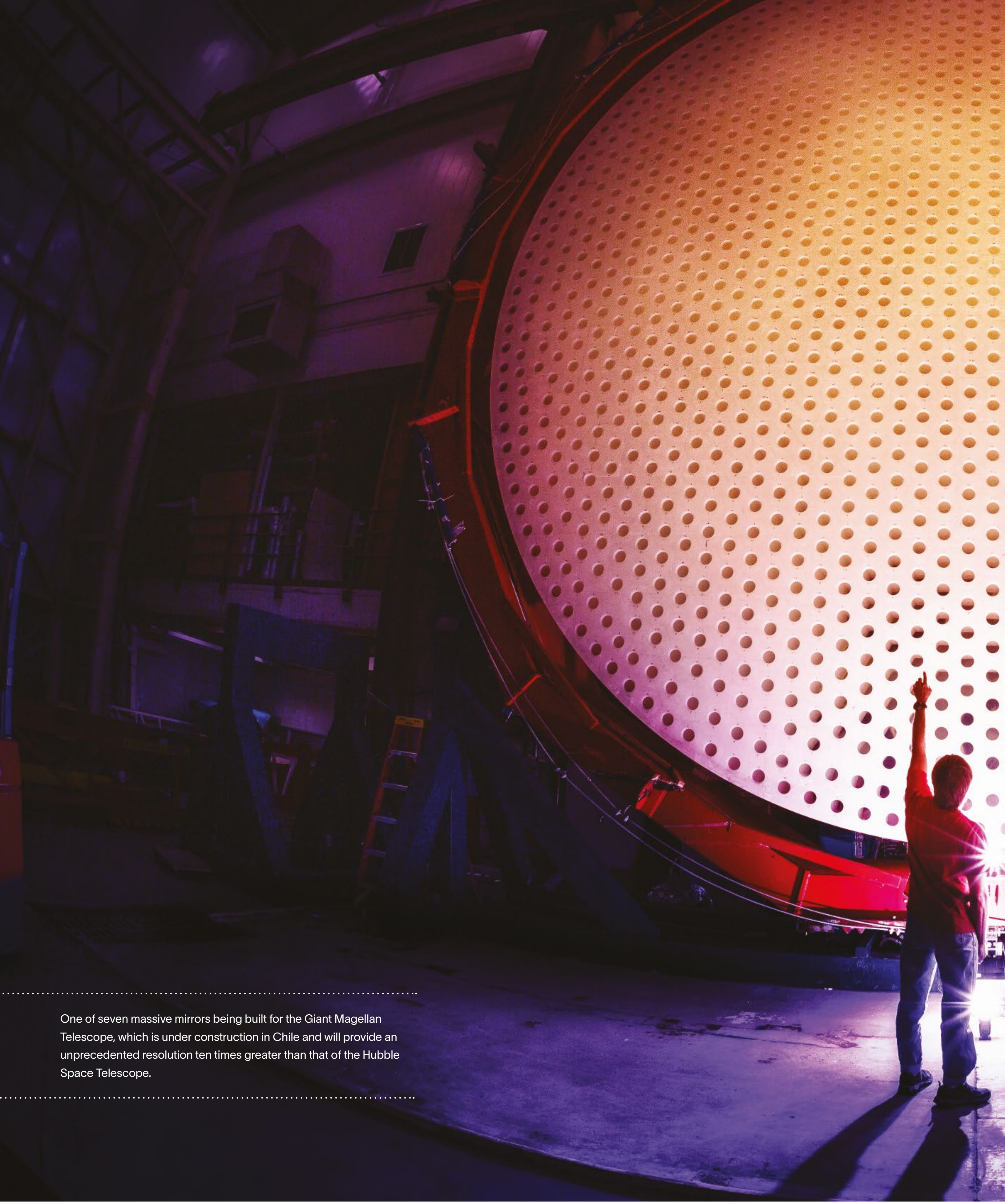


One of seven massive mirrors being built for the Giant Magellan Telescope, which is under construction in Chile and will provide an unprecedented resolution ten times greater than that of the Hubble Space Telescope.

EYES IN THE SKY

By Dan Rubinstein

ASTROPHYSICIST SAGI BEN-AMI BUILDS INSTRUMENTS TO PROBE THE ORIGINS OF THE UNIVERSE AND SEARCH FOR DISTANT LIFE

Growing up north of Tel Aviv, Sagi Ben-Ami spent as much time as possible in the fields and hills outside town, bringing a pair of binoculars and a notebook and scanning the sky for birds. He meticulously documented all the eagles, storks and vultures he saw — Israel is a stopping point on an important migratory flyway — and read all the birding and popular science books he could get his hands on. Today, Ben-Ami is still looking for life in the skies, only now as an astrophysicist who helps satellites and some of the world's most powerful telescopes search for clues about the origins of the universe and exoplanets with atmospheres that contain oxygen.

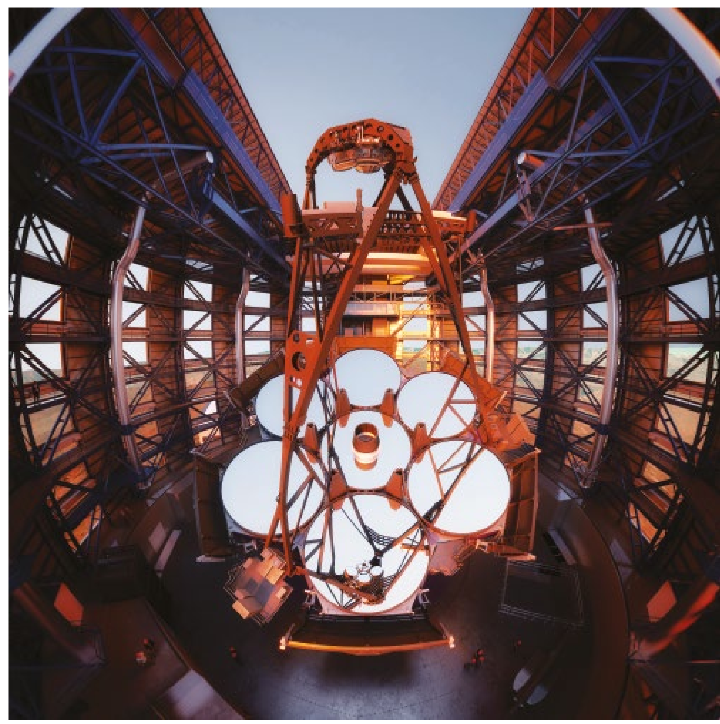
PHOTOGRAPH COURTESY GMTO CORPORATION

Ben-Ami, an Azrieli Early Career Faculty Fellow, is the head of the instrumentation group in the Department of Particle Physics and Astrophysics at the Weizmann Institute of Science. He moved back to Israel in spring 2020 after six years at the Center for Astrophysics | Harvard & Smithsonian, where he did a postdoctoral fellowship and then worked as an instrument scientist for five years. During his time in the United States, Ben-Ami continued to develop the type of technology that he began tinkering with when he was a PhD student at Weizmann.

Despite his omnivorous interest in all facets of science, Ben-Ami has become a specialist in the design and construction of spectrographs and fibre optic systems — instruments and interfaces that allow satellites and telescopes to capture and analyze light from distant stars. He was drawn to this area from high-energy physics because, unlike particle accelerators such as the Large Hadron Collider at CERN in Geneva, Switzerland (which he contributed to while working on his master's degree at the Technion – Israel Institute of Technology), astrophysics experiments tend to involve smaller teams and shorter timeframes. The $10 billion USD James Webb Space Telescope notwithstanding, astrophysics projects usually involve just a few dozen people, instead of several thousand collaborators chipping away for a couple decades, and projects can become operational within a few years, meaning that the impact one can have as an individual is more direct.

"There's something very physical about this work that I love," says Ben-Ami, whose PhD studies helped lead to the completion of a spectrograph called the SED Machine. It began collecting data at California's Palomar Observatory in 2016; since then, it has classified more supernovae — the source of virtually every element in the universe — than any other instrument. This has allowed researchers to sample rare celestial events such as superluminous supernovae (stellar explosions ten times more luminous than standard supernovae) and learn about the origin of heavy elements. Another spectrograph interface that Ben-Ami helped design, TRES, allows astrophysicists to distinguish between stars in binary systems and actual exoplanets. "You build a device for a telescope, it works, you get data," he says, noting that he is an "enabler" who builds instruments that others use to make illuminating discoveries. "There are some grey areas and approximations, of course, but we're studying things that are not based on what we think should happen. We're outside observers, trying to understand processes governed by laws we do not fully understand."

Ben-Ami is busy these days with a trio of major projects: designing a scientific payload for ULTRASAT, an Israeli-led satellite that's expected to launch within the next three years; collaborating with colleague Eran Ofek on the Weizmann Astrophysical Observatory, a network of telescopes that's being built in the Negev Desert; and building a spectrograph for the Giant Magellan Telescope (GMT) in Chile. The GMT, currently under construction at the mountaintop Las Campanas Observatory in the Atacama Desert, should be ready by the end of the decade. Its seven large mirrors are set in a hexagonal pattern and act in concert, forming a 24.5-metre diameter optical surface, and it will be able to collect 368



Sagi Ben-Ami is working on a spectrograph for the Giant Magellan Telescope (rendering above) that will help search for oxygen in the atmospheres of distant exoplanets, a biosignature that could indicate the possibility of life.

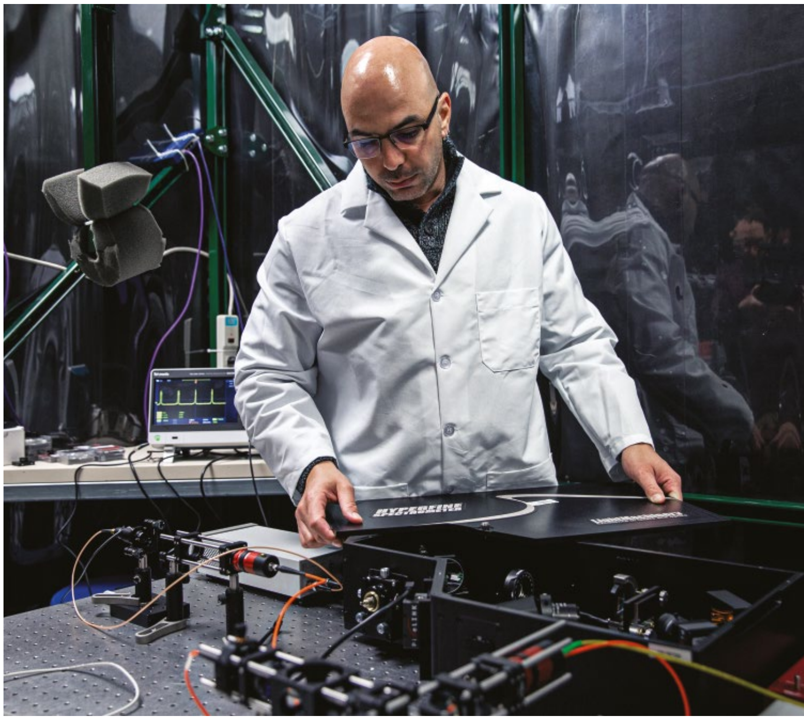
square metres of light — an unprecedented resolution ten times greater than that of the Hubble Space Telescope and four times greater than that of the recently launched James Webb Space Telescope.

Ben-Ami and principal investigator Andrew Szentgyorgyi at the Center for Astrophysics | Harvard & Smithsonian developed the GMT-Consortium Large Earth Finder (G-CLEF) spectrograph to be able to detect whether a star has an orbiting planet based on tiny movements caused by the gravitational pull of the planet. This will allow astronomers to determine the mass of Earth-sized planets, including some in a habitable zone that is far enough but not too far from their stars, where water could exist in liquid form on the planet's surface. When it is operational, G-CLEF will also be able to detect molecules in the atmospheres of these exoplanets, including oxygen, a biosignature that indicates the possibility of past or present life. There are already several strong candidates. Considering that scientists confirmed the existence of Earth-sized exoplanets for the first time about twenty-five years ago, this represents a tremendous leap forward.

Spectrographs work by breaking light into a spectrum of its constituent colours or wavelengths. The G-CLEF spectrograph, which will be connected to an already active pair of 6.5-metre Magellan telescopes in 2024 until the GMT is finished, will use a mosaic of dispersion grating to separate wavelengths of light based on the angle at which they emerge from the grating and record these wavelengths in a detector for analysis. When elements interact with light, unique information about those elements remains on the light. Every element leaves a specific fingerprint, allowing scientists to infer what the light touched on its journey toward Earth.

With this ability, and because the GMT will be able to observe faint targets, Ben-Ami believes that it could reveal whether any of these exoplanets have atmospheric oxygen. "One of the things we've learned from studying our own planet is that oxygen is the best sign of life," he says. "Given the fact that our planet is the only example of life that we have, it makes a lot of sense to look for oxygen."

Nearly twenty tons of glass (below) are put into a mould for each of the Giant Magellan Telescope's primary mirrors (left). The instrument will give astrophysicists such as Ben-Ami (below right) new insights into the origins of the universe.



IMAGES (FACING AND ABOVE) COURTESY GMTO CORPORATION; PHOTOGRAPH (RIGHT): CENTER FOR ASTROPHYSICS | HARVARD & SMITHSONIAN

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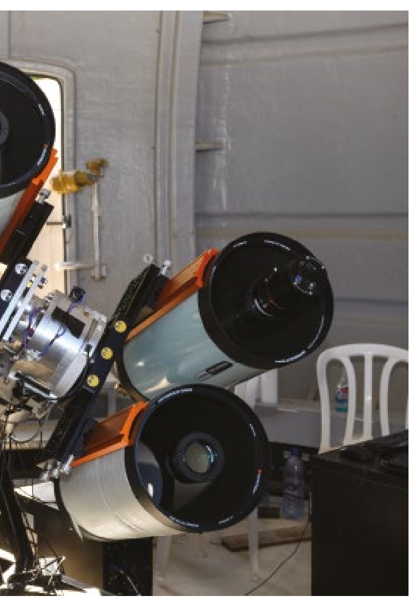
Ben-Ami and colleagues Juliana Garcia-Mejia and Surangkhana Rukdee (middle, left to right) at work at the Center for Astrophysics | Harvard & Smithsonian before he moved to the Weizmann Institute of Science. In addition to the Giant Magellan Telescope (top and left), Ben-Ami is also contributing to the Weizmann Astrophysical Observatory, which has set up some of its telescopes on the university’s campus (right) while the full network is being built in the Negev Desert.



IMAGES (TOP AND ABOVE LEFT) COURTESY GMTO CORPORATION; (MIDDLE) CENTER FOR ASTROPHYSICS | HARVARD & SMITHSONIAN; (RIGHT) WEIZMANN INSTITUTE OF SCIENCE

For the G-CLEF spectrograph to achieve the precision needed to measure the velocity of a distant star within ten centimetres per second, the spectrograph will be housed in a vacuum vessel about twenty metres away from the telescope to avoid any vibrations. Ben-Ami is designing a novel fibre optic system to connect the two, work that's predominantly taking place in his fibre lab at Weizmann, where he can determine the transmission properties of different types of fibre. He is using a unique twenty-five-micron fibre (a micron is one millionth of a metre) that will allow spectra to be captured by the detector in real time at an extremely high resolution.

"At the end of the day, one of the things that I think is really astounding is that it'll be a 24.5-metre telescope feeding a 25-micron fibre," says Ben-Ami. "This is a very difficult task that will require a closed loop of alignment across all the different components in our system. We're now testing different optical fibre geometries to make sure that the mating of the telescope to the instrument actually works.

"One of the biggest advantages of working in the academy is that you never need to do the same thing twice," he continues. "I don't want to build the same instrument I built yesterday. I want to work on something new. In the academy, unlike a company that needs to manufacture a product, we manufacture one-offs. We do one product and when it's finished, we move on to something new."

This fibre optic system can be adapted for use in other projects, such as linking a network of seventeen telescopes at the Weizmann Astrophysical Observatory, which is projected to be running within the coming year. This modular network is a powerful, cost-effective way for researchers to gain a large amount of spectroscopic data from various sources and phenomena, and decide which of these targets should be further observed with larger telescopes such as the GMT.

Meanwhile, for the ULTRASAT project, Ben-Ami is designing an ultraviolet (UV) telescope that will be able to take 200-square-degree images of UV light, which doesn't penetrate Earth's ozone layer. Ultraviolet light is important in astrophysics for several reasons. The first emissions from a supernova emerge in the UV range, Ben-Ami explains, so if you want to learn about the radius and other characteristics of a star that has exploded, you can't wait for the visible light. ULTRASAT will be able to detect and measure the emissions from explosions minutes after they occur, much faster than today's telescopic systems. "It's very difficult to know what a glass looked like after you throw it onto the floor and it breaks into a thousand pieces," says Ben-Ami. "If I can observe it at the moment that it hits, it has more of the shape of a glass. This is why we want UV."

Measuring the UV emissions from various stars is another way to look for environments that could support life. Ultraviolet light was also an important source of energy during Earth's early stages. Too much UV radiation would have broken biomolecules apart, but high enough levels were necessary to generate the chemical reactions that led to prebiotic molecules and the origins of life. "Characterizing UV radiation from stars will tell us which ones are more likely to host planets that can harbour life," says Ben-Ami.

"I don't think we're unique, that Earth is the only place with life," he adds. "I don't think I'll ever see little green men coming to visit us and I don't know if we'll find anything in my lifetime. But I won't be disappointed, because the journey is at least as much fun as the discovery itself. And if this is your approach, then you'll do good science because you're allowing yourself to be open to new things." ▲●■