Can we trust Type Ia Supernovae as cosmological tools?

Critical analysis and alternative processing of SCP Supernovae data

Clémentine Hauret & Pierre Magain
Institute of Astrophysics and Geophysics, University of Liège, Belgium

Scan me for a short presentation video and more informations about this work!

Why should we care?

Current processing to standardize Type Ia Supernovae data produces a significant bias in favour of a particular cosmological model, the flat ΛCDM model. To reduce this bias, we develop an alternative, model-independent, methodology.

Type Ia Supernovae as standard candles

Type Ia Supernovae (SNIa) are not perfect standard candles. Thus, to be able to use them as cosmological tools, one has to **standardise** them on the basis of their light curve and host galaxy characteristics. Mathematically speaking, one can compute SNIa ‘standard candle’ **absolute magnitude**, i.e. corrected peak absolute blue magnitude, by

$$M_{B,corr} = M_B - \alpha\, x_1 + \beta\, c + \delta\, P(M_{galaxy} < 10^{10}\, M_\odot)$$

where M_B is the absolute blue magnitude of the SNIa. x_1, c and P are respectively measurements of SNIa **light curve decline rate** [Phillips, 1993], SNIa **color** at maximum [Riess et al., 1996 ; Tripp, 1998] and probability that the SNIa **host galaxy** is less massive than $10^{10}\, M_\odot$ [Kelly et al., 2010 ; Lampeitl et al., 2010 ; Conley et al., 2011]. M_B, α, β and δ are thus parameters that must be determined in order to transform SNIa into genuine standard candles.

Credits: The Palm Beach Candle Company

Currently : Simultaneous fit

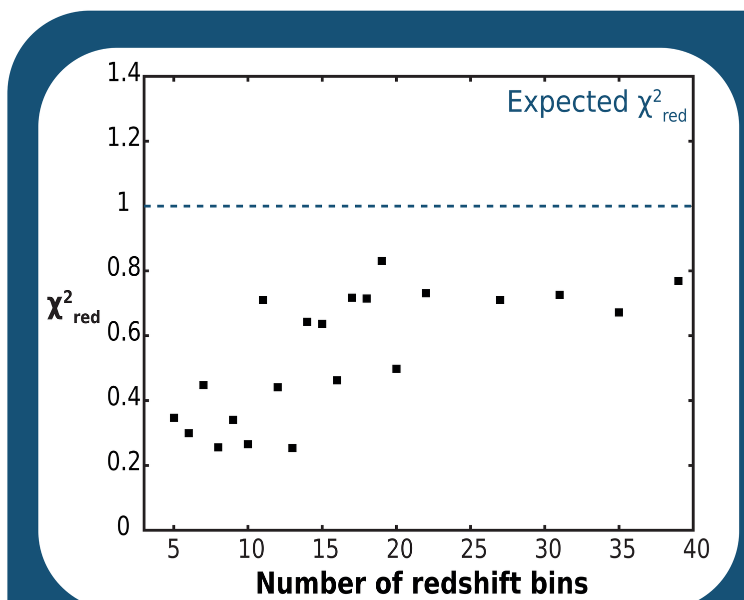
Since 1999, the M_B, α, β and δ parameters are **not independently calibrated** but are simultaneously fitted with the cosmological model when constructing Hubble diagrams. The data are thus **biased** in favour of the assumed cosmology, i.e. a **flat ΛCDM model**.

Alternative : Independent calibration

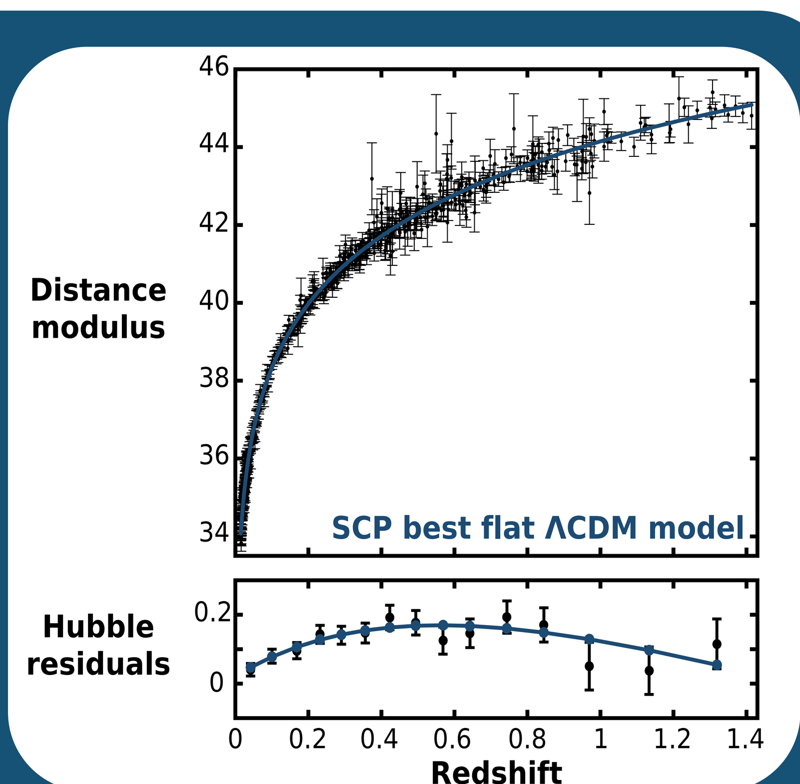
To reduce the bias within SNIa data, the correlation between $M_{B,corr}$, x_1, c and P is first **calibrated** on **nearby SNIa** in the Hubble flow. This **model-independent** calibration is then used for SNIa at all redshifts.

Statistical analysis : Evidence of bias through data binning

The bias in SNIa data can be highlighted by a study of the data correlations, illustrated here by analysing the effects of **averaging** the data in a varying number of **redshift bins**. We use SNIa observations from the **Union 2.1 compilation** [SCP ; Suzuki et al., 2012] and group them in redshift bins. We then fit SCP best **flat ΛCDM model** ($\Omega_{m,0} = 0.27$ & $H_0 = 70$ km/s/Mpc) on these binned data.



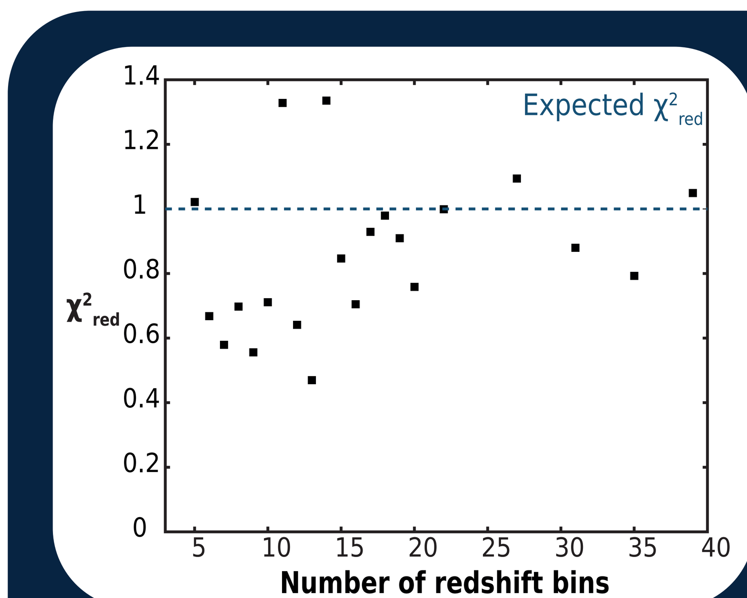
Reduced χ^2 values for the fit of SCP best flat ΛCDM model on different binnings of SCP data



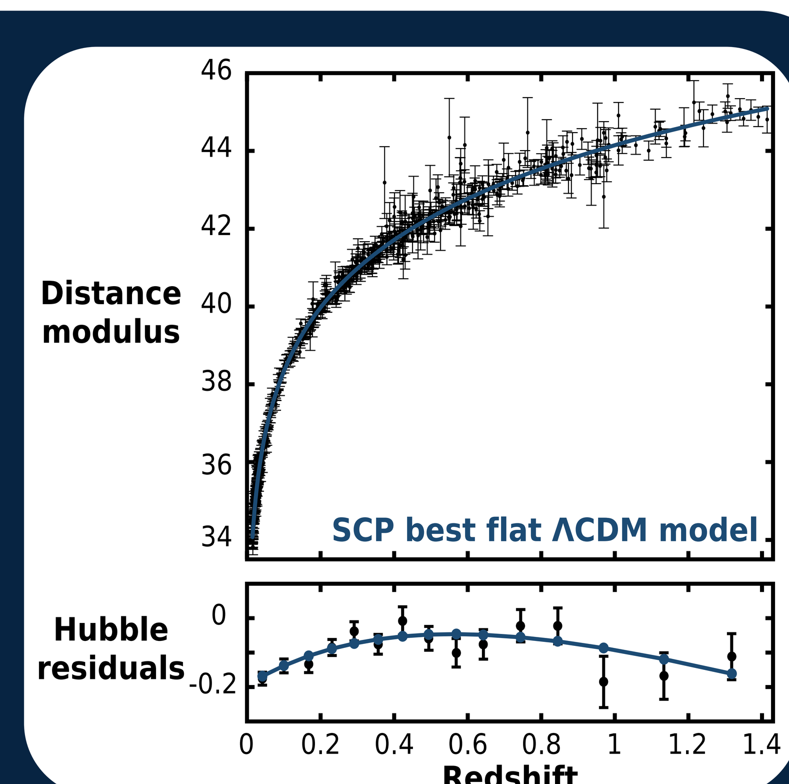
Hubble diagram of SCP data, Hubble residuals after subtraction of an empty model and comparison with SCP best flat ΛCDM model

Overfit of SCP best flat ΛCDM model

- χ^2_{red} values too low
- SCP model invariably stands within 1σ error bars



Reduced χ^2 values for the fit of SCP best flat ΛCDM model on different binnings of recalibrated SCP data



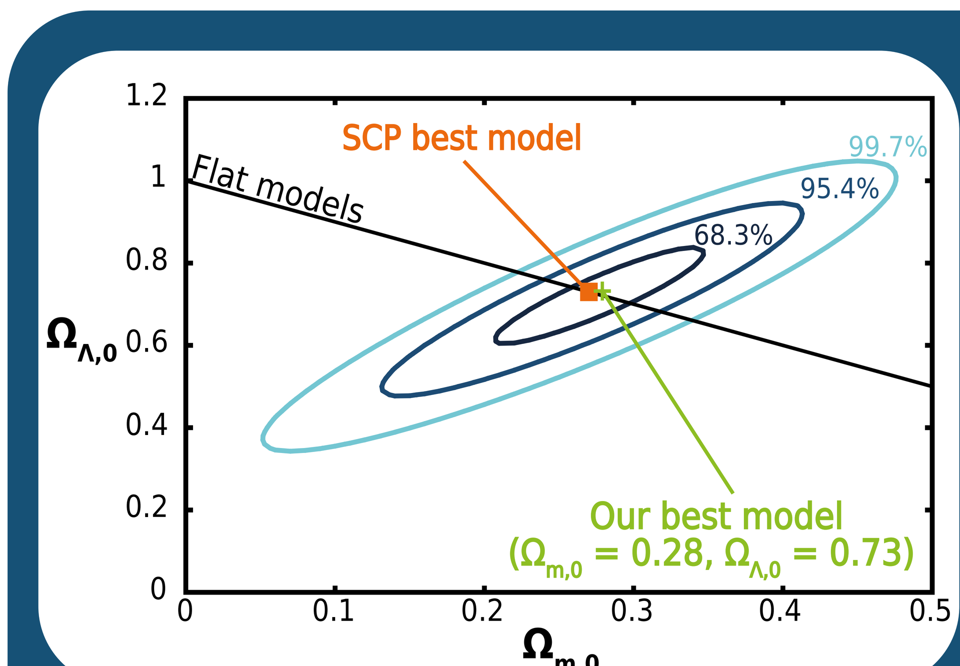
Hubble diagram of recalibrated SCP data, Hubble residuals after subtraction of an empty model and comparison with SCP best flat ΛCDM model

Reduction of the overfit

- Bias due to the current methodology (simultaneous fit) used to standardize SNIa

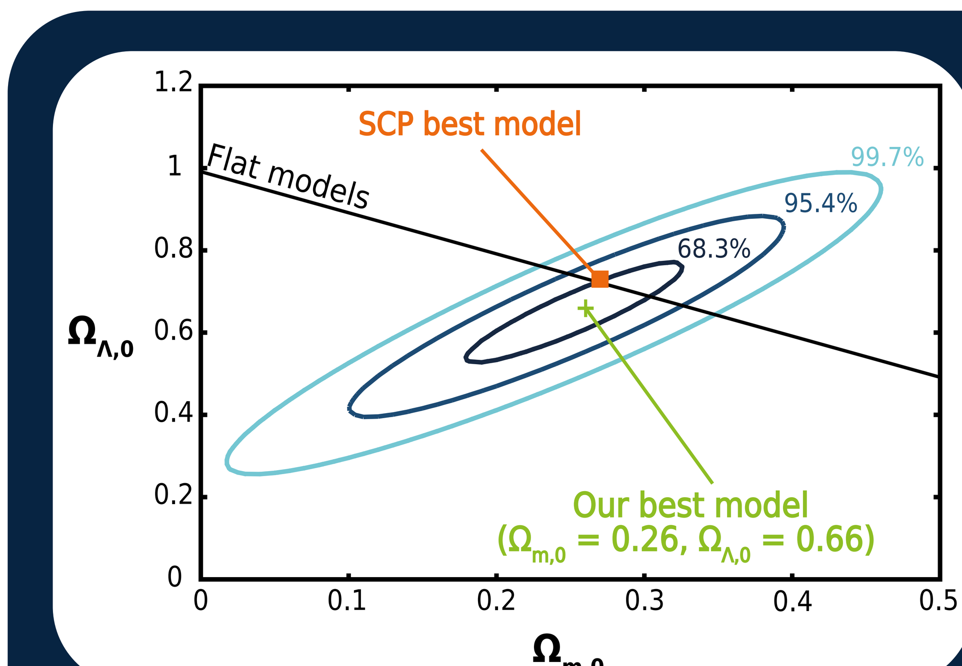
Cosmological analysis : Evidence of bias through cosmological fits

To quantify the bias in SNIa observations, we fit **different cosmological models** (open, flat and closed) on unbinned SCP data. These models are characterised by three parameters : the present density parameters for matter $\Omega_{m,0}$ and for dark energy $\Omega_{\Lambda,0}$ as well as the Hubble constant H_0, independently optimised for each fit.



Confidence regions for different open, flat and closed ΛCDM cosmological model fits on SCP data.

Confirmation of SCP best cosmological model : $\Omega_{m,0} = 0.27$ & $\Omega_{\Lambda,0} = 0.73$



Confidence regions for different open, flat and closed ΛCDM cosmological model fits on recalibrated SCP data.

Effects of bias

- on the best **cosmological model**
  SCP best model excluded at 1σ
- on **parameters** of the assumed cosmology
  New best flat model ($\Omega_{m,0} = 0.29$) compatible with Planck results [Planck Collaboration, 2015]

References

Phillips, M.M. 1993, ApJ, 413, L105 – *Riess, A.G., Press, W.H. & Kishner, R.P. 1996, ApJ, 473, 88* – Tripp, R. 1998, A&A, 325, 871 – *Kelly, P.L., Hicken, M., Burke, D.L., Mandel, K.S. & Kishner, R.P. 2010, ApJ, 715, 743* – Lampeitl, H., Smith, M., Nichol, R.C., et al. 2010, ApJ, 722, 566 – *Conley, A., Guy, J., Sullivan, M., et al. 2011, ApJ, 192, 1* – Suzuki, N., Rubin, D., Lindman, C., et al. 2012, ApJ, 746, 85 – *Planck Collaboration, 2015, ArXiv e-prints [arxiv:1502.01589]*

Contact

Clémentine Hauret
PhD Student & Assistant Teacher
University of Liège
Institute of Astrophysics and Geophysics – OrCA Group
0032 476 38 24 31 – clementine.hauret@ulg.ac.be

Scan me to visit my personal web page and have an easy access to my contact details