SUPERNOVAE AS A COSMOLOGICAL TOOL

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Cosmology can mean many different things to different people. Sandage (1970) once described it as "the search for two numbers" (H_o and q_o). At the other end of the spectrum, it may comprise almost all the interesting bits of astronomy and physics that bear on how the universe got to be the way it is. Supernovae can probe many of these bits because they are bright, have been going on for a long time, and contribute directly to the chemical and, perhaps, dynamical evolution of structure in the universe.

The most obvious application is the use of supernovae as distance indicators. The underlying philosophy is that it should be easier to understand the physics of one star than of a whole galaxy. (I'm not sure this is true; compare, for instance, psychiatry and sociology.) Three approaches have been tried. First, as originally suggested by Wilson (1939) and Zwicky (1939), one can regard SNe, or some subset, as standard candles, calibrating them on nearby galaxies and applying the result to more distant ones. A recent application of this method (Sandage and Tammann 1982) yielded $M_B^{max} = -19.65 \pm 0.19$ for Type I's and $H_o = 52 \pm 5$ km/sec/Mpc, in good accord with that found by the same authors using other methods.

Second, one can modify the Baade-Wesselink method for determining distances to variable stars and get an effective temperature for a supernova from its colors and its radius from integration of the radial velocity curve. Recent applications (e.g., Branch et al. 1981) have also yielded H_o near 50, at least toward the Virgo cluster. Conversion of colors to temperatures and line profiles to velocities requires, in practice, a fairly detailed model atmosphere. All analyses to date have neglected opacity due to scattering (Wagoner 1981) and the possibility of a shallow density profile in the SN envelope, both of which cause luminosities to be overestimated, and the observed UV deficiency of Type I's, which goes the other way (Arnett 1982).

Finally, one can start from a set of hydrodynamical models for the explosions, pick the right one out of the set using distance-independent properties like time scale, and use the model luminosity to get distance. Arnett's (1982) use of this method gave $H_o = 70 \pm 5$ km/sec/Mpc for Type I's in both Virgo and field ellipticals and a one-sigma

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dispersion in peak brightness of $0^{m}_{\cdot}4$. Sufficiently detailed models of the explosions will eventually predict line profiles and colors as well as light curves and radii, so that methods two and three will coalesce around a physical understanding of the events. Twenty percent accuracy in H_o should be possible from the ground and 50% in q_o from the Space Telescope (Colgate 1979).

Some participants in this meeting may live long enough to see light curves and spectra for supernovae at $z \gtrsim 1$. Heaven forbid that these should by then be needed to resolve the traditional cosmological problems or to measure distances to the parent galaxies, thus giving L(z), etc. But they will enable us to probe early galactic evolution and nucleosynthesis directly. Interesting data would include: a) supernova rates and types, b) distributions of SN positions in parent galaxies, and c) masses and compositions of parent stars (found by model fitting to light curves and spectra) all as a function of cosmological epoch and galaxy type. In addition, we could expect to see (or not see, at significant levels) supernovae contributing to nucleosynthesis in sites other than galaxies of recognizable types -- intergalactic and intercluster space; protogalactic star clusters or gas clouds; quasi-stellar objects and whatever else. Events recorded so far include one in a Seyfert galaxy (the Type I 1968a in NGC 1275) and one at least 50 kpc from the center of any galaxy (the Type I 1980i centered in a triangle formed by the ellipticals NGC 4375, 4387, and 4496; Smith 1981).

To make full use of such information, we clearly need the same kinds of statistical data for supernovae in galaxies (etc.?) here and now. These can be acquired with existing technology but require more systematic identification and study of extragalactic SNe than has so far been carried out. This is a plug for the supernova search projects currently underway or contemplated in Berkeley (Kare et al. 1982), Cambridge (Cawson and Kibblewhite 1982), New Mexico (Colgate 1982) and elsewhere.

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Discussion

Huchra: When people compute H_0 from the supernovae distances to Virgo, do they include the effect of our infall velocity?

Trimble: Everybody allows something for infall, but as they allow the same amount they obtained from other arguments, each author tends to report the same value for H_0 from supernovae that he gets from other methods.

M. Burbidge: In a Commission 28 (Galaxies and Cosmology) meeting in Patras, it was unanimously voted that supernovae should be reinstated in Commission 28 (where they belong), whether or not they are also included in the Commission on Variable Stars. It was remarked that what is needed is volunteers to form a Working Group, especially for the supernova search.

Trimble: An excellent idea! I would be happy to join the Working Group in its endeavors (except that I don't belong to Commission 28).