ASTRONOMY UPDATE 1994

James Kaler
Department of Astronomy
University of Illinois
Urbana, IL 61801

<u>Abstract:</u> Astronomical discoveries of the past year are reviewed. The Space Telescope was repaired; COBE, Magellan, and Clementine completed their mission; and the resolution of ground-based observations continues to improve.

Some ice may exist on Mercury, but the idea of an ancient ocean on Mars seems less likely. Io's volcanoes are probably silicate, surface features can be seen on Titan in the infrared, and many surface features on Miranda may be the result of internal convection. Pluto has a thin nitrogen atmosphere and its satellite Charon may have been broken off in a collision. Earlier comet collisions like that of Shoemaker-Levy 9 with Jupiter may have produced crater chains on other surfaces. Nine Kuiper belt comets are now known and Halley will be visible to aphelion. Aurorae on the Earth are caused by solar coronal outbursts, not flares.

New interstellar molecules include long-chain carbon molecules; ethanol, also found in comets; and glycene, the first amino acid. The discovery of planets around a pulsar shows that formation of planets may be a ubiquitous process.

Mass loss is a major limiting factor is predicting stellar evolution, especially for high-mass stars. The rare luminous blue variables like Eta Carinae and AG Carinae now appear to erupt periodically, like geysers. Supernova explosions may be non-central.

A new galaxy has been discovered in the Local Group and faint blue galaxies may be found nearby as well as at cosmological distances. Many galaxies, especially giant ellipticals, may have been formed been formed by mergers.

The dark matter problem remains unsolved. Some galaxies have dark matter and other do not. A survey of stars in the LMC reduced the likelihood of finding MACHOs in the halo of the our Galaxy.

Doppler surveys of galaxies in both hemispheres reveal an unknown scale of clumpiness out to at least 300 Mpc that can affect values of the Hubble constant derived locally. Neither the Hubble constant nor Omega are yet well-known.

There's a saxophone down here. Are you trying to tell me something? There's a joke there somewhere, but I can't quite think of what it is at the moment.

What's new in astronomy for this year? This is such a wonderful subject. As soon you think things are known, everything changes. You give an hour talk, you only skim the surface of what's new in this field.

Spacecraft and Resolution

At the top of the list is something I'm not allowed to talk about, the repair of the Hubble Space Telescope. You give all the good stuff to somebody else. This is my favorite image; I just love this. Look at the stellar images from Palomar on a good night compared with those from the WFPC 2. What a marvelous instrument this is. It's given a new life to the Hubble Space Telescope. And what they give me are death notices.

Like Magellan. According to CBS News, Magellan has been in orbit around Venus for five years and finally entered the gravitational field and crashed on the surface! (One wonders where it's been.) So farewell to Magellan, one of the most successful missions of all time. COBE was turned off, and is now dead too. It produced some spectacular images with which we will conclude this talk. Clementine died an untimely death, but not before doing some spectacular mapping of the moon that included this wonderful image of the lunar North Pole, which nobody had ever really seen in any kind of detail. There is still some speculation about the possibility of water on the Moon; it might exist in the shadowed craters at the poles. That is not a result, it's just speculation at this point.

Next is something again that I've harped on. More than anything else astronomical instrumentation is about resolution. You're looking at some laser beams being shot out of an observatory, creating an artificial star up in the upper atmosphere with which you can monitor the atmosphere and detwinkle starlight. Adaptive optics has become something of a cottage industry in the country. The Mt. Wilson 100-inch will be ultimately dedicated to this kind of observation.

But that can't begin to hold a comparison with this image, which I found absolutely remarkable. You are looking here at Auriga rising over the Oklahoma horizon and if you look just to the upper left of center you see Capella. They say Van Biesbrock, the famous double star astronomer, was able to resolve Capella. He in fact was turned down at the 200-inch to try to get its orbit. On a clear night, you can actually see an elongated image. This is a speckle image. There's Capella in the upper left. If you look carefully — the stars are very close together — you can see that each of the little speckles is doubled. The processed image is at the center and you can now resolve Capella A and B. There's a 180o ambiguity so you see Capella A in the middle and images of Capella B on both sides. Now look at what the Mark 3 interferometer can do. Not only can you resolve the pair, you can resolve the sizes of the stars themselves and see the difference between the G5 and the G0 components.

At some point — at least in terms of resolution — we're not going to need the Hubble. Of course we're not going to get the ultraviolet unless we start using a lot of old hairspray and get rid of *all* the ozone. But this type of ground-based resolution is rapidly getting better. I've heard people involved who say that within maybe ten or twenty years, you should be able to image the surfaces of other stars from the ground.

Of course the *ultimate* death notice was issued to these fellows [dinosaurs] looking up in the sky watching the big meteor stream to the earth, the one that produced the Chicxulub crater in the Yucatán Peninsula. What is remarkable is that they keep expanding the size of this thing. Now they've made gravity measurements of the crater, and if you look toward the very bottom of the slide you can see a separate outside ring that tends to make it look like it's somewhere around 300 kilometers in diameter. It's no wonder that 80% of the species on earth died at the time.

Terrestrial Planets

We speculated that there may be water on the surface of the moon, perhaps up in the Poles. I think the odds are very strongly against it. All the water molecules should have disappeared from the moon long ago, except perhaps for some being delivered back by comets. Mercury, on the other hand, may have some. It has been subject to many misconceptions. Back when I was a kid, Mercury was supposed to orbit in synchronous rotation with the Sun. It was supposed to be dry and hot. Now we find that it's in a weird synchronism, rotating with two thirds of its revolution period. Then V.L.A. observations showed bright spots at the poles. Last year I mentioned what appeared to be ice caps on Mercury's poles. The subject has been refined considerably. Here you can see not only ice caps, but they're in spots that actually match up with crater images from Mariner imagery, indicating water ice in the deep craters at the Mercurion poles where the sun does not shine. So in spite of Mercury's closeness to the sun, the ice can exist for eons, effectively perpetually. It's probably mixed with dust that keeps it from subliming away, and more of it keeps being delivered onto the planet by comets.

On the other hand, the water may be "disappearing," at least a little bit, from Mars. There was a strong feeling a few years ago that Mars may have had some deep oceans. You're looking at a drawing of what may have been Oceanis Borealis. It may have been several hundred meters deep and made of water that had been cooked out of the deep surface soils by volcanic action. The water may have produced a greenhouse atmosphere of a couple of bars, much thicker than the earth's atmosphere.

But planetary scientists are starting to back off on that a little bit. The idea is that if you have too much CO_2 in the Martian atmosphere, given its distance from the sun, the CO_2 would just precipitate out. You really can't have a terribly thick greenhouse atmosphere. There is clearly a lot of water — you do have channels on Mars — but perhaps not the ocean that has been rather popular in the last couple of years.

This is the sort of subject that waffles back and forth. You just can't seem to keep up with opinions. It's very difficult to reconstruct something that happened three or four billion years ago from the kind of data that we have. The Mars Observer may have resolved some of these issues, but unfortunately we will never know.

Outer planet satellites

Moving out a little bit now, to Io. We love to tell students about it because it's a sulfurous surface and one of the weirdest objects in the solar system. Certainly it is the most volcanically active body in the solar system. It's being pulled around by the gravitational fields of Europa and Callisto. It gets tidally flexed. The satellite changes its shape a little bit, which heats the interior, and the stuff pours out. New measurements have shown that Io is hotter than previously expected. The volcanoes are probably silicate volcanoes rather than sulfurous volcanoes. The sulfur is probably mixed in with the silicates. The new measurements are actually ground based, and getting good enough to be able to do some real physics and astrophysics on a tiny satellite that you can barely resolve from the earth.

Titan is one of the stranger bodies in the solar system, the only satellite with a thick atmosphere. It was the source of great disappointment to Voyager scientists, because they thought they would be able to image the surface and really see what was going on. Unfortunately, it is surrounded by a methane haze, and you can't see anything at all optically. The infrared astronomers have actually managed to punch through the haze and locate surface features to show that it is in synchronous rotation relative to Saturn, as it ought to be. The point that I am trying to illustrate here is the remarkable advances that have been made in ground-based astronomy. We can do serious work on distant satellites, so we can continue research that was really begun with the Voyager spacecraft.

Miranda is a case of another possible misconception. The chevron feature, and the many other odd features on the surface, have been touted as being produced by the restitching together of a satellite after it was broken apart. At least some planetary scientists are backing off on that idea too. The claim from theory is that these features could just as easily have been produced by convection from below without the satellite having broken apart at all. Again, we see constant changes of opinion. I know this makes it very difficult for us as teachers and public educators. You tell people one thing and then the next year it changes, and then the next year it changes back again. It is both frustrating and fun at the same time because you never quite know what's going to happen.

Pluto

Pluto has a little atmosphere. They have recently discovered that the atmosphere, which is about 10-5 bar or so, is probably 98% nitrogen, which falls to the ground as snow. When Pluto goes near aphelion, all the atmosphere seems to precipitate as ice and falls down to the ground as snow: the ultimate in meteorology. The planet actually is at its brightest at aphelion rather than perihelion because the albedo goes up so much.

Pluto is also the source of considerable controversy. What is the thing? There was actually a kind of a silly editorial in *Sky and Telescope*: "Is Pluto a Planet?" "Yes." "Is Pluto a Planet?" "No." It's all semantics, how you want to define a planet. I'm teaching it now as a rather bizarre little body that doesn't really belong in the category of major planets. It's the same size as Triton and the growing feeling is that you are looking at a very large example of a planetesimal rather than at a planet, or even a protoplanet, things that assembled from the smaller bodies that ultimately produced the planets.

Pluto is certainly one of the more enigmatic bodies of the solar system. It's the only planet that has not been visited yet by spacecraft. It is more like a double planet than anything else in the solar system, more certainly so than the Earth-Moon system. It's critical that we be able to get the mass of Pluto and its satellite. You have probably seen this Space Telescope visualization. You can also see Charon resolved now. You can see the satellite and the planet orbiting their common center of mass as the resolution improves. From that orbital motion you are able to derive the mass ratio of the two bodies. This is one of the initial results of the old Hubble Telescope. They derived a mass of Charon 8% that of Pluto, which makes its density too low, and which gives us a problem in terms of the collision hypothesis for the formation of Pluto and Charon.

Someone recently did this kind of analysis from the ground and located the center of mass, and now the mass of Charon has gone up to 16% the mass of Pluto. The mass of the satellite has doubled overnight which brings the densities of the two together and provides much greater support for the collision hypothesis, that Charon was broken off of Pluto in a major collision much as the Earth-Moon system was created.

The point again is that ground-based astronomy is not dead just because we have a Hubble Space Telescope. The Hubble does things that no other instrument can do, yet ground-based astronomy is very far from dead. In fact, ground-based astronomy has received much new life over the last ten years in terms of its ability to resolve and to do things that we thought only the Hubble could possibly do.

Now move to protoplanets and asteroids. Nobody quite knows what to do with an asteroid with a satellite. This is Ida, one of the two asteroids we've imaged with Galileo. If you look just to the right of Ida, you can see its little satellite, which is only a kilometer or so across. They have somewhat different compositions. So then how did they form? Nobody really knows how these double and multiple asteroids develop and nobody knows how common they are.

Comets

No talk on "what's new in astronomy" would be complete without this. (I don't care who else talks about it, and I understand Ray Villard is. I'm giving my talk first and I'm going to talk about it too.) You can't possibly ignore The Great Comet Crash. It probably did more for public education in astronomy than anything else I can think of. I don't know what kind of questions you got while this was going on. I know I was asked: "Is Jupiter going to explode?" I think somebody asked if it was safe to go outside the night that the collision was to take place. It was like the eclipse of the sun where a guy called and said, "Can I go out and play golf during the eclipse?" I couldn't go out and play golf during the eclipse because I don't play golf. I told him it was probably safe.

I want to run through a series of slides here so that you can relive the experience. I know that everybody knows what was going on, but it's just fun to see these all over again: Comet Shoemaker-Levy 9 unresolved from the ground; closer view from the Hubble Space Telescope; yet a closer view in which we watch all the pieces spread out as the comet gradually approached the planet.

How many of you thought nothing would happen? Okay, let's be honest now. How many of you thought it was going to be the greatest event of the century? Oh, one! You are as conservative as I am. I was telling people: "you're not going to see anything." I've been burned too many times, by Halley's Comet, the Great Perseid Meteor Storm, Comet Kohoutek, you name it. And forget it. I'm not going to tout *this*. Of course it *did* turn out to be one of the really spectacular events of the century. From Kitt Peak you could see pieces of the comet approaching Jupiter. Here's a beautiful computer image that showed what might happen when the comet entered the atmosphere and the shock wave heated up and exploded the comet, the fireball exploding upward. I was saying, "Oh sure, all of you theoreticians don't know what's going on. This is not going to happen." But it did.

I love this picture. That's the K fragment, seen in the infrared. The newspapers didn't know what to do with it, and made it sound like Jupiter was exploding. In the optical you didn't see this, but in the infrared it was absolutely spectacular, as the fireball rose up. The impact was really amazing. The K fragment hit here in the southern hemisphere, disturbed the magnetic field of Jupiter, and produced an aurora in the *northern* hemisphere. Here, we're watching all the pieces spread out. Watch the shock wave of the G fragment impact, and then watch the spread as we begin to observe the winds in the Jovian atmosphere, which will ultimately serve to tell us a great deal about atmospheric motions. All I can tell people when I lecture about this stuff is that it will ultimately feed back into our studies of the terrestrial atmosphere, so we begin to understand our own planet a little bit better.

Has it happened before? Almost certainly. No one knew what caused these crater chains on Callisto. Now that we saw SL9 — ah ha! it hit the satellite instead of hitting the planet. Crater chains like this have been found on our own moon as well. It may also have happened in the recent past. This is a drawing of Saturn yanked from a Sky and Telescope article. It was made by Antoniadi in the 1920's. Nobody knew what to do with these mysterious spots. An astronomer in Iowa started looking at old drawings and found pictures of Jupiter also with mysterious spots. I had always wondered what would happen if these weird spots suddenly appeared and nobody had ever found SL9, which would have been quite likely 20 or 30 years ago. What would the theoreticians have done with it? Just think about it for a minute. You can come with some wonderful scenarios.

Comets have always fascinated me and are among the most amazing bodies in the solar system. They appear to have been instrumental in assembling the planets. This is Temple-Swift, the comet in which ethanol was discovered. The number of different ices is really quite remarkable: water ice, ammonia ice, methane ice, and now methanol ice. Hey, if there's methanol, ethanol can't be far behind. Just think of the idea of going out and mining booze. You might even be able to get a grant from Congress to do that.

This is object 1993RO. We're beginning to look outward into the zone of the comets and see where they are. They appear, at least theoretically, to be in two zones. One is the vast Oort comet cloud, which are comets that were probably thrown out of the solar system by Uranus and Neptune. Jupiter and Saturn's gravitational fields probably kicked comets out of the solar system altogether, and gave them escape velocity from the sun. Uranus and Neptune probably threw them into the Oort cloud, at least that's the speculation.

But there's another set of comets in the Kuiper Belt, which are original comets in the disk of the planetary system. They were probably just too sparse to assemble into a major planet beyond Neptune. When you look at Beta Pictoris, you can apparently see its Kuiper Belt. We should have one that extends tens of AU farther from the Sun than Neptune. A group in Hawaii is beginning to pick them up. So far we've found nine of them, two of which have orbital semi-major axes greater than that of Pluto. They really are on the average beyond Pluto, and we are beginning to plow out farther and farther.

I did a Halley's Comet tour in Chile when Halley came by last time. We had a guy on the tour who was about 80 years old who had seen Halley's Comet back in 1910 and wanted to see it again. He got to make one of the ultimate statements of his lifetime. He was quite fragile and we were off in a desert; he had to walk across the rocks from the bus. We got the guy over there and he managed to look through the telescope. We had to hold him up the telescope because he wasn't feeling well. He managed to see Halley's Comet for the second time and he got to say, "Well, it sure doesn't look as good as it did in 1910." And he went back to the bus. So there were a few people who got to see Halley's Comet twice. I, and many of you who are of my age, are *aphelion* people. I fell in love with astronomy when Halley's Comet was at its last aphelion and I spent a lot a good part of my life watching it come to perihelion, saw it, and I hope to live through its second aphelion apparition, as will many of you. It's not like something you can explain to the general public, but I find it kind of exciting.

This time Halley's Comet will be visible at aphelion. We'll be able to see it all the way around its orbit. It was picked up recently about at 19 astronomical units. They can still image it with CCDs without too much difficulty. I realized when I saw that picture that I wanted to put this into the lecture and it would be fun to have a little bit of a Halley Comet retrospective for those of us who love the little guy. I took images that were taken at our one meter telescope at Mount Laguna and made a Halley Comet movie. We're getting closer and closer, now we're getting farther and farther away. There it is, at Uranus. You can see the star trails getting longer as the comet is moving faster and faster as it gets nearer the Earth.

Aurorae and Eclipses

Back to the earth for a moment. There's been a major misconception about the aurora borealis, the northern lights, that I came on by accident, although one solar astronomer has been touting it vigorously. You'll find it stated in almost every textbook that they are produced by particles from solar flares. Apparently that is not true. They are produced by coronal mass ejections, not by flares. Sometimes these coronal events will be accompanied by a solar flare. The trouble is that in the optical, you can't see them. They are apparently produced by the release of the magnetic field that confines coronal matter. They may also *not* be accompanied by a solar flare. This explains the fact that you don't get a perfect correlation between auroral events and solar flares.

I can't talk about the sun without talking about the May eclipse. Here's a picture of the sidewalk outside my office of that wonderful annular eclipse. Champaign-Urbana was right smack on the path. We had a gorgeous day, one of these perfect days with no clouds in the sky. I think what impressed me more than anything else was how cold it got. My wife and I were standing outside and we're starting to freeze. And I realized that this is what it feels like on Mars, actually a little bit beyond Mars. No wonder the place is so darn cold.

Stars

Suns. You want suns? Here is Omega Centauri. When I first wrote an article that included Omega Centauri, I said, "A million stars." I have a globular cluster friend (a friend who studies globular clusters, he's not a globular cluster himself). He said, "No, come on, it's not a million stars, a half million at most." There is a new mass for it: *five* million solar masses. Is this a globular cluster or a dwarf spheroidal galaxy? It's almost a crossover object. If you've ever been to the Southern Hemisphere, you wonder about that fuzzy thing in the sky in Centaurus. You forget it's fourth magnitude, and easily visible to the naked eye. It's a spectacular object: five million or more strong.

Polaris has long been known as a Cepheid variable. Over the last several years, however, the pulsations have been dampening down. It has been classified at times as a W Virginis star, but that's neither here nor there because it's stopped pulsating. It's one of the few times we have been able to actually watch a star like this change, actually see the evolution in front of our eyes.

Interstellar Molecules

We'll now work our way out into space a little bit farther. These are examples of molecules you find in interstellar space: ethanol up at the top (I seem to have a fixation on ethanol), then one of the long-chain carbon molecules, a benzene ring, and a buckyball, C_{60}. There has a been a very long standing problem with what are called diffuse interstellar bands in stellar spectra. They're very broad absorption line features, and no one had any idea what to do with them. It was thought for a long time they might be produced by crystal structures in solids. Apparently they are beginning to be related to some of these long carbon chain molecules. If that's the case, it's the resolution of a problem that goes back thirty years or more.

The benzene rings get together to produce PAHs (polycyclic aromatic hydrocarbons) and some very complex structures. The buckyballs have been controversial: there have been reports of spectroscopic observations of the existence of these C_{60} molecules in interstellar space. Then the identifications were replaced by the PAHs. Now these buckyballs (buckminsterfullerene it's actually called) have been found in meteorites, not only C_{60} but apparently C_{80} as well. The only place we think it could have come from is interstellar space. If you look in the carbonaceous chondrites, you do see interstellar grains.

So we're able to do interstellar chemistry from the meteorites. This is a direct connection between ourselves and what made us, between the dust that made our own earth and interstellar space, the dust that came out of stars, carbon stars, Mira stars, and others. We can begin to see our origins a little bit better.

One of the most exciting discoveries of the year in interstellar chemistry is the probable discovery of glycene, the first amino acid in interstellar space. Only one line is observed at this point, and of course, you really have to have additional spectral lines for confirmation, but they're pretty sure of their identification. Amino acids are found in meteorites, so we begin to see where they came from.

Circumstellar Disks

We have got a disk around our star, the Kuiper Belt; we're starting to probe into it. We know disks exist around other stars: Beta Pictoris, Vega, Fomalhaut, several other A main sequence stars. We're see indirect evidence of disks around T Tauri stars from the jets that come flowing off of them. The Hubble Space Telescope has found many of these disks in star forming regions within the Orion Nebula; all of the color you see in there is from the nebulous gases. We're now looking at these protostars with the surrounding disks. At least we're pretty sure that's what they are.

No talk of this sort would be complete without the latest discovery of a brown dwarf. Brown dwarf discoveries have half-lives of about six months. This one seems to be 0.03 solar masses, but then maybe again it isn't a brown dwarf; nobody knows. The fact is that even now, nobody has yet confirmed the discovery of a brown dwarf.

Beta Pictoris' disk may be its Kuiper belt. We know we have a disk around our sun, and we know it contains planets. Does the disk of Beta Pictoris contain planets too? Maybe. If you look in toward the center of the star, you see that the disk dims, as if there might be planets orbiting around the star that are sweeping the zone clear of dust. This is at least speculative, indirect, evidence of the possibility.

Mass Loss and Stellar Evolution

I want now to move on from star formation to stellar evolution. Here are two Space Telescope images of Nova Cygni 1975. This a pre-fix image on the left, a post-fix image on the right, and you can see changes in the structure of the ejected nova shell. Novae are produced by lower mass stars, by a white dwarf in orbit around a main sequence star, not a giant. They're probably lower main sequence K and M dwarfs. As a result of the evolutionary changes in the star that made the white dwarf, the two stars have orbits so close together that the white dwarf can tidally distort the main sequence star, pulling mass onto its surface. The fresh hydrogen then ignites by the CN cycle, which produces the nova. These are low mass configurations.

Novae are low-mass configurations. High mass configurations can be much more exciting. This is R136A in the Large Magellanic Cloud. At one time this was touted as a superstar of a thousand solar masses, showing what bad resolution can do. Then speckle interferometry broke up the superstar into a number of O stars, and then Hubble Space Telescope resolves it into a whole cluster. The Hubble is good enough to be able to pick out individual stars and do spectroscopy on them with the High Resolution Spectrograph. What we find are mass loss rates in these stars that are far greater than anybody expected them to be.

Mass loss turns out to be a limiting factor in the predictions made by stellar evolution theory, especially for high mass stars. Nobody can predict what the mass loss rates should be. Mass loss will seriously affect the evolution of the stars over long periods of time, and nobody really knows how.

We do know, however, that some of these high mass stars do some wonderful things. This is an image of Eta Carinae taken by the Hubble Space Telescope. Eta Carinae was the second brightest star in the sky around the time of the Civil War. In fact, you could see Sirius, Eta Carinae, and Canopus all in a line. It must have been quite a sight. Then Eta Carinae faded.

Eta Carinae is an example of a luminous blue variable. Such stars are very rare; they are thought to be stars of around a hundred solar masses, stars that are not allowed to evolve into the red supergiant region of the HR diagram because they lose mass at such fierce rates. A recent article calls them "geyser stars," acting kind of like Old Faithful. They sit there for a while and bubble up and build up a pressure. All of a sudden the gas gets released in a tremendous outflow that produces dust that can bury the star within. There's probably a hundred solar mass star within this cloud, and you can see so beautifully the matter coming out in a bipolar fashion. Use your visual imagination; you can see the disk of dust — the thick disk in the middle that's forcing these bubbles to flow out in a bipolar flow. Improved resolution is allowing us better and better to see how this flow appears.

This is AG Carinae, another luminous blue variable in the southern hemisphere, once thought to be a planetary nebula because it had a little disk of gas around it. The mass flow is anything but uniform. Matter is coming off in puffs and bubbles that nobody understands. There's no theory for this kind of ejection. Of course the observations should come first and then the theoreticians should get busy, which I am sure they are. These observations are going to produce another little industry on mass outflows from high mass stars, with which we will begin to understand their evolution and the creation of supernovae and supernova remnants.

Now turn to supernova 1987a. We see again a highly touted image. The star has these rings around it that nobody really understands. The supernova is illuminating matter that has been lost previously in ways that nobody understood or expected. Mass loss is a major problem in stellar evolution that is poorly understood, from the creation of planetary nebulae to the creation of supernova remnants.

When the supernovae explode, they apparently do not explode centrally, that is, ignition may take place off center. That does some interesting things. It can squirt the matter off to the side. That fits in with the fact that some pulsars are not centered in their supernova remnants. They are moving at very high velocity as if there had been some kind of kick given to them when the supernova exploded. It may have been an off-center explosion.

Extrasolar planets

The pulsars seem to have planets. That will be a subject for history books because the first planets discovered orbiting a pulsar turned out to be simply observations of the eccentricity of the earth's orbit. At the same time the astronomer was withdrawing the discovery, somebody else had discovered two real planets. The discovery comes from variations in the pulse timings. But no one quite knew whether something funny was going on with the pulsar or whether they were actually planets that make the pulsar orbit a common center of mass.

If you know the planets are there, however, then you can use orbital theory to predict the perturbations that each planet should have on the other. You can then predict what the pulse changes should be in the pulsar. The pulsar's pulse-changes matched the predictions of perturbation theory. So it is almost certain that this pulsar does indeed have two, and maybe even three, planets in orbit around it.

The origin of these planets is different than those in our own solar system. The pulsar's planets probably formed from the debris of the star that the pulsar (this is a millisecond pulsar) evaporated. But the point is that given a source of raw material, planets are going to assemble. I think that gives a lot of confidence to the SETI people; planets are probably ubiquitous in the universe.

SETI itself has also been in the news. Congress does not like SETI and cut its funding, which has been picked up privately. They are expected to start observations again in Australia soon. So it is going to go forward, which, as a working astronomer, I feel is a wonderful idea. Whether they will ever find anything is problematic, but if you don't look, you're not ever going to. So why not at least look?

New Galaxies

We've added a new galaxy to Local Group using radio observations. It appears to be very close, right on the outside of the spiral arms, and may be the closest galaxy to us. We are still assembling a census of what is up there. It is true of the planetary system, of the Galaxy, and of the Universe as well. Our ignorance is deep.

When you look out into distant space, you see a lot of faint blue galaxies. We don't quite know where they come from because we haven't seen a lot of faint blue galaxies near us. But perhaps we do. There seems to be a whole collection of what are called "low surface brightness galaxies" that have all the Hubble types. Star formation is proceeding within them at such a slow rate that they are mostly interstellar matter and very faint, and they couldn't be photographed before. We are only starting to image them now with CCDs. So we may be entering a whole new era of galaxy research *again*, building up the census of the universe. These galaxies may be important to the dark matter problem and therefore to the closure of the universe.

M87 made the news, rather its central black hole. The evidence keeps getting stronger and stronger that it exists. These two spots illustrate positions where HST observers were able to make spectral observations to find the velocity of the gas circulating around the central black hole. You can see the Doppler shifts here of the 5007 forbidden oxygen III line. We're able to confirm that there may be a multi-million solar mass black hole at the center of M87.

The Dark Matter Problem

The dark matter problem is still with us. It looked like for a while that we had some of the problem solved with the so-called MACHOs, the massive compact halo objects. The idea was to look at, and monitor, stars in the Large Magellanic Cloud. If you look at the rotation curve of our galaxy, it looks fairly flat. In fact, the rotation speed of the galaxy just keeps increasing all the way out to 20 kiloparsecs from the galactic center. The only way you can account for this is to have a lot of mass out there that keeps the rotation speeds high; but you can't see it, it's not in stars. So, it's in dark matter, but nobody knows what that is. The dark matter ought to fill up not the disk of the Galaxy, but the halo.

No one knows that nature of the dark matter. But if one of these hypothesized massive compact halo objects positions itself in between the Earth and one of the stars in the LMC, it will produce a gravitational lensing that will the star brighten. This graph has been rather widely touted as being the discovery of a massive compact halo object. However, you can account for this observation by the microlensing of stars just getting in one another's way within the Large Magellanic Cloud itself. Thus disappeareth the MACHO objects in the halo. Another death notice perhaps, I don't know. So we still don't know what the dark matter is.

Oddly, some galaxies don't appear to have dark matter. These are planetary nebulae in M105, and they *do* show Keplerian rotational velocities and indicate no dark matter in this galaxy. The same is true of M81. This is a radio image of M81 showing the Doppler Shifts. A little exaggerated, but you get the idea. M81 also appears to have Keplerian rotation and no significant dark matter. Why some galaxies have it and others don't is a mystery. The whole dark matter problem is up for grabs at this point. You want a Nobel Prize? Figure out what dark matter is.

Galaxy Mergers

We can use new instruments, the Hubble and the ground-based Keck, to look farther and farther into space. You're looking here at galaxy mergers in a cluster of galaxies three billion light years from the earth. The idea that galaxies' structures are largely a result of previous mergers, even that a whole population component of our galaxy may be the result of our Galaxy tidally disrupting others galaxies away — so their material gets dumped into ours. That picture may explain the younger set of globular clusters

Here we look out to such high redshifts that we can see these mergers taking place. In fact what you see when you use the natural time machine in the universe and go out into great distances is that you have a higher proportion of spirals at greater distances than you do at low redshifts, implying that many of the elliptical galaxies are the result of the mergers of spirals. Mergers help to produce a giant elliptical, or one these supergiant diffuse galaxies, at the centers of big clusters of galaxies, as the debris flows into the middle to make them.

What can you say about gamma ray bursts? It depends on what month it is. Nobody knows what they are. There's still a whole camp that says that they're local, that they're in our galaxy. Another camp says, no they are at cosmological distances. The number of theories is remarkable: collisions between neutron stars, between neutron stars and black holes, between comets and neutron stars. Then here we apparently have a superposition of two events that look like gamma ray bursts aren't so random. This one source has gone off twice. At this point, we have observations with no firm theory at all. They could be galactic, extragalactic, cosmological — nobody has a clue. What the gamma ray bursts *are* is certainly one of the more intriguing mysteries of the universe.

The Hubble Constant and Closure of the Universe

The northern hemisphere has been well surveyed to establish the locations of galaxies via Doppler shifts. A comparable Doppler survey in the southern hemisphere has now been completed allowing us to place galaxies in three dimensions. Not surprisingly, the southern hemisphere looks just like the northern, a very satisfying result. You see the same kinds of walls, and strings and superclusters of galaxies, that have given so much difficulty to the people that are trying to understand galaxy formation.

The lumpiness scale of the galaxies is still not known, making a locally derived Hubble constant uncertain. The lumpiness scale now extends out to at least three hundred megaparsecs.

I hope you got as big a kick as I did out of Sky and Telescope's attempt to rename the Big Bang. I think the New York Times or Wall *Street Journal actually took them to task for it* as an attempt to be politically correct. That wasn't the idea. The Big Bang is really a misnomer that Fred Hoyle coined to try to annoy George Gamow. Hoyle wanted to perpetuate the Steady State theory, and he still does. I think there were 13,000 names submitted in the contest. The ones that stuck in my mind were Bertha D. Universe, God's Logon, The Big Boot, and You'll Never Get It All Back In There Again. They wound up with the Big Bang because none of the others were any good. Big Bang does at least give you an idea of what was going on.

And what do you do with the Hubble Constant? It has been changing its measured value ever since Hubble found it to be something like 600 kilometers per second per megaparsec. It actually *does* change. It should be getting lower as a result of the gravitational action of the universe. What is the current value? The matter is still not settled.

We just learned from observations of Cepheids in the Virgo Cluster that the short distance scale is correct, which implies the validity of the higher Hubble Constant is correct. Yet there is another measurement that gives only thirty-five kilometers per second per megaparsec. This determination solves the age anomaly of the globular clusters, which are measured to be older than the universe if the higher Hubble constant is used. That is a problem that has still not been resolved, in spite of the new opacity calculations that have revolutionized the stellar interiors' business. So the Hubble Constants are still going anywhere from around 35 to up to around 75 or 85 or so.

The measurement of Omega is equally uncertain. Is the universe closed or not? From compact radio sources, we find an Omega of one, telling us that the universe is indeed marginally closed or marginally open, however you want to look at it.

But there is a new measurement of the deuterium abundance, which depends upon the density of the universe at the time of the creation of the deuterium, which in turn relates to the current density, which then relates to Omega. From this observation, the Universe is open. From observations of active galaxies and an application of theory, we get distances and an Omega of only a tenth.

So we have an uncertainty of a factor of ten. But what's an order of magnitude among astronomers? — that's almost agreement, you know. I always get a kick out of the fact that people say, "Well, look what we have done, look at this, how close the globular clusters are to the age of the universe." They are; they're within a factor of two. We tout that as, "Boy we know what we're doing." But then when we look at it closer, the globular clusters are older than the universe itself, so I guess we don't know what we're doing. They are both valid points, but try to get *that* across to the public or to your students. It's not an easy thing to do.

Nevertheless, as little as we know about the universe, why not do some theory on it? These are the images made with a supercomputer at the University of Illinois. This comes from a combination of both cold dark matter and hot dark matter in an expanding universe. This picture shows a local area, and what you find in fact is a simulation of galaxies that look startlingly like what you actually observe.

So in spite of the fact that we don't know what dark matter is, we can still construct theories. I don't think it's all that arrogant to do that. Why not? You don't know what it is, but you know it's out there, you know it has its gravitational effects. You can at least produce something of the structure of the universe on a computer. This is hardly a proof that the theories are right, but at least you do get the right picture and it's encouraging. In this picture, we are right here, the result of the origin of the universe, combined with the formation of the galaxies, combined with the formation of a single galaxy, out of which condense the stars, out of which condense the earth. Go on outside in this wonderful lodge and see the real result of what you see up there on the screen. Thank you.