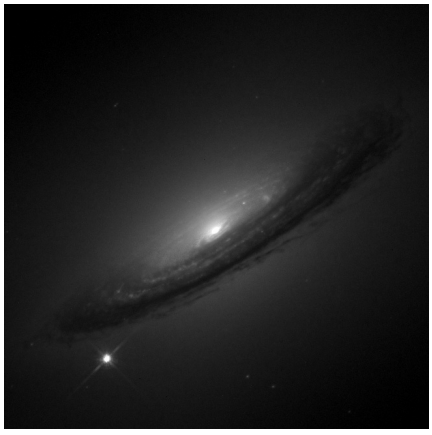
Modern cosmology 2: Type Ia supernovae and Λ

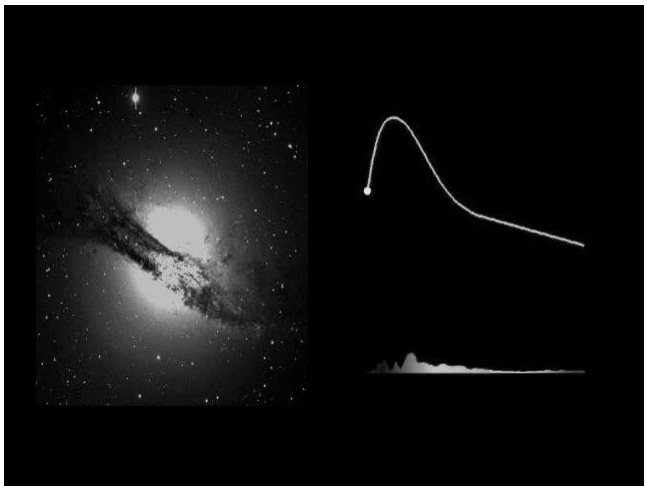
- **Distances at z ~1**
- **Type Ia supernovae**
- **SNe Ia and cosmology**
- **Results from the Supernova Cosmology Project, the High z Supernova Search, and the HST**
- **Conclusions**

Type Ia Supernovae

- **Observational properties**
  - **no hydrogen lines, but strong Si line at ~600 nm**
  - **occur in all types of galaxies; about 1/galaxy/ century**
  - **peak absolute magnitude ~ −19 to −20**
  - **peak followed by steady exponential decay**

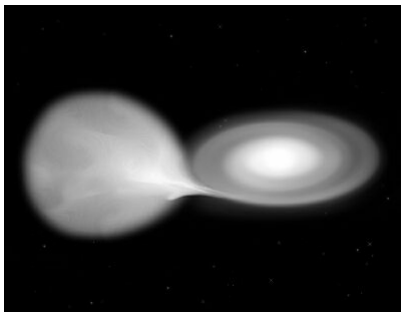


Type Ia Supernovae



Type Ia Supernovae

- **Physical properties**
  - **gravitational collapse of white dwarf followed by runaway carbon fusion**
  - **unclear whether collapse triggered by coalescence of double-white-dwarf system or accretion from main-sequence or giant companion**
  - **either way, $1.4M_{\odot}$ of carbon/oxygen blows up!**



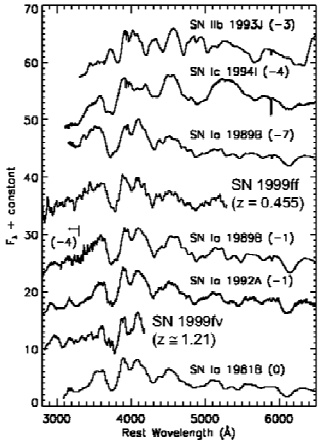
SNe Ia and Cosmology

Aim: investigate deviations from Hubble's law at large z

- **Requirements**
  - **range out to $z \sim 1$**
  - **no evolutionary effects**
    - or evolutionary effects under control
  - **reasonable statistics**
    - tens or hundreds of galaxies over good range of z
- **Type Ia supernovae**
  - **current record $z \sim 1.6$**
  - **expect effect is small**
    - 1.4 $M_\odot$ of carbon much the same at any time
  - **current sample ~200**
    - several large-scale surveys designed to pick up candidates for spectroscopic follow-up

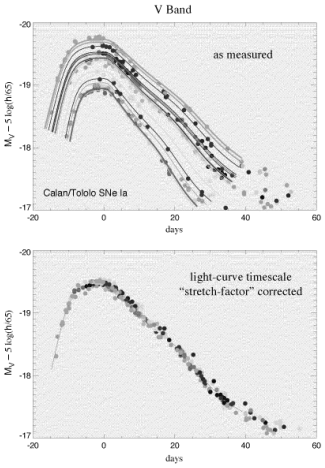
Basic requirements

- **Identify candidates**
  - **survey by looking at difference images**
  - **follow up spectroscopically and with photometry**
- **Standardise light-curves**
  - **including absorption effects**
  - **this gives *M*, and hence μ**
- **Get redshift from galaxy spectrum**



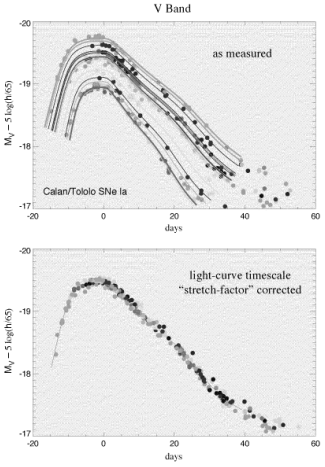
Type Ia supernovae as "standardisable candles"

- **SNe Ia do not all have *exactly* the same absolute magnitude**
  - **but absolute magnitude is strongly correlated with rate of decline (faster = fainter)**
  - **apply "stretch factor" to compensate for this**
  - **also need to correct for spectral redshift and interstellar absorption**

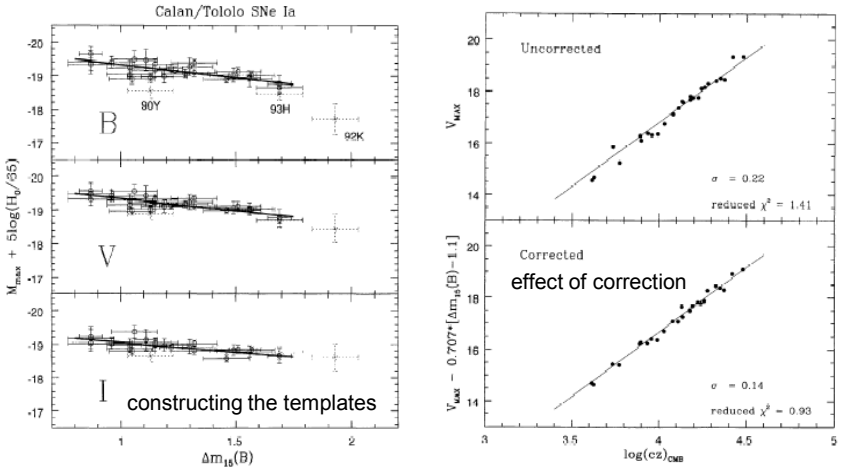


Type Ia supernovae as "standardisable candles"

- **Methods for standardising light curves**
  - **Δm_{15}**
    - look at decrease in brightness 15 days after peak
  - **MLCS**
    - "Multi-colour Light Curve Shape"
    - fit light curve to templates derived from nearby SNe Ia
    - multi-colour aspect allows correction for absorption

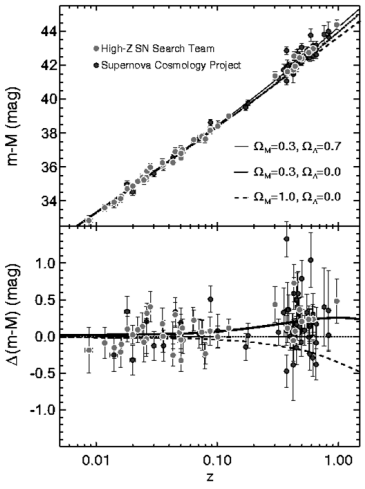


The nearby sample



M. Hamuy et al., *AJ* **112** (1996) 2398

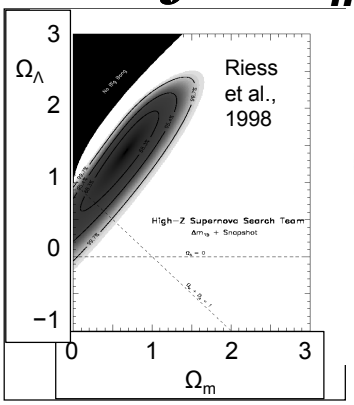
Results from SCP and HZSS

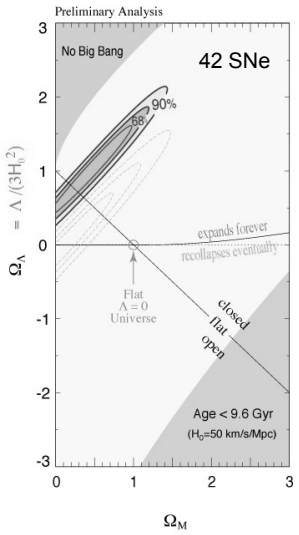


- **Data from two independent teams are consistent**
  - **both show SNe at large *z* *fainter* than expected for flat matter-dominated universe (i.e. $q < ½$)**
  - **clear tendency to lie above "empty universe" line (i.e. $q < 0$)**

Results for Ω_m and Ω_Λ

Note that, in models with positive Λ, a closed universe does not in general recollapse





Roughly, the data constrain the difference $\Omega_\Lambda - \Omega_m$

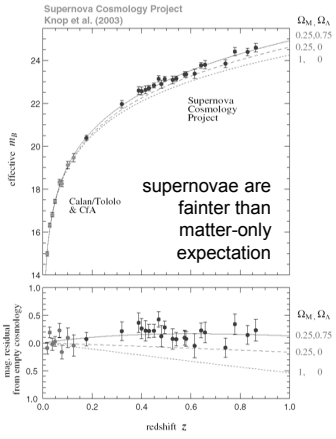
Perlmutter et al., 1998

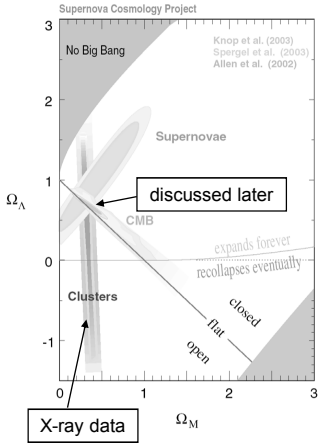
Results from HST

Results using 11 SNe Ia ($0.36 < z < 0.86$) observed with HST

(Knop et al., *ApJ* **598** (2003) 102)

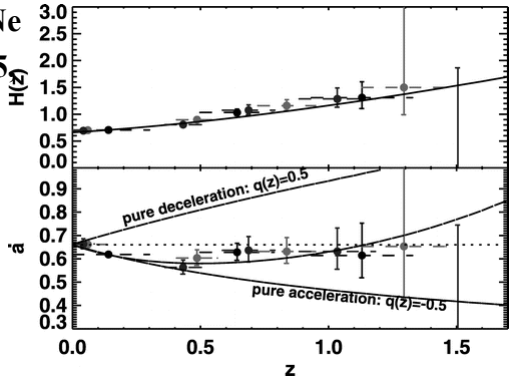
Nicer data, same results





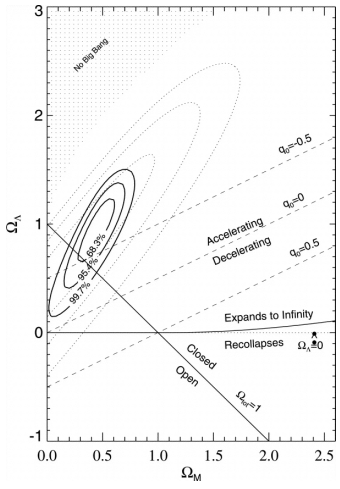
Going to higher z

- **High *z* SNe identified using HST ACS data**
  Riess et al. (*ApJ* **659** (2007) 98)
- **Combine with low and intermediate *z* samples**
  - **~200 well analysed SNe**
- **See acceleration to $z \sim 0.5$ and deceleration earlier**
  - **very consistent with a model with both Ω_m and Ω_Λ non-zero**



Going to higher z

- **Wider range of *a* reduces degeneracy between Ω_m and Ω_Λ**
  - **result is consistent with a flat universe in which $\Omega_\Lambda \approx 0.7$ and $\Omega_m \approx 0.3$**
  - **this is the "benchmark universe" derived from the WMAP results (see later)**
- **Switch from acceleration to deceleration eliminates several alternative explanations**



Riess et al. (*ApJ* **607** (2004) 665)

Conclusion

- **Now several independent teams reporting results on Type Ia supernovae**
  - **results consistently require positive Ω_Λ and are consistent with (but do not require) $k = 0$**
    - definitely not consistent with $\Omega_m = 1$, $k = 0$
    - definitely requires $q_0 < 0$ (acceleration)
  - **turnover from acceleration to deceleration at $z \sim 0.5$**