ASTRONOMY UPDATE 1992

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<u>Abstract</u>: Astronomical research during 1992 is reviewed, with the frequent theme "now you see it, now you don't." Solar system topics include Magellan mapping of Venus, meteorites from Mars, past water on Mars and ice caps on Mercury, the photo of Gaspara, and the discovery of 1992QB1 at 50 A.U. from the Sun. Stellar topics include the solar neutrino problem, ultraviolet observations of the EUVE satellite, binary star phenomena, and searches for extra-solar planets. Other topics include the M87 counter-jet, gamma ray bursts, and the Hubble constant.

Thank you. It's really an honor for me to be asked back.

We had a terrific start to this year, as if the gods were telling us something good as they projected a wonderful solar eclipse on to the sky. It had no real scientific interest, but drew public attention, got people out to watch and interested in astronomy, and sent them into planetariums to learn a little bit more. Here it is, the climax of the great annular eclipse last January, with the Sun setting, over the Pacific Ocean. A wonderful sight.

Earth

We sometimes forget that the Earth is a planet. We're on it. This is our home and we look out at Mars, Venus and Mercury, and they are planets, but not our own. We are just the Earth. We forget what a tremendously active planet this is. If you saw the spectacular show in the Omnimax theatre last night on the Ring of Fire, here is one of the results, a blanket of dust that has completely encircled the Earth, and is driving some astronomers crazy because they have to look through it. The dust blanket is from Mt. Pinatubo. It encircled the globe and has been responsible for some of the most wonderful sunsets you're going to see for a long time. These volcanic sunsets are quite spectacular. They are produced by aerosols and particles high in the atmosphere. You can see this sight almost every night and at sunrise in the morning.

The Earth and the Sun have a remarkable relationship that is slowly being understood. Someone made the remarkable discovery this year that the length of the solar cycle is apparently linked to the average temperature of the Earth. Everybody talks about the 11 year solar cycle, but of course it's not 11 years, it could be as short as 8 or as long as 13 or 14 years. It's really quite erratic for reasons that no one understands; no one really understands why there's a solar cycle in the first place. But it seems that the shorter the solar cycle period, the higher the temperature of the Earth. The two track together remarkably well. It's very difficult to factor this sort of thing into global warming. There are many factors apparently involved in the climate and the weather of the Earth. We're only beginning to figure them out. You simply can not do it without examination of this Sun of ours.

Venus

One of the great experiments of all time has got to be the Magellan Mission. Venus is a cloud-covered planet and you're going to be learning quite a bit more about it later. I will give you just a brief overview of what Magellan has done. It has been a continuing theme in these talks. The first talk I gave at the Champaign meeting involved Magellan just after they had launched it. It was in cruise at the time and nobody knew what it was going to do, and it has produced some of the best planetary images that we've ever seen, certainly comparable to the Voyager and to the Viking images from Mars. The spacecraft is now in polar orbit around Venus and imaging with radar. It's completed a couple of sweeps. It's now breaking down. NASA is expected to close the mission down in 1993.

If there is a theme in this talk, it's "now you see it, now you don't." There was a fuss in the press for a while about the great landslide on Venus that you can see over to the left. Then Magellan made another pass and the landslide disappeared. It shows you the difficulty of imaging with radar. You're really looking at radar reflectivity and the brightness of the surface depends on the angle with which it's illuminated. So at a different angle the so-called landslide disappeared. On the other hand, it looks as if there might be some dust storms on Venus. At the top was the first pass, the lower one is the second pass, and it looks as if the surface has changed. One of the things we are looking for on the planet is changes as the spacecraft sweeps around it.

But these are minor matters compared to some of the wonderful digital reconstructions of the images that let us see the planet as viewed from the surface or as flying from an airplane. This is Sapis Mons, one of the great volcanoes. The dark areas probably represent relatively recent lava flows that haven't yet had time to weather. I'm sure everybody has seen these, but it's worth putting them up again because it's just fun to look at them. You can imagine yourself flying over the surface of an alien planet looking at the volcano in the distance.

This is a crater field north of Alpha Regio toward the equator. We can see three separate meteor craters. They don't weather away like they do on the earth. The wind velocities are relatively low. There's no water, having baked away, destroyed by the Sun as it floats to the upper atmosphere. So there's not much to take the craters away and, unlike the situation on Earth, you see them when they're really quite old, so that the surface of this planet is covered not only with volcanic lavas but with these meteor craters. The great reconstruction, though, was the linking of all of these images to give you a view of what the surface actually looks like while flying over it. I think you saw this (it made the national news), and I'm sure many of you have this video at home, but it's worth seeing again. You are in the Aphrodite Terra Region down toward the equator, which is cut through by a huge fault running east-west.

Mars

Even the old Mars pictures have been reconstructed. They've been able to reconstruct some of the old Viking images and give you a view of what Mars looks like at a height of about 2500 kilometers above the surface. This is not a full hemisphere. Here you see a beautiful picture of Valles Marineris. Noctis Labyrinthus is over at the left and the volcanoes and the Tharsis Bulge are over at the very far left, all showing you what a very different planet this is.

They're all so similar, Mercury, Venus, the Earth and Mars; at the same time, they are all so different. They are all worlds in their own right, all worlds to explore. We're going to have a wonderful couple of centuries looking at them as we send spacecraft out toward them.

Every square kilometer of ground on the earth is hit by a meteorite about once every thousand years or so. They litter the earth. We found a few meteorites that have actually been blasted off the moon, perhaps by the formation of Tycho. To everyone's surprise there are a couple of meteorites that don't fit the lunar compositions and they don't fit the ordinary meteorite compositions. The prevailing view is that they've been blown off Mars, and that we actually have pieces of Mars we can pick up and bring into the laboratory. There are not very many of them, maybe three or four of these meteorites are available for study. Here's one of them here that is called a "shergotite". They actually have found what may have been the launch site. There's an oblong crater just north of a volcano on the north edge of the Tharsis Bulge, north of the very large volcano, Olympus Mons. From the shape of the crater, it's been conjectured that this may have been the launch site of at least one of the SNC meterorites, the ones that appear to come from Mars.

The remarkable thing about Mars, of course, is that it once had water. There are channels all over the surface of the planet. The existence of these channels means that Mars must once have had a reasonably thick atmosphere. Viking, of course, showed that there is no life on Mars and yet, as we saw on the Omnimax presentation last night, life just couldn't wait to get started on Earth. One mystery of Mars is, when Mars had a thick atmosphere and water, why isn't there life on Mars? Mars presents a constant conundrum to us. We don't really understand what is going on on this planet.

Now we have a chance to look at a sample of rock. Someone convinced the owners of one of these very rare rocks to allow it to be ground up and examined. Here's a slice of one of them. The light colored areas are basalts, pyroxene, and olivine, the sort of the things that you find on the earth. The dark areas, however, are clays. It's quite remarkable. When they ground it up they found water. This thing has been soaked in water for a very long time. Even more remarkably, when they examined the oxygen isotope ratios ($0^{18}/0^{16}$), they found that the isotope ratios of the water that they ground out of the rock were different from the isotope ratios of the rock itself. So the water is not indigenous to the planet. The conjecture is that the water on Mars is come from impacting comets, from a different source than from the planet itself. And that's what thought to be the case on Earth. All the water should have boiled away on Earth when Earth was made and the water was returned to the earth by impacting comets, the same comets and planetesimals that banged up the moon so very badly.

Mars is going to be studied very avidly. Here's the Mars Observer, which was launched last June. It's on its way; it's now in cruise to the planet. This is quite a remarkable machine. It has remote sensing devices, spectrometers for doing remote sensing of the chemical composition of the surface, plus a CCD camera that will be able to get resolutions of 1.5 meters. You would be able to see the elephants walking around on Mars, if there were any. It's not going to examine the whole planet with a resolution that high, but it can zoom in on particularly interesting areas. A laser altimeter is going to be able to give us very high quality maps. I think it's going to send back some absolutely spectacular images when it arrives there. It's due to get there next August, and mapping will start next December.

Mercury

Well, everybody looks at Venus, everybody looks at Mars, but nobody pays a lot of attention to poor little Mercury. Mercury just sort of gets the tail end of everybody's interest. It is elusive and hard to find in the sky. Mercury has a long and checkered history of erroneous statements. When I was a kid it was thought that Mercury was tidally locked to the sun and now we know that it's in a 2/3 tidal locking. The surface on one side is hot enough to melt lead, and it's freezing on the other side. It seems like a terrible place to go. Then they illuminated it with radar and saw bright spots up at the poles. The thing has got polar caps; talk about a surprise! One explanation for this observation is ice. Mercury's axis is almost vertical to its orbital plane, and if you're at the pole you're looking at the sun practically on the horizon. The grazing angle is so low that there is apparently a reasonable chance that it is just very cold up there. And if you get ice mixed with the regolith and you've got some insulation, or a deep crater, the ice can apparently survive. So don't make any assumptions: a planet will fool you.

Asteroids

Go out farther into the solar system and we look at asteroids, the banged up remains of the planetesimals that formed the Earth, the terrestrial planets, even probably the jovian planets. They are in a region where Jupiter did not allow a planet to form. There used to be some bigger bodies in there, but they have been smashed up. There had to be bigger bodies, because they differentiated and produce iron cores, and the iron meteorites you can find in most science museums.

The number of asteroids is mind boggling. The count just passed 5,000. Here's a map of them. You can see Jupiter up there, and at 60° away, you can see the trapped asteroids at the Lagrangian points. The number is going up at the rate of several hundred per year, about a thousand every two years or so. I don't know where it is going to stop, as the techniques get better and better. These asteroids are constantly straying inward, and are hitting the earth all the time, producing a vast majority, if not all, of the meteorites that we have in the museums.

Galileo is now on its way to Jupiter and, if everything works well, is going to drop a probe into the planet's atmosphere. The antenna is stuck, as you all know. They are going to try to jerk it loose this January by rapidly turning it on and off, so if it doesn't break the spacecraft in half it will maybe spring the antenna loose. Right now the bit rate coming back from it is very low. It takes a very long time to get an image.

Yet with enough processing and enough time they were able to capture this absolutely marvelous picture of Gaspara, an asteroid that the Galileo passed on its way to Jupiter. It shows a remarkable coloration with some interesting variations in chemical composition. It appears to be an iron-rich silicate structure with perhaps pure metals mixed in. So it's kind of a stony metal type of asteroid, the kind of thing that would produce the stony metal meteorites that we have on Earth. It looks for the all world like the moons of Mars. There doesn't seem to be much doubt that the satellites of Mars are small captured asteroids. If you could look closely at some of the outer satellites of Jupiter you would probably see the same thing. Craters are everywhere. This thing has been banged many times. In fact it's been chipped apart. You can see how irregular it is. It's about 10 or so kilometers across. It's clearly a piece of a once much-larger asteroid. These things are constantly banging into one another over the lifetime of the solar system. The whole asteroid belt is slowly grining itself into a powder.

Comets

Looking farther out, everybody remembers the spectacular view we all had here of Halley's Comet several years ago. I'm sure you could see it flying over the skies of St. Louis. I didn't have any trouble in Champaign. I could at least see it with binoculars every night. I know a number of people identified some really nifty contrails with Halley's Comet and went away happy. We're looking at it now out beyond Saturn. The thing I think will clearly be imaged at aphelion. I don't have much doubt about it. It should be visible.

The remarkable finding is that this thing is still active, although over 10 A.U. away from the Sun. It's now between Saturn and Uranus, going really quite slowly as it drifts away from the Sun. If you look at the sequence of pictures from upper left, top one is April '88, Jan. '89 and all of a sudden in Feb. '91, bang! It popped a gassy dust cloud or a dusty gas cloud or whatever it was, but it suddently became active, something nobody expected. The first suggestion was that an asteroid had run into Halley's Comet and knocked a piece loose. The theoreticians now seem to suggest more that it was a shock wave in the solar wind that hit it. Comets are very fragile and have extremely low densities, the order of one gram or so per cubic centimeter. I'm not sure you'd be able to stand on the surface of Halley's Comet, so it probably doesn't take a lot to knock a piece off it and to produce a little bit of activity, but it sure came as a surprise to everybody.

Another famous comet that you can see flying over the St. Louis sky, Grigg-Skjellerup. Remember that Giotto is the spacecraft that imaged Halley's Comet several years ago, and produced this wonderful peanut-shaped picture that we've all come to know and love. Giotto was partially destroyed in the mission from the high speed bullets, literally, of dust coming off Halley's Comet. But there was still some life left in the old bird, and they flew it past Grigg-Skjellerup and found dust a couple hundred kilometers away from the comet. Now it's practically dead. I don't think there is anything much left they can do with it. It was nice to see this spacecraft being recycled. To me one of the most exciting discoveries of the year however was the extension of the solar system. Object 1992QB1 was found by Jewett et al. There have been attempts for years and years to try to find another planet X, a planet out beyond Neptune. Neptune I say, not Pluto, because I don't think anyone really believes Pluto is a planet anymore. Well, it goes around the sun. It's been called a planet for 50 years but what is the thing? It looks like Triton, Neptune's satellite; it has been in fact called the world's biggest planetesimal. It may represent a whole new class of objects out beyond the real planets. Of course this is just semantics, but there must be something else, there must be a lot of stuff out there. The comets are coming in from these outer fringes all the time. We can see them on their highly elliptical orbits.

The planet Uranus doesn't really behave all that well. It still doesn't quite match the predicted position. That may be simply due to observational error. It is very difficult to track down the exact position of the center of an extended object. Or the positional difference may be due to yet another planet beyond Neptune. Clyde Tombaugh didn't find it, and he examined the entire ecliptic several times. Of course it may not be near the ecliptic. The last prediction I heard was that the thing might be in Serpens. IRAS, the infrared satellite, didn't find anything, and I think the general feeling is that we've probably reached the edge of the planetary system, as such, with Neptune.

Yet it was a startling surprise for me to find this object that seems to lie between 40 and 60 astronomical units from the Sun, with a semi-major axis of around 50 astronomical units, which makes it about 20% farther than Pluto. You can just barely see it here. This was a delibrate search, so all the star images are elongated. They track the camera at the rate which a distant object should appear to remain stationary. There it is. You can see the motion of it relative to the stars. These other little things are just noise on the CCD. This is now the most distant thing that we have ever seen within the confines of the solar system, and it's about 200 kilometers across. It may represent the inner edge of the Kuiper belt of comets. Can you imagine what kind of a comet this would produce if it could get into highly elliptical orbit and pass by the Sun. You wouldn't have any trouble seeing it over St. Louis, you could see it in the middle of Busch Stadium during a ball game. I'm sorry—Wrigley Field—we've got to remain loyal to the troops up in the northland.

The comets are apparently coming in from two different regions around the solar system. The first is so-called Oort cloud that produces the highly inclined comets, the ones with long periods, the ones on practically parabolic orbits, the comet Bennetts and Wests. You can see it's spread all around the solar system. Here's the solar system right in here. The Oort Cloud may extend for a hundred thousand astronomical units away from the sun, perhaps out halfway to the star Alpha Centauri. The Oort Cloud is stirred up by passing stars and probably more likely by passing massive clouds of interstellar gas and dust. Some of these cometary bodies are half rock, half water, maybe 80% water ices and a variety of other ices as well. They stray close to the sun and you see a comet tail streaming across the sky. The Oort Cloud really can't explain the rather large number of periodic, or short period, comets, the Halleys and the Enckes, which tend to cluster more in the plane of the solar system. So Kuiper hypothesized a long time ago that there was yet another belt that formed a disk around the Sun. It's kind of like a picture of the galaxy, with a disk and big halo around it. 1992QB1 may represent the inner edge of the Kuiper belt. They've been looking for it for quite a while. We're working our way slowly out into the solar system. We'd sure like a census of solar system bodies. We'd like to know how the solar system was formed, and we can't do it very well. We can hardly do it if we don't know what's in the solar system, and our census of the outer parts of it extremely poor.

The Sun

Our star of course is shining outside today on this nice day. The Astrophysical Journal started a new way of publishing data. This is taken from the first Ap. J. tape. (Second video please.) What it's going to show you is granulation at the surface of the Sun in a way I've never seen it before, sped up about 1300 times so you can actually see the boiling surface of the Sun. In the past the only way you could publish data would be with a few sequential pictures showing motion. A few months ago those of us who subscribe to the Astrophysical Journal instead got a paper version and then a VHS video tape with quite a remarkable number of images on it. I'm going to show you a couple of them here. You can watch the granulation on the Sun, look at it boil. It goes backward and forward. You can't do this on a paper copy. I've never seen granulation like this at all. The resolution is just a second or so of arc, and that's only a 40-second-wide image.

We don't get a very good view of the Sun from here. All you see is the equator of the Sun. You can't see the poles. Much of the action is taking place at the poles. And it looks very much as if the solar cycle begins near the poles. It actually seems to take some 22 years to roll its way all the way down the surface. So we can't really begin to understand the sun until we can see the poles. Ulysses is now on its way. Of course, the way NASA does things, Ulysses was sent to the Sun by throwing it first at Jupiter. We had to; it's the only way you can get something out of the plane of the solar system. You have to use the gravitational attractions of the planets, which is why Voyager 1 is now on its way to the north of the ecliptic plane. Saturn shot it up that way. So you send a spacecraft to Jupiter, you accelerate it, and then you change the direction of its motion. It will go under the south solar pole in 1994 and over the north pole in 1995. It's working reasonably well and it's on its way and I think in a couple of years we should get some spectacular views of the polar regions of the Sun, something we can't do from here.

The Sun presents a constant mystery to us. It shines by thermonuclear reactions deep in the core. These reactions produce neutrinos. For twenty years there has been a neutrino experiment in Lead, South Dakota, with a big tank of cleaning fluid that captures a few neutrinos now and then, turning chlorine atoms into radioactive isotopes that can be measured. Consistently, the people with the neutrino telescope observe about 1/3 of the neutrinos that are supposed to be produced. This has caused great consternation among the theoreticians who are worried about the standard solar model being wrong, yet they can't they can't find the problem. What's happening to the neutrinos? Something like 10^{10} of the little massless particles pass through every square centimeter of your body every second, so maybe that little creepy crawling feeling you have is just neutrinos passing through you all the time. The whole earth is transparent to neutrinos. They just go through harmlessly. It's very difficult to pick them up. Chlorine is especially sensitive to them. You get a few reactions in a two week period in a hundred thousand gallon vat of cleaning fluid. Well, the trouble with that experiment is that it picks up only high energy neutrinos from side chains of the proton-proton reaction that actually operates in the Sun. We'd like to pick them all up. There are two more experiments now operating: SAGE in the former Soviet Union and GALLEX, both using expensive heavy metals. The SAGE experiment picked up zero neutrinos for a while and GALLEX is now picking up about half or 60% of the expected number and these experiments are consistent with the low count rate from the South Dakota experiment. We still don't know what's going on.

The prevailing view is that the problem is with the neutrinos, that they're changing themselves into forms that can't be observed. The only way they can do that is to have mass. Neutrinos are supposed to have no mass according to the original theory. If they have a little mass, they could be a significant contributor to the so-called missing mass. So the Sun presents a natural laboratory toward looking out to the edge of the universe itself. The integration of the various aspects of astronomy is an important factor in our understanding. You can't understand the universe until you can understand the Sun. You can't understand distant stars until you can really understand, believe it or not, our own planetary system. You can't isolate one area of astronomy from any of the other any more than you can isolate astronomy from any of the other sciences.

EUVE Satellite

Looking out deeper into the sky, we saw the launching of the EUVE satellite this year. We're slowly closing the gaps in the electromagnetic spectrum in which we can observe. The IUE, the International Ultraviolet Explorer, was supposed to live for three years; it's now on its 16th year and still going great. It never makes the press because it doesn't produce pictures. It just produces spectra, beautiful spectra, from around 1200 Ångstroms up to the atmospheric cutoff at 3000 Ångstroms. We've got the ROSAT, the Roentgen satellite, working in the x-ray, but then there's a gap from 100 Ångstroms on up to about a 1000 Ångstroms and the EUVE fills it. To give you an example of the kind of thing that it can do, this is a flare observed by a space telescope. The Sun produces enormous and devastating flares that correlate with the solar cycle, and they're produced by the release of magnetic energy from magnetic loops that hang above active magnetic regions on the sun. This is a magnetic flare on AU Microscopii, and it produces a tremendous burst of particles that go slamming down into the surface of the star and make it bright down on the photosphere. And that's what you see from the earth. And all the sudden this star would jump in brightness by a factor of two.

One of the things EUVE did was to catch the spectrum of AU Microscopii during a flare. All of a sudden, bang, there were all these emission lines. The wavelength region is a remarkable 140 to 380 Ångstroms. They're still doing calibrations on this satellite and haven't even actually started the observer program yet. The point is, we're filling in the gaps of the electromagnetic spectrum all the way from the gamma ray region of the spectrum into the far radio region.

So you think stars are round, do you? Take a look at the Sun. Now take a look at Mira on the left. I've sort of harped on these talks over the last four years on resolution, resolution I don't care what else you give me, but give me resolution. That's the key to learning something in astronomy. This is how good the people who are doing speckle interferometry are getting. They're imaging Mira, and the darn thing is 20% flattened and nobody knows why. We thought we understood Mira variable stars at least reasonably well. Does it have something to do with rotation, or is it shocks, or is it some kind of weird pulsation? We don't really understand it at all. The star to the right is 82 Ceti, which is just your nice, normal, round star like the Sun.

Black holes and globular clusters

Globular clusters ought to have black holes in the middle. The stars should collapse into the center. Yet we don't really see the evidence for them. The Hubble Space Telescope has imaged the centers of globular clusters and it does not find the intense concentration of light that we should if there were black holes there. So why aren't there black holes? That's the big problem. Well, if you take good close-ups in the middles of globular clusters, you see truckloads of binary stars. The binaries are sort of a battery for energy, and as they revolve around one another they keep the interior of the globular cluster stirred up. If a star, for example, gets too close to one of these rapidly revolving binaries, it will receive kinetic energy and get a kick out of the center, so binaries keep the cluster from collapsing in the middle. No black holes in the middle of globular clusters! In a remarkable view, you're looking smack into the center of 47 Tucanae, imaging impossible to do from the earth given the present technology. The Hubble, however, which is working quite well, thank you, in spite of all its difficulties, gives us a view into the middle. Binaries can also blow gas out of the clusters, which also explains why gas from Mira variable winds doesn't accumulate there.

Binaries also explain the so-called blue stragglers. If you look at the HR diagram of a globular cluster, there are a few bright blue stars that shouldn't be there. They didn't make it into the giants, and at first glance it looks as if they were born late. It turns out these blue stragglers are either binaries or merged binaries. These stars are very close together and evolution can eventually make the two stars merge together and produce a high mass star, one that can still sit on the main sequence for a period of time. So the Hubble has solved interesting problems in the way of the globular clusters.

Remember Geminga, the "Gemini gamma ray source"? No one knew what it was. It presented an enormous puzzle, a black hole perhaps. It was unique. Well all of a sudden someone discovered it pulsated. In fact it's a pulsar. You're looking at x-ray pictures at the top. It's a soft x-ray image, long wave x-rays. The bottom is a hard x-ray image, and oddly enough Geminga is a strong gamma ray source, yet it's faint where it ought to be bright. Nevertheless it is seen to pulse in the gamma ray region and the x-ray region. It's an odd one though, a pulsar that does not pulse in the radio part of the spectrum. At least it's never been seen, which still makes it unique.

Another "now you see it now you don't." The black hole business is a tough one. We keep finding them and then they keep disappearing. You might remember SS443 that produces these incredible beams of radiation, where you have hydrogen lines in the spectrum moving back and forth across the spectrum at speeds up to a third that of light. It was thought to be a good candidate for a black hole.

Well, the black hole you can see on this drawing, has now turned into a neutron star of only about eight or nine tenths of a solar mass, and can't possibly be a black hole. So the black hole "disappeared." The best candidate however, is V404 Cygni. It was recently discovered to have a mass of greater than 6.3 solar masses. Neutron stars cannot have masses more than about 3 solar masses. At masses above that, the neutrons can't support the star, and it collapses. It almost has to be a black hole. Now this is theoretical reasoning; we can't prove it's a black hole. This shows an outburst in the black hole, probably caused by an instability in the accretion disk around it. Black holes, of course, can be quite bright, because the only way you can see it is for it to be in a binary system in which one star feeds matter into the black hole.

The Great Annihilator

In the middle of the Galaxy is a very strange source that produces x-rays at 511 kilovolts. That is the wavelength or the energy that you would expect for annihilation of matter, anti-matter, electrons and positrons. The anti-matter matter problem can get very deep. Why is the universe made out of matter? Where's the anti-matter? Anti-matter has been used in science fiction to accelerate spaceships. Anti-matter is very difficult to deal with. It's very easy to test for anti-matter. As you know, all you have to do is put it in contact with anything, and if it explodes, it's anti-matter.

We've got a wonderful case for it here. There's the galactic center, and there's a bright source up there that goes by the romantic name of the "Great Annihilator". It sounds like a wrestling program on television, whereas in fact what appears to be happening is that you actually have active annihilation of matter and antimatter. We think it's a black hole in which gamma rays are so dense that they collide into one another and produce electron-positron pairs that get ejected from the black hole in a stream. That has just been imaged; you are apparently looking at streams of antimatter flying away from the Great Annihilator. As the streams of anti-matter smash into the surrounding interstellar clouds, they glow. You have actual annihilation of matter. Antimatter is very real stuff and apparently can exist over a fair degree of time, enough for it to get into these clouds. This is thought to be very similar to Cygnus X-1 except around Cygnus X-1, there aren't any interstellar clouds so consequently we can't really see the antimatter ejection.

Extrasolar planets

Neutron stars have given us another example of "now you see it, now you don't." Probably if there were Nobel Prizes for embarassment in science, the guy who did this would probably win it. You may remember the planet around the pulsar. The pulse timings exhibited a perfectly regular sine wave, and this was touted as the first discovery of a planet outside the solar system. The poor guy came back to an American Astronomical Society Meeting last year and said, "Well, it seems that we forgot to account for the eccentricity of the Earth's orbit." So what you are looking at is the eccentricity of the Earth's orbit. Yet in one of the most remarkable coincidences I have seen—I think it was at the same meeting—somebody else discovered another pulsar with variations in it, and this is not the eccentricity of the Earth's orbit. There seems to be no other explanation for this other than that there are two planets of the order of three or four terrestrial masses, or perhaps somewhat greater, going around this pulsar and producing this rather complicated curve. It may be the first indication of another planetary system outside of our own. But they've got to be very weird planets. No one knows how such a planet could survive the supernova explosion that causes a pulsar in the first place. They may have formed from debris from some smashed up star. We really don't understand it. The only way we're going to be able to pin down whether these are a real planet is to look for gravitational perturbations, so if this curve changes in a predictable fashion over a period of time, we then have proof.

Do other planets exist? Almost certainly. Look at the famous picture of Beta Pictoris with its disk. Remember the pictures I showed you earlier of 1992QB1 and the Kuiper Belt? This looks like the Kuiper Belt around Beta Pictoris. You can begin to see the construction of our own solar system coming into agreement with what we see around other stars. More recent observations of Beta Pictoris show the disk; here's the extended disk coming out. The yellow represents ices, apparently methane, ammonia and water ices, and the red represents silicates. It's the same kind of stuff that we find in the outer extended disk of our own planetary system. So if we could step back and look from a great distance at our Sun edge on, it might look just like Beta Pictoris. We think that in the middle of this disk, maybe down close to the star, there might actually be planets, real planets, planets like ours, although we have yet to see them.

George Weatherill, who has done most of the modeling of the production of planets in our solar system, claims in the most recent work that if you have a disk of dust around a star you will invariably get the formation of an earthlike planet between 0.8 and 1.3 astronomical units away from it. The idea then is that planet formation is a very natural thing as a star forms from the interstellar medium. As the material that doesn't fall into the star spins out into a disk, planets will simply accumulate from the dust. And unless a close binary fouls up the process, it probably happens for all stars, or a great many of them.

Of course if there are planets, there ought to be, there might be, could be, (sounds like Harry Caray) life. People have been looking for it since Frank Drake turned a Greenbank radio telescope onto a couple of stars. The pace of looking for extraterrestrial civilizations has increased dramatically. On October 12, they turned on (I love this name) the MOP, the Microwave Observing Program. They didn't want to get too fancy with the name because then Congress would look at them and say "What're you looking for, interstellar life?", and then they'll turn off their funds, as they do periodically. So if you just call it the Microwave Observing Project you can hide what you're really doing, which is trying to look for extraterrestrial civilizations with a million channel receiver. If they pick up anything, and they haven't yet, and you sure would have read about it in the newspapers.

The idea is to look for pulses of radiation and to look for what are called drift tracks. If some extraterrestrial little green or whatever out there are beaming pulses into the cosmos, then you will see a Doppler shift in the pulses, as the speed of the Earth changes in its orbit around the Sun. They have some very very sophisticated codes that will pick out these drift tracks from patterns that the human eye cannot even begin to sense. Nobody has found any.

They've got two programs. One targets stars and the other is a survey. The slide you just saw is the Goldstone tracking facility which will be used for the MOP project when it's not being used to track spacecraft. There are about three or four other programs of this sort. Who knows, maybe we'll find something, and then maybe we won't. Are we unique, or are we one of a billion civilizations? It's certainly one of the great unanswered questions. Right now we've got one data point, not enough to construct a correlation—at least for most astronomers, although believe it or not, I've seen it done.

Galaxies

Black holes are in our galaxy, and they apparently are in other galaxies as well. The most famous may be for Messier 87, Virgo A, one of the brightest radio sources in the sky. Down in the center of this thing is a jet of material coming out of a presumably billion or so solar mass black hole which was imaged beautifully by the Hubble Space Telescope both in the ultraviolet and in the infrared. They appropriately colored it red for us. You can see the core of the nucleus sending out a jet that extends for an enormous distance away from the core, an absolutely straight line, but oddly enough no counter-jet. We think there's probably a black hole in here, surrounded by an accretion disk, and then the material is being shot perpendicular to the accretion disk, but why only in one direction? (Next video.) This is a Hubble Space Telescope realization of what the black hole in M87 ought to look like. This is the interior of M87. It's not a spiral galaxy, it's an elliptical galaxy. This would be the accretion disk around the black hole in the middle that you're zooming in on. There's the density peak and the black hole is right in the middle, and it's blowing out matter perpendicular to the accretion disk. Very straight, highly collimated, yet you notice there's no jet in the other direction. This has been confusing, and then it freeze-frames into the ultraviolet accretion disk, or the actual image from the HST.

So's where's the counter jet? The single jet is thought to be a realitivistic single jet phenomenon. The jet is actually coming at us at an angle. If you have a high speed flow of matter, the brightness will be greatly amplified. The counter jet going in the other direction is greatly reduced in brightness so we don't see it. But for all the Hubble Space Telescope's ability, when the ESA telescopes in the southern hemisphere imaged it, there it is. They finally found the counter jet to M87. As you can see, it's right over there. Black holes seem to be everywhere. M32 is a nice benign elliptical galaxy, the companion of M31, yet it seems to have a black hole inferred from the brightness of the core and the velocities around the core. You just use Kepler's Laws to determine the mass, and it comes up to be a billion or so solar masses packed within a very, very small volume of space, and what else could it be but a black hole? That is perhaps a bit of a leap in logic, but nobody can think of anything else, so it probably is a black hole. Another good case was provided by M51, the Whirlpool Galaxy, where you can (this is Hubble Space

Telescope again) see the accretion disk and then the jets themselves that are perpendicular to the accretion disk. You are looking right down in the inner arc second or so of M51, the galaxy in which spiral arms were discovered by Lord Rosse back in the 18th century.

I didn't know where to put this slide. It doesn't fit anywhere. There are lots of gamma ray bursts in the Galaxy, I just stuck it in here, because I guess it sort of fits in the flow of things. Gamma ray bursts were thought to be part of the Galaxy. We now have the gamma ray satellite flying around the earth. It's been able to pinpoint the positions of these gamma ray bursts, and they are not confined to the galaxy. They're all over the place. They are coming from outside somewhere. We don't think it's the halo of our galaxy. We think it's extragalactic. There are all kinds of wacky explanatory ideas like collisions between black holes and neutron stars in other galaxies that could produce them, but nobody really believes that. But nobody can think of anything else. So there's something else out there that causing gamma ray bursts, and we don't have the faintest idea of what it is. I sometimes am amused by our assumptions in trying to put together theories of the universe at large when, again, we don't have a census of what's out there. Every time you build a new machine, you find new stuff.

Everybody knows globular clusters are red. There are a few blue stars in them, but they're generally reddish things. The light from globulars is caused mostly by giant stars that are evolving from very low mass main sequence stars. Globulars are old, the oldest things in our galaxy. The current ages in our galaxy tend to be put at 13-16 billion years. And yet here's a galaxy in which we have blue globular clusters. They're recent. Why are they being formed now in this galaxy rather than long ago? Why don't we have them in our galaxy? We think they may be the result of mergers of galaxies, which stirs things up so much that it vastly increases the rate of star formation, and you begin to get globulars again. One school of thought holds that elliptical galaxies are caused by the mergers of spiral galaxies. They simply collide and produce giant ellipticals like this one here, and for a short period of time a considerable amount of star creation.

(The last video please.) The Astrophysical Journal tape has produced spectacular computer images of colliding and merging galaxies, just like that one there. These are all computer simulations, which require supercomputer operations to do because it requires gravitational interactions of millions of stars. Two galaxies collide, and what do you get in the middle, but a merged system.

We're beginning to understand a little about how galaxies are formed, why there are spirals and why there are ellipticals. Hubble again imaged very distant galaxies showing mergers. Two galaxies are close together here, apparently in the process of colliding. They are all over the place, including the Ring Tail Galaxy that was actually featured in the planetarium show you saw last night with Sherlock, or Starlock, Holmes.

The Universe

More "now you see it, now you don't." Remember the Great Attractor? Astronomers are wonderful aren't they, Great Annihilator, the Great Attractor. It is supposed to be a big blob of galaxies out somewhere beyond Centaurus and Scorpio hidden by the dust clouds of the Milky Way. Here's a gravity map; we're right in the middle. Here's the Virgo Cloud over here, and apparently this huge Great Attractor over here. Last year, I showed you this graph. Here's the model of the Hubble flow including the Great Attractor. This is what you should get if this Great Attractor is there, and the points just follow along very nicely. Then somebody else does another study and it's gone. Then somebody else did yet another study, and showed that it was there. The fact is that we still don't have a census of the universe at large.

We're not aware of what the dark matter is. It's quite possible that the illuminated stars are only 1% of the matter in the universe. What is the rest? Perhaps brown dwarfs? Neutrinos, perhaps? Strange atomic particles, cold dark matter, as it is called? We don't really know. But it's certainly there. If you look at this distant cluster of galaxies, you see arcs, they are all over the picture, another one up here, another one up here. They are caused by gravitational lensing of distant objects by the dark matter within the cluster of galaxies. You can estimate from this image that the cluster of galaxies contains 10 times as much matter as is actually visible to you optically. We don't know what form it's in. Again, we don't have a census of what is out there.

It's no great surprise that we can't really confirm how the universe was born or how it was formed or under what conditions it was formed. There's still an argument as to whether the Big Bang really happened. There's a small minority of astronomers who think that the universe controlled by electromagnetic forces, that there was no Big Bang, just a whole lot of little bangs.

Opposition to the Big Bang was supported by the early COBE results (the Cosmic Background Explorer) that showed in an all sky picture an absolute smoothness to the cosmic background radiation. The only deviation is from the Doppler effect caused by the motion of the Earth and Galaxy through the local supercluster. The book Did the Big Bang Really Happen? was based to a degree on images like this. Well they finally broke the background radiation up as you know. There do seem to be microkelvin temperature fluctuations in the Big Bang background, which implies that in fact the Big Bang really did happen, and that these may be the beginning stages of the formation of clusters of galaxies. On the other hand, someone has suggested that the fluctuations may be due to gravity waves. Again, we really don't know. But this certainly got to be one of the most dramatic pictures of the year.

Yet for all of that we still don't know the age of the universe. Again, no surprise, as we don't even yet have a census of what's in it. These are Hubble pictures of a Cepheid variable star at a great distance. You can see it fluctuate here in this distant galaxy. From this Allan Sandage established a Hubble constant of 50 kilometers per second per megaparsec. Yet there was an enormous paper published at the same time by a large group of astronomers in the Publications of the Astronomical Society of the Pacific, that called for 85 kilometers per second per megaparsec. Yet when you look at the globular clusters, you find that the globular clusters deny the broad consensus of astronomers in the world. These globular clusters are13-16 billion years old. If you take a high value of the Hubble constant, you get an age of the universe of less than the age of the globular clusters, which makes no sense at all. So who's right and who's wrong? Are the observers wrong or are the theoreticians who try to get the ages of the globular clusters wrong?

To know the universe you have to know the stars. To know the stars you have to know the Sun. It's all integrated, and it's all constantly changing from one year to the next. Isn't this a great business to be in? Thanks.