Gamma ray bursts may be blueshifted bundles of the relic radiation

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(Dated: )

A hypothesis is proposed that the gamma-ray bursts (GRBs) may arise by blueshifting the emission of the relic radiation of hydrogen and helium generated during the last scattering epoch. The blueshift mechanism is provided by such a Lemaître – Tolman (L–T) model, in which the bang-time function \( t_B(r) \) is not everywhere constant. Blueshift arises on radial rays that are emitted over regions where \( dt_B/dr \neq 0 \). The paper presents an L–T model adapted for this purpose and shows how it accounts for the observed properties of the GRBs; some properties are accounted for only qualitatively.

PACS numbers:

Keywords:

I. MOTIVATION AND BACKGROUND

In the Lemaître \(^1\) – Tolman \(^2\) (L–T) models, in which the bang-time function \( t_B(r) \) is not everywhere constant, radial light rays emitted close to those points of the Big Bang (BB) at which \( dt_B/dr \neq 0 \) display blueshifts to later observers (the blueshift is infinite, \( z = -1 \), on rays emitted exactly at the BB \(^3\)).

On the other hand, gamma-ray bursts (GRBs) are observed and are believed to originate at large distances from our Galaxy, up to several billion light years \(^4\). The question thus arises: could GRBs have been emitted in regions where the BB occurred earlier than in the background? The technical problem to solve is: regions where the BB occurred earlier than in the background generate shell crossing singularities \(^3\) \(^4\).

For the blueshift mechanism to work, the GRBs would have to originate in regions that emerged from a locally delayed BB.\(^3\) The relic radiation is emitted a finite time after the BB, so its blueshift must be bounded from below (\( z \geq z_{\text{min}} > -1 \)). The technical problem to solve is: is \( z_{\text{min}} \) sufficiently small that, with the free functions of the L–T model suitably chosen, the frequencies are blueshifted from the range of the emission spectra of hydrogen and helium (the only elements present in large amounts during last scattering) to the gamma-ray range observed today? The present paper attempts to answer this question in the positive – see Sec. \(^5\).

Section \(^1\) provides the most basic information on the GRBs. Section \(^3\) is an introduction to the L–T models, and Sec. \(^4\) provides information on light propagation in these models. Section \(^5\) presents the current best-fit L–T model that reflects the properties of the GRBs, and discusses improvements in the model needed to achieve a full quantitative fit. Conclusions are summarized in Sec. \(^6\).

II. BASIC FACTS ABOUT THE GRBS

The following properties of the GRBs need to be accounted for \(^6\):

1. Their frequencies extend from \( \nu_{\text{min}} \approx 0.24 \times 10^{19} \) Hz to \( \nu_{\text{max}} \approx 1.25 \times 10^{23} \) Hz \(^7\) (see also Ref. \(^1\)).
2. They last from less than a second to a few minutes.
3. They are probably focussed into narrow jets.
4. A GRB is sometimes followed by a longer-lived and fainter “afterglow” at larger wavelengths.
5. Nearly all GRBs come from very large distances, from over \( 10^8 \) to several billion light years.

Currently, there is no generally accepted explanation of origins of the GRBs. There exist only attempts at explanation by known astrophysical phenomena such as gravitational collapse to a black hole, a supernova explosion or a collision of ultra-dense neutron stars \(^8\).

The model presented in Sec. \(^5\) accounts quantitatively for the lower limit in property (1) and for (5), qualitatively for (3–4), and is not in contradiction with (2). References to these properties will be marked there by bullets \( \circ \). To achieve a quantitative agreement, more elaborate fitting will be needed.

III. THE L–T MODELS

The metric of the L–T models is:

\[
d s^2 = d t^2 - \frac{R_r^2}{1 + 2 E(r)} d r^2 - R^2(t, r)(d \vartheta^2 + \sin^2 \vartheta d \varphi^2),
\]

(3.1)

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\(^{1}\) Regions where the BB occurred earlier than in the background generate shell crossing singularities \(^3\) \(^4\).

\(^{2}\) Converted from keV to Hz by: \( 1 \text{eV} = 1.6 \times 10^{-19} \text{J} = h \times 0.24 \times 10^{13} \) Hz, where \( h = 6.626 \times 10^{-34} \) J s \(^8\) \(^9\).
where $E(r)$ is an arbitrary function. The source in the Einstein equations is dust; its (geodesic) velocity field is

$$u^\alpha = \delta^\alpha_0.$$  

(3.2)

Because of the assumption $\rho = 0$ built into this model, it is inadequate before the last-scattering epoch.

The function $R(t, r)$ is determined by

$$R_r^2 = 2E(r) + 2M(r)/R,$$  

(3.3)

$M(r)$ being another arbitrary function; we neglect the cosmological constant. We will consider only the models with $R_{,t} > 0$ and $E > 0$. The solution of (3.3) is then:

$$R(t, r) = \frac{M}{2E}(\cosh \eta - 1),$$

$$\sinh \eta - \eta = \frac{(2E)^{3/2}}{M}[t - t_B(r)],$$

(3.4)

where $t_B(r)$ is one more arbitrary function; the BB occurs at $t = t_B(r)$. The mass density is

$$\kappa \rho = \frac{2M_r}{R^2 R_r}, \quad \kappa \overset{\text{def}}{=} \frac{8\pi G}{c^2},$$

(3.5)

The $r$-coordinate is chosen so that

$$M = M_0 r^3,$$

(3.6)

and $M_0 = 1$ (kept in formulae for dimensional clarity).

The units used in numerical calculations were introduced and justified in Ref. [13]. Taking [13]

$$1\text{ pc} = 3.086 \times 10^{13}\text{ km}, \quad 1\text{ y} = 3.156 \times 10^7\text{ s},$$

(3.7)

the numerical length unit (NLU) and the numerical time unit (NTU) are defined as follows:

$$1\text{ NTU} = 9.8 \times 10^{10}\text{ y}.$$  

(3.8)

IV. LIGHT RAYS IN AN L–T MODEL

The geodesic null vector fields $k^\alpha$ in (3.3) obey [13]

$$(k^\alpha)^2 - \frac{R_r}{1 + 2E} \frac{k^\alpha}{k^\nu} - \frac{C^2}{R^2} = 0,$$  

(4.1)

with $C$ being constant along a geodesic.

The general formula for redshift is [14]

$$1 + z = \frac{(u_\nu k^\nu)_{\alpha}}{(u_\nu k^\nu)_{\nu}},$$

(4.2)

where $k^\mu$ is an affinely parametrised vector field tangent to a light ray connecting the source and the observer, both comoving with the cosmic medium with the four-velocity $u^\alpha$. The subscript “$e$” means “at the emission event”, “$o$” means “at the observation event”. We will consider past-directed rays, on which $k^t < 0$. We can rescale the affine parameter $\lambda$ so that

$$k^t(t_o) = -1.$$  

(4.3)

Then, with $u^\alpha$ being given by [13], we have

$$1 + z = -k^t.$$  

(4.4)

For nonradial rays, on which $C \neq 0$, the last term in (4.1) will go to infinity when $R \to 0$. Thus, at the BB

$$\lim_{R \to 0} |k^t| = \infty.$$  

(4.5)

Equations (4.3) and (4.4) imply that $z \to \infty$ at the BB on all nonradial rays, in agreement with Ref. [4].

For radial rays, $z \to -1$ as $R \to 0$ when $dt_B/dr \neq 0$ at the intersection of the ray with the BB, and $z \to \infty$ when $dt_B/dr = 0$ [13]. The result $z = -1$ implies infinite blueshift for all observers. Rays emitted close to, but not right at the BB will acquire a finite blueshift that can be overcompensated by later-acquired redshifts if the observation is carried out sufficiently far to the future from the emission point.

In consequence of (4.3), blueshifts may arise only on radial rays. Thus, for an observer re-directing her telescope away from the direction to the center of the radiation source, the transition from blueshift to redshift would occur abruptly – if the real Universe were exactly modelled by the L–T geometry. In reality, the changeover from blueshift to redshift can be expected to occur in a finite, but short time. This would account for the short-livedness of the GRBs (property (2) in Sec. II), their “afterglows” (property (4)) – see Sec. V for details.

In the following, past-directed radial rays are dealt with, on which $C = 0$. Using [11], the equations to be integrated numerically are:

$$\frac{dt}{d\lambda} = k^t,$$

$$\frac{dk^t}{d\lambda} = -(k^t)^2 \frac{R_{,tr}}{R_{,r}},$$

(4.6)

$$k^r = \pm \sqrt{1 + \frac{2E}{R_{,r}}} k^t,$$

$$\frac{dr}{d\lambda} = k^r,$$

(4.7)

with the initial condition (4.3). The sign in (4.7) is + on past-inward rays and − on past-outward rays.

In a general L–T model with $E \neq 0$ we have [7]

$$R_{,r} = \left(\frac{M_r - E_{,r}}{M} - \frac{E_{,r}}{E}\right) R + \Psi(t, r) R_{,t},$$

(4.8)

$$R_{,tr} = \frac{E_{,r}}{2E} R_{,t} - \frac{M_{,r}}{M} \Psi(t, r),$$

(4.9)

$$\Psi(t, r) \overset{\text{def}}{=} \left(\frac{3E_{,r}}{2E} - \frac{M_{,r}}{M}\right) (t - t_B) - t_{B,t}.$$  

(4.10)

As can be seen from (4.6) and (4.4), $R_{,tr} = 0$ is the locus of extrema of redshift along radial rays; we call it the maximum-redshift hypersurface (MRH).

Consider a radial ray proceeding to the past from an initial point that lies later than the MRH. The redshift
z on it increases from 0 to a maximum, achieved at the MRH. Further down the ray, z decreases. If the ray could continue to the BB, z would decrease to −1. However, the L–T model ceases to apply at the last-scattering hypersurface (LSH). Can z become sufficiently negative before the ray crosses the LSH for shifting the optical frequencies to the gamma-ray range? It is shown in Sec. V that this is indeed possible when the functions $E(r)$ and $t_B(r)$ are suitably chosen, and the observer is put in the right place at the right time.

**V. FITTING THE L–T MODEL TO OBSERVATIONS AND MEASUREMENTS**

The mass density at the instant of last scattering in the standard ΛCDM model is

$$\kappa_0 \rho_{05} \approx 88 \times 10^{9} \text{ (NLU)}^{-2}. \quad (5.1)$$

We assume that the recombination occurs at the same density also in an inhomogeneous Universe. The density along a ray is calculated using $5.2$, and the value of z at the moment when $\rho = \rho_{05}$ emerges from $5.2$ and $5.3$.

The GRBs cannot arise by blueshifting the whole black-body spectrum of the relic radiation to the gamma-ray range. First, the spectra of the GRBs do not have the black-body forms (example: Ref. $16$). Second, the intensity of a GRB created in this way would exceed the observed ones by tens of orders of magnitude.$^3$ So, if the GRBs arise by blueshifting the relic radiation, then the different frequencies have to be blueshifted individually.

To shift the lowest frequency of the hydrogen emission spectrum $15$, $\nu_{\text{Hmin}} = 4.054 \times 10^{13}$ Hz (corresponding to the wavelength of 7400 nm) to the lowest observed frequency of the gamma-ray bursts, $\nu_{\text{min}} \approx 0.24 \times 10^{19}$ Hz $8$, the blueshift $1 + z \approx 1.667 \times 10^{-3}$ is needed. To shift the frequency of the most intense line in the hydrogen spectrum, $2.1876 \times 10^{15}$ Hz (corresponding to 656.2852 nm) to the same minimum gamma-ray frequency, $1 + z \approx 1.9 \times 10^{-4}$ is needed. To shift the maximum measured hydrogen emission frequency, $\nu_{\text{Hmax}} = 3.2 \times 10^{15}$ Hz (corresponding to 93.782 nm) to the maximum recorded cosmic gamma-ray frequency, $\nu_{\text{max}} \approx 1.25 \times 10^{23}$ Hz $8$, $1 + z \approx 2.56 \times 10^{-8}$ is needed.$^4$

The configuration shown in Fig. 1 was obtained by fitting the functions $E(r)$ and $t_B(r)$ and the position of the observer by trial and error so as to make $1 + z$ as close to zero as possible. The current best result is

$$1 + z_{\text{mb}} = 1.23007568 \times 10^{-5} \quad (5.2)$$

between the LSH and now. This accounts for the lower end of frequencies in Property (1). This is the minimum z within the chosen class of BB profiles; other profile classes may possibly lead to smaller z.

![FIG. 1: The blueshifted ray, the bang-time profile and the profile of the maximum-redshift hypersurface in the L–T model described in the text. See the Appendix for the parameters of $t_B(r)$. The MRH is symmetric around the $r = 0$ line, but its left part is suppressed in this graph.](image)

For simplicity, $E$ was chosen the same as in a Friedmann model, with

$$2E/r^2 \text{ def } = -k = -0.4. \quad (5.3)$$

A general $E$ would have $-k$ replaced by $(−k + F(r))$, where $F(0) = 0$, but otherwise is arbitrary $7$. This would provide further parameters for fine-tuning.

The BB profile consists of a spherically symmetric hump surrounding the center of symmetry out to a finite distance; further away from the center $t_B$ is constant, and so the geometry is Friedmannian. The present time is $t = 0$, and the flat part of $t_B$ was chosen at

$$t \text{ def } t_B = -0.139455468904649 \text{ NTU} \approx -13.67 \times 10^9 \text{ years}; \quad (5.4)$$

this is the asymptotic value of $t_B$ in the L–T model that imitates accelerated expansion using nonconstant $t_B$ $3$.

A radial cross-section through the hump in the BB is shown in Fig. 2. It consists of two ellipse arcs (see Fig. 3 in the Appendix) that are connected by a straight line segment in the neighbourhood of the point, where the full ellipses would be tangent to each other. The lower ellipse arc is tangent to the flat part of the $t_B$ profile. This shape is determined by five parameters: four semi-axes of the two ellipses, and the tilt of the straight segment (see the Appendix for their values).

The inset in Fig. 2 shows the neighbourhood of the maximum of $t_B(r)$. The ray passes $D_t = 0.125 \times 10^{-3}$ NTU = $1.225 \times 10^5$ years over this maximum. The $D_t$ is also an adjustable parameter. The blueshift at the observer position is sensitive to the value of $D_t$ in certain ranges. For example, $D_t = 0.126395 \times 10^{-3}$ NTU results

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$^3$ The Planck formula and the current CMB spectrum $17$ imply $1.295 \times 10^9$ W/(cm$^2$ × sr × Hz) for the maximum intensity of the black-body spectrum blueshifted from LSH by $1 + z = 10^{-5}$. Observed GRBs have intensities below $10^{-24}$ W/(cm$^2$ × Hz) $24$.

$^4$ The most intense helium emission lines have wavelengths between 388 nm and 846 nm, i.e. within the range of the hydrogen spectrum $20$. 

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in $1 + z \approx 3.9 \times 10^{-5}$, while $\Delta t_c = 0.1264 \times 10^{-3}$ NTU results in $1 + z \approx 4.5 \times 10^{-2}$. Thus, a change in $\Delta t_c$ by $5 \times 10^{-5}$ NTU $\approx 49$ years causes that $1 + z$ goes up by the factor $0.87 \times 10^3$ – enough for the observed radiation to drift from the gamma-range into the ultraviolet [21]. The 49 years is not a sufficiently short time to account for the abrupt end of a GRB quantitatively, but the qualitative effect of afterglow is here, and thereby Property (4) is qualitatively accounted for.

But the abrupt beginning and end of a GRB and the afterglow should rather be associated with the center of the radiation source going into and off the line of sight than with the passage of time at the observer (see Sec. IV). The model predicts a discontinuous jump from redshift to blueshift and back to redshift for an arbitrarily small change in the direction of observation (which qualitatively accounts for Property (3)). In reality such a change might be provided, for example, by the orbital motion of the Earth. Then, the blueshifted ray would stay within the observer’s field of view only briefly, and this would implicitly account for Property (2).

If the center of the BB hump would stay in the observer’s line of sight all the time, then she would see the gamma radiation persisting for nearly the whole $\Delta t_c = 1.225 \times 10^7$ years. (But this is a property only of the concrete BB profile of Fig. 2. This does not exclude the existence of profiles providing shorter viewing times.) It would show up abruptly, because the ray emitted near the top of the hump would have large redshift.

The model of Fig. 1 cannot explain the highest-frequency end of the GRB spectrum [8] by means of blueshifting from the hydrogen emission range. This does not yet imply that the high-frequency GRBs must arise by a different mechanism: it is still an open question whether a finer-tuned L–T model could do the job.

A cosmological model that would account for the multitude of observed GRBs should be imagined as a Friedmann background containing many humps like the one in Fig. 2 of different shapes, different spatial extents and different heights above the flat part of $t_B(r)$, placed at different comoving positions.

Redshift is used in astronomy as the measure of distance. But blueshifting renders redshift – distance relations multivalued [12]. No operational method of determining the distance is known when blueshifts are present. The distance from the observer to the source of the ray in Fig. 1 can be estimated in two ways:

1. The intersection of the ray with the LSH occurs $\approx 13.3764 \times 10^9$ years ago, so by conventional accounting the source would be $13.3764 \times 10^9$ light years from the observer. This is $6.83 \times 10^8$ years later than the BB of the $\Lambda$CDM model, whose present age is 22.

$$T = 13.819 \times 10^9 \; y = 0.141 \; \text{NTU}. \quad (5.5)$$

2. The sum of the values of the $r$-coordinate of the observer ($r_O = 0.41946$) and of the intersection of the ray with the LSH ($r_{LSH} = 0.09841$) is $r_e = 0.51787$. The $r_e$ determines the active gravitational mass contained within the $r = r_e$ sphere centered at the observer by $M = M_0 r_e^3$. In the $\Lambda$CDM model, the same $r_e$ (corresponding to the same mass) is reached by the present observer’s past light cone at $t = t_e = -0.1279$ NTU, i.e. $\approx 1.25 \times 10^9$ years ago, which implies the distance $\approx 1.25 \times 10^9$ light years. This number is within the range of distances inferred from observations of the GRBs [6], and thereby Property (5) is accounted for.

The most obvious possibility to improve the model is to manipulate the shape and size of the BB hump seen in Fig. 1, for example, by putting more parameters into it. This may result in the rays staying before the MRH for a longer segment of the affine parameter, and thus in smaller observed values of $1 + z$.

The second possibility is to model the BB hump by the Szekeres metric [24, 25, 17]. It contains the L–T model as a subcase, but in general has no symmetry. Therefore, it must be verified what directions in the Szekeres class of metrics go over into the L–T radial directions, and whether blueshifts appear on them. A Szekeres model might produce a different time-profile of the observed frequency, and a better quantitative agreement with the observed properties of the GRBs.

VI. CONCLUSIONS

The model proposed here deals satisfactorily with the low end of the GRB frequency range (property (1) in Sec.
II) and with the low end of the distance range (property (5)). It also deals qualitatively with properties (3) and (4). Re (3): an arbitrarily small misalignment between the line of sight and the direction to the center of the radiation source causes the gamma-ray impulse to disappear. Re (4): the afterglow is present in the model of Sec. V, but its duration does not agree with observations. The only property not explicitly accounted for is (2). In order to account for it, one should calculate the change of observed frequency induced by a small change in the direction of observation. This is possible to do in the present model, but requires numerical calculations of a much higher precision.

Using a BB profile with more parameters, and modelling the BB hump using a Szekeres rather than the L–T metric may lead to a full quantitative agreement between the model and the observations.

Appendix A: The BB profile

The hump in the BB profile consists of two ellipse arcs and of a straight line segment joining them that passes through the point where the full ellipses would touch each other – see Fig. 3. The values of the parameters in Fig.

1 are $B_0 = 0.01$, $B_1 = 0.09$, $A_0 = 0.016$, $A_1 = 0.018$, $x_0 = 0.000859$. The other ones are uniquely determined by these. The units for $A_0$ and $B_0$ are NTU; the other parameters are dimensionless. The values of $A_0$ and $B_0$ imply for the time difference between the maximum of $t_B$ and its flat part 0.026 NTU = $2.548 \times 10^9$ years (0.18 of the age of the Universe given by 5.5).

FIG. 3: Parameters of the bang-time profile (drawn not to scale for better readability). See text for the actual values.