Non-baryonic Galactic Dark Matter close to a paradigm (certainly in the mind of many) but yet to be detected.

~20-30% Cold (non-relativistic) DM presently favored (we don’t seem to be able to explain large scale structure of the universe without WIMPs –Weakly Interacting Massive particles-, relics of early stages)

Cautious strategy: start by looking first for non-ad hoc particle candidates, i.e., those already invoked by particle theories (E.g., neutralino ↔ MSSM, axions ↔ strong CP problem)

WIMPs: dominant interaction via low-energy nuclear elastic scattering, expected rates << 1 kg target / day in the keV region. (local ρ~0.4 GeV/cm³, <v>~300 km/s, σ<10⁻⁴² cm²).

Supersymmetric WIMPS can have rates as low as 1 recoil/tonne/yr!

The challenge: build cost-effective tonne or multi-tonne detectors sensitive exclusively to WIMP-induced nuclear recoils (down to 1/year) and nothing else. Not even neutron recoils. Nada. Zilch.

The scale of things: a 1-kg Ge detector fires in this room at the tune of ~1 kHz (OK to giggle at this point).
Some Desirable Features
in a Next Generation WIMP Detector

⇒ Background rejection as near to 100% as humanly possible

⇒ Large, safe and inexpensive target mass: room temperature operation can go a long way to help here.

⇒ Simple target replacement to help ascertain a WIMP signal (e.g. neutron background and WIMP signal do not scale the same way in different target materials).

⇒ Simultaneous sensitivity to spin-dependent and -independent neutralino cross sections, maximal on both (fluorine then a must for the first, a heavy nucleus for 2nd).

⇒ Lowest possible energy threshold to maximize acceptance of signal.

⇒ Neutron background rejection (the ultimate nemesis).

Is there such a thing?
Superheated liquids:

- Two ongoing experiments (SIMPLE, PICASSO) exploit Superheated Droplet technique (SDD)
- Sexy heavy-liquid targets such as CF$_3$Br and CF$_3$I impossible to manufacture as SDDs ⇒ try bulk (=Bubble Chambers, a much trickier endeavor). Safe and non-toxic (used in fire extinguishers).
- Total insensitivity to MIPs, yet sensitive to low-E nuclear recoils (tunable dE/dx and E thresholds)
- ~$40/kg, room T… first one tonne WIMP detector?
First prototypes:
~20 ml active volume
Pressure: 0-150 psi
Temp: -80 to + 40 degrees C

Stereo photography of bubbles
Three triggers: acoustic, pressure and video

Propylene glycol buffer liquid prevents evaporation of superheated liquid.

Glass dewar with heat-exchange fluid
Quartz pressure vessel
Acoustic sensor

Safety shield box
Glass dewar
Superheated CF$_3$Br
Camaras
Recirculating chiller (-10 degrees)
A Typical Scattering Event with Am-Be Neutron Source
(bubble expansion ~1 mm/ms)

X Camera

Y Camera
Old Bubble Chambers radiation-ready for only few ms at a time (coincident with beam spill)

Gas pockets in surface imperfections and motes can act as inhomogeneous nucleation centers.

A WIMP BC must remain superheated indefinitely, except for radiation-induced events. Low superheat helps, but is not enough.

Recent progress in neutralization of inhomogeneous nucleation sites (from work unrelated to bubble chambers). E.g. use of liquid “lid”, outgassing in presence of buffer liquid, cleaning techniques and wetting improvement via vapor deposition.
**Background Counting Rate under ~ 6 m.w.e.**

- Mean survival time for superheated state varies due to periodic episodes of nucleation on chamber walls, but is usually ~ 10 minutes.
- Live time (due to long recompression cycle) is already 62%.
- Counting rate for “real events” is 4/hour (compatible with measured fast neutron flux in the lab).
- **Gamma rejection factor (from absence of excess nucleation rate in presence of $Y-88 \Rightarrow 1.3E6$ gamma interactions / s) is $\geq 1E9$**

<table>
<thead>
<tr>
<th>Energy</th>
<th>Neutron Flux (n/cm²/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ground Level</td>
</tr>
<tr>
<td>$&lt;.5$ eV</td>
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<tr>
<td>.5eV-100keV</td>
<td>0.00384</td>
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<tr>
<td>100keV-10MeV</td>
<td>0.0015</td>
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<tr>
<td>10 MeV-50MeV</td>
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<tr>
<td>Total</td>
<td>0.01382</td>
</tr>
</tbody>
</table>

Bonner sphere(s) n flux measurement in LASR underground lab
Well-defined low energy threshold:

Sensitivity to < 7 keV recoils demonstrated (while having no response to 3mCi $\gamma$ source).
In agreement with models.

Sensitivity to ~1 keV recoils in progress (Sb-124/Be source)

Monochromatic Si filter neutron calibrations at KSU reactor planned

Detector is insensitive to gammas (see previous transparency) yet fully responsive to low-E recoils

Lines show Seitz model prediction for top boundary of data point distribution (onset of sensitivity)
Fancy: Position Reconstruction

- Bubble positions can be reconstructed in 3 dimensions by scanning images taken by two cameras offset by 90 degrees.
- Position resolution is currently 530 microns r.m.s. (approximately 1/4 bubble diameter)
- Uniform spatial distribution of background events, consistent with background neutrons.

163 background events (1.5 live days)
Neutron Background Rejection Potential

• Multiple simultaneous bubbles are present in ~4% of events in our “background” data set. Neutrons can do this, WIMPs cannot.

• The response to neutrons and WIMPs interacting mostly via SI is very different for refrigerants containing F only (C₃F₈) and F+I (CF₃I); much more favorable situation than Ge/Si to verify a WIMP signal.
Larger chambers are “self-shielding” (innermost fiducial volume will have good rejection of energetic neutrons able to penetrate moderator)

This might reduce sensitivity to dreaded high energy “punch through” neutrons down to the ~1 count/tonne/month range ⇒ allowing for exhaustive exploration of supersymmetric WIMP models.
Design Concept for a Large Chamber
(2 kg target, delivery April 2004)

- Central design issue is how to avoid metal contact with superheated liquid.
- Fabrication of large quartz or glass pressure vessels is not practical, but industrial capability exists for thin-walled vessels up to ~ 1 m³ in volume.
COUPP (Chicago Observatory for Underground Particle Physics)

Where we *might* be by fall of 2004  (take these with a grain of salt)

are these projections overly cautious? Better safe than sorry (e.g., alpha backgrounds from Rn emanation from steel - however only few µBq/m² expected if some precautions taken -)