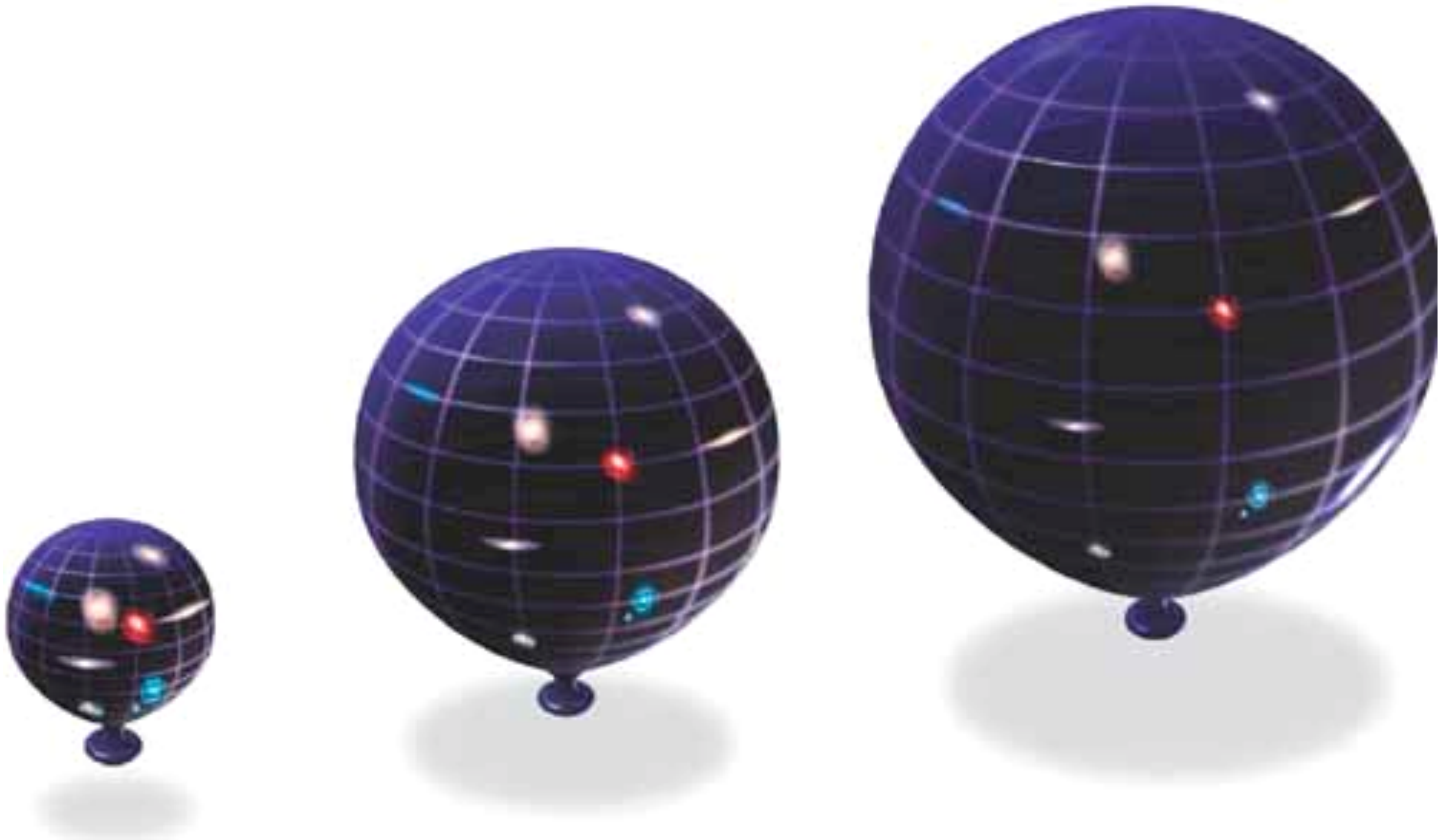
Tests for the Expansion of the Universe



Tests for the Expansion of the Universe

- Tolman surface brightness (SB) test
  - In a stationary, Euclidean universe $SB = const.$
  - In an expanding universe, $SB \sim (1+z)^{-4}$
  - In a "tired light" model, $SB \sim (1+z)^{-1}$
- Time dilation of Supernova light curves
  - Time stretches by a factor of $(1+v/c) = (1+z)$
- The match between the energy density and T^4 for the blackbody and the CMBR
  - For a blackbody, energy density $u \sim T^4$
  - In an expanding universe, for photons, energy density is $u \sim (1+z)^4$, and since $T \sim 1/\lambda \sim (1+z)$, $u \sim T^4$

The Tolman Test

Surface brightness is flux per unit solid angle: $$B = \frac{f}{d\omega}$$

This is the same as the luminosity per unit area, at some distance D. In cosmology,

$$B = \frac{L}{D_L^2} \frac{D_A^2}{dl^2}$$

In a stationary, Euclidean case, $D = D_L = D_A$, so the distances cancel, and $SB = const$. But in an expanding universe, $D_L = D\,(1+z)$, and $D_A = D\,/\,(1+z)$, so:

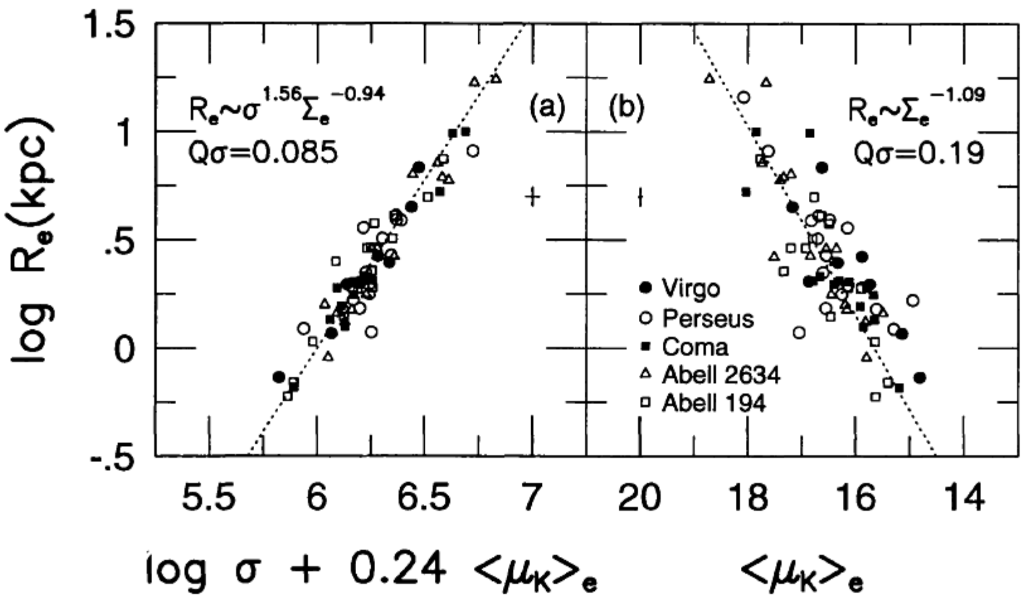
$$B = \frac{L}{dl^2} \frac{D_A^2}{D_L^2} = \frac{L}{dl^2}(1+z)^{-4}$$

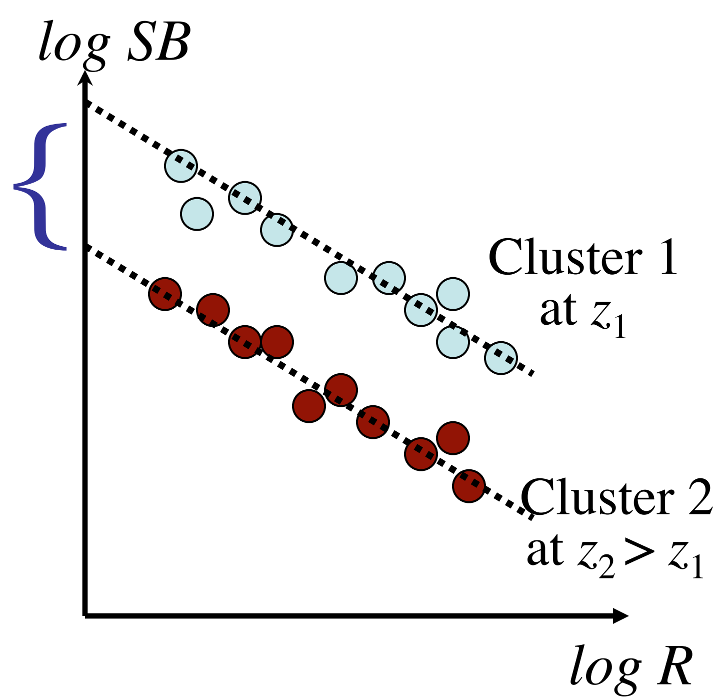
Note that this is independent of cosmology!

Performing the The Tolman Test

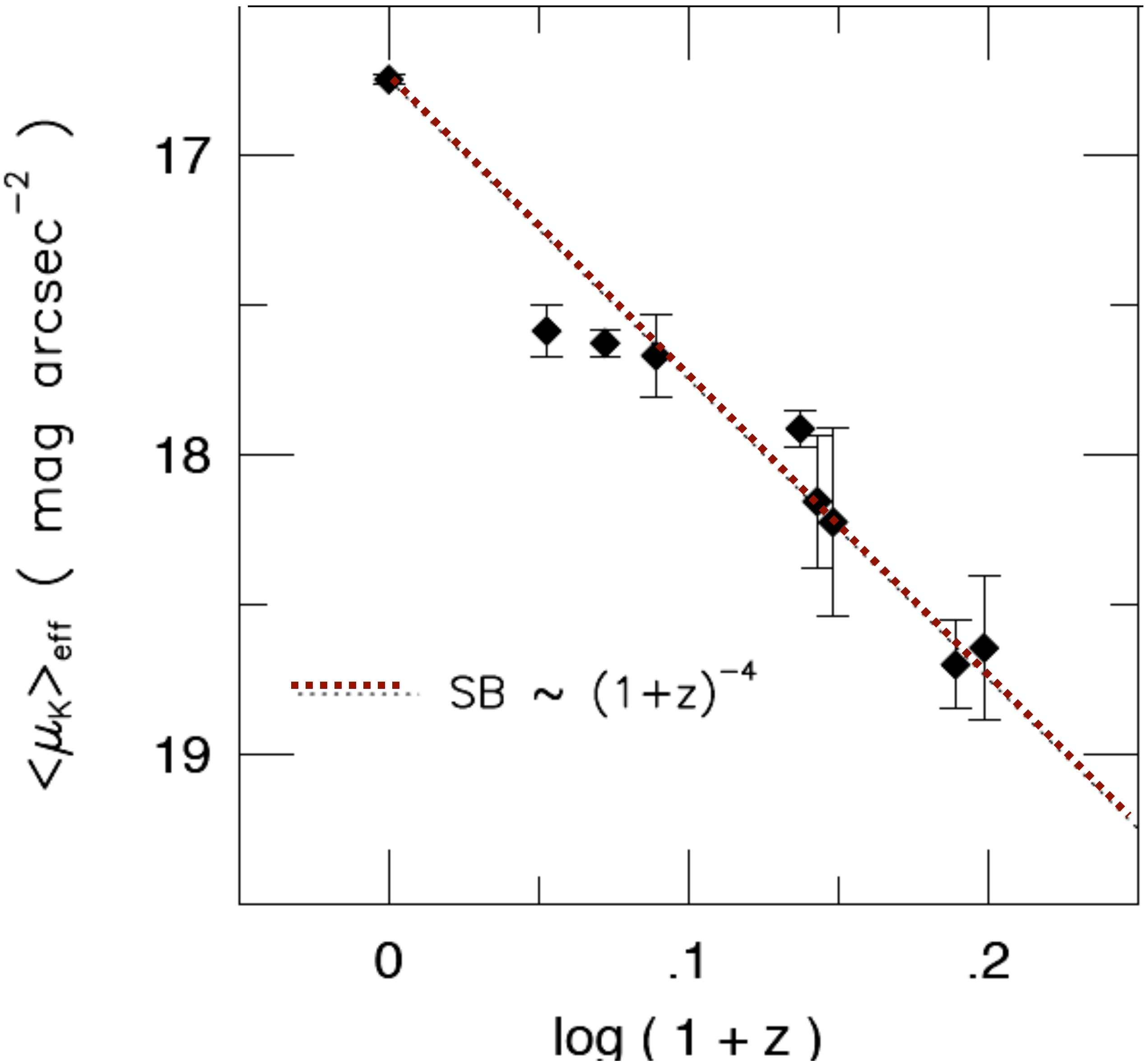
We need a standard (constant) unit of surface brightness = luminosity/area, to observe at a range of redshifts (a "standard fuzz"?)

A good choice is the intercept of surface brightness scaling relations for elliptical galaxies in clusters





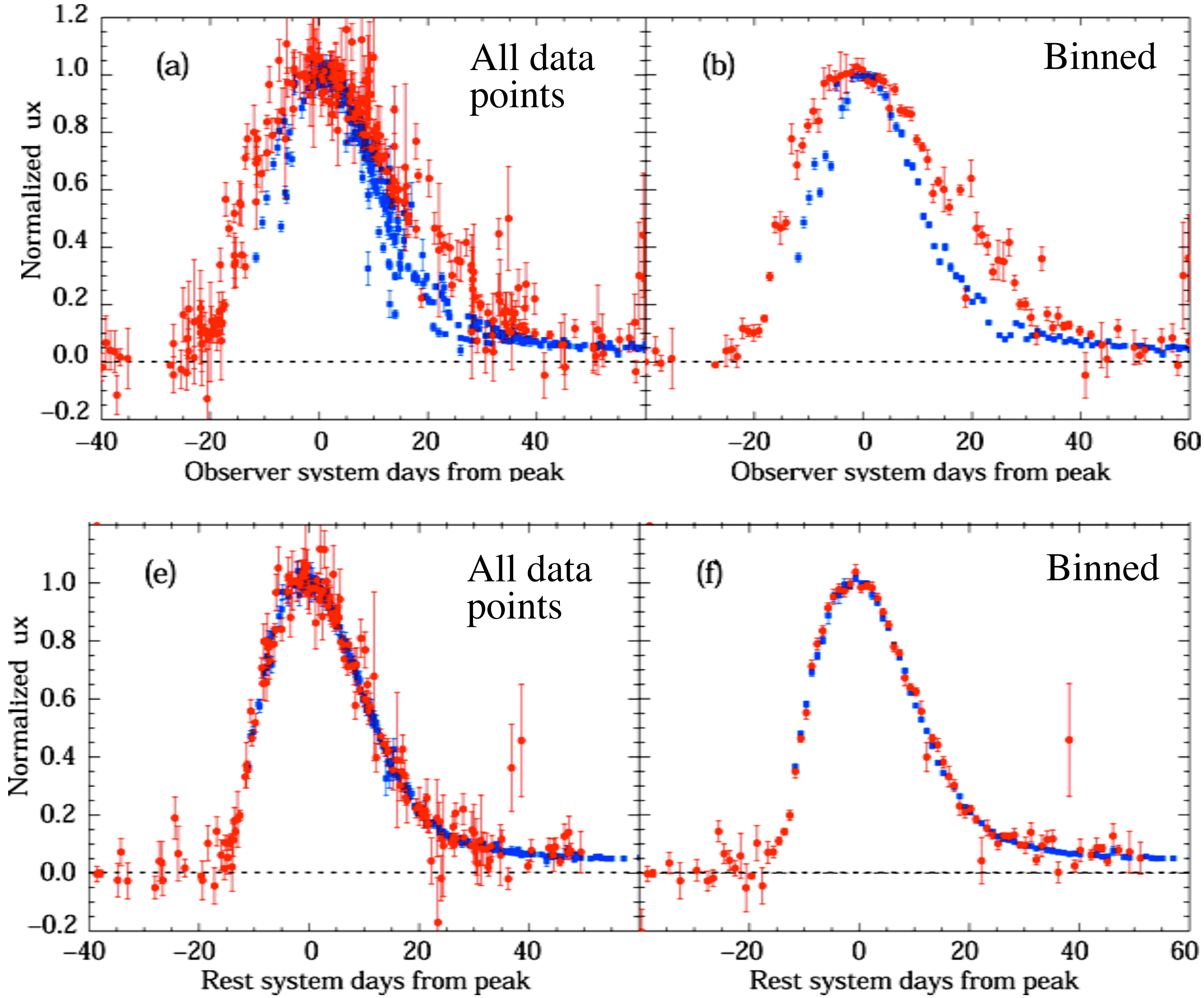
The Tolman Test Results



Surface brightness intercept of the Fundamental Plane correlation, for elliptical galaxies in clusters out to z ~ 0.6. It assumes a reasonable galaxy evolution model correction.

(from Pahre et al.)

Time Dilation of Supernova Lightcurves



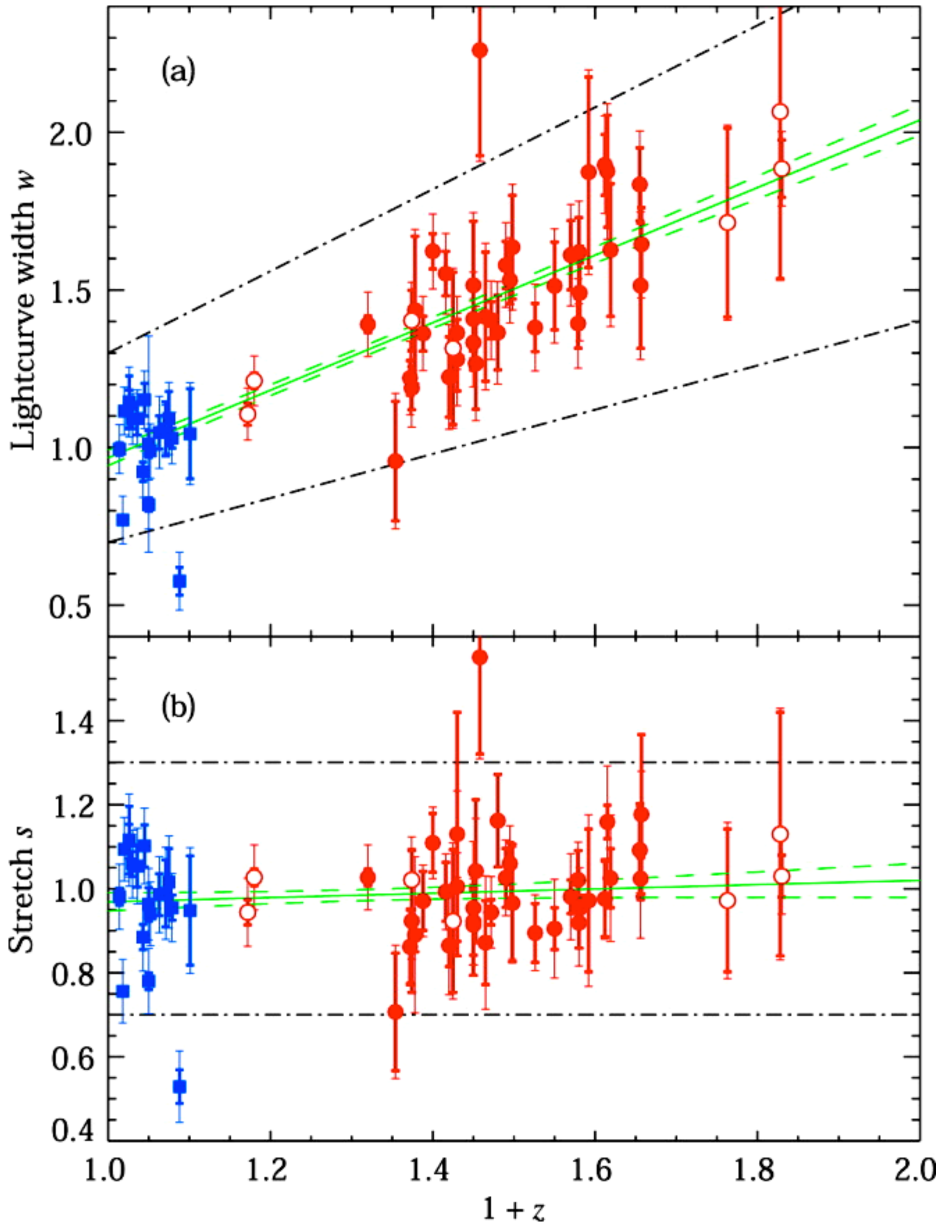
Blue dots: a low-z dataset

Red dots: a high-z dataset

After applying the proper stretch factor

(Goldhaber et al.)

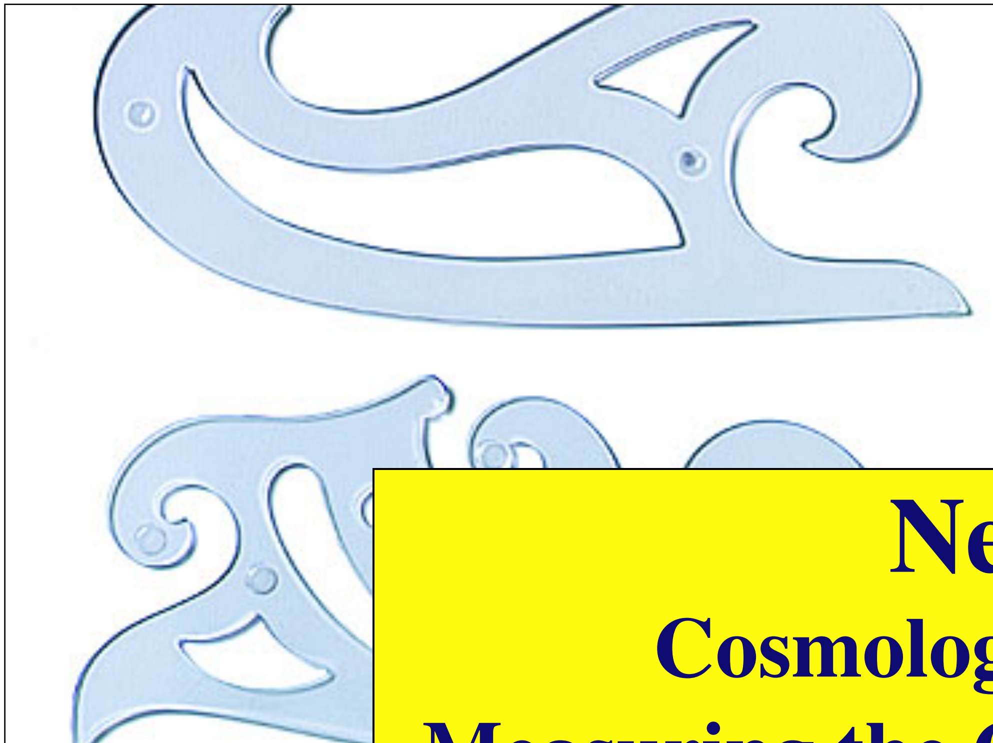
Time Dilation of Supernova Lightcurves

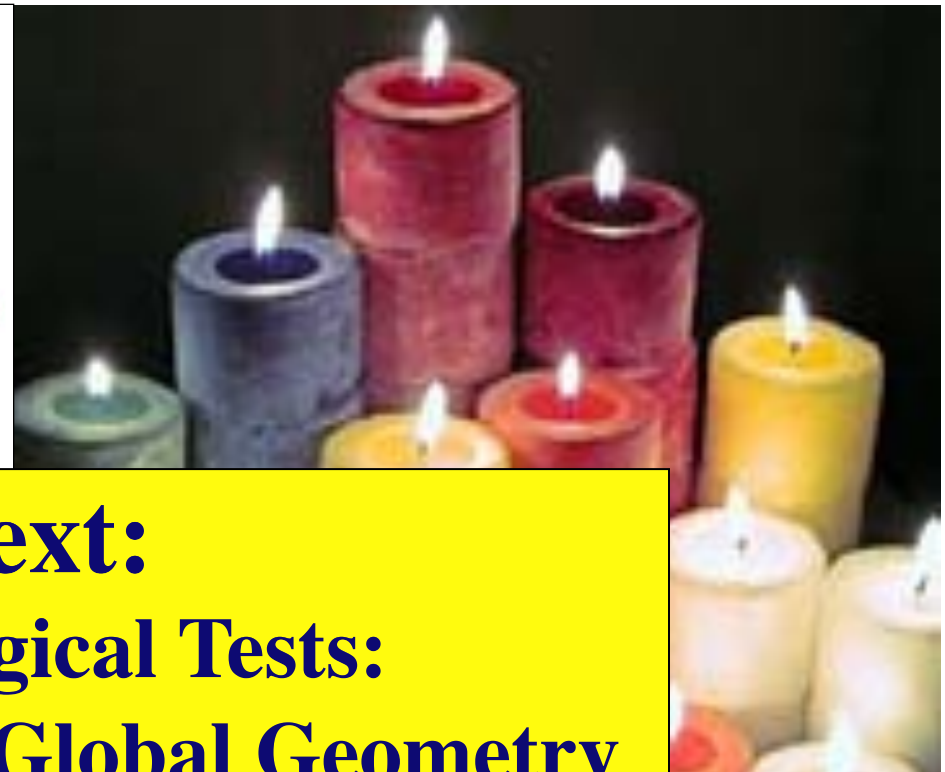


Normalized lightcurve width increases linearly with (1+*z*), as expected in an expanding universe

After correcting for the expansion, the stretch is constant

(Goldhaber et al.)





Next:

Cosmological Tests:

Measuring the Global Geometry and Dynamics of the Universe