HPGS: High Pressure Gas Scintillation for dark matter detection

C J Martoff (Temple) & P F Smith (RAL, Temple)

- most dark matter experiments use cryogenic solid or liquid targets

- Gases at ambient temperature also give ionization and scintillation signals which could be used to detect nuclear recoils

- Could be used at 5-10 bar to provide lower cost high sensitivity detectors operating at room temperature and scalable to ton level
Brief history of dark matter detectors

1986 --> 1990  

**Bolometers for ν**
Cabrera, Fiorini, Stodolski, vonFeilitzsch, Seidel, Pretzl…

**Semiconductors for ββ**
Avignone, Caldwell, Boehm…

**Crystal scintillators for particle detection**
Owen (1959), Doll….

**Liquid Ar & Xe studies for solar ν & rare events**
Rubbia, Cline, Aprile….

**Noble gas studies for charged particles & γ**
M Suzuki, Saito, Flaks….

1990

Ionization/bolometers
Low bkgd Ge
NaI, CsI pulse shape
Liquid Xe ioniz’n/scint’n
Liquid Ar ioniz’n/scint’n

2000

Suggested high pressure noble gas DM expts
RAL, RAL/Ohio, HELLAZ, SIGN
Funding for r&d relatively small

Balloon Xe gas X-ray telescopes SIGHT, AXEL
Signal options

Field reduces recombination scintillation output, but more measurements needed.

Assume scintillation only
Scintillation pulse shape discrimination in Xe gas (zero electric field)

M Suzuki 1982
NIM 192, 623

1000000 background
10 nuclear recoils

Assume alphas ~ nuclear recoils

Time cut $t = t_1$
Signal sensitivity versus total background

Thus nuclear recoil population of 10 recoils/year detectable for background 1E6 gammas/year
Possible module sizes

- Copper vessel
  - R8778 pmts inside vessel
  - Xe gas @ 10 bar = 34kg
  - 0.6m

- Xe gas @ 5 bar = 34kg
  - 0.75m
  - 2.5 m
Neutron & Gamma/beta Backgrounds

- rock U/Th/K
- water γ/n shield
- pmts U/Th
- Kr85 in Xe
- Cu detector vessel U/Th
Low energy background levels

- Gammas from rock
- Neutrons from rock U/Th
- Neutrons from water muons
- Neutrons from rock muons
- DM sensitivity $1 \times 10^{-8}$ pb
- DM sensitivity $1 \times 10^{-10}$ pb
- Gammas from Cu vessel 0.1 ppb U/Th
- Gammas from pmts 2 inch R8778
- Neutrons from metal vessel 0.1 ppb U/Th
- Neutrons from R8778 PMTs
Estimated WIMP sensitivity

Single 34 kg module (10 bar) in 3m water shield
Light collection simulation gives energy threshold 2-3 keV
Total gammas < 40 keV = 8E5/year
Total neutrons < 40 keV = 5/year
90% WIMP proton cross section in 360 days full operation < 3E-9 pb

12 modules (400 kg)
N backgrounds reduced 1/10 by veto
90% WIMP proton cross section in 360 days full operation = < 4E-10 pb
Illustrative 1000 kg gas detector system

Based on individual Xe modules with local pmts
Some modules with Ar or Ar/Xe to confirm $A^2$ dependence

water shield

30 x 2m x 0.6m (34kg) modules

End planes of pmts
Alternative large scale configuration
suggested by F Calaprice (Princeton) - based on Borexino principles

- Target vessels with transparent silica walls + wavelength shifters
- Optional scintillator veto region
- Surrounding water-shielded PMT array
- Water shield
• If nuclear recoils give pulse shapes similar to alphas then DM sensitivity levels in range 1E-8-1E-9pb possible for Xe gas target masses 30-100kg, using scintillation only.

• Sensitivity 1E-9 - 1E-10pb possible with 100-1000kg and existing pmt backgrounds. Target sizes reasonable for 5-10 bar gas pressure.

• Different gases easily compared for A-dependence.

• Room temperature simplifies design and operation

• Large mass room temp gas detectors could be lower cost than mK bolometers and noble liquids for same sensitivity.
High dark matter sensitivity with simple room temperature detector using scintillation only

Published scintillation pulses from Xe gas show large pulse shape difference between $\gamma$s and $\alpha$s (representative of nuclear recoils).

Gives significant signal for 10 nuclear recoil events in background of 1E6 gammas.

Size reasonable at 5-10 bar - 2m x 0.6m module gives 34kg Xe gas. Internal PMTs give energy threshold 2-3keV.

Backgrounds with water shielding, Cu vessel, R8778 PMTs, allow sensitivity 3E-9pb in 360 days running for single 34kg module.

24 modules (1000kg) gives sensitivity 1-2E-10pb in 360 days running

Ambient temperature operation simpler & cheaper than cryogenic techniques.