Supernovae as sign posts – comparing the apparent brightness to the known intrinsic brightness allows a measure of distances.

Type Ia supernovae – brightest, best current tool for measuring distances.

Types of Universes – "flat" infinite in extent, will expand forever; "open" infinite in extent, will expand forever at finite velocity; "closed" finite in extent, will recollapse (neglecting cosmological constant).

Big Bang – the initial expansion of the Universe from a condition of very high density and temperature ("singularity").

Expansion of the Universe – space expands and pulls all distant galaxies apart with a speed that increases with distance.

Age of the Universe – about 15 billion years, determined from the distance to supernovae (and other things) and the velocity of recession as measured by the Doppler shift.

Accelerating Universe – measurement of supernovae has suggested that the expansion of the Universe is not decelerating as expected, but accelerating.

Cosmological Constant – if the Universe is accelerating there must be an extra force associated with empty space. In the context of Einstein's theory of gravity, this force could be provided by the cosmological constant. Physically, this quantity is associated with an energy of the vacuum of space, a Dark Energy.

Quintessence – one possible model of the vacuum energy that could account for the accelerating Universe.

Gamma-ray bursts – flashes of gamma-ray energy detected by satellites about once per day lasting about 10 to 30 seconds.

Distribution in space – the gamma-ray bursts occur randomly all over the sky, so they are not associated with our Galaxy.

Optical Counterparts – discovered only in the last four years, these allow gamma-ray bursts to be associated with other phenomena. In particular, Doppler shifts have been measured and they are at cosmological distances.

Energy requirements – at cosmological distances the energy required is comparable to the complete annihilation of a star if the energy emerges equally in all directions.

Collimation – if the gamma-ray energy flows only in a narrow "jet" the energy required to produce an observed gamma-ray burst is less, but the events must occur more often since many will not be "pointed" at the Earth.

Afterglow – the radiation emitted in optical, radio, and X-ray radiation that has been seen for days or weeks after some gamma-ray bursts.

Gamma-ray bursts and massive stars – gamma-ray bursts occur in galaxies in regions of active young star formation, hence they are somehow associated with the deaths of massive stars, perhaps black hole formation.

Supernovae and Gamma-ray Bursts – SN 1998bw resembled a Type Ic supernova (with some odd characteristics) and seemed to be associated with a gamma-ray burst. The supernova was exceptionally bright, but if it was associated, the gamma-ray burst was much less powerful than the cosmological gamma-ray bursts. In other cases, a supernova-like

increase in light was seen superimposed on the afterglow of "normal" gamma-ray bursts a few weeks after the original burst. Gamma-ray bursts are much more rare than supernovae.

Carl Sagan's "Contact" - Catalyst of work on wormholes and time machines.

Exotic matter - like the tension in a rubber band only with an energy greater than the mass energy, mc^2. Rather than adding to the weight of gravity like ordinary pressure/energy, the "negative pressure" of exotic matter repels against gravity (related in principle to Dark Energy).

Worm holes - exotic matter could, in principle, be used to hold off the effects of gravity and maintain the opening of a worm hole to connect two distant places in the Universe.

Shape of a wormhole - a three dimensional worm hole is not a "tube" as it appears in its two-dimensional embedding diagram, but rather a spherical space that can be approached from any direction.

Travel through a worm hole - one would proceed "straight" along a radius toward the center of the spherical space, but eventually find oneself moving away from the center and out into normal space, without ever changing direction.

View inside a wormhole - one should be able to see through a worm hole looking along the radius toward the center of the spherical space, but if one looks "sideways," perpendicular to the radius, one would see light that traveled around the highly curved space and returned to its origin.

Time and Special Relativity - if two observers are in uniform motion, each will see the other aging more slowly.

The twin paradox - if one twin remains stationary, and the other is subjected to an acceleration, either by traveling out and back or by venturing in a stronger gravity, then the twin who has experienced the acceleration, not uniform motion, will be absolutely younger.

Time machines - if worm holes exist, then they can, in principle, be used to make a time machine through the twin paradox mechanism. After one end of the worm hole is accelerated and returned, it will thereafter be absolutely younger than the mouth of the worm hole that remained at rest or in uniform motion.

Grandfather paradox - the notion that since time machines can violate causality (“cause” before “effect”) a situation, like traveling back in time to kill your Grandfather, can arise that can be neither true or not true.

Novikov consistency conjecture - the conjecture that physics must be self-consistent and simply does not allow paradoxes even if time travel exists.

The pool ball crisis - the idea that a simple mechanical example could be invented to show that time machines will always come with paradoxes. A pool ball rolling into one end of a worm hole can come out in the past and hit itself before it goes in, thereby preventing it from entering the worm hole in the first place.

Resolution of pool ball crisis - Novikov and Thorne and associates showed that the pool ball problem satisfies the consistency conjecture. No case was found that gave rise to a paradox. The past and future pool balls could just "kiss" with a slight deflection of the trajectory, but a "hard" collision with the first pool ball being knocked away from the worm hole, thus giving a paradox, simply did not and cannot arise.

Free will and time machines - if time machines exist and the consistency conjecture holds, then is everything pre-ordained, and there is no free will?

Changing the future - if the consistency conjecture is true, then the future cannot be "altered" by current acts.

Vacuum energy and time machines - vacuum quantum energy could travel into the past, pile up, and create such a high gravity that any worm hole would be quickly sealed. This issue cannot be resolved without a complete theory of quantum gravity.

Plank Scale – the length (10^{-33}cm) and time (10^{-43}seconds) on which Einstein's theory of curved-space gravity and the Quantum Theory became fundamentally mutually contradictory. The true "size" of the singularity.

Quantum Foam – the notion that space and time may be fundamentally quantum uncertain and hence, "foamy" at the Plank Scale. In modern view might be an assemblage of strings.

String Theory – "particles" are actually strings in a space of 10 dimensions plus time. The theory "contains" Einstein's General Relativity and has been used to compute the entropy and temperature of a black hole from basic theory.

Fundamental forces – according to string theory all the basic forces, electricity, magnetism, strong force, weak force – are confined to regular three-dimensional space. Gravity – the creature of space-time – can "leak" into higher dimensions, if they exist.

Extra dimensions – in the first version of string theory, all the extra dimensions were "wrapped up" on a scale comparable to the Plank Scale. Thought to be necessary so that gravity would have inverse-with-distance-squared behavior.

Calabi Yau – a space – special 6-dimensional geometry that could be the shape of the wrapped-up dimensions.

Finite extra dimensions – the realization, guided by string theory, that some of the extra dimensions could be "large." Experimental limits would not rule out one millimeter. Only gravity could go there.

Branes – membranes in the higher dimensional spaces of string theory. Two dimensional "sheets" are 2-branes; higher dimensional "slices" are possible, p-branes, where p is the dimension of the membrane.

Bulk – the large, higher-dimensional space surrounding a brane.

Brane world – further work showed that even if one of the extra dimensions is very large, gravity might still be nearly confined to the 3-dimensional brane of our Universe. Our Universe could be a 3-D brane floating in a huge surrounding 4-D bulk. Our Universe might be expanding into this 4-D bulk.

Ekpyrotic Universe - the idea that another 3-D brane floating in the 4-D bulk collided with ours creating the huge, but finite, temperatures that launched the Big Bang without requiring any "singularity."