Classic papers course:

Riess et al - Evidence for an accelerated expansion

- **What is the paper about?**
  The paper is about the observational evidence from luminosity distance measurements of SNe Ia for a positive non-zero cosmological constant and the accelerated expansion of the universe.
- **What are the physical assumptions made?**
  The paper assumes a universe with (positive) matter energy density and a cosmological constant.
- **What is the most important conclusion?**
  The most important conclusion is the existence of a non-zero and positive cosmological constant, and the accelerated expansion of the universe.
- **What is the secondary conclusion?**
  The secondary conclusion is the estimate of the age of the universe to be about 14.2Gyr, and that the flat universe with only matter is ruled out at very high sigma. It also found a value for the Hubble parameter.
- **What has the impact of the paper on the field been?**
  The paper showed that contrary to the current belief that the expansion of the universe was slowing down, it was actually accelerating, and provided evidence for the existence of a dark energy.
- **Is the work still important?**
  It is still important in the sense that it laid the observational foundation for research into the nature of dark energy which is still ongoing.

Other notes:

- Used SNe Ia because they are believed to be very regular in their characteristics. This is because they are exploding white dwarfs that exceeds the Chandrasekar mass-limit through accretion, so the initial state will be very similar for all such SNe.
- Used two methods to determine the absolute magnitude of observed SN Ia, a template fitting based on nearby SN, and a so-called “linear estimation algorithm”, or the “MLCS” method. There was also a third method (so-called “snapshot” method) used on four SN that were too sparsely sampled for the above two methods to be applicable.
- The dominant source of statistical uncertainty is from the excitation measurements.
- The paper makes several different analysis: They include and exclude in different combinations SN data that for some reason could be bad (e.g. nearby SN that could be inside a local void, or SN data that could be another type of SN than SN Ia). They use various prior, such as assuming a flat space, zero cosmological constant. Despite this they always get that a non-zero and positive cosmological constant is preferred.
- The confidence intervals are very elliptical (see fig 7), and lie approximately along the lines of equal age for the universe (see fig 9), so that even though the constraints on Omega_m0 and Omega_Lambda0 separately are weak, the age of the universe could still be determined quite well.

- The age of the universe from the paper is consistent with stellar theory and radioactive dating.

Systematic uncertainties considered:

- **Evolution:**
  The local sample of SN show a weak correlation between light curve shape and host galaxy type, and there are observations that could indicate an evolution of SNe Ia with progenitor age. Since the early-times and late-time galaxy types differ there could be a difference in the SN they host. However, it was not found to change the result of a positive non-zero cosmological constant.
- **Extinction:**
  Extinction is a major source of error in the distance uncertainties. It could be that the size of the dust grains vary from early-times to late-times, causing a redshift-dependent extinction that was not considered. Or it could induce a dispersion in the derived distances. However, both effects were concluded to not be plausible explanations for the observed faintness of high-redshift SNe Ia.
- **Selection Bias:**
  Sample selection bias could distort the comparison between nearby and distant SNe. Examples of selection biasas are that the SN searched preferentially detect intrinsically luminous SNe, or “brighter-than-usual” SNe for a particular light curve shape, and that different types of searches select SNe Ia with different parameters or environments, so that a comparison is affected. It is concluded that more work is needed and that they must continue to be wary of subtle biases that affect the comparisons of neaby and distant SNe Ia.
- **Effect of a Local Void:**
  In another work (Zehavi et al 1998) it was noted that the local expansion is greater than that measured for more distant objects. This could be because we are in a local void, i.e. lower mean matter density than the global mean. Since the paper is probing the global expansion, this local effect could give a false impression of a non-zero positive cosmological constant. They test the effect of a local void on the cosmological parameters by excluding the nearby SNe Ia in this possible local void and find that the effect is relatively small, and doesn’t change the conclusion.
- **Weak Gravitational Lensing:**
  It is expected that SNe light will on average be demagnified, or dimmed, by 0.5% at $z=0.5$ and 1% at $z=1$ due to gravitational lensing. While this effect could give a false impression of a cosmological constant, it is far too small to affect the analysis. They also considered if matter was clumped in stars and DM MACHOs, which would give a larger microlensing, but it would still be too small to explain the observed SNe distances without a cosmological constant.
- **Light Curve Fitting Method:**
  While they find a few differences with the two methods, such as a small difference in distances and scatter, which results in slightly different confidence intervals (see figs 6, 7, 8 and Table 8), both methods favor the existence of a non-zero positive cosmological constant and accelerated expansion.

- **Sample Contamination**
  It could be that SN types that are not Ia contaminated the data-set, which would make some of the distance measurements incorrect and could result in an incorrect conclusion. The classification of a SN is determined from the presence or absence of specific characteristics in the spectrum. But for SNe at high redshift some of these characteristics are shift out of the observer's frequency range, and there are low signal-to-noise ratio cases. In the paper they do their analysis both with and without two of the most likely SN samples to be a contamination to see its effect on the result, which was found to be very small. However, they note that contamination of future samples is a concern.