A Progress Report on the Berkeley Search for Distant Supernovae to Measure {Omega}

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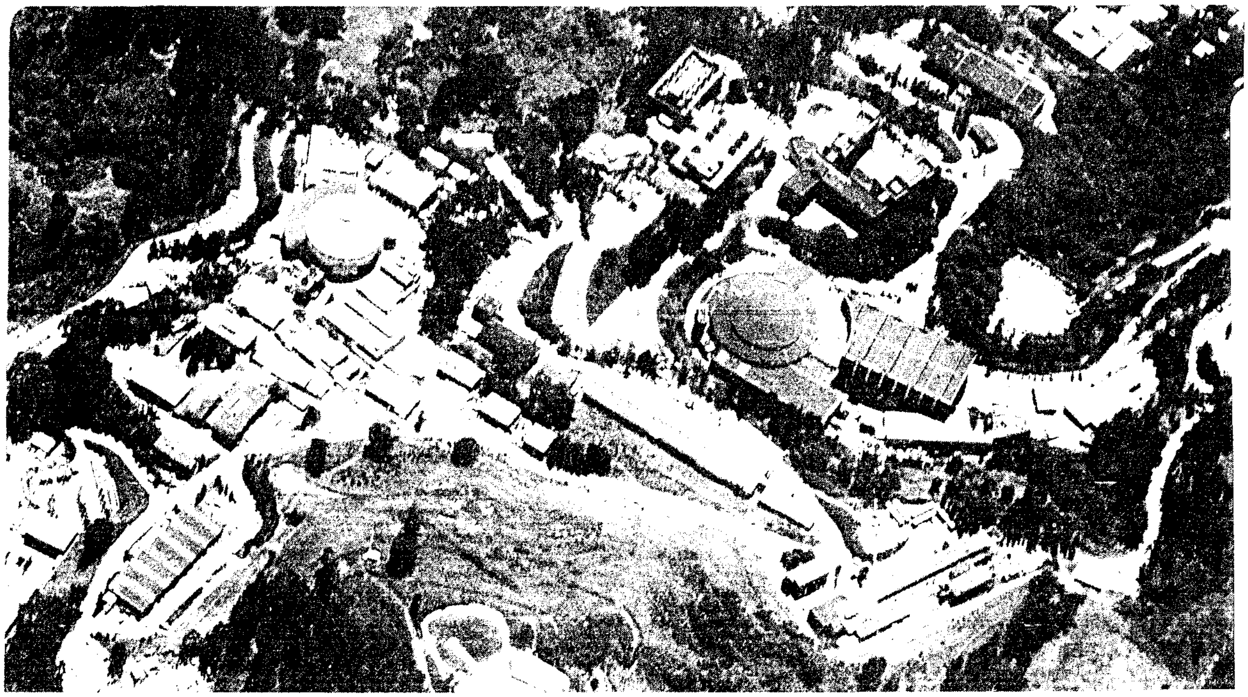

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A Progress Report on the Berkeley Search for Distant Supernovae to Measure Ω

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Abstract

Over the past two years, in collaboration with the Anglo-Australian Observatory, we have constructed a prototype version of the hardware and software needed to discover distant supernovae for a measurement of Ω, the ratio of the average density of the universe to the critical density. To make this measurement, we will use Type Ia supernova, which are now thought to be adequate standard candles for this purpose.

I. Introduction

Ω is one of the most fundamental parameters of cosmology, yet is one of the least accurately known. The present measurements of Ω indicate that it is somewhere between 0.1 and 1.5 (see, e.g. Rowan-Robinson, 1985). We propose to use supernovae to make a new measurement of Ω.

The best current photometry compilations indicate that Type Ia supernovae are probably adequate standard candles. When a cut is made to discard the 25% intrinsically dimmest supernovae (these supernovae probably suffer absorption by interstellar dust in the parent galaxy),the root-mean-square error of peak magnitude is less than 25%. Supernovae can be discovered at a redshift of between 0.3 and 0.5 with our system -- with these we plan to measure Ω to a precision of about 30% over the next few years. In the following sections, we review the rationale behind these plans, the hardware and software, the present status, and the future plans of our search.

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II. Results from Nearby Supernova and the ESO Discovery of One High-redshift Supernova

Over the last few years, we have found 20 nearby (most with recession velocity less than 3000 km/sec) supernovae with the Berkeley automated supernova search system (see Table 1). This system regularly scans several hundred galaxies (up to 600 on a clear winter night), and in real time undertakes a computer comparison between the old image of the galaxy and the new image. One of the new developments from this search has been the discovery of a high rate (about once very 30 years in late spirals of Milky Way luminosity) of Type II and Type Ib or Type Ic supernovae. This search has been paced by the development of real-time software for image analysis and telescope control. Many of the image analysis techniques have been ported to the search for high redshift supernova (z ~ 0.35).

Supernova Discoveries of the Berkeley Group

SN	Galaxy	galaxy type	IAU circ. #	date	type	mag.
1986I	NGC 4254	Sc	4219	5/17	II	14
1986N	NGC 1667	Sc	4287	12/11	Ia	15
1986O	NGC 2227	Scd	4298	12/24	Ia	14
1987K	NGC 4651	Sc	4426	7/28	II/Ic	15
1988H	NGC 5878	Sb	4560	3/3	II	15.5
1988L	NGC 5480	Sc	4590	5/3	Ic	16.5
1989A	NGC 3687	Sbc	4721	1/19	Ia	15.3
1989B*	NGC 3627	Sb	4726	1/30	Ia	12
1989L	NGC 7339	Sbc	4791	6/1	II	16
1990B	NGC 4568	Sbc	4949	1/20	Ic	16.0
1990E	NGC 1035	Sc	4965	2/15	II	16.7
1990H	NGC 3294	Sc	4992	4/9	II	16.5
1990U	NGC 7479	Sc	5063	7/28	Ic	16
1990aa	UGC 540	Sc	5087	9/4	Ic	17
1991A	UGC 6872	Sc	5153	1/2	Ic	17
1991B	NGC 5426	Sc	5163	1/12	Ia	16
1991G*	NGC 4088	Sbc	5188	3/11	II	17
1991M	IC1151	Sc	5207	3/13	Ia	16.7
1991N	NGC 3310	Sc	5227	3/30	?	15
1991T*	NGC 4527	Sbc	5239	4/16	Ia	11

* SNe discovered automatically, but not first reported by Berkeley.

In addition, over the last decade, a much stronger case has been made that Type Ia are standard enough candles for this measurement (see e.g. Miller and Branch, 1990, or Leibundgut and Tammann, 1991). This is not to say that Type Ia supernova all have similar spectra -- Branch noted SN1984A had very broad spectral lines, yet this supernova's brightness was within one sigma of the peak absolute luminosity. Apparently Type Ia spectra can differ somewhat, but the energy output and the optical luminosity, which is dominated by the conversion of the standard amount of Ni56 decay energy into light, is relatively constant.

One high-redshift supernova has been discovered by a group at ESO (see Norgaard-Nielsen et al, SN1988U), and was used to place limits on Ω. We plan to find some 35 or so supernovae in our search , and improve the measurement due to better statistics, and discovery during the peak of the light curve.

III. Hardware and Software

Our present system consists of a 1000 x 1000 pixel Thomson CCD and associated focal reducing optics at the prime focus of the Anglo-Australian Telescope, the "AAT", in Coonabarabran, Australia. The read-out noise of the CCD is about 2 electrons rms., although the noise in our exposures is dominated by the Poisson fluctuations in the night sky background. The optics converts the beam of the telescope into an F/1 system, yielding a plate scale of 1.05" per pixel, and a field of 17' on a side. We use a filter that passes light of 5000 to 7000 angstroms, and our search images consist of two separate 150 seconds exposures of the same field, co-added. The two exposures allow rejection of cosmic rays and asteroids. In tests, we are able to reliably find (80% efficiency) 22.5 magnitude simulated supernovae in these images.

We have two software schemes for finding supernovae: one uses simple aperture photometry of the 1200 or so objects in each field to compare the brightness of each object to its brightness in previous images. (Only about 150 of these objects are galaxies at the redshift of interest). A candidate consists of an object that has brightened to about 22.5 magnitudes. This software runs at the telescope and completes the analysis of each night's data (about 50 fields) within 36 hours after the run.

The second software system utilizes subtraction of the old image from the new. This software seems intrinsically more sensitive than the method described above, possibly because of the subtraction's lack of sensitivity to systematic errors in photometry due to seeing and other changes from image to image. We are presently developing our algorithms to allow the subtraction to run in near real time. At present the subtractions are done with the full image data, express shipped to Berkeley from Australia.

Given these sensitivities and number of galaxies in the images, we expect about one supernova discovered per night with this prototype system.

IV. Results to Date

So far we have met three of the goals of the search:

1) We have developed a system capable of reaching to the magnitudes of interest for distant supernovae; a $z = 0.3$ supernova reaches 21.3 magnitudes at maximum light -- our system has sensitivity enough to reliably find these supernovae before maximum light so that we can then follow them over their light curve.

2) We are able to run our software and analyze the data within 36 hours of data taking. This results in candidates that collaborators will then observe at other telescopes, within the same dark period. Speed is of the essence in this business -- usually delaying spectroscopy until the next dark period means the supernova has faded beyond measurability by current telescopes.

3) We have found, characterized, and developed the means to reject the principal source of backgrounds in this experiment: quasars. From tests of known quasar fields, about 30% of the known quasars in one of our fields have varied significantly enough to be detected over our baseline of about a year. We believe that eventually all of the quasars in our fields will vary above our threshold. We can now reject these quasars by a variety of schemes: first, quasars that have varied in previous images are thrown out; clearly as we build up our observational baseline, more and more quasars are discarded with this method. The additional three methods use the fact that quasars are point-like and galaxies have a larger point spread function to discriminate quasars from galaxies; the first scheme is to use the FOCAS software on our images to discriminate stars from galaxies. This software picks up most of our galaxies in tests. Second, we are now taking reference images (first looks) in fields where high resolution AAT plates exist so we can use these AAT plates for star/galaxy discrimination. Thirdly, if candidates pass all of these tests, we have them imaged at a telescope in a site with good seeing using a high resolution CCD.

V. Future Plans

To bring this project to completion, we need 35 supernovae. We are building two systems that will help us reach this number of discoveries. The first system is a single 2048 x 2048 pixel squared CCD (Loral/Fairchild CCD) system, to be mounted at the 2.5 meter Isaac Newton Telescope ("INT") in the Canary Islands. Because the seeing disk at the INT is half that of the AAT site, this telescope of smaller aperture has almost the same effectiveness as the AAT for supernova finding. This system, because of its higher resolution and better seeing, allows sound rejection of the QSO background. We have applied for larger blocks of time at the INT than we could expect to be granted at the AAT, and we expect to find some five or so supernovæ at this telescope with the present generation system.

In addition, we are making plans for a 2 CCD x 2 CCD or 3 CCD x 3 CCD array of 2048 x 2048 pixel Loral/Fairchild CCD's. These systems should, respectively, find something like four to nine supernovae per night. Photometric follow-up can be accomplished with the same telescope. Spectroscopic follow-up will need some ten nights of four meter time, and this may be accomplished with a number of collaborating telescopes..

VI. Conclusion

Based on the progress in the new systems based on larger CCD chips, the performance of our software, and the apparent standardness of Type Ia supernova, within a few years we expect to measure Ω to 30% accuracy. This measurement should be free of evolutionary effects.

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