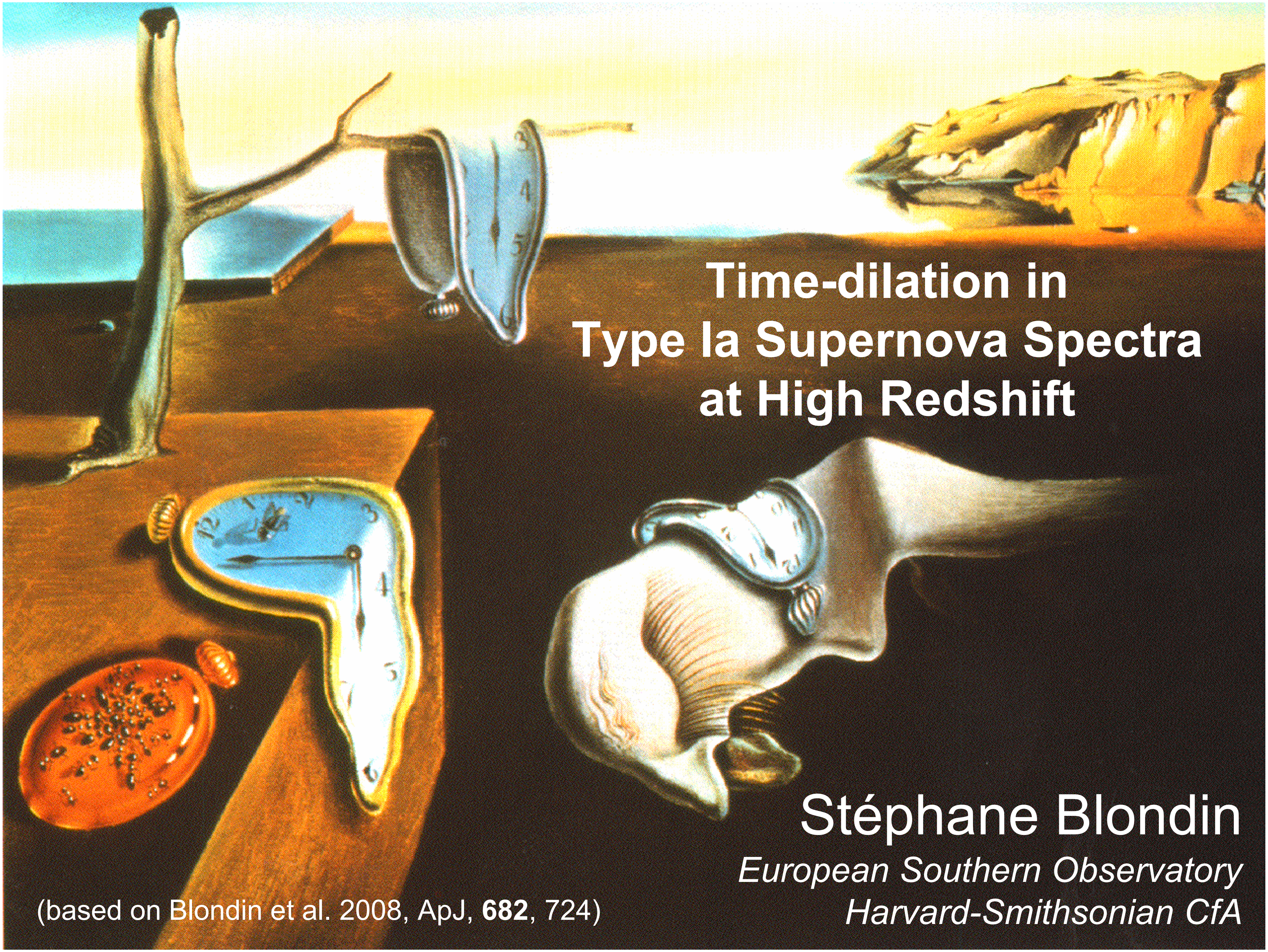


Time-dilation in Type Ia Supernova Spectra at High Redshift

Stéphane Blondin
European Southern Observatory
Harvard-Smithsonian CfA

(based on Blondin et al. 2008, ApJ, **682**, 724)

Time-dilation in a FLRW universe

In a **homogeneous**, **isotropic**, and **expanding** universe:

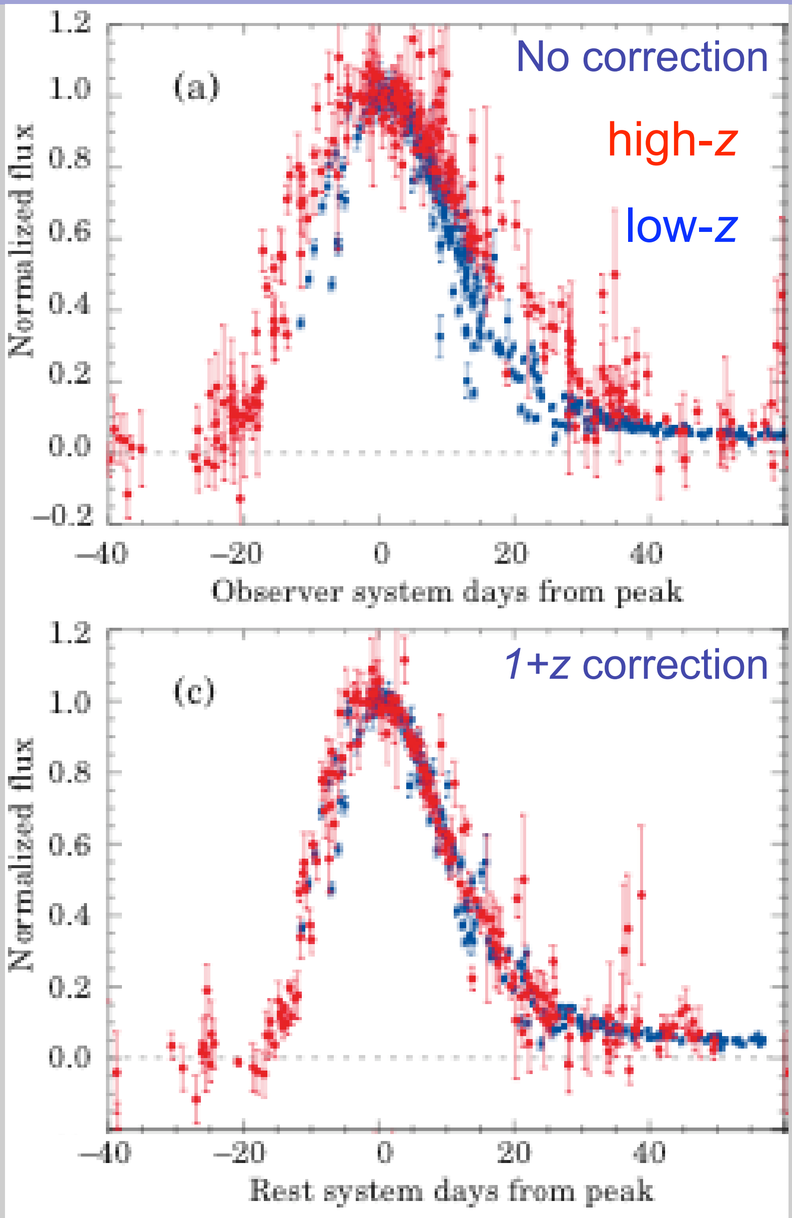
Time interval at receiver

$$\frac{\Delta t_{obs}}{\Delta t_{rest}} = 1 + z_c$$

Time interval at emitter

First suggestion to use SN Ia to test this by Wilson (1939)

SN Ia light curves confirm dilation



High-z light curves same as low-z ones stretched by *1+z*

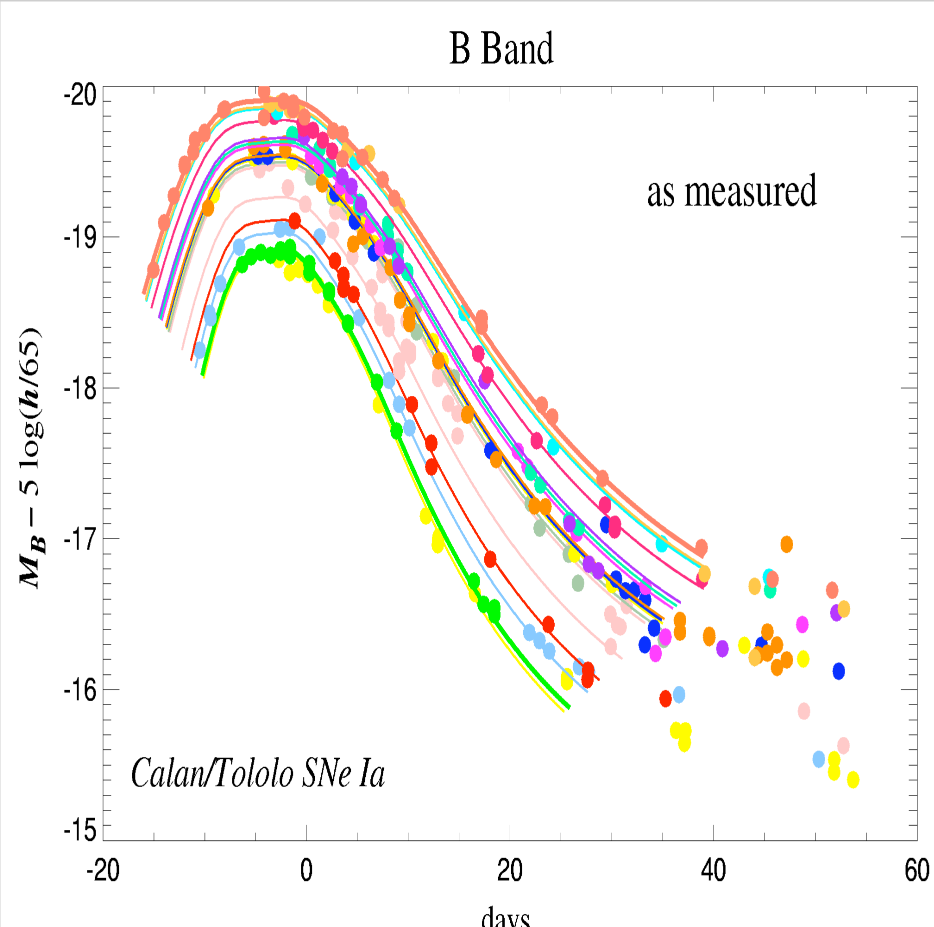
1974: Rust (PhD thesis)
z < 0.05 only

1996: Leibundgut et al.
SN1995K; z = 0.48

2001: Goldhaber et al.
42 SNe Ia; 0.17 ≤ z ≤ 0.83

Goldhaber et al. 2001

Pb.#1: Intrinsic width



Kim et al. 1997

$$w = s \times (1 + z)$$

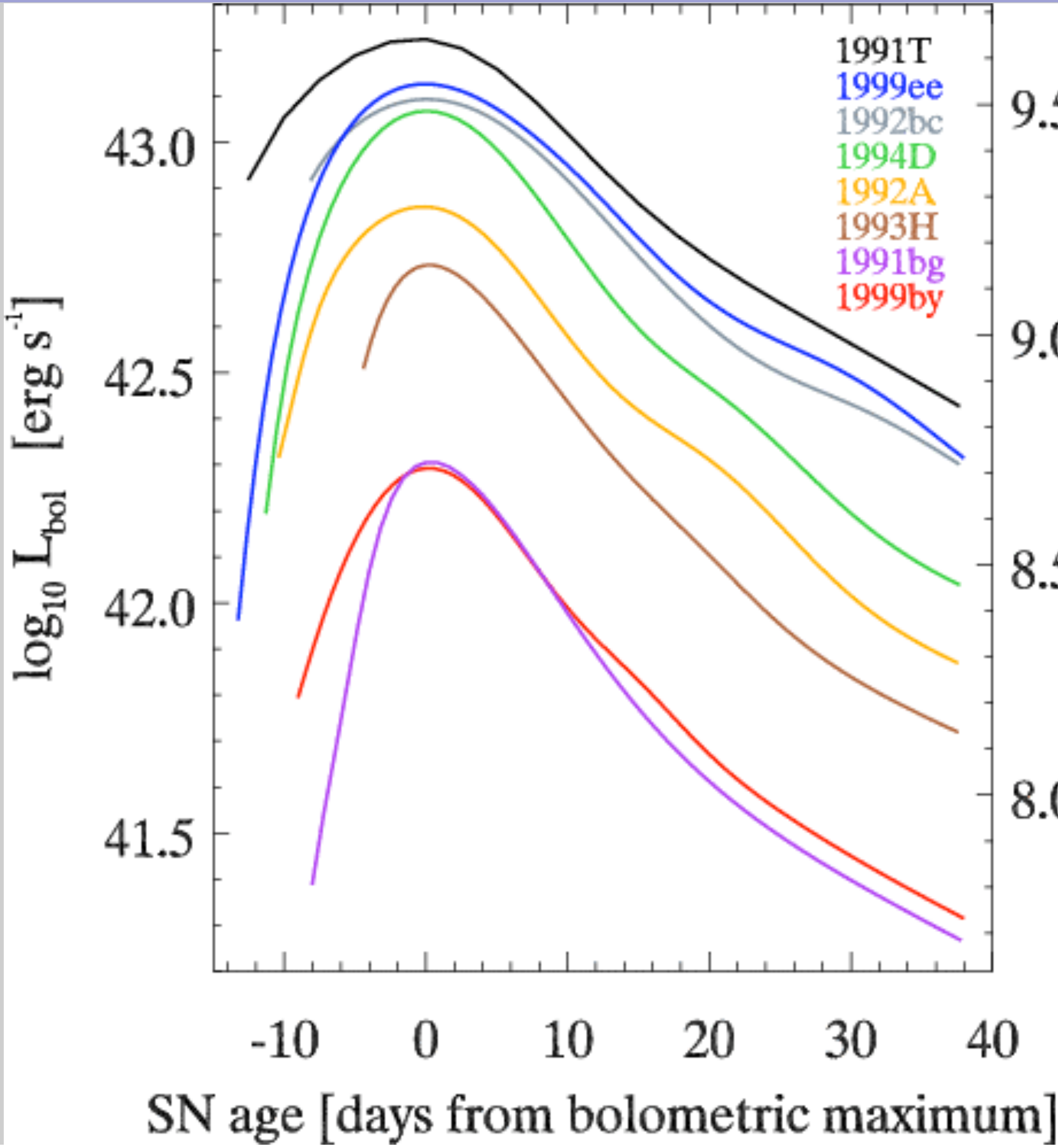
Intrinsic *width ("stretch")*

Observed *width*

To test time-dilation hypothesis:

1. know $s_{z=0}$ distribution and $s(z)$
2. probe $1+z \gg s$

Pb.#2: Selection effect

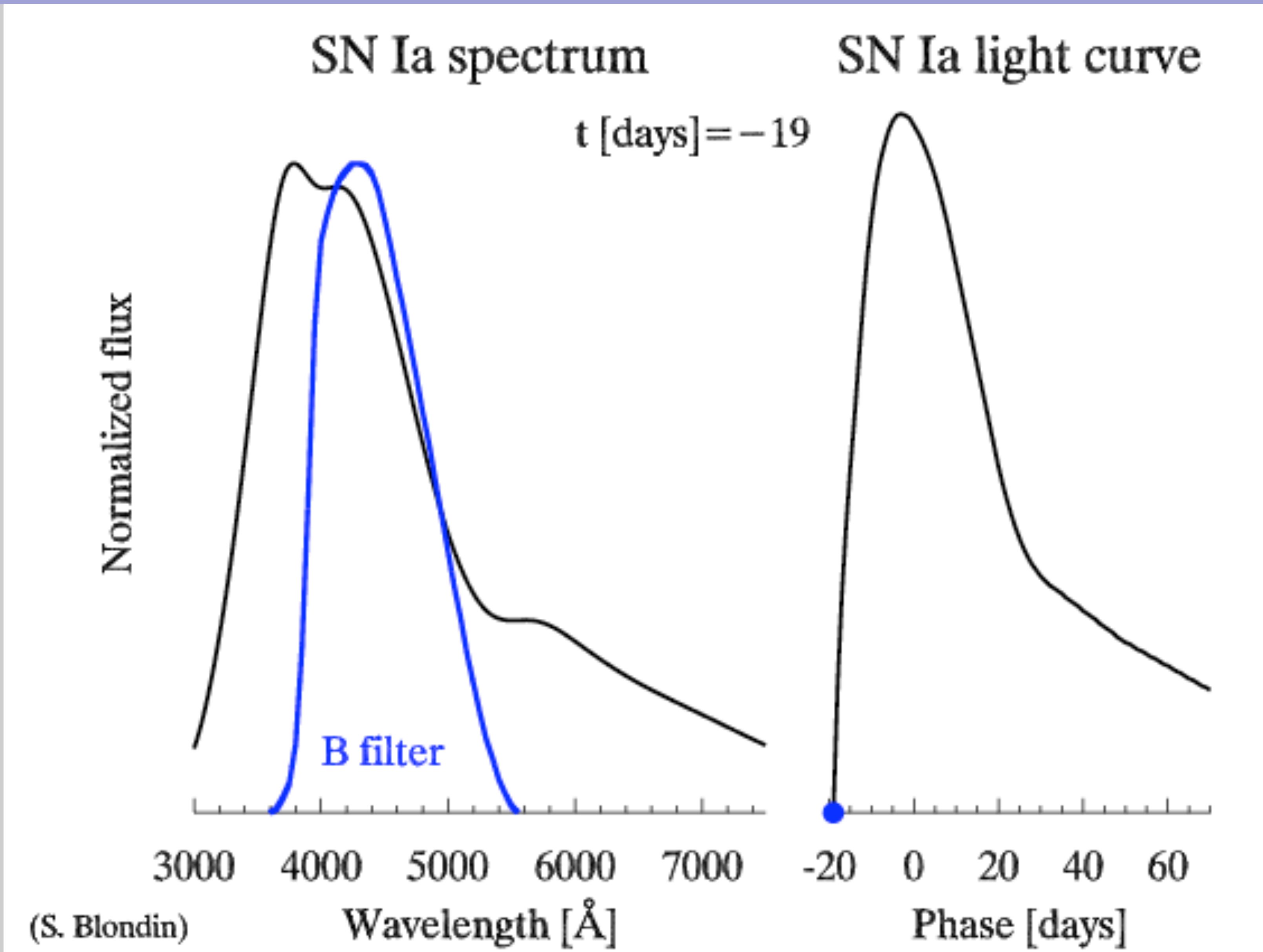


Brighter SN Ia have ***broader*** light curves

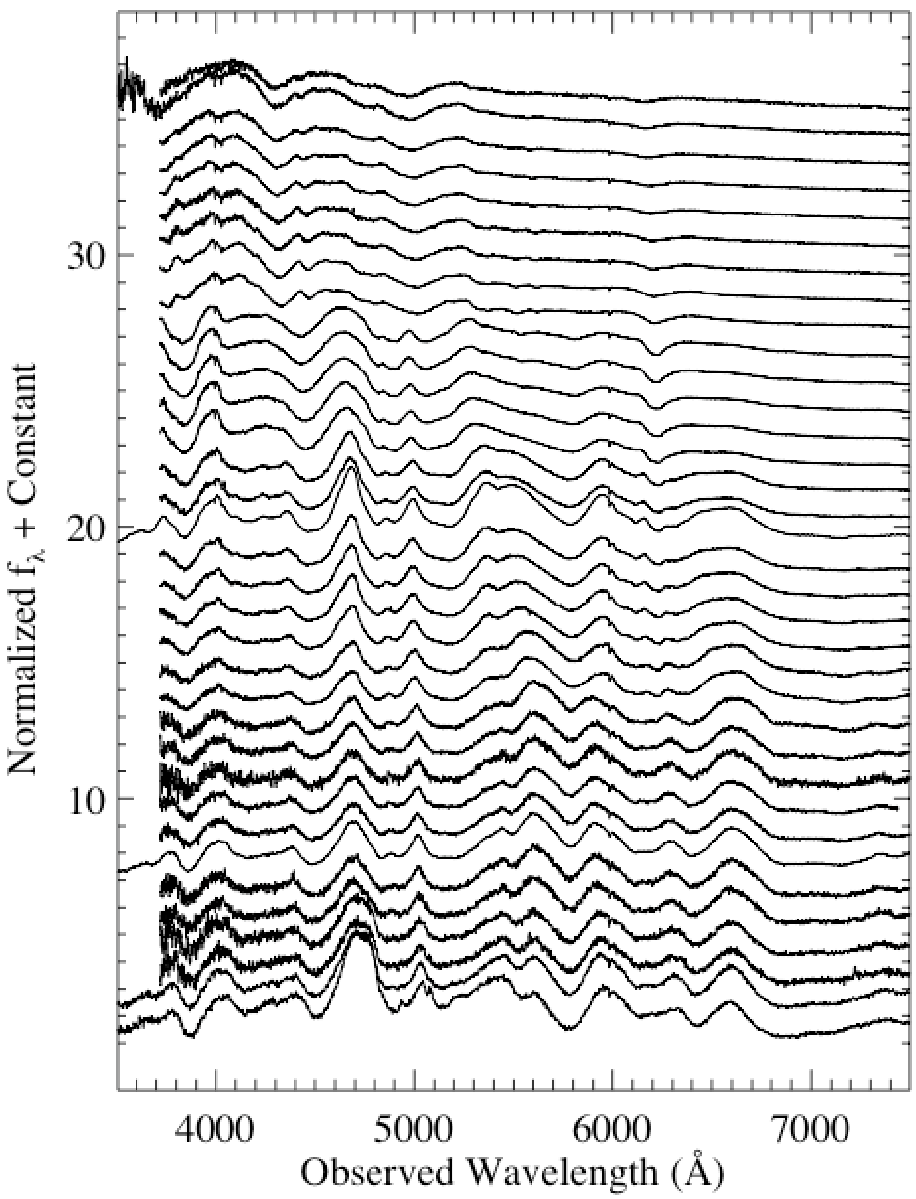
At high redshift, preferentially select brighter (i.e. broader) SN Ia

adapted from Stritzinger (2005)

SN Ia Spectra: Rapid Evolution



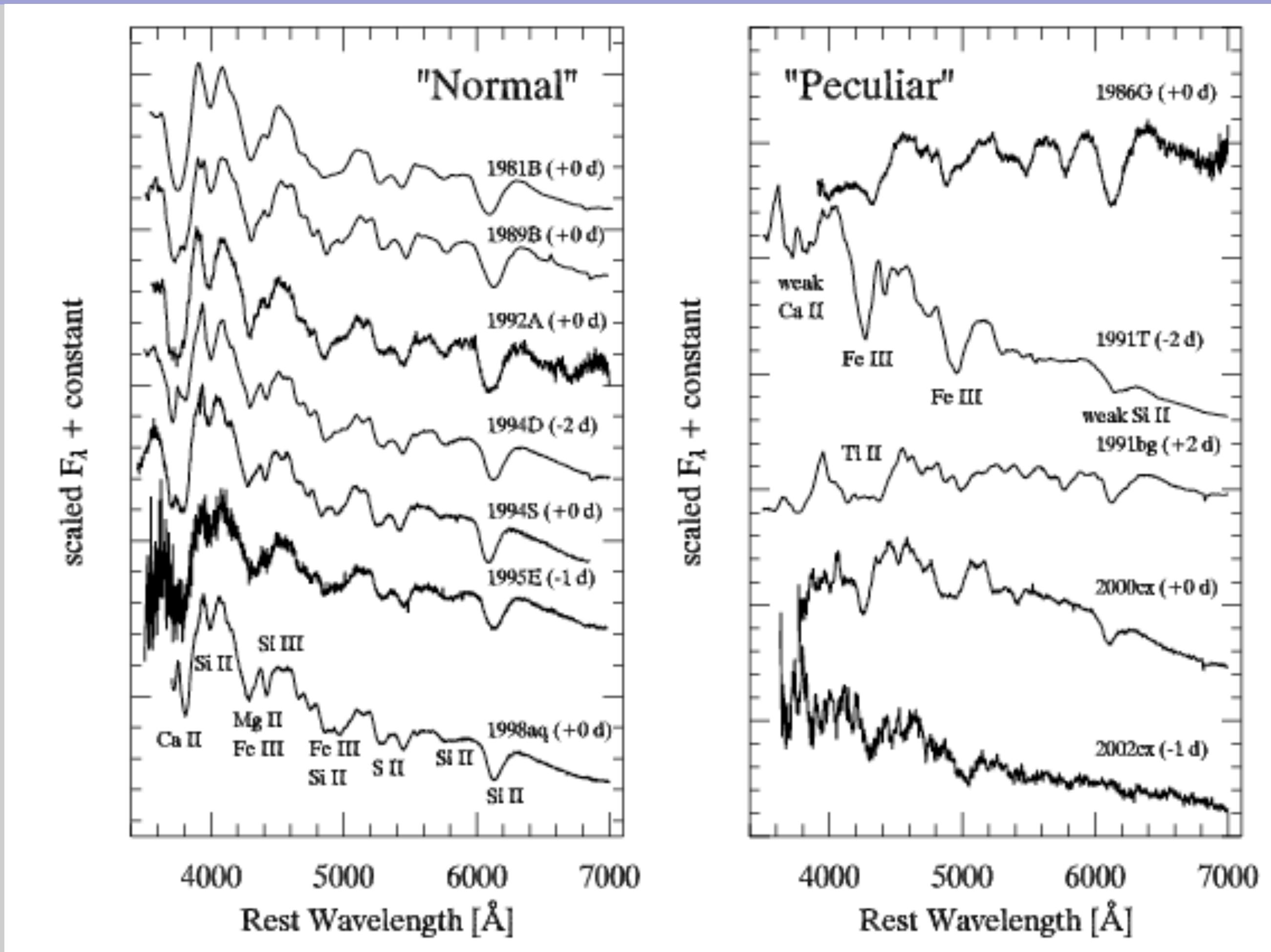
SN Ia Spectra: Rapid Evolution



Evolution over ~2 months

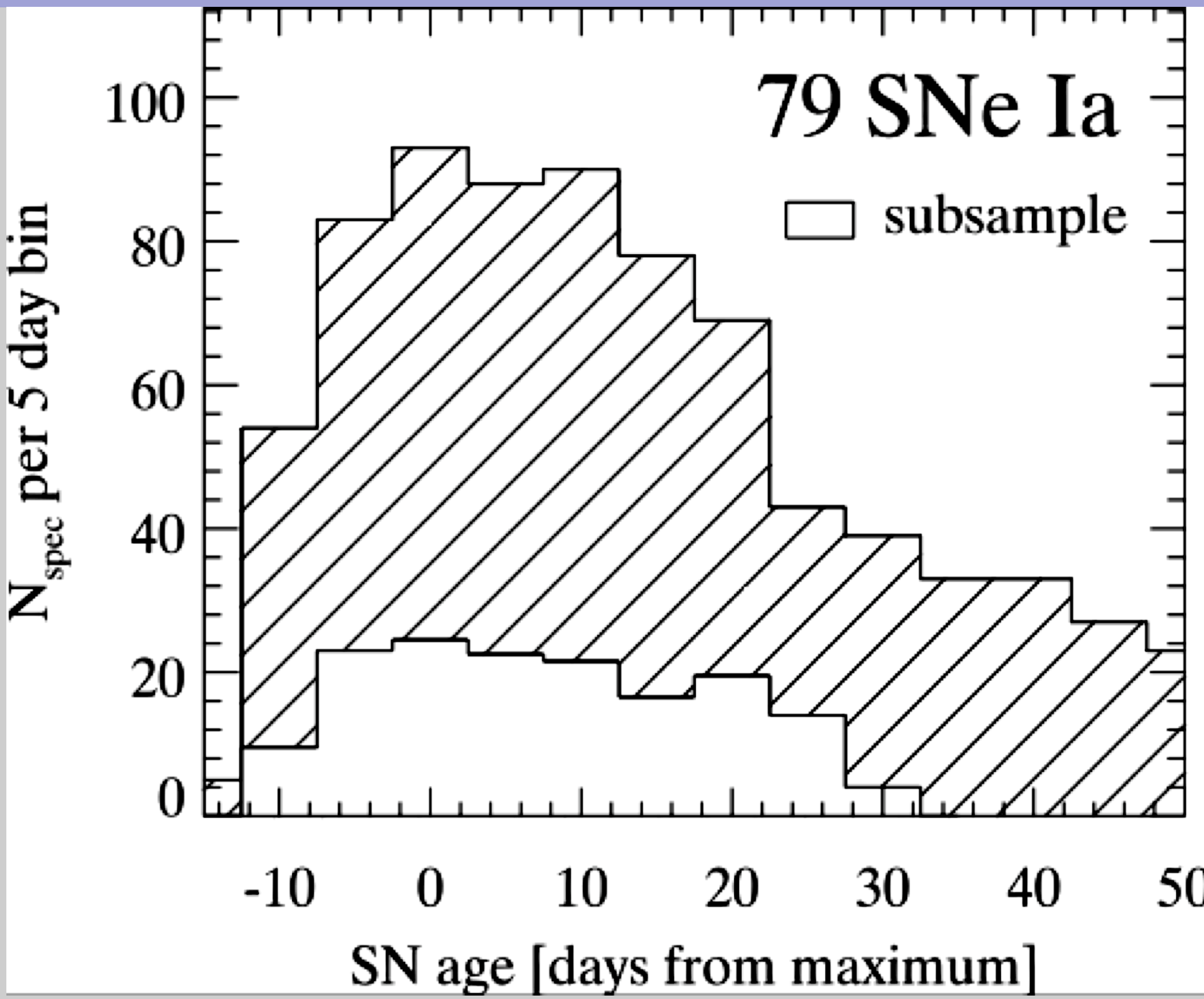
35 spectra of SN 2001V
(Matheson et al. 2008)

SN Ia Spectra: Homogeneity



Most SN Ia have similar spectra at a given age, ***independent of intrinsic light-curve width**,* i.e. possible to determine *rest-frame* age of a single spectrum to 1-3 days

Large spectral database at *z*~0

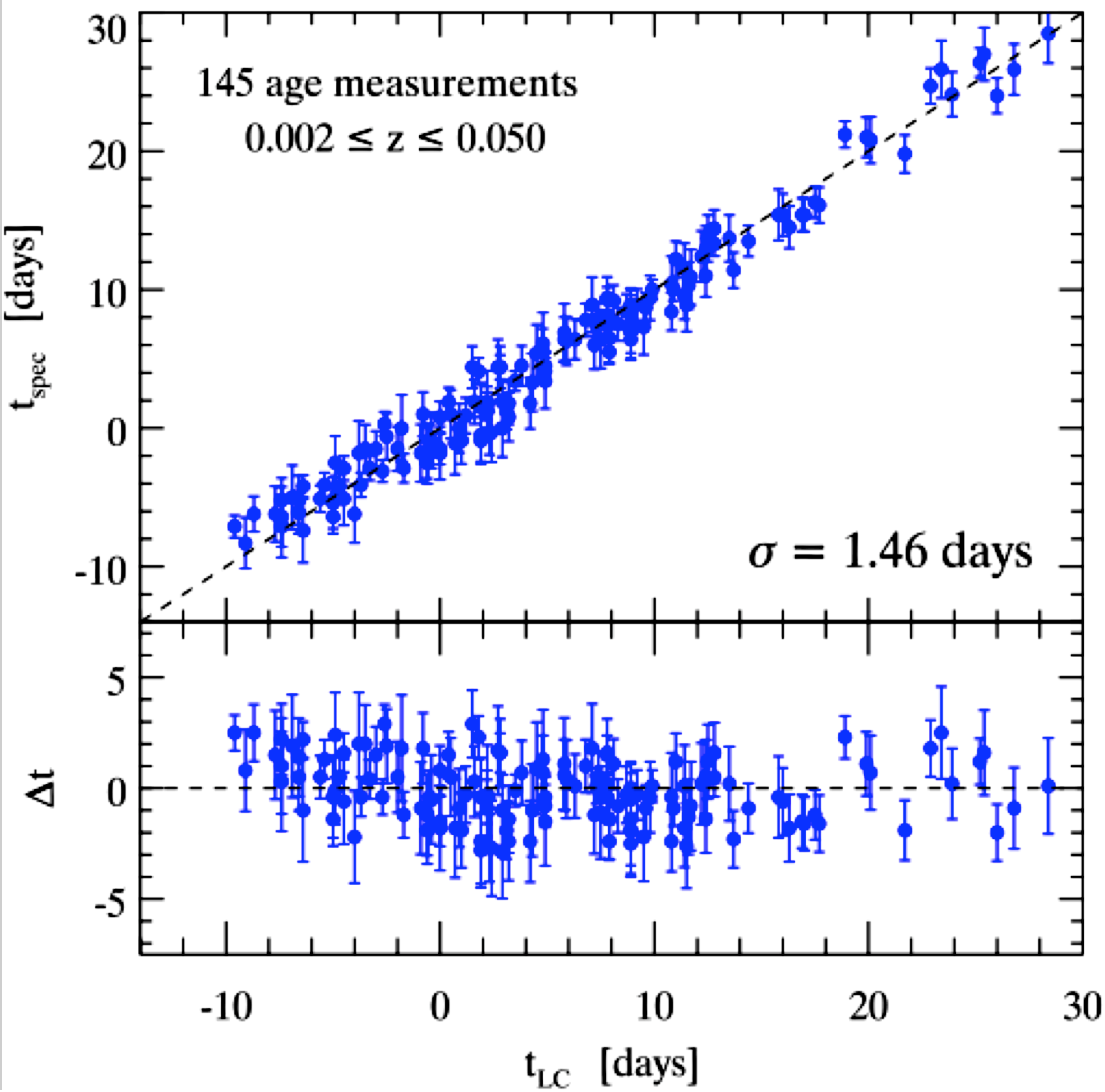


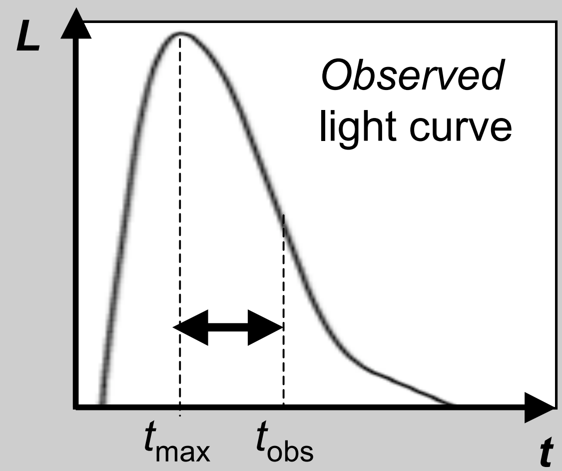
Blondin & Tonry (2007)

Cross-correlation with a large database of SN Ia spectra at *z* ≈ *0*

75% of spectra from CfA SN Program

Spectrum *vs.* light-curve ages



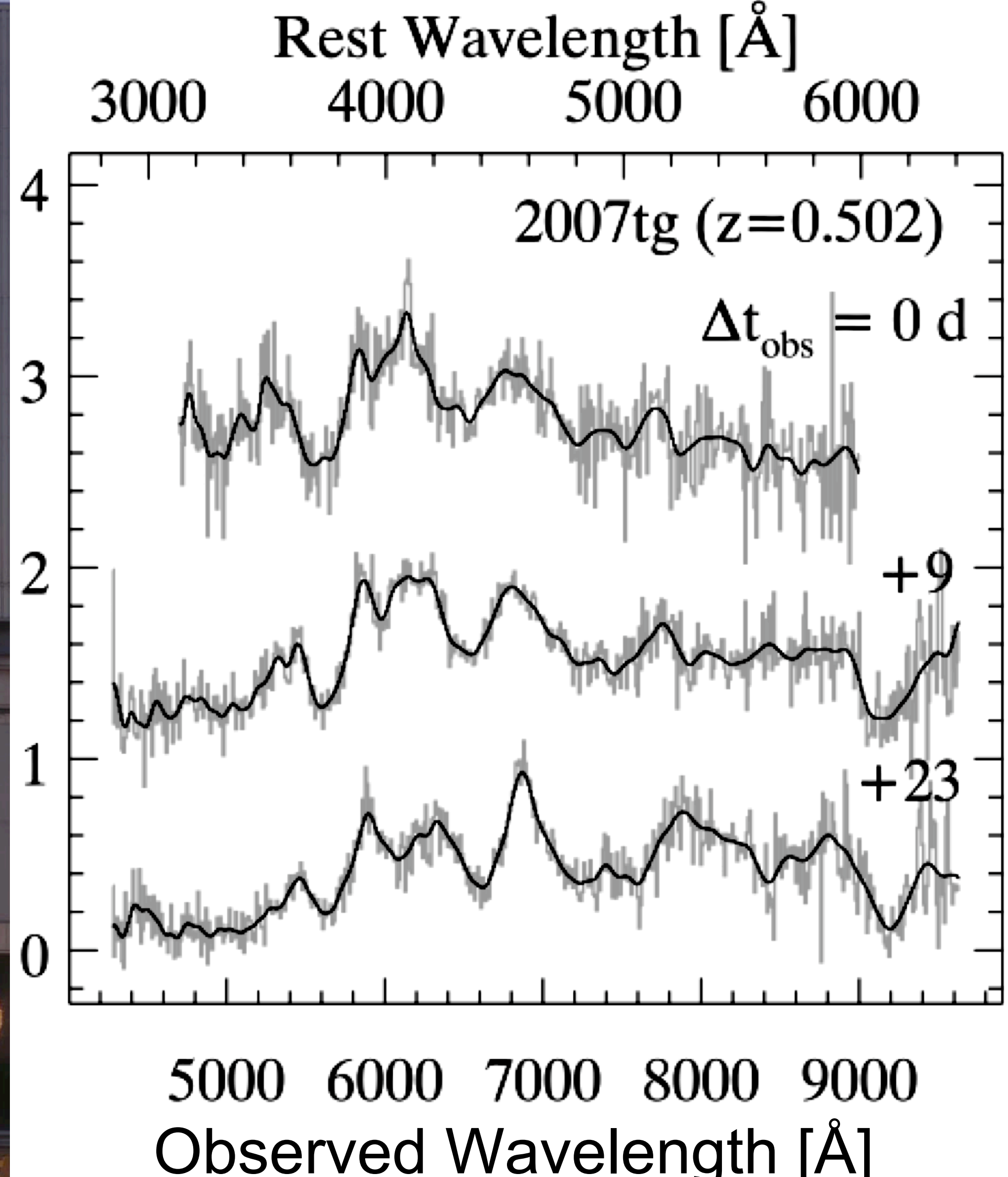


$$t_{LC} = \frac{t_{obs} - t_{\max}}{1+z}$$

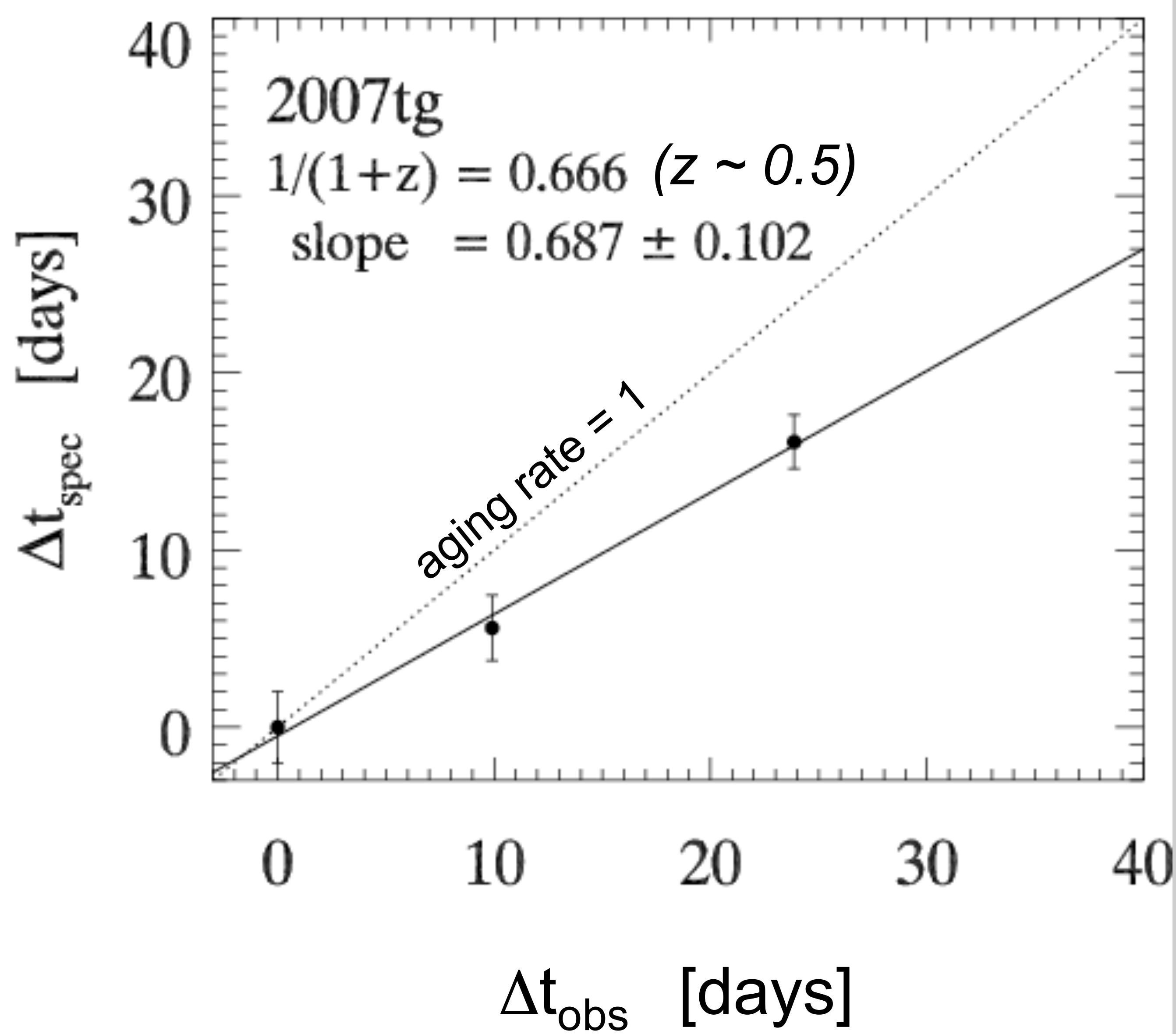
NOTE: *(1+z) ≈ 1*

[negligible time-dilation]

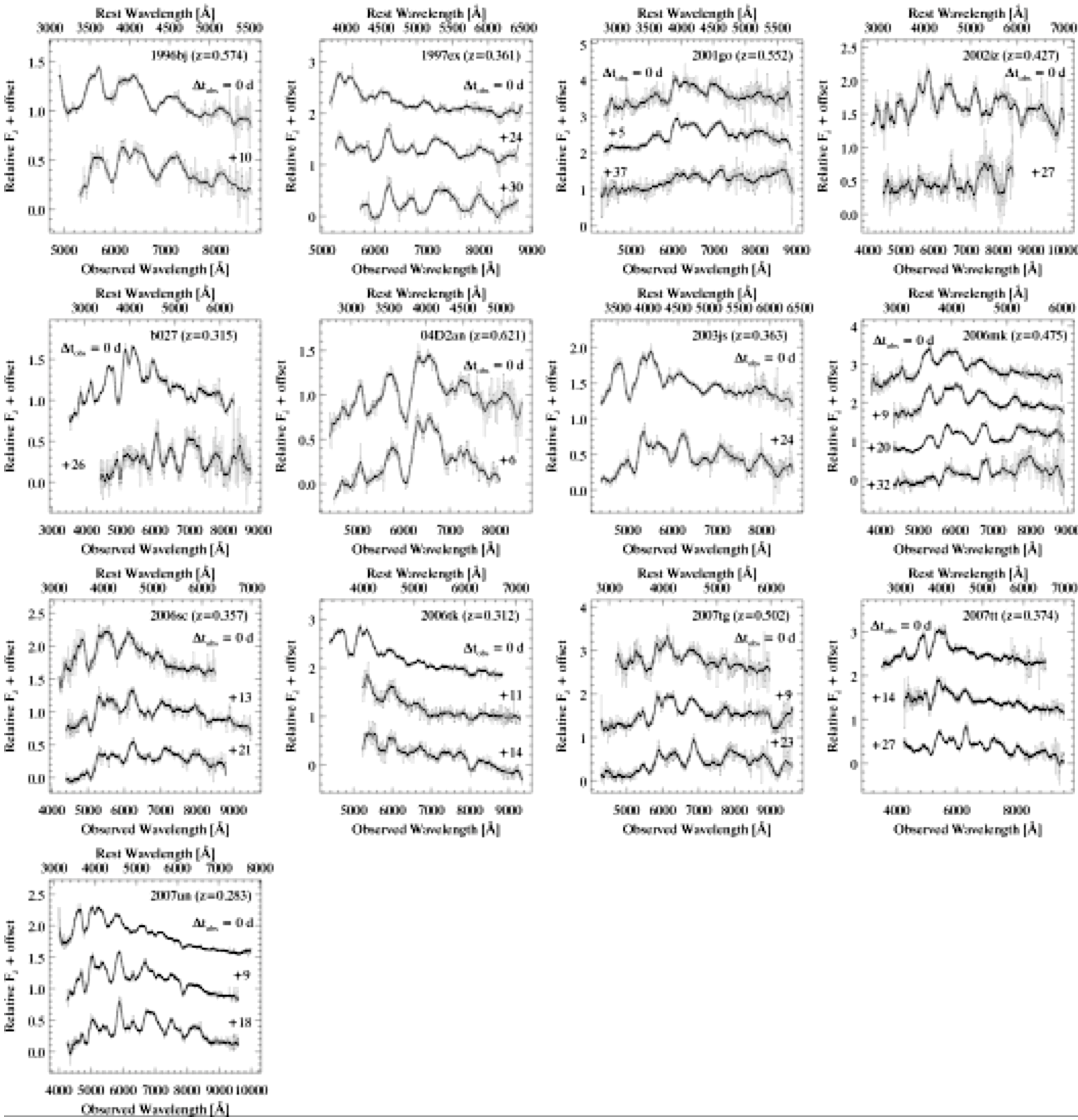
High-redshift SN Ia spectra



Aging rates



>3σ detection of time dilation for one object

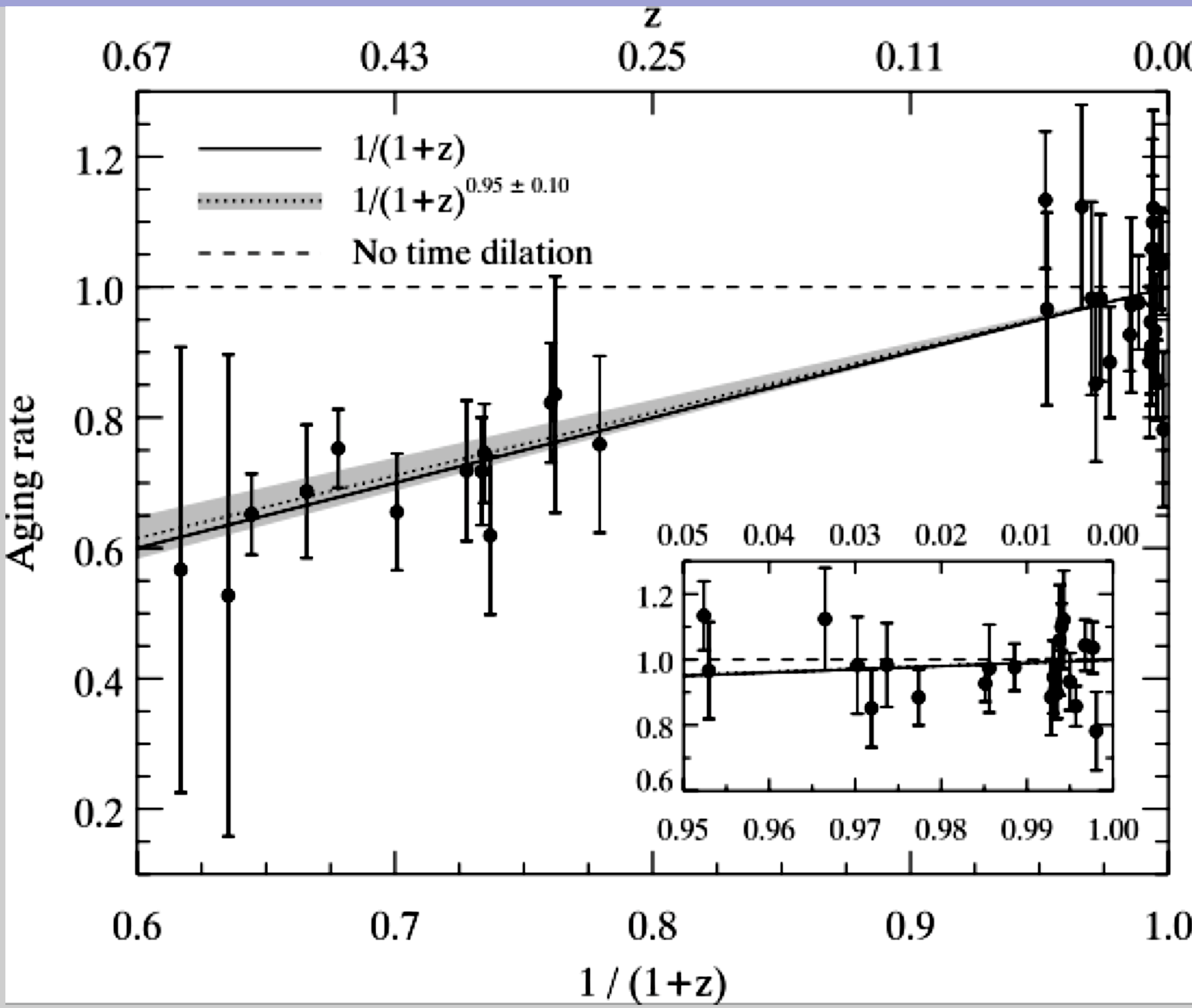


Data

35 spectra of
13 high-*z* SN Ia
(0.28 ≤ z ≤ 0.62)

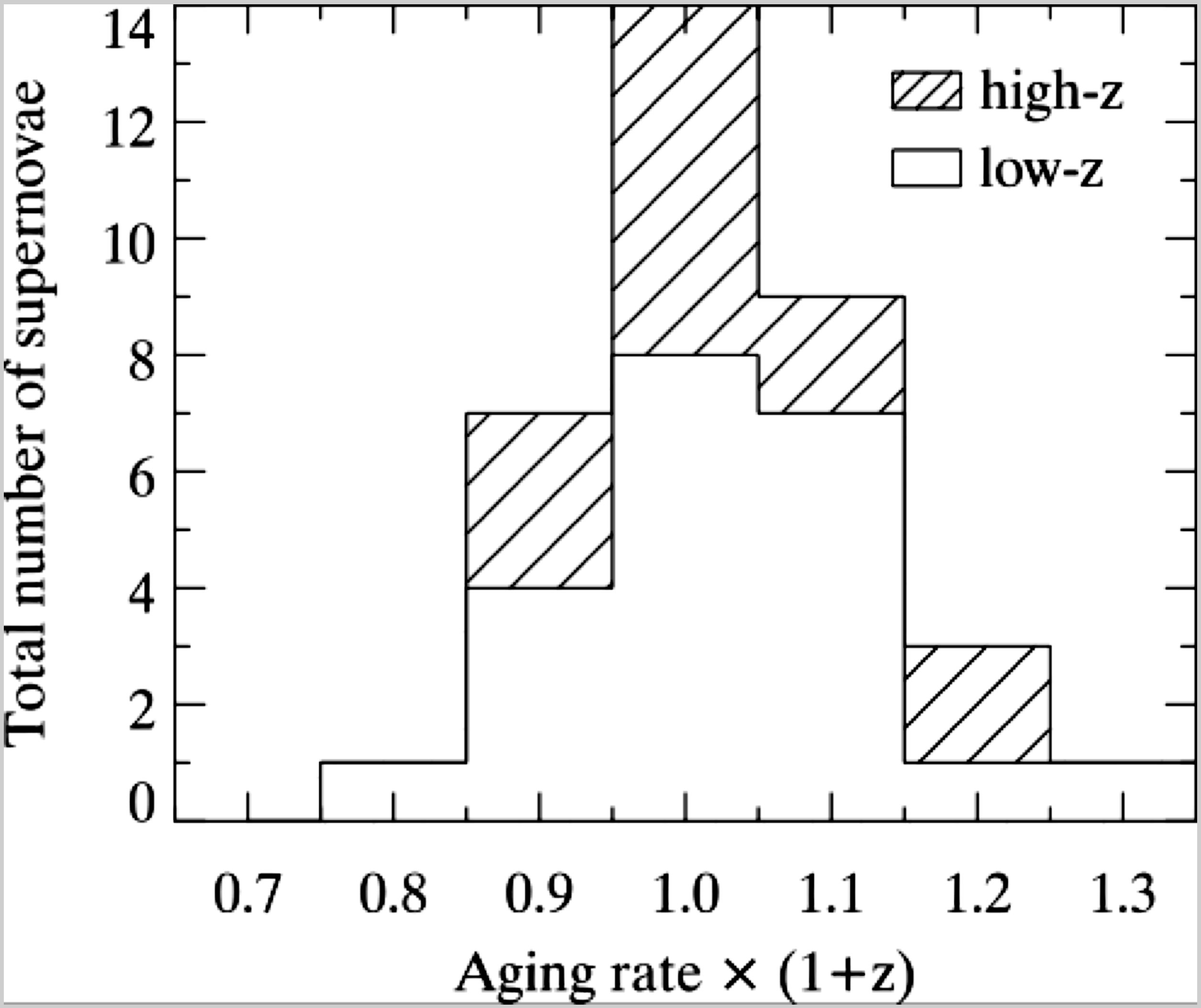
1. VLT ToO [5]
2. ESSENCE [4]
3. Published [3]
4. VLT SNLS [1]

Confirmation of 1/(1+z) dilation



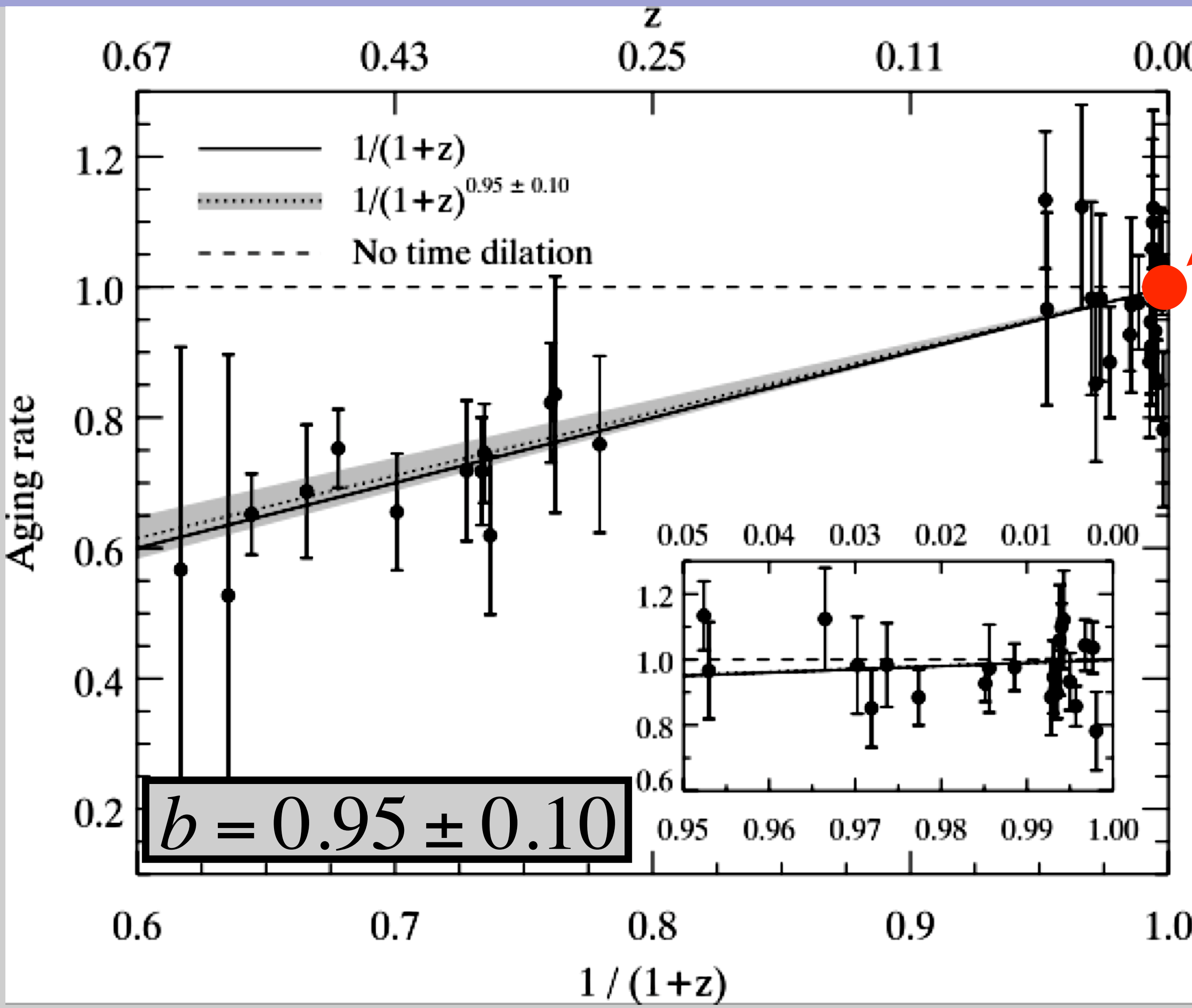
Zwicky's "tired light" hypothesis excluded beyond doubt ($\Delta\chi^2 = 120$)

Confirmation of 1/(1+z) dilation



Apparent bias to > 1.0 *not* statistically significant (error ~ 1 bin size)

Testing alternative "models"



aging rate = 1 at $z = 0$

i.e. $\propto 1/(1+z)^b$

Conclusion

Using spectra of high-redshift Type Ia supernovae, we have *directly* confirmed the *1/(1+z)* time-dilation hypothesis *over a large redshift range (0 ≤ z ≤ 0.62)*

Fundamental test of FLRW cosmology!

Conclusion

Using spectra of high-redshift Type Ia supernovae, we have *directly* confirmed the *1/(1+z)* time-dilation hypothesis *over a large redshift range (0 ≤ z ≤ 0.62)*

Fundamental test of FLRW cosmology!

Null hypothesis of no time dilation rejected beyond doubt ($\Delta\chi^2 = 120$)

Conclusion

Using spectra of high-redshift Type Ia supernovae, we have *directly* confirmed the *1/(1+z)* time-dilation hypothesis *over a large redshift range (0 ≤ z ≤ 0.62)*

Fundamental test of FLRW cosmology!

Null hypothesis of no time dilation rejected beyond doubt ($\Delta\chi^2 = 120$)

Alternative dependence of aging rate on redshift reduces to the expected factor:

$$1/(1+z)^b \text{ with } b = 0.95 \pm 0.10$$