Type Ia Supernovae as Distance Indicators [1]

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1 Introduction

Type Ia Supernovae (SNe Ia) have become the principal distance indicator for the determination of distances in the Hubble flow and, in connection with their calibration through Cepheids, the Hubble constant (Hamuy et al. 1996, Riess et al. 1996, Saha et al. 1997). They also are currently the only serious competitor for a measurement of the cosmological deceleration (Perlmutter et al. 1995, 1997, Schmidt et al. 1998). In spite of this wide usage as distance indicators it should be kept in mind that we do not know which stellar systems evolve into SNe Ia (Branch et al. 1995) and no satisfactory theory of these explosions has been proposed yet. It is thus very important to understand the sample properties as exactly as possible. There is little doubt that SNe Ia can be successfully used do measure H_0 despite the current disagreements which are purely due to sample selection and treatment (e.g. Hamuy et al. 1996, Riess et al. 1996, Saha et al. 1997, contributions by Lukas Labhardt and Wendy Freedman). A careful investigation of sources of uncertainty and systematics is quintessential.

2 The Hubble Constant

The small scatter in the Hubble diagram (recession velocity vs. peak magnitude) of appropriately chosen samples of SNe Ia has now been shown many times (Tammann & Leibundgut 1990, Branch & Miller 1993, Vaughan et al. 1995, Sandage & Tammann 1995, Hamuy et al. 1996, Riess et al. 1996). The debate centers on the absolute magnitude of SNe Ia and the compatibility of the nearby, Cepheid calibrated, sample and the one of distant supernovae. Absolute magnitudes have been measured for a small number of very close supernovae and is fairly well established (Saha et al. 1997, contribution by Lukas Labhardt). The Hubble diagram from Hamuy et al. (1996) and Riess et al. (1996) also tie down the line in the Hubble diagram very well. The zero-point of this relation depends on H_0 and M_{peak} alone (e.g. Leibundgut & Pinto 1992). There are, however, some systematics in determining the correct location of the line in the Hubble diagram. Depending on its zero-point the Hubble constant can change by almost 40% for a given absolute magnitude (cf. Leibundgut & Pinto 1992). This is often ignored. Other sources of uncertainties which affect this measurement are photometric errors, the determination of the peak magnitude, the light curve shape correction, if it is to be applied, and extinction. While modern CCD photometry is mostly accurate to better than 5%, the peak magnitude is often derived by some light curve fitting procedure

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(Leibundgut et al. 1991, Hamuy et al. 1996, Riess et al. 1996, Vacca & Leibundgut 1996). It is very difficult to judge the accuracy of these procedures. For some data sets the coverage of the light curve peak is dense and the derived peak magnitude is very accurate. In other cases the peak magnitude has to be extrapolated and systematic uncertainties from assumptions about light curve families can be introduced (e.g. Hamuy et al. 1994 for SN 1992K). Light curve shape corrections are controversial, although Riess et al. (1996) presented powerful statistical arguments why they are tenable. By selecting only a subsample, as proposed by Vaughan et al. (1995), some of these problems may be avoided. Extinction is either deduced from external indicators, or treated implicitly (Riess et al. 1996). All these arguments explain why the measurement of H_0, although simple in principle, is still debated.

3 Universal deceleration

Even though only a relative distance measurement is required for the determination of q_0, contrary to the absolute measurement needed for the Hubble constant, it is a very tight error game as well. This is mostly due to the small effect ($\sim$0.2 magnitudes at z=0.3 difference between a closed and an open universe). Two groups have recently undertaken the task to find supernovae at redshifts larger than 0.3 (Perlmutter et al. 1995, 1997, Leibundgut et al. 1996, Leibundgut & Spyromilio 1997, Schmidt et al. 1998). These searches are now contributing the majority of all supernovae discovered. As of to date (July 1997) there are 86 supernovae reported in IAU Circulars at redshifts larger than 0.3 amongst which 70 spectroscopically confirmed to be SNe Ia (29 from the High-z SN Team and 41 by the Berkeley Cosmology Project). All technical aspects can be controlled fairly well. The CCD photometry can be performed to almost the same accuracy ($\sim$10%) as with nearby supernovae. The peak magnitude can be measured quite accurately due to the specific search techniques employed in these distant searches which ensure observations near maximum light (Perlmutter et al. 1997, Schmidt et al. 1998). K-corrections can be calculated accurately ($<$5%) for SNe at redshifts below 0.55 and above 0.9 due to the particular filter distribution (Kim et al. 1995, Schmidt et al. 1998). By observing the supernovae in two filters and with a sufficient light curve coverage the light curve correction methods can be used for the correction of extinction and the peak magnitude.

Perlmutter et al. (1997) published the data of the first seven SNe at $z>0.3$. Unfortunately, some of those supernovae lack spectral confirmation and they have been observed only in one filter severely compromising detection of extinction. Two of the seven supernovae also have light curve shapes which are not consistent with any SN Ia observed in the nearby universe. The High-z Team has now also seven supernovae at hand all spectroscopically confirmed to be regular SNe Ia and with two filter light curves (rest frame B and V).

Time dilation has already been shown to act on the light curves of these distant supernovae (Leibundgut et al. 1996, Goldhaber et al. 1997). The light curve of SN 1995K could not be understood in the framework of known SNe Ia if time dilation would not be present (Leibundgut et al. 1996). The claim, however, that this is proof for the expansion of the universe has been contested (Segal 1997, Narlikar & Arp 1997).

4 Conclusions

Type Ia Supernovae are probably the best standard candles known in cosmology. They will be further employed to narrow down the range of the Hubble constant with more observations of Cepheid distances. What clearly is missing is an understanding of the explosion and radiation physics which occur SNe Ia. There are still a few thorny problems in SN research. The light curves are not understood to a level which makes one comfortable to use SNe Ia 'blindly' for distance measurements. The secondary peak in the red light curves (Suntzeff 1996) and the occurrence of this bump into the bolometric light curve (Vacca & Leibundgut 1996, Contardo et al. 1998) are not convincingly explained by theory.

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