Search for Type Ia Supernovae beyond z=1 at CFHT

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We report on a search $z > 1$ type Ia supernovae conducted, at the Canada-France-Hawaii Telescope (CFHT) at fall 99. From the photometric measurement of such objects, we expect to gain on the accuracy of cosmological parameters, both statistically, and systematically.

1 Introduction

Type Ia Supernovae have been used to measure the cosmology by using the classical magnitude-redshift relation for standard candles (objects of fixed or calibrable intrinsic luminosity). To date, two groups[1,2] have measured Ω_M and Ω_Λ using supernovae at redshifts z $\in$ [0.4,0.8] compared to nearby ones. They very well agree on the results, exclude a flat Ω_M=1 universe, and show evidence for a non zero cosmological constant. We will first review the motivations for searching at higher redshifts than aimed at in past searches. We will then describe the pilot search at CFHT we carried out at fall 99. The SCP already found one $z > 1$ supernova at Keck in 98.

2 Motivations

Supernovae measurements for cosmology imply 3 types of observations: the search which is done by difference imaging at 2 epochs 3 to 4 weeks apart, then spectroscopy of candidates just after the second epoch, and finally photometry to sample the light curve in order to measure both its maximum light and width. The brightness of the supernova used for cosmological measurements is derived from the maximum light.

As one may notice on figure 1, the higher the redshift, the higher the separation of different cosmological scenarios. Going to higher redshifts than available data is only meaningful if the precision of measurements does not degrade significantly. This implies in practice that photometric measurements have to be made on 8 m class telescopes and on the HST.

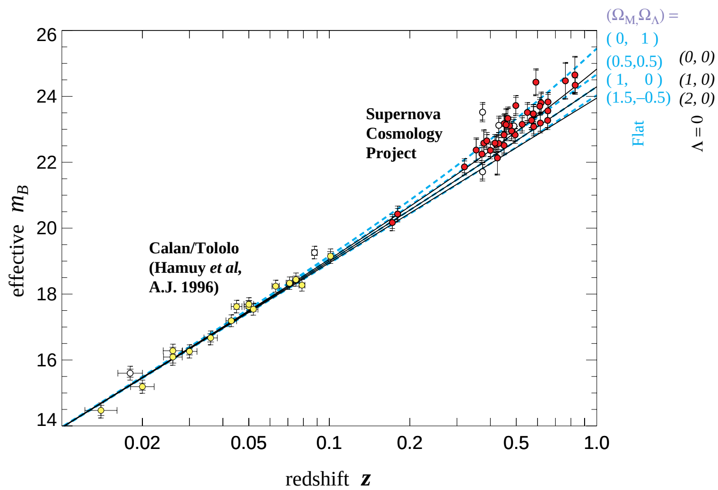

Figure 1: Hubble diagram of 42 distant supernovae (plus 18 nearby ones).

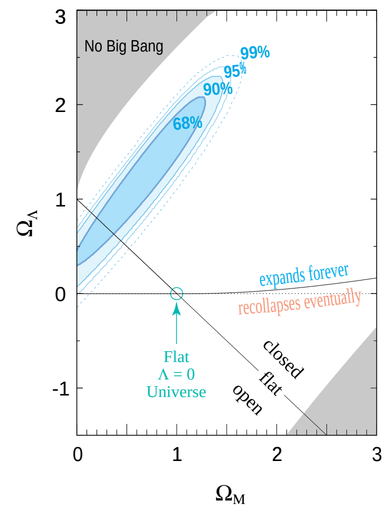

Figure 2: Confidence contours in the $(\Omega_M,\Omega_\Lambda)$ plane.

At a given object redshift, this measurement of cosmology relies on only one datum: the apparent brightness of a standard candle. This cannot determine both Ω_M and Ω_Λ but rather a combination of them. The direction constrained by this combination changes significantly with z (figure 3), but moderately with the actual values of Ω_M and Ω_Λ. Because of the limited z span of the data, the $(\Omega_M,\Omega_\Lambda)$ degeneracy is still striking on the confidence contours in the plane of the two variables (figure 2). At an average redshift of ~ 0.5, the present data measure a combination close to Ω_M- Ω_Λ. One will measure 2 Ω_M- Ω_Λ at a redshift of 1, where adding a few supernovae dramatically reduces the major axis of confidence ellipses.

A third motivation to search for high redshift supernovae is the fundamental observation of supernovae being fainter than expected at a redshift of $\sim$ 0.5, which translates into the evidence for a positive cosmological constant. This light dimming could be explained by some grey dust absorbing light in the intergalactic medium[3]. Although grey dust properties have to be fine tuned to accommodate observational constraints (both from supernovae and other sources), and some new results make it more unlikely, we may rule out this possibility using supernovae themselves. The cosmological constant affects the brightness of standard candles across redshifts with a very specific pattern, that absorption by dust cannot mimic. The same argument applies (maybe less stringently) to brightness modifications due to evolution of supernovae themselves.

3 The search

We searched for distant supernovae at the CFHT telescope (3.6 m) at fall 99, following the standard procedure which consists in subtracting images of the same regions of the sky taken 3 to 4 weeks apart.

The CFHT 12k camera [4] covers 40′x 30′on the sky with a pixel size of 0.2″, and with an unprecedented sensitivity for this large a field of view. The quality of the site and of the overall optics provide a median seeing of about 0.8″. This is certainly the best instrument to date to search for distant supernovae.

We had twice 1.5 night of observing time but lost a half night at the second epoch due to bad weather. We finally had in hand 2 pointings with 2 times 3.5 hours for the first one and 2

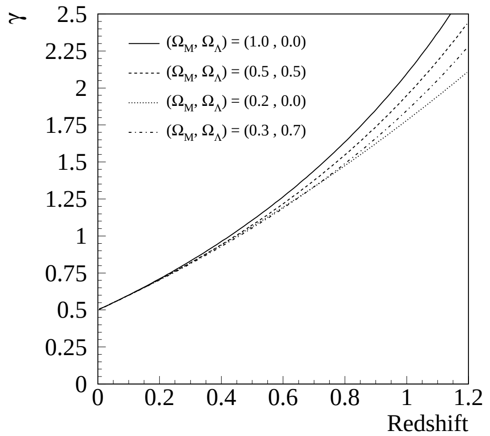

Figure 3: Tangent of the (Ω_M,Ω_Λ) degeneracy angle, for various cosmological scenarios. At a redshift z=0, one measures q_0 = Ω_M / 2 -Ω_Λ with corresponds to a tangent of 0.5; at z=0.1, one measures Ω_M- Ω_Λ, and at z=1 one measures 2Ω_M-Ω_Λ.

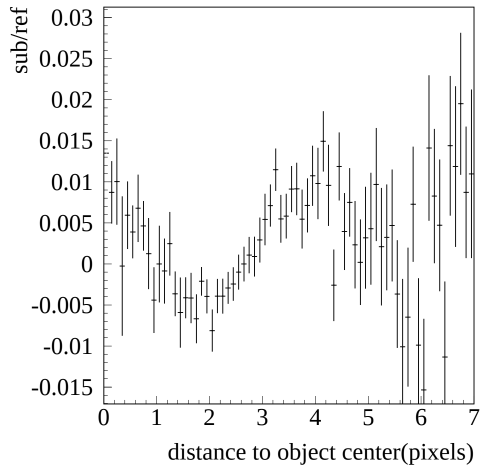

Figure 4: subtraction residuals ($< \mathrm{sub(d)/ref(d)} >$, averaged on several hundred objects) as a function of distance to object center. one may notice that they are at the 1% level.

times 3 hours for the second, all in the I band. With 2 / 3 of a square degree, extrapolatiing rates measured at $z \simeq 0.5$[5], we expect about 6 type Ia supernovae, 2 at $z < 0.8$, 2 at $0.8 < z < 1.0$, and 2 at $z > 1$.

We flatfielded the images using a double flat technique: the difference between a superflat and a twilight flat provides the fringe pattern, which we subtracted from both the superflat and the science images. The 18 images from each epoch were aligned and co-added using a simple clipped mean. We could check that this efficiently cleans up cosmics, most of CCD defects (due to dithering of exposures) and fast enough asteroids. The sky fluctuations we get result in the signal to noise expected for 17 images (only 12 if one uses a straight median rather than a clipped mean), and the seeing deterioration with respect to individual exposures is less than 5%.

When images are all aligned on the same grid, the subtraction 'only' involves the degradation of the best seeing image to the worst seeing one, using an ad-hoc convolution kernel. We determined this convolution kernel using a technique due to Alard[6], which consists in minimizing the subtraction residuals with respect to the convolution kernel, expressed as a linear combination of basis functions:

$$Q = \int dxdy (W - B \otimes (\sum_{i=1}^{N} \alpha_i K_i))^2$$

where B and W stand for the best and worst seeing images, the K_i are the N basis kernels and the α_i are the coefficients we minimize upon. During the minimization, only image stamps around unsaturated bright objects are considered (we take 100 objects to fit), so that the fit only takes around 30 seconds with N = 50.

For a search of faint objects on a subtraction, the principal concern is the systematic subtraction residual of bright objects due to imperfect matching of the involved PSF's. We measured it by averaging the normalized residual (subtraction / reference, where reference stands for any of both terms of the subtraction). As it remains below 1 % on the core of bright objects (see fig 4), systematic subtraction residual did not cause fake triggers.

The detection of candidates used a matched gaussian filter which approximates the expected shape of point-like objects on the subtraction. For pixels of the convolved subtraction which are above a 3 σ threshold (where σ is simply the r.m.s fluctuation of the "sky" of the convoluted subtraction), we measured the brightness of the detection on the unconvolved subtraction using aperture photometry. We vetoed detections close to objects saturated on any of the input images.

We then visually inspect detections which had a signal to noise above 4. We selected 14 candidates at an average I magnitude of 24.6 (a Ia supernova at a redshift of 1 has a peak brightness I=23.7, and we could detect sn1999fd at I=25.3 with a S/N of 5). We got spectra 6 nights after the CFHT observations at Keck (on LRIS) for 6 of them[7]. Although the depth was sufficient, we did not get objects beyond a redshift of 1 and the HST went unfortunaltely out of service when it could have provided the expected photometric follow-up. We ony followed up sn1999fd (z = 0.87) at VLT, and got 4 data points in I band for it.

4 Conclusions

With about 3 hours of integration, the 12k camera at CFHT can certainly detect type Ia supernovae at redshifts beyond 1. Since the spectroscopy of such objects requires typically 4 hours of integration on the Keck telescope, the overall efficiency would benefit of confirmation images to select rising objects. The photometry along the light curve is the least tricky part of the observations, especially if carried out in queue schedule mode as done at the VLT. We hope this program to be allocated enough telescope time to build a significant sample of 10 to 20 objects in the forthcoming years.

References

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