



FEATURES

The Hunt for Earth 2.0: An Interview with Professor Andrew Szentgyorgyi

Photo courtesy of NASA/JPL-Caltech

Ori Shi '29

Humanity has marveled at the mystery of the cosmos since the beginning of civilization. Although we first searched for answers with our naked eyes, we eventually developed telescopes for magnified observation, then invented complex electronic instruments to “see”—or rather, translate—numerous wavelengths beyond visible light. One leading pioneer of such technology today is Dr. Andrew Szentgyorgyi, Principal Investigator of the Giant Magellan Telescope (GMT)-Consortium Large Earth Finder (G-CLEF) project at the Harvard & Smithsonian Center for Astrophysics. Having previously worked across neutrino physics, high-energy astrophysics, and astronomical instrumentation, Dr. Szentgyorgyi is now building a spectrograph to detect Earth-like exoplanets.

Ori Shi (OS): Thank you for taking the time to speak with me! I would love it if you could tell me a little bit about yourself and what brought you to the Center for Astrophysics.

Andrew Szentgyorgyi (AS): I went to high school for three years, and I do not have a high school diploma. I tried

very, very hard for my PhD, but I couldn't make my first degree happen. So I went to Syracuse University School of Art for a while. It was the Great Recession of 1971–1972, so eventually my father couldn't pay the tuition, and I was thrown out of art school. After a bunch of jobs, I got a job in a machine shop in a physics department. I decided physics was a lot easier than art, so I majored in physics. After I started doing particle physics and cosmic ray physics about 33 years ago, Dan Fabricant—who's down the hall—and I started a group building a number of robotic things for the MMT Observatory, which is operated by the University of Arizona and the Smithsonian Institution. Now, the group that we have today builds fairly large instrumentation for really big telescopes, such as the Giant Magellan Telescope (GMT).

The instrument I'm building is called the GMT-Consortium Large Earth Finder (G-CLEF). It's the spectrograph to search for Earth analogs—or Earth 2.0s—and then interrogate their atmospheres for biomarkers.

It turns out that to find Earth 2.0, you don't actually find the planet itself. You measure the motion of the star that it orbits. As the planet goes in a big orbit, the sun itself shifts just a little tiny bit in response to the planet's

gravity. And as the star gets pulled back and forth, you look at the shift of its light's detected velocity (called a velocity shift), like a policeman measuring the speed of a car with his radar gun. In fact, the maximum velocity shift is 10 centimeters a second. That's about as fast as a Galapagos turtle walks.

So, to separate the shifts due to the planet from Earth's environmental effects, we put the spectrograph in a vacuum chamber. It's like the high-tech version of what they make surfboards out of—like fiberglass—except it's a \$3 million machine.

OS: Could you walk me through how exactly G-CLEF will use this light shift to detect oxygen?

AS: This is what the end product looks like: The G-CLEF breaks the light up into this high-resolution spectrum (Fig. 1). We optically take each little chunk and separate them out vertically, so it fits on a rectangle. Each one of these dark bands corresponds to something in the outer atmosphere of the star, the space between us and the star, or the Earth's atmosphere. And so you can use these bands to find out what the composition is.

But also, when you look at stars, you experience something called the Doppler shift. When the star moves towards you, this whole spectrum gets a little bluer. When it's moving away from you, the spectrum gets a little redder. And then, because our instrument is very stable, we can sense the motion of these dark lines going back and forth as the star moves, as I say, 10 centimeters a second.

This is the spectrum of a star called Procyon (the eighth brightest star in our night sky and part of the constellation Canis Minor). Here (orange boxes), you can see it has sodium in it. This big dark thing up here (green box) is because there's

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hydrogen. The important thing is, you see up here (blue box), there are these little, sort of regular dark bands. Those aren't the stars. They're here because light has to come through the Earth's atmosphere, and what you're seeing is the absorption of

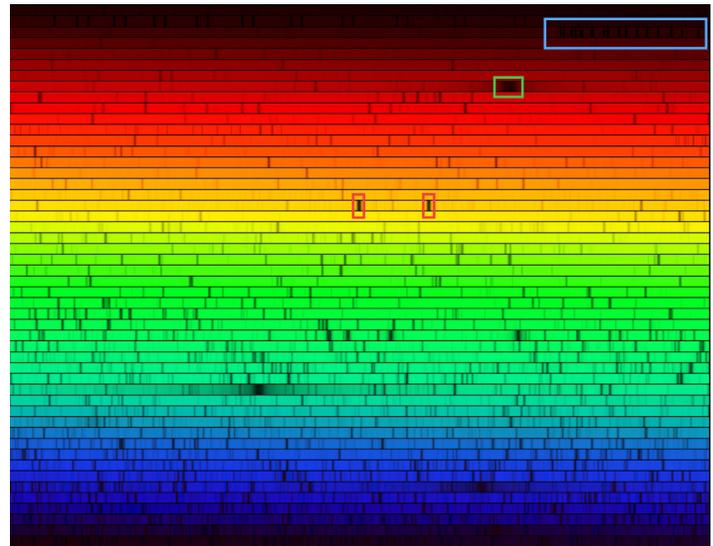


Figure 1. Light spectrum from the star Procyon featuring absorption lines from sodium (red boxes) and hydrogen (green box) in the star's gas, as well as Earth's atmospheric oxygen (blue box). Courtesy of Dr. Andrew Szentgorygi.

molecular diatomic oxygen in the Earth's atmosphere. That's really interesting, because the presence of oxygen is entirely due to life on Earth. Earth's atmosphere is about 21% diatomic oxygen, which doesn't happen naturally without life. If you turned off life on the surface of the Earth, that 21% oxygen would go down to a fraction of a percent in about 45,000 years. In terms of cosmic time, that's a heartbeat. That's why some of us feel strongly that the right place to search for evidence of life beyond the solar system is to look for these diatomic oxygen hallmarks in the spectra of exoplanets. When the exoplanet goes in front of the star, the star's light comes through the exoplanet's atmosphere, allowing us to see that atmosphere's makeup.

You might be worried that the oxygen in the exoplanet's spectra would be swamped by the Earth's atmosphere. But it turns out that because of the Doppler effect, all of those exoplanet atmosphere lines are shifted a little bit, so they're not right on top of Earth's lines.

To get these spectra, we collect light with the telescope and send it to the G-CLEF through an optical fiber. Inside the instrument, the light fans out, and ultimately, multiple cameras make an image right there on a charge-coupled device, the same thing in your iPhone.

OS: Since the G-CLEF is one component of the much larger GMT, could you tell me more about who else is involved in the GMT and the topics they're exploring?

AS: The GMT is actually a large consortium. The CfA is leading the development, but it also involves people from the University of Chicago, Carnegie Mellon University,

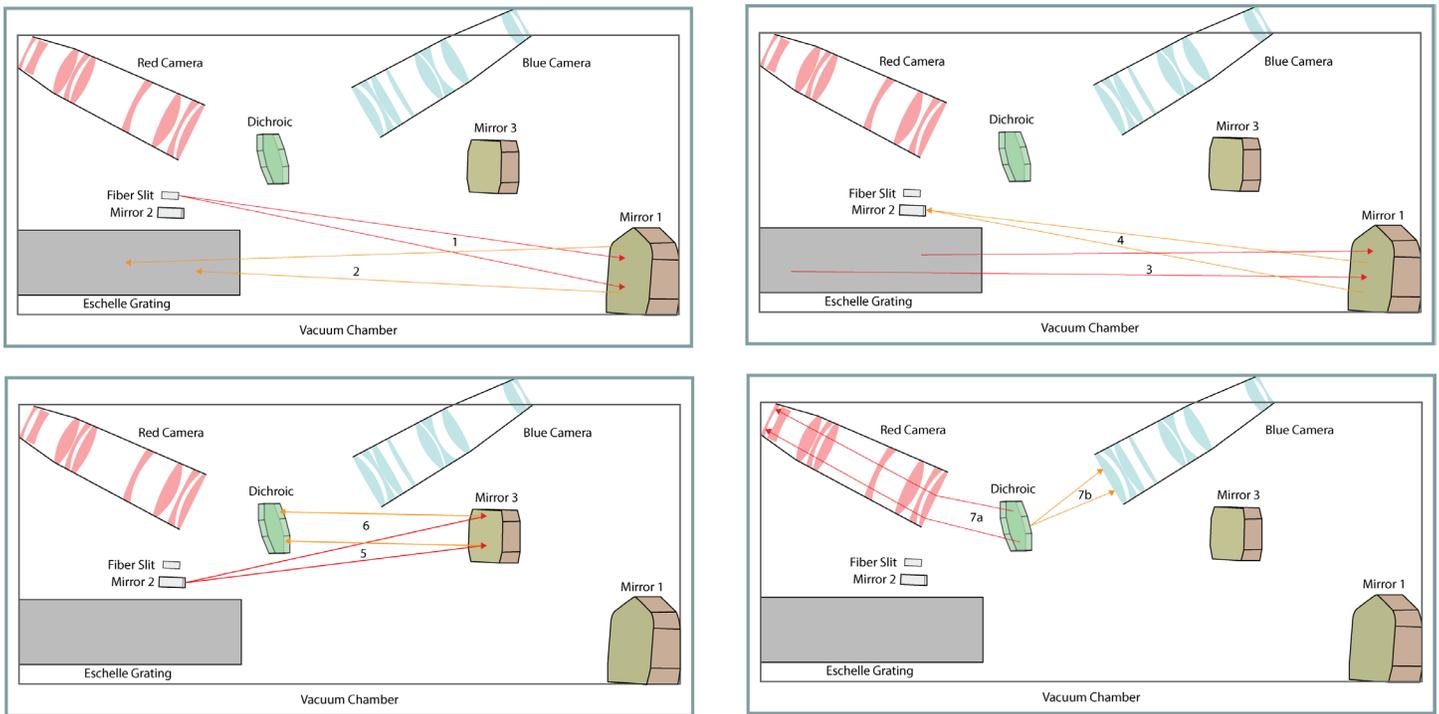


Figure 2. Labeled cross-section of the G-CLEF with received light’s path. Courtesy of Iris Sung.

the Massachusetts Institute of Technology, the Taiwanese Institute of Astronomy, the Korea Astronomy and Space Sciences Institute, the Weizmann Institute of Science in Israel, the University of São Paulo in Brazil, and many more. We’re also now expecting that the National Science Foundation will become a major partner, which means the whole United States astrophysics community will have access.

People will be doing a lot of different things. They’ll be looking at supernovas and doing research about dark energy in the universe. They’ll also be studying the earliest phases of structure formation in the universe and how planets and stars form. Other than Earth 2.0s, scientists will be using the G-CLEF to look for “ultra metal poor stars,” which are the fossils of the earliest stars formed 13 to 14 billion years ago.

In the last 40 years, we realized that the universe isn’t just a picture—it’s a movie. It’s a very, very dynamic place. So now, many people are studying what we call transient phenomena, which are stars exploding and black holes colliding. Many groups in the consortium will have a note that hangs on their boards that says, “If this kind of star goes off, stop doing what you’re doing and look at it.”

OS: We’ve talked a lot about the scientific importance of the G-CLEF and the GMT. But there are many who wonder if it’s worthwhile to spend billions on instruments

that look unreachably far away. How would you describe the value of instruments such as the GMT to society?

AS: There are lots of different takes on that. What I’m about to tell you is personal. I think that there’s a tendency to try and find practical applications that we develop in astronomy. I used to keep a list of things that astronomers discovered. But the list of things that aren’t curiosity-driven research is actually very small. And so my answer to you is that it’s important to cure disease, develop technology, grow the economy, and all of those wonderful things that keep people well fed and safe. But if you don’t interrogate what man’s place in the universe is, all that stuff becomes essentially meaningless.

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And I don’t just mean man’s place in the universe in terms of whether there’s life elsewhere. The universe is investigated by everybody: the humanities, philosophy, and creative arts. These are all endeavors to supply context for what it means to be human, and the minute you stop asking that question, you’re just an animal.

OS: That's very insightful. Speaking of life elsewhere, do you think it is probable that the G-CLEF will detect diatomic oxygen?

AS: Oh, well, I'm very agnostic about that. I don't want to pretend for a minute that I'm some gleaming hero who is finally going to answer one of the most fundamental questions. On the other hand, it's probably the first time in history where we really can, in a qualitative way, answer the question of how likely it is that we're alone in the universe. Even a null result would be really, really huge. I don't really care, almost. I'm mostly interested in finding out more.

I do want to say that, if I find evidence of diatomic oxygen in nearby exoplanets, that's not the end of the story. The European Southern Observatory is building a similar instrument. And if we find O₂ first, we need them to find it too and confirm. People always say, "Well, how do you know you *need* water and oxygen for life?" The answer is, I don't. But that's why we have to do this search.

This interview has been edited for length and clarity.