Constraining spacetime variations of nuclear decay rates from light curves of type Ia supernovae

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Introduction

- The study of the possible space-time deviations from the known laws of nature is essential for improving existing models and finding the New Physics.
- The supernovae Ia give an unique opportunity to make the constraints on the variation of the ^{56}Ni decay rate.
- Brand new observational data on the supernovae Ia for redshifts up to $z \simeq 1$.

Supernovae type Ia

- Ionized Si line in the spectrum.
- Probable scenario of the explosion: two stars, one of which is a white dwarf; because of the accretion of the matter it reaches Chandrasekhar limit.
- Used as the standard candles.

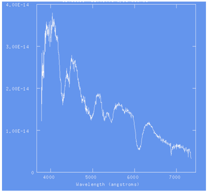


Figure: Spectrum of SN1998aq, a Type Ia supernova, one day after maximum light in the B band

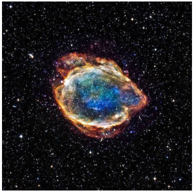
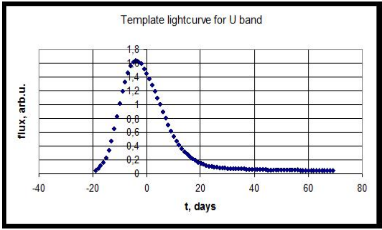
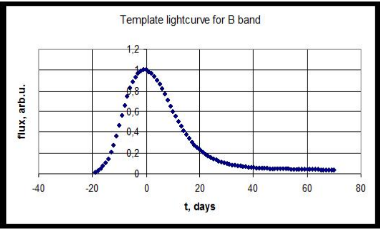
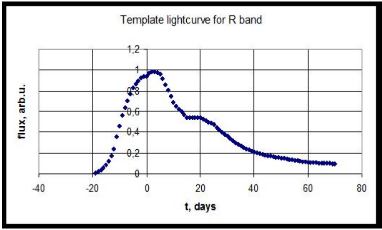


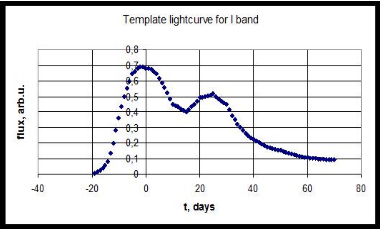
Figure: G299 Type Ia supernova remnant.

Standard lightcurves



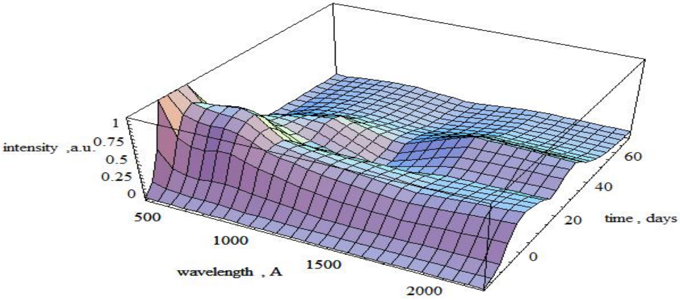






The template

The eight standard lightcurves (UBVRIJHK) were interpolated into a common template.



Fitting function

- It appears that all the lightcurves in the given band can be fitted to the standard one by a simple contraction of the time axis and tuning the maximum intensity.
- The contraction parameter (width factor) for a lightcurve can be defined by fitting it with the template. The fitting function is:

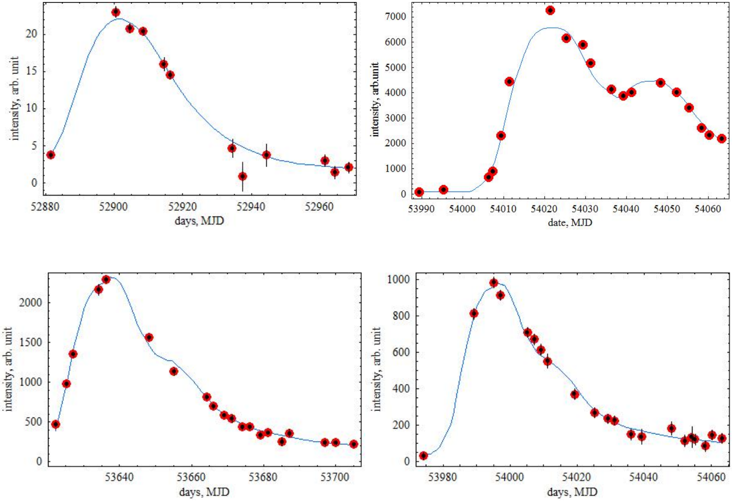
$$I = I_0 \left[f\left(\frac{t - t_0}{w} \right) + b \right], \qquad (1)$$

where f — template function, (t_0, I_0) — point of maximum, b — background.

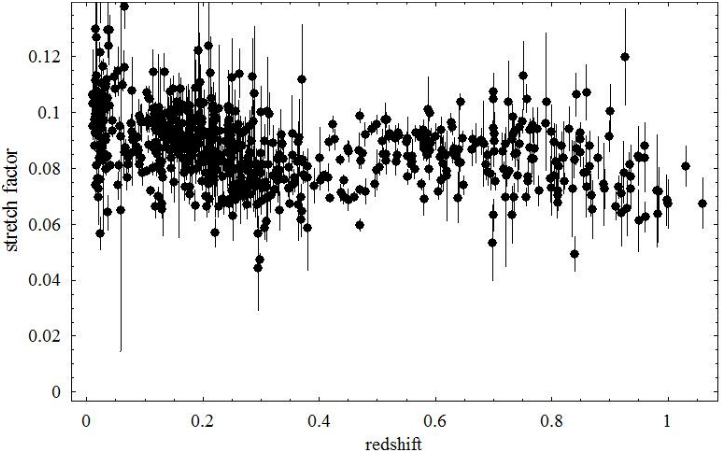
Fitting details

- For each supernova we took the lightcurve in R band. Template curve was chosen so that the corresponding wavelength is the emitted wavelength: $\lambda = \frac{\lambda_R}{1+z}$.
- The time intervals in the supernova system of reference and on Earth differ by factor $1 + z$. We see already stretched lightcurve.
  Thus width factor is $w = s(1 + z)$, where s – stretch-factor.

Fitting process



The dependence of the stretch-factor on the redshift

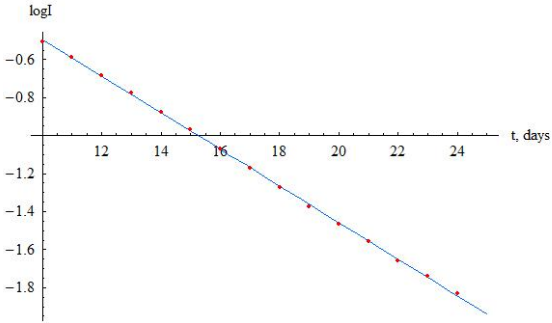


Connection between the stretch-factor and the decay constant

- The decline of the lightcurve corresponds to the decays of ^{56}Ni and ^{56}Co – two exponents.

- Then we can get the decay constant $\lambda : I \sim \exp(-\lambda t)$
- We have calculated λ for a standard lightcurve ($s = 1$). It is evident that $\lambda \sim s$.

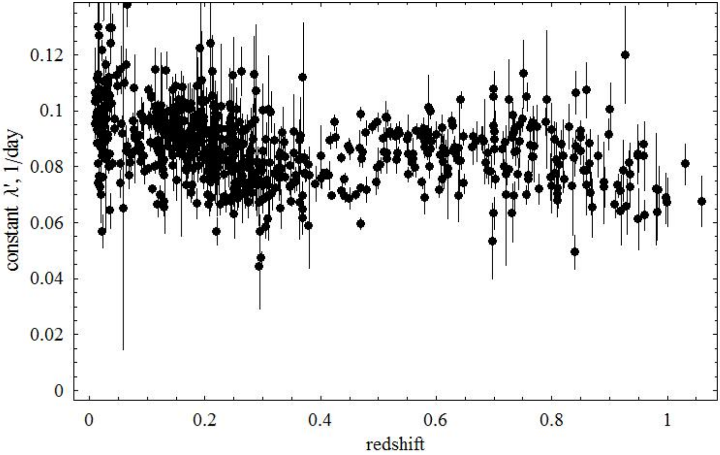
Standard lightcurve slope



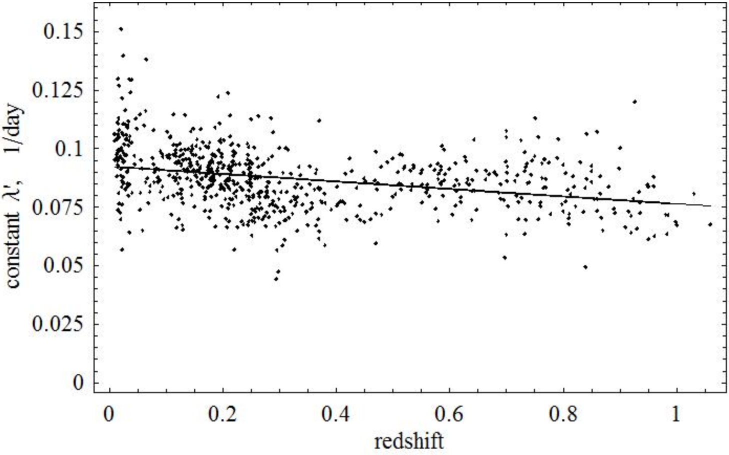
$$\lambda'_{st} = 0.0964 \pm 0.0005 \quad (2)$$

Less than the Earth value ($\lambda = 0.11410 \pm 0.00019$).

The dependence of the constant λ' on the redshift



Possible slope $\Delta\lambda'$



Variation of the decay rate λ

$$\Delta\lambda' = 0.0168 \pm 0.0019 \tag{3}$$

where $\Delta\lambda' = \lambda'(z = 1.06) - \lambda'(z = 0.009819)$. Then we get:

$$\frac{\Delta\lambda}{\lambda} = -0.182 \pm 0.021. \tag{4}$$

So the final constraint is

$$\left|\frac{\Delta\lambda}{\lambda}\right| < 0.223 \quad (95\%\ \mathrm{CL}). \tag{5}$$

The future work: to take into account the stellar evolution.

Constraints

The decay rate $\lambda \sim G_F^2$, Fermi coupling constant G_F is connected unambiguously to the vacuum expectation value v of the Brout-Englert-Higgs field, so that $\lambda \sim v^{-4}$. So we can get the constraints on the latter two values:

$$\left|\frac{\Delta G_F}{G_F}\right| < 0.111 \quad (95\%\ \mathrm{CL}) \tag{6}$$

$$\left|\frac{\Delta v}{v}\right| < 0.056 \quad (95\%\ \mathrm{CL}) \tag{7}$$

Variations may be constrained in a self-consistent (not dependent on the system of units) way for dimensionless constants only. The result of this work can be used for constraining a particular physical model predicting the variations of the entire set of fundamental constants.

Conclusion

- The constraints on the variations of the decay rate of ^{56}Ni, Fermi coupling constant and vacuum expectation of the Higgs field were calculated processing the brand new astrophysical experiment data.
- The direct result of the work — constraint on the variation of the decay rate of ^{56}Ni — is the most precise constraint on the space-time variation of a decay rate.
- The result can be used for making constraints on the models of the New Physics.

Thank you for attention!