the Moon, in a cloudless sky without hazes. That is why we consider the apparent magnitude of easy visibility in the daytime much brighter than Venus.

3.4. Twilight and Nighttime Limiting Visibility

The "guest star" underwent another 10-magnitude drop, from $m_v = -5.4$ to $m_v = +4.6$, to reach the limiting visibility to the naked eye in twilight, as was reported on 6 April 1056, according to the *Sung-hui-yao* chronicle. The same power law represented in Figure 1 requires a factor of 10^{-4} for a 10-magnitude drop, and it would require some 10^8 s or 3 years instead of 21 months.

The hypernova correlated with the GRB would explain well the initial gamma-ray fireball at 11 UT of 3 July 1054, seen only in Europe; the extraordinary appearance at the dawn of 4 July 1054, 0 UT, as seen by Chinese astronomers. The 23 days of continuous visibility in the daytime, the 21 months of total visibility, and, noteworthy, the present values in Optical, X-ray, and GeV energy bands are reproduced with this comparison.

The plague spread into Egypt, Syria, and Iraq after the appearance of this spectacular star, as reported by Ibn Butlān and in the Rampona chronicle, could be explained by the gamma-ray irradiation on the Earth's atmosphere [14,15]. The hypernova culminated in the sky on 3 July at 11 UT, in the Central European time zone (CET), while in China, it was below the horizon.

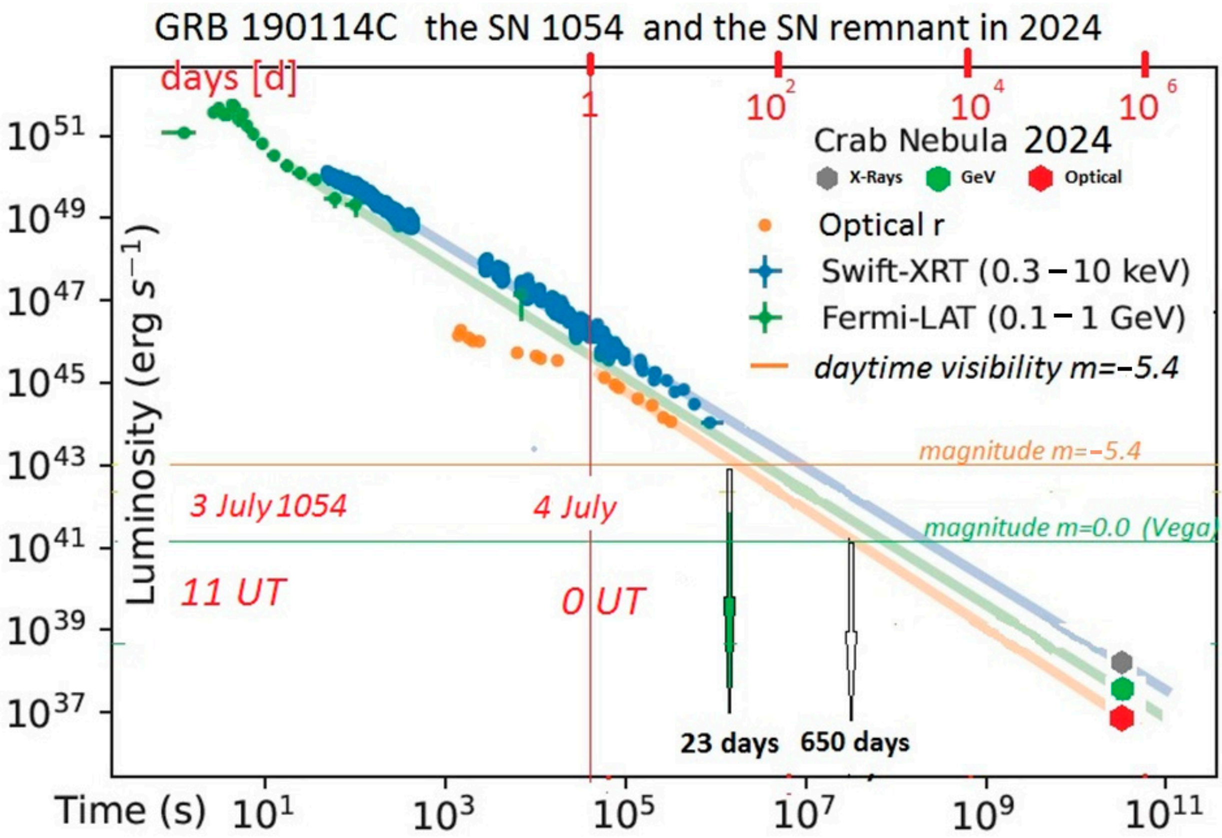

Figure 1. The light curve of the GRB 190114C extrapolated for 10^3 years or $3{\cdot}10^{10}$ s. Each 10^2 factor in luminosity corresponds to 5 magnitudes (Pogson's law).The Crab Nebula integrated flux values are represented by the three colored hexagons in Optical (red), X-rays (grey), and GeV (green). The apparent magnitudes are calculated if this GRB would have exploded at the distance of the Crab. Daytime visibility is better established with a magnitude brighter than $m_v = -5.4$ (Venus is $m_v = -4.5$ at its maximum), and the Supernova remained visible 23 days in the daytime, according to the *Sung-hui-yao* chronicle. After 21 months or 650 days, the optical afterglow of our reference GRB would reach the magnitude of Vega.

This date of 3 July 1054 is compatible with the Nile being low, as described by Ibn Butlān, and by the noon time mentioned in the fireball phenomena described by other European chronicles, such as Historia Ecclesia S. Petri Aldenburgensis and De Obitu Leonis [8], without considering their conflicting dates. The Chinese astronomers saw the new star only after it rose above the horizon, about half a day later on 4 July 1054, when the tremendous luminosity had already decreased by 10^6 times or 15 magnitudes.

4. GRB Prompt Emission for 30 Minutes Observed in Belgium and in Rome

The starting emission of the GRB, the one at 10^{46} erg/s or $m_v = -16$ of apparent magnitude, has its duration limited to 10^3 s, with the first five-magnitude drop. An event that lasted 30 min, visible in the daytime, would be in perfect agreement with this requirement. In the chronicle Aldenburgensis, such a duration was described.

4.1. *Tractatus de Ecclesia S. Petri Aldenburgensi:*

> *"...on the 18th day before the first of May, a Monday, around midday [...] all over the World there appeared to men a circle (orb) in the sky of extraordinary brightness which lasted about half an hour."*

The day was 11 April 1054, the very day and hour of death of the blessed pope Leo IX. The conclusion of this text is

"Perhaps the Lord wished to say that he [the Pope] was worthy to received a crown in Heaven between those who love Him." (Polcaro and Martocchia, 2006) [8].

Besides the obvious comments about a typical hagiographic language, in which the sphere of light is associated with the soul ascending into heaven of a saint at the moment of his death, the description of the appearance at noon of a bright sphere of about 30 min may be considered as astrophysically relevant.

4.2. De Obitu Leonis in Rome

The supernatural explanation related to the soul of Pope Leo IX rising to heaven is natural in the Christian cultural context of the XI century. The possibility that really a "brilliant orb" was seen in the sky for half an hour at noon, as described in the independent chronicles of De Ecclesia S. Petri Alderburgensi (Oudembourg, Belgium) and De Obitu Leonis (Rome), cannot be discarded "tout-court". Libuinus in De Obitu Leonis described the soul of Leo being taken by angels up to heaven (Collins et al., 1999):

"as along a path strewn with shining garments and lit by innumerable brilliant lamps".

4.3. Ordinary vs. Exceptional Events

Ancient chronicles cannot include ordinary atmospheric events like parhelia or meteors; they have included the very rare total solar eclipses, the aurora borealis in the nighttime, and even some daytime bright meteors. A great meteor would not have lasted half an hour, just a few minutes with a long-lasting trail, as in the Chelyabinsk event (2013).

Exceptional or supernatural vs. ordinary explanations are invocated only for some lifetime events, as it could have been seeing a brilliant orb in the sky in the daytime, lasting 30 min, which did not have any natural explication or previous experience.

The Book of Prodigies, published in Venice by Aldo Manuzio (1508)[2] [18], included events from 249 to 11 BC selected by Julius Obsequens: the majority of the events of astronomical nature are now easily explicable without recurring to supernatural exceptions.

The case of the bright orb could be explained by the prompt GRB emission.

4.4. Innumerable Lamps and Cosmic Rays Air Shower

The description of such a brilliant orb, sparkling with innumerable lamps, can be consistent with an air shower arising from cosmic rays coming from the GRB. The full Moon, even if it has a magnitude up to $m_v = -13.6$, has no innumerable lamps around it. This fireball was luminous enough to be seen clearly in full daytime, at 35° from the meridian Sun in Europe, and it was luminous enough and long-lasting to wake all the people sleeping in America, even being near their horizon. The Supernova did not explode over the Chinese's horizon; otherwise, they would have seen it.

4.5. Crab Supernova Rock Art in North America, Awakened by the GRB

Starting from 1955, a series of rock art items associated with the Crab Supernova have been studied, and recently, E. C. Krupp (2015) [19] reviewed them. The dimensions of the asterism associated with the Supernova always appear to be big compared to the Moon, so the association with a "normal galactic Supernova" was excluded [19].

Our hypothesis on the explosion of the Supernova-induced GRB around 11 UT of 3 July 1054 would explain why that new star is so big to appear as an orb (see Figures 2 and 3); they may have assisted this explosion at dawn, with the phenomenon very close to the eastern horizon, of an unprecedented brightness, second only to the Sun. A few degrees from the horizon (10° for New Mexico at 11 UT of 3 July 1054), the luminosity of the GRB could have been even brighter than the Sun at the horizon, while the nearly five airmasses would have shielded better the native Indians from gamma rays' effects.

Figure 2. Pictograph at the White Mesa (Arizona) already interpreted as the Crescent of the Moon and the Supernova since 1955. As with other pictographs of this type, the star appears always of similar size to the Moon, rayed or surrounded by circles, as in the case of fireball.

Figure 3. The most famous "Supernova Pictograph" at the Penasco Blanco Canyon (New Mexico). The Supernova is as big as the Moon. In our vision, this was the dawn of 3 July 1054, at 11 UT, with the GRB exploded, around 10° above the east horizon still dark.

5. Conclusions: New Inferences on the Historical Observations of 3–4 July 1054

The current Crab emissions (X-ray, gamma ray, and visible light [20]) and the 1054 event observations are fitted with the GRB 190114C light curve, extrapolated to nearly 1000 years. This fit reproduces well the 23 days of daytime visibility and the current X-ray and GeV emissions. The optical Supernova associated with the GRB could easily explain the duration of 21 months of total visibility of the 1054 "guest star".

The Supernova-rise [4] of the gravitational collapse of the CO-core star released ejecta that accreted onto the close orbiting neutron star, creating a fast-spinning black hole. Consequently, a GRB fireball appeared, and it was observed for 30 min in Oudembourgh (now in Belgium) and in Rome (strewing lights). After, the Supernova peaked around 15 days later and continued to be visible in the daytime for 23 days. A new neutron star (the new pulsar) was left by the CO-core star that collapsed. The prompt emission of the GRB occurred at local noon (as mentioned in two European chronicles), 11 UT, necessarily on 3 July 1054, instead of the "adjusted" dates (on or around 19 April 1054) to fit the death of Pope Leo IX in the chronicle *Aldenburgensis* (Belgium) and in *De Obitu Leonis*, written in Rome. At 11 UT on July 3rd in China, it was evening time, and the Crab was invisible under their horizon. The Chinese saw the new star only after its rise, the following morning of July 4th, about twelve hours or 4.3×10^4 s after the prompt GRB emission, with 10^3 less intensity or six magnitudes less at $m_v = -7$. On 3 July 1054 at 11 UT in Arizona, it was dawn, and the native Indians could have seen this extremely brilliant phenomenon in a dark sky; they were awakened by the great luminosity, which lasted until sunrise, and this is the reason why they represented it in many pictographs.

Moreover, the physician Ibn Batlān, in his Arabic account of 1054, mentioned a plague "As this spectacular star appeared in the sign of Gemini, which is the ascendant of Egypt, it caused the epidemic to break out in Old Cairo [Fustat], when the Nile was low, at the time of its appearance" [2].

Melott et al. (2005) [15] studied the biological effects of GRB radiation. Spinelli and Ghirlanda (2023) [15] fixed the security minimal distance from the strongest GRB to be safe as 15 Kpc from the GRB 221009A, the brightest of all time. Its energy flux within this distance would deplete the O_3 layer of our atmosphere. These considerations support our hypothesis that the intense gamma-ray radiation hitting the Earth's atmosphere around 11 UT of 3 July 1054 was followed by an intense cosmic ray air shower, which produced, on the people in the European area, acute radiation syndrome of burns on the skin, driving rapidly to the death of many people. The European people assisting that phenomenon were protected by only one airmass at noon time. The vision of the GRB prompt emission near the horizon, as occurred in North America, implied more than five airmasses to shield the observers from the lethal radiations.

The plagues connected with that star are mentioned also in the Rampona chronicle [8,9]. The etymology of the Latin word "disaster = negative star" would then be extraordinarily supported by this peculiar physical influence of a very far galactic source, the GRB Supernova, located at 2 Kpc from the Earth.

In the following Table 1, the airmasses have been calculated in the various places mentioned in the text at the moment of the explosion that we posed at 11 UT of 3 July 1054.

Table 1. Airmass calculated for different locations at the moment of the explosion of the Supernova.

Location	Crab Altitude above the Horizon	Airmass [X]	Damage to Exposed Skin [%]
White Mesa (Arizona)	13.3°	4.3	4
Penasco Blanco (New Mexico)	15.5°	3.73	7
Oudembourgh (Belgium)	53.7°	1.24	79
Rome (Italy)	53.9°	1.24	79
Constantinople (Istanbul)	42.2°	1.49	61
Cairo (Egypt)	41.4°	1.52	59
Beijing (China)	−18°, below	Not visible	0

In the American locations, the Sun was below the horizon; in central Europe, it was noon time, and it was afternoon in Constantinople and Cairo, the cities where the plague spread immediately; in China, the Crab was already below the horizon, while the Sun was setting.

The protection offered by the atmosphere is due to the transparency, proportional to exp(-X). The presence of clouds increased the protection against X-rays and gamma rays because they increase the interposed airmass X.

The interaction of X and gamma photons with the atmosphere changes with the wavelength of the photons; for X-rays, the ionization in the atmosphere of O_2, N_2, O_3, and H_2O first occurs; after the dominating process, the Compton scattering acts in an increasingly hot atmosphere [21]; for gamma rays, the electromagnetic air shower is the process through which by successive degradation, the energy comes to the ground. The energy of that GRB at the distance of the Crab would have impacted the Earth's magnetosphere and atmosphere with an initial flux about 1010 times the flux of the solar X-ray background (C1-class of X-ray flares). The maximum flux of X-rays of that GRB was corresponding to a solar flare 10^5 times an X-class flare (10^{-4} W/m^2 or 10^{-1} erg/s·cm^2), corresponding to a Miyake event [22,23].

The present interpretation of the SN 1054 event is very well-framed in the BdHN-GRB model [5], which explains how the GRB prompt energy is released after a hypernova, which also leaves a new neutron star, the pulsar [24], after it; the rotational energies of the black hole and of the pulsar are still enormous nowadays, thousand years after, to empower the Crab spectrum from GeV to radio.

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Data Availability Statement: The data discussed in this paper are plotted in the Figure 1, and are available in the references [4,5].

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Conflicts of Interest: The authors declare no conflicts of interest.

Notes

[1] Aldebaran is northwest of the new star, only at its rise. In the Equatorial System of celestial coordinates (with the star's order as it appears at the meridian transit), the Crab Nebula is southeast of Beta Tauri by several inches and one inch northwest with respect to Zeta Tauri, which is Tianguan or Tian-Kuan.

[2] Iulii Obsequentis ab anno Urbis conditae quingentesimo quinto prodigiorum liber, **1508** Aldo Manuzio, Venezia. https://thelatinlibrary.com/obsequens.html (accessed on 20 June 2024).

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