Tired Light and Type Ia Supernovae Observations

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Abstract

The phenomenon known as "supernova timescale stretching" was discovered by measuring the observed light curve broadening and by measuring the rate of spectra evolution (aging) for Type Ia supernovae. In modern cosmology this phenomenon is widely considered as one that rules out the "tired light" hypothesis. The redefined "tired light" hypothesis presented in this paper not only agrees with the supernova timescale stretching but actually explains it without employing universe expansion. Using Type Ia supernova spectra template, I have conducted a computer simulation study of light propagation from a supernova to an observer based on the tired light assumptions. The results of the simulation for "at rest" UBVRIYJHK bands do not contradict the astronomical observations related to light curve broadening and spectra aging.

1. Introduction

In 2001, a group of cosmologists from Supernova Cosmology Project lead by Gerson Goldhaber published an article "Timescale Stretch Parameterization of Type Ia Supernova B-band Light Curves" [1]. While analyzing explosions of Type Ia supernovae, they discovered a dependency of the width of B-band light curves on the supernova redshift. They found that the light curve width is proportional to factor (1+Z), where Z is redshift. In the article they came to the conclusion that this dependency *"provides independent evidence for cosmological expansion as the explanation of redshifts".* The conclusion is based on the idea that supernovae with high redshift are receding from us so fast that the light emitted at the end of the explosion travels a much longer way than the light emitted at the beginning of the explosion. As a result, the observed light curve gets broaden. The important part of the work is the proof of universality timescale stretching. The authors rule out tired light theories because they *"would not yield this slowing of the light curves".*

In 2008, a group of cosmologists lead by Stéphane Blondin suggested another approach for measuring the timescale stretching of supernova explosion. In their work "Time Dilation in Type Ia Supernova Spectra at High Redshift" [2], they suggested to measure timescale stretching by the rate of spectra aging. They found that the spectra of low redshift supernovae changes in a consistent way. By comparing the rate of spectra aging for low and high redshift supernovae, it is possible to measure timescale stretching factor. They found that the aging rate is proportional to 1/(1+Z) factor, which conforms to the results of Goldhaber group and supports *"homogeneous and isotropic expanding universe".* Blondin et al. also rules out the tired light hypothesis saying *"this hypothesis does not predict a time dilation effect"*.

In my work I show that the tired light hypothesis does not contradict to astronomical observations related to light curve broadening and spectra aging of Type Ia supernovae. Furthermore, these observations can be explained within the tired light paradigm.

2. Explaining timescale stretching in Type Ia supernovae within "tired light" paradigm

Term "tired light" covers a class of theories that explain the redshift by the photon energy depletion effect. These theories differ from one another by physical mechanism of energy depletion. Louis Marmet presented detailed overview of tired light mechanisms suggested over the years [3]. These mechanisms can be divided into two major categories: light interactions with baryonic matter and non-baryonic interactions of light.

The interactions with baryonic matter include the following: gravitational drugging [4], Compton effect [4], atomic secondary emission [5], electronic secondary emission [6], interactions with intergalactic gas [7], plasma redshift [8]. The Stark effect suggested for plasma redshift was recently observed in laboratory [9].

The non-baryonic interactions include a loss of energy due to light interaction with microwaves and radio-waves [10], finite conductivity and viscosity of vacuum in space [11], losing energy into quantum vacuum [12], constant fading of light as a physical wave in the propagation medium [13]. The last three mechanisms actually may be united into one as they all are based on the idea of constant energy loss into light propagation medium – aether or quantum vacuum. This mechanism does not imply such phenomena as scattering, blurring or non-uniform redshift which are traditionally attributed to "tired light" model by its opponents. The mechanism of constant energy loss does not violate the laws of conservation of energy and momentum because considers a photon as an open system interacting with the propagation medium and not as an isolated system in empty space.

The further development of "tired light" model suggests that the portions of light moving in interstellar space should experience slight variations in speed due to variations in the properties of light propagation medium. Such variations are the subject of modern quantum physics which suggests that the refractive index of vacuum gets affected by quantum fluctuations and by the presence of electrical and magnetic fields. Stephen Barnett states that vacuum "*is not an empty nothing but contains randomly fluctuating electromagnetic fields… Light propagating through space interacts with the vacuum fields, and observable properties, including the speed of light, are in part determined by this interaction*" [14]. Ellis et al. argue that *"quantum-gravitational fluctuations in the space-time background give the vacuum non-trivial optical properties ... causing stochastic fluctuations in the velocity of light in vacuo*" [15]. Klaus Scharnhorst states that "*QED vacua under the influence of external conditions (background fields, finite temperature, boundary conditions) can be considered as dispersive media whose complex behaviour can no longer be described in terms of a single universal vacuum velocity of light c*" [16]. Leuchs et al. suggest that the permittivity and the permeability of free space "*would be connected to fundamental physical processes, the polarization and the magnetization of virtual pairs in vacuum*" [17].

In simple words, the photons travel in interstellar space by "bumpy road". Based on the Central Limit Theorem one may suggest that the travelling time of photons has Gauss distribution. The idea of photon travelling time having Gauss distribution was suggested by Alexander Chepick [18][19]. The longer the travelling path, the higher the standard deviation of photons travelling time. Higher standard deviation leads to the observation of longer duration of supernova explosion, lower brightness and slower specta aging.

3. Computer simulation of light propagation

In my study I express the standard deviation in days and assume that zero redshift corresponds to zero standard deviation. The intrinsic stretch-factor *s* is not taken into consideration and assumed to be equal to 1. Another assumption is that the standard deviation is the same for all the wavelengths, even though it is possible to suggest that the standard deviation may depend on wavelength. The latter is the subject for a future research.

To test the redetermined tired light hypothesis I have developed a computer program that simulates propagation of photons from a supernova to an observer on Earth. The simulation can be executed in two modes: “tired light” and “standard cosmology”. The program is implemented in the C# programming language. It is available for download as open source freeware [20]. I use a spectral template of Type Ia supernovae with zero redshift maintained by Eric Hsiao [21][22] for input data. This template is based on more than 1000 spectral measurements and contains data for each day (epoch) of explosion in the range from -20 to 84 epochs. The data for each day contains spectral flux density characteristics in the range from 1000 to 25000 Angstrom binned to 10 Angstrom. Another portion of input data are filter transmission curves for UBVRIYJHK bands. I apply UBVRI transmission data of Johnson-Bessel filters used in the MONET project [23]. For YJHK bands I use transmission data of filters used in the LBT telescope at Mount Graham International Observatory [24].

The photons get emitted with interval of 0.01 day. On each emission the number of photons for each spectral bin is determined by the formula

$$N_\lambda(t) = k \cdot F_\lambda(t) \cdot \lambda \qquad (1)$$

$F_\lambda(t)$ - Spectral flux density for certain wavelength and moment of time in the supernova reference frame. It is calculated on the basis of the spectral template using linear approximation.

λ - Wavelength

t - Moment of time in the supernova reference frame; at the beginning moment of the explosion $t = 0$

k - Arbitrary coefficient

The number of photons is a factitious value. The coefficient k is chosen in a way that provides a sufficient number of photons that is large enough to ensure statistical quality and low enough to have reasonable simulation running time.

The energy possessed by each photon on emission is calculated by formula (2).

$$e_\lambda(t) = \frac{F_\lambda(t) \cdot 1s \cdot 10\text{Å} \cdot 1\text{m}^2}{N_\lambda(t)} \qquad (2)$$

The value of $e_\lambda(t)$ is also a factitious value which is required solely for the reconstruction of spectrum in the observer’s frame of reference.

For each emitted photon the program calculates the arrival moment of time t' in the observer reference frame. For the “standard cosmology” mode, the arrival moment of time is calculated by formula (3).

$$t' = t \cdot (1 + Z) + T_0 \qquad (3)$$

Z - Redshift

T_0 - Travelling time of the photons emitted at the beginning moment of the explosion.

For "tired light" mode, the arrival moment is calculated as follows.

$$t' = t + Gauss(T, \sigma) \qquad (4)$$

$Gauss$ - Random number generator with Gauss distribution

T - Mean of photon travelling time

σ - Standard deviation of photons travelling time entered as an input parameter

The values of T_0 and T are chosen arbitrary. The only consideration is that they should be essentially larger than any observed duration of the explosion. At the observer' site, for each received photon the values of wavelength, energy and arrival time are known; therefore it is possible to reconstruct spectra of received light with or without redshift. The non-shifted spectra can be determined using formula (5). From here on I use term "non-shifted" instead of "at rest" because in the tired light model both supernova and the observer are at rest (in cosmological scale).

$$F_\lambda(t') = \frac{\sum e_\lambda(t')}{1s \cdot 10\text{Å} \cdot 1\text{m}^2} \qquad (5)$$

A non-shifted light curve in terms of flux at certain band is determined as follows.

$$F(t') = 1s \cdot \sum_\lambda \left[I_\lambda(t') \cdot r_\lambda \cdot 10\text{Å} \right] \qquad (6)$$

r_λ - Filter transmission coefficient for specific wavelength

The non-shifted light curve in terms of the magnitude is determined as follows.

$$m(t') = -2.5 \cdot Log_{10}\left(\frac{F_{B\max}}{F(t')} \right) \qquad (7)$$

$F_{B\max}$ - Maximum flux in B-band

The simulation output includes spectra, flux light curves, and magnitude light curves that are mapped to epochs in a way that epoch 0 corresponds to the moment of t' when the flux in the B-band has maximum value.

4. Light curve broadening in UBVR bands

The fact that spectral template of Eric Hsiao ends on the 85th day since B-maximum imposes certain limitations on simulation results. The problem is that the photons that would be issued after 85th day, but with the travelling time less than the mean, do not contribute to the simulation results. In order to cut off incorrect output data I use the rule of “three sigma”. For example, if the standard deviation of travelling time is 10 days, then the results after 55th day should be ignored.

The magnitude light curves (non-shifted) for various standard deviations in UBVR bands are shown with some magnitude offset in Figure 1.

The width-factor w of timescale stretching was determined as a ratio between light curve widths with non-zero and zero standard deviations. The measurements were taken for rising and falling fragments of the light curve as well as for the whole curve at certain magnitude offsets (Δm) from the maximum. The summary of measurements of light curve broadening in UBVR bands is shown in Table 1.

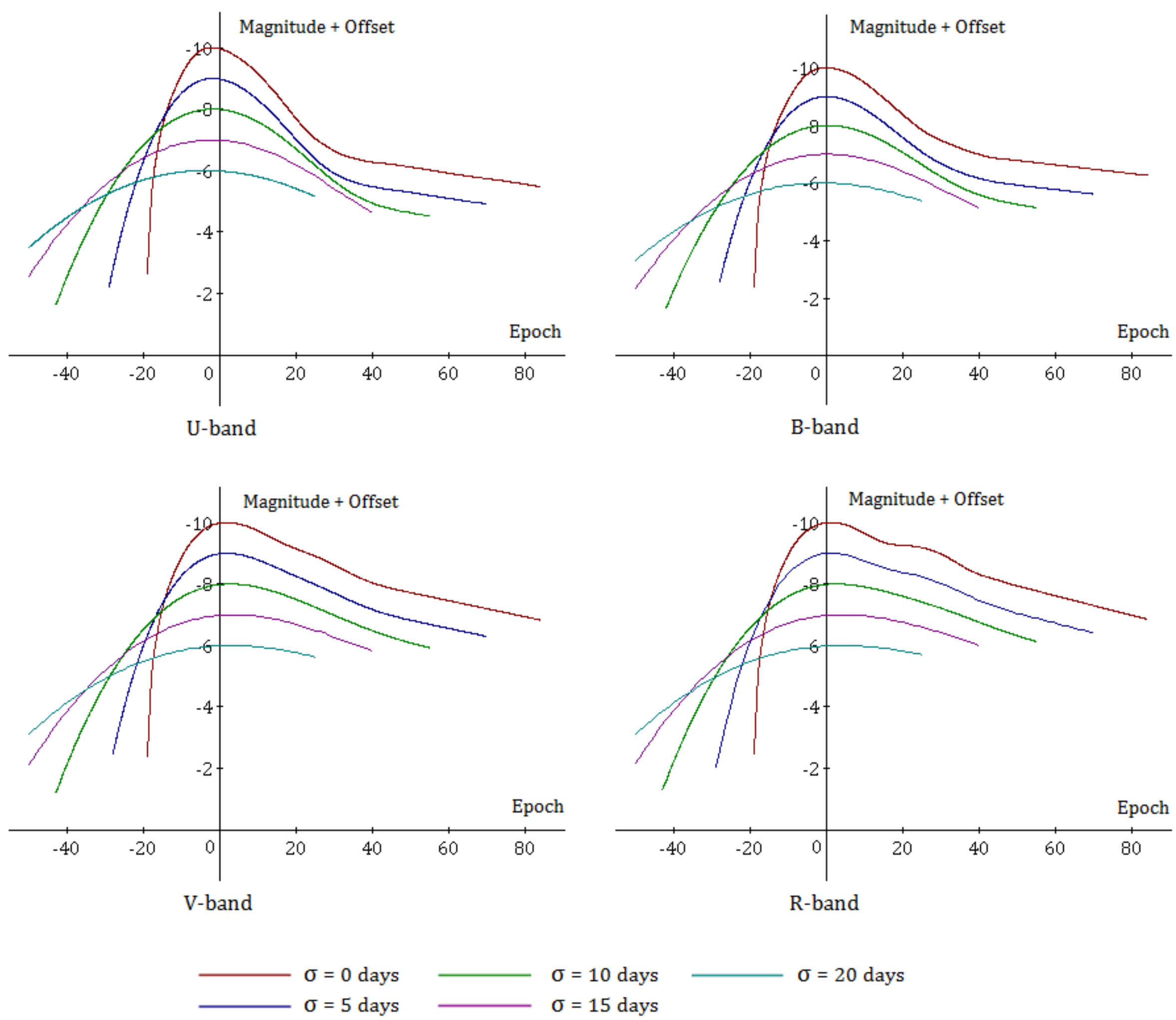


Figure 1

The magnitude light curves in non-shifted UBVR bands

Table 1 - Measurements of light curve broadening in non-shifted UBVR bands

Fragment	Δm	U		B		V		R	
		Width	w	Width	w	Width	w	Width	w
σ = 0 days									

Rise	0.5	7.2	1	7	1	8.5	1	8	1
Rise	1	9.5	1	9.5	1	11.5	1	10.8	1
Rise	2	12.8	1	13.1	1	15	1	14.4	1
Rise	3	14.9	1	15.4	1	17.4	1	16.7	1
Fall	0.5	7.6	1	9.6	1	11.5	1	11.3	1
Fall	1	12	1	14.4	1	21	1	28.5	1
Fall	2	18.8	1	23.2	1	38.5	1	47	1
Fall	3	26.2	1	39.8	1	75.5	1	78.4	1
Whole	0.5	14.8	1	16.6	1	20	1	19.3	1
Whole	1	21.5	1	23.9	1	32.5	1	39.3	1
Whole	2	31.6	1	36.3	1	53.5	1	61.4	1
Whole	3	41.1	1	55.2	1	92.9	1	95.1	1
σ = 5 days									
Rise	0.5	8.3	1.15	9.0	1.29	10.1	1.19	9.6	1.20
Rise	1	11.4	1.20	12.4	1.31	13.8	1.20	13.1	1.21
Rise	2	15.8	1.23	16.9	1.29	18.6	1.24	19	1.32
Rise	3	18.9	1.27	20.2	1.31	22.0	1.26	21.4	1.28
Fall	0.5	9.9	1.30	10.6	1.10	13.4	1.17	14.9	1.32
Fall	1	14.4	1.20	15.8	1.10	22.6	1.08	29.2	1.02
Fall	2	21.9	1.16	25.6	1.10	42.2	1.10	50.6	1.08
Fall	3	30.7	1.17	46.0	1.16	-	-	-	-
Whole	0.5	18.2	1.23	19.6	1.18	23.5	1.18	24.5	1.27
Whole	1	25.8	1.20	28.2	1.18	36.4	1.12	42.3	1.08
Whole	2	37.7	1.19	42.5	1.17	60.8	1.14	69.6	1.13
Whole	3	49.6	1.21	66.2	1.20	-	-	-	-
σ = 10 days									
Rise	0.5	12	1.67	12.7	1.81	14	1.65	14.3	1.79
Rise	1	16.7	1.76	17.4	1.83	19.3	1.68	19.8	1.83
Rise	2	23.4	1.83	24.4	1.86	28.5	1.90	26.8	1.86
Rise	3	28.6	1.92	29.6	1.92	31.8	1.83	32.2	1.93
Fall	0.5	13.2	1.74	14.5	1.51	17	1.48	19.8	1.75
Fall	1	18.8	1.57	20.8	1.44	26.5	1.26	31.6	1.11
Fall	2	28.5	1.52	33.3	1.44	49.3	1.28	-	-
Fall	3	40.7	1.55	-	-	-	-	-	-
Whole	0.5	25.2	1.70	27.2	1.64	31	1.55	34.1	1.77
Whole	1	35.5	1.65	38.2	1.60	45.8	1.41	51.4	1.31
Whole	2	51.9	1.64	57.7	1.59	77.8	1.45	-	-
Whole	3	69.3	1.69	-	-	-	-	-	-
σ = 15 days									
Rise	0.5	16.5	2.29	16.70	2.39	17.60	2.07	18.70	2.34
Rise	1	23.2	2.44	23.50	2.47	24.70	2.15	26.00	2.41
Rise	2	32.6	2.55	33.10	2.53	34.50	2.30	35.70	2.48
Rise	3	39.6	2.66	40.20	2.61	42.00	2.41	43.20	2.59
Fall	0.5	16.9	2.22	18.20	1.90	21.50	1.87	23.70	2.10
Fall	1	24.4	2.03	25.40	1.76	33.00	1.57	36.20	1.27
Fall	2	37	1.97	42.20	1.82	-	-	-	-
Whole	0.5	33.4	2.26	34.90	2.10	39.10	1.96	42.40	2.20
Whole	1	47.6	2.21	48.90	2.05	57.70	1.78	62.20	1.58
Whole	2	69.6	2.20	75.30	2.07	-	-	-	-
σ = 20 days									
Rise	0.5	19.6	2.72	22.7	3.24	22	2.59	23.30	2.91
Rise	1	28.2	2.97	31.3	3.29	30.9	2.69	32.40	3.00
Rise	2	40.3	3.15	43.6	3.33	43.2	2.88	45.20	3.14
Fall	0.5	23.2	3.05	21.7	2.26	27	2.35	27.30	2.42
Whole	0.5	42.8	2.89	44.4	2.67	49	2.45	50.60	2.62

The measurement results in graphical form are shown in Figure 2 in form of dependency of width-factor w on standard deviation of travelling time σ for various fragments and magnitude offsets from the maximum.

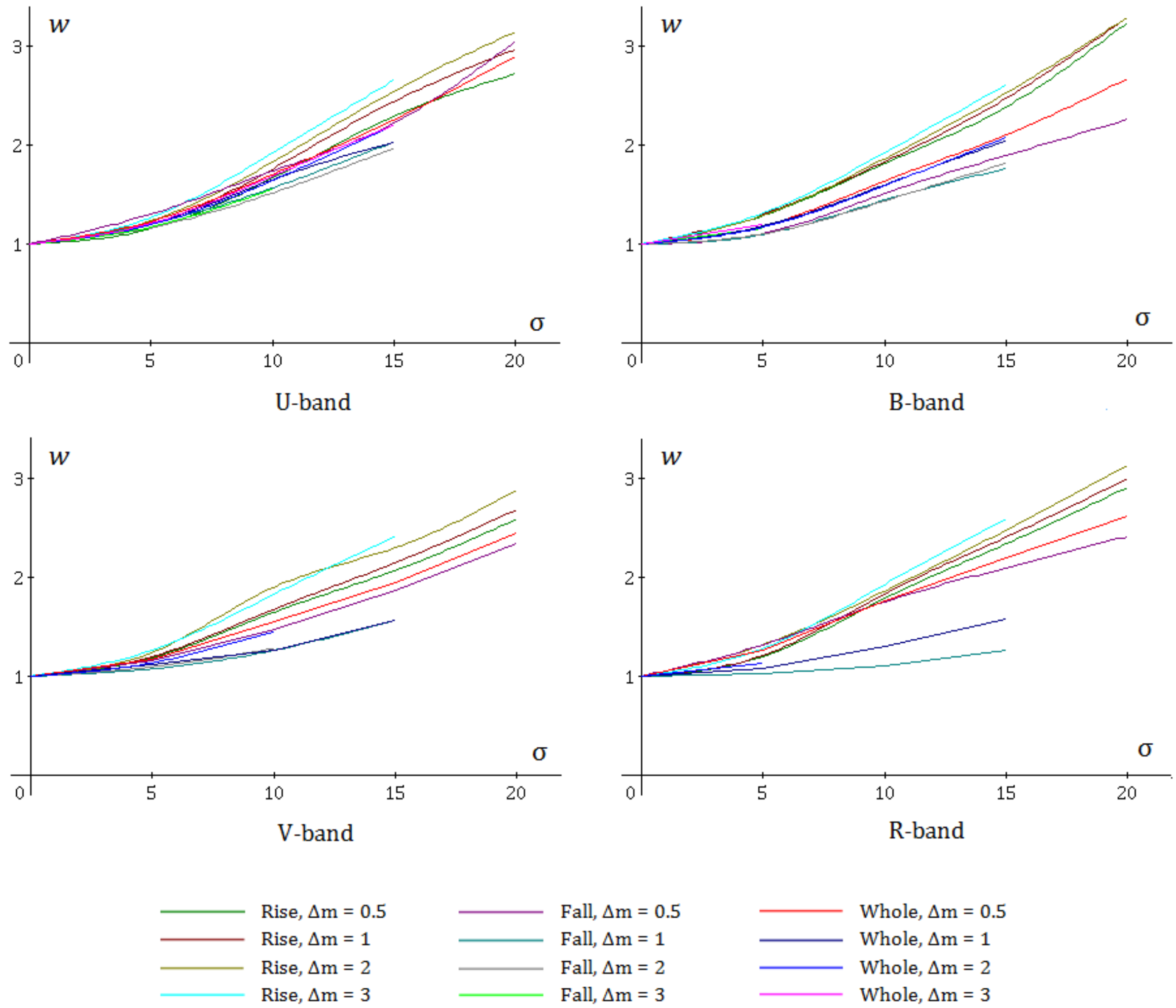


Figure 2

Dependency of width-factor on standard deviation of photons travelling time in non-shifted UBVR bands

The width-factor measurements presented in Table 1 and Figure 2 show that timescale stretching is not universal in tired light model. It varies depending on the band, magnitude offset from maximum and the fragment of a light curve. This contradicts the results reported by Goldhaber et al. [1]. The Goldhaber group was analyzing timescale stretching of Type Ia supernova light curves in B-band using the method of Composite Light Curve on the basis of photometric measurements of 12 low redshift supernovae from Calán/Tololo Survey and 35 high redshift supernovae reported by The Supernova Cosmology Project (SCP). They found it remarkable that the final composite light curve (Figure 1f in [1]) appeared homogeneous. This result was presented as a proof of the universality of timescale stretching. The intermediate transformations applied while building the composite light curve were based on the values of width-factor w and stretch-factor s measured by Perlmutter et al. [25] for the SCP high-redshift supernovae. The Perlmutter group has measured light curve widths, width- and stretch-factors by fitting observed photometric points to B-band light curve template and applying timescale stretching factor *1+Z* universally. It is no mystery why the Goldhaber composite light curve looks so homogeneous. In simple words the logic used by the Goldhaber group can be expressed like this: *If A is true then A is true, therefore A is correct*. The proof of the universality of timescale stretching based on such logic cannot be accepted.

The light curves for UBVR bands in terms of normalized flux are shown in Figure 3. The flux is normalized to the unity of flux maximum at zero redshift.

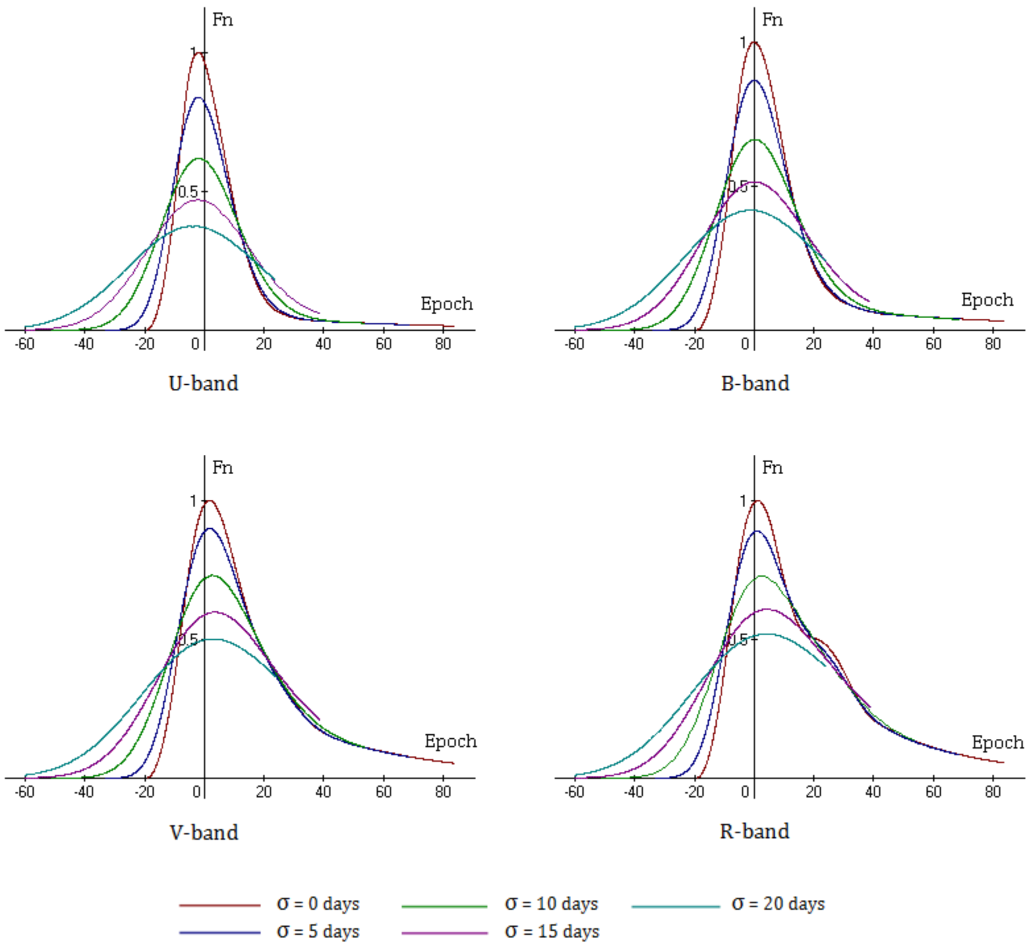


Figure 3

Normalized flux light curves in non-shifted UBVR bands

5. Light curve broadening in IYJHK bands

The magnitude light curves (non-shifted) for various standard deviations in IYJHK bands are shown in Figure 4 with some magnitude offset. The width-factor for light curves in IYJHK bands cannot be measured separately for rising and falling parts because two maximums in a curve gradually transform into one with the increase of standard deviation of travelling time. So the width-factors were determined by measuring the total width. The results are presented in Table 2 and Figure 5.

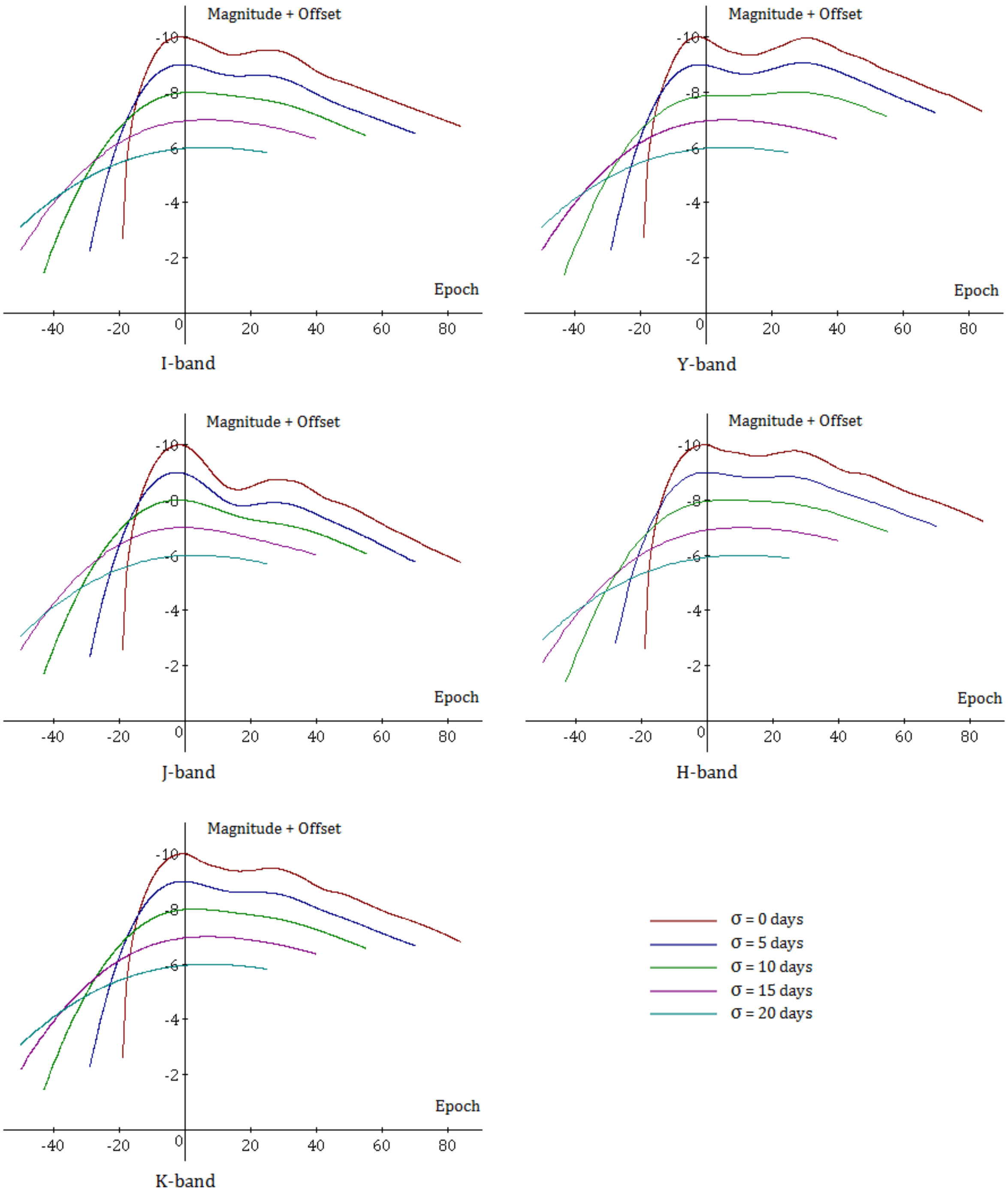


Figure 4

The magnitude light curves in non-shifted IYJHK bands

Table 2 - Measurements of light curve broadening in non-shifted IYJHK bands

Fragment	Δm	I		Y		J		H		K	
		Width	w	Width	w	Width	w	Width	w	Width	w
σ = 0 days											
Whole	0.5	36.2	1	49.4	1	12.9	1	42.4	1	34.0	1
Whole	1	47.7	1	61.6	1	18.8	1	54.1	1	47.9	1

Whole	1.5	57.1	1	73.3	1	49.3	1	68.8	1	61.5	1
Whole	2	70.3	1	84.8	1	57.9	1	81.8	1	72.6	1
σ = 5 days											
Whole	0.5	39.9	1.10	55.6	1.13	16.9	1.31	46.10	1.09	40.0	1.18
Whole	1	52.1	1.09	68.3	1.11	25.3	1.35	61.20	1.13	53.9	1.13
Whole	1.5	63.4	1.11	94.1	1.28	55.3	1.12	75.00	1.09	67.2	1.09
Whole	2	76.8	1.09	-		66.8	1.15	88.60	1.08	79.9	1.10
σ = 10 days											
Whole	0.5	43.6	1.20	57.7	1.17	28.1	2.18	50.00	1.18	45.2	1.33
Whole	1	61.1	1.28	73.6	1.19	53.2	2.83	68.00	1.26	62.9	1.31
Whole	1.5	75.3	1.32	-	-	69.1	1.40	-	-	77.5	1.26
Whole	2	-	-	-	-	81.6	1.41	-	-	-	-
σ = 15 days											
Whole	0.5	49.2	1.36	59.5	1.20	42.3	3.28	52.8	1.25	49.8	1.46
Whole	1	-	-	-	-	65	3.46	-	-	71.4	1.49

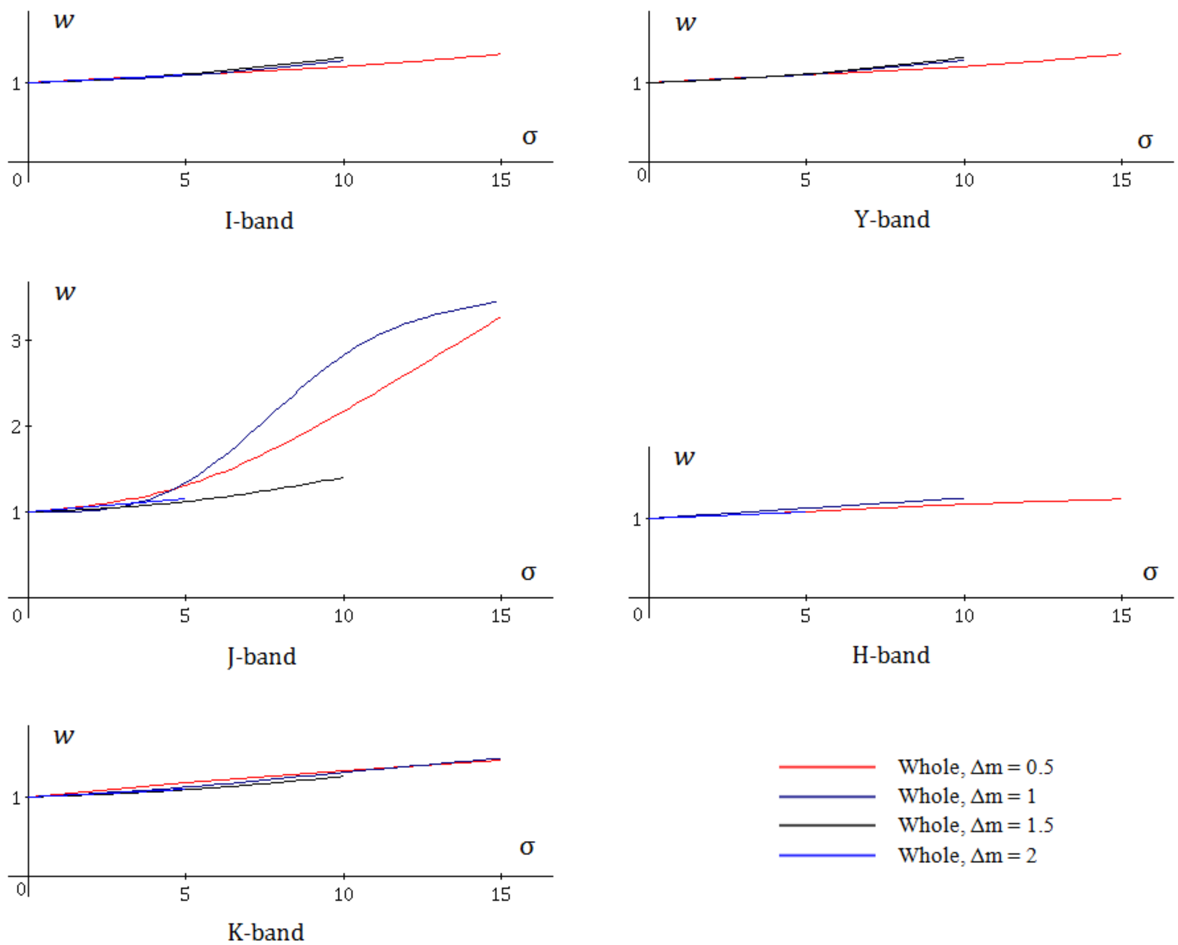


Figure 5

Dependency of the width-factor on standard deviation of photons travelling time in non-shifted IYJHK bands

The light curves for IYJHK bands in terms of normalized flux are shown in Figure 6. The flux is normalized to the unity of flux maximum at zero redshift.

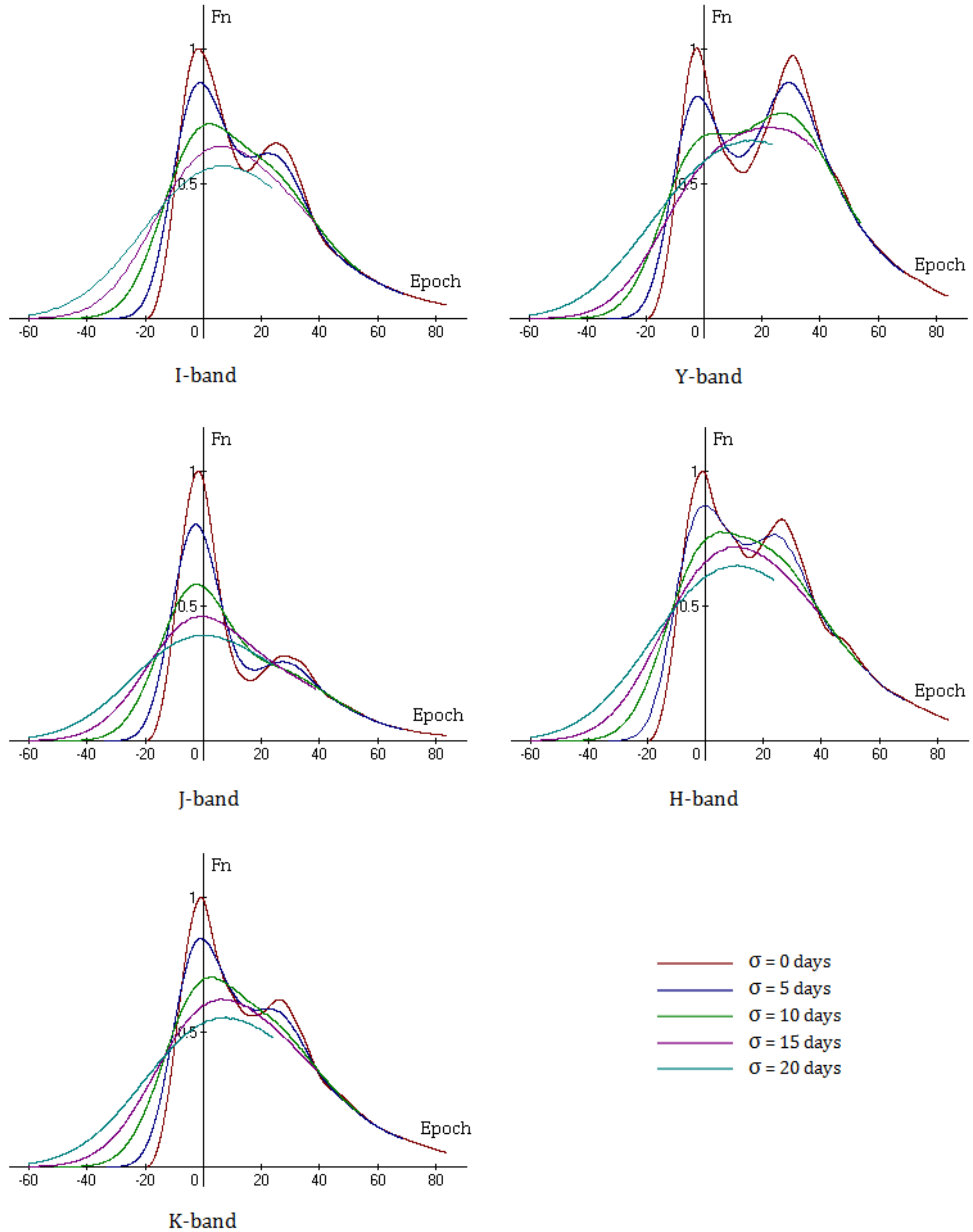


Figure 6

Normalized flux light curves in non-shifted IYJHK bands

Figures 4 and 6 show that with the increase of the standard deviation of travelling time, the second maximum gradually disappears from the IYJKH light curves. This can be used as a good test for the validity of tired light paradigm. In order to validate this result against available observations I reviewed photometric measurements in non-shifted ("at rest") I-band for 21 high-Z supernova which are listed in Table 3. These measurements are available at The Carnegie Supernova Project web-site [26].

Table 3 - Reviewed SN from Carnegie Supernova Project

SN	Z	Source	SN	Z	Source	SN	Z	Source
SN6699	0.311	SDSS	05D2dw	0.417	SNLS	05D1dn	0.566	SNLS
SN4679	0.332	SDSS	04D1rh	0.435	SNLS	03D4gl	0.571	SNLS
d149wcc4_11	0.342	Essence	e108wdd8_4	0.469	Essence	04D1oh	0.590	SNLS
05D2mp	0.354	SNLS	05D2bv	0.474	SNLS	04D2an	0.620	SNLS
05D4fo	0.373	SNLS	05D1ix	0.490	SNLS	04D1sk	0.663	SNLS
05D4cw	0.375	SNLS	04D1pg	0.515	SNLS	05D2bt	0.679	SNLS
SN5183	0.390	SDSS	05D2eb	0.534	SNLS	05D2ck	0.698	SNLS

Most of the SNs have photometric measurements that do not provide a clear indication of the presence or absence of the second maximum. One may consider SN 05D4cw as fitting to a light curve template with two maximums but on the other hand it has only three photometric points and fits well enough to the light curve with one maximum as it is shown in Figure 7 (highlighted by red). Another striking case is 05D2bv which fits better to one-maximum curve than to two-maximum (Figure 8). The original images for Figures 7 and 8 are obtained from CSP web-site.

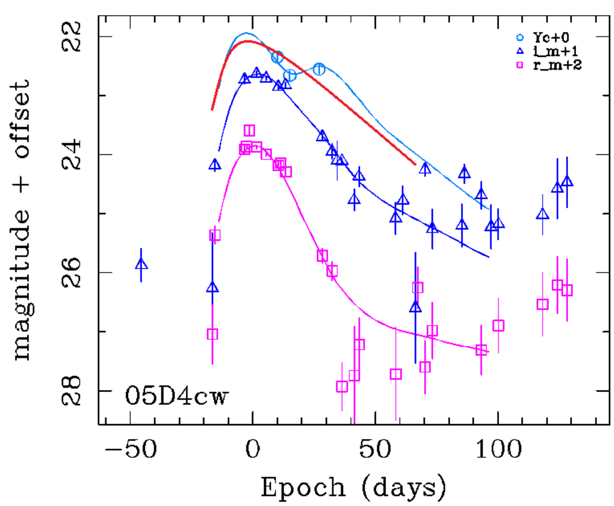


Figure 7

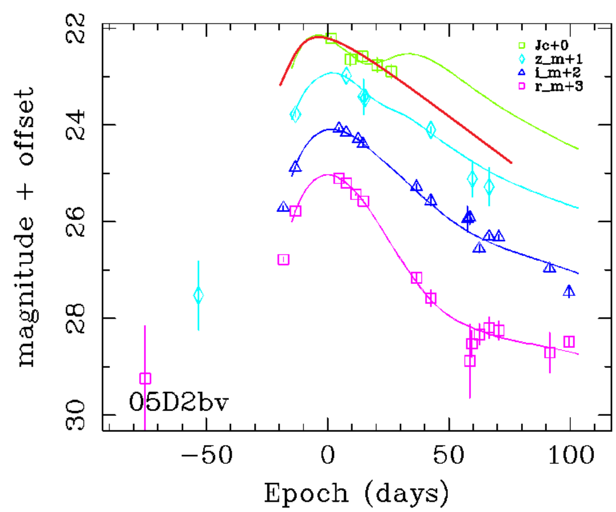


Figure 8

The photometric observations in infrared and near-infrared bands available today for high-Z supernovae cannot be used to confirm or rule out the tired light hypothesis. These measurements should be more systematic and have better frequency and accuracy. However, it is possible to say that at least the tired light hypothesis does not contradict to available observations in infrared and near-infrared bands.

6. Spectra Aging

In the presented tired light model the photons issued at the same time will reach the observer on different days. This means that the observed spectra will differ from the original. The conducted simulation study shows that with the increase of standard deviation of travelling time the spectrum gets more blurry but still remains recognizable as Type Ia. Figure 9 shows spectrum at Epoch 0 for various values of σ.

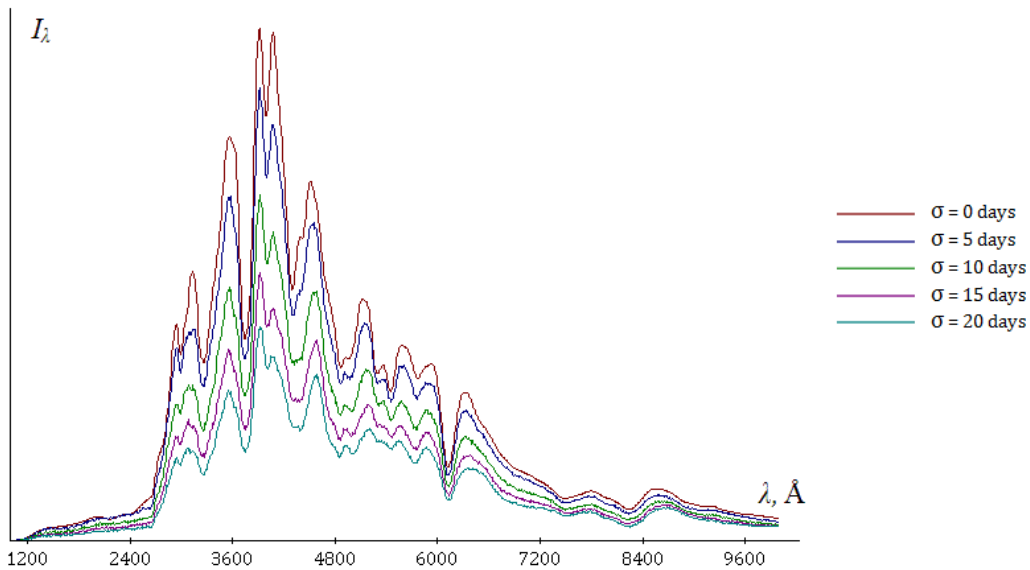
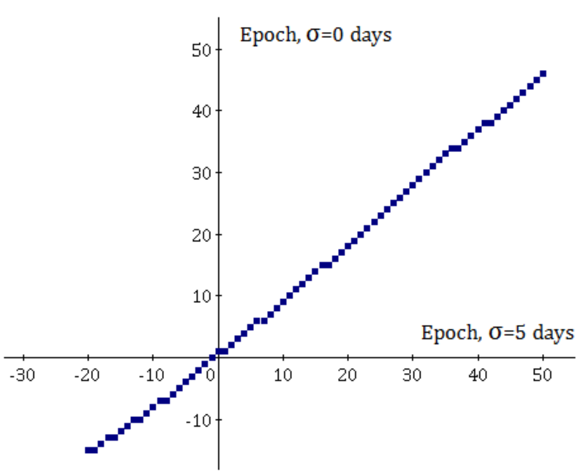
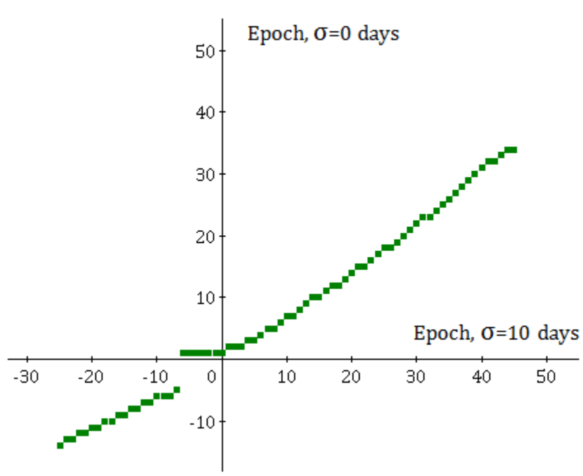


Figure 9

The fact that the spectrum remains recognizable makes it possible to conduct a spectra aging study using the approach suggested by Blondin et. al [2]. In order to do that I have normalized each epoch spectrum of certain standard deviation to the unity of maximum spectral flux density at this standard deviation. The wavelength range for the spectra is from 3000Å to 7000Å. Then I matched normalized spectra of each epoch at σ >0 to normalized spectra of each epoch at σ =0 using the least square method. The results of the matching process are shown in Figure 10. The software that I have developed for matching spectra is available for download as open source and freeware [27].





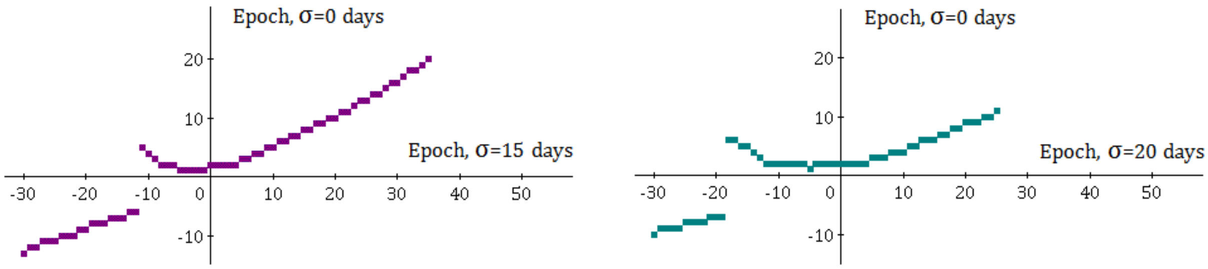


Figure 10

Matching spectra for different σ

Blondin et al. have matched spectra for epochs in the range from 0 to 30. The results of matching the simulated spectra after epoch 0 are shown on Figure 11. The matching points fit to right lines very well, which indicates that the tired light model is in consistence with the results of Blondin et al.

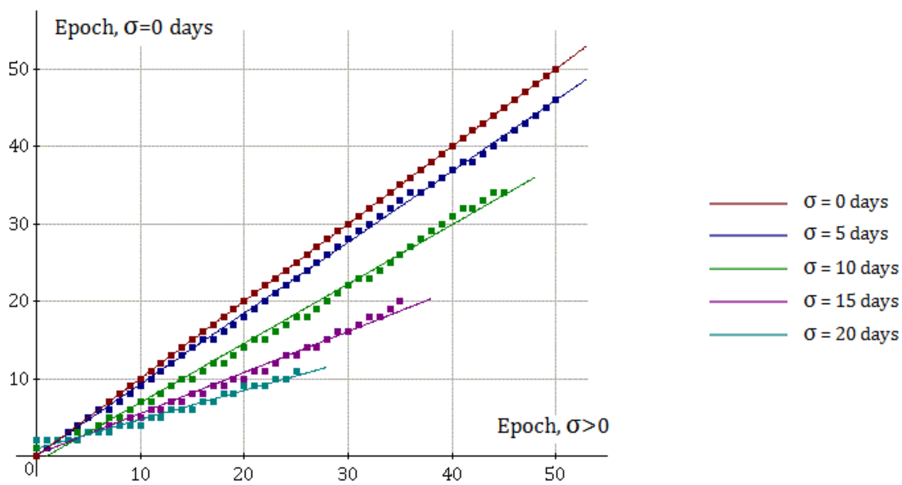


Figure 11

Matching spectra after epoch 0

The significance of the results of spectra aging study conducted by Blondin et al. is that they were obtained without applying any subjective fitting. According to Blondin et al. the linear coefficient k of matching line is related to redshift as $k=1/(1+Z)$. Assuming that the results of Blondin et al. are correct, it is possible to establish relation between Z and σ. To be precise, it is not known if σ is the same for all wavelengths. So in this relation σ should be regarded as weighted average for the range 3000...7000Å. The relation between Z and σ is shown in Table 4 and Figure 12.

Table 4

σ	k	Z
0	1.000	0.000
5	0.917	0.090
10	0.766	0.305
15	0.529	0.890
20	0.376	1.657

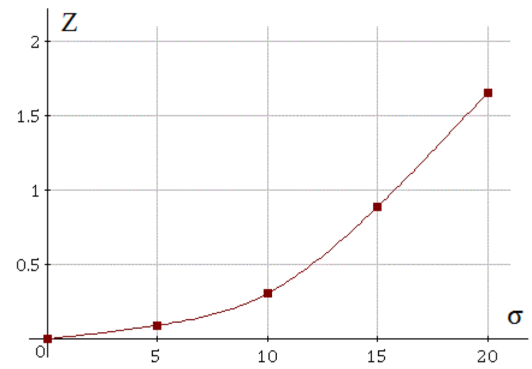


Figure 12

7. Discussion

The tired light model of redshift is supplemented with the idea of portions of light having random travelling time ("bumpy road" mechanism) which explains timescale stretching effects for Type Ia supernovae. The conducted simulation study shows that observations related to light curve broadening as well as for spectra aging do not contradict to the tired light model. Therefore, the timescale stretching in Type Ia supernovae cannot be used as an argument for ruling out the "tired light" model of redshift.

In order to confirm or rule out either "tired light" or "expanding Universe" model by timescale stretching effects of Type Ia supernovae, the following directions of further research should be taken:

- Universality of stretching parameter should be tested for different bands, fragments of light curve and magnitude offsets without fitting to universally stretched light curve templates.
- Systematic observations are required to detect presence or absence of the second maximum in infrared and near-infrared bands for distant supernovae.
- On determining the type of distant supernova, the absence of the second maximum in infrared and near-infrared bands should not be used as a criterion of categorization.
- Spectra aging study should be conducted for epochs before 0.
- Expanding spectra template for Z=0 at least up to 120 epochs after 0 will extend simulation results for tired light models.

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