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[FELICE FRANKEL] So I'm sitting here in Kim Vandiver's office.

And actually, Kim was the very first person who got what I was trying to do.

I knocked on his door, basically.

Isn't that right?

Basically knocked on your door and said, "can I please come here and make science pictures?" This was in 1994.

You were the director of the new Edgerton Center that just formed.

And you said sure, let's give it a shot.

And I just started making more science pictures.

And that kind of grew into something more wonderful here at MIT.

So thanks, Kim, for giving us some time.

We're really eager to see this little story about Doc, and certainly about the pictures that he made, what he's known for, and some of your pictures, too.

It would be fun to tell a bit of a story for us.

[KIM VANDIVER] Thank you.

I'm really looking forward to talking with you.

It should be a lot of fun.

[FF] You bet.

So what drew me to the Edgerton Center is that people knew about it.

And that's really where very exciting photography of science was taking place.

And so it was a natural place for me to at least start.

[KV] Right.

It had the Doc Edgerton history, and lots of famous photographs.

And she didn't know me from Adam.

Right?

I was just the director of the Edgerton Center at the time.

[FF] What gave me the impetus was that I had been starting playing around at Harvard with George Whitsides' work.

And I did, in fact, have a very small portfolio of some pictures that I made in a science lab.

And so I had something to show.

It wasn't that I just came in and said, hire me.

[KV] Right.

You had the Whitesides' pictures at the time.

[FF] I had the Whitesides' pictures.

And I think I might have had a cover at that point.

[KV] I think you did.

You had the cover of the liquids on the hydrophobic and hydrophilic surfaces.

[FF] You remember?

[KV] Absolutely.

[FF] Oh my gosh.

Yeah.

But still, I'll be forever indebted to Kim for opening up the doors.

That's basically what you did for me.

[KV] That's what we intended to do.

That's what the Edgerton Center was supposed to be for.

So Doc first published his photographs in a book in the 1930's.

And the first book was edited by Jim Kelly, who, at that time, was the director of Technology Review.

And he later became the president of MIT.

[FF] Killian.

OK.

There we go.

I know that name somewhere.

[KV] And so Killian-- and if you had noticed, even this book is-- this one was published in the late '70s.

And again, it's still Edgerton and Killian.

[FF] Interesting.

[KV] So Killian edited the first three books with Doc.

[FF] And where do you come in?

[KV] Well, where I came in was I was a grad student here for a year in 1968.

And when you come here to MIT in the '60s, you heard about Doc.

He was a phenomenon at MIT.

But then I left and went those two years in the Army, and I took up photography as a hobby and developed my own-- built in Trang, Vietnam in 1970, a darkroom that anybody could use, but then developed my own color slides while I was there.

[FF] Kodachrome or E6?

[KV] No.

The only thing-- [FF] That couldn't have been Kodachrome.

[KV] No.

I think it was-- the only one that you could get the process for, I think, was Ectochrome.

[FF] Which is E6.

[KV] Yeah.

And so built this photo lab on my spare time in Trang, Vietnam in 1970 and taught myself to develop color film, which is a painful process.

[FF] Awful.

[KV] Temperature controls and all of that.

So then I show up back at MIT in January of 1972, and I'm facing taking my doctoral exams to qualify for the PhD program.

And I was taking all these hard, dreary subjects to prepare.

And I wanted to do one thing for fun.

And so I went and knocked on Doc's door.

Didn't know him, but told him about what I had been doing and said, I really want to learn how to do strobe photography.

Can I take your undergraduate course?

And he said, sure, we'll let anybody in.

[FF] "Anybody", even you, right? [laughing] [KV] Yeah.

Even me, right?

And so I took the subject that spring, which is called Strobe Project Lab, which we still teach today.

I was a grad student, and I had had dozens of lab courses.

And so the lab work was a lark.

It was just fun.

And I just had a blast.

And he needed a TA the following year, and so hired me to be his teaching assistant.

And that's when we really got to know one another.

[FF] What a story.

A little like-- not quite our story, but I met you when I, too, knocked on your door.

[KV] Same door.

[FF] Same door.

I said, I'd really like to make science pictures.

And you said, we'll take anybody. [laughing] And at that point, you were terrific.

You just said, yeah, let's see what we could do.

And it expanded through the years.

[KV] Well, and that's the spirit of Doc that I wanted to have in what we call the Edgerton Center.

When Doc died in January of 1990, I proposed to MIT that, as a legacy to Doc, we turn his laboratory into a place where MIT students could come knocking on the door and get help to be able to pursue hands-on experiential projects that they wanted to do.

And essentially, that was the beginning.

And the Edgerton Center was formally founded in August of '92.

And no now we're pushing 25 years.

[FF] That's right.

You might have a celebration at some point.

[KV] Yeah.

We have to think about that.

So we're almost 25 years old, and the initial vision was to have it continue to be a go-to place for know how in high speed photography.

So we continue to teach the subjects.

We continue to do a professional development course in the summer.

[FF] It's the go-to place, no question.

[KV] We try to still do that.

But we also wanted to help MIT students who had projects that they wanted to work on outside of the classroom.

And so today, the way that is embodied in the Edgerton Center is, we sponsor about a dozen student clubs and teams that build stuff-- so the Solar Electric Vehicle Team and Underwater Autonomous Vehicle Team, Formula SAE, Robotics, Aerial Vehicles, a team that rides coast to coast called Spokes.

They ride bikes across the country in the summertime, stopping along the way to teach middle school lessons in science.

[FF] Oh, man.

I love that.

That's wonderful.

Let's turn to some of Doc's pictures.

[KV] Alright.

[FF] And maybe if we can concentrate on what have become iconic, in a way.

This is your story.

We're looking at books on the desk, and Kim is going to look with me at some images.

And I might ask some questions.

We'd like to teach our students taking our course-- we'd like to introduce them to some of the techniques.

We don't want to go too deeply, because we're not actually doing this in this course.

But I felt it was important for them to be aware of this kind of photography for later on, maybe.

[KV] Right.

I thought mostly what I would talk about today doesn't actually have a lot to do with high speed techniques.

It has more to do with why was Doc a great photographer.

[FF] OK, great.

Let's go.

[KV] And that's relevant to anybody who's trying to take a picture.

So I'm going to do it a little bit chronologically.

Doc was fascinated with liquids and water and taking pictures of those things, for some reason, very early on.

And he claims the very first picture that he took of that wasn't of an electric motor.

And he was taking pictures of electric motors because that was his PhD thesis, and he needed the strobe to help him understand motors.

He claimed the first picture that he took using a flash, of something else, was water coming out of a faucet.

And for the rest of his life, he took pictures of water.

Water is tricky.

It's hard to take pictures of it.

And then his iconic photograph is the crown splash, called "Coronet," the splash of the milk drop.

And the original black and white of it, which we're looking at right here, was included in the first ever photographic exposition at the Museum of Modern Art.

And I guess before that, they didn't consider photography art.

But it's there.

It's in the collections.

And it was 1937.

So there's that picture, and that's liquid again.

But really, an amazing picture that nobody had ever seen before.

Because really good stop motion pictures hadn't existed before.

But actually, in fact, that's a lie.

I went back recently and did a little work, because I helped with somebody giving a talk in Cambridge.

And there's some pictures of splashes of milk drops that go back to about the turn of the century.

[FF] I know.

[KV] And now I've forgotten the name of the guy who did it.

Famous guy.

[FF] I wrote it down somewhere.

I just saw it at the Victoria-- no, I'm sorry.

I saw it at the London-- it's at the Science Museum in London.

[KV] That's right.

[FF] And I just saw it a month ago.

I said, wait a second.

That's before Doc.

[KV] That's right.

So I think Doc had to have known about those and seen them.

But the fellow who had done them, this was before good electronic triggering.

And this is about all I'll say about high speed photography-- the key to high speed photography is to have a very short duration flash, but to have a way of knowing when to make it go off.

In the trade, we call that "triggering".

How do you trigger the flash to make it go off?

And the way you take a bullet picture is you use a microphone.

And when the shock wave from the bullet passes the microphone, the microphone sets off the flash.

And in a darkened room, you can look at where the bullet is supposed to be.

You shoot the gun, the flash goes off, your eye sees it exactly where it is.

And if you want your picture to have the bullet three inches to the left, you take the microphone-- which is down below, out of sight-- move it three inches to the left, do it again, and it's exactly where you want it.

[FF] That's brilliant.

[KV] So triggering is a lot of the story about high speed once you have a source of a high speed flash.

[FF] So you're actually triggering the light.

[KV] Triggering the timing and the light.

It takes two things-- good timing and a very short duration burst of light.

So one of the two inventors of photography was William Henry Fox Talbot.

And in 1859, he took a flash picture.

So the first flash photograph is 1859, and it was an air gap spark of a capacitor discharge.

And it was a piece of newspaper spinning on a disc.

So flash photography goes back a long way.

[FF] Do I remember correctly that he tried it with water and eventually decided to-- [KV] I honestly don't know.

My guess is he-- I'm sure he tried it wither water first.

And in fact, my guess is he saw it in water and he said, oh, that is cool.

How can we really do it?

[FF] So is this just milk?

[KV] Yeah.

I know they used milk early on.

And of course, milk turns sour in the lab in not very long.

And so pretty soon after that, they figured out how to do it with fake milk, so that it would last a little bit longer.

So that picture, then, was taken in the mid '30s.

And then when color film came out, then Doc took the picture again in color.

And that's the iconic one in red that's on postcards everywhere.

[FF] I sort of like this one better myself.

[KV] I'll tell a lot of stories.

A couple of other stories about Doc-- he knew he had a good thing, but the world didn't know he had a good thing.

And he went Kodak and said, you ought to make a product out of this and sell cameras with flash units, with electronic flash.

And at that time, people were using flashbulbs.

And they said, well, we looked into it.

We figured we could sell about 50 units a year.

It just isn't worth it.

This is in the '40s.

And so Doc set out then to prove them wrong and to generate so much demand that they couldn't ignore it.

And so he started building the first portable units, battery operated.

He equipped sports photographers with portable units.

And so there's a picture I didn't dig out today.

It's in the Boston Garden, and it's an indoor track meet.

And it's a runner coming around the curve.

And it's just absolutely crisp stop motion shot of this guy.

And it was the first high speed flash sports photograph to go out on AP wire photo.

And then after that, there's another fantastic image.

So Doc, he said, I'm going to prove them wrong.

I'm going to show people that this is the way to do it.

And the other picture that I didn't pull out today is the absolutely classic sports shot, which is the knockout punch from Joe Lewis.

It's the Joe Lewis shot.

When that went out on AP, that was a show-stopper picture.

OK.

There we go.

And that is the Chilean Arturo Godoy in 1940.

[FF] Can you imagine seeing something like that for the first time?

Opening up a whole new world.

Very exciting.

[KV] So it didn't take, I think, too many pictures like that.

[FF] No, that's all you need.

[KV] And the photography industry started to say, there's something important here.

So then he got really fascinated with speed.

And what would impress people more than to be able to stop a bullet in flight?

I think that Doc said, we got to do that.

And so he took lots of bullet pictures.

So people know pictures of bullets through apples and all sorts of things.

[FF] And people are doing it in classes.

[KV] Yeah.

And we show our students how to take a bullet picture every year, because it's just so cool.

But the picture that I pulled out to talk about is a picture that has three balloons in a row with a bullet passing one after another through the third.

And so the first one is in almost complete disintegration.

The second one is partially gone, and the third one is just barely showing the effects of being shot.

This essentially, in a single photograph with a single flash of light, does a wonderful job of showing the passage of time.

So I think this is just a brilliantly crafted photograph to tell a story in a single picture.

[FF] That's mind blowing.

[KV] He was really clever at that kind of thing.

And they took lots of bullet pictures, but this is one of my favorites, because it was so cleverly done.

And this was before the development of high-speed, multiple flash cameras.

So Doc's contribution to high-speed photography was the perfection of two things.

The electronic controls-- so now you had transistors and modern things that you could switch current very quickly-- and also, very short duration sources of light, and in particular, the xenon flash tube, which is in every camera that you buy.

So he perfected the xenon flash tube, which gives out very bright, daylight color spectrum light in a very short duration.

[FF] Kim, around what year are we talking about, roughly?

[KV] Well, there were strobes available when he was doing his PhD work in the late-- he started about 1928.

Then these pictures, like the one in the Museum of Modern Art, early and mid '30s, by that time, I think he was using Xenon.

He was developing flash tube technology back then.

And I was a TA in 1972, one of the labs that you did is you went in the lab and made your own flash tube.

Doc really understood flash tube technology.

You had made your own.

And so we had Pyrex glass and glass blowing setup.

And you took the glass, and you learned how to embed the electrodes in it to conduct the electricity inside.

You filled it with xenon at the right pressure, and then you pinched it off, and you had your own tube.

[FF] Talk about hands on.

[KV] Yeah.

[FF] That's what he was all about.

[KV] When you took the course in those days, you tested flash tubes.

You made your own.

And you also then went and took pictures of bullets, and had to do a project of your own.

It was called Strobe Project Lab.

In the second half of the course, you had to choose something of your own to do.

And so students, by that time, had pushed multiple pianos off the top of dorms and taken pictures of them and stuff like that.

But I was an ocean engineer, and I took on a project of taking high speed technical photographs for quantitative purposes of propellers in a water tunnel.

Because propellers under certain conditions generate bubbles, and you may see this helix going downstream, and it's called cavitation.

The propeller cavitates, it erodes it very fast and damages it.

And if you're a submarine, it makes a horrendous amount of noise and makes it easy to detect you.

So cavitation is important.

But pictures of things with bubbles around them in water are actually kind of hard to take.

So we have a propeller tunnel here in the Ocean Engineering department, and they had been taking pictures in it, but they weren't very good.

And so I actually took a lot of pictures and then wrote the manual on how to actually take good pictures.

[FF] Fantastic.

[KV] I think it's still in the drawer over there.

Lighting is the most critical part.

Bubbles reflect so much.

And the windows, you've got to take pictures through windows, which is a problem.

[FF] Major problem.

[KV] So you learn all about how to take the things that reflect on you, and bubbles reflect like crazy.

So getting the lighting, the exposure correct is a tricky part.

[FF] Yeah.

We talk a lot about that.

[KV] Doc was an opportunist, but he was also very creative.

Another thing that Doc did-- he was an MIT professor, and to this day, high speed photography's probably greatest use is in industrial settings.

Doc soon was sought out by people in industry to use high speed photography to troubleshoot.

All through his life, he did lot of what turned out to be really interesting consulting jobs.

So he was always carrying his camera.

And he would take pictures of opportunities when he thought they were just really cool pictures.

And this is one of my favorite ones.

This shows a mill worker sometime in 1937.

This is the paper mill.

And paper mills are notorious for-- have you ever seen a newspaper being printed or something like that?

The paper is streaming across rollers at very high speed.

And if something goes wrong, you get an enormous mess in a hurry.

And it's going so fast.

The paper is moving so fast.

You can't see with your eye what the problem is.

And so Doc's new high speed photography was a real blessing for people in industry with things that were very high speed and could get in trouble.

But this is an example of that.

He was no doubt working on a consulting job.

You can see in the background these big rolls of paper that are going through this mill.

He had probably been taking very technical pictures, probably trying to get them to understand something.

And then he saw this fellow, this worker, with a pitchfork with this enormous mass of trimmings off the edges of a paper roll forking this big-- like it's hay, but it's not hay.

It's paper.

But it's a beautiful picture.

.

[FF] It's wonderful.

[KV] And so his sense of seeing a good picture and saying, I've got to do this, and then his craftsmanship of being able to make it a great picture, not just an ordinary picture.

[FF] What kind of camera was he lugging around?

[KV] This was probably a four by five.

He used a lot of four by five.

I've forgotten the term.

I haven't used one in so long.

[FF] Cassettes or-- [KV] Yeah.

With the back on it, and you put it in and pull the slide out and took you picture.

[FF] Which is considerably cumbersome.

This is without a tripod?

[KV] My guess is-- I don't know.

He would also, then-- he would just carry along a 35-millimeter of what camera was available at the time just to be able to take setup pictures and quick stuff.

But when he then really wanted a good picture, he'd get out the four by five, and he'd put it on a tripod if he had one there and do it right.

And this is a big version of this picture in the hallway outside.

[outside Kim's office] You were standing almost in front of if out there.

[FF] Oh, OK.

[KV] So that's one of my favorite Doc "opportunity" kind of pictures that came from his consulting.

So what's that?

Stonehenge.

[FF] Wow.

[KV] Yeah.

It's a "wow" picture of Stonehenge that was another opportunity.

He had to plan this rather carefully.

Here's this sister picture to this that's upstairs.

And if we go upstairs, you can see it.

It's this dull looking, why do you bother to put that image on the wall picture.

But this photograph is taken at midnight, thereabouts.

And the sister companion picture that goes with it is a photograph from a night reconnaissance aircraft.

The pilots are practicing for taking photographs using brand new Edgerton strobe equipment to take photographs of Normandy in June of 1944.

So this is leading up to that.

They've installed these brand new electronic means of taking reconnaissance photographs and put them in US Army Air Force airplanes and are teaching the pilots to do it.

Prior to the use of flash, you would have one plane fly over high altitude-- like 5,000 or 10,000 feet-- and drop flares on parachutes, and then the reconnaissance plane would have to fly in at 1,500 feet illuminated, backlit by the flares so that people with guns could see it.

And so it was really dangerous work.

And then you'd fly over with the lights from the flares, taking the pictures, but also getting shot at.

So that had been the standard way to do reconnaissance photographs.

The Army Air Force came to him early in the war and said, can we use your flash technology to take pictures at nighttime?

And so they started developing really powerful flashes.

So your typical camera flash might be five watt seconds of energy.

That's a measure of electric power.

So five.

So by the end of the war, Edgerton flash units that were being carried in reconnaissance aircraft were 50,000 watt seconds.

[FF] I can't even imagine.

[KV] And one of the movies about Doc that shows him in a classroom, and he's got a yardstick with a sheet of newspaper taped to it, hanging from it, and he's standing about as far from you to here.

So the 50,000-watt second flash unit has a reflector about this big around, and a flash tube with the xenon in it.

It's a coil, a helix about this big around.

And you shoot it off, and the piece of newspaper would just burst into flames.

That's how much heat is coming off of this thing with the light.

So they were installing units.

They wanted to send the pilots out to practice with it.

And he said, let's take a picture of Stonehenge.

And so he was on the ground, and he set his four by five camera on a fence post, and he knew when they were coming.

And he just opened the shutter and waited for the night reconnaissance.

[FF] Are you telling me the light was coming from the-- [KV] The light comes from the airplane.

[FF] And it traveled that far?

It was so strong.

[KV] Because the airplane is trying to take a picture of what's on the ground.

So the photograph that's upstairs is the photograph of Stonehenge taken by the aircraft.

So you can see the aircraft photograph, and this is the companion photograph that goes with it.

[FF] That's an absolutely fabulous story.

[KV] So taking photographs of things in wartime is pretty commonplace.

But knowing to be here with your camera on the fencepost and get this image that no one else before or since has been able to take...

[FF] That's absolutely fabulous.

[KV] So this just shows his brilliance as a photographer.

So I really love that picture.

Then this is the more recent typical bullet through apple making applesauce.

Doc's comment was, it takes a microsecond to take the picture and all morning to clean up.

And so I was his teaching assistant in '73 - '74 in this subject we called Stobe Project Lab.

And he was exactly my age now when I was working for him.

He had just retired, and he was 69.

Retirement meant to him that he got to keep his lab, but he only had to do what he wanted to do, basically.

He was so important MIT.

He said, look, I'll tell you what.

I'll stop drawing salary, but you let me keep my lab.

And they said fine.

And so he kept coming to work every day until 1990.

So this was 1972.

So I had been in the class in the spring.

In the summertime, I'd talked to him and found out he needed a TA.

I was a doctoral student in ocean engineering.

In May of '72, I did pass the exams.

And my one fun thing for the term had been taken the high speed photography course.

And Doc and I agreed that I'd be the TA in the fall.

So I showed up about Labor Day, and there was a letter waiting for me.

And the letter said, Doc says, sorry I can't be there, Kim.

My mother's not feeling well.

And at the time I said-- he's 69 years old.

Your mother is not feeling well?

She was 98 or something like that, and he was off visiting with her in Nebraska.

And he said, well, I'd like you to think about working on a project while you're my TA.

That's kind of unusual.

TAs usually grade the lab books and helps in the lab, but you don't do some research as well.

Doc says, why don't you do a project?

And he says, I've never done Color Schlieren photography.

Now, Schlieren photography had already been used for many, many years in the aircraft industry to take photographs of aircraft models in supersonic speeds.

Because at supersonic speeds, everybody knows about sonic booms-- you have a shock wave that comes off of the aircraft.

And a shock wave is a high intensity sound wave.

In the aircraft industry, you could study the shock waves in a wind tunnel if you had a photographic technique that would make shock waves visible.

So it was called Schlieren, and they did it in black and white.

And there were a few color techniques.

But Doc says, so I've done Schlieren before, but I've ever done color Schlieren.

Why don't you see if you can do that?

So that was September.

I want to the library, found four different ways of doing Schlieren photography in color, all the technical journals.

Built my first setup, took my first pictures.

And Doc has come back by now.

And I take them in to him, and he takes that his 10 power loop, which he always carried with him.

And he holds the 35-millimeter film up, and he looks at it and he says, Van, it looks a little out of focus to me.

And it wasn't because I couldn't focus a camera.

But that's just the nature of that particular method.

So then I went back to the library and built another system and did it differently, and walked in a couple weeks later and showed Doc the pictures.

And remember, this is color.

Black and white was easy in Schlieren.

This was color.

So I walk in, and Van, I don't like the color.

So you have to understand that one of the reasons it took so long is you get the system set up, you take some black and white pictures just to make sure it was looking OK.

Because you could take three or four frames of 35-millimeter black and white film, walk across to the photo lab, develop it right on the spot, and hold it up wet to see what you got.

And if it looked right, then you went back across the hall, put the color film on the camera, took a whole roll of pictures, and then set it off and waited a week.

In 1972, you had to wait a week.

[FF] I remember those days.

It's called film.

[KV] Right.

It's film, and not instant film, either.

And it took a week to get them back.

So that was all part of the process.

So it wasn't until December or so-- I was getting pretty frustrated, and I found an article in Scientific American.

And there was a fellow by the name of CL Stong, who for decades had a column in Scientific American called The Amateur Scientist.

And it was basically the do-it-yourself science column inside Scientific American.

And he would accept contributions from people and choose which ones he liked.

And each month, there'd be another build your own radio or do this or do that.

And there was an article on a new way to do color Schlieren.

And it had been developed by a graduate student at the University of Tennessee, a guy by the name of Gary Settles.

And he hadn't done the high speed photography part, but he had come up with a better way to do the color.

So I built that, and I took the pictures, and I had three four of them.

And I think one of the earliest pictures I took was very much like this one.

And I walked into Doc's office one morning, and I handed him this 35-millimeter color slide.

And he looks up, and he says, Van, I think you've got it.

[FF] Oh my gosh.

Hallelujah.

You must have felt-- [KV] September, October, November, December, January.

[FF] Whoa.

[KV] But then once we had it-- once he saw a picture like this, we knew we had it.

And so then he just encouraged me to take pictures of everything under the sun.

And so we just tried all sorts of stuff.

[FF] So we're seeing-- am I right?

We're seeing changes of index of refraction.

[KV] Yeah.

So color Schlieren allows you to see changes in index in a transparent medium-- so water, air, anything that light will pass through, you can take a Schlieren picture of it.

So this is a candle.

This is just the ordinary hot air above a candle, which you normally can't see, except it's a mirage effect, like when you're looking down a highway in the desert.

And this is a 22-caliber bullet, and this is the shock wave that accompanies it.

And the amazing thing about shock waves is they make a V.

And the angle of the V-- one over the sine of this angle is the mach number.

So if that angle is 30 degrees, sine of 30 is 1/2.

1 over 1/2 is 2.

That bullet is traveling mach 2, or twice the speed of sound.

[FF] That's fabulous.

[KV] So in pictures like this, there's a lot of really interesting physics and things to talk about.

The color in this particular Schlieren technique-- the color you see tells you the direction in which the light was refracted.

So this is a little bubble, just a ball of hot air.

It's hottest in the center, it's cooling radially.

In all directions, the temperatures are dropping.

So the index of refraction is increasing radially in all directions.

So if the light radios into the upper part here, the light bends toward increasing index.

Up here, the light was bent up.

Here, it was bent to the right.

Here, it was bent to the left, and in there, it was bent down.

So up is yellow, down is blue, left is green, right is red.

[FF] So this is highly informational.

[KV] Lots really cool information.

[FF] Besides being stunning to look at.

[KV] So then you look at a picture like this-- you can see the candle flame nicely.

Now, that's itself illumination.

That light is coming from the flame.

The light that took the rest of the picture is coming from your high speed source, which is 1/3 of a microsecond in duration, which allows you to stop a bullet in its tracks.

But the light to get the candle flame comes from the candle flame itself.

But if you only had the shutter open 1/3 of a microsecond, that's not enough light from a candle flame.

So in fact, the way you take the picture is you turn off all the lights in the room, you open the shutter on the camera for 1/4, maybe 1/2 a second.

And when the person on the gun hears the shutter click, they pull the trigger.

The bullet travels across the system.

The microphone is sitting right here, by the way.

You can see the shock wave right down here out of sight as the microphone.

The shock wave hits the microphone, the microphones sets off the flash, takes the picture.

So the flash is a third of a microsecond in duration.

And that's the exposure time for everything you see here.

But the shutter has been open a half a second.

And so you have a half a second exposure time of the candle flame.

So they're always blurry, because they flicker when the shock wave goes by.

[FF] But he got past that, right?

[KV] Oh yeah.

And that's a sparkler.

So if you knew what you shutter time was, your exposure time-- let's say it was 1/8 of a second or something, or maybe less-- these little trails are the sparks.

You could figure out how fast they're going.

[FF] Oh gosh.

Of course.

[KV] So if you know how long-- this is then a time exposure of the trail of a spark as it travels through the air.

[FF] Like subatomic particles.

[KV] Yeah, in a way.

It's kind of like a smoke chamber.

So actually, here's one of my favorite pictures of my own stuff.

And I'll talk about both of these.

This is a picture just of a soap bubble, and it's just about life size.

And soap bubbles in Schlieren systems turn out to be really interesting.

You see things you don't normally see.

So this is a rubber hose.

It was dunked in the soap solution, and then you blow on the end of the hose to make the bubble.

These are little streamers of soapy solution that are actually flowing on the surface of the bubble.

And they do most interesting things.

They go along, and then they divide, and then they divide again.

And a movie of this is just fascinating.

In a picture like this, if you look carefully, you can actually see-- this is a shock wave, but that's reflected shock wave that has actually hit the rubber hose and bounced off.

And down here, there's an arc.

That's sound that's being reflected off the bubble.

So bubbles are a lot of fun.

And then this picture is fun in a sense in that Doc took this picture in another form many, many years before.

So that's 1930s.

It's an old house fan, and it's spinning.

And just above it is artificial smoke.

It's basically chemical smoke.

And as the propeller blade passes by off the tip of any surface, it's generating lift.

There's a vortex.

And he put the smoke there so it gets sucked into the vortex and shed downstream as a helix.

So in this picture, you can see that vortex forming in the smoke.

And this is the same photograph with the same fan-- because he still had it around the lab -- in Schlieren.

[FF] This picture has the fan.

The fan is-- [KV] This picture is the whole fan.

This one-- this is an alcohol lamp.

Usually, a little, tiny blue flame.

This is just hot air.

The hot air is being sucked into the vortex, and then it is shed down.

Here's the helix.

It's this core vorticity that goes off this way.

So there's another one of the subjects that we took pictures of.

So Schlieren photographs were a lot of fun.

And then there's one other bit of story that is appropriate to, of course, where you're teaching grad students and that sort of thing about taking photographs.

This picture, Doc really liked.

And he said, OK, Kim.

He says, you need to write a paper, and then we're going to go to this conference and show your stuff.

Give this paper at the 11th International Congress on High Speed Photography in London in, I think, the summer of 1973.

So I had this venue were Doc was the grand old man.

He was the father of modern high speed photography.

It was at University College London.

They filled the auditorium.

And all these old cronies that were friends of Doc that he'd worked with through the war and afterwards, he was famous with these people.

So here I was under his wing, getting to go everywhere he went and treated like royalty.

So I gave them my paper, showed 30 or 40 of these beautiful color images that people hadn't seen before.

But he had also taken about a dozen pictures, had them enlarged to 16 by 20, sent them ahead, and they'd all been set up in a gallery.

So anybody coming through the place could walk through this gallery and see all these photographs.

So while I was there, this fella comes up to me and he said, I really like your photographs.

And he said, I'd like to use them.

I said OK.

And so this picture was a cover photograph on Nature Magazine.

[FF] Oh gosh.

[KV] So this was my first professional publication as a grad student.

It was a little short article in Nature with this photograph on the cover.

[FF] What year?

[KV] '74.

There might be a copy of it around here somewhere.

Talk about having-- [FF] I get it.

[KV] To have your first publication when you're applying as a professor or something somewhere, to be a cover photograph in Nature, that's a pretty good place to start.

[FF] It's a pretty good place to start. [laughing] This is great.

Oh, Kim, thank you.

This is a wonderful, wonderful story.

Not bad.

[KV] So that was my first professional publication as a graduate student.

And it was a nice thing to have on my resume going forward.

I've said many times, I wouldn't be here today if I hadn't had that experience with Doc Edgerton.

Even though I was an ocean engineer and I didn't continue professionally in high speed photography as his mentee, what it did for me is the year I worked for him as a teaching assistant was a year I was not doing something in ocean engineering.

And that was because I hadn't found a thesis topic that I really liked.

And it gave me a year of extra time that I could go do something fantastically fun and find a good thesis topic.

So by the end of that year, I not only got to give this paper, but I had come up with a super thesis topic, which then that opened the doorways for me to becoming a professor of ocean engineering.

[FF] Timing.

[KV] Timing, a little luck.

And not being afraid to knock on the door.

[FF] There you go.

Thank you.

Exactly.

Good job, Kim.

[KV] Yeah.

Thank you.