Galaxy Zoo and the

KEVIN SCHAWINSKI

Seeking advice from an expert can be dangerous. Experts may know more about their area than anyone else, but they're still human. How can you tell if they are correct if you're hearing just one opinion? That's why astronomy researchers have been turning to the collective wisdom of crowds on the internet to help answer some of the most compelling questions in modern astrophysics.

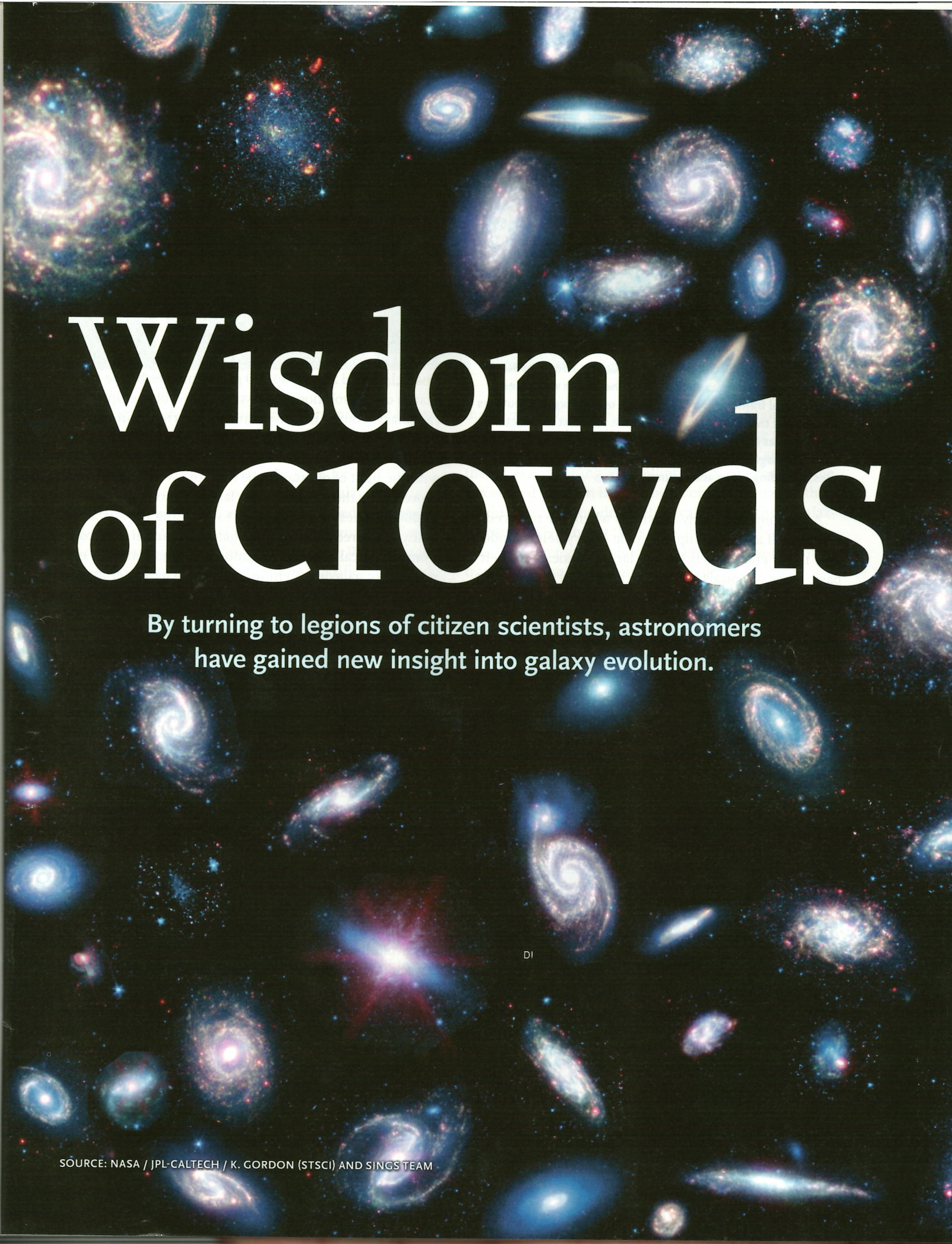
One would not want to randomly pluck people off the street to perform open-heart surgery, but in certain cases, the consensus of a group of laymen is more reliable tha the opinion of a single expert. For example, fill a jar wi jellybeans and ask a Ph.D. engineer to estimate how ma beans are inside the container. The engineer might ma some brief calculations and add a dose of experience ar give you an answer that will probably be way off the ma But if you turn to a large crowd and ask each person to guess the number, and then take the average, you will probably get much closer to the truth.

SLOAN DIGITAL SKY SURVEY (2)

BASIC GALAXY TYPES These Sloan Digital Sky Survey images show the elliptical galaxy M87 *(left)* and the classic spiral galaxy M101 *(right)*. M101 shines brightly in the predominantly blue light of massive young stars. In contrast, M87 stopped forming stars in appreciable numbers billions of years ago, so its color is dominated by the redder light of old stars.

Wisdom of crowds

By turning to legions of citizen scientists, astronomers have gained new insight into galaxy evolution.



SOURCE: NASA / JPL-CALTECH / K. GORDON (STSCI) AND SINGS TEAM

GALAXY ZOO

GALAXY ANALYSIS Visitors to the Galaxy Zoo website would encounter pages such as this. The Zooite would see a large central frame with a Sloan image of a galaxy, and buttons on the right that would allow the citizen scientist to select a specific galaxy type from several basic categories. Links at the top of the page could take the visitor to any number of related sites, including blogs and forums.

Astronomy has many questions where the nuanced response of a large group of people is very helpful indeed. One major challenge is sorting large galaxies into their basic types — spirals and ellipticals — and then dissecting them into finer classes. Ever since Edwin Hubble first divided galaxies into these two classes, astronomers have wondered how the two relate to each other. Does one type turn into the other? Can galaxies move back and forth as they evolve, or is it a one-way street? For most of the 20th century, astronomers classified galaxies by eye, first into spirals and ellipticals, and then into increasingly elaborate schemes that still color the debate.

With the rise of large-scale surveys such as the Sloan Digital Sky Survey (SDSS), astronomers had to cope with such large numbers of galaxies that classifying them all by eye appeared impossible. They developed new computer algorithms to classify galaxies, but they could never fully reproduce the human ability to tell galaxy classes apart. Even the most sophisticated computer programs trying to mimic the way the brain works would often miss an obvious set of spiral arms and declare a beautiful spiral to be an elliptical. Instead, the computers generally measured "structural parameters" that conveyed useful physical quantities, but they didn't provide the same information as a human classifier.

JONATHAN SAYERS

BIRTHPLACE OF GALAXY ZOO Author Kevin Schawinski and astronomer Chris Lintott hatched the idea for Galaxy Zoo while downing pints of fine British ale at The Royal Oak, a pub in Oxford, England.

The Power of the Human Brain

As part of my own graduate research at Yale University, I had classified almost 50,000 galaxy images by eye in search of an evolutionary missing link: a blue elliptical galaxy. Young, massive stars shine brightly in blue wavelengths, so blue is the characteristic color of a galaxy that's still forming stars. But most ellipticals shine red with the light of old stars. The human eye and brain proved to be the most reliable classification tool, but 50,000 galaxies proved to be just scratching the surface. Many of the recent insights in galaxy evolution have come from statistical analyses of hundreds of thousands or even millions of galaxies. To figure out which galaxy properties are important, we needed to group galaxies into categories by characteristics such as mass, environment, star-formation rate, and shape.

Thus the idea of Galaxy Zoo was born in the spring of 2007 at a pub in Oxford, England, as Chris Lintott (Adler Planetarium and Oxford University) and I tried to come up with a better way to classify large numbers of galaxies by eye. We were inspired by the success of the Stardust@home project, which had enlisted the help of people across the internet to hunt for comet dust collected by NASA's Stardust spacecraft. If people were willing to look for dust particles, we thought, perhaps we could persuade them to classify gorgeous images of galaxies.

The Sloan Digital Sky Survey's (SDSS) 2.5-meter robotic telescope in New Mexico had been scanning the skies for years, and it was clear to us that if human eyes could classify the nearly 1 million galaxies it had observed, we could produce exciting new insights into galaxy evolution. After classifying 50,000 SDSS galaxies by myself, I realized that analyzing a million would require a lot of help. Turning to the internet seemed an obvious route, so Chris and I hoped to excite a group large enough that we could classify every one of the million galaxies in a few years.

Things moved quickly and **galaxyzoo.org** went live on July 12, 2007. The start quickly went viral on the internet. The global response was so enthusiastic that the Fermilab servers providing SDSS images soon struggled to keep up and finally crashed when a cable melted. Just a few hours after launch, galaxyzoo.org had died. Fortunately, our col-

KEVIN SCHAWINSKI

CAROLIN CARDAMORE (X) / SDSS

BLUE ELLIPTICALS The Zooites helped find a crucial "missing link" in galaxy evolution: elliptical galaxies that shine with the predominantly blue light of young stars. Three examples are shown here. Despite the fact that the blue ellipticals unveiled by Galaxy Zoo are relatively low in mass, they may shed light on how their larger red-and-dead cousins formed.

GREEN PEAS Thanks to citizen scientists, the Galaxy Zoo project discovered a new class of compact galaxy whose members shine at greenish wavelengths. These "green peas" are living fossils with no counterparts in our local universe. Exactly how they fit into the overall evolutionary sequence of galaxies remains a mystery.

leagues at the Johns Hopkins University mounted a quick rescue operation and cloned the SDSS SkyServer on some spare machines to cope with the demand.

When we first summarized our goals for Galaxy Zoo, we hoped that each of the 1 million galaxies in the SDSS sample would be viewed and classified once, and estimated that this would take perhaps as many as five years. We were off by orders of magnitude. Within hours, citizen scientists had made 1 million classifications, and the torrent of clicks continued. Just over a year into the project, when we decided that further clicks were no longer improving the results, each galaxy had been viewed *more than 70 times*.

Discoveries

When our international Galaxy Zoo science team had collected enough clicks to start analyzing the results, we turned the user classifications into science while using a blog and forum (**galaxyzooblog.org** and **galaxyzooforum.org**) to interact with the citizen scientists. We considered this crucial because we viewed the citizen scientists as our collaborators who deserved credit for discoveries and to be fully informed with what we did with their hard work. This caused some consternation with academic journals when we inquired whether we would be allowed to submit papers with more than 100,000 coauthors. The journals said our request was unfeasible, so instead each paper links to a web poster where we list everyone who volunteered to have their username made public (**http://zoo1.galaxyzoo.org/Volunteers.aspx**).

By the time we decided that Galaxy Zoo had completed its objectives, we had accumulated enough clicks for every galaxy that we had the consensus vote for each one (survey says: it's a spiral!) and a measurement of how certain the classification was (for example, only 55 out of 70 citizen scientists agree that it's a spiral).

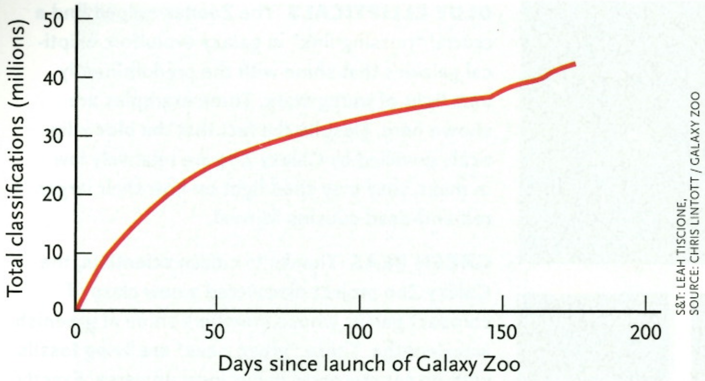
Our main goal was to classify galaxies by shape alone and thus find the odd galaxies that can perhaps teach us the most about galaxy evolution. We quickly found large numbers of galaxies that did not fit the traditional profile of passive red ellipticals and blue star-forming spirals. When spiral galaxies collide, the interaction can destroy their disks, resulting in an elliptical galaxy where all the gas is used up in an intense burst of star formation that produces a "red-and-dead" elliptical. Alternatively, galaxies can slowly exhaust their gas supply or perhaps lose it as they enter galaxy clusters, leading to a more gentle transformation as the spiral arms fade.

Blue ellipticals that are currently forming stars, sometimes at prodigious rates, showed up rapidly in the Galaxy Zoo data and may constitute 5% to 10% of all

TRY YOUR HAND

SDSS / KEVIN SCHAWINSKI

These Sloan Digital Sky Survey images show galaxies that are very easy to categorize as *(top to bottom)* a normal spiral, a barred spiral, and an elliptical galaxy. If you want to try your hand at classifying other galaxies imaged by SDSS, including examples that are less obvious, visit **SkyandTelescope.com/GalaxyZoo**.



RAPID RISE This graph plots the unanticipated rapid rise in the number of galaxy classifications made by citizen scientists. It took less than two weeks to hit the 1 million mark.

ellipticals, most of which are gas poor and can no longer form stars. But unlike most elliptical galaxies, which are much larger than our Milky Way, none of the blue ellipticals are particularly massive. Since the most massive ellipticals formed in the early universe, perhaps these less massive blue ellipticals are scaled-down versions of those resulting from the processes that formed their massive cousins. Many of these elliptical galaxies show indications of debris and tidal tails, suggesting one or more recent major mergers. Their star formation seems to have come to a rather rapid halt.

Similarly, red spirals abound. While many spirals have a plentiful supply of gas to form stars, these red spiral galaxies no longer appear capable of forming stars. But unlike the elliptical galaxies, the red spirals seem to have experienced a protracted period of declining star formation. As they move from sparse environments to denser ones such as galaxy clusters, they gently slip from active growth by star formation to lower and lower star-formation rates over at least a billion years or so. Dramatic events such as galaxy collisions do not appear to be involved.

The user classifications also helped reveal some surprising results about the galaxies that feed their central supermassive black holes, and those that do not. We asked a simple question: What kind of galaxies feed their central black holes, and does the energy given off by the feeding black hole affect the gas and dust in the host galaxy?

The answer, it turns out, depends on whether the galaxy is a spiral or an elliptical. Ellipticals feed their black holes when they are passing from star formation to quiescence, suggesting that the black hole plays a role in this transformation. In contrast, spirals randomly feed their black hole, and the energy from their black holes does little to change their evolutionary trajectories.

But we were most surprised when we asked what kind of galaxy is most likely to feed its central black hole. It turns out that relatively massive spiral galaxies with rather anemic star-formation rates — in other words, galaxies like our own Milky Way — are the most likely. This is consistent with recent observations by high-energy space telescopes such as INTEGRAL and Suzaku that show that the Milky Way's central black hole was much more active in the very recent past.

Discovering Hanny's Voorwerp

Back in the summer of 2007, not long after the Galaxy Zoo project had gone live, Queen's guitarist and astrophysicist

THE DISCOVERER Dutch educator Hanny van Arkel became world famous in the astronomy community for discovering the strange "voorwerp" (object) that now bears her name.

Brian May mentioned it on his website. As a teacher I was on my summer break and was aimlessly surfing the internet when I came across these beautiful pictures. Brian mentioned you could help the astronomers — without being a scientist yourself — by sorting through the galaxies. And so I signed up.

Not even considering myself an amateur astronomer at that time, I read the tutorial carefully and looked at all the examples. Within a week of classifying galaxies I saw a picture on my screen with something I hadn't seen before: a bluish blob near the galaxy IC 2497. Not realizing that nobody had seen such a "thing" before, I asked what it was out of curiosity. But nobody had an answer.

After a year of investigations it became clear I had discovered something new, something rare. Another Zooite had quickly come up with the pet name Hanny's Voorwerp, which stuck even in the scientific papers for which I was invited to be coauthor. The Galaxy Zoo science team made sure that I, and the other Zooites, felt involved in the unraveling of this mystery.

Four years later I have traveled around the world, given interviews to

Citizen Science

The Galaxy Zoo citizen scientists, or Zooites as they soon called themselves, quickly built a community around the Zoo on our message board. The forum became a place for participants to share their favorite objects, organize their own science projects, and come up with astronomy-related puns.

One project that brought together all of these elements was the search for the "pea galaxies." The Zooites began spotting small, round, and green galaxies that they naturally called "peas." They formed the "peas corps" to give these unusual peas a chance. Upon closer inspection, Yale graduate student Carolin Cardamone, in collaboration with the citizen scientists, discovered that these peas are compact galaxies undergoing very intense bursts of star formation. They are very much unlike any galaxies in the nearby universe. Since the gas being turned into stars in the peas has not been polluted with heavy elements from previous episodes of star formation, they emit powerfully in doubly ionized oxygen, giving them their characteristic greenish color. Because the peas have an uncanny resemblance to galaxies in the early universe, the Zooites discovered living fossils.

A great advantage of humans over computer algorithms is the ability of the brain to spot something unusual or new. So when Zooite Hanny van Arkel, a teacher from the Netherlands, was shown the image of the galaxy IC 2497 and asked to classify it, she instead wondered about a neighboring blue blob (some images show it as green). The blob had been in publicly available data for years, yet it went unrecognized by sophisticated computer programs. She quickly posted a link to the image to the forum where the strange blog was named Hanny's Voorwerp ("object" in Dutch).

When our team was alerted to this strange object, we made the decision to post as much information as possible on our public blog as we investigated it. Data came in from a variety of telescopes and we simply reported what we saw on our blog. Hanny's Voorwerp turned out to be a large cloud of gas that is fluorescing after being energized by a quasar jet (June issue, page 14).

Citizen science is more than just asking the public to help with science projects; it's also about getting people around the world involved in research and to inspire them to pursue their own interests. On the forum, people with common interests got together to pursue projects and discussions. This involved amazing amounts of self-organization, from people creating their own classification interfaces to citizen scientists organizing their own meetings across the globe. Several citizen scientists were ultimately inspired to take their interests further and return to education.

In the meantime, the citizen scientists told us that what they really wanted was the opportunity to classify

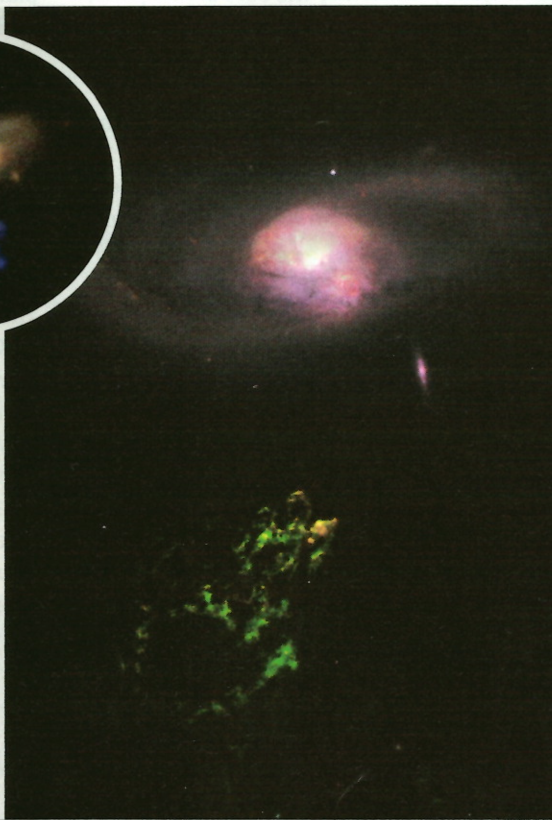
To view weblinks for currently active citizen-scientist Zooniverse projects, visit SkyandTelescope.com/GalaxyZoo.

international media, given lectures about the citizen-science project that taught me so much, and I am still involved in the outreach work. I co-moderate the Galaxy Zoo forum, I write and blog, and I show people how they too can participate.

It has been a wonderful experience, and best of all, I get to share what I have learned with a great bunch of people I met through the forum and whom I now consider to be some of my best friends. Needless to say, I'm very grateful to the Galaxy Zoo team.

***Hanny van Arkel** lives in Heerlen, the Netherlands, and teaches biology, Dutch, and English at the Citaverde College.*

SDSS



HANNY'S VOORWERP
Hanny van Arkel noticed a strange blue blob in the Sloan image at *left*. The later Hubble Space Telescope image at *right* shows Hanny's Voorwerp in more detail, and with a different color palette in which the blob appears green. Studies using HST and other professional telescopes provide a plausible explanation for the voorwerp: It's a gas cloud fluorescing after being blasted with energy from the active nucleus in the nearby galaxy IC 2497 (above the cloud). The active nucleus has recently shut down, but the blob continues to glow as a light echo. Citizen scientists have since found other voorwerps near galaxies.

NASA / ESA / WILLIAM KEEL / GALAXY ZOO

WILLIAM KEEL (UNIVERSITY OF ALABAMA)

ZOOITES During a meeting in 2009, members of the Galaxy Zoo science team posed with other interested scientists and citizen scientists in front of the Royal Greenwich Observatory in England. Hanny van Arkel is in the front row, wearing a solid green shirt.

galaxies in more detail than just sorting them into a few broad categories. Thus Galaxy Zoo 2 was born, where we asked users a series of questions about each galaxy to investigate features such as the number of arms and bars in spiral galaxies or the presence of dust lanes indicative of recent merger-induced star formation. Work by Karen Masters (University of Portsmouth, England) using Galaxy Zoo 2 results showed that bars are more common in red spirals. It's unclear yet whether the bars are responsible for turning spiral galaxies red, or whether they appear as a consequence of the slow shutdown of star formation.

Struck by the huge numbers of citizen scientists that joined the Zoo, we wondered why so many people around the world volunteered their time. Surveys sent out to users revealed the answer: people got involved because they wanted to actively contribute to research; they wanted to take part in the actual science.

Future

Although Galaxy Zoo 1 and 2 have officially come to an end, the wisdom of the crowd of citizen scientists across the internet has proved to be a powerful new tool in the arsenal of scientists trying to understand the universe. Inspired by the success of the Galaxy Zoo, new projects were born, first in astronomy but then spreading to topics further afield. The immediate successor of Galaxy Zoo is the Hubble Zoo (still at **www.galaxyzoo.org**), where users classify images of galaxies in the early universe taken by the Hubble Space Telescope. Citizen scientists can also explore the plane of the Milky Way Galaxy with the Milky Way Project (**www.milkywayproject.org**) and hunt for planets around other stars at Planethunters (**www.planethunters.org**).

The data flood in the coming decade is going to be one of the great challenges of astronomy. Professional astronomers will need to become proficient database managers and develop sophisticated statistical tools to cope with the output of facilities such as the Large Synoptic Survey Telescope (LSST), which will image the entire sky visible from its location in Chile every three nights. In order to make full use of the torrent of data, professionals will have to turn to citizen scientists for help in exploring it and making discoveries.

Crowd-sourced data mining will be a growing part of astronomy's future, especially after LSST comes online around 2020. I predict these projects will become a major way that new people find out about astronomy as a hobby and learn about science in general. Ultimately, citizen scientists will have to be an integrated part of the scientific process of large facilities, not just in astronomy, but in other fields as well. ✦

Listen to an AUDIO AUTHOR INTERVIEW

NASA / CARLA CIOFFI

To listen to an audio interview with author Kevin Schawinski, visit SkyandTelescope.com/GalaxyZoo.

__Kevin Schawinski__ is an Einstein Fellow at Yale University. He works on the formation of galaxies and supermassive black holes and their coevolution.