

tively light monopoles, is less convincing for the superheavy monopole predicted by the grand unified theories. Citing recent calculations by theoretical groups at Cornell² and Caltech,³ he contends that GUTS monopoles would be too heavy to escape the Galaxy, spending part of their time giving energy back to the currents generating the galactic field. In that case, Cabrera suggests, the relevant limit on the flux of superheavy monopoles is the "dark" mass of the Galaxy, estimated to be about ten times its visible mass. If the monopole mass is 10^{17} GeV, for example, a flux of about 4×10^{-11} $\text{cm}^{-2}\text{sec}^{-1}\text{sr}^{-1}$ monopoles with an average velocity of $10^{-3}c$ would account for the entire hidden mass. Cabrera's group has already penetrated below this effective limit.

Frisch and his collaborators, Myron Campbell, Joe Incandela and Sunil Somalwar (Chicago), Moises Kuchnir (Fermilab) and Richard Gustafson (University of Michigan), taking the Parker bound more seriously, have set their sights on a gradiometer as large as 1000 m^2 . They regard their present detector⁴—a sandwich of two gradiometer planes each with an area of 3000 cm^2 —as a prototype to investigate the feasibility of a much larger detector. Thus they have eschewed any shielding scheme that would not be feasible on the large scale. A superconducting inner shield remains necessary to reduce fluctuations of the ambient field, but in place of the expensive mu-metal outer shields used by the other induction-detector groups, Frisch makes do with a simple steel shield, arguing that an ambient field on the order of 10 milligauss is acceptable. In place of ultralow ambient fields, the group has stressed the mechanical rigidity of their detector, which can be achieved much more cheaply and monitored with accelerometers and strain gauges.

The gradiometer planes are superconducting niobium wire checkerboards with equal-area cells of alternating sense. "We refer to the system as 'macramé' because we wove the originals by hand," Frisch told us. The group has thus far seen no monopole candidate in about 60 days of running.

The two-plane configuration was adopted to provide a coincidence constraint intended to compensate for the higher noise levels the group feared might accompany the higher ambient fields. But, happily, the noise levels have turned out to be sufficiently low that the group has been able to quote a monopole flux limit from the absence of single (non-coincidence) signals, in which case the effective 4π area of the detector is 1500 cm^2 . This corresponds to about $2/3$ of Cabrera's total exposure (area $\times$ time) to date. With the coincidence requirement, where some mono-



poles would be lost by traversing only one plane, the effective area is only half as large, but if monopole candidates are eventually seen, Frisch explains, a coincidence signal would provide essential confirmation.

The IBM gradiometer. Tesche and her IBM colleagues, Stuart Bermon, Praveen Chaudhari, Cheng-chung Chi and Chang Tsuei, have been running since October with a system⁵ of six gradiometer planes enclosing a rectangular parallelepiped, yielding a 4π -averaged collecting area of 1000 cm^2 . This closed-box arrangement insures that every monopole trajectory must intersect precisely two gradiometer planes, providing an inevitable coincidence signal. A signal in only one plane or simultaneous signals in more than two planes are taken to be spurious. The detector sits in a microgauss ambient field, intermediate between Cabrera's ultralow nanogauss field and Frisch's economy-model shielding. In four months of running, the IBM detector has seen no monopole candidates, yielding a flux limit close to that published by Cabrera's group in October. "We will publish a new flux limit when we pass Cabrera's area $\times$ time, some time this spring," Tesche told us. If one combines the exposures of the three induction-detector groups as of this writing, one can say, at the 90% confidence level, that the local monopole flux does not exceed $6 \times 10^{-12} \text{ cm}^{-2}\text{sec}^{-1}\text{sr}^{-1}$.

The IBM gradiometer pattern is more elaborate⁶ than the equal-area checkerboard employed at Chicago. A complex pattern of alternating-polarity cells of varying area is precisely de-

signed to cancel out successive terms in the Taylor-series expansion of the ambient field fluctuations. Arguing that extraneous signals from the superconducting shield would all look very much like external point sources of magnetic field, the Chicago-Fermilab-Michigan group contends that the simpler checkerboard pattern is more appropriate.

Because the current induced in the gradiometer by a monopole is inversely proportional to its inductance, which in turn is directly proportional to the total length of wire, the IBM group had developed a clever algorithm for minimizing the wire length of its elaborate gradiometer pattern. The resulting increased sensitivity lets one dispense with the amplifying transformers required by the Chicago group to link the gradiometer planes to the squids. Such superconducting transformers could be insidious sites for trapped flux, which can produce spurious signals when jumping from one pinning site to another. "But if we want to build really large detectors," says Frisch, "we'll all have to learn to live with trapped flux." The IBM detector is immersed in liquid helium, while the Chicago-Fermilab-Michigan collaboration makes do with a vacuum environment which, they claim, will be cheaper to scale up.

A year from now the IBM group expects to be operating a new gradiometer detector with an effective collecting area thirty times that of their present system. It will, among other things, exploit the new ultrasensitive dc squids recently developed at IBM. The group is also working with collaborators at Brookhaven to explore the feasibility of a 100-m^2 gradiometer detector.

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References

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in brief

The Tevatron at Fermilab accelerated a proton beam to 800 GeV on 15 February; the beam was then extracted and transported to an experimental area. The official Tevatron dedication is scheduled for 28 April.