Karoo contender. The four sites competing for the SKA's core include this stretch of the Karoo semidesert in South Africa.

RADIO ASTRONOMY

Candidate Sites for World's Largest Telescope Face First Big Hurdle

For more than a decade, the Square Kilometer Array has been a paper project, an instrument for astronomers to dream about. Now it's time to start getting real

CAPE TOWN, SOUTH AFRICA—One site is a barren tract of South Africa's Karoo semidesert, so quiet that the only sound is a hawk's cry. Another, 12,000 kilometers away, is an arid plain that stretches to western Australia's horizon. Yet another site is across the Pacific Ocean, in Argentina's high, dry plateaus; the fourth is nestled in natural bowls between the angular karst hills of southeastern China.

The challenge for a select group of radio astronomers this summer is to recommend which site would potentially make a suitable home for the largest astronomical instrument ever built: the International Square Kilometer Array (SKA). Planned as a network of some 4000 radio dishes spread over an area several thousand kilometers across, SKA—whose name refers to the total collecting area of the planned instruments—will be 100 times as sensitive as today's best radio telescopes. In choosing which locations will work, SKA's international steering committee is looking for a stable ionosphere, predictable weather, and good infrastructure. But radio silence, perhaps above all else, is golden, as is the host government's ability to maintain it.

At a meeting in Germany at the end of this month, the committee is to whittle down, on scientific and technical grounds, the current four to a short list of acceptable SKA sites. Then begins the delicate political dance of persuading funders to bankroll it and agreeing on the final site.

With a price tag likely to be at least $1 billion, the SKA collaboration is treading carefully. The project has already been working for more than a decade; a reference design for the telescope was completed only this year, and the array itself is unlikely to be finished before 2020. But the team doesn't want to force the pace and fall into the traps that have beset other recent international collaborations such as the International Thermonuclear Experimental Reactor (*Science*, 1 July 2005, p. 28) and the Atacama Large Millimeter Array (ALMA), a telescope under construction in Chile (*Science*, 19 May, p. 990).

From the start, SKA has been a grassroots project, and with scientists at more than 50 institutes in 17 countries involved, there is a strong emphasis on collaboration. Bo Peng of China's National Astronomical Observatories in Beijing says that SKA "has been a very successful international project for a decade, on the basis of cooperation, not so much competition for SKA science, technology, and even site ranking."

In the competing regions, the site selection has energized radio astronomy and engineering with new instruments, more government backing, and scientific networking. "It is having a tremendous focusing impact on scientists," says Netherlands-based astronomer Richard Schilizzi, director of the SKA project.

"The collaboration is fantastic," agrees Australia's SKA planning office chief, astrophysicist Michelle Storey, "not only within Australia's radio community but also among astronomers from all the countries involved in the SKA." Astronomer Justin Jonas, South Africa's SKA project scientist, foresees "a tremendous boost to astronomy and to science in general in southern Africa." Jin Chengjin of the National Astronomical Observatories says his nation's radio-astronomy community is being opened up by the SKA effort because "the competition helps us in communicating with international astronomical and technological communities." Ricardo Morras of the Argentine Radio Astronomy Institute says winning the SKA site would be "a major breakthrough in the history of radio astronomy in Latin America."

What a dish. China's proposed SKA site lies in a lush valley surrounded by karst hills. Proponents say natural depressions there are ideal for building fixed dish antennas.

Probing dark matter and energy

SKA's main aim is to search for faint radio signals from the most distant reaches of the universe, helping scientists examine clues to what existed before the first stars were born and to probe the nature of dark matter and dark energy.

CREDITS (TOP TO BOTTOM): ROB MILLENAAR; CHINESE NATIONAL ASTRONOMICAL OBSERVATORIES

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George Miley of Leiden University in the Netherlands says the instrument has the potential to be "a giant step forward for radio astronomy." By exploiting new technologies such as steering the observing direction electronically instead of by moving the dish, unprecedented supercomputing power, and multibeaming—observing several regions of the sky simultaneously—SKA will attain orders-of-magnitude improvement in frequency resolution and the area of sky that can be observed at any given time.

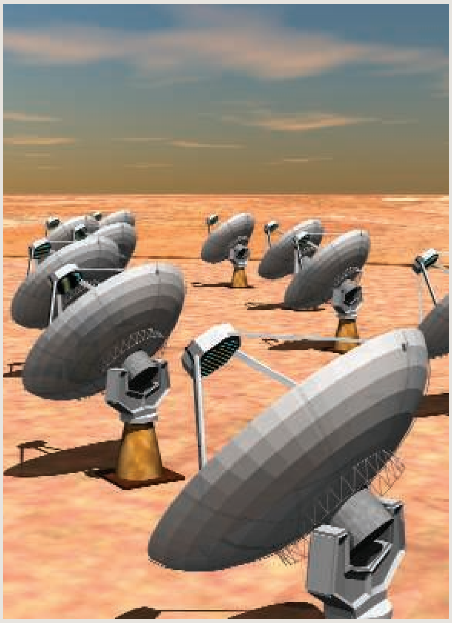
Astronomer James Cordes of Cornell University, head of the U.S. SKA team, agrees that the telescope "will be a fantastic discovery instrument." Schilizzi points out that "radio astronomy over the years has resulted in many unexpected discoveries, from the cosmic microwave background to pulsars to quasars to dark matter in galaxies." By peering into the early universe, SKA "will give us a handle on the effects of dark energy and its evolution as the universe expands," he adds.

Miley says data from SKA would help scientists study astrophysical phenomena that are impossible to probe using optical telescopes or millimeter arrays such as ALMA. Examples include neutral hydrogen, a diagnostic of the early universe in an era before the first galaxies formed, and synchrotron emission, radiation given off when electrons are accelerated—a unique probe of magnetic fields throughout the universe.

From KAT to FAST, Telescope Project Sprouts Test Beds

High-tech radio-astronomy dishes are popping up in several remote areas of the world as demonstrators for the International Square Kilometer Array (SKA). Although each will be only a tiny fraction of the size of the planned SKA, the instruments will be capable of conducting cutting-edge science. Scientists in three of the candidate countries—Australia, China, and South Africa—have persuaded their governments to back the design and initial construction of prototype projects that are roughly 1% of SKA's dish area or smaller but that would demonstrate key technologies near the same core sites that are proposed for SKA itself.

Australia's Extended New Technology Demonstrator (xNTD) is planned as a full-system prototype, making use of an innovative phased focal-plane array, a detector made of a patchwork of antenna elements that can steer its field of view electronically. The demonstrator, operating over the frequency range of 0.8 to 1.8 gigahertz, will be built at the Mileura site, with completion targeted for 2009. Others are in the works too: the SKA Molonglo Prototype from the University of Sydney for low-frequency radio astronomy, and the Mileura Widefield Array–Low Frequency Demonstrator, built in partnership with the Massachusetts Institute of Technology's Haystack Observatory.



Aussie array. Artist's drawing shows part of the array of dishes planned for Australia's Extended New Technology Demonstrator (xNTD).

Meanwhile, South Africa's planned Karoo Array Telescope (KAT) is expected to have 20 dishes, each 15 meters in diameter, with innovative "smart" feeds in the focal plane. The South African government has committed the equivalent of about $50 million so far, and the prototype dish will be ready next year, with first light in 2009.

China's planned demonstrator instrument, the 500-meter-diameter Aperture Spherical Radio Telescope (FAST), would have a cable-supported reflector made up of 1800 hexagons—the world's largest single dish. Built in one of the karst depressions in Guizhou Province that are envisioned to be part of SKA, FAST "may be seen as a forerunner or prototype of the Chinese SKA concept," says Jin Chengjin of the National Astronomical Observatories in Beijing.

Although FAST is a somewhat different design, astrophysicist Michelle Storey, head of Australia's SKA planning office, says KAT and xNTD "are similar in many ways." That's a reason to be cautious, says Renee C. Kraan-Korteweg, who heads the University of Cape Town's astronomy department. It is important for the SKA competitors to make sure their demonstrator instruments and scientific goals complement one another. "Both the KAT and xNTD are interesting scientific instruments. But we need to communicate and avoid doing the same things," Kraan-Korteweg says.

No matter where SKA itself is eventually located, director Richard Schilizzi says, "all of these projects will generate great science, and technically they are taking innovative approaches, for example in terms of utilizing focal-plane arrays." They are also fostering a sense of community, says Kraan-Korteweg: "There is competition at one level, but there also is a great deal of collaboration, especially with the Australians and the groups at ASTRON [in the Netherlands] and in England. The Australian and South African groups have been sharing information in a cooperative way." **–R.K.**

Site competition, science cooperation

But there is much still to do before observations can begin. Officials of the four national site planning offices have been competing hotly behind the scenes. On 4 July, a parade of these officials presented their proposals separately at a meeting in Cambridge, U.K.

The Australians argue that their core site in Mileura and their proposed remote sites have the lowest radio frequency interference (RFI) and that all are located in Australia, with the option of extra stations in New Zealand. Australia has a "very strong tradition in radio astronomy," Storey says, and several of its leading universities already are intensely involved in SKA research and development.

The South Africans contend that their site, northwest of the town of Carnarvon in the arid Karoo region, offers "very good radio-quiet status, excellent ionospheric and tropospheric conditions, strong government support and infrastructure," says former astronomer Bernie Fanaroff, South Africa's SKA chief. Remote array stations would be located in seven other African countries, bolstering astronomy and engineering across the southern part of the continent.

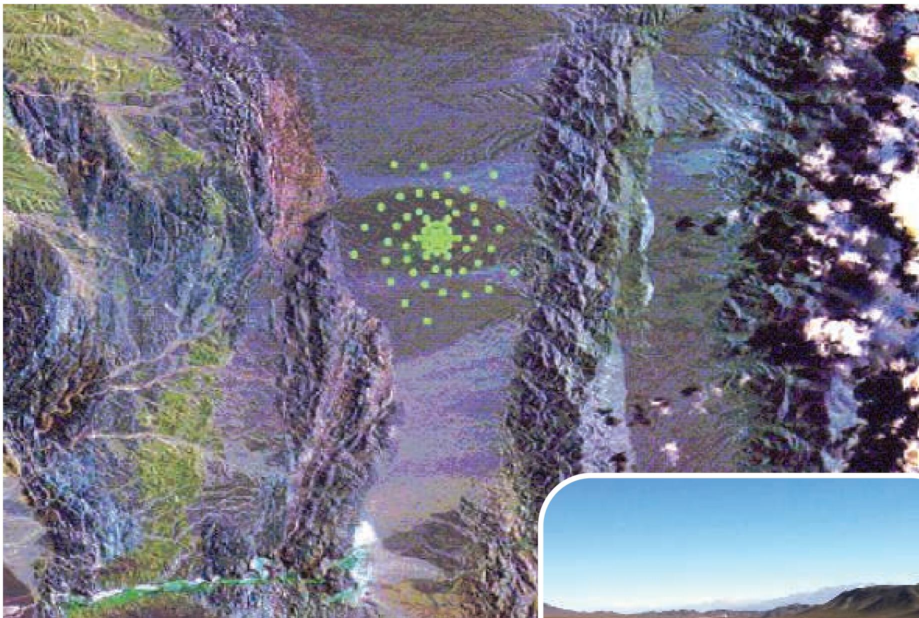
The Chinese say their bid is strong because of the site's relatively quiet electromagnetic environment and because the karst depressions offer the possibility of building a smaller number of huge static dishes, which would "ease the correlation process and help in calibrating the network effectively," Jin says. He adds that the valleys offer "good local shielding against radio interference from outside."

The Argentineans maintain that their site, in a high, arid plain about 1100 kilometers west of

CREDIT: CENTRE FOR ASTROPHYSICS & SUPERCOMPUTING, SWINBURNE UNIVERSITY OF TECHNOLOGY

Buenos Aires, offers the best combination of key factors. Morras says the proximity of existing or planned "frontline 21st century astronomical facilities," such as ALMA, the European Southern Observatory's Very Large Telescope, and the Magellan 6-meter telescopes, all sited in Chile, "will allow simultaneous observations with a great number of telescopes operating on a wide range of different frequencies."

Each site also has its drawbacks. Some astronomers worry that the ionosphere above the proposed Argentine location is less stable than that over the others. Morras concedes that "there are signal fluctuations, known as ionospheric scintillation, in that region." But he says the Argentinean site's core "is near the southern limit" of the scintillation phenomenon.



Big sky country. Artist's drawing (*above*) shows possible dish array at SKA core site on a high, arid plain (*right*) near the Andes Mountains in Argentina.

CREDIT: SKA

The China site, meanwhile, is in the Northern Hemisphere, which would limit SKA's ability to observe our Milky Way galaxy, whose center is visible in the Southern Hemisphere. Another possible disadvantage, Jin concedes, is that the site's humid climate "is not suitable for observations at frequencies higher than 10 gigahertz."

Regional politics may also become an issue. South Africa's roping in of Namibia, Botswana, Mozambique, Kenya, Madagascar, Ghana, and Mauritius has the advantage of boosting the bid's political clout but could also increase the risk that politics or economic problems might affect the remote stations. The Australian site, meanwhile, does not share any part of the sky with Europe and may involve higher construction costs.

In an effort to keep down levels of RFI from humanmade sources such as cell phones, TV transmitters, car ignitions, and power lines, Australia, South Africa, and Argentina are establishing "radio-astronomy reserves" around their candidate sites. Proximity to major cities could be another big RFI headache; one analysis suggests that the SKA core site would need to be at least 500 kilometers away from major urban centers. This could be another problem for the Argentinean site, which has two cities located about 100 kilometers away.

Power and money

Although the details of the final design cannot be fixed until the site is known, SKA will likely include a network of 4000 or more small dishes (each about 10 meters in diameter) operating at frequencies from 1 to 25 GHz and aperture arrays (flat collections of detectors, looking a bit like solar panels, that can see many parts of the sky at once) operating from 100 MHz to 1 GHz, all connected together in a giant interferometer. Half of the total collecting area will be concentrated in the 5-kilometer-wide core, with the rest spread over several thousand kilometers.

SKA's current timeline calls for system design to begin in 2008—by which time the final site should have been chosen—and for construction to start on the first 10% of the collecting area in 2011. SKA would start collecting data in 2014 and would be fully operational by 2020. That scope and schedule depends on funding. So far, the largest contributions in the current Pathfinder phase have come from Europe (€10.4 million from the European Union and €28 million from national funding agencies) and from in-kind R&D contributions from South Africa and Australia related to their demonstrator projects (see sidebar, p. 911).

The biggest funding question mark is the U.S. National Science Foundation (NSF), which so far has avoided making a firm commitment. "We foresee that this will be an issue for the next Decade Survey, which is likely to start in about a year from now," says the director of NSF's astronomical sciences division, Wayne Van Citters. He adds that, given NSF's commitment to complete ALMA and other major projects "that are more advanced in planning" than is SKA, "we are realistically quite a few years away from any consideration of a construction project of this magnitude."

Over the past 4 years, NSF has provided about $1.8 million for SKA "technology development" in grants to Cordes's team at Cornell. The U.S. SKA team has also been kept busy with university funding and money from the likes of Microsoft Corp. co-founder Paul Allen. Allen has part-funded the Allen Telescope Array (ATA), formerly called the One Hectare Telescope, a joint effort by the SETI Institute and the University of California, Berkeley. The ATA project has involved developing many components relevant to SKA, such as relatively inexpensive antennas and mounts, broadband feeds, and some signal-processing hardware. Schilizzi says the American work on the Allen instrument "will be of crucial importance to the technology of the SKA."

NSF's initial reluctance to commit large sums to SKA was a major reason why the U.S. SKA consortium opted last year not to submit a site proposal, Cordes says. But Schilizzi says he is "still hopeful" that NSF eventually will allocate substantial money to the project. "It may be that funding will come in a phased way, with one region dominating the early funding and another region contributing more later," he says.

Such staggered funding would not be at odds with the slow but steady approach that SKA researchers have adopted. Despite the uncertainties, team members remain confident. Miley says that funding for large telescopes always seems to be up in the air: "In my view, the question is not whether SKA will be funded but rather *when* this will occur."

–ROBERT KOENIG