1991 ASTRONOMY UPDATE

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<u>Abstract</u>: A wide-ranging review of astronomical research in the past year, including solar system, stellar, and galactic astronomy and cosmology. Topics include high-tech ground- and space-based telescopes; Magellan studies of Venus; earth-crossing asteroids; chemical abundances in stars, stellar remnants, and the interstellar medium; x-ray astronomy; galaxies; extrasolar planetary systems; and many more.

I seem to be plagued with a particular problem. I work with a symphony orchestra back home. Well, what does this have to do with astronomy? We have a manager who gives a report on the state of orchestra and then gives all of the details on a business campaign that I chair. Then I come up a little later with my report that she's already given. So there's nothing to say, and I sit down. This happens every month and has been going on for something like two years now. Then I come to this meeting to present an update on astronomy and Randy Olson gives this nice talk about the Hubble Space Telescope and Ron Parise gave a talk on Astro. Half my slides are gone, so I shouldn't have any trouble getting you in to lunch on time.

Okay now let's have the lights out.

The newest astronomy involves four meter telescopes, 10 meter telescopes, the Hubble Space Telescope, and Astro. These are high tech multi-million dollar operations. But astronomy also involves something that touched me deeply this year, and that's simply a look at the night time sky and attempts at trying to educate people about astronomy. This scene was taken by a local amateur in the Black Hills of South Dakota. But the reason I put this constellation photo up is that this is where the education in astronomy starts.

Some of the biggest news in the whole year was The Astronomers program on PBS. The first program did not necessarily focus on the high tech operation; they open up with a Dobsonian telescope, the sky being shown through a telescope on the streets of San Francisco. This is where new scientists come from. It reminds me of a story, showing someone a scene through a telescope very much like this on a street corner. A woman walked by—this is the level that we're dealing with here—a woman walked by and said, "What are you looking at?" He said, "I'm showing people the moon." She said, "Oh, I've heard of that."

High-tech Observatories

The high tech work now has to take the center stage. The Keck Observatory is on its way; it is now larger than the 200-inch. It is an extraordinary operation; rather than casting a 10 meter blank, they are using segmented mirrors. Here is a picture of it taken from overhead before most of the mirrors were installed. You can see a couple of them put in place. There are installing in groups. They're approximately 1-meter hexagonal mirrors. They will eventually have the light-collecting area of a full ten meter telescope. The mirrors are all aspheric; they had to grind them as segments of a paraboloid which was quite a challenge, but now they're working. The telescope has had its first light, imaging a planetary nebula, my favorite objects. Here is NGC2392 in glorious false color. I've always thought that most high tech astronomy people, especially Europeans, have pictures of their grandmothers on the wall in false color.

The Hubble Space Telescope is—forgive me, but I'm going to show my slides anyway—in trouble. You know that already. They apparently made the supports for the solar panels with dissimilar metals. When the telescope goes in and out of the Earth's shadow, they flex by as much as a 70 degree angle. There's some fear that they are going to break off. The Hubble does work however. The gyro problem turns out to be not so difficult. Here you get a sense of how the thing is rotating and how it moves through space and how you can at least point. It is not a very efficient instrument. One of the reasons is that it takes so long to set up and of course now the exposure times are longer because of the aberration. They massage data through various computer codes to improve the image, but a lot of light is thrown away. So, the data are coming in at a relatively slow rate.

Nevertheless, you're getting some good stuff; we can prove it by a picture of Mars here. It's almost as good as a photograph taken at Pic du Midi last year, actually somewhat better. On the other hand, as you will see, the images and views that were taken from the Earth are clearly approaching the Hubble. And it wouldn't be surprising that over the next few years the Hubble is simply going to be a very large ultraviolet-infrared telescope. It also took several views of Saturn. And you see here the Great White Spot. Every Jovian planet has some kind of spot: the Great Red Spot on Jupiter, the Great Dark Spot on Neptune. The Great White, however, is a seasonal apparition. It comes along approximately once every 29 years when the Southern Hemisphere of Saturn faces the Sun. Then we begin to see the Great White develop sometime when Saturn is in Sagittarius. No one really knows why something like this does not develop in the other hemisphere. The Spot started small and then spread throughout most of the equatorial zone.

You saw this before. It is a stunning picture of the Orion nebula with extraordinary filamentary structure. These filaments are all over the Orion region and you can also see star formation in the nebulosity. The Hubble High Resolution spectrograph has problems probably as a result of a solder connection, perhaps because it's been in storage for so long. On the other hand, I have an old radio that's been around for 30 years, and it still seems to work. When it works, the high resolution spectrograph is a wonderful device as you can see here.

The IUE, by the way, continues to make news; it's an extraordinary instrument going into its thirteenth or fourteenth year, which is not bad since it was designed to last only a few years. NASA can certainly do something like this if they try.

As I guess you know by now, Astro II is now scheduled. At first, NASA decided, "Well we did it, now we'll throw the instrument away. What's a few hundred million dollars?" ASTRO obtained a good fraction of its scheduled observations. But remember that for every instrument that goes in space, about half of it isn't going to work. It takes time to get the thing operative. You simply cannot test a spacecraft in the laboratory; it's not possible. The only laboratory you've got is out in space, so you don't know what could go wrong. Nevertheless, the Astro has gotten some wonderfully useful data.

Here is a different false color view of w Centauri. These are blue stars. They are horizontal branch stars, highly evolved stars, that are beyond the giant branch. At least some will eventually produce planetary nebulae. They are the stars that are going to produce white dwarfs. These are actually photographs that were developed back here. That is, they are not CCD or video images. Film is not photometrically linear and gives you problems with quantitative measurement. However it does still have a far superior resolution than does a CCD. Here is another ASTRO photo. The blue stars are visible in the galactic disk, and scattered around the blue stars are HII regions, the diffuse nebulae, regions of truly active star formation where you find locations of bright O and B stars that are hot enough to illuminate their surroundings. So I think Astro II is going to do some wonderful things.

The Gamma Ray Observatory launch is shown here. It is now in a one year survey mode of the sky in gamma rays that will examine high energy processes. There is an image of the backside of the moon taken by Galileo on its way out to Jupiter. In 11 days it is supposed to pass by Gaspra.

In the three years I've given this talk, I have harped on the subject of high resolution, and I'm going to harp on it again because the news gets better and better and better. Here is a picture of Xi Ursae Majoris A, which is a visual binary as well. Here is a photograph of it on the left as you would take with your ordinary 2-meter. And what does Hubble love? In the last several years adaptive optics, which involves jiggling the telescope mirror, allows the distinct separation into two stars. In order to make an adaptive optic system work you have to monitor the twinkling of a star, and then you flex your mirror to detwinkle the star. The trouble is you have to have a bright star near tenth magnitude. A better method is to project a laser up into the upper atmosphere and make your own star. Then you monitor the laser beam and you detwinkle anything around it. You are able to get to within several tenths of a second of arc. It's not very good for imaging a whole galaxy, but for small sections of the galaxy it will work.

The resolution is now getting good enough to actually identify a couple of Cepheid variable stars in the Virgo cluster of galaxies. This is perhaps the first real step taken toward defining what the Hubble constant actually is. Because we haven't been able to see Cepheids, we haven't been able to get distances to sufficiently distant galaxies. Once you can identify a few, we can actually nail down the distance to the Virgo cloud.

I sort of hesitate to show you this because I only saw about a 10% partial phase through clouds, and a lot of you folks here actually you saw the whole thing. I'll show you pictures of this spectacular eclipse anyway.

Ulysses is now working its way toward the sun. It will measure the solar winds at the poles, but there have been ways of doing it from the earth as well. This rather unusual graph shows how the solar wind is cyclic in nature, the blue is the slow wind from the sun. You can see that during solar maximum it's coming off the poles. The solar magnetic cycle, of course, has a very powerful impact on the earth. It has produced a number of nice aurorae over the last couple of years. The space shuttle took this picture of the aurora australis from this remarkable perspective from above rather than below. The aurora is produced by a disturbance in the large electric current that flows around the magnetic poles.

I remember as a kid people talking about the possibility of a satellite at the lunar Lagrangian point. This is the analog to the Trojan asteroids of Jupiter. There was long suspected to be a cloud satellite at the 60 degree point in front of the moon and at the 60 degree point in the back. It appears to have been recovered. It's probably just an assemblage of debris, but it's trapped in the stable orbit where the moon's gravity allows the bodies to be.

Mercury

We learned in school that Mercury has no atmosphere. But apparently it does. It traps some from the sun. But most of Mercury's atmosphere is apparently sodium that has been sputtered off the planet by particles that get trapped in Mercury's magnetic field. Similar particles get trapped in the earth's magnetic field, but don't get near the surface. They hit the atmosphere and cause this beautiful aurora that we saw before. But Mercury has such a small atmosphere that they slam in the ground and liberate sodium and other atoms as well. Sodium is a relatively abundant element, and it's heavy, so it just sits there. So Mercury has an atmosphere that actually is sodium-helium, with sodium dominating. It's only about one trillionth the terrestrial atmospheric density, but at least it's there and it's remarkably heavy. Mercury has a weird orbit and the best observations of Mercury have been made in the radio spectrum with the Very Large Array in New Mexico. The rotation period of Mercury is synchronously locked at 2/3 the orbital period. It has the spin period it would have if it had a semi-major axis equal to its perihelion distance. It's spinning faster than it ought, with a 59-day rotation period. The result is that Mercury turns alternate faces to the sun every sidereal revolution, first side A and then side B, and consequently it has hot poles near the equator. And every two sidereal years this hot spot will face toward the sun and the insulating properties of the planet are such that it stays hot for a long period of time. So it's got not only rotational poles but thermal poles as well. Mercury is indeed a curious place.

Venus

Even as a stellar astronomer, I am absolutely fascinated by the images of Venus taken by Magellan over the past year. See all the clouds, wonderful sulfuric acid clouds, sulfuric acid falling as rain toward the 700 degree Kelvin surface. Of course, it evaporates before it gets there. No astronaut has actually seen the surface, and I doubt that any will actually see it. So we rely on radar. This famous map was made several years ago and shows an almost earth-like view. The blue regions are actually rolling plains, but are reminiscent of the earth's ocean basins. There is very little water on Venus. Any water long ago drifted to the upper atmosphere where it photodissociated into hydrogen and oxygen and disappeared. If there were water, maybe there were once oceans, but we don't know.

There are also two large "sort of" continents: Ishtar Terra up there on the top, and Aphrodite Terra down there on the lower right. Alpha Regio on the far left—and there are a few other high spots around as well. Is this planet really earth-like or is it not? What causes the so-called continents? Is it volcanic action or is it plate tectonics like on the earth? It's a question that Magellan may eventually solve.

This was one of NASA's lower budget operations. I'm not quite sure why the low budget operation always seem to do so much better than the high budget ones. You can over-tech things perhaps. Magellan didn't work when it first arrived at Venus. It has serious communication problems. They lost track of it completely, but it has a mode that allows it to sweep through space and to lock back on the earth. It made a one year survey of the surface of Venus, and sent back some absolutely spectacular shots with kilometer resolution, better than anything you can get on the moon with an earth based telescope. We now have a superb view of what this planet is like. Magellan is still in orbit around the planet. They are eventually going to bring it in and let it drag on the atmosphere and get closer and closer and I think they're hoping at some point to achieve 100-meter resolution over certain parts of the planet before the craft finally gets destroyed.

Here are two volcanoes on the surface of Venus, Sif Mons and Gula Mons. All these features on Venus's surface are named after after women. The one exception which is Maxwell Montes. Here you can see the lava flows running down the surface. Venus has been very active volcanically. There is no reason to think that it is not still active. The feeling is that the whole surface of the planet has been resurfaced within the last one billion years, which is relatively short when you think about the moon with its ancient 3 1/2 billion year old surface, Mercury with its 3 1/2 - 4 billion year old surface. It is quite likely that volcanic action is going on today. After all it is going on on the surface of the earth, at a very high rate. Now with the wonders of computer technology, since you've got a full data set on altitudes and positions, you can command the computer to turn the image around and see as if you are viewing from the surface. So think of yourself as an astronaut standing on the ground. You just got up in the morning after a very long night, and are looking at Gula Mons. Here you see lava flowing down the side of a volcano. These are shield volcanoes. They are relatively safe, that is, they are not going to blow you away. Whether they are active volcanoes, we really don't know; we still haven't seen actual activity.

Here you can see a dike from lower left up to upper right. There was liquid lava here that breached the dike and flowed all the way down here. This sort of thing happens on earth as well. There seem to be massive volcanic flows from fissures. We do see this on earth. The Deccan Plains of India are an example, huge, kilometer-thick, over hundreds of kilometers across. We also see much the same thing in the Northwestern United States where you have volcano flows that are not coming from volanoes as such, they're coming from fissures in the ground. The same kind of thing that caused lava to flow into the basins on the moon to make the maria.

Craters, craters everywhere. Of course you've got craters on the earth too. They are all over the place. Here they tend to erode away. Venus, however, has a very thick atmosphere. There is going to be a little erosion, but the wind doesn't blow very fast, only about five miles an hour at the surface. You get massive solar heating, but you don't have a big differential. The atmosphere's so thick that the equatorial temperature is the same as the polar temperature, the day the same as the night. The weather forecast: the wind will be out of the east at five miles an hour for the next 200 days and the same thing is true at night and never changes. Nor is there any erosion by water. The only effective erosion is volcanic, which covers over some features. Consequently, the surface of Venus is rather heavily pitted with craters. They're a little bit different than you see on the moon and on Mercury. You see a lobate structure here. The atmosphere is so thick that when the meteorite hits the globe, it liquifies the local rock and entrains the thick atmosphere which turns the rock into kind of slurry that flows out until it freezes and produces a lobate structure. You get the same kind of crater on Mars caused by entrainment of subsurface ice.

There are multiple craters also all over the place. The atmosphere is so thick that the meteoroid, the asteroid, simply can't get through; it gets crushed by its own sonic boom. A meteorite gets crushed into several particles and all these particles can separate out, spraying to the ground, producing multiple impacts. The biggest ones, of course, would probably stay more or less together and the explosion is so large that it produces the craters we saw before. The crushing is so great that you get these funny features here on the ground. Some meteors are crushed out of existence. Their sonic booms go all the way to the ground and crush. That gives you a sense of the power of the shock wave produced by these massive particles in Venus' 80-bar thick atmosphere. This kind of thing is unimaginable on the earth.

Maxwell Montes is about as high as Everest using the average radius of the planet as a reference. We still don't know from the Magellan data what is going on. There may be a combination of some plate tectonics trying to work but failing, coupled with volcanic action. Much of Aphrodite Terra consists of a large ring around a volcanic caldera. These mountains may in fact be raised up by volcanic fluids rather than plate tectonics. But there's another camp that says, no there may be some plate tectonics at work as well. Aphrodite Terra does have rifts, Alpha Regio has rifts similar perhaps to the Great Rift of Africa, as though plates were trying to develop but couldn't quite do it. Why they didn't on Venus and did on the earth is a mystery. Venus has 80% the mass of the earth and that may be the critical difference. An 80-bar atmosphere at 800 degrees on top of the crust is going to have an effect as well.

Outer Solar System

Move away now from Venus to some of the other planets in the solar system. This is a sodium cloud around Jupiter 6 degrees across, big enough to see with the naked eye. Most of this material was sputtered off the satellites, particularly Io. This is an image of Callisto taken at Pic du Midi. It is not a Space Telescope image. You can actually see detail on the surface of the satellites of Jupiter from here. This is the kind of resolution slowly being achieved on the earth.

These are two shepherd satellites of Saturn. Here you can see the F-ring. The F-ring, like many of the narrow rings, are being gravitationally shepherded by satellites. These satellites actually appear to be re-collections of particles, and are made out of rubble. They have a very low density. They are probably recompacted bodies that were once shattered. We see shattered bodies all throughout the solar system. They are basically just junk piles. They may be typical of the shepherd satellites of Uranus and Neptune as well.

Halley's Comet is now out at 14 1/2 astronomical units. Suddenly it blossomed out, becoming more than a thousand times brighter than it was supposed to be. It's got a coma around it—nobody expected this—well out beyond the orbit of Saturn. In fact we probably have the technology now to be able to follow Halley's Comet all the way to aphelion. Unlike Mark Twain, I was born around the time of Halley's aphelion .... just wait ... (laughter).

Here, a Geminid meteor shoots through the Hyades. The Geminids appear in December, coming apparently from an asteroid. How can an asteroid produce a meteor shower? Well, obviously, the asteroid ain't an asteroid. It's a comet. It used to be that you had the planets, the comets, and the asteroids. Things were all nice and simple and laid out. Now we're not quite sure what's going on. We all know there used to be nine planets. Is Pluto a planet? No, Pluto is now a planetesimal. It's not a planet at all, so we've got eight planets. Triton is another planetesimal, it's not a planet either. Now the asteroids are comets, and the comets are asteroids. There are a lot of asteroids that cross the orbit of the earth, the so-called Aten-Apollo-Amor asteroids, depending on where their perihelia are. They're basically earth-crossing asteroids and it seems that 20-30% of them are dead comets. Not all comets like Biela's Comet break up and disappear. They get rid of their volatiles and they keep going around the sun in elliptical orbits, so you can't easily tell them from asteroids that have been kicked into elliptical orbits from the asteroid belt by Jupiter.

Asteroids

Here's another one, 1991 BA; it comes near the orbit of the earth and gets kicked out all the way to Uranus. Now is it an asteroid or is it a comet? We don't really know. There's its picture up here as it came by the earth; asteroids aren't supposed to have elliptical orbits like this. They're supposed to have fairly circular orbits between Mars and Jupiter. So we're confusing the issue again. And of course there's always Chiron, which is between Saturn and Uranus, which everybody thought was a big asteroid and now has a coma around it as it approaches perihelion. It's a big comet. Is there really a difference between the two? The asteroids are planetesimals. They are planetesimals that were not allowed to agglomerate into a planet because of the action of Jupiter. Jupiter apparently threw enough large bodies through the asteroid belt in the early days of the solar system to keep them all stirred up. They never were able to get together. Some of the asteroids have more water, especially the ones farther out. They start to look like comets and comets have a lot of water in them. I don't think there's necessarily a complete gradation but it gets a little bit hard to tell the two apart, not only by orbit, but by composition as well.

1991 BA came between the earth and the moon. Only one hundred thousand miles away, it's the smallest body ever seen, only 10 meters across. Ten meters. That's okay as long as hits Iowa and not here. You can imagine what I'd say if I were giving this talk in Iowa, wouldn't you? It does pose a problem. You know there are not a lot of AAA asteroids. You know why there aren't a lot of them? That's why there aren't a lot of them.

Every year somebody says, "I found the crater from the asteroid that killed the dinosaurs. That seems to be pretty well stabilized these days. Most scientists view the catastrophe as the event that killed the dinosaurs and 70%, 80% of the species alive on earth at the time, which apparently is the reason that we're here. The mammals were allowed to take over. There is this enormous meteor crater off the coast of the Yucatan Peninsula that goes way out to sea; you get some idea here of the size of it. This was first found, I think, by oil drillers. Its age is about right. Nevertheless, it does illustrate very nicely that we get hit every once in a while and we're going to get hit again.

NASA just recently announced, that we should find all the AAA asteroids so that we know where they are and can shoot one down when it gets too close to the earth. It's only going to cost a couple of hundred million dollars. Actually, it's not a bad idea. There is already an organization in this country that has been promoting the idea of looking for these asteroids, so we can get rid of them before they hit the earth. Because we know it's going to happen again. If we get hit by a kilometer size asteroid, we're in a lot of trouble. It may wipe out humanity. It's certainly not going to do us any good. We have probably found about 1% of the bodies big enough to do serious damage. One almost a hundred feet across skipped off the earth's atmosphere in 1973, sort of like a rock off a lake. You may remember this daylight meteorite which was observed from New Mexico all the way up into Canada. Thank goodness it didn't strike us. We've got the technology to find an awful lot of them before they do strike the earth.

Chemical Abundances

Well, enough of disasters; on to other subjects. With improved resolution, astronomers are close to seeing the surfaces of the stars. We can actually examine such surfaces by the Doppler effect. A number of stars that have spots on them. Peculiar A stars, the A magnetic stars, have regions of enhanced elements: calcium, scandium, europium, etc. These seem to isolate themselves into magnetic areas. As the star rotates, the lines from these enhanced elements get Doppler shifted to one direction and then get Doppler shifted to the other direction. And by looking at the way that the absorption lines shift back and forth you can reconstruct the image of the surface of the star. This is the surface of θ Aurigae. The red areas show enhanced calcium, the green areas show depleted calcium, and you can actually watch the star rotate. Isn't that marvelous! You're looking at the surface of the star. All through the magic of the computer.

I love this. This sort of thing happens all the time. Here is the Ring Nebula. Sky and Telescope and Astronomy Magazine made a big splash with this picture of the huge halo around the Ring Nebula. This is the wind of the old asymptotic giant branch star from mass lost before the white dwarf in the middle was exposed. Duncan discovered this halo in 1934. I'm sure this would have amazed him to realize that it's making today's news. They just keep rediscovering the same old ring. The new CCD technology takes you farther out, but these rings around planetaries are not terribly uncommon. If you look at a planetary nebula deeply enough you've got to find it, because the planetary is only the inner illuminated portion of the much more extensive envelope.

We see Mira stars, the long period variables, and planetary nebulae, which succeed them. But we've never really seen the planetary nebulae being produced. Maybe this is one here. You can see rings of dust surrounding the star in the middle, but you can't actually see the star itself. They may represent pulses of mass that are being blown off the star, perhaps due to what is called thermal pulsing of the interior when the hydrogen and helium burning shells in the core switch on and off. When the helium shell switches on, it does so explosively and probably produces a blast wave in the star. It may help drive a shell of mass off the star as it passes. It's very difficult to see the birth of a planetary because when the transformation occurs during the Mira phase, the star just hides itself in a very big cloud of dust, and then all of a sudden we see the planetary nebula. And what went on in between? We still don't know.

The chemistry of interstellar space is fascinating. When I first learned this subject we saw CH and CN and that was about it. Then the radio astronomers found ammonia and water, and then methyl alcohol, ethyl alcohol, formyl ions, formaldehyde, and long carbon chains. Where does it all end? The earth was made from dust that came from interstellar space. In meteorites we're able to see odd isotope abundances of the kind that were apparently produced in asymptotic giant branch stars. So we know where the dust came from. The solar system was formed from the dust of interstellar space, which means it had to come from the molecules of interstellar space. So after the earth was formed, comets rained down upon us and delivered fresh molecules from the interstellar medium. Maybe that is where the seeds of life came from, from out here. At least that is one speculative viewpoint.

So what is the most complicated thing to be observed? The popular choice these days is buckminsterfullerene, made of 60 carbon atoms. Where does it all end? What is the most complicated thing you can get? We don't know. It is hard to examine the spectra of complex molecules that you can't produce on earth.

Here is a generic view of old stars, ω Centauri. It is somewhere around 13-15 billion years old. We know its age by first establishing its H-R diagram, rather its color-magnitude diagram, then by matching it up with the theoretical. We find how long it takes to evolve the kind giant stars that you are looking at here, the red ones. We're finding quite an age range among globulars, maybe up to 6 billion years. The galaxy did not collapse all of a sudden. It produces globulars over a very long period, and we don't know why. The oldest is maybe 16 billion years old. Now reverse 16 billion years and you get a Hubble constant of about 60 or something like that, which is not compatible with other, direct measures of the Hubble constant. The globulars are telling us something, but we cannot yet interpret the message.

The Big Bang produced helium, that's it. All the heavy elements, the stuff that we're made out of, should have been produced in the stars. Therefore there should be stars in the galaxy with no metals at all, hydrogen-helium stars. We've never found them. It's been something of a problem in theories of the origin of the Galaxy. Where are the no-metal stars? The metallicities of stars have now been measured down to an extraordinary one ten-thousandth that of the sun. We're able to actually look that far back in time, but we still haven't gone down to zero. It's a stumbling block. You get around it by a couple of ad hoc assumptions. Perhaps only high mass stars formed. Then they all burned out quickly so now we don't see any. So it doesn't really pose a problem for the theoreticians. However, it poses a bit of a problem for the observers—it sure would be nice to find them. It's a missing link in the theories of galactic evolution. But the news here is that stars with one 10,000th the metallicity of the Sun have been seen. If not the first generation, they are the 1.1 generation.

Randy already showed this slide of the interior of M15. But I want to show this more than anything as a planetarian's dream or perhaps nightmare. Can you imagine being on a planet in the center of this thing? There are thousands of stars packed within one light year. You'd have a sky alight with thousands of first magnitude stars in it. Try to project that on the dome. It's remarkable how dense these things are in their cores. Yet the news about M15 (this is a Hubble telescope image) is that there don't seem to be black holes here.

Explosive Events

Here is an old drawing of the nebula around R Aquarii. I recently gave a talk to the Okie-Tex star party in Oklahoma. There were 200 amateurs that showed up for it. I thought, oh I'm going to give these people a challenge. Amateurs showed up with 24" telescopes. Go out and find it. Some had indeed seen it. The Mira has a white dwarf companion. Here is a jet coming out of it. And here's a Space Telescope picture. You can see the jet right down here in the middle. This is a beautiful image, by far the best image ever taken of R Aquarii.

In the video, here is R Aquarii, and here is the white dwarf. Now watch. You can see the interaction taking place. This is probably a good rendition of what actually happens. The red giant is losing mass continually, the white dwarf is spiralling close. Now the jet shoots out, and then there is an explosive event. R Aquarii is merely the tip of the iceberg, the most active of these symbiotic systems. They are called symbiotic variables because the spectrum has both high and low excitation features. But in a sense one star really does feed off the other. You see the white dwarf eating part of the giant, and in this case producing a kind of nova outburst. Now whether R Aquarii produces a real nova outburst is debatable. But every thirty years or so it does produce a major flare in which nuclear reactions take place on the white dwarf.

Here is an X-ray nova. Most of them are visible in the optical. This one is also visible in the X-ray part of the spectrum, and is very powerful. All standard novae are produced by the infall of matter onto a white dwarf. The fresh hydrogen gets heated and then blows itself off. The brightness jumps 12-15 magnitudes. This may be an example of a nova on a neutron star rather than a white dwarf. And the event is so energetic that most of the energy comes out in the X-ray part of the spectrum.

Here is Cygnus X-1; well at least the star around Cyg. X-1. This is a powerful x-ray source that's long been thought to be the prime candidate for a black hole. We still do not know if black holes really exist. We may not know for a long time. People are assuming that they are there because it's the only way to explain certain phenomena. This is an O star, maybe an early type B star, we're not entirely certain. It is producing x-rays like crazy. No normal O star or B star should produce such x-rays. It is also a single-line spectroscopic binary. We watch the star's lines move back and forth and throw that into the equations with a few assumptions. But we estimate that the O star must have a companion of 15 solar masses. But can't find it. Any star of 15 solar masses should be visible. White dwarfs cannot exist at 15 solar masses. Beyond the Chandrasekhar limit they cannot be supported by their electrons, so they should collapse into black holes or into neutron stars. This body is also too heavy for a neutron star; it should be a black hole. Well is it or isn't it?

There is a recent announcement of something called a Q star. How they came up with this name, I don't know. But they're involved with neutrons held together not by gravity, but by the strong force itself, the nuclear force. They are not black holes.

The Galaxy, it has been announced, may be a barred spiral. When I first got to Illinois in 1964, Stan Wyatt, who many of you may remember produced one of the better textbooks of the era, wrote a paper saying the Milky Way is a barred spiral. The idea has been around for a while. However, the data are getting better and better, and astronomers claim we can really see the bar. We may live in a barred spiral rather than a normal spiral.

Next is the Great Annihilator. Oh, the names we have in this business. The Great Annihilator. Don't get close to the Great Annihilator. This is a region in the center of the galaxy that produces gamma rays by the annihilation of positrons and electrons. We thought it was at galactic center itself, but better resolution shows it is not. It is off the galactic center. The galactic center is supposed to be a massive black hole. Over here, you see the Great Annihilator. It's an odd source whether it's a black hole or not.

The search of the galactic center continues. People keep finding the galactic center and then losing it. What was thought to be the center turns out to be something else. But it's getting harder and harder to hide it. Is there a black hole in there? There's certainly something producing a lot of energy. The question remains unsolved.

This Crab Nebula picture was made by ASTRO. The Crab is an odd supernova remnant. It's called a pleirion. It's a filled supernova shell produced in 1054 AD. Here is another one discovered in the Large Magellanic Cloud. So we have a chance to examine another object similar to the Crab. Most supernovae remnants are shells produced by the blast wave when the star blew up. You don't actually see most of the material that has been ejected by the star. It gives you a good chance to study the chemical composition of a destroyed star.

Galaxies

The way to get funding for astronomy out of the National Science Foundation or anybody else, is to do things bigger and better. Professional astronomers, like anybody else I suppose, get very competitive, and are often competitive about somewhat strange things. Here's the results of the biggest galaxy contest. It's really enormous,16 million light years across. Here's our galaxy by comparison here. Well, my galaxy's bigger than your galaxy. Maybe I'll go look for another one. Here's the results of the dirtiest galaxy contest. Spiral galaxies are a lot filthier than anybody thought they were. The dogma was that you can examine a spiral galaxy face on and you didn't have to worry about interstellar dust. You just forget about it. Well apparently you can't. There may be enormous quantities of dust that skew all the observations made about spiral galaxies. So a lot of what you read about them maybe is wrong.

Next is the black hole contest. There may be a billion solar mass black hole apparently in a galaxy. You get this by looking at radial velocities of stars near the core. You see how fast they're moving. You can then estimate how big a mass there must be in the middle. If there is enough mass within a small enough volume, its got to be a black hole. A cheap piece of logic perhaps, but we can't think of anything else. Well, my black hole's bigger than yours;. There's a billion solar mass black hole in mine.

The farthest galaxy contest: That's one that everybody gets into with the big telescopes. This is an extraordinary picture. People occasionally ask, what's the faintest star you've even observed? When I was a mere youth it was 22nd magnitude. Now you can easily see 20th magnitude with video finders attached to these telescopes. The arrows are pointing to 29th magnitude galaxies. The Hubble Space Telescope was supposed to image 30th magnitude. That was the big deal, but now we're getting close to that from the ground. The big blobs here are galaxies. These are very faint galaxies. Who knows how far?

BL Lacertae objects were once thought to be variable stars and they turned out to be elliptical galaxies. They were long thought to be the elliptical counterparts of Seyfert galaxies. Seyfert galaxies are spirals that have very active nuclei. Now we find disks associated with BL Lacertae objects. We thought we had this all ordered and now we don't know anymore. The more you learn the more confusing things can become.

First we had the Great Annihilator, now the Great Attractor. It's a good thing the Great Annihilator ain't a great attractor or ...... The Great Attractor was supposed to be a big mysterious mass disturbing the Hubble flow. Now the feeling is that it's not such a big deal after all. You can account for it with normal galaxies. Okay, a lot of galaxies; but that's all it is; it's not some kind of monster out there that's going to eat us all up, which is the way it was actually sort of touted in the press.

This X-ray image is 1 degree across. These are all quasars. Imagine the fantastic number of them across the whole sky. The quasars appear to solve now the problem of the soft x-ray background. If you look with low resolution you see x-rays coming at you from all over the place. This is yet another reason for higher resolution.

The problem with the distribution of galaxies is getting worse. They are so clumpily distributed that the cold dark matter theory people are saying it doesn't work, because how can you produce this kind of clumpiness and still have the 3 degree Kelvin background radiation as smooth as it is. For some, it places the Big Bang theory in doubt. Yet the Big Bang does support most of what we observe. For example, it explains the deuterium and lithium abundances in the universe. It is a partial theory. Most theories are partial, not complete. If the Big Bang was a complete theory, we could all fold our tents and go home.

Light is a principal way of examining the universe. But when we use it, we can see only 1 percent of the matter that is in the universe. That's a stunning statistic. We try to construct theories of the universe based on the 1 percent of it that we can see. If you use gravity, you can see that there is ten times as much matter in the universe as we can see with our telescopes. Then if you evoke the Big Bang theory, which says that in order for the universe to be even close to closure, it has to be the exactly closed, the amount of mass required increases by another factor of ten.

Planetary Systems

The biggest issue, of course, is where does Star Trek's Mr. Spock come from. One source says 40 Eridani, another ε Eridani. How do we resolve the problem. 40 Eri has an activity cycle. Magnetic fields act as a brake that slows a star. The older the star the slower it's spinning, and the less the activity. 40 Eri has a solar type cycle, and we find it in all kinds of stars. From the activity level, 40 Eri is about the right age for a civilization to have developed. However, if you look at 40 Eridani close up, you see 40 Eridani B, a white dwarf. 40 Eridani B has a little companion called 40 Eridani C, a red dwarf; it's a triple system. If you have a white dwarf in the system, you know it used to be an asymptotic giant branch star, which is about as big as the orbit of the earth. And it probably has an absolute magnitude of -3, maybe -4. Now, would you like to be a member of a civilization of a planet around 40 Eridani A with a star like that in your neighborhood? I doubt it. I like ε Eridani better.

There are important radial velocity studies going on now at the Dominion Astrophysical Observatory in Canada. They are actually able to measure radial velocities to plus or minus 10 meters per second. And lo and behold, what does ε Eridani do? It varies irregularly in radial velocity over a several year period. The analysis of this is a little tricky, because it's a single line spectroscopic binary. The data gives you a complex function of the mass of the companion and the orbital inclination. But if you make a few assumptions, you may be looking at a motion that is being produced by a planet about one to five Jupiter masses. So we've got evidence here of a planetary system. I think it makes much more sense to have Spock come from e Eridani rather than from 40 Eridani.

The point I'm making is that we're beginning to detect planetary systems around other stars. And if this one isn't such a system, and there may be other reasons for these long period radial velocity fluctuations, discovery will not be long in coming. The most fascinating news is an apparent planet orbiting a pulsar near the center of the Galaxy. Try as they might nobody has been able to beat this down. The pulses of the pulsar keep accelerating and decelerating, accelerating, decelerating. And the only explanation is that there is a small body in orbit around the pulsar. This actually may be the first real unequivable detection of a planetary system. Now if you think life was tough on 40 Eridani with a red giant, try it with a supernova and a pulsar. At the distance of earth from the Sun the radio radiation from a pulsar would be lethal in just one pulse.

But, now return to the nighttime sky, to millions of serene stars. Here is a toast to finding out a lot more over the next year. Thank you very much.