Modern cosmology 1: The Hubble Constant

- Extragalactic distance measurements
- Classical Cepheid calibration
- HST Key Project results
- Independent measurements

Extragalactic distance measurements

- Cepheid-calibrated
  - Whole-galaxy methods: Tully-Fisher, fundamental plane, surface-brightness fluctuations
  - Type Ia supernovae
- Cepheid-checked
  - Type II supernovae
- Cepheid-independent
  - Sunyaev-Zeldovich effect
  - Gravitational lensing
**Systematic errors**

- The Key Project systematic error budget:
  - LMC distance: \( \pm 5\% \)
  - HST WFPC2 zero point: \( \pm 3\frac{1}{2}\% \)
  - Reddening estimate: \( \pm 1\% \)
  - Metallicity effects: \( \pm 4\% \)
  - Bias: \( \pm 1\% \)
  - Crowding: \( +5\%, -0\% \)
  - Bulk flows: \( \pm 5\% \)

- Total: \( +10\%, -9\% \)

Systematics dominated. No single source dominant – so improvement difficult.
Results for $H_0$

- Results are all consistent within statistical errors
  - FP a bit high
  - mean $72\pm3\pm7$ km/s/Mpc
  - SN II result very consistent with earlier result from Schmidt et al.
  - Error is dominated by systematics, so little point in collecting more data

Update on $H_0$

- Since Key Project, systematics improved by
  - using ACS/WFC3 instead of WFPC2 on HST
  - better Cepheid parallaxes (HST)
  - using maser galaxy NGC 4258 instead of LMC as basis of distance scale
  - focus on SNe Ia as distance indicator
- Result is to halve systematic error from $\pm10\%$ to $\pm5\%$ (Riess et al., ApJ 699 (2009) 536)
  - result: $74.2\pm3.6$ km s$^{-1}$ Mpc$^{-1}$
Independent measurements

- Gravitational lensing and Sunyaev-Zeldovich distances are in principle geometric
  - both tend to give lower values (~60 km/s/Mpc)
  - both are new and difficult techniques
- CMB fits give completely consistent result
  - $70.1 \pm 1.3$ km/s/Mpc (WMAP+BAO+SN, 2008)

Conclusions

- Precision of Hubble constant measurements driven by systematic errors in calibration
  - best long-range geometric measurements are lower than best conventional values, but not convincingly so
- Best estimate (HST Key Project 2001, WMAP fit 2008) is ~70 km/s/Mpc
  - error ~10% from HST, ~2% from CMB
  - much better than factor 2 error in 1980s!