less weight and are much less likely to survive the next winter.

He points out that although Adélie populations have fluctuated over millennia, the current decline is unprecedented. Within a decade, there may be no more Adélies within 200 kilometers of Palmer Station.

This doomsday prediction doesn’t tell the whole story, however. As Adélie penguins lose ground, other species are thriving. Species that prefer open ocean used to be limited to the north and east parts of the peninsula, where the ocean didn’t freeze during the winter. Now, with ever more open water, these species are expanding their ranges.

In the past decade, Palmer Station has seen a huge proliferation of southern fur seals and southern elephant seals—species that were present only as small colonies in the 1990s. In one case, a population of six seals now numbers 5000. The presence of these species suggests that a sub-Antarctic ecosystem is replacing the polar ecosystem of Adélies and silverfish.

But as this ecosystem moves southward, so too is the “polar” world, and that’s good news for the overall survival of Adélie penguins. Some 400 kilometers south of Palmer Station, the populations of Adélies in Marguerite Bay have tripled since the 1950s. Just as Adélies don’t like a lack of ice, they also dislike a surfeit—the greater expanse makes it strenuous to reach open water for foraging. The warming climate and reduced sea ice are apparently making Marguerite Bay a nicer place for Adélies to live. That’s true farther south too, says David Ainley of H. T. Harvey & Associates in San Jose, California, who studies Adélies in the southern Ross Sea. “As ice shelf breaks up, there should be more habitat, and we should be seeing more penguins.”

Still, Ainley and others caution that it’s dicey to predict exactly what will happen as ecosystems continue to respond to climate change. But looking back on the fate of the Adélies he has watched for 3 decades, Fraser offers a warning: “If Antarctica is a model for how ecosystems might change in other parts of the world, the changes will be severe.”

—ERIK STOKSTAD

For Extreme Astronomy, Head Due South

Over the past decade, small telescopes in Antarctica have revealed key features of the early universe. Now astronomers are rolling out the big guns

Some astronomers choose to build telescopes in idyllic locations—atop Mauna Kea in Hawaii, for instance, or in the Canary Islands. Not John Carlstrom. During the just-finished austral summer, his team shipped 270 metric tons of equipment to the South Pole and raced to assemble a new radio telescope with a 10-meter dish before winter shuts down flights and maroons Amundsen-Scott South Pole Station for 9 months. “Everything has to be ready to go,” says Carlstrom, of the University of Chicago in Illinois. “There’s only so much you can do in 3 months.”

To extreme astronomers, Antarctica’s uninvaded view of the stars makes the prodigious and risky work to build a scope there worthwhile. Water vapor, the enemy of radio astronomers who tune in to microwave signals, is virtually absent at the bone-dry pole. And microwaves are not the only game in town. Alongside Carlstrom’s South Pole Telescope (SPT), a giant neutrino observatory, IceCube, is taking shape.

They are the vanguard. Surveys on the Antarctic plateau have pinpointed perches with little atmospheric turbulence, ideal for astronomy at infrared wavelengths. “These are the best sites in the world by a big factor,” argues astronomer Edward Kibblewhite of the University of Chicago. As a result, optical astronomers are hatching plans for front-rank observatories across the frozen continent.

Some astronomers are hedging their bets on whether the risk is worth taking. “Almost every common system that we use at our very large telescopes now would fail in the extreme conditions in Antarctica,” says Daniel Fabricant of the Harvard-Smithsonian Center for Astrophysics in Cambridge, Massachusetts. Today’s pioneers have yet to prove that big optical or infrared scopes in Antarctica are feasible, he says. Kibblewhite, for one, is taking up the gauntlet: “The pain of building there is offset by the fantastic capabilities.”

Cold, high, and dry

Since the early 1990s, astrophysicists have eagerly pitched camp in Antarctica to study the cosmic microwave background (CMB) radiation, a relic of the early universe when the plasma of electrons and protons coalesced into atoms and the universe became transparent. Over the eons, photons from that primordial fog have cooled to microwave wavelengths. Since the CMB’s discovery in 1965, researchers have interrogated it for clues to what the universe was like in those early days and to test various models of the big bang.

Because water vapor absorbs microwaves, CMB astrophysicists must put their telescopes in space or some other ultradry place. Some flocked to mountaintops or deserts. Others chose Antarctica, where moisture freezes out of the air. Early scopes on the ice looked for wrinkles in the CMB—variations in the radiation’s temperature across the sky. The field really took off after the Cosmic Background Explorer satellite charted wrinkles over the whole sky in the early 1990s. The satellite’s map revealed an early universe of uneven density, in which denser regions led to galaxy clusters seen today.

Continuing the work, the Degree Angular Scale Interferometer, based at the South Pole, discovered in 2002 that CMB radiation is slightly polarized, giving a picture of how regions of different densities were moving early on. And BOOMERANG, a CMB telescope flown over Antarctica by balloon in 1998 and 2003, allowed cosmologists to estimate the universe’s overall density, leading to the conclusion that spacetime has no overall curvature: The universe is flat.

The latest CMB scope at the pole is QUaD. It is scrutinizing polarization in an attempt to put limits on certain properties of the early universe, such as how much normal matter there was. But in QUaD’s first season in 2005, the experiment almost ground to a halt when it nearly exhausted South Pole station’s liquid nitrogen and helium, used to chill the scope’s detectors to 0.3 kelvin. “The biggest challenge is having no access [during the winter],” making maintenance difficult, says QUaD astronomer Walter Gear of the University of Cardiff, United Kingdom.
Another recent arrival at the pole is the Background Imaging of Cosmic Extra-galactic Polarization (BICEP) telescope. BICEP aims to answer one of the burning questions of cosmology. Big bang theory predicts that the infant universe underwent a rapid expansion known as inflation. It’s impossible to peer into the opaque young universe to verify that inflation occurred. But if it did, it would have created a cosmic per- fusion of gravitational waves—something absent from other theories. The technology does not exist to detect a gravitational-wave background, but the waves should have left a faint fingerprint in the form of a slight swirl in the CMB’s polarization. BICEP is the first scope designed to detect this, says project leader Andrew Lange of the California Institute of Technology in Pasadena.

To perceive gravity’s subtle signature in the early universe, a telescope must peer at one patch of sky for days on end. “At the South Pole, you can stare relentlessly at the target,” Lange says, because the same stars circle the pole at the same elevation. After BICEP’s first season last year, the team is honing its detectors and expects to reach the required sensitivity in the next year or two. “We could see something soon,” says Lange.

**Big science arrives**

With the installation of the 10-meter SPT, a behemoth has taken its place beside the much smaller scopes. Although the CMB is also the target of this newcomer, its principal goal is not to study the early universe but rather to probe the nature of dark energy, a mysterious, unseen force that is speeding up the universe’s expansion. SPT will study the evolution of galaxy clusters over the universe’s history. Because dark energy seems to push everything apart, it inhibits the growth of galaxy clusters over the universe’s history.

“SPT will look for the imprint they have left on the CMB as it has wafted through space,” Lange says, because the same stars circle the pole at the same elevation. After BICEP’s first season last year, the team is honing its detectors and expects to reach the required sensitivity in the next year or two. “We could see something soon,” says Lange.

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Building the delicate instrument at the pole was no mean feat. All moving parts must be sheltered for warmth, while the exposed dish’s aluminum panels are kept ice-free with electric heaters. It took three field seasons to assemble the scope; after finishing its construction in January, most SPT crew members flew home and will control the scope from the relative comfort of Chicago. Three colleagues will winter at the pole to ensure SPT runs smoothly. The scope saw first light on 16 February, and Carlstrom expects initial science results this austral winter.

SPT’s completion was a sprint compared to IceCube, one of two major rivals in observing neutrinos from deep space. These particles are born in the hearts of stars and cosmic calamities such as supernovae and gamma ray bursts. They are chargeless, nearly massless, and race by at close to light speed. Space is teeming with them. But they rarely interact with normal matter. Billions pass right through your body every second without ever interacting.

Researchers detect the ghostly particles by putting a large volume of water under surveillance. After a neutrino strikes a nucleus, the streaking subatomic shards produce a flash of light that spreads in a cone shape. The cone’s orientation reveals the direction the neutrino came from, making it possible to retrace the neutrino’s path—but perhaps all the way back to the cosmic event that spawned it.

Researchers estimate that roughly a cubic kilometer of water is necessary to get a fix on neutrino sources. A European team plans to use the Mediterranean as an instrument by floating strings of detectors anchored to the sea floor. Their U.S. counterparts are using ice rather than water, boring into the Antarctic plateau with a hot water drill and then lowering strings of detectors into the holes, which will fill with water and freeze. It’s a mammoth undertaking. Each borehole is 2.5 kilometers deep, takes 48 hours to drill, and creates 750,000 liters of water.

IceCube’s crew members have been honing their techniques: Two years ago, they dug a single hole; in 2005–06, they managed eight; and this season, the team sank 13. The target is now 14 holes per season; with at least 70 planned, installation has a few years to go.

Other astronomers, inspired by the groundbreaking polar work, are hoping to get in on the action. Three years ago, Michael Burton and his colleagues at the University of New South Wales in Sydney, Australia, used an automated test scope to survey Dome C, a bulge on the plateau that’s home to the French-Italian Concordia station. There they found “uniquely stable conditions,” Burton says, “two times better than any temperate latitude site.” The key is scant turbulence above about 30 meters that can be corrected using adaptive optics, Kibblewhite says.

As part of the International Polar Year, the Australian team in 2007–08 will set up another test scope at Dome A, where China has ambitious plans for astronomy (see p. 1516). The Australians’ long-term goal is to erect a 2-meter telescope called PILOT at Concordia. “Big enough to do interesting science, but not too expensive,” Burton says. PILOT’s images, he predicts, will be similar in quality to those of the Hubble Space Telescope. Kibblewhite and U.S. collaborators have grander plans: a 15-meter telescope at one of the domes, with a mirror made of many small segments to reduce weight and cost. Planning is in the early stages.

Kibblewhite believes that with astronomy’s history of international collaboration, it won’t be long until nations work together to build large observatories in Antarctica. If so, they will owe a debt to Carlstrom and other polar astronomy pioneers.

—DANIEL CLERY