40 Astro notes 2018/12/5 - Wed - Cosmology - acceleration

40.1 Homework discussion

Big blue bump problem

40.2 Expansion history

So far we have seen the metric for a homogenous, isotropic universe, as well as the dynamical equation for how the expansion factor depends on the makeup of the universe as parameterized by $\Omega_{M,0}$, $\Omega_{rel,0}$ and $\Omega_{\Lambda,0}$, the current ratios of the density of each component to the critical ration ρ_c. Frequently, including below, the "0" will be dropped. You will need to infer whether Ω_M is a parameter or a scale-factor-dependent quantity based on whether it is multiplied by factors of $(1+z)$ or not. If the factors of $(1+z)$ are put in explicity, it is generally the current value of the parameter. Also, I, and others, will sometimes use $\Omega_{\rm rad}$, for the "radiation" component, rather than Ω_{rel}, but they are generally the same for cosmological purposes.

In order to *measure* the values of these parameters, we need some observables that depend on them. It turns out that the relation of luminosity distance to redshift measures the expansion history of the universe. Luminosity distance is just the distance given by a naive interpretation of observed flux, i.e.

$$F = \frac{L}{4\pi D_L^2} \qquad D_L = \sqrt{\frac{L}{4\pi F}}$$

where L is the known isotropic luminosity of an object, F is its observed flux (observed brightness) and D_L is then the luminosity distance. By integrating through a spacetime like we have been discussing, we find that the luminosity distance is given by:

$$D_L = \frac{c(1+z)}{H_0} \int_0^z \left[\Omega_M (1+z')^3 + \Omega_\Lambda (1+z')^{3(1+w)}\right]^{-1/2} dz'$$

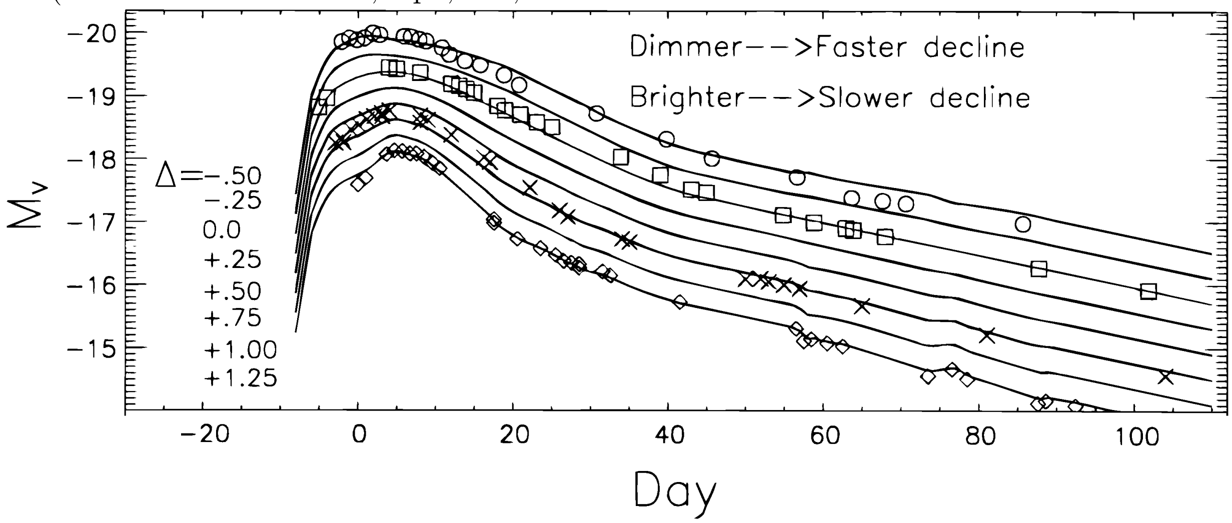
(For more information see: Carroll, Press, Turner 1992, ARA&A, 30, 499; Riess et al. 1998, AJ, 116, 1009; Garnavich et al. 1998, ApJ, 509, 74. The last gives this relation for luminosity distance.)

So if we have D_L and z for objects over a range of z we can fit the parameters of this relation.

40.3 measuring with supernovae

The luminosity of a Type Ia supernova can be determined with decent accuracy from its fading rate. This relation is determined (calibrated) using supernovae that are nearby enough to have known distance.

(From Riess et al. 1996, ApJ, 473, 88:



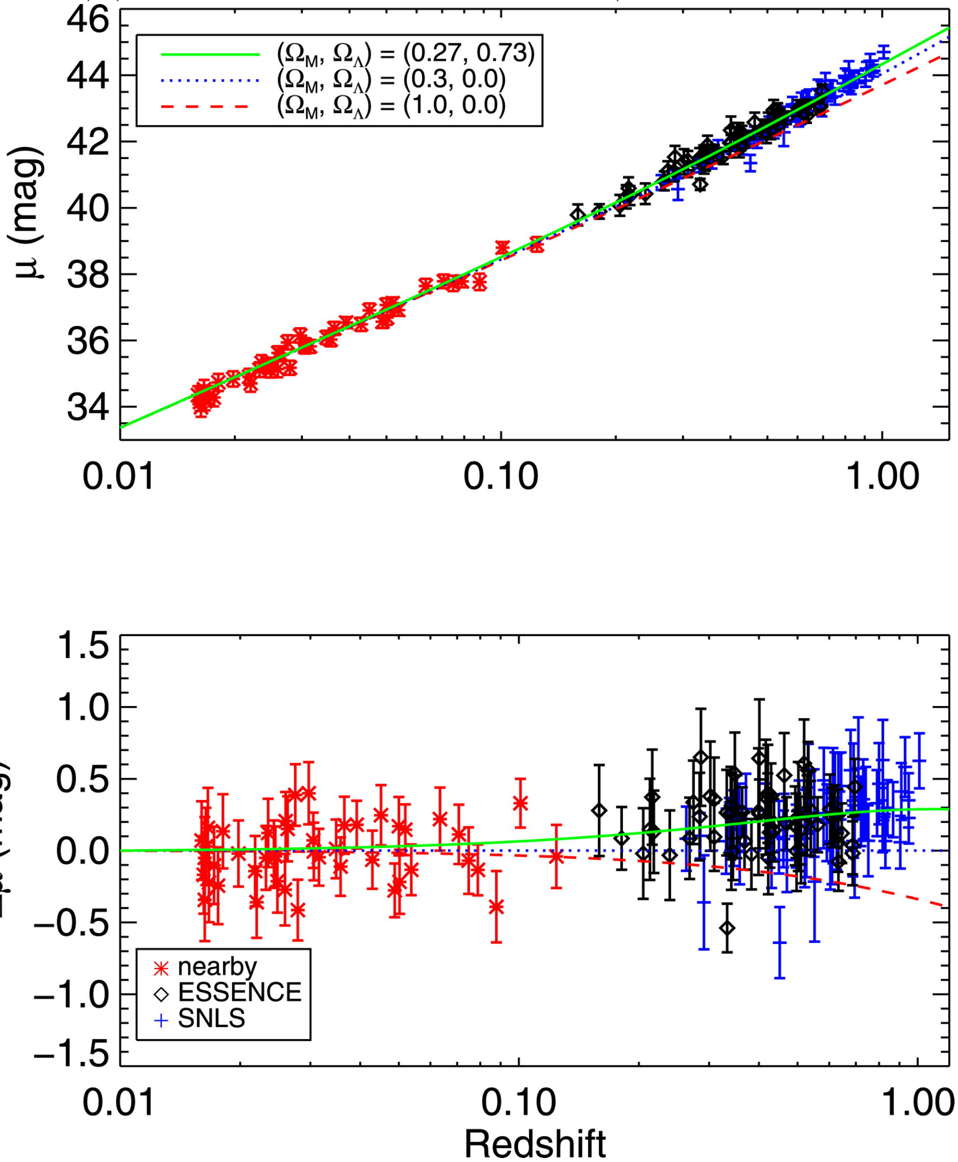
What is actually measured is luminosity distance, often shown as "distance modulus" μ in magnitudes as a function of redshift. where m is the apparent magnitude (from observed flux) and M is the absolute magnitude (from Luminosity)

$$\mu = m - M = 2.5 \log_{10} \left[\left(\frac{d}{10 \text{ pc}} \right)^2 \right]$$

Recall that redshift is basically just the ratio of the expansion factor now vs. that when the light was emitted. So this measures the expansion history.

The acceleration of the expansion was discovered in 1998, but I will show more recent work that has better statistics.

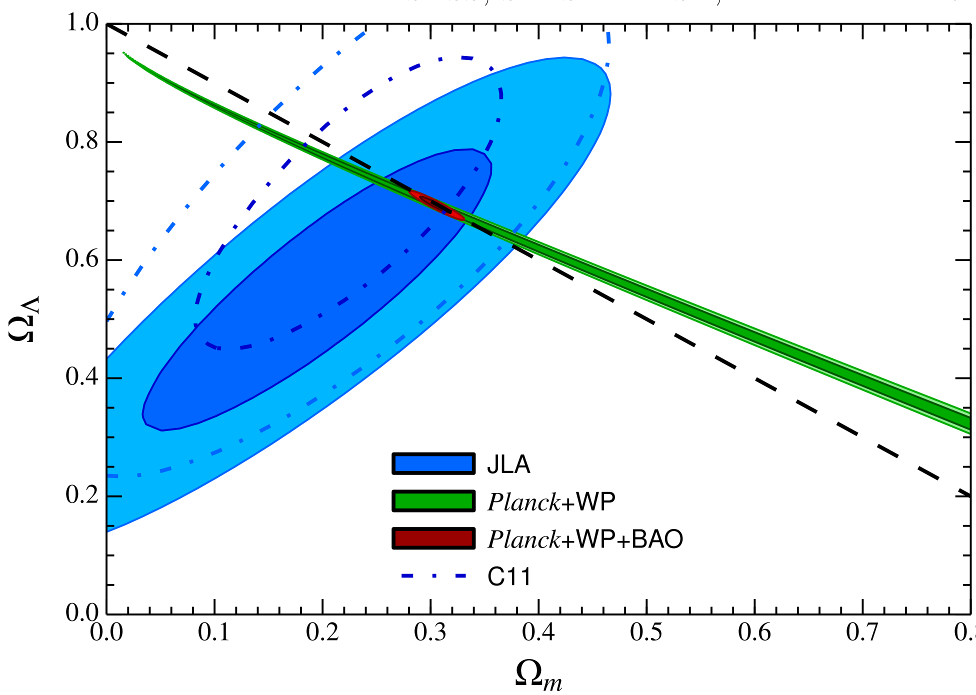
One example from a study from about a decade ago (Wood-Vasey et al. 2007, ApJ, 666, 694) (shown here because it is a clear plot):



Here the difference is shown from a flat cosmology with $\Omega_M = 1$ and an open cosmology with $\Omega_M = 0.3$, the value favored by measurements of galaxy clusters.

40.4 More state of the art

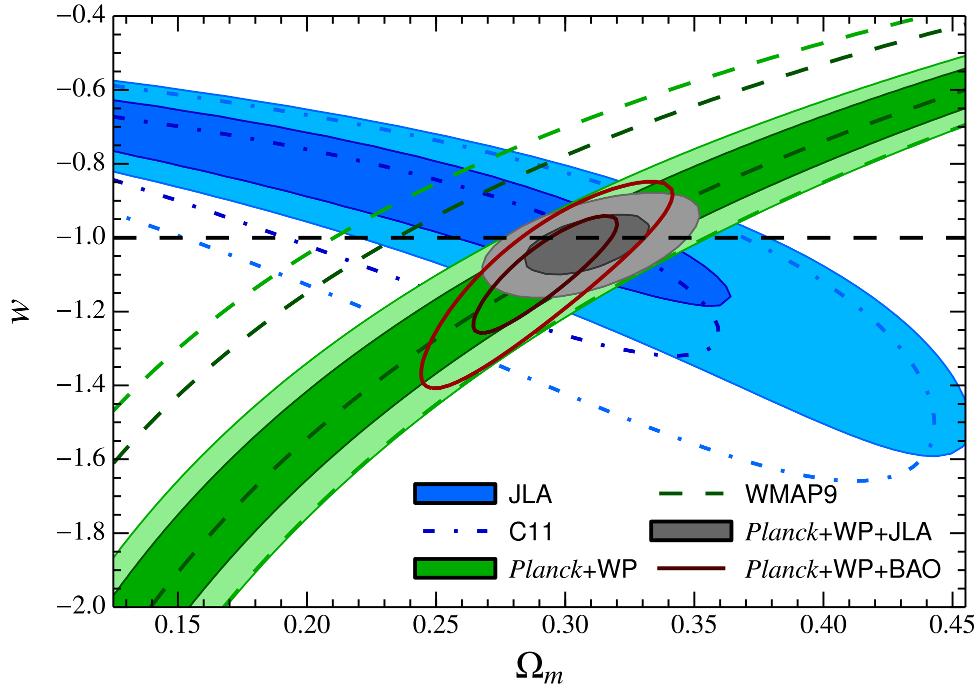
Currently the Ω parameters are very well measured. From a more recent reference that selects the best understood data - SDSS, SNLS and HST, Betoule et al. 2014, A&A, 568,

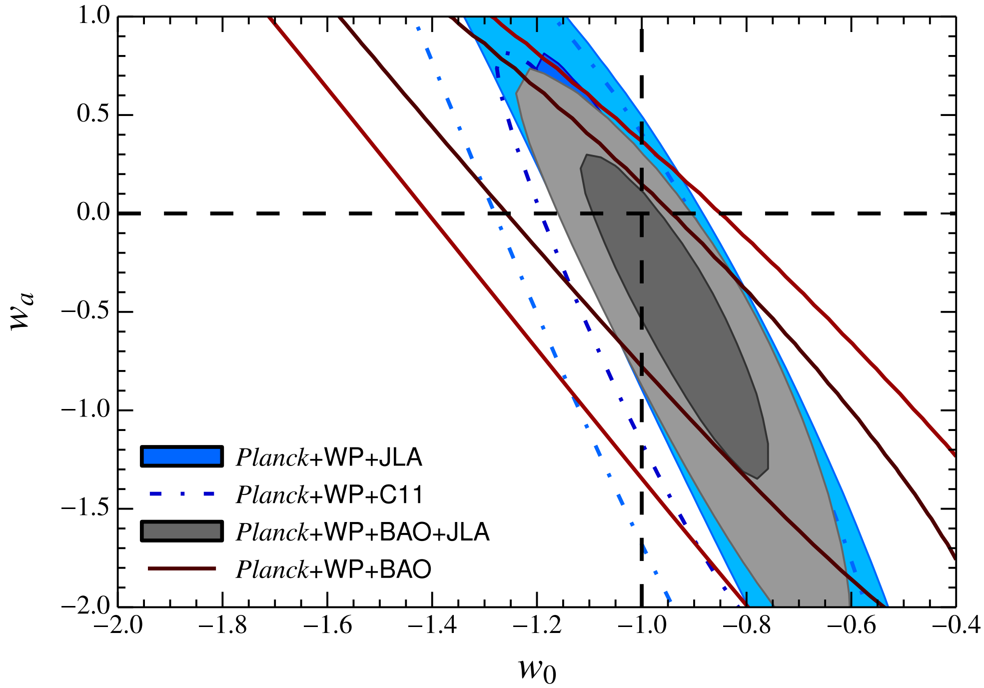


A22:

These are contours of 1 and 2 sigma likelyhood (basically probability that a particular parameter combination is the correct one, given the uncertainty in the data and measurement and the finite number of measurements made. There is a 68% chance the correct value is in the 1σ region and a 95% chance that it is in the, larger, 2σ region) SNIa ("JLA" = "Joint Light-curve Analysis") is consistent with Planck combined with BAO (Baryon acoustic oscillations, a standard ruler technique.)

But state-of-the-art goes on to measure both the parameter w, which allows the Dark Energy to have some other dependence on the scale factor other than being a cosmological constant ($w = -1$), and also the first derivative of w, w_a:





Things mostly consistent, but will be interesting as Planck and more BAO results are released.

40.5 Course reviews

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