Notes for Dr. Edie Widder's slide show, "Secret Lights in the Sea"
modified from the narration of her COSEE-West presentation on April 26, 2008

Slide 1: talk title

Slide 2: Earth from space

We live on an ocean planet. Seventy-one percent of the surface of our Earth is covered by water. But that's just surface area. If you think in terms of the living space on the planet, what's known as our biosphere, our ocean represents more than 99% of our biosphere. We just live on a few little dry islands that we call continents, surrounded by this vast watery world that we know surprisingly little about. It's been estimated that we've explored only about 5% of our ocean.

Slide 3: calm ocean

One reason that we know so little about the ocean is because of its inhospitableness to human exploration. Usually when people show you pictures of the ocean they look like this. That's only because on days like this we take our cameras out.

Slide 4: high waves

All too often the ocean looks like this, which is problematic -- or it used to be anyway -- if you wanted to be a marine biologist.

Slide 5: research ship

A lot of what we used to do as marine biologists, and in fact still do, is go out on little ships like this, which is a real problem if you get seasick.

Slide 6: pulling in net

Fortunately, nowadays it's possible to be a marine biologist without actually going to sea. But usually, to find out about the life in the ocean, we drag nets behind these ships and bring the animals up into our world where we're comfortable, but unfortunately they're not.

Slide 7: animals collected in a net

A lot of these animals come up dead. Many people think that it's because of the pressure change, which is true for many of them. Those that have air-filled spaces in their bodies, like swim bladders, can actually explode if you bring them up into surface waters. But a lot of other animals don't have air-filled spaces in their bodies, and they die because of the temperature change. The depths of the ocean are very, very cold. When you bring them up into warm surface waters, they're cooked alive. Sometimes you can keep them alive for short periods if you bring them up in a cold state, which we do by using a thermally insulated end-capture device on a net.

Slide 8: one-person submersible, the "WASP"

Clearly, if you want to study the life in the ocean, it's far better if you go to it than trying to bring it to you. One way you can do that is with SCUBA, but humans have air-filled spaces in our bodies, so we're still limited to the thin surface layers of the ocean. If you want to go deeper, you need to protect yourself from the crushing pressure. Water is heavy. I sometimes tell kids to think about how heavy a bucket of water is, and then imagine 1,000 buckets of water on top of your head -- you're going to be crushed.

You need to protect yourself from that crushing pressure. You can do that with something called either a submarine or a submersible. (The only difference between a submarine and a submersible is that the submarine has enough power to leave port and come back to port under its own steam. A submersible has limited power supply so it needs a mother ship in order to take it to where it's going to dive and to collect it afterwards.)

The very first submersible with which I had any experience was a strange-looking contraption called WASP. WASP was developed by the offshore oil industry for diving on oil rigs. It could go down to 2,000 feet. I was lucky enough to be included in a group of scientists that tested this for the very first time as a tool for ocean exploration.

Diving in WASP completely changed my understanding of the nature of life in the ocean. It also changed my understanding of the expression "colder than a witch's tit." Because, as I mentioned, the ocean is cold; generally about 40-45 degrees Fahrenheit. I made dives in WASP that were as long as five-and-a-half hours long, and it gets pretty chilly down there. You'll note my wool cap and my wool sweater and the gloves. They say you lose maybe 80-90% of your body heat through your head, which makes it sound like if you just had the right hat you could ski naked, but you'd definitely get very chilly even with a warm cap on.

In fact, when I came back from one of these dives and my teeth were chattering and my lips were blue, the old oil rig diver, Charlie, who was in charge of these dives, took pity on me. He took me aside and he put his arm around my shoulder, and he said, "Look, I'll let you in on a little secret, but you've got to promise not to tell any of these other guys." I said, "Yeah, Charlie, sure, what is it?" "Pantyhose!" Which is like silk underwear, and it really does work. But I was never sure whether it was the pantyhose keeping me warm, or the image in my mind of Charlie wearing pantyhose.

You'll note that WASP doesn't have any legs for walking on the bottom. It's a midwater suit that is flown around with thrusters. It's got these Michelin-Man arms, and I had to lift weights for a year to get strong enough to move those arms. I never really needed them, but I had to close a shackle under water in order to qualify as a pilot. I was really proud that I'd lifted weights, but when I went to do the test, I discovered my arms were too short! So I had to figure out a way to do it one arm at a time, and it took me about an hour to close that shackle, but I did get it done.

Slide 9: bioluminescent siphonophore

My very first open ocean dive in the WASP was in the evening, and it was dark out. I went down to 880 feet. I turned out the lights, and I was treated to the greatest light show on the planet! This is a photo of a siphonophore chain, basically a colony of jellyfish. It was longer than this room and it was pumping out so much light that I could read all the dials and gauges inside the submersible.

Slide 10: luminescent puff emitted by siphonophore

Puffs of what looked like blue smoke were exploding all around the WASP, and blue sparks would swirl up out of the thrusters, just like when you throw a log on a campfire and embers swirl up off the campfire, only these were blue embers.

Slide 11: bioluminescent “sparks”

It was absolutely breathtaking! It wasn’t like I discovered bioluminescence. It's been known since ancient times. I even knew the statistics about how much luminescence was down there, but there's something about seeing it with your own eyes. I came away from that experience feeling that this has to be one of the most important processes in the ocean, and I couldn’t understand why more people weren't studying it.

Actually, that dive completely changed the course of my career, because I was a neurobiologist. I had a postdoctoral fellowship in membrane biophysics lined up in the middle of the country with just a super scientist, and it was all great. But I turned it down in order to do more submersible dives. I look back now with amazement that I did that, but I'm so, so glad that I did, because I personally think I've had the best job in the world.

Slide 12: firefly

If you're familiar with bioluminescence at all, and most people have heard of it, it's created by these guys, fireflies. A few other land animals can make light. Some snails and earthworms and insects do. But in general, on land, bioluminescence is very rare. I think that people assume that the same thing must be true in the ocean. Nothing could be further from the truth.

Slide 13: luminescent marine organisms

In the ocean, bioluminescence is the rule rather than the exception. If I go offshore and I drag a net from 1,000 meters (3,300 feet) to the surface, anywhere in the open ocean, approximately 80-90% of the animals that I bring up in that net make light. Think about that! You could actually make the claim that bioluminescence may be the most common form of communication on the planet, given the volume of water that these organisms inhabit. And yet, it's practically unknown.

If you go out on the ocean at night, you’ll see that this is not just a deep-sea phenomenon; it also occurs in surface waters. On the ocean at night, you may see bioluminescence in the wake of your boat, which is pretty spectacular.

Unfortunately, that's often not where people see bioluminescence for the first time. Usually, people see it in the head on the ship. (For those of you that are landlubbers, that's the toilet on a ship.) Toilets on ships are flushed with unfiltered seawater that often has bioluminescent plankton in it.

Slide 14: blank

Slide 15: dolphin swimming in bioluminescent plankton

This is another way you sometimes see bioluminescence, with dolphins swimming through bioluminescent plankton. This dolphin is swimming in San Diego Harbor, not someplace exotic like the bioluminescent bays down in Puerto Rico [http://www.biobay.com/cd/webhtml/right.htm]

Slide 16: bioluminescent dinoflagellates

The creatures that are most often responsible for this light are usually dinoflagellates. These come in a many different shapes and sizes. The ones in this slide are all bioluminescent.. Some of them are also photosynthetic, some of them aren't. Some of them have to eat other microplankton in order to survive.

Slide 17: *Pyrocistis fusiformis* (a dinoflagellate) – day phase

These are fantastic organisms to use to teach kids about cell biology, because they are huge for a cell. They can be as long as a millimeter. You can actually see them with a dissecting microscope. There's a nucleus, chloroplasts spread out all over the surface of the cell, and a large central vacuole.

Slide 18: *Pyrocistis fusiformis* (a dinoflagellate) – night phase

This is a *Pyrocistis* cell that's been under light in the day phase. Put it in the dark and it goes into what is called night phase, because it has a circadian rhythm [a roughly-24-hour cycle], and now it's bioluminescent. All that light comes from these little organelles that are called scintillons, that are spread out all over the surface of the cell.

The incredible thing about a circadian rhythm is that at night these scintillons migrate out over the surface of the cell and the chloroplasts all migrate into the cell, around the nucleus. When it goes back into day phase; those chloroplasts migrate out and the scintillons come in around the nucleus in order to recharge. You'd think there'd be a traffic jam!

If you try to stimulate bioluminescence in the cells in day phase, nothing happens. They're not luminescent. They control their ability to make light, so they do so only when it's useful, in the night phase.

You can order live *Pyrocystis fusiformis* for your classroom from Sunnyside Sea Farms in Santa Barbara (http://seafarms.com/). Keep them at room temperature under constant fluorescent light, and they'll survive for two or three months. They're photosynthetic so you don't need to feed them. Then, when you want them to be luminescent, you put them in the dark for two hours before you want them to go luminescent.

Slide 19: Functions of bioluminescence

Why is there so much bioluminescence in the ocean? What are the functions of bioluminescence that make it so prevalent? Well, it is useful in the basic things needed to survive in this world - finding food, attracting mates, and defense. I'm going to give you a few examples of each of these.

Slide 20: flashlight fish

Finding food: If you've ever tried to make a sandwich in the dark, you know that a flashlight's a pretty useful thing to have. This is called, in fact, a flashlight fish. It has a light organ under the eye. A common error that you'll find in textbooks is the claim that all bioluminescence is bacterial in origin. This is not true. I think that this misconception got started because this flashlight fish is one of the few bioluminescent fish that aquariums can put on display. There'll be a banner over this fish with its beautiful little light organ glowing and it will read, "This fish produces light based on a symbiotic relationship with bacteria," which is absolutely true. But apparently these same people then write books and encyclopedias without doing any more research on the subject, because although some animals use symbiotic relationships with bacteria in order to produce their light, others produce their own chemicals.

Slide 21: loose jaw fish

This fish has a light organ, another flashlight, right behind the eye. But it produces its own bioluminescent chemicals. It doesn't have luminescent bacteria in it at all. This fish is called a loose jaw, because of this very bizarre jaw structure. You're actually seeing the back of the mouth and the bottom of the mouth attached by a ligament. With this very strange jaw structure the fish can actually unhinge its jaw and open its mouth wide to swallow things bigger than itself. The gills are the reddish structure behind the jaw.

It looks like a monster in the photograph, but this fish was only about a foot long. But it's very scary looking, nonetheless. And of course, kids love "scary looking!"

Slide 22: lantern fish

This is a very common deep-sea fish, a lantern fish. It has three flashlights on its face, on either side. The amazing thing is, they're different colors. One is blue and two are red. In fact, I think they're two different colors of red. I don't know what that's about.

A number of fish can produce both blue and red light. In fact, bioluminescence does come in all colors -- red, orange, yellow, blue, green and violet -- but most of the bioluminescence in the open ocean is blue. If you've ever opened your eyes under seawater, I think you know why. Blue is the color that travels furthest through sea water. Seawater acts like a filter. It absorbs and scatters the reds, the oranges, the yellows. Blue travels the furthest, so that is the wavelength that most of the animals have evolved to see with and to communicate with. So, most bioluminescence is blue, and most of the animals are what we call monochromats; they can only see one color and that is blue light.

Slide 23: fish that uses red light

This fish is a very interesting exception. Not only does it produce blue light and see blue light, but it also produces red light and it can see red light. It uses red light like a sniper scope. It puts out a red beam of light that is totally invisible to all the other animals down in the deep, totally dark sea, and it can sneak up on animals totally unseen. Students understand this concept very clearly.

Slide 24: viperfish

Another way to find food in the ocean is to attract it to you, and you can do that with a lure. There are all different kinds of lures out there. This viperfish has a modified dorsal fin ray, with a light organ on the end of it. The fish arches this ray in front of the toothy jaw that gives the viperfish its name.

Slide 25: head of viperfish

The viperfish's teeth are so long that if they closed inside its mouth, they would actually impale its own brain. So instead, the teeth slide in grooves on the outside of the head.

This is an absolute Christmas tree of a fish! Everything on this fish lights up. Besides the lure, it has a flashlight, it has beautiful light organs on its belly that are called photophores, and it has light organs in the mouth. Notice that the teeth are transparent, they're almost like fiber optics. When the lights in the mouth flash, they make the teeth look like they're flashing. There's a string of light organs there. There's a light organ in every single scale. There are light organs in the fins, and there are light organs in the mucous layer on the back and on the belly. Just absolutely incredible!

Slide 26: anglerfish in *Finding Nemo*

Another type of lure, one that the public is a little more familiar with, thanks to *Finding Nemo*, is used by the anglerfish. I do wish, though, that Pixar, with its enormous budget, had spent just a little more money to hire a graduate student as a consultant, to tell them that the fish that they used as a model had been preserved in formalin. Those are dead eyes on that dead fish.

Slide 27: live anglerfish (female)

The eyes of a live angler fish actually look like this. This lovely little lady has a lure on a stalk above her mouth. She has a symbiotic relationship with bacteria, so bacteria are living in this lure. The lure does act the way they showed in *Finding Nemo*. It does tend to attract potential predators that are actually not wowed by the light, but think that the lure might be a tasty morsel. This is because a lot of the food that filters down in the deep sea from the surface is fecal matter, basically fish poop. The fish poop gets covered by bioluminescent bacteria that glow. That's what this lure is meant to look like, so some unsuspecting little fish or shrimp will come along to nibble on what looks like a tasty morsel and find itself engulfed in this living mousetrap of needle-sharp teeth.

Slide 28: anglerfish (female), front view

Anglerfish come in a lot of interesting shapes and sizes and so do their lures. This lovely lady has interesting threads coming off her lure, which is called an "esca." We used to think that different shapes of the lure were to attract different prey, just the way a fisherman will use different lures, depending on what he's trying to catch. But scientists have done gut content analyses on these deep-sea anglerfish and discovered that they all eat pretty much the same things.

Slide 29: anglerfish (male)

It is believed that the male finds the female in the deep sea by the shape of her lure. Because the males in the anglerfish world are what are known as "dwarf males." This little guy has no teeth, he has no lure; in fact, he has no visible means of self-support! His only hope for existence is to be a gigolo. He needs to find himself a babe and latch on for life.

Slide 30: male anglerfish attached to female anglerfish

This little guy has found himself this babe. You will note that he has had the good sense to attach himself in such a way that he doesn't have to look at her! In some of these species the male's flesh actually fuses with the female's flesh, her bloodstream grows into his body, and he becomes nothing more than a little sperm sac. This is the deep-sea version of women's lib. She always knows where he is and she doesn't have to remain monogamous, because we find these female angler fish with multiple males.

Slide 31: transparent anglerfish

I think the record is eight males attached to one female. This is a transparent anglerfish with a very odd-shaped lure, and also horns.

Slide 32: bioluminescence as defense (viperfish & shrimp)

Another use of bioluminescence is as defense. Blinding and distraction are common ways of getting away from a predator. As a squid or an octopus will release an ink cloud in the face of a predator, a lot of these animals release their bioluminescent chemicals into the water to blind or distract a predator.

This shrimp is actually spewing luminescence, like a fire-breathing dragon, out of its mouth. It produces the luminescent chemicals in the shrimp equivalent of a liver, called a hepatopancreas, releases them into the stomach and then shoots them out of the mouth.

I need to point out this is not actually an image you could ever see in real life. If there's enough light to see the animals in bright, living color, there's too much light to see the bioluminescence. I tried for years to get this image as a double exposure , with a bulb exposure on the luminescence and then a flash on the animal. It wasn't going to happen in my lifetime, so I finally videotaped this shrimp spewing its luminescence. I grabbed a still frame of the luminescence, took a flash photo of the shrimp, another flash photo of the viperfish, and through the wonders of Photoshop, you get to see what this phenomenon really looks like.

Slide 33: shining tube-shoulder

This deep-sea fish, called a shining tube-shoulder, actually does have a tube on its shoulder. I was lucky enough to catch one of these. I was a consultant on the "Blue Planet" series for "The Deep" episode, and a lot of the animals that you see on that show were actually filmed up in our world. We were on a trawling expedition off the northwest coast of Africa, and we were bringing the animals up as healthy as possible. We had an enormous net with a thermally insulated closing "cod end," basically a bucket that can close at the end of the net, so we could bring this animal up alive.

Slide 34: shining tube-shoulder in lab

I brought it into the lab, and that's me holding it. I'm about to touch the tube on its shoulder. When I did, the tube not only squirted out luminescence, it also squirted out luminescent cells, which is very, very unusual. Most of these animals only squirt out luminescent chemicals. But this fish quirts out whole cells with nuclei and mitochondria, and it's energetically very costly for this fish to do this.

Interestingly, a colleague of mine recently discovered that this fish has the largest brain-to-body size of any known deep-sea fish. So it really has some interesting natural history for someone to learn about some day.

Slide 35: comb jelly (ctenophore)

This is a little comb jelly, very common in the Gulf of Maine where I've done a lot of my research. The colors in this photo are not bioluminescence, but simply reflection and refraction of light produced by the camera flash. To show you what its luminescence defense mechanism looks like, I first need to show you a technique that I developed when working from a little single-person submersible called *Deep Rover*.

Slide 36: *Johnson-Sea-Link* submersible

I eventually adapted this technique to the four-person *Johnson-Sea-Link* submersible. A screen mounted on a hoop is fastened to the front of the submersible in front of the observation sphere. The screen is a meter, or about three feet, across. Inside the sphere with me is an intensified video camera that views the screen. We turn on the camera, turn out the lights. Once the submersible begins to move forward, animals bump into the screen and they're stimulated to bioluminesce.

When I first developed this technique, all I was trying to do was count the number of luminescent sources in the water. I knew my forward speed and I knew the area I was looking at, so I could say how many sources there were per cubic meter. But I started to realize I could identify animals by the type of luminescence they produced. For example, the little comb jelly I showed you produced enormous clouds of bioluminescent particles that streamed back around the sphere. We must have looked like a meteor going through the darkness! It is absolutely the greatest light show on the planet. You can see this on a video that I lent to David Gallo for a TEDTalk (http://www.ted.com/index.php/talks/david_gallo_shows_underwater_astonishments.html).

Slide 37: Functions of Bioluminescence

We've talked about one type of defense, which is blinding and distraction. Another type is camouflage.

Slide 38: open ocean, looking up at the surface from underwater

Camouflage is a tricky business in the open-ocean environment. Think about it - the open ocean is the biggest ecosystem on the planet, and there's no place to hide - no trees or bushes to hide behind. So a lot of animals have evolved the ultimate cloaking device, which is to be transparent.

Slide 39: transparent comb jelly (ctenophore)

A lot of animals in the upper-ocean environment use transparency. Bill and Peggy Hamner were the pioneers in this field of looking at these creatures for the very first time, and studying them, and understanding how important they are to the ocean ecosystem.

Slide 40: transparent pelagic worm

This is a transparent, pelagic worm.

Slide 41: transparent fish larva

This is a fish larva. The only parts that are not transparent are its little, tiny head and its eyes. So that's one way to be invisible when there are no hiding places.

Slide 42: SCUBA diver silhouetted against ocean surface

But what if you've got more complex organs that don't allow you to be transparent? Then you have to worry about the silhouette that you cast, because there are an awful lot of predators down there looking for just that kind of silhouette.

Slide 43: shark

This predator has eyes looking upward to look for prey, but it also has a black back and a white belly. If you're swimming around above it and looking down against the blackness of the depths of the ocean, that black back blends in pretty well. The white belly, not so much. But what does he care?

Slide 44: hatchet fish

This is another predator, a hatchet fish. It's got upward pointed eyes and an upward pointed mouth, and it swims around with those eyes looking up for some little shadow against the sunlight that will tell it that there's a tasty morsel up there.

But all the time he's doing that, he has to worry about bigger and nastier things under him doing exactly the same thing. So he has a very narrow silhouette, and silver sides, which are characteristic of many fish. That narrow silhouette is not for hydrodynamic reasons. If you want to swim fast through water, you're big and round like a tuna. That narrow silhouette is a camouflage technique.

Slide 45: photophores on ventral surface of fish

An enormous number of animals take camouflage in the open ocean one step further and they replace the light that's being absorbed by their backs by emitting light from their bellies. They have light organs on their bellies that are called photophores. In this photo, these photophores look pink, and I have actually seen books that claim they emit pink light, which would completely obviate the point of what they're doing. Those are pink filters that actually narrow the spectrum of light so that the light emitted by the photophores is an absolutely perfect match to the downwelling sunlight shining down around the fish's body.

Slide 46: luminescing photophores on ventral surface of fish

You may wonder about the spots, but if you've ever opened your eyes under water, you know how quickly light scatters under water. So the spots of light blur together very quickly. But it's still another one of those things you've got to see to believe.

Slide 47: counterillumination experiment

An experiment that demonstrates how a backlit fish can disappear was done in the lab of my former major professor, Jim Case. This is the underside of a tank, and there are two fish in that tank. The one close to the side is not producing light from its belly, and another one, that you can't see here, is luminescing. When you turn out the light, suddenly the one that is not producing light, disappears. The second one fades its light, so it disappears pretty quickly as well.

Basically, there's a feedback control system in these fish so that when a cloud goes over the sun and dims the sunlight, they dim their bioluminescence. They absolutely disappear. It's a phenomenal thing to see, and it's very, very common.

Slide 48: benttooth bristlemouth (*Cyclothone*)

This little fish is called the benttooth bristlemouth. It has tiny light organs on its belly. Its not that spectacular, but the benttooth bristlemouth is probably something that more people should know about, because this is the most common vertebrate on our planet - the most common animal with a backbone on Earth. It's sometimes called the trash fish of the ocean. The Latin name is *Cyclothone*.

Slide 49: bioluminescing benttooth bristlemouth (*Cyclothone*)

Imagine, the most common vertebrate on the planet is bioluminescent, and most people don't even know about bioluminescence! It produces this same pattern of lights that would blur together if you were looking at them through the water.

Slide 50: krill

Krill, which are so common that they are the food source for baleen whales, are all bioluminescent, with the exception of one deep-sea species, because biology requires an exception to every rule!. This krill,a species of shrimp, has light organs on its belly. These light organs are so amazing because not only can it control the intensity, it controls the direction of the light. The light organs are on swivels, so if the animal tilts its body to swim up, the light organs swivel down, so that they're pointing straight down all the time. It's a phenomenal adaptation.

Slide 51: bioluminescing squid (*Abralia veranyi*)

This squid, which we caught in the Bahamas, can actually change the color of its luminescence, depending on whether it's camouflaging itself against sunlight or moonlight – this camouflage technique is called counterillumination. When it comes up to surface waters at night the squid counterilluminates against moonlight which has a broad spectrum, with more orange and yellow in it. So the squid changes the color of the light it emits. Then when the squid goes down deeper, it changes to a very narrow spectrum that's pretty much a pure blue. It's another phenomenal adaptation.

Slide 52: Functions of Bioluminescence: Defense

There are many different types of defense. I'm only telling you about three of them: blinding/distraction, camouflage, and burglar alarms. Burglar alarms are just what they sound like. You have a burglar alarm in your car so that, if somebody tries to steal your car, the horn beeps and the lights flash. It's meant to attract attention ultimately of the police who will take this person away that's trying to steal your car.

If an animal is caught in the clutches of a predator, its only hope for escape may be to attract the attention of a bigger predator that can come in and attack the animal that is attacking it. For example, if a flimsy little jellyfish is being attacked by a fish, and the jellyfish start flashing like crazy and attracts the attention of a shark, the shark doesn't want to eat the jellyfish, but he'll eat the fish, and that gives the jellyfish a chance to escape.

So any animal that has bioluminescence, for whatever reason -- finding food, attracting mates, camouflage – is going to use everything it's got to scream for help with light when it is caught in the clutches of a predator. This is the same reason that birds and monkeys have fear screams.

Slide 53: black dragon fish

This is a black dragon fish, and it has a light organ under each eye that's a flashlight. It has a chin barbel that is a lure. It has organs all along its belly that it uses for camouflage. It has lights in its fins. Normally we never get to see the actual bioluminescence of these fish. We just know it exists because they come up with these light organs that we know can produce light. There might be a dim, pathetic glow, but when you capture them in a net, they're so exhausted from being stimulated and stirred around, they don't have any light-producing capability when you get them up. And we can't keep them alive long enough to recharge them.

I managed to get a display from this particular fish because of the way we caught it. We were working on an experiment off of North Carolina with a laser scanning system on which my husband was a co-inventor. We were set up at about 2,800 feet, ready to run an experiment, and this fish swam by. I'd never seen one of these fish before from the submersible – and haven't since - but I knew what it was. And I turned to the pilot, Phil Santos, next to me in the *Johnson-Sea-Link*, and I said, "Get it."

Slide 54: black dragon fish photographed at depth from submersible

The thing with Phil is, once you tell him to get it, you really can't call him off. He's kind of like a terrier. It turned out that the top swimming speed of this fish was one knot, which also happens to be the top speed of the *Johnson-Sea-Link* submersible, so we had to chase it for a very long time. It finally got so exhausted that Phil actually managed to capture it in one of these samplers on the front of the submersible that are so amazing that they barely touch the animal, so it came up in perfect condition.

Slide 55: *Atolla*, a deep-sea jellyfish

Another animal that produces a pretty spectacular burglar alarm is this very common deep-sea red jellyfish called *Atolla*.. We chased it down with a submersible. This picture was taken with the white lights of the submersible. There's no luminescence, just the submersible's light reflecting from the gonads.

Slide 56: *Atolla wyvillei*

We captured this *Atolla* in a very special capture device that kept it virtually pristine and brought it up into the lab on the ship. To produce a bioluminescent display, all I did was touch it once per second on the nerve ring - the nervous system of the animal - with a dental pick, which is sort of like the sharp tooth of a fish. In response the *Atolla* produced a pinwheel display that was just breathtaking. It went on and on and on. I've done calculations that indicate that this display could be seen from as far away as 100 meters by a deep-sea fish.

So I reasoned, "You know, that kind of light display might actually be a very good lure for us to attract animals." One of my frustrations as a deep-sea explorer is that the primary way we learn about what lives in the ocean is by using nets, which I spoke about earlier. According to a British colleague of mine, nets only capture the slow, the stupid and the greedy. "Greedy" because of net feeding; sometimes large predators will swim into the net to try to eat whatever's in it.

Slide 57: Deep-sea exploration platforms

The other way we know what lives in the ocean is to go down with these exploration platforms. In the upper left is the *Johnson-Sea-Link* manned submersible. The other two, that I've used a lot, are the *Tiburon*, and the *Ventana.* They are remotely operated vehicles (ROVs) owned by the Monterey Bay Aquarium Institute (MBARI).

When I'm sitting inside the *JSL*, we're surrounded by the light that we're pumping out and the noise from our thrusters. I wonder how many things are out there in the dark looking at us that I can't see because they're just going to stay far away from this big monstrous thing!
But I'd always had the impression that I saw more animals when I was working with the *Johnson-Sea-Link* than I saw when I was working with the *Tiburon*, and I saw more animals when I was working with the *Tiburon* than with the *Ventana*. We think we've solved this particular little mystery recently, because we recorded the sounds under water that these machines make. With the *JSL* you don't hear anything over the local noise levels. The *Tiburon* is also electrically powered, and electric motors tend to be very quiet, but even that is pretty noisy under water. Animals are going to hear it from a long way off; sound travels easily through water. Then we have the *Ventana*, which is all hydraulic and very noisy.

Slide 58: Eye-in-the-Sea

Back in 1994 I proposed the idea of a camera system that we could leave on the bottom of the ocean that was battery powered, that was quiet. Okay, that's not exactly novel; a lot of people have done that. But what was novel is that I wanted to use red light that is invisible to most of the deep-sea animals. That's challenging because red light gets absorbed so quickly through sea water.

My concept was this camera system called Eye-in-the-Sea. But in marine science, funding is so limited that they will not give you a grant unless you can tell them what you're going to discover, which was sort of a Catch-22. But I really wanted to do this, so eventually what I ended up doing was to have the Harvey Mudd Engineering Clinic build it as a student project. We gave them the bits and pieces from stuff we had around the lab, including a pretty crummy old surveillance camera, but it was intensified.

I am an Adjunct Scientist at the Monterey Bay Aquarium Research Institute. It paid for the battery, and, more importantly, it paid for the tests with its remotely-operated vehicle. And then I talked NOAA, the National Oceanographic and Atmospheric Administration, into paying for the underwater housing and the frame that we put the whole thing in.

So it was kind of a kludge job; in fact, it was so much of a kludge job that the first time we tested it, it flooded - on national television, by the way! If you saw "Midwater Mysteries," there's a lovely sequence of me opening the camera housing for the first time and seeing water run out of it.

Slide 59: schematic of Eye-in-the-Sea

Eventually, we got this Eye-in-the-Sea to work with the assistance of a colleague of mine named Lee Fry, an engineer. It's a pretty impressive piece of equipment, despite its ignoble beginnings. It has an intensified camera controlled by a computer, it uses red light, it's battery powered, and it's got this electronic "jellyfish."

Slide 60: Graph of wavelengths of red light, & Eye-in-the-Sea on deck in front of a ROV

For the red light, we spent a lot of time trying to figure out the optimum red light to use. We started out with something that was sort of orange-y light. We've now added a filter, so we've pushed it off into the farther red. We're kind of at the limit here, because the further out in the red you go, the less far the light will travel through seawater. But we have a balance now that works pretty well.

Slide 61: optical lure (electronic "jellyfish")

This electronic jellyfish that we developed was just 16 blue LEDs that could be programmed. You'll note it's in an epoxy mold. You can actually still read "Ziploc" on the container. It can produce a single dim LED glow or a single bright LED glow. (LED stands for light emitting diode.) Or all the LEDs can flash at once. We can produce a pinwheel display like that of the *Atolla* jellyfish, or we can have one of the LEDs flash at any frequency we want.

Slide 62: research site, Gulf of Mexico

The very first time I got to test this was in the Gulf of Mexico. We took it to this amazing place that is at the northern end of the Gulf of Mexico. In the drawing the coastline is drawn with a white line and all of the map below that white line is under water. Down near the left corner is a phenomenal place that's called a brine pool. It's basically an underwater lake that is full of water that is so salty and so dense that it forms an underwater lake which actually has a shoreline. If you try to penetrate it with a submersible, you can't, but you'll actually create waves that lap up along the shore. Methane bubbles up through this pool, and clams and worms along the edge feed off that methane through bacterial symbionts.

The point is that this brine pool is an oasis on the bottom of the ocean, which is mostly a desert, so this seemed like a place where large predators might patrol. It was a perfect place to put the camera for the first time. It was a really crummy camera, as I said, but I was thrilled, because I had my window into the deep sea. The thing actually worked, and the animals did not seem to be responding to it at all.

We had programmed the camera system so that the electronic jellyfish came on for the first time four hours into the deployment, with that pinwheel display. Eighty-six seconds after we activated it for the first time, we recorded a squid over six feet long that is so new to science that it cannot even be placed in any known scientific family! I could not have asked for a better proof of concept. In fact, I went back to the National Science Foundation and, on the basis of this, got a half a million dollars to do it right.

Slide 63: Eye-in-the-Sea on deck

When we looked at the video we couldn't see the electronic jellyfish in the field of view. When we had set the camera system down, we put the jellyfish in the bait bag two meters out in front of the camera. Apparently the camera tilted back a little bit after we left it, so the e-jellyfish was out of the field of view, which was frustrating. When we brought the instrument back that night, we stood around talking about what we could do to fix this problem. We needed something that would hold the jellyfish in place in front of the camera system. (This is sort of how marine biology really gets done.)

So I was standing around with my graduate student and a colleague of ours from Australia, Justin Marshall, and we all agreed that what we needed was some kind of rigid frame that we could hold out in front, but that it had to be able to fold up in order to launch and recover the Eye-in-the-Sea off the submersible.

We all agreed that was a great idea. Then I went to bed, and my graduate student and Justin ended up staying up all night. They found an old aluminum ladder and got permission to cut it up. They figured out a way to fold it up and latch it with a spring.

Slide 64: CLAM

We now call this thing the CLAM, not just because it folds up so nicely, but because it stands for Cannibalized Ladder Alignment Mechanism. We've actually published that.

Slide 65: preparing Eye-in-the-Sea for deployment

They painted the CLAM black, eventually, and they put the electronic jellyfish on it, and fish heads and a bag of bait.

Slide 66: Close-up of ladder with e-jellyfish & bait

Basically it's a sushi platter, meant to attract anything and everything that we possibly could in the deep sea. And it actually worked so well that we now use it routinely.

Side 67: Attaching Eye–in-the-Sea to submersible

You can see that it's held on the front of the *Johnson-Sea-Link* by two spikes that slide out, so they can lift it off the deck. It's a pretty hairy operation, launching and recovering this thing.

Slide 68: MARS Ocean Observing System

I want to tell you about this half million dollars I got from the National Science Foundation. We're still doing operations with the kludge job, although we've improved it a little bit. But we're also working on a much better version of the Eye-in-the-Sea that is going to go into the Monterey Canyon on this cabled network.

A cable runs from shore for 52 kilometers out into the canyon off of Monterey, California, and basically it's an electric plug in the bottom of the ocean. The battery that runs the Eye-in-the-Sea is only good for about 36 to 48 hours, maximum, and then we have to recover the system. So we only had very brief opportunities to put it out in the ocean to see what we can see.

Slide 69: moored Eye-in-the-Sea

With this new power source on the bottom of the ocean, we're going to be able to plug it in. So we've created the new version of the Eye-in-the-Sea that you see here. We liked the CLAM so much that we now have three CLAMs. One of them will hold the electronic jellyfish, one will occasionally hold bait, and the third will hold a current meter.

[To see a short QuikTime animation of how Eye-in-the-Sea will arrive and start work at MARS, go to http://www.mbari.org/mars/general/images/EITS_MARS2.mov]

Now we will, for the first time in human history, have a window into the deep sea, an unobtrusive window which we can peek through at any time we want to see what's going on down there. One of our problems, remarkably enough, is going to be too much data. It's like drinking from a fire hose. We're going to be buried alive. It takes us months to analyze the data that we've been getting from just a 36-hour deployment. We're not even going to have the opportunity to look at all of this data.

The engineers at the Monterey Bay Aquarium Research Institute have been working on a computer image analysis program called AVED, for Autonomous Video Event Detection. Once we're convinced that it's working properly, we will only save video that has things moving in the field of view. So any video that we have will have something happening on it. But even then we think we're going to have more than we can deal with. So one of our concepts, which will depend upon funding to implement it, is to have the Eye-in-the-Sea data come to shore.

Slide 70: Eye-in-the-Sea web interface

Eventually, I would love to have the data available in real time on the Web. That's going to take more money than we have right now. We could either burn the data to CD or have the raw data available in packets on the Web for downloading,.

MBARI has been working on a common species key of all the animals you're likely to see in the Monterey Canyon. We're working on some video modules that teach the physical aspects of the deep sea, animal adaptations to the deep sea, equipment adaptations to the deep sea and data collection protocols. We'll have a prelabeled spreadsheet set up.

We're hoping that we can get students to help us be deep-sea explorers by looking at this data for us. I think it would be a great outreach tool, but once again it's a funding issue; how will we implement that?

Our goal would be to have a Web-based electronic journal. We'd like to have student chatrooms where the students can talk to each other about the data they're analyzing. We'd like to have an Ask-the-Scientist bulletin board where students can email their questions about things that they see, and we could post answers that will stay up for everybody to see.

Slide 71: ORCA logo (final slide)