DURATION OF DISTANT SUPERNOVA OF TYPE Ia

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ABSTRACT

Durations of distant Supernovae of type Ia were estimated from published light curves. The obtained relation between duration of spark and redshift (i.e. distance to Supernova) is closely consistent with eternal Universe.

INTRODUCTION

Presumably, Supernova arises due to detonation of atmosphere of old massive star, which is followed by ejection of huge amount of substance, comparable with mass of Sun. However, the ejected substance is just a small fraction of star, and spark of Supernova is not a “death of star”. Majority of observed Supernovae corresponds to “type Ia”. This type is specified by the absence of hydrogen and by abundance of silicon in the ejected substance (mostly carbon and oxygen). Supernovae of type Ia are expected to be almost identical, and spark from Supernova of this kind is often used as “standard candle” for estimation of distances in the Universe.

As rule, measurements of Supernova luminosity are performed with use of broad-band color filters. Popular UBVRI standard system of broad-band color filters is specified in Tab. 1. This system consists of 5 color filters for measurements at 5 passbands: U-band (dark violet to near ultraviolet), B-band (deep blue), V-band (visually colorless), R-band (red), I-band (dark red to near infrared).

Tab. 1 UBVRI (Johnson-Cousins) broad-band standard system (Bessel, 2005).

Passband	Central (effective) wavelength	Peak wavelength[a]	Mean spectral range (>50 % of peak)	Cut-off spectral range (>5 % of peak)[a]
I-band	7980 Å	~8060 Å	7210-8750 Å	~7120-9080 Å
R-band	6407 Å	~6000 Å	5617-7197 Å	~5520-8370 Å
V-band	5448 Å	~5300 Å	5028-5868 Å	~4820-6470 Å
B-band	4361 Å	~4280 Å	3916-4806 Å	~3720-5400 Å
U-band	3663 Å	~3700 Å	3338-3988 Å	~3080-4100 Å

[a] values taken from graph in Bessel (2005)

In accordance with Big Bang theory, any extragalactic object moves outward the Earth. Thus, duration of Supernova spark should increase with its velocity in accordance with Doppler law:

$$d = d_o\{1+v/c\} \qquad (1)$$

Here d_o is “true duration” of spark, v is velocity of Supernova, and c is speed of light. Time dilation arises because the emission from decaying spark comes to observer from distance $r_o + vd_o$, with delay in time by vd_o/c.

In accordance with Hubble law, velocity of extragalactic object is defined by:

$$v/c = \lambda/\lambda_o - 1 = Z \qquad (2)$$

Here Z is scaled redshift, λ_o is initially emitted wavelength, λ is observed wavelength.

Thus, apparent duration of spark should rise with redshift in accordance with:

$$w = d/d_o = (1+Z\} \qquad (3)$$

Here w is so called "width factor".

As obtained by Goldhaber et al (2001), Eq (3) is almost exact relation, and thus, "tired-light theories" of eternal Universe are "simply ruled out". Theory is a fine thing, but let us cast a look on observations.

LIGHT CURVES

The flux light curves of Supernovae of type Ia, measured with broad-band filters, are closely consistent with semi-empirical approximation (see Fig.1):

$$F = a\times\{(t-b)/2 + |t-b|/2\}^2\times\exp\{-6\times(t-b)/d\} \qquad (4)$$

Here F is flux (i.e. luminosity of spark) measured on arbitrary linear scale (e.g. counts per second), a is scaling factor, b is timescale offset, 6 is conversion factor, and d is duration of spark. The conversion factor 6 was introduced in order to adjust parameter d to the duration of spark, which may be estimated "by eye" from the shape of light curve. If flux is measured, e.g., in ergs per day and per m^2, parameter a in Eqs (4) has units of ergs per day^3 and per m^2.

At timescale offset b = 0, Eq. (4) is reduced to:

$$F = a\times t^2\times\exp(-6\times t/d) \qquad (5)$$

Initial parabolic rise of emission (see Eq. 5) is conditioned by almost linear rise in size and thus, parabolic rise in area of Supernova image, whereas exponent term reflects cooling of Supernova due to energy losses on light emission. Initially measured flux always contains contribution from background emission. As a common rule, observers present flux data with subtracted background. Because of this, measured flux rises from zero and then drops to zero.

It should be noted, that the "apparent duration of spark" varies with definition of this parameter. Because of this, values of duration of spark, reported by different authors, can not be compared directly. From the other hand, duration of spark, defined by Eq. (4), gives exact value for model "rise time":

$$t_{rise} = d/3 \qquad (6)$$

Rise time, t_{rise}, is duration of rising branch of light curve, taken from zero to maximum flux. This parameter is weakly dependent on applied approximation. Because of this, rise times, reported in various studies, are more or less comparable.

In Fig. 1, the light curves for distant supernovae are shown, as reported by Guy el al (2007), Astier et al (2006), Goldhaber et al (1996), Knop et al (2003), and Howell et al (2005) are shown. Solid curves are best fits to data in accordance with Eq. (4). The best-fit values of durations of sparks are given in Tab. 2.

Tab. 2 Best fit values of duration (in accordance with Eq. 4) of distant Ia type Supernovae at Red (d_R), and Infrared (d_I) passbands at various redshifts (Z).

Z	d_R, days	d_I, days	Name	Reference
0.285	68.44[a]	78.38[a]	SNLS-03D4ag	Guy et al (2007)
0.358	59.74[a]	74.63[a]	SNLS-04D3fk	Astier et al (2006)
0.374	63.29	-	SN 1994H	Goldhaber (1996)
0.44	61.71	76.03[b]	SN 1998aw	Knop et al (2003)
0.497	61.45	-	SN 1998ax	Knop et al (2003)
0.516	65.16[a]	79.62[a]	04D4in	Howell et al (2005)
0.543	66.12[a]	72.49[a]	SN 2000fr	Knop et al (2003)
0.644	45.89	65.35[b]	SN 1998be	Knop et al (2003)
0.74	57.40	68.80[b]	SN 1998bi	Knop et al (2003)
0.91	49.35[a]	64.99[a]	SNLS-04D3gx	Astier et al (2006)

[a] best-fit offsets to timescale, b (see Eq. 4), for Red and Infrared passbands were averaged

[b] value of the offset to timescale, b (see Eq. 4), was set equal to best-fit value for Red passband

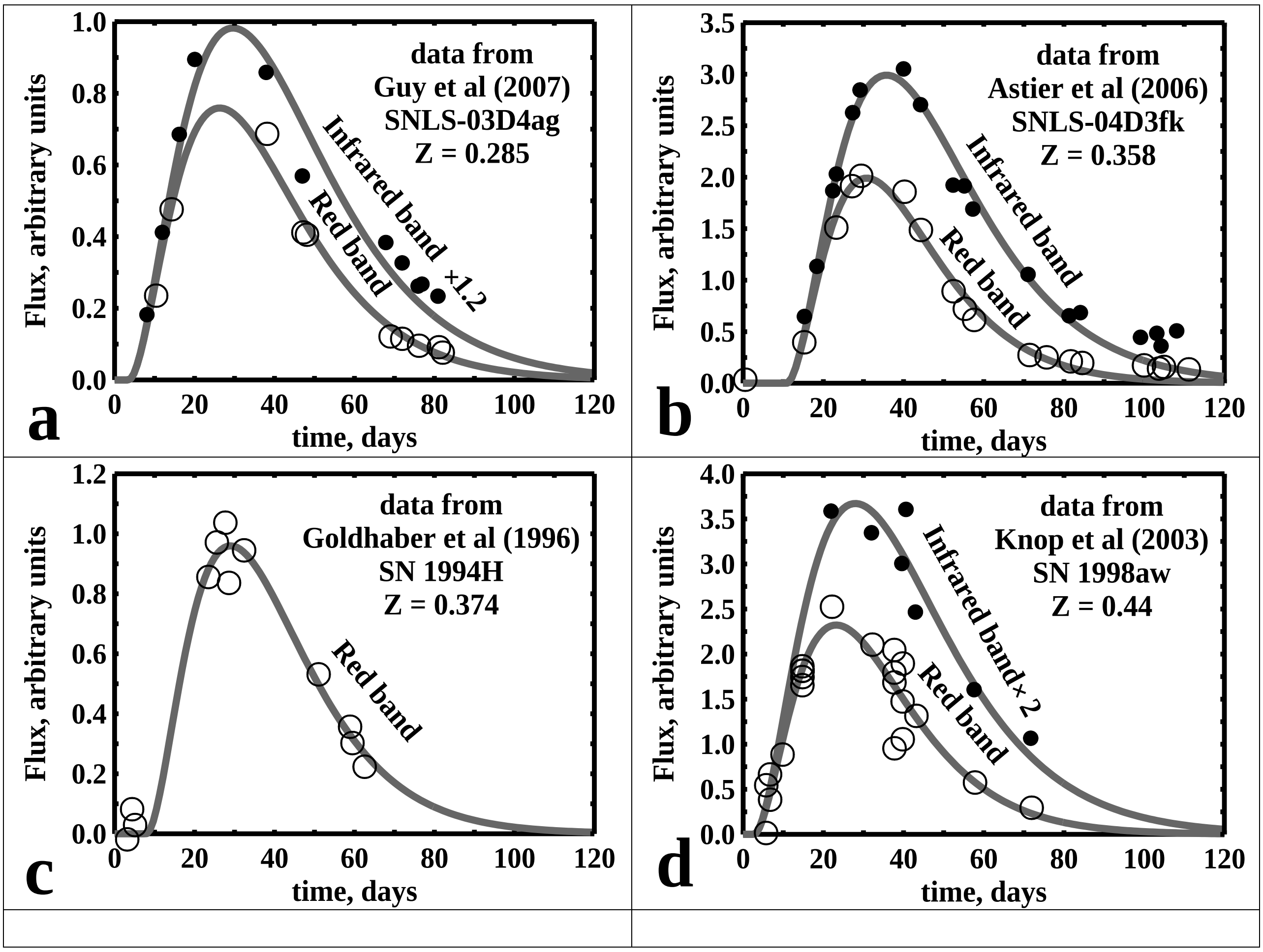

Fig. 1 Light curves of distant Supernovae. Data (a) from Guy (2007); (b, j) from Astier et al (2006); (c) from Goldhaber et al (1996); (d, e, g, h, i) from Knop et al (2003); (f) from Howell et al (2005). Time scales are given with arbitrary offsets to original timescales. Open circles: Red band data. Closed circles: Infrared band data. Curves: best fits to data, calculated with use Eq. (4). Data given with arbitrary offsets to original timescales.

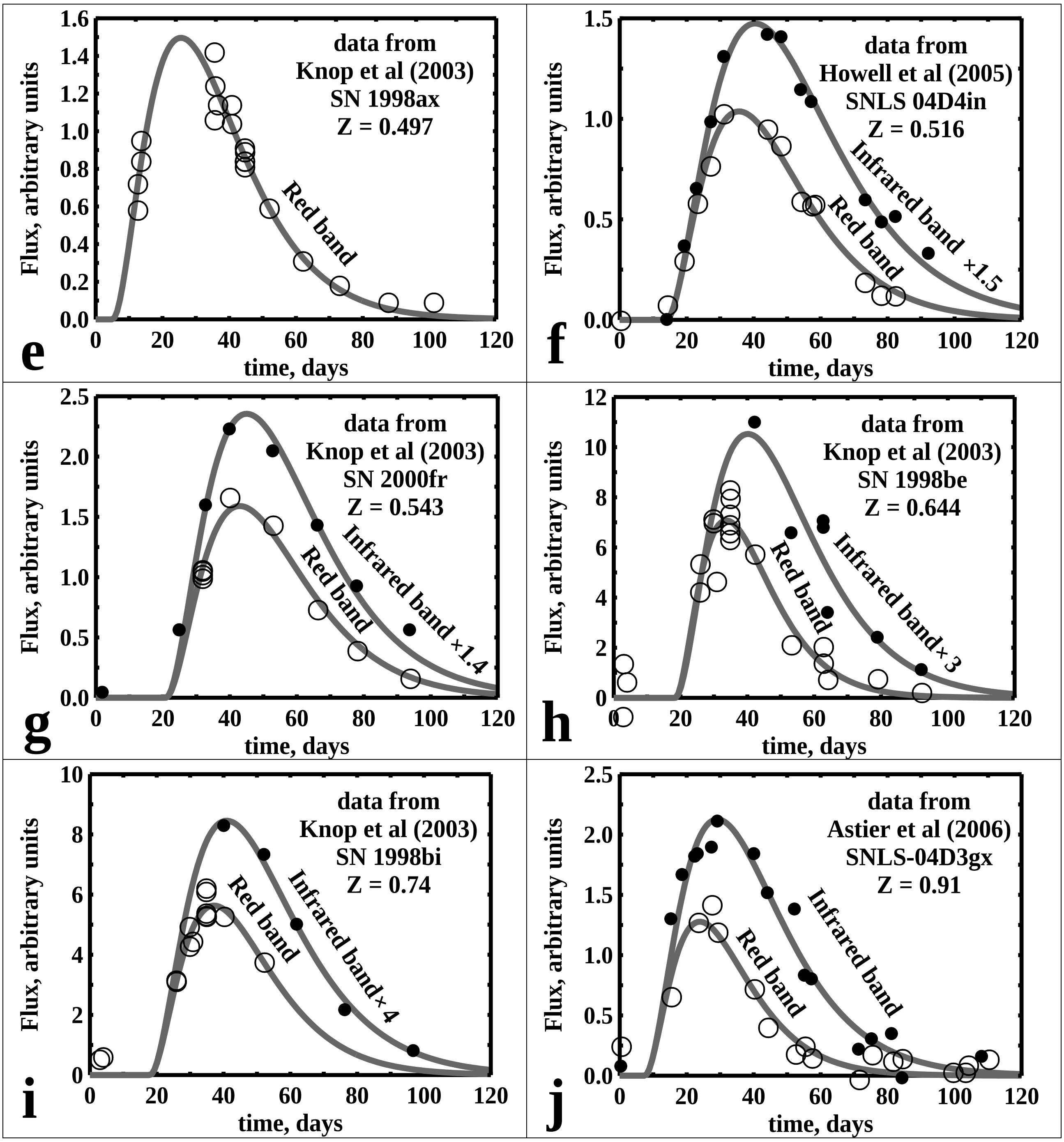

Fig. 1 (continued)

ANALYSIS OF MODEL RESULTS

In Fig. 2, the best fit durations of sparks from Tab. 2 are plotted versus redshift. Dashed curve is best fit to data, calculated in accordance with Goldhaber equation (Eq. 3):

$$d,\ \text{days} = 41.55\times(1+Z) \qquad (7)$$

Standard deviation of Eq (7) is 14.76 days; maximum deviation from data is 30.01 days. Much closer consistence with data in Fig. 2 was obtained with use of approximation (see solid curves):

$$d,\ \text{days} = 0.01909\times[\lambda_{CW},\ \text{Å}]/(1 + Z + 0.01909\times[\lambda_{CW},\ \text{Å}]/251) \qquad (8)$$

Here λ_{CW} is central wavelength of corresponding color filter of UBVRI standard system (6407 Å for Red band and 7980 Å for Infrared band; see Tab 1), Z is redshift, parameter = 251 days is expected duration of heat emission in the limit $\lambda \rightarrow \infty$. Standard deviation of Eq. (8) is 4.63 days, maximum deviation from data is 11.5 days.

Evidently, duration of distant Supernovae decreases with redshift. Fortunately, this does not mean that all these Supernovae are falling onto our heads with sub-light speeds, as may be expected from Eq. (1). As may be clearly seen in Fig. 1, duration of hot (red) emission is substantially shorter than that for cold (infrared) emission. As Supernova cools down upon explosion, this is expectable result. From the other hand, observed red emission at redshift Z = 0.3÷0.9 was initially more hot (green-to-violet). Thus, decrease of duration with redshift is also expectable result.

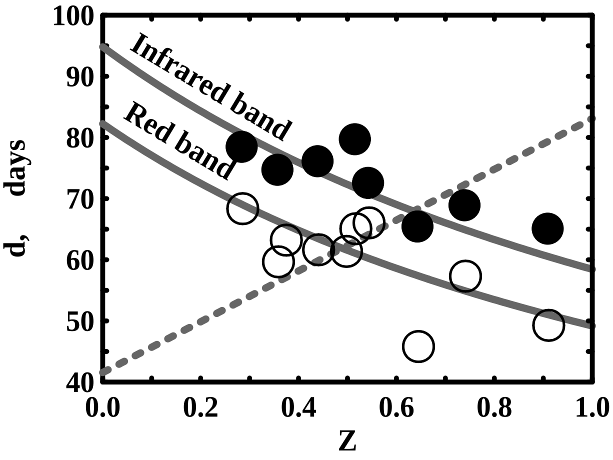

Fig. 2 Best-fit durations of distant Supervovae at Red (open circles) and Infrared (closed circles) bands (see Tab 2). Dashed curve: Eq. (7). Solid curves: Eq. (8).

Initially emitted wavelength may be estimated from redshift and central (~ observed) wavelength of color filter:

$$\lambda_o \approx \lambda_{CW}/(1+Z) \qquad (9)$$

With use of this relation, Eq. (8) may be rewritten as:

$$d,\ \text{days} \approx 0.01909\times[\lambda_o,\ \text{Å}]/(1+0.01909\times[\lambda_o,\ \text{Å}]/251) \qquad (10)$$

As may be seen from Eq. (10), at any initial wavelength, duration of Supernova is independent on the distance to the Earth, as expected from theory of tired light (see Pivovarov, 2016).

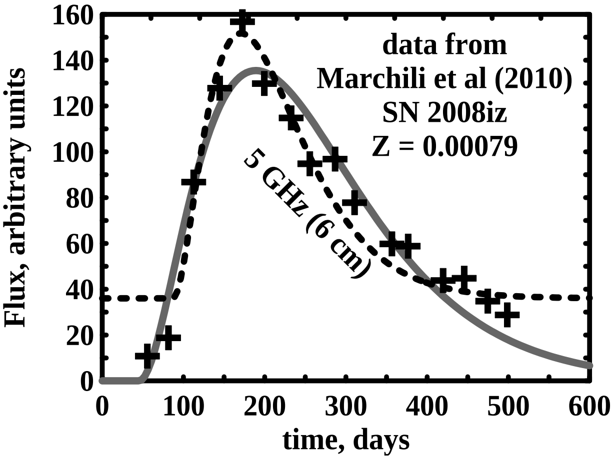

Fig. 3 Radio light curve from SN 2008iz at 5 GHz (= 6 cm). Data from Marchili et al (2010). Zero time is 1 January 2008. Solid curve: best fit with Eq. (4). Dashed curve was calculated with correction to background emission and duration fixed at d = 251 days.

In Fig. 3, the radio light curve of Supernova SN 2008iz at 5 GHz (λ = 6 cm) from Marchili et al (2010) is shown. Distance to host galaxy M82 was estimated at 3.5 Mps (thus, Z = 0.00079). The best fit duration of radio emission is 431 days (see solid curve in Fig. 3). This value is substantially larger than 251 days, expected from Eq. (8). However, taking into account for extremely distant extrapolation, this seems to be rather close hit. Besides, due to large background emission (peak flux in Fig. 3 is ~ 4.5 % of background), the value d = 251 days may be even closer to reality (see dashed curve in Fig. 3).

In Fig 4, the light curves for two nearby Supernovae: “overluminous” SN 2007if (Scalzo et al, 2010) and “extremely low luminosity” SN 2008ha (Foley et al, 2009). As reported by Scalzo et al (2010) redshift for SN 2007if is 0.07416. The distance to the host galaxy (UGC 12682) of SN 2008ha was reported by Foley et al (2009) at 21.3 Mpc. Thus, redshift of SN2008ha is 0.0048. Based on spectral data, both SN 2007if and SN 2008ha were classified to Ia type, with remarks “peculiar”, and “unusual”. In both cases, data were presented as magnitudes. In Fig. 4, these values were converted to arbitrary flux scale with use of common relation:

$$F_m = 10^{\wedge}\{0.4\times(m_{peak} - m)\} \qquad (11)$$

Here F_m is flux, converted from measured magnitude m, m_{peak} is measured magnitude at peak luminosity. Data in Fig. 4 were fitted to

$$F_m = a\times\{(t-b)/2 + |t-b|/2\}^2\times\exp\{-6\times(t-b)/d\} + f \qquad (12)$$

Here f is additional fitting parameter, accounting for background emission.

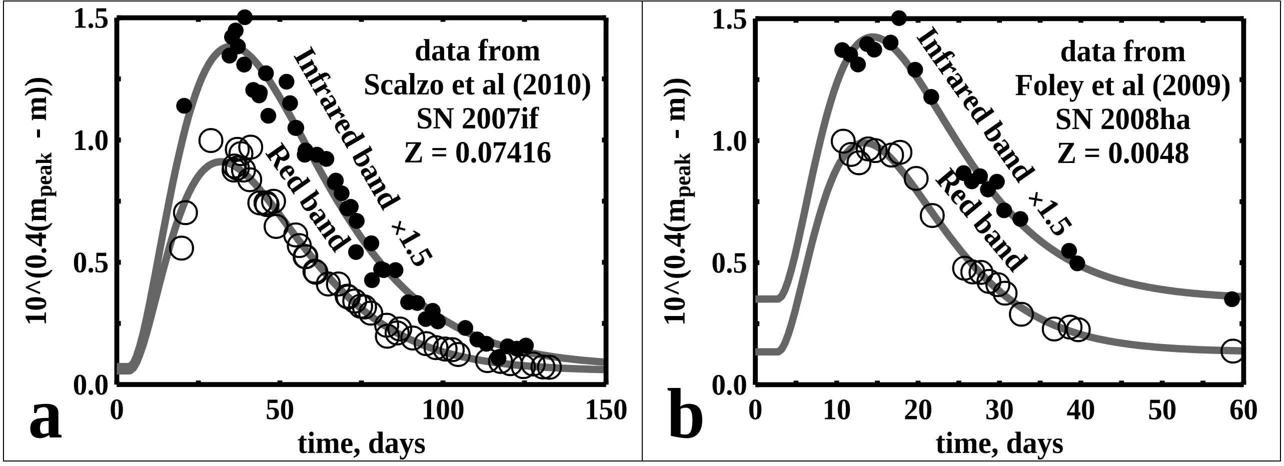

Fig. 4. Red (open circles) and Infrared (closed circles) light curves for “overluminous” SN 2007if (a) and “extremely low luminosity” SN 2008ha (b). Data (a) from Scalzo et al (2010) and (b) from Foley et al (2009). Data given with arbitrary offsets to original timescales. Curves: best fits (Eq. 12).

The best fit duration of SN 2007if (see Fig 4a) is 84.14 and 93.70 days at Red and Infrared bands, correspondingly. These values are close to predictions of Eq. (8): 78.33 and 90.62 days, correspondingly. Thus, it is likely, that Eq. (8) reflects sequence of "overluminous" Supernovae.

Integration of Eq. (5) from $t = 0$ to $t = \infty$ gives relation:

$$E = (2a/6^3)\times d^3 = 0.25\times a\times t_{rise}^3 \qquad (13)$$

Here E is energy, collected by telescope during event (at given passband). As may be seen from Eq. (13), energy, emitted by Supernova, is directly proportional to cube of duration of spark. Light emission comes from hot substance, ejected by Supernova. Thus, similar relation may be expected also for ejected mass.

Best fit duration of SN 2008ha (see Fig 4b) is 31.94 and 34.92 days at Red and Infrared bands, correspondingly. These values are 2.57 ÷ 2.71 times smaller than expected from Eq. (8). Thus, total mass, ejected by SN 2008ha, was ~ 2.64^3 = 18 times smaller then that for average "overluminous" Supernova. For instance, as estimated by Foley et al (2009), SN 2008ha ejected 0.15 Solar masses, whereas "total mass of system" (?) for "overluminous" SN 2007if was estimated by Scalzo et al (2010) at ~ 2.4 Solar masses, i.e. 16 times larger than for SN 2008ha.

Almost all observed nearby Supernovae fall into the range between SN 2007if and SN 2008ha. However, "overluminous" Supernova is not an upper limit. There are also "monsters".

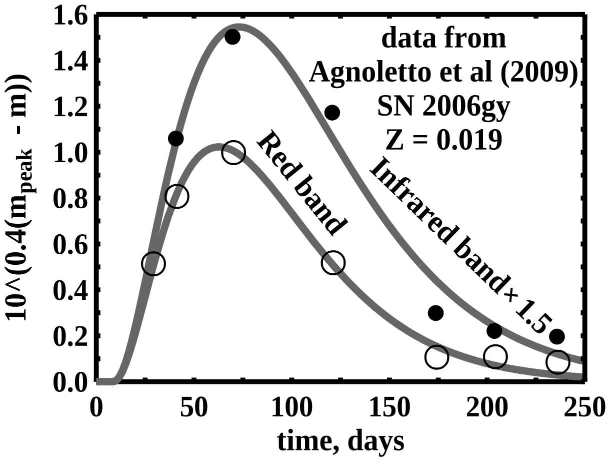

Fig. 5 Red (open circles) and Infrared (closed circles) light curves of SN 2006gy. Data from Agnoletto et al (2009). Zero time is 20 August 2006. Curves: best fits to data (Eq. 4).

Perhaps, an absolute record is nearby (Z ~ 0.019) SN 2006gy (see Fig 5). This Supernova was spectrally classified to IIn type (i.e., this event is slightly outside of scope), and "M_{ej}" (?) was estimated at 5 ÷ 14 Solar masses (Agnoletto et al, 2009), i.e. ~2 ÷ 6 times larger than for "overluminous" SN 2007if, and ~ 33 ÷ 93 times larger than for "extremely low luminosity" SN 2008ha. From Eq. (4), best fit duration of SN 2007if is 161.6 and 192.5 days at Red and Infrared bands, correspondingly (see solid curves in Fig.5). These values are 1.99 ÷ 2.05 times larger than expected from Eq. (8). Thus, total mass, ejected by Supernova SN 2006gy, was about ~ 2^3 = 8 times larger than for average "overluminous" Supernovae, and ~ 8×2.64^3 = 147 times larger than for "extremely low luminosity" Supernova.

Variability of ejected masses may explain result, obtained Goldhaber (2001). Indeed, "extremely low luminosity" Supernovae are invisible at large distances, and observations are limited to explosions from the most massive stars. Thus, combining average data for nearby Supernovae with data for "overluminous" Supernovae at Z ~ 0.5, one may obtain distinctive illusion of time dilation.

CONCLUDING REMARKS

Dilation of time is absent. Observations of distant Supernovae are consistent with eternal Universe. NO BIG BANG!!! UNIVERSE FOREVER!!!

REFERENCES

Agnoletto I., Benetti S., Cappellaro E., Zampieri L., Turatto M., Mazzali P., Pastorello A., Della Valle M., Bufano F., Harutyunyan A., Navasardyan H., Elias-Rosa N., Taubenberger S., Spiro S. (2009) SN 2006gy: Was it really extraordinary? The Astrophysical Journal 691 (2009) 1348-1359. (www.iopscience.iop.org/article/10.1088/0004-637X/691/2/1348/pdf)

Astier P. Guy J., Regnault N., Pain R., Aubourg E, Balam D., Basa S., Carlberg R.G., Fabbro S., Fouchez D., Hook I.M., Howell D.A., Lafoux H., Neill J.D., Palanque-Delabrouille N., Perrett K., Pritchet C.J., Rich J., Sullivan M., Taillet R., Aldering G., Antilogus P., Arsenijevic V., Balland C., Baumont S., Bronder J., Courtois H., Ellis R.S., Filiol M., Gonçalves A.C., Goobar A., Guide D., Hardin D., Lusset V., Lidman C., McMahon R., Mouchet M., Mourao A., Perlmutter S., Ripoche P., Tao C., Walton N. (2006) The Supernova Legacy Survey: measurement of Ω_M, Ω_Λ and w from the first year data set. Astronomy & Astrophysics 447 (2006) 31-48. (www.aanda.org/articles/aa/pdf/2006/07/aa4185-05.pdf)

Bessel M.S. (2005) Standard photometric systems. Annu. Rev. Astron. Astrophys 43 (2005) 293-336. (www.astro.caltech.edu/~george/ay122/Bessel2005ARAA43p293.pdf)

Foley R.J., Chornock R., Filippenko A.V., Ganeshalingam M., Kirshner R.P., Li W., Cenko S.B., Challis P., Friedman A.S., Modjaz M., Silverman J.M., Wood-Vasey W.M. (2009) SN 2008ha: An extremely low luminosity and extremely low energy Supernova. The Astrophysical Journal 138 (2009) 376-391.
(www.web.mit.edu/asf/www/Papers/Foley_et_al_2009.pdf)

Goldhaber G., Deustua S., Gabi S., Groom D., Hook I., Kim A., Kim M., Lee J., Pain R., Pennypacker C., Perlmutter S., Small I., Goobar A., Ellis R., McMahon R., Boyle B., Bunclark P., Carter D., Glazebrook K., Irwin M., Newberg H., Filippenko A.V., Matheson T., Dopita M., Mould J., Couch W. (1996) Observation of cosmological time dilation using type Ia Supernovae as clocks. The Supernova Cosmology Project: III. (http://arxiv.org/pdf/astro-ph/9602124.pdf)

Goldhaber G., Groom D.E., Kim A., Aldering G., Astier P., Conley A., Deustua S.E., Ellis R., Fabbro S., Fruchter A.S., Goobar A., Hook I., Irwin M., Kim M., Knop R.A., Lidman C., McMahon R., Nugent P.E., Pain R., Panagia N., Pennypacker C.R., Perlmutter S., Ruiz-Lapuente P., Schaefer B., Walton N.A., York T. (2001) Timescale stretch parameterization of type Ia Supernova B-band light curves. The Astrophysical Journal 558 (2001) 359-368.
(www.iopscience.iop.org/article/10.1086/322460/pdf)

Guy J., Astier P., Baumont S., Hardin D., Pain R., Regnault N., Basa S., Carlberg R.G., Conley A., Fabbro S., Fouchez D., Hook I.M., Howell D.A., Perrett K., Pritchet C.J., Rich J., Sullivan M., Antilogus P., Aubourg E., Bazin G., Bronder J., Filiol M., Palanque-Delabrouille N., Ripoche P., Ruhlmann-Kleider V. (2007) SALT2: Using distant Supernovae to improve the use of type Ia supernovae as distance indicators. Astronomy & Astrophysics 466 (2007) 11-21.
(www.aanda.org/articles/aa/pdf/2007/16/aa6930-06.pdf)

Howell D.A. Sullivan M., Perret K., Bronder T.J., Hook I.M., Astier P., Aubourg E., Balam D., Palanque-Delabrouille N., Pritchet C.J., Regnault N., Rich J., Taillet R., Knop R., McMahon R.G., Perlmutter S., Walton N.A. (2005) Gemini Spectroscopy of Supernovae from the Supernova Legacy Survey: improving high-redshift Supernova selection and classification. The Astrophysical Journal 634 (2005) 1190-1201.
(www.iopscience.iop.org/article/10.1086/497119/pdf)

Knop R.A., Aldering G., Amanullah R., Astier P., Blanc G., Burns M.S., Conley A., Deustua S.E., Doi M., Ellis R., Fabbro S., Folatelli G., Fruchter A.S., Garavini G., Garmond S., Garton K., Gibbons R., Goldhaber G., Goobar A., Groom D.E., Hardin D., Hook I., Howell D.A., Kim A.G., Panagia N., Pennypacker C.R., Perlmutter S., Quimby R., Raux J., Regnault N., Ruiz-Lapuente P., Sainton G., Schaefer B., Schahmaneche K., Smith E., Spadafora A.L., Stanishev V., Sullivan M., Walton N,A., Wang L., Wood-Vasey W.M., Yasuda N. (2003) New constrains on Ω_M, Ω_Λ and w from an independent set of 11 high-redshift Supernovae observed with HST. The Astrophysical Journal 598 (2003) 102-137.
(www.www-supernova.lbl.gov/public/papers/knop03/knop03_ApJ.pdf)

Marchili N., Martí-Vidal I., Brunthaler A., Krichbaum T.P., Müller P., Liu X., Song H.-G., Bach U., Beswick R., Zensus J.A. (2010) The radio lightcurve of SN 2008iz in M82 revealed by Urumqi observations. Astronomy & Astrophysics 509 (2010) A47
(www.aanda.org/articles/aa/pdf/2010/01/aa13126-09.pdf)

Pivovarov S. (2016) Universal red shift. Basis, The Journal of Basic Science 4 (2016) 19-26. (www.basisj.narod.ru/Basis2016_19-26.pdf)

Scalzo R.A., Aldering G., Antilogus P., Aragon C., Bailey S., Baltay C., Bongard S. Buton C., Childress M., Chotard N., Copin Y., Fakhouri H.K., Gal-Yam A., Gangler E., Hoyer S., Kasliwal M., Loken S., Nugent P., Pain R., Pécontal E., Pereira R., Perlmutter S., Rabinowitz W., Rau A., Rigaudier G., Gunge K., Smadja G., Tao C., Thomas R.C., Weaver B., Wu C. (2010) Nearby Supernova factory observations of SN 2007if: first total mass measurement of a super-Chandrasekhar-mass progenitor. The Astrophysical Journal 713 (2010) 1073-1094.
(www.iopscience.iop.org/article/10.1088/0004-637X/713/2/1073/pdf)